Spin Physics with A Fixed Target ExpeRiment @ the LHC (AFTER@LHC)

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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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- 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 target proton spin

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  - Very large PDF uncertainties for $x \gtrsim 0.5$.
    [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
  - Relevance of nuclear PDF to understand the initial state of heavy-ion collisions
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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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- Let us simply avoid the forward region ! How ?

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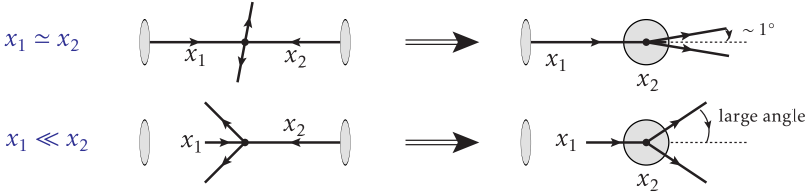
Hadron center-of-mass system | Target rest frame



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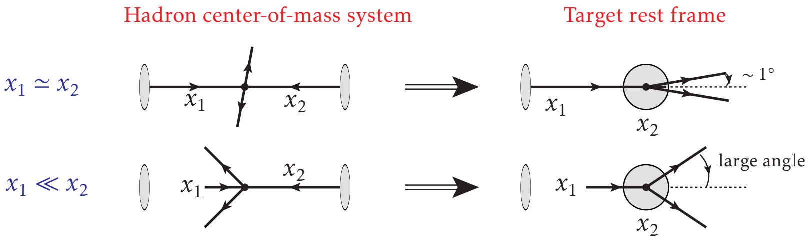

backward physics = large-x_2 physics

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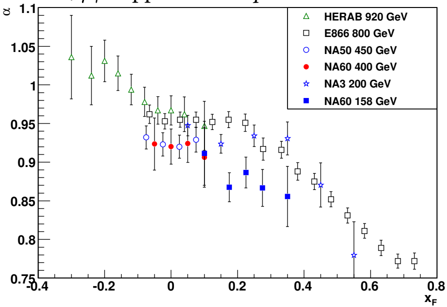

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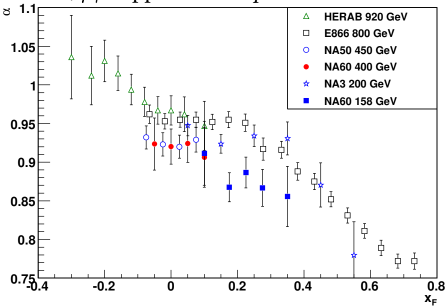

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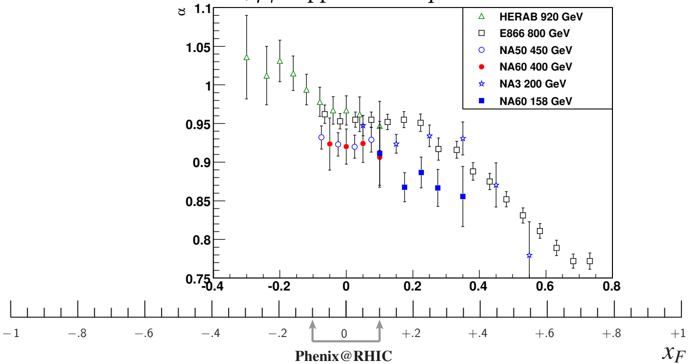

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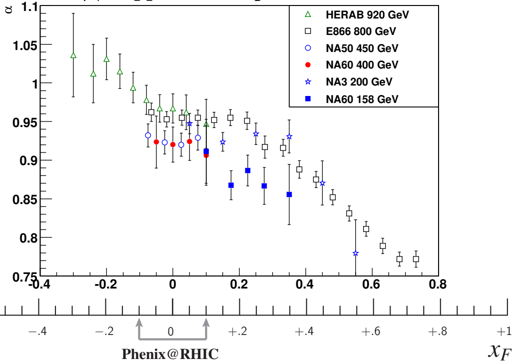

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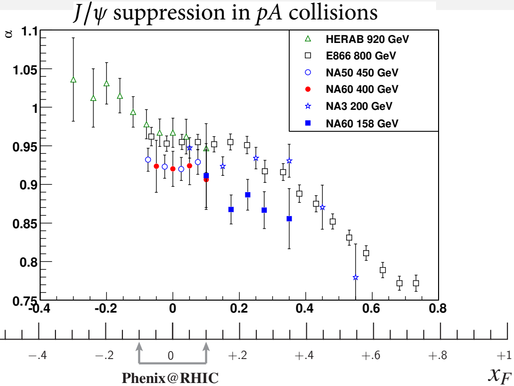

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- If we measure $\Upsilon(b\bar{b})$ at $y_{\rm cms} \simeq -2.5 \Rightarrow x_F \simeq \frac{2m_\Upsilon}{\sqrt{s}} \sinh(y_{\rm cms}) \simeq -1$

Part III

Colliding the LHC beams on fixed targets: 2 options

The extracted-beam option

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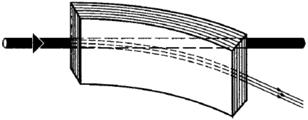

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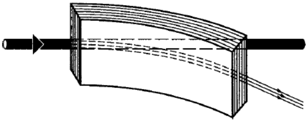

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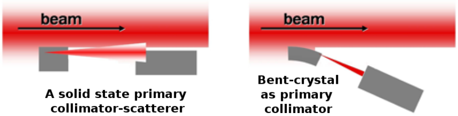

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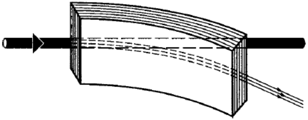

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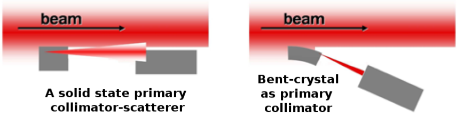

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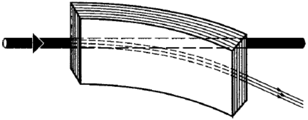

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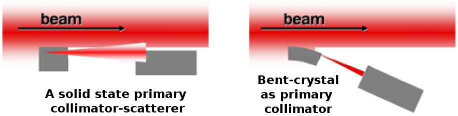

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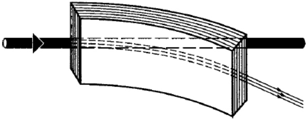

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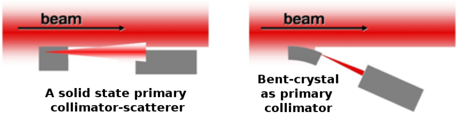

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1m Liq. D_2	0.16	2	**2400**	**24**
1cm Be	1.85	9	**62**	**.62**
1cm Cu	8.96	64	**42**	**.42**
1cm W	19.1	185	**31**	**.31**
1cm Pb	11.35	207	**16**	**.16**

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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 ?

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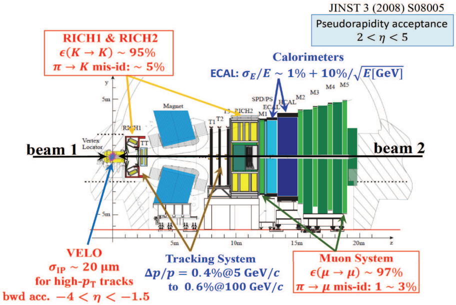
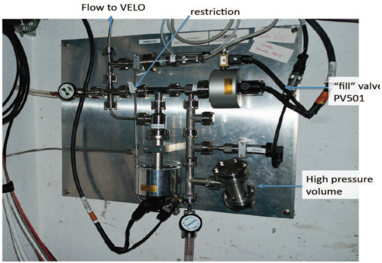


SMOG: System for Measuring Overlap with Gas



➜ injection of Ne-gas into VELO

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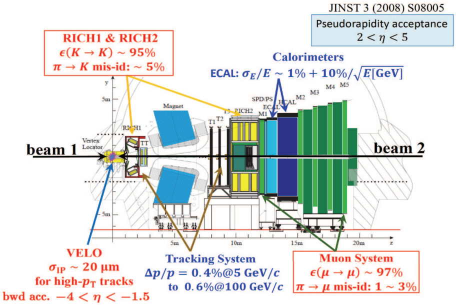

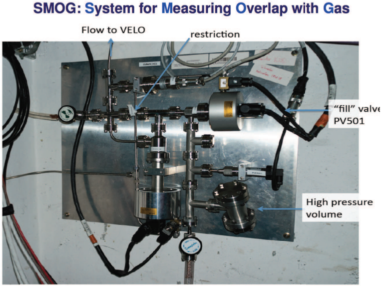

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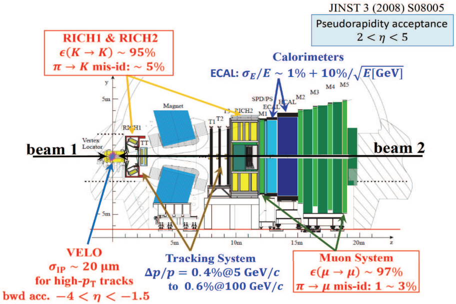

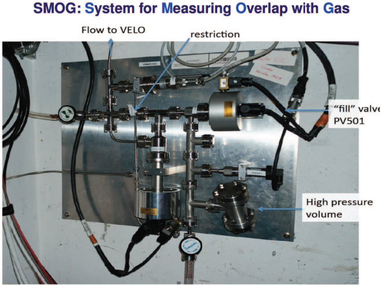

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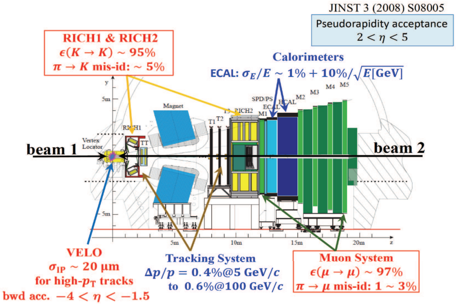

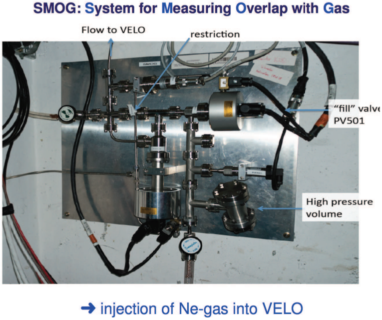

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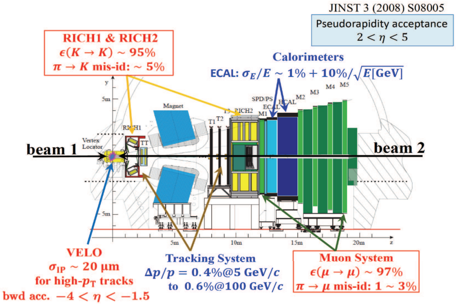

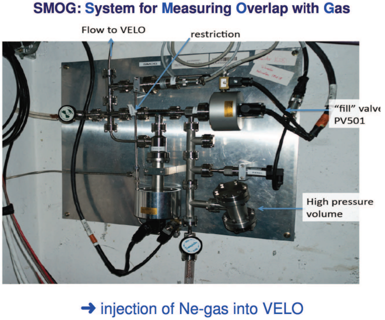

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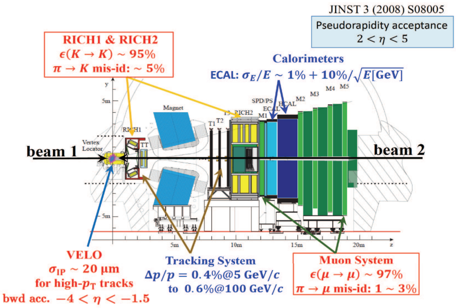

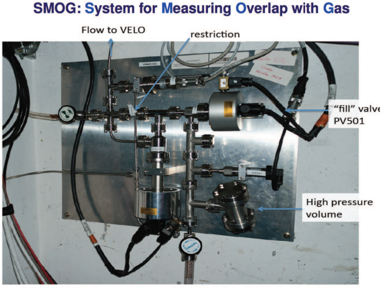

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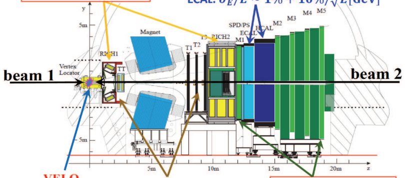

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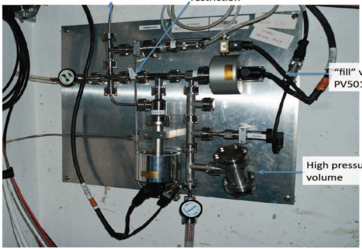

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- Target unpolarised with the current SMOG system
- SMOG test : no decrease of LHC performances observed

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) ID:463141; See E. Steffens's talk at PSTP 2015

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- Simply scaled up, this would give, for Pbp or PbA, 100 $\text{nb}^{-1} y^{-1}$.

  ⇒ For PbA, limitations would come first from the beam lifetime.

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- Simply scaled up, this would give, for Pbp or PbA, 100 $\text{nb}^{-1} y^{-1}$.

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- A specific gas target can be 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]

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[4] *Physics Institute, Friedrich-Alexander University Erlangen-Nürnberg, 91058 Erlangen, Germany*

We discuss the application of an open storage cell as gas target for a proposed LHC fixed-target experiment AFTER@LHC. The target provides a high areal density at minimum gas input, which may be polarized ^{1}H, ^{2}H, or ^{3}He gas or heavy inert gases in a wide mass range. For the study of single-spin asymmetries in pp interaction, luminosities of nearly 10^{33}/cm^{2} s can be produced with existing techniques.

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The authors claim that the COMPASS type frozen spin target machinery takes too much space in the LHC tunnel. Instead, a UVa-type NH_3 DNP target* with smaller target set-up may be considered for this comparison with parameters§:

$$n_t = 1.5\ 10^{23}/\mathrm{cm}^2,\ \ P_p = 0.85,\ \ \text{dilution } f = 0.17.$$

This results in a $\mathrm{FoM} = n_t\, P^2\, f^2 = 3.1\cdot 10^{21}/\mathrm{cm}^2$. As the beam intensity i_p also enters the measurement quality, we define

$$\mathrm{FoM}^* = i_p \cdot \mathrm{FoM} = P^2 \cdot f^2 \cdot i_p \cdot n_t = P^2 \cdot f^2 \cdot \mathcal{L}$$

E. Steffens's talk at PSTP 2015

"The authors"= we

"claim" = in fact, we believe so, but may be mislead

Results:

UVa-target and bent-crystal extr. beam	$\mathrm{FoM}^* = 1.57\cdot 10^{30}/\mathrm{cm}^2$ s
'COMPASS-target " " "	$\mathrm{FoM}^* = 1.87\cdot 10^{32}/\mathrm{cm}^2$ s
'HERMES' target and full LHC beam ($T = 300/100$ K, $P = 0.85$, $\alpha = 0.95$)	$\mathrm{FoM}^* = 0.60/1.04\cdot 10^{33}/\mathrm{cm}^2$ s

*) from talk N. Doshita – AFTER@LHC 2014

§) note that n_t = density of target nucleons; then $f \cdot n_t$ is the number of polarizable nucleons

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 : $f_{1T}^{\perp}(x, \vec{k}_\perp^2)$

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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
  - P1027: valence quarks using a polarised proton beam (120 GeV) on an unpolarised proton target
  - P1039: sea quarks using an unpolarised proton beam (120 GeV) on a polarised proton target

SSA in Drell-Yan studies with AFTER@LHC

➟ Relevant parameters for existing and 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)	$x_p^\uparrow$	$\mathcal{L}$ ($nb^{-1}s^{-1}$)
AFTER	$p + p^\uparrow$	7000	115	$0.01 \div 0.9$	1
COMPASS	$\pi^\pm + p^\uparrow$	160	17.4	$0.2 \div 0.3$	2
COMPASS (low mass)	$\pi^\pm + p^\uparrow$	160	17.4	~ 0.05	2
P1039	$p + p^\uparrow$	120	15	$0.1 \div 0.3$	400-1000
P1027	$p^\uparrow + p$	120	15	$0.35 \div 0.85$	400-1000
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
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➟ Relevant parameters for existing and proposed polarized DY experiments.

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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	$0.01 \div 0.9$	1
COMPASS	$\pi^\pm + p^\uparrow$	160	17.4	$0.2 \div 0.3$	2
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P1039	$p + p^\uparrow$	120	15	$0.1 \div 0.3$	400-1000
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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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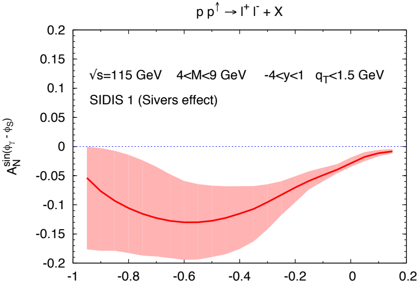

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M. Anselmino, U. D'Alesio, S. Melis. Adv.Hi.En.Phys. (2015) ID 475040

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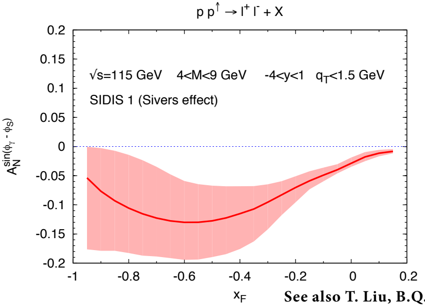

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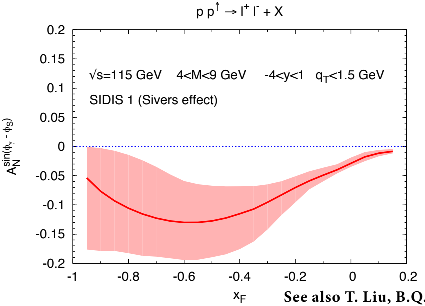

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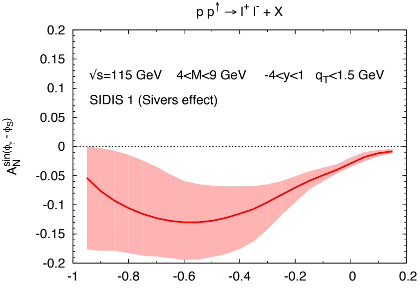

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- W and Z should be reachable with 10 fb^{-1}: $x^{\uparrow} \simeq 0.7 \div 0.8$

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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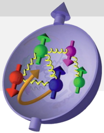

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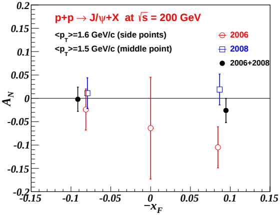

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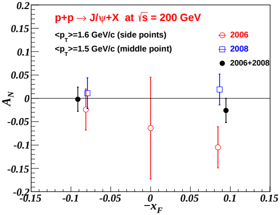

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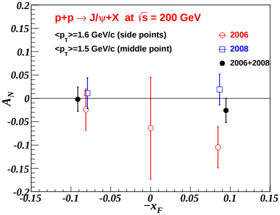

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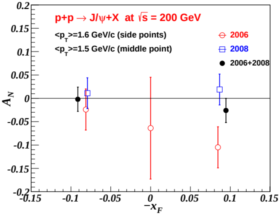

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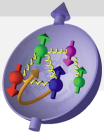

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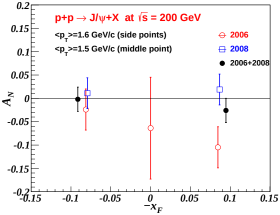

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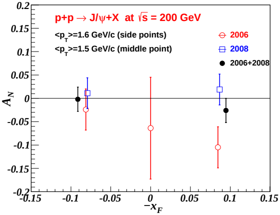

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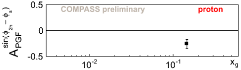
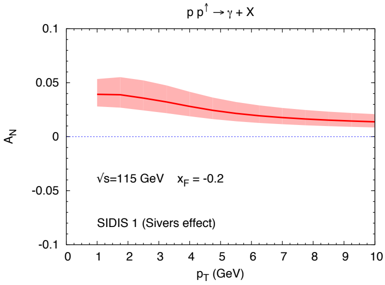


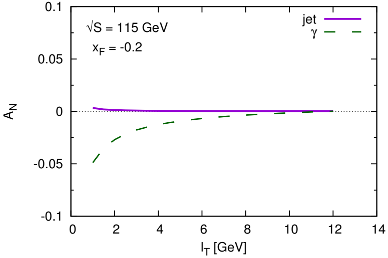
G. Mallot, this conference

Further studies of the Sivers effect

- A_N^γ is predicted to have an opposite sign between the Generalised Parton Model (GPM) and the Collinear-Twist 3 (CT3) approach

GPM: M. Anselmino, U. D'Alesio, S. Melis. Adv.Hi.En.Phys. (2015) ID:475040
CT3: K. Kanazawa, Y. Koike, A. Metz, and D. Pitonyak. Adv.Hi.En.Phys. (2015) ID:257934.





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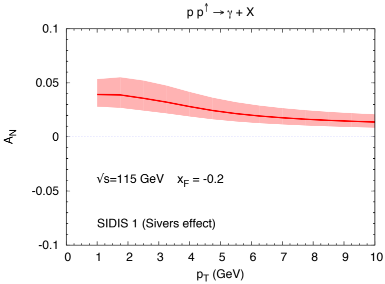

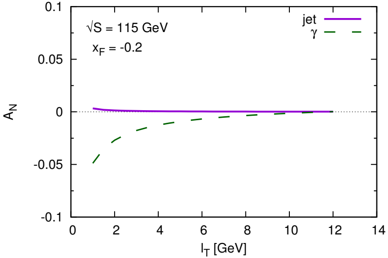

- A_N^{π}: sign mismatch issue with $f_{1T}^{\perp,q}(x,\vec{k}_\perp^2)$ extracted from SIDIS
  - A_N^{jet}: complementary since no "contamination" (fragmentation Collins effect)
  - A_N^{π} should be measured at larger p_T

Part V

First simulation results

First simulation: is the boost an issue ?

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

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- We have compared the multiplicity as function of η in the collider mode ($\sqrt{s}$ = 5 TeV) vs. that in fixed target mode ($\sqrt{s}$ = 115 TeV) using EPOS

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

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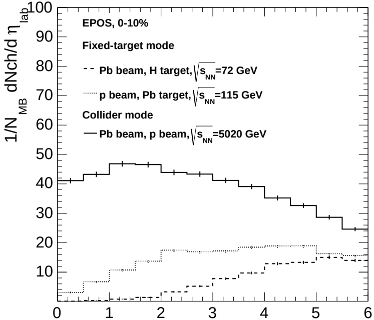
- We have compared the multiplicity as function of η in the collider mode ($\sqrt{s}$ = 5 TeV) vs. that in fixed target mode ($\sqrt{s}$ = 115 TeV) using EPOS



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

First simulation: is the boost an issue ?

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

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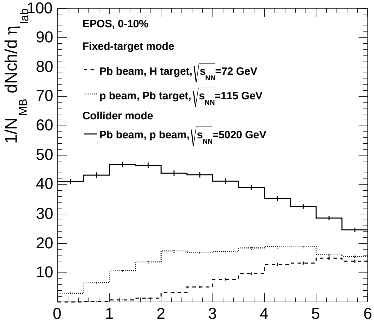


- Despite the boost, the multiplicity in the LHCb acceptance [forward η] is lower in the fixed mode than in the collider mode (at higher $\sqrt{s}$)
- Simulation backed-up with a comparison of the number-of-track distribution between simulations at the detector level and data

Z. Yang, private comm.

Fast simulation using LHCb reconstruction parameters

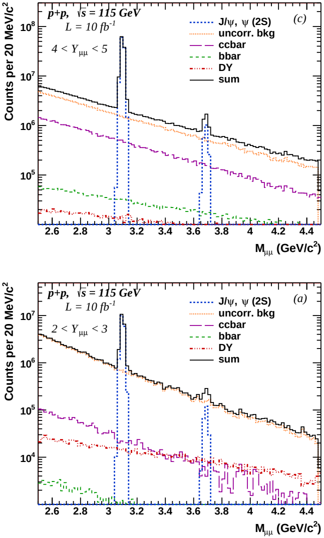
Projection for a LHCb-like detector

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

Charmonium background & its rapidity dependence

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



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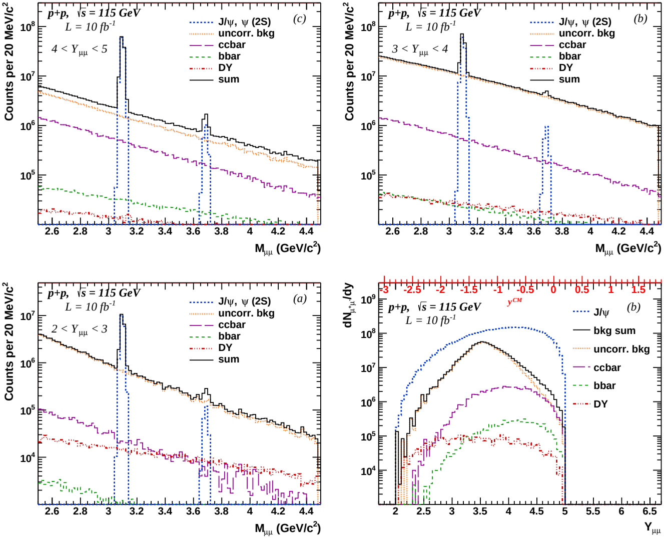
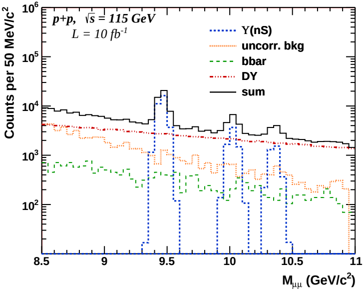


Bottomonium background & signal reach

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



The dominant background is Drell-Yan

3 peaks well resolved

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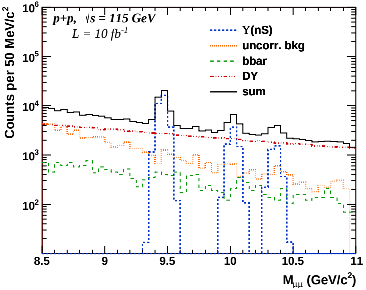
B. Trzeciak, L. Massacrier *et al.*, 1504.05145 [hep-ex], Adv.Hi.En.Phys. (2015) ID:986348

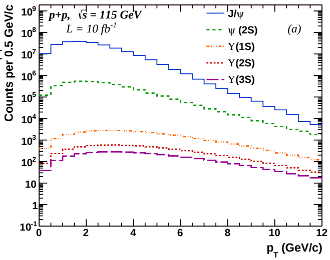


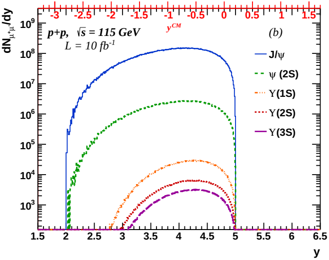
The dominant background is Drell-Yan

3 peaks well resolved

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

Υ : 200 events at $P_T \simeq 12$ GeV



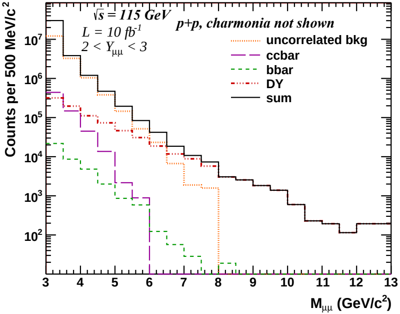


J/ψ: reach cut by the detector acceptance

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

Drell-Yan background & signal reach

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



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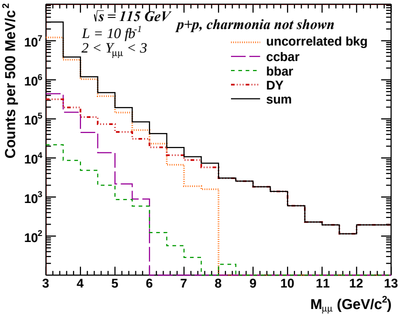

- Charm and beauty background can be cut (2nd vertex) but interesting on their own

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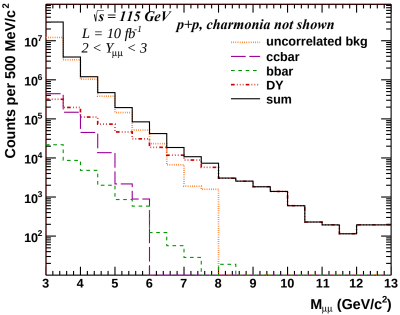

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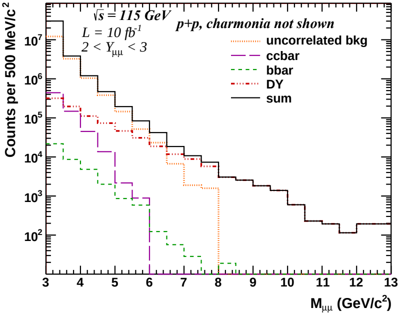

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Drell-Yan background & signal reach

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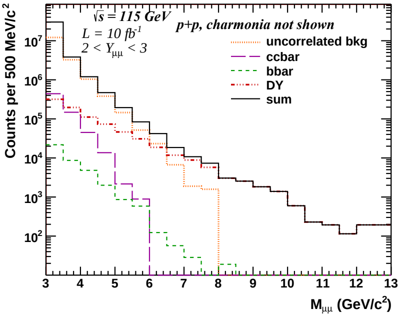

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- Still 4000+ DY events left in $2 < Y < 3$ for $8 < M < 9$ GeV, *i.e.* at $x^{\uparrow} \simeq 0.7$
- Should yield to precise measurements of A_N^{DY} at large x

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]. To appear in JHEP
- *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) 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]]. To appear in Nucl. Phys. B
- *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.

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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

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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  - The large x frontier: new probes of the confinement
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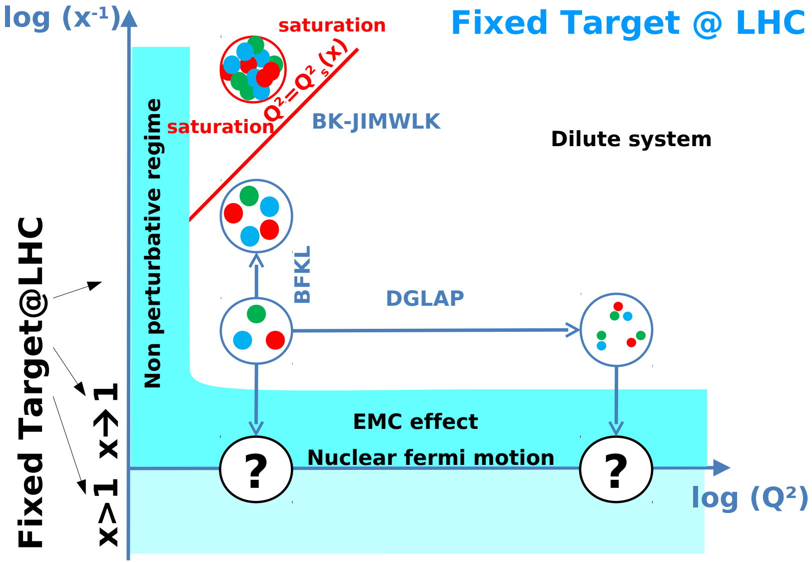
Part VIII

Backup slides

Overall


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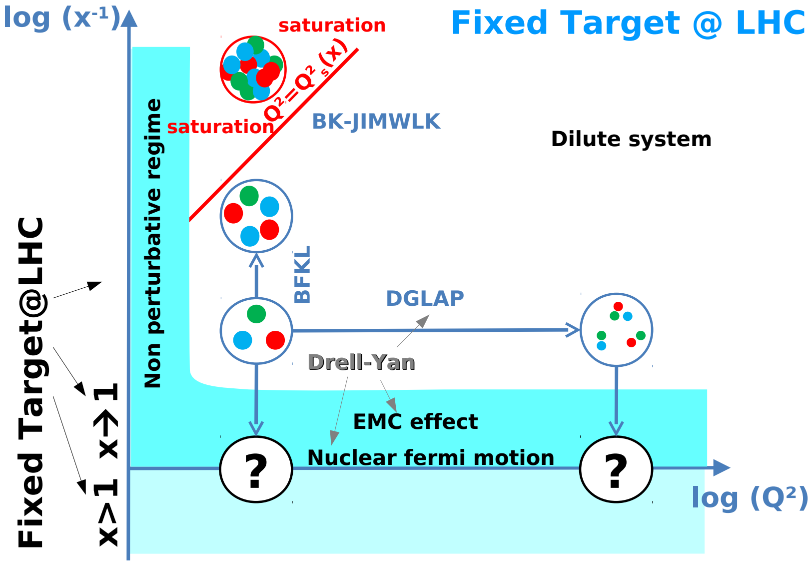
x>1
EMC effect
Nuclear fermi motion
?
?
log (Q²)

Overall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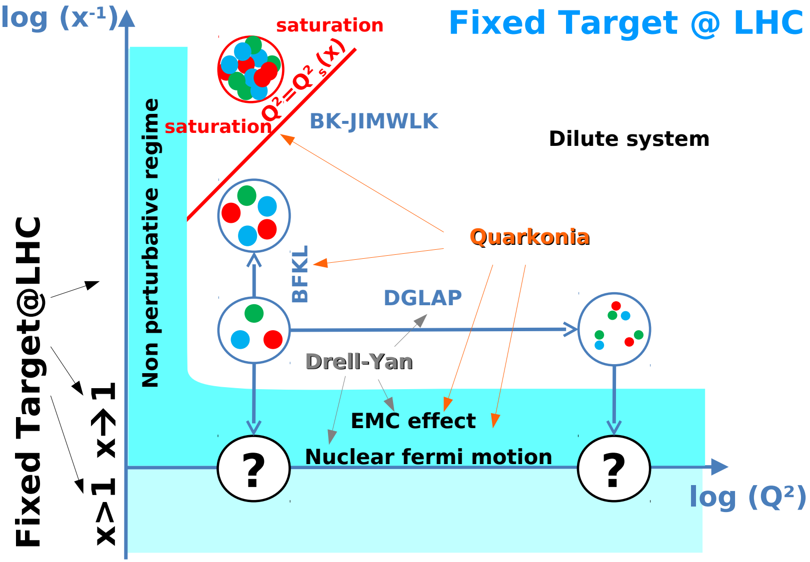

log (x^{-1})
Fixed Target @ LHC
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$Q^2=Q^2_s(x)$
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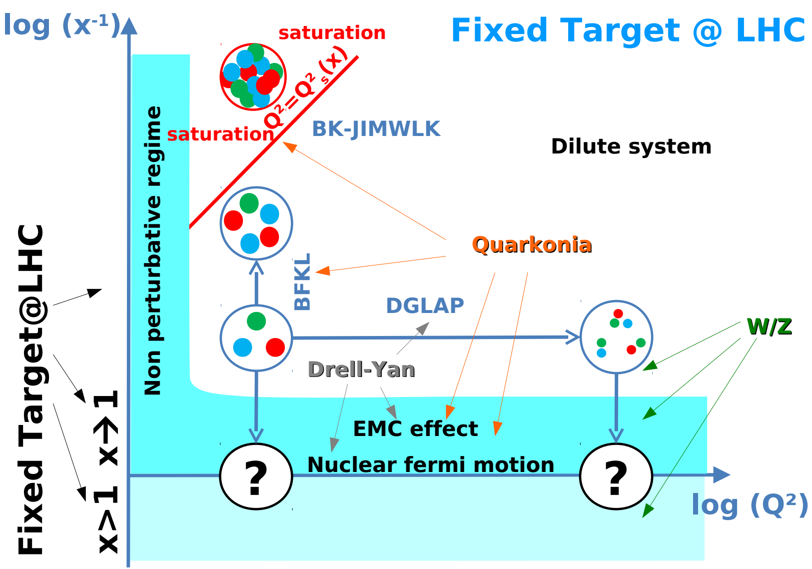
?
?
log (Q^2)
Fixed Target@LHC
x>1
x→1

Overall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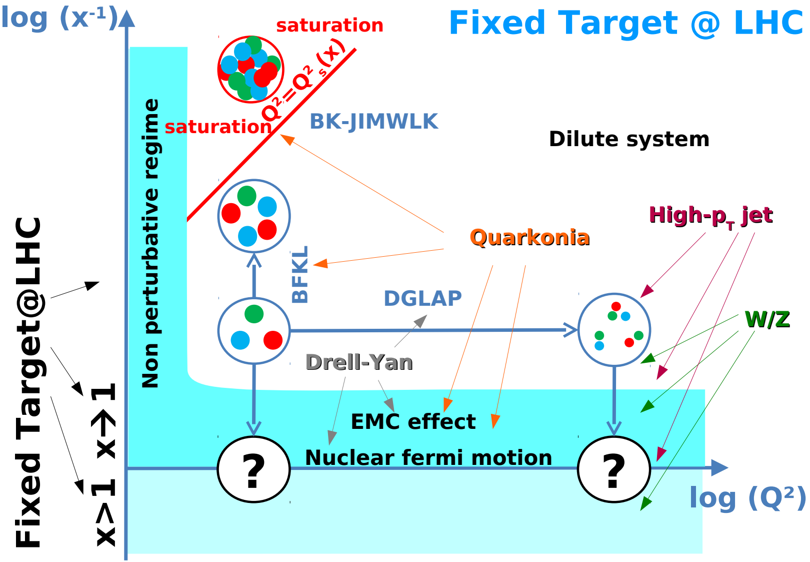
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Fixed Target @ LHC
Q²=Q²ₛ(x)
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x>1 x→1
EMC effect
?
Nuclear fermi motion
?
log (Q²)

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

→ 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).

Accessing the large *x* glue with quarkonia:

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

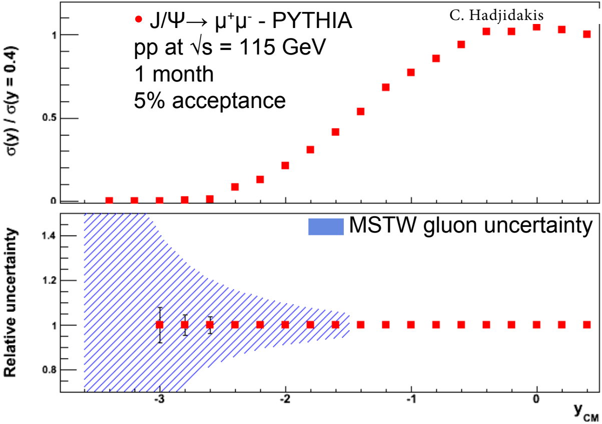
Statistical relative uncertainty
Large statistics allow to access very backward region

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

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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Distribution of linearly polarised gluons in unpolarised protons

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

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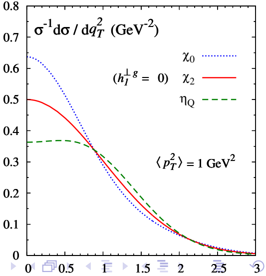
(R involves $f_1^g(x, k_T, \mu)$ and $h_1^{\perp g}(x, k_T, \mu)$)



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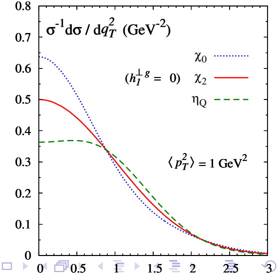

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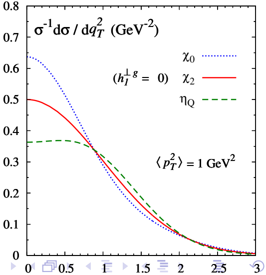

Access to $h_1^{\perp g}$: II

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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

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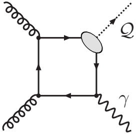

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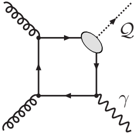

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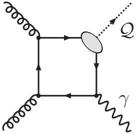

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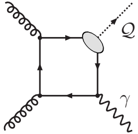

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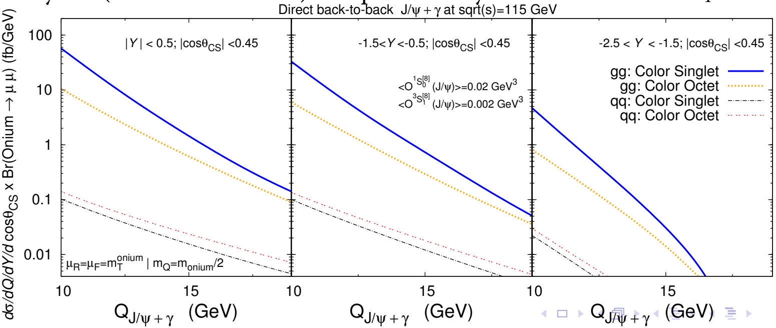

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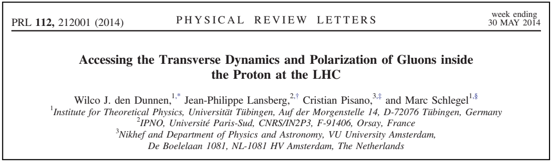
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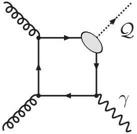

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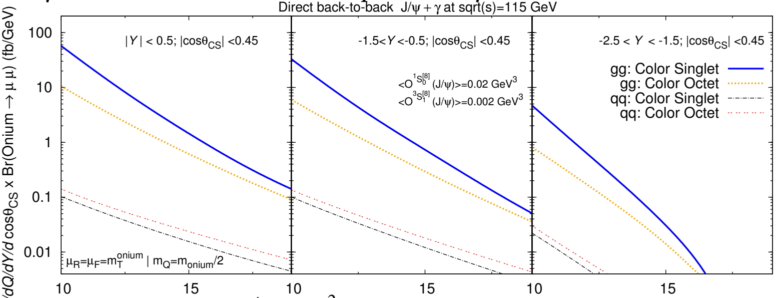

At $Y \simeq -2$, $x_2 \simeq 10/115 \times e^2 \simeq 0.65$. Yet, $g - g > q - \bar{q}$!

Luminosities with extracted-lead beams

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- Instantaneous Luminosity:

  $\mathcal{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathcal{N}_A)/A$

  $\Phi_{beam} = 2 \times 10^5$ 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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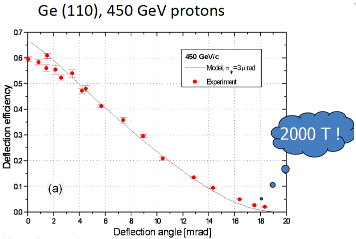
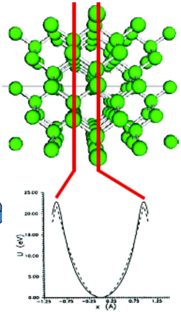
- Planned lumi for PHENIX Run15AuAu 2.8 nb^{-1} (0.13 nb^{-1} at 62 GeV)
- Nominal LHC lumi for PbPb 0.5 nb^{-1}

The beam extraction with a bent crystal

- Inter-crystalline fields are huge





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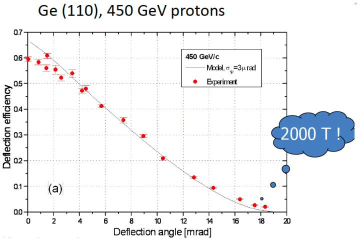

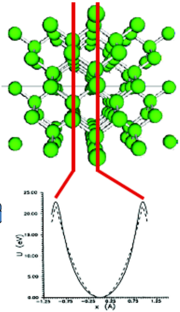

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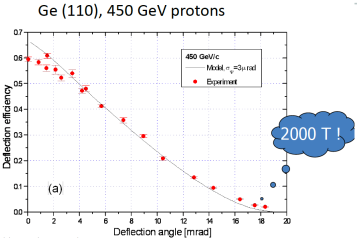

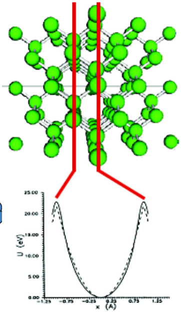

- The channeling efficiency is high for a deflection of a few mrad
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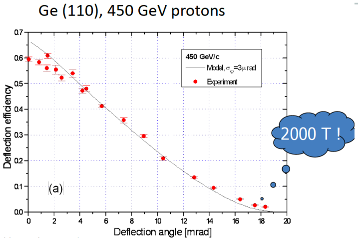

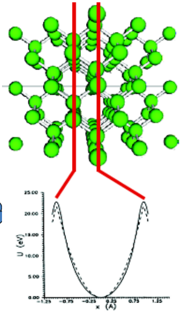

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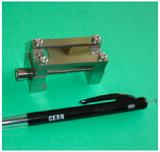
- One can extract a significant part of the beam loss ($10^9 p^+ s^{-1}$)
- Simple and robust way to extract the most energetic beam ever:

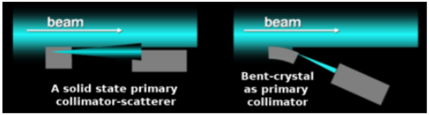


The beam extraction: news

[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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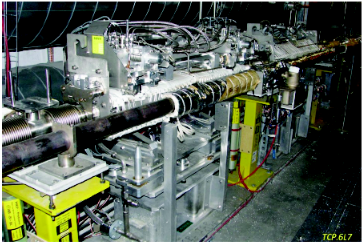

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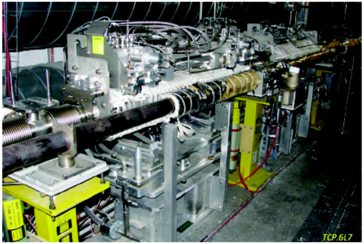

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Towards an installation in the LHC : propose and install during LS1 a min. number of devices

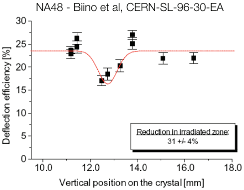
- 2 crystals

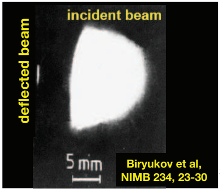
Long term plan is ambitious : propose a collimation system based on bent crystals for the upgrade of the current LHC collimation system

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





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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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  - one extracts $5.10^8/3.10^7 \simeq$ $15p^+$ from each bunch at each pass
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- Extraction over a 10h fill:
  - $5 \times 10^8 p^+ \times 3600$ s h$^{-1} \times 10$ h $= 1.8 \times 10^{13} p^+$ fill^{-1}
  - This means $1.8 \times 10^{13}/3.2 \times 10^{14} \simeq 5.6\%$ of the p^+ in the beam

These protons are lost anyway !

A few figures on the (extracted) proton beam

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

- Extraction over a 10h fill:
  - $5 \times 10^8 p^+ \times 3600$ s h$^{-1} \times 10$ h $= 1.8 \times 10^{13} p^+$ fill^{-1}
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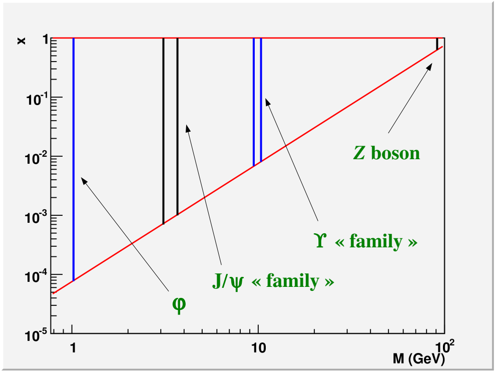
- similar figures for the Pb-beam extraction

AFTER@LHC: A dilepton observatory ?

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



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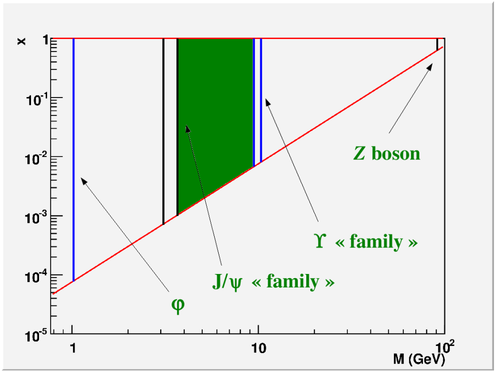

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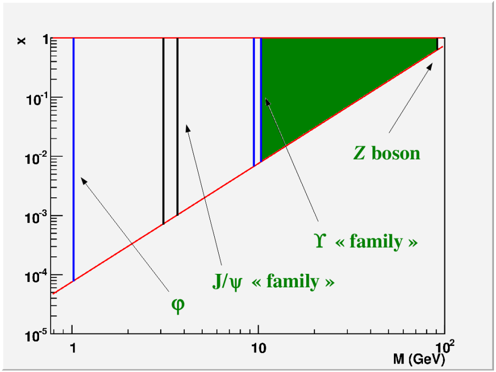

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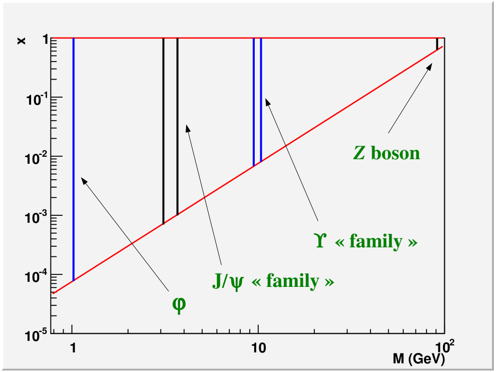

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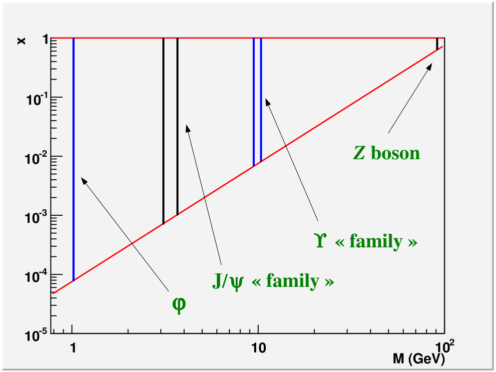

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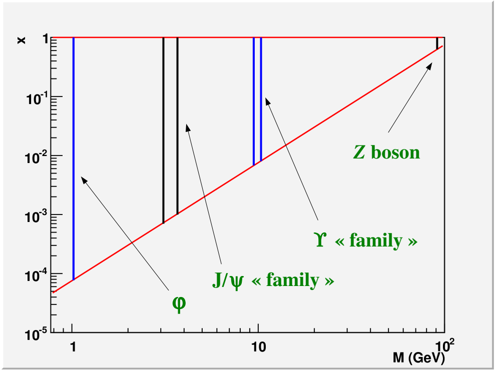

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➠ To do: to look at the rates to see how competitive this will be

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

- Interpolating the world data set:

Target	$\int\mathcal{L}$ ($fb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Psi$	N(Υ) yr^{-1} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
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LHC pp 14 Tev (low pT)	0.05 (ALICE) 2 LHCb	$3.6\ 10^7$ $1.4\ 10^9$	$1.8\ 10^5$ $7.2\ 10^6$
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Structure-function analysis and ψ, jet, W, and Z production:
Determining the gluon distribution

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W. J. Stirling
Department of Physics, University of Durham, Durham, England
(Received 27 July 1987)

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

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

AFTER: also a quarkonium observatory in *pA*

Target	A	$\int\mathcal{L}$ ($fb^{-1}.yr^{-1}$)	$N(J/\Psi)\ yr^{-1} = A\mathcal{L}\mathcal{B}\sigma_\Psi$	$N(\Upsilon)\ yr^{-1} = A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
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1cm Cu	64	**0.42**	**$5.3\ 10^8$**	**$1.1\ 10^6$**
1cm W	185	**0.31**	**$1.1\ 10^9$**	**$2.3\ 10^6$**
1cm Pb	207	**0.16**	**$6.7\ 10^8$**	**$1.3\ 10^6$**
LHC pPb 8.8 TeV	207	**10^{-4}**	**$1.0\ 10^7$**	**$7.5\ 10^4$**
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  - not to mention ratio with **open charm, Drell-Yan,** etc ...

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- One should be careful with factorization breaking effects:

This calls for multiple measurements to (in)validate factorisation

AFTER: also an heavy-flavour observatory in *PbA*

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

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- Yields similar to those of RHIC at 200 GeV,
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- Yields similar to those of RHIC at 200 GeV, 100 times those of RHIC at 62 GeV
- Also very competitive compared to the LHC.

AFTER: also an heavy-flavour observatory in *PbA*

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

Target	A.B	$\int \mathcal{L}$ ($nb^{-1}.yr^{-1}$)	N(J/Ψ) yr^{-1} = $AB\mathcal{L}\mathcal{B}\sigma_\Psi$	N(Υ) yr^{-1} = $AB\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	207.1	800	$3.4\ 10^6$	$6.9\ 10^3$
1cm Be	207.9	25	$9.1\ 10^5$	$1.9\ 10^3$
1cm Cu	207.64	17	$4.3\ 10^6$	$0.9\ 10^3$
1cm W	207.185	13	$9.7\ 10^6$	$1.9\ 10^4$
1cm Pb	207.207	7	$5.7\ 10^6$	$1.1\ 10^4$
LHC PbPb 5.5 TeV	207.207	0.5	$7.3\ 10^6$	$3.6\ 10^4$
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The same picture also holds for open heavy flavour

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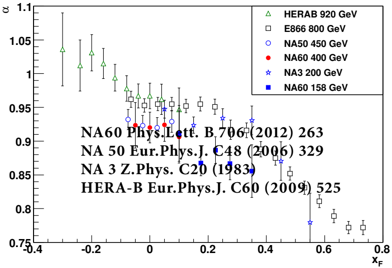
- the possibilities for $c\bar{c}$ recombination
  - Open charm studies are difficult where recombination matters most

    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



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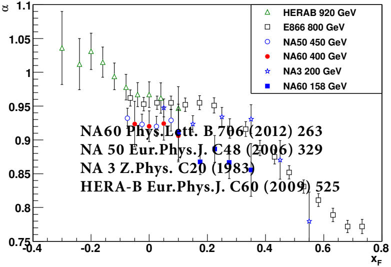

NA60 Phys.Lett. B 706 (2012) 263
NA 50 Eur.Phys.J. C48 (2006) 329
NA 3 Z.Phys. C20 (1983)
HERA-B Eur.Phys.J. C60 (2009) 525

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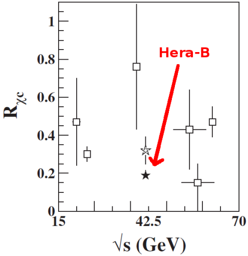

HERA-B PRD 79 (2009) 012001, and ref. therein

LHB

Our idea is not completely new

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

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

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

Flavio Costantini

University of Pisa and INFN, Italy

A fixed target experiment at LHC to measure CP violation in B mesons is presented. A description of the proposed apparatus is given together with its sensitivity on the CP violation asymmetry measurement for the two benchmark decay channels $B^0 \to J/\psi + K_s^0$, $B^0 \to \pi^+\pi^-$. 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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1. Introduction

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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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LETTER OF INTENT

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- After a year, one simply moves the crystal by less than one mm ...