TMD studies with a fixed-target experiment using the LHC beams

AFTER@LHC: A fixed-target programme at the LHC for heavy-ion, hadron, spin and astroparticle physics

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

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AFTER@LHC Study group: http://after.in2p3.fr/after/index.php/Current_author_list

Part I

Why a new fixed-target experiment for High-Energy Physics now ?

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  - Proton charm content important to high-energy neutrino & cosmic-rays physics
  - EMC effect is an open problem; studying a possible gluon EMC effect is essential
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Heavy-ion collisions towards large rapidities

- Explore the longitudinal expansion of QGP formation with new hard probes
- Test the factorisation of cold nuclear effects from $p + A$ to $A + B$ collisions
- Test the formation of azimuthal asymmetries: hydrodynamics vs. initial-state radiation

Part II

A fixed-target experiment using the LHC beam(s): AFTER@LHC

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- Let us simply avoid the forward region ! How ?

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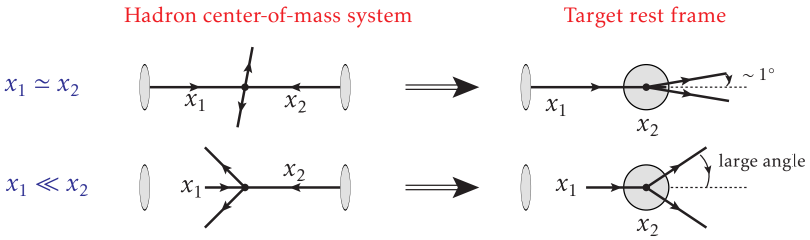

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Hadron center-of-mass system — Target rest frame

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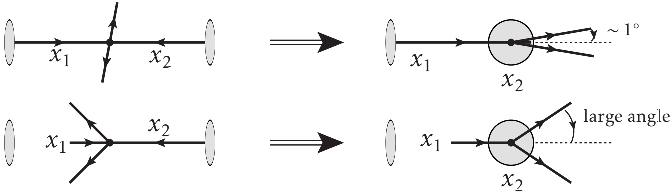

backward physics = large-x_2 physics

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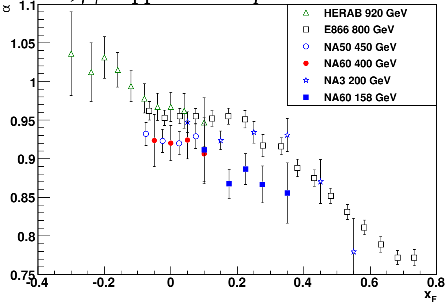

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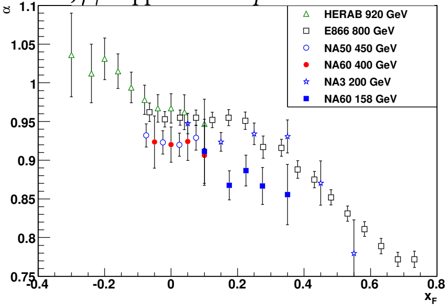

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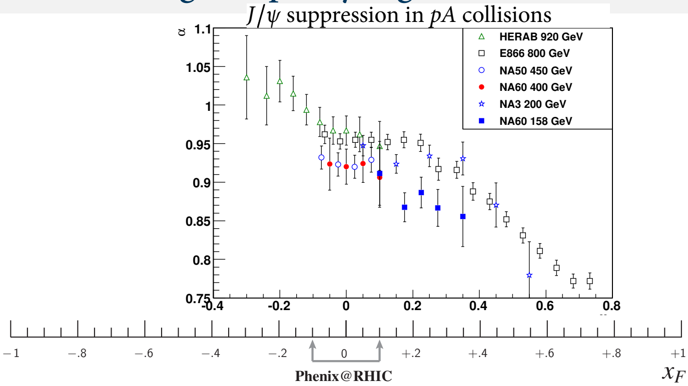

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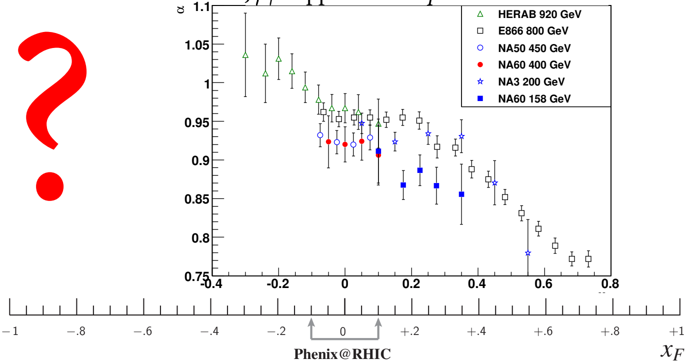

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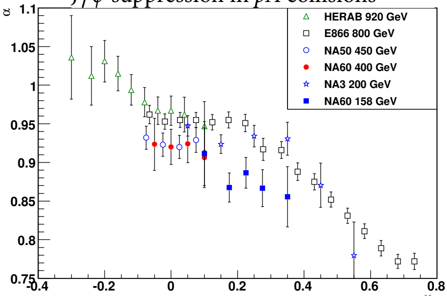

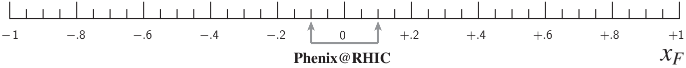

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- If we measure $\Upsilon(b\bar{b})$ at $y_{\rm cms} \simeq -2.5 \Rightarrow x_F \simeq \frac{2m_\Upsilon}{\sqrt{s}} \sinh(y_{\rm cms}) \simeq -1$

Part III

Colliding the LHC beams on fixed targets: 2 options

The extracted-beam option

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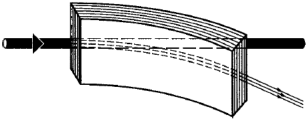

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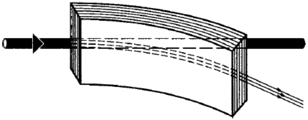

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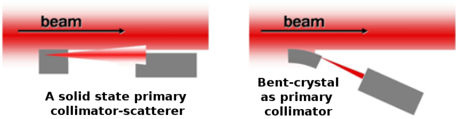

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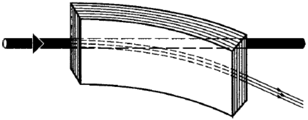

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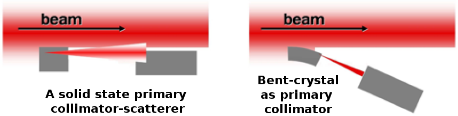

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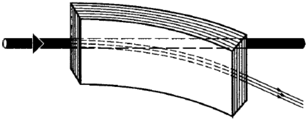

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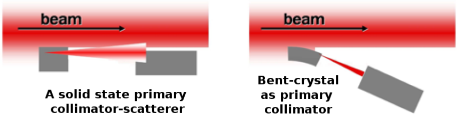

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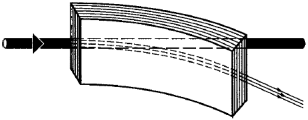

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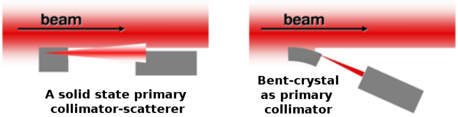

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- Integrated luminosity: $\int dt\mathcal{L}$ over 10^7 s for p^+ and 10^6 for Pb

[the so-called LHC years]

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- Integrated luminosity: $\int dt \mathcal{L}$ over 10^7 s for p^+ and 10^6 for Pb

[the so-called LHC years]

Target	ρ (g.cm⁻³)	A	$\mathcal{L}$ (μb⁻¹.s⁻¹)	$\int \mathcal{L}$ (fb⁻¹.yr⁻¹)
1m Liq. H_2	0.07	1	**2000**	**20**
1m Liq. D_2	0.16	2	**2400**	**24**
1cm Be	1.85	9	**62**	**.62**
1cm Cu	8.96	64	**42**	**.42**
1cm W	19.1	185	**31**	**.31**
1cm Pb	11.35	207	**16**	**.16**

Luminosities with extracted-proton beams

- Expected proton flux $\Phi_{beam} = 5 \times 10^8\ p^+ s^{-1}$
- Instantaneous Luminosity:

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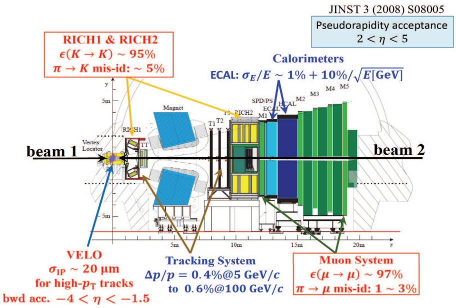
- For *pp* and *pd* collisions : $\mathcal{L}_{H_2/D_2} \simeq 20\ \text{fb}^{-1} y^{-1}$

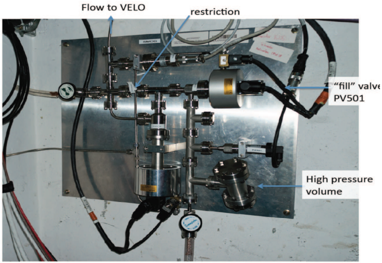
3 orders of magnitude larger than RHIC (200 GeV)

SMOG@LHCb: the first step towards an internal (polarised) target ?

SMOG@LHCb: the first step towards an internal (polarised) target ?



SMOG: System for Measuring Overlap with Gas



➜ injection of Ne-gas into VELO

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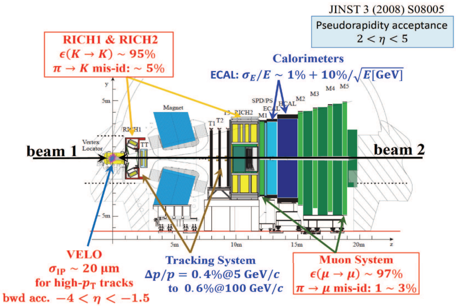

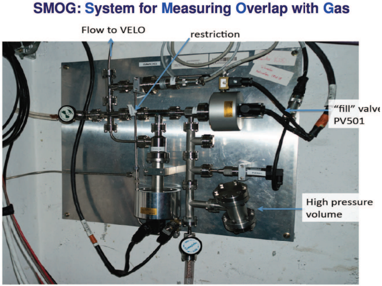

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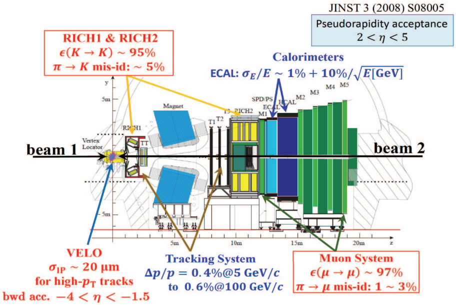

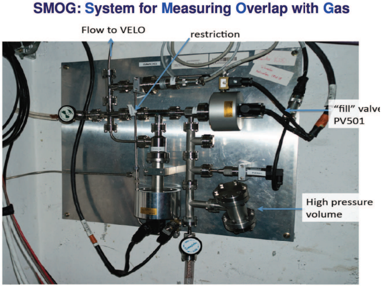

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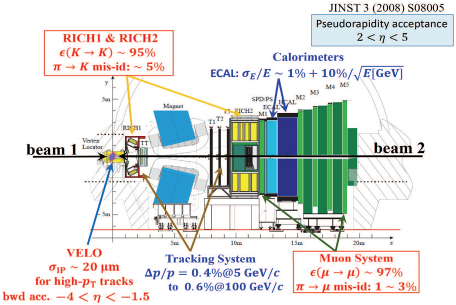

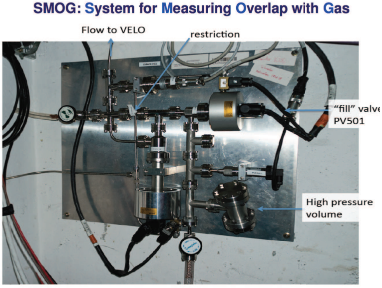

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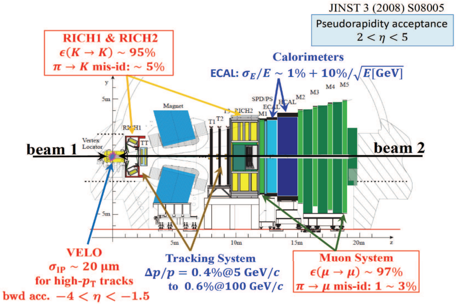

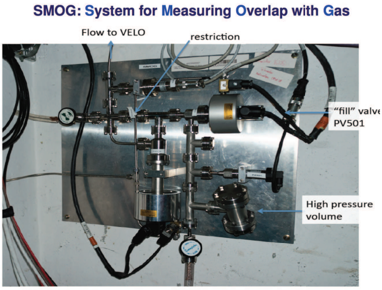

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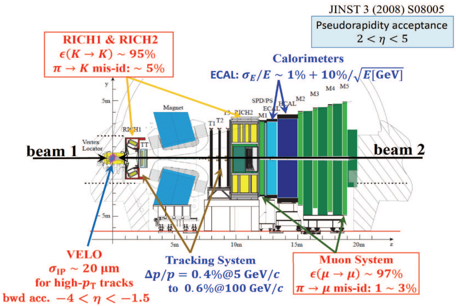

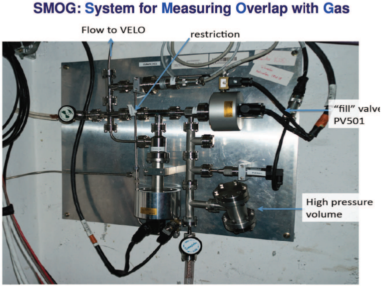

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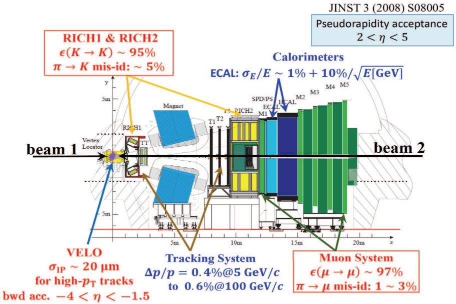

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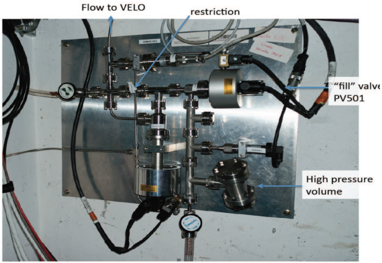

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- SMOG test : no decrease of LHC performances observed

Luminosities with the internal-gas-target option

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C. Barschel, P. Lenisa, A. Nass, and E. Steffens, Adv.Hi.En.Phys. (2015) 463141; See E. Steffens's talk at PSTP 2015

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A specific gas target is a competitive alternative to the beam extraction

Luminosities with a polarised internal-gas-target option

Advances in High Energy Physics
Volume 2015, Article ID 463141, 6 pages
http://dx.doi.org/10.1155/2015/463141

A Gas Target Internal to the LHC for the Study of pp Single-Spin Asymmetries and Heavy Ion Collisions

Colin Barschel,[1] Paolo Lenisa,[2] Alexander Nass,[3] and Erhard Steffens[4]

[1] *LHCb Collaboration, CERN, 1211 Geneva 23, Switzerland*
[2] *University of Ferrara and INFN, 44100 Ferrara, Italy*
[3] *Institut für Kernphysik, FZJ, 52425 Jülich, Germany*
[4] *Physics Institute, Friedrich-Alexander University Erlangen-Nürnberg, 91058 Erlangen, Germany*

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[1] $T = 300K$

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Figures-of-merit Comparison : $\mathrm{FoM} = P^2 \times \{f^2, \alpha^2\} \times \theta$ [**E. Steffens at PSTP 2015**]

$$\mathrm{FoM}^* = \phi \times \mathrm{FoM} = P^2 \times \{f^2, \alpha^2\} \times \phi \times \theta = P^2 \times f^2 \times \mathcal{L}$$

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Target and mode	Target characteristics	FoM*
NH_3 UVa-target & extr. beam	$P = 0.85$; $f = 0.17$; $\theta = 1.5 \times 10^{23}$ cm^{-2}	1.6×10^{30} cm^{-2} s^{-1}
NH_3 COMPASS & extr. beam	$P = 0.9$; $f = 0.176$; $\theta = 2.8 \times 10^{25}$ cm^{-2}	3.5×10^{32} cm^{-2} s^{-1}
'HERMES' H target[1] & LHC beam	$P = 0.85$; $\alpha = 0.95$; $\theta = 2.5 \times 10^{14}$ cm^{-2}	6×10^{32} cm^{-2} s^{-1}

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Part IV

AFTER@LHC: the case of spin physics

The quest for the orbital angular momentum of the quarks and gluons

The quest for the orbital angular momentum of the quarks and gluons

- Quark/Gluon Sivers function: distortion in the distribution of an unpolarised partons with momentum fraction x and transverse momentum $k_\perp$ due to the proton transverse polarisation : $f_{1T}^{\perp}(x, \vec{k}_\perp^2)$

The quest for the orbital angular momentum of the quarks and gluons

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- First suggested by D. Sivers to explain the large observed left-right single transverse spin asymmetries A_N in $p^\uparrow p \to \pi X$

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- Several experiments wish to measure $A_N^{Drell-Yan}$ to extract $f_{1T}^{\perp q}(x, \vec{k}_\perp^2)$
  - COMPASS: valence quarks using a pion beam (160 GeV) on a polarised proton target
  - E1027: valence quarks using a polarised proton beam (120 GeV) on an unpolarised proton target
  - E1039: sea quarks using an unpolarised proton beam (120 GeV) on a polarised proton target

SSA in Drell-Yan studies with AFTER@LHC

➟ Some parameters of existing and proposed polarised DY experiments.

S.J. Brodsky, F. Fleuret, C. Hadjidakis, JPL, Phys. Rep. 522 (2013) 239
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Experiment	particles	energy (GeV)	$\sqrt{s}$ (GeV)	$x_p^\uparrow$	$\mathcal{L}$ ($nb^{-1}s^{-1}$)
AFTER	$p + p^\uparrow$	7000	115	0.01 ÷ 0.9	$\mathcal{O}(1)$
COMPASS	$\pi^\pm + p^\uparrow$	160	17.4	0.2 ÷ 0.3	2
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- AFTER could be the only project able to reach $x^\uparrow = 10^{-2}$ and $x^\uparrow > 0.4$

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Expected asymmetries

The target-rapidity region (negative x_F) corresponds to high $x^{\uparrow}$

where the k_T-spin correlation is the largest

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How large ?

Azimuthal asymmetries in lepton-pair production at a fixed-target experiment using the LHC beams (AFTER)

Tianbo Liu[1], **Bo-Qiang Ma**[1,2,a]

[1]School of Physics and State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China
[2]Center for High Energy Physics, Peking University, Beijing 100871, China

Transverse Single-Spin Asymmetries in Proton-Proton Collisions at the AFTER@LHC Experiment in a TMD Factorisation Scheme

M. Anselmino,[1,2] U. D'Alesio,[3,4] and S. Melis[1]

[1]Dipartimento di Fisica, Università di Torino, Via P. Giuria 1, 10125 Torino, Italy
[2]INFN, Sezione di Torino, Via P. Giuria 1, 10125 Torino, Italy
[3]Dipartimento di Fisica, Università di Cagliari, Cittadella Universitaria, 09042 Monserrato, Italy
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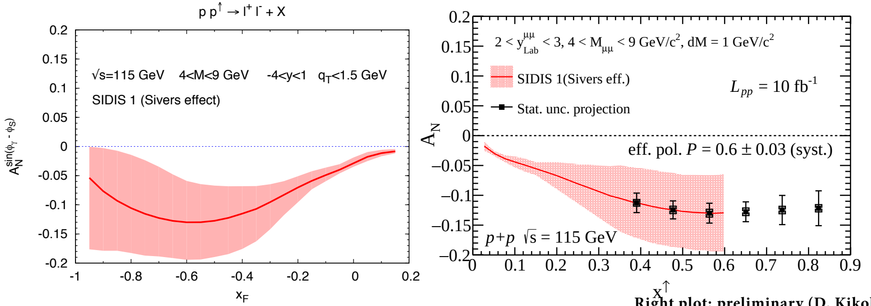

M. Anselmino, U. D'Alesio, S. Melis. Adv.Hi.En.Phys. (2015) 475040

Right plot: preliminary (D. Kikola)

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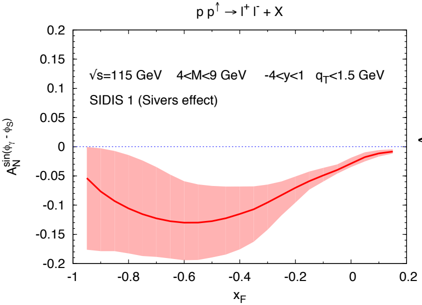

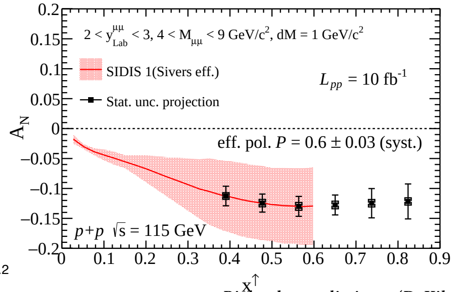

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Right plot: preliminary (D. Kikola)

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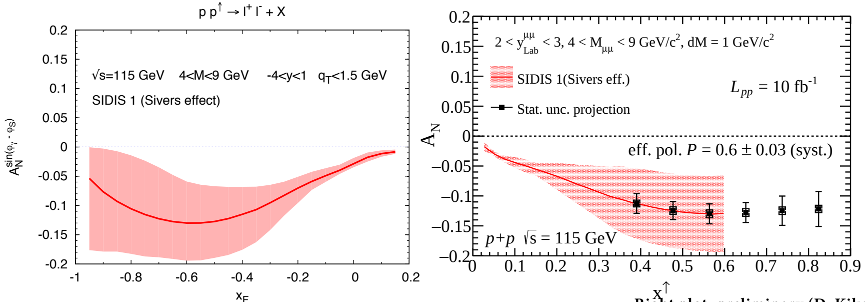

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- With 10 fb^{-1}, one can indeed expect up to 10^6 DY events in $4 < M < 9$ GeV
- W and Z should be reachable with 10 fb^{-1}: $x^{\uparrow} \simeq 0.7 \div 0.8$

Fast simulation using LHCb reconstruction parameters

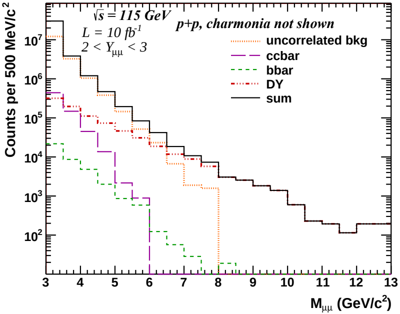
Projection for a LHCb-like detector

L. Massacrier, B. Trzeciak, *et al.*, Adv.Hi.En.Phys. (2015) 986348

- Simulations with Pythia 8.185
- the 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
- Muon misidentification:
  - If π and K decay before the calorimeters (12m), they are rejected by the tracking
  - otherwise a misidentification probability is applied following: F. Achilli et al, arXiv:1306.0249

Drell-Yan background & signal reach

- At backward rapidities, quark-induced processes are favoured ⇒ Bkgd get smaller



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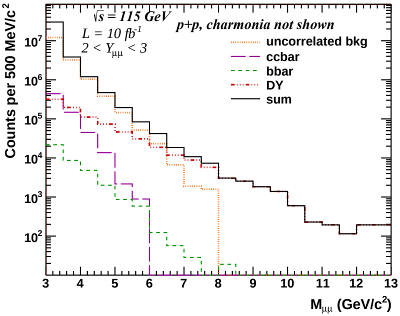

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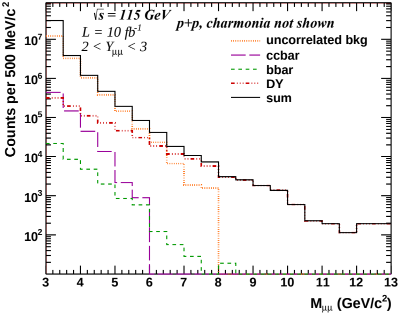

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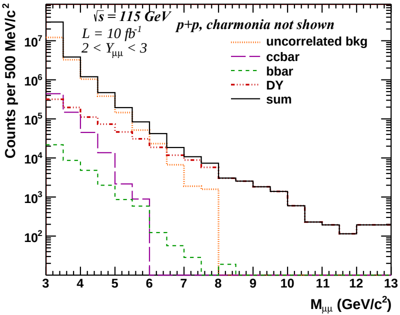

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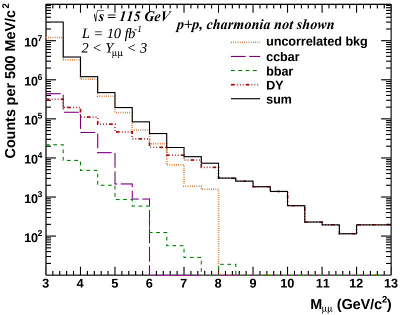

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- Yields to precise measurements of A_N^{DY} at large x as seen above

The gluon OAM contribution to the proton spin

- Gluon Sivers effect essentially unconstrained

D. Boer, C. Lorcé, C. Pisano,J. Zhou. Adv.Hi.En.Phys. (2015) ID:371396

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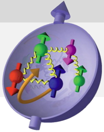

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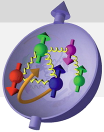

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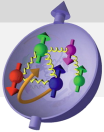

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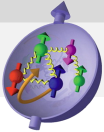

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- All these measurements can be done with AFTER@LHC with the required precision: 10^9 J/ψ, 10^6 Υ, 10^8 B, etc ...

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- It can be measured via A_N of gluon sensitive probes [as opposed to DY for quarks]
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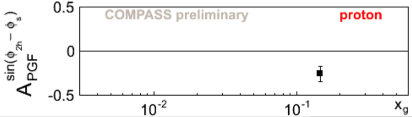
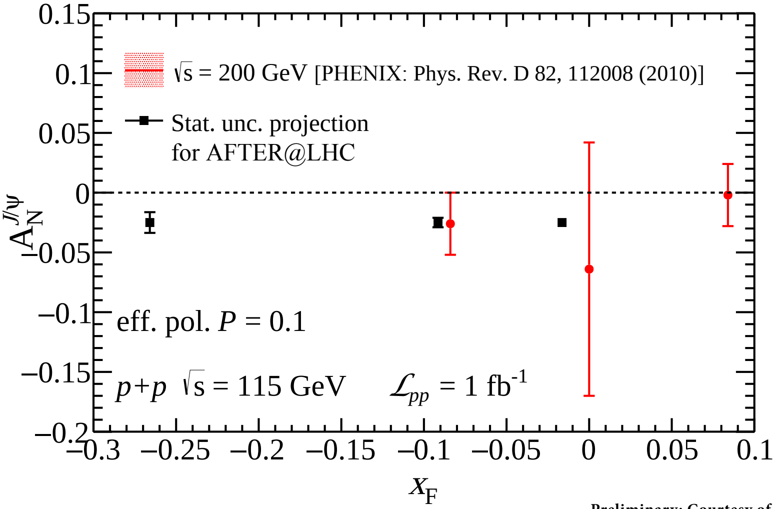
- quarkonia (J/ψ, Υ, χ_c, η_c, ...) F. Yuan, PRD 78 (2008) 014024; A. Schaefer, J. Zhou, PRD (2013) PHENIX Phys.Rev. D86 (2012) 099904
- B & D meson production M. Anselmino, *et al.* PRD 70 (2004) 074025.
- γ, γ-jet, $\gamma - \gamma$ A. Bacchetta, *et al.*, PRL 99 (2007) 212002; J.W. Qiu, *et al.*, PRL 107 (2011) 062001
- $J/\psi + \gamma$: the cleanest; sensitive to gluons up to $x^\uparrow \simeq 0.5$

W. den Dunnen, J.P.L., C. Pisano, M. Schlegel, PRL 112, 212001 (2014); J.P.L., C. Pisano, M. Schlegel (work in pogress)

- All these measurements can be done with AFTER@LHC with the required precision: 10^9 J/ψ, 10^6 Υ, 10^8 B, etc ...
- Hint of nonzero gluon Sivers effect in $ep^\uparrow \to hh$: talk by A. Szabelski, yesterday



J/ψ A_N projection (vs. current PHENIX data)



Preliminary; Courtesy of D. Kikola

Nota: *P* was choosen to be smaller than above, otherwise the statistical uncertainties are invisible

Part V

From the gluon PDF $g(x)$ to the gluon TMD $h_1^{\perp g}(x, k_T)$

Gluons in the proton

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

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  - Not easily accessible in DIS
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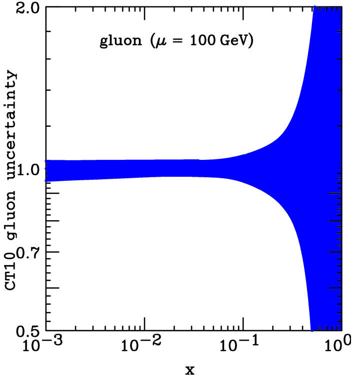

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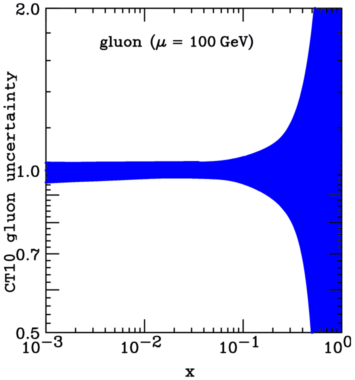

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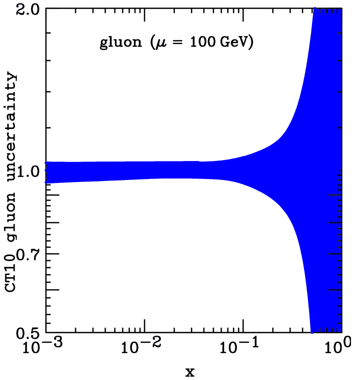

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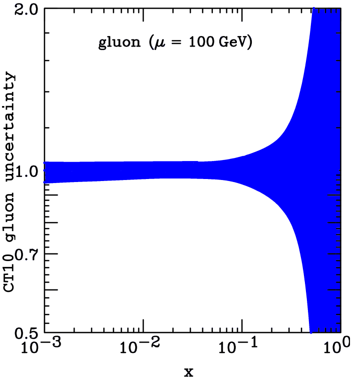

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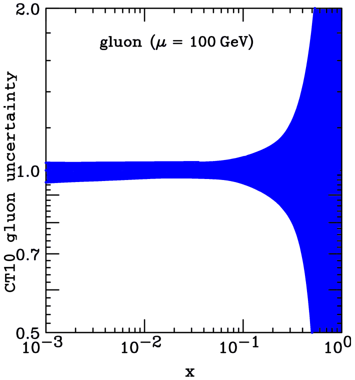

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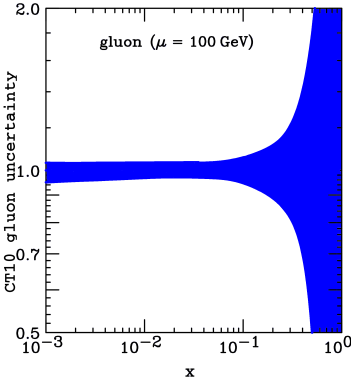

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Multiple probes needed to **check factorisation**

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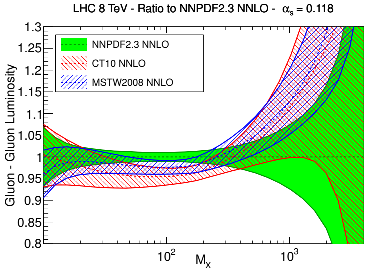

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Large-x gluons: important to characterise some possible BSM findings at the LHC

Distribution of linearly polarised gluons in unpolarised protons: $h_1^{\perp g}$

Distribution of linearly polarised gluons in unpolarised protons: $h_1^{\perp g}$

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†
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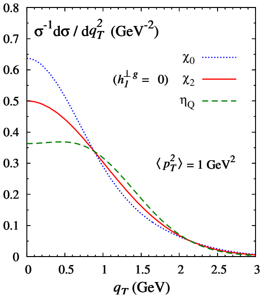
- Affect the low P_T spectra:

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

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



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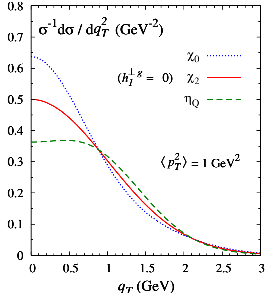
- The boost is of great help to access low P_T P-wave quarkonia



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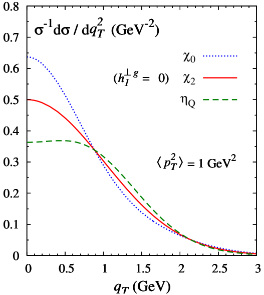

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- $h_1^{\perp g}$ is connected to the Higgs transverse-momentum distribution **D. Boer,** *et al.* **PRL 108 (2012) 032002**

Access to $h_1^{\perp g}(x, k_T, \mu)$ II

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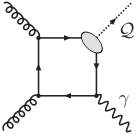
PRL **112,** 212001 (2014) PHYSICAL REVIEW LETTERS week ending 30 MAY 2014

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

Wilco J. den Dunnen,[1,*] Jean-Philippe Lansberg,[2,†] Cristian Pisano,[3,‡] and Marc Schlegel[1,§]
[1]Institute for Theoretical Physics, Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany
[2]IPNO, Université Paris-Sud, CNRS/IN2P3, F-91406, Orsay, France
[3]Nikhef and Department of Physics and Astronomy, VU University Amsterdam, De Boelelaan 1081, NL-1081 HV Amsterdam, The Netherlands



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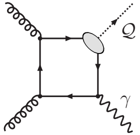

- $h_1^{\perp g}$ (“gluon B-M”) can also be accessed via back-to-back $\psi/\Upsilon + \gamma$ associated production at the LHC. Also true at AFTER !

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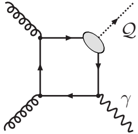

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- Smaller yield (14 TeV → 115 GeV) compensated by an access to lower P_T

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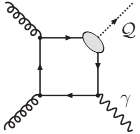

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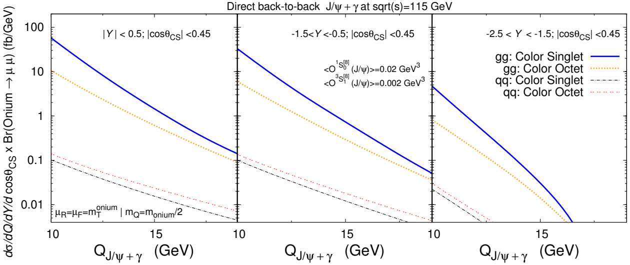

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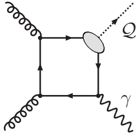

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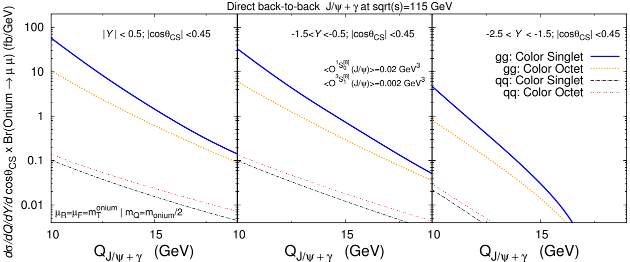

At $Y \simeq -2$, $x_2 \simeq 10/115 \times e^2 \simeq 0.65$. Yet, $g - g > q - \bar{q}$! [solid vs. dashed curves]

Part VI

More with AFTER@LHC

Things I have no time to cover

- Heavy-quark distributions (at high x) and connections UHE cosmic neutrinos

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- Gluon nuclear PDF at large x

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- Gluon PDF in the deuteron (via pd data)

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  (via double heavy-flavour production ($D + D$, $\psi + D$, $\psi + \psi$))

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- Υ sequential melting between SPS and RHIC energies
- χ_c production in heavy-ion collisions
- Check of nPDF factorisation with DY in $A + B$ collisions
- Fracture function studies with DY + hadron, etc.

Further readings

Heavy-Ion Physics

- *Gluon shadowing effects on J/ψ and Υ production in p+Pb collisions at $\sqrt{s_{NN}} = 115$ GeV and Pb+p collisions at $\sqrt{s_{NN}} = 72$ GeV at AFTER@LHC* by R. Vogt. Adv.Hi.En.Phys. (2015) 492302.
- *Prospects for open heavy flavor measurements in heavy-ion and p+A collisions in a fixed-target experiment at the LHC* by D. Kikola. Adv.Hi.En.Phys. (2015) 783134
- *Quarkonium suppression from coherent energy loss in fixed-target experiments using LHC beams* by F. Arleo, S.Peigné. [arXiv:1504.07428 [hep-ph]]. Adv.Hi.En.Phys. (2015) 961951
- *Anti-shadowing Effect on Charmonium Production at a Fixed-target Experiment Using LHC Beams* by K. Zhou, Z. Chen, P. Zhuang. Adv.High Energy Phys. 2015 (2015) 439689
- *Lepton-pair production in ultraperipheral collisions at AFTER@LHC*
  By J.P. Lansberg, L. Szymanowski, J. Wagner. JHEP 1509 (2015) 087
- *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.

Further readings

Spin physics

- *Transverse single-spin asymmetries in proton-proton collisions at the AFTER@LHC experiment* by K. Kanazawa, Y. Koike, A. Metz, and D. Pitonyak. [arXiv:1502.04021 [hep-ph]. Adv.Hi.En.Phys. (2015) 257934.
- *Transverse single-spin asymmetries in proton-proton collisions at the AFTER@LHC experiment in a TMD factorisation scheme* by M. Anselmino, U. D'Alesio, and S. Melis. [arXiv:1504.03791 [hep-ph]]. Adv.Hi.En.Phys. (2015) 475040.
- *The gluon Sivers distribution: status and future prospects* by D. Boer, C. Lorcé, C. Pisano, and J. Zhou. [arXiv:1504.04332 [hep-ph]]. Adv.Hi.En.Phys. (2015) 371396
- *Azimuthal asymmetries in lepton-pair production at a fixed-target experiment using the LHC beams (AFTER)* By T. Liu, B.Q. Ma. Eur.Phys.J. C72 (2012) 2037.
- *Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER* By D. Boer, C. Pisano. Phys.Rev. D86 (2012) 094007.

Further readings

Hadron structure

- *Double-quarkonium production at a fixed-target experiment at the LHC (AFTER@LHC).*
  by J.P. Lansberg, H.S. Shao. [arXiv:1504.06531 [hep-ph]]. Nucl.Phys. B900 (2015) 273-294
- *Next-To-Leading Order Differential Cross-Sections for Jpsi, psi(2S) and Upsilon Production in Proton-Proton Collisions at a Fixed-Target Experiment using the LHC Beams (AFTER@LHC)*
  by Y. Feng, and J.X. Wang. Adv.Hi.En.Phys. (2015) 726393.
- *η_c production in photon-induced interactions at a fixed target experiment at LHC as a probe of the odderon*
  By V.P. Goncalves, W.K. Sauter. arXiv:1503.05112 [hep-ph].Phys.Rev. D91 (2015) 9, 094014.
- *A review of the intrinsic heavy quark content of the nucleon*
  by S. J. Brodsky, A. Kusina, F. Lyonnet, I. Schienbein, H. Spiesberger, and R. Vogt. Adv.Hi.En.Phys. (2015) 231547.
- *Hadronic production of Ξ_{cc} at a fixed-target experiment at the LHC*
  By G. Chen *et al.*. Phys.Rev. D89 (2014) 074020.

Further readings

Feasibility study and technical ideas

- *Feasibility studies for quarkonium production at a fixed-target experiment using the LHC proton and lead beams (AFTER@LHC)* by L. Massacrier, B. Trzeciak, F. Fleuret, C. Hadjidakis, D. Kikola, J.P.Lansberg, and H.S. Shao arXiv:1504.05145 [hep-ex]. Adv.Hi.En.Phys. (2015) 986348
- *A Gas Target Internal to the LHC for the Study of pp Single-Spin Asymmetries and Heavy Ion Collisions* by C. Barschel, P. Lenisa, A. Nass, and E. Steffens. Adv.Hi.En.Phys. (2015) 463141
- *Quarkonium production and proposal of the new experiments on fixed target at LHC* by N.S. Topilskaya, and A.B. Kurepin. Adv.Hi.En.Phys. (2015) 760840

Generalities

- *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.

http://www.hindawi.com/journals/ahep/si/354953/

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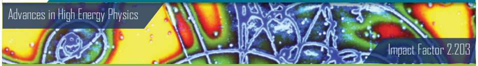

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Physics at a Fixed-Target Experiment Using the LHC Beams

Guest Editors: Jean-Philippe Lansberg, Gianluca Cavoto, Cynthia Hadjidakis, Jibo He, Cédric Lorcé, and Barbara Trzeciak

Advances in High Energy Physics

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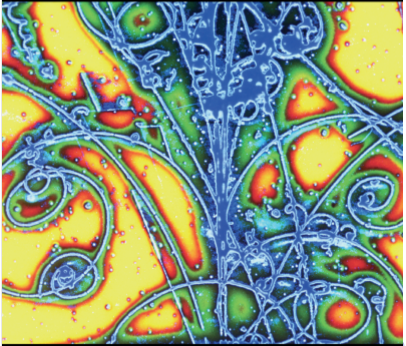

See also

Physics Reports 522 (2013) 239–255

Contents lists available at SciVerse ScienceDirect

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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

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Part VII

Conclusion and outlooks

Conclusion

- Three main themes push for a fixed-target program at the LHC
  [without interfering with the other experiments]

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

Part VIII

Backup slides

First simulation: is the boost an issue ?

B. Trzeciak, L. Massacrier *et al.*, Adv.Hi.En.Phys. (2015) 986348

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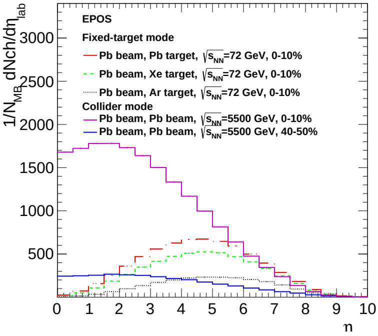

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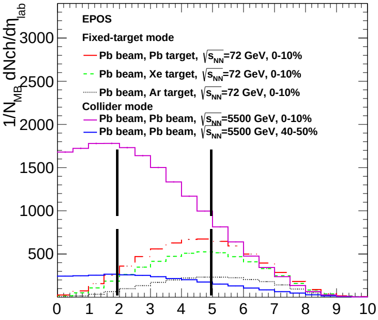

- Despite the boost, the multiplicity in the LHCb acceptance [forward η] is lower in the fixed mode than in the collider mode (at higher $\sqrt{s}$)

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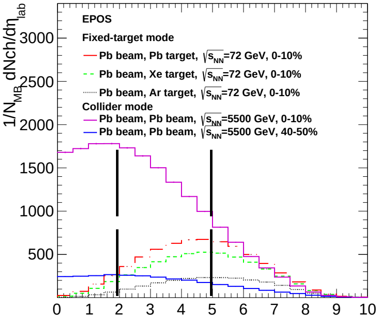
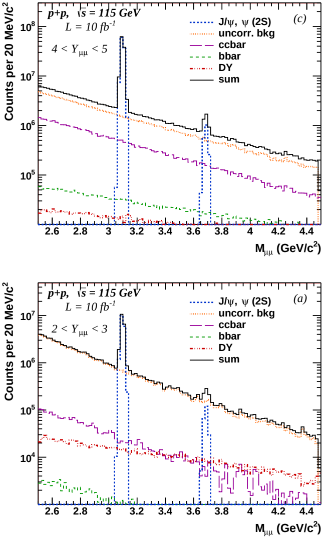


- Despite the boost, the multiplicity in the LHCb acceptance [forward η] is lower in the fixed mode than in the collider mode (at higher $\sqrt{s}$)
- Simulation backed-up with a comparison of the number-of-track distribution between simulations at the detector level and data

Z. Yang, private comm.

Charmonium background & its rapidity dependence

B. Trzeciak, L. Massacrier *et al.*, 1504.05145 [hep-ex], Adv.Hi.En.Phys. (2015) 986348



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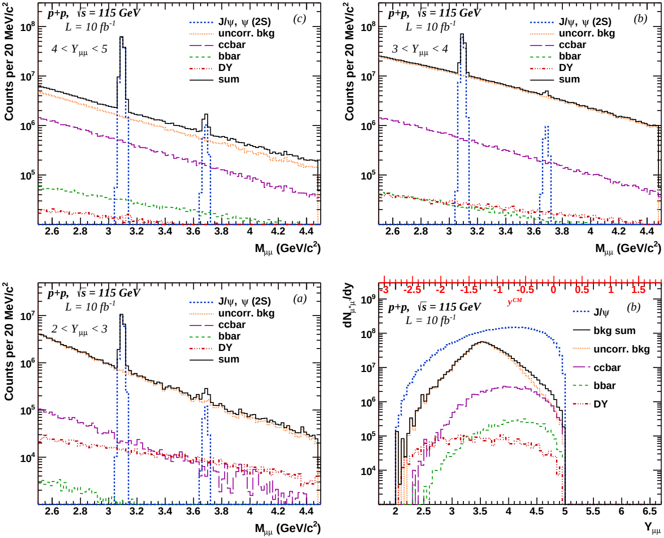

Bottomonium background & signal reach

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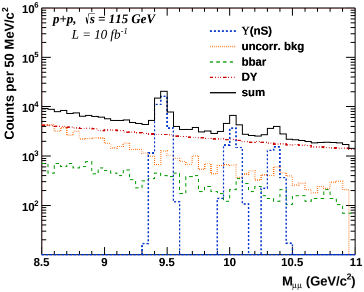

The dominant background is Drell-Yan

3 peaks well resolved

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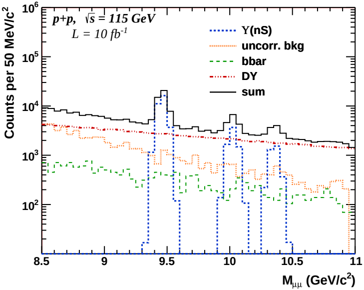

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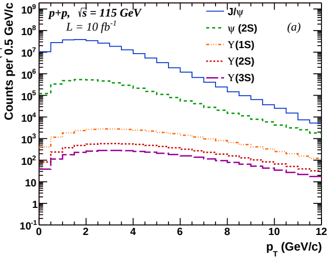
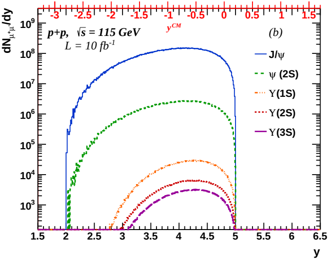
J/ψ: 10^4 events at $P_T \simeq 12$ GeV

Υ : 200 events at $P_T \simeq 12$ GeV

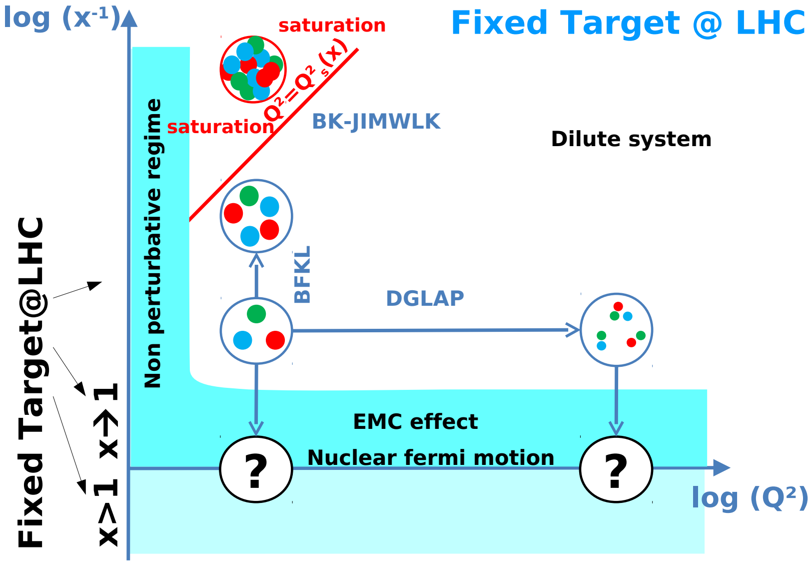




J/ψ: reach cut by the detector acceptance

Υ : 200 events at $y^{\Upsilon}_{c.m.s.} \simeq -2.1$, i.e. $x_2 \simeq 0.7$

Overall


log (x⁻¹)
saturation
Fixed Target @ LHC
Q²=Q²s(x)
saturation
BK-JIMWLK
Dilute system
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BFKL
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x>1 x→1
EMC effect
Nuclear fermi motion
?
?
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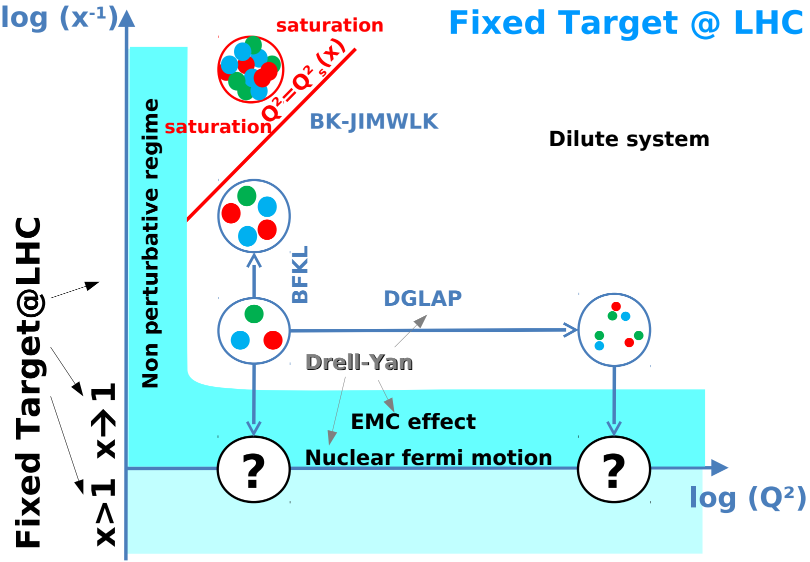

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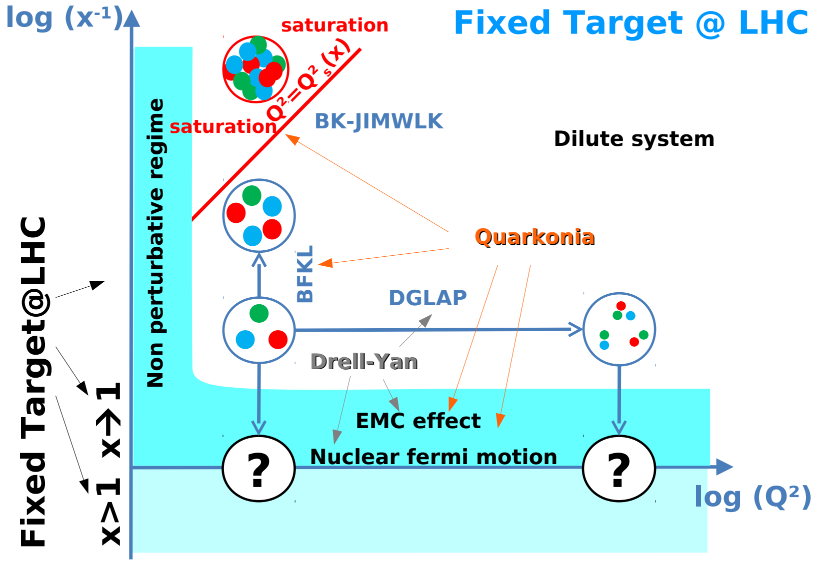
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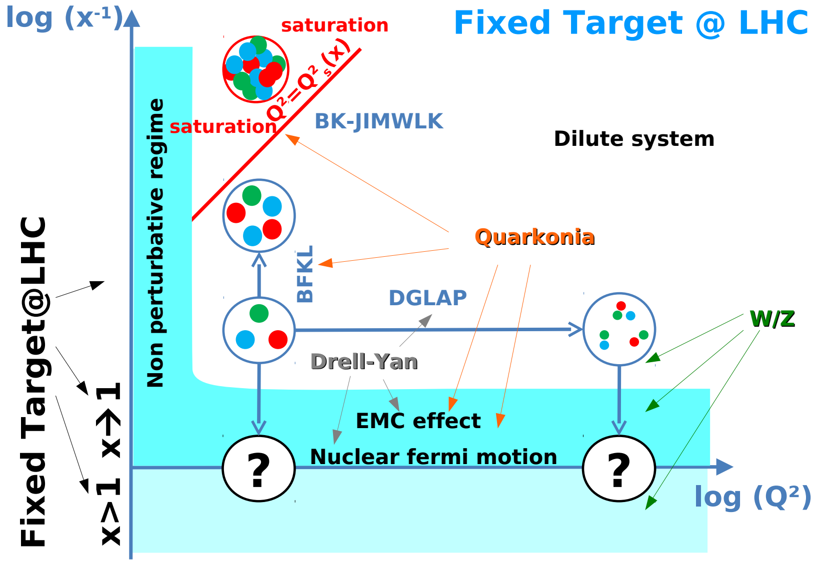
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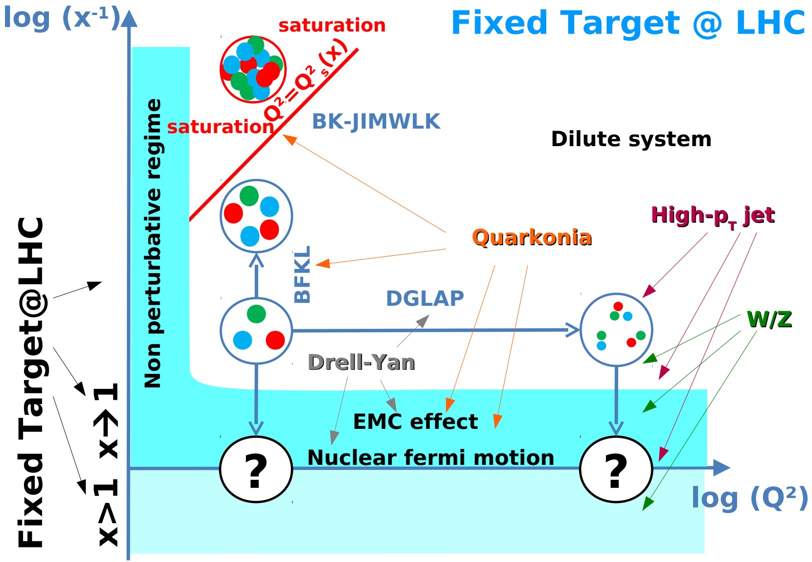

log (x⁻¹)
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Q²=Q²s(x)
Fixed Target @ LHC
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Dilute system
Non perturbative regime
High-pT jet
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BFKL
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x>1 x→1
EMC effect
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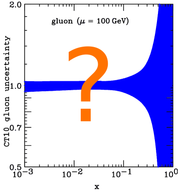
?
log (Q²)

pd physics: gluons in the neutron and the deuteron



Gluon PDF for the neutron unknown

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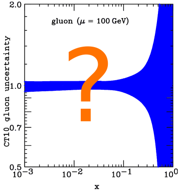

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- heavy quarkonia
- isolated photons
- jets

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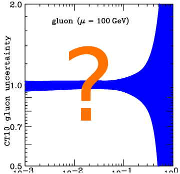

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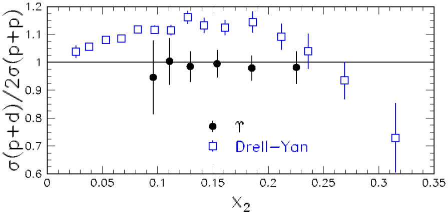

Pioneer measurement by E866

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

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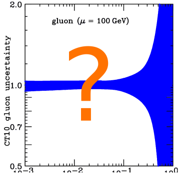

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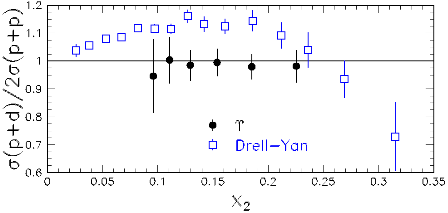

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could be extended with AFTER

- using J/ψ, ..., $C = +1$ onia, ...
- wider x range & lower Q^2

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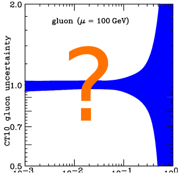

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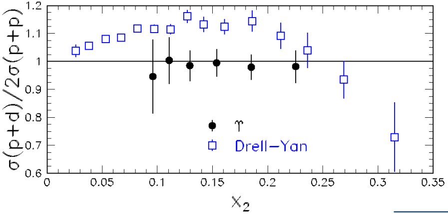

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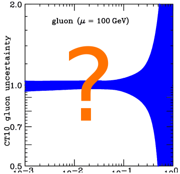

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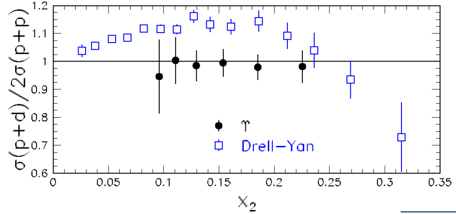

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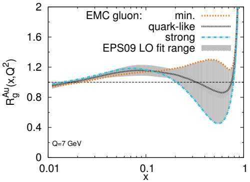
If $g_n(x) - g_p(x)$ is too small, this measurement would anyhow be sensitive to the EMC and Fermi-motion effects in the deuteron

pA studies: large-x gluon content of the nucleus

pA studies: large-*x* gluon content of the nucleus

- Large-*x* gluon nPDF: unknown

- **Gluon EMC effect: unknown**



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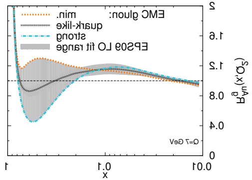
- Hint from Υ data at RHIC



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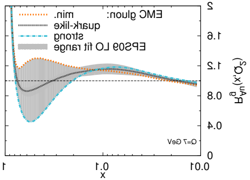

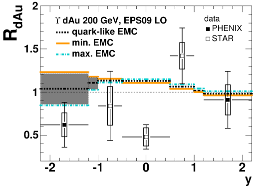

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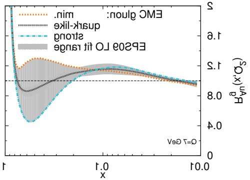

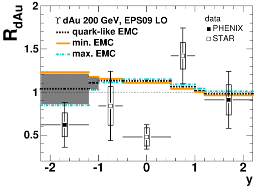

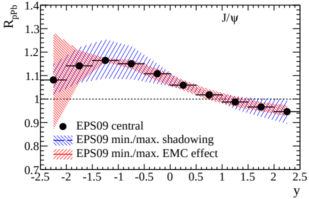

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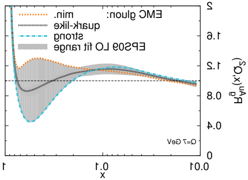
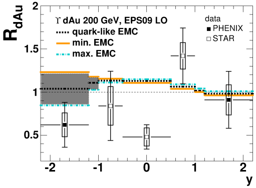
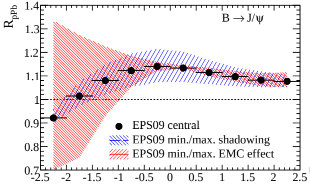
- Quest for the gluon antishadowing with J/ψ
- Quest for the gluon EMC effect for bottom(onium)







L. Massacrier *et al.*, Adv.Hi.En.Phys. (2015) 986348

Gas target

C. Barschel, P. Lenisa, A. Nass, and E. Steffens, Adv.Hi.En.Phys. (2015) 463141

Table 1: Comparison of gas targets in storage rings with a hypothetical target for the proposed AFTER@LHC initiative [1, 2].The target gas ^{1}H, ^{2}D, or ^{3}He is assumed to be spin polarized.

Storage ring	Particle	E_{max} [GeV]	Target type	L [m]	T [K]	L_{max} [1/cm^2 s]	Remarks	Reference
HERA-e DESY (term. 2007)	$e^{\pm}$ pol.	27.6	Cell ^{1}H, ^{2}D, ^{3}He	0.4	100 25	$2.5 \cdot 10^{31}$ $2.5 \cdot 10^{32}$	HERMES exp. 1995–2007	[9]
RHIC-p BNL	p pol.	250	Jet	—	—	$1.7 \cdot 10^{30}$	Absolute p polarimeter	[10]
COSY FZ Jülich	p, d pol.	3.77 $T = 49.3$ MeV	Cell ^{1}H, ^{2}D Cell ^{1}H	0.4	300	10^{29} $2.75 \cdot 10^{29}$	ANKE exp. PAX exp.	[4, 5] [11]
LHC CERN (proposed)	p unpol. heavy ions	7,000 $2{,}760 \cdot A$	Cell ^{1}H, ^{2}D Xe $M \approx 131$	1.0	100 ≥100	10^{33} 10^{27}–10^{28}	Based on techn. of HERMES target	this paper

→ beam lifetime with $\mathcal{L}_{pp} = 10^{33}\text{cm}^{-2}\text{s}^{-1} = 10\ \text{nb}^{-1}\text{s}^{-1}$ of 2×10^{6} s (or 23 days).

Heavy-quark content of the proton

- Heavy-quark distributions (at high x_B)

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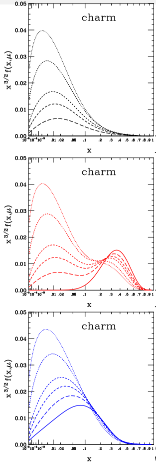

DGLAP

BHPS

Sea-like

3 sets from CTEQ6c (Pumplin *et al.*)

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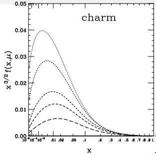

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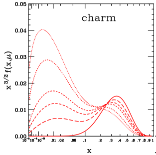

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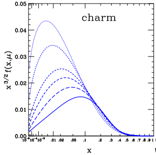

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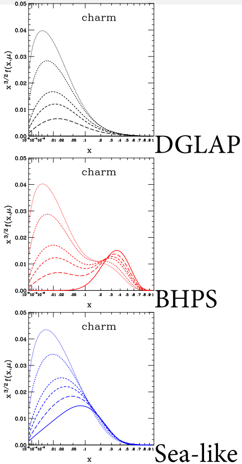

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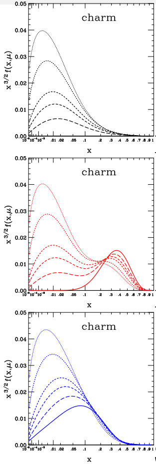

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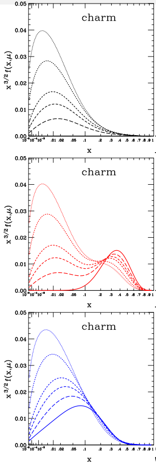

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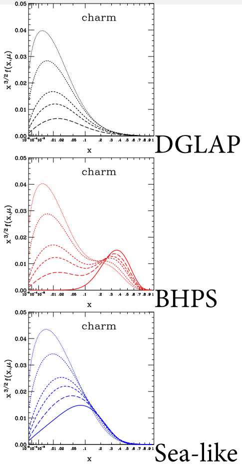

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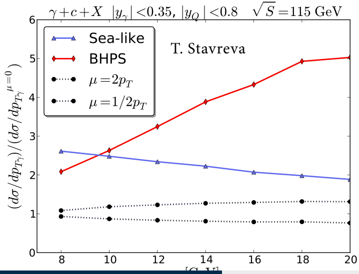

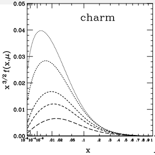

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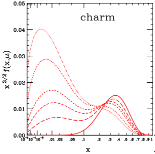

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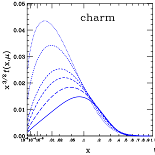

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QCD uncertainties in PeV neutrino studies

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  IceCube collab. PRL 111 (2013) 021103; Science 342 (2013) 1242856

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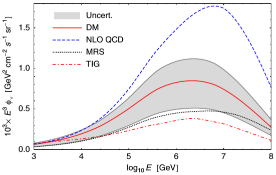

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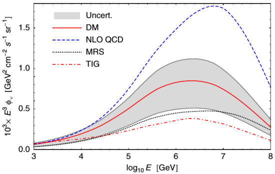

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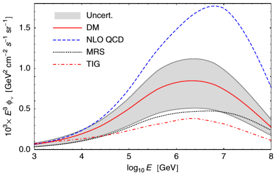

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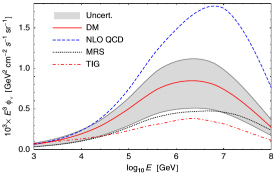

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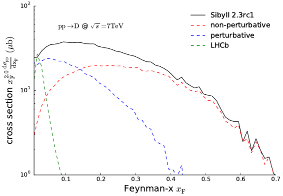

Figure 8. Weighted spectrum for *D*-mesons in SIBYLL at $\sqrt{s}$ = 7 TeV. The contributions from the perturbative and non-perturbative model components are shown by the blue and red lines, respectively. Note the negligible contribution to the energy spectrum from the phase space covered by the LHCb experiment ($2.5 < y < 4.5$, green line).

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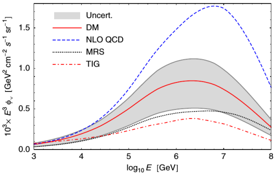
$$x_F^{collider} = \frac{2m_T}{2E_{beam}} \sinh\left(y^{lab.}\right) \; ; \; x_F^{FT} = \frac{2m_T}{\sqrt{2m_N E_{beam}}} \sinh\left(y^{lab.} - 4.8\right)$$

$$x_F^{FT}(P_T^D = 0, y^{lab.} = 2) \simeq -0.2 \; ; \; x_F^{FT}(P_T^D = 4\text{GeV}, y^{lab.} = 2) \simeq -0.6$$



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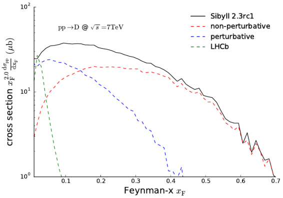

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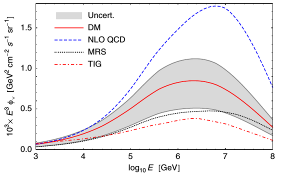
Similar conclusion for the ALICE muon spectrometer



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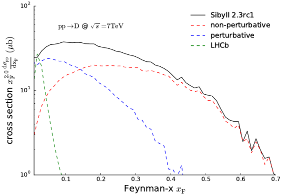

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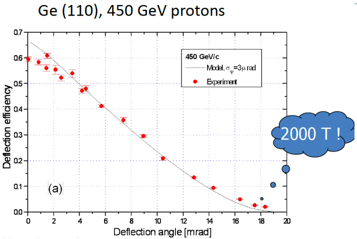
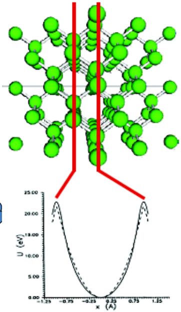
The beam extraction with a bent crystal

- Inter-crystalline fields are huge





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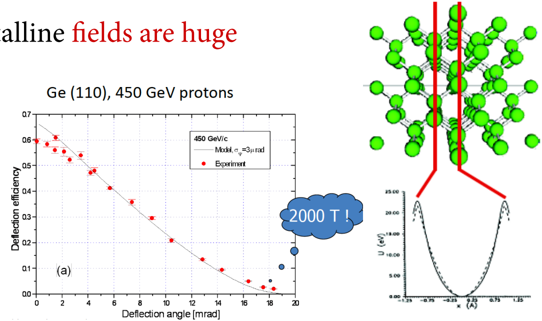

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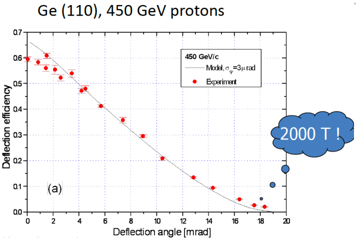

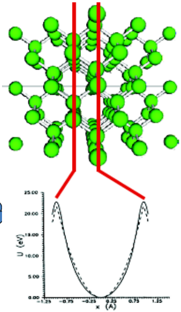

- The channeling efficiency is high for a deflection of a few mrad
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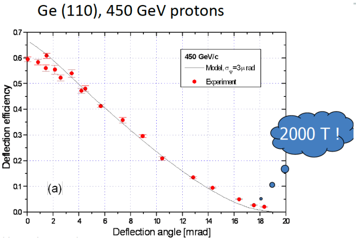

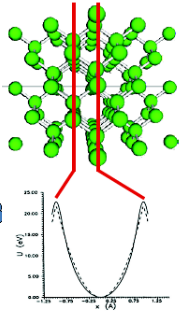

- The channeling efficiency is high for a deflection of a few mrad
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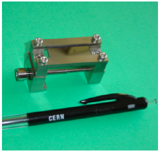
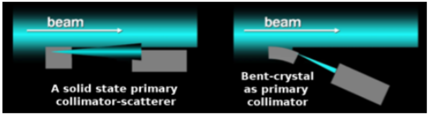
- Simple and robust way to extract the most energetic beam ever:



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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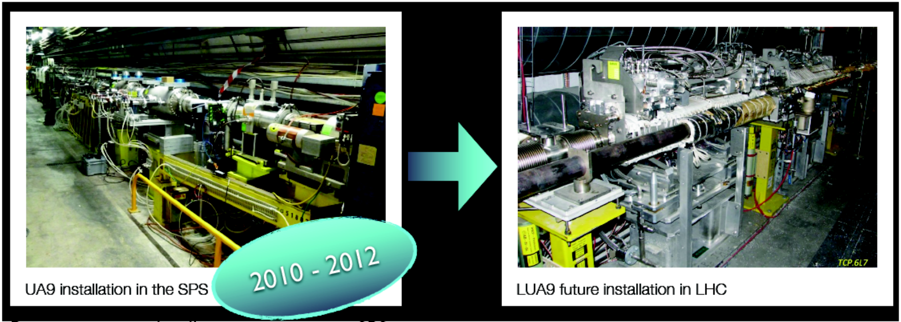

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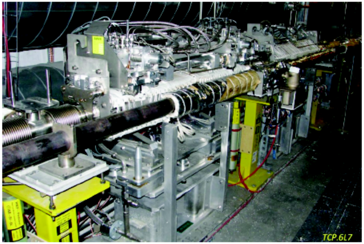
2010 - 2012



LUA9 future installation in LHC

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

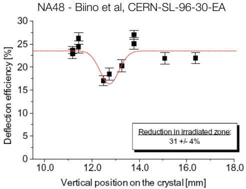
- 2 crystals

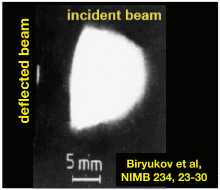
Long term plan is ambitious : propose a collimation system based on bent crystals for the upgrade of the current LHC collimation system

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)

A few figures on the (extracted) proton beam

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- Extracted intensity: $5 \times 10^8\ p^+ s^{-1}$ (1/2 the beam loss)

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- similar figures for the Pb-beam extraction

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 $B^0 \to J/\psi + K_s^0$, $B^0 \to \pi^+\pi^-$. 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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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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- 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 ...

Accessing the large *x* glue with quarkonia:

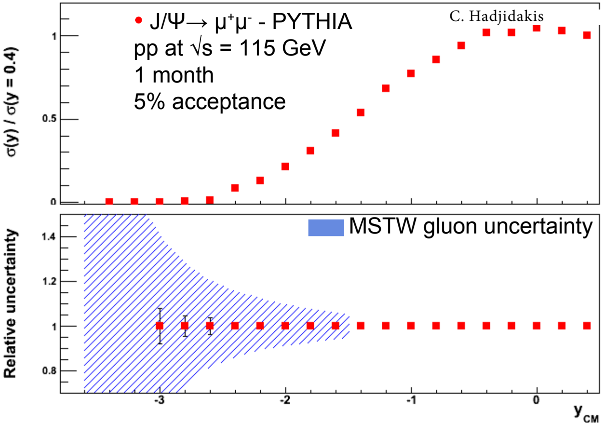
PYTHIA simulation
σ(y) / σ(y=0.4)
statistics for one month
5% acceptance considered

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
$y_{CM} \sim 0 \rightarrow x_g = 0.03$
$y_{CM} \sim -3.6 \rightarrow x_g = 1$

Υ: larger x_g for same y_{CM}
$y_{CM} \sim 0 \rightarrow x_g = 0.08$
$y_{CM} \sim -2.4 \rightarrow x_g = 1$



⇒ Backward measurements allow to access large x gluon pdf

Assuming that we understand the quarkonium-production mechanisms