MVD Reaction Plane analysis

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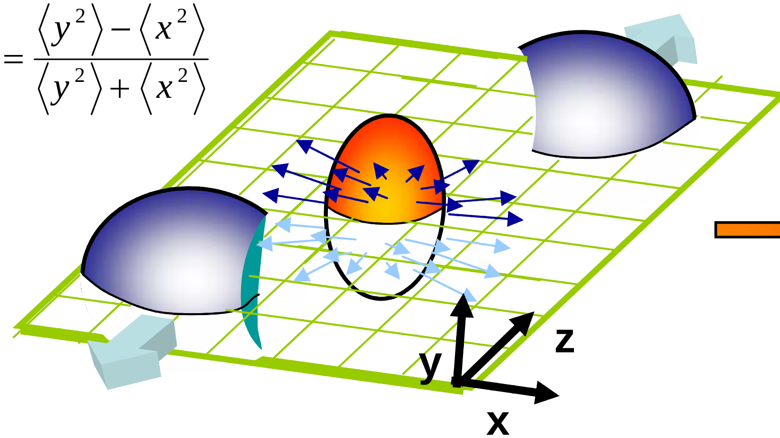
Definitions

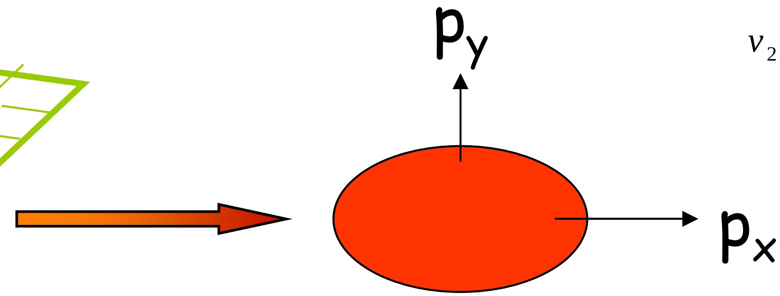
Reaction plane defined by (1) **beam direction** and (2) **impact parameter**

$$\varepsilon = \frac{\langle y^2 \rangle - \langle x^2 \rangle}{\langle y^2 \rangle + \langle x^2 \rangle}$$



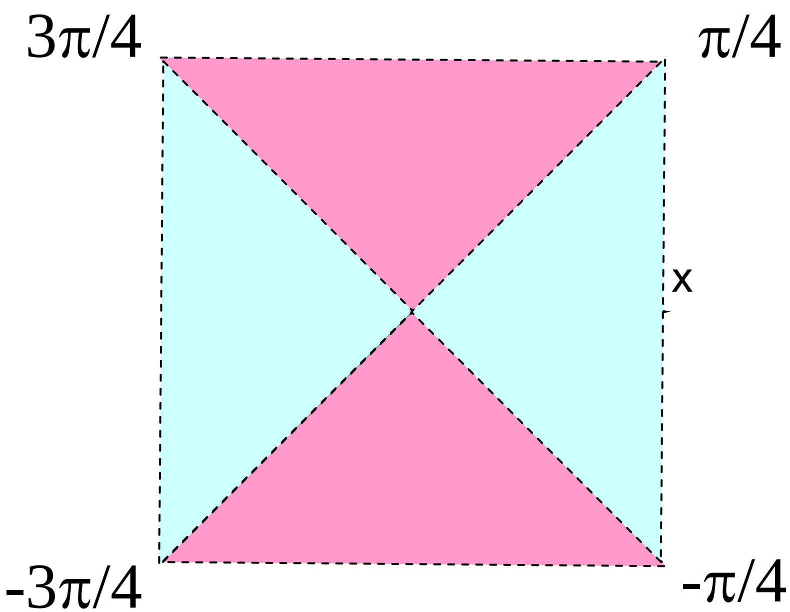
initial spatial anisotropy

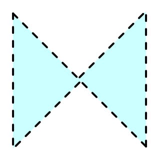
$$v_2 = \frac{\langle p_x^2 \rangle - \langle p_y^2 \rangle}{\langle p_x^2 \rangle + \langle p_y^2 \rangle}$$



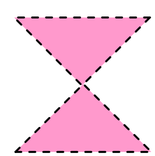
$$\phi = \operatorname{atan} \frac{p_y}{p_x}$$

anisotropy in momentum space





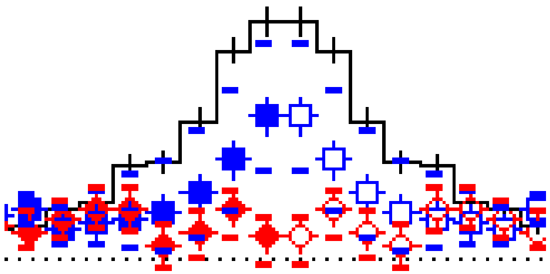
"In-plane" region



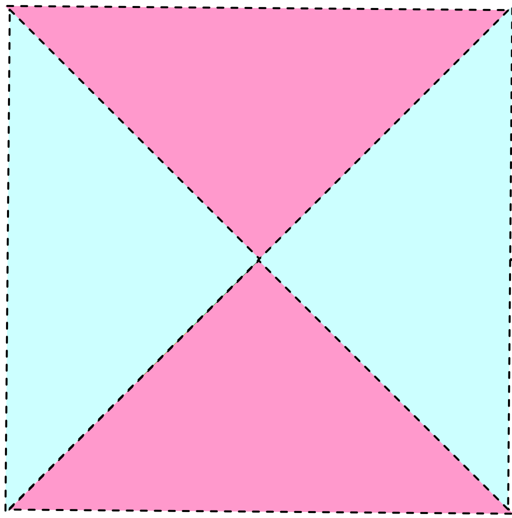
"Out-of-plane" region

Physics Motivation

- At DNP (10/03) and QM04, STAR demonstrated the suppression of hadrons as a function of orientation wrt/ the reaction plane.

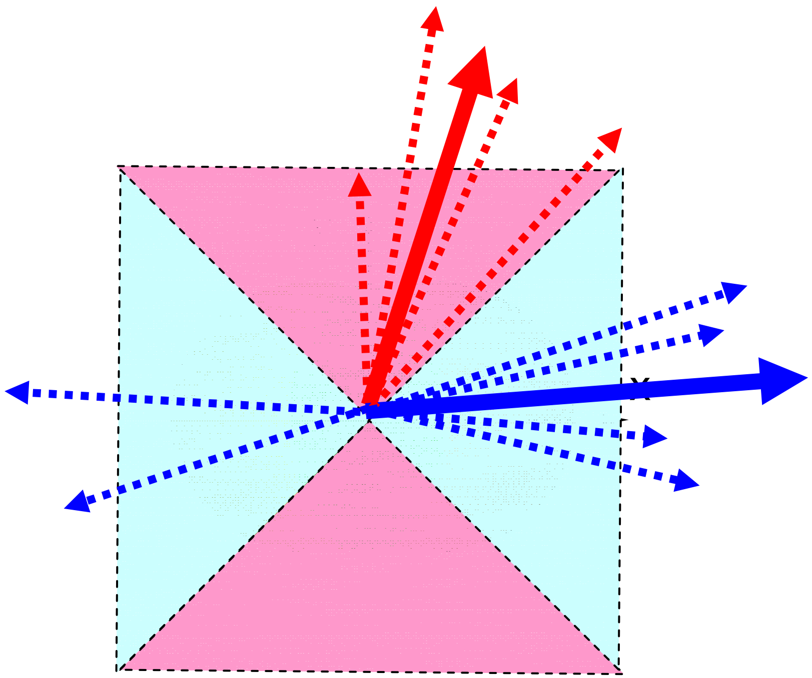


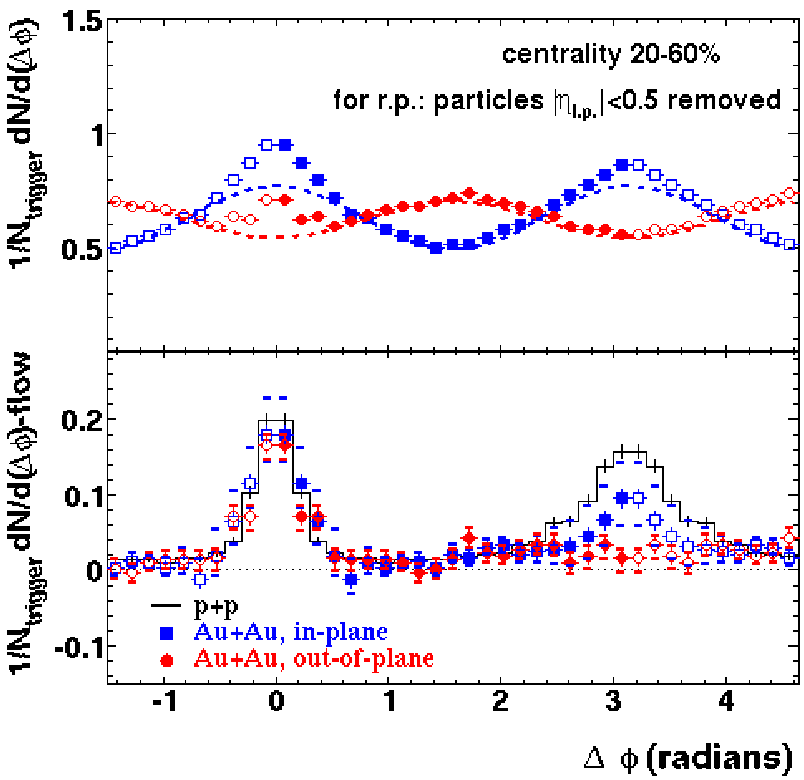
- Reaction plane measurement allows studying path-length dependence (medium modification) of charmonium and open charm.



High p_T pairs wrt reaction plane

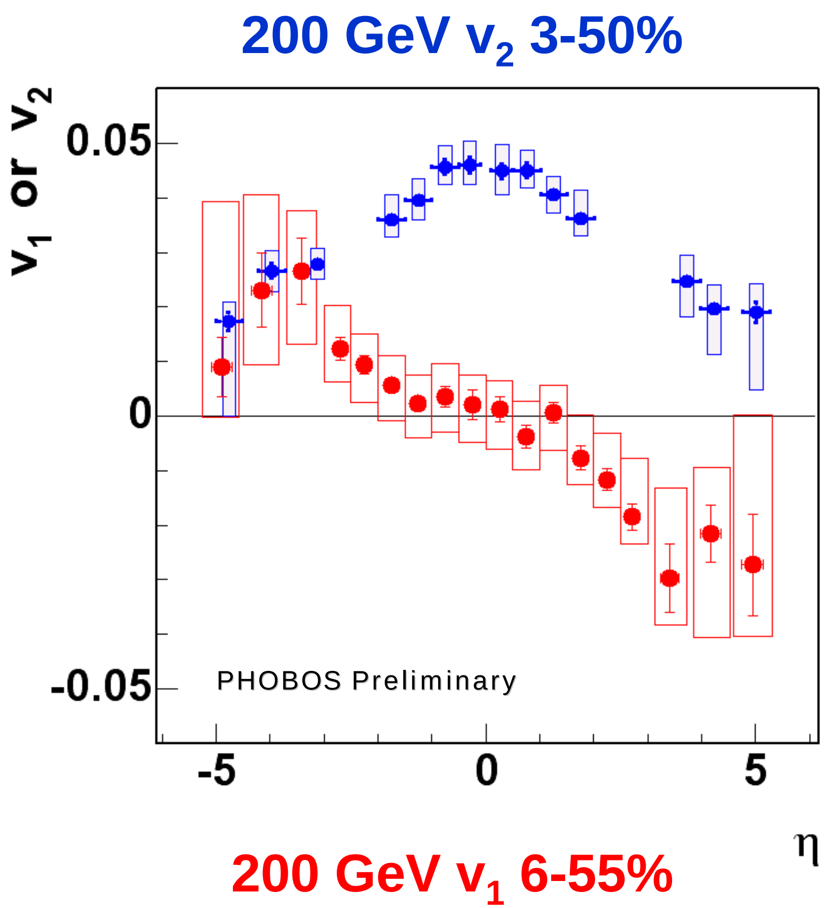
- Trigger on one high pT particle, plot azimuthal distribution of the rest.
- 2 Effects seen:
  - v2 (elliptic flow)
  - forward/back jet correlations
- Away-side suppression enhanced for out-of-plane sample





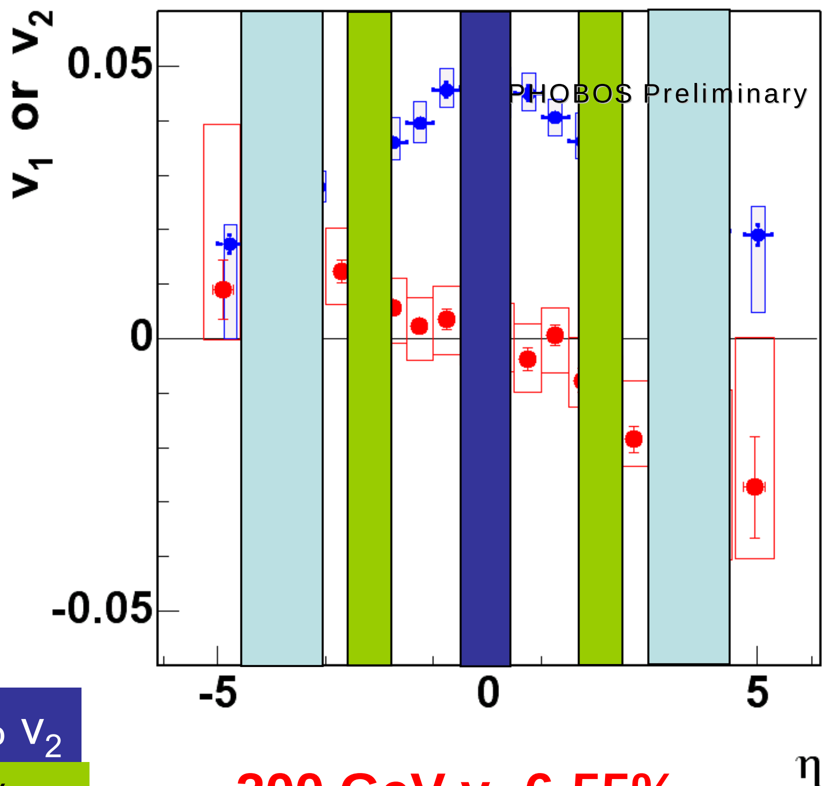
How much asymmetry?

- v_1, v_2 measure asymmetry of system
- Forget flow for now
- effects are at the few % level
  - nontrivial measurement
  - must understand asymmetric efficiency/ acceptance/ background



How much asymmetry? ctd

200 GeV v_2 3-50%



200 GeV v_1 6-55%

v_2 decreases with η

v_1 increases with η

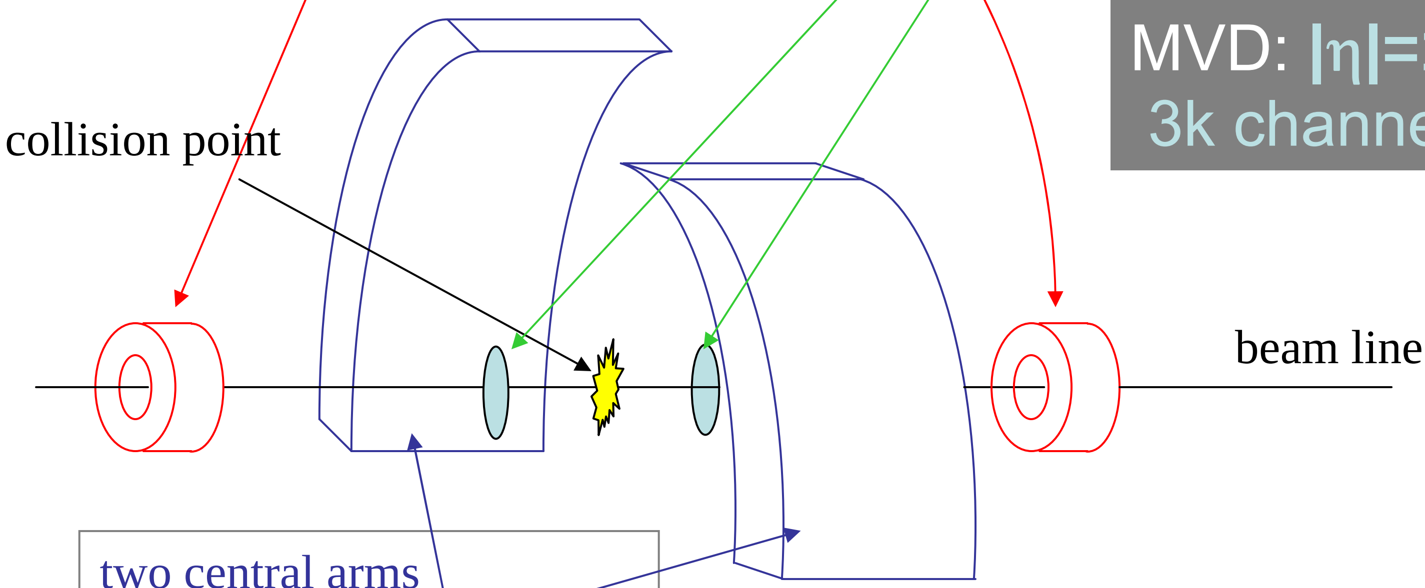
MVD sees somewhat stronger v_2 signal than BBC

STAR TPC:	4.5% v_2
PHENIX MVD:	3.3% v_2
PHENIX BBC:	2.8% v_2

Where does the MVD sit?

Beam-beam counter
(BBC) |η|=**3~4**
64pmts in each BBC
charged particles

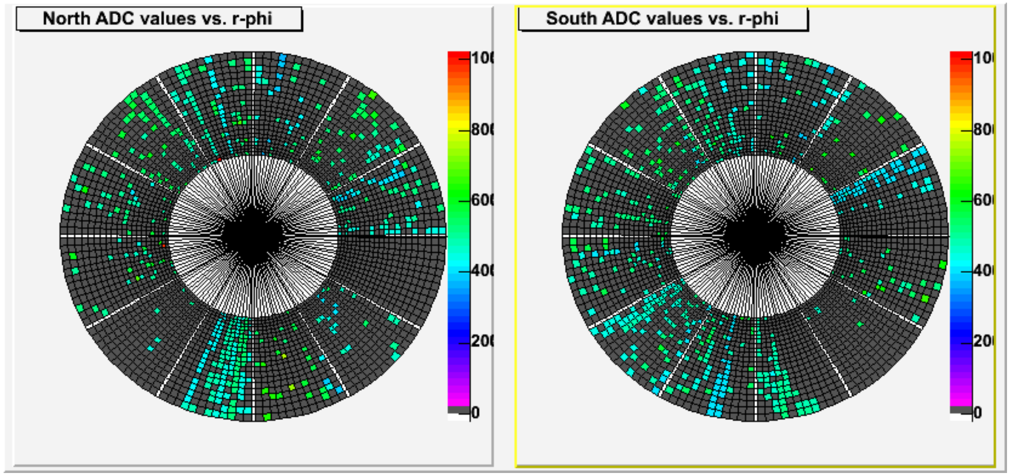
MVD: |η|=1.8-2.6
3k channels per side!



two central arms
(CNT) |η|<**0.35**
Dch,PCs,TOF,EMCAL
tracking, momentum, PID

Intro to the MVD pad planes

- $z = \pm 35$ cm
- $1.8 < \eta < 2.6$
- 6048 channels
- ϕ resolution of 2.4°
- r resolution of 2-4.5 mm



How to calculate reaction plane (Ψ)?

- In general,

$$\tan(2\Psi_2) = \frac{\Sigma\ w_i*\sin(2\phi_i)}{\Sigma\ w_i*\cos(2\phi_i)}$$

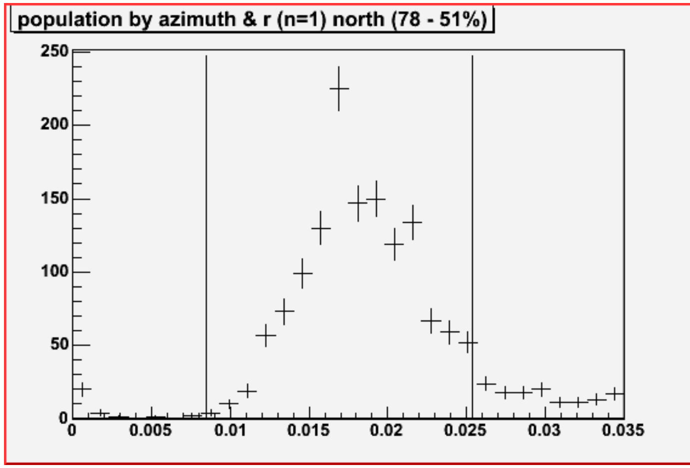
- In practice, the procedure is involved:
  - Determine efficiency/acceptance/background correction for each channel (w_i)
  - Subtract $<w_i*\sin>$, $<w_i*\cos>$ to better isolate azimuthal anisotropy.

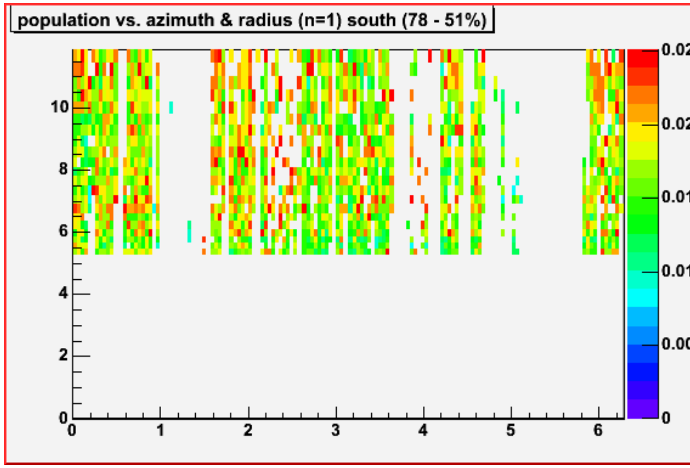
$$\tan(2\Psi_2) = \frac{\Sigma\ w_i*\sin(2\phi_i) - <w_i*\sin(2\phi i)>}{\Sigma\ w_i*\cos(2\phi_i) - <w_i*\cos(2\phi i)>}$$

  - Flatten Ψ distribution by shifting to remove remaining asymmetries

Acc/Eff/Bck correction

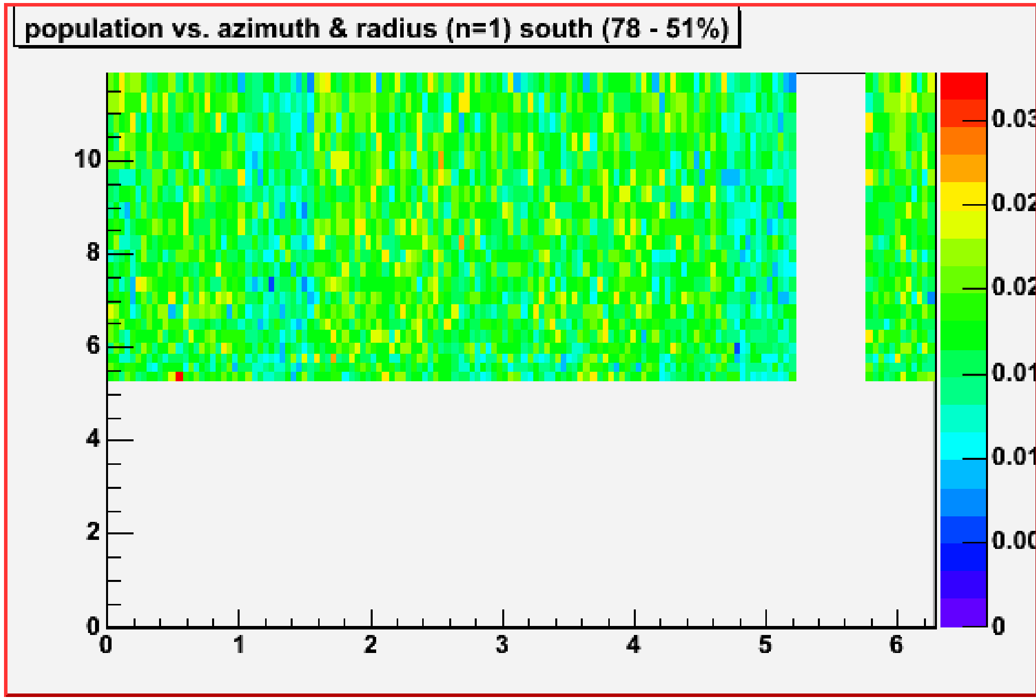
- Integrate hits for entire data set
- Find most probable **population** (≡ #hits/#events) over all channels
- Select only channels within 50% of the population MPV. This removes hot/dead channels from consideration. Large corrections are useless: If a channel is on 50% of the time, it will bias the ϕ distribution in all events (weighted either too much or too little)





Poisson Fill

- In excluded (dead/hot) channels near healthy channels, we can do a Poisson fill on an event by event basis



Event plane distribution

- After subtracting <w*sin> and <w*cos> and poisson-filling excluded channels, the distribution of Ψ should be flat (assuming isotropic acceptance).
- Any remaining structure is due to asymmetric acceptance.
- This remaining structure can be corrected by the "shifting method": Fourier decomposition of distribution

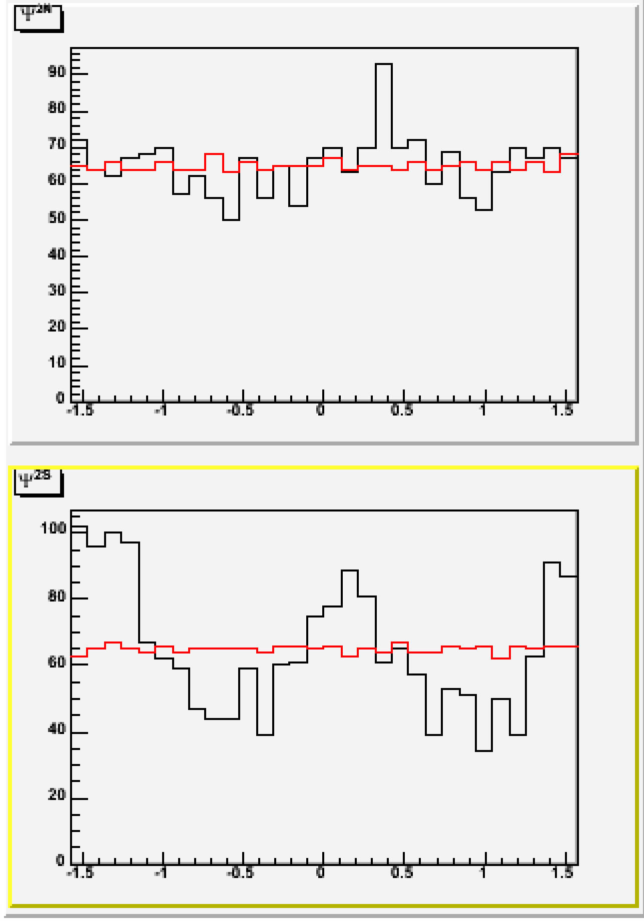
“Shifting Method”

$$\Psi_1' = \Psi_1 + \Delta\Psi_1.$$

$$\Delta\Psi_1 = \sum_n (A_n \cos(n\Psi_1) + B_n \sin(n\Psi_1))$$

$$B_n = \frac{2}{n}\langle \cos(n\Psi_1)\rangle,$$

$$A_n = -\frac{2}{n}\langle \sin(n\Psi_1)\rangle,$$



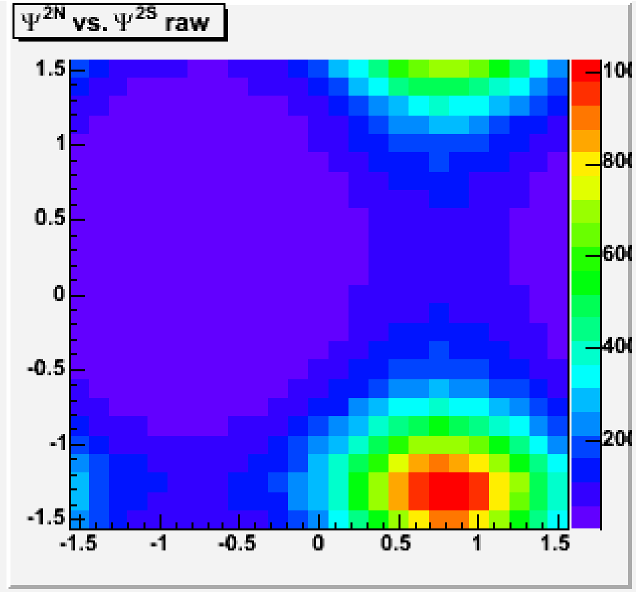
Usually 1 <= n <= 32

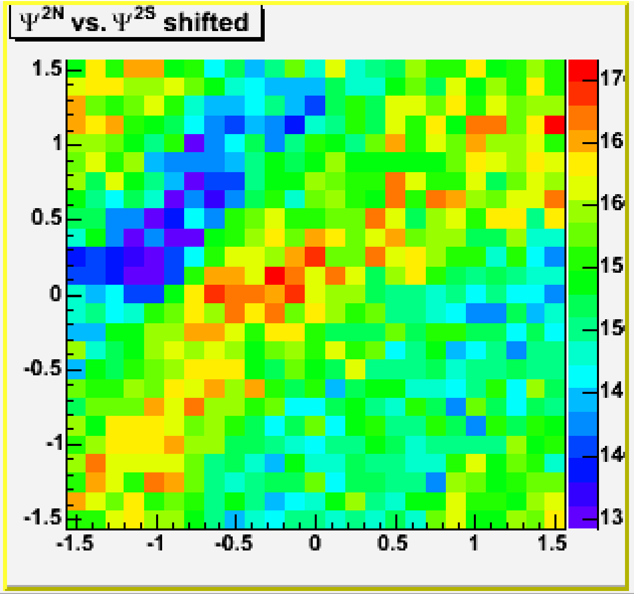
$$\Psi_1' = \Psi_1 + \sum_n \frac{2}{n}\left(-\langle \sin(n\Psi_1)\rangle \cos(n\Psi_1) + \langle \cos(n\Psi_1)\rangle \sin(n\Psi_1)\right)$$

Does shifting work?

- One measure of effectiveness is correlation between Ψ^{North} and Ψ^{South}.
- See results for toy MC of MVD:

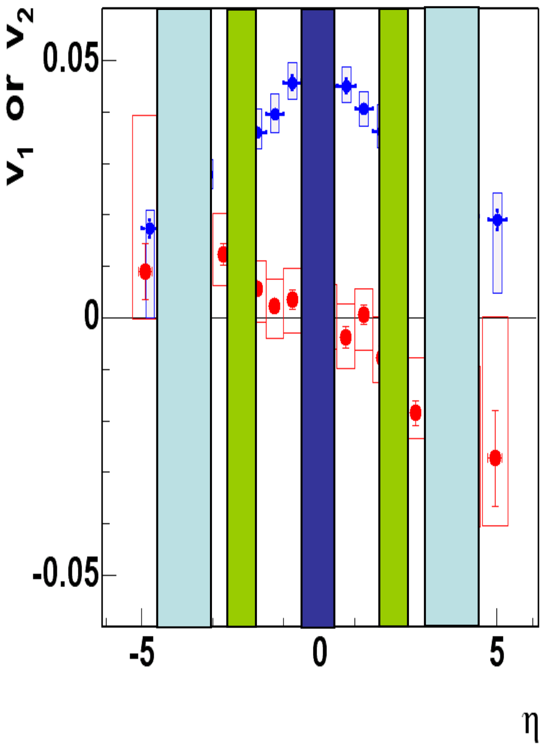
•Throw Ψ flat
•Smear Ψ^N & Ψ^S with gaussian
•Throw hits in N & S according to Ψ^N, Ψ^S
•Remove hits in dead sectors
•Recalculate Ψ^N, Ψ^S





Correlation => correct Ψ?

- Does correlating the north & south imply correct determination of plane?
- Try more toy MC and compare BBC, MVD, and STAR TPC. (PHOBOS data => different v_2 => different sensitivity to Ψ. Also different rapidity ranges and number of particles measured.)

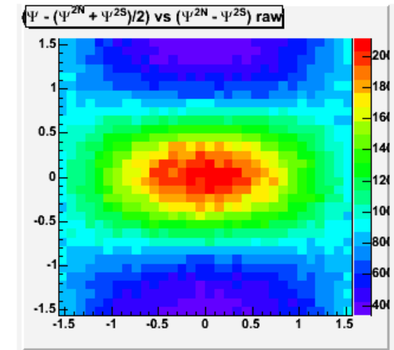


Correct Ψ? ctd

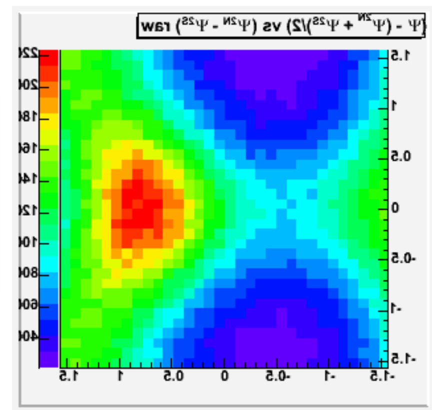
- **Q**: Grossest binning in Ψ is ±π/4 (in-plane vs. out-of-plane). If we require $|\Psi^N - \Psi^S| < \pi/4$, how often to we guess the true reaction plane within ±π/4?
- **A**: 70-75% in all cases (50% means no resolving power)

Ψ Resolution vs N/S average Ψ

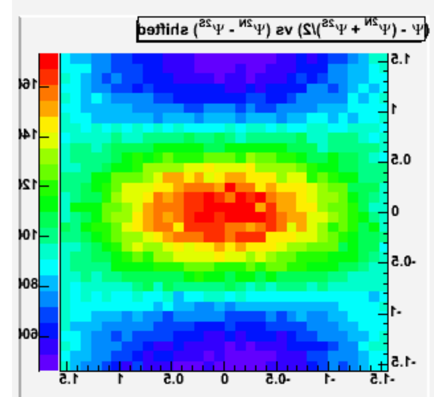
BBC
~125 hits/side
$V_2 \sim 4.5\%$



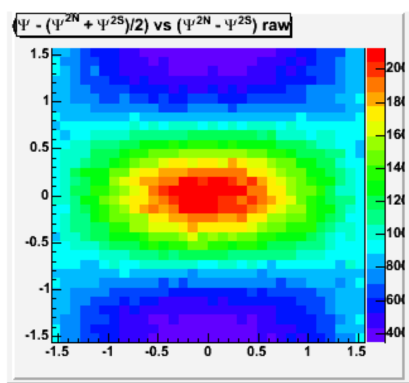
MVD (raw)
~75 hits/side
$V_2 \sim 3.3\%$



MVD (shifted)
~75 hits/side
$V_2 \sim 3.3\%$

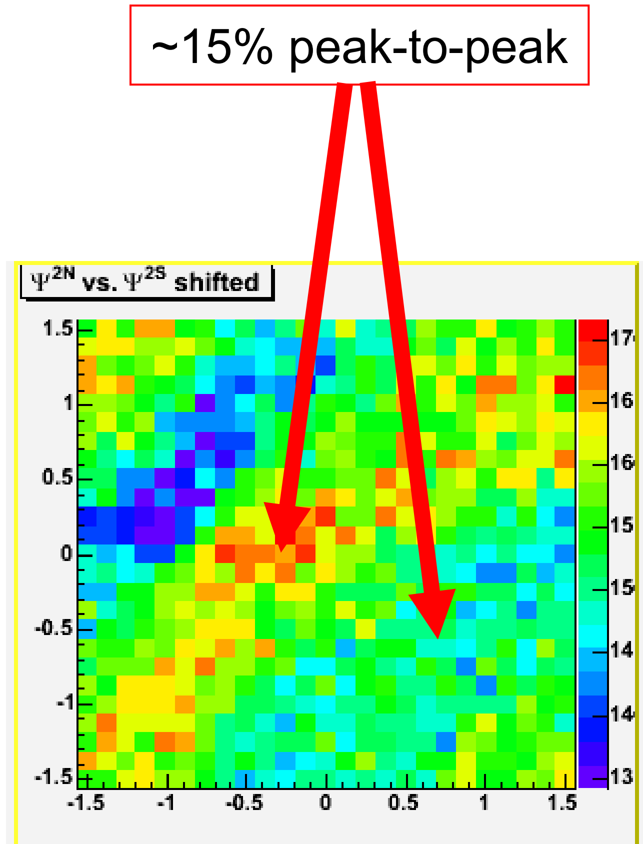


STAR TPC
~50 hits/side
$V_2 \sim 2.8\%$



Current status of MVD Analysis

- As soon as expected N/S correlation is observed, single muon and J/Ψ vs reaction plane analysis can begin.
- Only limitation right now is statistics. We expect a ~15% peak->peak correlation between N & S, statistical errors are higher than that for the current sample. A larger sample is being processed as we speak.



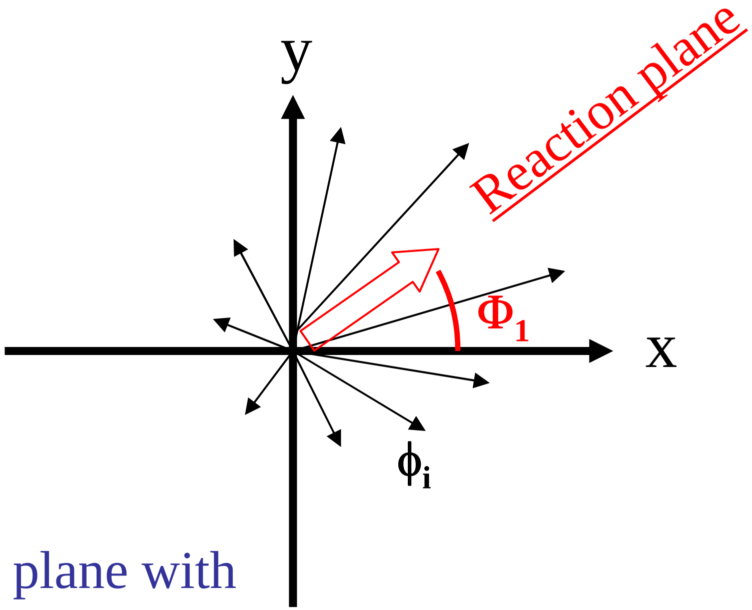
Summary

- MVD analysis is more complicated than BBC due to large acceptance gaps.
- MVD reaction plane is progressing, so far results are promising.
- Capability to extract MVD reaction plane will be in CVS by the time run 4 AuAu analysis code is run.
- The MVD (hits) will live in EVE_DST and be available on disk.

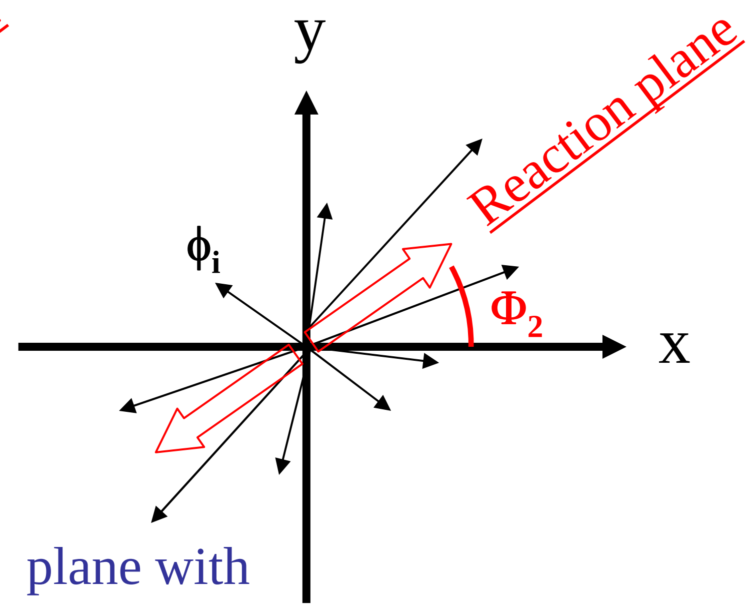
Extras

Reaction plane defined

ShinIchi Esumi



plane with
the directed moment



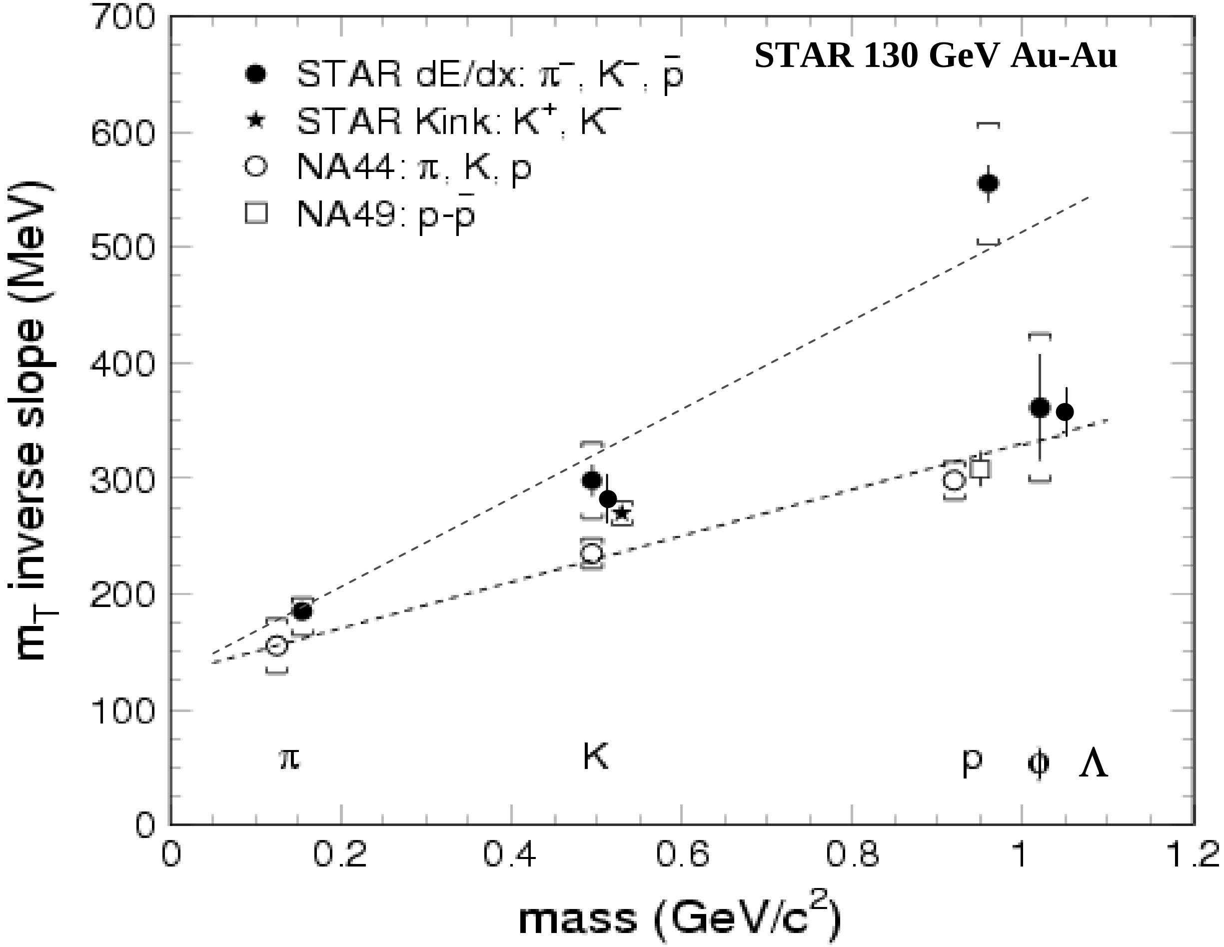
plane with
the elliptic moment

$$\tan(\Phi_1) = \frac{\Sigma\ w_i * \sin(\phi_i)}{\Sigma\ w_i * \cos(\phi_i)}$$

$$\tan(2\Phi_2) = \frac{\Sigma\ w_i * \sin(2\phi_i)}{\Sigma\ w_i * \cos(2\phi_i)}$$

(w_i: 1 or p_T)

Mass dependence of m_T slope - Radial Flow



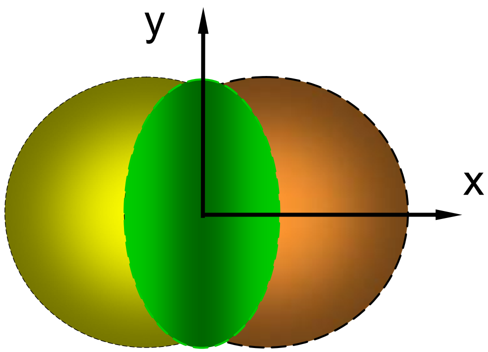
- The different m_T slopes indicate that the slope should not be interpreted as a simple thermal temperature.
- It also has a component from collective radial velocity.

$$\frac{1}{m_T}\frac{d^2N}{dm_T dy} \propto e^{-\frac{(m_T - m)}{T}}$$

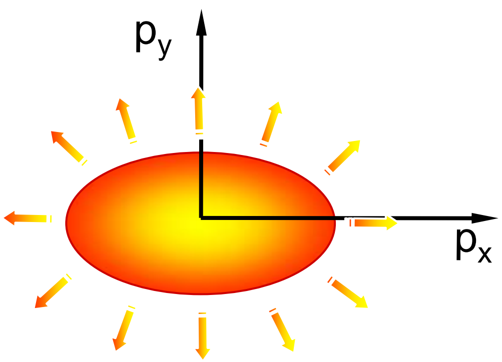
$$T = T_{Th} + m\beta^2$$

Why is elliptic flow interesting?

coordinate space



Momentum space

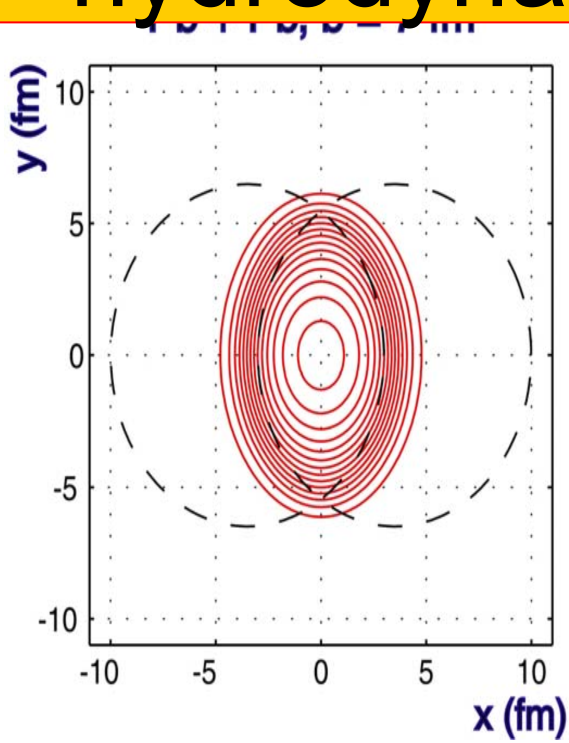


- Coordinate space configuration anisotropic (almond shape) however, initial momentum distribution isotropic (spherically symmetric)
- Only interactions among constituents generate a pressure gradient, which transforms the initial coordinate space anisotropy into a momentum space anisotropy (no analogy in pp) It's strictly a **medium effect**.
- Multiple interactions lead to thermalization -> limiting behavior ideal hydrodynamic flow

$$E\frac{d^3N}{d^3p}=\frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1+\sum_{n=1}^{\infty}2v_n\cos\left(n\left(\varphi-\Psi_r\right)\right)\right)$$

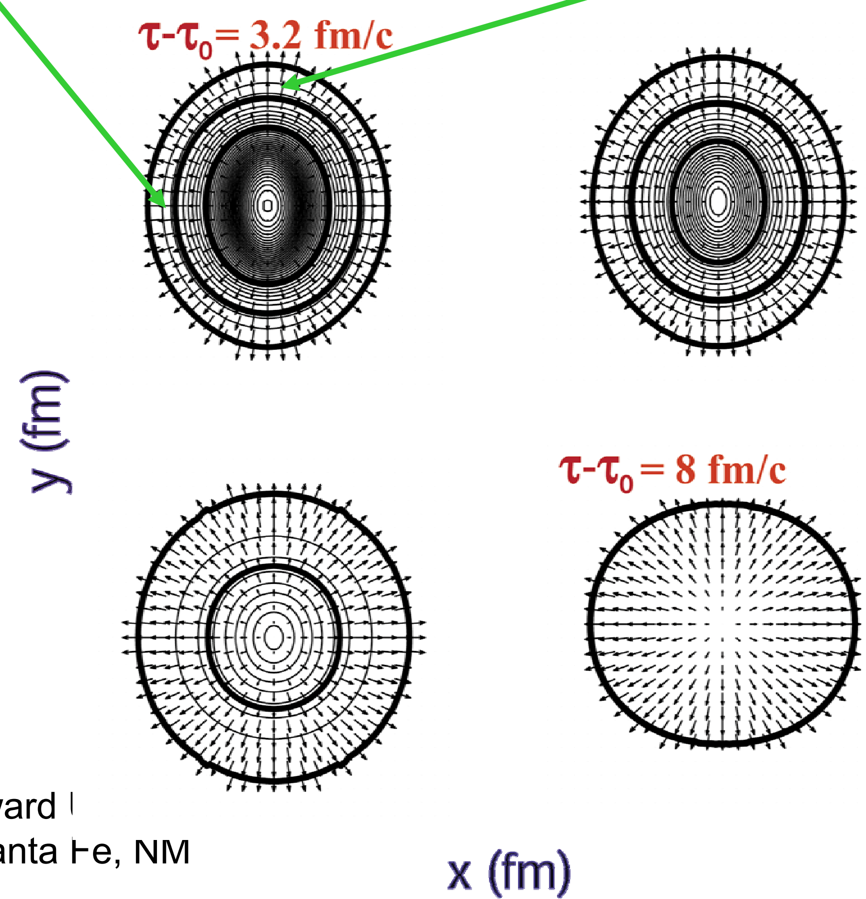
$$v_2=\left\langle\cos 2(\varphi-\Psi_r)\right\rangle,\quad \varphi=\tan^{-1}\left(\frac{p_y}{p_x}\right)$$

Time evolution in a ideal hydrodynamic model calculation



dn/dr (dP/dr) higher

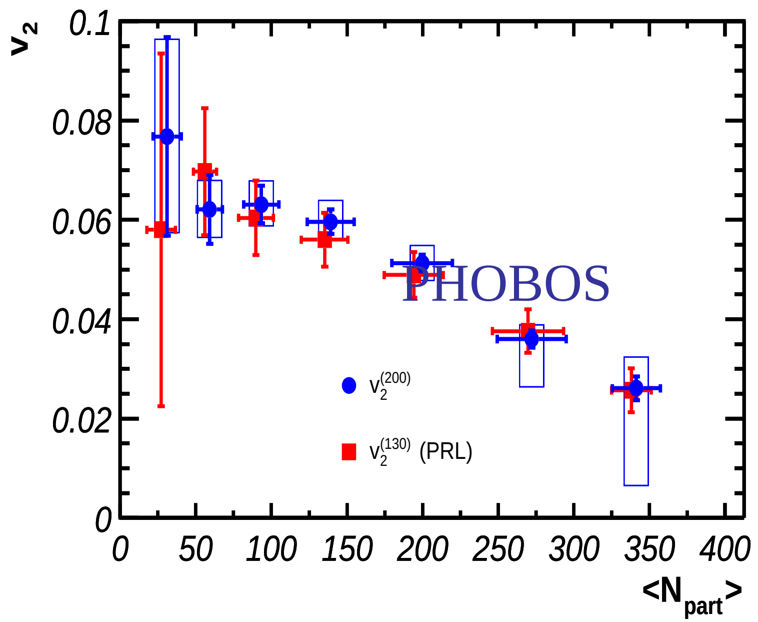
dn/dr (dP/dr) lower

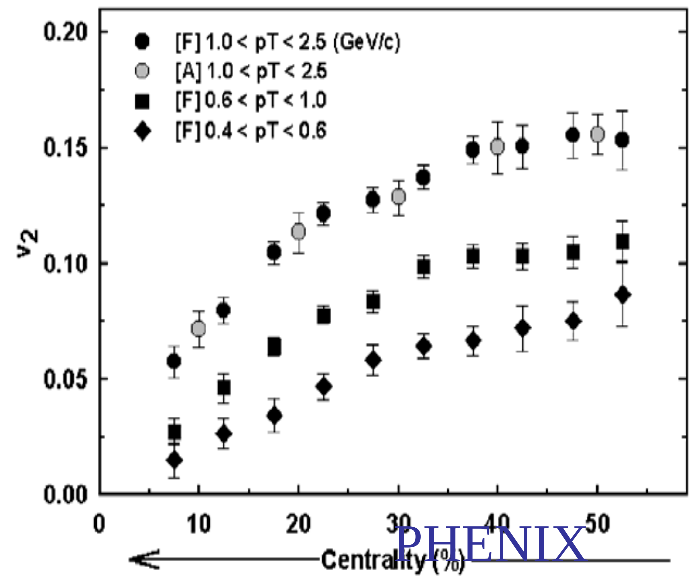


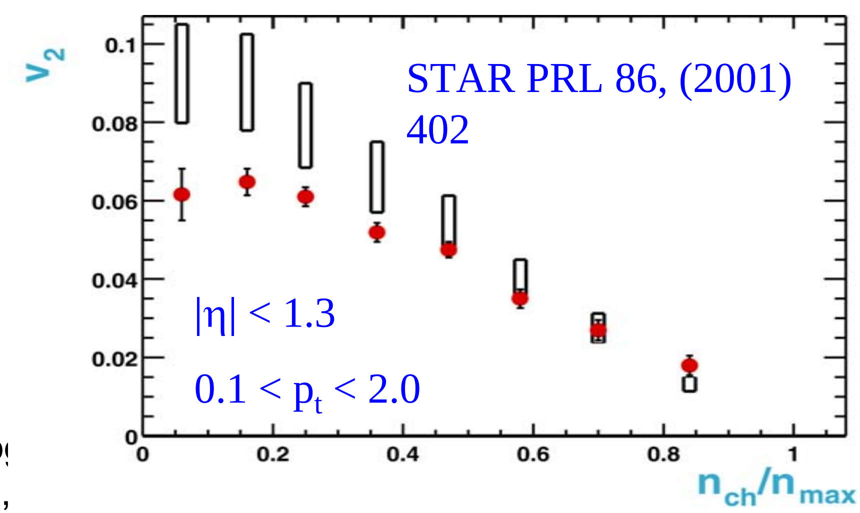
- Elliptic Flow reduces spatial anisotropy -> shuts itself off

“PV = nRT” ➔ dP ~ dn

v_2 versus centrality







First time in Heavy-Ion Collisions a system created which at low p_t is in quantitative agreement with hydrodynamic model predictions for v_2 up to mid-central collisions