The France-Stanford Center for Interdisciplinary Studies

AFTER @ LHC

A Fixed-Target ExpeRiment using the proton and lead LHC beams

Jean-Philippe Lansberg
IPN Orsay, Université Paris-Sud

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AFTER @ LHC

ICHEP2012 Melbourne

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

The European strategy for particle physics

Approved by the CERN council at the special Session held in Lisbon on 14 July, 2006

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pg. 37 of the Strategy Brochure

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- with virtually no limit on particle-species studies (except top quark)

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- with an outstanding luminosity
- with virtually no limit on particle-species studies (except top quark)
- with modern detection techniques

Part I

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

A Fixed Target ExperRiment using the LHC beams

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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without any performance decrease of the LHC !

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- Pb*p* or Pb*A* with a 2.75 TeV Pb beam : $\sqrt{s_{NN}} \simeq 72$ GeV
- Crystal channeling is also possible for heavy-ion beams

Recent test with Pb at SPS: W. Scandale *et al.*, PLB 703 (2011) 547

- If required, bent diamonds may provide a crystal highly resistant to radiations

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- Tests will be performed on the LHC beam:

LUA9 proposal approved by the LHCC

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

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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**
W	19.1	185	**31**	**310**
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- Lumi for Pb runs in the backup slides

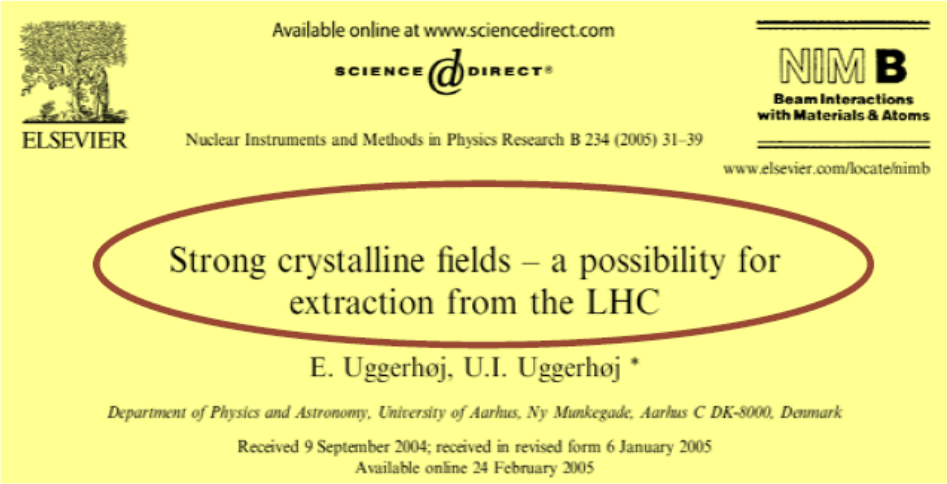
Beam extraction

- **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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Strong crystalline fields – a possibility for extraction from the LHC

E. Uggerhøj, U.I. Uggerhøj *

Department of Physics and Astronomy, University of Aarhus, Ny Munkegade, Aarhus C DK-8000, Denmark

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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.

Part II

AFTER: a couple of flagships measurements

Key studies

- Gluon distribution at mid, high and ultra-high x_B in the

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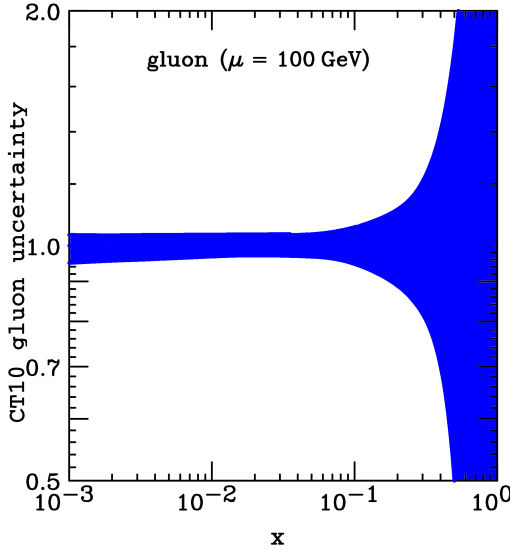
  - proton



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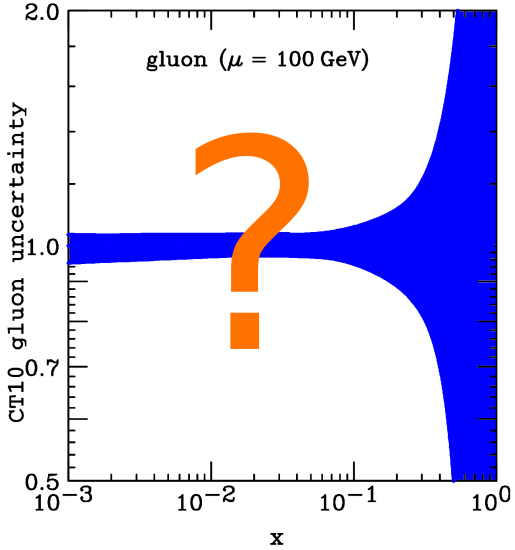

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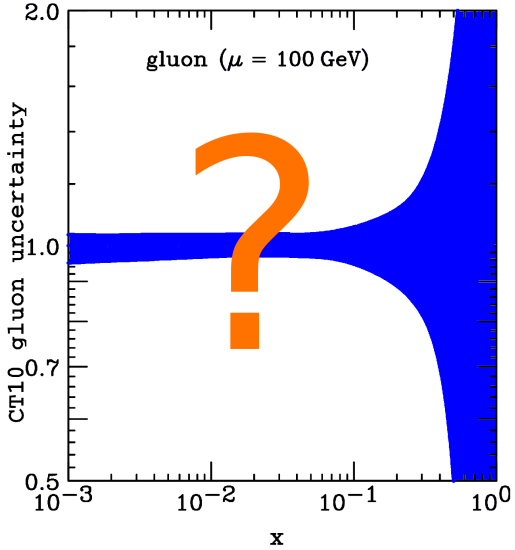

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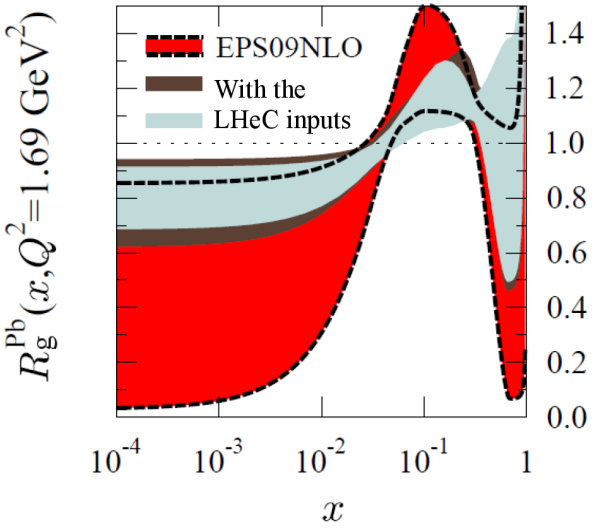

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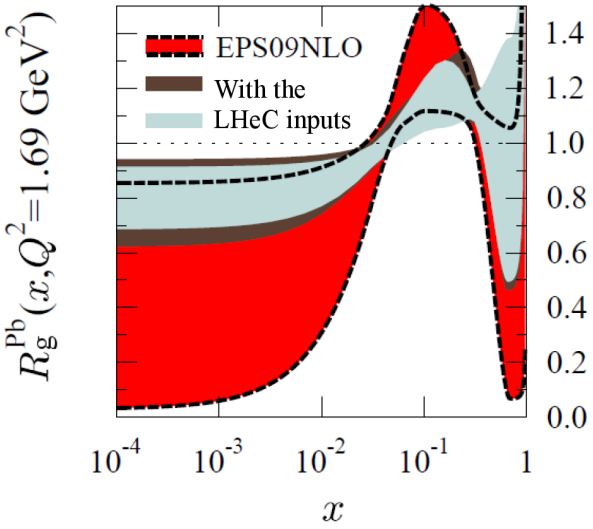

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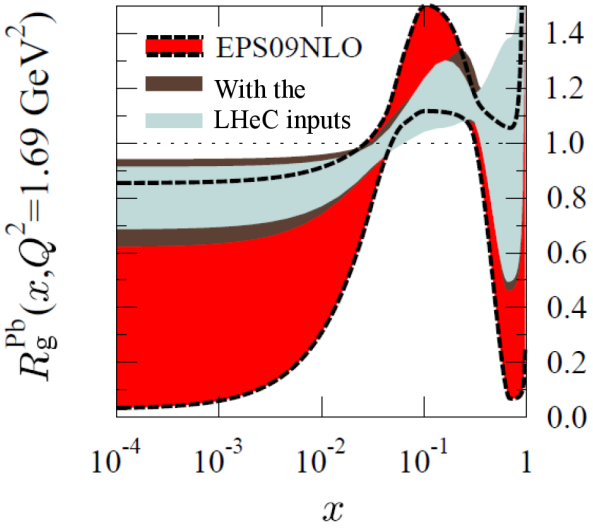

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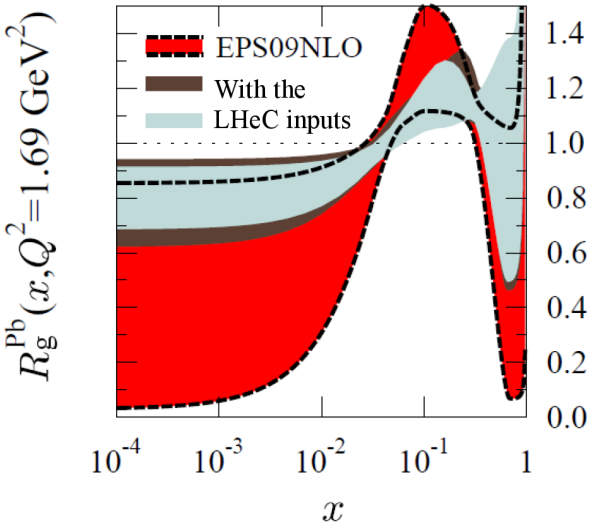

with

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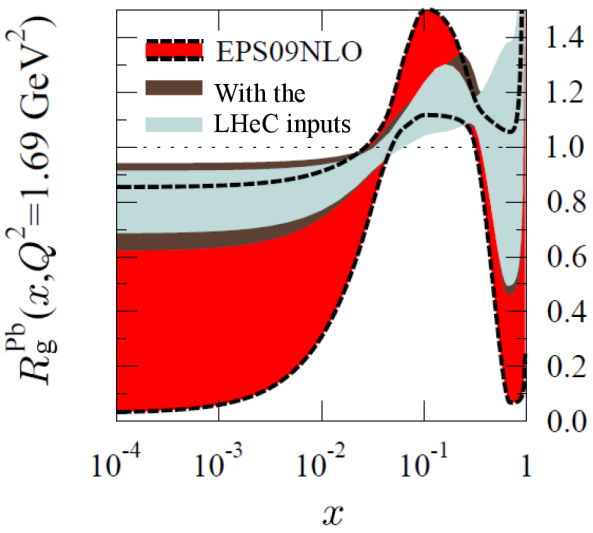

with

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

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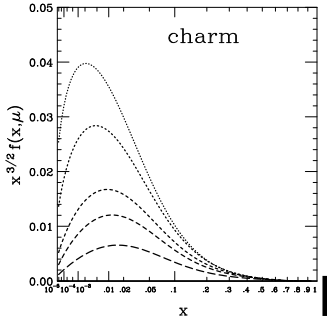
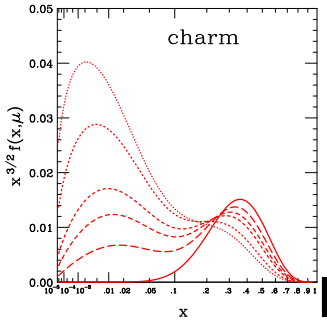
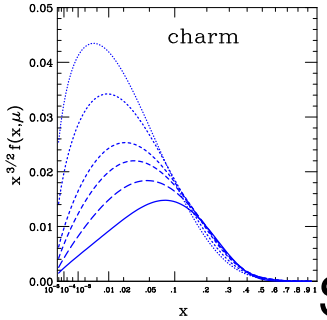


DGLAP



BHPS



Sea-like

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

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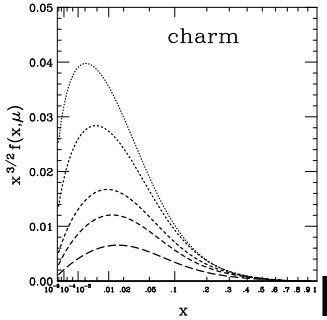
  - Total open charm and beauty cross section (down to $P_T \to 0$)



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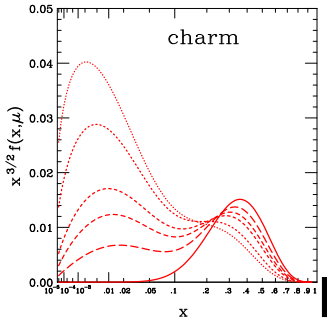

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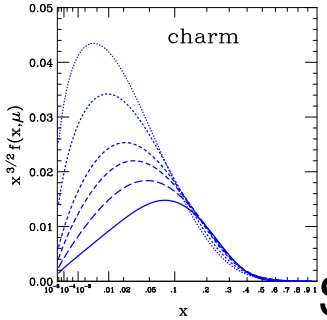

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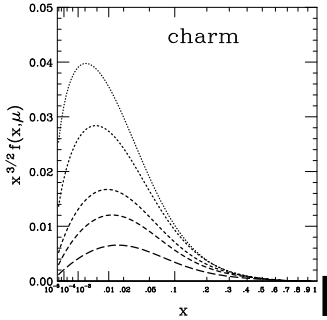

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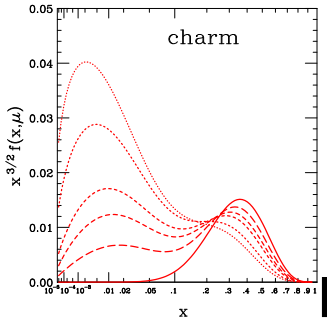

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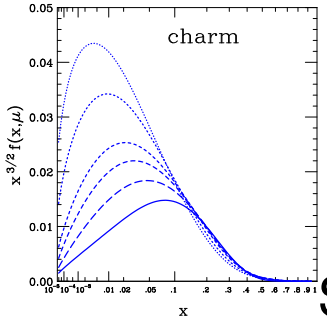

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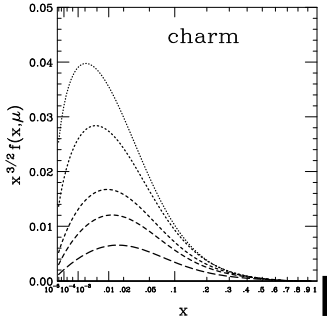

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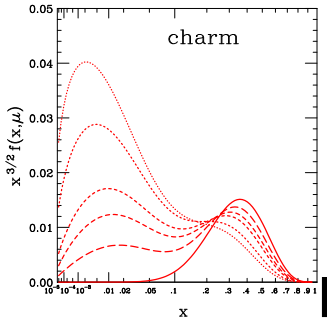

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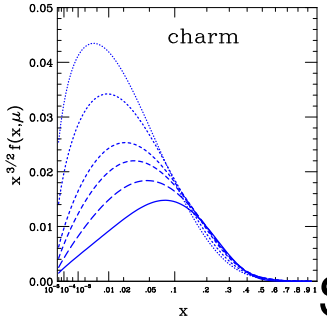

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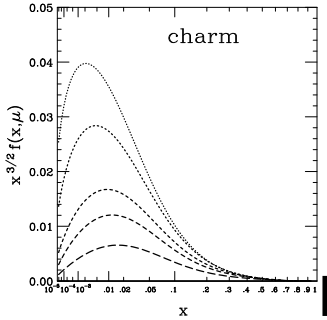

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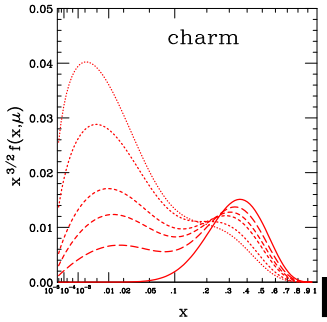

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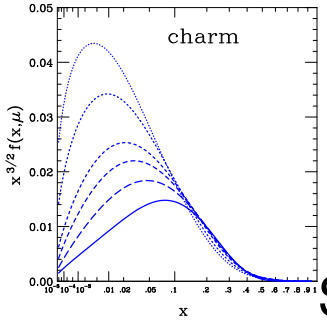

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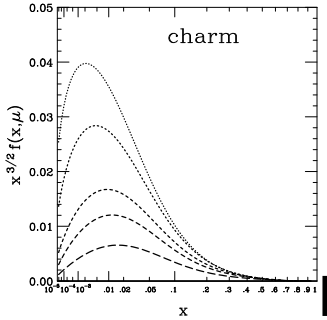

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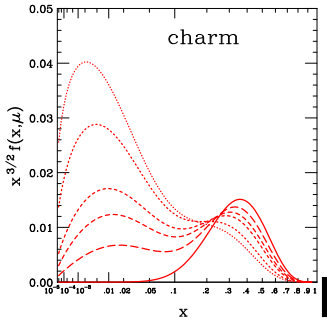

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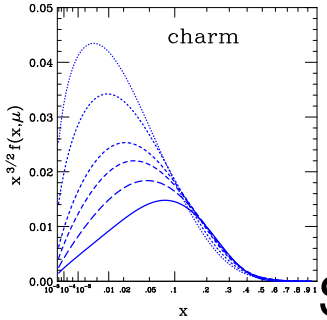

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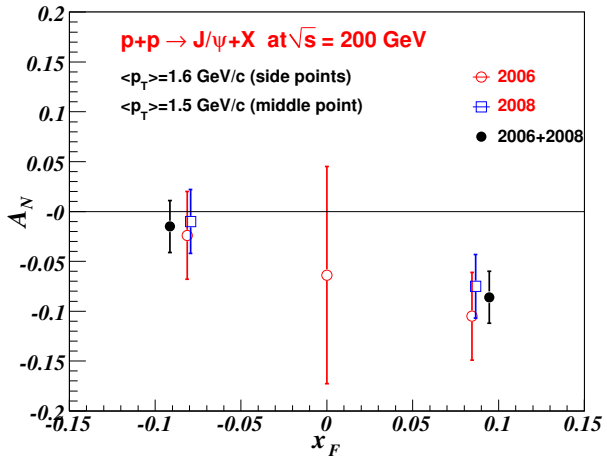

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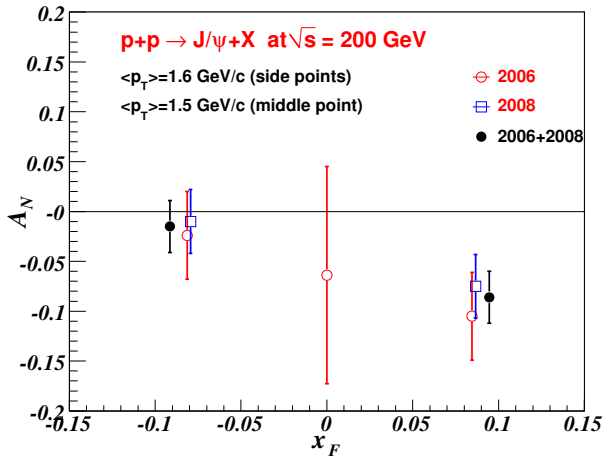

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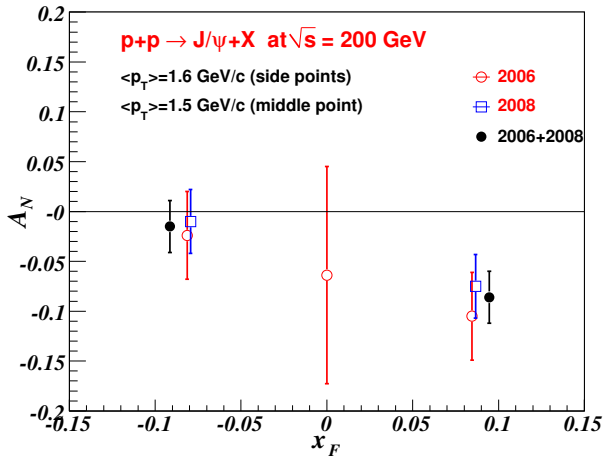

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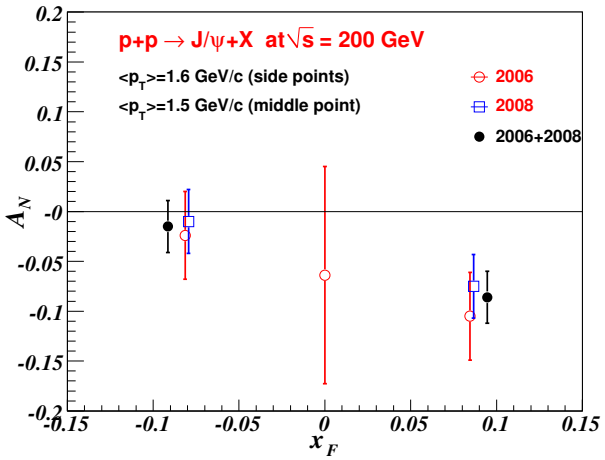

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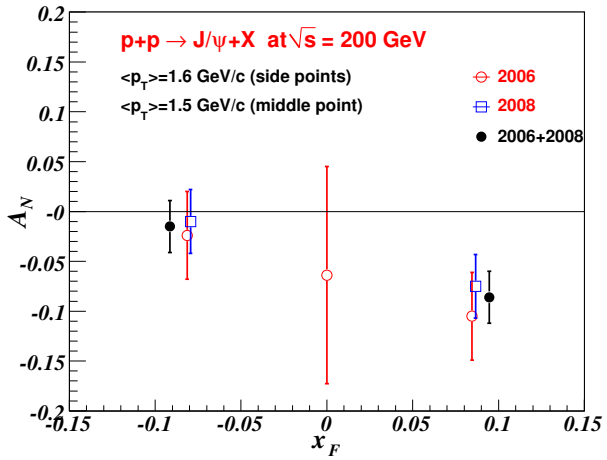

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- the target-rapidity region corresponds to high $x^{\uparrow}$ where the k_T-spin correlation is the largest
- In general, one can carry out an extensive spin-physics program

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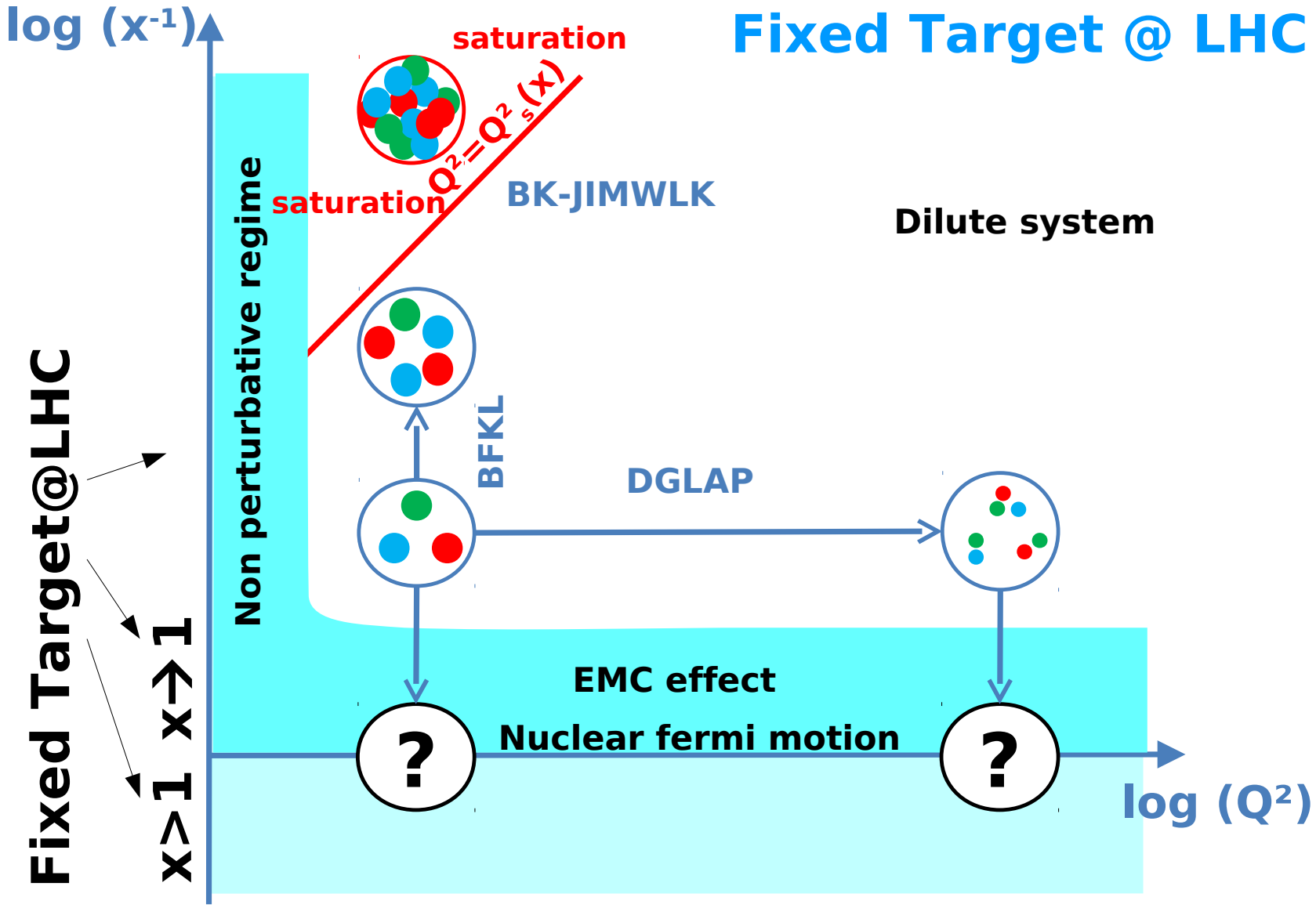
- Multiply heavy baryons: discovery potential ? ($\Omega^{++}(ccc)$, ...)
- Very forward (backward) physics:
  - semi-diffractive events
  - Ultra-peripheral collisions, etc.

Overall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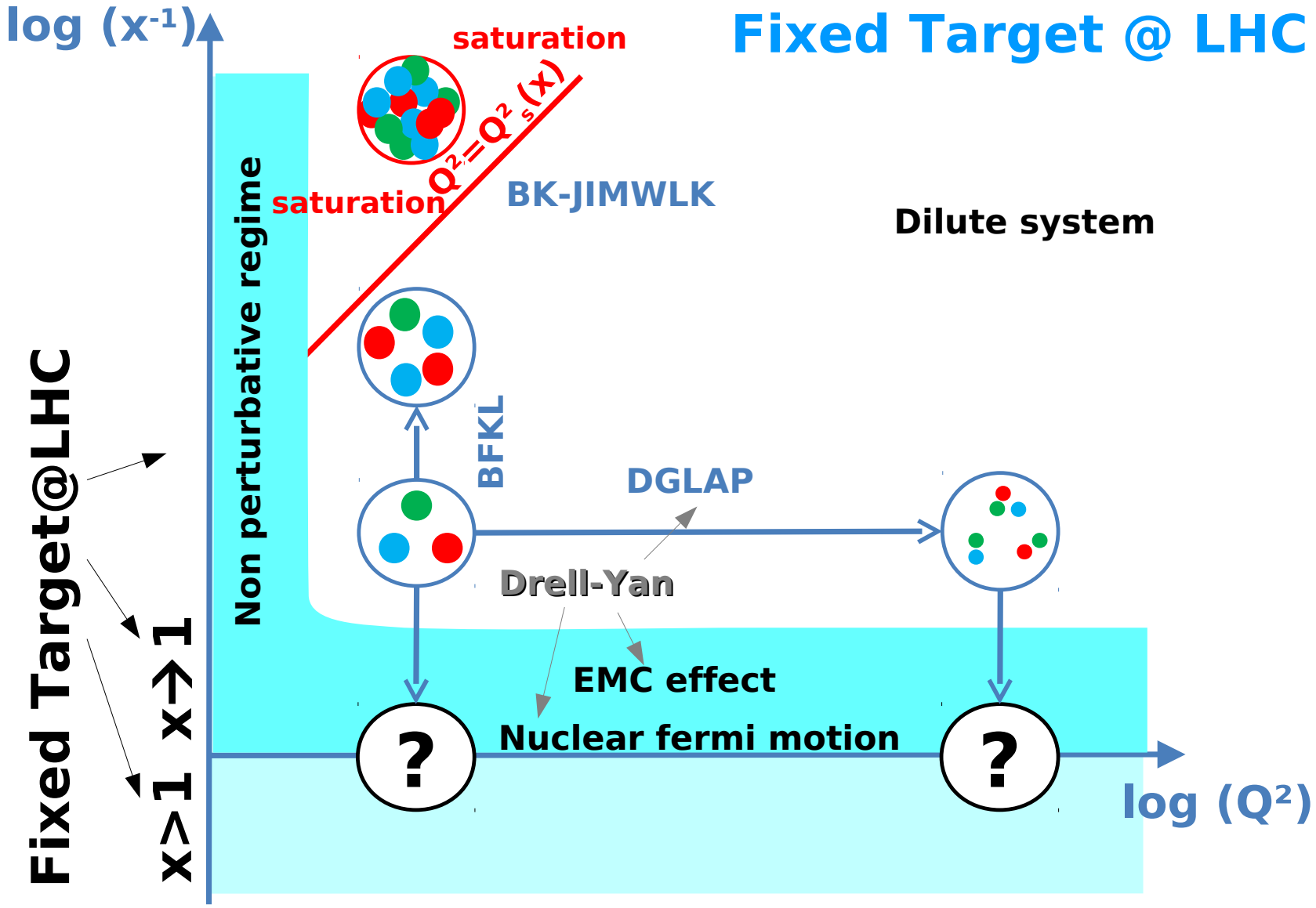
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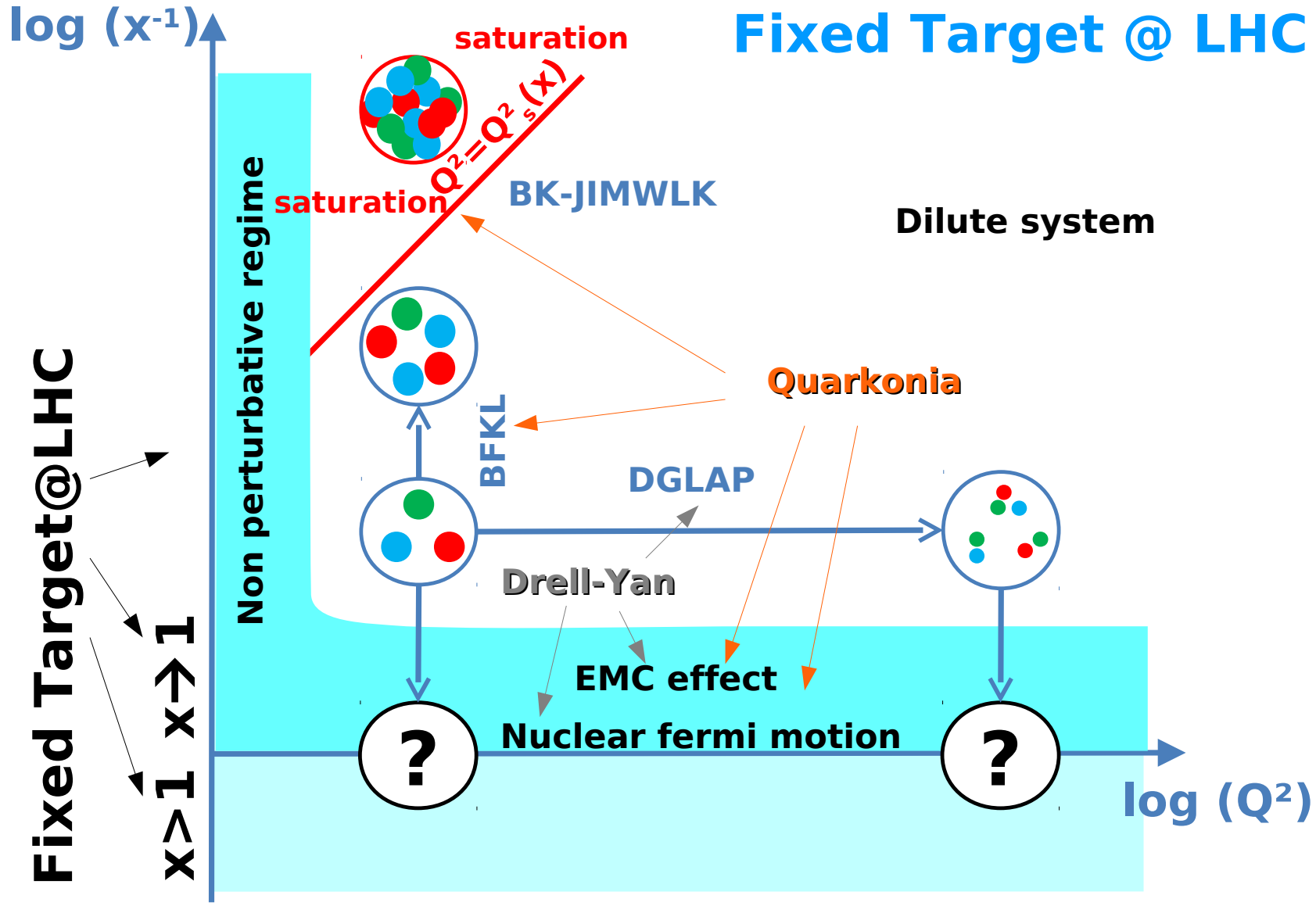
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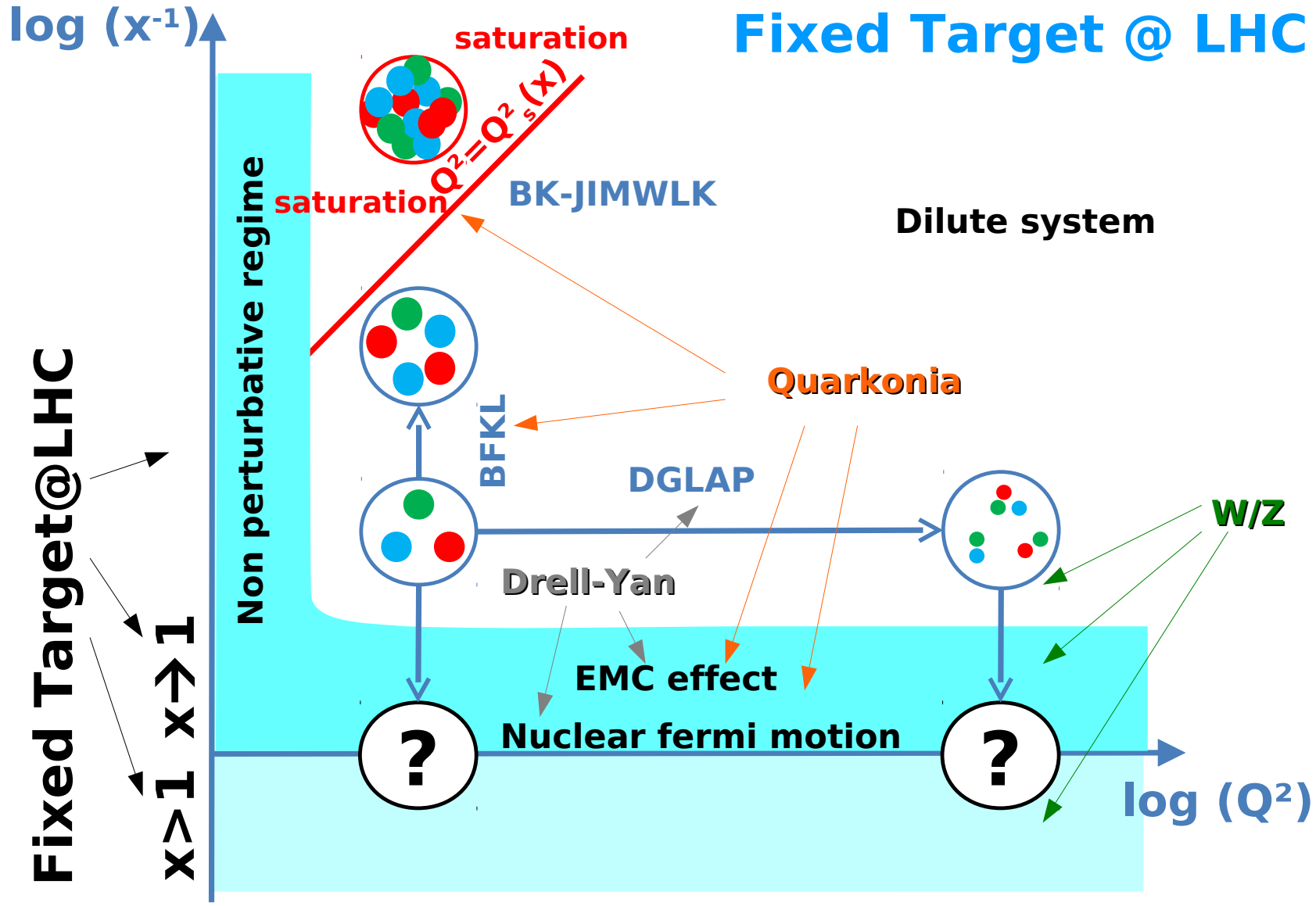
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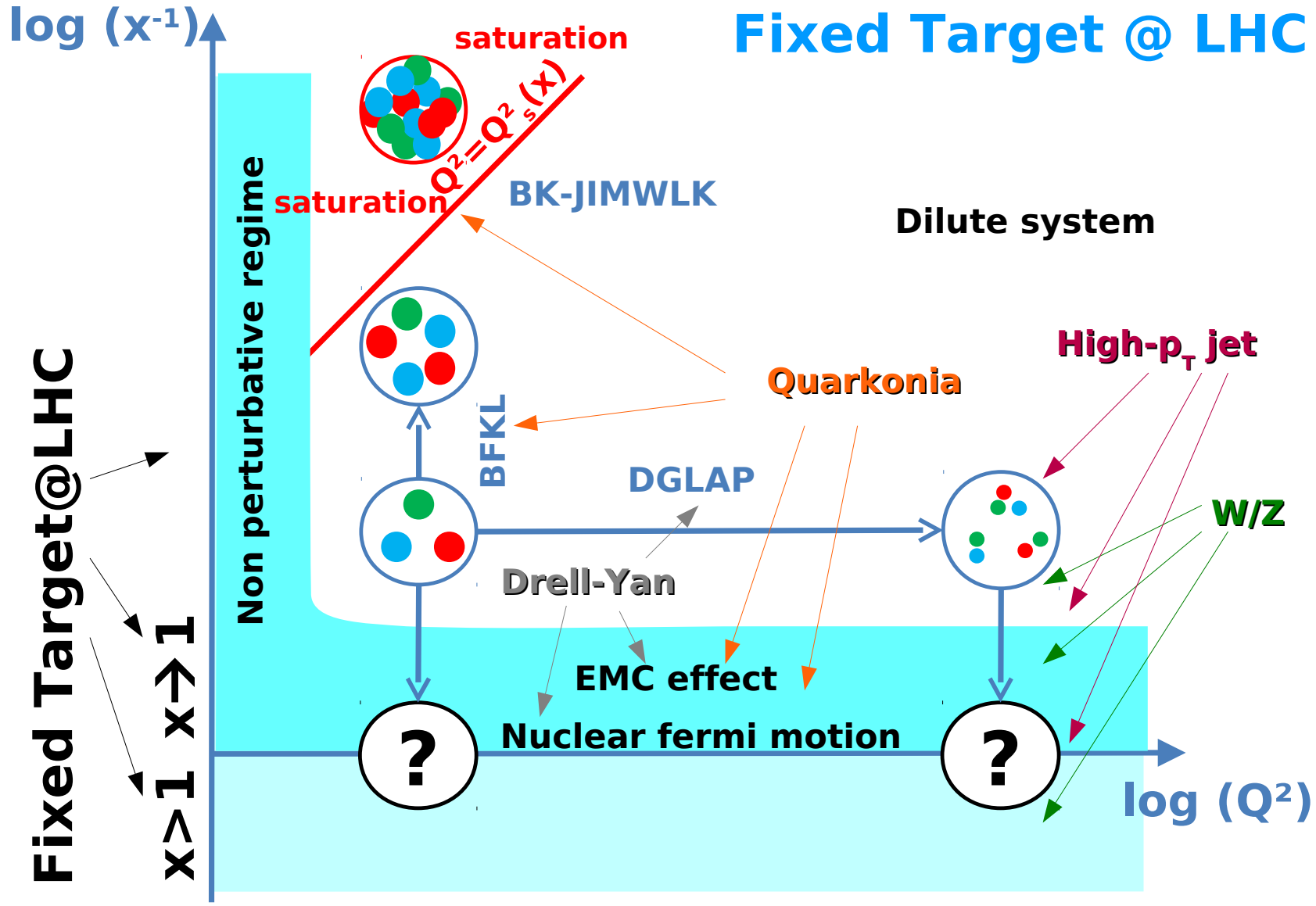
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More details in arxiv:1202.6585

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]

[1]SLAC National Accelerator Laboratory, Theoretical Physics, Stanford University, Menlo Park, California 94025, USA
[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

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Contents

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Part III

Conclusion and outlooks

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- Very good complementarity with electron-ion programs

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

Part IV

Backup slides

Luminosities

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

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} =$A\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
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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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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}**
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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$\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
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**
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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

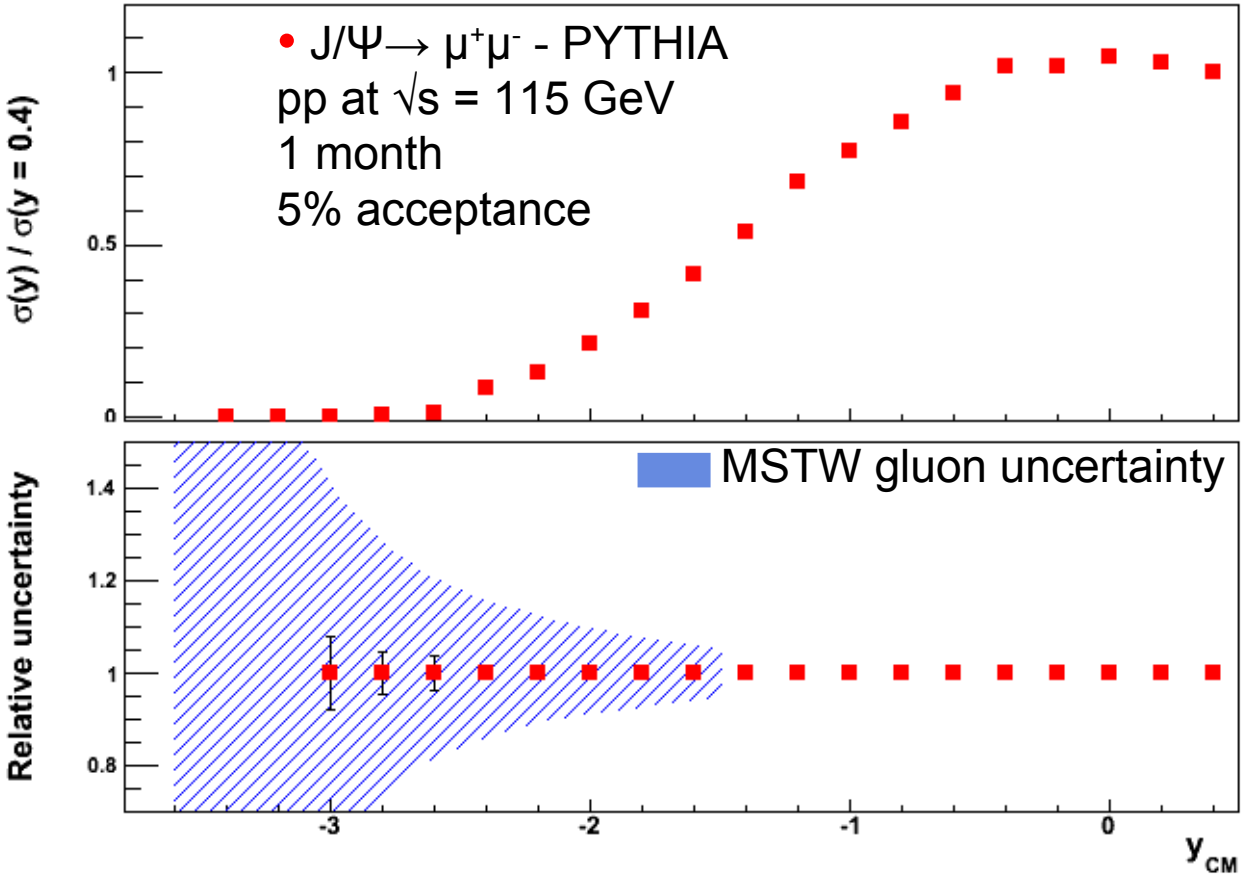
Statistical relative uncertainty
Large statistics allow to access very backward region

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

Y: 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