Synergies of (UPC) pA collisions with EIC

Daniel Tapia Takaki

Synergies of pp and pA collisions with an EIC
Brookhaven National Lab
27 June 2017

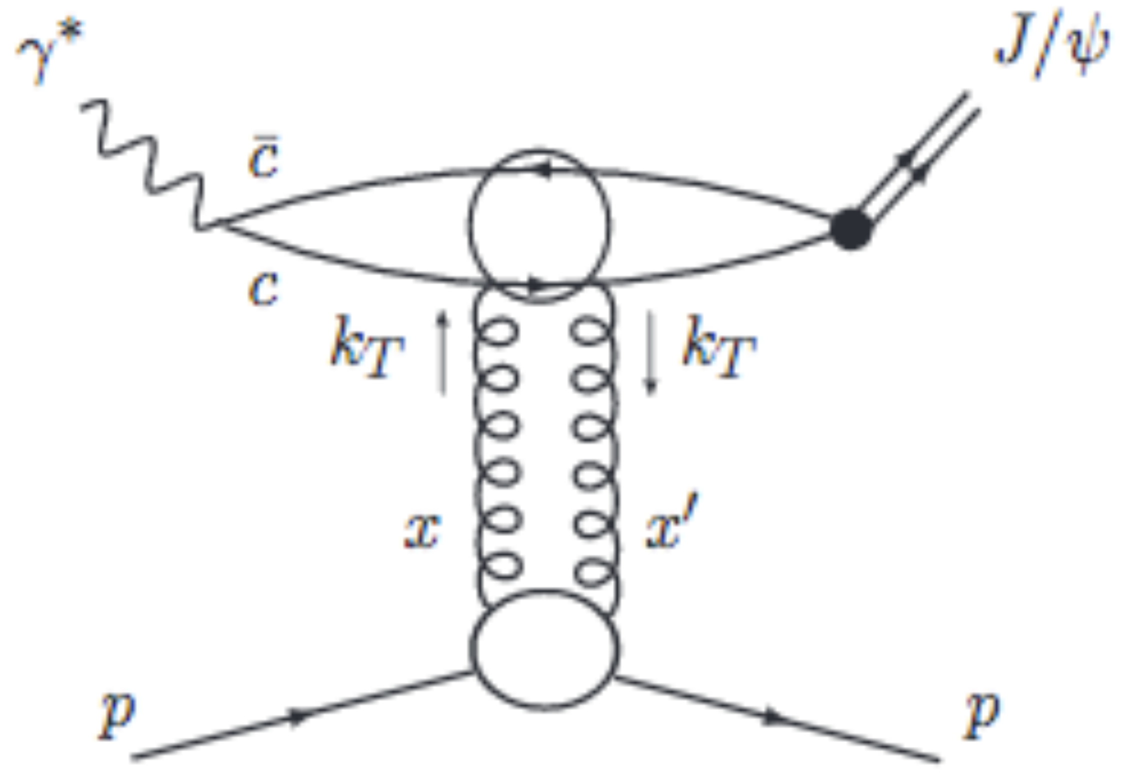
Plan of this talk

- Status of LHC analyses
- Presentation of "Energy dependence of dissociative J/ψ photoproduction as a signature of gluon saturation at the LHC"
  J. Cepina, J.G. Contreras and DTT
  Phys. Lett. B766 (2017) 186-191

Low x/dipole - type approaches to exclusive VM production

Ryskin;
Marti,Ryskin,Teubner;
Jones, Martin, Ryskin,Teubner

See A. Stasto talk at PHOTON'17



In the proton rest frame: the formation time of dipole is much longer than the interaction time with the target. Allows to factorize the process.

Lowest order: non-relativistic approximation to J/Ψ wave function

$$\boxed{\frac{\mathrm{d}\sigma}{\mathrm{d}t}(\gamma^* p \to J/\psi\ p)\Big|_{t=0} = \frac{\Gamma_{ee} M^3_{J/\psi}\pi^3}{48\alpha}\left[\frac{\alpha_s(\bar{Q}^2)}{\bar{Q}^4} xg(x,\bar{Q}^2)\right]^2 \left(1+\frac{Q^2}{M^2_{J/\psi}}\right)}$$

$$\bar{Q}^2 = (Q^2 + M^2_{J/\psi})/4\,, \qquad x = (Q^2 + M^2_{J/\psi})/(W^2 + Q^2)$$

In principle need to take into account skewed gluon distribution.

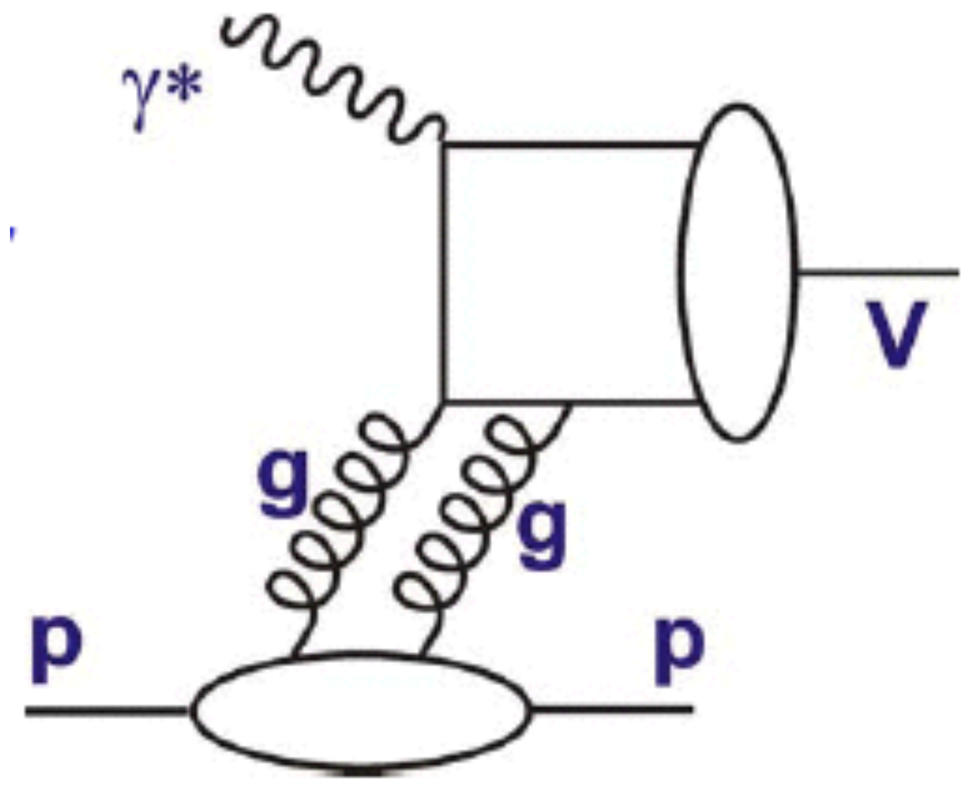
$$R_g = \frac{2^{2\lambda+3}}{\sqrt{\pi}} \frac{\Gamma(\lambda+\frac{5}{2})}{\Gamma(\lambda+4)} \qquad \text{with} \qquad \lambda(Q^2) = \partial\left[\ln(xg)\right]/\partial\ln(1/x)$$

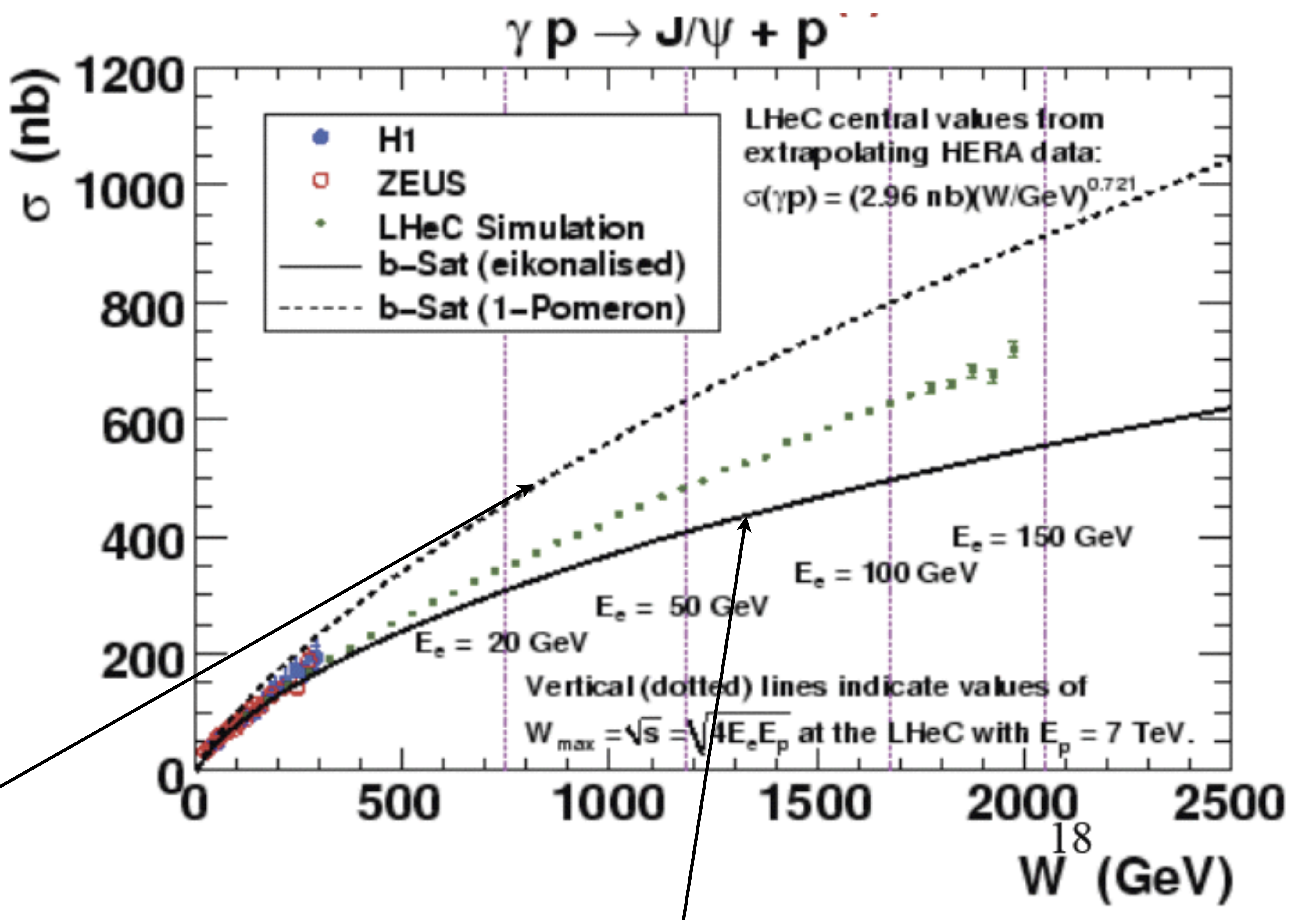
Shuvaev,Golec-Biernat,Martin,Ryskin

Effectively, multiplicative factor taken into account

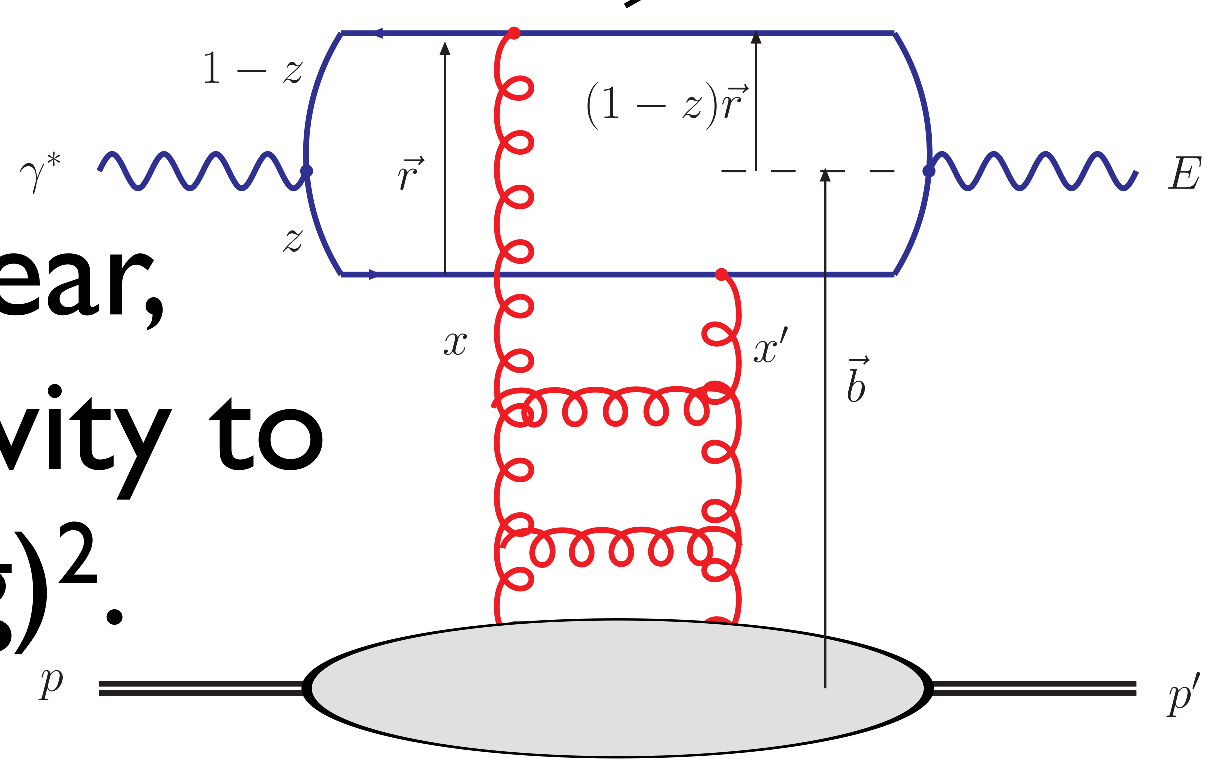
$k - \frac{1}{2}\Delta$
$k + \frac{1}{2}\Delta$
$P - \frac{1}{2}\Delta$
$P + \frac{1}{2}\Delta$
$\Delta = 0$
parton correlation function
$H(k, P, \Delta)$
$f(k, P)$ parton correlation function
$\int dk^-$
$\xi = 0$
$H(x, \boldsymbol{k}, \xi, \boldsymbol{b})$
FT
$H(x, \boldsymbol{k}, \xi, \boldsymbol{\Delta})$
GTMD
$W(x, \boldsymbol{k}, \boldsymbol{b})$ Wigner distribution
$\int d^2\boldsymbol{k}$
$\int d^2\boldsymbol{b}$
$H(x, \xi, \boldsymbol{b})$
$H(x, \xi, \Delta^2)$
GPD
$f(x, \boldsymbol{z})$
$f(x, \boldsymbol{k})$
TMD
$f(x, \boldsymbol{b})$ impact parameter distribution
$\int dx\, x^{n-1}$
$\sum_{k=0}^{n} A_{nk}(\Delta^2)\,(2\xi)^k$
GFFs
Standard collinear PDFs
$f(x)$
PDF
$F_n(\boldsymbol{b})$
$F_n(\Delta^2)$
form factor
9
Diehl: Eur. Phys. J. A (2016) 52: 149

Exclusive VM photoproduction

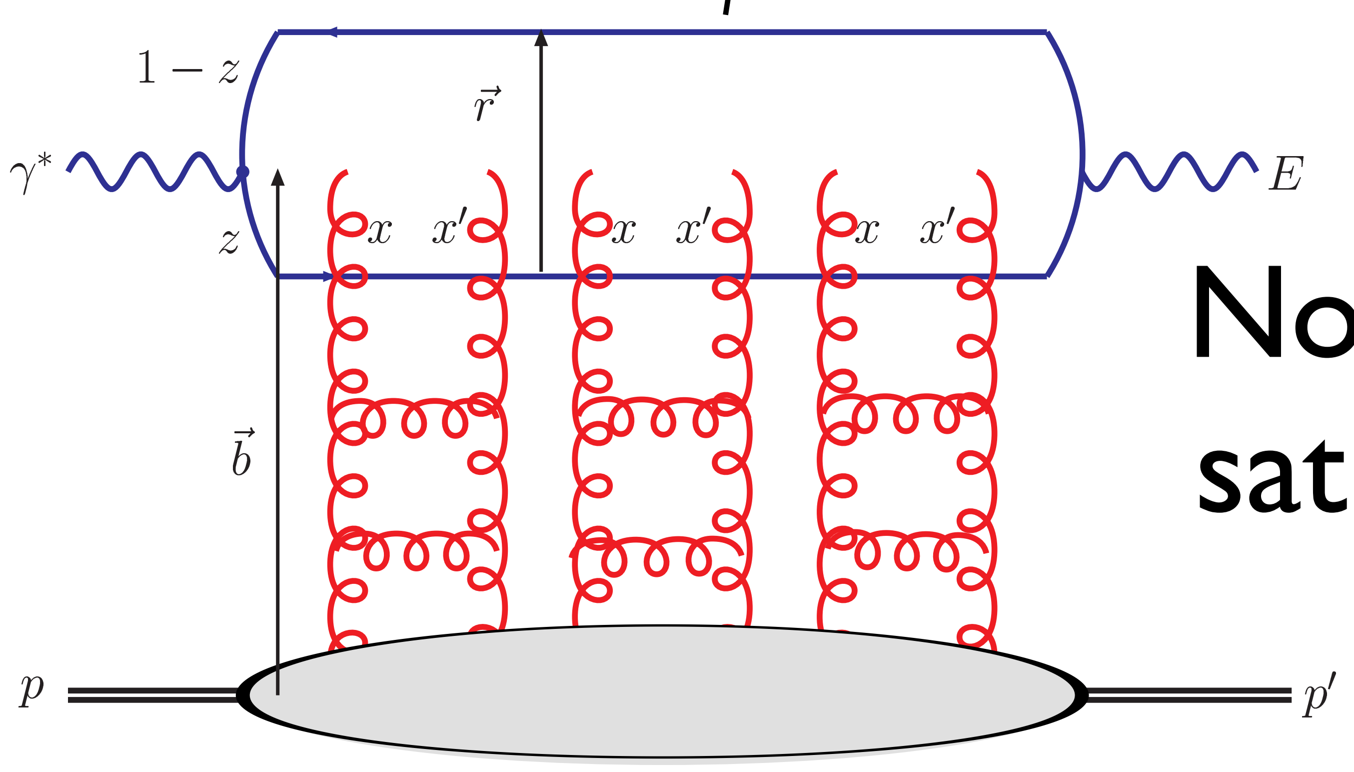




- Elastic J/ψ production appears as a candidate to signal saturation effects at work



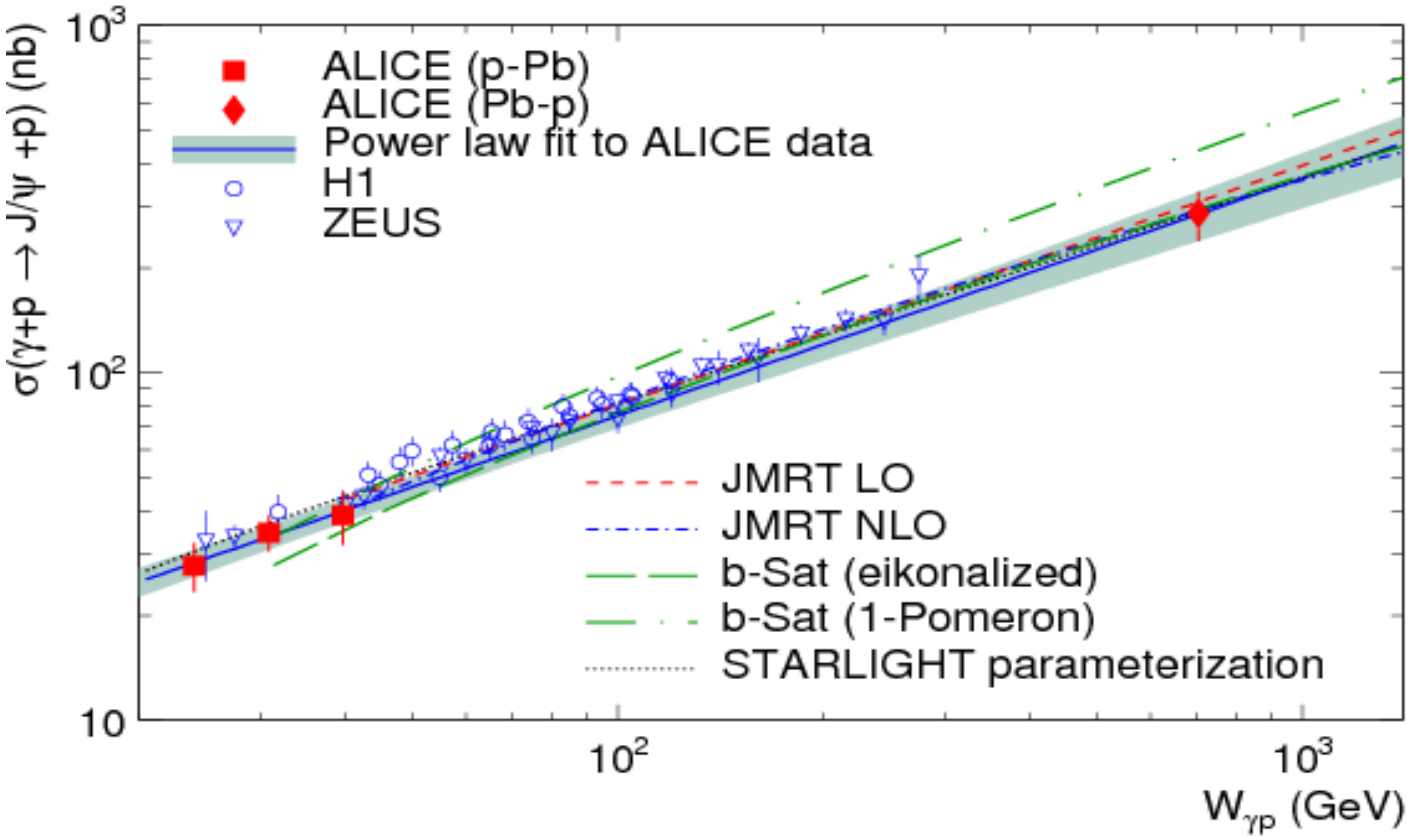
Linear, sensitivity to $(xg)^2$.

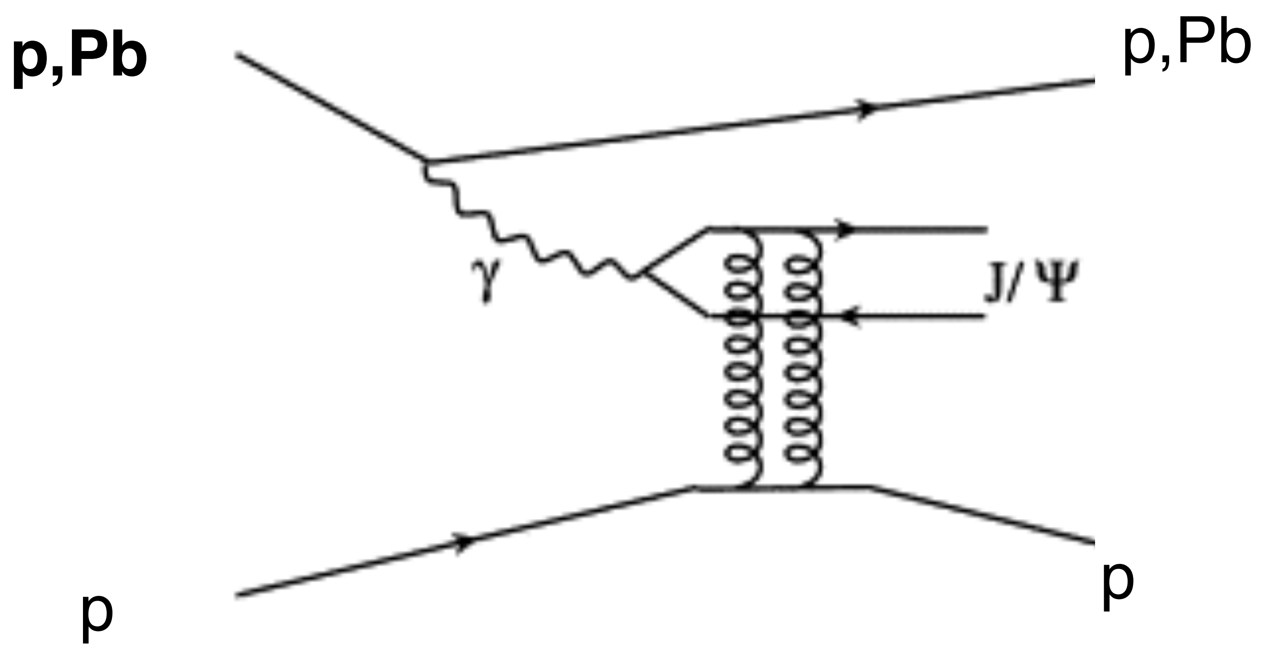


Non-linear, saturation.

Exclusive J/ψ photoproduction

Phys.Rev.Lett. 113 (2014) 23, 232504

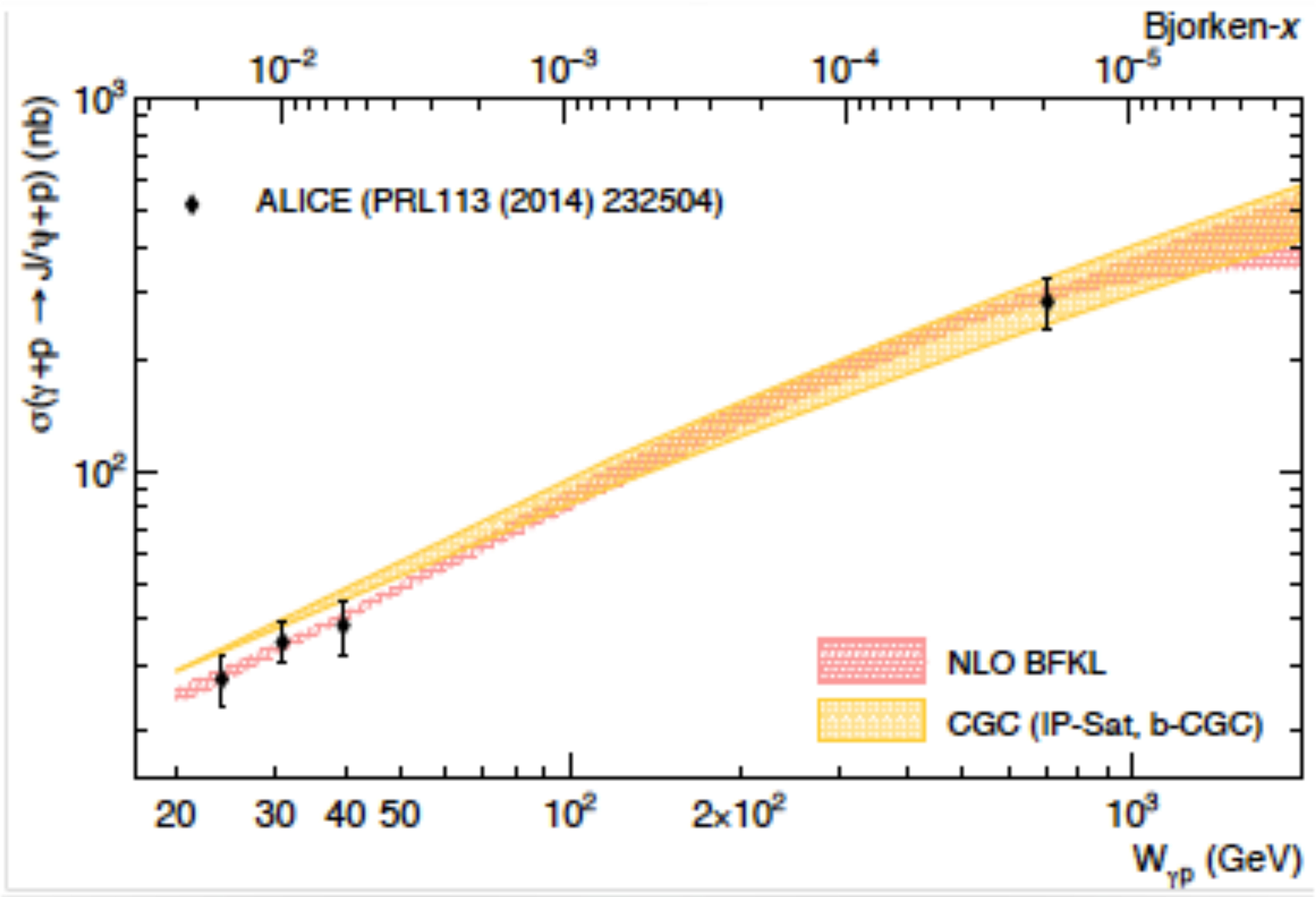




A natural explanation is that no change in the behaviour of the gluon PDF in the proton is observed between HERA and LHC energies" PRL 113 (2014) 232504.

Exclusive J/ψ photoproduction

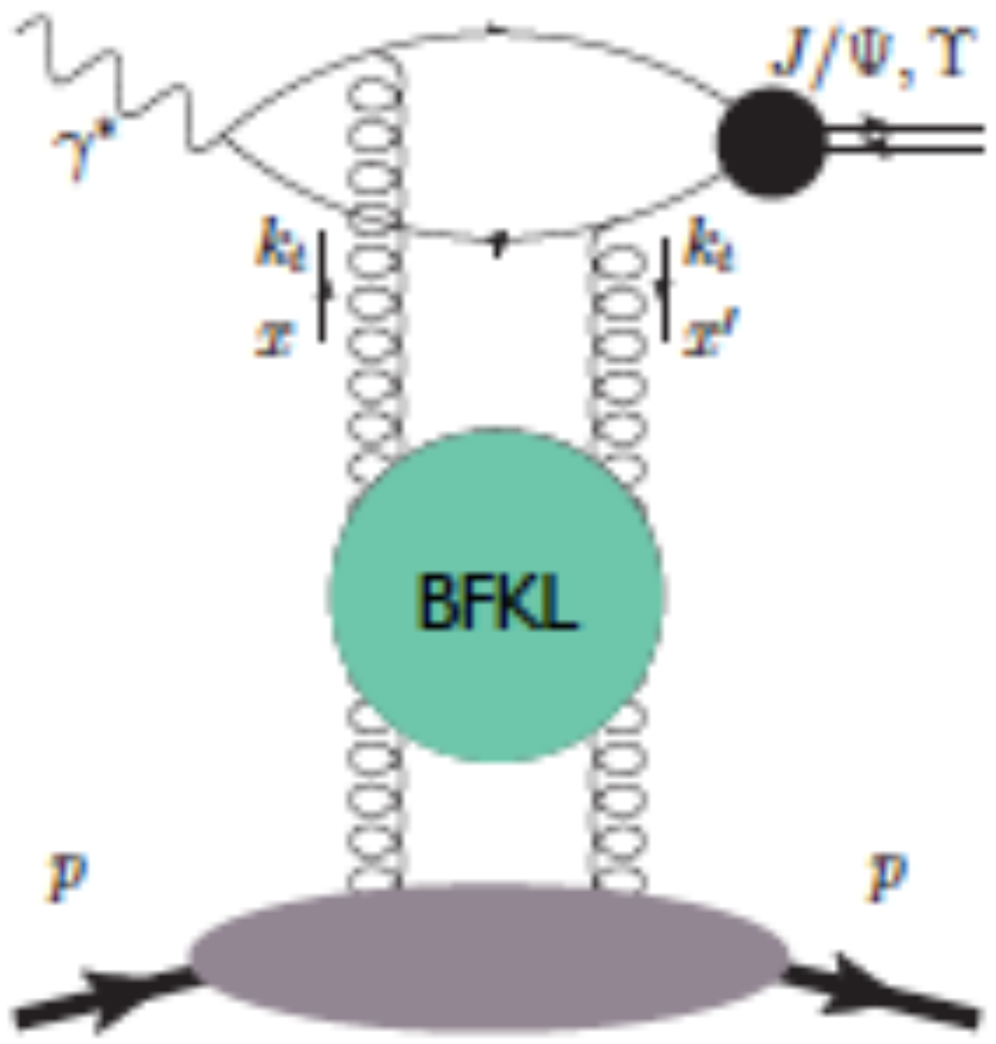
In pPb in ALICE, $W_{\gamma p}$ from 20 GeV to 1.5 TeV



WG2: Low x and Diffraction

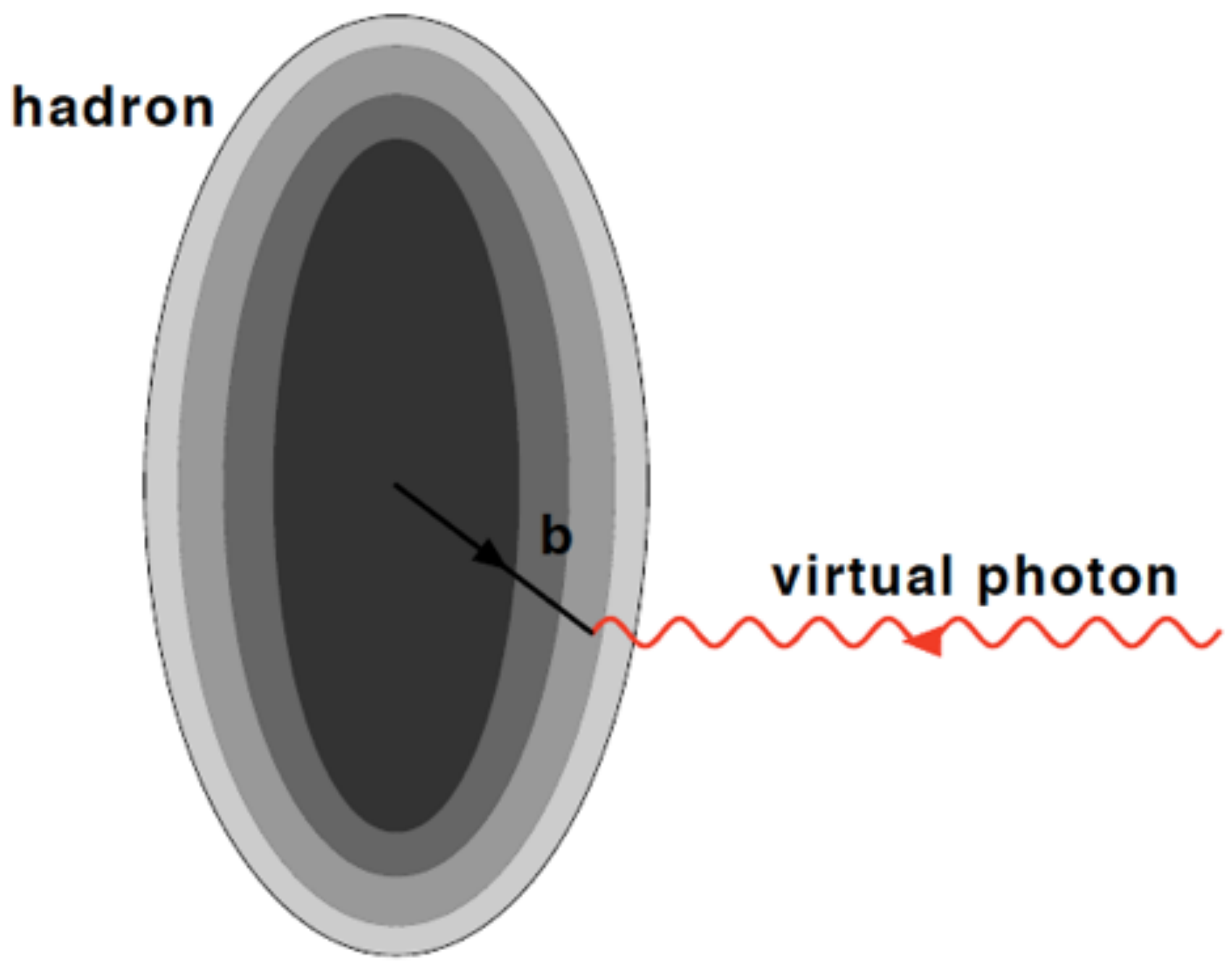
Martin Hentschinski

NLL BFKL calculation - no saturation
Very good description of the data
Approaches with saturation work well too..

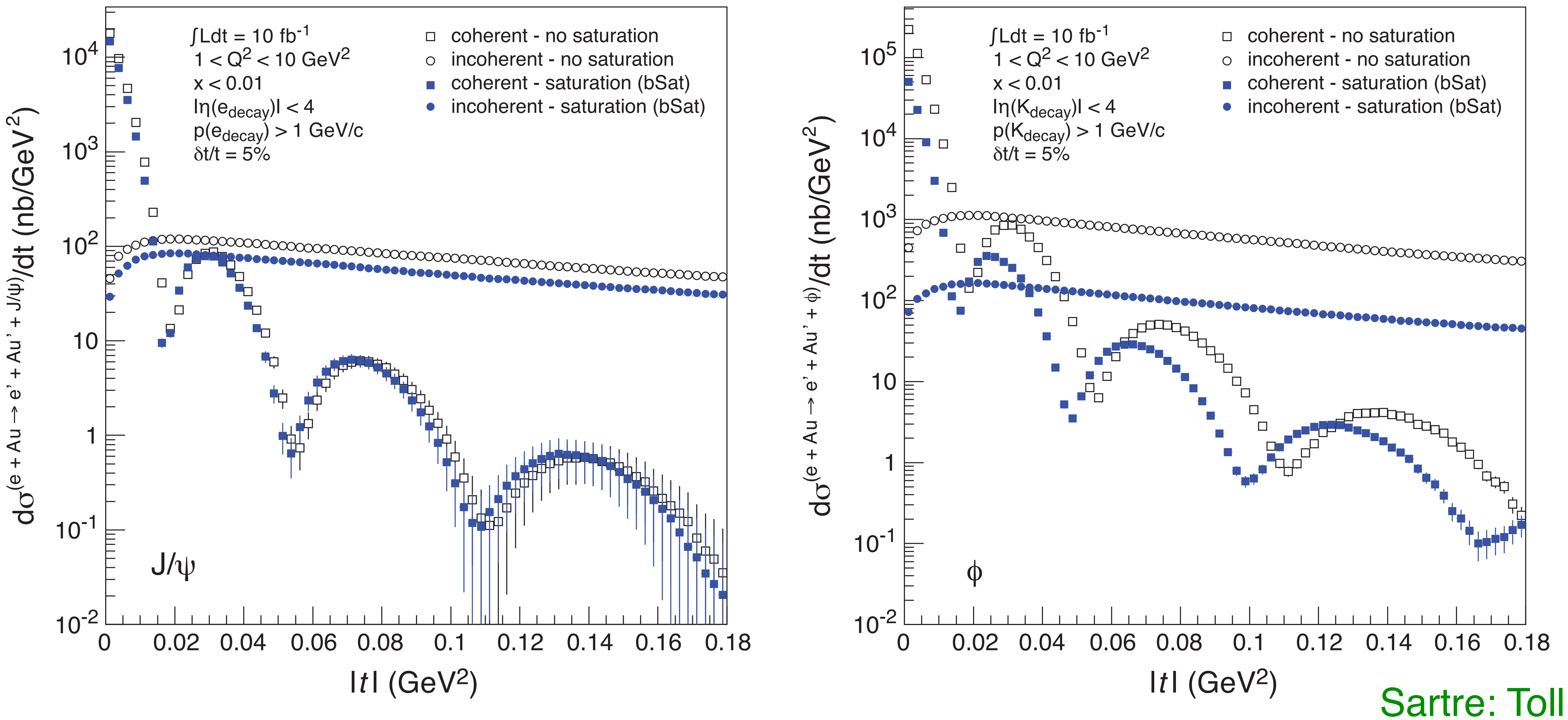


t-dependence

- t-differential measurements give a gluon tranverse mapping of the hadron/nucleus.



Exclusive Vector Meson Production in e+A



Sartre: Toll, Ullrich, Phys.Rev. C87, 024913 (2013)

- Low-t: coherent diffraction dominates - gluon density
- High-t: incoherent diffraction dominates - gluon correlations

➡Need good breakup detection efficiency to discriminate between the two scenarios

- unlike protons, forward spectrometer won't work for heavy ions
  - measure emitted neutrons in a ZDC
- rapidity gap with absence of break-up fragments sufficient to identify coherent events

IS2014: macl@bnl.gov

29

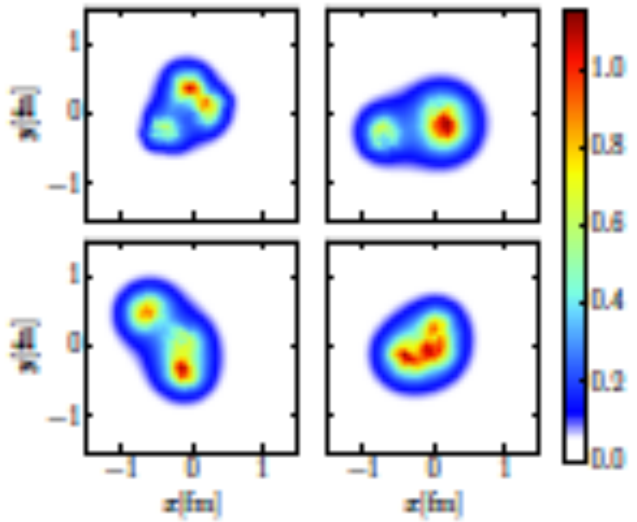
VM exclusive and dissociative production

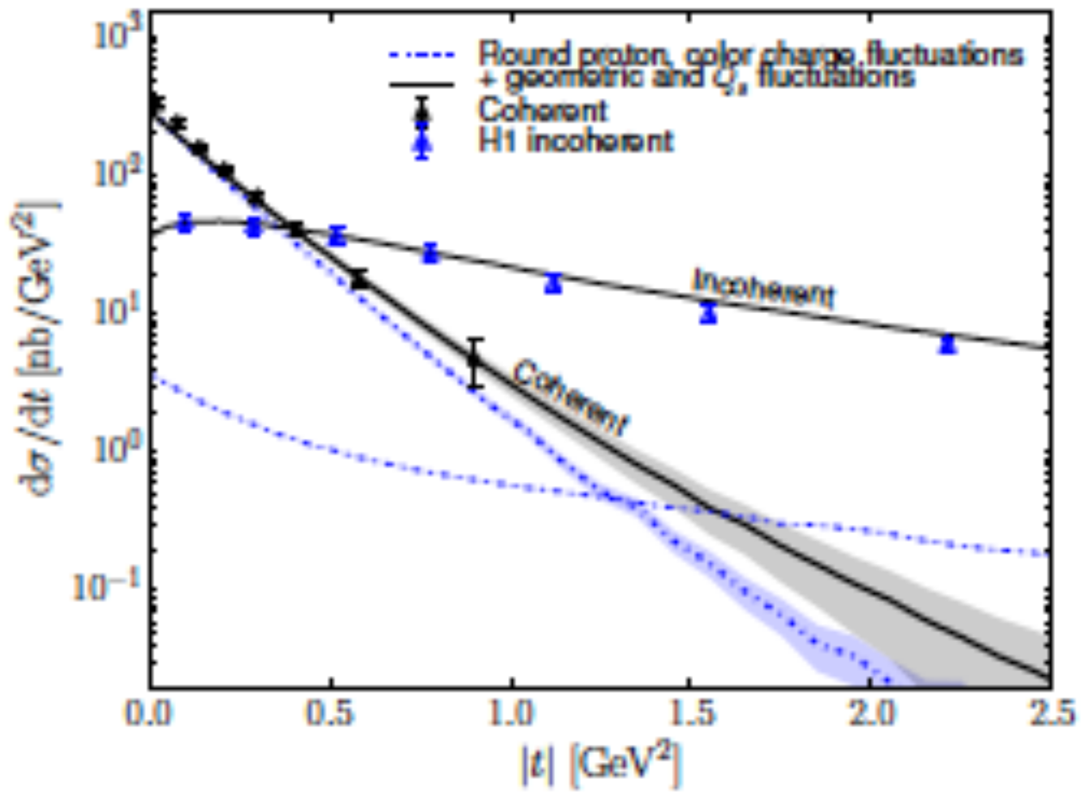
...so we do not know if gluon density *saturates* (yet), but maybe it *fluctuates*?

Heikki Mantysaari

Model the geometric fluctuations of density inside the proton

Parameters fitted to H1 data





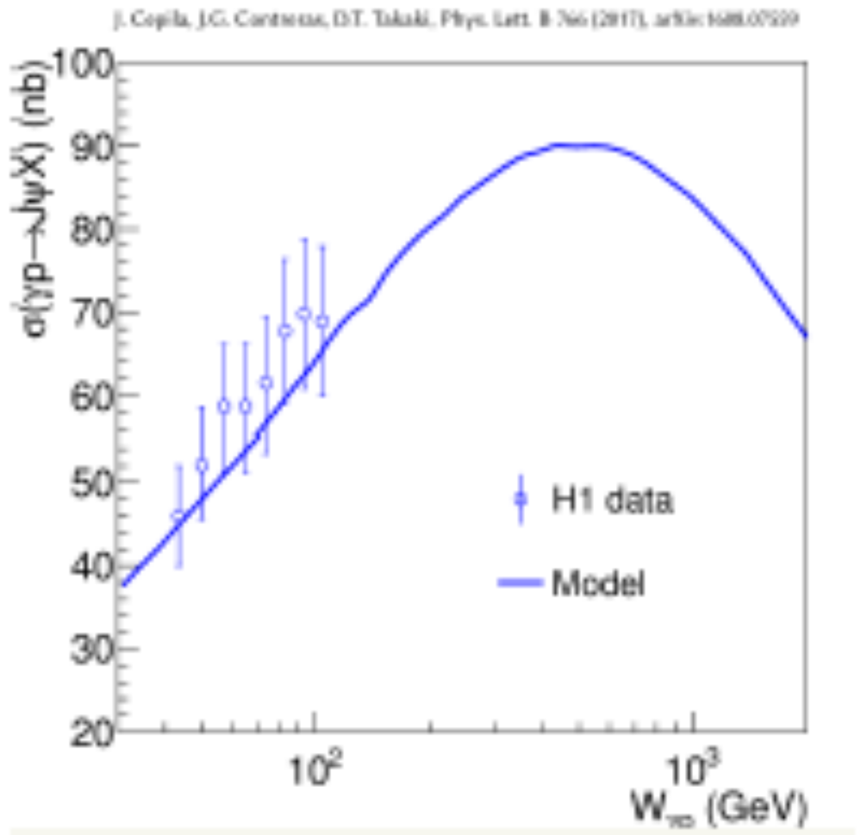
WG2: Low x and Diffraction

Coherent VM production: target stays intact

$$\frac{d\sigma^{\gamma^* p \to Vp}}{dt} \sim |\langle \mathcal{A}(x, Q^2, t)\rangle|^2$$

Incoherent VM diffraction: target breaks up.

$$\frac{d\sigma^{\gamma^* p \to Vp^*}}{dt} \sim \langle |\mathcal{A}(x, Q^2, t)|^2\rangle - |\langle \mathcal{A}(x, Q^2, t)\rangle|^2$$



Jan Cepila

At high energies the incoherent cross section decreases with energy, due to increase and overlap of hotspots

Physics Letters B 766 (2017) 186–191

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Energy dependence of dissociative J/ψ photoproduction as a signature of gluon saturation at the LHC

J. Cepila [a], J.G. Contreras [a,*], J.D. Tapia Takaki [b]

[a] Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Czech Republic
[b] Department of Physics and Astronomy, The University of Kansas, Lawrence, KS, USA

ARTICLE INFO

Article history:
Received 30 August 2016
Received in revised form 1 December 2016
Accepted 23 December 2016
Available online 10 January 2017
Editor: M. Doser

Keywords:
Gluon saturation
Vector meson photoproduction
LHC

ABSTRACT

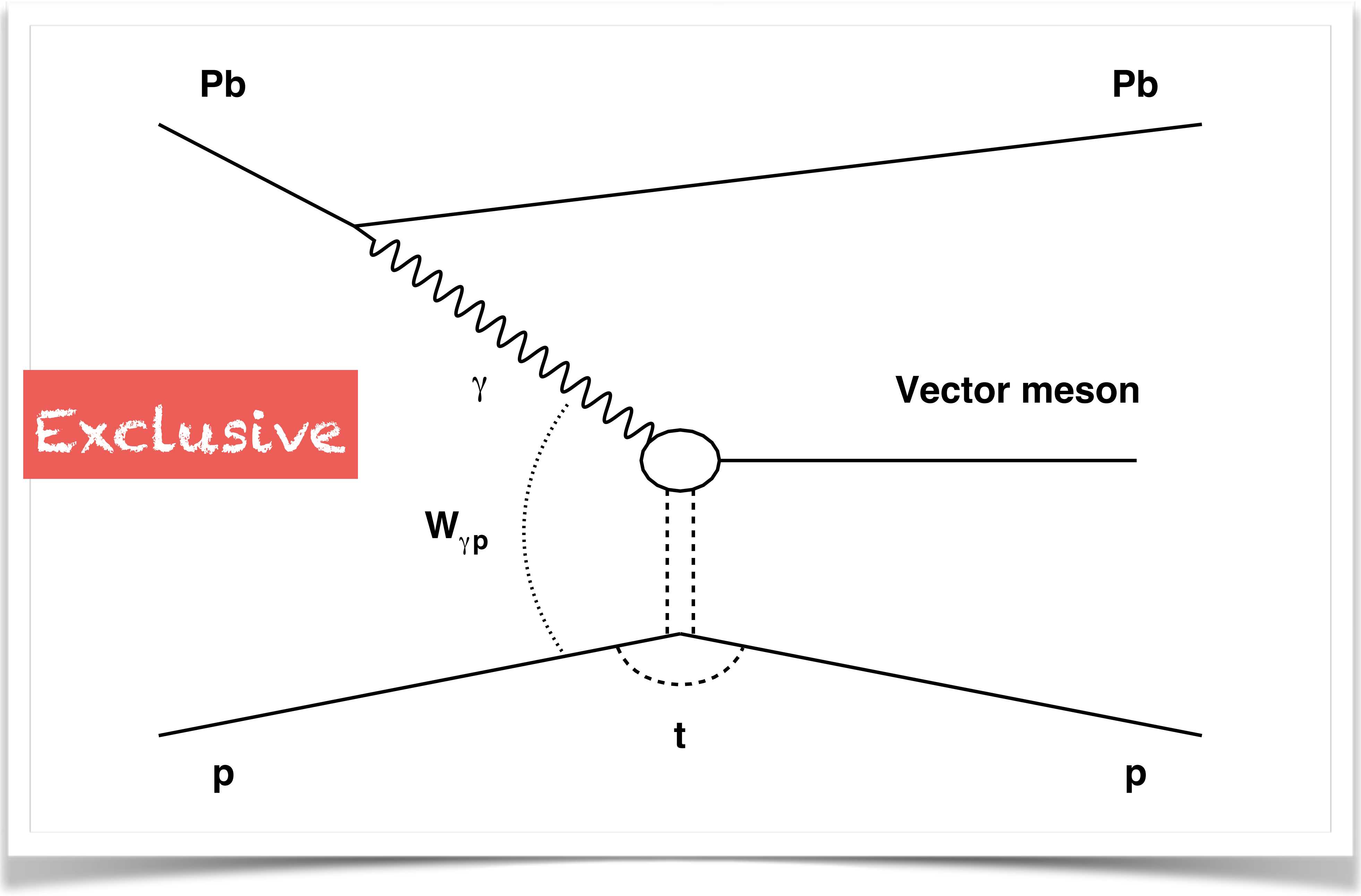
We have developed a model in which the quantum fluctuations of the proton structure are characterised by hot spots, whose number grows with decreasing Bjorken-x. Our model reproduces the $F_2(x, Q^2)$ data from HERA at the relevant scale, as well as the exclusive and dissociative J/ψ photoproduction data from H1 and ALICE. Our model predicts that for $W_{\gamma p} \approx 500$ GeV, the dissociative J/ψ cross section reaches a maximum and then decreases steeply with energy, which is in qualitatively good agreement to a recent observation that the dissociative J/ψ background in the exclusive J/ψ sample measured in photoproduction by ALICE decreases as energy increases. Our prediction provides a clear signature for gluon saturation at LHC energies.

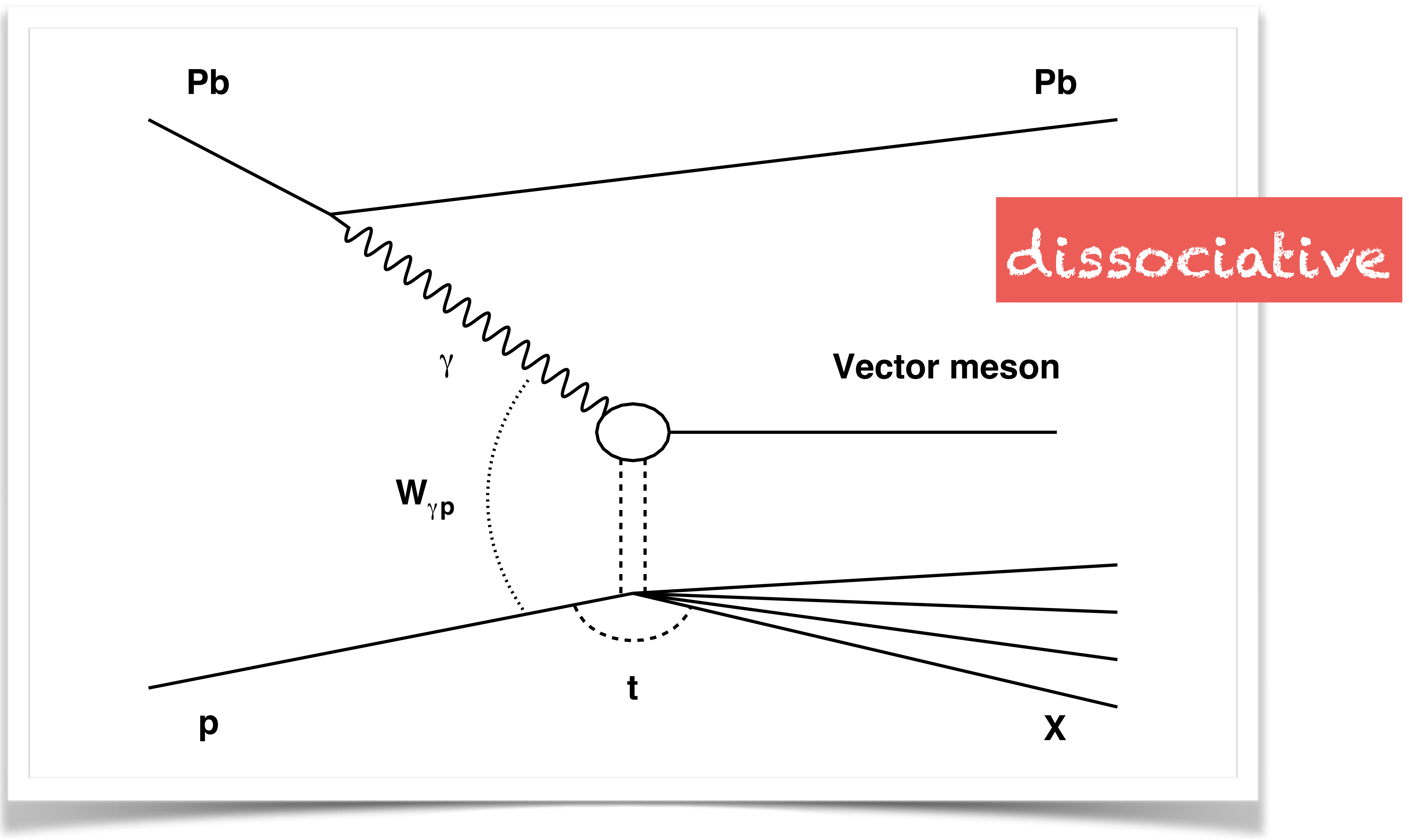
Dissociative production of J/ψ and gluon saturation

Daniel Tapia Takaki
University of Kansas

Work in collaboration with J. Cepina and J. G. Contreras
Phys. Lett. B766 (2017) 186-191

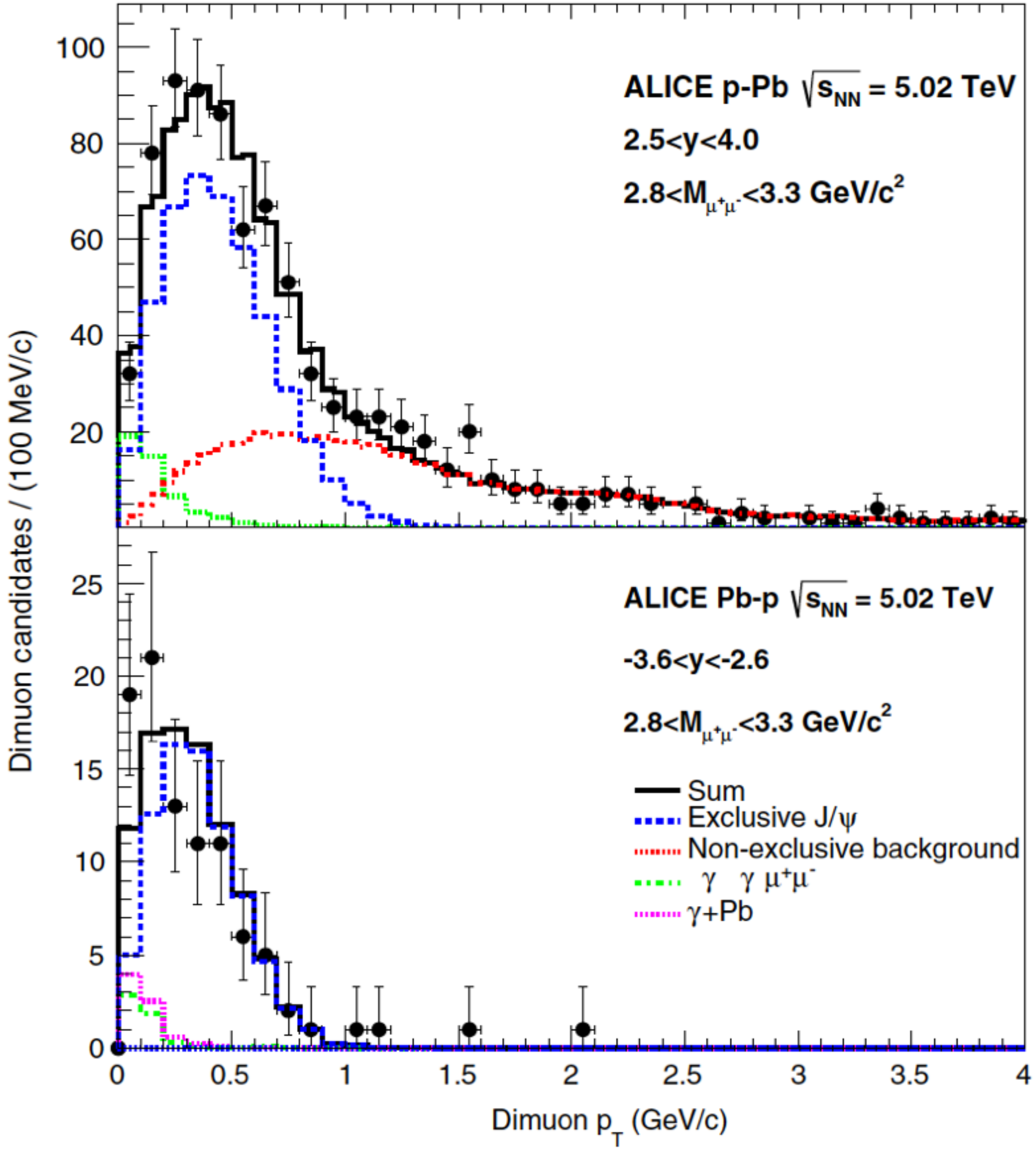
Exclusive and dissociative J/ψ production





Prediction for dissociative production

Phys.Rev.Lett. 113 (2014) 23, 232504



Low W_{gp} energy point
$\langle W_{gp} \rangle \sim 30$ GeV

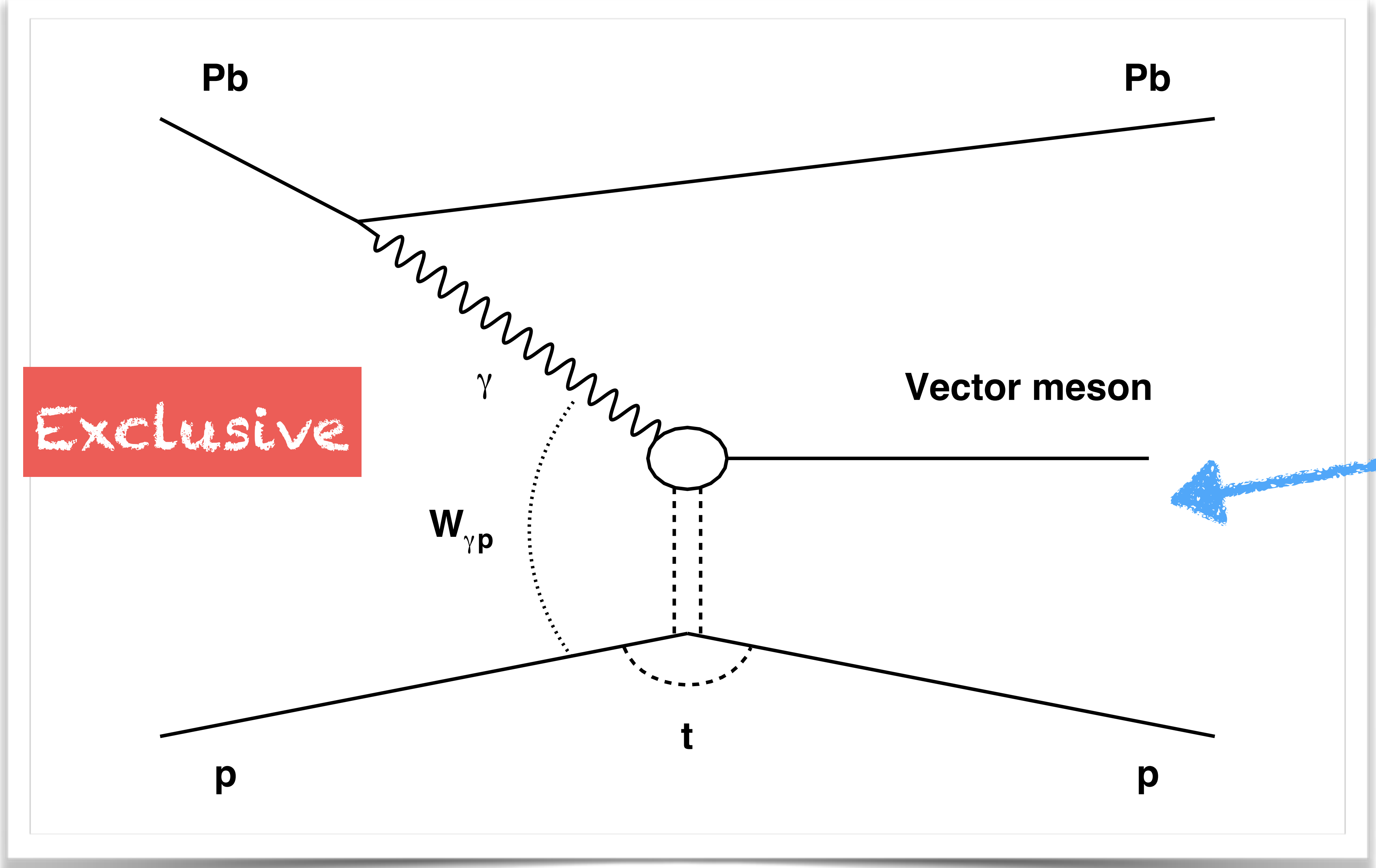
High W_{gp} energy point
$\langle W_{gp} \rangle \sim 700$ GeV

Exclusive and dissociative J/ψ production

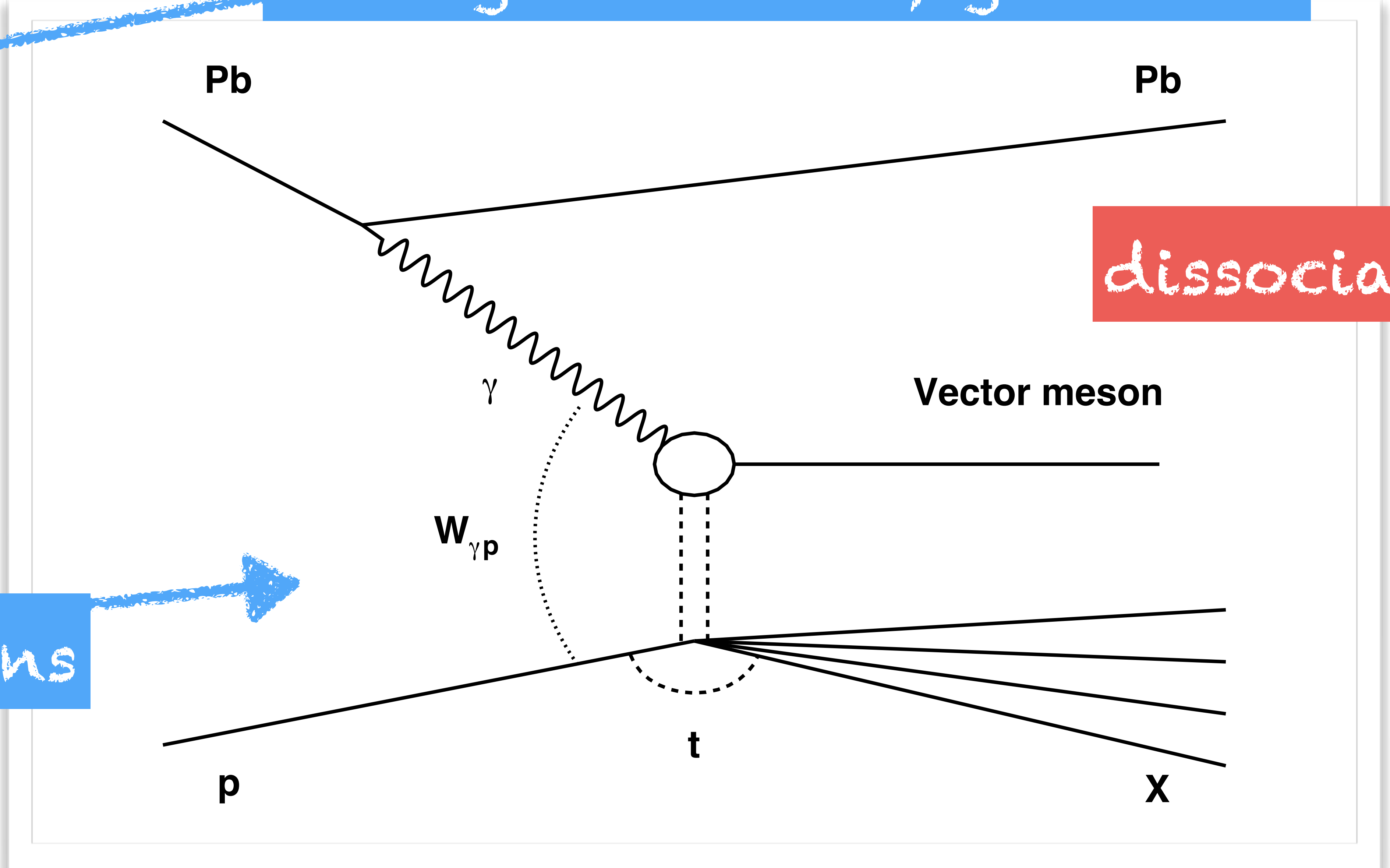
$$\frac{d\sigma(\gamma p \to \mathrm{J}/\psi p)}{dt} = \frac{R_g^2}{16\pi}\left|\left\langle A(x,Q^2,\vec{\Delta})\right\rangle\right|^2$$

Average over configurations

Exclusive



dissociative



Variance over configurations

$$\frac{d\sigma(\gamma p \to \mathrm{J}/\psi Y)}{dt} = \frac{R_g^2}{16\pi}\left(\left\langle\left|A(x,Q^2,\vec{\Delta})\right|^2\right\rangle - \left|\left\langle A(x,Q^2,\vec{\Delta})\right\rangle\right|^2\right)$$

The amplitude in the dipole picture

x related to W γ p which is related to the rapidity of the vector meson V

Δ^2=-t

dipole size

quark energy fraction

impact parameter

$$A(x, Q^2, \vec{\Delta})_{T,L} = i \int d\vec{r} \int_0^1 \frac{dz}{4\pi} (\Psi^* \Psi_V)_{T,L} \int d\vec{b}\, e^{-i(\vec{b}-(1-z)\vec{r})\cdot\vec{\Delta}} \frac{d\sigma_{\mathrm{dip}}}{d\vec{b}}$$

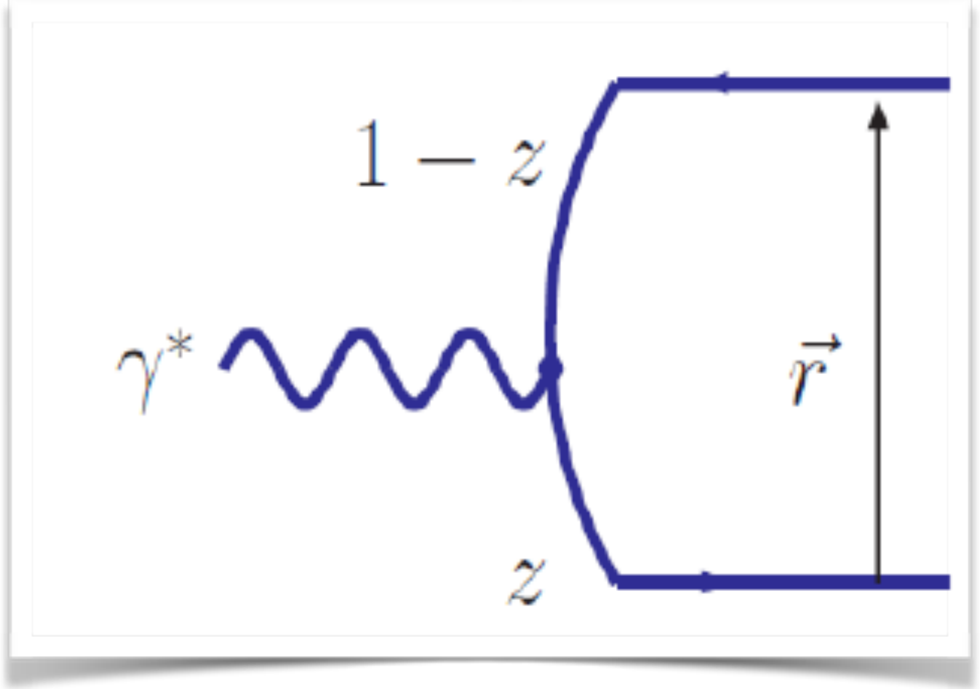
photon virtuality

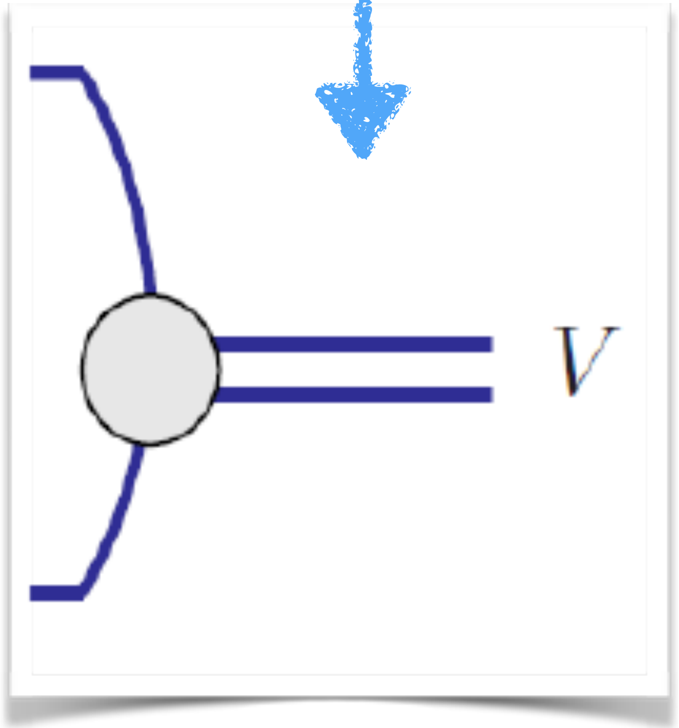
Transverse, Longitudinal photons

vector meson wave function

photon-dipole wave function

Dipole-Target cross section
pQCD physics gets here!





The dipole-target cross section

dipole target amplitude

$$\frac{d\sigma_{\text{dip}}}{d\vec{b}} = 2N(x, \vec{r}, \vec{b})$$

Factorised assumption

$$N(x, r, b) = \sigma_0 N(x, r) T(\vec{b})$$

Golec-Biernat Wuesthoff model

$$N^{\text{GBW}}(x, r) = \left(1 - e^{-r^2 Q_s^2(x)/4}\right)$$

$$Q_s^2(x) = Q_0^2 (x_0/x)^\lambda$$

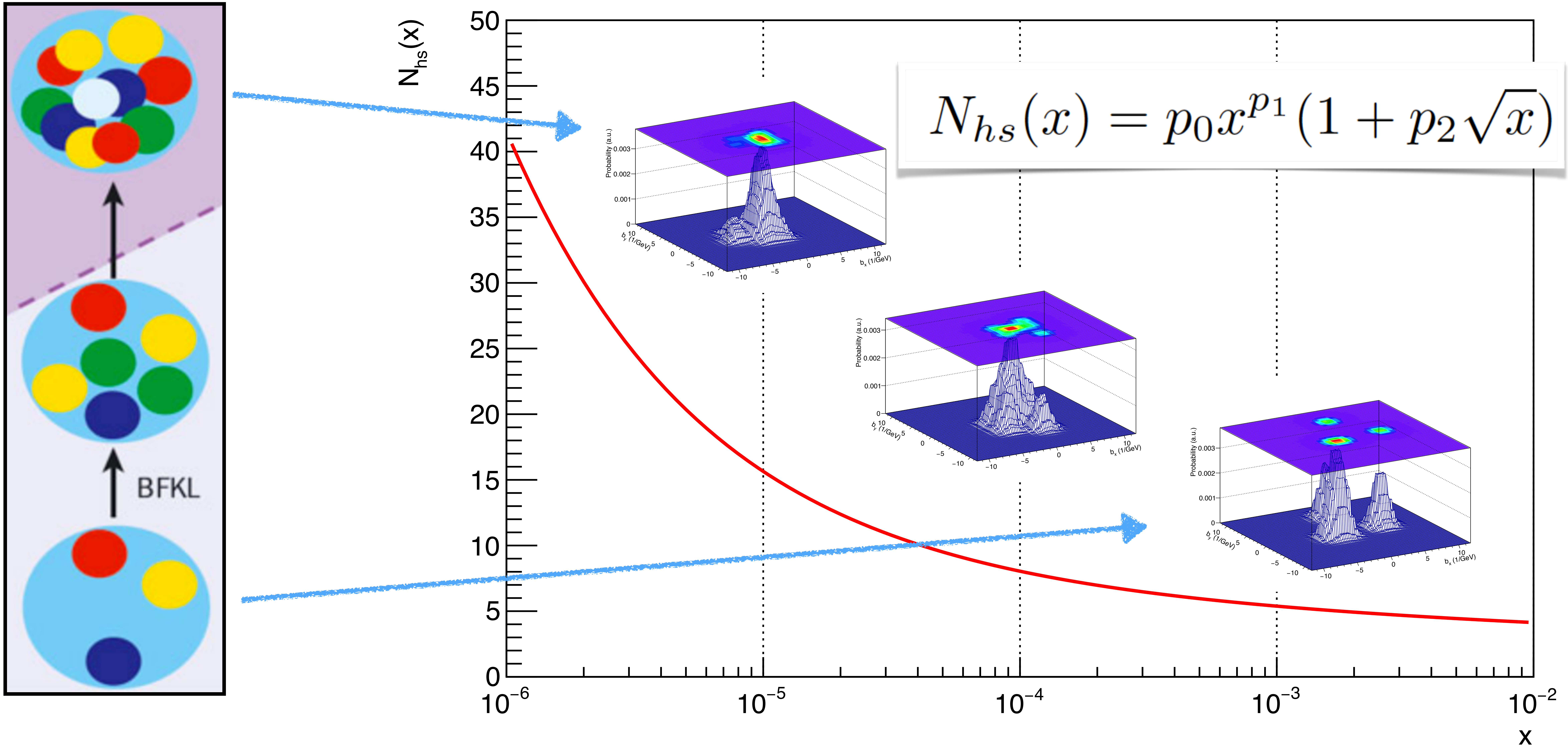
Proton is a sum of hot spots

$$T(\vec{b}) = \frac{1}{N_{hs}} \sum_{i=1}^{N_{hs}} T_{hs}(\vec{b} - \vec{b_i})$$

Gaussian hot spots

$$T_{hs}(\vec{b} - \vec{b_i}) = \frac{1}{2\pi B_{hs}} e^{-\frac{(\vec{b} - \vec{b_i})^2}{2B_{hs}}}$$

Number of hot spots



$$N_{hs}(x) = p_0 x^{p_1}(1 + p_2\sqrt{x})$$

This only redistributes T(b) in impact parameter. At each x the integral of T(b) over b² is one

Comparison to data

Parameters fixed using data:

λ using x dependence of exclusive vector meson production

σ_0 using t dependence of exclusive production

x_0 normalisation of x dependence of exclusive production

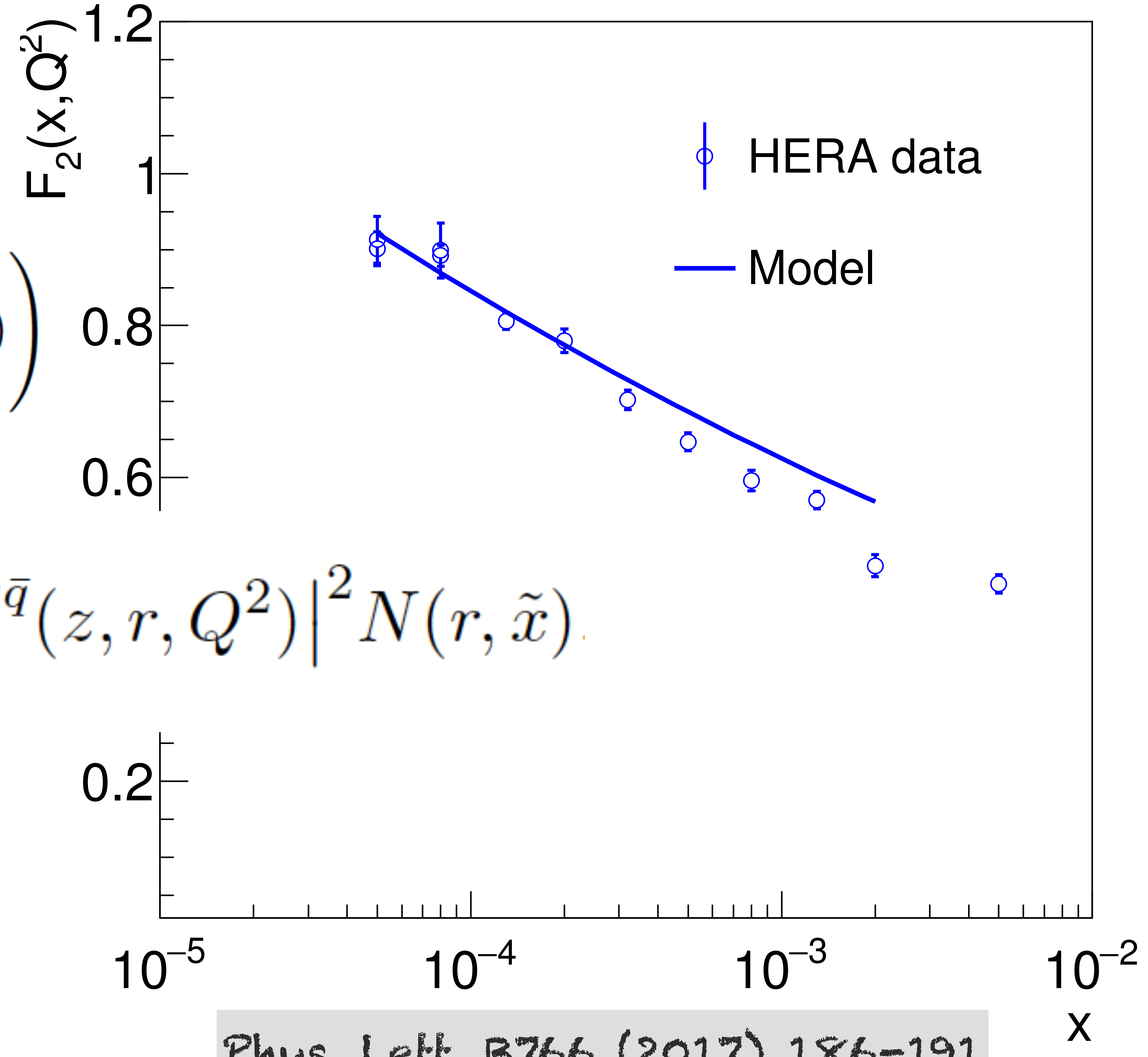
hot spot width from t dependence of dissociative production

Number of hot spots from x dependence of dissociative production

Comparison to inclusive data

$$F_2(x,Q^2) = \frac{Q^2}{4\pi^2\alpha_{em}}\left(\sigma_T^{\gamma^* p}(x,Q^2) + \sigma_L^{\gamma^* p}(x,Q^2)\right)$$

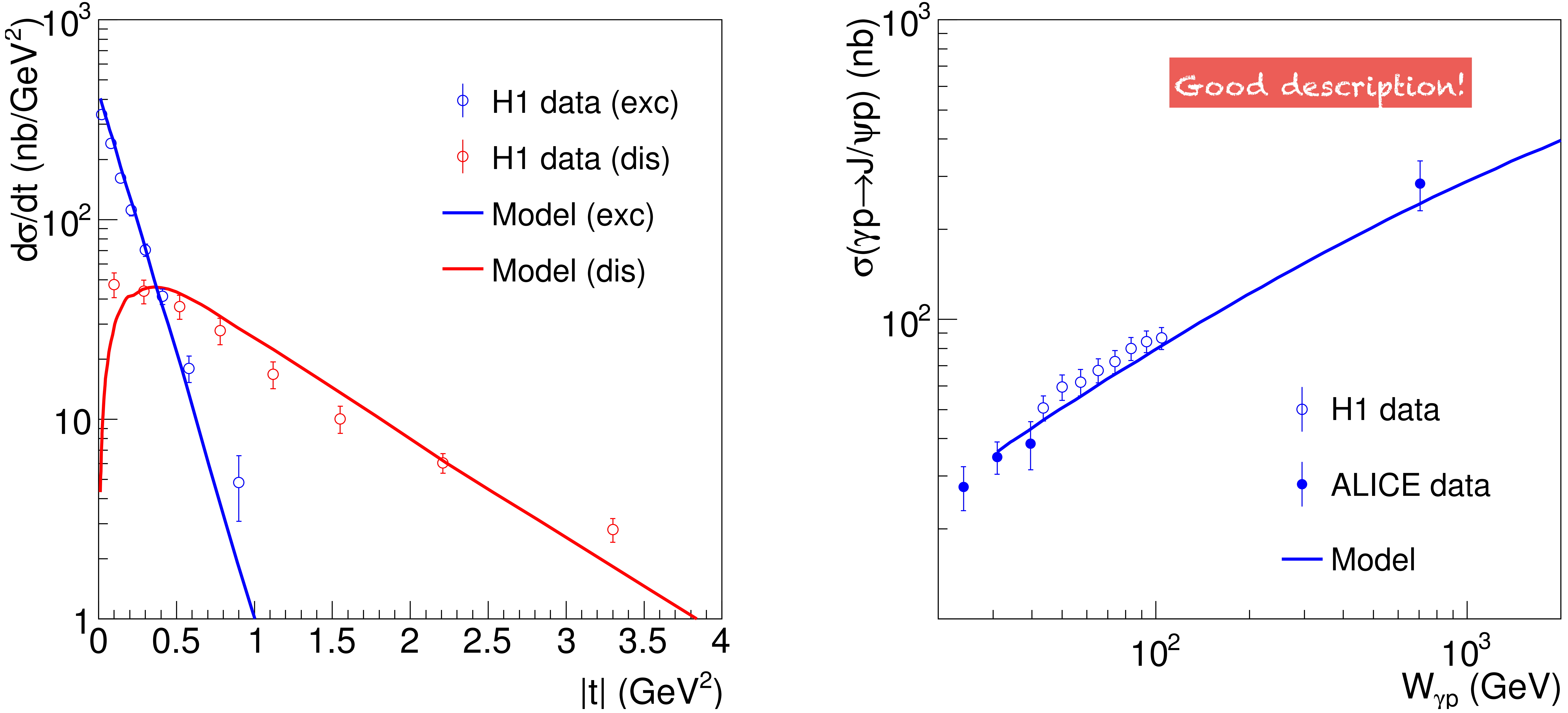
$$\sigma_{T,L}^{\gamma^* p}(x,Q^2) = \sigma_0 \int d\vec{r} \int_0^1 dz \left|\Psi_{T,L}^{\gamma^* \to q\bar{q}}(z,r,Q^2)\right|^2 N(r,\tilde{x})$$



Good description even though the model was developed for vector meson production

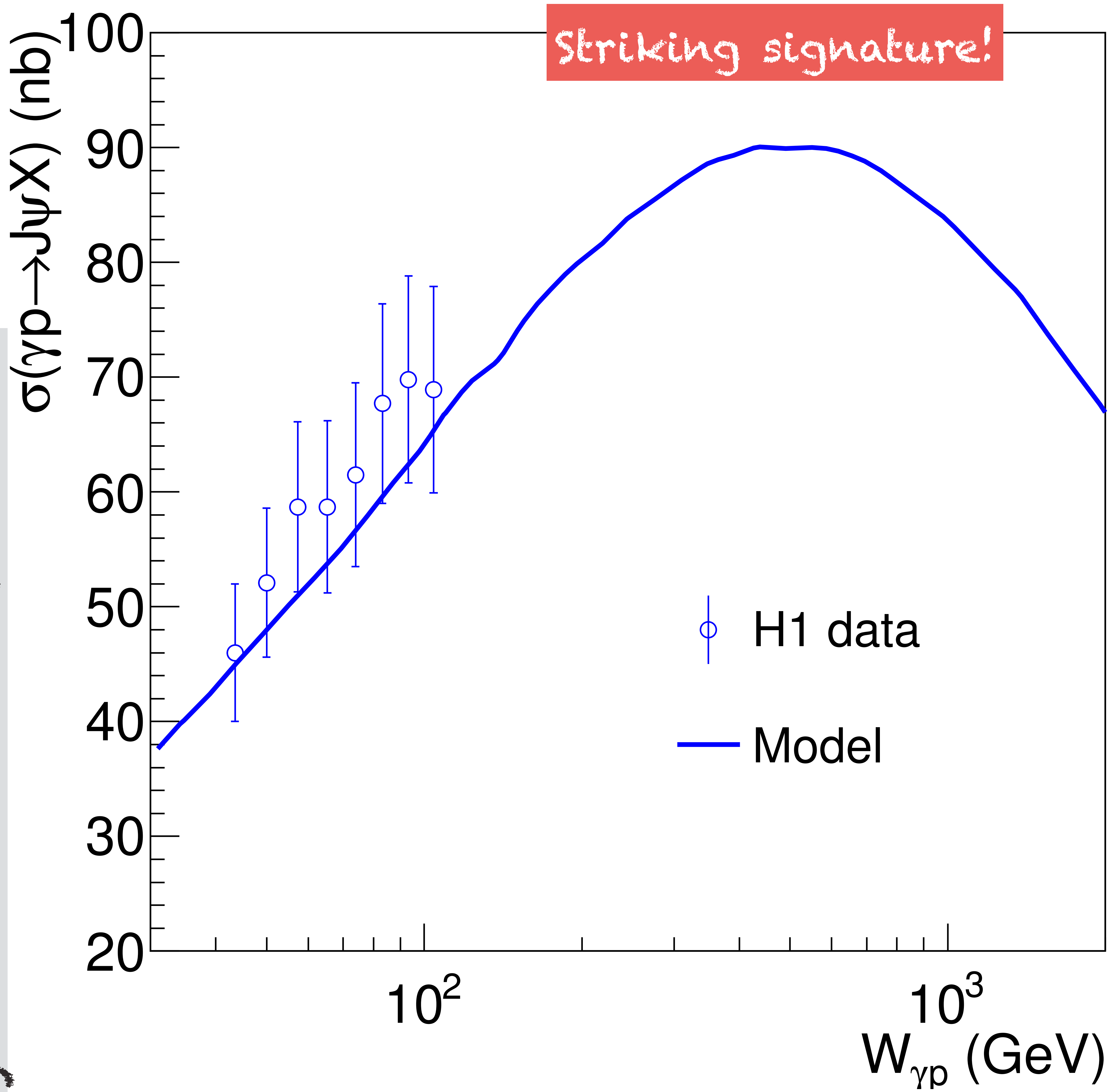
Phys. Lett. B766 (2017) 186-191

Comparison to vector meson data

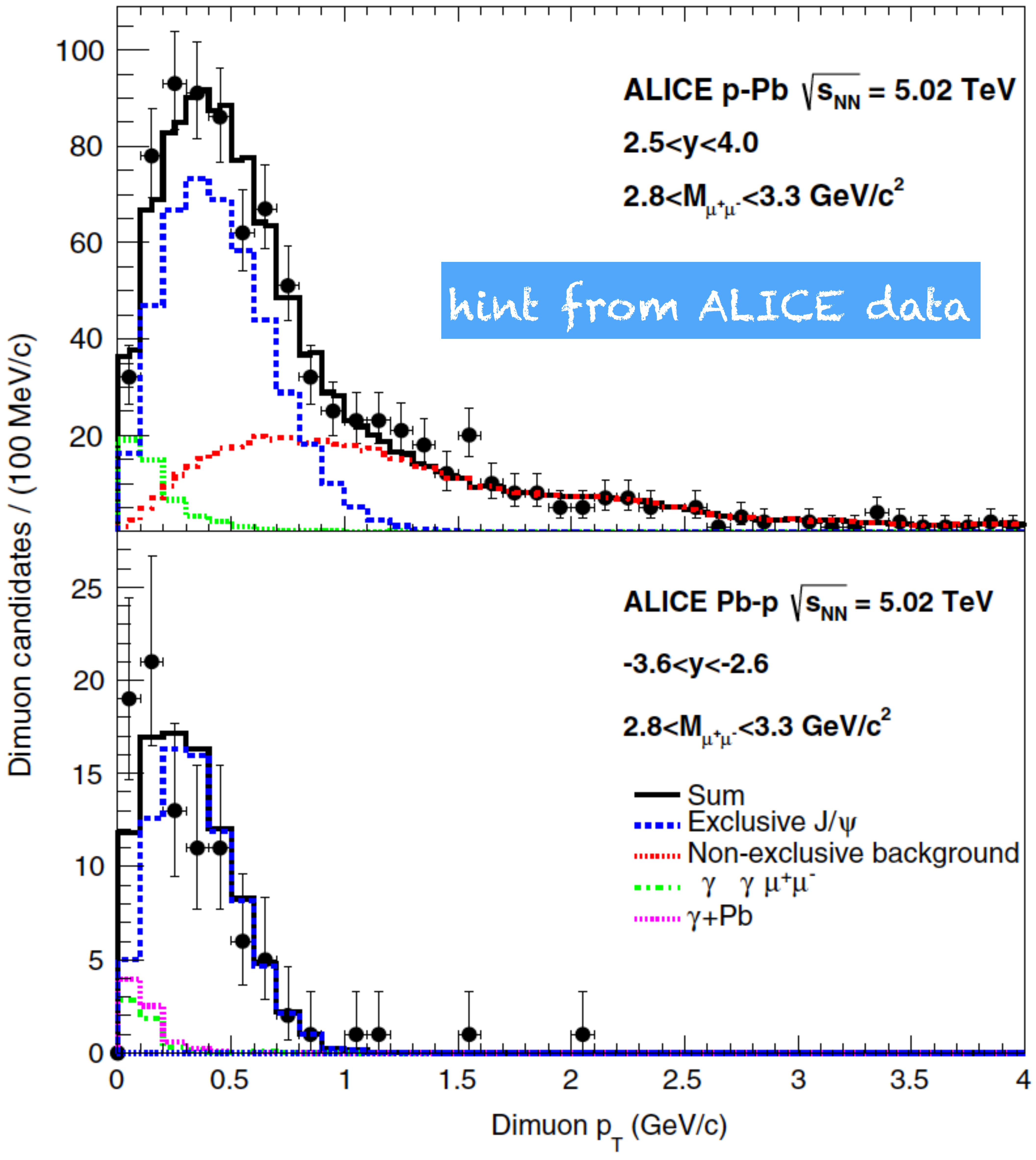


Phys. Lett. B766 (2017) 186-191

Prediction for dissociative production



Phys. Lett. B766 (2017) 186-191



PRL 113, 232504 (2014)

Some comments

- The parameters take expected values (see discussion in the paper).
- Even though the model describes reasonably well data, it is a simple model, so the main conclusion is qualitative: at large energies the dissociative production cross section turns around and decreases.
- The turn around has a geometric origin reminiscent of percolation, and implies that all configurations of a black disk look the same and the variance then disappears.
- Quantitatively, the turn around in the model happens at $W_{\gamma p}$ around 500 GeV
- ALICE and H1 data suggest that in reality it may even happen at smaller energies

Summary and outlook

- Dissociative photoproduction of J/ψ vector mesons can be used to look for gluon saturation
- The signature is striking: the cross section rises with energy up to a maximum to decrease steeply afterwards
- There are experimental and phenomenological suggestions that this is happening within the energy range accessible at the LHC
- It would be very interesting if we could measure the energy dependence of the dissociative production cross section

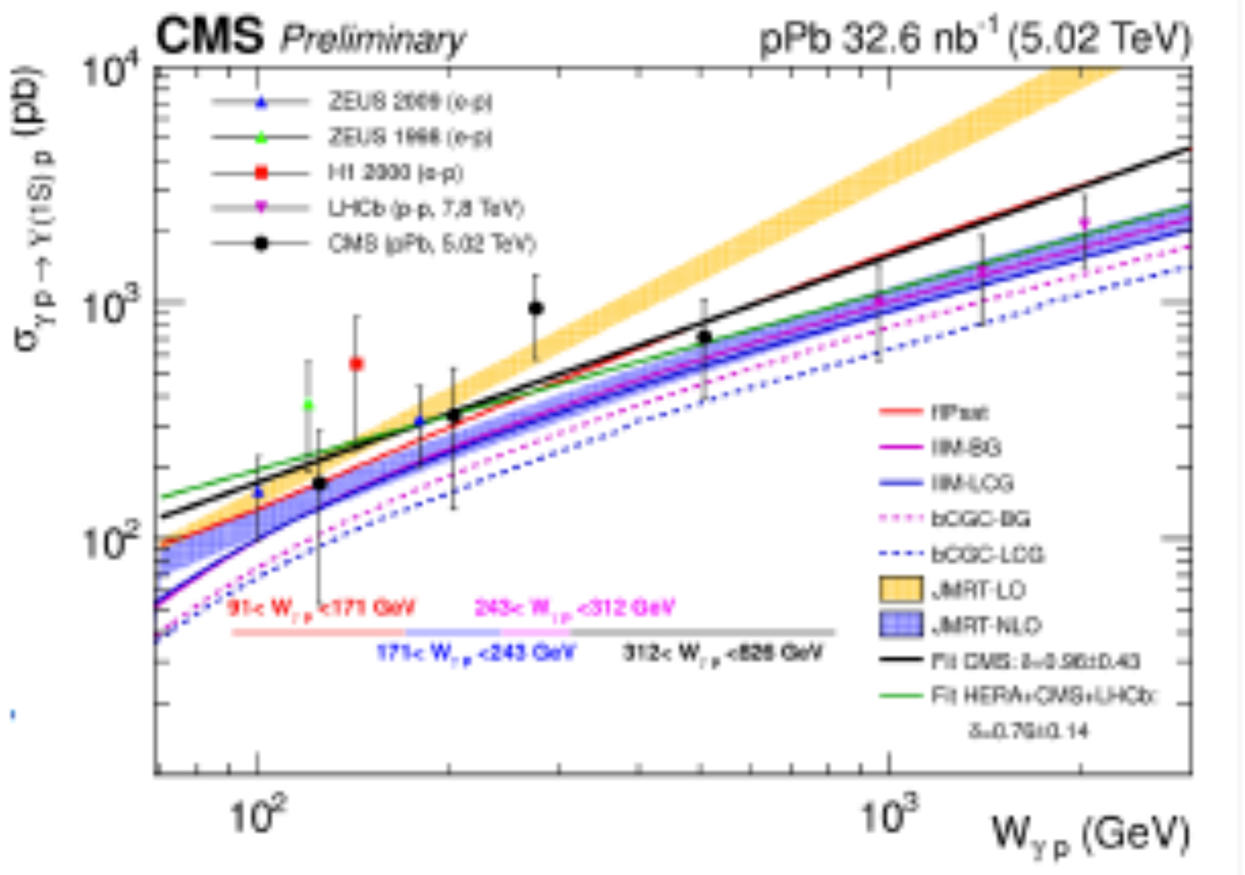
Exclusive production of ψ(2s) and ϒ

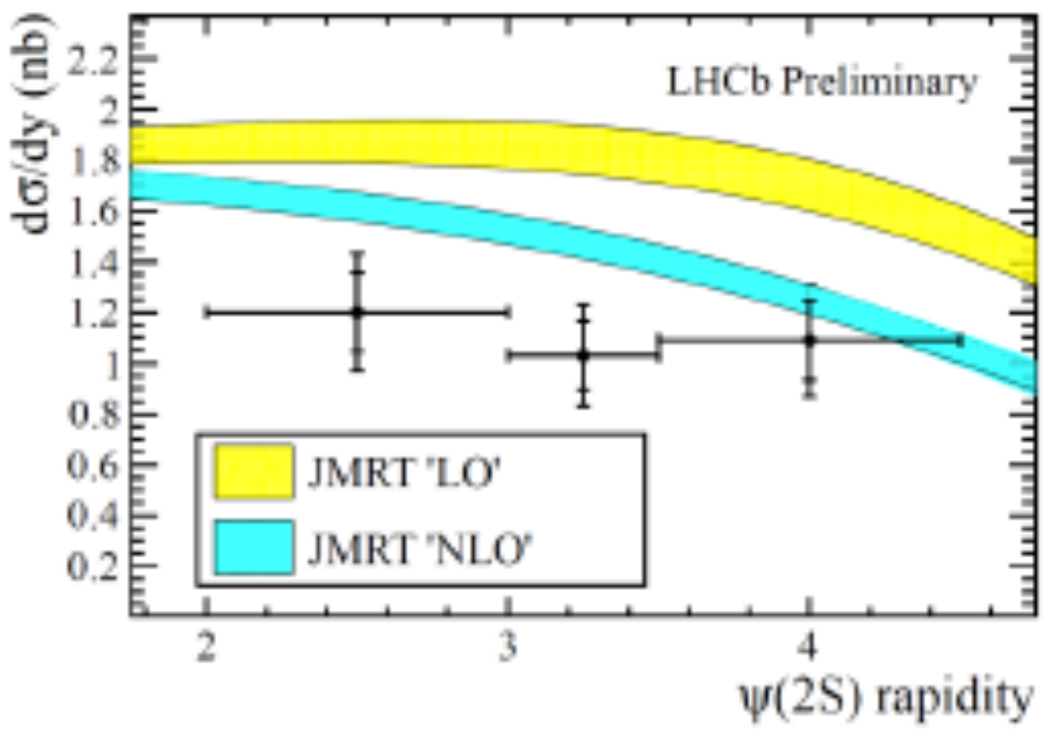
Bartłomiej Rachwał
LHCb

Exclusive production ψ(2s) at 13 TeV

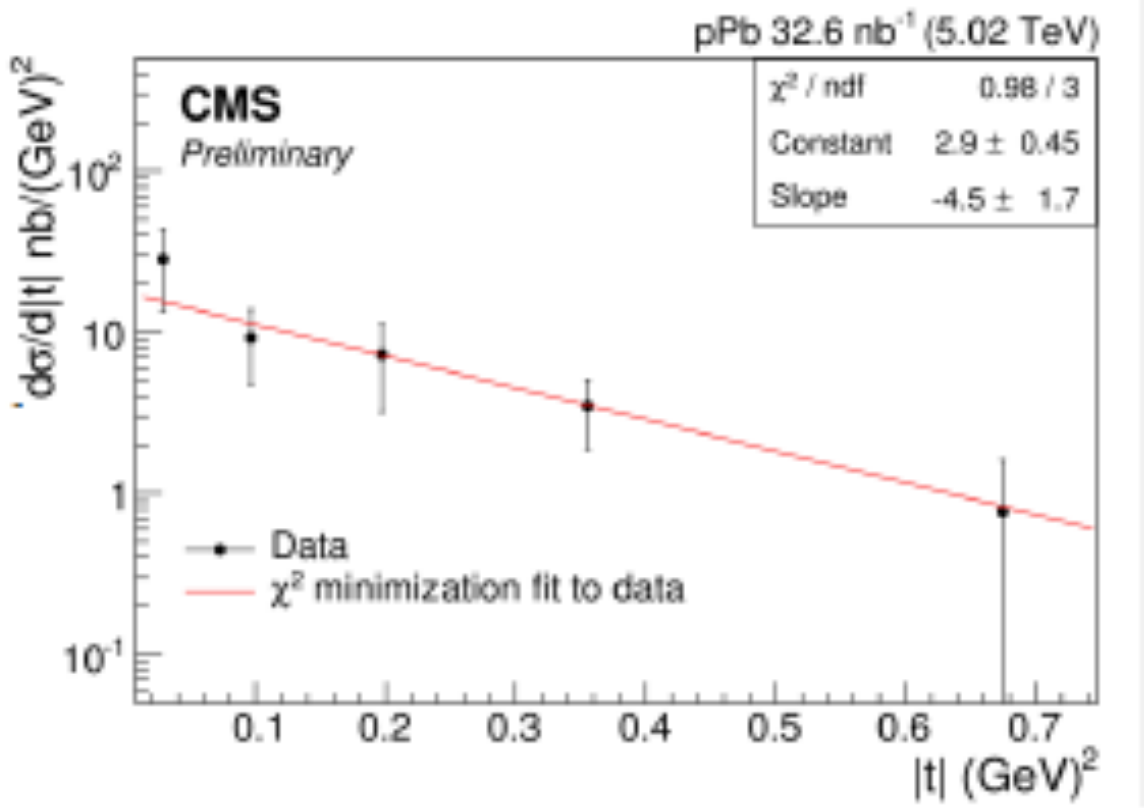
$$\sigma_{\psi(2S)\to\mu^+\mu^-}(2.0 < \eta(\mu^{\pm}) < 4.5) = 9.4 \pm 1.3(stat) \pm 0.5(sys) \pm 0.4\text{pb}$$

Alexander Bylinkin
CMS





A fit with power-law A X $(W/400)^{\delta}$ to the CMS data
$\delta = (0.96 \pm 0.43)$, A = 655 ± 196
Data compatible with power-law dependence of $\sigma(W_{\gamma p})$, disfavours LO pQCD predictions



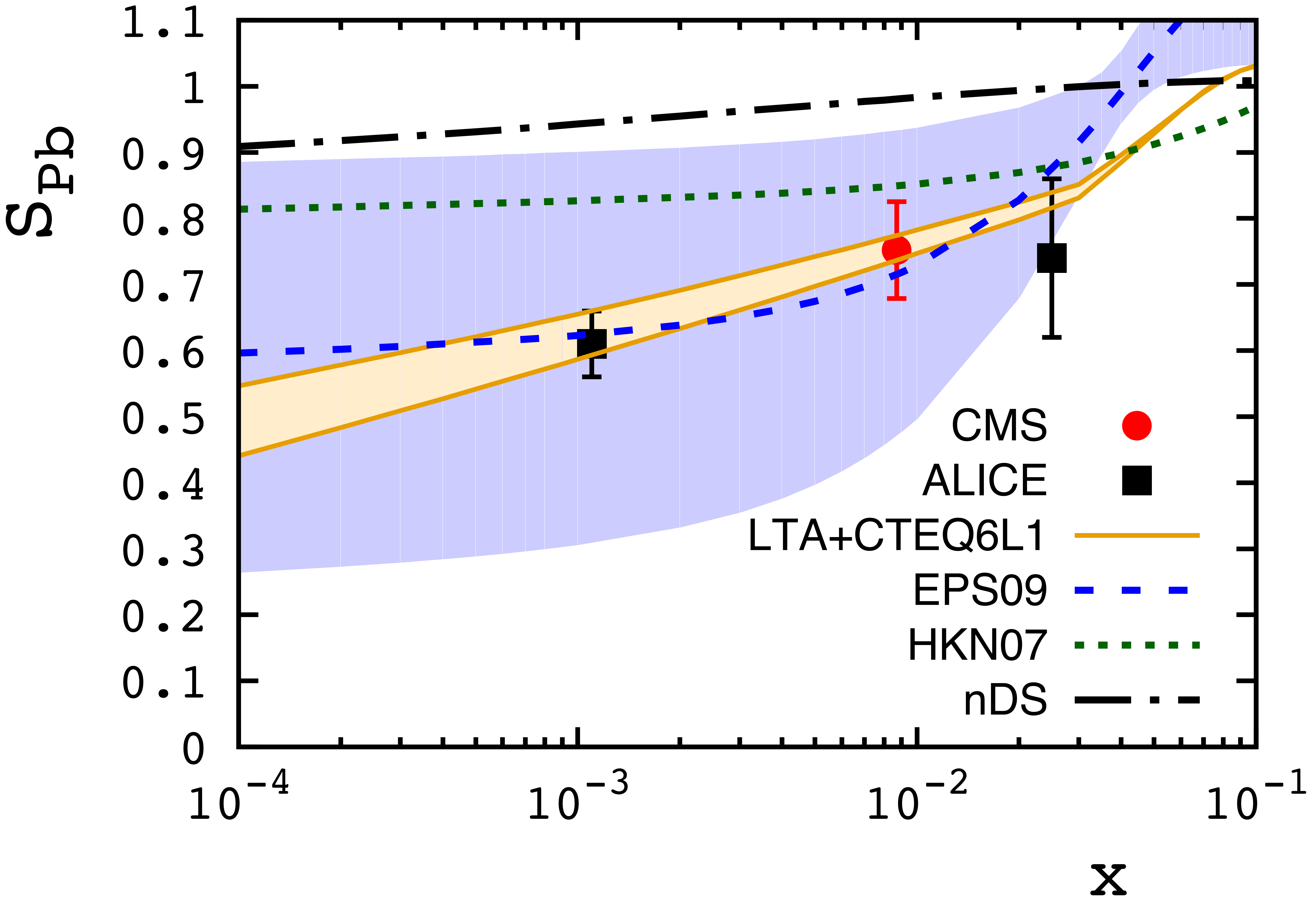
Still missing: energy dependence of t distribution for vector meson

WG2: Low x and Diffraction

One more thing …

Nuclear suppression factor in Pb (S)

See V. Guzey talk today



Vector meson photoproduction in UPC Pb-Pb

Neutron dependence

$$d\sigma(\mathrm{total})/dy = d\sigma(\mathrm{0n0n})/dy + 2d\sigma(\mathrm{0nXn})/dy + d\sigma(\mathrm{XnXn})/dy$$

There is a factor 2… the emitted neutrons and the photoproduced J/ψ events appear to be independent processes within the current uncertainty (0nXn ~ Xn0n)

Vector meson photoproduction in UPC Pb-Pb

Neutron dependence

$$d\sigma(\text{total})/dy = d\sigma(\text{0n0n})/dy + 2d\sigma(\text{0nXn})/dy + d\sigma(\text{XnXn})/dy$$

There is a factor 2 since the neutron and the coherent J/ψ are independent processes (confirmed by data)

Two components:

High-x: **J/ψ and the emitted neutrons: same rapidity hemisphere**

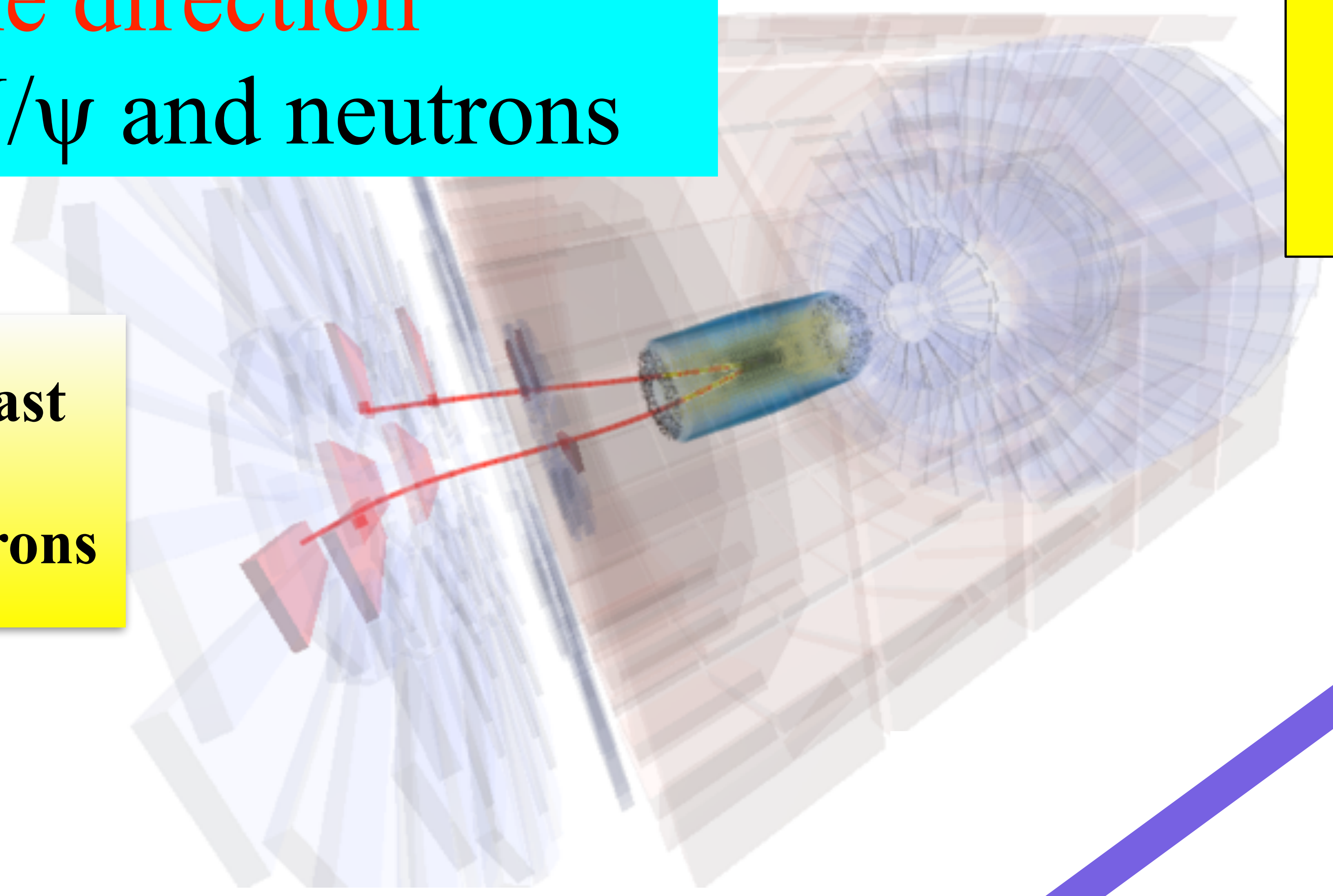
Low-x: **J/ψ and the emitted neutrons: opposite rapidity hemisphere**

Two different type of topologies

Same direction for J/ψ and neutrons

No neutrons

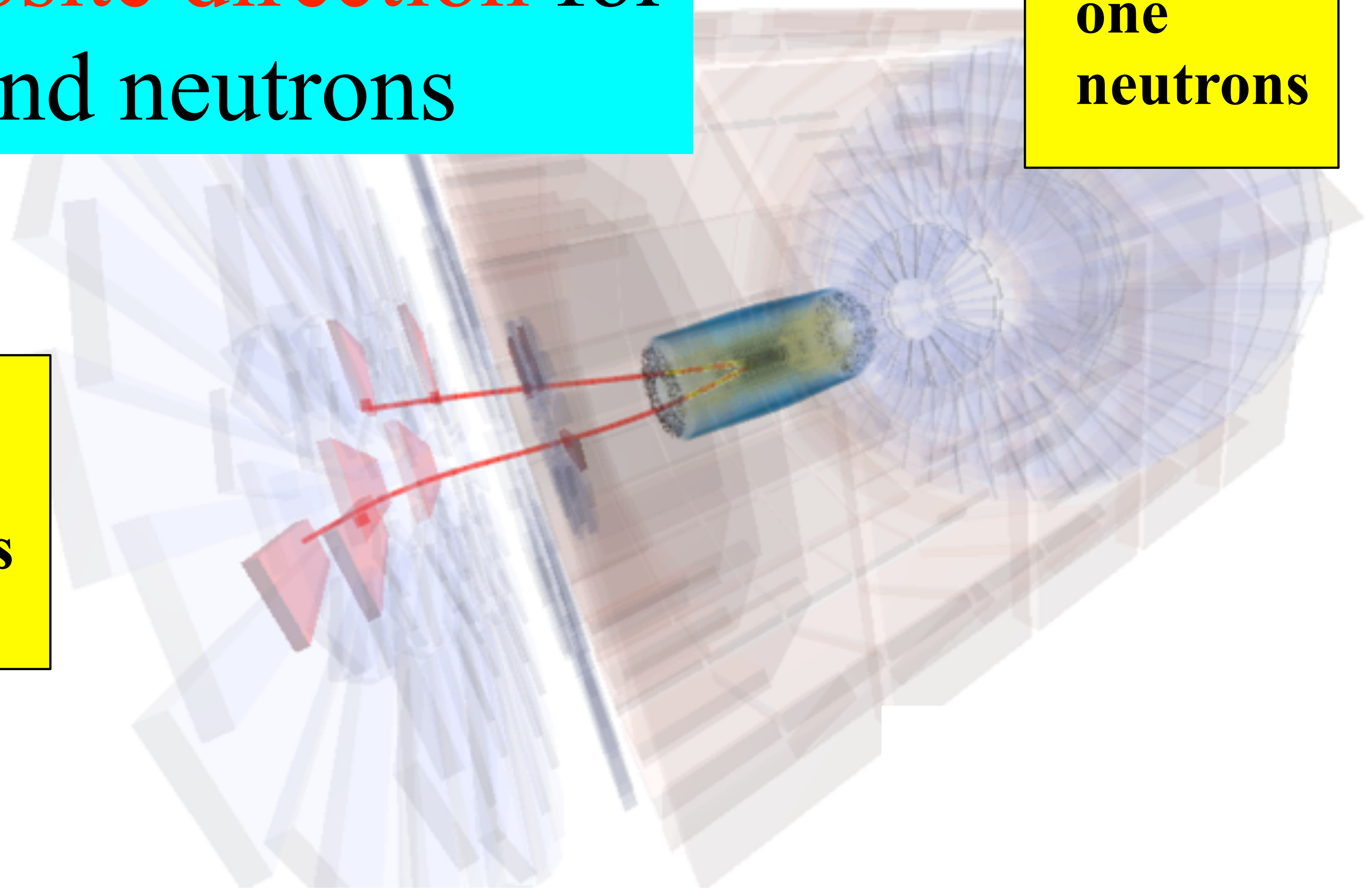
At least one neutrons



Opposite direction for J/ψ and neutrons

At least one neutrons

No neutrons

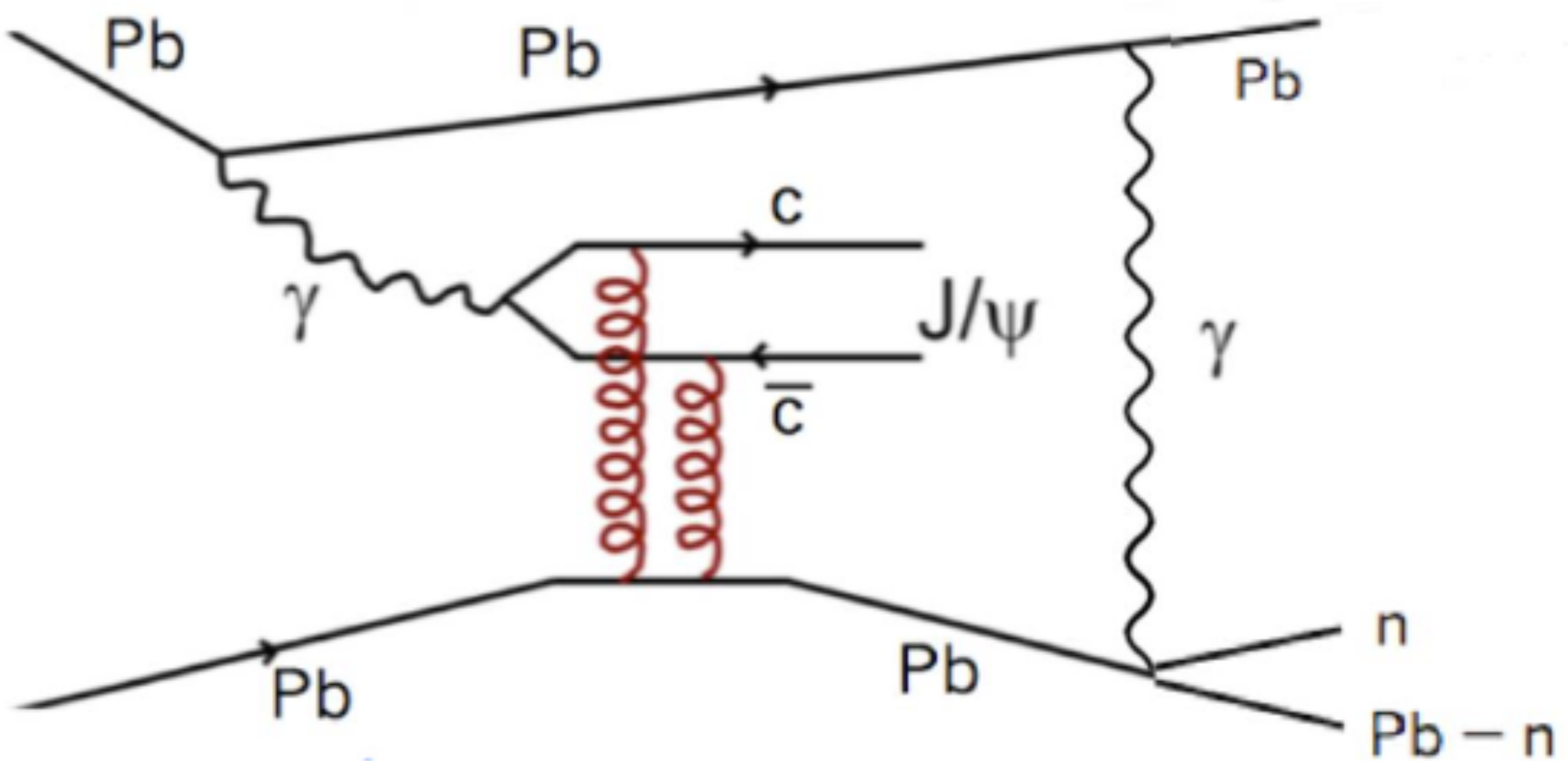


Incoherent photoproduction in UPC Pb-Pb

Total cross section

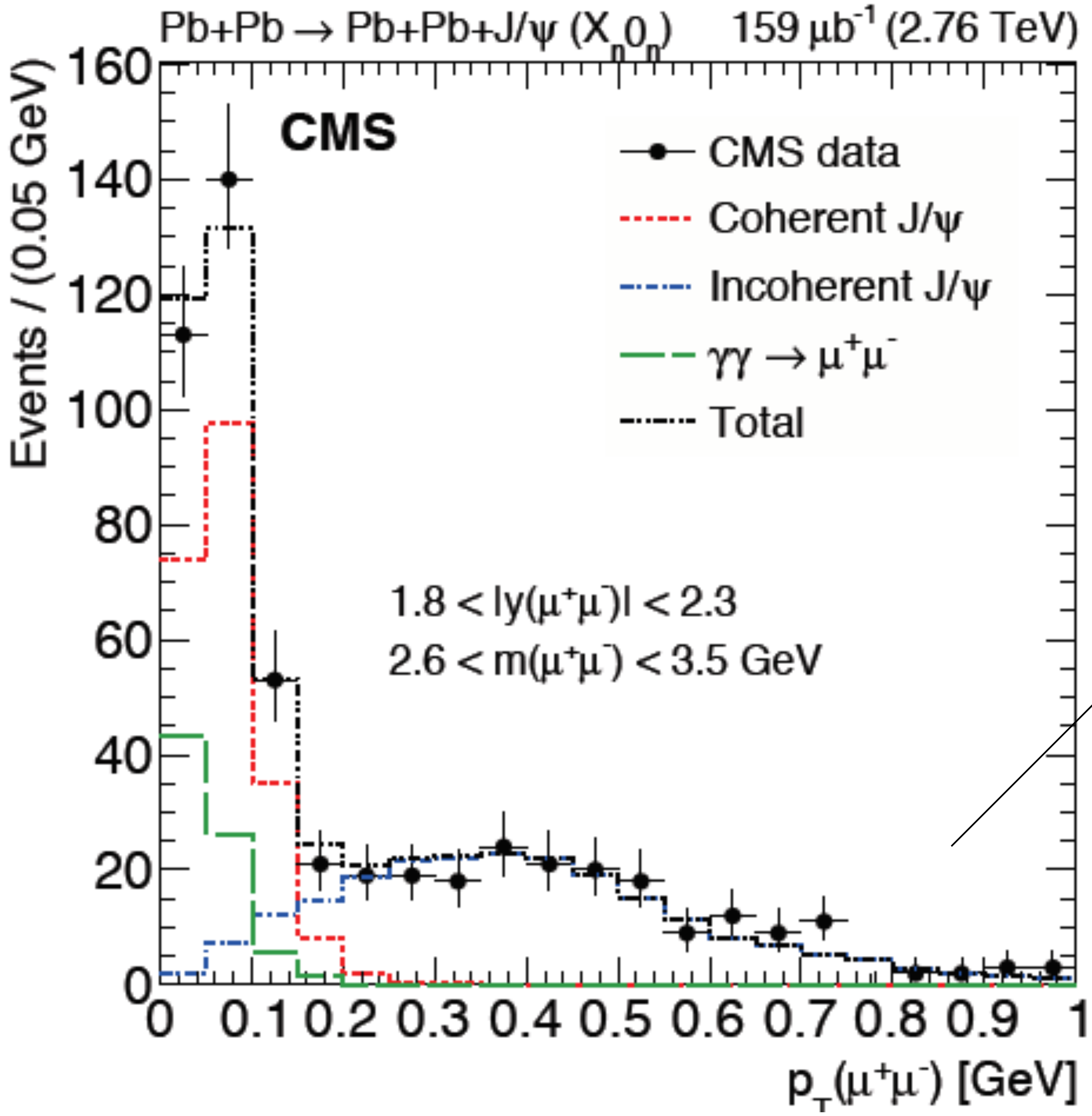
Low W: x~ 10-2 **High W: x~ 10-4**

$$\frac{d\sigma_{\mathrm{PbPb}}(y)}{dy} = N_{\gamma/\mathrm{Pb}}(y,M)\sigma_{\gamma\mathrm{Pb}}(y) + N_{\gamma/\mathrm{Pb}}(-y,M)\sigma_{\gamma\mathrm{Pb}}(-y)$$



Incoherent production is expected to be more sensitive to the photon direction (energy dependence). Here 0nXn and Xn0n will unfold the two x-values

Energy dependence of Incoherent J/ψ



Incoherent background is the High-x region

Incoherent J/ψ background (Xn0n): ***Events are in the High-x region.***

At Low-x, incoherent production is very strongly suppressed wrt to High-x region - First time seen in γ+Pb interactions

One more thing …

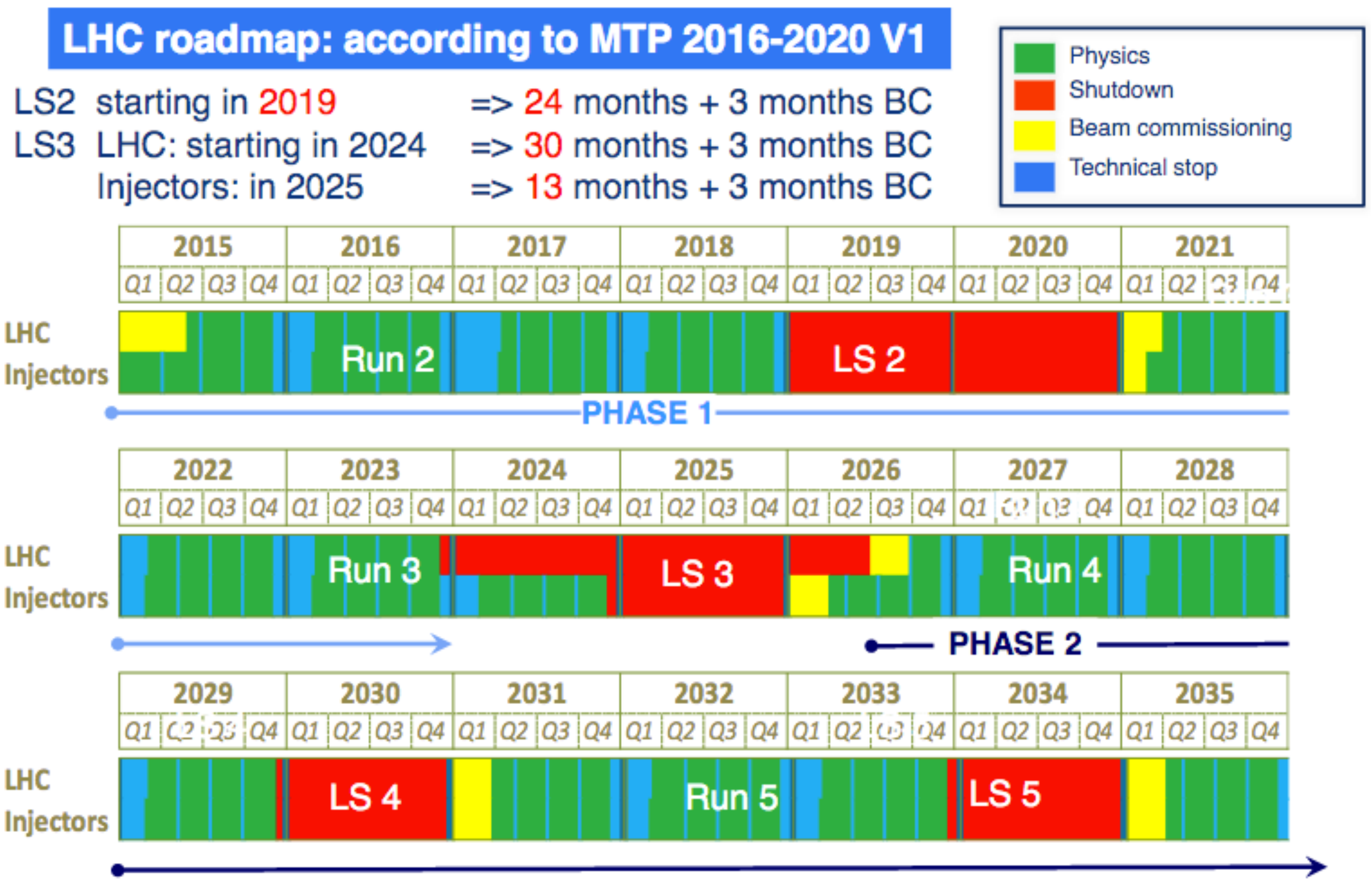
White paper

- Following the INT workshop, a White Paper on photon-nucleus/proton will be prepared

  Coordinated by DTT and in preparation…

LHC schedule

CERN Yellow Report: *CERN-PH-LPCC-2015-001*



Additional slides

Forward detectors at CMS