(First suggestions for a)
Physics case for a fixed-target experiment with the proton and lead LHC beams

Jean-Philippe Lansberg
IPNO, Paris-Sud XI U.

One-day Meeting: fixed-target projects at CERN
July 7, 2011
IPN Orsay, France

with F. Fleuret (LLR), S.J. Brodsky (SLAC), . . .

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- Very forward (backward) physics: diffraction, ...

Part I

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

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Target	ρ (g.cm^{-3})	A	$\mathcal{L}$ (μb^{-1}.s^{-1})	$\mathcal{L}$ (pb^{-1}.y^{-1})
Liq. H_2	0.07	1	21	210
Liq. D_2	0.16	2	24	240
Be	1.85	9	60	600
Cu	8.96	64	40	400
W	19.1	185	30	300
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- Using **NA51**-like 1.2m-long liquid H_2 & D_2 targets, $\mathcal{L}_{H_2/D_2} \simeq 20$ fb$^{-1}y^{-1}$
- For comparison, PHENIX recorded lumi for Run9 pp at 200 GeV: 16 pb^{-1} & Run8 *d*Au at 200 GeV : 0.08 pb^{-1}

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P. Ballin *et al.*, **NIMB 267 (2009) 2952**

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- For comparison, Phenix recorded lumi for Run10
  AuAu at 200 GeV: 1.3 nb^{-1} & AuAu at 62 GeV: 0.11 nb^{-1}

Part II

AFTER as a quarkonium observatory in *pp*

(constraining the glue at large x in the proton)

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PHYSICAL REVIEW D VOLUME 37, NUMBER 5 1 MARCH 1988

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

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W. J. Stirling
Department of Physics, University of Durham, Durham, England
(Received 27 July 1987)

We perform a next-to-leading-order structure-function analysis of deep-inelastic μN and νN scattering data and find acceptable fits for a range of input gluon distributions. We show three equally acceptable sets of parton distributions which correspond to gluon distributions which are (1) "soft," (2) "hard," and (3) which behave as $xG(x) \sim 1/\sqrt{x}$ at small x. J/ψ and prompt photon hadroproduction data are used to discriminate between the three sets. Set 1, with the "soft"-gluon distribution, is favored. W, Z, and jet production data from the CERN collider are well described but do not distinguish between the sets of structure functions. The precision of the predictions for σ_W and σ_Z allow the collider measurements to yield information on the number of light neutrinos and the mass of the top quark. Finally we discuss how the gluon distribution at very small x may be directly measured at DESY HERA.

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

J/ψ Production at large transverse momentum at hadron colliders

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Received 7 October 1987

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

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PHYSICAL REVIEW D VOLUME 48, NUMBER 11 1 DECEMBER 1993

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

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

(E537 Collaboration)

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[2] *Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
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[5] *Shandong University, Jinan, People's Republic of China*
(Received 9 February 1993)

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

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  - Yet, very sensitive on $g(x, Q^2)$ where it is not well known

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  - a study of direct J/ψ yield (χ_c only measured in *pp* by CDF and PHENIX)
  - a study of direct $\Upsilon(nS)$ (χ_b only measured in *pp* by CDF (1 point))
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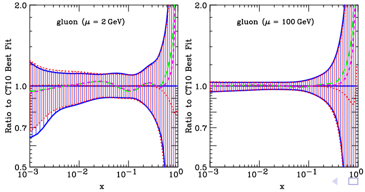

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- Use of *pp* vs *pd* $\rightarrow$ access to the
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cf. E866, Phys. Rev. Lett. 100 062301 (2008)

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Glue in the neutron and in the deuteron

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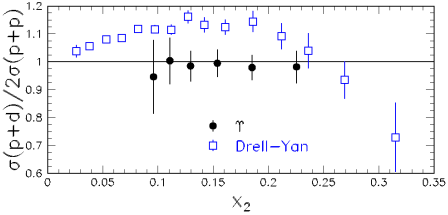

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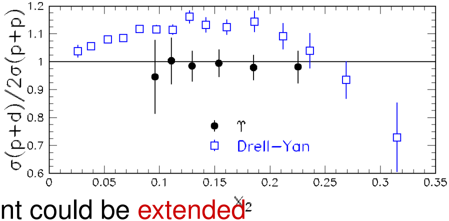

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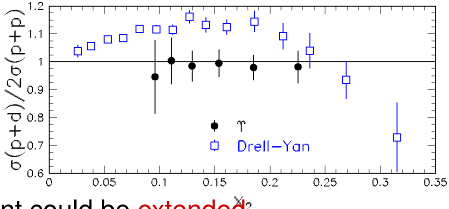

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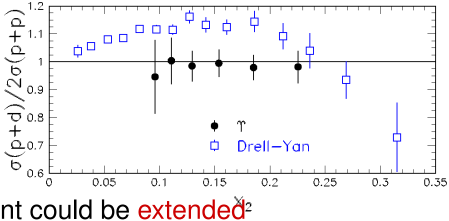

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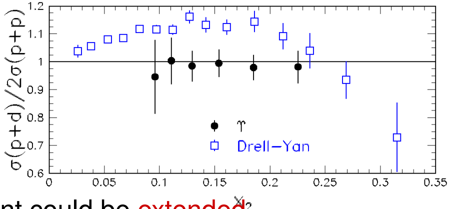

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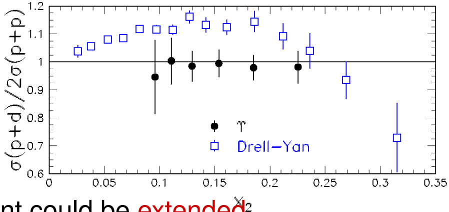

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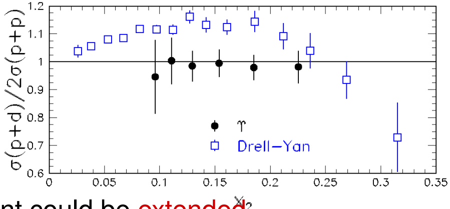

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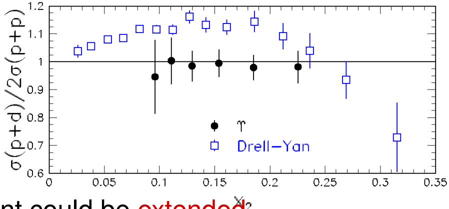

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Part III

AFTER as a quarkonium observatory in *pA*

(Precision analysis of Cold Nuclear Matter Effects)

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Liq. H^2 (1m)	$0.6\ 10^9$	10^6
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  - not to mention ratio with open charm, Drell-Yan, etc ...

Part IV

Heavy-ion physics with AFTER in *PbA* collisions

(the quest for sequential quarkonium suppression)

Observation of J/ψ sequential suppression seems to be hindered by

- the Cold Nuclear Matter effects: non trivial and

... not well-known, after all

A Fixed Target ExpeRiment: a quarkonium observatory in *PbA*

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  - χ_c never studied in *AA* collisions
  - $\psi(2S)$ not yet studied in *AA* collisions at RHIC and the LHC
- 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 too !
  - not clear what v_2 tells us

A Fixed Target ExpeRiment: a quarkonium observatory in *PbA*

- The excellent capabilities in *pA* should help
  - to reduce the CNM uncertainties
  - to measure their dependence in y and P_T

Rough estimation of the yield: $2 \times 10^7 J/\psi$, $10^4 \Upsilon$ per year (10^6 sec)

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- As STAR people suggested, why not to look for gluon quenching
  in J/ψ+hadron correlations vs. centrality
  (I suspect that we need a good *pA* baseline)

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Part V

Spin Physics with AFTER

(the quest for gluon spin contributions)

- A further undisputable property of fixed-target experiments is
  the possibility of polarising the target

see COMPASS, HERMES, CLAS, ...

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  polarised PDFs
- Double Transverse Spin Asymmetries probe transversity
- The beam may become transversely polarised during the crystal extraction

  M. Ukhanov, Nucl. Instrum. Meth. A 582 (2007) 378.

  $\rightarrow$ to be experimentally checked . . .

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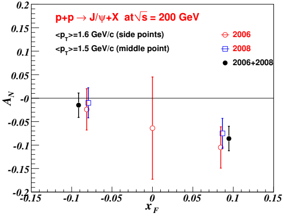

PHENIX, PRD 82, 112008 (2010)

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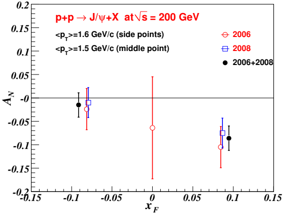

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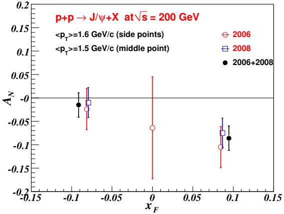

PHENIX, PRD 82, 112008 (2010)

- At $x_F > 0$, the gluon from the $p^{\uparrow}$ has a larger x_B
- It knows more about the proton spin than at low x_B → SSA grows

Spin Asymmetries and quarkonia

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- Of course, transverse SSA can be studied in parallel for other mesons (*D*, *B*, ...)
- In general, the backward region is the most favourable allowing for measurements in the large *x* region of the polarised nucleon

Part VI

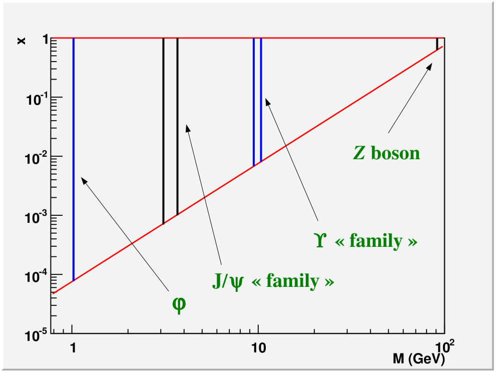
More with AFTER

(Drell-Yan, jet and W/Z)

A Fixed Target ExpeRiment

A dilepton observatory

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



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  - Above $c\bar{c}$: $x \in [10^{-3}, 1]$
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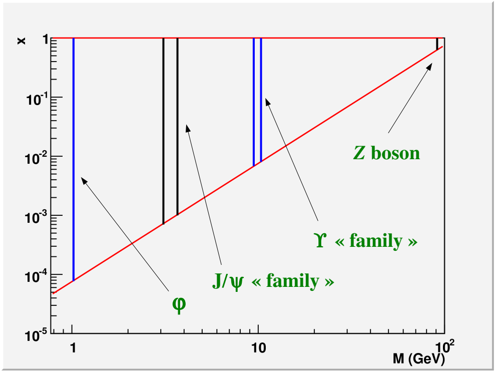

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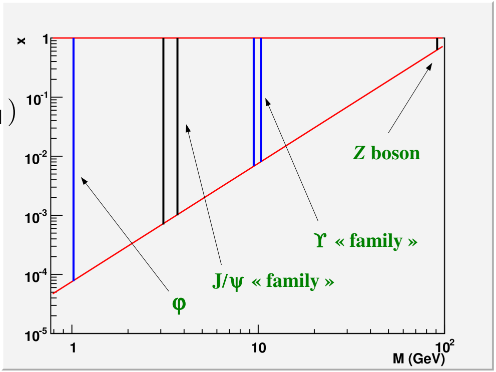
"backward" region



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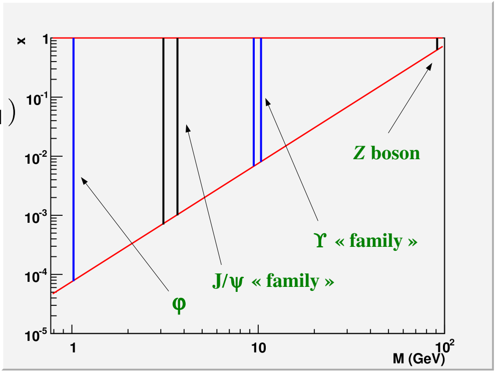
→ sea-quark asymetries
via p and d studies

- at large(est) x: backward ("easy")

- at small(est) x: forward (need to stop the (extracted) beam)



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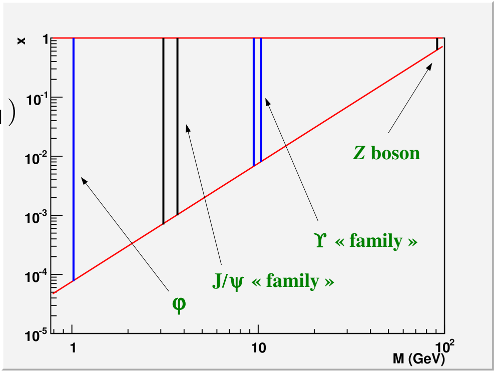
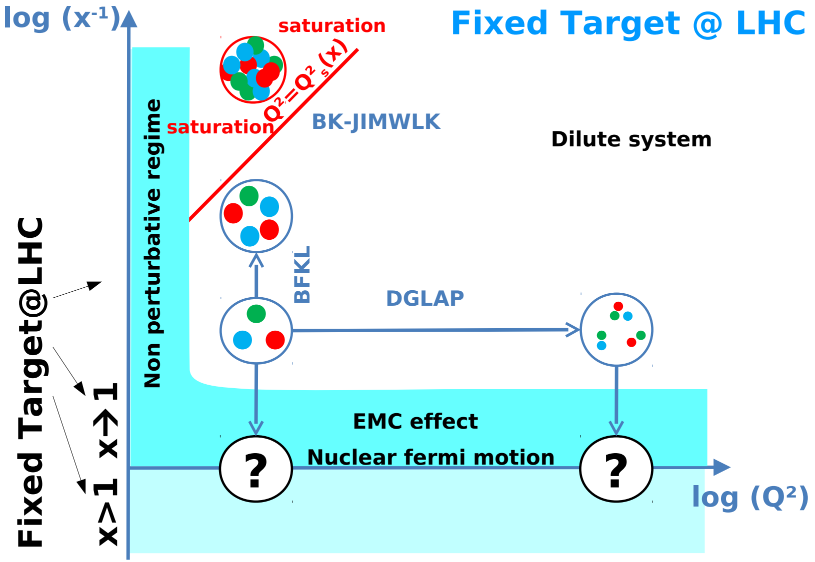
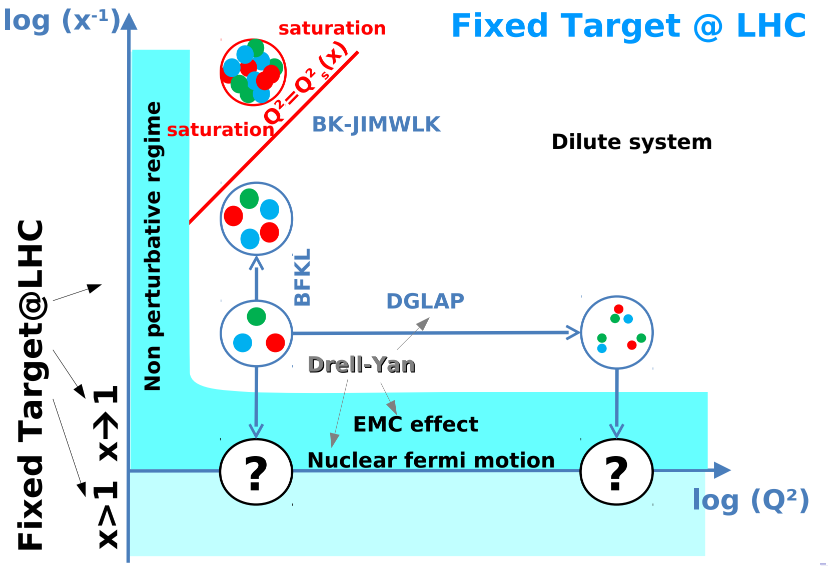


➟ To do: to look at the rates to see how competitive this will be

Overall


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

Overall



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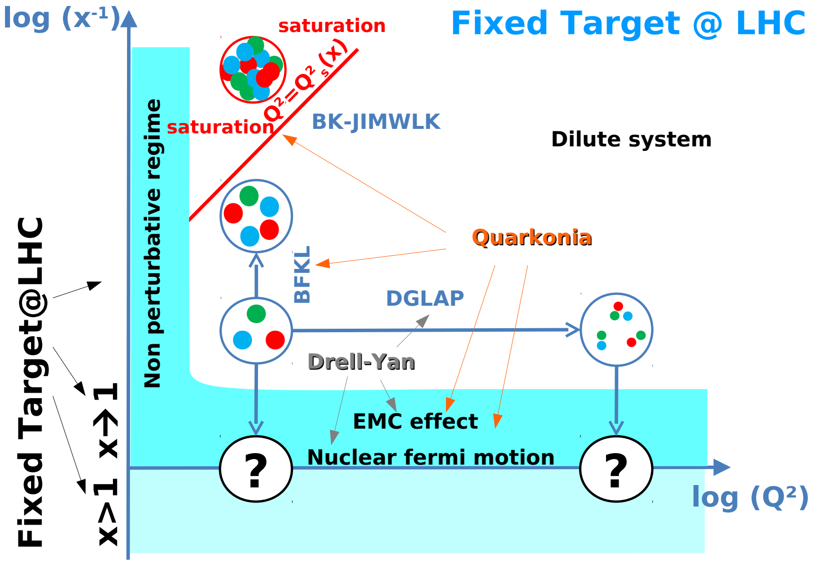

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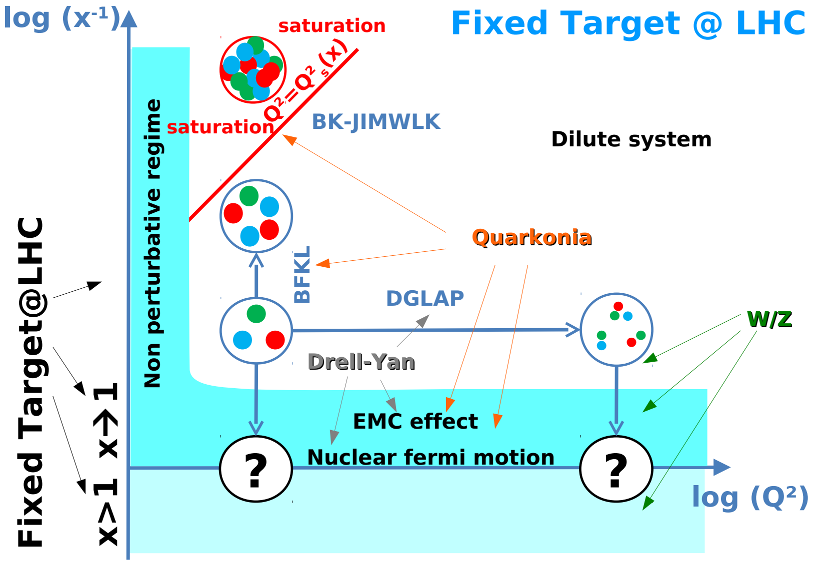

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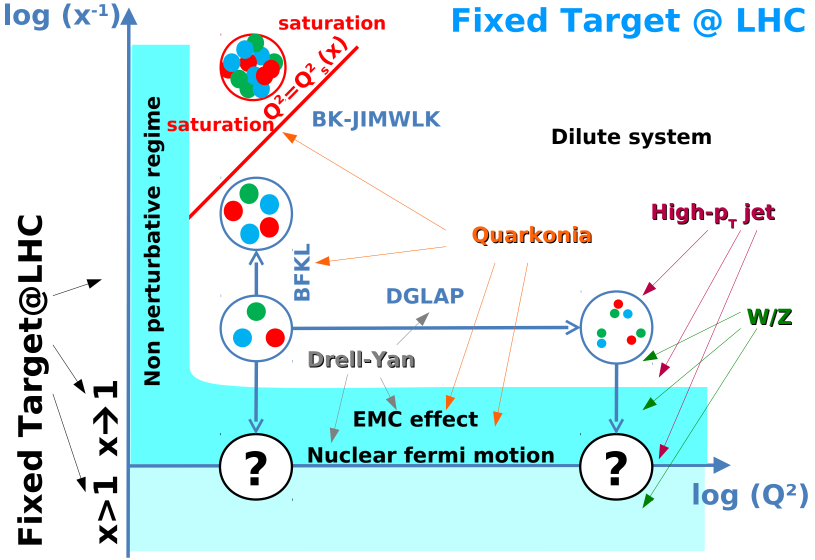

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?
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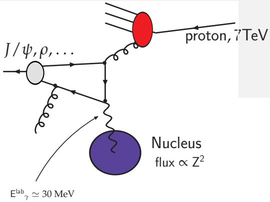
log (Q²)

Part VII

AFTER as photon-proton collider

One exotic illustration of the potentialities:

Ultra-peripheral collisions



Inelastic photoproduction of J/ψ via UPC*

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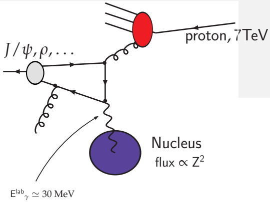

Inelastic photoproduction of J/ψ via UPC*

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A Fixed Target ExpeRiment

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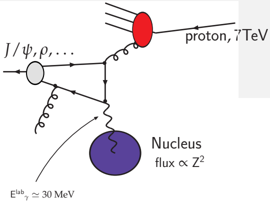

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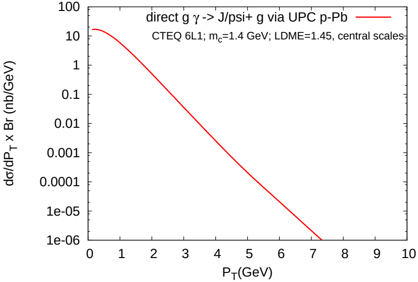

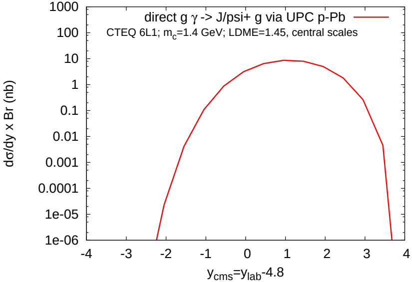

Disclaimer: these numbers suppose a dedicated trigger and are preliminary

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- True also for diffractive J/ψ photoproduction
- Handle on gluons (not sure though that one can compete in some way with EICs)

Z. Phys. C 76, 231–239 (1997)

ZEITSCHRIFT FÜR PHYSIK C

Diffractive J/ψ photoproduction as a probe of the gluon density

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[2] Rutherford Appleton Laboratory, Chilton, OX11 0QX, UK
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[4] School of Astronomy and Physics, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel Aviv University, Tel Aviv, Israel

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Abstract. We use perturbative QCD, beyond the leading $\ln Q^2$ approximation, to show how measurements of diffractive J/ψ production at HERA can provide a sensitive probe of the gluon density of the proton at small values of Bjorken x. We estimate both the effect of the relativistic motion of the c and $\bar{c}$ within the J/ψ and of the rescattering of the $c\bar{c}$ quark pair on the proton. We find that the available data for diffractive J/ψ photoproduction can discriminate between the gluon distributions of the most recent sets of partons.

Part VIII

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Part IX

Backup slides

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Double J/ψ production: a probe of gluon polarization?

S.P. Baranov[1], H. Jung[2]

[1]P.N.Lebedev Physical Institute, Moscow 117924, Russia
[2]III. Physikalisches Institut, Lehrstuhl B, RWTH Aachen, Germany

Received: 5 July 1994/Revised version: 5 October 1994 Z. Phys. C 66, 647–651 (1995)

Abstract. We consider the process of direct simultaneous production of two J/ψ particles and discuss the possibility that it can be used as a tool to measure the gluon polarization in the colliding particles.

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PHYSICAL REVIEW D VOLUME 49, NUMBER 9 1 MAY 1994

Associated $J/\psi + \gamma$ production as a probe of the polarized gluon distribution

M. A. Doncheski*
Department of Physics, University of Wisconsin, Madison, Wisconsin 53706

C. S. Kim
Department of Physics, Yonsei University, Seoul 120, Korea

(Received 15 March 1993)

Associated production of J/ψ and a γ has recently been proposed as a clean probe of the gluon distribution. The same mechanism can be used to probe the polarized gluon content of the proton in polarized proton-proton collisions. We study $J/\psi + \gamma$ production at both polarized fixed target and polarized collider energies.

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Pair production of J/ψ as a probe of double parton scattering at LHCb

C. H. Kom* and W. J. Stirling†
Cavendish Laboratory, J.J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom

A. Kulesza‡
Institute for Theoretical Particle Physics and Cosmology, RWTH Aachen University D-52056 Aachen, Germany

(Dated: May 24, 2011)

We argue that the recent LHCb observation of J/ψ–pair production indicates a significant contribution from double parton scattering, in addition to the standard single parton scattering component. We propose a method to measure the double parton scattering at LHCb using leptonic final states from the decay of two prompt J/ψ mesons.

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- Double J/ψ, $J/\psi+\gamma$, $J/\psi+D$, ... can of course be studied with AFTER