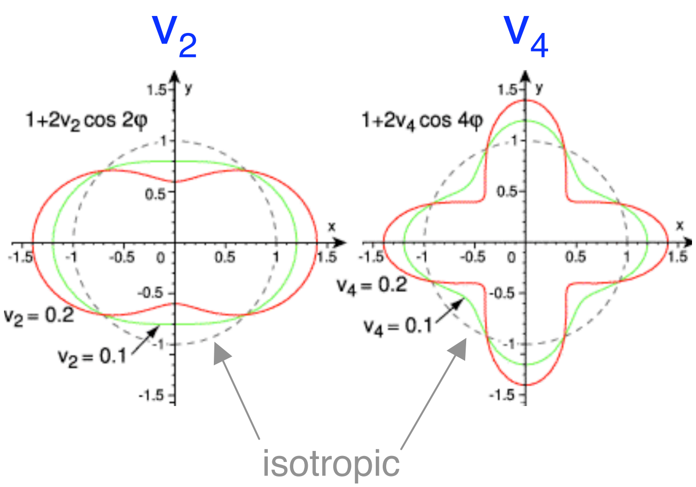
Azimuthal Anisotropy: The Higher Harmonics

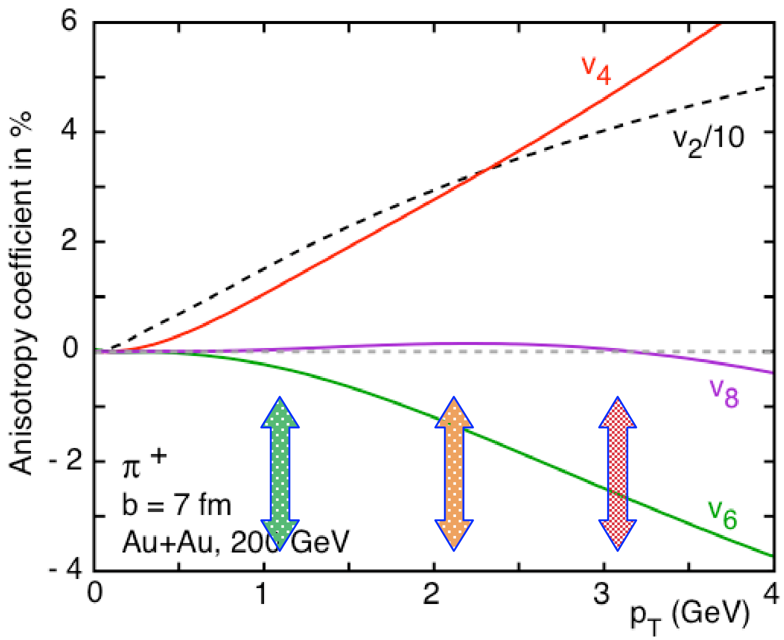
Art Poskanzer for the STAR Collaboration

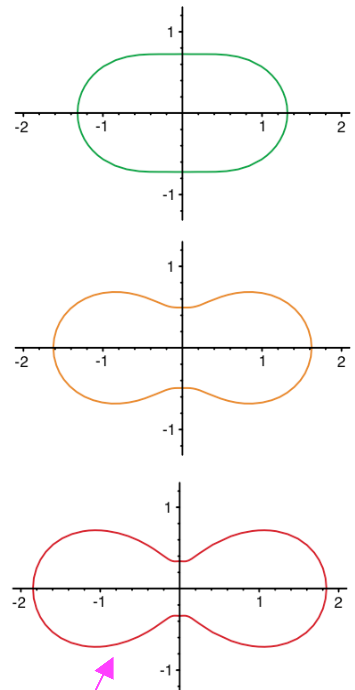
Peter Kolb

- **v_4 - a small, but sensitive observable for heavy ion collisions: PRC 68, 031902(R)**
  - **Strong potential to constrain model calculations and carries valuable information on the dynamical evolution of the system**
  - **Magnitude, and even the sign, sensitive to initial conditions of hydro**



momentum space





peanut shape

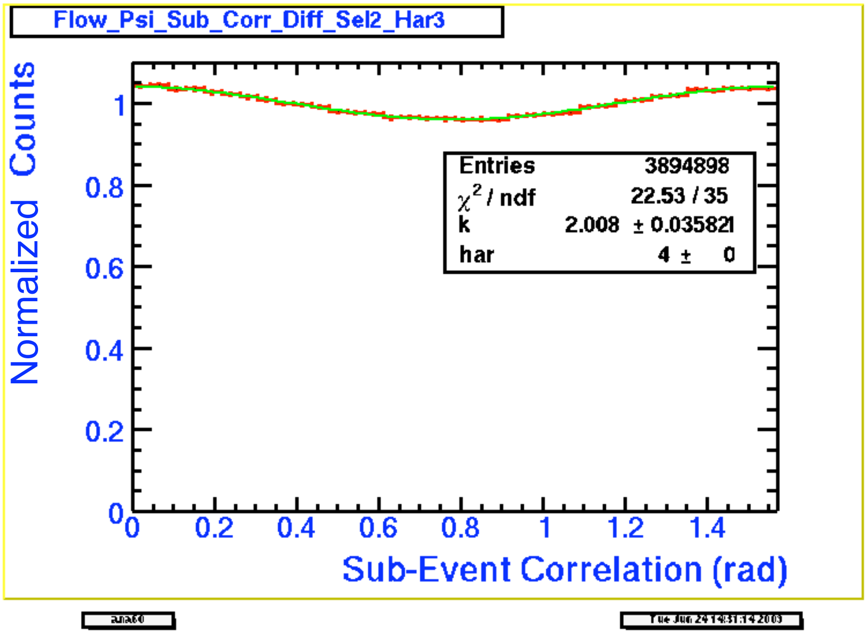
v_2 determines the reaction plane

- v_1 (STAR talk by Aihong Tang), v_4 v_6 and v_8 using **second** harmonic particles
- Possible because v_2 is so large at RHIC and event plane resolution is so good in STAR

Correlation of two event planes:

4^{th} harmonic of one subevent relative to 2^{nd} harmonic of other subevent

v_4 is positive



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Terminology

- n = harmonic number
- Common usage
  - v_n = harmonic order n with respect to event plane of same order
  - $v_n\{N\}$ = N-particle cumulant for v_n
- New addition
  - $v_n\{EP_2\}$ = harmonic order n with respect to event plane of order 2

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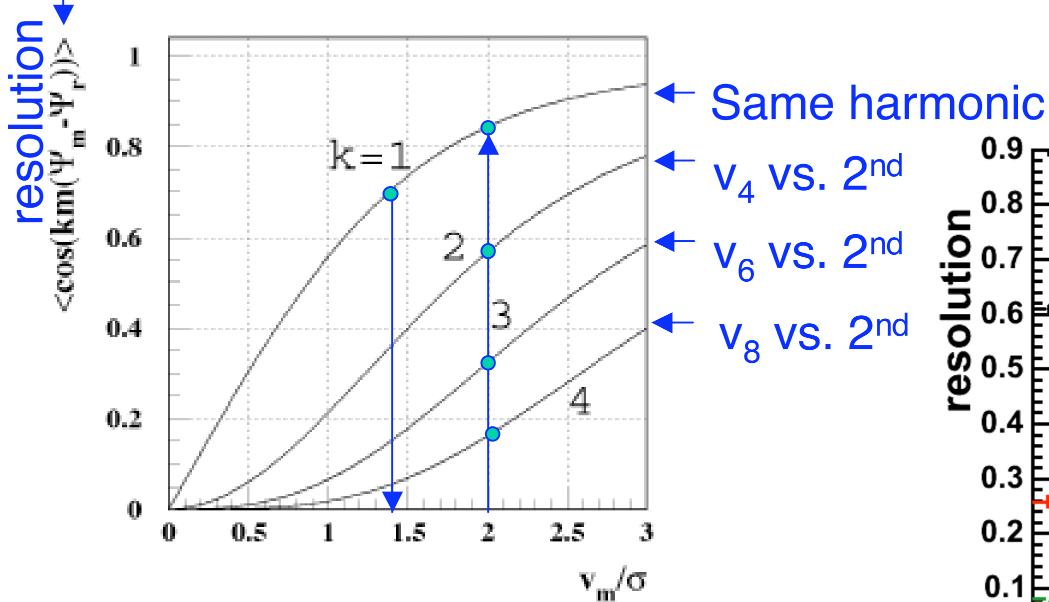
Method

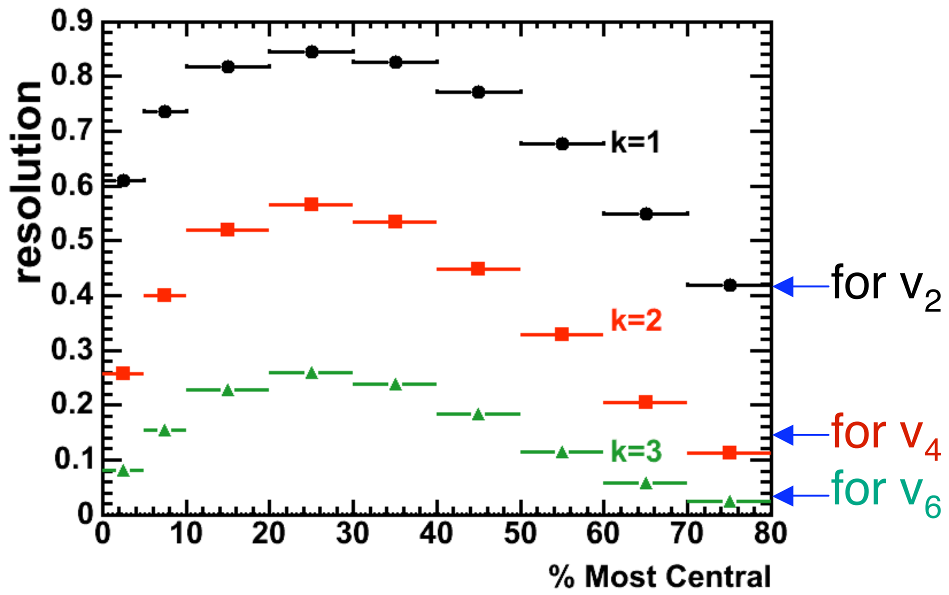
- **Described in methods paper:**
  - **Poskanzer and Voloshin, Phys. Rev. C 58, 1671 (1998)**

$$v = \frac{v_{observed}}{resolution}$$

Square-root of subevent correlation



Signal to fluctuation noise



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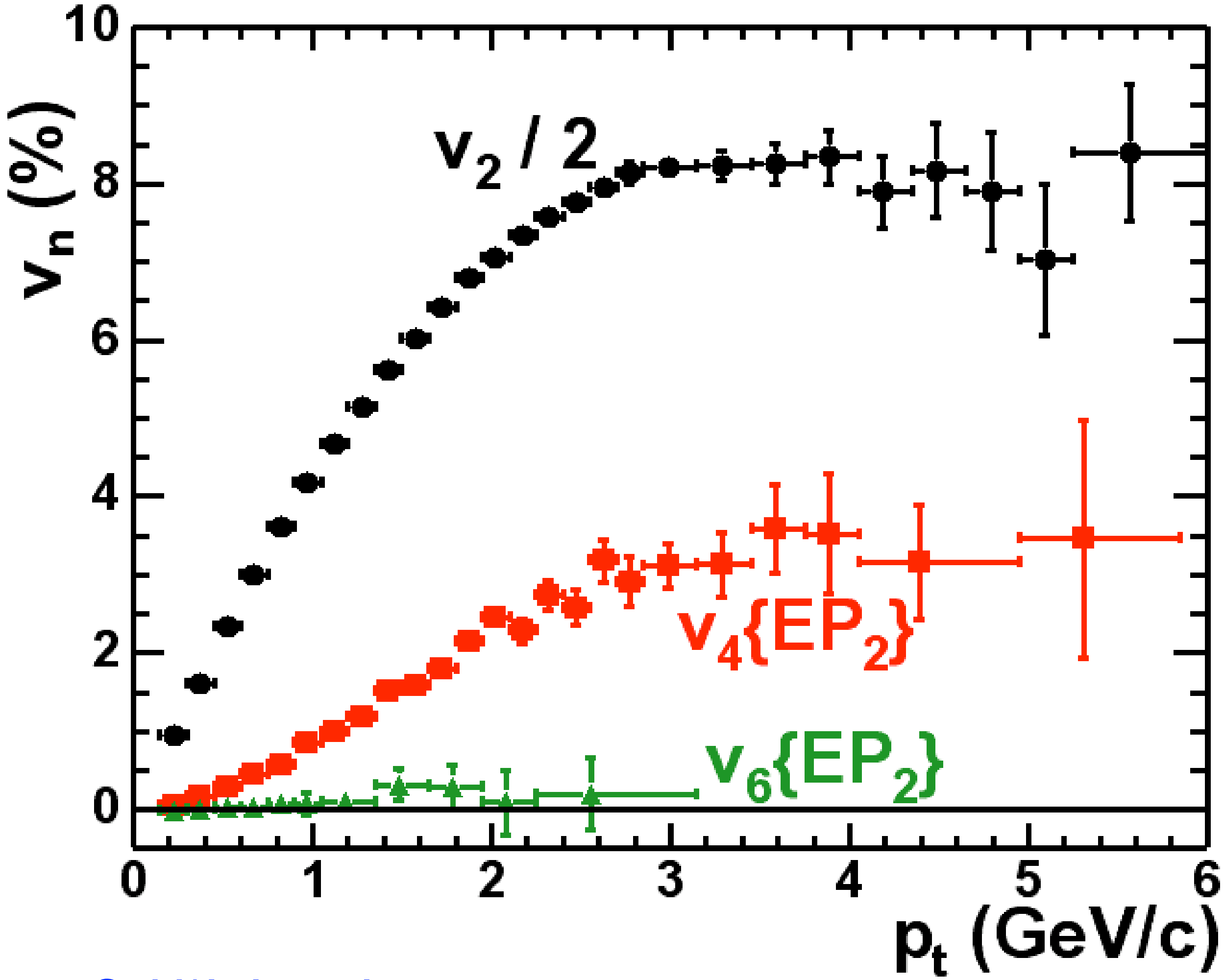
$v_4(p_t)$



200 GeV/A Au + Au

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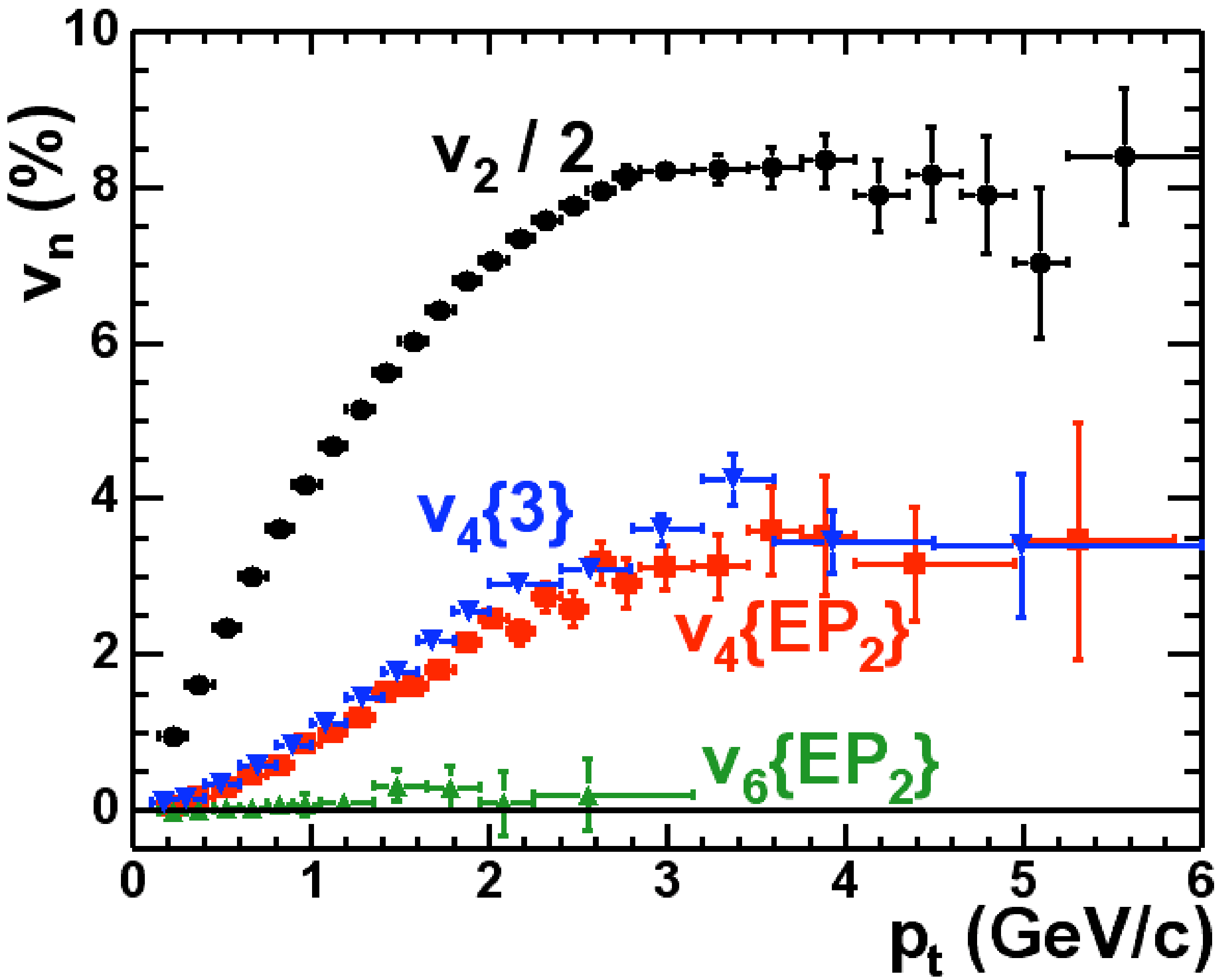
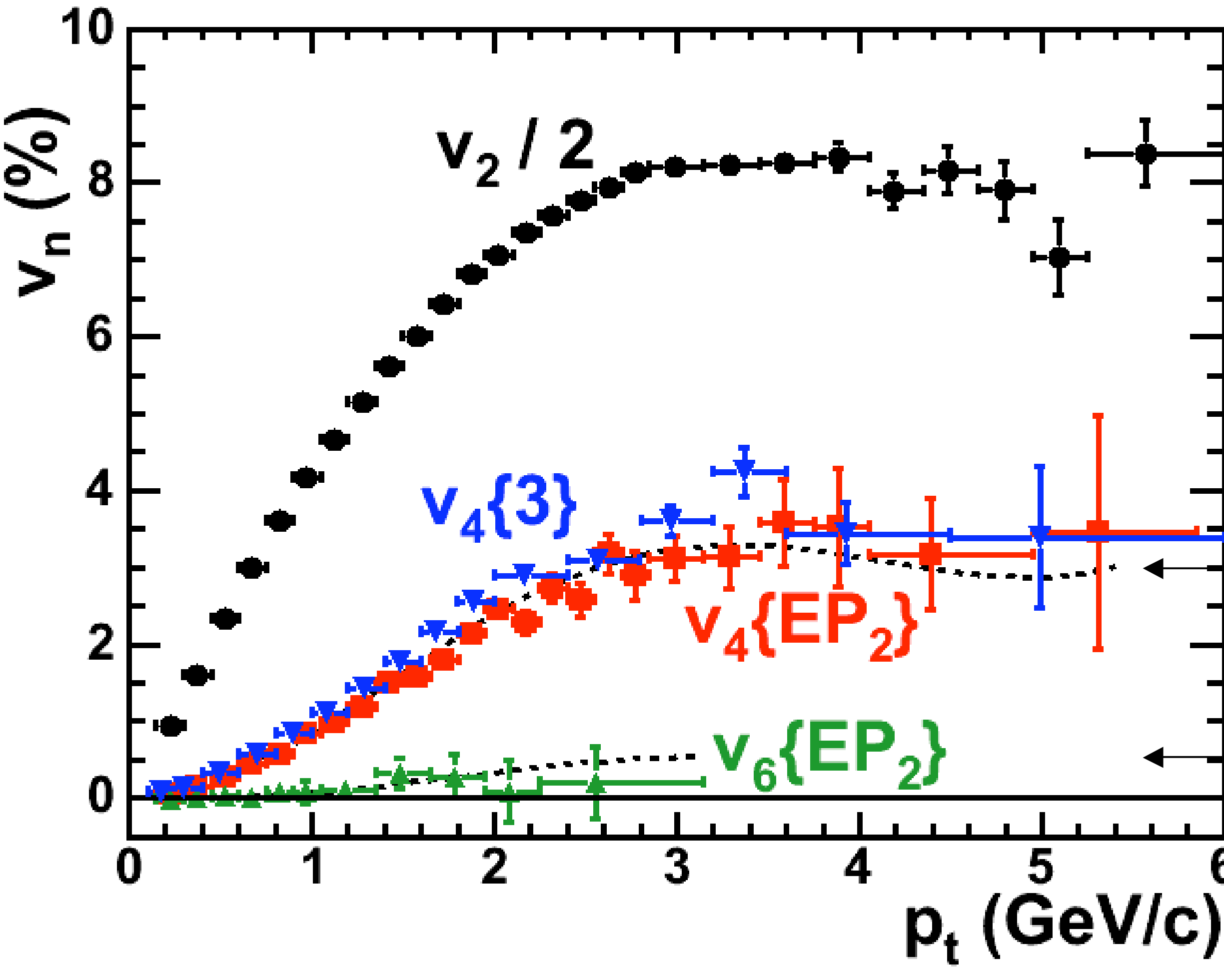
$v_4(p_t)$



$v_4(p_t)$

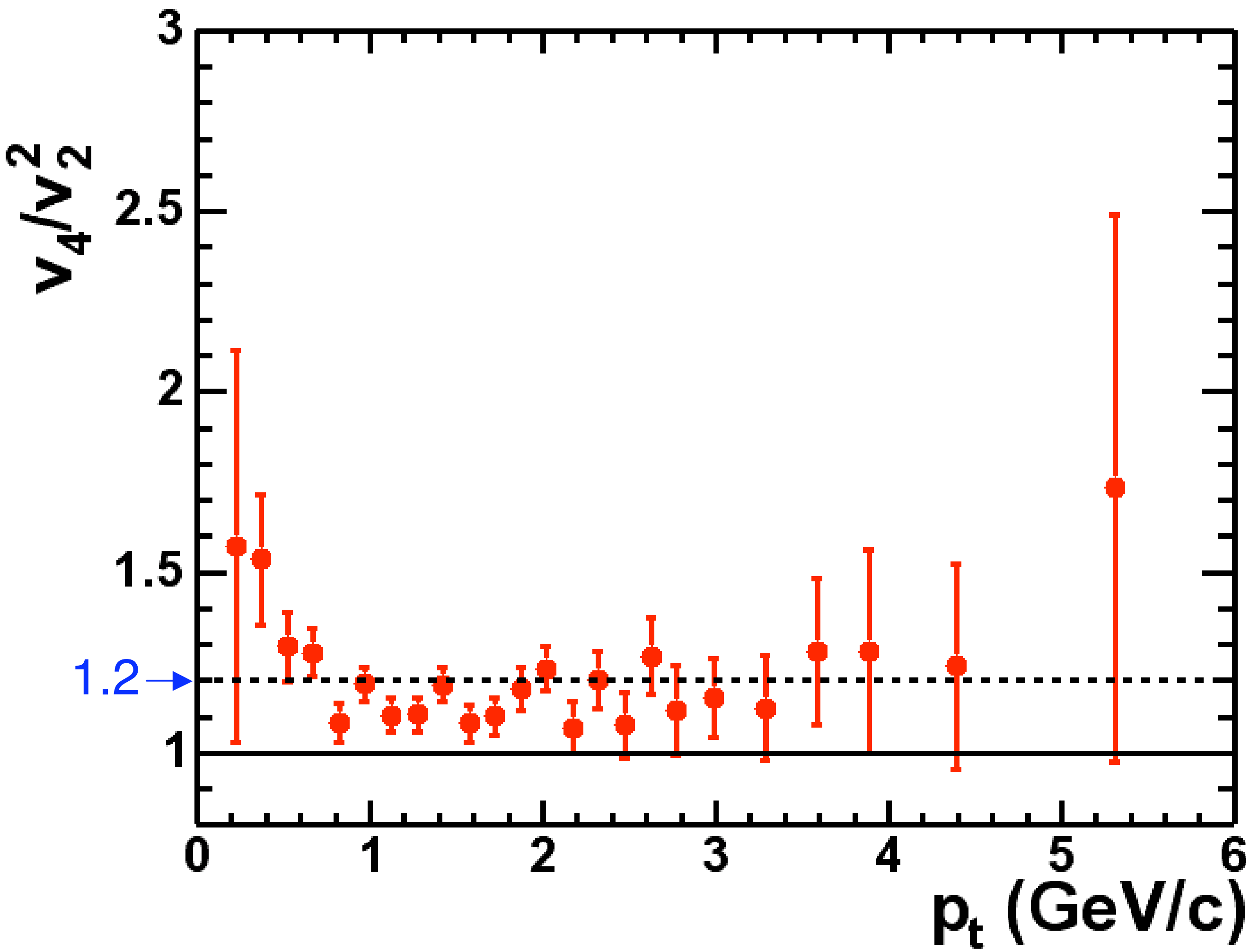


$v_n \sim v_2^{n/2}$

$1.2\ v_2^2$

$1.2\ v_2^3$

$v_4(p_t)$ Scaling



Definitely greater than 1.

v_4 from f_2

$$\rho(\phi) = \rho_0\left(1 + 2f_2\cos(2\phi) + 2\cancel{f_4}\cos(4\phi) + 2\cancel{f_6}\cos(6\phi) + \ldots\right)$$

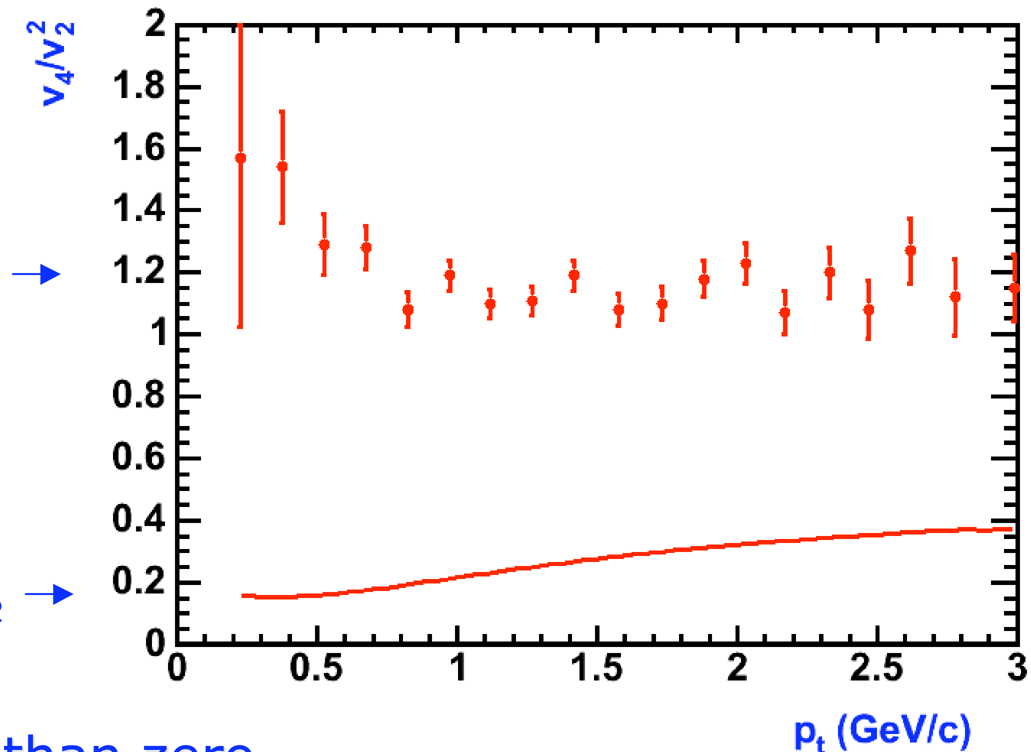
$$v_n(p_T) = \frac{\int d\phi\cos(n\phi)\,\mathrm{I}_n(k\alpha(\phi))\,\mathrm{K}_1(k\beta(\phi))}{\int d\phi\,\mathrm{I}_0(k\alpha(\phi))\,\mathrm{K}_1(k\beta(\phi))}$$

Blast Wave

Fit v_2

1.2 →

only f_2 →



Therefore, f_4 is greater than zero

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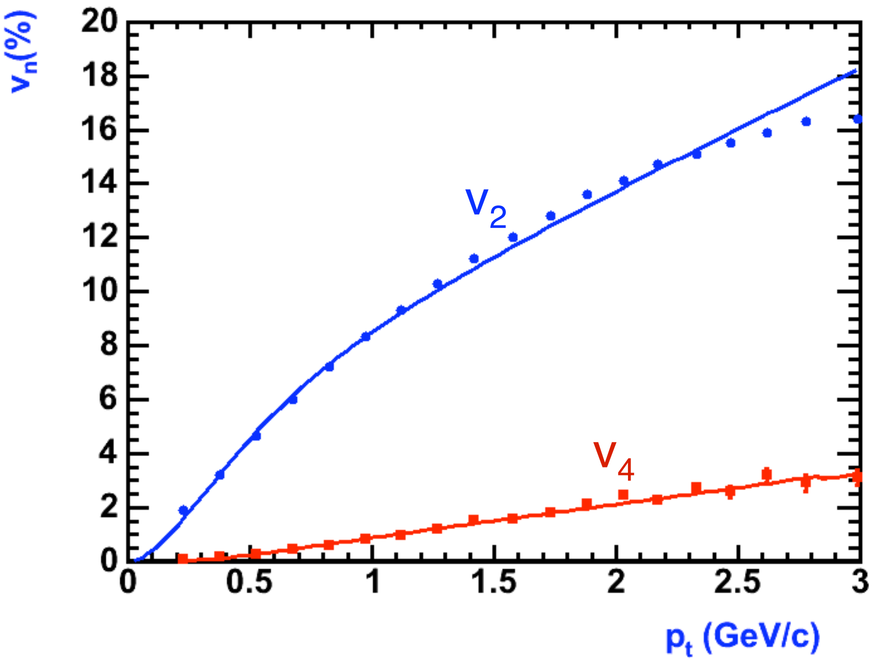
Blast Wave v_4 fit

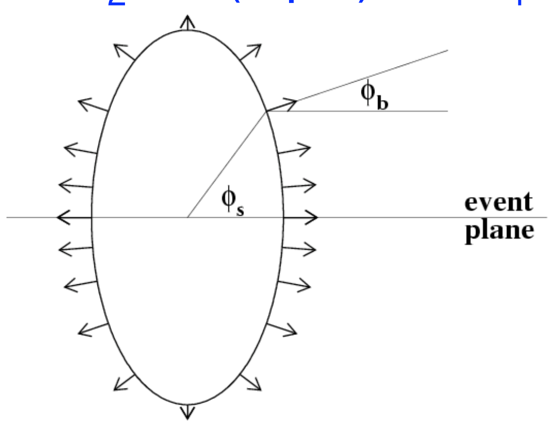


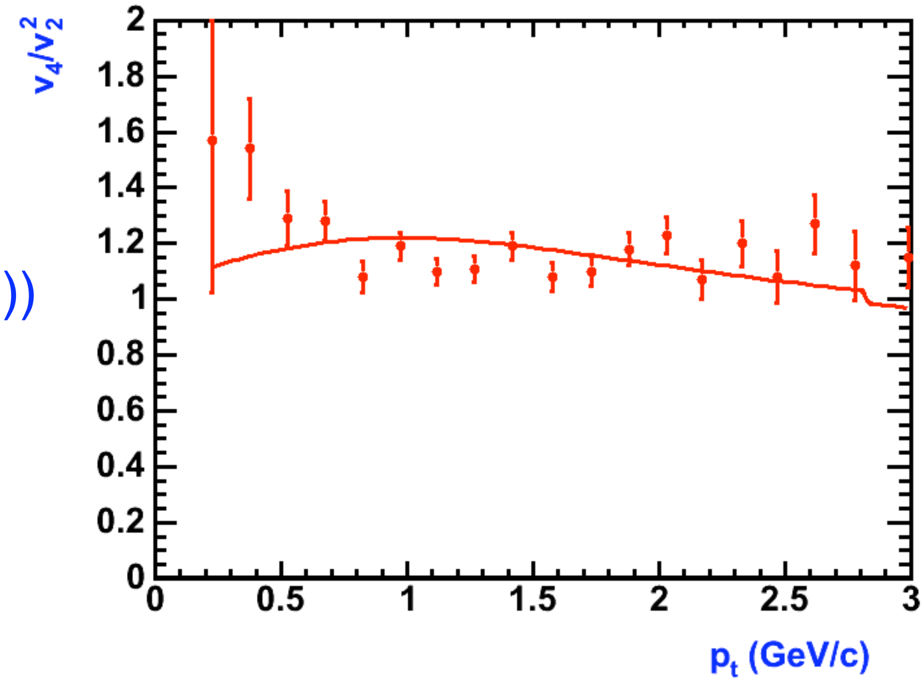
T = 0.1 GeV ρ_0 = 1.08

f_2 = 1.2 % s_2 = 7.4 %

f_4 = 0.15 % s_4 = 1.2 %

(1 + 2 s_2 cos(2 phi) + 2 s_4 cos(4 phi))





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Parton Coalescence and Scaling

Assuming coalescence of quarks:

$$\frac{dN_n}{dy p_T dp_T d\varphi} \sim (1 + 2\, v_2^q \cos(2\,\varphi) + 2\, v_4^q \cos(4\,\varphi) + \ldots)^n$$

quarks

2 for mesons

$v_4 \,/\, v_2^2 \approx$ $1/4 + 1/2\ (v_4^q/(v_2^q)^2)$, but experimentally it is 1.2

Therefore, v_4^q is greater than zero

Assuming scaling for quarks:

$v_n^q = (v_2^q)^{(n/2)}$

$v_4 \,/\, v_2^2 \approx$ $1/4 + 1/2 = 3/4$, but experimentally it is 1.2

Therefore, v_4^q is even greater than simple parton scaling would indicate

Voloshin, Kolb, Chen, Ko, and Lin

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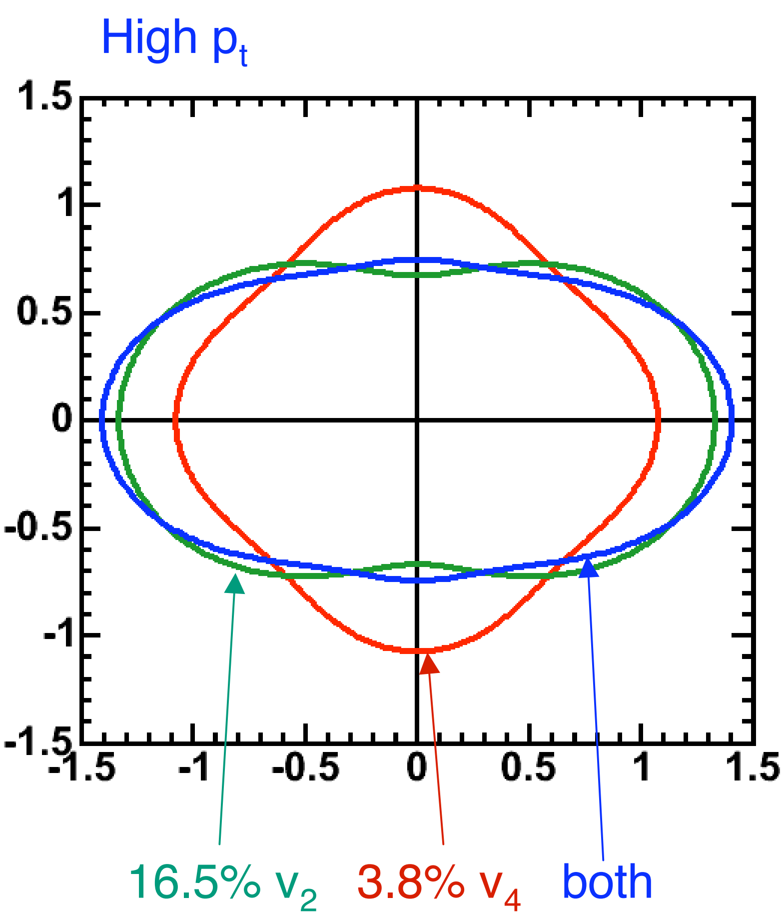
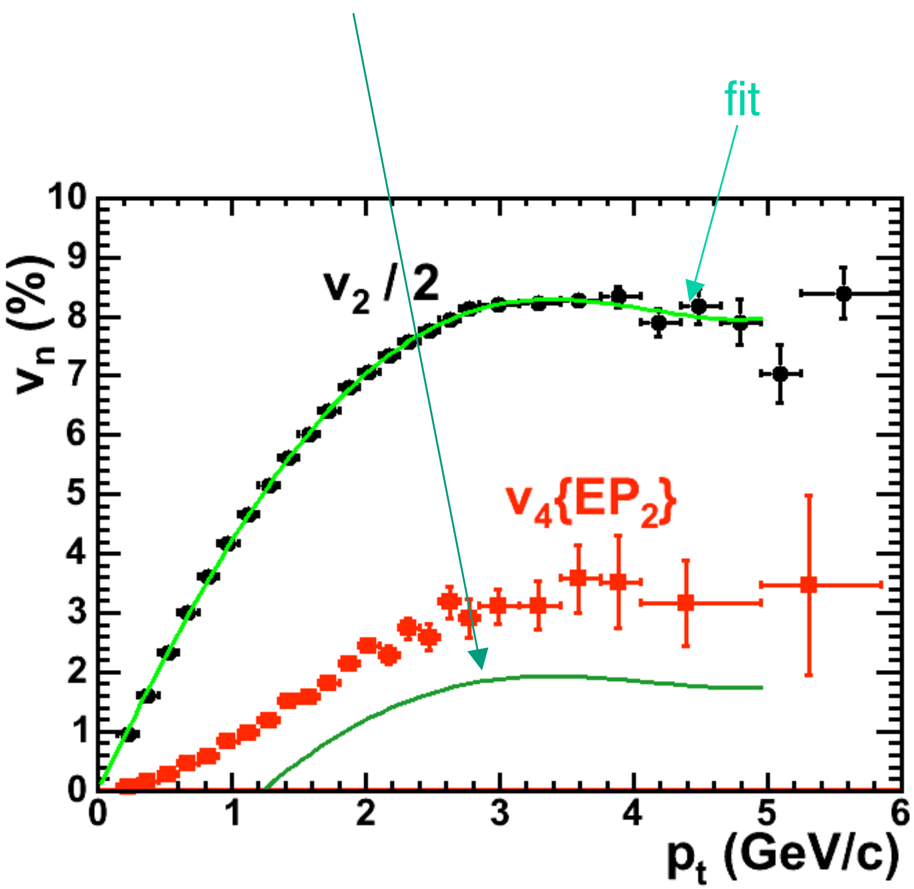
The Peanut Waist

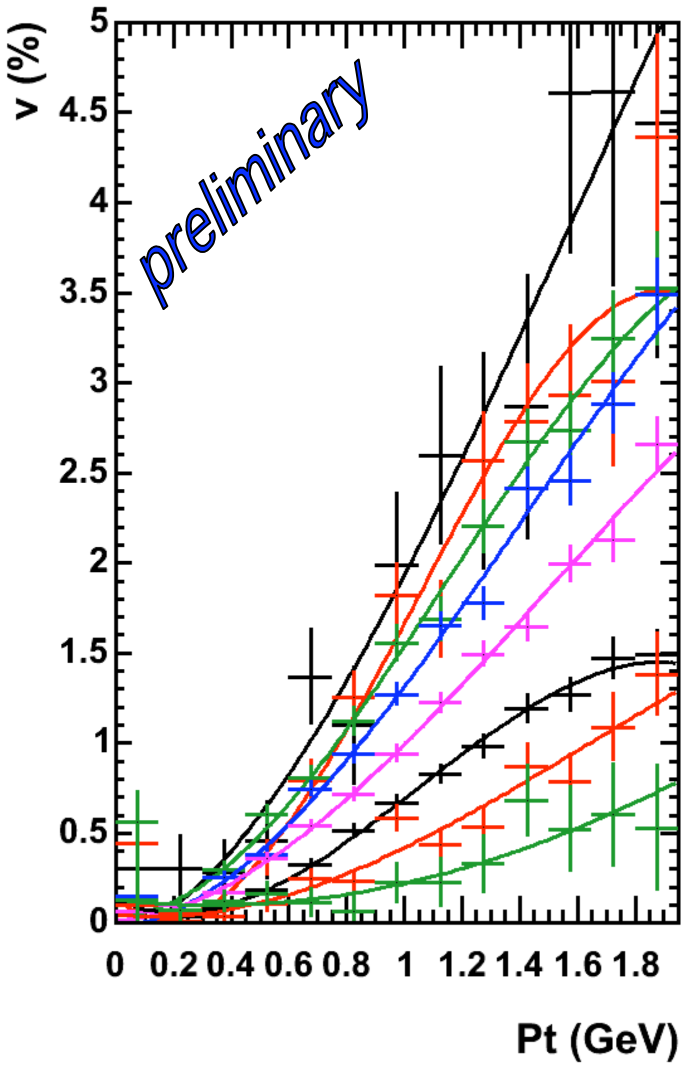


- **No waist:**
  - $v_4 = (10 * v_2 - 1) / 34$



Kolb

$v_4(p_t, cent)$



Centrality

70 - 80 %

60 - 70 %

50 - 60 %

40 - 50 %

30 - 40 %

20 - 30 %

10 - 20 %

5 - 10 %

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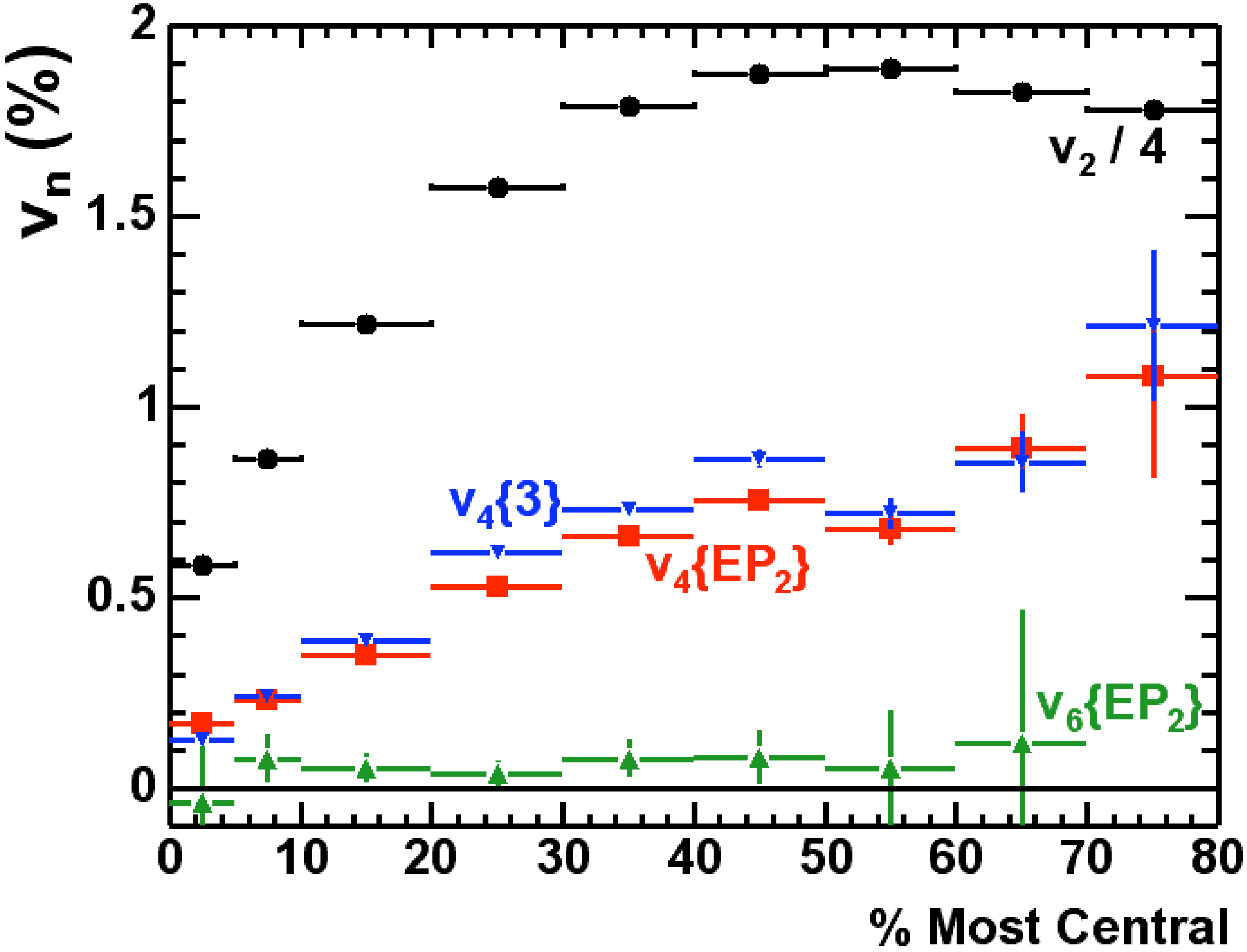
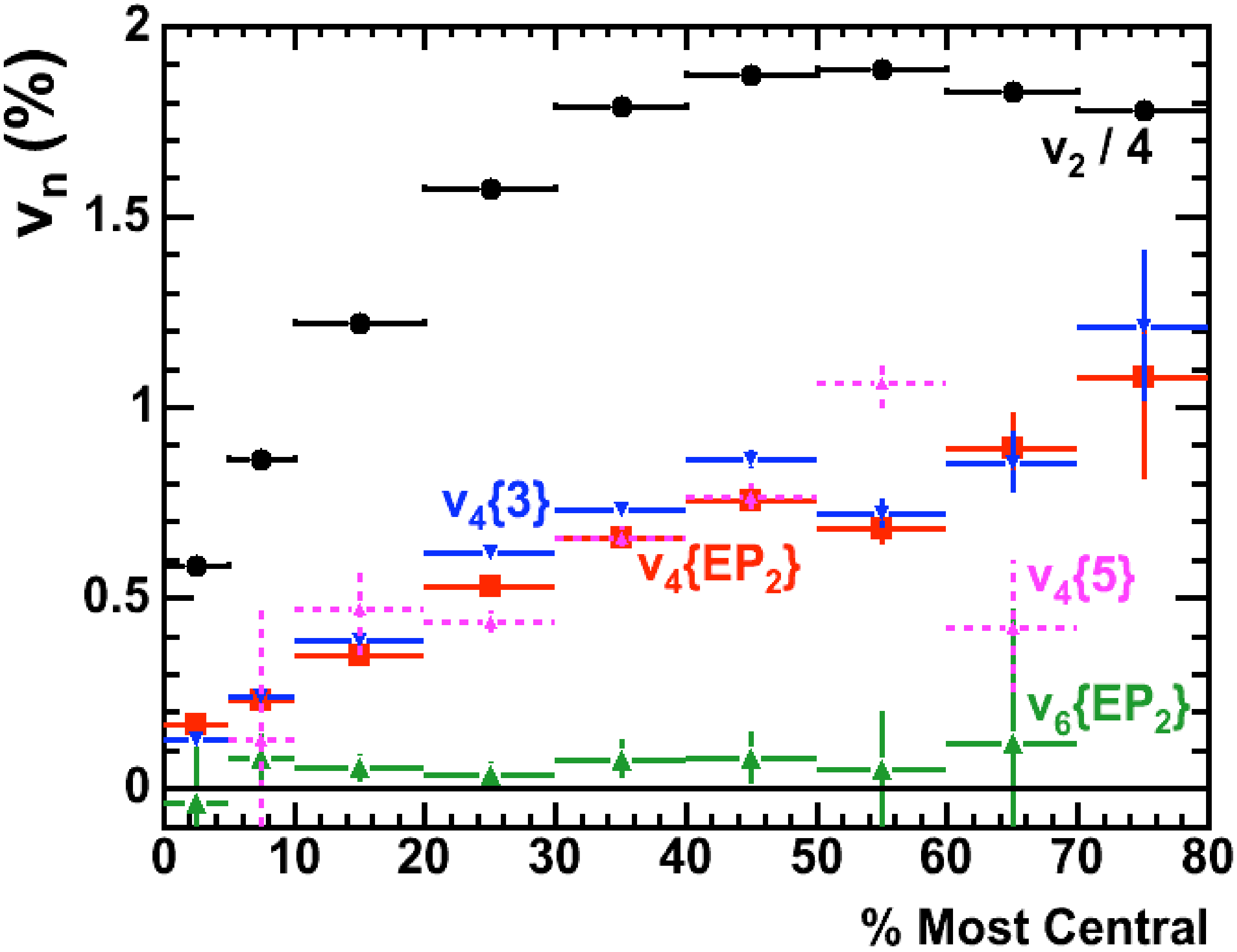
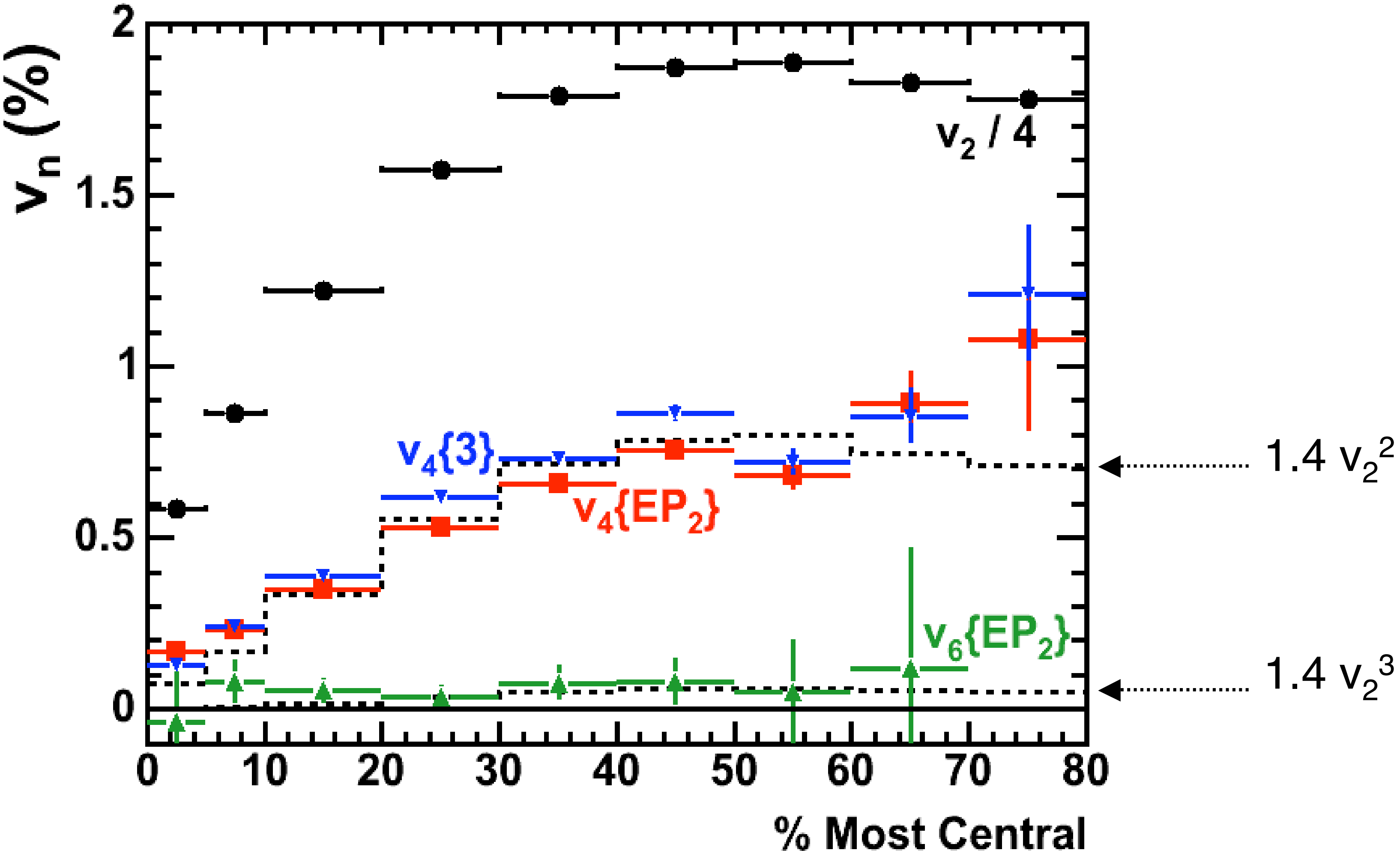
v_4(centrality)



v_4(centrality)



v_4(centrality)



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v triply integrated
in MTPC

v	%
2	5.18 +/- 0.005
4	0.44 +/- 0.009
6	0.043 +/- 0.037
8	-0.06 +/- 0.14

Two sigma upper limit is 0.1%

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Conclusions

- v_4
  - Integrated, a factor of 12 smaller than v_2
  - v_2^2 scaling
  - Small, but significant
- v_6
  - Probably another factor of 10 smaller
  - Consistent with v_2^3 scaling
- Blast Wave
  - f_4 finite, s_4 needed for good fit
- Parton coalescence
  - v_4^q finite and greater than $(v_2^q)^2$
- Hydro
  - Predicts a waist, but not observed