Ultra-peripheral collisions

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Universidad de Alcalá de Henares

AdTCM

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Aussois, France
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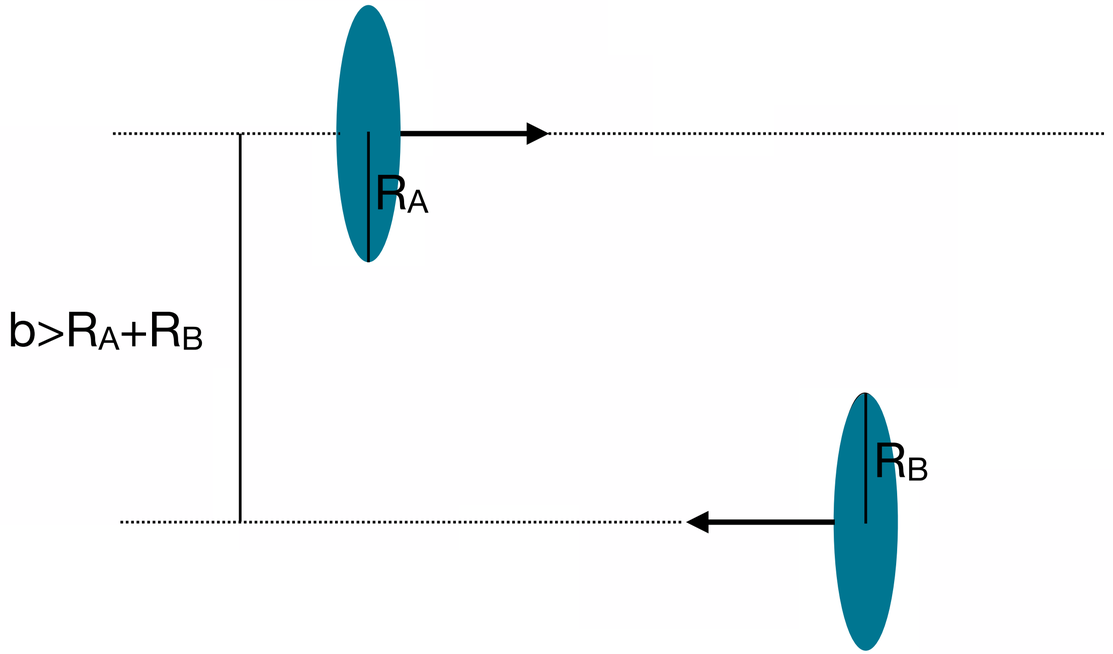
Ultra-peripheral collisions

large–impact-parameter interactions



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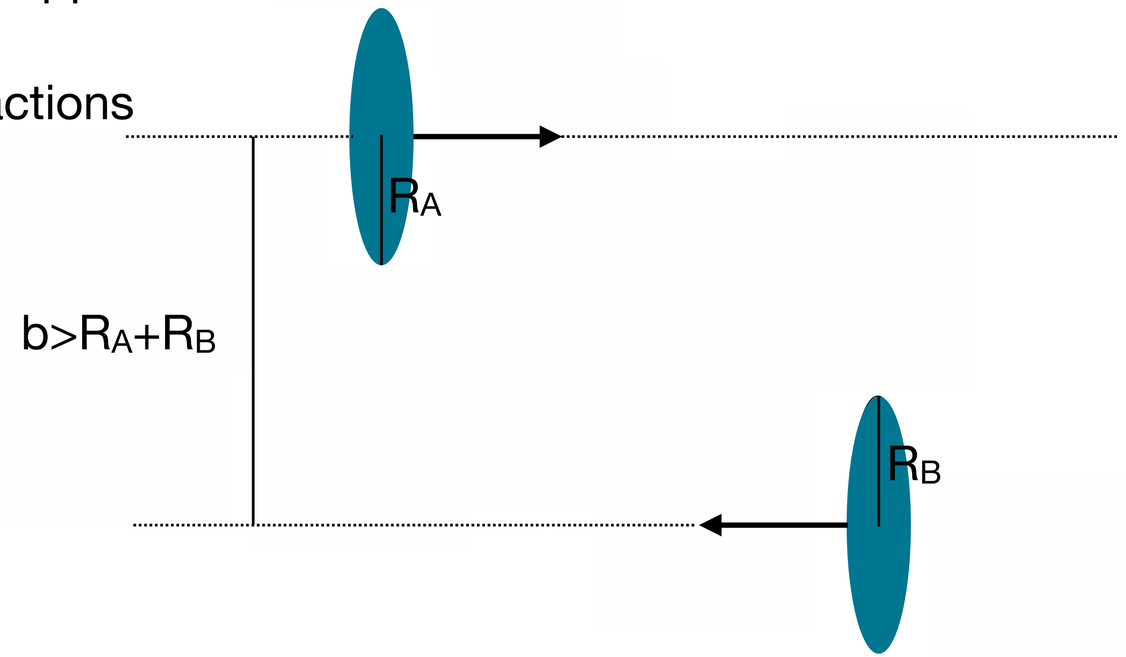

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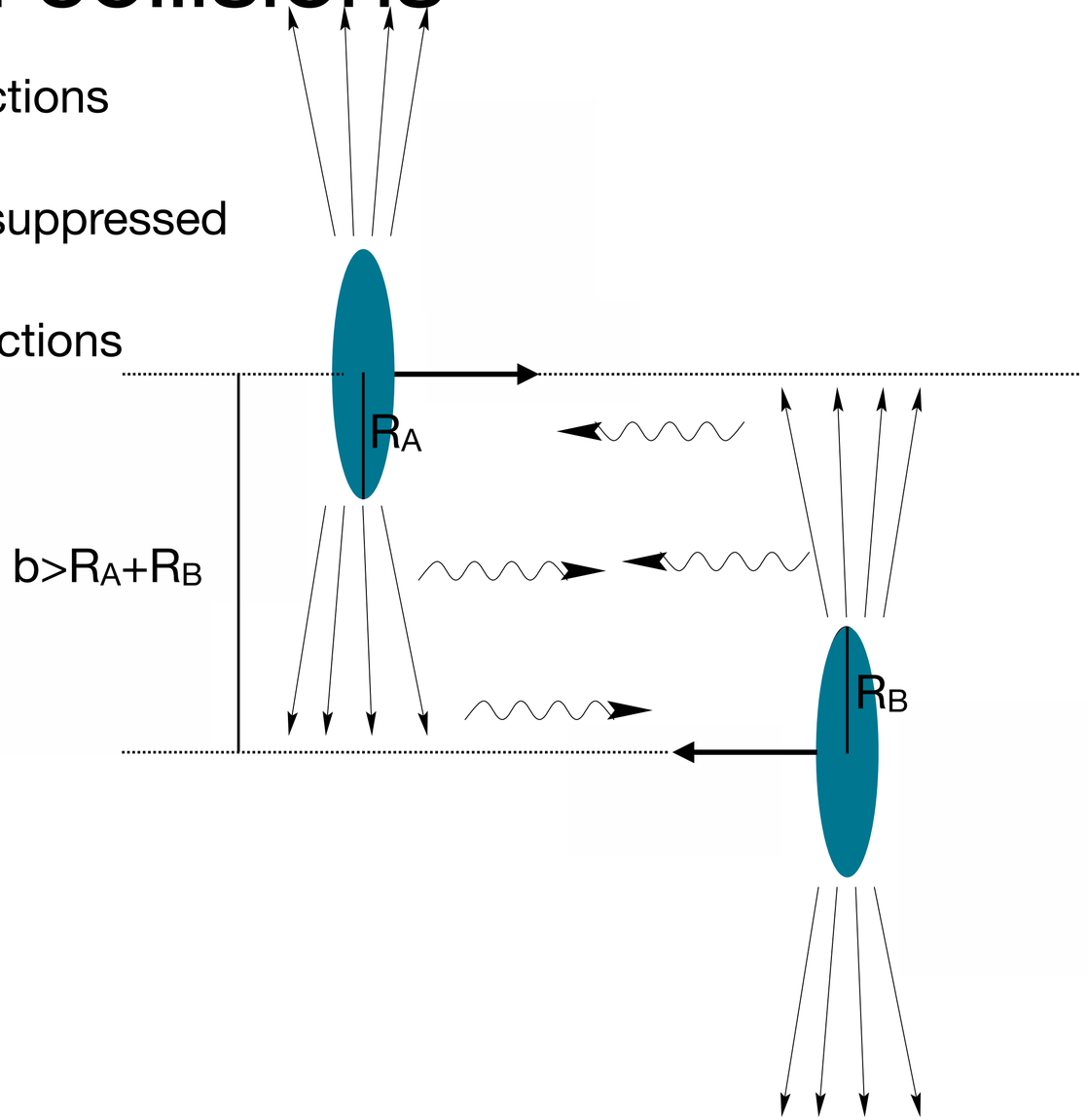

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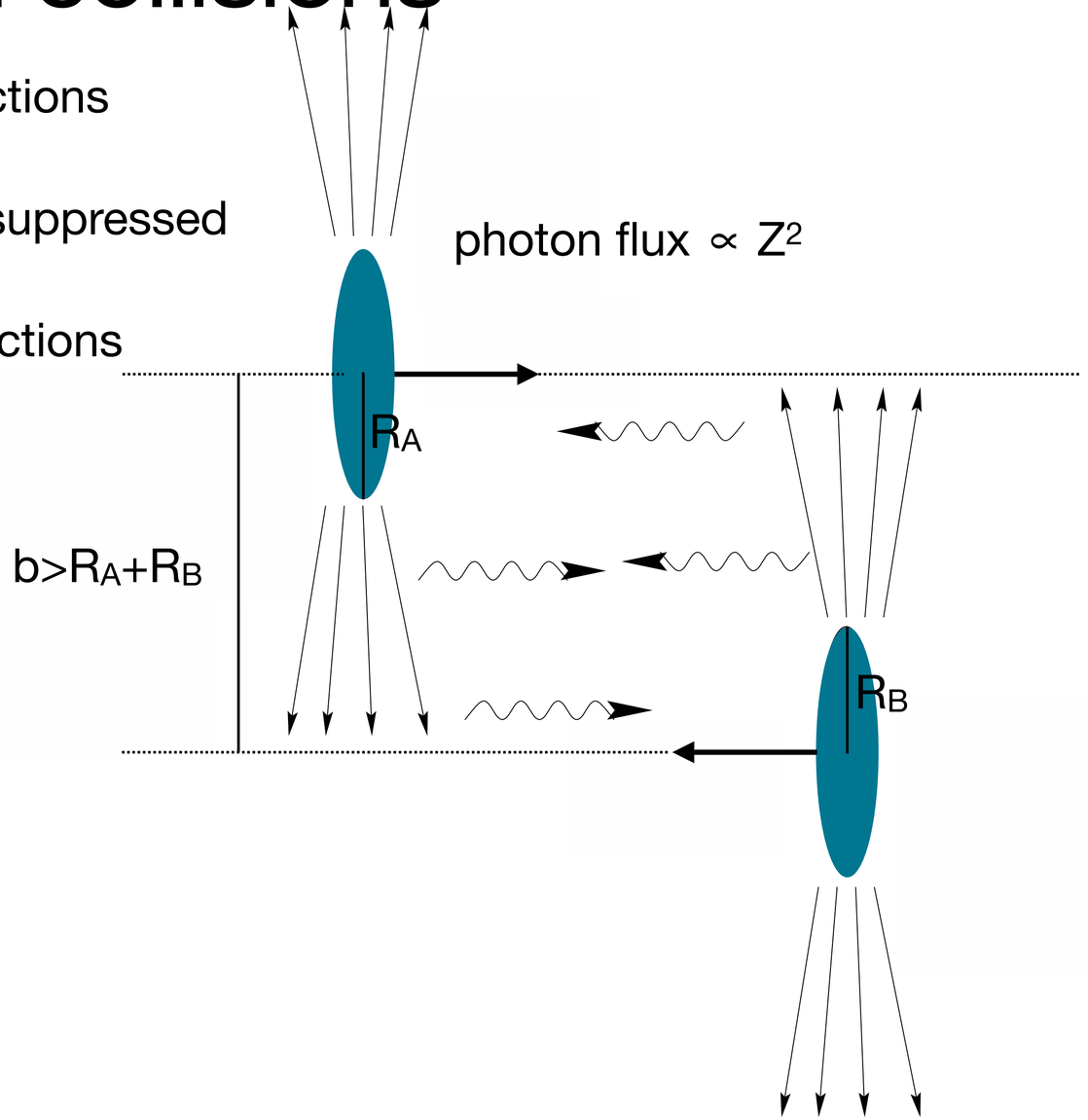

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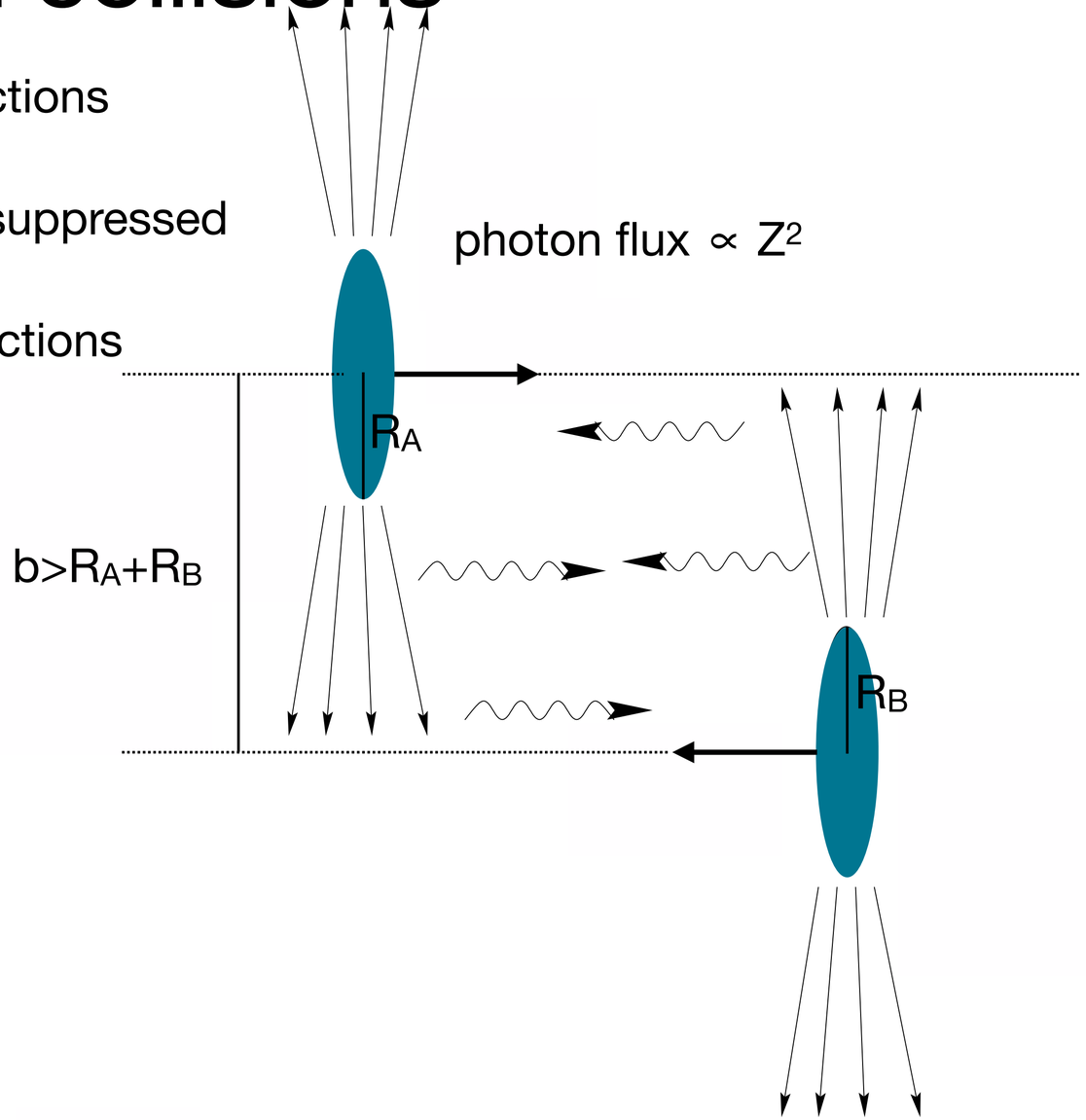

photon virtuality $Q^2 < \left(\frac{\hbar c}{R_A}\right)^2$

→ quasi-real photons

maximum photon energy = $\frac{2\gamma\hbar c}{b_{\min}}$

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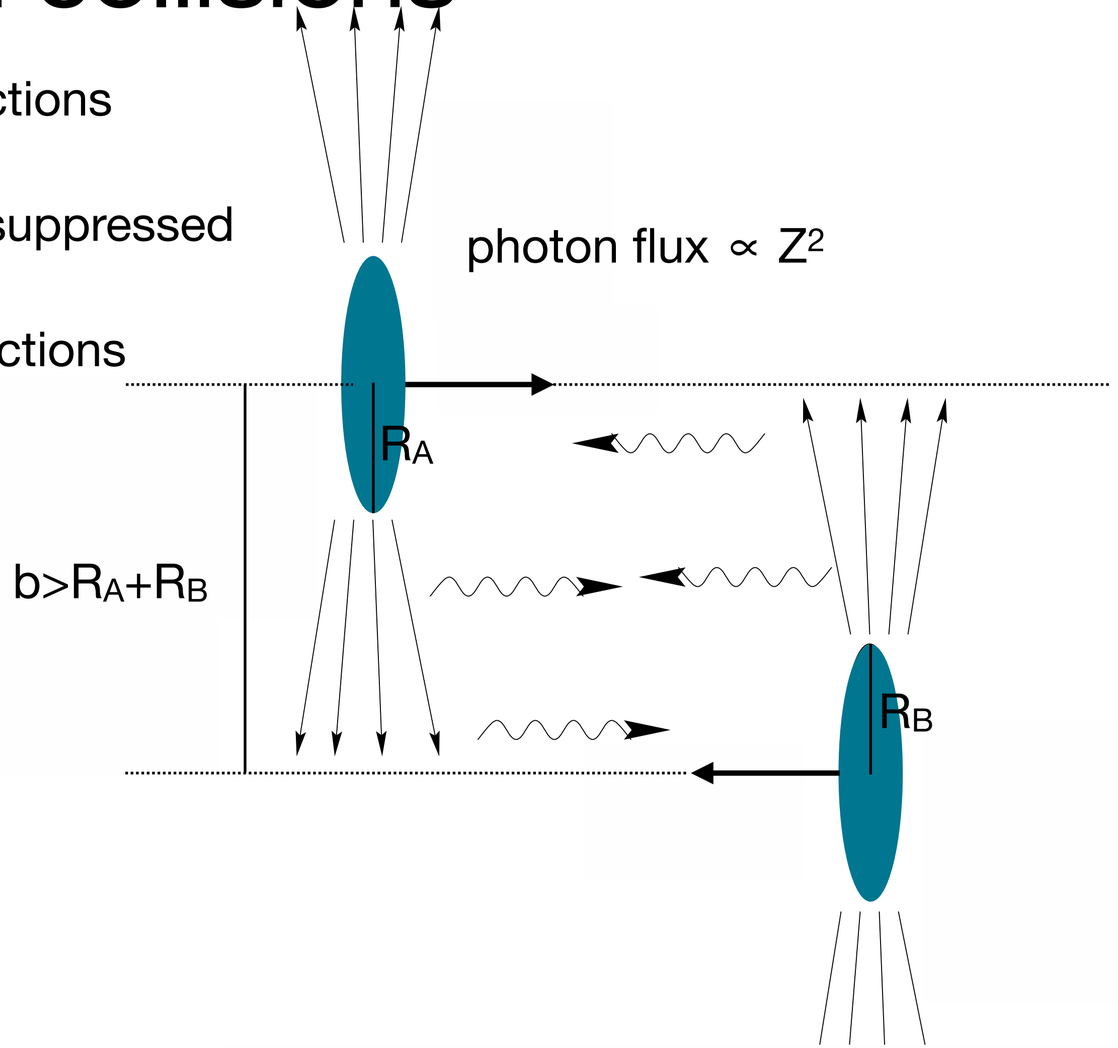

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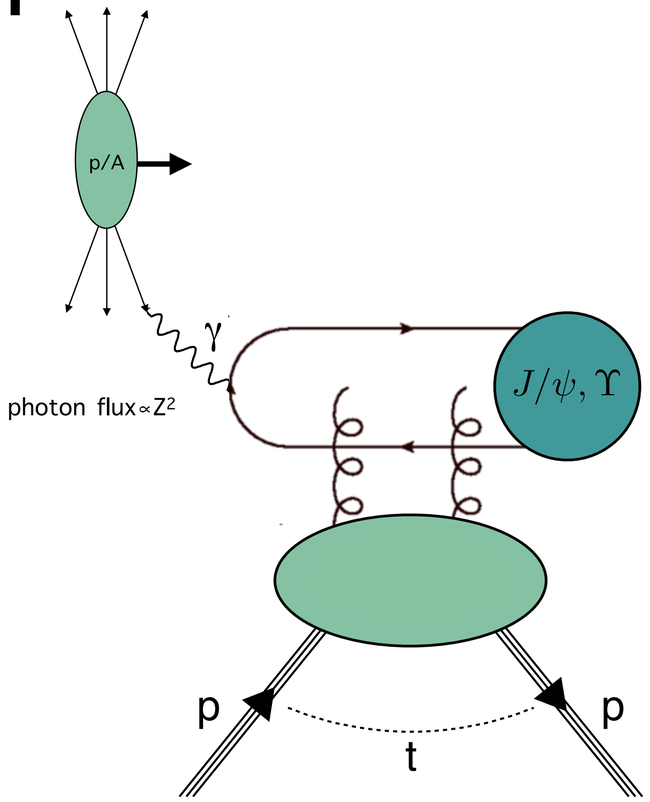
System	$\sqrt{s_{AB}}$	E_A	E_B	(a) $\gamma_{A\leftrightarrow B}$	(b) $E_{\gamma Max}$	(c) $E^{rest}_{\gamma Max}$	(d) $W^{max}_{\gamma p}$
pPb	5.02 TeV	4 TeV	1.567 TeV	1.43×10^7	28 MeV	0.4 PeV	0.86 TeV
pPb	8.16 TeV	6.5 TeV	2.56 TeV	3.78×10^7	28 MeV	1 PeV	1.4 TeV
pp	13 TeV	6.5 TeV	6.5 TeV	9.6×10^7	116 MeV	11 PeV	4.6 TeV

table: K. Lynch

Ultra-peripheral collisions in pPb

- Photon flux $\propto Z^2$

⟶ at first order: use the photon emitted by the Pb ion to probe the proton



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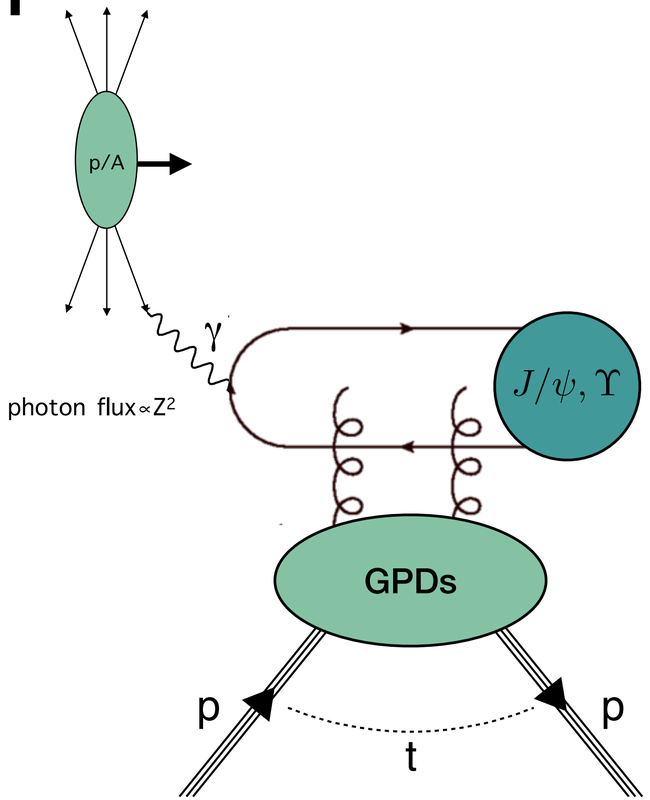

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Generalised parton distributions (GPDs)

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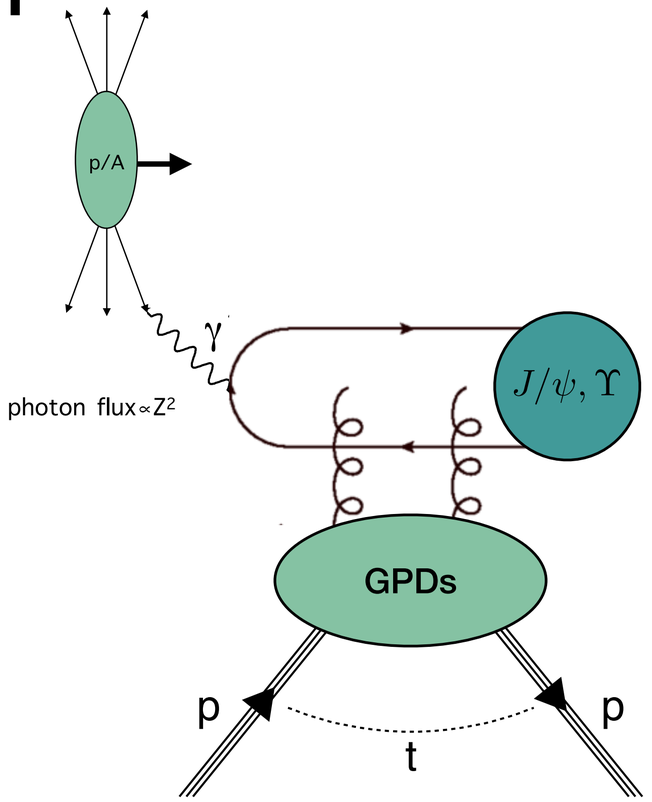

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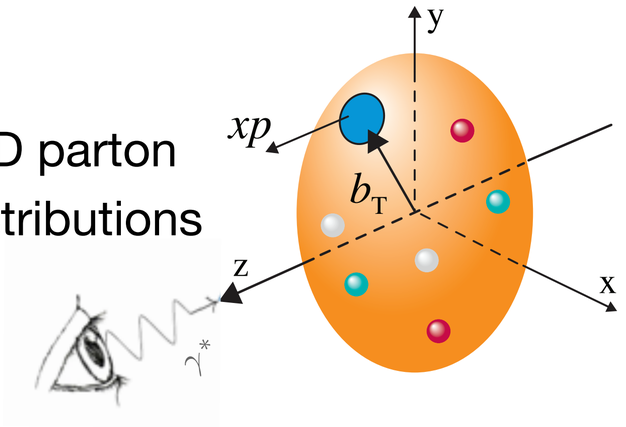
Generalised parton distributions (GPDs)

Fourier transform

3D parton distributions



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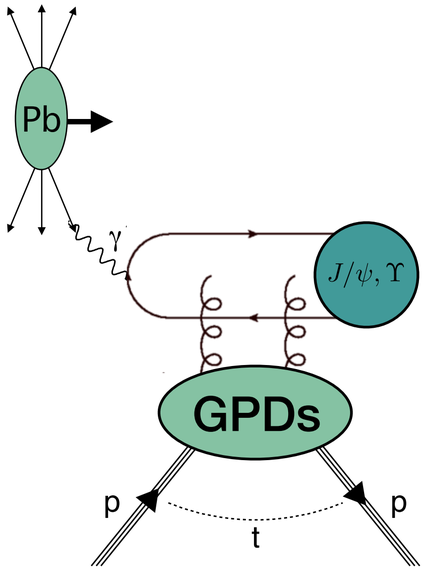

pPb: use Z^2 dependence of photon flux

→ Pb is predominantly photon emitter

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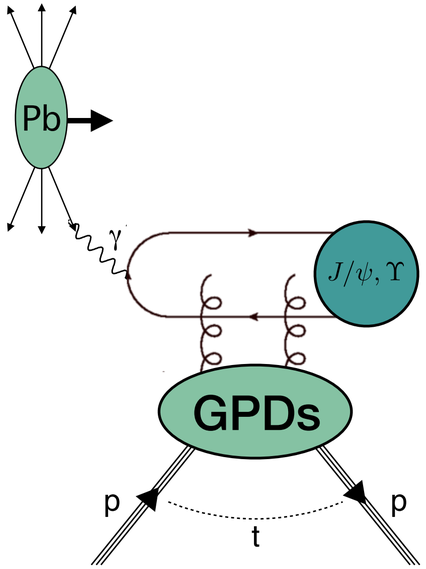

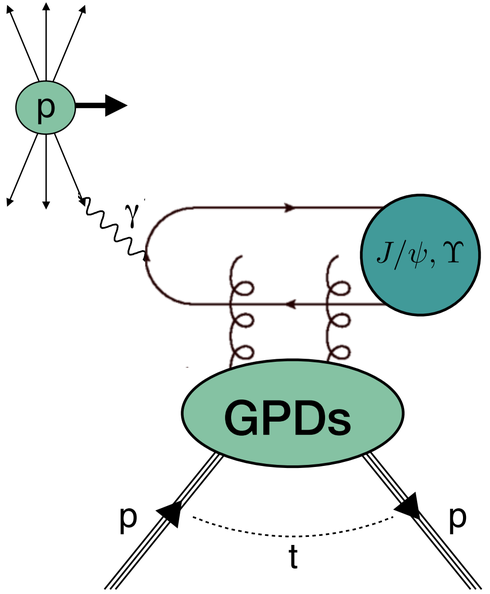

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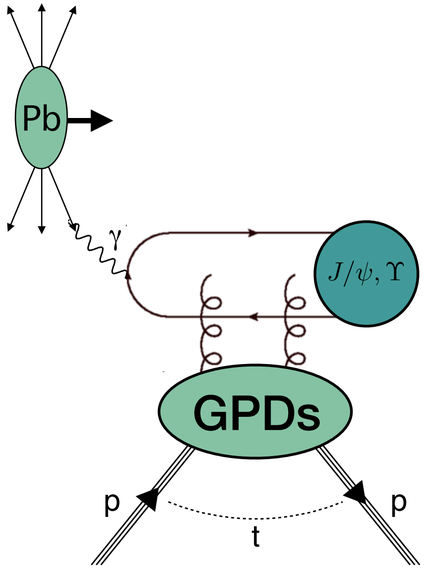

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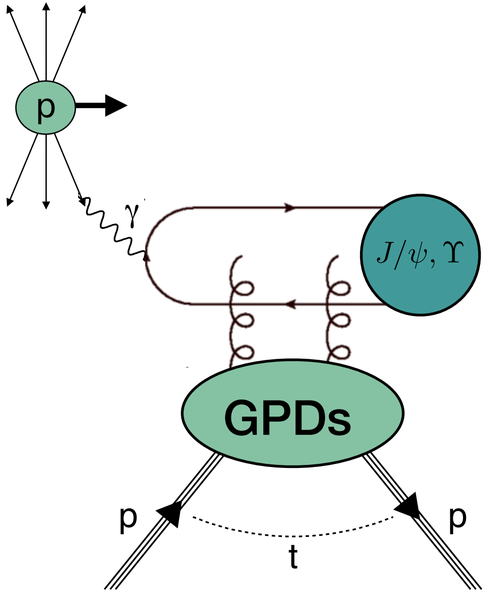

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- r = gap survival factor
- $k_{\pm} = \frac{M_{\psi}}{2} e^{\pm y}$ = photon energy
- $\frac{dn}{dk_{\pm}}$ = photon flux
- $W_{\pm}^2 = 2k_{\pm}\sqrt{s}$ = γp invariant mass

relation pp and γp cross section:

$$\sigma_{pp\to p\psi p} = r(W_+)k_+ \frac{\mathrm{d}n}{\mathrm{d}k_+}\sigma_{\gamma p\to\psi p}(W_+) + r(W_-)k_- \frac{\mathrm{d}n}{\mathrm{d}k_-}\sigma_{\gamma p\to\psi p}(W_-)$$

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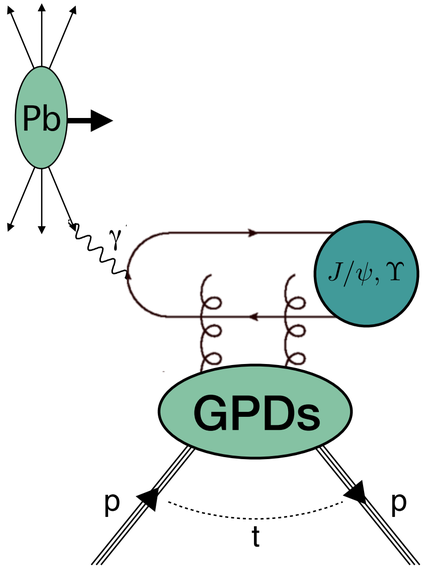

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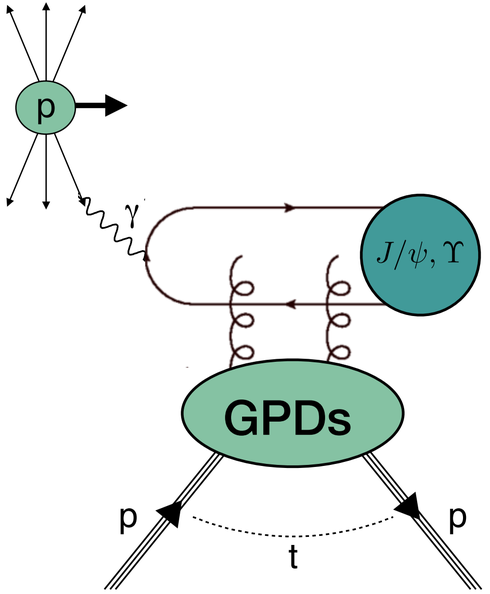

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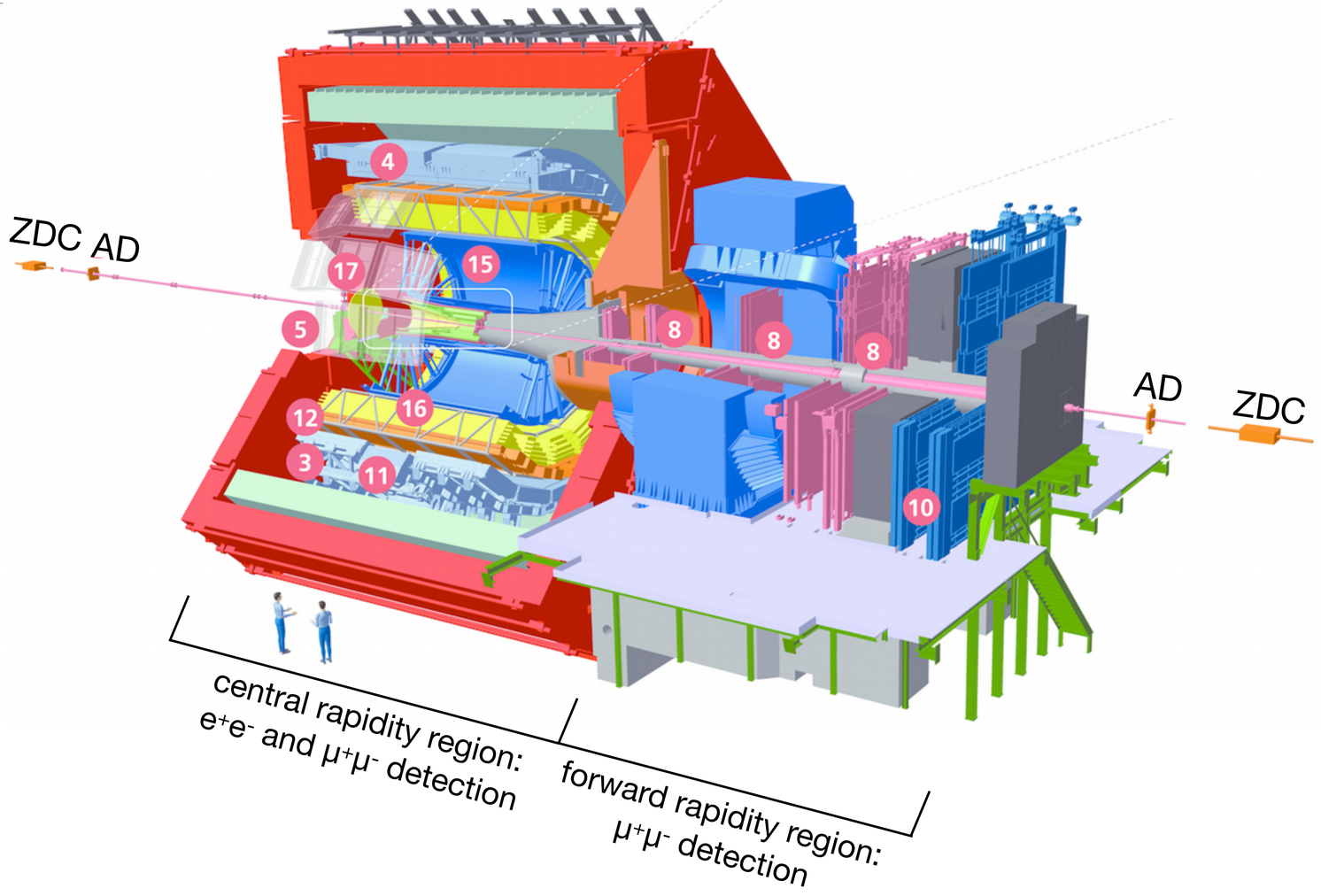
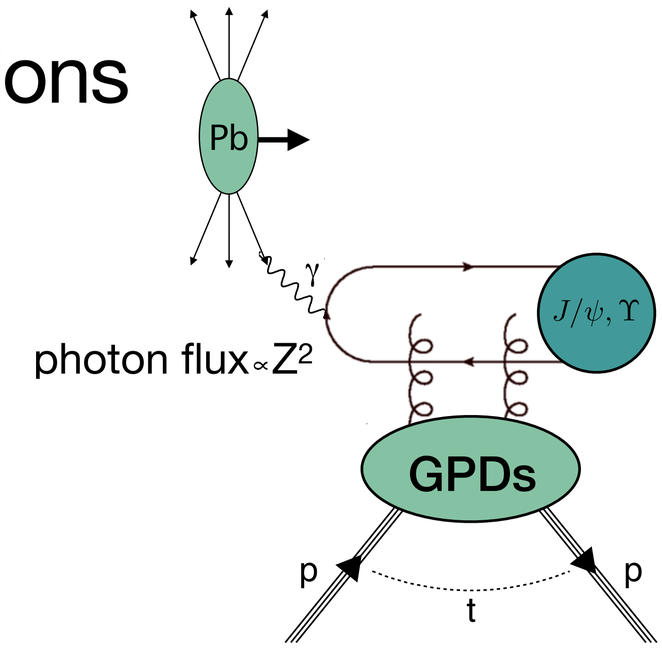
LHCb used HERA data for low-E_γ (W_-) contribution.

ALICE: exclusive single-J/ψ production in pPb collisions





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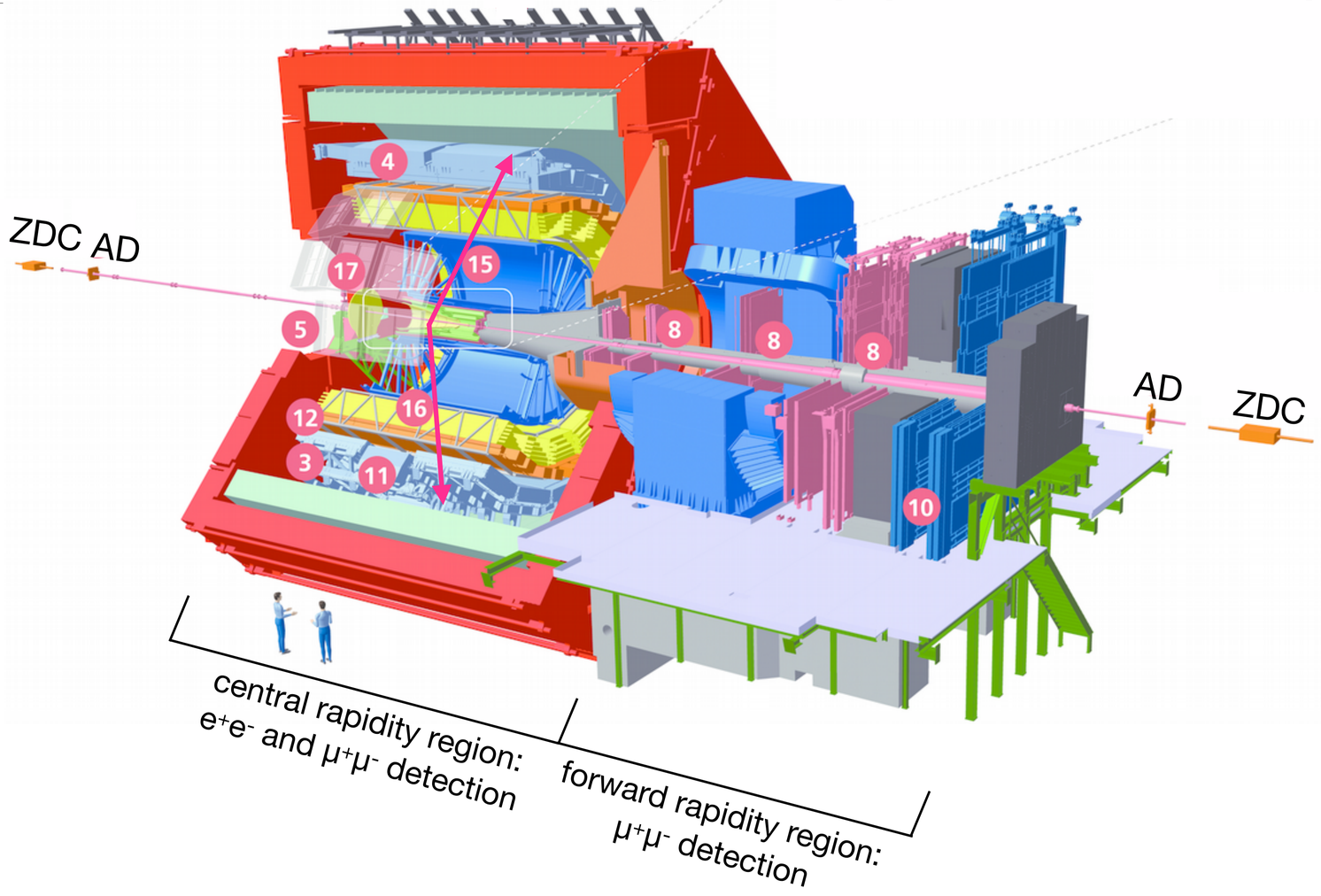

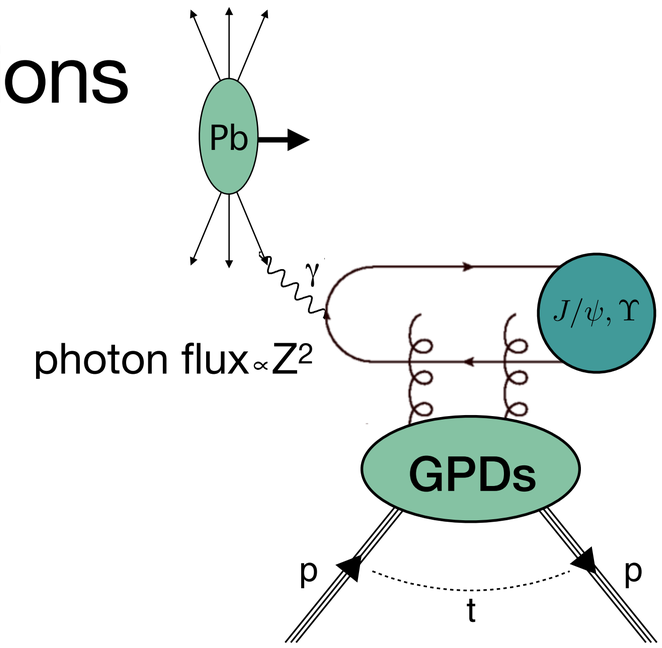

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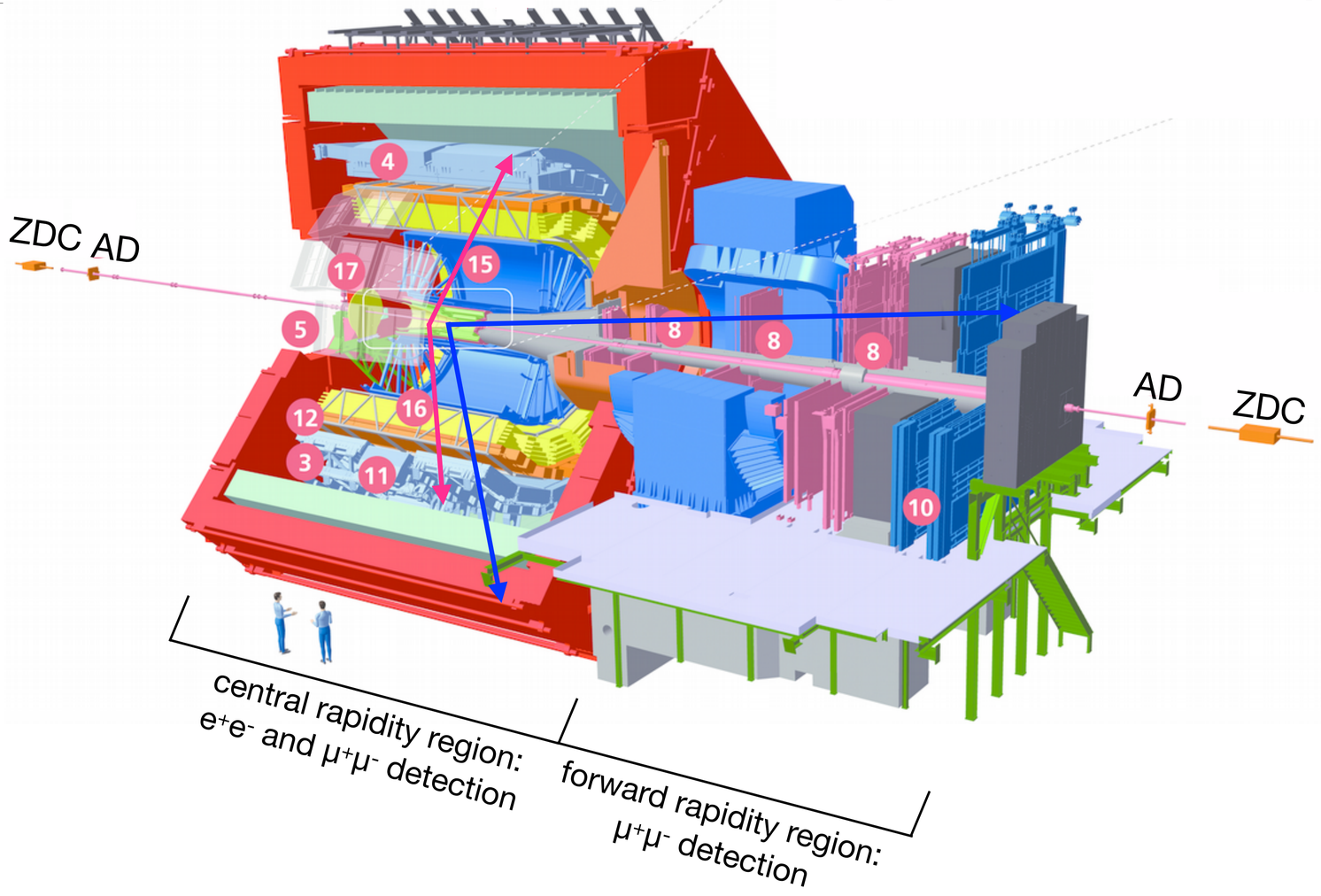

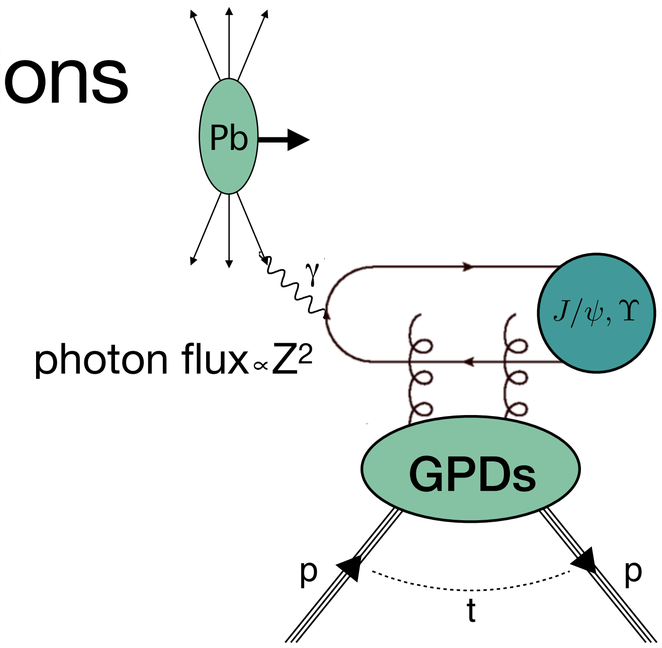

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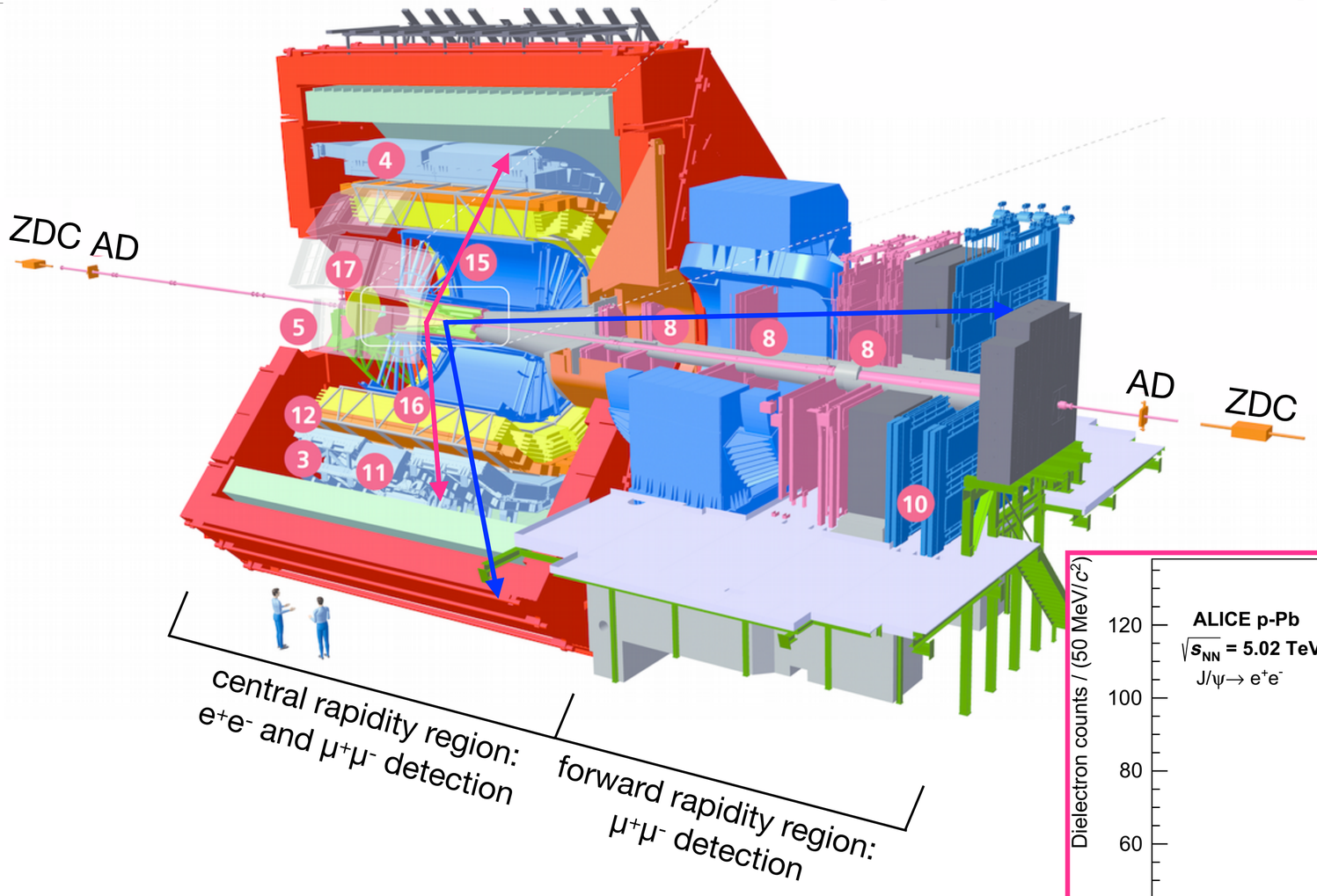

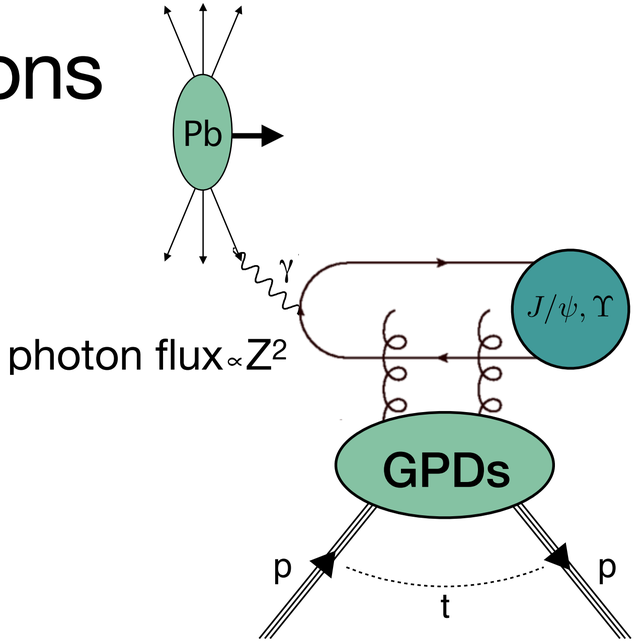

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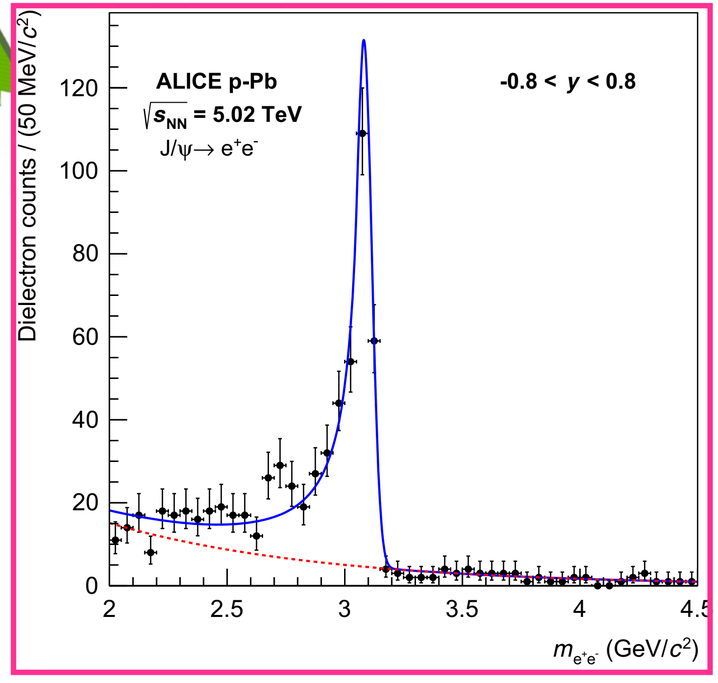
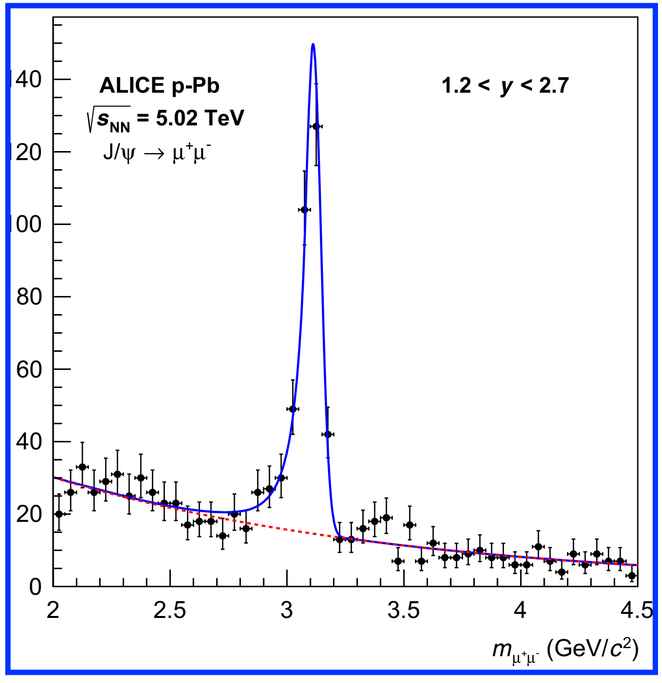
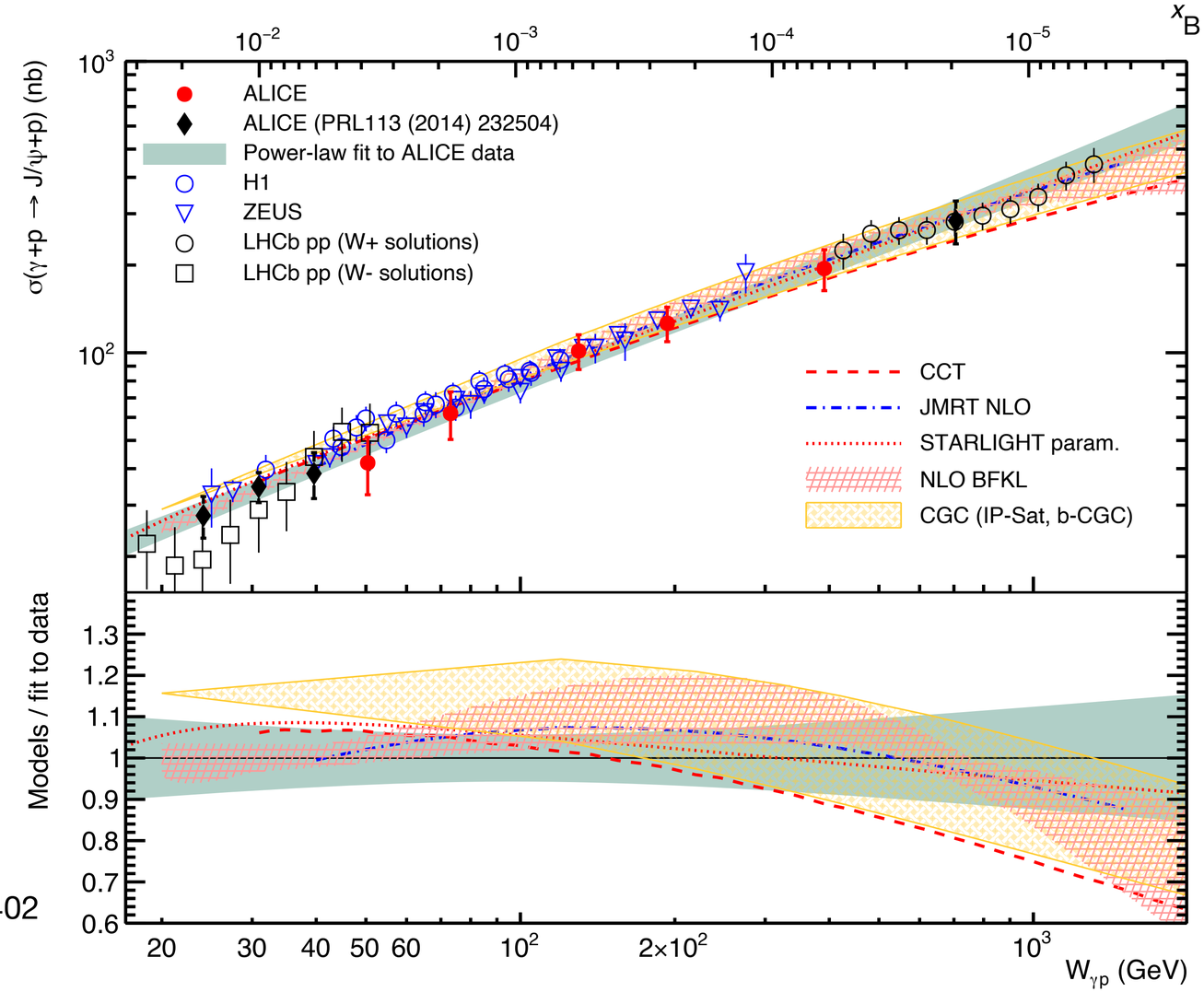




γp cross section



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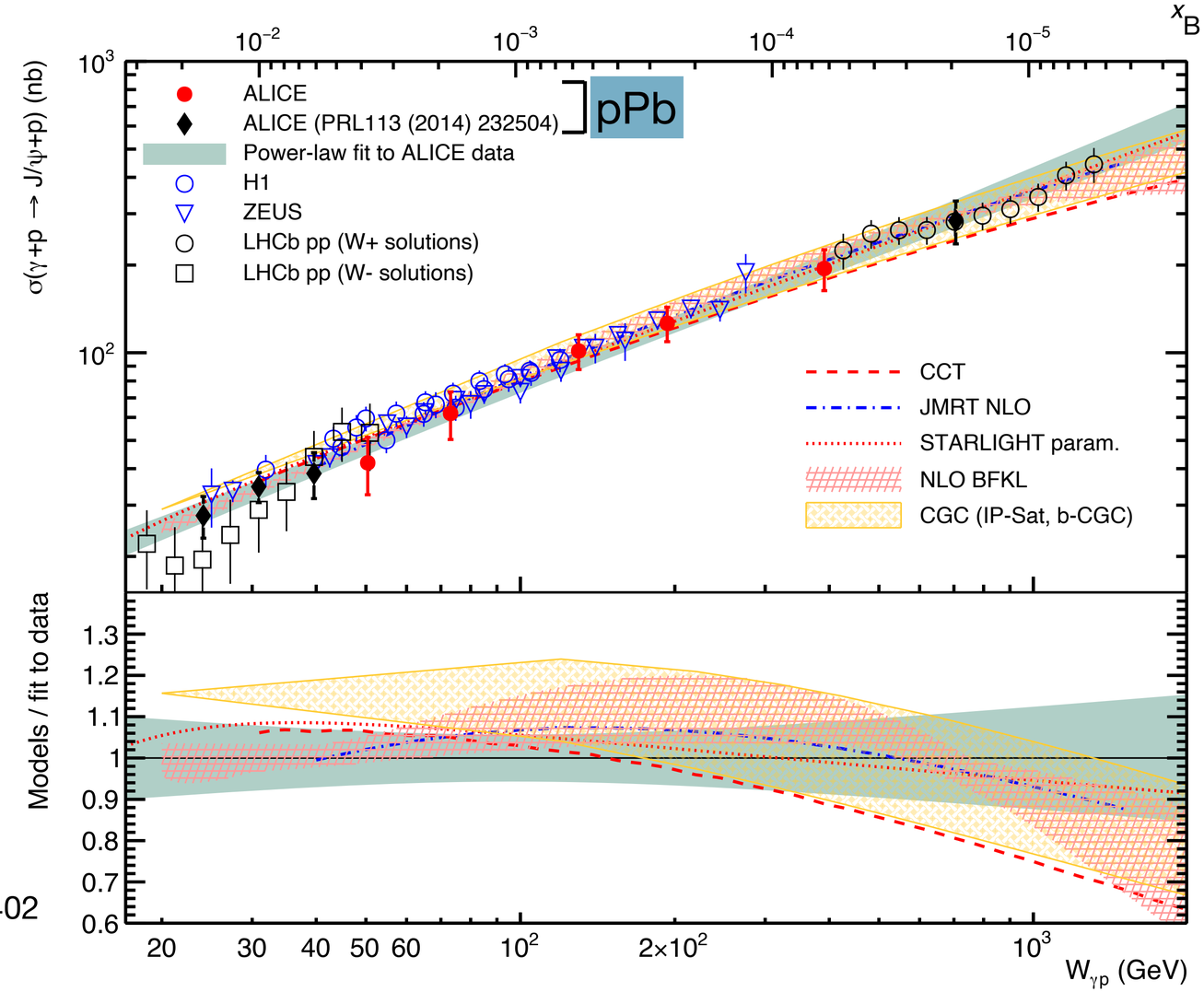

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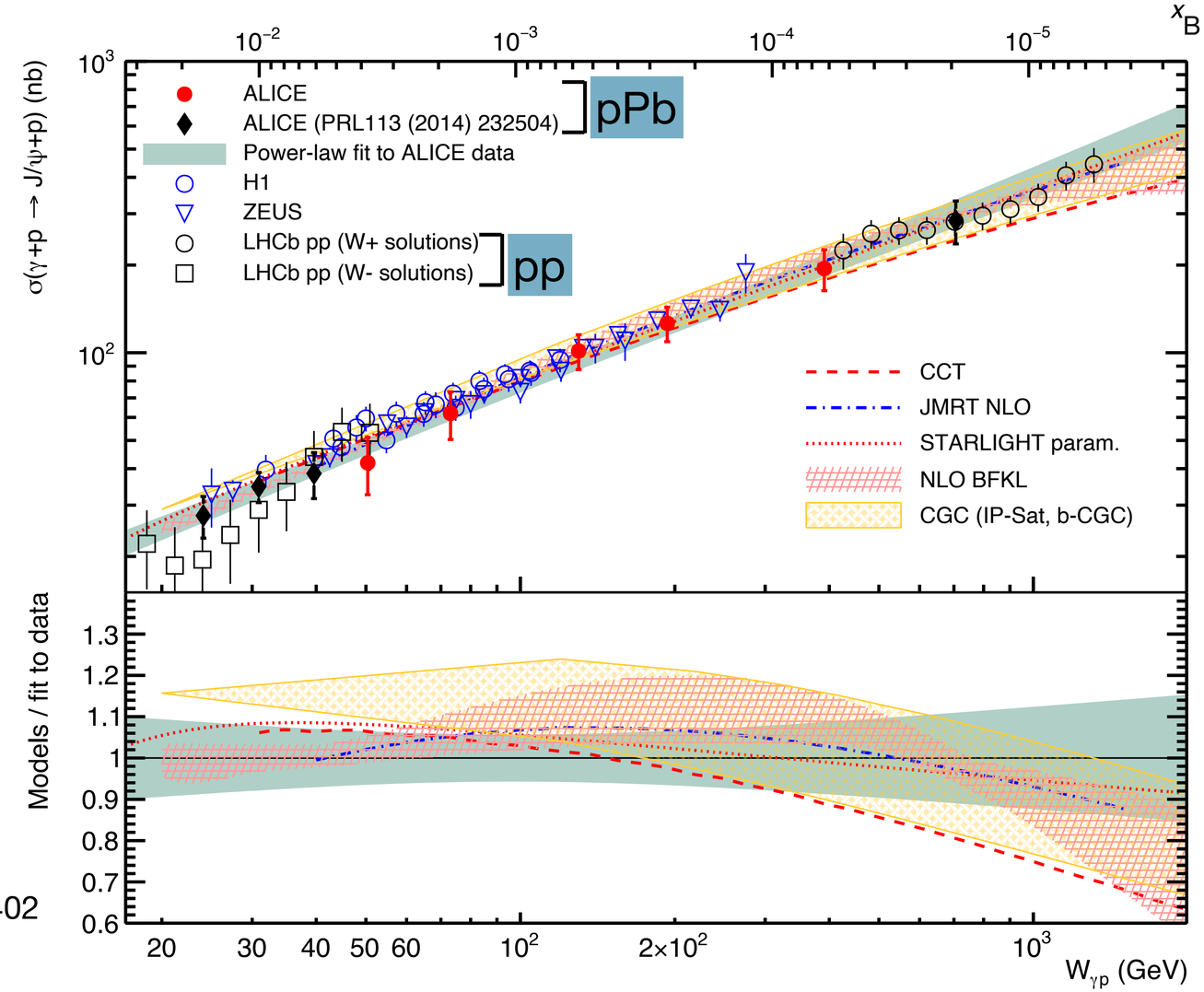

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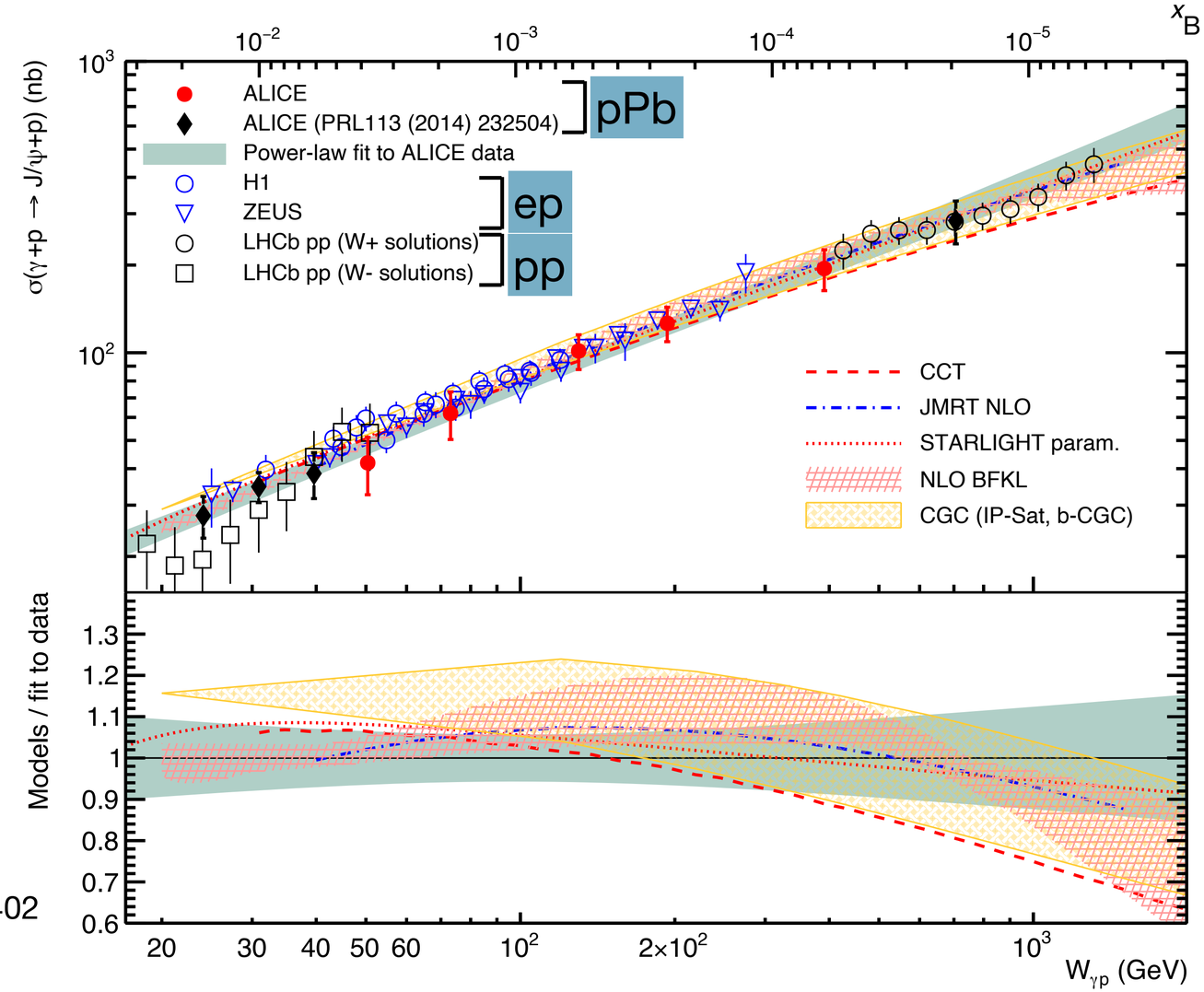

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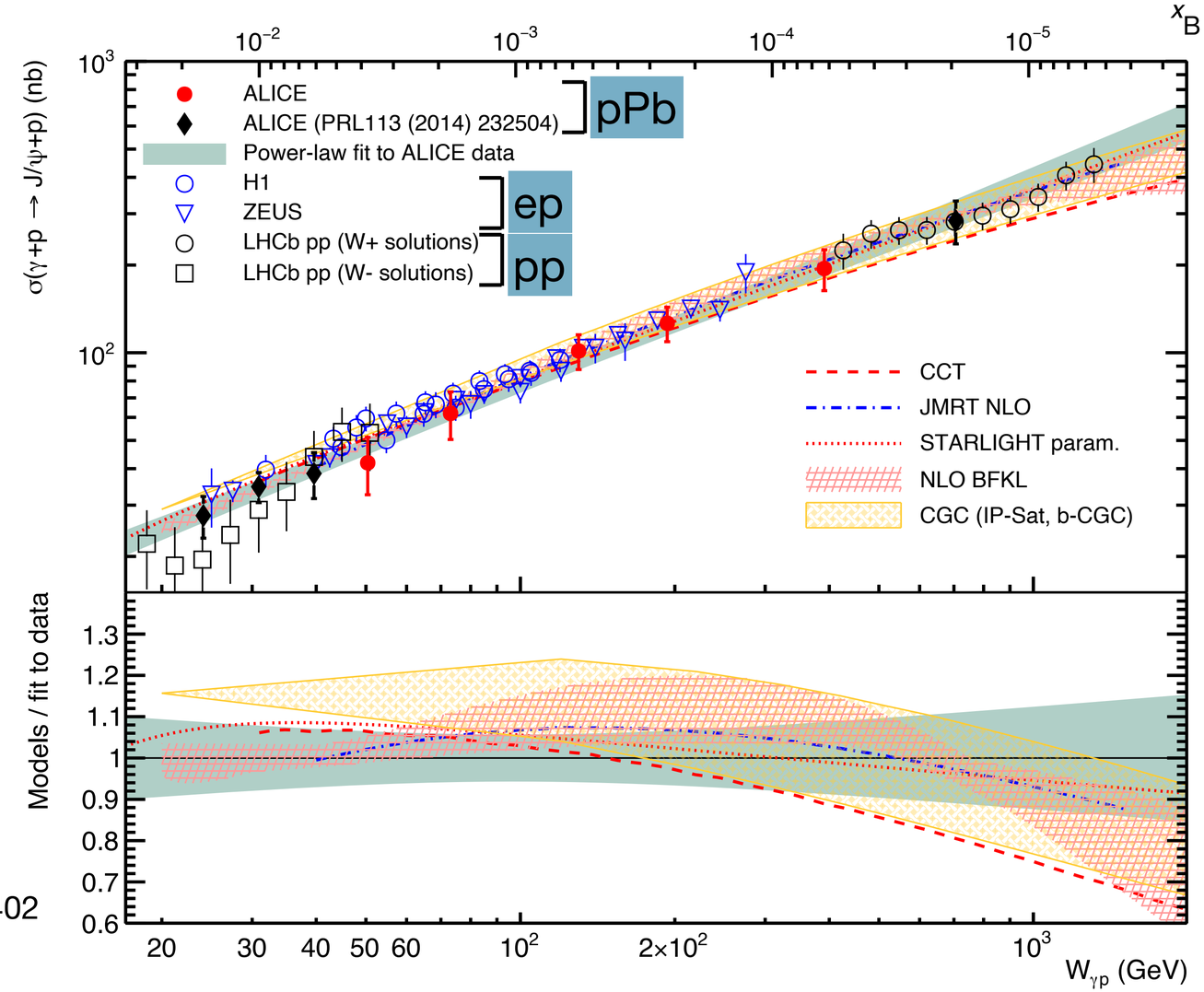

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overall compatibility between pp, Pbp and ep data: hint of universality of underlying physics

Ultra-peripheral collisions in PbPb

What object are we probing?

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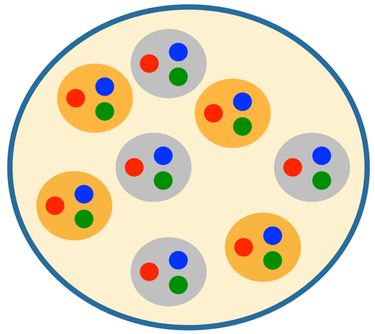

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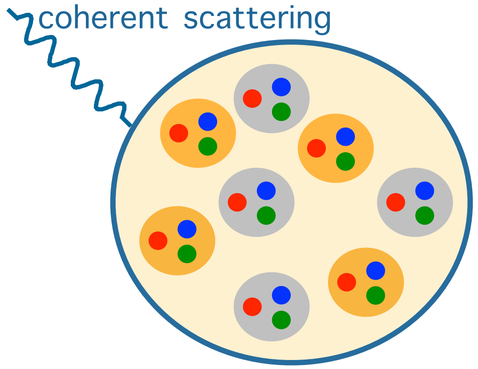

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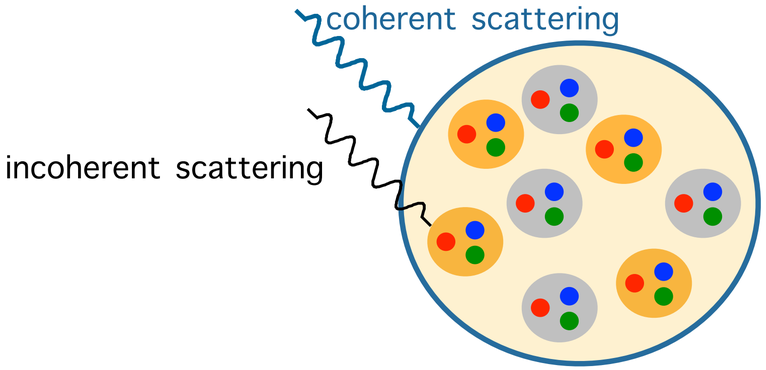

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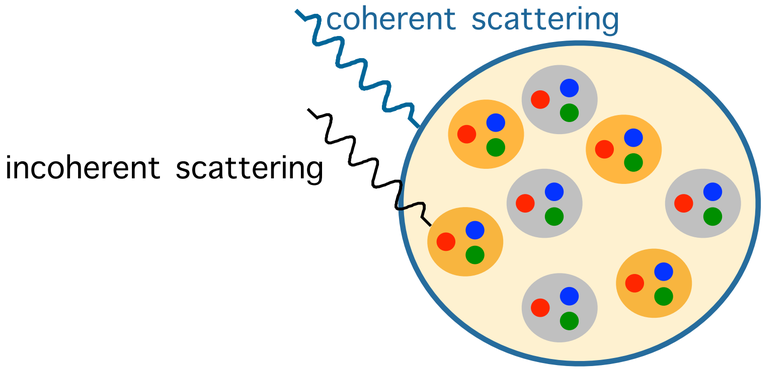

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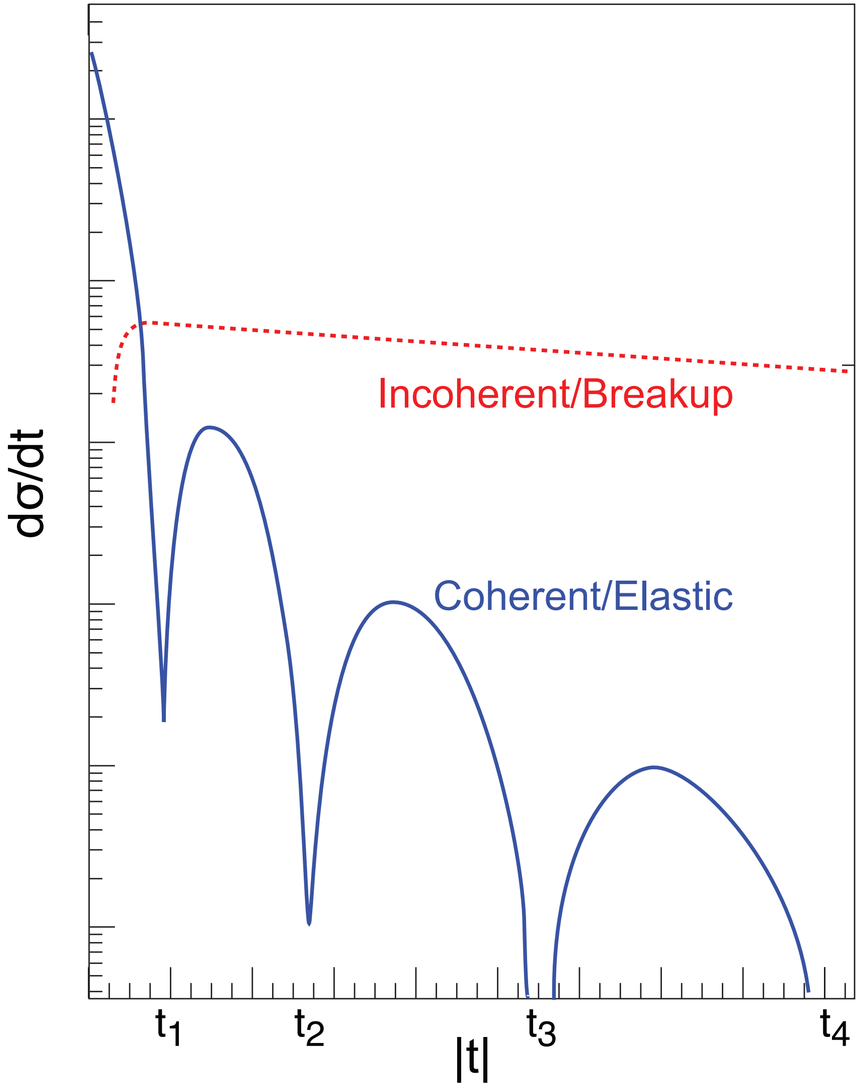
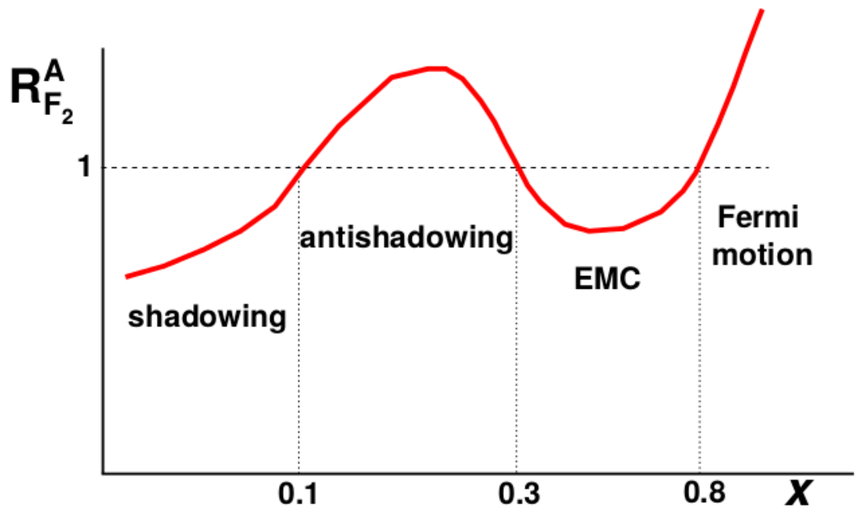


Coherent production

Nuclear GPDs (PDFs at low x_B)



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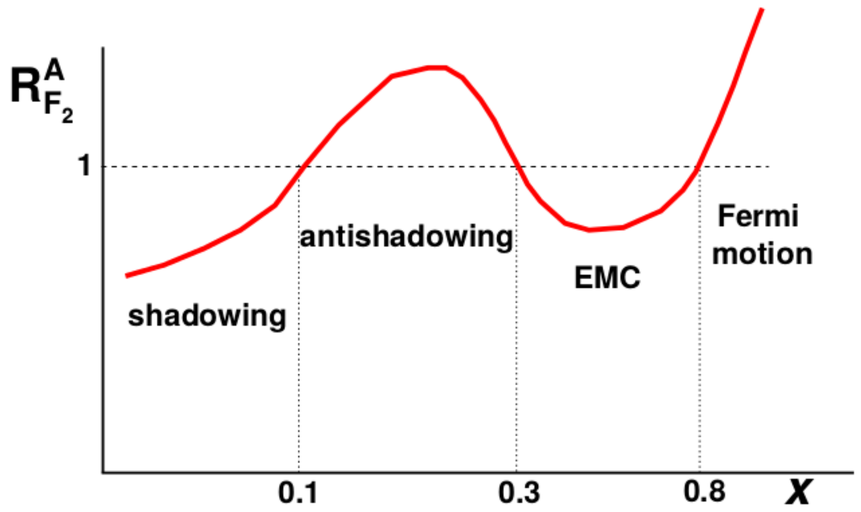
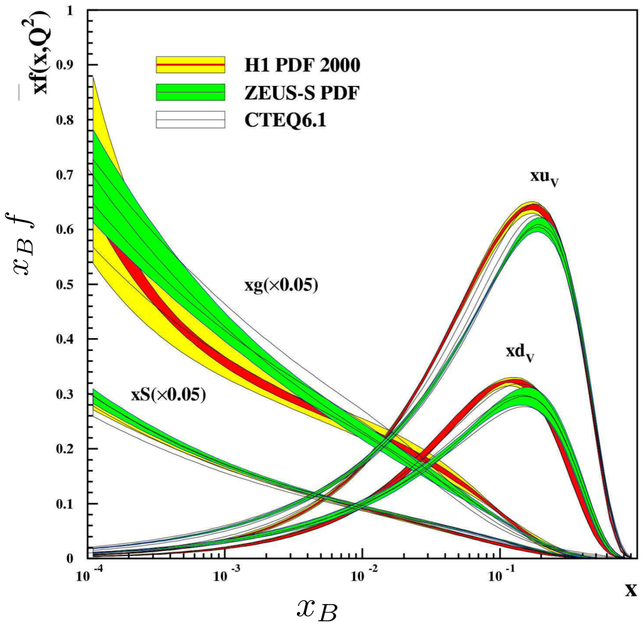


Probing saturation



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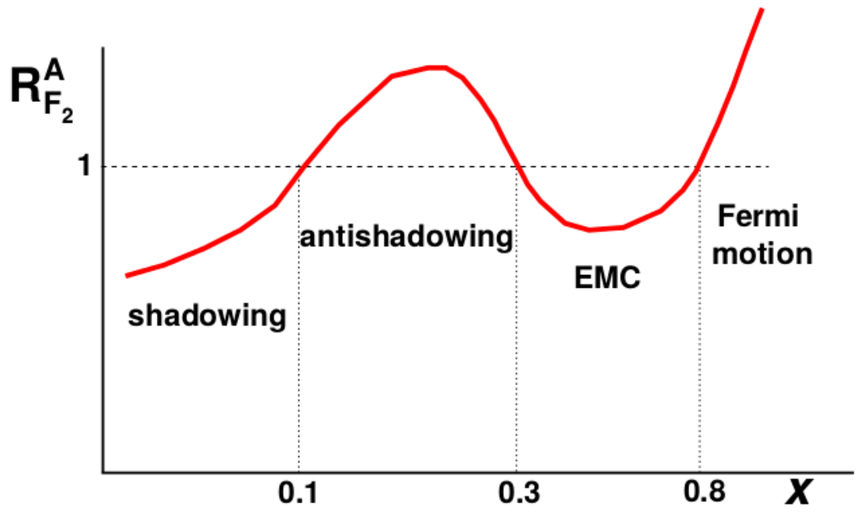

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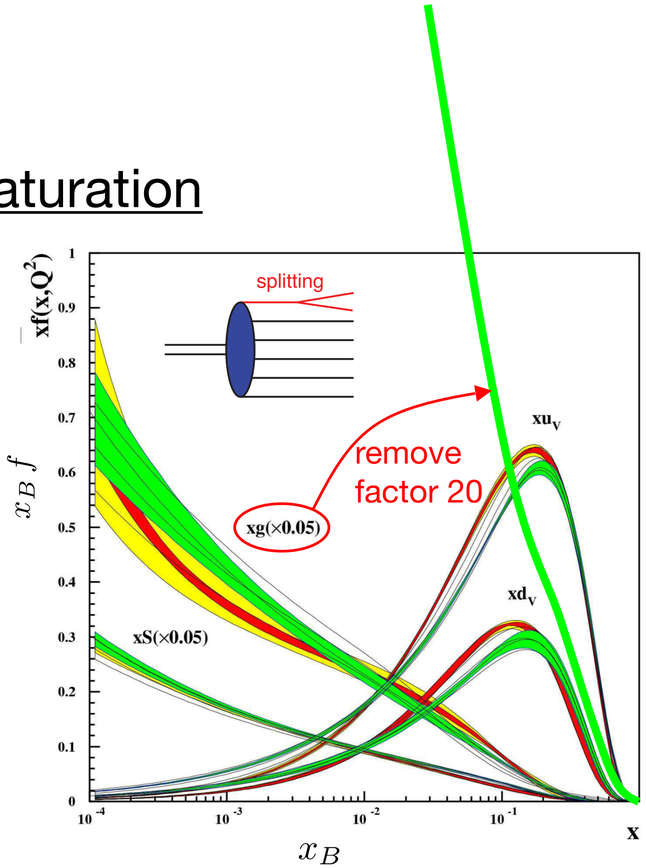

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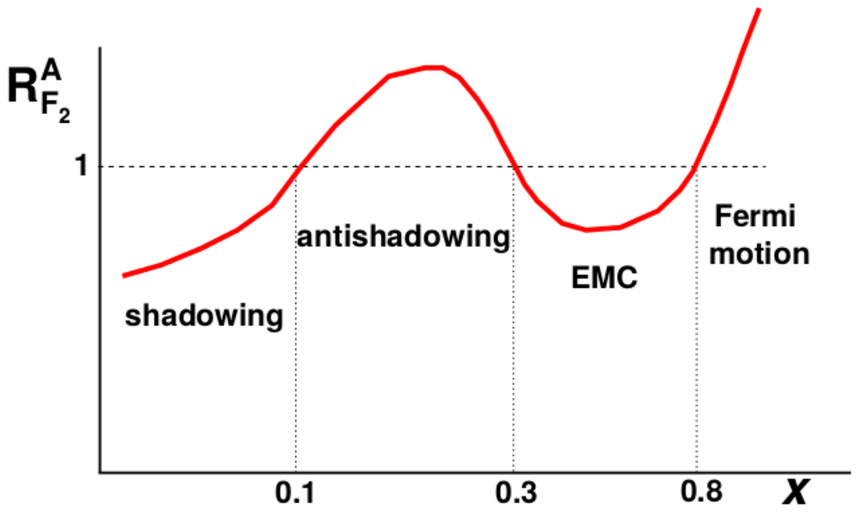

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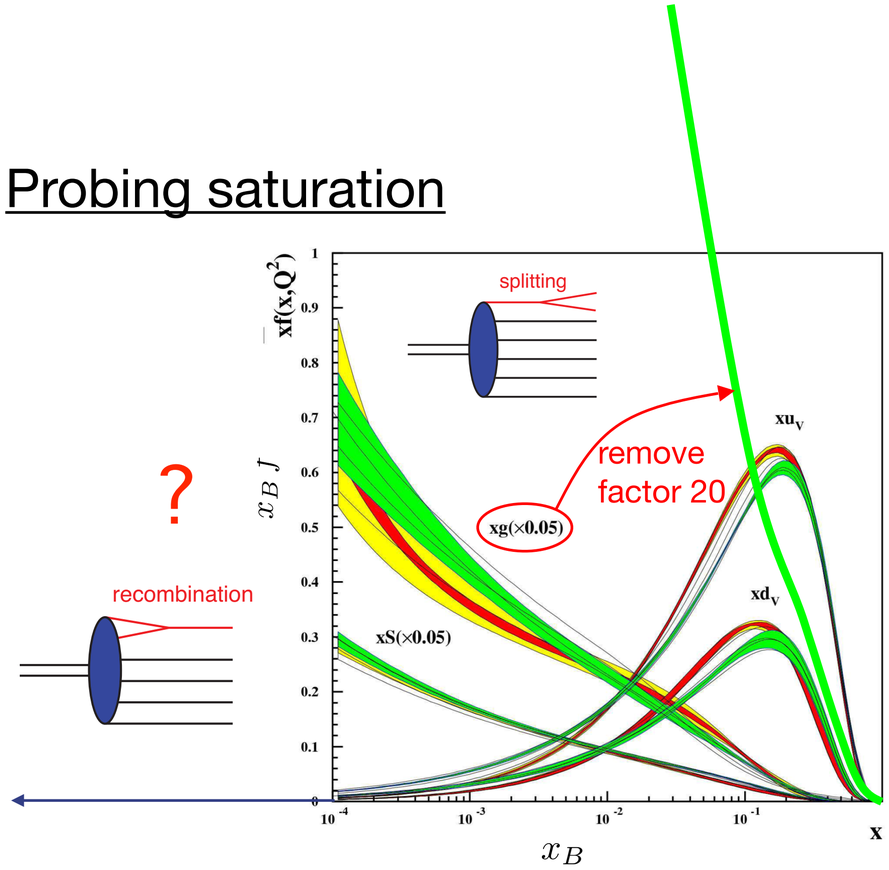

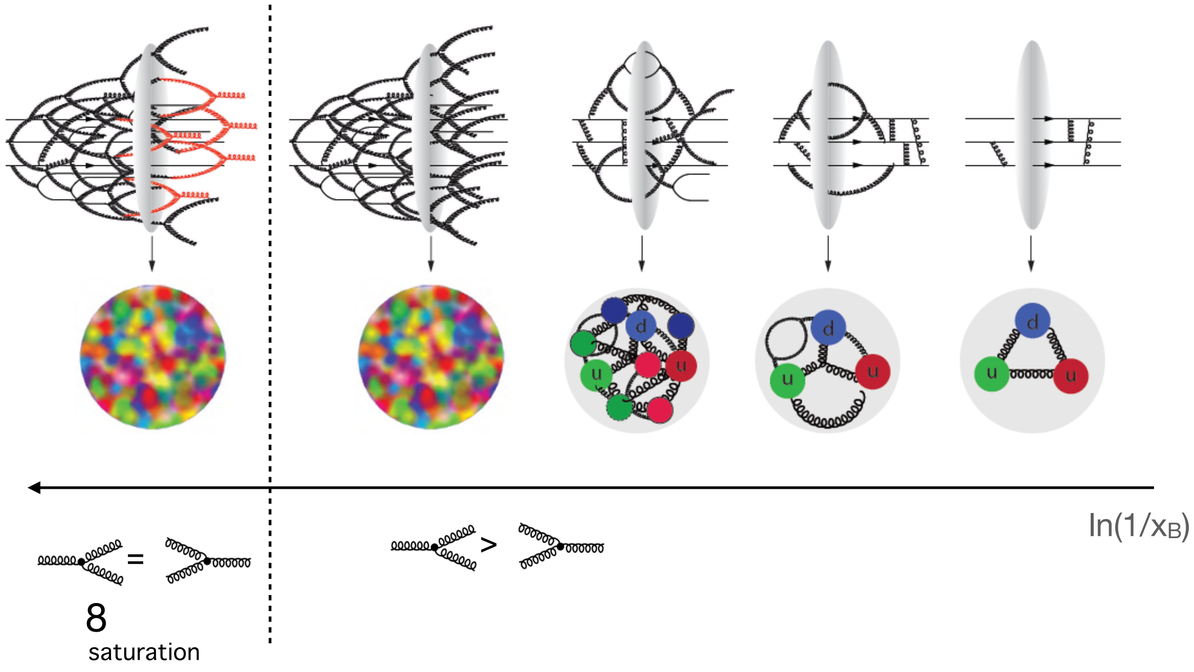

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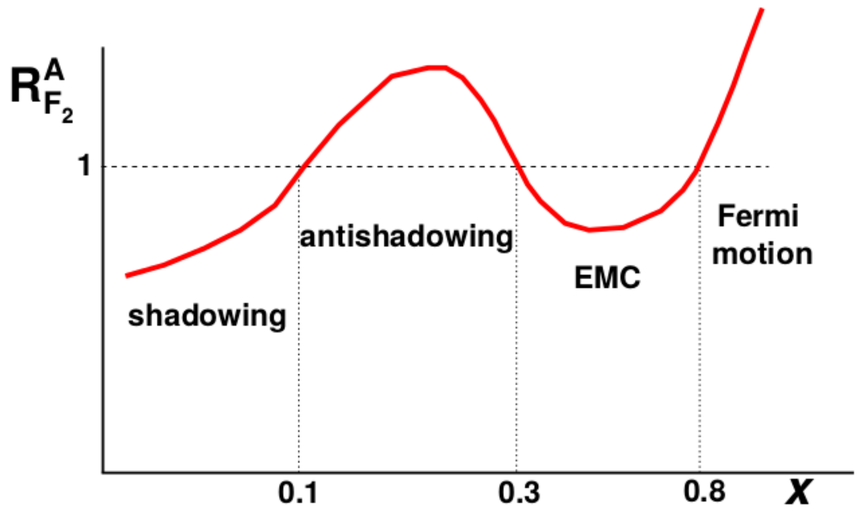

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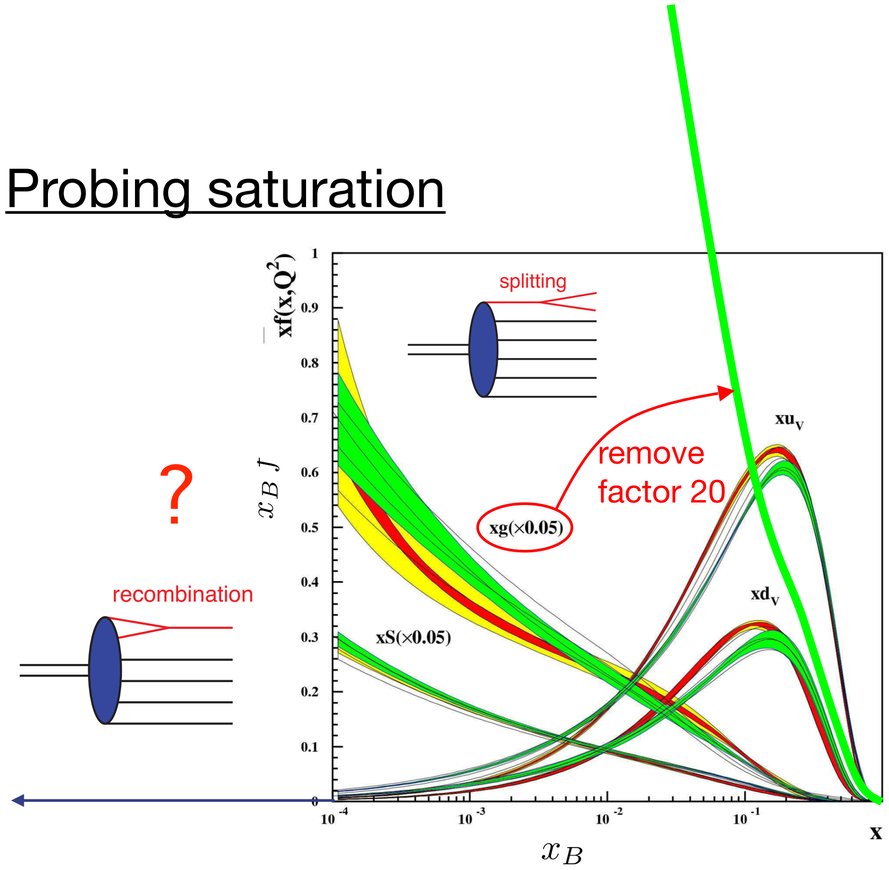
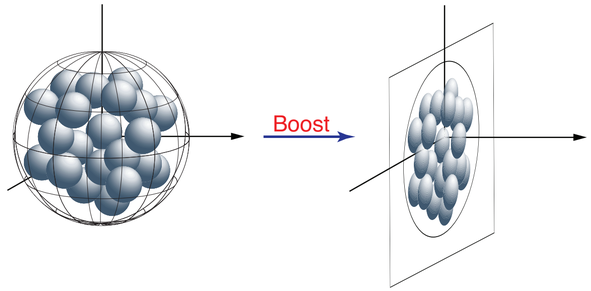
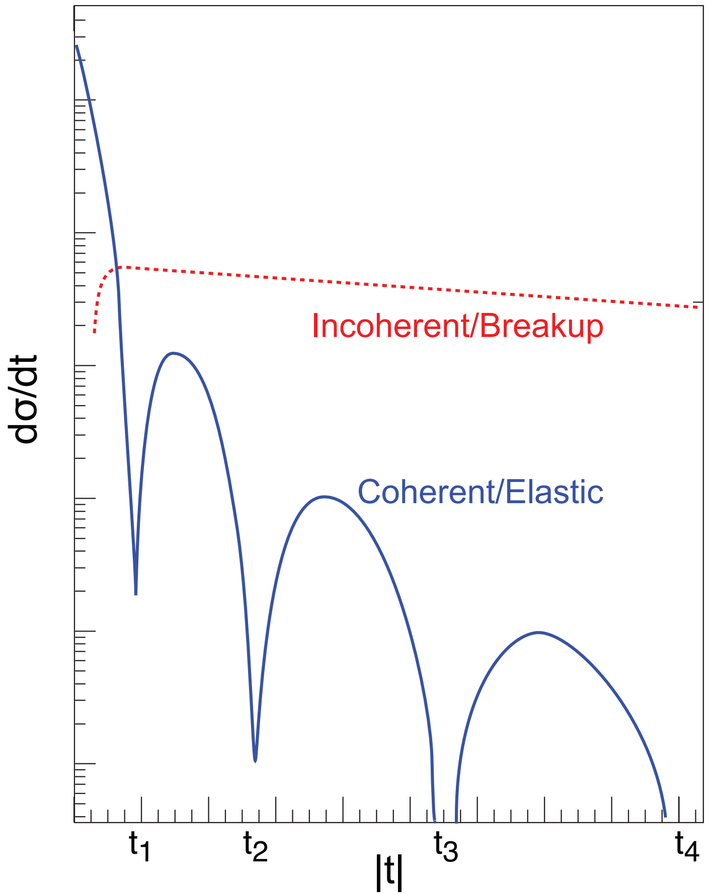




$A^{1/3}$ enhancement
of saturation effect for ions

Experimental important points

- Good separation of coherent and incoherent production. Not easy!



t= squared momentum transfer to target

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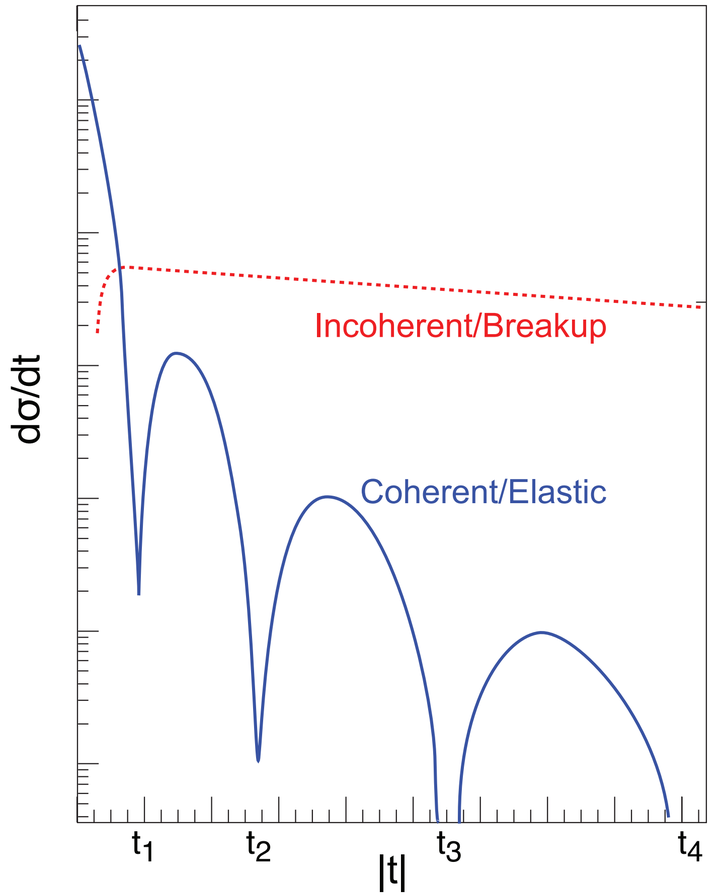
$$\int_0^{\infty} d\Delta_\perp \; \mathrm{GPD}(x, 0, \Delta_\perp)\; e^{-ib_\perp \Delta_\perp}$$

Experimentally limited by maximum transverse momentum.
Need to extend p_T range as much as possible in measurement.
~third diffractive minimum.



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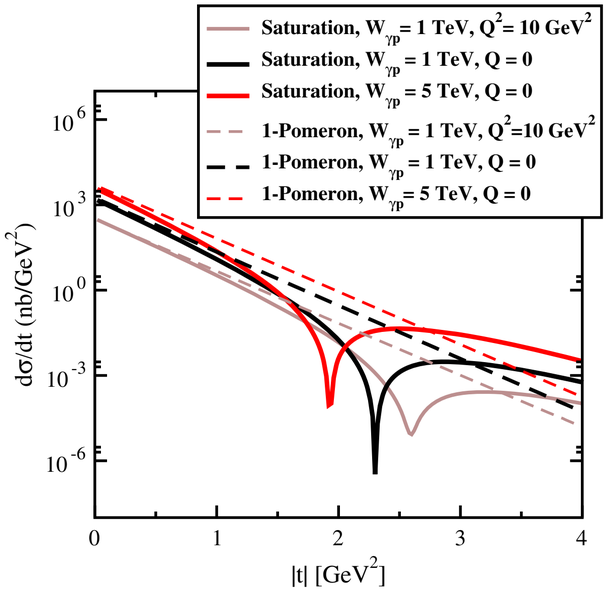
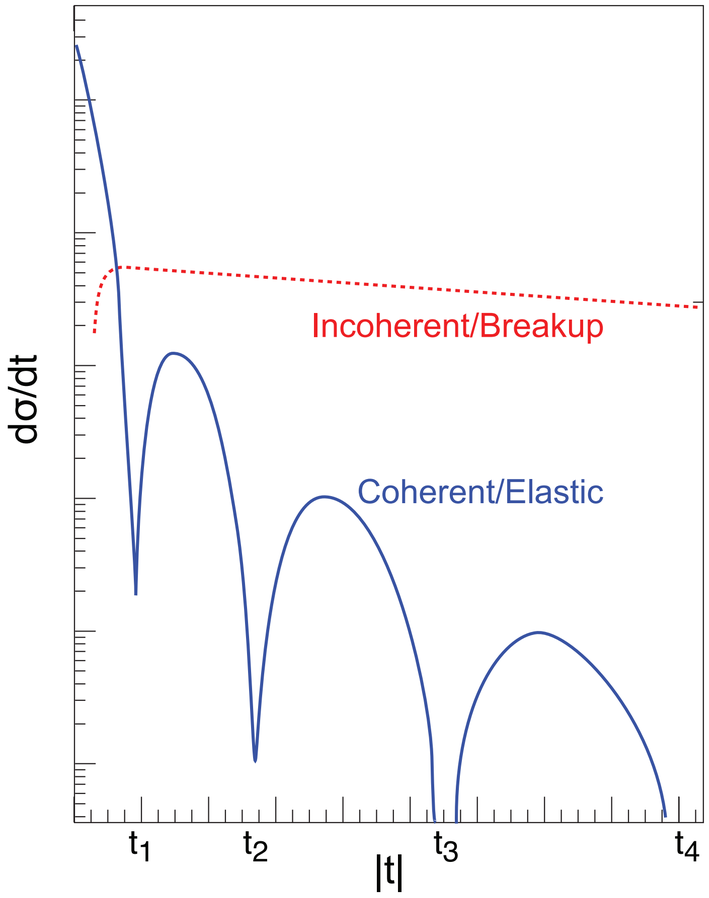
- Saturation:

  determine dip position indirectly
  via slope and probe its dependence
  With $W_{\gamma p}$

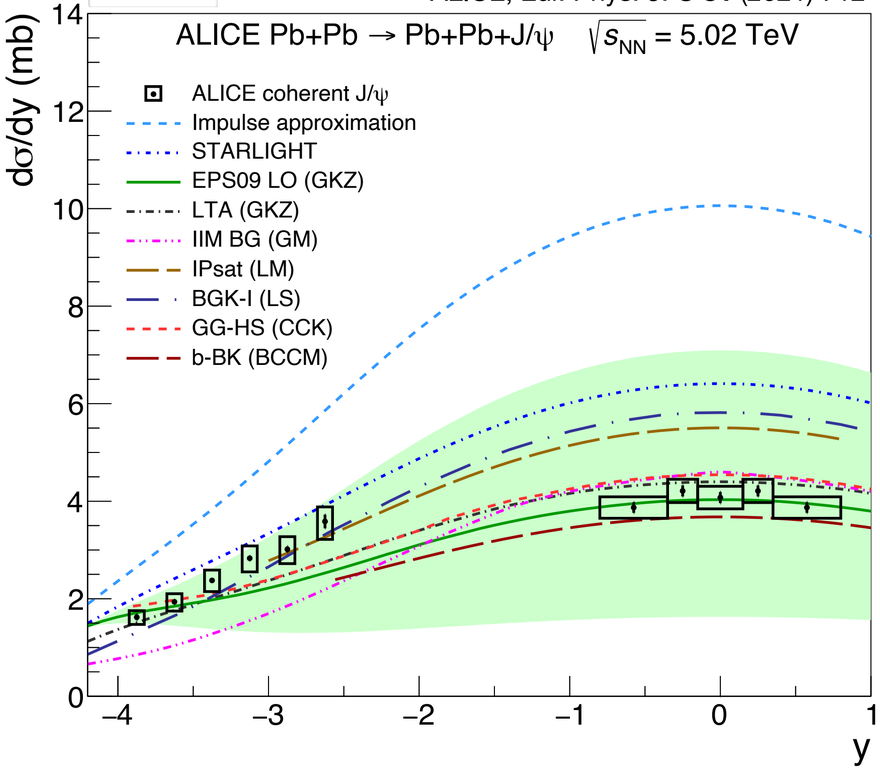




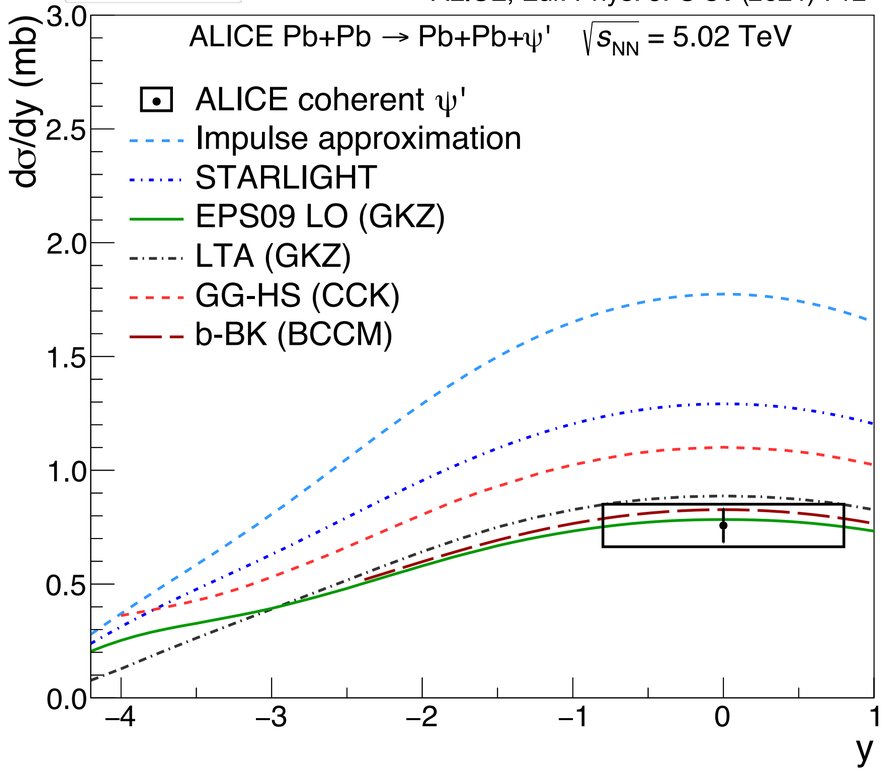
t= squared momentum transfer to target

Coherent photoproduction in PbPb at ALICE: y dependence

J/ψ



$\psi(2S)$



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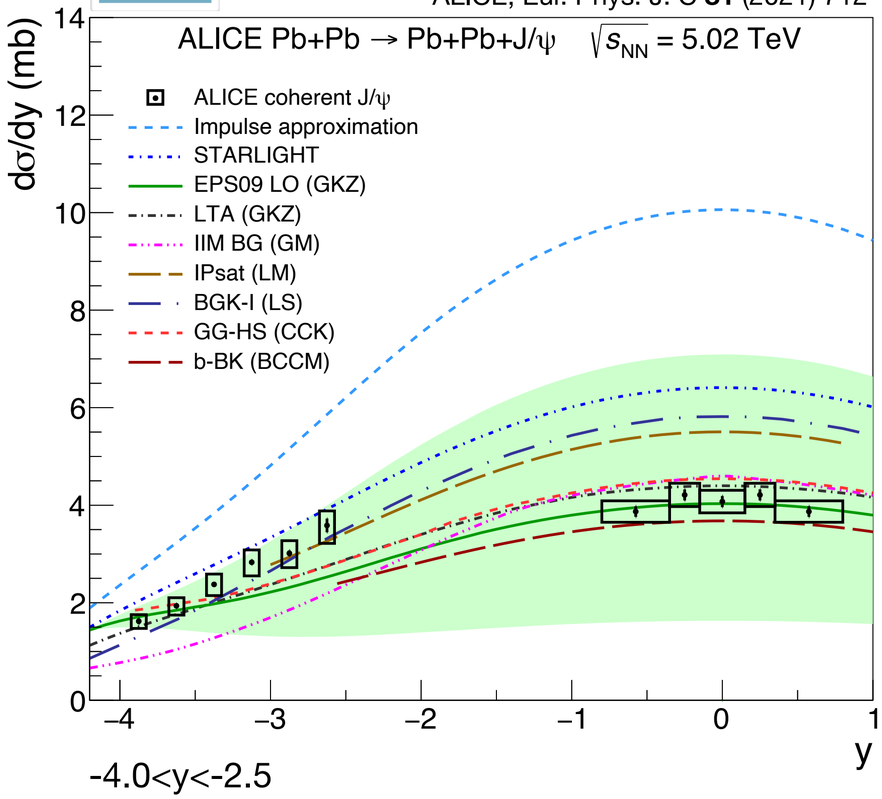

-4.0<y<-2.5

$0.7 \times 10^{-2} < x_B < 3.3 \times 10^{-2}$ (dominant)

$1.1 \times 10^{-5} < x_B < 5.1 \times 10^{-5}$

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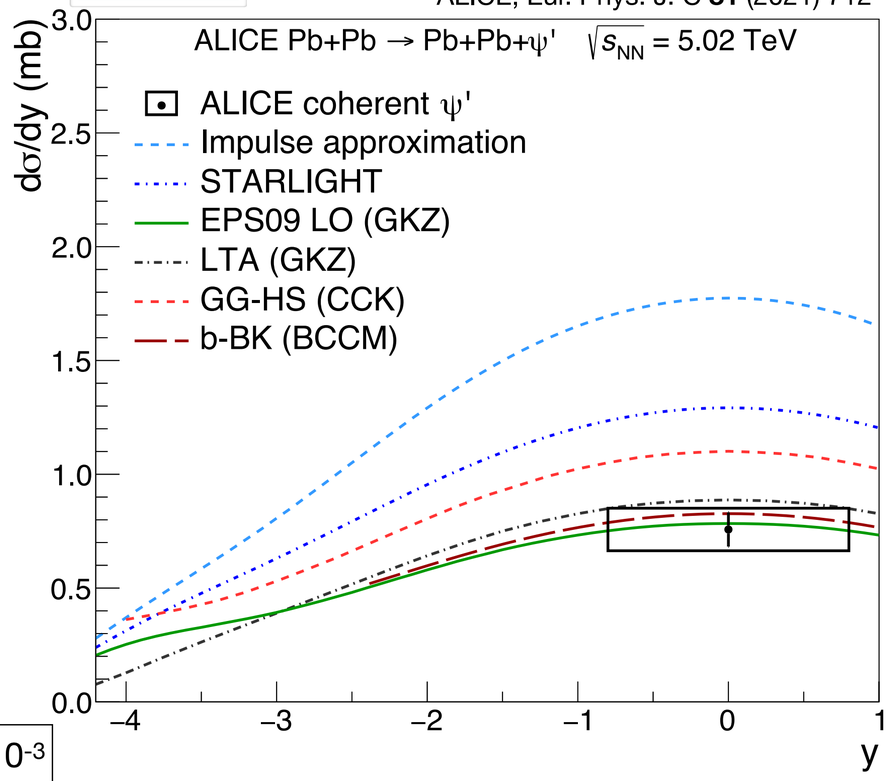
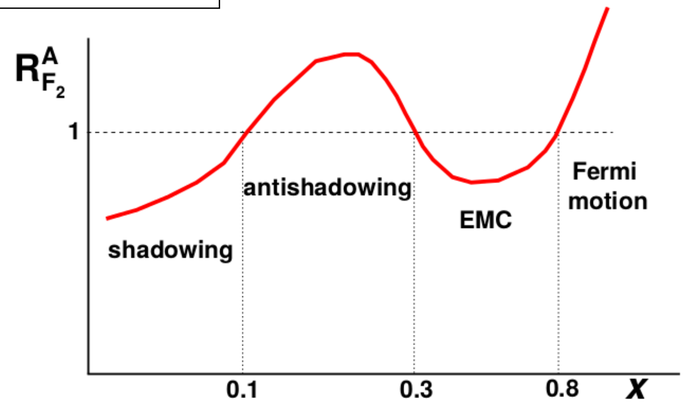


$|y|<0.8 \longleftrightarrow 0.3 \times 10^{-3} < x_B < 1.4 \times 10^{-3}$



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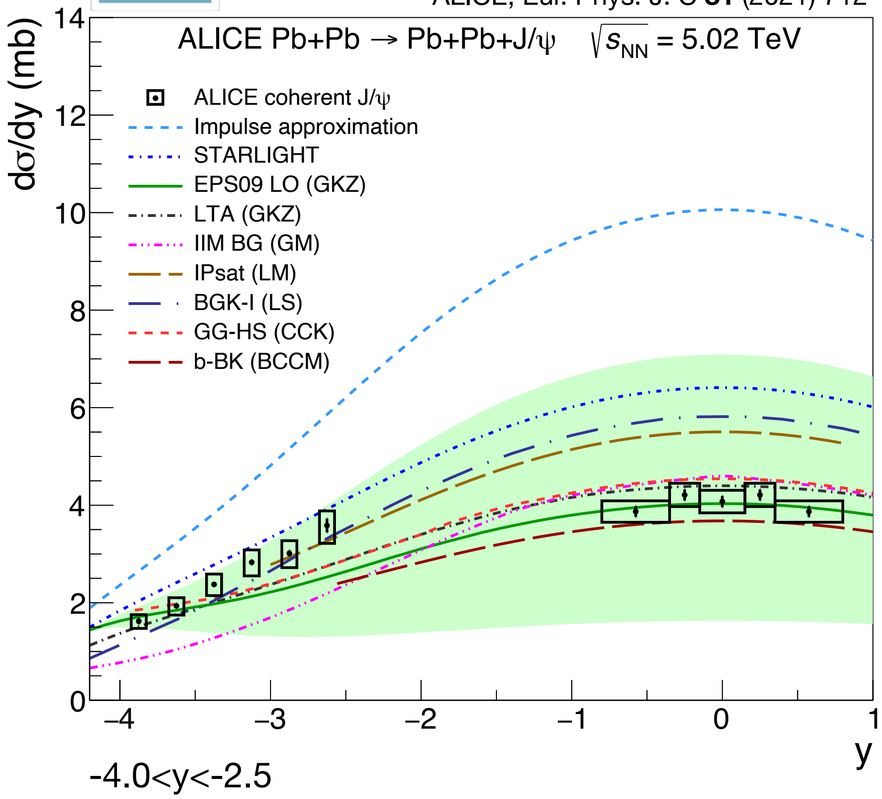

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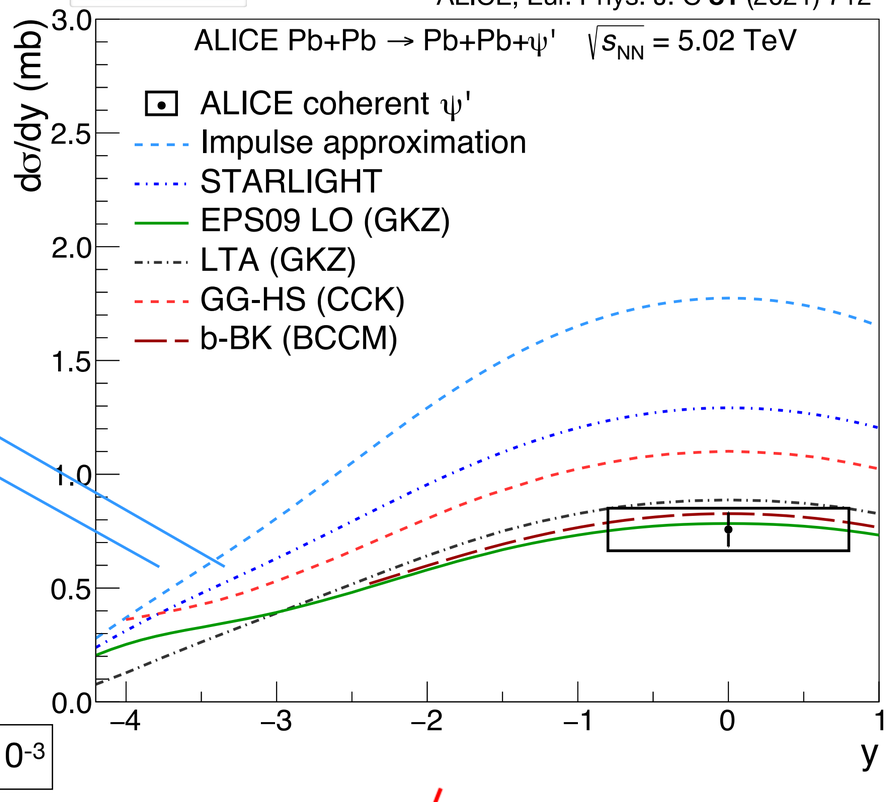

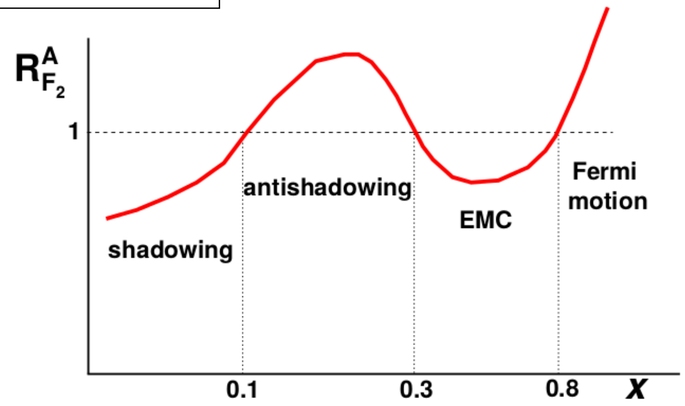

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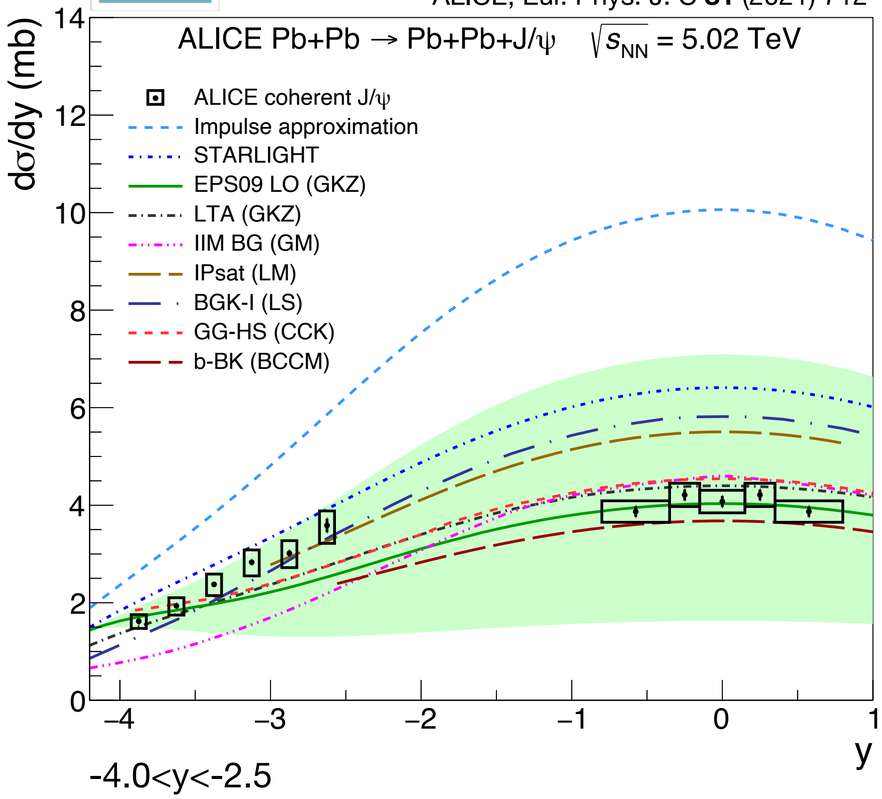

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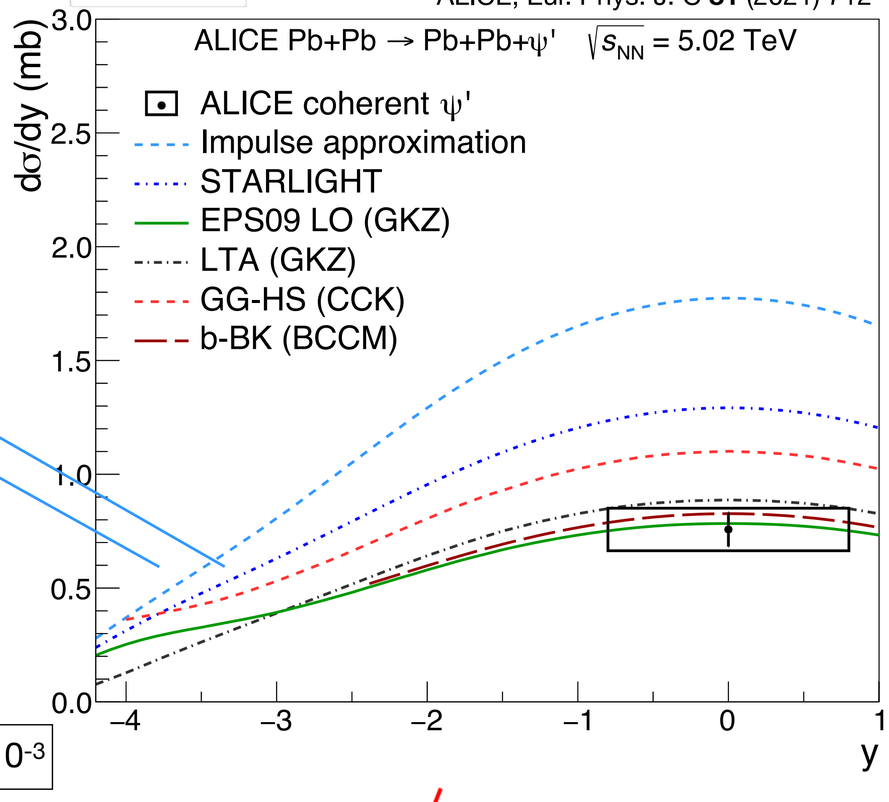
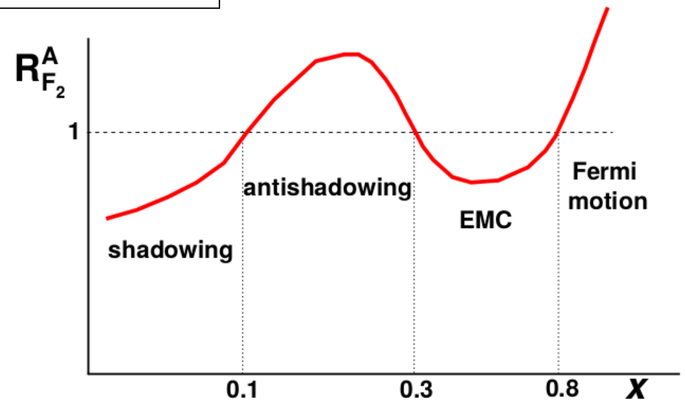


Results indicate shadowing in gluon PDF

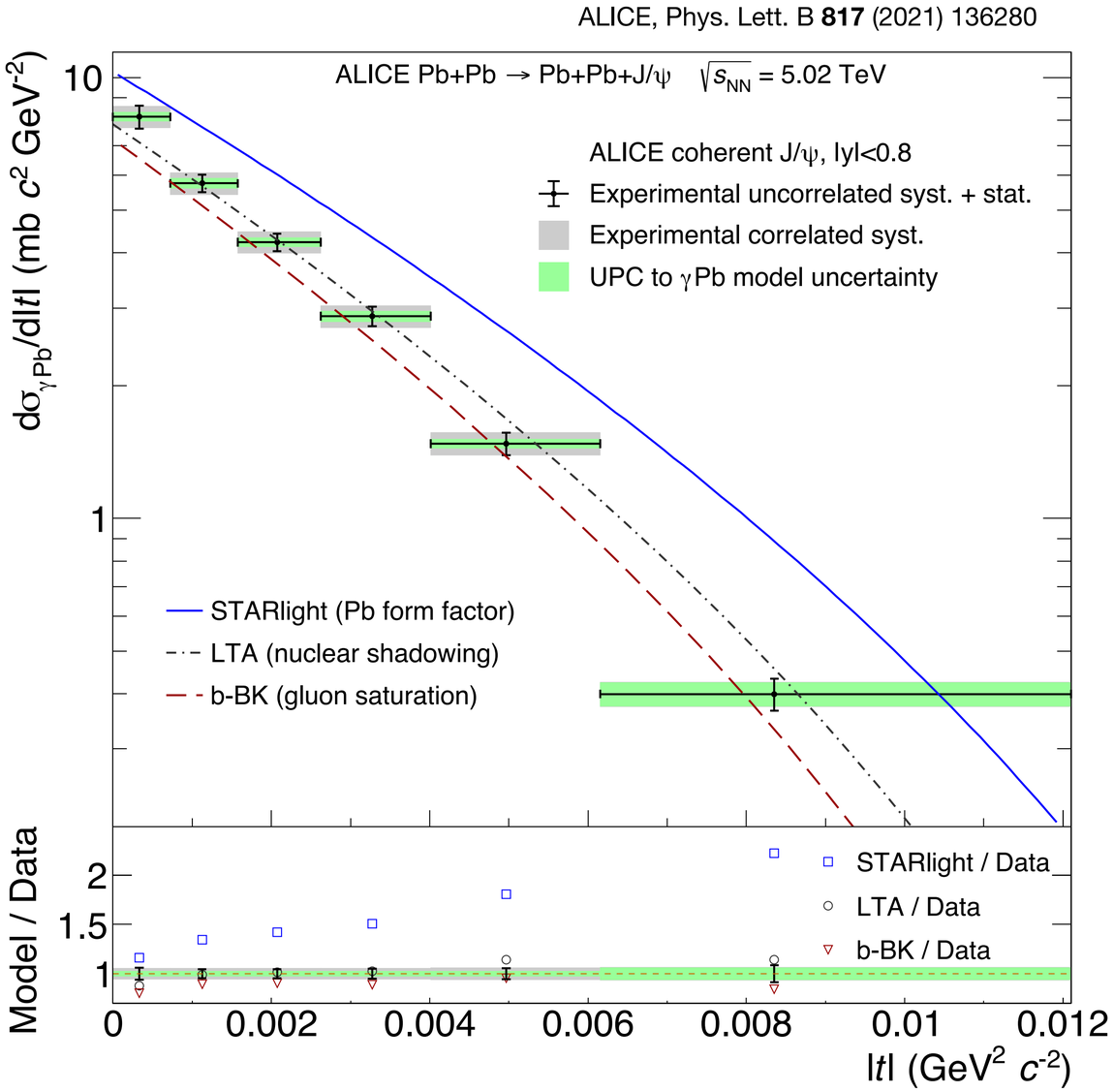
$$R_g = \frac{g^{Pb}}{A\, g^{p}} \approx 0.65 \text{ at } x \approx 10^{-3}$$



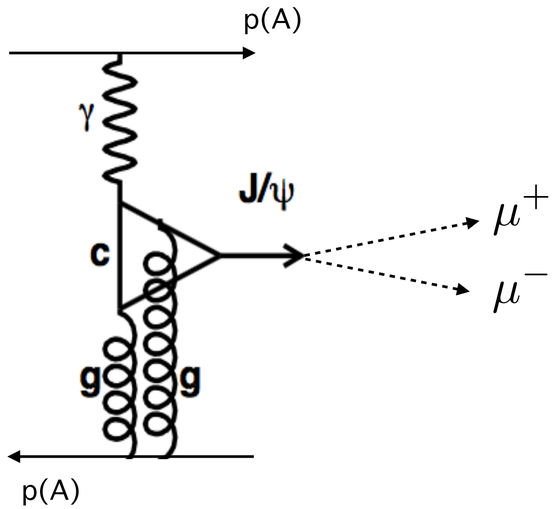
ALICE: γPb cross section

$$\mathrm{Pb} + \mathrm{Pb} \rightarrow \mathrm{Pb} + \mathrm{Pb} + J/\psi \quad \text{at} \quad |y_{J/\psi}| < 0.8$$

$$\frac{d\sigma_{\gamma Pb}}{d|t|} = \frac{1}{2N_{\gamma Pb}(y=0)} \frac{d^2\sigma^{\mathrm{coh}}_{J/\psi}}{dy\, dp_T^2}$$



LHCb: Coherent photoproduction in PbPb



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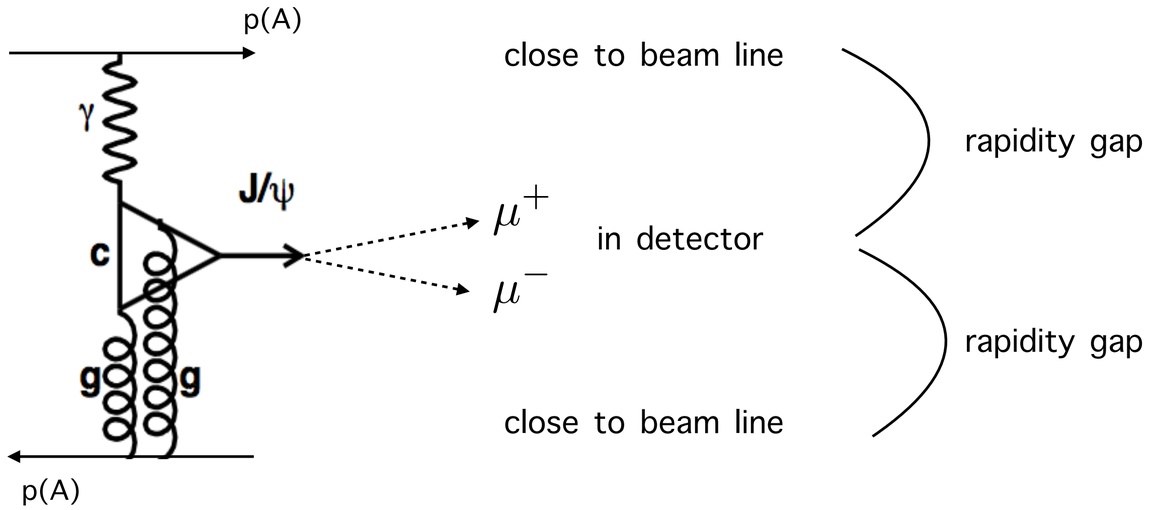

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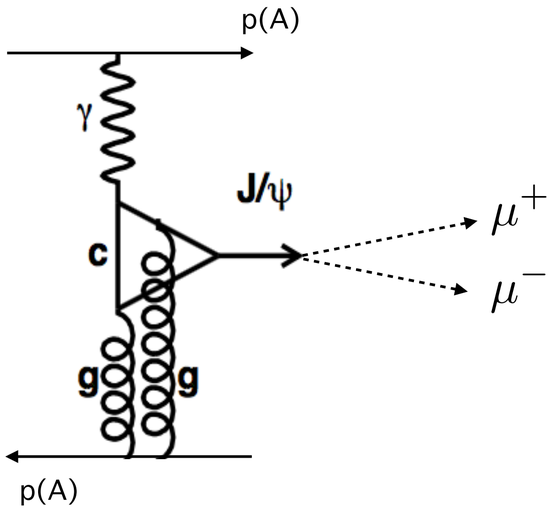
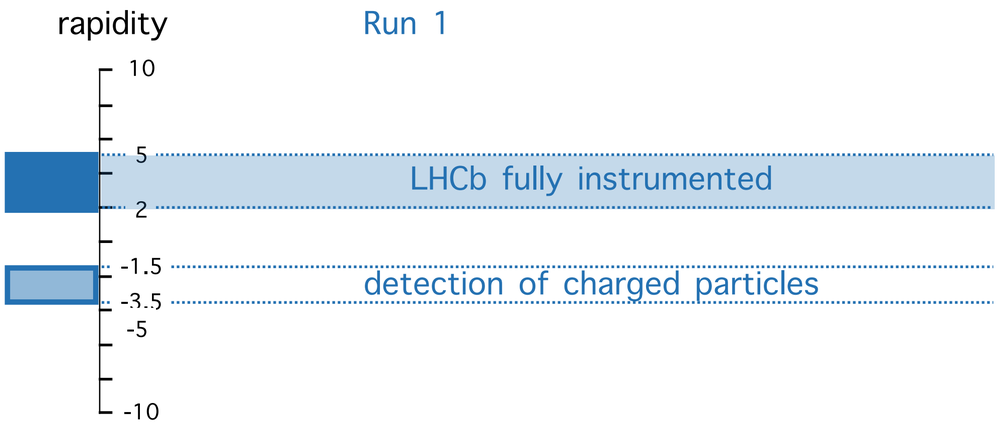
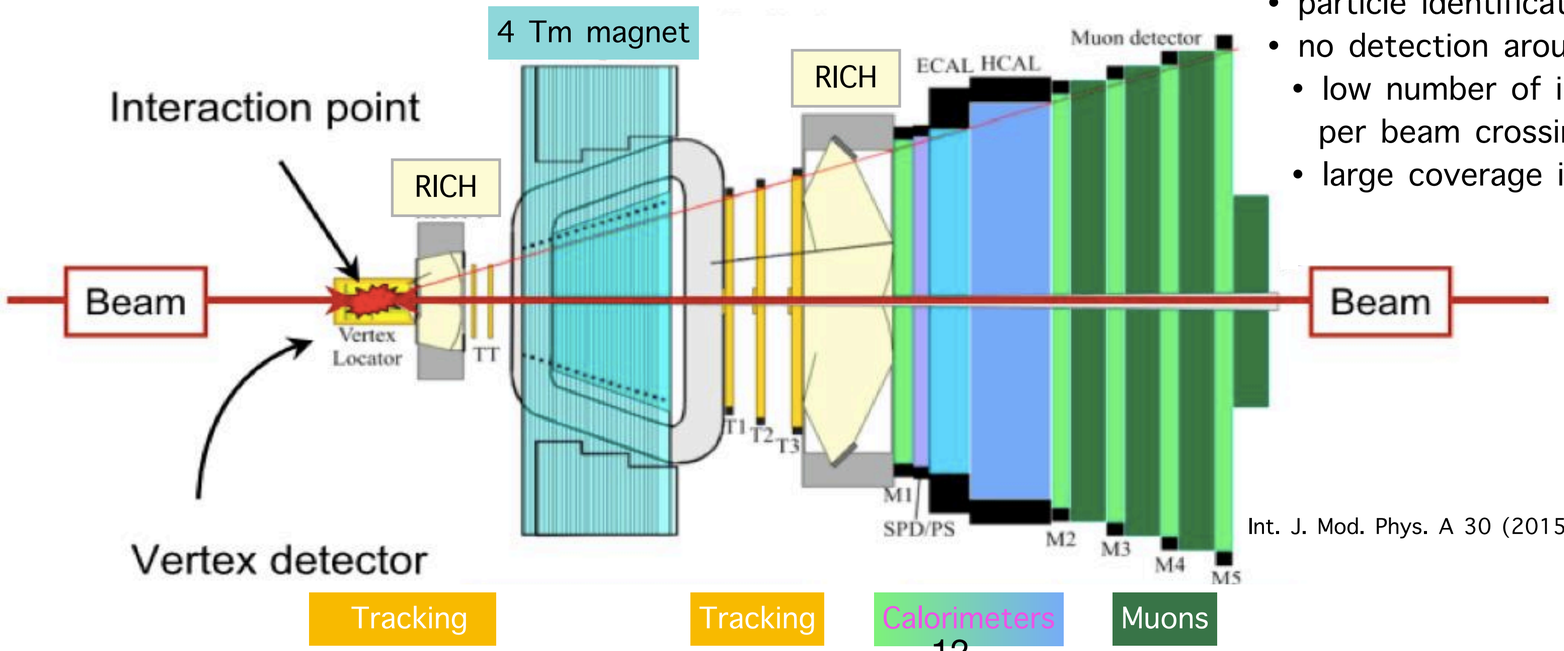




- low p_T threshold: p_T>400 MeV
- particle identification
- no detection around beam line but
  - low number of interactions per beam crossing: 1.1–1.5
  - large coverage in rapidity



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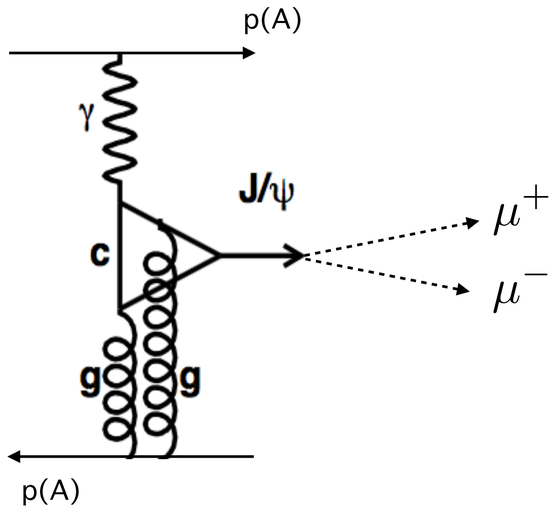

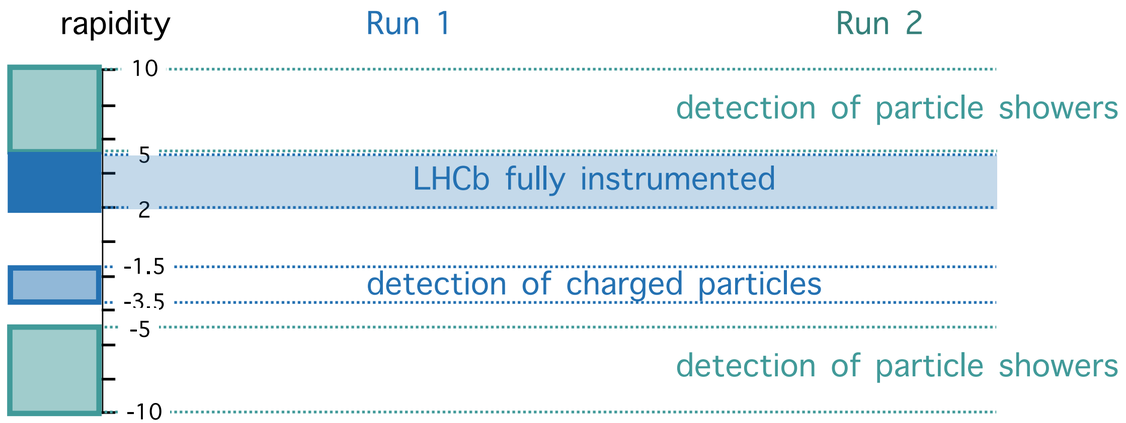

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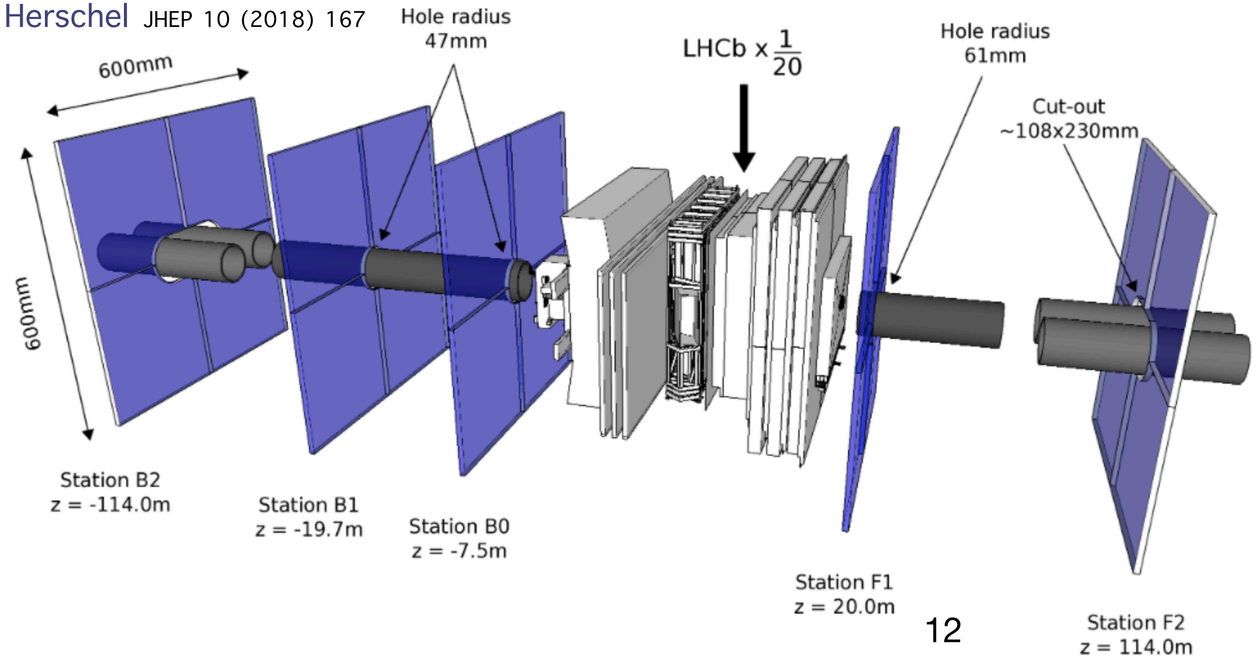
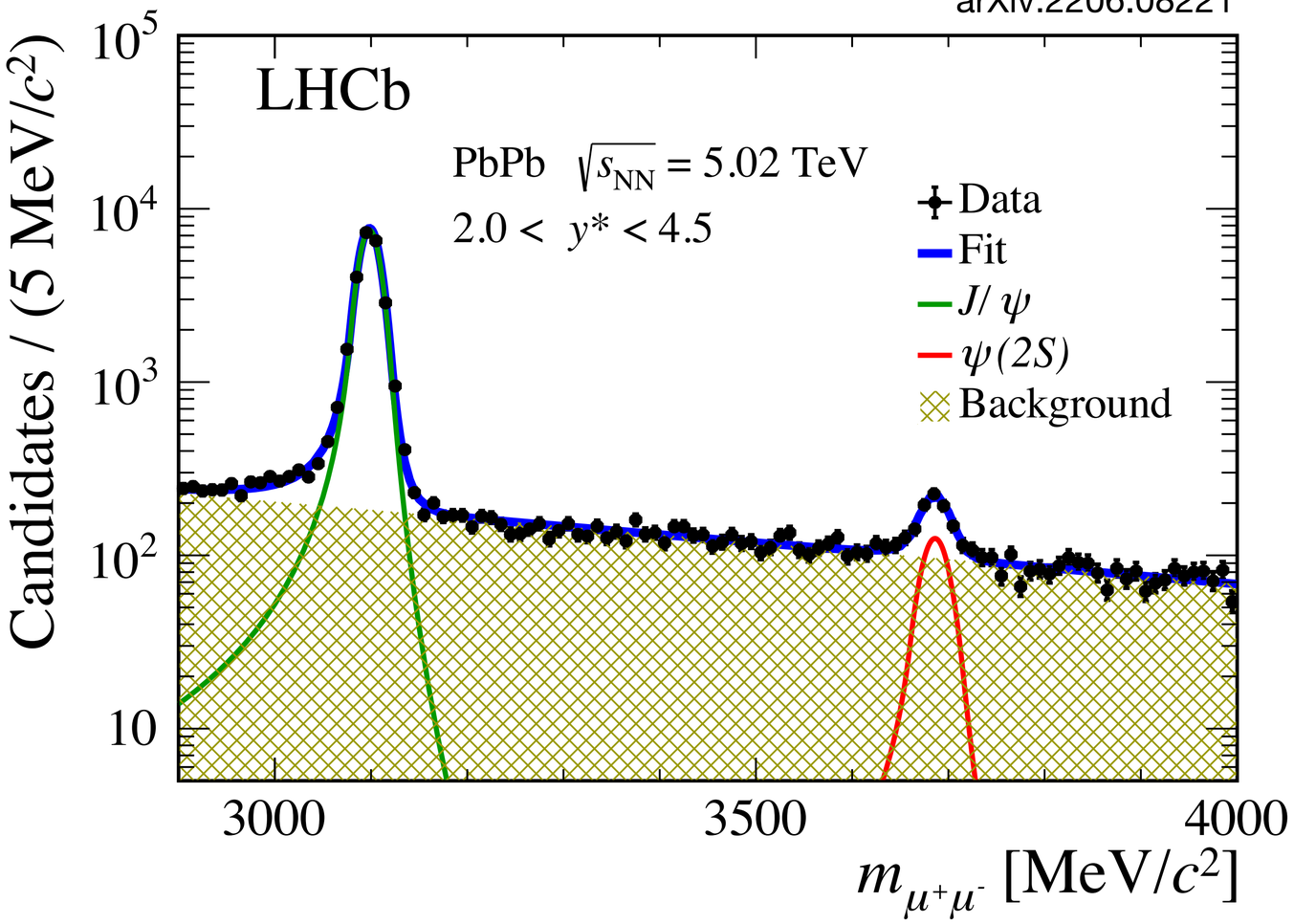
Herschel JHEP 10 (2018) 167



Coherent J/ψ in PbPb UPCs – selection

- Reconstruction via dimuon decay, with offline selection: $2<\eta_\mu<4.5$ and $p_{T,\mu}> 700$ MeV
- $2<y_{J/\psi}<4.5 \rightarrow x_B$ down to 10^{-5}
- $p_T<1$ GeV

arXiv:2206.08221



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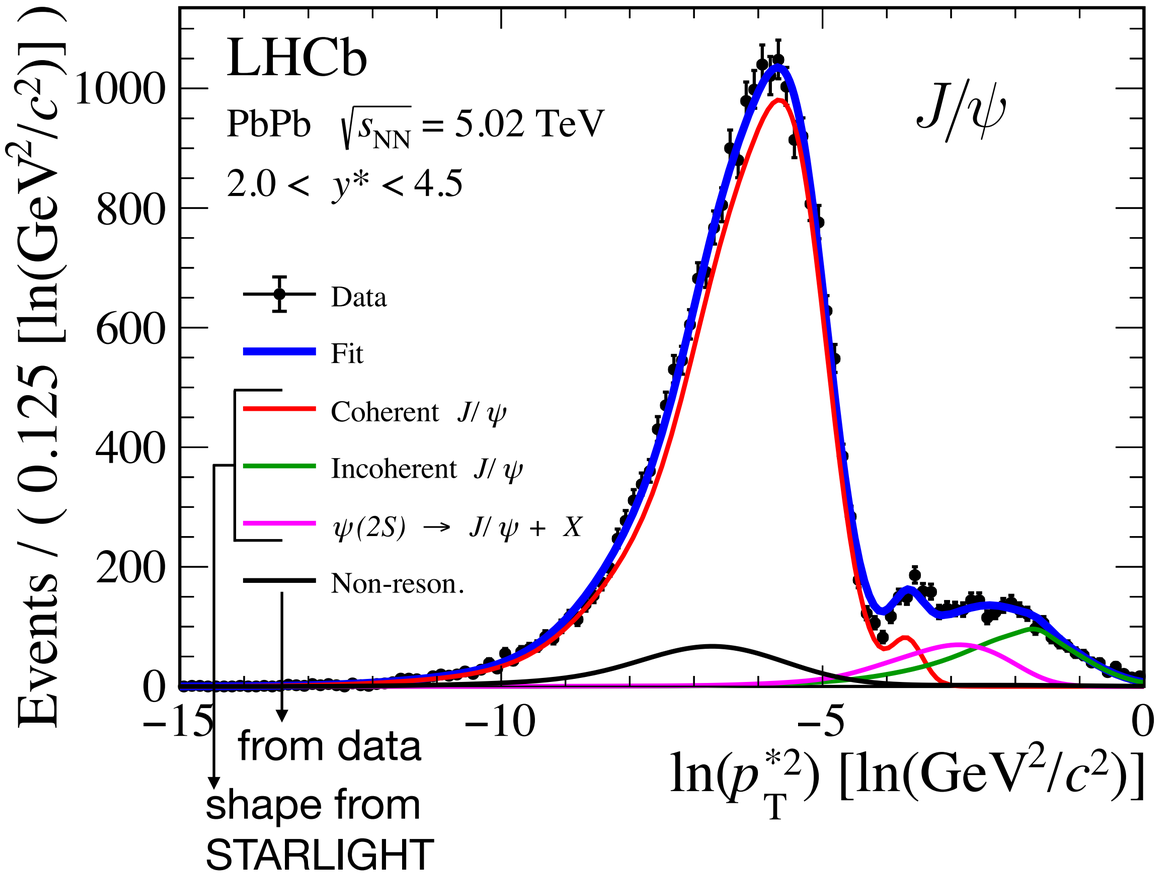
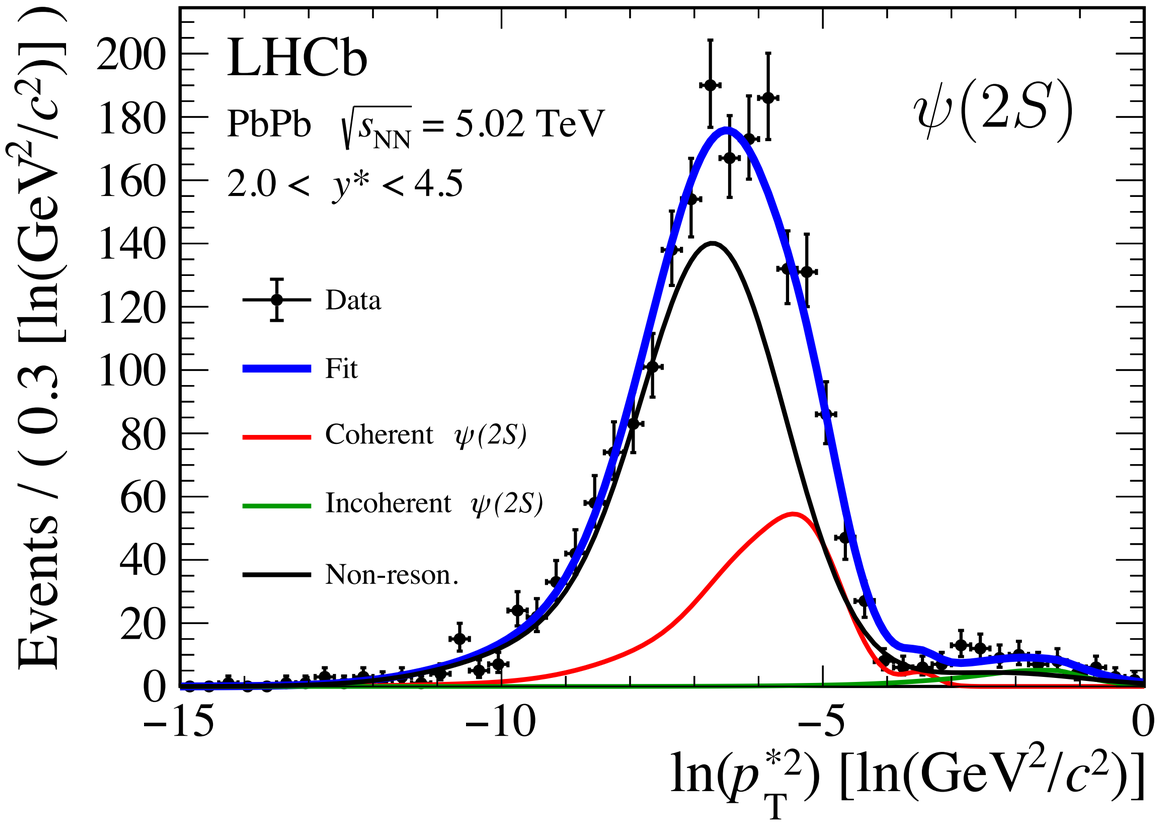
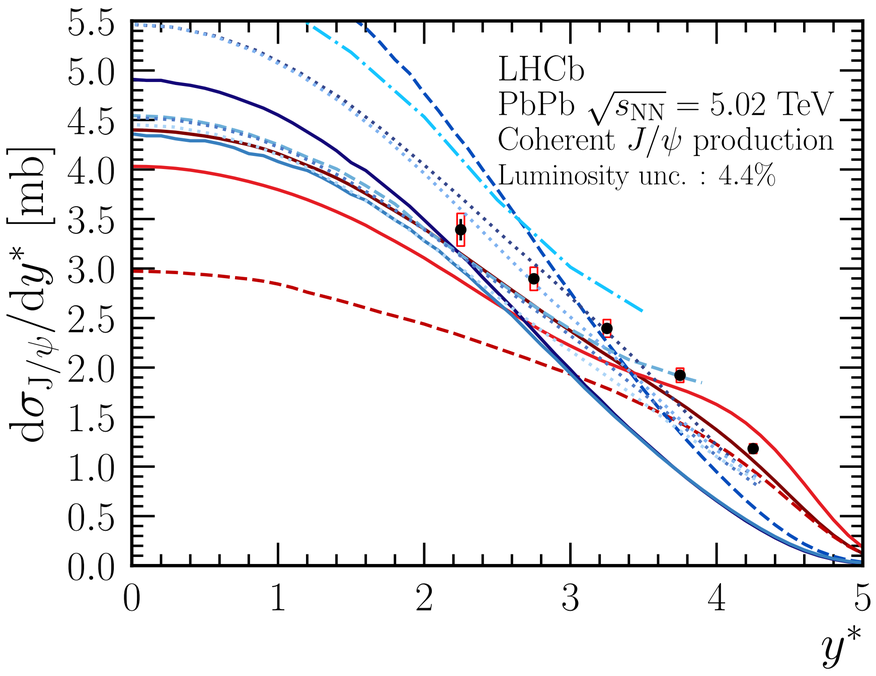


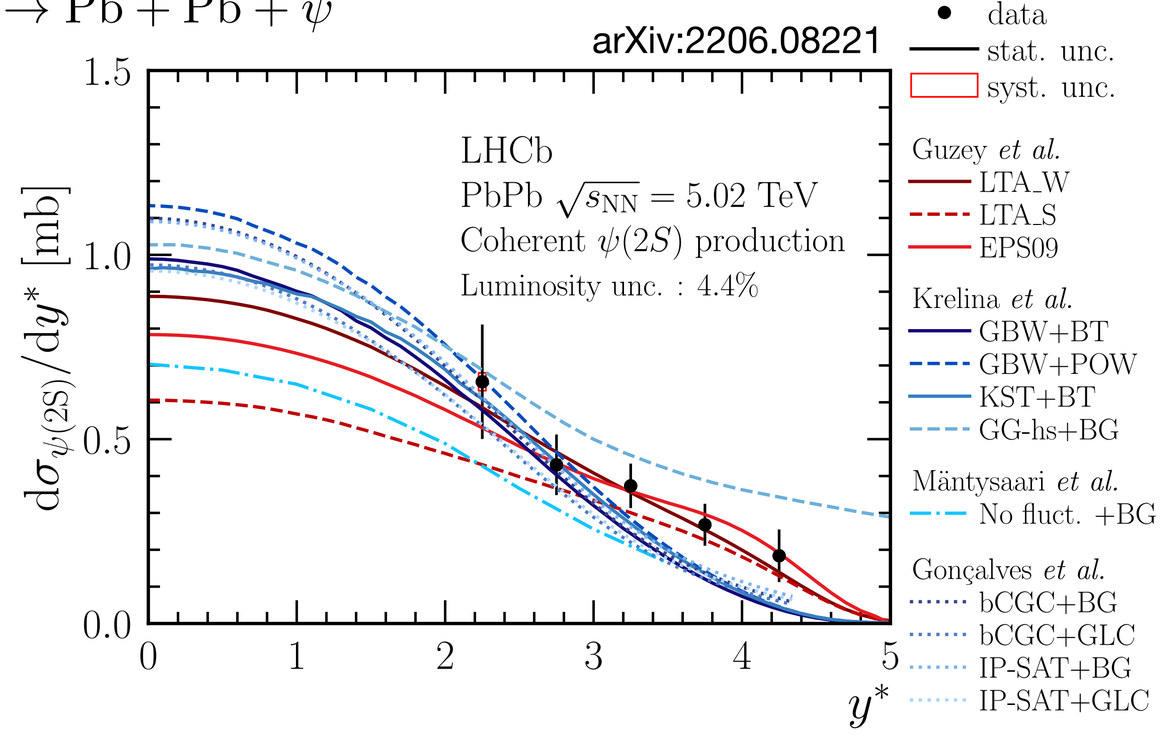


Coherent photoproduction in PbPb at LHCb: y dependence

$$\sigma^{\rm coh}_{J/\psi} = 5.965 \pm 0.059 \pm 0.232 \pm 0.262\,{\rm mb}$$
$$\sigma^{\rm coh}_{\psi(2S)} = 0.923 \pm 0.086 \pm 0.028 \pm 0.040\,{\rm mb}$$

$\mathrm{Pb} + \mathrm{Pb} \to \mathrm{Pb} + \mathrm{Pb} + \psi$





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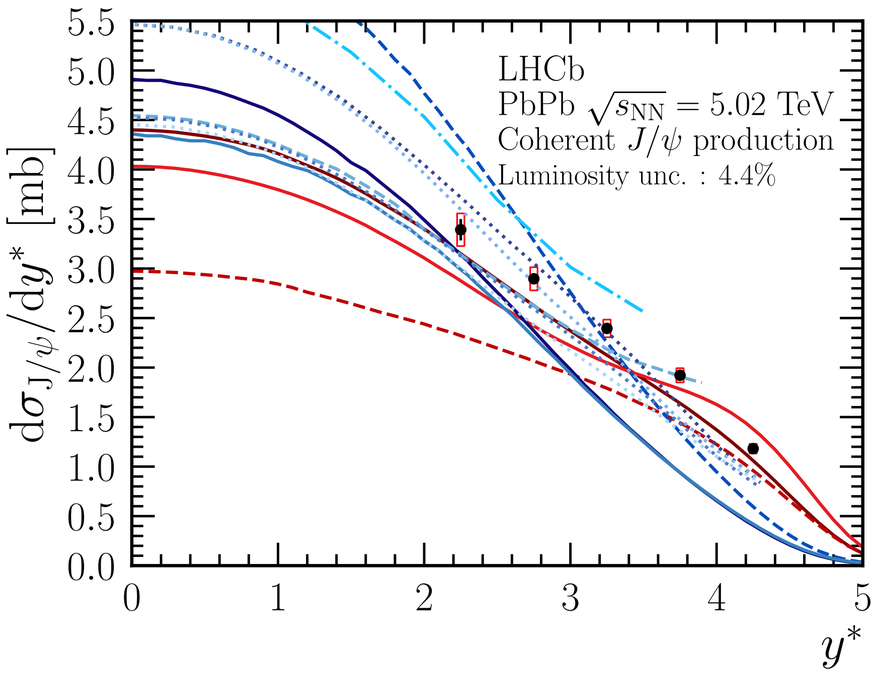

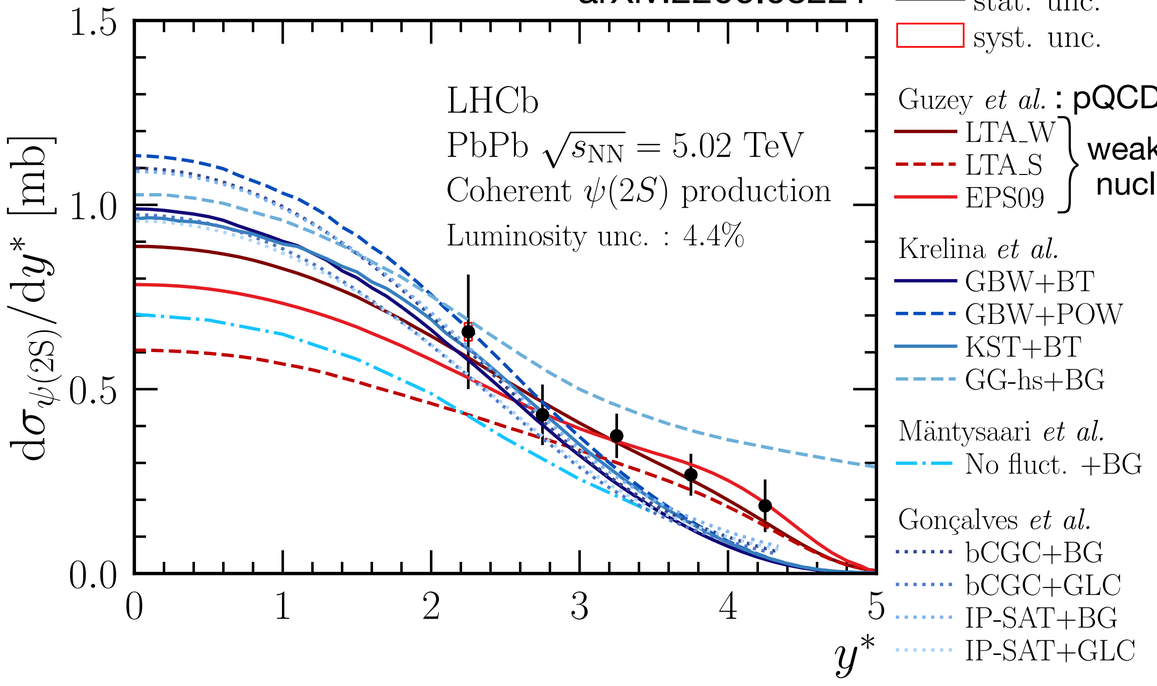

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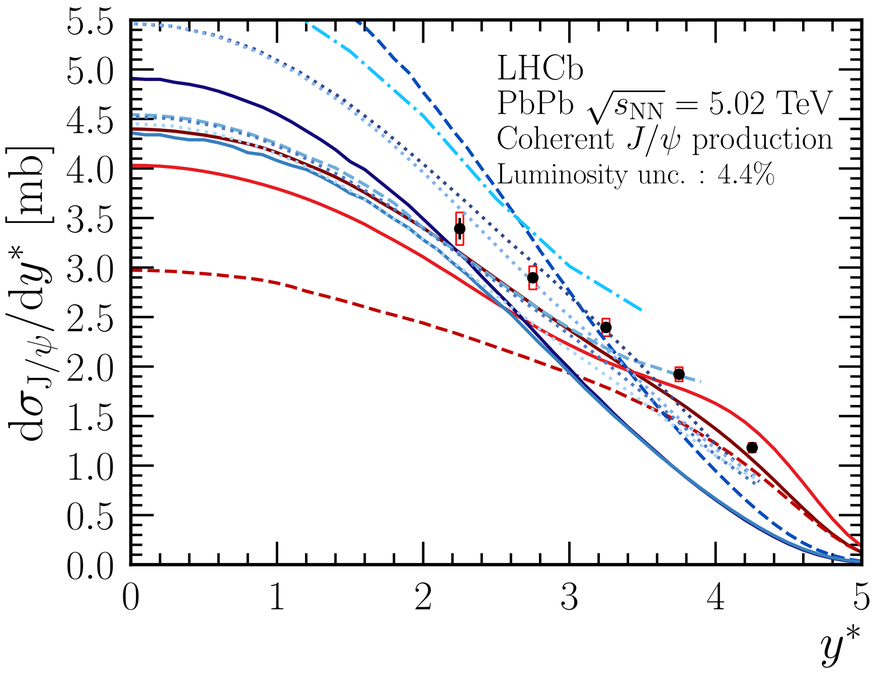
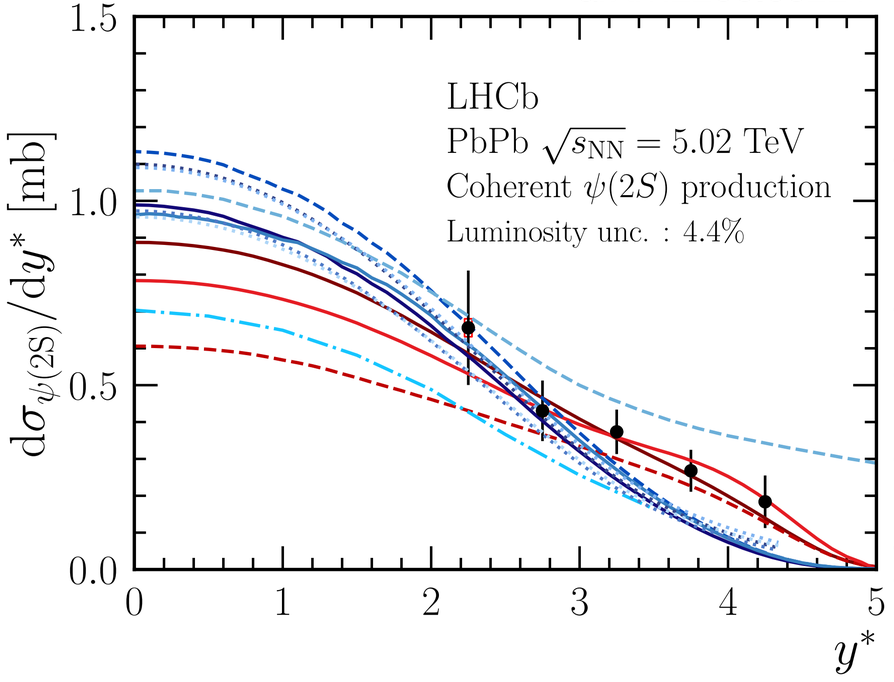




data
stat. unc.
syst. unc.

Guzey *et al.* : pQCD
- LTA_W
- LTA_S
- EPS09

} weak (W), strong (S) and leading-twist nuclear shadowing models

Krelina *et al.* : colour-dipole model, with saturation
- GBW+BT
- GBW+POW
- KST+BT

} LF dipole+charmonium production tuned to ep data

GG-hs+BG : dipole-p σ+ hotspots

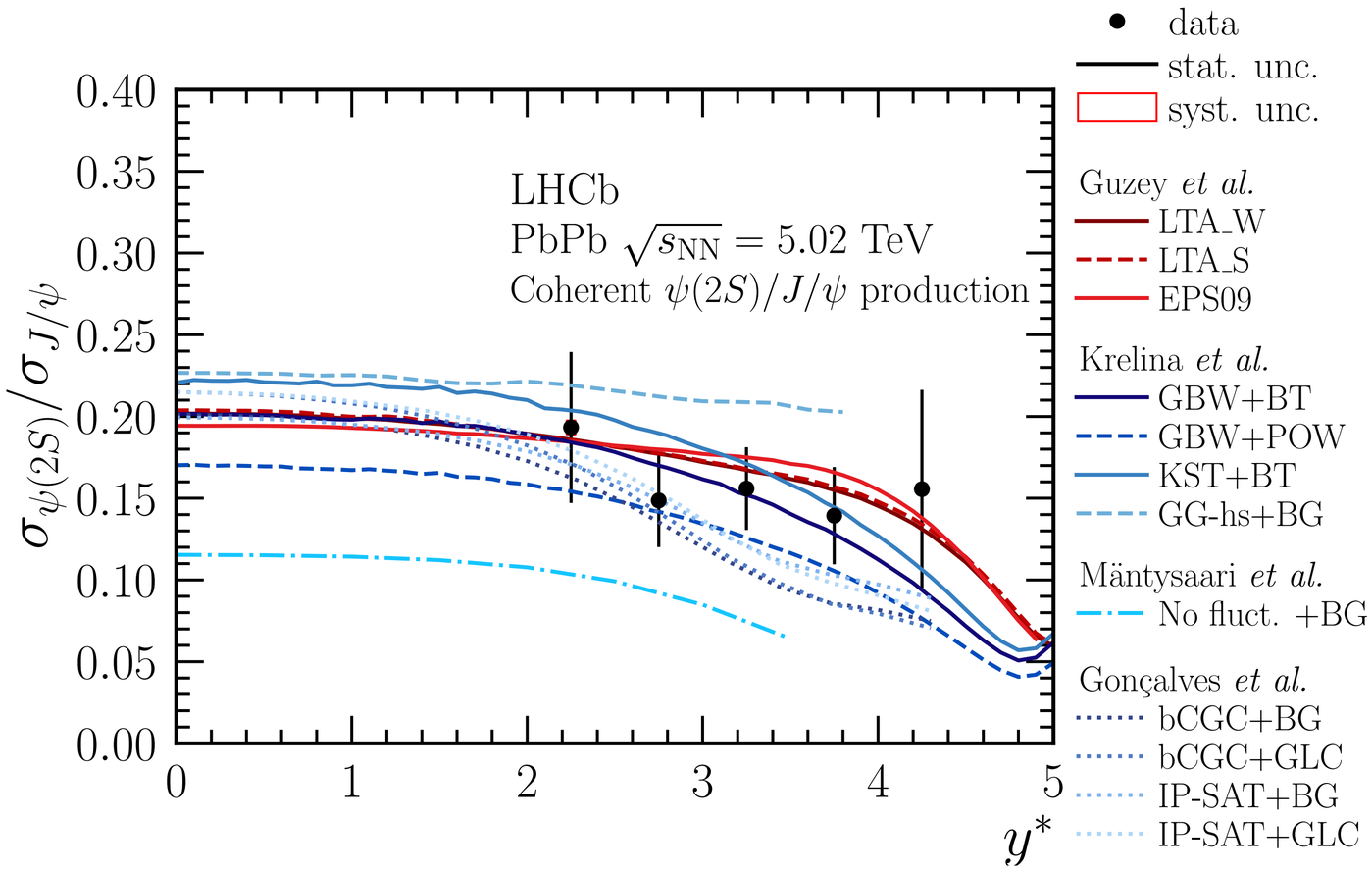
Mäntysaari *et al.*: colour-dipole model, with saturation
- No fluct. +BG: no sub-nucleonic fluctuations

Gonçalves *et al.* : colour-dipole model, with saturation
- bCGC+BG
- bCGC+GLC
- IP-SAT+BG
- IP-SAT+GLC

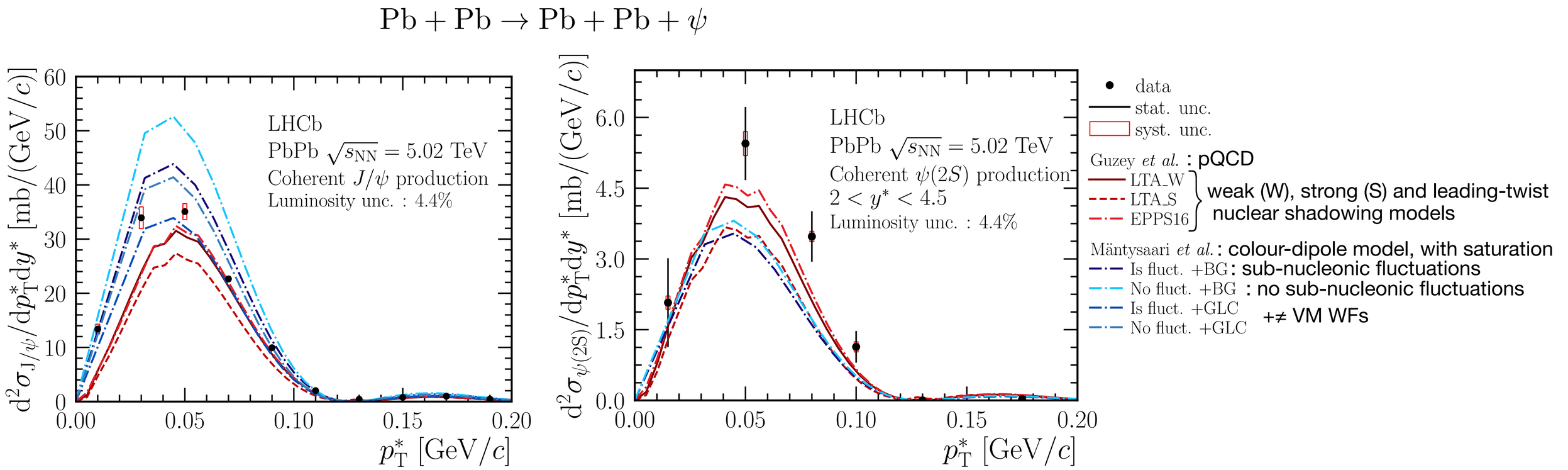
} dipole-p σ+VMWF, tuned to HERA data

LHCb: ψ(2S)/J/ψ (y-dependent) cross-section ratio

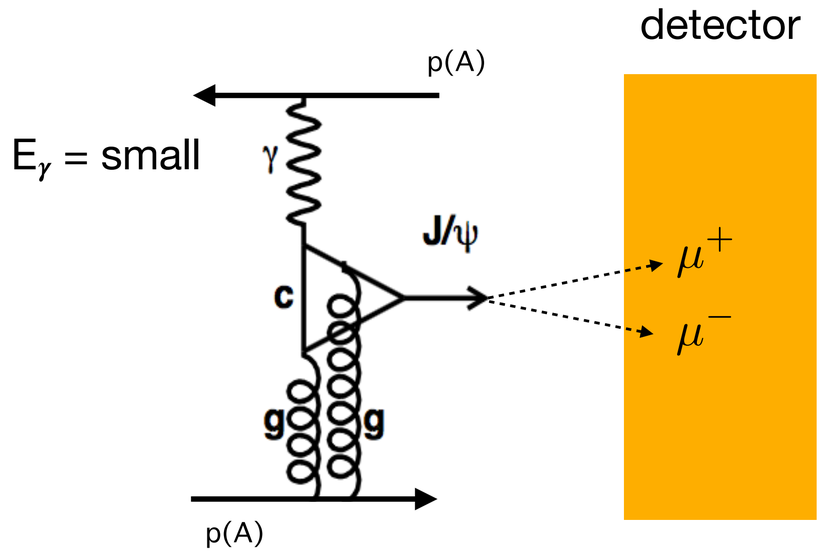
$$\sigma^{\mathrm{coh}}_{\psi(2S)}/\sigma^{\mathrm{coh}}_{J/\psi} = 0.155 \pm 0.014 \pm 0.003$$



Coherent photoproduction in PbPb at LHCb: p_T dependence



Disentangling the ambiguity on the ID of the γ emitter



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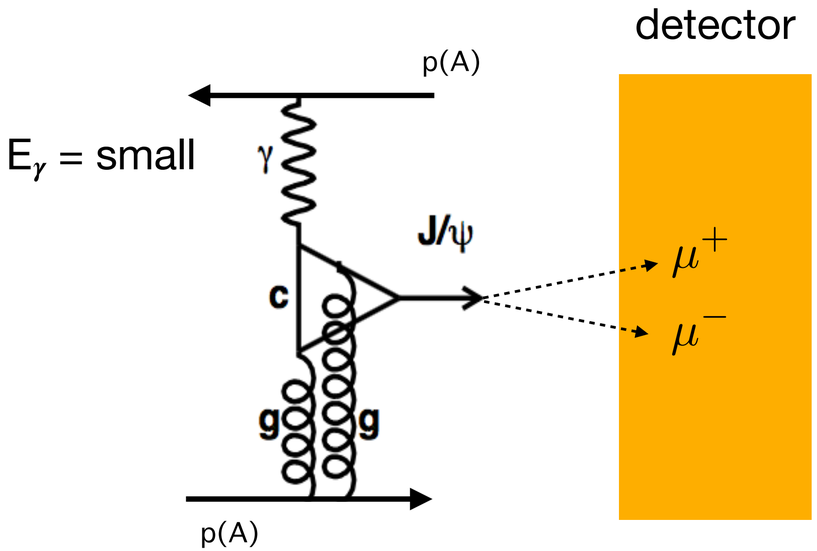

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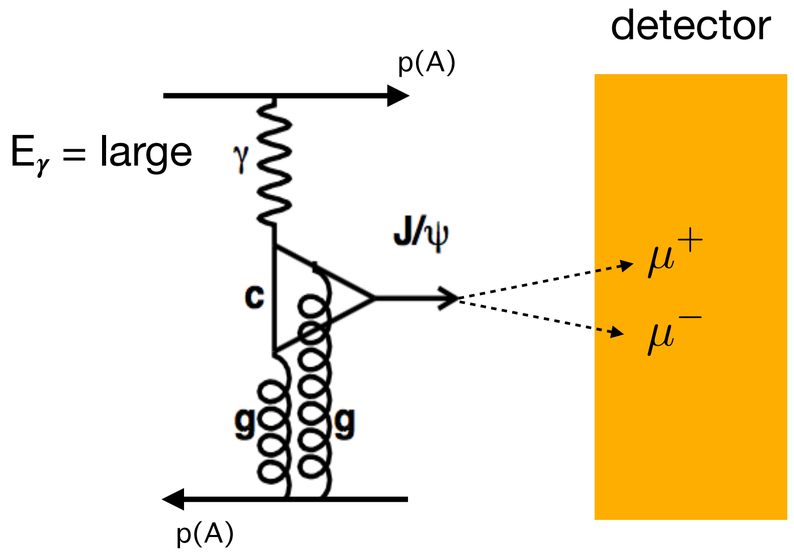

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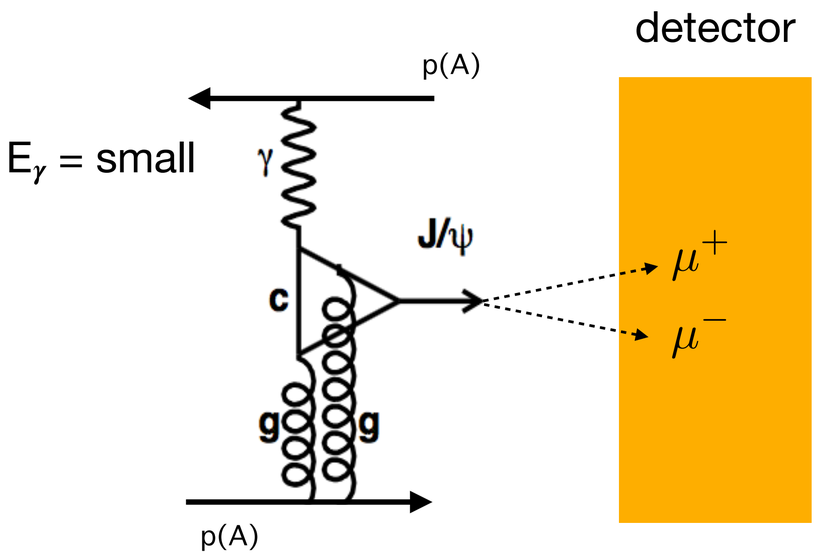

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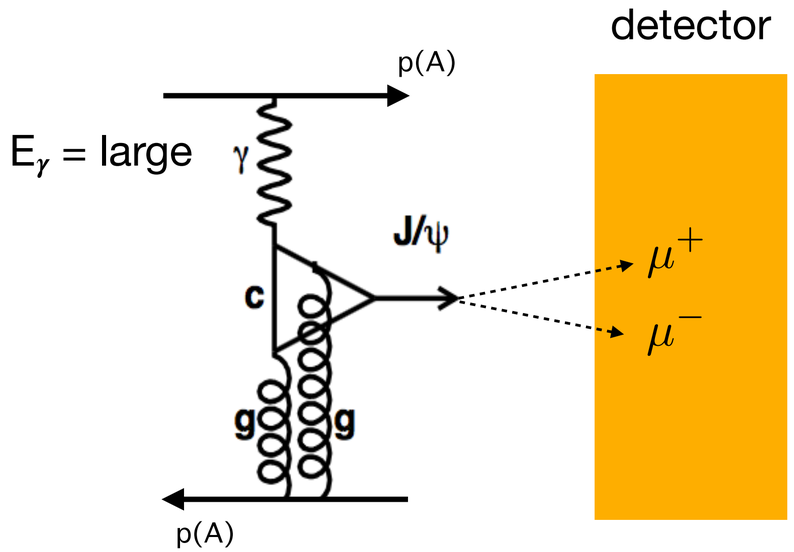

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enhanced for large E_γ at small impact parameter.

Small impact parameter , b ⟶ higher probability for exciting ($\propto 1/b^2$) ⟶ higher probability to emit neutrons.

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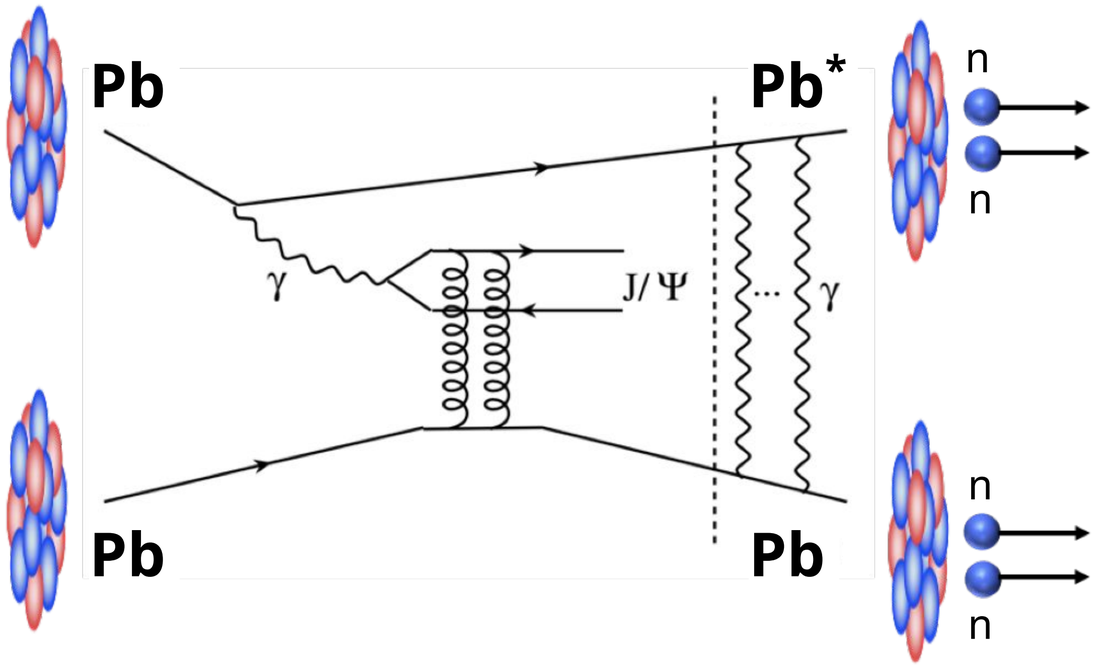

Picture from André Ståhl

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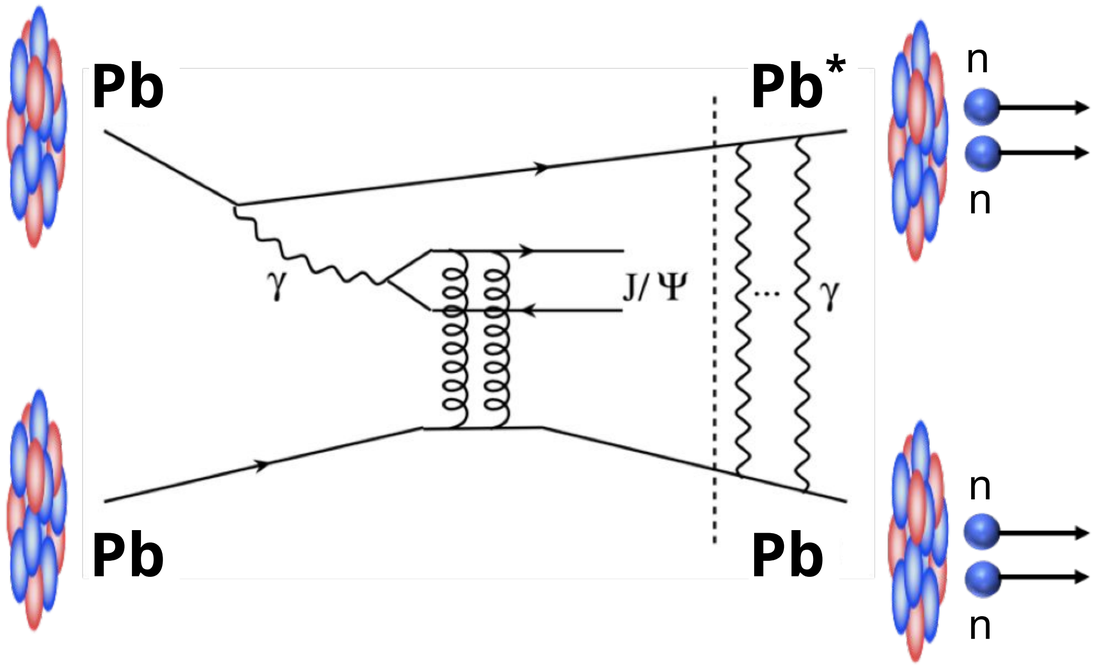
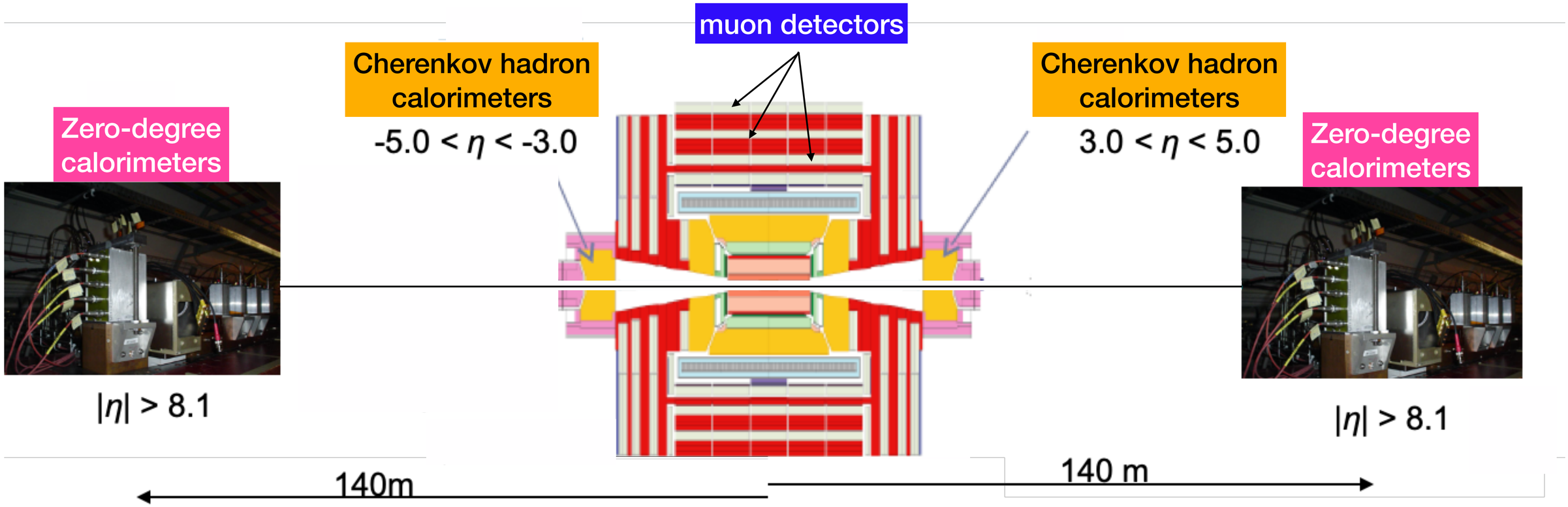


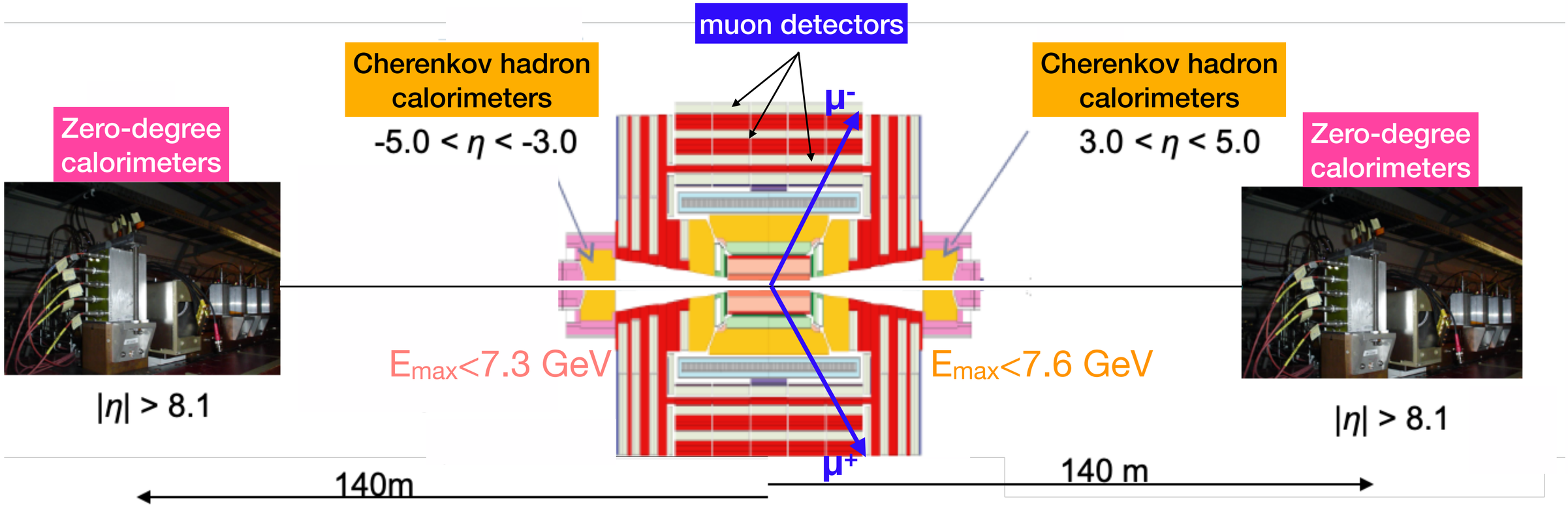
⟶ Make measurement with possibility to detect neutrons

Picture from André Ståhl

CMS central detector and the (far-)forward region

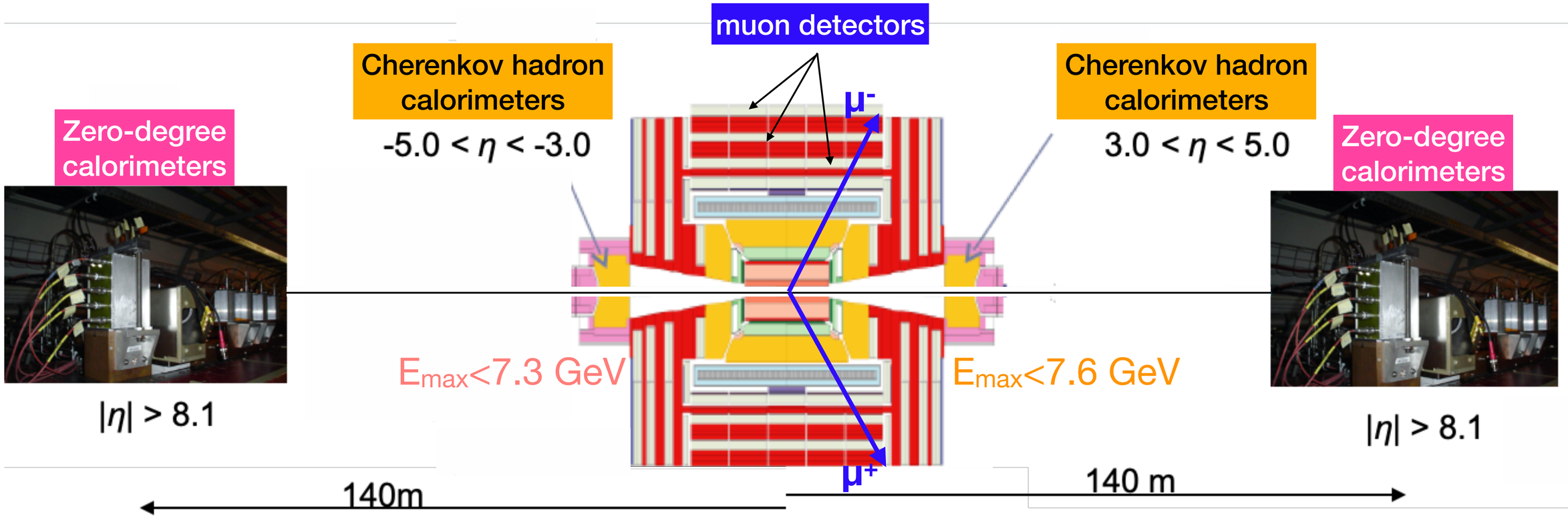


CMS central detector and the (far-)forward region



$$1.6 < |y_{\mu^+\mu^-}| < 2.4$$

CMS central detector and the (far-)forward region



$$1.6 < |y_{\mu^+\mu^-}| < 2.4$$

0 neutrons
≥1 neutron

0n0n
0nXn
XnXn

0 neutrons
≥1 neutron

Disentangling the ambiguity on the ID of the γ emitter

$$\sigma^{0n0n}(y) = N^{0n0n}_{\gamma/A}(E_{\gamma,s})\ \sigma_{J/\psi}(E_{\gamma,s}) + N^{0n0n}_{\gamma/A}(E_{\gamma,l})\ \sigma_{J/\psi}(E_{\gamma,l})$$

$$\sigma^{0nXn}(y) = N^{0nXn}_{\gamma/A}(E_{\gamma,s})\ \sigma_{J/\psi}(E_{\gamma,s}) + N^{0nXn}_{\gamma/A}(E_{\gamma,l})\ \sigma_{J/\psi}(E_{\gamma,l})$$

$$\sigma^{XnXn}(y) = N^{XnXn}_{\gamma/A}(E_{\gamma,s})\ \sigma_{J/\psi}(E_{\gamma,s}) + N^{XnXn}_{\gamma/A}(E_{\gamma,l})\ \sigma_{J/\psi}(E_{\gamma,l})$$

measured

Disentangling the ambiguity on the ID of the γ emitter

$$\sigma^{0n0n}(y) = N^{0n0n}_{\gamma/A}(E_{\gamma,s})\,\sigma_{J/\psi}(E_{\gamma,s}) + N^{0n0n}_{\gamma/A}(E_{\gamma,l})\,\sigma_{J/\psi}(E_{\gamma,l})$$

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$$\sigma^{XnXn}(y) = N^{XnXn}_{\gamma/A}(E_{\gamma,s})\,\sigma_{J/\psi}(E_{\gamma,s}) + N^{XnXn}_{\gamma/A}(E_{\gamma,l})\,\sigma_{J/\psi}(E_{\gamma,l})$$

measured — **computed (StarLight)** — **computed (StarLight)**

Disentangling the ambiguity on the ID of the γ emitter

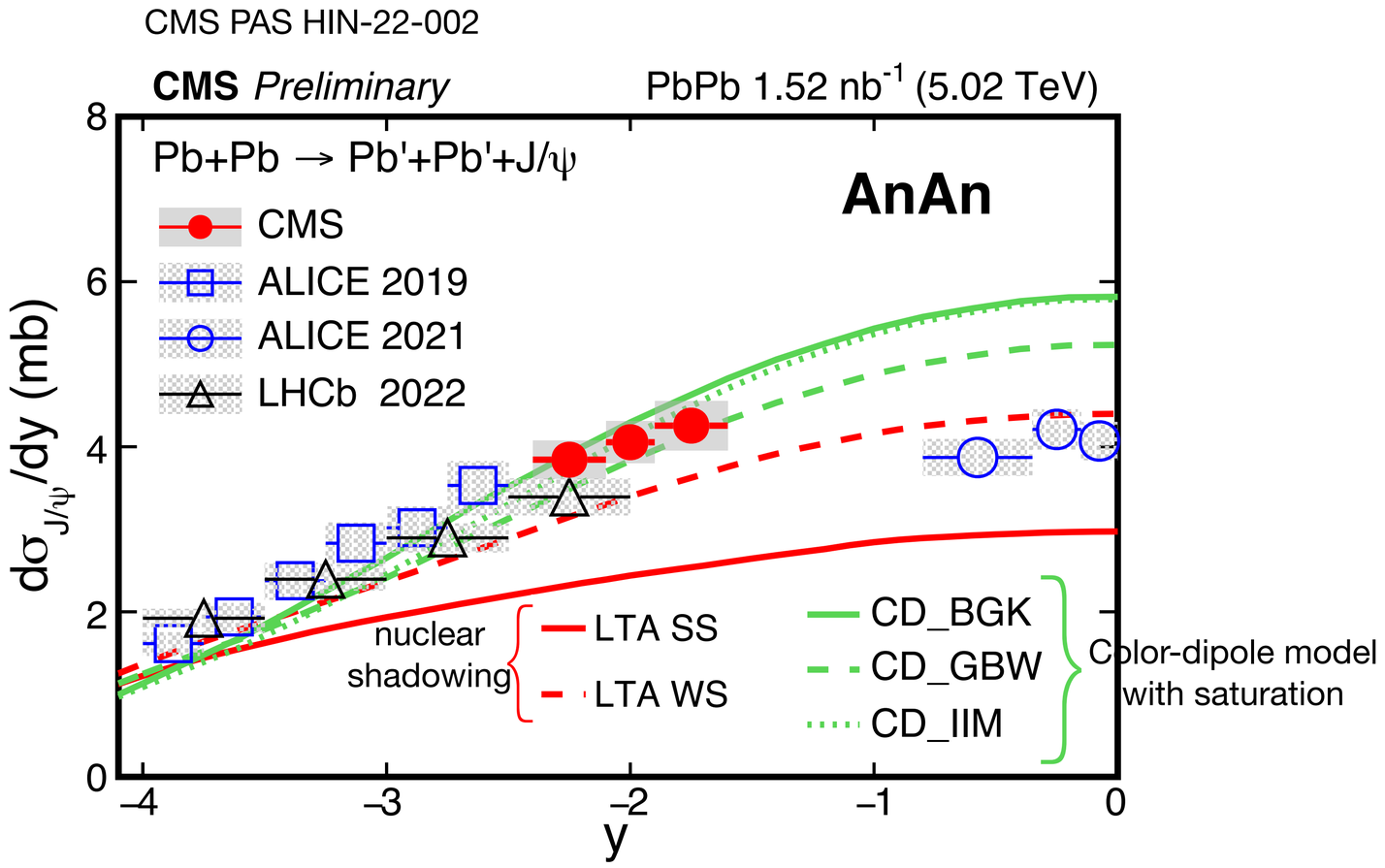
$$\sigma^{0n0n}(y) = N^{0n0n}_{\gamma/A}(E_{\gamma,s})\,\sigma_{J/\psi}(E_{\gamma,s}) + N^{0n0n}_{\gamma/A}(E_{\gamma,l})\,\sigma_{J/\psi}(E_{\gamma,l})$$

$$\sigma^{0nXn}(y) = N^{0nXn}_{\gamma/A}(E_{\gamma,s})\,\sigma_{J/\psi}(E_{\gamma,s}) + N^{0nXn}_{\gamma/A}(E_{\gamma,l})\,\sigma_{J/\psi}(E_{\gamma,l})$$

$$\sigma^{XnXn}(y) = N^{XnXn}_{\gamma/A}(E_{\gamma,s})\,\sigma_{J/\psi}(E_{\gamma,s}) + N^{XnXn}_{\gamma/A}(E_{\gamma,l})\,\sigma_{J/\psi}(E_{\gamma,l})$$

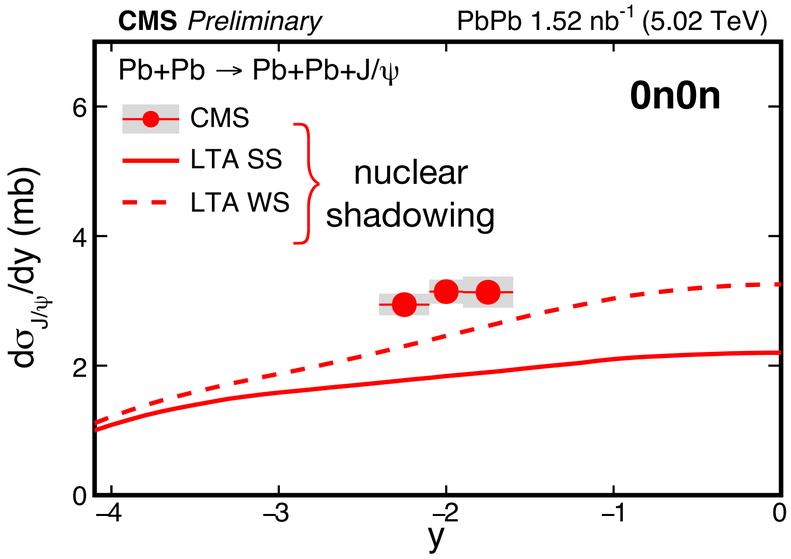
measured | **computed (StarLight)** | **extracted** | **computed (StarLight)** | **extracted**

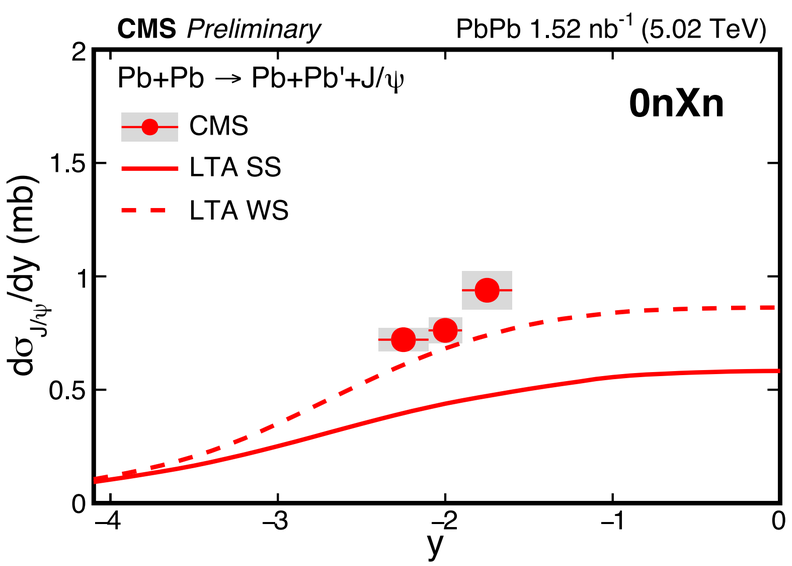
CMS results: no requirement on neutron detection

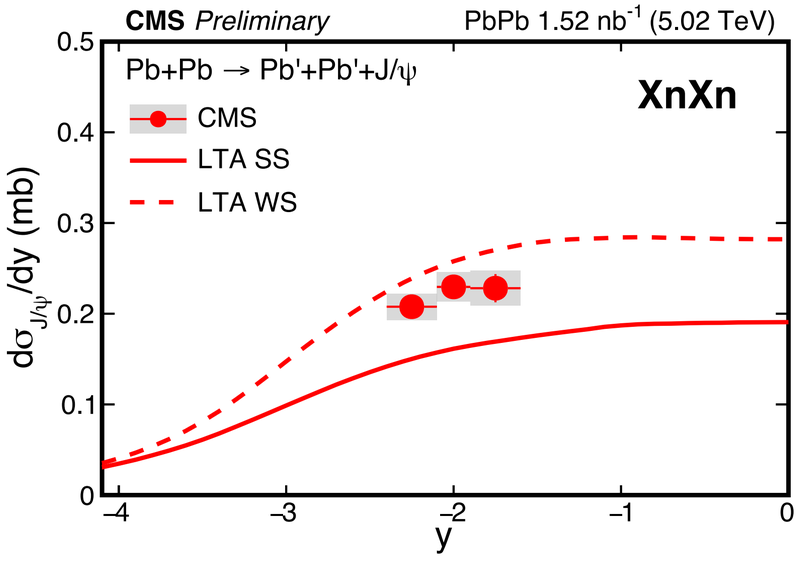


CMS results: different neutron-detection requirements

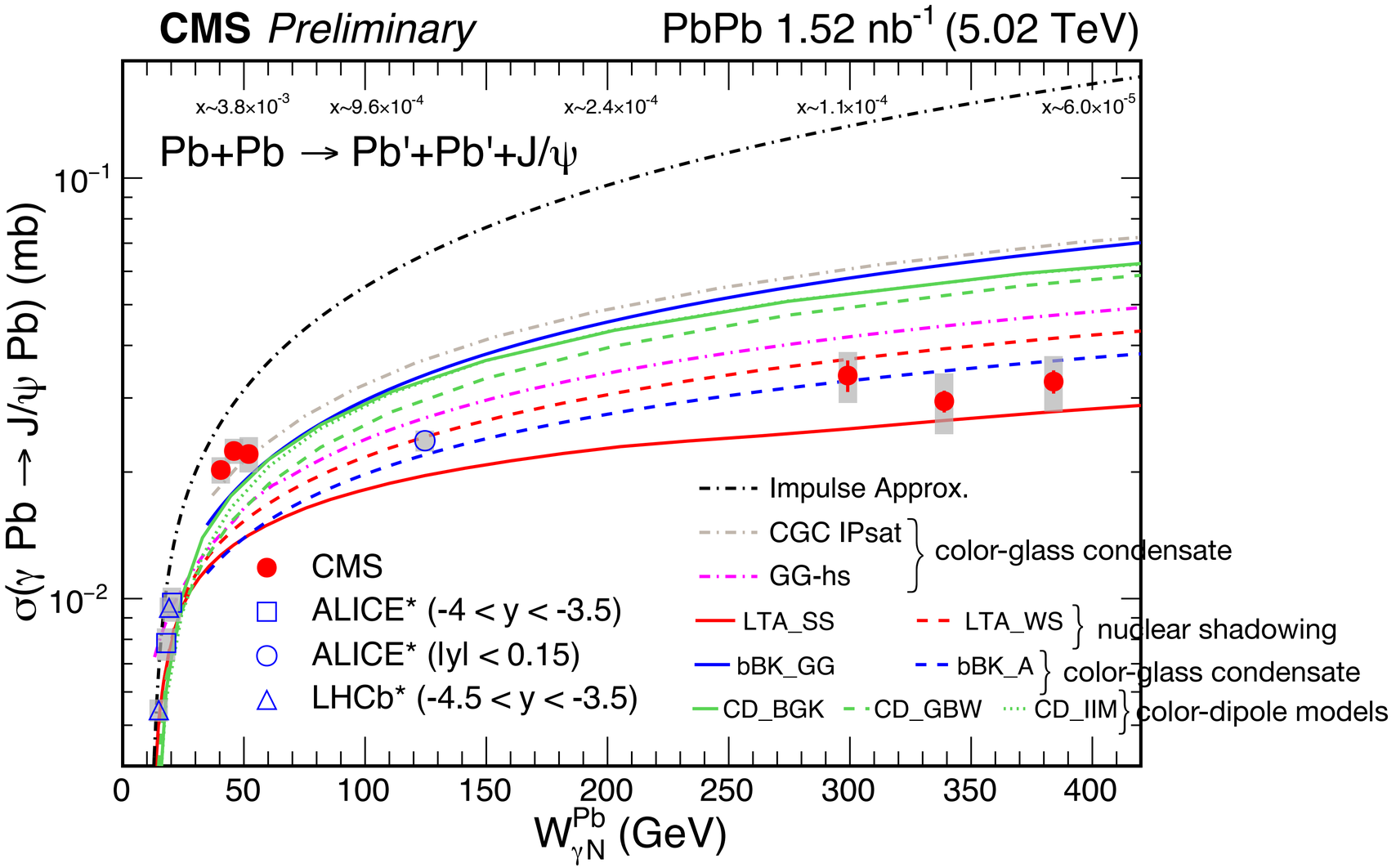
CMS PAS HIN-22-002







CMS: γPb cross section, energy dependence



Summary

- Exclusive proton-nucleus collisions

- Exclusive nucleus-nucleus collisions
  - ALICE:
    - tension between mid and forward rapidity?
    - possibility to extract t-dependent γPb cross section at mid rapidity
  - LHCb: better connection to ALICE results at mid rapidity?
  - CMS: neutron tagging: intriguing small linear rise of cross section for $W_{\gamma N}$>40 GeV

Back up

CMS results: nuclear gluon suppression factor