IPN
INSTITUT DE PHYSIQUE NUCLÉAIRE
ORSAY

ICA
Division of International Comparative & Area Studies

The France-Stanford Center for Interdisciplinary Studies

CNRS IN2P3
Les deux infinis

Physics opportunities of a fixed-target experiment using LHC beams extracted by a bent crystal

Jean-Philippe Lansberg
IPN Orsay, Université Paris-Sud

SLAC COLLOQUIUM SERIES

AFTER @ LHC

thanks to F. Fleuret (LLR), S.J. Brodsky (SLAC), C. Hadjidakis (IPNO), M. Anselmino (Torino), R. Arnaldi (Torino), V. Chambert (IPNO), J.P. Didelez (IPNO), B. Genolini (IPNO), E.G. Ferreiro (USC), C. Lorcé (IPNO),A. Rakotozafindrabe (CEA), P. Rosier (IPNO), I. Schienbein (LPSC), E. Scomparin (Torino), and U.I. Uggerhøj (Aarhus)

Outline

Part 1: Why a new fixed-target experiment for HEP now ?

Outline

Part 1: Why a new fixed-target experiment for HEP now ?

Part 2: A Fixed-Target ExpeRiment using LHC beams: AFTER@LHC

Outline

Part 1: Why a new fixed-target experiment for HEP now ?

Part 2: A Fixed-Target ExpeRiment using LHC beams: AFTER@LHC

Part 3: Flagship studies

Outline

Part 1: Why a new fixed-target experiment for HEP now ?

Part 2: A Fixed-Target ExpeRiment using LHC beams: AFTER@LHC

Part 3: Flagship studies

Part 4: AFTER and the heavy flavours

Outline

Part 1: Why a new fixed-target experiment for HEP now ?

Part 2: A Fixed-Target ExpeRiment using LHC beams: AFTER@LHC

Part 3: Flagship studies

Part 4: AFTER and the heavy flavours

Part 5: Back to the future

Outline

Part 1: Why a new fixed-target experiment for HEP now ?

Part 2: A Fixed-Target ExpeRiment using LHC beams: AFTER@LHC

Part 3: Flagship studies

Part 4: AFTER and the heavy flavours

Part 5: Back to the future

Conclusions and Outlooks

Part I

Why a new fixed-target experiment for HEP now ?

Decisive advantages of Fixed-target experiments

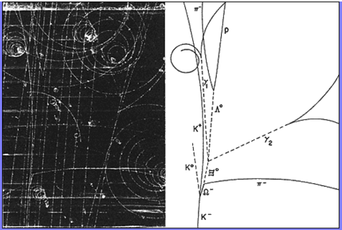
- They brought essential contributions to particle & nuclear physics

Decisive advantages of Fixed-target experiments

- They brought essential contributions to particle & nuclear physics
  - particle discoveries ($\Omega^-(sss)$, J/ψ, Υ,...)

Decisive advantages of Fixed-target experiments

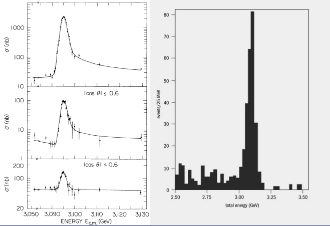
- They brought essential contributions to particle & nuclear physics
    - particle discoveries ($\Omega^-(sss)$, J/ψ, Υ,...)



Ω(*sss*) discovery @ BNL

Decisive advantages of Fixed-target experiments

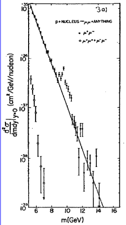
- They brought essential contributions to particle & nuclear physics
  - particle discoveries ($\Omega^-(sss)$, J/ψ, Υ,...)



$J/\psi(c\bar{c})$ discovery @ SLAC & BNL

Decisive advantages of Fixed-target experiments

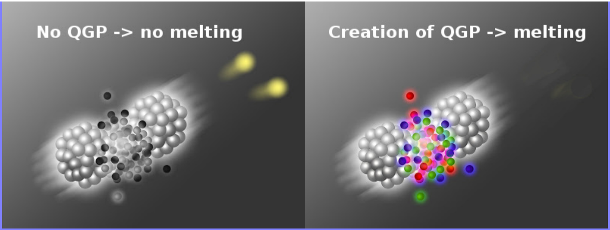
- They brought essential contributions to particle & nuclear physics
  - particle discoveries ($\Omega^-(sss)$, J/ψ, Υ,...)



$\Upsilon(b\bar{b})$ discovery @ Fermilab

Decisive advantages of Fixed-target experiments

- They brought essential contributions to particle & nuclear physics
  - particle discoveries ($\Omega^-(sss)$, J/ψ, Υ,...)
  - evidence for the novel dynamics of quarks and gluons in HIC (QGP)



$J/\psi \to \mu\mu$ anomalous suppression @ CERN-SPS

Decisive advantages of Fixed-target experiments

- They brought essential contributions to particle & nuclear physics
  - particle discoveries ($\Omega^-(sss)$, J/ψ, Υ,...)
  - evidence for the novel dynamics of quarks and gluons in HIC (QGP)
  - observation of surprising QCD phenomena
    - · breakdown of the Lam-Tung relation,
    - · colour transparency,
    - · higher-twist effects in forward meson production ,
    - · anomalously large Single & Double Spin Asymetries,
    - · factorisation breakdown in forward J/ψ production in pA

Decisive advantages of Fixed-target experiments

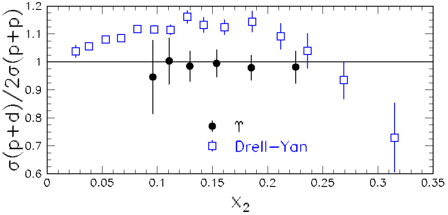
- They brought essential contributions to particle & nuclear physics
  - particle discoveries ($\Omega^-(sss)$, J/ψ, Υ,...)
  - evidence for the novel dynamics of quarks and gluons in HIC (QGP)
  - observation of surprising QCD phenomena
    - · breakdown of the Lam-Tung relation,
    - · colour transparency,
    - · higher-twist effects in forward meson production ,
    - · anomalously large Single & Double Spin Asymetries,
    - · factorisation breakdown in forward J/ψ production in pA
- Fixed-target experiments offer specific advantages that are still nowadays difficult to challenge by collider experiments

Decisive advantages of Fixed-target experiments

- They brought essential contributions to particle & nuclear physics
  - particle discoveries ($\Omega^-(sss)$, J/ψ, Υ,...)
  - evidence for the novel dynamics of quarks and gluons in HIC (QGP)
  - observation of surprising QCD phenomena
    - · breakdown of the Lam-Tung relation,
    - · colour transparency,
    - · higher-twist effects in forward meson production ,
    - · anomalously large Single & Double Spin Asymetries,
    - · factorisation breakdown in forward J/ψ production in pA
- Fixed-target experiments offer specific advantages that are still nowadays difficult to challenge by collider experiments
- They exhibit 4 decisive features,
  - accessing the high Feynman x_F domain ($x_F \equiv p_z/p_{z\,\max}$)
  - achieving high luminosities with dense targets,
  - varying the atomic mass of the target almost at will,
  - polarising the target.

E866 at Fermilab with the Tevatron beam

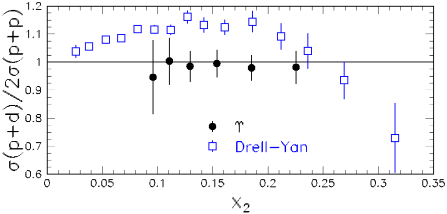
– **Precision Υ studies in *pp* and *pd* collisions** **E866 PRL 100 (2008) 062301**



Precision: necessary to show a different behaviour from DY

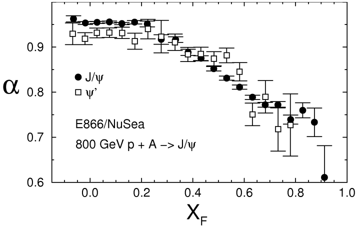
E866 at Fermilab with the Tevatron beam

– **Precision Υ studies in *pp* and *pd* collisions** **E866 PRL 100 (2008) 062301**



Precision: necessary to show a different behaviour from DY

– **Precision J/ψ and $\psi(2S)$ studies in *pA* collisions** **E866 PRL 84 (2000) 3256**

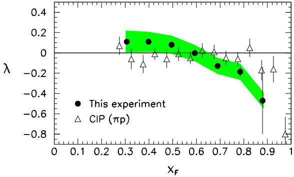


Precision: necessary to show a different behaviour of $\psi(2S)$ vs. J/ψ

E866 and before

– **Precision J/ψ polarisation (in the CS frame) studies at large x_F**

Chicago-Iowa-Princeton PRL 58, 2523 (1987); E866 PRL 91 (2003) 211801

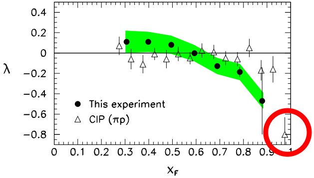


Precision and reach in x_F: necessary to show the change of pol. pattern

E866 and before

– **Precision J/ψ polarisation (in the CS frame) studies at large x_F**

Chicago-Iowa-Princeton PRL 58, 2523 (1987); E866 PRL 91 (2003) 211801

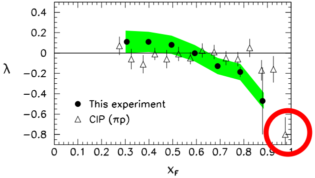


Precision and reach in x_F: necessary to show the change of pol. pattern

E866 and before

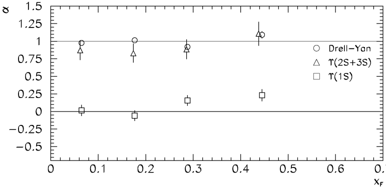
– **Precision J/ψ polarisation (in the CS frame) studies at large x_F**

Chicago-Iowa-Princeton PRL 58, 2523 (1987); E866 PRL 91 (2003) 211801



Precision and reach in x_F: necessary to show the change of pol. pattern

– **Precision $\Upsilon(nS)$ polarisation (in the CS frame) studies**



E866 PRL 86 2529 (2001)

Precision: necessary to show the different polarisation pattern between 1S and 2S+3S

The European strategy for particle physics

Approved by the CERN council at the special Session held in Lisbon on 14 July, 2006

The European strategy for particle physics

Approved by the CERN council at the special Session held in Lisbon on 14 July, 2006

9. A variety of important research lines are at the interface between particle and nuclear physics requiring dedicated experiments; *Council will seek to work with NuPECC in areas of mutual interest, and maintain the capability to perform fixed target experiments at CERN.*

pg. 37 of the Strategy Brochure

The European strategy for particle physics

Approved by the CERN council at the special Session held in Lisbon on 14 July, 2006

9. A variety of important research lines are at the interface between particle and nuclear physics requiring dedicated experiments; *Council will seek to work with NuPECC in areas of mutual interest, and maintain the capability to perform fixed target experiments at CERN.*

pg. 37 of the Strategy Brochure

The European strategy for particle physics

Approved by the CERN council at the special Session held in Lisbon on 14 July, 2006

9. A variety of important research lines are at the interface between particle and nuclear physics requiring dedicated experiments; *Council will seek to work with NuPECC in areas of mutual interest, and maintain the capability to perform fixed target experiments at CERN.* **pg. 37 of the Strategy Brochure**

Using the LHC beams, for the first time,

the 100-GeV frontier can be broken at a fixed target experiment,

The European strategy for particle physics

Approved by the CERN council at the special Session held in Lisbon on 14 July, 2006

9. A variety of important research lines are at the interface between particle and nuclear physics requiring dedicated experiments; *Council will seek to work with NuPECC in areas of mutual interest, and maintain the capability to perform fixed target experiments at CERN.*

pg. 37 of the Strategy Brochure

Using the LHC beams, for the first time,

the 100-GeV frontier can be broken at a fixed target experiment,

- without affecting the LHC performance
- with an extracted beam line using a bent crystal

The European strategy for particle physics

Approved by the CERN council at the special Session held in Lisbon on 14 July, 2006

9. A variety of important research lines are at the interface between particle and nuclear physics requiring dedicated experiments; *Council will seek to work with NuPECC in areas of mutual interest, and maintain the capability to perform fixed target experiments at CERN.*

pg. 37 of the Strategy Brochure

Using the LHC beams, for the first time,

the 100-GeV frontier can be broken at a fixed target experiment,

- without affecting the LHC performance
- with an extracted beam line using a bent crystal
- with the possibility of polarising the target
- without target-species limitation

The European strategy for particle physics

Approved by the CERN council at the special Session held in Lisbon on 14 July, 2006

9. A variety of important research lines are at the interface between particle and nuclear physics requiring dedicated experiments; *Council will seek to work with NuPECC in areas of mutual interest, and maintain the capability to perform fixed target experiments at CERN.*

pg. 37 of the Strategy Brochure

Using the LHC beams, for the first time,

the 100-GeV frontier can be broken at a fixed target experiment,

- without affecting the LHC performance
- with an extracted beam line using a bent crystal
- with the possibility of polarising the target
- without target-species limitation
- with an outstanding luminosity
- with virtually no limit on particle-species studies (except top quark)

The European strategy for particle physics

Approved by the CERN council at the special Session held in Lisbon on 14 July, 2006

9. A variety of important research lines are at the interface between particle and nuclear physics requiring dedicated experiments; *Council will seek to work with NuPECC in areas of mutual interest, and maintain the capability to perform fixed target experiments at CERN.*

pg. 37 of the Strategy Brochure

Using the LHC beams, for the first time,

the 100-GeV frontier can be broken at a fixed target experiment,

- without affecting the LHC performance
- with an extracted beam line using a bent crystal
- with the possibility of polarising the target
- without target-species limitation
- with an outstanding luminosity
- with virtually no limit on particle-species studies (except top quark)
- with modern detection techniques

Part II

A fixed-target experiment using the LHC beam(s): AFTER@LHC

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\boxed{\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}}$$

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy
  $$\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}$$
- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy
$$\boxed{\sqrt{s} = \sqrt{2m_N E_p} \simeq 115 \text{ GeV}}$$
- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\boxed{\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$
  - Consider a photon emitted at 90° w.r.t. the z-axis (beam) in the CM: $(p_{z,CM} = 0,\ E_{CM}^{\gamma} = p_T)$

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy
  $$\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}$$
- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$
  - Consider a photon emitted at 90° w.r.t. the z-axis (beam) in the CM: $(p_{z,CM} = 0,\ E_{CM}^{\gamma} = p_T)$
  - $\begin{pmatrix} E_{Lab} \\ p_{z,Lab} \end{pmatrix} = \begin{pmatrix} \gamma & \gamma\beta \\ \gamma\beta & \gamma \end{pmatrix} \begin{pmatrix} p_T \\ 0 \end{pmatrix}$

Generalities

- pp or pA collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma^{Lab}_{CM} = \frac{\sqrt{s}}{2m_p} \simeq 60$
  - Consider a photon emitted at 90° w.r.t. the z-axis (beam) in the CM: $(p_{z,CM} = 0,\ E^{\gamma}_{CM} = p_T)$
  - $\begin{pmatrix} E_{Lab} \\ p_{z,Lab} \end{pmatrix} = \begin{pmatrix} \gamma & \gamma\beta \\ \gamma\beta & \gamma \end{pmatrix} \begin{pmatrix} p_T \\ 0 \end{pmatrix}$
  - $p_{z,Lab} \simeq 60 p_T$! [A 67 MeV γ from a π^0 at rest in the CM can easily be detected.]

Generalities

- pp or pA collisions with a 7 TeV p^+ on a fixed target occur at a CM energy
  $$\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}$$
- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$
  - Consider a photon emitted at 90° w.r.t. the z-axis (beam) in the CM: $(p_{z,CM} = 0,\ E_{CM}^{\gamma} = p_T)$
  - $\begin{pmatrix} E_{Lab} \\ p_{z,Lab} \end{pmatrix} = \begin{pmatrix} \gamma & \gamma\beta \\ \gamma\beta & \gamma \end{pmatrix} \begin{pmatrix} p_T \\ 0 \end{pmatrix}$
  - $p_{z,Lab} \simeq 60 p_T$! [A 67 MeV γ from a π^0 at rest in the CM can easily be detected.]
- Angle in the Lab. frame: $\tan\theta = \frac{p_T}{p_{z,Lab}} = \frac{1}{\gamma\beta} \Rightarrow \theta \simeq 1^\circ$.

  [Rapidity shift: $\Delta y = tanh^{-1}\beta \simeq 4.8$]

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\boxed{\sqrt{s} = \sqrt{2m_N E_p} \simeq 115 \text{ GeV}}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$
  - Consider a photon emitted at 90° w.r.t. the z-axis (beam) in the CM: $(p_{z,CM} = 0,\ E_{CM}^{\gamma} = p_T)$
  - $\begin{pmatrix} E_{Lab} \\ p_{z,Lab} \end{pmatrix} = \begin{pmatrix} \gamma & \gamma\beta \\ \gamma\beta & \gamma \end{pmatrix} \begin{pmatrix} p_T \\ 0 \end{pmatrix}$
  - $p_{z,Lab} \simeq 60 p_T$! [A 67 MeV γ from a π^0 at rest in the CM can easily be detected.]
- Angle in the Lab. frame: $\tan\theta = \frac{p_T}{p_{z,Lab}} = \frac{1}{\gamma\beta} \Rightarrow \theta \simeq 1^\circ$.

  [Rapidity shift: $\Delta y = tanh^{-1}\beta \simeq 4.8$]
- The entire forward CM hemisphere ($y_{CM} > 0$) within $0^\circ \leq \theta_{Lab} \leq 1^\circ$

  [$y_{CM} = 0 \Rightarrow y_{Lab} \simeq 4.8$]

Generalities

- *pp* or *pA* collisions with a 7 TeV p^+ on a fixed target occur at a CM energy

$$\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115 \text{ GeV}$$

- In a symmetric collider mode, $\sqrt{s} = 2E_p$, *i.e.* much larger
- Benefit of the fixed target mode : boost: $\gamma_{CM}^{Lab} = \frac{\sqrt{s}}{2m_p} \simeq 60$
  - Consider a photon emitted at 90° w.r.t. the z-axis (beam) in the CM: $(p_{z,CM} = 0,\ E_{CM}^{\gamma} = p_T)$
  - $\begin{pmatrix} E_{Lab} \\ p_{z,Lab} \end{pmatrix} = \begin{pmatrix} \gamma & \gamma\beta \\ \gamma\beta & \gamma \end{pmatrix} \begin{pmatrix} p_T \\ 0 \end{pmatrix}$
  - $p_{z,Lab} \simeq 60 p_T$! [A 67 MeV γ from a π^0 at rest in the CM can easily be detected.]
- Angle in the Lab. frame: $\tan\theta = \frac{p_T}{p_{z,Lab}} = \frac{1}{\gamma\beta} \Rightarrow \theta \simeq 1°$.

  [Rapidity shift: $\Delta y = tanh^{-1}\beta \simeq 4.8$]
- The entire forward CM hemisphere ($y_{CM} > 0$) within $0° \leq \theta_{Lab} \leq 1°$

  [$y_{CM} = 0 \Rightarrow y_{Lab} \simeq 4.8$]
- Good thing: small forward detector ≡ large acceptance
- Bad thing: high multiplicity ⇒ absorber ⇒ physics limitation

Backward physics ?

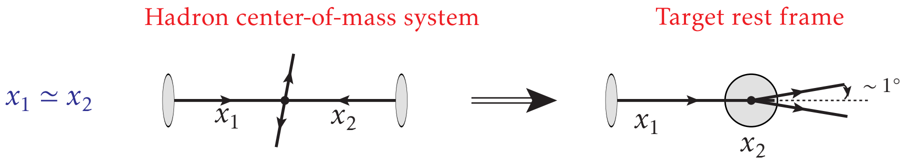
- $\sqrt{s}$ is large, let's adopt a different strategy and look at larger angles
  · particles with sufficient p_T to be detected
  · heavy particles whose decay product have enough p_T to be detected
  [not very heavy in fact: $J/\psi \to \mu\mu$ or $D \to K\pi$ are fine for current detectors]

Backward physics ?

- $\sqrt{s}$ is large, let's adopt a different strategy and look at larger angles
  · particles with sufficient p_T to be detected
  · heavy particles whose decay product have enough p_T to be detected
  [not very heavy in fact: $J/\psi \to \mu\mu$ or $D \to K\pi$ are fine for current detectors]
- Advantages:
  · reduced multiplicities at large(r) angles
  · access to partons with momentum fraction $x \to 1$ in the target
  · last, but not least, no geometrical constrain (e.g. beam pipe) at $\theta_{CM} \simeq 180^\circ$

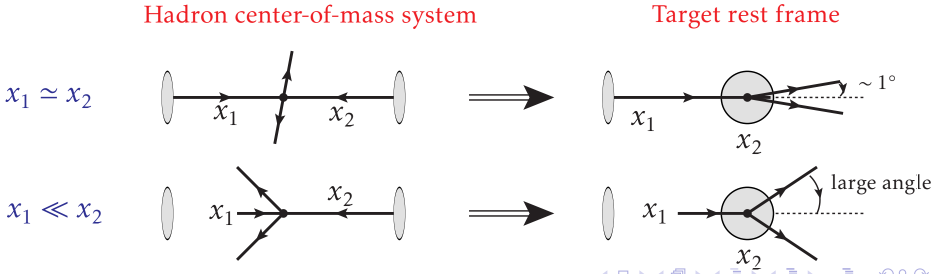
Backward physics ?

- $\sqrt{s}$ is large, let's adopt a different strategy and look at larger angles
  · particles with sufficient p_T to be detected
  · heavy particles whose decay product have enough p_T to be detected
  [not very heavy in fact: $J/\psi \to \mu\mu$ or $D \to K\pi$ are fine for current detectors]
- Advantages:
  · reduced multiplicities at large(r) angles
  · access to partons with momentum fraction $x \to 1$ in the target
  · last, but not least, no geometrical constrain (e.g. beam pipe) at $\theta_{CM} \simeq 180^\circ$



Backward physics ?

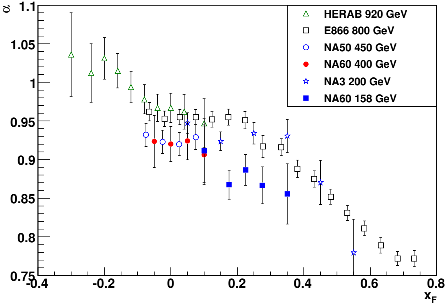
- $\sqrt{s}$ is large, let's adopt a different strategy and look at larger angles
  · particles with sufficient p_T to be detected
  · heavy particles whose decay product have enough p_T to be detected
  [not very heavy in fact: $J/\psi \to \mu\mu$ or $D \to K\pi$ are fine for current detectors]
- Advantages:
  · reduced multiplicities at large(r) angles
  · access to partons with momentum fraction $x \to 1$ in the target
  · last, but not least, no geometrical constrain (e.g. beam pipe) at $\theta_{CM} \simeq 180^\circ$



First systematic access to the target-rapidity region ($x_F \to -1$)

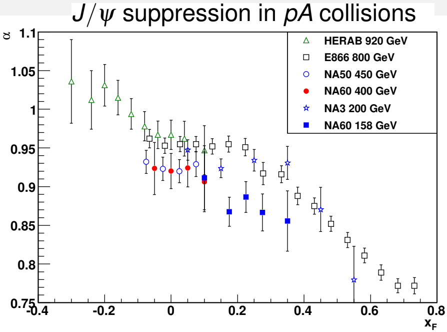
First systematic access to the target-rapidity region ($x_F \to -1$)

J/ψ suppression in pA collisions



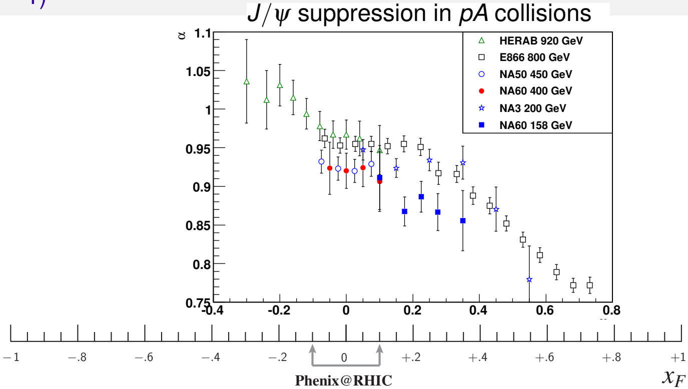
- x_F systematically studied at fixed target experiments up to +1

First systematic access to the target-rapidity region ($x_F \to -1$)



- x_F systematically studied at fixed target experiments up to +1
- Hera-B was the only one to really explore $x_F < 0$, up to -0.3

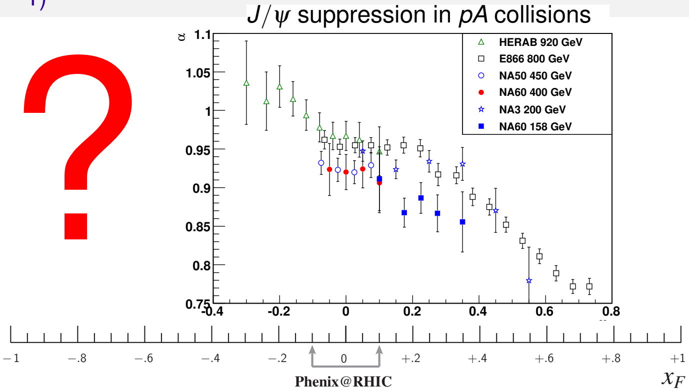
First systematic access to the target-rapidity region ($x_F \to -1$)



- x_F systematically studied at fixed target experiments up to +1
- Hera-B was the only one to really explore $x_F < 0$, up to -0.3
- PHENIX @ RHIC: $-0.1 < x_F < 0.1$ [could be wider with Υ, but low stat.]
- CMS/ATLAS: $|x_F| < 5 \cdot 10^{-3}$; LHCb: $5 \cdot 10^{-3} < x_F < 4 \cdot 10^{-2}$

First systematic access to the target-rapidity region ($x_F \to -1$)

?

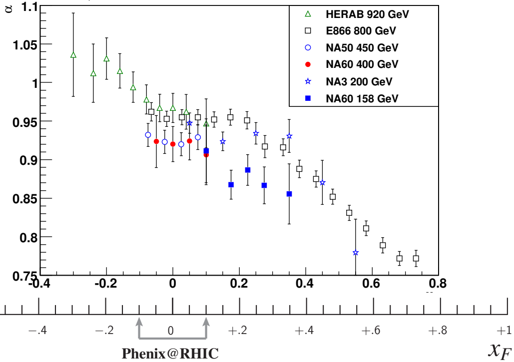


- x_F systematically studied at fixed target experiments up to +1
- Hera-B was the only one to really explore $x_F < 0$, up to -0.3
- PHENIX @ RHIC: $-0.1 < x_F < 0.1$ [could be wider with Υ, but low stat.]
- CMS/ATLAS: $|x_F| < 5 \cdot 10^{-3}$; LHCb: $5 \cdot 10^{-3} < x_F < 4 \cdot 10^{-2}$

First systematic access to the target-rapidity region ($x_F \to -1$)

?

J/ψ suppression in pA collisions



- x_F systematically studied at fixed target experiments up to +1
- Hera-B was the only one to really explore $x_F < 0$, up to -0.3
- PHENIX @ RHIC: $-0.1 < x_F < 0.1$ [could be wider with Υ, but low stat.]
- CMS/ATLAS: $|x_F| < 5 \cdot 10^{-3}$; LHCb: $5 \cdot 10^{-3} < x_F < 4 \cdot 10^{-2}$
- If we measure $\Upsilon(b\bar{b})$ at $y_{\rm cms} \simeq -2.5 \Rightarrow x_F \simeq \frac{2m_\Upsilon}{\sqrt{s}} \sinh(y_{\rm cms}) \simeq -1$

The lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon

The lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon
- In the fixed target mode, PbA collisions at $\sqrt{s_{NN}} \simeq 72$ GeV

The lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon
- In the fixed target mode, PbA collisions at $\sqrt{s_{NN}} \simeq 72$ GeV
- Half way between BNL-RHIC (AuAu, CuCu @ 200 GeV) and CERN-SPS (PbPb @ 17.2 GeV)

The lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon
- In the fixed target mode, PbA collisions at $\sqrt{s_{NN}} \simeq 72$ GeV
- Half way between BNL-RHIC (AuAu, CuCu @ 200 GeV) and CERN-SPS (PbPb @ 17.2 GeV)
- Example of motivations:

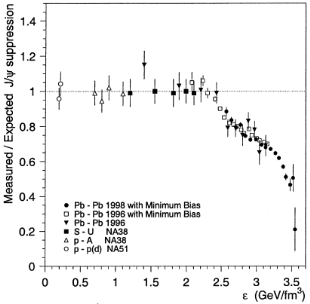


Fig. 7. Measured J/ψ production yields, normalised to the yields expected assuming that the only source of suppression is the ordinary absorption by the nuclear medium. The data is shown as a function of the energy density reached in the several collision systems.

The lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon
- In the fixed target mode, PbA collisions at $\sqrt{s_{NN}} \simeq 72$ GeV
- Half way between BNL-RHIC (AuAu, CuCu @ 200 GeV) and CERN-SPS (PbPb @ 17.2 GeV)
- Example of motivations:

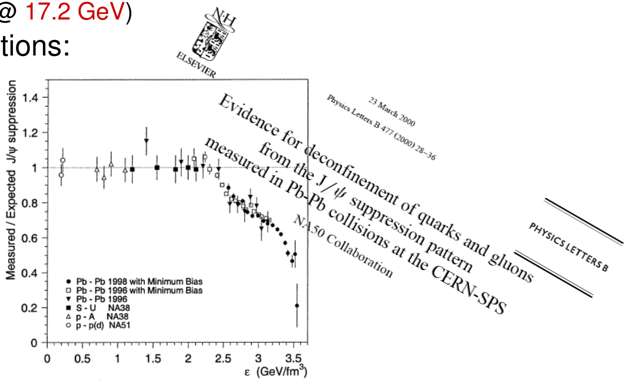


Fig. 7. Measured J/ψ production yields, normalised to the yields expected assuming that the only source of suppression is the ordinary absorption by the nuclear medium. The data is shown as a function of the energy density reached in the several collision systems.

The beam extraction

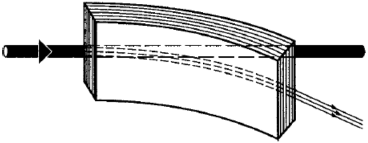
★ The LHC beam may be extracted using “Strong crystalline field” **without any decrease in performance of the LHC !**

E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131

The beam extraction

★ The LHC beam may be extracted using "Strong crystalline field" **without any decrease in performance of the LHC !**

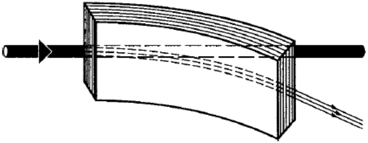
E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131



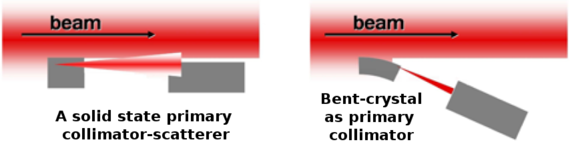
The beam extraction

★ The LHC beam may be extracted using “Strong crystalline field”
without any decrease in performance of the LHC !

E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131



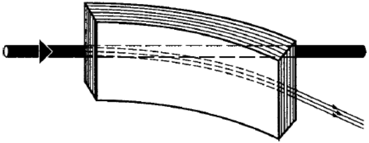
★ Illustration for collimation



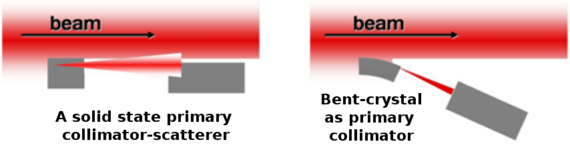
The beam extraction

★ The LHC beam may be extracted using "Strong crystalline field"
without any decrease in performance of the LHC !

E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131



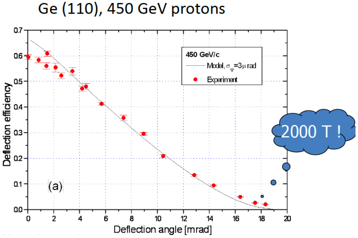
★ Illustration for collimation



★ Tests will be performed on the LHC beam:
LUA9 proposal approved by the LHCC

The beam extraction

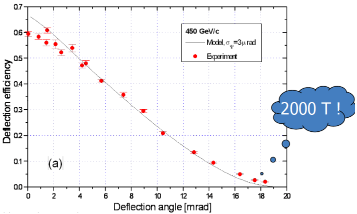
- Inter-crystalline fields are huge



The beam extraction

- Inter-crystalline fields are huge

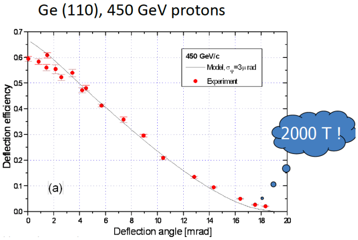
Ge (110), 450 GeV protons



- The channeling efficiency is high for a deflection of a few mrad

The beam extraction

- Inter-crystalline fields are huge

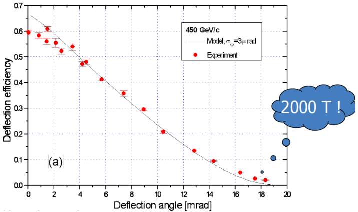


- The channeling efficiency is high for a deflection of a few mrad
- One can extract a significant part of the beam loss ($10^9 p^+ s^{-1}$)

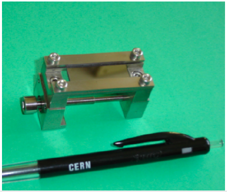
The beam extraction

- Inter-crystalline fields are huge

Ge (110), 450 GeV protons



- The channeling efficiency is high for a deflection of a few mrad
- One can extract a significant part of the beam loss ($10^9 p^+ s^{-1}$)
- Simple and robust way to extract the most energetic beam ever:



Luminosities

- Expected proton flux $\Phi_{beam} = 5 \times 10^8\ p^+ s^{-1}$

Luminosities

- Expected proton flux $\Phi_{beam} = 5 \times 10^8 \; p^+ s^{-1}$
- Instantaneous Luminosity:

$$\mathscr{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathscr{N}_A)/A$$

[ℓ: target thickness (for instance 1cm)]

Luminosities

- Expected proton flux $\Phi_{beam} = 5 \times 10^8\ p^+ s^{-1}$
- Instantaneous Luminosity:

$$\mathscr{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathscr{N}_A)/A$$

[ℓ: target thickness (for instance 1cm)]

- Integrated luminosity: $\int dt \mathscr{L}$ over 10^7 s for p^+ and 10^6 for Pb

[the so-called LHC years]

Luminosities

- Expected proton flux $\Phi_{beam} = 5 \times 10^8\ p^+ s^{-1}$
- Instantaneous Luminosity:

$$\mathscr{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathscr{N}_A)/A$$

[ℓ: target thickness (for instance 1cm)]

- Integrated luminosity: $\int dt \mathscr{L}$ over 10^7 s for p^+ and 10^6 for Pb

[the so-called LHC years]

Target	ρ (g.cm^{-3})	A	$\mathcal{L}$ (μb^{-1}.s^{-1})	$\int\mathcal{L}$ (pb^{-1}.yr^{-1})
Sol. H_2	0.09	1	**26**	**260**
Liq. H_2	0.07	1	**20**	**200**
Liq. D_2	0.16	2	**24**	**240**
Be	1.85	9	**62**	**620**
Cu	8.96	64	**42**	**420**
W	19.1	185	**31**	**310**
Pb	11.35	207	**16**	**160**

Luminosities

- 1 meter-long liquid H_2 & D_2 targets can be used (see NA51, . . .)

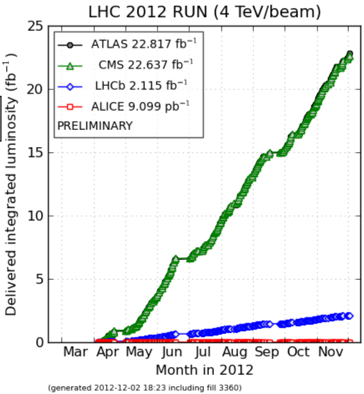
Luminosities

- 1 meter-long liquid H_2 & D_2 targets can be used (see NA51, . . .)
- This gives: $\mathscr{L}_{H_2/D_2} \simeq 20\ \text{fb}^{-1} y^{-1}$

Luminosities

- 1 meter-long liquid H_2 & D_2 targets can be used (see NA51, ...)
- This gives: $\mathscr{L}_{H_2/D_2} \simeq 20\ \text{fb}^{-1} y^{-1}$
- Recycling the LHC beam loss, one gets

a luminosity comparable to the LHC itself !

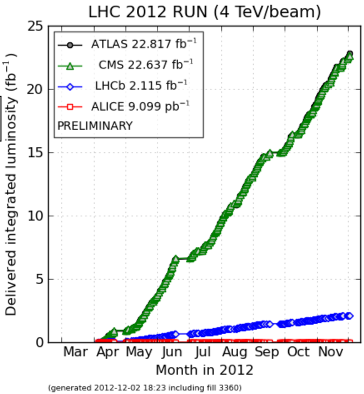


Luminosities

- 1 meter-long liquid H_2 & D_2 targets can be used (see NA51, ...)
- This gives: $\mathscr{L}_{H_2/D_2} \simeq 20\ \mathrm{fb}^{-1} y^{-1}$
- Recycling the LHC beam loss, one gets

a luminosity comparable to the LHC itself !

- PHENIX lumi in their decadal plan
  - · Run14pp 12 pb^{-1} @ $\sqrt{s_{NN}} = 200$ GeV
  - · Run14dAu 0.15 pb^{-1} @ $\sqrt{s_{NN}} = 200$ GeV



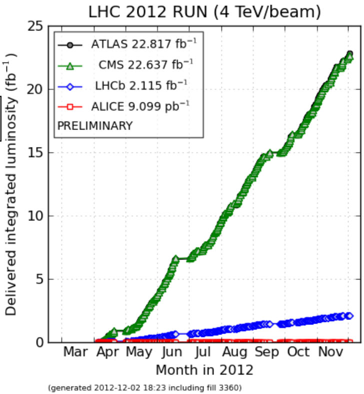
Luminosities

- 1 meter-long liquid H_2 & D_2 targets can be used (see NA51, . . .)
- This gives: $\mathscr{L}_{H_2/D_2} \simeq 20\ \mathrm{fb}^{-1} y^{-1}$
- Recycling the LHC beam loss, one gets

a luminosity comparable to the LHC itself !

- PHENIX lumi in their decadal plan
  - · Run14pp 12 pb^{-1} @ $\sqrt{s_{NN}} = 200$ GeV
  - · Run14dAu 0.15 pb^{-1} @ $\sqrt{s_{NN}} = 200$ GeV
- AFTER vs PHENIX@RHIC:

  3 orders of magnitude larger



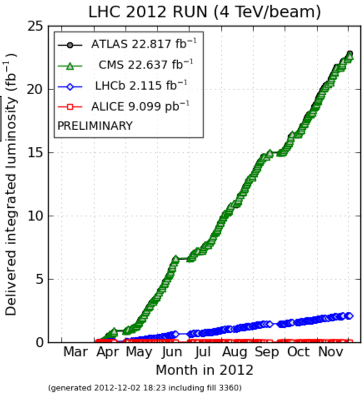
Luminosities

- 1 meter-long liquid H_2 & D_2 targets can be used (see NA51, ...)
- This gives: $\mathscr{L}_{H_2/D_2} \simeq 20 \text{ fb}^{-1} y^{-1}$
- Recycling the LHC beam loss, one gets

a luminosity comparable to the LHC itself !

- PHENIX lumi in their decadal plan
  · Run14pp 12 pb^{-1} @ $\sqrt{s_{NN}} = 200$ GeV
  · Run14dAu 0.15 pb^{-1} @ $\sqrt{s_{NN}} = 200$ GeV
- AFTER vs PHENIX@RHIC:
  3 orders of magnitude larger
- Lumi for Pb runs in the backup slides

(roughly 10 times that planned for the LHC)



Part III

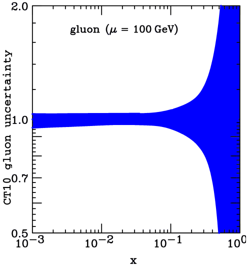
AFTER: flagships measurements

Key studies

- Gluon distribution at mid, high and ultra-high x_B in the

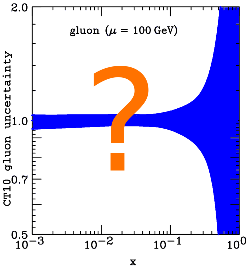
Key studies

- Gluon distribution at mid, high and ultra-high x_B in the
    - proton



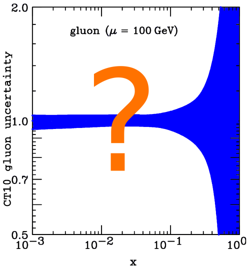
Key studies

- Gluon distribution at mid, high and ultra-high x_B in the
  - proton
  - **neutron** (via deuteron target)



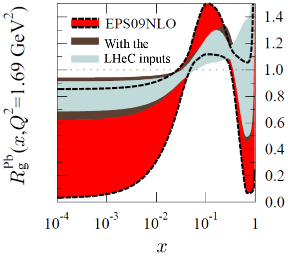
Key studies

- Gluon distribution at mid, high and ultra-high x_B in the
  - proton
  - **neutron** (via deuteron target)
    unique measurement !



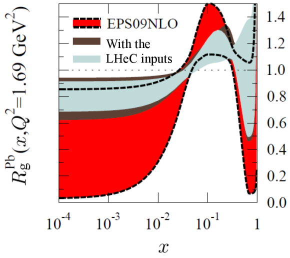
Key studies

- Gluon distribution at mid, high and ultra-high x_B in the
  - proton
  - **neutron** (via deuteron target)
    unique measurement !
  - nucleus



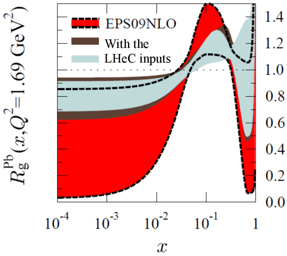
Key studies

- Gluon distribution at mid, high and ultra-high x_B in the
  - proton
  - **neutron** (via deuteron target)
    unique measurement !
  - nucleus
    absolutely complementary with LHeC



Key studies

- Gluon distribution at mid, high and ultra-high x_B in the
  - proton
  - **neutron** (via deuteron target)
    unique measurement !
  - nucleus
    absolutely complementary with LHeC

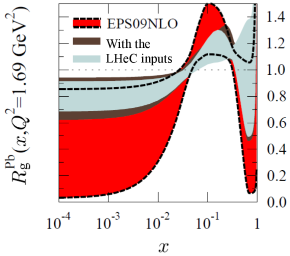


with gluon sensitive probes, namely

- quarkonia

Key studies

- Gluon distribution at mid, high and ultra-high x_B in the
  - proton
  - **neutron** (via deuteron target)
    unique measurement !
  - nucleus
    absolutely complementary with LHeC

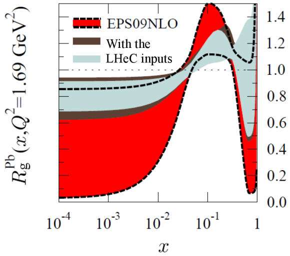


with gluon sensitive probes, namely

- quarkonia
- Isolated photon

Key studies

- Gluon distribution at mid, high and ultra-high x_B in the
  - proton
  - **neutron** (via deuteron target)
    unique measurement !
  - nucleus
    absolutely complementary with LHeC



with gluon sensitive probes, namely

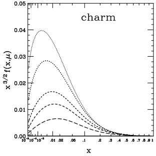
- quarkonia
- Isolated photon
- jets (we should access $P_T \in [20, 40]$ GeV)

Key studies

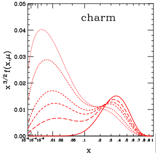
- Heavy-quark distributions (at high x_B)

Key studies

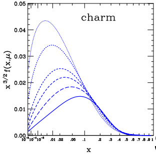
- Heavy-quark distributions (at high x_B)
  - Pin down instrinsic charm, ... at last



DGLAP



BHPS

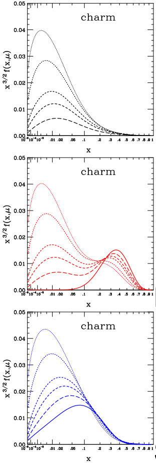


Sea-like

All 3 compatible with DIS data (Pumplin *et al.*)

Key studies

- Heavy-quark distributions (at high x_B)
  - Pin down instrinsic charm, ... at last
  - Total open charm and beauty cross section (aim: down to $P_T \to 0$)



DGLAP

BHPS

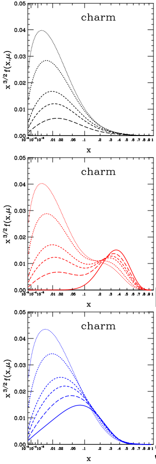
Sea-like

All 3 compatible with DIS data (Pumplin *et al.*)

Key studies

- Heavy-quark distributions (at high x_B)
  - Pin down instrinsic charm, ... at last
  - Total open charm and beauty cross section (aim: down to $P_T \to 0$)

requires



DGLAP

BHPS

Sea-like

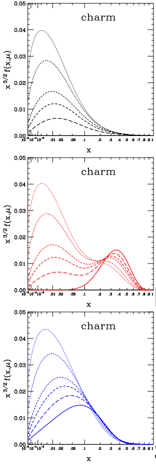
All 3 compatible with DIS data (Pumplin *et al.*)

Key studies

- Heavy-quark distributions (at high x_B)
  - Pin down instrinsic charm, ... at last
  - Total open charm and beauty cross section (aim: down to $P_T \to 0$)

requires

  - several complementary measurements



DGLAP

BHPS

Sea-like

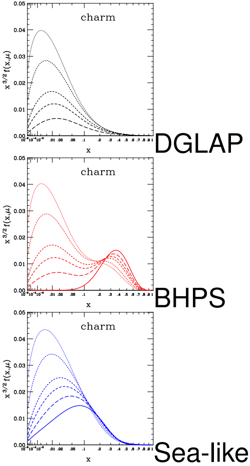
All 3 compatible with DIS data (Pumplin *et al.*)

Key studies

- Heavy-quark distributions (at high x_B)
  - Pin down instrinsic charm, ... at last
  - Total open charm and beauty cross section (aim: down to $P_T \to 0$)

requires

  - several complementary measurements
  - good coverage in the target-rapidity region



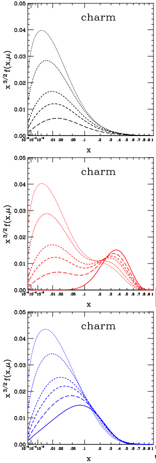
All 3 compatible with DIS data (Pumplin *et al.*)

Key studies

- Heavy-quark distributions (at high x_B)
    - Pin down instrinsic charm, ... at last
    - Total open charm and beauty cross section (aim: down to $P_T \to 0$)

requires

- several complementary measurements
- good coverage in the target-rapidity region
- high luminosity to reach large x_B



DGLAP

BHPS

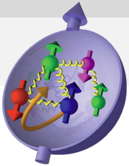
Sea-like

All 3 compatible with DIS data (Pumplin *et al.*)

Key studies

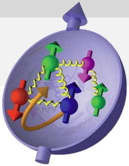
- Gluon Sivers effect: correlation between
  the gluon transverse momentum & the proton spin

Key studies



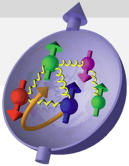
- Gluon Sivers effect: correlation between
  the gluon transverse momentum & the proton spin
  - Transverse single spin asymmetries
    using gluon sensitive probes

Key studies



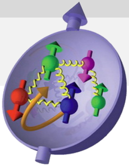
- Gluon Sivers effect: correlation between
  the gluon transverse momentum & the proton spin
  - Transverse single spin asymmetries
    using gluon sensitive probes
  - quarkonia (J/ψ, Υ, χ_c, $\ldots$) **F. Yuan, PRD 78 (2008) 014024**

Key studies



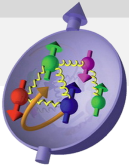
- Gluon Sivers effect: correlation between the gluon transverse momentum & the proton spin
  - Transverse single spin asymetries using gluon sensitive probes
  - quarkonia (J/ψ, Υ, χ_c, $\ldots$) **F. Yuan, PRD 78 (2008) 014024**
  - *B* & *D* meson production

Key studies



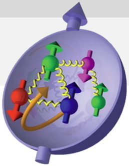
- Gluon Sivers effect: correlation between the gluon transverse momentum & the proton spin
  - Transverse single spin asymmetries using gluon sensitive probes
  - quarkonia (J/ψ, Υ, χ_c, ...) **F. Yuan, PRD 78 (2008) 014024**
  - B & D meson production
  - γ, γ-jet, $\gamma-\gamma$ **A. Bacchetta, *et al.*, PRL 99 (2007) 212002**
    J.W. Qiu, *et al.*, PRL 107 (2011) 062001

Key studies



- Gluon Sivers effect: correlation between the gluon transverse momentum & the proton spin
  - Transverse single spin asymmetries using gluon sensitive probes
  - quarkonia (J/ψ, Υ, χ_c, ...) **F. Yuan, PRD 78 (2008) 014024**
  - B & D meson production
  - γ, γ-jet, $\gamma - \gamma$ **A. Bacchetta, *et al.*, PRL 99 (2007) 212002** **J.W. Qiu, *et al.*, PRL 107 (2011) 062001**
- the target-rapidity region corresponds to high $x^{\uparrow}$ where the k_T-spin correlation is the largest

Key studies



- Gluon Sivers effect: correlation between the gluon transverse momentum & the proton spin
  - Transverse single spin asymmetries using gluon sensitive probes
  - quarkonia (J/ψ, Υ, χ_c, ...) **F. Yuan, PRD 78 (2008) 014024**
  - B & D meson production
  - γ, γ-jet, $\gamma - \gamma$ **A. Bacchetta, *et al.*, PRL 99 (2007) 212002** **J.W. Qiu, *et al.*, PRL 107 (2011) 062001**
- the target-rapidity region corresponds to high $x^\uparrow$ where the k_T-spin correlation is the largest
- In general, one can carry out an extensive spin-physics program

Key studies

- For the first time, one would study W/Z production in their threshold region

Key studies

- For the first time, one would study W/Z production in their threshold region
  - Unique opportunity to measure QCD/threshold effects on W/Z production

Key studies

- For the first time, one would study W/Z production in their threshold region
  - Unique opportunity to measure QCD/threshold effects on W/Z production
  - If W'/Z' exist, their production may share similar threshold corrections to that of W/Z, but at LHC energies

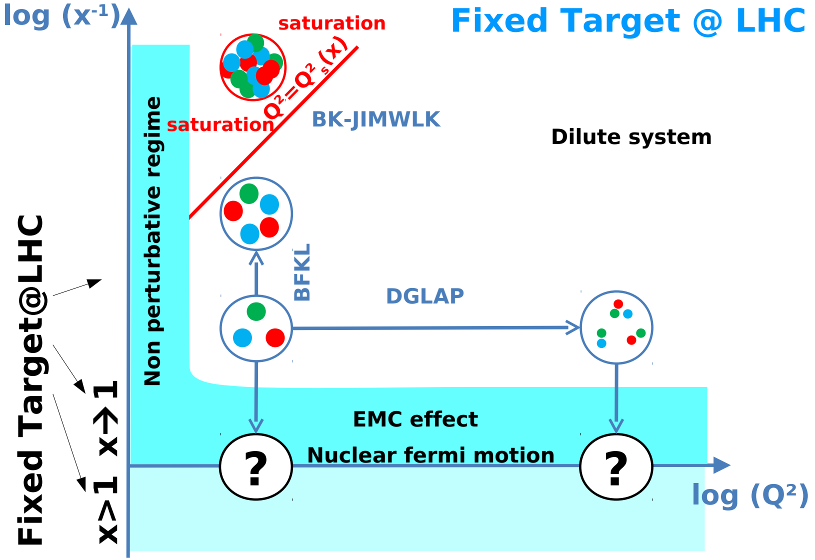
Key studies

- For the first time, one would study W/Z production in their threshold region
  - Unique opportunity to measure QCD/threshold effects on W/Z production
  - If W'/Z' exist, their production may share similar threshold corrections to that of W/Z, but at LHC energies
  - Reconstructed rate are most likely between a few dozen to a few thousand / year

Key studies

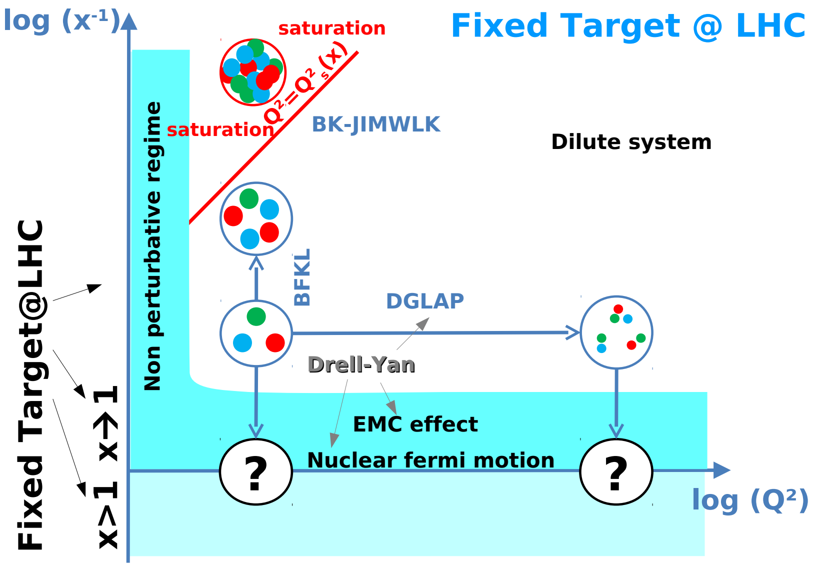
- For the first time, one would study W/Z production in their threshold region
  - Unique opportunity to measure QCD/threshold effects on W/Z production
  - If W'/Z' exist, their production may share similar threshold corrections to that of W/Z, but at LHC energies
  - Reconstructed rate are most likely between a few dozen to a few thousand / year
- Multiply heavy baryons: discovery potential ? ($\Omega^{++}(ccc)$, ...)
- Very forward (backward) physics:
  - semi-diffractive events
  - Ultra-peripheral collisions, etc.

Overall

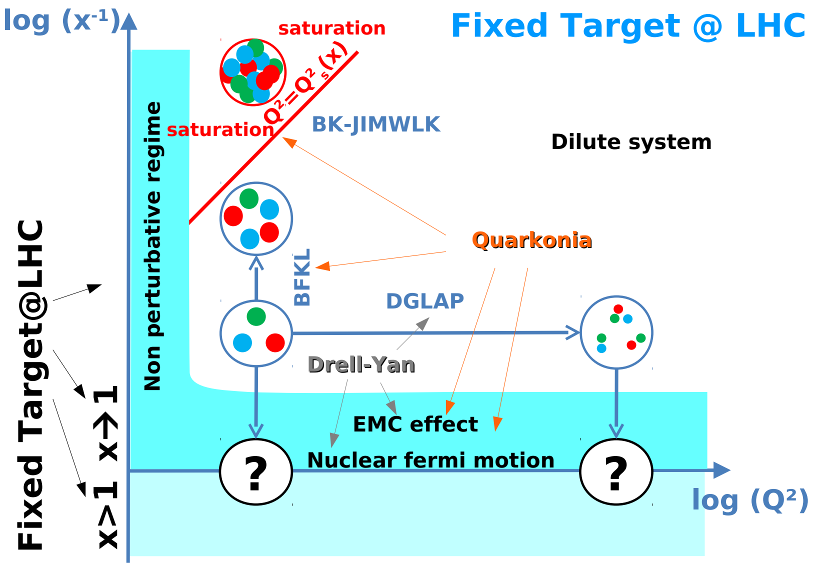


log (x⁻¹)
saturation
Fixed Target @ LHC
Q²=Q²s(x)
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
Fixed Target@LHC
x>1 x→1
BFKL
DGLAP
EMC effect
Nuclear fermi motion
?
?
log (Q²)

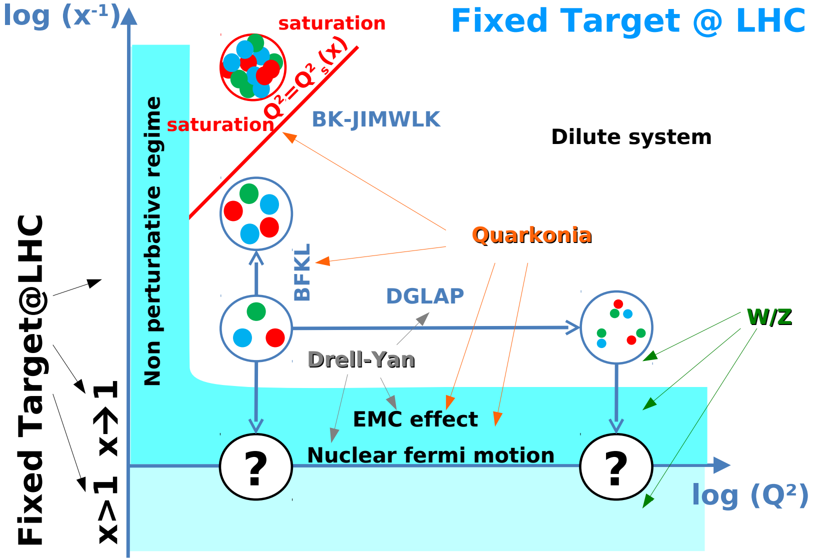
Overall


log (x⁻¹)
saturation
Fixed Target @ LHC
$Q^2=Q^2_s(x)$
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
Fixed Target@LHC
BFKL
DGLAP
Drell-Yan
x→1
x>1
EMC effect
Nuclear fermi motion
?
?
log (Q²)

Overall

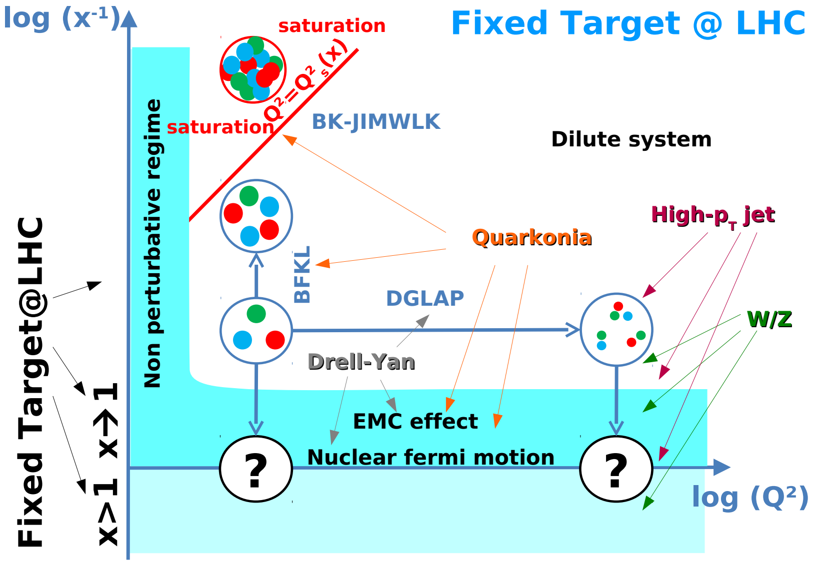

log (x⁻¹)
saturation
Fixed Target @ LHC
$Q^2=Q^2_s(x)$
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
Quarkonia
BFKL
Fixed Target@LHC
DGLAP
Drell-Yan
x>1 x→1
EMC effect
Nuclear fermi motion
?
?
log (Q²)

Overall



log (x-1)
saturation
Fixed Target @ LHC
Q2=Q2s(x)
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
Quarkonia
BFKL
DGLAP
W/Z
Fixed Target@LHC
x→1
x>1
Drell-Yan
EMC effect
?
Nuclear fermi motion
?
log (Q2)

Overall


log (x⁻¹)
saturation
Fixed Target @ LHC
$Q^2=Q^2_s(x)$
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
High-p_T jet
Quarkonia
BFKL
DGLAP
W/Z
Fixed Target@LHC
x>1 x→1
Drell-Yan
EMC effect
Nuclear fermi motion
?
?
log (Q²)

Part IV

AFTER and the heavy flavours

AFTER, among other things, a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int\mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(ϒ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	20	$4.0\ 10^8$	$8.0\ 10^5$
1 m Liq. D_2	24	$9.6\ 10^8$	$1.9\ 10^6$
LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	$3.6\ 10^7$ $1.4\ 10^9$	$1.8\ 10^5$ $7.2\ 10^6$
RHIC pp 200GeV	$1.2\ 10^{-2}$	$4.8\ 10^5$	$1.2\ 10^3$

AFTER, among other things, a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int \mathcal{L}$ ($fb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_{\Psi}$	N(Υ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1 m Liq. H_2	20	4.0 10^{8}	8.0 10^{5}
1 m Liq. D_2	24	9.6 10^{8}	1.9 10^{6}
LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	3.6 10^{7} 1.4 10^{9}	1.8 10^{5} 7.2 10^{6}
RHIC pp 200GeV	1.2 10^{-2}	4.8 10^{5}	1.2 10^{3}

- 1000 times higher than at RHIC;comparable to ALICE/LHCb at the LHC

AFTER, among other things, a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int \mathcal{L}$ ($fb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_{\Psi}$	N(Υ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1 m Liq. H_2	20	4.0 10^8	8.0 10^5
1 m Liq. D_2	24	9.6 10^8	1.9 10^6
LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	3.6 10^7 1.4 10^9	1.8 10^5 7.2 10^6
RHIC pp 200GeV	1.2 10^{-2}	4.8 10^5	1.2 10^3

- 1000 times higher than at RHIC;comparable to ALICE/LHCb at the LHC
- Numbers are for only one unit of rapidity about 0

AFTER, among other things, a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int \mathcal{L}$ ($fb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(ϒ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	20	4.0 10^8	8.0 10^5
1 m Liq. D_2	24	9.6 10^8	1.9 10^6
LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	3.6 10^7 1.4 10^9	1.8 10^5 7.2 10^6
RHIC pp 200GeV	1.2 10^{-2}	4.8 10^5	1.2 10^3

- 1000 times higher than at RHIC;comparable to ALICE/LHCb at the LHC
- Numbers are for only one unit of rapidity about 0
- Unique access in the backward region

AFTER, among other things, a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int \mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(Υ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	20	$4.0\ 10^8$	$8.0\ 10^5$
1 m Liq. D_2	24	$9.6\ 10^8$	$1.9\ 10^6$
LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	$3.6\ 10^7$ $1.4\ 10^9$	$1.8\ 10^5$ $7.2\ 10^6$
RHIC pp 200GeV	$1.2\ 10^{-2}$	$4.8\ 10^5$	$1.2\ 10^3$

- 1000 times higher than at RHIC;comparable to ALICE/LHCb at the LHC
- Numbers are for only one unit of rapidity about 0
- Unique access in the backward region
- Probe of the (very) large *x* in the target

Need for a quarkonium observatory

- Many hopes were put in quarkonium studies to extract gluon PDF

Need for a quarkonium observatory

- Many hopes were put in quarkonium studies to extract gluon PDF
  - in photo/lepto production (DIS)
  - but also *pp* collisions in *gg*-fusion process
  - mainly because of the presence of a natural “hard” scale: m_Q
  - and the good detectability of a dimuon pair

Need for a quarkonium observatory

- Many hopes were put in quarkonium studies to extract gluon PDF
  - in photo/lepto production (DIS)
  - but also *pp* collisions in *gg*-fusion process
  - mainly because of the presence of a natural "hard" scale: m_Q
  - and the good detectability of a dimuon pair

PHYSICAL REVIEW D VOLUME 37, NUMBER 5 1 MARCH 1988

Structure-function analysis and ψ, jet, W, and Z production: Determining the gluon distribution

A. D. Martin
Department of Physics, University of Durham, Durham, England

R. G. Roberts
Rutherford Appleton Laboratory, Didcot, Oxon, England

W. J. Stirling
Department of Physics, University of Durham, Durham, England

(Received 27 July 1987)

We perform a next-to-leading-order structure-function analysis of deep-inelastic μN and νN scattering data and find acceptable fits for a range of input gluon distributions. We show three equally acceptable sets of parton distributions which correspond to gluon distributions which are (1) "soft," (2) "hard," and (3) which behave as $xG(x) \sim 1/\sqrt{x}$ at small x. J/ψ and prompt photon hadroproduction data are used to discriminate between the three sets. Set 1, with the "soft"-gluon distribution, is favored. W, Z, and jet production data from the CERN collider are well described but do not distinguish between the sets of structure functions. The precision of the predictions for σ_W and σ_Z allow the collider measurements to yield information on the number of light neutrinos and the mass of the top quark. Finally we discuss how the gluon distribution at very small x may be directly measured at DESY HERA.

Need for a quarkonium observatory

- Many hopes were put in quarkonium studies to extract gluon PDF
  - in photo/lepto production (DIS)
  - but also *pp* collisions in *gg*-fusion process
  - mainly because of the presence of a natural "hard" scale: m_Q
  - and the good detectability of a dimuon pair

PHYSICAL REVIEW D VOLUME 37, NUMBER 5 1 MARCH 1988

Structure-function analysis and ψ, jet, W, and Z production: Determining the gluon distribution

A. D. Martin
Department of Physics, University of Durham, Durham, England

R. G. Roberts
Rutherford Appleton Laboratory, Didcot, Oxon, England

W. J. Stirling
Department of Physics, University of Durham, Durham, England

(Received 27 July 1987)

We perform a next-to-leading-order structure-function analysis of deep-inelastic μN and νN scattering data and find acceptable fits for a range of input gluon distributions. We show three equally acceptable sets of parton distributions which correspond to gluon distributions which are (1) "soft," (2) "hard," and (3) which behave as $xG(x) \sim 1/\sqrt{x}$ at small x. J/ψ and prompt photon hadroproduction data are used to discriminate between the three sets. Set 1, with the "soft"-gluon distribution, is favored. W, Z, and jet production data from the CERN collider are well described but do not distinguish between the sets of structure functions. The precision of the predictions for σ_W and σ_Z allow the collider measurements to yield information on the number of light neutrinos and the mass of the top quark. Finally we discuss how the gluon distribution at very small x may be directly measured at DESY HERA.

- Production puzzle $\rightarrow$ quarkonium not used anymore in global fits

Need for a quarkonium observatory

- Many hopes were put in quarkonium studies to extract gluon PDF
  - in photo/lepto production (DIS)
  - but also *pp* collisions in *gg*-fusion process
  - mainly because of the presence of a natural "hard" scale: m_Q
  - and the good detectability of a dimuon pair

PHYSICAL REVIEW D VOLUME 37, NUMBER 5 1 MARCH 1988

Structure-function analysis and ψ, jet, W, and Z production: Determining the gluon distribution

A. D. Martin
Department of Physics, University of Durham, Durham, England

R. G. Roberts
Rutherford Appleton Laboratory, Didcot, Oxon, England

W. J. Stirling
Department of Physics, University of Durham, Durham, England
(Received 27 July 1987)

We perform a next-to-leading-order structure-function analysis of deep-inelastic μN and νN scattering data and find acceptable fits for a range of input gluon distributions. We show three equally acceptable sets of parton distributions which correspond to gluon distributions which are (1) "soft," (2) "hard," and (3) which behave as $xG(x) \sim 1/\sqrt{x}$ at small x. J/ψ and prompt photon hadroproduction data are used to discriminate between the three sets. Set 1, with the "soft"-gluon distribution, is favored. W, Z, and jet production data from the CERN collider are well described but do not distinguish between the sets of structure functions. The precision of the predictions for σ_W and σ_Z allow the collider measurements to yield information on the number of light neutrinos and the mass of the top quark. Finally we discuss how the gluon distribution at very small x may be directly measured at DESY HERA.

- Production puzzle $\to$ quarkonium not used anymore in global fits
- With systematic studies, one would restore its status as gluon probe

AFTER: also a quarkonium observatory in *pA*

Target	A	$\int \mathcal{L}$ ($fb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_{\Psi}$	N(ϒ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1cm Be	9	**0.62**	**$1.1\ 10^{8}$**	**$2.2\ 10^{5}$**
1cm Cu	64	**0.42**	**$5.3\ 10^{8}$**	**$1.1\ 10^{6}$**
1cm W	185	**0.31**	**$1.1\ 10^{9}$**	**$2.3\ 10^{6}$**
1cm Pb	207	**0.16**	**$6.7\ 10^{8}$**	**$1.3\ 10^{6}$**
LHC pPb 8.8 TeV	207	**10^{-4}**	**$1.0\ 10^{7}$**	**$7.5\ 10^{4}$**
RHIC dAu 200GeV	198	**$1.5\ 10^{-4}$**	**$2.4\ 10^{6}$**	**$5.9\ 10^{3}$**
RHIC dAu 62GeV	198	**$3.8\ 10^{-6}$**	**$1.2\ 10^{4}$**	**18**

- In principle, one can get 300 times more J/ψ –not counting the likely wider *y* coverage– than at RHIC, allowing for

AFTER: also a quarkonium observatory in *pA*

Target	A	$\int \mathcal{L}$ ($fb^{-1}.yr^{-1}$)	$N(J/\Psi)\ yr^{-1}$ $= A\mathcal{L}\mathcal{B}\sigma_{\Psi}$	$N(\Upsilon)\ yr^{-1}$ $= A\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1cm Be	9	0.62	$1.1\ 10^{8}$	$2.2\ 10^{5}$
1cm Cu	64	0.42	$5.3\ 10^{8}$	$1.1\ 10^{6}$
1cm W	185	0.31	$1.1\ 10^{9}$	$2.3\ 10^{6}$
1cm Pb	207	0.16	$6.7\ 10^{8}$	$1.3\ 10^{6}$
LHC pPb 8.8 TeV	207	10^{-4}	$1.0\ 10^{7}$	$7.5\ 10^{4}$
RHIC dAu 200GeV	198	$1.5\ 10^{-4}$	$2.4\ 10^{6}$	$5.9\ 10^{3}$
RHIC dAu 62GeV	198	$3.8\ 10^{-6}$	$1.2\ 10^{4}$	18

- In principle, one can get 300 times more J/ψ –not counting the likely wider *y* coverage– than at RHIC, allowing for
  - χ_c measurement in *pA* via $J/\psi + \gamma$ (extending Hera-B studies)

AFTER: also a quarkonium observatory in *pA*

Target	A	$\int \mathcal{L}$ ($fb^{-1}.yr^{-1}$)	$N(J/\Psi)\ yr^{-1}$ $= A\mathcal{L}\mathcal{B}\sigma_\Psi$	$N(\Upsilon)\ yr^{-1}$ $= A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1cm Be	9	0.62	$1.1\ 10^8$	$2.2\ 10^5$
1cm Cu	64	0.42	$5.3\ 10^8$	$1.1\ 10^6$
1cm W	185	0.31	$1.1\ 10^9$	$2.3\ 10^6$
1cm Pb	207	0.16	$6.7\ 10^8$	$1.3\ 10^6$
LHC pPb 8.8 TeV	207	10^{-4}	$1.0\ 10^7$	$7.5\ 10^4$
RHIC dAu 200GeV	198	$1.5\ 10^{-4}$	$2.4\ 10^6$	$5.9\ 10^3$
RHIC dAu 62GeV	198	$3.8\ 10^{-6}$	$1.2\ 10^4$	18

- In principle, one can get 300 times more J/ψ –not counting the likely wider *y* coverage– than at RHIC, allowing for
  - χ_c measurement in *pA* via $J/\psi + \gamma$ (extending Hera-B studies)
  - Polarisation measurement as the centrality, *y* or P_T

AFTER: also a quarkonium observatory in *pA*

Target	A	$\int \mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(ϒ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1cm Be	9	0.62	$1.1\ 10^8$	$2.2\ 10^5$
1cm Cu	64	0.42	$5.3\ 10^8$	$1.1\ 10^6$
1cm W	185	0.31	$1.1\ 10^9$	$2.3\ 10^6$
1cm Pb	207	0.16	$6.7\ 10^8$	$1.3\ 10^6$
LHC pPb 8.8 TeV	207	10^{-4}	$1.0\ 10^7$	$7.5\ 10^4$
RHIC dAu 200GeV	198	$1.5\ 10^{-4}$	$2.4\ 10^6$	$5.9\ 10^3$
RHIC dAu 62GeV	198	$3.8\ 10^{-6}$	$1.2\ 10^4$	18

- In principle, one can get 300 times more J/ψ –not counting the likely wider y coverage– than at RHIC, allowing for
  - χ_c measurement in *pA* via $J/\psi + \gamma$ (extending Hera-B studies)
  - Polarisation measurement as the centrality, y or P_T
  - Ratio ψ' over direct J/ψ measurement in *pA*

AFTER: also a quarkonium observatory in *pA*

Target	A	$\int\mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(Υ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1cm Be	9	0.62	1.1 10^8	2.2 10^5
1cm Cu	64	0.42	5.3 10^8	1.1 10^6
1cm W	185	0.31	1.1 10^9	2.3 10^6
1cm Pb	207	0.16	6.7 10^8	1.3 10^6
LHC pPb 8.8 TeV	207	10^{-4}	1.0 10^7	7.5 10^4
RHIC dAu 200GeV	198	1.5 10^{-4}	2.4 10^6	5.9 10^3
RHIC dAu 62GeV	198	3.8 10^{-6}	1.2 10^4	18

- In principle, one can get 300 times more J/ψ –not counting the likely wider *y* coverage– than at RHIC, allowing for
  - χ_c measurement in *pA* via $J/\psi + \gamma$ (extending Hera-B studies)
  - Polarisation measurement as the centrality, *y* or P_T
  - Ratio ψ' over direct J/ψ measurement in *pA*
  - not to mention ratio with **open charm, Drell-Yan,** etc ...

What for ?

- The target versatility of a fixed-target experiment is undisputable

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects
- Strong need for cross checks from various measurements

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects
- Strong need for cross checks from various measurements
- The backward kinematics is very useful for large-x_{target} studies

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects
- Strong need for cross checks from various measurements
- The backward kinematics is very useful for large-x_{target} studies
  - What is the amount of Intrinsic charm ? Is it color filtered ?

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects
- Strong need for cross checks from various measurements
- The backward kinematics is very useful for large-x_{target} studies
  - What is the amount of Intrinsic charm ? Is it color filtered ?
  - Is there an EMC effect for gluon ? (reminder: EMC region $0.3 < x < 0.7$)

What for ?

- The target versatility of a fixed-target experiment is undisputable
- A wide rapidity coverage is needed for:
  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects
- Strong need for cross checks from various measurements
- The backward kinematics is very useful for large-x_{target} studies
  - What is the amount of Intrinsic charm ? Is it color filtered ?
  - Is there an EMC effect for gluon ? (reminder: EMC region $0.3 < x < 0.7$)
- One should be careful with factorization breaking effects:

This calls for multiple measurements to (in)validate factorization

AFTER: also an heavy-flavour observatory in *PbA*

- Luminosities and yields with the extracted 2.76 TeV Pb beam ($\sqrt{s_{NN}} = 72$ GeV)

Target	A.B	$\int \mathcal{L}$ ($nb^{-1}.yr^{-1}$)	$N(J/\Psi)\ yr^{-1} = AB\mathcal{L}\mathcal{B}\sigma_{\Psi}$	$N(\Upsilon)\ yr^{-1} = AB\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
1 m Liq. H_2	207.1	800	$3.4\ 10^6$	$6.9\ 10^3$
1cm Be	207.9	25	$9.1\ 10^5$	$1.9\ 10^3$
1cm Cu	207.64	17	$4.3\ 10^6$	$0.9\ 10^3$
1cm W	207.185	13	$9.7\ 10^6$	$1.9\ 10^4$
1cm Pb	207.207	7	$5.7\ 10^6$	$1.1\ 10^4$
LHC PbPb 5.5 TeV	207.207	0.5	$7.3\ 10^6$	$3.6\ 10^4$
RHIC AuAu 200GeV	198.198	2.8	$4.4\ 10^6$	$1.1\ 10^4$
RHIC AuAu 62GeV	198.198	0.13	$4.0\ 10^4$	61

AFTER: also an heavy-flavour observatory in *PbA*

- Luminosities and yields with the extracted 2.76 TeV Pb beam ($\sqrt{s_{NN}} = 72$ GeV)

Target	A.B	$\int \mathcal{L}$ ($nb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $AB\mathcal{L}\mathcal{B}\sigma_\Psi$	N(Υ) yr^{-1} = $AB\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	207.1	800	$3.4\ 10^6$	$6.9\ 10^3$
1cm Be	207.9	25	$9.1\ 10^5$	$1.9\ 10^3$
1cm Cu	207.64	17	$4.3\ 10^6$	$0.9\ 10^3$
1cm W	207.185	13	$9.7\ 10^6$	$1.9\ 10^4$
1cm Pb	207.207	7	$5.7\ 10^6$	$1.1\ 10^4$
LHC PbPb 5.5 TeV	207.207	0.5	$7.3\ 10^6$	$3.6\ 10^4$
RHIC AuAu 200GeV	198.198	2.8	$4.4\ 10^6$	$1.1\ 10^4$
RHIC AuAu 62GeV	198.198	0.13	$4.0\ 10^4$	61

- Yields similar to those of RHIC at 200 GeV, 100 times those of RHIC at 62 GeV

AFTER: also an heavy-flavour observatory in *PbA*

- Luminosities and yields with the extracted 2.76 TeV Pb beam ($\sqrt{s_{NN}} = 72$ GeV)

Target	A.B	$\int \mathcal{L}$ (nb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} = AB$\mathcal{L}\mathcal{B}\sigma_\Psi$	N(ϒ) yr^{-1} =AB$\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	207.1	800	3.4 10^6	6.9 10^3
1cm Be	207.9	25	9.1 10^5	1.9 10^3
1cm Cu	207.64	17	4.3 10^6	0.9 10^3
1cm W	207.185	13	9.7 10^6	1.9 10^4
1cm Pb	207.207	7	5.7 10^6	1.1 10^4
LHC PbPb 5.5 TeV	207.207	0.5	7.3 10^6	3.6 10^4
RHIC AuAu 200GeV	198.198	2.8	4.4 10^6	1.1 10^4
RHIC AuAu 62GeV	198.198	0.13	4.0 10^4	61

- Yields similar to those of RHIC at 200 GeV, 100 times those of RHIC at 62 GeV
- Also very competitive compared to the LHC.

AFTER: also an heavy-flavour observatory in *PbA*

- Luminosities and yields with the extracted 2.76 TeV Pb beam ($\sqrt{s_{NN}} = 72$ GeV)

Target	A.B	$\int \mathcal{L}$ ($nb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $AB\mathcal{L}\mathcal{B}\sigma_\Psi$	N(Υ) yr^{-1} = $AB\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	207.1	800	3.4 10^6	6.9 10^3
1cm Be	207.9	25	9.1 10^5	1.9 10^3
1cm Cu	207.64	17	4.3 10^6	0.9 10^3
1cm W	207.185	13	9.7 10^6	1.9 10^4
1cm Pb	207.207	7	5.7 10^6	1.1 10^4
LHC PbPb 5.5 TeV	207.207	0.5	7.3 10^6	3.6 10^4
RHIC AuAu 200GeV	198.198	2.8	4.4 10^6	1.1 10^4
RHIC AuAu 62GeV	198.198	0.13	4.0 10^4	61

- Yields similar to those of RHIC at 200 GeV, 100 times those of RHIC at 62 GeV
- Also very competitive compared to the LHC.

The same picture also holds for open heavy flavour

What for ?

Observation of J/ψ sequential suppression seems to be hindered by

- the Cold Nuclear Matter effects: non trivial and

  ... not well understood

What for ?

Observation of J/ψ sequential suppression seems to be hindered by

- the Cold Nuclear Matter effects: non trivial and

  ... not well understood

- the difficulty to observe directly the excited states

  which would melt before the ground states

  - χ_c never studied in *AA* collisions
  - $\psi(2S)$ not yet studied in *AA* collisions at RHIC

What for ?

Observation of J/ψ sequential suppression seems to be hindered by

- the Cold Nuclear Matter effects: non trivial and
  ... not well understood
- the difficulty to observe directly the excited states
  which would melt before the ground states
  - χ_c never studied in AA collisions
  - $\psi(2S)$ not yet studied in AA collisions at RHIC
- the possibilities for $c\bar{c}$ recombination
  - Open charm studies are difficult where recombination matters most
    i.e. at low P_T
  - Only indirect indications –from the y and P_T dependence of R_{AA}–
    that recombination may be at work
  - CNM effects may show a non-trivial y and P_T dependence ...

Part V

Back to the future ...

LHB

Our idea is not completely new

Nuclear Instruments and Methods in Physics Research A 333 (1993) 125–135
North-Holland

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

LHB, a fixed target experiment at LHC to measure CP violation in B mesons

Flavio Costantini

University of Pisa and INFN, Italy

A fixed target experiment at LHC to measure CP violation in B mesons is presented. A description of the proposed apparatus is given together with its sensitivity on the CP violation asymmetry measurement for the two benchmark decay channels $B^0 \to J/\psi + K^0_s$, $B^0 \to \pi^+\pi^-$. The possibility of obtaining an extracted LHC beam hinges on channeling in a bent silicon crystal. Recent results on beam extraction efficiencies measured at CERN SPS based on this technique are presented.

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\overline{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} $cm^{-2}s^{-1}$ luminosity [5].

LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} $cm^{-2}s^{-1}$ luminosity [5].

10^{10} $B\bar{B}$ pairs per year

LARGE HADRON BEAUTY FACTORY

LETTER OF INTENT

- *B*-factories: 1 ab^{-1} means $10^9 B\bar{B}$ pairs

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} $cm^{-2}s^{-1}$ luminosity [5].

10^{10} $B\bar{B}$ pairs per year

LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

- B-factories: 1 ab^{-1} means $10^9 B\bar{B}$ pairs
- For LHCb, typically 1 fb^{-1} means $\simeq 2 \times 10^{11} B\bar{B}$ pairs at 14 TeV

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} $cm^{-2}s^{-1}$ luminosity [5].

10^{10} $B\bar{B}$ pairs per year

LHB
LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

- B-factories: 1 ab^{-1} means $10^9 B\bar{B}$ pairs
- For LHCb, typically 1 fb^{-1} means $\simeq 2 \times 10^{11} B\bar{B}$ pairs at 14 TeV
- LHB turned down in favour of LHCb mainly because of the fear of a premature degradation of the bent crystal due to radiation damages.

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} $cm^{-2}s^{-1}$ luminosity [5].

10^{10} $B\bar{B}$ pairs per year

LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

- B-factories: 1 ab^{-1} means $10^9 B\bar{B}$ pairs
- For LHCb, typically 1 fb^{-1} means $\simeq 2 \times 10^{11} B\bar{B}$ pairs at 14 TeV
- LHB turned down in favour of LHCb mainly because of the fear of a premature degradation of the bent crystal due to radiation damages.
- Nowadays, degradation is known to be $\simeq 6\%$ per 10^{20} particles/cm^2
- 10^{20} particles/cm^2 : one year of operation for realistic conditions

LHB

Our idea is not completely new

1. Introduction

...

This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} cm^{-2}s^{-1} luminosity [5].

10^{10} $B\bar{B}$ pairs per year

LHB
LARGE HADRON BEAUTY FACTORY
LETTER OF INTENT

- B-factories: 1 ab^{-1} means $10^9 B\bar{B}$ pairs
- For LHCb, typically 1 fb^{-1} means $\simeq 2 \times 10^{11} B\bar{B}$ pairs at 14 TeV
- LHB turned down in favour of LHCb mainly because of the fear of a premature degradation of the bent crystal due to radiation damages.
- Nowadays, degradation is known to be $\simeq$ 6% per 10^{20} particles/cm^2
- 10^{20} particles/cm^2 : one year of operation for realistic conditions
- After a year, one simply moves the crystal by less than one mm ...

Part VI

Conclusion and outlooks

Conclusion

- Both *p* and *Pb* LHC beams can be extracted without disturbing the other experiments

Conclusion

- Both *p* and *Pb* LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity pp, pA and PbA collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity pp, pA and PbA collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- **Example**: precision quarkonium studies taking advantage of

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow$ 5×10^8 protons per sec
- This allows for high luminosity pp, pA and PbA collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- **Example**: precision quarkonium studies taking advantage of
  - high luminosity (reach in y, P_T, small BR channels)
  - target versatility (nuclear effects, strongly limited at colliders)
  - modern detection techniques (e.g. γ detection with high multiplicity)

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity pp, pA and PbA collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- **Example**: precision quarkonium studies taking advantage of
  - high luminosity (reach in y, P_T, small BR channels)
  - target versatility (nuclear effects, strongly limited at colliders)
  - modern detection techniques (e.g. γ detection with high multiplicity)
- This would likely prepare the ground for $g(x, Q^2)$ extraction

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity pp, pA and PbA collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- **Example**: precision quarkonium studies taking advantage of
  - high luminosity (reach in y, P_T, small BR channels)
  - target versatility (nuclear effects, strongly limited at colliders)
  - modern detection techniques (e.g. γ detection with high multiplicity)
- This would likely prepare the ground for $g(x, Q^2)$ extraction
- A wealth of possible measurements:
  DY, Open b/c, jet correlation, UPC... (not mentioning secondary beams)

Conclusion

- Both *p* and *Pb* LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam → 5×10^8 protons per sec
- This allows for high luminosity *pp*, *pA* and *PbA* collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- **Example**: precision quarkonium studies taking advantage of
  - high luminosity (reach in y, P_T, small BR channels)
  - target versatility (nuclear effects, strongly limited at colliders)
  - modern detection techniques (e.g. γ detection with high multiplicity)
- This would likely prepare the ground for $g(x, Q^2)$ extraction
- A wealth of possible measurements:
  DY, Open b/c, jet correlation, UPC... (not mentioning secondary beams)
- Planned LHC long shutdown ($<$ 2020 ?) could be used to install the extraction system

Conclusion

- Both *p* and *Pb* LHC beams can be extracted without disturbing the other experiments
- Extracting a few per cent of the beam $\rightarrow 5 \times 10^8$ protons per sec
- This allows for high luminosity *pp*, *pA* and *PbA* collisions at $\sqrt{s} = 115$ GeV and $\sqrt{s_{NN}} = 72$ GeV
- **Example**: precision quarkonium studies taking advantage of
  - high luminosity (reach in y, P_T, small BR channels)
  - target versatility (nuclear effects, strongly limited at colliders)
  - modern detection techniques (e.g. γ detection with high multiplicity)
- This would likely prepare the ground for $g(x, Q^2)$ extraction
- A wealth of possible measurements:
  DY, Open b/c, jet correlation, UPC... (not mentioning secondary beams)
- Planned LHC long shutdown ($<$ 2020 ?) could be used to install the extraction system
- Very good complementarity with electron-ion programs

Outlooks

- First physics paper to appear in Phys. Repts., 10.1016/j.physrep.2012.10.001.

Outlooks

- First physics paper to appear in Phys. Repts., 10.1016/j.physrep.2012.10.001.
- A 10-day exploratory workshop will be held at ECT* Trento, February 4-13, 2013 http://indico.in2p3.fr/event/AFTER@ECTstar

Outlooks

- First physics paper to appear in Phys. Repts., 10.1016/j.physrep.2012.10.001.
- A 10-day exploratory workshop will be held at ECT* Trento, February 4-13, 2013 http://indico.in2p3.fr/event/AFTER@ECTstar
- Everybody is welcome (email us at AFTERatECTstar@ipno.in2p3.fr)
  (experimentalist, theorist, beam expert, senior colleague, postdoc, student,. . .)

Outlooks

- First physics paper to appear in Phys. Repts., 10.1016/j.physrep.2012.10.001.
- A 10-day exploratory workshop will be held at ECT* Trento, February 4-13, 2013 http://indico.in2p3.fr/event/AFTER@ECTstar
- Everybody is welcome (email us at AFTERatECTstar@ipno.in2p3.fr)
  (experimentalist, theorist, beam expert, senior colleague, postdoc, student,. . .)
- Bring your model, discuss it, run it & make predictions for 115/72 GeV !
- We are looking for more experimentalist partners to start

Outlooks

- First physics paper to appear in Phys. Repts., 10.1016/j.physrep.2012.10.001.
- A 10-day exploratory workshop will be held at ECT* Trento, February 4-13, 2013 http://indico.in2p3.fr/event/AFTER@ECTstar
- Everybody is welcome (email us at AFTERatECTstar@ipno.in2p3.fr)
  (experimentalist, theorist, beam expert, senior colleague, postdoc, student,. . .)
- Bring your model, discuss it, run it & make predictions for 115/72 GeV !
- We are looking for more experimentalist partners to start
  - doing first simulations

Outlooks

- First physics paper to appear in Phys. Repts., 10.1016/j.physrep.2012.10.001.
- A 10-day exploratory workshop will be held at ECT* Trento, February 4-13, 2013 http://indico.in2p3.fr/event/AFTER@ECTstar
- Everybody is welcome (email us at AFTERatECTstar@ipno.in2p3.fr)
  (experimentalist, theorist, beam expert, senior colleague, postdoc, student,. . .)
- Bring your model, discuss it, run it & make predictions for 115/72 GeV !
- We are looking for more experimentalist partners to start
  - doing first simulations
  - thinking about possible designs

Outlooks

- First physics paper to appear in Phys. Repts., 10.1016/j.physrep.2012.10.001.
- A 10-day exploratory workshop will be held at ECT* Trento, February 4-13, 2013 http://indico.in2p3.fr/event/AFTER@ECTstar
- Everybody is welcome (email us at AFTERatECTstar@ipno.in2p3.fr)
  (experimentalist, theorist, beam expert, senior colleague, postdoc, student,. . .)
- Bring your model, discuss it, run it & make predictions for 115/72 GeV !
- We are looking for more experimentalist partners to start
  - doing first simulations
  - thinking about possible designs
  - thinking about the optimal detector technologies

Outlooks

- First physics paper to appear in Phys. Repts., 10.1016/j.physrep.2012.10.001.
- A 10-day exploratory workshop will be held at ECT* Trento, February 4-13, 2013 http://indico.in2p3.fr/event/AFTER@ECTstar
- Everybody is welcome (email us at AFTERatECTstar@ipno.in2p3.fr)
  (experimentalist, theorist, beam expert, senior colleague, postdoc, student,. . .)
- Bring your model, discuss it, run it & make predictions for 115/72 GeV !
- We are looking for more experimentalist partners to start
  - doing first simulations
  - thinking about possible designs
  - thinking about the optimal detector technologies
- Theorist colleagues are encouraged to think about additional ideas of physics

already 2 papers on the physics at AFTER:
T. Liu, B.Q. Ma, EPJC (2012) 72:2037
D. Boer, C. Pisano, Phys.Rev. D86 (2012) 094007

Outlooks

- First physics paper to appear in Phys. Repts., 10.1016/j.physrep.2012.10.001.
- A 10-day exploratory workshop will be held at ECT* Trento, February 4-13, 2013 http://indico.in2p3.fr/event/AFTER@ECTstar
- Everybody is welcome (email us at AFTERatECTstar@ipno.in2p3.fr)
  (experimentalist, theorist, beam expert, senior colleague, postdoc, student,. . .)
- Bring your model, discuss it, run it & make predictions for 115/72 GeV !
- We are looking for more experimentalist partners to start
  - doing first simulations
  - thinking about possible designs
  - thinking about the optimal detector technologies
- Theorist colleagues are encouraged to think about additional ideas of physics

already 2 papers on the physics at AFTER:
T. Liu, B.Q. Ma, EPJC (2012) 72:2037
D. Boer, C. Pisano, Phys.Rev. D86 (2012) 094007

- Do not hesitate to contact us

Outlooks

- First physics paper to appear in Phys. Repts., 10.1016/j.physrep.2012.10.001.
- A 10-day exploratory workshop will be held at ECT* Trento, February 4-13, 2013 http://indico.in2p3.fr/event/AFTER@ECTstar
- Everybody is welcome (email us at AFTERatECTstar@ipno.in2p3.fr)
  (experimentalist, theorist, beam expert, senior colleague, postdoc, student,. . .)
- Bring your model, discuss it, run it & make predictions for 115/72 GeV !
- We are looking for more experimentalist partners to start
  - doing first simulations
  - thinking about possible designs
  - thinking about the optimal detector technologies
- Theorist colleagues are encouraged to think about additional ideas of physics

already 2 papers on the physics at AFTER:
T. Liu, B.Q. Ma, EPJC (2012) 72:2037
D. Boer, C. Pisano, Phys.Rev. D86 (2012) 094007

- Do not hesitate to contact us
- Webpage: **http://after.in2p3.fr**

ECT* ‘exploratory’ workshop: “Physics at a fixed target experiment using the LHC beams”

- February 4 - February 13, 2013

‘This is an exploratory workshop which aims at studying in detail the opportunity and feasibility of fixed-target experiments using the LHC beam.’

Part VII

Backup slides

Luminosities

- Instantaneous Luminosity:

  $\mathscr{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathscr{N}_A)/A$

  $\Phi_{beam} = 2 \times 10^5$ Pb s^{-1}, $\ell = 1$ cm (target thickness)
- Integrated luminosity $\int dt \mathscr{L} = \mathscr{L} \times 10^6$ s for Pb
- Expected luminosities with 2×10^5Pb s^{-1} extracted (1cm-long target)

Target	ρ (g.cm^{-3})	A	$\mathcal{L}$ (mb^{-1}.s^{-1})=$\int\mathcal{L}$ (nb^{-1}.yr^{-1})
Sol. H_2	0.09	1	**11**
Liq. H_2	0.07	1	**8**
Liq. D_2	0.16	2	**10**
Be	1.85	9	**25**
Cu	8.96	64	**17**
W	19.1	185	**13**
Pb	11.35	207	**7**

- Planned lumi for PHENIX Run15AuAu 2.8 nb^{-1} (0.13 nb^{-1} at 62 GeV)
- Nominal LHC lumi for PbPb 0.5 nb^{-1}

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+ s^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+ s^{-1}$ (1/2 the beam loss) **E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31**

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+ \mathrm{s}^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+ \mathrm{s}^{-1}$ (1/2 the beam loss) **E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31**
- Number of p^+: 2808 bunches of $1.15 \times 10^{11} p^+ = 3.2 \times 10^{14} p^+$

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+\mathrm{s}^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+\mathrm{s}^{-1}$ (1/2 the beam loss) **E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31**
- Number of p^+: 2808 bunches of $1.15 \times 10^{11} p^+ = 3.2 \times 10^{14} p^+$
- Revolution frequency: Each bunch passes the extraction point at a rate of 3.10^5 km.s^{-1}/27 km $\simeq$ 11 kHz

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+ \mathrm{s}^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+ \mathrm{s}^{-1}$ (1/2 the beam loss) E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31
- Number of p^+: 2808 bunches of $1.15 \times 10^{11} p^+ = 3.2 \times 10^{14} p^+$
- Revolution frequency: Each bunch passes the extraction point at a rate of 3.10^5 km.s$^{-1}/27$ km $\simeq 11$ kHz
- Extracted "mini" bunches:
  - the crystal sees $2808 \times 11000\ \mathrm{s}^{-1} \simeq 3.10^7$ bunches s^{-1}
  - one extracts $5.10^8/3.10^7 \simeq 16 p^+$ from each bunch at each pass
  - Provided that the probability of interaction with the target is below 5%, no pile-up...

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+ s^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+ s^{-1}$ (1/2 the beam loss) **E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31**
- Number of p^+: 2808 bunches of $1.15 \times 10^{11} p^+ = 3.2 \times 10^{14} p^+$
- Revolution frequency: Each bunch passes the extraction point at a rate of 3.10^5 km.s^{-1}/27 km $\simeq$ 11 kHz
- Extracted "mini" bunches:
  - the crystal sees 2808×11000 s$^{-1} \simeq 3.10^7$ bunches s^{-1}
  - one extracts $5.10^8/3.10^7 \simeq 16 p^+$ from each bunch at each pass
  - Provided that the probability of interaction with the target is below 5%, no pile-up...
- Extraction over a 10h fill:
  - $5 \times 10^8 p^+ \times 3600$ s h$^{-1} \times 10$ h $= 1.8 \times 10^{13} p^+$ fill^{-1}
  - This means $1.8 \times 10^{13}/3.2 \times 10^{14} \simeq$ 5.6% of the p^+ in the beam

These protons are lost anyway !

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+ s^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+ s^{-1}$ (1/2 the beam loss) E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31
- Number of p^+: 2808 bunches of $1.15 \times 10^{11} p^+ = 3.2 \times 10^{14} p^+$
- Revolution frequency: Each bunch passes the extraction point at a rate of 3.10^5 km.s^{-1}/27 km $\simeq$ 11 kHz
- Extracted "mini" bunches:
  - the crystal sees 2808×11000 s^{-1} $\simeq 3.10^7$ bunches s^{-1}
  - one extracts $5.10^8/3.10^7 \simeq 16 p^+$ from each bunch at each pass
  - Provided that the probability of interaction with the target is below 5%, no pile-up...
- Extraction over a 10h fill:
  - $5 \times 10^8 p^+ \times 3600$ s h^{-1} $\times$ 10 h $= 1.8 \times 10^{13} p^+$ fill^{-1}
  - This means $1.8 \times 10^{13}/3.2 \times 10^{14} \simeq 5.6\%$ of the p^+ in the beam

    These protons are lost anyway !
- similar figures for the Pb-beam extraction

Beam extraction

- **Beam extraction @ LHC**

… there are extremely promising possibilities to extract 7 TeV protons from the circulating beam by means of a bent crystal.

… The idea is to put a bent, single crystal of either Si or Ge (W would perform slightly better but needs substantial improvements in crystal quality) at a distance of $\simeq 7\sigma$ to the beam where it can intercept and deflect part of the beam halo by an angle similar to the one the foreseen dump kicking system will apply to the circulating beam.

… ions with the same momentum per charge as protons are deflected in a crystal with similar efficiencies

Available online at www.sciencedirect.com
SCIENCE @ DIRECT®
ELSEVIER
Nuclear Instruments and Methods in Physics Research B 234 (2005) 31–39
NIM B Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

Strong crystalline fields – a possibility for extraction from the LHC

E. Uggerhøj, U.I. Uggerhøj *

Department of Physics and Astronomy, University of Aarhus, Ny Munkegade, Aarhus C DK-8000, Denmark

Received 9 September 2004; received in revised form 6 January 2005
Available online 24 February 2005

If the crystal is positioned at the kicking section, the whole dump system can be used for slow extraction of parts of the beam halo, the particles that are anyway lost subsequently at collimators.

More details in arxiv:1202.6585

SLAC-PUB-14878

Physics Opportunities of a Fixed-Target Experiment using the LHC Beams

S.J. Brodsky[1], F. Fleuret[2], C. Hadjidakis[3], J.P. Lansberg[3]

[1]*SLAC National Accelerator Laboratory, Theoretical Physics, Stanford University, Menlo Park, California 94025, USA*
[2]*Laboratoire Leprince Ringuet, Ecole polytechnique, CNRS/IN2P3, 91128 Palaiseau, France*
[3]*IPNO, Université Paris-Sud, CNRS/IN2P3, 91406 Orsay, France*

Abstract

We outline the many physics opportunities offered by a multi-purpose fixed-target experiment using the proton and lead-ion beams of the LHC extracted by a bent crystal. In a proton run with the LHC 7-TeV beam, one can analyze *pp*, *pd* and *pA* collisions at center-of-mass energy $\sqrt{s_{NN}} \simeq 115$ GeV and even higher using the Fermi-motion of the nucleons in a nuclear target. In a lead run with a 2.76 TeV-per-nucleon beam, $\sqrt{s_{NN}}$ is as high as 72 GeV. Bent crystals can be used to extract about 5×10^8 protons/sec; the integrated luminosity over a year would reach 0.5 fb^{-1} on a typical 1 cm-long target without nuclear species limitation. We emphasize that such an extraction mode does not alter the performance of the collider experiments at the LHC. By instrumenting the target-rapidity region, gluon and heavy-quark distributions of the proton and the neutron can be accessed at large x and even at x larger than unity in the nuclear case. Single diffractive physics and, for the first time, the large negative-x_F domain can be accessed. The nuclear target-species versatility provides a unique opportunity to study nuclear matter versus the features of the hot and dense matter formed in heavy-ion collisions, including the formation of the Quark-Gluon Plasma (QGP), which can be studied in *PbA* collisions over the full range of target rapidities with a large variety of nuclei. The polarization of hydrogen and nuclear targets allows an ambitious spin program, including measurements of the QCD lensing effects which underlie the Sivers single-spin asymmetry, the study of transversity distributions and possibly of polarized parton distributions. We also emphasize the potential offered by *pA* ultra-peripheral collisions where the nucleus target *A* is used as a coherent photon source, mimicking photoproduction processes in *ep* collisions. Finally, we note that *W* and *Z* bosons can be produced and detected in a fixed-target experiment and in their threshold domain for the first time, providing new ways to probe the partonic content of the proton and the nucleus.

Keywords: LHC beam, fixed-target experiment

More details in arxiv:1202.6585

Contents

More details in arxiv:1202.6585

Accessing the large *x* glue

PYTHIA simulation
$\sigma(y) / \sigma(y=0.4)$
statistics for one month
5% acceptance considered

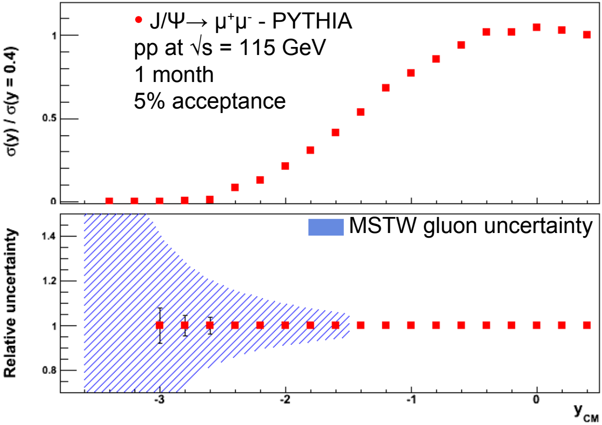
Statistical relative uncertainty
Large statistics allow to access very backward region

Gluon uncertainty from MSTWPDF
- only for the gluon content of the target
- assuming

$$x_g = M_{J/\Psi}/\sqrt{s}\, e^{-y_{CM}}$$

J/Ψ
$y_{CM} \sim 0 \rightarrow x_g = 0.03$
$y_{CM} \sim -3.6 \rightarrow x_g = 1$

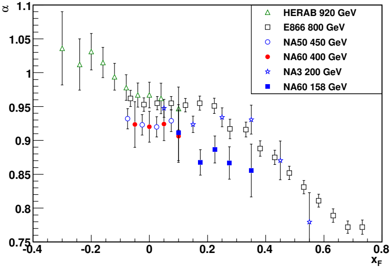
Υ: larger x_g for same y_{CM}
$y_{CM} \sim 0 \rightarrow x_g = 0.08$
$y_{CM} \sim -2.4 \rightarrow x_g = 1$



⇒ Backward measurements allow to access large x gluon pdf

SPS and Hera-B

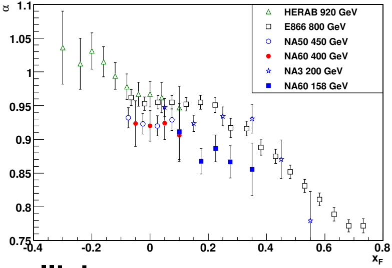
– J/ψ **data in** pA **collisions**



NA60 Phys.Lett. B 706 (2012) 263
NA 50 Eur.Phys.J. C48 (2006) 329
NA 3 Z.Phys. C20 (1983)
HERA-B Eur.Phys.J. C60 (2009) 525

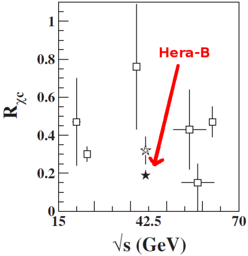
SPS and Hera-B

– J/ψ data in pA collisions



NA60 Phys.Lett. B 706 (2012) 263
NA 50 Eur.Phys.J. C48 (2006) 329
NA 3 Z.Phys. C20 (1983)
HERA-B Eur.Phys.J. C60 (2009) 525

– χ_c data in pA collisions



HERA-B PRD 79 (2009) 012001, and ref. therein