Physics case for a polarised target for 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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    [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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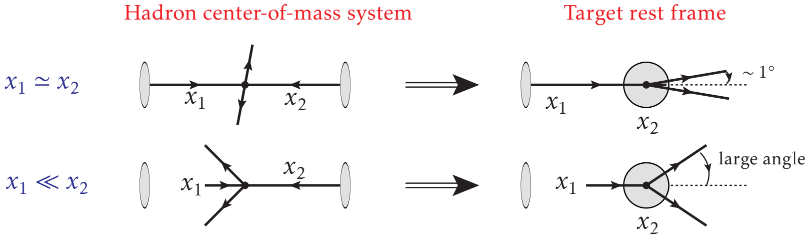

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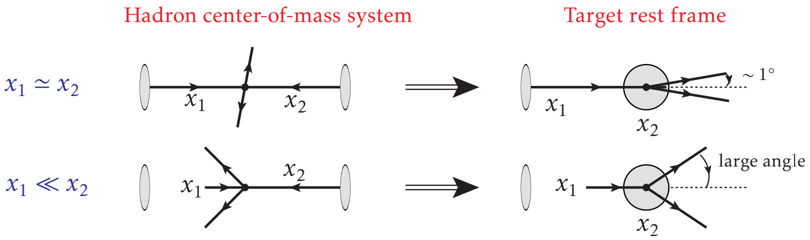

$$\boxed{\text{backward physics} = \text{large-}x_2\text{ physics}}$$

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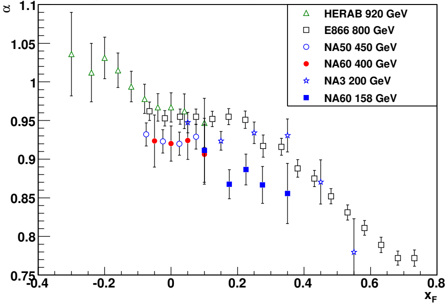

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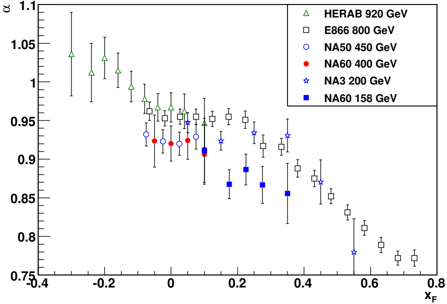

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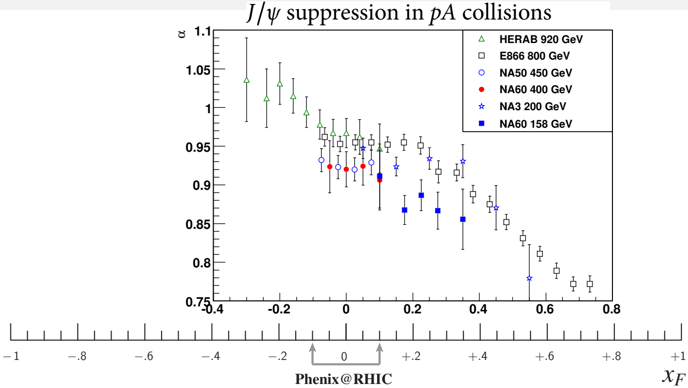

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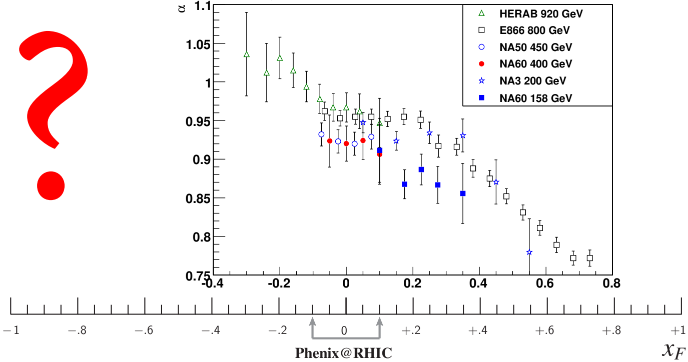

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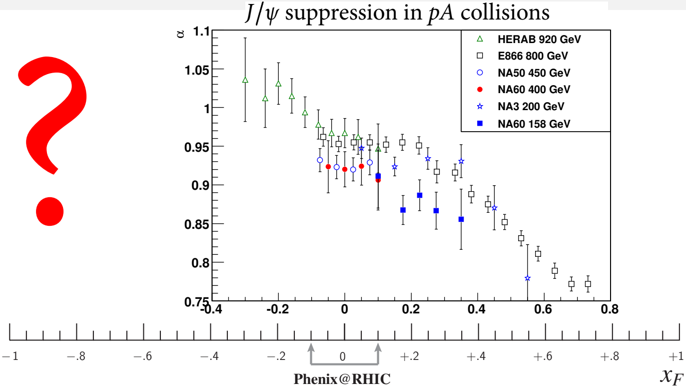

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- If we measure $\Upsilon(b\bar{b})$ at $y_{\text{cms}} \simeq -2.5$ $\Rightarrow x_F \simeq \frac{2m_\Upsilon}{\sqrt{s}} \sinh(y_{\text{cms}}) \simeq -1$

Part III

Colliding the LHC beams on fixed targets: 2 options

The extracted-beam option

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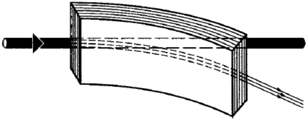

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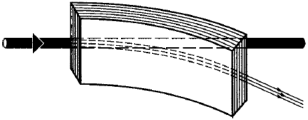

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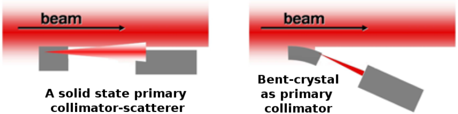

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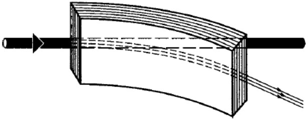

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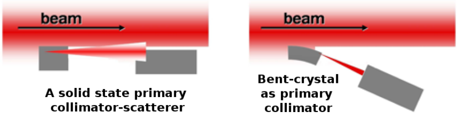

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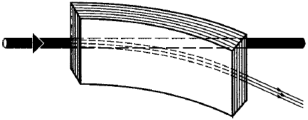

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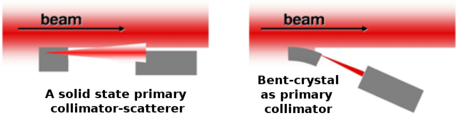

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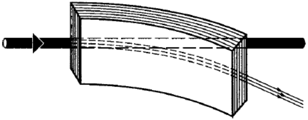

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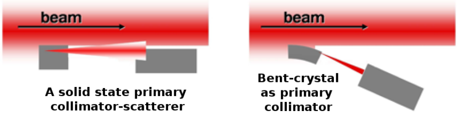

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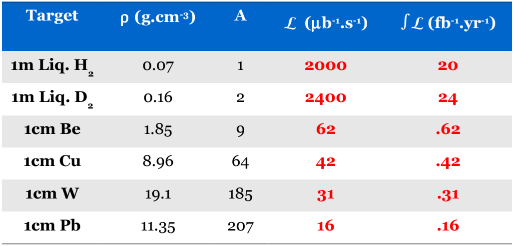

Target	ρ (g.cm^{-3})	A	$\mathcal{L}$ (μb^{-1}.s^{-1})	$\int\mathcal{L}$ (fb^{-1}.yr^{-1})
1m Liq. H_2	0.07	1	**2000**	**20**
1m Liq. D_2	0.16	2	**2400**	**24**
1cm Be	1.85	9	**62**	**.62**
1cm Cu	8.96	64	**42**	**.42**
1cm W	19.1	185	**31**	**.31**
1cm Pb	11.35	207	**16**	**.16**

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

[ℓ: target thickness (for instance 1cm)]

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

[the so-called LHC years]

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

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

3 orders of magnitude larger than RHIC (200 GeV)

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

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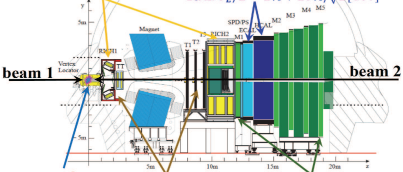
JINST 3 (2008) S08005

Pseudorapidity acceptance
$2 < \eta < 5$

RICH1 & RICH2
$\epsilon(K \to K) \sim 95\%$
$\pi \to K$ mis-id: ~ 5%

Calorimeters
ECAL: $\sigma_E/E \sim 1\% + 10\%/\sqrt{E[\mathrm{GeV}]}$



VELO
$\sigma_{\mathrm{IP}} \sim 20\ \mu$m
for high-p_T tracks
bwd acc. $-4 < \eta < -1.5$

Tracking System
$\Delta p/p = 0.4\%$@5 GeV/c
to 0.6%@100 GeV/c

Muon System
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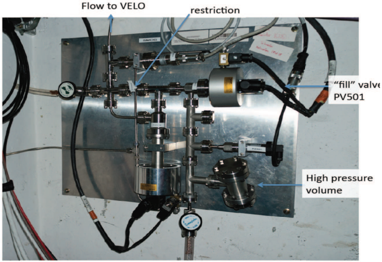
SMOG: System for Measuring Overlap with Gas



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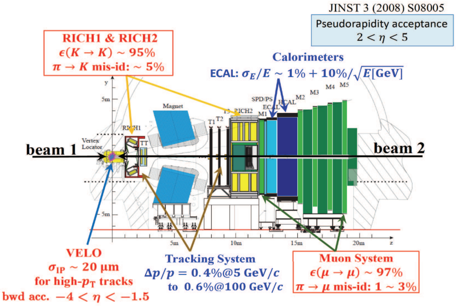

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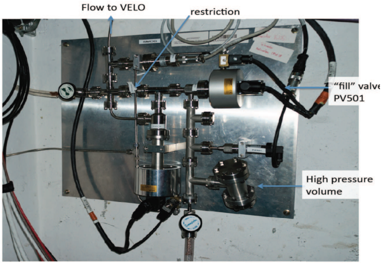

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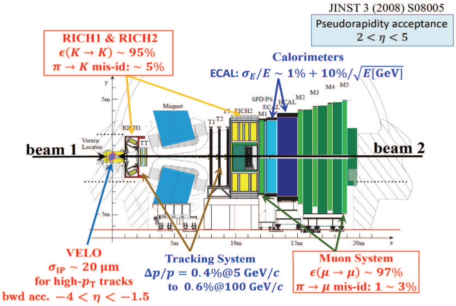

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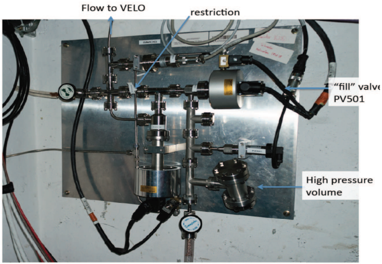

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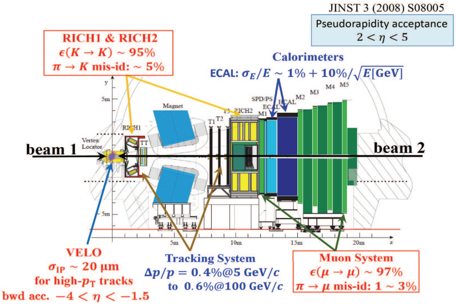

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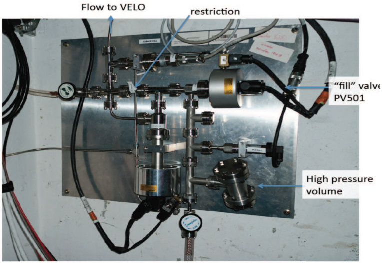

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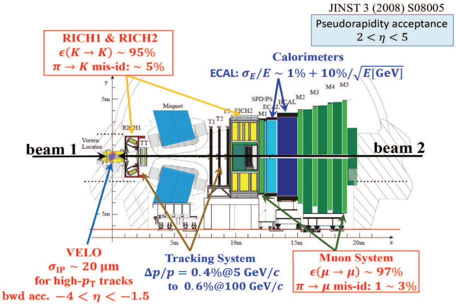

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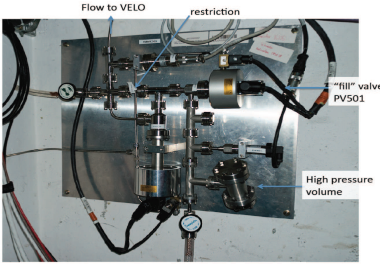

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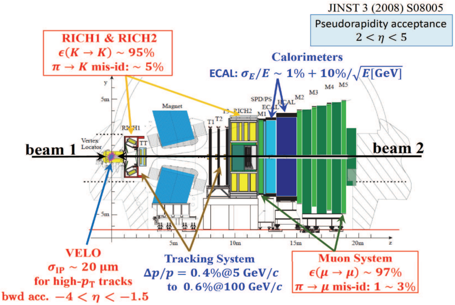

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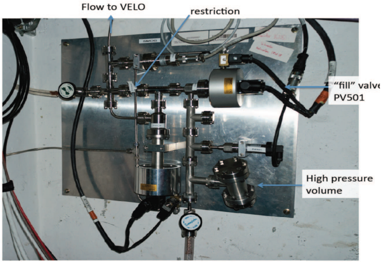

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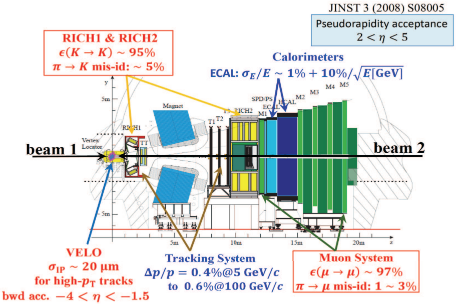

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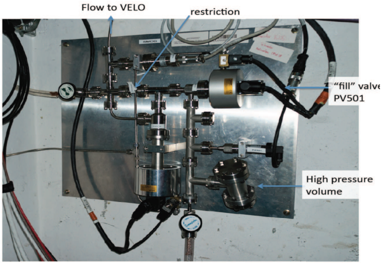

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Luminosities with the internal-gas-target option

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which **could be polarised**

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

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

Part IV

AFTER@LHC: the case of spin physics

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

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- 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 exisiting 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 ÷ 0.9	1
COMPASS	$\pi^{\pm} + p^{\uparrow}$	160	17.4	0.2 ÷ 0.3	2
COMPASS (low mass)	$\pi^{\pm} + p^{\uparrow}$	160	17.4	~ 0.05	2
P1039	$p + p^{\uparrow}$	120	15	0.1 ÷ 0.3	400-1000
P1027	$p^{\uparrow} + p$	120	15	0.35 ÷ 0.85	400-1000
RHIC	$p^{\uparrow} + p$	collider	500	0.05 ÷ 0.1	0.2
J–PARC	$p^{\uparrow} + p$	50	10	0.5 ÷ 0.9	1000
PANDA (low mass)	$\bar{p} + p^{\uparrow}$	15	5.5	0.2 ÷ 0.4	0.2
PAX	$p^{\uparrow} + \bar{p}$	collider	14	0.1 ÷ 0.9	0.002
NICA	$p^{\uparrow} + p$	collider	20	0.1 ÷ 0.8	0.001
RHIC Int.Target (1,2)	$p^{\uparrow} + p$	250	22	0.2 ÷ 0.5	(2,60)

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Experiment	particles	energy (GeV)	$\sqrt{s}$ (GeV)	$x_p^\uparrow$	$\mathcal{L}$ (nb^{-1}s^{-1})
AFTER	$p + p^\uparrow$	7000	115	0.01 ÷ 0.9	1
COMPASS	$\pi^\pm + p^\uparrow$	160	17.4	0.2 ÷ 0.3	2
COMPASS (low mass)	$\pi^\pm + p^\uparrow$	160	17.4	~ 0.05	2
P1039	$p + p^\uparrow$	120	15	0.1 ÷ 0.3	400-1000
P1027	$p^\uparrow + p$	120	15	0.35 ÷ 0.85	400-1000
RHIC	$p^\uparrow + p$	collider	500	0.05 ÷ 0.1	0.2
J–PARC	$p^\uparrow + p$	50	10	0.5 ÷ 0.9	1000
PANDA (low mass)	$\bar{p} + p^\uparrow$	15	5.5	0.2 ÷ 0.4	0.2
PAX	$p^\uparrow + \bar{p}$	collider	14	0.1 ÷ 0.9	0.002
NICA	$p^\uparrow + p$	collider	20	0.1 ÷ 0.8	0.001
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SSA in Drell-Yan studies with AFTER@LHC

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- AFTER could be the only project able to reach $x^\uparrow = 10^{-2}$ and $x^\uparrow > 0.4$

SSA in Drell-Yan studies with AFTER@LHC

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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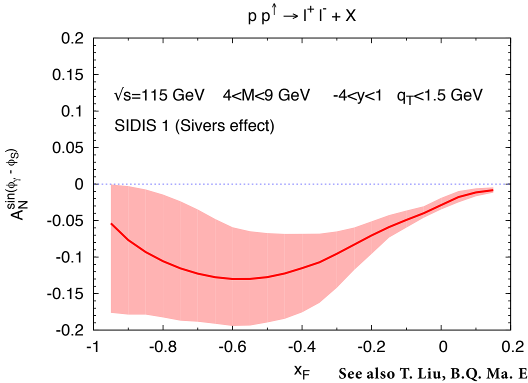

M. Anselmino, U. D'Alesio, S. Melis. Adv.Hi.En.Phys. (2015) ID:475040

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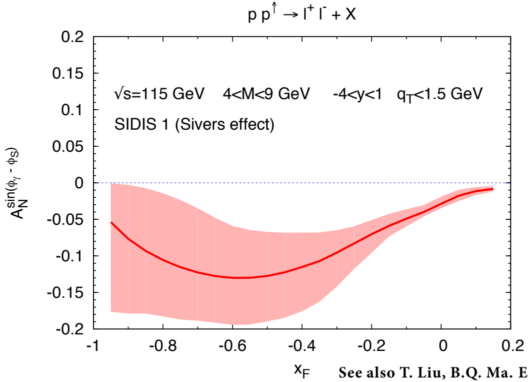

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Experimental goal: to measure asymmetries on the order of 5-10 % at $x_F < 0$

With 10 fb^{-1}, one can expect up to 10^6 DY events in $4 < M < 9$ GeV (see later)

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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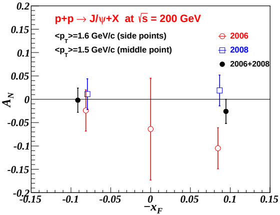

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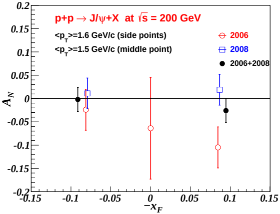

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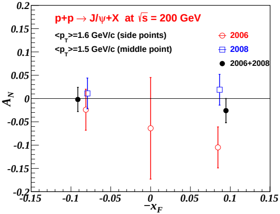

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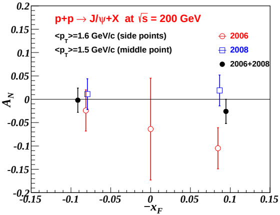

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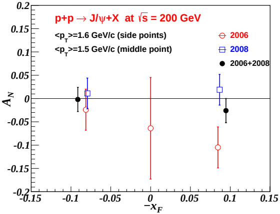

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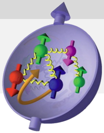
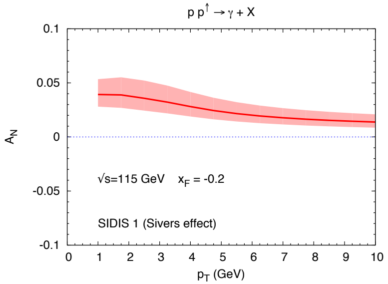
- All these measurements can be done with AFTER@LHC with the required precision: 10^9 J/ψ, 10^6 Υ, 10^8 B, etc ...

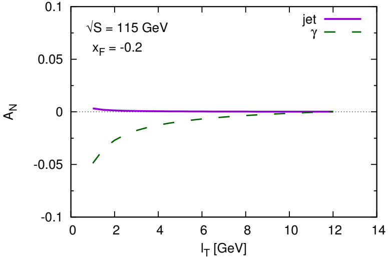
Further studies of the Sivers effect



- 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.





- 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], to appear in Adv.Hi.En.Phys.**

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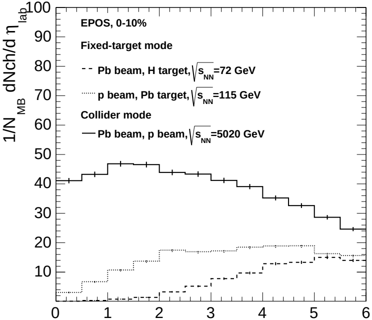

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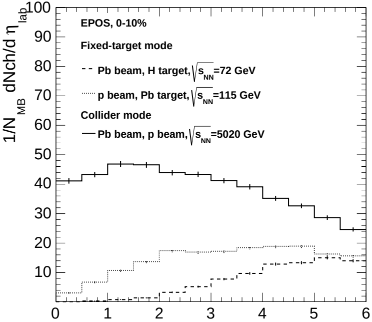

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- Simulation backed-up with a comparison of the number-of-track distribution between simulations at the detector level and data

Z. Yang, private comm.

Fast simulation using LHCb reconstruction parameters

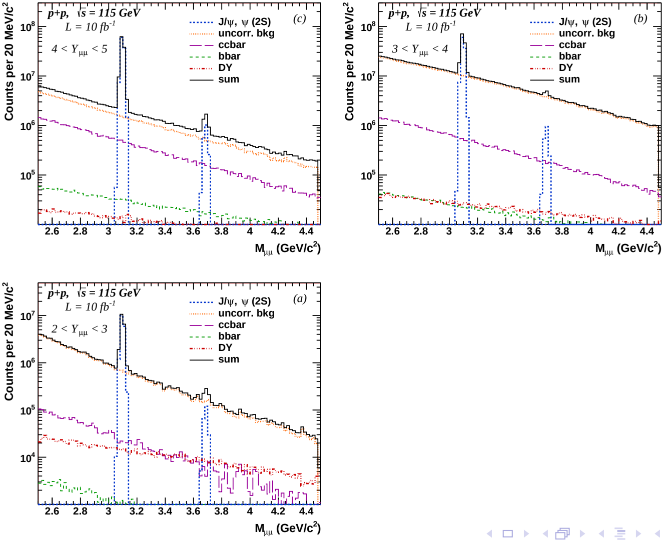
Projection for a LHCb-like detector

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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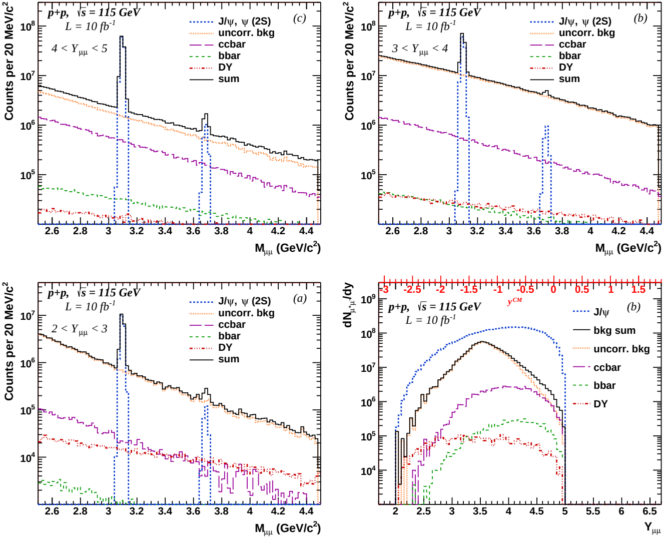

Bottomonium background & signal reach

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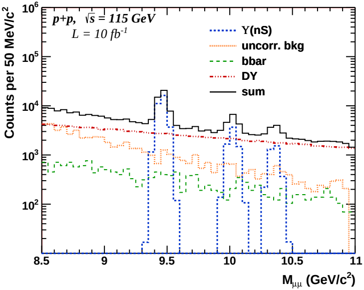

The dominant background is Drell-Yan

3 peaks well resolved

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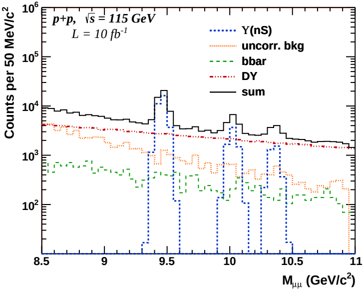

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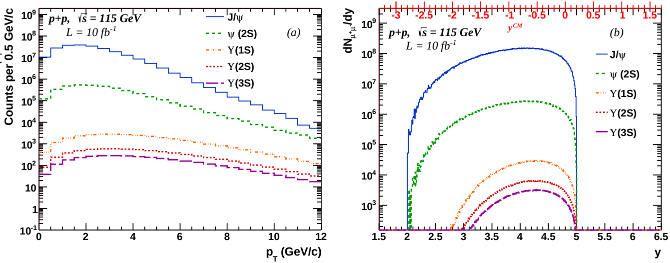
J/ψ: 10^4 events at $P_T \simeq 12$ GeV

Υ : 200 events at $P_T \simeq 12$ GeV

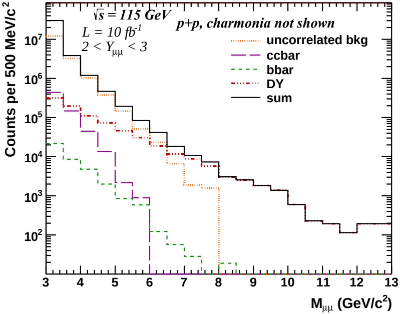


J/ψ: reach cut by the detector acceptance

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

Drell-Yan background & signal reach

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



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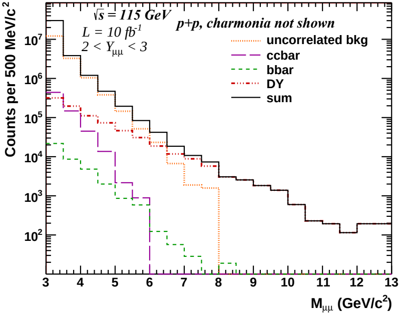

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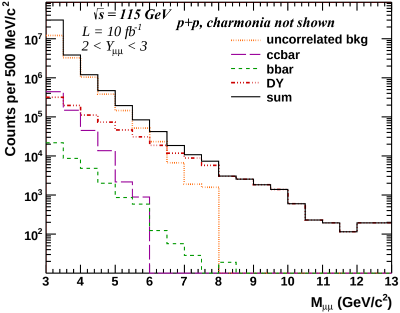

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- Uncorrelated background can be subtracted by the mixing-event method
[up to which S/B depends on the systematics of the subtraction]

Drell-Yan background & signal reach

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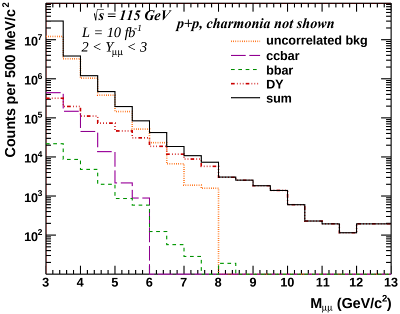

- Charm and beauty background can be cut (2nd vertex) but interesting on their own
- Uncorrelated background can be subtracted by the mixing-event method [up to which S/B depends on the systematics of the subtraction]
- Still 4000+ DY events left in $2 < Y < 3$ for $8 < M < 9$ GeV, *i.e.* at $x^{\uparrow} \simeq 0.7$

Drell-Yan background & signal reach

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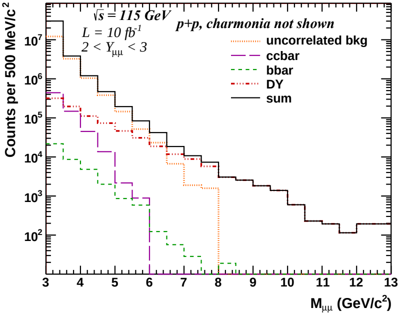

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- Still 4000+ DY events left in $2 < Y < 3$ for $8 < M < 9$ GeV, *i.e.* at $x^{\uparrow} \simeq 0.7$
- Should yield to precise measurements of A_N^{DY} at large x

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.

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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- THREE MAIN THEMES PUSH FOR A FIXED-TARGET PROGRAM AT THE LHC
  [without interfering with the other experiments]
  - The large x frontier: new probes of the confinement
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  - The large x frontier: new probes of the confinement and connections with astroparticles
  - The nucleon spin and the transverse dynamics of the partons

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  - The approach to the deconfinement phase transition:
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- 2 ways towards fixed-target collisions with the LHC beams
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- Large potential for spin physics with
  - extracted beam + polarised target as COMPASS, P1039, JLab ...
  - polarised gas target

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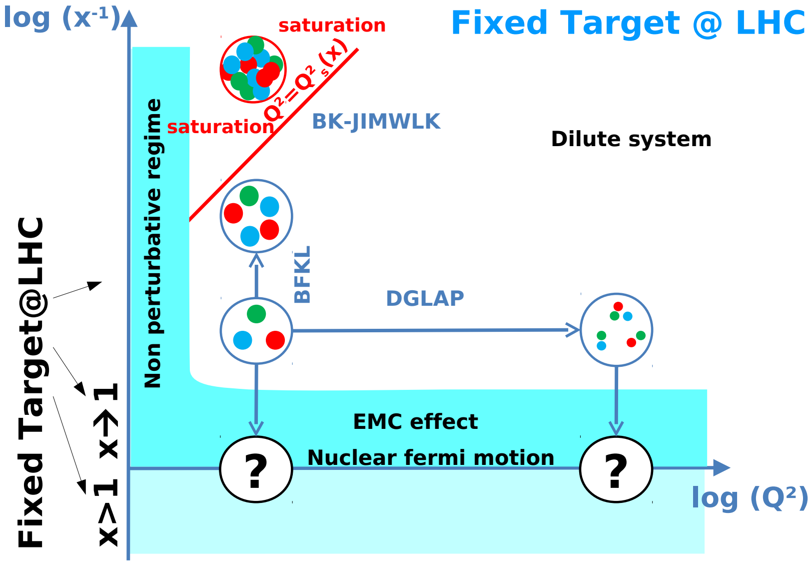
- Webpage: `http://after.in2p3.fr`

Part VIII

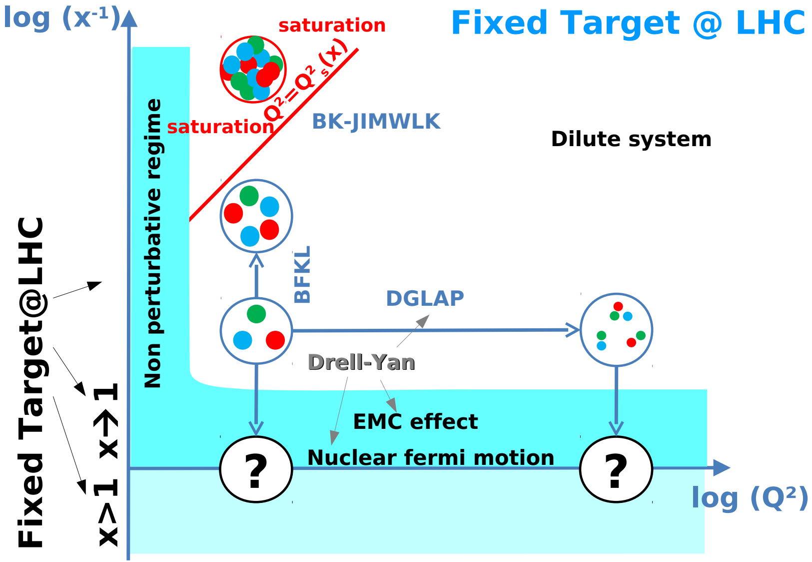
Backup slides

Overall



log (x^{-1})
saturation
Fixed Target @ LHC
$Q^2=Q^2_s(x)$
saturation
BK-JIMWLK
Dilute system
Non perturbative regime
BFKL
DGLAP
Fixed Target@LHC
x→1
x>1
EMC effect
Nuclear fermi motion
?
?
log (Q^2)

Overall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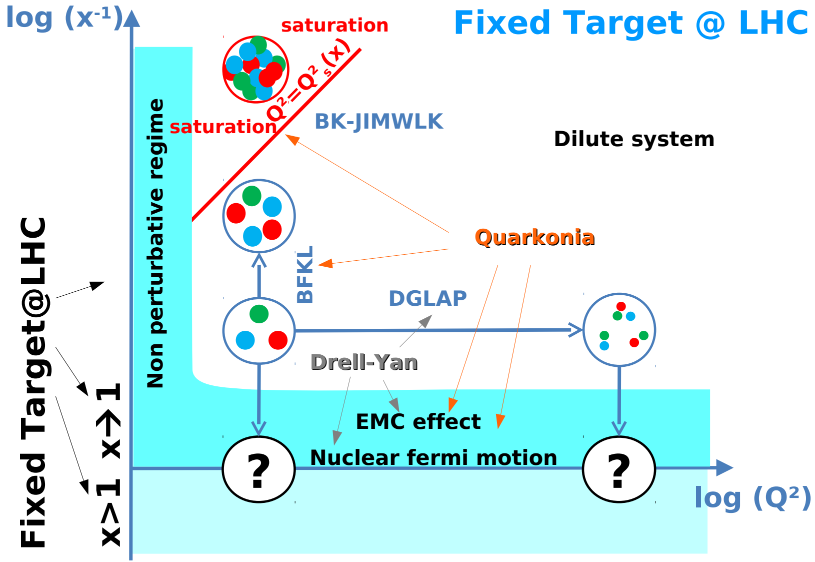
log (x⁻¹)
saturation
Fixed Target @ LHC
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saturation
BK-JIMWLK
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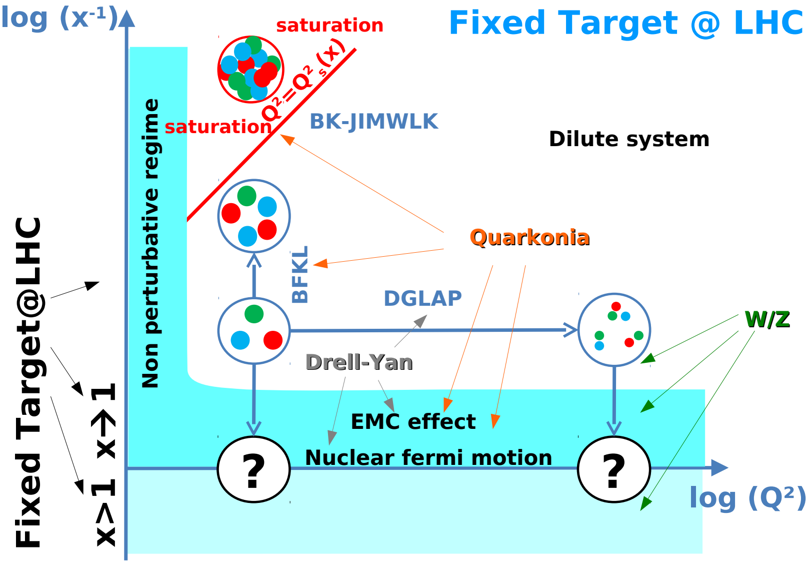
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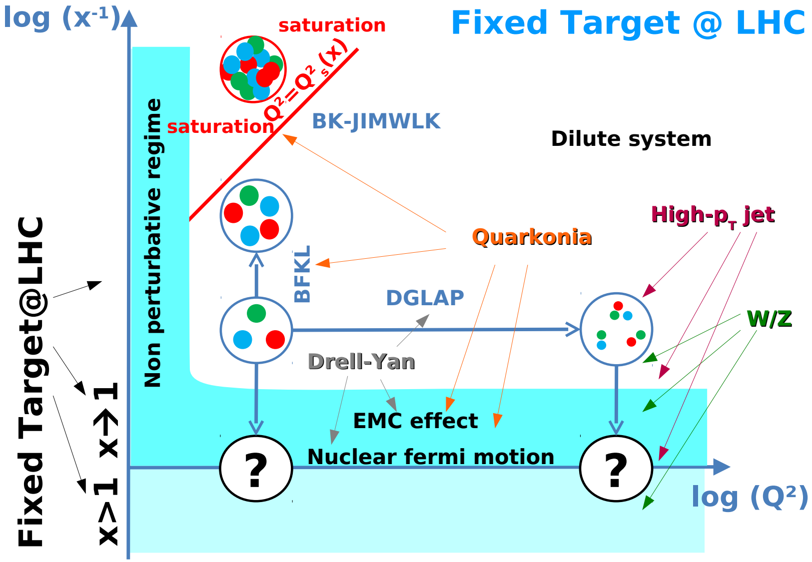
Overall


log (x⁻¹)
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Fixed Target @ LHC
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saturation
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EMC effect
x→1
x>1
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?
?
log (Q²)

Gas target

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

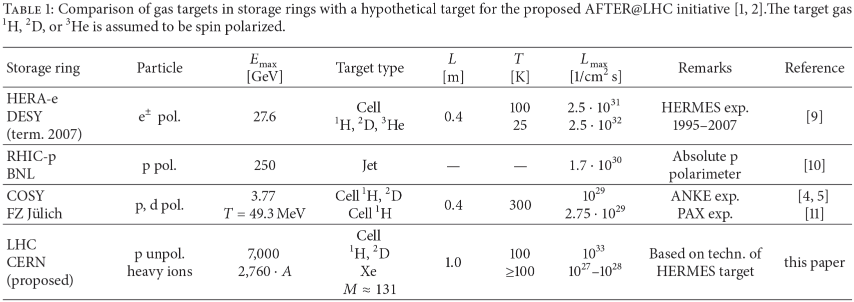


TABLE 1: Comparison of gas targets in storage rings with a hypothetical target for the proposed AFTER@LHC initiative [1, 2].The target gas ^{1}H, ^{2}D, or ^{3}He is assumed to be spin polarized.

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

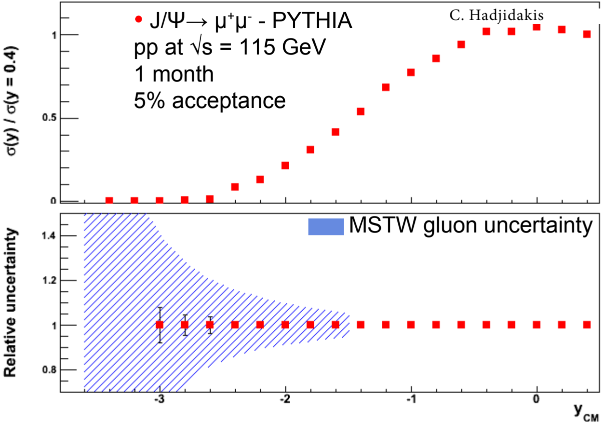
Statistical relative uncertainty
Large statistics allow to access very backward region

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*

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

Cristian Pisano†

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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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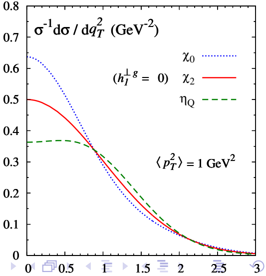
- Affect the low P_T spectra:

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

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



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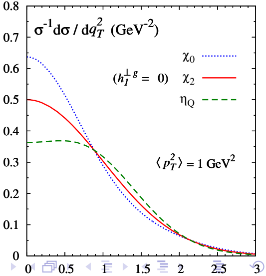
- The boost is of great help to access low P_T P-wave quarkonia



Distribution of linearly polarised gluons in unpolarised protons

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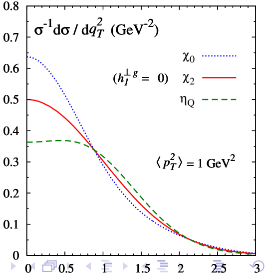
- $h_1^{\perp g}$ is connected to the Higgs transverse-momentum distribution **D. Boer,** *et al.* **PRL 108 (2012) 032002**



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

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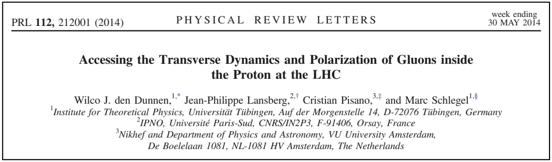
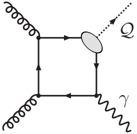


PRL **112,** 212001 (2014) PHYSICAL REVIEW LETTERS week ending 30 MAY 2014

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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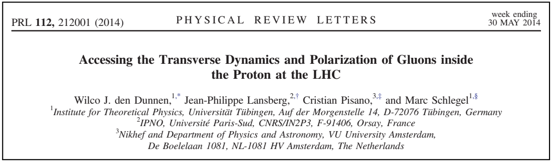

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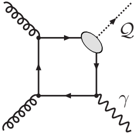

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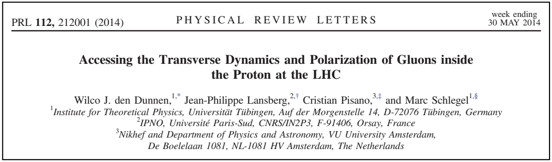

PRL **112,** 212001 (2014) PHYSICAL REVIEW LETTERS week ending 30 MAY 2014

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

Wilco J. den Dunnen,[1,*] Jean-Philippe Lansberg,[2,†] Cristian Pisano,[3,‡] and Marc Schlegel[1,§]
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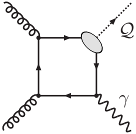

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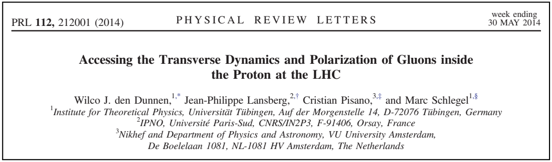

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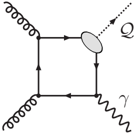

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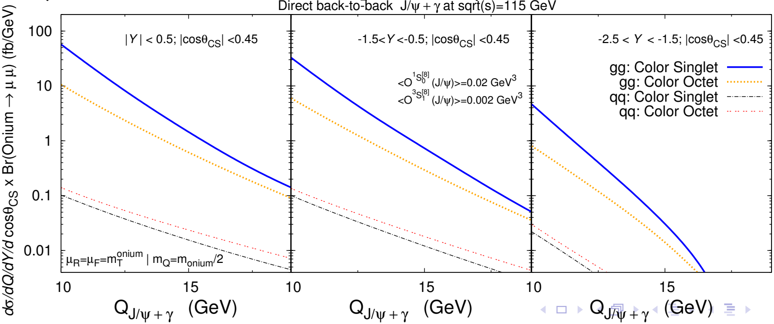

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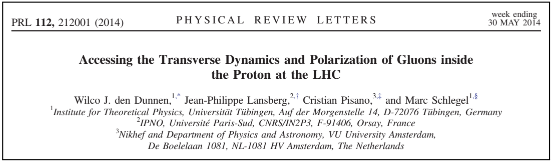

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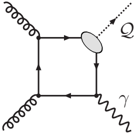

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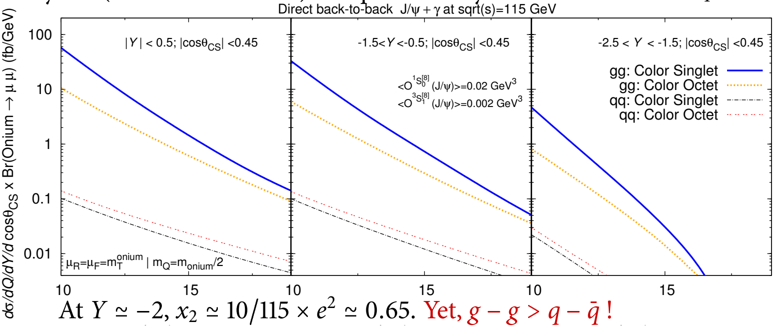

At $Y \simeq -2$, $x_2 \simeq 10/115 \times e^2 \simeq 0.65$. Yet, $g-g > q-\bar{q}$!

Luminosities with extracted-lead beams

Luminosities with extracted-lead beams

- Instantaneous Luminosity:

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

  $$\Phi_{beam} = 2 \times 10^5 \text{ Pb s}^{-1}, \quad \ell = 1\,\text{cm (target thickness)}$$

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Target	ρ (g.cm^{-3})	A	$\mathcal{L}$ (mb^{-1}.s^{-1})=∫$\mathcal{L}$ (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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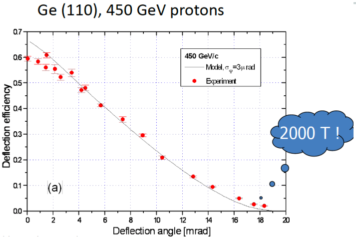
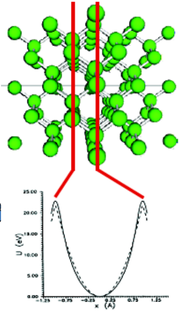
- Planned lumi for PHENIX Run15AuAu 2.8 nb^{-1} (0.13 nb^{-1} at 62 GeV)
- Nominal LHC lumi for PbPb 0.5 nb^{-1}

The beam extraction with a bent crystal

- Inter-crystalline fields are huge





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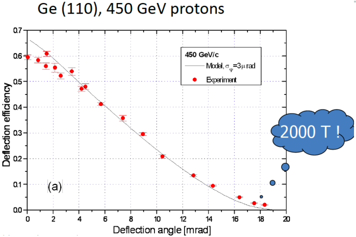

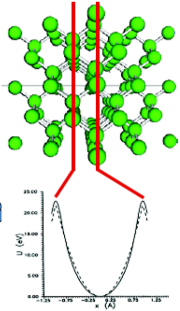

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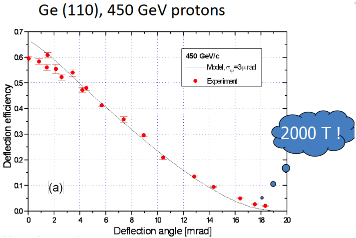

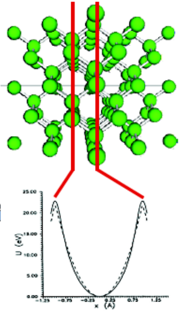

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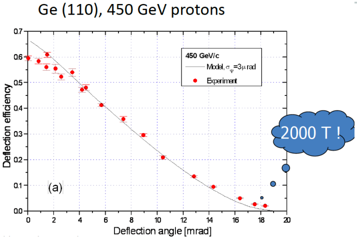
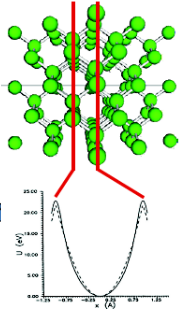
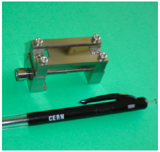




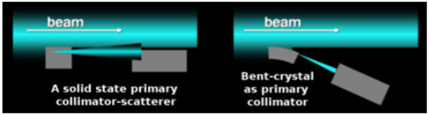
- The channeling efficiency is high for a deflection of a few mrad
- One can extract a significant part of the beam loss ($10^9 p^+ s^{-1}$)
- Simple and robust way to extract the most energetic beam ever:



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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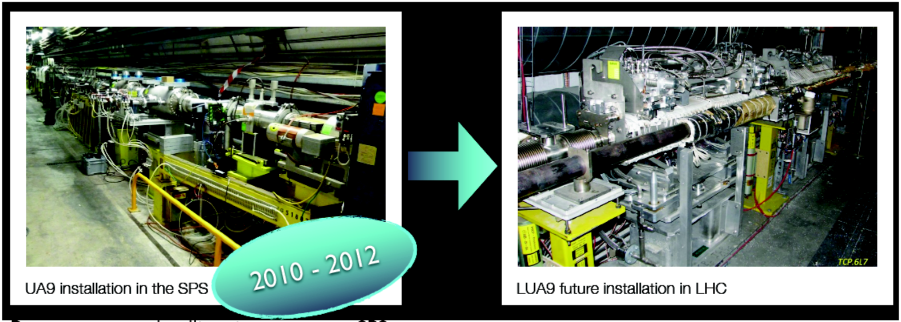
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2010 - 2012

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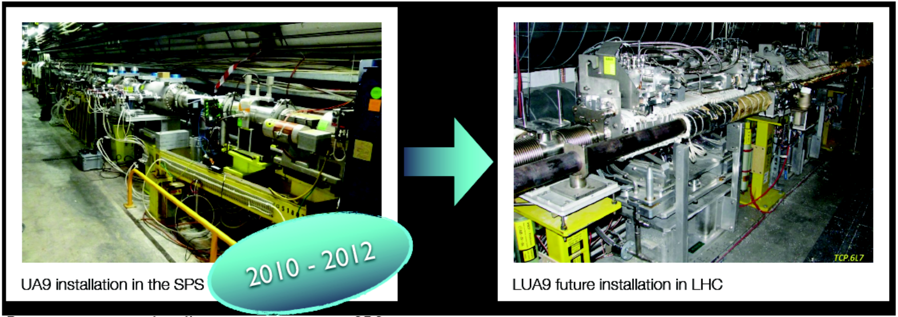

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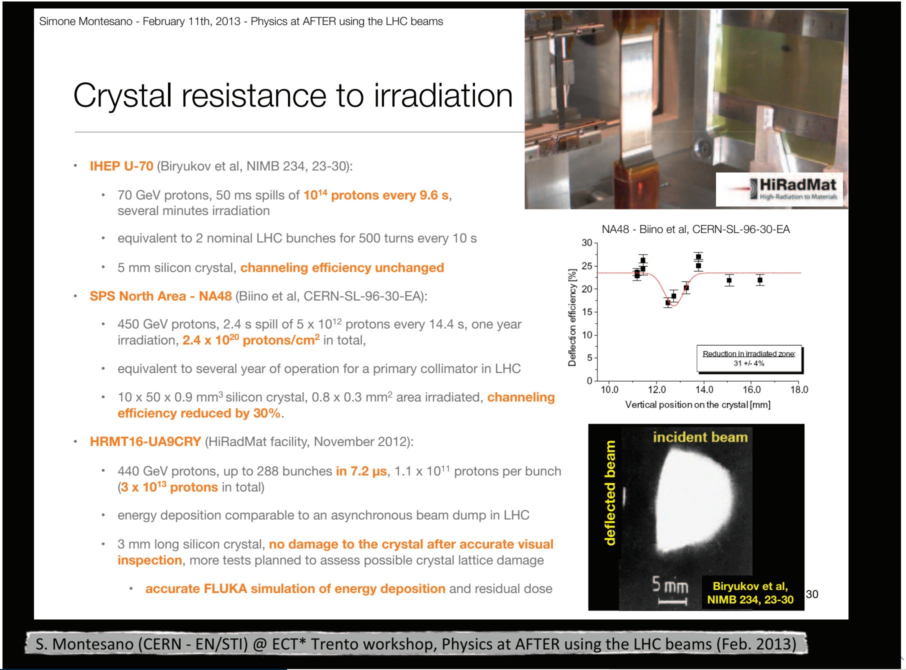
Towards an installation in the LHC : propose and install during LS1 a min. number of devices

- 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 5×10^{12} protons every 14.4 s, one year irradiation, **2.4×10^{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**, 1.1×10^{11} protons per bunch (**3×10^{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

Biryukov et al, NIMB 234, 23-30

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

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+ \mathrm{s}^{-1}$
- Extracted intensity: $5 \times 10^8\ p^+ \mathrm{s}^{-1}$ (1/2 the beam loss)

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  - one extracts $5.10^8/3.10^7 \simeq 15 p^+$ from each bunch at each pass
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  - This means $1.8 \times 10^{13}/3.2 \times 10^{14} \simeq$ 5.6% of the p^+ in the beam

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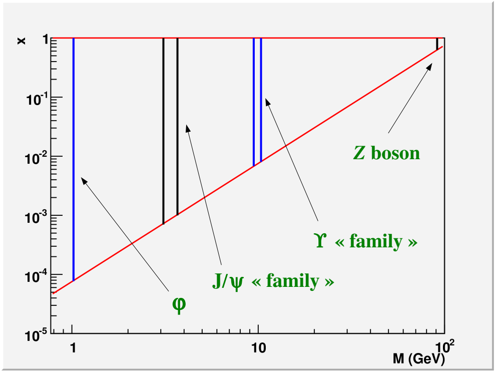
- Region in x probed by dilepton production as function of $M_{\ell\ell}$



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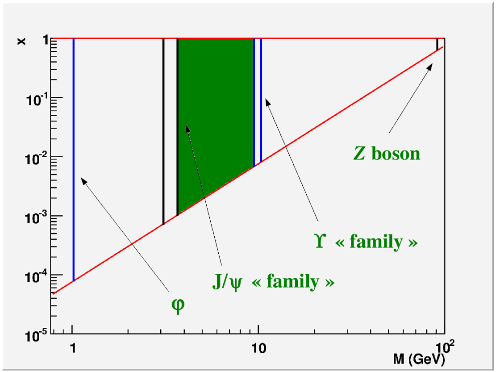

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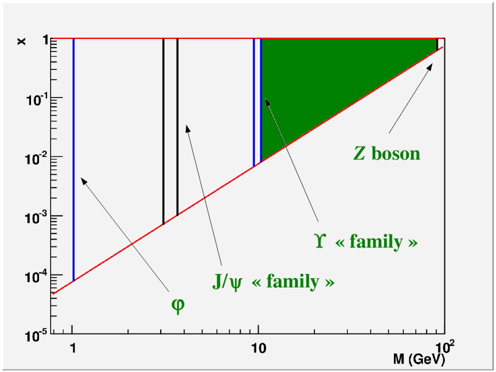

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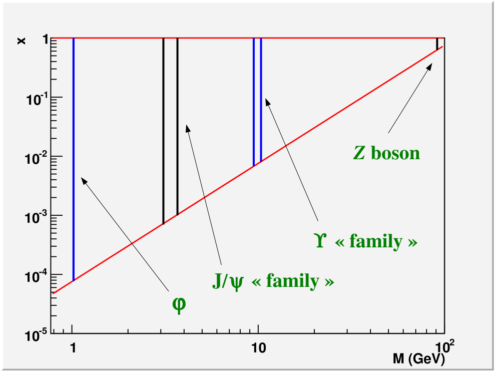

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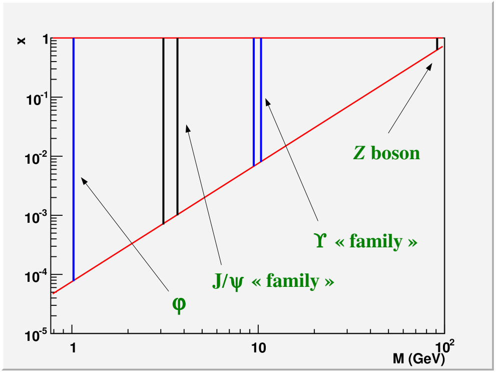

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via p and d studies

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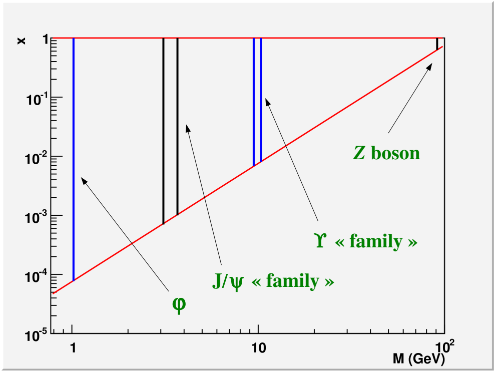
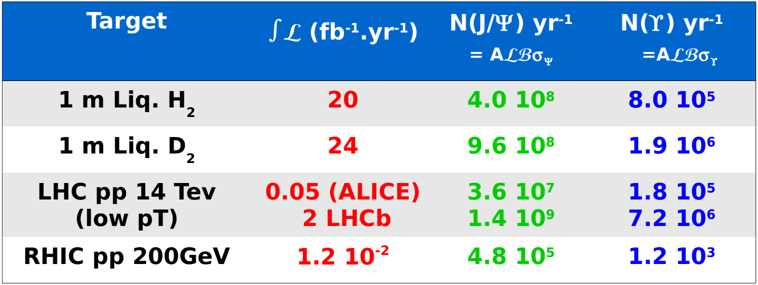


➟ To do: to look at the rates to see how competitive this will be

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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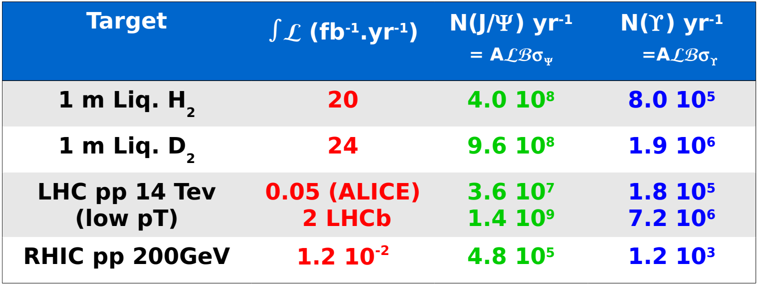

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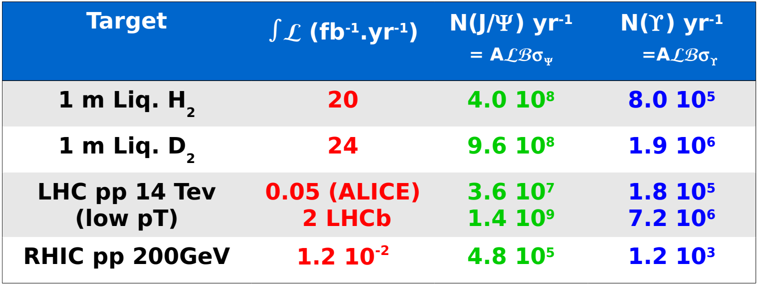

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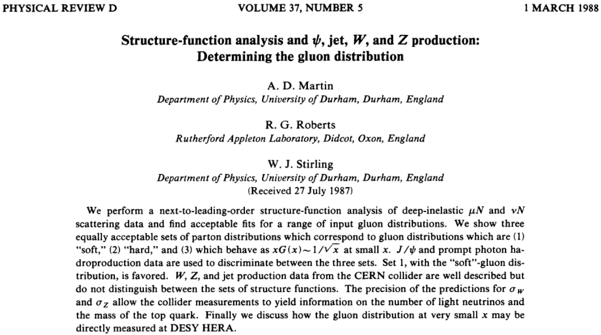

PHYSICAL REVIEW D **VOLUME 37, NUMBER 5** **1 MARCH 1988**

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

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W. J. Stirling
Department of Physics, University of Durham, Durham, England

(Received 27 July 1987)

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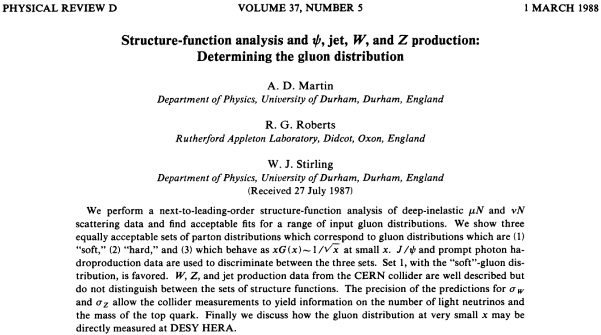

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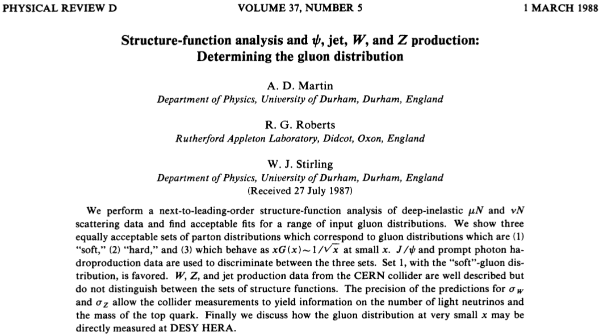

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- Production puzzle → quarkonium not used anymore in global fits
- With systematic studies, one would restore its status as gluon probe

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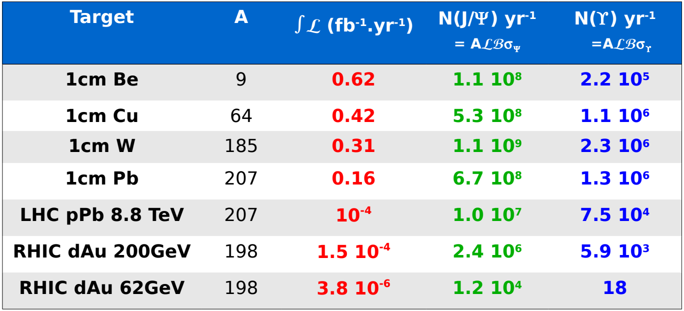

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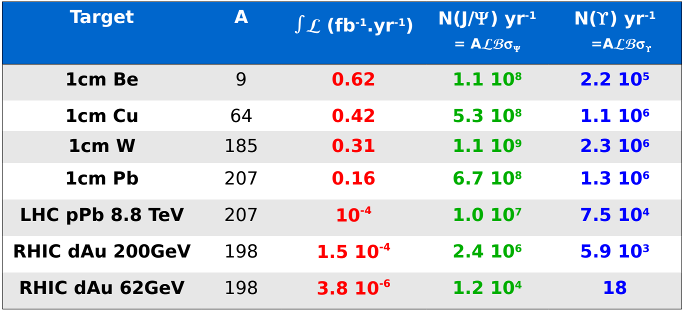

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  - not to mention ratio with **open charm, Drell-Yan,** etc ...

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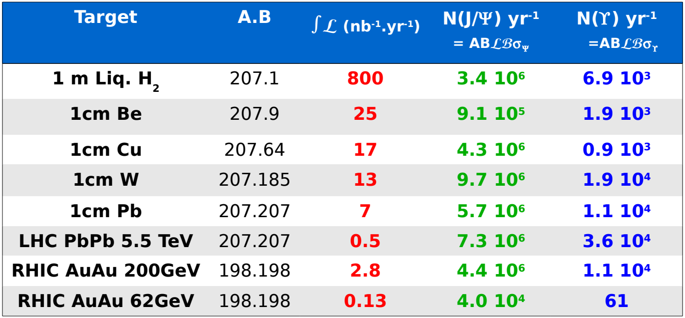
- One should be careful with factorization breaking effects:

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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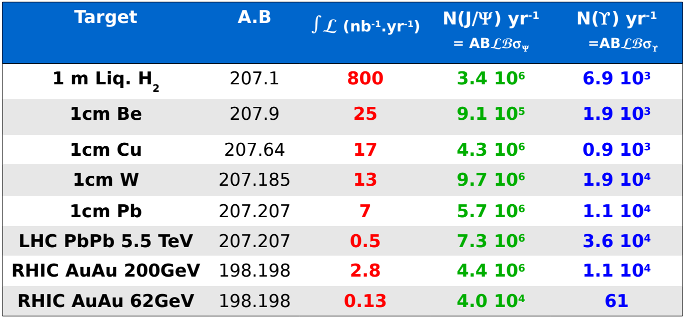

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1cm Pb	207.207	**7**	**$5.7\ 10^6$**	**$1.1\ 10^4$**
LHC PbPb 5.5 TeV	207.207	**0.5**	**$7.3\ 10^6$**	**$3.6\ 10^4$**
RHIC AuAu 200GeV	198.198	**2.8**	**$4.4\ 10^6$**	**$1.1\ 10^4$**
RHIC AuAu 62GeV	198.198	**0.13**	**$4.0\ 10^4$**	**61**

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

The same picture also holds for open heavy flavour

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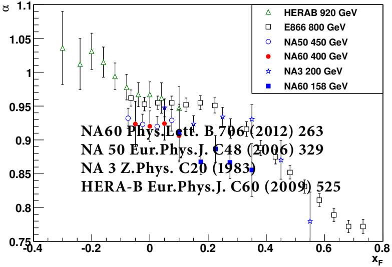
- the possibilities for $c\bar{c}$ recombination
  - Open charm studies are difficult where recombination matters most
    i.e. at low P_T
  - Only indirect indications –from the y and P_T dependence of R_{AA}– that recombination may be at work
  - CNM effects may show a non-trivial y and P_T dependence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

SPS and Hera-B



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

- **J/ψ data in pA collisions**

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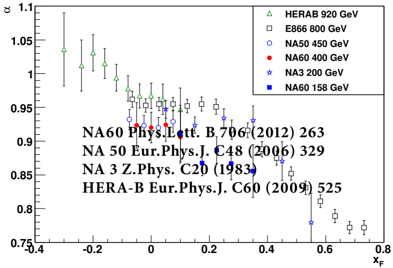

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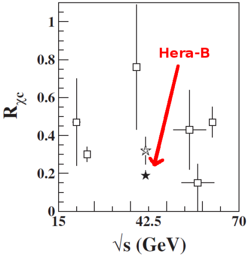
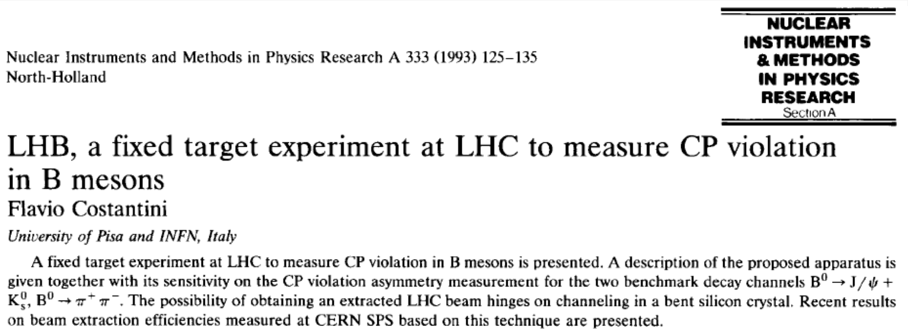


HERA-B PRD 79 (2009) 012001, and ref. therein

LHB

Our idea is not completely new



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

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

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

Flavio Costantini

University of Pisa and INFN, Italy

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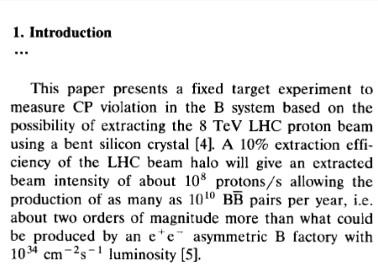

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This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted 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].

LHB

LARGE HADRON BEAUTY FACTORY

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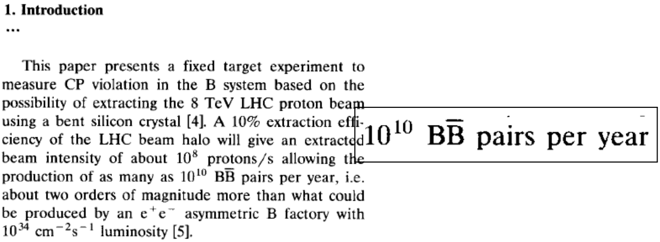

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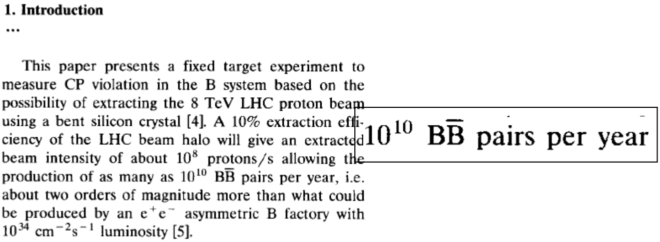

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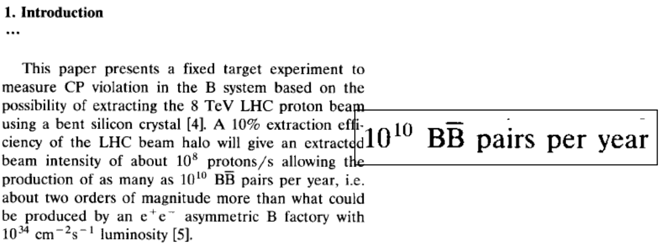

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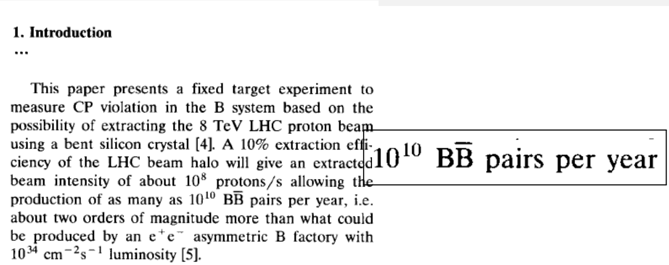

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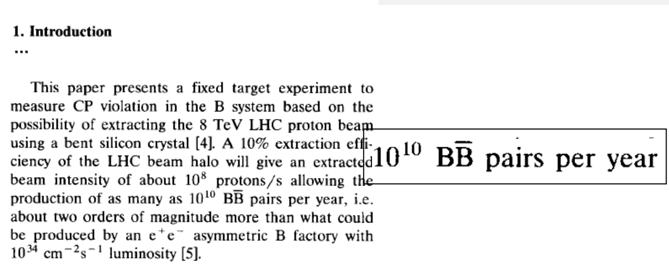

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