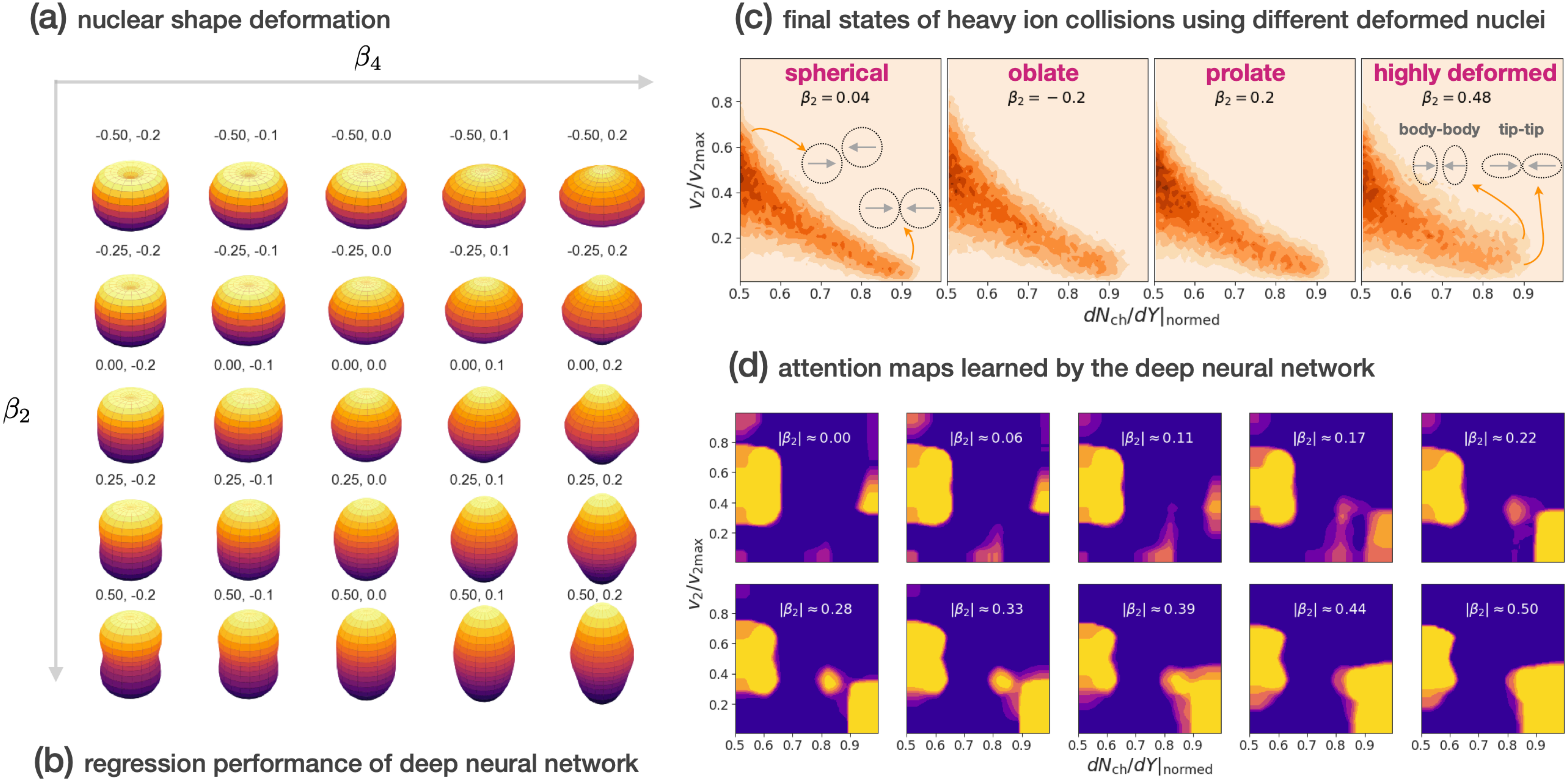
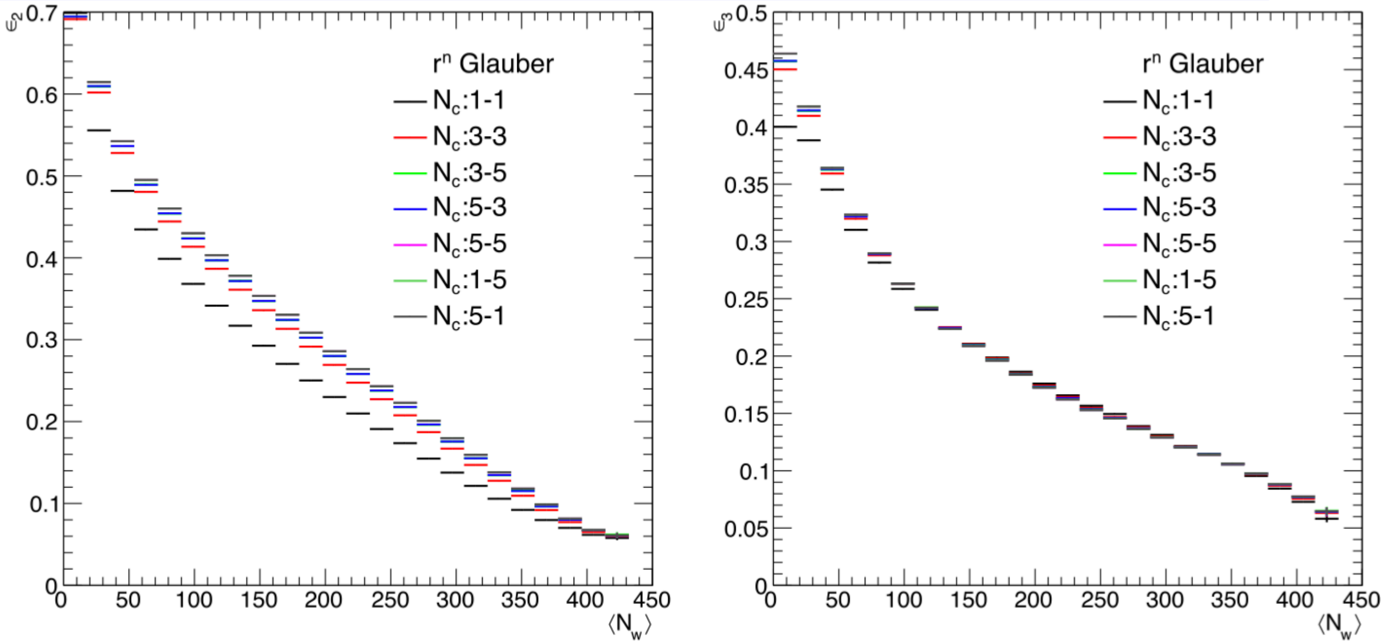
Nuclear deformation

https://arxiv.org/pdf/1906.06429.pdf



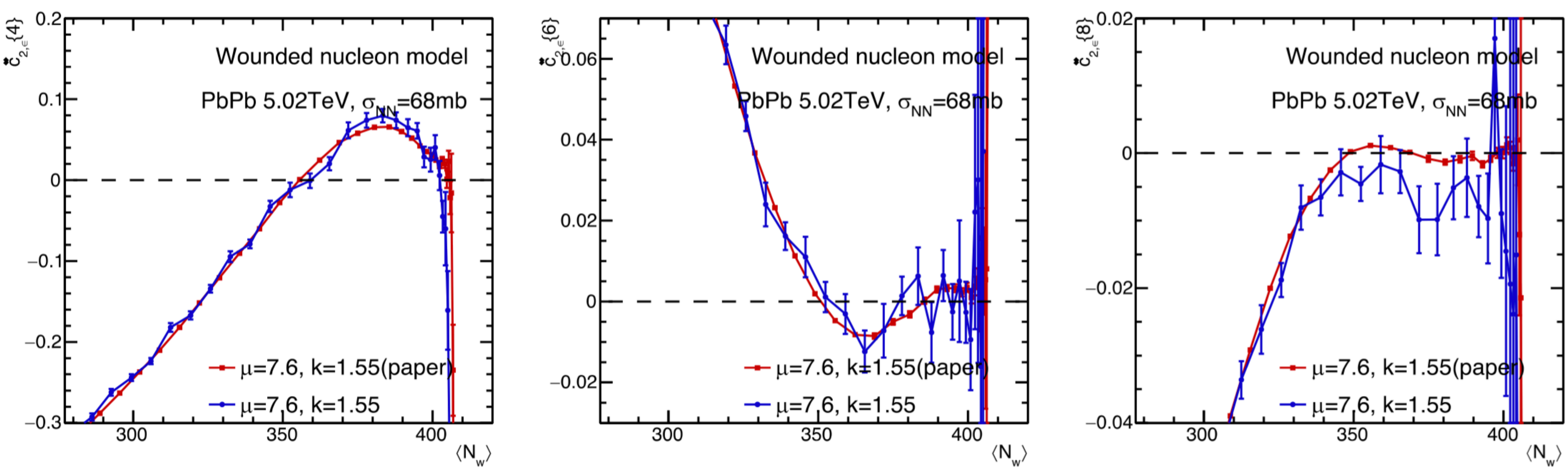
in large Nch: larger v2 fluctuation, sensitive to the beta2

Calculation 1



$$\epsilon_n = \epsilon_n e^{in\Phi_n} \equiv -\frac{\langle r^n e^{in\phi}\rangle}{\langle r^n\rangle}$$

$$\begin{aligned}
c_n\{2\} &= \langle v_n^2\rangle \\
c_n\{4\} &= \langle v_n^4\rangle - 2\langle v_n^2\rangle^2 \\
4c_n\{6\} &= \langle v_n^6\rangle - 9\langle v_n^4\rangle\langle v_n^2\rangle + 12\langle v_n^2\rangle^3 \\
33c_n\{8\} &= \langle v_n^8\rangle - 16\langle v_n^6\rangle\langle v_n^2\rangle - 18\langle v_n^4\rangle^2 + 144\langle v_n^4\rangle\langle v_n^2\rangle^2 - 144\langle v_n^2\rangle^4 .
\end{aligned}$$

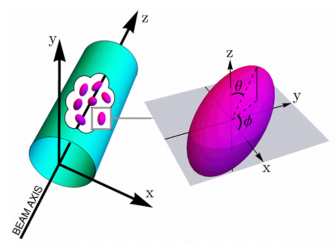


Calculation 2

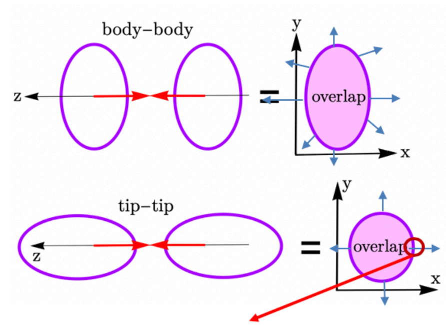
Mechanism

Physics motivation

Some ideas in hydro calculations:



nucleus-nucleus collision events



Fluid cell follows hydro calculation(Cooper-Frye freeze-out)

smaller $R \Rightarrow$ larger $\bar{p}_t$

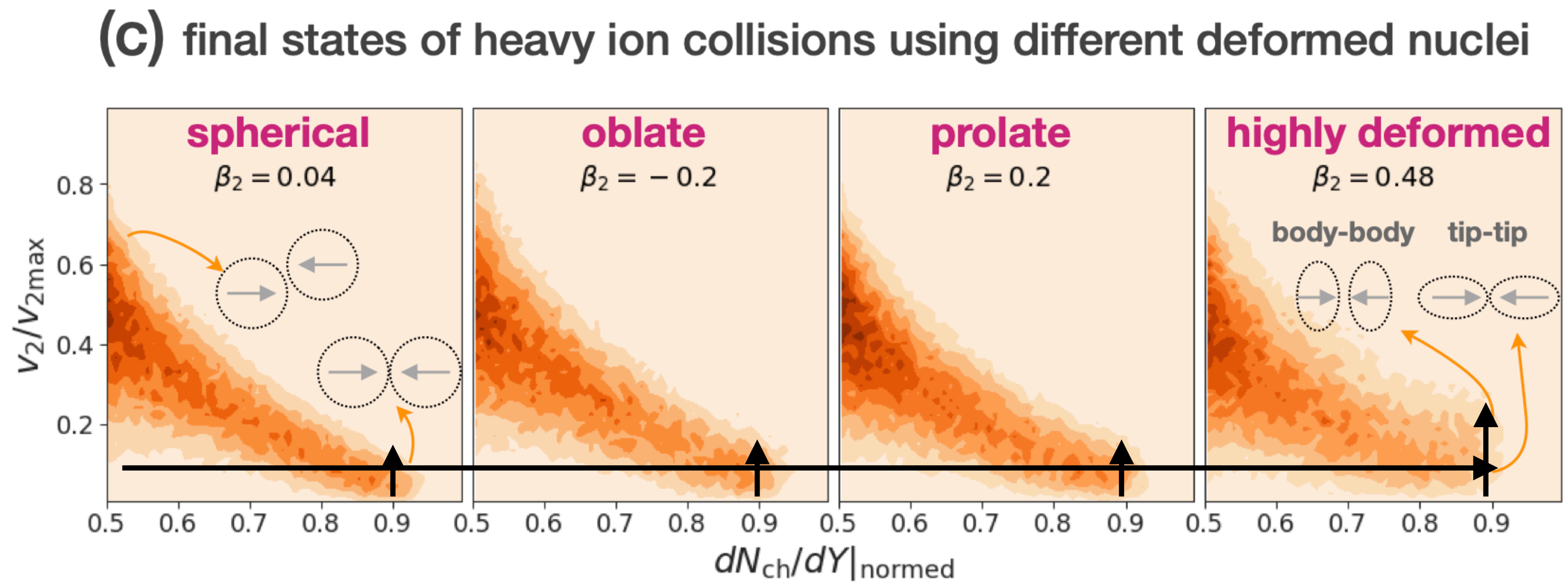
Elliptic flow is essentially a linear response to the initial eccentricity:

$$v_2 = \kappa_2 \varepsilon_2$$

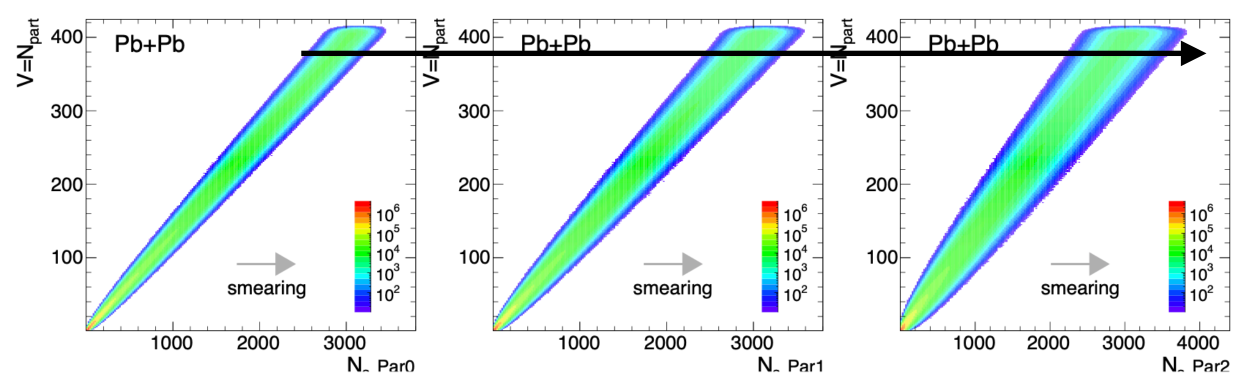
The value of elliptic flow saturates around a value, so $v_2 = \beta\kappa_2$

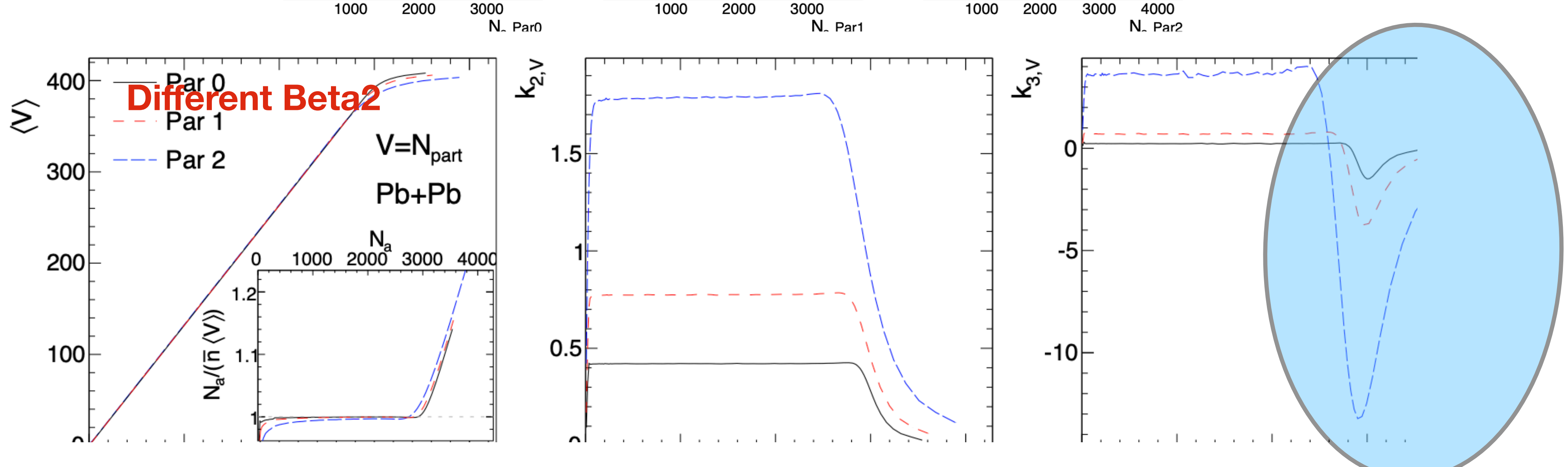
arXiv:1910.04673

4

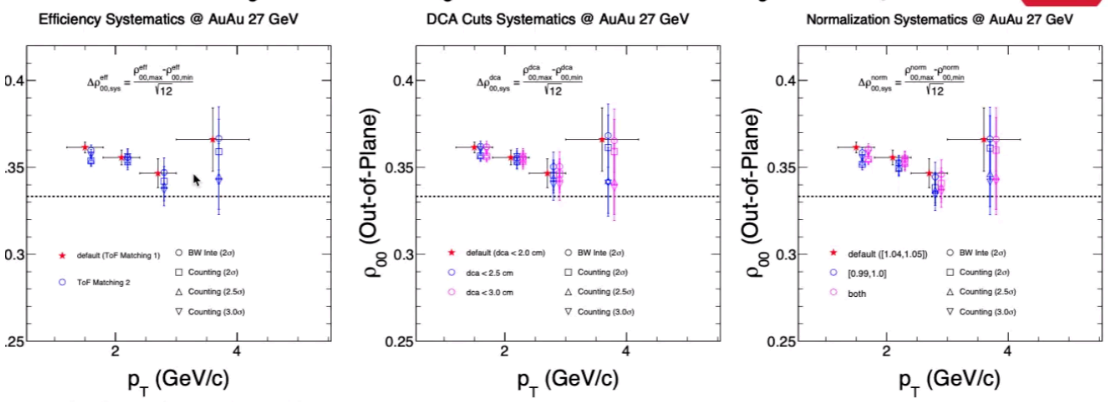


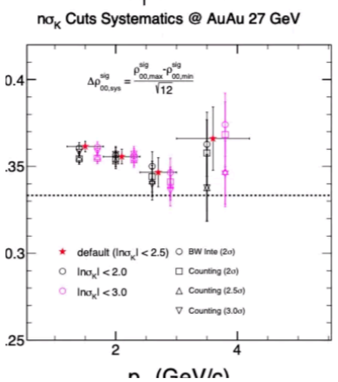
Vary beta2 in Glauber and then calculate the eccentricity cumulant~Npart/Nch





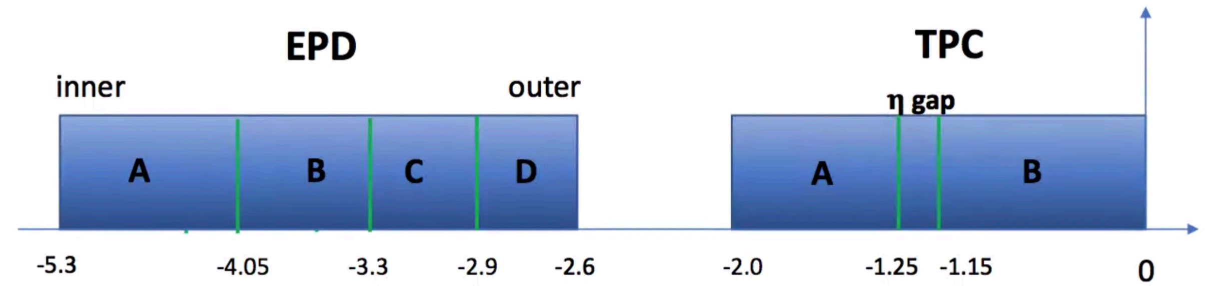
Point-by-Point Systematic Study @ 27 GeV

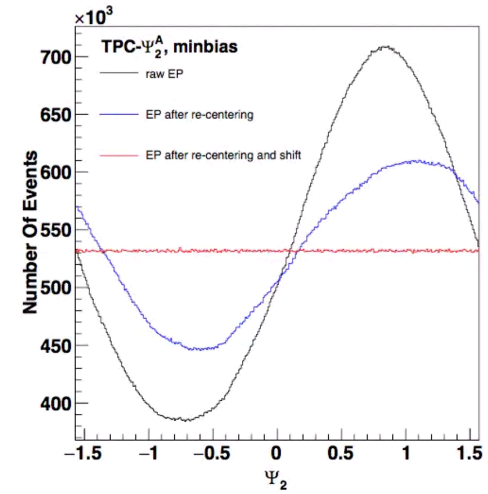




- Systematic error contribution of each set of cut is calculated by: $\Delta\rho_{00,sys}^{cuts} = \frac{\rho_{00,max}^{cuts} - \rho_{00,min}^{cuts}}{\sqrt{12}}$.
- Total systematic errors for each pT bin is calculated by: $\Delta\rho_{00,sys} = \sqrt{\sum_i (\Delta\rho_{00,sys}^{i})^2}$.

Event Plane Reconstruction





- Second harmonic event plane angle:

$$\Psi_2 = tan^{-1}\left(\frac{\sum_i w_i sin(2\phi_i)}{\sum_i w_i cos(2\phi_i)}\right)/2$$

- Re-centering calibration:

$$\vec{Q}_{raw} = \frac{1}{N}\sum_i^N \begin{pmatrix} w_i cos(2\phi_i) \\ w_i sin(2\phi_i) \end{pmatrix}, \vec{Q}_{rc} = \vec{Q}_{raw} - \left\langle \vec{Q}_{raw} \right\rangle$$

- Shift calibration:

$$\Psi_{2,shift} = \sum_n \frac{1}{n}[-\langle sin(2n\Psi_{2,rc})\rangle\, cos(2n\Psi_{2,rc}) + \langle cos(2n\Psi_{2,rc})\rangle\, sin(2n\Psi_{2,rc})]$$

$$\Psi_2 = \Psi_{2,rc} + \Psi_{2,shift}$$

Momentum-conservation correction

- Methods for correcting for momentum conservation effects on flow and event-plane resolution are known [1]
  - But they require the knowledge of particle transverse momentum
- There's no way to get this information from the EPD
  - Must know p_T of each track used in event-plane determination

$$f \equiv \frac{\langle w p_T\rangle}{\sqrt{\langle w^2\rangle \langle p_T^2\rangle}} = \langle w p_T\rangle_Q \sqrt{\frac{M}{\langle w^2\rangle_Q N \langle p_T^2\rangle}}$$

[1] N. Borghini, et al. "Effects of momentum conservation on the analysis of anisotropic flow". https://arxiv.org/pdf/nucl-th/0202013.pdf

Analysis Details

Data tree, PID strategy same with
STAR (Jowzaee, Llope, et al.) arXiv:1906.09204

PID	$\pi^{\pm}$	$K^{\pm}$	p(p)
TPC *$0.2<p_T, p<0.6$ GeV*	$n\sigma_{\pi}<2$, $n\sigma_{K,p}>2$	$n\sigma_{K}<2$, $n\sigma_{\pi}>3$, $n\sigma_{p}>2$	
TPC *$0.4<p_T, p<0.9$ GeV*			$n\sigma_{p}<2$, $n\sigma_{\pi}>3$, $n\sigma_{K}>2$
TPC + TOF *$0.6<p, p_T<2.0$ GeV*	$-0.15<m^2<0.15$	$0.15<m^2<0.4$	
TPC + TOF *$0.9<p, p_T<2.5$ GeV*			$0.65<m^2<1.1$

QA'd data tree generated by Bill Llope.

Analysis done separately for + & - magnetic field polarities, then weighted averaged the R2 results.

Event selection:
200 GeV Au-Au 2010
Accepted events: $2*10^7$,
Trigger: Minimum Bias,
Centrality selection: refmult, refmult2, refmult3 (default)
Longitudinal event vertex position range: $|Vz| < 30$ cm,
Vz 6 cm bin for R_2, then weighted average R_2.

Track selection:
$N_{TPCclusters} > 18$ out of a maximum of 45,
nhitratcut = 0.52,
$|y| <= 0.6$,
DCA < 2 cm,

Centrality definitions:
refmult — charged multiplicity measured in TPC for $|\eta| < 0.5$ (not corrected for reconstruction efficiency);
refmult2 — charged multiplicity measured in TPC for $0.5 < |\eta| < 1.0$ (not corrected for reconstruction efficiency);
refmult3 — charged multiplicity measured in TPC for $|\eta| < 1.0$ (not corrected for reconstruction efficiency) excluding protons and antiprotons.

Event Plane method

- Q vector calculation
  :ω_i = (mip>3) ? 3 : mip

$$Q_x = \sum_{i=0}^{N} \omega_i \cos(2\phi_i)$$

$$Q_y = \sum_{i=0}^{N} \omega_i \sin(2\phi_i)$$

$$Q_w = \sum_{i=0}^{N} \omega_i$$

- Normalization

$$Q'_x = \frac{Q_x}{\sqrt{Q_w}} \quad Q'_y = \frac{Q_y}{\sqrt{Q_w}}$$

- Ψ

$$\Psi = \tan^{-1}\left(\frac{Q_y}{Q_x}\right)/2$$

- Weight (ω_i) nmipmax = 3

	ω_i
EPD Q_1	$\langle \cos[\Psi_1^{E\eta 3} - \Psi_1^{W\eta 0,1,2,3}] \rangle$ * mip
EPD Q_2	mip
TPC Q_1	η
TPC Q_2	p_T

- V_n

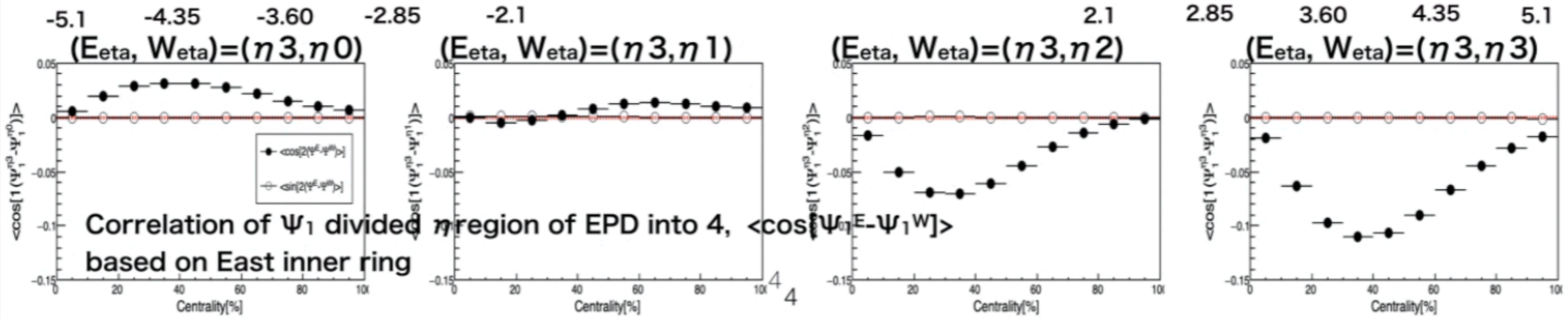
TPC region : $v_2^{EPDEW} = \dfrac{\langle \cos[2(\phi - \Psi_2^{EPDEW})] \rangle}{\sigma_{EPDEW}}$ $\quad v_2^{TPC} = \dfrac{\langle \cos[2(\phi - \Psi_2^{TPC})] \rangle}{\sigma_{TPC}}$

EPD region : $v_1^{EPD\_West} = \dfrac{\langle W' \cos(\phi - \Psi_1^{TPC}) \rangle}{R^{(1)}_{EP,TPC} \langle W' \rangle}$ $\quad v_1^{EPD\_East} = \dfrac{\langle W' \cos(\phi - \Psi_1^{TPC}) \rangle}{R^{(1)}_{EP,TPC} \langle W' \rangle}$

σ^{EPDEW} and σ^{TPC} are the each Ψ_n resolution for each centrality

EPD East					EPD West			
η3	η2	η1	η0	※η0 is most outer ring	η0	η1	η2	η3

-5.1 -4.35 -3.60 -2.85 -2.1 2.1 2.85 3.60 4.35 5.1



Correlation of Ψ_1 divided η region of EPD into 4, $\langle \cos[\Psi_1^E - \Psi_1^W] \rangle$ based on East inner ring

Run14 AuAu

https://drupal.star.bnl.gov/STAR/system/files/Dstar%20ana%20in%20200GeV.pdf

Dataset and reconstruction method

- **Dataset:**

✓ Run 14: AuAu @ 200 GeV;

✓ The analysis uses picoDst produced from MuDst and picoD0 tree produced from picoDst;

✓ The dataset is processed with SL16d library;

✓ MB trigger:

Trigger ID	description
450050	vpdmb-5-nobsmd-hlt
450060	vpdmb-5-nobsmd-hlt
450005	vpdmb-5-nobsmd
450015	vpdmb-5-nobsmd
450025	vpdmb-5-nobsmd

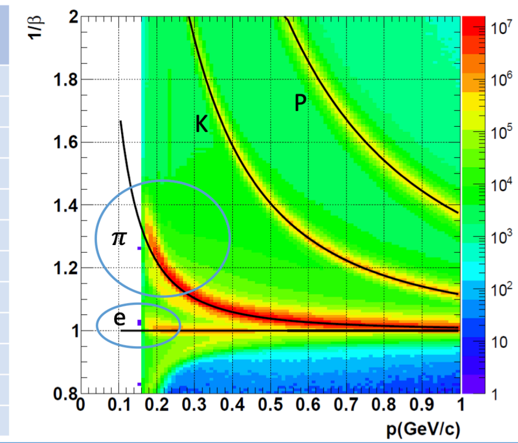
Softpion Tof PID cut

✓ $\Delta\frac{1}{\beta} = \frac{1}{\beta_{exp}} - \frac{1}{\beta_{th}}$

✓ This cut is defined according to $\pi's\ \Delta\frac{1}{\beta}$ distribution, ~(mean-3*σ, mean+3*σ)

(pion sample is extracted from ${K_s}^0 \rightarrow \pi^+\pi^-$)

p_T range/GeV	$\Delta 1/\beta$_low	$\Delta 1/\beta$_high
$0.15 \le p_T < 0.16$	-0.03	0.18
$0.16 \le p_T < 0.17$	-0.03	0.178
$0.17 \le p_T < 0.18$	-0.022	0.095
$0.18 \le p_T < 0.19$	-0.02	0.073
$0.19 \le p_T < 0.2$	-0.02	0.059
$0.2 \le p_T < 0.21$	-0.02	0.05
$0.21 \le p_T < 0.22$	-0.0218	0.05
$0.22 \le p_T < 0.23$	-0.0226	0.047
$0.23 \le p_T < 0.24$	-0.023	0.043
$0.24 \le p_T < 0.25$	-0.0235	0.0386
$0.25 \le p_T < 0.3$	-0.025	0.035
$p_T > 0.3$	-0.03	0.03



In low p region (0.15~0.3GeV), the mean of $\frac{1}{\beta_{\pi;exp}}$ is about one sigma higher than $\frac{1}{\beta_{\pi;th}}$.

Cuts condition

- **D^0 reconstruction cut:**

|Rapidity|$_{D^0}$<1;

k/π : p_T >0.3GeV;

k/π : $|\eta|$<1;

k/π : at least one hit in layer of PXL and IST

π PID : Based on TPC dEdx: $|n\sigma|<3$;

If TOF available: $|\frac{1}{\beta} - \frac{1}{\beta_{exp}}|<0.03$;

k PID : Based on TPC dEdx: $|n\sigma|<3$;

If TOF available: $|\frac{1}{\beta} - \frac{1}{\beta_{exp}}|<0.03$;

D0 standard topological cut.

- **$K\pi$ invariant mass for D^0 candidates:**

$1.83<M(D^0)<1.90$ GeV/c^2

- **π_{soft} cut:**

$p_T>0.15$ GeV/c^2;

nHitsFit>=20;

gDca<=3cm;

$|\eta|<1$;

PID: Based on TPC dEdx: $|n\sigma|<3$;

If TOF available: $|\frac{1}{\beta} - \frac{1}{\beta_{exp}}|<0.03$, pt>0.3;

low[i]$<\frac{1}{\beta} - \frac{1}{\beta_{exp}}<$high[i], $0.15<p_T<0.3$;

Spectra from TOF

- From TOF, we find the spectra using m^2 distribution in different p_T bins*.
- m^2 is calculated as,

$$m^2 = p^2\left(\frac{c^2T^2}{l^2} - 1\right) \tag{4}$$

Here, T = time of flight, l = pathlength, p = momentum, c = speed of light

- We can find a $T_{expected}$ using the PDG value of the mass of a particular hadron.

$$T^{had}_{exp} = \frac{l}{c}\left(\frac{m^2_{had}}{p^2} + 1\right)^{1/2} \tag{5}$$

Where, $had = \pi$, K or p

$$\left(\frac{dE}{dx}\right)_{theory} = q^2 \exp\left(B\left(\log_{10}\left(\frac{p|q|}{M_{part}}\right)\right)\right) \tag{2}$$

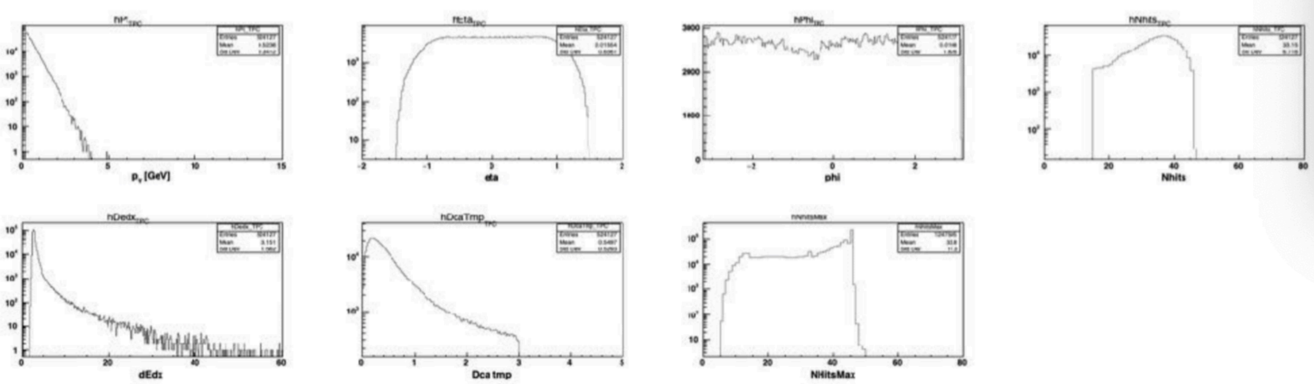
Where, q = charge, p = momentum, $M_{part} = M_\pi$ or M_K or M_{proton}. B is the Bischel function. [1]

https://drupal.star.bnl.gov/STAR/system/files/Spectra.pdf

27 GeV data analysis

Data set analyzed and cuts applied

- Run18, Au+Au 27GeV, P19ib
- MB trigger = 610001, 610011, 610021, 610031, 610041, 610051
- Eventcuts: $|Vz|$ <70cm, $VtxR$<1.0cm, $|Vz-VPD|$ <5cm
- Primary Track cuts: DCA < 3cm, 0.15 < pT < 2.0 GeV/c, $|\eta|$ < 1.5, NhitsFit > 15
- EPD setup: 0.3 < $nMip$
- StRefmultCorr is used for centrality



Event Plane method

- Q vector calculation
  :ωᵢ = (mip>3) ? 3 : mip

$$Q_x = \sum_{i=0}^{N} \omega_i \cos(2\phi_i)$$

$$Q_y = \sum_{i=0}^{N} \omega_i \sin(2\phi_i)$$

$$Q_w = \sum_{i=0}^{N} \omega_i$$

- Normalization

$$Q'_x = \frac{Q_x}{\sqrt{Q_w}} \quad Q'_y = \frac{Q_y}{\sqrt{Q_w}}$$

- Ψ

$$\Psi = \tan^{-1}\left(\frac{Q_y}{Q_x}\right)/2$$

- Weight (ω_i) nmipmax = 3

	ω_i
EPD Q_1	$<\cos[\Psi_1^{E\eta 3}-\Psi_1^{W\eta 0,1,2,3}]>$ * mip
EPD Q_2	mip
TPC Q_1	η
TPC Q_2	p_T

- Vn

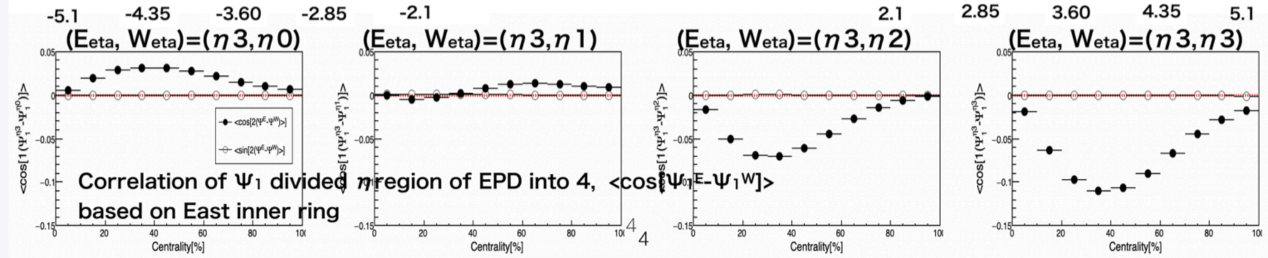
TPC region : $v_2^{EPDEW} = \frac{<\cos[2(\phi-\Psi_2^{EPDEW})]>}{\sigma_{EPDEW}}$ $v_2^{TPC} = \frac{<\cos[2(\phi-\Psi_2^{TPC})]>}{\sigma_{TPC}}$

EPD region : $v_1^{EPD\_West} = \frac{\langle W'\cos(\phi-\Psi_1^{TPC})\rangle}{R^{(1)}_{EP,TPC}\langle W'\rangle}$ $v_1^{EPD\_East} = \frac{\langle W'\cos(\phi-\Psi_1^{TPC})\rangle}{R^{(1)}_{EP,TPC}\langle W'\rangle}$

σ^{EPDEW} and σ^{TPC} are the each Ψ_n resolution for each centrality

EPD East: η3, η2, η1, η0 — ※η0 is most outer ring — EPD West: η0, η1, η2, η3

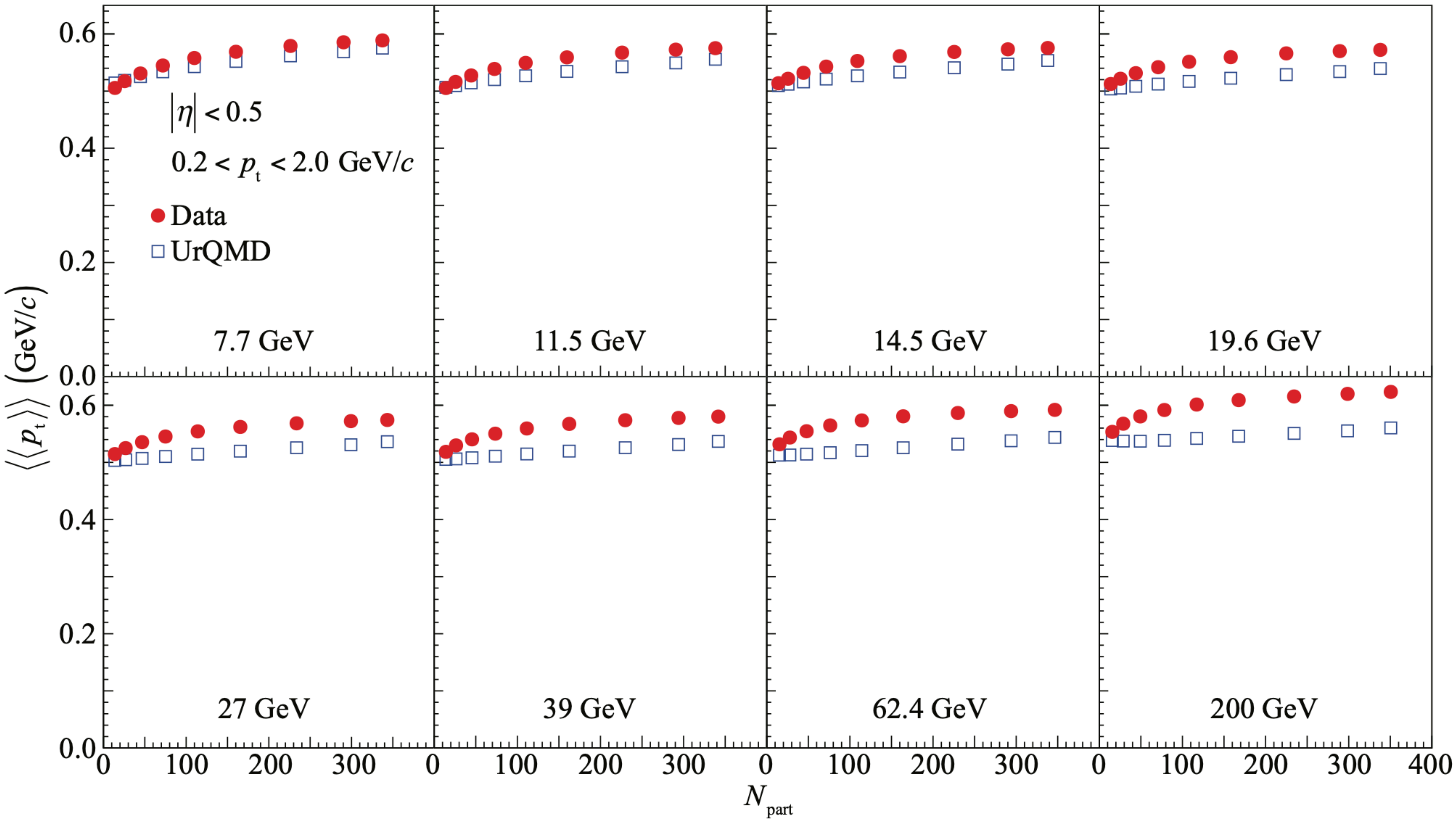
-5.1, -4.35, -3.60, -2.85, -2.1 | 2.1, 2.85, 3.60, 4.35, 5.1



Correlation of Ψ_1 divided η region of EPD into 4, $<\cos[\Psi_1^E-\Psi_1^W]>$ based on East inner ring

https://www.dropbox.com/s/1xarzcsmvboaekz/pwg0318.pdf?dl=0

24/02/ presentation



It shows the average transverse momentum as a function of collision energy and collision centrality in data and UrQMD calculations..

Our absolute \eta range is in 0.5 and transverse momentum is from 0.2 to 2 GeV.

Mean pt is increasing from peripheral to central collisions.

We also can see that as the collision energy is raised, UrQMD tends to under predict ⟨⟨pt⟩⟩.

The system created in ultra-relativistic heavy-ion collisions is expected to reach a state close to thermal equilibrium [70, 72]. Such a thermal system can be described by the appropriate thermodynamic ensemble. In heavy-ion collisions, typically only a subsystem can be analysed due to the restriction of the measurement to the (pseudo-)rapidity range of the detectors. Therefore, this subsystem is embedded in the heat bath of the overall system and it is able to exchange energy and particles with this bath. Hence in most cases, the grand-canonical ensemble is the appropriate choice [70, 72]. Considering a measurement of rare particles with specific quantum numbers, the conservation of this quantum number within the subsystem has to be taken into account and the canonical ensemble has to be applied.

In the grand-canonical ensemble a system is characterised by the pressure $P(T, V, \vec{\mu})$, which depends on the temperature T, the volume V and the chemical potentials $\vec{\mu}$ of the system. The chemical potentials ensure the conservation of all relevant charges within the full system. In the strongly interacting matter produced in a heavy-ion collision, these charges are the baryon number B, the electric charge Q and the strangeness S [72]. Therefore, the relevant chemical potentials are $\vec{\mu} = (\mu_B, \mu_Q, \mu_S)$.

Event-by-event fluctuations of the temperature and the conserved charges can reveal properties of the strongly interacting matter created in heavy-ion collisions. One of the most important applications is the investigation of the phase transitions described in section 1.1.2 and depicted in figure 1.1. As discussed there, the exact location and properties of these phase transitions are not known. Phase transitions are expected to have a strong influence on fluctuation signals, especially in the vicinity of a possible critical endpoint of a potential first-order phase-transition line [25, 26, 70, 71]. In addition, fluctuations may provide insight into the relevant degrees of freedom within the collisions, i.e. whether the initial state of the collisions is compatible with a nucleonic scattering scenario, or whether the sub-nuclear partonic structure has to be taken into account [73, 74].

```
      write(52,124) IAEVT,IARUN,nhadron,bimp,npart1,npart2,
    1   NELP,NINP,NELT,NINTHJ
czcj        write(52,*)HINT1(21),HINT1(22),HINT1(23),HINT1(24),HINT1(25),
czcj     1  IHNT2(9)
czcj        write(52,*)HINT1(31),HINT1(32),HINT1(33),HINT1(34),HINT1(35),
czcj     1  IHNT2(10)
czcj        write(52,*)VVX,VVY

 124       format(3(i7),f10.4,5x,6(i4))

      DO 1001 I = 1, MULTI1(J)
         ITYP = ITYP1(I, J)
         PX = PX1(I, J)
         PY = PY1(I, J)
         PZ = PZ1(I, J)
         EE = EE1(I, J)
         XM = XM1(I, J)
         GX = GX1(I,J)
         GY = GY1(I,J)
         GZ = GZ1(I,J)
         FT = FT1(I,J)
         WRITE(52,123)I,ITYP,PX,PY,PZ,XM,GX,GY,GZ,FT
 123  format(I6,1x,I6,2(1x,f8.3),1x,f10.3,1x,f6.3,4(1x,f8.2))
```

amptsub.f

```
OPEN (52, FILE = 'ana/ampt1.dat', STATUS = 'UNKNOWN')
```

Initial ampt

```
c
c          write(16,190) IAEVT,IARUN,nlast,bimp,npart1,npart2,
c      1 NELP,NINP,NELT,NINTHJ
clin-2/2012:
c          write(16,190) IAEVT,IARUN,nlast-ndpert,bimp,npart1,npart2,
c      1 NELP,NINP,NELT,NINTHJ
         write(16,190) IAEVT,IARUN,nlast,bimp,npart1,npart2,
     1 NELP,NINP,NELT,NINTHJ
czcj          write(16,*)HINT1(21),HINT1(22),HINT1(23),HINT1(24),HINT1(25),
czcj      1   IHNT2(9)
czcj          write(16,*)HINT1(31),HINT1(32),HINT1(33),HINT1(34),HINT1(35),
czcj      1   IHNT2(10)
czcj          write(16,*)VVX,VVY
         do 1008 ip=1,nlast
            if(amax1(abs(xlast(1,ip)),abs(xlast(2,ip)),
     1           abs(xlast(3,ip)),abs(xlast(4,ip))).lt.9999) then
            write(16,211) ip,INVFLV(lblast(ip)), plast(1,ip),
     1           plast(2,ip),plast(3,ip),plast(4,ip),
     2           xlast(1,ip),xlast(2,ip),xlast(3,ip),xlast(4,ip)
            else
c     change format for large numbers:
            write(16,211) ip,INVFLV(lblast(ip)), plast(1,ip),
     1           plast(2,ip),plast(3,ip),plast(4,ip),
     2           xlast(1,ip),xlast(2,ip),xlast(3,ip),xlast(4,ip)
            endif
 1008    continue
```

linana.f

```
OPEN (16, FILE = 'ana/ampt2.dat', STATUS = 'UNKNOWN')
```

Final ampt

zpc.f

Line 6808

```fortran
      write (54, 104) i, ityp(i),
     &     px(i), py(i), pz(i), xmass(i),
     &     gx(i), gy(i), gz(i), ft(i)
 99     continue

     event = event + 1

 101     format (a12)
 102     format (2(a8, 2x), '(',i3, ',',i6, ')+(',i3, ',', i6, ')',
     &     2x, a4, 2x, e10.4, 2x, i8)
 103     format (i10, 2x, i10, 2x, f8.3, 2x, f8.3)
cglma 104     format (i10, 2x, i10, 2x, 9(e12.6, 2x))
 104     format(I10, 1x,I6,2(1x,f8.3),1x,f10.3,1x,f6.3,4(1x,e9.3))
 105     format(3(i7),f10.4,5x,6(i4))
    return
    end
```

partontimets0.dat

```
         1     142   14.1744        0    0    1    2    1    4
0.00000000       0.00000000       0.00000000       0.00000000       0.00000000               0
0.00000000       0.00000000       0.00000000       0.00000000       0.00000000               0
0.00000000       0.00000000
         1     -2    0.165   -0.117      0.205  0.006 -.285E+01 -.154E+01 -.208E-01 0.103E+00
         2      2   -0.314   -1.569     -0.611  0.006 -.285E+01 -.154E+01 -.208E-01 0.103E+00
         3      2   -0.250   -0.261     -0.367  0.006 -.206E+01 -.501E+01 -.705E-01 0.121E+00
         4     -2    0.426   -1.573     -1.068  0.006 -.206E+01 -.501E+01 -.705E-01 0.121E+00
         5     -3   -1.418   -0.080      3.002  0.199 -.132E+01 0.921E+00 0.132E+00 0.158E+00
         6      2   -0.653   -0.067      0.433  0.006 -.132E+01 0.921E+00 0.132E+00 0.158E+00
         7     -2    0.311    0.126     -0.087  0.006 -.276E+01 -.137E+01 0.812E-01 0.161E+00
         8      1    0.516    0.758      0.917  0.010 -.276E+01 -.137E+01 0.812E-01 0.161E+00
         9      2   -0.165   -0.010      0.012  0.006 -.223E+01 -.496E+01 -.262E-01 0.172E+00
        10     -1   -0.951   -0.269     -0.191  0.010 -.223E+01 -.496E+01 -.262E-01 0.172E+00
        11      1   -0.201    0.686      0.201  0.010 -.482E+00 -.467E+01 0.104E+00 0.210E+00
        12     -1   -0.247    0.129      0.417  0.010 -.482E+00 -.467E+01 0.104E+00 0.210E+00
        13     -2    0.201    0.169      0.287  0.006 -.119E+01 0.915E+00 0.594E-01 0.211E+00
        14     -1    0.203   -0.356     -0.038  0.010 -.119E+01 0.915E+00 0.594E-01 0.211E+00
        15     -2   -0.162    0.131      0.035  0.006 -.119E+01 0.915E+00 0.594E-01 0.211E+00
        16     -2    0.322    0.031      1.271  0.006 -.118E+01 0.873E+00 0.186E+00 0.213E+00
        17     -2   -0.061   -0.044     -0.036  0.006 -.118E+01 0.873E+00 0.186E+00 0.213E+00
        18     -1    0.794   -0.959      2.164  0.010 -.118E+01 0.873E+00 0.186E+00 0.213E+00
        19     -2   -0.072   -0.104     -0.450  0.006 -.214E+01 -.498E+01 -.254E-01 0.221E+00
        20      1   -0.221   -0.145      0.346  0.010 -.214E+01 -.498E+01 -.254E-01 0.221E+00
        21      2   -0.399    0.120      0.356  0.006 -.135E+01 0.937E+00 0.834E-02 0.224E+00
        22     -2   -0.011   -0.079     -0.323  0.006 -.135E+01 0.937E+00 0.834E-02 0.224E+00
        23     -1    0.392    0.088      0.227  0.010 -.275E+01 -.136E+01 -.150E-01 0.233E+00
```

Event, run, multiplicity, impact parameter, projectile ,target , number of elastic in P, number of inelastic in T, number elastic in T, number of inelastic in T

0 0 0 0 0 0
0 0 0 0 0 0
0 0

counts, quark ID, px, py, pz, mass, x, y, z, t

`hijing1.383_ampt.f`

Line 1080

```fortran
      write(54,513) IAEVT,IARUN,mul,bimp,npart1,npart2,
     &  NELP,NINP,NELT,NINTHJ
      write(54,*)HINT1(21),HINT1(22),HINT1(23),HINT1(24),HINT1(25),
     &  IHNT2(9)
      write(54,*)HINT1(31),HINT1(32),HINT1(33),HINT1(34),HINT1(35),
     &  IHNT2(10)
      write(54,*)VVX,VVY
c       write(56,513) IAEVT,IARUN,mul,bimp,npart1,npart2,
c     &  NELP,NINP,NELT,NINTHJ
cglma add above
 513  format(3(i7),f10.4,5x,6(i4))

clin-6/2009:
      if(ioscar.eq.3) WRITE (95, *) IAEVT, mul
c.....call ZPC for parton cascade
      CALL ZPCMN

c     write out parton and wounded nucleon information to ana/zpc1.mom:
clin-6/2009:
c       WRITE (14, 395) ITEST, MUL, bimp, NELP,NINP,NELT,NINTHJ

      write(14,513) IAEVT,IARUN,mul,bimp,npart1,npart2,
     &  NELP,NINP,NELT,NINTHJ
      write(14,*)HINT1(21),HINT1(22),HINT1(23),HINT1(24),HINT1(25),
     &  IHNT2(9)
      write(14,*)HINT1(31),HINT1(32),HINT1(33),HINT1(34),HINT1(35),
     &  IHNT2(10)
      write(14,*)VVX,VVY
      DO 1013 I = 1, MUL
cc          WRITE (14, 411) PX5(I), PY5(I), PZ5(I), ITYP5(I),
c     &        XMASS5(I), E5(I)
c     change format for large numbers:
        write(14,211) I, ITYP5(I),
     1           PX5(I), PY5(I), PZ5(I), XMASS5(I),
     1           GX5(I), GY5(I), GZ5(I), FT5(I)
```

zpc.dat

```
              1     142   14.1744         0   0   1   2   1   4
 0.00000000        0.00000000        0.00000000        0.00000000        0.00000000              0
 0.00000000        0.00000000        0.00000000        0.00000000        0.00000000              0
 0.00000000        0.00000000
      1    -2    0.165   -0.117     0.205  0.006 -.285E+01 -.154E+01 -.208E-01 0.103E+00
      2     2   -0.314   -1.569    -0.611  0.006 -.285E+01 -.154E+01 -.208E-01 0.103E+00
      3     2   -0.250   -0.261    -0.367  0.006 -.206E+01 -.501E+01 -.705E-01 0.121E+00
      4    -2    0.426   -1.573    -1.068  0.006 -.206E+01 -.501E+01 -.705E-01 0.121E+00
      5    -3   -1.418   -0.080     3.002  0.199 -.132E+01 0.921E+00 0.132E+00 0.158E+00
      6     2   -0.653   -0.067     0.433  0.006 -.132E+01 0.921E+00 0.132E+00 0.158E+00
      7    -2    0.024    0.014     0.015  0.006 -.204E+01 -.108E+01 -.120E+00 0.964E+00
      8     1    0.516    0.758     0.917  0.010 -.276E+01 -.137E+01 0.812E-01 0.161E+00
      9     2   -0.165   -0.010     0.012  0.006 -.223E+01 -.496E+01 -.262E-01 0.172E+00
     10    -1   -0.951   -0.269    -0.191  0.010 -.223E+01 -.496E+01 -.262E-01 0.172E+00
     11     1   -0.201    0.686     0.201  0.010 -.482E+00 -.467E+01 0.104E+00 0.210E+00
     12    -1    0.102    0.579     0.931  0.010 -.115E+01 -.432E+01 0.124E+01 0.158E+01
     13    -2    0.207    0.015     0.178  0.006 -.112E+01 0.950E+00 0.242E+00 0.412E+00
     14    -1    0.112   -0.037    -0.248  0.010 -.115E+01 0.852E+00 0.462E-01 0.290E+00
     15    -2   -0.139    0.052     0.001  0.006 -.142E+01 0.110E+01 0.108E+00 0.506E+00
     16    -2    0.322    0.031     1.271  0.006 -.118E+01 0.873E+00 0.186E+00 0.213E+00
     17    -2    0.082   -0.217     0.104  0.006 -.120E+01 0.884E+00 0.147E+00 0.282E+00
     18    -1    0.570   -0.786     1.415  0.010 -.114E+01 0.822E+00 0.303E+00 0.347E+00
     19    -2   -0.072   -0.104    -0.450  0.006 -.214E+01 -.498E+01 -.254E-01 0.221E+00
     20     1   -0.221   -0.145     0.346  0.010 -.214E+01 -.498E+01 -.254E-01 0.221E+00
     21     2   -0.399    0.120     0.356  0.006 -.135E+01 0.937E+00 0.834E-02 0.224E+00
     22    -2   -0.039   -0.021     0.004  0.006 -.120E+01 -.718E+00 -.391E+01 0.448E+01
```

Event, run, multiplicity, impact parameter, projectile ,target , number of elastic in P, number of inelastic in T, number elastic in T, number of inelastic in T

0 0 0 0 0 0
0 0 0 0 0 0
0 0

counts, quark ID, px, py, pz, mass, x, y, z, t

```fortran
      WRITE(99,*) bimp,thetaP,phiP,thetaT,phiT
      write(60,513) IAEVT,IARUN,IHNT2(1)+IHNT2(3),bimp,npart1,npart2,
   &  NELP,NINP,NELT,NINTHJ
      write(60,*)HINT1(21),HINT1(22),HINT1(23),HINT1(24),HINT1(25),
   &  IHNT2(9)
      write(60,*)HINT1(31),HINT1(32),HINT1(33),HINT1(34),HINT1(35),
   &  IHNT2(10)
      write(60,*)VVX,VVY
      DO 203 JP=1,IHNT2(1)
         IF(NFP(JP,5).GT.-1) THEN
glma write out participant nucleons for projector
            WRITE (60, 396) '1', JP, YP(1,JP)+BBX, YP(2,JP)
       write(60,396) '1', JP, NFP(JP,3),NFP(JP,4), '0', '0',
    1 YP(1,JP)+BBX/2, YP(2,JP)+BBY/2, YP(3,JP), NFP(JP,5)
         ENDIF
203   continue
      DO 204 JT=1,IHNT2(3)
         IF(NFT(JT,5).GT.-1) THEN
glma write out participant nucleons for target
            WRITE (60, 396) '2', JT, YT(1,JT)+BBY, YT(2,JT)
       write(60,396) '2', JT, NFT(JT,3),NFT(JT,4), '0', '0',
    1 YT(1,JT)-BBX/2, YT(2,JT)-BBY/2, YT(3,JT), NFP(JP,5)
         ENDIF
204   continue
396   format(A,1X,I5,2X,I5,1X,I5,1X,A,1X,A,1X,
    1 F10.3,3X,F10.3,3X,F10.3,1X,I5)
```

```fortran
c
clin-4/2012 write out initial transverse positions of initial nucleons:
      write(94,*) IAEVT,MISS,IHNT2(1),IHNT2(3),bimp
      DO JP=1,IHNT2(1)
clin-12/2012 write out present and original flavor code of nucleons:
c           write(94,243) YP(1,JP)+0.5*BB*cos(phiRP),
c       1 YP(2,JP)+0.5*BB*sin(phiRP), JP, NFP(JP,5),yp(3,jp)
          write(94,243) YP(1,JP)+0.5*BB*cos(phiRP),
     1 YP(2,JP)+0.5*BB*sin(phiRP),JP, NFP(JP,5),yp(3,jp),
     2 NFP(JP,3),NFP(JP,4)
      ENDDO
```

```
    1       1     476     3.2078          0    0    3 191    5 200
  0.00000000       0.00000000       0.00000000       0.00000000       0.00000000         0
  0.00000000       0.00000000       0.00000000       0.00000000       0.00000000         0
  0.00000000       0.00000000
1     1       0  2212 0 0     1.335        0.229        7.119     3
1     2       0  2212 0 0    -1.082       -0.104        6.308     3
1     3       0  2212 0 0    -1.862        2.265        6.274     3
1     4       0  2212 0 0     2.185       -2.010        6.202     3
1     5       0  2212 0 0    -0.238       -4.472        6.090     3
1     6       0  2212 0 0     3.531       -3.710        5.683     3
1     7       0  2112 0 0    -1.045        0.051        5.552     3
1     8       0  2212 0 0     3.269        0.961        5.501     3
1     9       0  2212 0 0     1.474       -2.093        5.474     3
1    10       0  2112 0 0     2.835        4.767        5.457     3
1    11       0  2212 0 0     2.891        1.234        5.384     3
1    12       0  2212 0 0     4.916        2.394        5.244     3
1    13       0  2212 0 0     0.327       -1.120        5.095     3
1    14       0  2212 0 0     3.357       -1.917        5.078     3
1    15       0  2112 0 0    -0.096       -0.363        5.074     3
1    16       0  2212 0 0    -0.771        4.616        5.056     3
1    17       0  2212 0 0    -0.674        4.262        4.812     3
1    18       0  2212 0 0     0.072        2.998        4.774     3
1    19       0  2212 0 0    -1.280       -2.063        4.757     3
1    20       0  2212 0 0     3.569        1.994        4.679     3
1    21       0  2212 0 0    -0.514        3.624        4.553     3
1    22       0  2212 0 0     1.293        3.071        4.544     3
1    23       0  2212 0 0     1.141        1.615        4.509     3
1    24       0  2212 0 0     0.852        4.714        4.498     3
1    25       0  2212 0 0    -1.815        2.355        4.439     3
```

```
   1.335      0.229     1     3     7.119    0  2212
  -1.082     -0.104     2     3     6.308    0  2212
  -1.862      2.265     3     3     6.274    0  2212
   2.185     -2.010     4     3     6.202    0  2212
  -0.238     -4.472     5     3     6.090    0  2212
   3.531     -3.710     6     3     5.683    0  2212
  -1.045      0.051     7     3     5.552    0  2112
   3.269      0.961     8     3     5.501    0  2212
   1.474     -2.093     9     3     5.474    0  2212
   2.835      4.767    10     3     5.457    0  2112
   2.891      1.234    11     3     5.384    0  2212
   4.916      2.394    12     3     5.244    0  2212
   0.327     -1.120    13     3     5.095    0  2212
   3.357     -1.917    14     3     5.078    0  2212
  -0.096     -0.363    15     3     5.074    0  2112
  -0.771      4.616    16     3     5.056    0  2212
  -0.674      4.262    17     3     4.812    0  2212
   0.072      2.998    18     3     4.774    0  2212
  -1.280     -2.063    19     3     4.757    0  2212
   3.569      1.994    20     3     4.679    0  2212
  -0.514      3.624    21     3     4.553    0  2212
   1.293      3.071    22     3     4.544    0  2212
   1.141      1.615    23     3     4.509    0  2212
   0.852      4.714    24     3     4.498    0  2212
  -1.815      2.355    25     3     4.439    0  2212
   0.817      1.271    26     3     4.421    0  2212
```

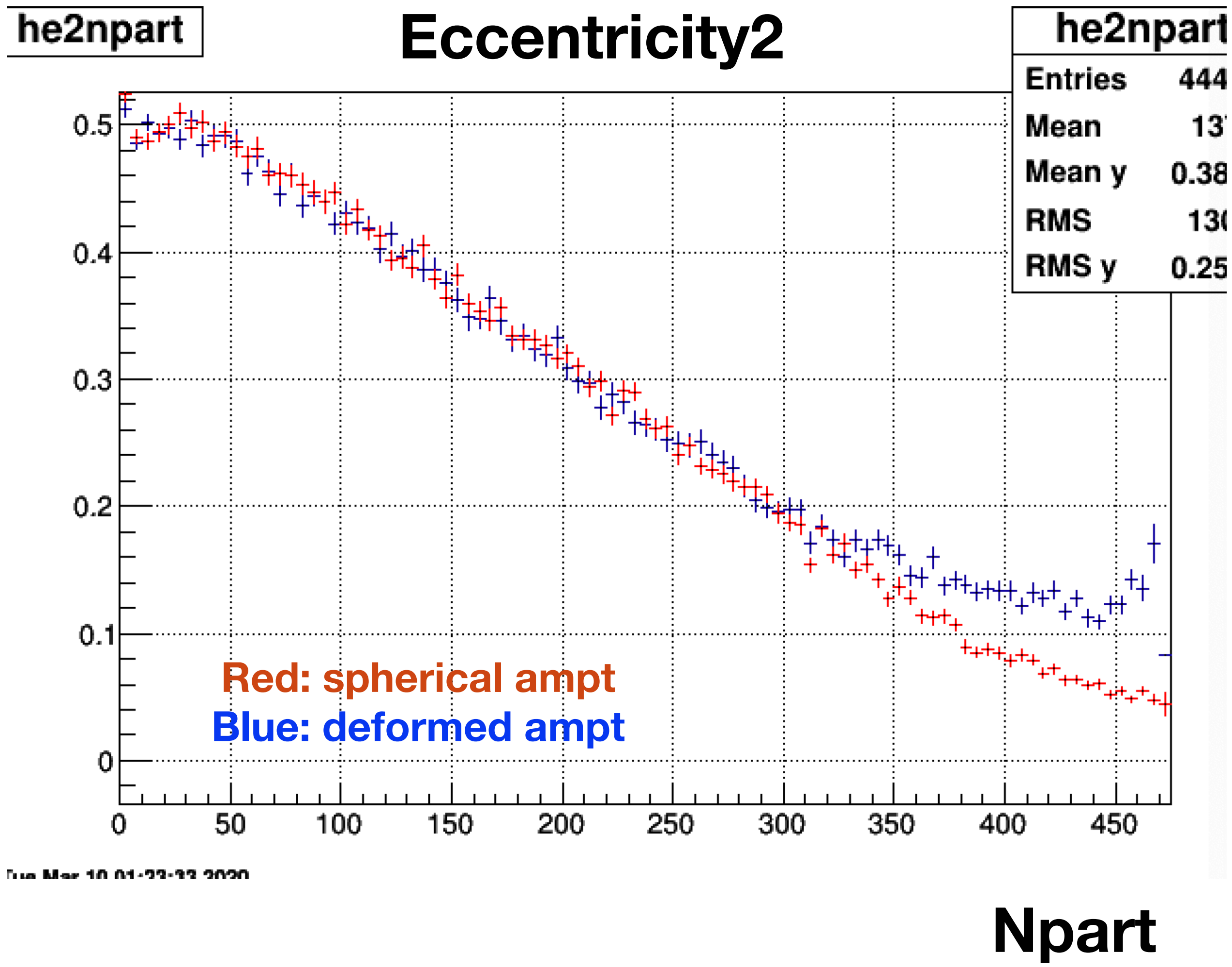
1.4.2. Basic concepts of fluctuation analyses

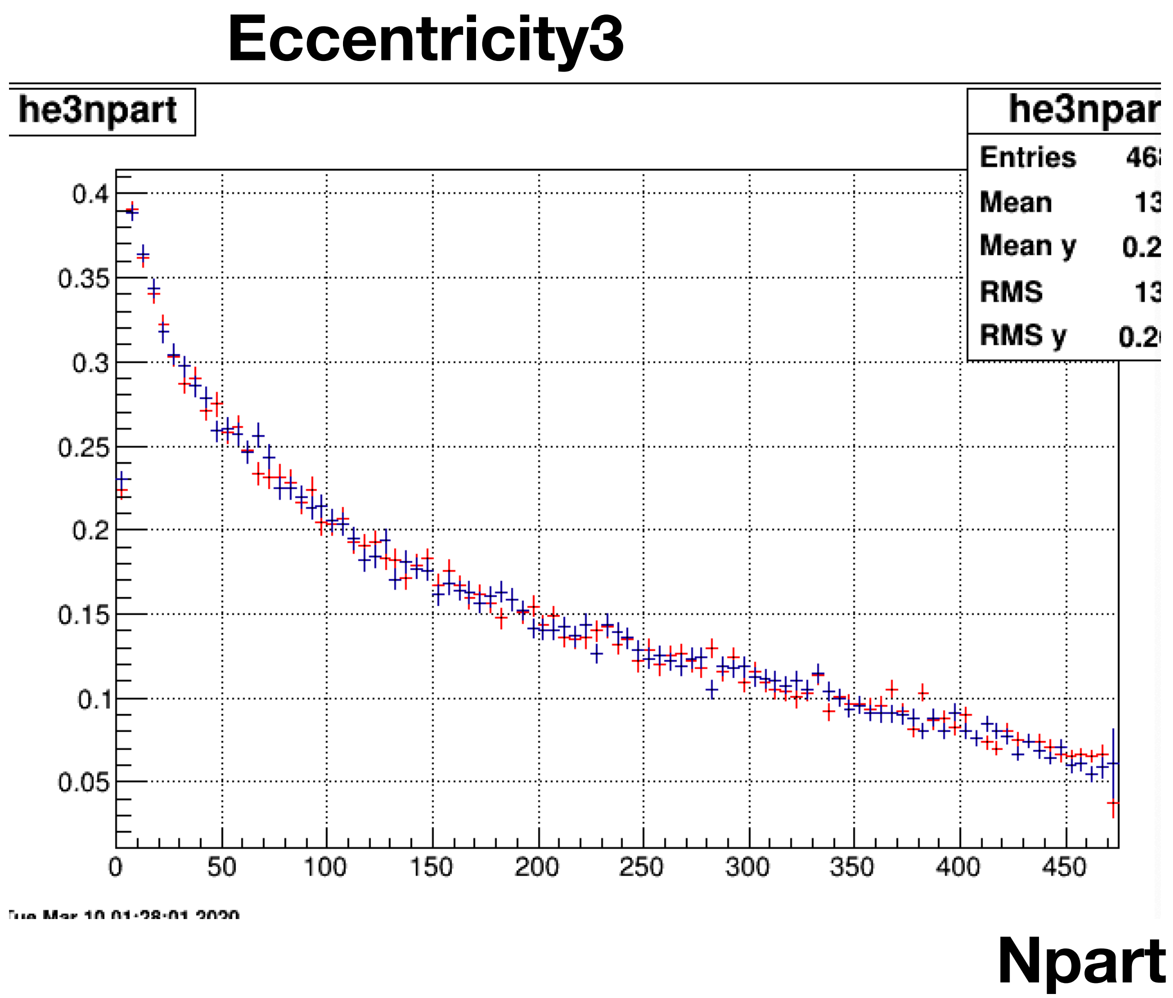
A brief introduction to the basic concepts of event-by-event fluctuation analyses in heavy-ion collisions is presented here. The principles of event-by-event fluctuations are discussed in more detail in [70] and a review of hadronic fluctuations and correlations can be found in [71].

The system created in ultra-relativistic heavy-ion collisions is expected to reach a state close to thermal equilibrium [70, 72]. Such a thermal system can be described by the appropriate thermodynamic ensemble. In heavy-ion collisions, typically only a subsystem can be analysed due to the restriction of the measurement to the (pseudo-)rapidity range of the detectors. Therefore, this subsystem is embedded in the heat bath of the overall system and it is able to exchange energy and particles with this bath. Hence in most cases, the grand-canonical ensemble is the appropriate choice [70,

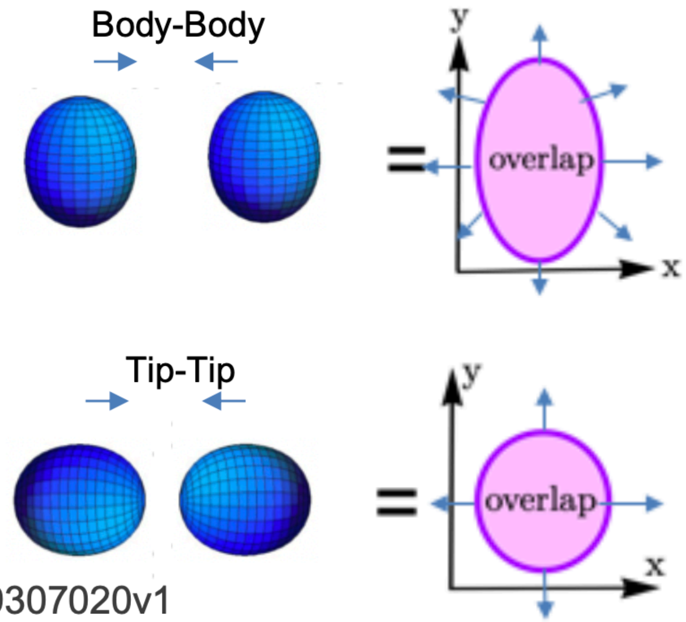
the fireball fluctuate. Even when we take a subsample with exactly the same number of participants, the size is slightly (a few percent) different from event to event. The amount of these fluctuations depends on a specific model of the nucleon structure and elementary collisions, but the effect persist as a generic phenomenon. If two fireballs created with the same number of participants (thus having nearly equal entropy) have different size, then the smaller one will lead to faster collective expansion (cf. Fig. 1). In hydrodynamics this is caused by a larger radial gradient of the pressure, whereas in transport models by a higher collision rate of partons. As a result, the smaller system leads to a larger radial flow, and consequently, a larger average transverse momentum in the event, denoted as $\langle p_T \rangle$. Thus, on these general grounds, we expect a strong negative correlation between the initial fireball size and $\langle p_T \rangle$.

Au+Au@200GeV ampt





1. Deformation has larger effect on eccentricity2 in UCC but no effect on eccentricity3. Because eccentricity3 is due to fluctuation not geometry.
2. 50000events in 0-100%



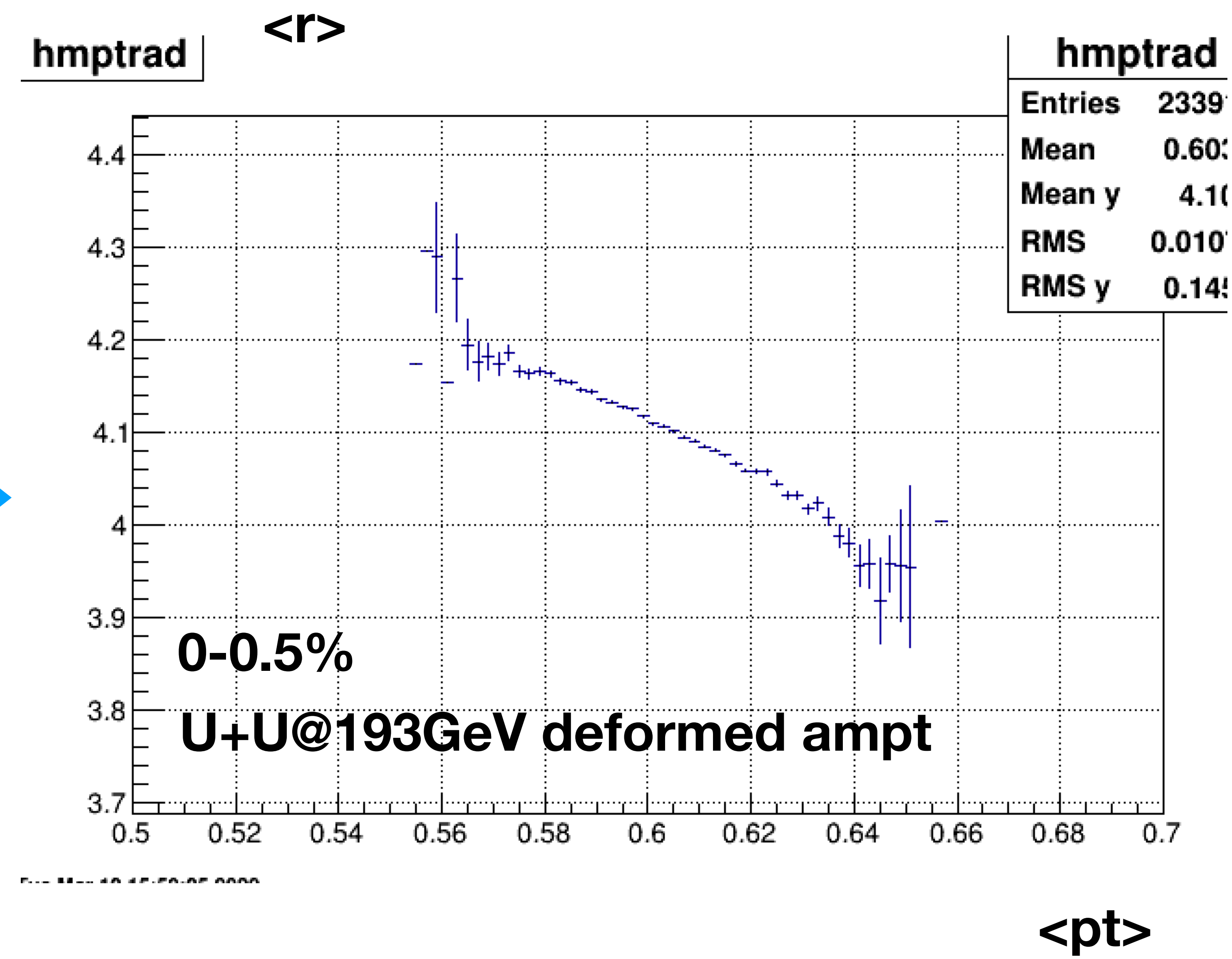
9307020v1
1612.07856
1701.09105

Size-mean p_T transmutation

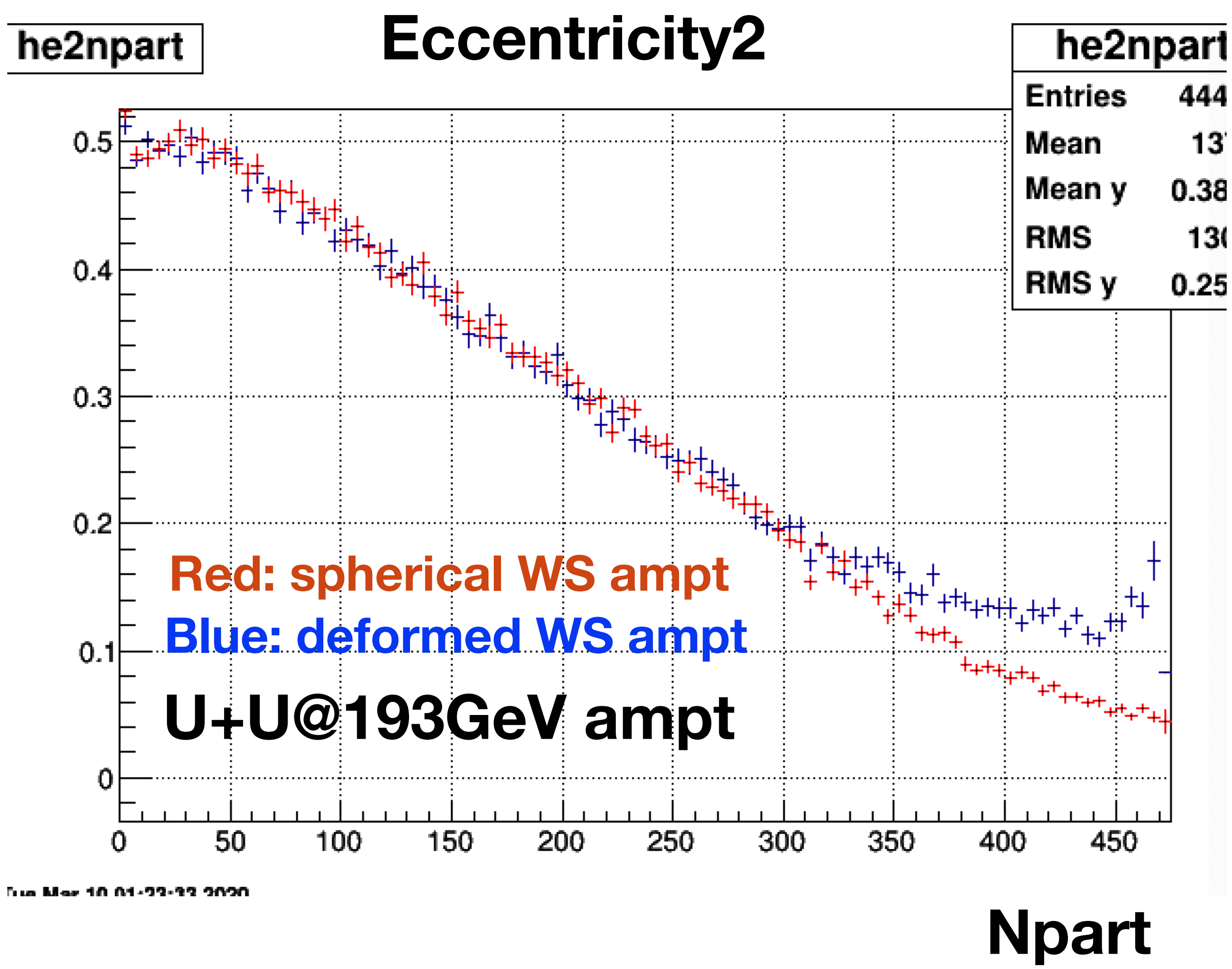
Smaller R (Same N_{part}) → Larger pressure gradient /higher collision rate of partons

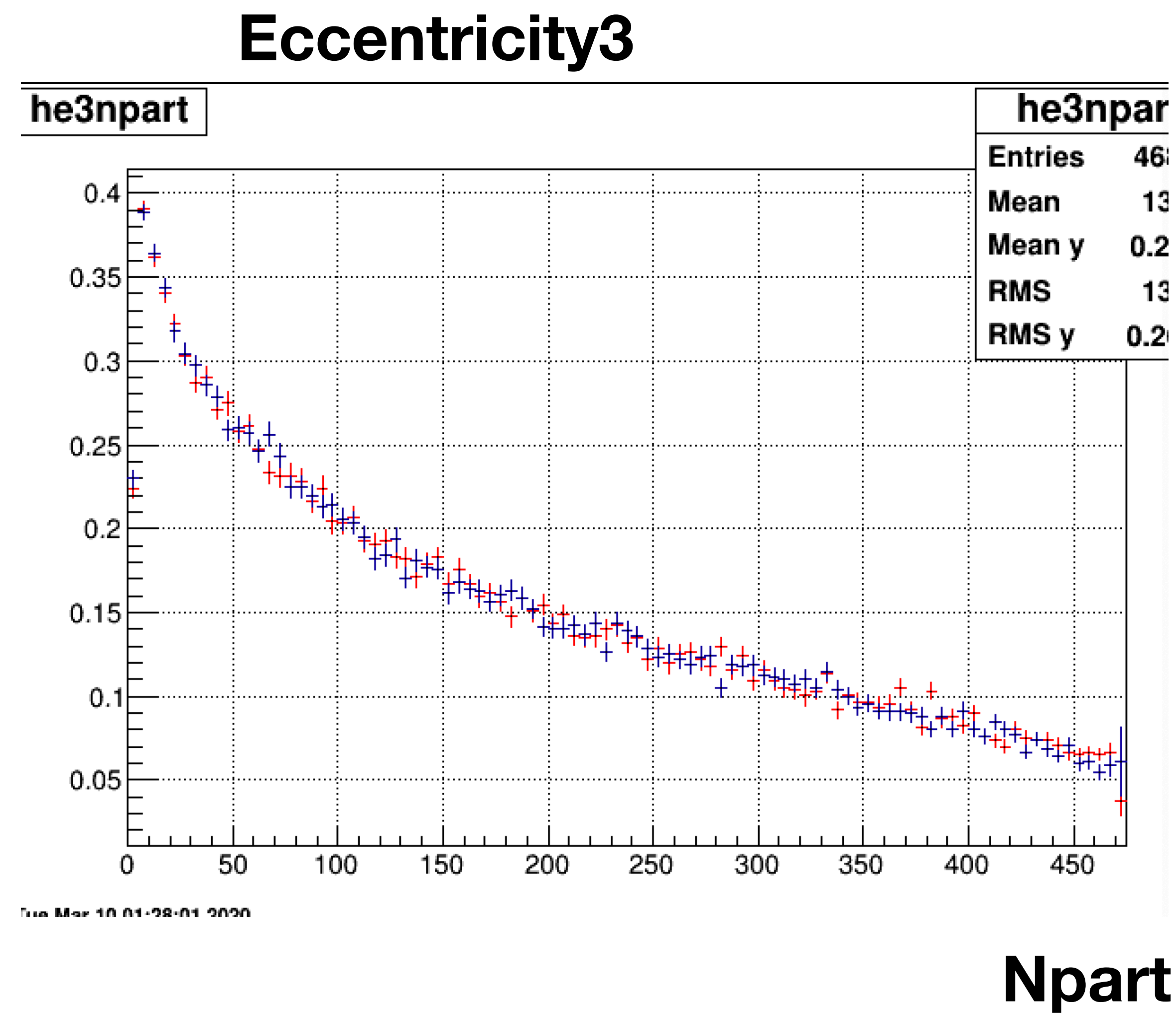
↓

Larger mean p_T ← Faster collective expansion, Larger radial flow



1. **Deformation has larger effect on initial geometry(<r>-<pt>)**



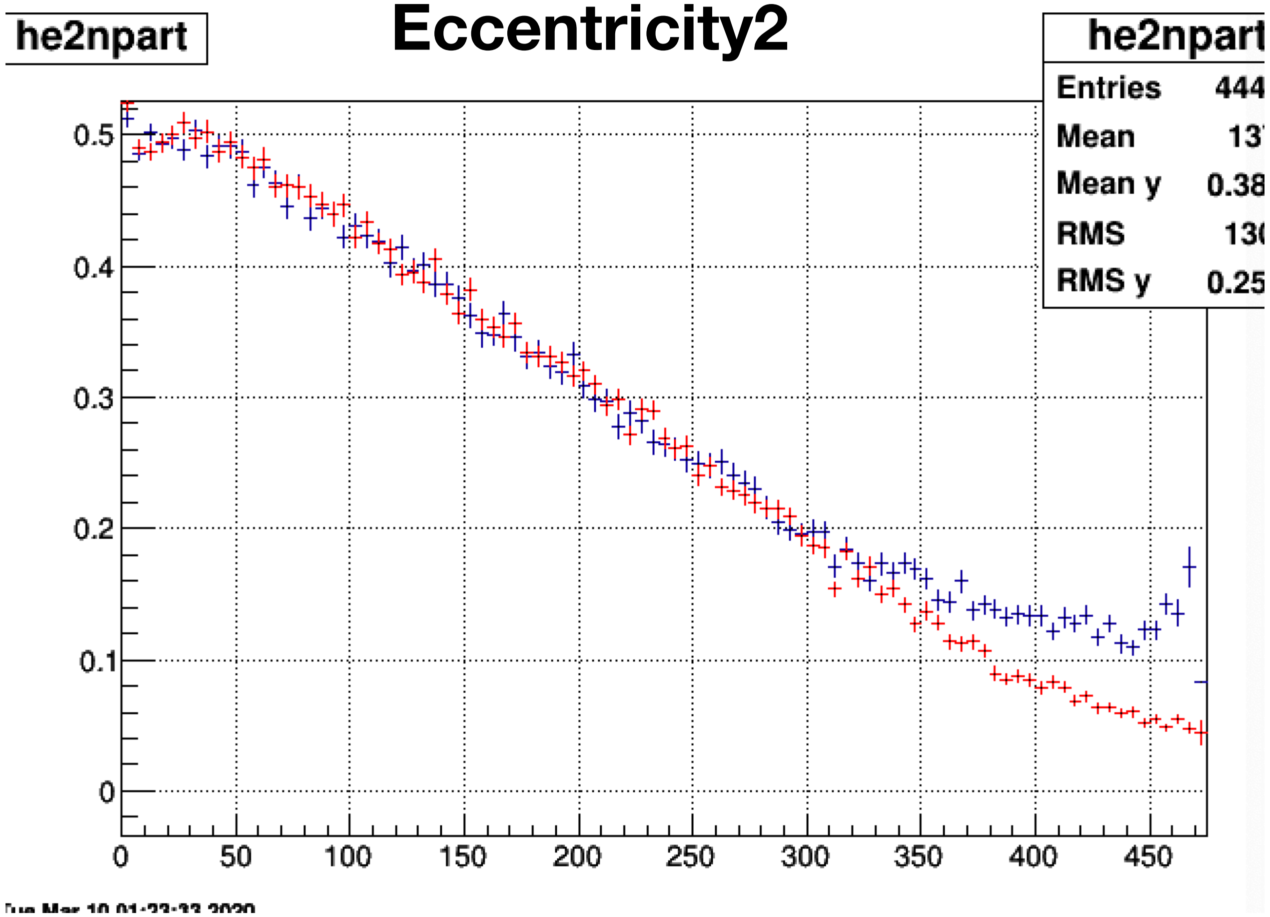


1. Deformation has larger effect on eccentricity2 in UCC but no effect on eccentricity3. Because eccentricity3 is due to fluctuation not geometry.
2. 50000events in 0-100%

Deformation in ampt

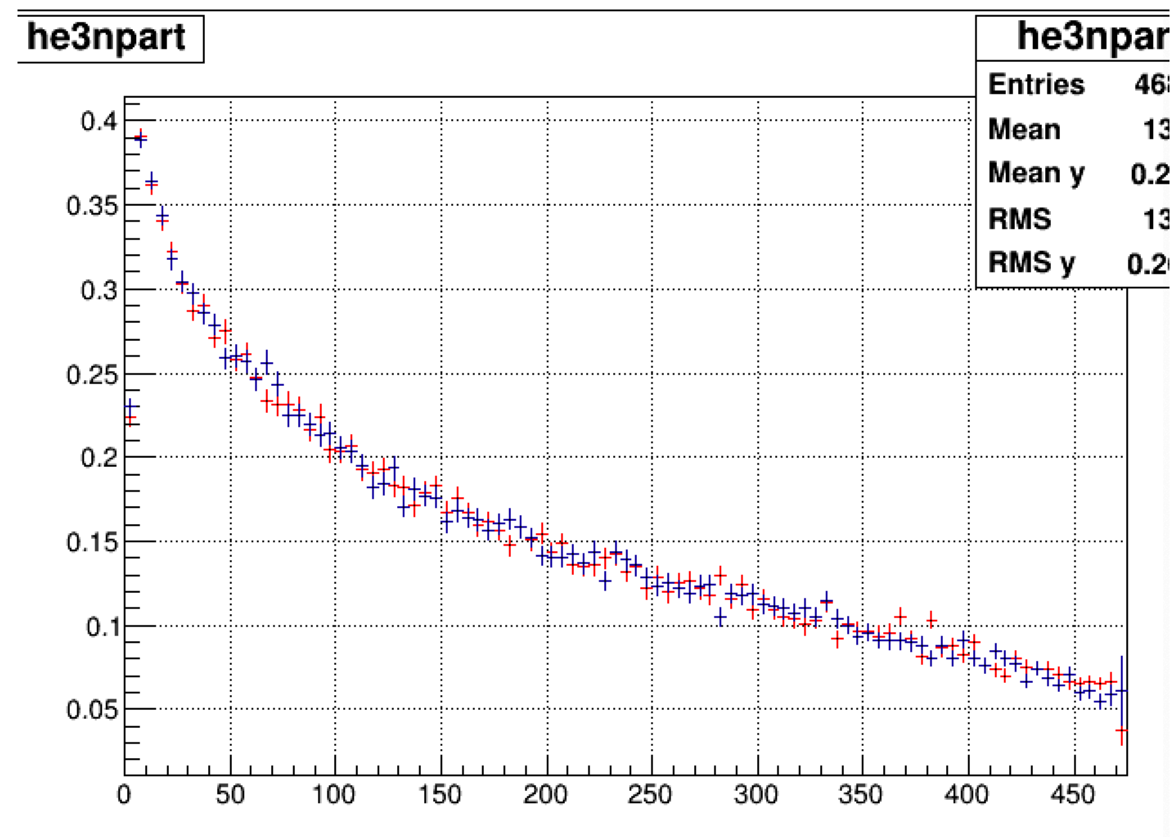
Red: spherical WS ampt Blue: deformed WS ampt

Eccentricity2



Npart

Eccentricity3



Npart

1. Deformation has larger effect on eccentricity2 in UCC but no effect on eccentricity3. Because eccentricity3 is due to fluctuation not geometry
2. 50000events in 0-100%

$$\langle r^2 \rangle = \frac{\int dx\,dy\,s_k(x,y)(x^2+y^2)}{\int dx\,dy\,s_k(x,y)}, \quad (3)$$

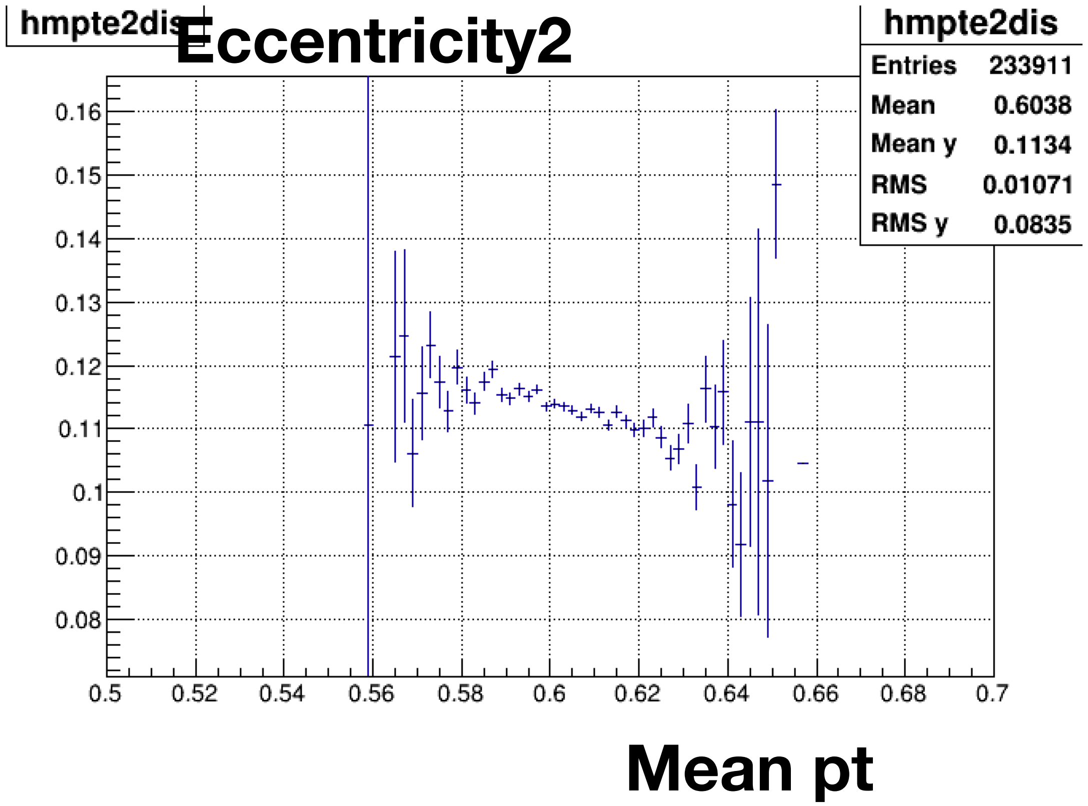
$$\langle r \rangle_k \equiv \sqrt{\langle r^2 \rangle}.$$

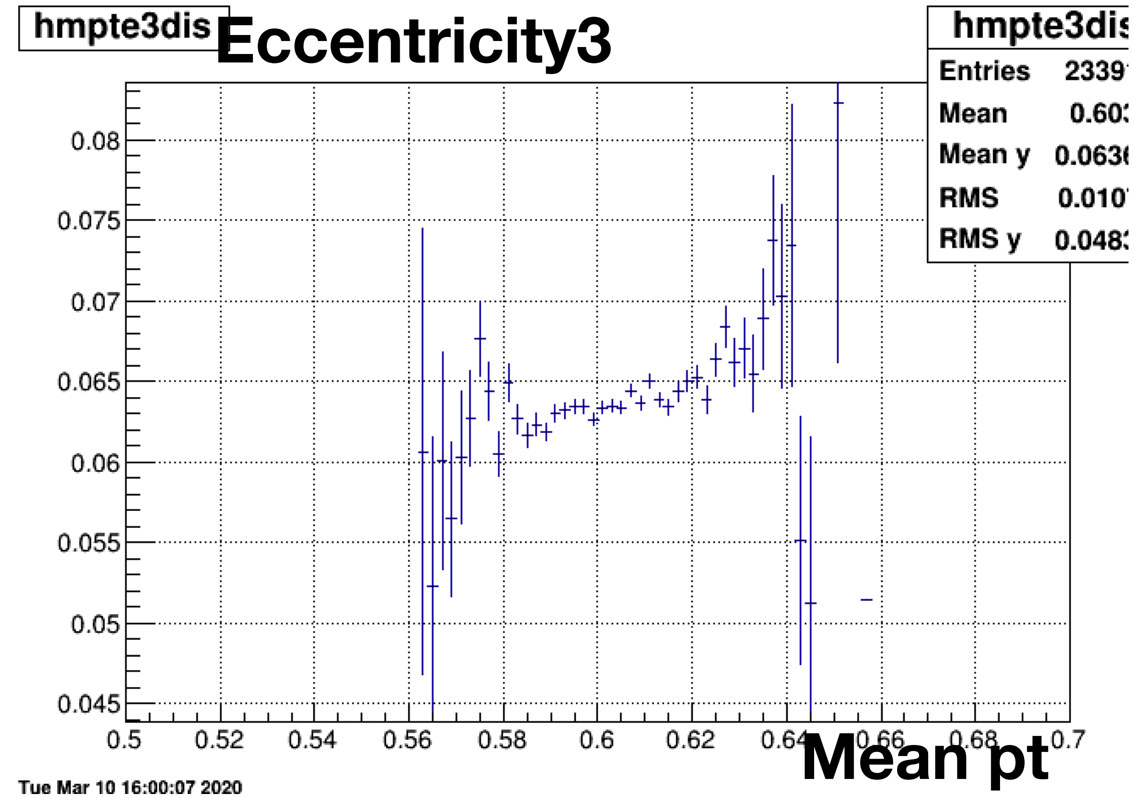
Averaging over $N_{\rm ev}$ events is denoted with another pair of brackets, for instance the event-averaged transverse size is denoted as

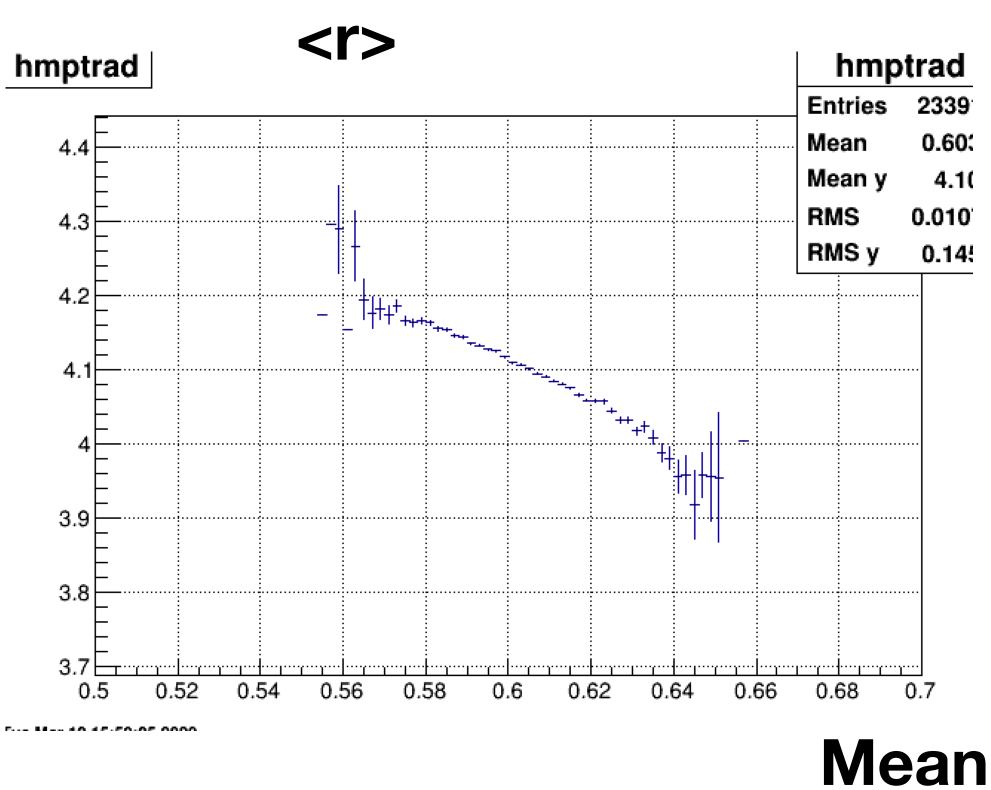
$$\langle\langle r \rangle\rangle = \frac{1}{N_{\rm ev}} \sum_{k=1}^{N_{\rm ev}} \langle r \rangle_k. \quad (4)$$

For sources with a large azimuthal deformation, a definition of the size parameter more appropriate for large

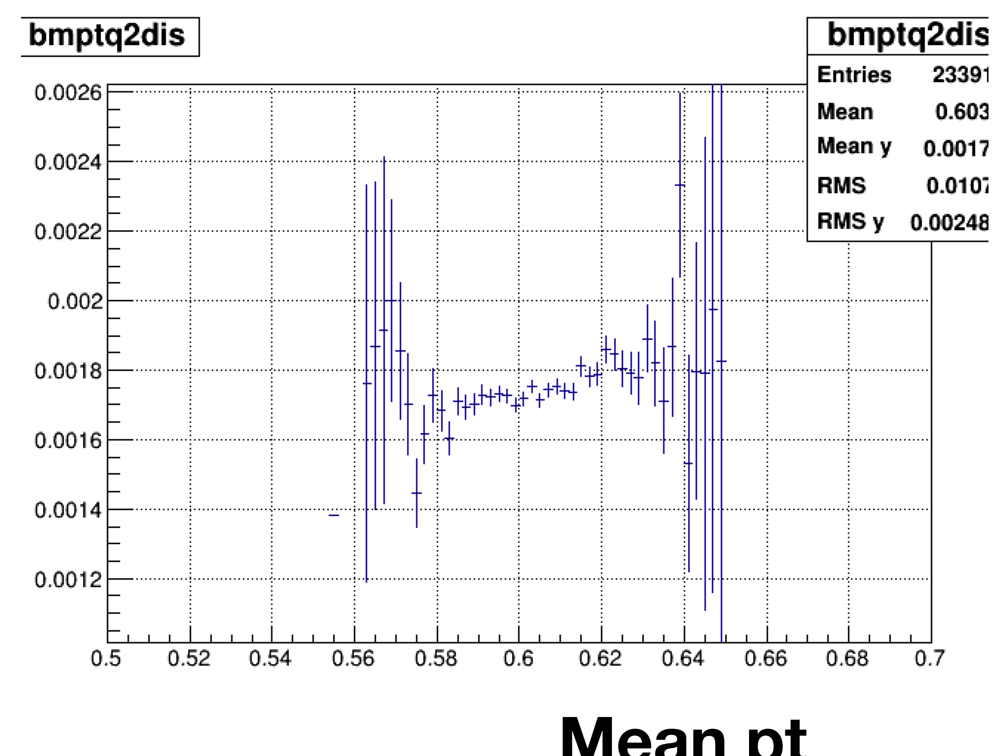
More statistics in deformed ampt



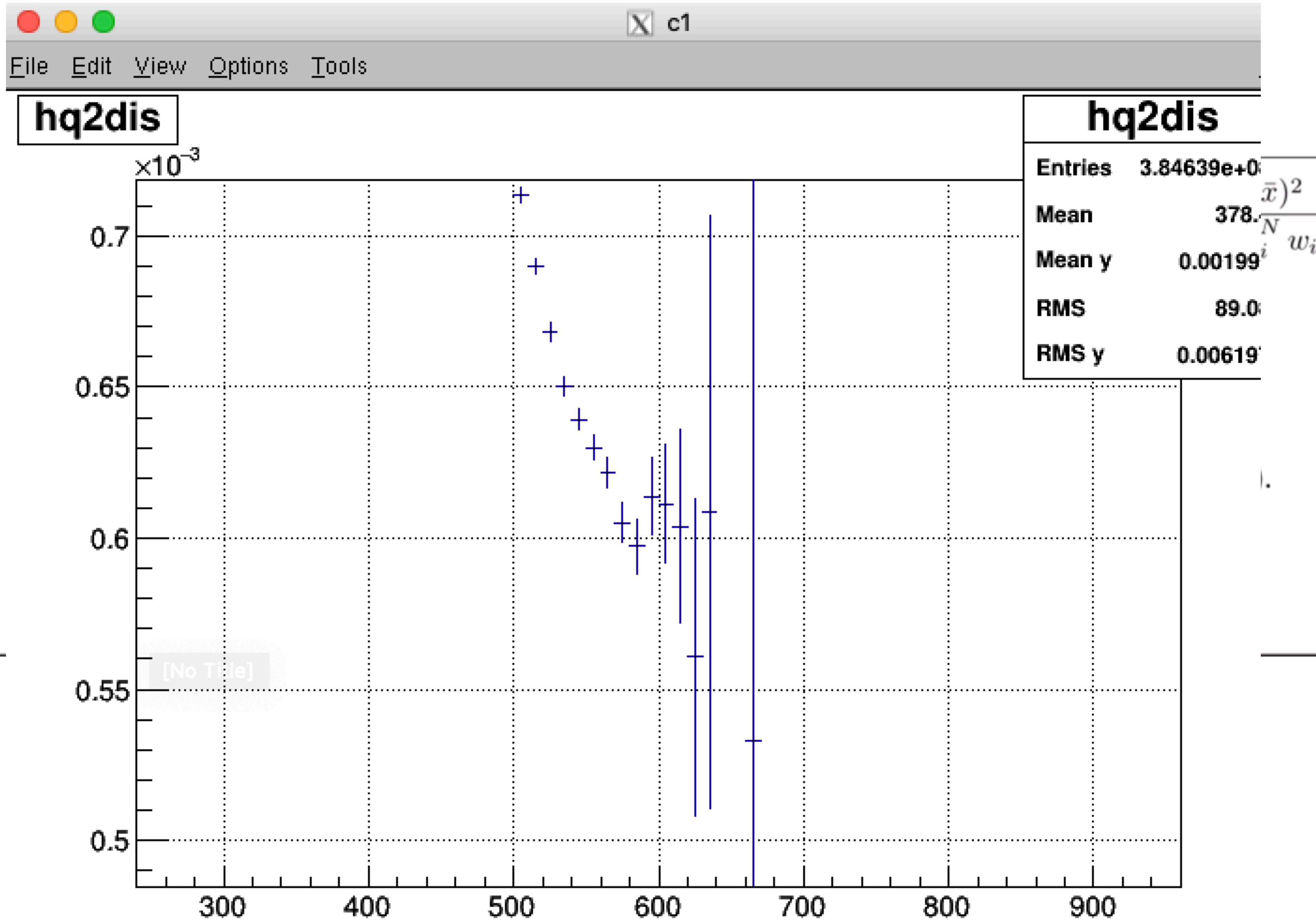




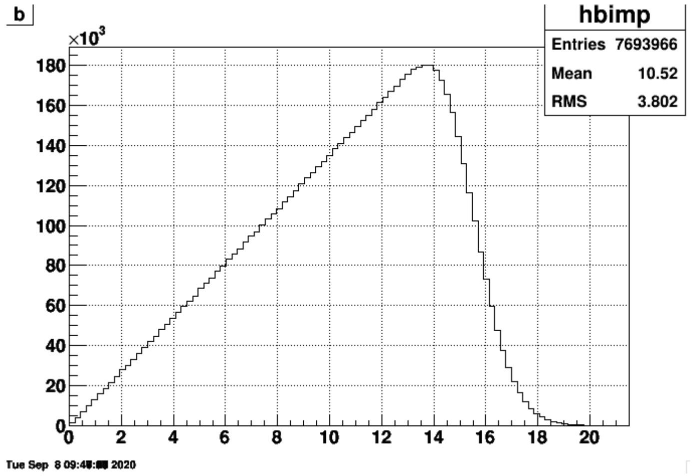
c2{2}, subevent (\eta, (-1,-0.1), (0.1,1))

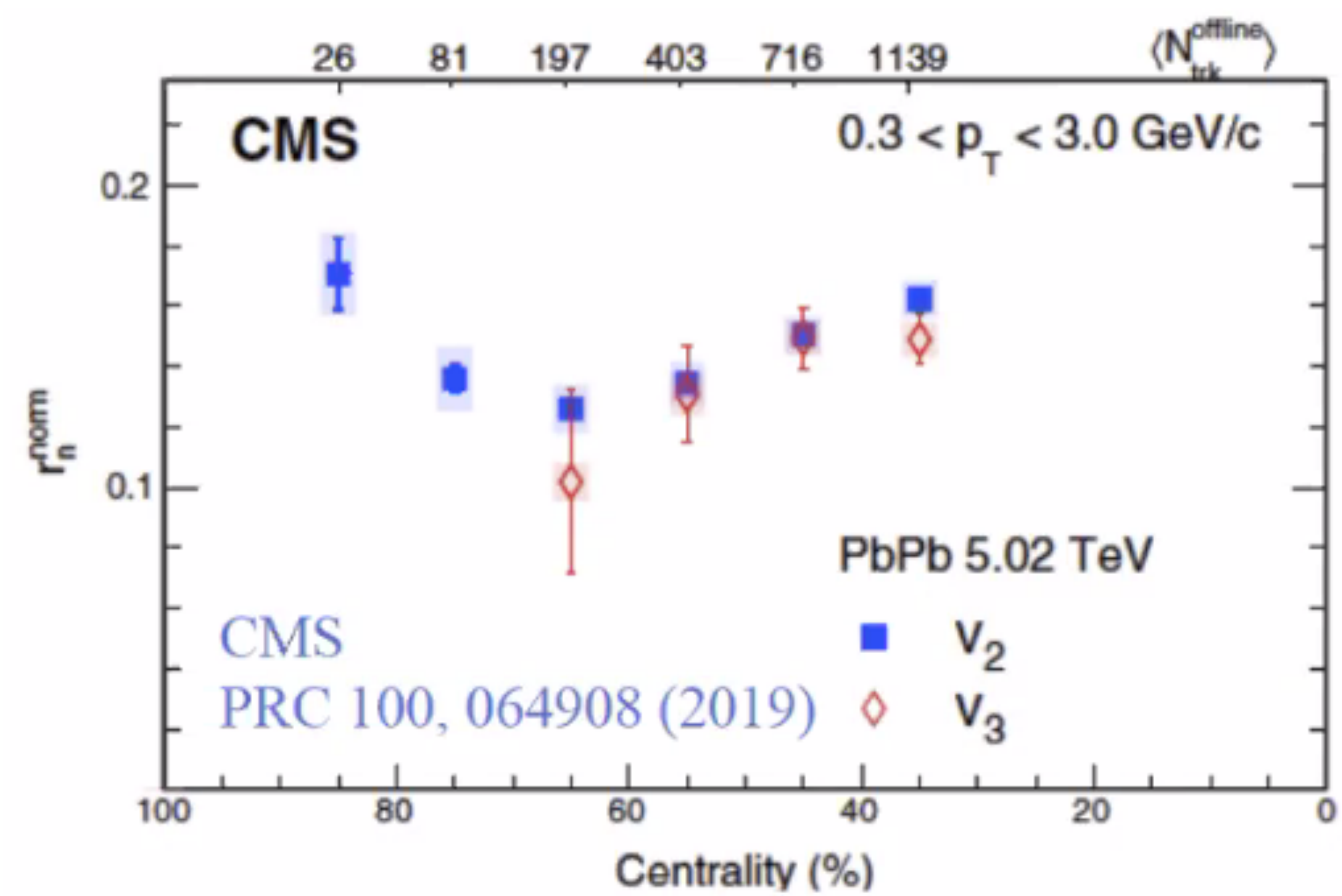


Run comparison



Define centrality





CMS
0.3 < p_T < 3.0 GeV/c
$\langle N_{trk}^{offline} \rangle$
26
81
197
403
716
1139
r_n^{norm}
0.2
0.1
PbPb 5.02 TeV
CMS
PRC 100, 064908 (2019)
v_2
v_3
100
80
60
40
20
0
Centrality (%)