POLYTECH
Peter the Great St.Petersburg Polytechnic University

PHENIX

7TH INTERNATIONAL CONFERENCE ON PARTICLE PHYSICS AND ASTROPHYSICS (ICPPA-2024)

MEPhI

# Elliptic flow of $\pi^0$ in U+U and $^3$He+Au collisions

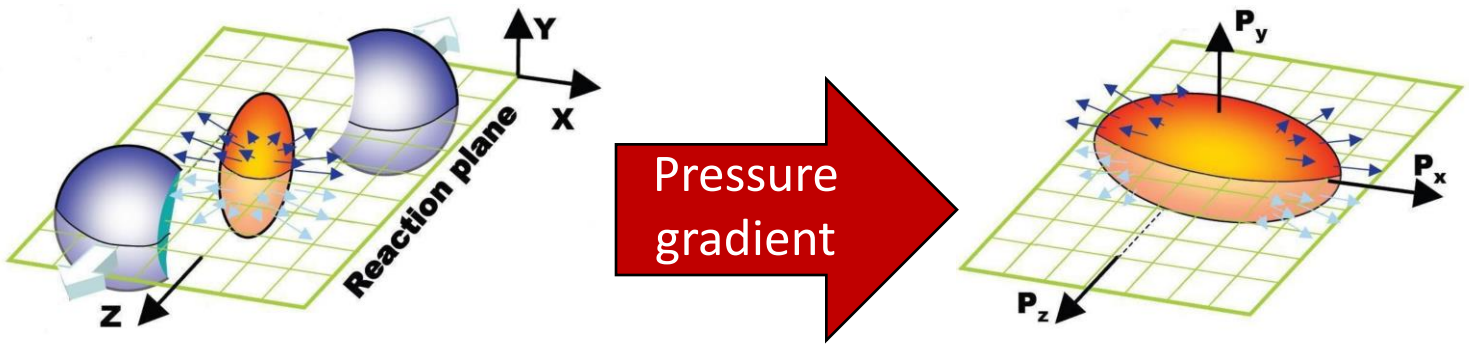
**E.V. Bannikov, Ya.A. Berdnikov, D.O. Kotov**

**(For the PHENIX Collaboration)**

***Peter the Great St.Petersburg Polytechnic University (SPbPU), Russia***

**We acknowledge support from Russian Ministry of Education and Science, state assignment for fundamental research (code FSEG-2024-0033)**

# 1. Azimuthal anisotropy




Spatial anisotropy

Momentum anisotropy

## Elliptic flow ($v_2$)

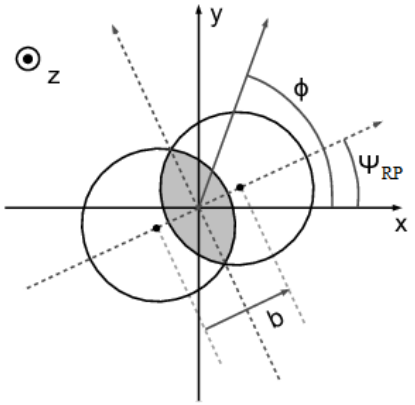
$$v_2 = \left\langle \frac{p_x^2 - p_y^2}{p_x^2 + p_y^2} \right\rangle$$

$$f(\varphi, p_T) \propto 1 + 2\sum_{n=1}^{\infty} v_n(p_T)\cos\left(n(\varphi - \Psi_{RP})\right)$$

$n = 2$

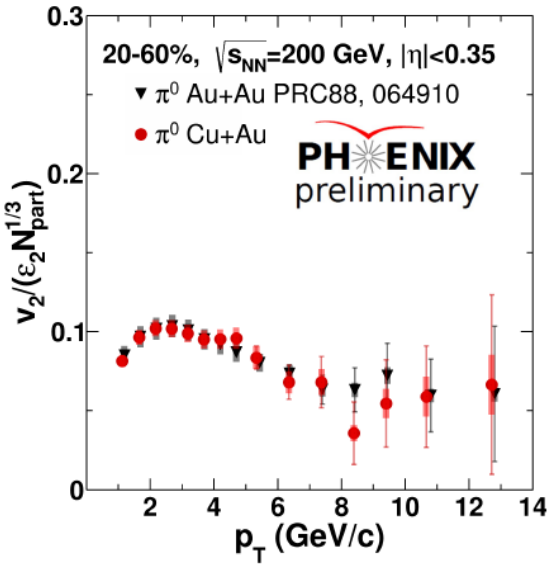
$$v_2 = \left\langle \cos\left(2(\varphi - \Psi_{RP})\right) \right\rangle$$

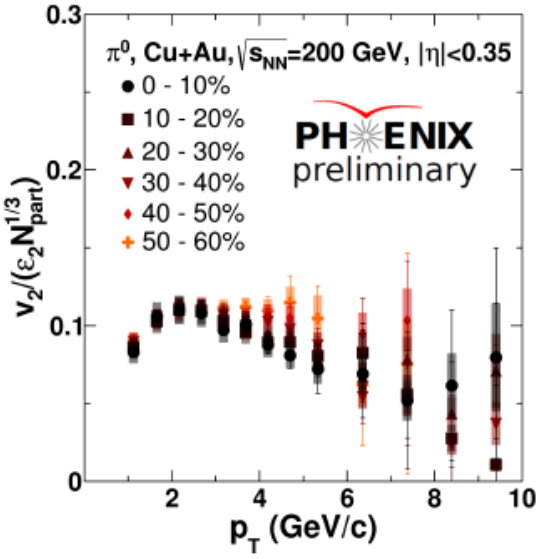
$v_2 > 0$ => the yields of emitted particles dominate along $p_x$



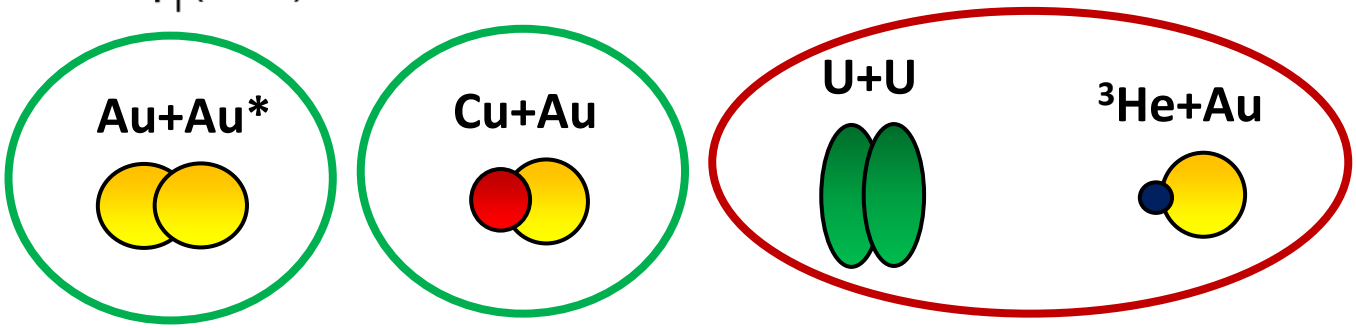
# 2. Motivation

## Our previous work: $v_2$ of $\pi^0$ in Cu+Au collisions at 200 GeV




U+U data will be presented today, $^3$He+Au analysis is still in progress




Previously obtained

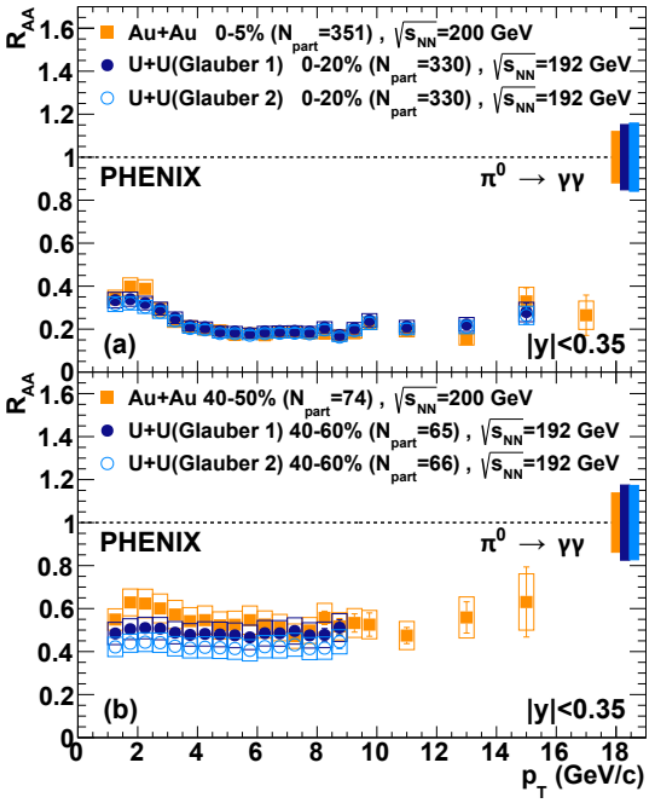
**Phys. Rev. C **88**, 064910 (2013)*

# 2. Motivation

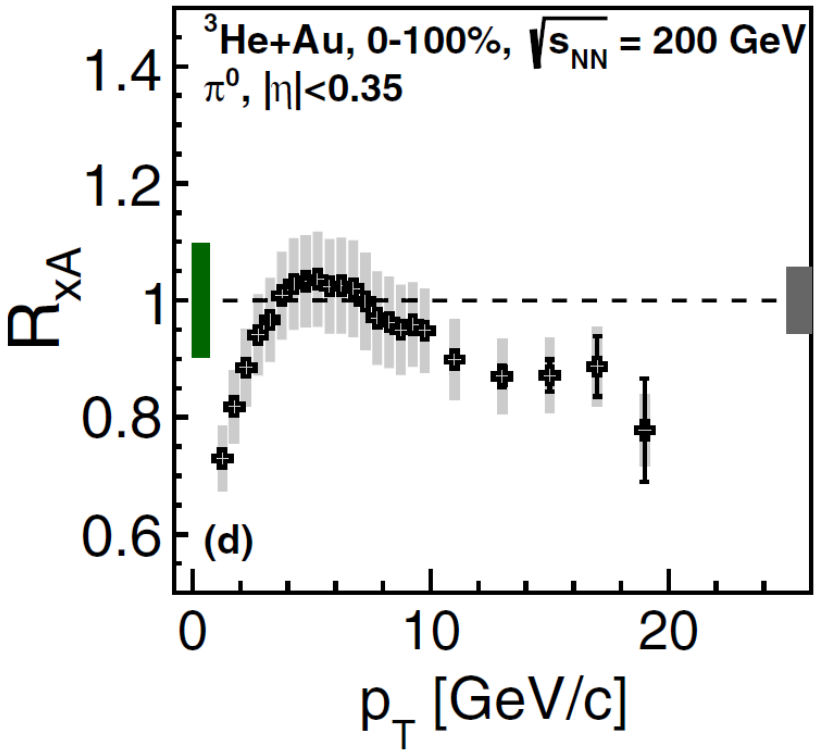
**1. $\pi^0$ mesons:**

Its production is measurable up to $\sim 16 - 20$ GeV/c

**=> Good probe to study the mechanism of $v_2$ development in different kinematic regions of large and small collision systems**




*Phys. Rev. C **102**, 064905 (2020)*




*Phys. Rev. C **105**, 064902 (2022)*

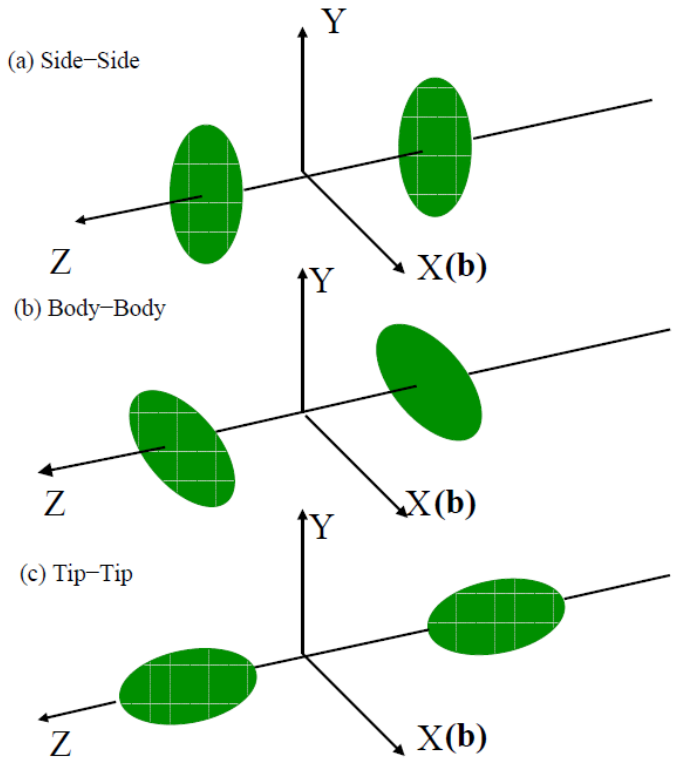
# 2. Motivation

**2. U + U collisions:**

$^{238}U$ has spherically asymmetric shape

$\Rightarrow$ Different type of initial configurations*

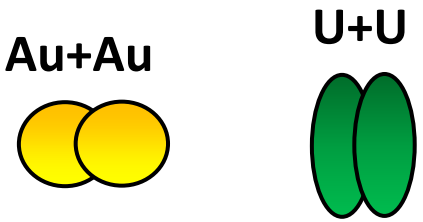
$\Rightarrow$ **Effective way to study the dependency of $v_2$ on the initial conditions**




**Au+Au ⇔ U+U**

In full-overlap U+U collisions, the eccentricity can be increased without decreasing the fireball size (tip-tip => side-side collisions)

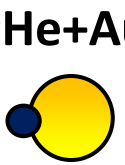
=> **Effective way to study parton energy losses (jet quenching)****




*Phys. Rev. C **85**, 034905 (2012)*

***Phys. Rev. Lett. **94**, 132301 (2005)*

# 2. Motivation

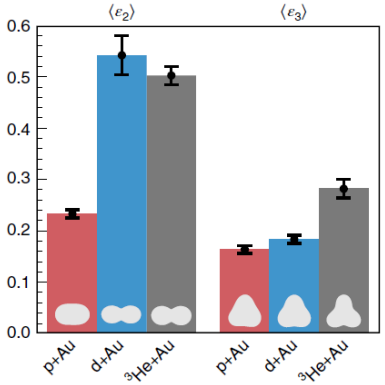


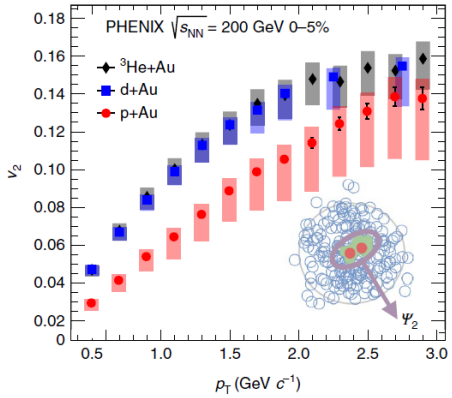

**3. $^3$He + Au collisions:**

The second order azimuthal anisotropy values in the most central collisions of small systems follow the prediction of hydrodynamical models:

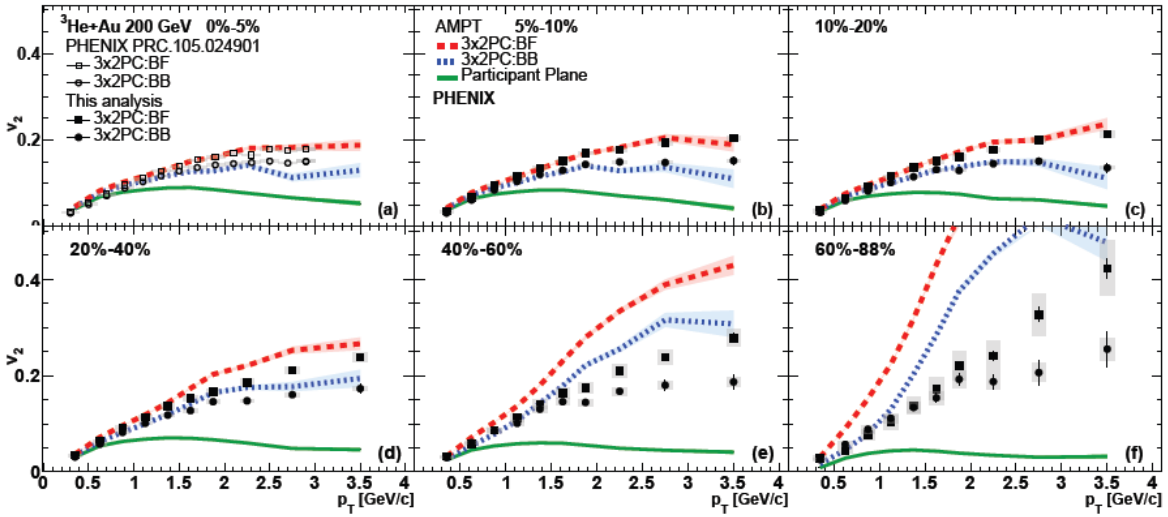
$$\varepsilon_2^{p+Au} < \varepsilon_2^{d+Au} \approx \varepsilon_2^{^3He+Au}$$

$$v_2^{p+Au} < v_2^{d+Au} \approx v_2^{^3He+Au}$$




*Nat. Phys.* ***15****, 214–220 (2019)*

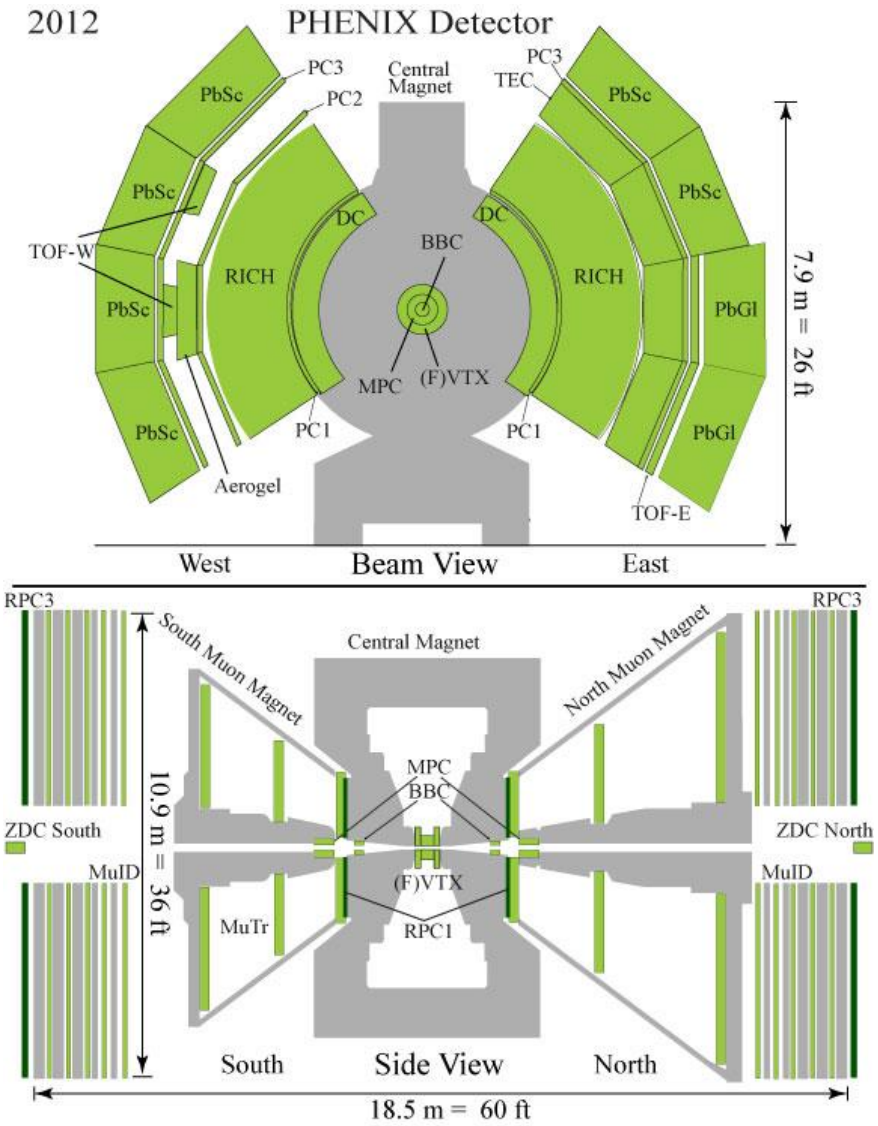



**Phys. Rev. C* ***107****, 024907 (2023)*

Extension of centrality range => $v_2$ **values – interplay between flow and nonflow effects.***

**The analysis of $v_2$ of $\pi^0$ in He+Au collision is still in work!**

# 3. PHENIX experiment at RHIC




- Located at Brookhaven National Laboratory (BNL) at the RHIC
- The class of event centrality was determined using beam-beam counters (**BBC**)
- The kinematic properties of the photons were determined using the electromagnetic calorimeter (EMCal), which consists of **6 PbSc and 2 PbGl sectors ($|\eta| < 0.35$)**.
- The muon piston calorimeter (**MPC**) and **BBC** were used for event plane determination ($3.1 < |\eta| < 3.9$)

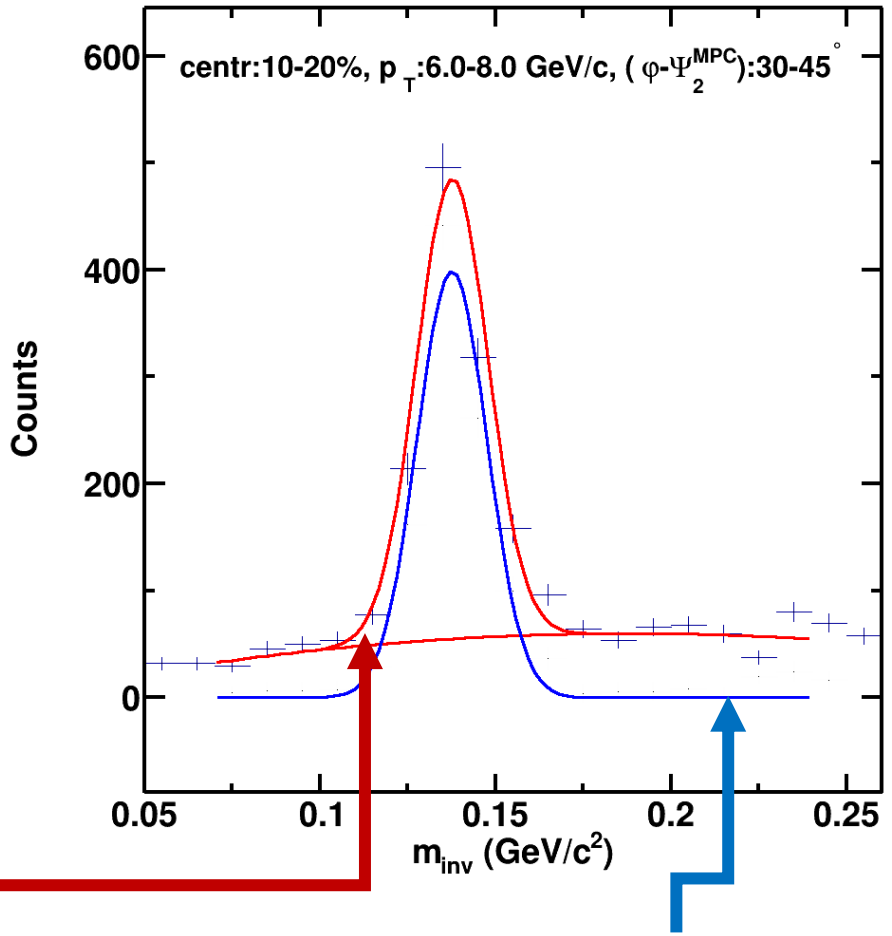
# 4. $\pi^0$ mesons yields extraction

The common procedure of signal extraction:
**Signal = Foreground – Background**

***EMCal*** was used to register photons, that passed all analysis cuts
-> **Foreground**

**Background:** the mixed event technique. Background consists of correlated and uncorrelated parts.

An example of signal photon pairs distribution after background subtraction (*Approximation*: gauss function for signal and pol2 for the correlated part of background)



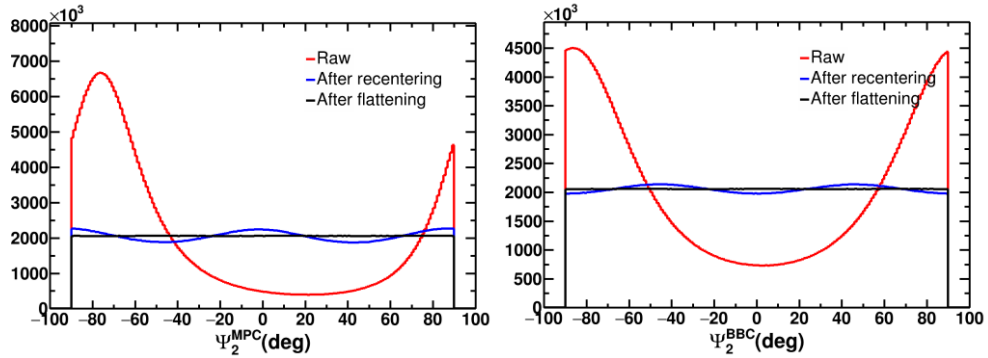

Clean signal after subtracting the correlated part of background (*Approximation*: gauss function)

# 5. Event plane. Resolution

To quantify $v_2$ of $\pi^0$ we used **event-plane method***.

Event plane distribution has anisotropy due to finite acceptance of detectors** (Raw) =>

- **Recentering**;
- **Flattening**

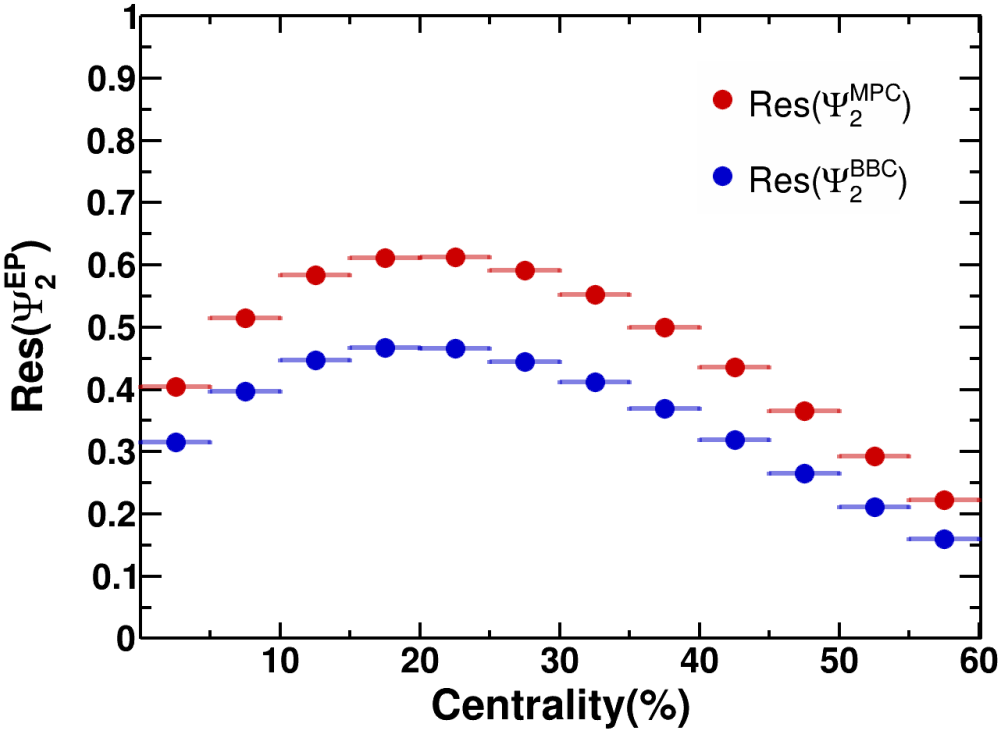



Resolution of the event plane was calculated via two sub-events method:

$$Res(\Psi_2^{MPC}) = \sqrt{2\langle \cos 2(\Psi_2^{MPCS} - \Psi_2^{MPCN})\rangle}$$

$$Res(\Psi_2^{BBC}) = \sqrt{2\langle \cos 2(\Psi_2^{BBCS} - \Psi_2^{BBCN})\rangle}$$

Final $v_2$ values are determined using the event plane measured in the MPC detector ($\Psi_2^{MPC}$).

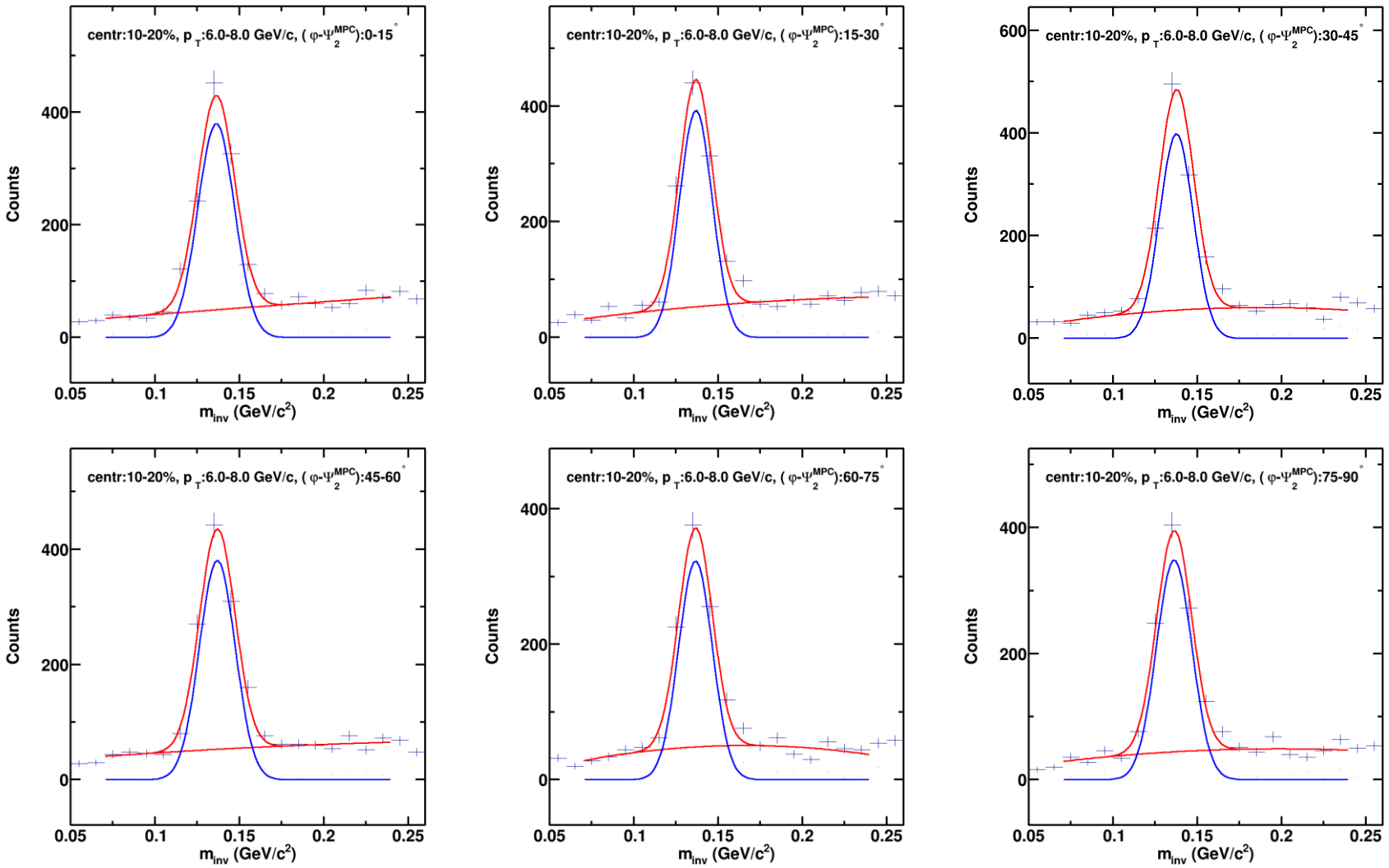



*arXiv:0809.2949

**Phys. Rev. C **77**, 034904 (2008)

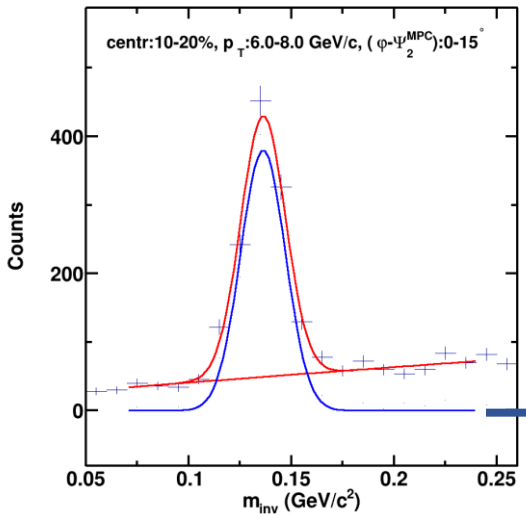
# 6. $v_2$ measurement method

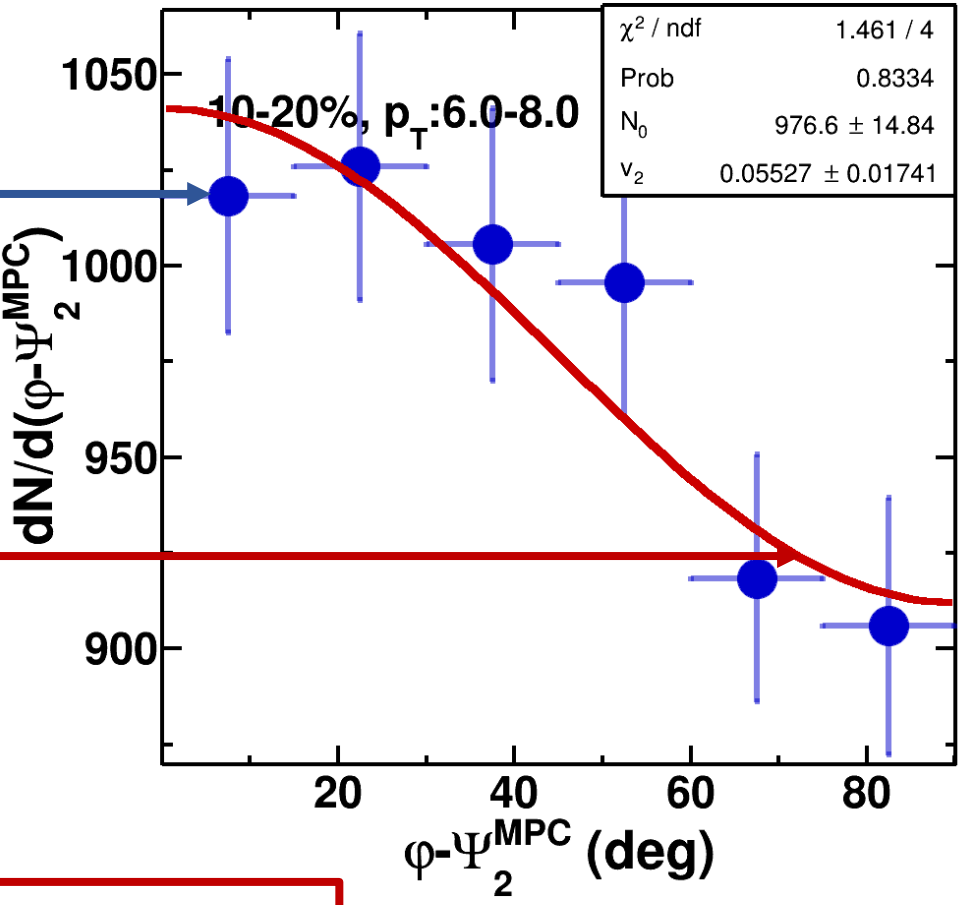
The raw yield extractions of $\gamma\gamma$ ($d\,N/d(\,\varphi - \Psi_2^{\mathrm{MPC}})$) were performed in ***6 ranges***:$0 < \varphi - \Psi_2^{MPC} < \pi/2$



# 6. $v_2$ measurement method

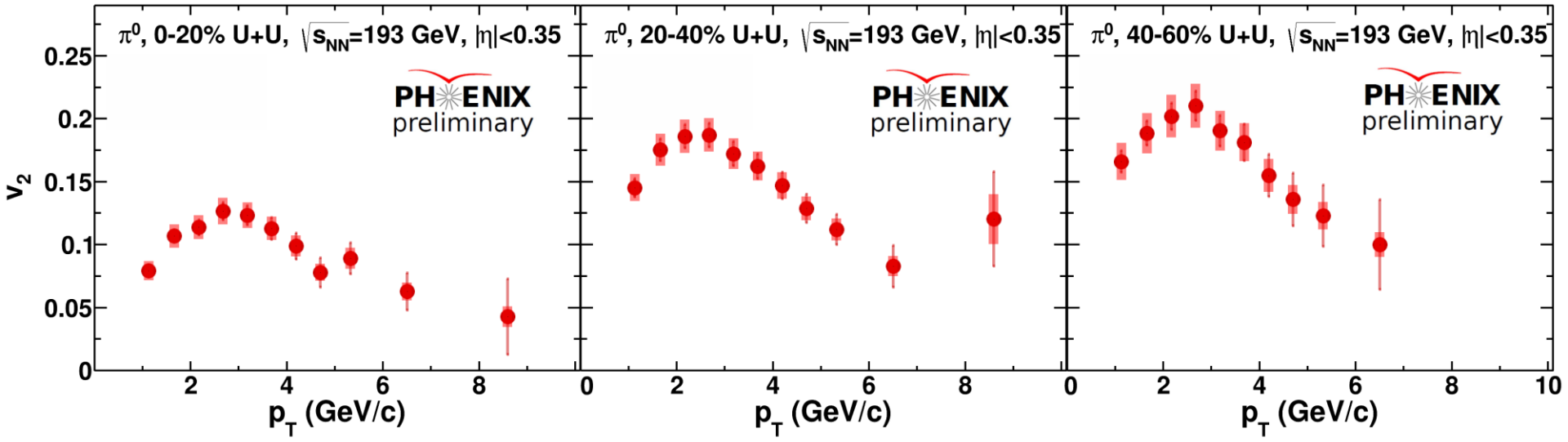
The raw yield extractions of $\gamma\gamma$ ($d\,N/d(\,\varphi - \Psi_2^{\mathrm{MPC}})$) were performed in ***6 ranges***: $0 < \varphi - \Psi_2^{MPC} < \pi/2$



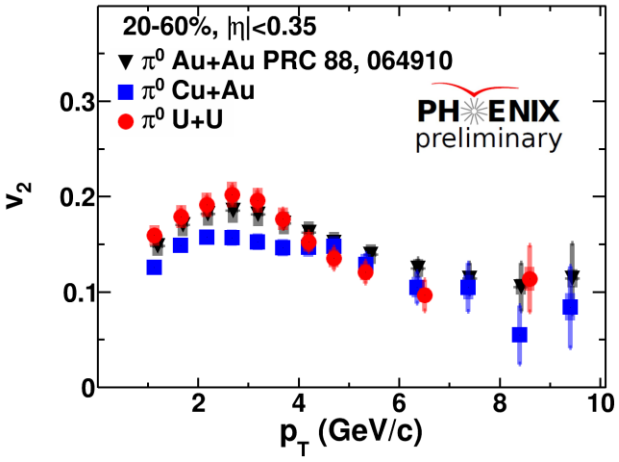

$$d\,N/d(\varphi - \Psi_2^{MPC}) = \mathrm{N_0}(1 + 2v_2\cos[2(\varphi - \Psi_2^{MPC})])$$

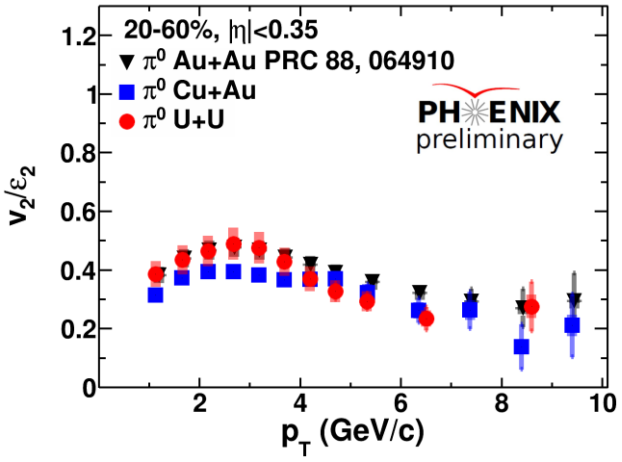
# 7. Results

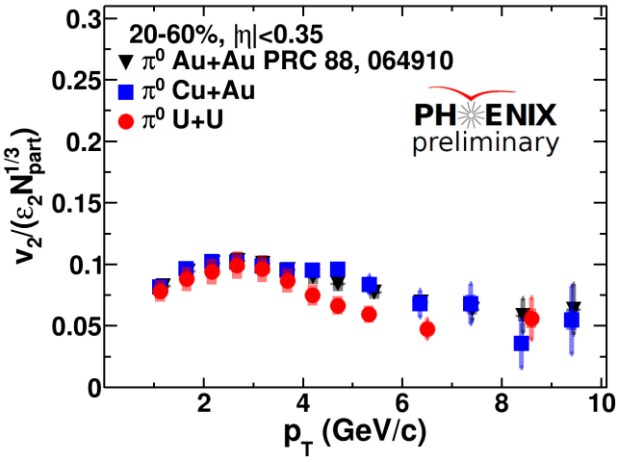



- The $v_2$ values increase with $p_T$ up to ~3 GeV/c and then tend to decrease
- Strong centrality dependence of $v_2$ values: the elliptic flow increases from central to peripheral
- The elliptic flow values are nonzero at $p_T > 5\ GeV/c$

# 7. Results

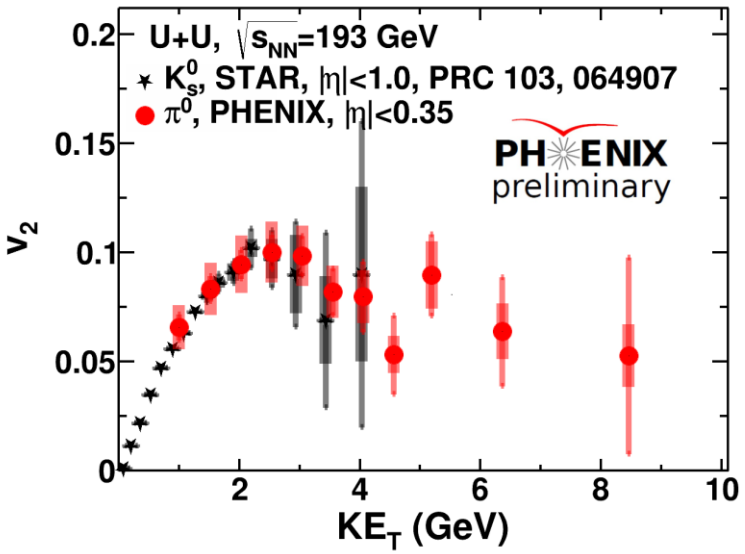



$\varepsilon_2$ and $N_{part}^{1/3}$ values for U+U collisions values are from *Phys. Rev. C* ***85****, 034905 (2012)*

- $v_2^{UU} \geq v_2^{AuAu} > v_2^{CuAu}$ up to ~4 GeV/cc
- The $v_2/\varepsilon_2 N_{part}^{1/3}$ values are consistent within the uncertainties in Cu+Au, Au+Au and U+U collisions up to ~4 GeV/c,
- at $p_T > 4$ GeV/c the $v_2/\varepsilon_2 N_{part}^{1/3}$ values of $\pi^0$ in U+U collisions differs from similar values in other systems.
- The $v_2$ values of $\pi^0$ and $K_s^0$ (from STAR) as a function of $KE_T$ are consistent within the uncertainties



# 8. Conclusions

- ✓ The $\pi^0$ elliptic flow values as a function of $p_T$ and centrality in U+U collision system at 193 GeV were obtained;
- ✓ It was found that the $v_2/\varepsilon_2 N_{part}^{1/3}$ values for $\pi^0$ are consistent within the uncertainties in Cu+Au, Au+Au and U+U collisions up to ~4 GeV/c => **the size and geometry of the collision system does not seem to affect the $v_2/\varepsilon_2 N_{part}^{1/3}$ values for $\pi^0$ (hydro region).** From ~4 GeV/c $v_2$ values of $\pi^0$ in U+U collisions are smaller than others => **It may be due to specific geometric configurations of the uranium nucleus.**
- ✓ Obtained $v_2$ values for $\pi^0$ are nonzero at high transverse momentum ($p_T > 5\ GeV/c$). It could be explained in terms of **parton energy loss models**. Further studies of $v_2$ of $\pi^0$ at high $p_T$ will allow to quantify the parton energy loss in the medium formed in U+U collisions **especially in the full-overlap region**;
- ✓ Further investigation of obtained $v_2$ values by using different Glauber parametrization of $^{238}U$ radius allow to investigate **the impact of the initial conditions on $v_2$ development;**
- ✓ The analysis devoted to $v_2$ measurement in $^3$He+Au collisions is still in progress. Stay tuned!

# 8. Conclusions

- ✓ The $\pi^0$ elliptic flow values as a function of $p_T$ and centrality in U+U collision system at 193 GeV were obtained;
- ✓ It was found that the $v_2/\varepsilon_2 N_{part}^{1/3}$ values for $\pi^0$ are consistent within the uncertainties in Cu+Au, Au+Au and U+U collisions up to ~4 GeV/c => **the size and geometry of the collision system does not seem to affect the $v_2/\varepsilon_2 N_{part}^{1/3}$ values for $\pi^0$ (hydro region).** From ~4 GeV/c $v_2$ values of $\pi^0$ in U+U collisions are smaller than others => **It may be due to specific geometric configurations of the uranium nucleus.**
- ✓ Obtained $v_2$ values for $\pi^0$ are nonzero at high transverse momentum ($p_T > 5\ GeV/c$). It could be explained in terms of **parton energy loss models**. Further studies of $v_2$ of $\pi^0$ at high $p_T$ will allow to quantify the parton energy loss in the medium formed in U+U collisions **especially in the full-overlap region**;
- ✓ Further investigation of obtained $v_2$ values by using different Glauber parametrization of $^{238}U$ radius allow to investigate **the impact of the initial conditions on $v_2$ development;**
- ✓ The analysis devoted to $v_2$ measurement in $^3$He+Au collisions is still in progress. Stay tuned!

Thank you for your attention!