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National Natural Science  
Foundation of China



# Tale of coherent photon products: from **UPC** to **HHIC**

Wangmei Zha

University of Science and Technology of China

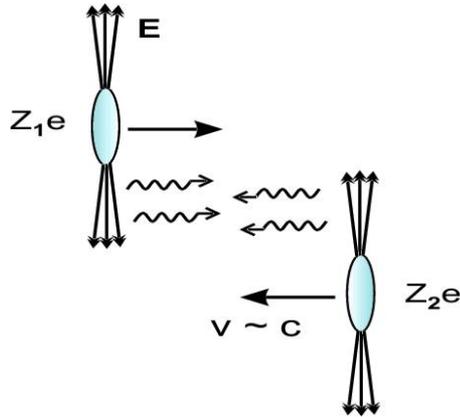
International Conference on Hard and Electromagnetic  
Probes of High-Energy Nuclear Collisions

Aix-Les-Bains, Savoie, France,

# Coherent photons as “partons” in heavy-ion collisions

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Coherent limitation:  $Q^2 \leq 1/R^2 \Rightarrow$  quasi-real !

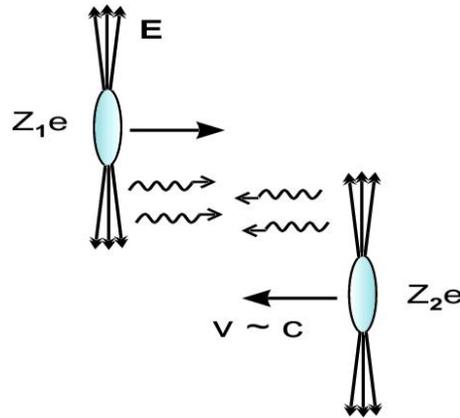
Photon four momentum:  $q^u = (\omega, \vec{q}_T, \omega/v)$

$$Q^2 = \frac{\omega^2}{\gamma^2} + q_T^2$$

$$\omega \leq \omega_{max} \sim \frac{\gamma}{R}$$

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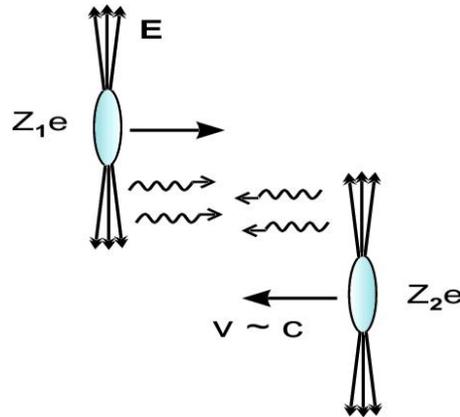
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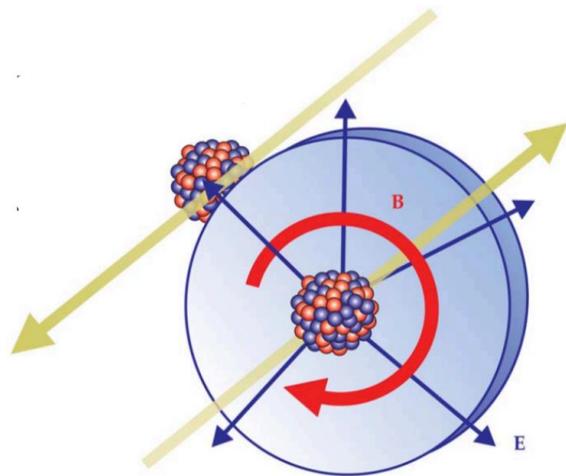
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- View photons as “partons” being present with fast moving ions!



The extent of photons swarming about the ions:

The radius of nuclear matter  $R_{Nuc} \sim 6.3$  fm (Au)

$R_{photons} \gg R_{Nuc}$

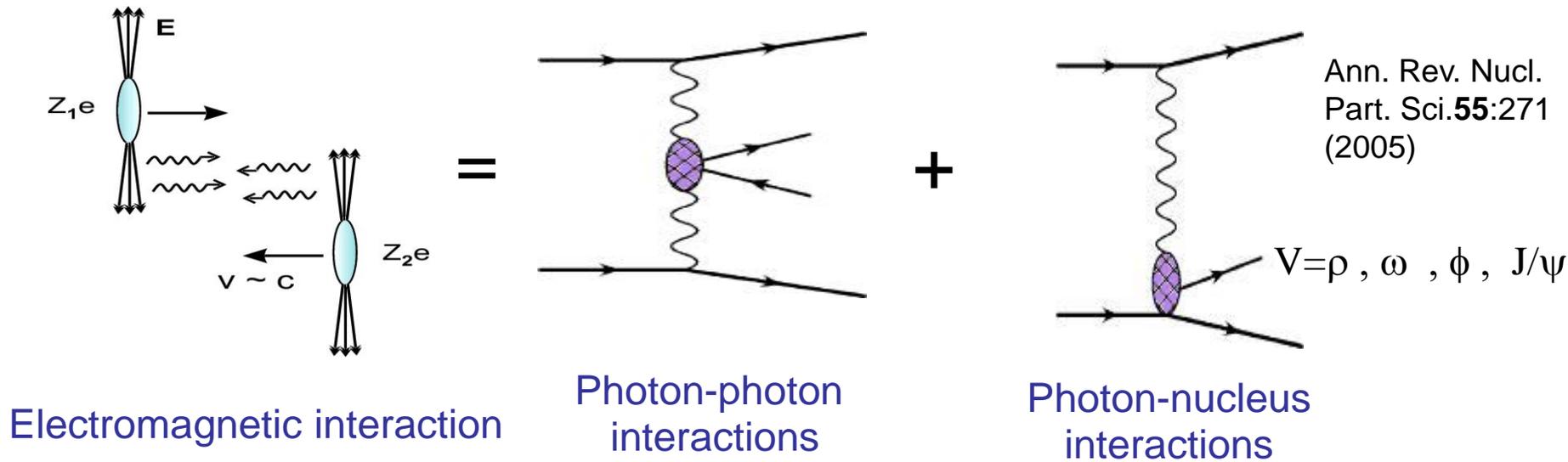
Take the photoproduction of  $\rho$  (Au+Au 200 GeV) in ultra-peripheral collisions (UPCs) as example:  $\langle R_{producton} \rangle \sim 40$  fm

Physics Today **70**, 10, 40 (2017)

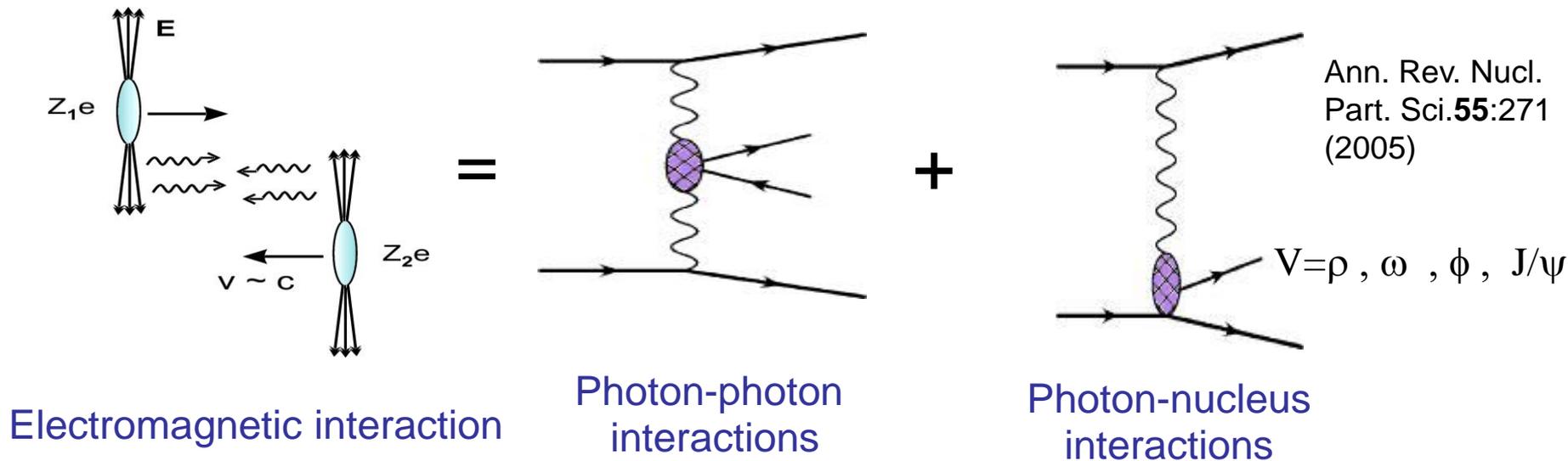
# Photon interactions in A+A

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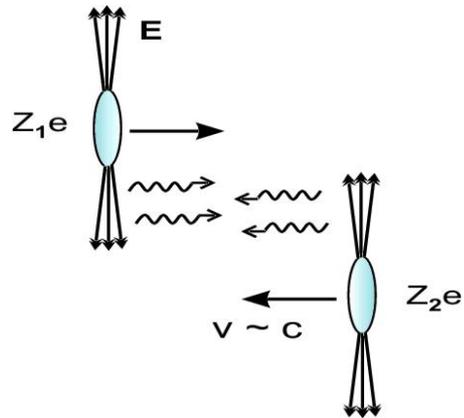
# Photon interactions in A+A



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

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

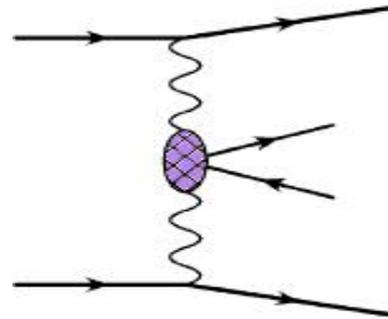
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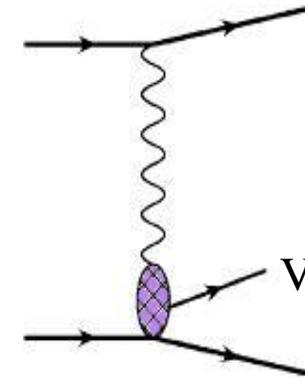
Electromagnetic interaction

J. Jowett *et al.*, IPAC 2016

collider species		RHIC Au+Au	RHIC U+U	LHC Pb+Pb
$\sqrt{s_{NN}}$	GeV	200	192.8	5520
BFPP	b	117	329	272
single EMD	b	94.15	150.1	215
mutual EMD	b	3.79	7.59	6.2
nuclear	b	7.31	8.2	7.9
total	b	218.46	487.3	494.9



Photon-photon interactions

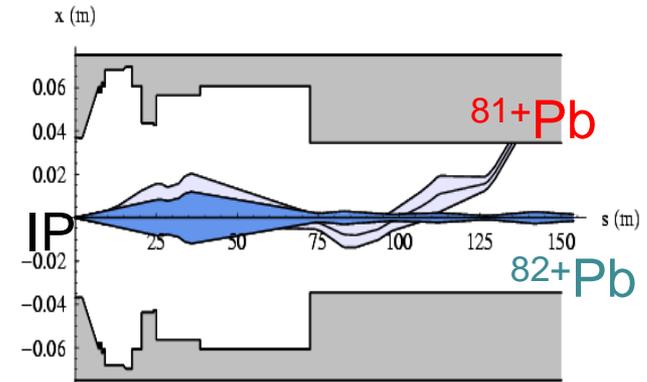


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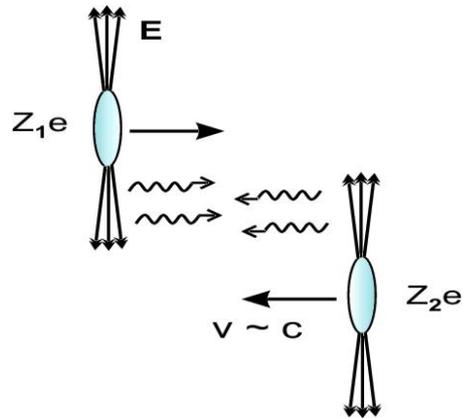
Ann. Rev. Nucl. Part. Sci. **55**:271 (2005)

$V = \rho, \omega, \phi, J/\psi$

The cross section is **huge!**  
Important source for beam loss!



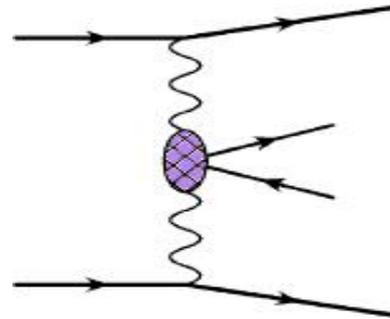
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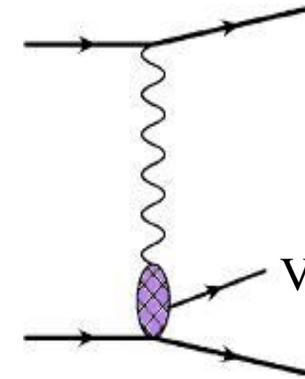
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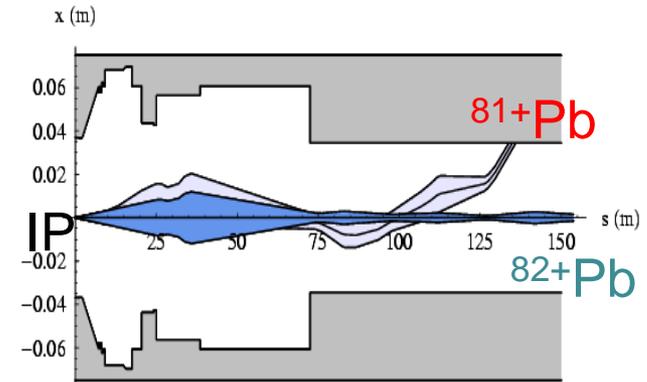


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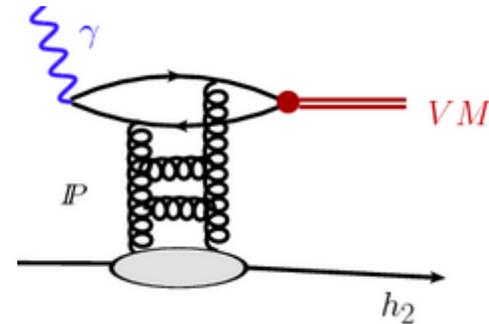
- Conventionally believed to be **only exist in ultra-peripheral collisions (UPC)** to keep “coherent”!

# Vector meson photon-production

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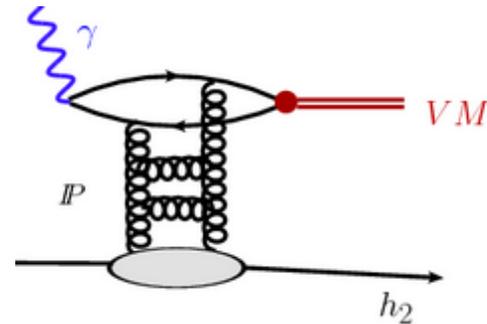
# Vector meson photon-production

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



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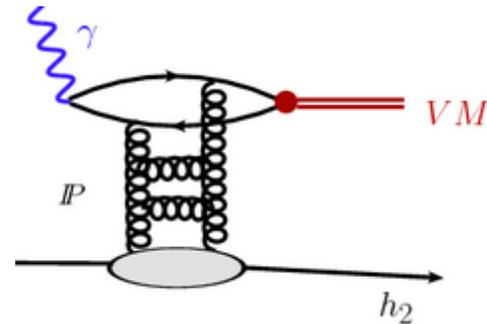
- Sensitive to the gluon distribution:

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

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

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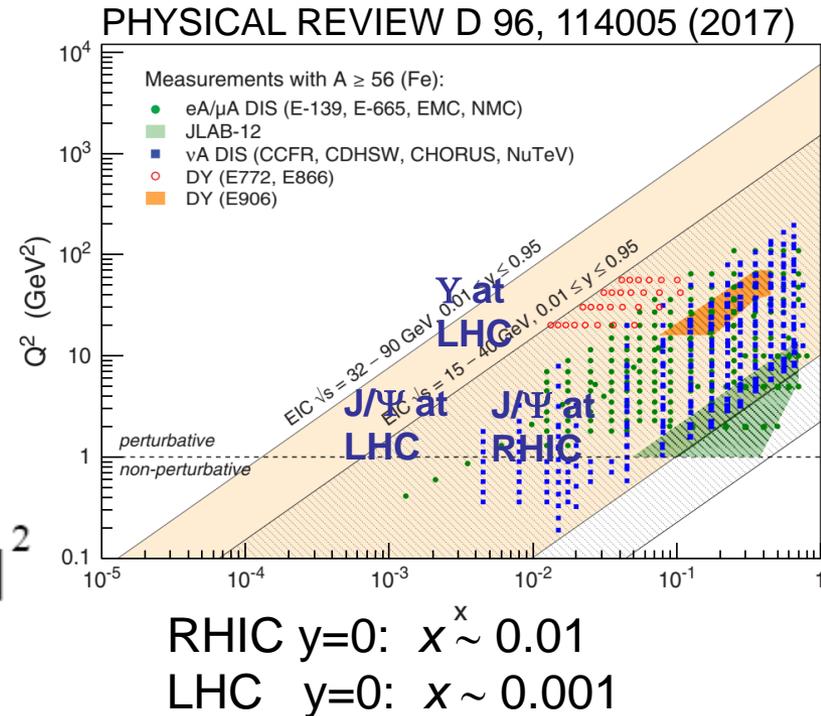
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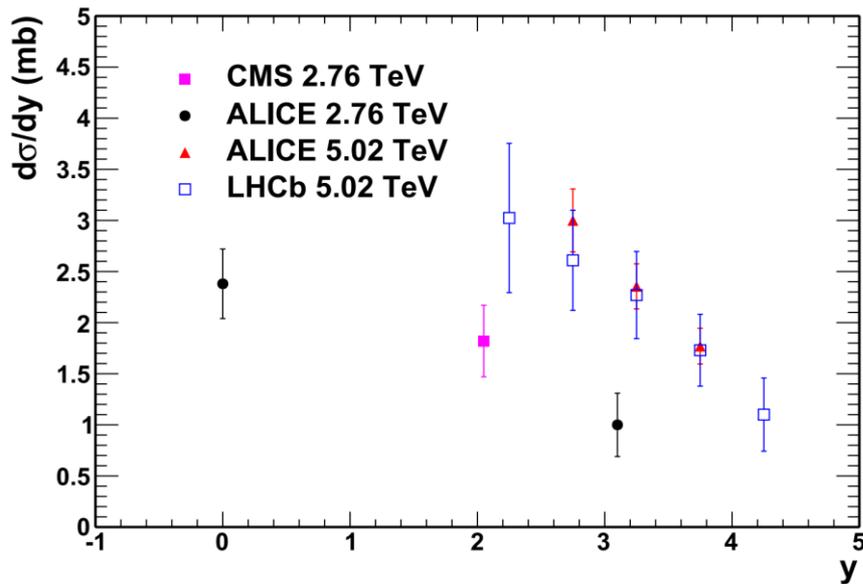
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LHCb-CONF-2018-003 EPJC **73** (2013) 2617

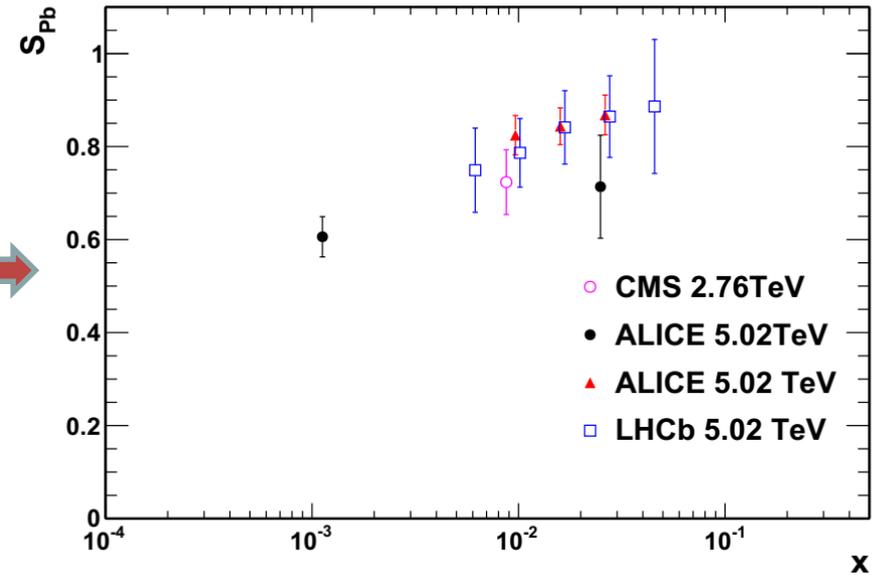
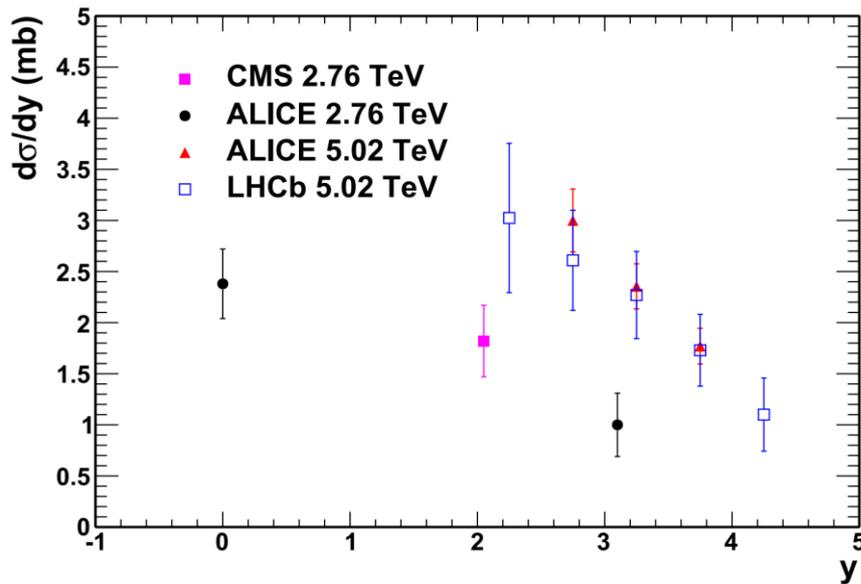
NPA **967** (2017) 273 PLB **718** (2013) 1273

PLB **772** (2017) 489

# Nuclear shadowing from $J/\psi$ measurements in UPCs

- Use impulse approximation for proton reference

JHEP 1310, 207 (2013)



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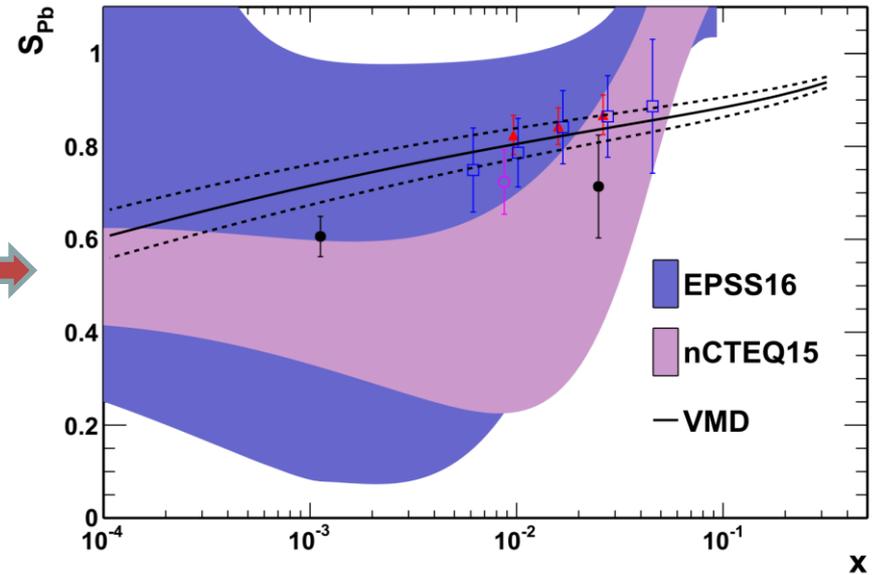
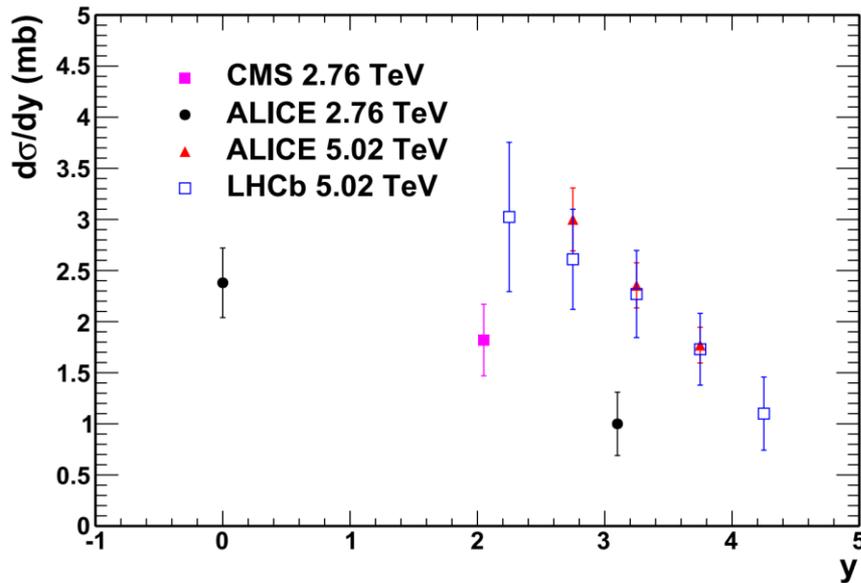
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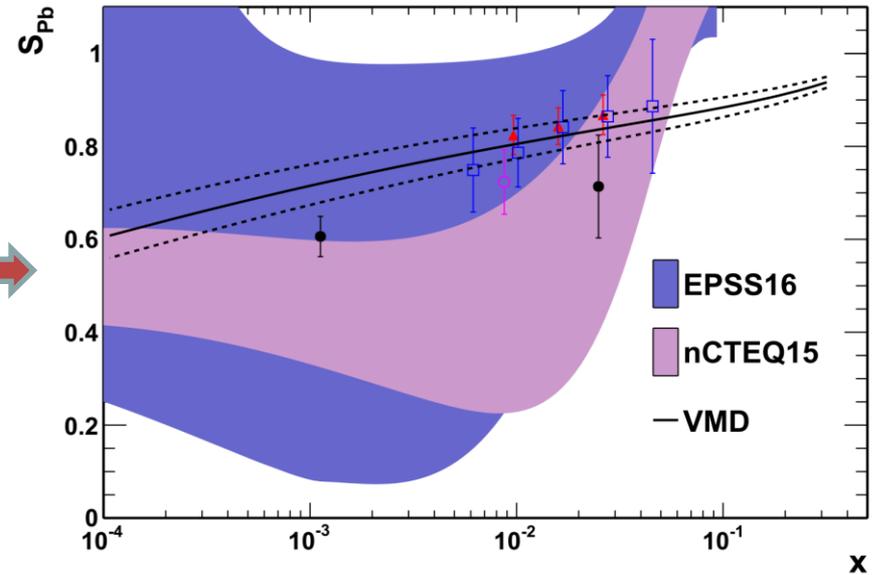
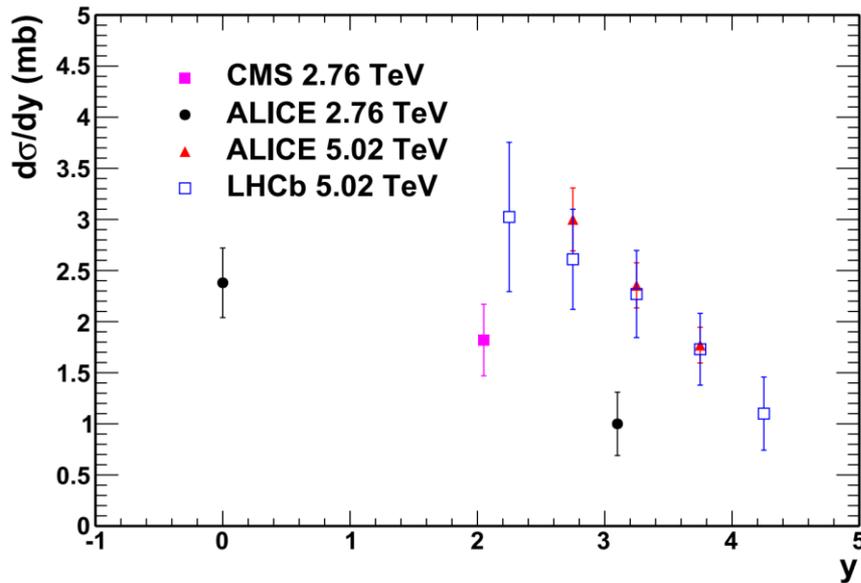
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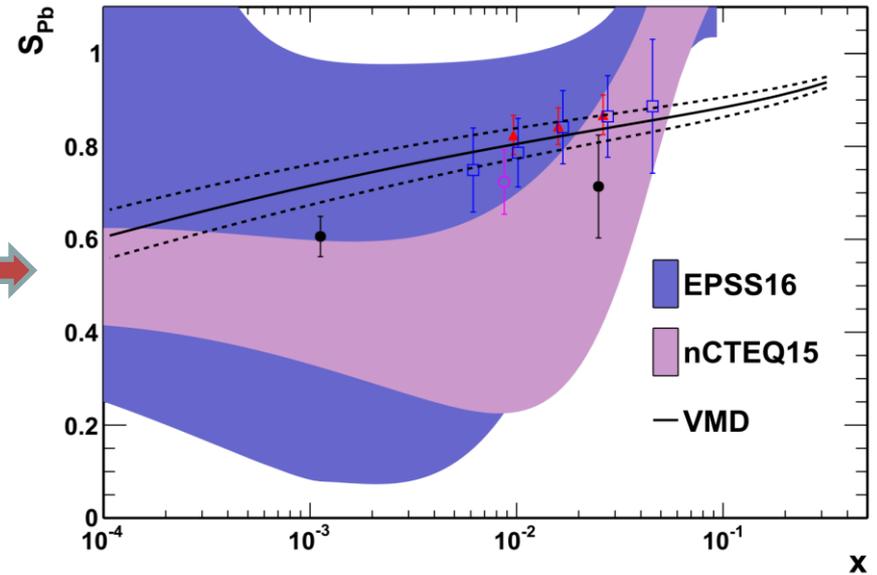
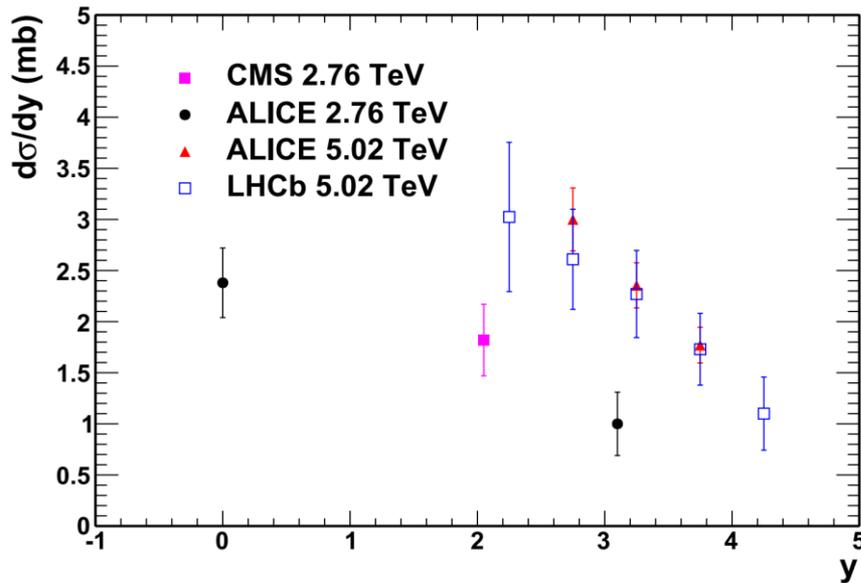
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More efforts to shrink the error band for gluon PDF!

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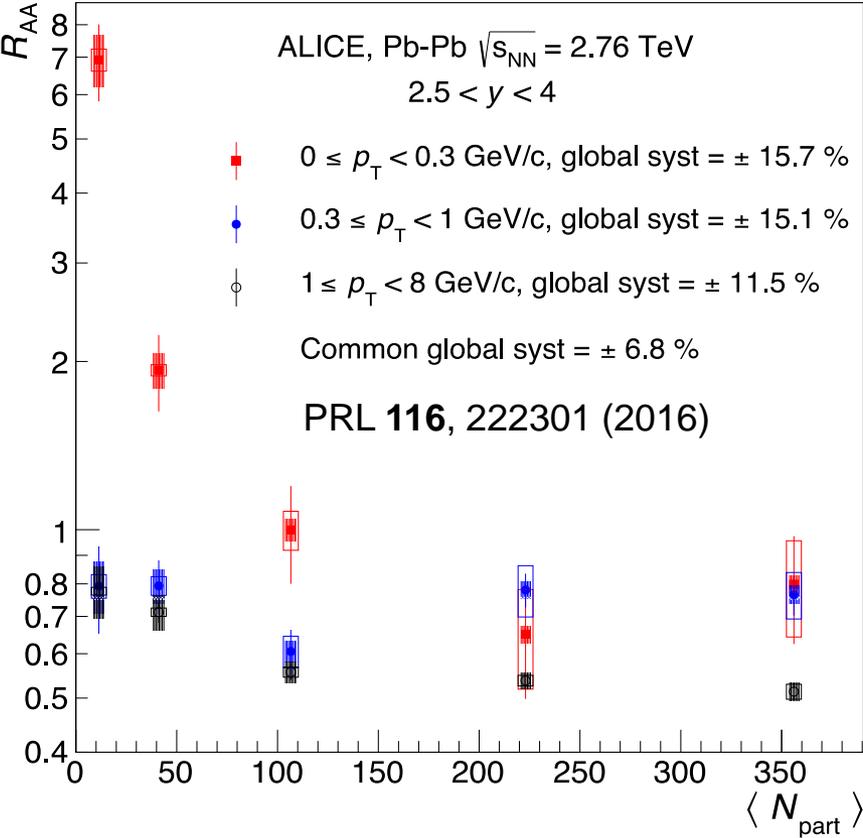
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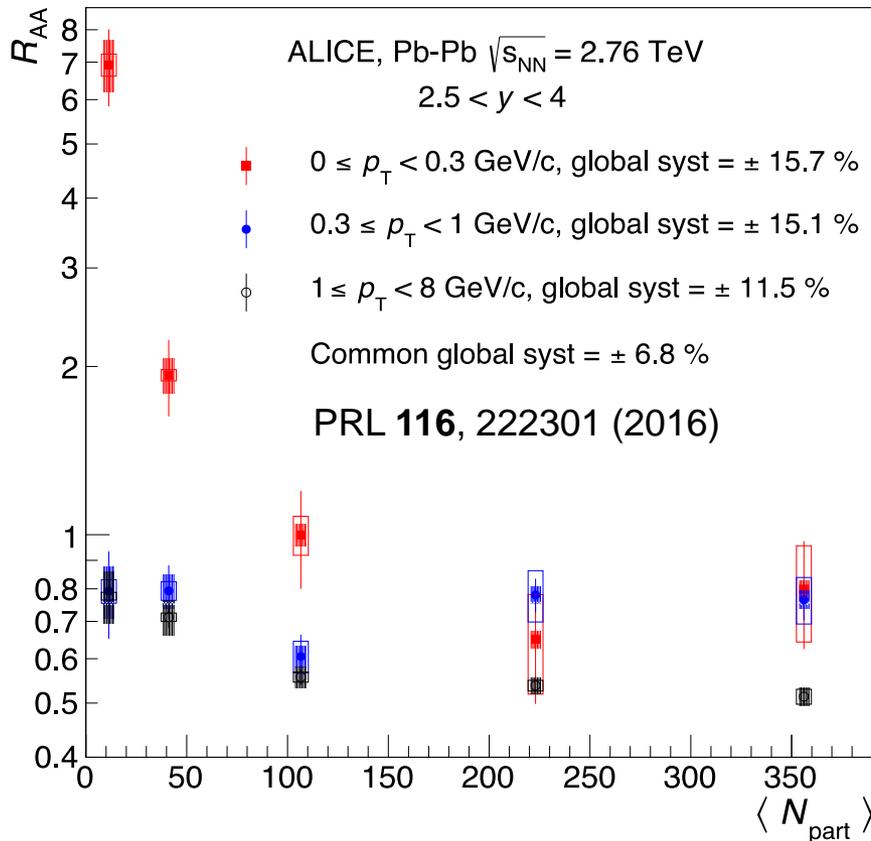
VMD approach describe the data reasonably well!

More efforts to shrink the error band for gluon PDF!

# Anomalous excess of J/ψ production observed at ALICE

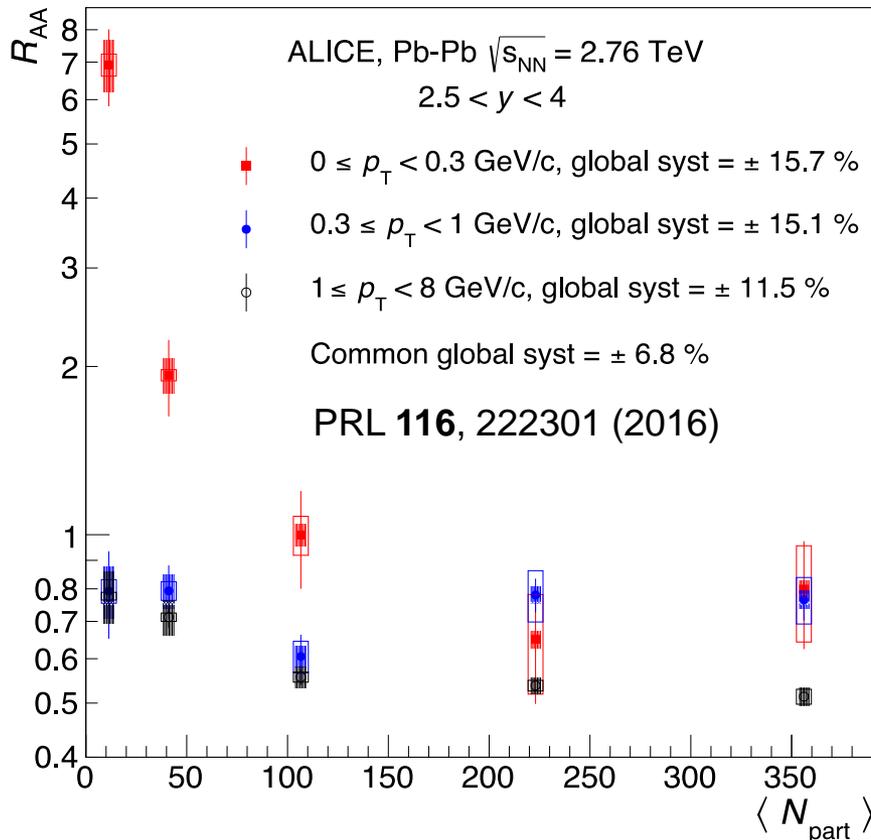


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- Significant enhancement of  $J/\psi$  yield observed in  $p_T$  interval 0 – 0.3 GeV/c for peripheral collisions (50 – 90%).
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- Origin from **coherent photon-nucleus interactions?**

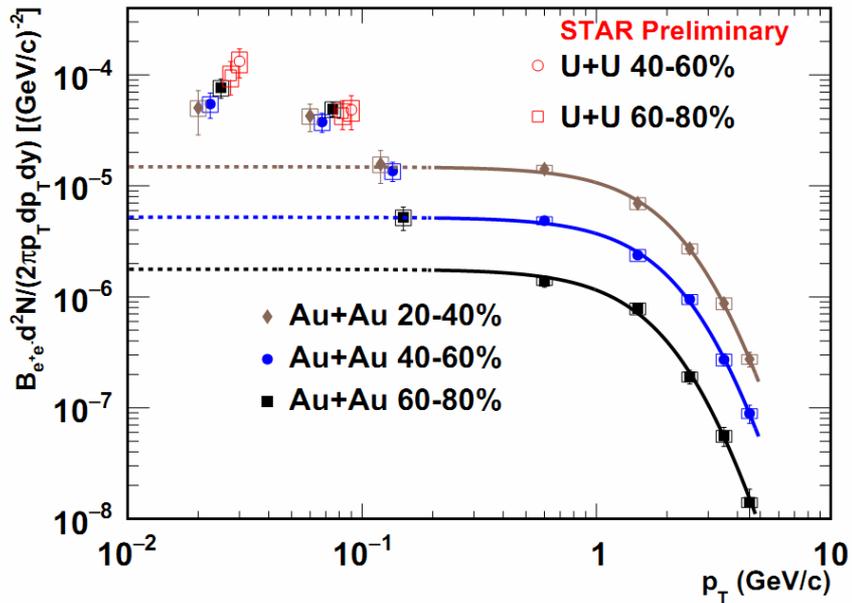
# What does STAR say for **the excess**?

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Journal of Physics: Conference Series **779**, 012039 (2017)

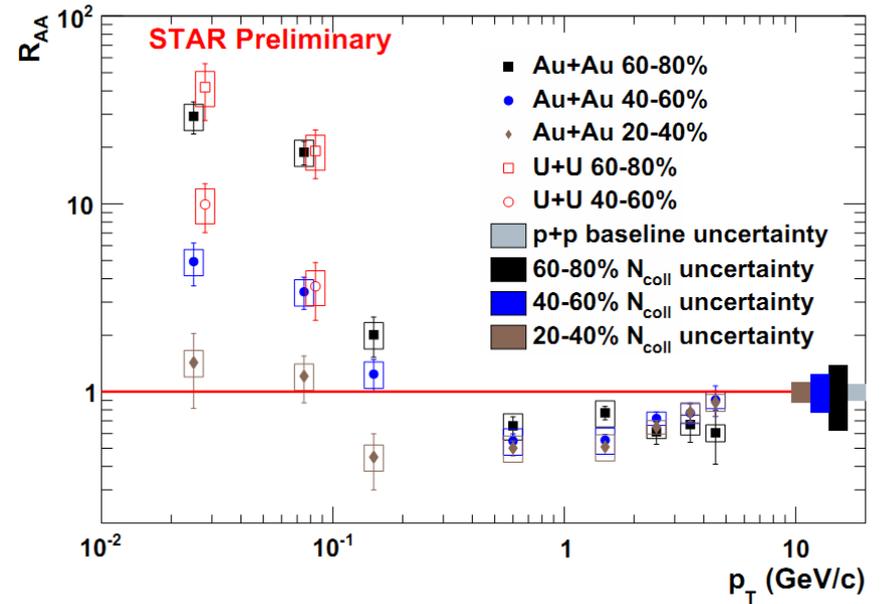
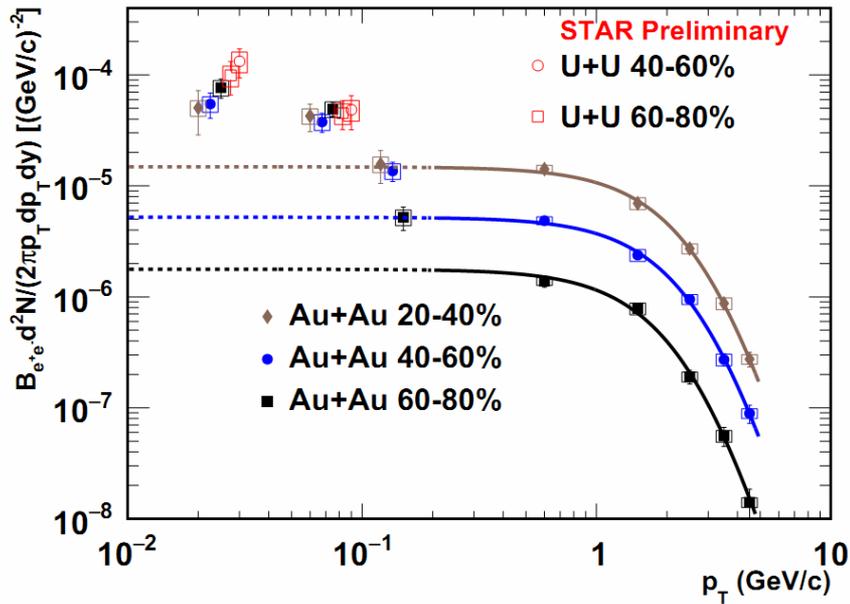
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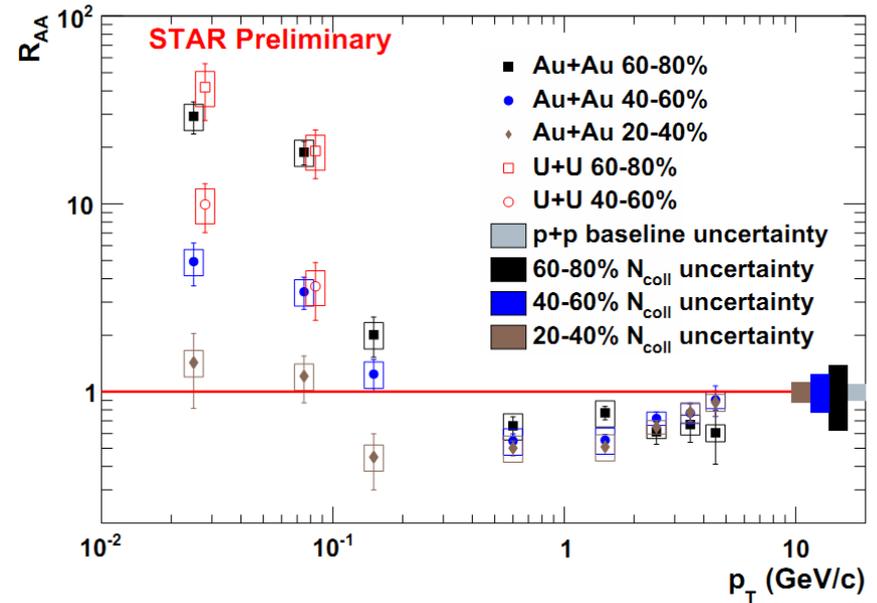
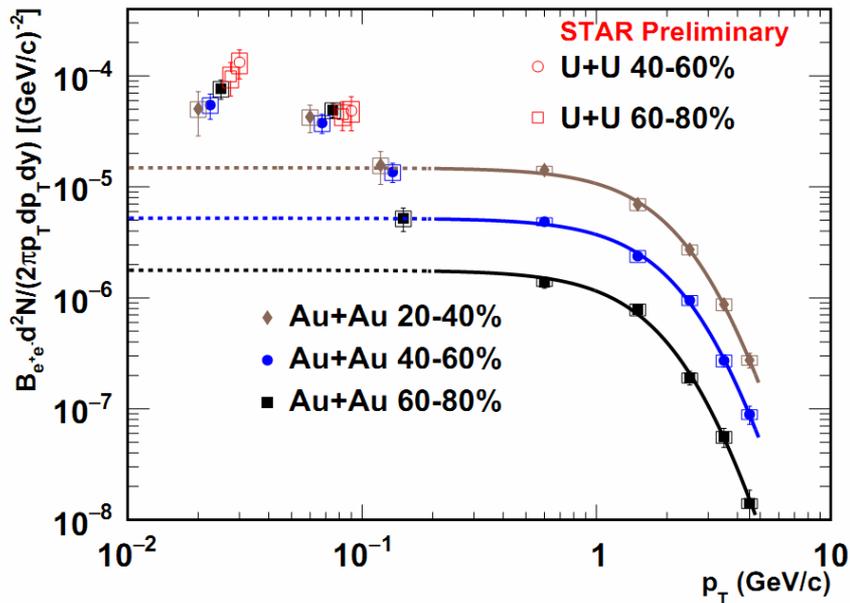
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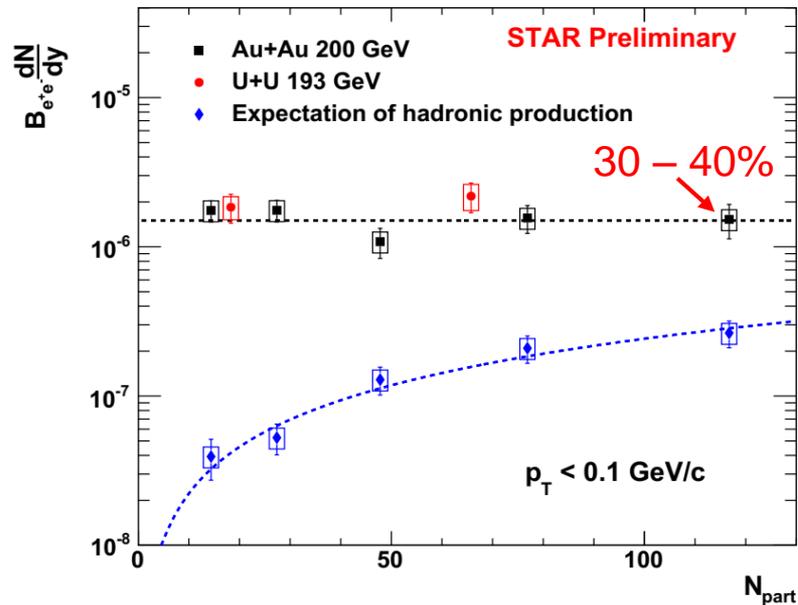


- Significant enhancement of  $J/\psi$  yield observed at  $p_T$  interval 0 – 0.2 GeV/c for peripheral collisions (40 – 80 %)!
- No significant difference between Au+Au and U+U collisions.

# The excess yield and $dN/dt$ distribution

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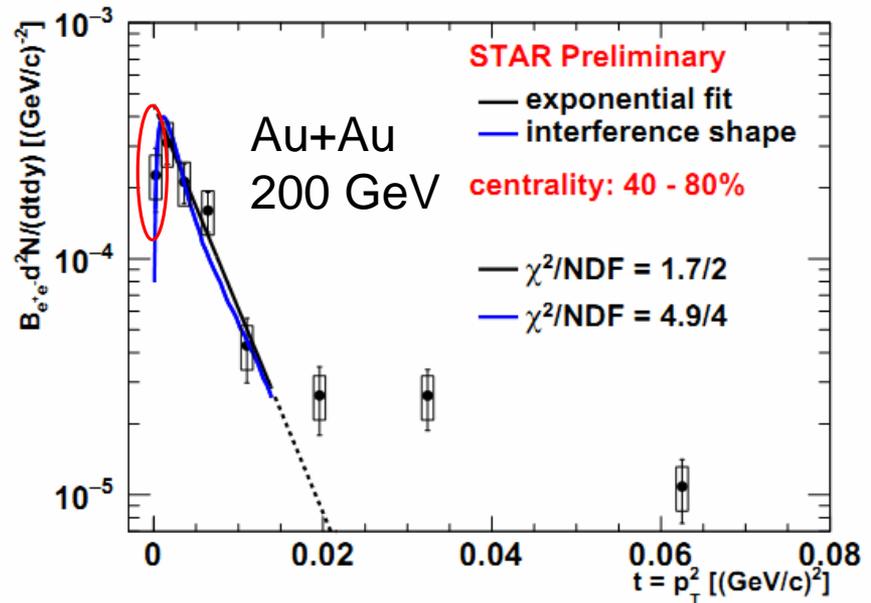
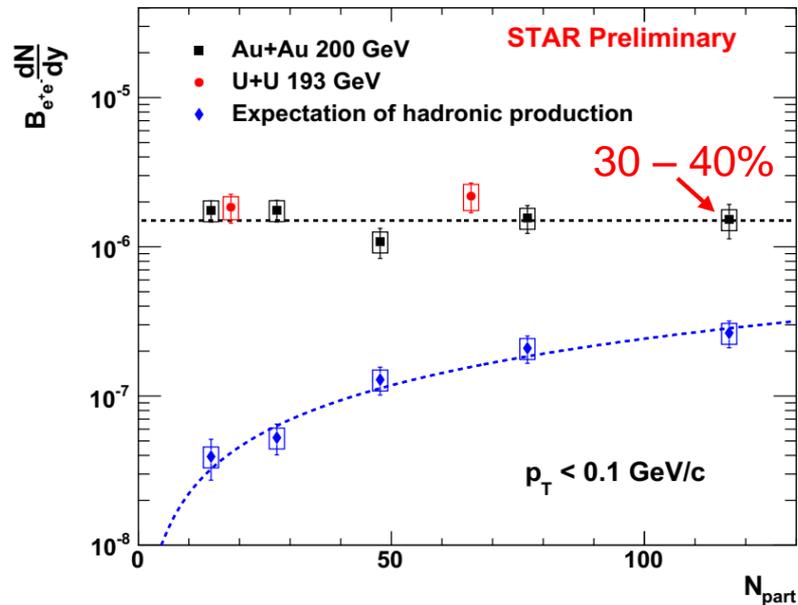
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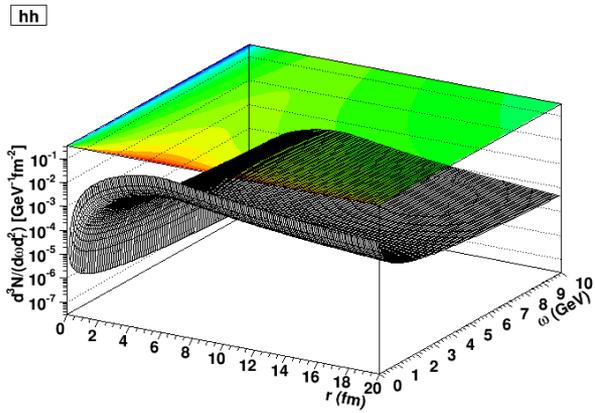
- Similar structure to that in UPC case!
- Indication of interference!
  - ✓ Interference shape from calculation for UPC case PRL **84** 2330 (2000)
- Similar slope parameter!
  - ✓ Slope from STARLIGHT prediction in UPC case –  $196 \text{ (GeV}/c)^{-2}$
  - ✓ Slope w/o the first point:  $199 \pm 31 \text{ (GeV}/c)^{-2}$   
 $\chi^2/NDF = 1.7/2$
  - ✓ Slope w/ the first point:  $164 \pm 24 \text{ (GeV}/c)^{-2}$   
 $\chi^2/NDF = 5.9/3$

# Calculation of photoduction in hadronic collisions

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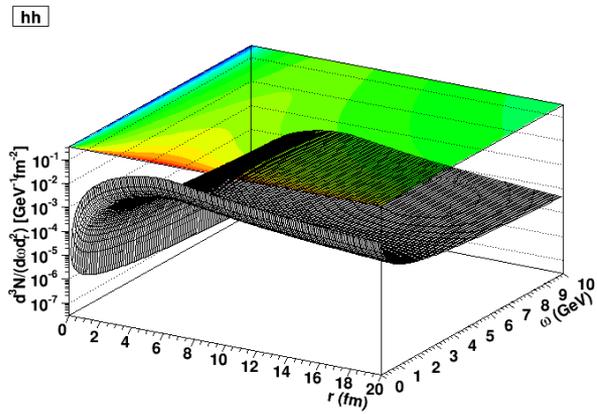
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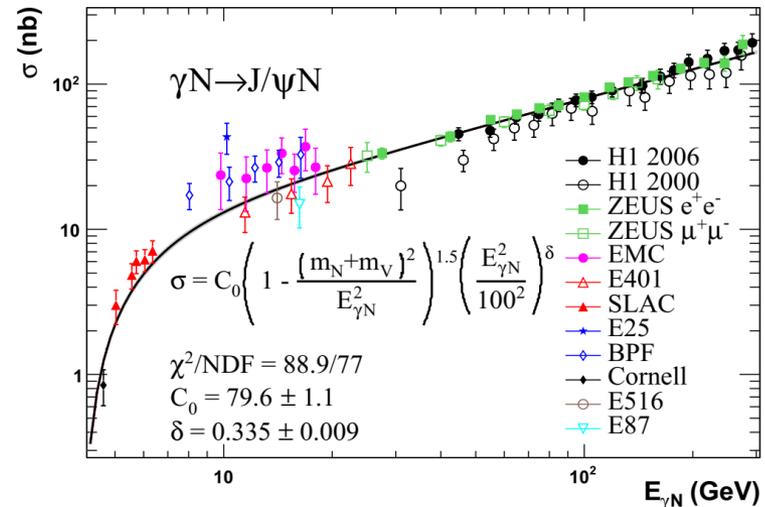
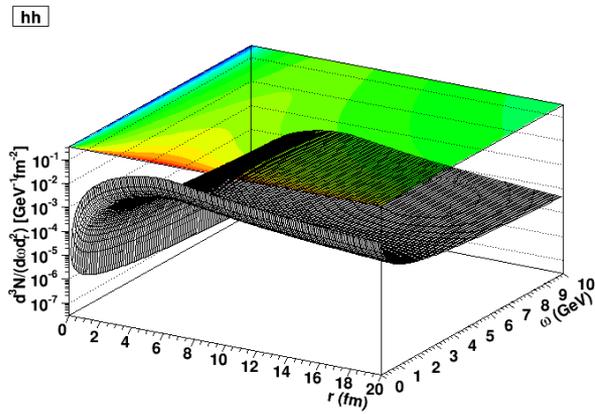
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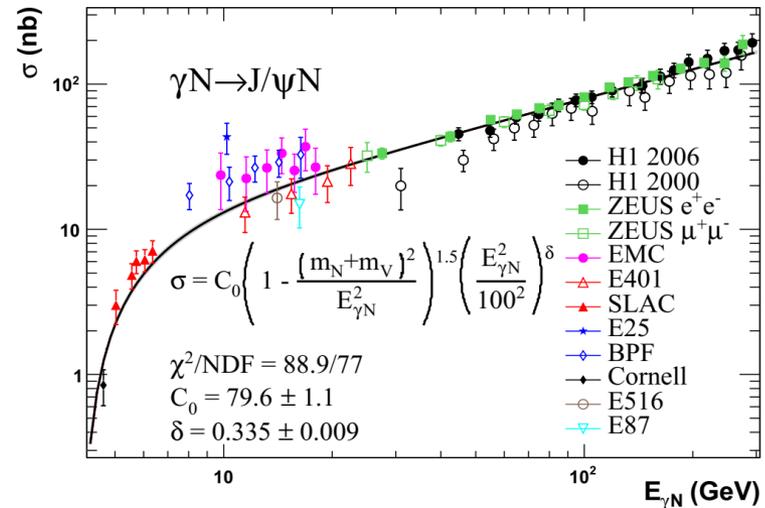
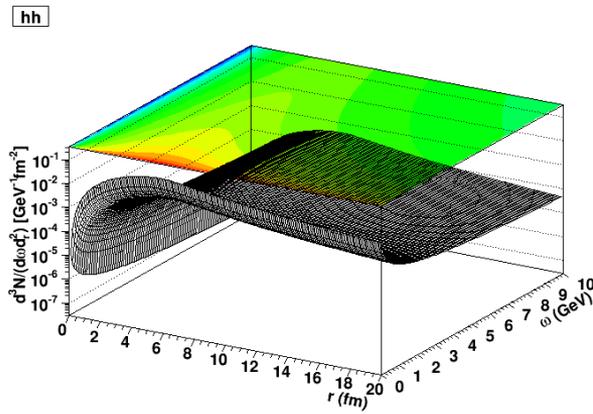


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- Microscope cross sections?
  - ✓ J/ψ cross section in γ+p convoluted with Glauber +VMD

W. Zha et al., PRC **97** (2018) 044910

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- Possible disruption by the hadronic collisions?

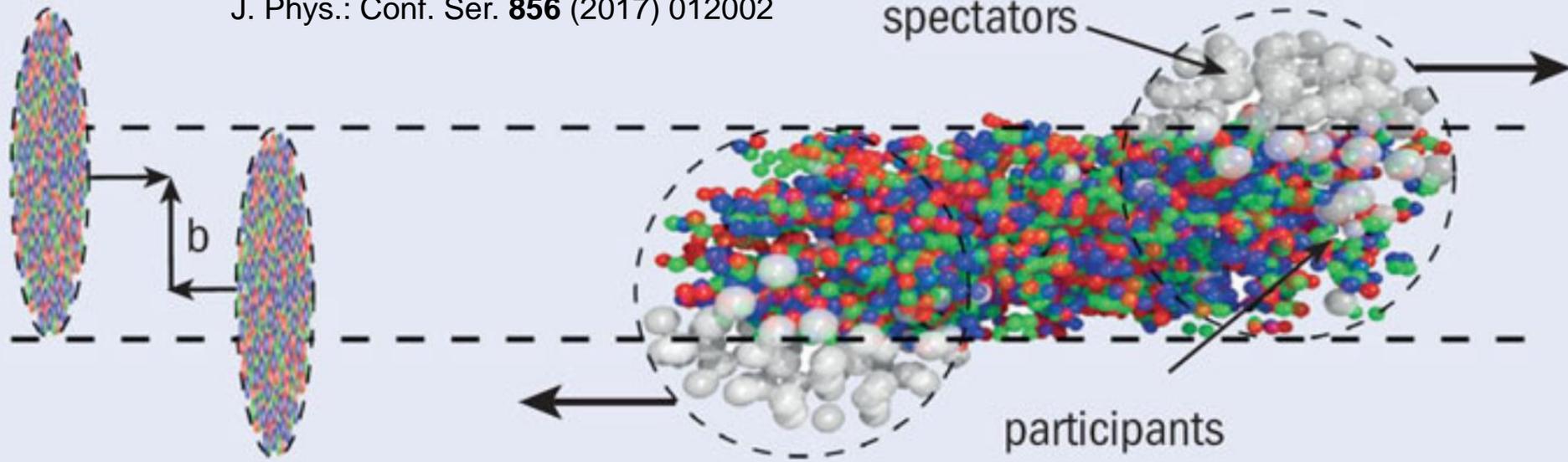
W. Zha et al., PRC **97** (2018) 044910

# Possible disruption from overlap region?

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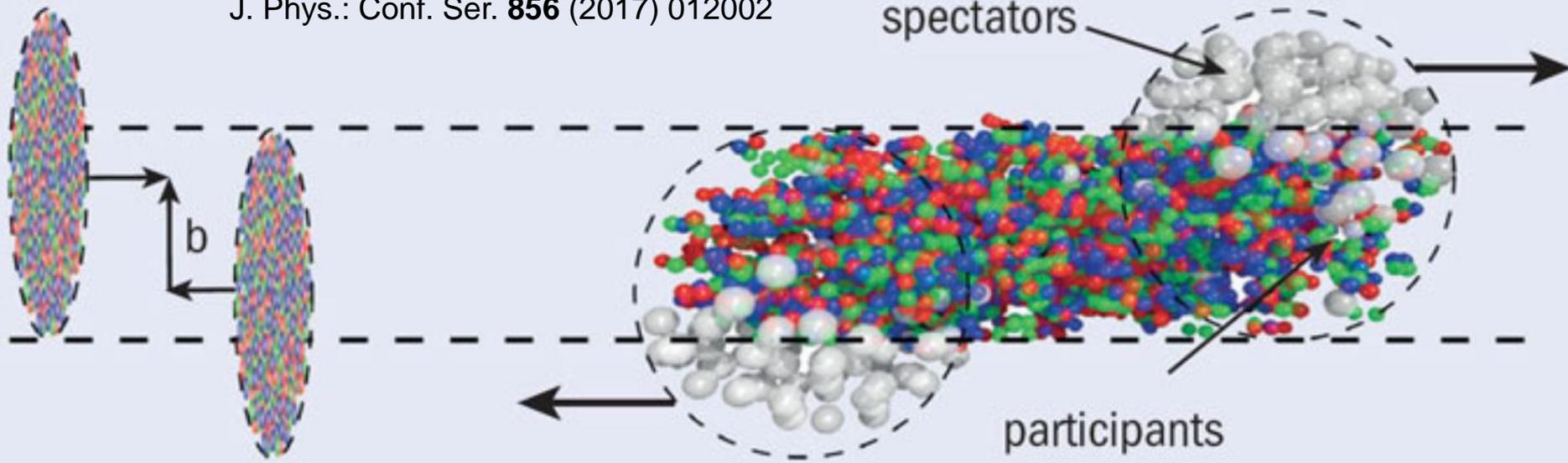
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J. Phys.: Conf. Ser. **856** (2017) 012002



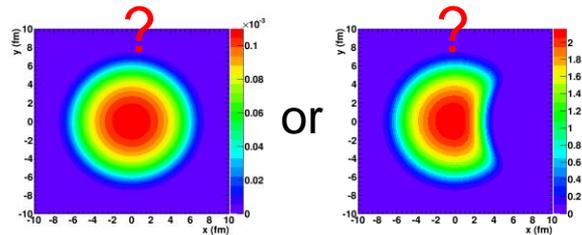
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J. Phys.: Conf. Ser. **856** (2017) 012002



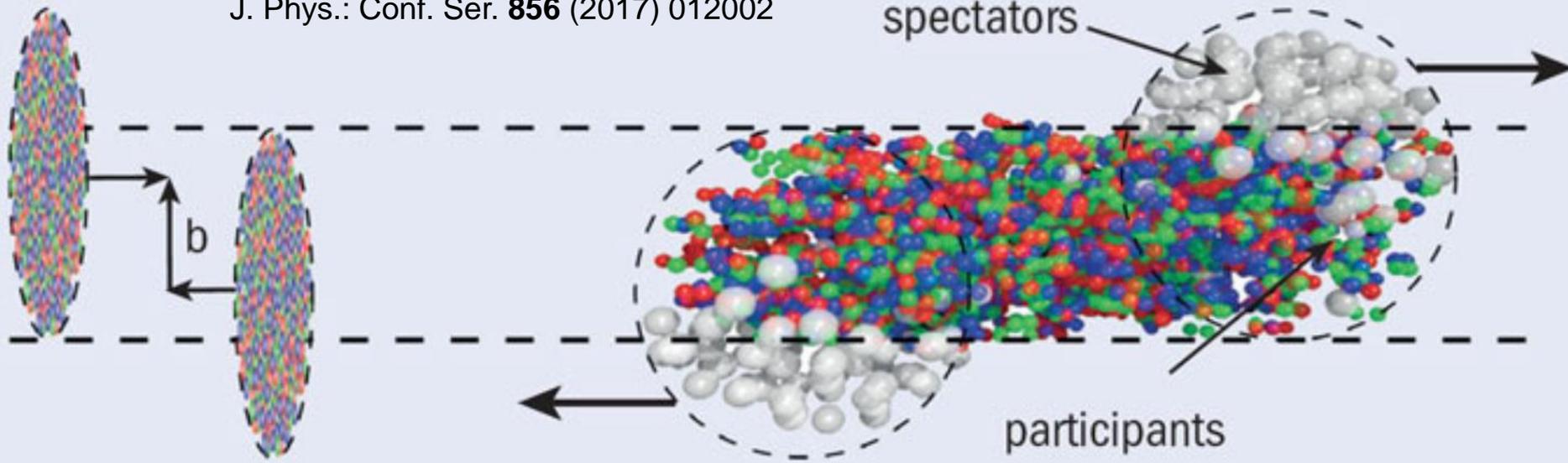
Photon emitter:

Pomeron emitter:



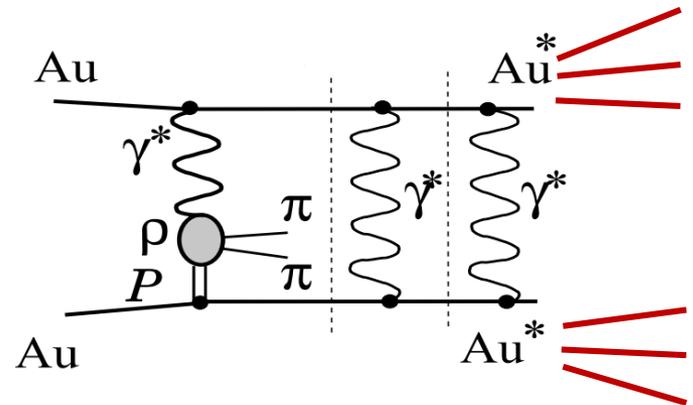
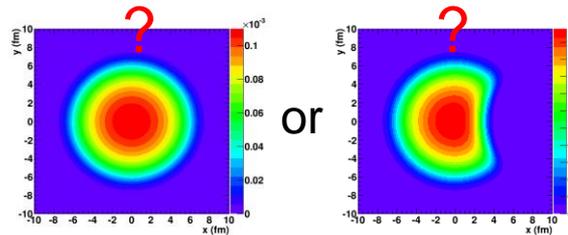
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Photon emitter:

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PRC **77** (2008) 34910

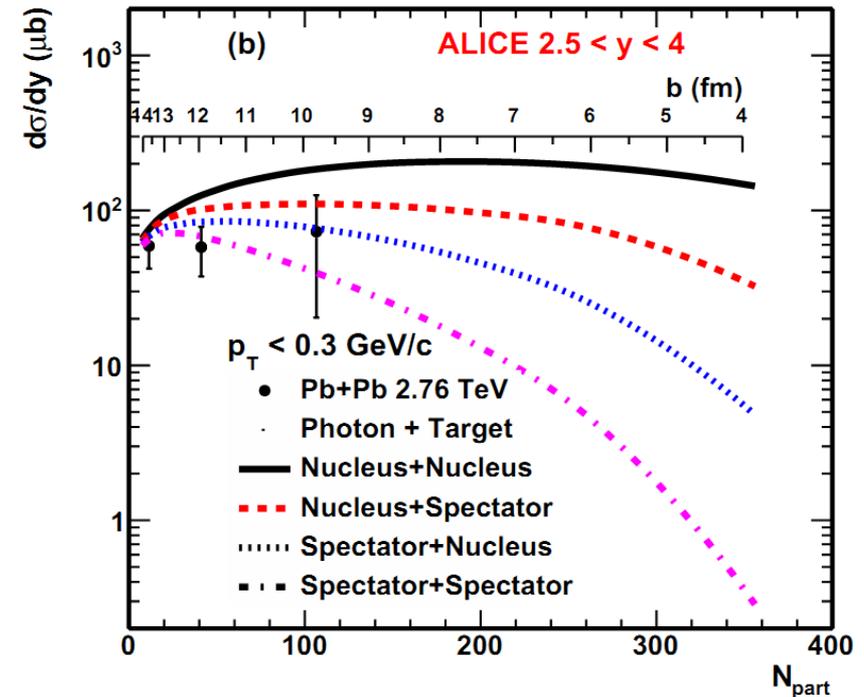
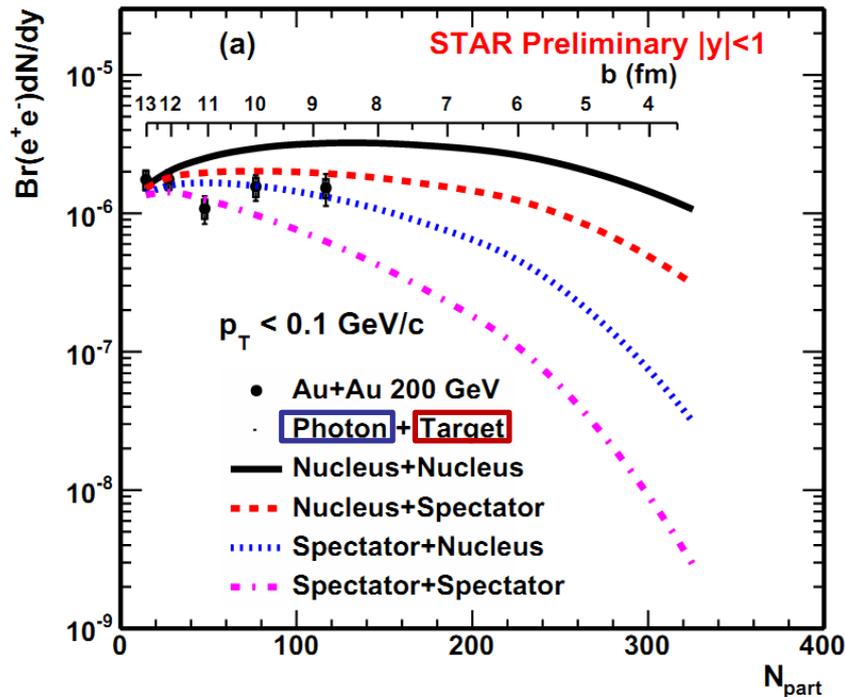
How **coherence** keep? --- **Time scale** matters

Collision (production) time  $>$  GeV

Fragment of spectator and nucleus excitation  $\sim$  MeV

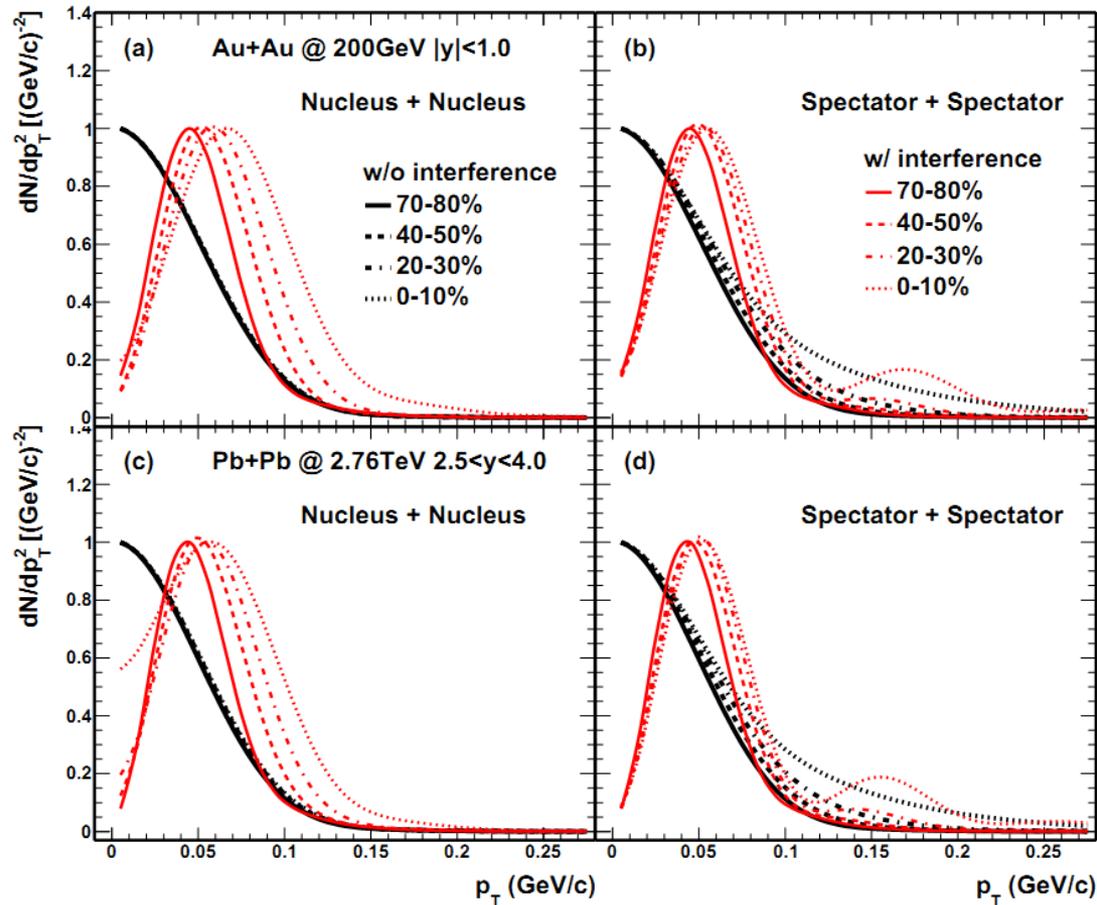
# Calculations with different scenarios

W. Zha et al., PRC **97** (2018) 044910



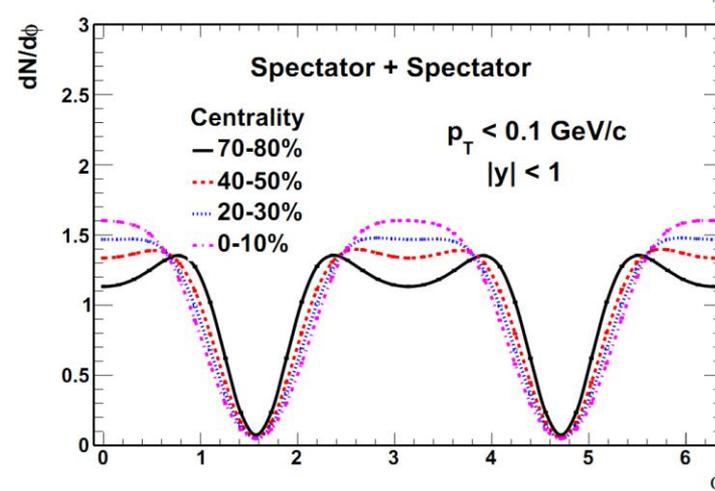
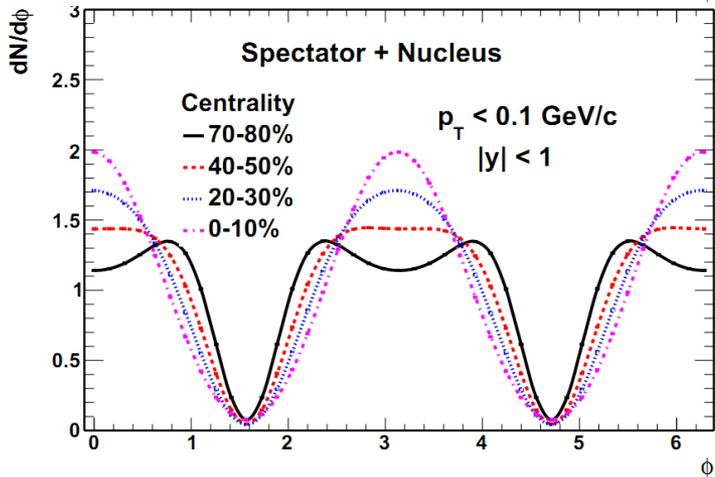
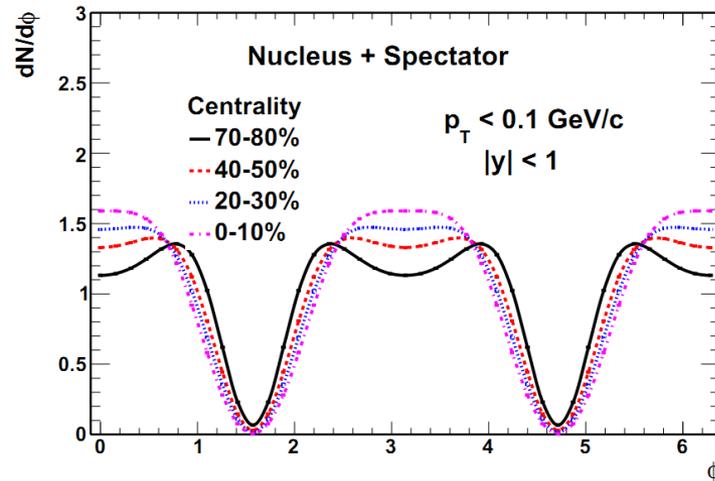
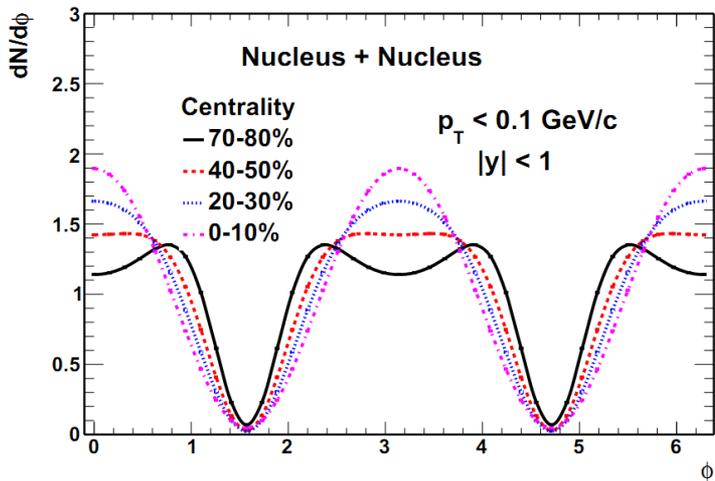
- All scenarios describe the data very well in peripheral collisions!
- Nucleus+Nucleus: overestimate the data in semi-central collisions.
- Spectator+Spectator: under predict the data in semi-central collisions.
- To distinguish the different scenarios, measurements at central collisions are needed!

# $p_T$ shape with interference



- Dramatically change the  $p_T$  spectra!  $\Rightarrow$  To determine the impact parameter?
- Different interference pattern in different centrality!
- The effect is relative small with spectator coupling!

# $\phi$ distribution with interference

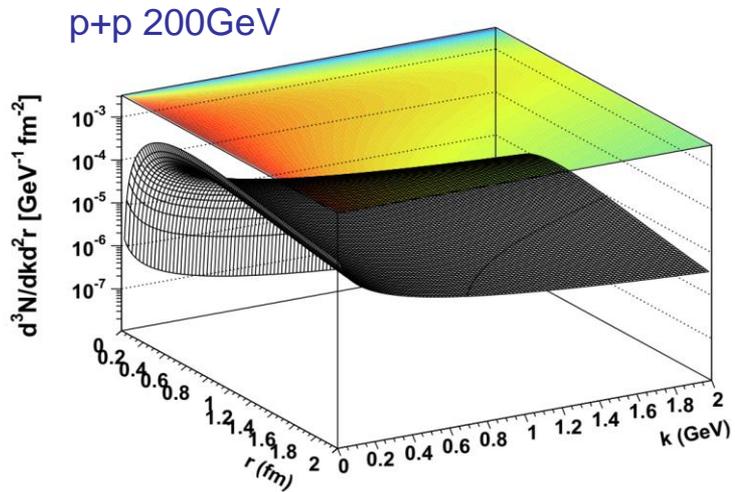


- Dramatically change  $\phi$  distribution!  $\Rightarrow$  Interference+Nucleus (or spectator) profile
- Sensitive to the reaction plane!  $\Rightarrow$  To evaluate the reaction plane?

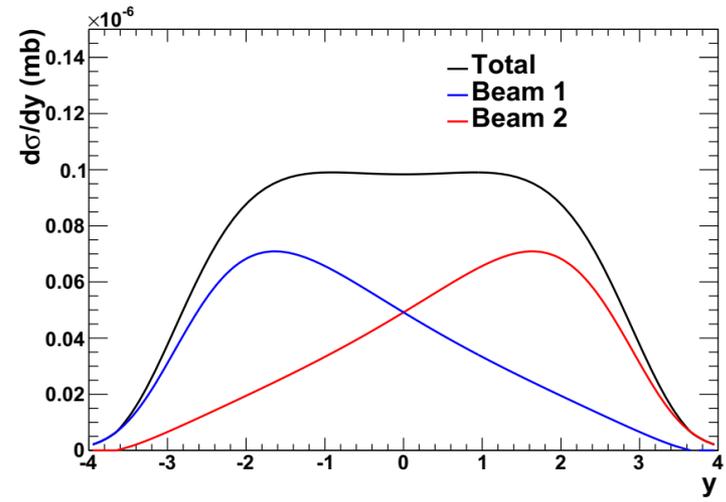
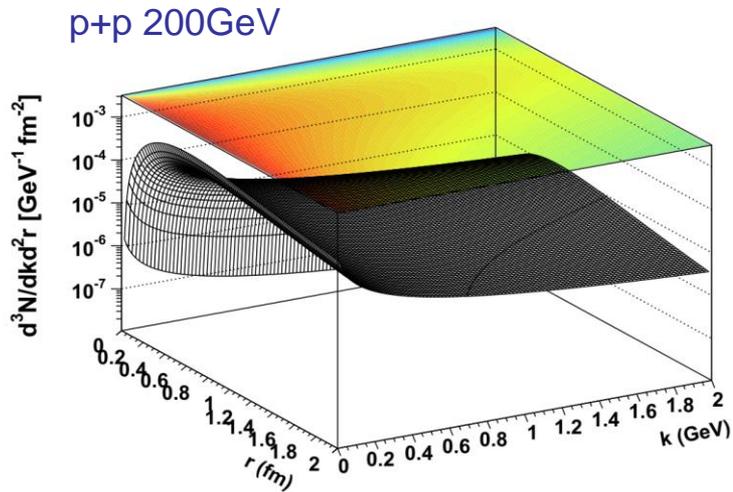
# Coherent $J/\psi$ production in NSD p+p collisions?

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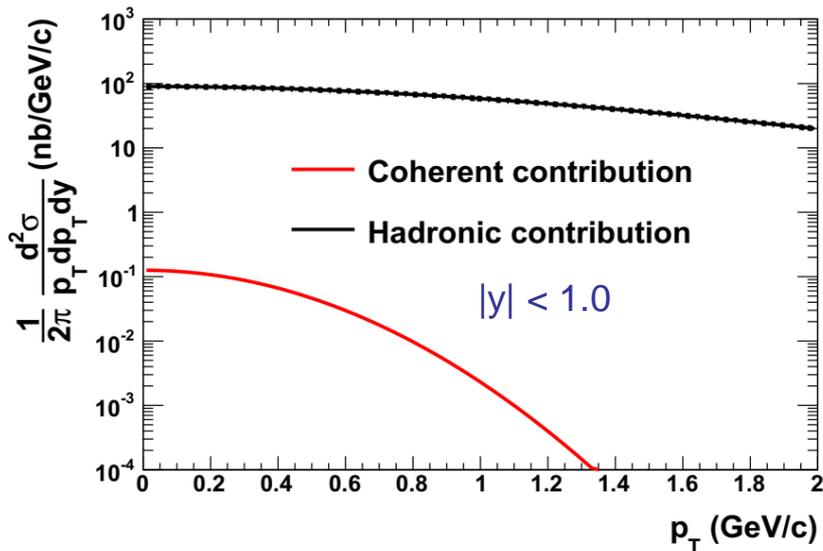
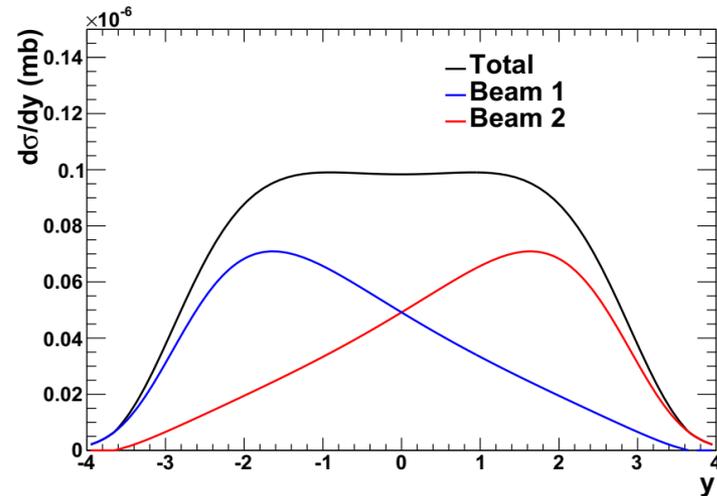
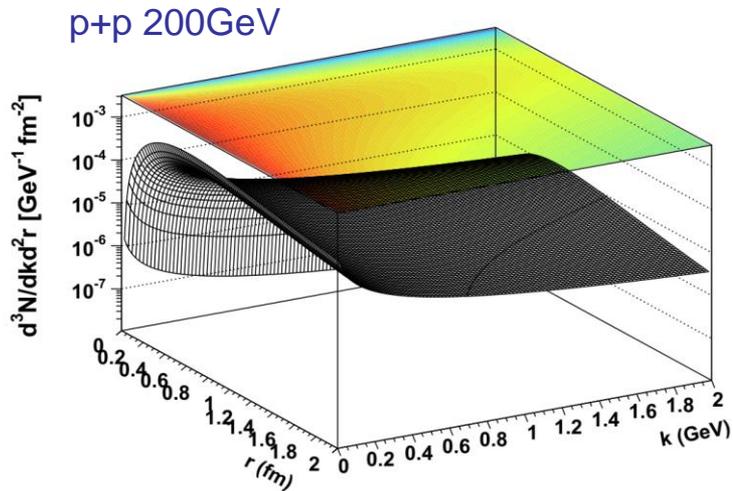
# Coherent $J/\psi$ production in NSD p+p collisions?



# Coherent $J/\psi$ production in NSD p+p collisions?



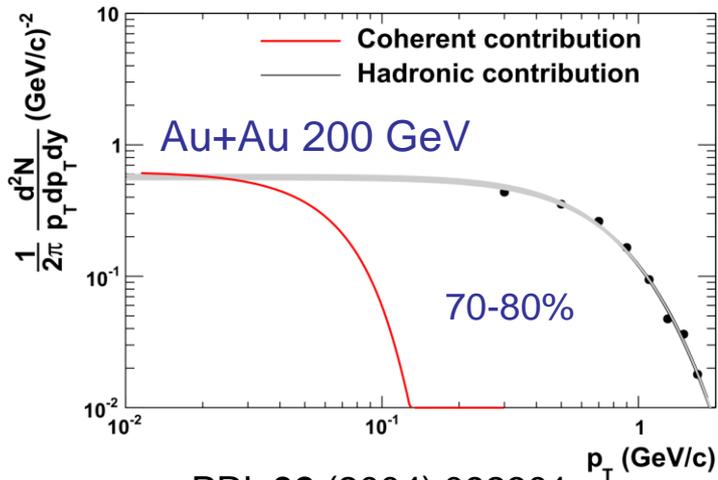
# Coherent J/ψ production in NSD p+p collisions?



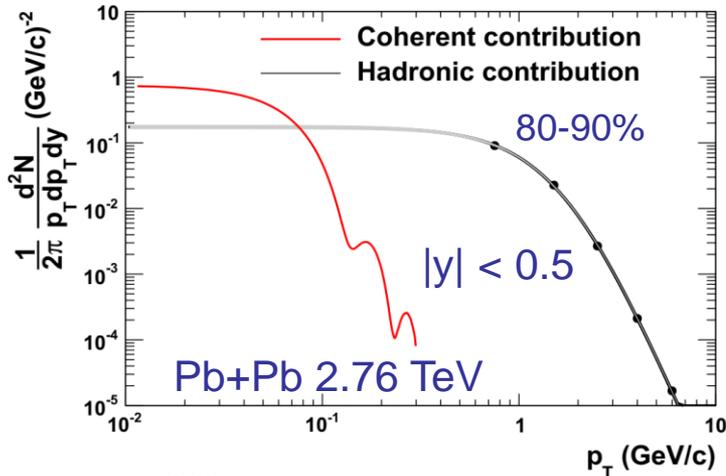
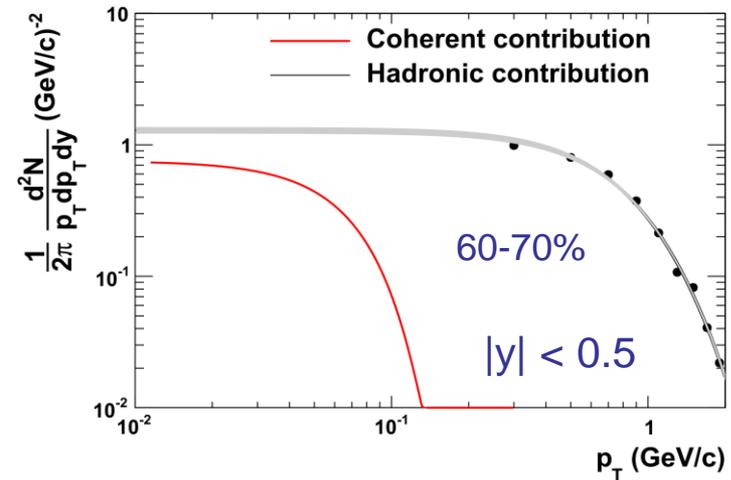
Hadronic contribution from:  
W. Zha et al, PRC **93** (2016) 024919

- **Negligible** in comparison to hadronic contributions!
- The extrapolation of pp baseline at very low  $p_T$  for  $R_{AA}$  is OK!

# How about coherent produced $\rho$ in HHIC?



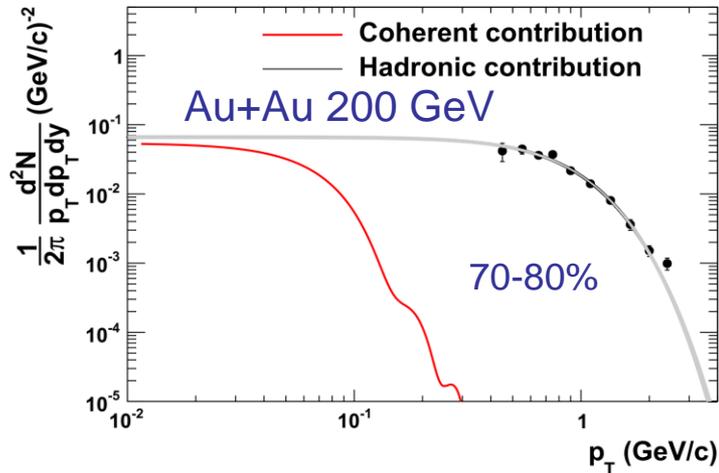
PRL **92** (2004) 092301



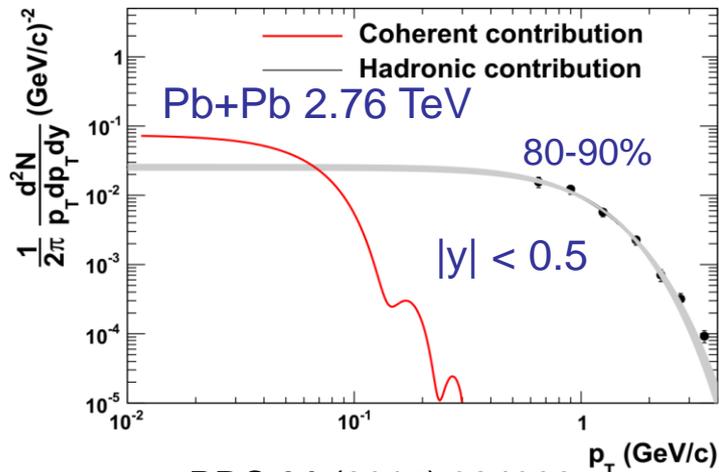
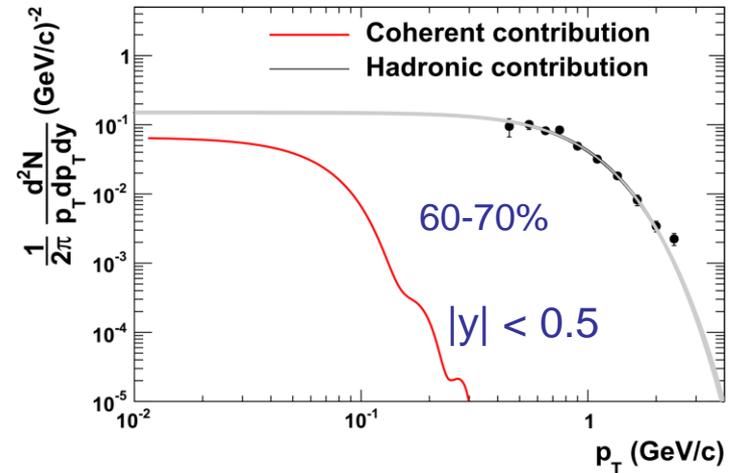
arXiv:1805.04365v1

- At RHIC, hadronic contribution dominant even at very low  $p_T$
- At LHC, **signal dominant** at the most peripheral collisions

# And $\phi$ ?



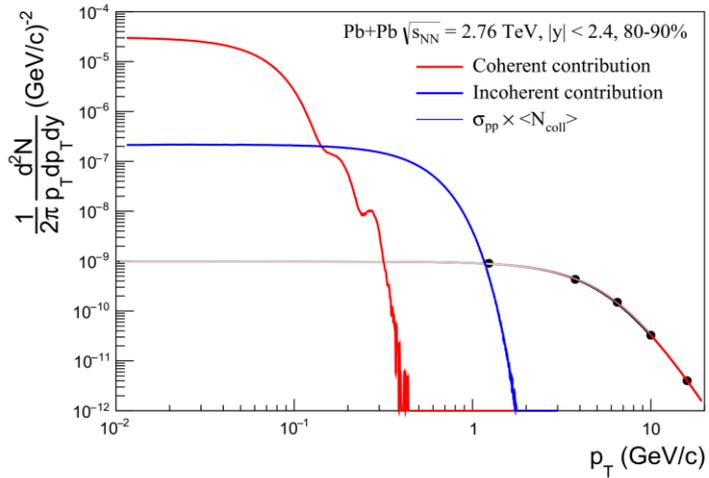
PLB 612 (2005) 181



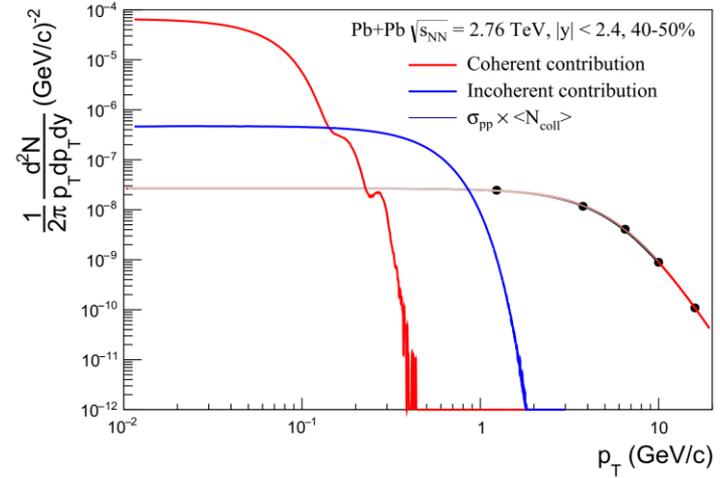
PRC 91 (2015) 024609

- At RHIC, hadronic contribution dominant even at very low  $p_T$
- At LHC, **signal dominant** at the most peripheral collisions

# $\Upsilon(1s)$ !

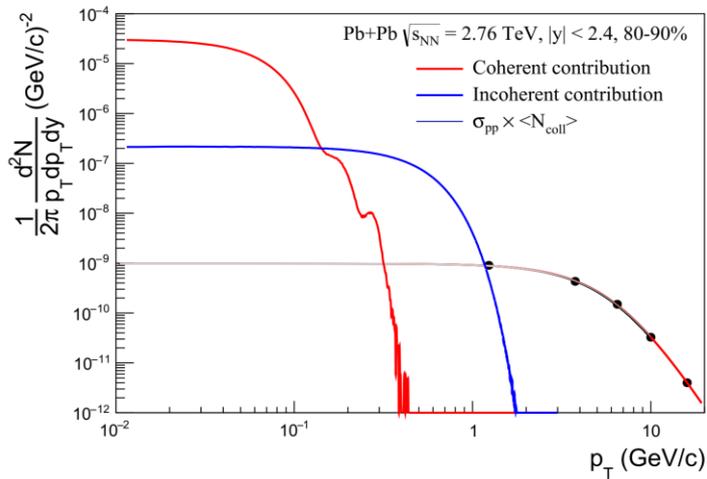


PLB 770 (2017) 357

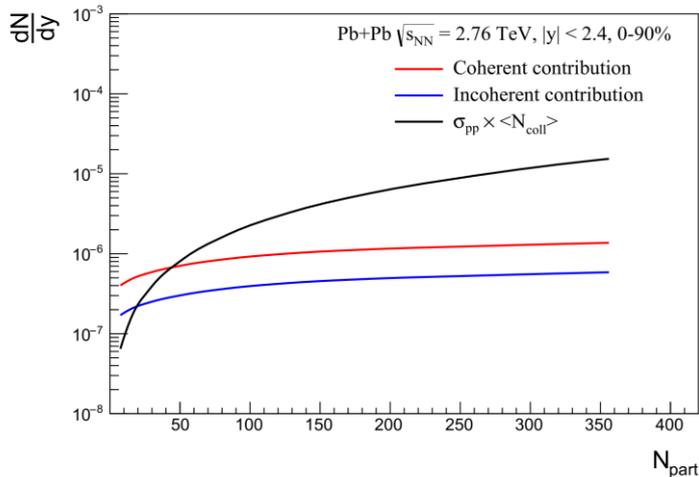
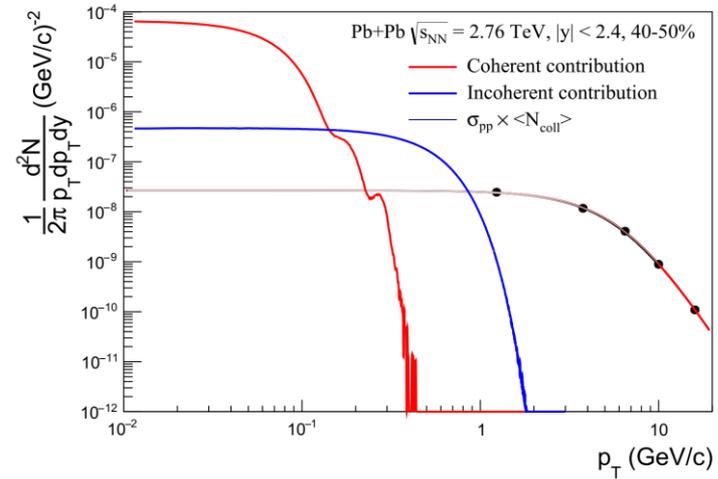


- Coherent and Incoherent photoproduction are dominant at low  $p_T$

# $\Upsilon(1s)$ !

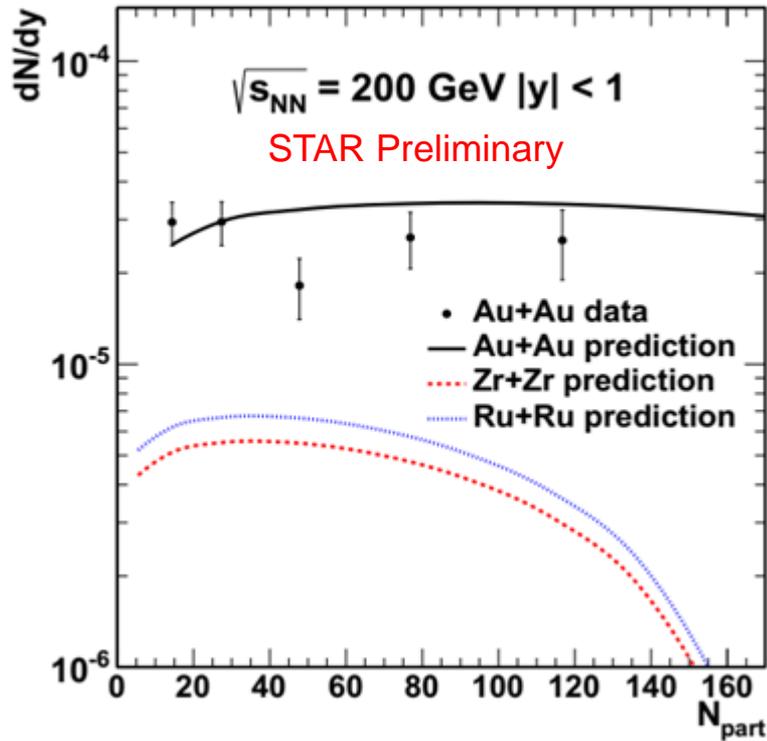


PLB 770 (2017) 357



- Coherent and Incoherent photoproduction are dominant at low  $p_T$
- Even the total cross section in most peripheral collisions!
- Very promising measurement!

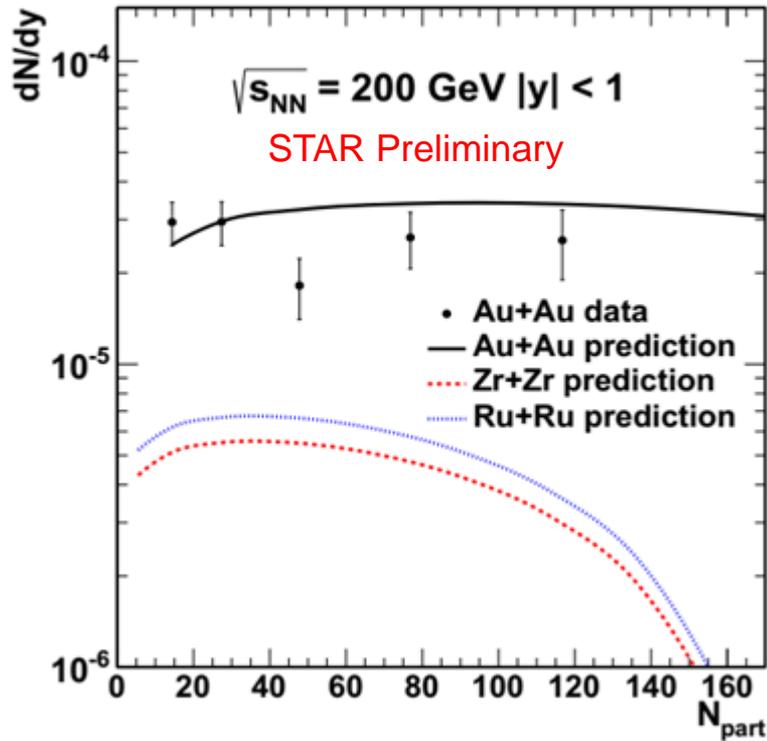
# Isobaric collisions: a perfect test!



Production rate  $\sim Z^2 A^2$

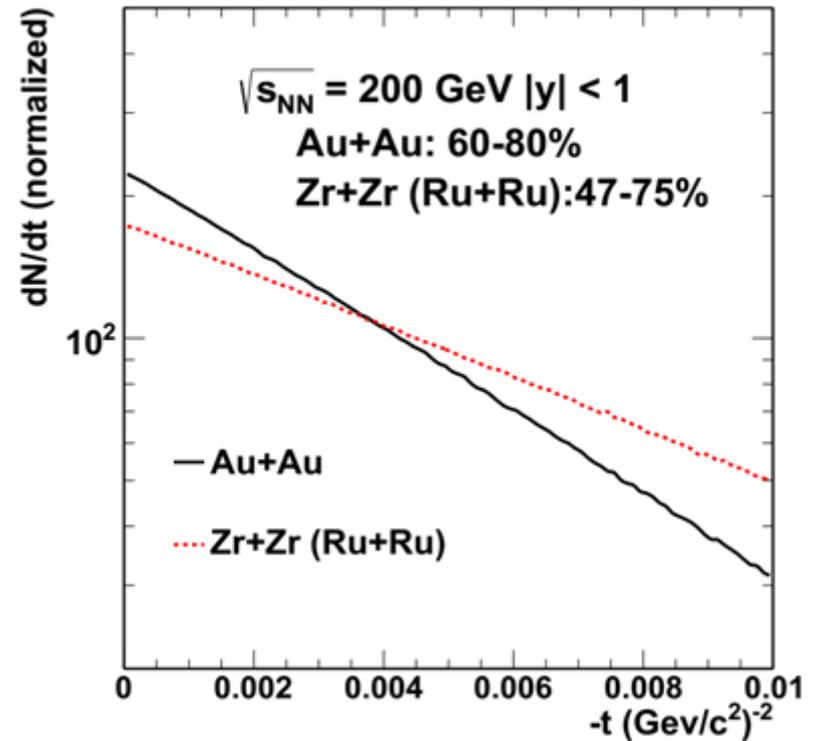
Small cross section!

# Isobaric collisions: a perfect test!



Production rate  $\sim Z^2 A^2$

Small cross section!



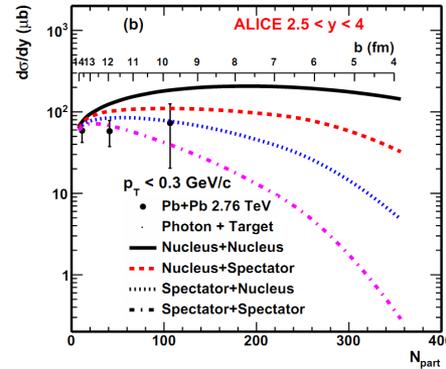
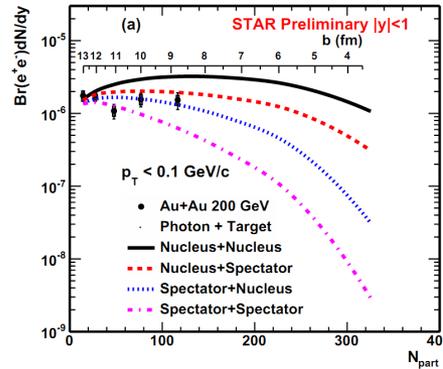
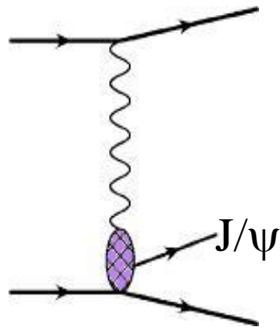
Slope parameter  $\sim 1/R_A$

Small slope parameters!

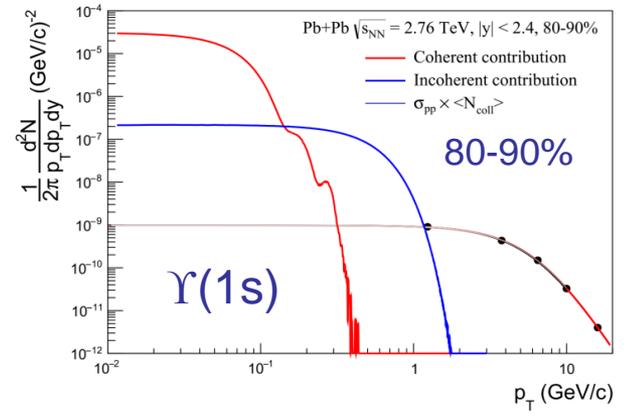
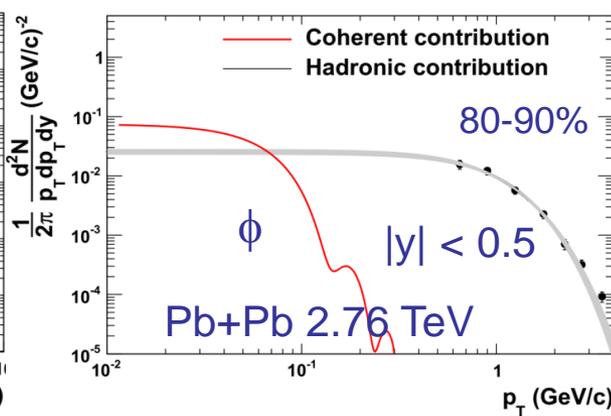
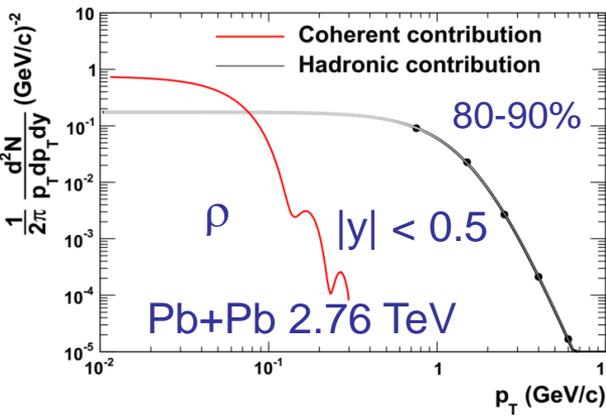
# Summary

- Excess of  $J/\psi$  at very low  $p_T$ !

✓ Consistent with coherent photonuclear production in **HHIC**!



- More coherent photon products are promising in HHIC!



- A perfect test --- isobaric collisions!

# Outlook

