A Fixed Target ExpeRiment using LHC beams

# AFTER @ LHC


M. Anselmino (Torino), R. Arnarldi (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), C. Lorcé (IPN), A. Rakotozafindrabe (CEA), P. Rosier (IPN), I. Schienbein (LPSC), E. Scomparin (Torino), U.I. Uggerhøj (Aarhus)

AFTER @ LHC

Andry Rakotozafindrabe
CEA (Saclay) IRFU

Irfu - CEA Saclay
Institut de recherche
sur les lois fondamentales
de l'Univers


*Prospects and challenges for future experiments in Heavy Ion collisions – EMMI workshop, GSI Darmstadt, Feb. 2013*

# A Fixed Target ExpeRiment at LHC

Use LHC beams on fixed target :

- LHC 7 TeV proton beam
  - $\sqrt{s} \sim 115$ GeV : p–p, p–d, p–A
- LHC 2.76 TeV lead beam
  - $\sqrt{s} \sim 72$ GeV : Pb–p, Pb–A

# A Fixed Target ExpeRiment at LHC

Use LHC beams on fixed target :

- LHC 7 TeV proton beam
  - $\sqrt{s} \sim 115$ GeV : p−p, p−d, p−A

comparable to RHIC energies

- LHC 2.76 TeV lead beam
  - $\sqrt{s} \sim 72$ GeV : Pb−p, Pb−A

# A Fixed Target ExpeRiment at LHC

Use LHC beams on fixed target :

- LHC 7 TeV proton beam
  - $\sqrt{s} \sim 115$ GeV : p–p, p–d, p–A

  comparable to RHIC energies

- LHC 2.76 TeV lead beam
  - $\sqrt{s} \sim 72$ GeV : Pb–p, Pb–A
- benefit from typical advantages of a fixed target experiment
  - high luminosity, high boost ($y_{CMS}$=4.8 @ 115 GeV), target versatility

# A Fixed Target ExpeRiment at LHC

Use LHC beams on fixed target :

- LHC 7 TeV proton beam
  - $\sqrt{s} \sim 115$ GeV : p–p, p–d, p–A

comparable to RHIC energies

- LHC 2.76 TeV lead beam
  - $\sqrt{s} \sim 72$ GeV : Pb–p, Pb–A
- benefit from typical advantages of a fixed target experiment
  - high luminosity, high boost ($y_{CMS}$=4.8 @ 115 GeV), target versatility
- multipurpose experiment, modern detection techniques

# A Fixed Target ExpeRiment at LHC

Use LHC beams on fixed target :

- LHC 7 TeV proton beam
  - $\sqrt{s}$ ~ 115 GeV : p–p, p–d, p–A

comparable to RHIC energies

- LHC 2.76 TeV lead beam
  - $\sqrt{s}$ ~ 72 GeV : Pb–p, Pb–A

- benefit from typical advantages of a fixed target experiment
  - high luminosity, high boost ($y_{CMS}$=4.8 @ 115 GeV), target versatility

- multipurpose experiment, modern detection techniques

spin physics

PDF and nPDF at large $x_B$

heavy quarkonium prod. and Cold Nuclear Matter effects

W, Z prod. near threshold

# A Fixed Target ExpeRiment at LHC

Use LHC beams on fixed target :

- LHC 7 TeV proton beam
  - $\sqrt{s} \sim 115$ GeV : p−p, p−d, p−A

comparable to RHIC energies

- LHC 2.76 TeV lead beam
  - $\sqrt{s} \sim 72$ GeV : Pb−p, Pb−A

spin physics

PDF and nPDF at large $x_B$

heavy quarkonium prod. and Cold Nuclear Matter effects

W, Z prod. near threshold

UPC

QGP studies, high precision heavy quarkonium observatory, high $p_T$ jets

diffractive physics

- benefit from typical advantages of a fixed target experiment
  - high luminosity, high boost ($y_{CMS}$=4.8 @ 115 GeV), target versatility
- multipurpose experiment, modern detection techniques

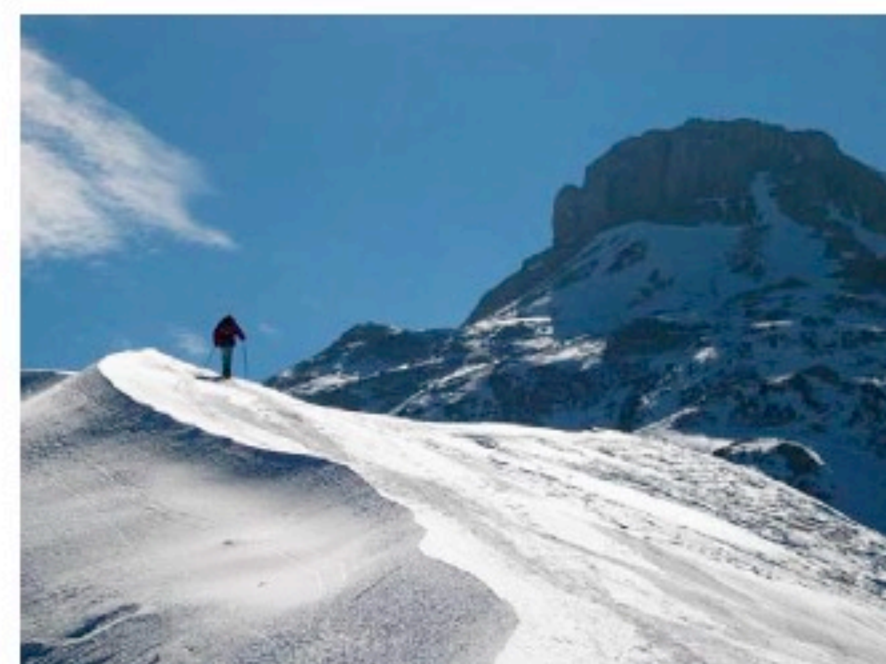
**ECT*** European Centre for Theoretical Studies in Nuclear Physics and Related Areas

About 40 participants
Institutes from Denmark, France, Germany, Italy, Japan, Mexico, Poland, Spain, Switzerland, Turkey, UK, USA


# 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.'*



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

About 40 participants
Institutes from Denmark, France, Germany, Italy, Japan, Mexico, Poland, Spain, Switzerland, Turkey, UK, USA


# 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.'*

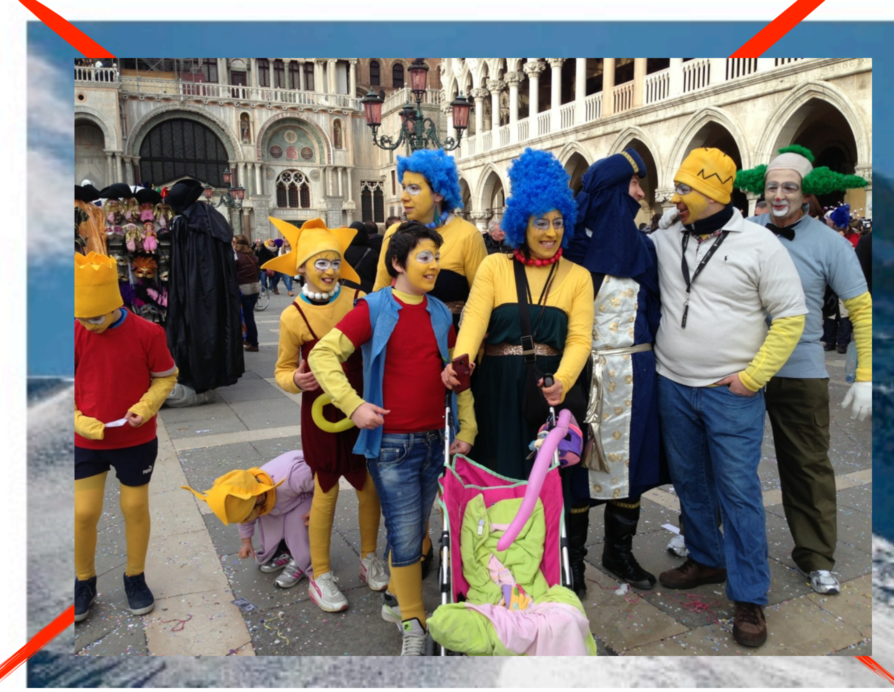
ECT* European Centre for Theoretical Studies in Nuclear Physics and Related Areas

About 40 participants
Institutes from Denmark, France, Germany, Italy, Japan, Mexico, Poland, Spain, Switzerland, Turkey, UK, USA


# ECT* 'exploratory' workshop: "Physics at a fixed target experiment using the LHC beams"

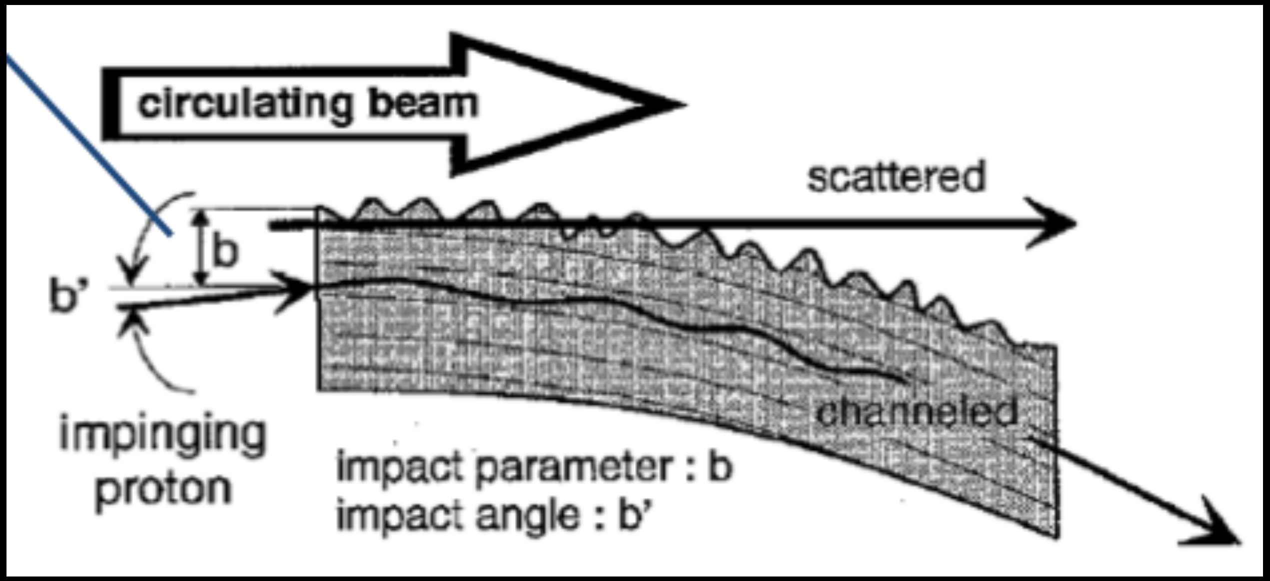

- February 4 - February 13, 2013

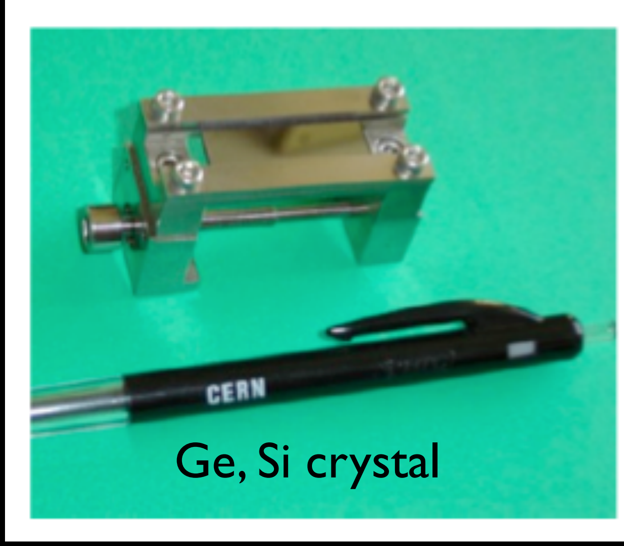
*'This is an exploratory workshop which aims at studying in detail the opportunity and feasibility of fixed-target experiments using the LHC beam.'*



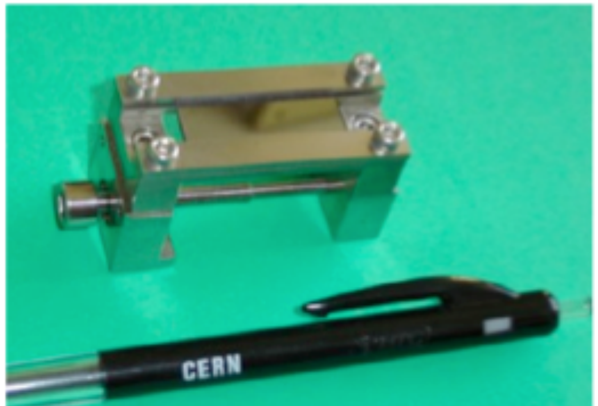
# LHC beam extraction

Use strong crystalline field in bent crystals :



# LHC beam extraction

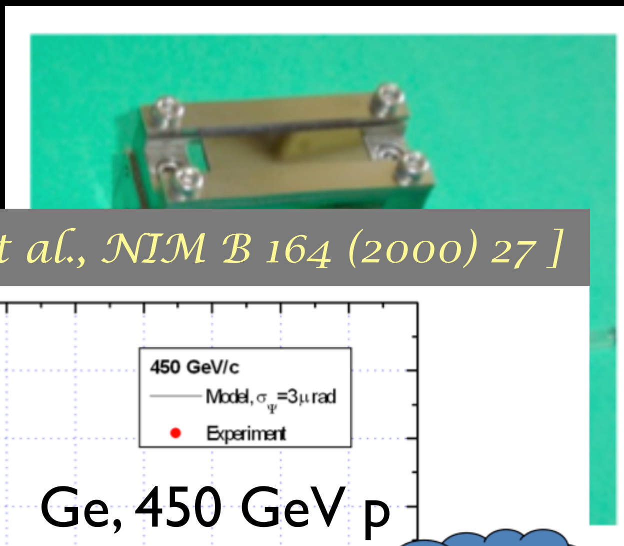



Ge, Si crystal

Use strong crystalline field in bent crystals :

- mature technique
  - successful for proton beam : RD22 @ SPS (1990), ..., Tevatron (2005), UA9 @ SPS (2008) *[ W. Scandale et al., JINST 6 (2011) T10002 ]*
  - test @ LHC recommended by LHCC ☛ LUA9 (2013)
  - ion beam : test at SPS *[ W. Scandale et al., PLB 703 (2011) 547 ]*

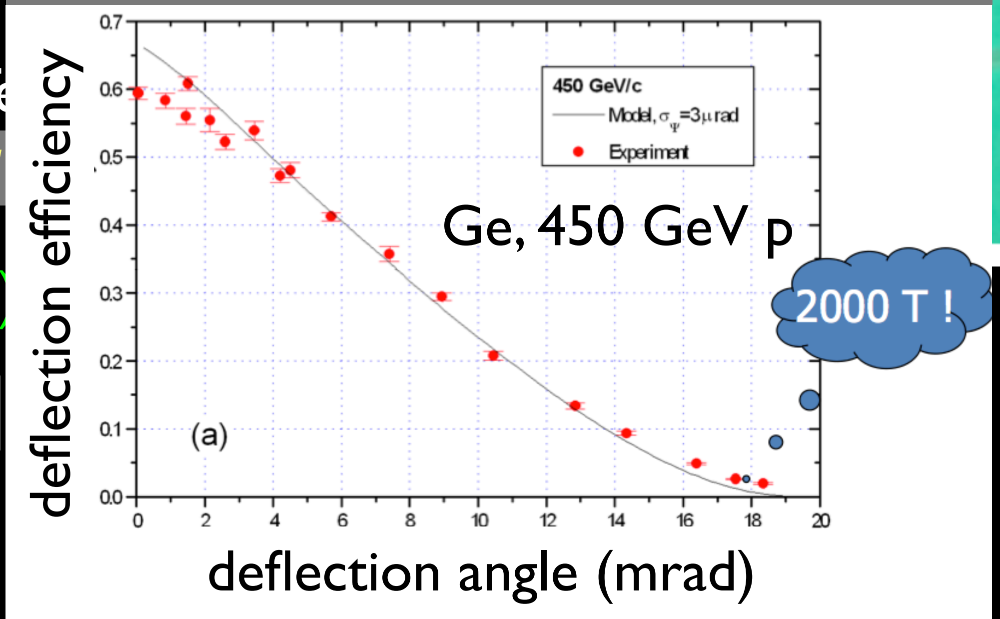
# LHC beam extraction



Use strong crystalline field in bent crystals :

- mature technique
    - successful for proton beam : RD22 @ SPS (1990), ...,Te
      UA9 @ SPS (2008) *[ W. Scandale et al., JINST 6 (2011) T10002 ]*
    - test @ LHC recommended by LHCC ☛ LUA9 (2013)
    - ion beam : test at SPS *[ W. Scandale et al., PLB 703 (2011) 547 ]*

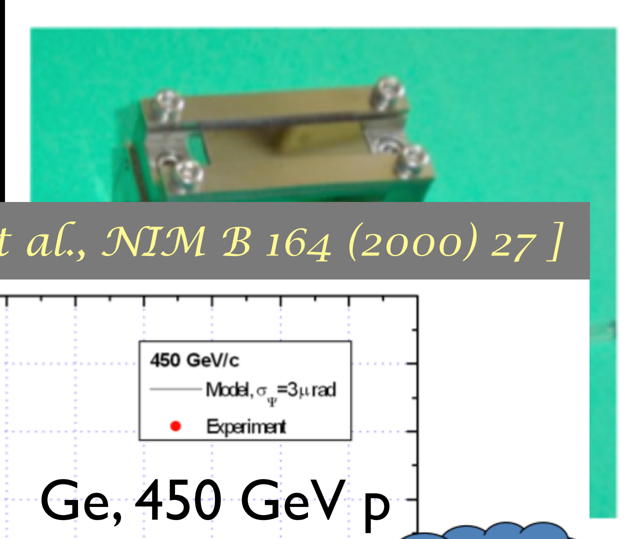
*[ A. Baurichter et al., NIM B 164 (2000) 27 ]*



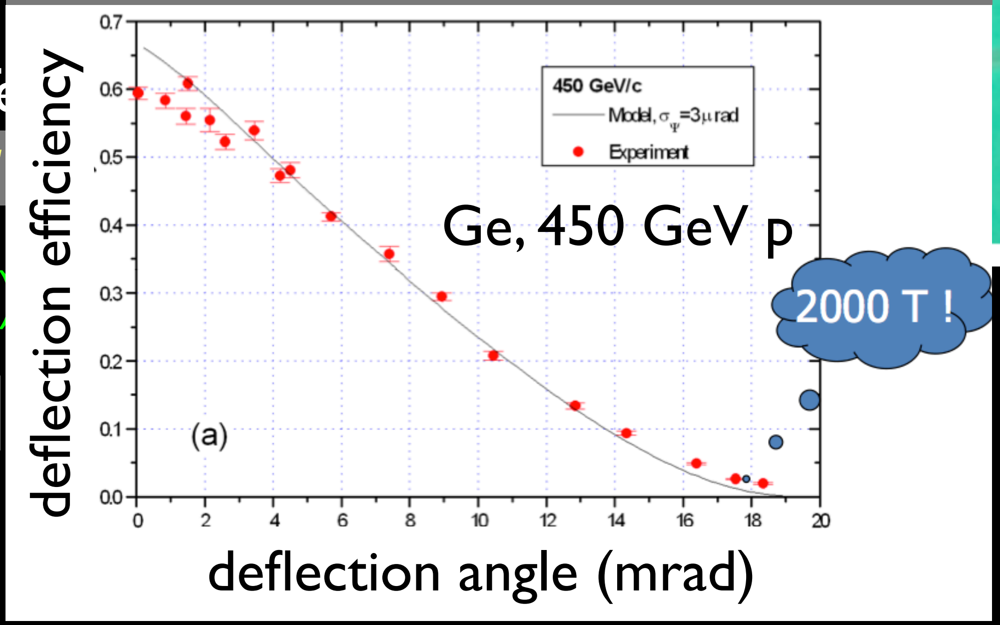
# LHC beam extraction

Use strong crystalline field in bent crystals :

- mature technique
  - successful for proton beam : RD22 @ SPS (1990), ...,Te
    UA9 @ SPS (2008) *[ W. Scandale et al., JINST 6 (2011) T10002 ]*
  - test @ LHC recommended by LHCC ☛ LUA9 (2013)
  - ion beam : test at SPS *[ W. Scandale et al., PLB 703 (2011) 547 ]*
- for extraction and collimation
  - extremely small emittance : beam size 950m after the extraction (in the extraction direction) ~ 0.3mm



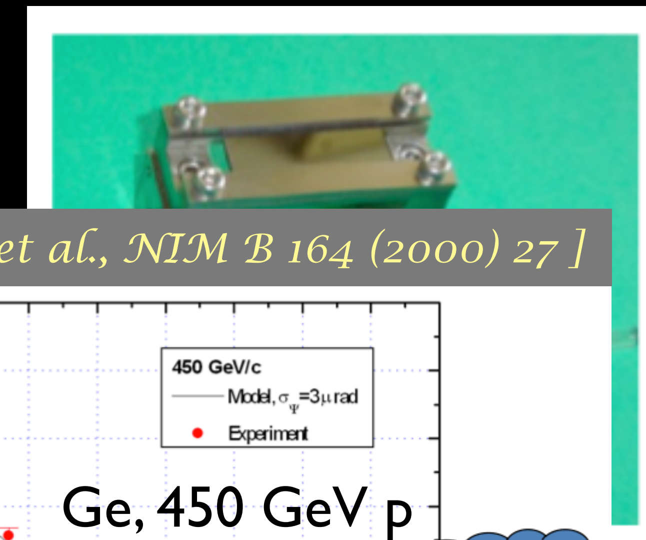
*[ A. Baurichter et al., NIM B 164 (2000) 27 ]*



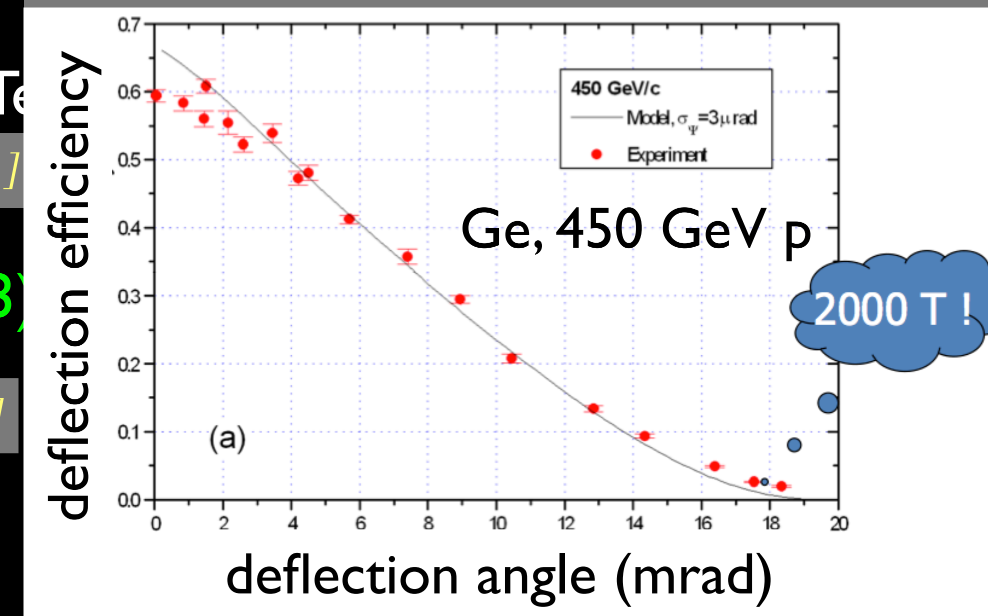
# LHC beam extraction

Use strong crystalline field in bent crystals :

- mature technique
  - successful for proton beam : RD22 @ SPS (1990), ...,Te
    UA9 @ SPS (2008) *[ W. Scandale et al., JINST 6 (2011) T10002 ]*
  - test @ LHC recommended by LHCC ☛ LUA9 (2013)
  - ion beam : test at SPS *[ W. Scandale et al., PLB 703 (2011) 547 ]*



*[ A. Baurichter et al., NIM B 164 (2000) 27 ]*



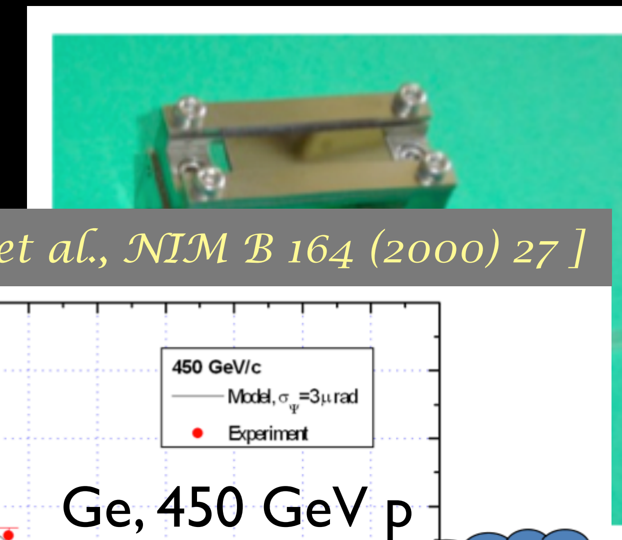

- for extraction and collimation
  - extremely small emittance : beam size 950m after the extraction (in the extraction direction) ~ 0.3mm
- Proposal : insertion in the halo (7σ) of the proton LHC beam
  - here with a deflection 0.275 mrad *[ E Uggerhoj and U.I. Uggerhoj, NIM B 234 (2005) 31 ]*
  - extraction eff. (multi pass) ~ 50% LHC beam loss ⇛ $5.10^8$ p/s extracted
  - yearly luminosity (1 cm thick target) : 0.1 to 0.6 fb$^{-1}$ in p−H(A), 7 to 25 nb$^{-1}$ in Pb−A

*[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, Phys. Rep. 522 (2013) 239 ]*

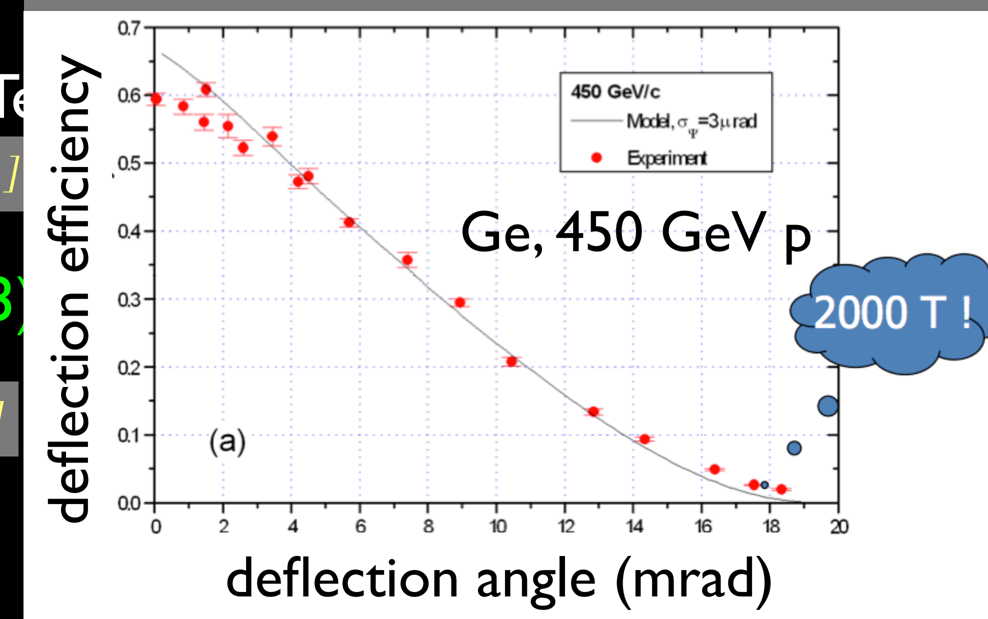
# LHC beam extraction

Use strong crystalline field in bent crystals :

- mature technique
  - successful for proton beam : RD22 @ SPS (1990), ..., Te
    UA9 @ SPS (2008) *[ W. Scandale et al., JINST 6 (2011) T10002 ]*
  - test @ LHC recommended by LHCC ☛ LUA9 (2013)
  - ion beam : test at SPS *[ W. Scandale et al., PLB 703 (2011) 547 ]*
- for extraction and collimation
  - extremely small emittance : beam size 950m after the extraction (in the extraction direction) ~ 0.3mm



*[ A. Baurichter et al., NIM B 164 (2000) 27 ]*




no performance decrease of the LHC

- Proposal : insertion in the halo (7σ) of the proton LHC beam
  *[ E Uggerhoj and U.I. Uggerhoj, NIM B 234 (2005) 31 ]*
  - here with a deflection 0.275 mrad
  - extraction eff. (multi pass) ~ 50% LHC beam loss ⇛ $5.10^8$ p/s extracted
  - yearly luminosity (1 cm thick target) : 0.1 to 0.6 $fb^{-1}$ in p−H(A), 7 to 25 $nb^{-1}$ in Pb−A

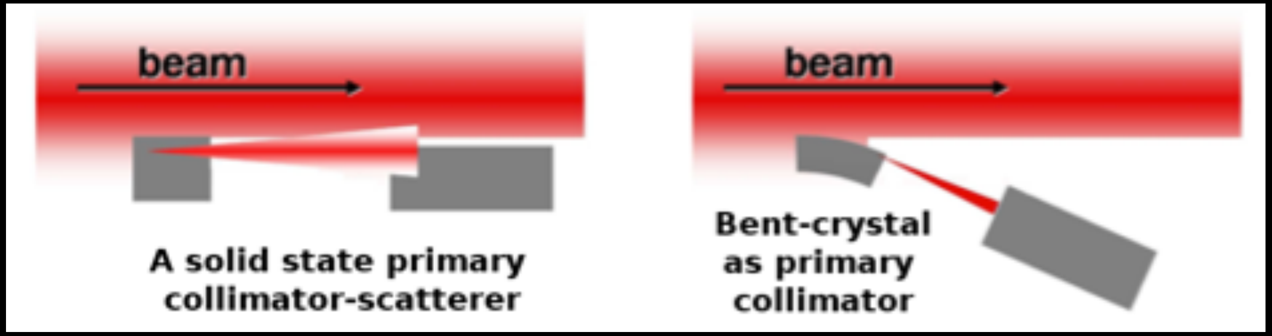
*[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, Phys. Rep. 522 (2013) 239 ]*

# UA9 → LUA9

*[ S. Montesano, Physics at AFTER using LHC beams, ECT* Trento, Feb. 2013]*

Goal : assess the possibility to use bent crystals as primary collimators in hadronic accelerators and colliders

UA9 installation in the SPS




Prototype crystal collimation system at SPS :

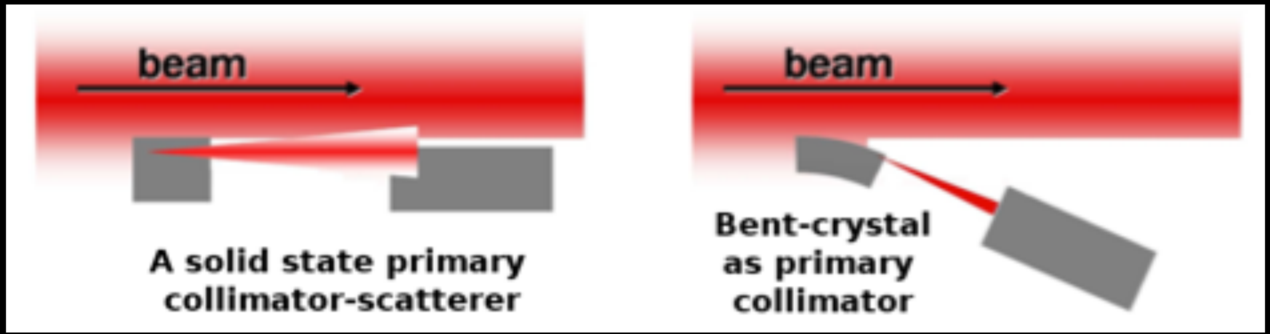
- local beam loss reduction (5÷20x reduction for proton beam)
- beam loss map show average loss reduction in the entire SPS ring
- halo extraction efficiency 70÷80% for protons (50÷70% for Pb)

# UA9 → LUA9

*[ S. Montesano, Physics at AFTER using LHC beams, ECT* Trento, Feb. 2013]*

Goal : assess the possibility to use bent crystals as primary collimators in hadronic accelerators and colliders

UA9 installation in the SPS




Prototype crystal collimation system at SPS :

- local beam loss reduction (5÷20x reduction for proton beam)
- beam loss map show average loss reduction in the entire SPS ring
- halo extraction efficiency 70÷80% for protons (50÷70% for Pb)

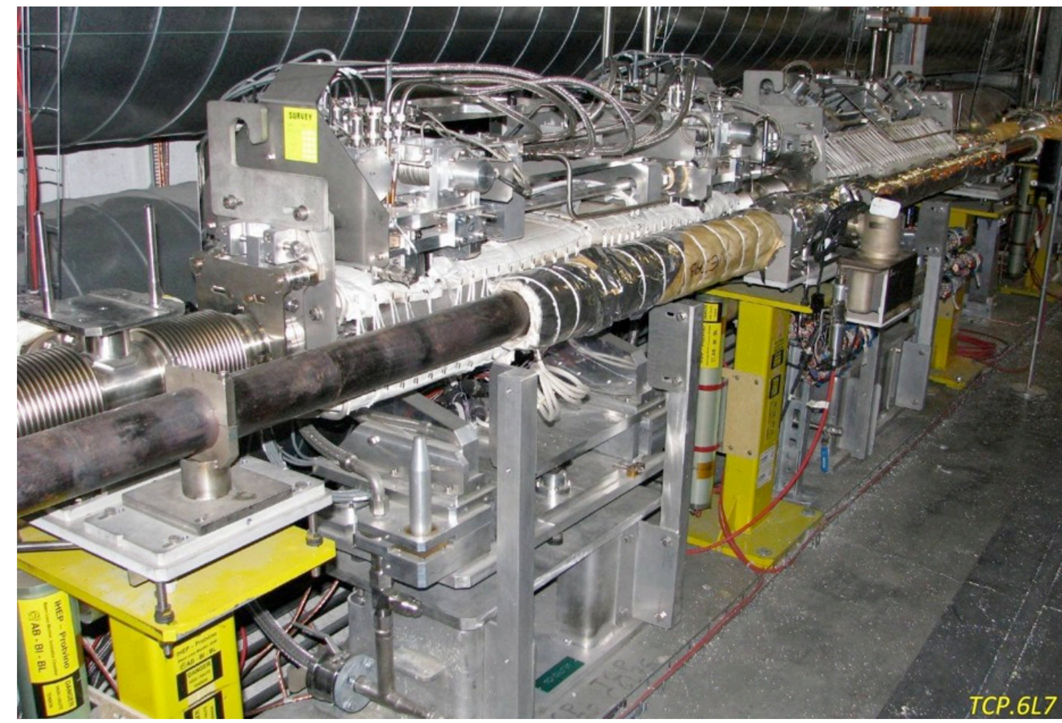
# UA9 → LUA9

[ S. Montesano, Physics at AFTER using LHC beams, ECT* Trento, Feb. 2013]

Goal : assess the possibility to use bent crystals as primary collimators in hadronic accelerators and colliders

UA9 installation in the SPS

2010 - 2012




LUA9 future installation in LHC

Prototype crystal collimation system at SPS :

- local beam loss reduction (5÷20x reduction for proton beam)
- beam loss map show average loss reduction in the entire SPS ring
- halo extraction efficiency 70÷80% for protons (50÷70% for Pb)

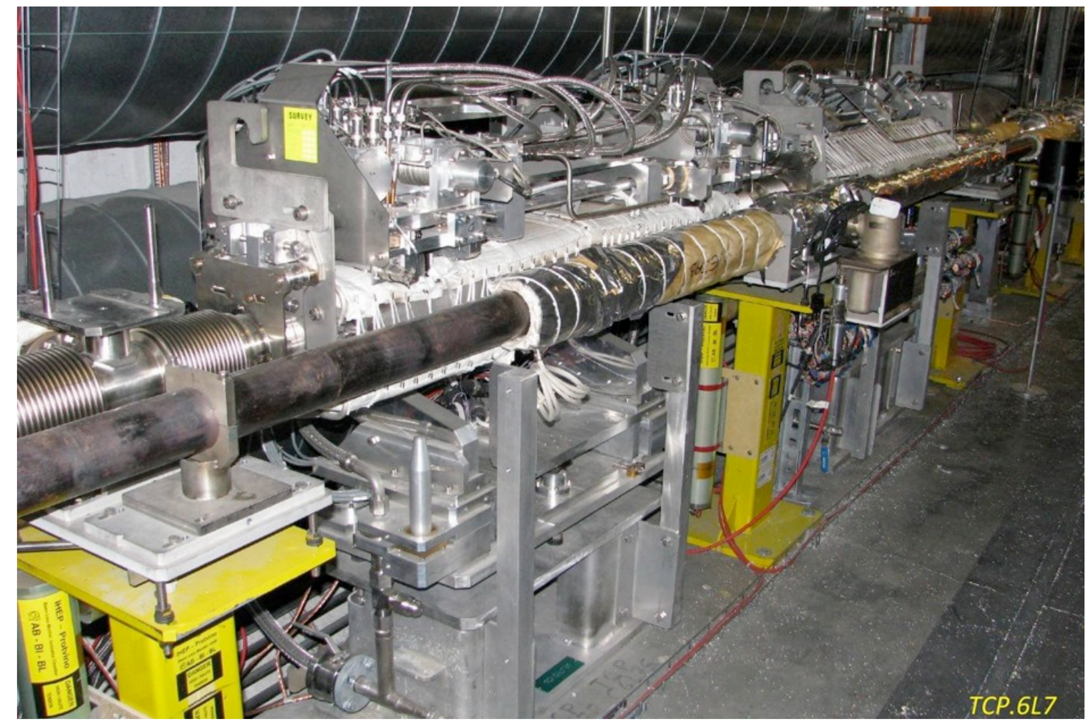
# UA9 → LUA9

*[ S. Montesano, Physics at AFTER using LHC beams, ECT* Trento, Feb. 2013]*

Goal : assess the possibility to use bent crystals as primary collimators in hadronic accelerators and colliders

UA9 installation in the SPS

2010 - 2012




LUA9 future installation in LHC

Prototype crystal collimation system at SPS :

- local beam loss reduction (5÷20x reduction for proton beam)
- beam loss map show average loss reduction in the entire SPS ring
- halo extraction efficiency 70÷80% for protons (50÷70% for Pb)

Towards an installation in the LHC : propose and install during LS1 a min. number of devices

- 2 crystals
- tests during LS2

Long term plan is ambitious : propose a collimation system based on bent crystals for the upgrade of the current LHC collimation system

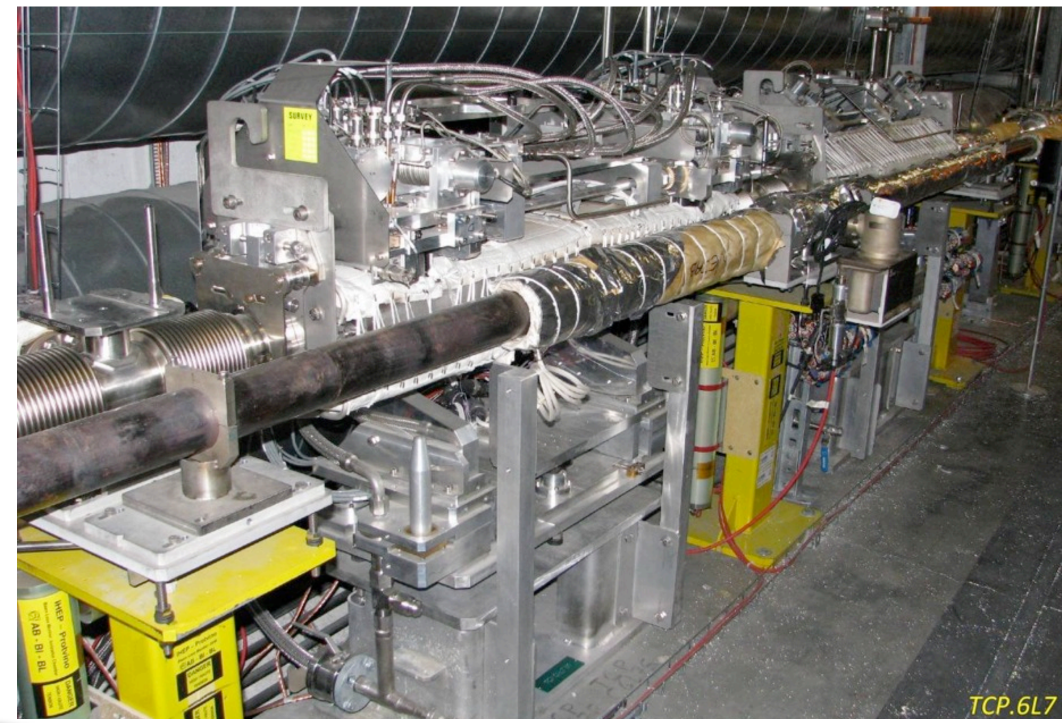
# UA9 → LUA9

[ S. Montesano, Physics at AFTER using LHC beams, ECT* Trento, Feb. 2013]

Goal : assess the possibility to use bent crystals as primary collimators in hadronic accelerators and colliders

UA9 installation in the SPS

2010 - 2012




NEW !

LUA9 future installation in LHC

Prototype crystal collimation system at SPS :

- local beam loss reduction (5÷20x reduction for proton beam)
- beam loss map show average loss reduction in the entire SPS ring
- halo extraction efficiency 70÷80% for protons (50÷70% for Pb)

Towards an installation in the LHC : propose and install during LS1 a min. number of devices

- 2 crystals
- tests during LS2

Long term plan is ambitious : propose a collimation system based on bent crystals for the upgrade of the current LHC collimation system

# Heavy Quarkonium yields in pH, pA

yield / dy ( $fb^{-1}$ $year^{-1}$) @ $\sqrt{s}$ = 115 GeV

*[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, Phys. Rep. 522 (2013) 239 ]*

| | Target | $\int dt \mathcal{L}$ | | J/ψ: $\mathcal{B}_{\ell\ell} \frac{dN_{J/\psi}}{dy}\Big\|_{y=0}$ | Υ: $\mathcal{B}_{\ell\ell} \frac{dN_{\Upsilon}}{dy}\Big\|_{y=0}$ |
|---|---|---|---|---|---|
| AFTER | 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 | | $6.7\ 10^8$ | $1.3\ 10^6$ |
| LHC | $pp$ low $P_T$ LHC (14 TeV) | 0.05 | ALICE | $3.6\ 10^7$ | $1.8\ 10^5$ |
| | | 2 | LHCb | $1.4\ 10^9$ | $7.2\ 10^6$ |
| | $p$Pb LHC (8.8 TeV) | $10^{-4}$ | | $1.0\ 10^7$ | $7.5\ 10^4$ |
| RHIC | $pp$ RHIC (200 GeV) | $1.2\ 10^{-2}$ | | $4.8\ 10^5$ | $1.2\ 10^3$ |
| | $d$Au RHIC (200 GeV) | $1.5\ 10^{-4}$ | | $2.4\ 10^6$ | $5.9\ 10^3$ |
| | $d$Au RHIC (62 GeV) | $3.8\ 10^{-6}$ | | $1.2\ 10^4$ | $1.8\ 10^1$ |

RHIC lumi. from PHENIX decadal plan (run plan 2011-2015)

detector geometrical acceptance ~ 8% for J/ψ (4π)→μ+μ−

from simulations with ALICE detector (−4< y <−2.5) used as fixed target exp. at LHC

*[ Kurepin et al., Phys. Atom. Nucl. 74 (2011) ]*

# Heavy Quarkonium yields in pH, pA

yield / dy ( $fb^{-1}$ $year^{-1}$) @ $\sqrt{s}$ = 115 GeV

[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, Phys. Rep. 522 (2013) 239 ]

| | Target | $\int dt \mathcal{L}$ | | J/ψ: $\mathcal{B}_{\ell\ell} \frac{dN_{J/\psi}}{dy}\Big\vert_{y=0}$ | Υ: $\mathcal{B}_{\ell\ell} \frac{dN_{\Upsilon}}{dy}\Big\vert_{y=0}$ |
|---|---|---|---|---|---|
| AFTER | 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 | | $6.7\ 10^8$ | $1.3\ 10^6$ |
| LHC | $pp$ low $P_T$ LHC (14 TeV) | 0.05 | ALICE | $3.6\ 10^7$ | $1.8\ 10^5$ |
| | | 2 | LHCb | $1.4\ 10^9$ | $7.2\ 10^6$ |
| | $p$Pb LHC (8.8 TeV) | $10^{-4}$ | | $1.0\ 10^7$ | $7.5\ 10^4$ |
| RHIC | $pp$ RHIC (200 GeV) | $1.2\ 10^{-2}$ | | $4.8\ 10^5$ | $1.2\ 10^3$ |
| | $d$Au RHIC (200 GeV) | $1.5\ 10^{-4}$ | | $2.4\ 10^6$ | $5.9\ 10^3$ |
| | $d$Au RHIC (62 GeV) | $3.8\ 10^{-6}$ | | $1.2\ 10^4$ | $1.8\ 10^1$ |

pp : 100 x RHIC, comparable to LHCb

RHIC lumi. from PHENIX decadal plan (run plan 2011-2015)

detector geometrical acceptance ~ 8% for J/ψ (4π)→μ+μ−

from simulations with ALICE detector (−4< y <−2.5) used as fixed target exp. at LHC

[ Kurepin et al., Phys. Atom. Nucl. 74 (2011) ]

# Heavy Quarkonium yields in pH, pA

yield / dy ( $fb^{-1}$ $year^{-1}$) @ $\sqrt{s}$ = 115 GeV

[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, Phys. Rep. 522 (2013) 239 ]

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

pp : 100 x RHIC, comparable to LHCb

RHIC lumi. from PHENIX decadal plan (run plan 2011-2015)

detector geometrical acceptance ~ 8% for J/ψ (4π)→μ+μ−

from simulations with ALICE detector (−4< y <−2.5) used as fixed target exp. at LHC

[ Kurepin et al., Phys. Atom. Nucl. 74 (2011) ]

# Heavy Quarkonium yields in pH, pA

yield / dy ( $fb^{-1}$ $year^{-1}$) @ $\sqrt{s}$ = 115 GeV

*[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, Phys. Rep. 522 (2013) 239 ]*

| | Target | $\int dt\mathcal{L}$ | $J/\psi$: $\mathcal{B}_{\ell\ell}\frac{dN_{J/\psi}}{dy}\Big\vert_{y=0}$ | $\Upsilon$: $\mathcal{B}_{\ell\ell}\frac{dN_{\Upsilon}}{dy}\Big\vert_{y=0}$ |
|---|---|---|---|---|
| AFTER | 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 | $6.7\ 10^8$ | $1.3\ 10^6$ |
| LHC | $pp$ low $P_T$ LHC (14 TeV) | 0.05 ALICE | $3.6\ 10^7$ | $1.8\ 10^5$ |
| | | 2 LHCb | $1.4\ 10^9$ | $7.2\ 10^6$ |
| | $p$Pb LHC (8.8 TeV) | $10^{-4}$ | $1.0\ 10^7$ | $7.5\ 10^4$ |
| RHIC | $pp$ RHIC (200 GeV) | $1.2\ 10^{-2}$ | $4.8\ 10^5$ | $1.2\ 10^3$ |
| | $d$Au RHIC (200 GeV) | $1.5\ 10^{-4}$ | $2.4\ 10^6$ | $5.9\ 10^3$ |
| | $d$Au RHIC (62 GeV) | $3.8\ 10^{-6}$ | $1.2\ 10^4$ | $1.8\ 10^1$ |

pp : 100 x RHIC, comparable to LHCb

pA : $10^2$-$10^3$ x RHIC

RHIC lumi. from PHENIX decadal plan (run plan 2011-2015)

detector geometrical acceptance ~ 8% for J/ψ (4π)→μ+μ−

from simulations with ALICE detector (−4< y <−2.5) used as fixed target exp. at LHC

*[ Kurepin et al., Phys. Atom. Nucl. 74 (2011) ]*

# Heavy Quarkonium yields in pH, pA

yield / dy ( $fb^{-1}$ $year^{-1}$) @ $\sqrt{s}$ = 115 GeV

*[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, Phys. Rep. 522 (2013) 239 ]*

J/ψ ↓ Υ ↓

| | Target | $\int dt\mathcal{L}$ | | $\mathcal{B}_{\ell\ell}\frac{dN_{J/\psi}}{dy}\Big\|_{y=0}$ | $\mathcal{B}_{\ell\ell}\frac{dN_{\Upsilon}}{dy}\Big\|_{y=0}$ |
|---|---|---|---|---|---|
| AFTER | 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 | | $6.7\ 10^8$ | $1.3\ 10^6$ |
| LHC | $pp$ low $P_T$ LHC (14 TeV) | 0.05 | ALICE | $3.6\ 10^7$ | $1.8\ 10^5$ |
| | | 2 | LHCb | $1.4\ 10^9$ | $7.2\ 10^6$ |
| | $p$Pb LHC (8.8 TeV) | $10^{-4}$ | | $1.0\ 10^7$ | $7.5\ 10^4$ |
| RHIC | $pp$ RHIC (200 GeV) | $1.2\ 10^{-2}$ | | $4.8\ 10^5$ | $1.2\ 10^3$ |
| | $d$Au RHIC (200 GeV) | $1.5\ 10^{-4}$ | | $2.4\ 10^6$ | $5.9\ 10^3$ |
| | $d$Au RHIC (62 GeV) | $3.8\ 10^{-6}$ | | $1.2\ 10^4$ | $1.8\ 10^1$ |

pp : 100 x RHIC, comparable to LHCb

pA : $10^2$-$10^3$ x RHIC

RHIC lumi. from PHENIX decadal plan (run plan 2011-2015)

detector geometrical acceptance ~ 8% for J/ψ (4π)→μ+μ−

from simulations with ALICE detector (−4< y <−2.5) used as fixed target exp. at LHC

*[ Kurepin et al., Phys. Atom. Nucl. 74 (2011) ]*

# Heavy Quarkonium yields in pH, pA

yield / dy ( $fb^{-1}$ $year^{-1}$) @ $\sqrt{s}$ = 115 GeV

*[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, Phys. Rep. 522 (2013) 239 ]*

J/ψ ↓ Υ ↓

| | Target | $\int dt\mathcal{L}$ | $\mathcal{B}_{\ell\ell}\frac{dN_{J/\psi}}{dy}\Big\|_{y=0}$ | $\mathcal{B}_{\ell\ell}\frac{dN_{\Upsilon}}{dy}\Big\|_{y=0}$ |
|---|---|---|---|---|
| AFTER | 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 | $6.7\ 10^8$ | $1.3\ 10^6$ |
| LHC | $pp$ low $P_T$ LHC (14 TeV) | 0.05 ALICE | $3.6\ 10^7$ | $1.8\ 10^5$ |
| | | 2 LHCb | $1.4\ 10^9$ | $7.2\ 10^6$ |
| | $p$Pb LHC (8.8 TeV) | $10^{-4}$ | $1.0\ 10^7$ | $7.5\ 10^4$ |
| RHIC | $pp$ RHIC (200 GeV) | $1.2\ 10^{-2}$ | $4.8\ 10^5$ | $1.2\ 10^3$ |
| | $d$Au RHIC (200 GeV) | $1.5\ 10^{-4}$ | $2.4\ 10^6$ | $5.9\ 10^3$ |
| | $d$Au RHIC (62 GeV) | $3.8\ 10^{-6}$ | $1.2\ 10^4$ | $1.8\ 10^1$ |

pp : 100 x RHIC, comparable to LHCb

pA : $10^2$-$10^3$ x RHIC

RHIC lumi. from PHENIX decadal plan (run plan 2011-2015)

Recycle the LHC beam loss → a luminosity comparable to the LHC itself !

# Heavy Quarkonium yields in PbA

yield / dy ( $nb^{-1}$ $year^{-1}$) @ $\sqrt{s}$ = 72 GeV

*[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, Phys. Rep. 522 (2013) 239 ]*

| | Target | $\int dt \mathcal{L}$ | $\mathcal{B}_{\ell\ell} \frac{dN_{J/\psi}}{dy}\Big\vert_{y=0}$ (J/ψ) | $\mathcal{B}_{\ell\ell} \frac{dN_{\Upsilon}}{dy}\Big\vert_{y=0}$ (Υ) |
|---|---|---|---|---|
| AFTER | 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 | $5.7\ 10^6$ | $1.1\ 10^4$ |
| RHIC | *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 | $4.0\ 10^4$ | $6.1\ 10^1$ |
| LHC | *p*Pb LHC (8.8 TeV) | 100 | $1.0\ 10^7$ | $7.5\ 10^4$ |
| | PbPb LHC (5.5 TeV) | 0.5 | $7.3\ 10^6$ | $3.6\ 10^4$ |

# Heavy Quarkonium yields in PbA

yield / dy ( $nb^{-1}$ $year^{-1}$) @ $\sqrt{s}$ = 72 GeV

J/ψ

ϒ

[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, Phys. Rep. 522 (2013) 239 ]

| | Target | $\int dt \mathcal{L}$ | $\mathcal{B}_{\ell\ell} \frac{dN_{J/\psi}}{dy}\Big\vert_{y=0}$ | $\mathcal{B}_{\ell\ell} \frac{dN_{\Upsilon}}{dy}\Big\vert_{y=0}$ |
|---|---|---|---|---|
| AFTER | 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 | $5.7\ 10^6$ | $1.1\ 10^4$ |
| RHIC | *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 | $4.0\ 10^4$ | $6.1\ 10^1$ |
| LHC | *p*Pb LHC (8.8 TeV) | 100 | $1.0\ 10^7$ | $7.5\ 10^4$ |
| | PbPb LHC (5.5 TeV) | 0.5 | $7.3\ 10^6$ | $3.6\ 10^4$ |

PbA :

same stat. w.r.t. RHIC @ 200 GeV and LHC

# Heavy Quarkonium yields in PbA

yield / dy ( $nb^{-1}$ $year^{-1}$) @ $\sqrt{s}$ = 72 GeV

J/ψ ↓ Υ ↓

*[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, Phys. Rep. 522 (2013) 239 ]*

| | Target | $\int dt\mathcal{L}$ | $\mathcal{B}_{\ell\ell}\frac{dN_{J/\psi}}{dy}\Big\|_{y=0}$ | $\mathcal{B}_{\ell\ell}\frac{dN_{\Upsilon}}{dy}\Big\|_{y=0}$ |
|---|---|---|---|---|
| AFTER | 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 $10^4$ |
| RHIC | $d$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 $10^1$ |
| LHC | $p$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 $10^4$ |

PbA :

same stat. w.r.t. RHIC @ 200 GeV and LHC

$10^2$ x RHIC @ 62 GeV

AFTER @ LHC

# More details

- in Phys. Rept. :

[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, Phys. Rep. 522 (2013) 239 ]

- on the website : after.in2p3.fr

## 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

published in Phys. Rep.



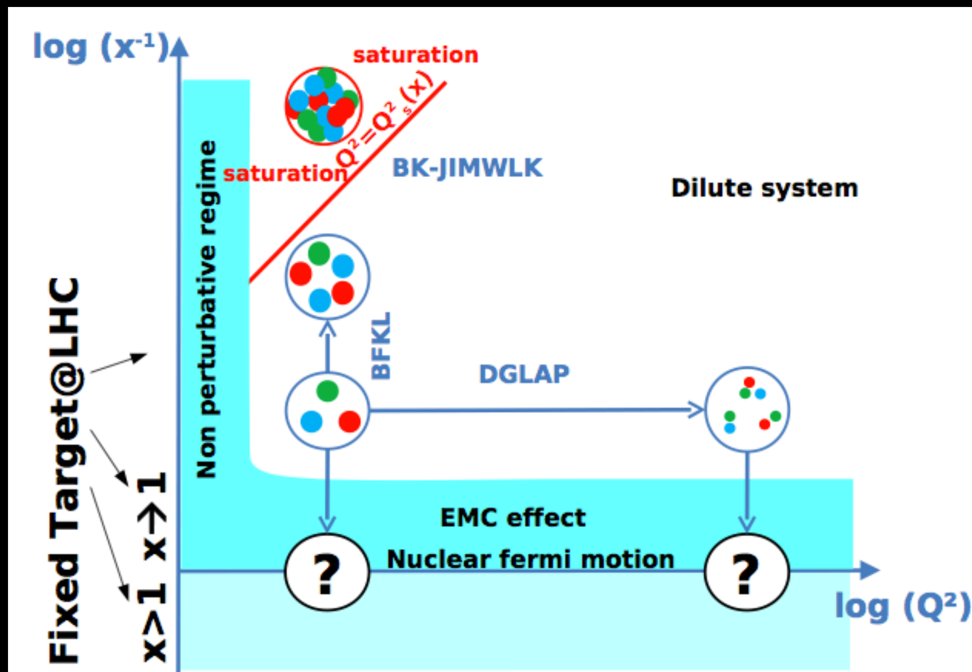
**Abstract**

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 $5 \times 10^8$ 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 $Pb A$ 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**

# QCD near the high x frontier



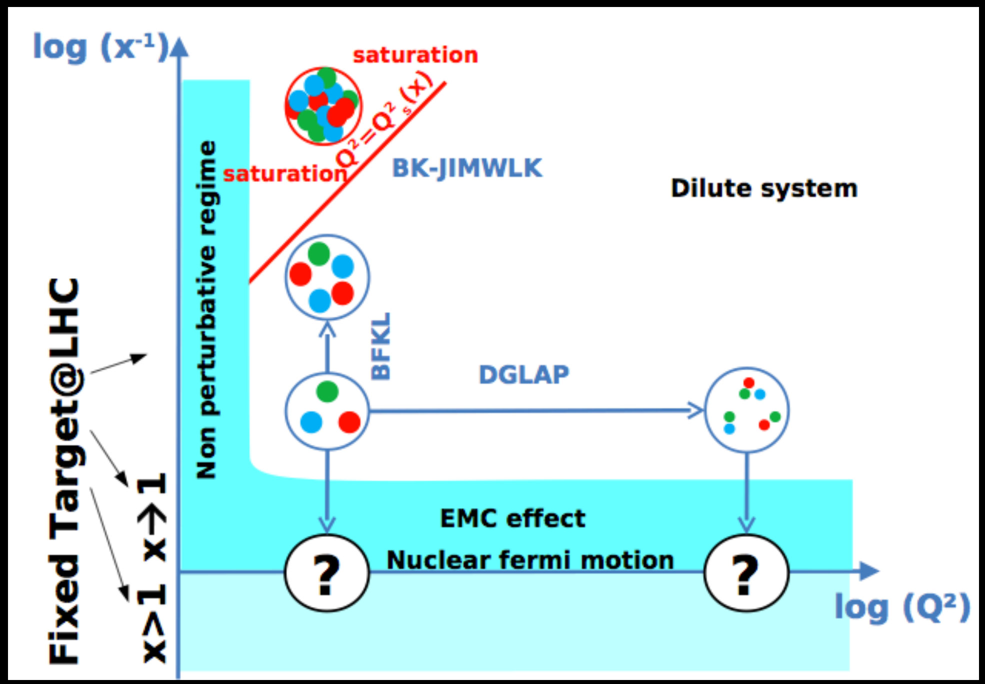

AFTER @ LHC

Test the high x frontier of QCD
x = 0.3 – 1

- Nucleon partonic structure (PDF)
- Correlations between partons (spatial position, momentum, spin ...)
  ➠ nucleon 3D structure

# QCD near the high x frontier

AFTER @ LHC




Test the high x frontier of QCD
x = 0.3 – 1

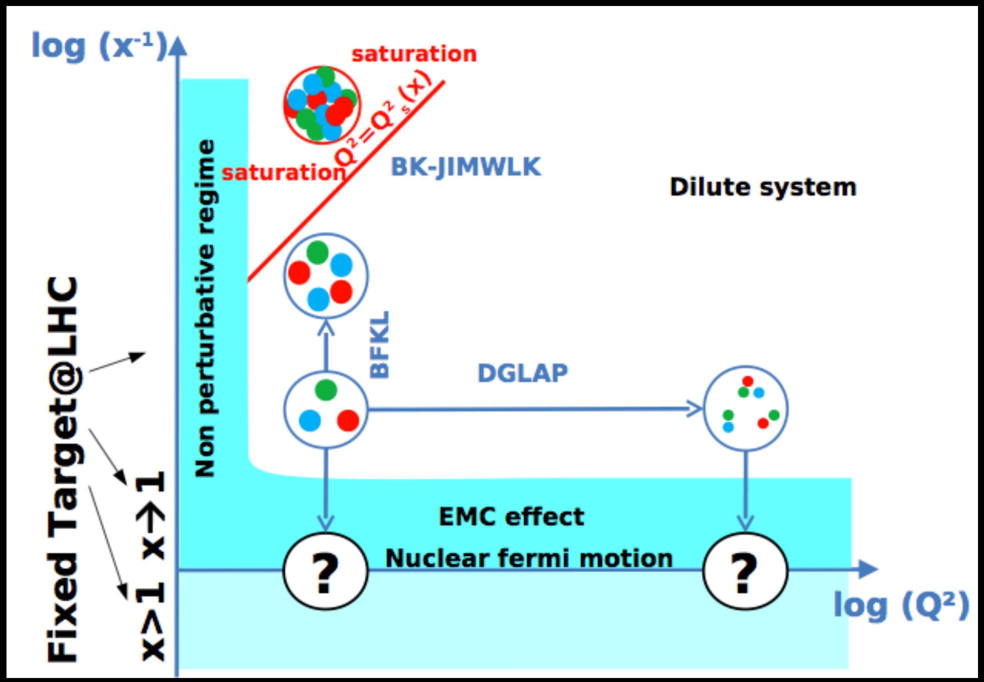
- Nucleon partonic structure (PDF)
- Correlations between partons (spatial position, momentum, spin ...)
  ➠ nucleon 3D structure

A Fixed Target ExpeRiment @ LHC :

- very energetic unpolarised p beam
- polarised or unpolarised nuclear target, where $(x^{\uparrow} = x_2)$
- full backward access, up to $(x_F \to -1) \Leftrightarrow (x^{\uparrow} \to 1)$
  - the target rapidity region corresponds to high $x^{\uparrow}$

high luminosity
&
scan in $x_F$

# QCD near the high x frontier




AFTER @ LHC

Test the high x frontier of QCD
x = 0.3 – 1

- Nucleon partonic structure (PDF)
- Correlations between partons (spatial position, momentum, spin ...) ➠ nucleon 3D structure

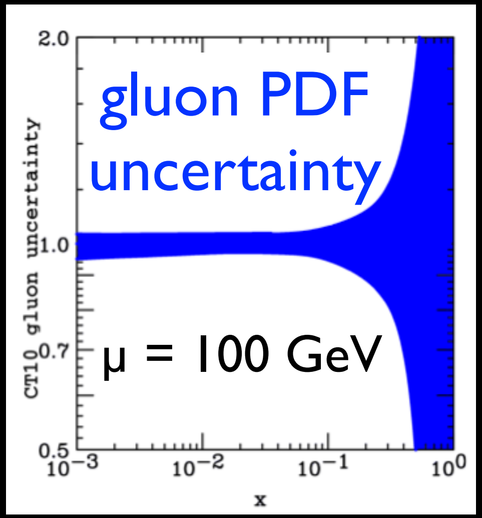
A Fixed Target ExpeRiment @ LHC :

- workshop @ ECT* Trento : confirmation of strong physics cases for spin physics
  - flavor separation
  - complementarity with JLAB (intermediate to large x) and LHeC (very low x)
- target : rather low heating (~50μW) due to the extracted LHC hadron beam
  ⇒ run duration up to ~23 days

*[ J.P. Didelez, Physics at AFTER using LHC beams, ECT* Trento, Feb. 2013]*

# Gluon and heavy quark PDF

p-p




gluon PDF at high x :

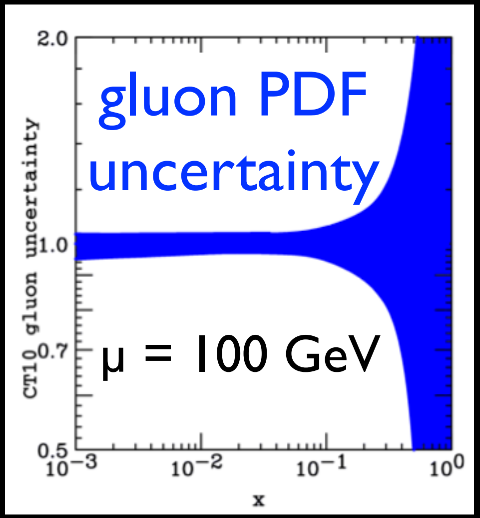
with large uncertainties for proton

exp. probes :

- heavy quarkonia (gg fusion at high energy)
- isolated photons (gq fusion)
- high $p_T$ jets ($p_T$ >20 GeV, accessible up to 40 GeV)

# Gluon and heavy quark PDF

p-p

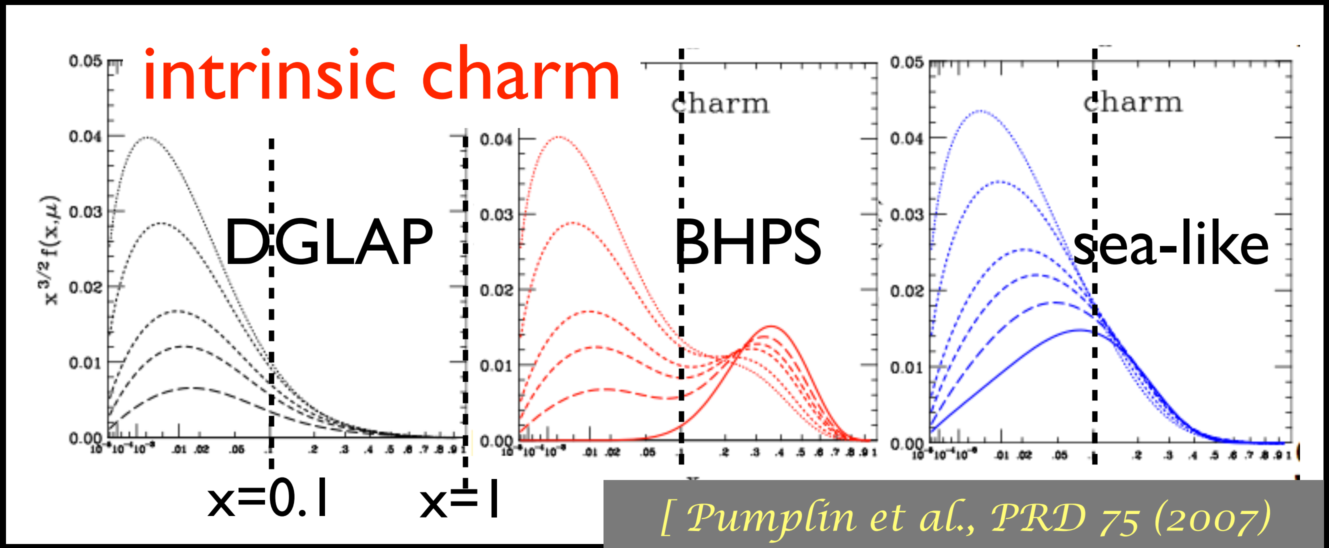



gluon PDF at high x :

with large uncertainties for proton

exp. probes :

- heavy quarkonia (gg fusion at high energy)
- isolated photons (gq fusion)
- high $p_T$ jets ($p_T$ >20 GeV, accessible up to 40 GeV)




*[ Pumplin et al., PRD 75 (2007) 054029]*

charm (and bottom) PDF at high x :

discriminate all charm PDFs currently in agreement with DIS data

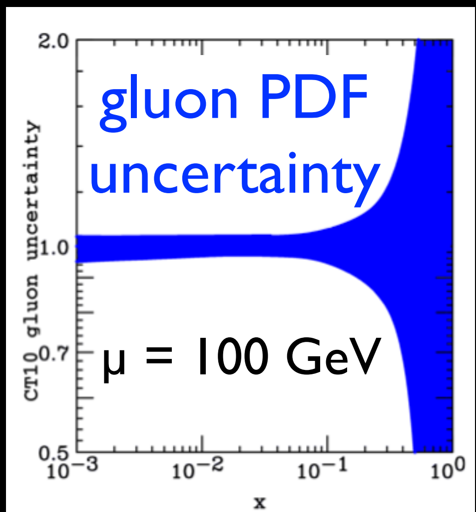
exp. probes :

- open charm, open beauty
- new open c, b hadrons at high $x_F$ ?

*[ Chang and Peng, PLB 704 (2011) 197 ]*

# Gluon and heavy quark PDF

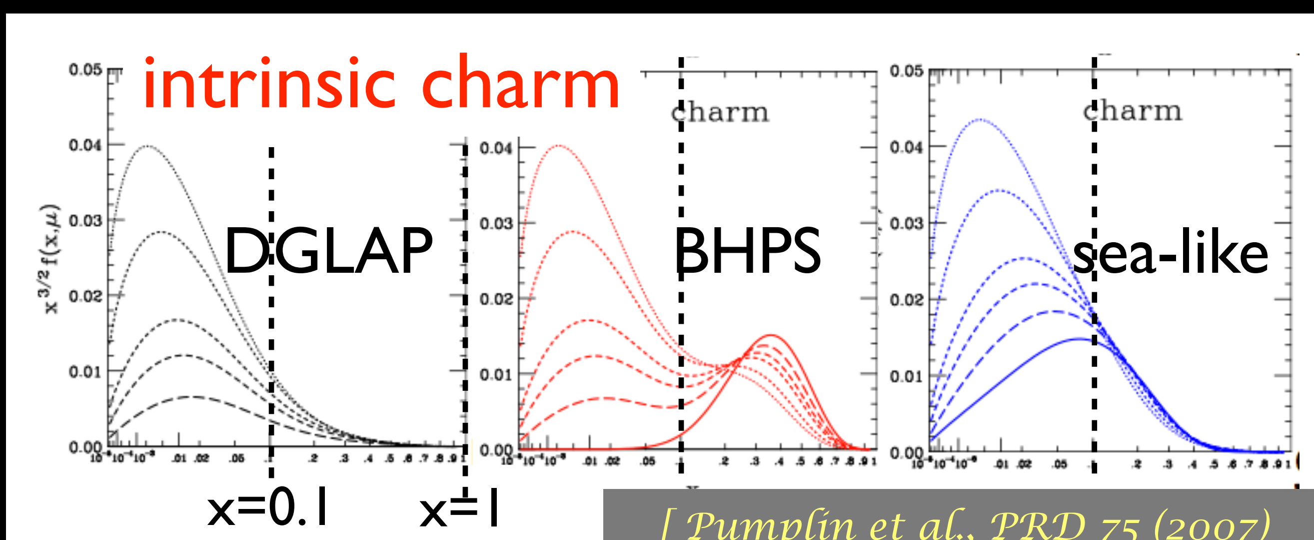
p-p




gluon PDF at high x :
with large uncertainties for proton

exp. probes :

- heavy quarkonia (gg fusion at high energy)
- isolated photons (gq fusion)
- high $p_T$ jets ($p_T$ >20 GeV, accessible up to 40 GeV)




[ *Pumplin et al., PRD 75 (2007) 054029* ]

charm (and bottom) PDF at high x :
discriminate all charm PDFs currently
in agreement with DIS data

exp. probes :

- open charm, open beauty
- new open c, b hadrons at high $x_F$ ?

[ *Chang and Peng, PLB 704 (2011) 197* ]

need high luminosity to reach large x
+ detailed studies on open heavy flavor and heavy QQbar prod.
before using them for gluon PDF extraction

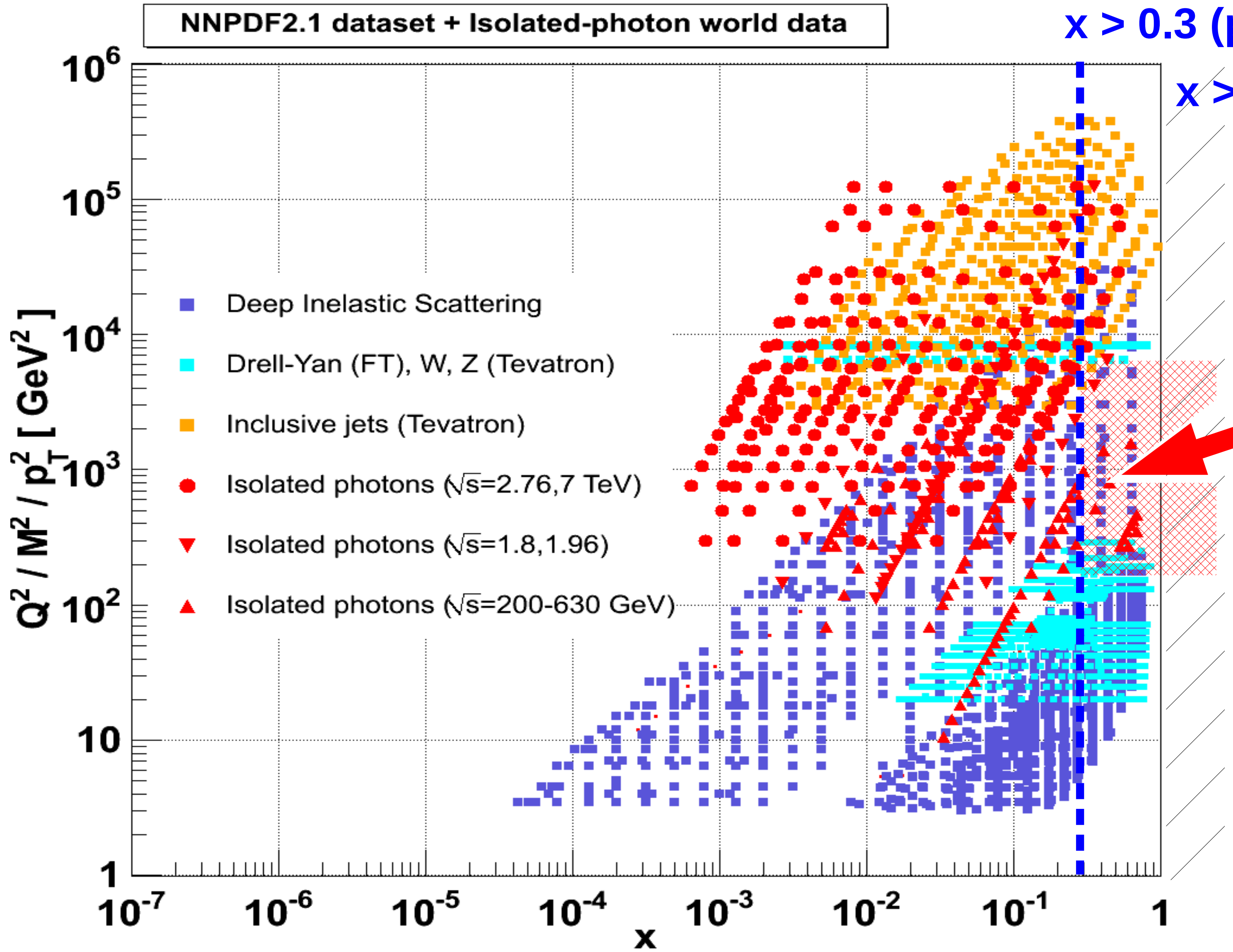
NEW !

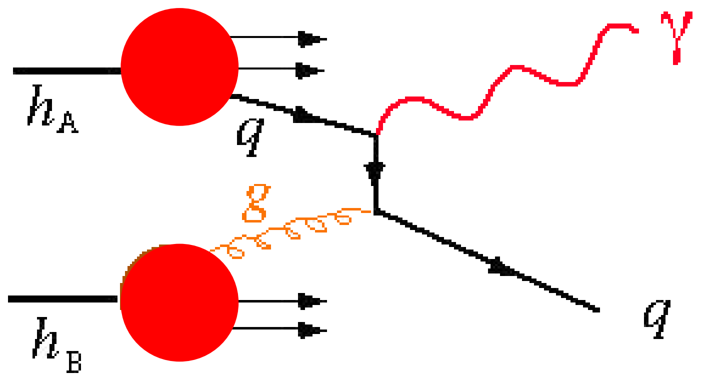
# (x,Q²) map of AFTER isolated-γ

[D.d'E & J.Rojo, NPB 860 (2012) 311]

- p-p kinematics at fixed-target LHC:

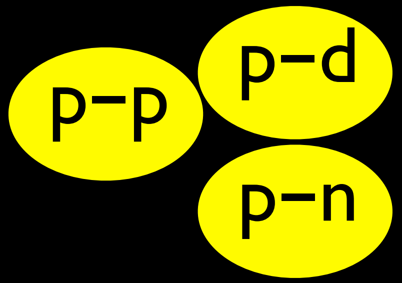
  To access x > 0.3 one needs isolated-γ with: $p_T = x_T\sqrt{s}/2 > 10\text{-}20$ GeV/c

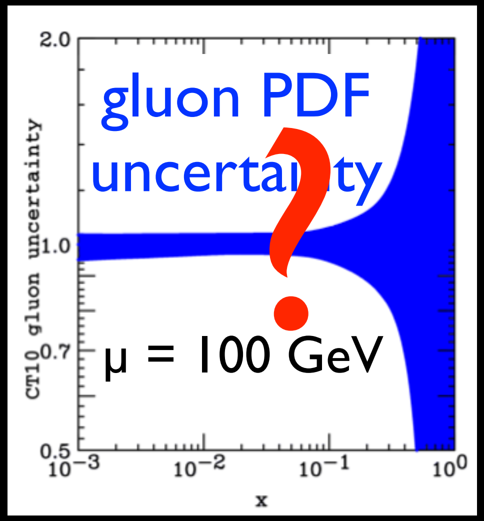



*[ D. D'Enterria, Physics at AFTER using LHC beams, ECT* Trento, Feb. 2013]*

# Gluon : proton vs neutron ?



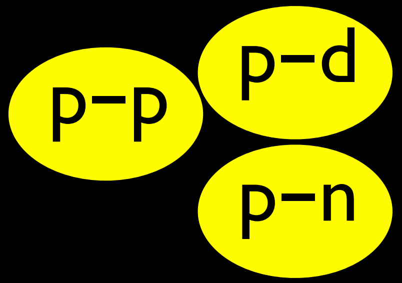



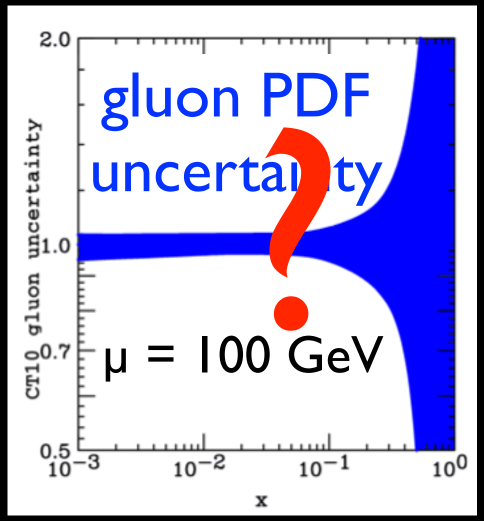

gluon PDF unknown for neutron

exp. probes :

- heavy quarkonia
- isolated photons
- high $p_T$ jets

# Gluon : proton vs neutron ?



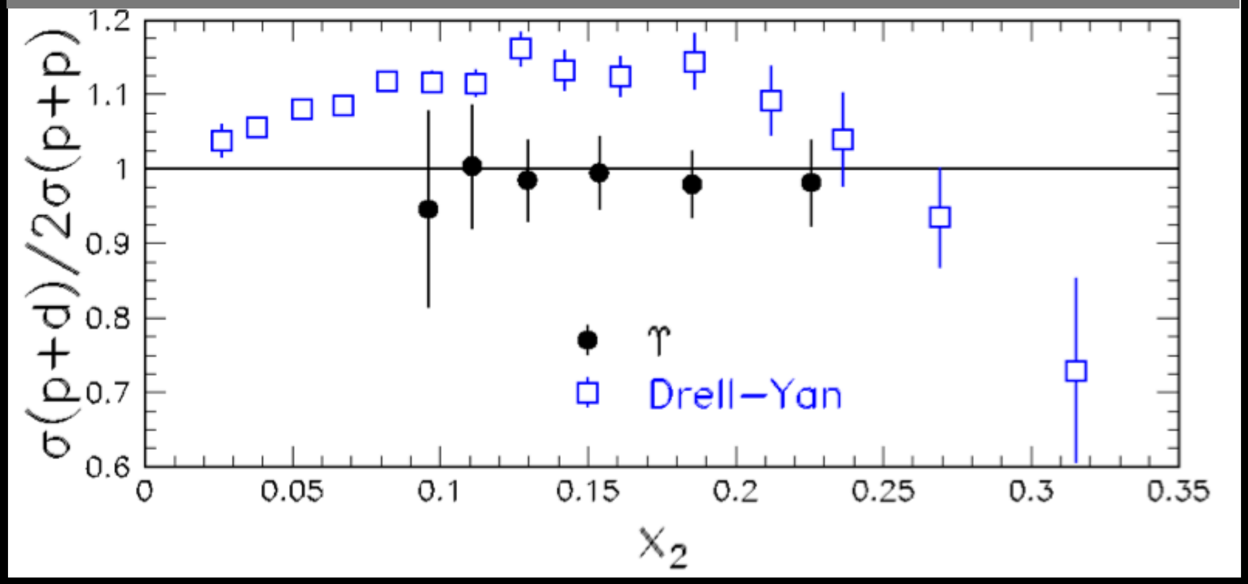




gluon PDF unknown for neutron

exp. probes :

- heavy quarkonia
- isolated photons
- high $p_T$ jets

[ E866, PRL 100 (2008) 062301 ]




Pioneering measurement by E866 @ Fermilab :

- using ϒ
- at $Q^2 \sim 100$ GeV$^2$ similar gluon distribution in proton and neutron

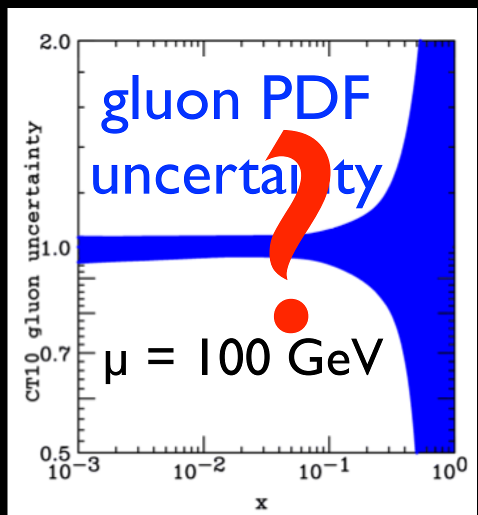
could be extended using J/ψ :

- to (~10x) lower x
- to lower $Q^2$

Need high luminosity.

# Gluon : proton vs neutron ?

p-p p-d p-n

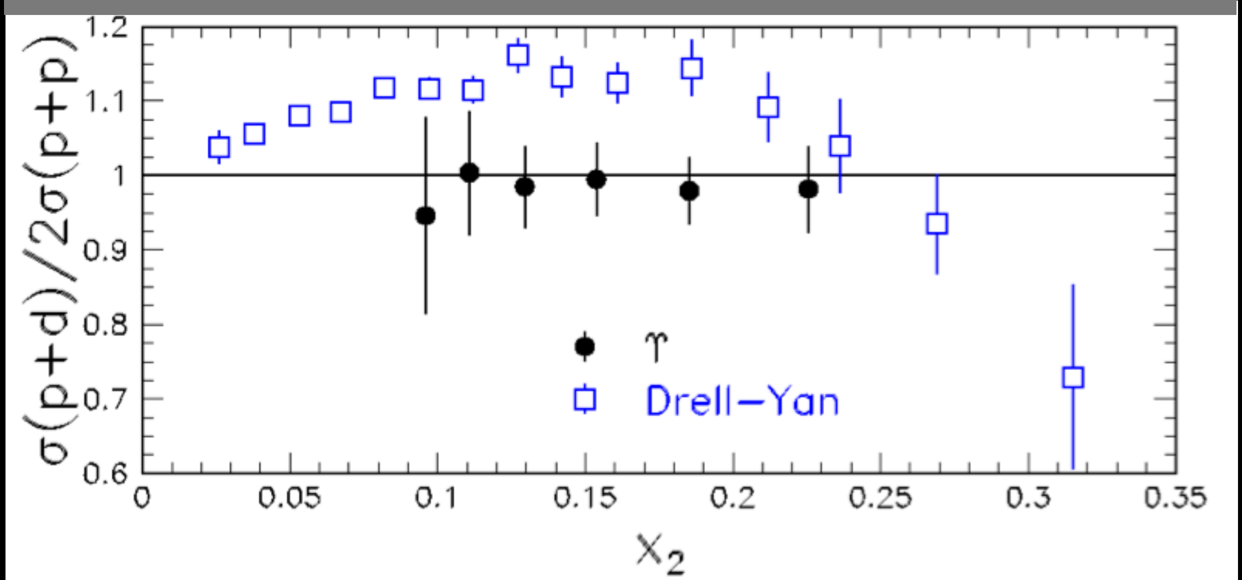



gluon PDF unknown for neutron

exp. probes :

- heavy quarkonia
- isolated photons
- high $p_T$ jets

[ E866, PRL 100 (2008) 062301 ]




Pioneering measurement by E866 @ Fermilab :

- using ϒ
- at $Q^2 \sim 100$ GeV$^2$ similar gluon distribution in proton and neutron

could be extended using J/ψ :

- to (~10x) lower x
- to lower $Q^2$

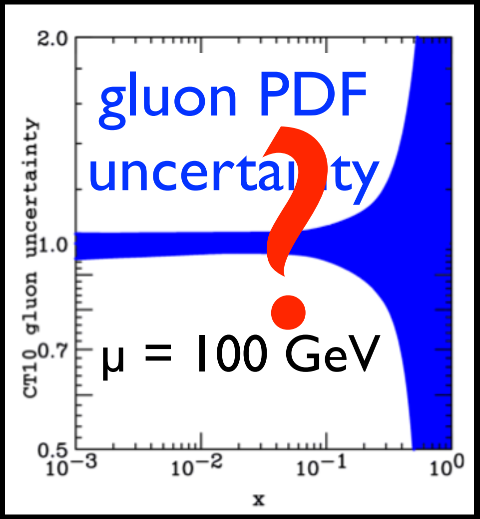
Need high luminosity.

[ Lansberg et al., FBS 53 (2012) 11]

| target | yearly lumi($fb^{-1}$) | $B_{ll} \frac{dN_{J/\psi}}{dy}\Big\|_{y=0}$ | $B_{ll} \frac{dN_{\Upsilon}}{dy}\Big\|_{y=0}$ |
|---|---|---|---|
| 1 m Liq. $H_2$ | 20 | $4.0\ 10^8$ | $8.0\ 10^5$ |
| 1 m Lid. $D_2$ | 24 | $9.6\ 10^8$ | $1.9\ 10^6$ |

# Gluon : proton vs neutron ?

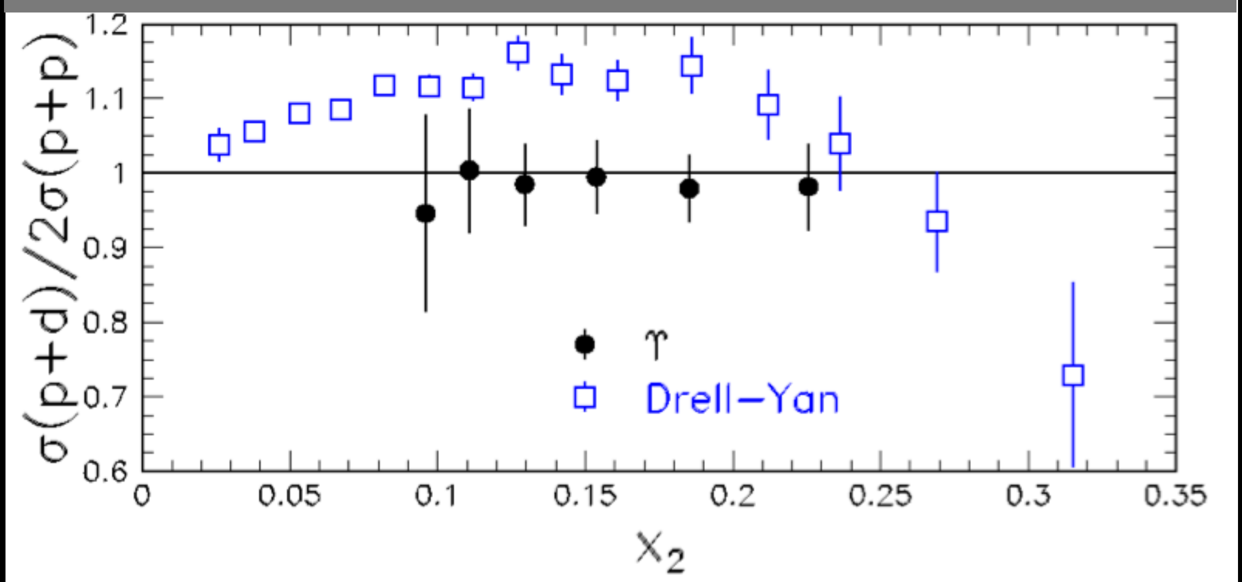
p-p
p-d
p-n




gluon PDF unknown for neutron

exp. probes :
- heavy quarkonia
- isolated photons
- high $p_T$ jets

[ E866, PRL 100 (2008) 062301 ]




Pioneering measurement by E866 @ Fermilab :
- using ϒ
- at $Q^2 \sim 100$ GeV$^2$ similar gluon distribution in proton and neutron

could be extended using J/ψ :
- to (~10x) lower x
- to lower $Q^2$

Need high luminosity.

[ Lansberg et al., FBS 53 (2012) 11]

| target | yearly lumi($fb^{-1}$) | $B_{ll} \frac{dN_{J/\psi}}{dy}\Big\vert_{y=0}$ | $B_{ll} \frac{dN_{\Upsilon}}{dy}\Big\vert_{y=0}$ |
|---|---|---|---|
| 1 m Liq. $H_2$ | 20 | $4.0\ 10^8$ | $8.0\ 10^5$ |
| 1 m Lid. $D_2$ | 24 | $9.6\ 10^8$ | $1.9\ 10^6$ |

High energy + deuteron target :
rare opportunity, feasible in AFTER

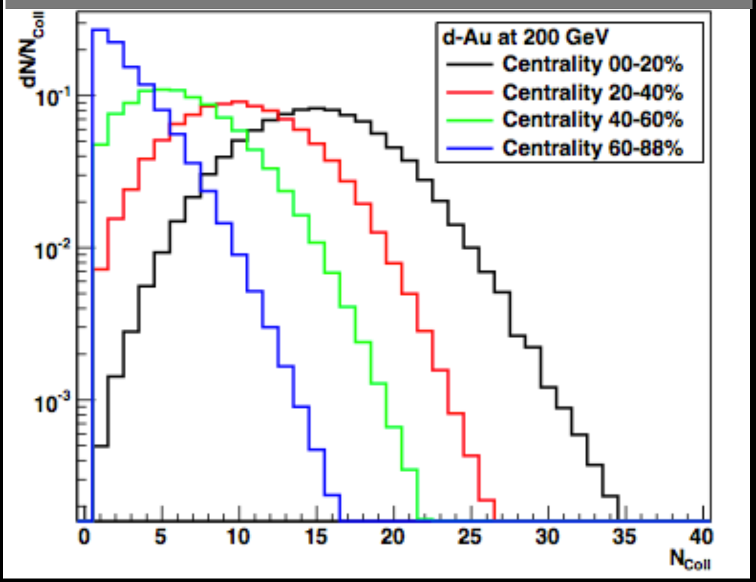
# Gluon nPDF

p–A

Pb–p

- A dependence thanks to target versatility

[ PHENIX, arXiv:1204.0777 ]




$\langle N_{coll} \rangle$ dependence ⇛ A dependence (à la NA50, NA60)

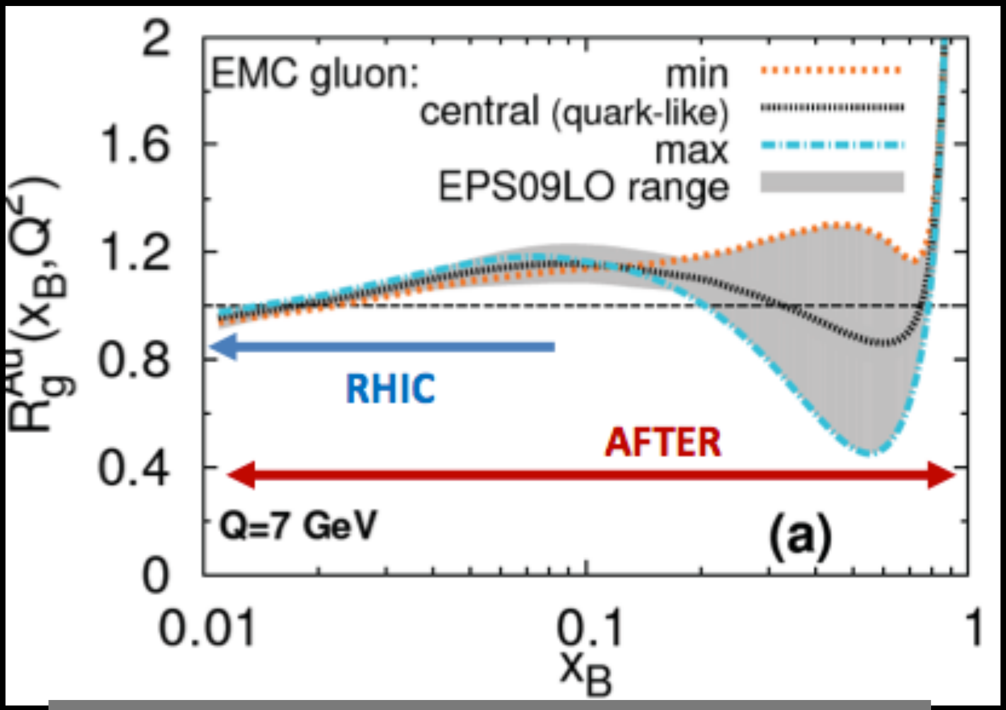
# Gluon nPDF

p-A

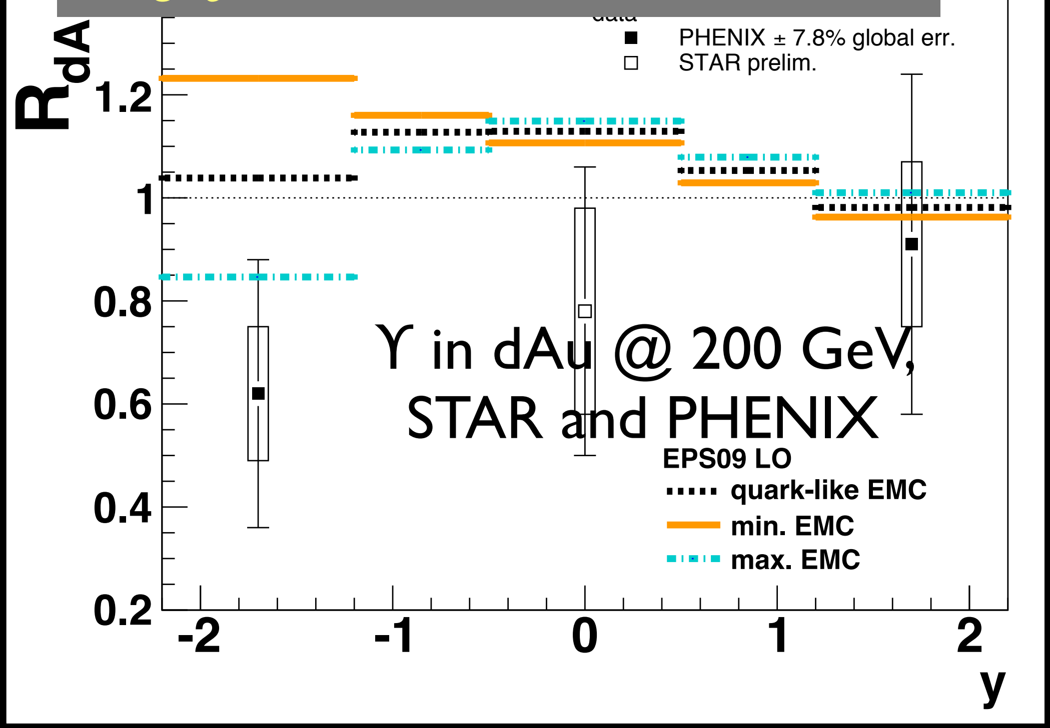
Pb-p

- A dependence thanks to target versatility
- nuclear PDF from intermediate to high x : antishadowing , EMC region , Fermi motion
- extraction using quarkonia, isolated photons, photon-jet correlation

nuclear modification of g PDF in Au




[ E.G. Ferreiro et al., arXiv:1110.5047 ]

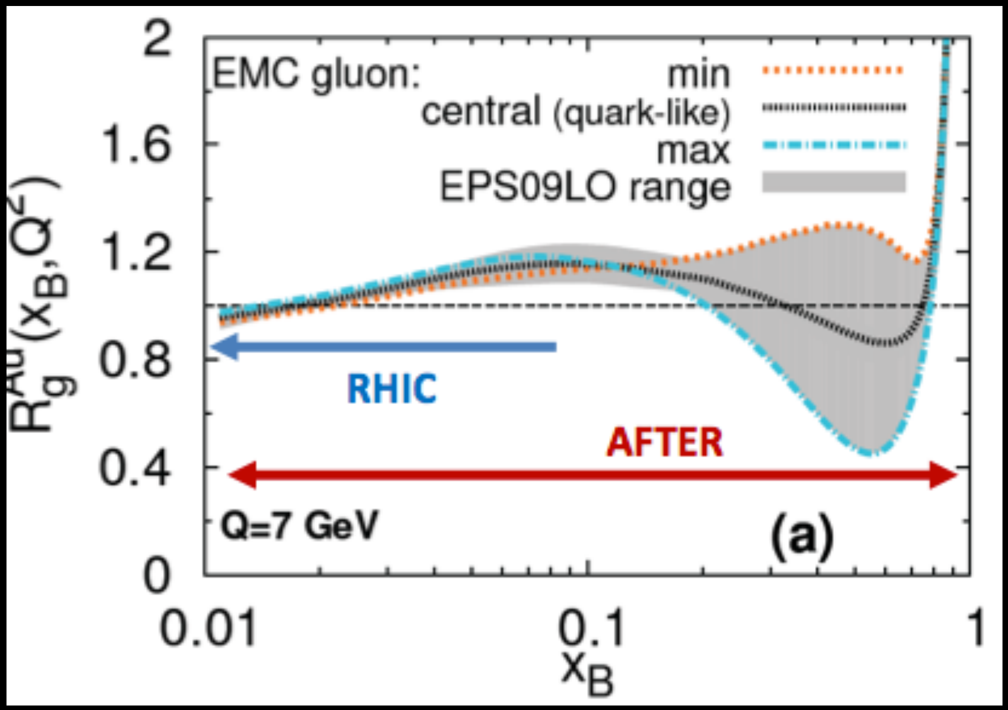


# Gluon nPDF

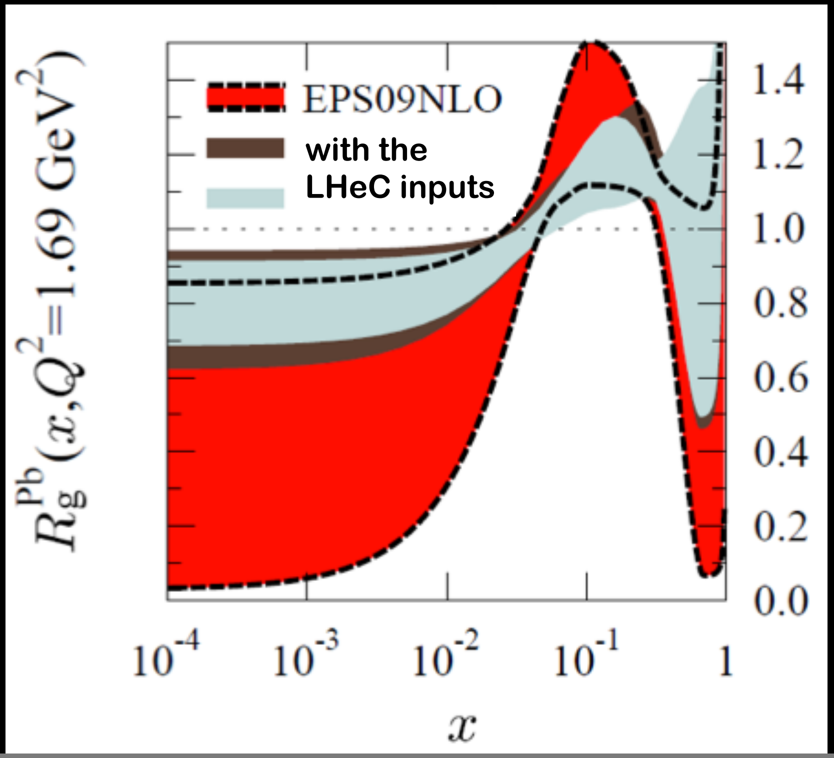
p–A
Pb–p

- A dependence thanks to target versatility
- nuclear PDF from intermediate to high x : antishadowing , EMC region , Fermi motion
- extraction using quarkonia, isolated photons, photon-jet correlation

nuclear modification of $g$ PDF in Au




nuclear modification of $g$ PDF in Pb




[ LHeC CDR, J. Phys. G 39 (2012) 075001 ]

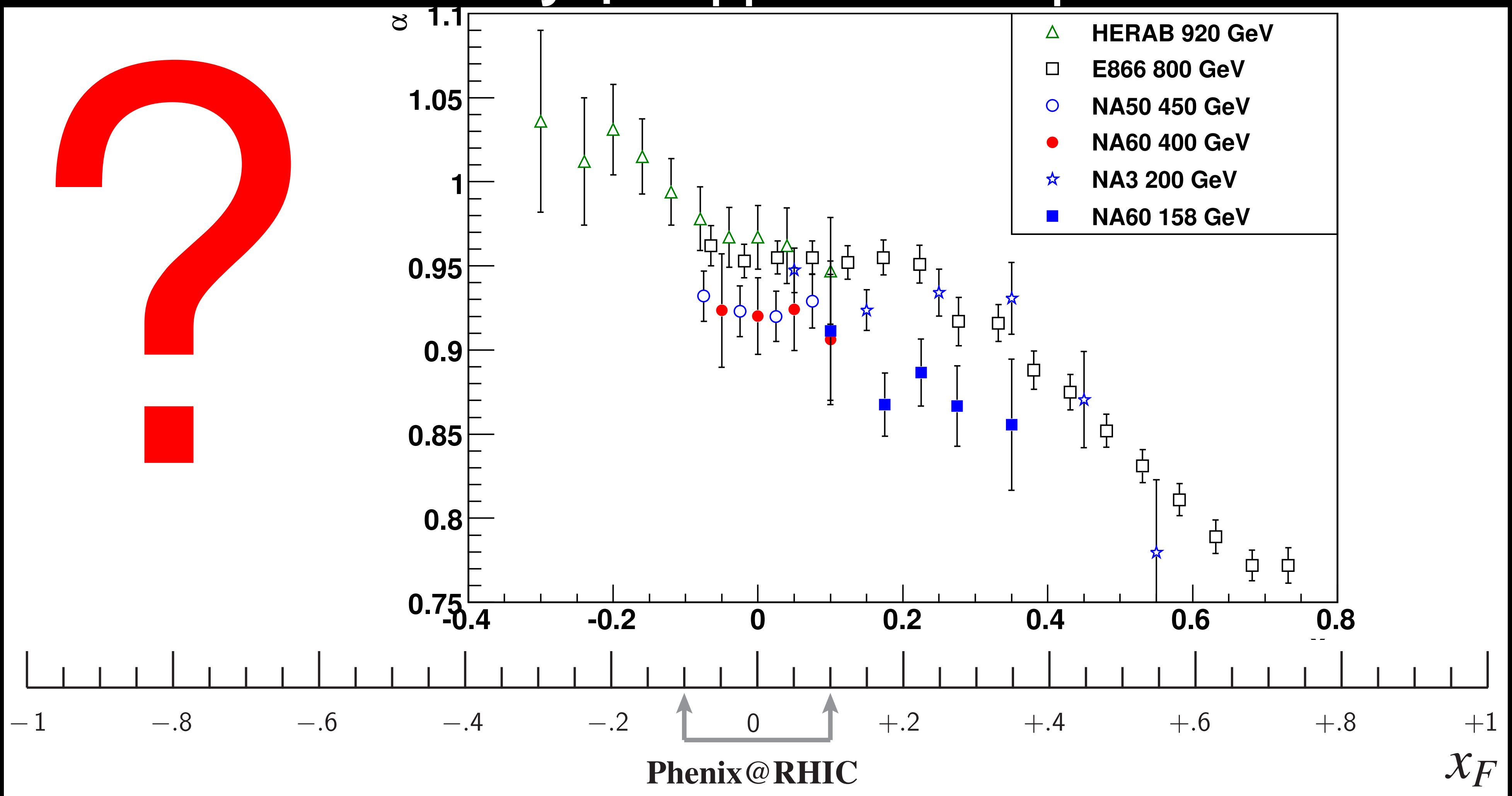
complementary with LHeC (focus at low x)

# The uncharted negative $x_F$ region

p-A

- HeraB down to $x_F = -0.3$
- PHENIX @ RHIC :
  $|x_F| < 0.1$
  (could be wider with Υ, but low stat.)
- CMS/ATLAS : $|x_F| < 5.10^{-3}$
- LHCb : $5.10^{-3} < x_F < 4.10^{-2}$

J/ψ suppression in pA




Precision studies of the nuclear matter :

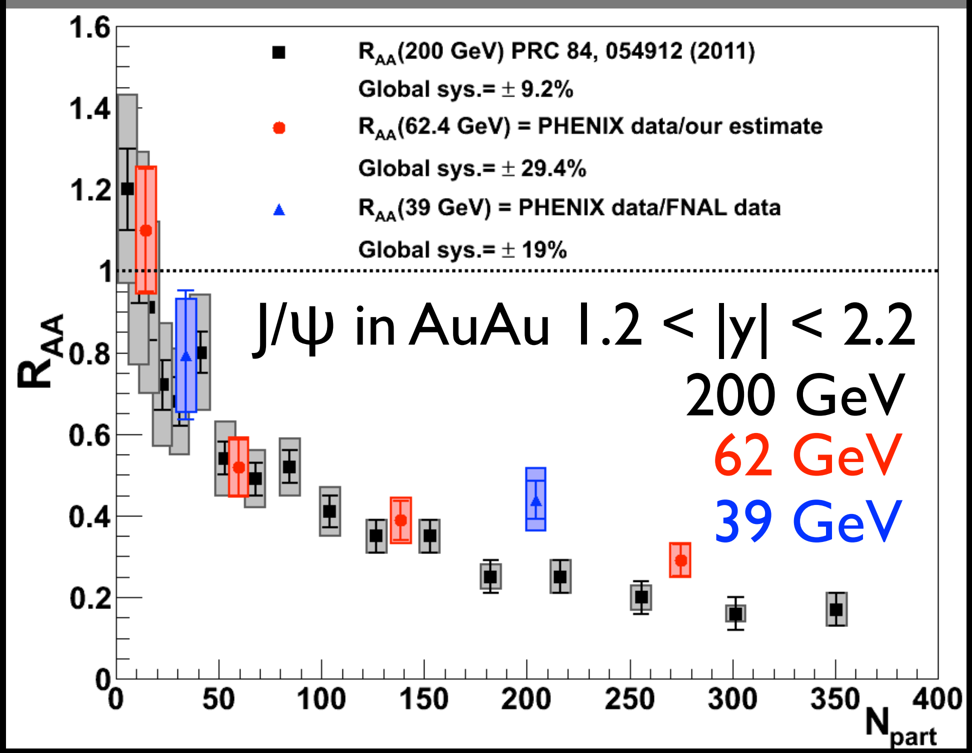
First systematic access to the target-rapidity region, down to $x_F \rightarrow -1$

# Physics in Pb–A

Precision studies of the deconfinement at RHIC energies :

- For e.g. quarkonium studies, a threefold improvement w.r.t. RHIC
  - much higher statistics compared to RHIC @ 62 GeV

[ M. Rosati for PHENIX, QM2012 ]

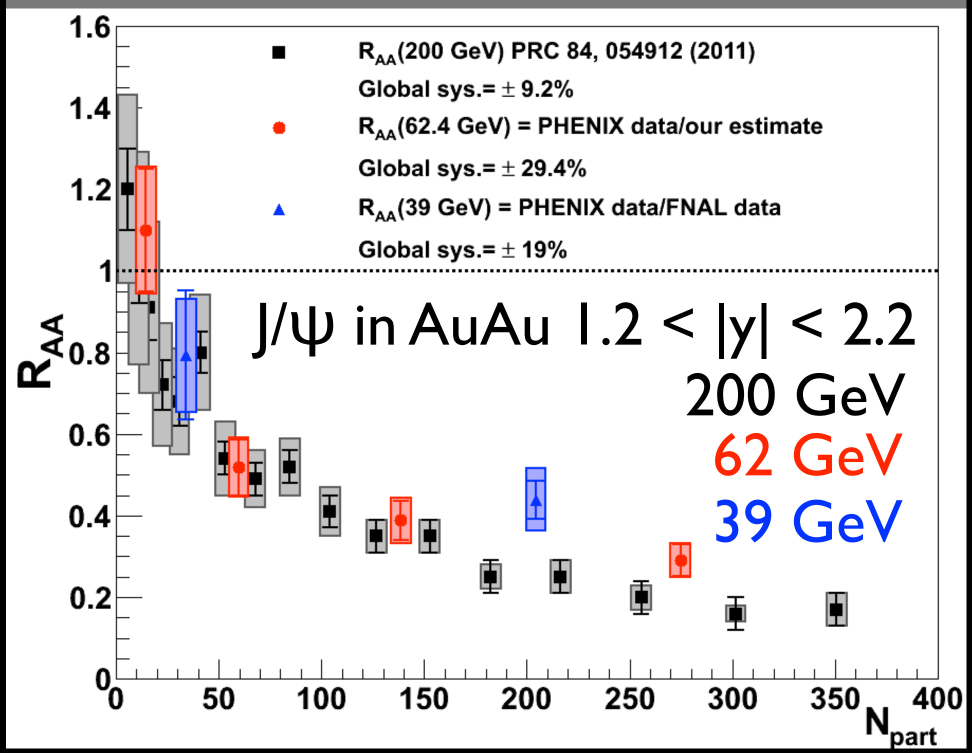


Precision studies of the deconfinement at RHIC energies :

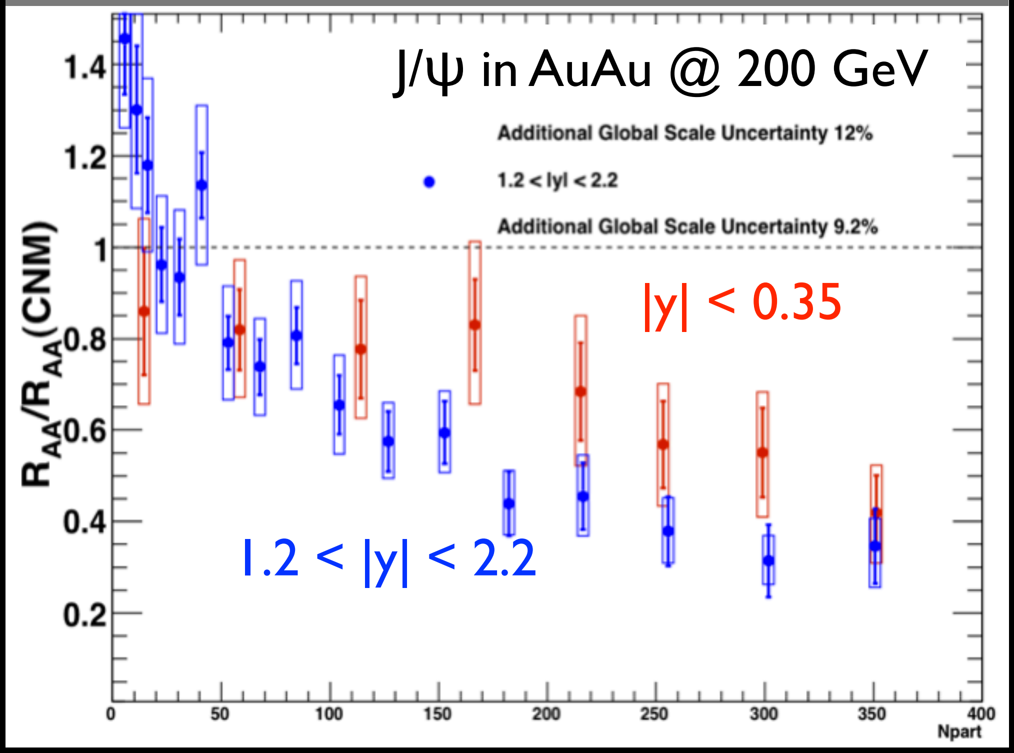
# Physics in Pb–A

- For e.g. quarkonium studies, a threefold improvement w.r.t. RHIC
  - much higher statistics compared to RHIC @ 62 GeV
  - much better control of Cold Nuclear Matter effects

[ M. Rosati for PHENIX, QM2012 ]



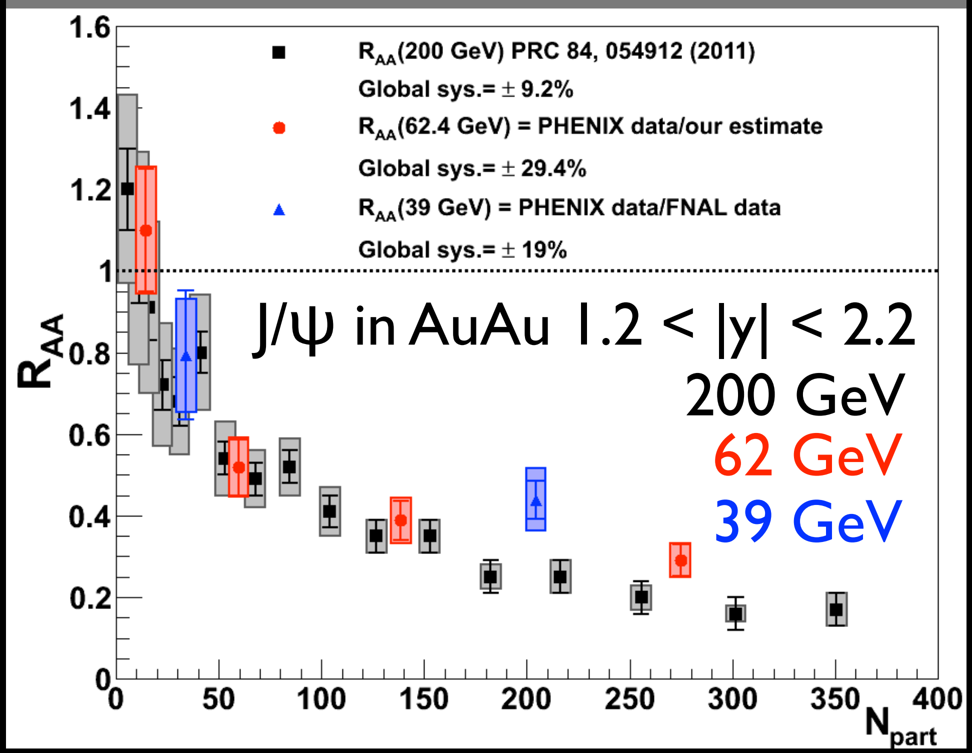

[ Frawley et al., EMMI2011 ]



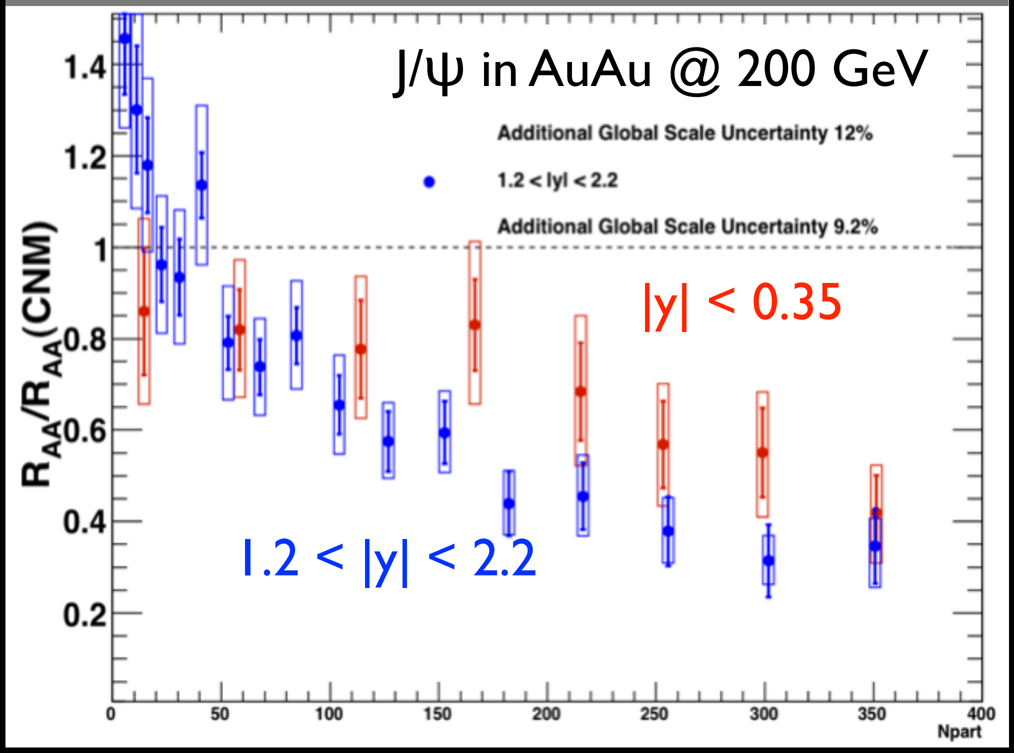
# Physics in Pb–A

- For e.g. quarkonium studies, a threefold improvement w.r.t. RHIC
  - much higher statistics compared to RHIC @ 62 GeV
  - much better control of Cold Nuclear Matter effects

[ M. Rosati for PHENIX, QM2012 ]




[ Frawley et al., EMMI2011 ]



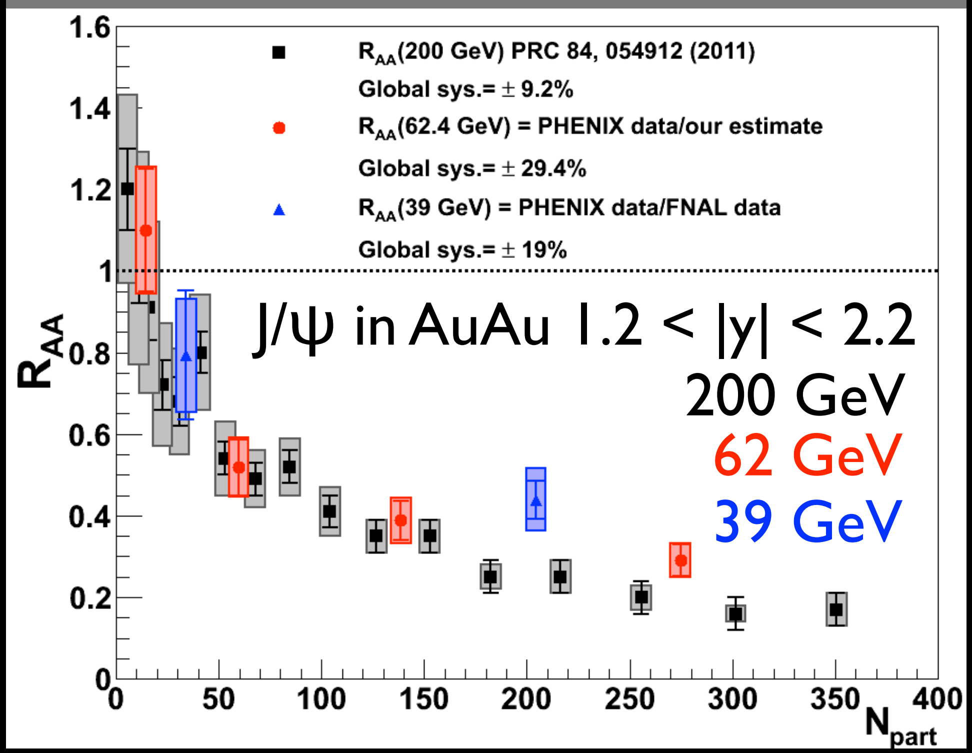

  - measure excited states, especially $\chi_c$ and $\chi_b$ with improved EMCal

Precision studies of the deconfinement at RHIC energies :

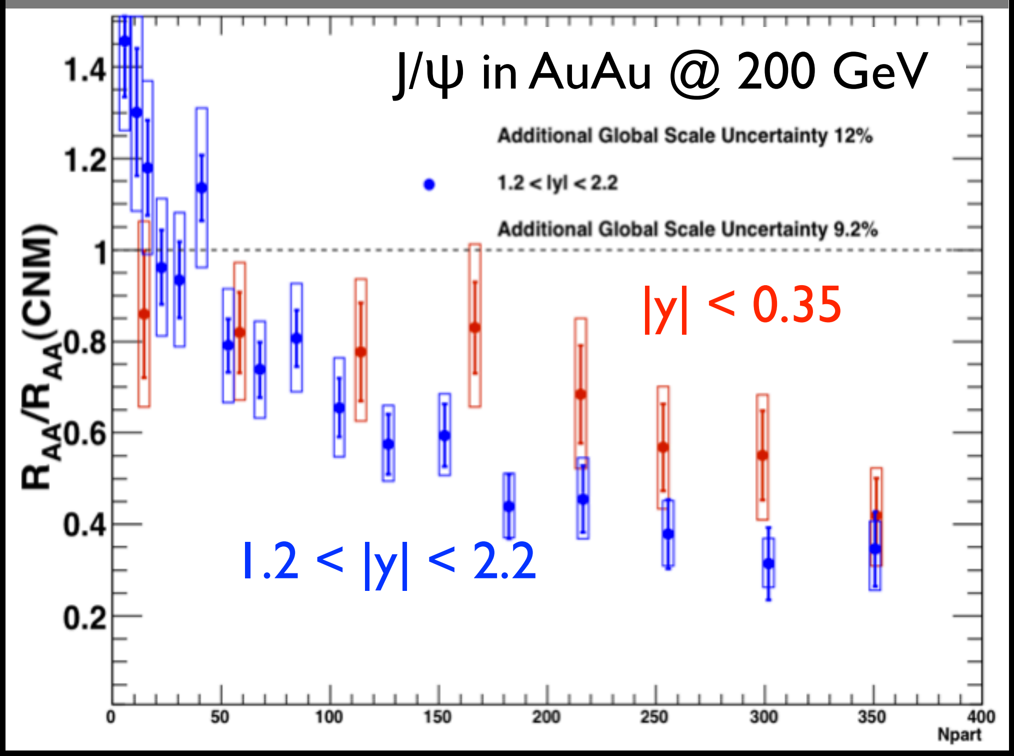
# Physics in Pb–A

- For e.g. quarkonium studies, a threefold improvement w.r.t. RHIC
  - much higher statistics compared to RHIC @ 62 GeV
  - much better control of Cold Nuclear Matter effects

[ M. Rosati for PHENIX, QM2012 ]




[ Frawley et al., EMMI2011 ]

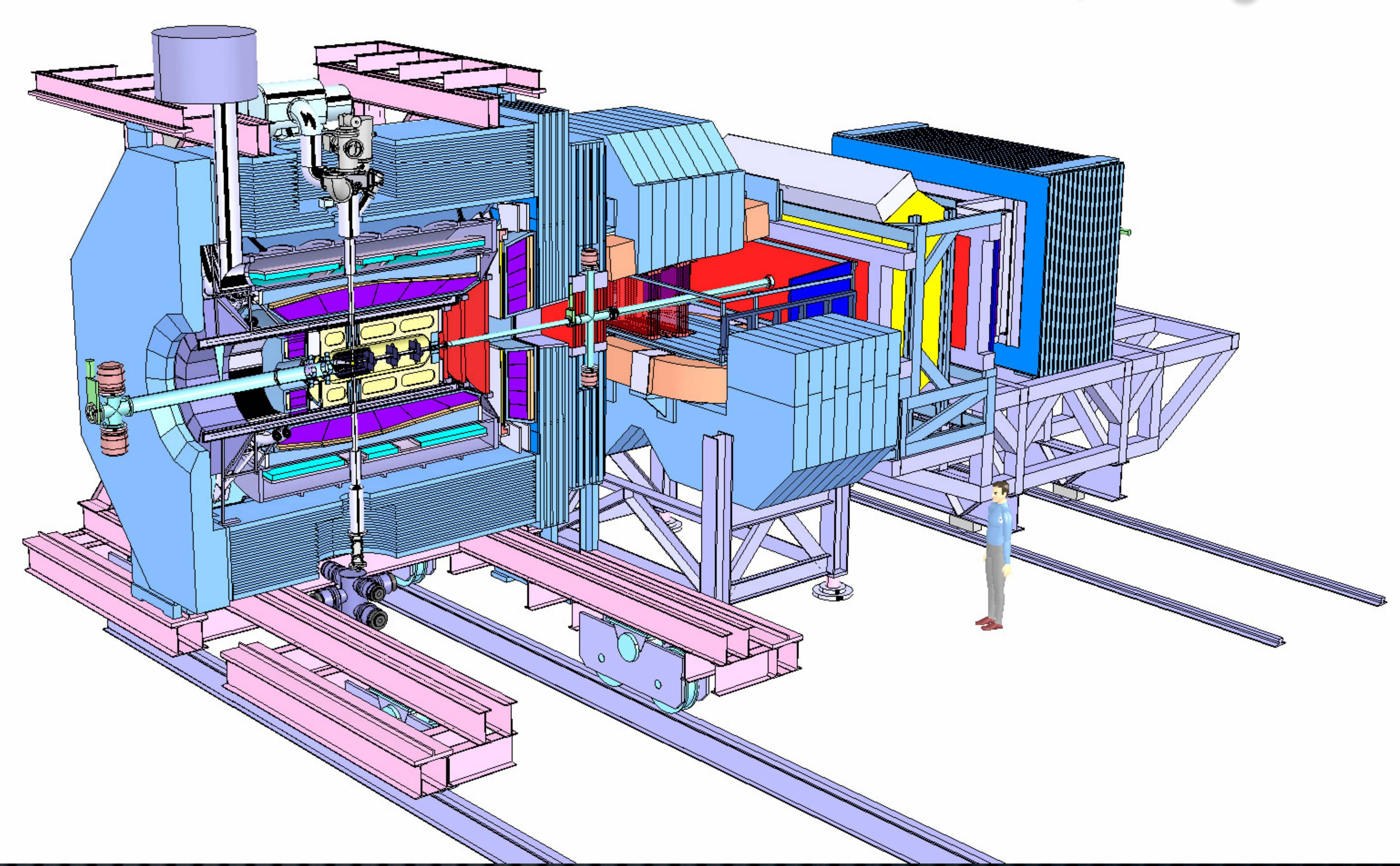



- measure excited states, especially $\chi_c$ and $\chi_b$ with improved EMCal

- also jet quenching, direct photon ...

# Detector : could be inspired by PANDA

Barrel + forward detector, 2 magnets



EmCal could be based on ultragranular CALICE, developed for ILC

# Status and outlooks

AFTER @ LHC

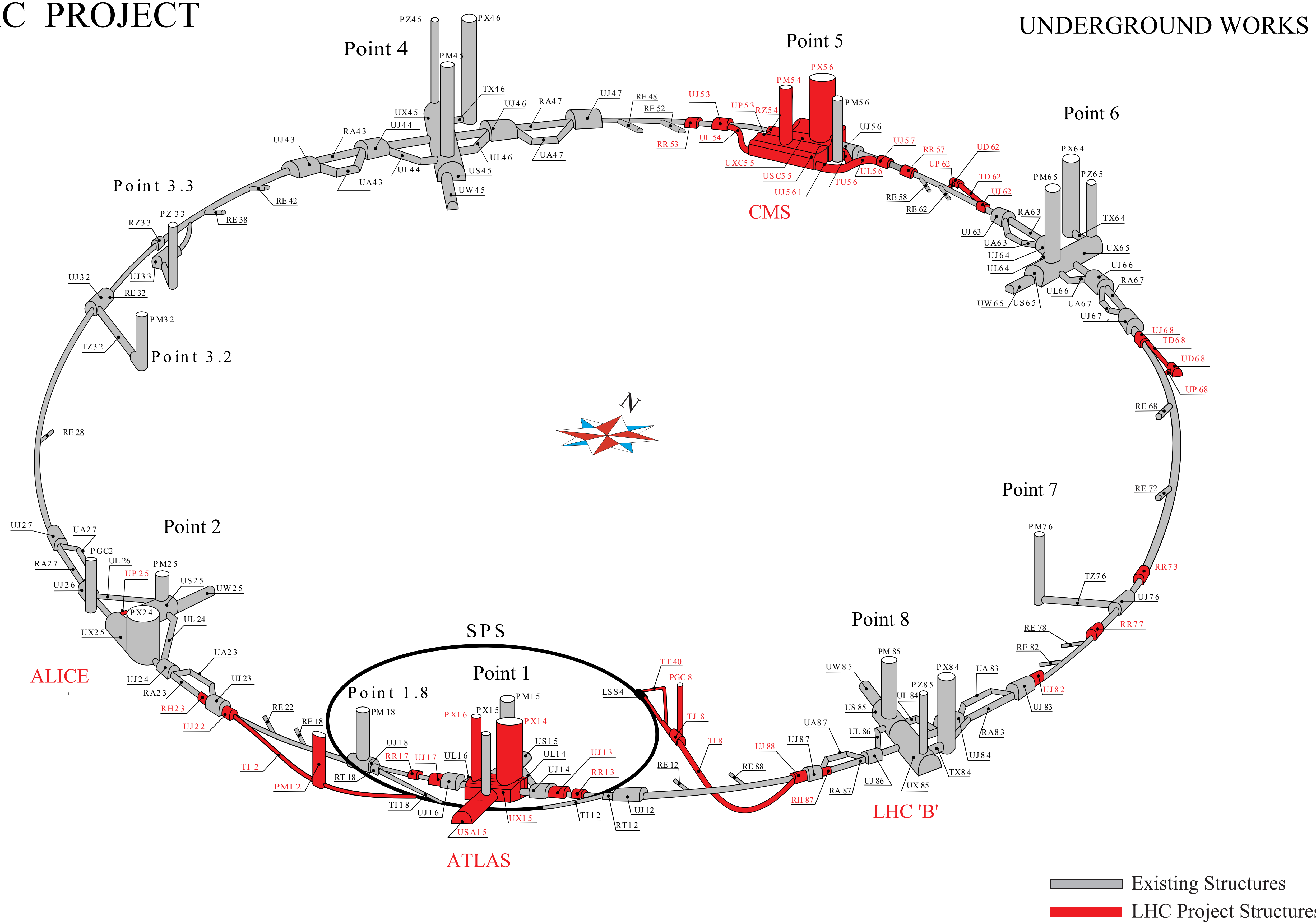
M. Anselmino (Torino), R. Arnaldi (Torino), S.J. Brodsky (SLAC), V. Chambert (IPN), J.P. Didelez (IPN), B. Genolini (IPN), E.G. Ferreiro (USC), F. Fleuret (LLR), C. Hadjidakis (IPN), J.P Lansberg (IPN), A. Rakotozafindrabe (CEA), P. Rosier (IPN), I. Schienbein (LPSC), E. Scomparin (Torino), U.I. Uggerhøj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

- first paper on physics opportunities Phys. Rep. 522 (2013) 239
- webpage after.in2p3.fr
- 3rd meeting in May 2012 in Grenoble
- a larger workshop (10 days) at Trento earlier in February 2013
- next workshop : probably 3 days next November at CERN ?
- supports :
  - 2011-2012 : support from France-Standford Interdisciplinaries studies
  - 2012 : support from CNRS PEPS-PTI
  - 2013 : support from CNRS PICS with Torino (expected : 3 years)
- Looking for partners !
- Target schedule : installation during LHC Long Shutdown 3

# SPARE SLIDES

# LHC PROJECT

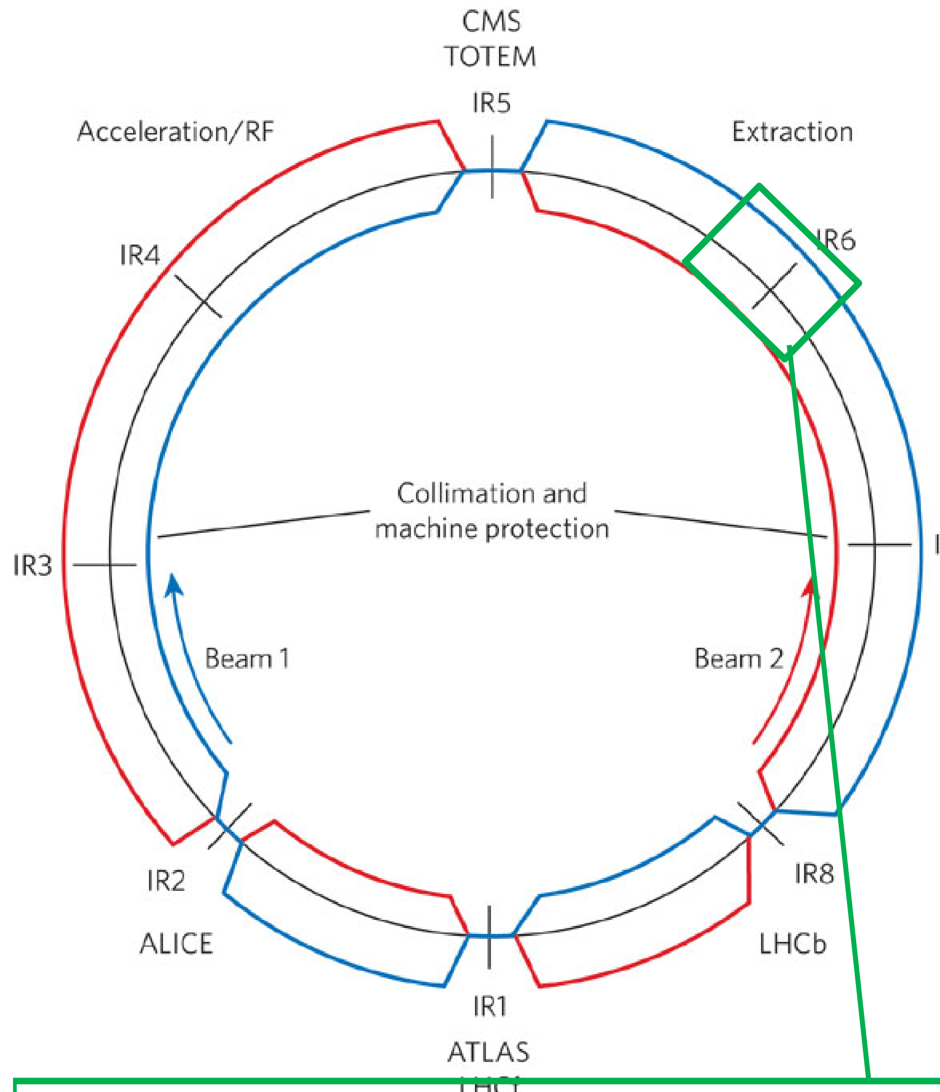
## UNDERGROUND WORKS




ST-CE/JLB-hlm
18/04/2003

# One new possibility: LHC dump, IR6


(IR7 and IR3 to be investigated)

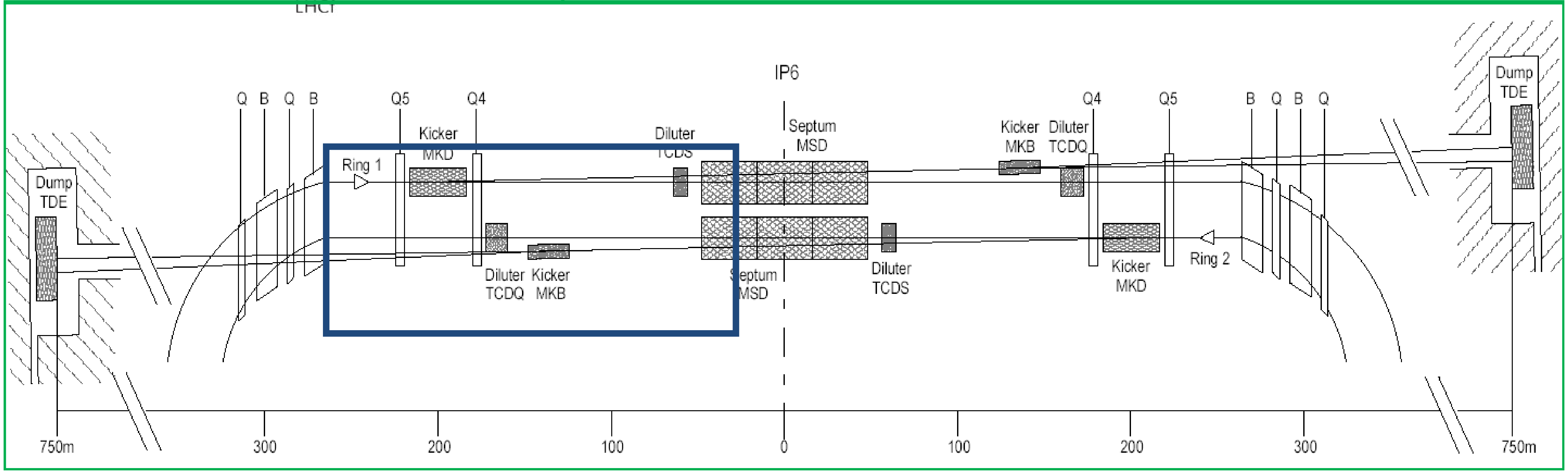



Nuclear Instruments and Methods in Physics Research B 234 (2005) 31–39

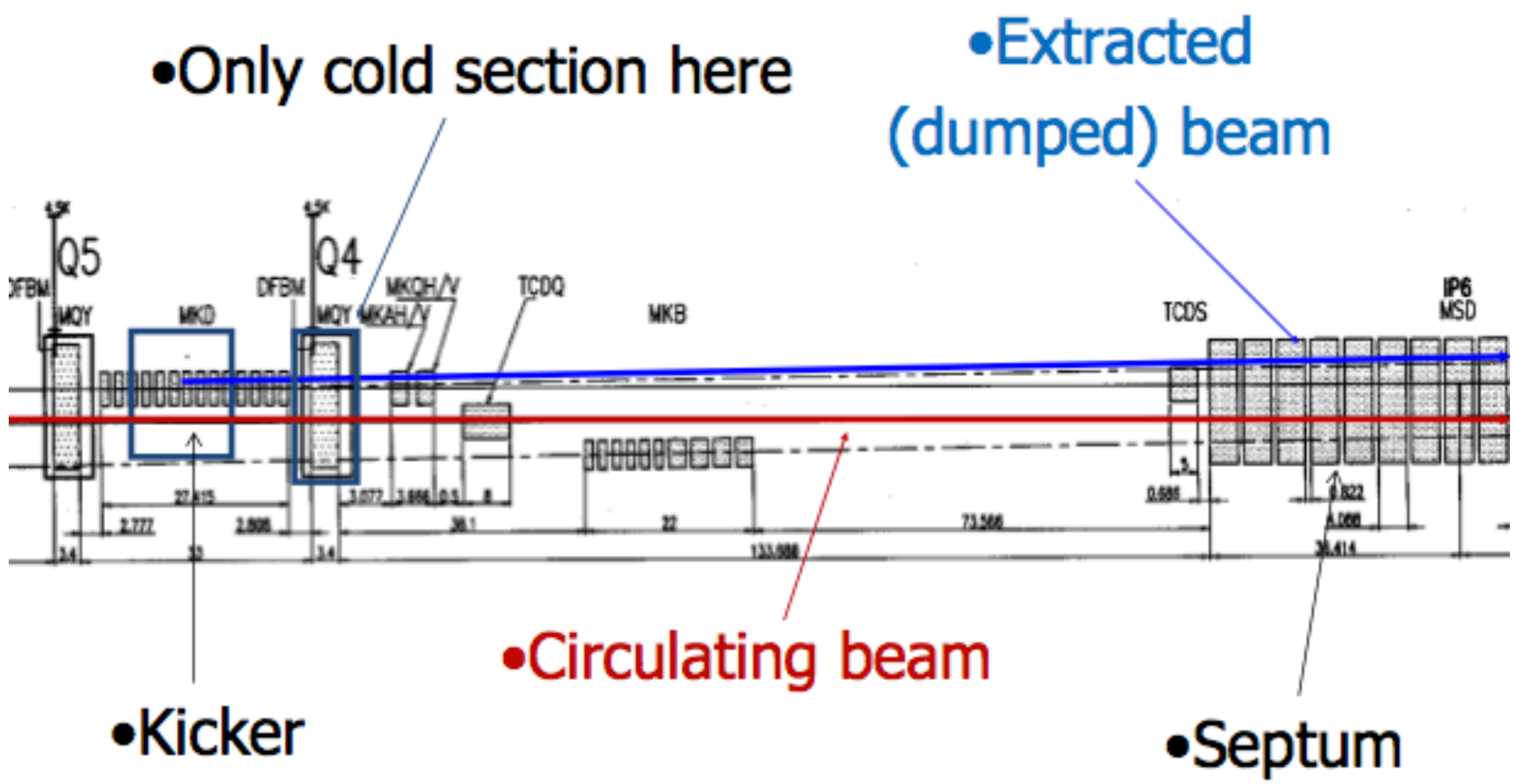
## Strong crystalline fields – a possibility for extraction from the LHC

E. Uggerhøj, U.I. Uggerhøj *

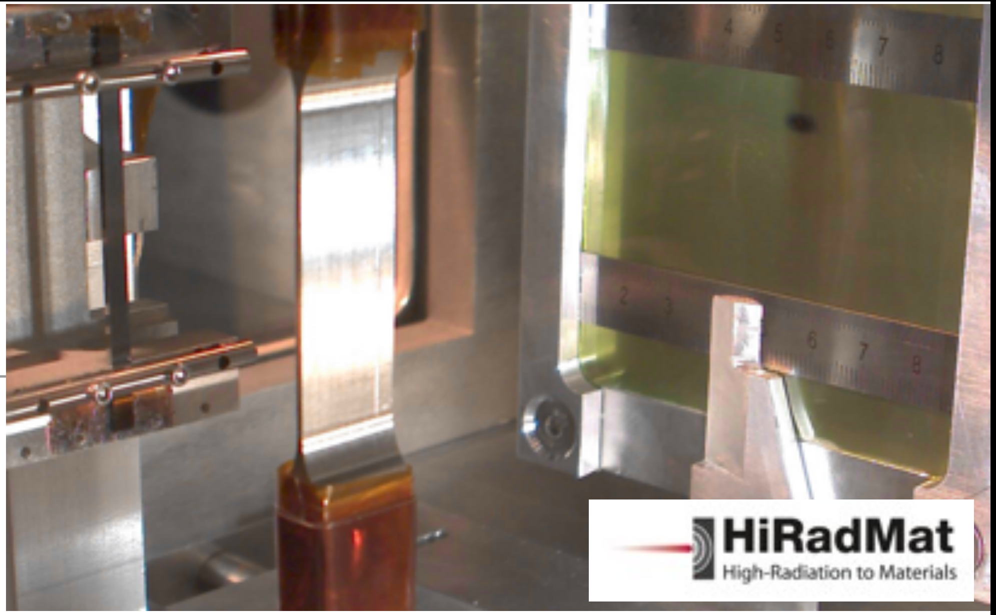
*Department of Physics and Astronomy, University of Aarhus,*



# LHC dump, IR6 zoom-in

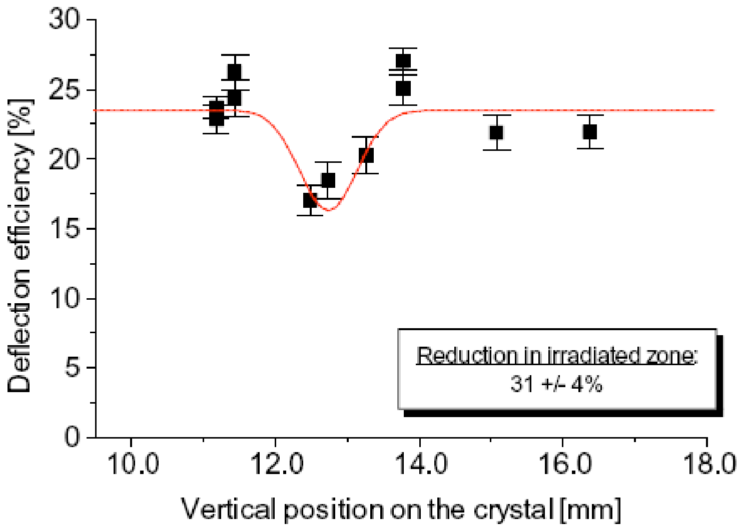


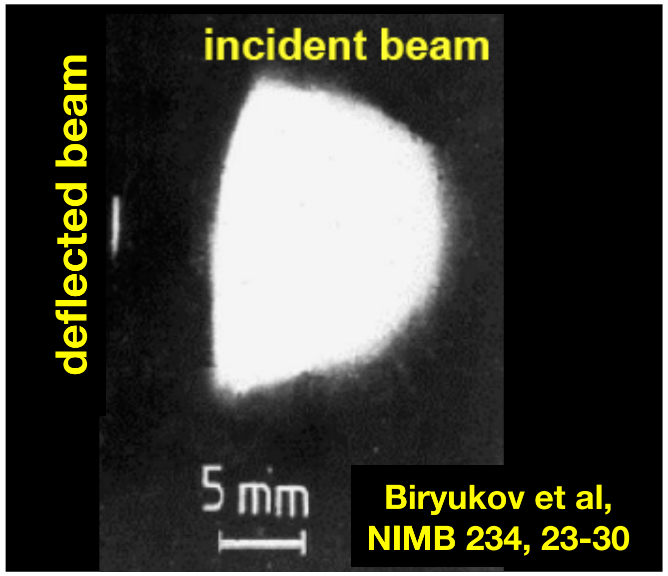
# Crystal resistance to irradiation




- **IHEP U-70** (Biryukov et al, NIMB 234, 23-30):
  - 70 GeV protons, 50 ms spills of **$10^{14}$ protons every 9.6 s**, several minutes irradiation
  - equivalent to 2 nominal LHC bunches for 500 turns every 10 s
  - 5 mm silicon crystal, **channeling efficiency unchanged**
- **SPS North Area - NA48** (Biino et al, CERN-SL-96-30-EA):
  - 450 GeV protons, 2.4 s spill of $5 \times 10^{12}$ protons every 14.4 s, one year irradiation, **$2.4 \times 10^{20}$ protons/cm$^2$** in total,
  - equivalent to several year of operation for a primary collimator in LHC
  - $10 \times 50 \times 0.9$ mm$^3$ silicon crystal, $0.8 \times 0.3$ mm$^2$ area irradiated, **channeling efficiency reduced by 30%**.
- **HRMT16-UA9CRY** (HiRadMat facility, November 2012):
  - 440 GeV protons, up to 288 bunches **in 7.2 μs**, $1.1 \times 10^{11}$ protons per bunch (**$3 \times 10^{13}$ protons** in total)
  - energy deposition comparable to an asynchronous beam dump in LHC
  - 3 mm long silicon crystal, **no damage to the crystal after accurate visual inspection**, more tests planned to assess possible crystal lattice damage
    - **accurate FLUKA simulation of energy deposition** and residual dose

NA48 - Biino et al, CERN-SL-96-30-EA

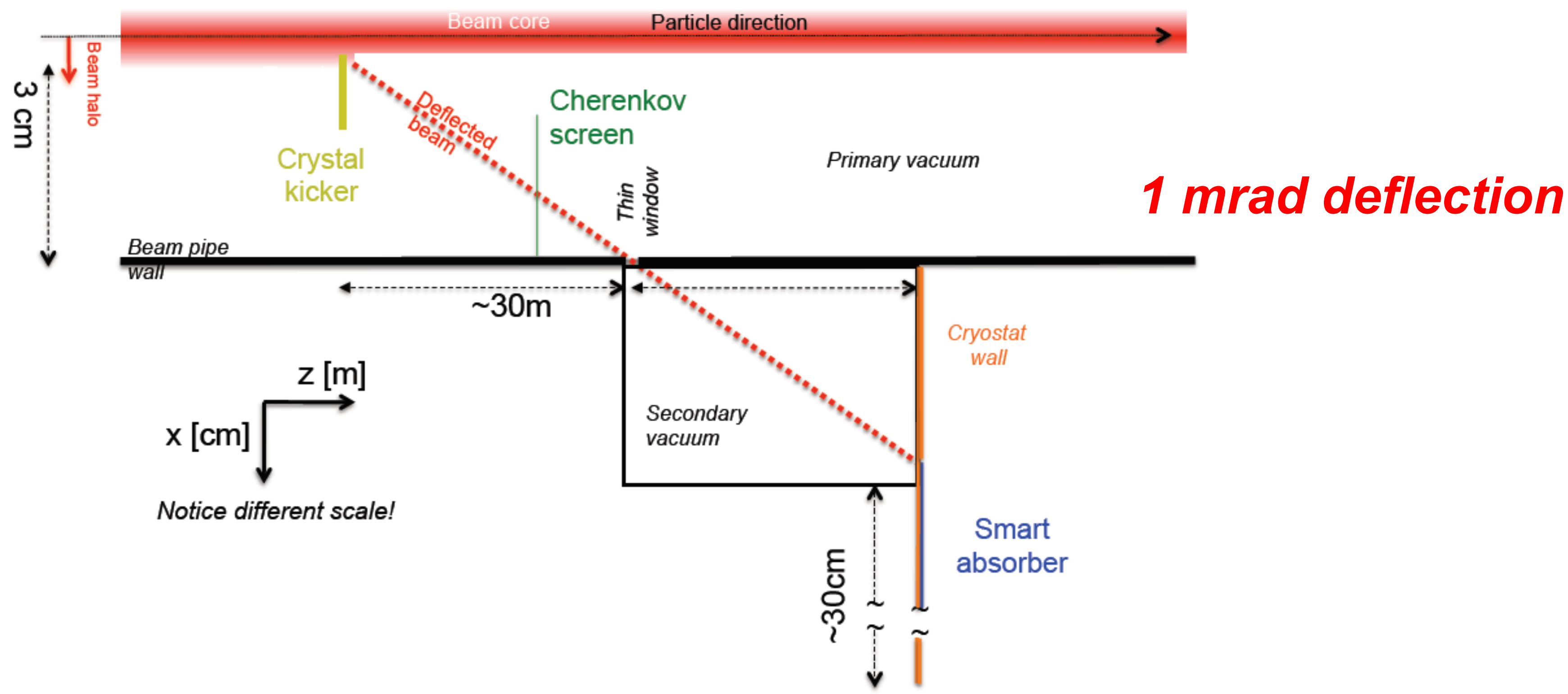



Biryukov et al, NIMB 234, 23-30

# UA9 2.0: CRYSBEAM

- A possible setup to extract a hadron beam (not for for collimation but sharing the same difficulties)
- Meant to work at high luminosity (high current)




**CRYS**tal channeling to extract a high energy hadron **BE**am from an **A**ccelerator **M**achine

***Presented for FP7 ERC CoG call***



CRYSBEAM could be ready for LS2

# 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 $2808 \times 11000\ s^{-1} \simeq 3.10^7$ bunches s$^{-1}$
  - one extracts $5.10^8/3.10^7 \simeq$ $16p^+$ from each bunch at each pass
  - Provided that the probability of interaction with the target is below 1%, 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 anyway lost !*
- similar figures for the Pb-beam extraction

# Luminosities using :

## 7 TeV proton beam
pp, pd, pA $\sqrt{s}$ = 115 GeV

## 2.76 TeV lead beam
Pbp, Pbd, PbA $\sqrt{s}$ = 72 GeV

[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, Phys. Rep. 522 (2013) 239 ]

| Target (1 cm thick) | $\rho$ (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 |

Table 1: Instantaneous and yearly luminosities obtained with an extracted beam of $5\times10^8$ p$^+$/s with a momentum of 7 TeV for various 1cm thick targets

| Target (1 cm thick) | $\rho$ (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 |

Table 2: Instantaneous and yearly luminosities obtained with an extracted beam of $2\times10^5$ Pb/s with a momentum per nucleon of 2.76 TeV for various 1cm thick targets

extracted beam $N_{beam} = 5\,.10^8$ p$^+$/s
9 months running / year $\Leftrightarrow 10^7$ s

extracted beam $N_{beam} = 2\,.10^5$ Pb/s
1 month running / year $\Leftrightarrow 10^6$ s

Instantaneous luminosity :
$L = N_{beam} \times N_{target} = N_{beam} \times (\rho\,.\,e\,.\,N_A)$ with e = target thickness

Planned luminosity for PHENIX :

- @ 200 GeV run14pp 12 pb$^{-1}$, run14dAu 0.15 pb$^{-1}$
- @ 200 GeV run15AuAu 2.8 pb$^{-1}$ ( 0.13 nb$^{-1}$ @ 62 GeV)

Nominal LHC luminosity PbPb 0.5 nb$^{-1}$

# 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 | $\sim 0.05$ | 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

# Accessing the large $x$ gluon pdf

**PYTHIA simulation**
σ(y) / σ(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**

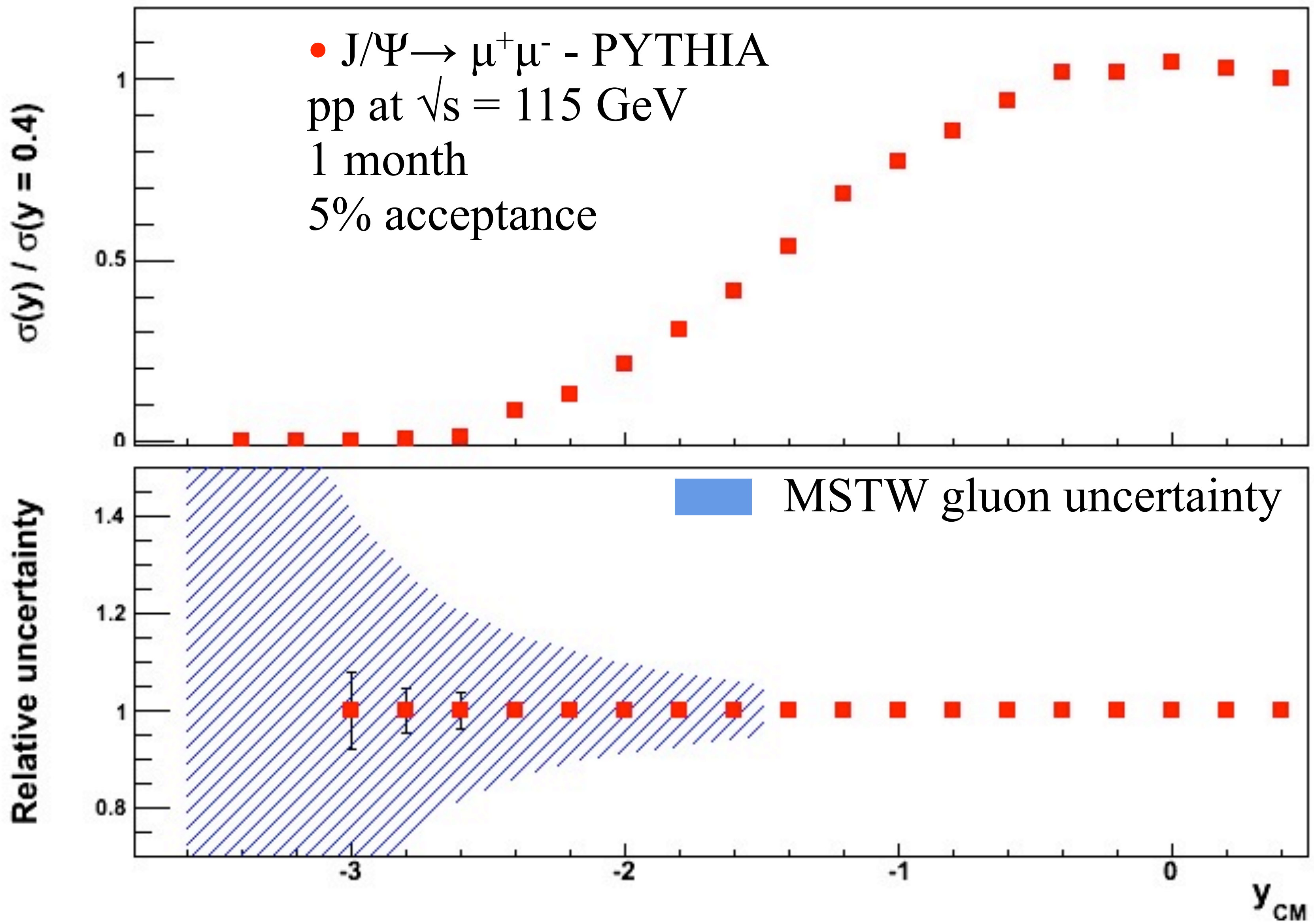
**$y_{CM} \sim 0 \rightarrow x_g = 0.03$**

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

**Υ: larger $x_g$ for same $y_{CM}$**

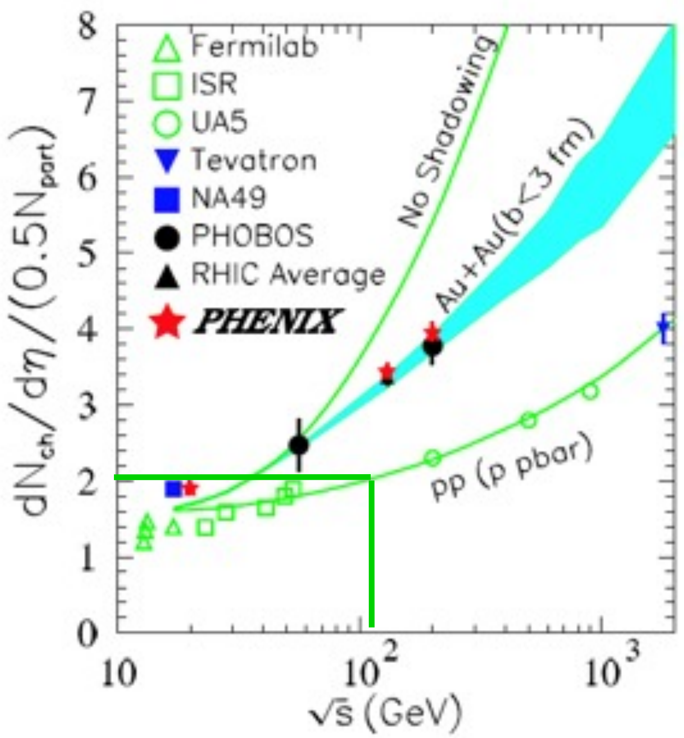
**$y_{CM} \sim 0 \rightarrow x_g = 0.08$**

**$y_{CM} \sim -2.4 \rightarrow x_g = 1$**

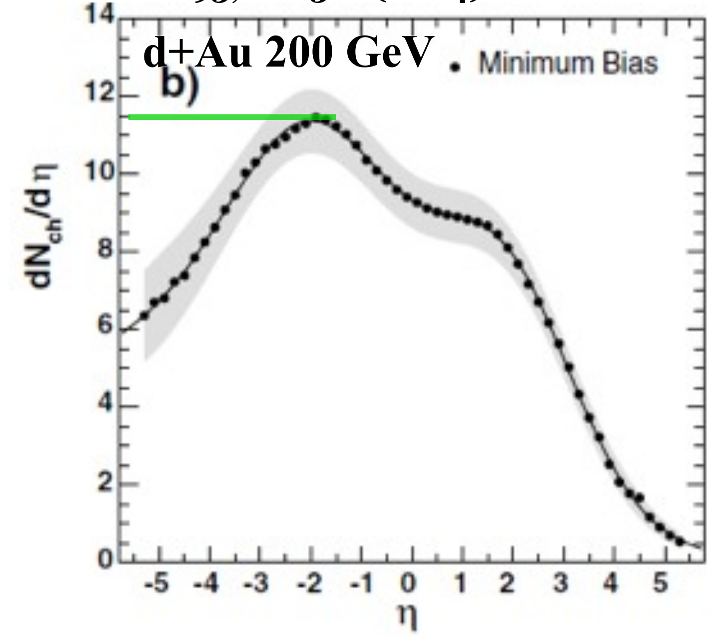



⇒ Backward measurements allow to access large $x$ gluon pdf

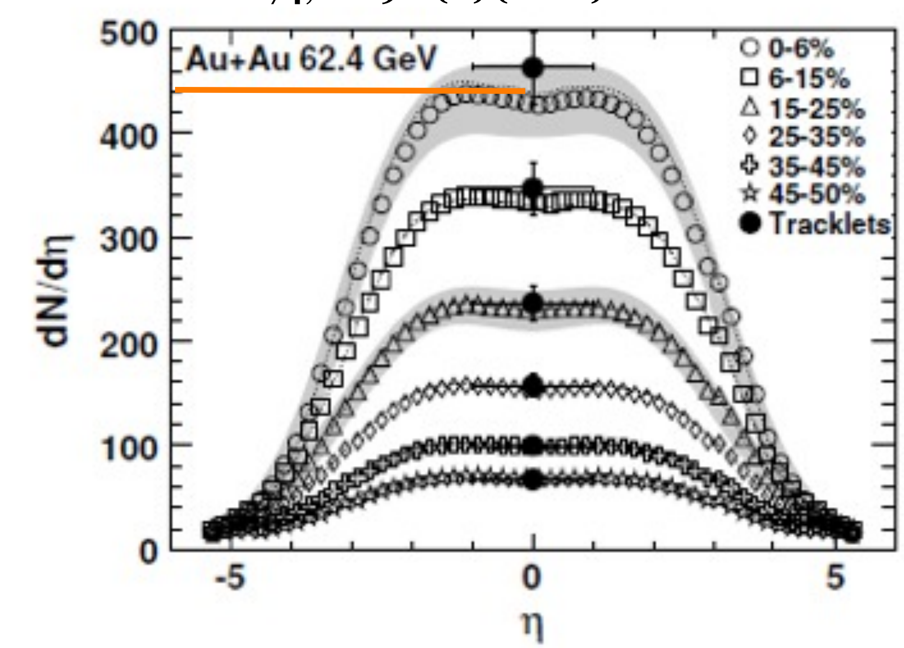
# Multiplicity




PRL **93, 082301 (2004)**



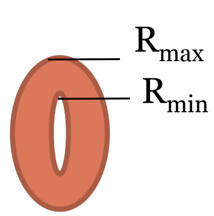

PRC **74, 021901(R) (2006)**




**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 ($cm^2$) |
|---|---|---|---|
| Vertex | 1.5 | 10 | ~ 300 |
| Calo | 10 | 40 | ~4700 |

**Vertex** ~ 450 part.

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

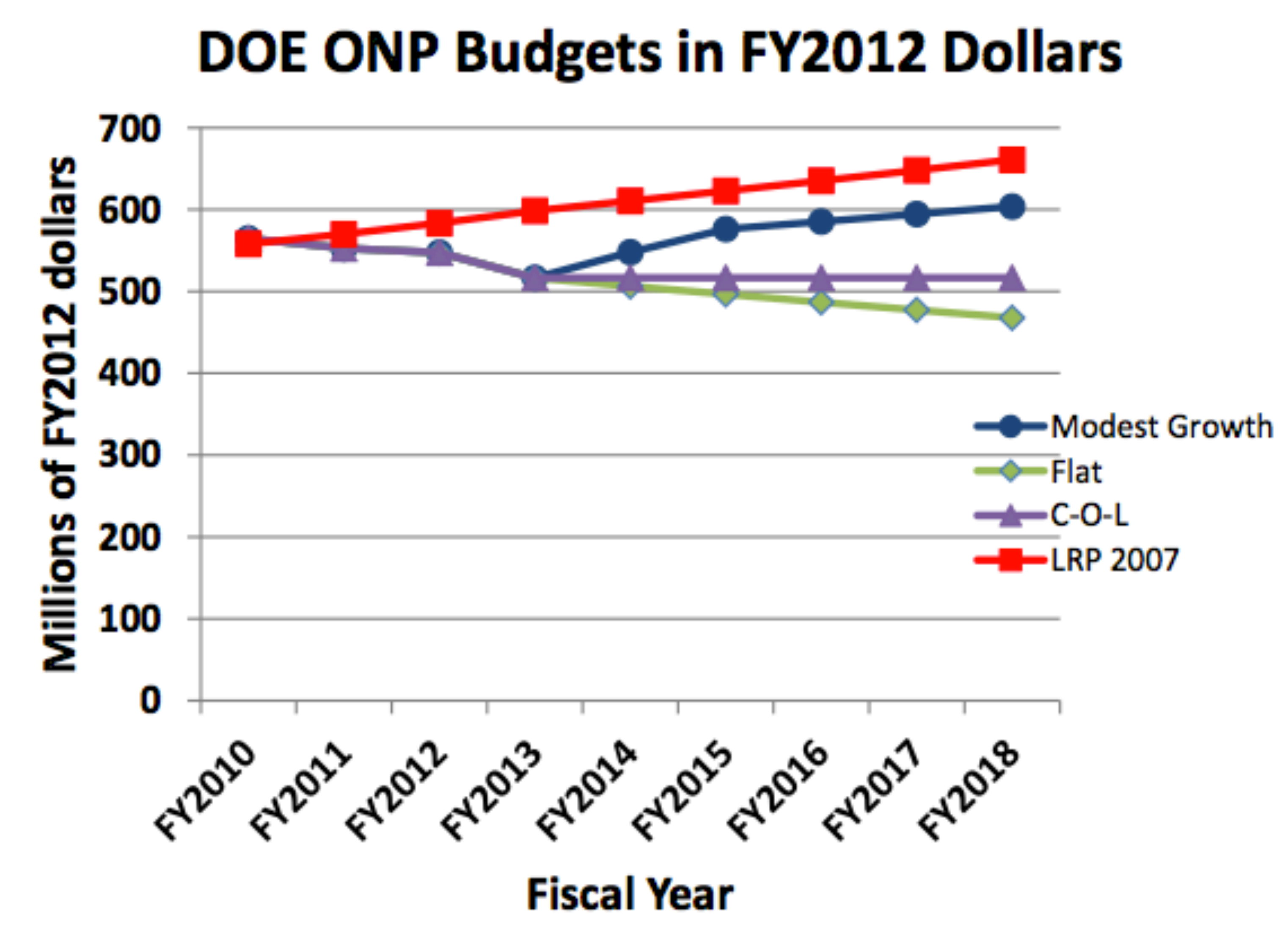
$$0.1\% \sim \frac{450}{300\times\left(\frac{1}{0.25\times0.25\ \text{mm}^2}\right)}$$

**Calo** ~ 700 part.

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

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

# NSAC report




http://science.energy.gov/np/nsac/reports/

budget scenarios discussed above would impact the field. Of the options considered, **the subcommittee was unanimous in endorsing the modest growth budget scenario as the minimum level of support that is needed to maintain a viable long-term U.S. nuclear science program that encompasses the vision of the LRP.** This endorsement, which was made fully recognizing the sacrifices that it would entail, preserves the tools needed for both the present and future program. It preserves a path to realize the long-term vision outlined in the 2007 Long Range Plan, in which there are two large nuclear science facilities in the U.S.: FRIB, devoted to the study of complex nuclei and their applications, and an Electron-Ion Collider (EIC) focused on questions at the frontier of QCD and the nature of the interactions of quarks and gluons.