

# Overview of UPC

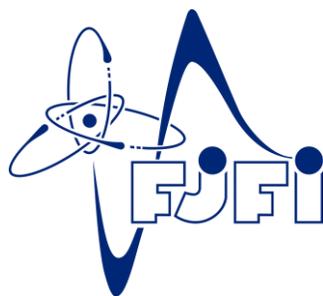
Tomáš Herman

Czech Technical University in Prague  
Faculty of Nuclear Sciences and Physical Engineering

Třetí miniworkshop difrakce a ultraperiferálních srážek

16.09.2020

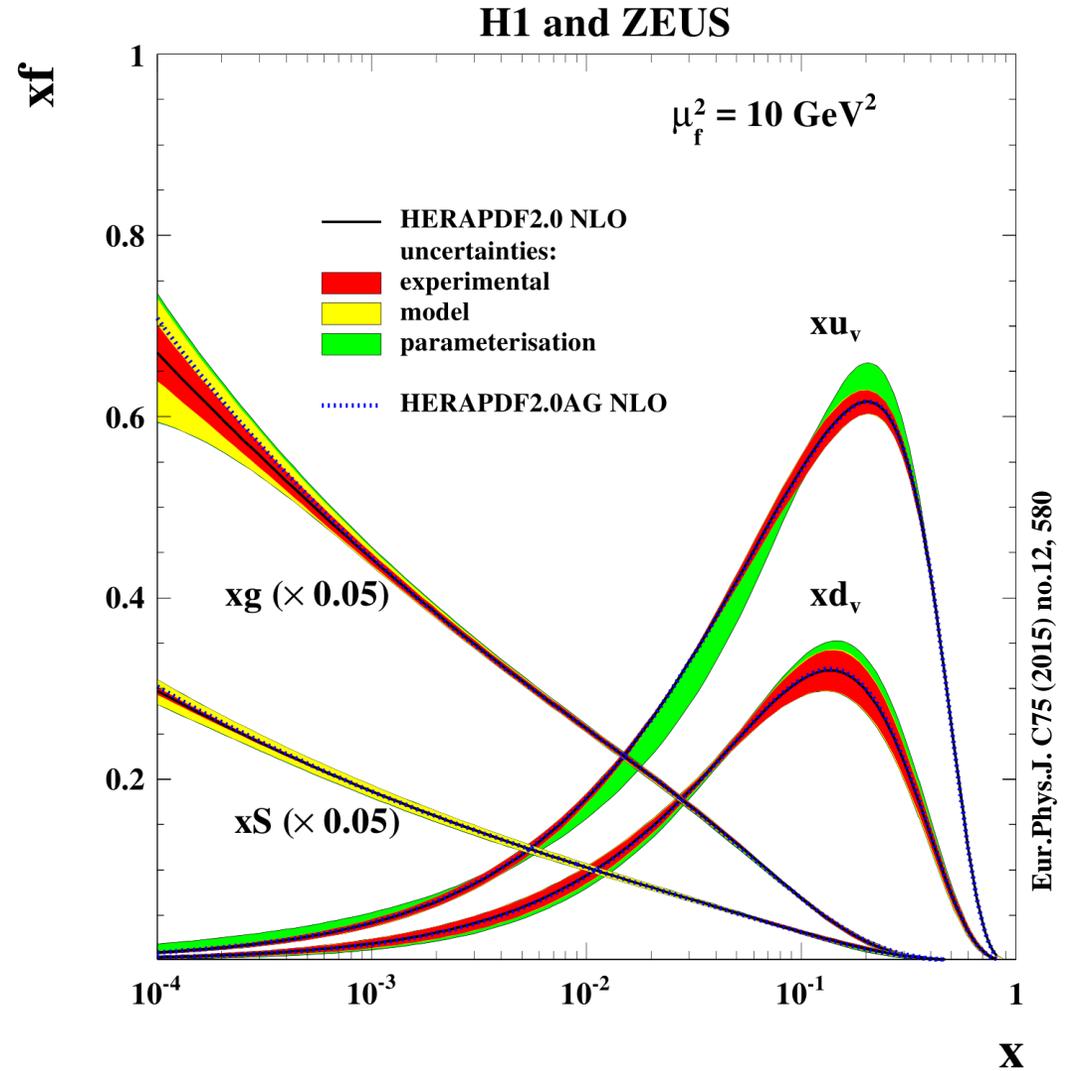
Děčín



- The **structure of proton** in DIS is described by the parton distribution functions  $xf(x, Q^2)$

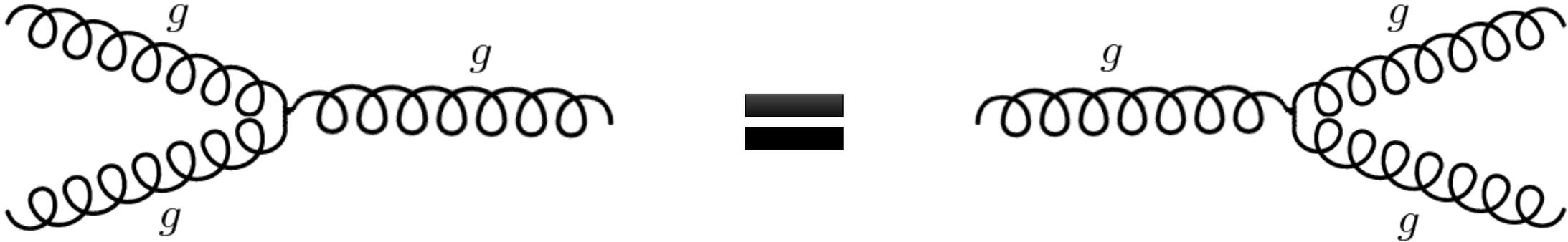
# Proton structure

- The **structure of proton** in DIS is described by the parton distribution functions  $xf(x, Q^2)$
- In leading order, distribution function  $xf(x, Q^2)$  can be interpreted as the contribution of the given partons to the proton composition
- At **low  $x$**  the **gluon** distribution function is **steeply rising**



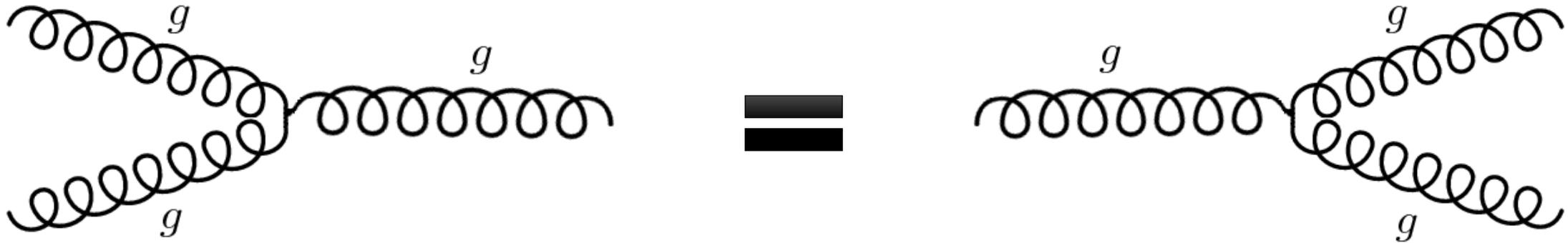
# Proton structure

- The number of gluons cannot grow indefinitely
- At some point they will recombine and split at the same rate



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→ **Saturation**

- Predicted by pQCD, but not yet conclusively observed

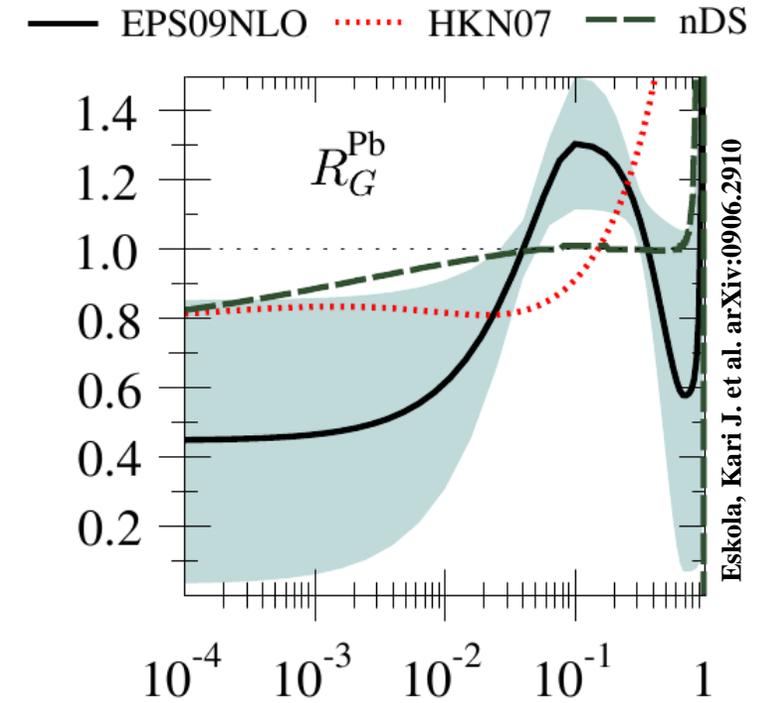
- Nucleus is not a simple sum of nucleons

$$R_{F_2}^A(x, Q^2) = \frac{F_2^A(x, Q^2)}{AF_2^{\text{nucleon}}(x, Q^2)} \neq 1$$

# Nucleus structure

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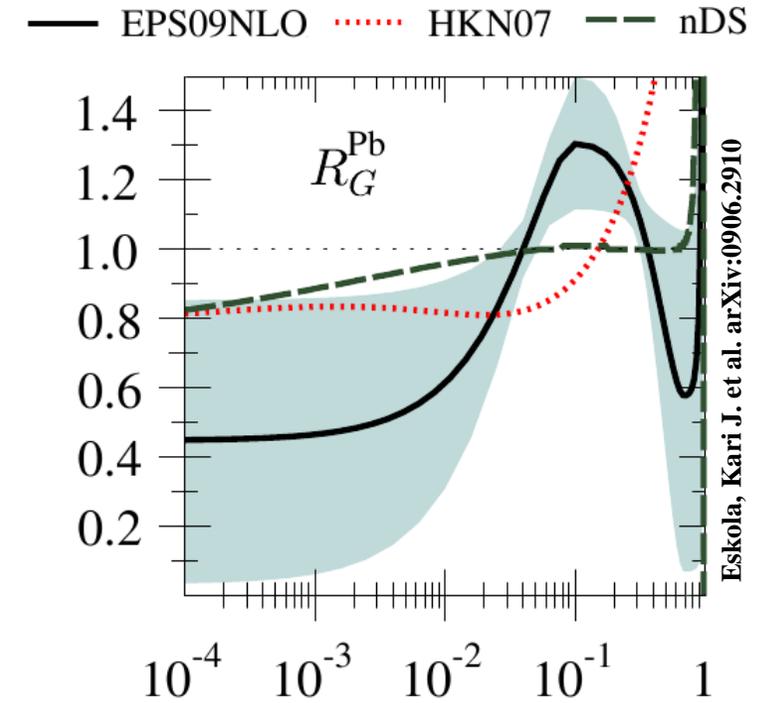
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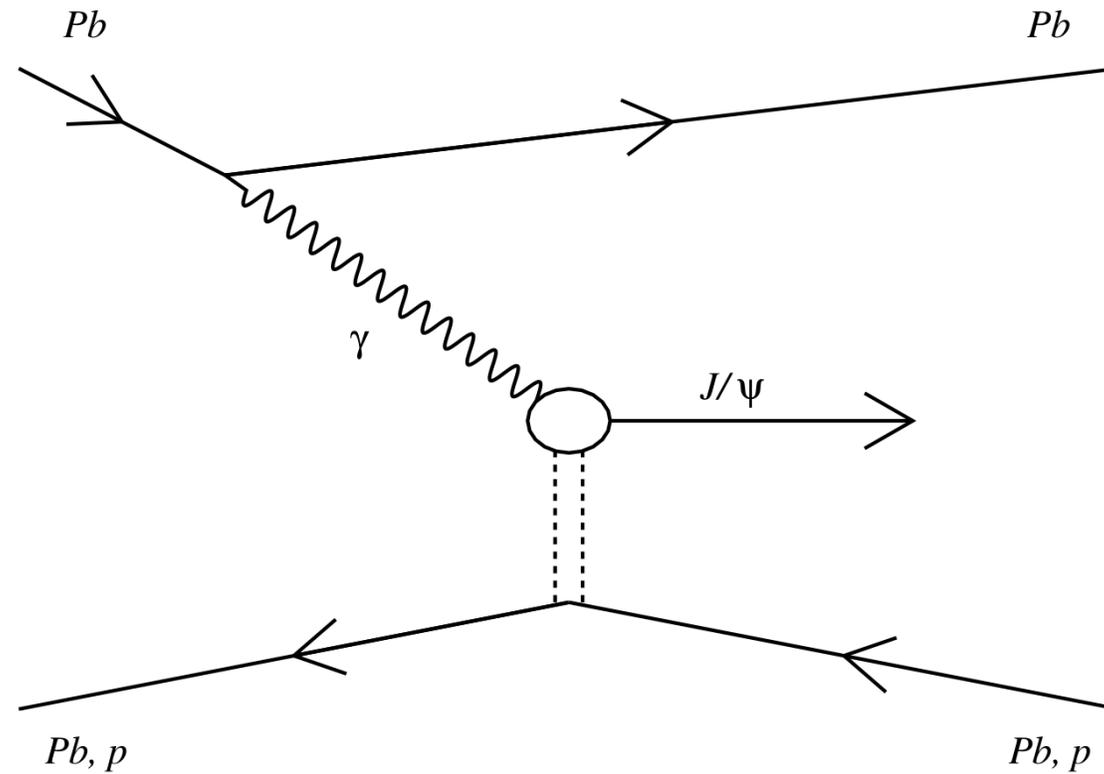
$$R_{F_2}^A(x, Q^2) = \frac{F_2^A(x, Q^2)}{AF_2^{\text{nucleon}}(x, Q^2)} \neq 1$$

→ **Nuclear shadowing**

- No satisfactory description by pQCD
  - Data is used to constraint models
- At low  $x$ :  $R_{F_2}^A(x, Q^2) < 1$ 
  - **Saturation** is expected to be one of the **contributions**
  - **Saturation** is expected to set in **at higher  $x$  in nuclei** w.r.t. nucleons

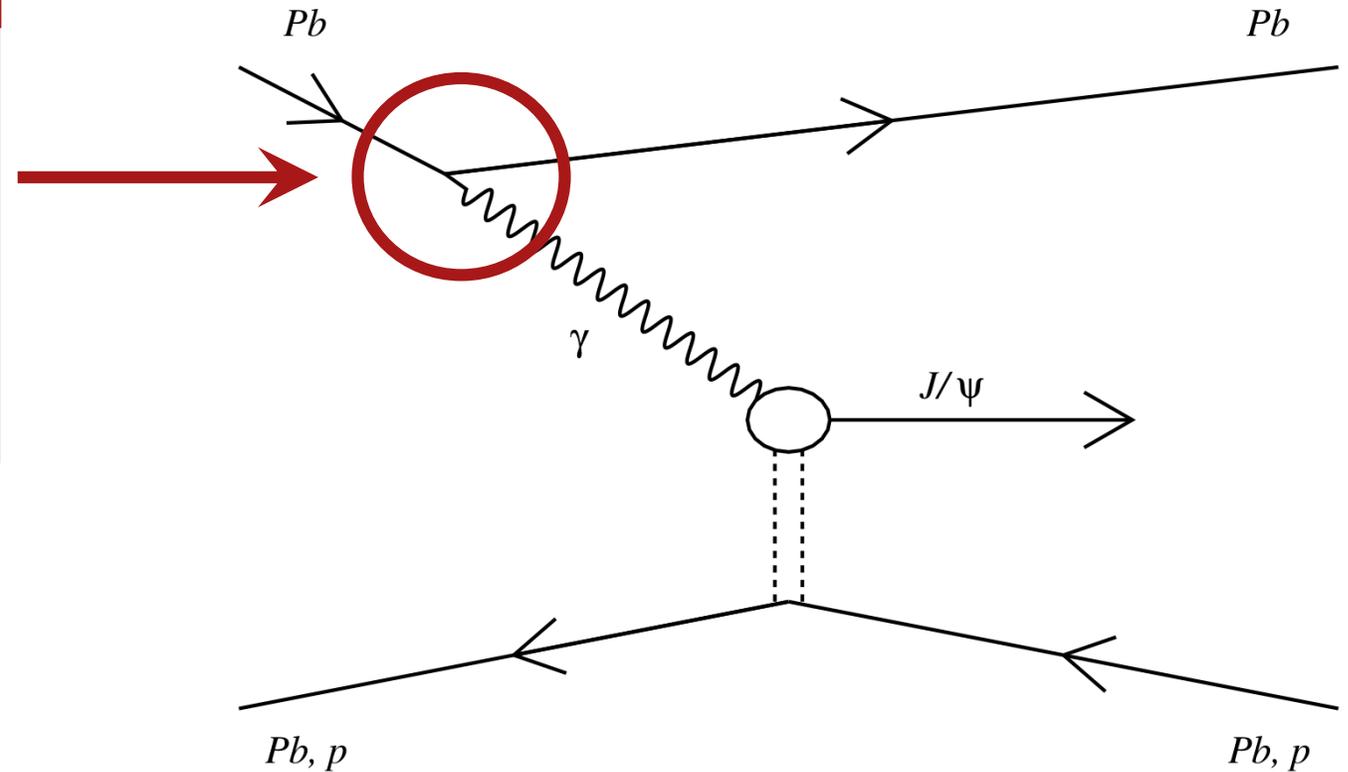


- The proton and nucleus structure can be studied with **photoproduction** of  $J/\psi$  in Pb-Pb/p collisions

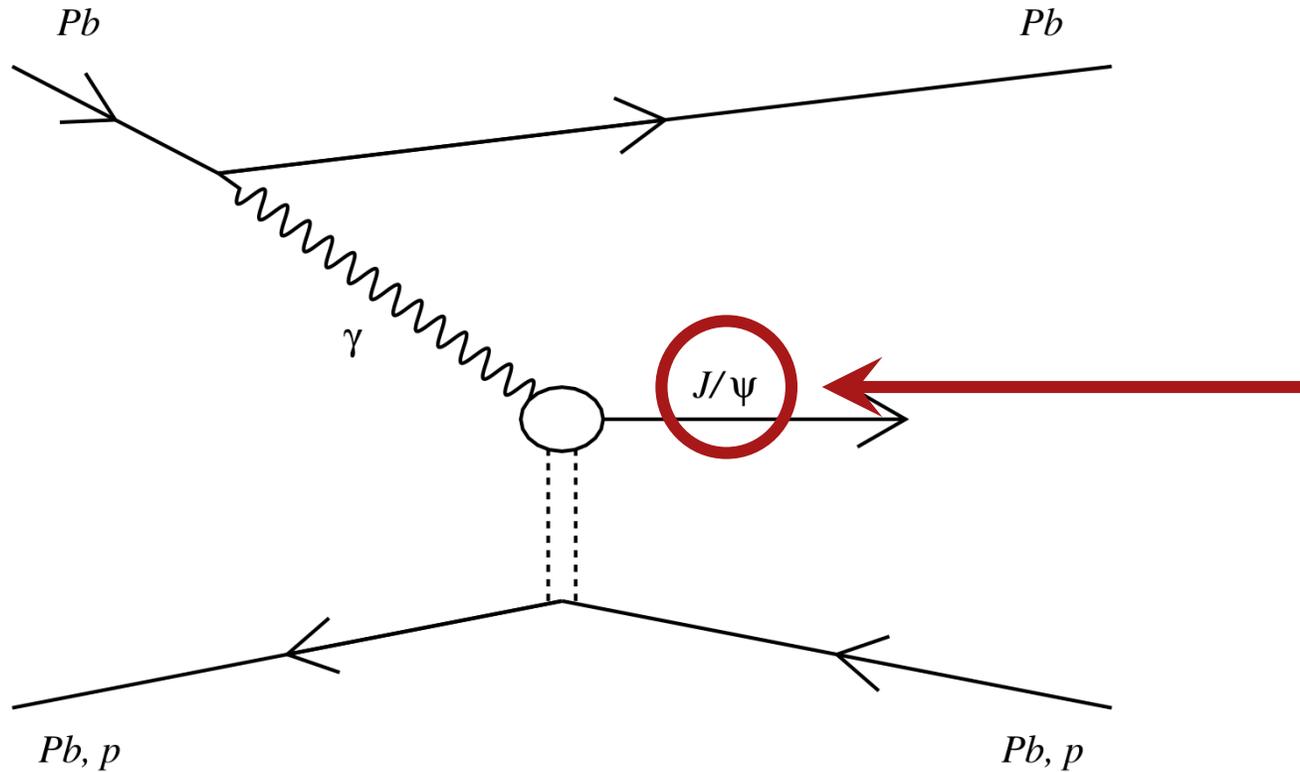


## Photon emission

- Photon flux intensity
  - Proportional to  $Z^2$
- Maximum photon energy
  - Given by the Pb ion Lorentz boost



# Photoproduction

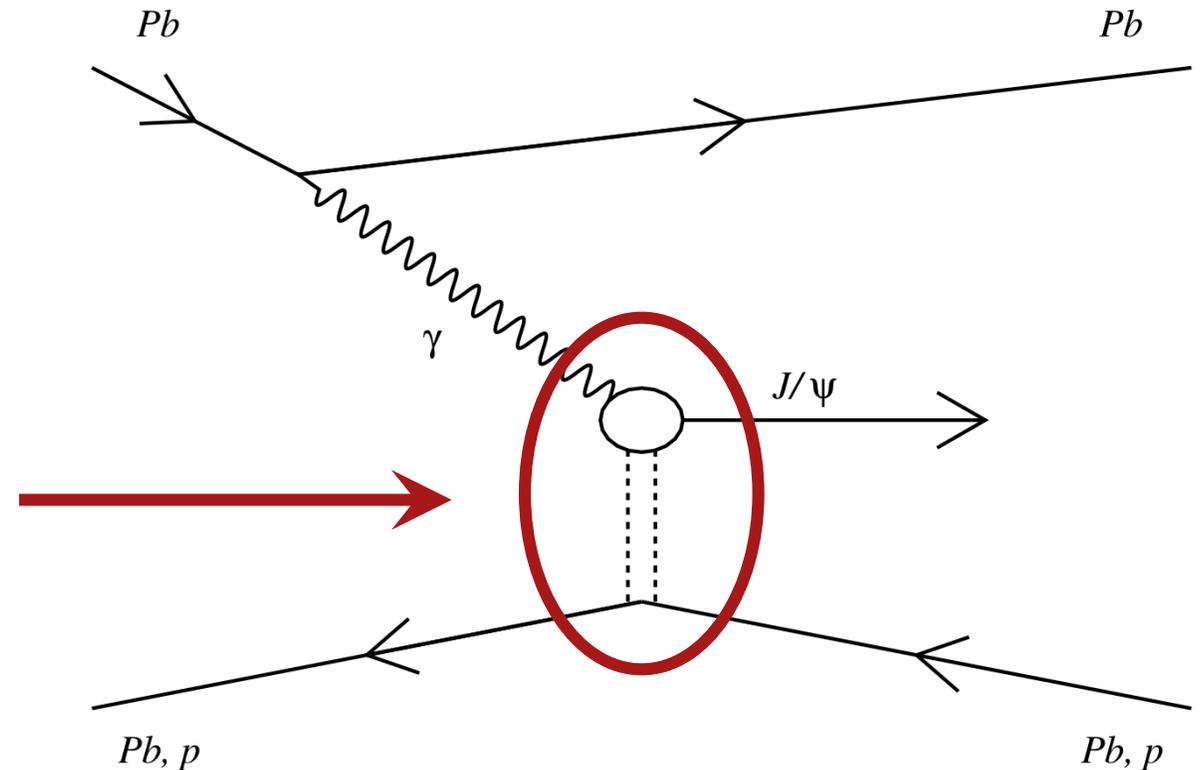


## $J/\psi$

- Vector meson
  - Quantum numbers of  $\gamma$
- Perturbative calculations
  - Large mass
- Clear experimental signal
  - Large lepton branching ratios
  - Small decay width

## Photon target interaction

- In LO pQCD
  - Cross section  $\propto$  **gluon density squared**
- Vector dominance model
  - $\gamma$  fluctuates into a  $J/\psi$
- Colour dipole model
  - $\gamma$  fluctuates into quark-antiquark dipole

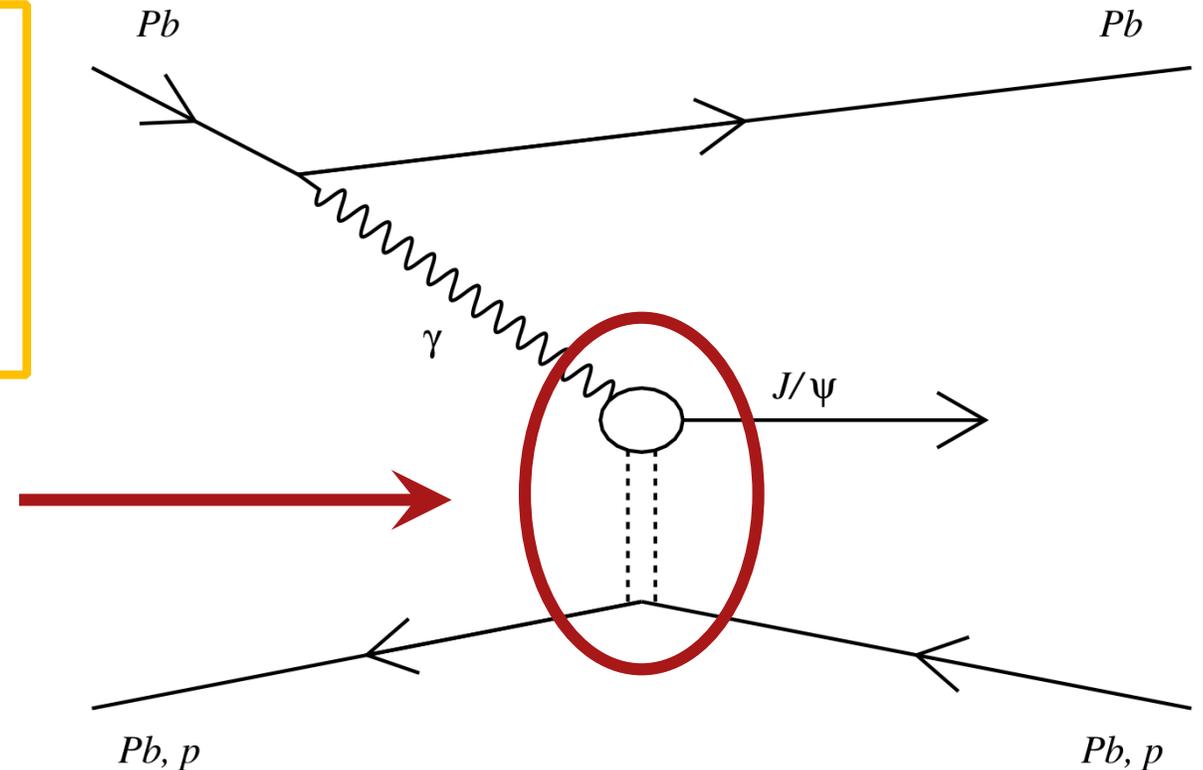


# Photoproduction

$$\left. \frac{d\sigma_{\gamma Pb}}{dt} \right|_{t=0} = \frac{16 \Gamma_{ee} \pi^3}{3 \alpha_{em} M_{J/\psi}^5} \{ \alpha_s(Q^2) G_{Pb}(x, Q^2) \}^2$$

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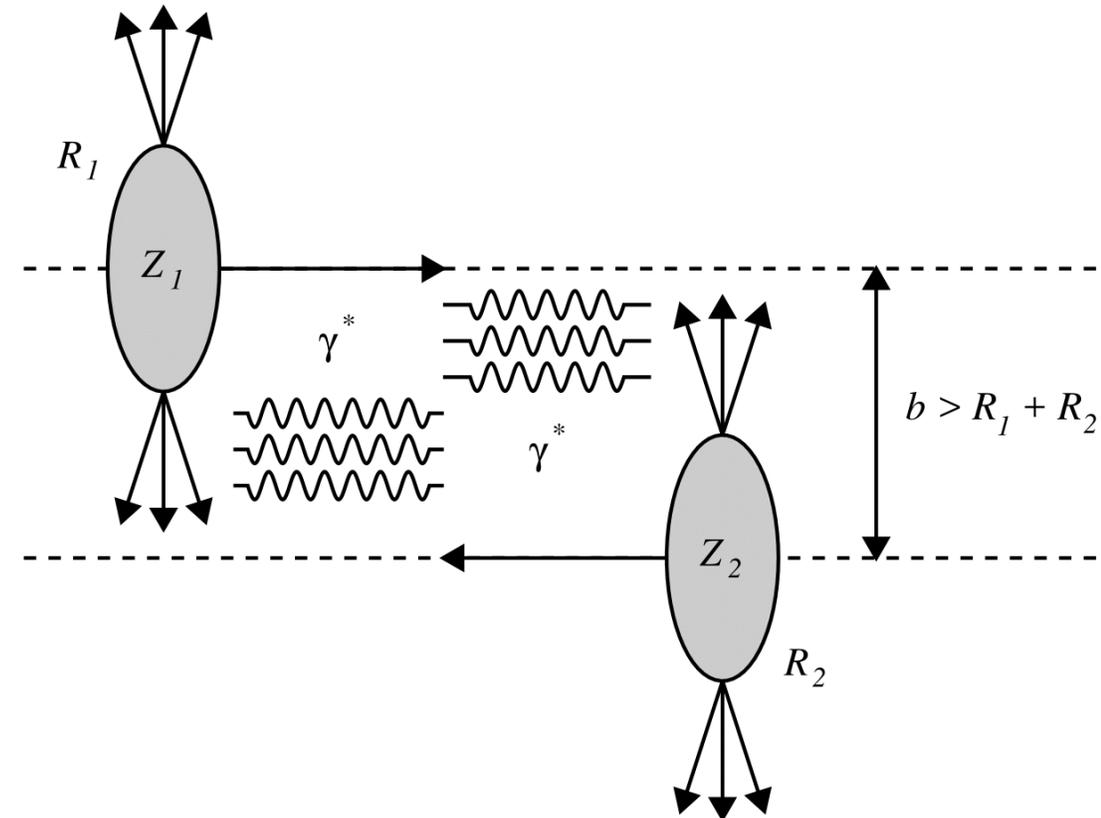
- We need to suppress hadronic interactions to measure photoproduction

# Ultra-peripheral collisions

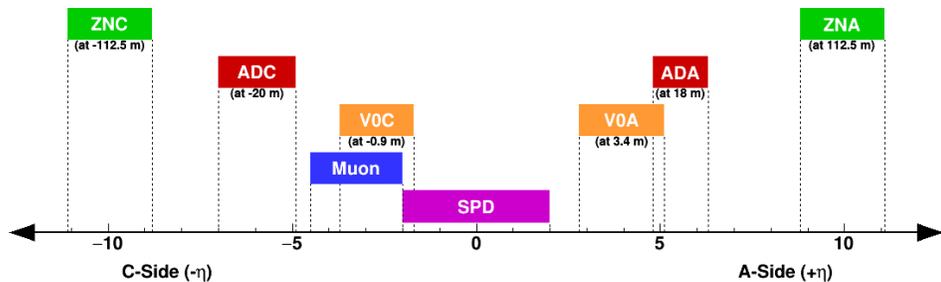
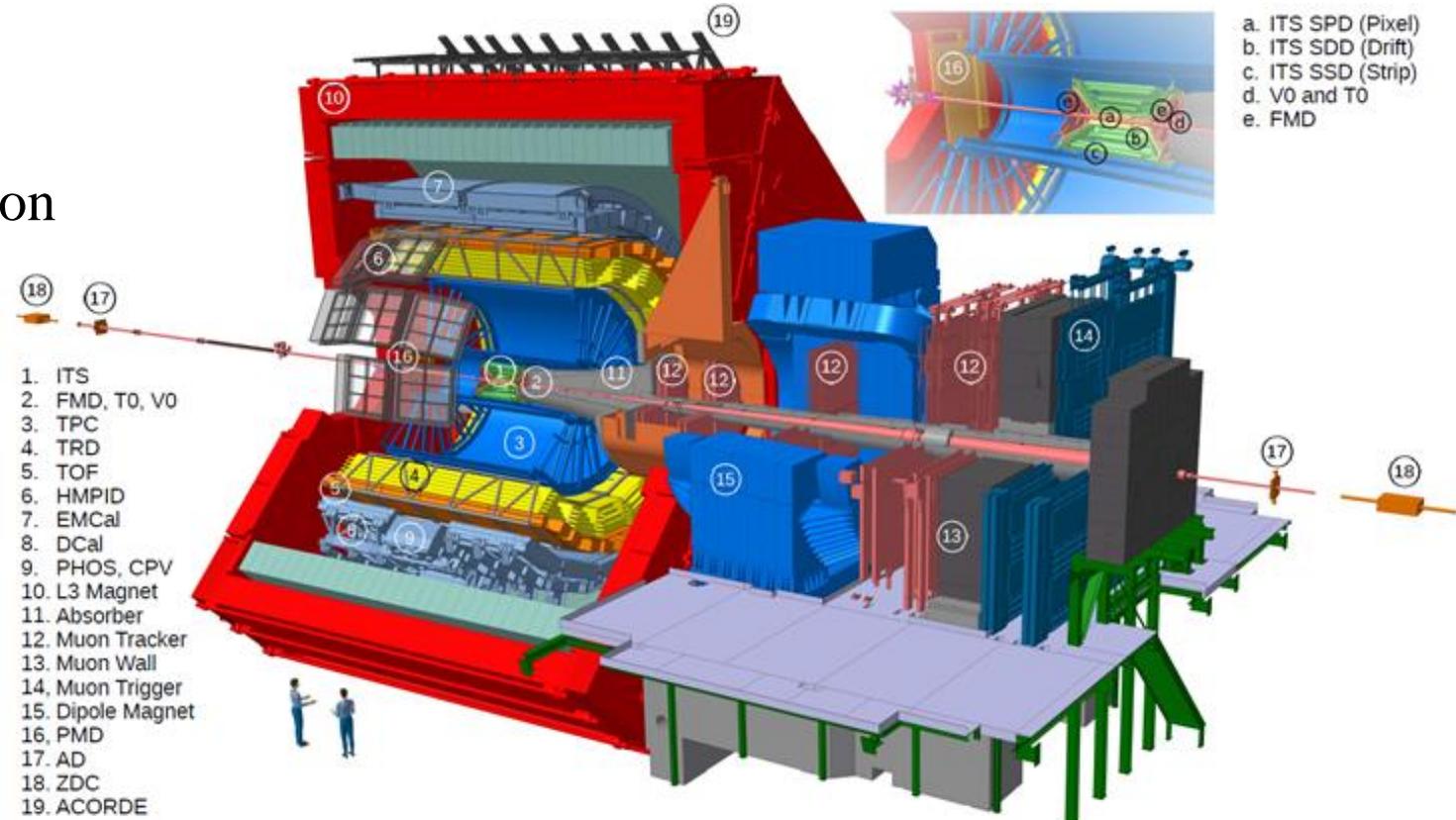
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## → Ultra-peripheral collisions

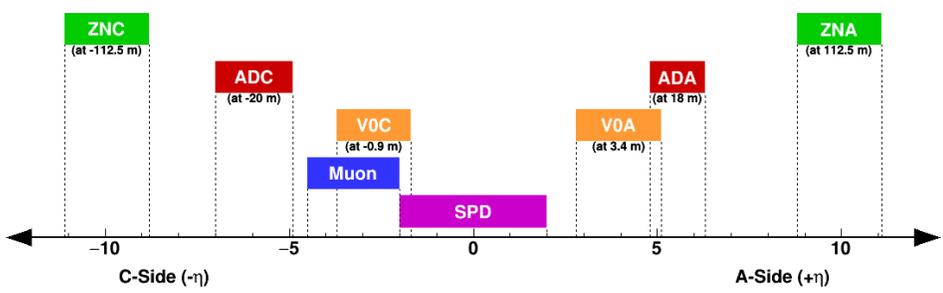
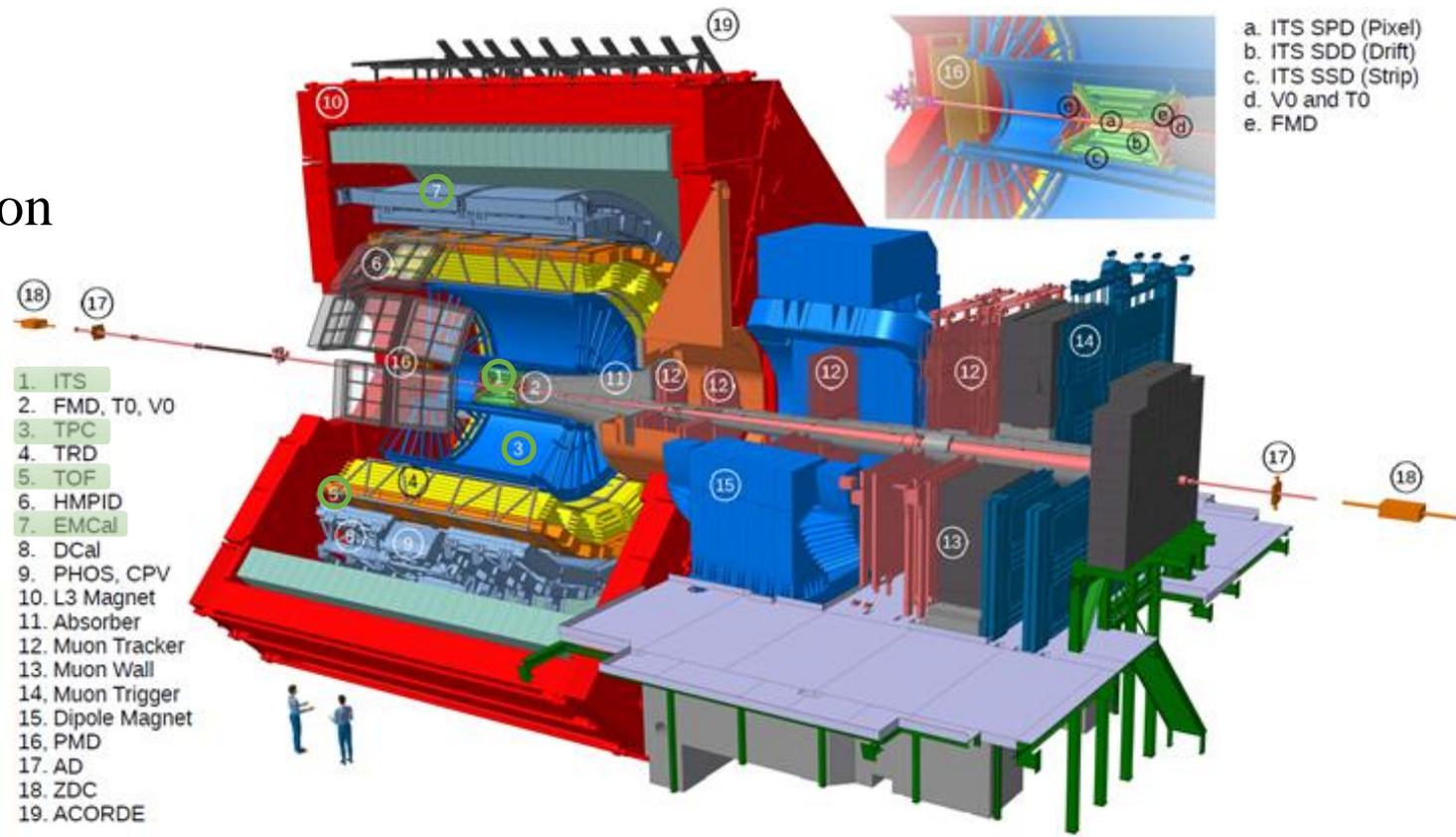
- Interactions at impact parameter  $b$  larger than the sum of the radii of the colliding particles  $R_1 + R_2$ , which involve at least one photon



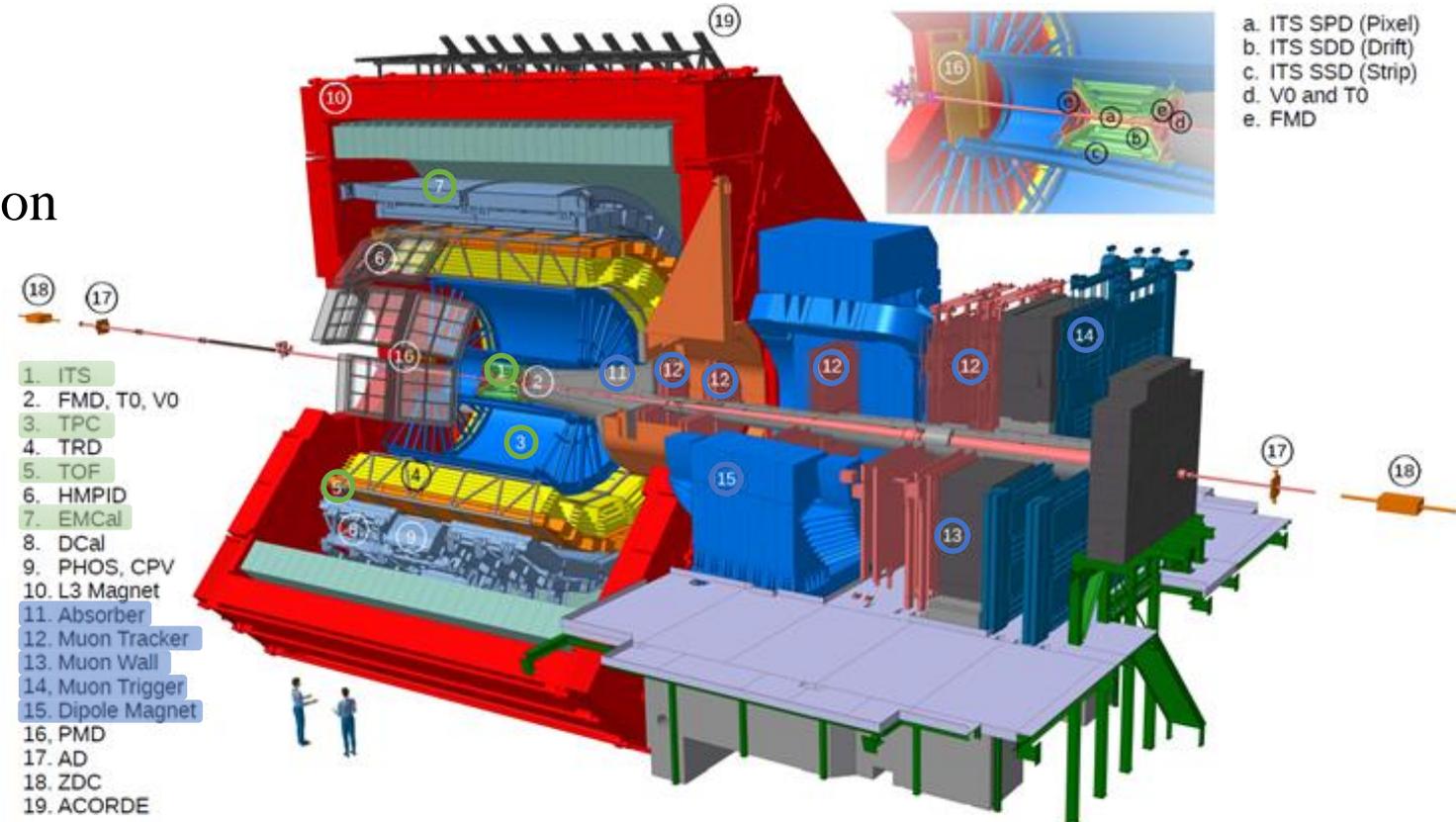
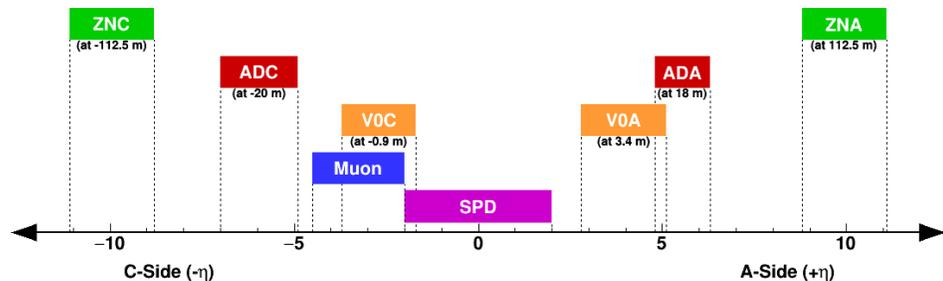
- We measure the  $J/\psi$  using its decay into pair of leptons in an otherwise empty detector:
  - $e^+e^-$  and  $\mu^+\mu^-$  in the central barrel
  - $\mu^+\mu^-$  in the muon spectrometer
- For triggering and background suppression
  - Detectors close to the beam line



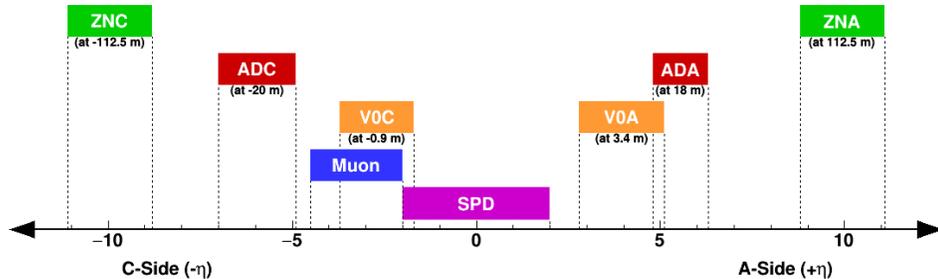
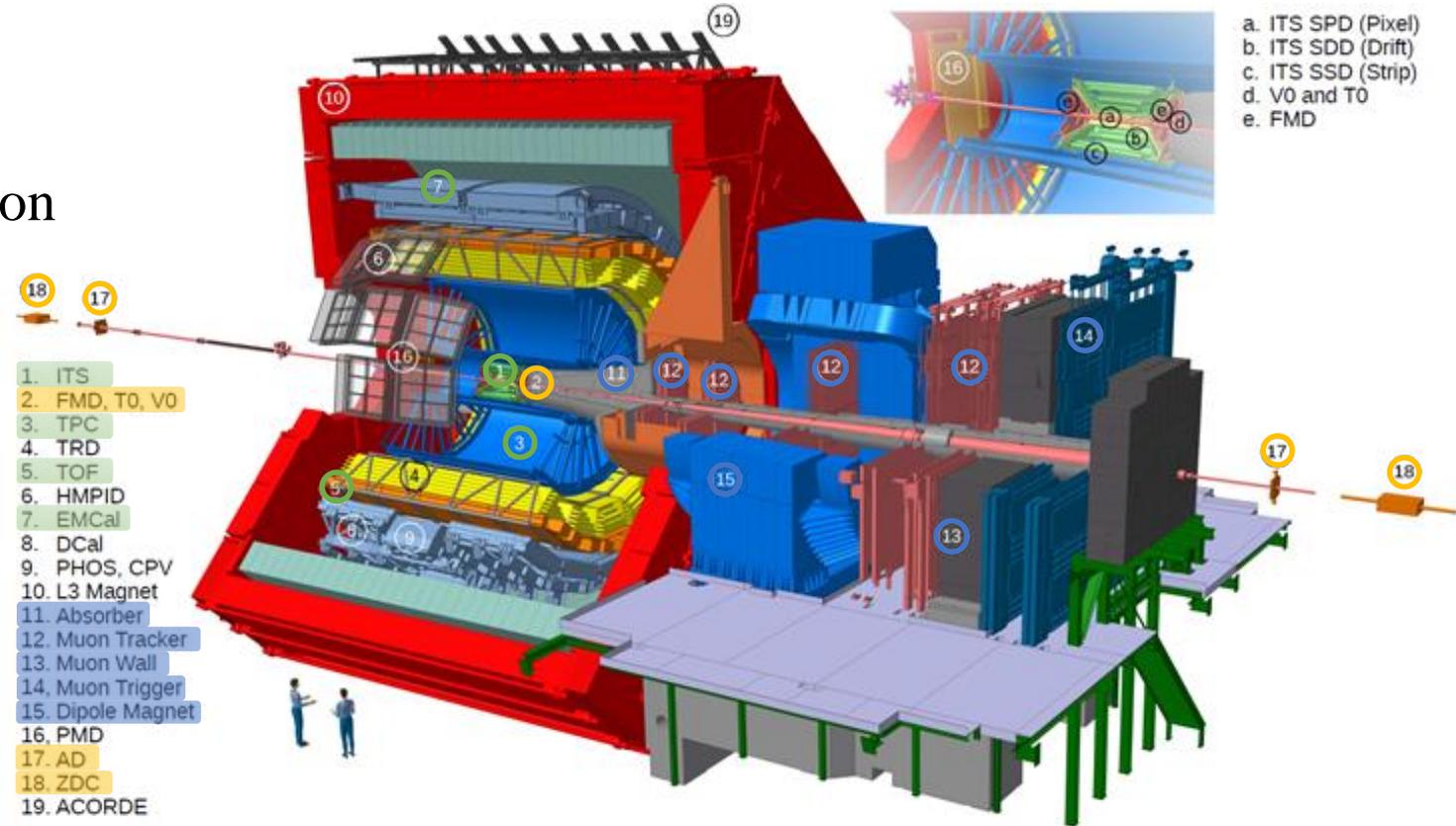
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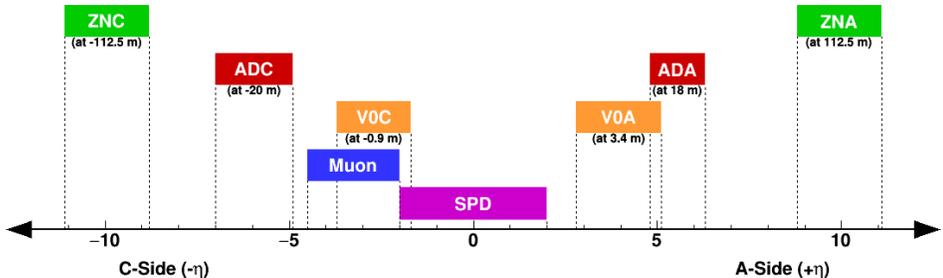
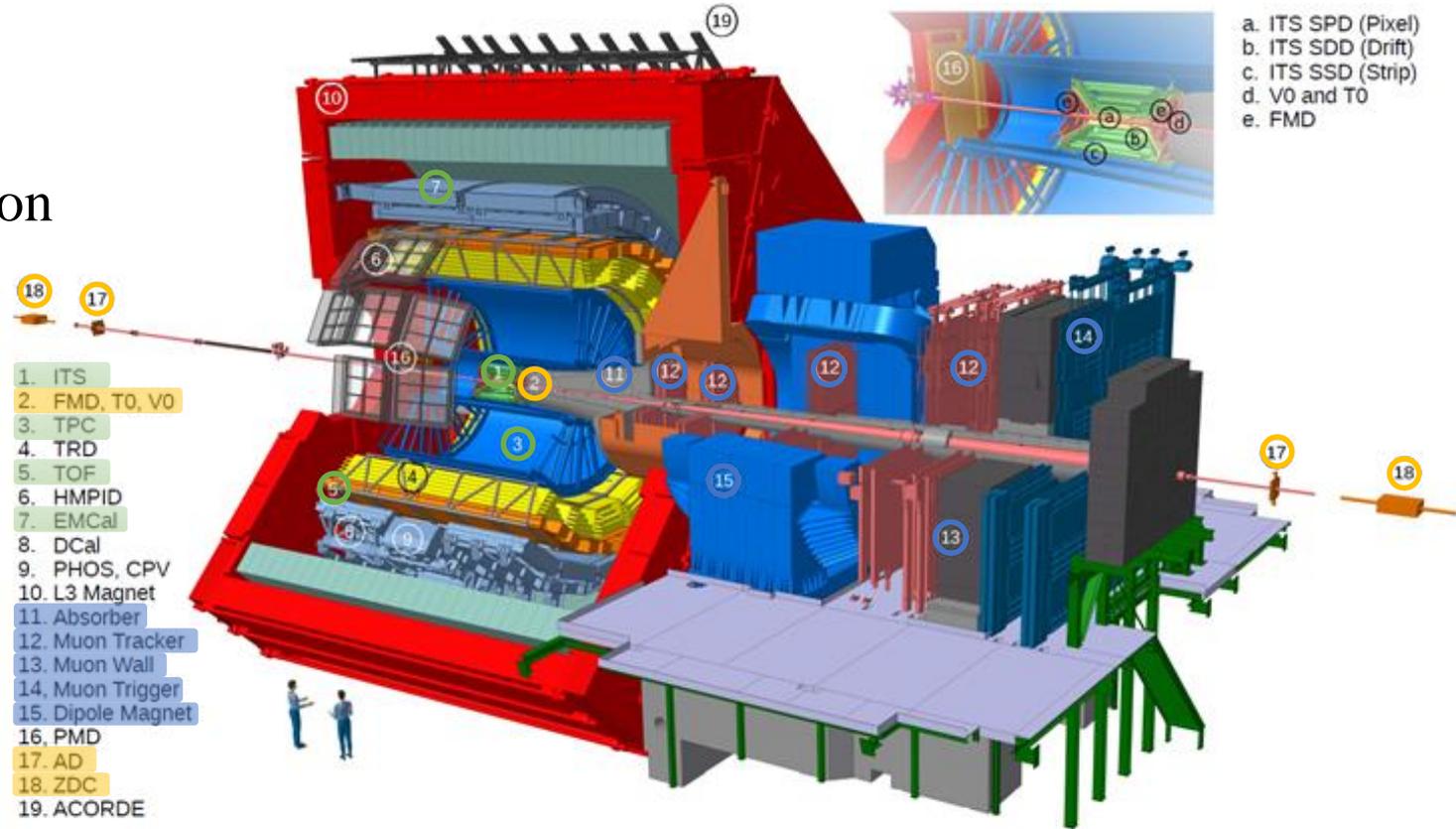


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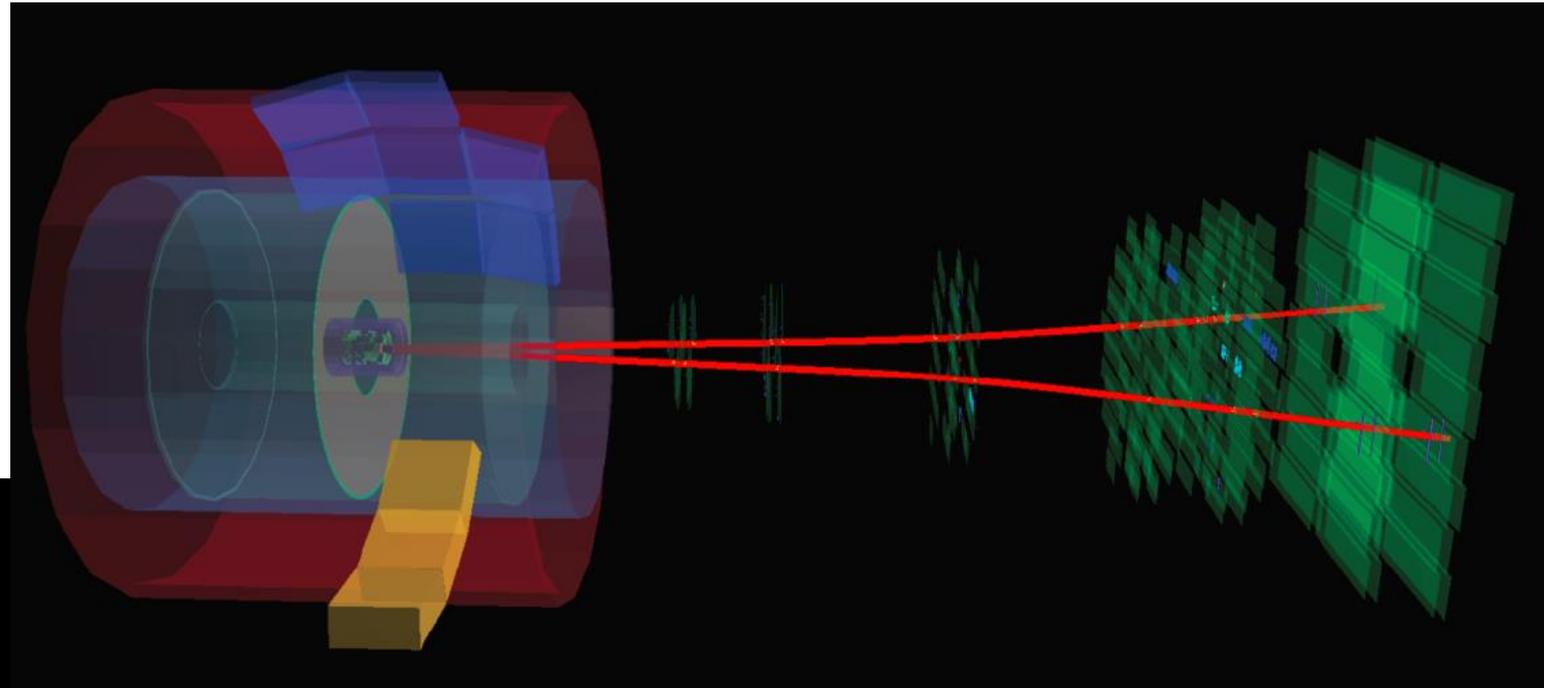
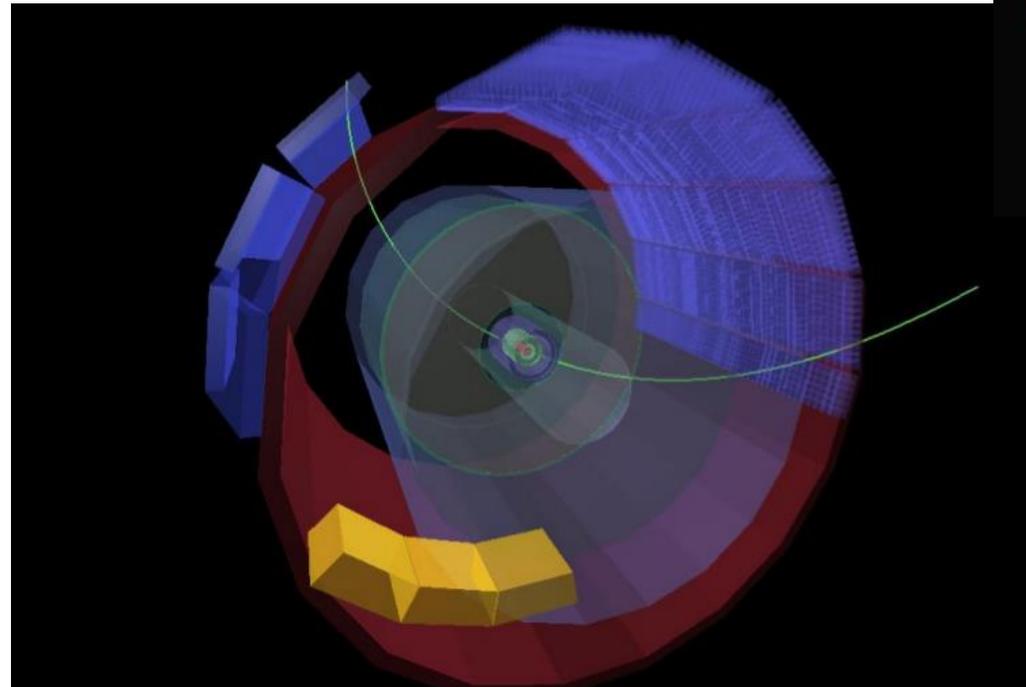
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MFT + FDD will improve this



# Ultra-peripheral collisions - $J/\psi$ candidate

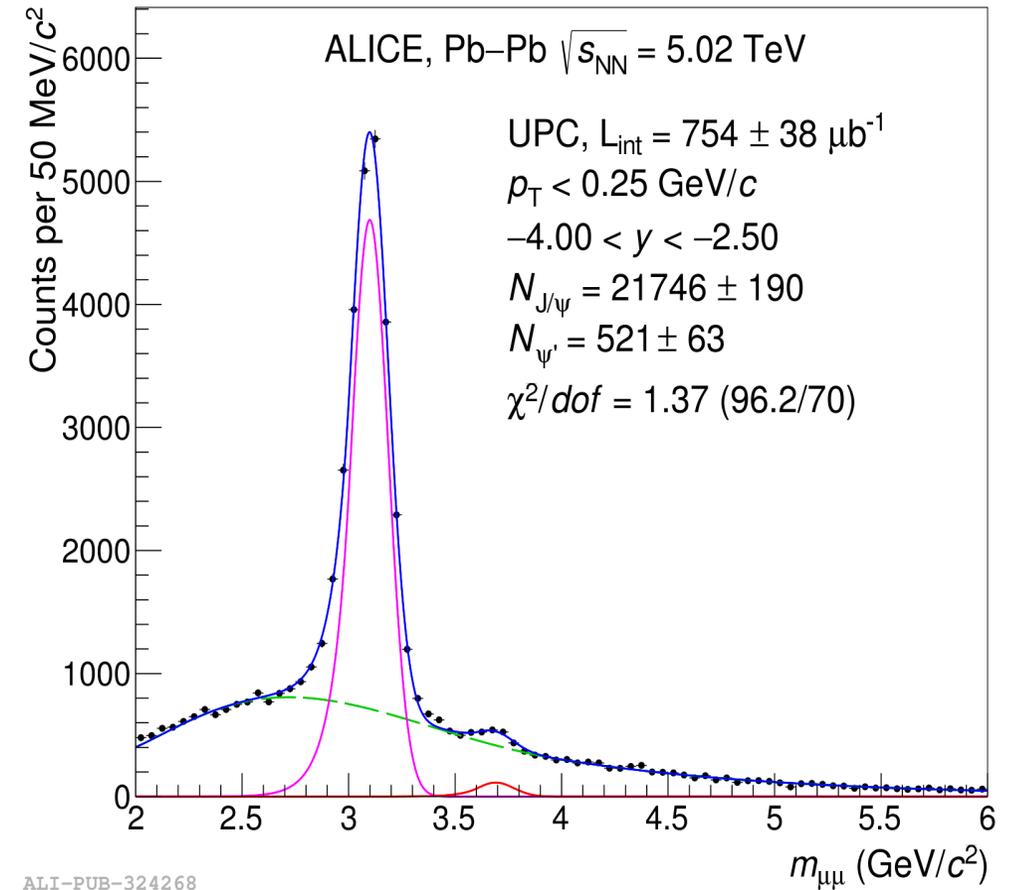
Central event



Forward event

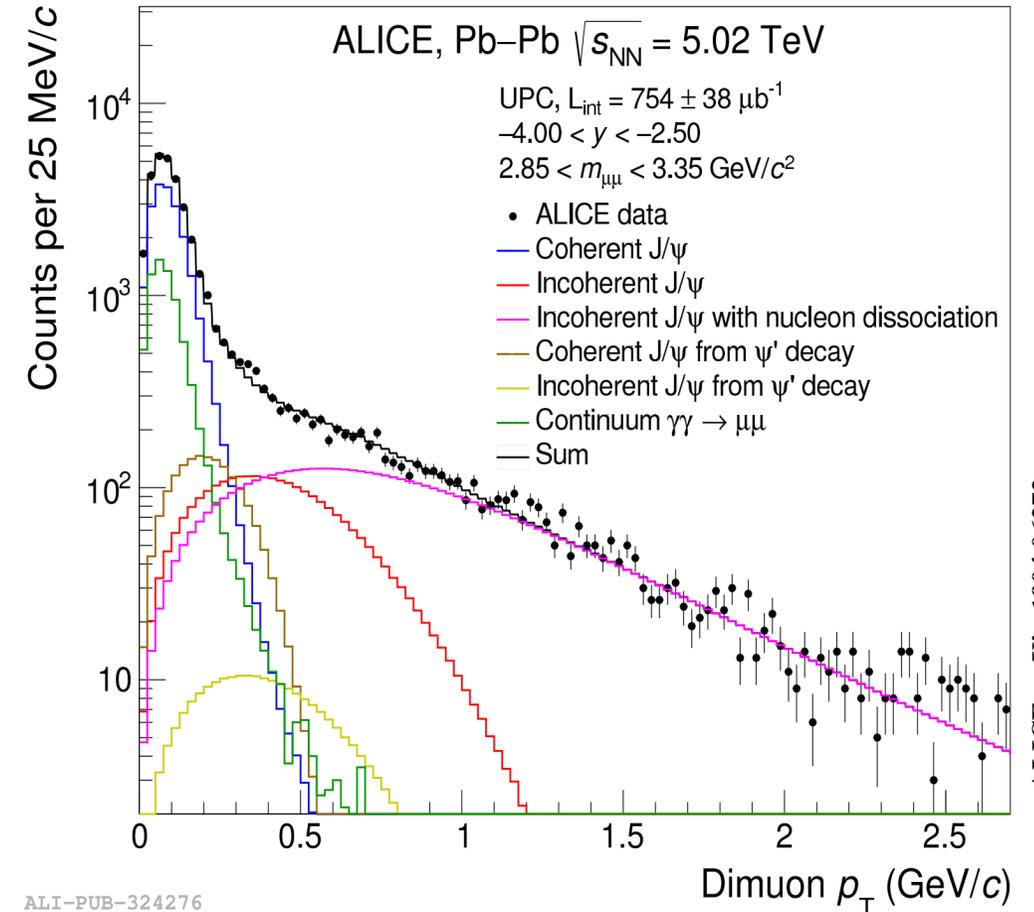
# Analysis – Invariant mass fit

- The raw  $J/\psi$  yield and the feed-down contribution from  $\psi'$  decays were extracted from the **invariant mass spectrum**



# Analysis – Transverse momentum fit

- The raw  $J/\psi$  yield and the feed-down contribution from  $\psi'$  decays were extracted from the **invariant mass spectrum**
- The coherent  $J/\psi$  contribution was determined from the  **$p_T$  spectrum**

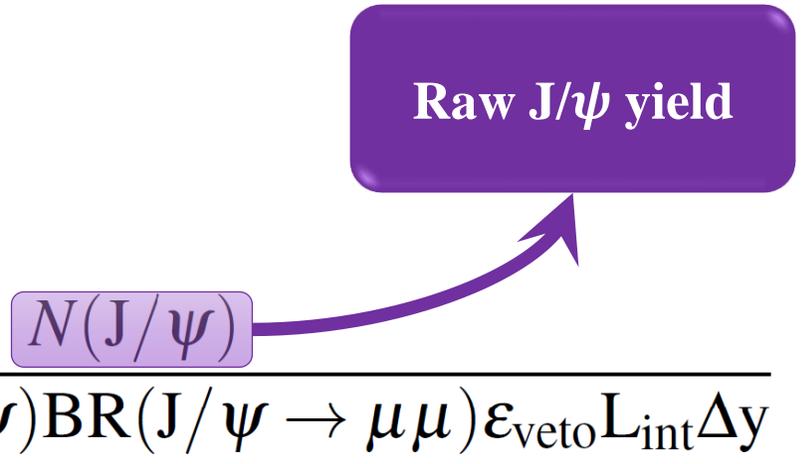


- The rapidity differential **cross section** for coherent  $J/\psi$  photoproduction is computed as

$$\frac{d\sigma_{J/\psi}^{\text{coh}}}{dy} = \frac{N(J/\psi)}{(1 + f_I + f_D)\epsilon(J/\psi)\text{BR}(J/\psi \rightarrow \mu\mu)\epsilon_{\text{veto}}L_{\text{int}}\Delta y}$$

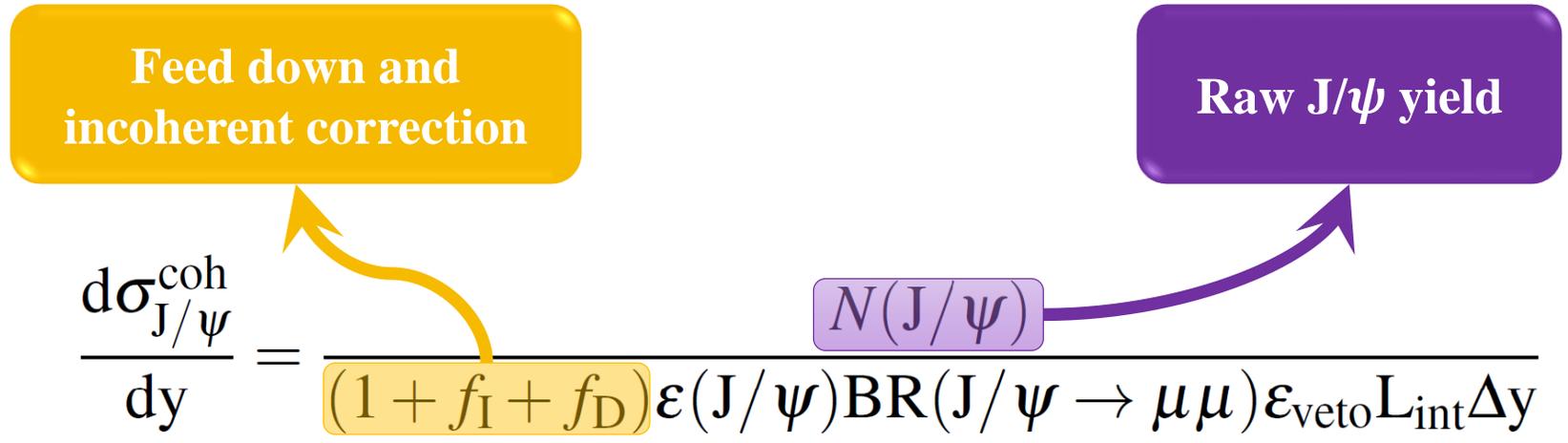
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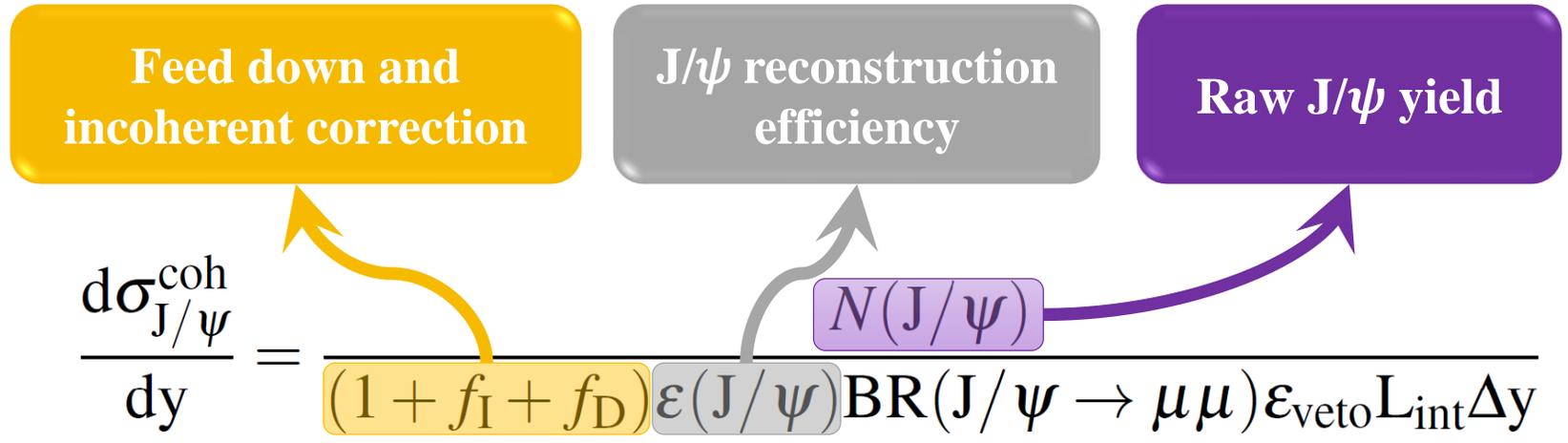
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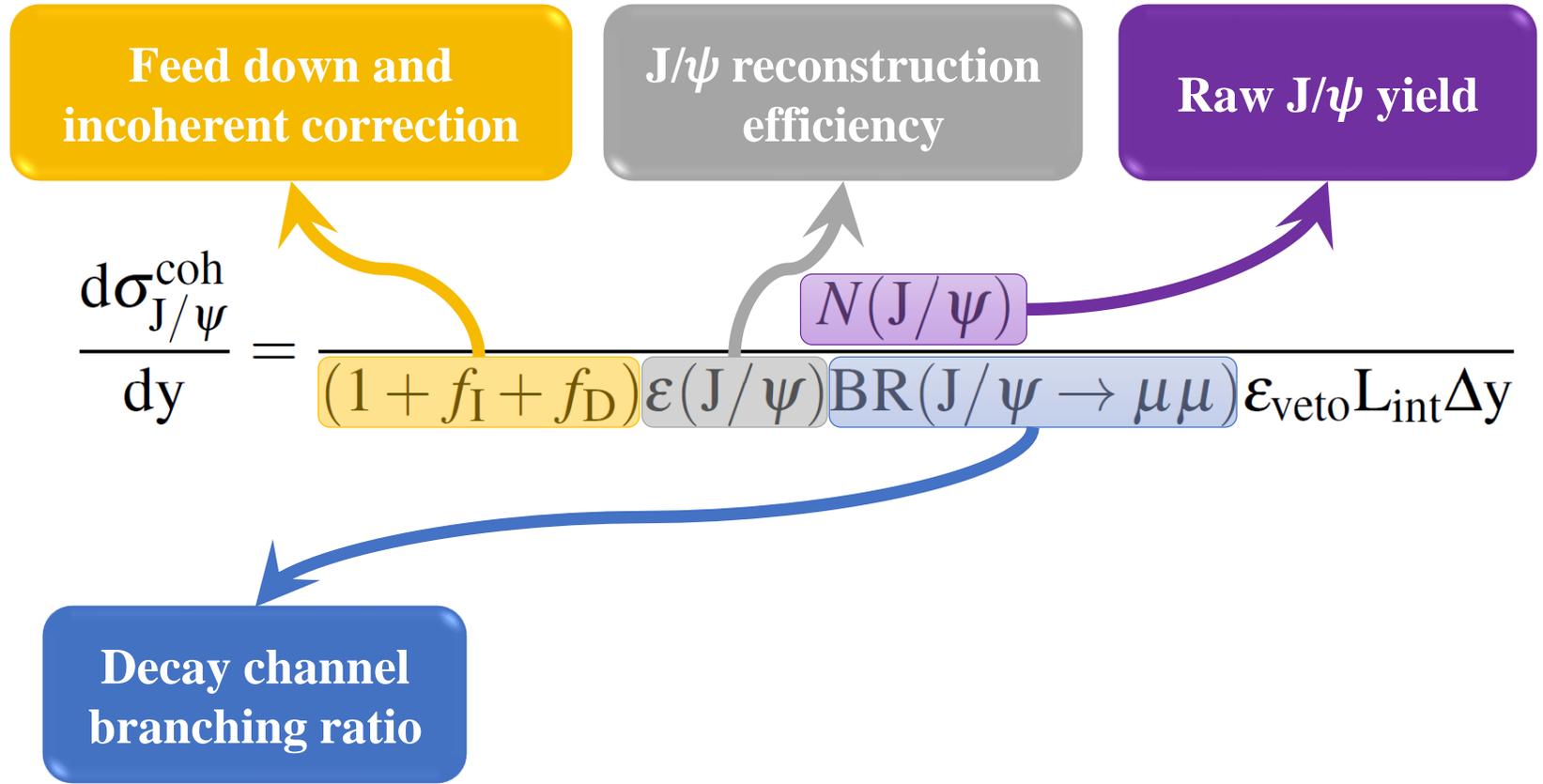
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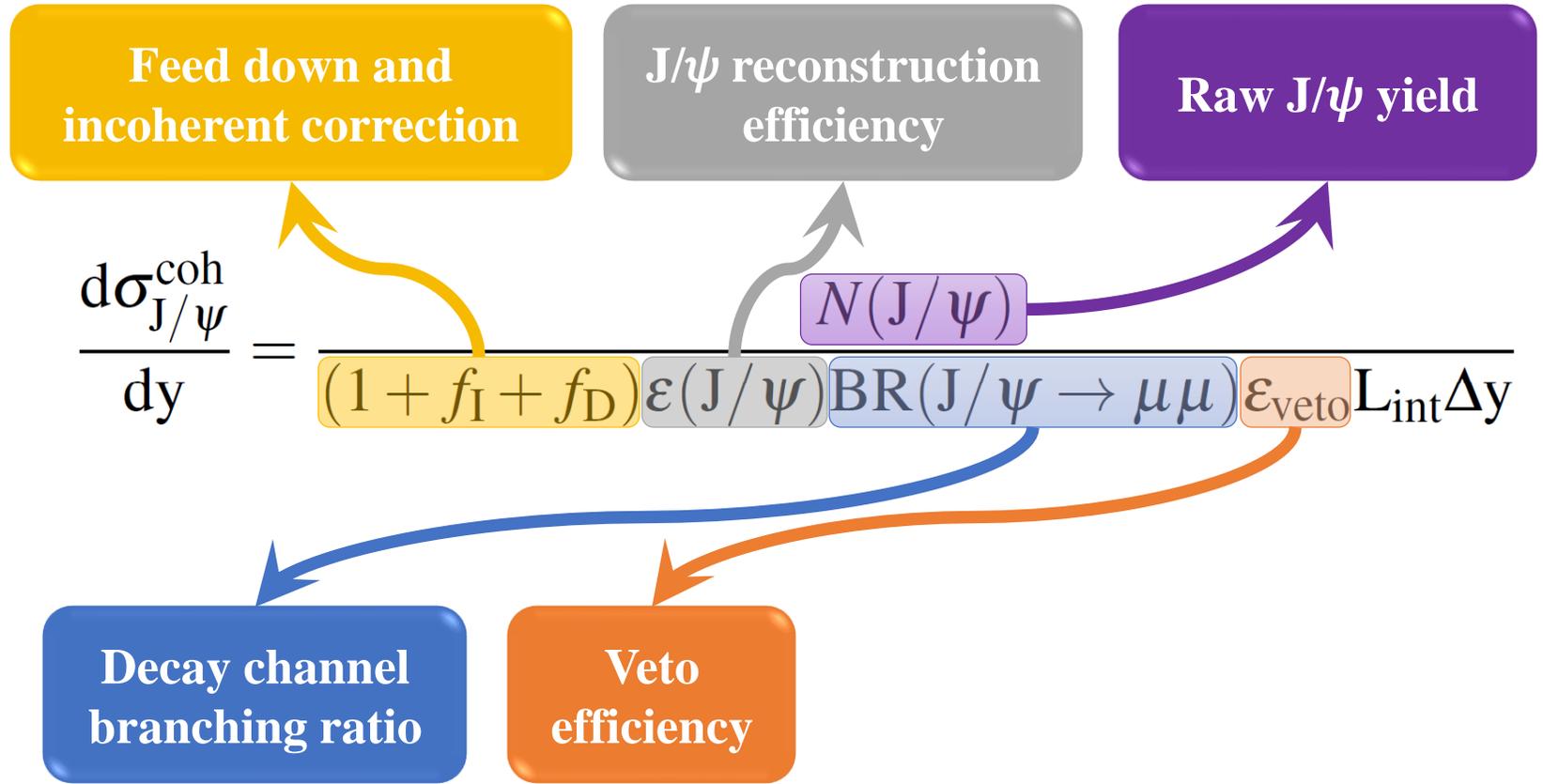
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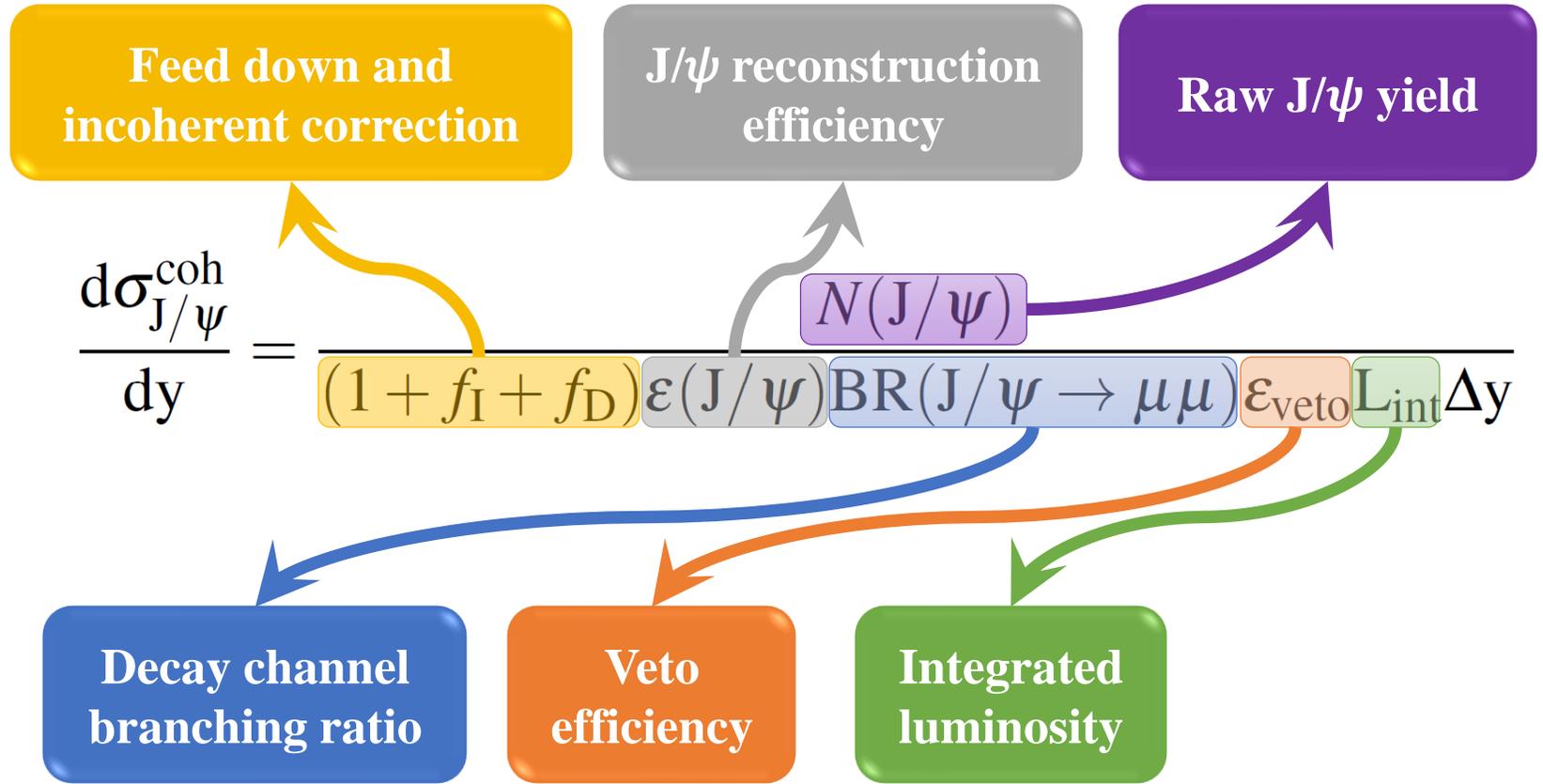
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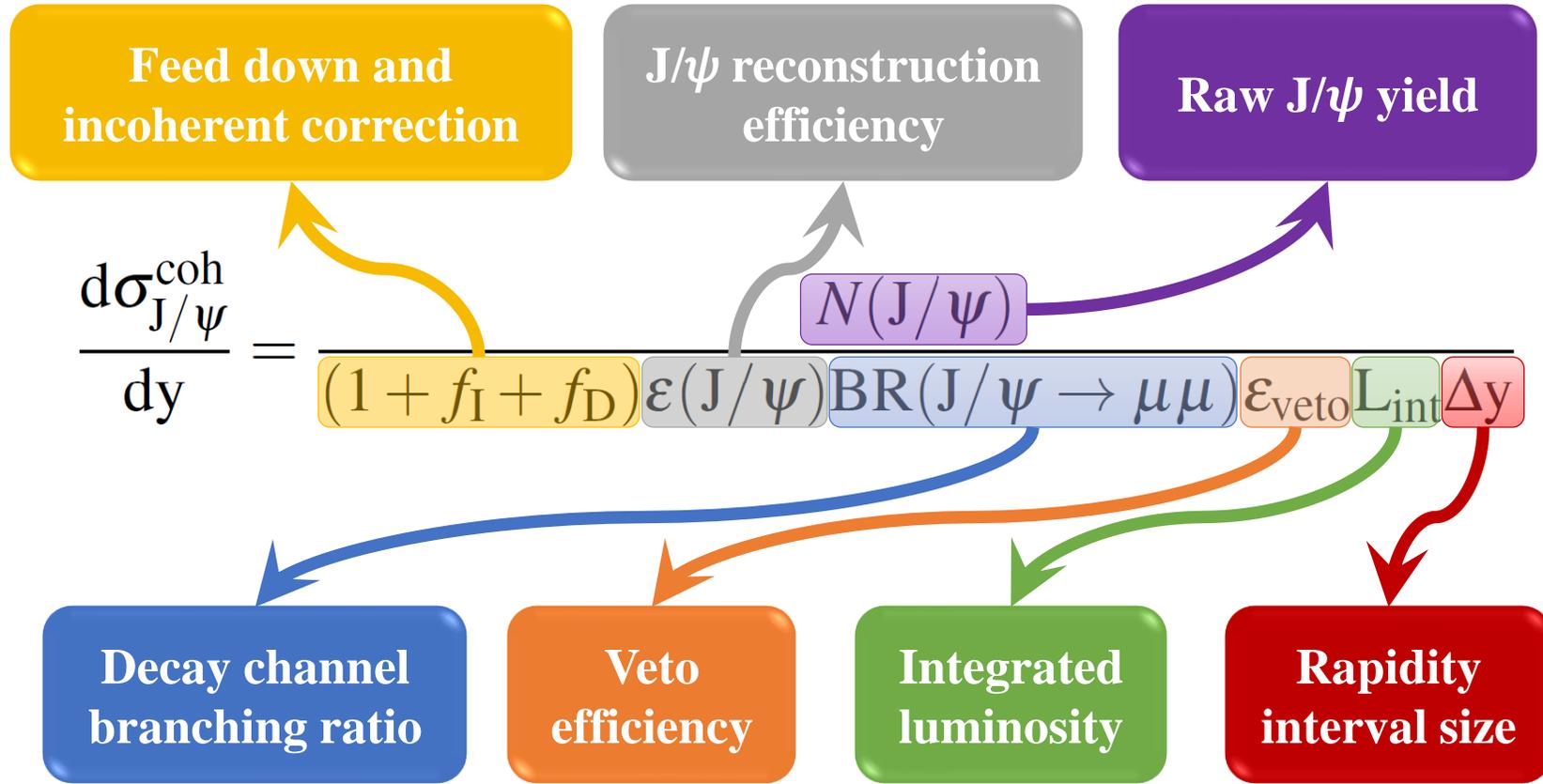
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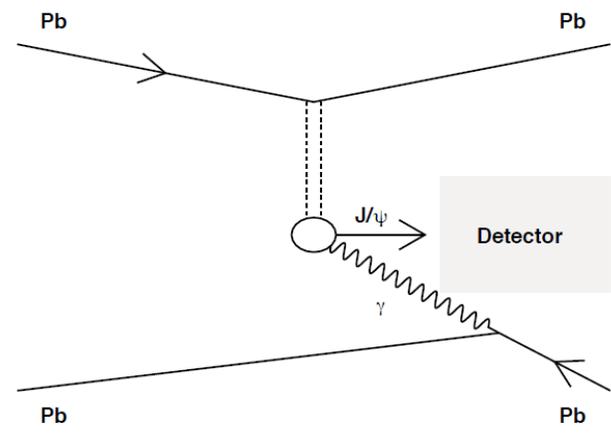


# Analysis - Bjorken $x$

$$\frac{d\sigma_{\text{PbPb}}(y)}{dy} = N_{\gamma}(y) \sigma_{\gamma\text{Pb}}(y)$$

Photon flux  $\rightarrow N_{\gamma}(y)$

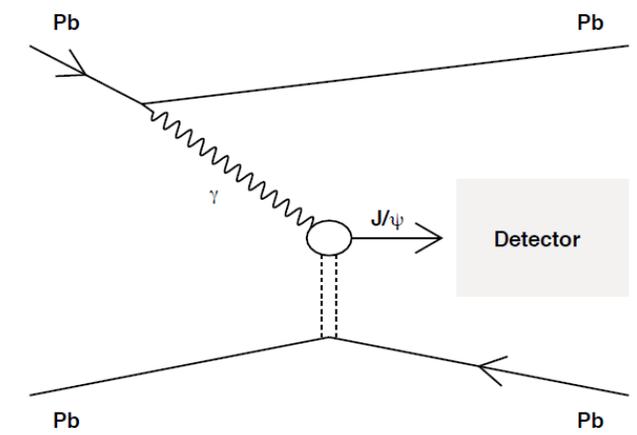
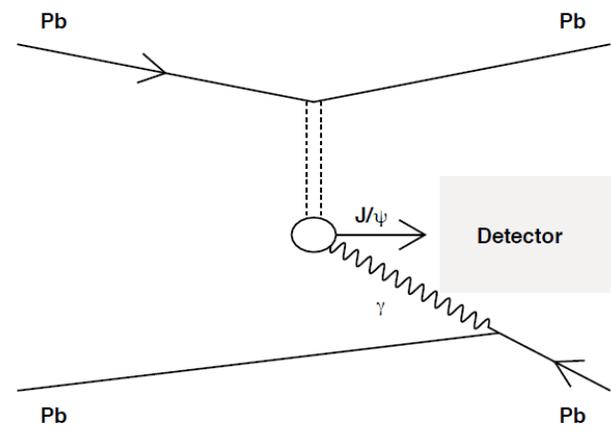
Photon-target cross section  $\rightarrow \sigma_{\gamma\text{Pb}}(y)$



# Analysis - Bjorken $x$

$$\frac{d\sigma_{\text{PbPb}}(y)}{dy} = N_{\gamma}(y) \sigma_{\gamma\text{Pb}}(y) + N_{\gamma}(-y) \sigma_{\gamma\text{Pb}}(-y)$$

Photon flux
Photon-target cross section

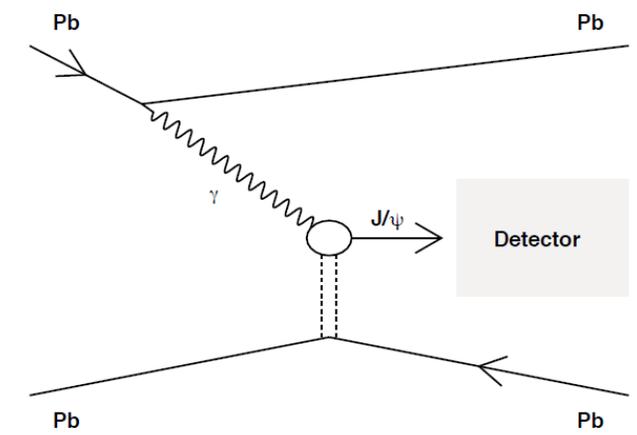
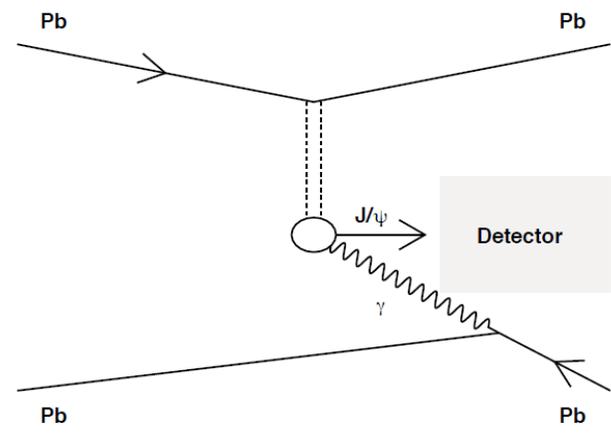


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Photon flux
Photon-target cross section

- At mid rapidity
  - Both contributions are same

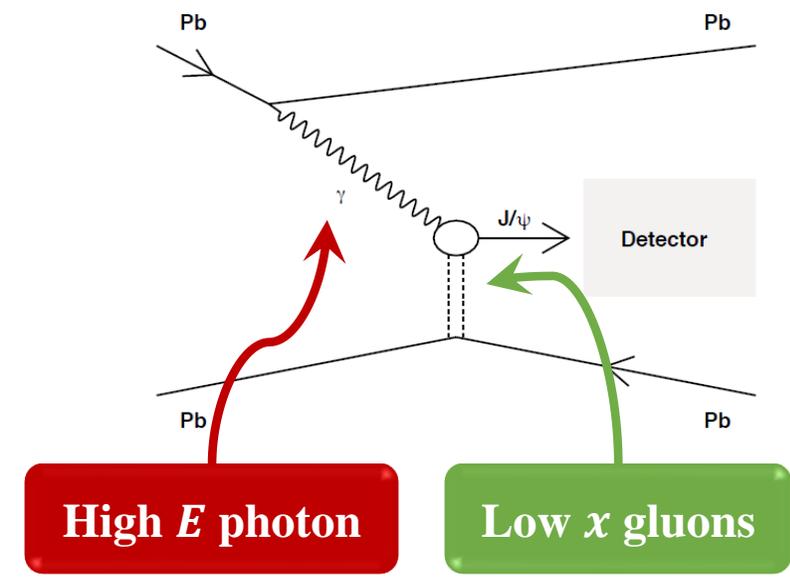
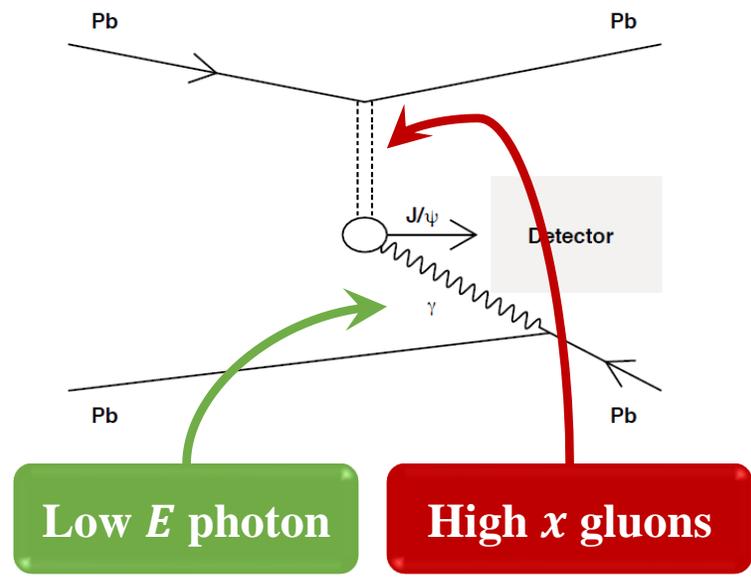


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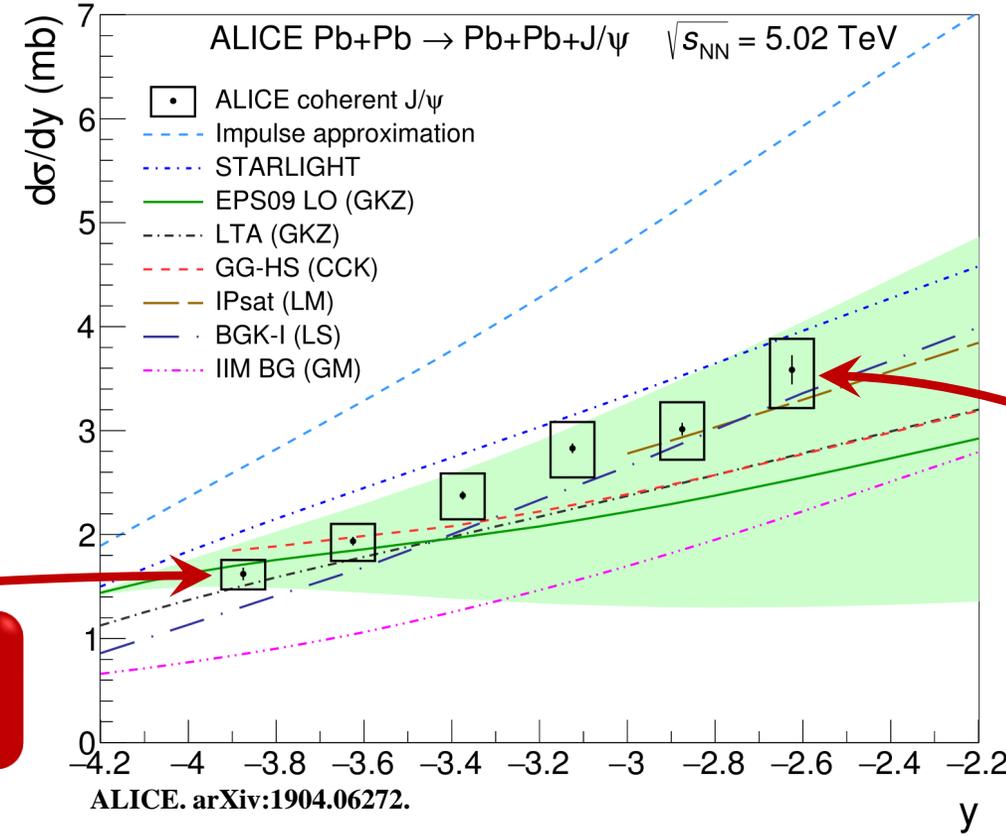
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Photon flux      Photon-target cross section

- At mid rapidity
  - Both contributions are same
- At forward rapidity
  - **Contributions are different**



# Analysis - Cross section

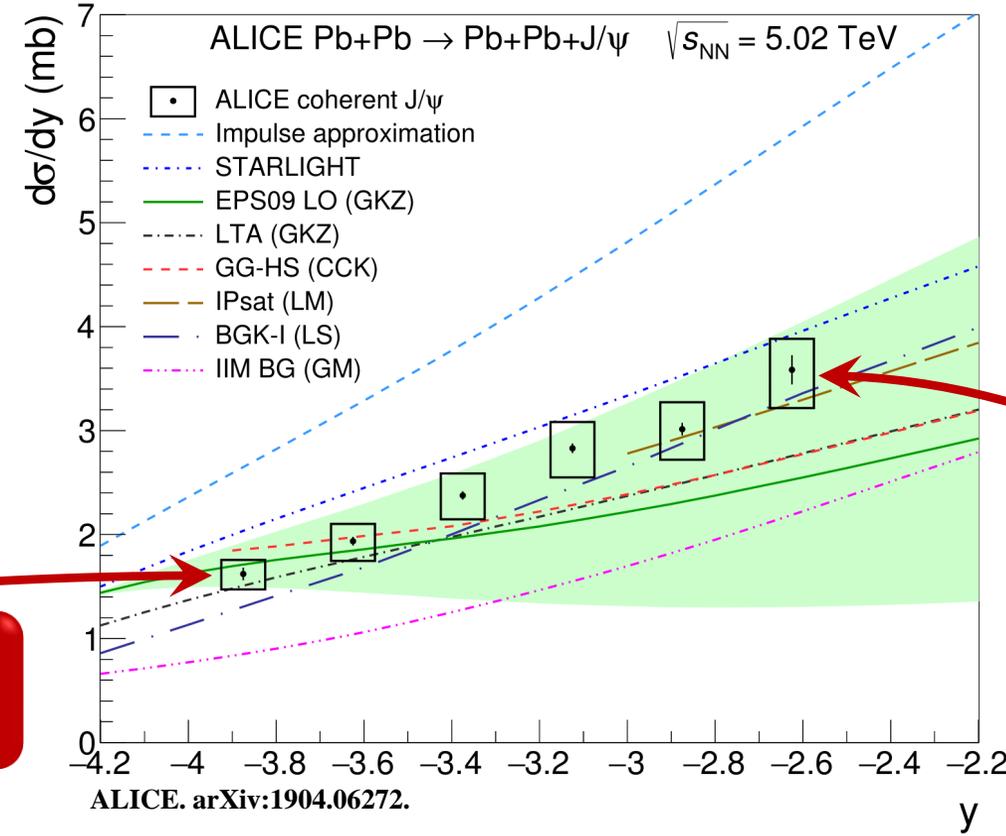


~ 95%:  $x = 3.3 \cdot 10^{-2}$   
 ~ 5%:  $x = 1.1 \cdot 10^{-5}$

~ 60%:  $x = 0.7 \cdot 10^{-2}$   
 ~ 40%:  $x = 5.1 \cdot 10^{-5}$

# Analysis - Cross section

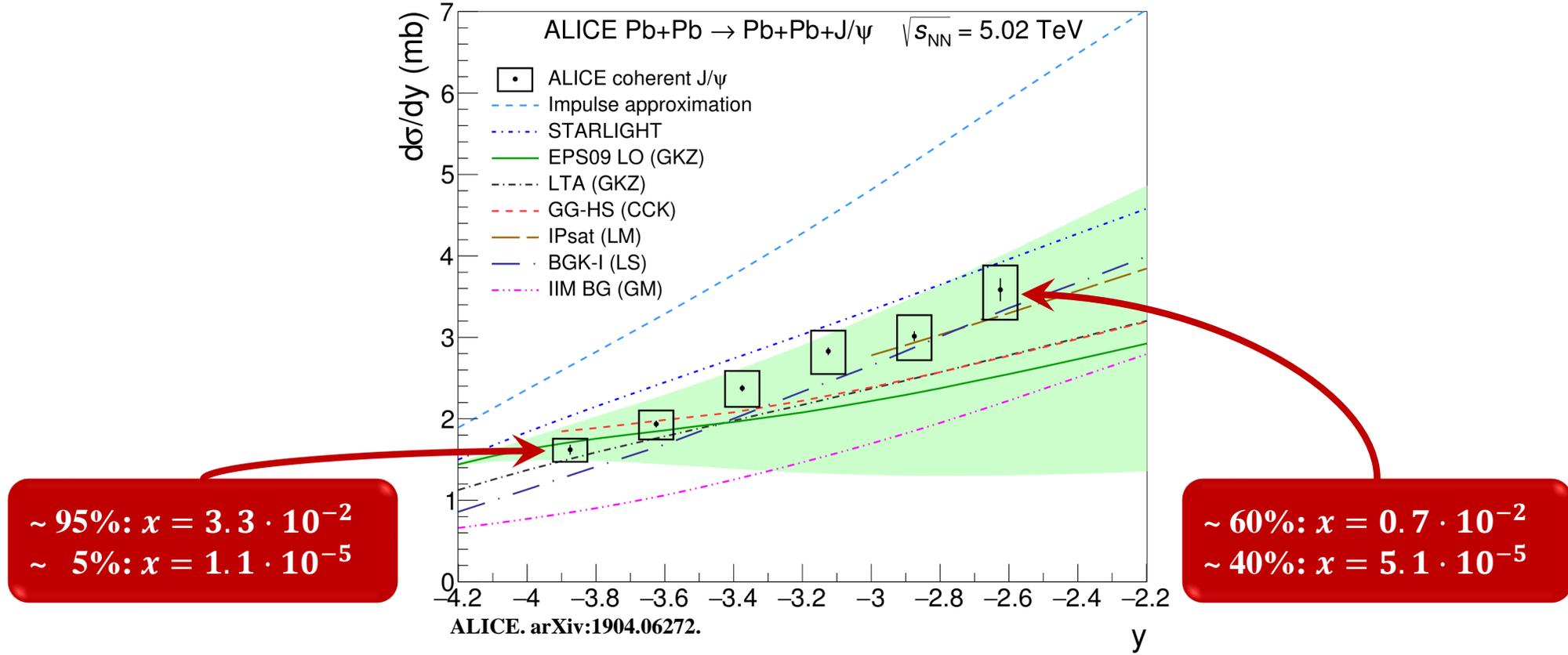
**Work in progress**  
 Trying to disentangle the two contributions using EMD



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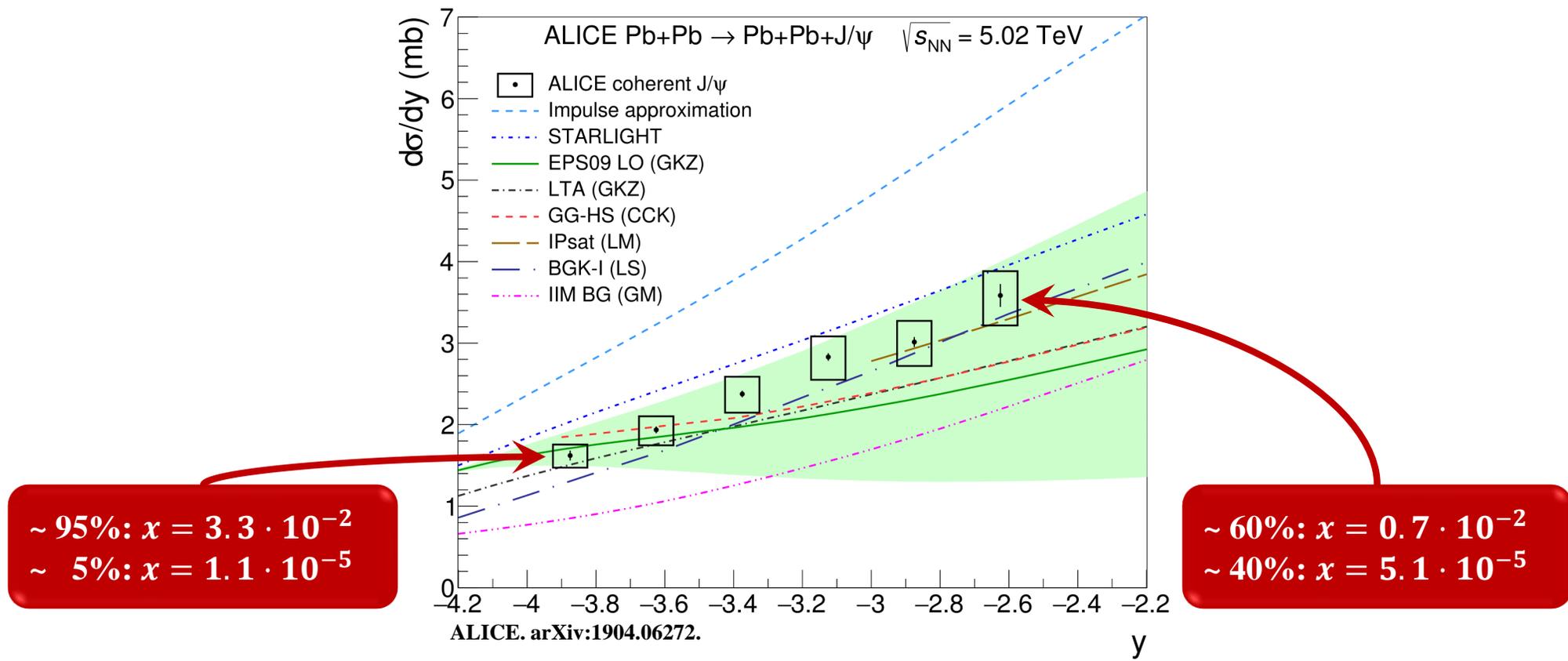
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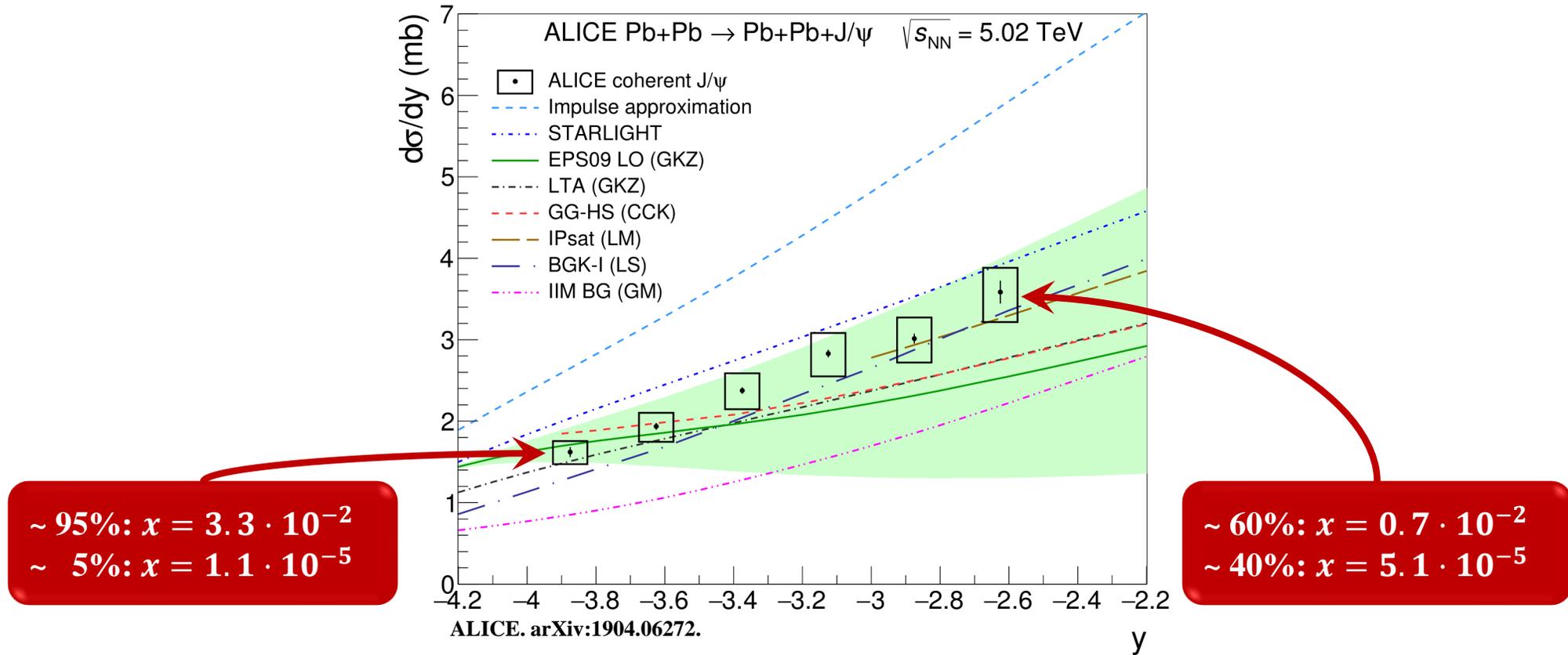
- The impulse approximation without any nuclear effects is rejected by the data

# Analysis - Cross section



- The impulse approximation without any nuclear effects is rejected by the data → **nuclear shadowing**

# Analysis - Cross section



- The impulse approximation without any nuclear effects is rejected by the data → **nuclear shadowing**
- Models based on the **colour dipole** model with **saturation** are best at describing the data
  - IPsat (LM), BGK-I (LS)

- Lot of work in progress or soon to be published
- Today you will hear more about:
  - Coherent  $J/\psi$  production at midrapidity
  - Incoherent cross section
  - Efficiency loss in Pb-Pb due to EMD
  - Recent results on coherent rho production
- In Run 3 there will be new detectors (MFT, FDD, new ITS) and much more data

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→ **Many new possibilities for us to look into!**

**Thank you for your attention!**

# Backup

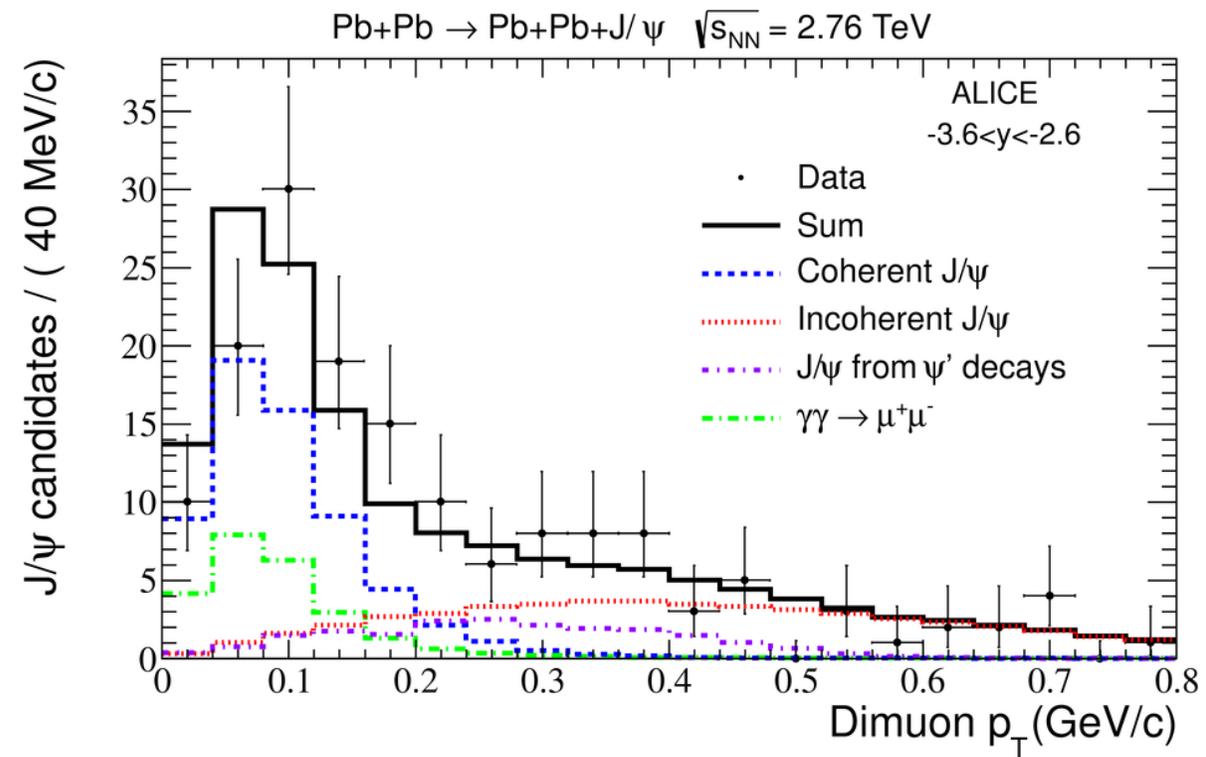
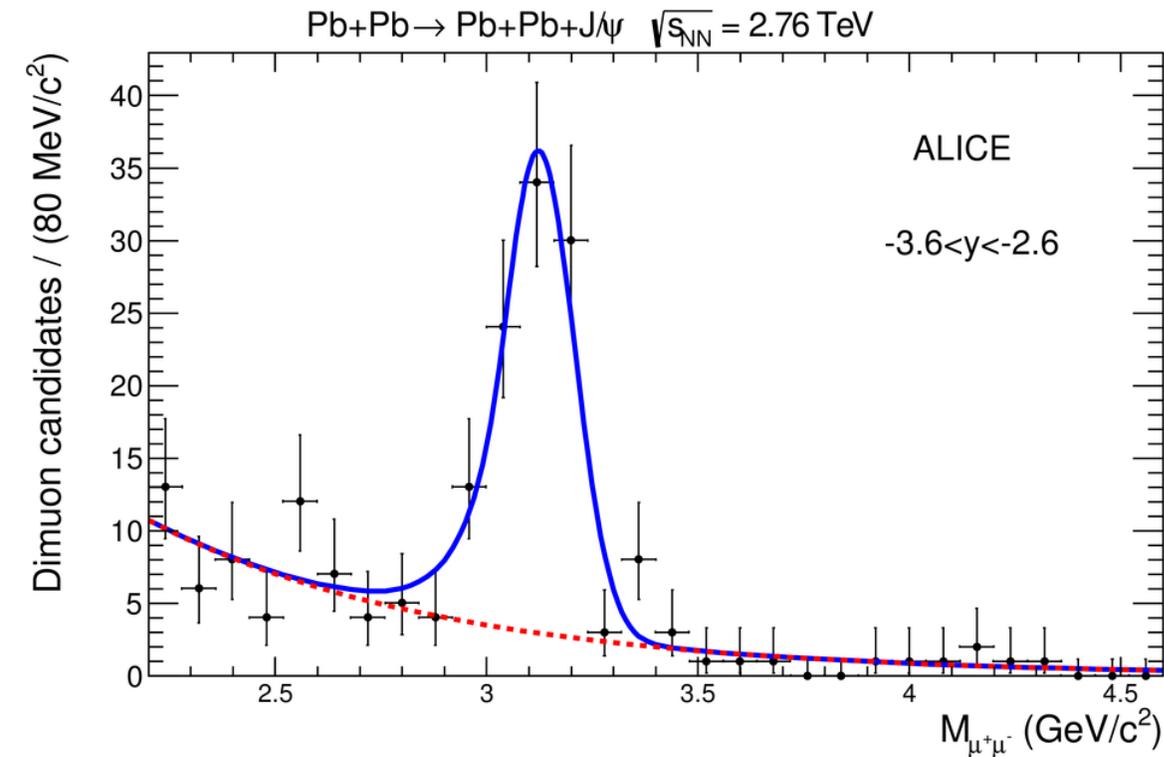
# Triggers analysed

- $\text{CMUP10-B-NOPF-MUFAST} = !0\text{VBA} \ \& \ !0\text{UBA} \ \& \ !0\text{UBC} \ \& \ 0\text{MSL}$
- $\text{CMUP11-B-NOPF-MUFAST} = !0\text{VBA} \ \& \ !0\text{UBA} \ \& \ !0\text{UBC} \ \& \ 0\text{MUL}$
- The two triggers were merged by offline requirement of 0MUL for all events, which is the unlike sign di-muon over low pT threshold in muon trigger.

# Trigger inputs

- 0VBA = signal in V0A in beam-beam timing
- 0VBC = signal in V0C in beam-beam timing
- 0UBA = signal in ADA in beam-beam timing
- 0UBC = signal in ADC in beam-beam timing
- 0MSL = single muon over low pT threshold in muon trigger
- 0MUL = unlike sign di-muon over low pT threshold in muon trigger
- 0MLL = like sign di-muon over low pT threshold in muon trigger

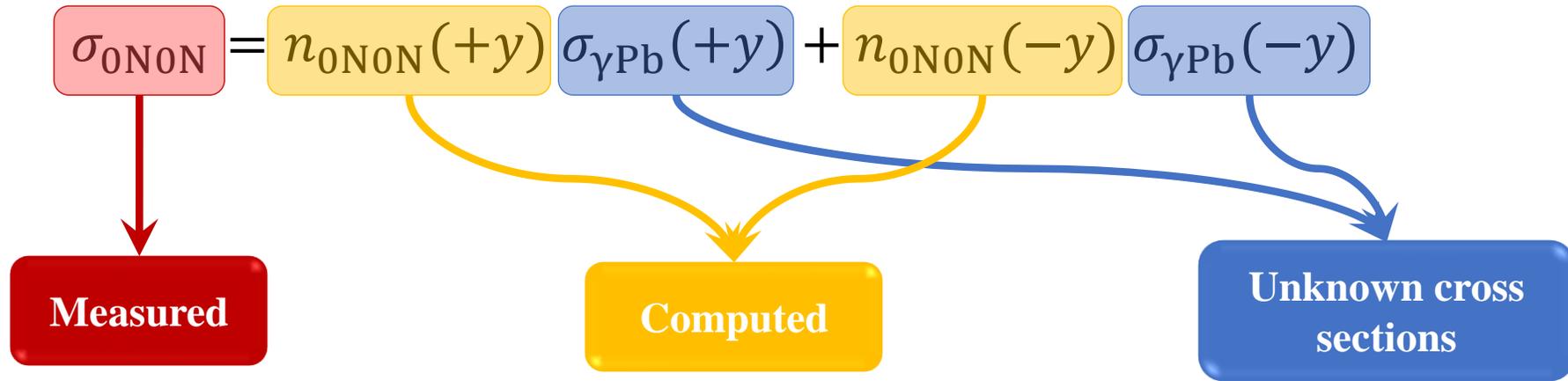
# ALICE Pb-Pb UPC at forward rapidity at $\sqrt{s_{NN}} = 2.76$ TeV



- Integrated luminosity of about  $55 \mu\text{b}^{-1}$

Phys. Lett. B 718 (2013) 1273-1283

# Analysis - Photoproduction



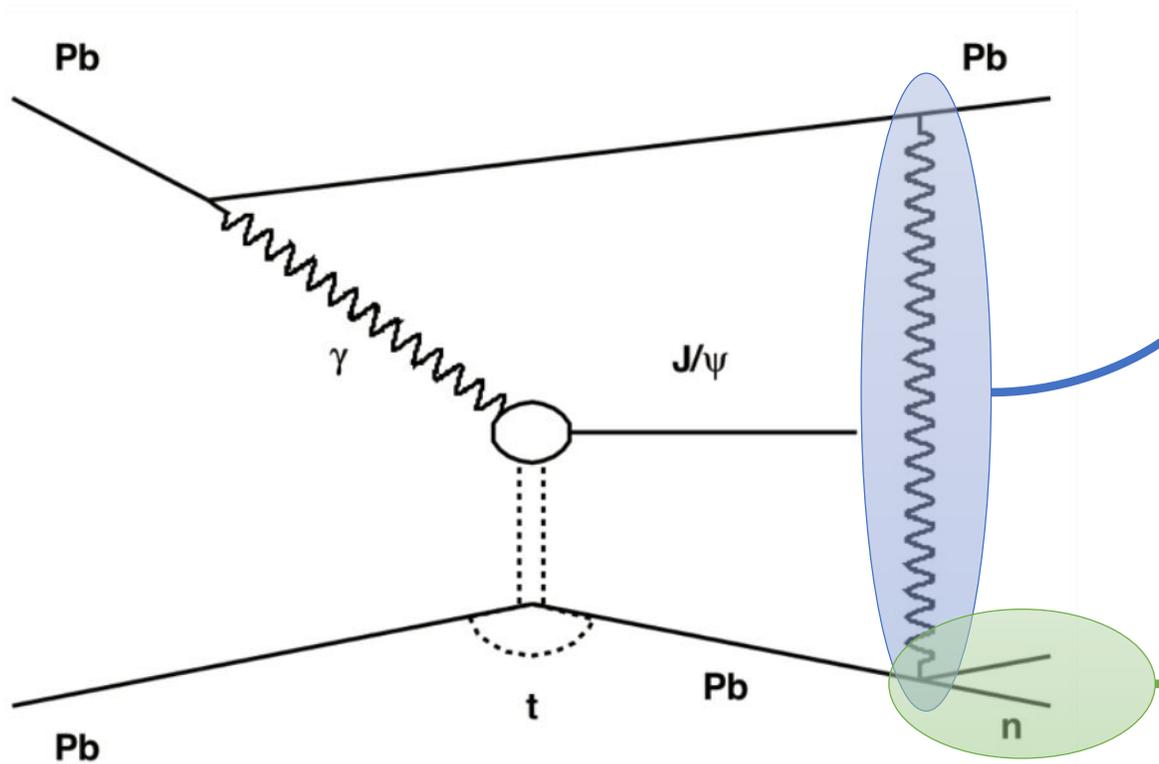
- There are both contributions
  - Two unknown variables
  - One equation



**Can't be distinguished**

# Analysis - Photoproduction with neutron emission

- Possible solution!

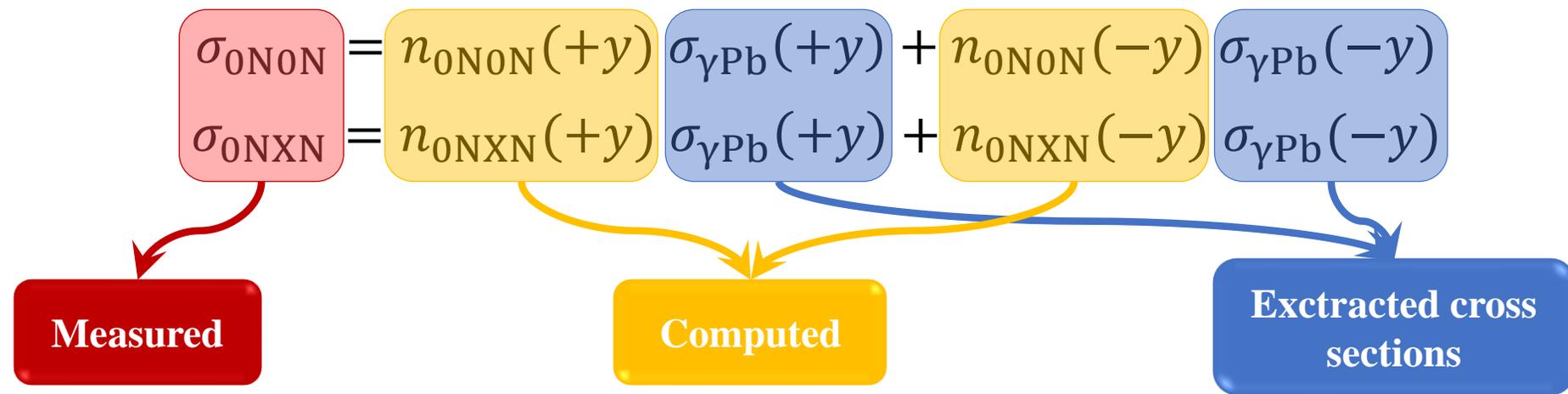


- **Independent** soft electromagnetic interactions

- Excitation of the outgoing lead ion
  - Emits **forward neutrons** upon de-excitation

- This can be measured and used to differentiate the high  $x$  and low  $x$  contribution!

# Analysis - Photoproduction with neutron emission



- There are both contributions
  - Two unknown variables
  - Two equations



**Can be distinguished**

