Physics opportunities at A Fixed-Target Experiment at the LHC (AFTER@LHC)
and why not FCC ?

Jean-Philippe Lansberg
IPN Orsay, CNRS/IN2P3, Université Paris-Sud

INT Program INT-14-3
Heavy Flavor and Electromagnetic Probes in Heavy Ion Collisions

thanks to M. Anselmino (Torino), R. Arnaldi (Torino), S.J. Brodsky (SLAC), V. Chambert (IPNO), J.P. Didelez (IPNO), E.G. Ferreiro (USC), F. Fleuret (LLR), B. Genolini (IPNO), Y. Gao (Tsinghua), C. Hadjidakis (IPNO), I. Hrvinacova (IPNO), C. Lorcé (SLAC), L. Massacrier (LAL), R. Mikkelsen(Aarhus), A. Rakotozafindrabe (CEA), P. Rosier (IPNO), I. Schienbein (LPSC), E. Scomparin (Torino), B. Trzeciak (Prague U.), U.I. Uggerhøj (Aarhus), R. Ulrich (KIT), Y. Zhang (Tsinghua)+ W. den Dunnen, C. Pisano, M.Schlegel

Part I

Introduction

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- Good thing: small forward detector $\equiv$ large acceptance
- Bad thing: high multiplicity $\Rightarrow$ absorber $\Rightarrow$ physics limitation

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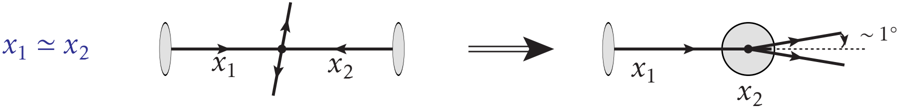
Hadron center-of-mass system

Target rest frame



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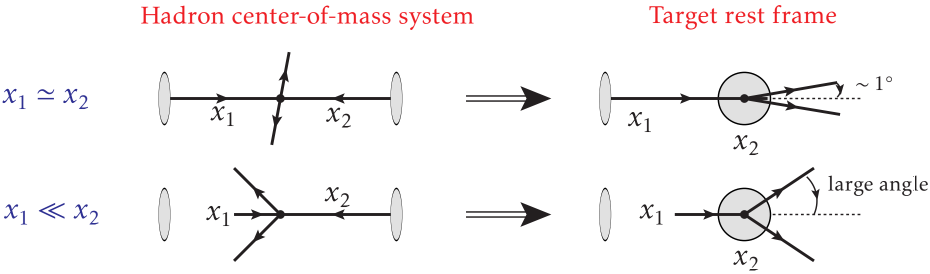

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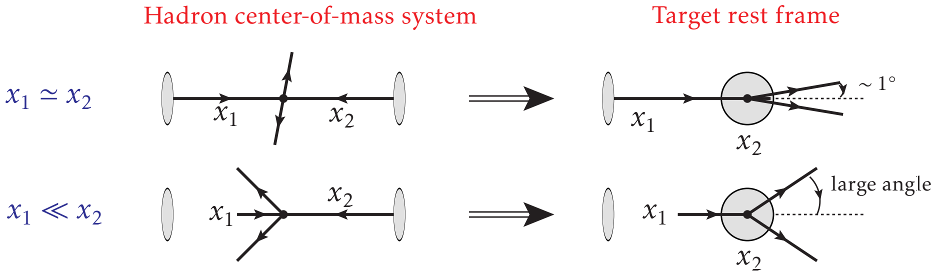

$\boxed{\text{backward physics = large-}x_2\text{ physics}}$

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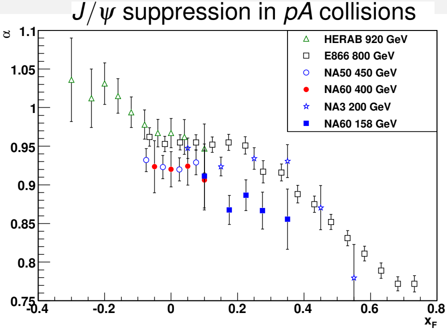

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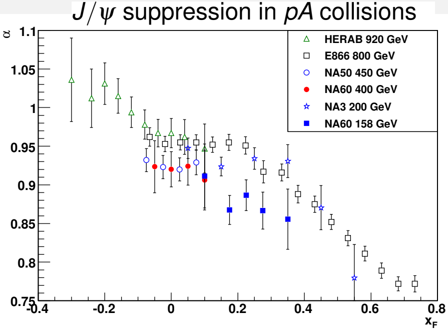

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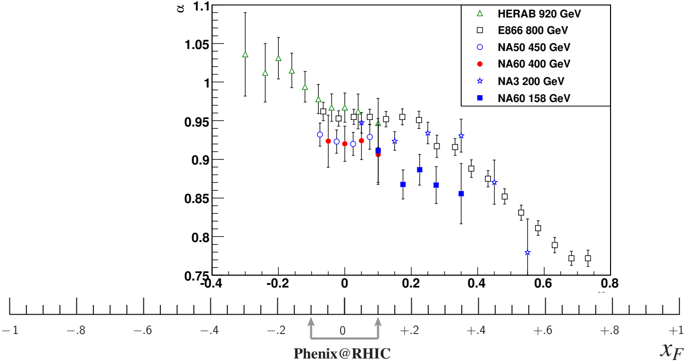

J/ψ suppression in pA collisions

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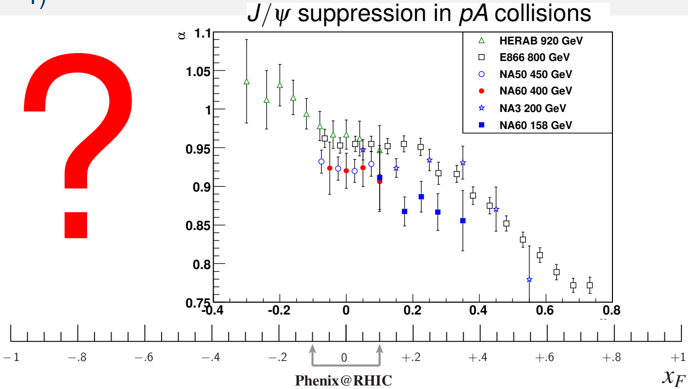

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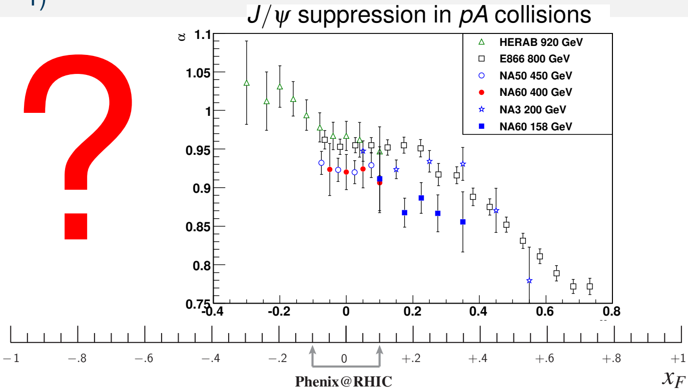
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- If we measure $\Upsilon(b\bar{b})$ at $y_{\rm cms} \simeq -2.5 \Rightarrow x_F \simeq \frac{2m_\Upsilon}{\sqrt{s}} \sinh(y_{\rm cms}) \simeq -1$

The beam extraction

★ The LHC beam may be extracted using “Strong crystalline field”
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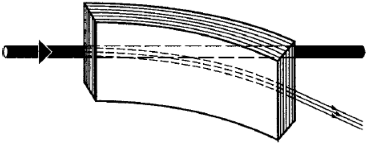

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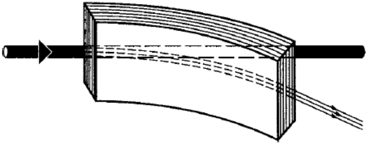

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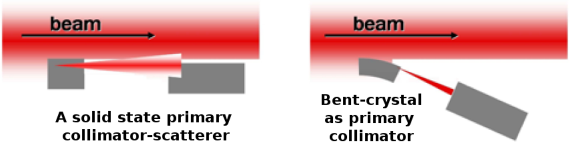

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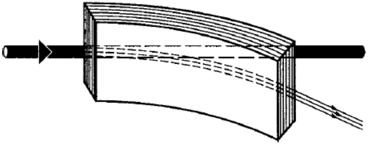

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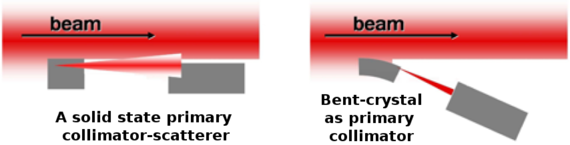

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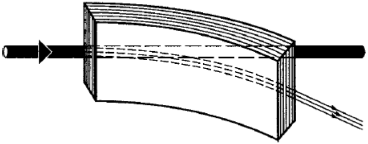

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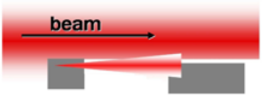
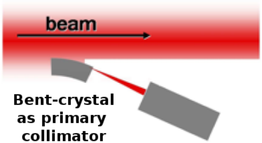


A solid state primary collimator-scatterer



Bent-crystal as primary collimator

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★ 2 crystals and 2 goniometers already installed in the LHC beampipe

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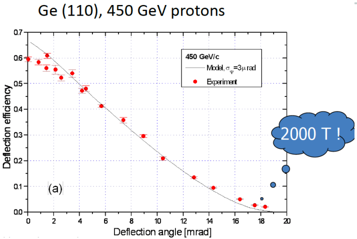

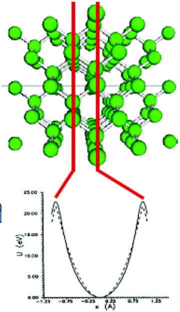

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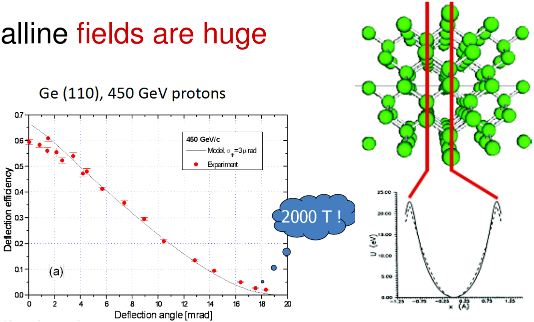

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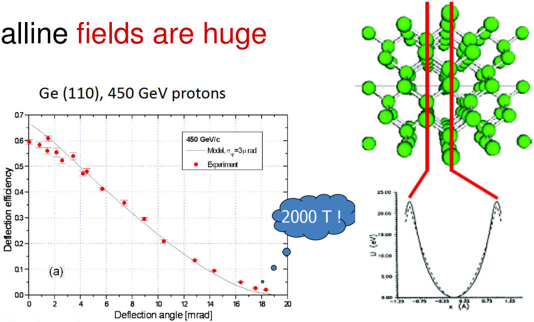

Ge (110), 450 GeV protons

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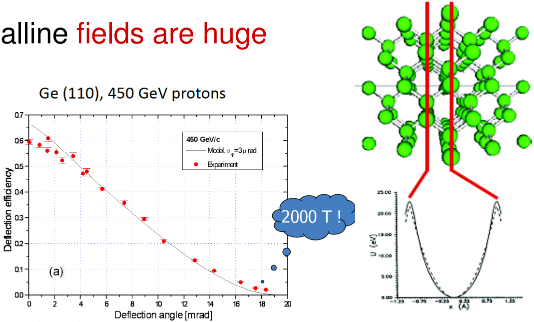

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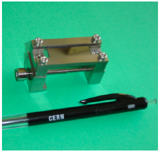
- Simple and robust way to extract the most energetic beam ever:



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Target	**ρ (g.cm^{-3})**	**A**	**$\mathcal{L}$ (μb^{-1}.s^{-1})**	**$\int\mathcal{L}$ (pb^{-1}.yr^{-1})**
Sol. H_2	0.09	1	**26**	**260**
Liq. H_2	0.07	1	**20**	**200**
Liq. D_2	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**

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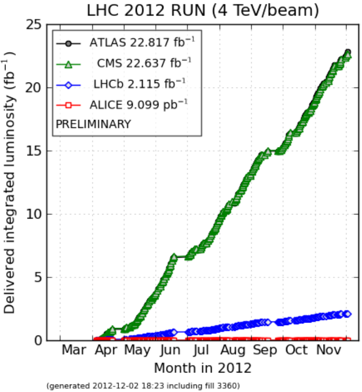

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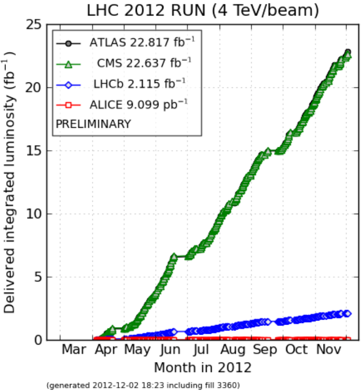

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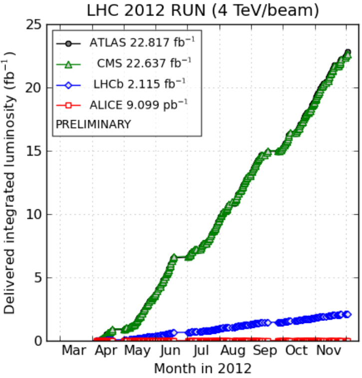
- AFTER vs PHENIX@RHIC:

  3 orders of magnitude larger



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Luminosities with lead beams

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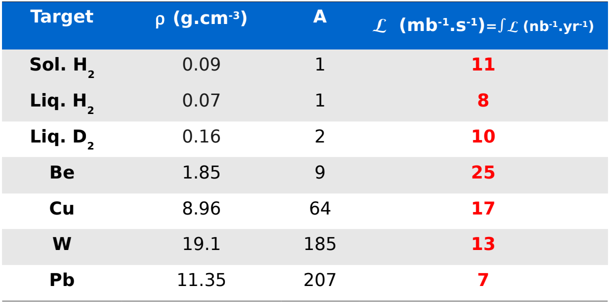
  $$\mathscr{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathscr{N}_A)/A$$
  $$\Phi_{beam} = 2 \times 10^5 \text{ Pb s}^{-1}, \quad \ell = 1 \text{ cm (target thickness)}$$
- Integrated luminosity $\int dt \mathscr{L} = \mathscr{L} \times 10^6$ s for Pb
- Expected luminosities with 2×10^5Pb s^{-1} extracted (1cm-long target)



Target	ρ (g.cm^{-3})	A	$\mathcal{L}$ (mb^{-1}.s^{-1})=$\int\mathcal{L}$ (nb^{-1}.yr^{-1})
Sol. H_2	0.09	1	**11**
Liq. H_2	0.07	1	**8**
Liq. D_2	0.16	2	**10**
Be	1.85	9	**25**
Cu	8.96	64	**17**
W	19.1	185	**13**
Pb	11.35	207	**7**

- Planned lumi for PHENIX Run15AuAu 2.8 nb^{-1} (0.13 nb^{-1} at 62 GeV)
- Nominal LHC lumi for PbPb 0.5 nb^{-1}

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+\mathrm{s}^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+\mathrm{s}^{-1}$ (1/2 the beam loss) **E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31**

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- Extracted "mini" bunches:
  - the crystal sees $2808 \times 11000\ \mathrm{s}^{-1} \simeq 3.10^7$ bunches s^{-1}
  - one extracts $5.10^8/3.10^7 \simeq 15p^+$ from each bunch at each pass
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- similar figures for the Pb-beam extraction

Part II

AFTER: flagship measurements

Key studies: gluons in the proton

- Gluon distribution at mid, high and ultra-high x_B in the proton

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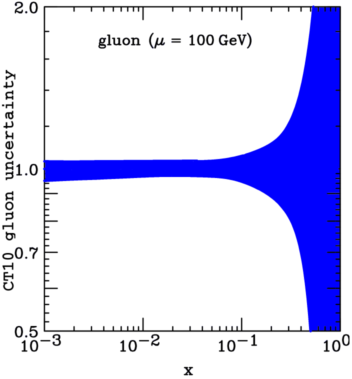
- Gluon distribution at mid, high and ultra-high x_B in the proton
  - Not easily accessible in DIS
  - ⇒ very large uncertainties



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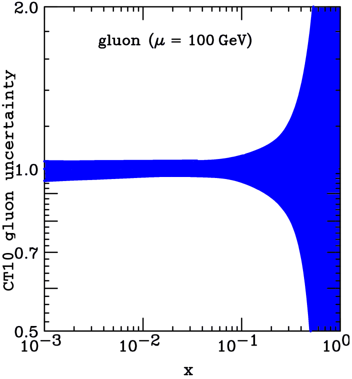

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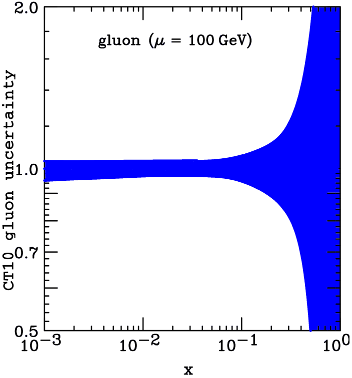

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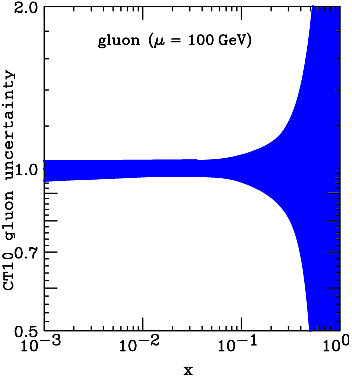

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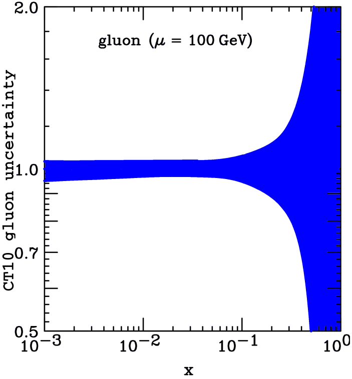

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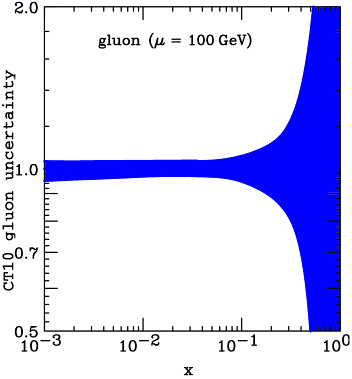

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Multiple probes needed to **check factorisation**

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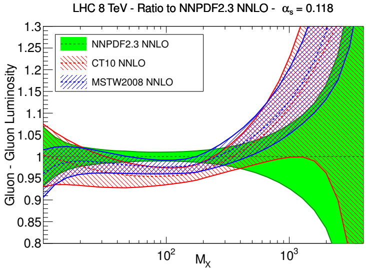

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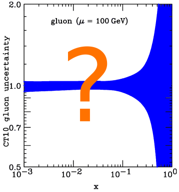
Large-x gluons: important for BSM searches at the LHC

Key studies: gluons in the neutron



Gluon PDF for the neutron unknown

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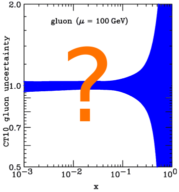

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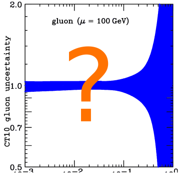

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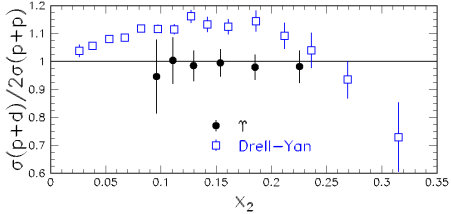

Pioneer measurement by E866

- using $\Upsilon \rightarrow Q^2 \simeq 100$ GeV^2
- outcome: $g_n(x) \simeq g_p(x)$

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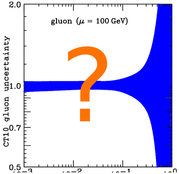

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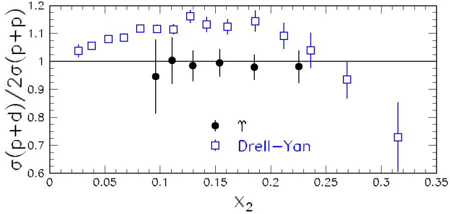

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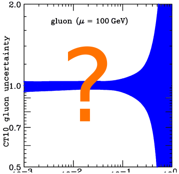

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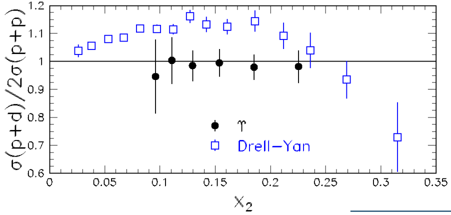

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target	yearly lumi	$\mathscr{B}\frac{dN_{J/\psi}}{dy}$	$\mathscr{B}\frac{dN_{\Upsilon}}{dy}$
1m Liq. H_2	20 fb^{-1}	4.0×10^8	9.0×10^5
1m Liq. D_2	24 fb^{-1}	9.6×10^8	1.9×10^6

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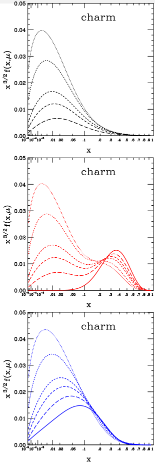

DGLAP

BHPS

Sea-like

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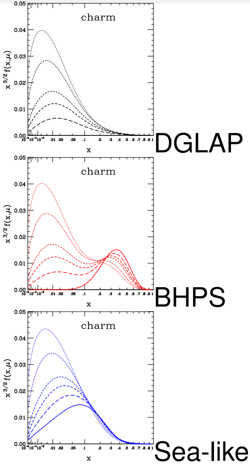

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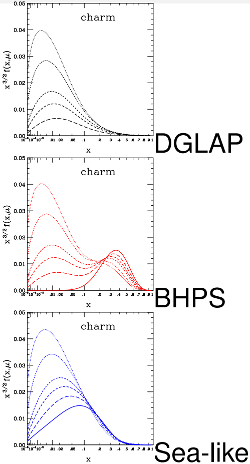

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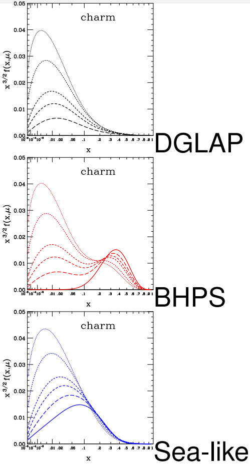

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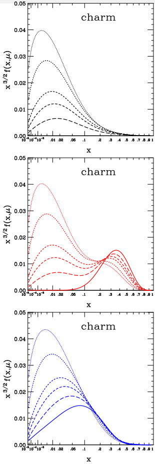

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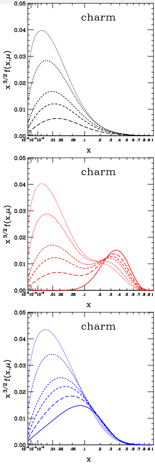

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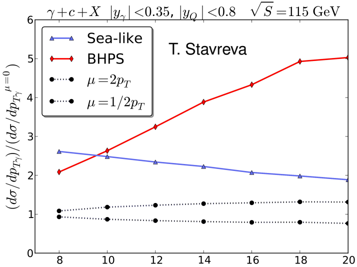

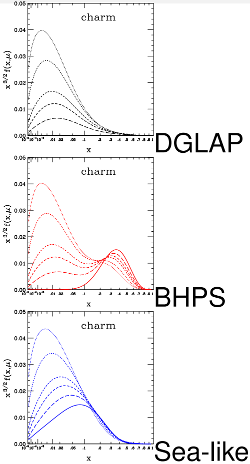

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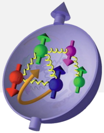

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- the target-rapidity region corresponds to high $x^{\uparrow}$
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- In general, one can carry out an extensive spin-physics program

Access to “Boer-Mulders”-like functions for gluons

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Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER

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Boer-Mulders effect: correlation between the **parton k_T** and **its spin** (in an unpolarized nucleon)

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- Low P_T C-even quarkonium production is a good probe of the gluon “B-M” functions
- Affect the low P_T spectra:

$$\frac{1}{\sigma}\frac{d\sigma(\eta_Q)}{d\mathbf{q}_T^2} \propto 1 - R(\mathbf{q}_T^2) \;\&\; \frac{1}{\sigma}\frac{d\sigma(\chi_{0,Q})}{d\mathbf{q}_T^2} \propto 1 + R(\mathbf{q}_T^2)$$

(R involves $f_1^g(x, k_T, \mu)$ and $h_1^{\perp g}(x, k_T, \mu)$)

Boer-Mulders effect: correlation between the **parton k$_T$** and its spin (in an unpolarized nucleon)

Access to “Boer-Mulders”-like functions for gluons

PHYSICAL REVIEW D **86,** 094007 (2012)

Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER

Daniël Boer[*]

Theory Group, KVI, University of Groningen, Zernikelaan 25, NL-9747 AA Groningen, The Netherlands

Cristian Pisano[†]

Istituto Nazionale di Fisica Nucleare, Sezione di Cagliari, C.P. 170, I-09042 Monserrato (CA), Italy

- Low P_T C-even quarkonium production is a good probe of the gluon “B-M” functions
- Affect the low P_T spectra:
  $$\frac{1}{\sigma}\frac{d\sigma(\eta_Q)}{d\mathbf{q}_T^2} \propto 1 - R(\mathbf{q}_T^2) \;\&\; \frac{1}{\sigma}\frac{d\sigma(\chi_{0,Q})}{d\mathbf{q}_T^2} \propto 1 + R(\mathbf{q}_T^2)$$
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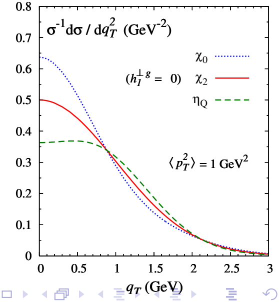

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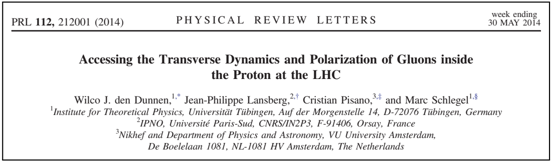

PRL **112,** 212001 (2014) PHYSICAL REVIEW LETTERS week ending 30 MAY 2014

Accessing the Transverse Dynamics and Polarization of Gluons inside the Proton at the LHC

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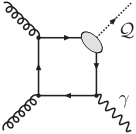

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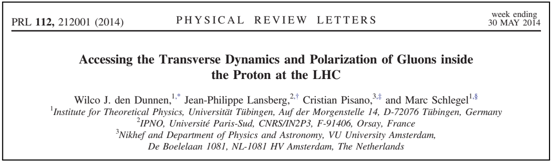

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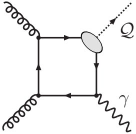

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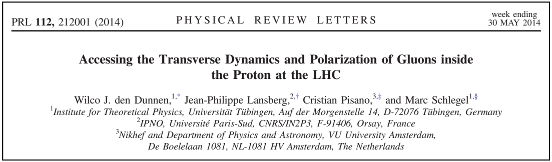

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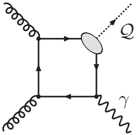

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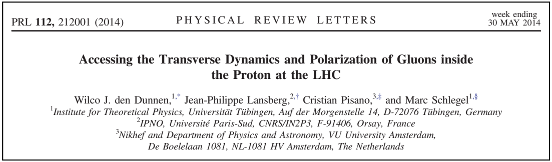

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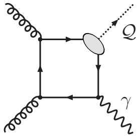

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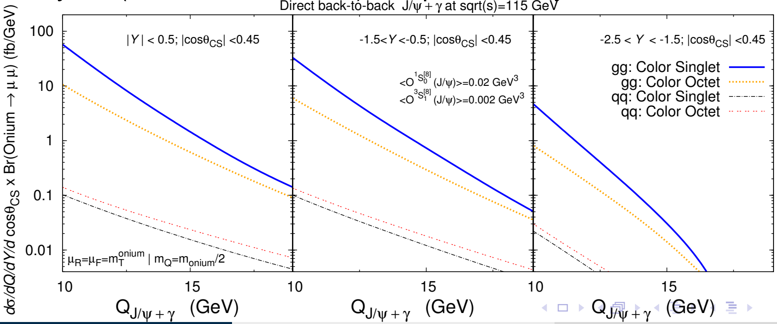

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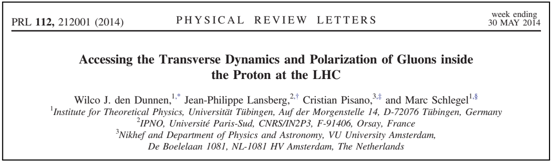

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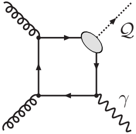

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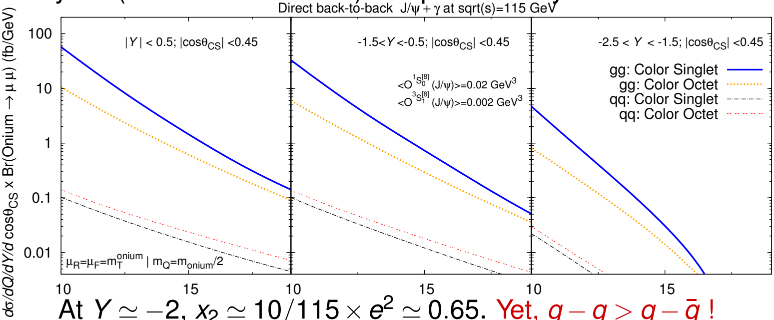

At $Y \simeq -2$, $x_2 \simeq 10/115 \times e^2 \simeq 0.65$. Yet, $g-g > q-\bar{q}$!

SSA in heavy-flavour studies with AFTER@LHC

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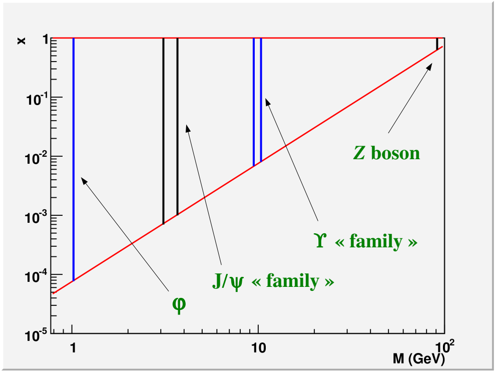
- $\psi +$ DY pair, i.e. $\psi + \ell\ell$, is another option, although with a small rate

AFTER@LHC: A dilepton observatory ?

- Region in x probed by dilepton production as function of $M_{\ell\ell}$



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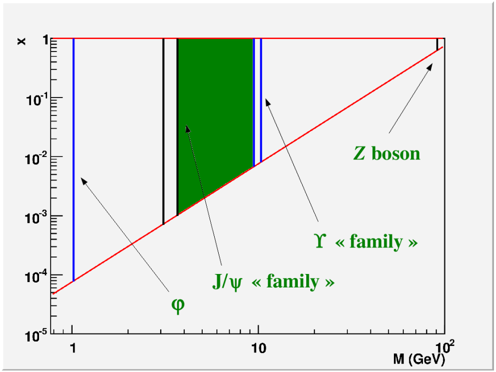

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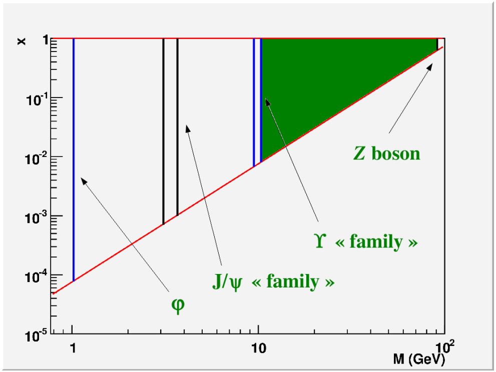

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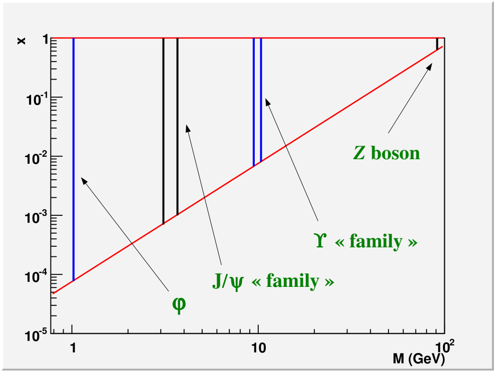

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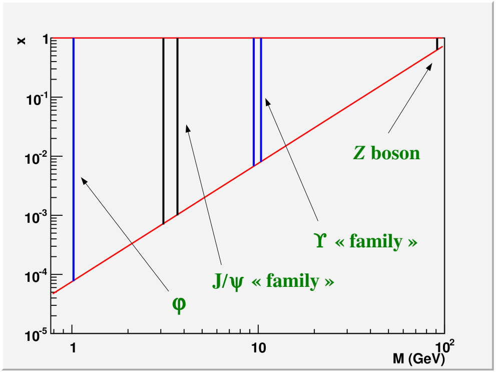

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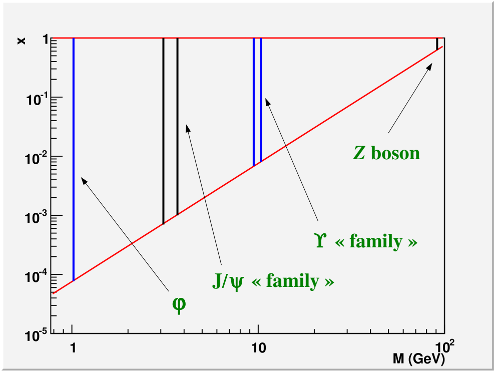

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➠ To do: to look at the rates to see how competitive this will be

SSA in Drell-Yan studies with AFTER@LHC

- Relevant parameters for the future proposed polarized DY experiments.

S.J. Brodsky, F. Fleuret, C. Hadjidakis, JPL, Phys. Rep. 522 (2013) 239
V. Barone, F. Bradamante, A. Martin, Prog. Part. Nucl. Phys. 65 (2010) 267.

Experiment	particles	energy (GeV)	$\sqrt{s}$ (GeV)	$x_p^\uparrow$	$\mathscr{L}$ ($\mathrm{nb}^{-1}\mathrm{s}^{-1}$)
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
P1027	$p^\uparrow + p$	120	15	$0.35 \div 0.85$	400-1000
P1039	$p+p^\uparrow$	120	15	$0.1 \div 0.3$	400-1000

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- $\ell^+\ell^-$ angular distribution: separation Sivers vs. Boer-Mulders effects

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RHI Int.T
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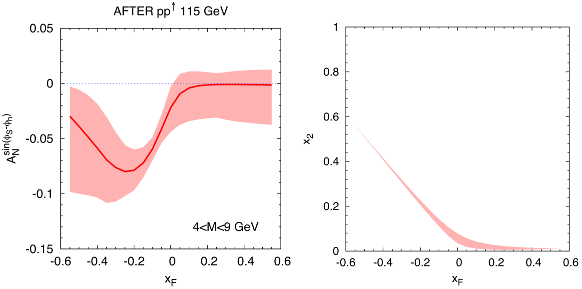
P10

expected Sivers asymmetry in
D-Y@AFTER, sign change,
no TMD evolution



M. Anselmino, ECT*, Feb. 2013 (Courtesy U. d'Alessio)

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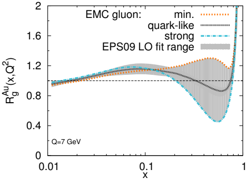

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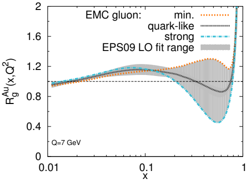

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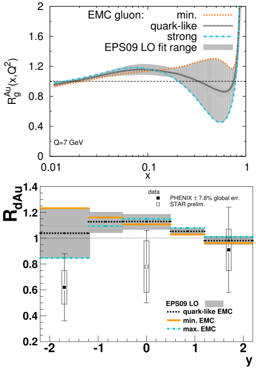

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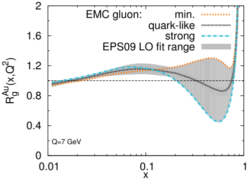

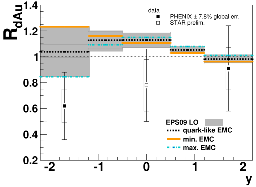

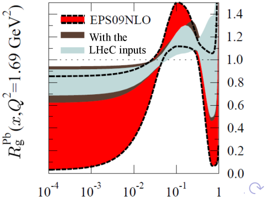

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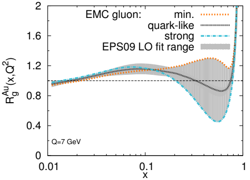
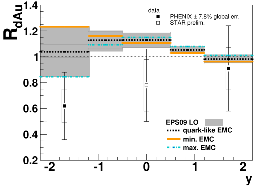
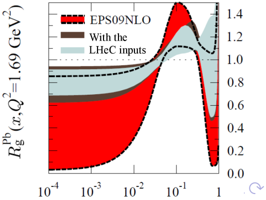
- Unique potential for gluons at $x > 0.1$







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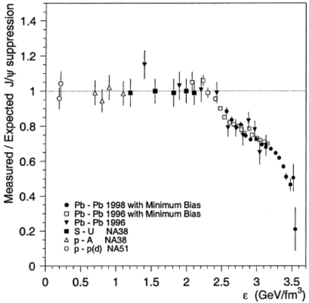

Fig. 7. Measured J/ψ production yields, normalised to the yields expected assuming that the only source of suppression is the ordinary absorption by the nuclear medium. The data is shown as a function of the energy density reached in the several collision

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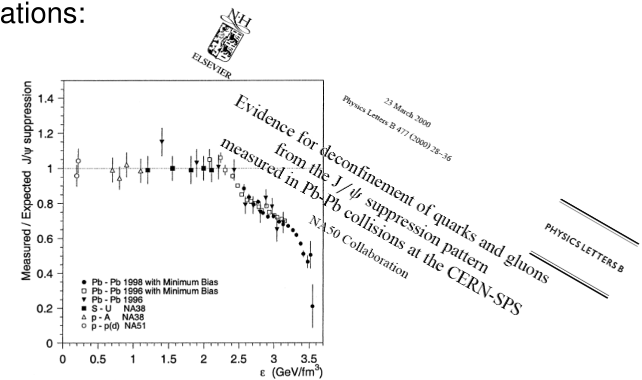

ELSEVIER

23 March 2000

Physics Letters B 477 (2000) 28–36

PHYSICS LETTERS B

Evidence for deconfinement of quarks and gluons from the J/ψ suppression pattern measured in Pb-Pb collisions at the CERN-SPS

NA50 Collaboration

Fig. 7. Measured J/ψ production yields, normalised to the yields expected assuming that the only source of suppression is the ordinary absorption by the nuclear medium. The data is shown as

Physics with the lead-ion beam

- Design LHC lead-beam energy: 2.76 TeV per nucleon
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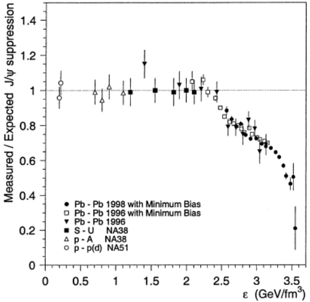

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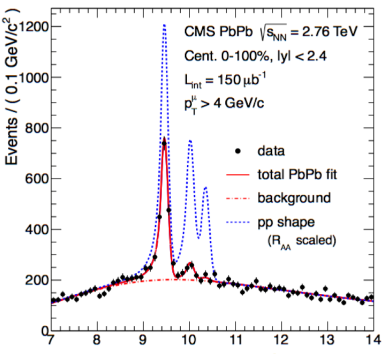
- Enough stat to perform the same study as CMS at low energy



Precision heavy-flavour studies in Heavy-Ion Collisions

- Very precise *pp* and *pA* baselines (yields, *A* & *y* dependences)

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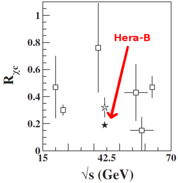

HERA-B PRD 79 (2009) 012001, and ref. therein

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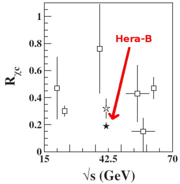

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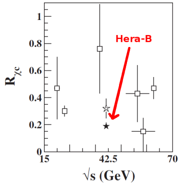

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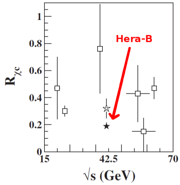
- Real hope of being able to look at the quarkonium sequential suppression



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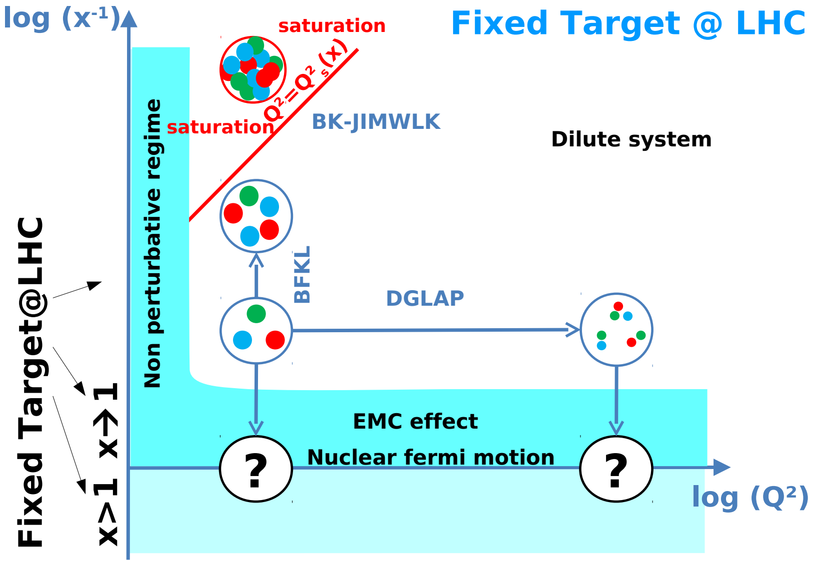
log (x⁻¹)
saturation
Fixed Target @ LHC
$Q^2=Q^2_s(x)$
saturation
BK-JIMWLK
Dilute system
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BFKL
DGLAP
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x>1
EMC effect
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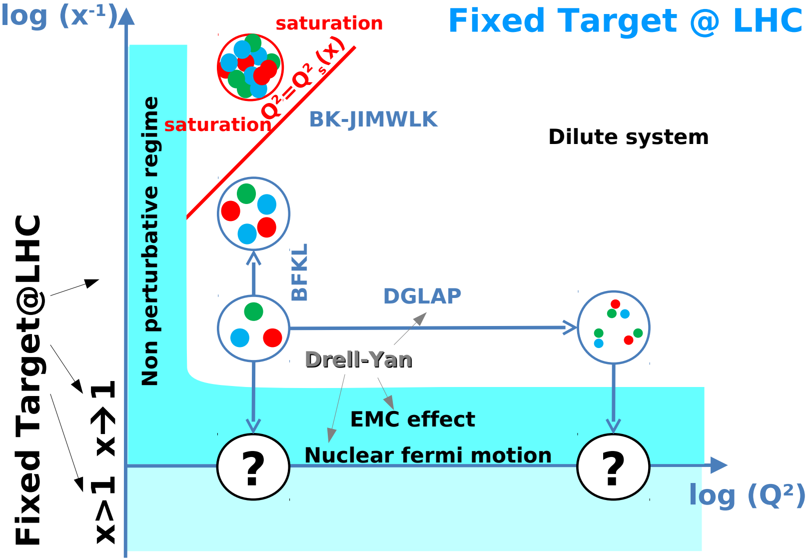
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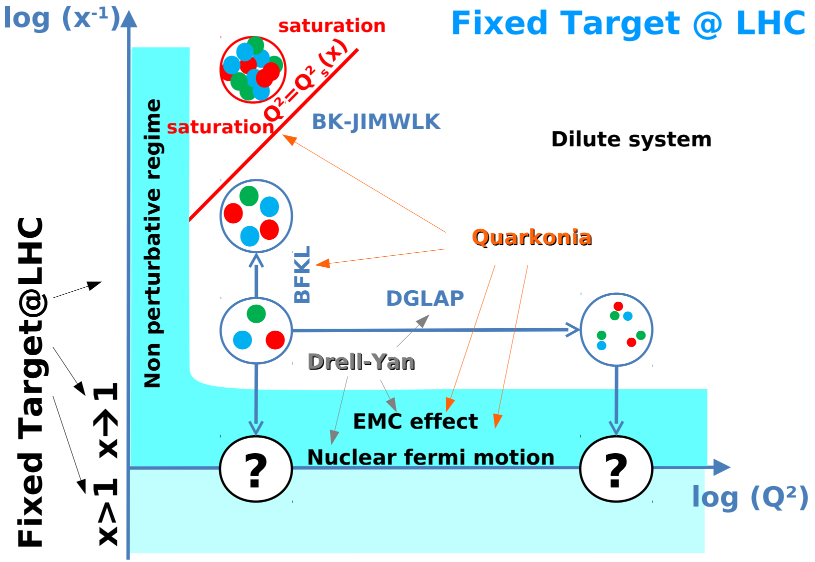
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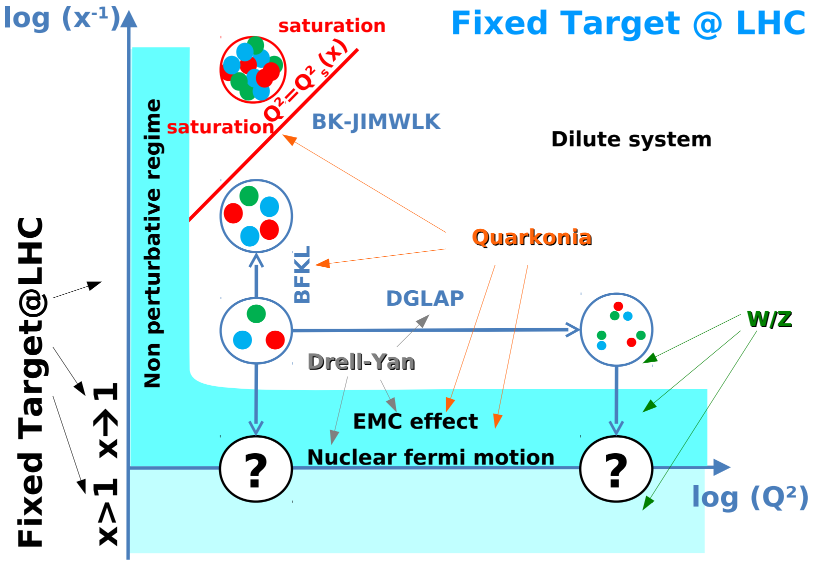
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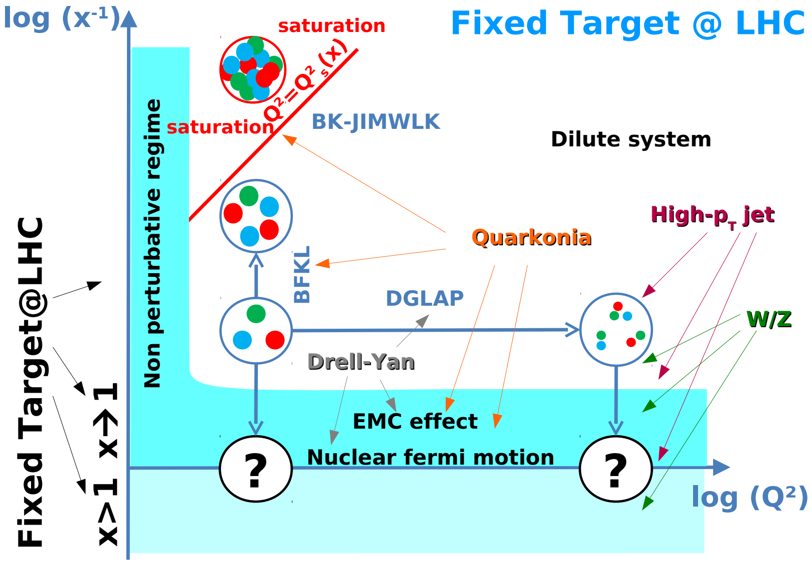
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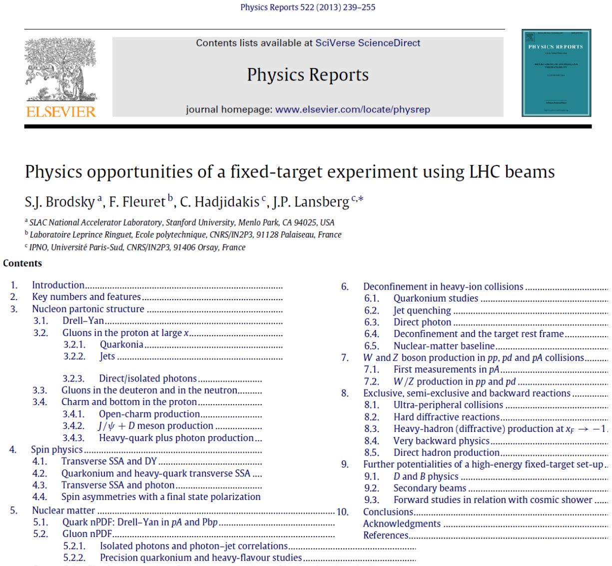
More details in



Physics Reports 522 (2013) 239–255

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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

Contents

Part III

First simulations

First simulation: is the boost an issue ?

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- LHCb has successfully carried out *p*Pb and Pb*p* analyses at 5 TeV

First simulation: is the boost an issue ?

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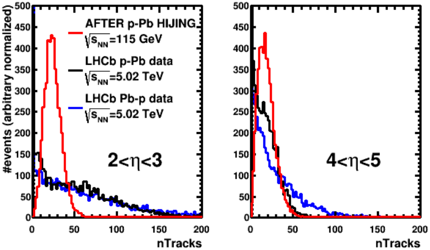

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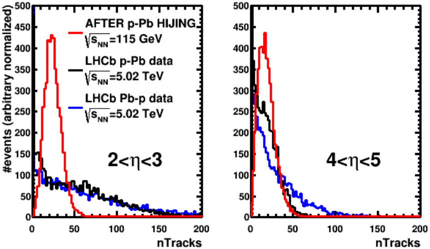


- Despite the boost, the number of tracks in the LHCb acceptance [forward η] is lower in the fixed mode than in the collider mode
- Very encouraging indication that the boost is not issue, but really an asset

FAST SIMULATIONS FOR QUARKONIA (pp $\sqrt{s}$ = 115 GeV) USING LHCB RECONSTRUCTION PARAMETERS

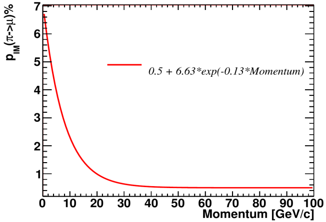
- ☐ Simulations with Pythia 8.185
- ☐ LHCb detector is NOT simulated but LHCb reconstruction parameters are introduced in the fast simulation (resolution, analysis cuts, efficiencies…)

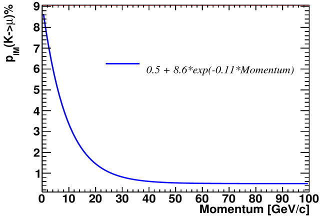
Requirements
Momentum resolution : $\Delta p/p = 0.5\%$
Muon identification efficiency: 98%

Cuts at the single muon level
$2 < \eta_\mu < 5$
$p_T^\mu > 0.7$ GeV/c

Muon misidentification
If π and K decay before the calorimeters (12m), they are rejected by the tracking
Else a misidentification probability is applied

[Performance of the muon identification at LHCb, F. Achilli et al, arXiv:1306.0249]



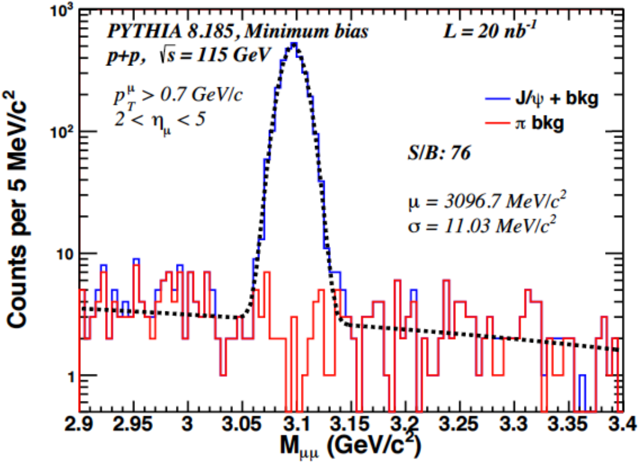


R. Mikkelsen, B. Trzeciak

J/Ψ →μ⁺μ⁻ IN MB pp @ 115 GEV

- ☐ **For 1m of H target and few tens of seconds of data taking**

B. Trzeciak, July 2014, Orsay



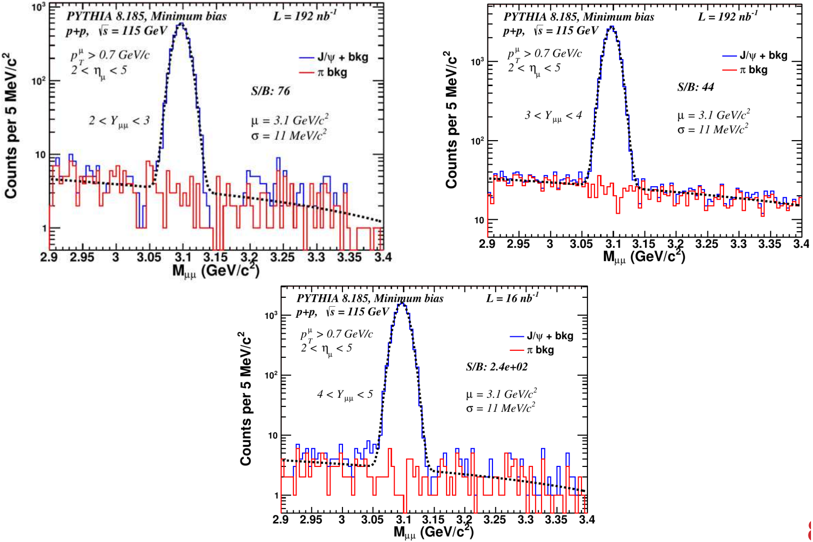
Misidentified pions is the dominant source of background

R. Mikkelsen, B. Trzeciak

$J/\Psi \rightarrow \mu^+\mu^-$ IN MB pp @ 115 GEV (BINS IN RAPIDITY)

- ☐ **For 1m of H target and few minutes of data taking**

B. Trzeciak, July 2014, Orsay



R. Mikkelsen, B. Trzeciak

Accessing the large *x* glue with quarkonia:

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

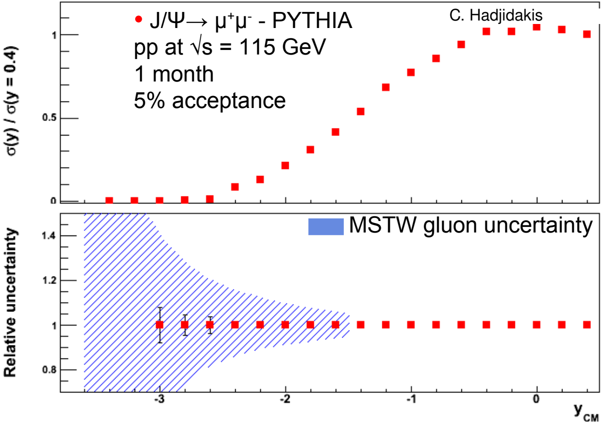
Statistical relative uncertainty
Large statistics allow to access
very backward region

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} ~ 0 → $x_g = 0.03$
y_{CM} ~ -3.6 → $x_g = 1$

Υ: larger x_g for same y_{CM}
y_{CM} ~ 0 → $x_g = 0.08$
y_{CM} ~ -2.4 → $x_g = 1$



⇒ Backward measurements allow to access large x gluon pdf

Assuming that we understand the quarkonium-production mechanisms

Part IV

Special Issue in Advances in High-Energy Physics & Workshop at CERN

Advances in High Energy Physics

Special Issue on

Physics at a Fixed-Target Experiment Using the LHC Beams

CALL FOR PAPERS

Fixed-target experiments (FTE) have brought essential contributions to particle and nuclear physics. They have led to particle discoveries (Ω, J/ψ, γ,...) and evidence for the novel dynamics of quarks and gluons in heavy-ion collisions. In accessing high x_F and in offering options for (un-) polarised proton and nuclear targets, they have also led to the observation of surprising QCD phenomena. They offer specific advantages compared to collider experiments: access to high x_F, high luminosities, target versatility, and polarisation.

The LHC 7 TeV protons on targets release a c.m.s. energy close to 115 GeV (72 GeV with Pb), in a range never explored so far, significantly higher than that at SPS and not far from RHIC. The production of quarkonia, DY, heavy flavours, jets, and γ in *pA* collisions can be studied with statistics previously unheard of and in the backward region, $x_F < 0$, which is uncharted. High precision QCD measurements can also obviously be carried out in *pp* and *pd* collisions with H_2 and D_2 targets. With the 50 TeV protons of the future circular collider (FCC), the c.m.s. energy could reach 300 GeV for original studies of W and Z boson, and perhaps H^0, production in *pp* and *pA* collisions.

With the LHC Pb beam, one can study the quark-gluon plasma (QGP) from the viewpoint of the nucleus rest frame after its formation. Thanks to modern technologies, studies of, for instance, direct γ and quarkonium *P*-waves production in heavy-ion collisions can be envisioned.

Polarising the target allows one to study single-spin correlations including the Sivers effect, hence, the correlation between the parton k_T and the nucleon spin.

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- TMDs and single-spin asymmetries
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- Secondary beams
- Simulation tools for high-energy physics
- Beam collimation and extraction with bent crystals
- Machine feasibility and radiological aspects
- Connection between UHECR studies and FTEs

Lead Guest Editor
Jean-Philippe Lansberg, Université Paris-Sud, Orsay, France
lansberg@in2p3.fr

Guest Editors
Gianluca Cavoto, Istituto Nazionale Di Fisica Nucleare, Roma, Italy
gianluca.cavoto@roma1.infn.it

Cynthia Hadjidakis, Université Paris-Sud, Orsay, France
cynthia@ipno.in2p3.fr

Jibo He, CERN, Geneva, Switzerland
jibo.he@cern.ch

Cédric Lorcé, Université de Liège, Liège, Belgium
c.lorce@ulg.ac.be

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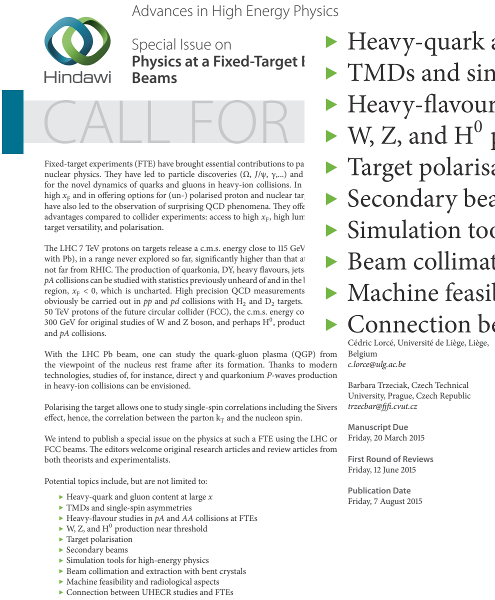

Advances in High Energy Physics

Hindawi

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  - Preparation of the Expression of Interest to be submitted to the LHCC (aim: first semester of 2015)
  - Special issue
  - Connexions & synergies with other projects at LHC or not (like E906,...)

Workshop at CERN on November 2014

- 5 days, from Monday Nov. 17 until Friday Nov. 21, 2014
- Half day introductory session on Monday morning
- 7 half-day sessions for 2 working groups of 10-20 people ((a) Physics & (b) Detector-Extraction)
- Topics to be discussed
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- Website: `http://indico.cern.ch/e/AFTER-Week-1114`

Part V

Conclusion and outlooks

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  Webpage: **`http://after.in2p3.fr`**

AFTER@FCC (work with R. Mikkelsen)

- Example: $E_P = 50$ TeV $\rightarrow \sqrt{s} = \sqrt{2 m_N E_p} \simeq 300$ GeV
- One example: extensive studies of W and Z near threshold

	SppC-1	SppC-2	HE LHC	FCC-hh
Beam Energy (TeV)	20	45	16.5	50
FT Energy (GeV)	193.7	290.6	175.9	306.3
Bunches	3000	6000	1404 (50 ns spacing)	10600/53000 (25 and 5 ns spacing)
N_p/bunch (10^{11})	$1.7 \cdot 10^{-3}$	$0.98 \cdot 10^{-3}$	1.3	1/0.2

	SppC-1	SppC-2	HE LHC	FCC-hh
Proton flux	$7.1 \cdot 10^5$	$8.1 \cdot 10^5$	$2.5 \cdot 10^8$	$1.5 \cdot 10^9$
$\mathscr{L}(\mu b^{-1} s^{-1})$	0.028/0.088/0.044	0.032/0.10/0.05	10/31/15	30/93/45
$\int \mathscr{L}(pb^{-1} yr^{-1})$	0.28 / 0.88 / 0.44	0.32/1.0/0.5	100/310/155	300/930/450

The proton flux is calculated by assuming that 5 % of the beam is used within a 10 hour period. The luminosities are calculated for the case of targets that are 1 cm thick. The three values displayed represent luminosities for three different targets: liquid Helium, Beryllium and Tungsten.

Further readings

- *Hadronic production of Ξ_{cc} at a fixed-target experiment at the LHC*
  By G. Chen *et al.*. [arXiv:1401.6269 [hep-ph]]. Phys.Rev. D89 (2014) 074020.
- *Quarkonium Physics at a Fixed-Target Experiment using the LHC Beams.*
  By J.P. Lansberg, S.J. Brodsky, F. Fleuret, C. Hadjidakis. [arXiv:1204.5793 [hep-ph]]. Few Body Syst. 53 (2012) 11.
- *Azimuthal asymmetries in lepton-pair production at a fixed-target experiment using the LHC beams (AFTER)*
  By T. Liu, B.Q. Ma. [arXiv:1203.5579 [hep-ph]]. Eur.Phys.J. C72 (2012) 2037.
- *Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER*
  By D. Boer, C. Pisano. [arXiv:1208.3642 [hep-ph]]. Phys.Rev. D86 (2012) 094007.
- *Ultra-relativistic heavy-ion physics with AFTER@LHC*
  By A. Rakotozafindrabe, *et al.* . [arXiv:1211.1294 [nucl-ex]]. Nucl.Phys. A904-905 (2013) 957c.
- *Spin physics at A Fixed-Target ExpeRiment at the LHC (AFTER@LHC)*
  By A. Rakotozafindrabe, *et al.* .[arXiv:1301.5739 [hep-ex]]. Phys.Part.Nucl. 45 (2014) 336.
- *Physics Opportunities of a Fixed-Target Experiment using the LHC Beams*
  By S.J. Brodsky, F. Fleuret, C. Hadjidakis, J.P. Lansberg. [arXiv:1202.6585 [hep-ph]]. Phys.Rept. 522 (2013) 239.

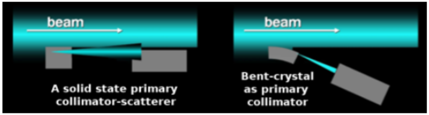
Part VI

Backup slides

The beam extraction: news

[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)

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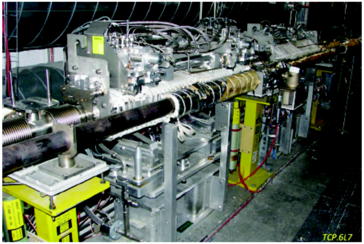

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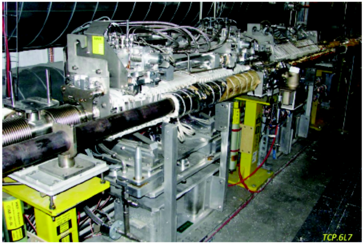
2010 - 2012



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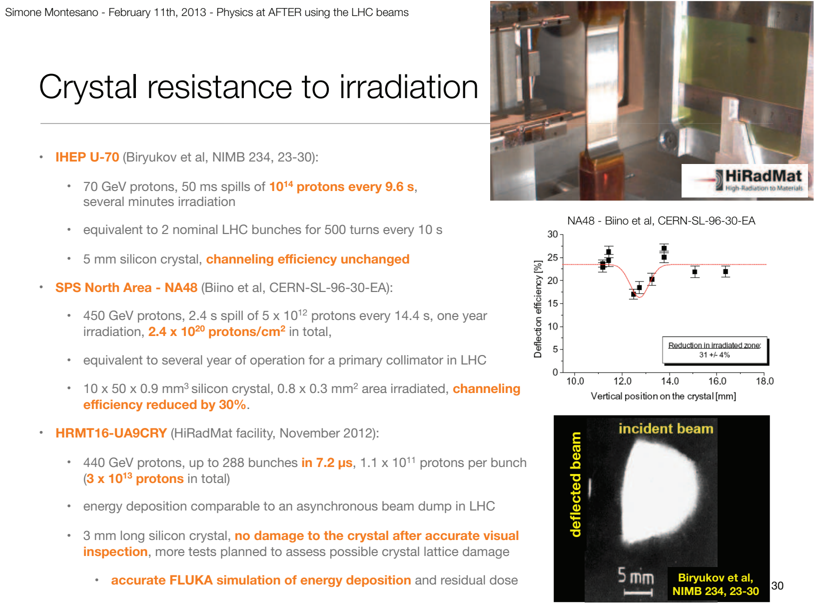
Towards an installation in the LHC : propose and install during LS1 a min. number of devices

- 2 crystals

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



Simone Montesano - February 11th, 2013 - Physics at AFTER using the LHC beams

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

30

S. Montesano (CERN - EN/STI) @ ECT* Trento workshop, Physics at AFTER using the LHC beams (Feb. 2013)

AFTER, among other things, a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int \mathcal{L}$ (fb^{-1}.yr^{-1})	N(J/Ψ) yr^{-1} $= A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(ϒ) yr^{-1} $=A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
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LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	3.6 10^7 1.4 10^9	1.8 10^5 7.2 10^6
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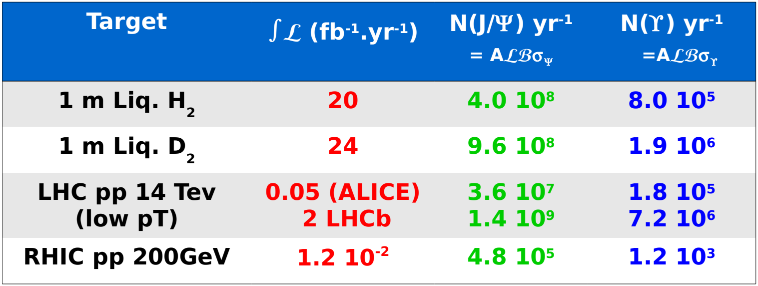

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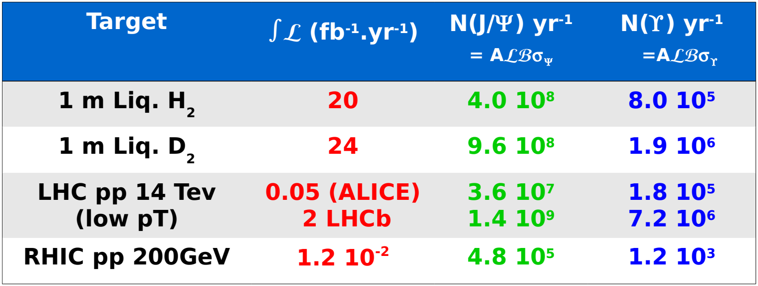

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- Probe of the (very) large *x* in the target

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    - in photo/lepto production (DIS)
    - but also *pp* collisions in *gg*-fusion process
    - mainly because of the presence of a natural “hard” scale: m_Q
    - and the good detectability of a dimuon pair

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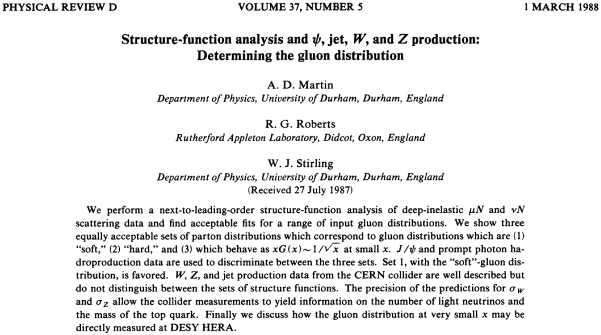

PHYSICAL REVIEW D VOLUME 37, NUMBER 5 1 MARCH 1988

Structure-function analysis and ψ, jet, W, and Z production: Determining the gluon distribution

A. D. Martin
Department of Physics, University of Durham, Durham, England

R. G. Roberts
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(Received 27 July 1987)

We perform a next-to-leading-order structure-function analysis of deep-inelastic μN and νN scattering data and find acceptable fits for a range of input gluon distributions. We show three equally acceptable sets of parton distributions which correspond to gluon distributions which are (1) “soft,” (2) “hard,” and (3) which behave as $xG(x) \sim 1/\sqrt{x}$ at small x. J/ψ and prompt photon hadroproduction data are used to discriminate between the three sets. Set 1, with the “soft”-gluon distribution, is favored. W, Z, and jet production data from the CERN collider are well described but do not distinguish between the sets of structure functions. The precision of the predictions for σ_W and σ_Z allow the collider measurements to yield information on the number of light neutrinos and the mass of the top quark. Finally we discuss how the gluon distribution at very small x may be directly measured at DESY HERA.

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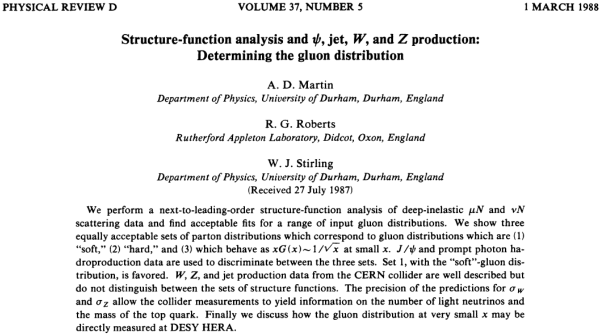

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- Production puzzle → quarkonium not used anymore in global fits

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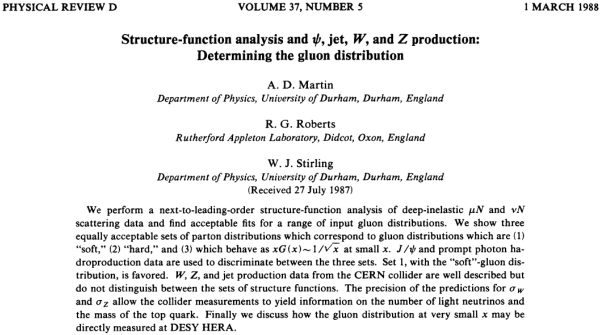

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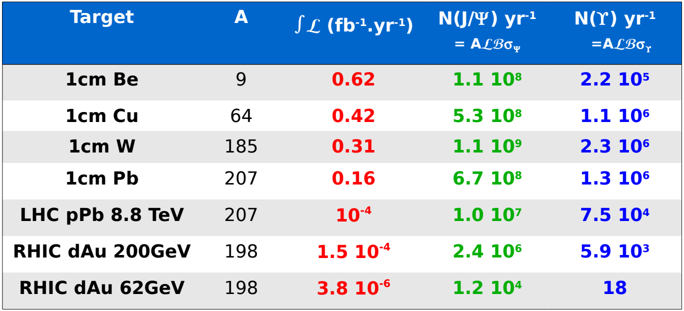
Department of Physics, University of Durham, Durham, England
(Received 27 July 1987)

We perform a next-to-leading-order structure-function analysis of deep-inelastic μN and νN scattering data and find acceptable fits for a range of input gluon distributions. We show three equally acceptable sets of parton distributions which correspond to gluon distributions which are (1) “soft,” (2) “hard,” and (3) which behave as $xG(x)\sim 1/\sqrt{x}$ at small x. J/ψ and prompt photon hadroproduction data are used to discriminate between the three sets. Set 1, with the “soft”-gluon distribution, is favored. W, Z, and jet production data from the CERN collider are well described but do not distinguish between the sets of structure functions. The precision of the predictions for σ_W and σ_Z allow the collider measurements to yield information on the number of light neutrinos and the mass of the top quark. Finally we discuss how the gluon distribution at very small x may be directly measured at DESY HERA.

- Production puzzle → quarkonium not used anymore in global fits
- With systematic studies, one would restore its status as gluon probe

AFTER: also a quarkonium observatory in *pA*



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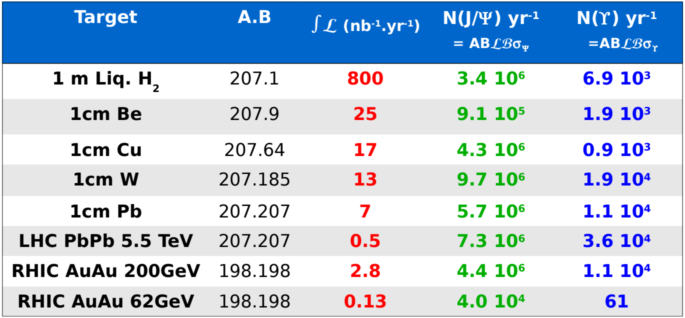

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The same picture also holds for open heavy flavour

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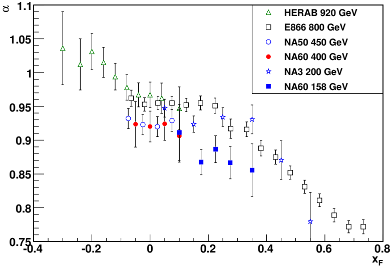
- the possibilities for $c\bar{c}$ recombination
  - Open charm studies are difficult where recombination matters most
    i.e. at low P_T
  - Only indirect indications –from the y and P_T dependence of R_{AA}–
    that recombination may be at work
  - CNM effects may show a non-trivial y and P_T dependence . . .

SPS and Hera-B

– J/ψ data in pA collisions



NA60 Phys.Lett. B 706 (2012) 263
NA 50 Eur.Phys.J. C48 (2006) 329
NA 3 Z.Phys. C20 (1983)
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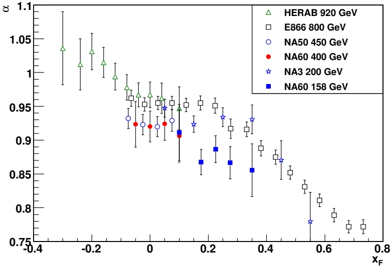

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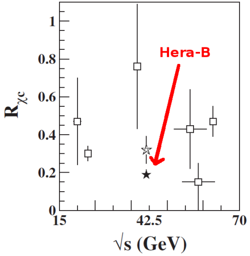
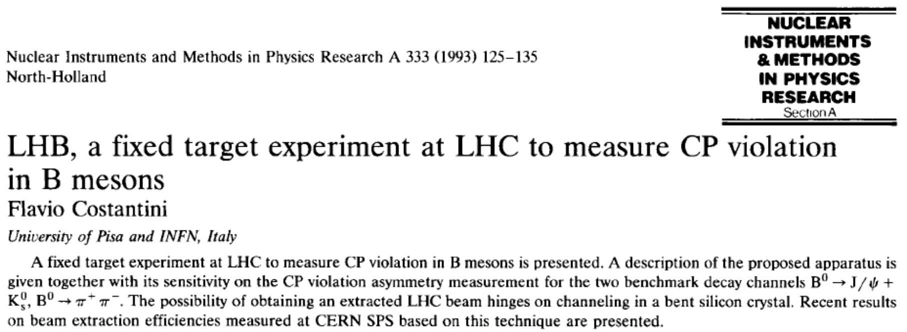


HERA-B PRD 79 (2009) 012001, and ref. therein

LHB

Our idea is not completely new



Nuclear Instruments and Methods in Physics Research A 333 (1993) 125–135
North-Holland

NUCLEAR
INSTRUMENTS
& METHODS
IN PHYSICS
RESEARCH
Section A

LHB, a fixed target experiment at LHC to measure CP violation in B mesons

Flavio Costantini

University of Pisa and INFN, Italy

A fixed target experiment at LHC to measure CP violation in B mesons is presented. A description of the proposed apparatus is given together with its sensitivity on the CP violation asymmetry measurement for the two benchmark decay channels $B^0 \to J/\psi + K^0_s$, $B^0 \to \pi^+\pi^-$. The possibility of obtaining an extracted LHC beam hinges on channeling in a bent silicon crystal. Recent results on beam extraction efficiencies measured at CERN SPS based on this technique are presented.

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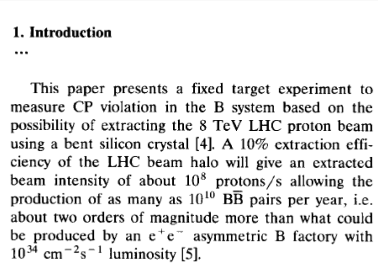

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This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\bar{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} $cm^{-2}s^{-1}$ luminosity [5].

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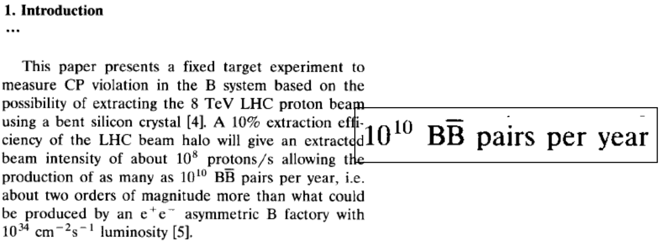

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LETTER OF INTENT

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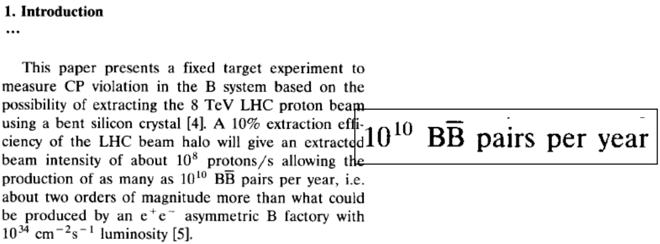

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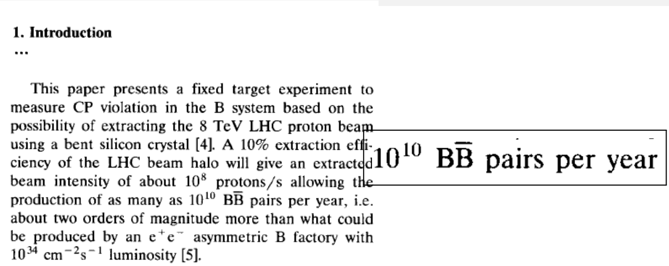

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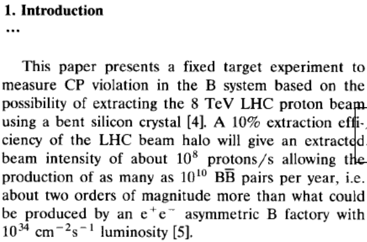

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- Nowadays, degradation is known to be $\simeq$ 6% per 10^{20} particles/cm^2
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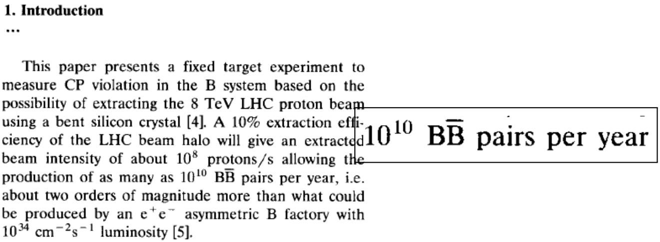

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- For LHCb, typically 1 fb^{-1} means $\simeq 2 \times 10^{11} B\bar{B}$ pairs at 14 TeV
- LHB turned down in favour of LHCb mainly because of the fear of a premature degradation of the bent crystal due to radiation damages.
- Nowadays, degradation is known to be $\simeq$ 6% per 10^{20} particles/cm^2
- 10^{20} particles/cm^2 : one year of operation for realistic conditions
- After a year, one simply moves the crystal by less than one mm ...

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  - they should also be calculated for $x_F \to -1$

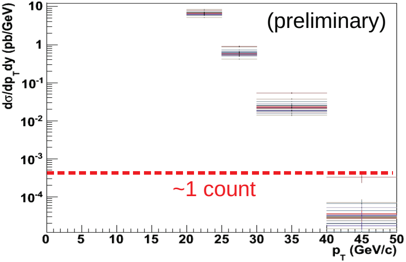
    where IQ could dominate

Isolated-γ in p(7 TeV)-p(rest): √s ~ 115 GeV

- p-p photon kinematics at fixed-target LHC (central rapidities):
  To access x > 0.3 one needs isolated-γ at: $p_T = x_T\sqrt{s}/2 > 20$ GeV/c
- JETPHOX NLO
  pQCD calculations:

  p-p at √s=115 GeV
  $|y|<0.5$, $p_T>20$ GeV/c
  Isolation: R=0.4, $E_T^{had}<5$ GeV

  $\mathcal{L}$(10 cm H_2-target) ~ 2•10^3 pb^{-1}/year



PDF: CT10 52 eigenval. (90% CL)
Scales: $\mu_i = p_T$
FF = BFG-II
x-section uncertainties(*) of ±150%

(*) (68%CL)/(90% CL) ~ 1.65