Elliptic flow fluctuations at NICA energy regime

Vinh Luong[1,2], Dim Idrisov[2], Peter Parfenov[2], Alexander Demanov[2], Arkadiy Taranenko[2]
[1]Joint Institute for Nuclear Research, Dubna, Russia
[2]National Research Nuclear University MEPhI, Moscow, Russia

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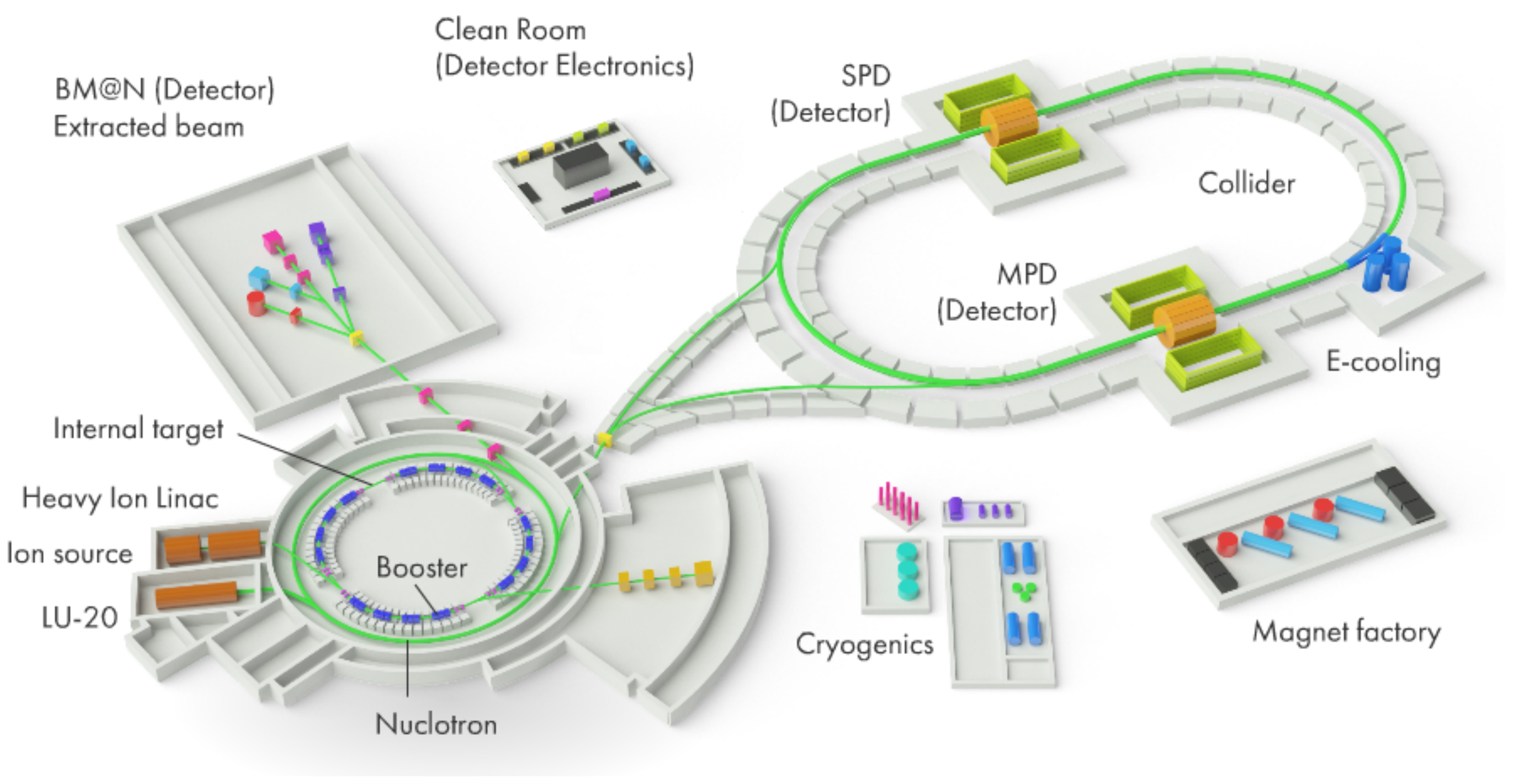
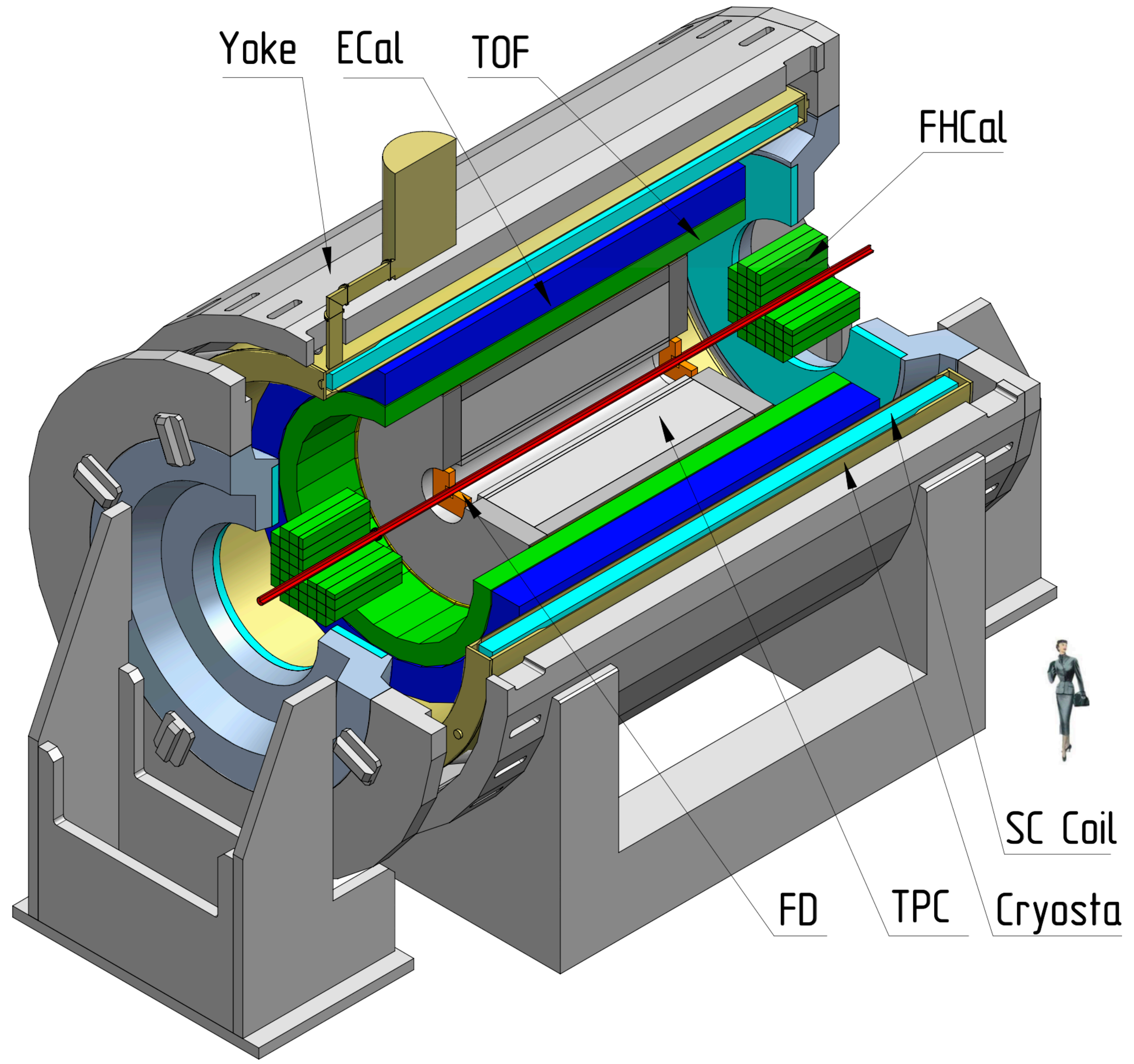
Outline

- Q-cumulants method
- Sensitivity of different order of Q-cumulants to flow fluctuations and non-flow
- Results from models on elliptic flow fluctuations at NICA energy regime
- Conclusion

MPD experiment at NICA

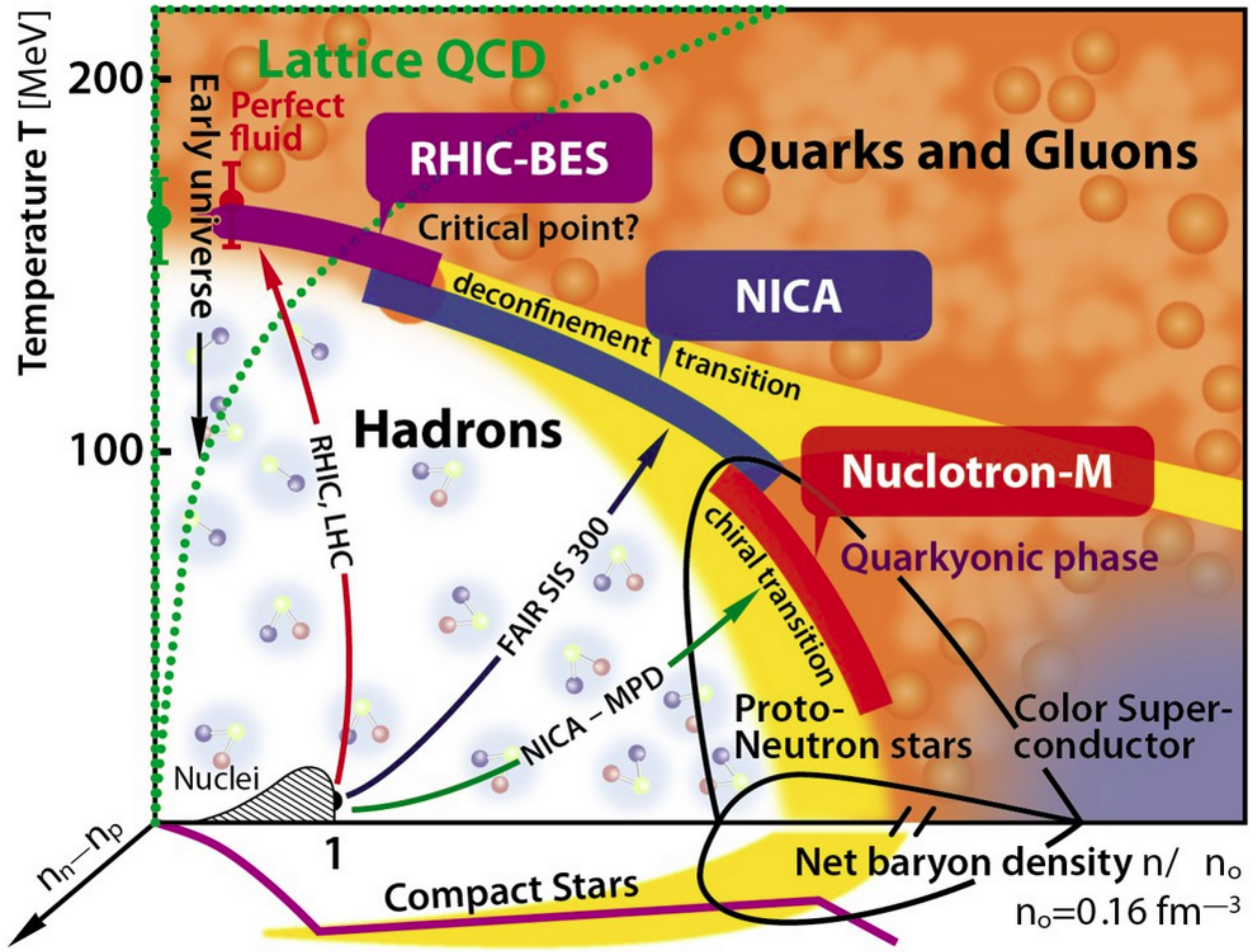


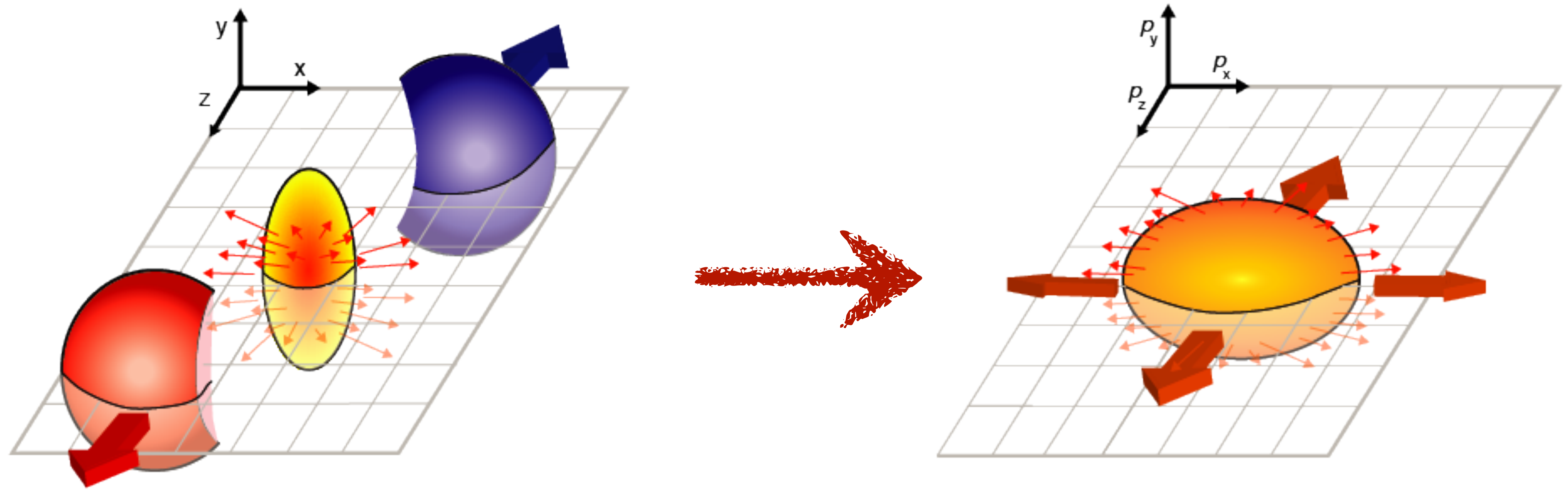
The NICA complex



MPD detector (stage 1)

Anisotropic flow phenomenon





$$\varepsilon_n = \sqrt{\frac{\langle r^n \cos n\psi \rangle + \langle r^n \sin n\phi \rangle}{\langle r^n \rangle}} \qquad \frac{dN}{d(\phi - \Psi_{RP})} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos\left[n(\phi - \Psi_{RP})\right]$$

$$v_n = \langle \cos\left[n(\phi - \Psi_{RP})\right] \rangle$$

- LHC/top RHIC: cross-over phase transition to the sQGP
- Beam energy scan programs: RHIC/SPS/FAIR/**NICA**: searching for the critical end point & 1st order phase transition

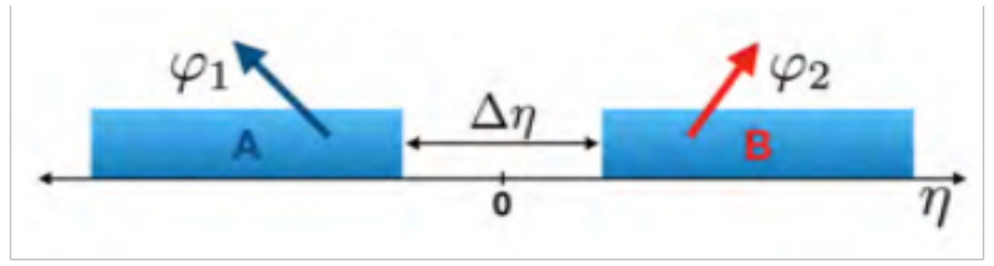
- Transfer of initial anisotropy ε_n in coordinate space to final anisotropy v_n in momentum space via the thermalized medium
- Anisotropic flow: sensitive probe to study the sQGP properties (η/s, ζ/s, EoS, …)

Q-cumulants $v_n\{\mathrm{QC}\}$ methods for flow measurements

- Ψ_{RP} **cannot be measured directly** → Multi-particle azimuthal correlations method is used:

$$\langle\langle 2\rangle\rangle = \left\langle\left\langle e^{in(\phi_1-\phi_2)}\right\rangle\right\rangle = \left\langle\left\langle e^{in[(\phi_1-\Psi_{RP})-(\phi_2-\Psi_{RP})]}\right\rangle\right\rangle = \left\langle\left\langle e^{in(\phi_1-\Psi_{RP})}\right\rangle\left\langle e^{-in(\phi_2-\Psi_{RP})}\right\rangle + \delta_2\right\rangle = \left\langle v_n^2 + \delta_2\right\rangle$$

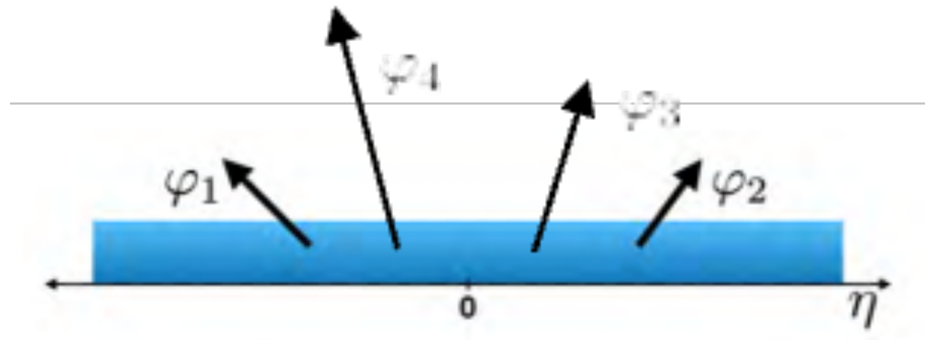
- **2-particle Q-cumulant:** $\Delta\eta$ = 0.1 is applied between 2 sub-events A and B to suppress 2-particle non-flow δ_2



$$Q_n = \sum_{j=1}^{M} e^{in\phi_j} \qquad \langle 2\rangle_{a|b} = \frac{Q_n^a Q_n^{b*}}{M_a M_b} \qquad v_n\{2\} = \sqrt{\langle\langle 2\rangle\rangle_{a|b}}$$

- **4-particle Q-cumulants**

$$\langle 2\rangle = \frac{|Q_n|^2 - M}{M(M-1)} \qquad \langle 4\rangle = \frac{|Q_n|^4 + |Q_{2n}|^2 - 2\,\mathrm{Re}[Q_{2n}Q_n^*Q_n^*] - 4(M-2)\,|Q_n|^2 - 2M(M-3)}{M(M-1)(M-2)(M-3)}$$



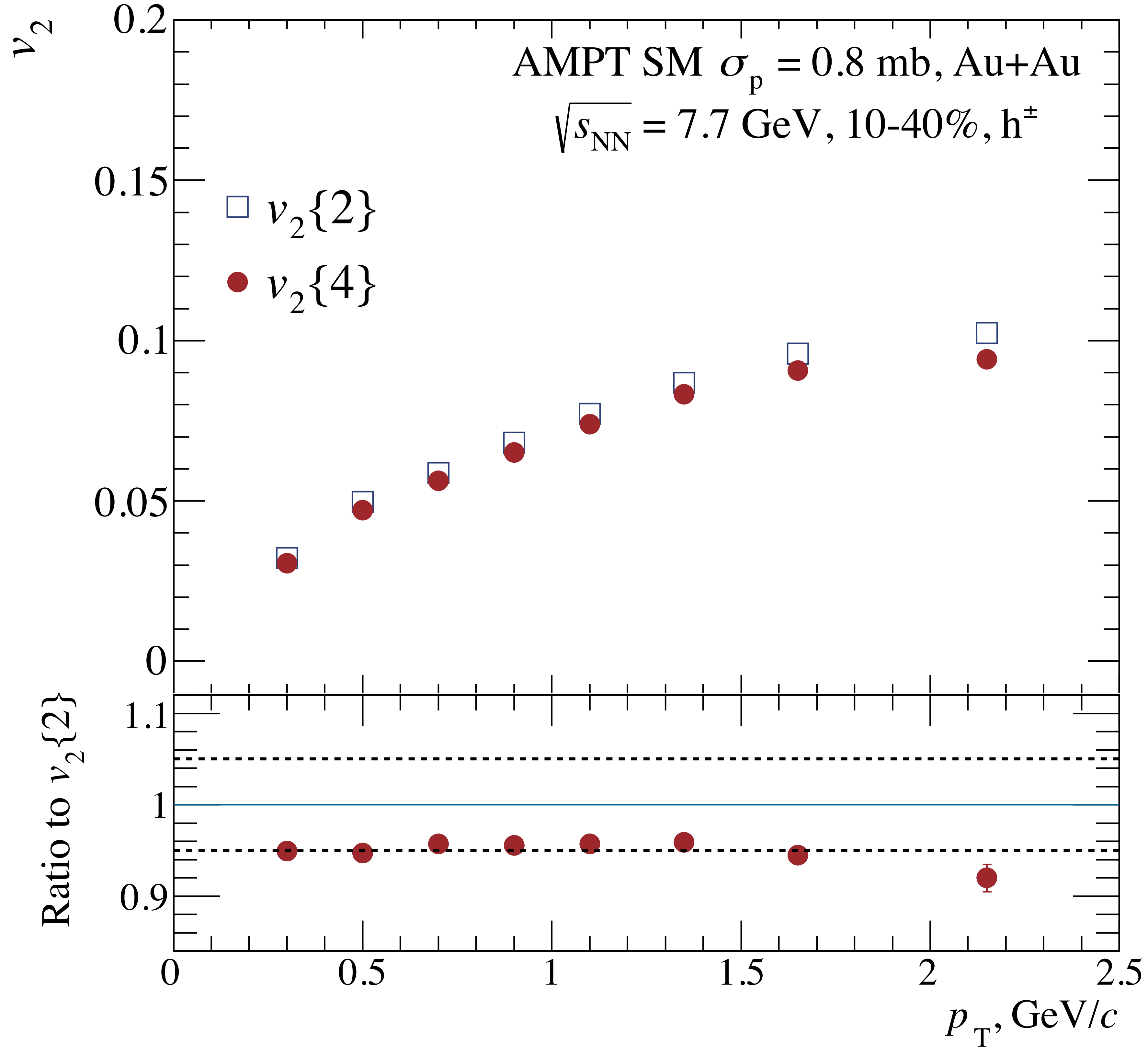
$$v_n\{4\} = \sqrt[4]{2\,\langle\langle 2\rangle\rangle^2 - \langle\langle 4\rangle\rangle}$$

Method's details described in N. Borghini, P. M. Dinh and J. Y. Ollitrault, PRC 63 (2001), 054906; A. Bilandzic et al, PRC 83 (2011), 044913

Sensitivity of $v_2\{\mathrm{QC}\}$ to flow fluctuations and non-flow

- Non-flow contribution for *k*-particle cumulants: $\delta_k \sim 1/M^{k-1}$
- Elliptic flow fluctuations: $\sigma_{v2}^2 = \langle v_2^2 \rangle - \langle v_2 \rangle^2$
- Assuming $\sigma_{v2} \ll \langle v_2 \rangle$, fluctuations enhance v2{2} and suppress v2{k,k=4,6} compared to $\langle v_2 \rangle$
  - $v_2\{2\} \approx \langle v_2 \rangle + \frac{1}{2}\frac{\sigma_{v2}^2}{\langle v_2 \rangle}$
  - $v_2\{4\} \approx \langle v_2 \rangle - \frac{1}{2}\frac{\sigma_{v2}^2}{\langle v_2 \rangle}$

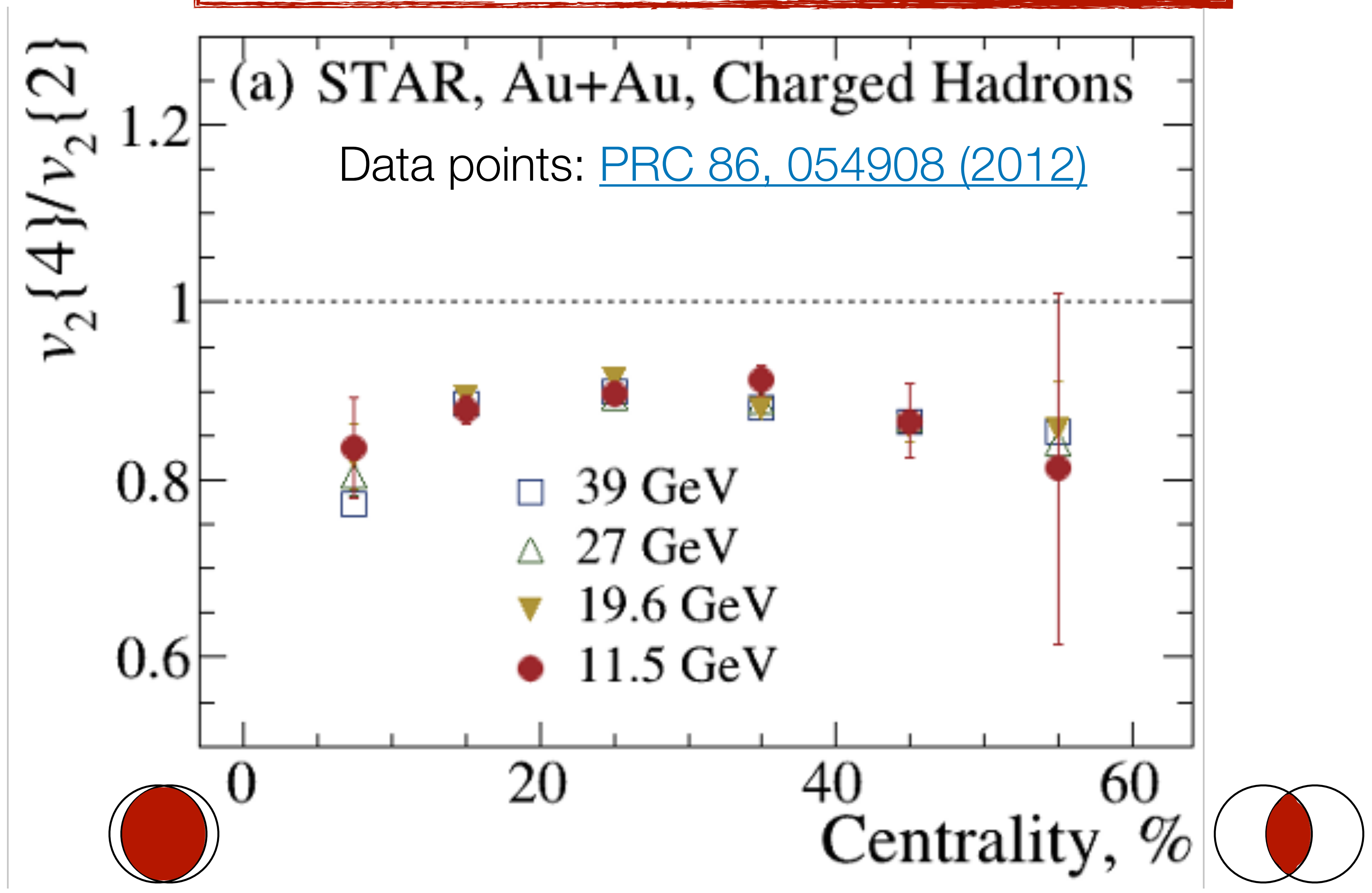
$v_2\{4\}/v_2\{2\} \approx 1$: small v_2 fluctuations
$v_2\{4\}/v_2\{2\} \ll 1$: large v_2 fluctuations

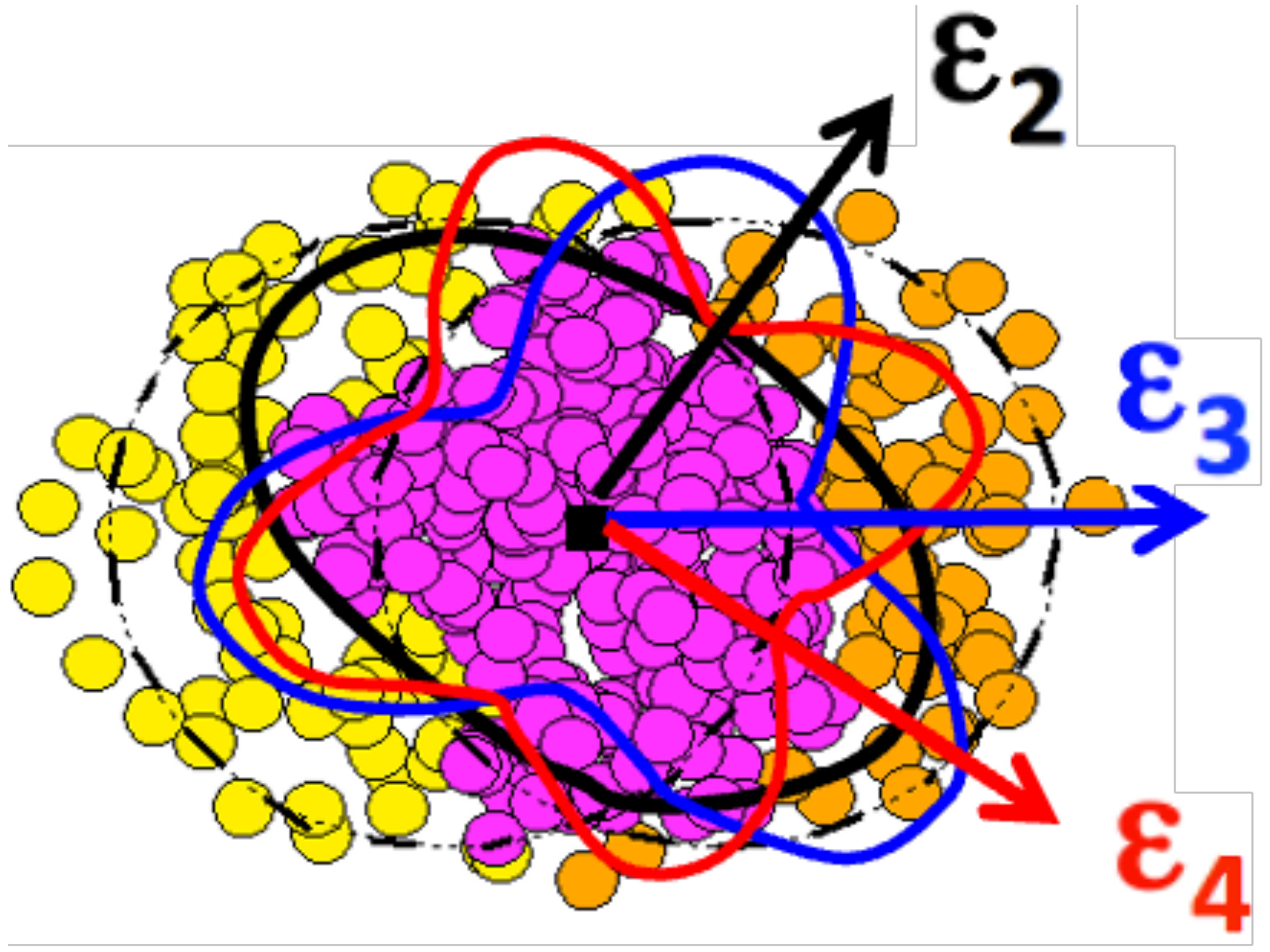


$v_2\{2\} > v_2\{4\}$

Motivation of elliptic flow fluctuation study

$v_2\{4\}/v_2\{2\} \approx 1$: small v_2 fluctuations
$v_2\{4\}/v_2\{2\} \ll 1$: large v_2 fluctuations

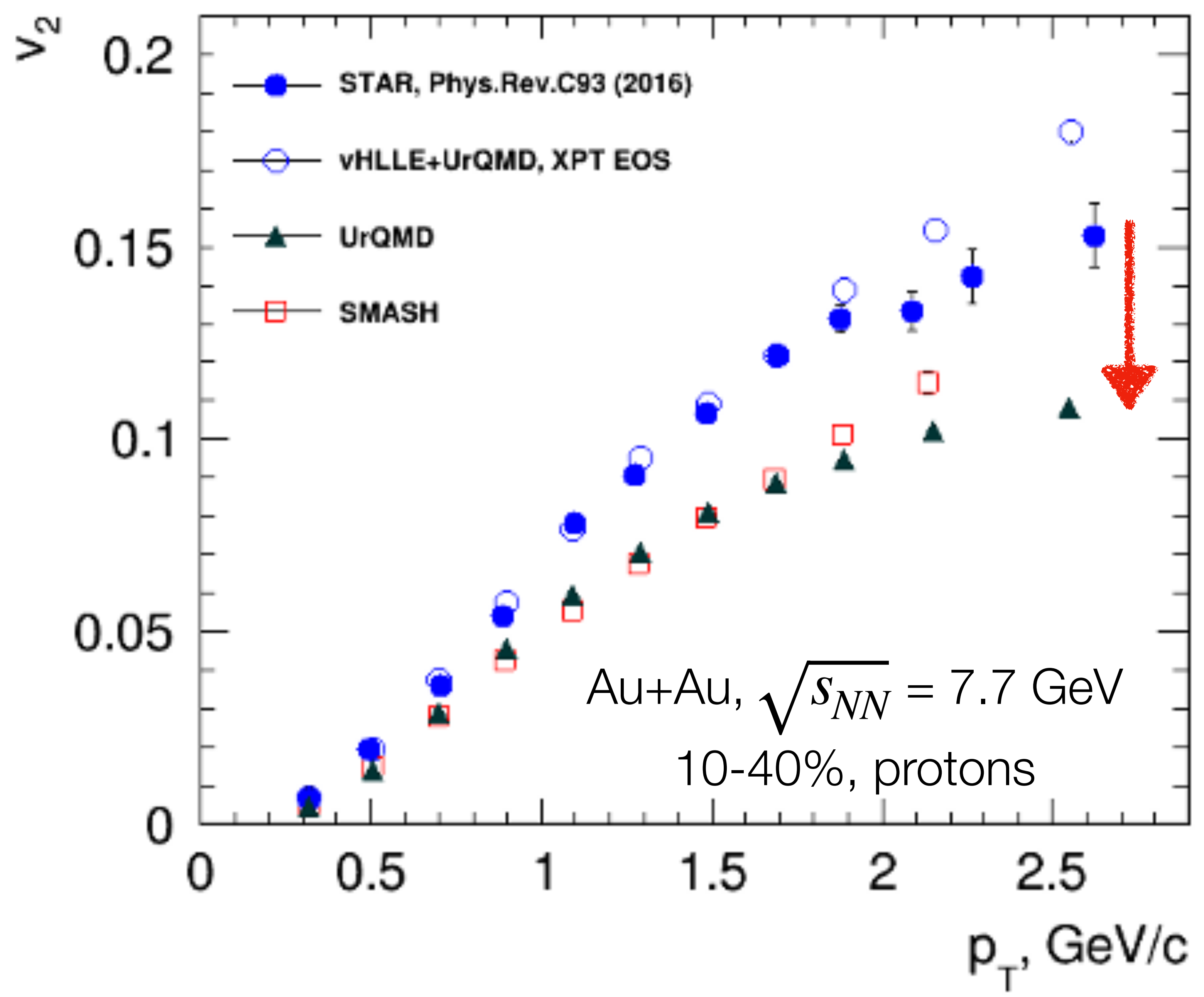


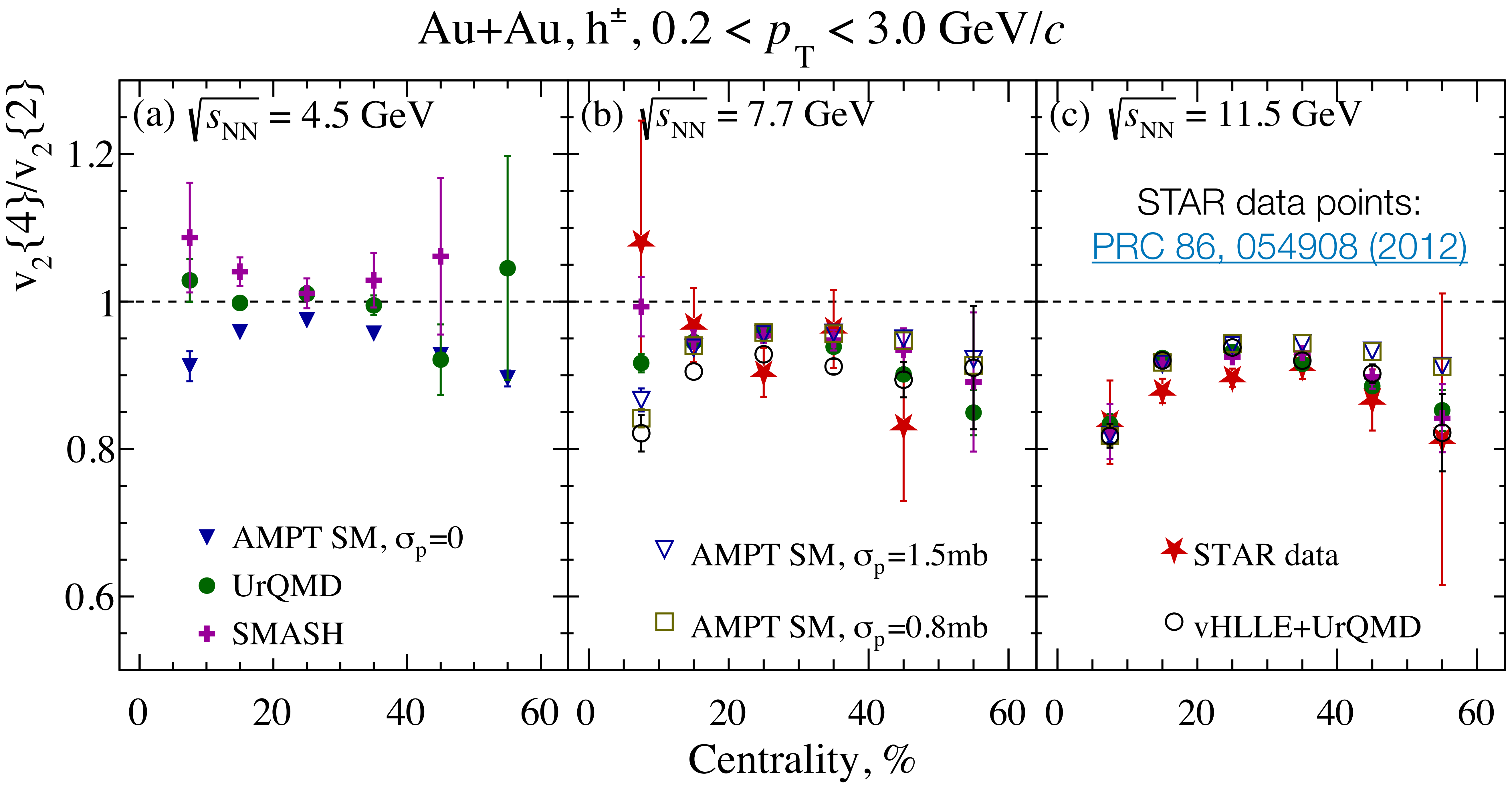


- v_2 fluctuations at $\sqrt{s_{NN}}$ = 11.5 — 39 GeV observed in STAR:
  - Weak dependence on collision energy
- Indicate a dominated initial state driven fluctuations $\sigma_{\varepsilon 2}$
- Provide constraints for IS models and shear viscosity $\eta(T/s)$

How about v_2 fluctuations at NICA energies?

v_2 fluctuations at NICA energy regime





- At $\sqrt{s_{NN}} \geq 7.7$ GeV pure string/cascade models without QGP description underestimate v_2 (UrQMD, SMASH)

- v_2 fluctuations observed in STAR can be reproduced by model either with QGP phase or without QGP phase description:
  - **v_2 fluctuations dominated by ε_2 fluctuations**
  - **$v_2\{4\}/v_2\{2\}$: direct probe for the initial state conditions**

Conclusion

- Models reproduce the similar magnitude of v_2 fluctuations at $\sqrt{s_{NN}}$ = 7.7 — 11.5 GeV observed in STAR experiment at RHIC
  - **v_2 fluctuations are mainly driven from ε_2 fluctuations**
- UrQMD, SMASH models predict zero v_2 fluctuations for 0-40% Au+Au collisions at $\sqrt{s_{NN}}$ = 4.5 GeV
  - Further study is needed
- Outlook: increase the statistic for the $v_2(p_T, \mathrm{PID})$ fluctuations study


MSU
Thanks for your attention!

Back-up slides

Models & statistics

Au+Au min. bias

- **Without QGP phase**
  - UrQMD v3.4 (cascade)
    - $\sqrt{s_{NN}}$ = 4.5 GeV: 115M
    - $\sqrt{s_{NN}}$ = 7.7 GeV: 88M
    - $\sqrt{s_{NN}}$ = 11.5 GeV: 50M
  - SMASH v1.8
    - $\sqrt{s_{NN}}$ = 4.5—11.5 GeV: 64M
  - AMPT SM $\sigma_p = 0$
    - $\sqrt{s_{NN}}$ = 4.5, 7.7 GeV: 120M
- **With QGP phase**
  - vHLLE+UrQMD
    - $\sqrt{s_{NN}}$ = 7.7, 11.5 GeV: 27M
  - AMPT SM σ_p = 0.8 mb
    - $\sqrt{s_{NN}}$ = 7.7 GeV: 72M
    - $\sqrt{s_{NN}}$ = 11.5 GeV: 35M
  - AMPT SM σ_p = 1.5 mb
    - $\sqrt{s_{NN}}$ = 7.7 GeV: 42M
    - $\sqrt{s_{NN}}$ = 11.5 GeV: 60M