Physics at A Fixed-Target ExpeRiment at the LHC: **AFTER@LHC**

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Part I

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

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- which are essential assets to study
  - rare proton fluctuations at large x
  - vector boson production near threshold and other rare processes
  - nuclear dependence in heavy-ion collisions
  - observables involving gluons and the proton spin

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    [could be crucial to characterise possible BSM discoveries]
  - 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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  - 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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- Bad thing: high multiplicity $\Rightarrow$ absorber $\Rightarrow$ physics limitation

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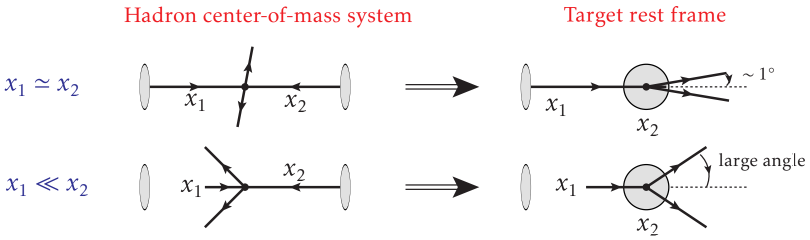

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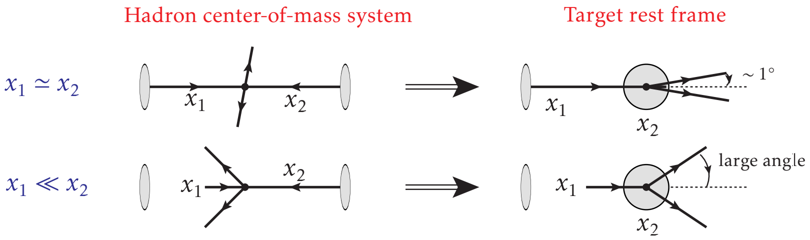

backward physics = large-x_2 physics

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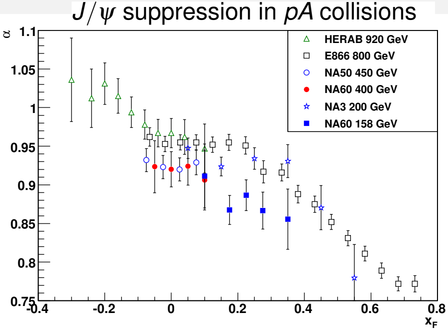

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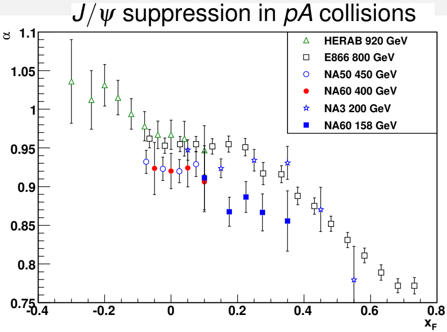

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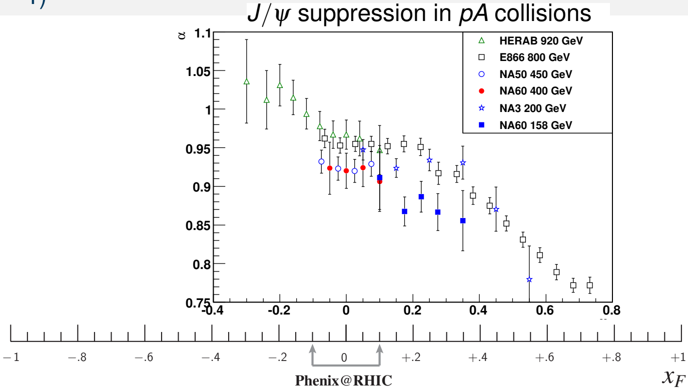

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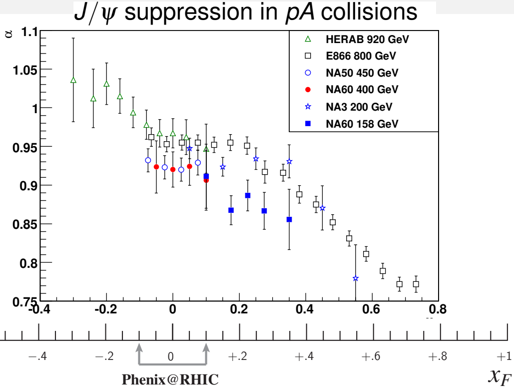

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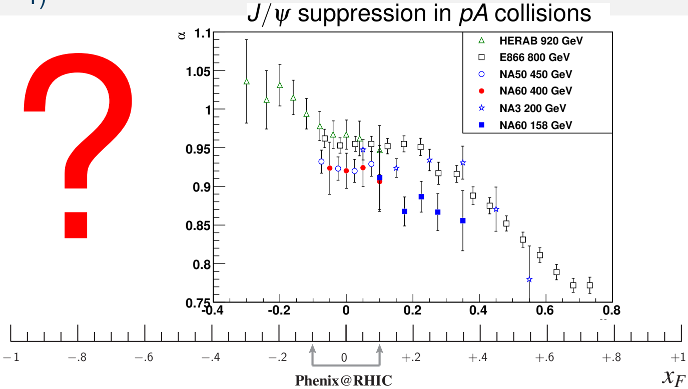

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- If we measure $\Upsilon(b\bar{b})$ at $y_{\rm cms} \simeq -2.5$ $\Rightarrow x_F \simeq \frac{2m_\Upsilon}{\sqrt{s}} \sinh(y_{\rm cms}) \simeq -1$

Part III

Colliding the LHC beams on fixed targets: 2 options

The extracted-beam option

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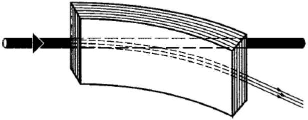

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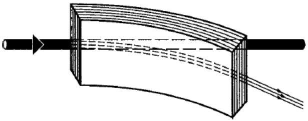

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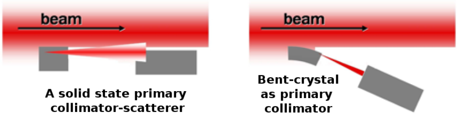

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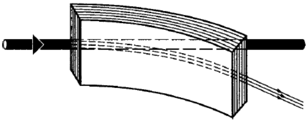

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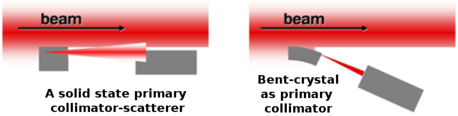

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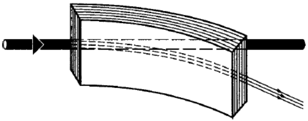

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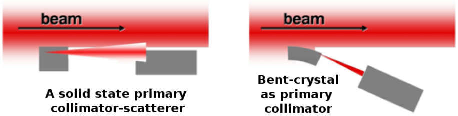

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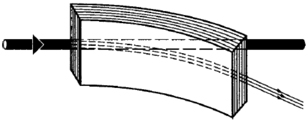

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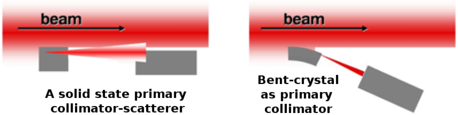

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1cm Be	1.85	9	62	.62
1cm Cu	8.96	64	42	.42
1cm W	19.1	185	31	.31
1cm Pb	11.35	207	16	.16

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1cm Cu	8.96	64	42	.42
1cm W	19.1	185	31	.31
1cm Pb	11.35	207	16	.16

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

3 orders of magnitude larger than RHIC

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

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- A specific gas target could be a competitive alternative to the beam extraction

Part IV

AFTER@LHC: a selection of key measurements

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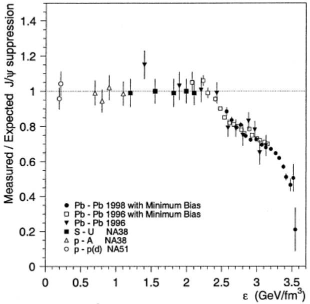

Fig. 7. Measured J/ψ production yields, normalised to the yields expected assuming that the only source of suppression is the ordinary absorption by the nuclear medium. The data is shown as a function of the energy density reached in the several collision

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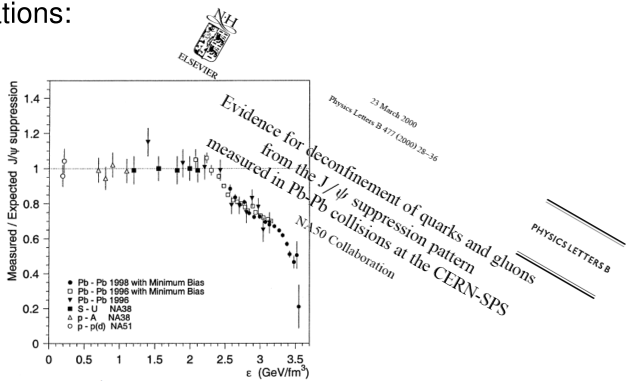

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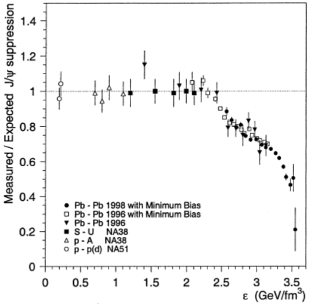

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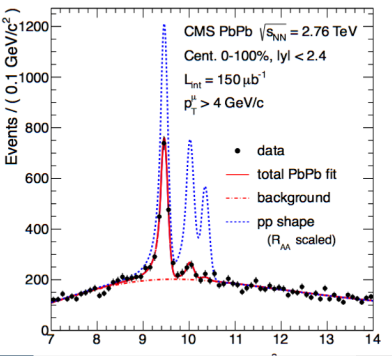


pA physics: understanding excited-quarkonium suppression

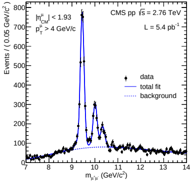
Selected for a Viewpoint in *Physics*
PRL **109,** 222301 (2012) PHYSICAL REVIEW LETTERS week ending 30 NOVEMBER 2012

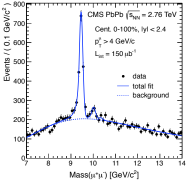
Observation of Sequential Υ Suppression in PbPb Collisions

S. Chatrchyan *et al.**
(CMS Collaboration)

pA physics: understanding excited-quarkonium suppression

CMS PRL 109 222301 (2012), JHEP04(2014)103





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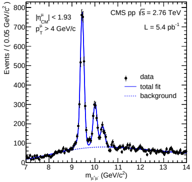

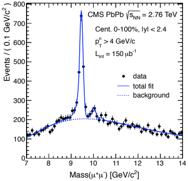

In addition to QGP formation, differences between quarkonium production yields in PbPb and pp collisions can also arise from cold-nuclear-matter effects [21]. However, such effects should have a small impact on the double ratios reported here. Initial-state nuclear effects are expected to affect similarly each of the three Υ states, thereby canceling out in the ratio. Final-state "nuclear absorption" becomes weaker with increasing energy [22] and is expected to be negligible at the LHC [23].

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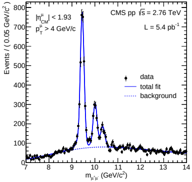

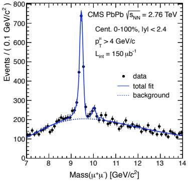

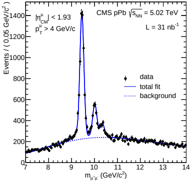

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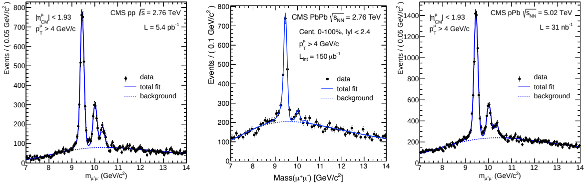

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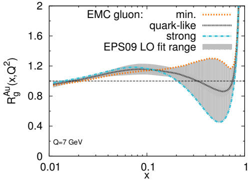

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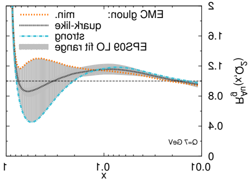

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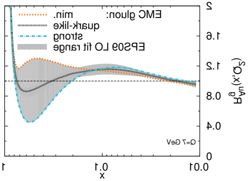

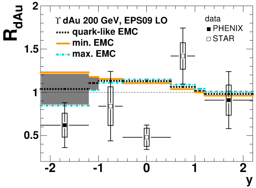

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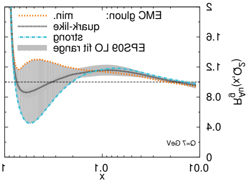

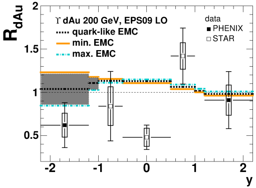

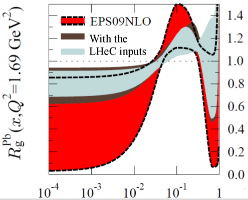

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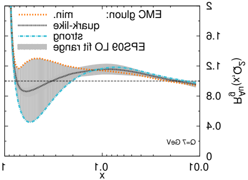

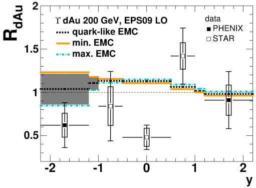

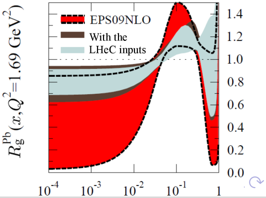

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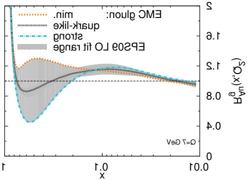
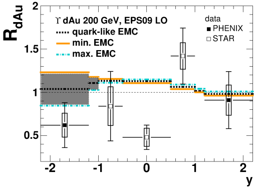
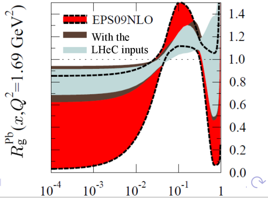
- AFTER allows for extensive studies of
  gluon sensitive probes in *pA*
- Unique potential for gluons at $x > 0.1$







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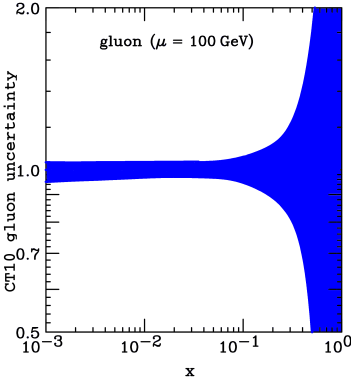

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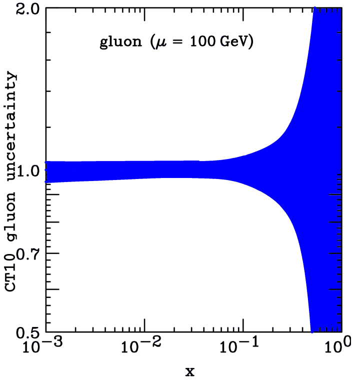

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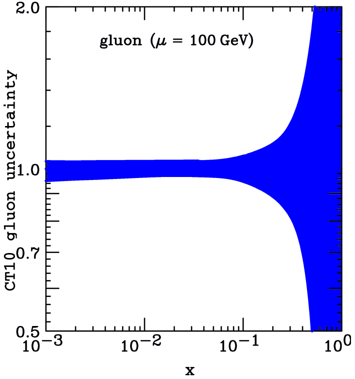

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- quarkonia
  see a recent study by D. Diakonov *et al.*, JHEP 1302 (2013) 069

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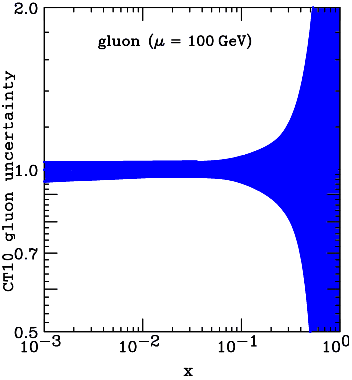

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see the recent survey by D. d'Enterria, R. Rojo, Nucl.Phys. B860 (2012) 311

pp physics: gluons in the proton

- Gluon distribution at mid, high and ultra-high x in the proton
  - Not easily accessible in DIS
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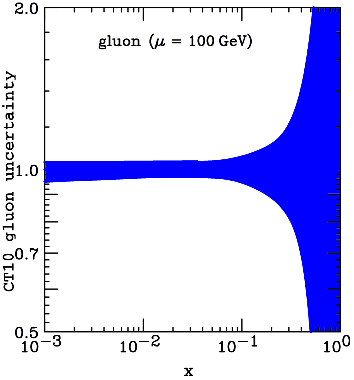

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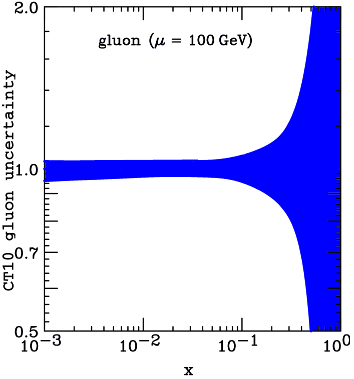

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Multiple probes needed to **check factorisation**

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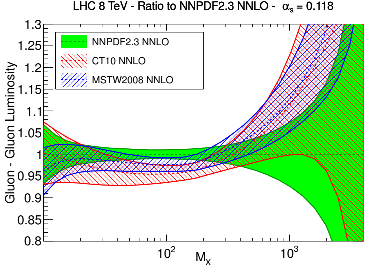

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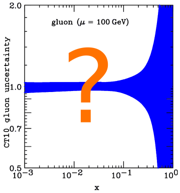
Large-x gluons: important to characterise some possible BSM findings at the LHC

pp physics: gluons in the neutron and the deuteron



Gluon PDF for the neutron unknown

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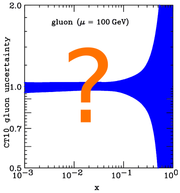

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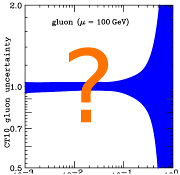

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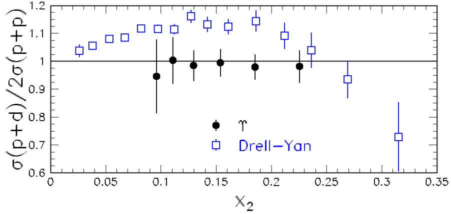

Pioneer measurement by E866

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

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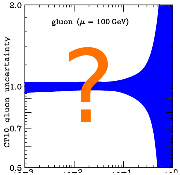

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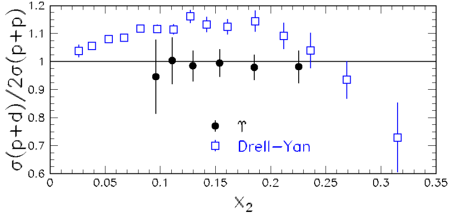

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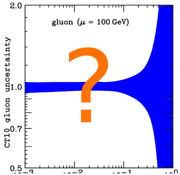

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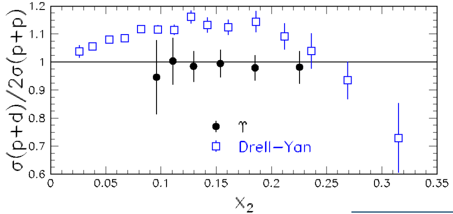

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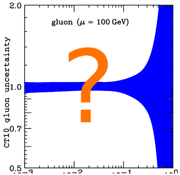

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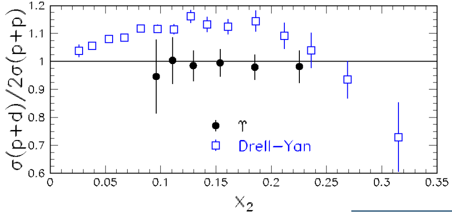

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If $g_n(x) - g_p(x)$ is too small, this measurement would anyhow be sensitive to the EMC and Fermi-motion effects in the deuteron

pp physics: heavy-quark content of the proton

- Heavy-quark distributions (at high x)

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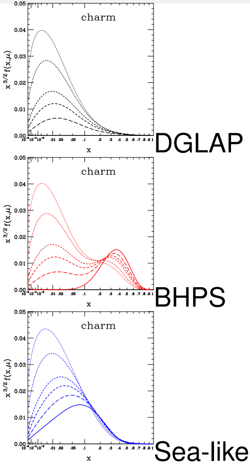
  - Pin down intrinsic charm, ... at last



3 sets from CTEQ6c
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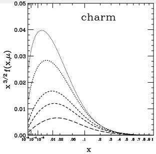
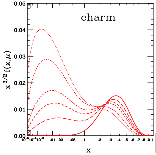
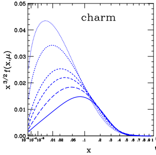


DGLAP



BHPS



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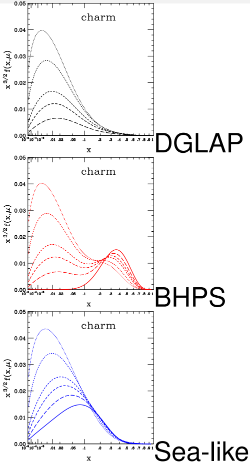

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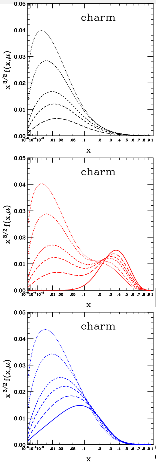

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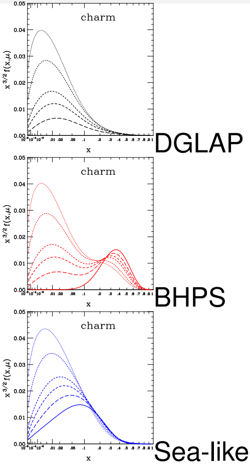

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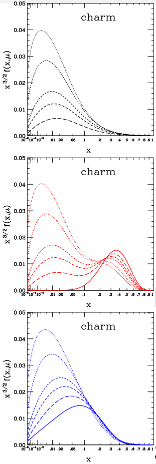

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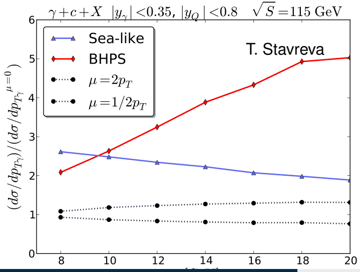

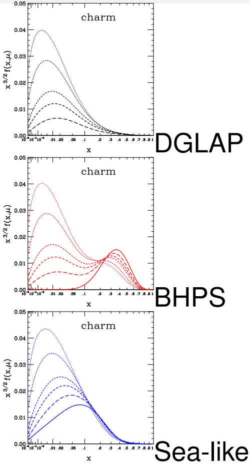

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S. J. Brodsky, *et al.*, Adv.Hi.En.Phys. (2015) ID:231547.

Spin physics: gluon contribution to the proton spin

- Gluon Sivers effect $\leftrightarrow$ correlation between
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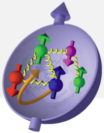

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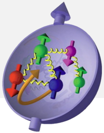

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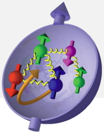

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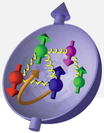

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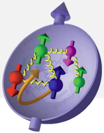

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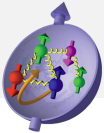

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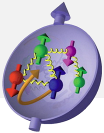

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- In general, one can carry out an extensive spin-physics program
- Even w/o target polarisation via the Boer-Mulders effect [backup slides]

Part V

First simulation results

First simulation: is the boost an issue ?

B. Trzeciak, L. Massacrier *et al.*, **1504.05145 [hep-ex], to appear in Adv.Hi.En.Phys.**

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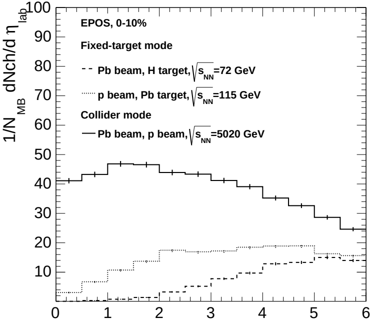

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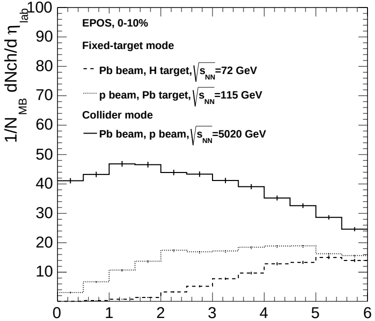


- Despite the boost, the multiplicity in the LHCb acceptance [forward η] is lower in the fixed mode than in the collider mode (at higher $\sqrt{s}$)
- Simulation backed-up with a comparison of the number-of-track distribution between simulations at the detector level and data

Z. Yang, private comm.

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

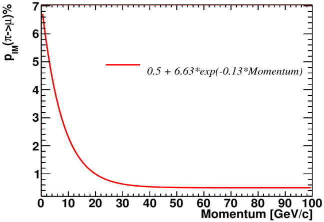
- Simulations with Pythia 8.185
- LHCb detector is NOT simulated but LHCb reconstruction parameters are introduced in the fast simulation (resolution, analysis cuts, efficiencies…)

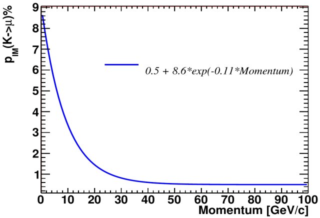
Requirements
Momentum resolution : $\Delta p/p = 0.5\%$
Muon identification efficiency: 98%

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]





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Charmonium background & its rapidity dependence

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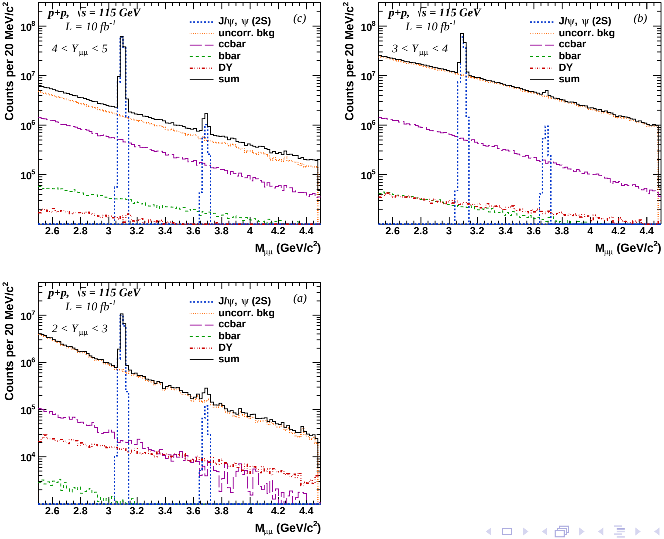

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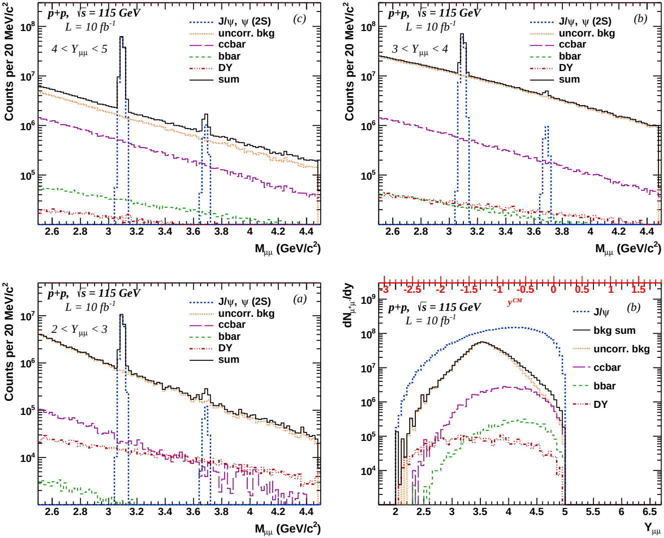

Bottomonium background & signal reach

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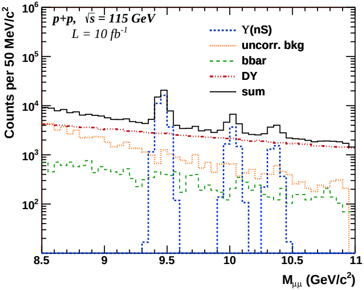
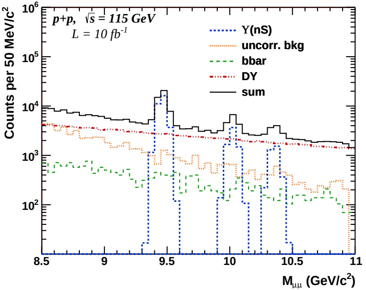


The dominant background is Drell-Yan

3 peaks well resolved

Bottomonium background & signal reach

B. Trzeciak, L. Massacrier *et al.*, 1504.05145 [hep-ex], to appear in Adv.Hi.En.Phys.

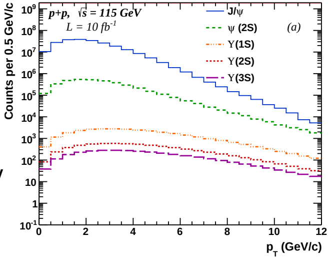


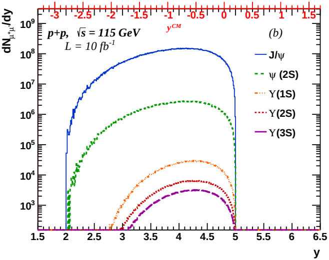
The dominant background is Drell-Yan

3 peaks well resolved

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. $x_2 \simeq 0.7$

Part VI

Further readings

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) ID: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) ID: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) ID:961951
- *Anti-shadowing Effect on Charmonium Production at a Fixed-target Experiment Using LHC Beams* by K. Zhou, Z. Chen, P. Zhuang. arXiv:1507.05413 [nucl-th].
- *Lepton-pair production in ultraperipheral collisions at AFTER@LHC* By J.P. Lansberg, L. Szymanowski, J. Wagner. arXiv:1504.02733 [hep-ph].
- *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, Andreas Metz, and D. Pitonyak. [arXiv:1502.04021 [hep-ph]. Adv.Hi.En.Phys. (2015) ID: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) ID: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) ID:371396
- *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.

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]].
- *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) ID:726393, in press.
- 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) ID:231547, in press.
- *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.

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) ID: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) ID: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) ID: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.

Part VII

Conclusion and outlooks

Conclusion

- Both p and Pb LHC beams can be extracted without disturbing the other experiments

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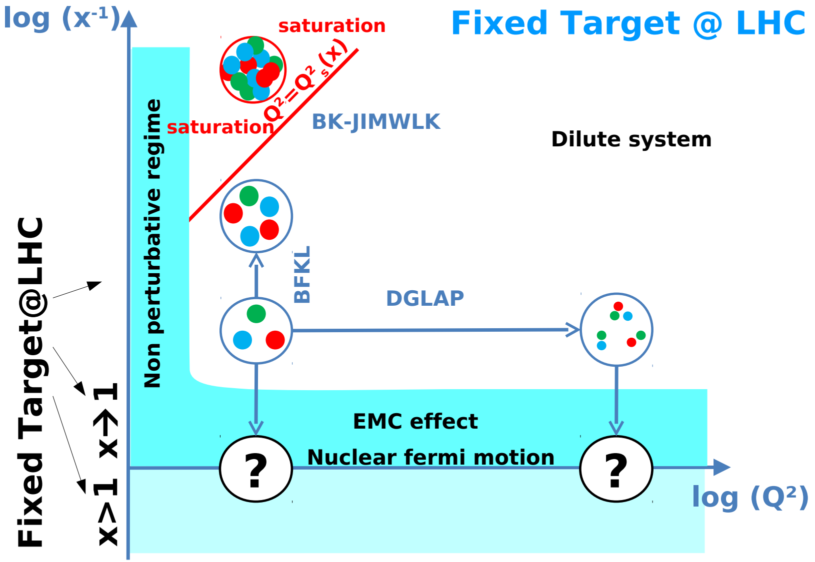
  - uncharted kinematical region (nucleus rapidity region)
  - high-potential with excited-state quarkonium studies
- A wealth of possible measurements:
  DY, Open b/c, jet correlation, UPC... (not mentioning secondary beams)

Part VIII

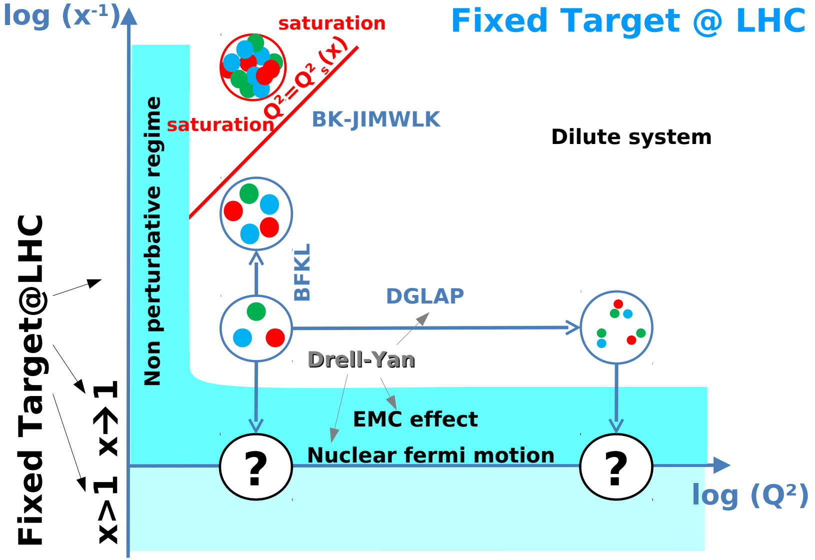
Backup slides

Overall



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

Overall


log (x-1)
saturation
Fixed Target @ LHC
Q2=Q2s(x)
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
BFKL
DGLAP
Fixed Target@LHC
x→1
x>1
Drell-Yan
EMC effect
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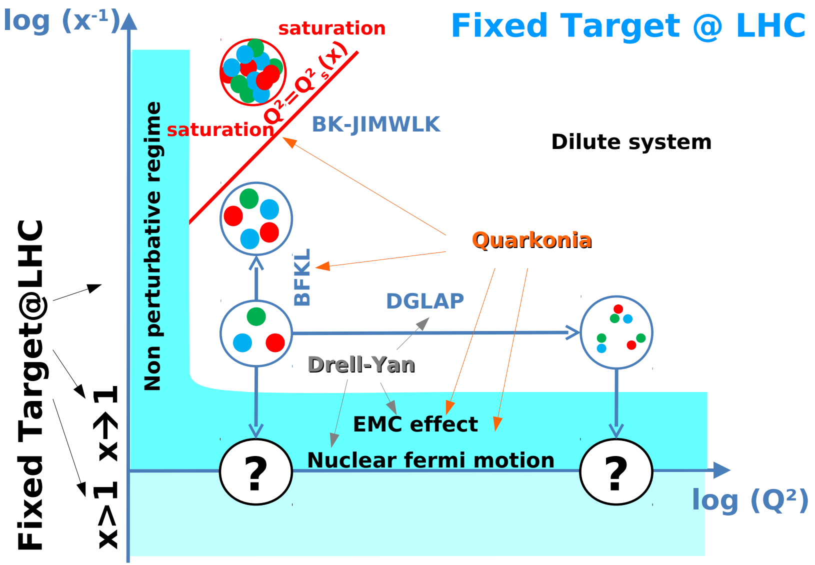
?
?
log (Q2)

Overall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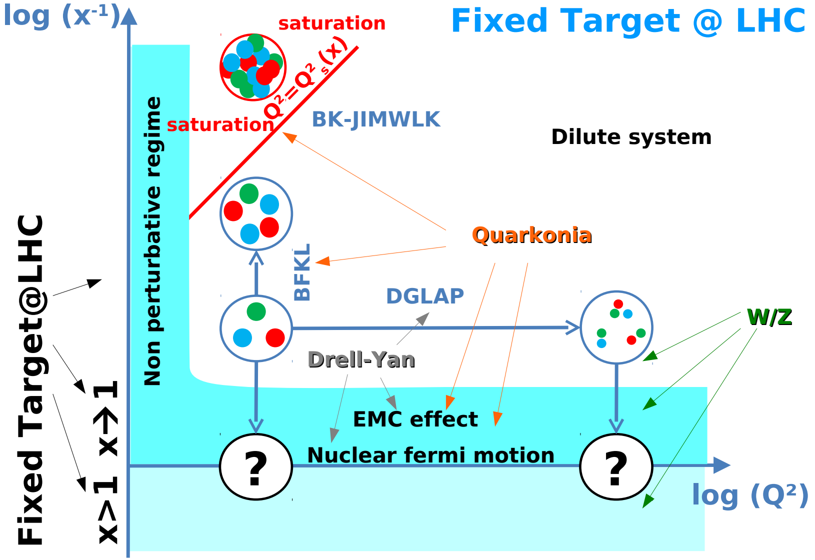
Overall



log (x⁻¹)
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?
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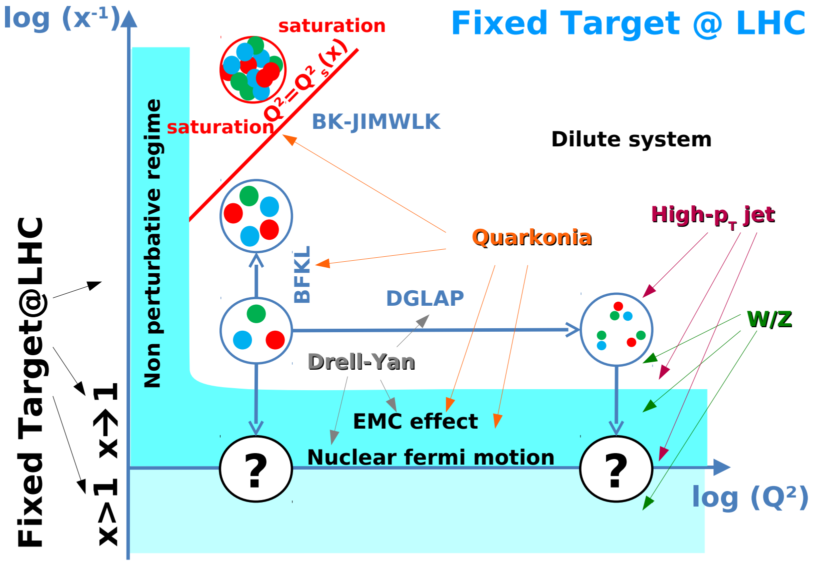
Overall


log (x⁻¹)
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Gas target

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

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

Accessing the large *x* glue with quarkonia:

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

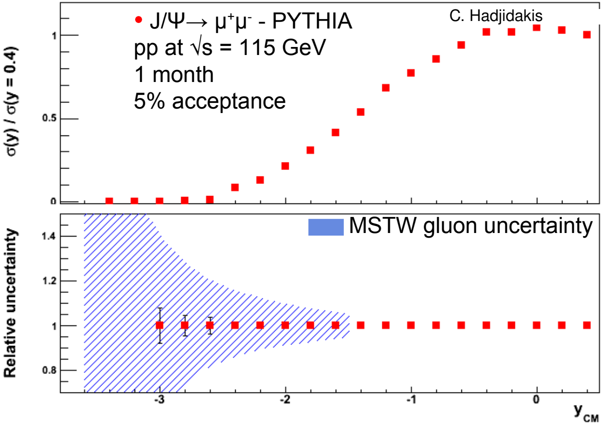
Statistical relative uncertainty
Large statistics allow to access very backward region

Gluon uncertainty from MSTWPDF
- only for the gluon content of the target
- assuming

$$x_g = M_{J/\psi}/\sqrt{s}\, e^{-y_{CM}}$$

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

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



⇒ Backward measurements allow to access large x gluon pdf

Assuming that we understand the quarkonium-production mechanisms

Distribution of linearly polarised gluons in unpolarised protons

Distribution of linearly polarised gluons in unpolarised protons

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

Polarized gluon studies with charmonium and bottomonium at LHCb and AFTER

Daniël Boer*

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- Low P_T C-even quarkonium production is a good probe of the distribution of linearly polarised gluons in unpolarised protons: $h_1^{\perp g}$

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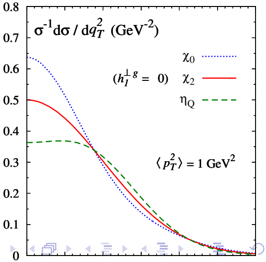
- Low P_T C-even quarkonium production is a good probe of the distribution of linearly polarised gluons in unpolarised protons: $h_1^{\perp g}$
- Affect the low P_T spectra:
  $\frac{1}{\sigma}\frac{d\sigma(\eta_Q)}{d\mathbf{q}_T^2} \propto 1 - R(\mathbf{q}_T^2)$ & $\frac{1}{\sigma}\frac{d\sigma(\chi_{0,Q})}{d\mathbf{q}_T^2} \propto 1 + R(\mathbf{q}_T^2)$
  (R involves $f_1^g(x,k_T,\mu)$ and $h_1^{\perp g}(x,k_T,\mu)$)



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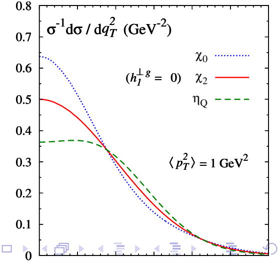

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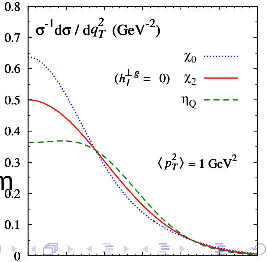
- $h_1^{\perp g}$ is connected to the Higgs transverse-momentum distribution **D. Boer,** *et al.* **PRL 108 (2012) 032002**



Access to $h_1^{\perp g}$: II

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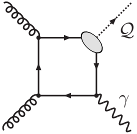
PRL **112,** 212001 (2014) PHYSICAL REVIEW LETTERS week ending 30 MAY 2014

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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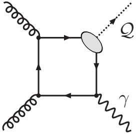

- Gluon B-M can also be accessed via back-to-back $\psi/\Upsilon + \gamma$ associated production at the LHC. Also true at AFTER@LHC !

Access to $h_1^{\perp g}$: II

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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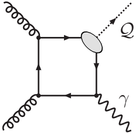
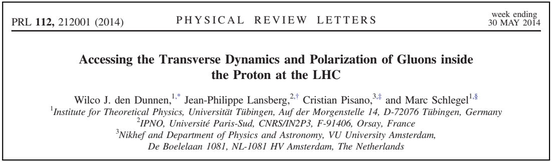
[1]*Institute for Theoretical Physics, Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany*
[2]*IPNO, Université Paris-Sud, CNRS/IN2P3, F-91406, Orsay, France*
[3]*Nikhef and Department of Physics and Astronomy, VU University Amsterdam, De Boelelaan 1081, NL-1081 HV Amsterdam, The Netherlands*



- Gluon B-M can also be accessed via back-to-back $\psi/\Upsilon+\gamma$ associated production at the LHC. Also true at AFTER@LHC !
- Smaller yield (14 TeV $\rightarrow$ 115 GeV) compensated by an access to lower P_T

Access to $h_1^{\perp g}$: II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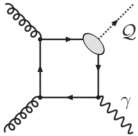

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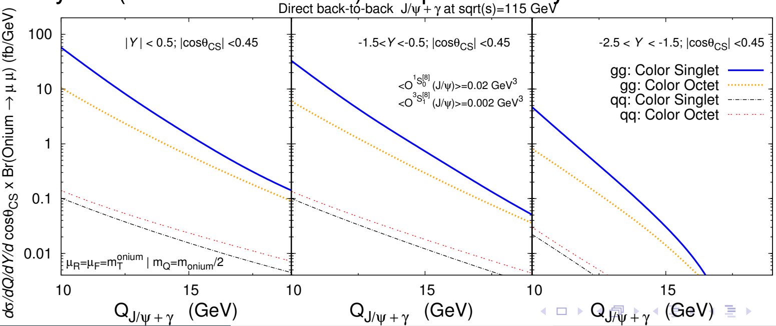

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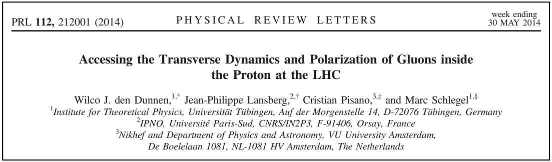
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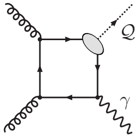

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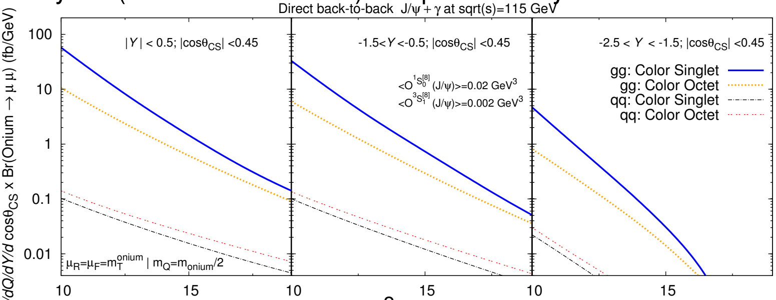

At $Y \simeq -2$, $x_2 \simeq 10/115 \times e^2 \simeq 0.65$. Yet, $g-g > q-\bar{q}$!

SSA in 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)	$x_p^{\uparrow}$	$\mathscr{L}$ ($\text{nb}^{-1}\text{s}^{-1}$)
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

➟ For AFTER, the numbers correspond to a 50 cm polarized *H* target.

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

SSA in Drell-Yan studies with AFTER@LHC

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267.

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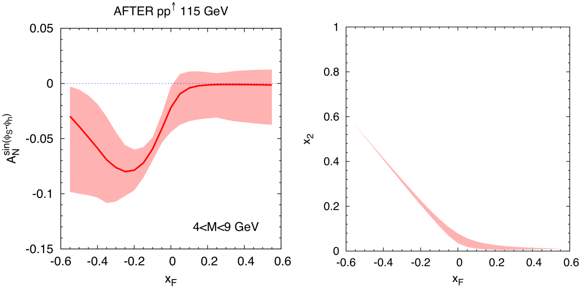
expected Sivers asymmetry in
D-Y@AFTER, sign change,
no TMD evolution



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

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Luminosities with extracted-lead beams

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- Instantaneous Luminosity:
  $\mathscr{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathscr{N}_A)/A$
  $\Phi_{beam} = 2 \times 10^5$ Pb s^{-1}, $\ell = 1$ cm (target thickness)

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Target	ρ (g.cm^{-3})	A	$\mathcal{L}$ (mb^{-1}.s^{-1})=$\int\mathcal{L}$ (nb^{-1}.yr^{-1})
1m Liq. H_2	0.07	1	800
1m Liq. D_2	0.16	2	1000
1cm Be	1.85	9	25
1cm Cu	8.96	64	17
1cm W	19.1	185	13
1cm Pb	11.35	207	7

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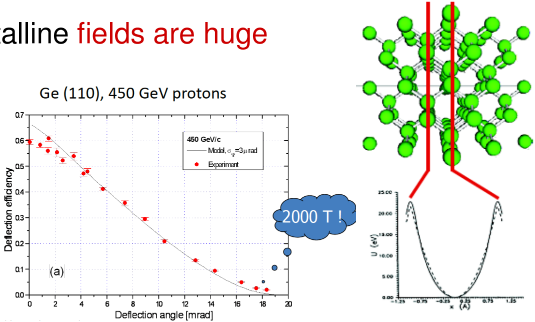
- Planned lumi for PHENIX Run15AuAu 2.8 nb^{-1} (0.13 nb^{-1} at 62 GeV)
- Nominal LHC lumi for PbPb 0.5 nb^{-1}

The beam extraction with a bent crystal

- Inter-crystalline fields are huge



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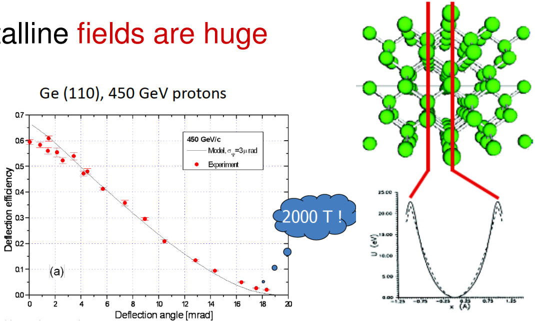

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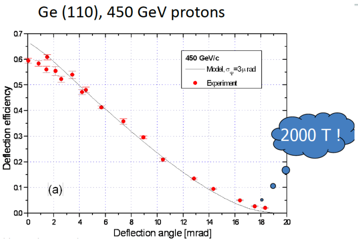

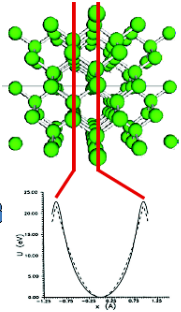

- The channeling efficiency is high for a deflection of a few mrad
- One can extract a significant part of the beam loss ($10^9 p^+ s^{-1}$)

The beam extraction with a bent crystal

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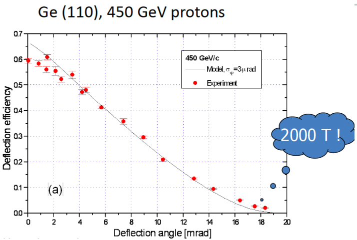
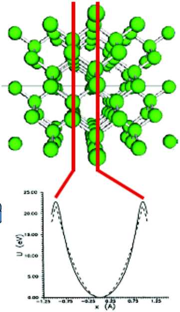
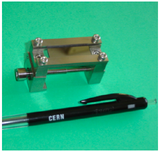




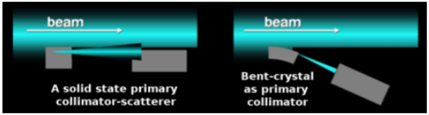
- The channeling efficiency is high for a deflection of a few mrad
- One can extract a significant part of the beam loss ($10^9 p^+ s^{-1}$)
- Simple and robust way to extract the most energetic beam ever:



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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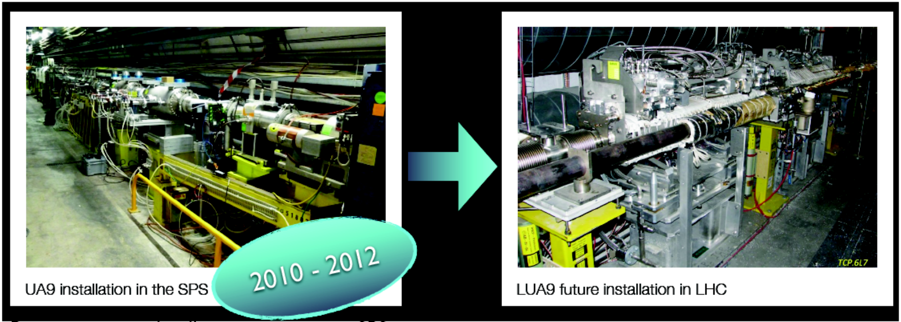

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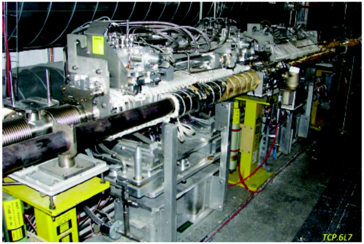
2010 - 2012



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

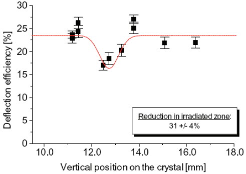
- 2 crystals

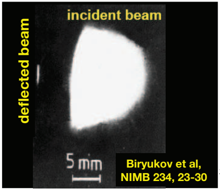
Long term plan is ambitious : propose a collimation system based on bent crystals for the upgrade of the current LHC collimation system

Crystal resistance to irradiation

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

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





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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

- 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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  - the crystal sees 2808×11000 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
  - Provided that the probability of interaction with the target is below 5%,

pile-up is not an issue

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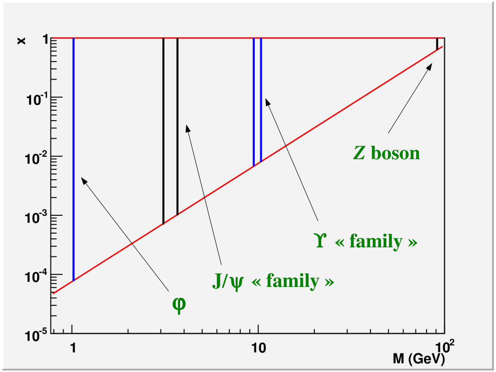
- similar figures for the Pb-beam extraction

AFTER@LHC: A dilepton observatory ?

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



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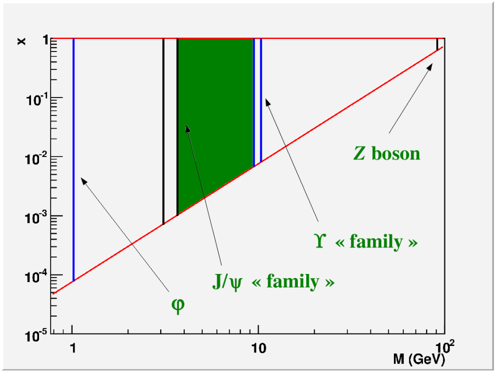

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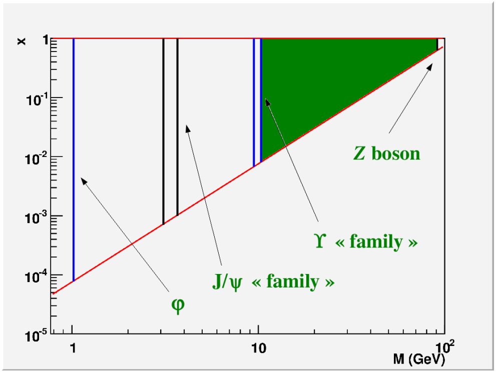

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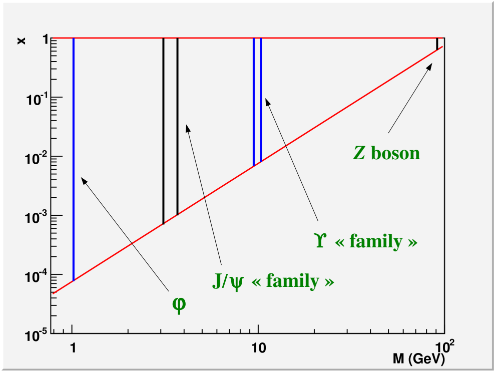
Note: $x_{target}(\equiv x_2) > x_{projectile}(\equiv x_1)$
"backward" region



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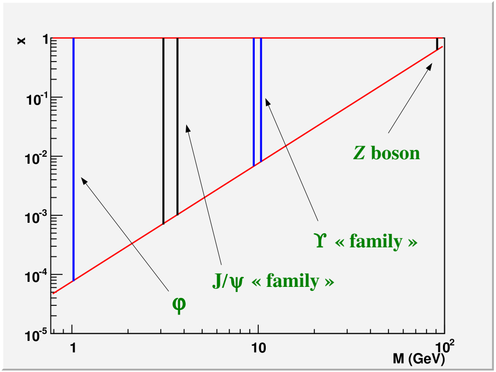

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"backward" region

→ sea-quark asymetries
via p and d studies

- at large(est) x: backward ("easy")

- at small(est) x: forward (need to stop the (extracted) beam)

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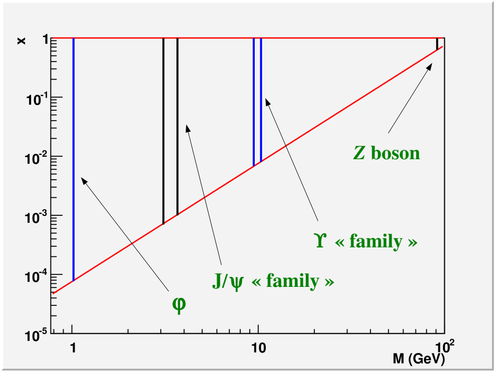

Note: $x_{target}(\equiv x_2) > x_{projectile}(\equiv x_1)$ "backward" region

→ sea-quark asymetries via p and d studies

- at large(est) x: backward ("easy")
- at small(est) x: forward (need to stop the (extracted) beam)

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

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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PHYSICAL REVIEW D VOLUME 37, NUMBER 5 1 MARCH 1988

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

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(Received 27 July 1987)

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

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  - not to mention ratio with **open charm, Drell-Yan,** etc ...

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This calls for multiple measurements to (in)validate factorisation

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- Luminosities and yields with the extracted 2.76 TeV Pb beam ($\sqrt{s_{NN}} = 72$ GeV)

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The same picture also holds for open heavy flavour

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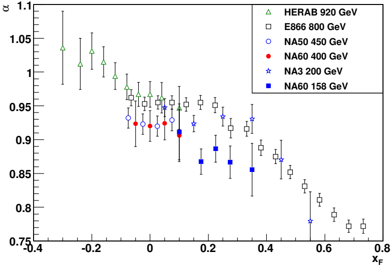
- the possibilities for $c\bar{c}$ recombination
  - Open charm studies are difficult where recombination matters most
    i.e. at low P_T
  - Only indirect indications –from the y and P_T dependence of R_{AA}–
    that recombination may be at work
  - CNM effects may show a non-trivial y and P_T dependence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

SPS and Hera-B

– J/ψ **data in** pA **collisions**



NA60 Phys.Lett. B 706 (2012) 263
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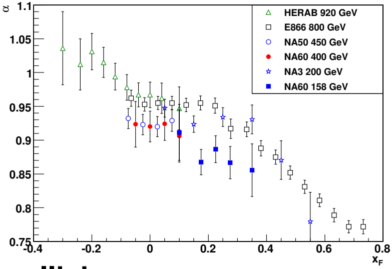

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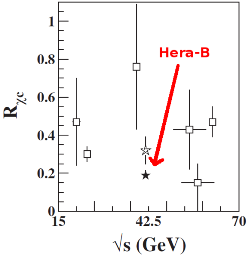

HERA-B PRD 79 (2009) 012001, and ref. therein

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

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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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- 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): $\sqrt{s}$ ~ 115 GeV

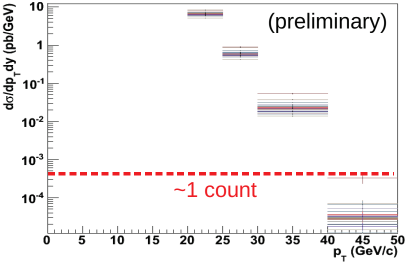
- p-p photon kinematics at fixed-target LHC (central rapidities):
  To access $x > 0.3$ one needs isolated-γ at: $p_T = x_T\sqrt{s}/2 > 20$ GeV/c
- JETPHOX NLO pQCD calculations:

  p-p at $\sqrt{s}$=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) ~ $2\bullet10^3$ 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