ALICE

# Measurement of an excess in the yield of J/ψ at very low $p_{\mathrm{T}}$ in Pb-Pb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV

- J/ψ production in heavy-ion collisions
- Vector meson photoproduction in ultra-peripheral collisions
- Analysis in Pb-Pb at 5.02 TeV
- Systematics on the tracking efficiency
- Conclusion and outlooks

cnrs IN2P3

Ophélie Bugnon - Subatech Nantes
Journées Rencontres Jeunes Chercheurs 2019

Subatech

# Quarkonia production in heavy-ion collisions

- **Quarkonia** are bound states of (anti-)charm and (anti-)beauty quarks
  - Charmonia ($c\bar{c}$) : J/ψ(1S), $\chi_{c1}$(1P) and ψ(2S)
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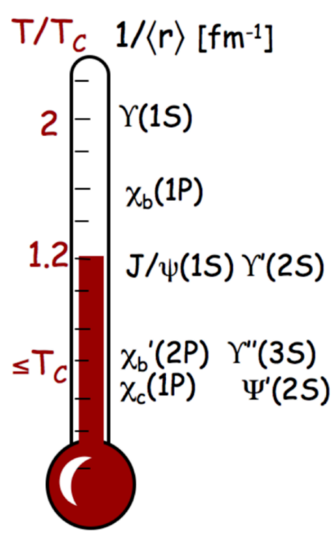


Eur. Phys. J. C61 (2009) 705

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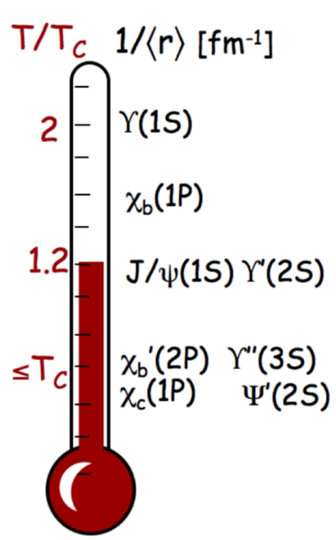


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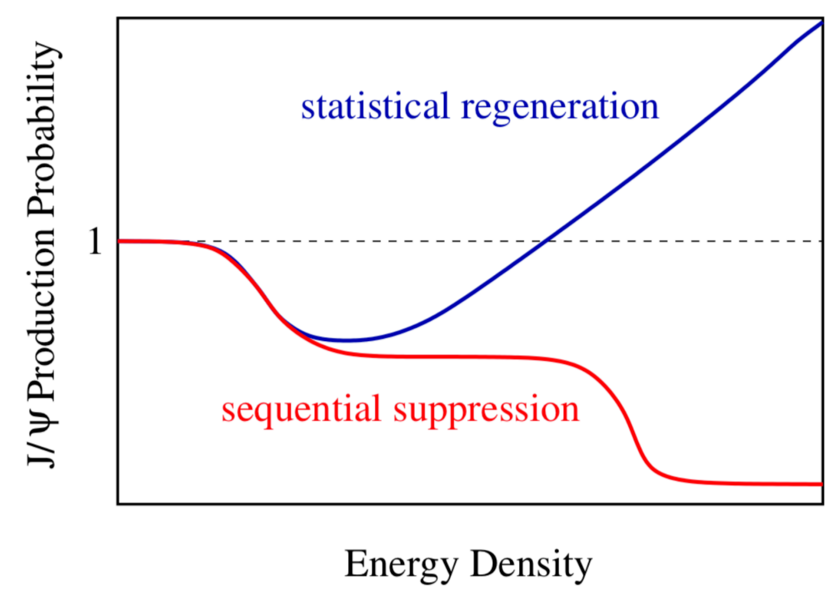
not so trivial




Nucl. Phys. Proc. Suppl. 214 (2011) 3

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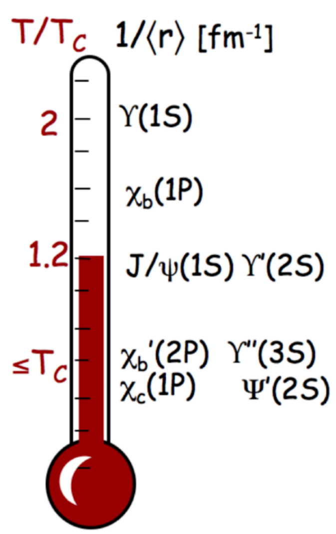


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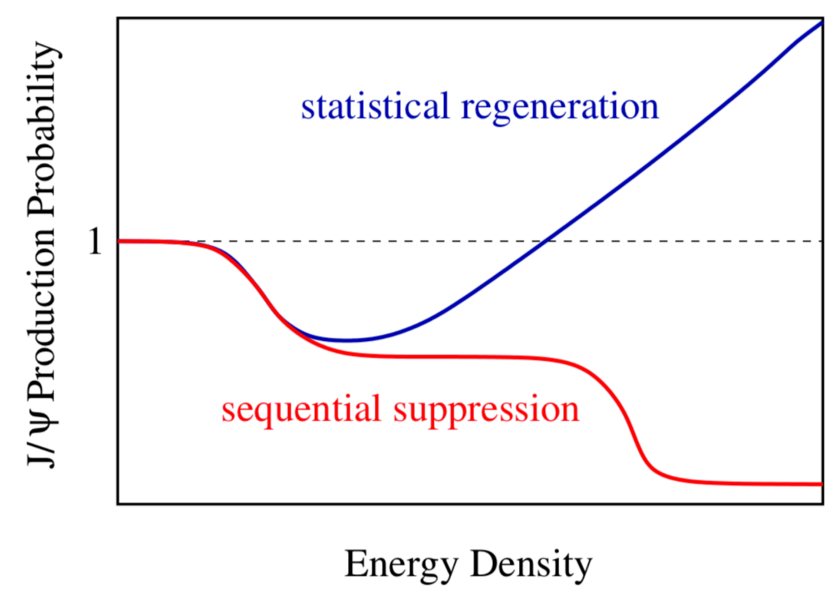


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❖ Need a well understanding of the production mechanisms

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  Reference for charmonium production mechanisms

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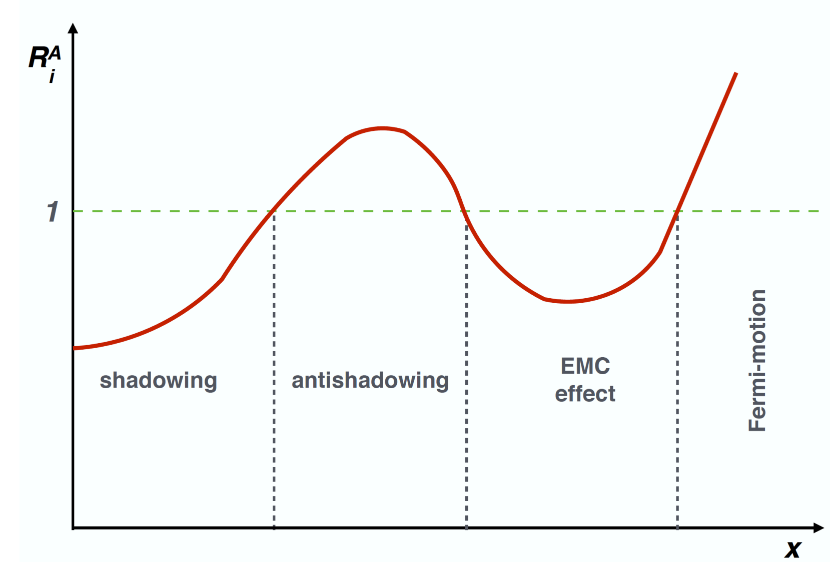
← pp vs pA →

Measure the probes in the three systems and compare




J. Phys. G32 (2006) R367

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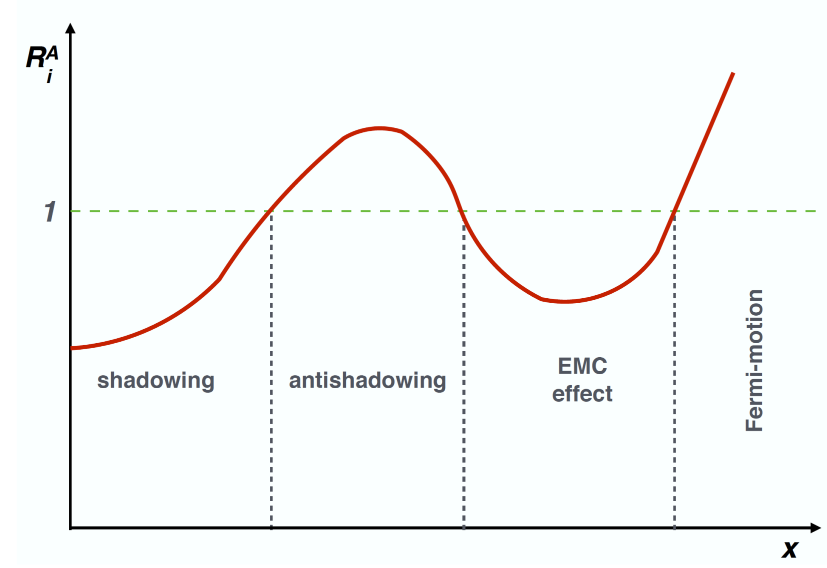
⚠ cold nuclear effects also in PbPb

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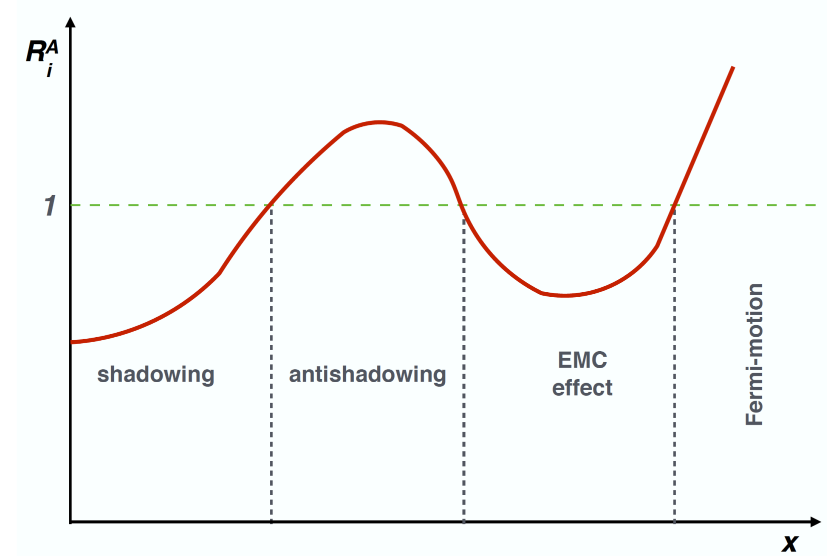


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- **AA** collisions
  access to hot nuclear matter affects and QGP properties ← pp vs AA

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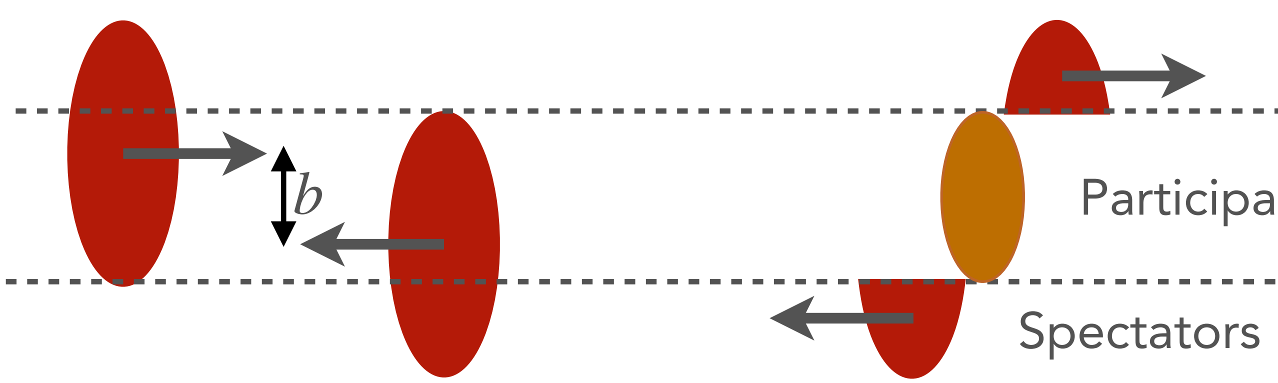
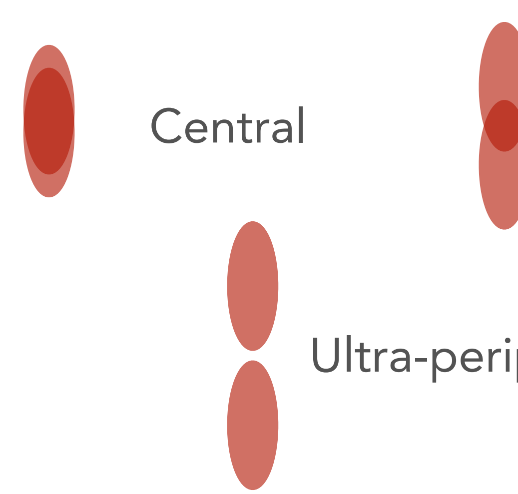
- Glauber Model to describe heavy ion collisions




Centrality class ↗ with $b$

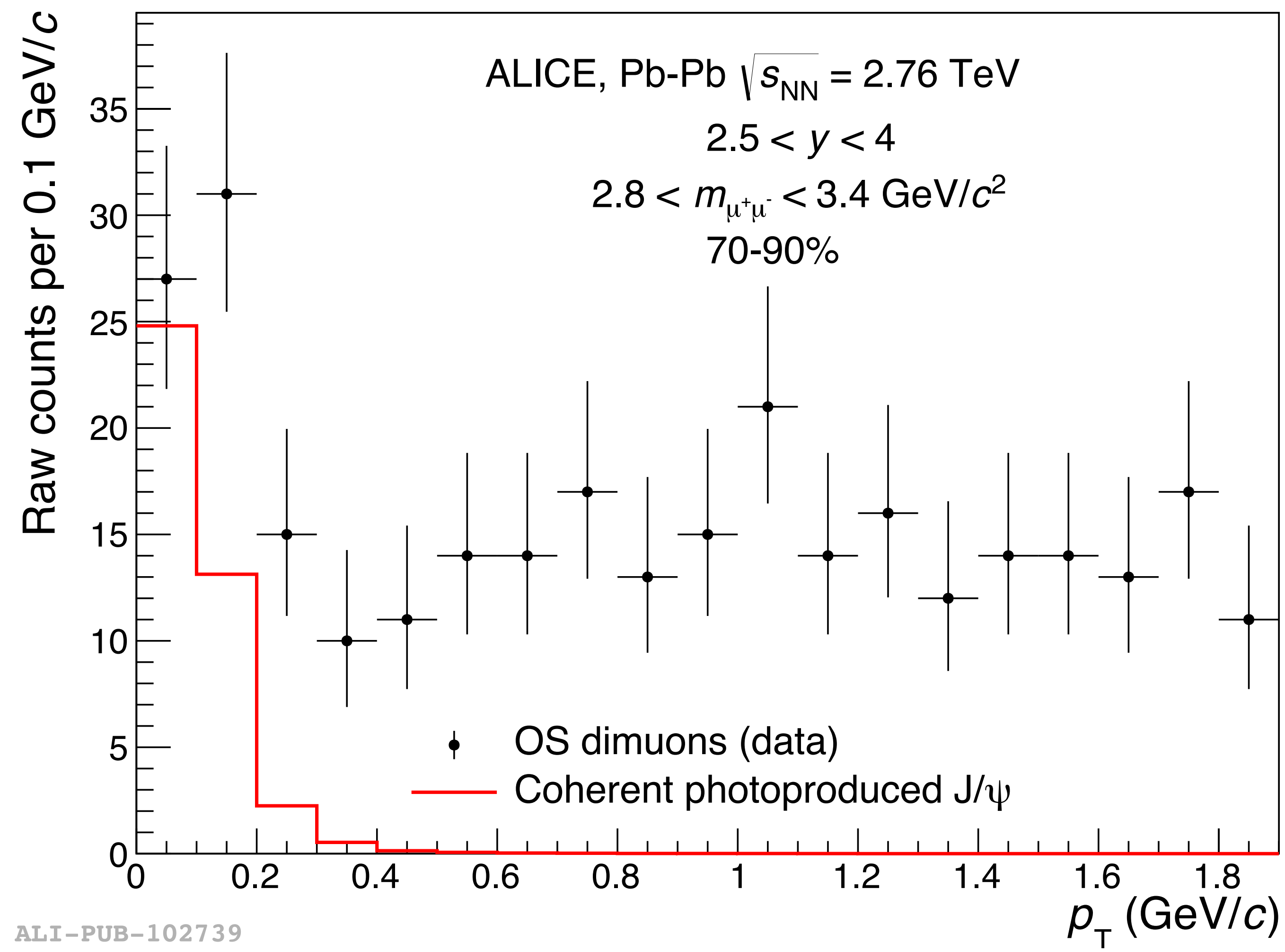
0% to 90%



# J/ψ excess at very low $p_T$ in Pb-Pb collisions at 2.76 TeV

- First measurement of an excess at very low $p_T$ in peripheral Pb-Pb collisions

  - Around the J/ψ mass
    $M_{J/\psi}$ = 3.096 GeV/$c$
  - At very low $p_T$
    $\langle p_T \rangle \simeq$ 0.055 GeV/c
  - For peripheral events only
  - Observed only in dimuon unlike sign events
  - Never reported in pp collisions
    ↳ will affect the $R_{AA}$

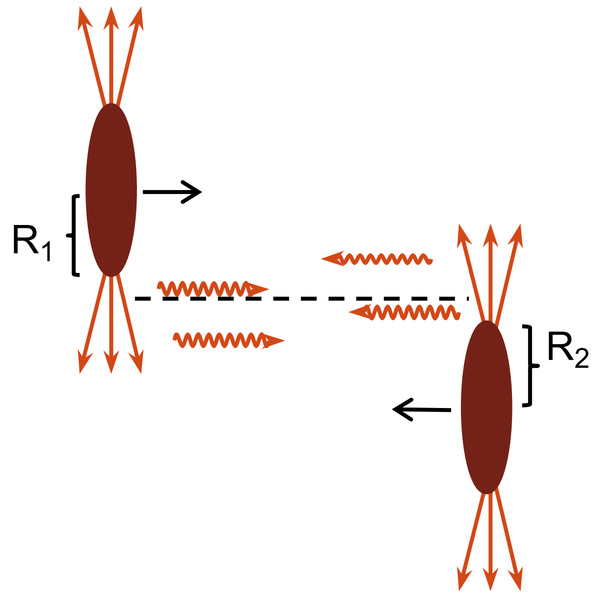


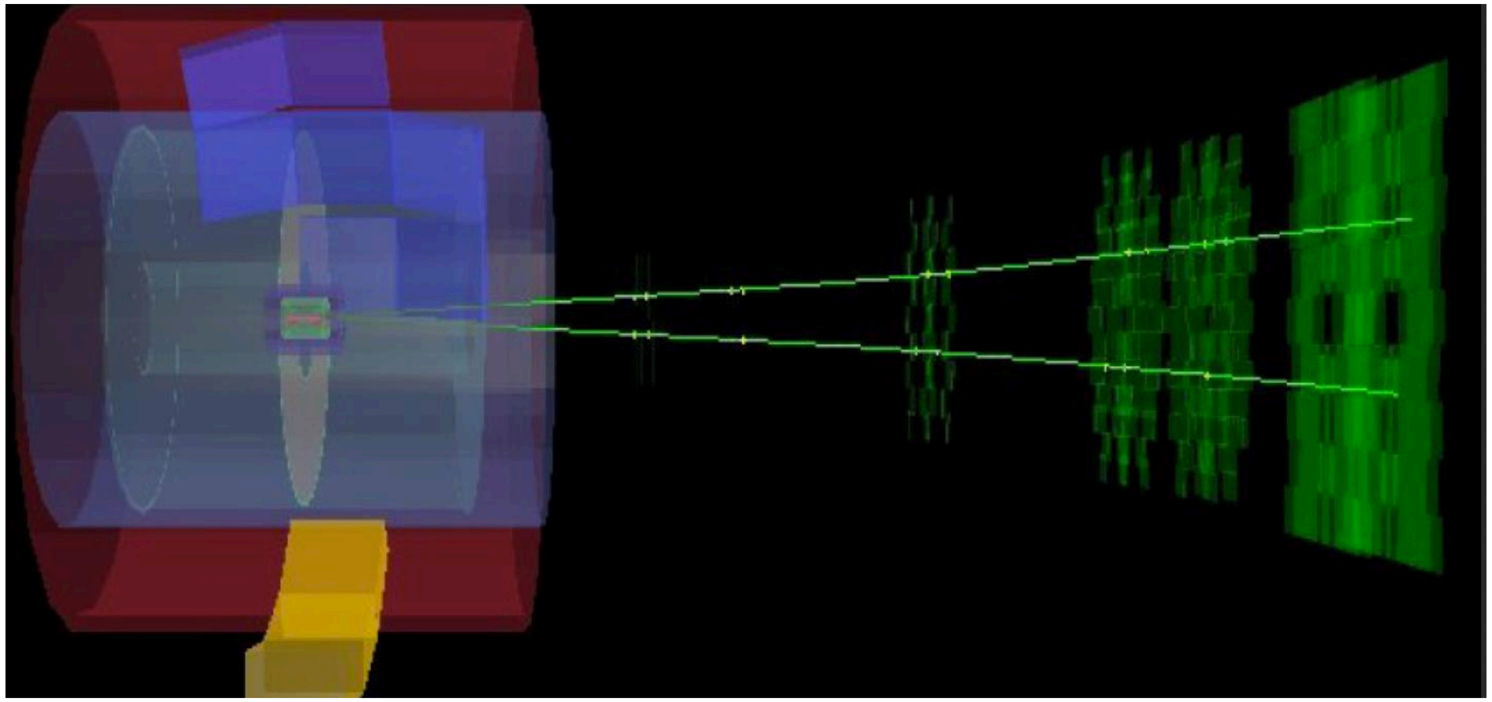

Phys. Rev. Lett. 116 (2016) 222301

# Ultra-peripheral collisions

**UPC** = impact parameter b > R1 + R2

- Hadronic interactions are strongly suppressed
- High electromagnetic field from ultra-relativistic Pb nuclei
  - Treated as quasi-real photons flux by the Weiszäcker-Williams approximation
  - Photon-flux ∝ $Z^2$



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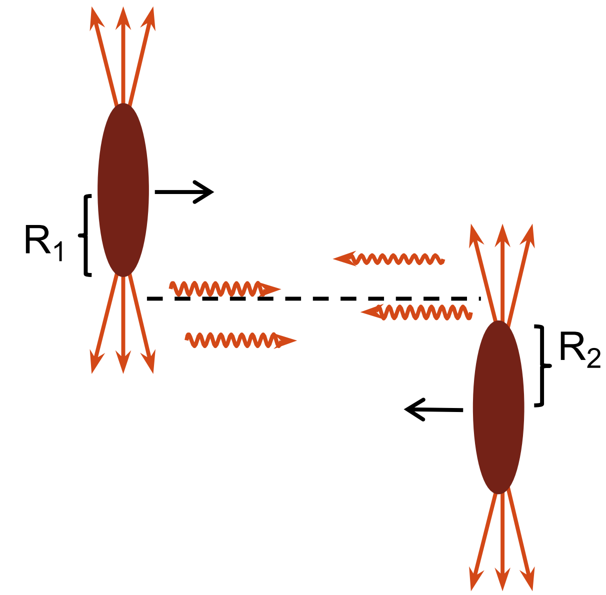


- Hadronic interactions are strongly suppressed
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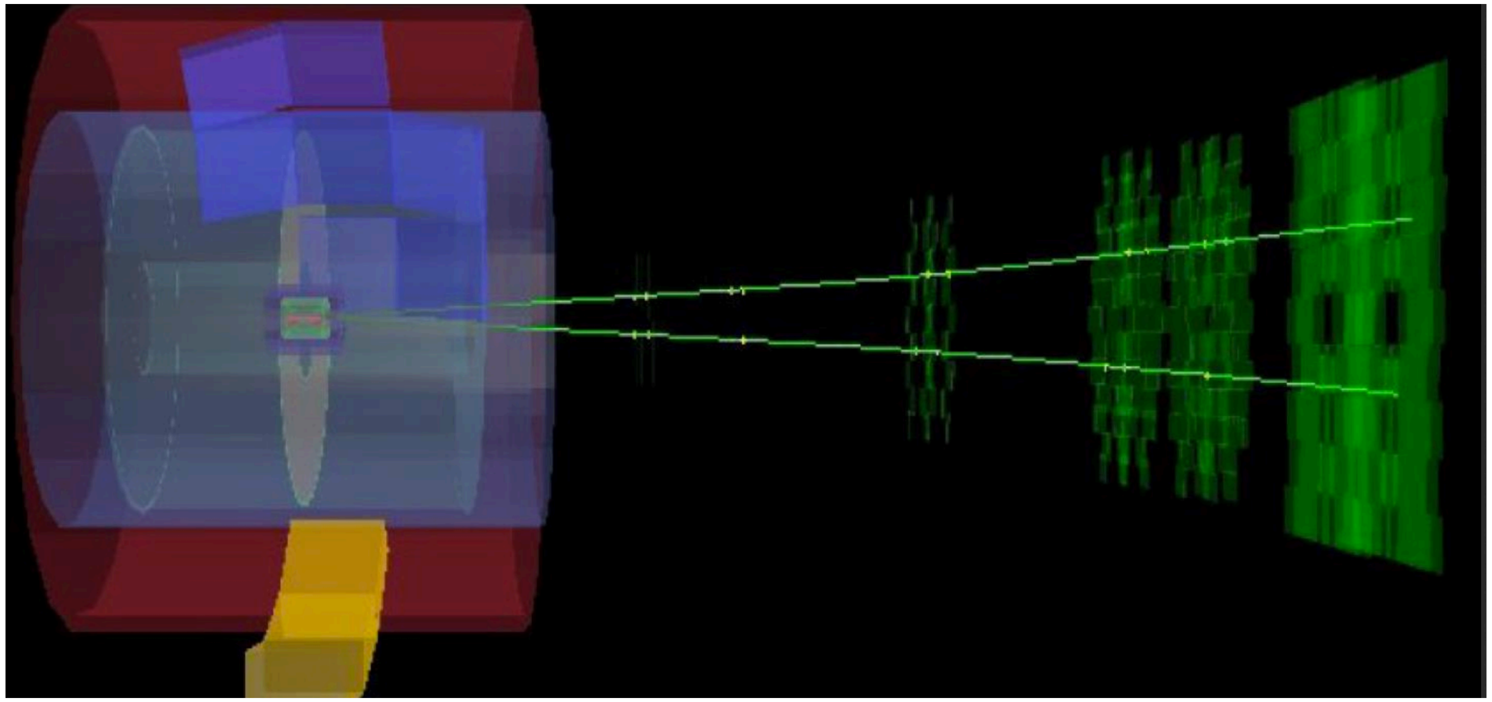
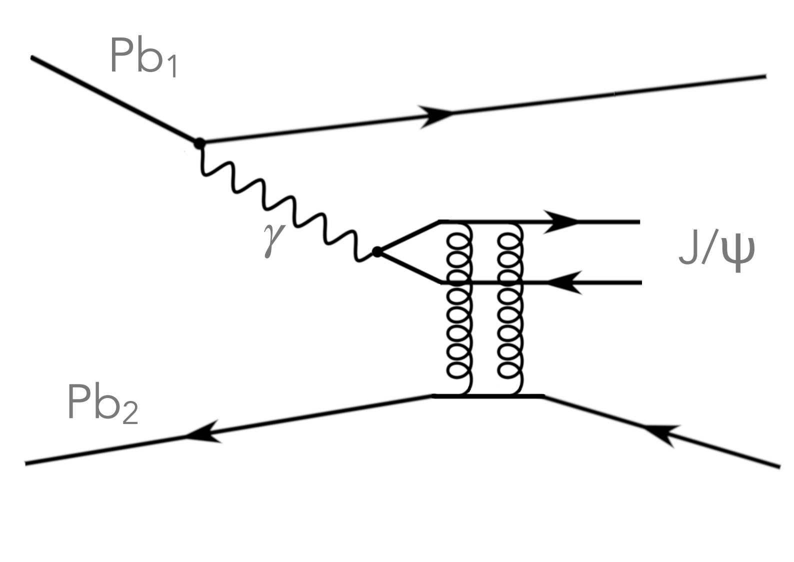
- High cross-section for photon induced processes in exclusive events



# Coherent J/ψ photoproduction in UPC

- QED part
  - Intense electromagnetic field of $Pb_1$ acts as quasi-real photon source
  - Flux of photons with a low transfer momentum $Q^2$

- QCD part
  - Photon fluctuates in a $q\bar{q}$ pair
  - $q\bar{q}$ pair scatters off $Pb_2$ → emerges as vector meson
  - Treated at Leading Order (LO) perturbative QCD (pQCD)
  - Photo-nuclear cross section $\sigma_{\gamma A} \propto$ (gluon density of the target nucleus)$^2$



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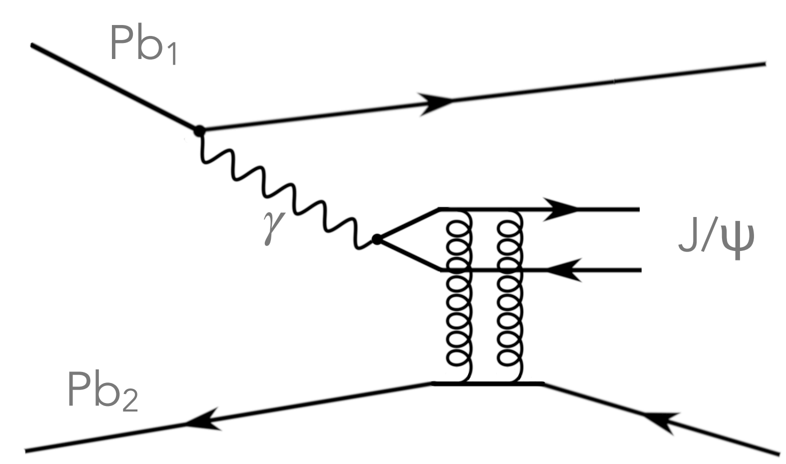


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❖ Used to probe the gluon distribution of the target nucleus at low Bjorken-$x$

$$x \approx \frac{M_{J/\psi}}{\sqrt{s_{NN}}} e^{\pm y}$$

Covering from $x = 10^{-5}$ to $x = 10^{-2}$ at LHC energies

- With the dipole model : study the gluon shadowing (nPDF)
- If not maybe more generalized parton distribution (GPD)

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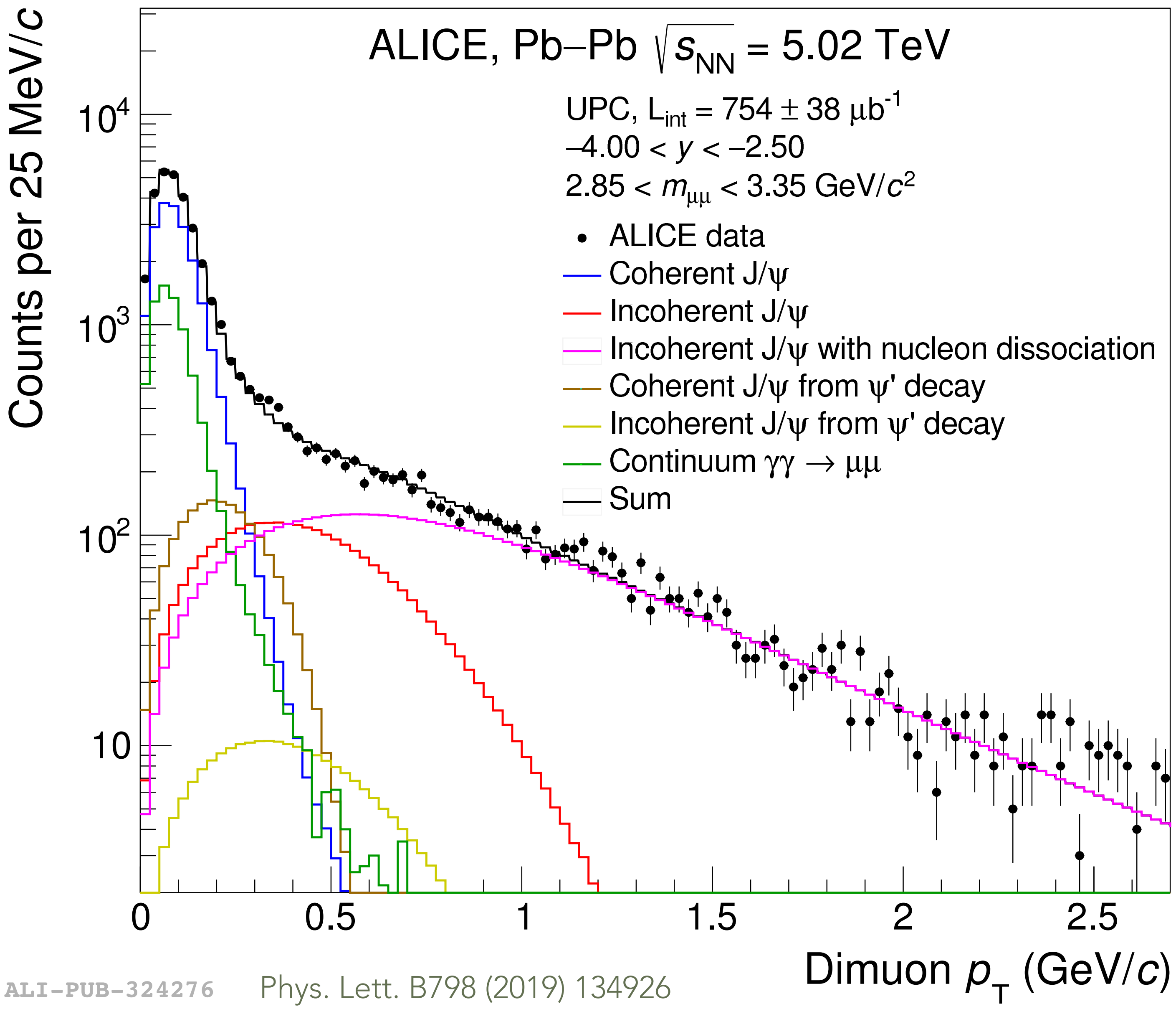


Phys. Lett. B798 (2019) 134926

Clear experimental signature :

- Exclusive vector meson with very **low** $p_{\mathrm{T}}$
- $\langle p_{\mathrm{T}} \rangle \approx 1/R_{\mathrm{T}}$

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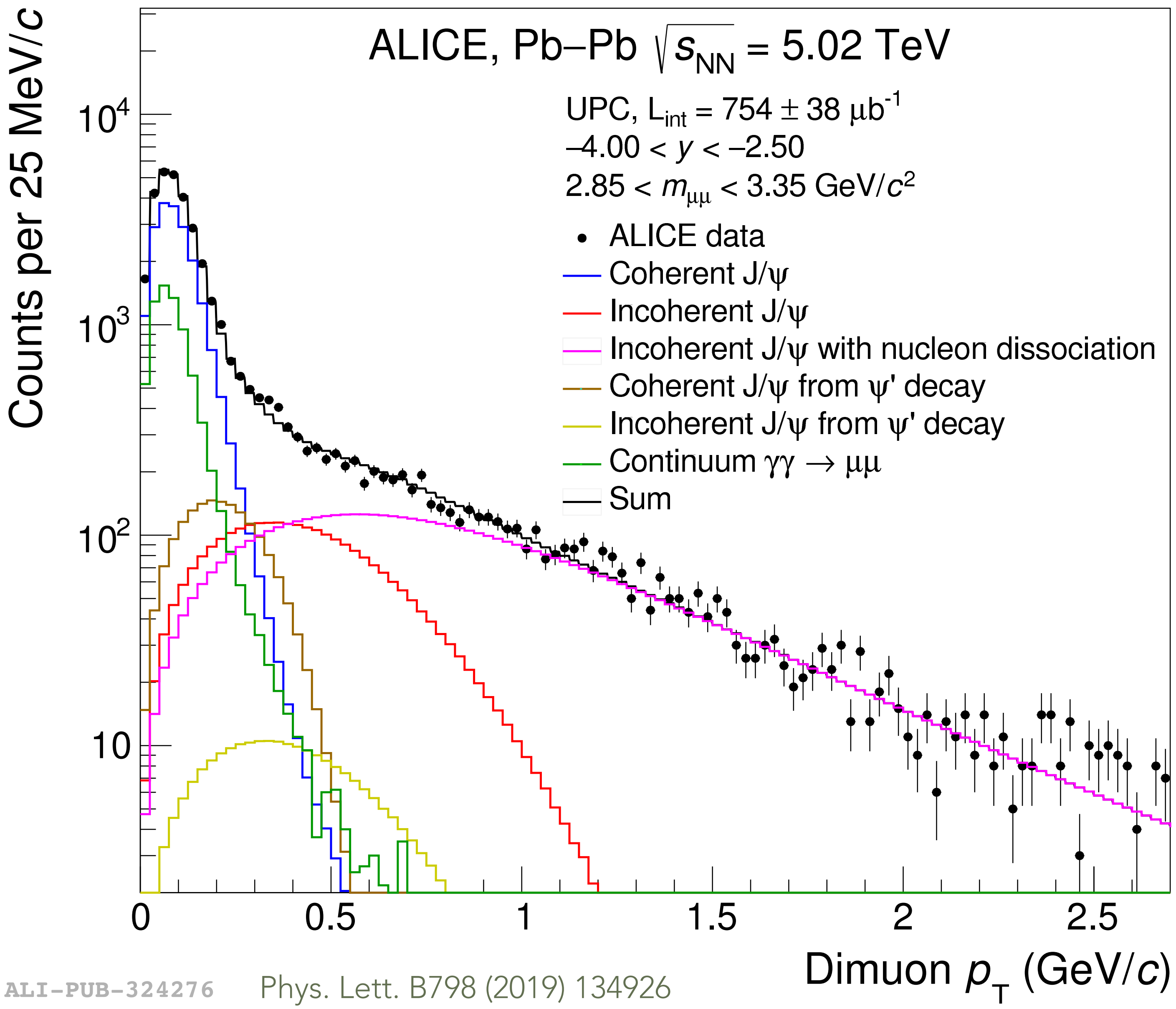


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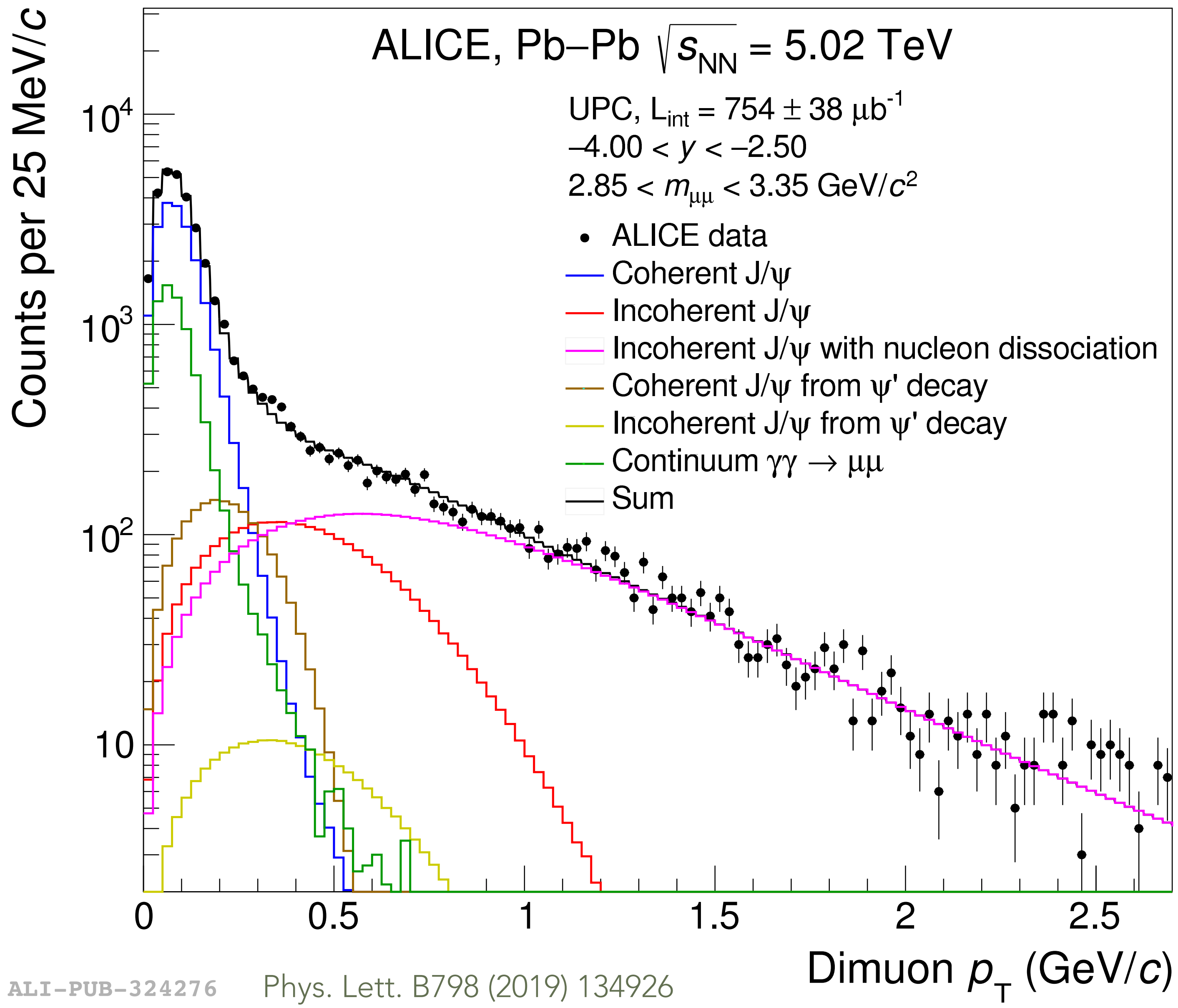


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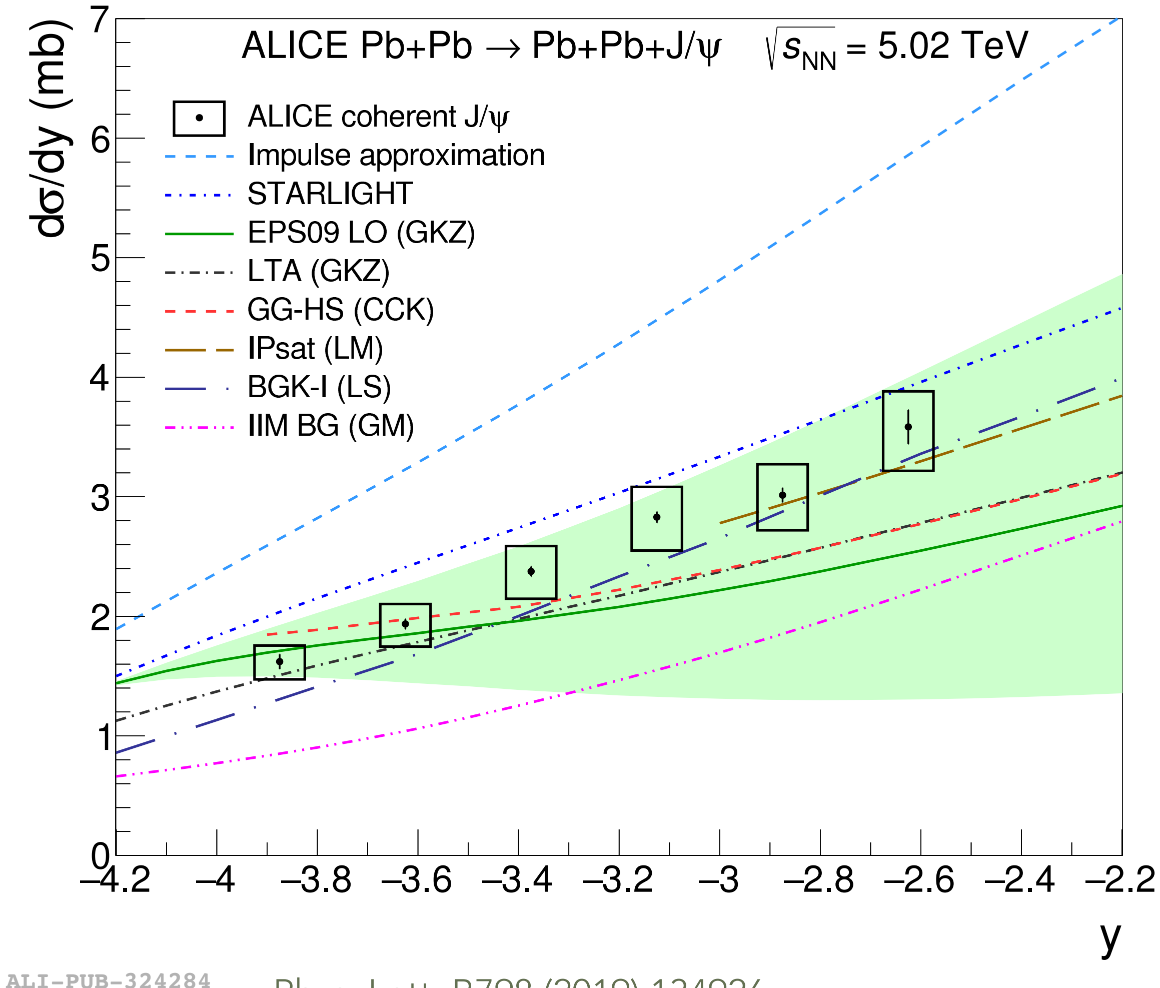
Distinction between :

- Coherent photoproduction
  - Photon interacts with **all nucleons** in the nucleus
  - $\langle p_T \rangle \simeq$ 60 MeV/c
  - Target nucleus don't breaks up
- Incoherent photoproduction
  - Photons interacts with one **single nucleon**
  - $\langle p_T \rangle \simeq$ 500 MeV/c
  - Target nucleus usually breaks up

# Coherent J/ψ photo production in UPC




Phys. Lett. B798 (2019) 134926

- Last results from UPC at 5.02 TeV
  - Cross section increase with energy $\sqrt{s_{NN}}$
  - Cross section increase with rapidity $y$

- Models
  - Without accounting for gluon shadowing overpredict data
  - With gluon shadowing underpredict data but remains in theoretical errors

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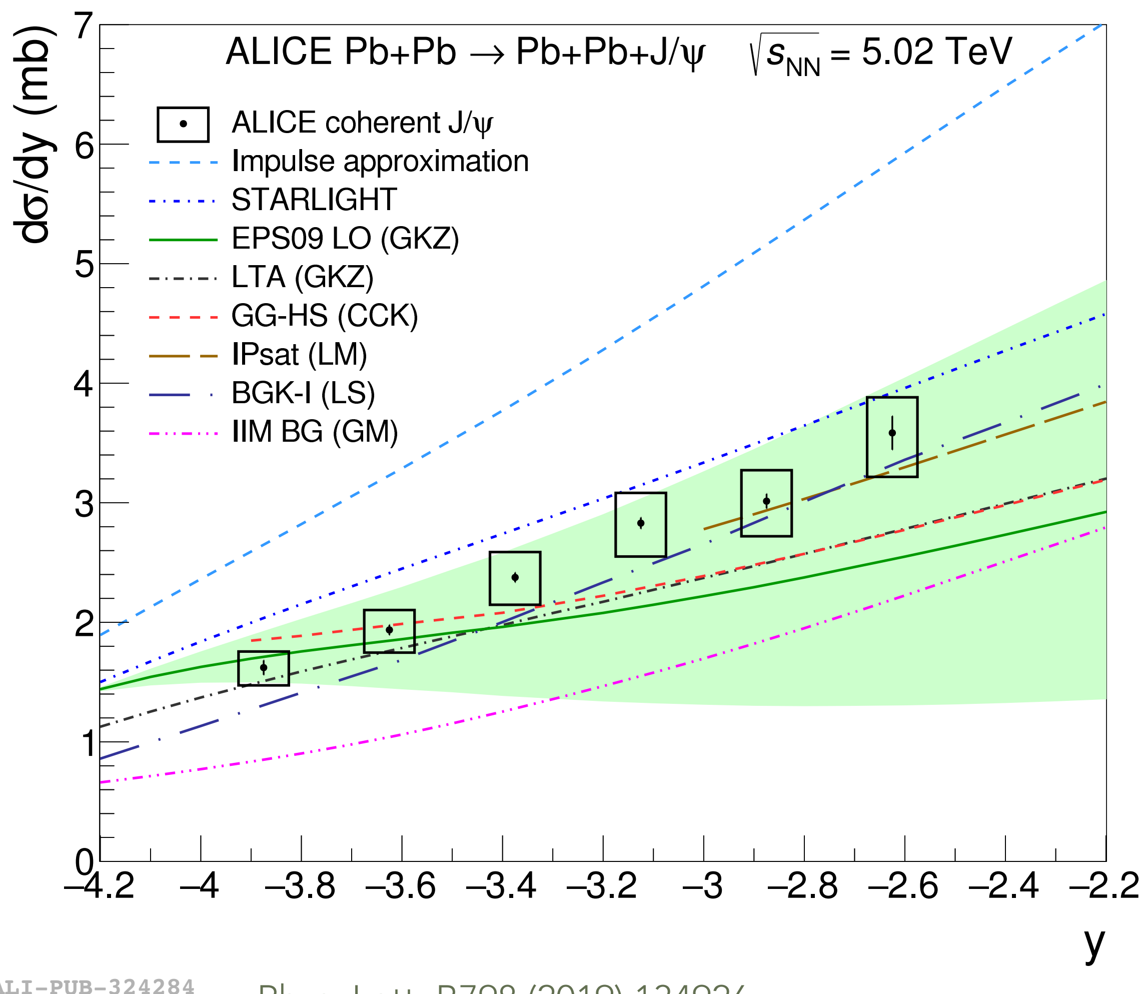


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For a measure at a given $y$ : cross section is a combination of **two contributions** according to which nucleus emits the $\gamma$

$$\frac{d\sigma_{PbPb}}{dy} = n_\gamma\left(+y,\{b\}\right)\sigma_{\gamma Pb}\left(+y\right) + n_\gamma\left(-y,\{b\}\right)\sigma_{\gamma Pb}\left(-y\right)$$

high energy $\gamma$ — $x = 10^{-5}$ — low energy $\gamma$ — $x = 10^{-2}$

Phys. Rev. C 96 (2017) 015203

# Conclusion on motivations

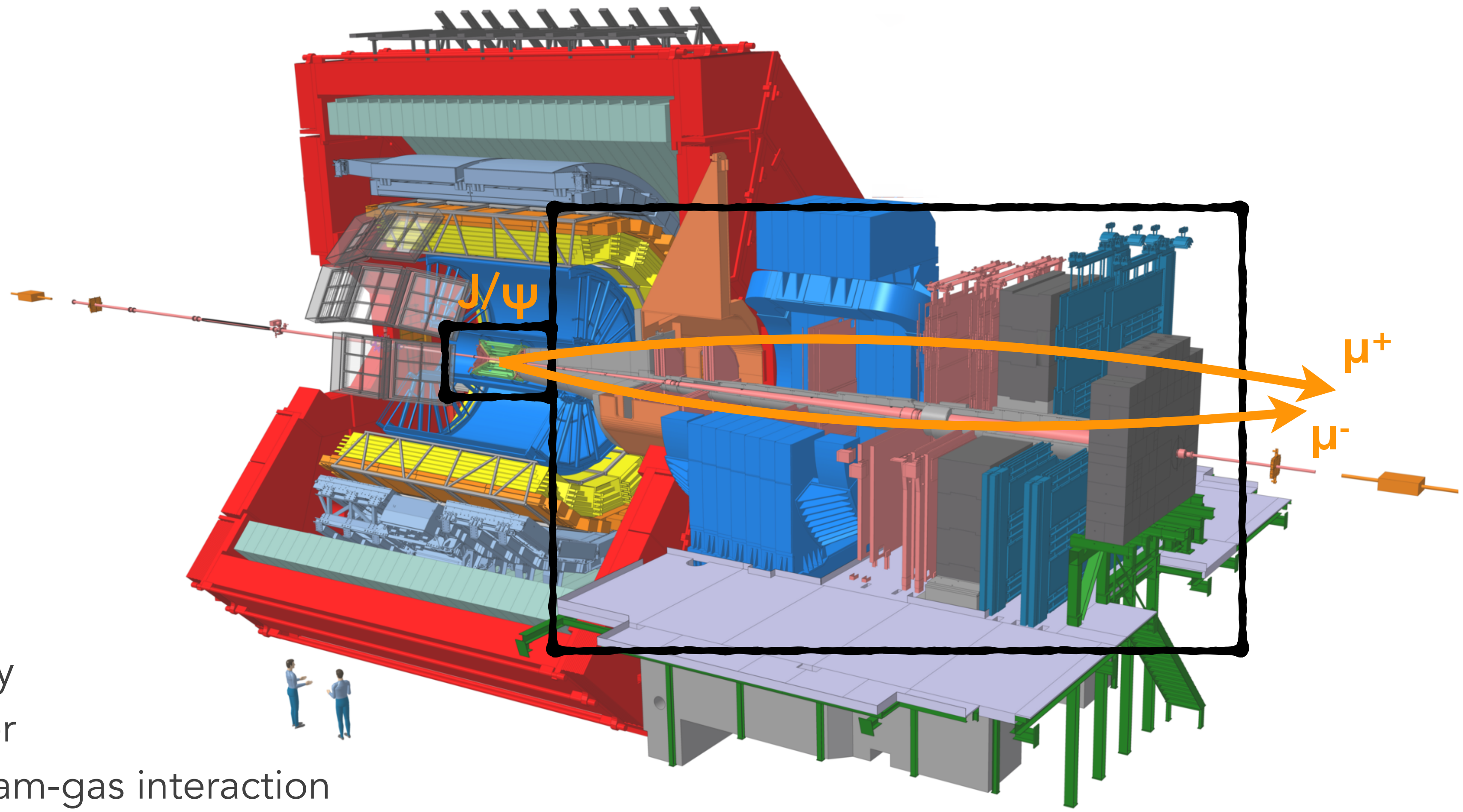
- Excess of J/ψ at very low $p_{\mathrm{T}}$ unexpected in Pb-Pb peripheral collisions
  Coherent photoproduction suggested as underlying mechanism

- Affect the $R_{\mathrm{AA}}$ and hot medium properties study

- How the excess can have a similar shape as in UPC despite the nuclear overlap ?
  How the coherence can exist in hadronic collisions ?
  - Coherence with the entire nucleus ? → $\langle p_{\mathrm{T}} \rangle \approx 1/R_{\mathrm{nucleus}}$
  - Coherence with the spectators ? → $\langle p_{\mathrm{T}} \rangle \approx 1/R_{\mathrm{spectator}}$

- Improve the statistics to study low Bjorken-$x$ physics

# Pb-Pb collissions at 5.02 TeV in ALICE



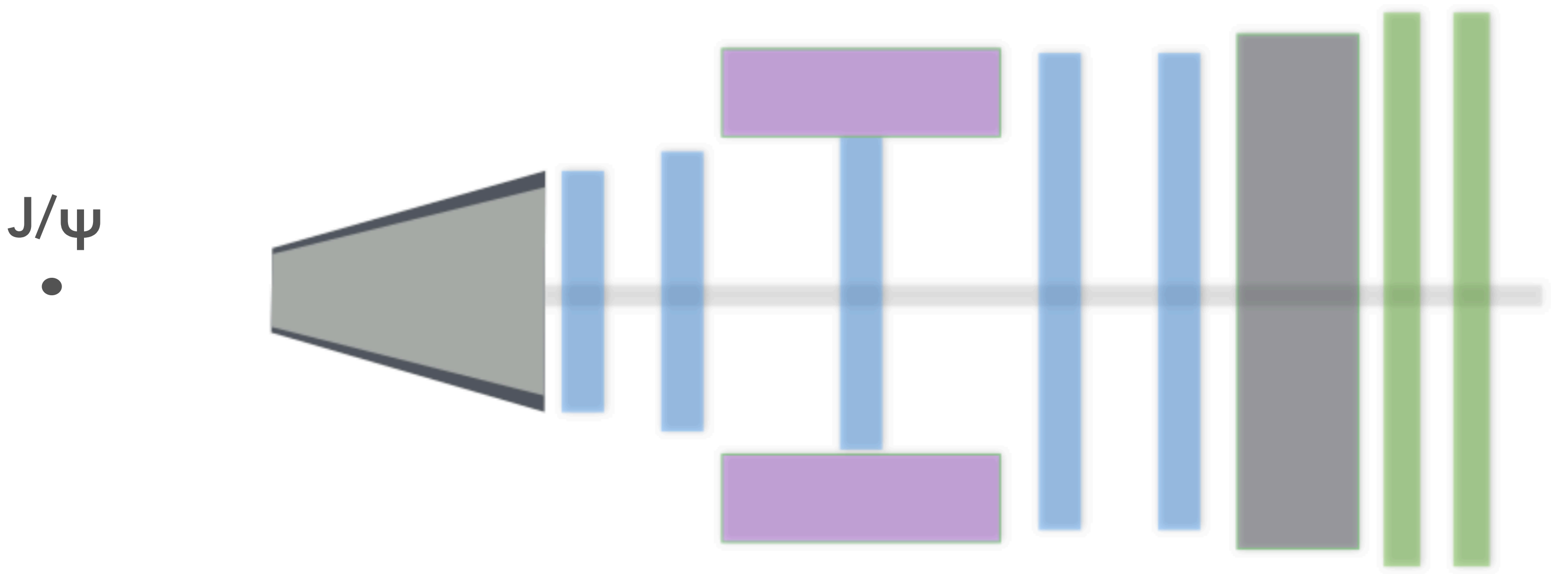

- **V0**
  - Centrality
  - Luminosity
  - MB trigger
  - Reject beam-gas interaction
- **SPD**
  - Vertex reconstruction
- **ZDC**
  - Electromagnetic background rejection
  - Spectator nucleons detection

- **Muon spectrometer**
  - Front absorber → reduce hadron contamination
  - Muon track reconstruction
  - Dimuon trigger
    → two opposite-sign muons with $p_{\rm T}$ > 1 GeV/c
- Acceptance
  - $-4 < \eta_{\mu} < -2.5$
  - $0° < \phi_{\mu} < 360°$

# Data sample and event selection

- Data Sample : Pb-Pb collisions at 5 TeV
  - 2015 : $L_{\text{int}} = 225\ \mu b^{-1}$
  - 2018 : $L_{\text{int}} = 525\ \mu b^{-1}$

- J/ψ are obtained by combining opposite-sign muons tracks



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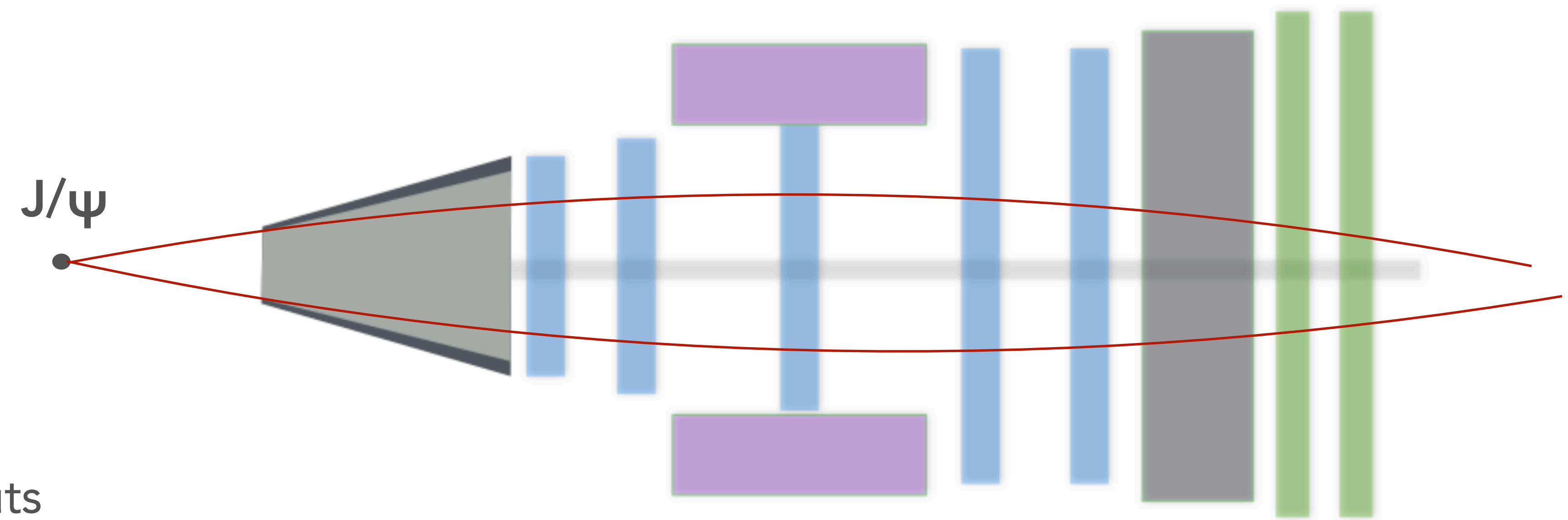


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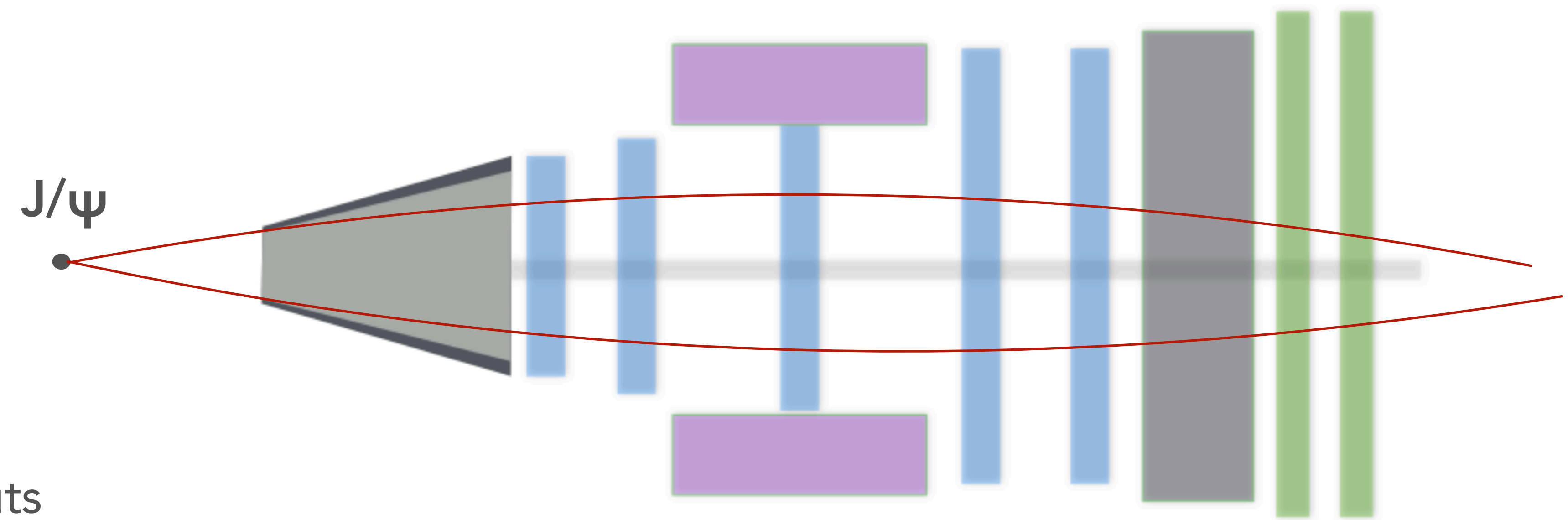


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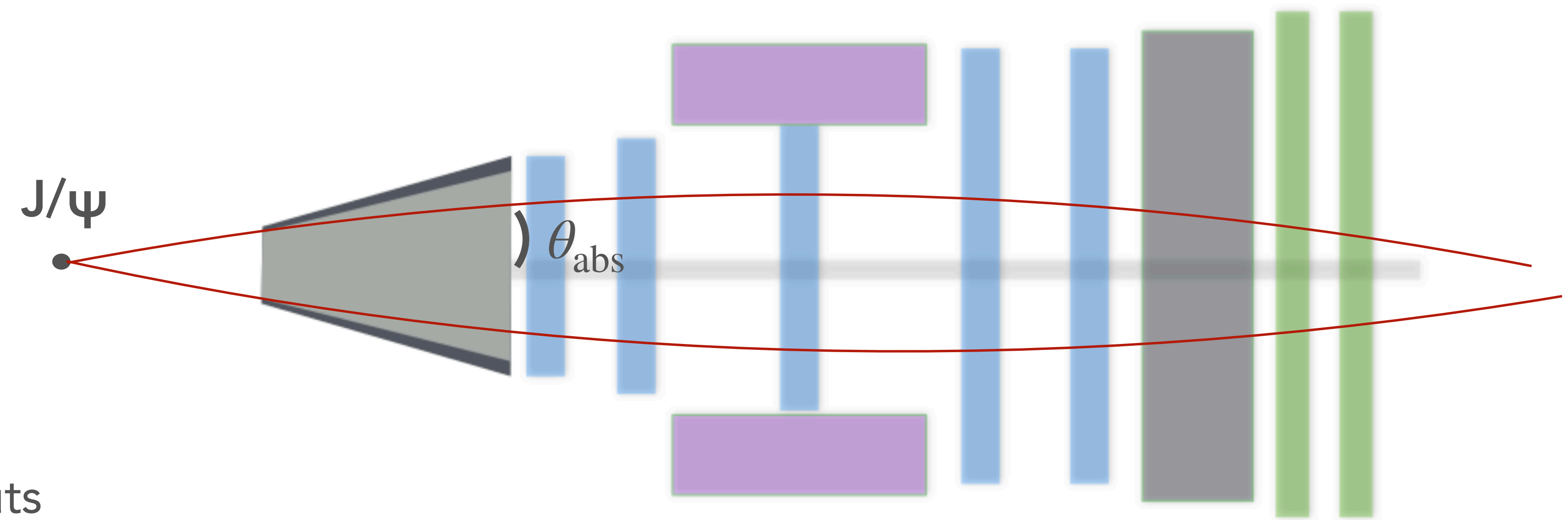


- Single muon cuts
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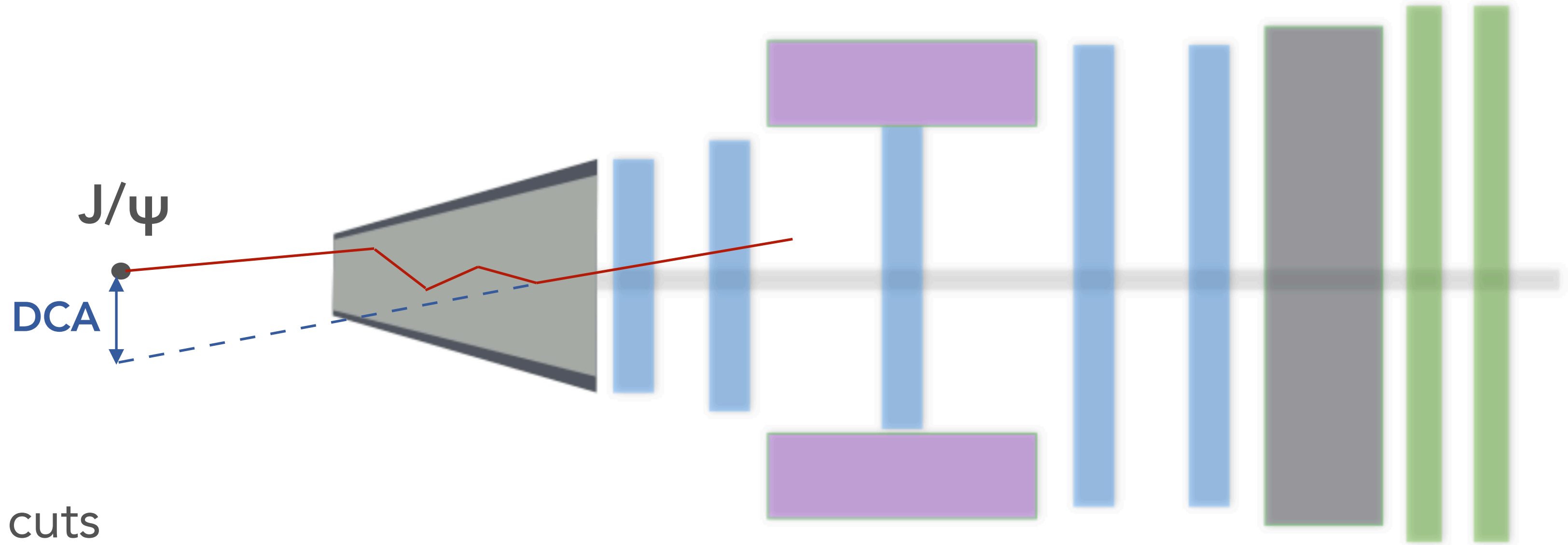


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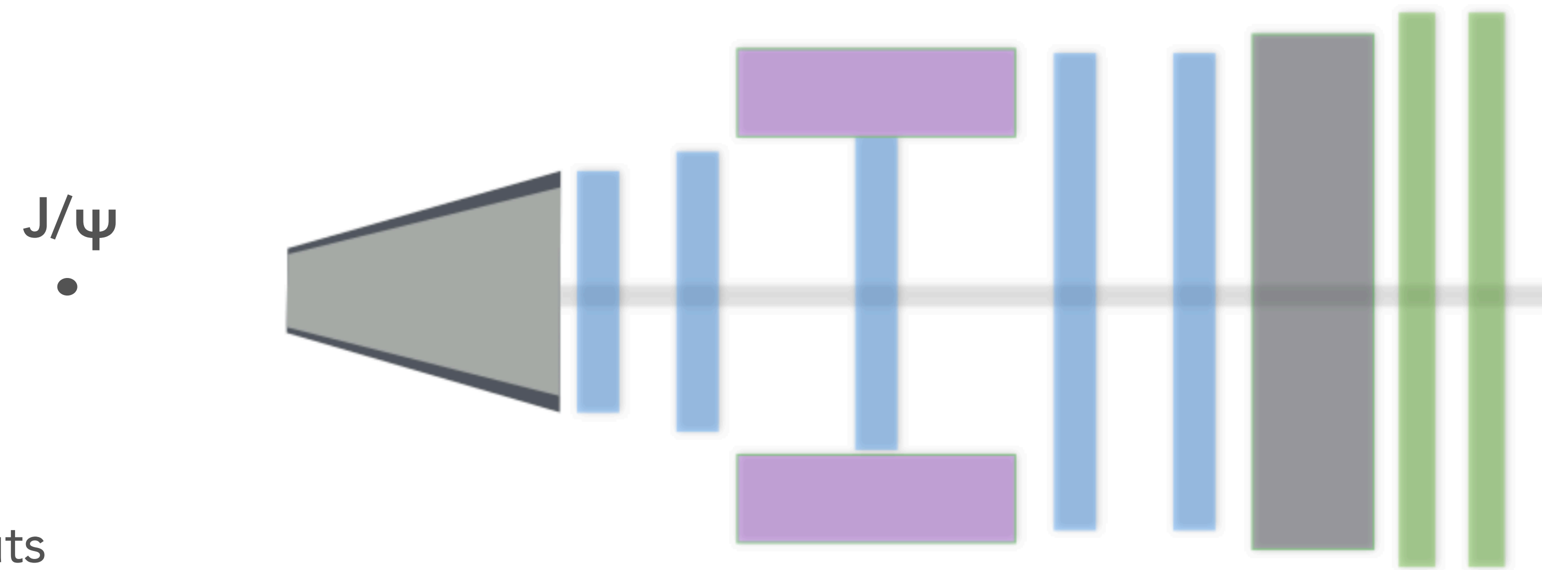


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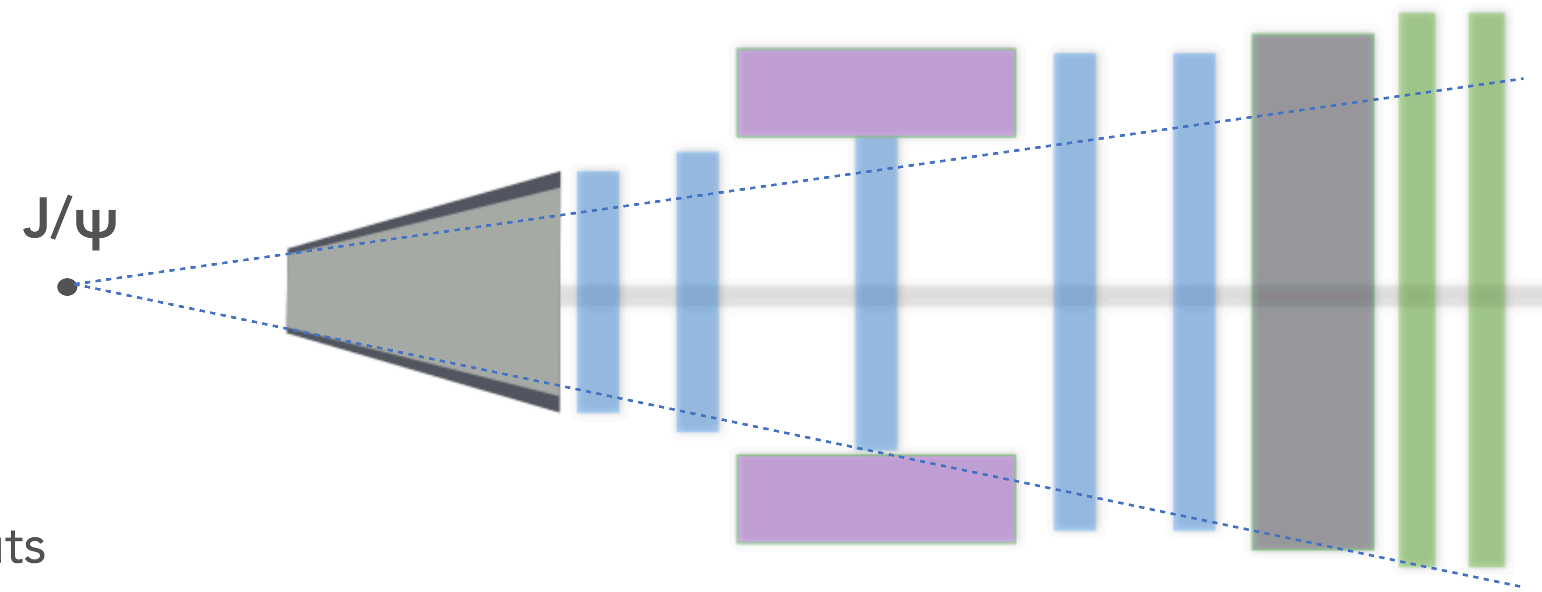


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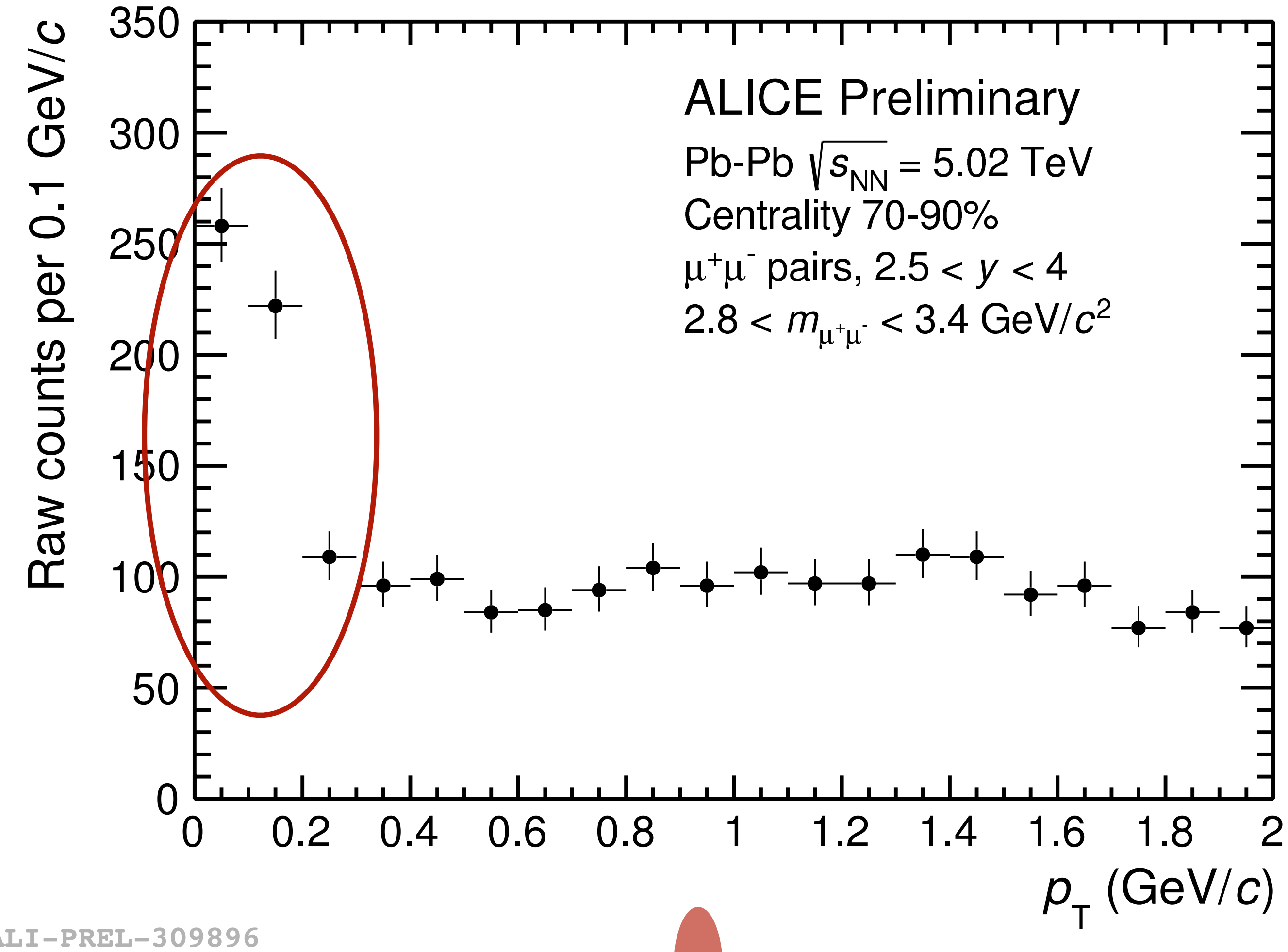
- Reconstructed dimuon cut
  - Rapidity : - 4 < $y_{\text{lab}}$ < - 2.5

# Transverse momentum distribution

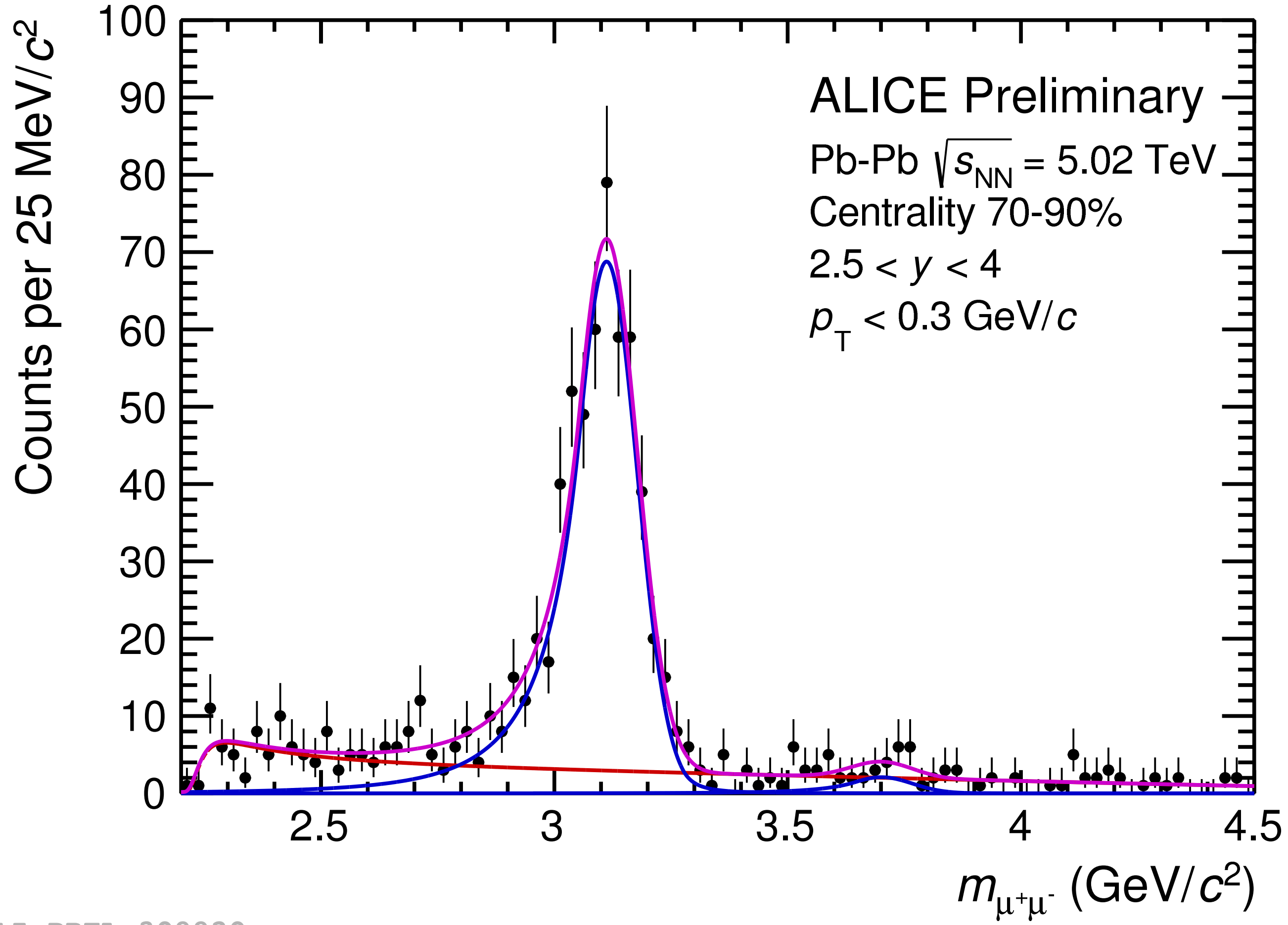
- Looking at the $p_T$ distribution, the excess is also observed in peripheral collisions at 5.02 TeV
  - In J/ψ mass range $2.85 < m_{\mu^+\mu^-} < 3.35$ GeV/$c^2$
  - For $p_T < 0.3$ GeV/$c$
  - Observed only for centrality class from 50% to 90%



# Signal extraction

Raw J/ψ number is extracting by fitting the opposite-sign invariant mass distribution

- 2 functions for signal and background + 3 sets of parameters




ALI-PREL-309920

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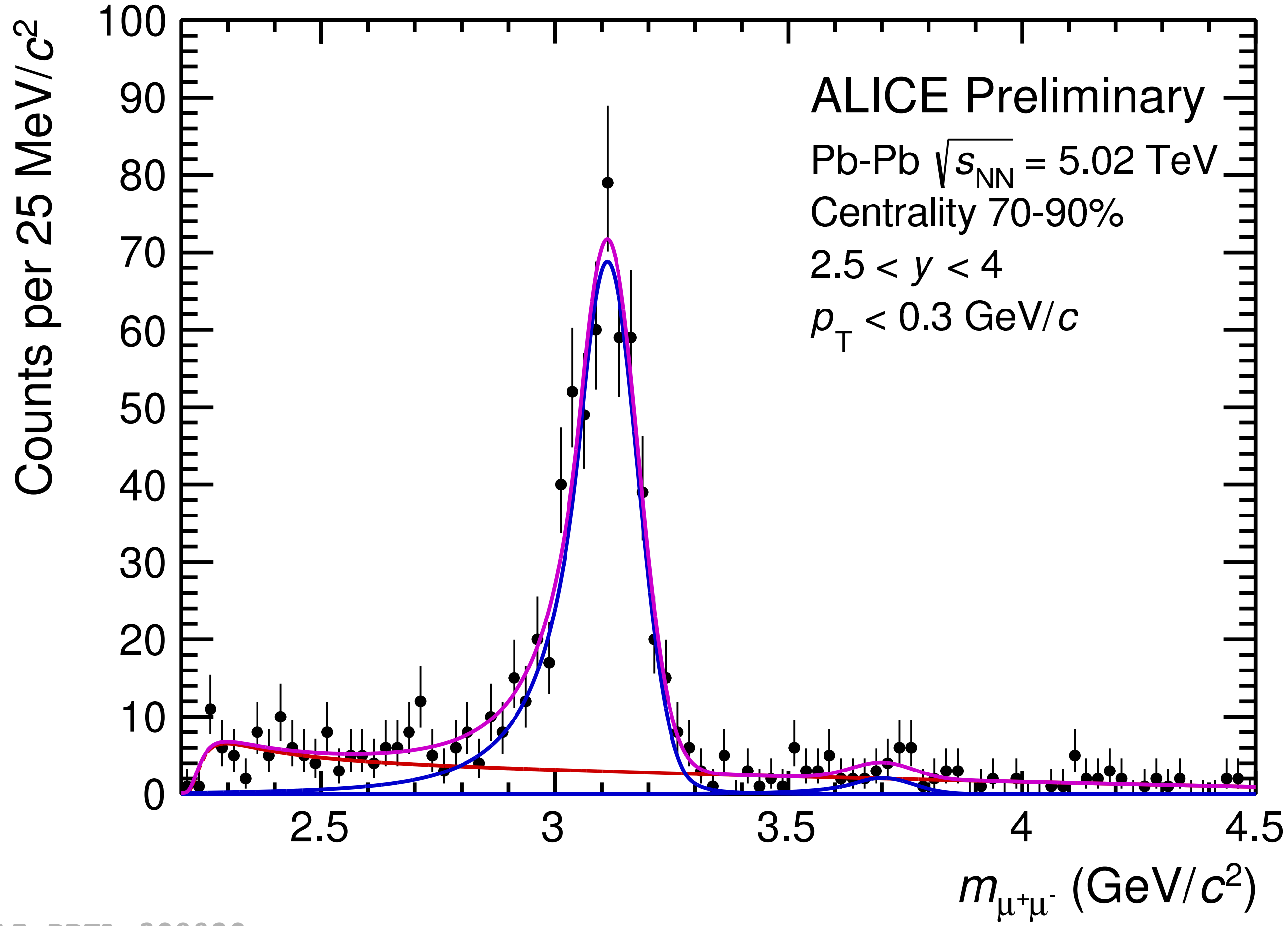
In 3 $p_T$ ranges to study different J/ψ production processes :

- Coherent production dominant : $p_T < 0.3$ GeV/c
- Incoherent production dominant : $p_T < 1$ GeV/c
- Hadronic production dominant : $p_T < 8$ GeV/c




ALI-PREL-309920

# Estimation of the hadronic componant

Number of J/ψ from **hadroproduction** is given by integrating the following parametrization for $p_T < 0.3$ GeV/$c$

$$\frac{\mathrm{d}N^{\mathrm{h}\ \mathrm{J}/\psi}_{\mathrm{AA}}}{\mathrm{d}p_{\mathrm{T}}} = \boxed{\mathcal{N}} \times \frac{\mathrm{d}\sigma^{\mathrm{h}\ \mathrm{J}/\psi}_{\mathrm{pp}}}{\mathrm{d}p_{\mathrm{T}}} \times R^{\mathrm{h}\ \mathrm{J}/\psi}_{\mathrm{AA}} \times (\mathcal{A}\times\epsilon)^{\mathrm{h}\ \mathrm{J}/\psi}_{\mathrm{AA}}$$

- J/ψ cross-section measured by ALICE in pp collisions a 5 TeV
- J/ψ nuclear modification factor in Pb-Pb collisions at 5 TeV
- Hadronic J/ψ acceptance times efficiency obtained by simulations
- Normalization factor as the number of J/ψ in $1 < p_T < 8$GeV/$c$ where hadronic component is expected to be dominant

$$\mathcal{N} = N_{\mathrm{J}\psi}\,(1-8\ \mathrm{GeV/c})/\int_{1\ \mathrm{GeV}/c}^{8\ \mathrm{GeV}/c} \frac{\mathrm{d}\sigma^{\mathrm{J}/\psi}_{\mathrm{pp}}}{\mathrm{d}p_{\mathrm{T}}} \times R^{\mathrm{J}/\psi}_{\mathrm{AA}} \times (\mathcal{A}\times\epsilon)^{\mathrm{J}/\psi}_{\mathrm{AA}}\left(p_{\mathrm{T}}\right)\mathrm{d}p_{\mathrm{T}}$$

# Coherent J/ψ photoproduction cross-section

- Extraction of the J/ψ number from coherent photoproduction

$$N_{coh}^{J/\psi} = \frac{N_{excess}^{J/\psi}}{1 + f_{incoh} + f_{coh}^{\psi'}} = \frac{N_{raw}^{J/\psi} - N_{had}^{J/\psi}}{1 + f_{incoh} + f_{coh}^{\psi'}}$$

$f_{incoh}$ is the fraction of J\ψ from incoherent photoproduction

$f_{coh}^{\psi'}$ is the fraction of J\ψ from the decay of coherently photoproduced ψ'

- Cross section evaluation

$$\frac{d\sigma_{coh}^{J/\psi}}{dp_T} = \frac{N_{coh}^{J/\psi}}{BR_{J/\psi\to\mu^+\mu^-} \times (\mathscr{A} \times \epsilon)_{coh}^{J/\psi} \times \mathscr{L}_{int} \times \Delta y}$$

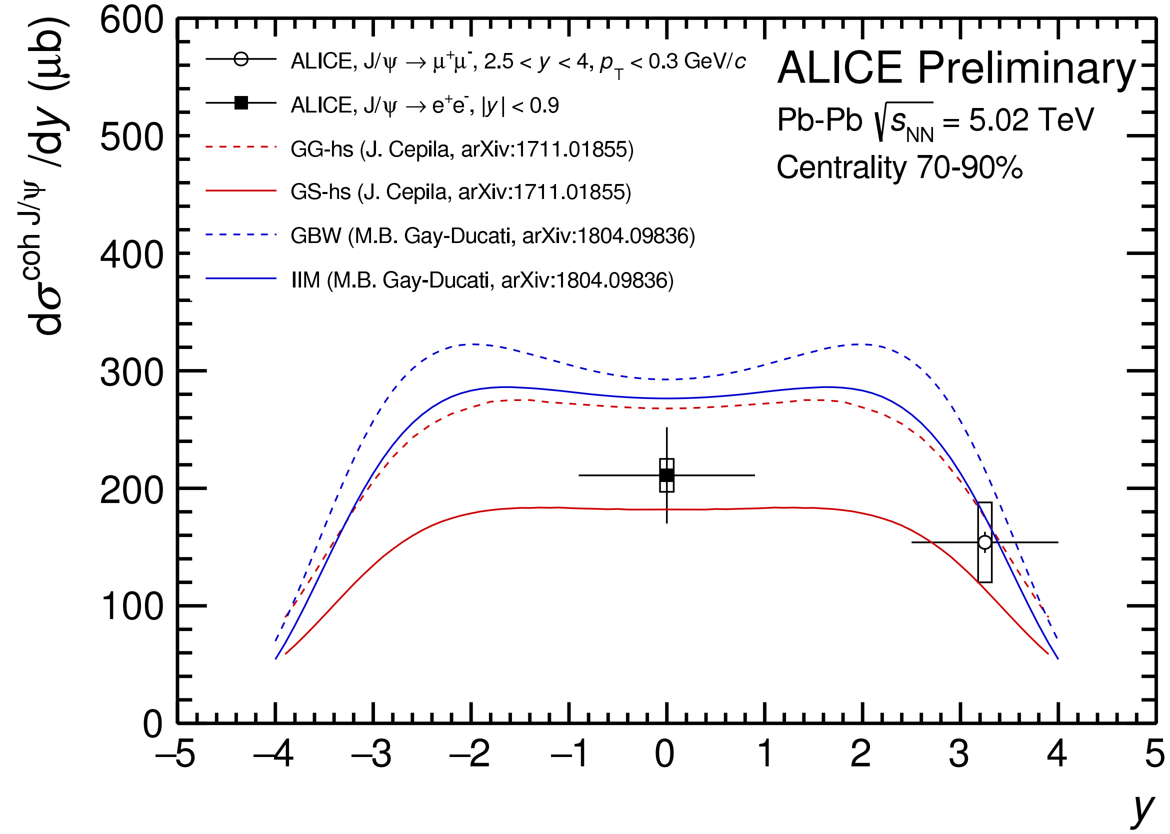
Branching ration = 5.93%

Acceptance x efficiency for coherent J/ψ

Integrated luminosity

Rapidity width

2015 data sample

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- Systematics uncertainties determination

# Muon tracking efficiency

- Estimation of the systematics on the tracking efficiency

Three main parts :

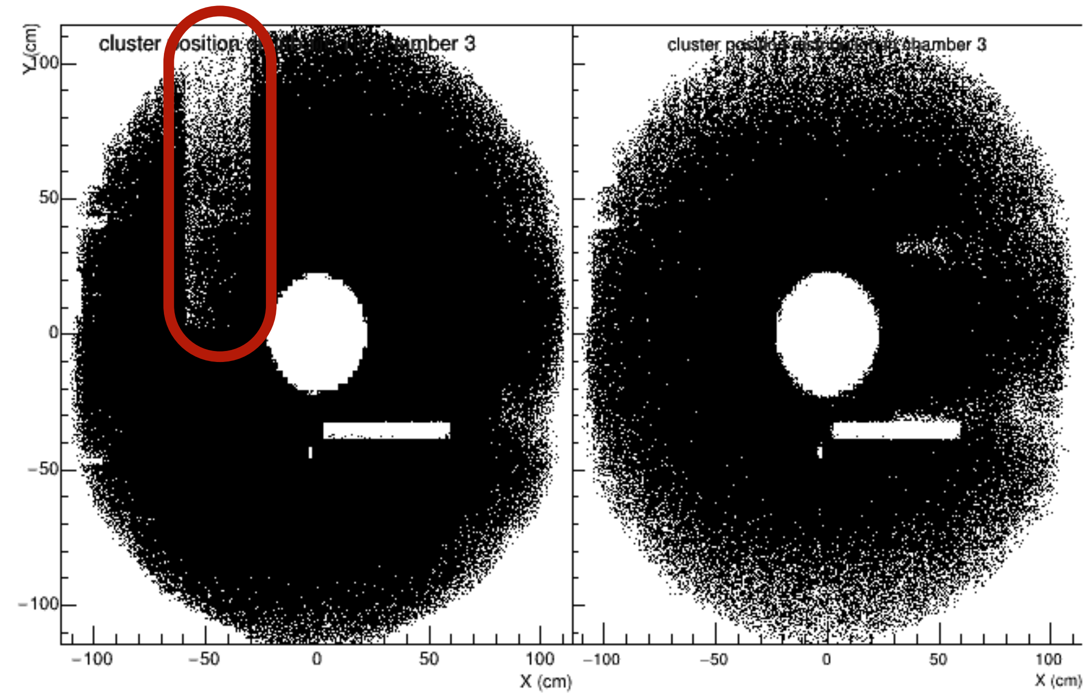
I. Cluster map Data/Monte Carlo comparison
- Spot the unexpected detector issues
- Include them in simulations

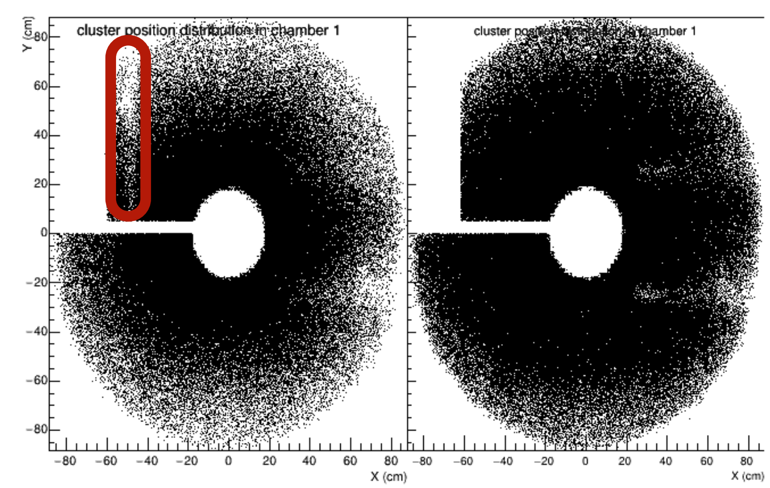
II. Tuning the kinematics distributions
- Parametrization of the kinematics distributions
- Make the most realistic simulations

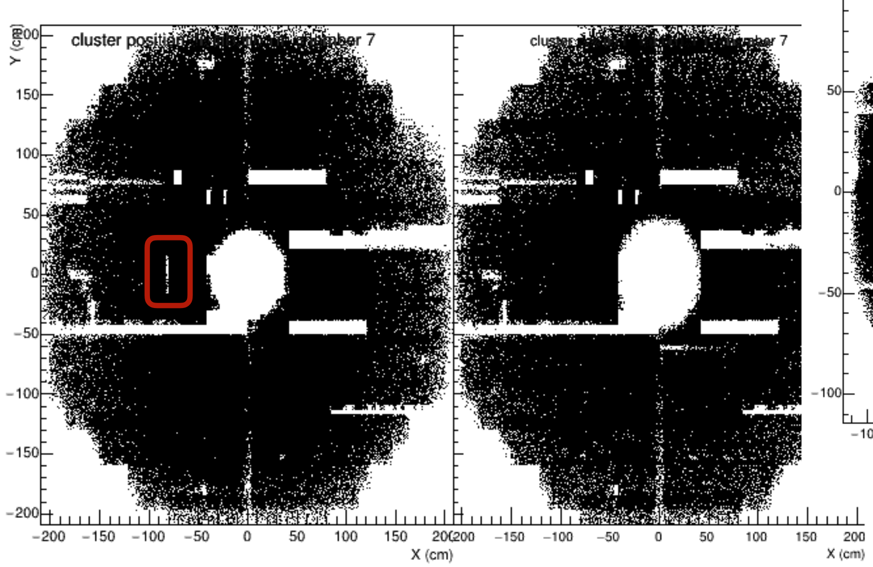
III. Acceptance x Efficiency and systematics
- Compute the Acceptance x Efficiency factor
- Quantify the residual data/MC discrepancies to be used as systematics

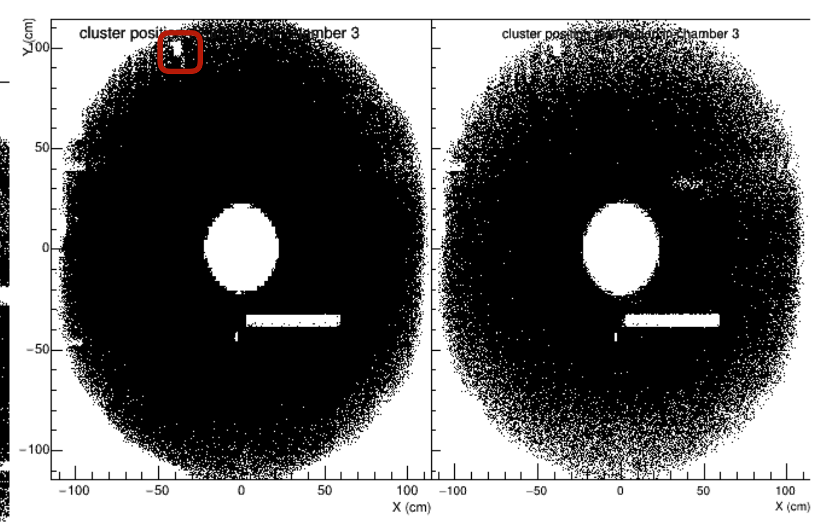
# Cluster map data/MC comparison

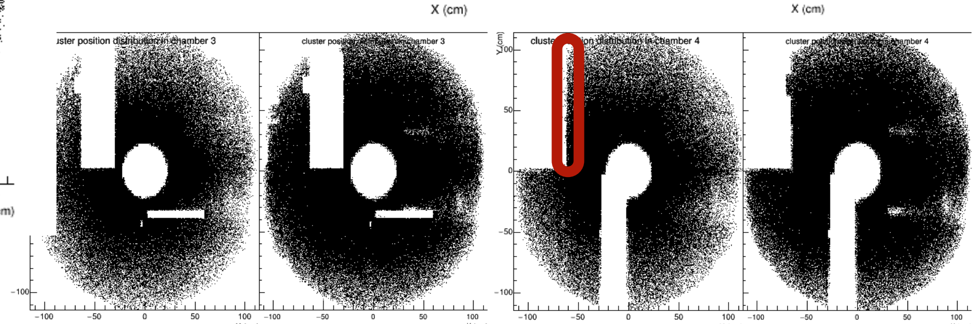
- Method
  - Perform single muon simulations
  - Compare data and simulations
  - Identify detector issues not included status map
  - Fix the problems :
    - detector status and/or offline rejection algorithm
    - add the dead detector elements to the rejectList



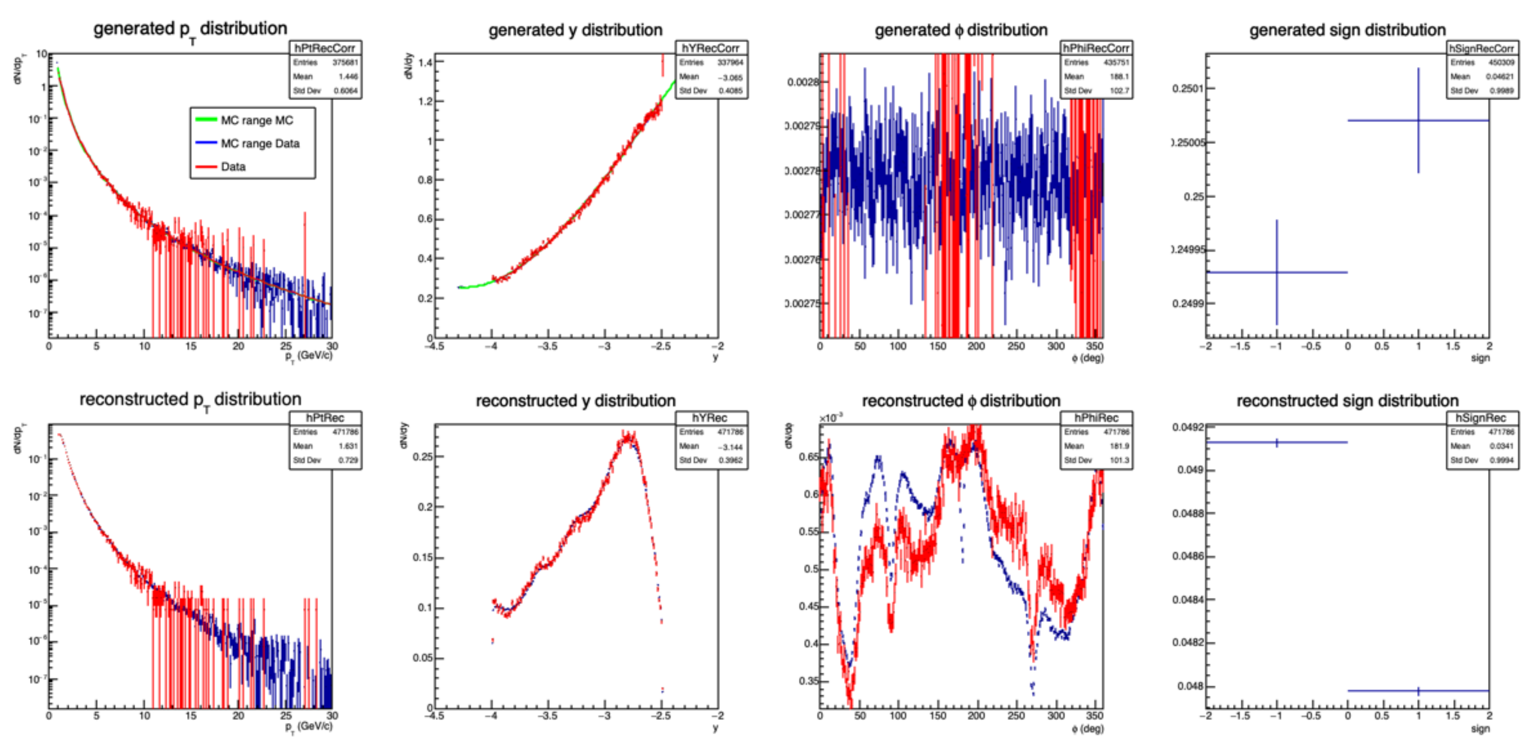



# Tuning the kinematics distributions : the data driven method

- Step 0 :
  single-muon simulations with parameters from previous period for the kinematic distributions

- Step n > 0 :
  - $\mathscr{A} \times \epsilon$ is measured from MC simulation
    and applied to the data reconstructed distribution
    → equivalent generated distribution
  - Fitting the new corrected data distributions
  - Compute the weight :
    ratio of the new function to the original generated MC distribution
    → Re-weight the gererated muons



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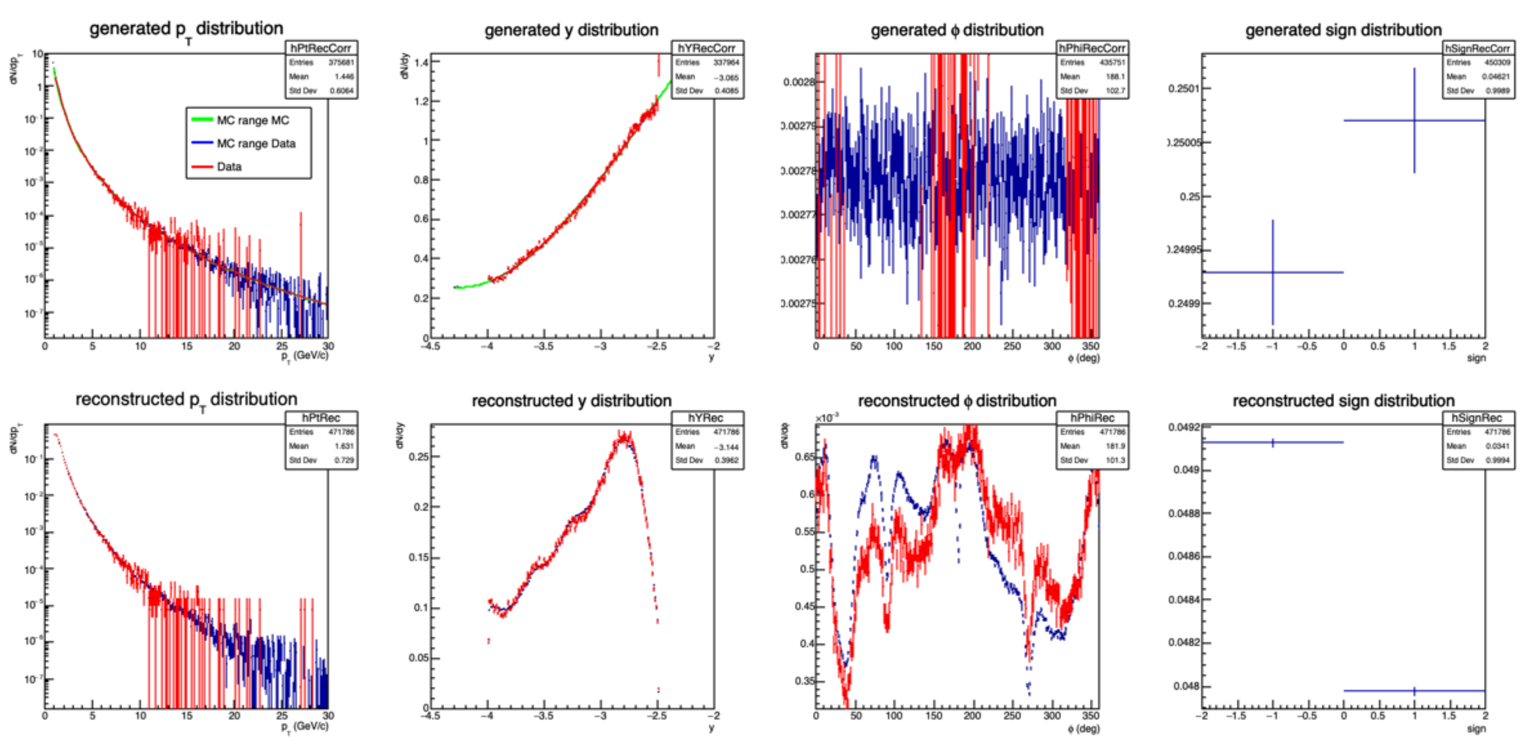
The procedure is done iteratively until parameters for generated MC distributions converged



# Acceptance times efficiency

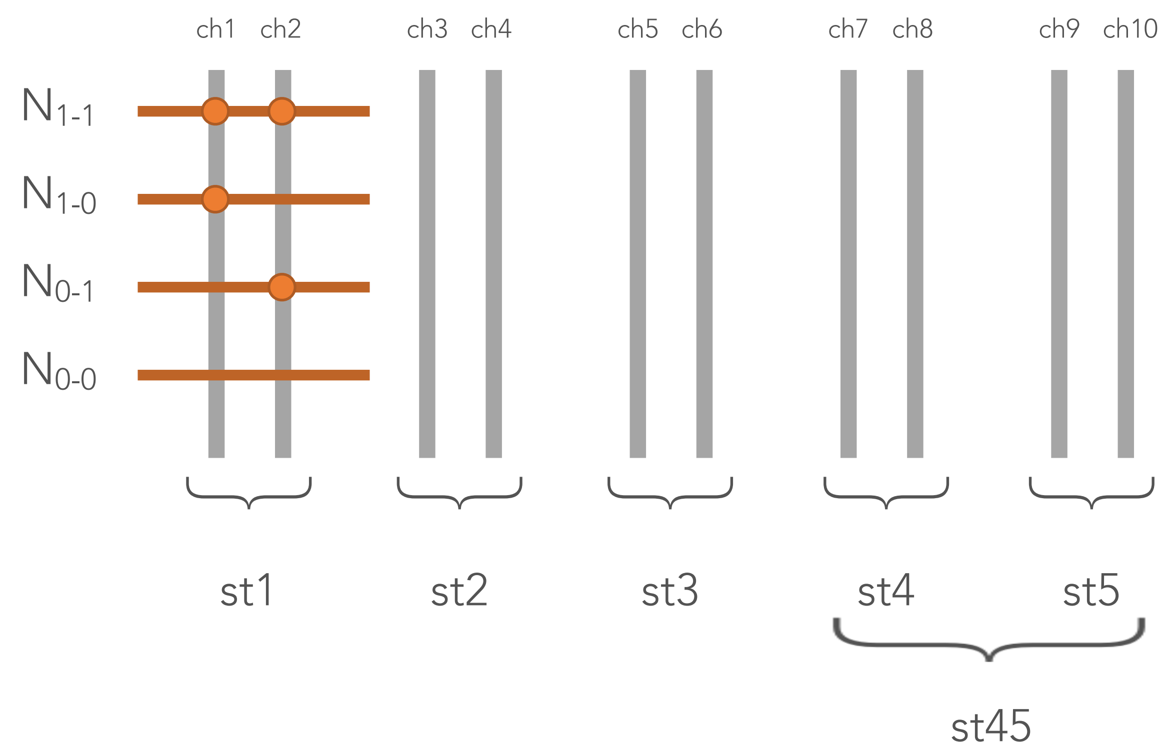
- Measure intrinsic efficiency :
  - Use the reconstructed tracks
  - Use the redundancy between chambers
  - Assuming the efficiency of one chamber is independent on the others

$$\epsilon_{ch\ i} = \frac{N_{i-j}}{N_{i-j} + N_{0-j}}$$

- Method based on the tracking algorithm properties
  - For stations 1, 2 and 3 :
    at least 1 cluster per station

$$\epsilon_{st\ 1(2)(3)} = 1 - \left(1 - \epsilon_{ch\ 1(3)(5)}\right)\left(1 - \epsilon_{ch\ 2(4)(6)}\right)$$

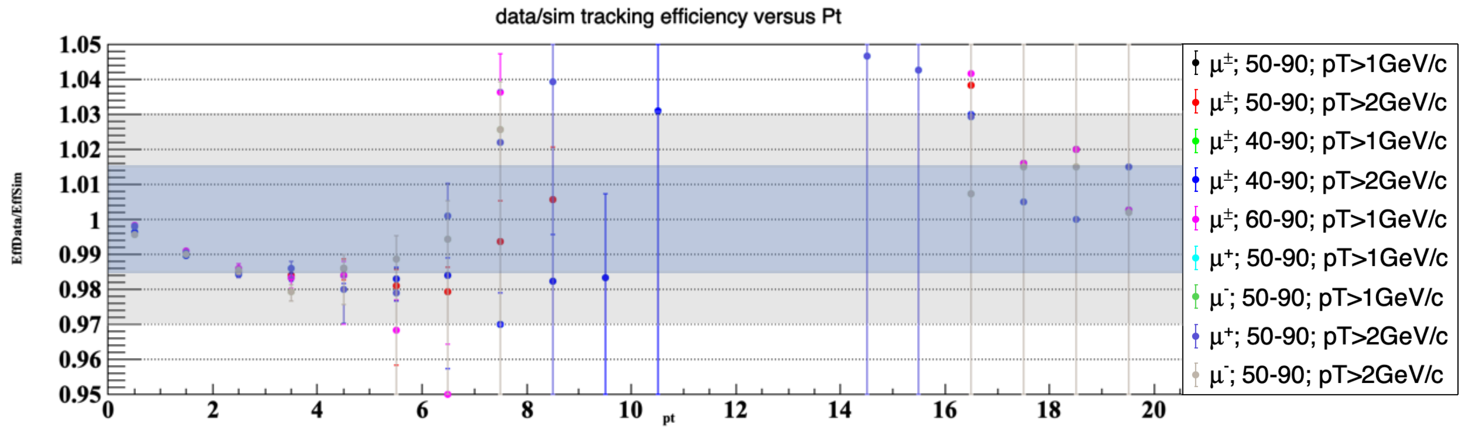
  - For stations 4 and 5 :
    at least 3 cluster in the last 4 chambers

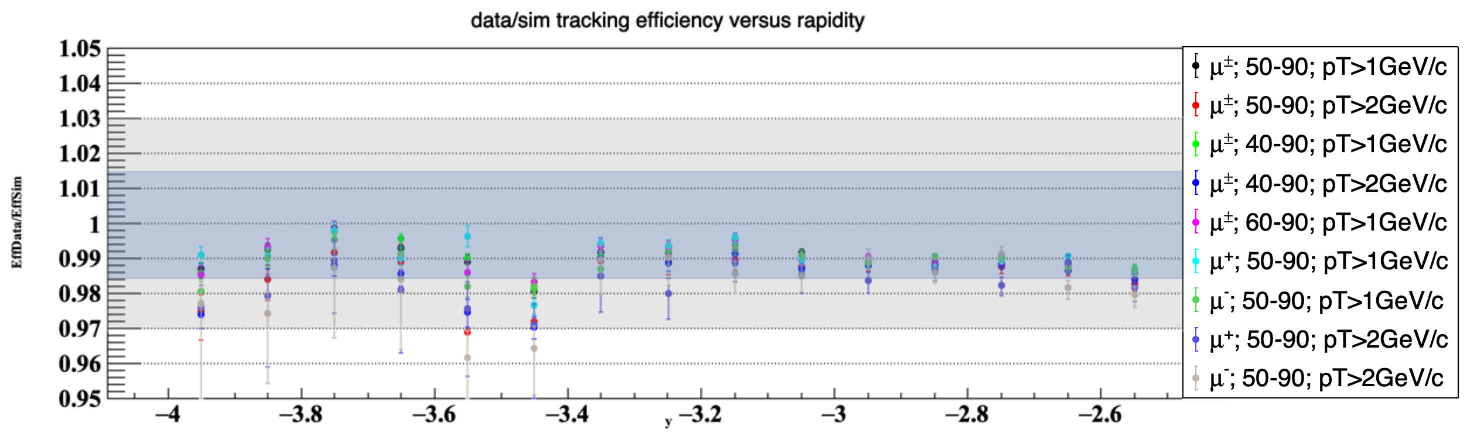


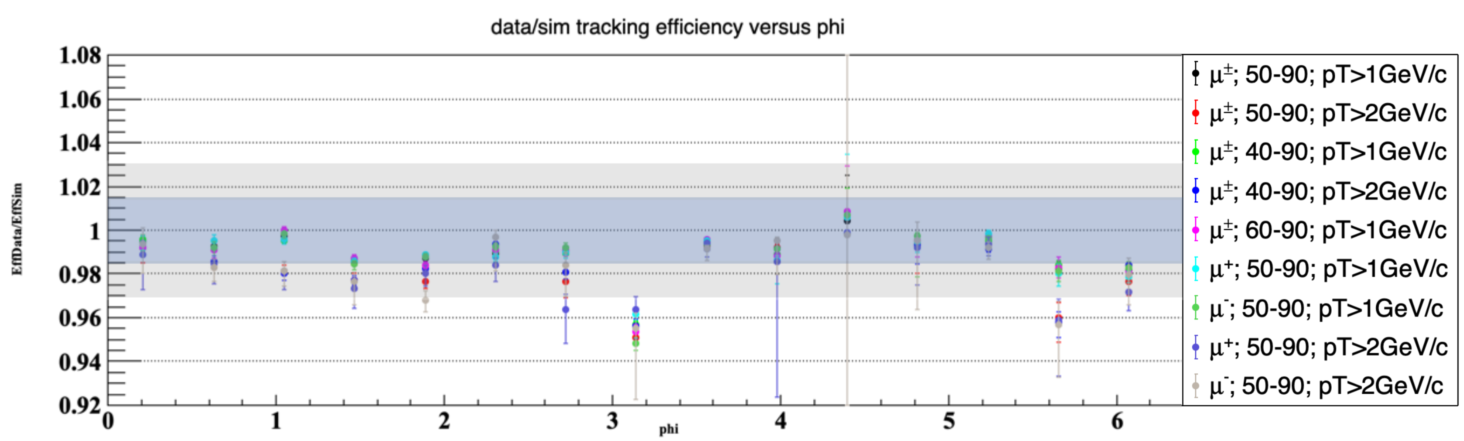

$$\epsilon_{st\ 45} = \prod_{i=7}^{1=10} \epsilon_{ch\ i} + \sum_{i=7}^{i=10} \left( (1 - \epsilon_{ch\ i}) \prod_{j=7;j\neq i}^{j=10} \epsilon_{ch\ j} \right)$$

$$\epsilon_{tracking} = \epsilon_{st1}\epsilon_{st2}\epsilon_{st3}\epsilon_{st45}$$

# Tracking systematics




- If we take a systematic of 1.5% all data/MC differences are within 2σ - 3σ

→ systematic of 3% for dimuons

# Conclusion and outlooks

- Excess in the yield of J/ψ at very low $p_{\mathrm{T}}$ confirmed in peripheral collisions at 5.02 TeV
- Excess is expected to be more significant with respect to 2.76 TeV

Analysis in progress

- Study of the $\langle p_{\mathrm{T}} \rangle$ of the J/ψ excess
- Will be extended to more central collisions
  - Centrality dependence of the $\langle p_{\mathrm{T}} \rangle$
  - Coherence condition
- Will be performed for more bins in rapidity
  - Rapidity dependence of the cross-section
  - Combine results with UPC analysis and extract $\sigma_{\gamma Pb}(+y)$ and $\sigma_{\gamma Pb}(-y)$
  - Probe the gluonic content for different Bjorken-$x$