The France-Stanford Center for Interdisciplinary Studies

Precision quarkonium studies using multi-purpose fixed-target experiments

(in particular, A Fixed-Target ExpeRiment using the proton and lead LHC beams)

Jean-Philippe Lansberg

IPN Orsay, Université Paris-Sud

5th International workshop on heavy quark production in heavy-ion collisions

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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)

Part I

Fixed-target experiments and quarkonia

Decisive advantages of Fixed-target experiments

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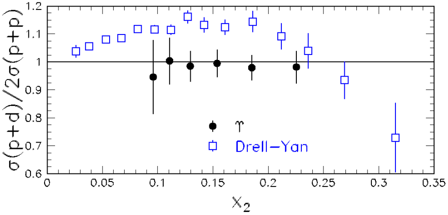
- They exhibit 4 decisive features,
  - accessing the high Feynman x_F domain,
  - achieving high luminosities with dense targets,
  - varying the atomic mass of the target almost at will
  - polarising the target.
- They brought essential contributions to particle & nuclear physics
  - particle discoveries ($\Omega^-(sss)$, J/ψ, Υ,...)
  - evidence for the novel dynamics of quarks and gluons in HIC (QGP)
  - observation of surprising QCD phenomena (at large x_F)

    · breakdown of the Lam-Tung relation,
    · colour transparency,
    · higher-twist effects at high x_F,
    · anomalously large SSA & DSA,
    · factorisation breakdown in high-x_F J/ψ production in pA

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 than DY

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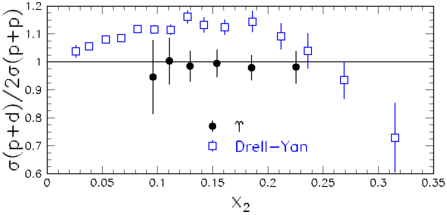
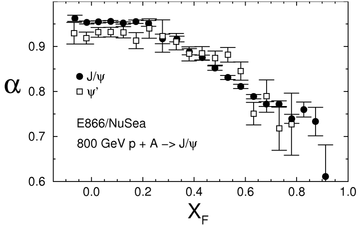


Precision: necessary to show a different behaviour than DY

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

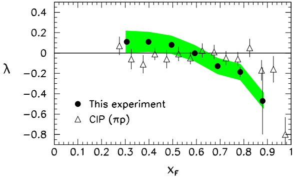


Precision:necessary to show a different behaviour of $\psi(2S)$ vs. J/ψ

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



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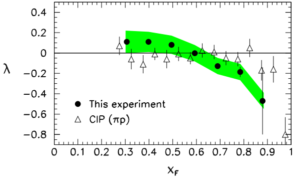

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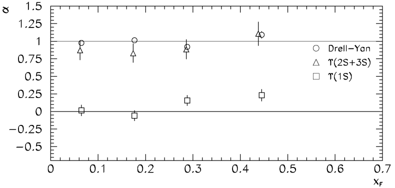
– **Precision $\Upsilon(nS)$ polarisation (in the CS frame) studies**

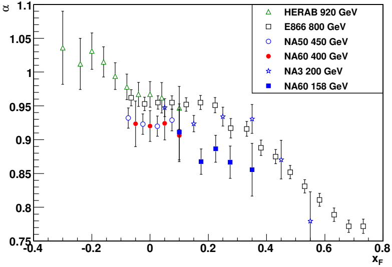
E866 PRL 86 2529 (2001)



Precision: necessary to show the diffent pol. pattern between 1S and 2S+3S

SPS and Hera-B

– **More 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

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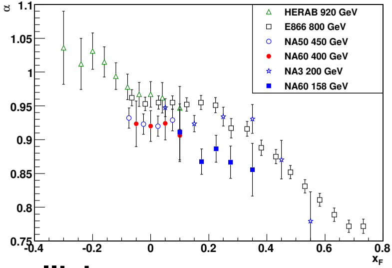

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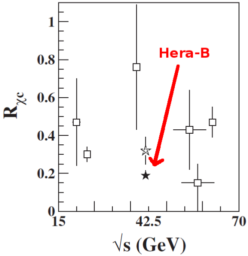
– χ_c **data in pA collisions**



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

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

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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**

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- with virtually no limit on particle-species studies (except top quark)

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- 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): generalities

A Fixed Target ExperRiment using the LHC beams

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- Crystal channeling is also possible for heavy-ion beams

  Recent test with Pb at SPS: W. Scandale *et al.*, PLB 703 (2011) 547
- If required, bent diamonds may provide a crystal highly resistant to radiations

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

Luminosities

- Instantaneous Luminosity:
  $\mathcal{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathcal{N}_A)/A$
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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**
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- Lumi for Pb runs in the backup slides (roughly 10 times that of the LHC)

Part III

AFTER and heavy-flavour physics

A Fixed Target ExpeRiment: e.g. 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
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  - χ_c measurement in *pA* via $J/\psi + \gamma$ (extending Hera-B studies)

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

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The same picture also holds for open heavy flavour

Part IV

AFTER: flagships measurements

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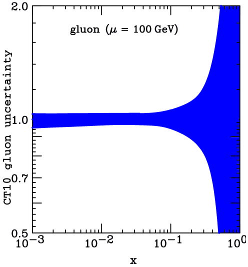
  - proton



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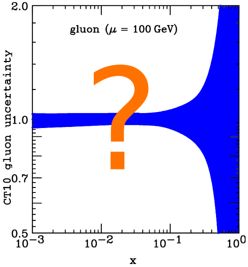

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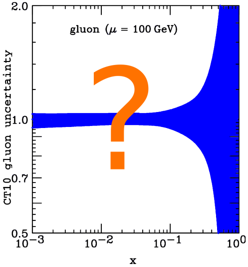

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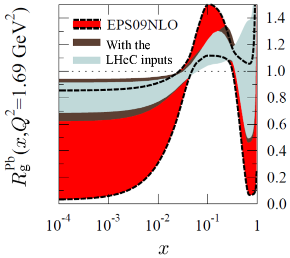

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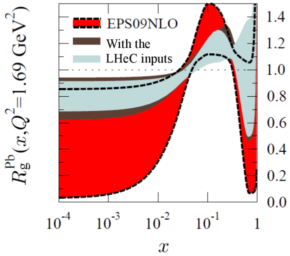
    absolutely complementary with LHeC



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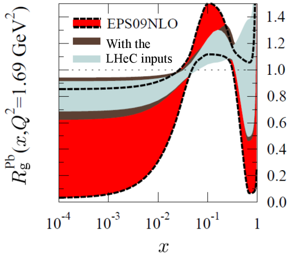

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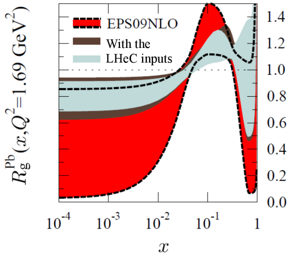

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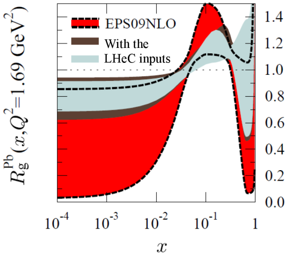

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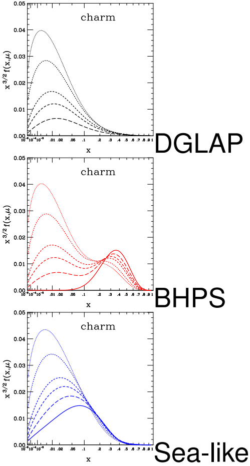

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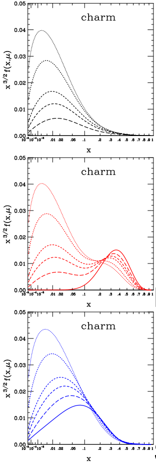

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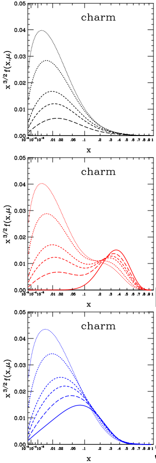

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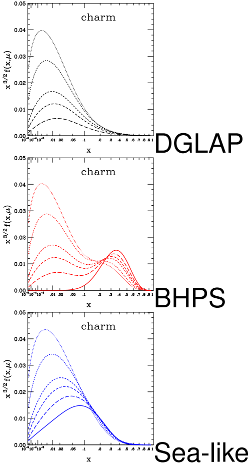

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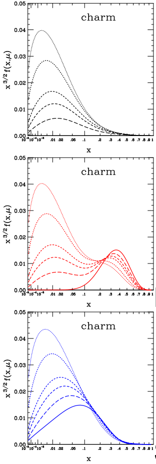

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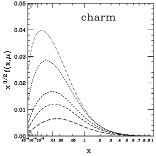

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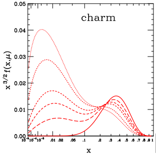

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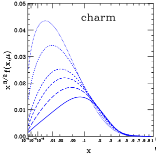

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A. Bacchetta, *et al.*, **PRL 99 (2007) 212002**
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- In general, one can carry out an extensive spin-physics program

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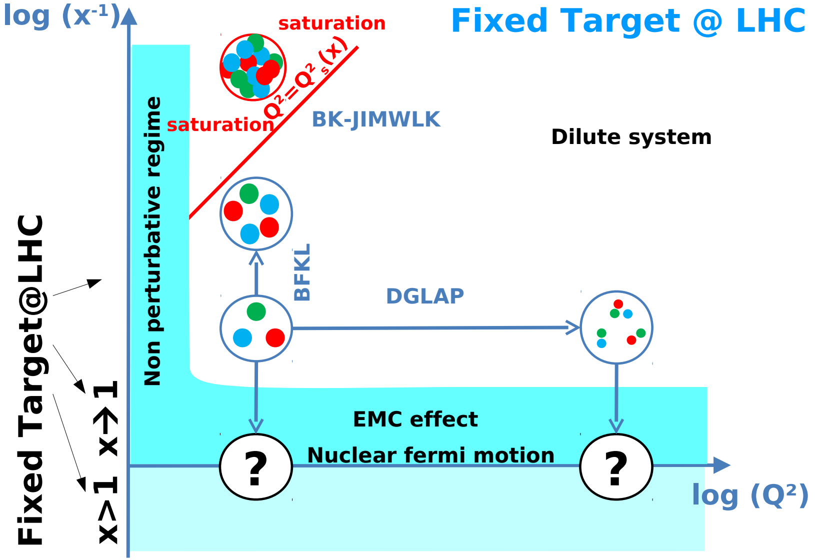
  - Reconstructed rate are most likely between a few dozen to a few thousand / year
- Multiply heavy baryons: discovery potential ? ($\Omega^{++}(ccc)$, ...)
- Very forward (backward) physics:
  - semi-diffractive events
  - Ultra-peripheral collisions, etc.

Overall



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Q²=Q²s(x)
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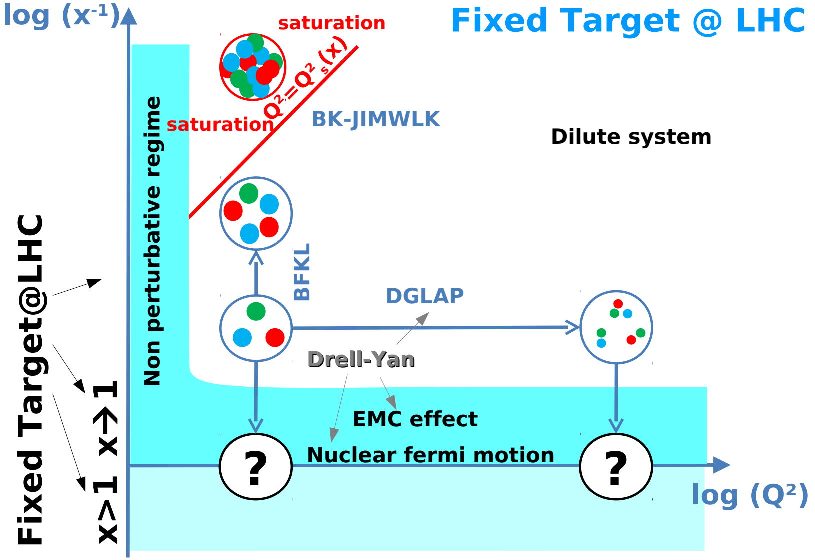

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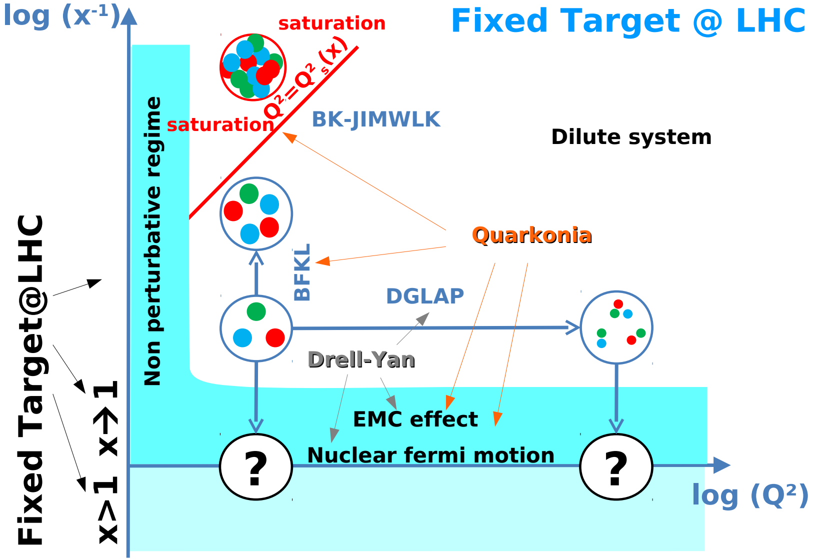

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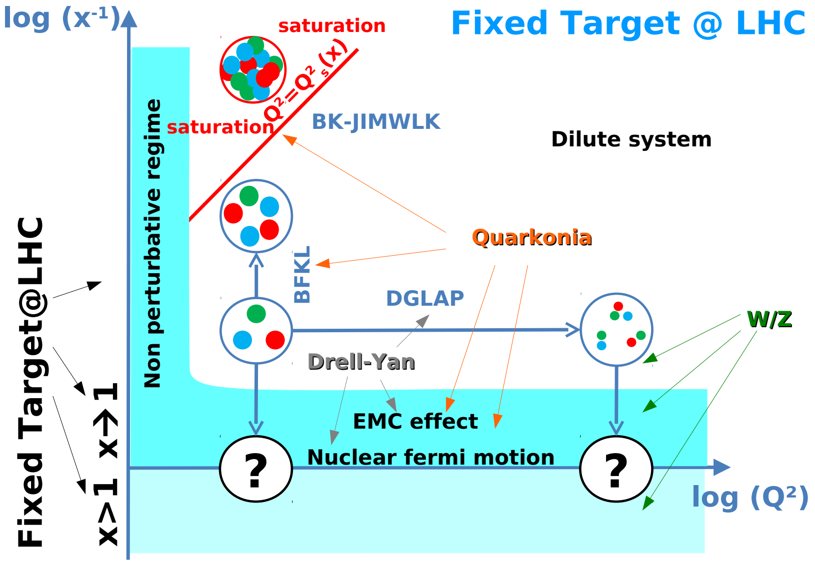
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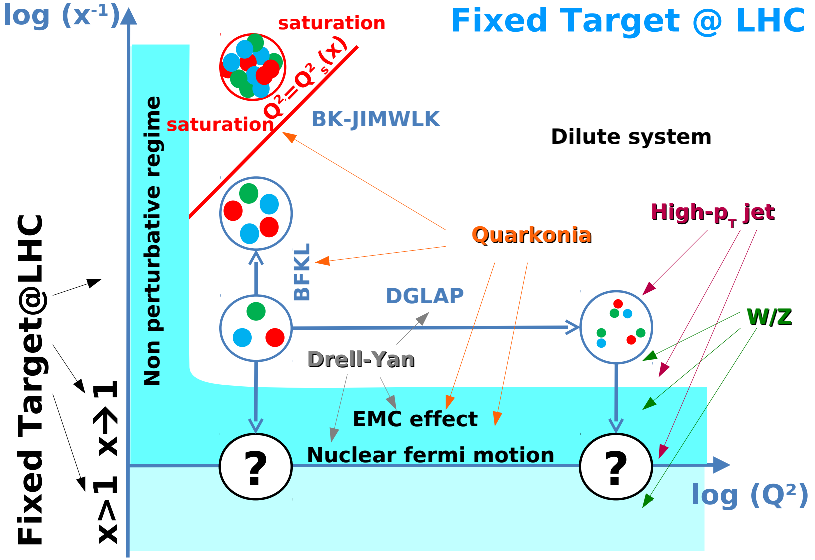

log (x⁻¹)
saturation
Fixed Target @ LHC
$Q^2=Q^2_s(x)$
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
High-p_T jet
Quarkonia
BFKL
DGLAP
W/Z
Fixed Target@LHC
Drell-Yan
x→1
x>1
EMC effect
?
Nuclear fermi motion
?
log (Q²)

Part V

Conclusion and outlooks

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- Very good complementarity with electron-ion programs

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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 VI

Backup slides

Luminosities

- Instantaneous Luminosity:
  $\mathcal{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathcal{N}_A)/A$
  $\Phi_{beam} = 2 \times 10^5$ Pb s^{-1}, $\ell = 1$ cm (target thickness)
- Integrated luminosity $\int dt \mathcal{L} = \mathcal{L} \times 10^6$ 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: $10^9\ p^+ \mathrm{s}^{-1}$
- 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**

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  - one extracts $5.10^8/3.10^7 \simeq 16 p^+$ from each bunch at each pass
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- Extraction over a 10h fill:
  - $5 \times 10^8 p^+ \times 3600\ \mathrm{s\ h}^{-1} \times 10\ \mathrm{h} = 1.8 \times 10^{13} p^+$ fill^{-1}
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These protons are lost anyway !

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- 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

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Nuclear Instruments and Methods in Physics Research B 234 (2005) 31–39
NIM B
Beam Interactions with Materials & Atoms
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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

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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

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Accessing the large x glue

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

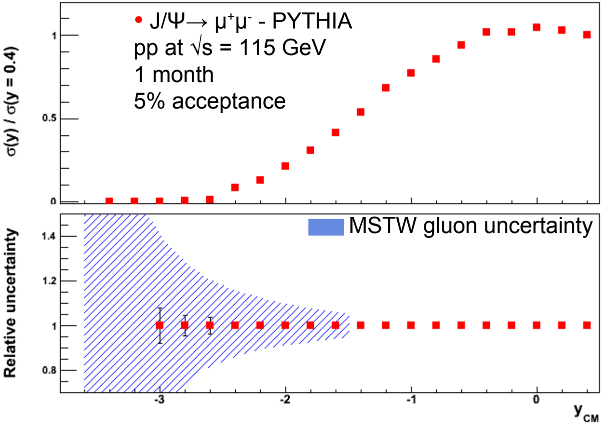
Statistical relative uncertainty
Large statistics allow to access very backward region

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