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The UPC related physics with STAR forward upgrades

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Workshop on STAR Forward Tracking Detector Upgrade and Related Physics
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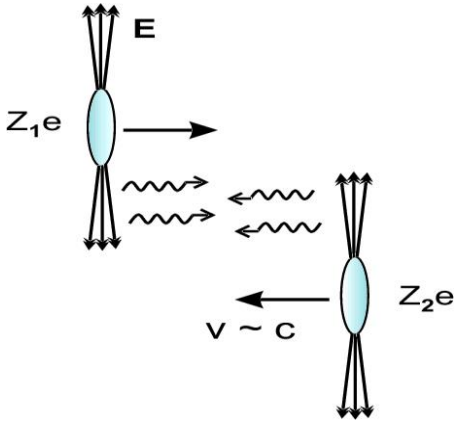
Coherent photons as “partons” in heavy-ion collisions



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

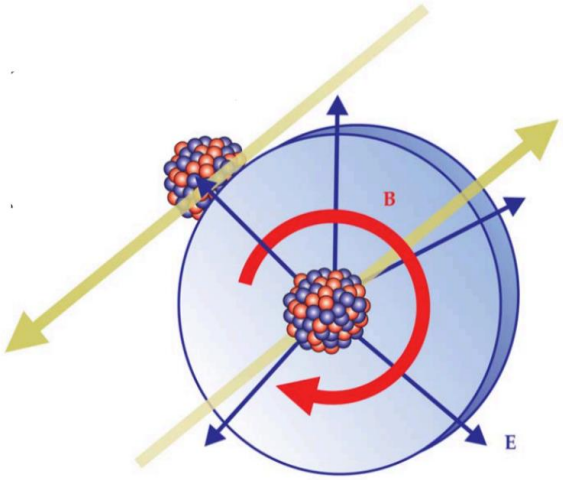
Photon four momentum: $q^u = (\omega,\ \vec{q}_T, \omega/v)$

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

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

$$q_T \leq 1/R$$

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



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

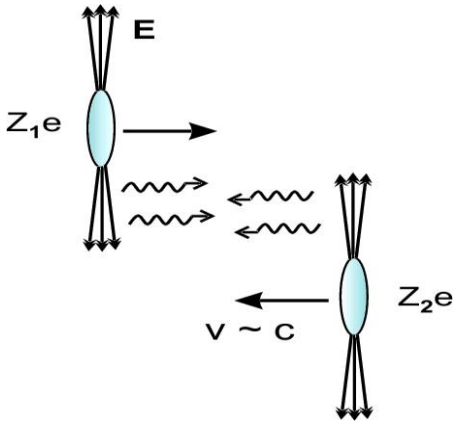
The extent of photons swarming about the ions:

The radius of nuclear matter R_{Nuc} ~ 6.3 fm (Au)

$R_{photons}$ >> R_{Nuc}

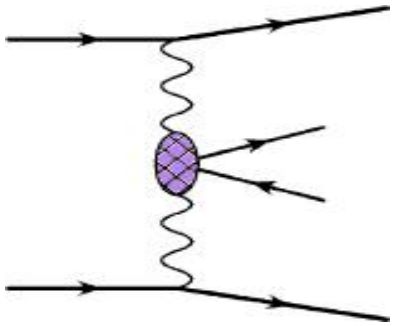
Take the photoproduction of ρ (Au+Au 200 GeV)in ultra-peripheral collisions (UPCs) as example: $<R_{producton}>$ ~ 40 fm

Photon interactions in A+A



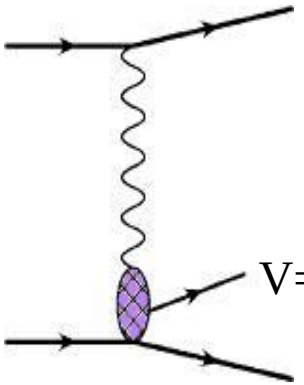
Electromagnetic interaction

=



Photon-photon interactions

+



Photon-nucleus interactions

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

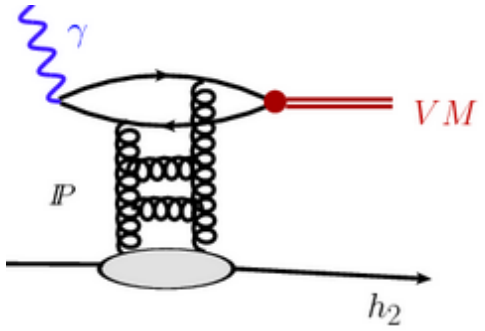
$V=\rho\ ,\ \omega\ ,\ \phi\ ,\ J/\psi$

- This large flux of quasi-real photons makes a hadron collider also a photon collider!
  - ✓ Photon-nucleus interactions: Vector meson
  - ✓ Photon-photon interactions: dileptons …

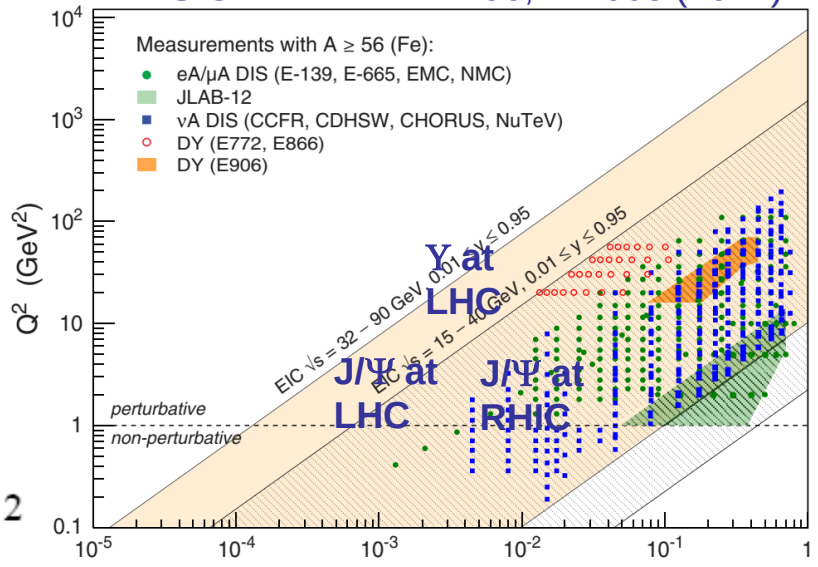
- Studied in ultra-peripheral collisions (UPC) to reject hadronic background.

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’, Υ(1S), Υ(2S), Υ(3S)…



PHYSICAL REVIEW D 96, 114005 (2017)



RHIC y=0: $x \sim 0.01$

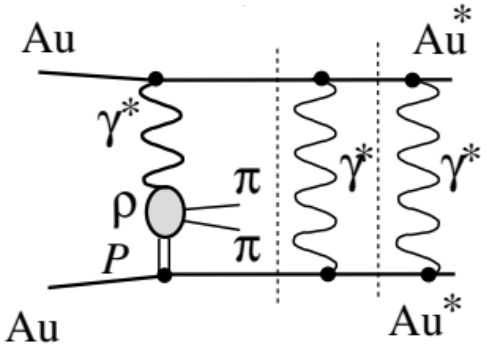
LHC y=0: $x \sim 0.001$

- Sensitive to the gluon distribution:

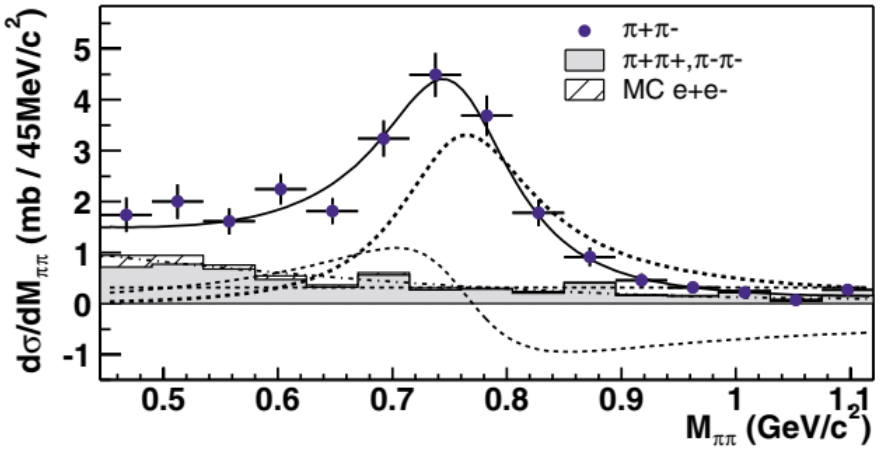
$$\left.\frac{d\sigma(\gamma A \to V A)}{dt}\right|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 \left[xG_A(x,Q^2)\right]^2$$

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

The ρ^0 photoproduction at STAR

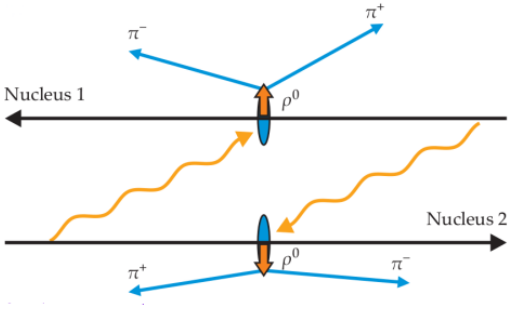


ρ^0 photoproduction with nuclear break-up

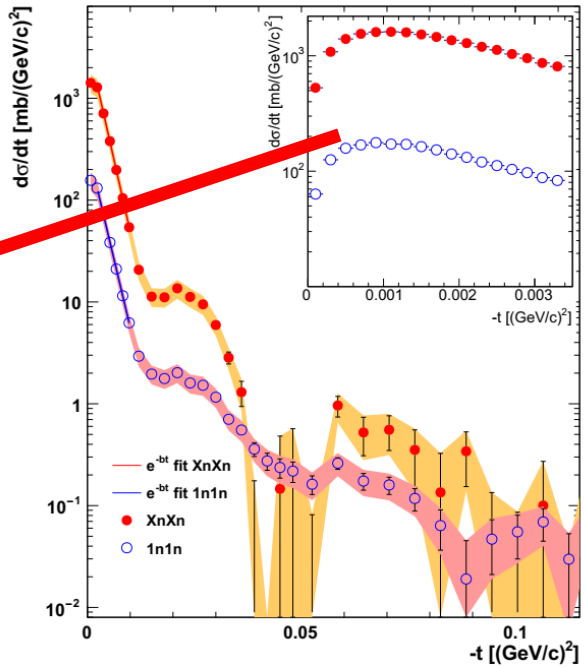


PRL **89** (2002) 272302

Interference



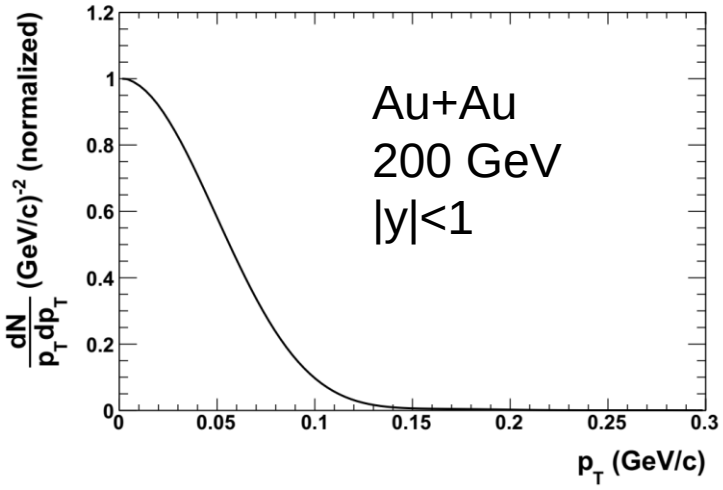
PRL **84** (2000) 2330



PRL **102** (2009) 112301

PRC **96** (2017) 054904

Coherent ϕ photoproduction with iTPC upgrade



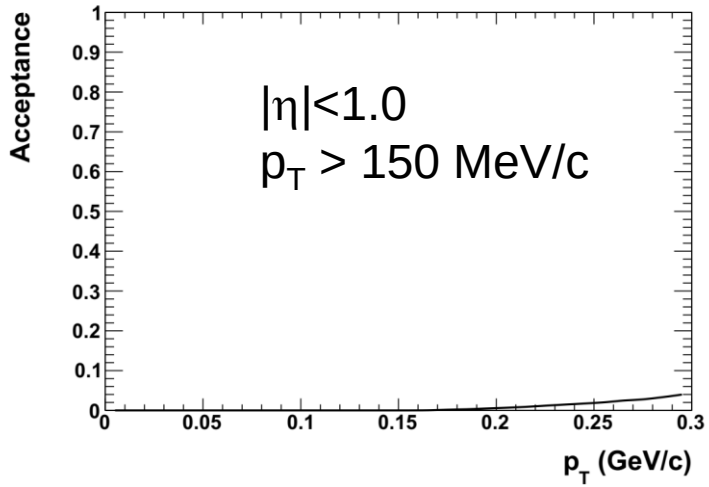
iTPC upgrade

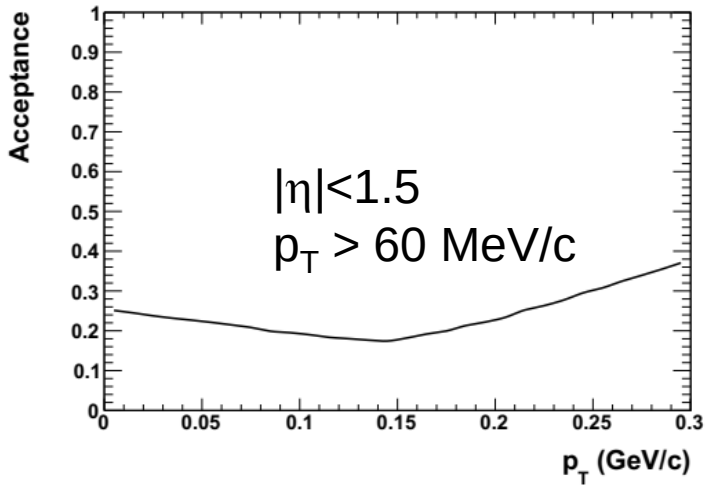
Continuous pad rows
Replace all inner TPC sectors

$|\eta| < 1.5$

$p_T > 60$ MeV/c

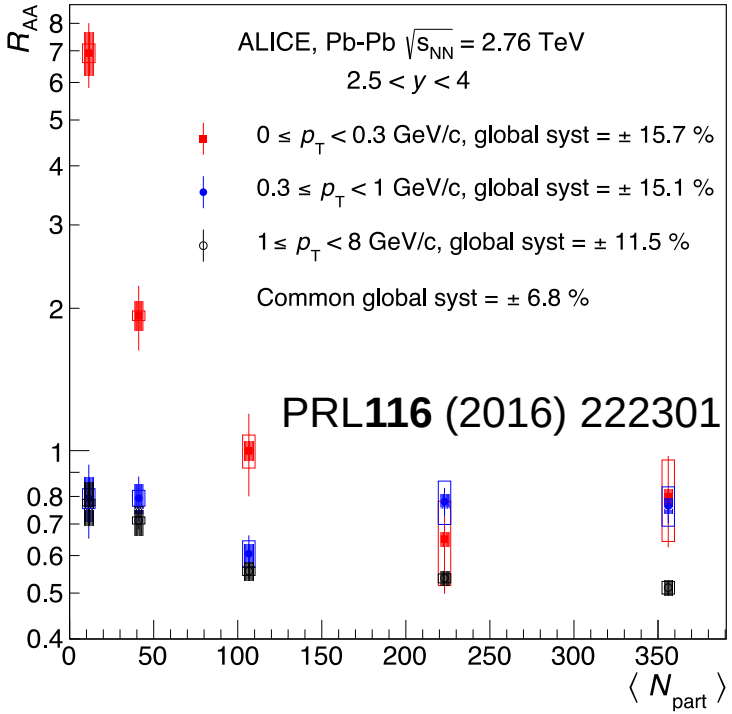
Better dE/dx resolution
Better momentum resolution

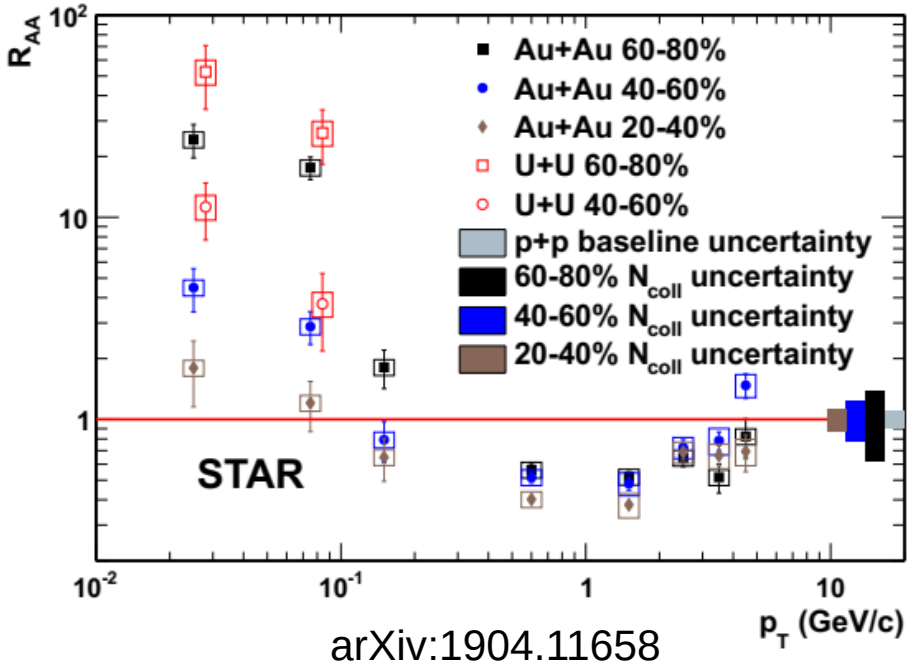




The first chance to access coherent ϕ photoproduction in heavy-ion collisions!

From UPC to HHIC: J/ψ excess

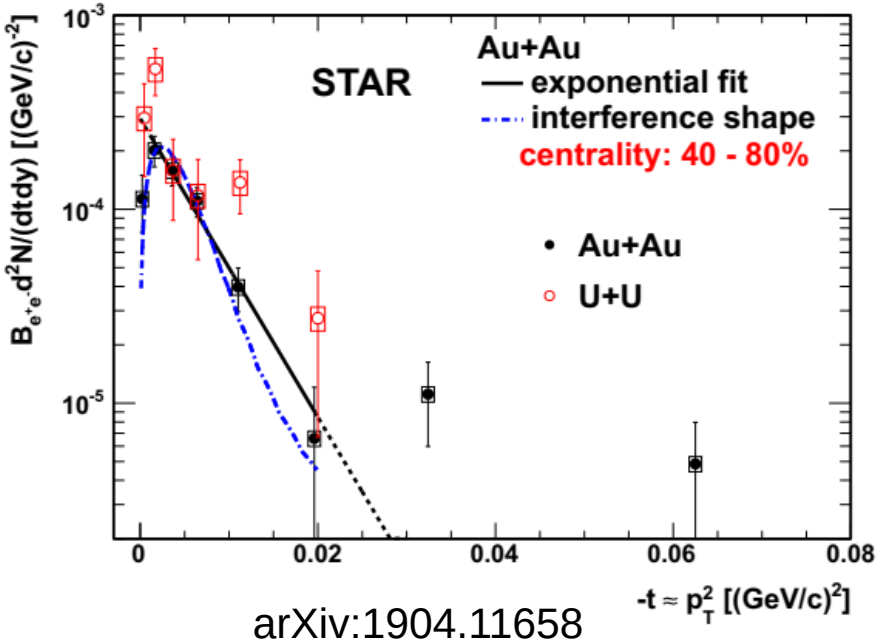




arXiv:1904.11658

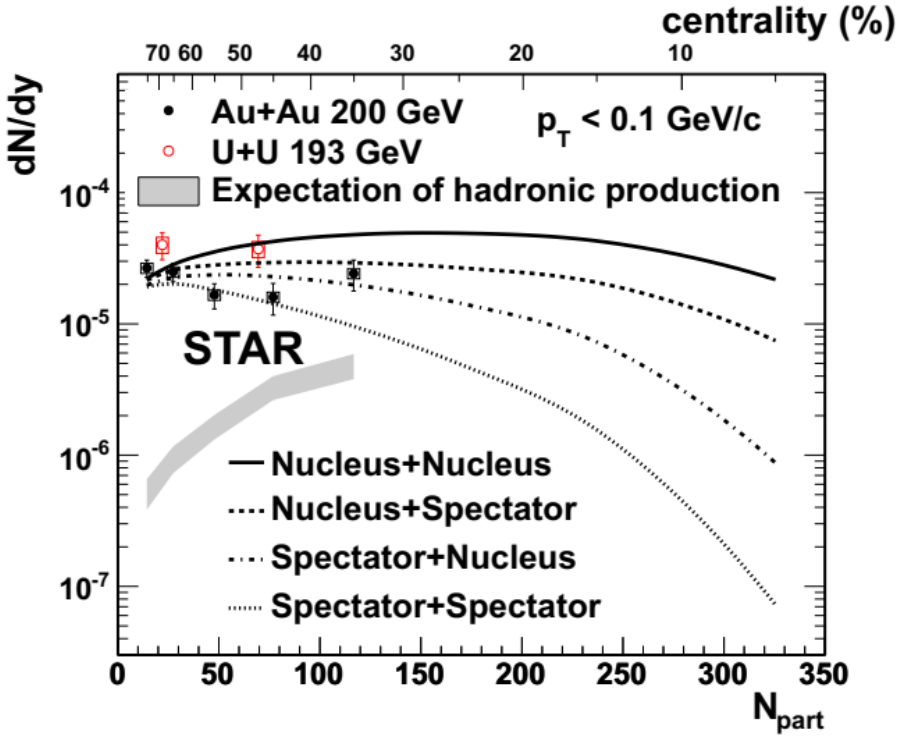
- Significant enhancement observed at very low p_T for peripheral collisions.
- Can not be described by the hot medium and cold nuclear matter effects!
- Origin from photo coherent interaction?

From UPC to HHIC: J/ψ excess



arXiv:1904.11658

- Similar structure to that in UPC case!
- Indication of interference!
  - ✓ χ^2/NDF = 4.8/4
- Similar slope parameter!
  - ✓ Slope from STARLIGHT prediction in UPC case – 199 (GeV/c)$^{-2}$
  - ✓ Slope w/o the first point: 177 ± 23(GeV/c)$^{-2}$



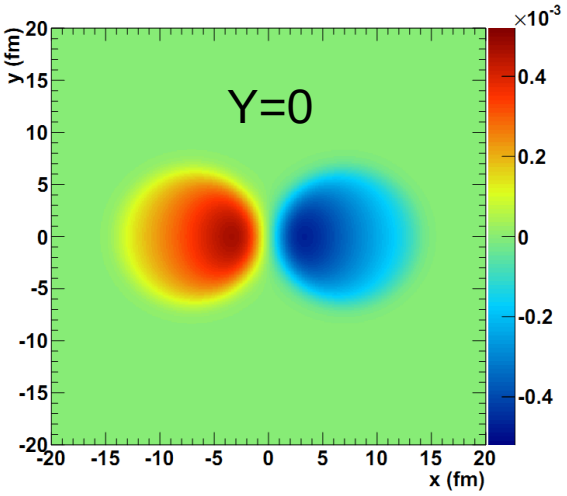
- Can be described by the coherent photoproduction!
- Reveal partial disruption by hadronic collisons

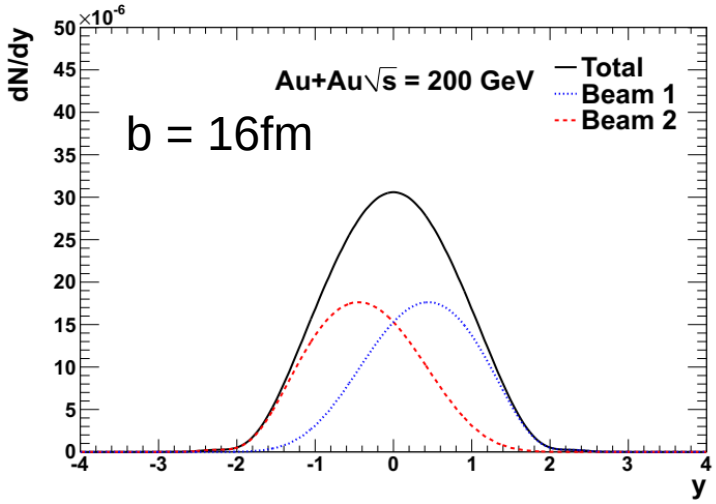
The gluon nPDF from J/ψ photoproduction

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

$$W_{\gamma A}(1) = \sqrt{m_p^2 + M_{J/\psi}e^{y}\sqrt{s_{NN}}} \qquad W_{\gamma A}(2) = \sqrt{m_p^2 + M_{J/\psi}e^{-y}\sqrt{s_{NN}}}$$

$$E_\gamma(1) = 0.5\, M_{J/\psi}e^{y} \qquad E_\gamma(2) = 0.5\, M_{J/\psi}e^{-y}$$

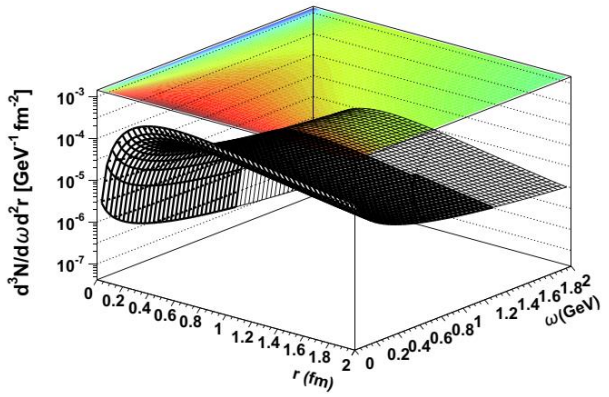




The $\gamma + A \to J/\psi + A$ cross section can be extracted with the deconvolution of photon flux (at mid-rapidity or forward rapidity).

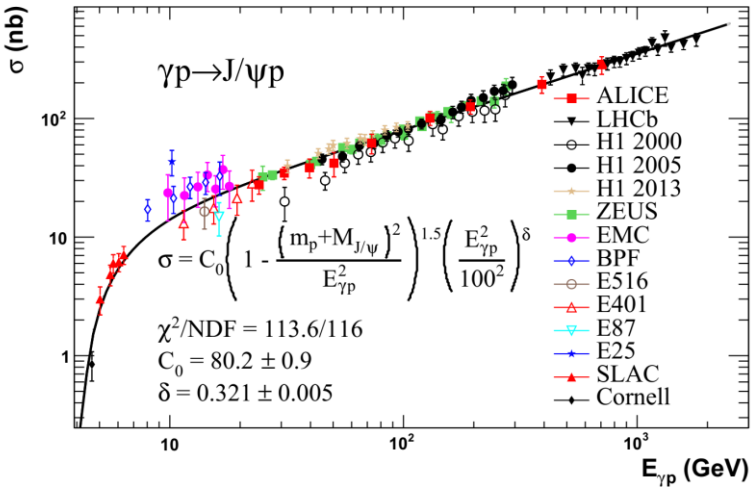
The gluon nPDF from J/ψ photoproduction

The photon Flux



Equivalent photon approximation

The γ+p baseline



$$\sigma(\gamma A \to \mathrm{J}/\psi A) = \left.\frac{d\sigma(\gamma A \to \mathrm{J}/\psi A)}{dt}\right|_{t=0} \times \int |F_P(\vec{k}_P)|^2 d^2\vec{k}_{P\perp} \qquad \vec{k}_P = (\vec{k}_{P\perp}, \frac{\omega_P}{\gamma_c})$$

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

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

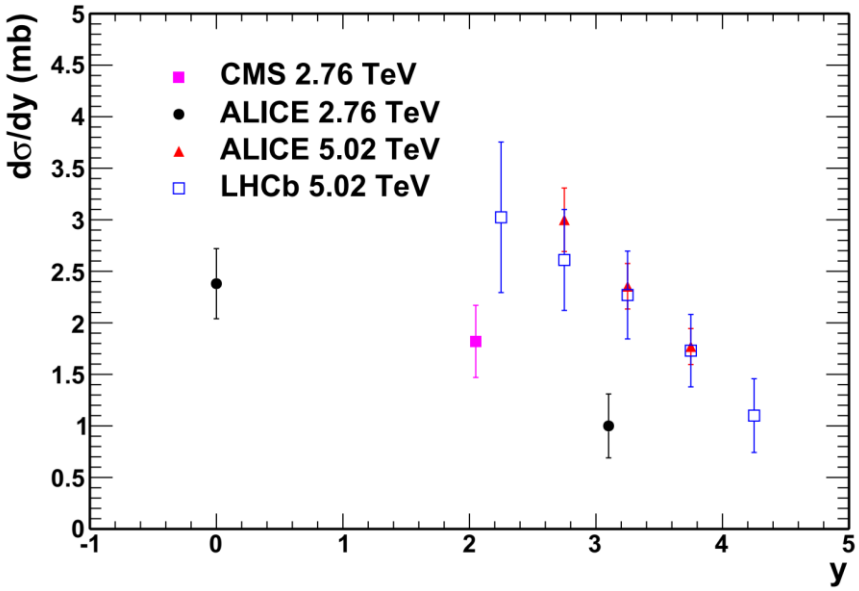
$$x = \frac{M_V e^{\pm y}}{\sqrt{s}} \qquad Q^2 = M_V^2/4$$

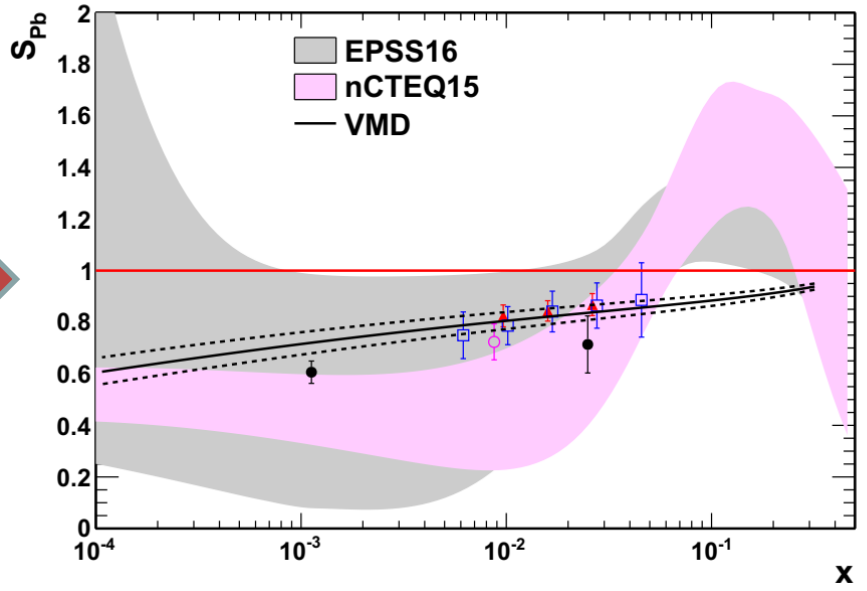
$$S_A(W_{\gamma A}) = \left(\frac{d\sigma_{\gamma A}/dt|_{t=0}}{d\sigma_{\gamma p}/dt|_{t=0} \times A^2}\right)^{1/2} = \frac{G_A(x, Q^2)}{A G_p(x, Q^2)}$$

Nuclear shadowing from J/ψ measurements in UPCs

- 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

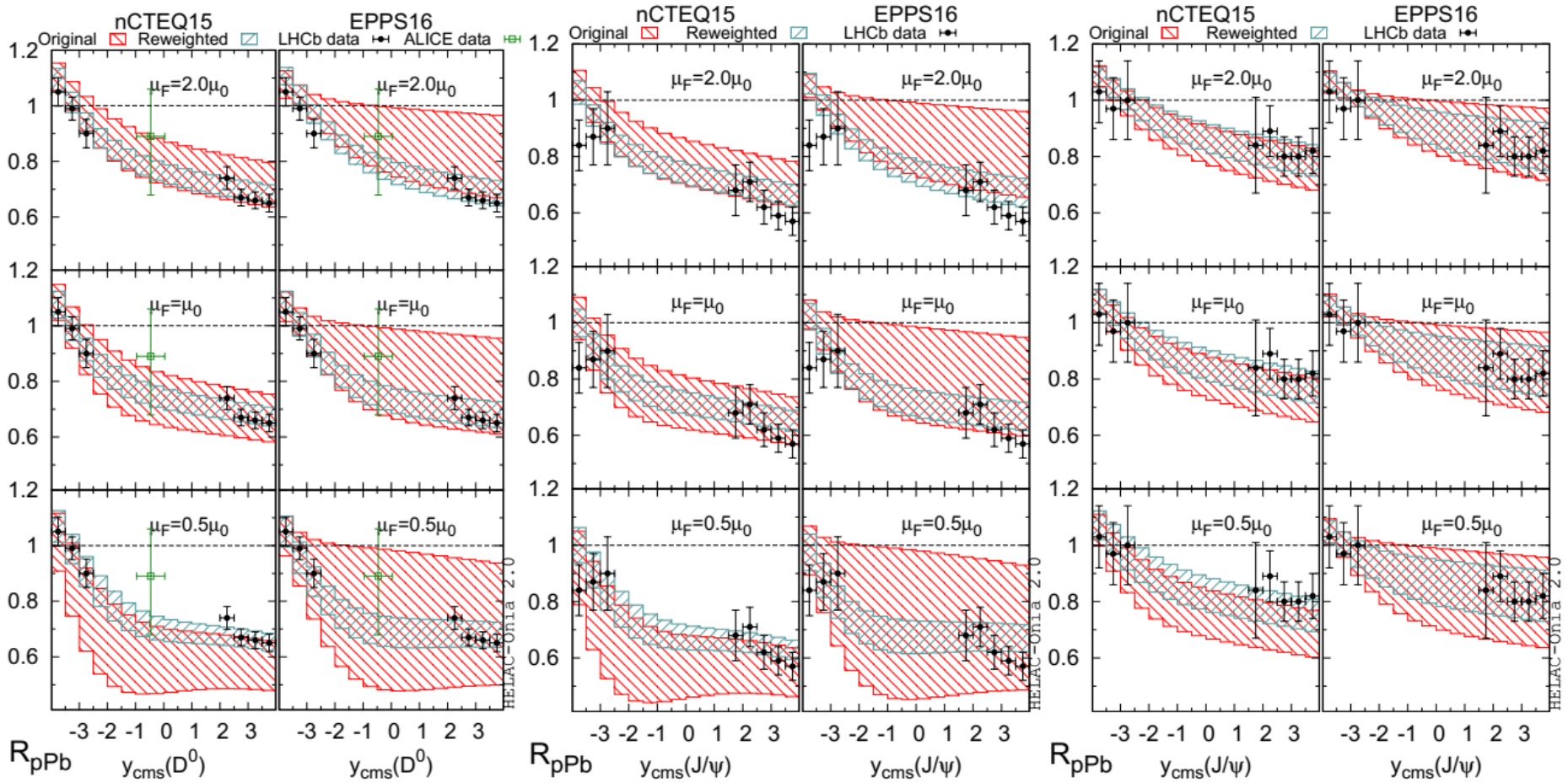
EPJC **77** (2017) 163 PRD **93** (2016) 085037

VMD approach describe the data reasonably well!

Significant shadowing effect at small x!

The nPDF from heavy flavor production in p+A at LHC

PRL **121** (2018) 052004



(a) Prompt D^0 (b) Prompt J/ψ (c) $B \to J/\psi$

- ✓ Significance of 7σ to a shadowed gluon distribution at small x.
- ✓ No significant anti-shadowing signal

The nPDF with STAR forward upgrades

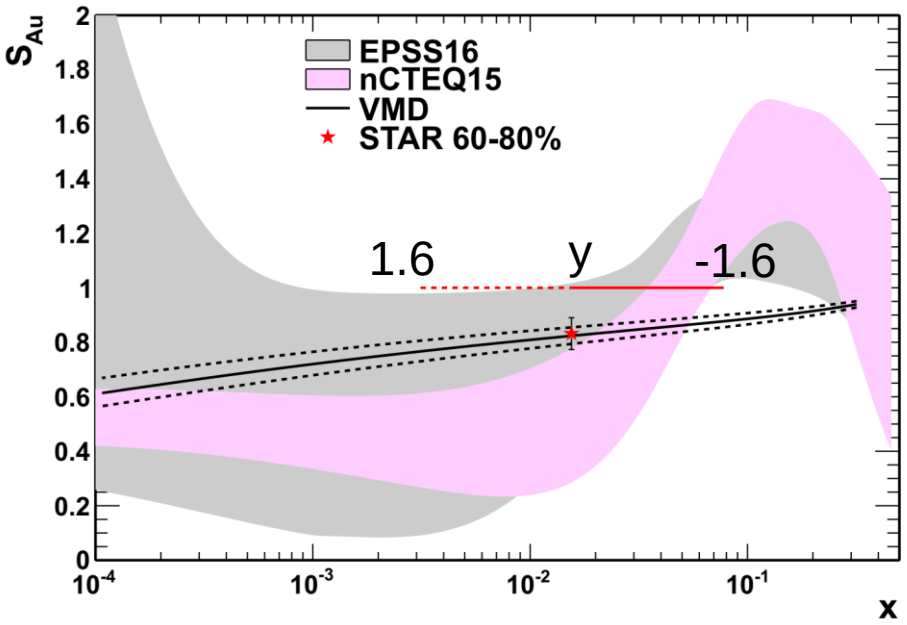
eTOF upgrade

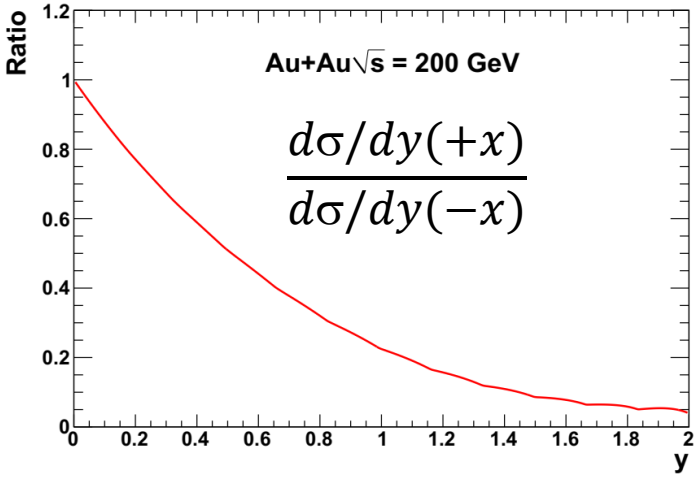
Add CBM TOF modules and electronics (FAIR Phase 0)

-1.6 < η < -1.1

Extend forward PID capability

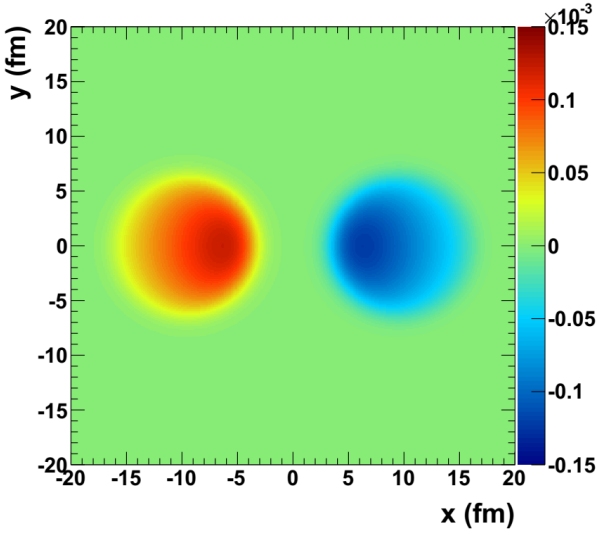
Allows higher energy range of Fixed-Target program

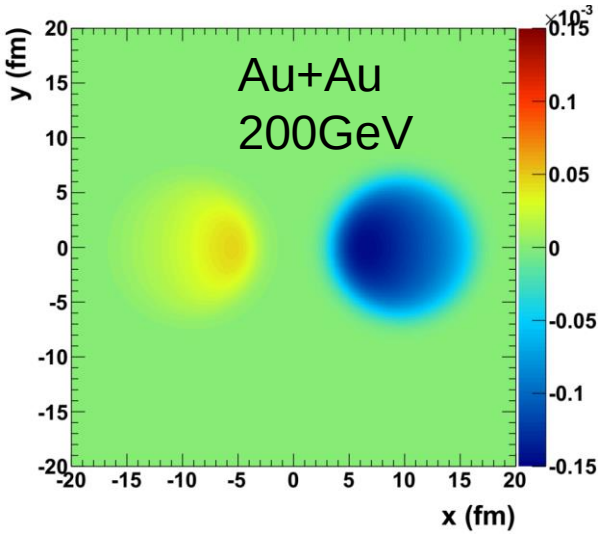


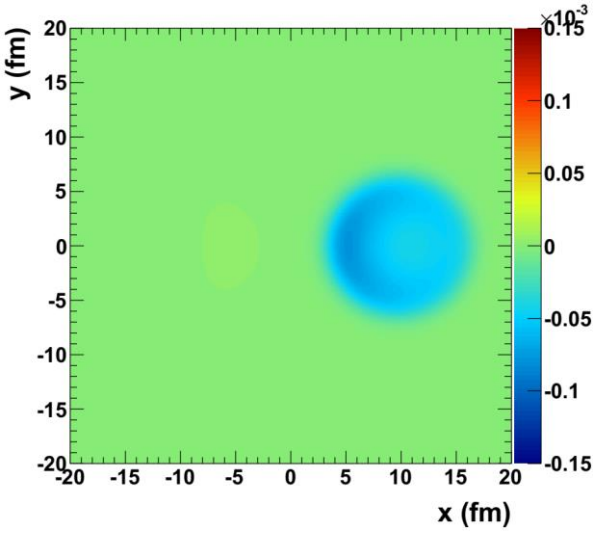


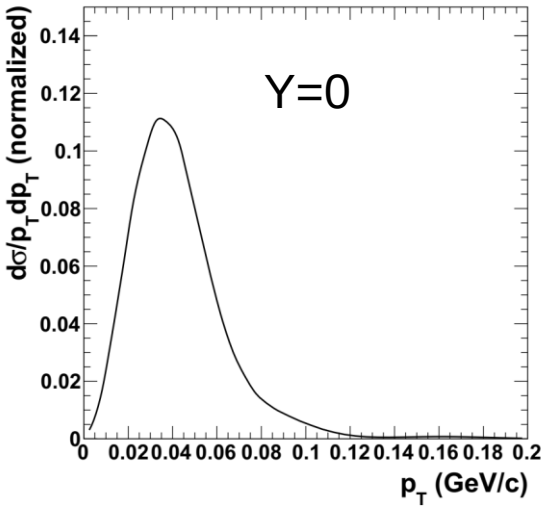
- ✓ Indication of shadowing with the STAR peripheral measurements.
- ✓ Get access to anti-shadowing range with the forward upgrades.

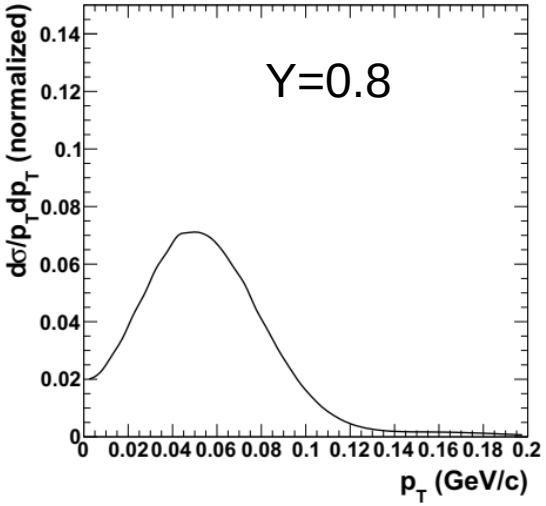
Interference versus rapidity

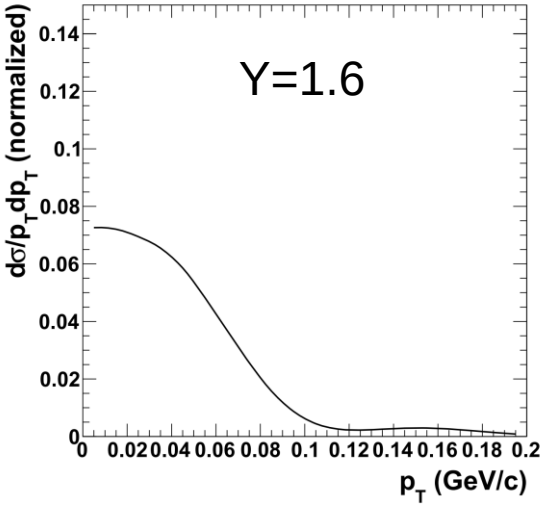












Diffraction pattern dominant over the p_T distribution at forward rapidity.

Coherent length effect

Longitudinal momentum transfer
Target frame

$$q_L = p^{\gamma} - p_V^L = \frac{Q^2 + M_V^2 + (p_V^T)^2}{2\nu}$$

$$Q^2 \approx 0 \quad (p_V^T)^2 \approx 0$$

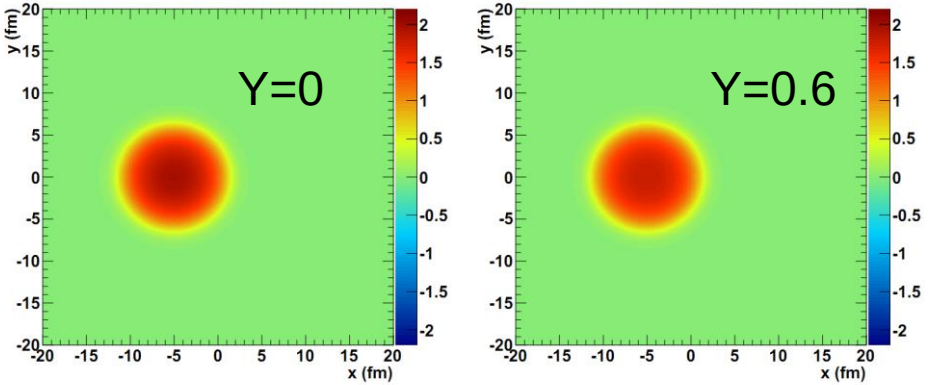
$$q_L = \frac{M_V e^{\pm y}}{2\gamma}$$

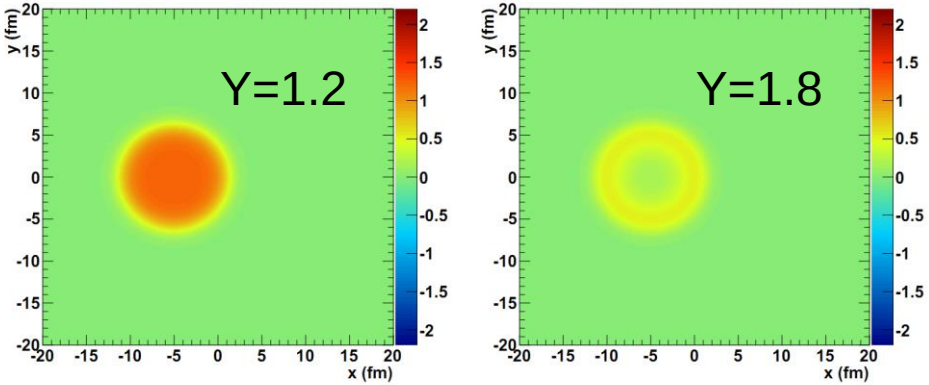
Nuclear density with coherent length effect:

$$T'(b) = \int_{-\infty}^{+\infty} dz\, \rho(b,z) e^{iq_L z}$$

Au+Au 200 GeV

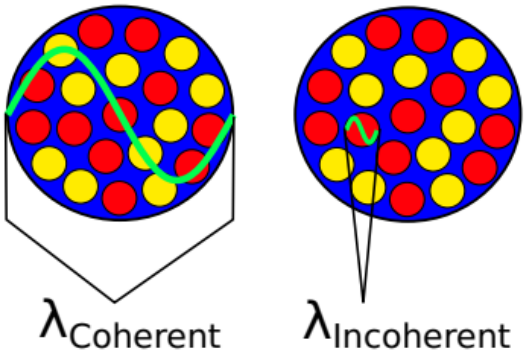
Choose the +y direction



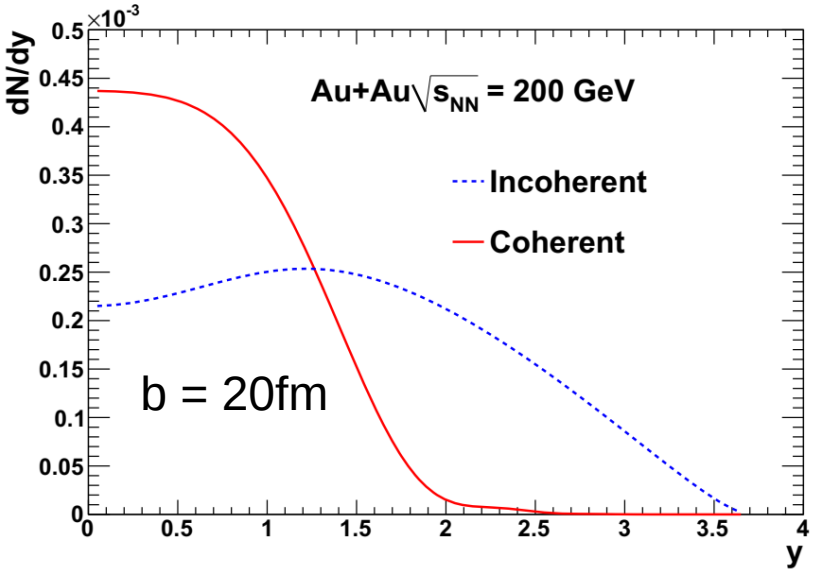


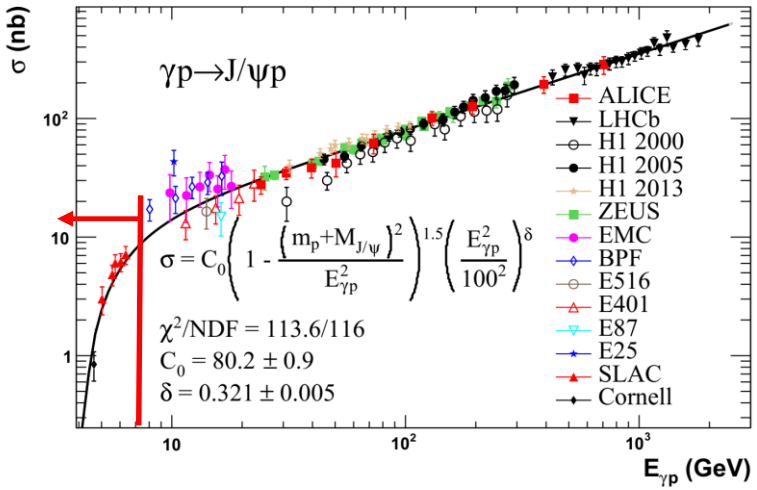
The coherent length effect significantly reduce the production at forward rapidities.

Coherent versus Incoherent



The Forward Calorimeter System (2.5 < η < 4.0):





- ✓ The incoherent contribution is dominant at forward rapidities
- ✓ Get access to the production near threshold.

Summary

- The first opportunity to access coherent ϕ photoproduction in heavy-ion collisions.
- Probe the gluon distribution in the shadowing and anti-shadowing region.
- Study the coherent length effect via coherent and incoherent production
- Fill the gap of J/ψ photoproduction measurements at low energy near threshold for $\gamma + N$.