J/ψ photoproduction in Pb-Pb ultra-peripheral collisions with ALICE

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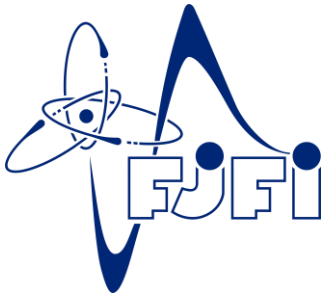
Workshop EJČF - Bílý Potok (u Frýdlantu)
18.1.2019



This work has been partially supported by the grant 18-07880S of the Czech Science Foundation (GACR).

Motivation

- The **structure of proton** in DIS is described by the parton distribution functions $xf(x, Q^2)$
  - x - fraction of momentum of proton carried by the parton
  - Q^2 - four momentum transferred in the collision
- In leading order, distribution function $xf(x, Q^2)$ can be interpreted as the contribution of the given partons to the proton composition

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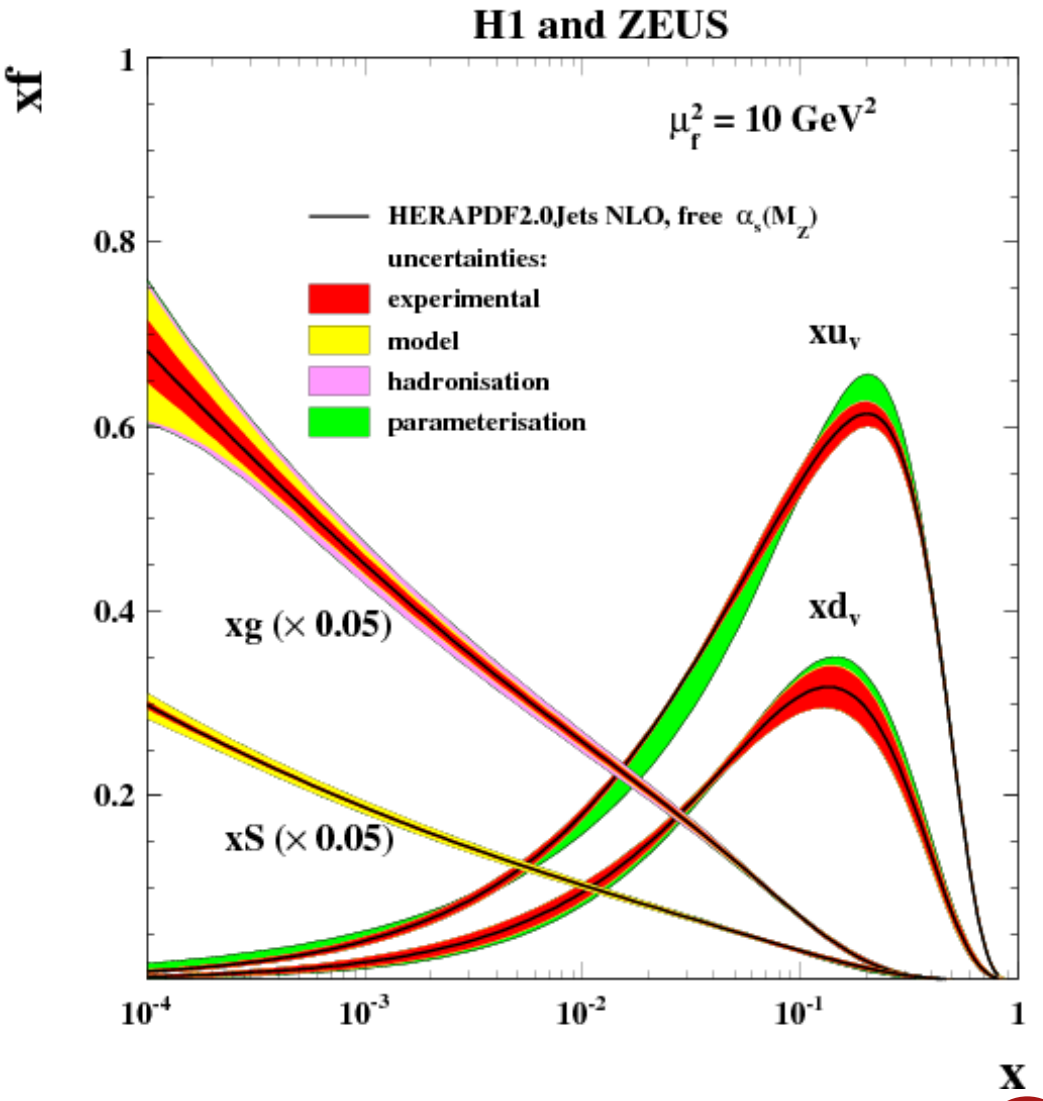

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  - x - fraction of momentum of proton carried by the parton
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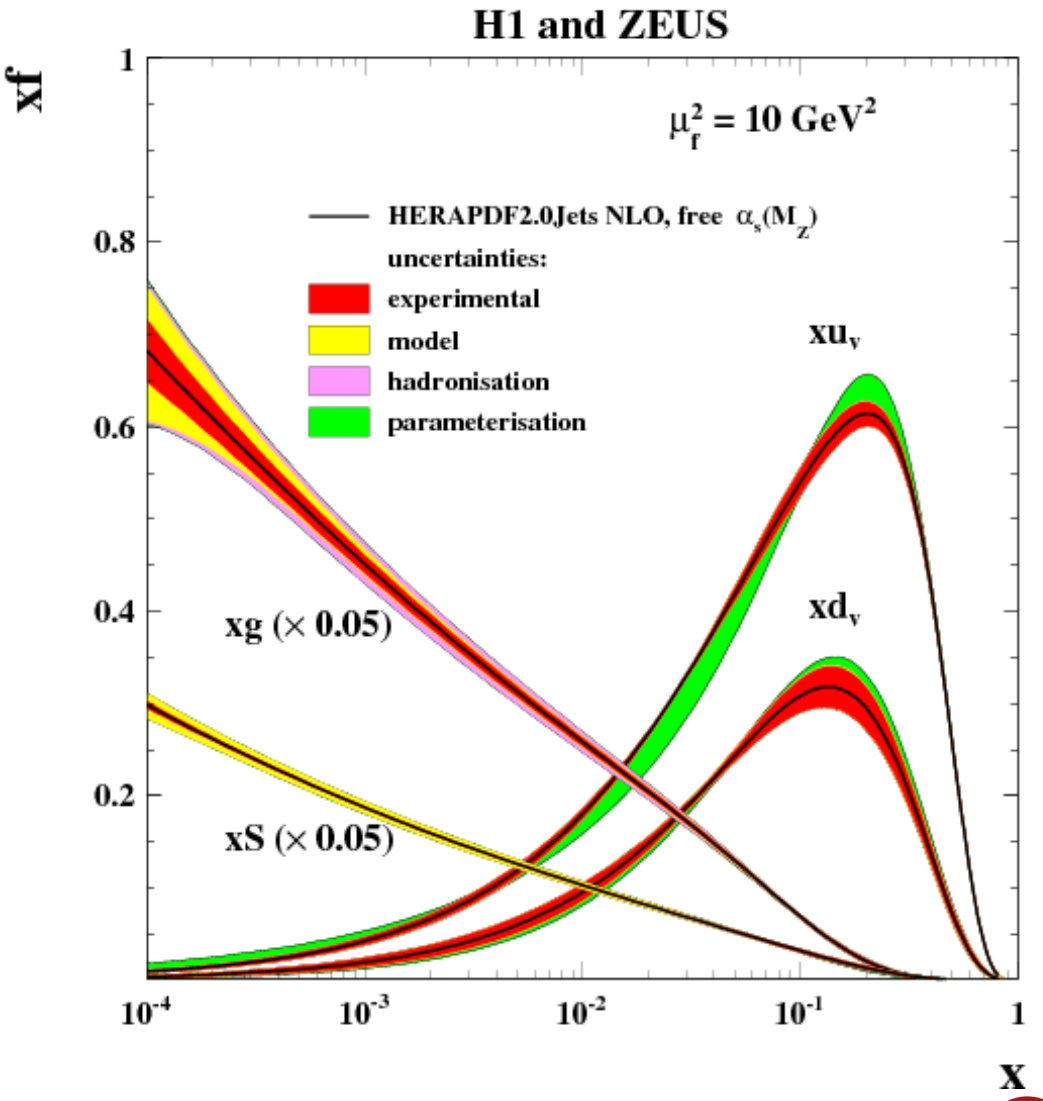
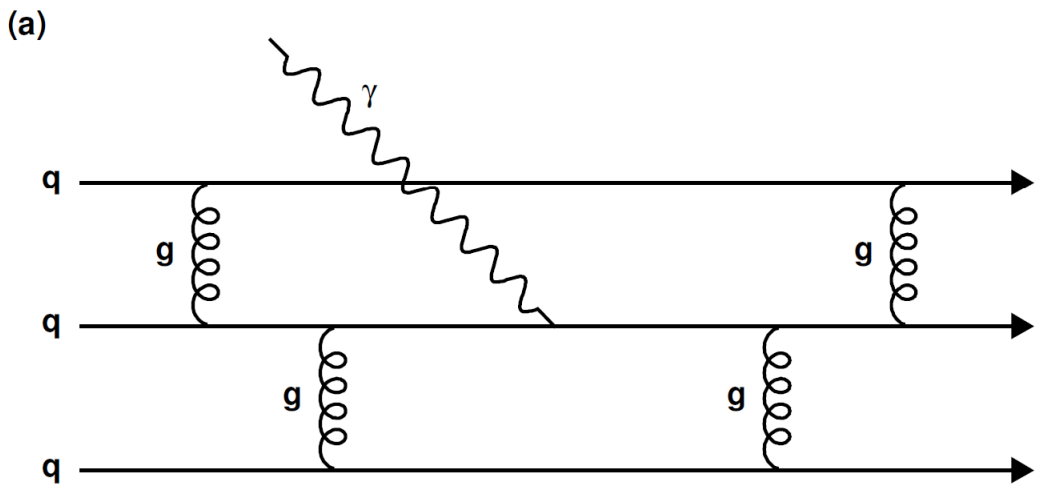
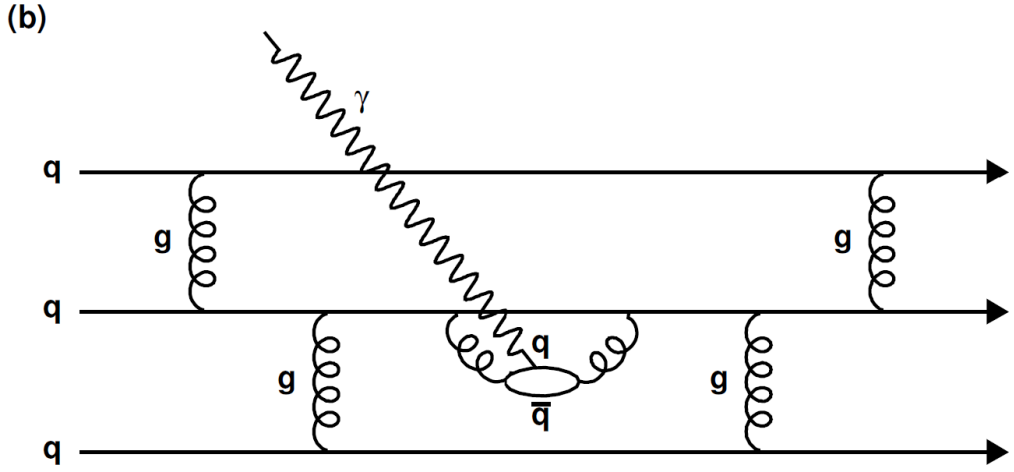
- In leading order, distribution function $xf(x, Q^2)$ can be interpreted as the contribution of the given partons to the proton composition
- At low x the main contribution is from gluons



Motivation

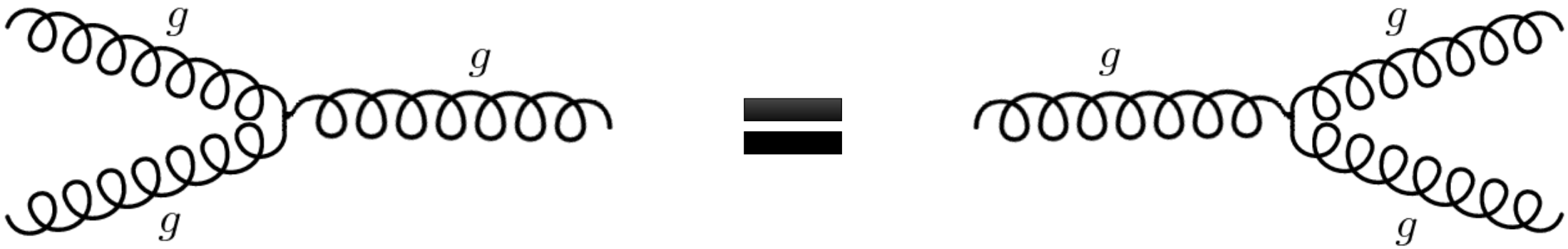
- The rise in the number of gluons and sea quarks can be interpreted as the ability to observe quantum sub-processes





Motivation

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



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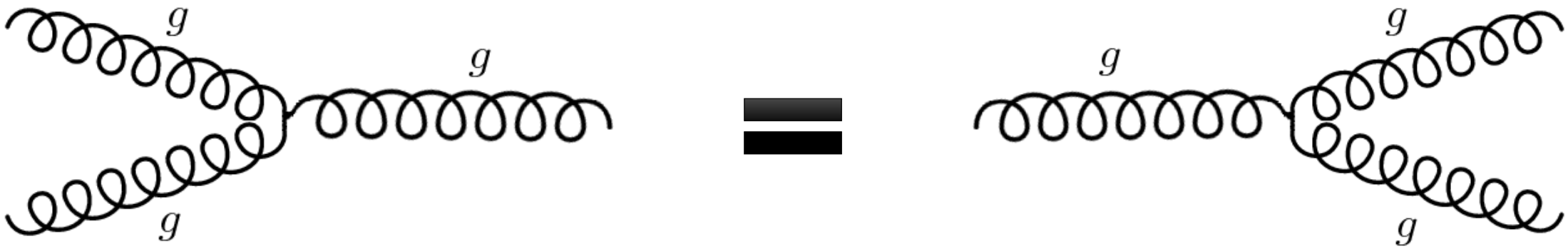

→ **Saturation**

- Predicted by pQCD, but not yet conclusively observed

Motivation

- In search for saturation we discovered that nucleus is not a simple sum of nucleons

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

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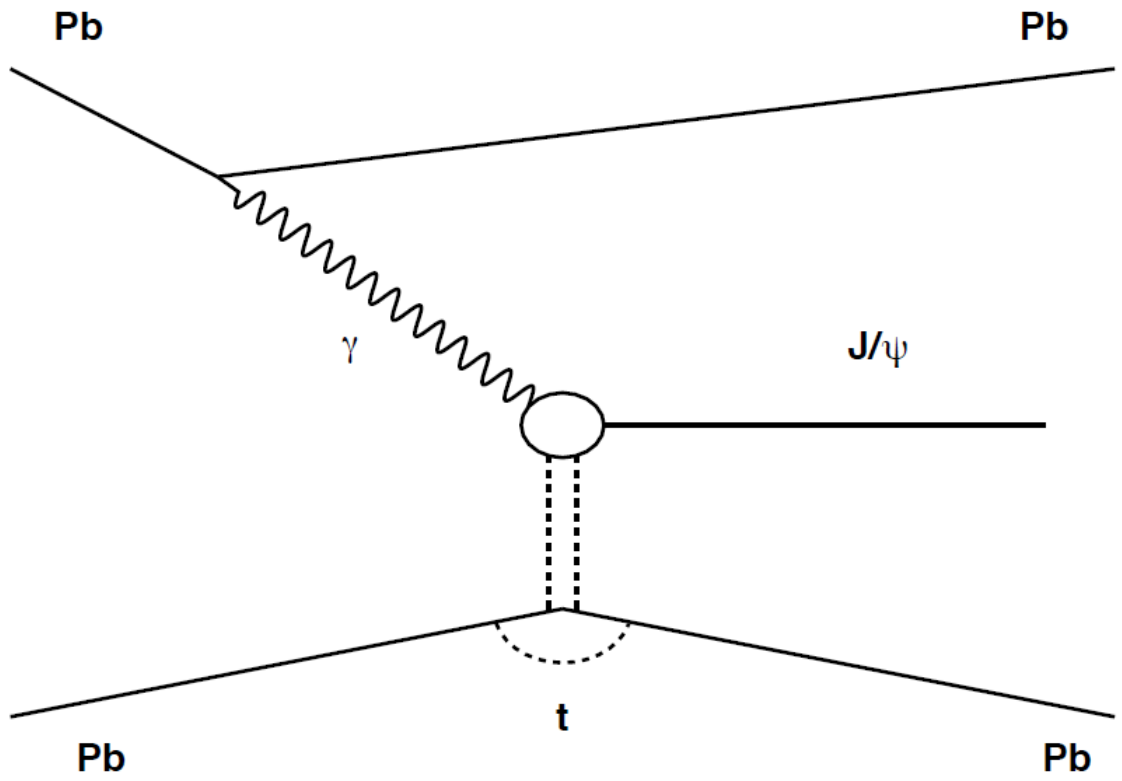
→ **Nuclear shadowing**

- Gluons from different nucleons may overlap
- No satisfactory description by pQCD
  - Data is used to constraint models

Photoproduction

- Coherent photoproduction of J/ψ in Pb-Pb collisions

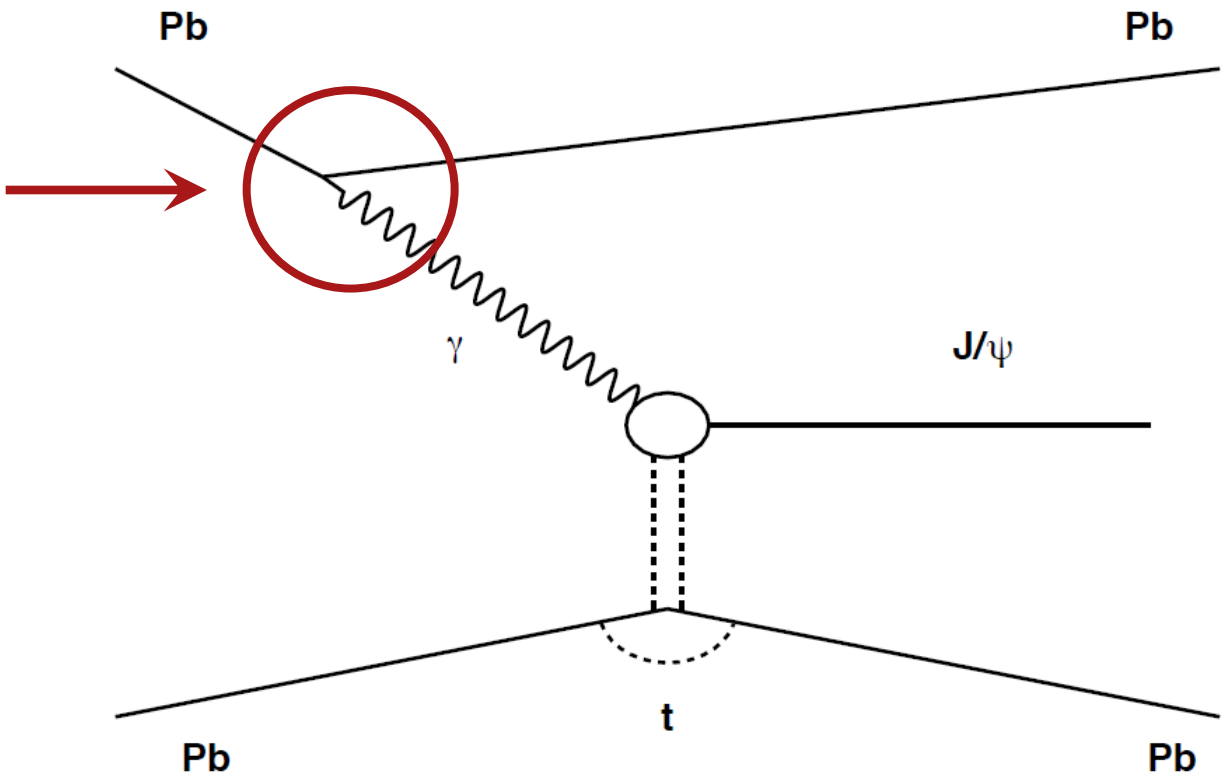


Photoproduction

Photon emission - QED

- Lead ion at speed close to c
- Its electromagnetic field is contracted
  - It can be described as a flux of quasi-real photons
  - Maximum energy of the photons is given by the Lorentz boost of the ion
- The intensity of the photon flux is proportional to Z^2

  → High Z ions such as lead are favoured



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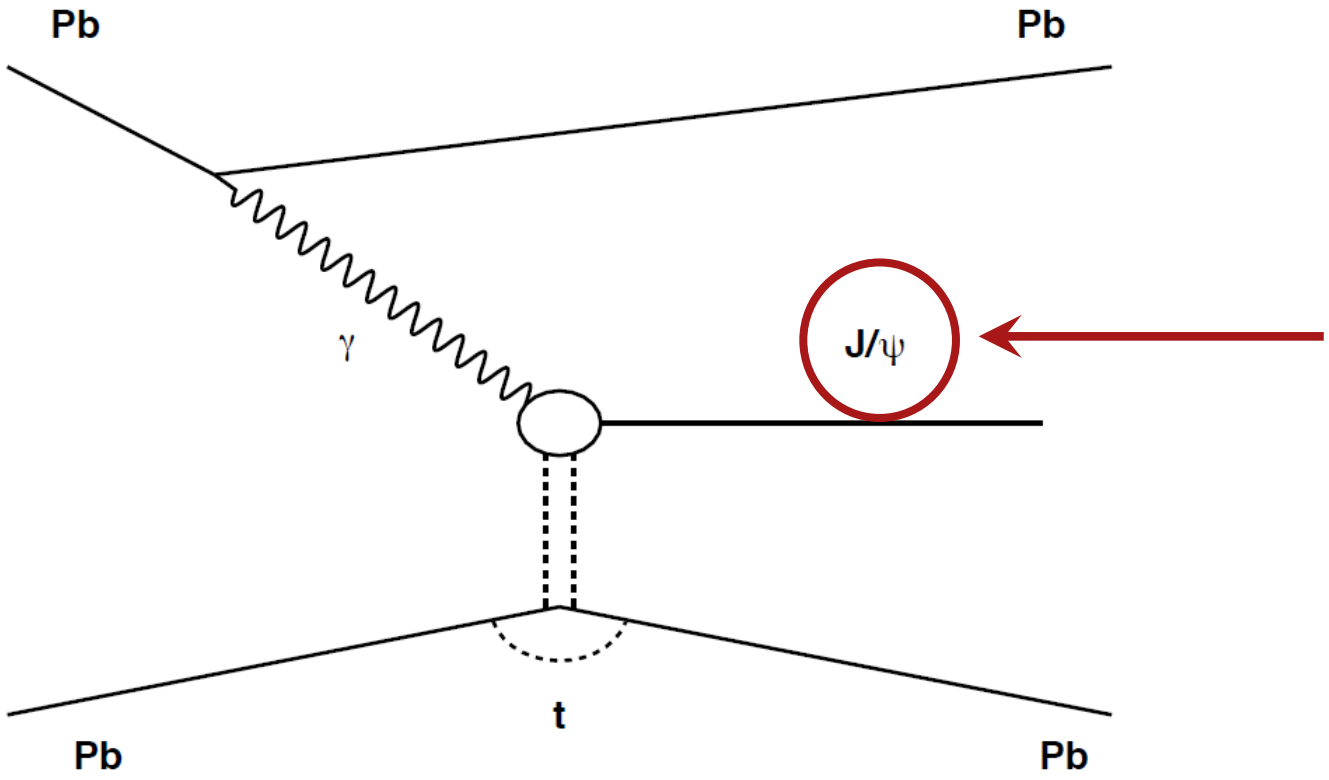


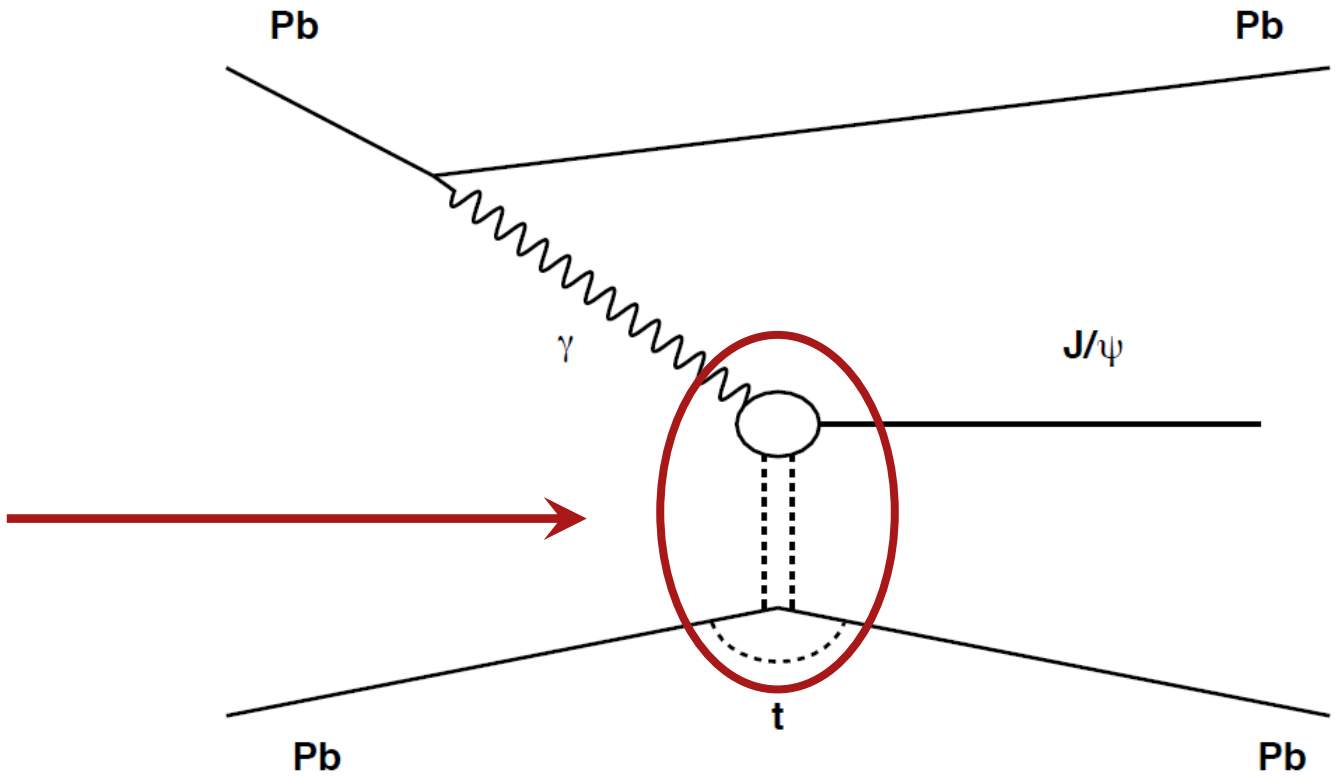
J/ψ

- Spin one and no net flavour
- High mass of the J/ψ
  → Perturbative calculations
- Small decay width and sizeable branching ratio to leptons
  → Clear experimental signal

Photoproduction

Photon target interaction - QCD

- In LO QCD
  - The coherent J/ψ photoproduction cross section $\propto$ gluon density squared
- Many models using various approaches to describe **nuclear shadowing**



M.G. Ryskin, Z.Phys. C57 (1993) 89-92

Photoproduction

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

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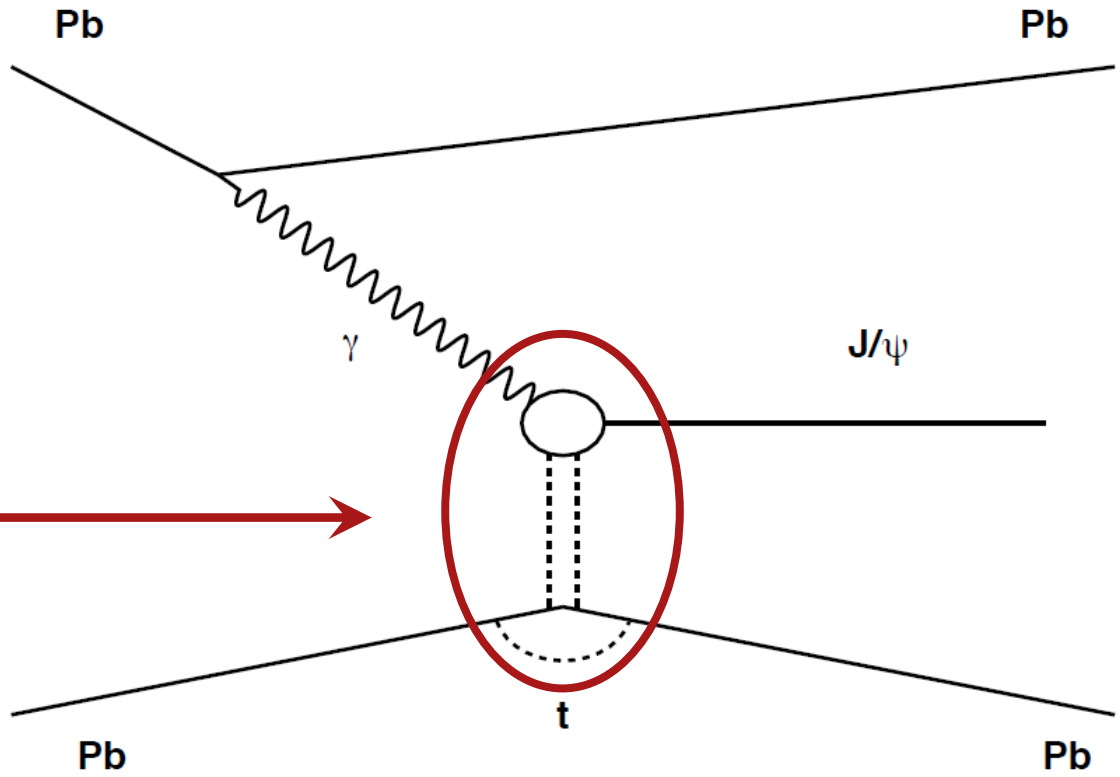

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Ultra-peripheral collisions

- We have to distinguish between photoproduction and hadronic interactions
  - The strong interaction is short range
  - Lead nucleus breaks after interacting via the strong force

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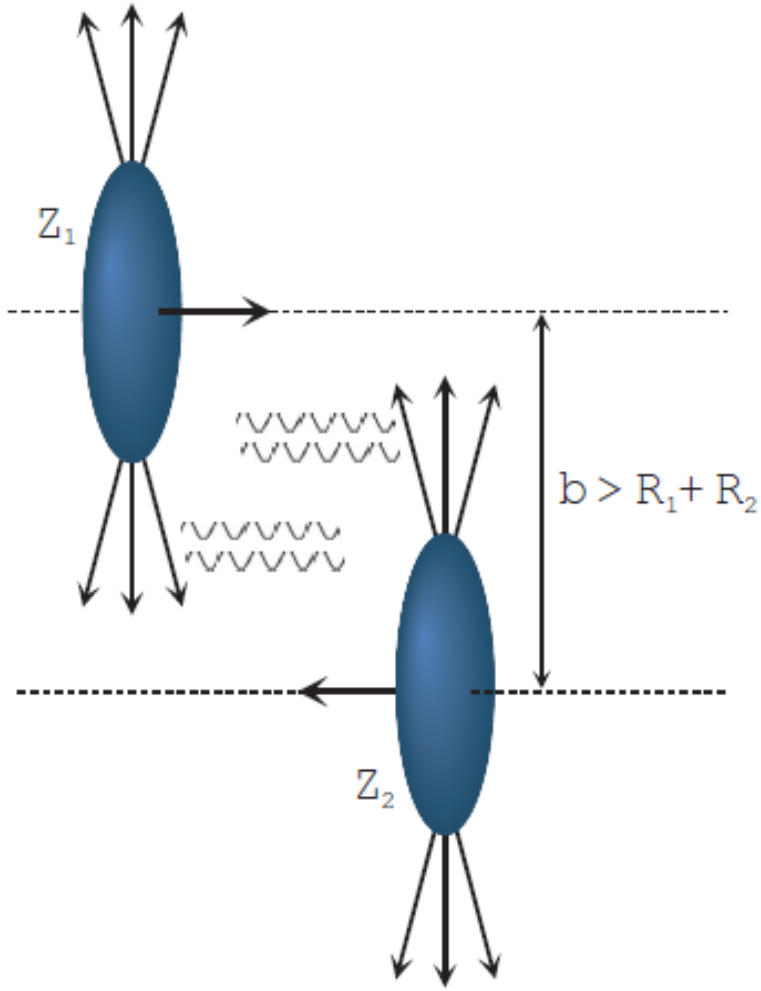
- Interactions at impact parameter b larger than the sum of the radii of the colliding particles $R_1 + R_2$, which involve at least one photon are called



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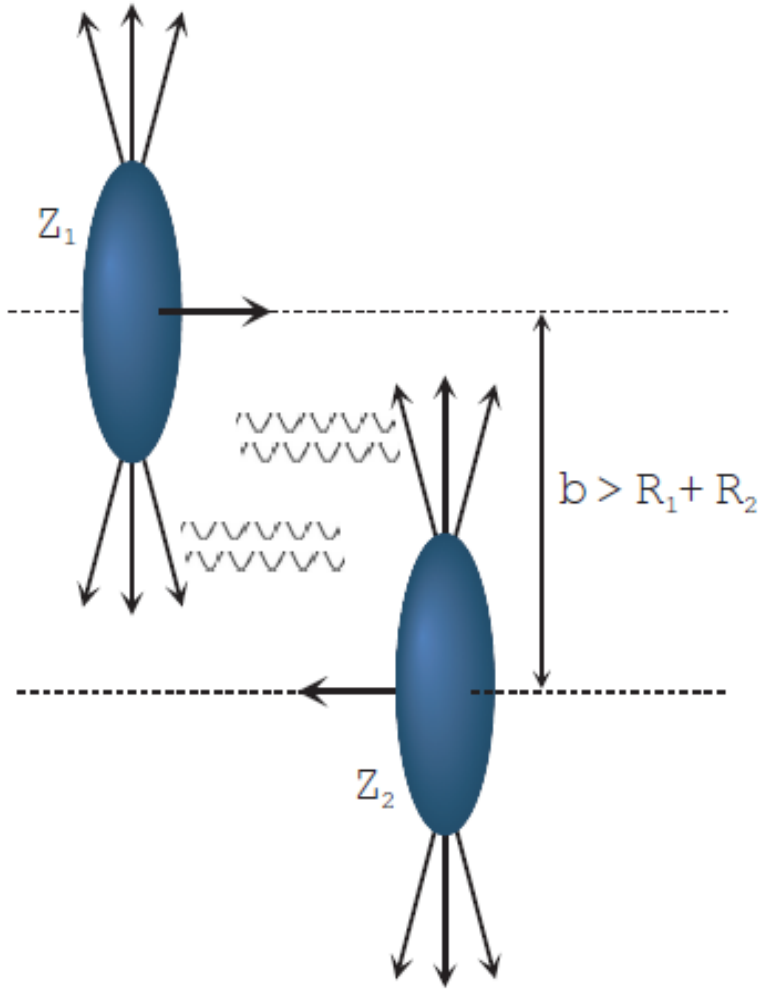
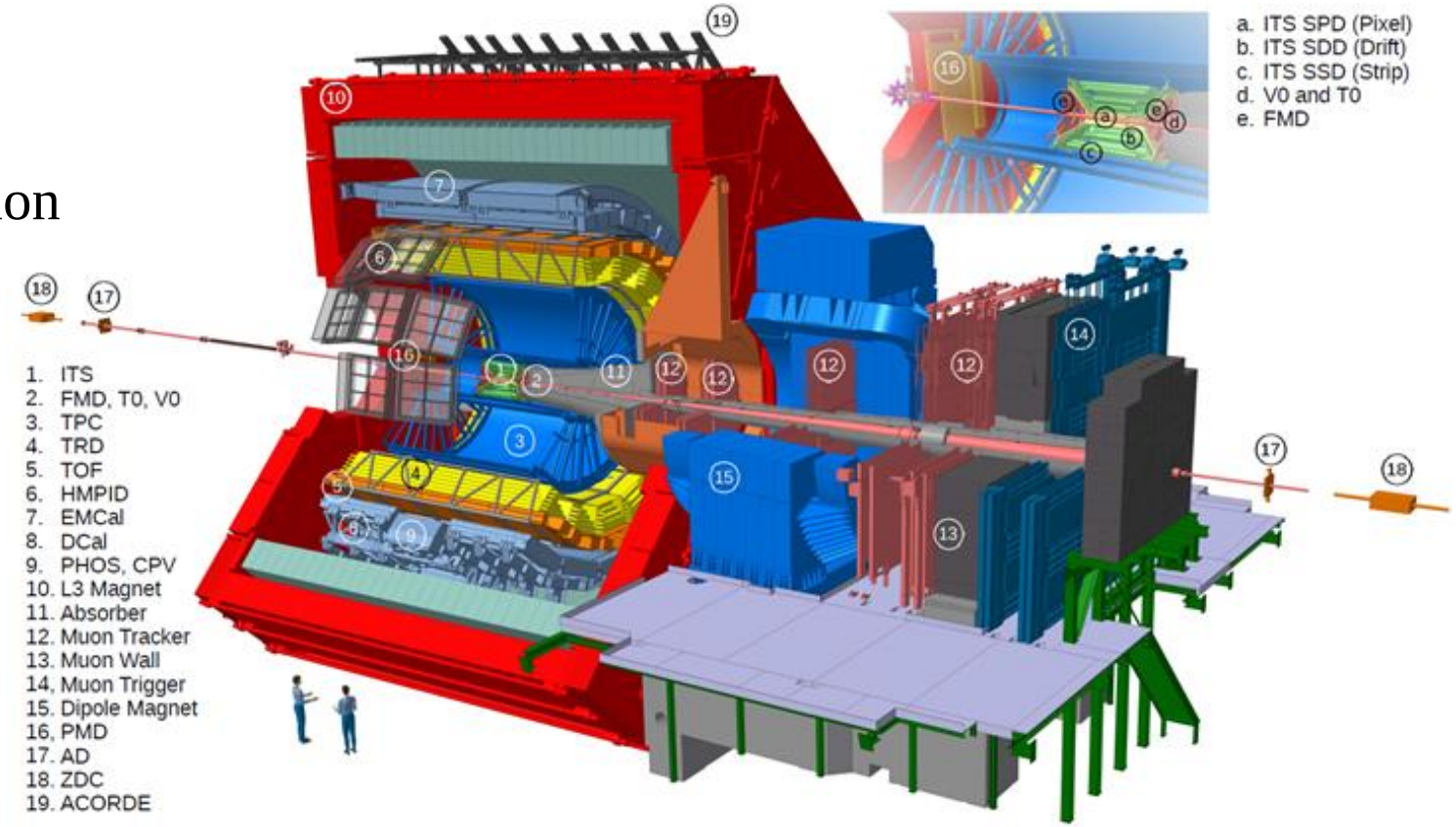
→ **Ultra-peripheral collisions**

- ALICE can determine if the colliding nuclei broke or not with high efficiency



- We measure the J/ψ 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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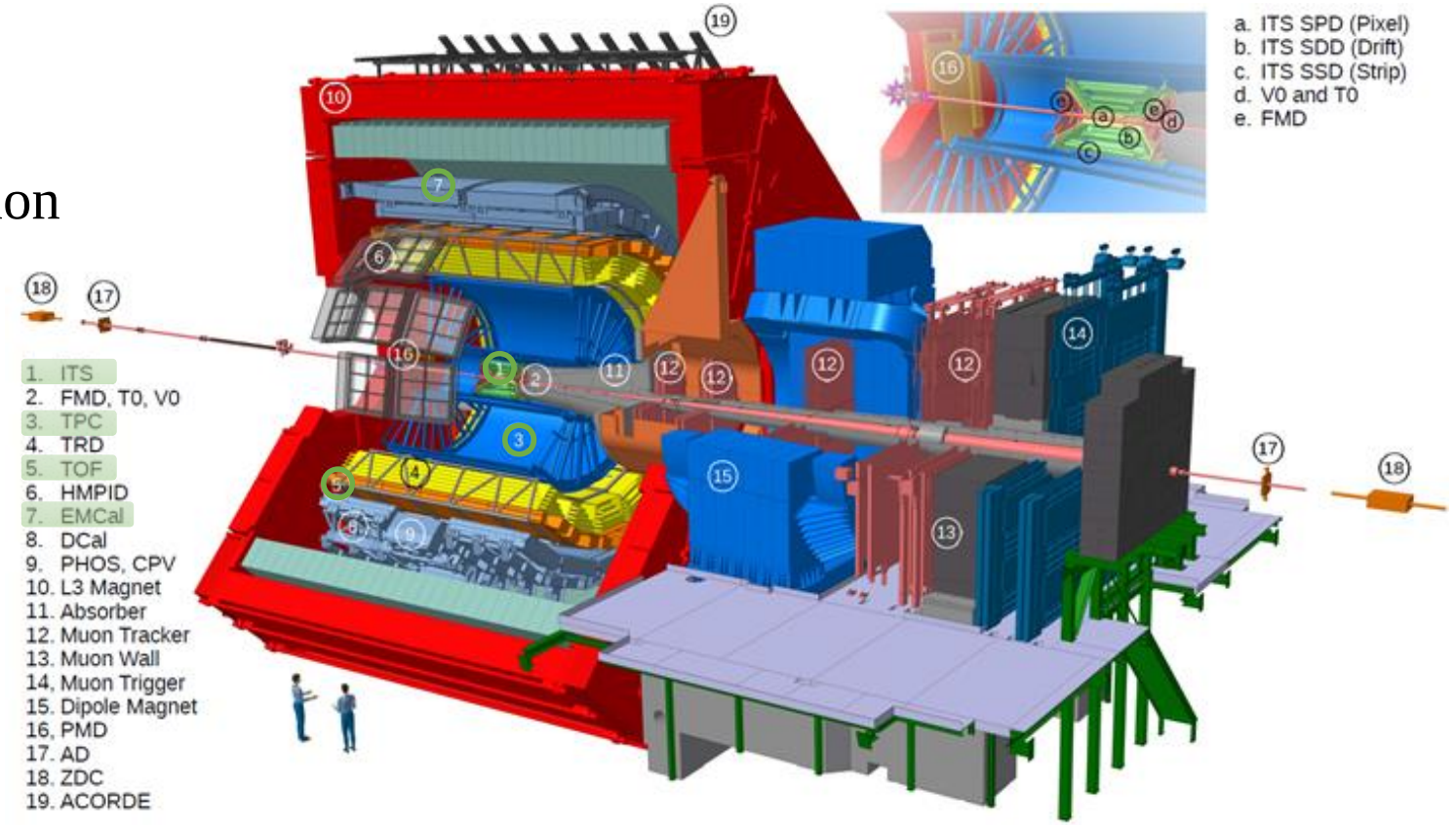

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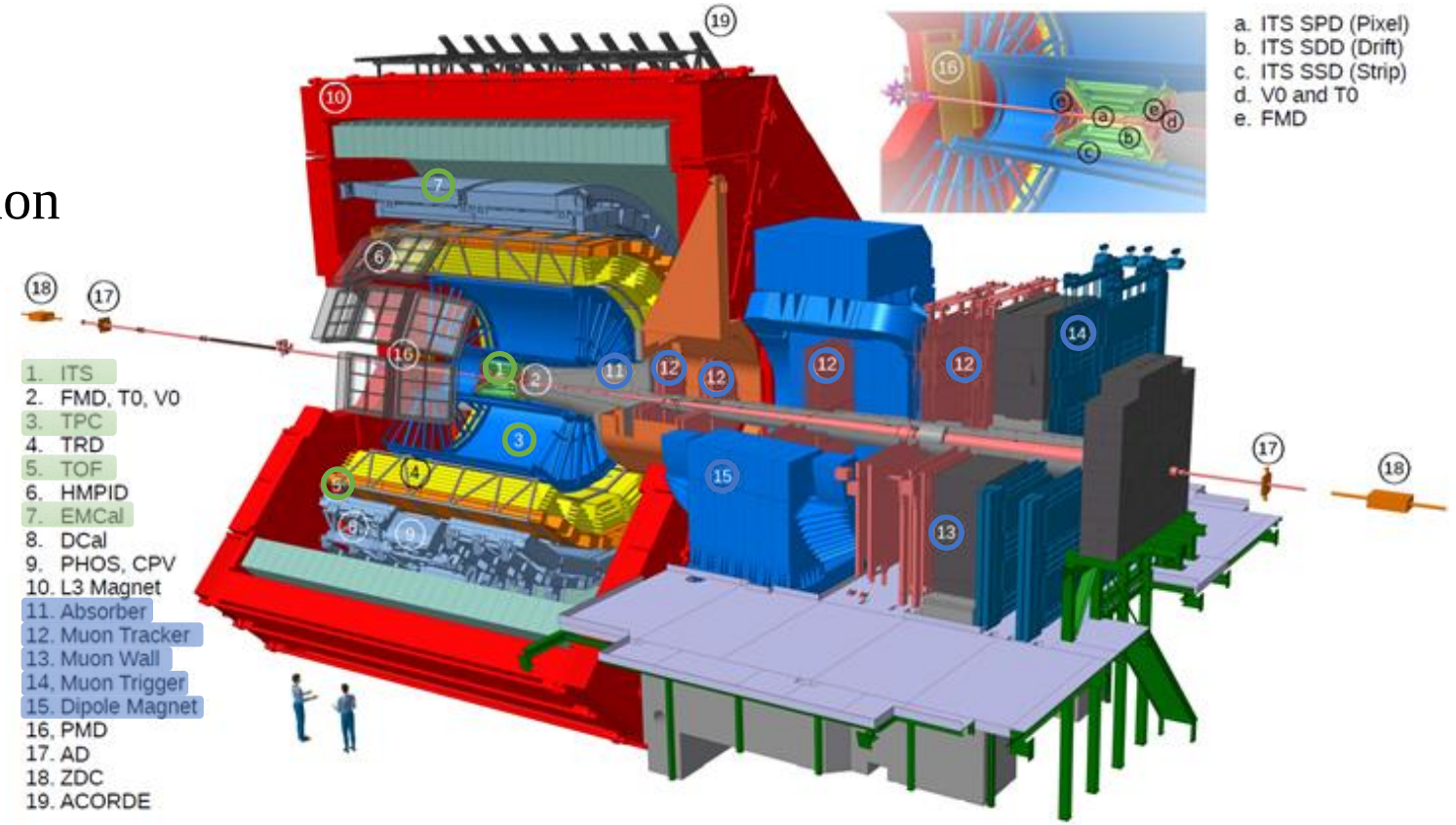

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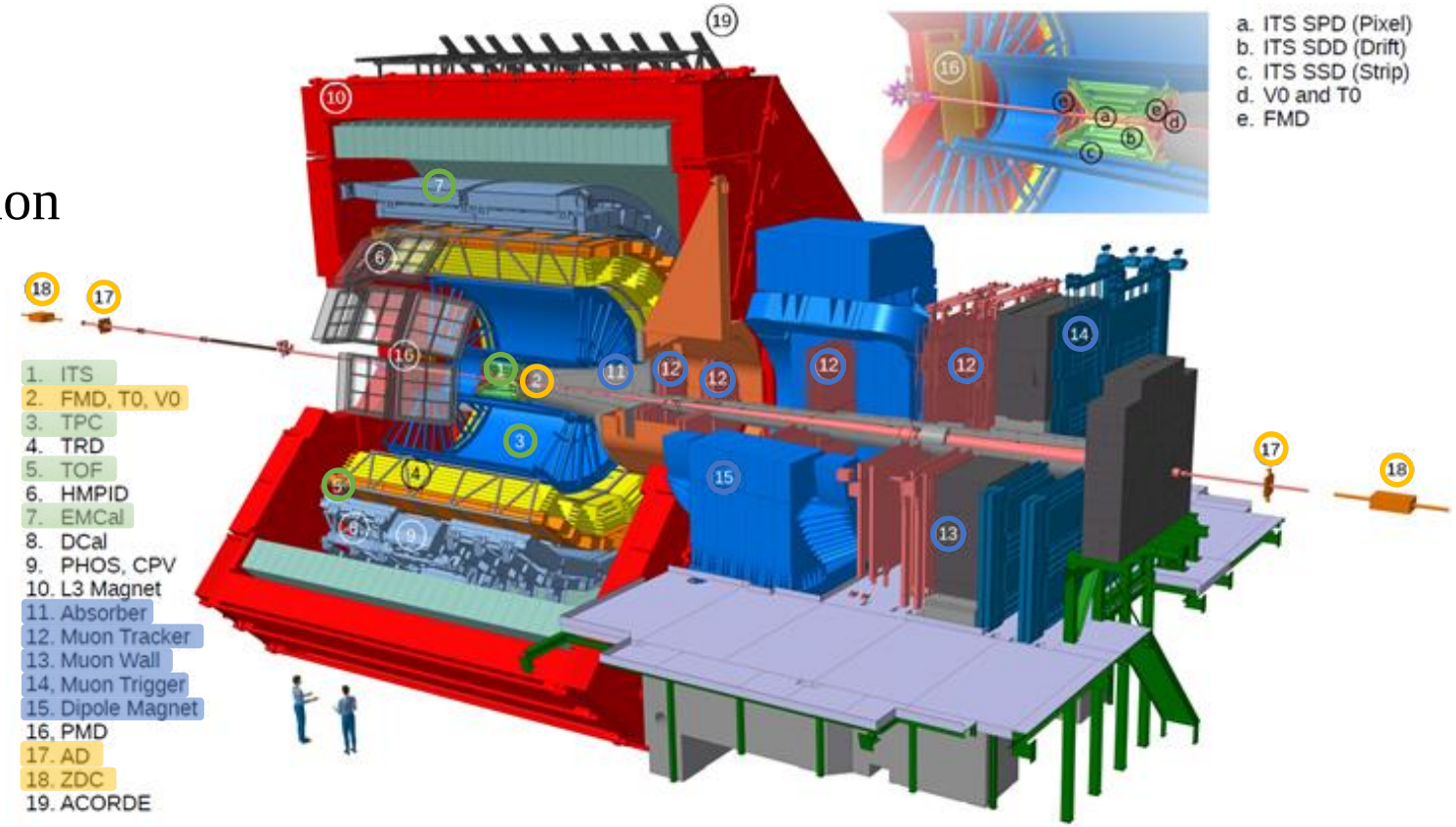
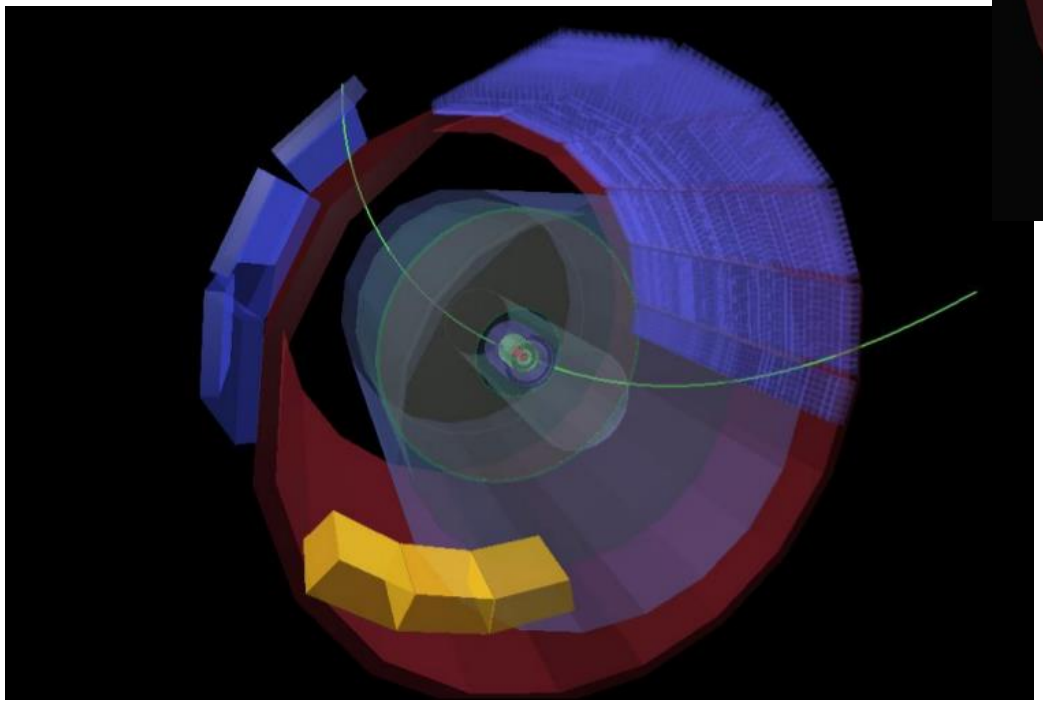
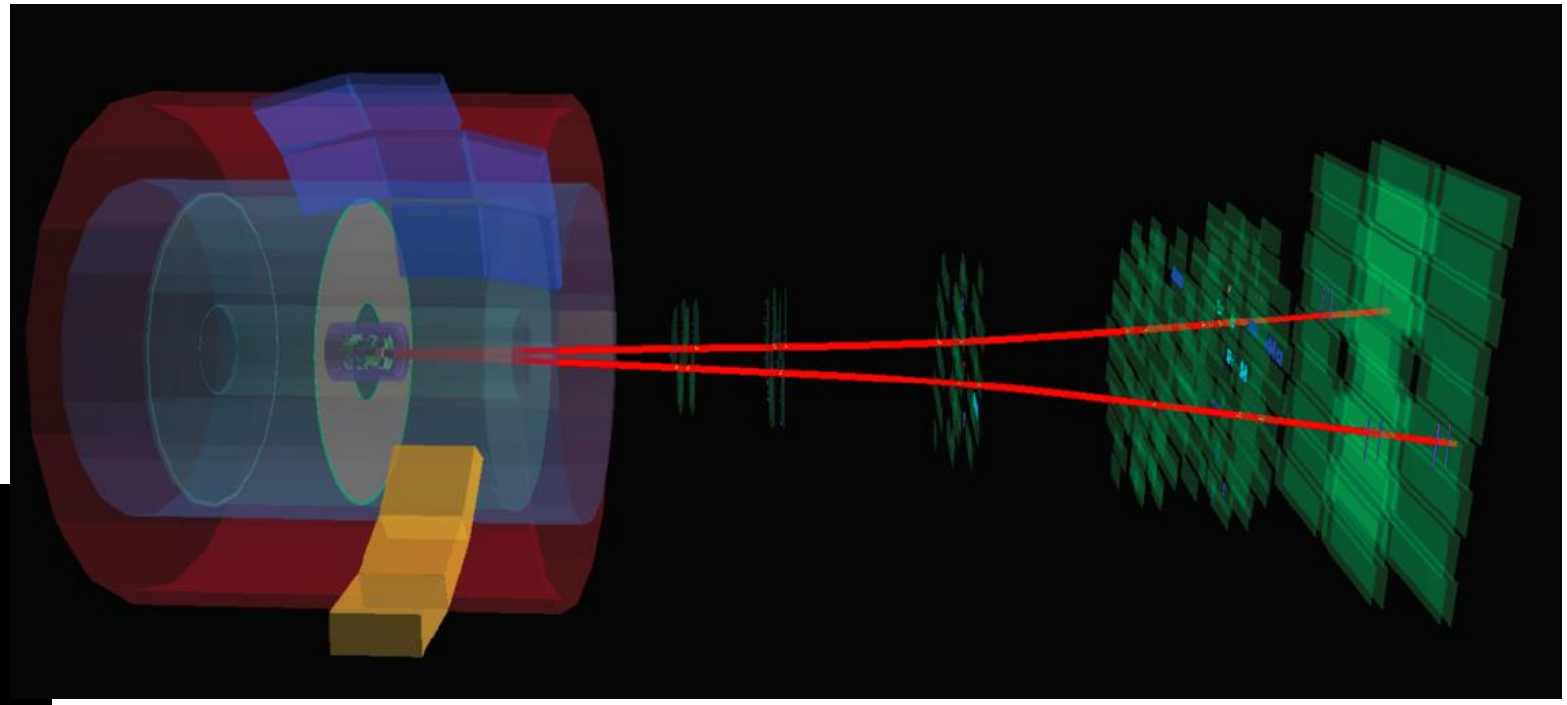


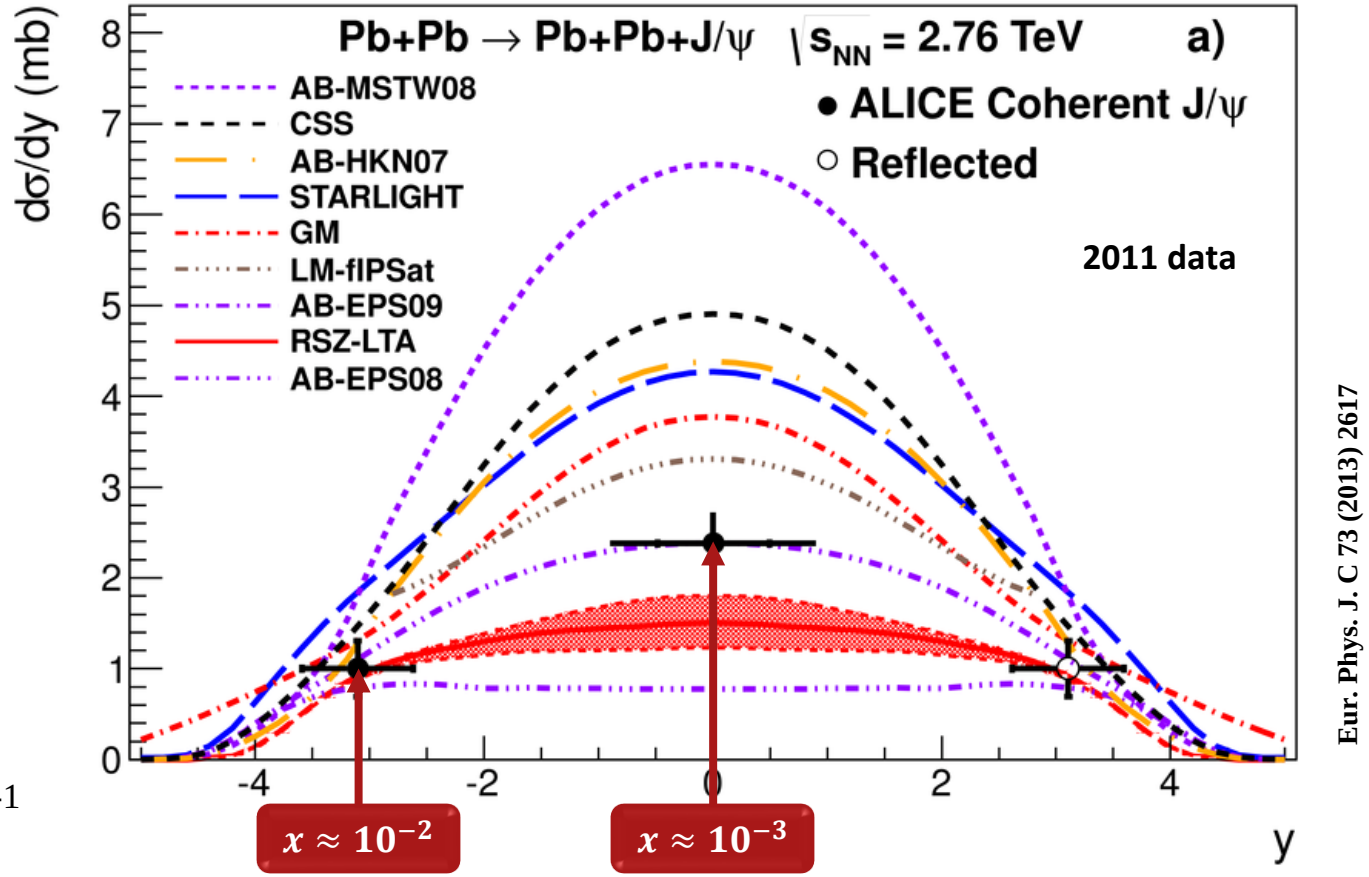
Central event





Forward event

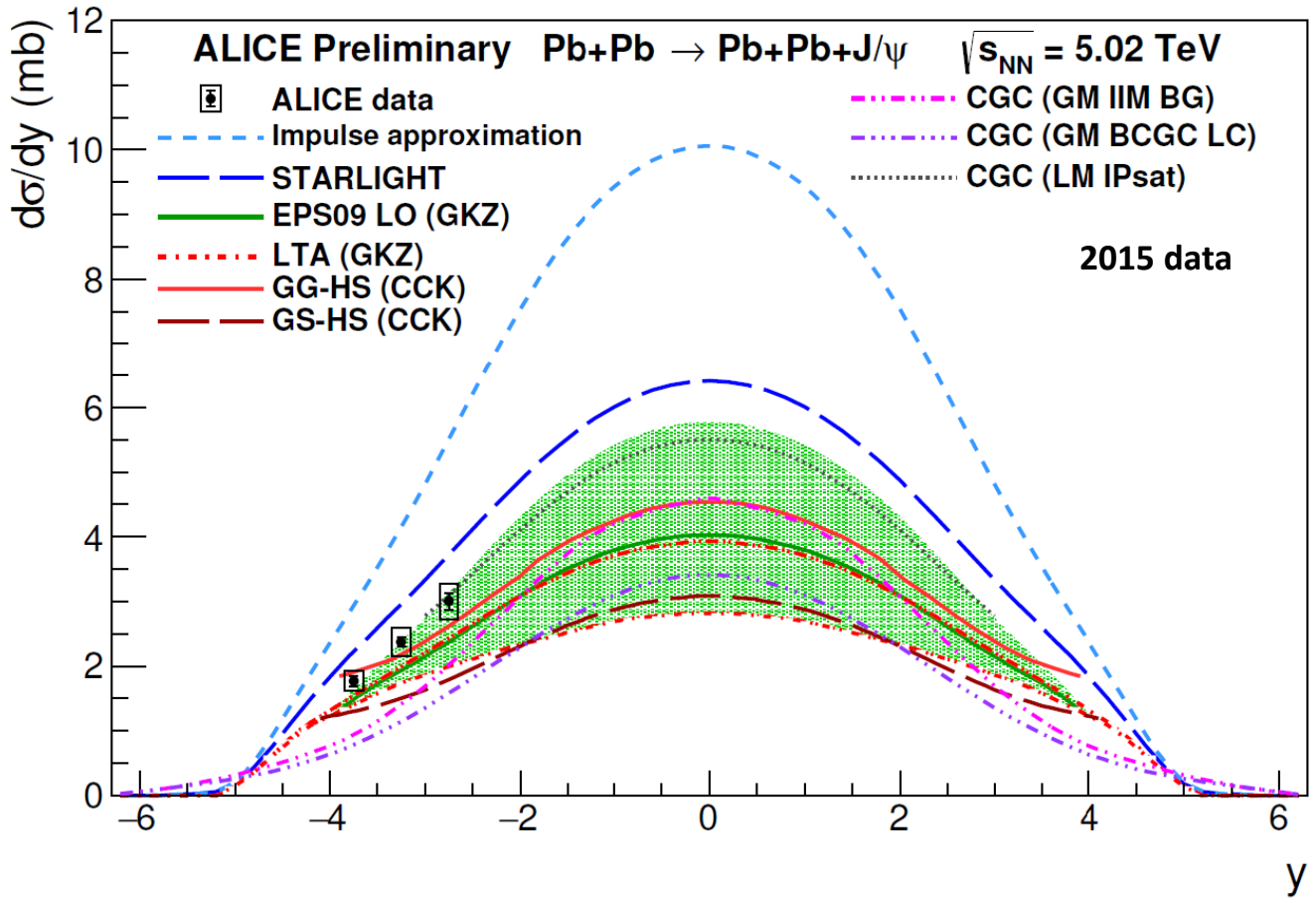
ALICE Pb-Pb UPC at $\sqrt{s_{NN}} = 2.76$ TeV - published



Eur. Phys. J. C 73 (2013) 2617

- $L = 55\ \mu b^{-1} + 23\ \mu b^{-1}$
- Measurement sensitive to nuclear shadowing
- Computation without shadowing rejected by data
- Models with **moderate nuclear shadowing** are favoured

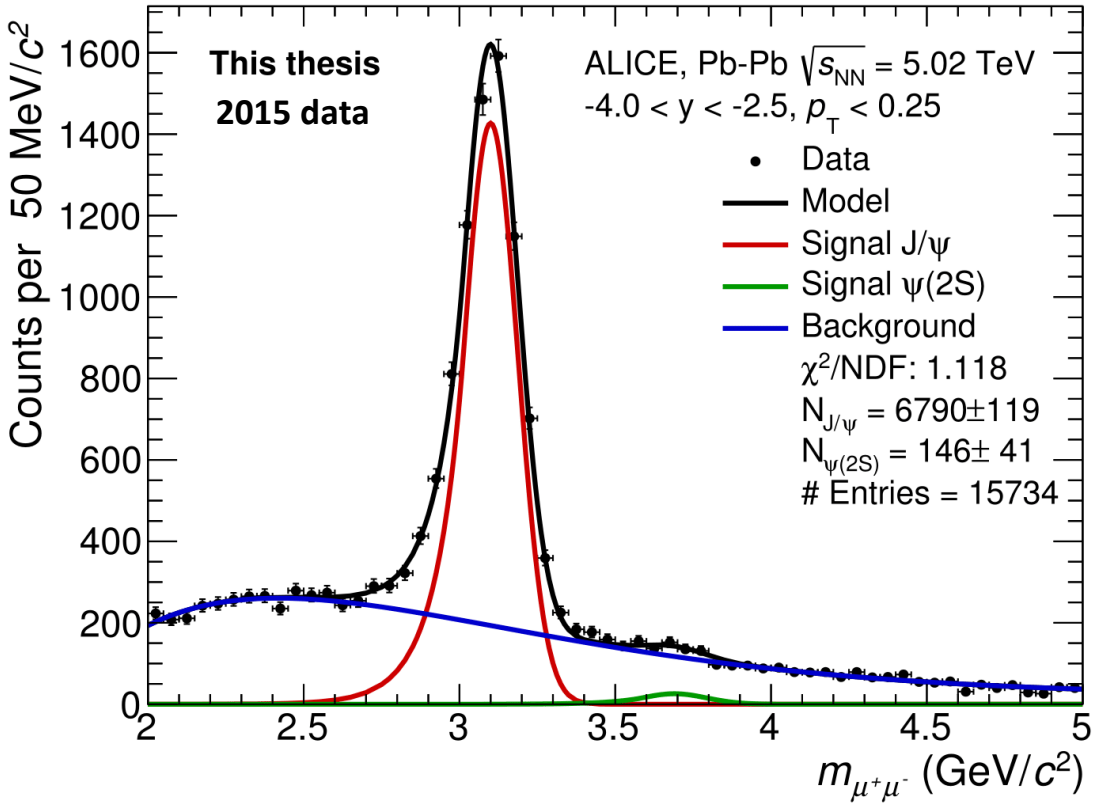
ALICE Pb-Pb UPC at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV - preliminary



- New run at larger $\sqrt{s_{\mathrm{NN}}}$
- $L = 216\ \mu b^{-1}$
- Larger sample and higher collisions energy → Stronger constraints to models
- Analysis in progress → Preliminary results again favor **moderate nuclear shadowing**

Analysis - Cross section measurement

- $N_{\mathrm{J}/\psi}^{\mathrm{coh}}$ can be extracted by fitting the invariant mass spectrum (Crystal Ball and Polynomial)
- But the number we obtain from this fit is actually N_{yield}
  - We have to make corrections



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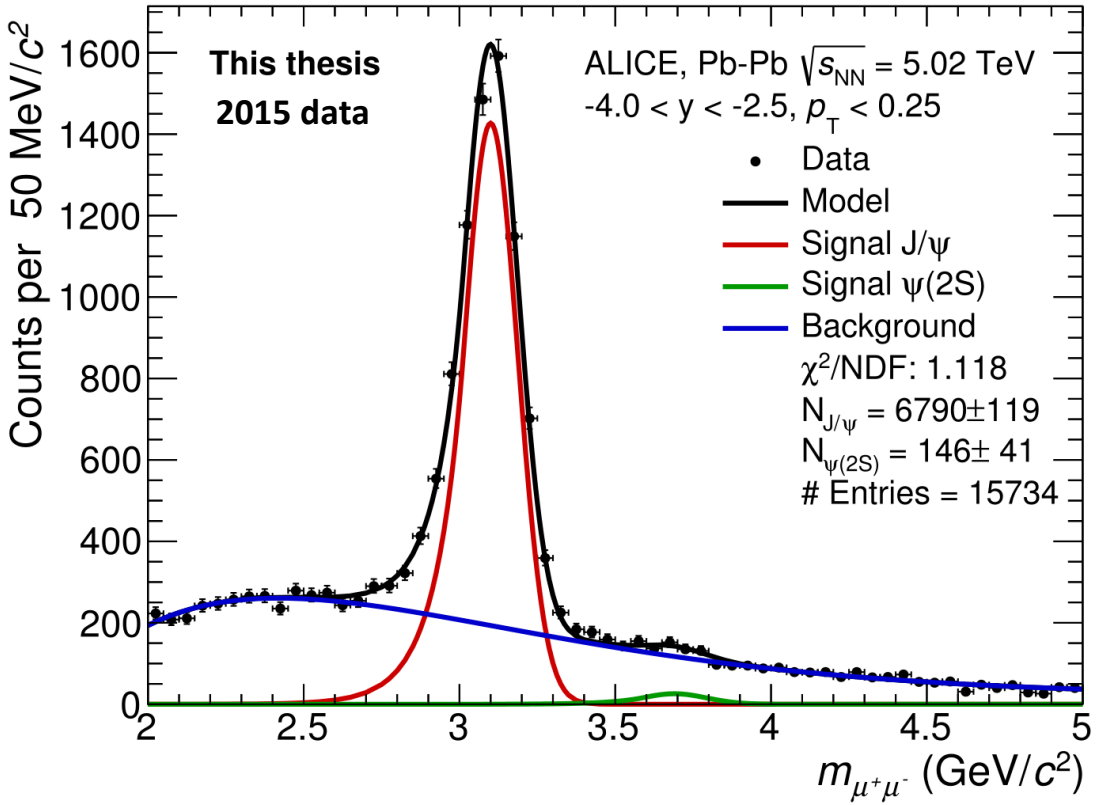
$$N_{J/\psi}^{coh} = \frac{N_{yield}}{1 + f_I + f_D}$$

Contribution from incoherent events

Feed down from ψ(2s) to J/ψ decay



Analysis - Cross section measurement

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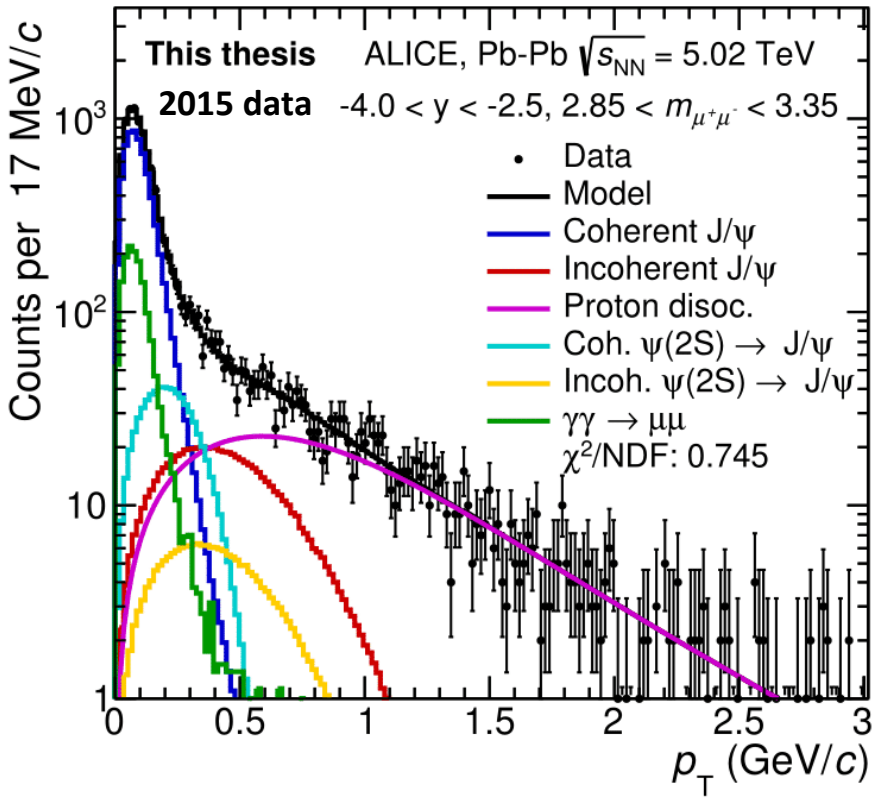
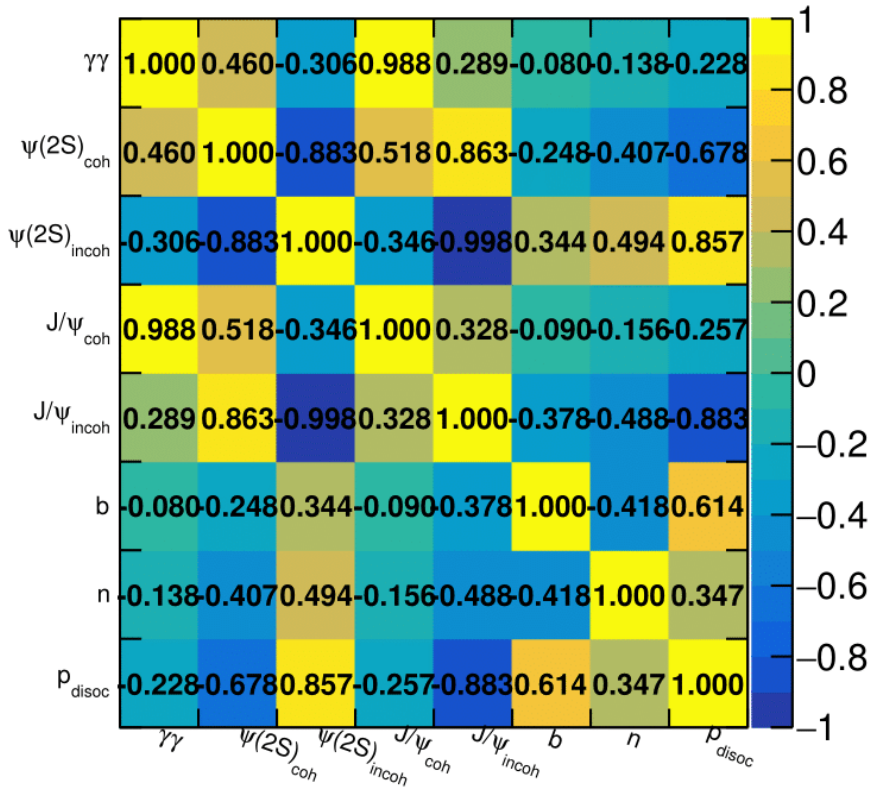
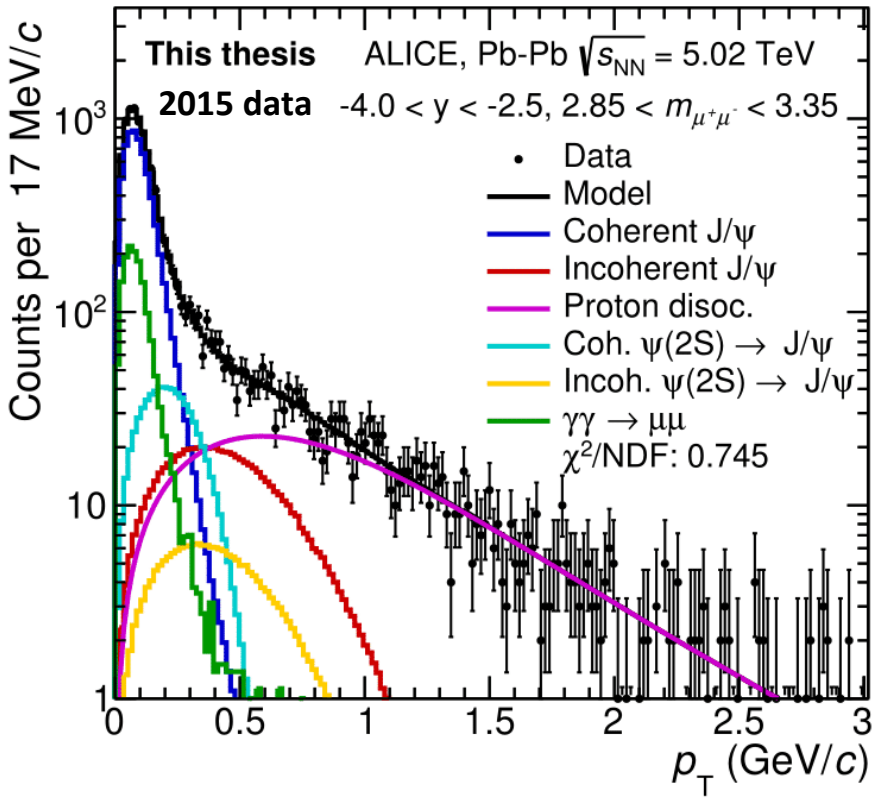
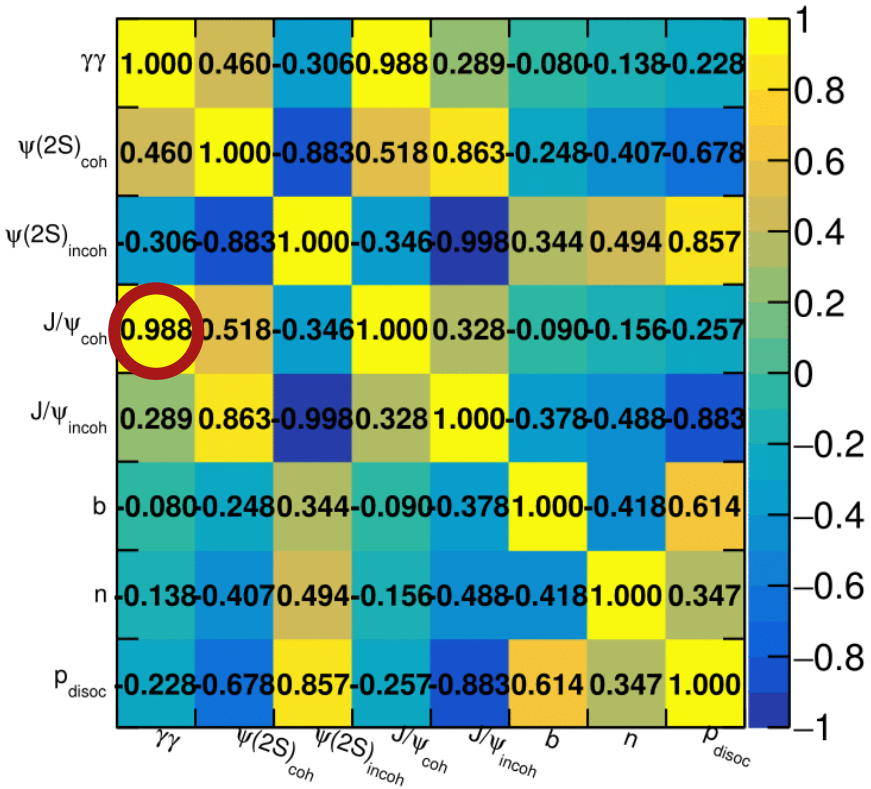




Analysis - Cross section measurement

- Different contributions can be determined by template fitting the transverse momentum spectrum
- Strong correlations → Large error bars and possible errors! → Constrains needed





Analysis - Cross section measurement

- We have to compute cross section from the measured data

$$\frac{\mathrm{d}\sigma^{\mathrm{coh}}_{\mathrm{J}/\psi}}{\mathrm{d}y} = \frac{N^{\mathrm{coh}}_{\mathrm{J}/\psi}}{(\mathrm{Acc}\times\varepsilon)_{\mathrm{J}/\psi}\cdot BR(\mathrm{J}/\psi \longrightarrow \mu^+\mu^-)\cdot \mathscr{L}_{\mathrm{int}}\cdot \Delta y}$$

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Number of produced J/ψ

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Acceptance and efficiency of the detector

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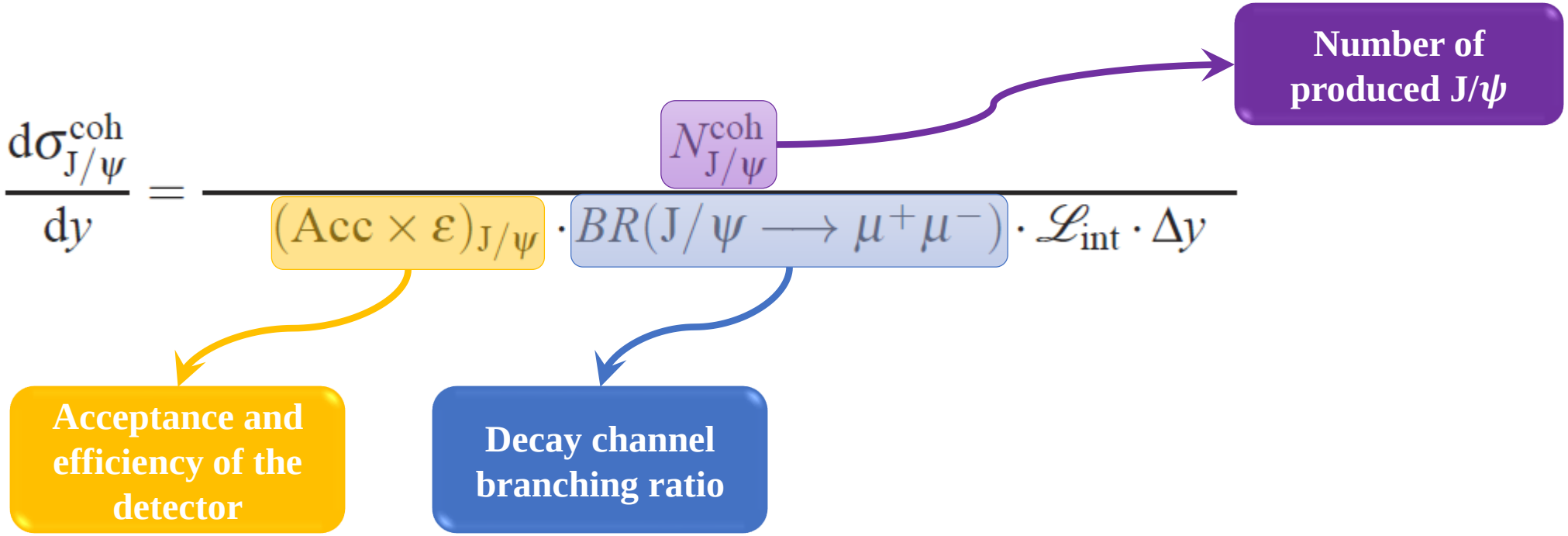

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Number of produced J/ψ

Acceptance and efficiency of the detector

Decay channel branching ratio

Integrated luminosity

Analysis - Cross section measurement

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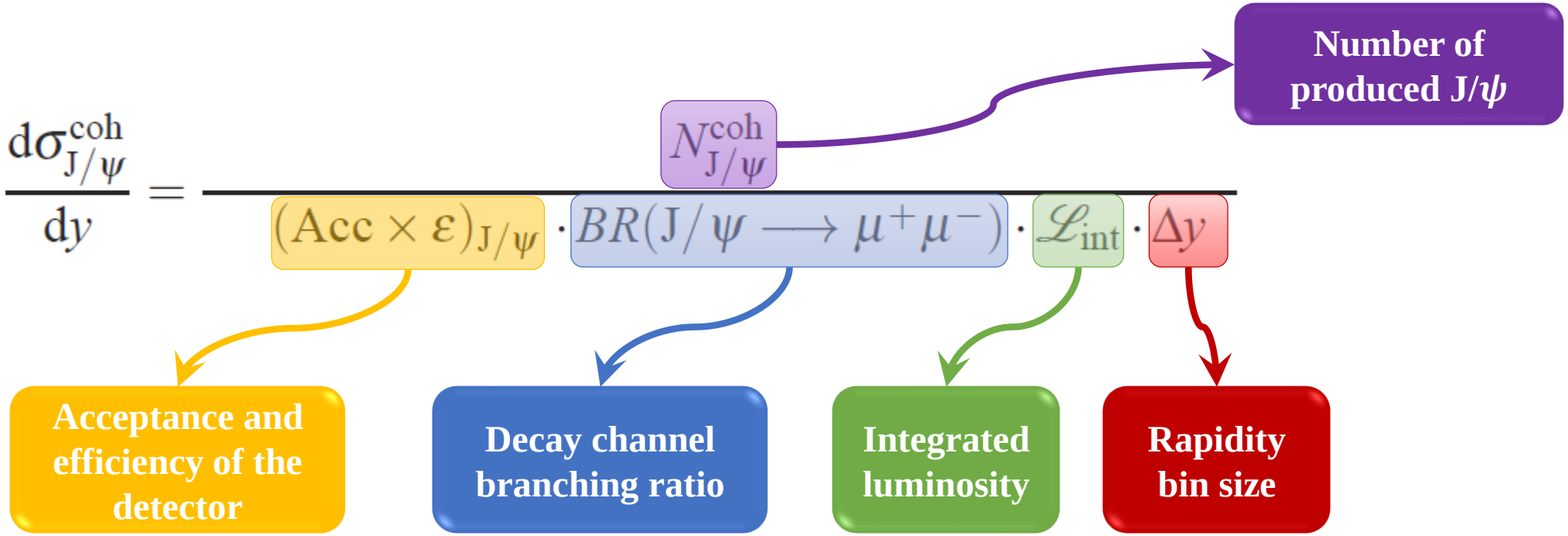
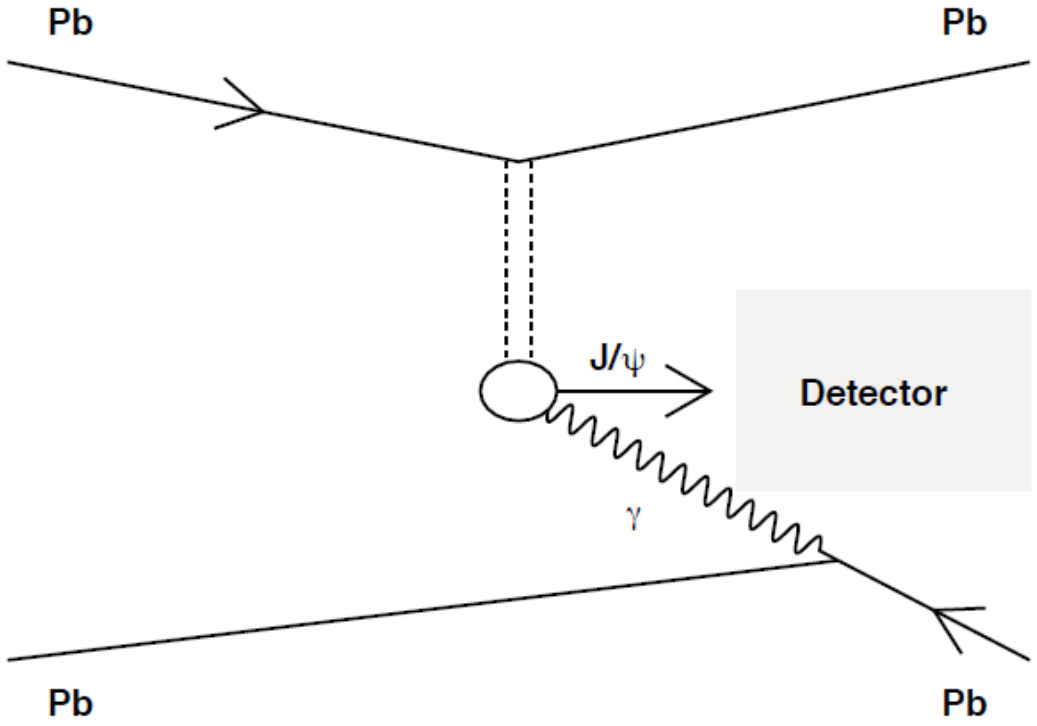


Analysis - Photoproduction

- Do you remember the photoproduction diagram?

Analysis - Photoproduction

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



Analysis - Photoproduction

Photon flux

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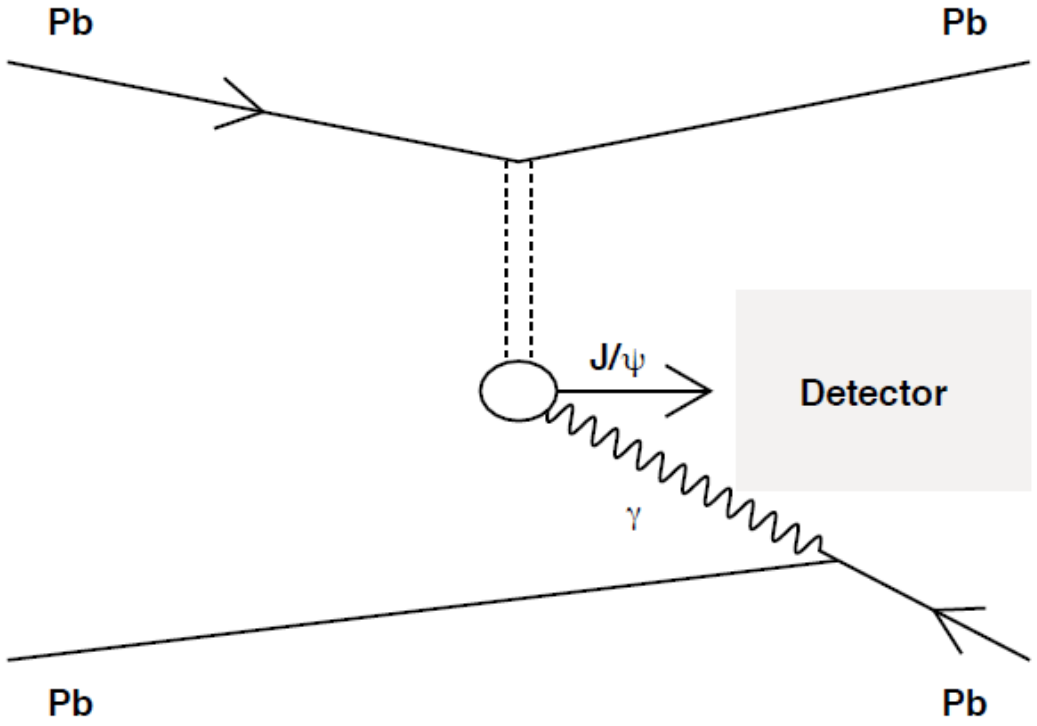

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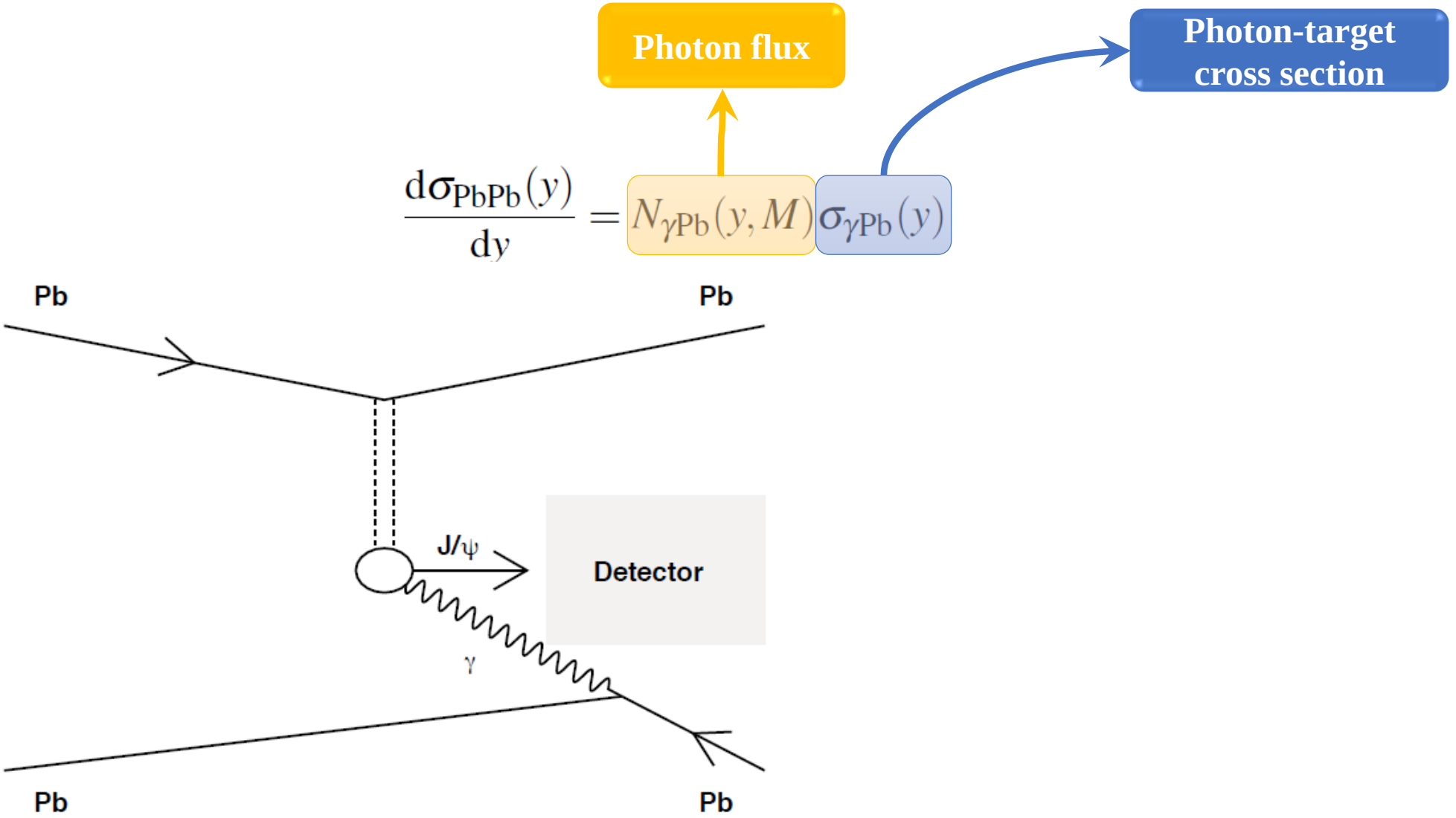
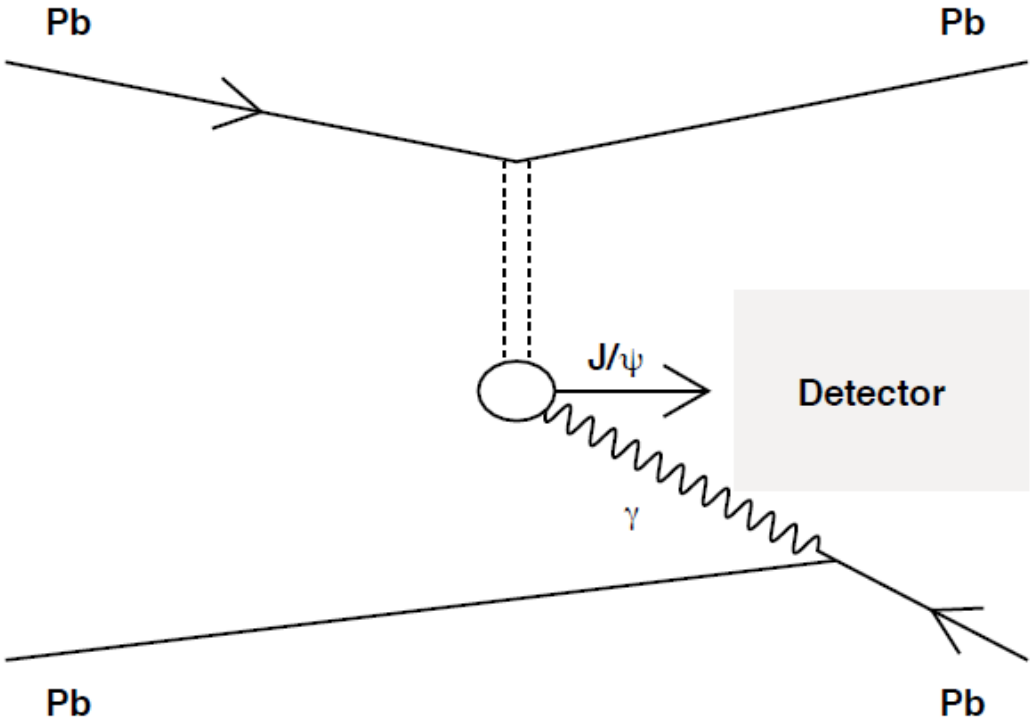


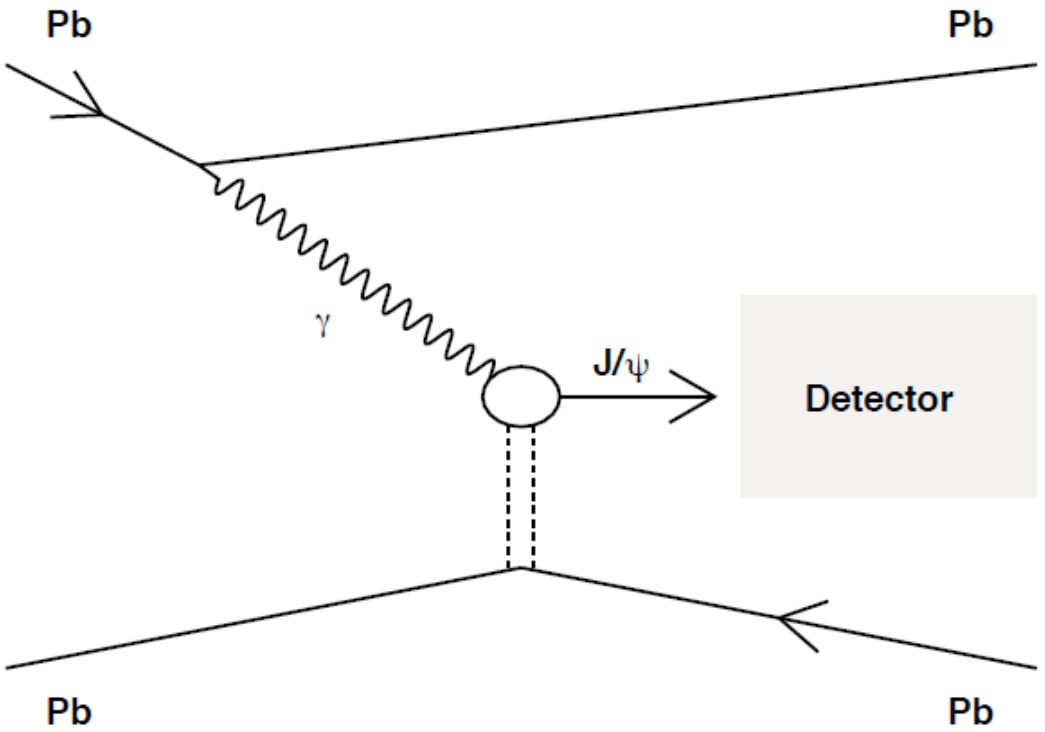
Analysis - Photoproduction

Photon flux

Photon-target cross section

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





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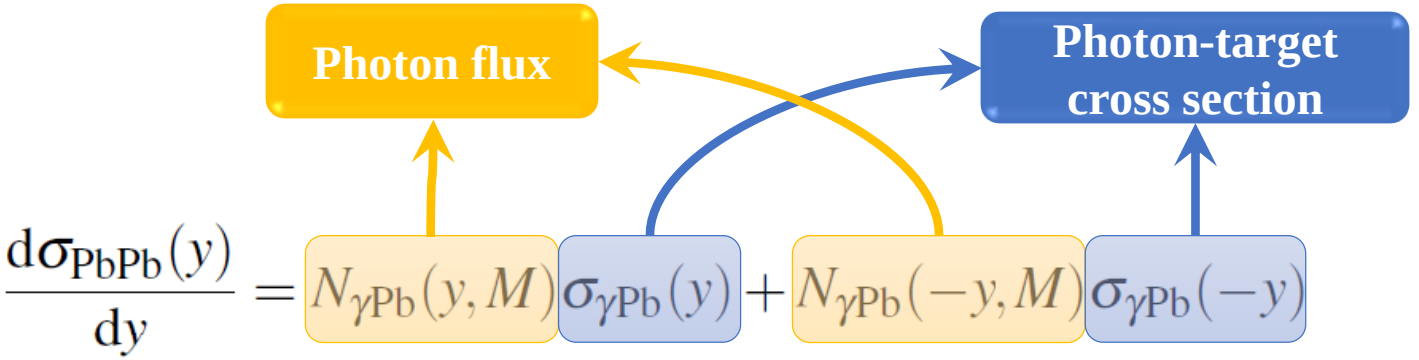
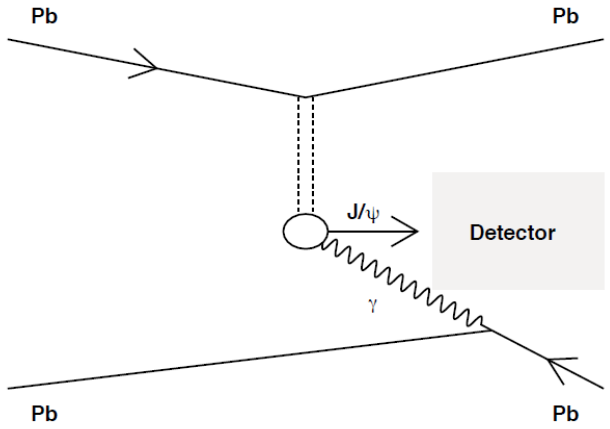
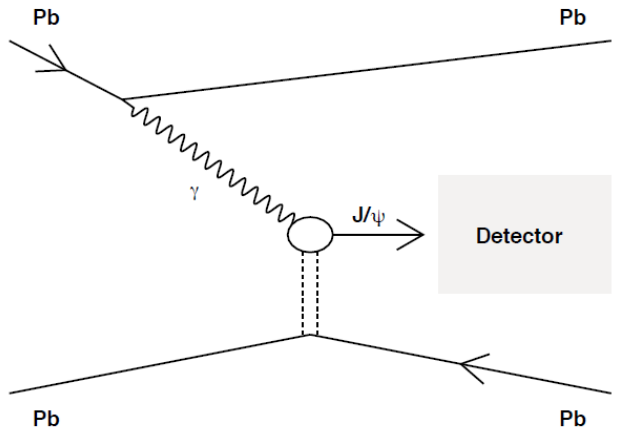


- At mid rapidity
  - Both contributions are same





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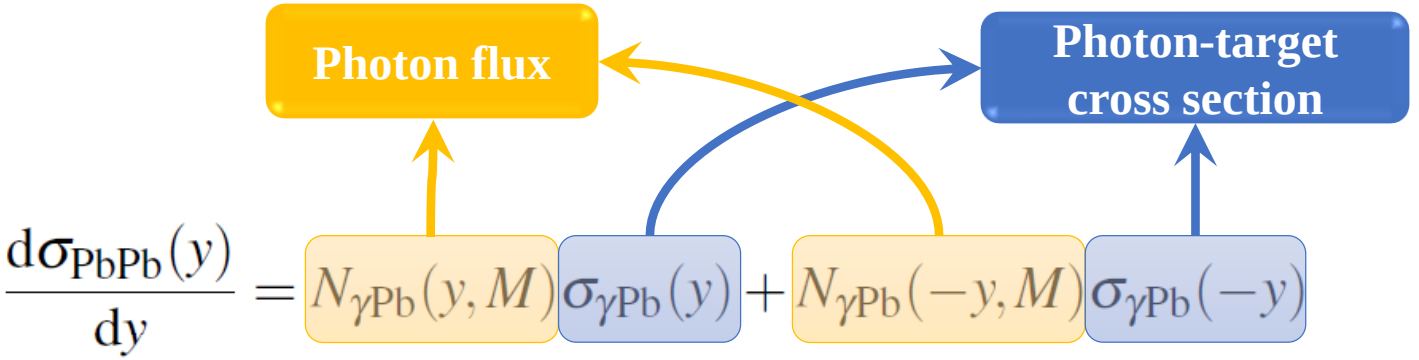
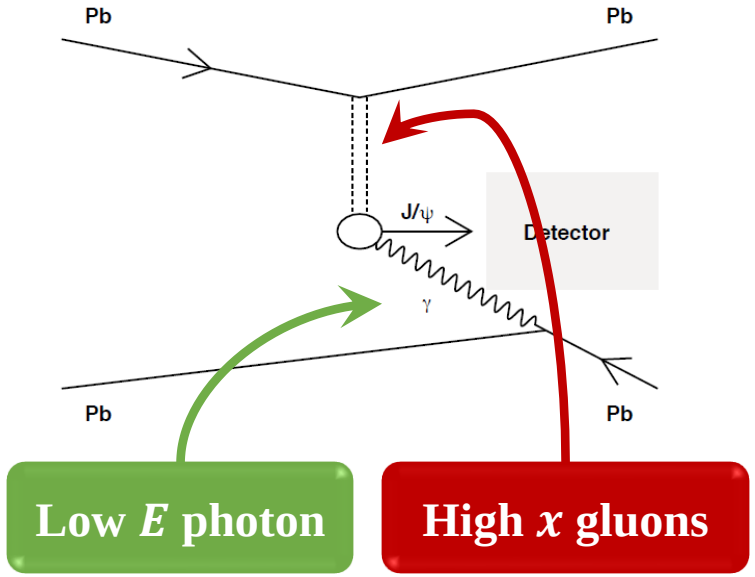
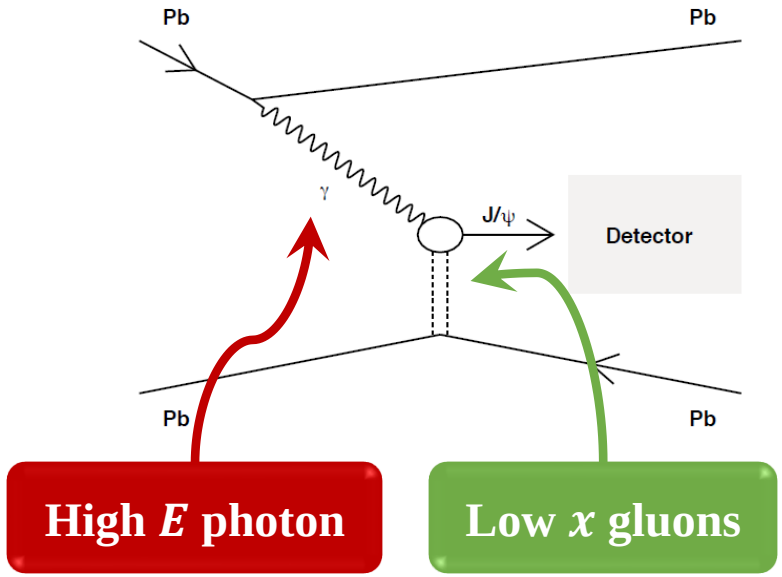


- At mid rapidity
  - Both contributions are same
- At forward rapidity
  - **Contributions are different**





Analysis - Photoproduction

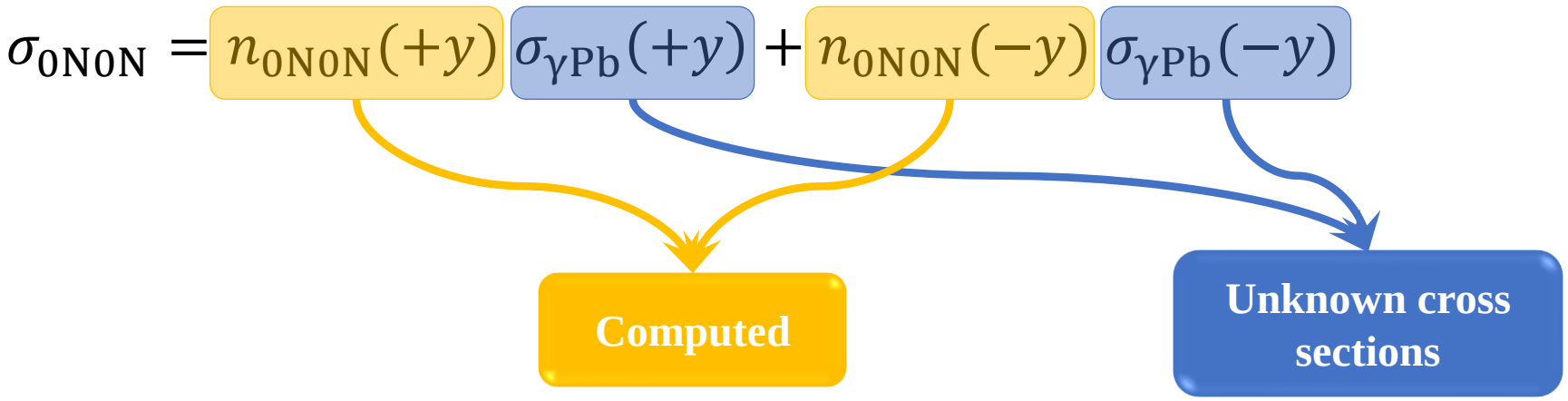
$$\sigma_{0\mathrm{N}0\mathrm{N}} = n_{0\mathrm{N}0\mathrm{N}}(+y)\,\sigma_{\gamma\mathrm{Pb}}(+y) + n_{0\mathrm{N}0\mathrm{N}}(-y)\,\sigma_{\gamma\mathrm{Pb}}(-y)$$

Analysis - Photoproduction

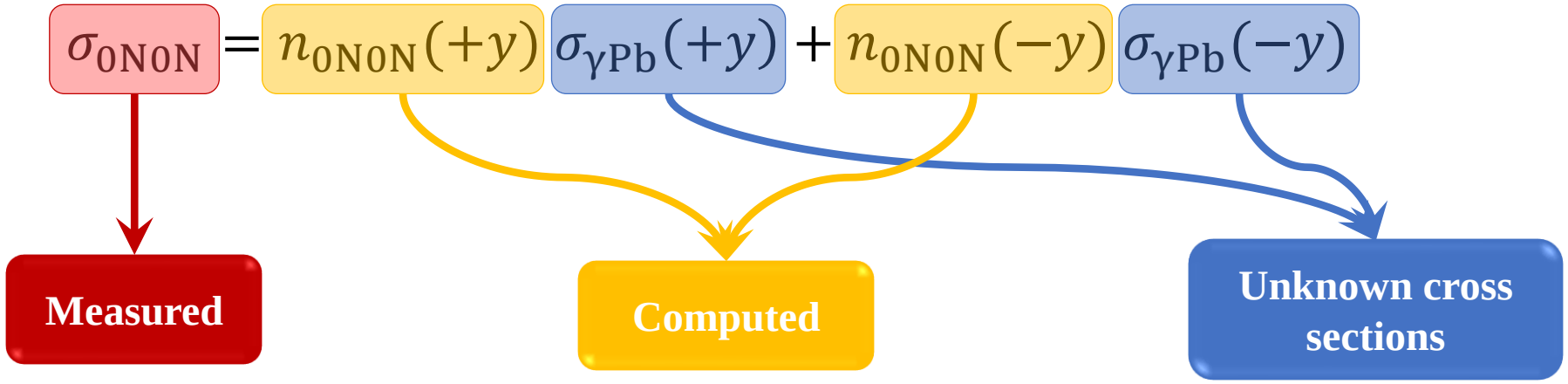
$$\sigma_{0N0N} = n_{0N0N}(+y)\,\sigma_{\gamma Pb}(+y) + n_{0N0N}(-y)\,\sigma_{\gamma Pb}(-y)$$

Computed

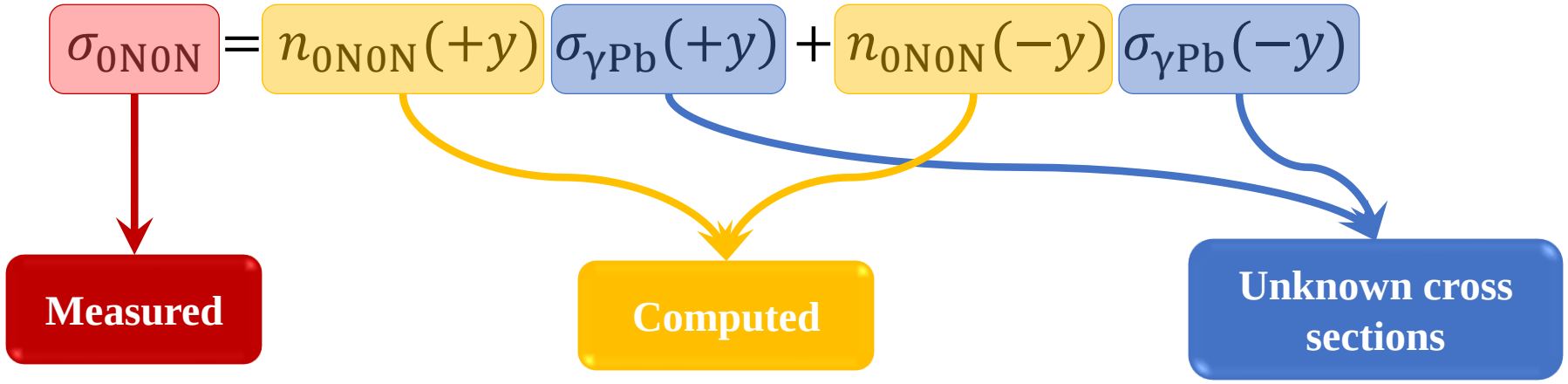
Analysis - Photoproduction



Analysis - Photoproduction

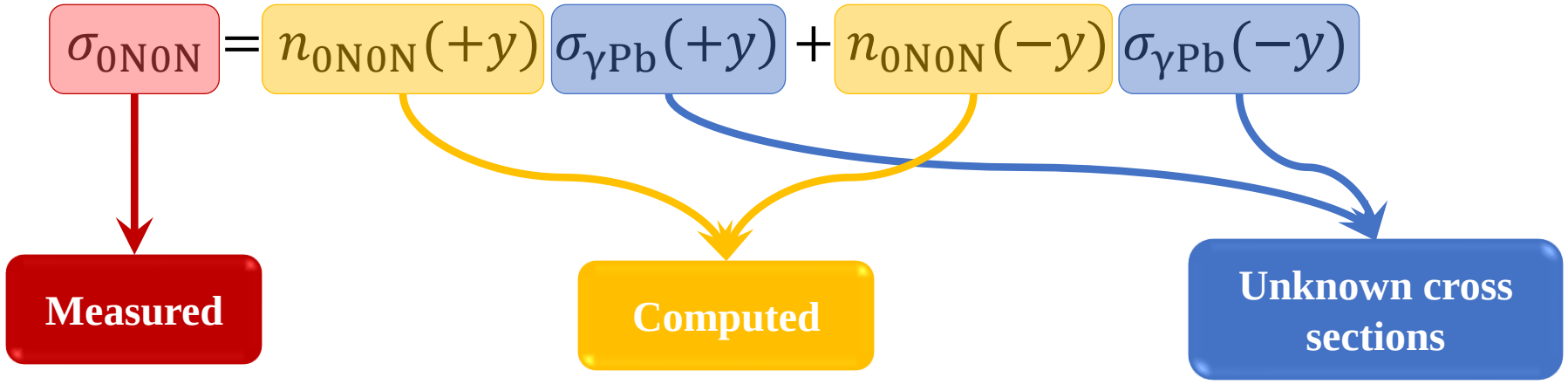


Analysis - Photoproduction



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

Analysis - Photoproduction

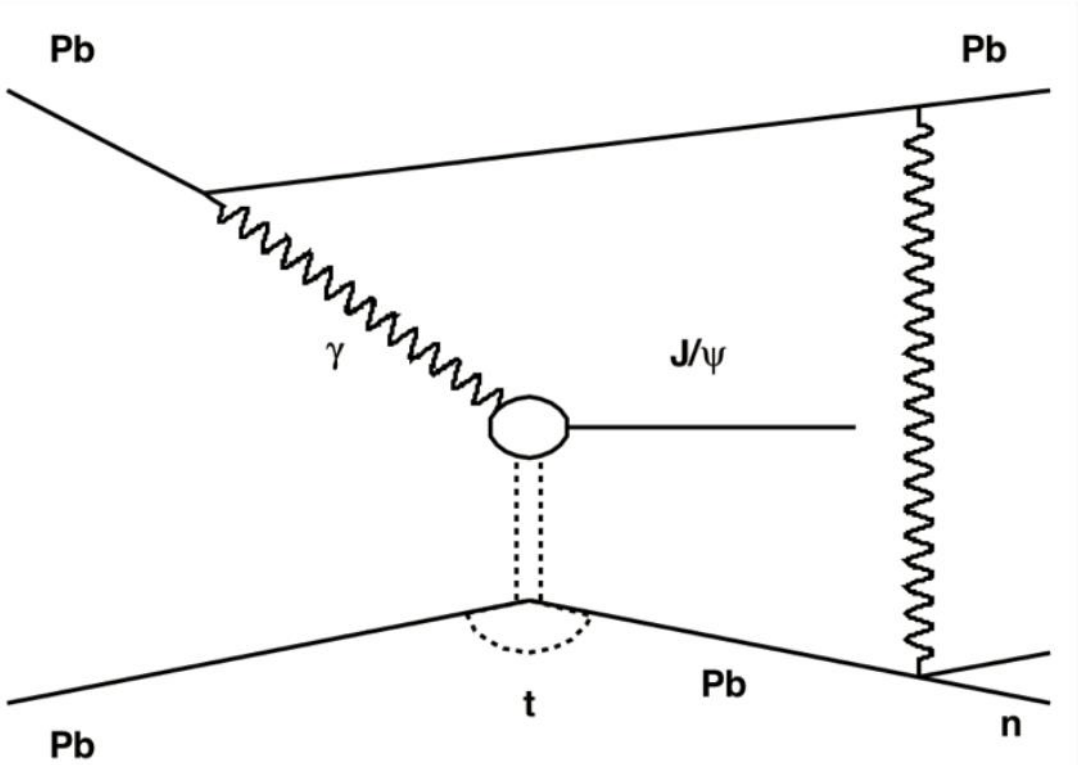


- There are both contributions
  - Two unknown variables
  - One equation

} ✗ **Can‘t be distinguished**

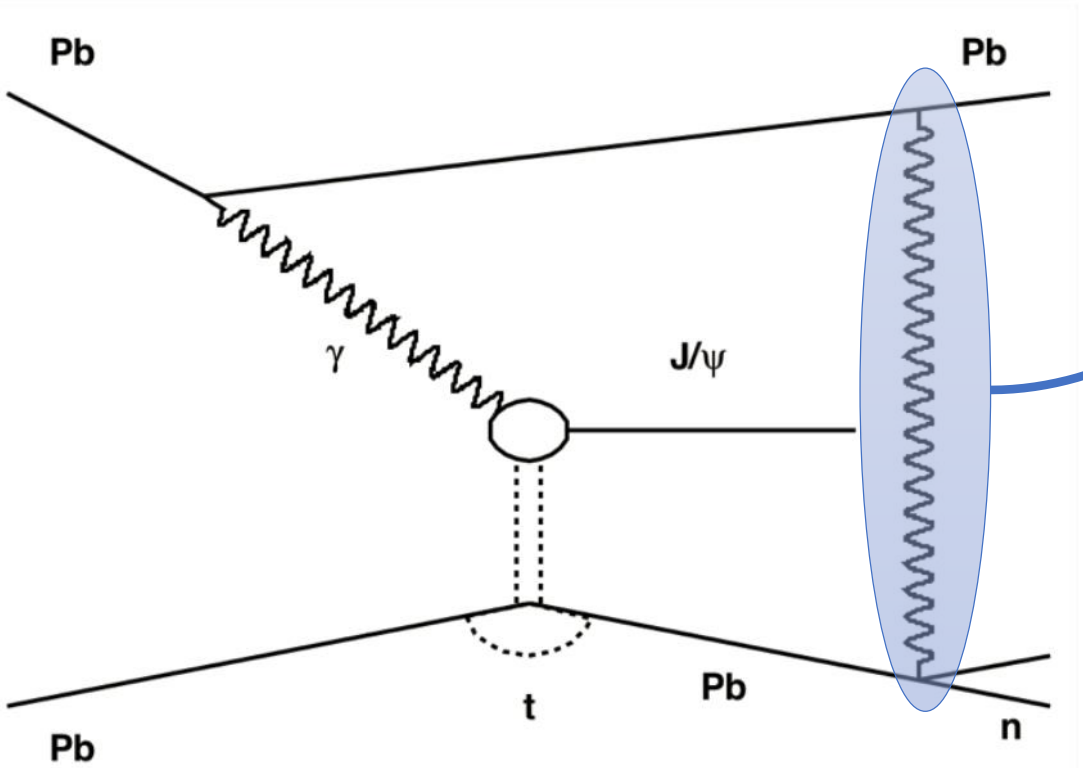
Analysis - Photoproduction with neutron emission

- Possible solution!



Analysis - Photoproduction with neutron emission

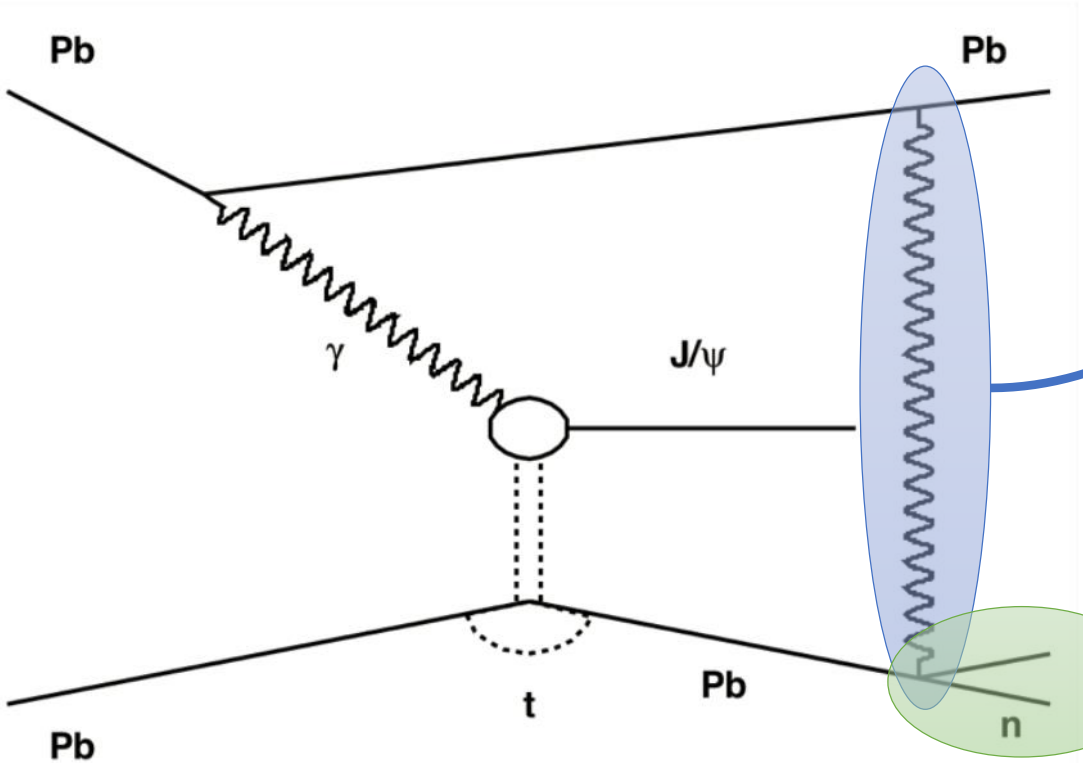
- Possible solution!



- **Independent** soft electromagnetic interactions

Analysis - Photoproduction with neutron emission

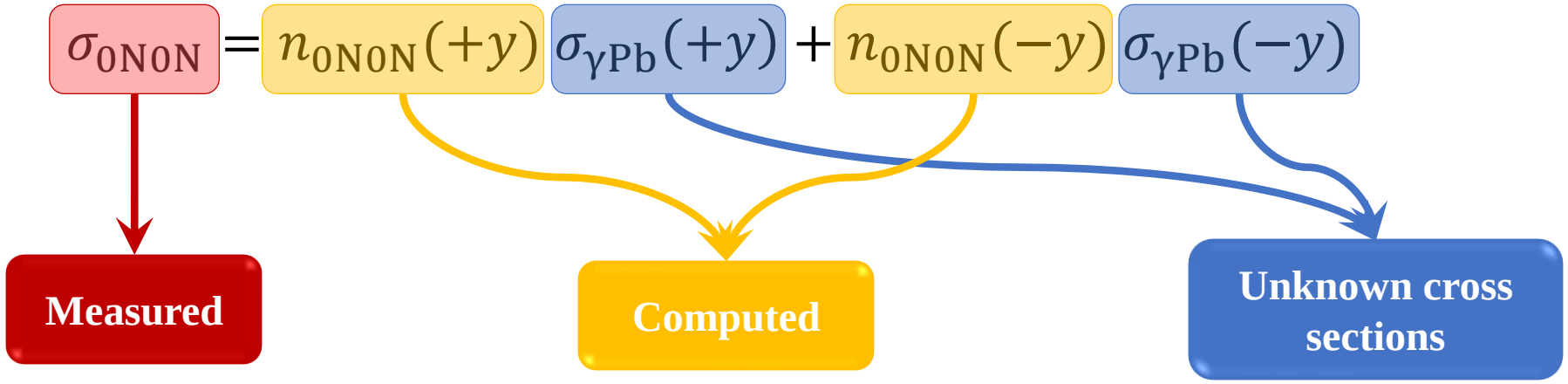
- Possible solution!



- **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



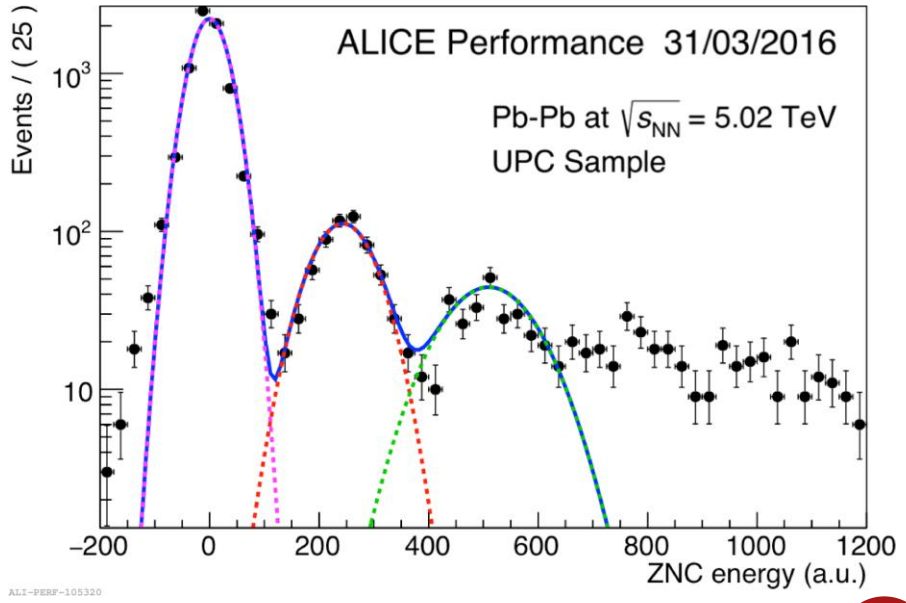
Analysis - Photoproduction with neutron emission

$$\sigma_{0N0N} = n_{0N0N}(+y)\,\sigma_{\gamma Pb}(+y) + n_{0N0N}(-y)\,\sigma_{\gamma Pb}(-y)$$
$$\sigma_{0NXN} = n_{0NXN}(+y)\,\sigma_{\gamma Pb}(+y) + n_{0NXN}(-y)\,\sigma_{\gamma Pb}(-y)$$

Measured

Computed

Exctracted cross sections



Analysis - Photoproduction with neutron emission

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$$\sigma_{0NXN} = n_{0NXN}(+y)\,\sigma_{\gamma Pb}(+y) + n_{0NXN}(-y)\,\sigma_{\gamma Pb}(-y)$$

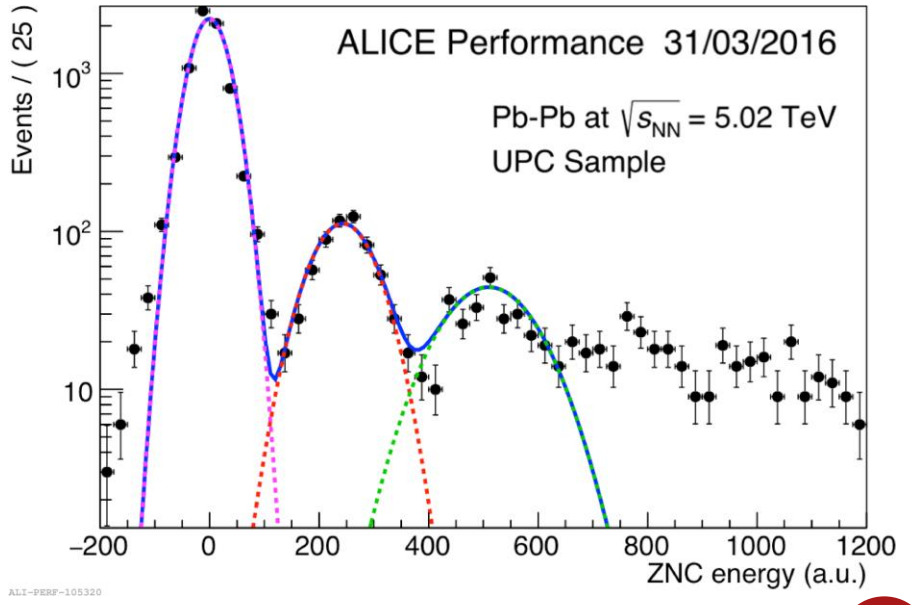
Measured — σ_{0N0N}, σ_{0NXN}

Computed — $n_{0N0N}(\pm y)$, $n_{0NXN}(\pm y)$

Exctracted cross sections — $\sigma_{\gamma Pb}(\pm y)$

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

} ✓ **Can be distinguished**



Conclusion

- Gluon structure of protons and nuclei at low Bjorken x can be studied by measuring the cross section of coherent J/ψ photoproduction
- Photoproduction cross section can be measured in UPC with ALICE
- Results overview → Moderate shadowing is favoured
- In progress
  - Constraining p_{T} fit
  - $Acc \times \varepsilon$, Luminosity

  } **Cross section** - Reproduce preliminary results from 2015 data
  - Analyse 2018 data → **More news coming soon!**
  $L = 546\ \mu b^{-1}$
- Future possibilities - Photoproduction with neutron emission

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- Future possibilities - Photoproduction with neutron emission

Thank you for your attention!

Backup

Selected runs

LHC15o - AOD_393_20181018-1138

246994, 246991, 246989, 246984, 246982, 246980, 246949, 246948, 246945, 246942, 246937, 246930, 246871, 246867, 246865, 246864, 246859, 246855, 246851, 246847, 246846, 246845, 246844, 246809, 246808, 246807, 246806, 246805, 246804, 246765, 246763, 246760, 246759, 246758, 246757, 246755, 246751, 246750, 246676, 246675, 246495, 246493, 246488, 246487, 246434, 246433, 246431, 246428, 246424, 246392, 246391, 246390, 246276, 246275, 246272, 246225, 246222, 246220, 246217, 246182, 246181, 246178, 246153, 246152, 246151, 246148, 246115, 246113, 246089, 246087, 246053, 246049, 246048, 246042, 246037, 246036, 246012, 246003, 246001, 245996, 245963, 245954, 245952, 245949, 245833, 245831, 245829, 245793, 245785, 245775, 245766, 245759, 245752, 245738, 245731, 245729, 245705, 245700, 245692, 245683, 245554, 245543, 245542, 245540, 245535, 245507, 245505, 245504, 245501, 245496, 245450, 245446, 245410, 245409, 245407, 245401, 245353, 245347, 245346, 245345, 245343, 245259, 245253, 245233, 245232, 245231, 245152, 245151, 245146, 245145, 245068, 245066, 245064, 244983, 244982, 244980, 244918

LHC18q+LHC18r -AOD_416_20181203-1743

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Triggers

LHC15o - AOD_393_20181018-1138

- CTEST63, CMUP10, CMUP11

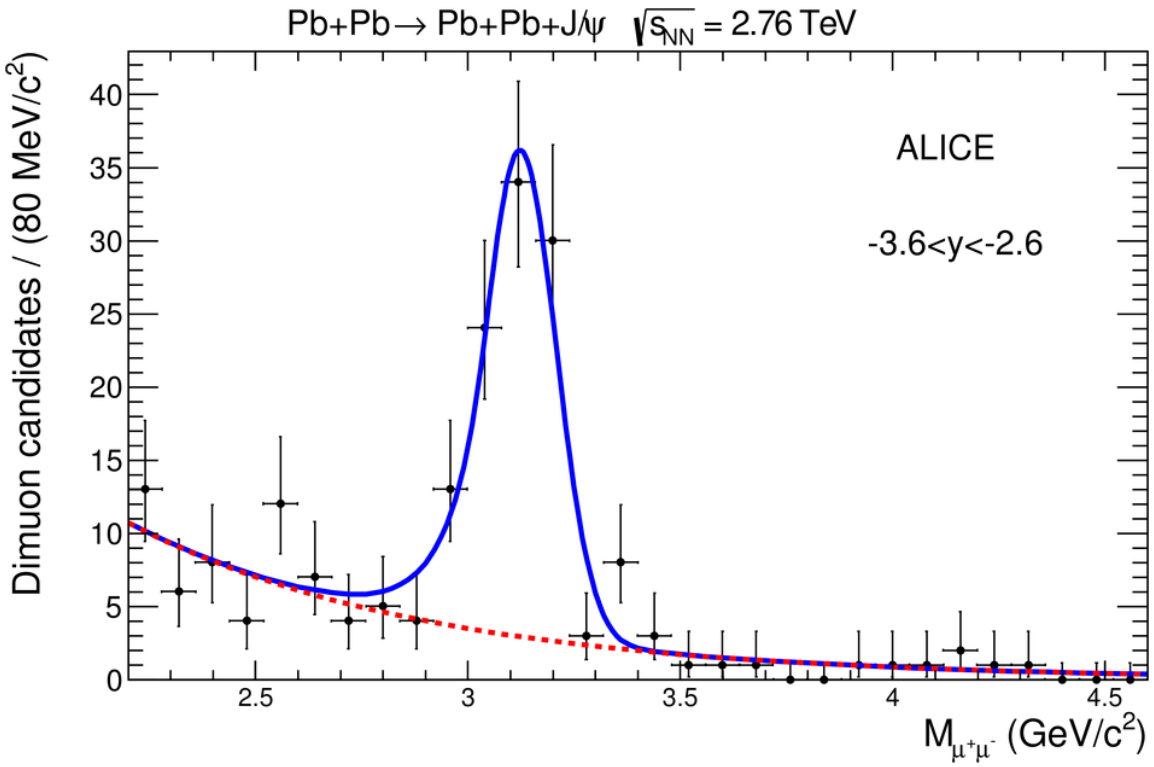
LHC18q+LHC18r -AOD_416_20181203-1743

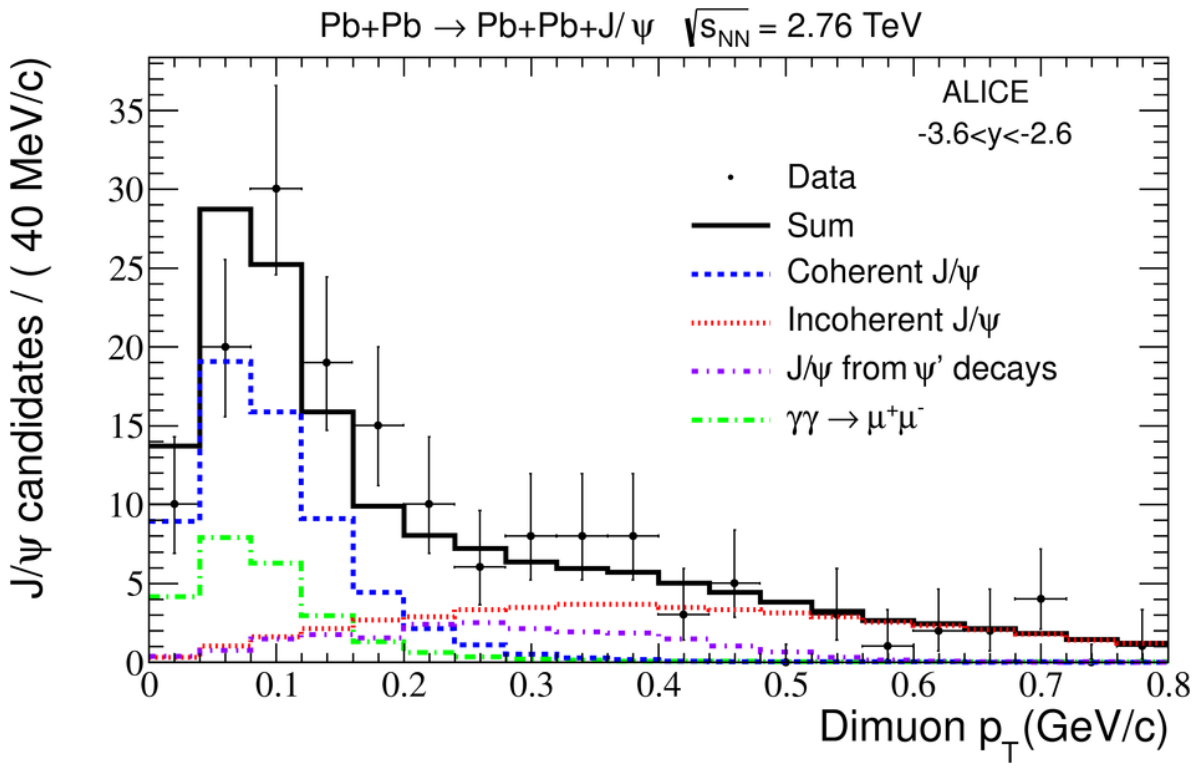
- CMUP11-B, CMUP6-B, CMUP26-B

Muon selection

- Tracks
  - Pseudorapidity of muon tracks: $-4.0 < \eta < -2.5$
  - Radial position at the end of the absorber: $17.5 < R_{\mathrm{abs}} < 89.5$
  - Only tracks with momentum dependent dca: $p_{\mathrm{x}}\mathrm{DCA}$
  - Minimum number of two tracks matched to the trigger above the threshold:
  - Only two tracks
  - Unlike-sign of dimuon pair
- Dimuon
  - Rapidity of dimuon: $-4.0 < y < -2.5$
  - Transversal momentum of dimuon: $0 < p_T < 5$
  - Mass of dimuon: $0 < m < 15$

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

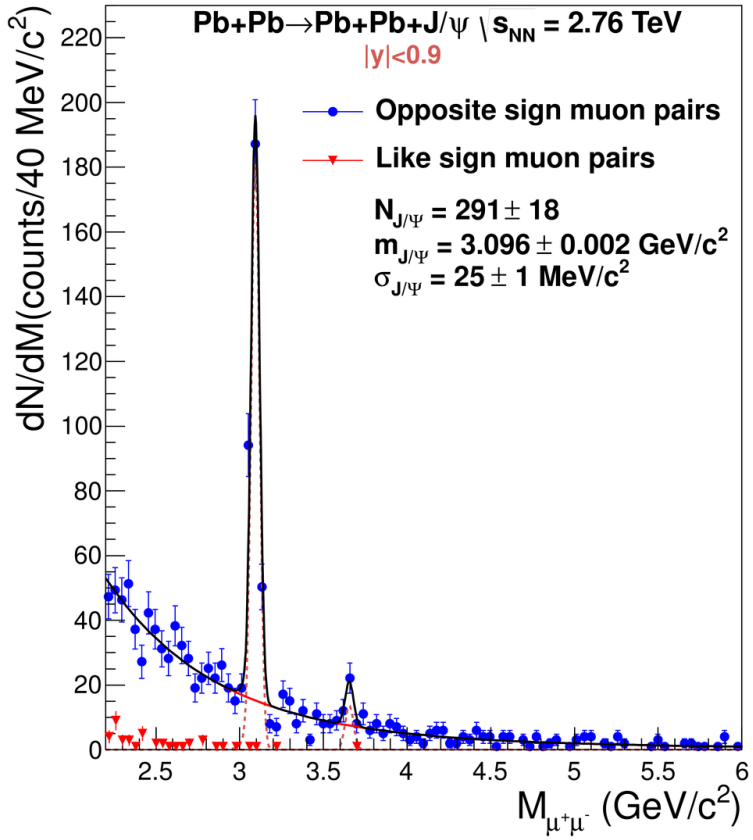


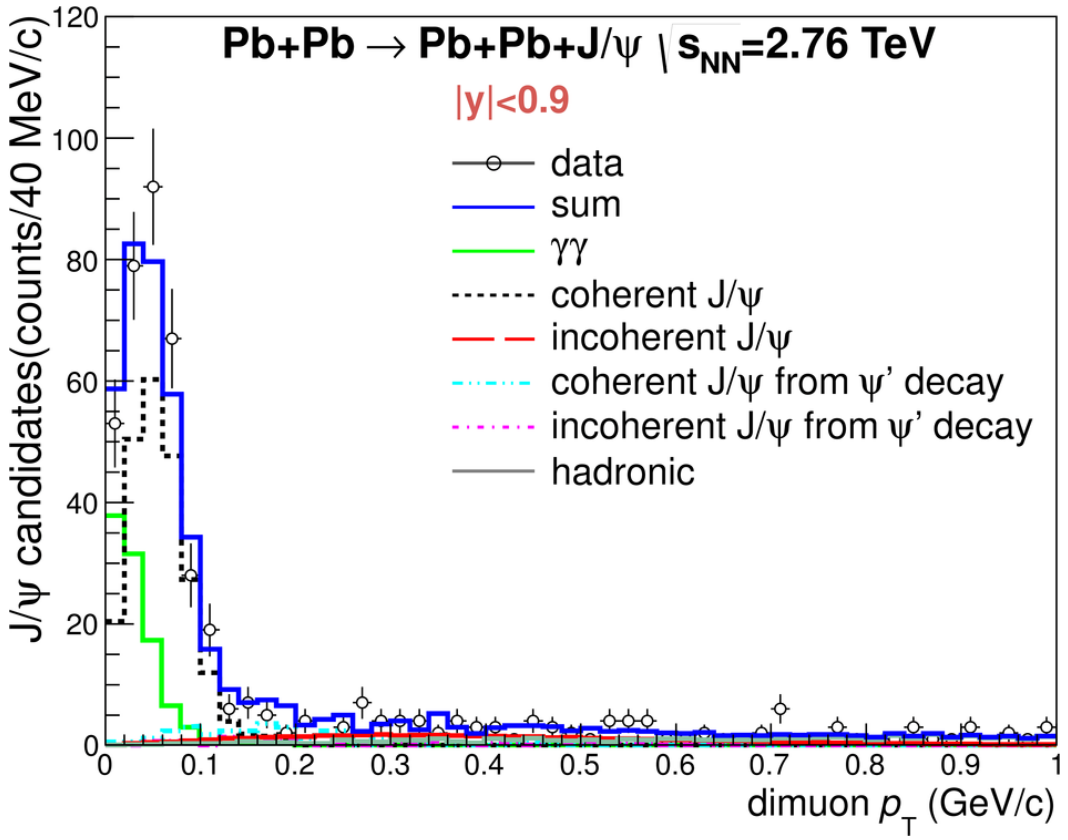


- Integrated luminosity of about 55 μb^{-1}
- p_T fit to determine the coherent contribution
  - At low p_T coherent contribution is dominant

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

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

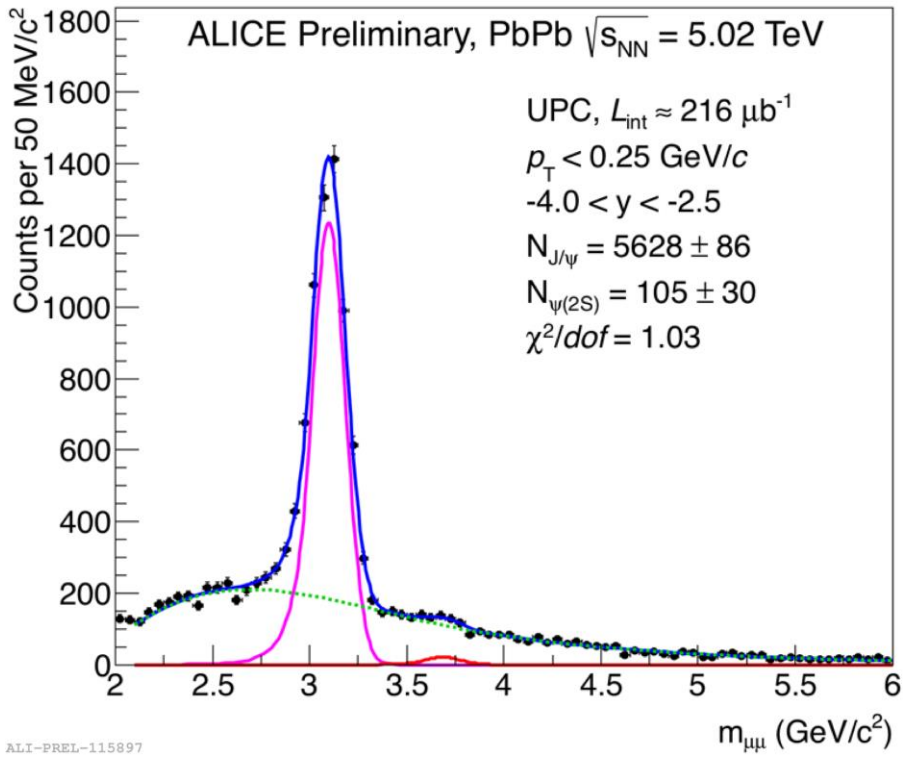


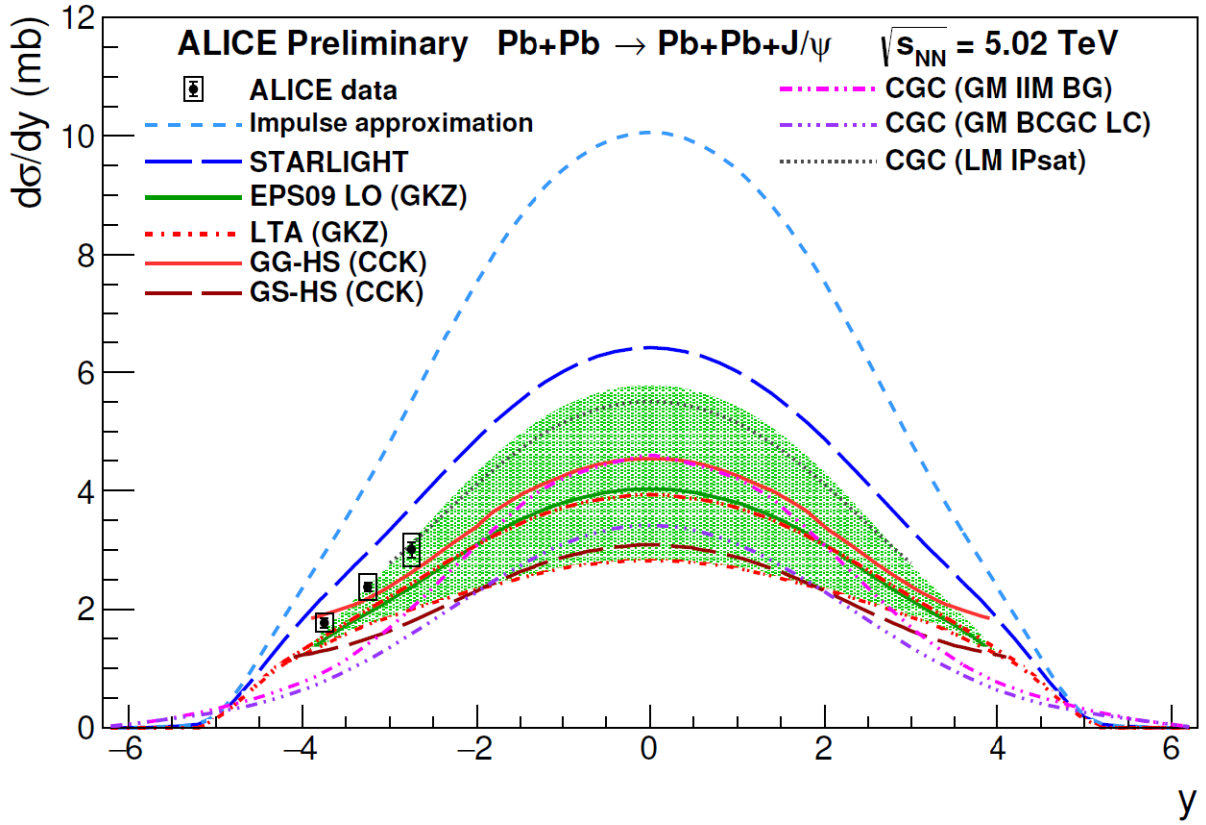


Eur. Phys. J. C 73 (2013) 2617

- Integrated luminosity of about 23 μb^{-1}
- p_T fit to determine the coherent contribution
  - At low p_T coherent contribution is dominant

ALICE Pb-Pb UPC $\sqrt{s_{NN}} = 5.02$ TeV





- New run at larger $\sqrt{s_{NN}}$
- Larger data sample ~ 50 times more data than in Run 1
- Larger sample and higher collisions energy → Better measurement → Stronger constraints to models
- Analysis in progress → Preliminary results again favor moderate nuclear shadowing