

A Fixed-Target Experiment (AFTER) using the LHC beams



AFTER @ LHC

Cynthia Hadjidakis



Annual meeting of the GDR PH-QCD
Orsay, December 7th 2012

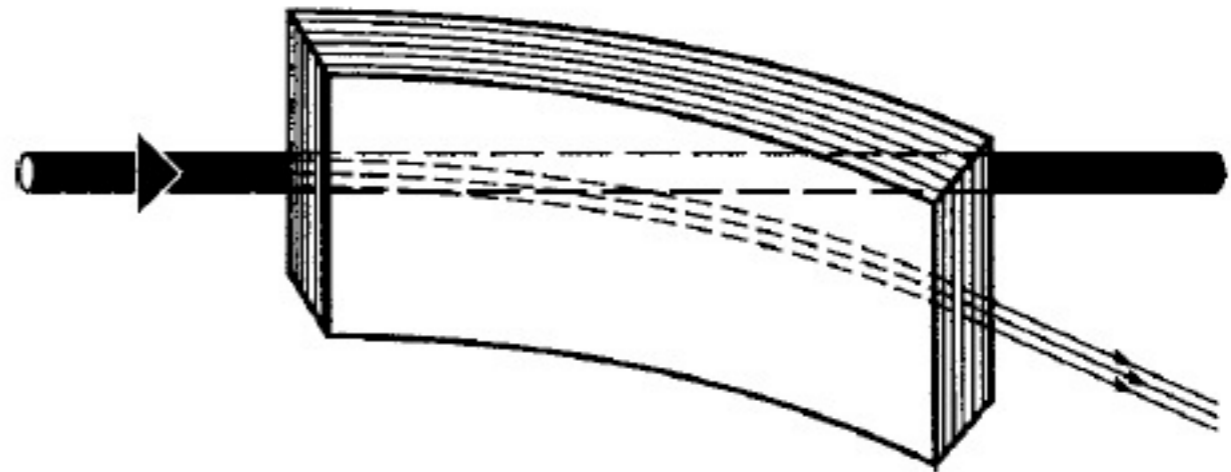
Overview

- Beam extraction using bent crystal and its application at the LHC
- Expected luminosities and physics opportunities for a fixed target experiment at the LHC
- Expected yields for quarkonium studies

Strong crystalline fields in bent crystals

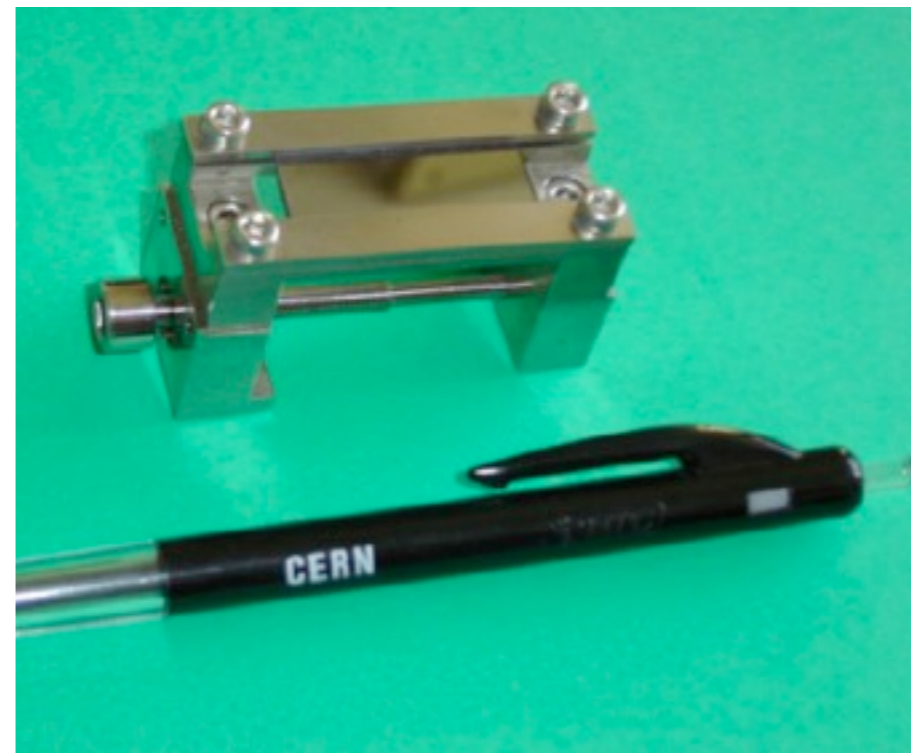
Strong electric fields in the lattice nuclei of a crystal in the rest frame of the crossing particles

In a bent crystal, guidance of particles \Leftrightarrow bending strength as for a magnetic dipole



Many experiments for proton beam extraction and collimation using crystals:

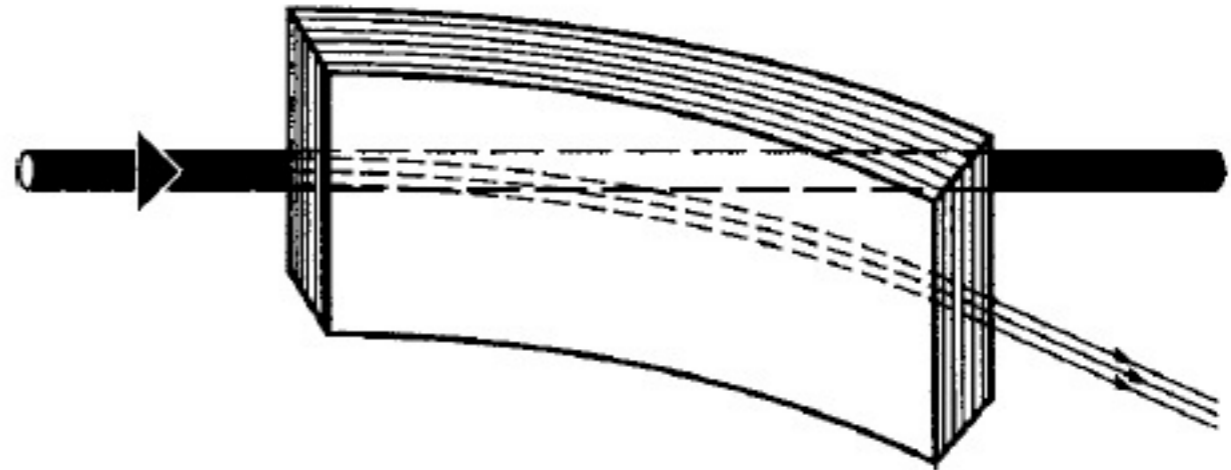
- RD22 @ CERN-SPS (1990-95)
- E853 @ FNAL-Tevatron (1993-97)
- INTAS @ U70 IHEP (2001-03)
- RHIC (2001-05)
- Tevatron (2005-11)
- UA9 @ SPS (2008-...)
- ...



Strong crystalline fields in bent crystals

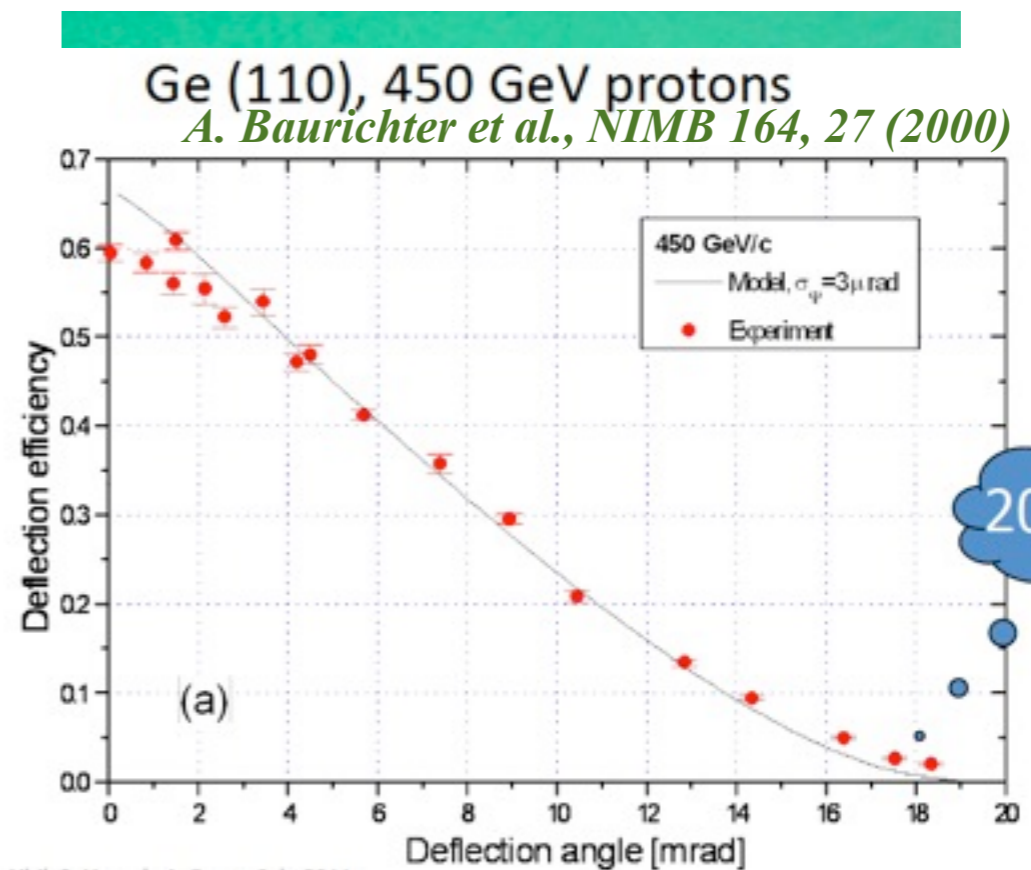
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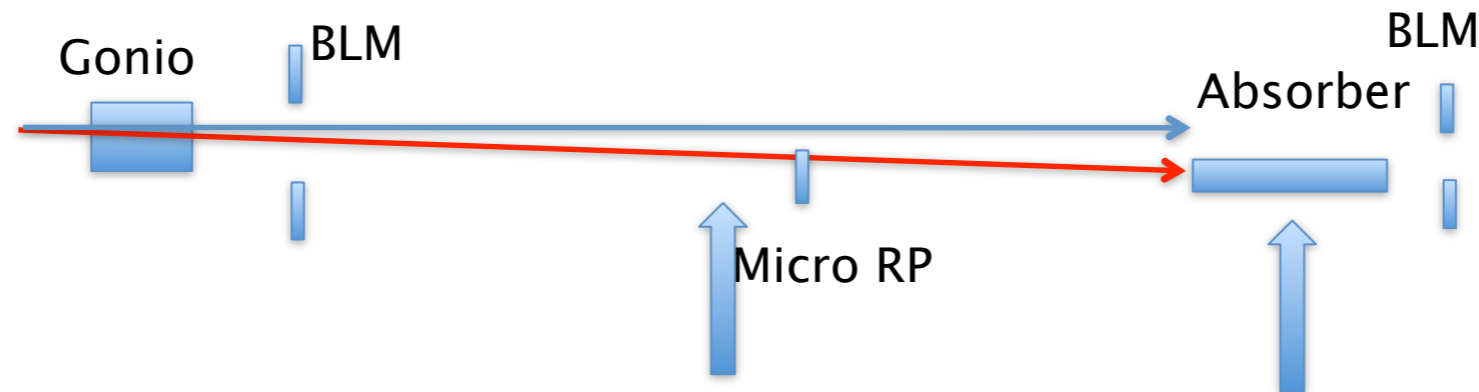
•Ulrik I. Uggerhøj, Orsay, July 2011

•11

Next: beam bending experiment @ LHC



W. Scandale et al., JINST 6 T10002 (2011)



- LHC Committee approved beam bending experiments using crystals at the LHC (LUA9 Collaboration)
- Beam collimation @ LHC: amorphous collimator: inefficiency @ 3.5 TeV proton beam = 0.2% → expected bent crystal inefficiency = 0.02%
- Tests at SPS in 2012 on proton and ion beams for a LHC setup
- Long Shutdown 1 (2013): bent crystals in LHC beams



W. Scandal

Gonio

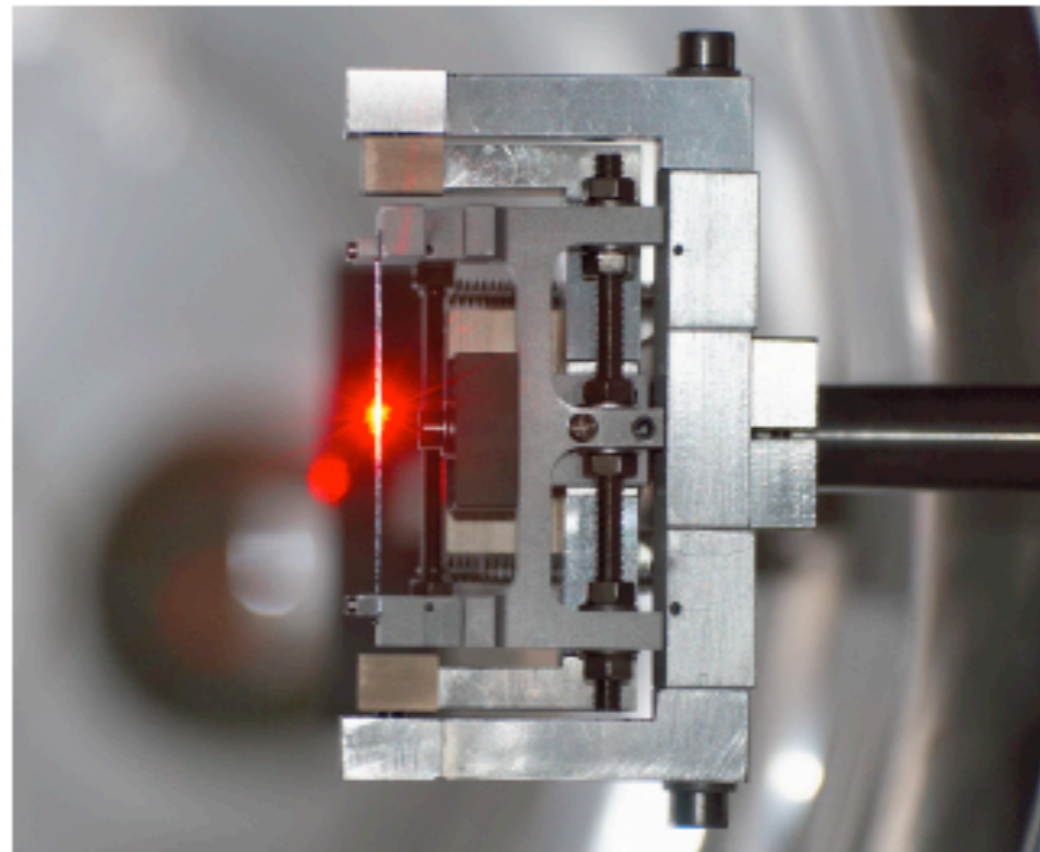


- LHC Commi
at the LHC (I
- Beam collima
3.5 TeV proto
0.02%
- Tests at SPS
- Long Shutdo



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Crystals in the LHC



UA9 bent crystal tested with a laser.

Bent crystals can be used to deflect charged particle beams. Their use in high-energy accelerators has been investigated for almost 40 years. Recently, a bent crystal was irradiated for the first time in the HiRadMat facility with an extreme particle flux, which crystals would have to withstand in the LHC. The results were very encouraging and confirmed that this technology could play a major role in increasing the beam collimation performance in future upgrades of the machine.



Particle physics: a valuable driver of innovation in medicine... and physics

This year marks the 10th anniversary of the European Network for Light Ion Therapy (ENLIGHT), which is a good occasion a look back over the important contributions particle physics has made to medicine over the years. It's hard to know exactly where to start, but since this year also marks the 20th anniversary of Georges Charpak's Nobel Prize, that seems as good a place as any.

(Continued on page 2)

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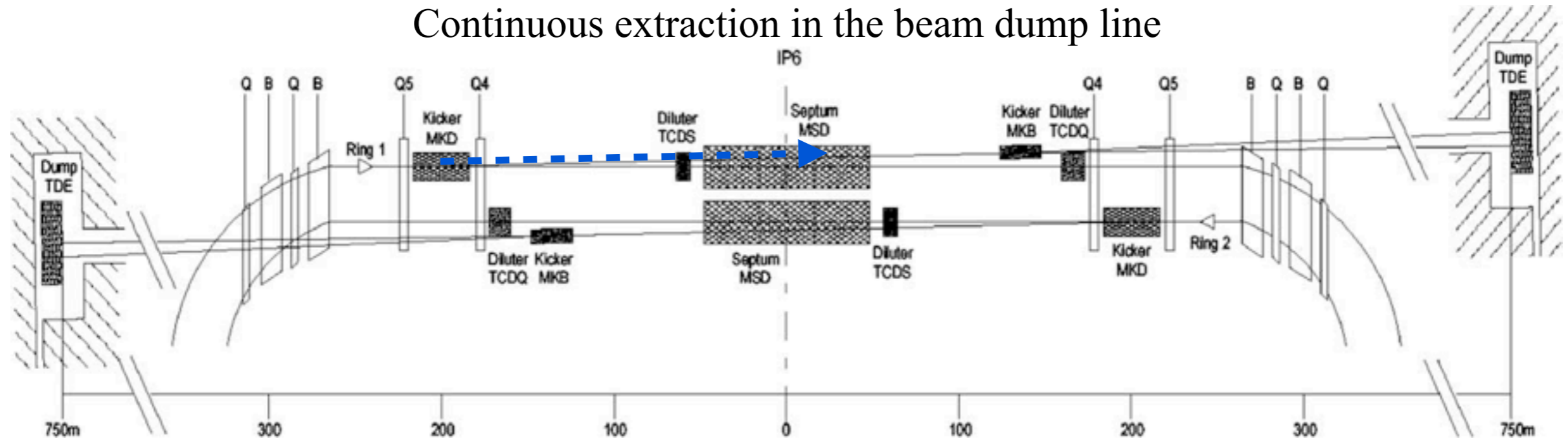
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Next: beam extraction experiment at the LHC

E. Uggerhoj and U.I Uggerhoj NIMB 234 (2005) 34

Continuous extraction in the beam dump line



- Proposal for the insertion of a bent crystal in the LHC beam
 - Bent, single crystal of Si or Ge - 17cm long crystal
 - MKD kicker section at ~ 200 m from IP6
 - Deflection angle = 0.257 mrad (~ 7 T.m equivalent magnet)
 - Distance of 7σ to the beam to intercept and deflect the beam halo
 - No loss in the LHC beam
 - Bent crystal acts as a beam collimator

• Proton beam extraction

- Single- or multi pass extraction efficiency of 50%
 - $N_{\text{beam loss LHC}} \sim 10^9$ p/s $\rightarrow N_{\text{extracted beam}} = 5 \cdot 10^8$ p/s
- Extremely small emittance: beam size in the extraction direction) 950 m after the extraction ~ 0.3 mm

• Ion beam extraction

- Ions extraction tested at SPS, is expected to be also possible at LHC but needs more study
- May require bent diamonds (highly resistant to radiations)

P. Ballin et al, NIMB 267 (2009) 2952

Luminosities in pH and pA @ 115 GeV

- **Intensity:** $N_{\text{beam}} = 5 \cdot 10^8 \text{ protons} \cdot \text{s}^{-1}$
 - **Beam:** 2808 bunches of $1.15 \times 10^{11} \text{ p} = 3.2 \times 10^{14} \text{ p}$
 - **Bunch:** Each bunch passes IP at the rate: $\sim 11 \text{ kHz}$
 - **Instantaneous extraction:** IP sees $2808 \times 11000 \sim 3 \cdot 10^7$ bunches passing every second \rightarrow extract ~ 16 protons in each bunch at each pass
 - **Integrated extraction:** Over a 10h run: extract $\sim 5.6\%$ of the protons stored in the beam

- **Instantaneous Luminosity**

$$L = N_{\text{beam}} \times N_{\text{Target}} = N_{\text{beam}} \times (\rho \times e \times N_A) / A$$
 - $N_{\text{beam}} = 5 \times 10^8 \text{ p}^+/\text{s}$
 - e (target thickness) = 1 cm
- **Integrated luminosity**
 - 9 months running/year
 - 1 year $\sim 10^7 \text{ s}$

Target (1 cm thick)	ρ (g cm^{-3})	A	\mathcal{L} ($\mu\text{b}^{-1} \text{s}^{-1}$)	$\int \mathcal{L}$ ($\text{pb}^{-1} \text{yr}^{-1}$)
solid H	0.088	1	26	260
liquid H	0.068	1	20	200
liquid D	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

\Rightarrow Large luminosity in pH(A) ranging from 0.1 and 0.6 fb^{-1} for a 1 cm thick target

\Rightarrow Larger luminosity with 50 cm or 1 m H₂ or D₂ target 20 fb^{-1} , i.e. the same

as the LHC in 2012, with 1m

Luminosities in PbA @ 72 GeV

- **Intensity:** $N_{\text{beam}} = 2.10^5 \text{ Pb.s}^{-1}$

- **Beam:** 592 bunches of 7×10^7 ions = 4.1×10^{10} ions
- **Bunch:** Each bunch passes IP at the rate $\sim 11 \text{ kHz}$
- **Instantaneous extraction:** IP sees $592 \times 11000 \sim 6.5 \cdot 10^6$ bunches passing every second \rightarrow extract ~ 0.03 ions in each bunch at each pass
- **Integrated extraction:** Over a 10h run: extract $\sim 15\%$ of the ions stored in the beam

- **Instantaneous Luminosity**

$$L = N_{\text{beam}} \times N_{\text{Target}} = N_{\text{beam}} \times (\rho \times e \times N_A) / A$$

- $N_{\text{beam}} = 2 \times 10^5 \text{ Pb/s}$
- e (target thickness) = 1 cm

- **Integrated luminosity**

- 1 months running/year
- 1 year $\sim 10^6 \text{ s}$

Target (1 cm thick)	ρ (g cm $^{-3}$)	A	\mathcal{L} (mb $^{-1}$ s $^{-1}$)	$\int \mathcal{L}$ (nb $^{-1}$ yr $^{-1}$)
solid H	0.088	1	11	11
liquid H	0.068	1	8	8
liquid D	0.16	2	10	10
Be	1.85	9	25	25
Cu	8.96	64	17	17
W	19.1	185	13	13
Pb	11.35	207	7	7

\Rightarrow AFTER provides a good luminosity to study QGP related measurements

Polarizing the hydrogen target

• Instantaneous Luminosity

$$L = N_{\text{beam}} \times N_{\text{Target}} = N_{\text{beam}} \times (\rho \times e \times N_A) / A$$

- $N_{\text{beam}} = 5 \times 10^8 \text{ p}^+/\text{s}$
- e (target thickness) = 50 cm

x_p^\uparrow range corresponds to Drell-Yan measurements

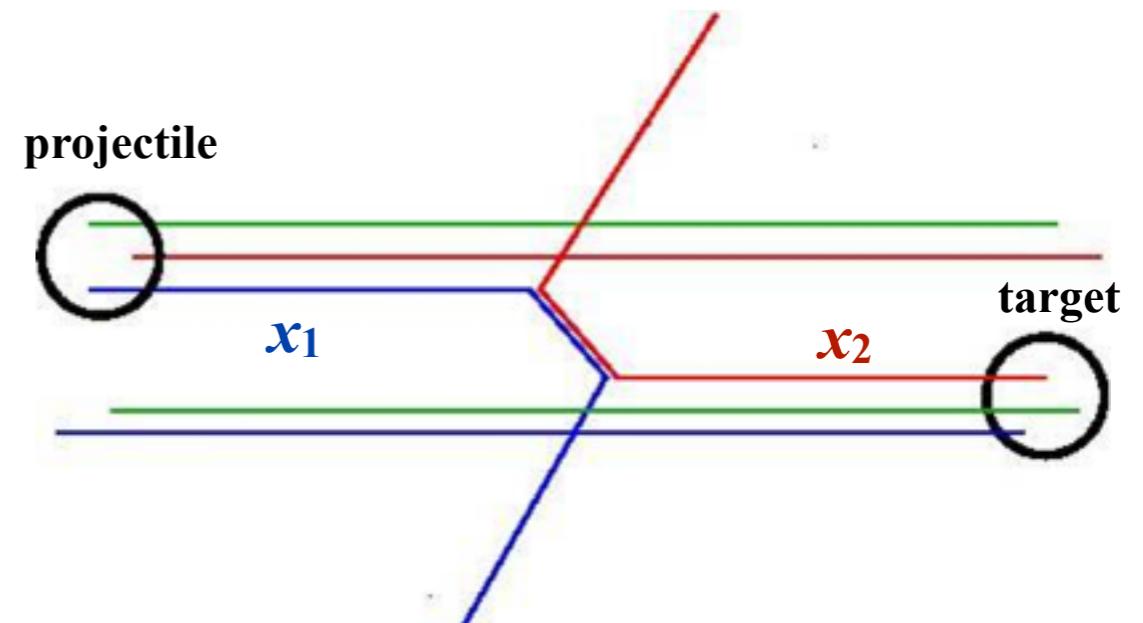
Experiment	particles	energy (GeV)	\sqrt{s} (GeV)	x_p^\uparrow	\mathcal{L} (nb ⁻¹ s ⁻¹)
AFTER	$p + p^\uparrow$	7000	115	0.01 ÷ 0.9	1
COMPASS	$\pi^\pm + p^\uparrow$	160	17.4	0.2 ÷ 0.3	2
COMPASS (low mass)	$\pi^\pm + p^\uparrow$	160	17.4	~ 0.05	2
RHIC	$p^\uparrow + p$	collider	500	0.05 ÷ 0.1	0.2
J-PARC	$p^\uparrow + p$	50	10	0.5 ÷ 0.9	1000
PANDA (low mass)	$\bar{p} + p^\uparrow$	15	5.5	0.2 ÷ 0.4	0.2
PAX	$p^\uparrow + \bar{p}$	collider	14	0.1 ÷ 0.9	0.002
NICA	$p^\uparrow + p$	collider	20	0.1 ÷ 0.8	0.001
RHIC	$p^\uparrow + p$	250	22	0.2 ÷ 0.5	2
Int.Target 1					
RHIC	$p^\uparrow + p$	250	22	0.2 ÷ 0.5	60
Int.Target 2					

⇒ AFTER provides a good luminosity to study target spin related measurements

⇒ Complementary x_p range with other spin physics experiments

Rapidity boost in a fixed target mode

- **Very high boost:**
 - With 7 TeV beam
 $\gamma = \sqrt{s}/(2m_p) = 61.1$ and $y_{\text{CMS}} = 4.8$
 - With 2.76 TeV beam
 $\gamma = 38.3$ and $y_{\text{CMS}} = 4.3$
- $y_{\text{lab}} = y_{\text{CM}} + y_{\text{CMS}}$
 - forward region:** $y_{\text{CM}} > 0$
 - backward region:** $y_{\text{CM}} < 0$
- $\eta = -\ln \tan \theta/2$ (= y for massless particles)
 - With 7 TeV beam
 $y_{\text{CM}} = 0 \Leftrightarrow \theta \sim 16 \text{ mrad} (0.9^\circ)$
 $y_{\text{CM}} = 0.5 \Leftrightarrow \theta \sim 10 \text{ mrad}$
 - With 2.76 TeV beam
 $y_{\text{CM}} = 0.5 \Leftrightarrow \theta \sim 16 \text{ mrad}$
 $y_{\text{CM}} = 1 \Leftrightarrow \theta \sim 10 \text{ mrad}$



For a $2 \rightarrow 1$ process (e.g. $gg \rightarrow QQ\bar{q}$)

$$x_2 = \frac{M}{\sqrt{s}} e^{-y_{\text{CM}}}$$

y_{CM} : $QQ\bar{q}$ CMS rapidity

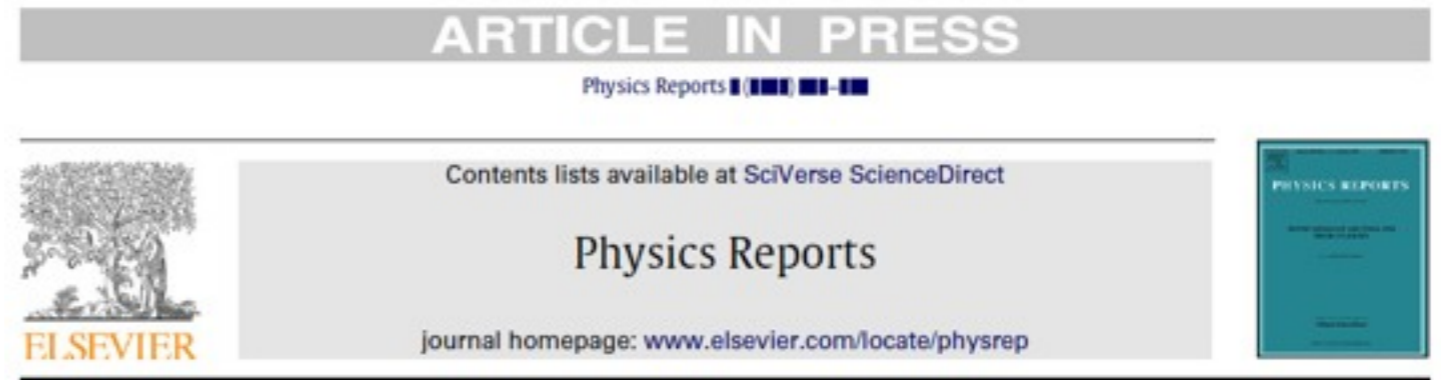
M : $QQ\bar{q}$ mass

- $y_{\text{CM}} = 0 \rightarrow x_1 = x_2$
- **backward region:** $y_{\text{CM}} < 0 \rightarrow x_1 < x_2$
- $y_{\text{lab}}(J/\Psi) \sim 1.2 \rightarrow x_2 = 1$
- $y_{\text{lab}}(Y) \sim 2.4 \rightarrow x_2 = 1$

Good condition to access large target x_2 and low $x_F = x_1 - x_2 \rightarrow -1$: target-rapidity region

Physics opportunities of A Fixed-Target Experiment (AFTER) @LHC

- **Idea: use LHC beams on fixed target**
 - 7 TeV proton beam ($\sqrt{s} \sim 115$ GeV)
 - p+H, p+A
 - 2.76 TeV Pb beam ($\sqrt{s_{NN}} \sim 72$ GeV)
 - Pb+A, Pb+H
- **High boost and luminosity giving access to**
 - QCD at large x
 - nPDF and nuclear shadowing
 - Spin physics using polarized target
 - W/Z production near threshold
 - Quark Gluon Plasma
 - Other ?
- **Multi-purpose experiment**



Phys. Rep. (2012), 10.1016

Physics opportunities of a fixed-target experiment using LHC beams

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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/s; the integrated luminosity over a year reaches 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, which can be studied in PbA collisions over the full range of target-rapidity domain 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.

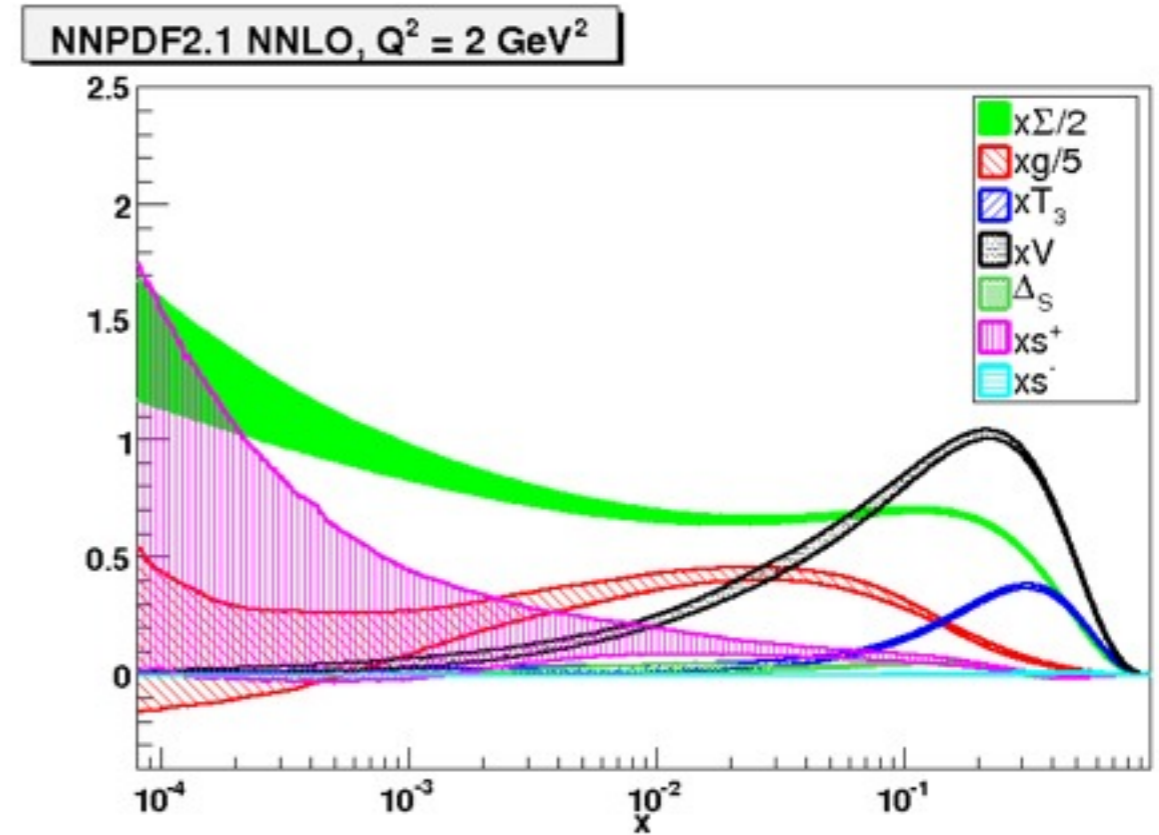
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Gluon distribution at large x

Gluon distribution function in the proton: very large uncertainty at large x also at large Q

Unknown for the neutron

Large uncertainty in nuclei at large x (LHeC will probe the low x)

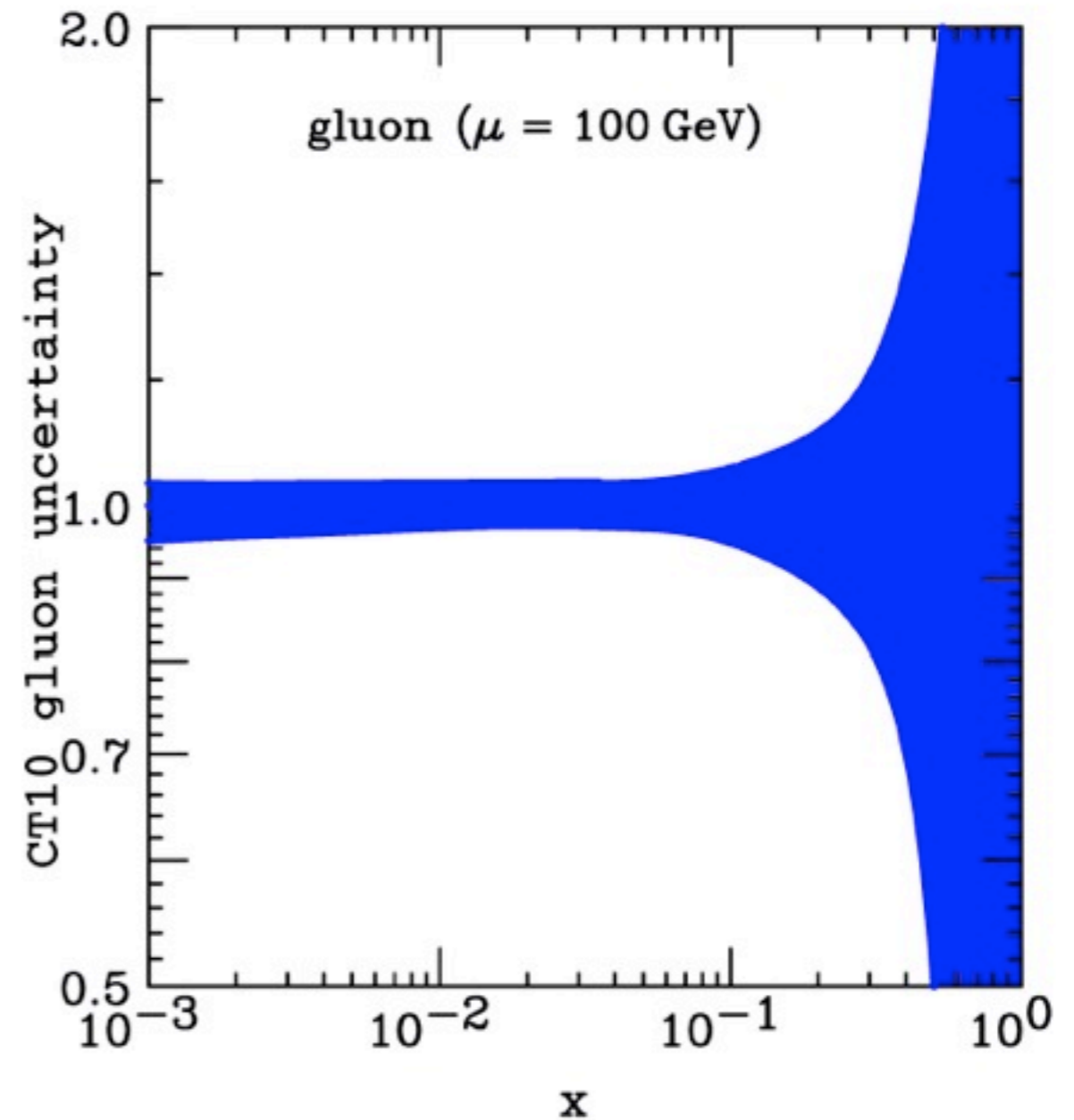


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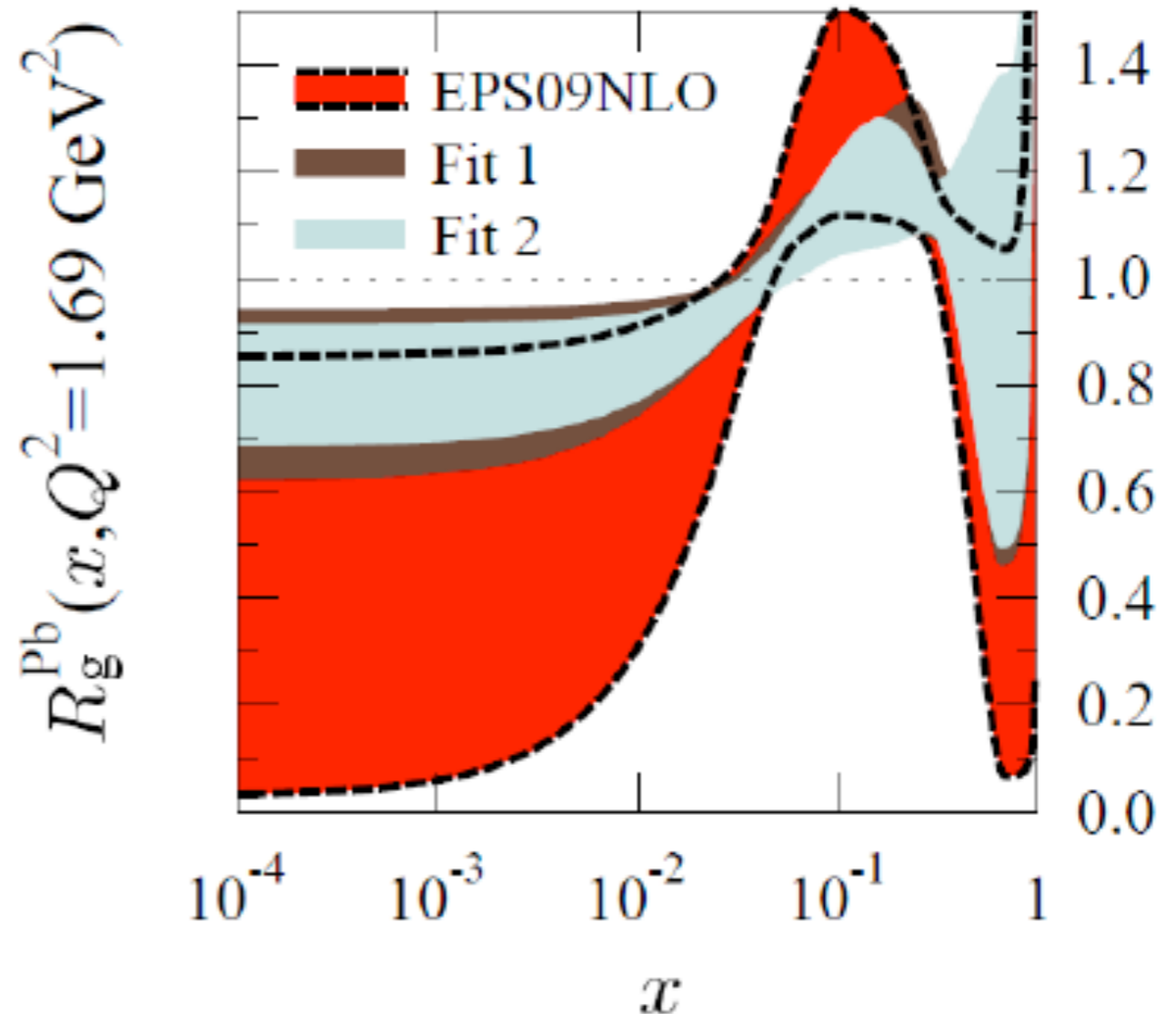
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LHeC CDR J. Phys. G 39 (2012) 075001



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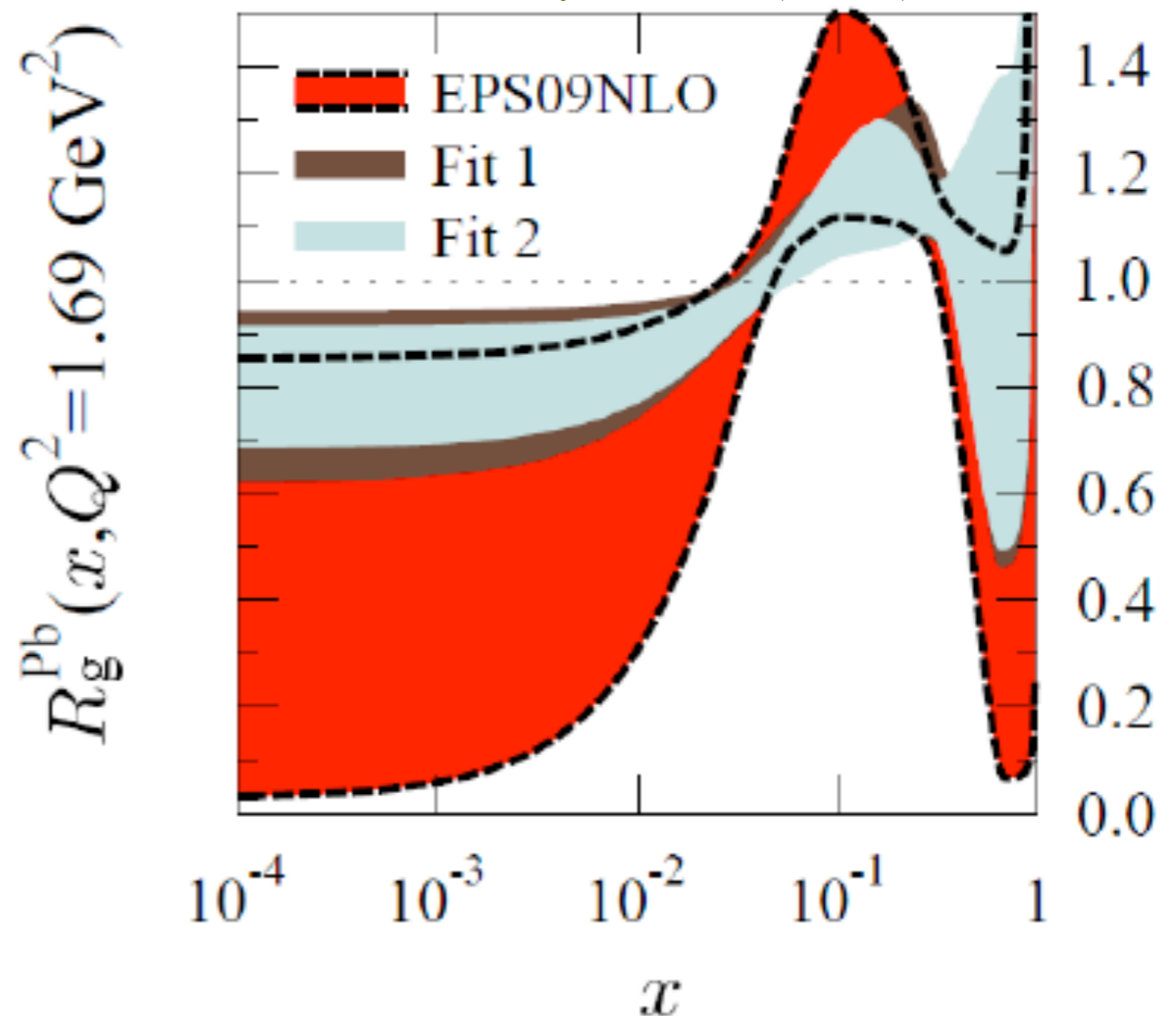
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Large uncertainty in nuclei at large x (LHeC will probe the low x)

- **Experimental probes @ AFTER**
 - Quarkonia
 - Isolated photons
 - High p_T jets ($p_T > 20$ GeV/c)
 - to access target $x_g = 0.3 - 1$ (>1 Fermi motion in nucleus)
- **Target versatility**
 - Hydrogen
 - Deuteron (neutron)
 - Nuclei

LHeC CDR J. Phys. G 39 (2012) 075001

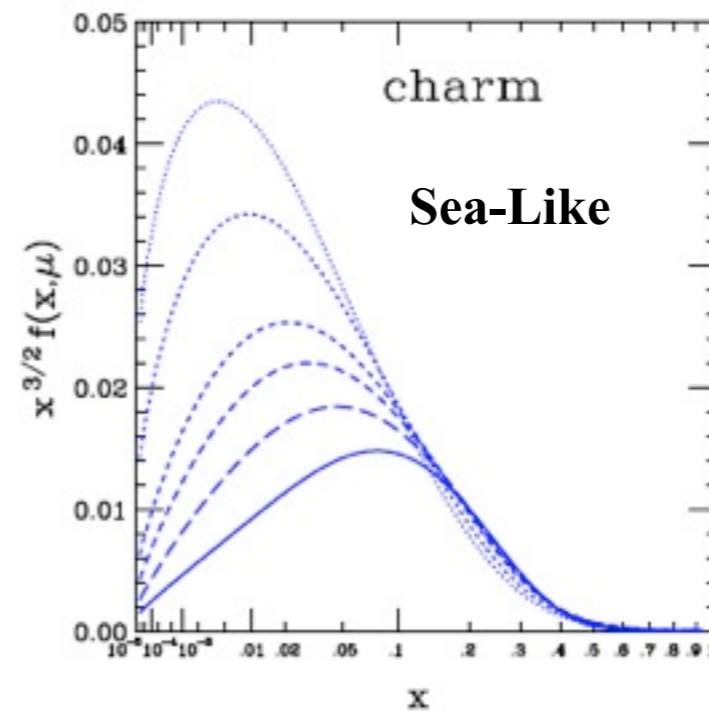
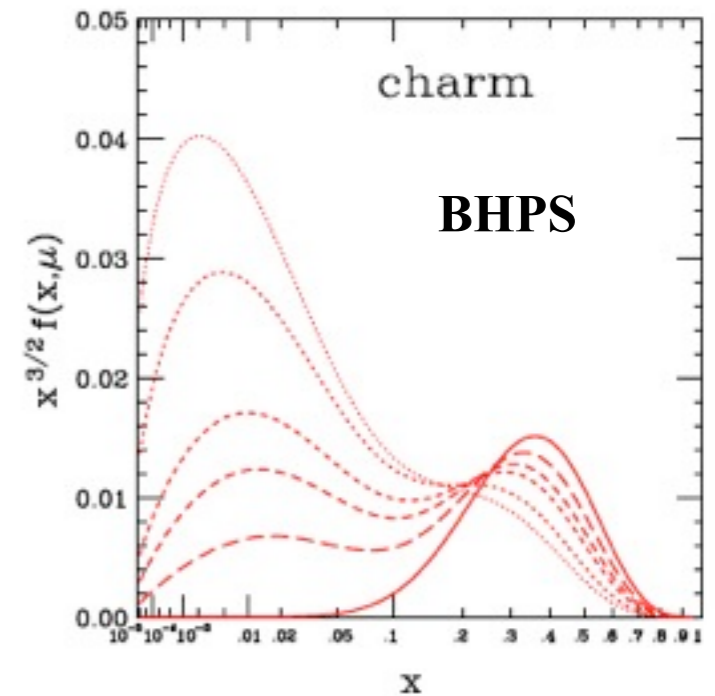
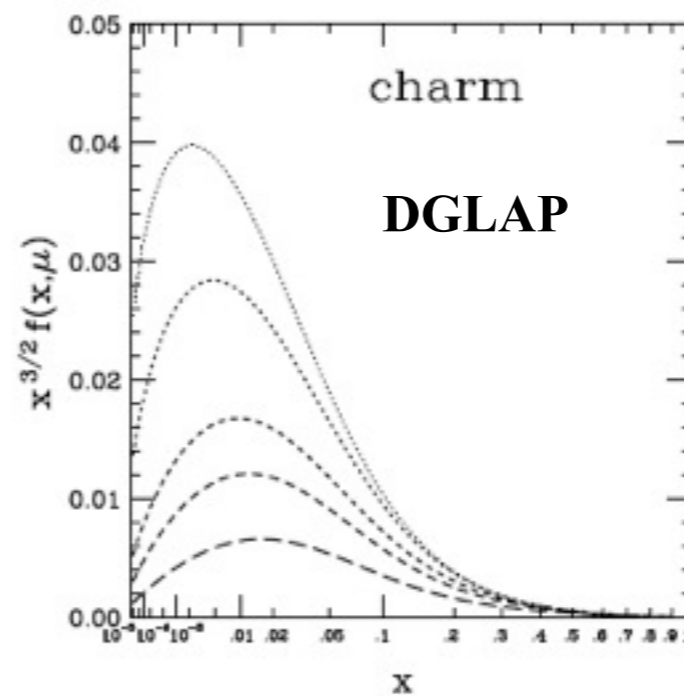


Heavy-quark distribution at large x

Pumplin et al. Phys.Rev. D75 (2007)

Intrinsic charm motivated by non perturbative models of hadron structure

All different charm pdfs (DGLAP or intrinsic charm) in agreement with DIS data



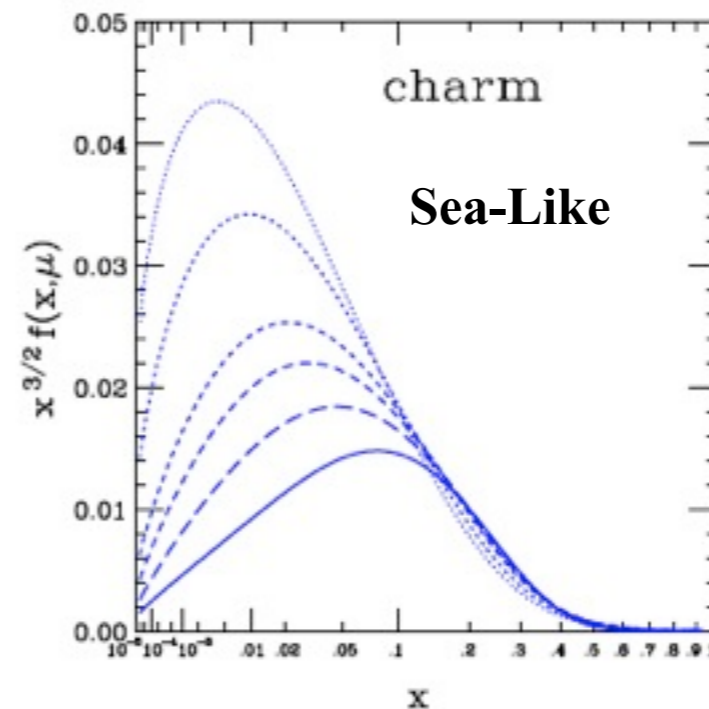
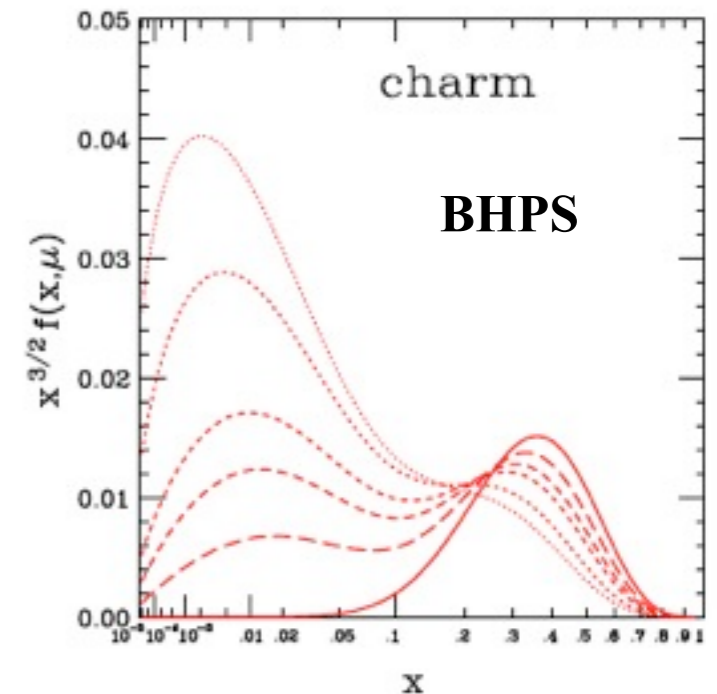
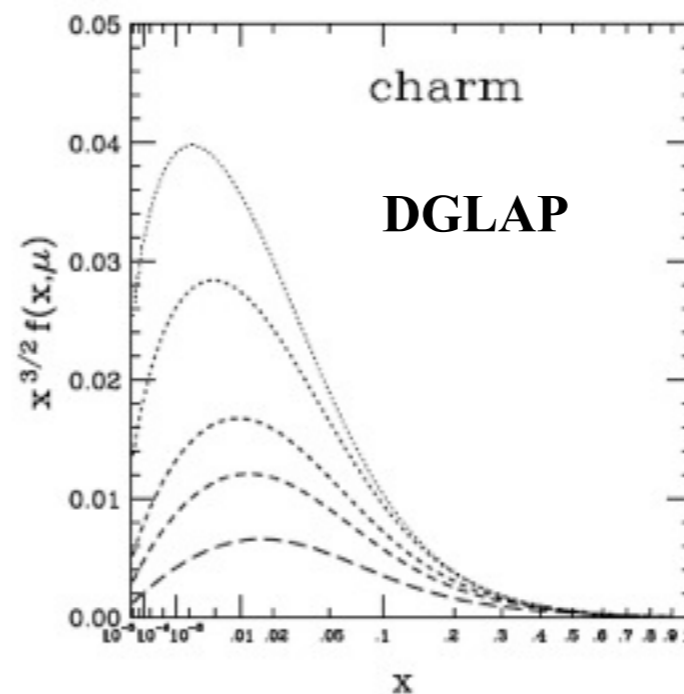
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- **Experimental probes @ AFTER**
 - Open charm (D meson or displaced-vertex lepton)
 - Open beauty



Boer-Mulders effect

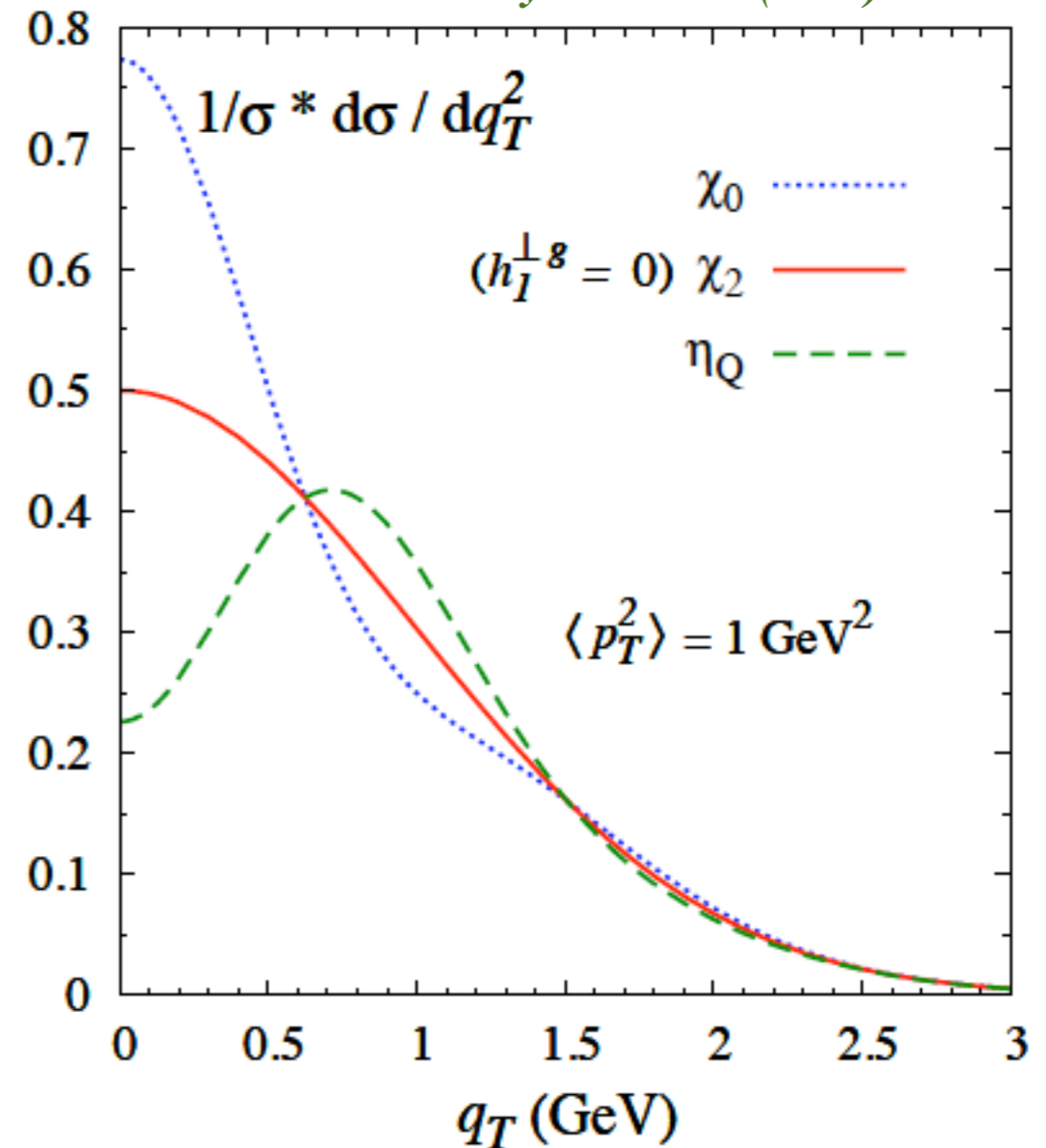
Parton distribution functions pdfs (x, Q^2) \rightarrow
(x, \mathbf{k}_T, Q^2): 3D or Transverse Momentum
Dependent (TMD) pdfs

Boer-Mulders effect: correlation between the
parton \mathbf{k}_T and its spin (in an unpolarized nucleon)

Double-node structure of transverse-momentum
distributions predicted for scalar and pseudoscalar
quarkonia \rightarrow give access to the Boer-Mulders
TMD pdf for gluons

scheme to describe Boer-Mulder effect

Boer and Pisano Phys.Rev. D86 (2012) 094007



Boer-Mulders effect

Parton distribution functions pdfs $(x, Q^2) \rightarrow (x, \mathbf{k}_T, Q^2)$: 3D or Transverse Momentum Dependent (TMD) pdfs

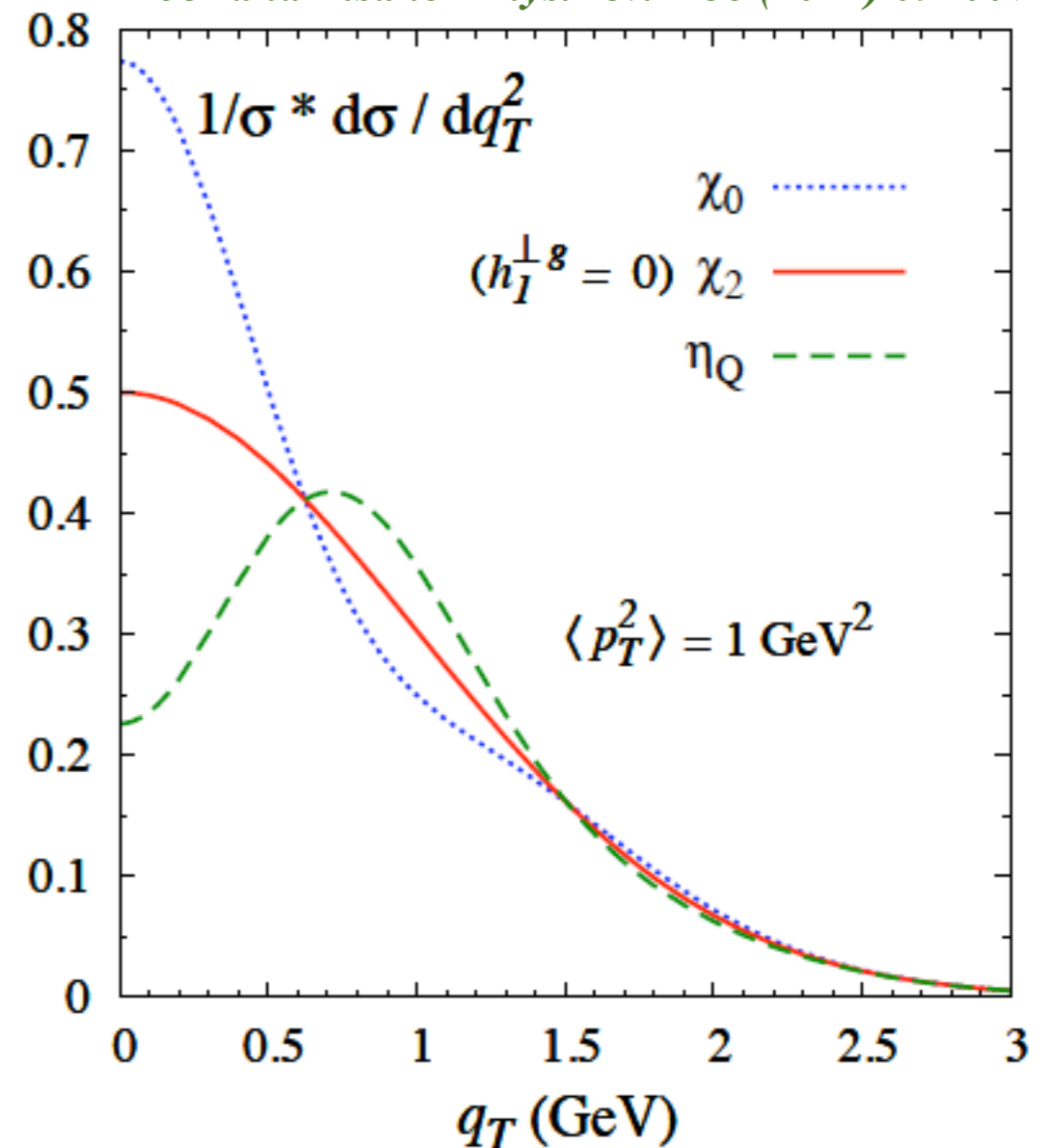
Boer-Mulders effect: correlation between the parton \mathbf{k}_T and its spin (in an unpolarized nucleon)

Double-node structure of transverse-momentum distributions predicted for scalar and pseudoscalar quarkonia \rightarrow give access to the Boer-Mulders TMD pdf for gluons

- **Experimental probes @ AFTER**
 - scalar and pseudoscalar quarkonia: χ_{c0} , χ_{b0} , η_c , η_b (PID and modern calorimetry)

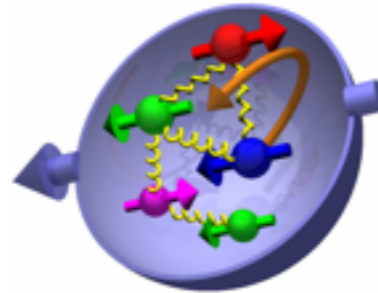
scheme to describe Boer-Mulder effect

Boer and Pisano Phys.Rev. D86 (2012) 094007



Sivers effect with a transversally polarized target

Sivers effect in a transversally polarized nucleon: correlation between the parton k_T and the proton spin

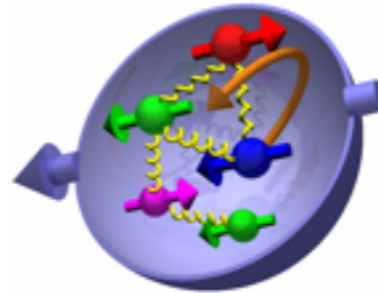


scheme to describe Sivers effect

Polarizing the target: measuring asymmetry to access the 3D or Transverse Momentum Dependent (TMD) pdfs.

Sivers effect with a transversally polarized target

Sivers effect in a transversally polarized nucleon: correlation between the parton k_T and the proton spin



scheme to describe Sivers effect

Polarizing the target: measuring asymmetry to access the 3D or Transverse Momentum Dependent (TMD) pdfs.

- **Experimental probes @ AFTER**

- Drell-Yan \rightarrow quark Sivers effect
- Quarkonia, Open Charm and Beauty (B and D mesons), isolated γ and γ -jet \rightarrow gluon Sivers effect

- **Large asymmetries ($\sim 20\%$) predicted in Drell-Yan** for the target-rapidity region ($x_F = x_{beam} - x_{target} < 0$) where the k_T spin correlation is the largest

T. Liu and B.Q. Ma Eur.Phys.J. C72 (2012) 2037

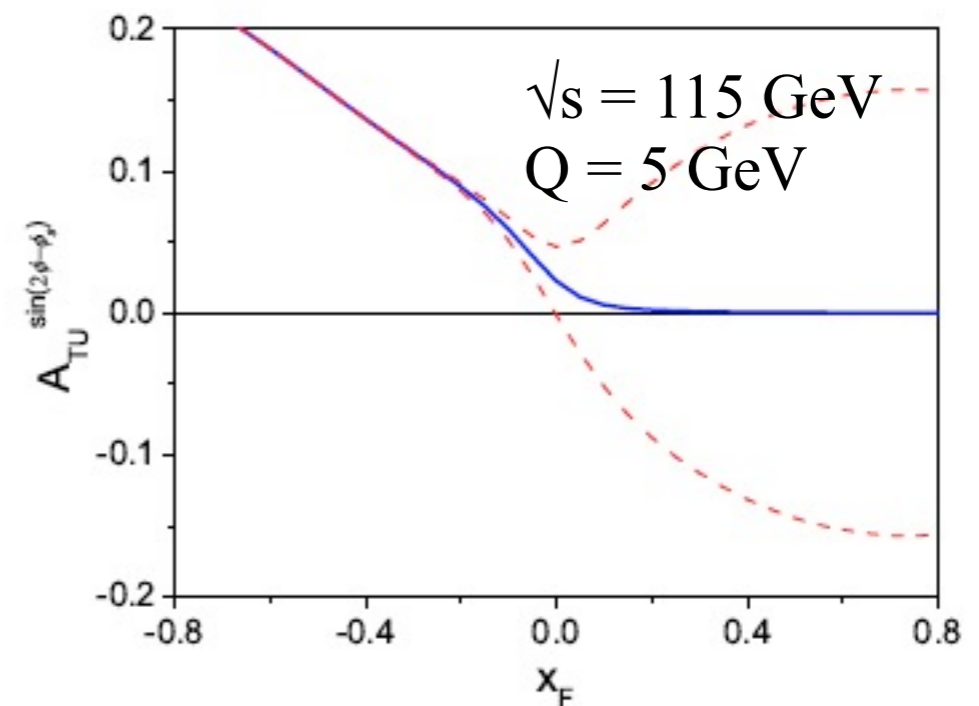


Fig. 29 The $\sin(2\phi - \phi_S)$ azimuthal asymmetry $A_{TU}^{\sin(2\phi - \phi_S)}$ depending on x_F of target proton polarized pp Drell-Yan process at $Q = 5$ GeV.

W, Z production in the threshold region...

With high luminosity fixed-target experiment, W and Z production accessible

Unique opportunity to study the W and Z production near threshold @ AFTER

Very large x partons in the nucleon/nucleus target probed

Large NLO and NNLO corrections: QCD laboratory near threshold at large scale

If W'/Z' exists, similar threshold corrections than W and Z

But also: very forward (backward) physics:

semi-diffractive physics

ultra-peripheral collisions in pp, pA and PbA → **Lech Szymanowski**

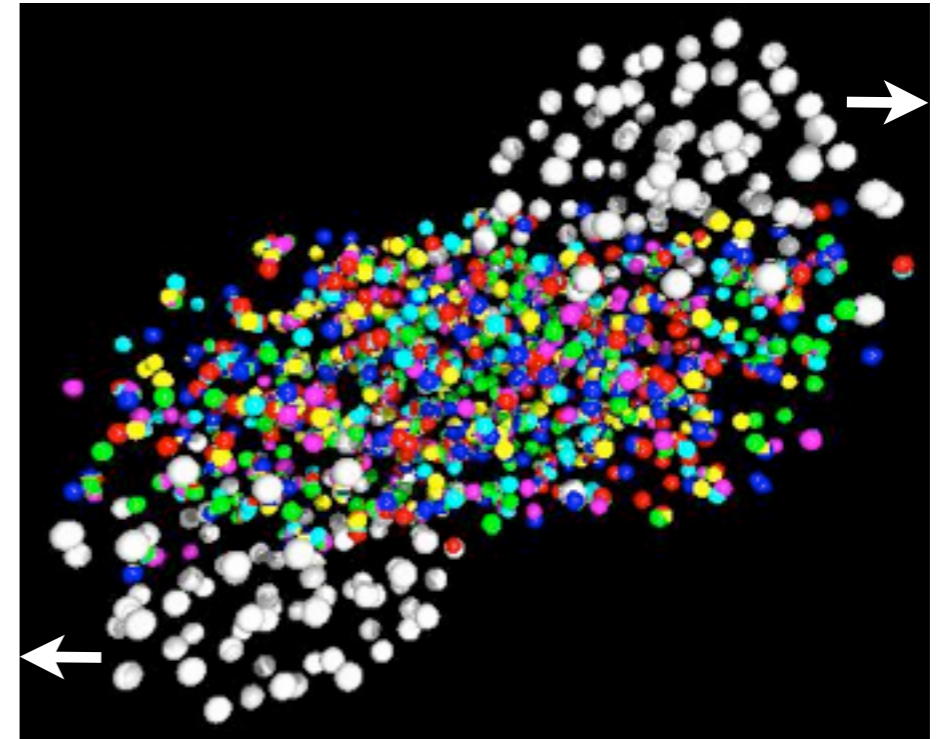
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Quark Gluon Plasma

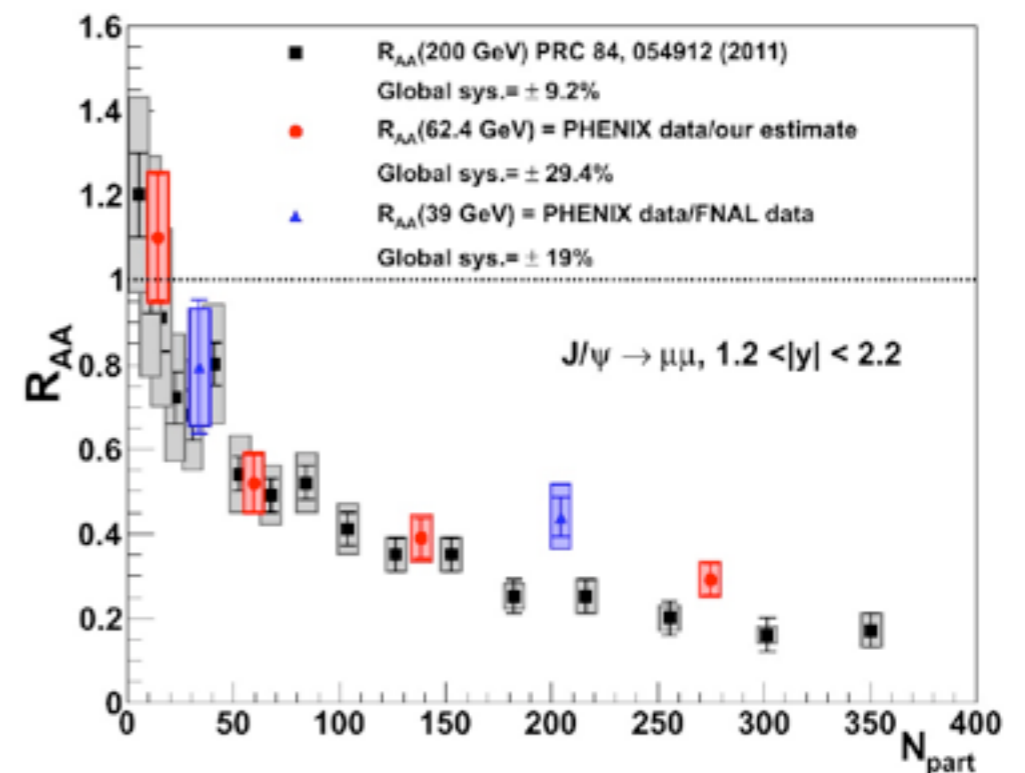
In nucleus-nucleus collisions at high ultra-relativistic energy \rightarrow Quark Gluon Plasma (QGP) formation

RHIC energy scan shows suppression of particles at $\sqrt{s_{NN}} = 39, 62, 200$ GeV (π^0 , J/Ψ , ...) but low statistics for $\sqrt{s_{NN}} < 200$ GeV and scarce / no pp and pA reference

Cold Nuclear Matter (i.e not Hot from QGP) measured in pA



PHENIX Collaboration arXiv 1208:2251



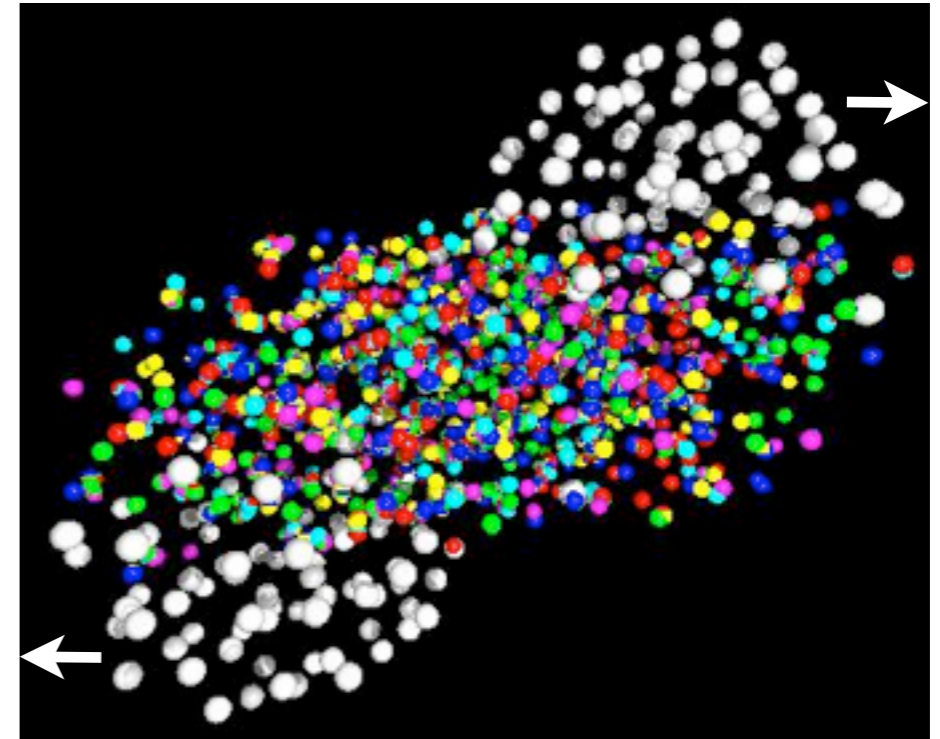
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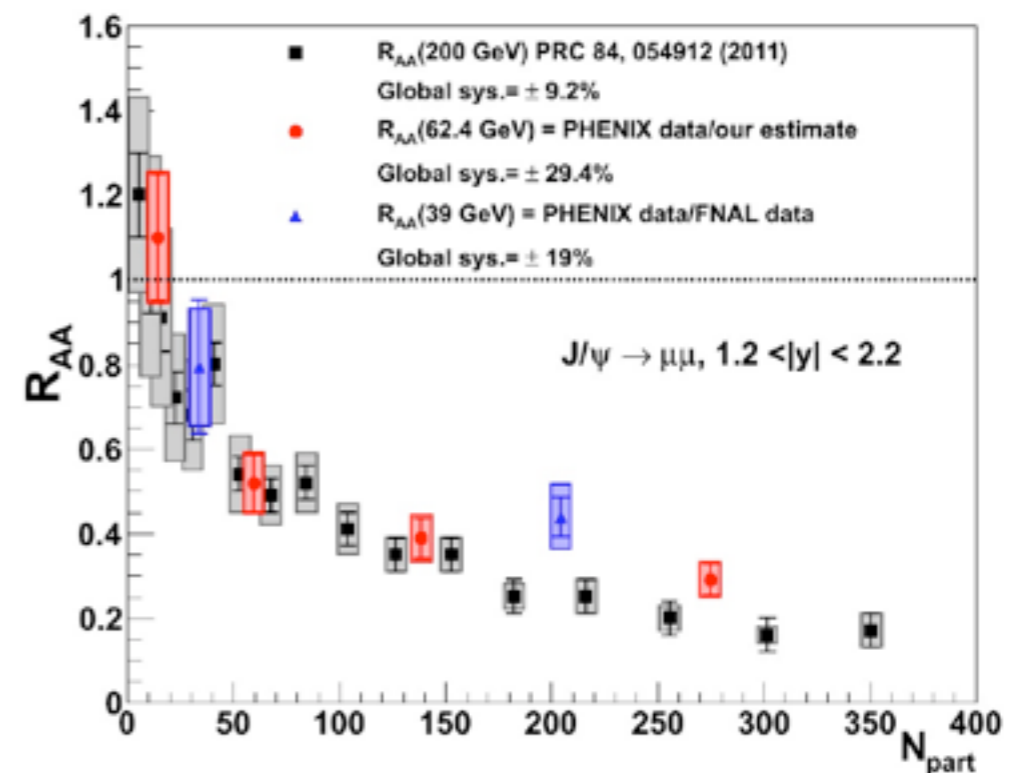
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Cold Nuclear Matter (i.e not Hot from QGP) measured in pA

- **Experimental probes @ AFTER $\sqrt{s} = 72$ GeV**
 - Quarkonia
 - Jets
 - Low mass lepton pairs
 - ...
- **Target versatility**
 - In PbA, different nuclei: A-dependent studies
 - In pA, precise estimate of Cold Nuclear effect with pA collisions



PHENIX Collaboration arXiv 1208:2251



Quarkonium yields in pH and pA @ 115 GeV

In pp

⇒ RHIC @ 200 GeV x 100 with 10 cm thick H target

⇒ Comparable to LHCb if 1m H target

⇒ Detailed studies of quarkonium production (p_T , y , polarization, different quarkonium states: χ_{c2} , χ_{b2} , η_c , η_b , new observables: J/Ψ pair, $J/\Psi+D$, $J/\Psi+\gamma$)

In pA

⇒ RHIC @ 200 GeV x 100 with 1 cm Pb target

⇒ Detailed studies of cold nuclear matter effect in pA (p_T , y , A , ...)

Also very promising in PbA

Target	$\int dt \mathcal{L}$	$\mathcal{B}_{\ell\ell} \frac{dN_{J/\psi}}{dy} \Big _{y=0}$	$\mathcal{B}_{\ell\ell} \frac{dN_{\Upsilon}}{dy} \Big _{y=0}$
10 cm solid H	2.6	$5.2 \cdot 10^7$	$1.0 \cdot 10^5$
10 cm liquid H	2	$4.0 \cdot 10^7$	$8.0 \cdot 10^4$
10 cm liquid D	2.4	$9.6 \cdot 10^7$	$1.9 \cdot 10^5$
1 cm Be	0.62	$1.1 \cdot 10^8$	$2.2 \cdot 10^5$
1 cm Cu	0.42	$5.3 \cdot 10^8$	$1.1 \cdot 10^6$
1 cm W	0.31	$1.1 \cdot 10^9$	$2.3 \cdot 10^6$
1 cm Pb	0.16	$6.7 \cdot 10^8$	$1.3 \cdot 10^6$
pp low P_T LHC (14 TeV) {	0.05	$3.6 \cdot 10^7$	$1.8 \cdot 10^5$
	2	$1.4 \cdot 10^9$	$7.2 \cdot 10^6$
pPb LHC (8.8 TeV)	10^{-4}	$1.0 \cdot 10^7$	$7.5 \cdot 10^4$
pp RHIC (200 GeV)	$1.2 \cdot 10^{-2}$	$4.8 \cdot 10^5$	$1.2 \cdot 10^3$
dAu RHIC (200 GeV)	$1.5 \cdot 10^{-4}$	$2.4 \cdot 10^6$	$5.9 \cdot 10^3$
dAu RHIC (62 GeV)	$3.8 \cdot 10^{-6}$	$1.2 \cdot 10^4$	$1.8 \cdot 10^1$

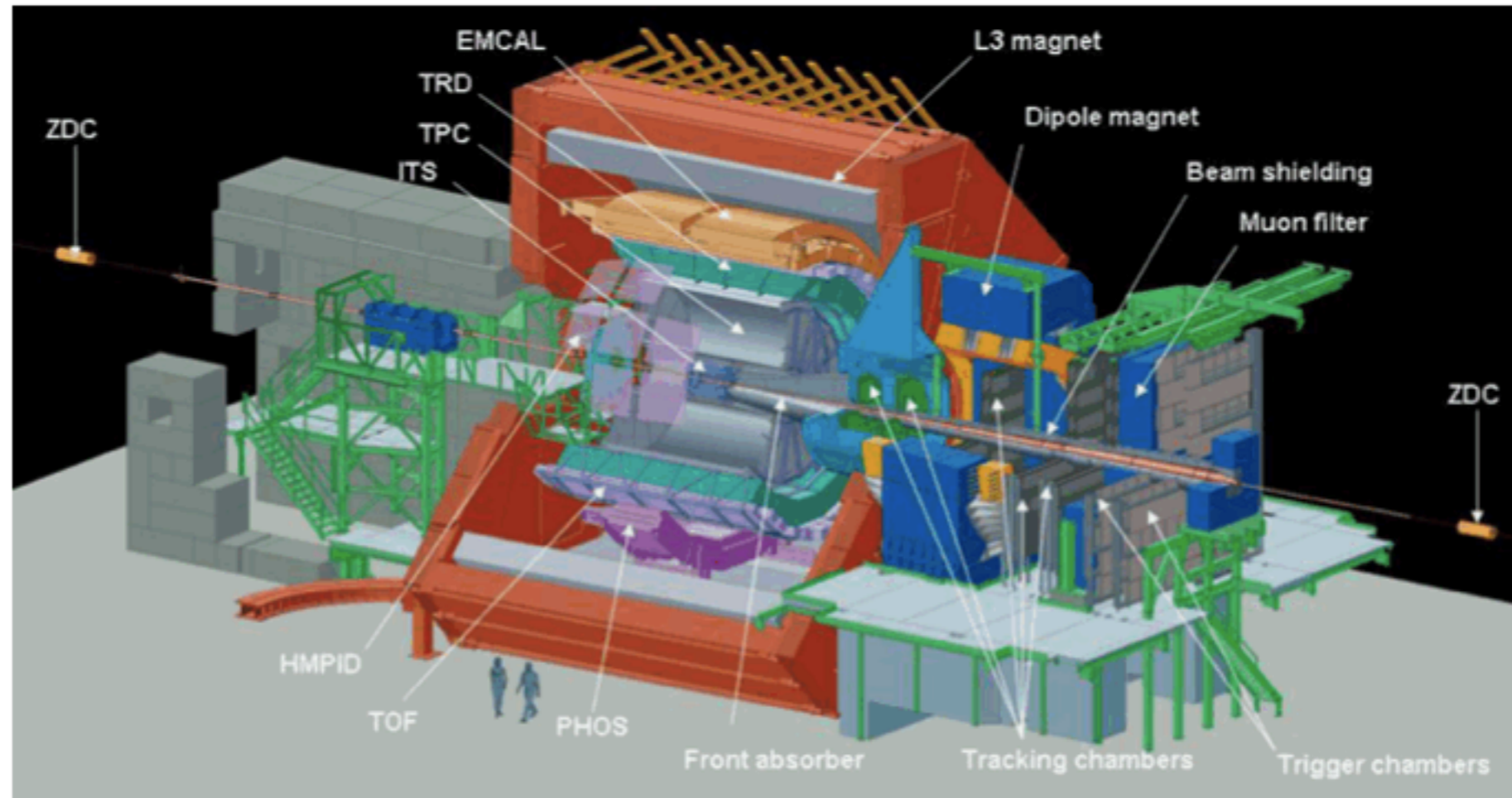
Luminosity per year in fb^{-1}

Earlier studies with ALICE as a fixed target experiment

Proposition

Using ALICE as a fixed target experiment

Kurepin et al. Phys.Atom.Nucl. 74 (2011)



Geometrical Acceptance @ 115 GeV

Simulation @ 115 GeV for $J/\psi \rightarrow \mu^+\mu^-$ with μ detected in the muon arm of ALICE ($2.5 < \eta < 4$)

A geometrical Acceptance of 8% for $J/\psi (4\pi) \rightarrow \mu^+\mu^- (2.5 < y < 4)$ is estimated

Accessing the large x gluon in the target

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

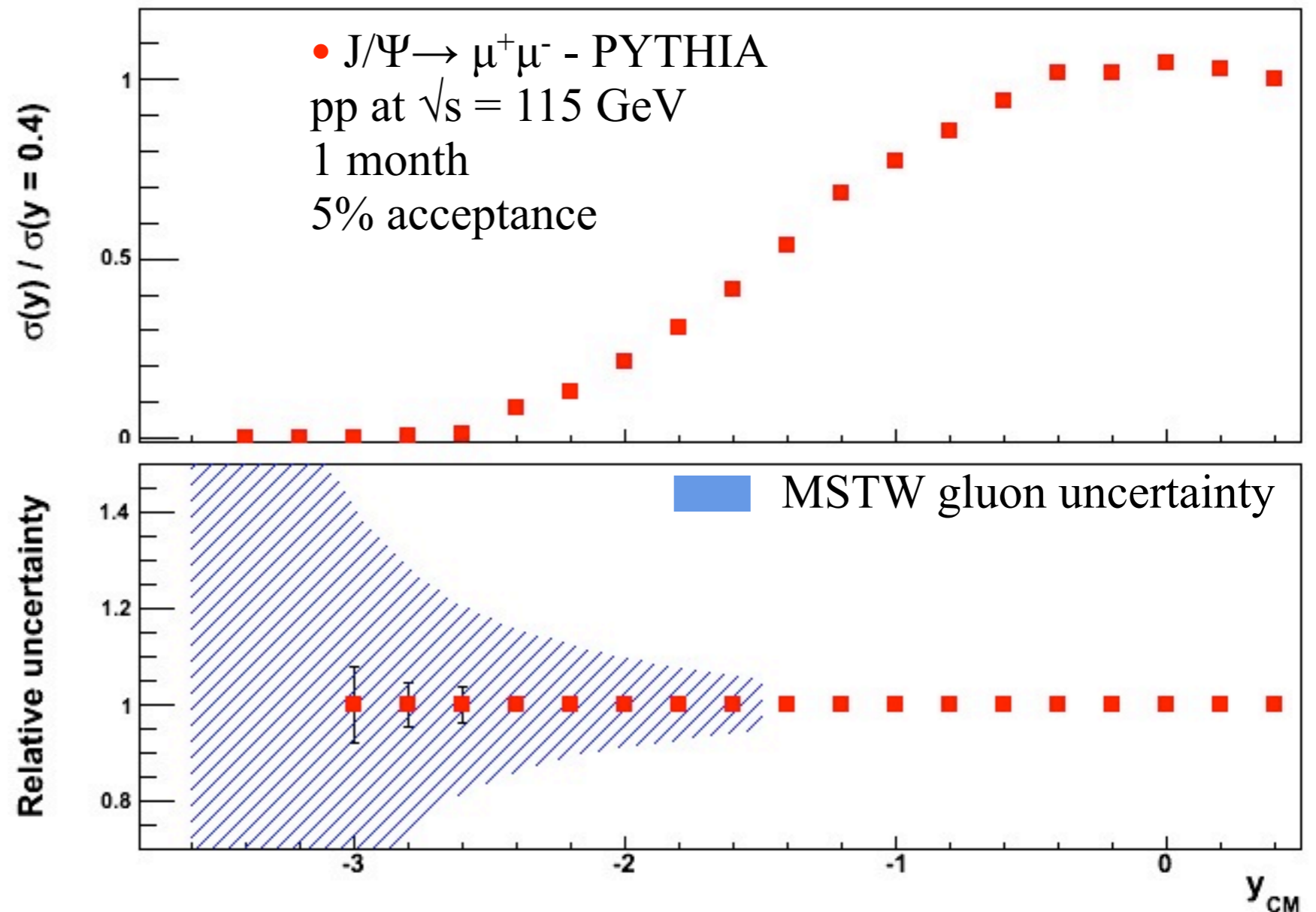
- assuming

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

J/Ψ

$$y_{CM} \sim 0 \rightarrow x_g = 0.03$$

$$y_{CM} \sim -3.6 \rightarrow x_g = 1$$



⇒ Precise measurements in the target-rapidity region allow to access large x gluon content of the target

⇒ Next: estimate the yield for $\eta_{b,c}$ and $\chi_{b,c}$ (cleaner theoretically)

Conclusion

- LHC proton and lead beams continuous extraction with bent crystal offers many physics opportunities
- Large luminosities provide access to large and very large parton x measurements for quarks and gluons: QCD laboratory at large x
- Fixed-target mode allows for target versatility: hydrogen, deuteron, nucleus (nuclear effect and QGP), polarized target (spin physics)
- AFTER designed as a multi-purpose experiment



AFTER @ LHC

<http://after.in2p3.fr>

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

Looking for partners!



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.'

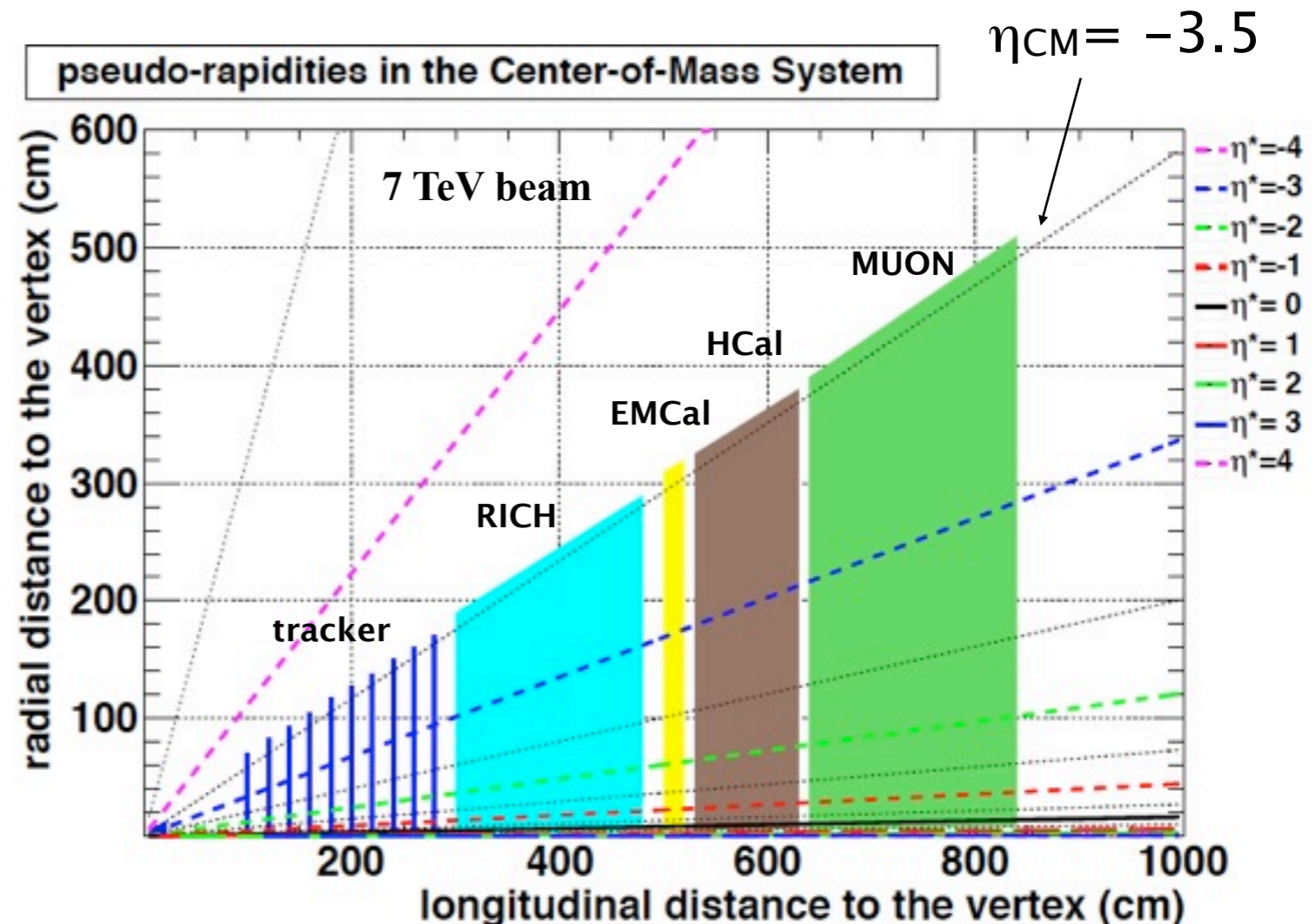


A tentative design for AFTER

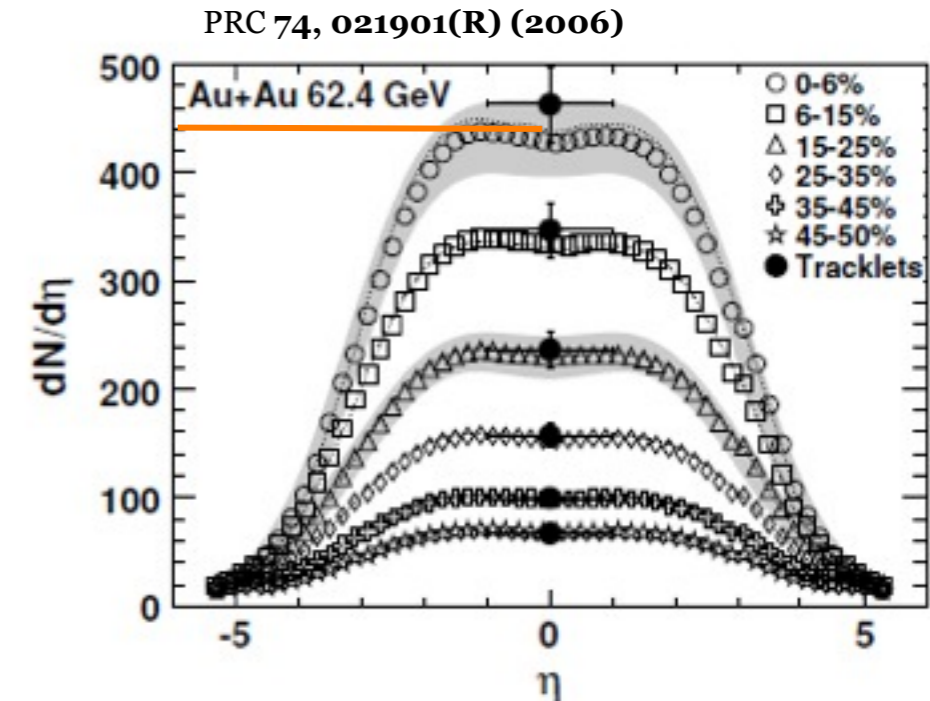
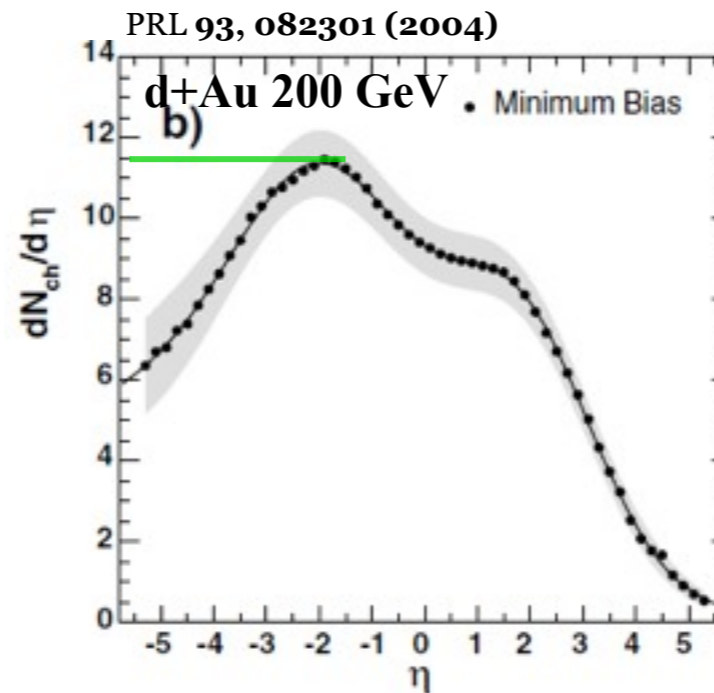
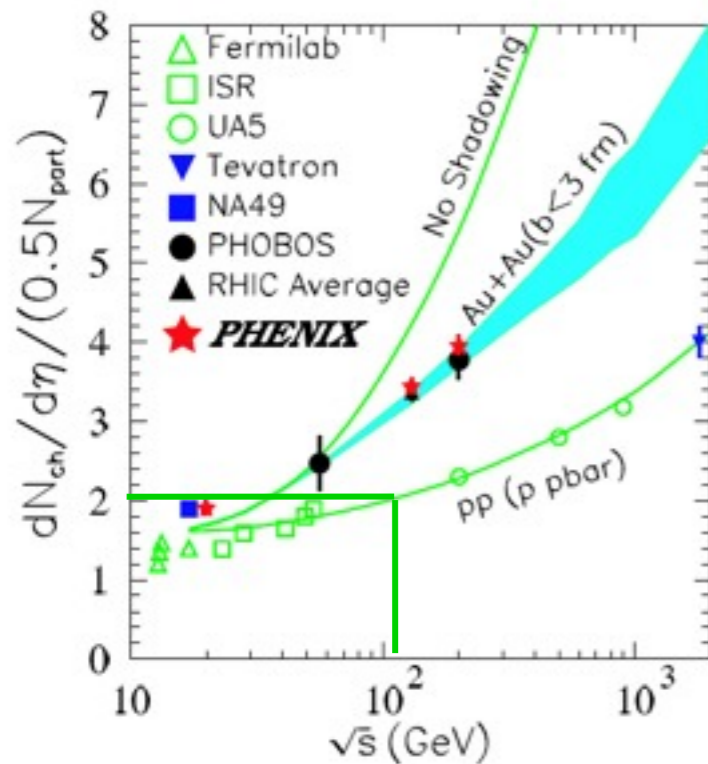
- **Tentative design** $1.3 < \eta < 5.3$
 - With 7 TeV beam : $-3.5 < y_{\text{CM}} < 0.5$
 - With 2.76 TeV beam: $-3 < y_{\text{CM}} < 1$
 - $\theta_{\text{min}} = 10 \text{ mrad}$
- **Multi-purpose detector**
 - Vertex
 - Tracking (+ dipole magnet)
 - RICH
 - Calorimetry
 - Muons
- **High boost** → forward and as compact as possible detector

• Technology

- Vertex, tracker: pixel detectors
- Ultra-granular EMCal: Tungsten/Si (Calice - ILC)
- Muons: Magnetize Fe (Minos)
- ...



Multiplicity



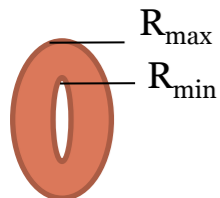
Charged particles per unit of rapidity: (x 1.5 = charged+neutral)

p+p @ 115 GeV ~ 2

d+Au @ 200 GeV : max ~11

Au+Au @ 62.4 GeV : max ~ 450

→ **A highly granular detector is needed**



$y < 0.5 $	R_{\min} (cm)	R_{\max} (cm)	Surface (cm ²)
Vertex	1.5	10	~ 300
Calo	10	40	~4700

Vertex ~ 450 part.

$$1\% \sim \frac{450}{300 \times \left(\frac{1}{0.8 \times 0.8 \text{ mm}^2} \right)}$$

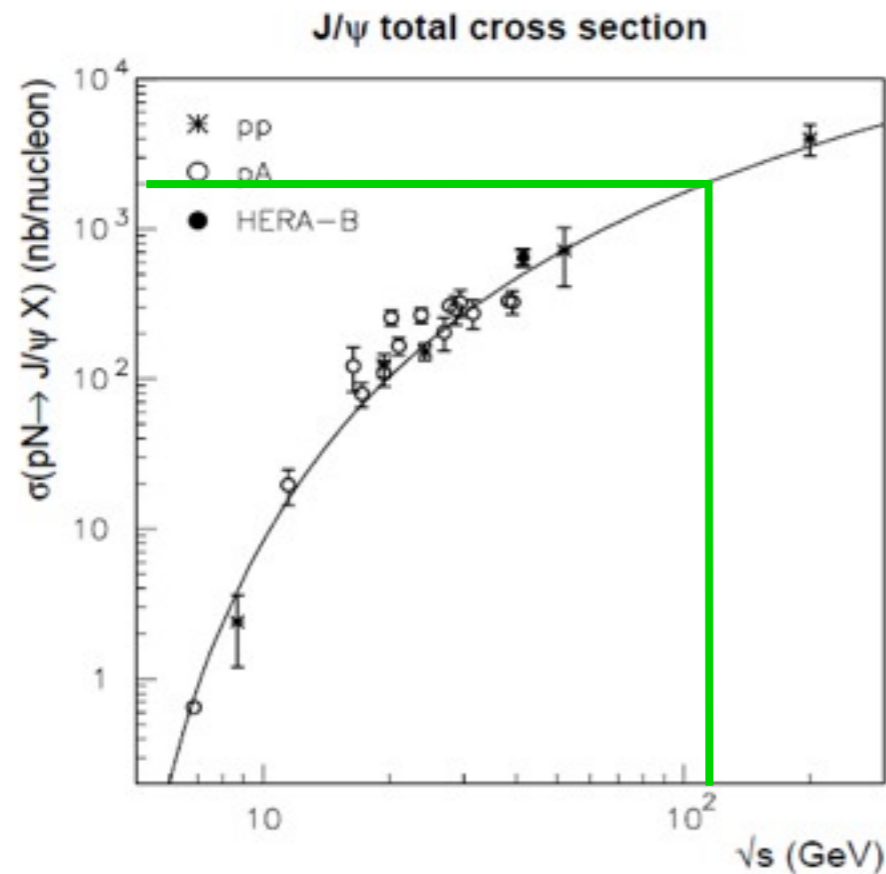
$$0.1\% \sim \frac{450}{300 \times \left(\frac{1}{0.25 \times 0.25 \text{ mm}^2} \right)}$$

Calo ~ 700 part.

$$\frac{700}{4700 \times \left(\frac{1}{1 \times 1 \text{ cm}^2} \right)} \sim 14\%$$

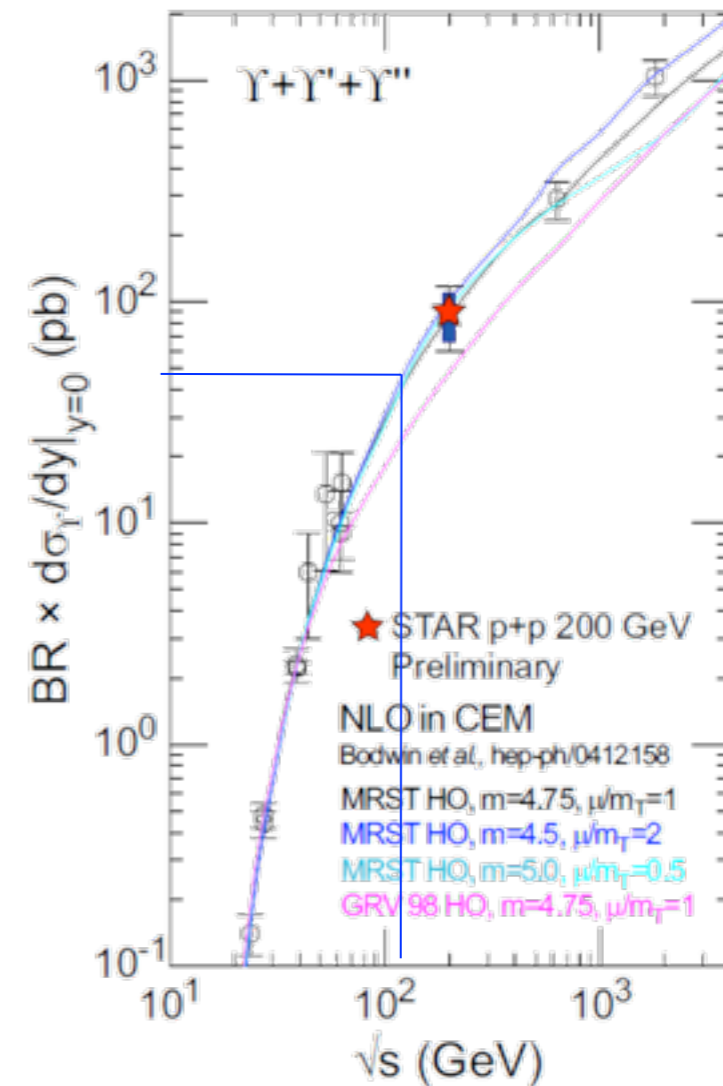
$$\frac{700}{4700 \times \left(\frac{1}{0.5 \times 0.5 \text{ cm}^2} \right)} \sim 3.7\%$$

Quarkonium cross-sections



Inclusive pp cross-sections

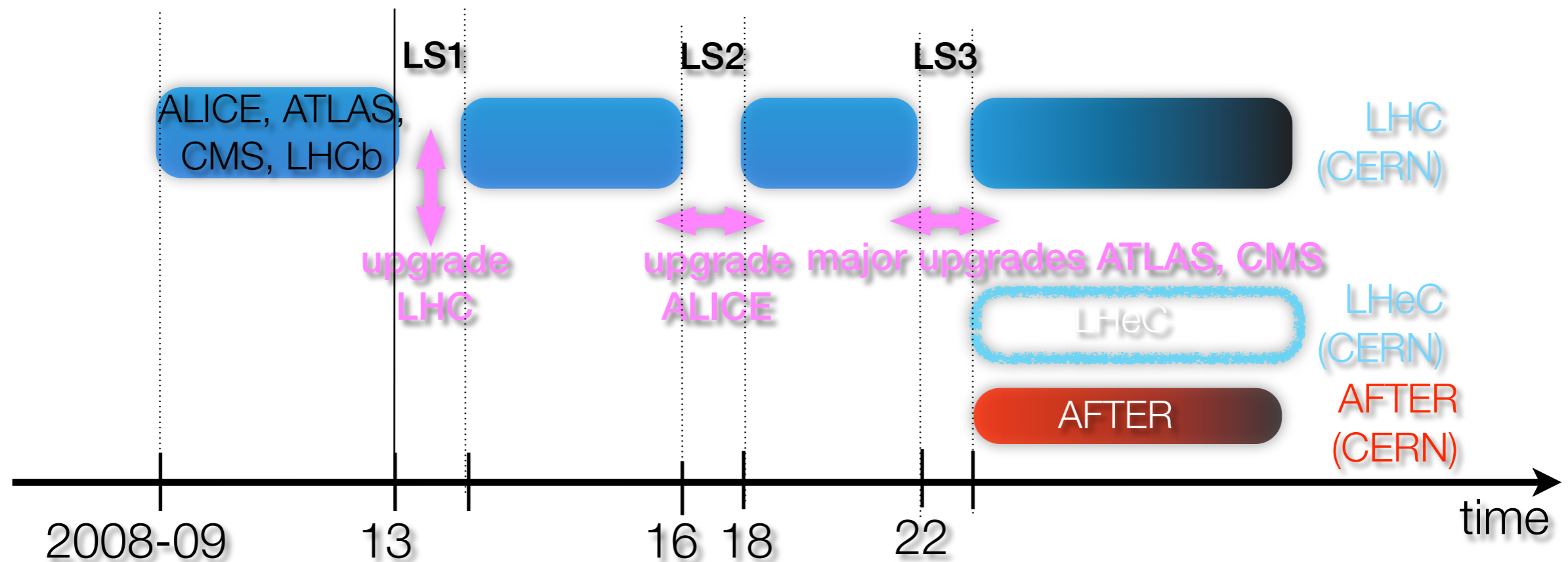
$B_{ll} d\sigma/dy|_{y=0}$ @ 115 GeV
 $J/\psi = 20$ nb
 $Y = 40$ pb



Inclusive pp cross-sections

$B_{ll} d\sigma/dy|_{y=0}$ @ 72 GeV
 $J/\psi = 10$ nb
 $Y = 15$ pb

Target schedule: LHC plan



J/Ψ in pp @ 115 GeV

Pythia: p (7 TeV) + p → J/Ψ

J/Ψ → μ⁺μ⁻

J/Ψ for 1.3 < y < 5.3

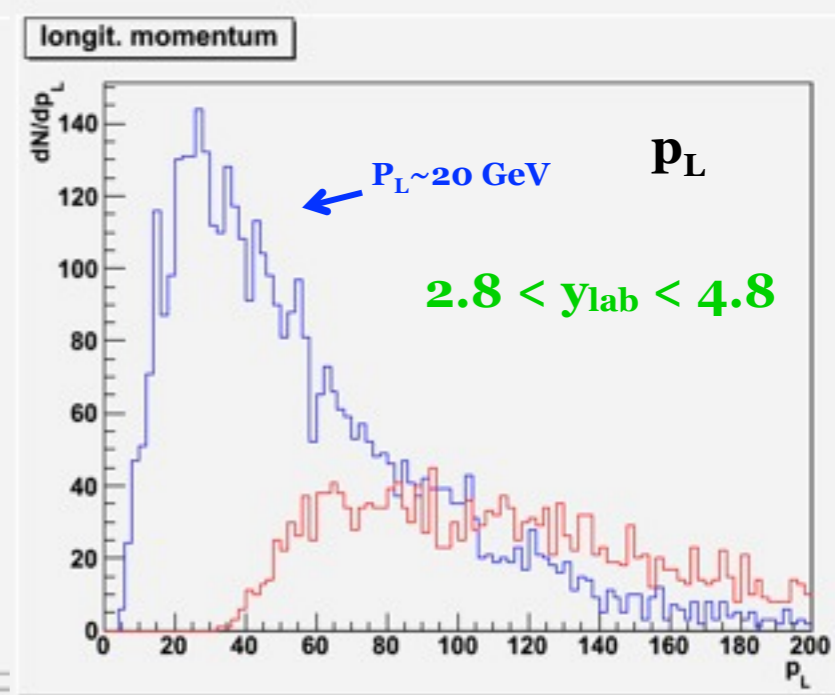
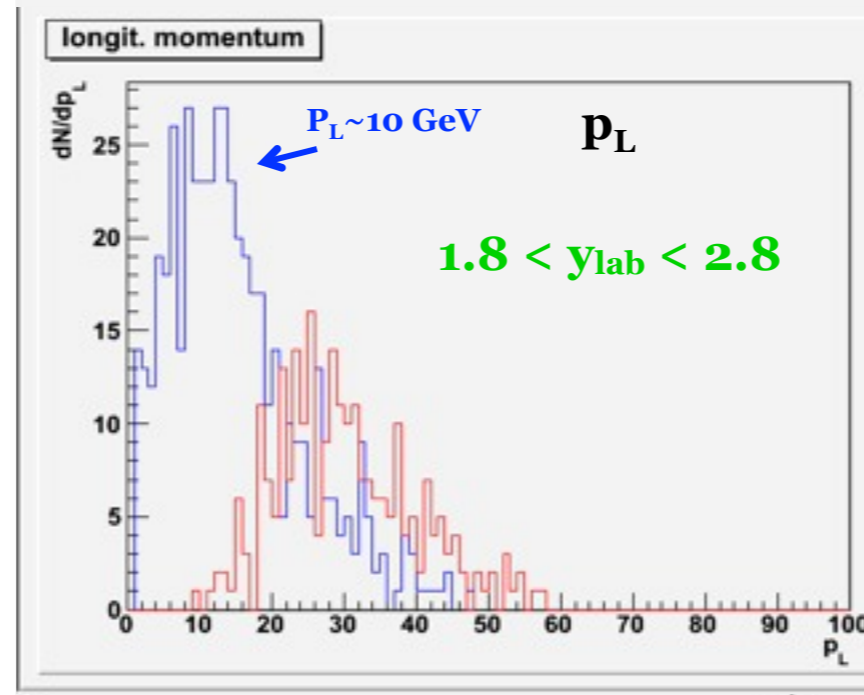
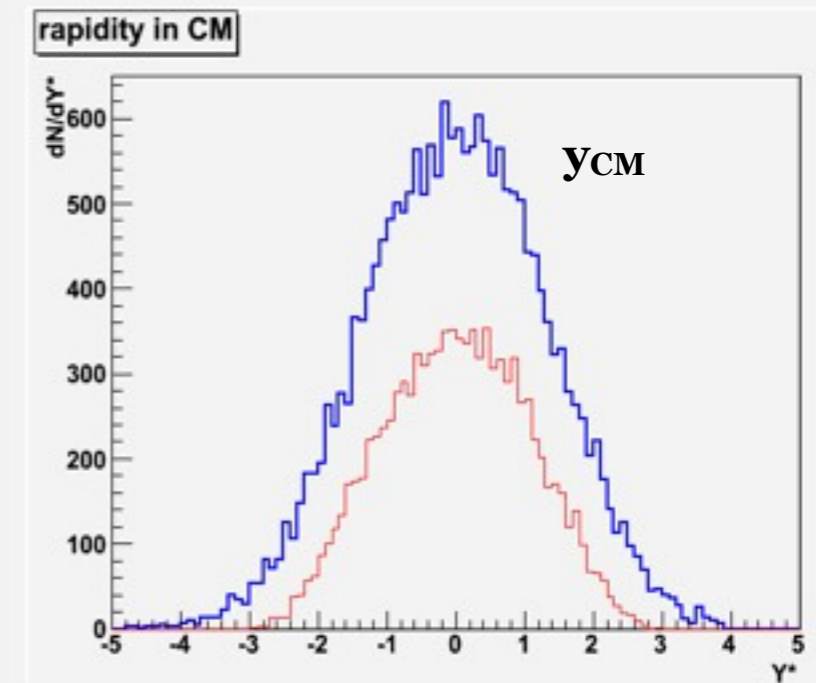
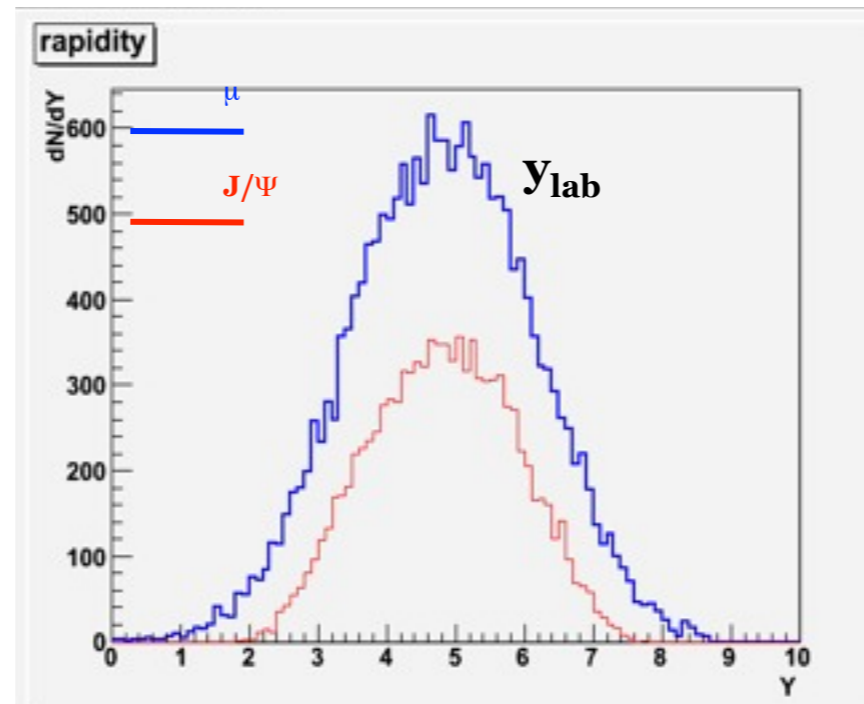
μ → P_T ~ 1.7 GeV

μ → P_L ~ 62 GeV

1.3 < y < 3.3 p_L (max) ~ 16 (50) GeV

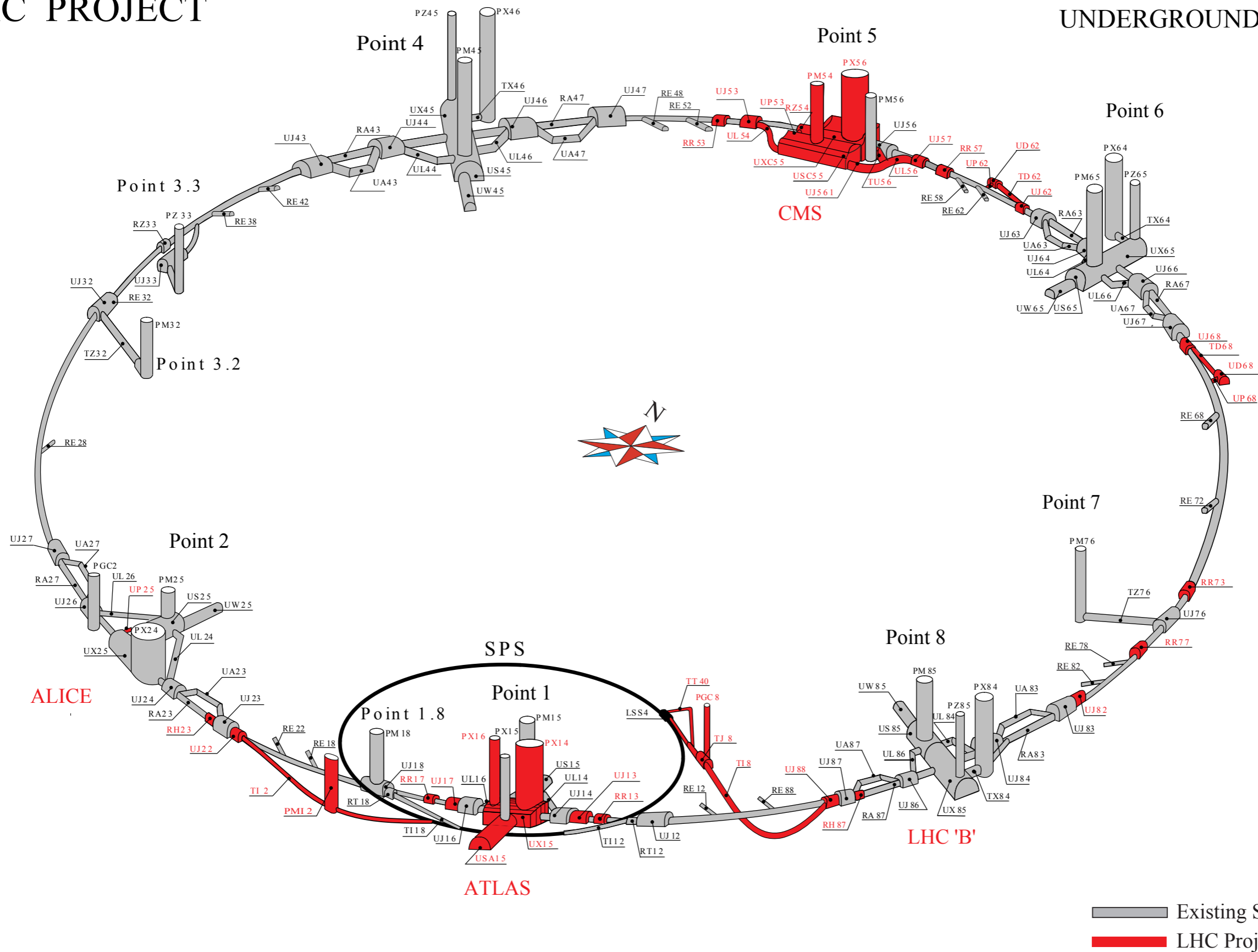
3.3 < y < 4.3 p_L ~ 45 (150) GeV

4.3 < y < 5.3 p_L ~ 120 (300) GeV



LHC PROJECT

UNDERGROUND WORKS



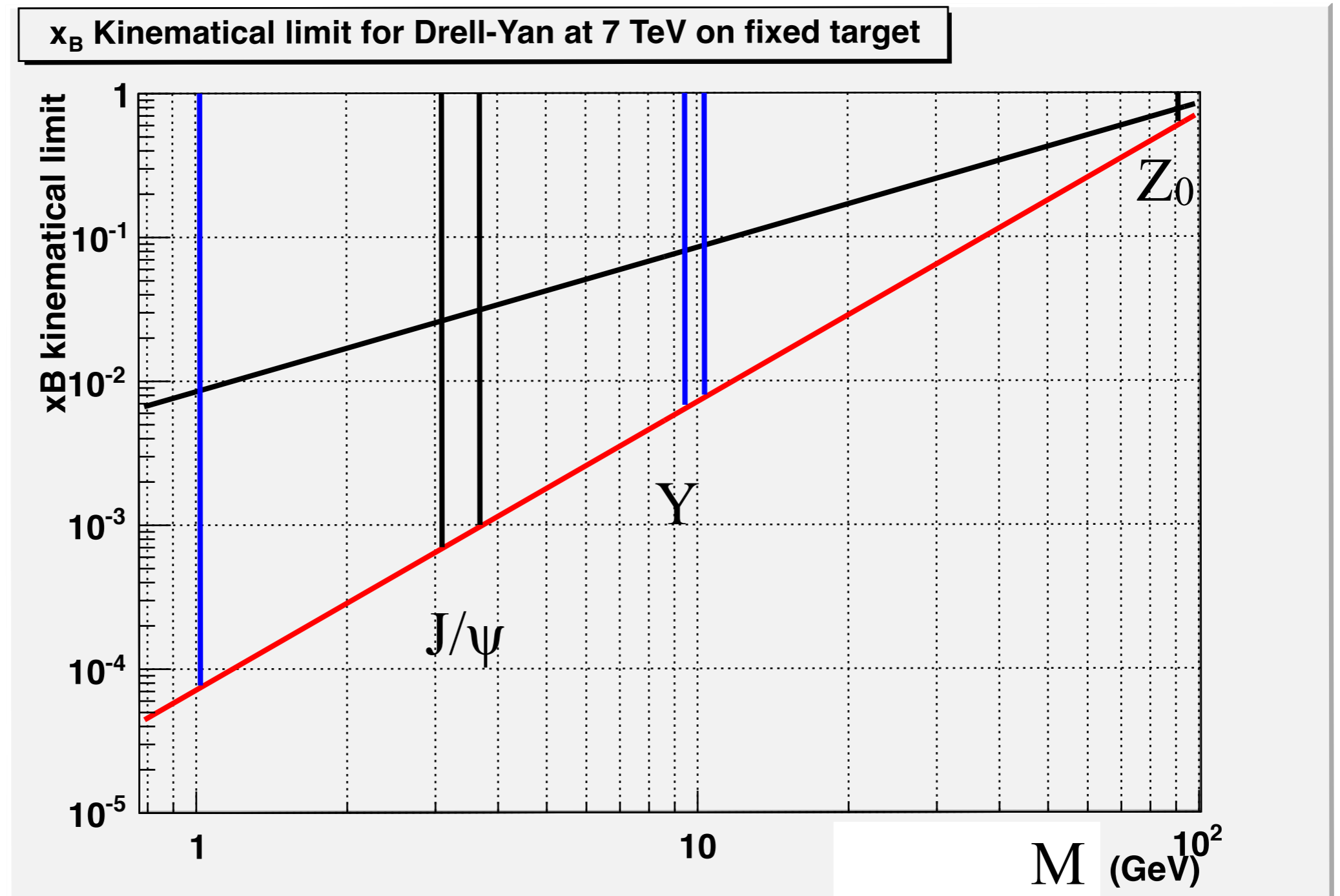
Drell-Yan continuum

backward region
forward region

x_{target}
 x_{beam}

$x_{\text{target}} = x_{\text{beam}}$

x_{beam}
 x_{target}



Drell-Yan measurements in pp

T. Liu and B.Q. Ma arXiv:1203.5579

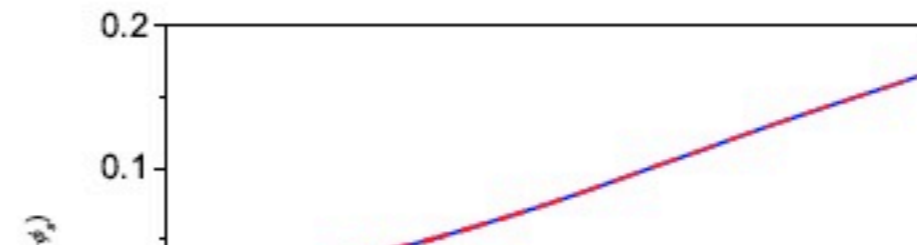
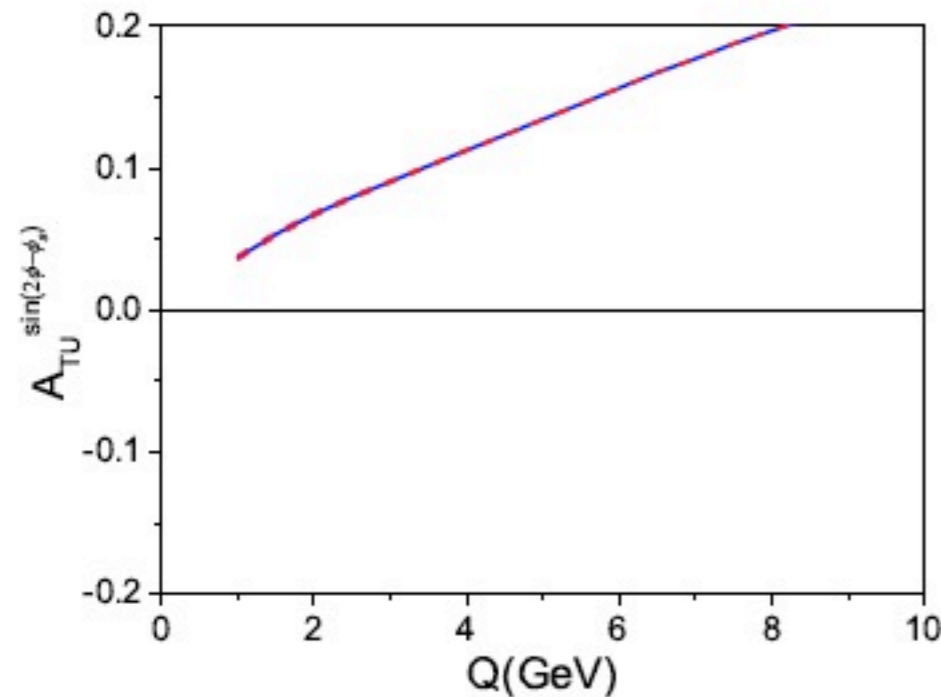
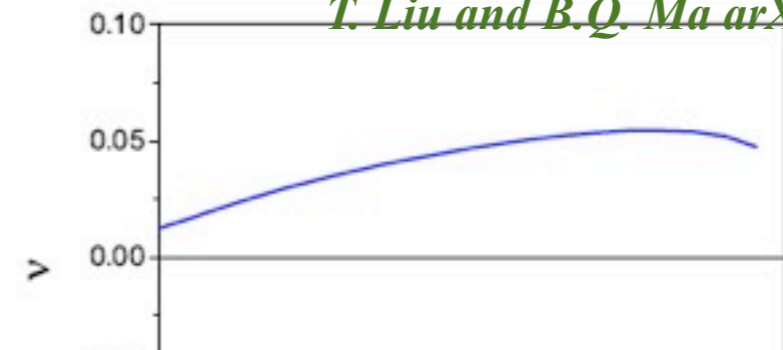
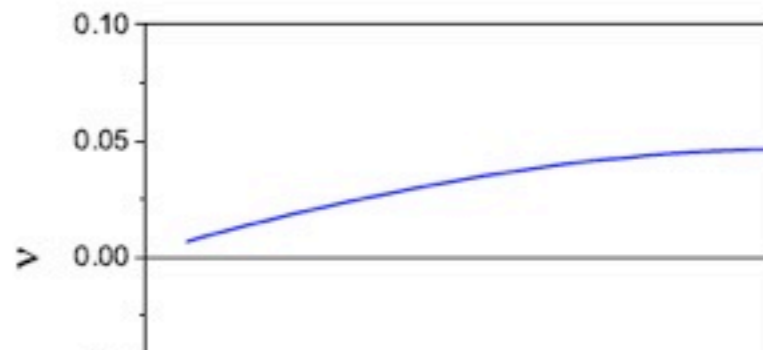


Fig. 17 The $\sin(2\phi - \phi_S)$ azimuthal asymmetry $A_{TU}^{\sin(2\phi - \phi_S)}$ depending on Q of target proton polarized pp Drell-Yan process with both γ^* and Z taken into account and allowed rapidity integrated in the cut $[-4.8, -2]$. The same cut of rapidity is chosen in Figs. 18-22.

Fi
or
an

as Figs. 18-40.

ized pp Drell-Yan process at $Q = 2$ GeV.

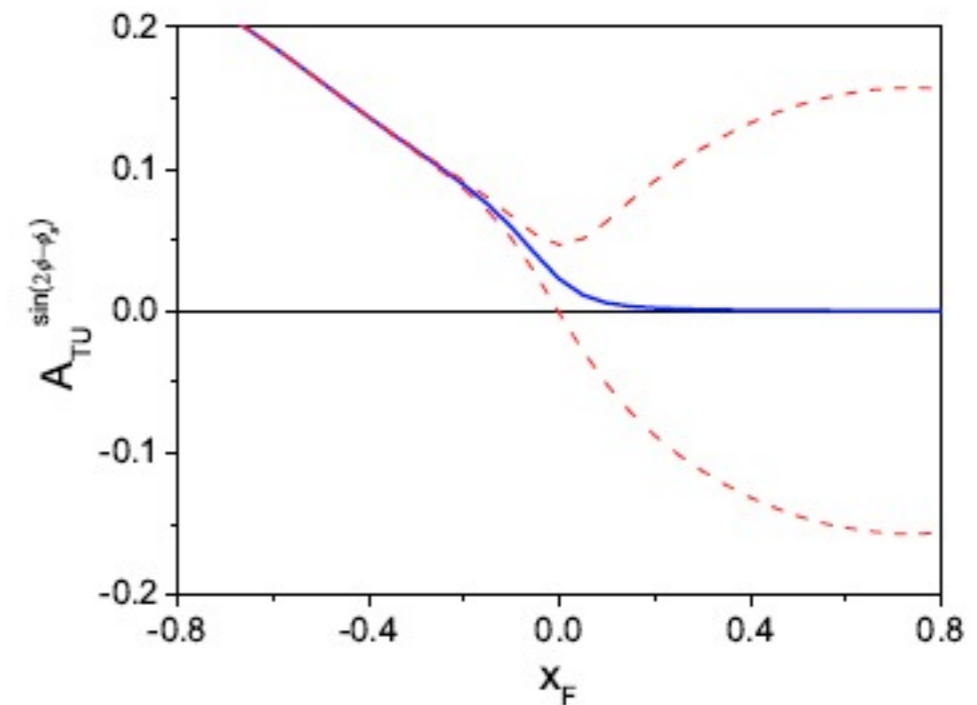


Fig. 29 The $\sin(2\phi - \phi_S)$ azimuthal asymmetry $A_{TU}^{\sin(2\phi - \phi_S)}$ depending on x_F of target proton polarized pp Drell-Yan process at $Q = 5$ GeV.

Drell-Yan measurements in pD

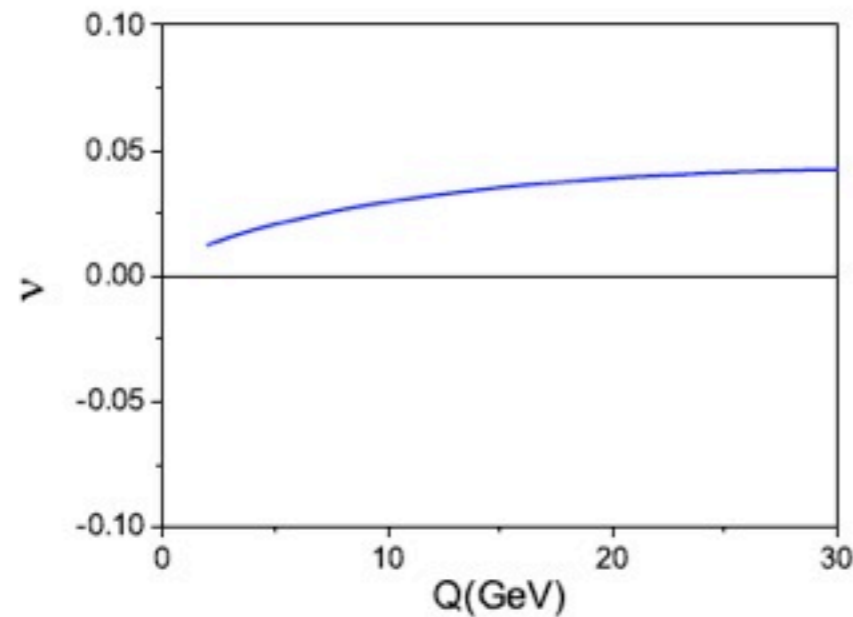


Fig. 7 The $\cos 2\phi$ azimuthal asymmetry depending on Q of unpolarized pd Drell-Yan process with both γ^* and Z taken into account.

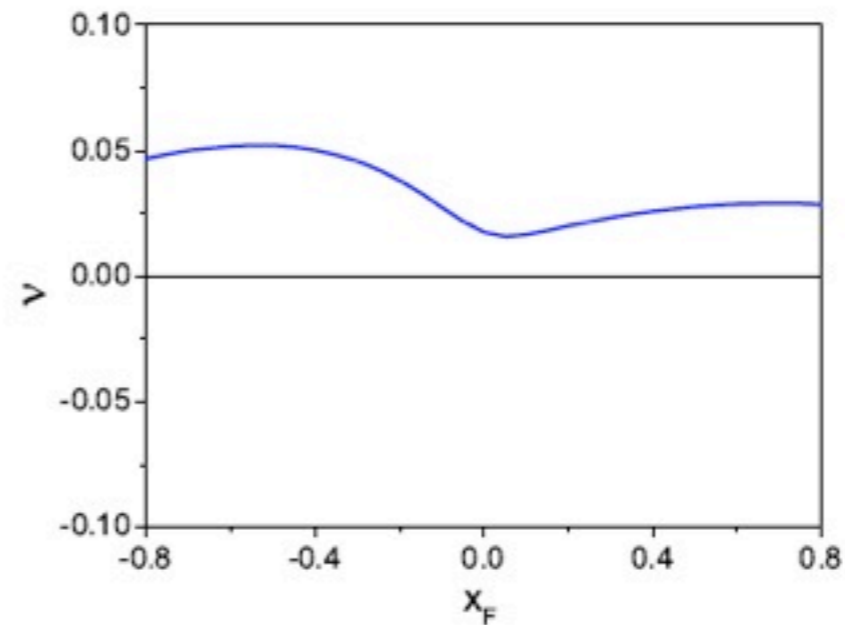


Fig. 9 The $\cos 2\phi$ azimuthal asymmetry depending on x_F of unpolarized pd Drell-Yan process at $Q = 5$ GeV.

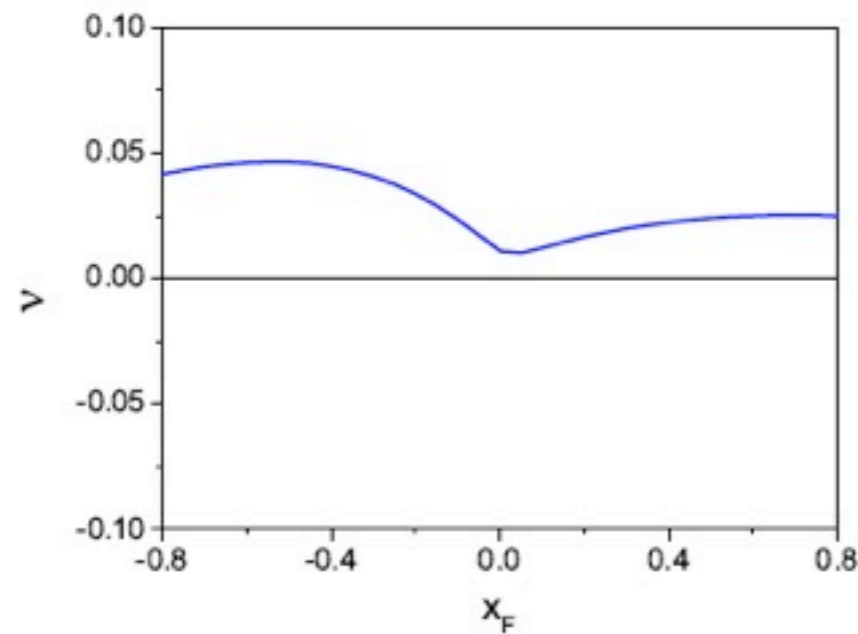


Fig. 8 The $\cos 2\phi$ azimuthal asymmetry depending on x_F of unpolarized pd Drell-Yan process at $Q = 2$ GeV.

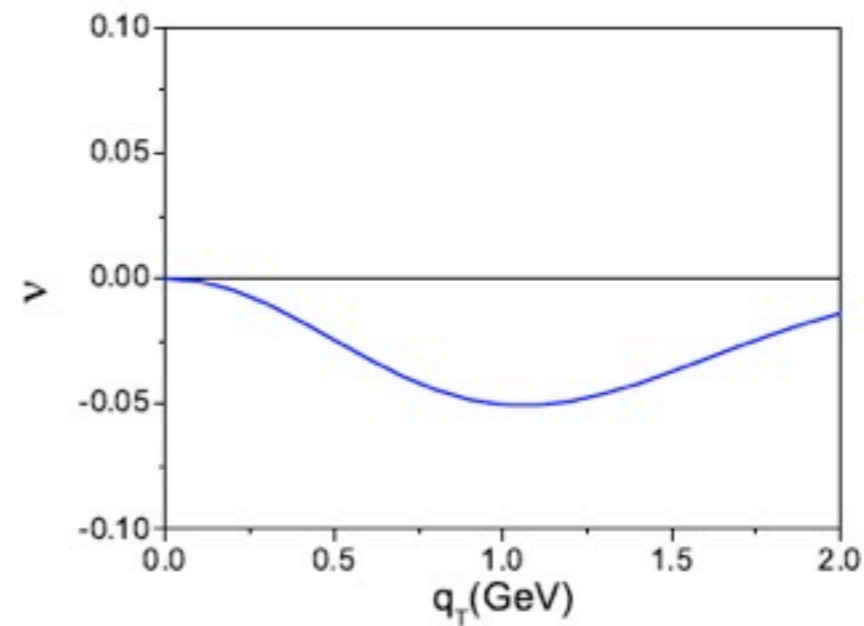


Fig. 10 The $\cos 2\phi$ azimuthal asymmetry depending on q_T of unpolarized pd process in Z resonance region.

Quarkonium yields in PbA @ 72 GeV

PbA

⇒ Same statistics than RHIC @ 200 GeV and LHC and 2 orders of magnitude larger than RHIC @ 62 GeV

⇒ Detailed studies possible for quarkonium states (ψ' , χ_c , A dependence, ...)

Target	$\int dt \mathcal{L}$	$\mathcal{B}_{\ell\ell} \frac{dN_{J/\psi}}{dy} \Big _{y=0}$	$\mathcal{B}_{\ell\ell} \frac{dN_{\Upsilon}}{dy} \Big _{y=0}$
10 cm solid H	110	$4.3 \cdot 10^5$	$8.9 \cdot 10^2$
10 cm liquid H	83	$3.4 \cdot 10^5$	$6.9 \cdot 10^2$
10 cm liquid D	100	$8.0 \cdot 10^5$	$1.6 \cdot 10^3$
1 cm Be	25	$9.1 \cdot 10^5$	$1.9 \cdot 10^3$
1 cm Cu	17	$4.3 \cdot 10^6$	$0.9 \cdot 10^3$
1 cm W	13	$9.7 \cdot 10^6$	$1.9 \cdot 10^4$
1 cm Pb	7	$5.7 \cdot 10^6$	$1.1 \cdot 10^4$
<i>dAu</i> RHIC (200 GeV)	150	$2.4 \cdot 10^6$	$5.9 \cdot 10^3$
<i>dAu</i> RHIC (62 GeV)	3.8	$1.2 \cdot 10^4$	$1.8 \cdot 10^1$
<i>AuAu</i> RHIC (200 GeV)	2.8	$4.4 \cdot 10^6$	$1.1 \cdot 10^4$
<i>AuAu</i> RHIC (62 GeV)	0.13	$4.0 \cdot 10^4$	$6.1 \cdot 10^1$
<i>pPb</i> LHC (8.8 TeV)	100	$1.0 \cdot 10^7$	$7.5 \cdot 10^4$
<i>PbPb</i> LHC (5.5 TeV)	0.5	$7.3 \cdot 10^6$	$3.6 \cdot 10^4$

Luminosity per year in fb^{-1}