AFTER @ LHC

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

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

Part I

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

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    - · breakdown of the Lam-Tung relation,
    - · colour transparency,
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- They exhibit 4 decisive features,
  - accessing the high Feynman x_F domain ($x_F \equiv p_z/p_{z\,\max}$)
  - achieving high luminosities with dense targets,
  - varying the atomic mass of the target almost at will,
  - polarising the target.

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- with modern detection techniques

Part II

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

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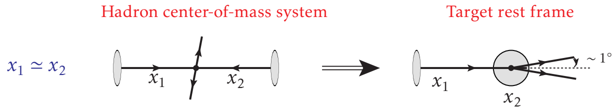

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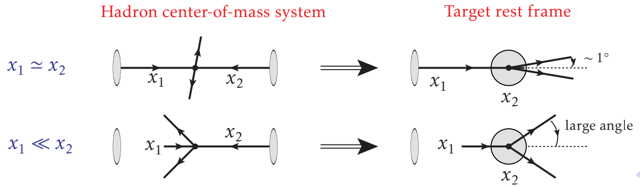

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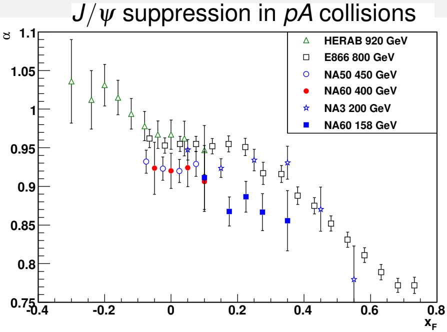

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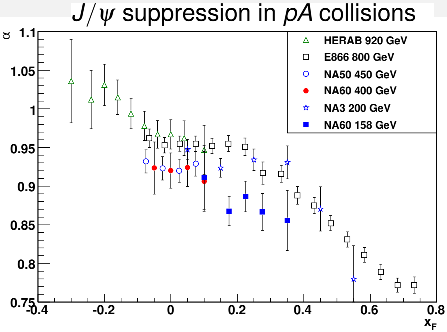

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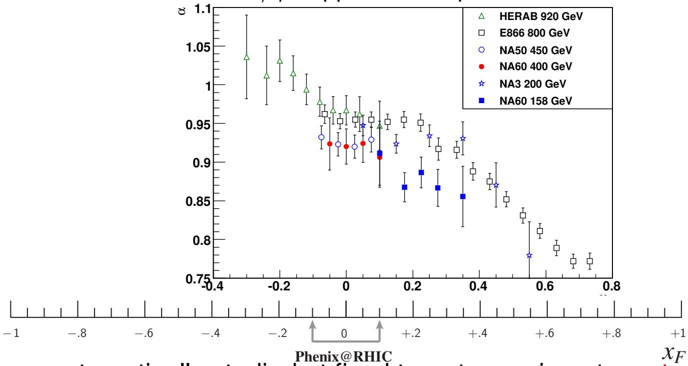

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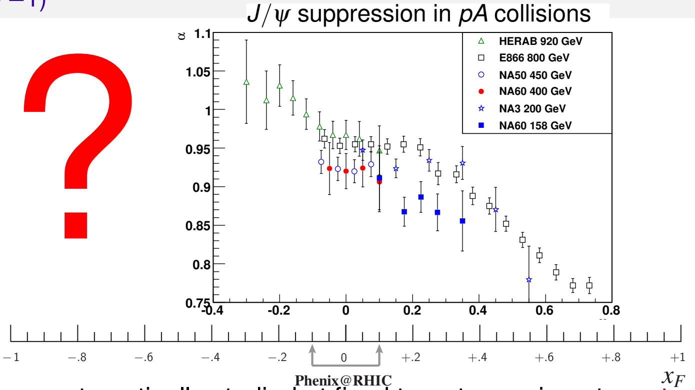

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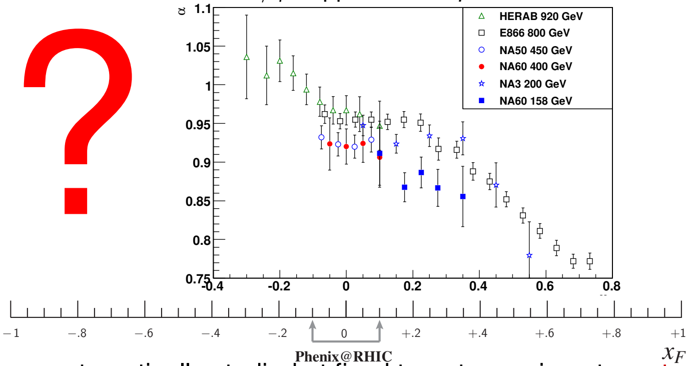

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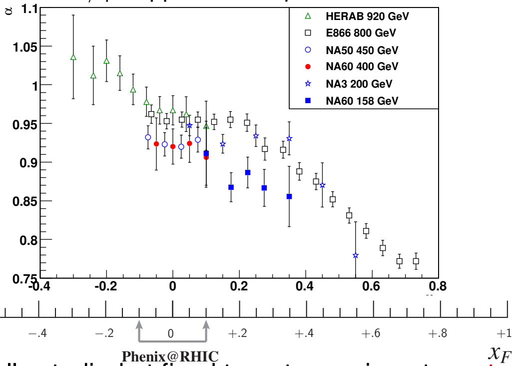

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- **Applies also to D/B mesons, isolated photons, Drell-Yan pairs, ...**

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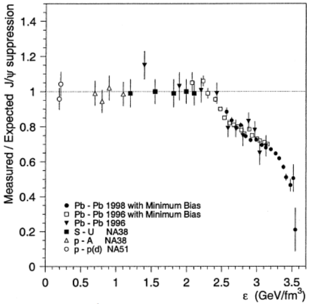

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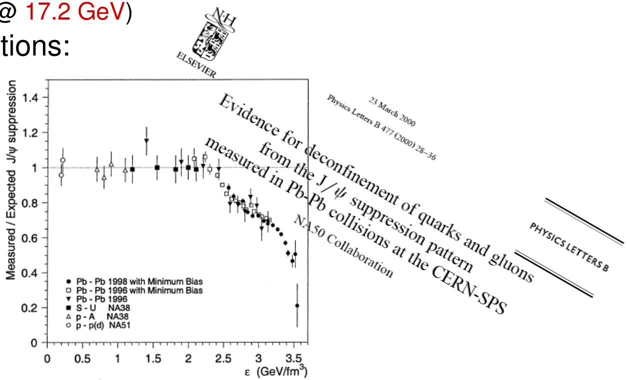

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Target	ρ (g.cm^{-3})	A	$\mathcal{L}$ (μb^{-1}.s^{-1})	$\int\mathcal{L}$ (pb^{-1}.yr^{-1})
Sol. H_2	0.09	1	**26**	**260**
Liq. H_2	0.07	1	**20**	**200**
Liq. D_2	0.16	2	**24**	**240**
Be	1.85	9	**62**	**620**
Cu	8.96	64	**42**	**420**
W	19.1	185	**31**	**310**
Pb	11.35	207	**16**	**160**

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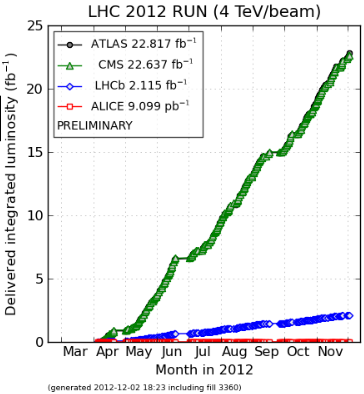

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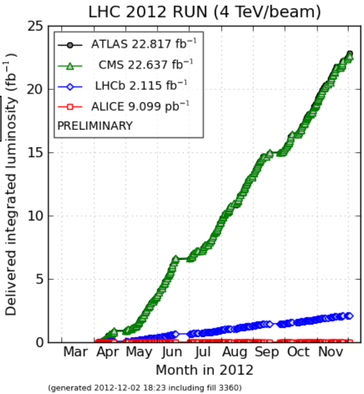

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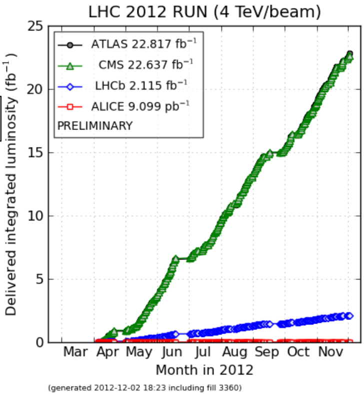

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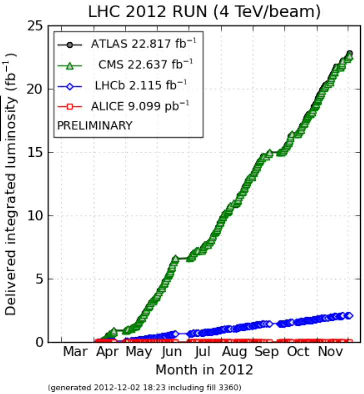
- Lumi for Pb runs in the backup slides

(roughly 10 times that planned for the LHC)



Part III

AFTER: some flagships measurements

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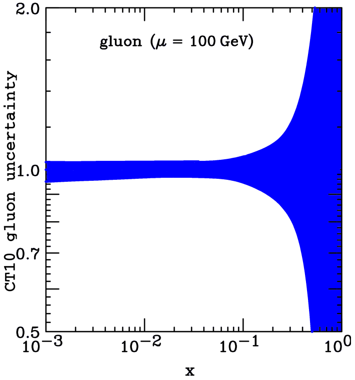

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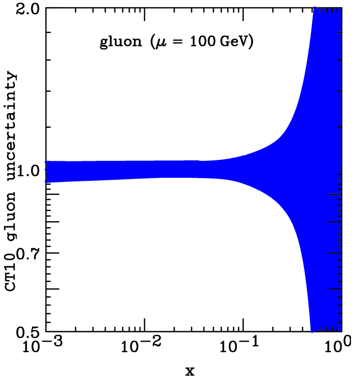

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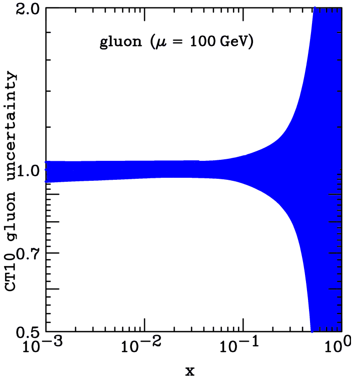

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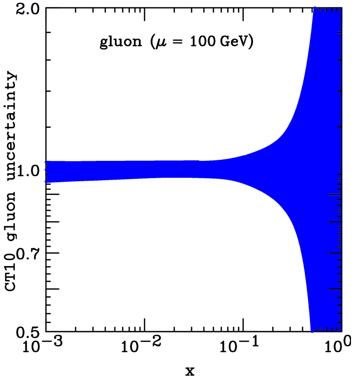

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  see a recent study by D. Diakonov *et al.*, JHEP 1302 (2013) 069

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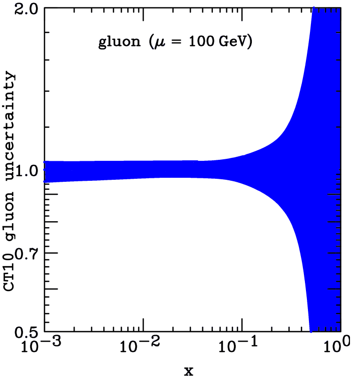

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  see a recent study by D. Diakonov *et al.*, JHEP 1302 (2013) 069
- Isolated photon
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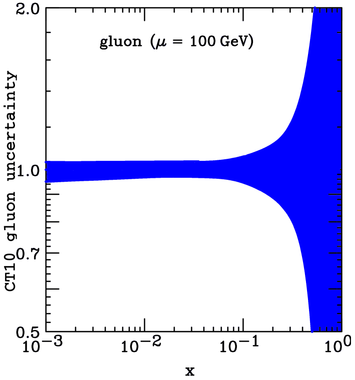
Key studies: gluons in the proton

- Gluon distribution at mid, high and ultra-high x_B in the proton
  - Not easily accessible in DIS
  - Very large uncertainties



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

Key studies: gluon contribution to the proton spin

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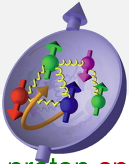

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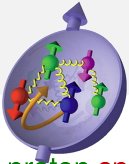

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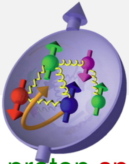

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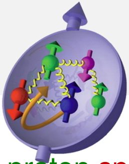

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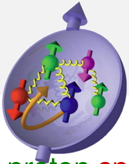

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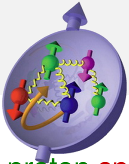

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- In general, one can carry out an extensive spin-physics program

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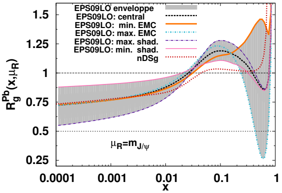

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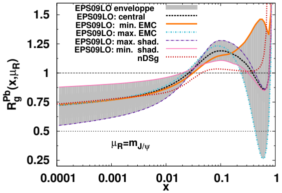

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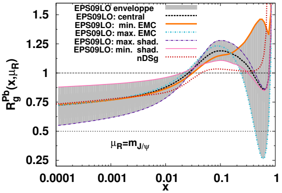

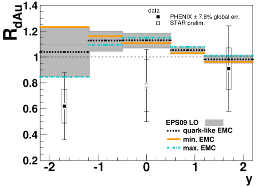

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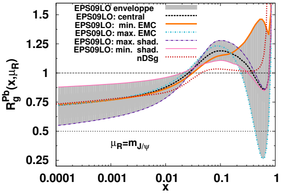

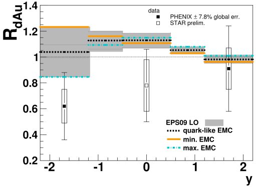

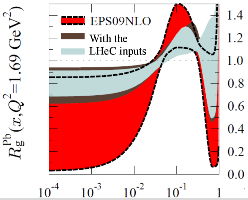

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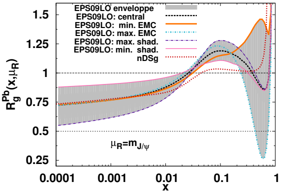
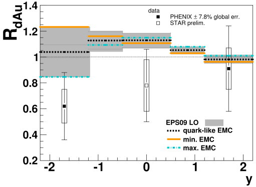
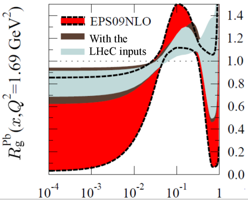
- AFTER allows for extensive studies of gluon sensitive probes in pA
- Unique potential for gluons at $x > 0.1$







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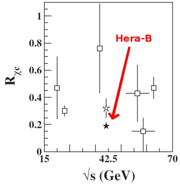

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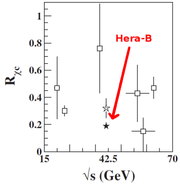

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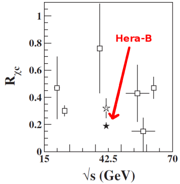

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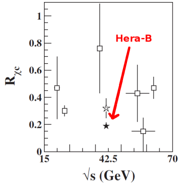

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Further studies and more details in

Physics Reports 522 (2013) 239–255

Contents lists available at SciVerse ScienceDirect

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Physics opportunities of a fixed-target experiment using LHC beams

S.J. Brodsky [a], F. Fleuret [b], C. Hadjidakis [c], J.P. Lansberg [c,*]

[a] SLAC National Accelerator Laboratory, Stanford University, Menlo Park, CA 94025, USA
[b] Laboratoire Leprince Ringuet, Ecole polytechnique, CNRS/IN2P3, 91128 Palaiseau, France
[c] IPNO, Université Paris-Sud, CNRS/IN2P3, 91406 Orsay, France

Contents

Part IV

Conclusion and outlooks

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Part V

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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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

E. Uggerhøj, U.I. Uggerhøj *
Department of Physics and Astronomy, University of Aarhus, Ny Munkegade, Aarhus C DK-8000, Denmark

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.

The beam extraction

★ The LHC beam may be extracted using “Strong crystalline field” **without any decrease in performance of the LHC !**

E. Uggerhøj, U.I Uggerhøj, NIM B 234 (2005) 31, Rev. Mod. Phys. 77 (2005) 1131

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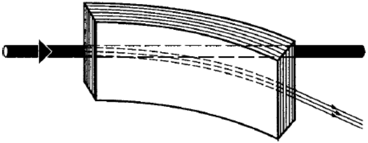

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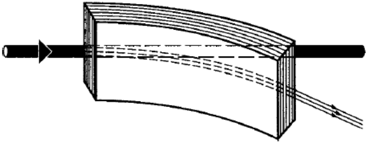

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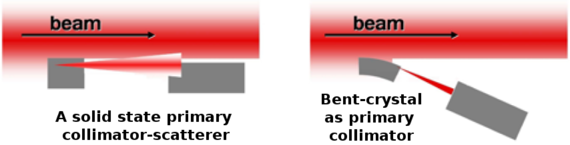

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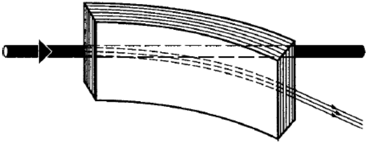

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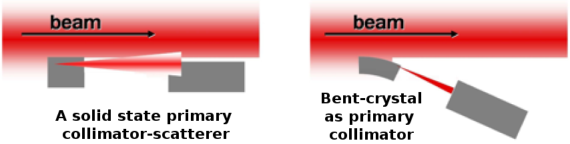
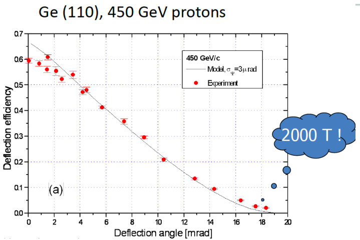
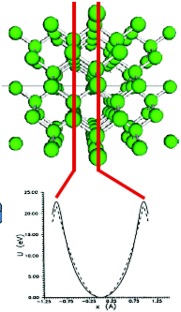


★ Tests will be performed on the LHC beam:
LUA9 proposal approved by the LHCC

The beam extraction

- Inter-crystalline fields are huge





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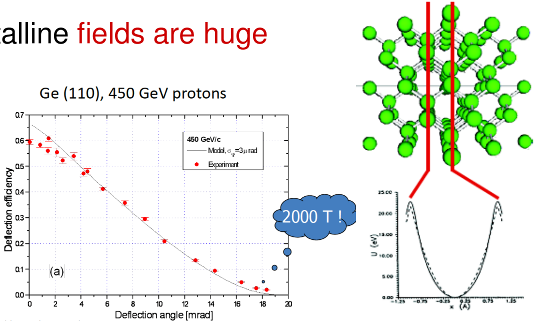

- The channeling efficiency is high for a deflection of a few mrad

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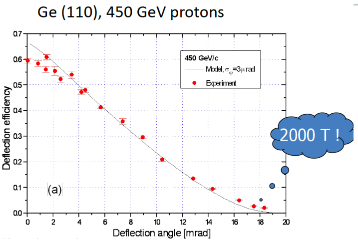

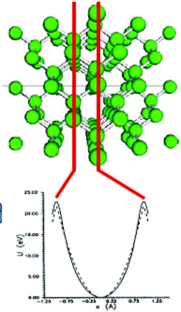

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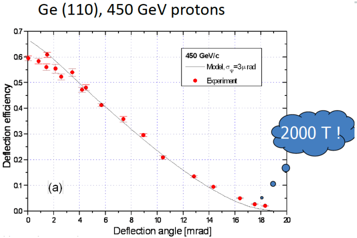

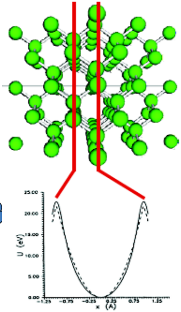

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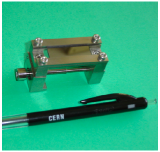
- One can extract a significant part of the beam loss ($10^9 p^+ s^{-1}$)
- Simple and robust way to extract the most energetic beam ever:



A few figures on the (extracted) proton beam

- Beam loss: 10^9 $p^+\mathrm{s}^{-1}$
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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

These protons are lost anyway !

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- similar figures for the Pb-beam extraction

Luminosities

- Instantaneous Luminosity:
  $\mathscr{L} = \Phi_{beam} \times N_{target} = N_{beam} \times (\rho \times \ell \times \mathscr{N}_A)/A$
  $\Phi_{beam} = 2 \times 10^5$ Pb s^{-1}, $\ell = 1$ cm (target thickness)
- Integrated luminosity $\int dt \mathscr{L} = \mathscr{L} \times 10^6$ 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**

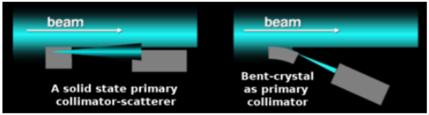
- Planned lumi for PHENIX Run15AuAu 2.8 nb^{-1} (0.13 nb^{-1} at 62 GeV)
- Nominal LHC lumi for PbPb 0.5 nb^{-1}

The beam extraction: news

[S. Montesano, Physics at AFTER using LHC beams, ECT Trento, Feb. 2013]*

Goal : assess the possibility to use bent crystals as primary collimators in hadronic accelerators and colliders

UA9 installation in the SPS



Prototype crystal collimation system at SPS :

- local beam loss reduction (5÷20x reduction for proton beam)
- beam loss map show average loss reduction in the entire SPS ring
- halo extraction efficiency 70÷80% for protons (50÷70% for Pb)

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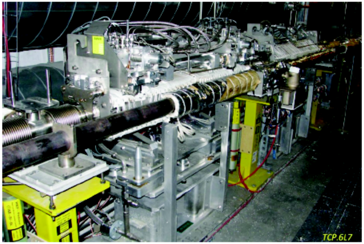

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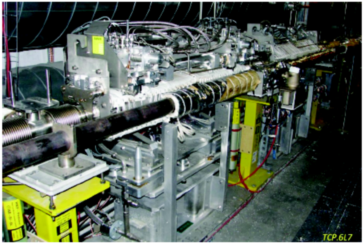

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Towards an installation in the LHC : propose and install during LS1 a min. number of devices

- 2 crystals

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

NEW !

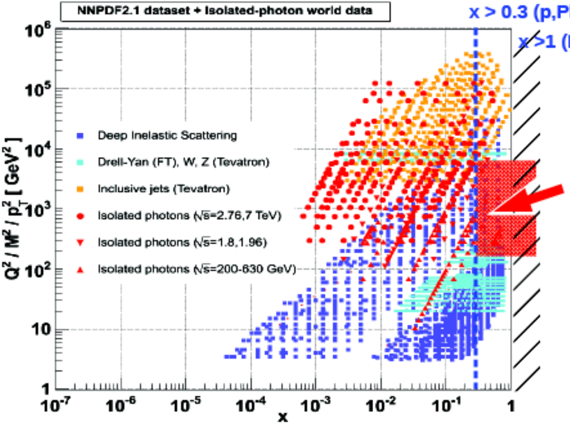
p–p

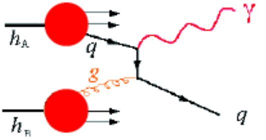
(x,Q^2) map of AFTER isolated-γ

[D.d'E & J.Rojo, NPB 860 (2012) 311]

- p-p kinematics at fixed-target LHC:

  To access x > 0.3 one needs isolated-γ with: $p_T = x_T\sqrt{s}/2 > 10\text{-}20$ GeV/c

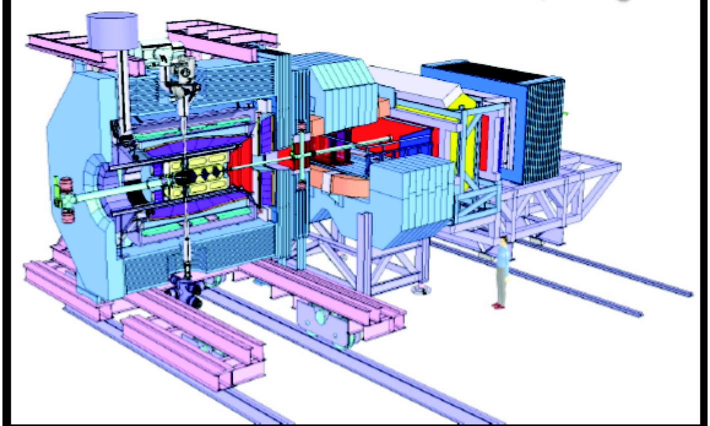




[D. D'Enterria, Physics at AFTER using LHC beams, ECT* Trento, Feb. 2013]

Detector : could be inspired by PANDA

Barrel + forward detector, 2 magnets



EmCal could be based on ultragranular CALICE, developed for ILC

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} = $A\mathcal{L}\mathcal{B}\sigma_{\Upsilon}$
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
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- Probe of the (very) large *x* in the target

Need for a quarkonium observatory

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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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Department of Physics, University of Durham, Durham, England

R. G. Roberts
Rutherford Appleton Laboratory, Didcot, Oxon, England

W. J. Stirling
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(Received 27 July 1987)

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

Accessing the large *x* glue with quarkonia

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

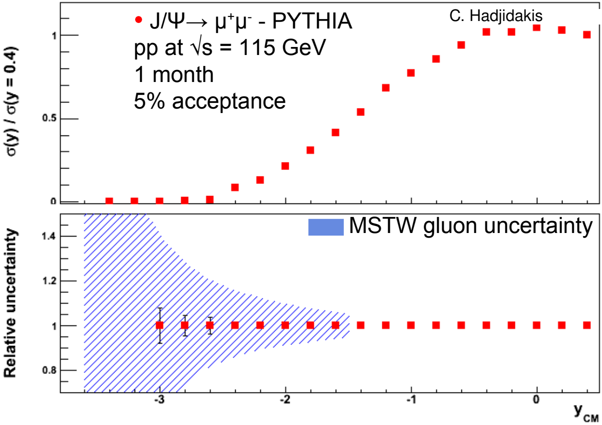
Statistical relative uncertainty
Large statistics allow to access very backward region

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

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

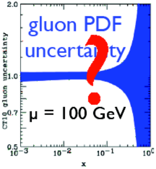
J/Ψ
$y_{CM} \sim 0 \rightarrow x_g = 0.03$
$y_{CM} \sim -3.6 \rightarrow x_g = 1$

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

Key studies: gluons in the neutron



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exp. probes :

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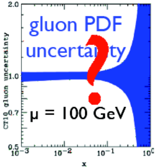

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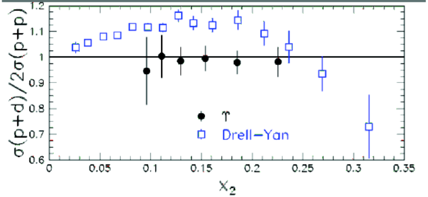
[E866, PRL 100 (2008) 062301]



Pioneering measurement by E866 @ Fermilab :

- using ϒ
- at $Q^2 \sim 100$ GeV^2 similar gluon distribution in proton and neutron

could be extended using J/ψ :

- to (∼10x) lower x
- to lower Q^2

[Lansberg et al., FBS 53 (2012) 11]

target	yearly lumi(fb^{-1})	$B_{ll} \frac{dN_{J/\psi}}{dy}\Big\vert_{y=0}$	$B_{ll} \frac{dN_{\Upsilon}}{dy}\Big\vert_{y=0}$
1 m Liq. H_2	20	4.0 10^8	8.0 10^5
1 m Lid. D_2	24	9.6 10^8	1.9 10^6

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

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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The same picture also holds for open heavy flavour

What for ?

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- the Cold Nuclear Matter effects: non trivial and

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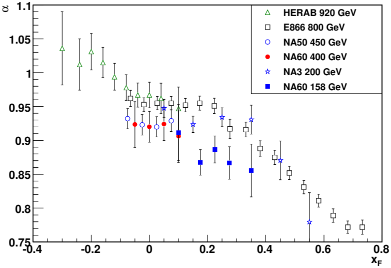
  - χ_c never studied in AA collisions
  - $\psi(2S)$ not yet studied in AA collisions at RHIC
- the possibilities for $c\bar{c}$ recombination
  - Open charm studies are difficult where recombination matters most
    i.e. at low P_T
  - Only indirect indications –from the y and P_T dependence of R_{AA}–
    that recombination may be at work
  - CNM effects may show a non-trivial y and P_T dependence . . .

SPS and Hera-B

– J/ψ data in pA collisions



NA60 Phys.Lett. B 706 (2012) 263
NA 50 Eur.Phys.J. C48 (2006) 329
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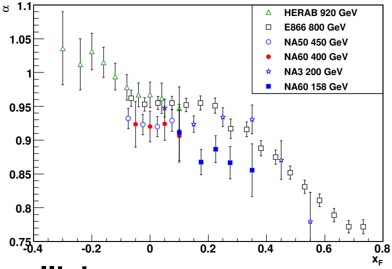

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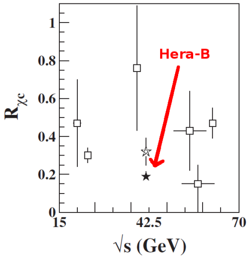
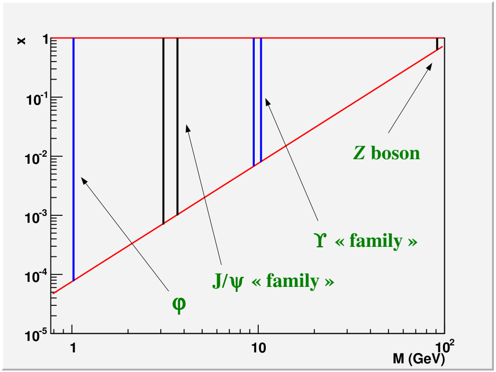


HERA-B PRD 79 (2009) 012001, and ref. therein

A Fixed Target ExpeRiment

A dilepton observatory

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



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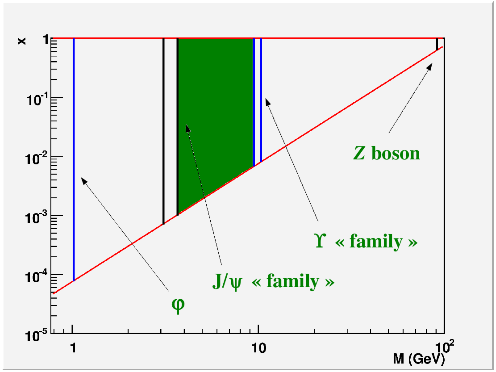

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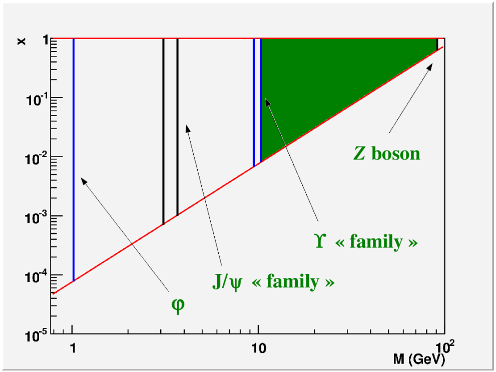

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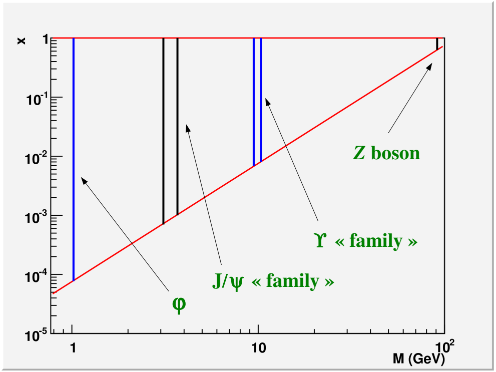

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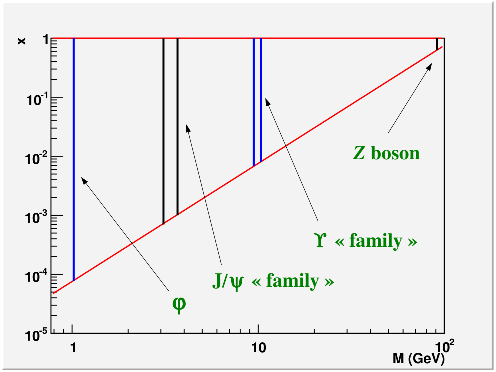

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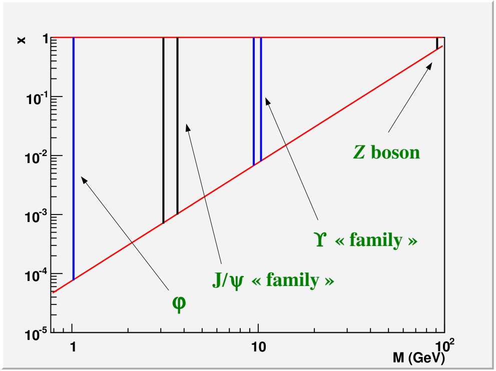

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➡ To do: to look at the rates to see how competitive this will be

A Fixed Target ExpeRiment

SSA in Drell-Yan studies

➟ Relevant parameters for the future planned polarized DY experiments.

Experiment	particles	energy (GeV)	$\sqrt{s}$ (GeV)	$x_p^\uparrow$	$\mathscr{L}$ ($\mathrm{nb}^{-1}\mathrm{s}^{-1}$)
AFTER	$p+p^\uparrow$	7000	115	$0.01 \div 0.9$	1
COMPASS	$\pi^\pm + p^\uparrow$	160	17.4	$0.2 \div 0.3$	2
COMPASS (low mass)	$\pi^\pm + p^\uparrow$	160	17.4	~ 0.05	2
RHIC	$p^\uparrow + p$	collider	500	$0.05 \div 0.1$	0.2
J–PARC	$p^\uparrow + p$	50	10	$0.5 \div 0.9$	1000
PANDA (low mass)	$\bar{p} + p^\uparrow$	15	5.5	$0.2 \div 0.4$	0.2
PAX	$p^\uparrow + \bar{p}$	collider	14	$0.1 \div 0.9$	0.002
NICA	$p^\uparrow + p$	collider	20	$0.1 \div 0.8$	0.001
RHIC Int.Target 1	$p^\uparrow + p$	250	22	$0.2 \div 0.5$	2
RHIC Int.Target 2	$p^\uparrow + p$	250	22	$0.2 \div 0.5$	60

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

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

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 $B^0 \to J/\psi + K^0_s$, $B^0 \to \pi^+ \pi^-$. The possibility of obtaining an extracted LHC beam hinges on channeling in a bent silicon crystal. Recent results on beam extraction efficiencies measured at CERN SPS based on this technique are presented.

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1. Introduction

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This paper presents a fixed target experiment to measure CP violation in the B system based on the possibility of extracting the 8 TeV LHC proton beam using a bent silicon crystal [4]. A 10% extraction efficiency of the LHC beam halo will give an extracted beam intensity of about 10^8 protons/s allowing the production of as many as 10^{10} $B\overline{B}$ pairs per year, i.e. about two orders of magnitude more than what could be produced by an e^+e^- asymmetric B factory with 10^{34} $cm^{-2}s^{-1}$ luminosity [5].

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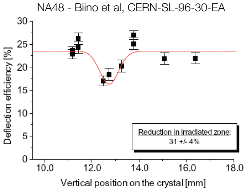
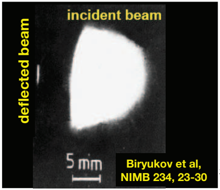
- Nowadays, degradation is known to be $\simeq$ 6% per 10^{20} particles/cm^2
- 10^{20} particles/cm^2 : one year of operation for realistic conditions
- After a year, one simply moves the crystal by less than one mm ...

Simone Montesano - February 11th, 2013 - Physics at AFTER using the LHC beams

Crystal resistance to irradiation

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





30

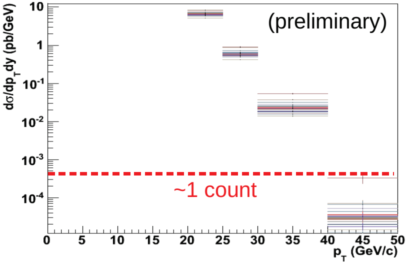
S. Montesano (CERN - EN/STI) @ ECT* Trento workshop, Physics at AFTER using the LHC beams (Feb. 2013)

Isolated-γ in p(7 TeV)-p(rest): √s ~ 115 GeV

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

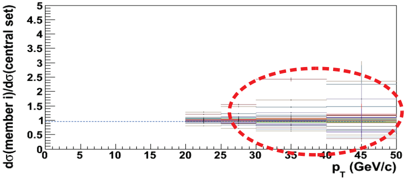
  p-p at √s=115 GeV
  |y|<0.5, p_T>20 GeV/c
  Isolation: R=0.4, E_T^{had}<5 GeV

  $\mathcal{L}$(10 cm H_2-target) ~ 2•10^3 pb^{-1}/year



PDF: CT10 52 eigenval. (90% CL)
Scales: $\mu_i = p_T$
FF = BFG-II
x-section uncertainties(*) of ±150%

(*) (68%CL)/(90% CL) ~ 1.65



Isolated-γ in p(7 TeV)-p(rest): √s ~ 115 GeV

- p-p photon kinematics at fixed-target LHC (backwards rapidities):
  To access x > 0.3 one needs isolated-γ at: $p_T = x_T\sqrt{s}/2e^{-y} > 10$ GeV/c
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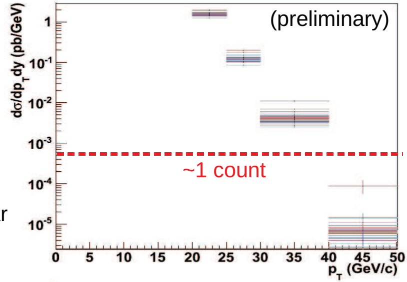

PDF: CT10 52 eigenval. (90% CL)
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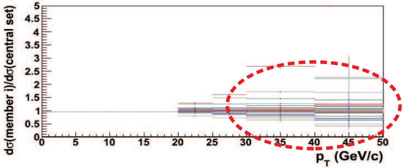

Key studies: **heavy-quarks in the proton**

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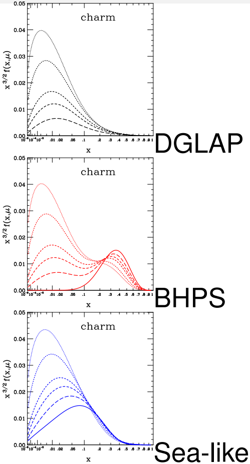

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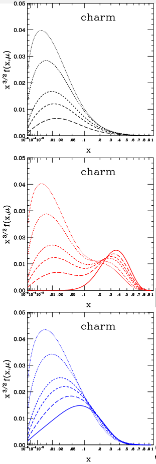

DGLAP

BHPS

Sea-like

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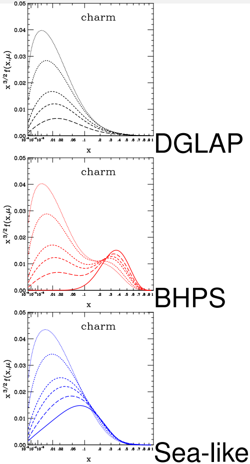

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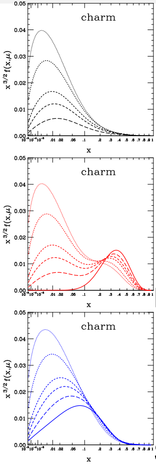
  - several complementary measurements



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BHPS

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  - Pin down intrinsic charm, ... at last
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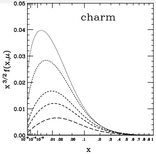

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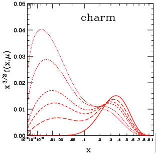

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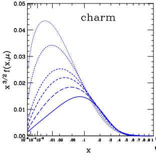

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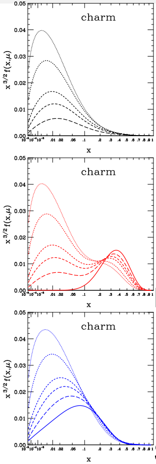

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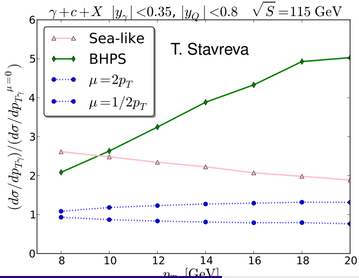

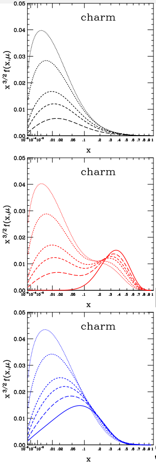

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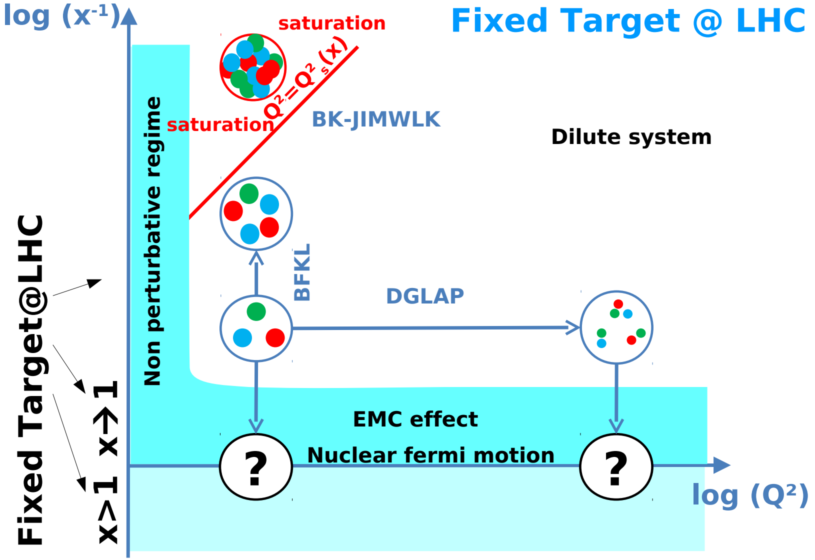
  - Reconstructed rate are most likely between a few dozen to a few thousand / year

Overall



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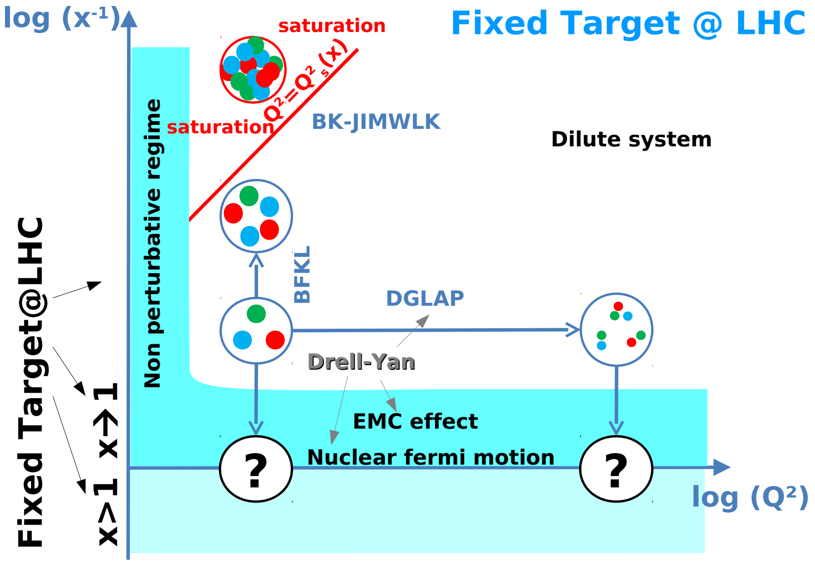
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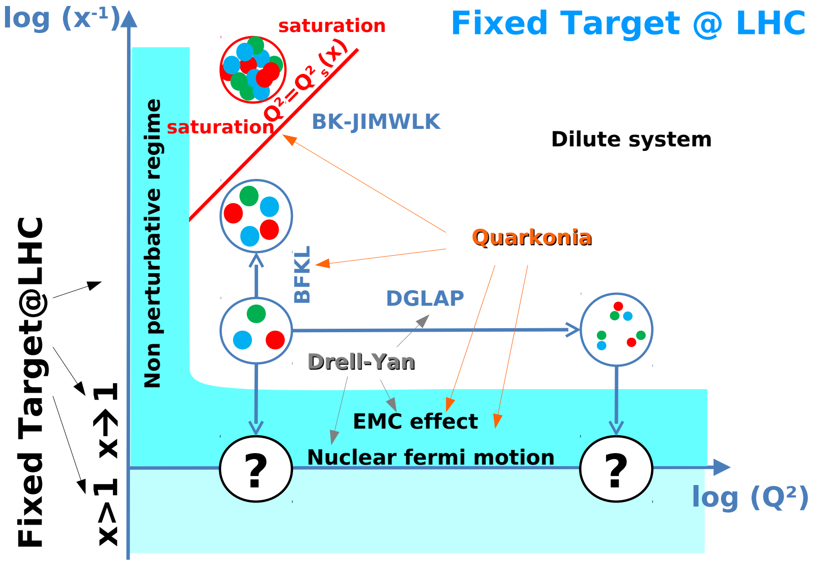

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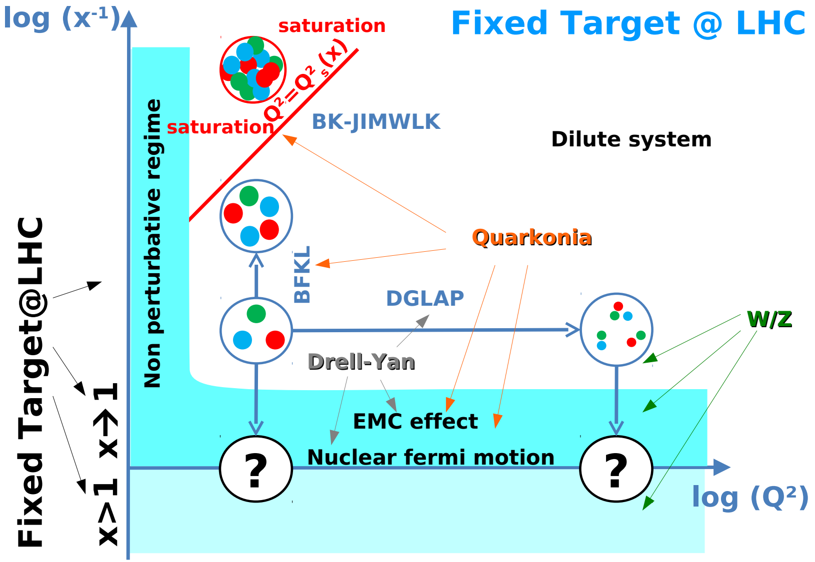
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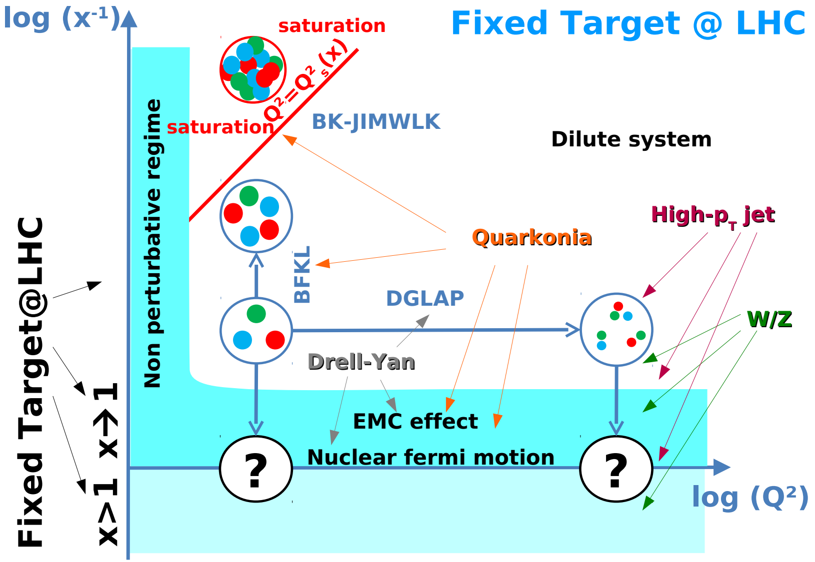
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