



National Natural Science
Foundation of China



The UPC related physics in heavy-ion collisions

查王妹

中国科学技术大学 近代物理系

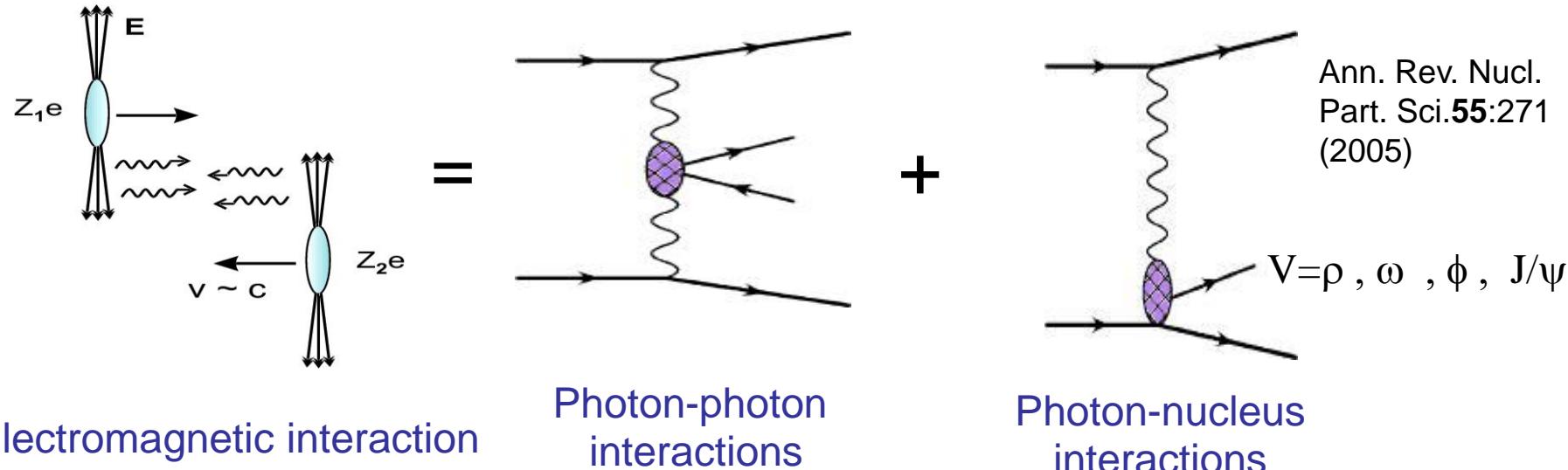
In collaborate with:
Zebo Tang,
Shuai Yang

Lijuan Ruan,
Zhangbu Xu

第十八届全国中高能核物理大会暨第十二届全国中高能
核物理专题研讨会

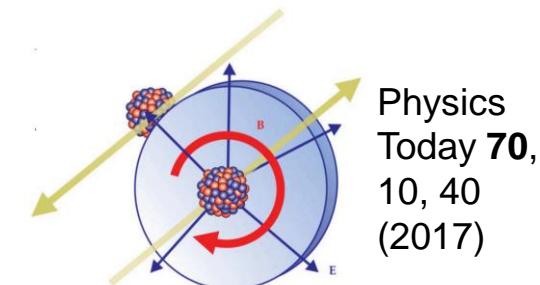
长沙, 湖南 2019年6月21-25日

Photon interactions in A+A



- This large flux of quasi-real photons makes a hadron collider also a photon collider!

- ✓ Photon-nucleus interactions: Vector meson
- ✓ Photon-photon interactions: dileptons ...



- Studied in ultra-peripheral collisions (UPC) to reject hadronic background.

Vector meson photon-production

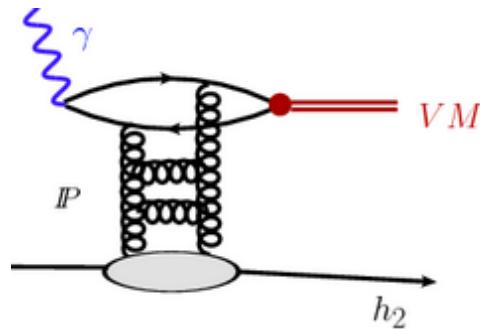
- Vector meson production:

- ✓ chargeless ‘Pomeron exchange’
- ✓ Light meson production usually treated via vector meson dominance model:
 ρ , direct $\pi^+\pi^-$, ω
- ✓ Heavy meson production treated with pQCD:
 J/ψ , ψ' , $Y(1S)$, $Y(2S)$, $Y(3S)$...

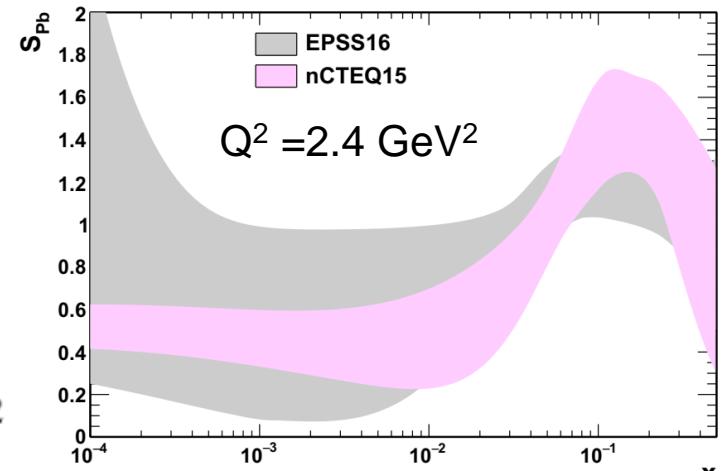
- Sensitive to the gluon distribution:

$$\frac{d\sigma(\gamma A \rightarrow VA)}{dt} \Big|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} [16\pi^3 x G_A(x, Q^2)]^2$$

$$x = \frac{M_V e^{\pm y}}{\sqrt{s}} \quad Q^2 = M_V^2/4$$



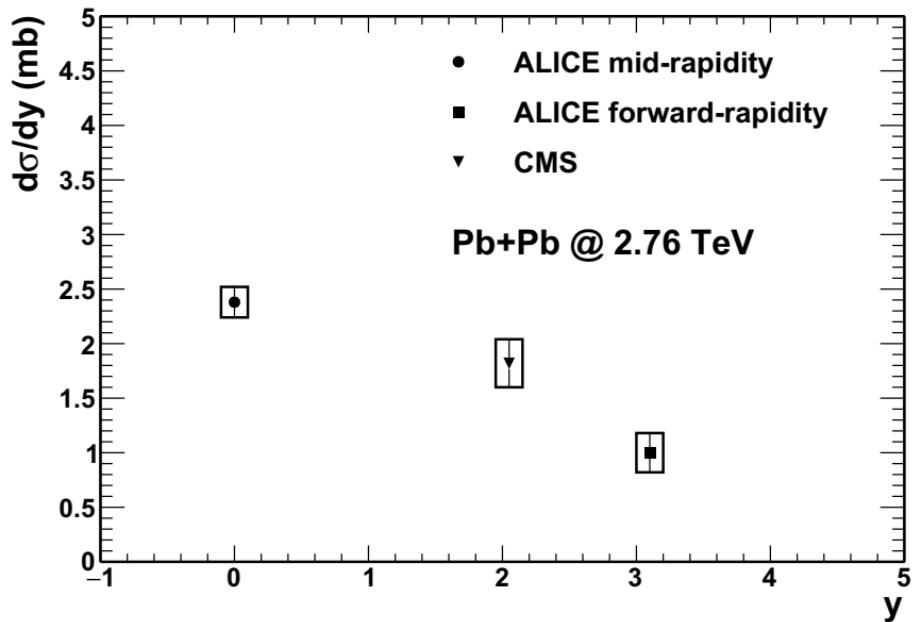
Huge uncertainties!



EPJC 77 (2017) 163

PRD 93 (2016) 085037

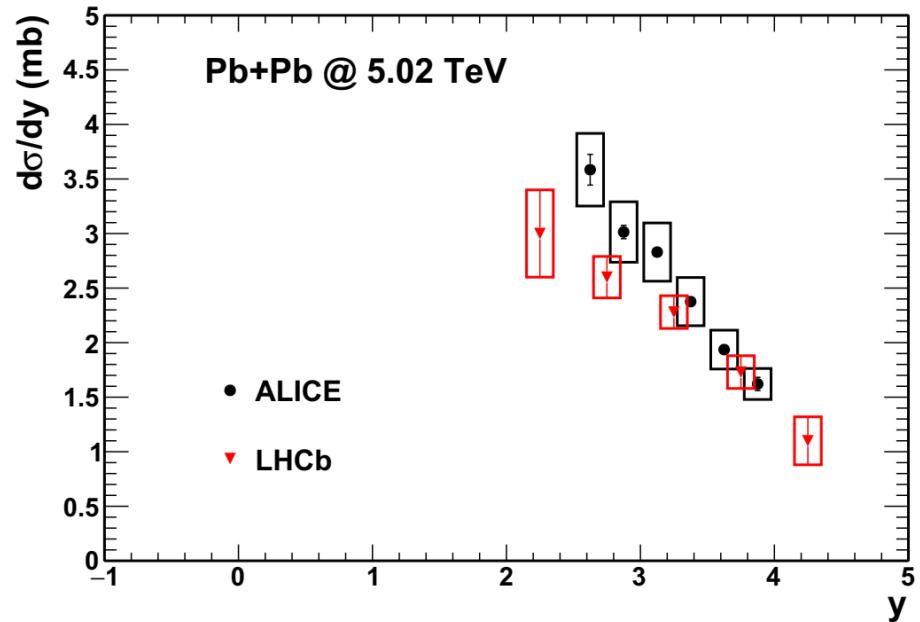
The J/ψ photoproduction in UPCs



EPJC 73 (2013) 2617

PLB 718 (2013) 1273

PLB 772 (2017) 489



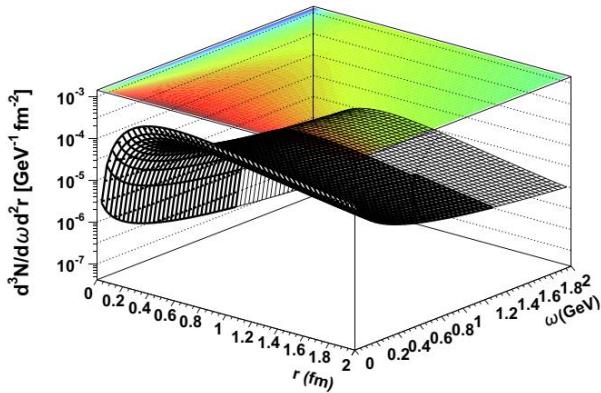
LHCb-CONF-2018-003

arXiv: 1904.06272

Various precise measurements!
The constrain on nPDF?

The framework: impulse approximation

$$\frac{d\sigma_{AA \rightarrow AA J/\psi}(y)}{dy} = N_{\gamma/A}(y)\sigma_{\gamma A \rightarrow J/\psi A}(y) + N_{\gamma/A}(-y)\sigma_{\gamma A \rightarrow J/\psi A}(-y)$$

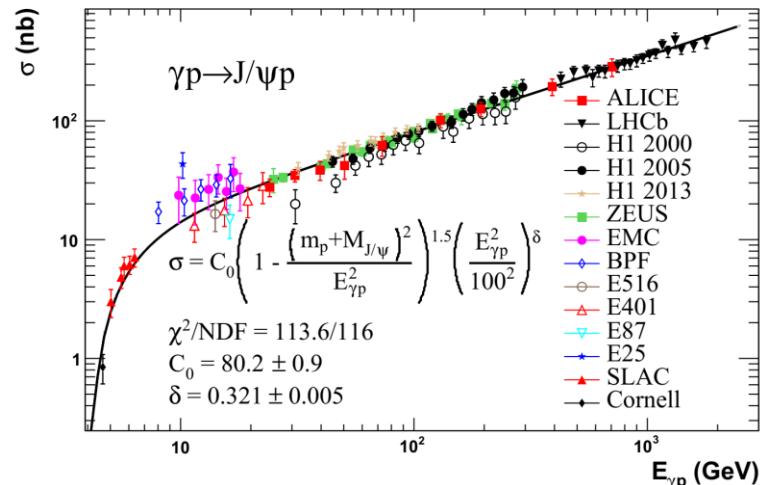


Equivalent photon approximation

$$\sigma(\gamma A \rightarrow J/\psi A) = \frac{d\sigma(\gamma A \rightarrow J/\psi A)}{dt} \Big|_{t=0} \times$$

$$\int |F_P(\vec{k}_P)|^2 d^2\vec{k}_{P\perp} \quad \vec{k}_P = (\vec{k}_{P\perp}, \frac{\omega_P}{\gamma_c})$$

$$\omega_P = \frac{1}{2} M_{J/\psi} e^{\pm y} = \frac{M_{J/\psi}^2}{4\omega_\gamma}$$



Z. Cao et al., Chin. Phys. C43
(2019) 064103

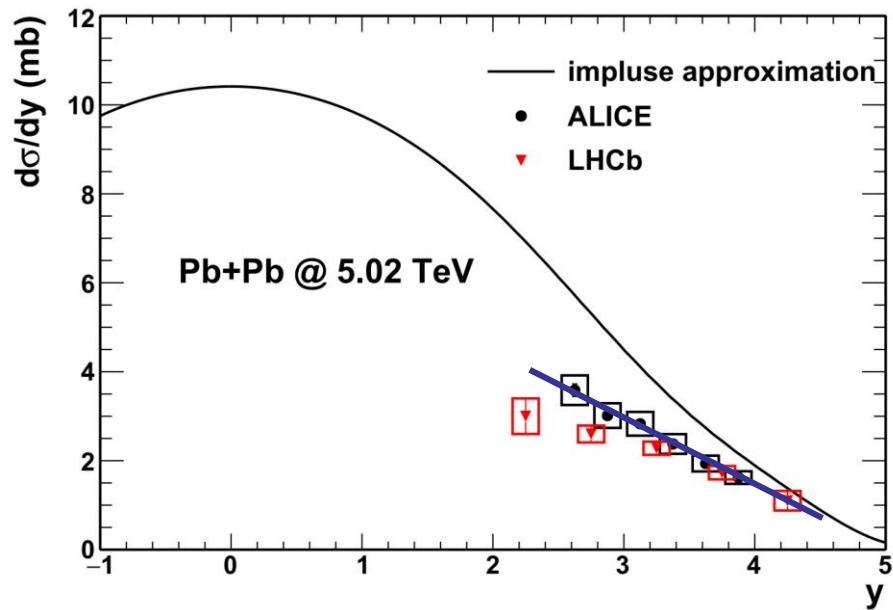
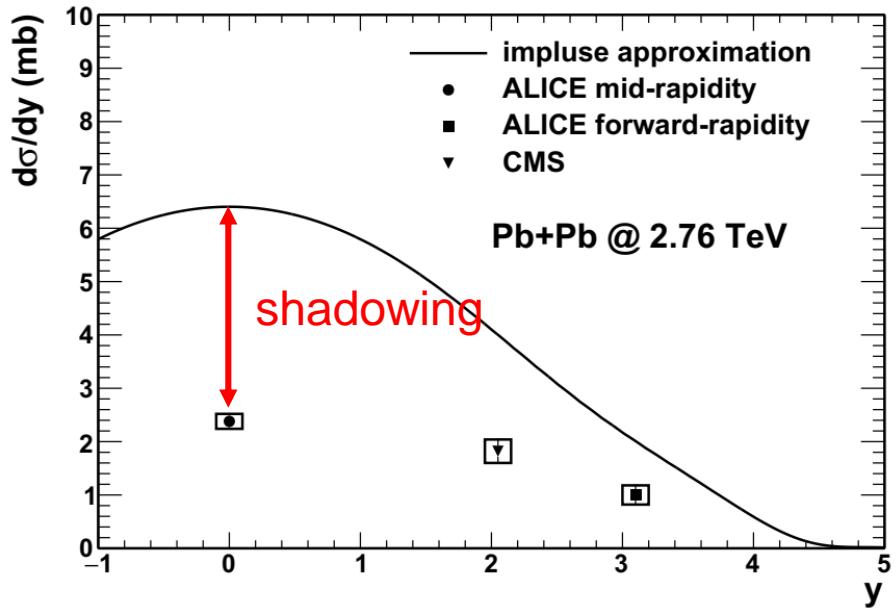
impulse approximation

$$d\sigma_{\gamma A}/dt|_{t=0} = d\sigma_{\gamma p}/dt|_{t=0} \times A^2$$

$$d\sigma_{\gamma p}/dt = \sigma_0 \times e^{-bt}$$

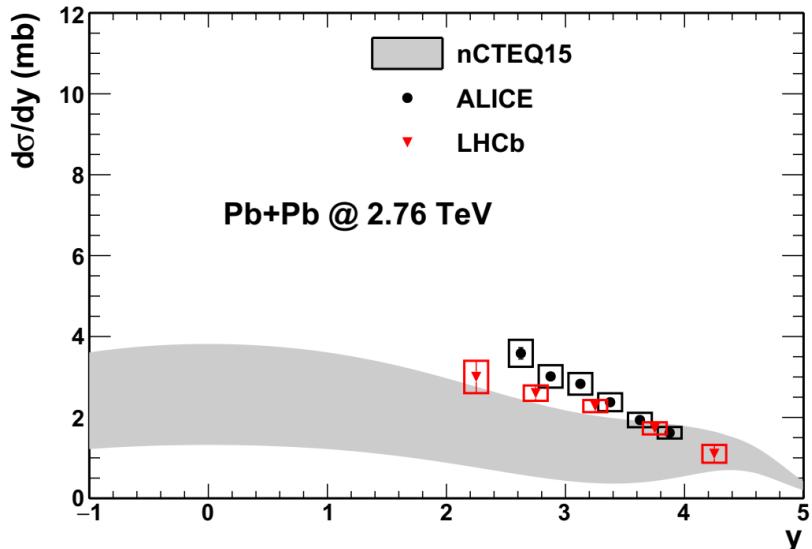
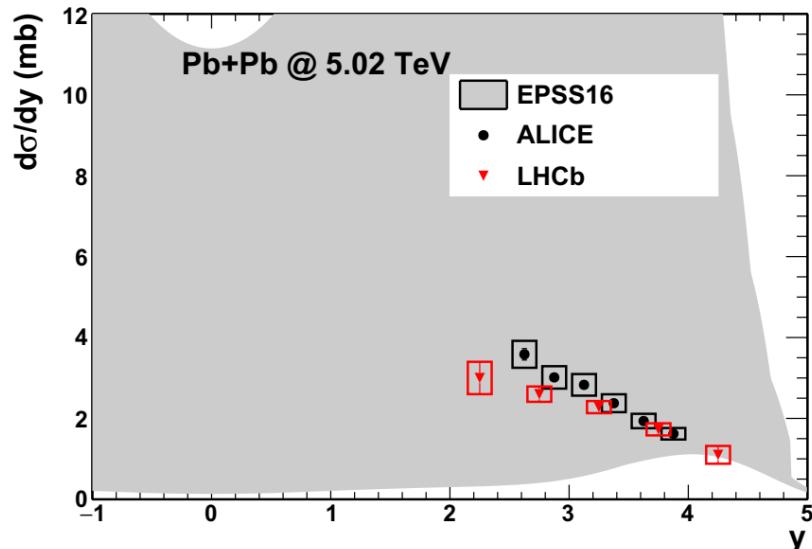
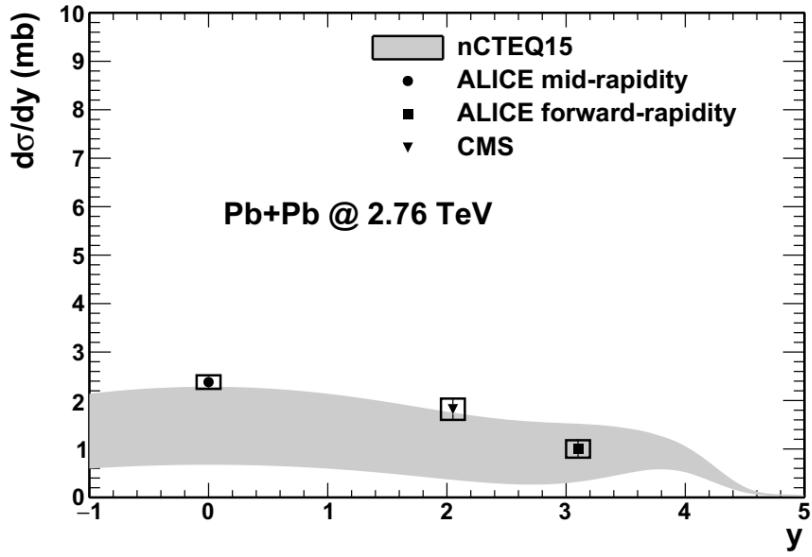
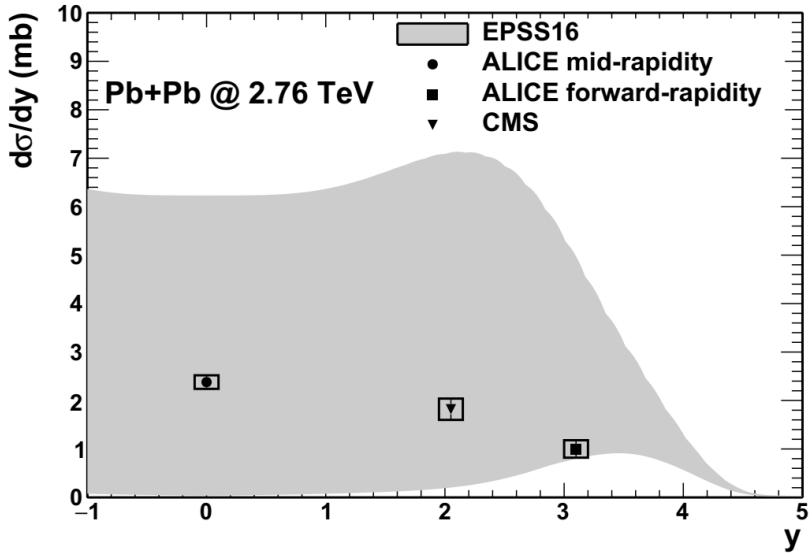
$$d\sigma_{\gamma p}/dt|_{t=0} = \sigma_{\gamma p} \times b$$

The results: impulse approximation



- The impulse approximation significantly overestimates the data => Significant shadowing effect
- The difference becomes smaller towards forward rapidity => Less shadowing effect towards high x

The EPSS16 and nCTEQ15 nPDF sets



The Bayesian reweighting of nuclear PDFs

The PDFs replica f_k can be constructed by the Hessian error set:

$$f_k \equiv f_{S_0} + \sum_i \left(\frac{f_{S_i^+} - f_{S_i^-}}{2} \right) R_{ik}$$

Any quantity $\mathcal{O}[f]$ depending on PDFs can be determined via:

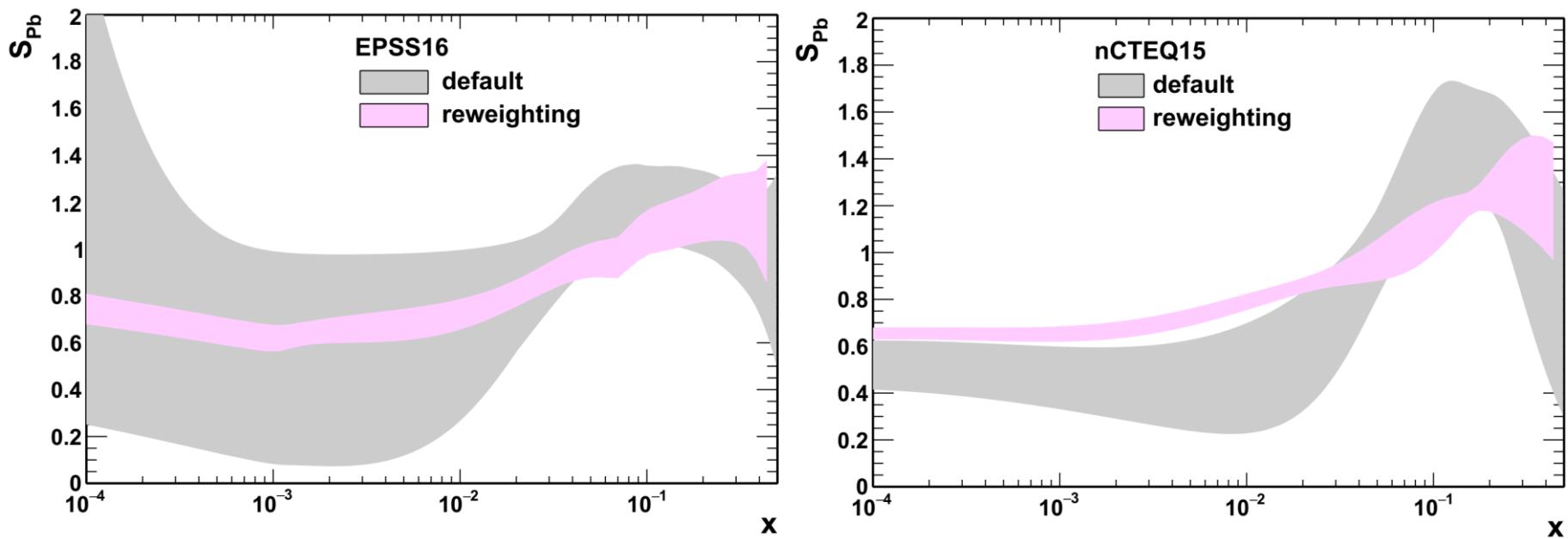
$$\langle \mathcal{O} \rangle = \frac{1}{N_{\text{rep}}} \sum_{k=1}^{N_{\text{rep}}} \mathcal{O}[f_k]$$

For a new measurement, $y = \{y_1, y_2, \dots, y_n\}$, the reweighted PDF could be evaluated by:

$$\langle \mathcal{O} \rangle_{\text{new}} = \frac{1}{N_{\text{rep}}} \sum_{k=1}^{N_{\text{rep}}} w_k \mathcal{O}[f_k]$$

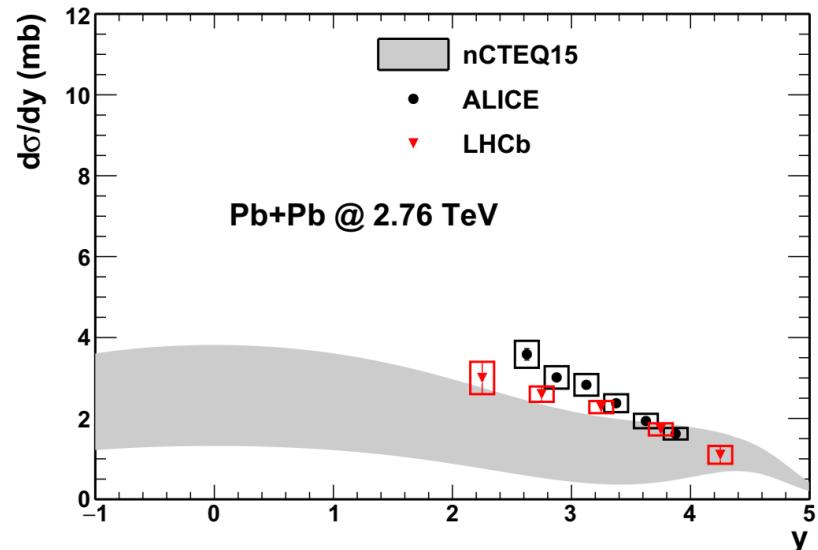
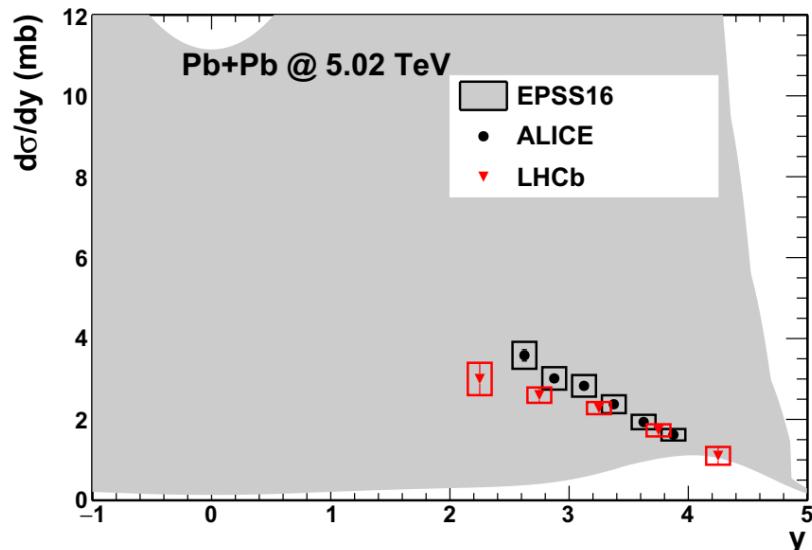
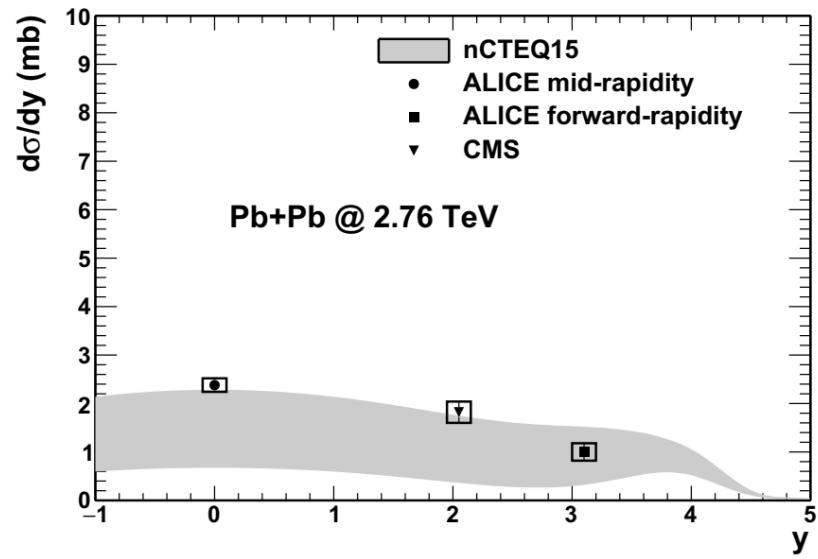
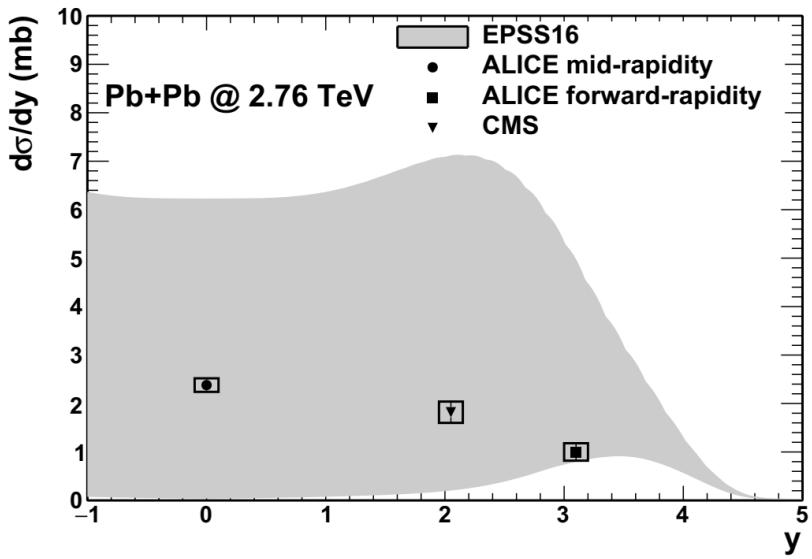
$$w_k = \frac{(\chi_k^2)^{\frac{1}{2}(n-1)} e^{-\chi_k^2/2}}{\frac{1}{N_{\text{rep}}} \sum_{k=1}^{N_{\text{rep}}} (\chi_k^2)^{\frac{1}{2}(n-1)} e^{-\chi_k^2/2}} \quad \chi_k^2(y, f_k) = \sum_{i,j=1}^n (y_i - y_i[f_k]) \text{cov}_{ij}^{-1} (y_j - y_j[f_k])$$

The reweighting nPDF for EPSS16 and nCTEQ15

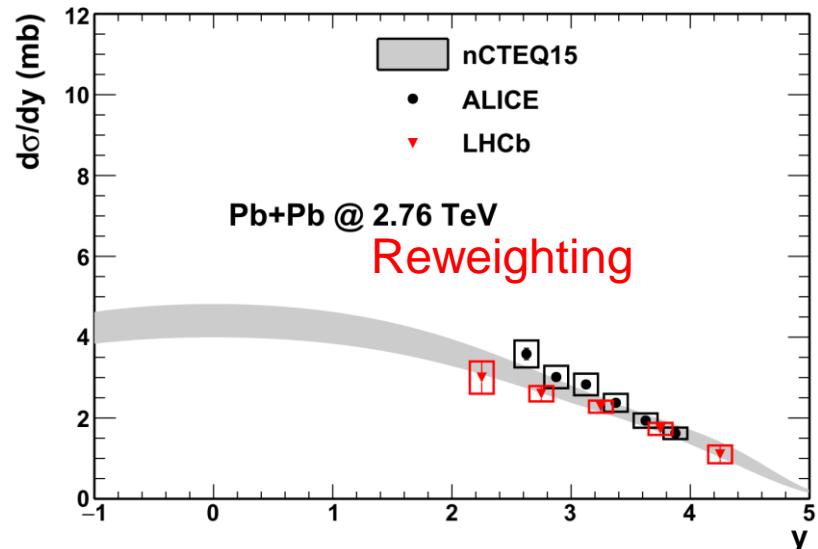
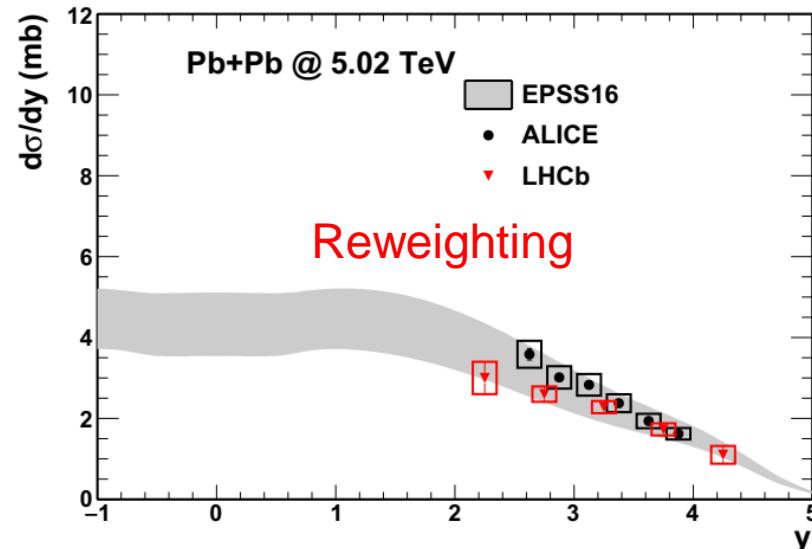
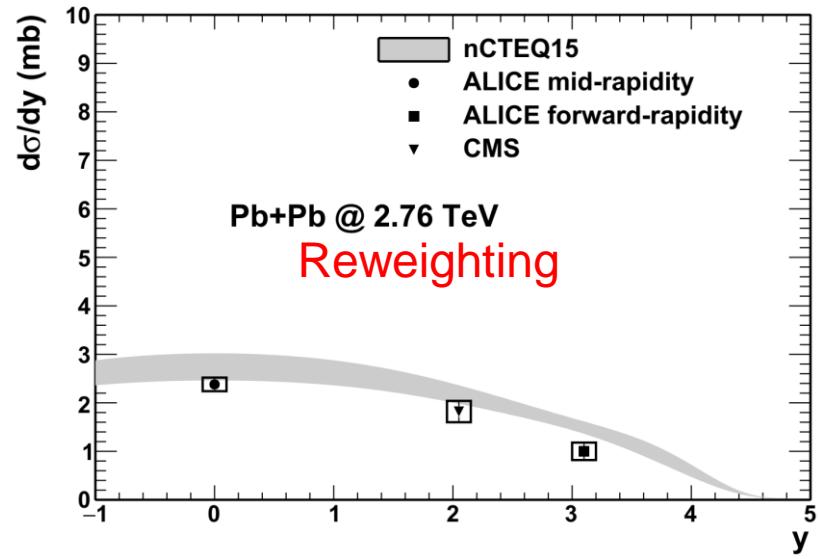
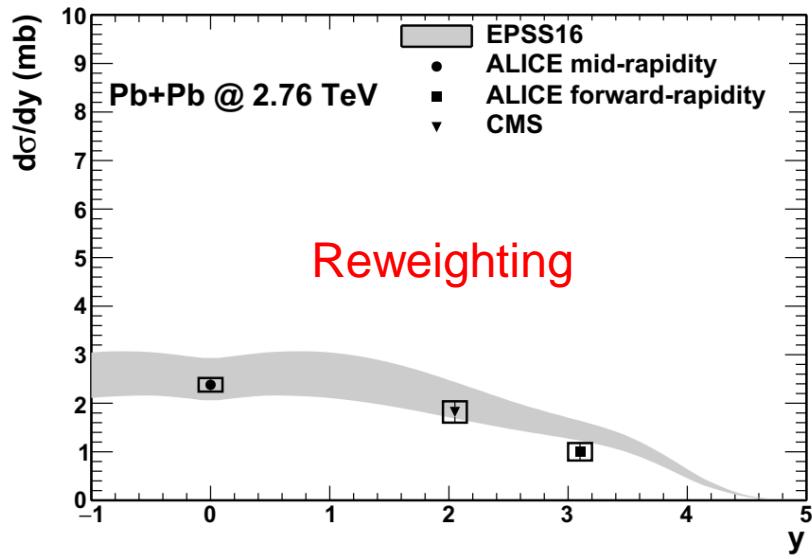


The reweighting **dramatically reduce** the uncertainty band of EPPS and nCTEQ15 PDF sets.
Significant shadowing effect has been observed in both reweighting PDF sets at small x .

The reweighting nPDF



The reweighting nPDF



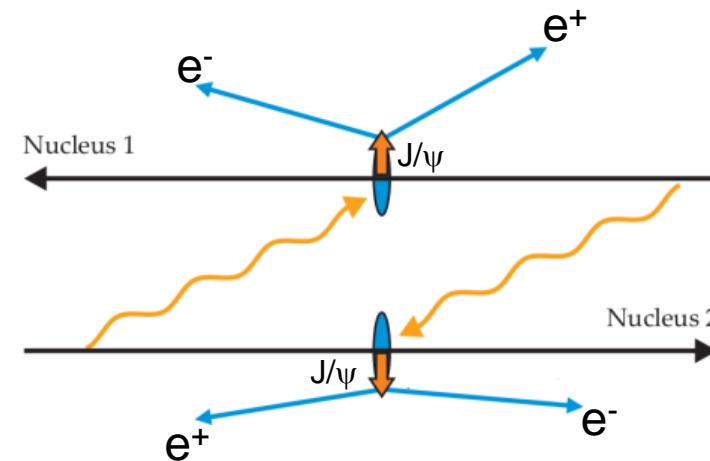
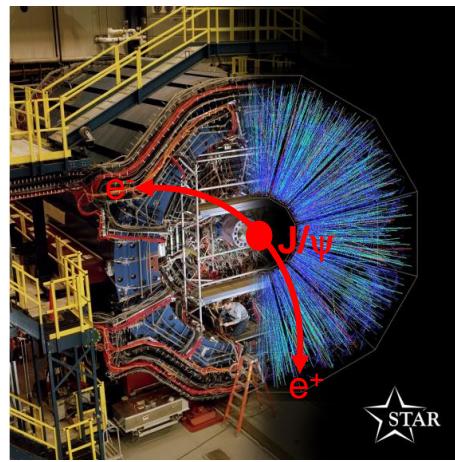
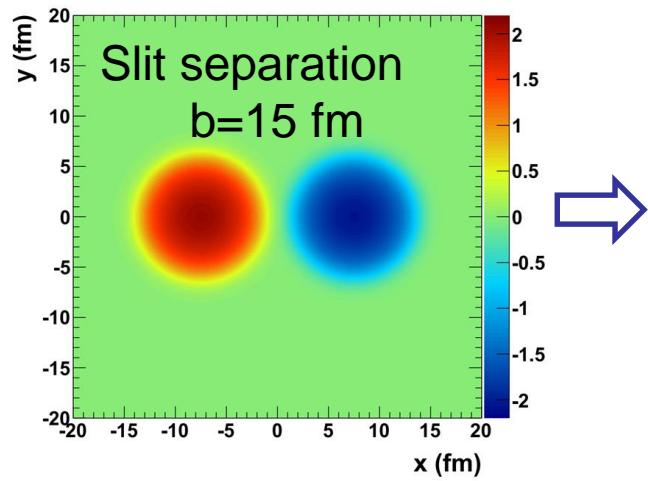
To test the Wave-particle duality

● The choice without information:

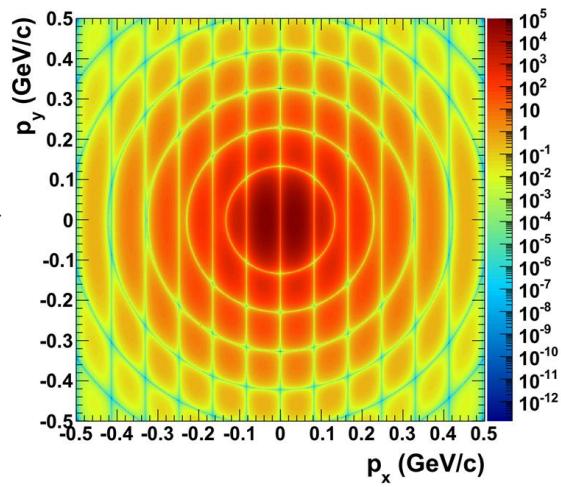
- ✓ Which is photon emitter?
- ✓ Which is the Pomeron provider?

The slits: two colliding nuclei
Interferometer of individual J/ ψ

The parity of J/ ψ is -1, the phase shift between the two slits is π

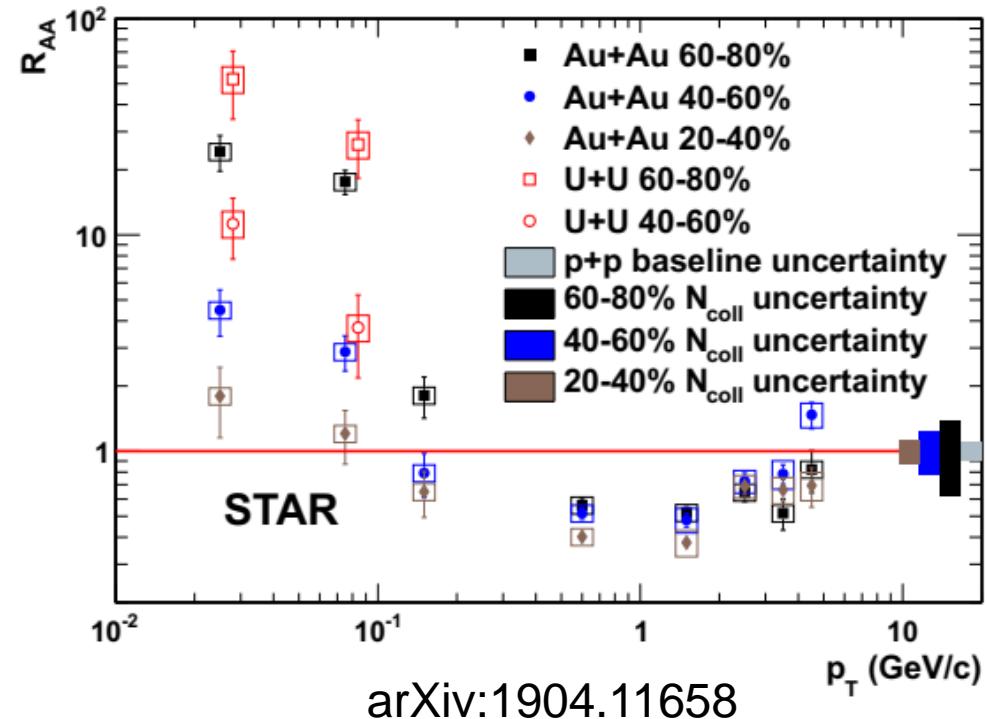
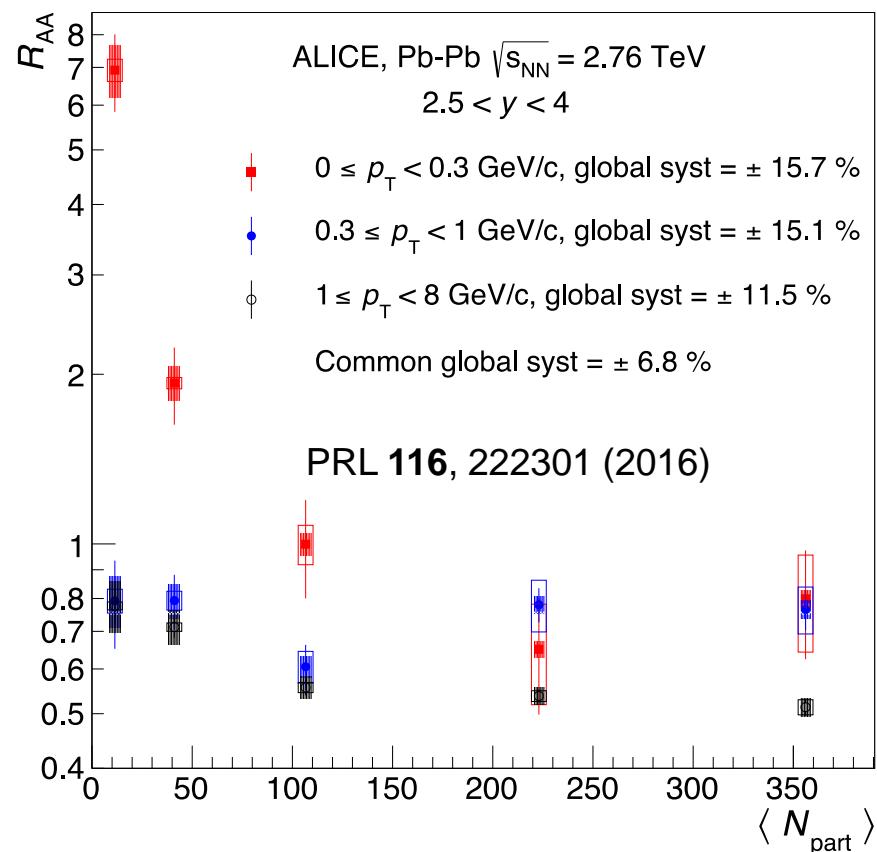


Interference of particle species: photon, electron, proton, neutron, atom, molecule, fullerene...



Interference fringes + diffraction rings

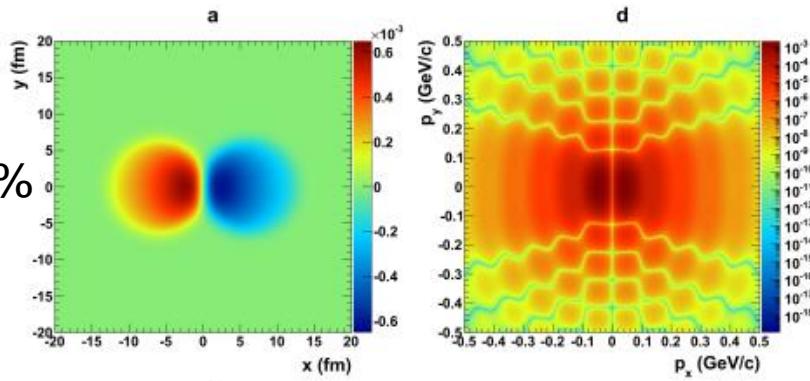
From UPC to HHIC: J/ ψ excess



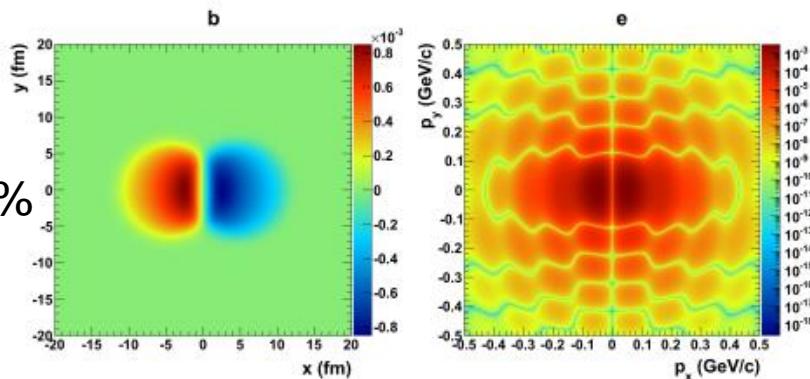
Coherent produced J/ ψ s are observed in HHIC!
 The reaction plane can be determined in HHIC.

Can we change the distance between the slits?

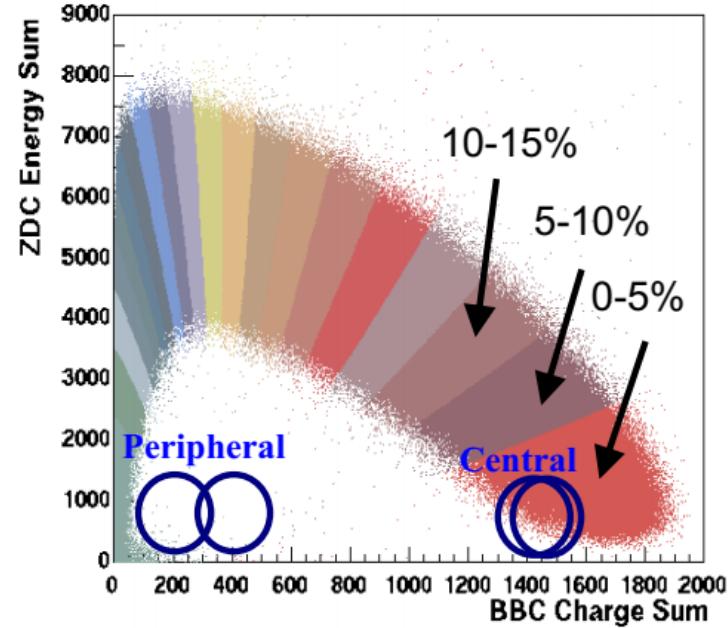
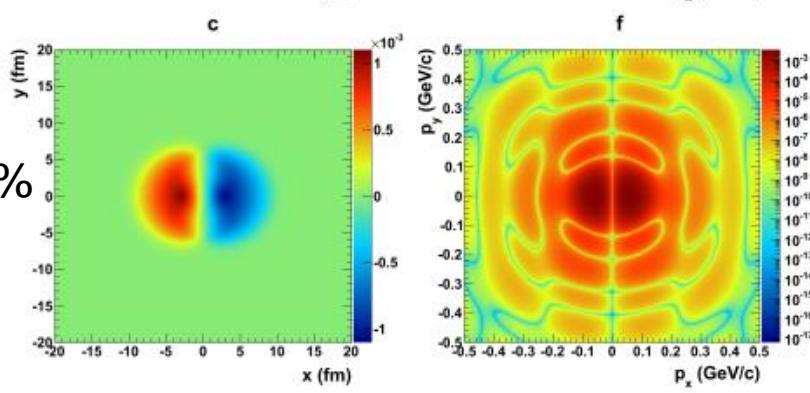
70 - 80%



40 - 50%

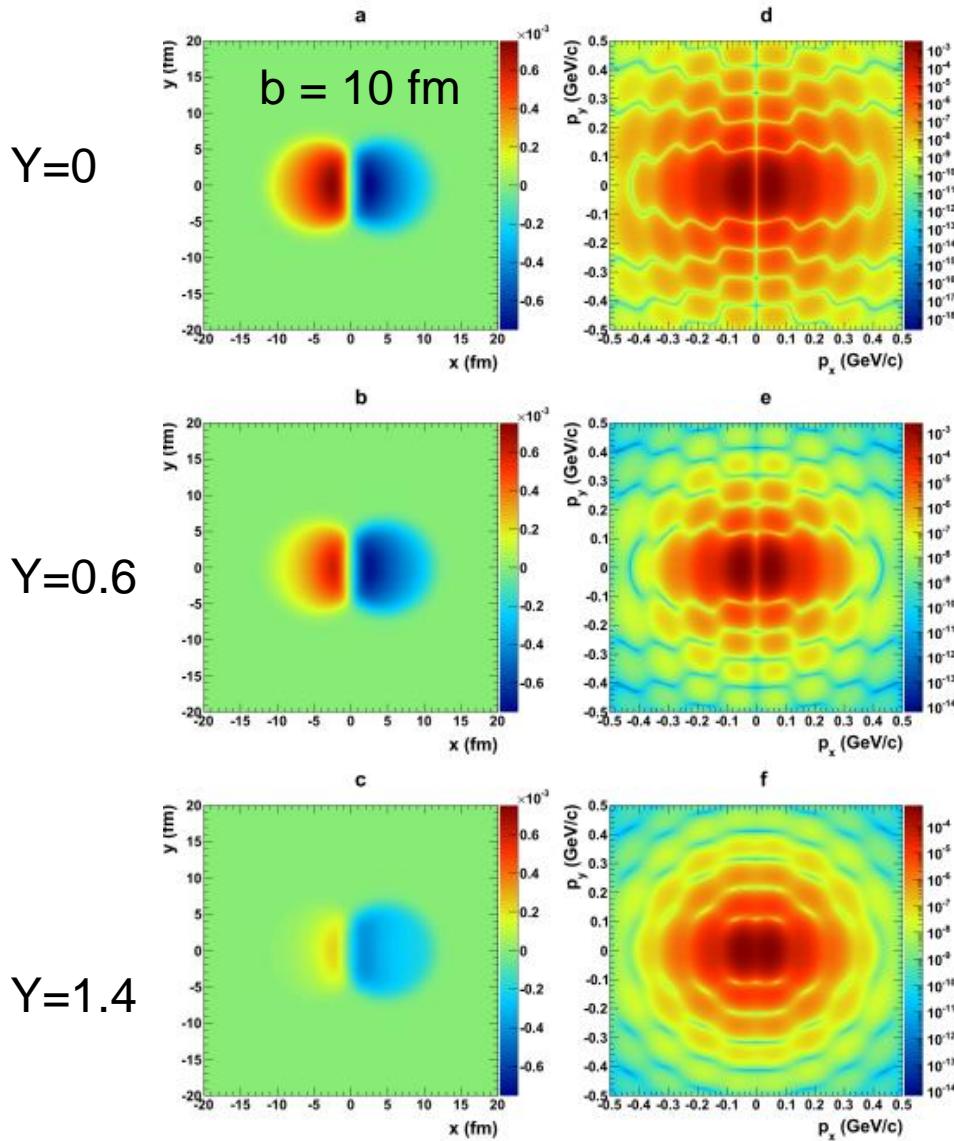


20 - 30%



- The slit separation --- impact parameter can be precisely determined by the detector!

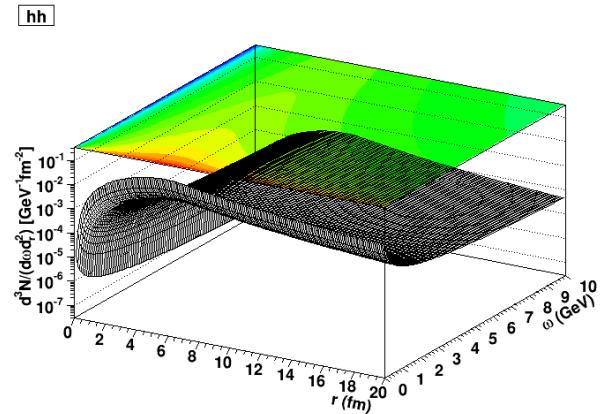
Can we dim one of the slits?



The photon energy from the two direction :

$$w_1 = \frac{1}{2} M_{J/\psi} e^{+y}$$

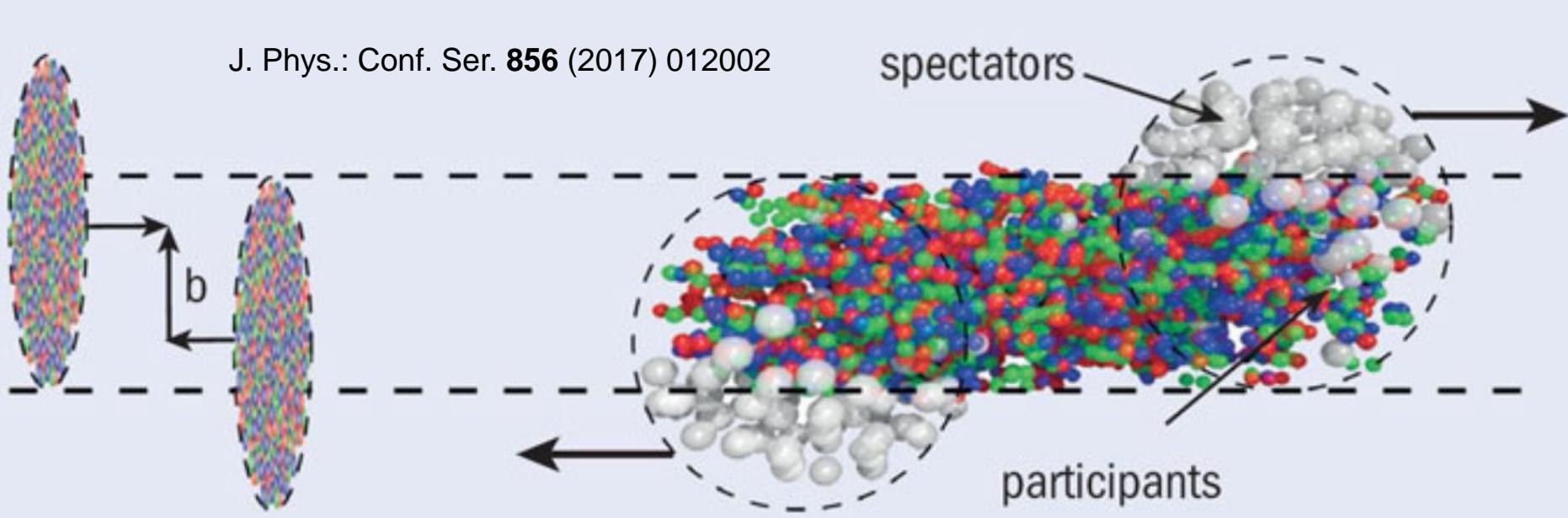
$$w_2 = \frac{1}{2} M_{J/\psi} e^{-y}$$



- The amplitude from the two direction will change with rapidity!

Observation Affects Reality!

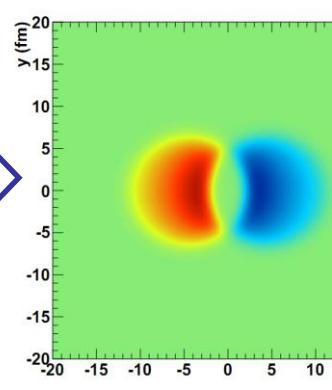
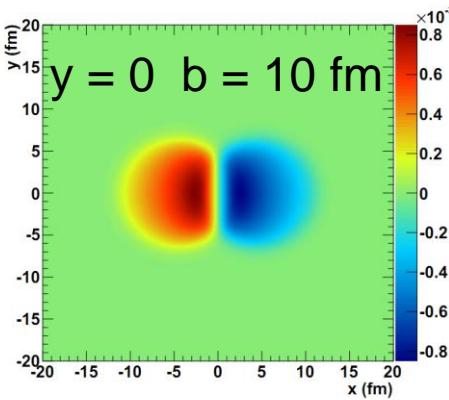
- Take the Young's Double-Slit Interference Experiment as example:
 - ✓ If we place detectors at the slits, knows which slit the photon goes ("which-way" or "path" solved), the interference pattern disappear!
--- Observation collapse the wave function!



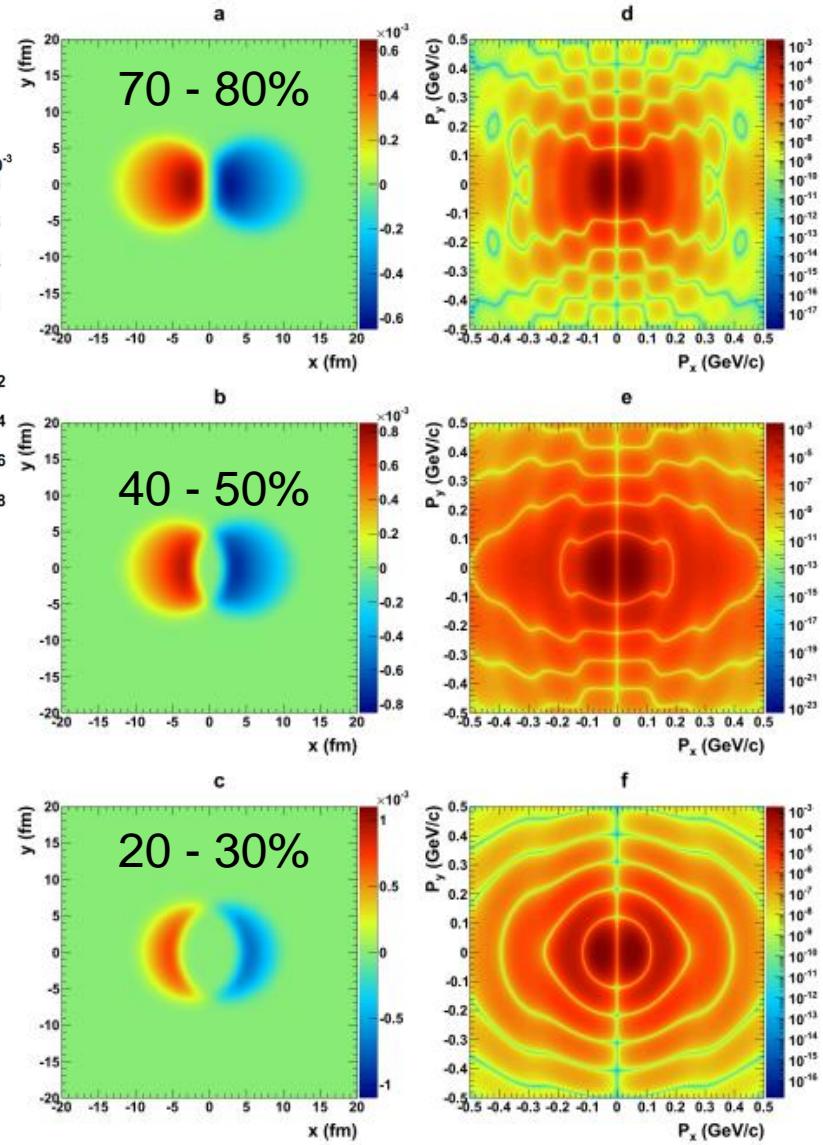
- The strong interactions in overlap region detect the J/ψ , and prohibit the coherent photoproduction?

The interference with observation effect

Exclude the amplitude in the overlap region!

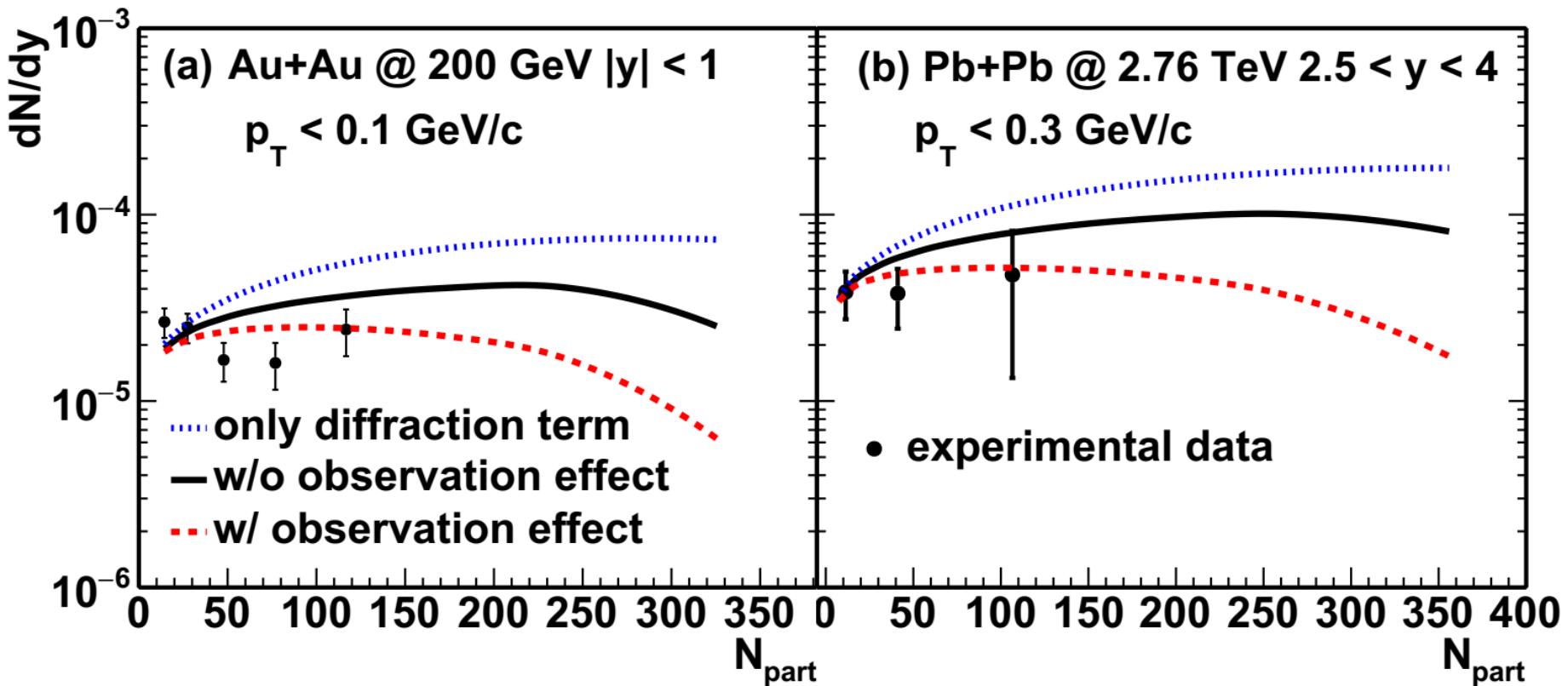


- The interference and diffraction pattern **change significantly with the observation effect!**



The observation effect on cross section

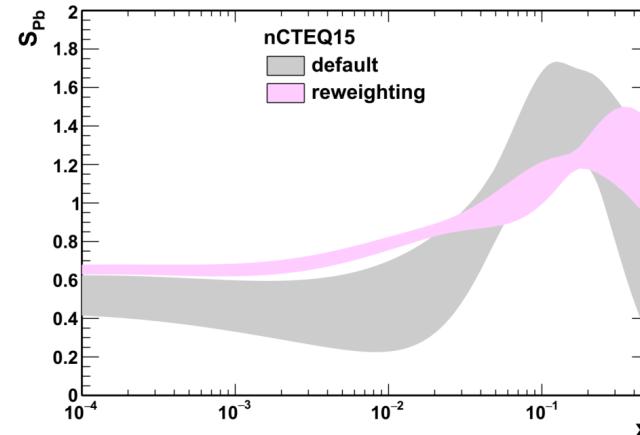
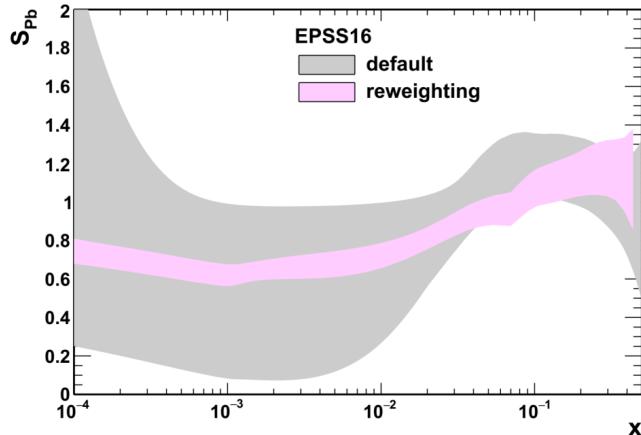
W. Zha et al., Phys. Rev. C 99, 061901(R)



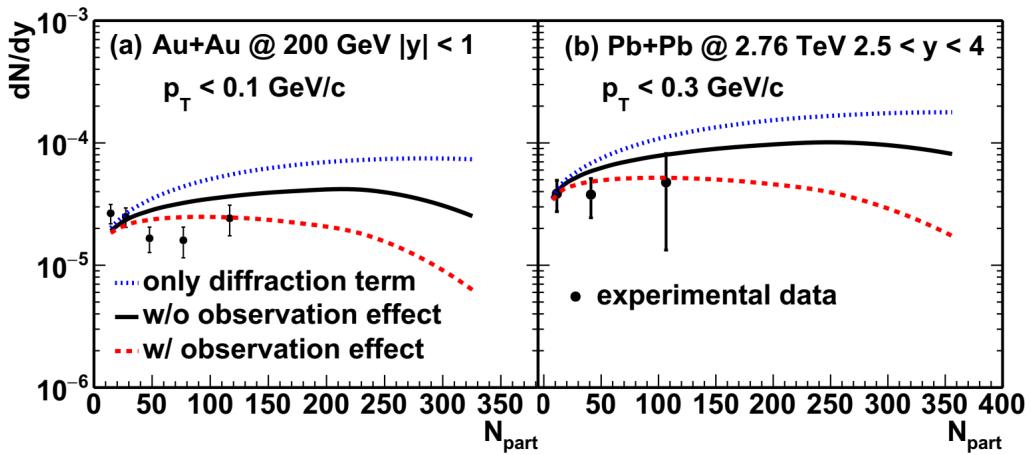
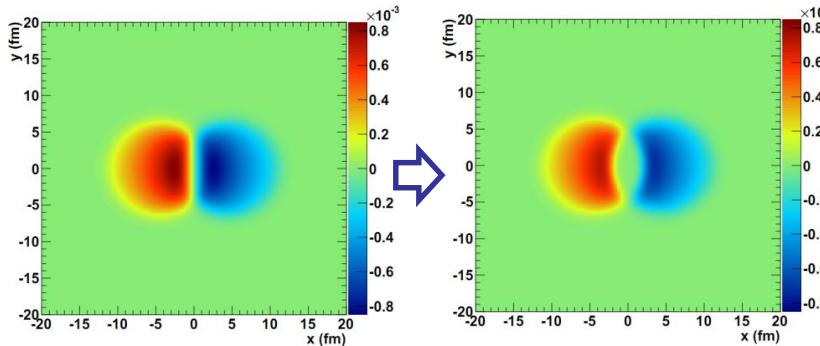
- The observation effect **significantly reduce** the cross section!
- The calculations with observation effect describe the data better!
- More precise experimental measurements are needed

Summary

□ Constrain the nuclear PDF:



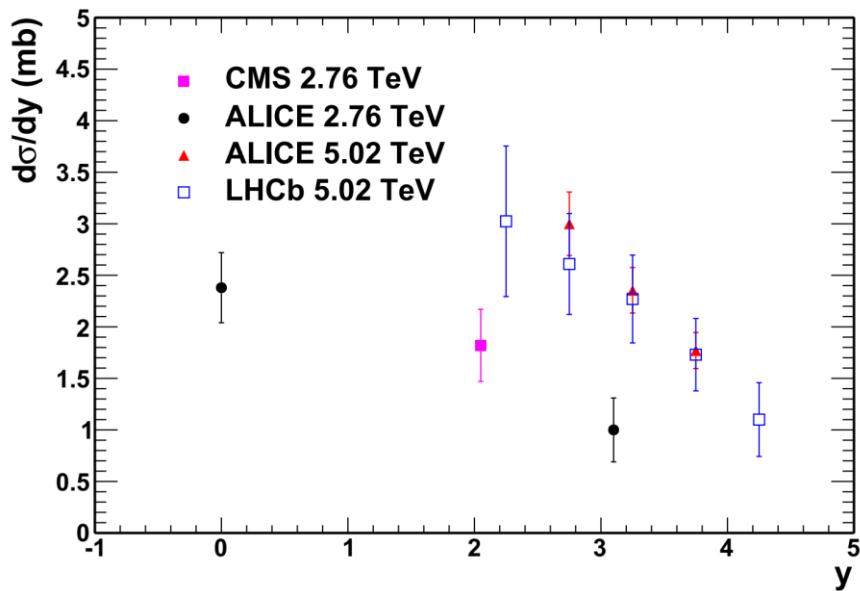
□ Test the Wave-particle duality



Backup

- Use impulse approximation for proton reference

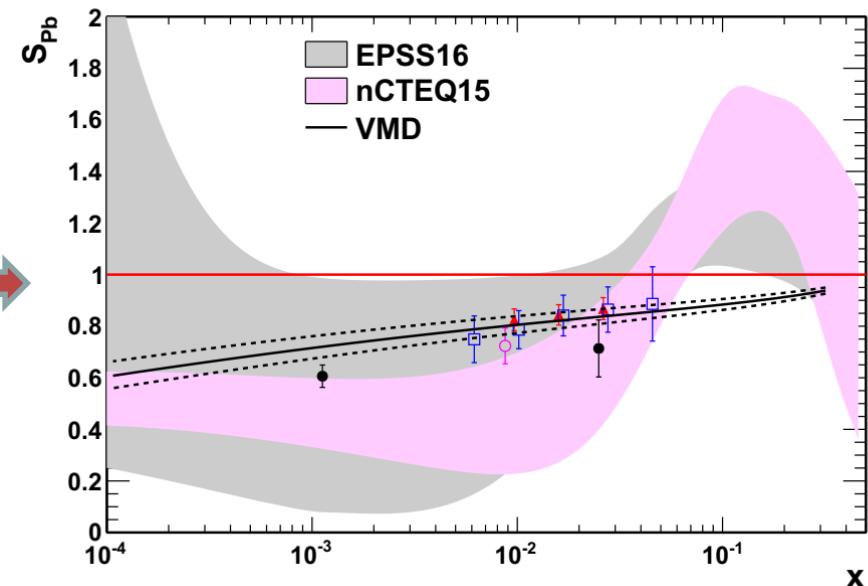
JHEP 1310, 207 (2013)



LHCb-CONF-2018-003 EPJC **73** (2013) 2617

NPA **967** (2017) 273 PLB **718** (2013) 1273

PLB **772** (2017) 489



EPJC **77** (2017) 163 PRD **93** (2016) 085037

VMD approach describe the data reasonably well!

Significant shadowing effect at small x !