

# STAR overview

Prithwish Tribedy for the STAR collaboration (Brookhaven National Laboratory)



**IS2021**

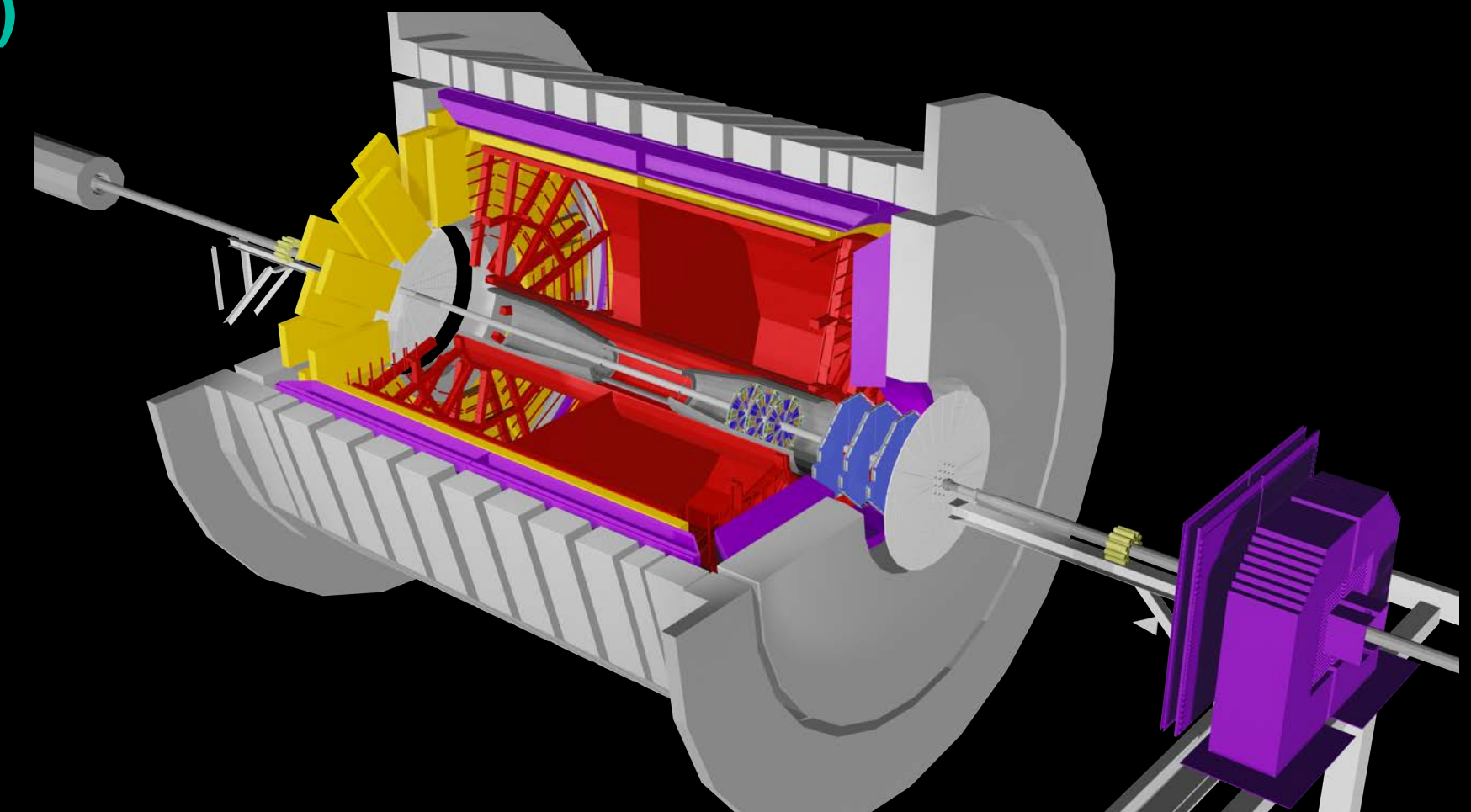
The VI<sup>th</sup> International Conference on the  
**INITIAL STAGES**  
OF HIGH-ENERGY NUCLEAR  
COLLISIONS



# Outline



- Small systems:
  - Forward di-hadron correlations **Talk by Xiaoxuan Chu (Tue 18:40)**
  - Collectivity in  $^3\text{He}+\text{Au}$ ,  $\text{d}+\text{Au}$  and  $\text{p}+\text{Au}$  **Talk by Shengli Huang (Tue 18:40)**
- Initial Stages of A+A:
  - Effect of deformation on  $v_n - \langle p_T \rangle$  correlations and  $\langle p_T \rangle$  fluctuations **Talk by Jiangyong Jia (Thu 16:35)**
  - Longitudinal de-correlations, (anti)-particle  $v_3$ , elliptic flow at high  $p_T$  **Talk by Maria Stefaniak (Tue 18:40)**
- Ultra-peripheral collisions and strong field effects:
  - Photoproduction of  $J/\psi$  in  $\text{d}+\text{Au}$  collisions **Talk by Xiaofeng Wang (Wed 18:45)**
  - Photoproduction of low  $p_T$  di-electron in UPC & peripheral A+A **Talk by Xiaofeng Wang (Wed 18:45)**
  - Probing nuclei with linearly polarized photons **Talk by Daniel Brandenburg (Wed 19:25)**
  - Search for the Chiral Magnetic Effect **Talk by Jie Zhao (Thu 15:55)**
- Forward upgrade and STAR beyond 2021+ **Talk by Ting Lin (Thu 16:35)**



## Small Systems

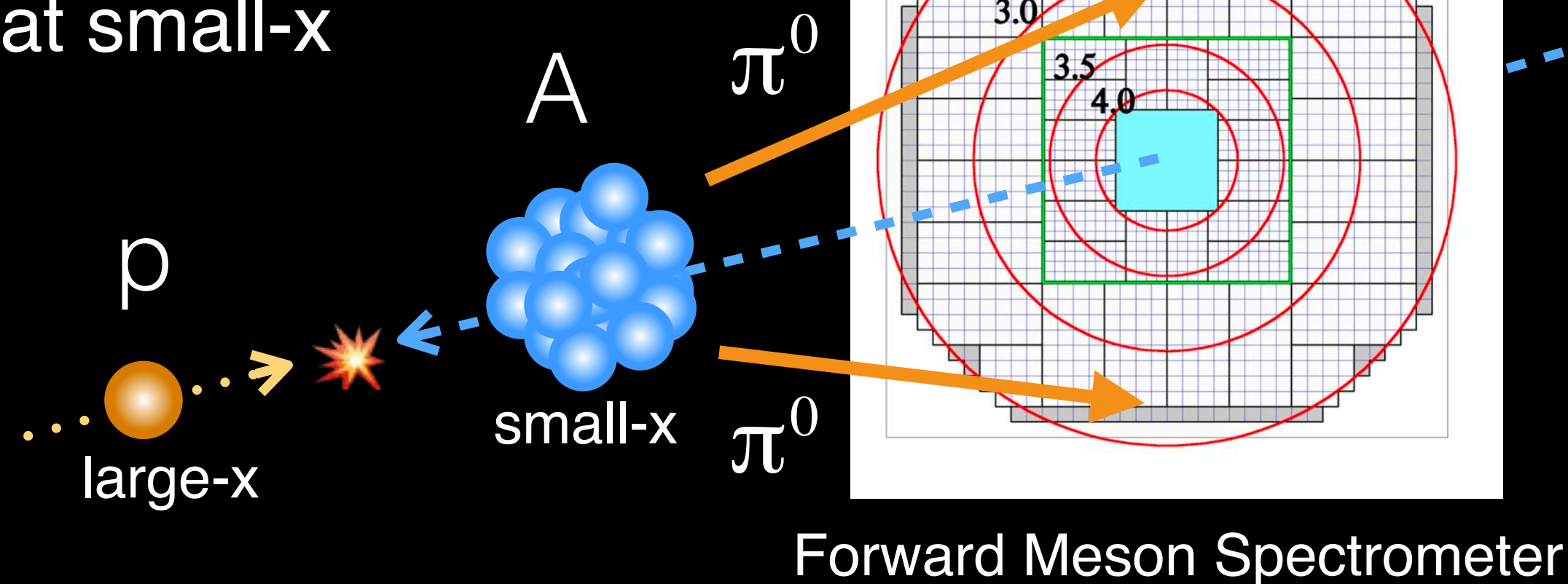
- Forward di-hadron correlations
- Collectivity in  $^3\text{He}+\text{Au}$ ,  $\text{d}+\text{Au}$  and  $\text{p}+\text{Au}$

# Forward di-hadron correlations in p+A collisions

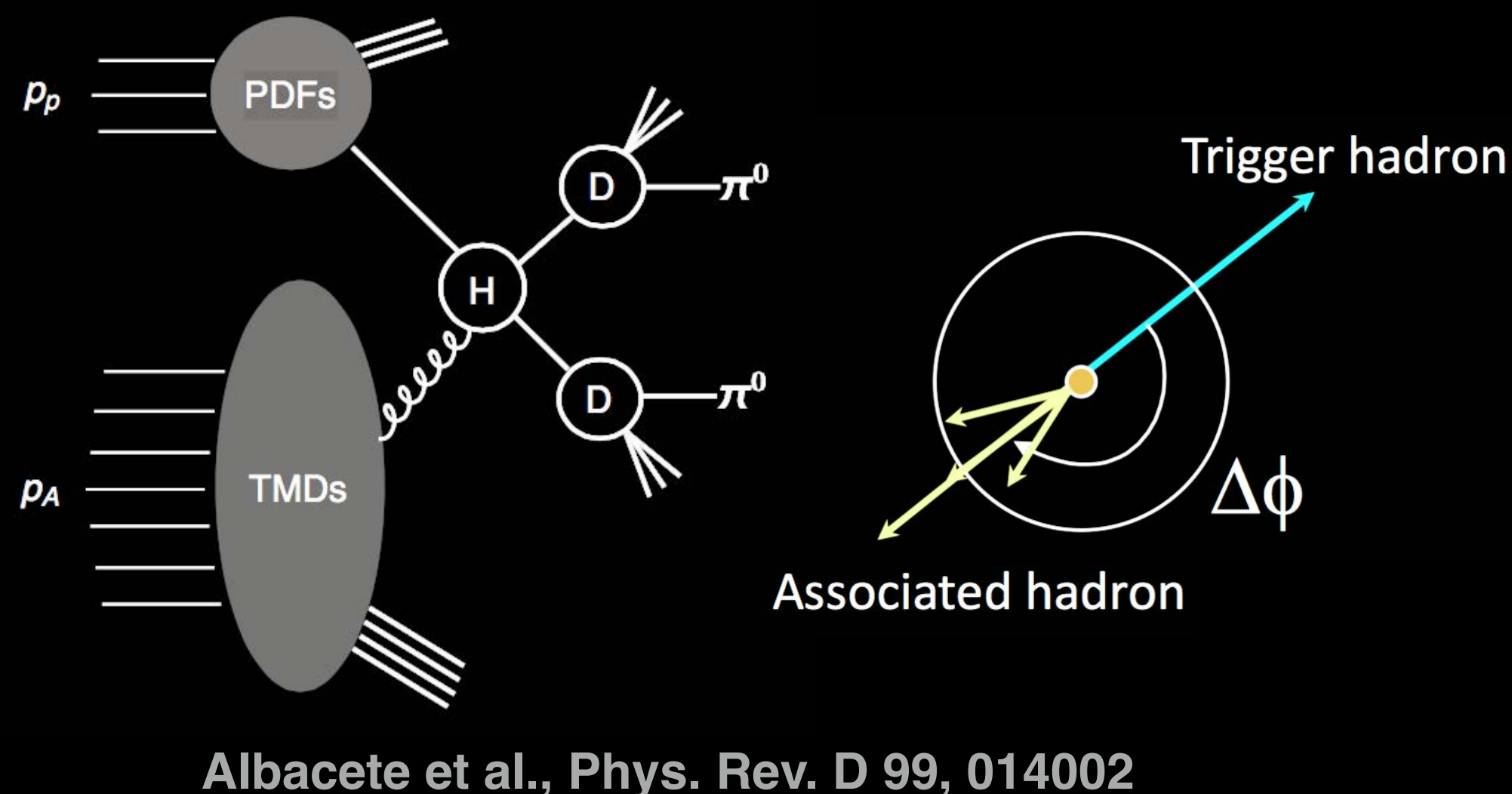
Talk by Xiaoxuan Chu  
(Tue 18:40)



Kinematics probe  
gluons inside nuclei  
at small-x



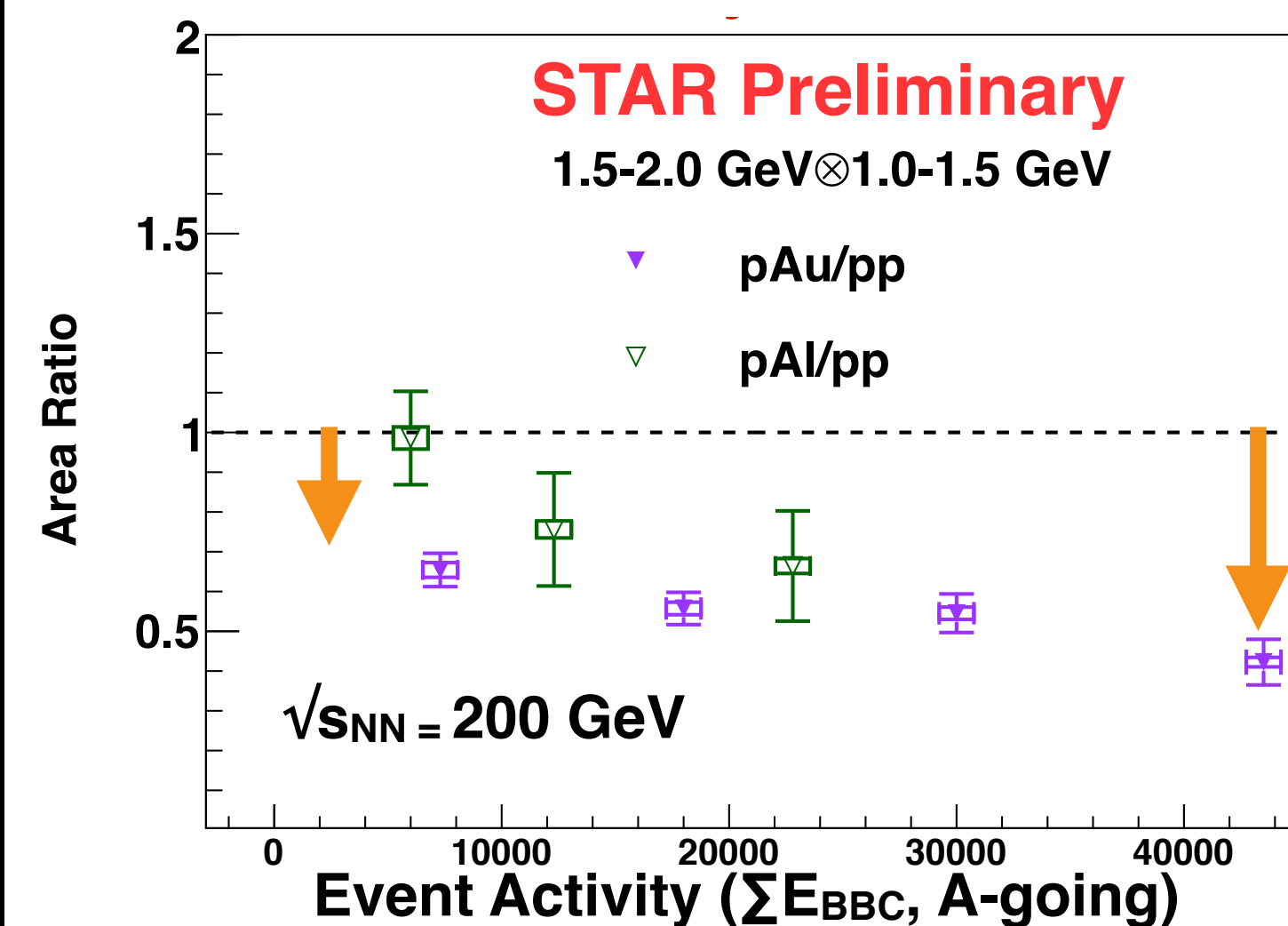
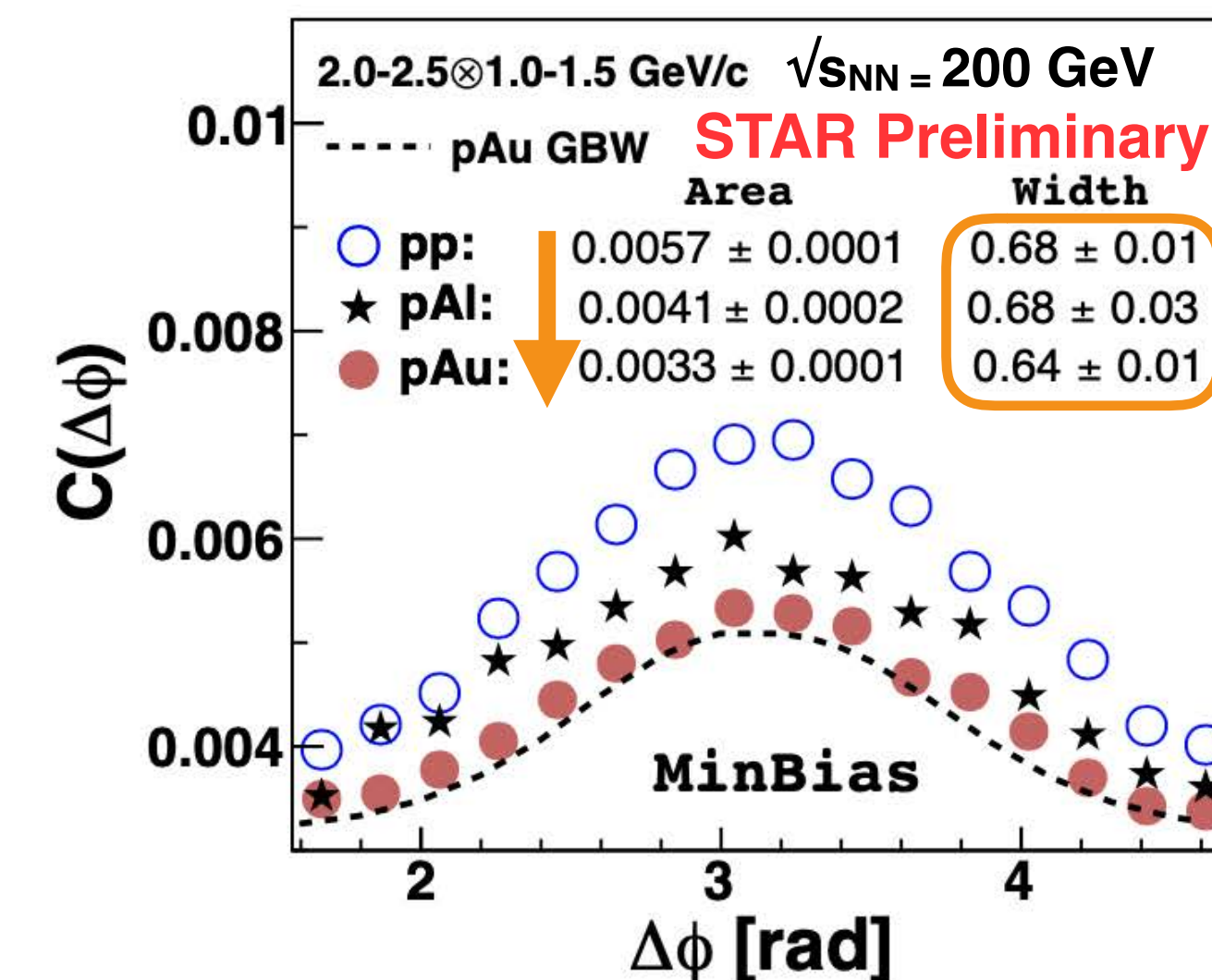
$$C(\Delta\phi) = \frac{N_{pair}(\Delta\phi)}{N_{trig} \times \Delta\phi}$$



Area of  $C(\Delta\phi)$  :  
 $p+p > p+Al > p+Au$

Width of  $C(\Delta\phi)$  :  
 $p+p \sim p+Al \sim p+Au$

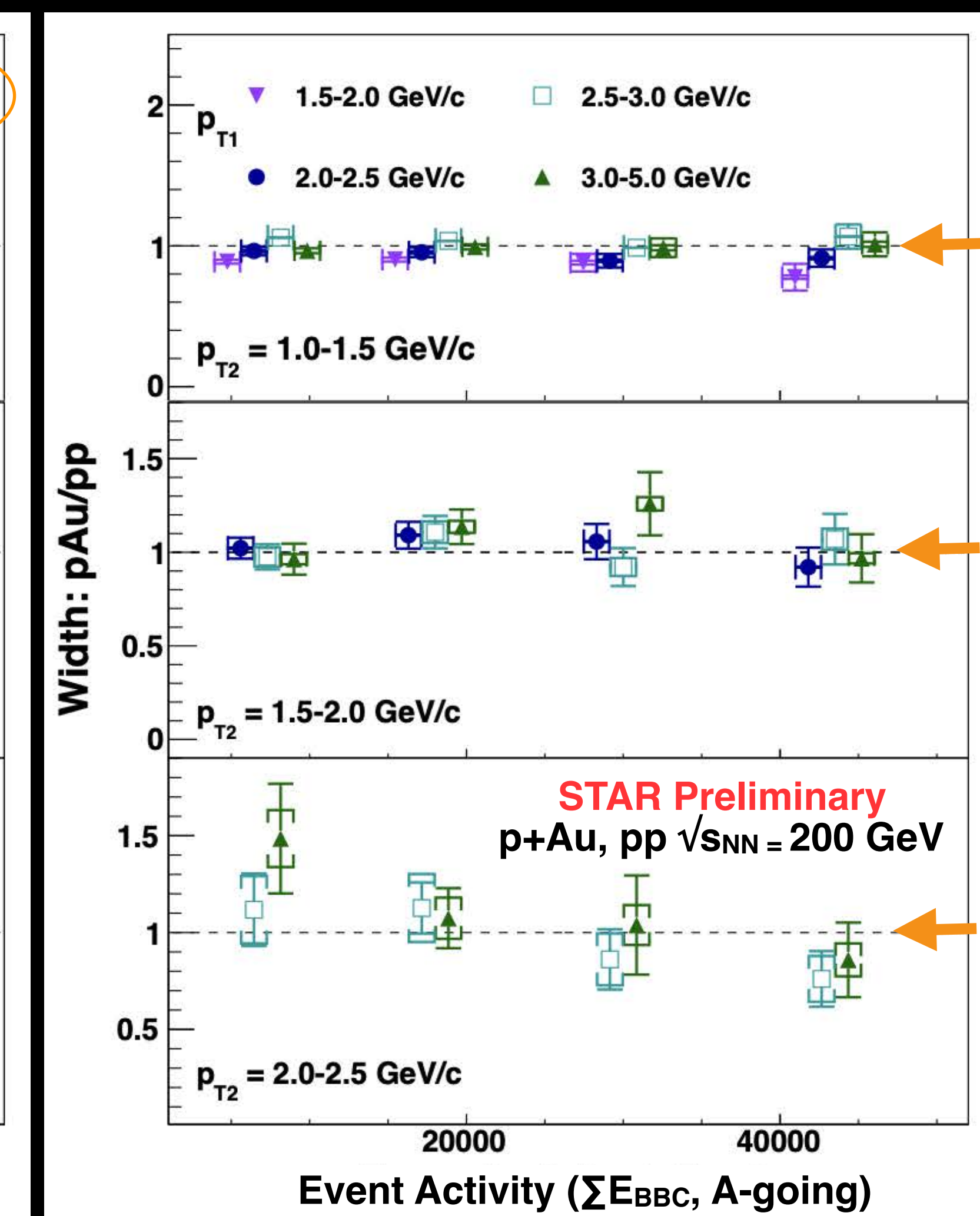
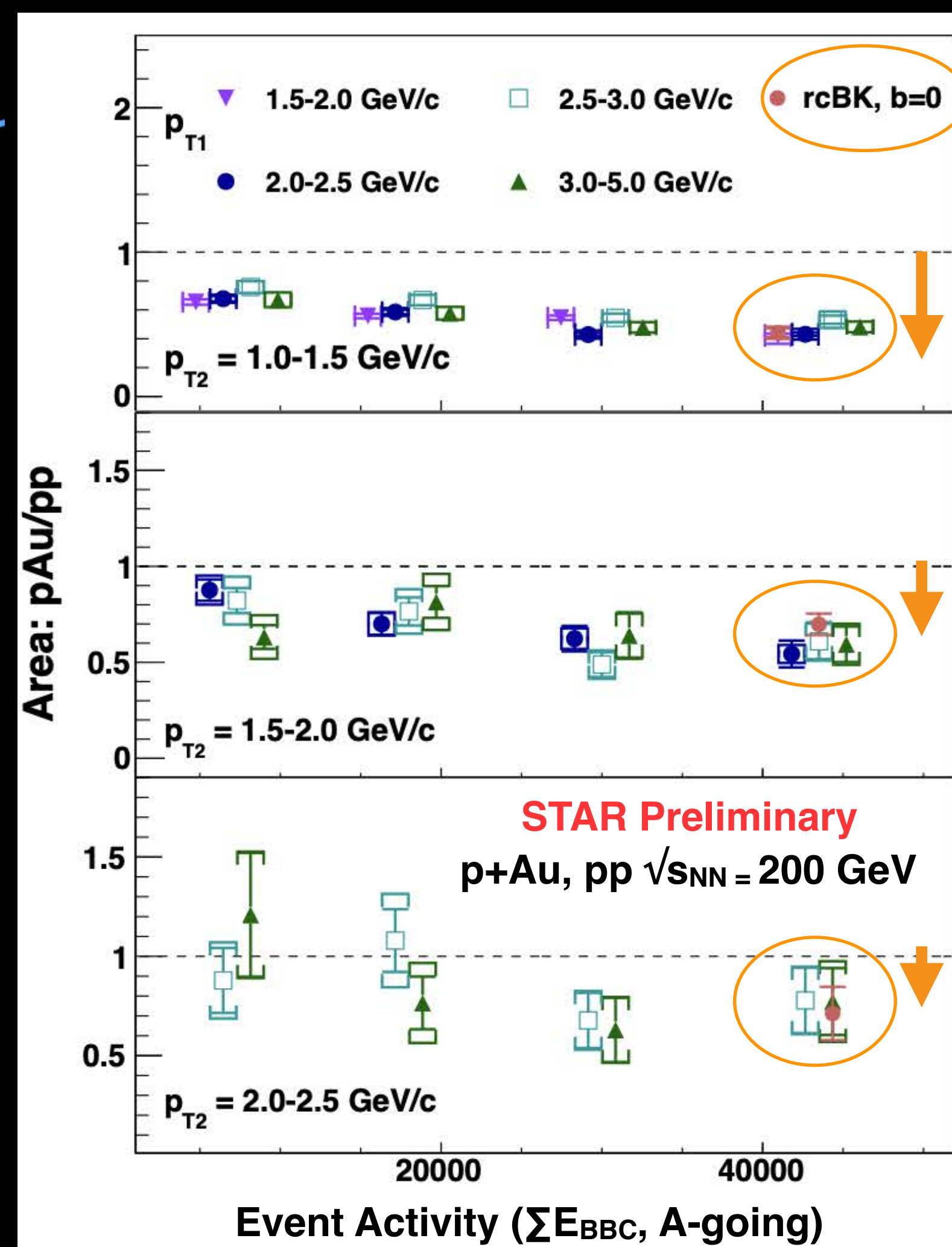
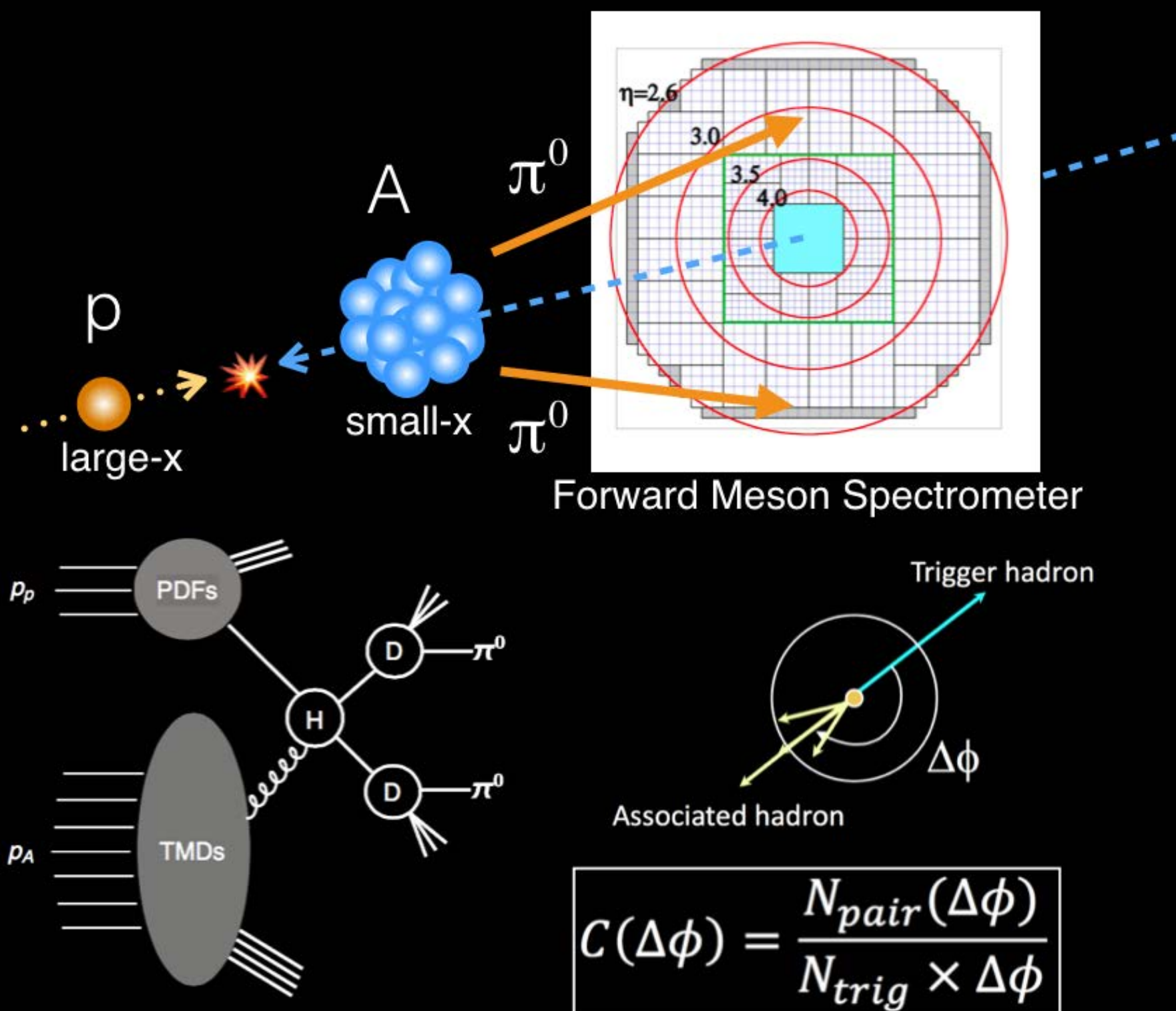
GBW model:  
Stasto et al., Phys. Lett. B,  
716(2012) 430-434



Suppression of back-to-back  $\pi^0$  pairs in p+A relative to p+p increases with A & event activity

# Forward di-hadron correlations in p+A collisions

Talk by Xiaoxuan Chu  
(Tue 18:40)



More significant suppression of area at lower  $p_T$  and no modification of width  
Saturation frameworks correctly predict the systematics of area suppression in p+A

# Collectivity in small collision systems

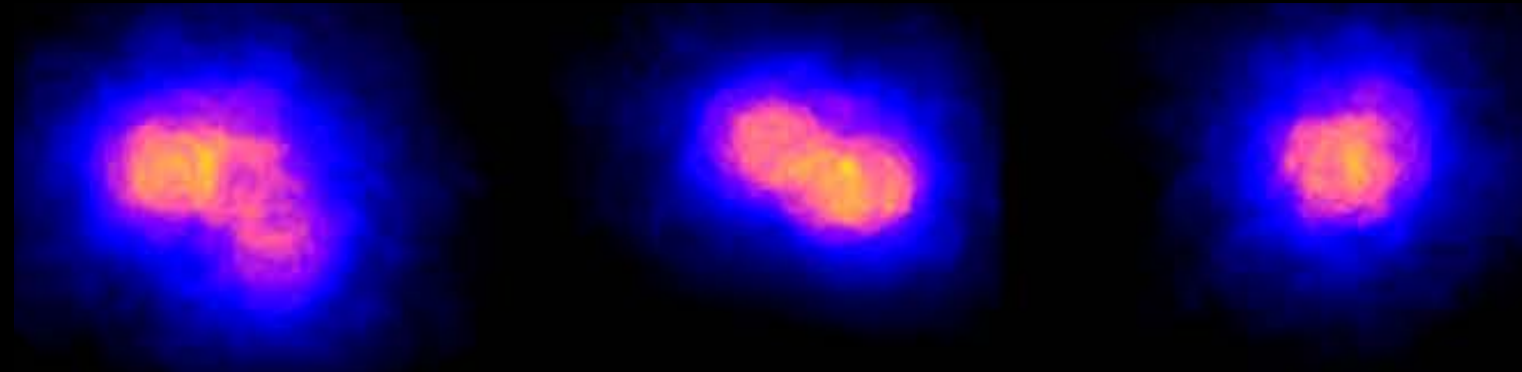
Talk by Shengli Huang  
(Tue 18:40)



$^3\text{He}+\text{Au}$

d+Au

p+Au

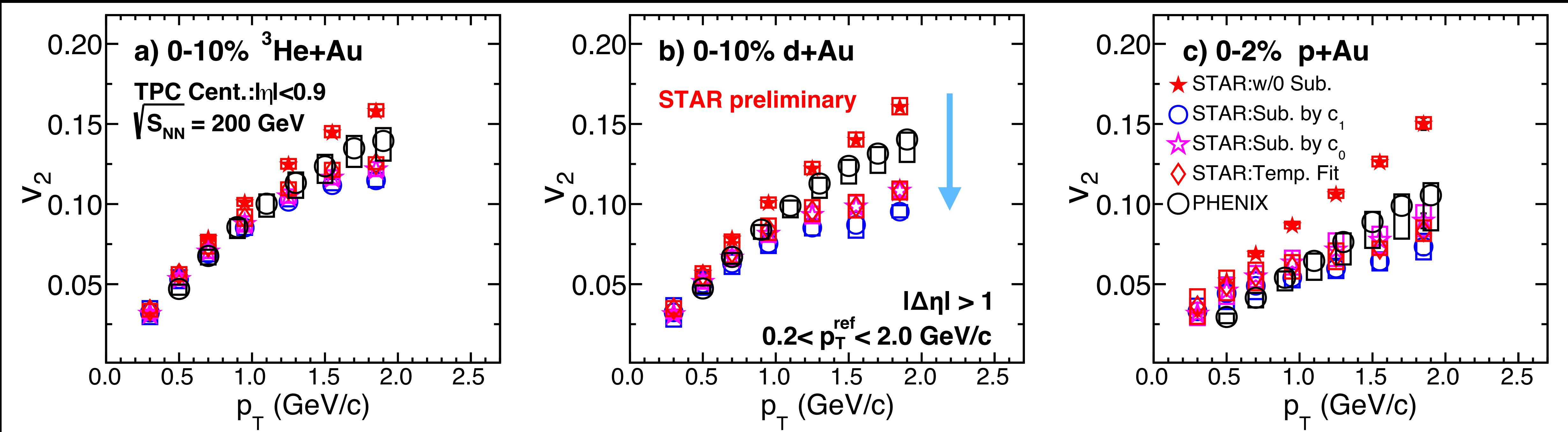


$$Y(\Delta\phi)^{\text{template}}(\text{sys}) = F \times Y(\Delta\phi)(pp) + Y(\Delta\phi)^{\text{ridge}}(\text{sys})$$

$$c_n^{\text{sub}}(\text{sys}) = c_n^{\text{raw}}(\text{sys}) - c_n(pp) \frac{N_{ch}(pp)}{N_{ch}(\text{sys})}$$

$$c_n^{\text{sub}}(\text{sys}) = c_n^{\text{raw}}(\text{sys}) - c_n(pp) \frac{c_1(pp)}{c_1(\text{sys})}$$

Consistent results using different methods  
of non-flow subtraction that decreases  $v_2$



$v_2(^3\text{He}+\text{Au}) \sim v_2(\text{d}+\text{Au}) > v_2(\text{p}+\text{Au})$ , ordering consistent with PHENIX results, role of final state is established

# Collectivity in small collision systems

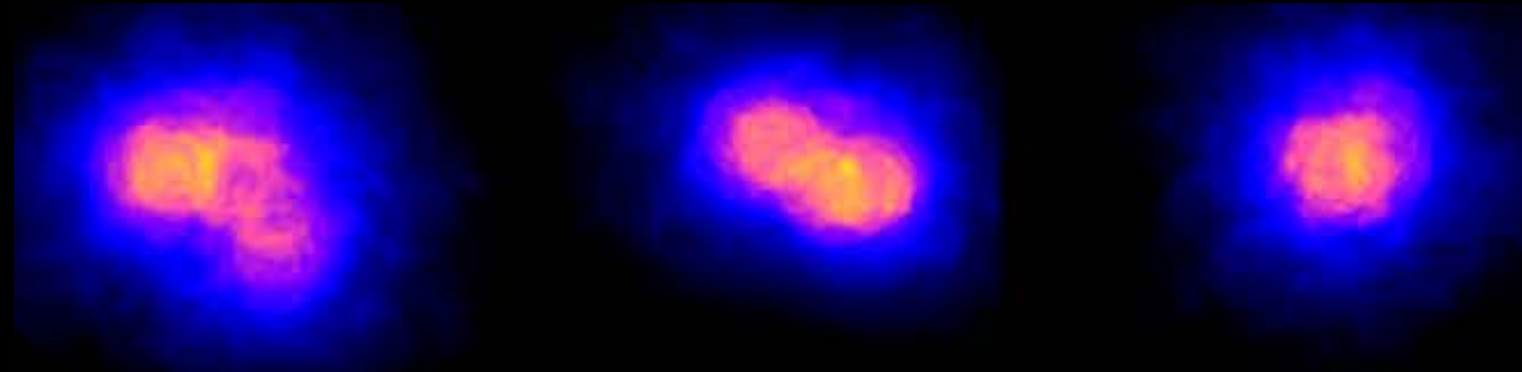
Talk by Shengli Huang  
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$^3\text{He}+\text{Au}$

$\text{d}+\text{Au}$

$\text{p}+\text{Au}$

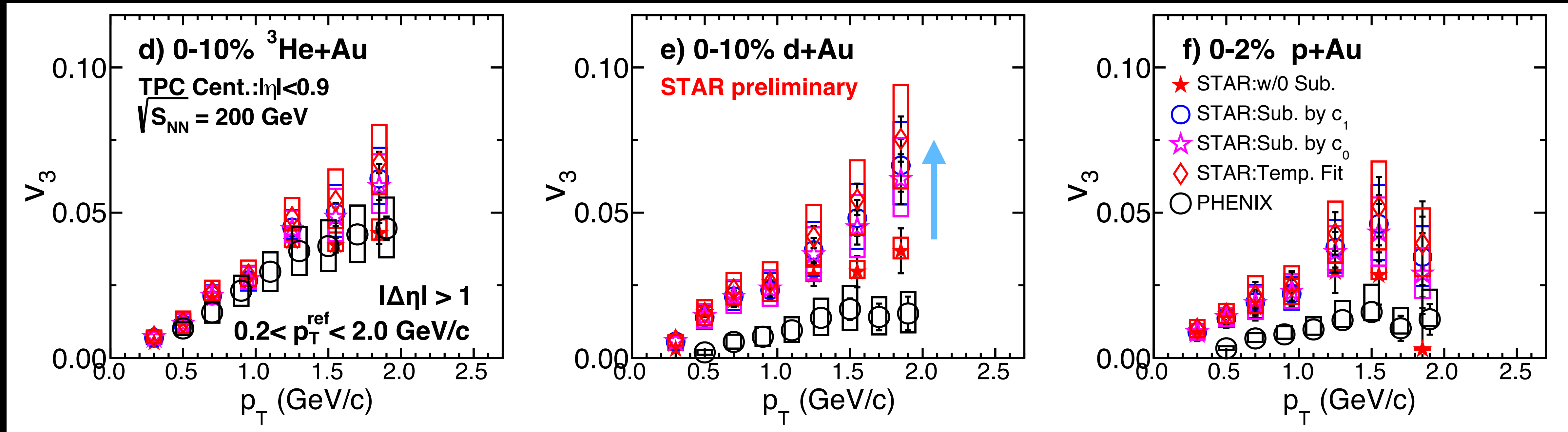


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Consistent results using different methods  
of non-flow subtraction that increases  $v_3$



STAR results:  $v_3(^3\text{He}+\text{Au}) \sim v_3(\text{d}+\text{Au}) \sim v_3(\text{p}+\text{Au})$ , using different methods & coverage from PHENIX  
Cross-experiment task force working to understand the apparent STAR-PHENIX discrepancy

## Initial Stages of A+A

- Effect of deformation on  $v_n - \langle p_T \rangle$  correlations and  $\langle p_T \rangle$  fluctuations
- Longitudinal de-correlations, (anti)-particle  $v_3$ , elliptic flow at high  $p_T$



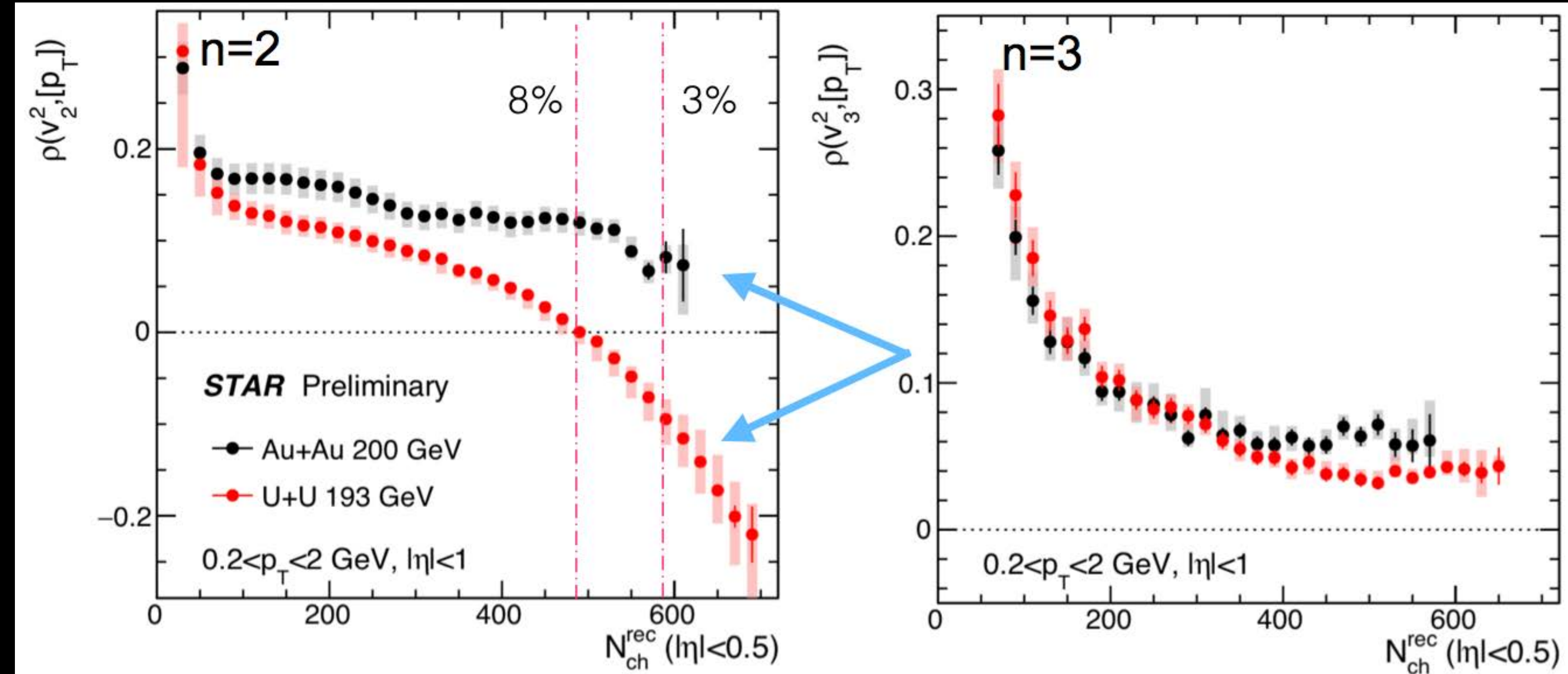
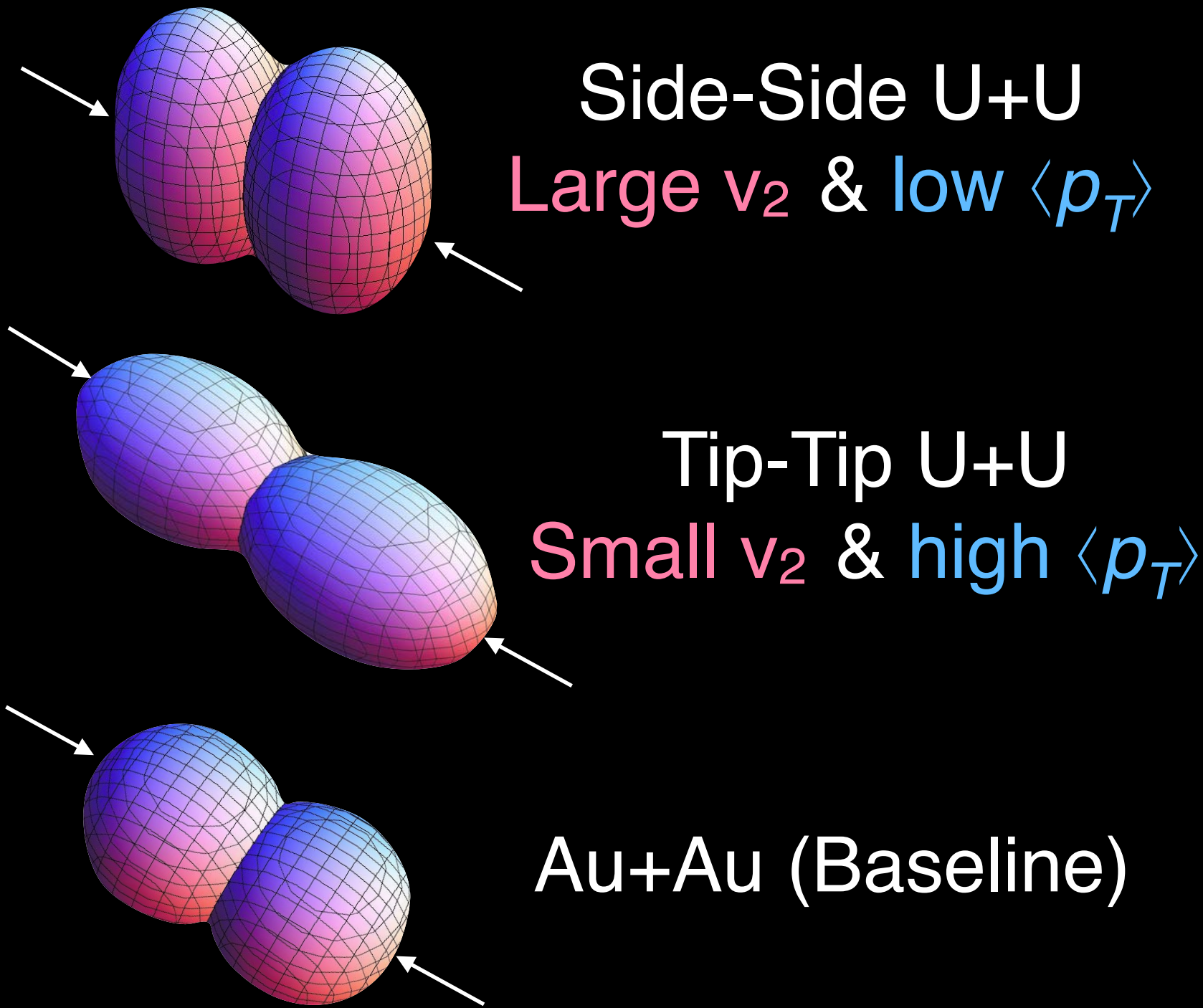
# Nuclear deformation & $v_n - \langle p_T \rangle$ fluctuations

Talk by Jianguyong Jia  
(Thu 16:35)



Poster by Chunjian Zhang (Mon 19:40)

Giacalone, Phys. Rev. Lett. 124, 202301 (2020)



$v_2$  (sensitive to shape) &  $\langle p_T \rangle$  correlations are negative in central U+U

$v_3$  (less sensitive to shape) &  $\langle p_T \rangle$  correlations are positive  
Au+Au results  $\rightarrow$  good baseline for nearly spherical shape

$$\rho(v_n^2, [p_T]) = \frac{\text{cov}(v_n^2, [p_T])}{\sqrt{\text{Var}(v_n^2)_{\text{dyn}} \langle \delta p_T \delta p_T \rangle}}$$

Anti-correlation of  $v_2$  and  $\langle p_T \rangle$  indicates possible sensitivity to deformed shape of Uranium

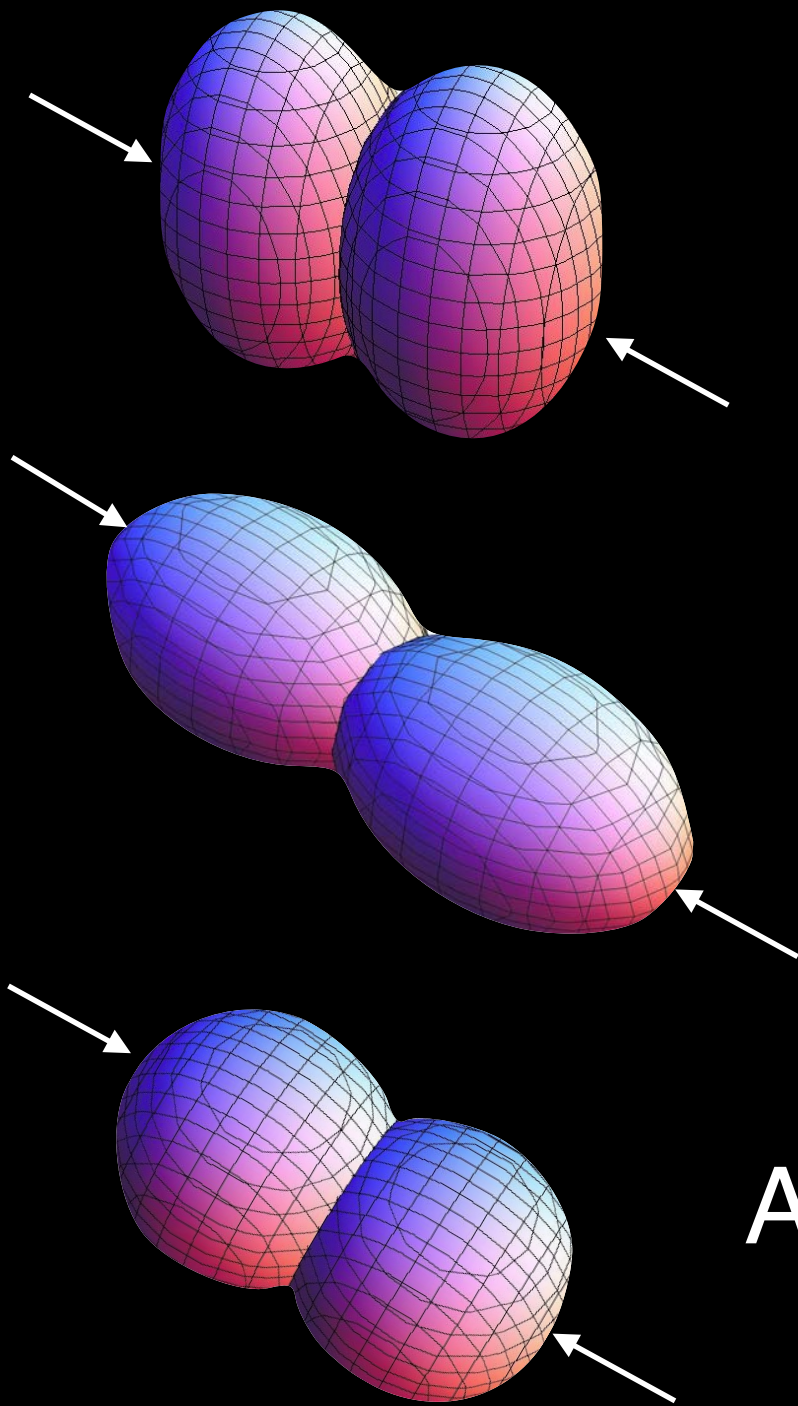
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Side-Side U+U  
low  $\langle p_T \rangle$

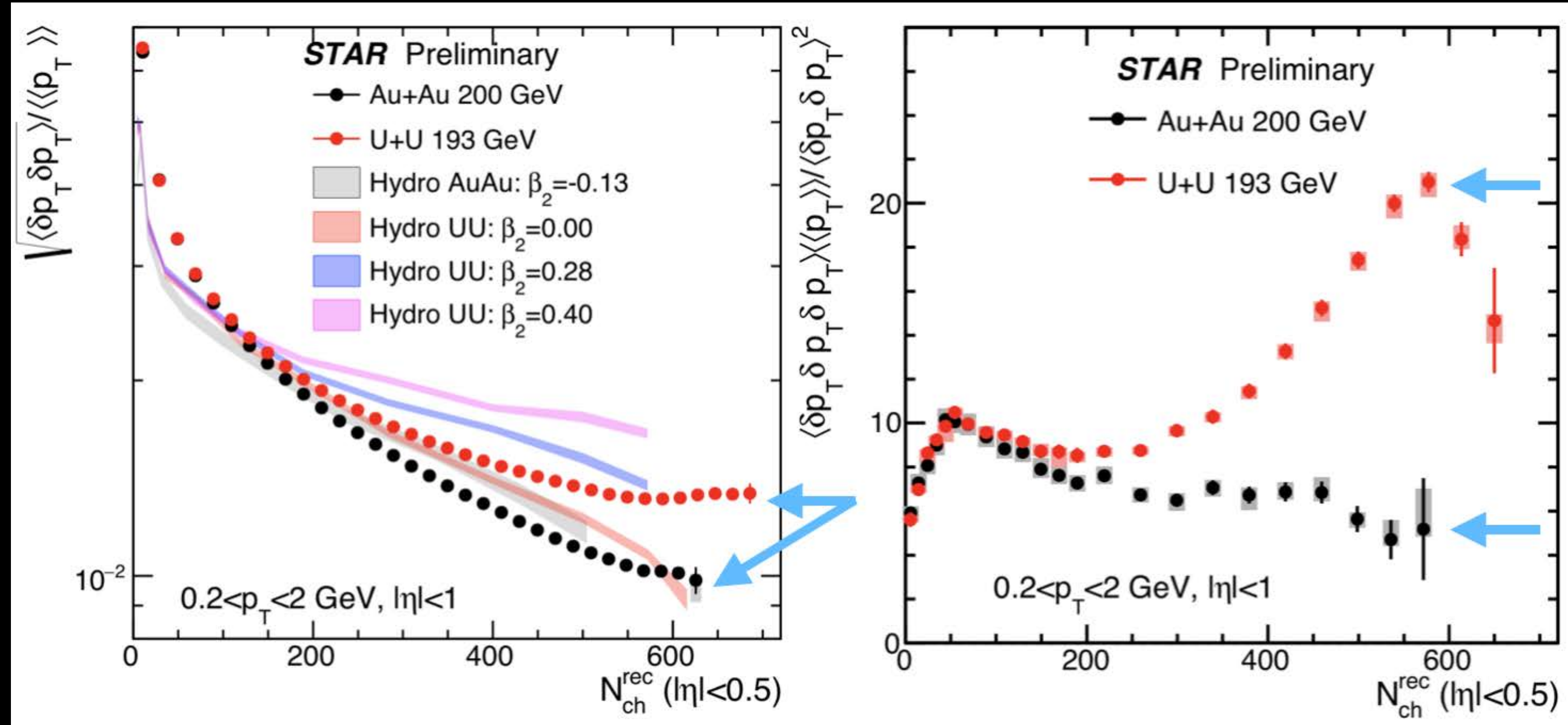
Tip-Tip U+U  
high  $\langle p_T \rangle$

Au+Au (Baseline)

$$\delta p_T = p_T - [p_T]$$

Standard Variance  $\sigma_{p_T} = \frac{\sqrt{\langle \delta p_T \delta p_T \rangle}}{\langle \langle p_T \rangle \rangle}$

Intensive Skewness  $\Gamma_{p_T} = \frac{\langle \delta p_T \delta p_T \delta p_T \rangle \langle \langle p_T \rangle \rangle}{\langle \delta p_T \delta p_T \rangle^2}$



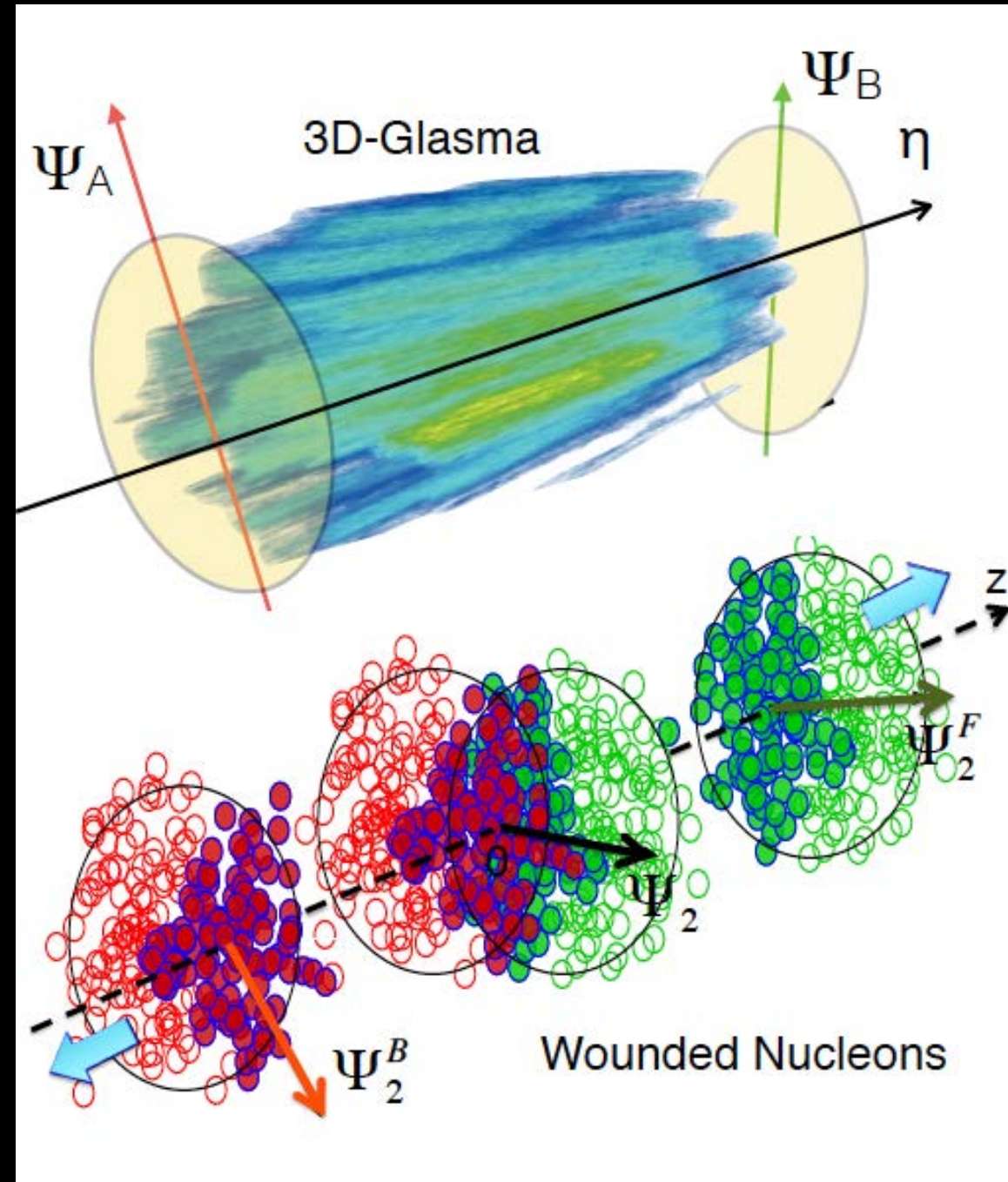
Higher order fluctuations of  $\langle p_T \rangle$  show difference in central U+U and Au+Au → sensitivity to deformation

# More on flow and de-correlation & 3D initial state

Talk by Maria Stefaniak  
(Tue 18:40)

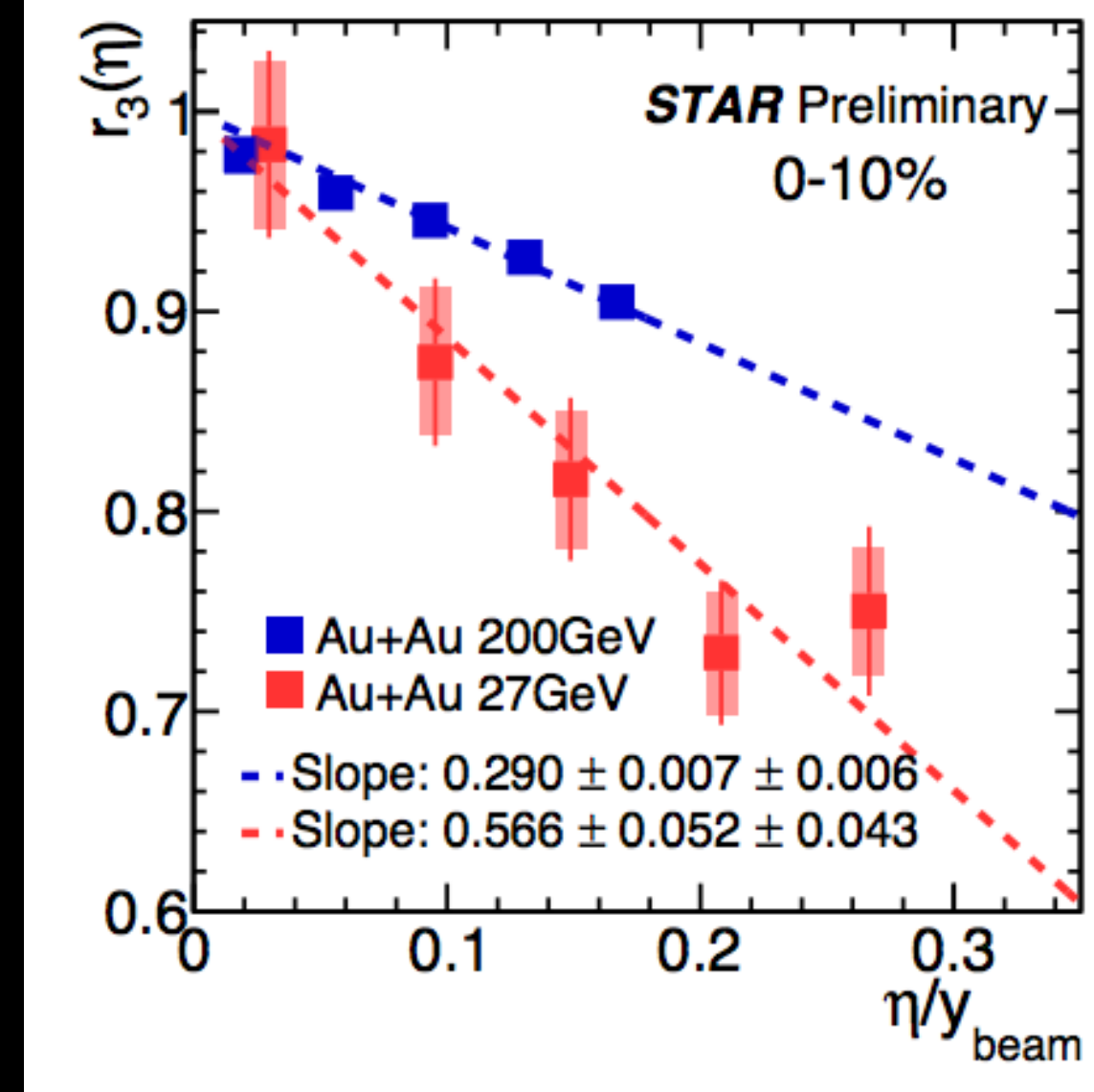
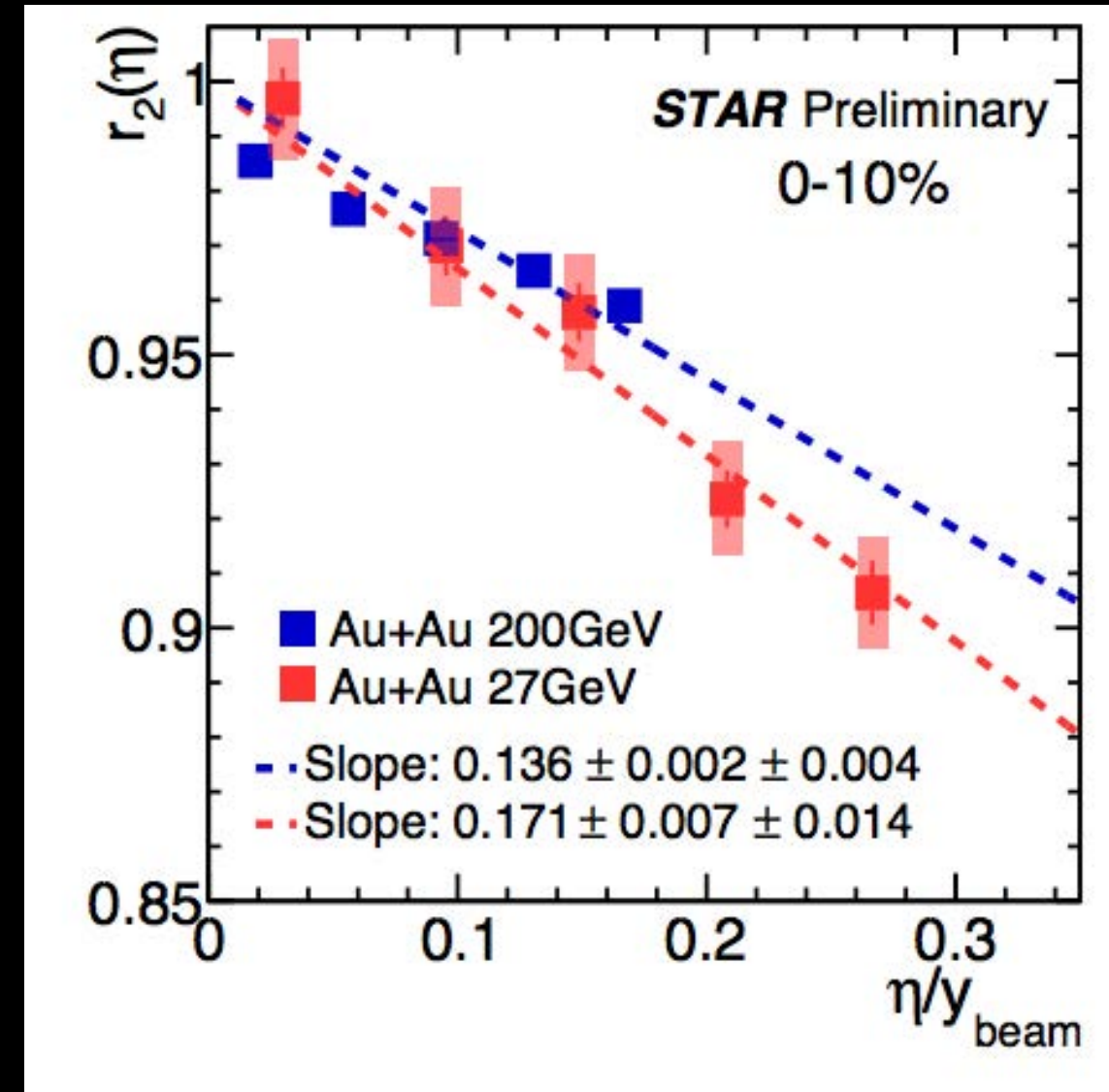


Poster by Maowu Nie (Mon 19:40)



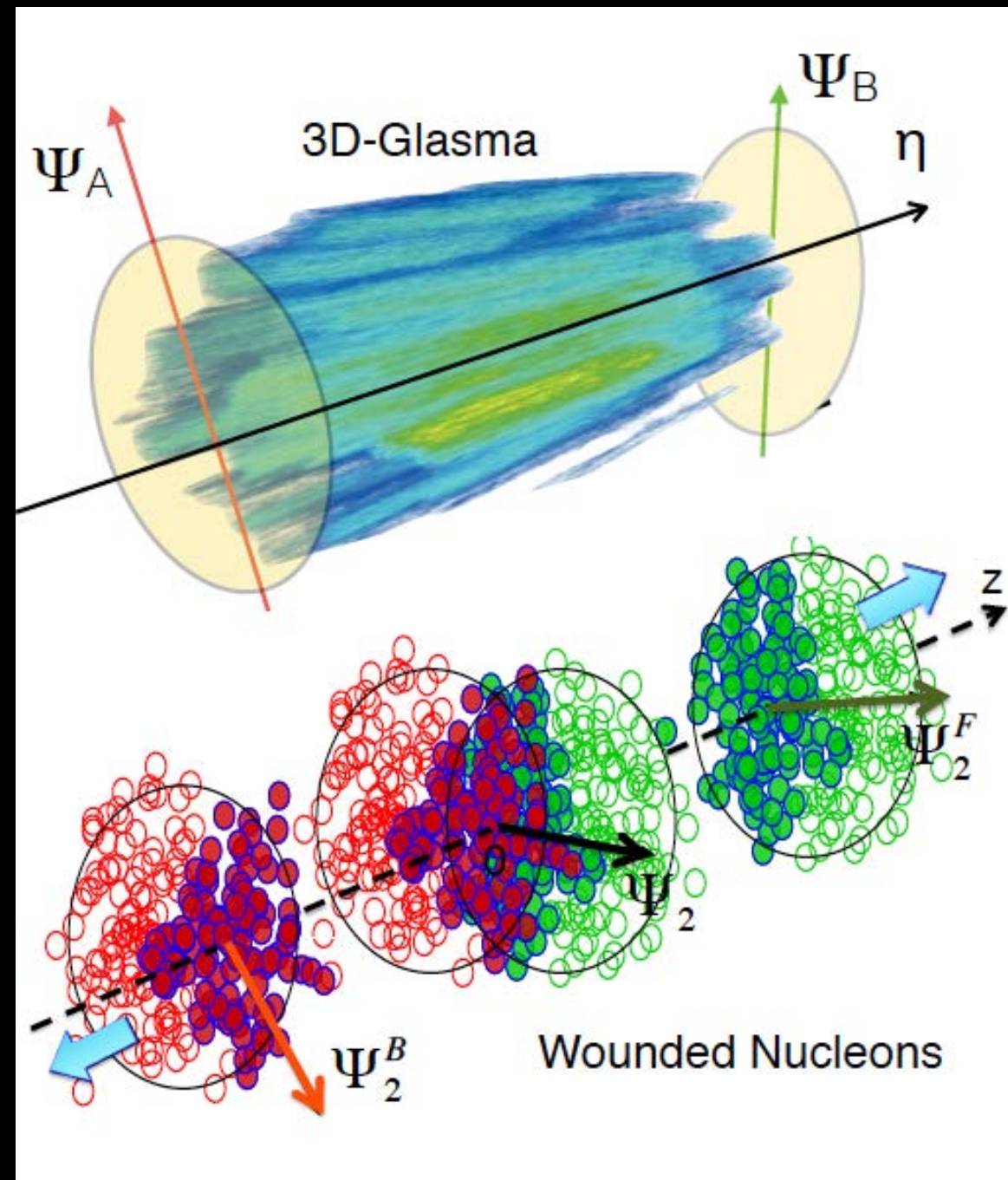
$$r_n(\eta^a, \eta^b) = \frac{V_{n\Delta}(-\eta^a, \eta^b)}{V_{n\Delta}(\eta^a, \eta^b)}$$

RHIC de-correlation  
results do not follow  
beam rapidity scaling

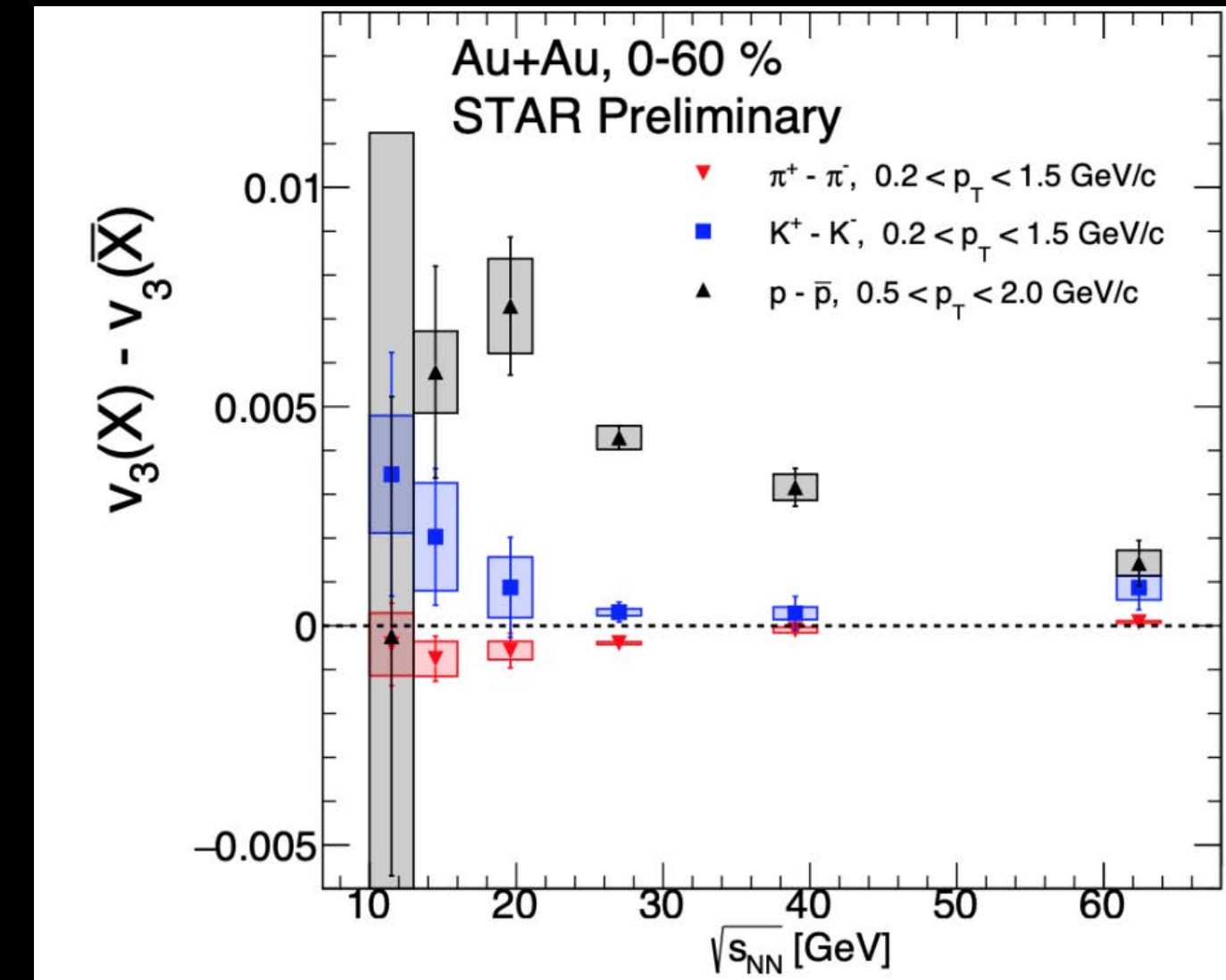
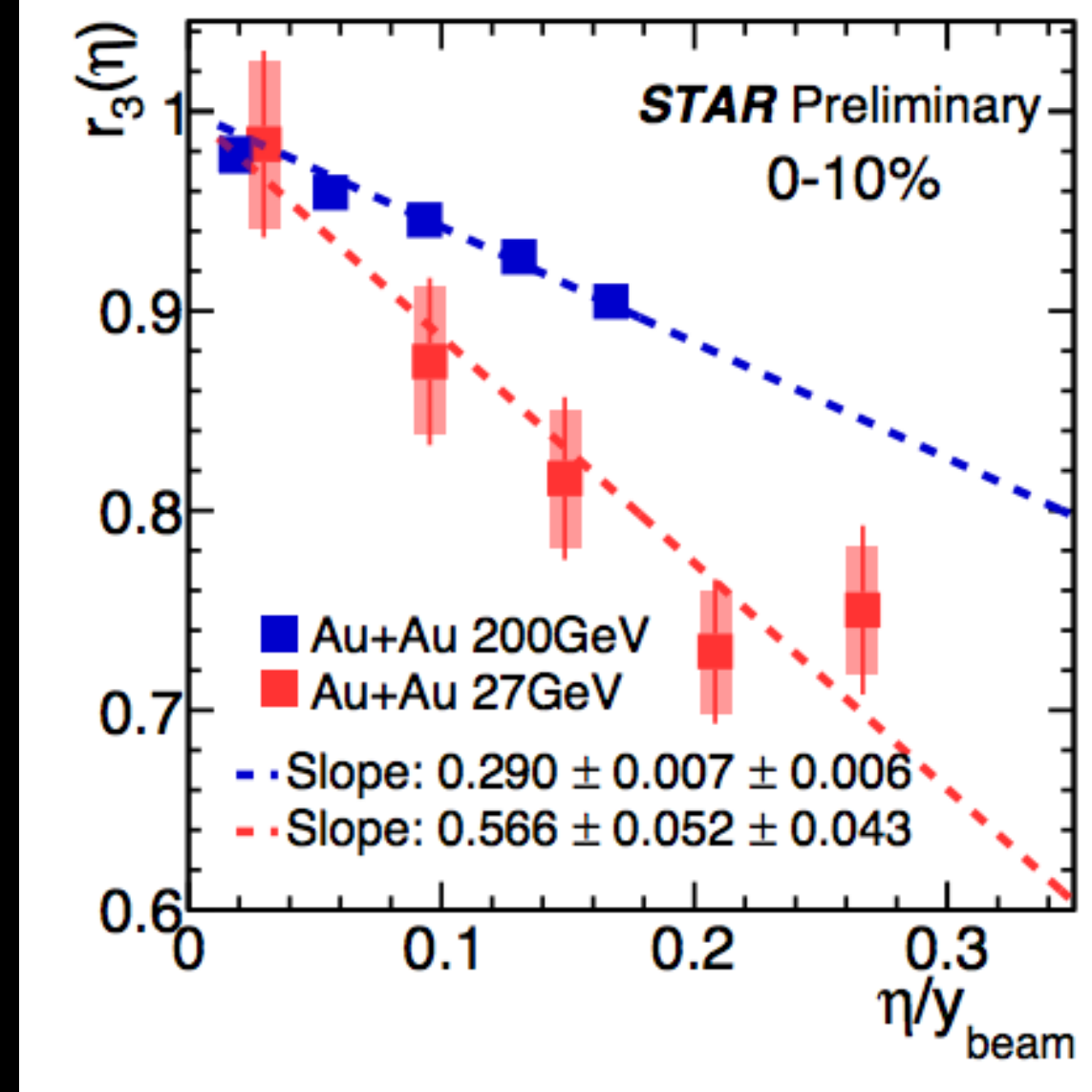
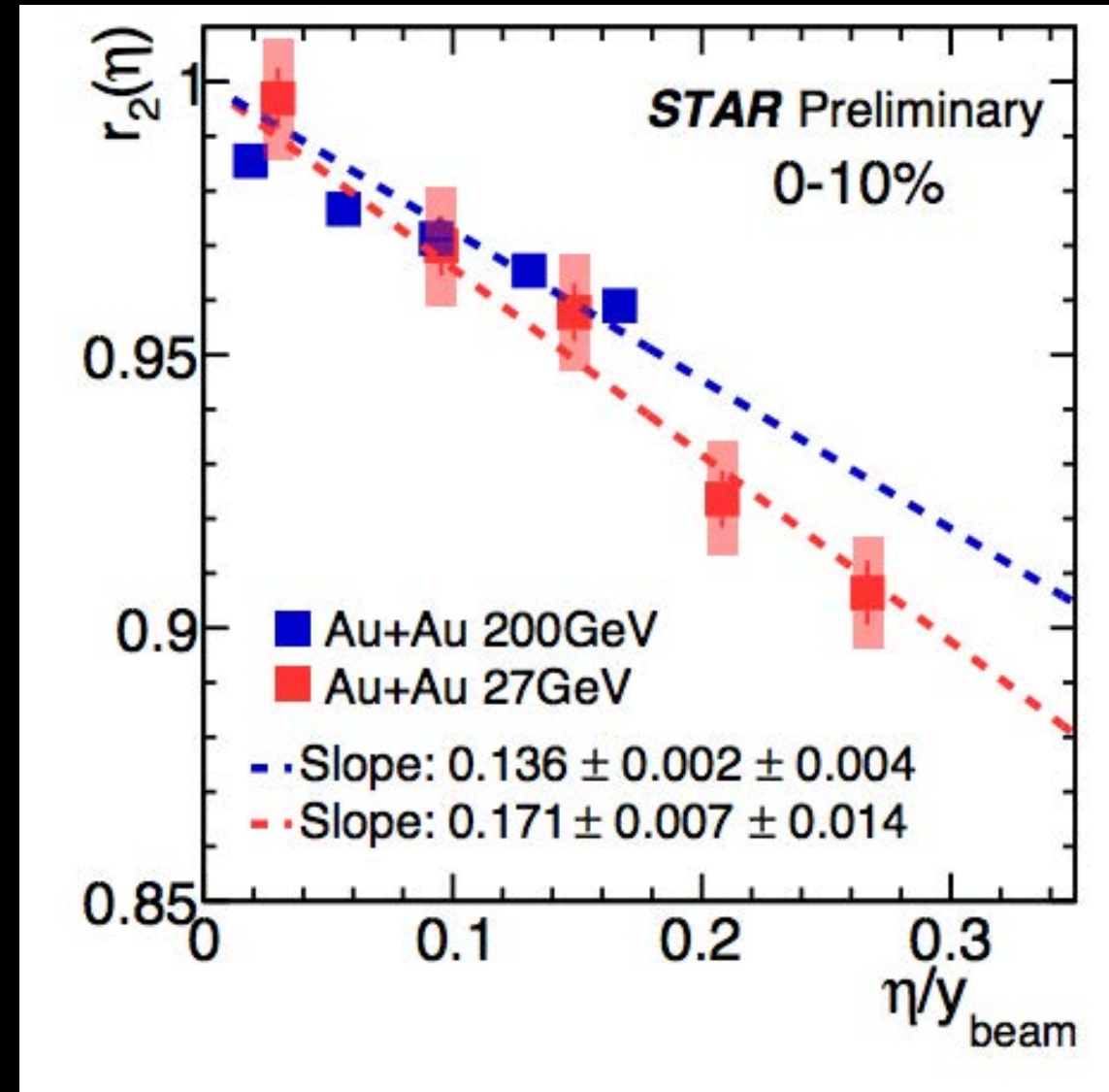


# More on flow and de-correlation & 3D initial state

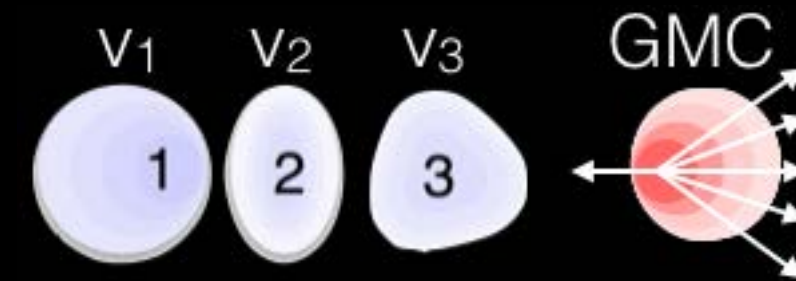
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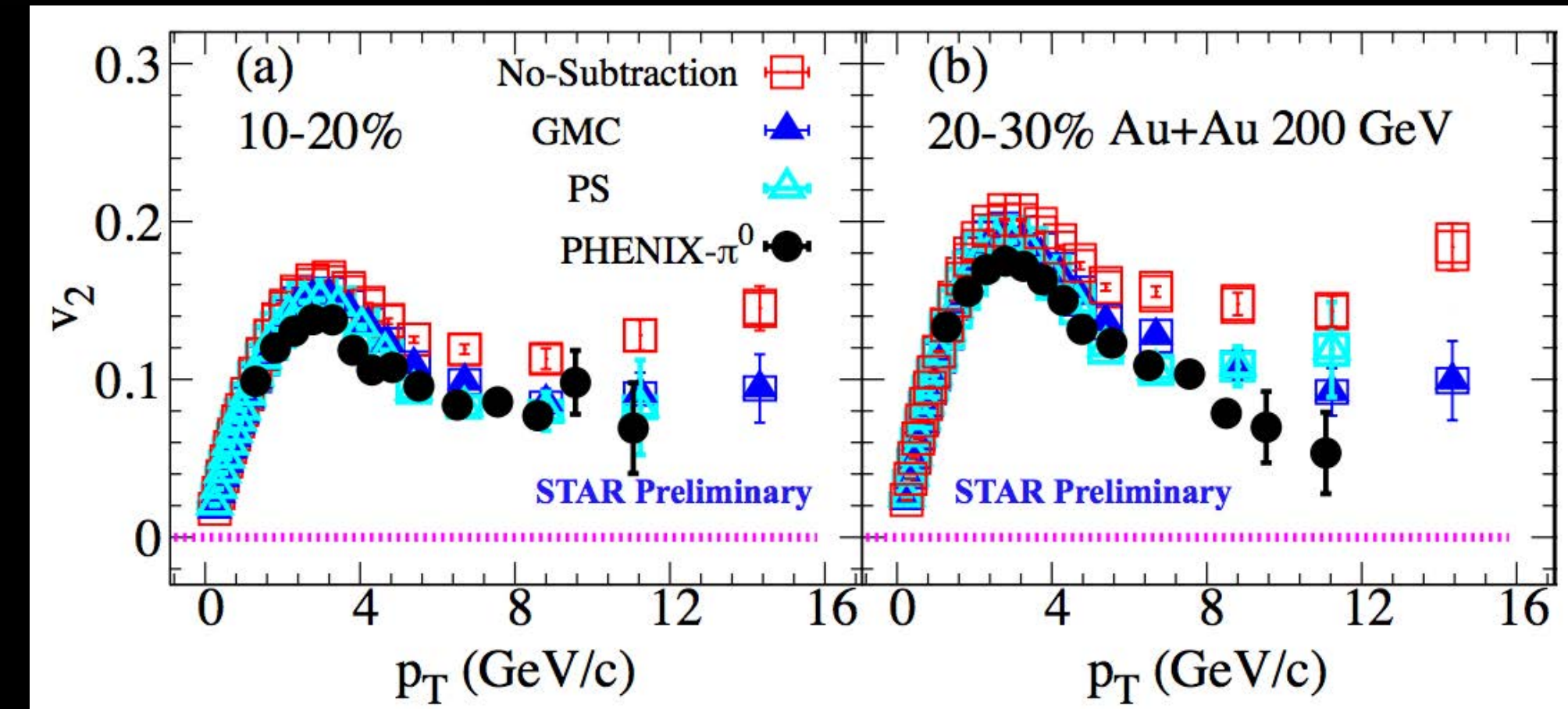
Anti-(particle)  $v_3$ :  
constraints on  
initial state  
models at low  $\sqrt{s}$



Isolating flow & global mom.  
conservation at high  $p_T$

$$r_n(\eta^a, \eta^b) = \frac{V_{n\Delta}(-\eta^a, \eta^b)}{V_{n\Delta}(\eta^a, \eta^b)}$$

RHIC de-correlation  
results do not follow  
beam rapidity scaling



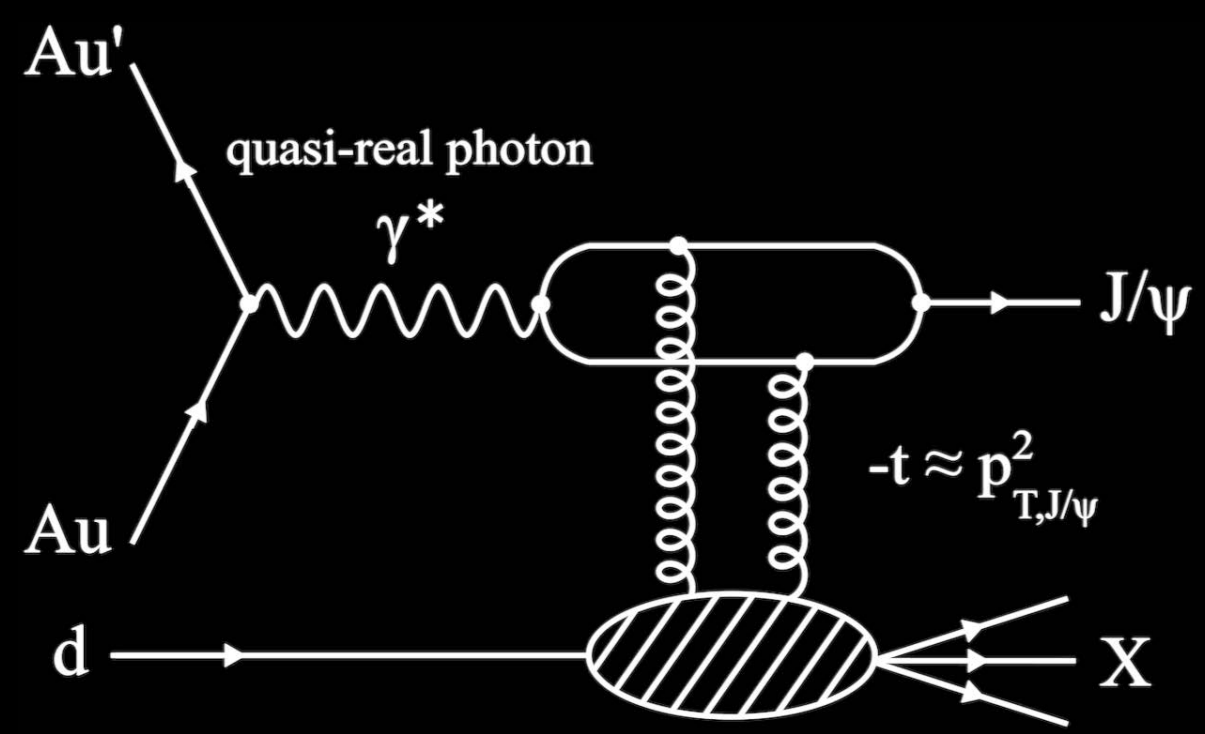
Poster by Niseem Magdy (Sun 19:45)

## Ultra-peripheral Collisions & Strong Fields

- Photoproduction of  $J/\psi$  in d+Au collisions
- Photoproduction of low  $p_T$  di-electron in UPC & peripheral A+A
- Probing nuclei with linearly polarized photons
- Search for the Chiral Magnetic Effect

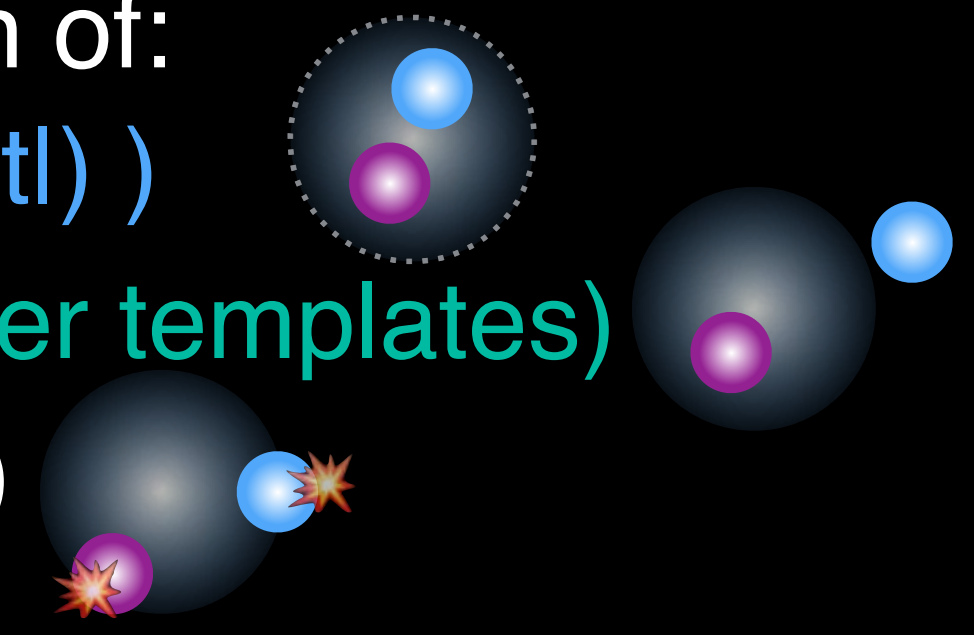
# Photoproduction of J/ψ in d+Au UPC

Talk by Xiaofeng Wang  
(Wed 18:45)

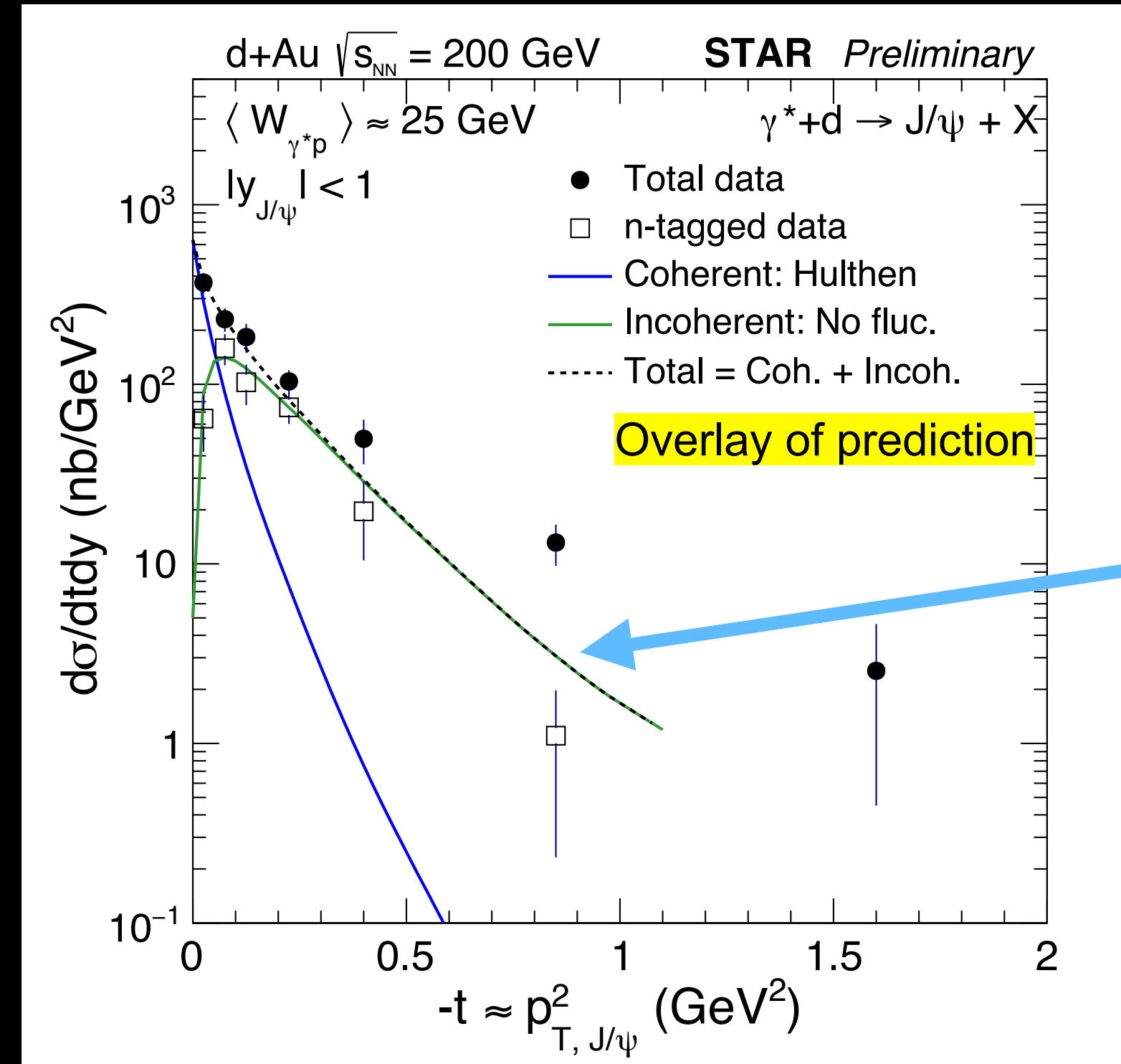
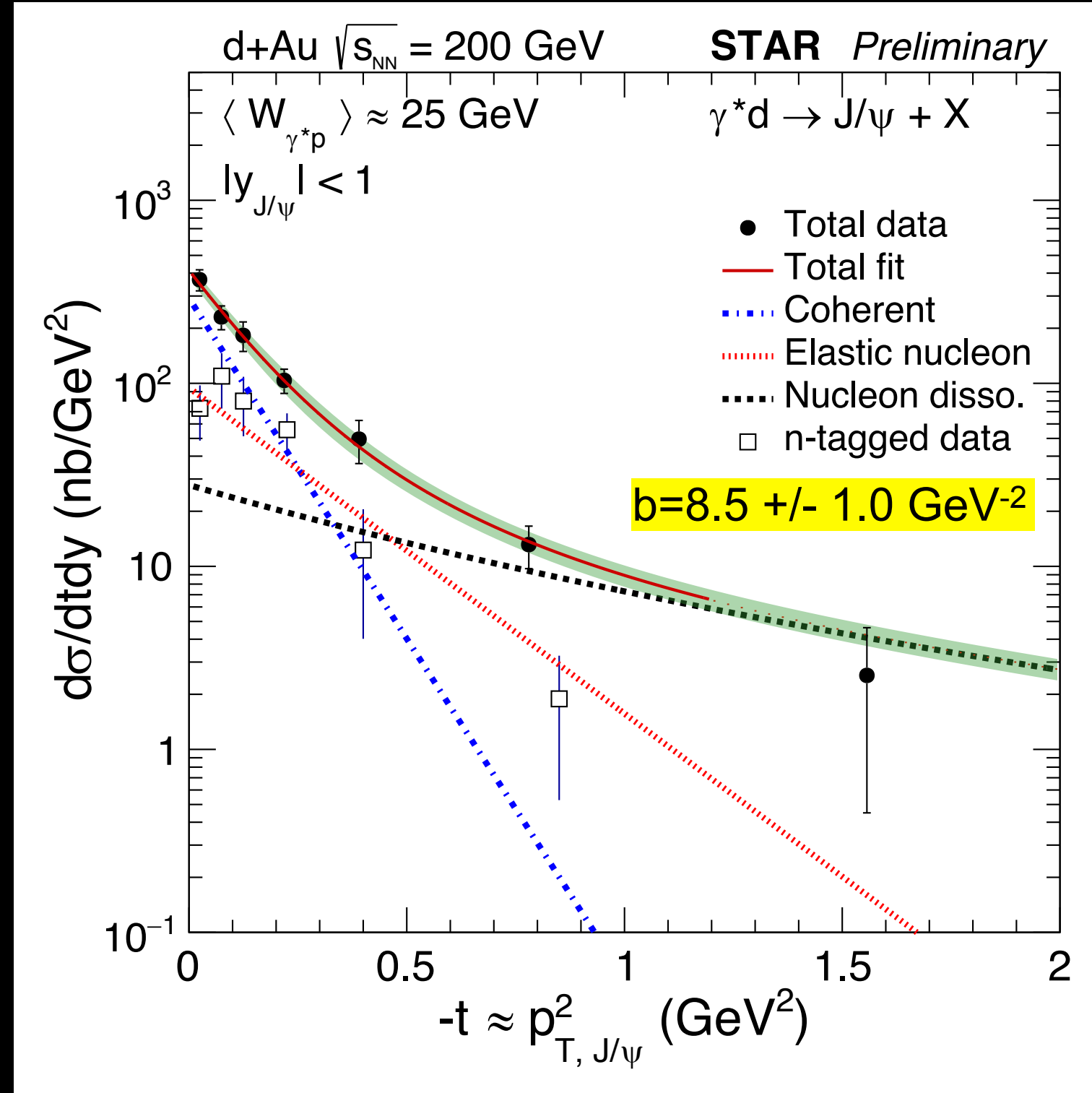


Total cross section is a combination of:

1. Coherent contribution ( $\sim \exp(-b|t|)$ )
2. Elastic nucleon (ep HERA & other templates)
3. Nucleon dissociative (ep HERA)

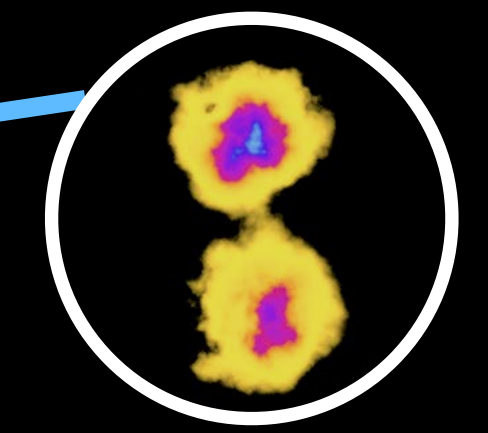


Fit to data:  
Coherent +  
Elastic nucleon +  
Nucleon disso:  
ep H1:  
Eur.Phys.J.C 73 (2013) 6,  
2466



Prediction:  
Hulthen+CGC

Mäntysaari, Schenke,  
Phys. Rev. C 101,  
015203 (2020)

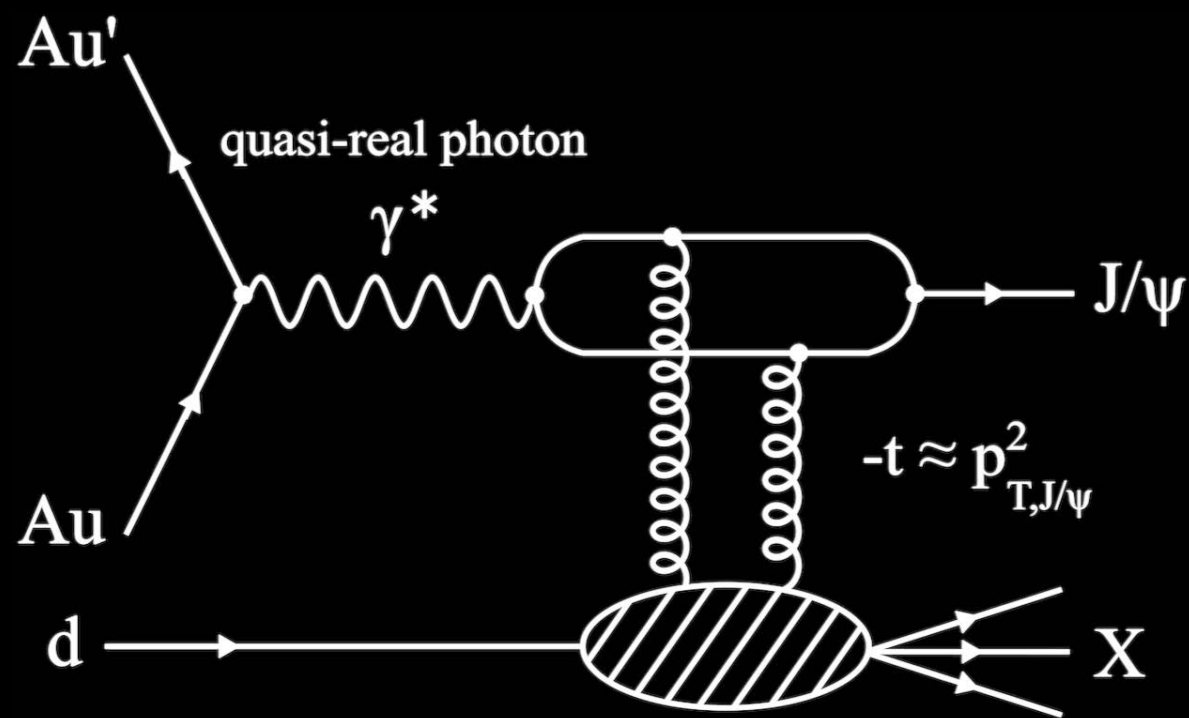


Without sub-nucleonic & Q<sub>s</sub> fluctuations

The coherent diffractive component extracted constrains gluon distribution inside deuteron

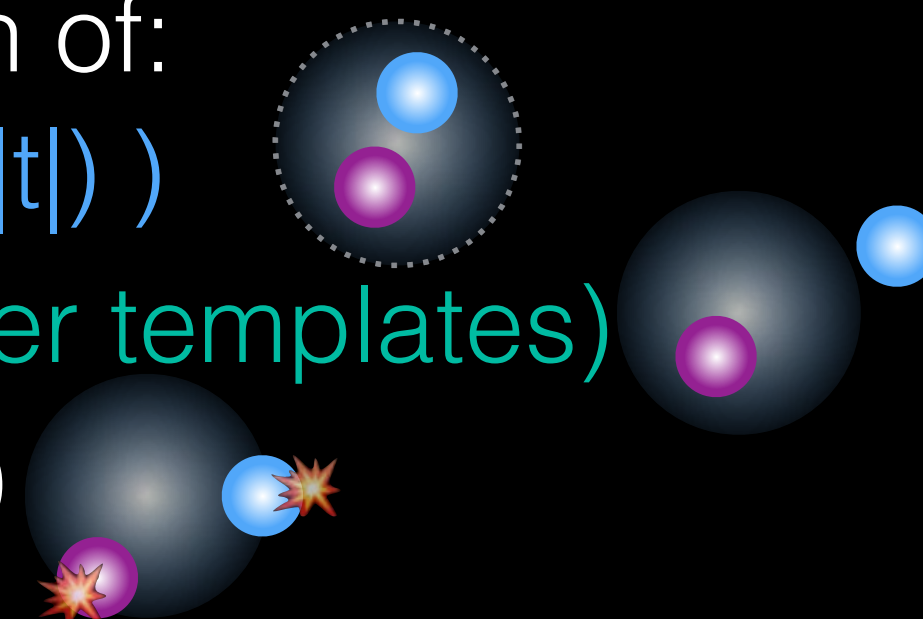
# Photoproduction of J/ψ in d+Au UPC

Talk by Xiaofeng Wang  
(Wed 18:45)



Total cross section is a combination of:

1. Coherent contribution ( $\sim \exp(-b |t|)$ )
2. Elastic nucleon (ep HERA & other templates)
3. Nucleon dissociative (ep HERA)



## Fit to data:

Coherent:

$$\sim \exp(-b |t|)$$

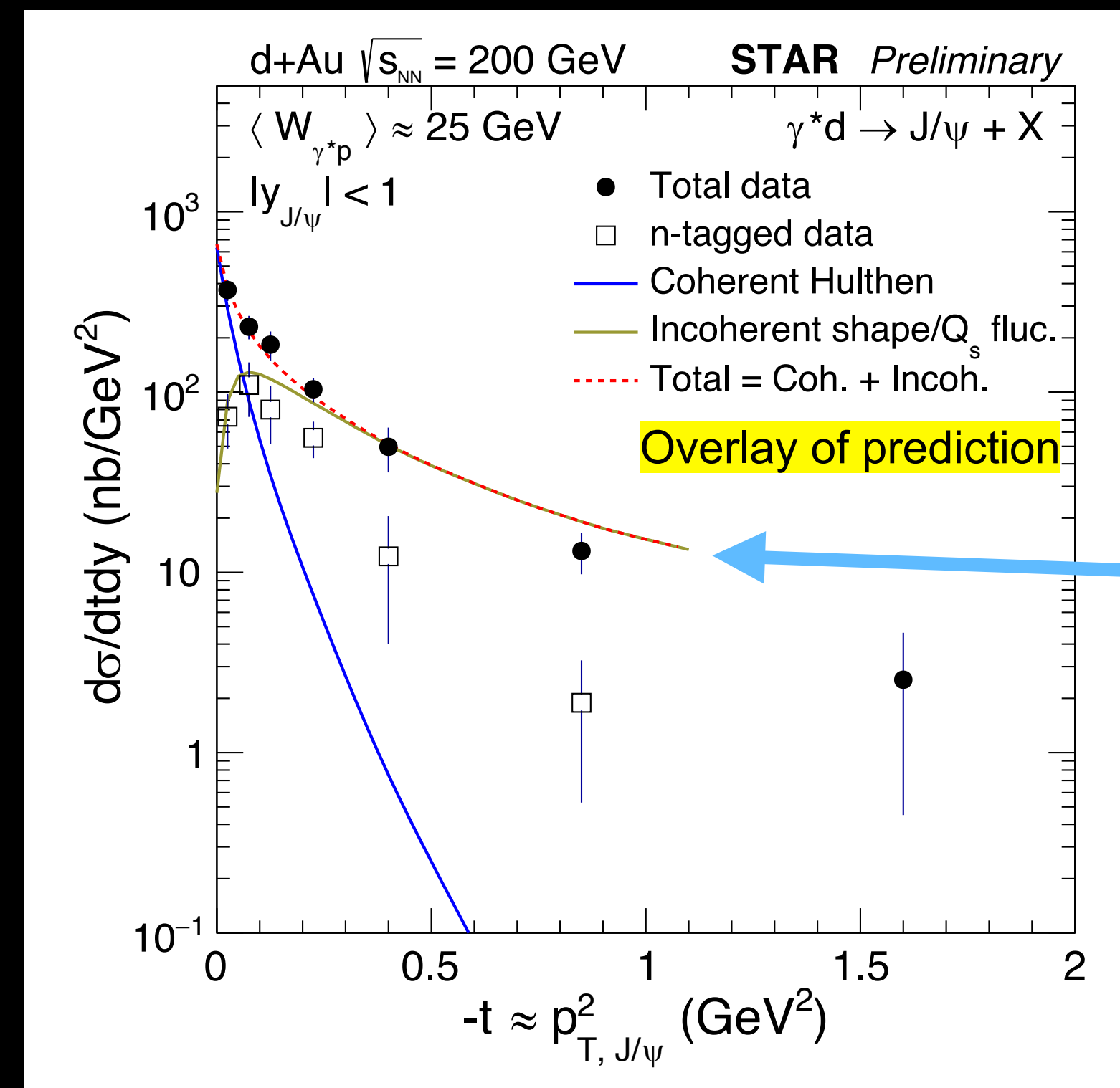
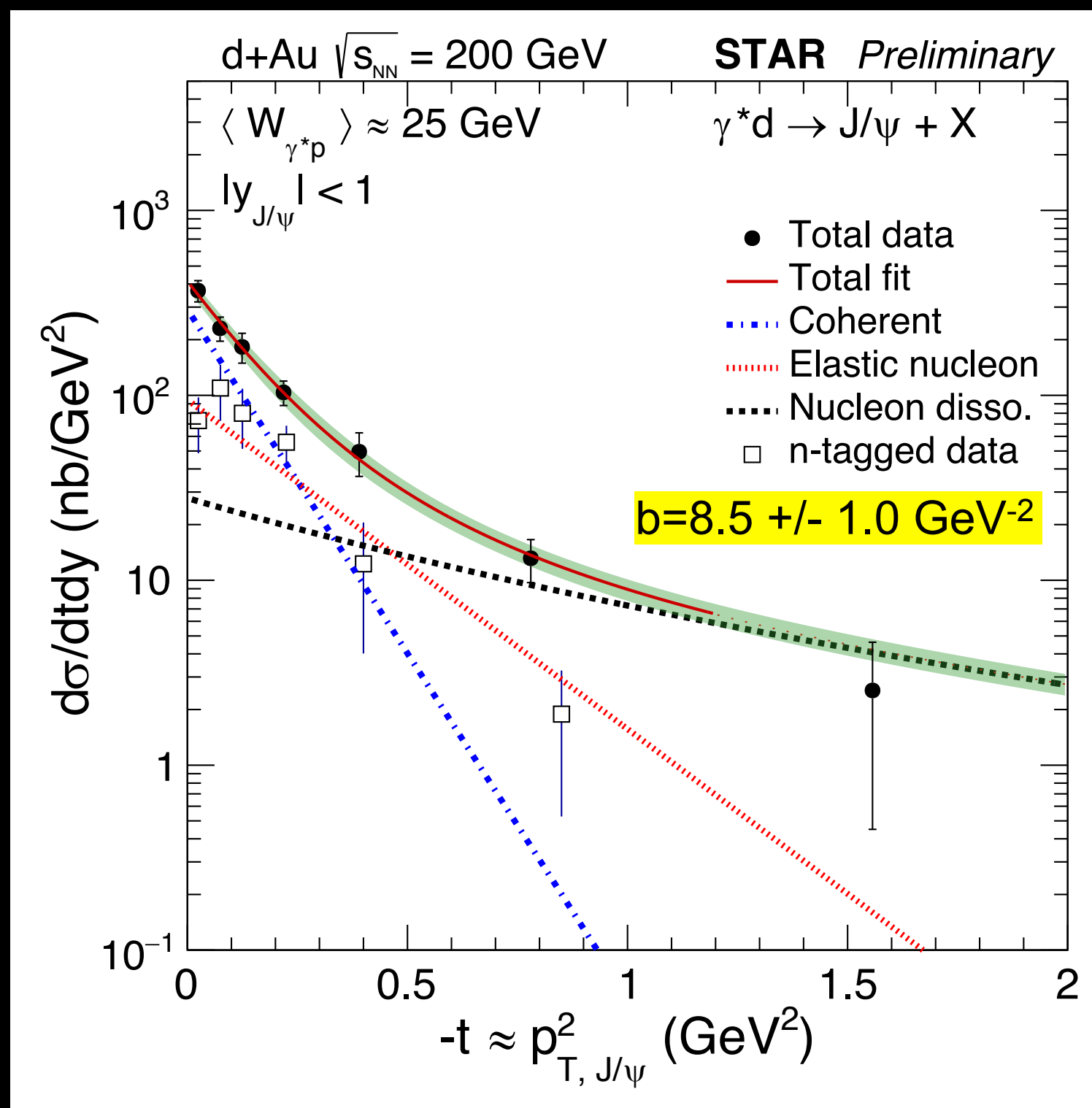
Elastic nucleon:

ep H1

Nucleon disso:

ep H1

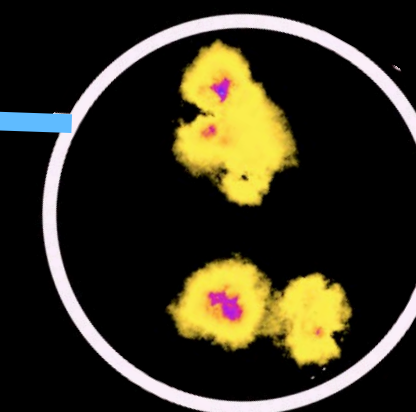
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## Prediction:

Hulthen+CGC

Mäntysaari, Schenke,  
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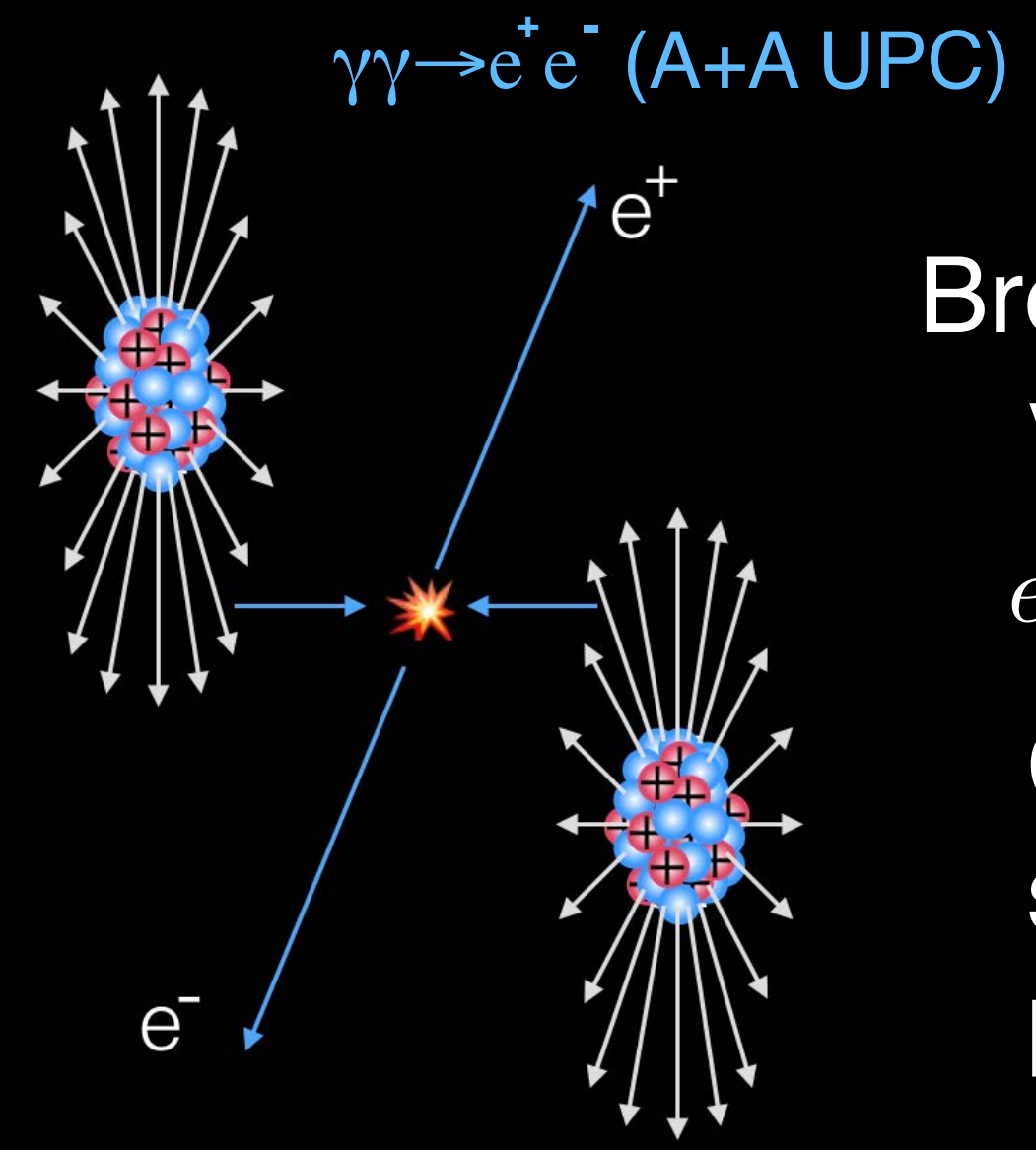


With sub-nucleonic &  $Q_s$  fluctuations

Data at large t (mostly incoherent) favors CGC predictions with sub-nucleon scale and  $Q_s$  fluctuations

# Photoproduction of low $p_T$ electron-positron

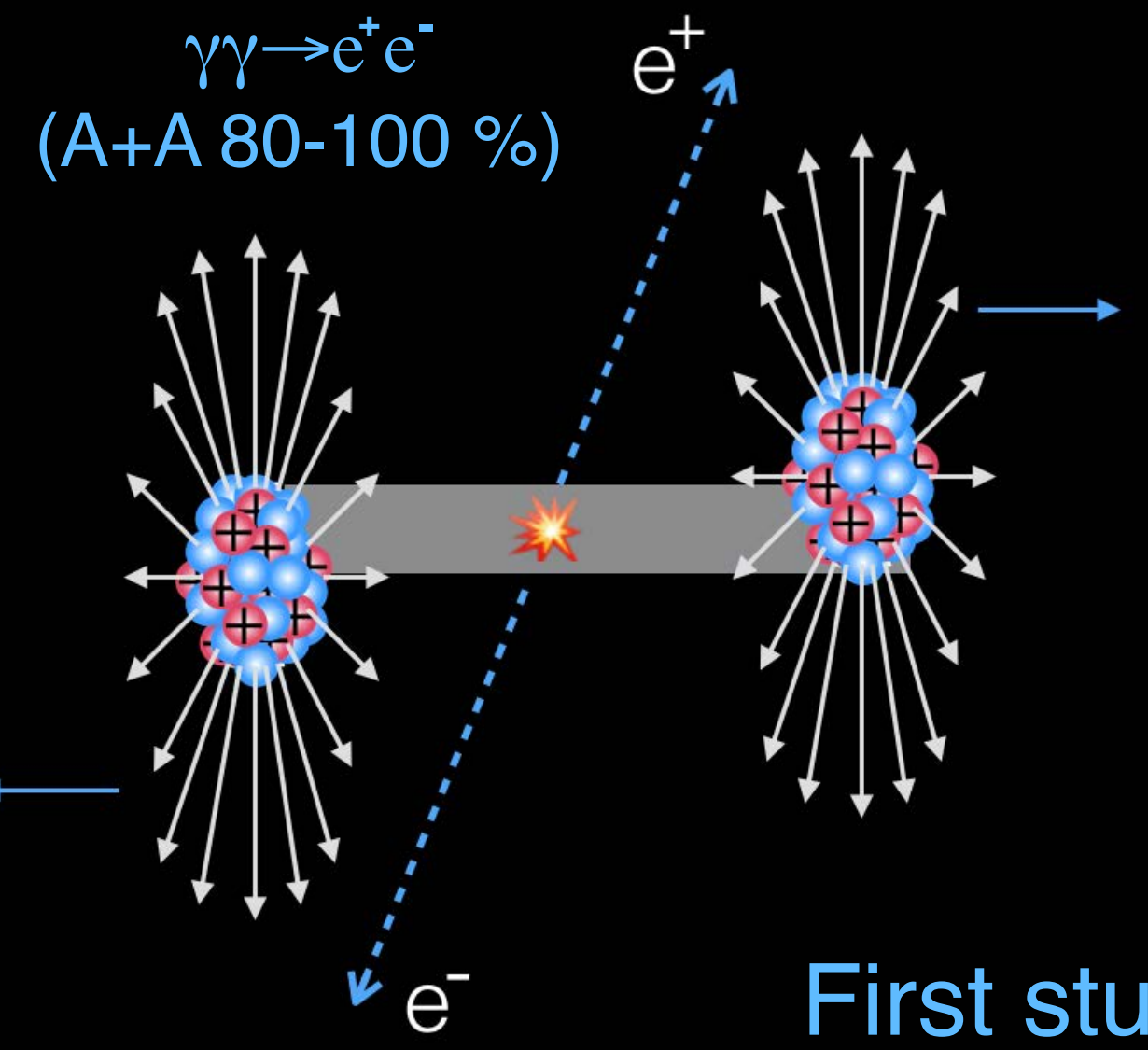
Talk by Xiaofeng Wang  
(Wed 18:45)



Breit-Wheeler Process and vacuum birefringence

$$eB > eB_C \approx m_e^2 \sim 10^8 T$$

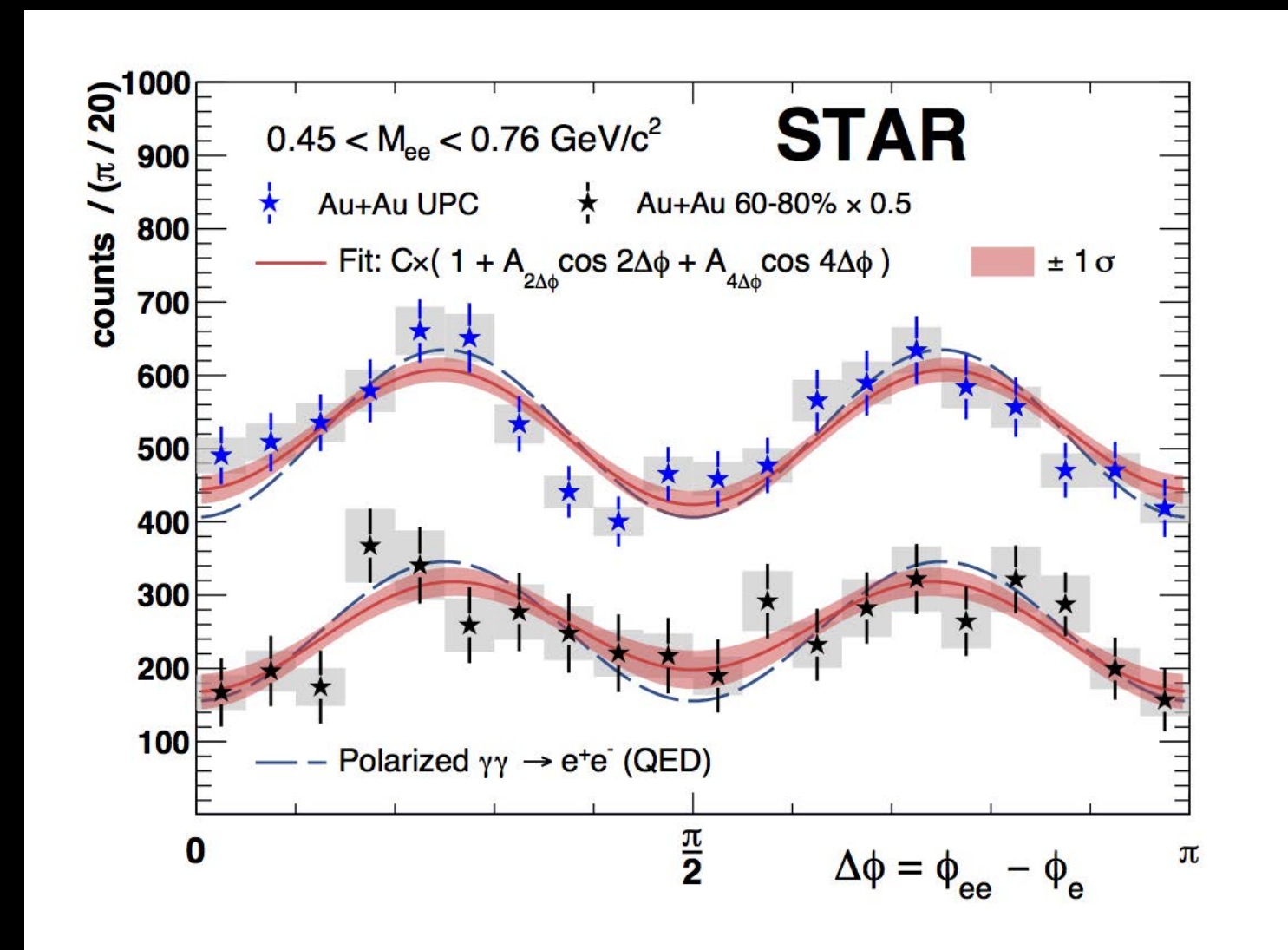
Constraints on B-field strength & linear polarization of photons



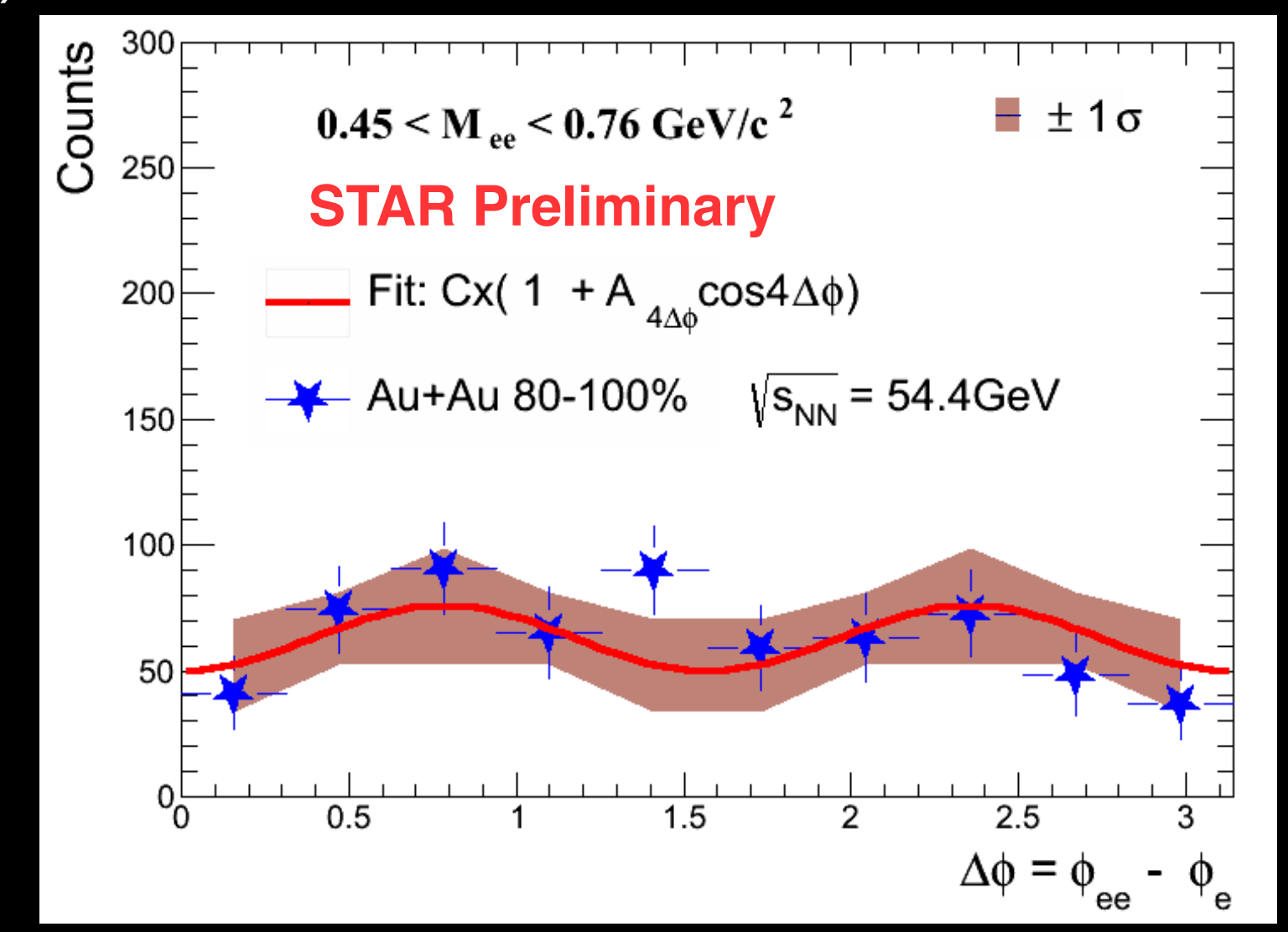
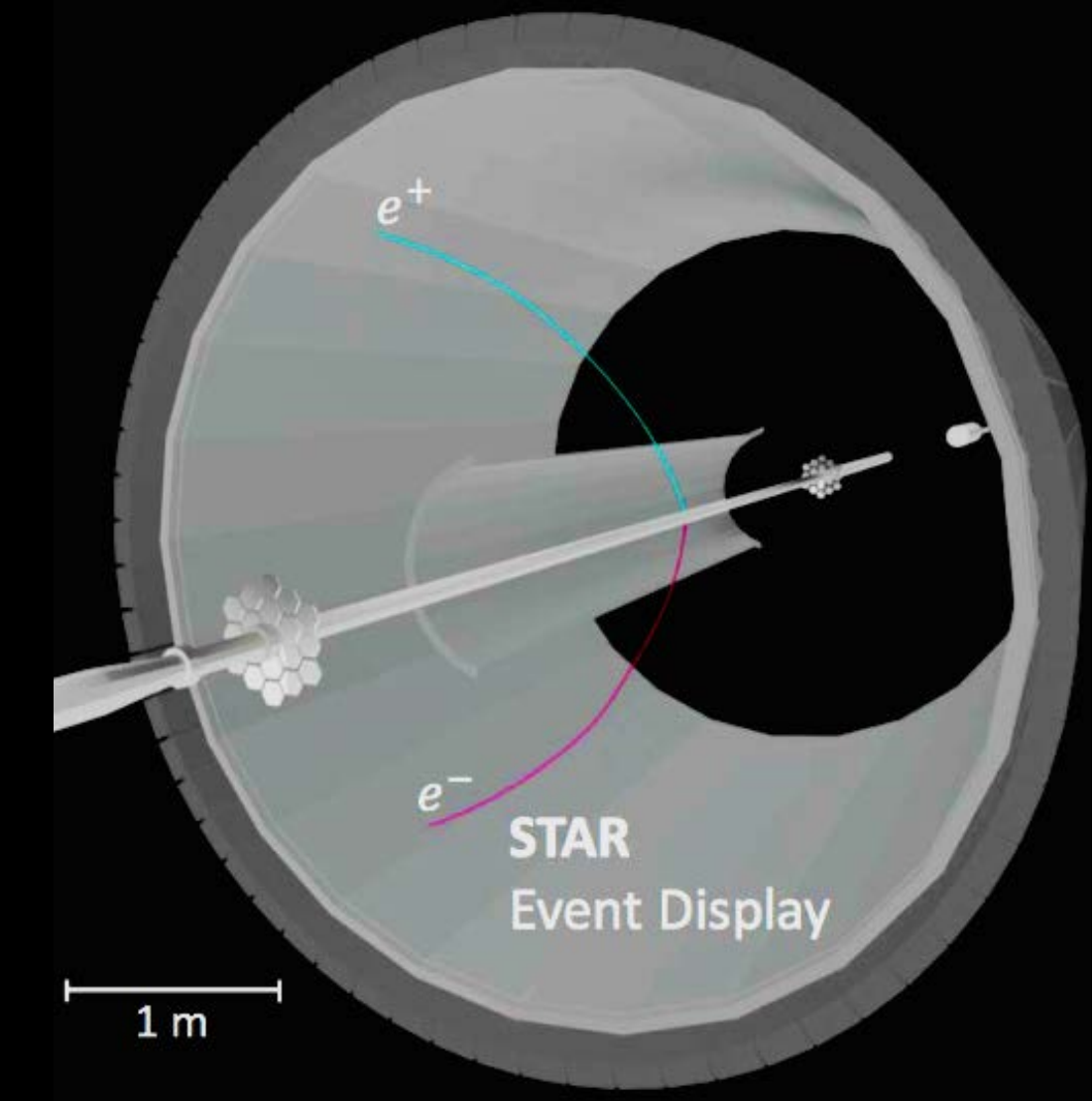
Excess of low  $p_T$  electron-positron production studied in 54.4 GeV peripheral Au+Au collisions

First study of azimuthal angular modulations of in peripheral AA and its energy dependence

STAR Collaboration, arXiv:1910.12400



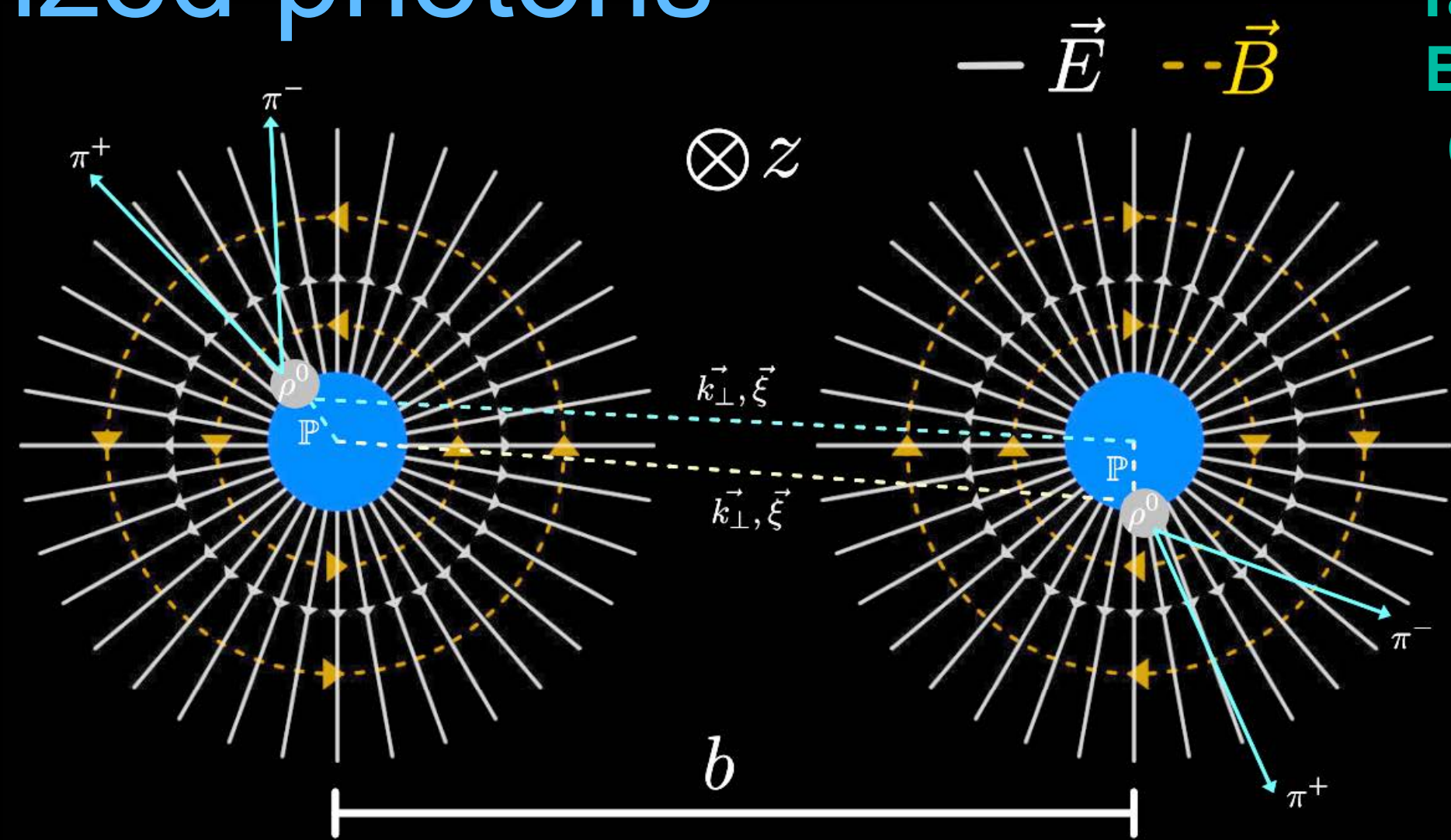
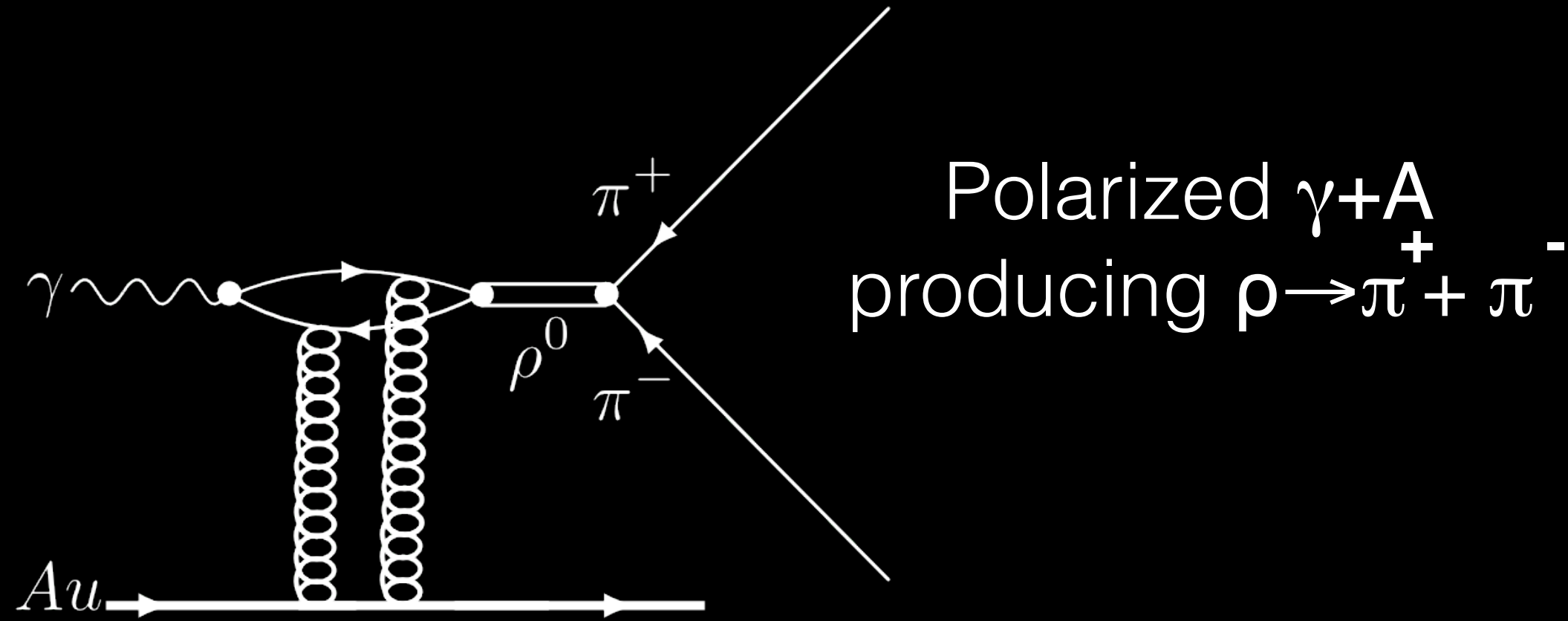
$\Delta\phi$  ( $[e^+ + e^-], [e^+ - e^-]$ )





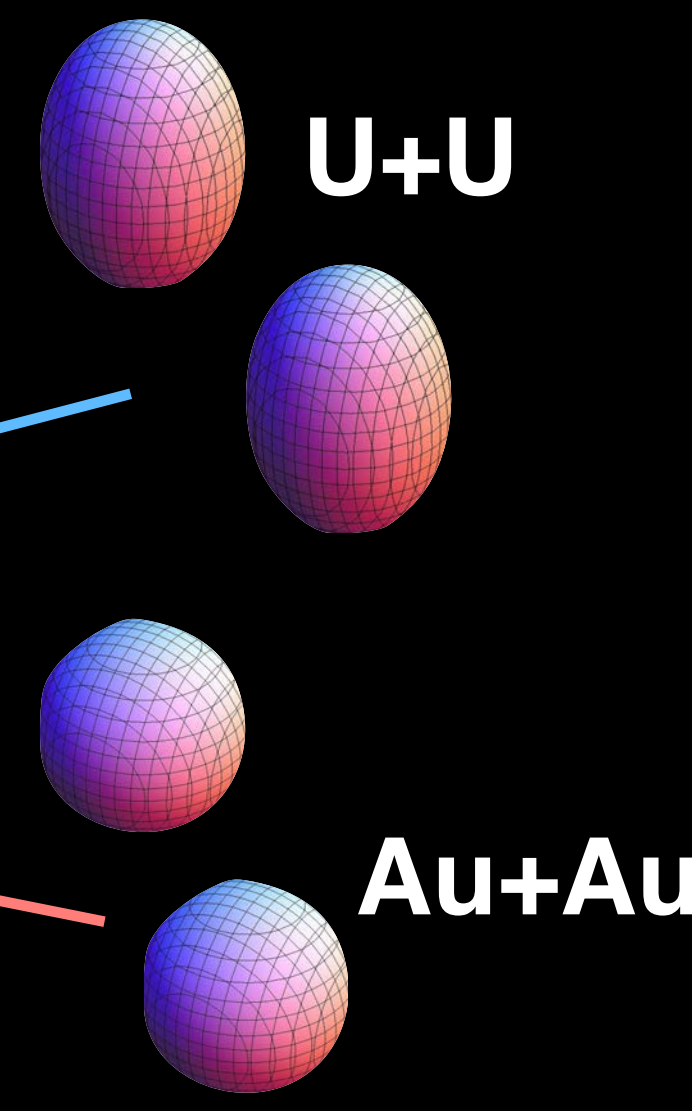
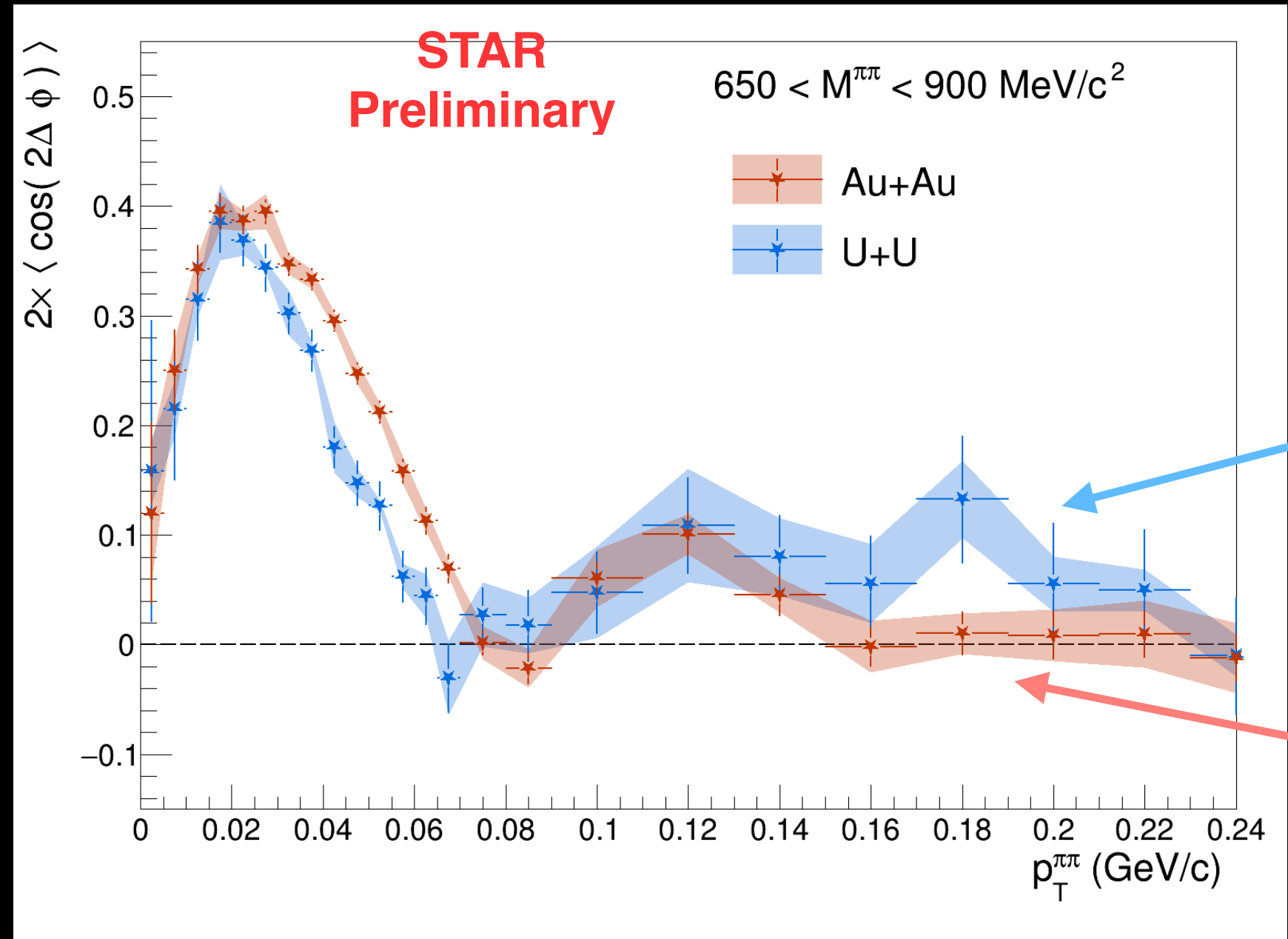
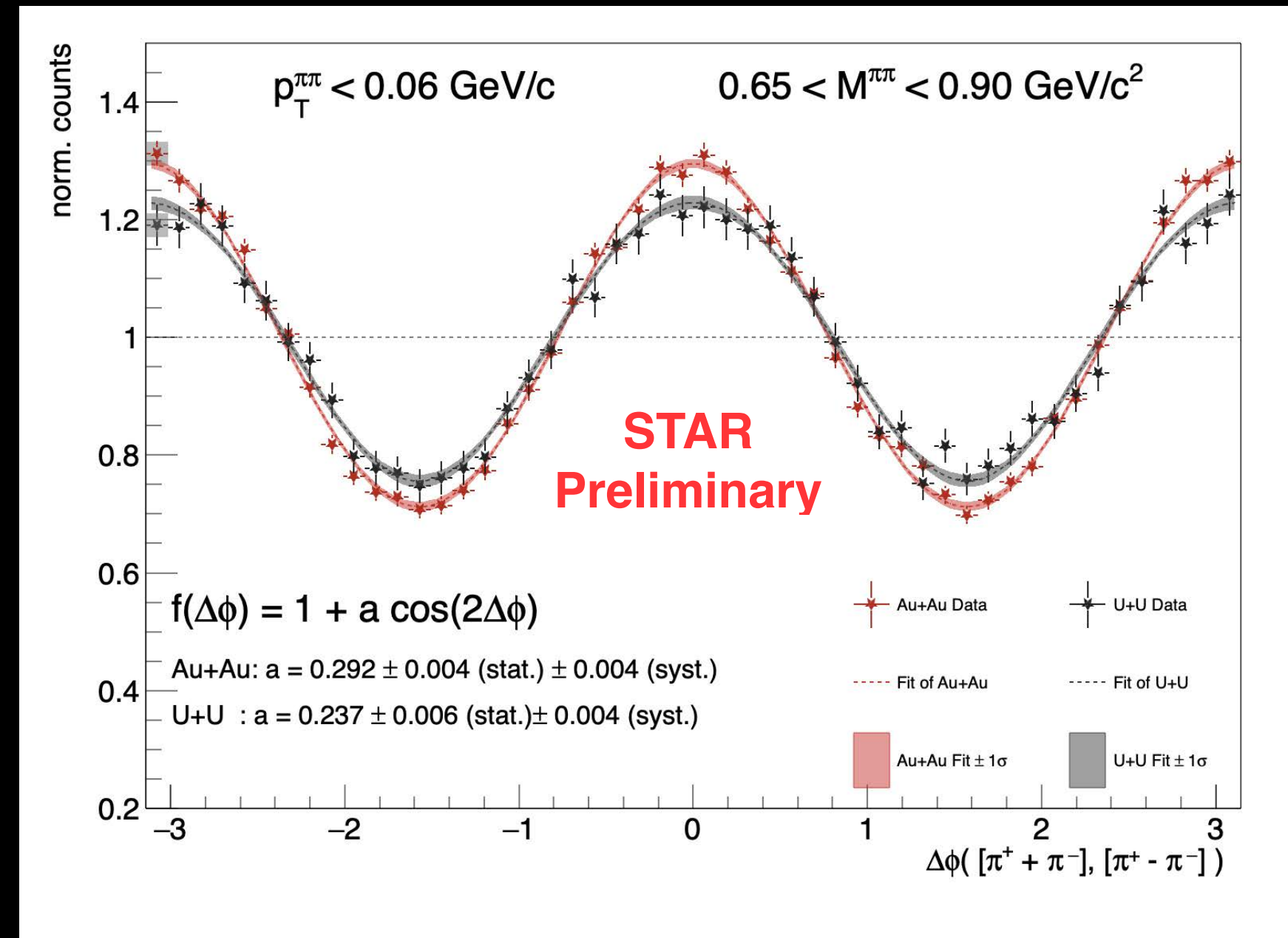
# Probing nuclei with linearly polarized photons

Talk by Daniel Brandenburg (Wed 19:25) 



Interference due to two nuclei

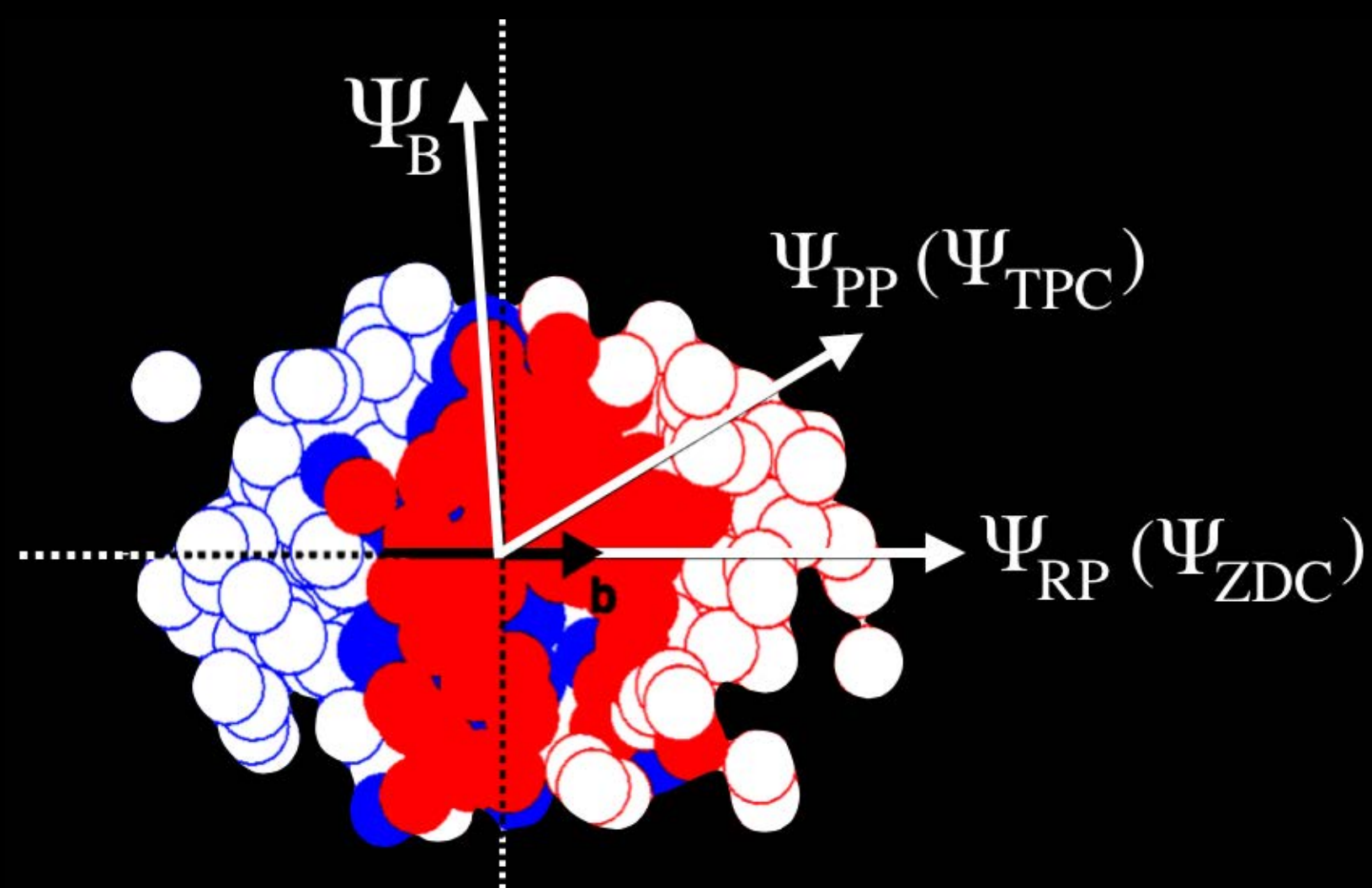
$\langle \cos(2\Delta\phi) \rangle$  modulation,  $\Delta\phi$  ( $[\pi^+ + \pi^-], [\pi^+ - \pi^-]$ )



Observation of two-source interference effects, amplitude shows structure & sensitivity to nucleus shape

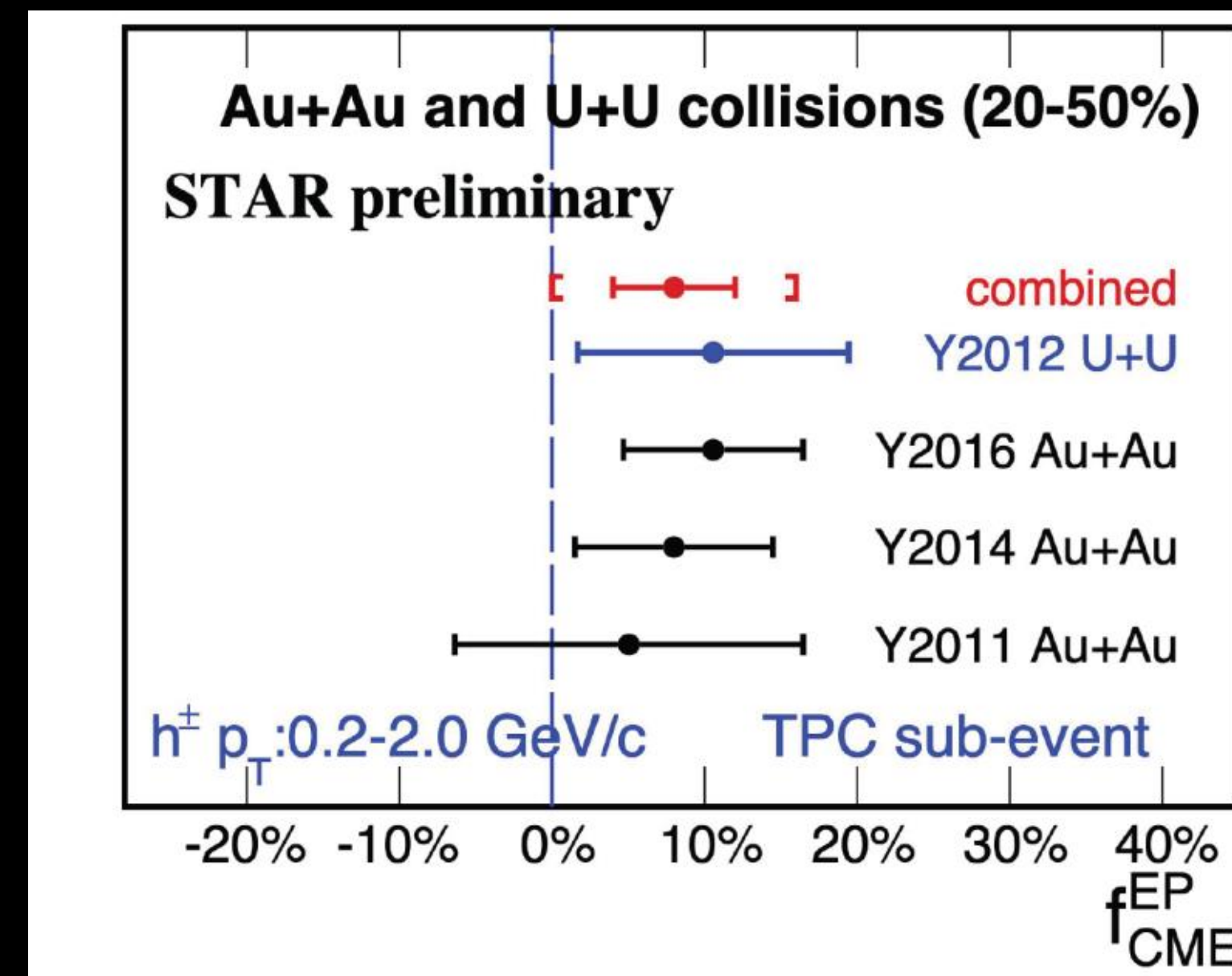
# Search for the Chiral Magnetic Effect

Talk by Jie Zhao  
(Thu 15:55)



$$\Delta\gamma = \Delta\gamma^{\text{sig}} + \Delta\gamma^{\text{bkg}}$$

$$f_{\text{CME}} = \frac{\Delta\gamma^{\text{sig}}}{\Delta\gamma}$$



Four equations, four unknowns:

$$\Delta\gamma^{\text{sig}}(\Psi_{\text{ZDC}}) + \Delta\gamma^{\text{bkg}}(\Psi_{\text{ZDC}}) = \Delta\gamma(\Psi_{\text{ZDC}})$$

$$\Delta\gamma^{\text{sig}}(\Psi_{\text{TPC}}) + \Delta\gamma^{\text{bkg}}(\Psi_{\text{TPC}}) = \Delta\gamma(\Psi_{\text{TPC}})$$

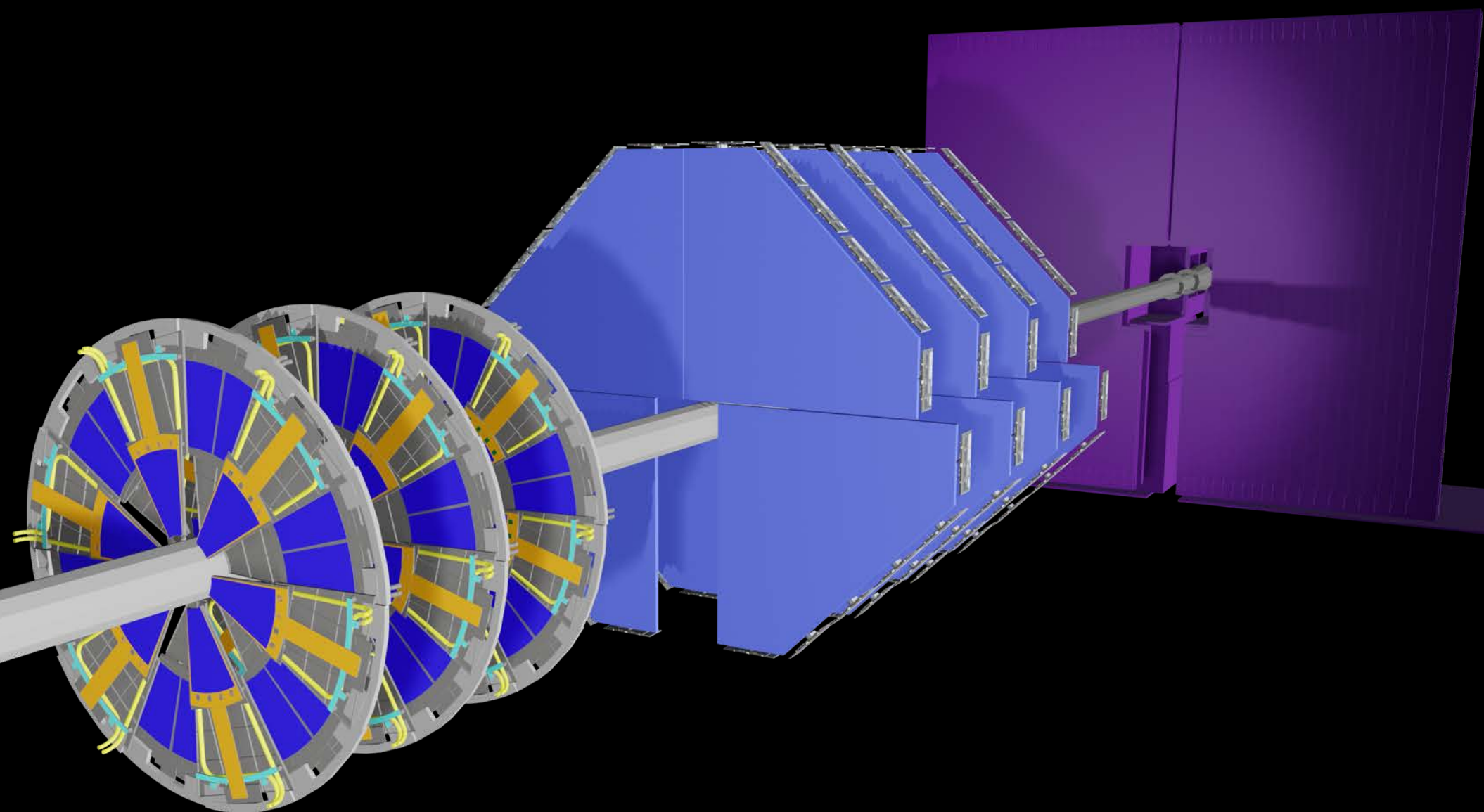
$$\Delta\gamma^{\text{bkg}}(\Psi_{\text{ZDC}})/\Delta\gamma^{\text{bkg}}(\Psi_{\text{TPC}}) = v_2(\Psi_{\text{ZDC}})/v_2(\Psi_{\text{TPC}})$$

$$\Delta\gamma^{\text{sig}}(\Psi_{\text{ZDC}})/\Delta\gamma^{\text{sig}}(\Psi_{\text{TPC}}) = v_2(\Psi_{\text{TPC}})/v_2(\Psi_{\text{ZDC}})$$

Case of CME from this analysis is  $f_{\text{CME}}(\text{Ru}) > f_{\text{CME}}(\text{Zr})$

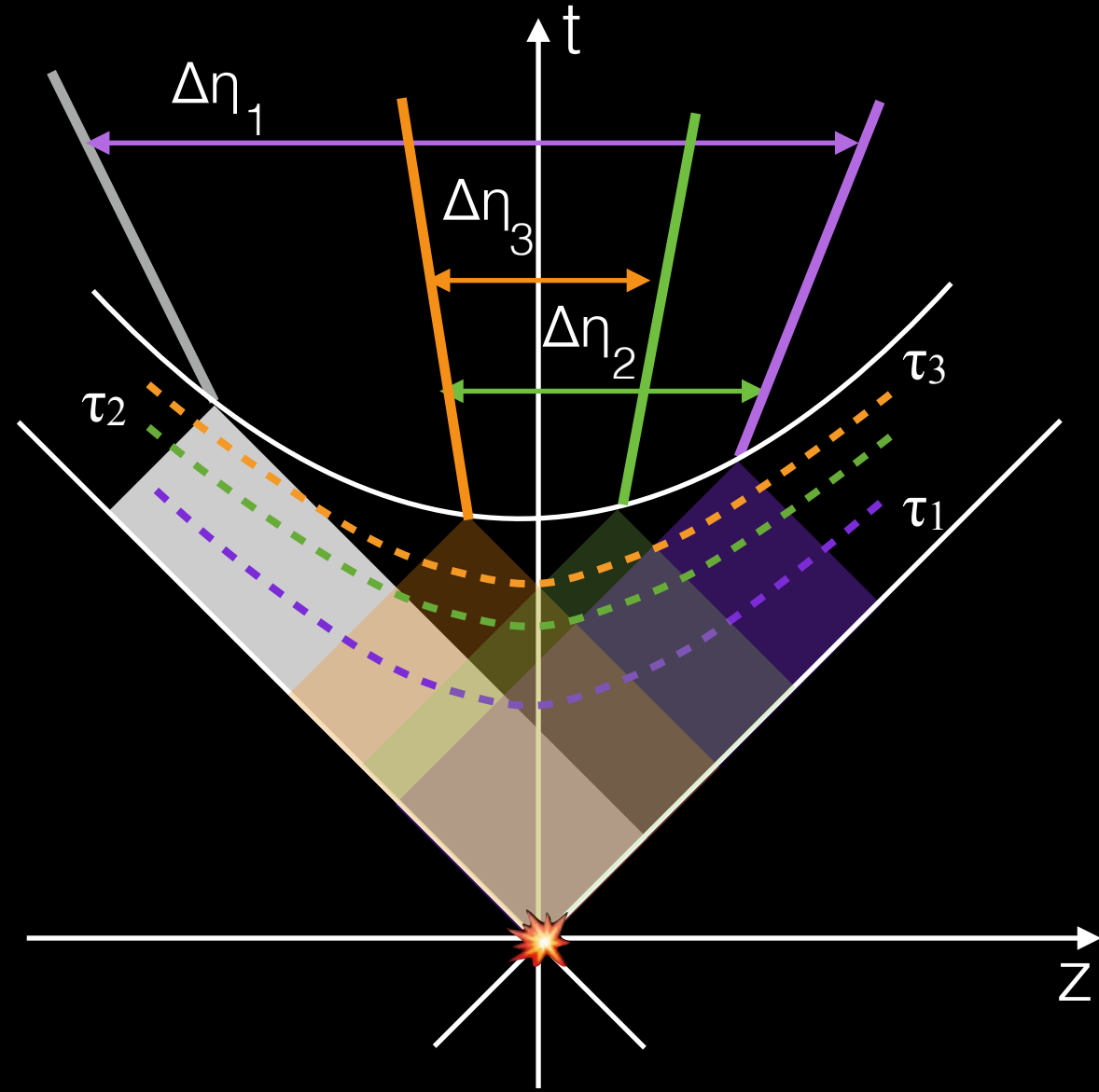


# Forward upgrade and STAR beyond 2021+



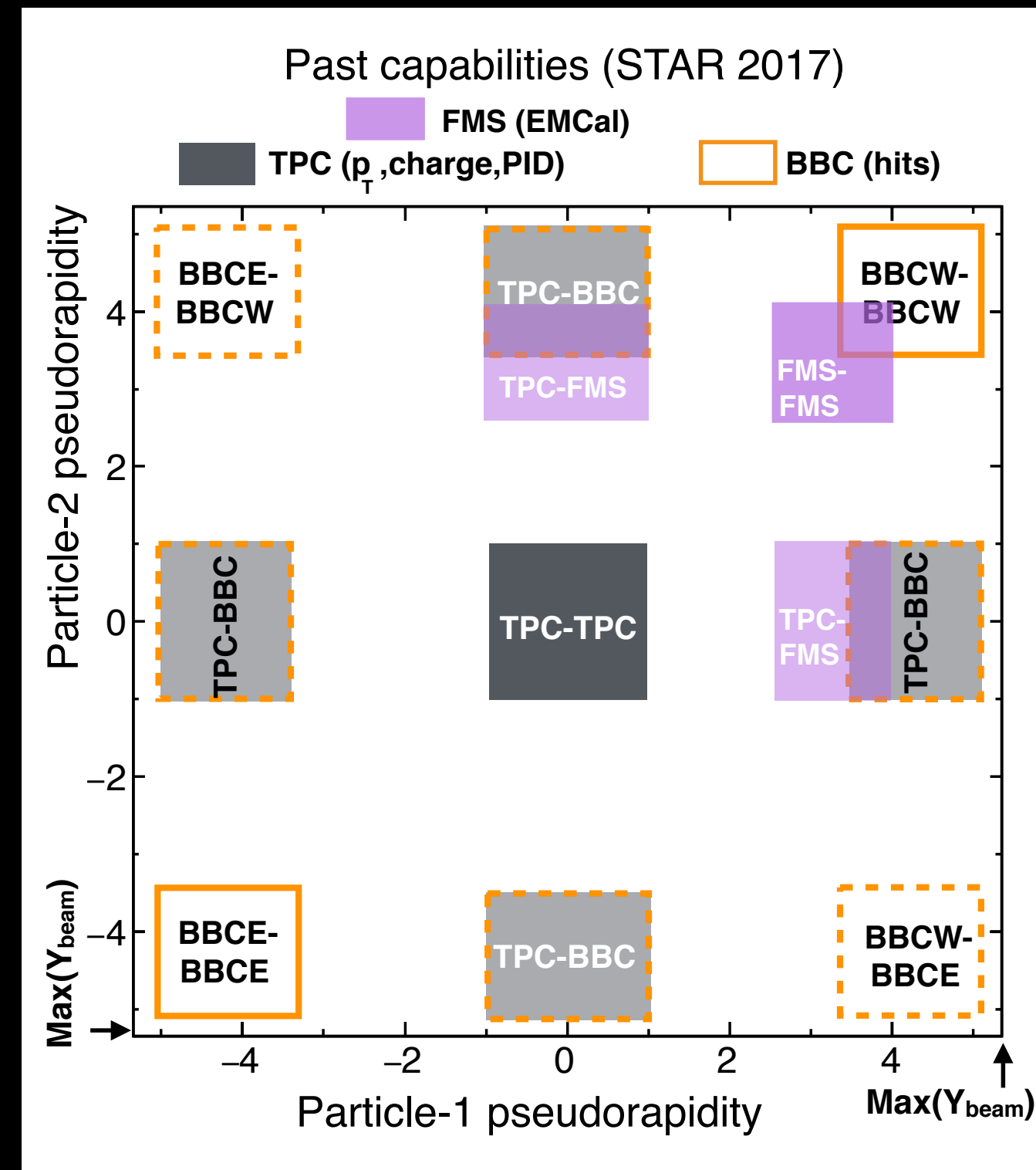
# Prospects of initial state physics: why STAR and RHIC ?

Causality precludes late-time correlations to spread over large  $\eta$  (wide acceptance  $\rightarrow$  strength)

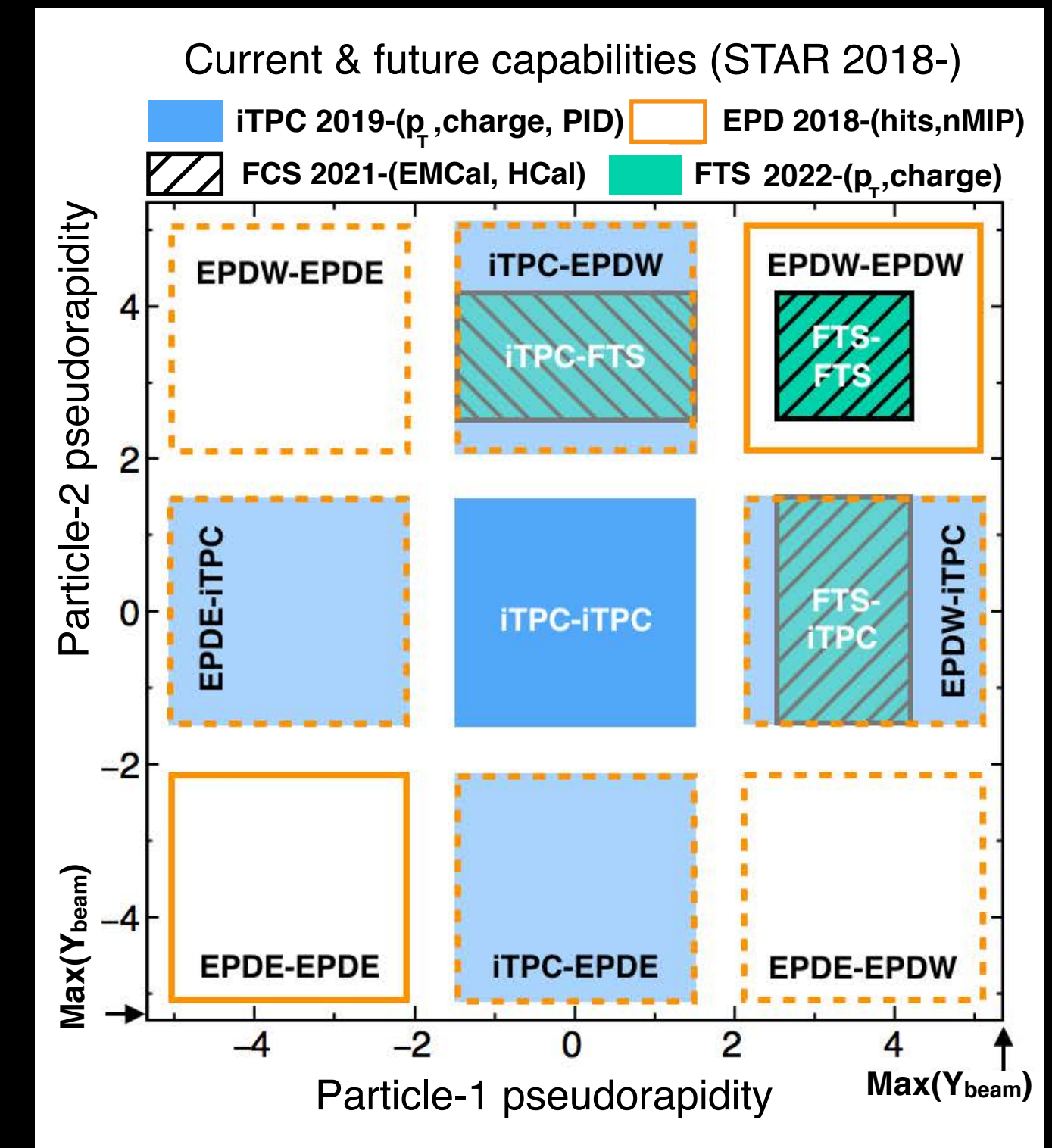


Wide range of species & energy  $\rightarrow$  strength

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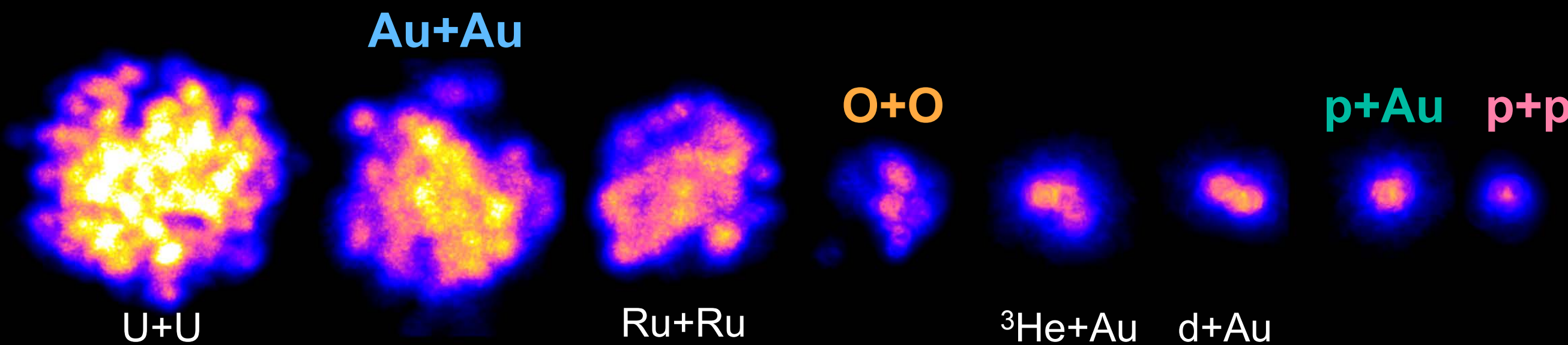


**IS 202N**



BES-II + Forward upgrade

At RHIC it is possible to build detectors that can span from mid-rapidity to beam rapidity



IP-Glasma initial energy density,  $\tau=0.4$  fm, single central event, fig: Chun Shen QM19

Goal: best utilize the remaining few years of RHIC running to better understand initial stages before the EIC era

# Prospects of future measurements (A+A)

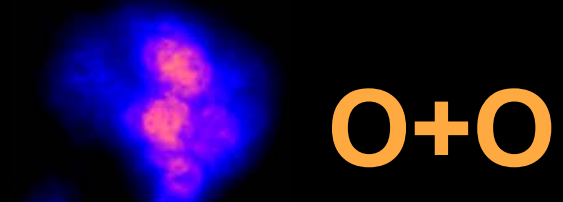
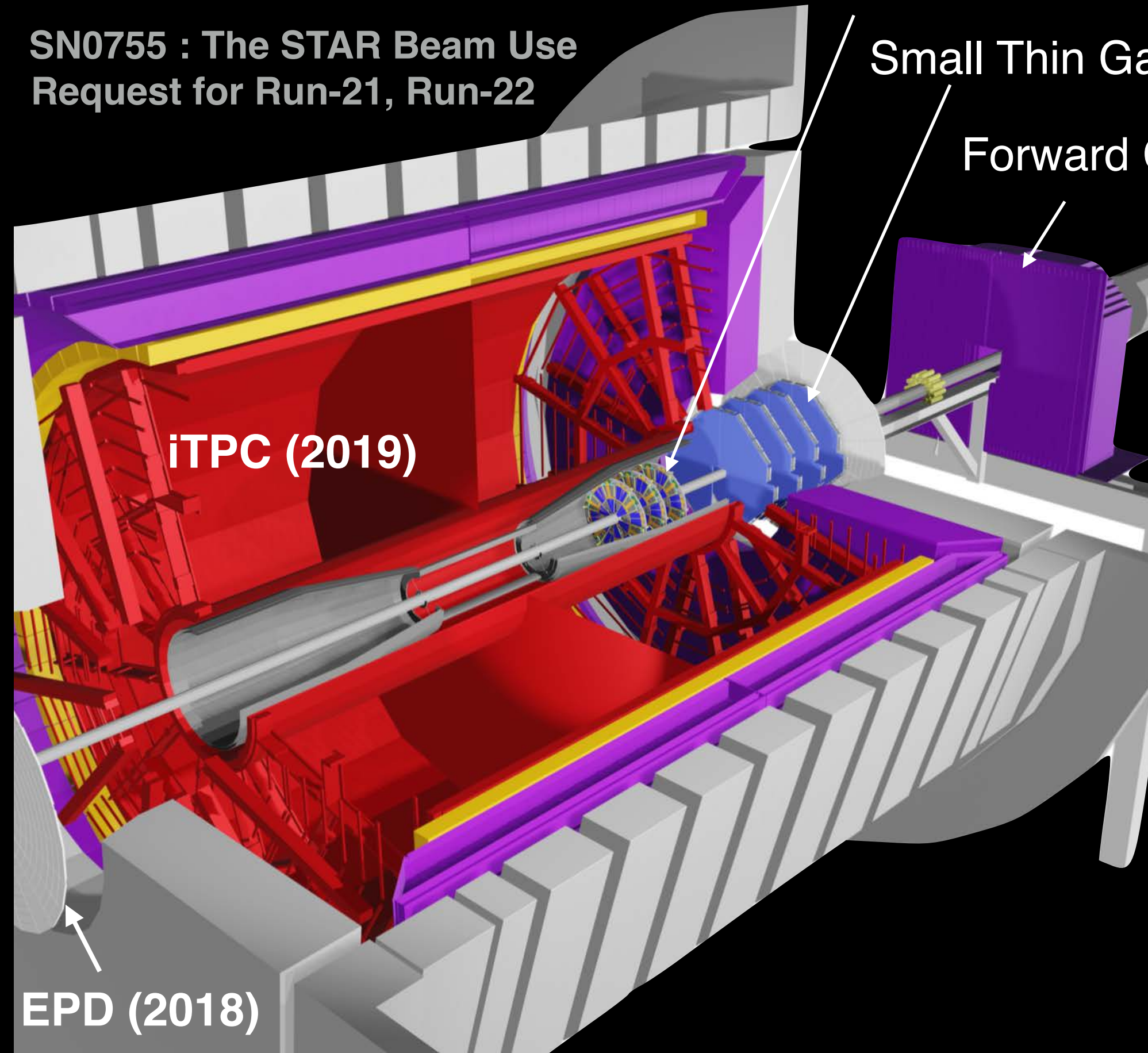
Talk by Ting Lin (Thu 16:35)

Poster by David Kapukchyan (Sun 19:45)

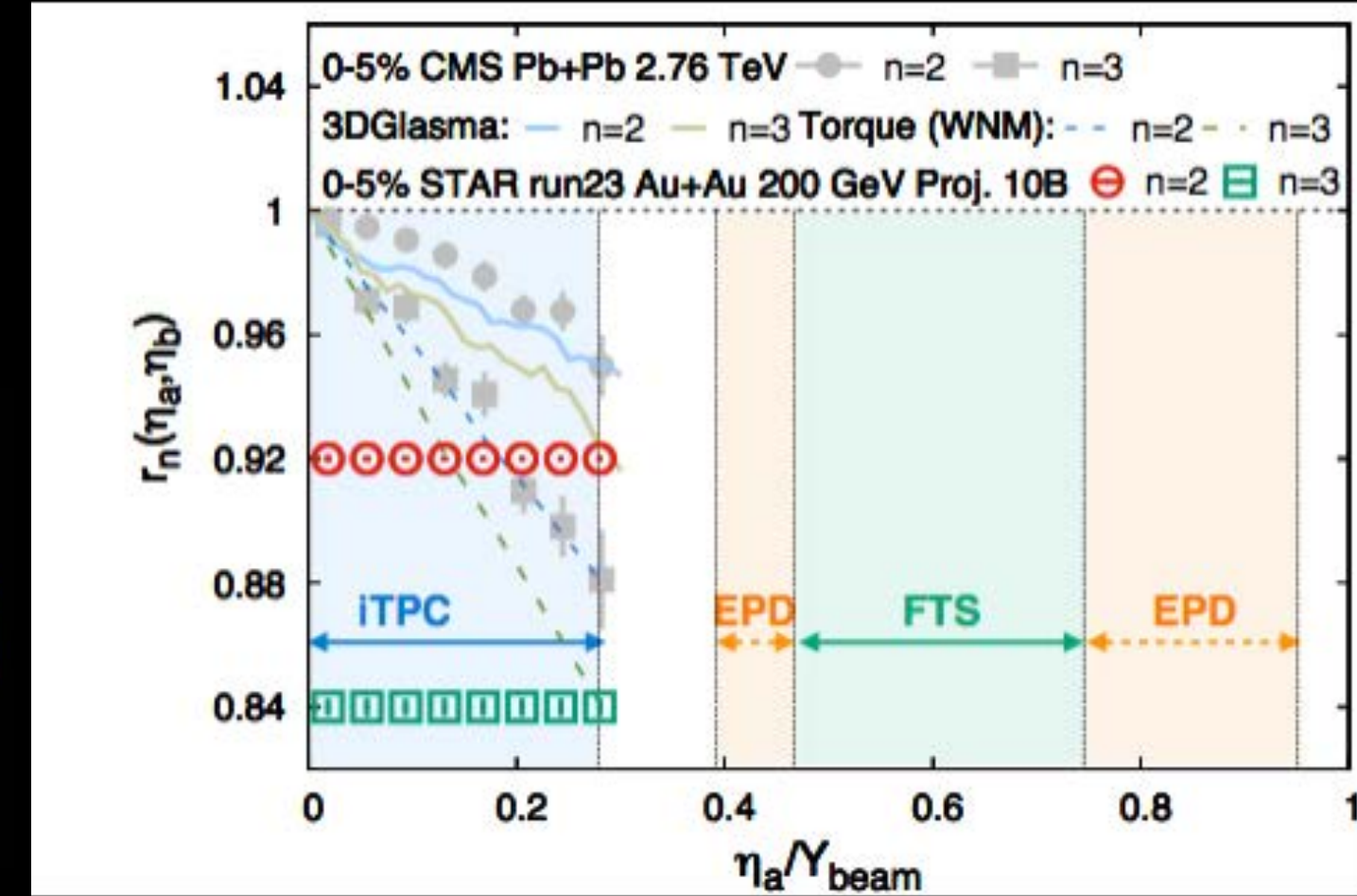
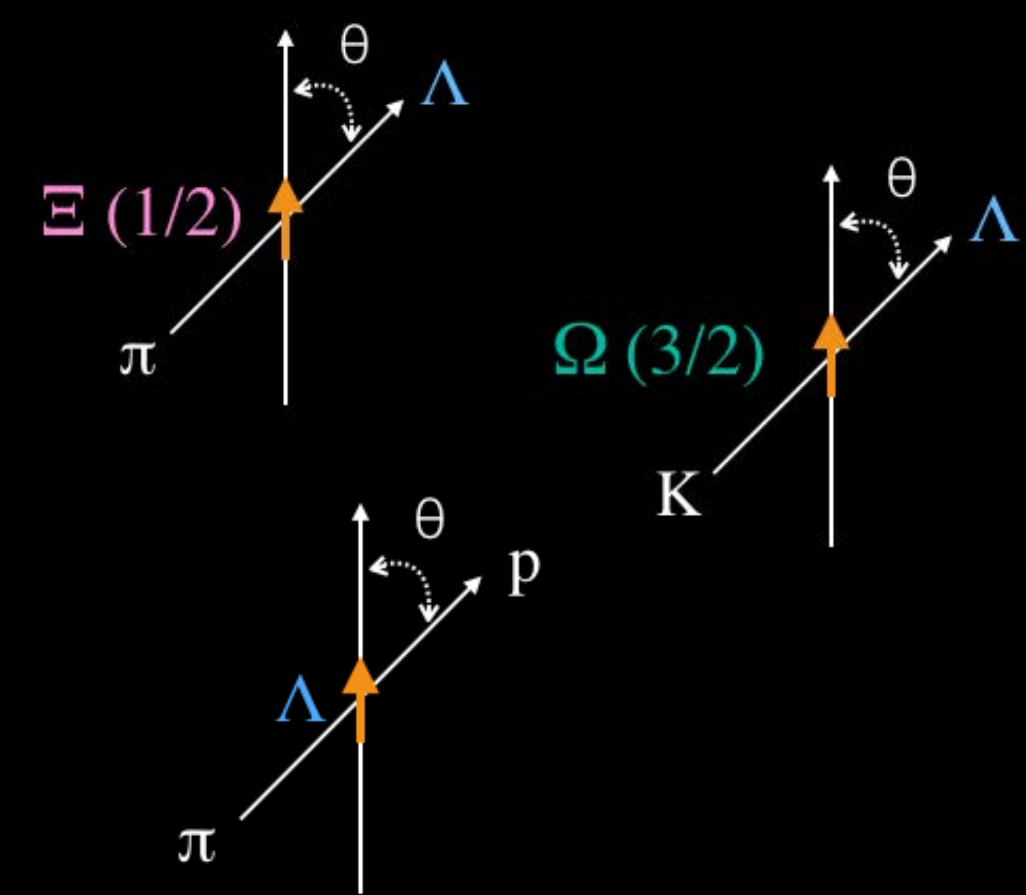
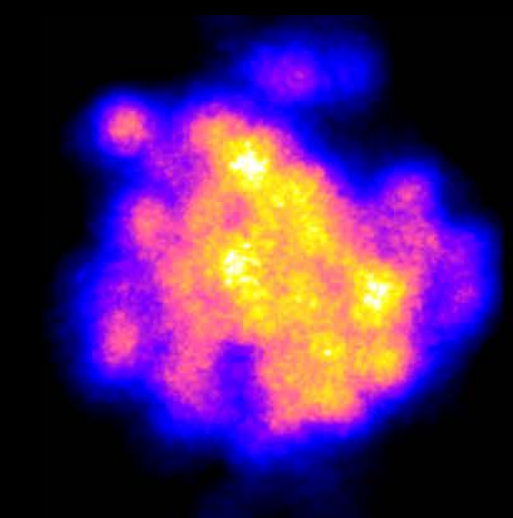


Forward Silicon Tracker (fall 2021)

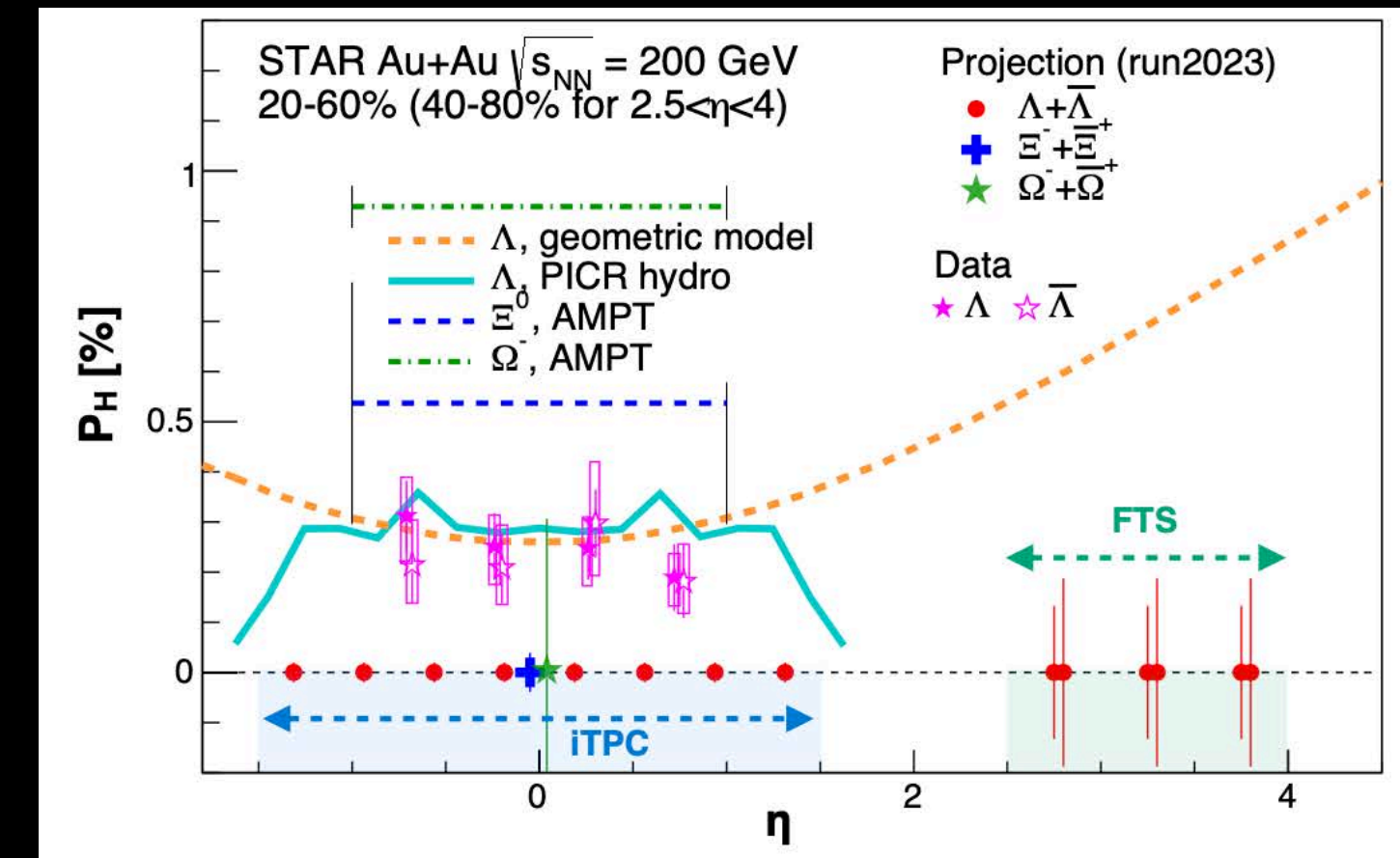
SN0755 : The STAR Beam Use Request for Run-21, Run-22



Au+Au



STAR collab., e-Print: 2012.13601 [nucl-ex]



Anticipated O+O: more insights on collectivity in small collision system  
 Au+Au: 3D initial state, space-time structure of vorticity with hyperon  $P_H(\eta)$

# Prospects of future measurements (p+p/A)

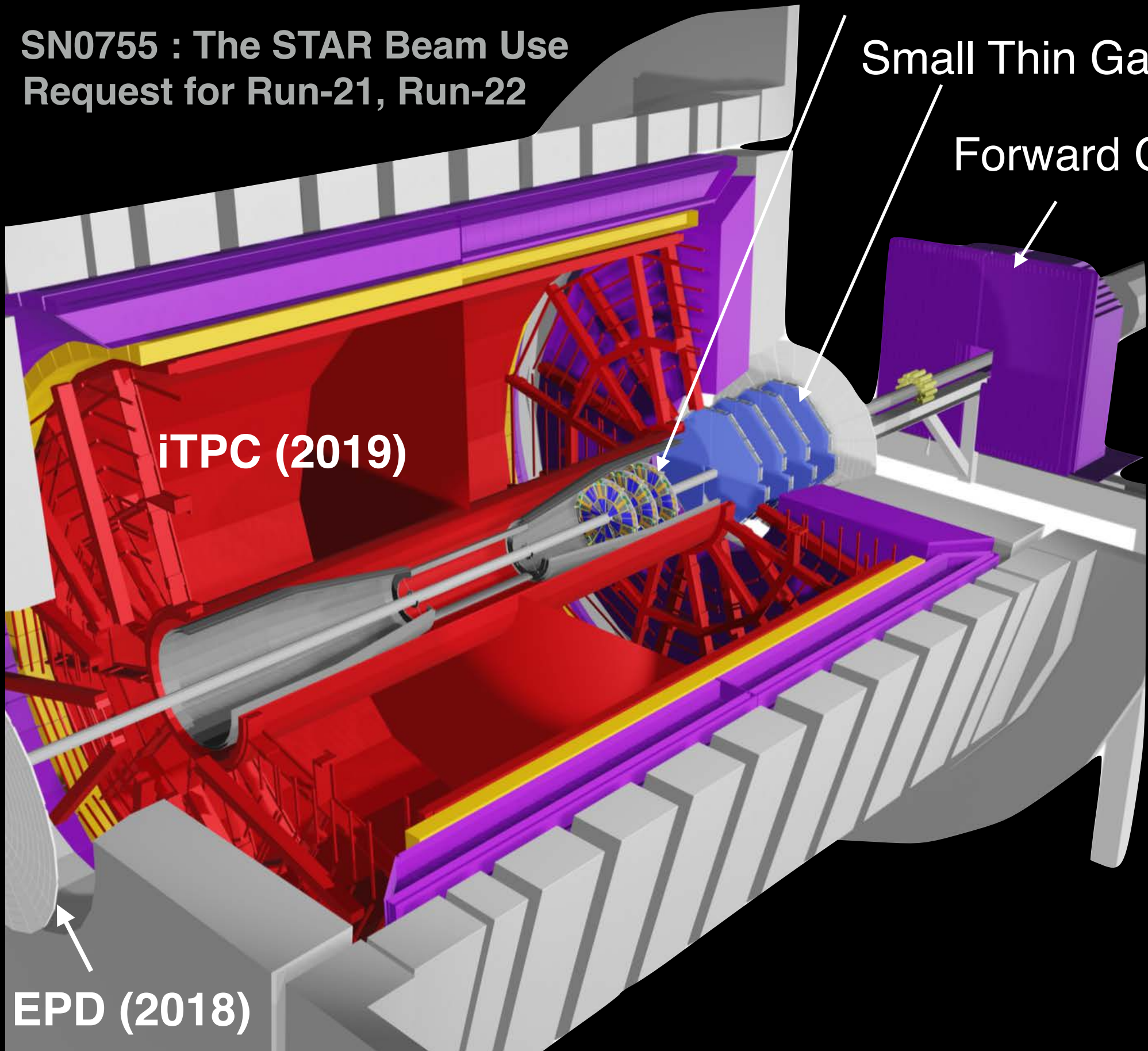
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Forward Silicon Tracker (fall 2021)

SN0755 : The STAR Beam Use Request for Run-21, Run-22



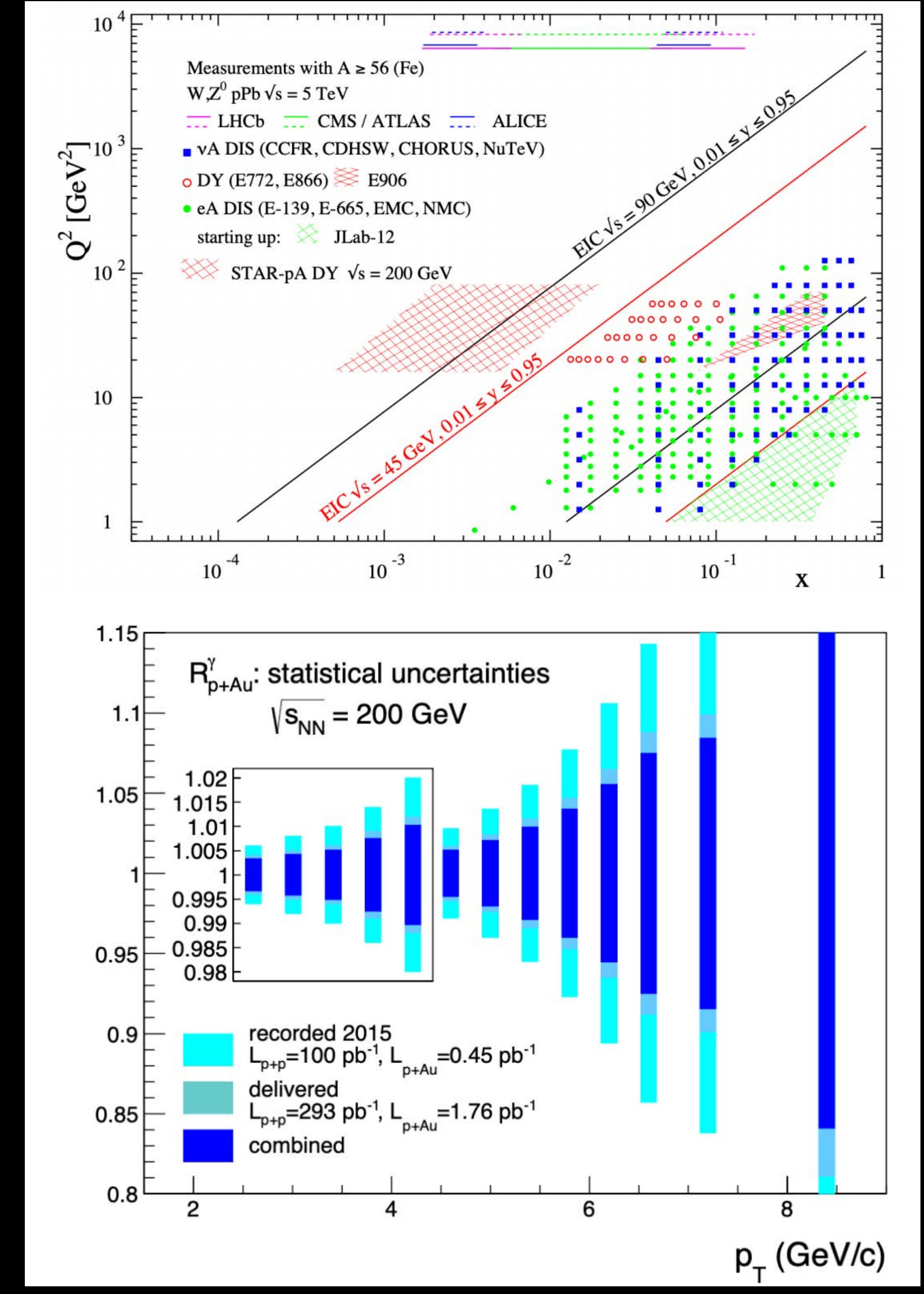
Small Thin Gap Chamber (fall 2021)

Forward Calorimetry (Jan 2021)

p+p  
p+Au

Kinematics of RHIC measurements is close to EIC

Direct photon & Drell-Yan measurements with STAR forward upgrade → strong constraints on nPDF, High statistics p+p/A → more insights on small system collectivity



# Summary & Take Stay Home



Interesting systematics of suppression of back-to-back forward di-hadron pairs in p+A relative to p+p

[More from Xiaoxuan Chu](#)

STAR observes consistent system independent  $v_3$  in p/d/He+Au with three non-flow subtraction methods

[More from Shengli Huang](#)

$v_2 - \langle p_T \rangle$  correlation and higher order fluctuations of  $\langle p_T \rangle$  hint sensitivity to deformed nuclear geometry

[More from Jiangyong Jia, Chunjiang Zhang \(poster\)](#)

Longitudinal de-correlation, (anti-)particle  $v_3$  and high  $p_T v_2$  revisited, many new insights

[More from Maria Stefaniak, Niseem Magdy \(poster\), Maowu Nie \(poster\)](#)

Photoproduction of J/ $\psi$  in d+Au UPC studied with different template to extract the coherent component

[More from Xiaofeng Wang](#)

Observation of two-source interference effects in polarized  $\gamma$ +A collisions, sensitive to colliding nuclei

[More from Daniel Brandenburg](#)

First observation of azimuthal angular modulations of di-electron in peripheral Au+Au at 54.4 GeV

[More from Xiaofeng Wang](#)

Isobar results to make decisive test of CME is coming soon, new techniques, prospects beyond isobar

[More from Jie Zhao](#)

The STAR Forward Upgrade is progressing very well, initial state physics will be of paramount interest

[More from Ting Lin, David Kapukchyan \(poster\)](#)