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

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Saclay, June 22nd 2012

Overview

- **Why extracting the LHC beams?**
  - The physics case of AFTER
- **How to extract the LHC beams?**
  - Beam extraction with crystal
- **Luminosities and yields**
  - Expected luminosities in pH, pA and PbA
  - Yields in quarkonium production
- **Tentative design for AFTER**
  - A forward experiment

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

- **Idea: use LHC beams on fixed target**
  - 7 TeV proton beam ($\sqrt{s}$ ~115 GeV)
    - p+H, p+A
  - 2.76 TeV Pb beam ($\sqrt{s_{NN}}$ ~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**

Physics Opportunities of a Fixed-Target Experiment using the 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/sec; 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.

Keywords: LHC beam, fixed-target experiment

Contents

Preprint submitted to ArXiv: SLAC-PUB-14878 *March 1, 2012*

Partonic structure of nucleon and nuclei

Nucleon constituents: quarks (u, d, s, ...) and gluons

Deep inelastic scattering experiments
l p → l X
scale = Q : virtual photon energy

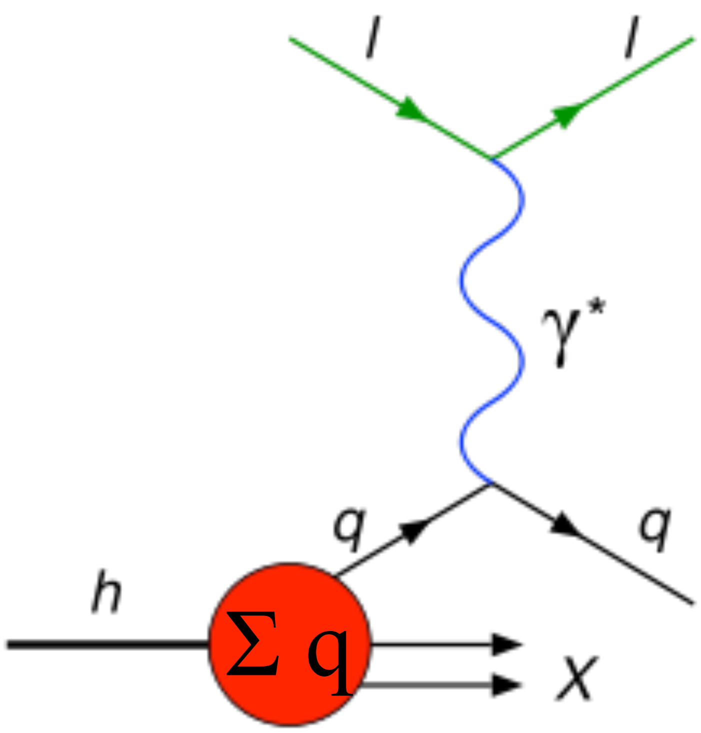
Drell-Yan
p p → $l^+ l^-$ X
scale = Q : $l^+ l^-$ invariant mass

q(x,Q^2): parton distribution functions (pdfs) = probability to find a parton in the nucleon with a longitudinal momentum fraction x at momentum transfer Q^2

$x = p_{quark} / p_{nucleon}$

pdfs for each partons u(x), d(x), ... in proton, neutron and for different nuclei extracted from the data

Deep Inelastic Scattering (DIS)



p p → jet
p p → W, Z
p p → Isolated photons

With nuclei
l A → l X
p A → $l^+ l^-$

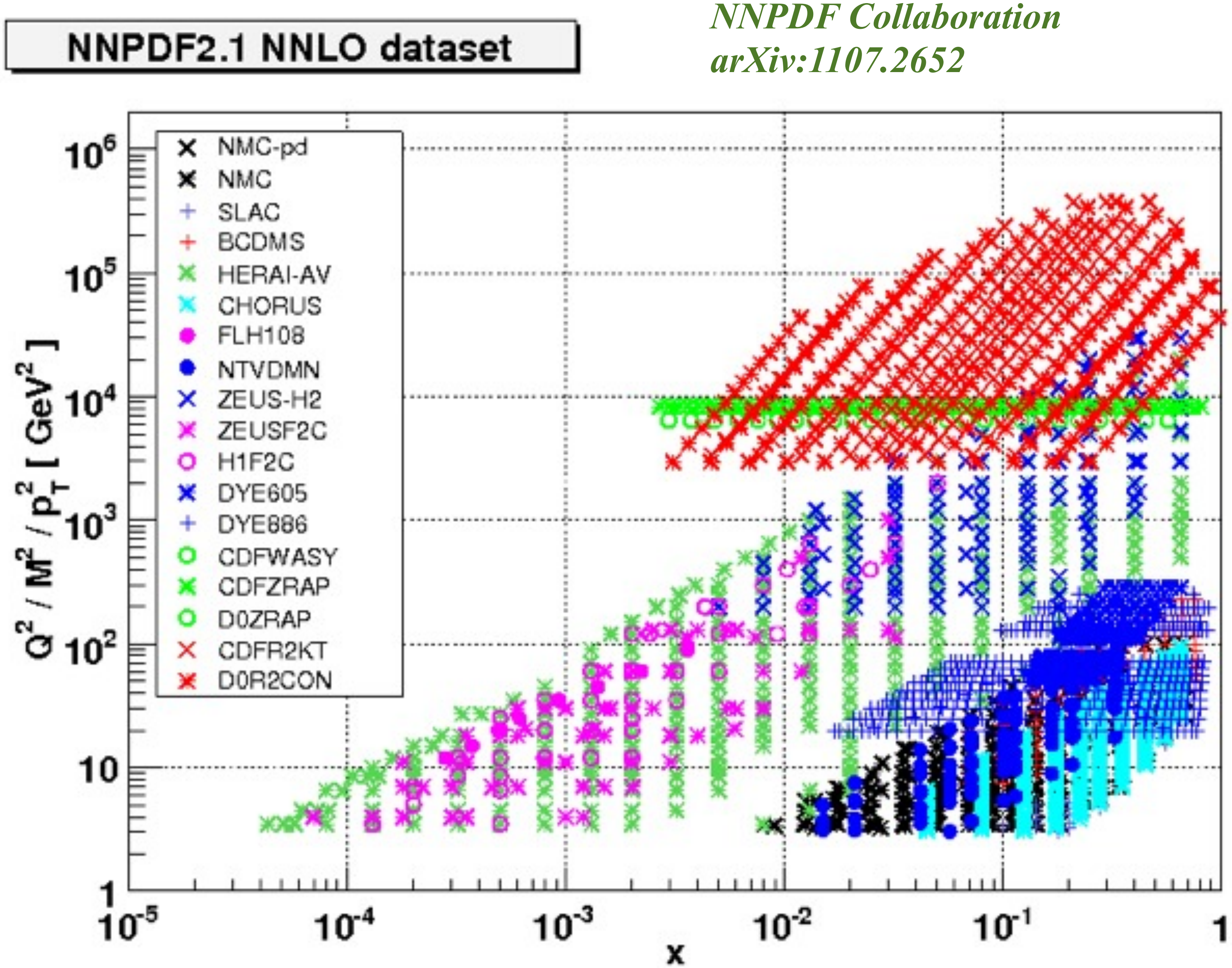
Proton structure: our current knowledge

Deep inelastic scattering (ep), hadronic collisions (pp): fixed-target or collider

High-*x* pdfs: few data available (DIS) and mostly sensitive to valence-quarks

Sea and gluon pdfs at large *x* extracted from DGLAP evolution equation → large uncertainty also for large scale

NNPDF Collaboration
arXiv:1107.2652



Proton structure: our current knowledge

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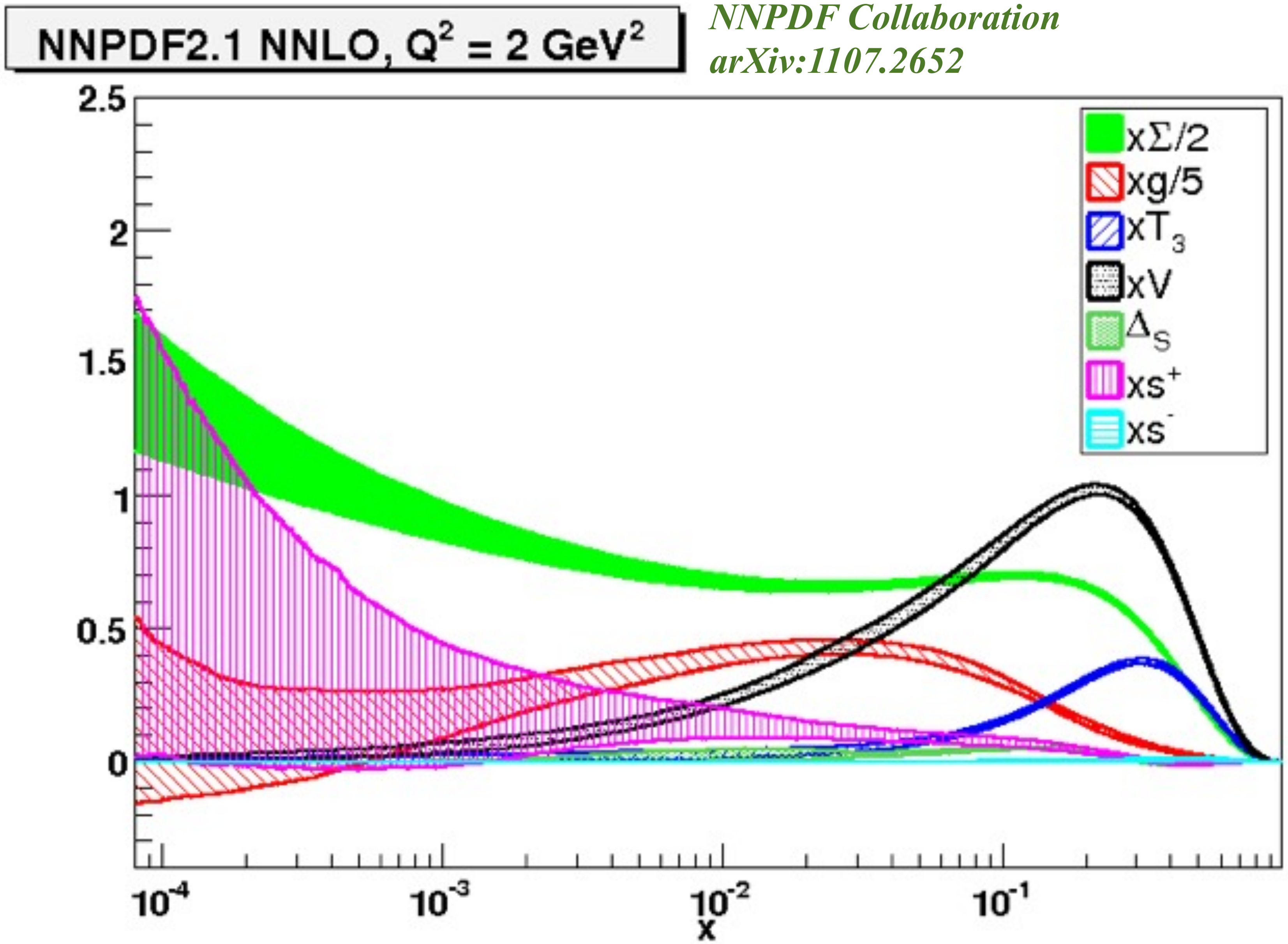
What about x = 0.3 - 1 in proton, neutron and nuclear matter (and x > 1 for nuclear matter) ?



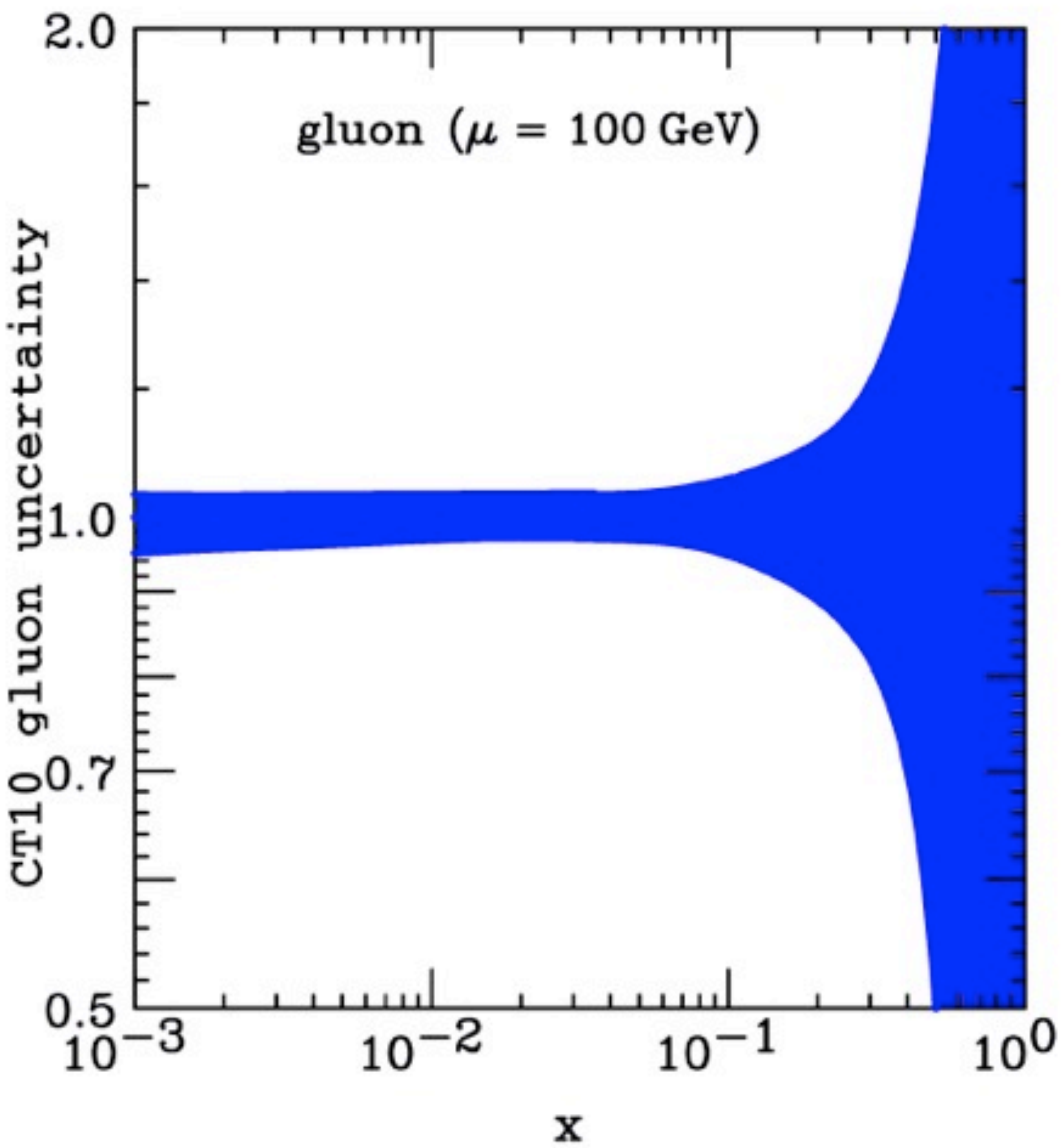
NNPDF Collaboration arXiv:1107.2652

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

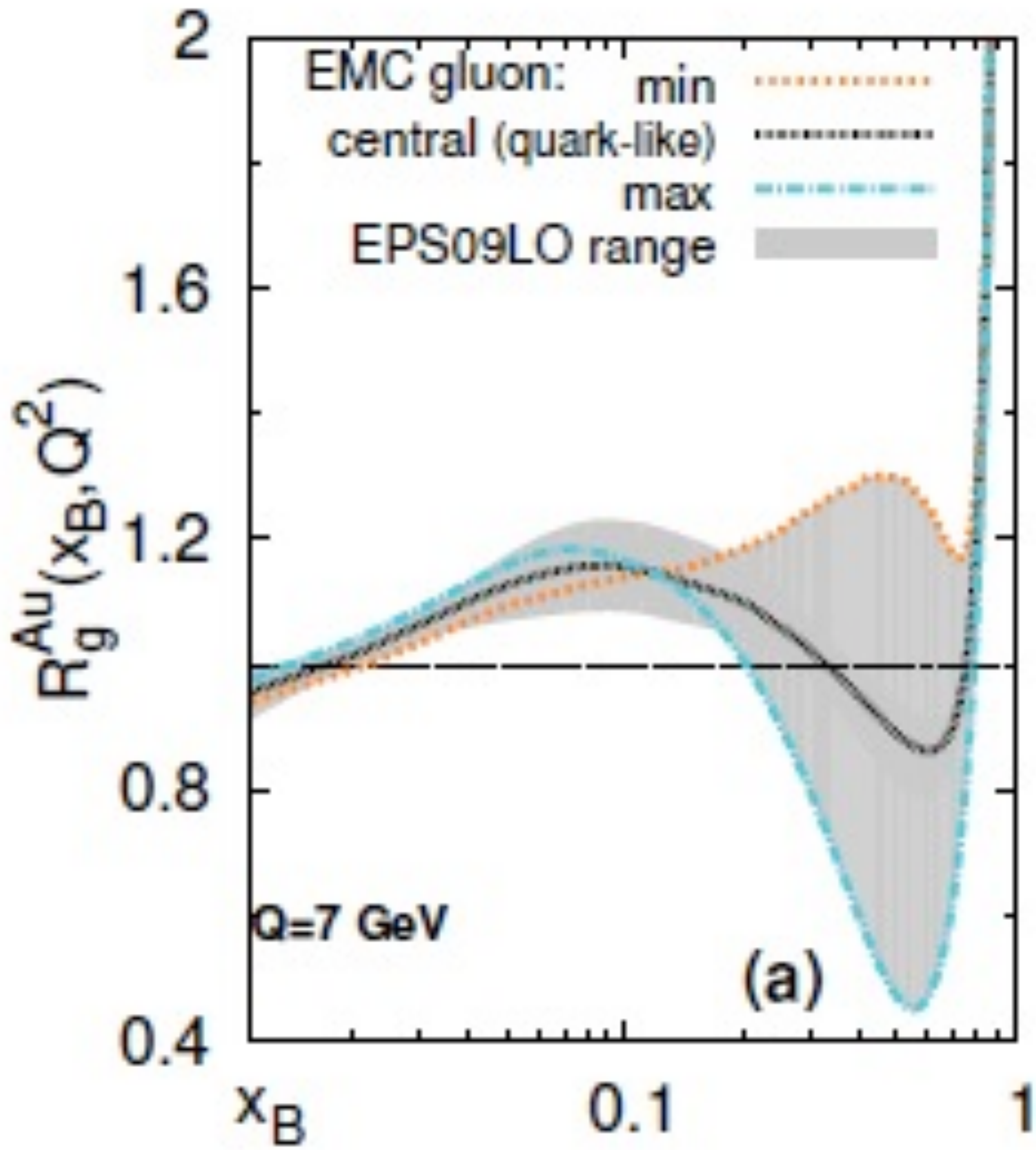


Gluon distribution at large *x*

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*



Gluon distribution at large x

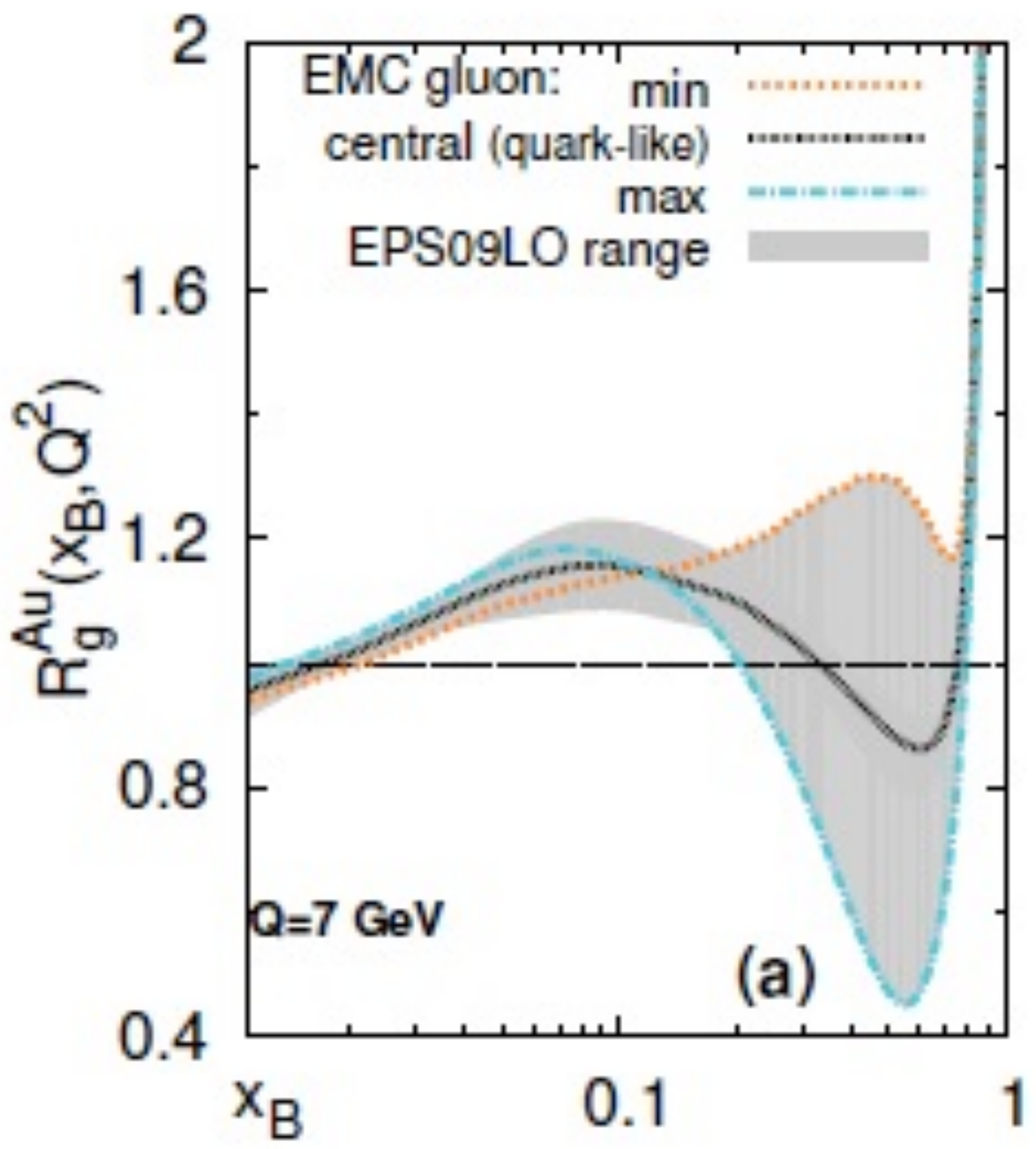
Gluon distribution function in the proton: very large uncertainty at large x also at large Q

Unknown for the neutron

Large uncertainty in nuclei at large x

- **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

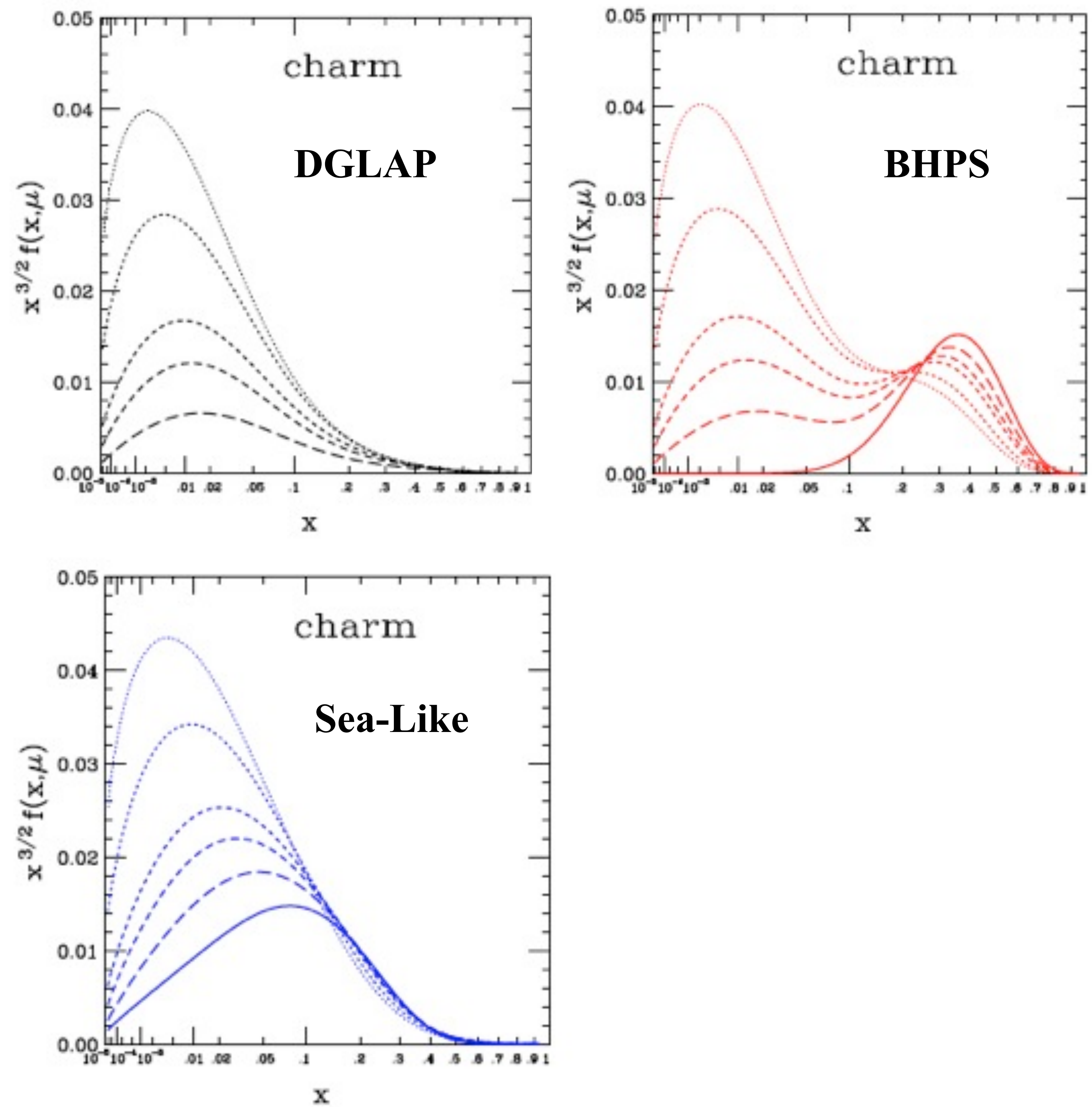


Heavy-quark distribution at large *x*

Intrinsic charm motivated by non perturbative models of hadron structure

All different charm pdfs extraction in agreement with DIS data

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



Heavy-quark distribution at large x

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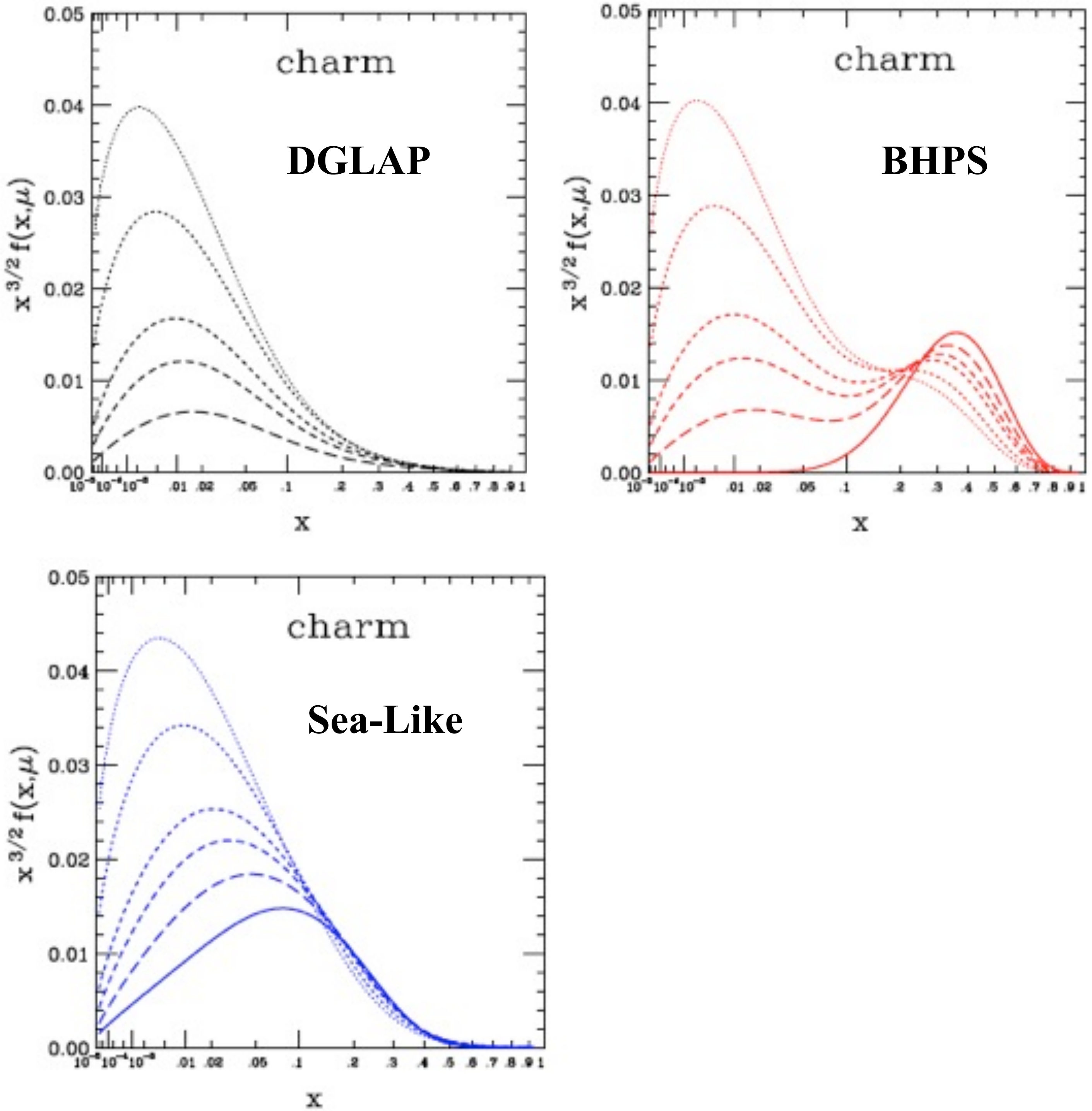
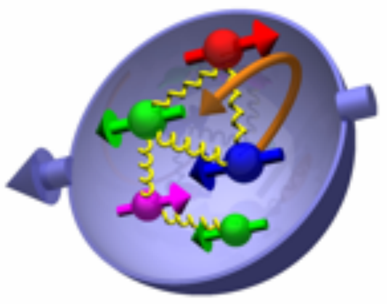
All different charm pdfs extraction in agreement with DIS data

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

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



Sivers effect

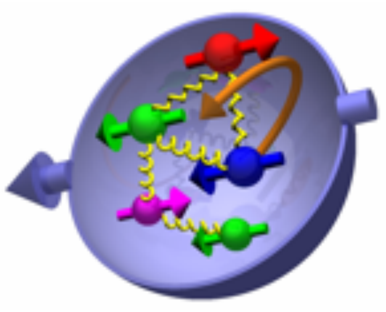


Polarizing the target: measuring asymmetry to access the 3D or Transverse Momentum Dependent (TMD) pdfs.

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

Sivers effect

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



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

- **Experimental probes @ AFTER**
  - Drell-Yan → quark Sivers effect
  - Quarkonia, Open Charm, Isolated photons, photon-jet → gluon Sivers effect
- **Large asymmetries (~20%) predicted in Drell-Yan** for the backward region ($x_F = x_{beam} - x_{target} < 0$)

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

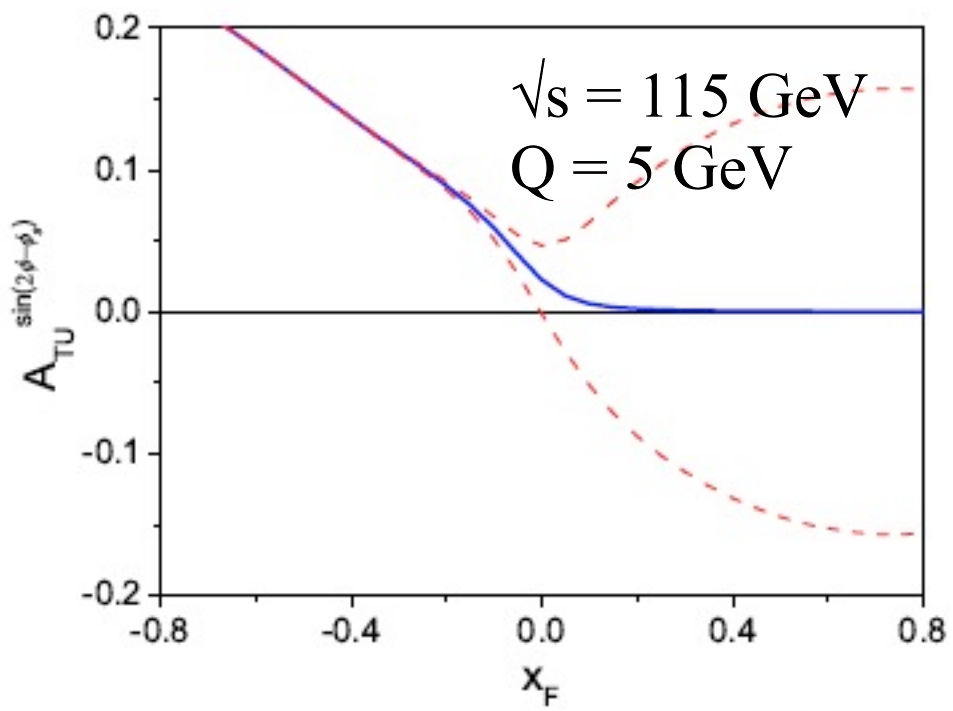


Fig. 29 The $\sin(2\phi - \phi_S)$ azimuthal asymmetry $A_{TU}^{\sin(2\phi-\phi_S)}$ depending on x_F of target proton polarized pp Drell–Yan process at $Q = 5$ GeV.

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

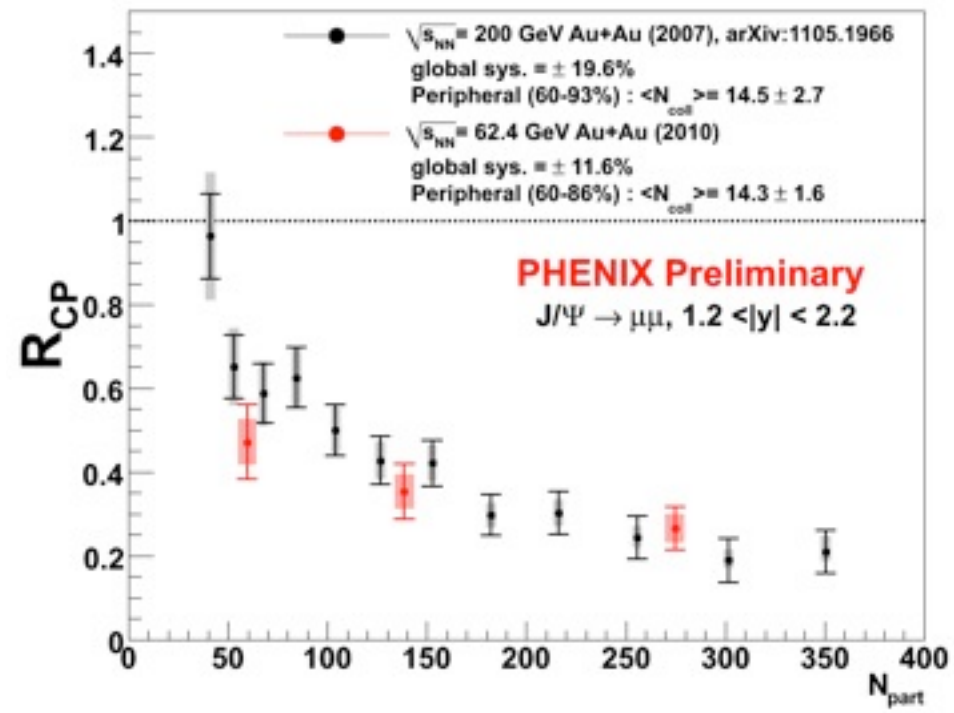
Quark Gluon Plasma

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

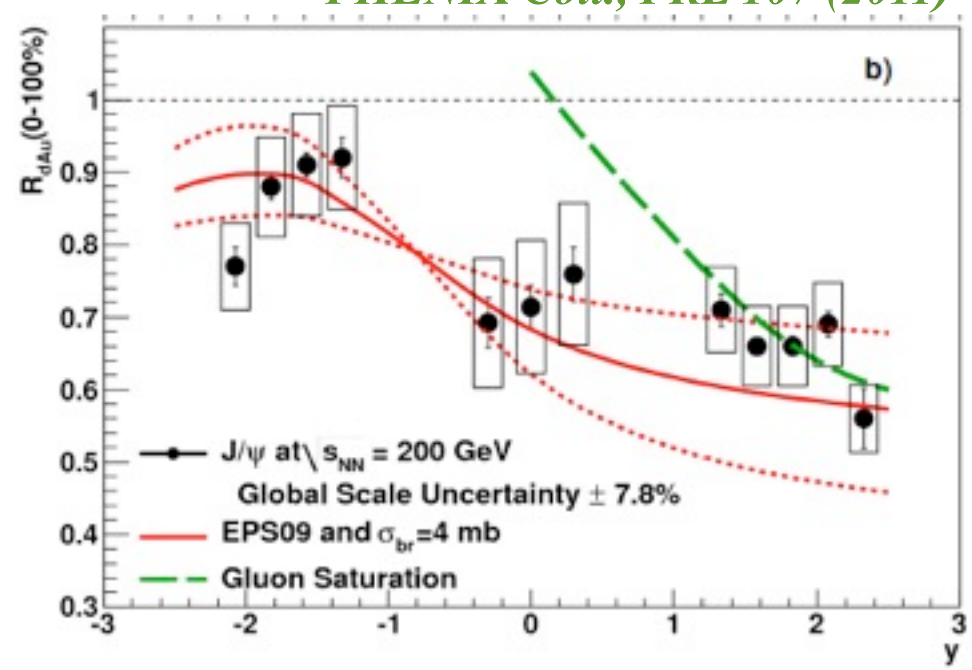
RHIC energy scan shows suppression of particles at $\sqrt{s_{NN}}$ = 32, 64, 200 GeV (π^0, J/Ψ, ...) but low statistics for $\sqrt{s_{NN}} \neq 200$ GeV

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

J. Phys. G: Nucl. Part. Phys. 38 124108



PHENIX Coll., PRL 107 (2011)



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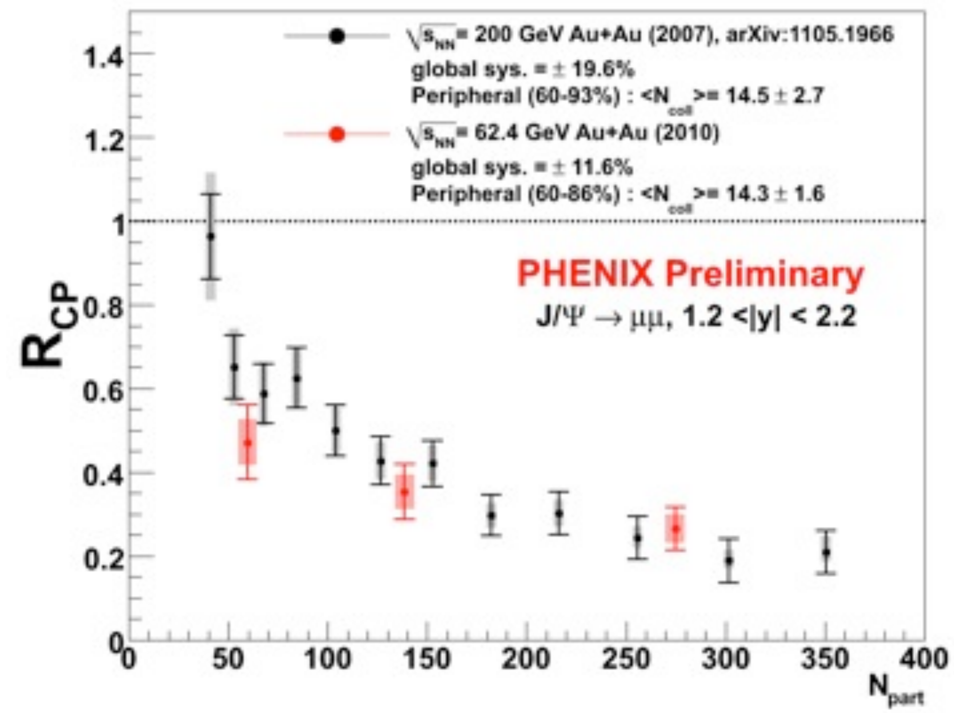
Cold Nuclear Matter (i.e not Hot from QGP) measured in dAu

- **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

J. Phys. G: Nucl. Part. Phys. 38 124108



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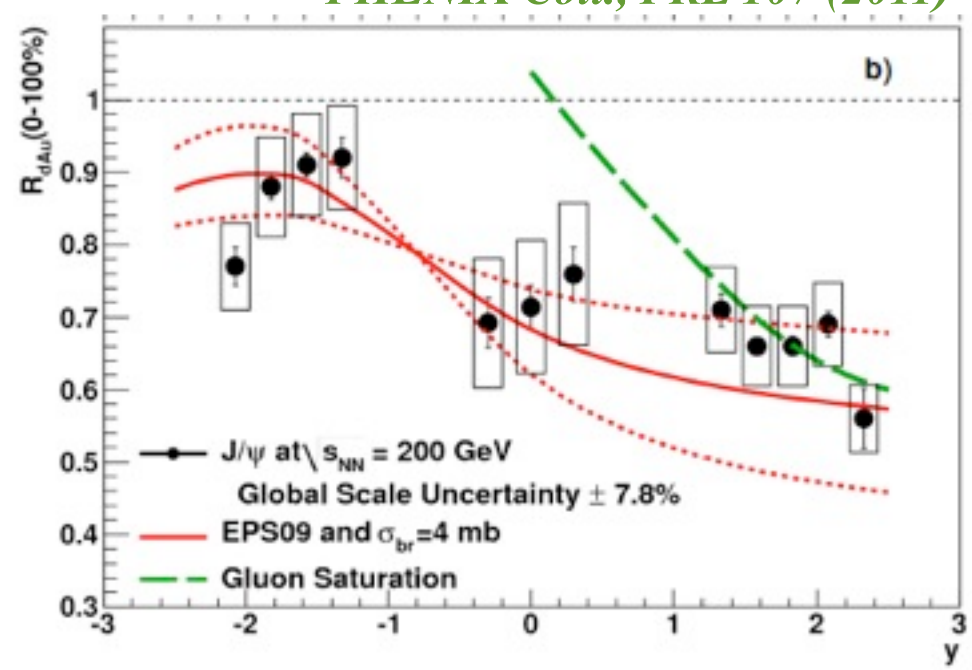
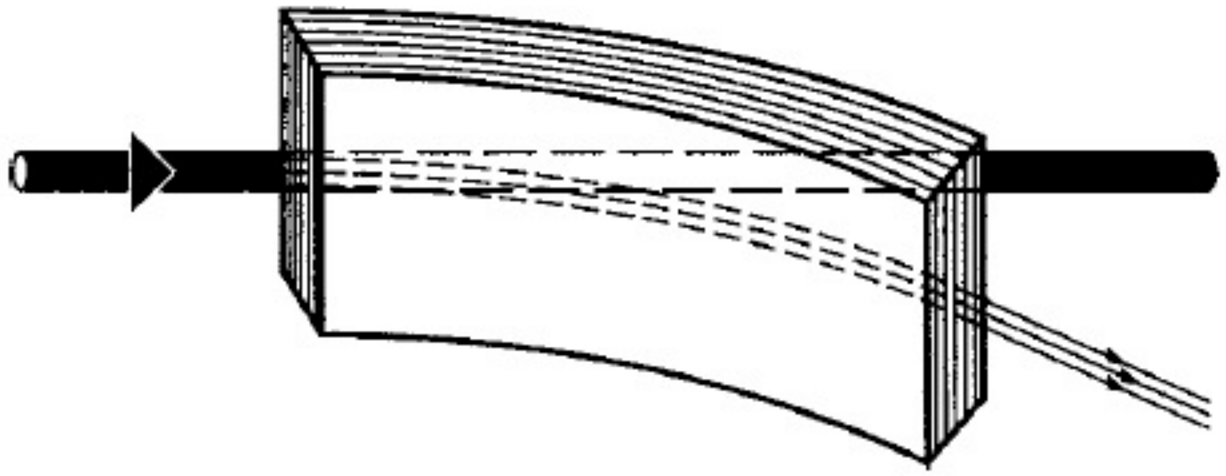


LHC proton and ion beam extraction

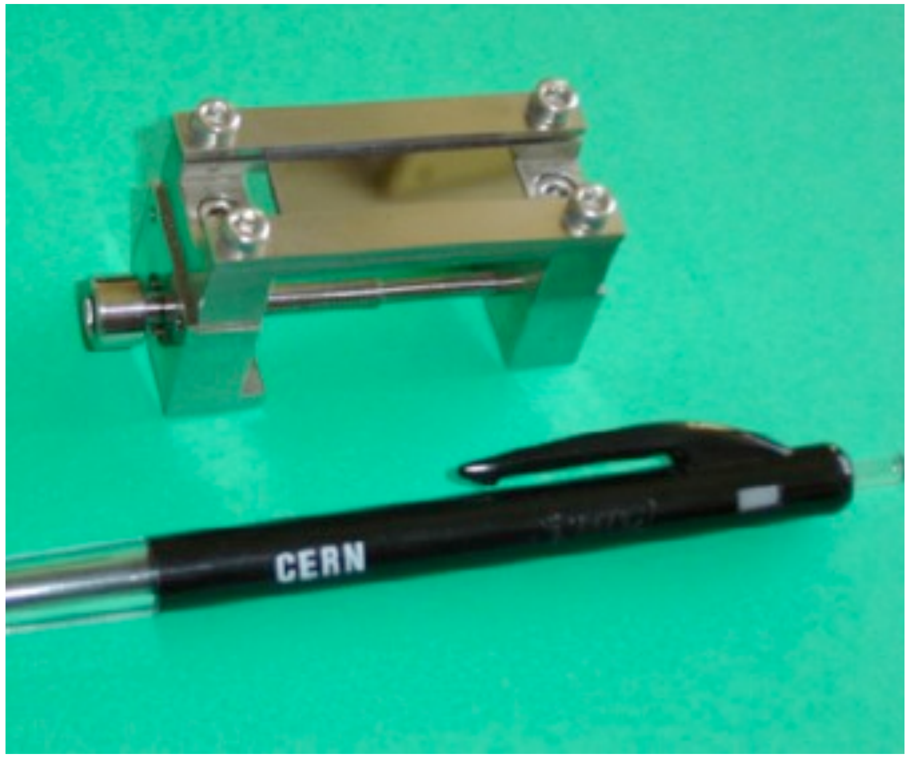
Strong crystalline fields in bent crystals

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 ⇔ 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-...)
- ...



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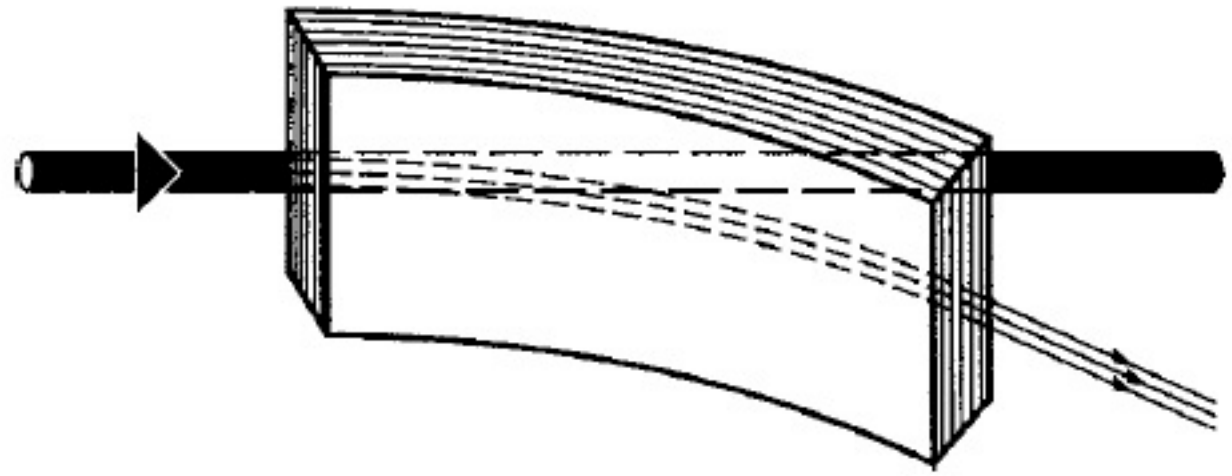

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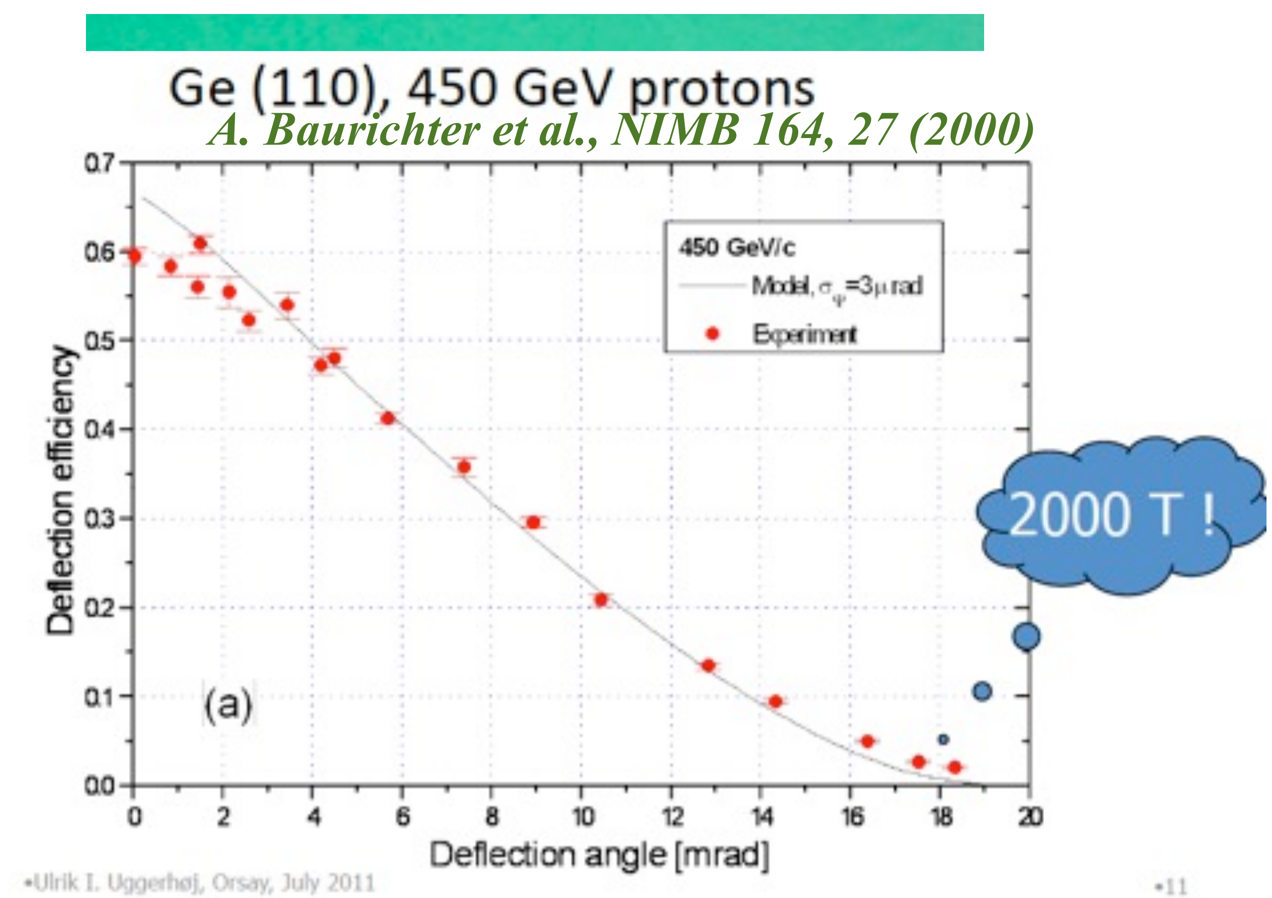
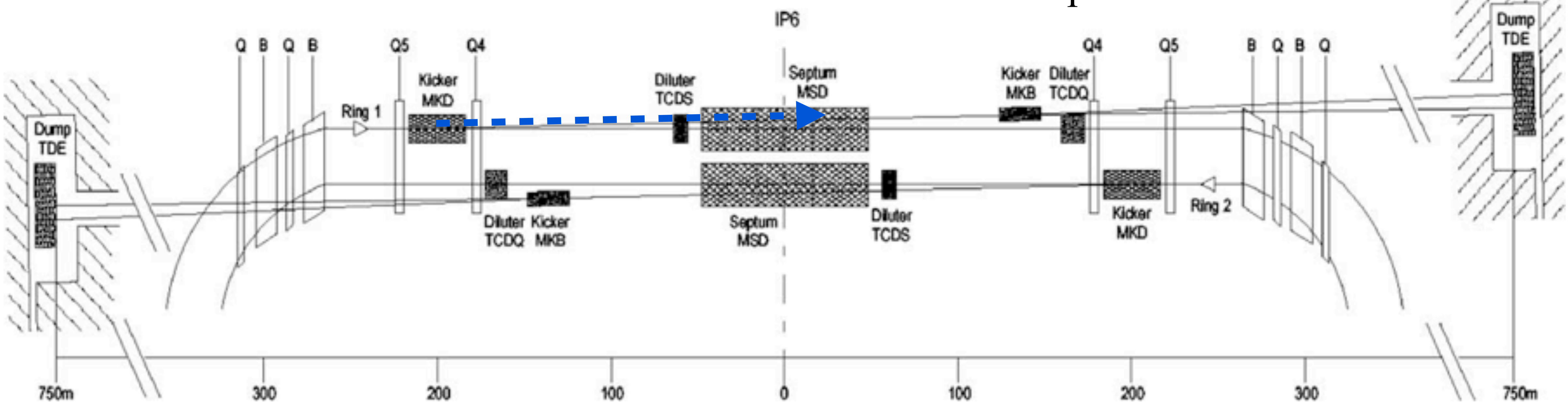


A possibility for proton and lead beam extraction at the LHC

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 7 σ to the beam to intercept and deflect the beam halo
- No loss in the LHC beam
- Bent crystal acts as a beam collimator

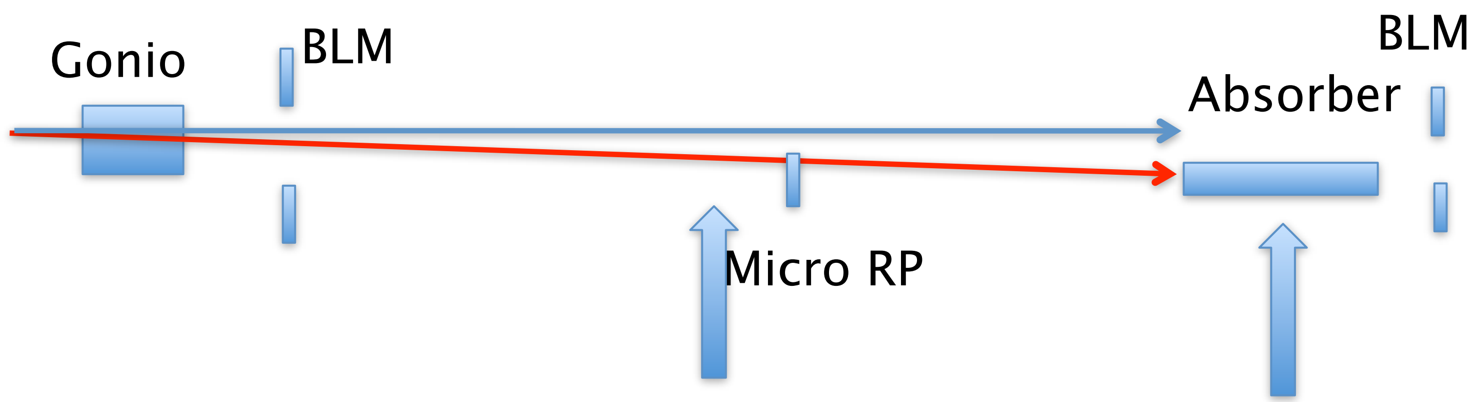
- Proton beam extraction
- Single- or multi pass extraction efficiency of 50%
  - $N_{\text{beam loss LHC}} \sim 10^9$ p/s $\rightarrow N_{\text{extracted beam}} = 5\ 10^8$ p/s
- Extremely small emittance: beam size in the extraction direction) 950 m after the extraction ~ 0.3 mm

- 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

Next: beam bending experiment @ LHC

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



- LHC Committee 14/10/2011 recommandation: beam bending experiments using crystals at the LHC by LUA9 Collaboration
- Beam collimation @ LHC: amorphous collimator: 0.2% inefficiency @ 3.5 TeV → crystal (expected) 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

Luminosities in pH, pA, PbH and PbA

Luminosities in pH and pA @ 115 GeV

- **Intensity: $N_{beam} = 5.10^8$ protons.s^{-1}**
  - Beam: 2808 bunches of 1.15×10^{11} p = 3.2×10^{14} p
  - Bunch: Each bunch passes IP at the rate: ~11 kHz
  - Instantaneous extraction: IP sees 2808 x 11000~3.10^7 bunches passing every second → extract ~16 protons in each bunch at each pass
  - Integrated extraction: Over a 10h run: extract ~5.6% of the protons stored in the beam

- **Instantaneous Luminosity**

  $L = N_{beam} \times N_{Target} = N_{beam} \times (\rho \times \mathbf{e} \times N_A)/A$
  - $N_{beam} = 5 \times 10^8\ p^+/s$
  - **e** (target thickness) = 1 cm

- **Integrated luminosity**
  - 9 months running/year
  - 1 year ~ 10^7 s

Target (1 cm thick)	ρ (g cm^{-3})	A	$\mathcal{L}$ ($\mu b^{-1}\ s^{-1}$)	$\int \mathcal{L}$ ($pb^{-1}\ yr^{-1}$)
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

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

⇒ Larger luminosity with 50 cm or 1 m H2 or D2 target

Luminosities in PbA @ 72 GeV

- **Intensity: $N_{beam} = 2.10^5$ Pb.s^{-1}**
- Beam: 592 bunches of 7×10^7 ions = 4.1×10^{10} ions
- Bunch: Each bunch passes IP at the rate ~ 11 kHz
- Instantaneous extraction: IP sees 592 x 11000~$6.5.10^6$ bunches passing every second → extract ~0.03 ions in each bunch at each pass
- Integrated extraction: Over a 10h run: extract ~15% of the ions stored in the beam

- **Instantaneous Luminosity**

  $L = N_{beam} \times N_{Target} = N_{beam} \times (\rho \times \mathbf{e} \times N_A)/A$
- N_{beam}=2 x 10^5 Pb/s
- **e** (target thickness) = 1 cm

- **Integrated luminosity**
- 1 months running/year
- 1 year ~ 10^6 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

⇒ AFTER provides a good luminosity to study QGP related measurements

Polarizing the hydrogen target

- **Instantaneous Luminosity**

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

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

$x_p^\uparrow$ range corresponds to Drell-Yan measurements

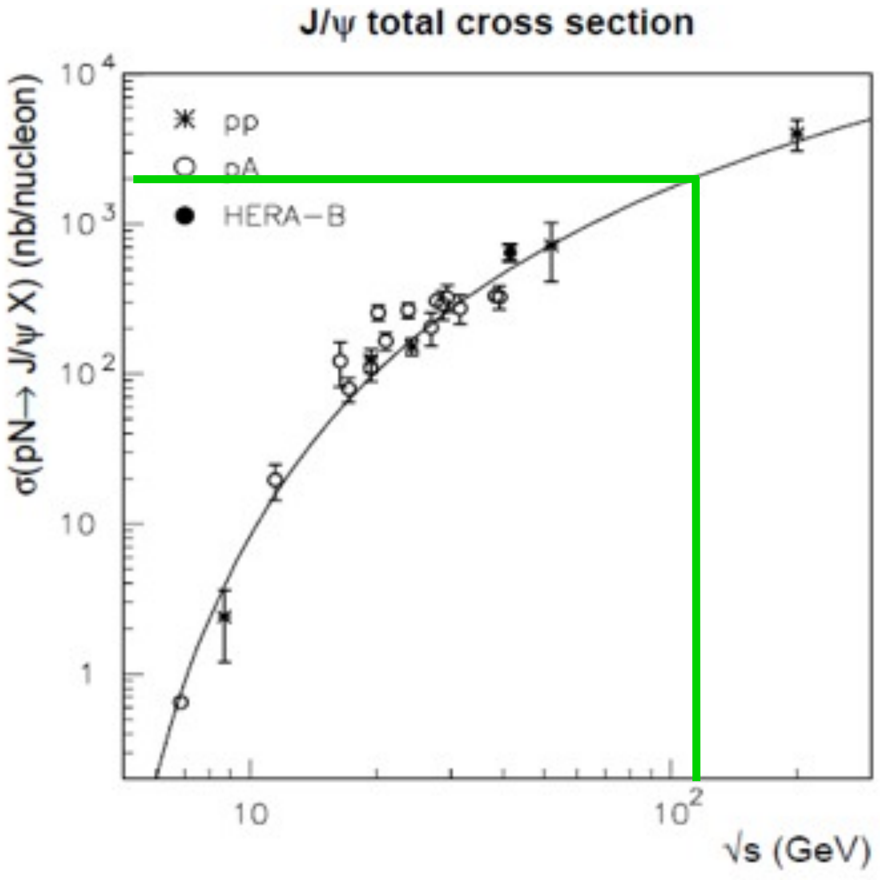
Experiment	particles	energy (GeV)	$\sqrt{s}$ (GeV)	$x_p^\uparrow$	$\mathcal{L}$ ($nb^{-1}s^{-1}$)
AFTER	$p + p^\uparrow$	7000	115	$0.01 \div 0.9$	1
COMPASS	$\pi^\pm + p^\uparrow$	160	17.4	$0.2 \div 0.3$	2
COMPASS (low mass)	$\pi^\pm + p^\uparrow$	160	17.4	~ 0.05	2
RHIC	$p^\uparrow + p$	collider	500	$0.05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

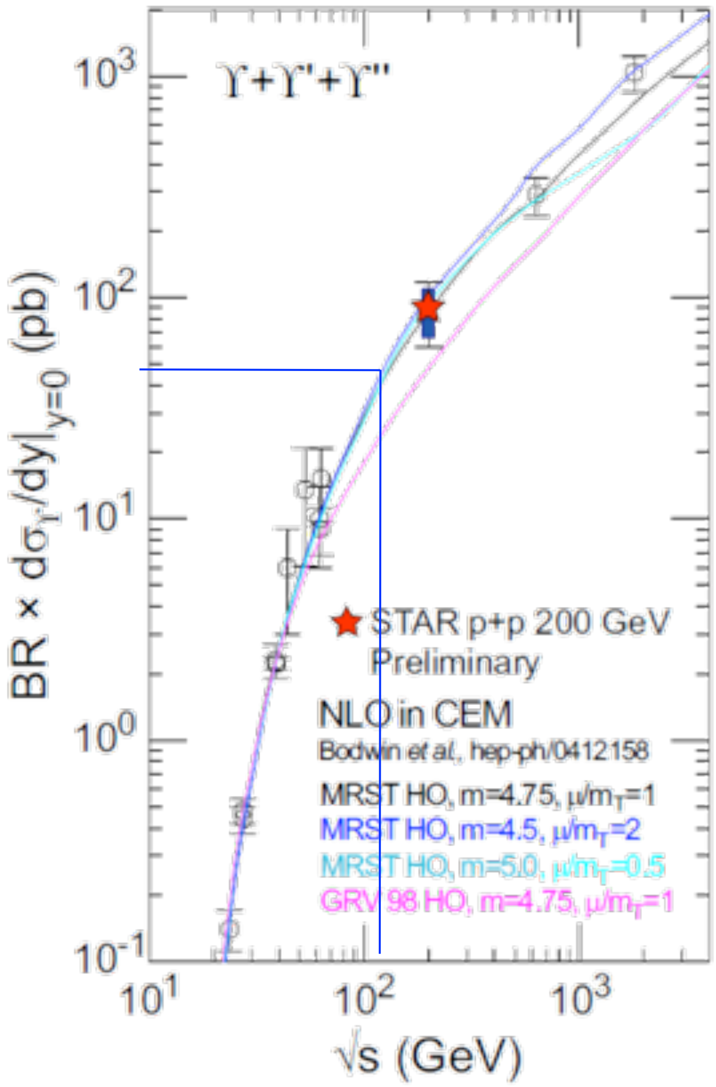
⇒ AFTER provides a good luminosity to study target spin related measurements

⇒ Complementary x_p range with other spin physics experiments

Quarkonium case: annual yields

Quarkonium cross-sections





Inclusive pp cross-sections

B_{ll} $d\sigma/dy|_{y=0}$ @ 115 GeV

J/ψ = 20 nb

Y = 40 pb

Inclusive pp cross-sections

B_{ll} $d\sigma/dy|_{y=0}$ @ 72 GeV

J/ψ = 10 nb

Y = 15 pb

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, ...)

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, ...)

Geometrical Acceptance
Simulations using ALICE as a fixed target experiment at LHC quotes a Geometrical Acceptance of 8% for J/ψ (4 π) → $\mu^+\mu^-$ (2.5< y < 4) using the Forward Muon Spectrometer @ 115 GeV

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

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

Luminosity per year in fb^{-1}

Accessing the large x gluon pdf

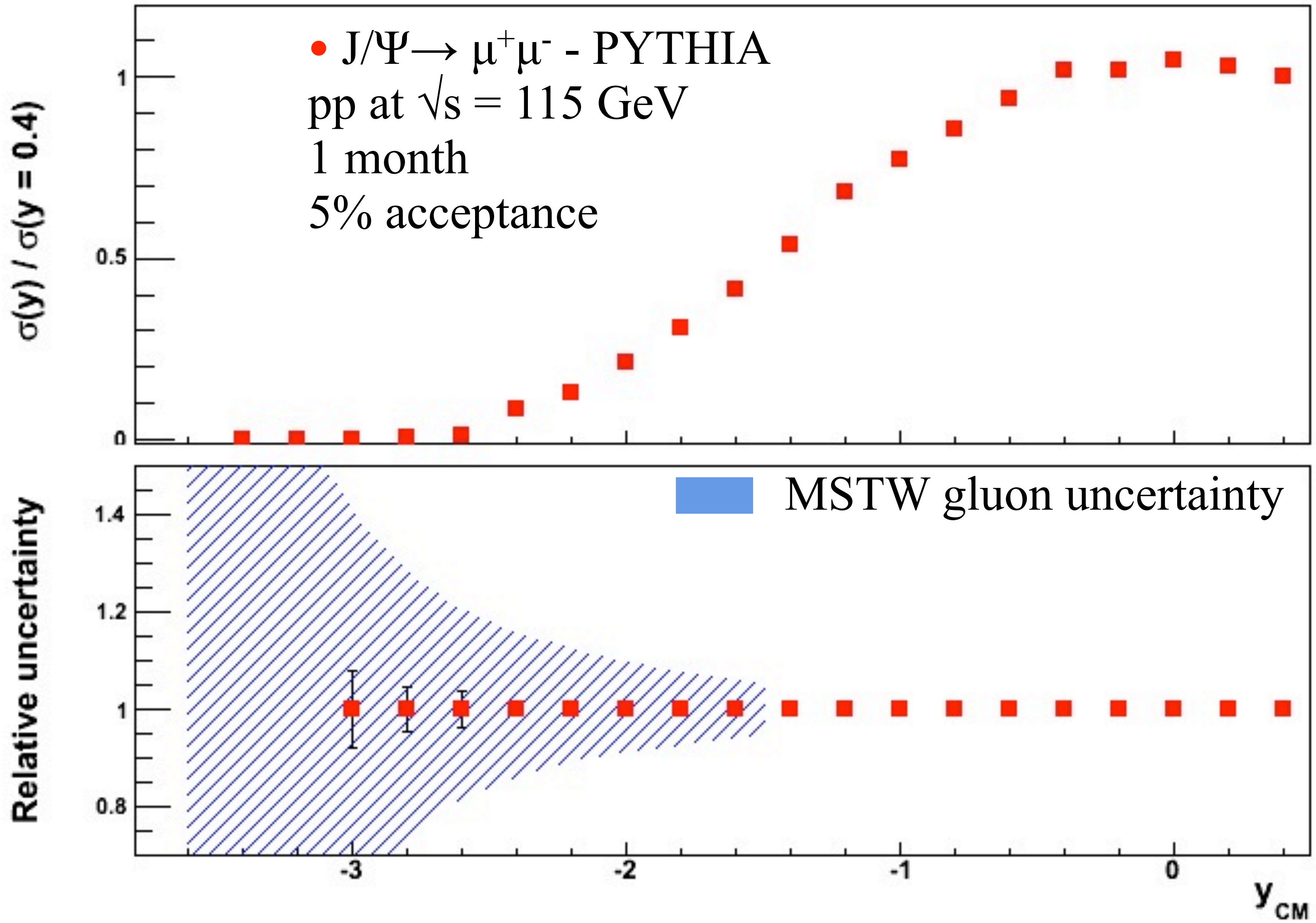
PYTHIA simulation
$\sigma(y) / \sigma(y=0.4)$
statistics for one month
5% acceptance considered

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

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

Luminosity per year in fb^{-1}

Tentative design for AFTER

Rapidity boost in a fixed target mode

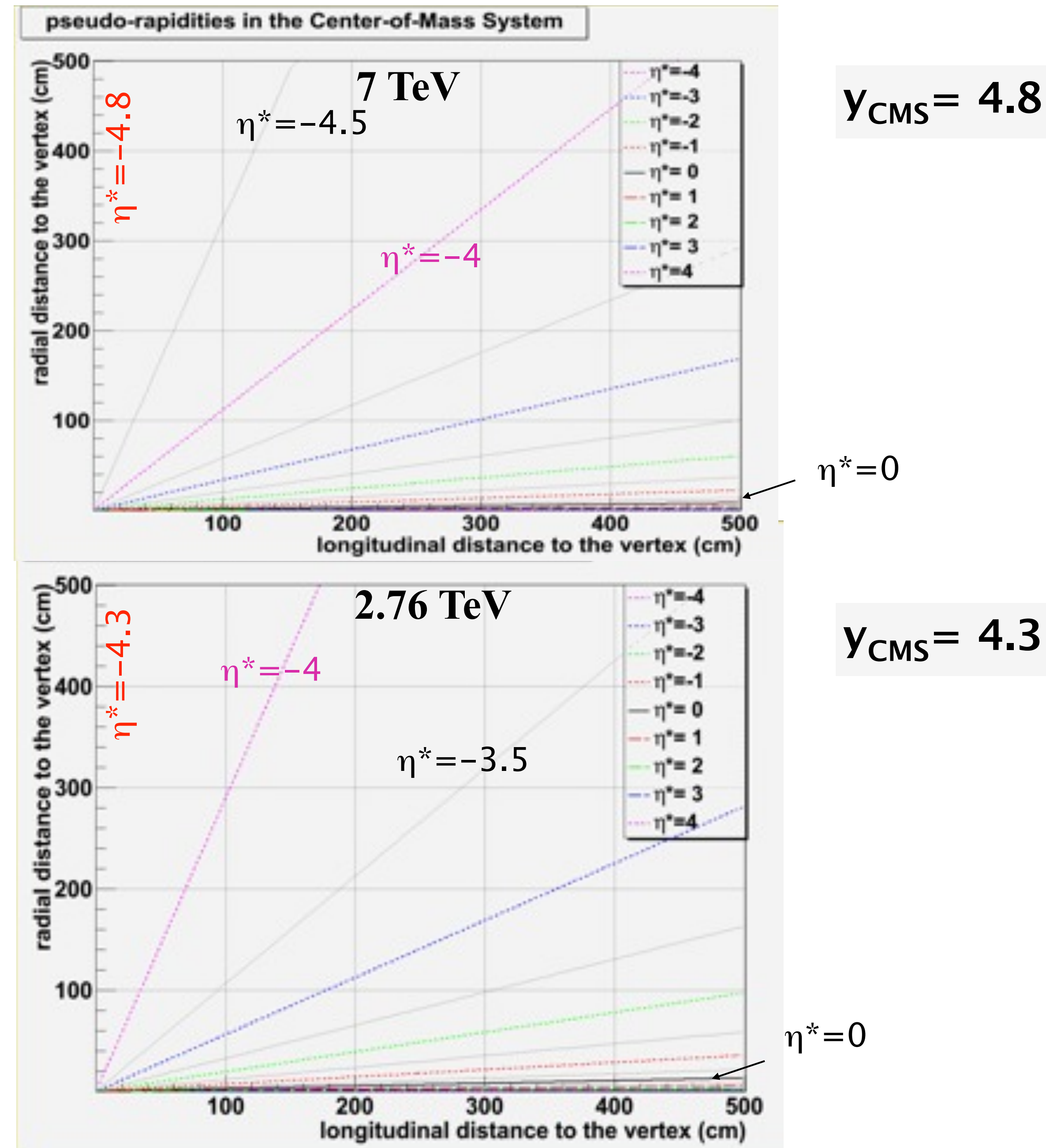
- **Very high boost:**
  - With 7 TeV beam
    $\gamma = 61.1$ and $y_{CMS} = 4.8$
  - With 2.76 TeV beam
    $\gamma = 38.3$ and $y_{CMS} = 4.3$

- $\eta_{CM} = \eta_{lab} - y_{CMS}$
  forward region: $\eta_{CM}>0$
  backward region: $\eta_{CM}<0$

- **Taking $x_2 = M/\sqrt{s}\, e^{-y_{CM}}$**
  - $x_2(J/\Psi) = 1 \rightarrow y_{lab}(J/\Psi) \sim 1.2$
  - $x_2(\Upsilon) = 1 \rightarrow y_{lab}(\Upsilon) \sim 2.4$

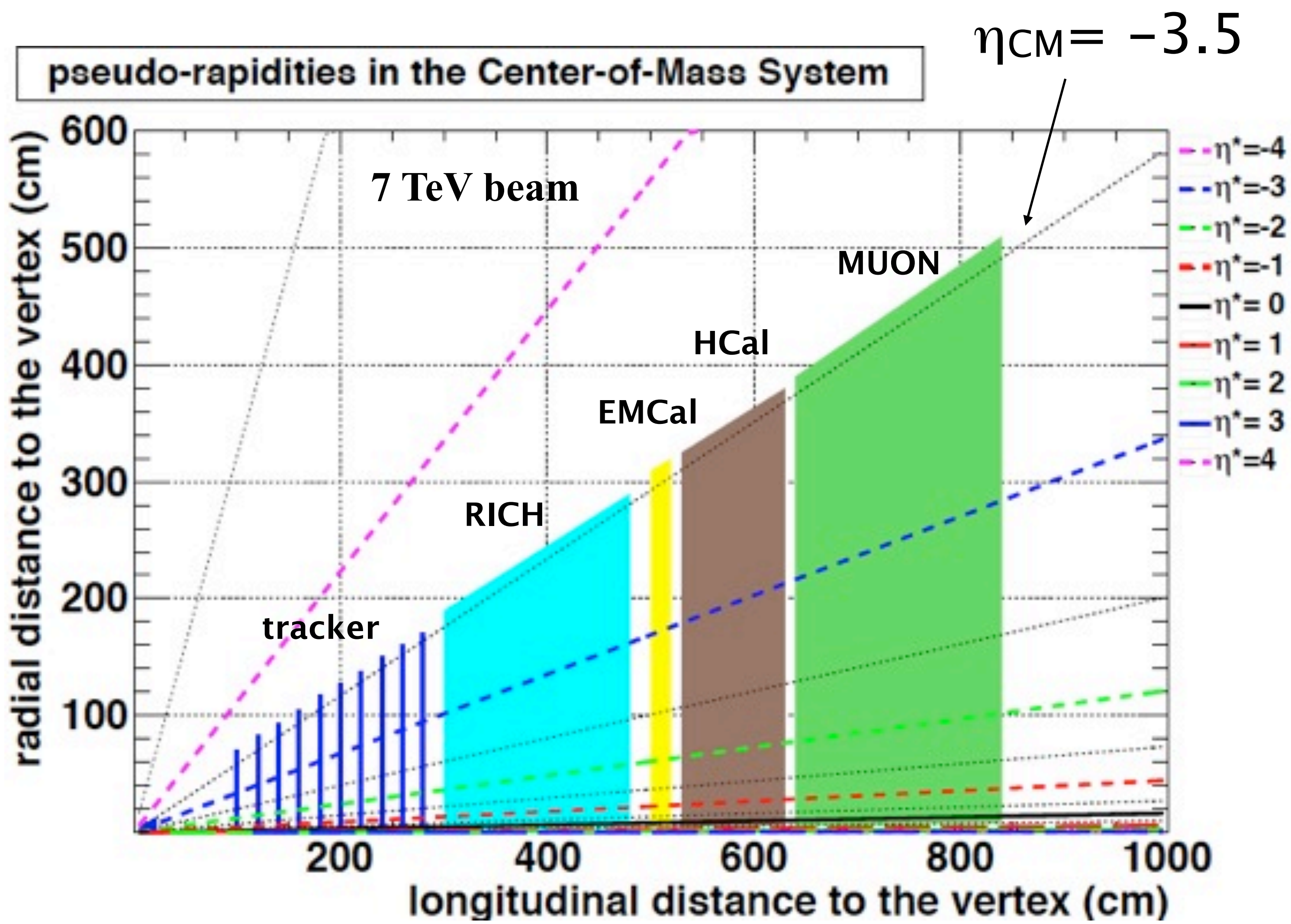
- $\eta = -\ln \tan \theta/2$
  $\rightarrow \theta\ (y_{CM}=0) \sim 0.9°$ (16 mrad)
  - $y_{lab}(J/\Psi) \sim 4.8 \rightarrow x_2(J/\Psi) = 0.03$
  - $y_{lab}(\Upsilon) \sim 4.8 \rightarrow x_2(\Upsilon) = 0.08$

- **Very well placed to access backward physics**



A tentative design for AFTER

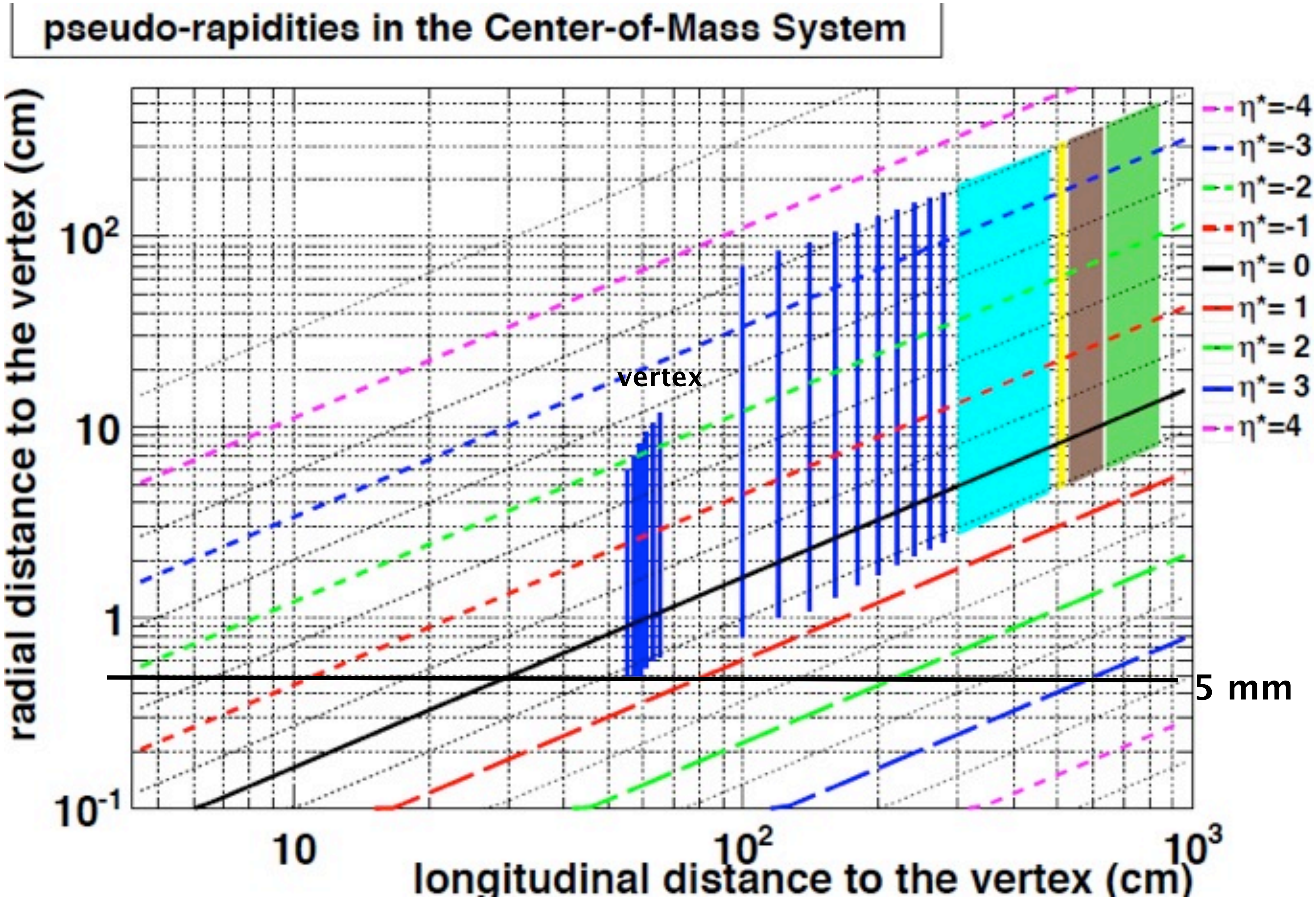
- **Tentative design** $1.3 < y_{lab} < 5.3$
  - With 7 TeV beam : $-3.5 < y_{CM} < 0.5$
  - With 2.76 TeV beam: $-3 < y_{CM} < 1$
  - $\theta_{min} = 10$ mrad
- **Multi-purpose detector**
  - Vertex
  - Tracking (+ dipole magnet)
  - RICH
  - Calorimetry
  - Muons
- **High boost** → forward and as compact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



Detector dimension

$1.3 < y_{lab} < 5.3$
$\theta_{min} = 10$ mrad

Detector	Z_{min}/Z_{max}	R_{min}/R_{max}
Vertex	55/65 cm	0.5/12 cm
Tracker	100/180 cm	0.8/170 cm
RICH	300/480 cm	2.7/290 cm
EMCal	500/520 cm	4.7/320 cm
HCal	530/630 cm	5.0/380 cm
Muons	640/840 cm	8/510 cm

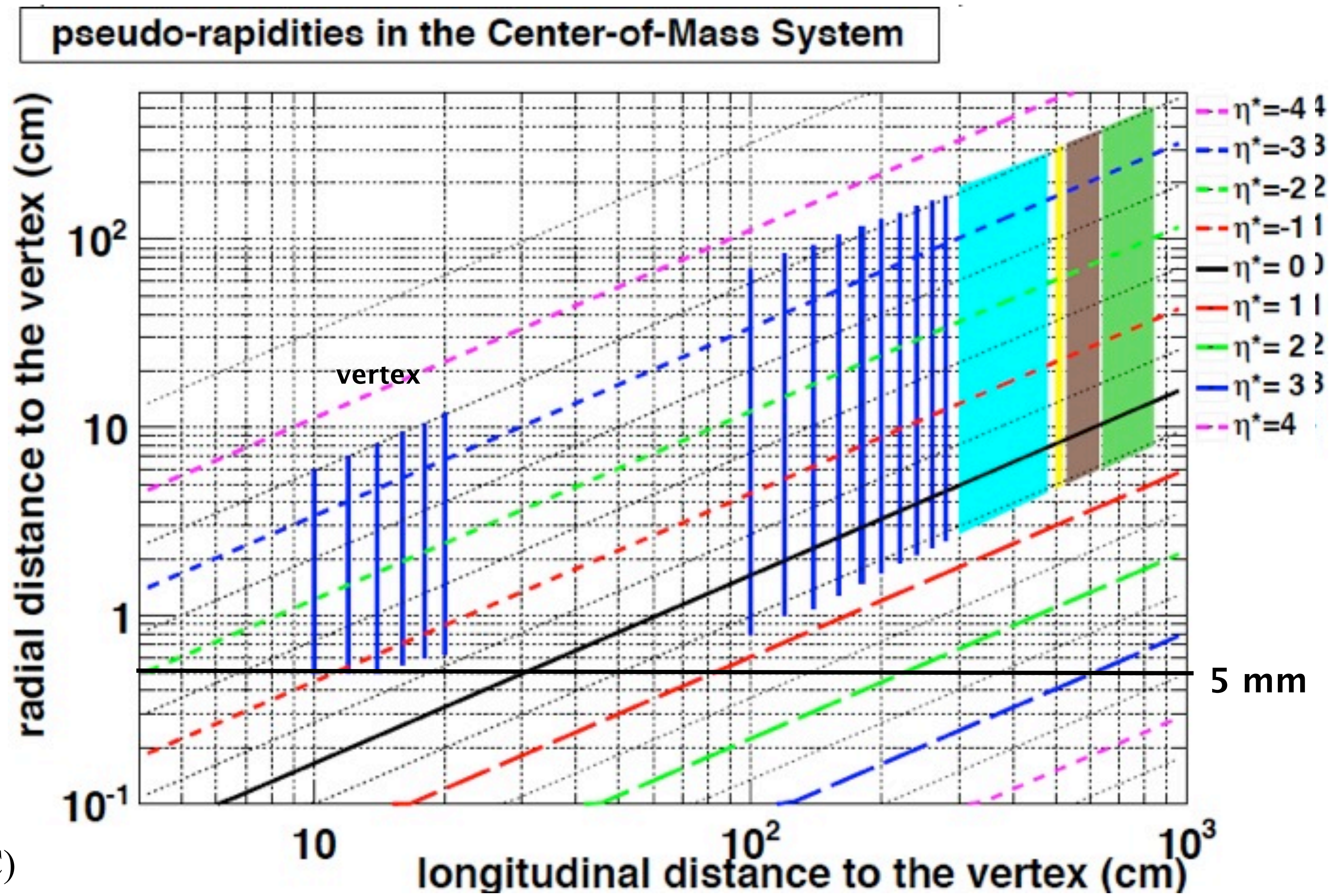


- **Technology**
- Vertex, tracker: pixel detectors
- EMCal: Tungsten/Si (Calice - ILC)
- Muons: Magnetize Fe (Minos)
- ...

Detector dimension

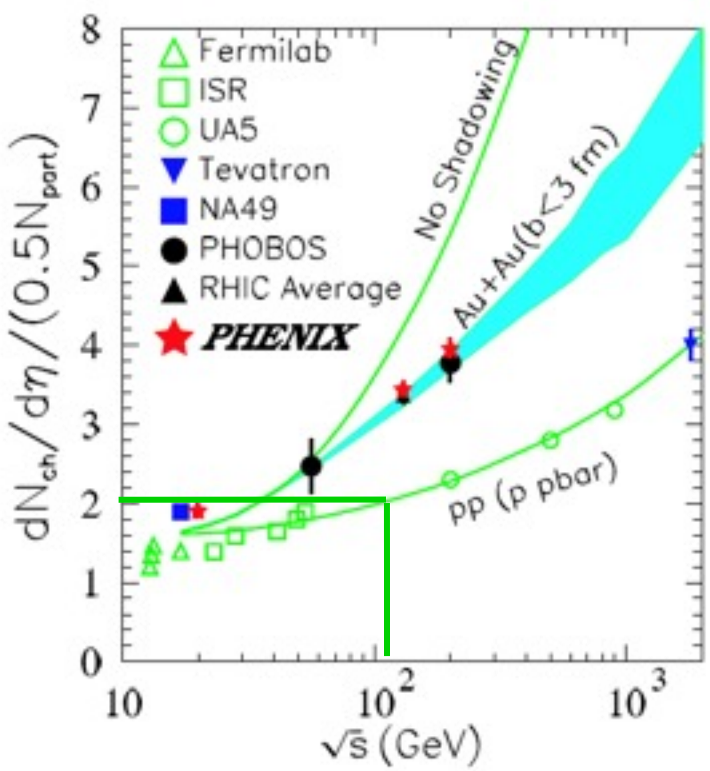
$1.3 < y_{lab} < 5.3$
$\theta_{min} = 10$ mrad

Detector	Z_{min}/Z_{max}	R_{min}/R_{max}
Vertex	10/20 cm	0.5/12 cm
Tracker	100/180 cm	0.8/170 cm
RICH	300/480 cm	2.7/290 cm
EMCal	500/520 cm	4.7/320 cm
HCal	530/630 cm	5.0/380 cm
Muons	640/840 cm	8/510 cm

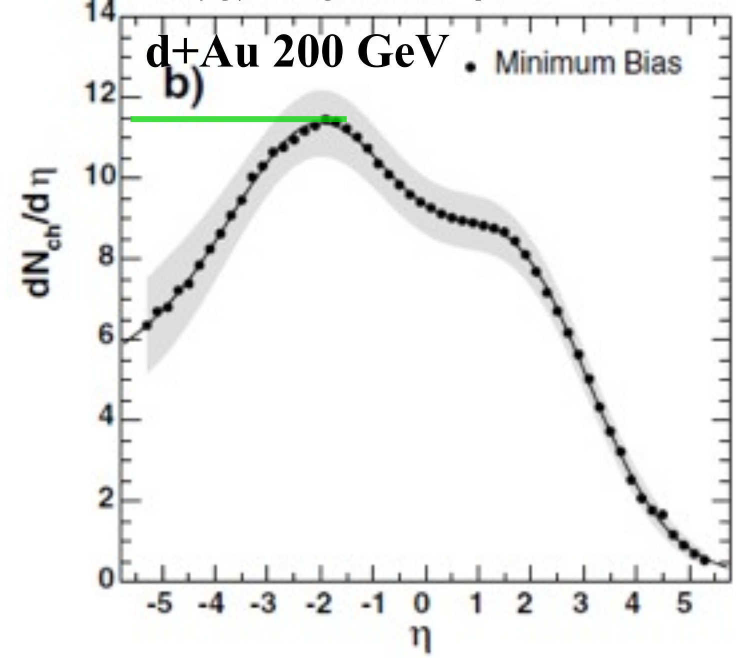


- **Technology**
- Vertex, tracker: pixel detectors
- EMCal: Tungsten/Si (Calice - ILC)
- Muons: Magnetize Fe (Minos)
- ...

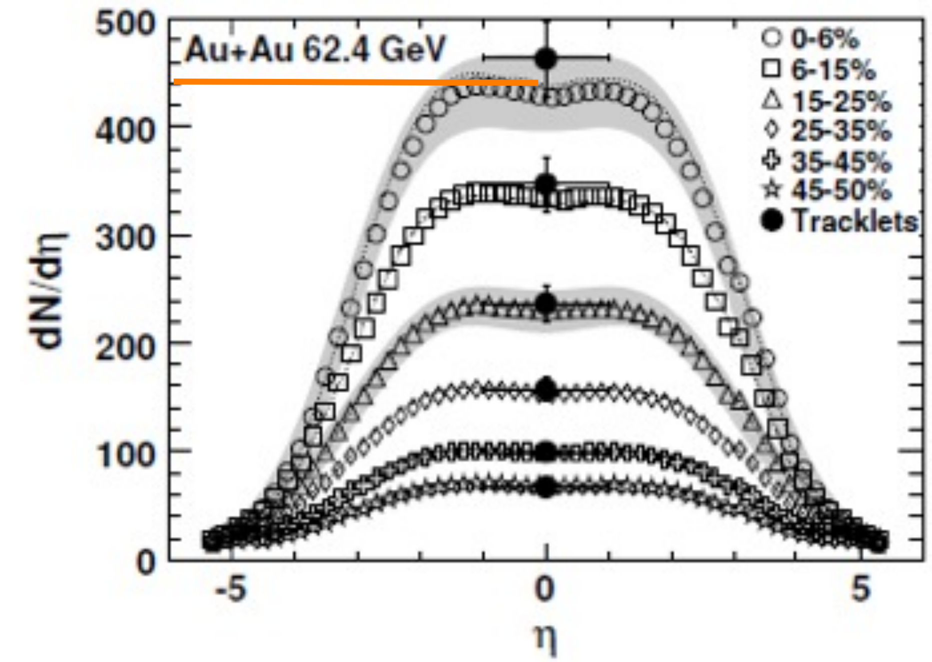
Multiplicity



PRL 93, 082301 (2004)



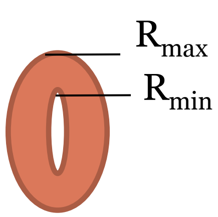
PRC 74, 021901(R) (2006)



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 (cm²)
Vertex	1.5	10	~ 300
Calo	10	40	~4700

Vertex ~ 450 part.

$$1\% \sim \frac{450}{300\times\left(\frac{1}{0.8\times0.8\ \text{mm}^2}\right)^{-1}}$$

$$0.1\% \sim \frac{450}{300\times\left(\frac{1}{0.25\times0.25\ \text{mm}^2}\right)^{-1}}$$

Calo ~ 700 part.

$$\frac{700}{4700\times\left(\frac{1}{1\times1\ \text{cm}^2}\right)^{-1}} \sim 14\%$$

$$\frac{700}{4700\times\left(\frac{1}{0.5\times0.5\ \text{cm}^2}\right)^{-1}} \sim 3.7\%$$

Conclusion and outlook

- 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

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

AFTER @ LHC

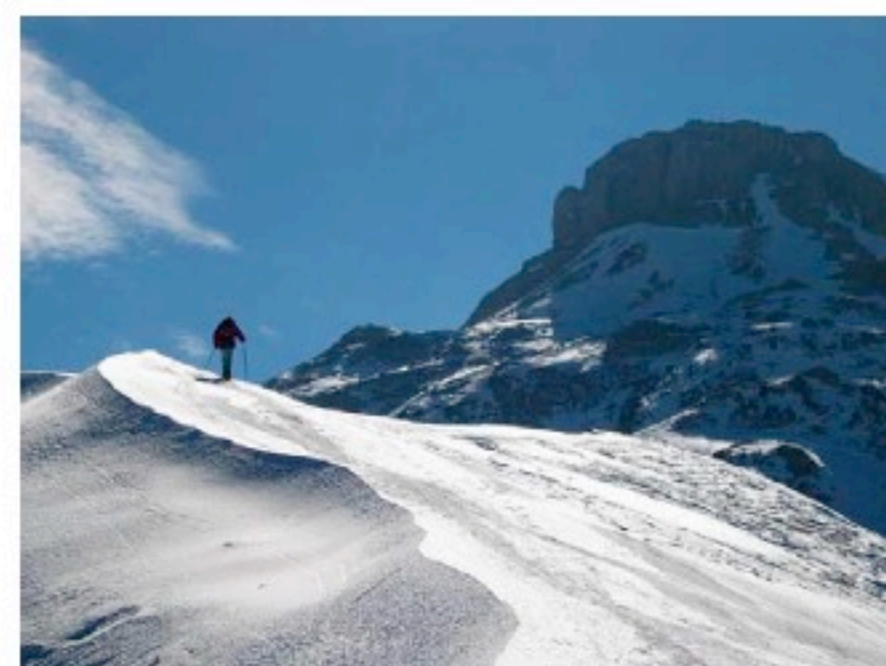
- 2011-2012: Support from France-Stanford Center for Interdisciplinaty Studies
- February 2012: Physics case submitted to Physics Reports (arXiv: 12020.6585)
- 2012: Support from CNRS PEPS-PTI
- 2013-2016: (expected) Support from CNRS PICS with Torino

ECT* European Centre for Theoretical Studies in Nuclear Physics and Related Areas

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.’



Drell-Yan continuum

backward region

forward region

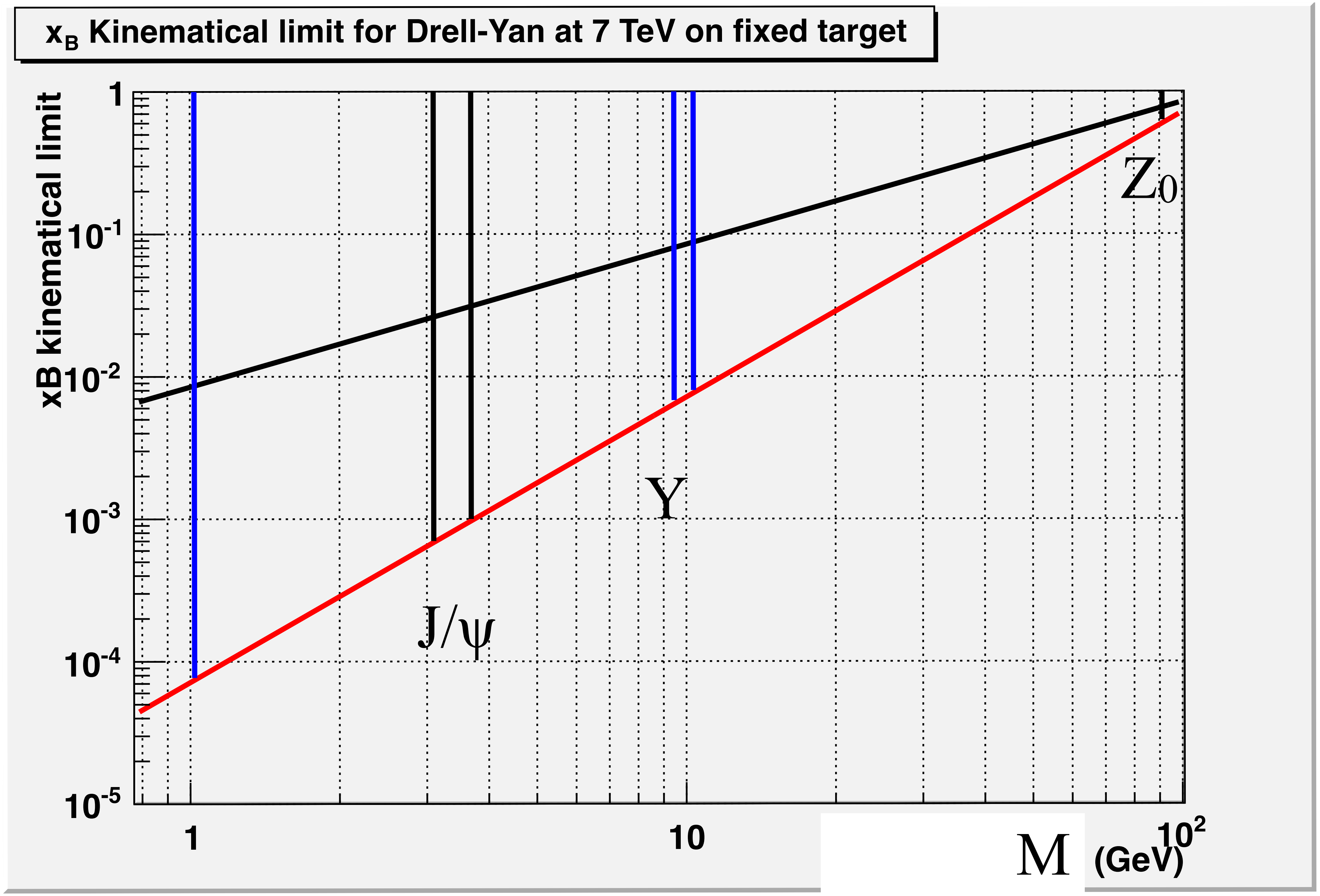
x_{target}

x_{beam}

$x_{target} = x_{beam}$

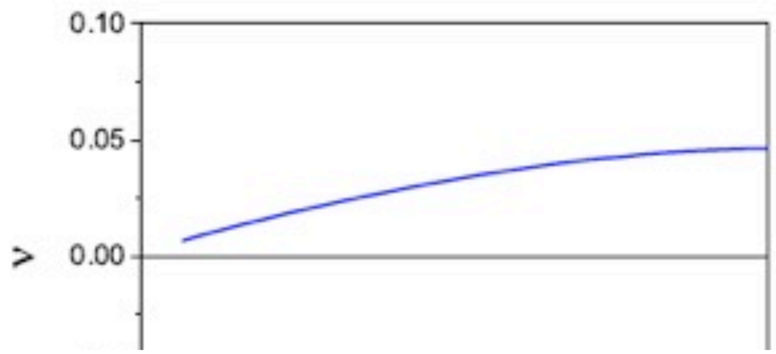
x_{beam}

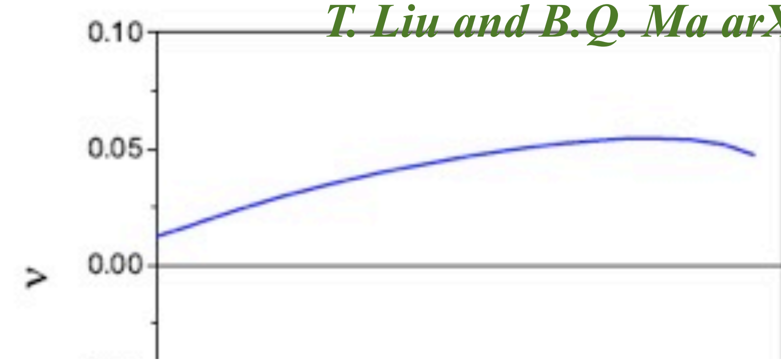
x_{target}



Drell-Yan measurements in pp

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





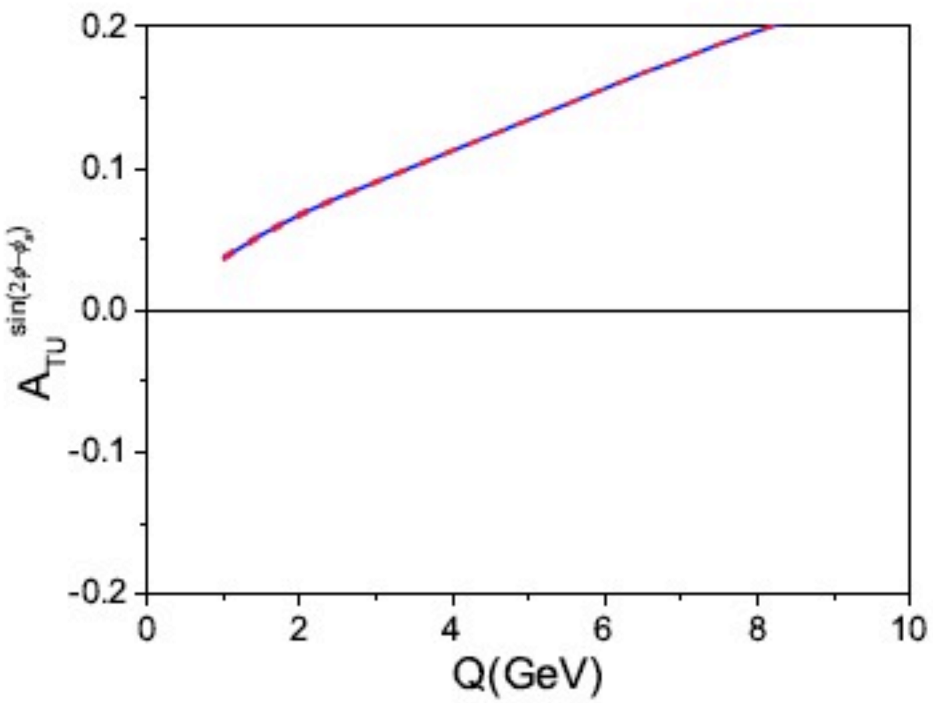
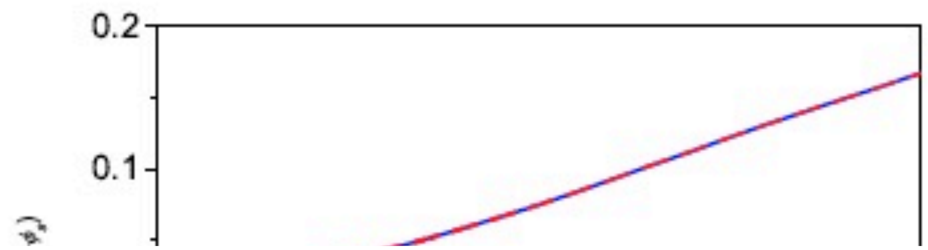


Fig. 17 The $\sin(2\phi - \phi_S)$ azimuthal asymmetry $A_{TU}^{\sin(2\phi-\phi_S)}$ depending on Q of target proton polarized pp Drell–Yan process with both γ^* and Z taken into account and allowed rapidity integrated in the cut $[-4.8, -2]$. The same cut of rapidity is chosen in Figs.18-22.

as Figs. 18–40.

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



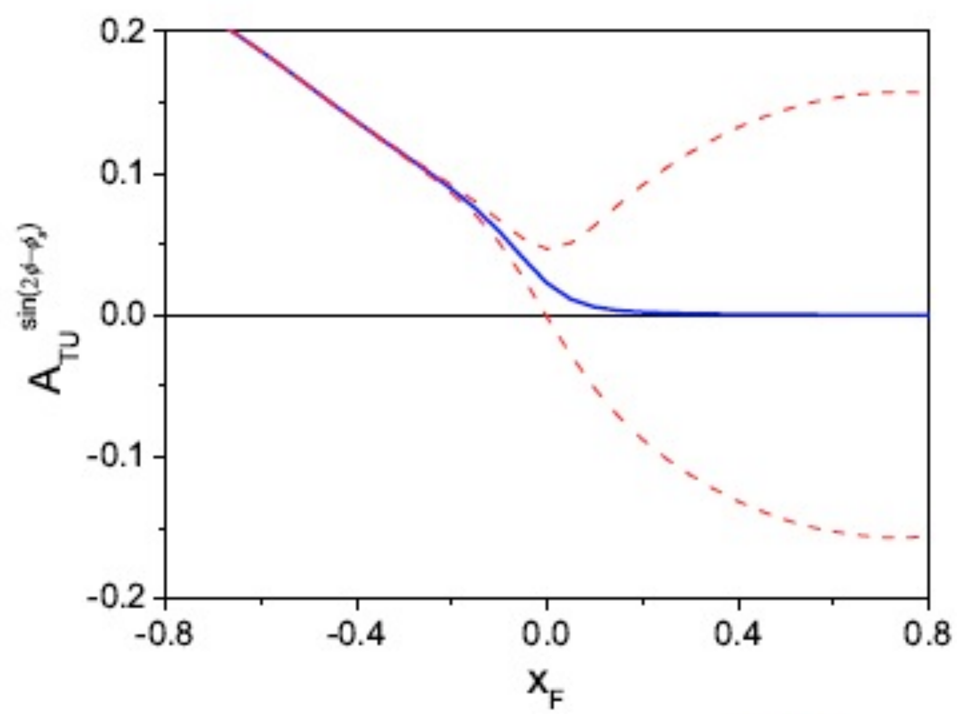


Fig. 29 The $\sin(2\phi - \phi_S)$ azimuthal asymmetry $A_{TU}^{\sin(2\phi-\phi_S)}$ depending on x_F of target proton polarized pp Drell–Yan process at $Q = 5$ GeV.

Drell-Yan measurements in pD

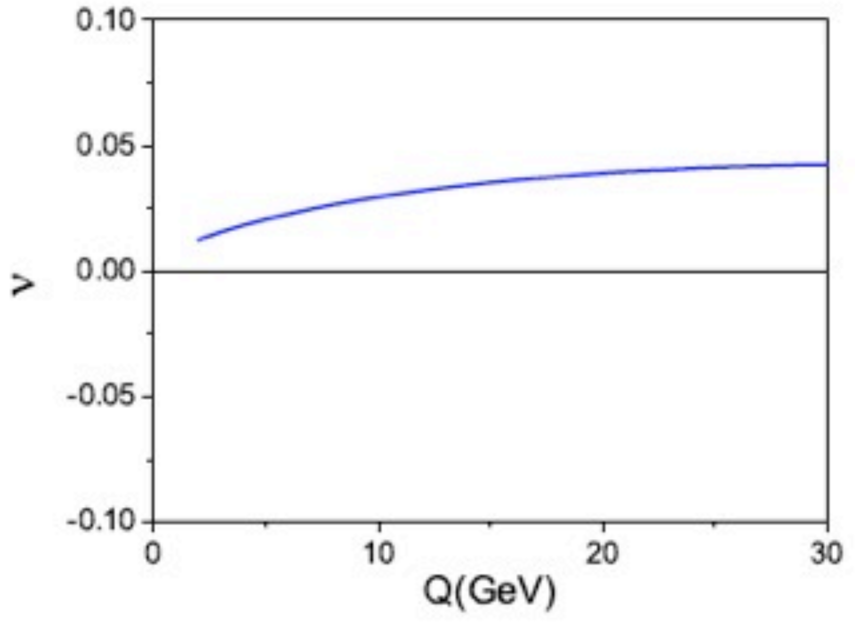


Fig. 7 The $\cos 2\phi$ azimuthal asymmetry depending on Q of unpolarized pd Drell–Yan process with both γ^* and Z taken into account.

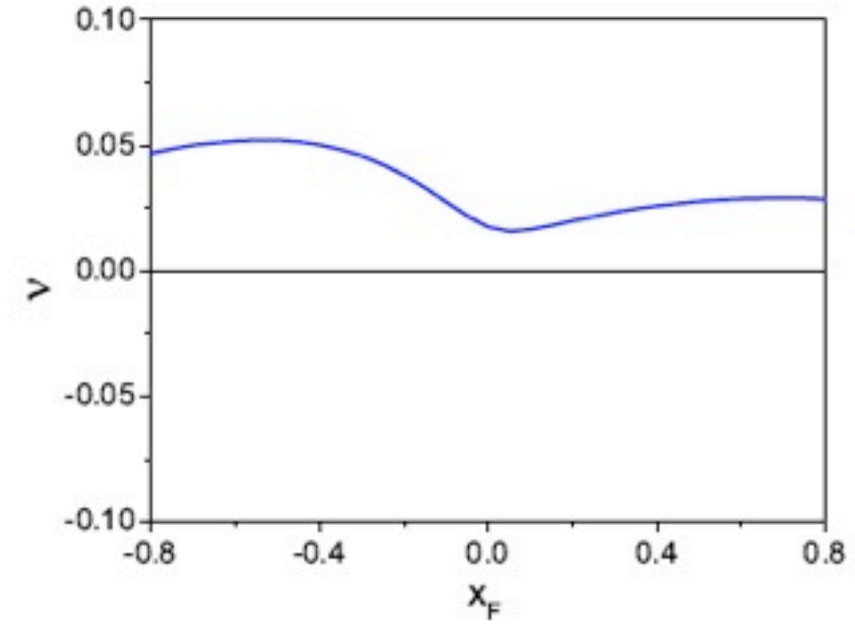


Fig. 9 The $\cos 2\phi$ azimuthal asymmetry depending on x_F of unpolarized pd Drell–Yan process at $Q = 5$ GeV.

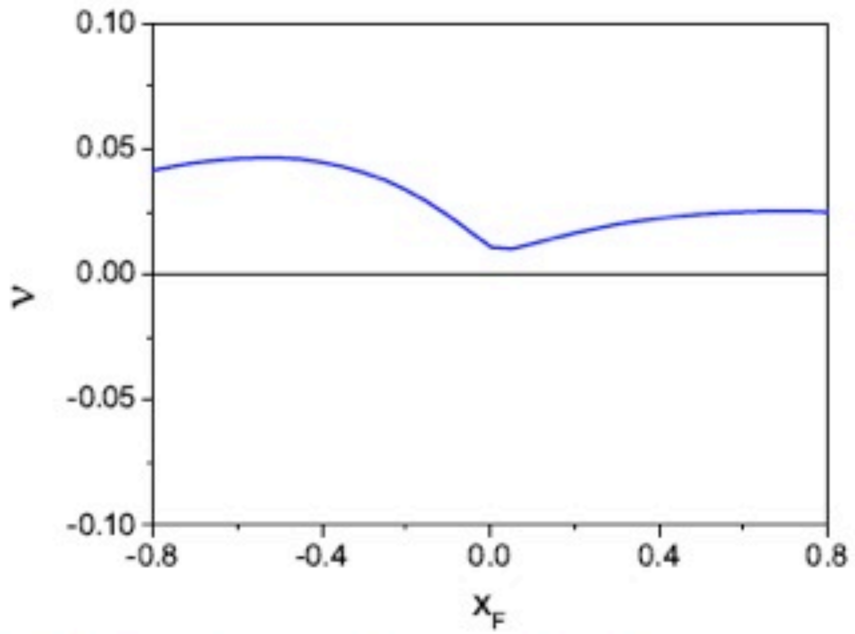


Fig. 8 The $\cos 2\phi$ azimuthal asymmetry depending on x_F of unpolarized pd Drell–Yan process at $Q = 2$ GeV.

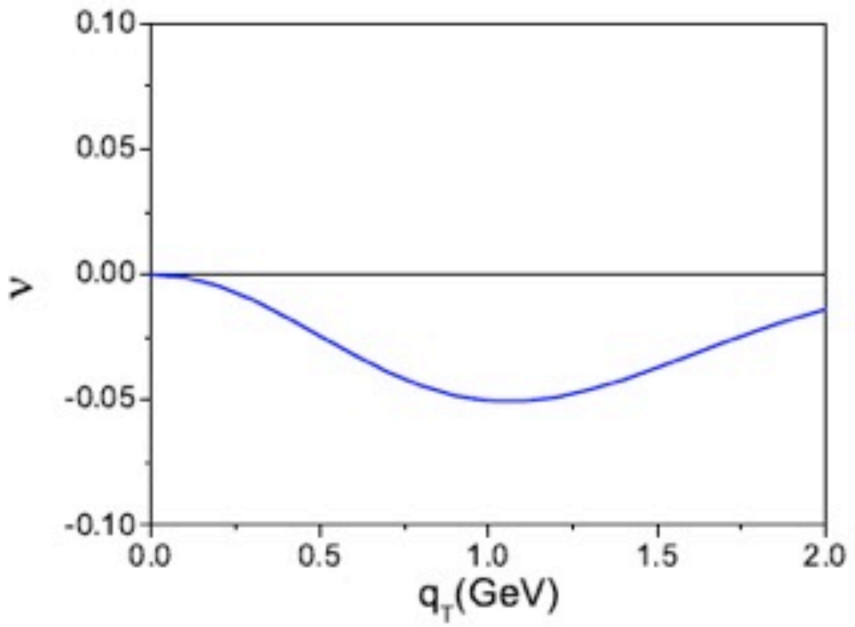
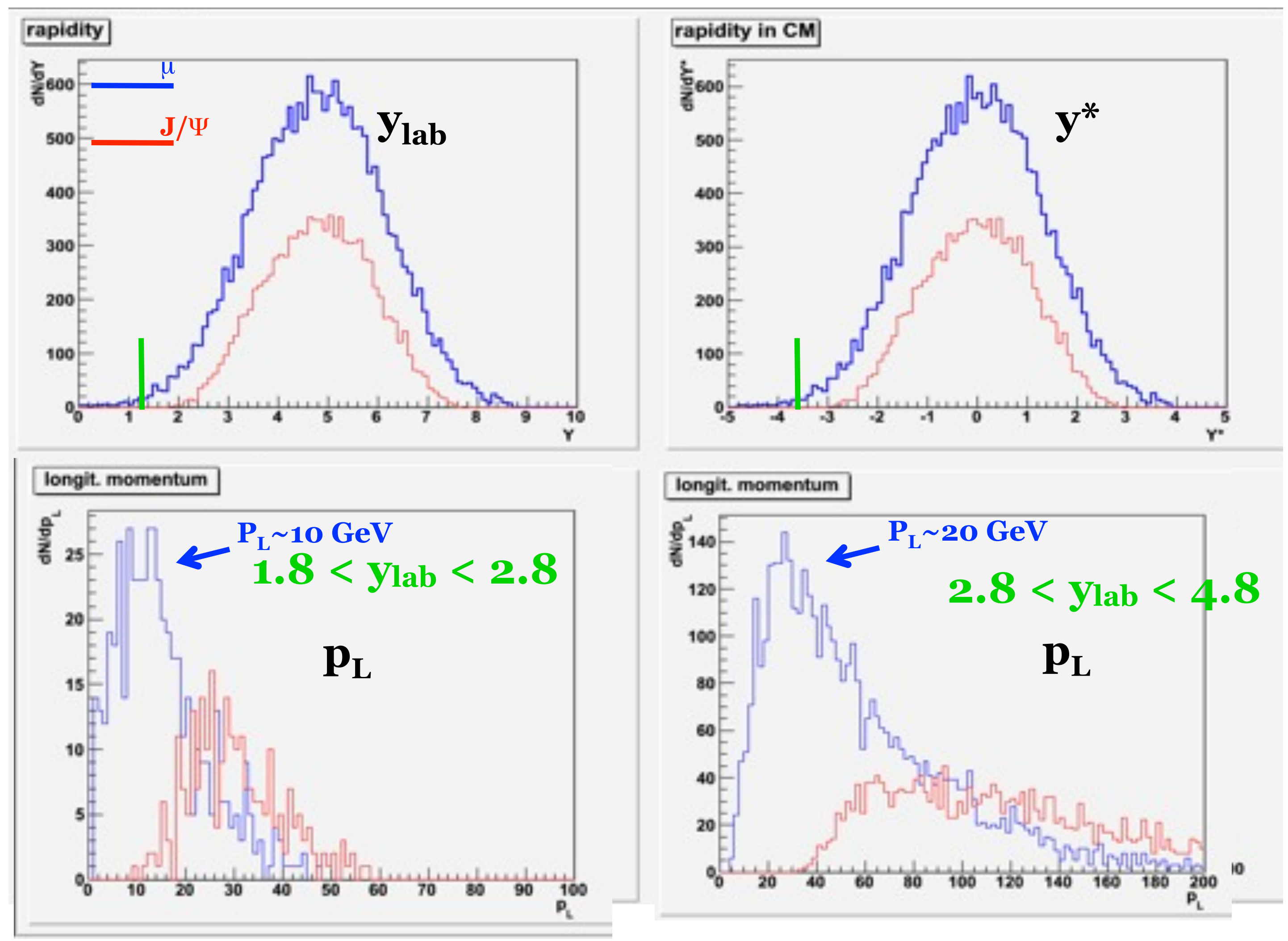


Fig. 10 The $\cos 2\phi$ azimuthal asymmetry depending on q_T of unpolarized pd process in Z resonance region.

Quarkonium distributions in pp @ 115 GeV

Pythia: p (7 TeV) + p → J/Ψ (isub=86)

J/Ψ → $\mu^+\mu^-$



J/Ψ for $1.3 < y < 5.3$

$\mu \rightarrow P_T \sim$ 1.7 GeV

$\mu \rightarrow P_L \sim$ 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

Physics case

- **QCD at large *x***
  - Gluon and heavy quarks distribution in the proton, neutron
  - W, Z production in the threshold region
- **nPDF and nuclear shadowing**
  - Gluon and heavy quarks distribution in the nucleus
- **Spin physics using polarized target**
  - Gluon Sivers effect (transversely polarized target asymmetry)
- **QGP**
- **Other ?**