AFTER @ LHC

Spin and diffractive physics with A Fixed-Target ExpeRiment @ LHC

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IPN Orsay and LPT Orsay, Université Paris-Sud

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AFTER @ LHC

on behalf of M. Anselmino (Torino), R. Arnaldi (Torino), S.J. Brodsky (SLAC), V. Chambert (IPNO), J.P. Didelez (IPNO), B. Genolini (IPNO), E.G. Ferreiro (USC), F. Fleuret (LLR), C. Hadjidakis (IPNO), J.P. Lansberg (IPNO), A. Rakotozafindrabe (CEA), P. Rosier (IPNO), I. Schienbein (LPSC), E. Scomparin (Torino) and U.I. Uggerhøj (Aarhus)

Part I

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

- *pp* or *pA* with a 7 TeV *p* beam : $\sqrt{s} \simeq 115$ GeV
- For *pA*, a Fermi motion of 0.2 GeV would induce a spread of 10 % of $\sqrt{s}$

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- Tests will be performed on the LHC beam:

LUA9 proposal approved by the LHCC

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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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- similar figures for the Pb-beam extraction

Luminosities

- Instantaneous Luminosity:
  $\mathcal{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathcal{N}_A)/A$
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Target	ρ (g.cm^{-3})	A	$\mathcal{L}$ (μb^{-1}.s^{-1})	$\int\mathcal{L}$ (pb^{-1}.yr^{-1})
Sol. H_2	0.09	1	**26**	**260**
Liq. H_2	0.07	1	**20**	**200**
Liq. D_2	0.16	2	**24**	**240**
Be	1.85	9	**62**	**620**
Cu	8.96	64	**42**	**420**
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- Lumi for Pb runs in the backup slides

Part II

AFTER: a couple of flagship measurements

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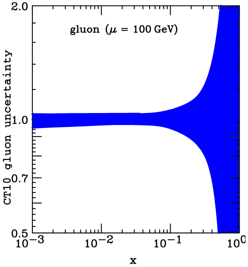
    - proton



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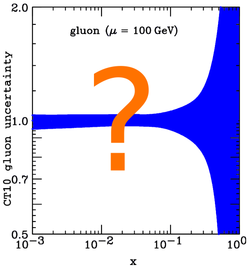

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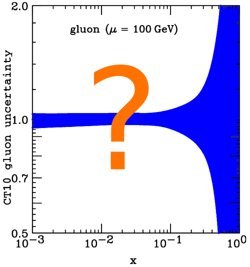

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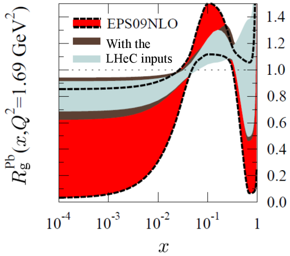

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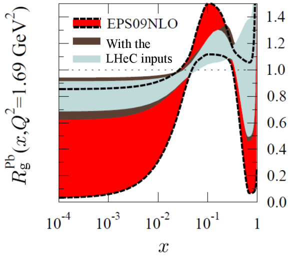

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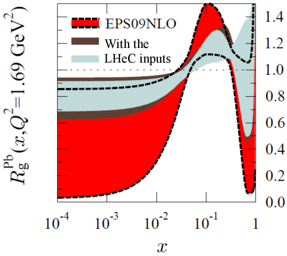

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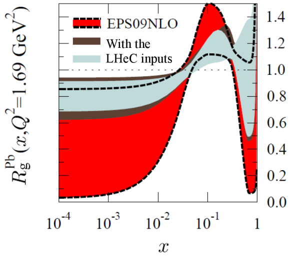

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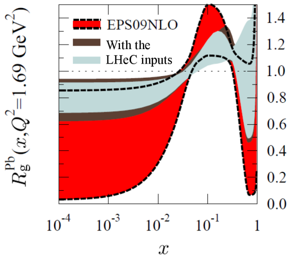

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- jets (we should access $P_T \in [20, 40]$ GeV)

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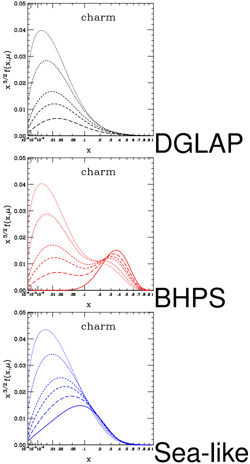

All 3 compatible with DIS data (Pumplin *et al.*)

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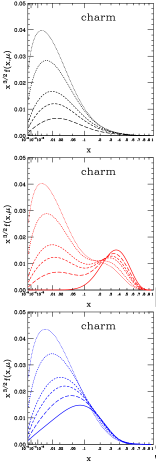

DGLAP

BHPS

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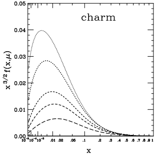

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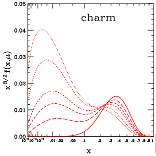

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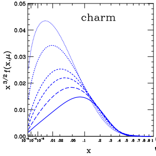

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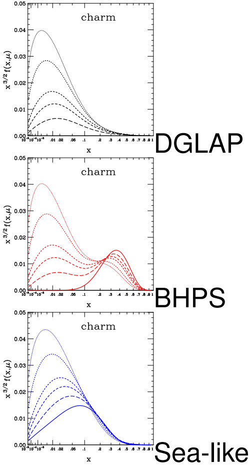

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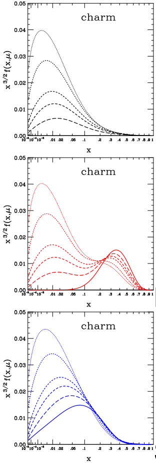

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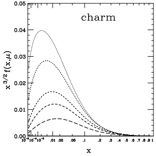
  - high luminosity to reach large x_B



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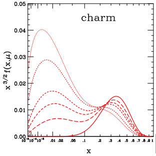

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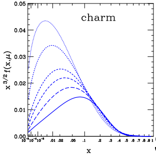

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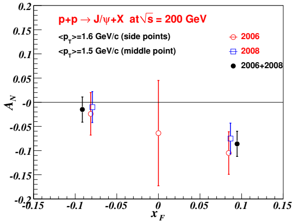

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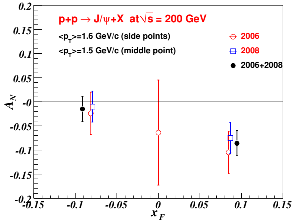

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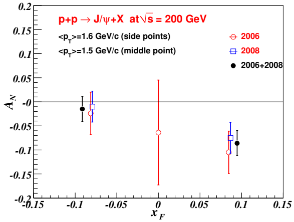
  - γ and γ-jet



(A. Bacchetta, *et al.* Phys. Rev. Lett. 99 (2007) 212002)

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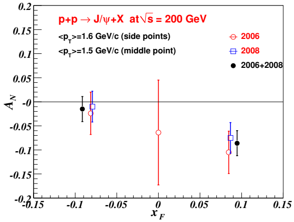
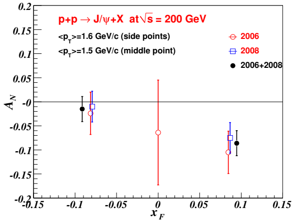


  - B & D meson production
  - γ and γ-jet (**A. Bacchetta,** *et al.* **Phys. Rev. Lett. 99 (2007) 212002**)
  - $\gamma\gamma$ (**W. Vogelsang,** *et al.* **Phys. Rev. Lett. 107 (2011) 062001**)

Key studies

- Gluon Sivers effect: correlation between
  the gluon transverse momentum & the proton spin
  - Transverse single spin asymetries
    using probes sensitive to gluons
  - quarkonia (J/ψ, Υ, χ_c, ...)



  - B & D meson production
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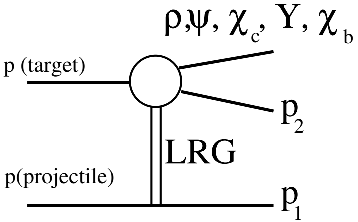
  - $\gamma\gamma$ (**W. Vogelsang,** *et al.* **Phys. Rev. Lett. 107 (2011) 062001**)
  - the target-rapidity region corresponds to high $x^\uparrow$
    where the k_T-spin correlation is the largest

Very forward (backward) physics ($x_F \to \pm 1$)

- Diffractive quarkonia production from intrisic charm

similar to Higgs production (**S. J. Brodsky** *et al.* **Phys. Rev. D 73, 113005 (2006)**)



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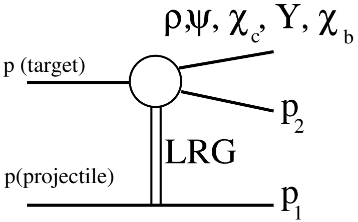

- (Semi-)diffractive events

Ultra-Peripheral Collisions

- $\sqrt{s_{\gamma p}}$ up to 60 GeV

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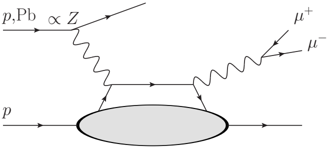
- inverse DVCS (GPDs)

(**B. Pire** *et al.* **Phys. Rev. D 79 (2009) 014010)**



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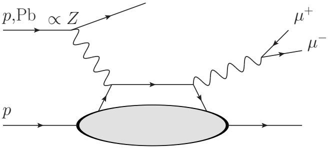
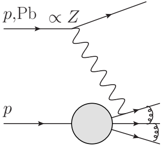


- proton dissociation (DAs)

(**L. Frankfurt and M. Strikman, hep-ph/0210087**)
(**D. Y. Ivanov** *et al.* **Phys. Lett. B 666 (2008) 245**)



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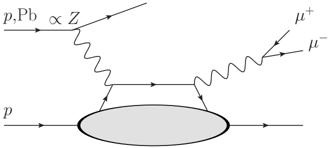

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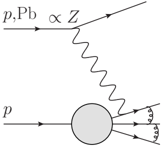
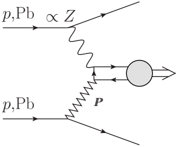


- vector meson photoproduction



More details in arxiv:1202.6585

SLAC-PUB-14878

Physics Opportunities of a Fixed-Target Experiment using the LHC Beams

S.J. Brodsky[1], F. Fleuret[2], C. Hadjidakis[3], J.P. Lansberg[3]

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[2] *Laboratoire Leprince Ringuet, Ecole polytechnique, CNRS/IN2P3, 91128 Palaiseau, France*
[3] *IPNO, Université Paris-Sud, CNRS/IN2P3, 91406 Orsay, France*

Abstract

We outline the many physics opportunities offered by a multi-purpose fixed-target experiment using the proton and lead-ion beams of the LHC extracted by a bent crystal. In a proton run with the LHC 7-TeV beam, one can analyze *pp*, *pd* and *pA* collisions at center-of-mass energy $\sqrt{s_{NN}} \simeq 115$ GeV and even higher using the Fermi-motion of the nucleons in a nuclear target. In a lead run with a 2.76 TeV-per-nucleon beam, $\sqrt{s_{NN}}$ is as high as 72 GeV. Bent crystals can be used to extract about 5×10^8 protons/sec; the integrated luminosity over a year would reach 0.5 fb^{-1} on a typical 1 cm-long target without nuclear species limitation. We emphasize that such an extraction mode does not alter the performance of the collider experiments at the LHC. By instrumenting the target-rapidity region, gluon and heavy-quark distributions of the proton and the neutron can be accessed at large x and even at x larger than unity in the nuclear case. Single diffractive physics and, for the first time, the large negative-x_F domain can be accessed. The nuclear target-species versatility provides a unique opportunity to study nuclear matter versus the features of the hot and dense matter formed in heavy-ion collisions, including the formation of the Quark-Gluon Plasma (QGP), which can be studied in *PbA* collisions over the full range of target rapidities with a large variety of nuclei. The polarization of hydrogen and nuclear targets allows an ambitious spin program, including measurements of the QCD lensing effects which underlie the Sivers single-spin asymmetry, the study of transversity distributions and possibly of polarized parton distributions. We also emphasize the potential offered by *pA* ultra-peripheral collisions where the nucleus target *A* is used as a coherent photon source, mimicking photoproduction processes in *ep* collisions. Finally, we note that *W* and *Z* bosons can be produced and detected in a fixed-target experiment and in their threshold domain for the first time, providing new ways to probe the partonic content of the proton and the nucleus.

Keywords: LHC beam, fixed-target experiment

More details in arxiv:1202.6585

Contents

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Part III

Conclusion and outlooks

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- Very good complementarity with electron-ion programs

Outlooks

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

Outlooks

ECT* **E**uropean **C**entre for **T**heoretical Studies in Nuclear Physics and Related Areas

ECT* 'exploratory' workshop:
"Physics at a fixed target experiment using the LHC beams"

- February 4 - February 13, 2013

'This is an exploratory workshop which aims at studying in detail the opportunity and feasibility of fixed-target experiments using the LHC beam.'

Part IV

Backup slides

Luminosities

- 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)
- Integrated luminosity $\int dt\mathcal{L} = \mathcal{L} \times 10^6$ s for Pb
- Expected luminosities with 2×10^5Pb s^{-1} extracted (1cm-long target)

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

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

Determination of the gluon PDFs

PHYSICAL REVIEW D VOLUME 37, NUMBER 5 1 MARCH 1988

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

A. D. Martin
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R. G. Roberts
Rutherford Appleton Laboratory, Didcot, Oxon, England

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.

Determination of the gluon PDFs

PHYSICAL REVIEW D VOLUME 48, NUMBER 11 1 DECEMBER 1993

ψ production in $\bar{p}N$ and $\pi^- N$ interactions at 125 GeV/c and a determination of the gluon structure functions of the $\bar{p}$ and the π^-

C. Akerlof,[4] H. Areti,[3,*] M. Binkley,[2] S. Conetti,[3,†] B. Cox,[2,†] J. Enagonio,[2]
He Mao,[5] C. Hojvat,[2] D. Judd,[2,‡] S. Katsanevas,[1] R. D. Kephart,[2] C. Kourkoumelis,[1] P. Kraushaar,[4,§]
P. Lebrun,[3,*] P. K. Malhotra,[2,‖] A. Markou,[1] P. O. Mazur,[2] D. Nitz,[4] L. K. Resvanis,[1] D. Ryan,[3]
T. Ryan,[3,¶] W. Schappert,[3,**] D. G. Stairs,[3] R. Thun,[4] F. Turkot,[2] S. Tzamarias,[1,††] G. Voulgaris,[1]
R. L. Wagner,[2] D. E. Wagoner,[2,‡] W. Yang,[2] and Zhang Nai-jian[5]

(E537 Collaboration)

[1]*University of Athens, Athens, Greece*
[2]*Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
[3]*McGill University, Montreal, Quebec, Canada H3A 2T8*
[4]*University of Michigan, Ann Arbor, Michigan 48109*
[5]*Shandong University, Jinan, People's Republic of China*
(Received 9 February 1993)

We have measured the cross section for production of ψ and ψ' in $\bar{p}$ and π^- interactions with Be, Cu, and W targets in experiment E537 at Fermilab. The measurements were performed at 125 GeV/c using a forward dimuon spectrometer in a closed geometry configuration. The gluon structure functions of the $\bar{p}$ and π^- have been extracted from the measured $d\sigma/dx_F$ spectra of the produced ψ's. From the $\bar{p}$W data we obtain, for $\bar{p}$, $xG(x)=(2.15\pm0.7)[1-x]^{(6.83\pm0.5)}[1+(5.85\pm0.95)x]$. In the π^- case, we obtain, from the W and the Be data separately, $xG(x)=(1.49\pm0.03)[1-x]^{(1.98\pm0.06)}$ (for π^-W), $xG(x)=(1.10\pm0.10)[1-x]^{(1.20\pm0.20)}$ (for π^-Be).

Determination of the gluon PDFs

Z. Phys. C – Particles and Fields 38, 473–478 (1988)

J/ψ Production at large transverse momentum at hadron colliders

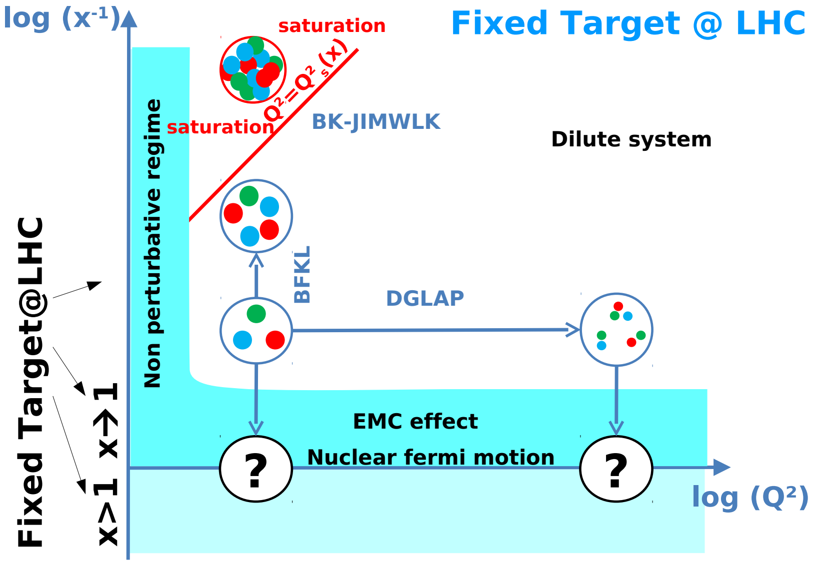
E.W.N. Glover[1]*, A.D. Martin[2], W.J. Stirling[2]

[1] Cavendish Laboratory, University of Cambridge, Cambridge, CB3 0HE, England
[2] Physics Department, University of Durham, Durham, DH1 3LE, England

Received 7 October 1987

Abstract. We calculate J/ψ hadroproduction and emphasize the importance of the J/ψ signal as a measure of $b\bar{b}$ production via the decay $B \to \psi X$ and of the gluon structure function at low x via χ hadroproduction followed by $\chi \to \psi \gamma$ decay. We compare with UA1 data and data at ISR energies and make predictions for ψ production at TEVATRON energies.

Overall


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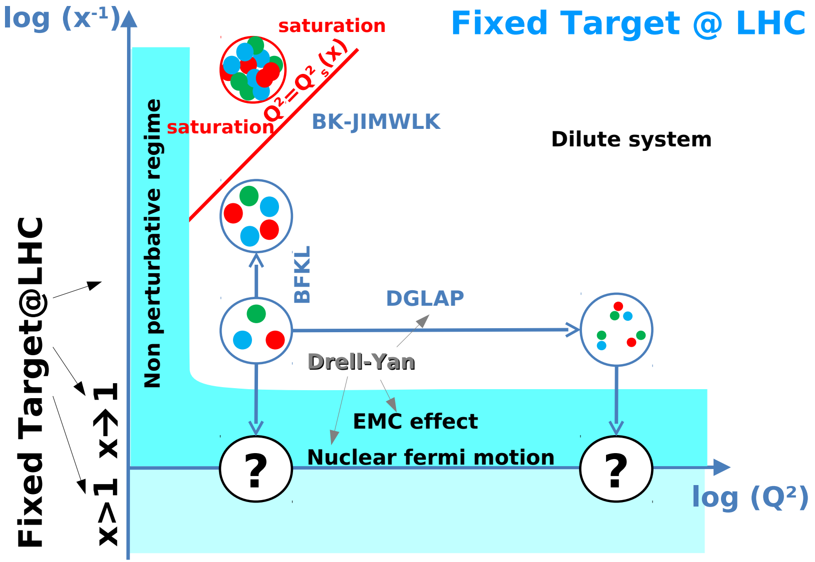

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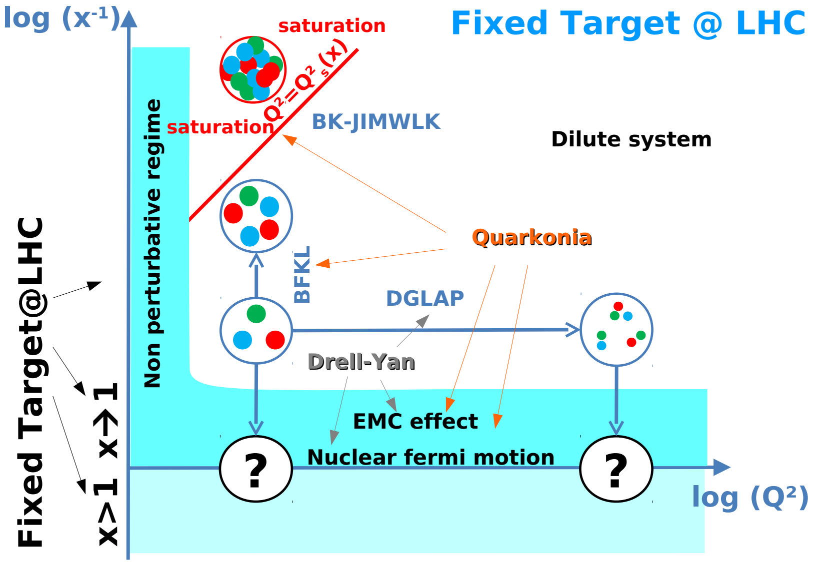
log (x-1)
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Fixed Target @ LHC
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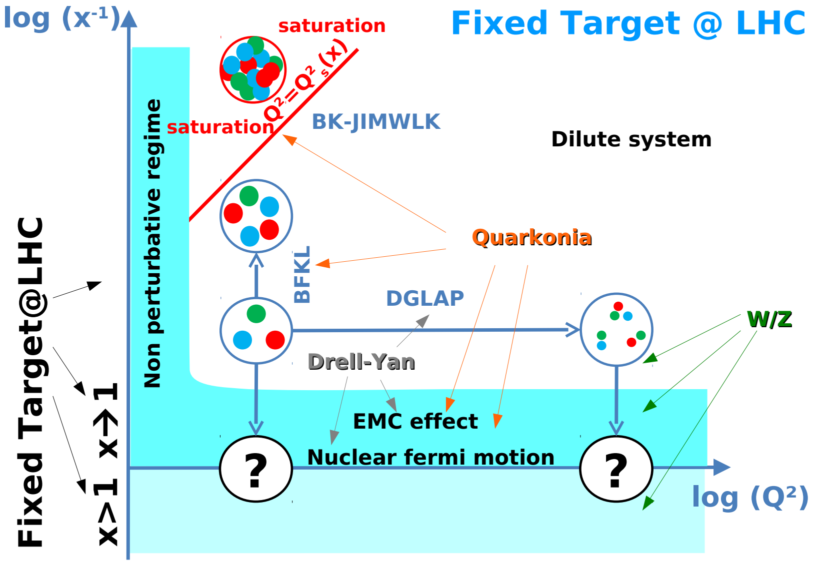

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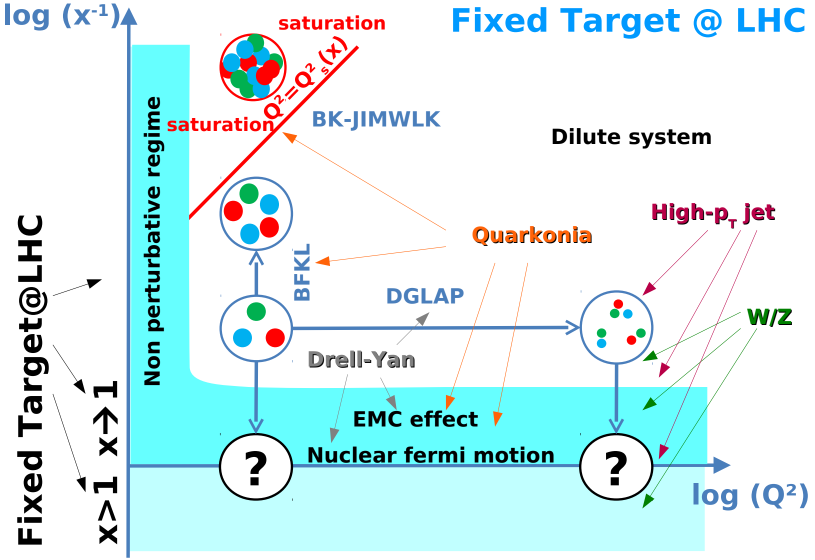

log (x⁻¹)
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Fixed Target @ LHC
$Q^2=Q^2_s(x)$
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Fixed Target@LHC
x>1 x→1

Beam extraction

- **Beam extraction @ LHC**

… there are extremely promising possibilities to extract 7 TeV protons from the circulating beam by means of a bent crystal.

… The idea is to put a bent, single crystal of either Si or Ge (W would perform slightly better but needs substantial improvements in crystal quality) at a distance of $\simeq 7\sigma$ to the beam where it can intercept and deflect part of the beam halo by an angle similar to the one the foreseen dump kicking system will apply to the circulating beam.

… ions with the same momentum per charge as protons are deflected in a crystal with similar efficiencies

Available online at www.sciencedirect.com
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Nuclear Instruments and Methods in Physics Research B 234 (2005) 31–39
NIM B Beam Interactions with Materials & Atoms
www.elsevier.com/locate/nimb

Strong crystalline fields – a possibility for extraction from the LHC

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Received 9 September 2004; received in revised form 6 January 2005
Available online 24 February 2005

If the crystal is positioned at the kicking section, the whole dump system can be used for slow extraction of parts of the beam halo, the particles that are anyway lost subsequently at collimators.

A Fixed Target ExpeRiment: e.g. 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} = $A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
1 m Liq. H_2	20	4.0 10^8	8.0 10^5
1 m Liq. D_2	24	9.6 10^8	1.9 10^6
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
RHIC pp 200GeV	1.2 10^{-2}	4.8 10^5	1.2 10^3

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- 1000 times higher than at RHIC;comparable to ALICE/LHCb at the LHC

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RHIC pp 200GeV	$1.2\ 10^{-2}$	$4.8\ 10^5$	$1.2\ 10^3$

- 1000 times higher than at RHIC;comparable to ALICE/LHCb at the LHC
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A Fixed Target ExpeRiment: e.g. a quarkonium observatory in *pp*

- Interpolating the world data set:

Target	$\int\mathcal{L}$ ($fb^{-1}.yr^{-1}$)	$N(J/\Psi)\ yr^{-1}$ $= A\mathcal{L}\mathcal{B}\sigma_\Psi$	$N(\Upsilon)\ yr^{-1}$ $=A\mathcal{L}\mathcal{B}\sigma_\Upsilon$
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- Probe of the (very) large x in the target

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1cm Be	9	0.62	$1.1\ 10^{8}$	$2.2\ 10^{5}$
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}	$1.0\ 10^{7}$	$7.5\ 10^{4}$
RHIC dAu 200GeV	198	$1.5\ 10^{-4}$	$2.4\ 10^{6}$	$5.9\ 10^{3}$
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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} $=AB\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
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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**
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The same picture also holds for open heavy flavour

Accessing the large *x* glue

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

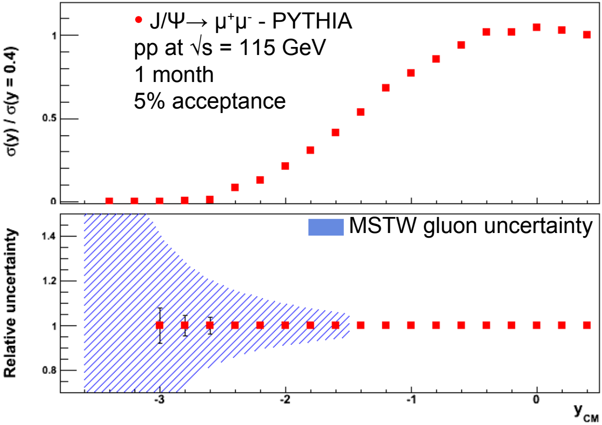
Statistical relative uncertainty
Large statistics allow to access very backward region

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