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AFTER @ LHC

A Fixed Target ExpeRiment using LHC beams

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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
- LHC 2.76 TeV lead beam
  - $\sqrt{s}$ ~ 72 GeV : Pb–p, Pb–A
- benefit from typical advantages of a fixed target experiment
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PDF and nPDF at large x_B

heavy quarkonium prod. and Cold Nuclear Matter effects

W, Z prod. near threshold

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UPC

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

diffractive physics

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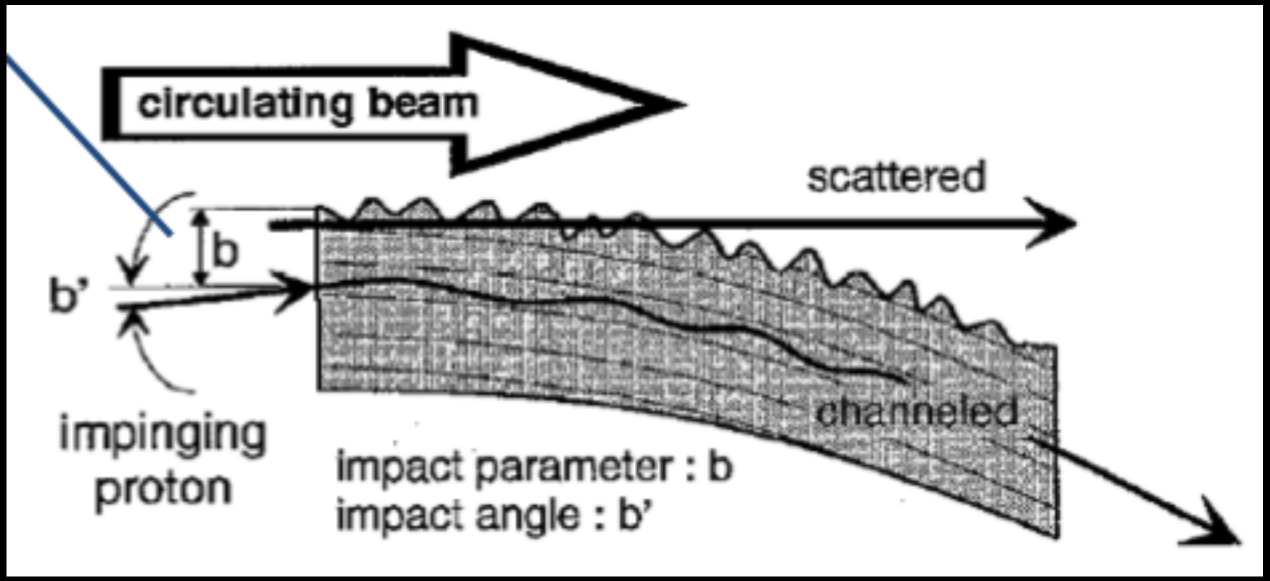
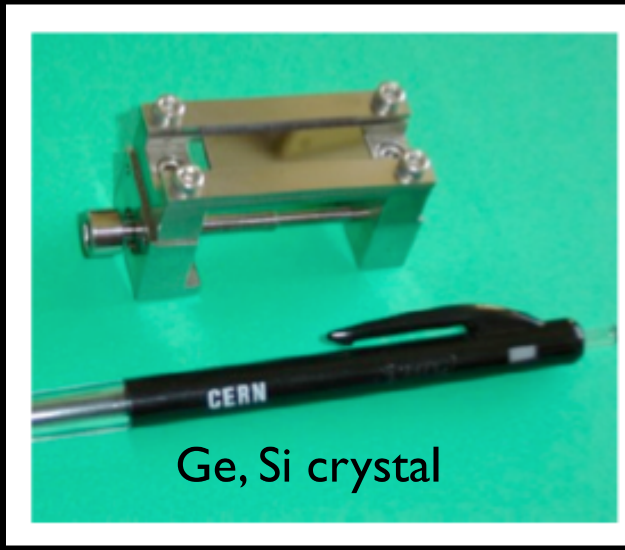
LHC beam extraction

Use strong crystalline field in bent crystals :





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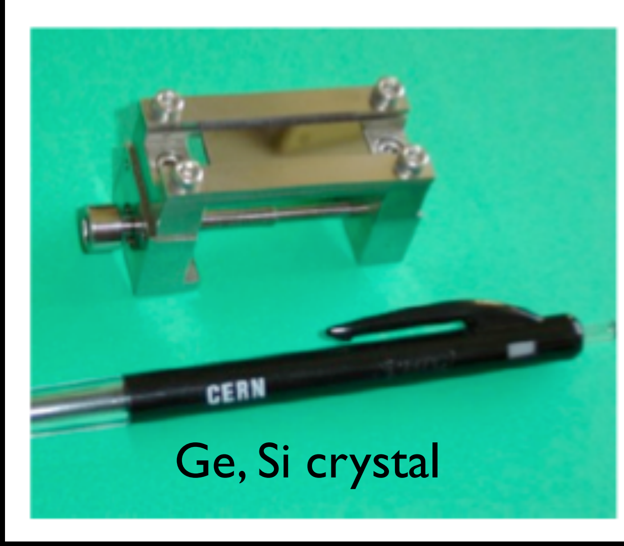

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  - successful for proton beam : RD22 @ SPS (1990), ..., Tevatron (2005), UA9 @ SPS (2008) *[W. Scandale et al., JINST 6 (2011) T10002]*
  - test @ LHC approved by LHCC ☛ LUA9 (2013)
  - ion beam : test at SPS *[W. Scandale et al., PLB 703 (2011) 547]*

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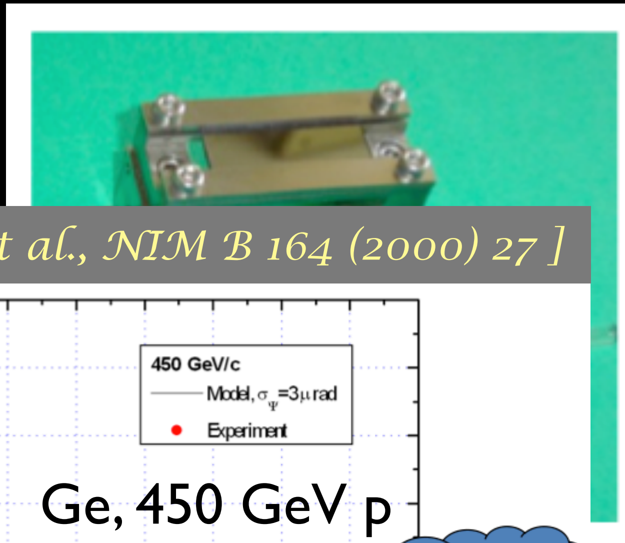
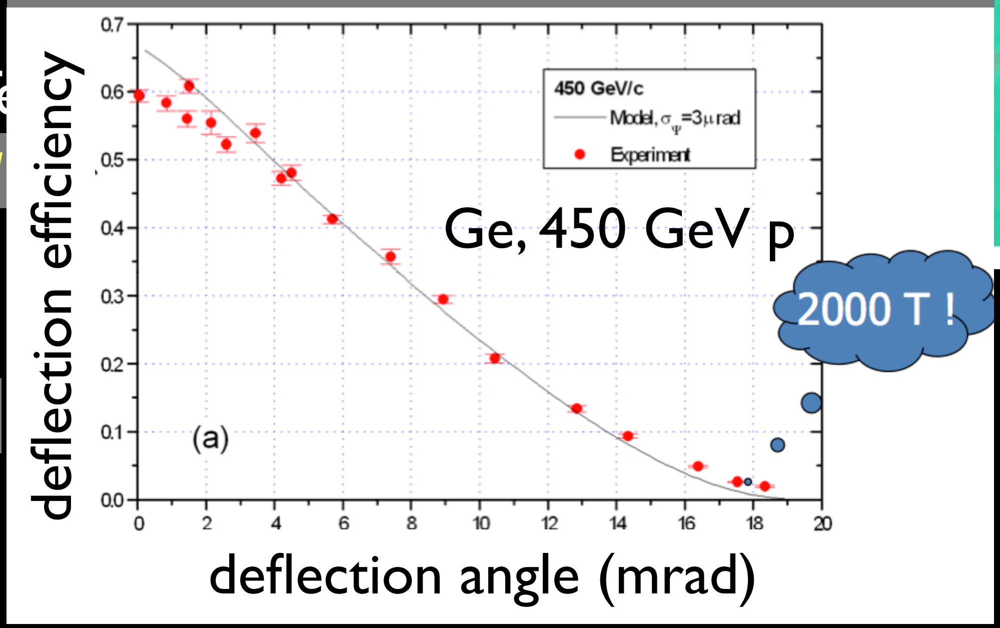


[A. Baurichter et al., NIM B 164 (2000) 27]



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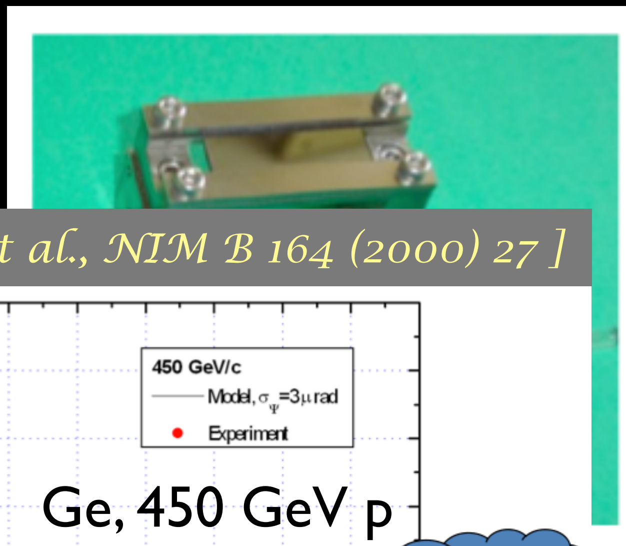
  - extremely small emittance : beam size 950m after the extraction (in the extraction direction) ~ 0.3mm



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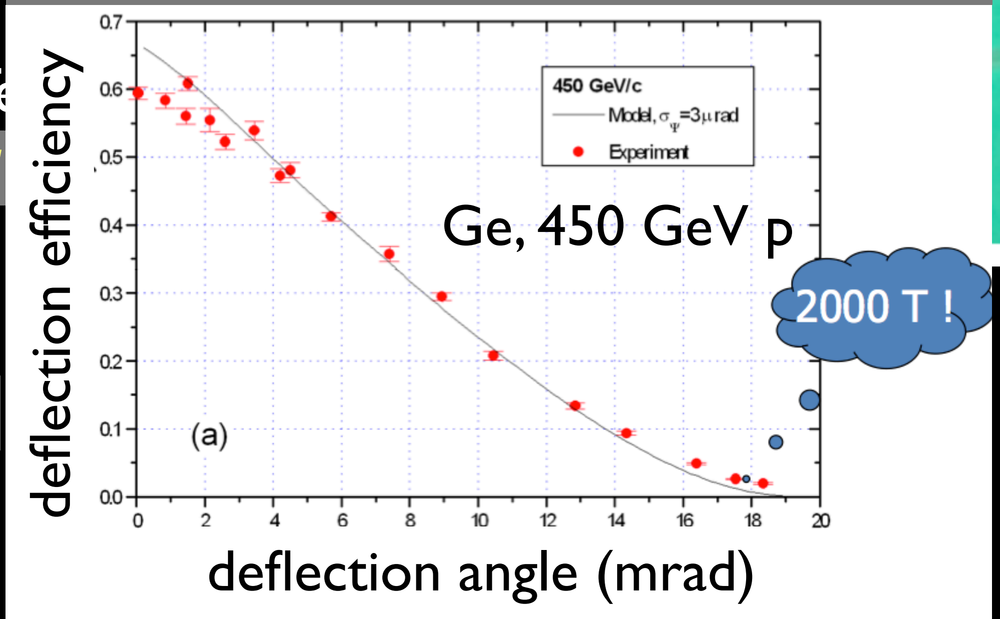

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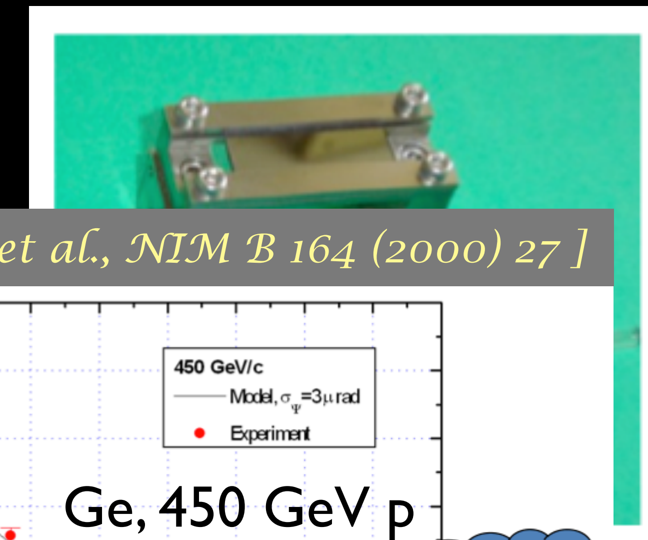

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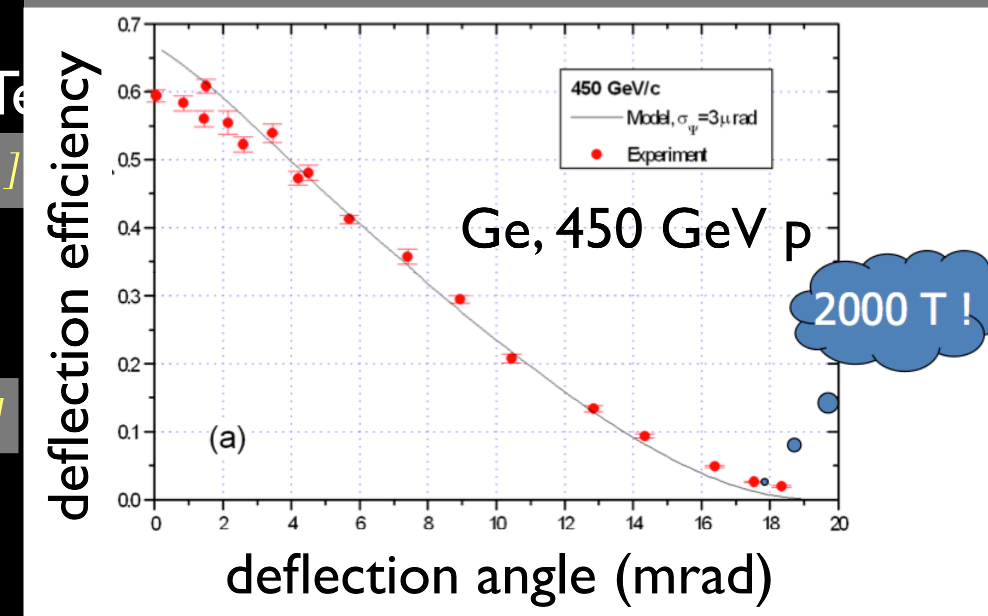

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- Proposal : insertion in the halo (7σ) of the proton LHC beam
  - here with a deflection 0.275 mrad *[E Uggerhoj and U.I. Uggerhoj, NIM B 234 (2005) 31]*
  - extraction eff. (multi pass) ~ 50% LHC beam loss ⇛ 5.10^8 p/s extracted
  - yearly luminosity (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, arXiv:1202.6585]

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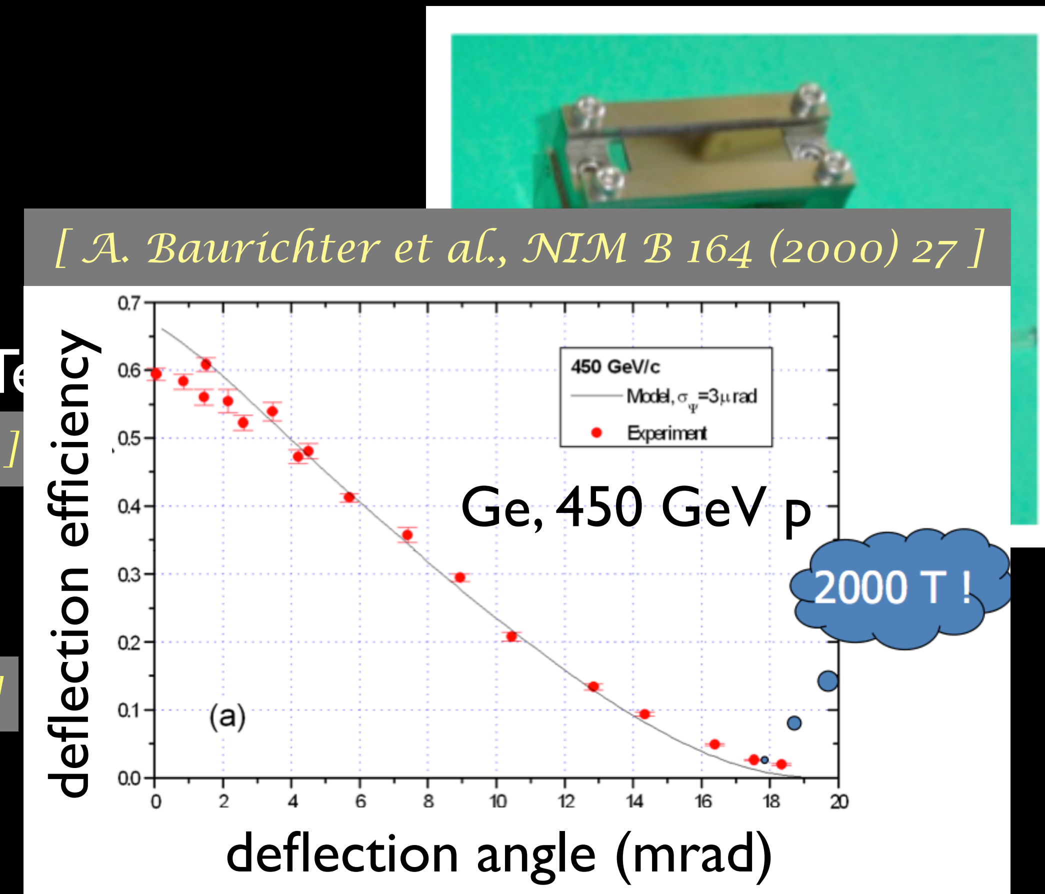

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no performance decrease of the LHC

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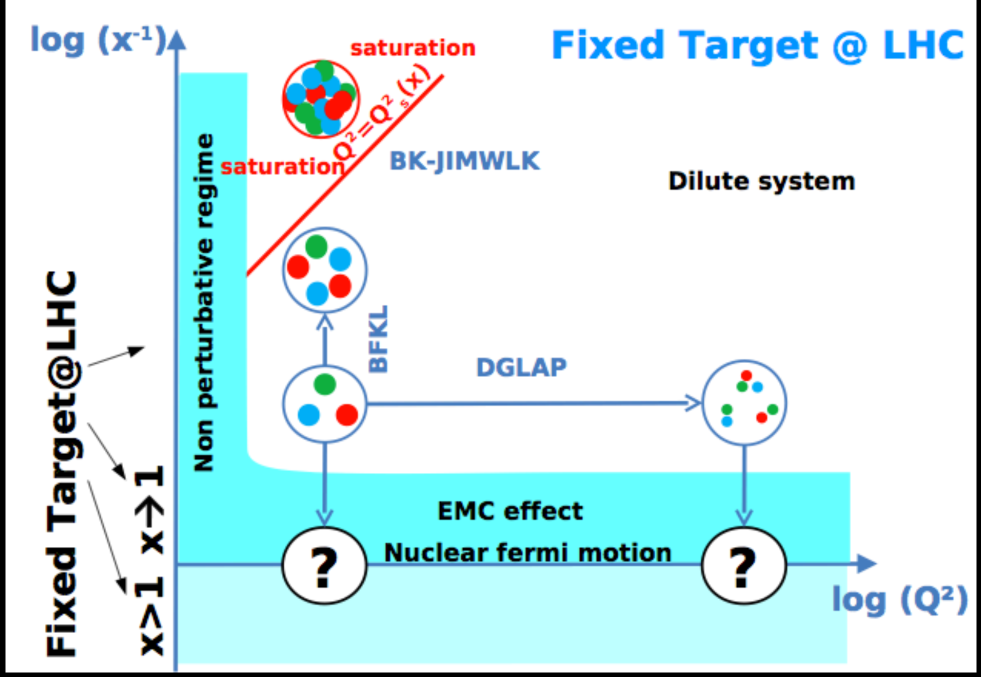
Physics in p–p(d)

Nucleon partonic structure : test the high x_B frontier of QCD

$x_B = 0.3 - 1$



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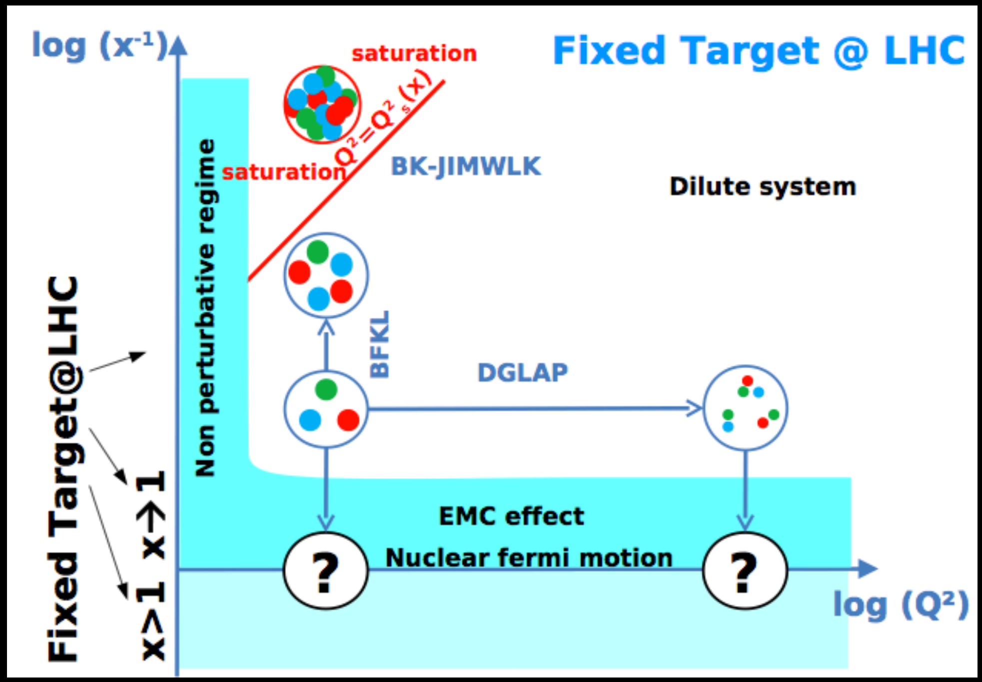

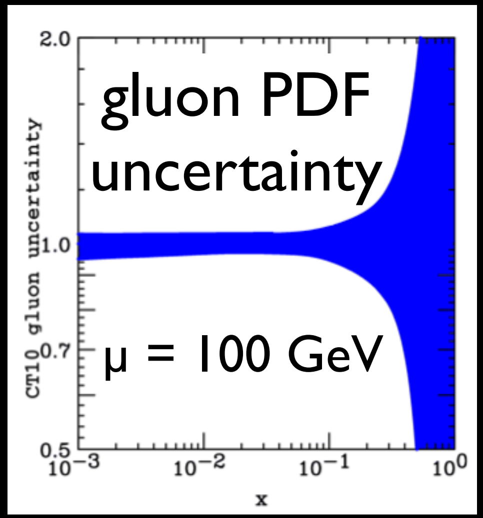

gluon PDF at high x :

with large uncertainties for proton,

unknown for neutron

exp. probes :

- heavy quarkonia
- isolated photons
- high p_T jets (p_T >20 GeV)

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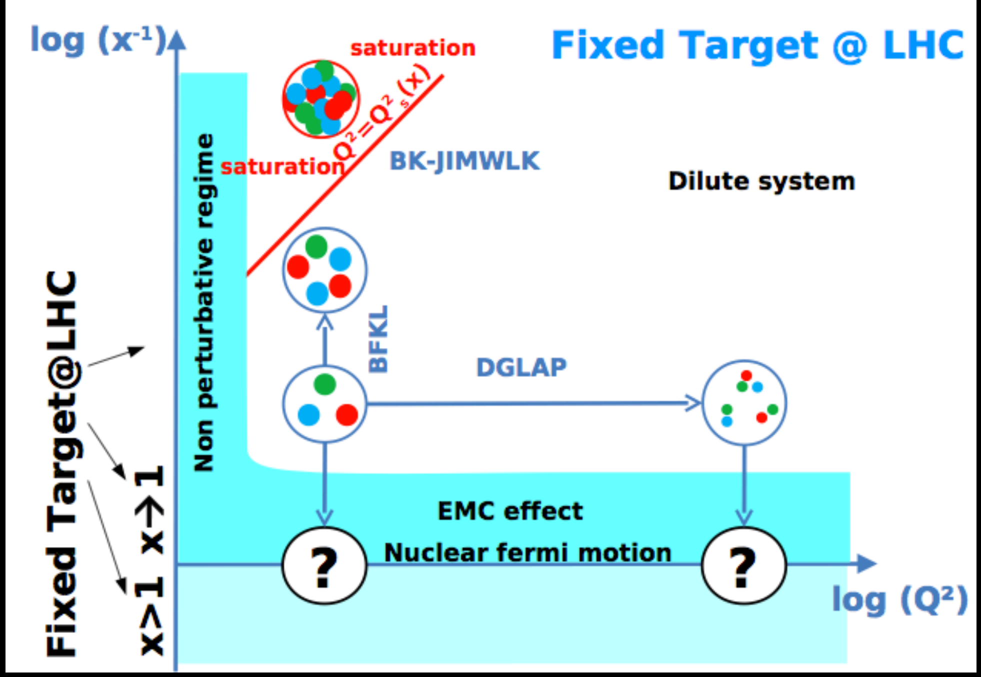

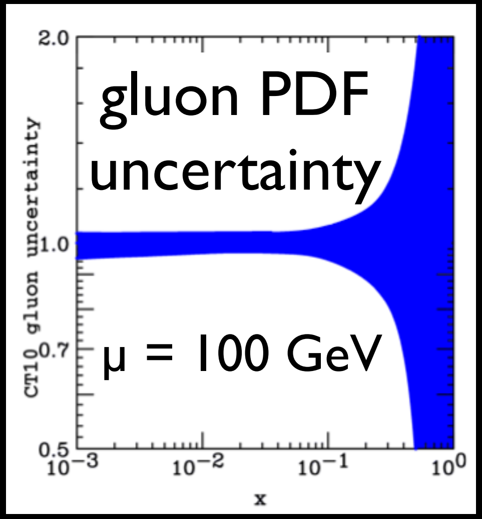

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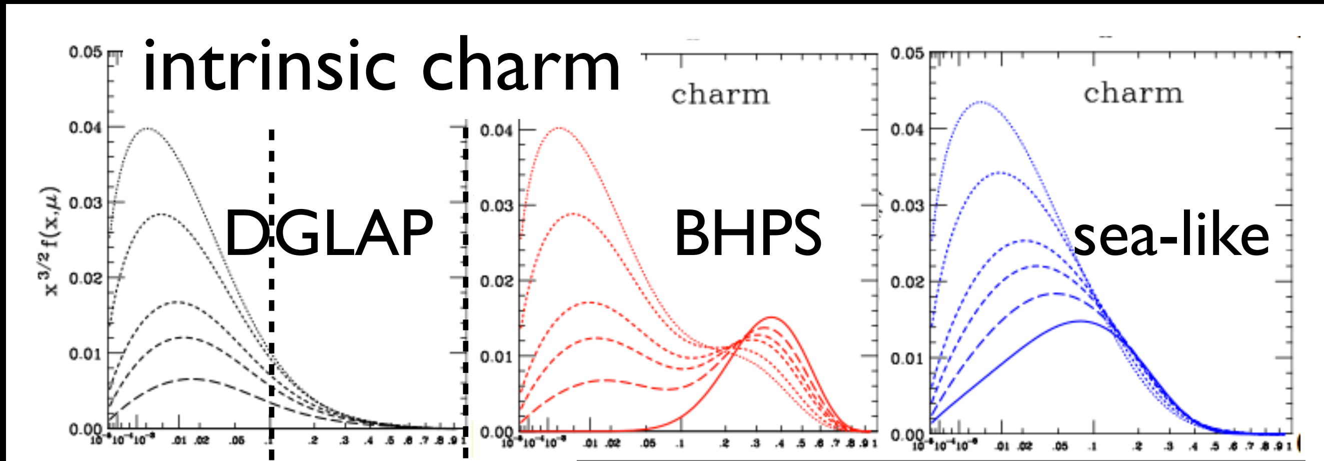

[Pumplin et al., PRD 75 (2007)]

charm PDF at high x :
discriminate all charm PDFs currently in agreement with DIS data

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- open beauty

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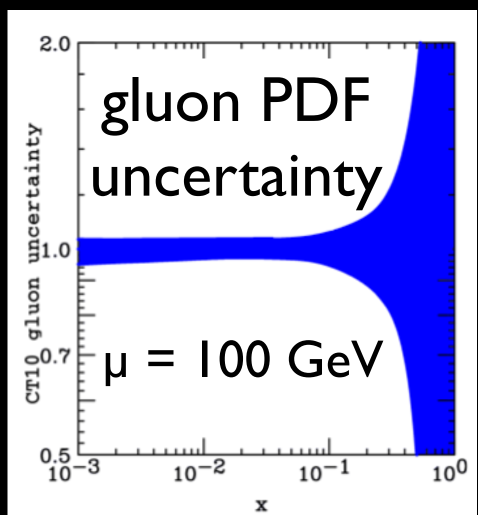

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asymetries,
Transverse Momentum
Dependent PDFs,
quark and gluon Sivers effect ...

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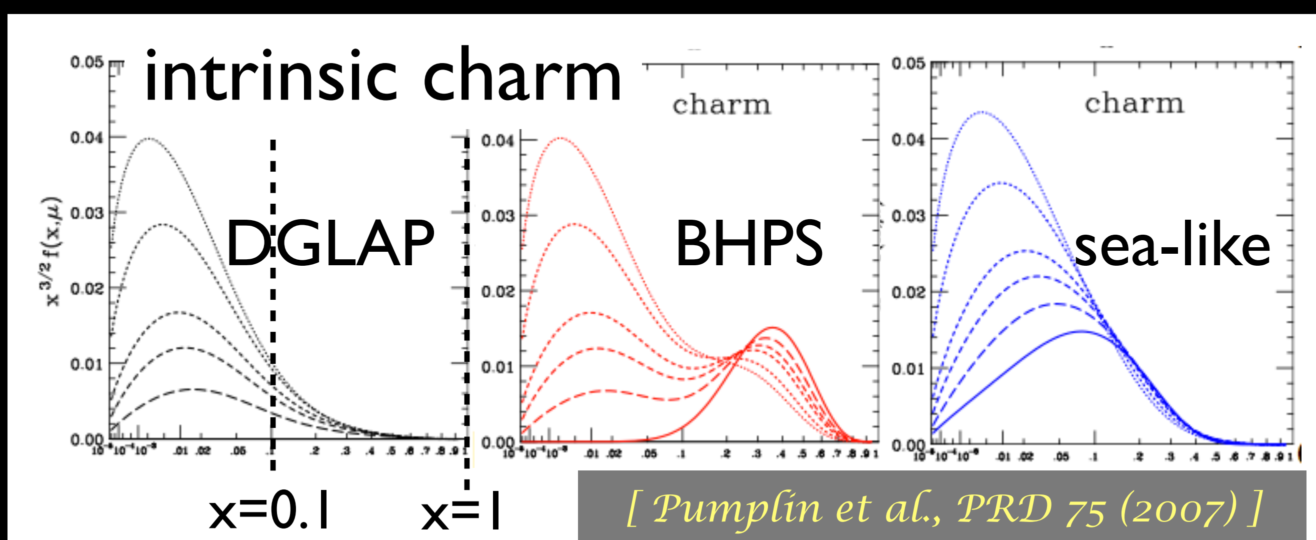
- Drell Yan as a probe of quark PDF



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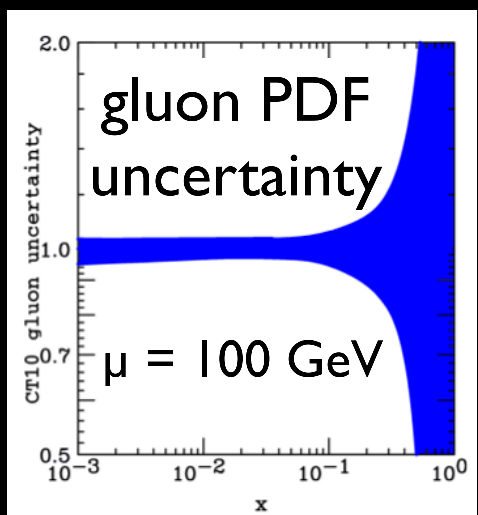

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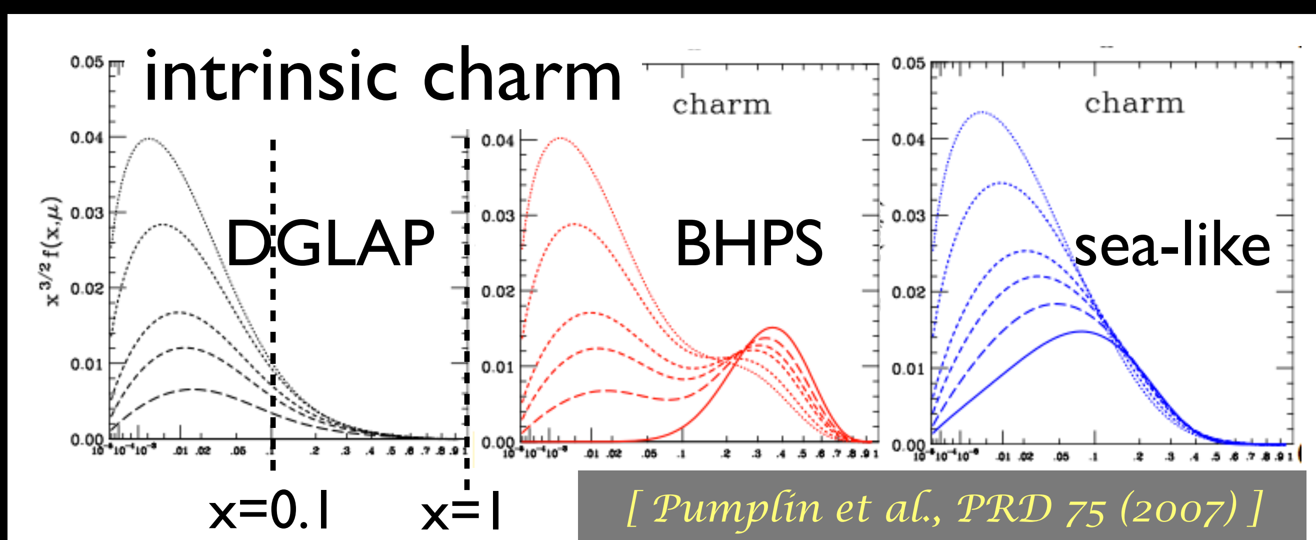

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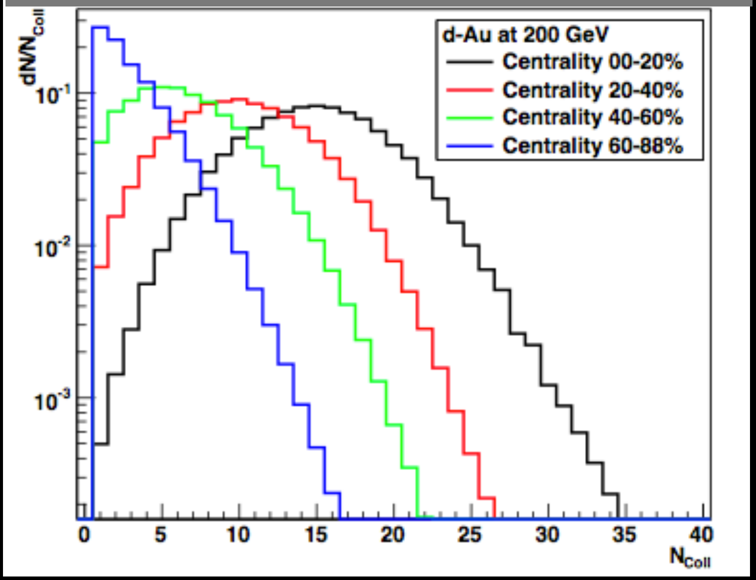
need high luminosity to reach large x_B
+ detailed studies on heavy QQbar prod. before
using them for gluon PDF extraction

Physics in p–A and Pb–p

Precision studies of the nuclear matter :

- **A dependence** (better than $\langle N_{coll} \rangle$) thanks to target versatility

[PHENIX, arXiv:1204.0777]



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

Physics in p–A and Pb–p

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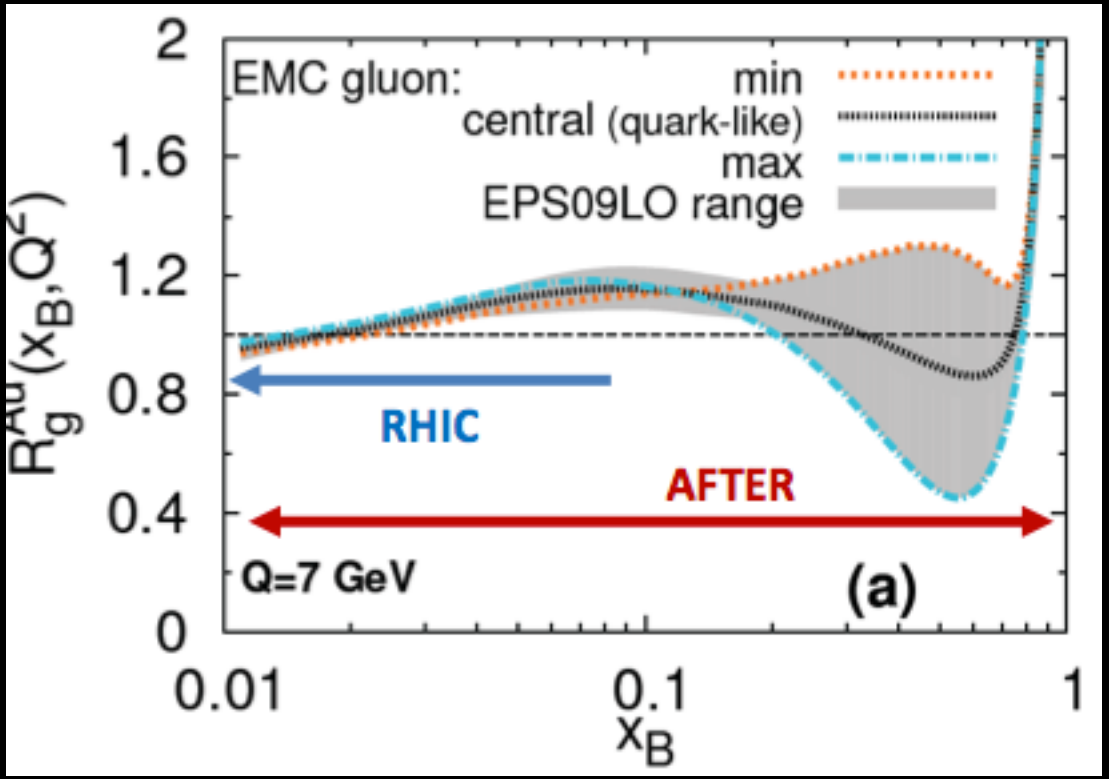

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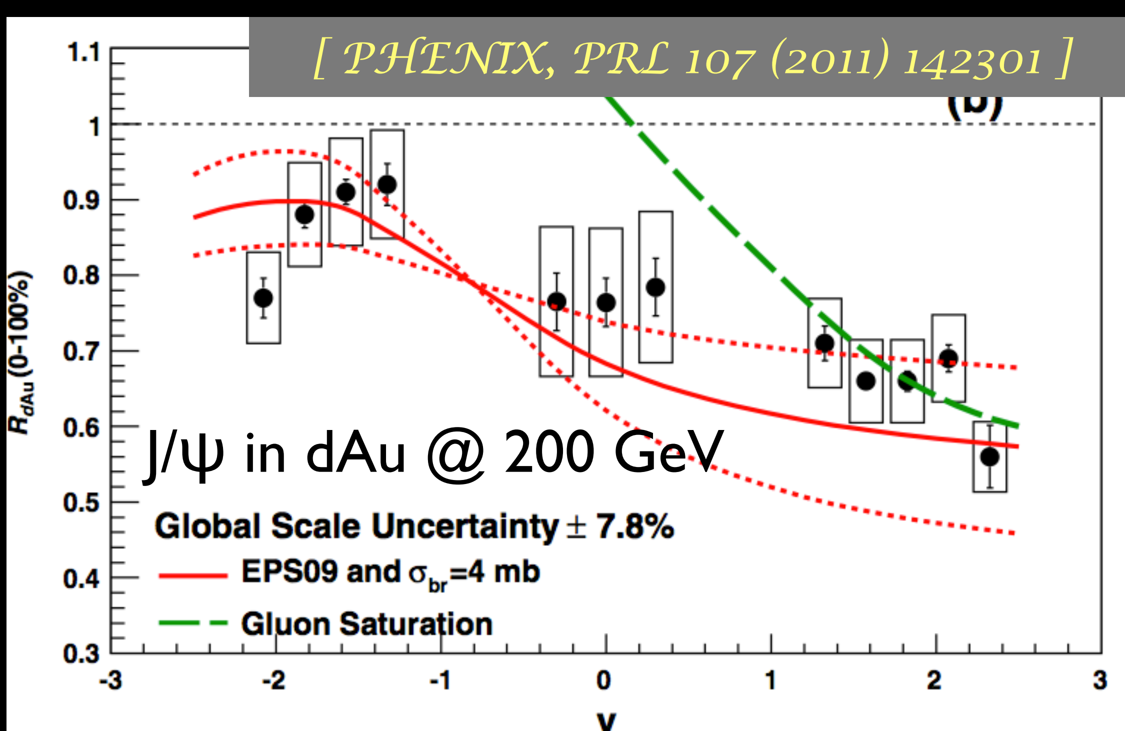
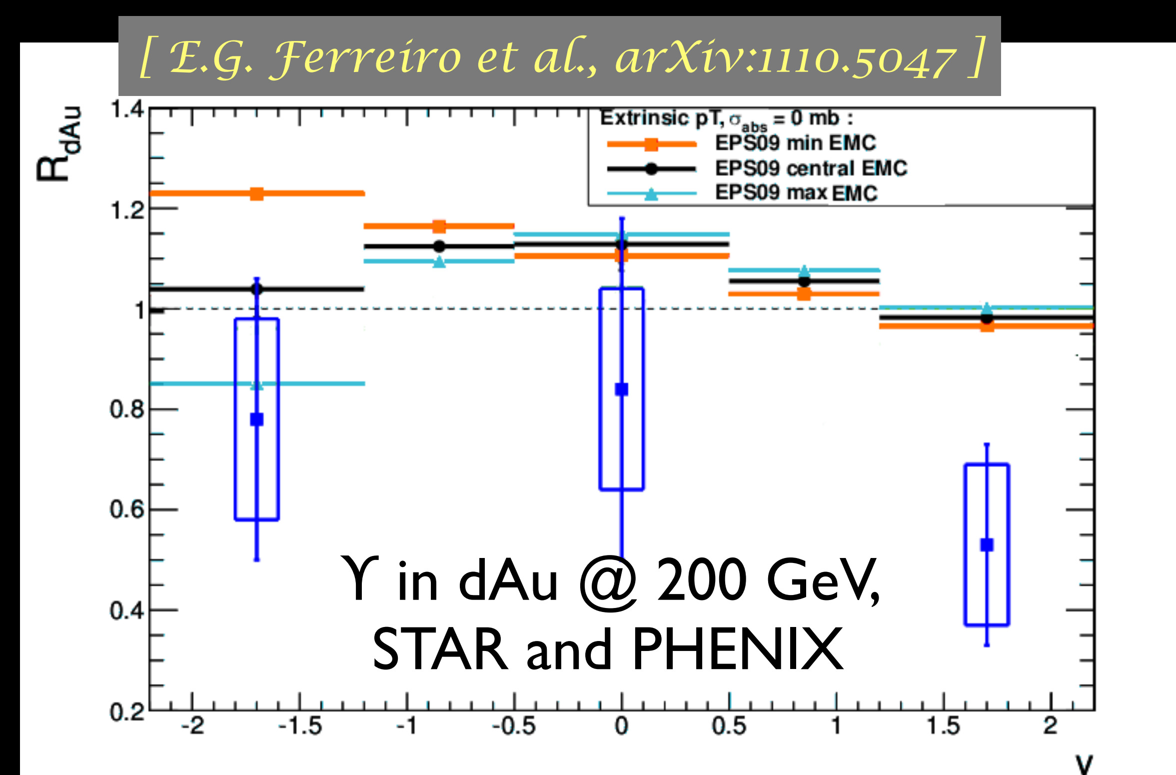


[PHENIX, PRL 107 (2011) 142301]



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

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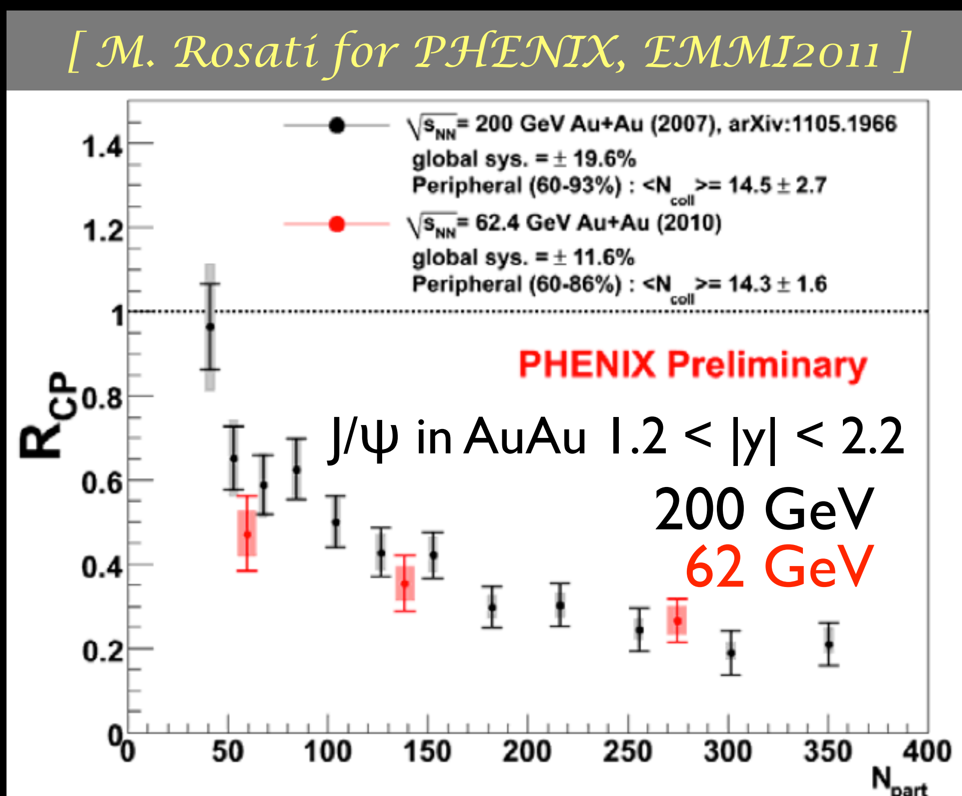
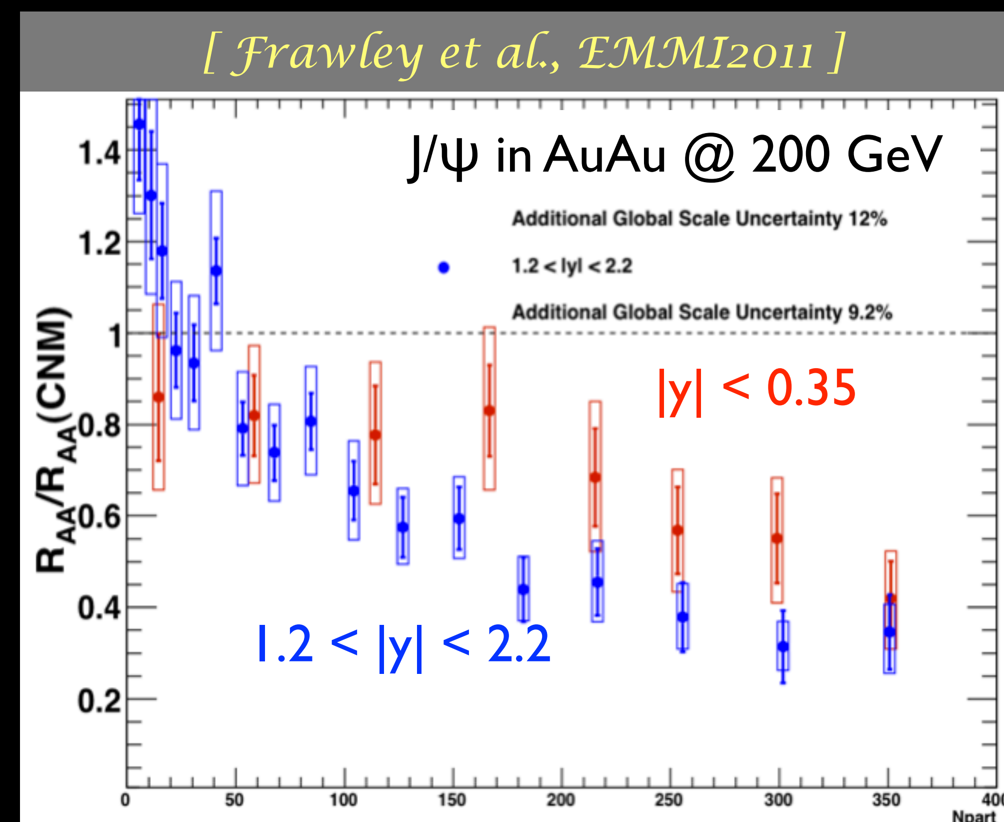
- test QCD factorization in charmonium production at high x_F
- these studies are needed to clear the current picture of charmonium as a hard probe of QGP from SPS to LHC energies, RHIC-like energies being a key step

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





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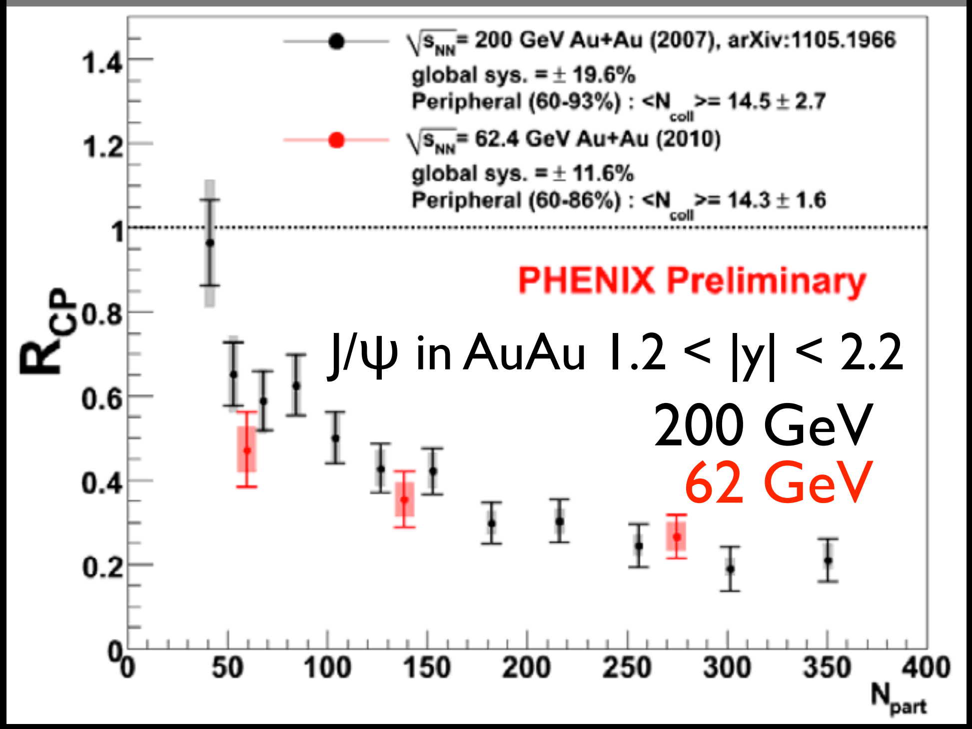
[M. Rosati for PHENIX, EMMI2011]



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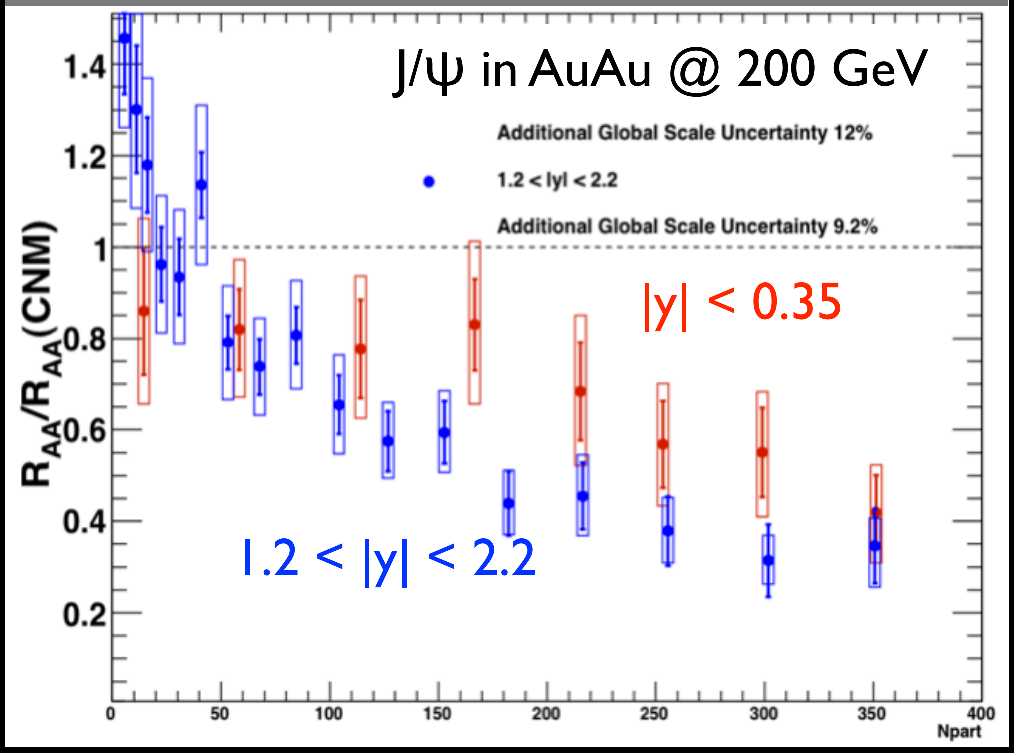

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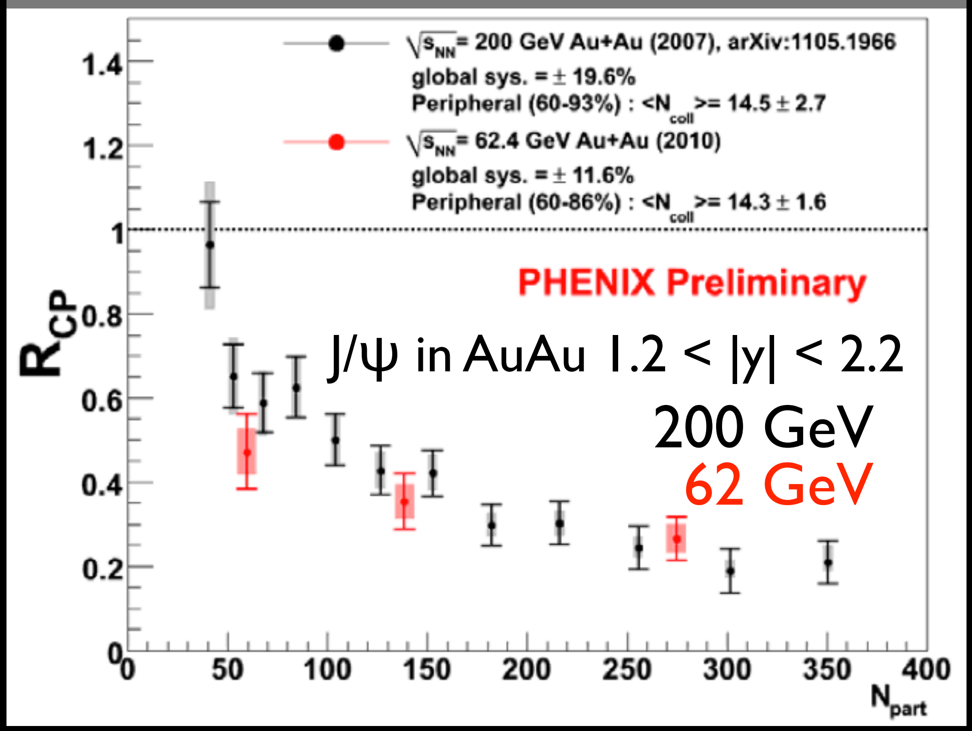

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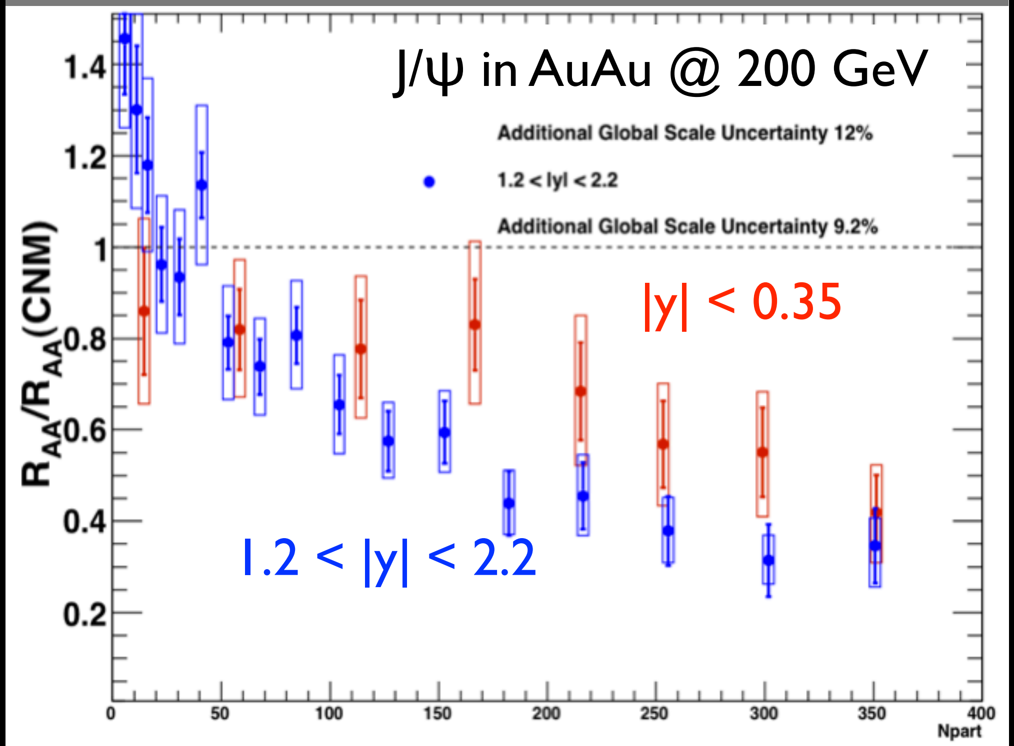

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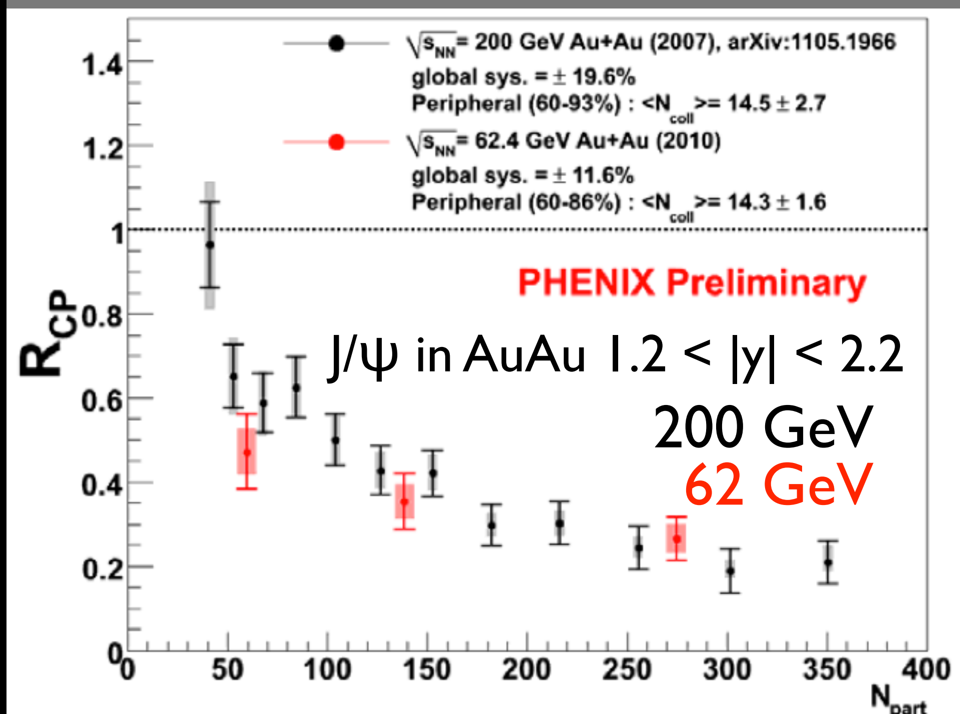

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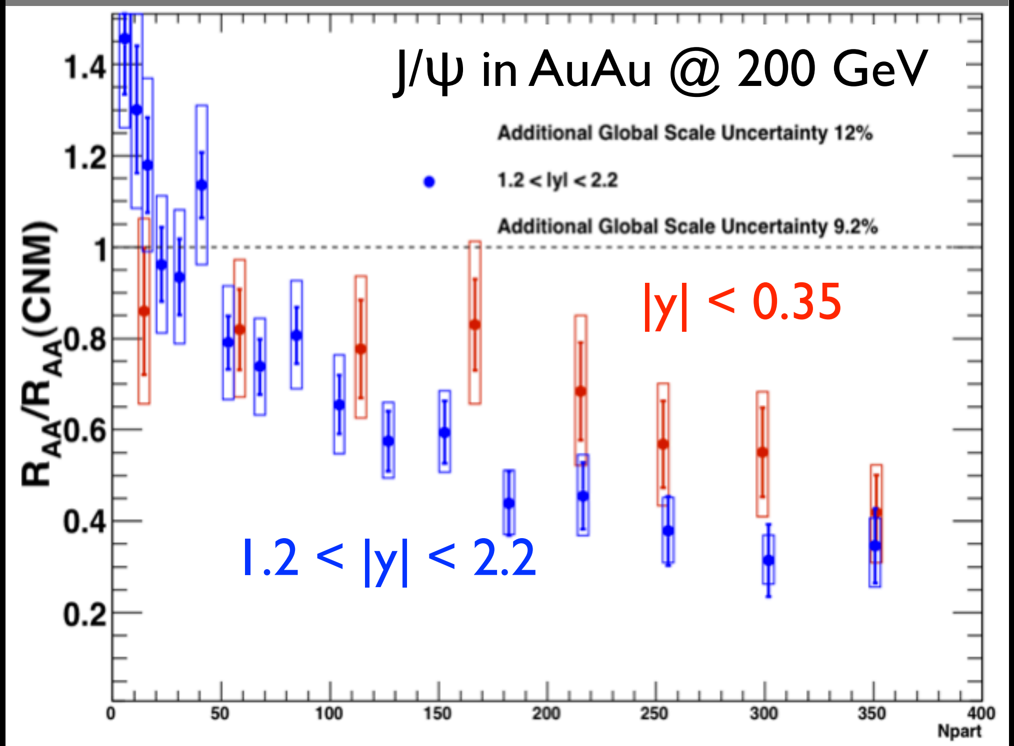


  - measure excited states, especially χ_c and χ_b with improved EMCal

- also jet quenching, direct photon ...

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, arXiv:1202.6585]

J/ψ ↓ Υ ↓

	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	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
	pPb 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
	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

pp : 100 x RHIC, comparable to LHCb

pA : 100 x RHIC

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 PbA

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

[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, arXiv:1202.6585]

	Target	$\int dt \mathcal{L}$	$\mathcal{B}_{\ell\ell} \frac{dN_{J/\psi}}{dy}\Big\|_{y=0}$ (J/ψ)	$\mathcal{B}_{\ell\ell} \frac{dN_{\Upsilon}}{dy}\Big\|_{y=0}$ (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

PbA :

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

10^2 x RHIC @ 62 GeV

AFTER : a multipurpose detector at backward-y

- Very high boost

  with 7 TeV beam, $\gamma = 61.1$ and $y_{CMS} = 4.8$

- backward region $\eta_{CMS} < 0$

  $\eta_{CMS} \triangleq \eta_{lab} - y_{CMS}$

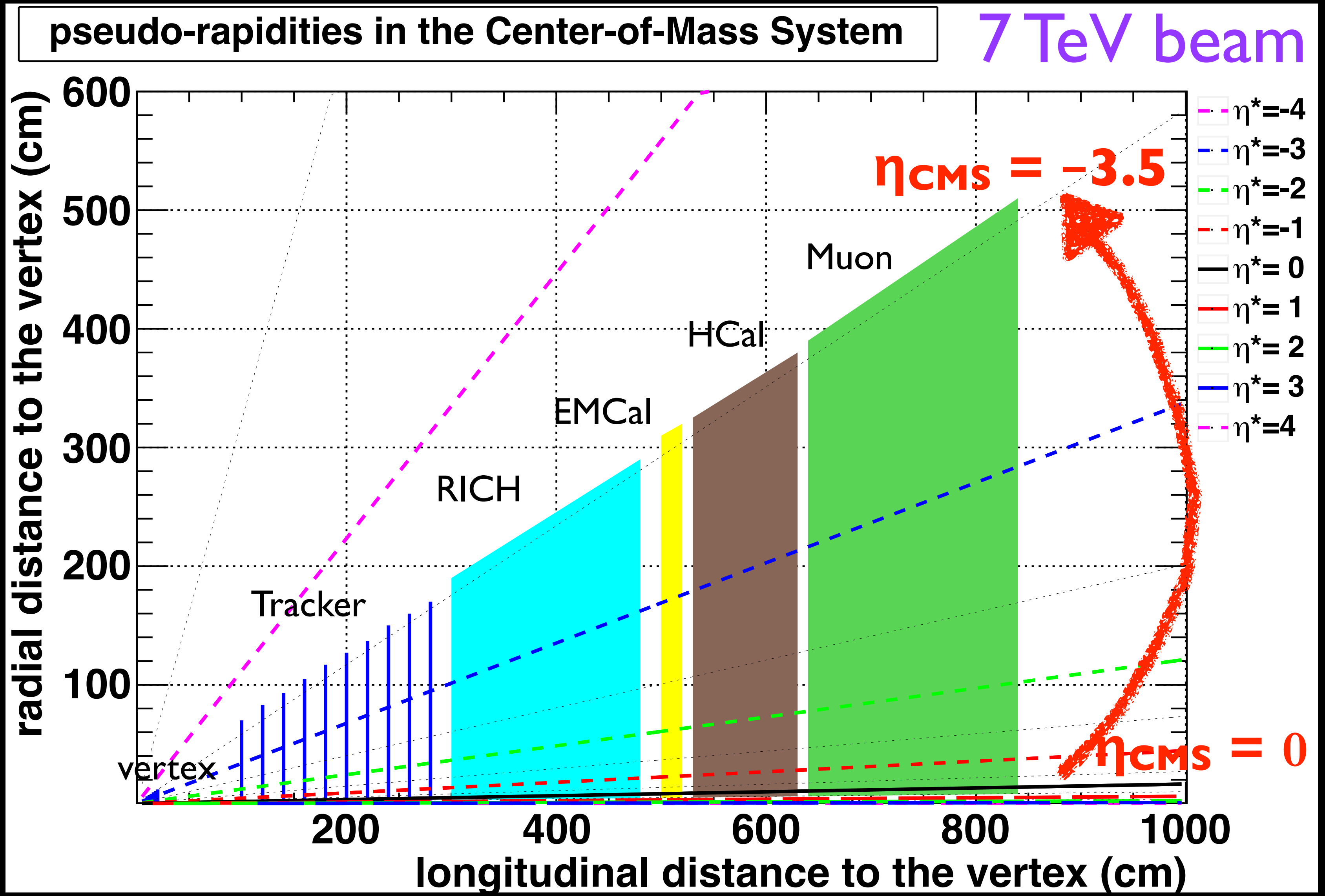
- detector as compact as possible in z direction

- highest $x_2 \sim 1$:

  $y_{lab}(J/\psi)(\Upsilon) \sim 1.2\ (2.4)$

- lowest x_2 for $y_{lab} \sim y_{CMS}$

  $x_2\ (J/\psi)(\Upsilon) \sim 0.03\ (0.08)$



Tentative design : $-3.5 < \eta_{CMS} < 0.5$

AFTER @ LHC

More details

- in arXiv :

[S. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg, arXiv:1202.6585]

- on the website : after.in2p3.fr

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

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submitted to 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 5×10^8 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

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)

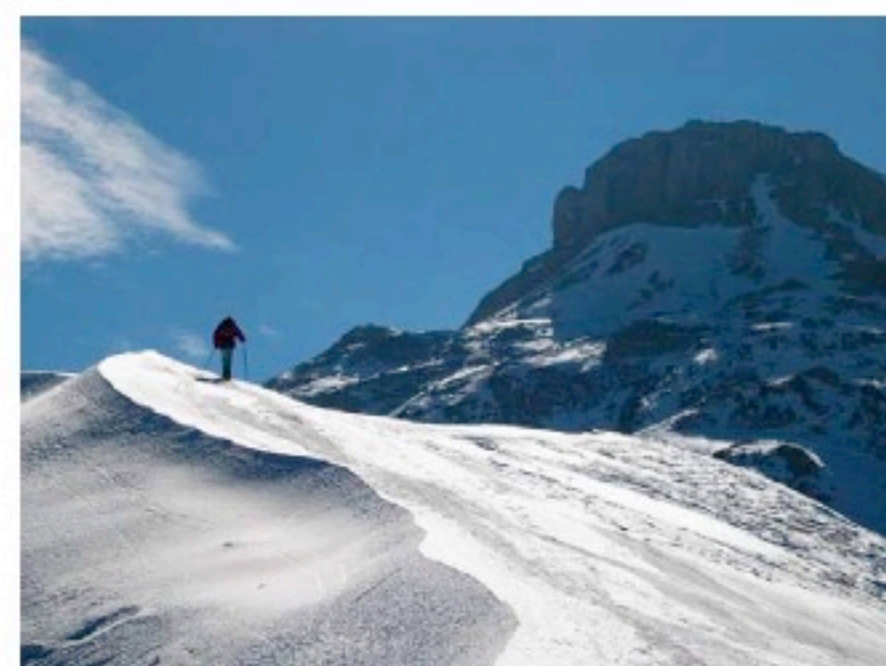
- first paper on physics opportunities arXiv:1202.6585
- webpage after.in2p3.fr
- 3rd meeting last may in Grenoble
- a larger workshop (10 days) at Trento in Feb. 2013
- ultra-granular detector technologies for EMCal could be evolved from CALICE
- supports :
  - 2011-2012 : support from France-Standford Interdisciplinaries studies
  - 2012 : support from CNRS PEPS-PTI
  - 2013-2016 : (expected) support from CNRS PICS with Torino
- Looking for partners !
- Target schedule : installation during LHC Long Shutdown 3

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”

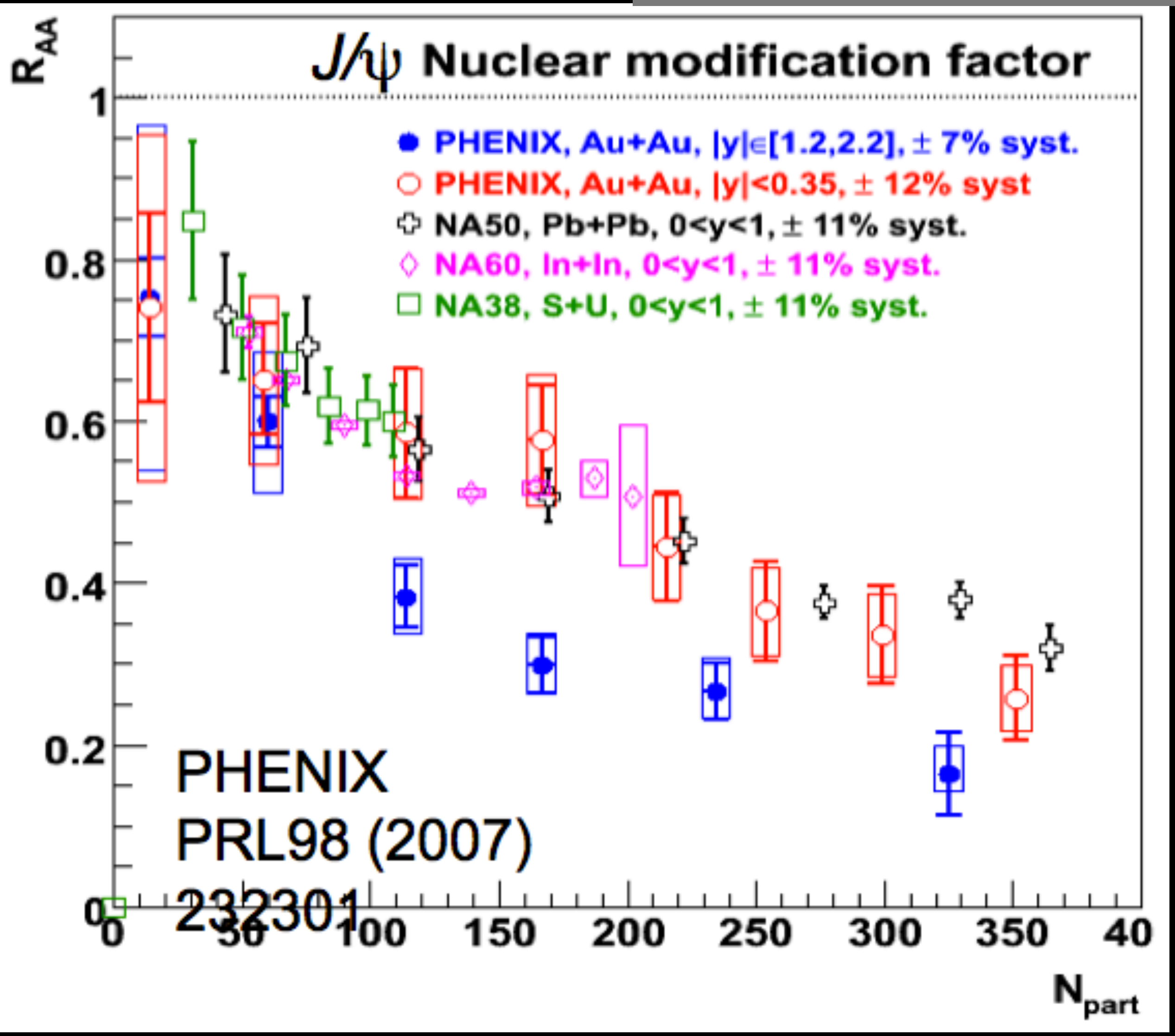
- February 4 - February 13, 2013

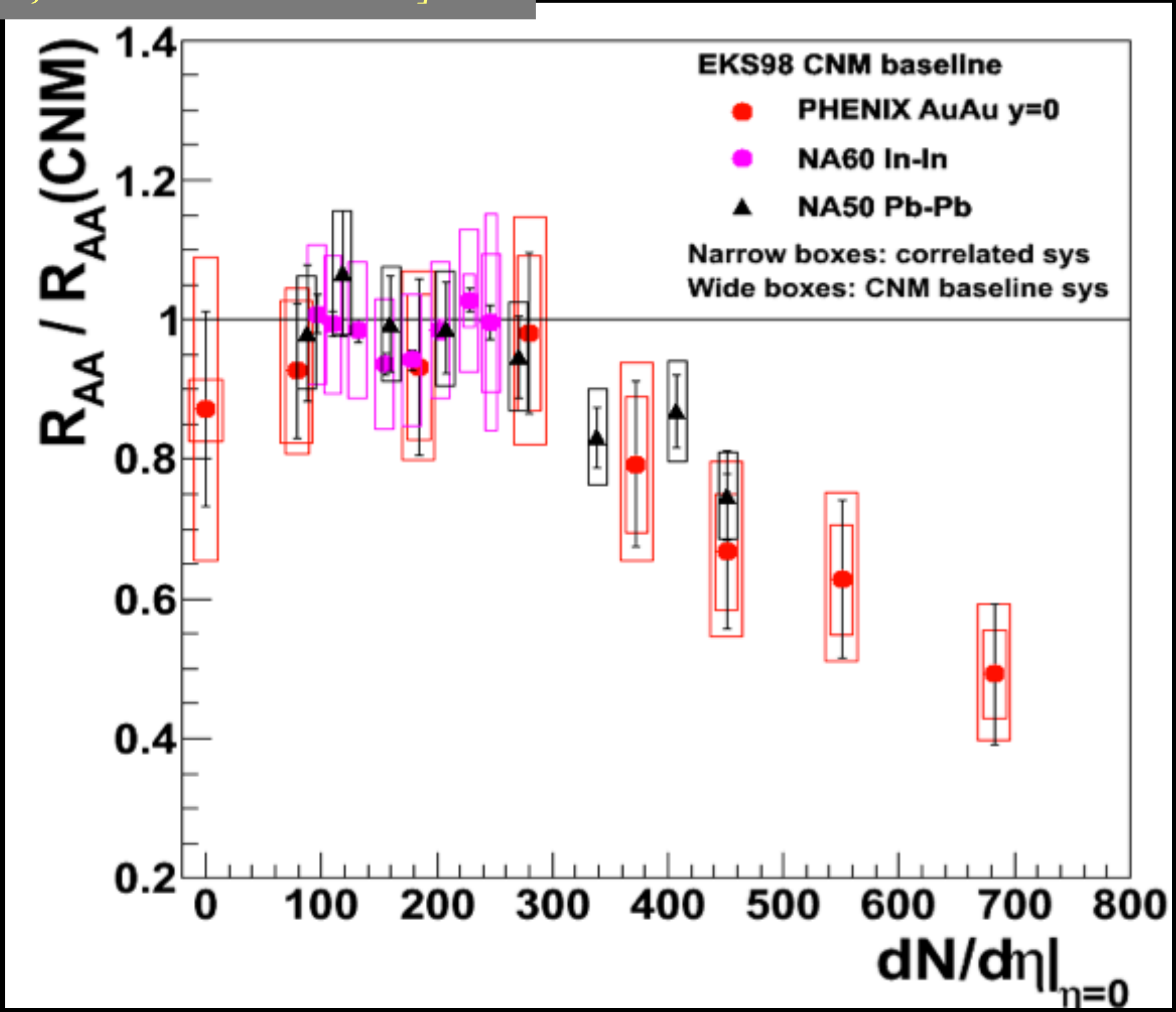
‘This is an exploratory workshop which aims at studying in detail the opportunity and feasibility of fixed-target experiments using the LHC beam.’



SPARE SLIDES

[Frawley for PHENIX, Hard Probes 2012]





A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+ s^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+ s^{-1}$ (1/2 the beam loss) **E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31**
- Number of p^+: 2808 bunches of $1.15 \times 10^{11} p^+ = 3.2 \times 10^{14} p^+$
- Revolution frequency: Each bunch passes the extraction point at a rate of 3.10^5 km.s^{-1}/27 km $\simeq$ 11 kHz
- Extracted "mini" bunches:
  - the crystal sees 2808×11000 s^{-1} $\simeq 3.10^7$ bunches s^{-1}
  - one extracts $5.10^8/3.10^7 \simeq 16p^+$ 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, arXiv:1202.6585]

Target (1 cm thick)	ρ (g cm^{-3})	A	$\mathcal{L}$ (μb^{-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 5×10^8 p$^+$/s with a momentum of 7 TeV for various 1cm thick targets

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

Table 2: Instantaneous and yearly luminosities obtained with an extracted beam of 2×10^5 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 ⇔ 10^7 s

extracted beam N_{beam} = 2 .10^5 Pb/s
1 month running / year ⇔ 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**

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

– $\mathbf{N_{beam}}=5 \times 10^8\ p^+/s$

– **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

Accessing the large x gluon pdf

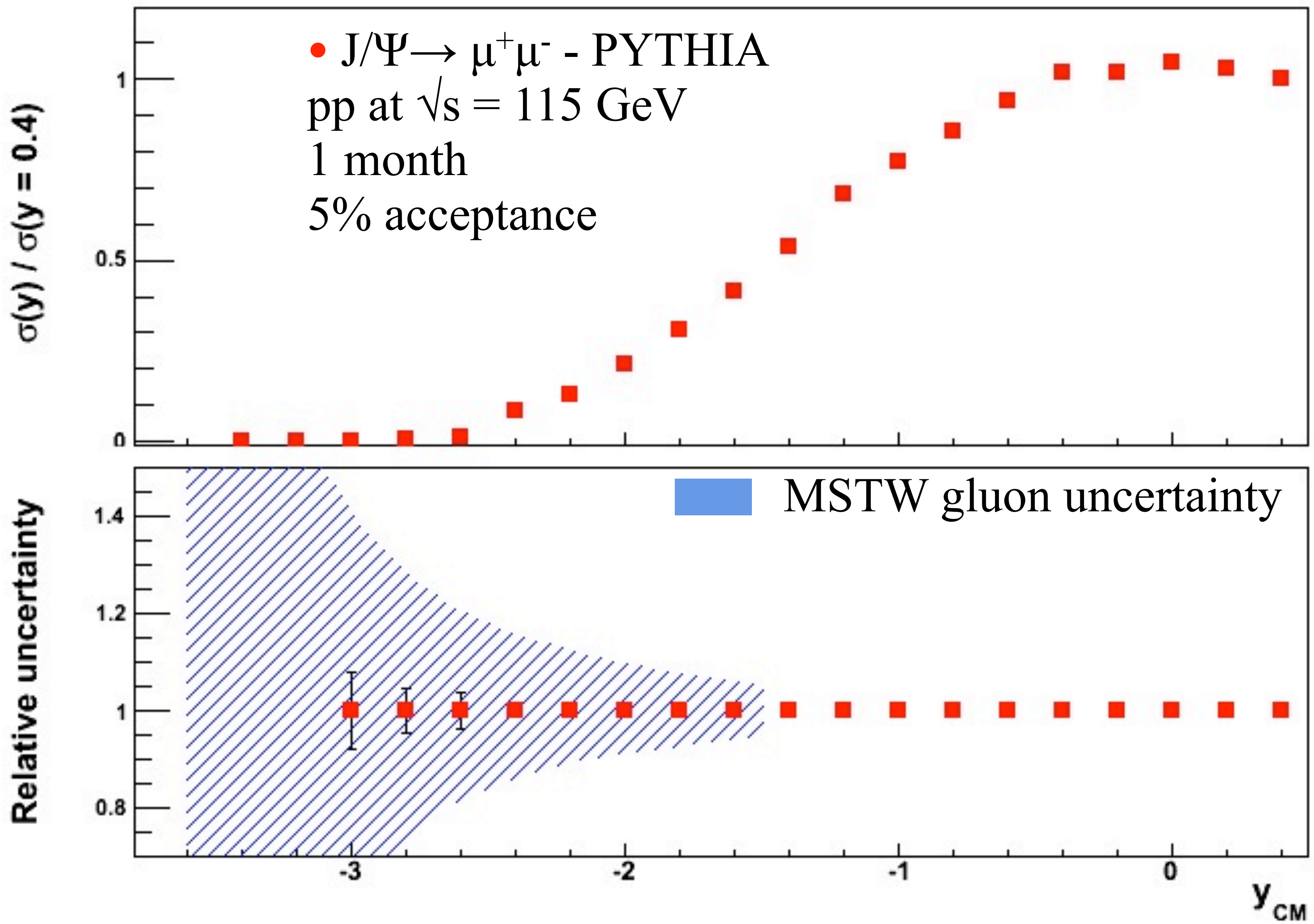
PYTHIA simulation
$\sigma(y) / \sigma(y=0.4)$
statistics for one month
5% acceptance considered

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}
$y_{CM} \sim 0 \rightarrow x_g = 0.08$
$y_{CM} \sim -2.4 \rightarrow x_g = 1$

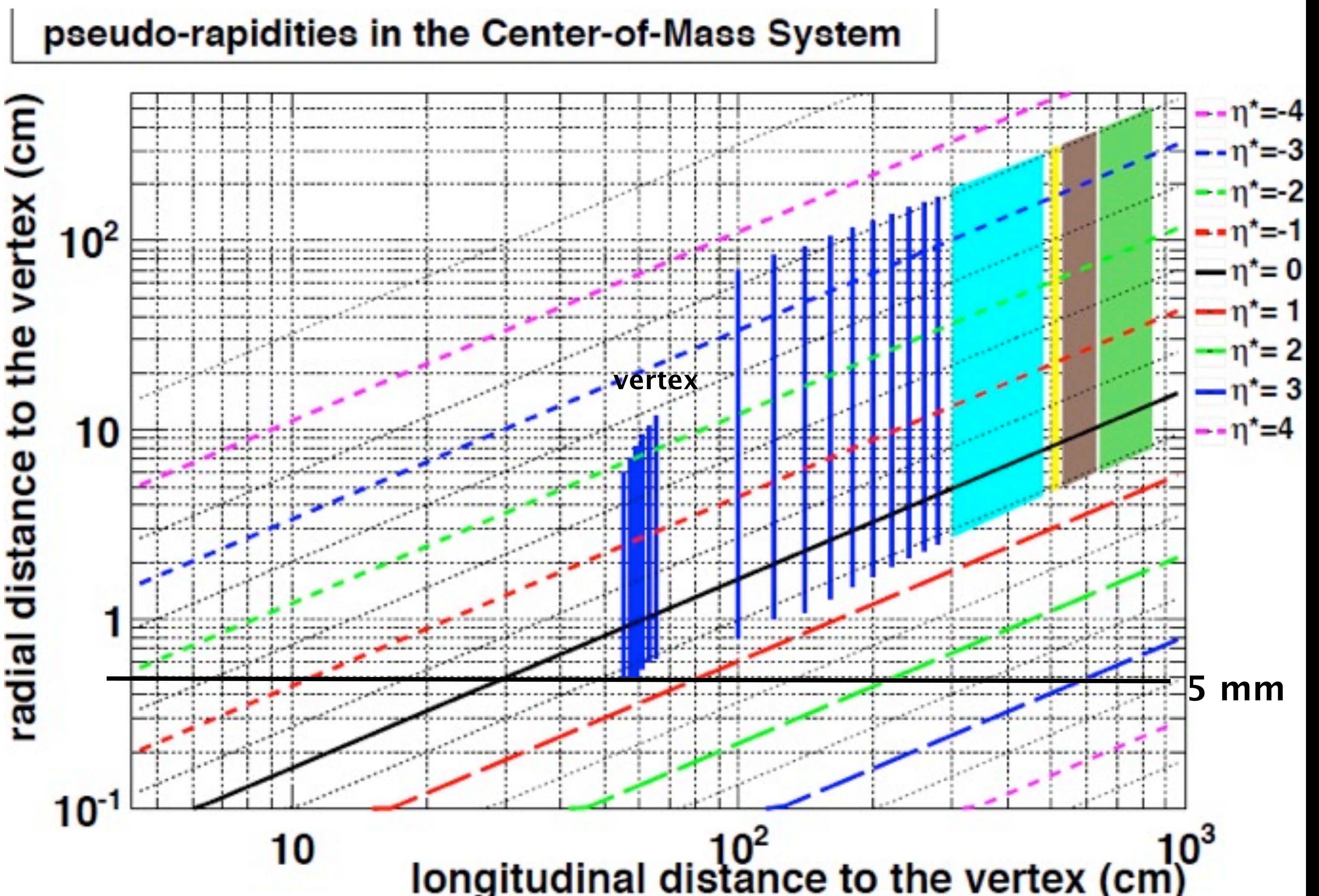


⇒ Backward measurements allow to access large x gluon pdf

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

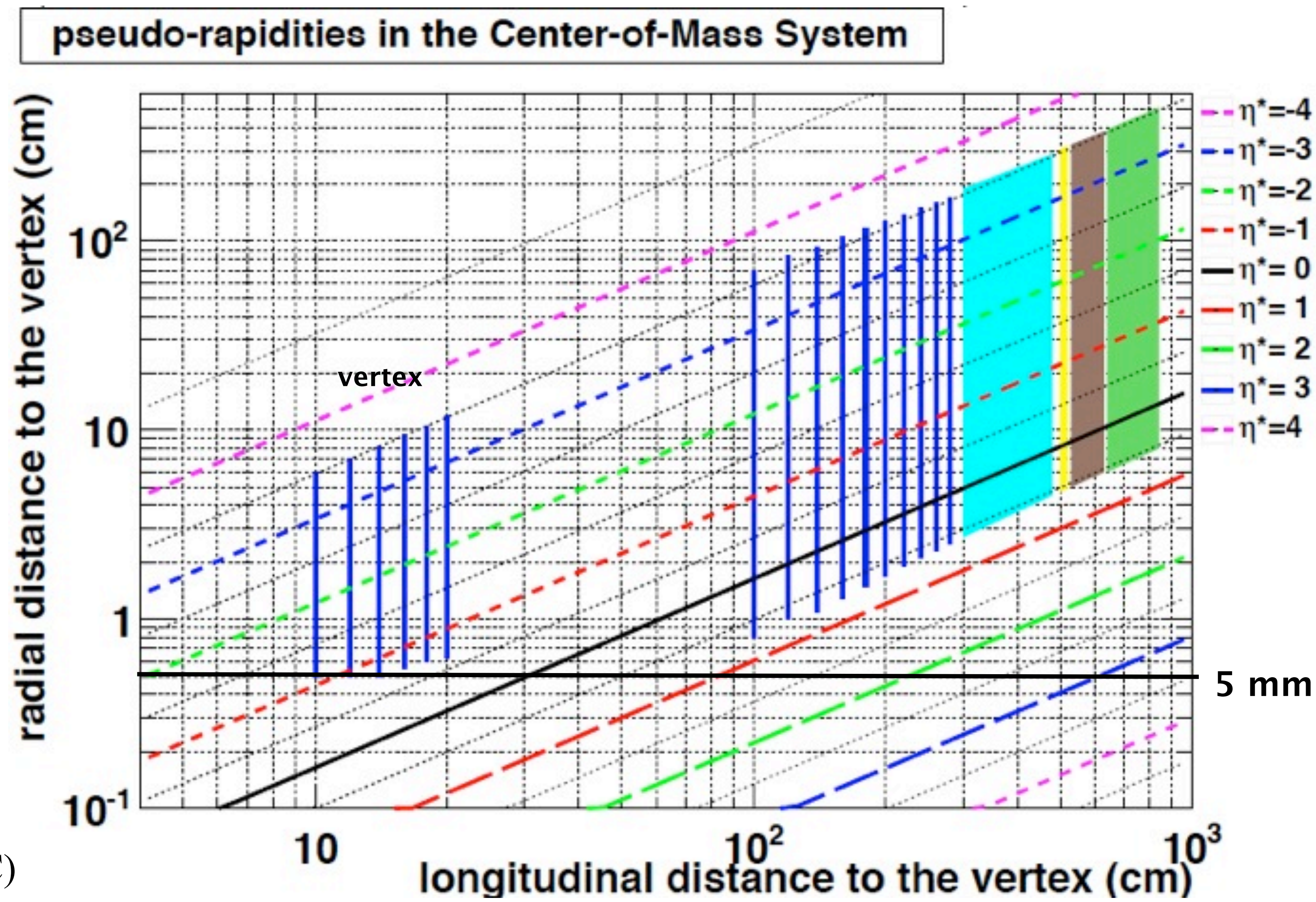


- **Technology**
- Vertex, tracker: pixel detectors
- EMCal: Tungsten/Si (Calice - ILC)
- Muons: Magnetize Fe (Minos)
- ...

Detector dimension

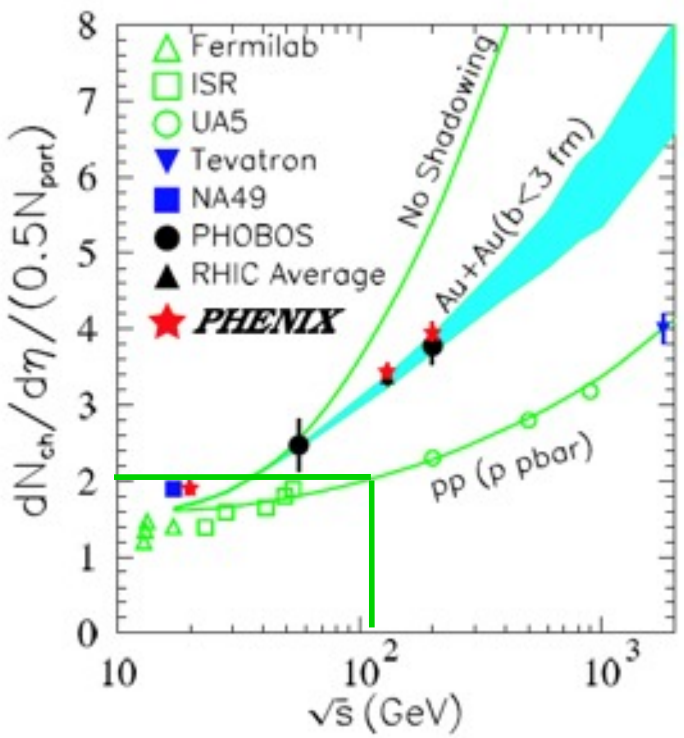
$1.3 < y_{lab} < 5.3$
$\theta_{min} = 10$ mrad

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

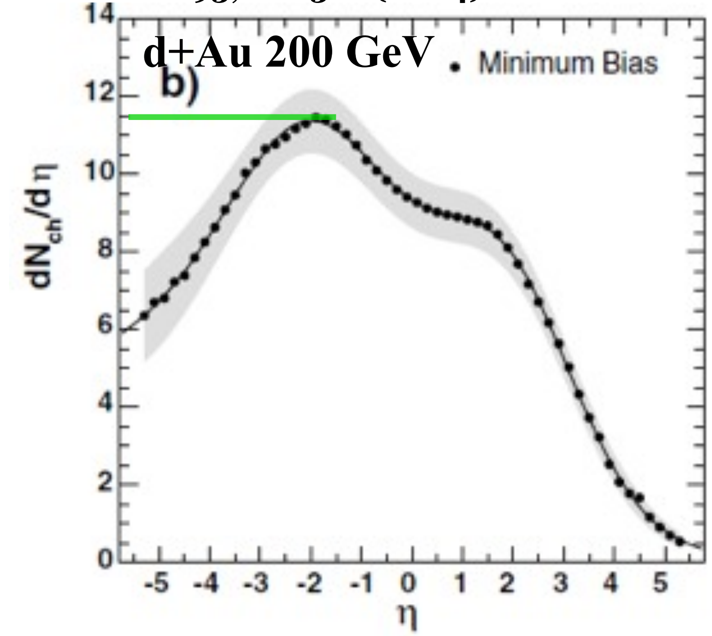


- **Technology**
- Vertex, tracker: pixel detectors
- EMCal: Tungsten/Si (Calice - ILC)
- Muons: Magnetize Fe (Minos)
- ...

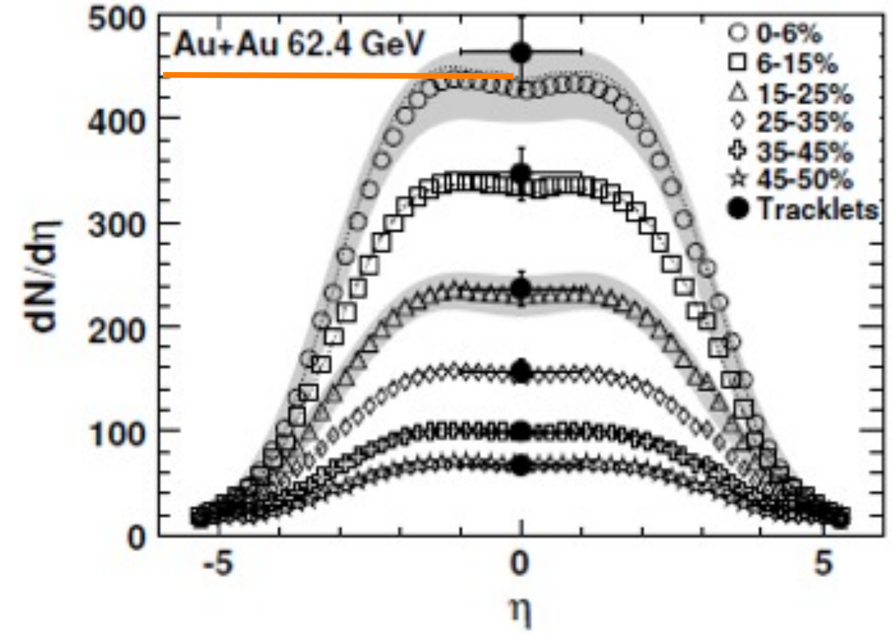
Multiplicity



PRL **93, 082301 (2004)**



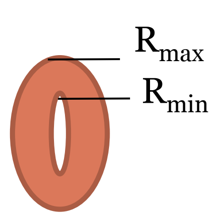
PRC **74, 021901(R) (2006)**



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.

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

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

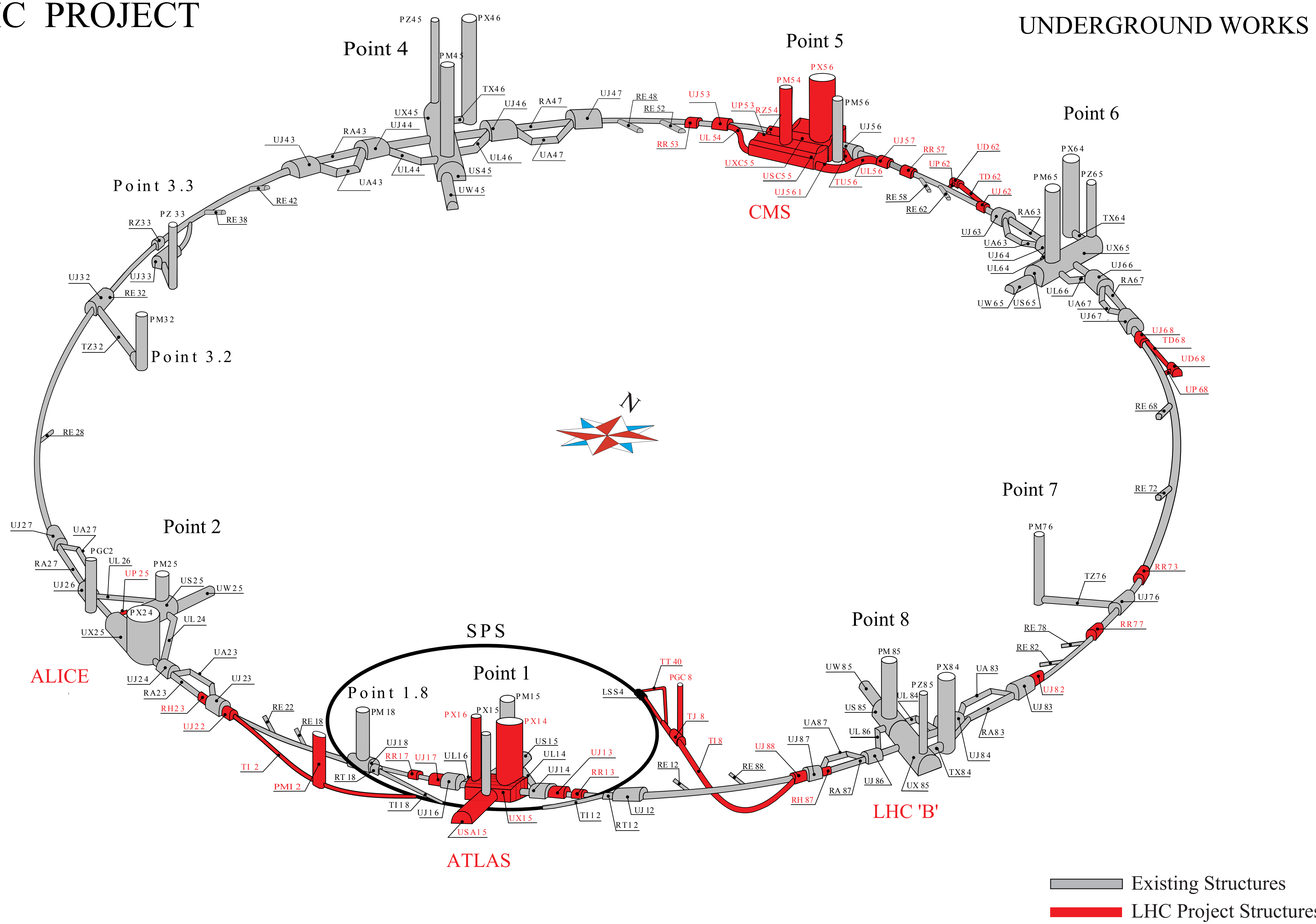
Calo ~ 700 part.

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

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

LHC PROJECT

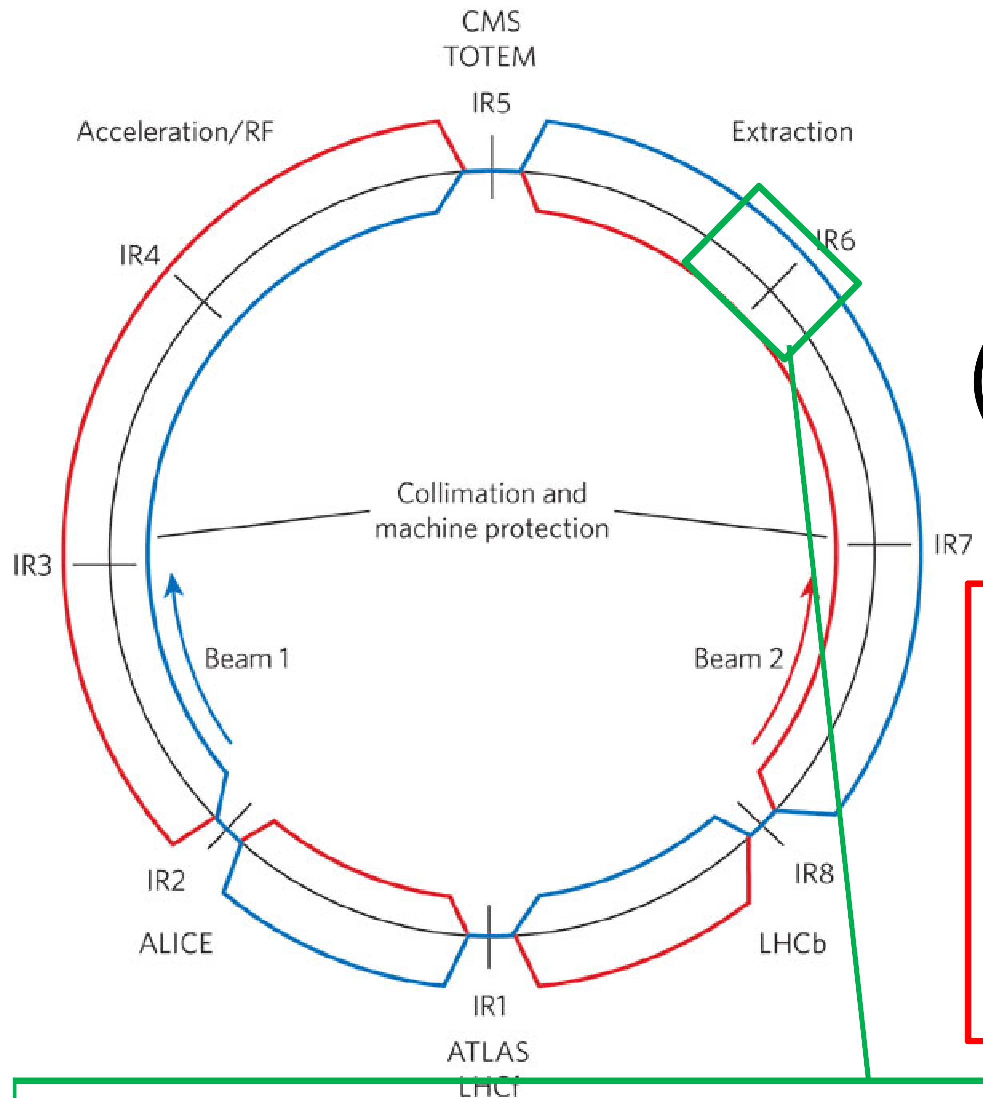
UNDERGROUND WORKS



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

One new possibility: LHC dump, IR6

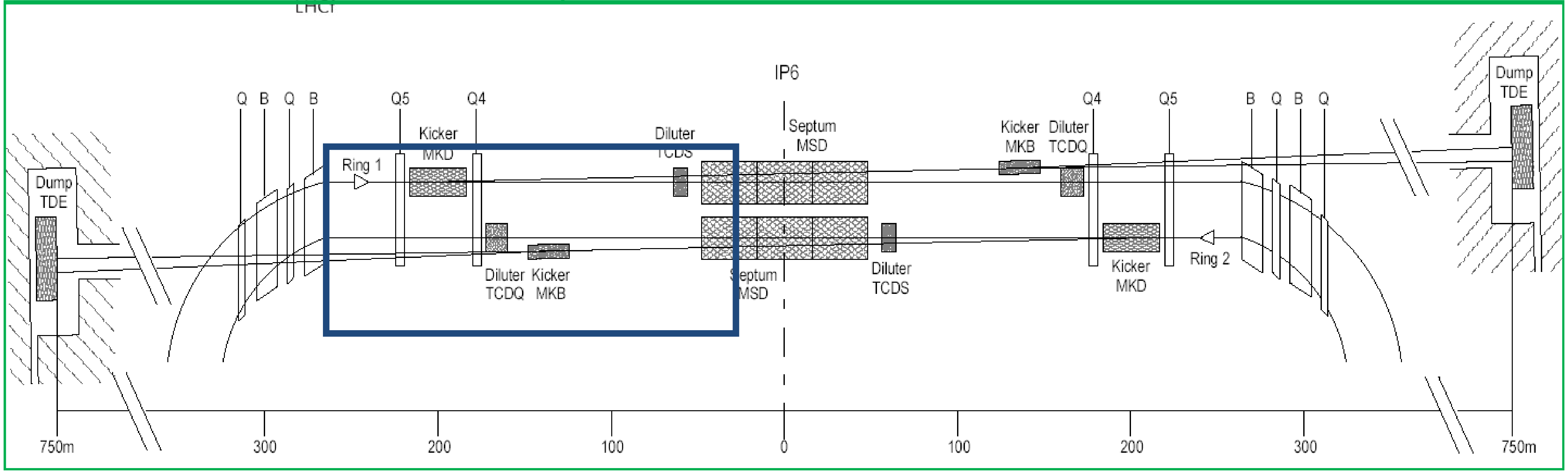
(IR7 and IR3 to be investigated)



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

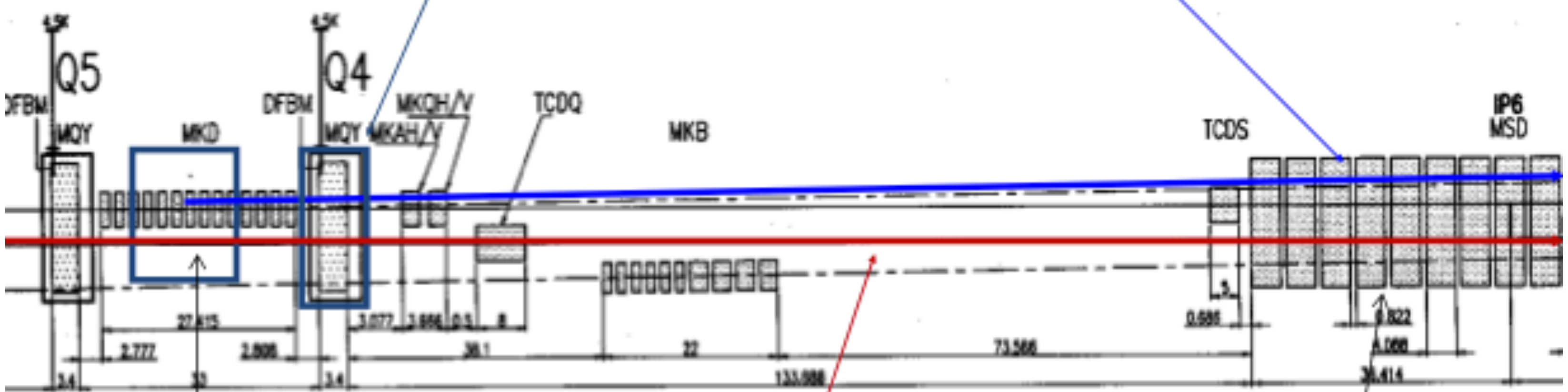
Strong crystalline fields – a possibility for extraction from the LHC

E. Uggerhøj, U.I. Uggerhøj *
Department of Physics and Astronomy, University of Aarhus,



LHC dump, IR6
zoom-in

- Only cold section here
- Extracted (dumped) beam



- Circulating beam
- Kicker
- Septum