News from AFTER@LHC

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Outline

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Conclusions and Outlooks

Part I

Why a new fixed-target experiment for HEP now ?

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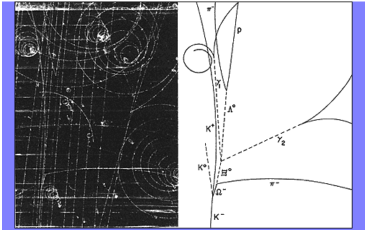

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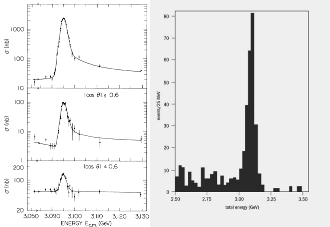

$J/\psi(c\bar{c})$ discovery @ SLAC & BNL

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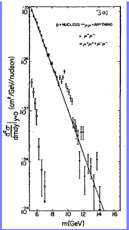

$\Upsilon(b\bar{b})$ discovery @ Fermilab

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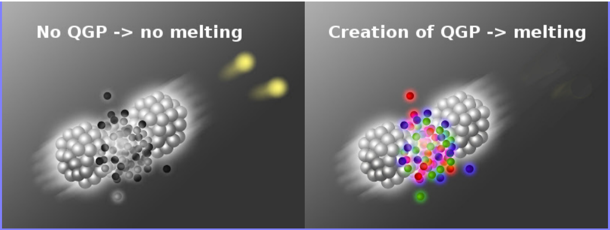

$J/\psi \to \mu\mu$ anomalous suppression @ CERN-SPS

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  - observation of surprising QCD phenomena
    - · breakdown of the Lam-Tung relation,
    - · colour transparency,
    - · higher-twist effects in forward meson production ,
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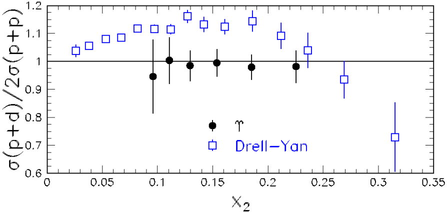
- They exhibit 4 decisive features,
  - accessing the high Feynman x_F domain ($x_F \equiv p_z/p_{z\,\mathrm{max}}$)
  - achieving high luminosities with dense targets,
  - varying the atomic mass of the target almost at will,
  - polarising the target.

E866 at Fermilab with the Tevatron beam

– **Precision** Υ **studies in *pp* and *pd* collisions** **E866 PRL 100 (2008) 062301**



Precision: necessary to show a different behaviour from DY

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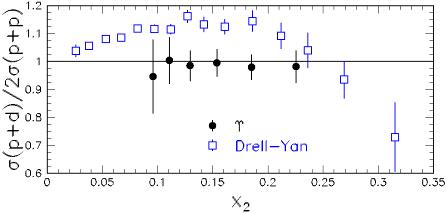

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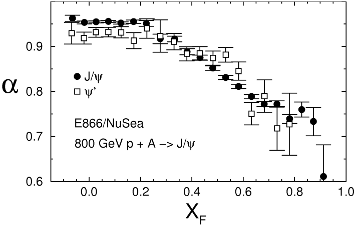

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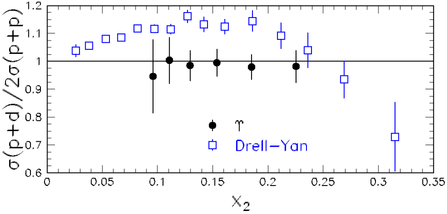

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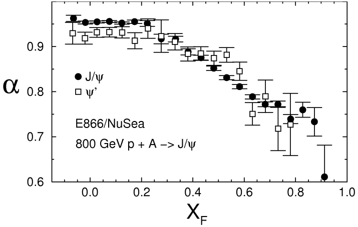

vs. 1 single preliminary $\psi(2S)$ point at RHIC in *d*Au collisions

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E866 and before

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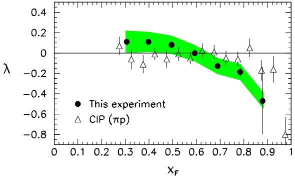
Chicago-Iowa-Princeton PRL 58, 2523 (1987); E866 PRL 91 (2003) 211801



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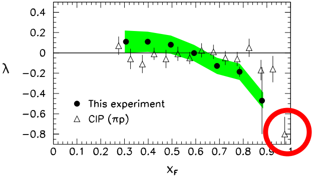

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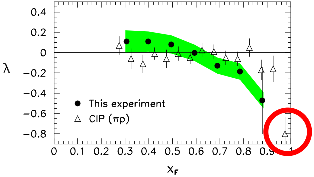

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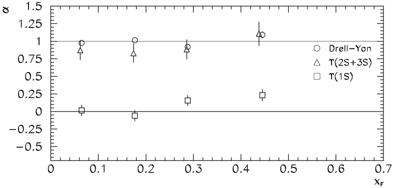

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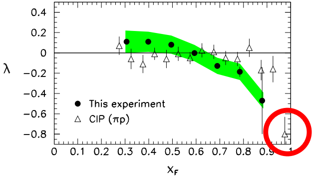

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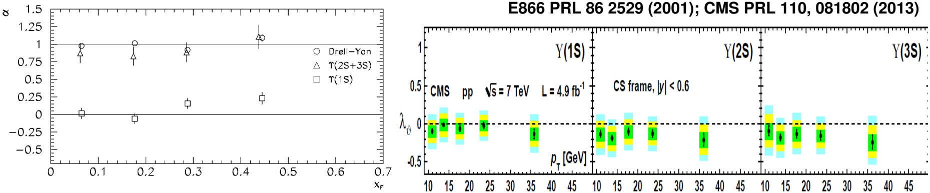

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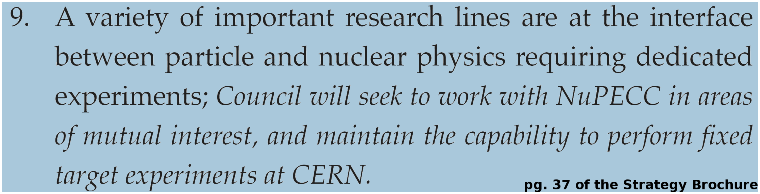

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pg. 37 of the Strategy Brochure

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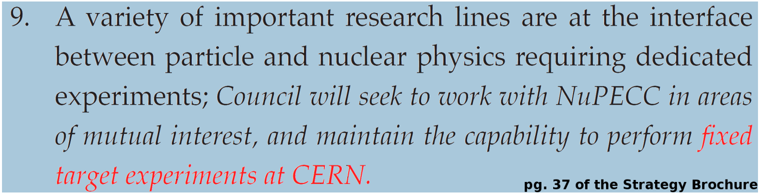

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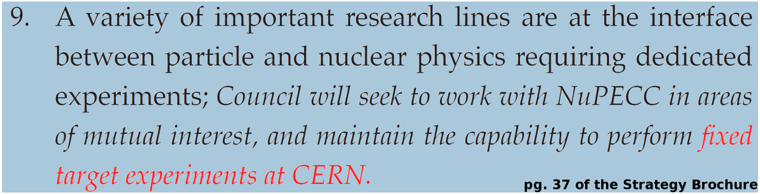

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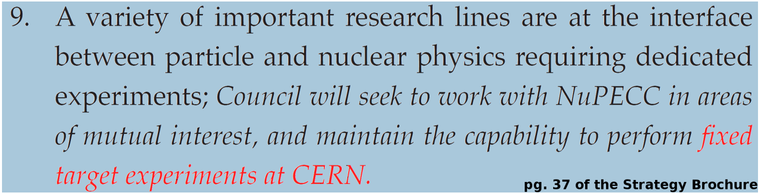

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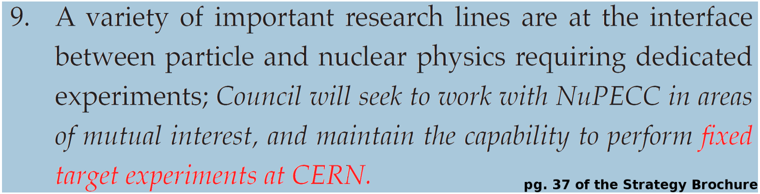

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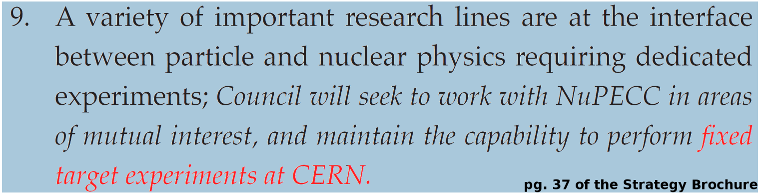

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- with modern detection techniques

Part II

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

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- The entire forward CM hemisphere ($y_{CM} > 0$) within $0^\circ \leq \theta_{Lab} \leq 1^\circ$

  [$y_{CM} = 0 \Rightarrow y_{Lab} \simeq 4.8$]
- Good thing: small forward detector $\equiv$ large acceptance
- Bad thing: high multiplicity $\Rightarrow$ absorber $\Rightarrow$ physics limitation

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- Let's adopt a novel strategy and look at larger angles
  · particles with sufficient p_T to be detected
  · heavy particles whose decay product have enough p_T to be detected
  [not very heavy in fact: $J/\psi \to \mu\mu$ or $D \to K\pi$ are fine for current detectors]

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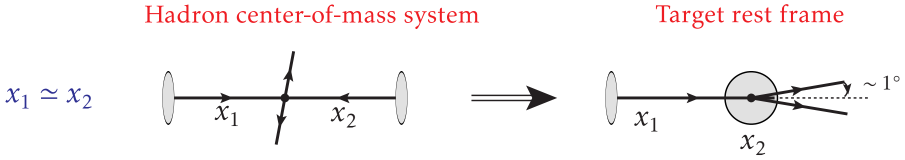

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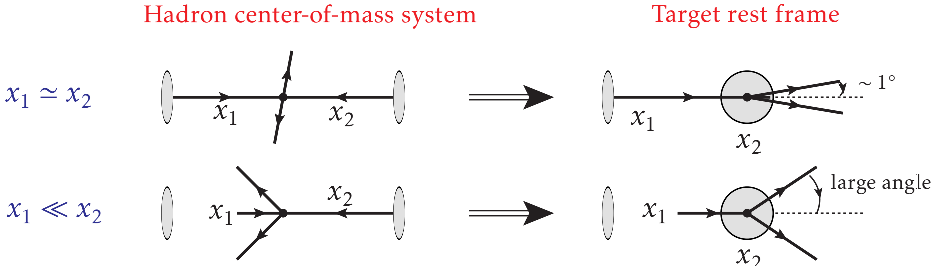

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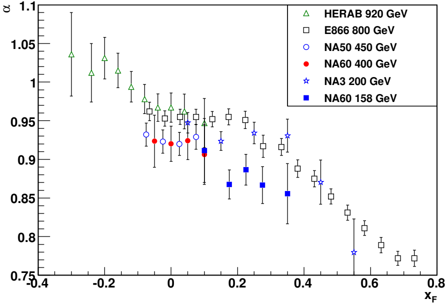

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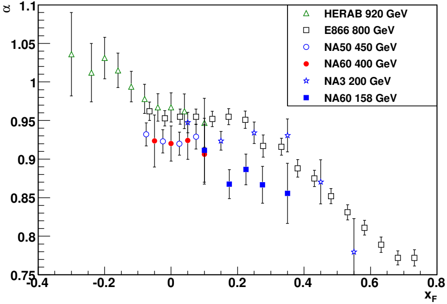

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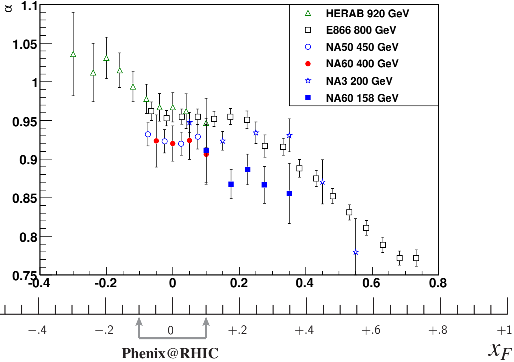

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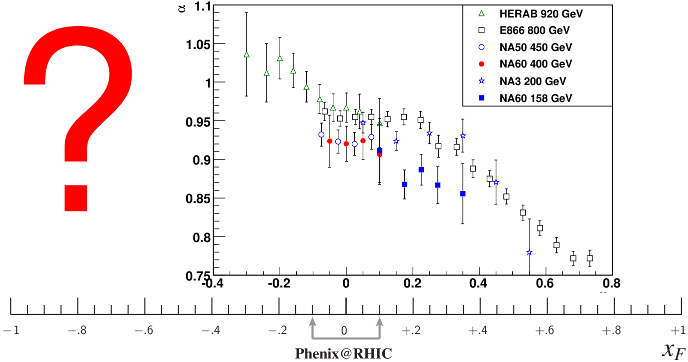

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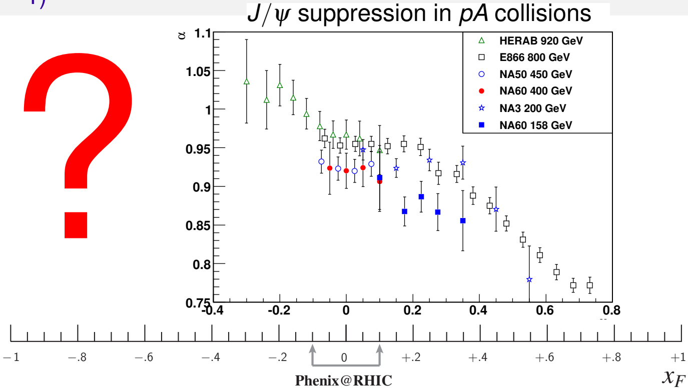

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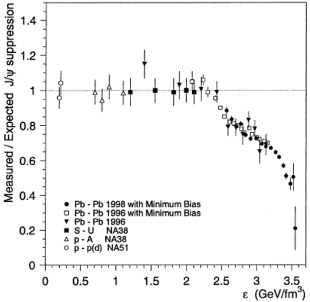

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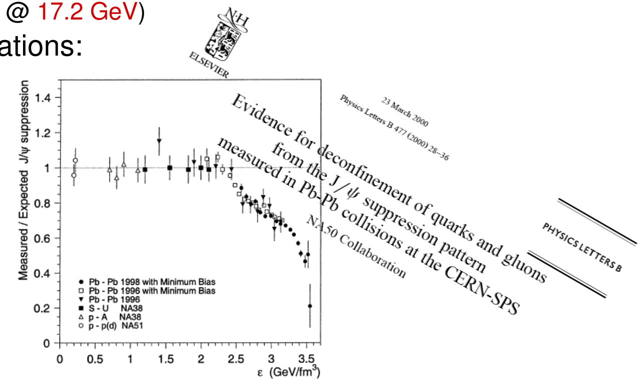

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23 March 2000

Physics Letters B 477 (2000) 28–36

PHYSICS LETTERS B

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NA50 Collaboration

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

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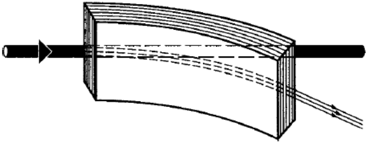

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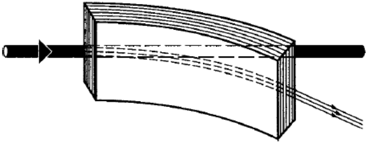

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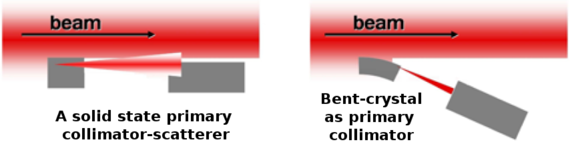

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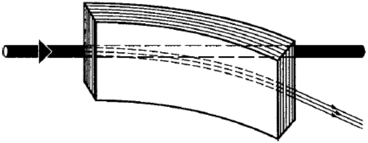

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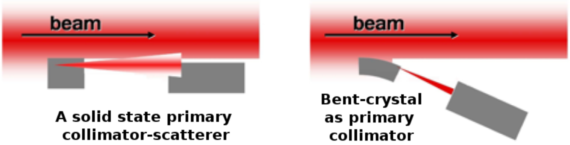

- ★ Tests will be performed on the LHC beam:

LUA9 proposal approved by the LHCC

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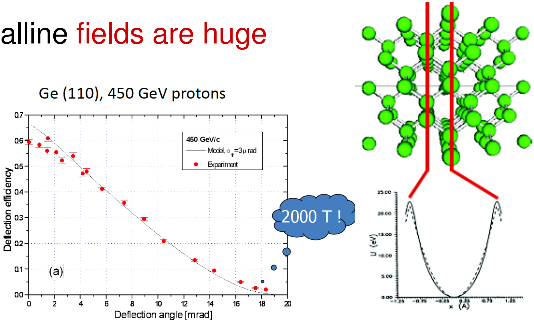
- Inter-crystalline fields are huge



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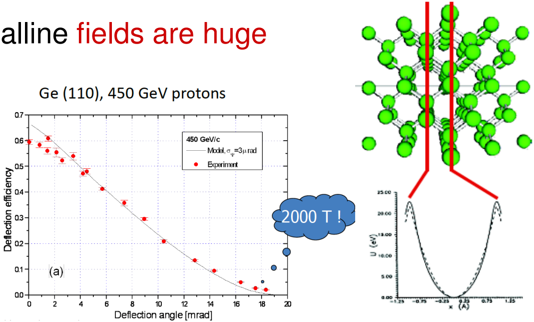

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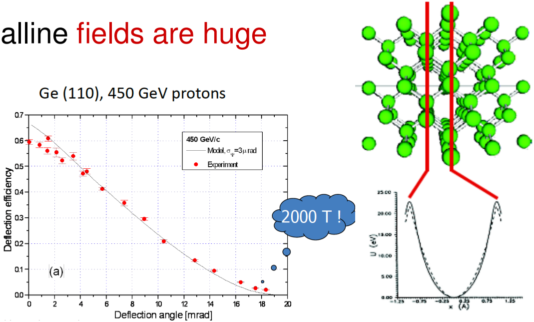

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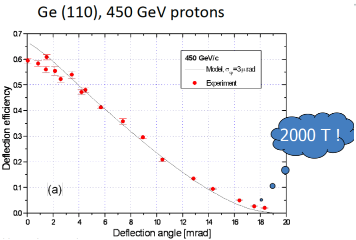

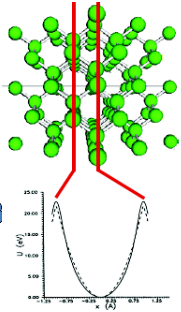

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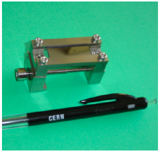
- Simple and robust way to extract the most energetic beam ever:



The beam extraction: news

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

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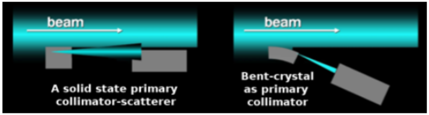
Goal : assess the possibility to use bent crystals as primary collimators in hadronic accelerators and colliders



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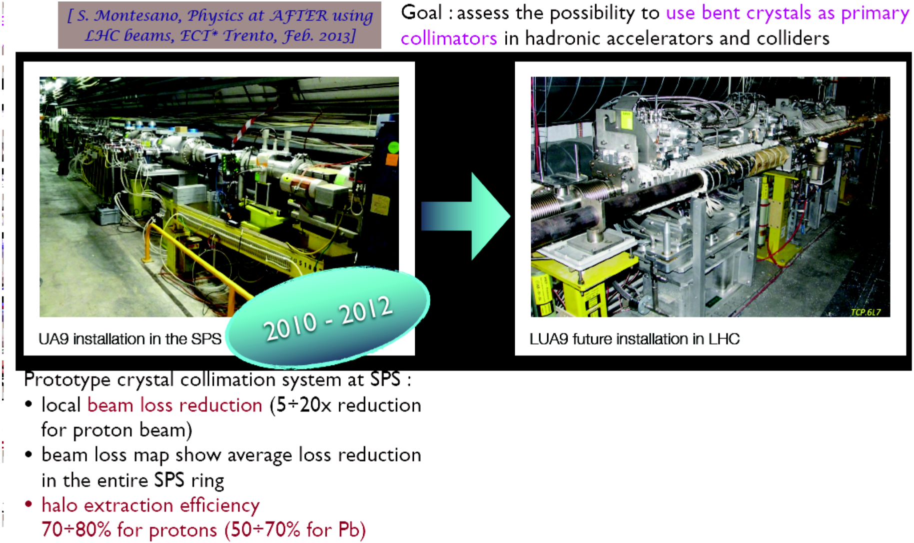

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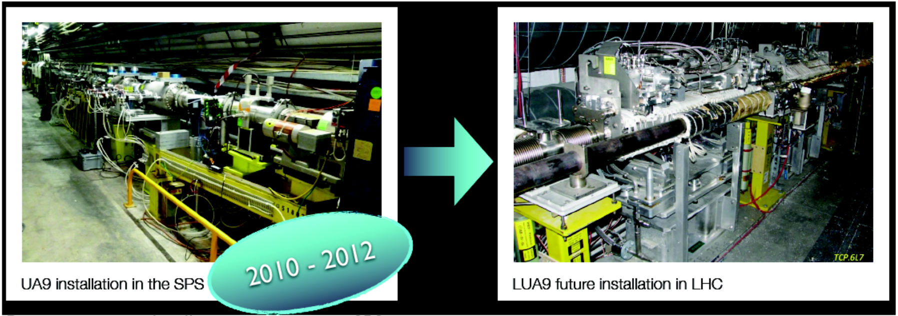

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Towards an installation in the LHC : propose and install during LS1 a min. number of devices

- 2 crystals

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

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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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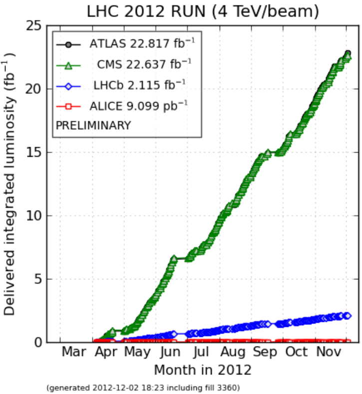

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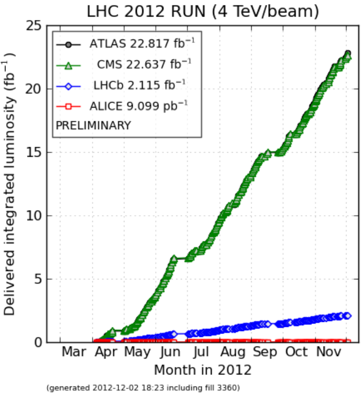

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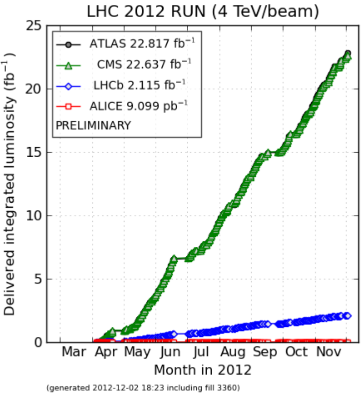

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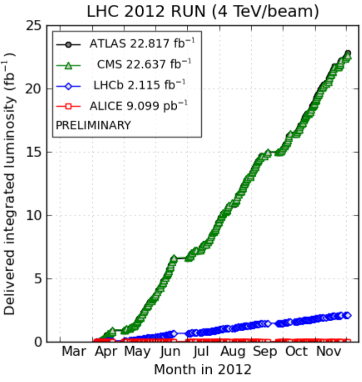

(generated 2012-12-02 18:23 including fill 3360)

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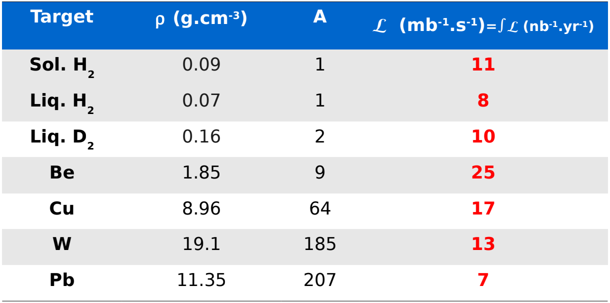
- Integrated luminosity $\int dt \mathscr{L} = \mathscr{L} \times 10^6$ s for Pb
- Expected luminosities with 2×10^5Pb s^{-1} extracted (1cm-long target)



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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}

A few figures on the (extracted) proton beam

- Beam loss: $10^9\ p^+ \mathrm{s}^{-1}$
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These protons are lost anyway !

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    These protons are lost anyway !
- similar figures for the Pb-beam extraction

Part III

AFTER: flagships measurements

Key studies: gluons in the proton

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

Key studies: gluons in the proton

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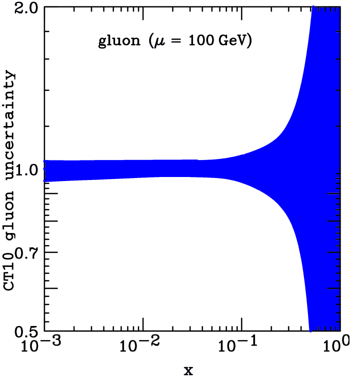

Key studies: gluons in the proton

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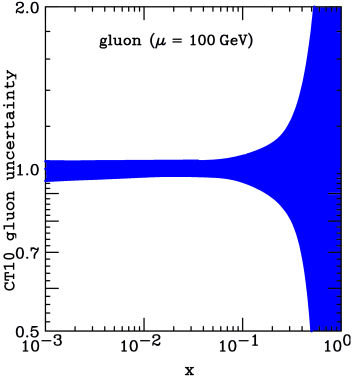

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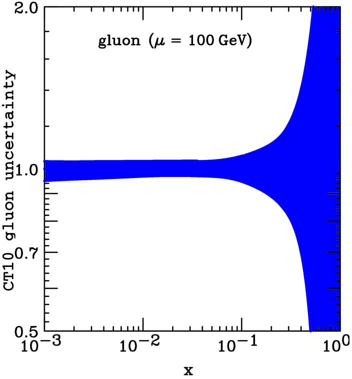

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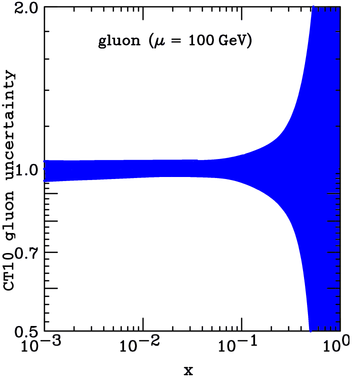

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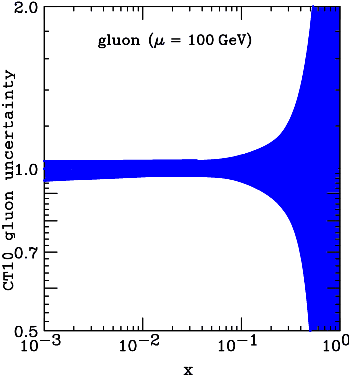

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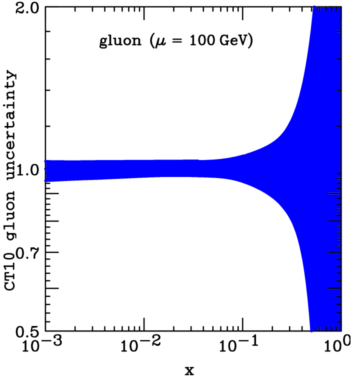


Accessible thanks gluon sensitive probes,

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

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

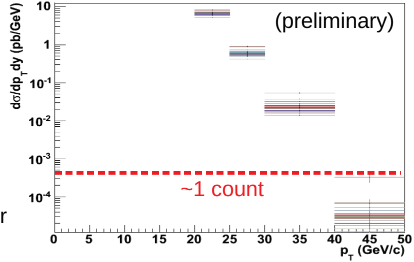
- p-p photon kinematics at fixed-target LHC (central rapidities):

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

- JETPHOX NLO
  pQCD calculations:

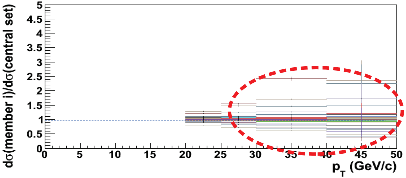
  p-p at √s=115 GeV
  |y|<0.5, p_T>20 GeV/c
  Isolation: R=0.4, E_T^{had}<5 GeV

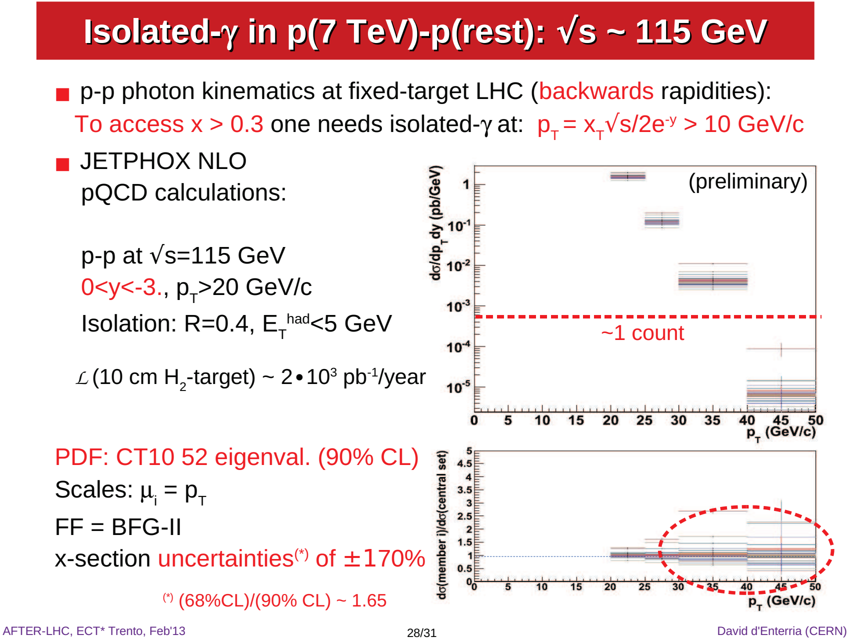
  $\mathcal{L}$(10 cm H_2-target) ~ 2•10^3 pb^{-1}/year



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
- JETPHOX NLO pQCD calculations:

  p-p at √s=115 GeV

  0<y<-3., p_T>20 GeV/c

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x-section uncertainties$^{(*)}$ of ±170%

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AFTER-LHC, ECT* Trento, Feb'13 28/31 David d'Enterria (CERN)

Accessing the large *x* glue with quarkonia

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

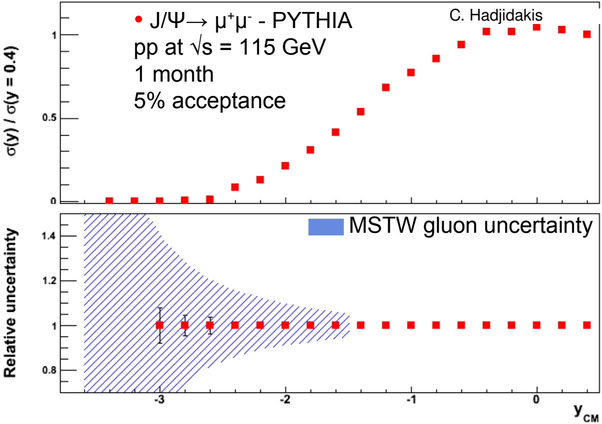
Statistical relative uncertainty
Large statistics allow to access
very backward region

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

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

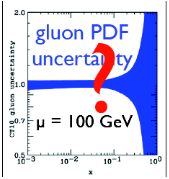
J/Ψ
$y_{CM} \sim 0 \rightarrow x_g = 0.03$
$y_{CM} \sim -3.6 \rightarrow x_g = 1$

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



gluon PDF unknown for neutron

exp. probes :

- heavy quarkonia
- isolated photons
- high p_T jets

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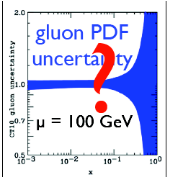

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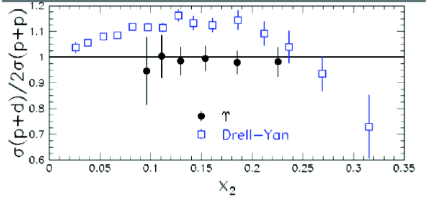
[E866, PRL 100 (2008) 062301]



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

Need high luminosity.

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

target	yearly lumi(fb^{-1})	$B_{ll}\frac{dN_{J/\psi}}{dy}\Big\|_{y=0}$	$B_{ll}\frac{dN_{\Upsilon}}{dy}\Big\|_{y=0}$
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

Key studies

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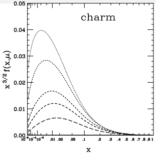
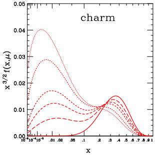


DGLAP



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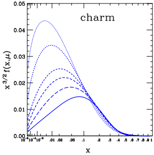

Sea-like

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

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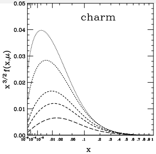

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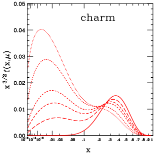

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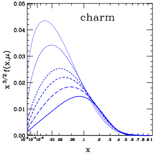

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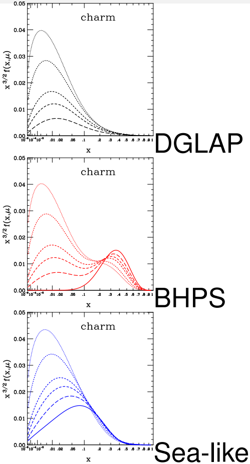

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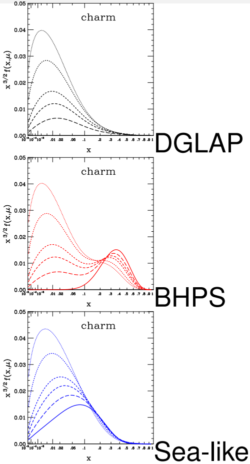

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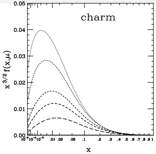

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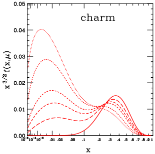

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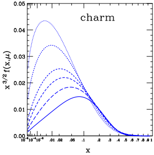

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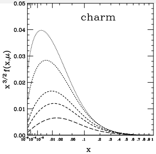

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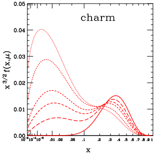

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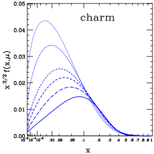

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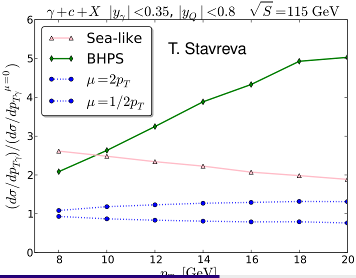

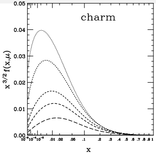

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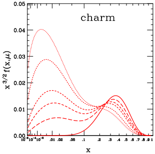

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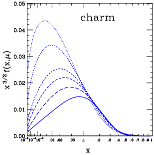

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Key studies: gluon contribution to the proton spin

- Gluon Sivers effect: correlation between
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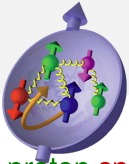

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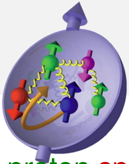

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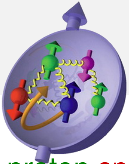

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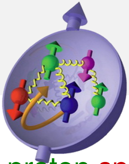

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  - γ, γ-jet, $\gamma - \gamma$

A. Bacchetta, ***et al.*****, PRL 99 (2007) 212002**
J.W. Qiu, ***et al.*****, PRL 107 (2011) 062001**

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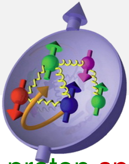

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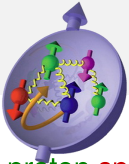

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- In general, one can carry out an extensive spin-physics program

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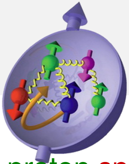

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  - *B* & *l*
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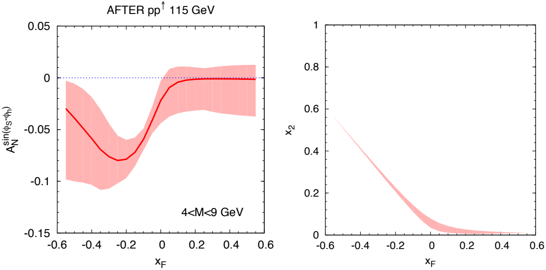
- the target ne largest
- In genera rogram

expected Sivers asymmetry in
D-Y@AFTER, sign change,
no TMD evolution



M. Anselmino, Trento, February 2013

Key studies: large-x gluon content of the nucleus

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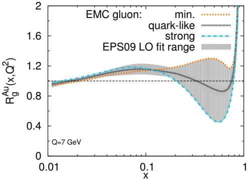

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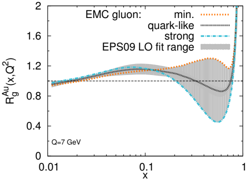

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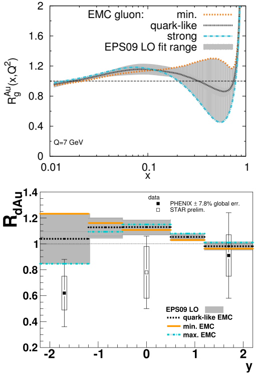

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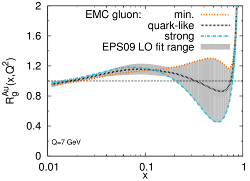

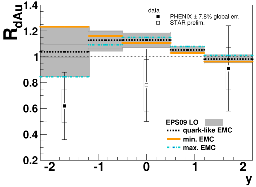

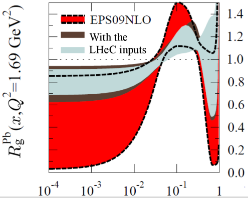

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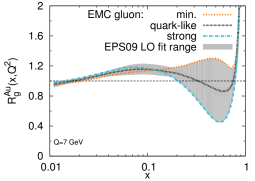
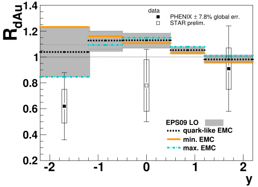
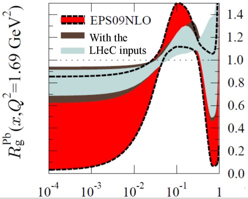
- Gluon EMC effect ?
- Hint from Υ data at RHIC
- Strongly limited in terms of statistics after 10 years of RHIC:
- DIS contribution expected for low *x* mainly projected contribution of LHeC:
- AFTER allows for extensive studies of gluon sensitive probes in *pA*
- Unique potential for gluons at $x > 0.1$







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

Further key studies ?

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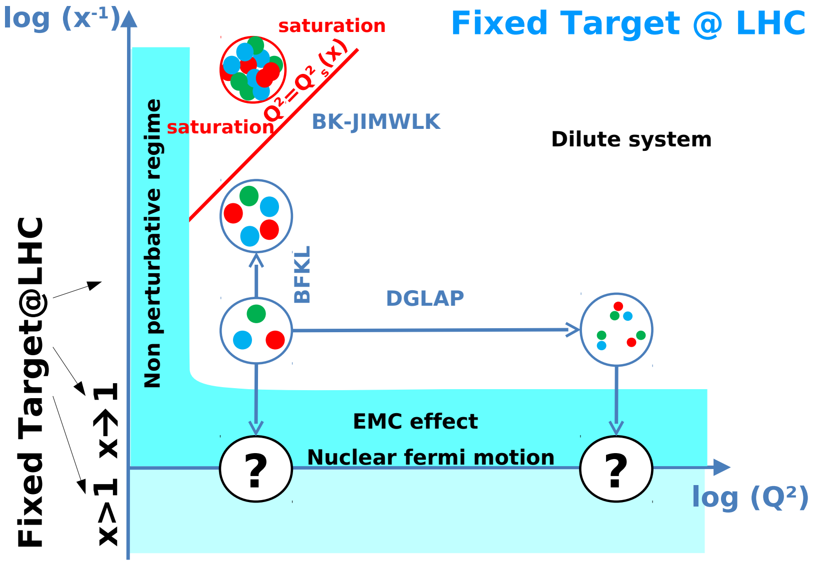
- Semi-diffractive events
- Ultra-peripheral collisions via γp interaction
  - $\gamma_{\rm lab}^{\rm beam} \simeq 7000$
  - $E_{\gamma,\rm lab}^{\rm max} \simeq \gamma_{\rm lab}^{\rm beam} \times 30$ MeV
  - $\sqrt{s_{\gamma p}} = \sqrt{2 m_p E_\gamma}$ up to 20 GeV

Overall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Fixed Target @ LHC
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saturation
BK-JIMWLK
Dilute system
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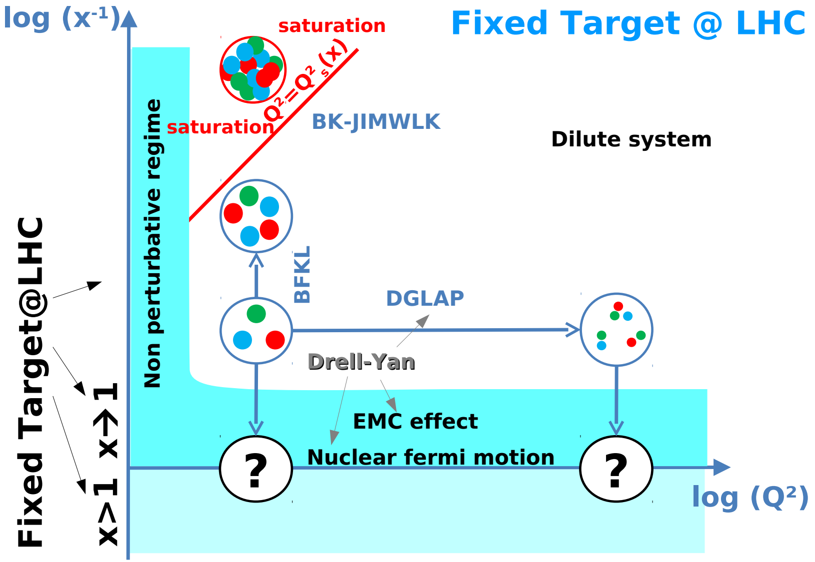
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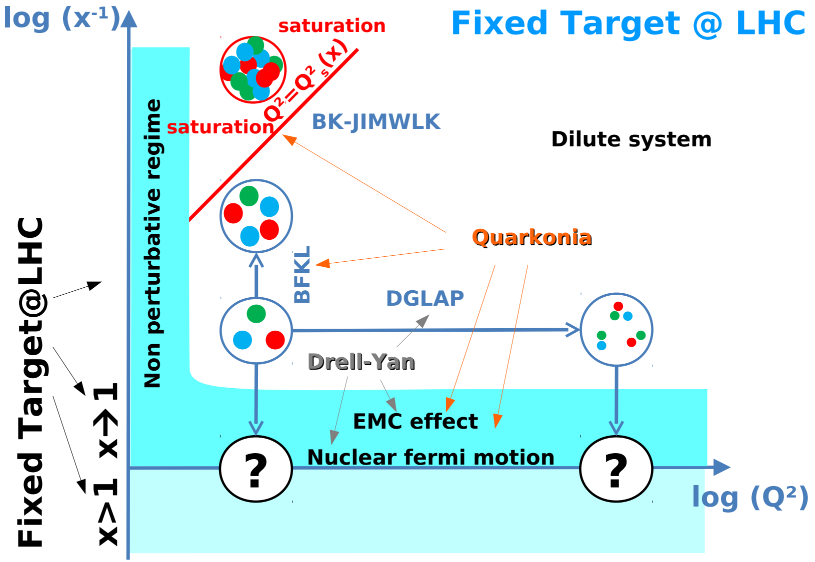

Fixed Target @ LHC

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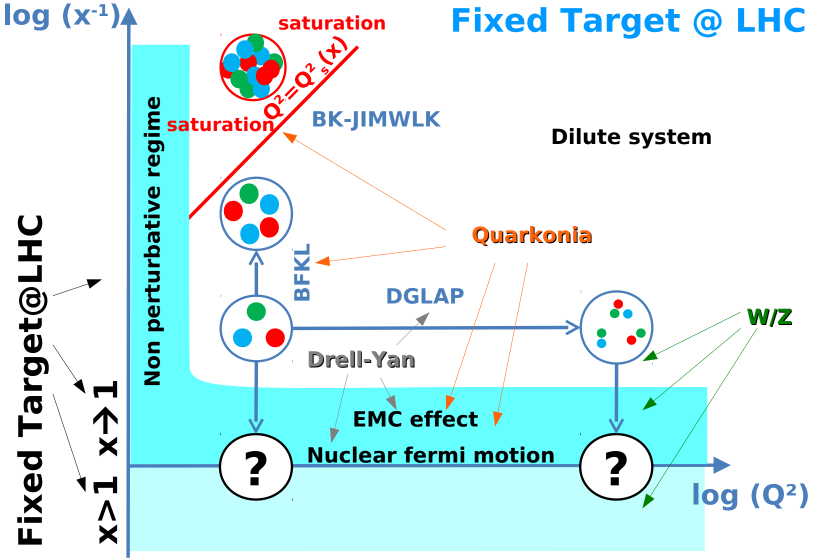
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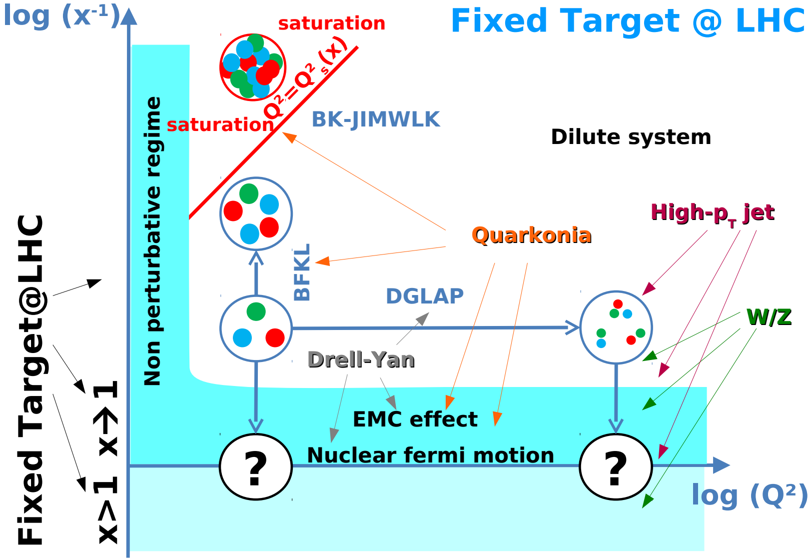
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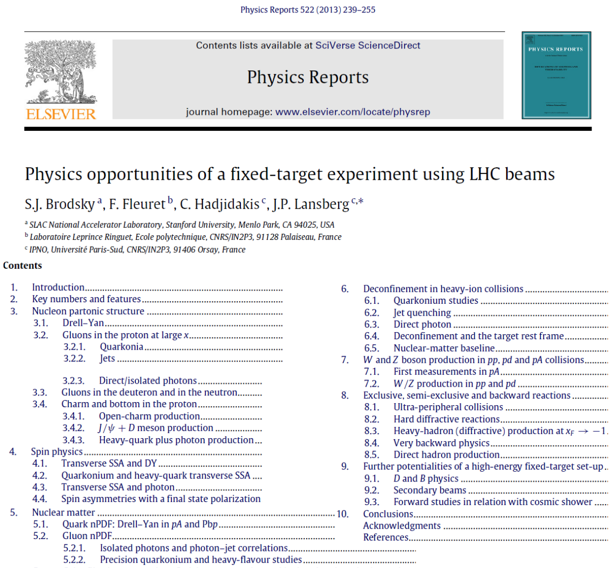

Physics Reports 522 (2013) 239–255

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journal homepage: www.elsevier.com/locate/physrep

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

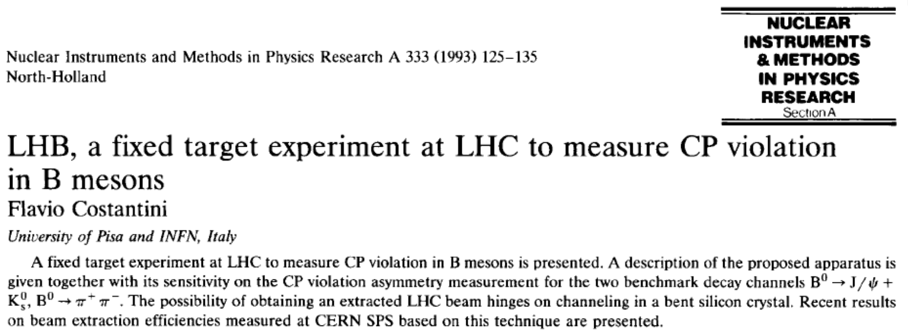
Contents

Part IV

Back to the future ...

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 $B^0 \rightarrow J/\psi + K_s^0$, $B^0 \rightarrow \pi^+\pi^-$. 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.

LHB

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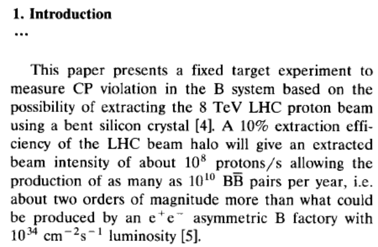

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LARGE HADRON BEAUTY FACTORY

LETTER OF INTENT

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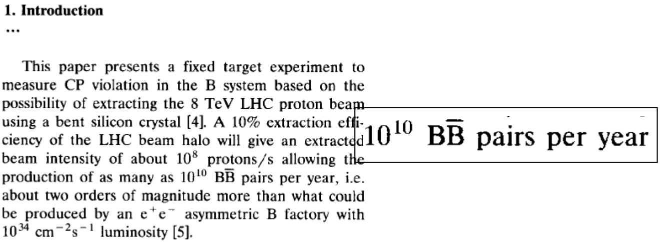

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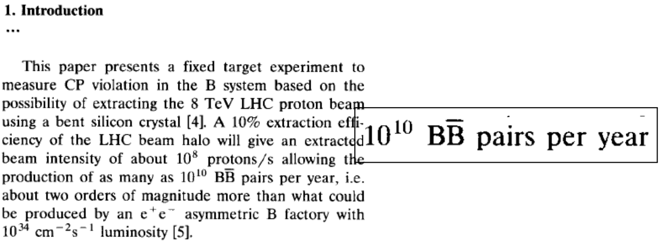

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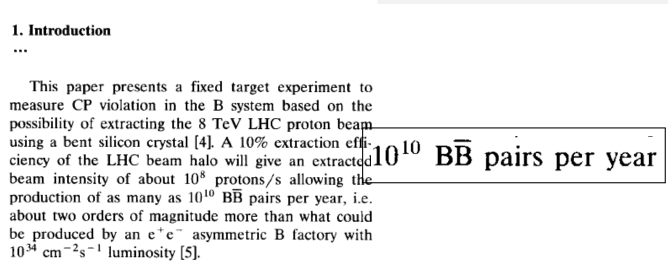

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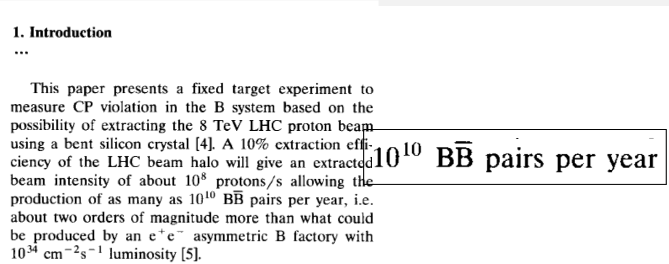

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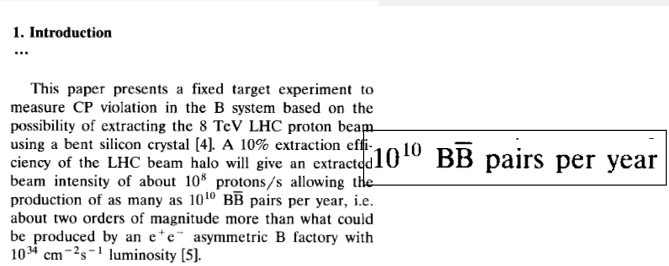

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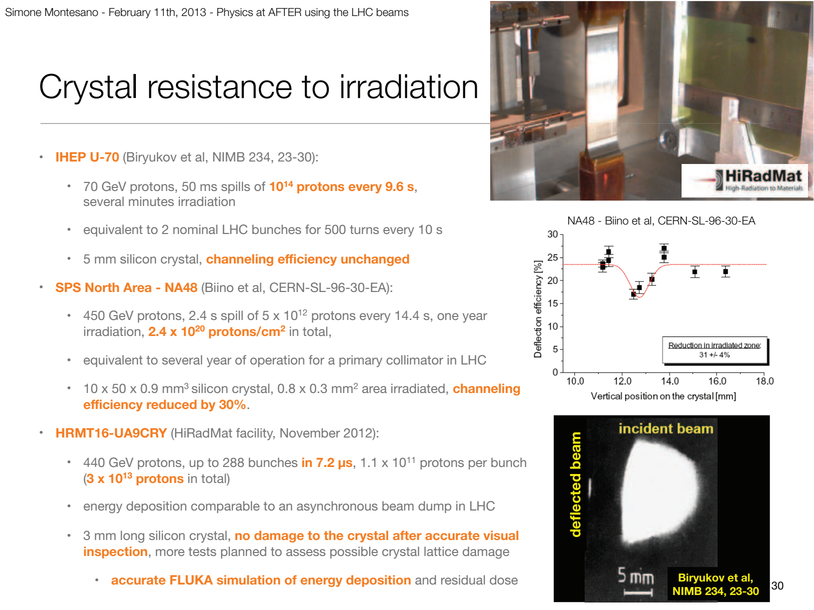

Simone Montesano - February 11th, 2013 - Physics at AFTER using the LHC beams

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

Biryukov et al, NIMB 234, 23-30

30

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

Part V

Conclusion and outlooks

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Outlooks

- First physics paper Physics Reports 522 (2013) 239
- A 10-day exploratory workshop at ECT* Trento, February 4-13, 2013 slides at `http://indico.in2p3.fr/event/AFTER@ECTstar`
- NEW: Workshop in Les Houches on 12-17 January 2014 and we plan for a 3 day workshop at CERN in the 2nd part of October within the GDR PH-QCD
- We are looking for more partners to
  - do first simulations (we are getting ready for fast simulations)
  - think about possible designs
  - think about the optimal detector technologies
  - enlarge the physics case (cosmic rays, flavour physics, ...)
- Theorist colleagues are encouraged to think about additional ideas of physics

already 2 papers on the physics at AFTER:
T. Liu, B.Q. Ma, EPJC (2012) 72:2037
D. Boer, C. Pisano, Phys.Rev. D86 (2012) 094007

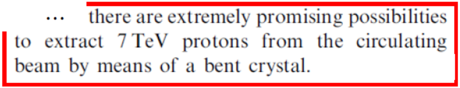
- Do not hesitate to contact us
- Webpage: **`http://after.in2p3.fr`**

Part VI

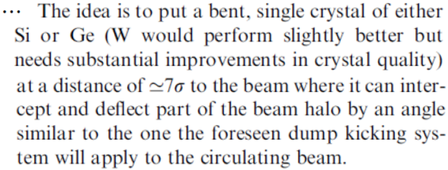
Backup slides

Beam extraction

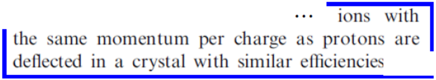
- **Beam extraction @ LHC**



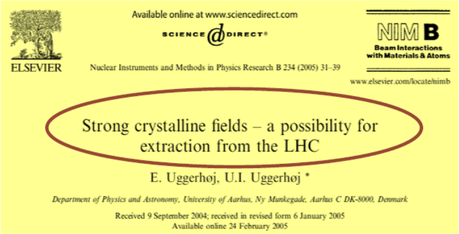
… there are extremely promising possibilities to extract 7 TeV protons from the circulating beam by means of a bent crystal.



… 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

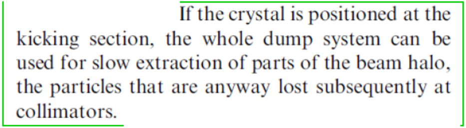
www.elsevier.com/locate/nimb

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.

NEW !

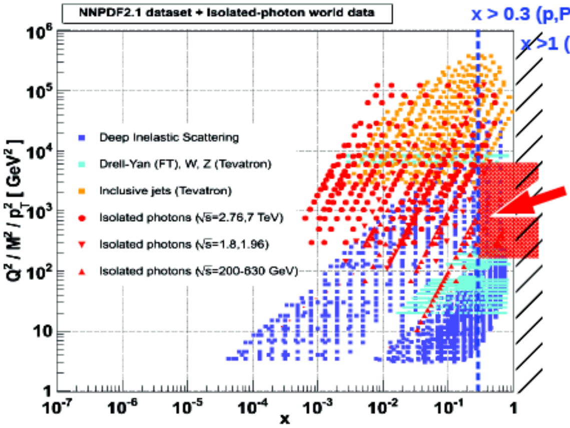
p−p

(x,Q²) map of AFTER isolated-γ

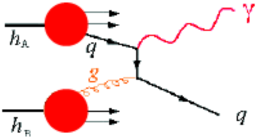
[D.d'E & J.Rojo, NPB 860 (2012) 311]

- p-p kinematics at fixed-target LHC:

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

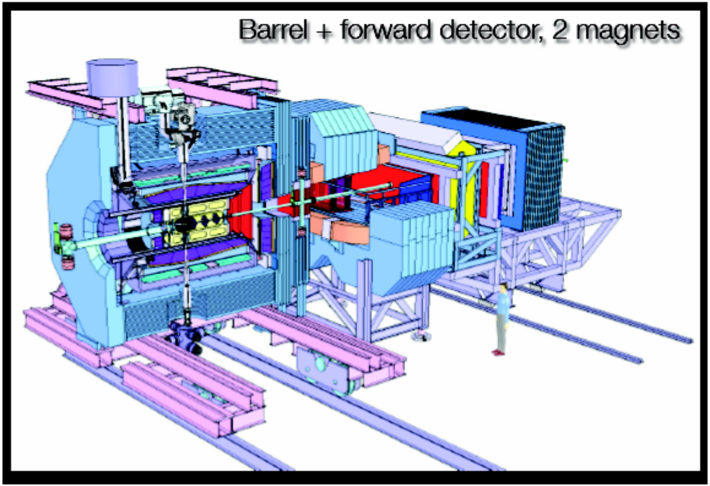


AFTER region: pp → γ X



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

Detector : could be inspired by PANDA

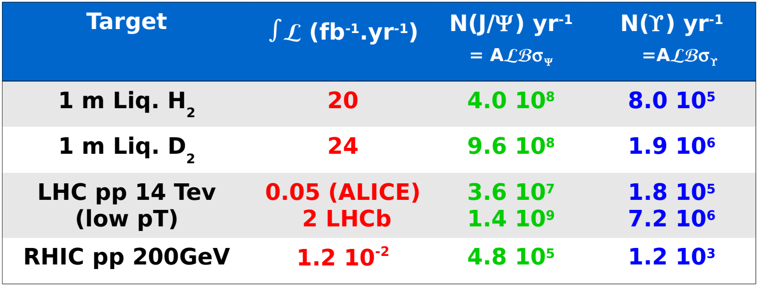


Barrel + forward detector, 2 magnets

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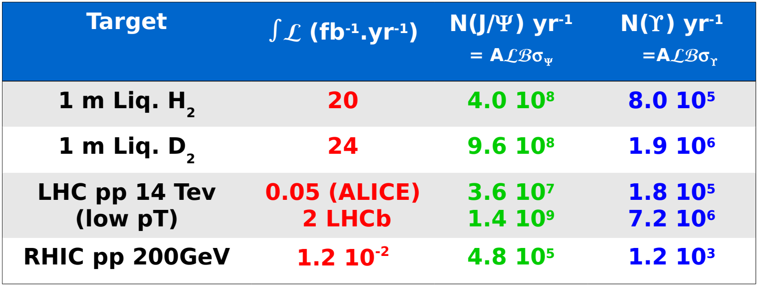

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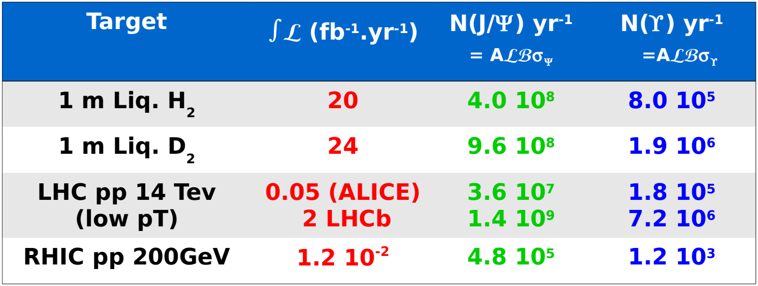

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- Probe of the (very) large *x* in the target

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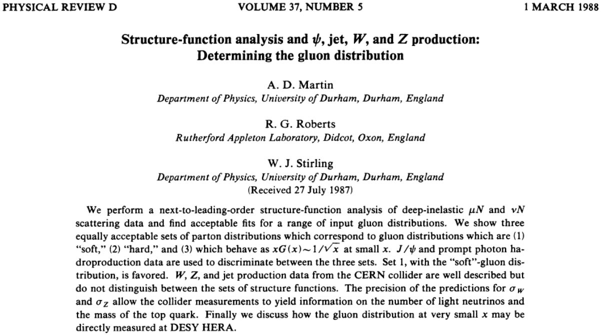

PHYSICAL REVIEW D VOLUME 37, NUMBER 5 1 MARCH 1988

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

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R. G. Roberts
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W. J. Stirling
Department of Physics, University of Durham, Durham, England

(Received 27 July 1987)

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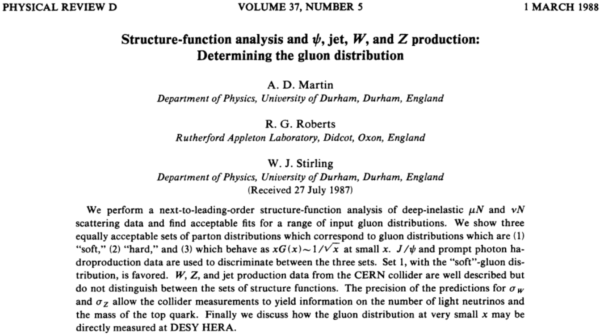

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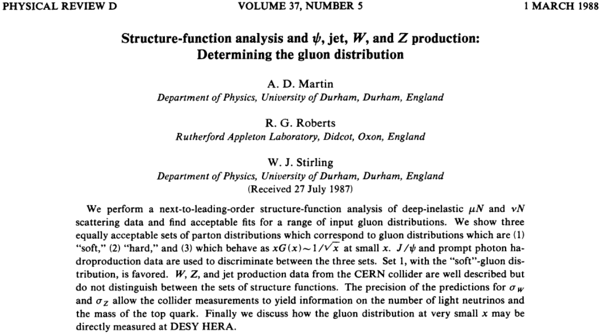

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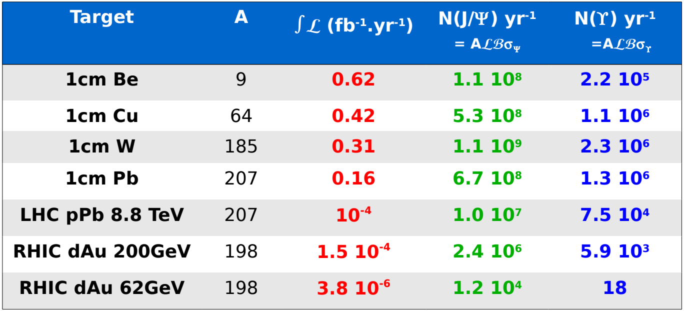
- Production puzzle → quarkonium not used anymore in global fits
- With systematic studies, one would restore its status as gluon probe

AFTER: also a quarkonium observatory in *pA*



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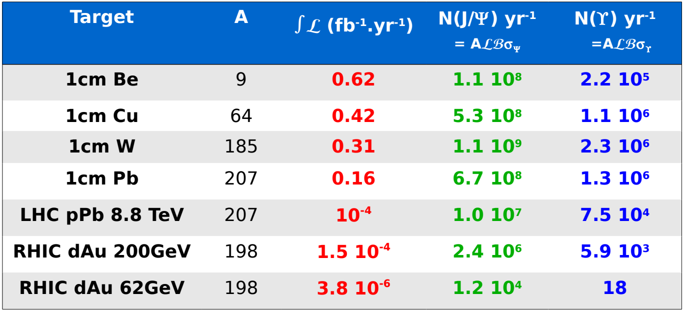

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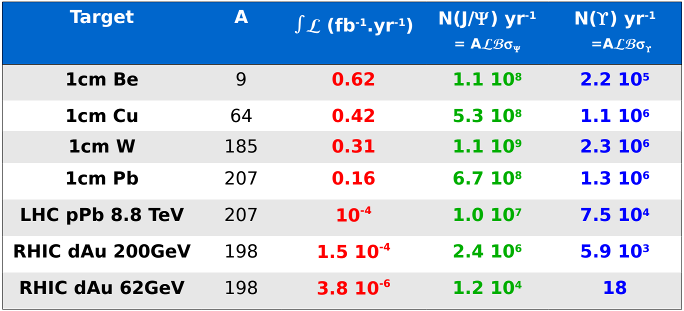

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  - not to mention ratio with **open charm, Drell-Yan,** etc ...

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    - What is the amount of Intrinsic charm ? Is it color filtered ?
    - Is there an EMC effect for gluon ? (reminder: EMC region $0.3 < x < 0.7$)

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  - a precise analysis of gluon nuclear PDF: $y, p_T \leftrightarrow x_2$
  - a handle on formation time effects
- Strong need for cross checks from various measurements
- The backward kinematics is very useful for large-x_{target} studies
  - What is the amount of Intrinsic charm ? Is it color filtered ?
  - Is there an EMC effect for gluon ? (reminder: EMC region $0.3 < x < 0.7$)
- One should be careful with factorization breaking effects:

This calls for multiple measurements to (in)validate factorization

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- 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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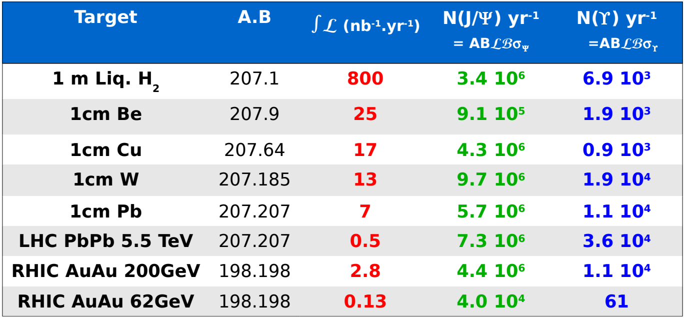

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The same picture also holds for open heavy flavour

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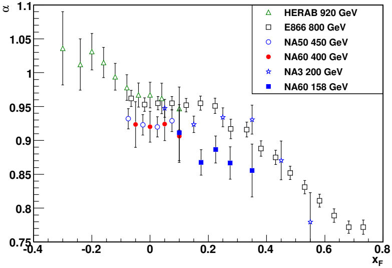
- the possibilities for $c\bar{c}$ recombination
  - Open charm studies are difficult where recombination matters most i.e. at low P_T
  - Only indirect indications –from the y and P_T dependence of R_{AA}– that recombination may be at work
  - CNM effects may show a non-trivial y and P_T dependence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

SPS and Hera-B

– J/ψ data in pA collisions



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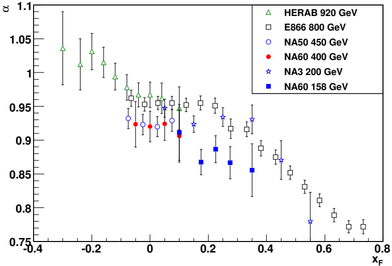

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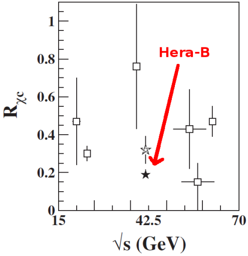

HERA-B PRD 79 (2009) 012001, and ref. therein