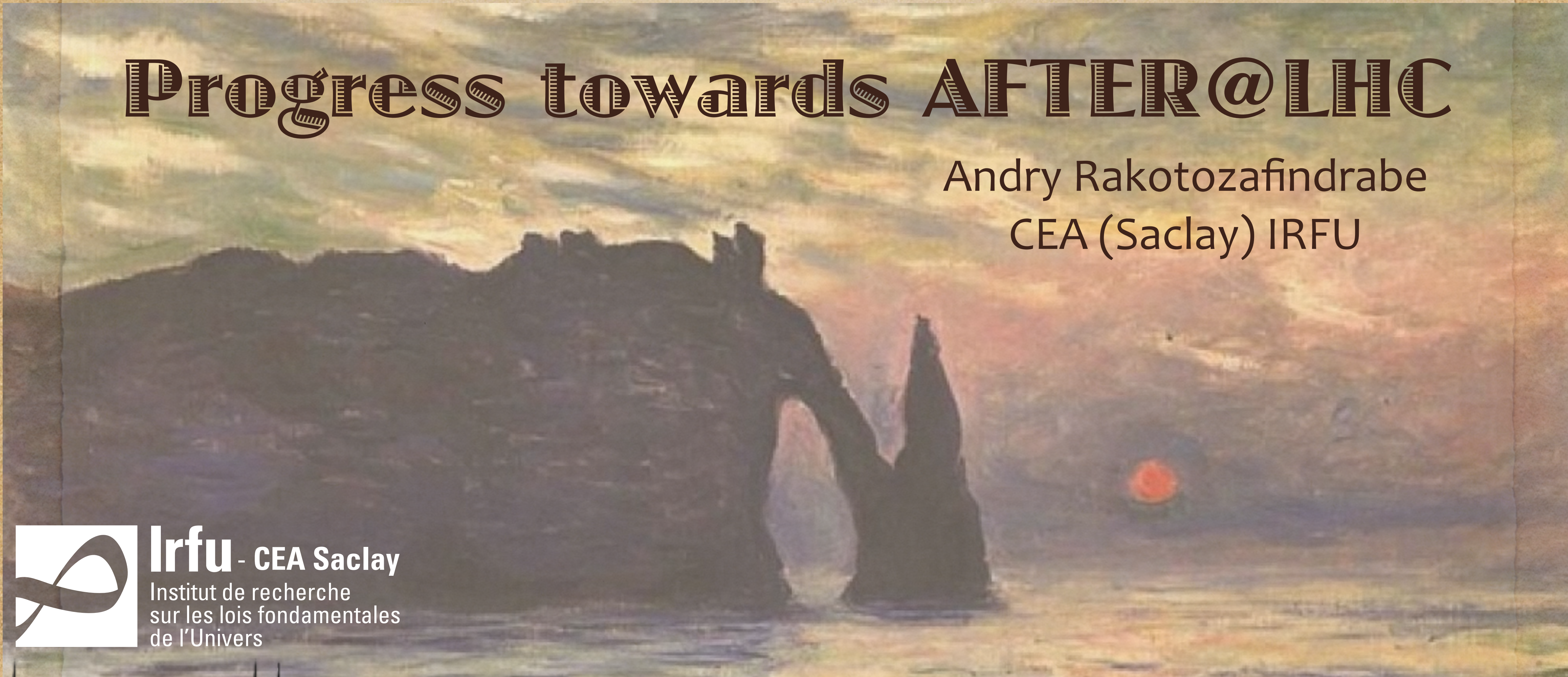
Rencontres QGP-France, Sept. 2014, Etretat



Progress towards AFTER@LHC

Andry Rakotozafindrabe
CEA (Saclay) IRFU

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

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), Y. Gao (Tsinghua), C. Hadjidakis (IPN), J.P. Lansberg (IPN), C. Lorcé (IPN), L. Massacrier (LAL), R. Mikkelsen (Aarhus), A. Rakotozafindrabe (CEA), P. Rosier (IPN), I. Schienbein (LPSC), E. Scomparin (Torino), B. Trzeciak (CTU), U.I. Uggerhøj (Aarhus), R. Ulrich (Karlsruhe), Z. Yang (Tsinghua)

AFTER

A Fixed Target ExpeRiment using LHC beams

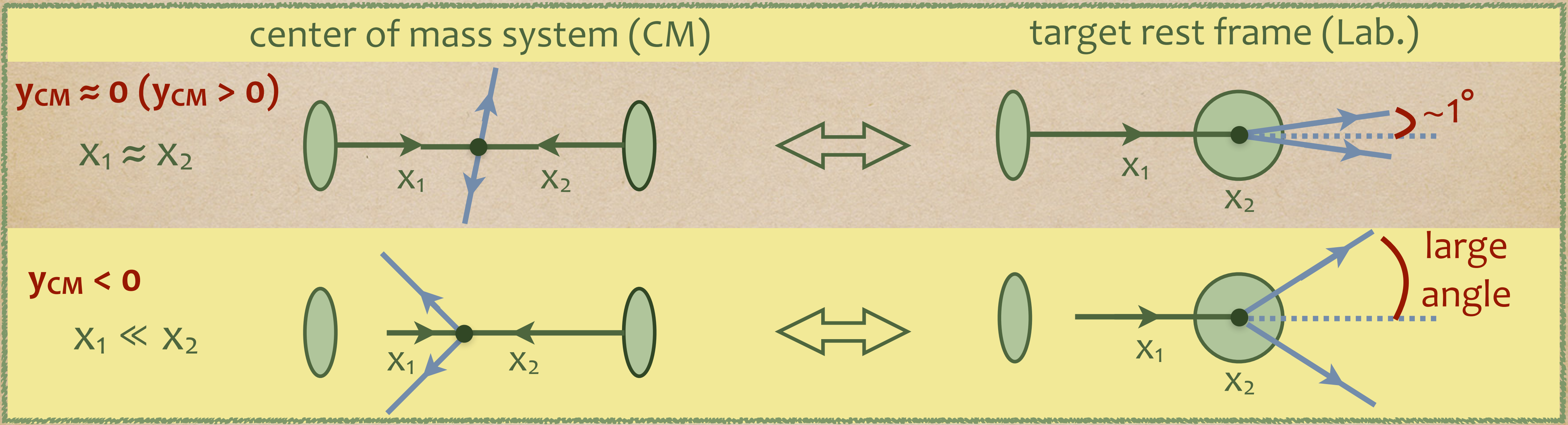
WHY A FIXED TARGET EXPERIMENT @ LHC ?

WHY A FIXED TARGET EXPERIMENT @ LHC ?

✓ provide a novel testing ground for QCD in the high x frontier :

WHY A FIXED TARGET EXPERIMENT @ LHC ?

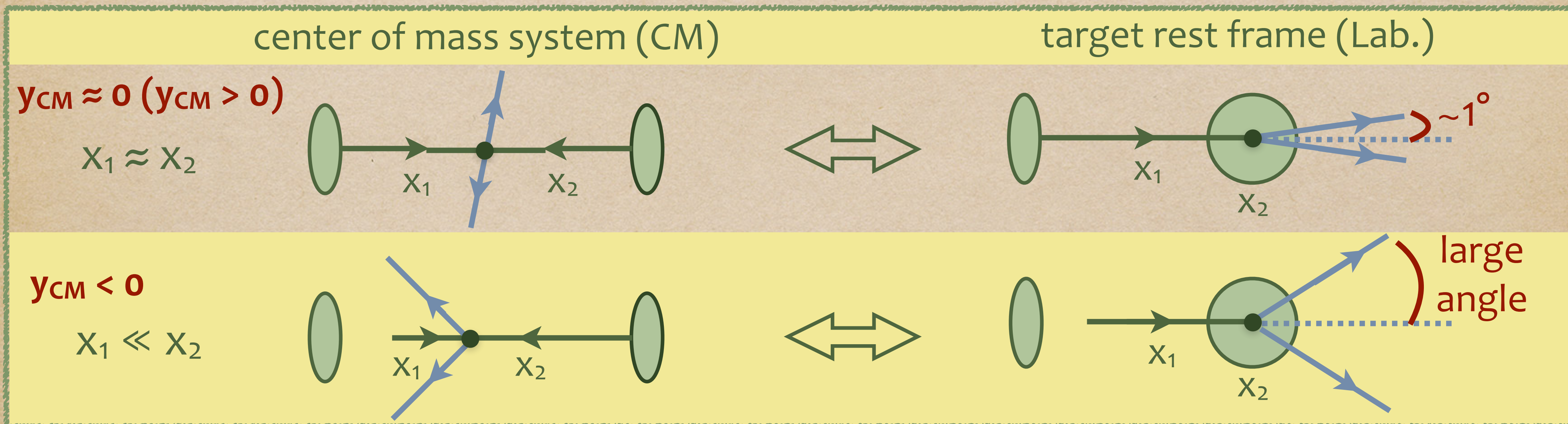
✓ provide a novel testing ground for **QCD in the high x frontier** :



- very energetic beam ⟹ boost ⟹ **access to partons with ($x_2 \longrightarrow 1$)** in the target, i.e. **($x_F \longrightarrow -1$)** which is **largely uncharted**
- this corresponds to the region : $y_{CM}<0$ i.e. **backwards physics**, large angles in the Lab. frame

WHY A FIXED TARGET EXPERIMENT @ LHC ?

✓ provide a novel testing ground for QCD in the high x frontier :



- very energetic beam ⟹ boost ⟹ **access to partons with ($x_2 \longrightarrow 1$)** in the target, i.e. **($x_F \longrightarrow -1$)** which is **largely uncharted**
- this corresponds to the region : $y_{CM}<0$ i.e. **backwards physics**, large angles in the Lab. frame

Some numbers : if using a 7 TeV p^+ beam on a fixed target ...

▸ CM energy : $\sqrt{s} = \sqrt{2 m_N E_p} \simeq 115\,\mathrm{GeV}$	▸ Rapidity shift : $y_{\mathrm{CM}} = 0 \Leftrightarrow y_{\mathrm{Lab}} = 4.8$
▸ boost : $\gamma_{\mathrm{CM}}^{\mathrm{Lab}} = \sqrt{s}/2m_p = 60$	

A large palette of measurements

✓ AFTER@LHC : decisive advantages of the fixed-target setup

- access to high $|x_F|$
- dense targets ⟹ high luminosities
- target versatility
- polarise (or not) the target

A LARGE PALETTE OF MEASUREMENTS

✓ AFTER@LHC : decisive advantages of the fixed-target setup

- access to high $|x_F|$
- dense targets ⟹ high luminosities
- target versatility
- polarise (or not) the target

▸ $\sqrt{s}$ ~ 115 GeV : p−p, p−d, p−A

- using LHC 7 TeV p^+ beam
- comparable to RHIC energies

spin physics

PDF and nPDF at large x

heavy quarkonium prod. and Cold Nuclear Matter effects

W, Z prod. near threshold

A LARGE PALETTE OF MEASUREMENTS

✓ AFTER@LHC : decisive advantages of the fixed-target setup

- access to high $|x_F|$
- dense targets ⟹ high luminosities
- target versatility
- polarise (or not) the target

‣ √s ~ 115 GeV : p−p, p−d, p−A

- using LHC 7 TeV p^+ beam
- comparable to RHIC energies

spin physics

PDF and nPDF at large x

heavy quarkonium prod. and Cold Nuclear Matter effects

W, Z prod. near threshold

‣ √s ~ 72 GeV : Pb−p, Pb−A

- using LHC 2.76 TeV Pb beam
- between SPS and top RHIC energies

Ultra Periph. Collisions

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

diffractive physics

A LARGE PALETTE OF MEASUREMENTS

✓ AFTER@LHC : decisive advantages of the fixed-target setup

- access to high $|x_F|$
- dense targets ⟹ high luminosities
- target versatility
- polarise (or not) the target

▸ $\sqrt{s} \sim 115$ GeV : p–p, p–d, p–A

- using LHC 7 TeV p^+ beam
- comparable to RHIC energies

spin physics

PDF and nPDF at large x

heavy quarkonium prod. and Cold Nuclear Matter effects

W, Z prod. near threshold

▸ $\sqrt{s} \sim 72$ GeV : Pb–p, Pb–A

- using LHC 2.76 TeV Pb beam
- between SPS and top RHIC energies

Ultra Periph. Collisions

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

diffractive physics

> Only a few measurements will be presented here !

MORE DETAILS :

Contents

Aller à la page 242

- in Phys. Rept. :

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

Physics Reports 522 (2013) 239–255

ELSEVIER

Contents lists available at SciVerse ScienceDirect

Physics Reports

journal homepage: www.elsevier.com/locate/physrep

AFTER

Physics opportunities of a fixed-target experiment using LHC beams

S.J. Brodsky [a], F. Fleuret [b], C. Hadjidakis [c], J.P. Lansberg [c,*]

[a] *SLAC National Accelerator Laboratory, Stanford University, Menlo Park, CA 94025, USA*

[b] *Laboratoire Leprince Ringuet, Ecole polytechnique, CNRS/IN2P3, 91128 Palaiseau, France*

[c] *IPNO, Université Paris-Sud, CNRS/IN2P3, 91406 Orsay, France*

- on the website : after.in2p3.fr

some key studies

GLUON PDF IN FREE AND BOUND NUCLEON

✓ AFTER@LHC : precision studies of gluon sensitive probes

quarkonia, isolated photon, photon-jet correlation, high pT jets

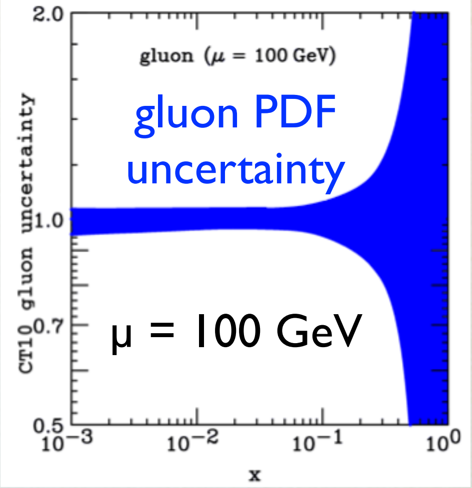
p-p

p-d

p-n

✳ gluon PDF at high x :

- not easily accessible in DIS
- large uncertainties for the proton (unknown for the neutron)
- limit the precision on reference processes used for BSM searches at LHC



some key studies

GLUON PDF IN FREE AND BOUND NUCLEON

✓ AFTER@LHC : precision studies of gluon sensitive probes

quarkonia, isolated photon, photon-jet correlation, high pT jets

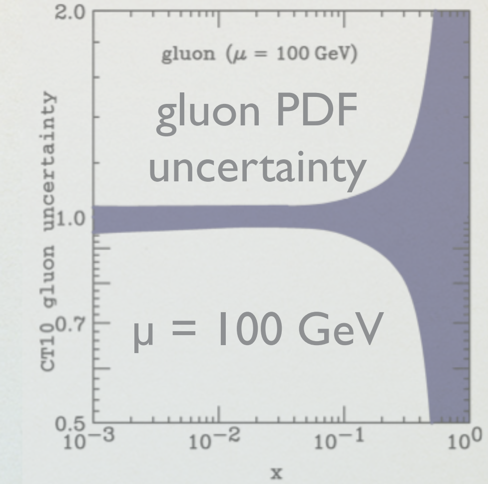
p-p

p-d

p-n

✳ **gluon PDF at high x :**

- not easily accessible in DIS
- large uncertainties for the proton (unknown for the neutron)
- limit the precision on reference processes used for BSM searches at LHC



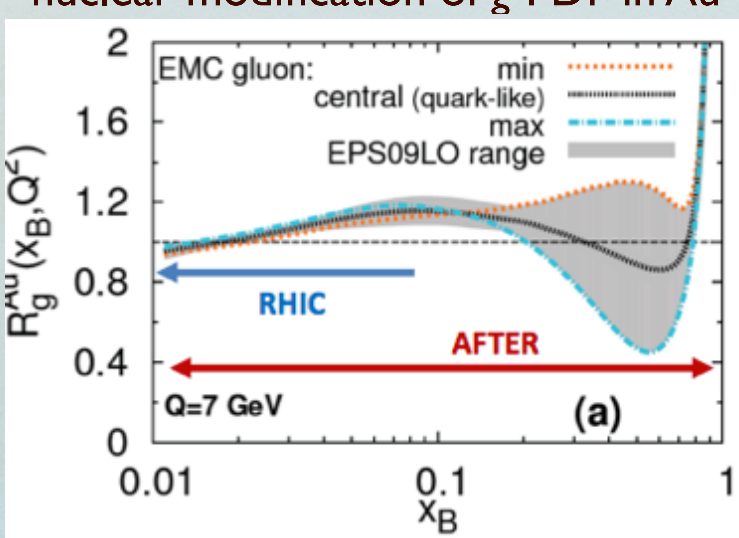
p-A

Pb-p

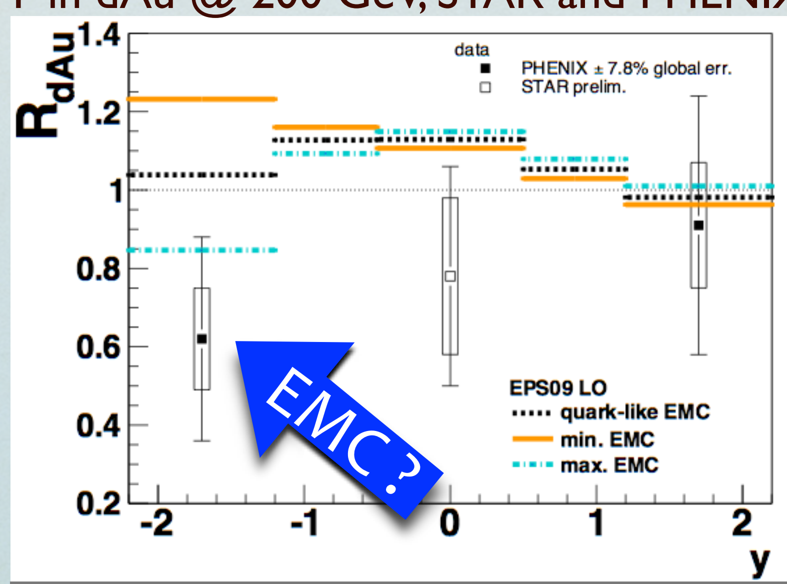
✳ gluon nuclear PDF at large x :

- unknown gluon EMC effect
- hint from ϒ data from RHIC, strongly limited by the statistics
- AFTER : complementarity with LHeC (focus at low x)

nuclear modification of g PDF in Au

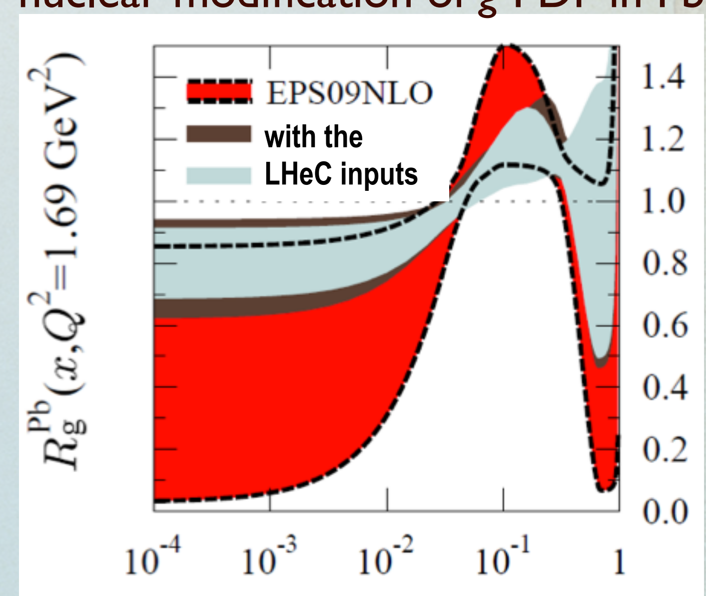


ϒ in dAu @ 200 GeV, STAR and PHENIX



[E.G. Ferreiro et al., EPJ C73 (2013) 2427]

nuclear modification of g PDF in Pb

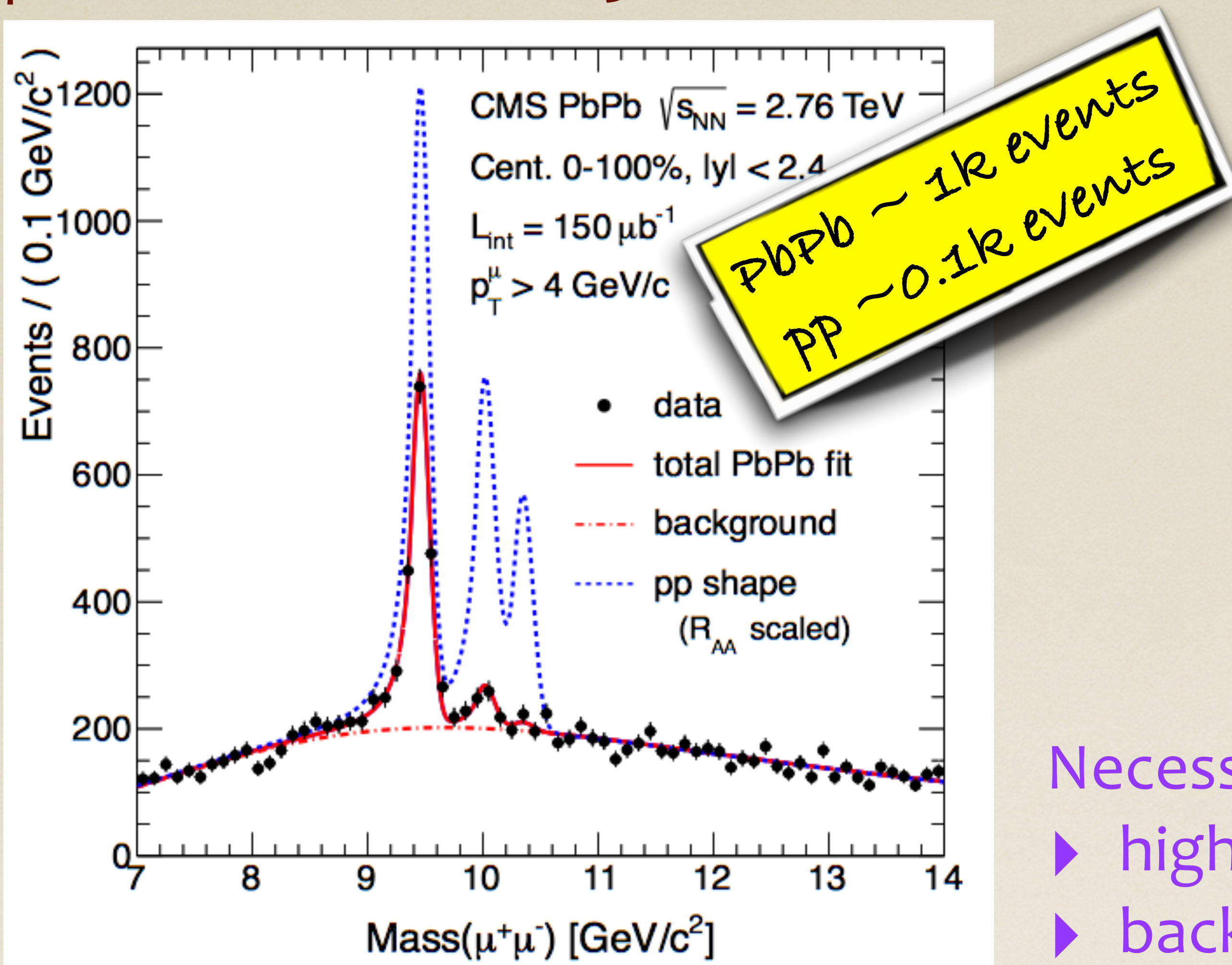


[LHeC CDR, J. Phys. G 39 (2012) 075001]

BOTTOMONIUM SEQUENTIAL MELTING @ LHC

A–A

Serious candidate for a « textbook-like » plot at Hard Probes 2013 conference



[CMS, PRL 109 (2012) 222301]

Sequential suppression seen :

- (3S) completely melted ?
- (2S) very suppressed
- direct (1S) not affected

Necessary ingredients :

- high inv. mass resolution in p-p and Pb-Pb
- background under control

> Could be used as a genuine QGP thermometer *if* the sequential suppression is due to QGP effects *only*

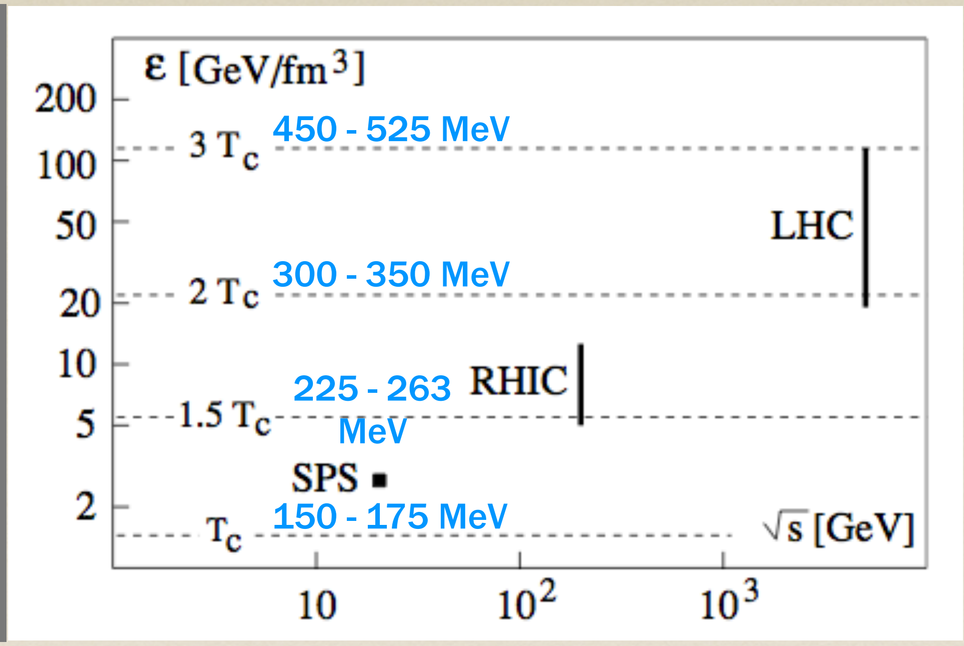
some key studies

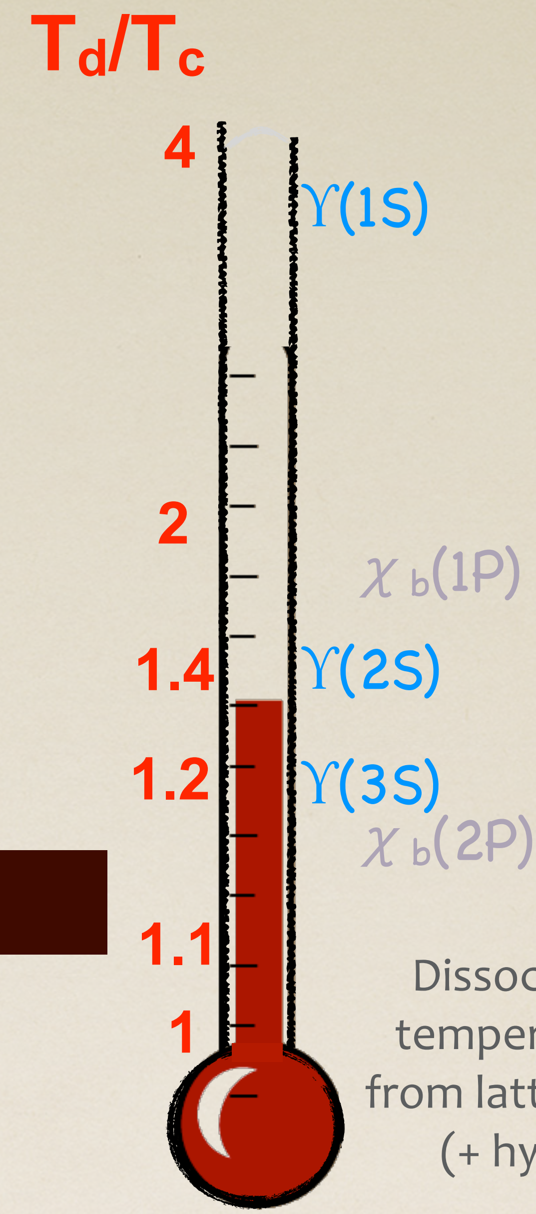
A–A

USE BOTTOMONIUM AS A THERMOMETER @ RHIC ?

Energy density, maximum collision energy and temperature :

[Satz, J.Phys. G32 (2006) R25]





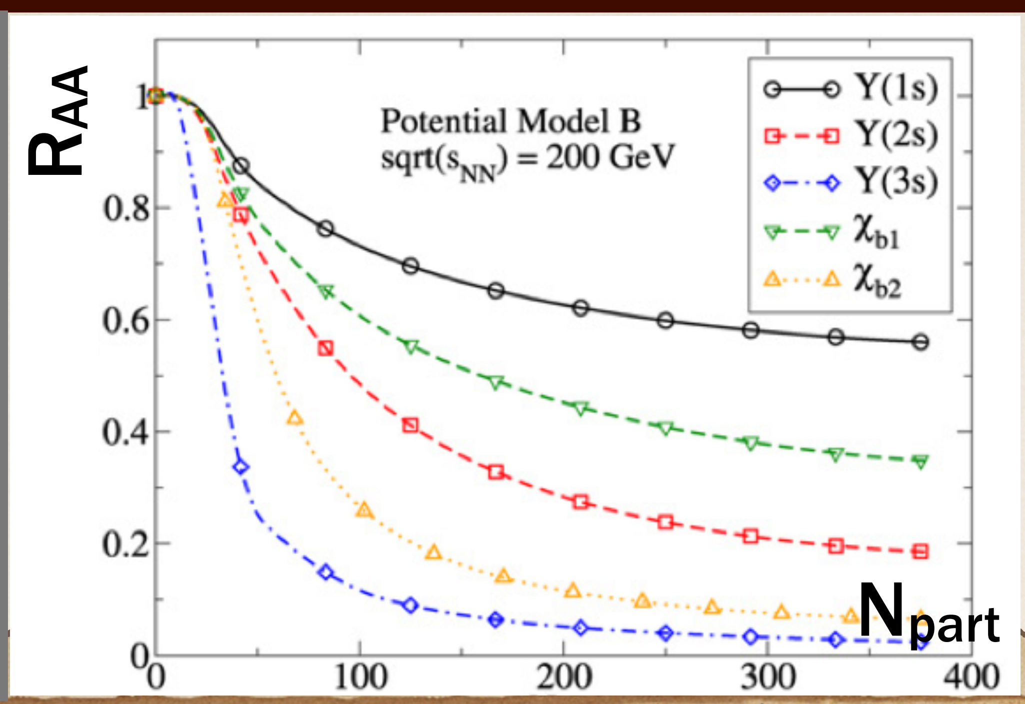
Dissociation temperatures from lattice QCD (+ hydro)

[Mocsy et al., Int.J.Mod.Phys. A28 (2013) 1340012]

Bottomonium family : broad range in temperature and energy density

Dreamed measurements :

[Strickland et al., NPA 879 (2012) 25-58]



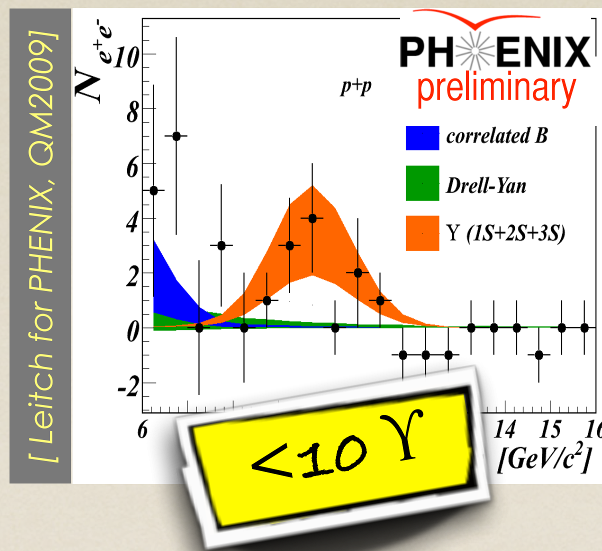
some key studies

A–A

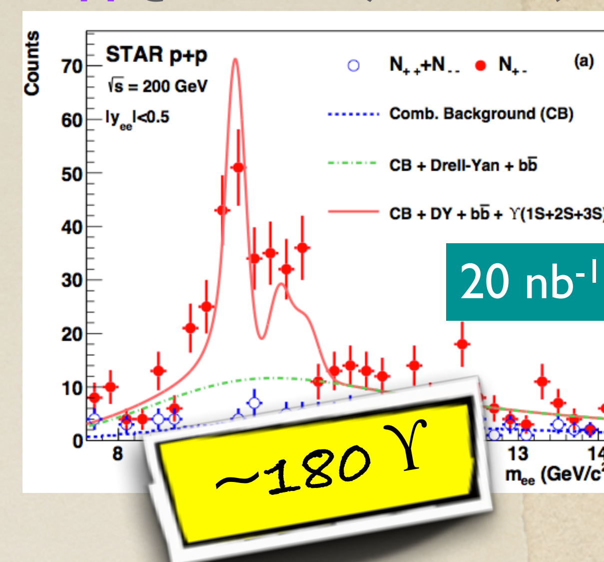
USE BOTTOMONIUM AS A THERMOMETER @ RHIC ?

> Need enough stat. and resolution to separate the ϒ(nS) states

pp@200 GeV (run 2006)



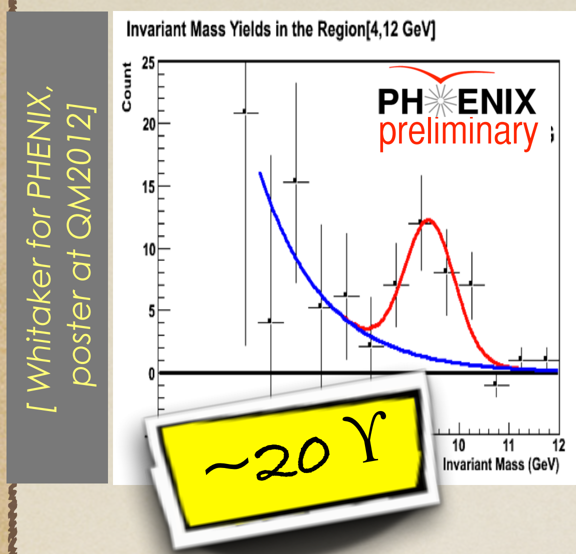
pp@200 GeV (run 2009)



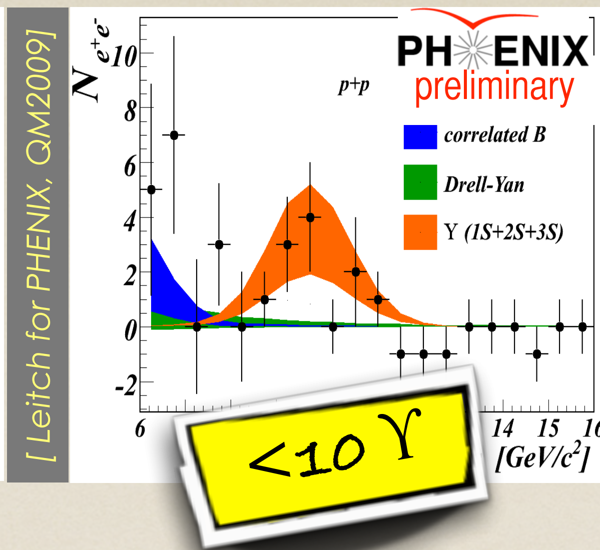
USE BOTTOMONIUM AS A THERMOMETER @ RHIC ?

Need enough stat. and resolution to separate the Υ(nS) states

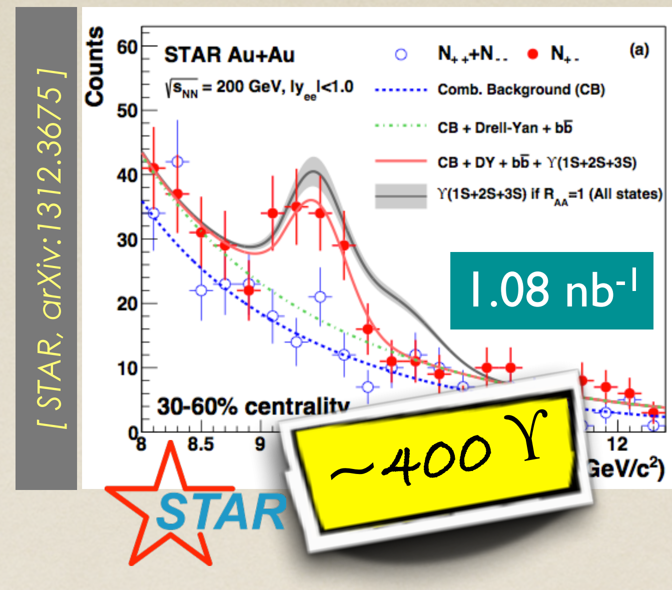
AuAu@200 GeV (run 2010)



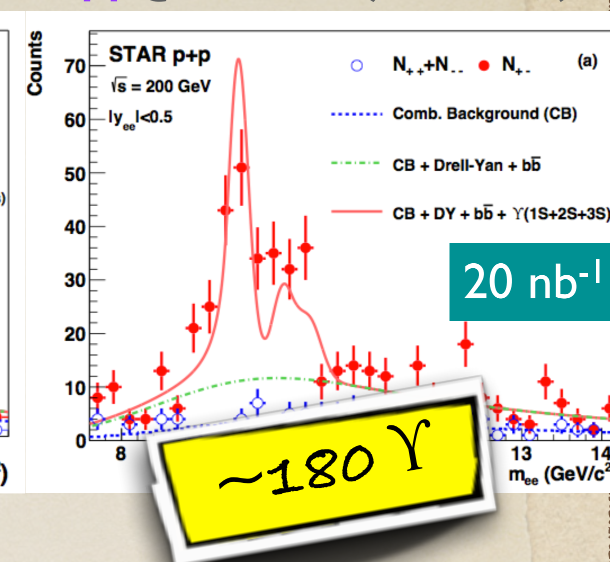
pp@200 GeV (run 2006)



AuAu@200 GeV (run 2010)



pp@200 GeV (run 2009)



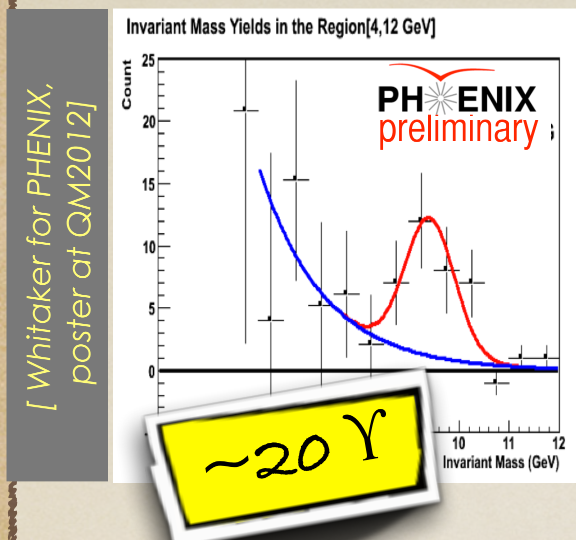
some key studies

A–A

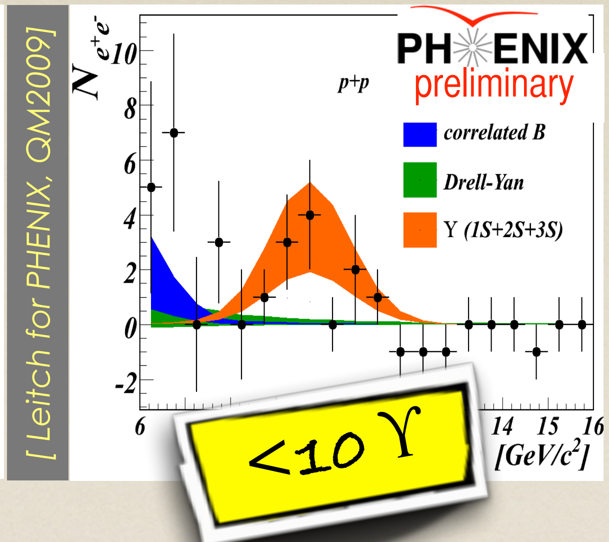
USE BOTTOMONIUM AS A THERMOMETER @ RHIC ?

Need enough stat. and resolution to separate the ϒ(nS) states

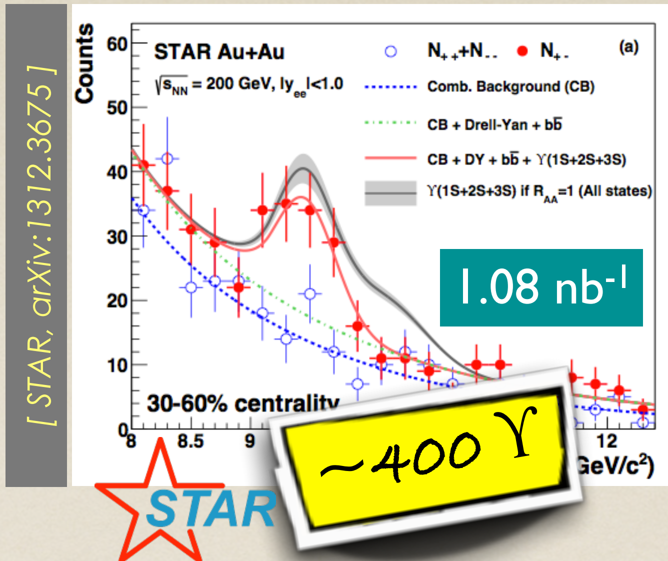
AuAu@200 GeV (run 2010)



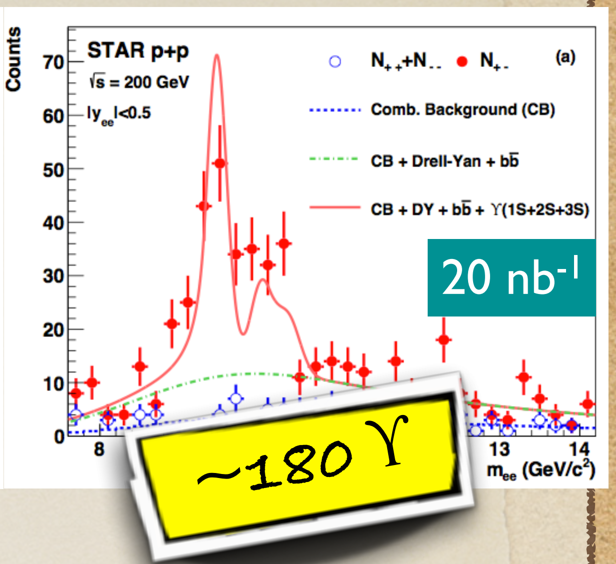
pp@200 GeV (run 2006)



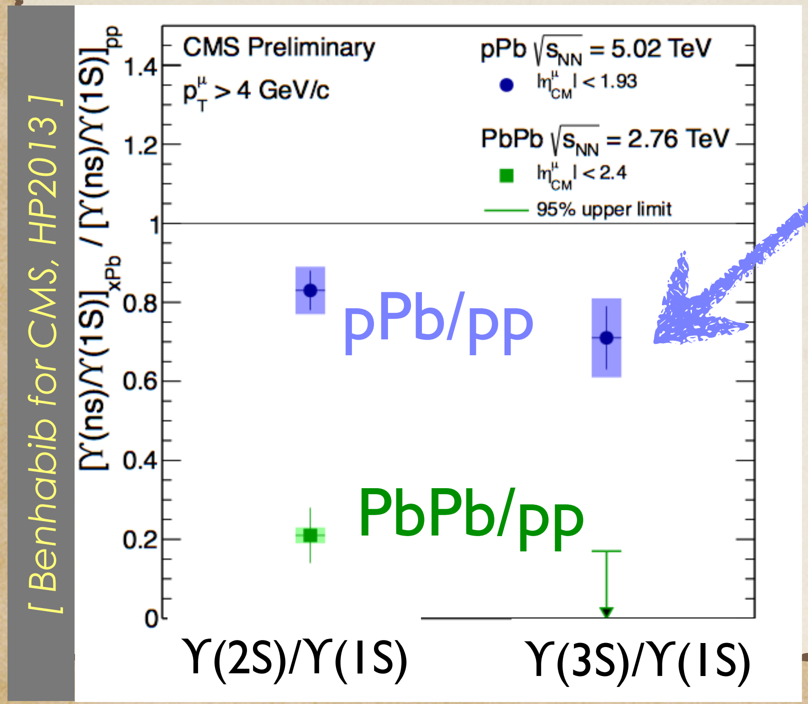
AuAu@200 GeV (run 2010)



pp@200 GeV (run 2009)



Need more studies and precise measurements of cold effects



Non trivial cold effects : excited states suppressed more than the ground state

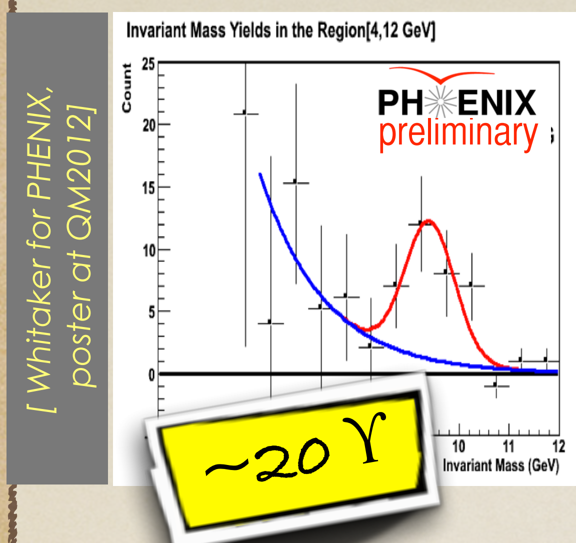
some key studies

A–A

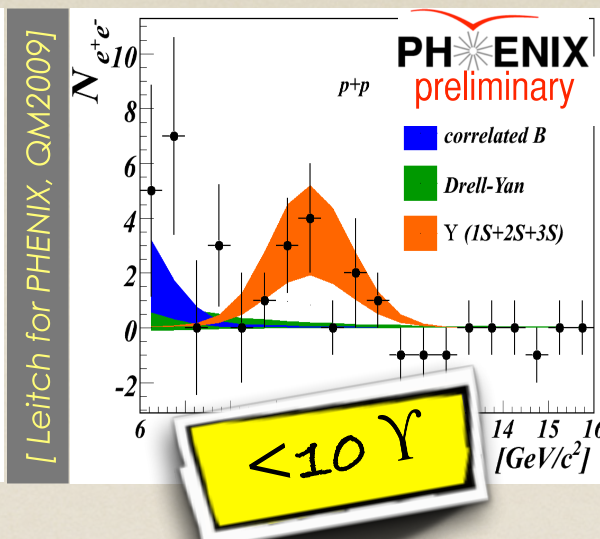
USE BOTTOMONIUM AS A THERMOMETER @ RHIC ?

Need enough stat. and resolution to separate the Υ(nS) states

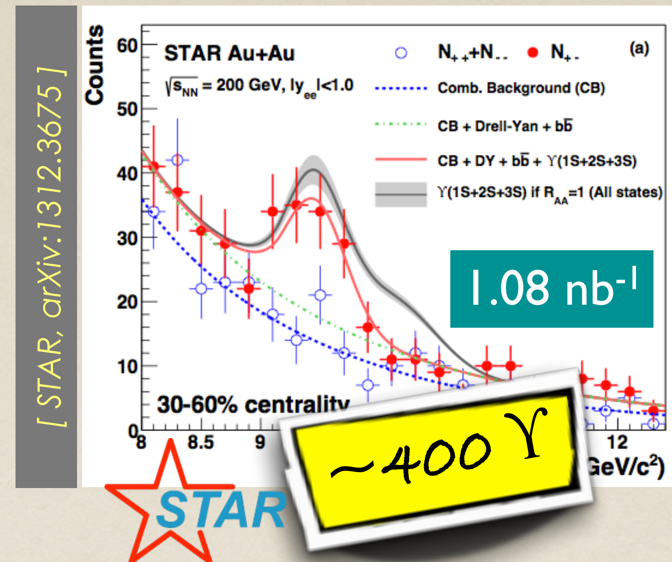
AuAu@200 GeV (run 2010)



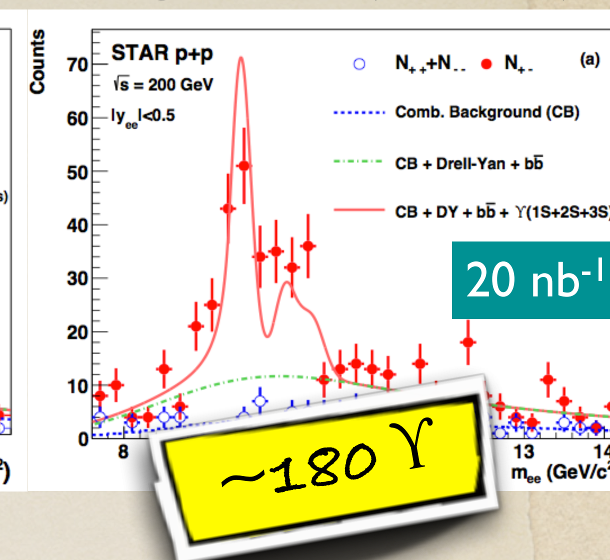
pp@200 GeV (run 2006)



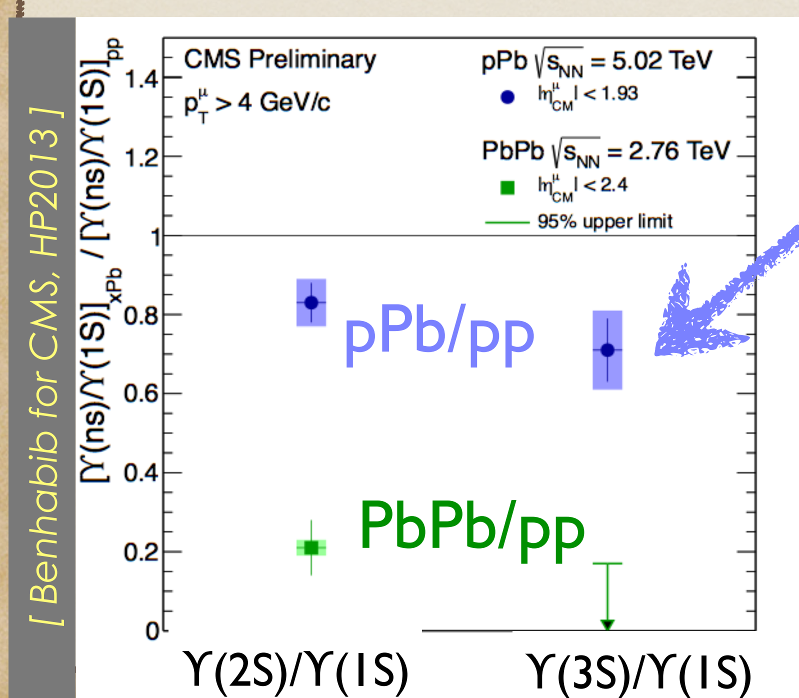
AuAu@200 GeV (run 2010)



pp@200 GeV (run 2009)



Need more studies and precise measurements of cold effects



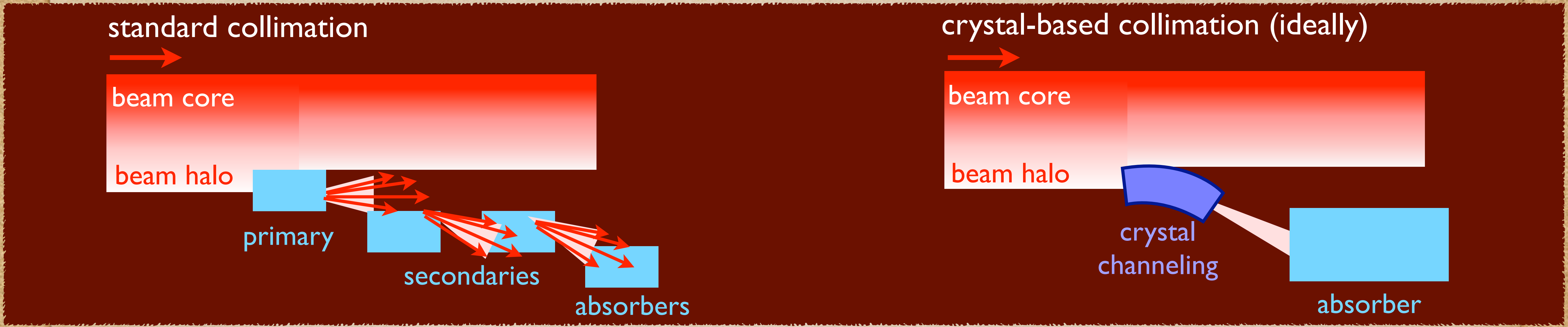
Non trivial cold effects : excited states suppressed more than the ground state

➡ could be beautifully addressed by AFTER

Beam extraction : the parasitic mode

- From standard collimation
  today

BEAM EXTRACTION : THE PARASITIC MODE

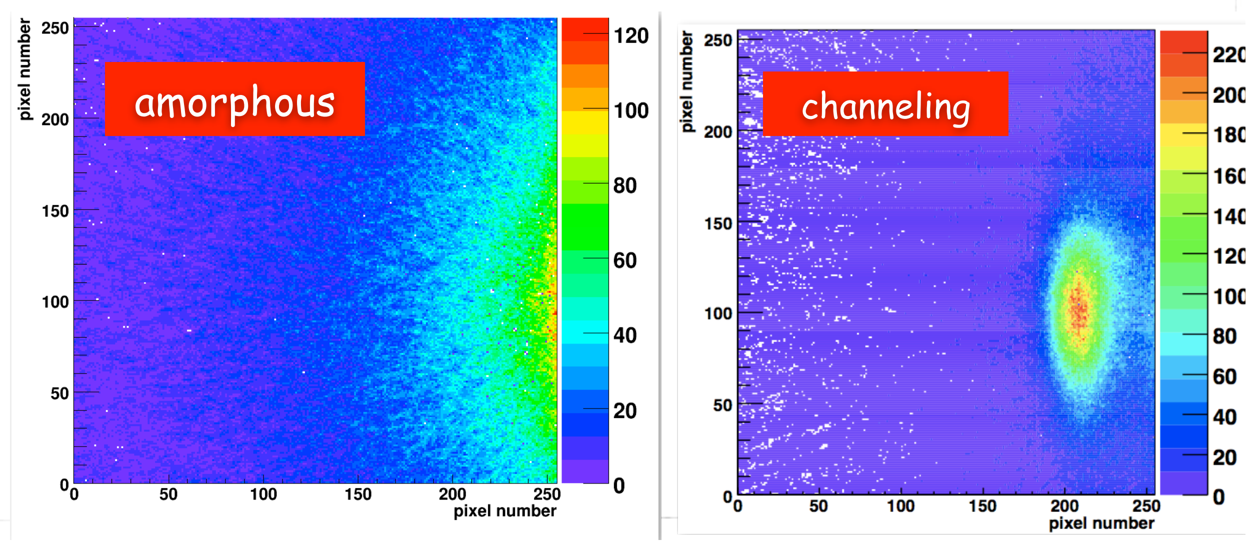


- From standard collimation to crystal-based collimation …
  today SPS (UA9)
  LHC (LUA9)

BEAM EXTRACTION : THE PARASITIC MODE

- From standard collimation to crystal-based collimation …
  today
  SPS (UA9)
  LHC (LUA9)

Direct view of the channeled beam

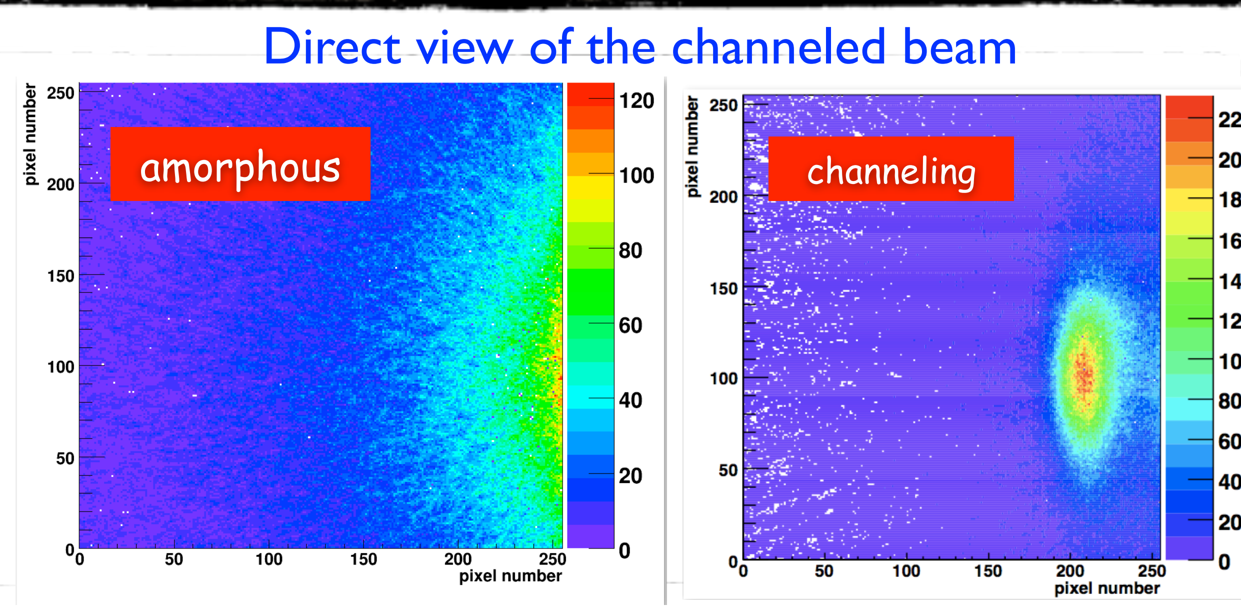


[S. Montesano, W. Scandale, Joint LUA9-AFTER meeting, Nov. 2013]

BEAM EXTRACTION : THE PARASITIC MODE

- From standard collimation to crystal-based collimation … and to **beam extraction**

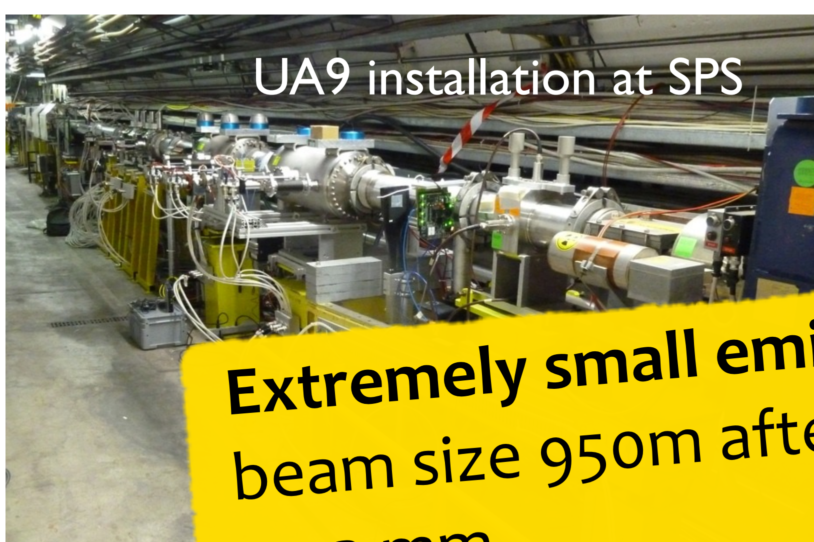
From standard collimation	to crystal-based collimation …	and to **beam extraction**
today	SPS (UA9)	CRYSBEAM (SPS then LHC)
	LHC (LUA9)	AFTER (LHC)

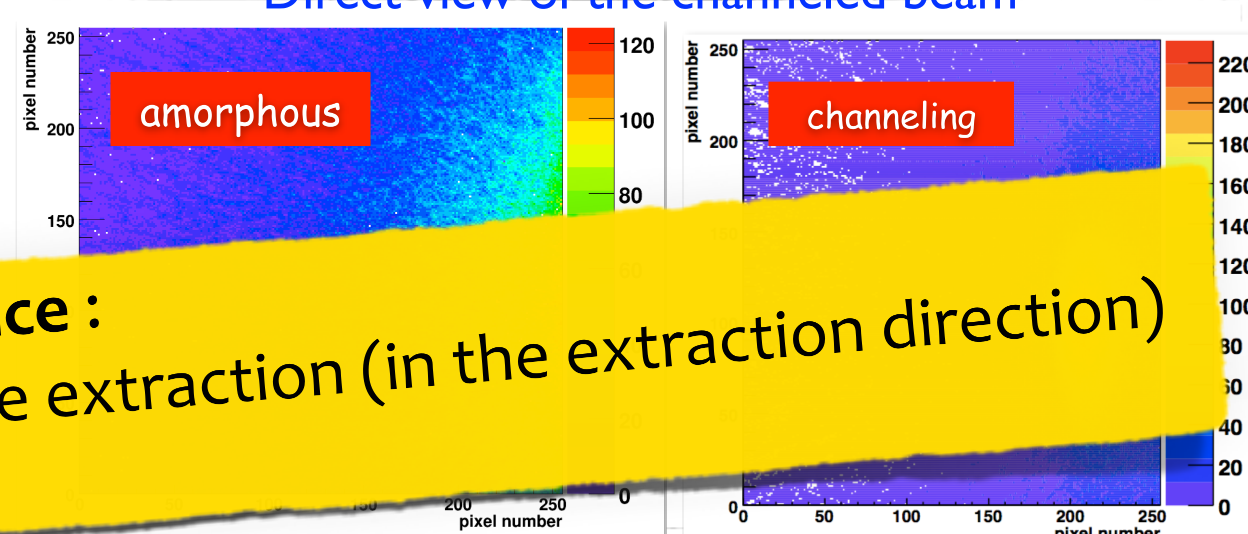


[S. Montesano, W. Scandale, Joint LUA9-AFTER meeting, Nov. 2013]

Beam extraction : the parasitic mode

- From standard collimation today … to crystal-based collimation SPS (UA9), LHC (LUA9) … and to **beam extraction** CRYSBEAM (SPS then LHC), AFTER (LHC)

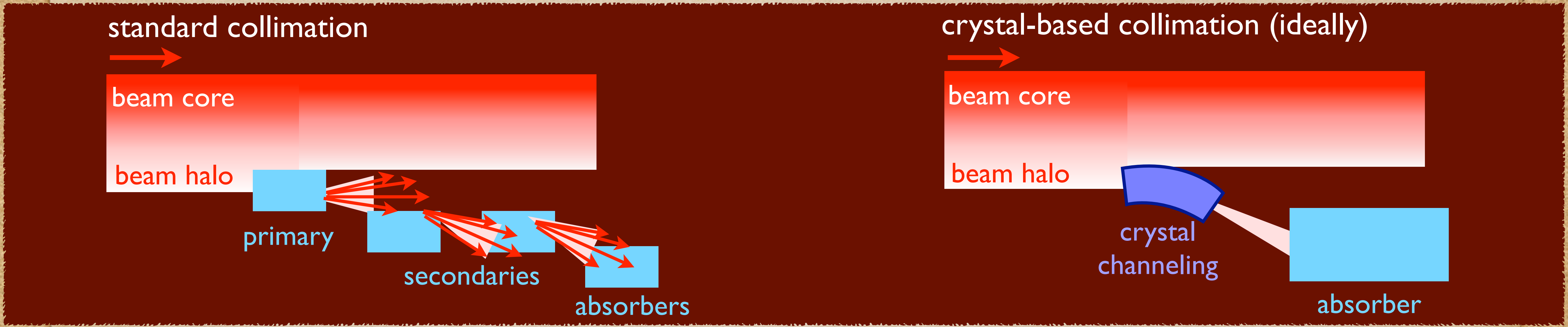




Extremely small emittance :
beam size 950m after the extraction (in the extraction direction) ~0.3 mm

[S. Montesano, W. Scandale, Joint LUA9-AFTER meeting, Nov. 2013]

BEAM EXTRACTION : THE PARASITIC MODE



- From standard collimation, to crystal-based collimation ... and to **beam extraction**

  today — SPS (UA9), LHC (LUA9) — CRYSBEAM (SPS then LHC), AFTER (LHC)

- UA9 : a complete crystal collimation prototype is installed in the SPS
  - ✓ **Multi-turn channeling efficiency : 70÷80% for protons, 50÷70% for ions**
  - ✓ Loss reduction rate at crystal : 20× for protons, 7× for ions
  - ✓ Off-momentum loss reduction : 6× for protons, 7× for ions (currently, LHC is limited by dispersion losses)

[S. Montesano, Joint LUA9-AFTER meeting, Nov. 2013]

- LUA9 : approved by the LHCC
  - ✓ 2 crystals already installed in the LHC beam pipe
  - ✓ **first tests with beam possibly in 2015/2016**

BEAM EXTRACTION : THE PARASITIC MODE

- From standard collimation, to crystal-based collimation … and to **beam extraction**

standard collimation	crystal-based collimation	beam extraction
today	SPS (UA9) LHC (LUA9)	CRYSBEAM (SPS then LHC) AFTER (LHC)

- UA9 : a complete crystal collimation prototype is installed in the SPS
  - ✓ **Multi-turn channeling efficiency : 70÷80% for protons, 50÷70% for ions**
  - ✓ Loss reduction rate at crystal : 20× for protons, 7× for ions
  - ✓ Off-momentum loss reductio… di…
- LUA9 …
  - ✓ 2 c…
  - ✓ **firs… beam possibly in 2015/2016**

Proposal :
recycle the beam loss by inserting the crystal **in the halo (7σ)** of the LHC beam *[E Uggerhoj and U.I. Uggerhoj, NIM B 234 (2005) 31]*
⇒ **no performance decrease of the LHC** ☺

LUMINOSITIES

For pp, pA @ $\sqrt{s}$ = 115 GeV, estimates based on :

- extraction eff. (multi pass) **~50% LHC beam loss ⟹ 5.10^{8} p^{+}/s extracted**
- 1 year = 10^{7} s for p^{+} beam

✓ AFTER@LHC : outstanding luminosities ⟹ precision studies

115 GeV p–H

Target	Luminosity / year		yield / unit of rapidity at y=0: J/ψ	yield / unit of rapidity at y=0: Υ
10 cm solid H	2.6	fb^{-1}	5.2 10^{7}	1.0 10^{5}

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

LUMINOSITIES

For pp, pA @ $\sqrt{s}$ = 115 GeV, estimates based on :

- extraction eff. (multi pass) ~**50% LHC beam loss ⟹ 5.10^8 p^+/s extracted**
- 1 year = 10^7 s for p^+ beam

✓ AFTER@LHC : outstanding luminosities ⟹ precision studies

	Target	Luminosity / year	yield / unit of rapidity at y=0 J/ψ	Υ
115 GeV p–H	10 cm solid H	2.6 fb^{-1}	$5.2\ 10^7$	$1.0\ 10^5$
115 GeV p–A	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 Pb	0.16	$6.7\ 10^8$	$1.3\ 10^6$

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

LUMINOSITIES

For pp, pA @ $\sqrt{s}$ = 115 GeV, estimates based on :

- extraction eff. (multi pass) **~50% LHC beam loss ⟹ 5.10^8 p^+/s extracted**
- 1 year = 10^7 s for p^+ beam

✓ AFTER@LHC : outstanding luminosities ⟹ precision studies

	Target	**Luminosity / year**		yield / unit of rapidity at y=0: J/ψ	yield / unit of rapidity at y=0: Υ
115 GeV p-H	10 cm solid H	2.6	**fb^{-1}**	$5.2\ 10^7$	$1.0\ 10^5$
115 GeV p-A	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 Pb	0.16		$6.7\ 10^8$	$1.3\ 10^6$
72 GeV A-A	1 cm Be	25	**nb^{-1}**	$9.1\ 10^5$	$1.9\ 10^3$
	1 cm Cu	17		$4.3\ 10^6$	$0.9\ 10^3$
	1 cm Pb	7		$5.7\ 10^6$	$1.1\ 10^4$

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

LUMINOSITIES

For pp, pA @ $\sqrt{s}$ = 115 GeV, estimates based on :

- extraction eff. (multi pass) ~**50% LHC beam loss ⟹ 5.10^{8} p^{+}/s extracted**
- 1 year = 10^{7} s for p^{+} beam

✓ AFTER@LHC : outstanding luminosities ⟹ precision studies

		Target	Luminosity / year		yield / unit of rapidity at y=0: J/ψ	yield / unit of rapidity at y=0: Υ
115 GeV	p–H	10 cm solid H	2.6	fb^{-1}	5.2 10^{7}	1.0 10^{5}
115 GeV	p–A	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 Pb	0.16		6.7 10^{8}	1.3 10^{6}
72 GeV	A–A	1 cm Be	25	nb^{-1}	9.1 10^{5}	1.9 10^{3}
		1 cm Cu	17		4.3 10^{6}	0.9 10^{3}
		1 cm Pb	7		5.7 10^{6}	1.1 10^{4}

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

Compare to :

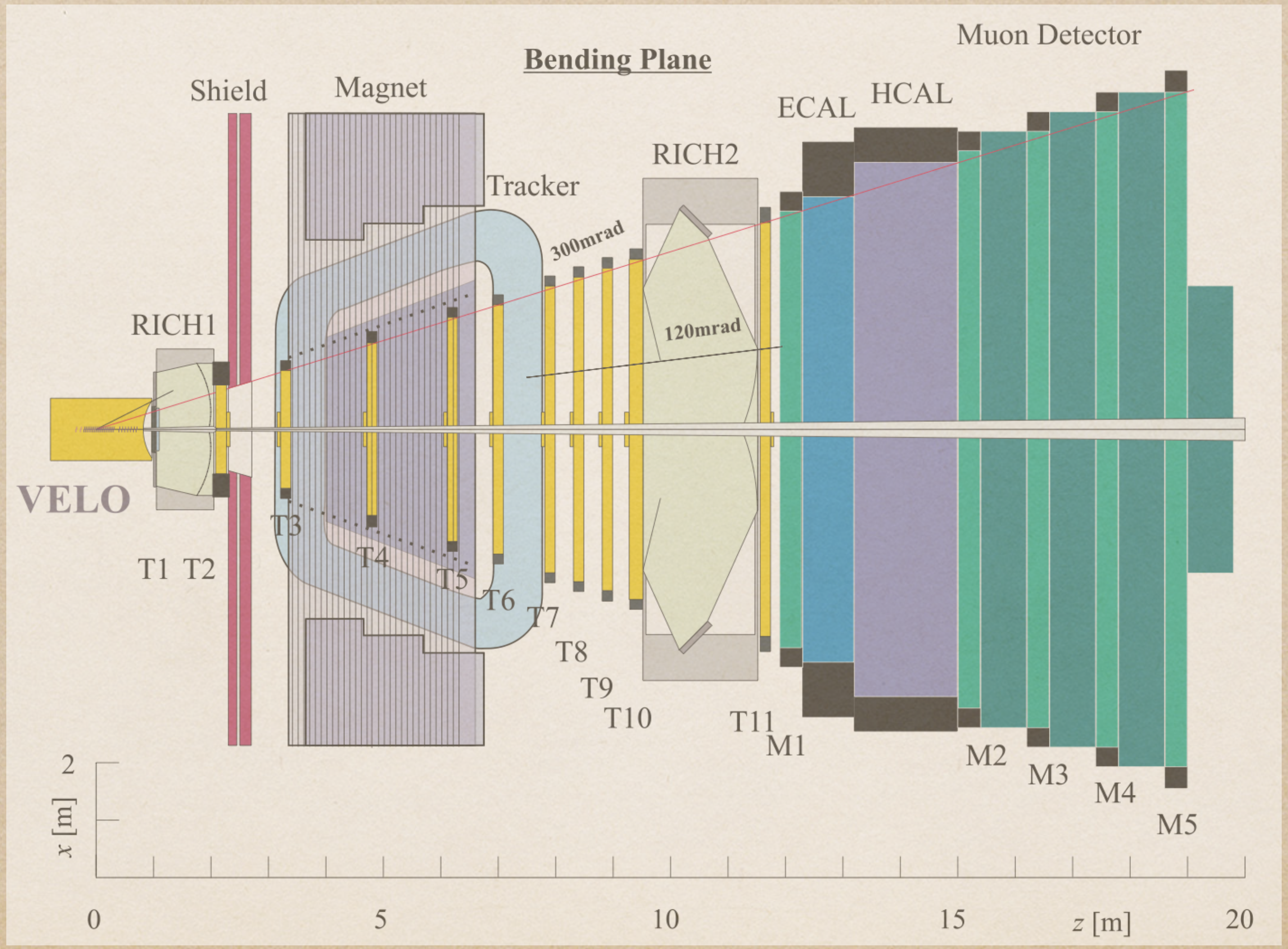
- LHC 2012 Run (4 TeV p+ beam), delivered luminosity at **LHCb 2.115 fb^{-1}**
- **RHIC** expected luminosity (PHENIX decadal plan) in 2014/15
  pp @ 200 GeV **1.2 10^{-2} fb^{-1}**, **dAu** @ 200 GeV **1.5 10^{-4} fb^{-1}**, **AuAu** @ 62 GeV **0.13 nb^{-1}**

TOWARDS A FORWARD DETECTOR

- Focus on (y_{CM}<0) i.e. « large » angles (θ>1°) but still forward angles in the Lab.
- What needs to be improved w.r.t. known detector performances ?

TOWARDS A FORWARD DETECTOR

- Focus on ($y_{CM}<0$) i.e. « large » angles ($\theta>1°$) but still forward angles in the Lab.
- What needs to be improved w.r.t. known detector performances ?
- for e.g. a LHCb-like detector : $2 < \eta < 5$

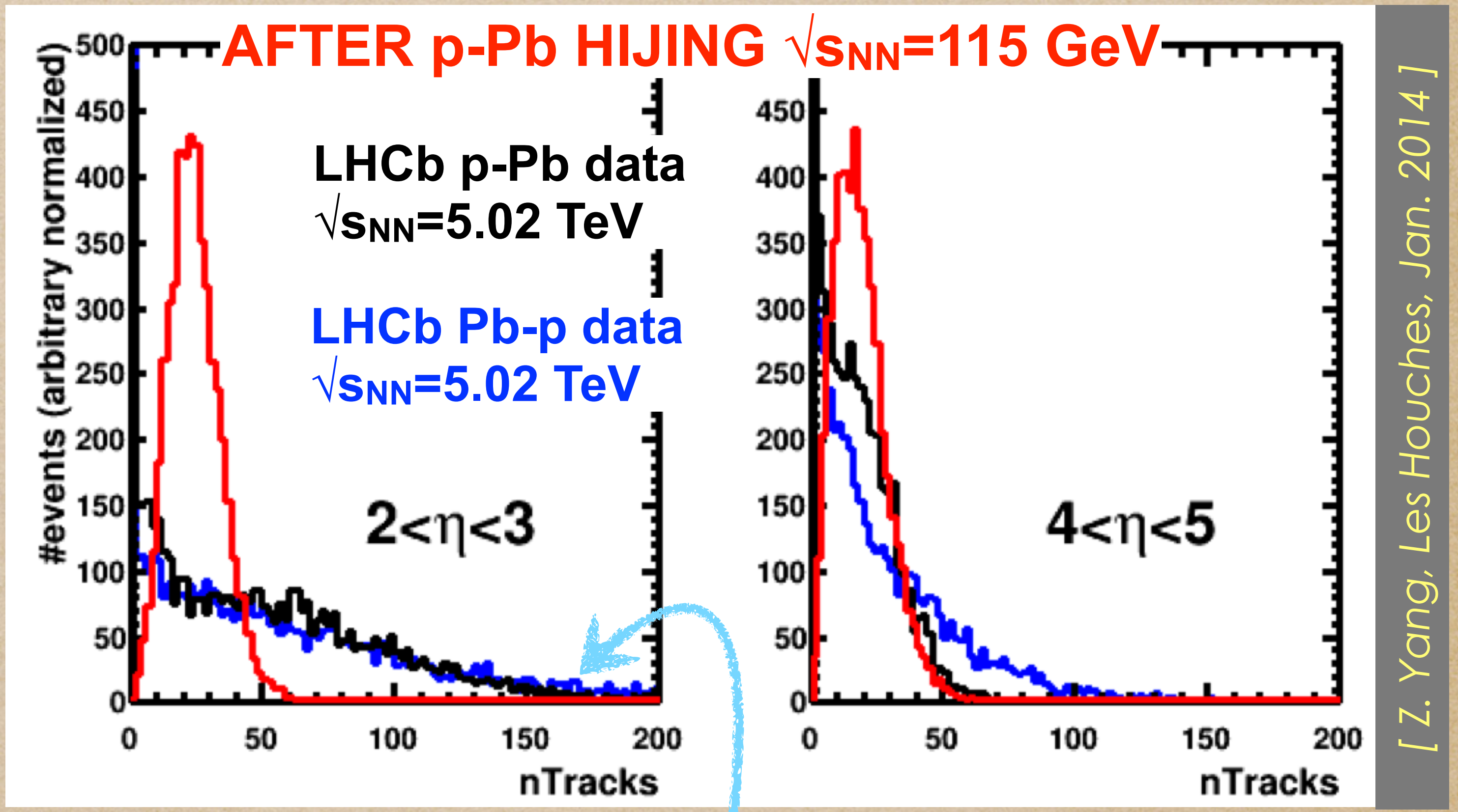


TOWARDS A FORWARD DETECTOR

- Focus on (y_{CM}<0) i.e. « large » angles (θ>1°) but still forward angles in the Lab.
- What needs to be improved w.r.t. known detector performances ?
- for e.g. a LHCb-like detector : 2 < η <5

✓ Track multiplicity : cope with the boost

Despite the boost, the track multiplicity is lower in the fixed target mode than in the collider mode



highest multiplicity/event ever experienced so far by LHCb

TOWARDS A FORWARD DETECTOR

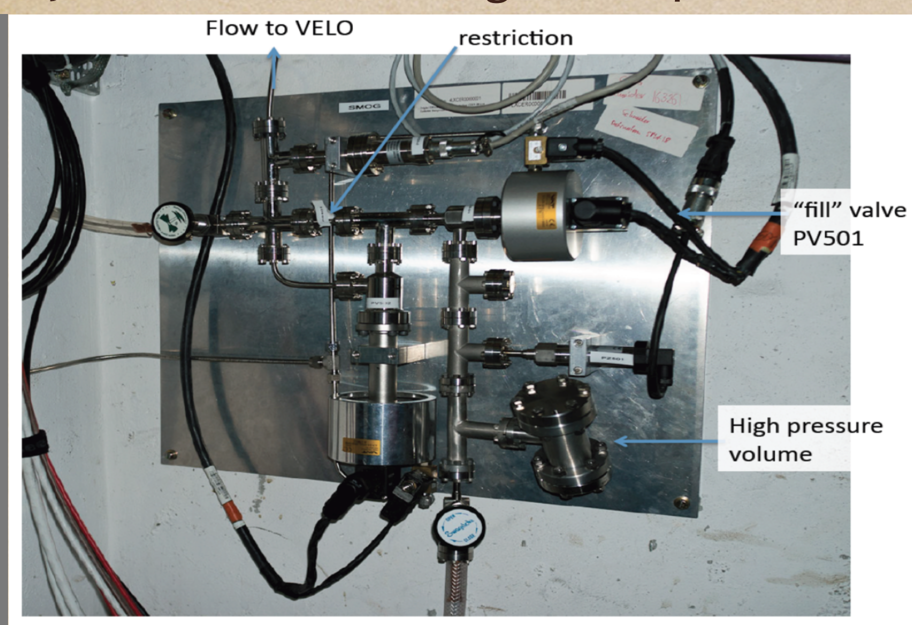
- Focus on (y_{CM}<0) i.e. « large » angles (θ>1°) but still forward angles in the Lab.
- What needs to be improved w.r.t. known detector performances ?
- for e.g. a LHCb-like detector : 2 < η <5

✓ Track multiplicity : cope with the boost

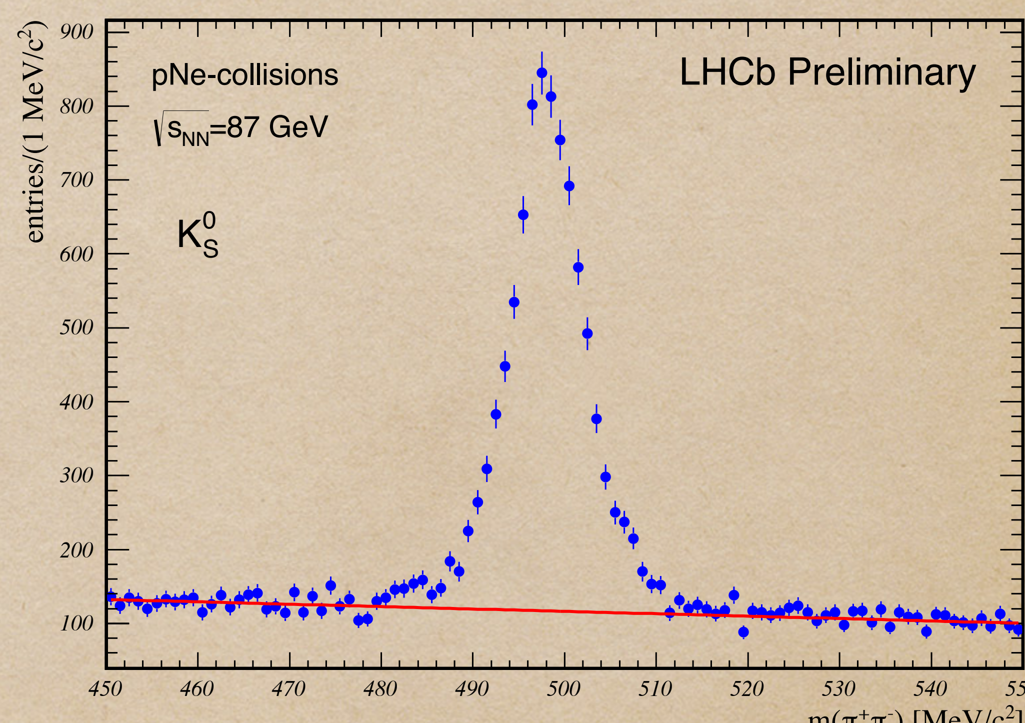
✓ SMOG pilot run : a proof of principle

System for Measuring Overlap with Gas

[M. Schmelling, Les Houches, Jan. 2014]



Inject rare gas (Ne) in the VELO, for luminosity measurements ⟹ **LHCb taking data in fixed-target mode, with gaseous target**



[LHCb-Conf-2012-034]

Strangeness production (for .e.g K^0_s)
4 TeV proton beam on gaseous Ne target

TOWARDS A FORWARD DETECTOR

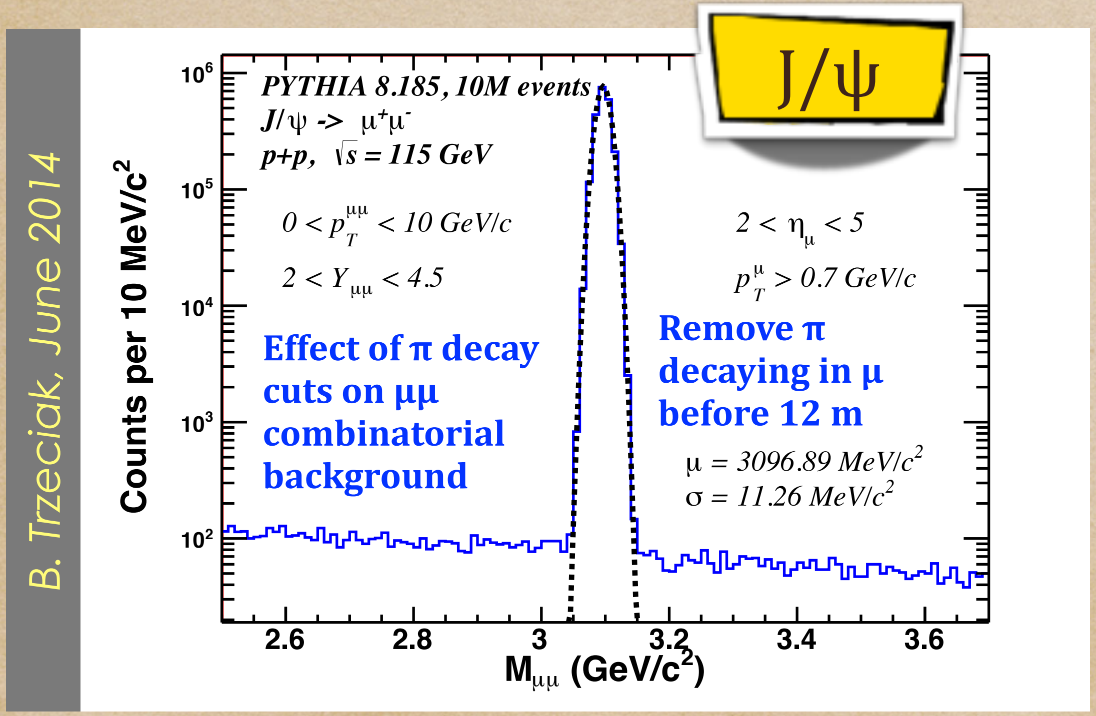
- Focus on (y_{CM}<0) i.e. « large » angles (θ>1°) but still forward angles in the Lab.
- What needs to be improved w.r.t. known detector performances ?
- for e.g. a LHCb-like detector : 2 < η <5

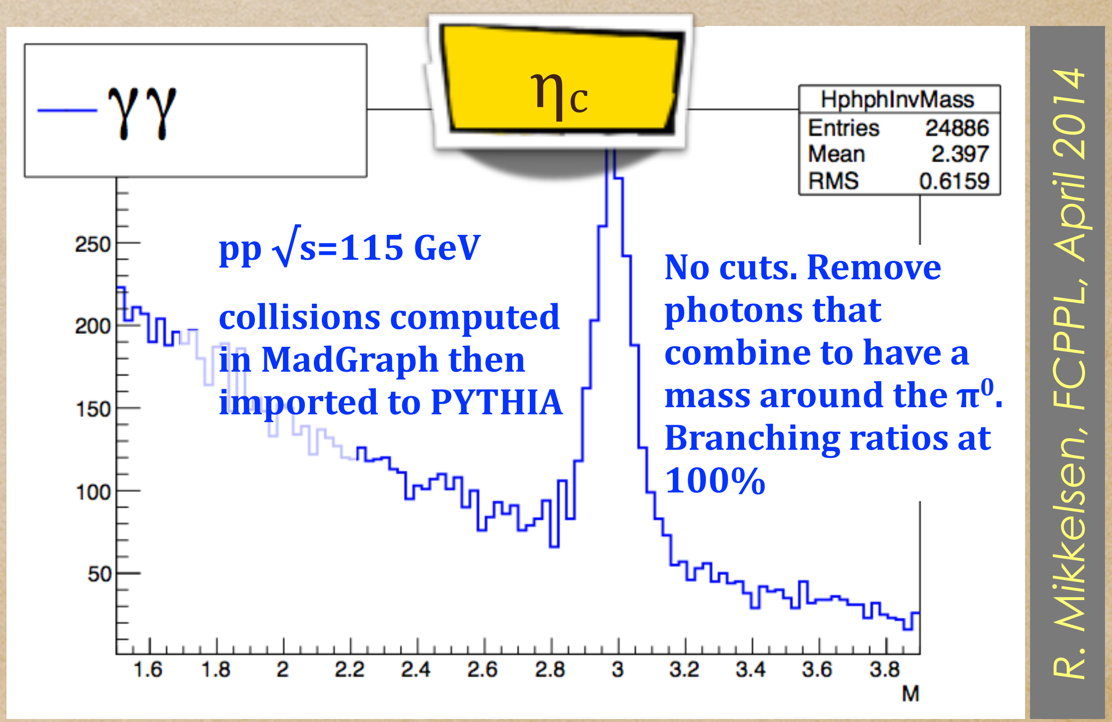
✓ Track multiplicity : cope with the boost

✓ SMOG pilot run : a proof of principle

✓ Fast simulations : first look at the background for quarkonium

Using η coverage, photon ΔE/E, muon Δp/p of LHCb detector, + their usual cuts on muon p_T to improve the S/B ratio





SUMMARY

AFTER : **A F**ixed-**T**arget **E**xpe**R**iment using LHC beams

- provide a novel testing ground for QCD in the high-x frontier
- despite recycling the LHC beam loss, outstanding luminosities are achievable in pp, pA at $\sqrt{s_{NN}}$ = 115 GeV and in PbA at $\sqrt{s_{NN}}$ = 72 GeV, thanks to high density targets
- high-x frontier ⇔ backward physics (y_{CM}<0) ⇔ forward detector in the Lab.
- first simulation studies using a LHCb-like detector : promising setup !

Next : ✷ Expression of Interest in 2015

✷ AFTER week @ CERN, 17-21 Nov. 2014

We're looking for more partners. Join us !

webpage : after.in2p3.fr

SPARE SLIDES

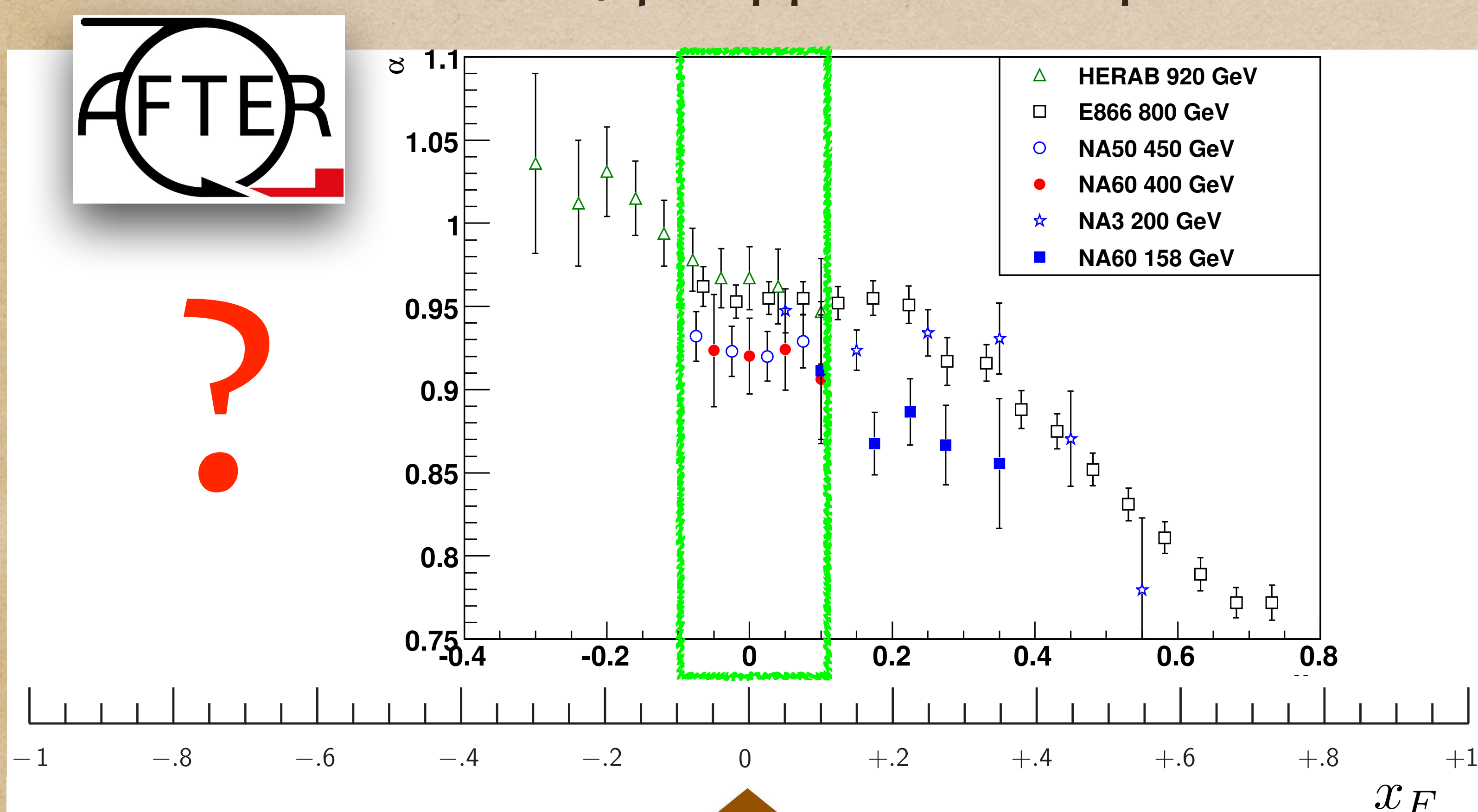
THE UNCHARTED NEGATIVE x_F REGION

p-A

AFTER : precision studies of the nuclear matter

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

J/ψ suppression in pA

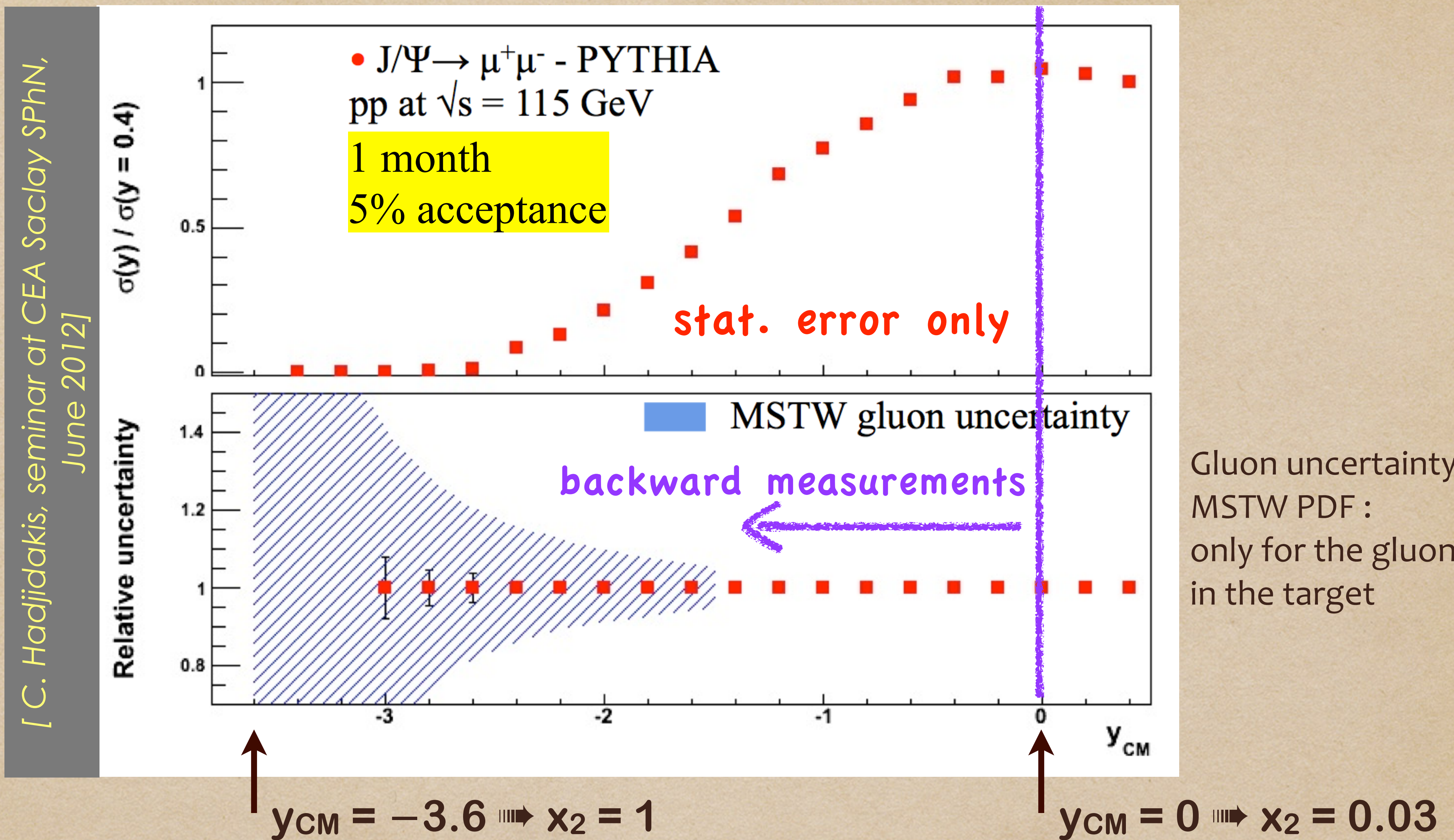


- HeraB down to $x_F = -0.3$
- PHENIX@RHIC : $|x_F| < 0.1$

  (could be wider with ϒ, but low stat.)
- CMS/ATLAS : $|x_F| < 5.10^{-3}$
- LHCb : $5.10^{-3} < x_F < 4.10^{-2}$

Collider mode : narrow range around x_F ~ 0

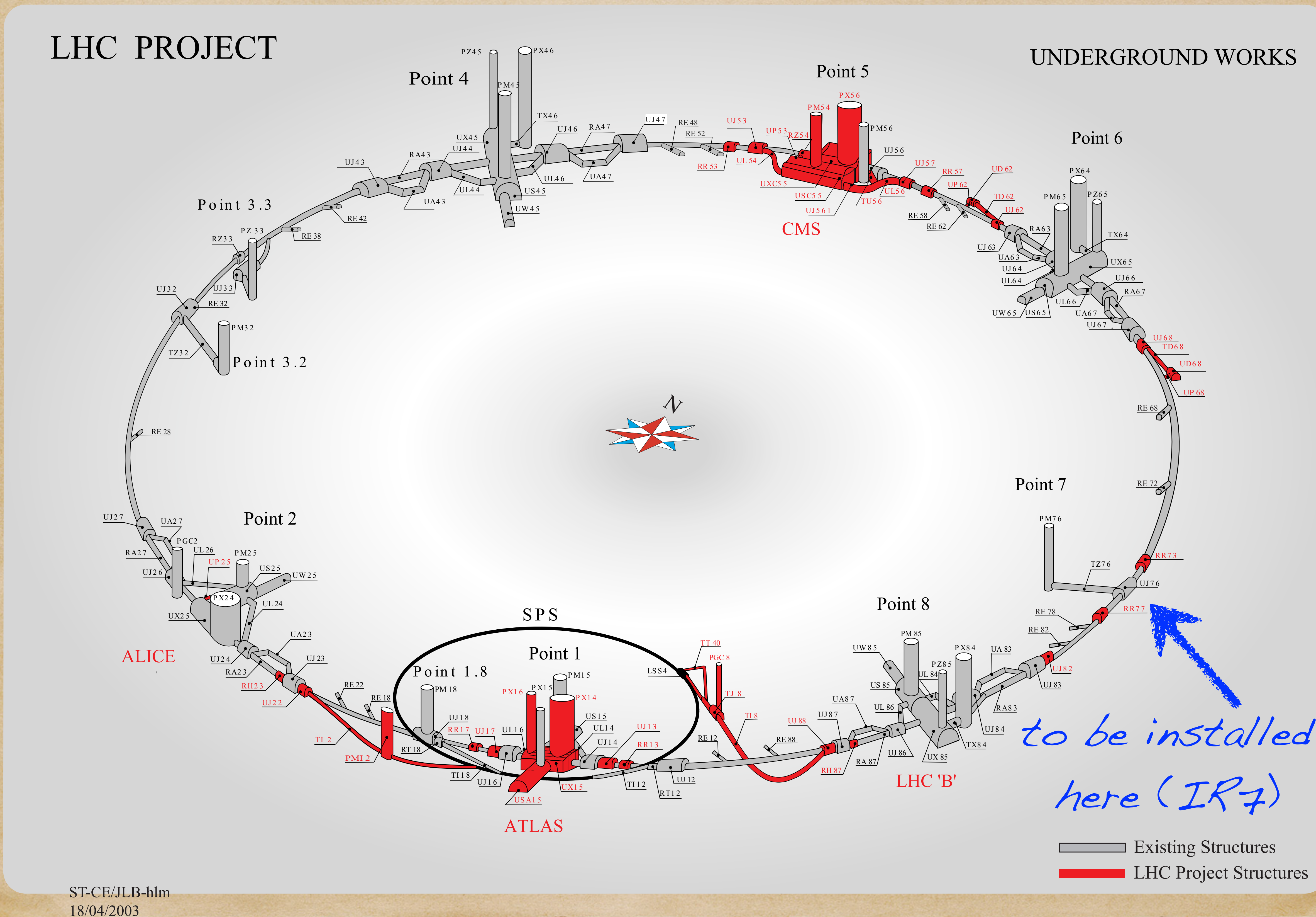
For e.g. statistical precision on large x gluon PDF



Gluon uncertainty from MSTW PDF :
only for the gluon content in the target

- Using **J/ψ as a probe of the gluon PDF**
- assuming initial gluon in the target $x_2 = (M_{J/\psi}/\sqrt{s})\,\exp^{-y_{\rm CM}}$
- **stat. error only** (no propagation of the uncertainties that originate from our understanding of the J/ψ production mechanism)
- **similar measurements can/should be done with other states to reduce the model dependence**

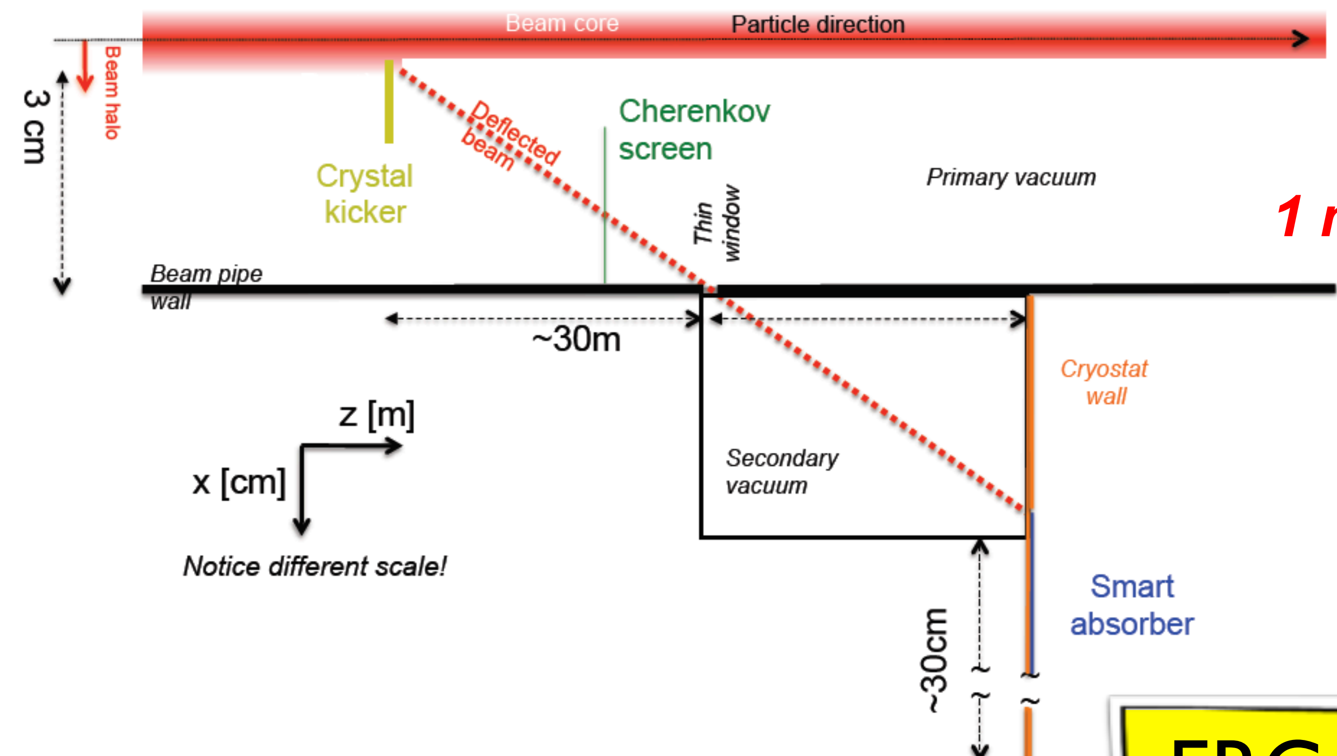
LUA9 @ LHC



LHC PROJECT
UNDERGROUND WORKS
Point 4
Point 5
Point 6
Point 3.3
Point 3.2
Point 2
Point 7
Point 8
SPS
Point 1
Point 1.8
CMS
ALICE
ATLAS
LHC 'B'
N
to be installed here (IR7)
Existing Structures
LHC Project Structures
ST-CE/JLB-hlm
18/04/2003

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)



1 mrad deflection

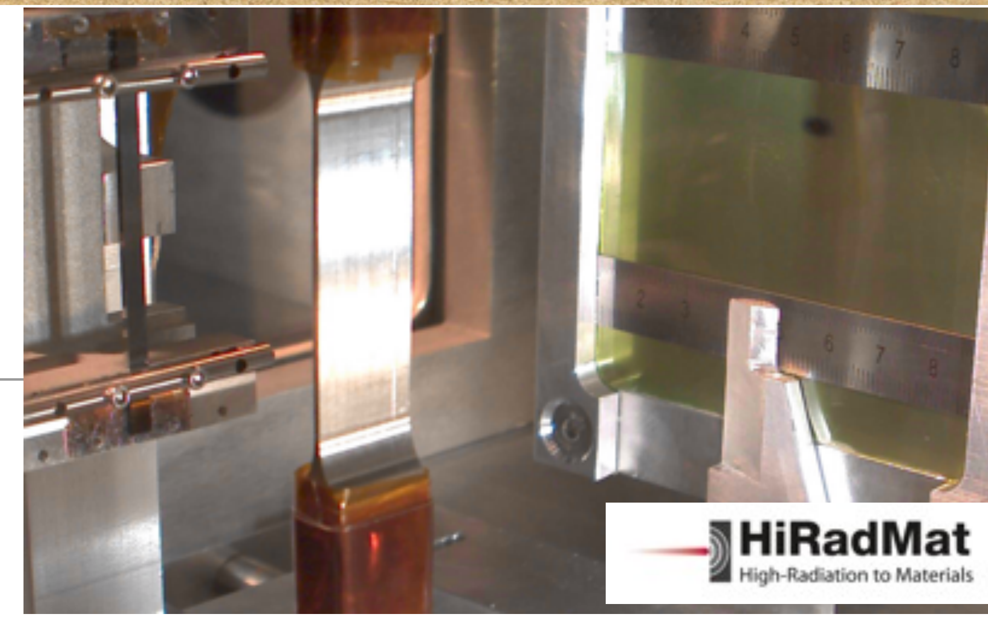
CRYStal channeling to extract a high energy hadron **BE**am from an **A**ccelerator **M**achine

ERC grant accepted in Nov 2013

[G. Cavoto, Physics at AFTER using LHC beams, ECT Trento, Feb. 2013]*

3

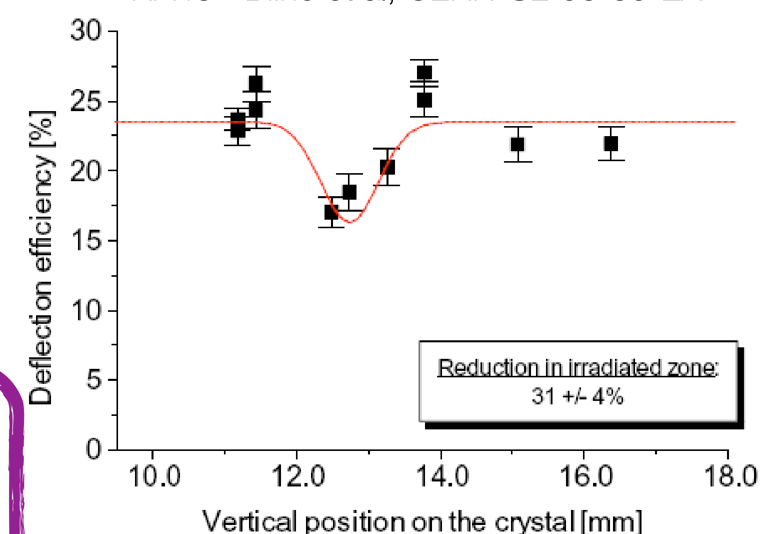
CRYSBEAM could be ready for LS2

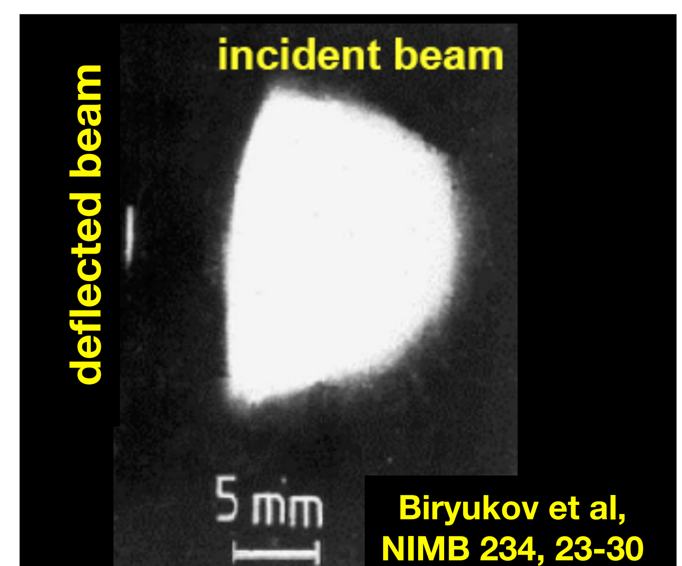


Crystal resistance to irradiation

- **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 x 10^{12} protons every 14.4 s, one year irradiation, **2.4 x 10^{20} protons/cm^2** in total,
  - equivalent to several year of operation for a primary collimator in LHC
  - 10 x 50 x 0.9 mm^3 silicon crystal, 0.8 x 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 x 10^{11} protons per bunch (**3 x 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





30

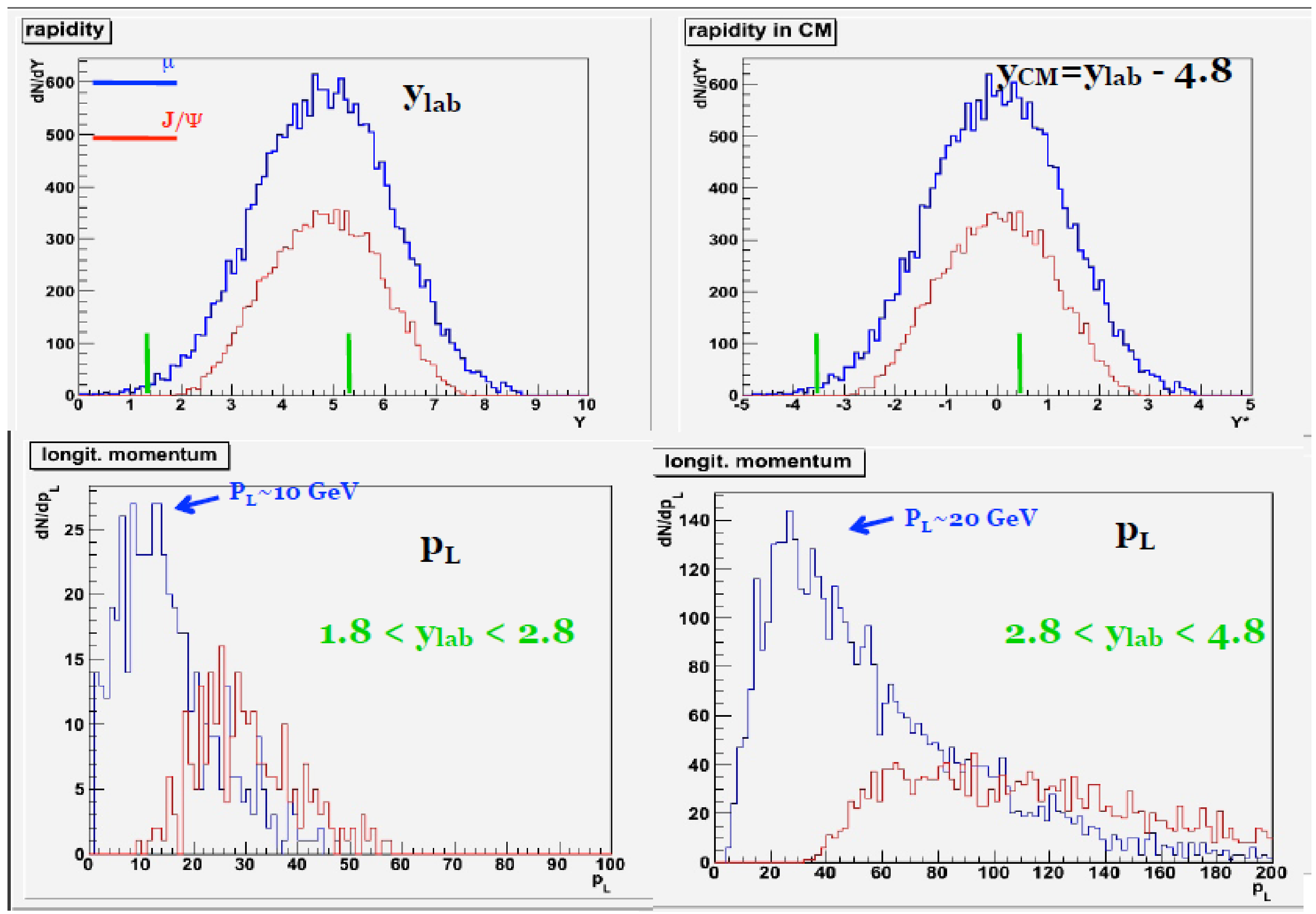
[S. Montesano, Physics at AFTER using LHC beams, ECT Trento, Feb. 2013]*

Some quarkonium and decay-product distributions at 115 GeV in the backward hemisphere ($y_{Lab} < 4.8$)

Pythia 6.4.21: p (7 TeV) + p → J/ψ (isub=86)
J/Ψ → $\mu^+\mu^-$

μ from J/ψ for $1.3 < y_{lab} < 5.3$
$P_T \sim$ 1.7 GeV
$P_L \sim$ 62 GeV

Longitudinal muon momentum
$1.3 < y_{lab} < 3.3$
p_L(max) ~ 16 (50) GeV
$3.3 < y_{lab} < 4.3$
p_L(max)~ 45 (150) GeV
$4.3 < y_{lab} < 5.3$
p_L(max)~ 120 (300) GeV



[J.P. Lansberg, DIS 2014, Apr. 2014]

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)	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 :

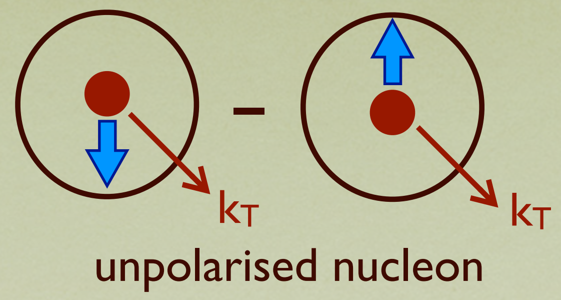
- @ 200 GeV run14pp 12 pb^{-1}, run14dAu 0.15 pb^{-1}
- @ 200 GeV run15AuAu 2.8 nb^{-1} (0.13 nb^{-1} @ 62 GeV)

Nominal LHC luminosity PbPb 0.5 nb^{-1}

some key studies

GLUON MOMENTUM TOMOGRAPHY

p–p



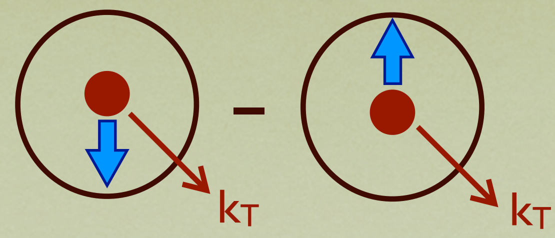
Boer-Mulders function:
Correlation between the gluon k_T and the gluon transverse spin

- **Low p_T C-even quarkonium prod.** is a good probe of the gluon « Boer-Mulders » functions

some key studies

p-p

GLUON MOMENTUM TOMOGRAPHY



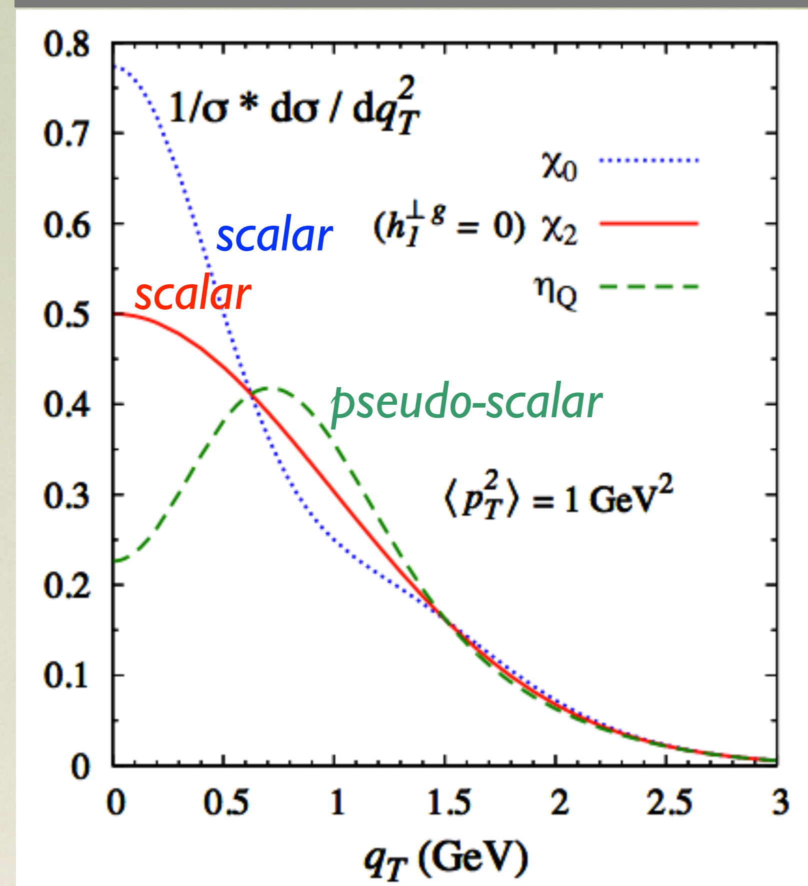
unpolarised nucleon

Boer-Mulders function:
Correlation between the gluon k_T and the gluon transverse spin

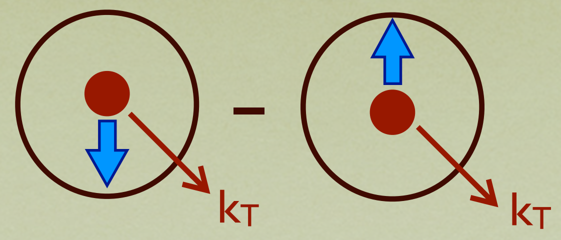
- **Low p_T C-even quarkonium prod.** is a good probe of the gluon « Boer-Mulders » functions
- In particular, the p_T spectra of scalar and pseudo-scalar **$J^{PC}=0^{\pm+}$ quarkonium (χ_{c0}, χ_{b0}, η_c, η_b)** are affected differently by **linearly polarized gluon in unpolarized N**
- Linearly polarized gluon distr. in unpolarized N is unknown, but it is **a tool to determine if Higgs is a scalar or pseudo-scalar boson**

[Boer et al, PRL 108 (2012) 032002]

[Boer, Pisano, PRD 86 (2012) 094007]



GLUON MOMENTUM TOMOGRAPHY



Boer-Mulders function:
Correlation between the gluon k_T and the gluon transverse spin

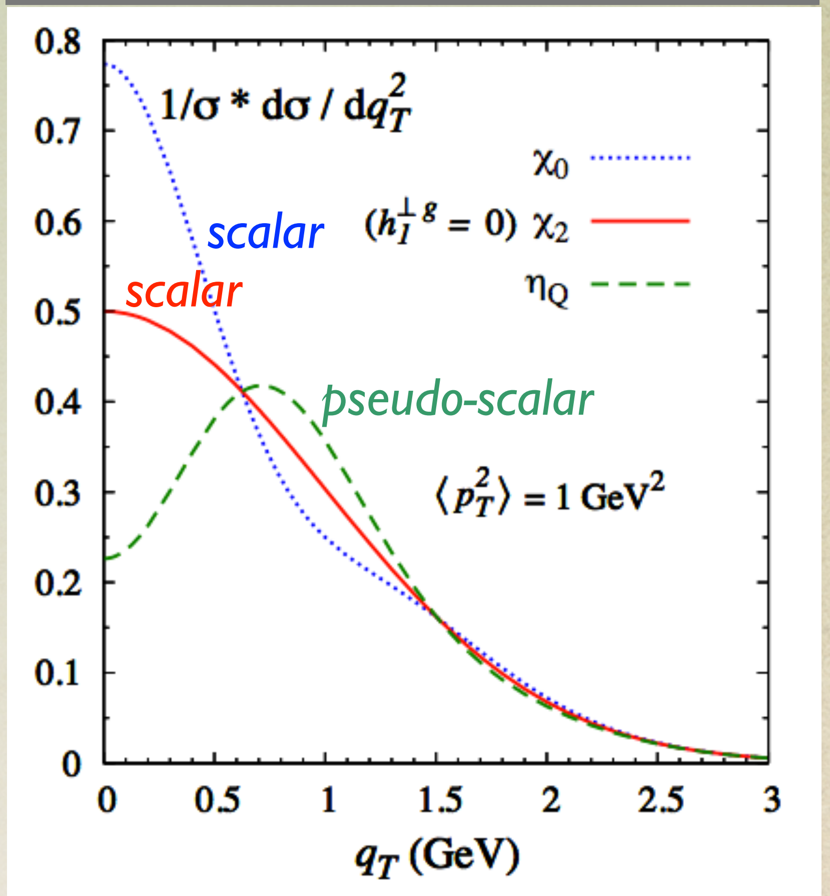
- **Low p_T C-even quarkonium prod.** is a good probe of the gluon « Boer-Mulders » functions
- In particular, the p_T spectra of scalar and pseudo-scalar **$J^{PC}=0^{\pm+}$ quarkonium (χ_{c0}, χ_{b0}, η_c, η_b)** are affected differently by **linearly polarized gluon in unpolarized N**
- Linearly polarized gluon distr. in unpolarized N is unknown, but it is **a tool to determine if Higgs is a scalar or pseudo-scalar boson**

[Boer et al, PRL 108 (2012) 032002]

- back to back **J/ψ + isolated γ** also a good probe of the gluon « Boer-Mulders » functions

[den Dunnen et al., PRL 112 (2014) 212001, J.P. Lansberg, Transversity 2014]

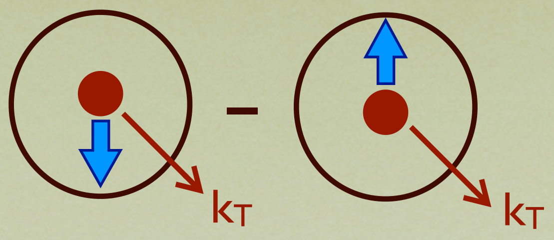
[Boer, Pisano, PRD 86 (2012) 094007]



some key studies

GLUON MOMENTUM TOMOGRAPHY

p–p



Boer-Mulders function:
Correlation between the gluon k_T and the gluon transverse spin

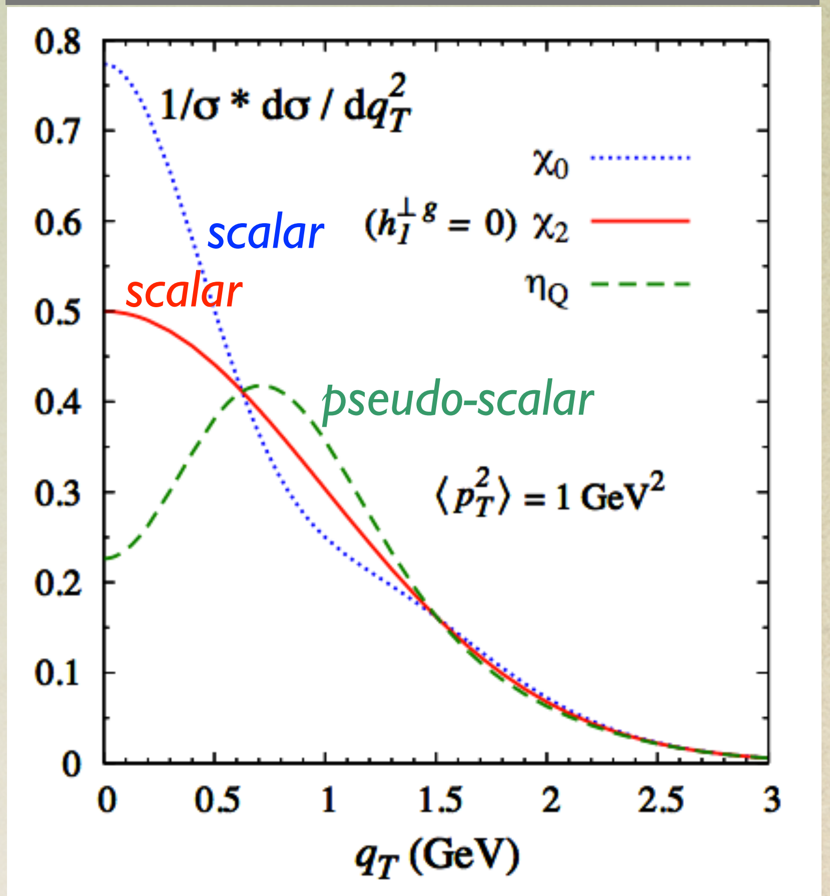
- **Low p_T C-even quarkonium prod.** is a good probe of the gluon « Boer-Mulders » functions
- In particular, the p_T spectra of scalar and pseudo-scalar **$J^{PC}=0^{\pm+}$ quarkonium (χ_{c0}, χ_{b0}, η_c, η_b)** are affected differently by **linearly polarized gluon in unpolarized N**
- Linearly polarized gluon distr. in unpolarized N is unknown, but it is **a tool to determine if Higgs is a scalar or pseudo-scalar boson**

[Boer et al, PRL 108 (2012) 032002]

- back to back **J/ψ + isolated γ** also a good probe of the gluon « Boer-Mulders » functions

[den Dunnen et al., PRL 112 (2014) 212001, J.P. Lansberg, Transversity 2014]

[Boer, Pisano, PRD 86 (2012) 094007]



AFTER :

✓ **boost ⟹ easier access to low p_T C-even quarkonia**

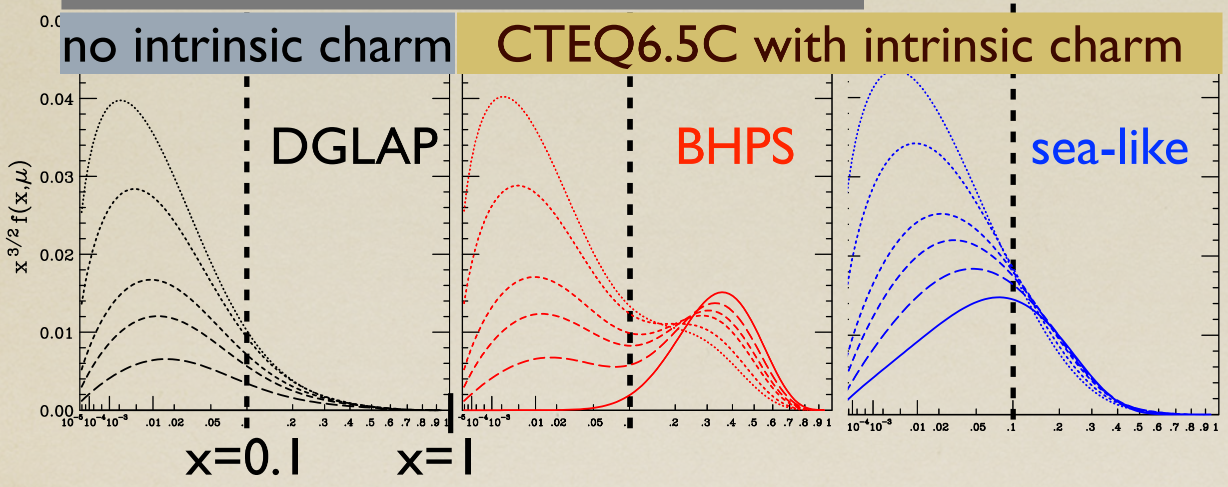
✓ **large quarkonium yields + modern calorimetry (χ_Q detection)**

some key studies

p-p

HEAVY QUARKS AT HIGH X

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



charm (and bottom) PDF at high x :

- first hint of intrinsic charm at large x in F_2^C data from μ⁺-Fe scattering

[EMC Collaboration, NPB 213 (1983) 31]

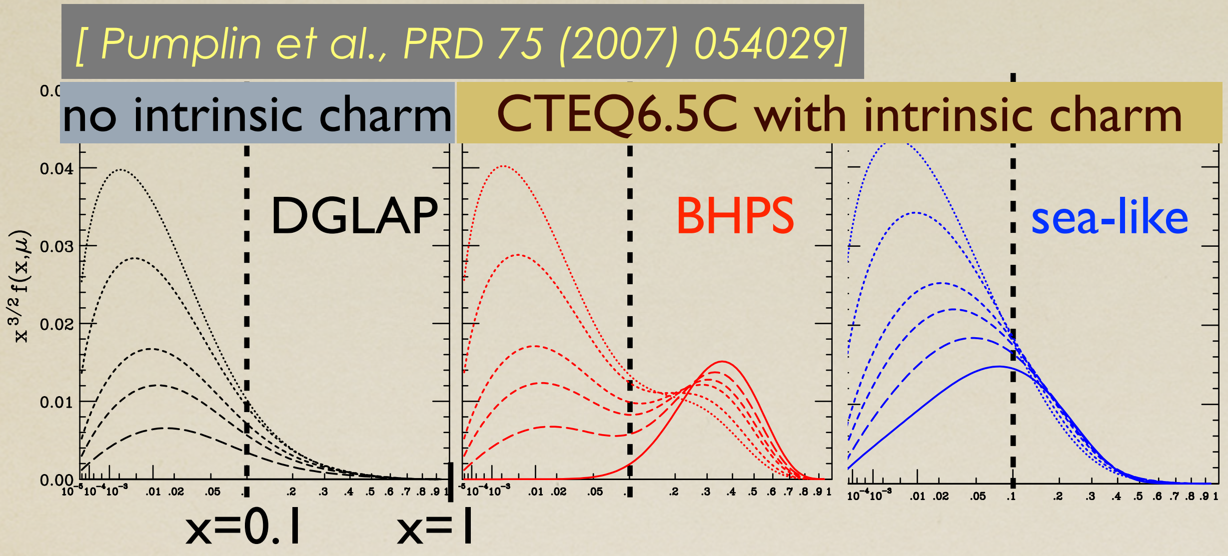
- but with large uncertainties on the derived IC probability (0.86±0.60)%

[Harris et al., NPB 461 (1996) 181]

some key studies

p-p

HEAVY QUARKS AT HIGH X



charm (and bottom) PDF at high x :

- first hint of intrinsic charm at large x in F_2^c data from μ^+-Fe scattering

[EMC Collaboration, NPB 213 (1983) 31]

- but with large uncertainties on the derived IC probability (0.86±0.60)%

[Harris et al., NPB 461 (1996) 181]

exp. probes :

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

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

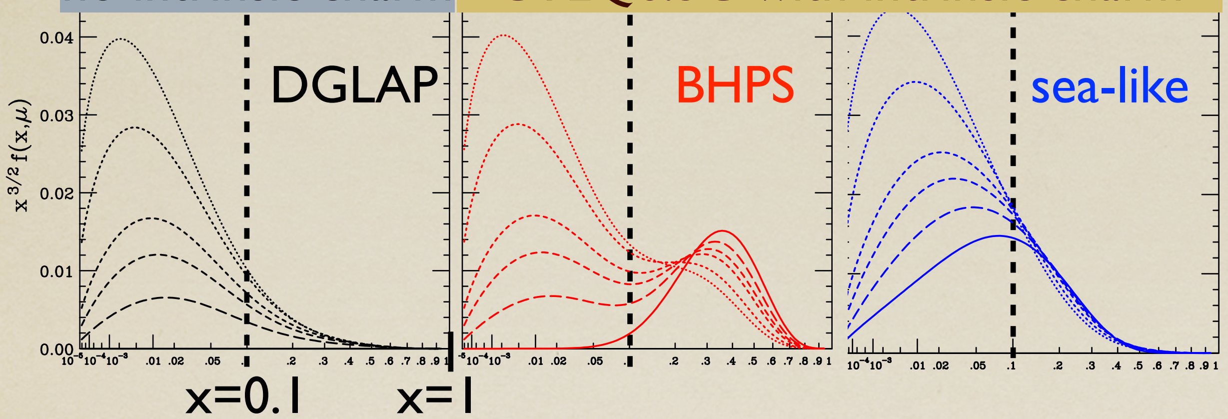
some key studies

p–p

HEAVY QUARKS AT HIGH X

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

no intrinsic charm | CTEQ6.5C with intrinsic charm



charm (and bottom) PDF at high x :

- first hint of intrinsic charm at large x in F_2^c data from μ^+-Fe scattering

[EMC Collaboration, NPB 213 (1983) 31]

- but with large uncertainties on the derived IC probability (0.86±0.60)%

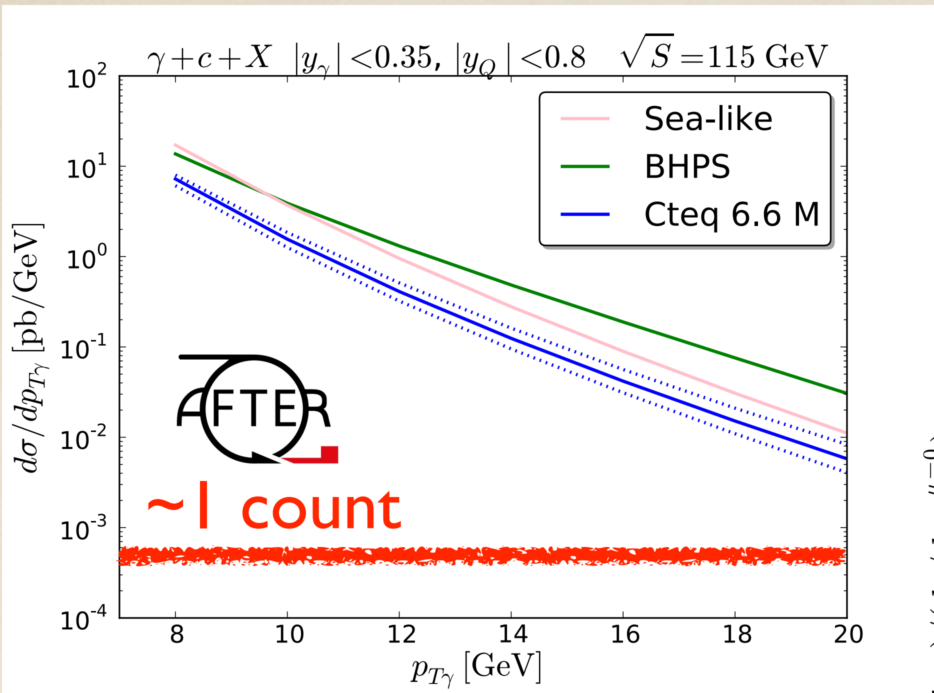
[Harris et al., NPB 461 (1996) 181]

exp. probes :

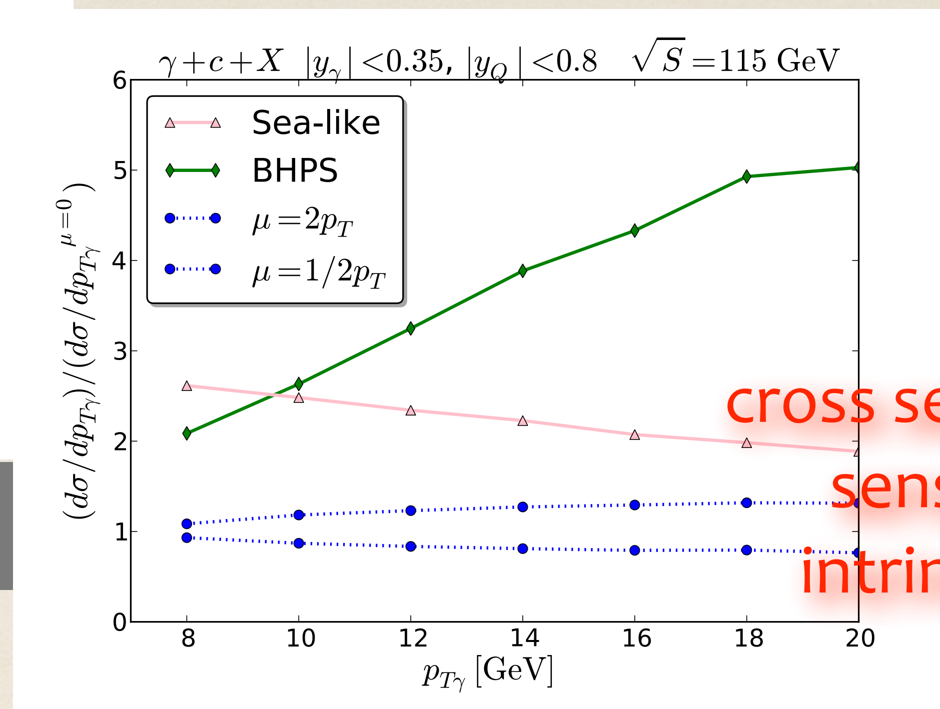
- open charm, open beauty
- new open c, b hadrons at high x_F ?

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

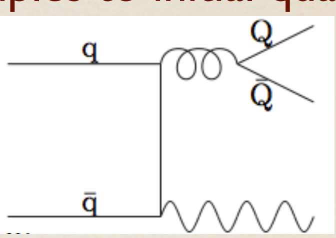
- **γ + c , γ + b production**



[T. Stavreva, Physics at AFTER using LHC beams, ECT* Trento, Feb. 2013]



dominant diagram : photon couples to initial quarks



cross section : good sensitivity to intrinsic charm