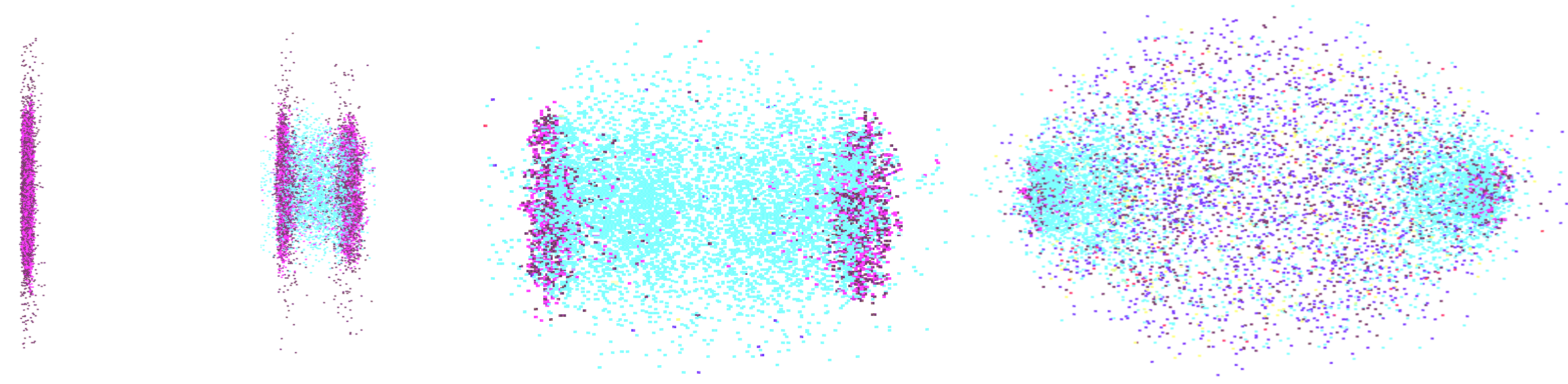
What do we learn from PHENIX high pt results



Jiangyong Jia

State University of NewYork at StonyBrook

For the **PHENIX** Collaboration

Outline

- Quick overview of high pT results from 200GeV
  - Jet-like angular correlation identified
  - High pT suppression continues to highest pT measured
  - Large v2 at high pT
- High pT proton and antiproton from PHENIX
  - Analysis
  - Yield and scaling behavior
- What have we learned
- Comparison with simple geometrical model calculation.
  - Consistent with high pT yield and di-jet suppression
  - Insufficient to describe v2
- Conclusion

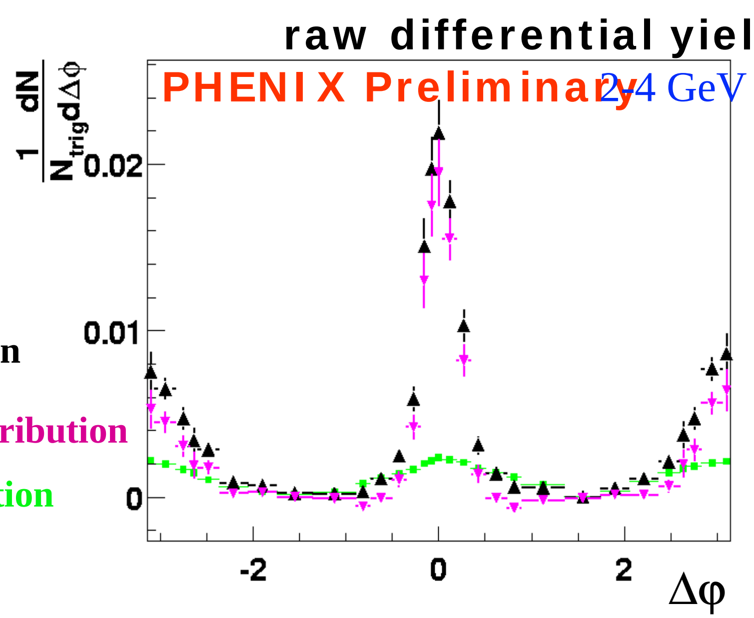
Direct observation of jets

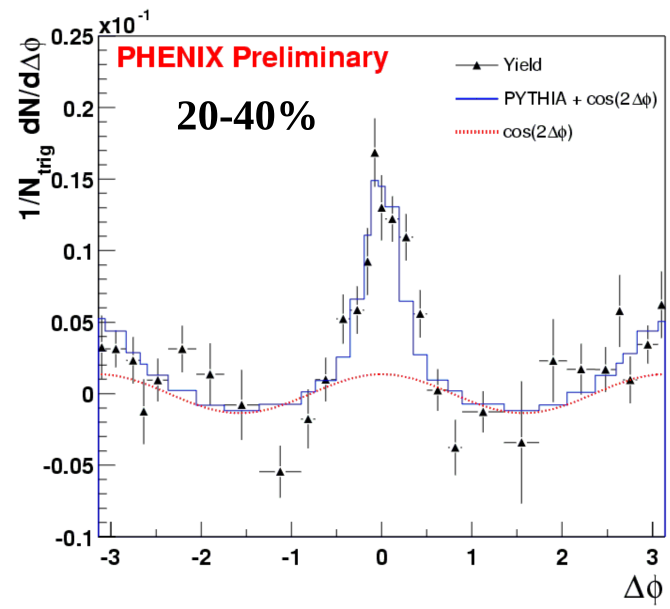
- **Leading particle + angular correlation**
  - **Trigger photon E_{γ}>2.5 GeV**
  - **Correlate with partner charged particle**
- **Jet like near angle correlation for p+p and Au+Au**
  - **Similar width**
  - **Jet fragmentation not modified much?**

Pair distribution

Subtracted distribution

Mixed distribution

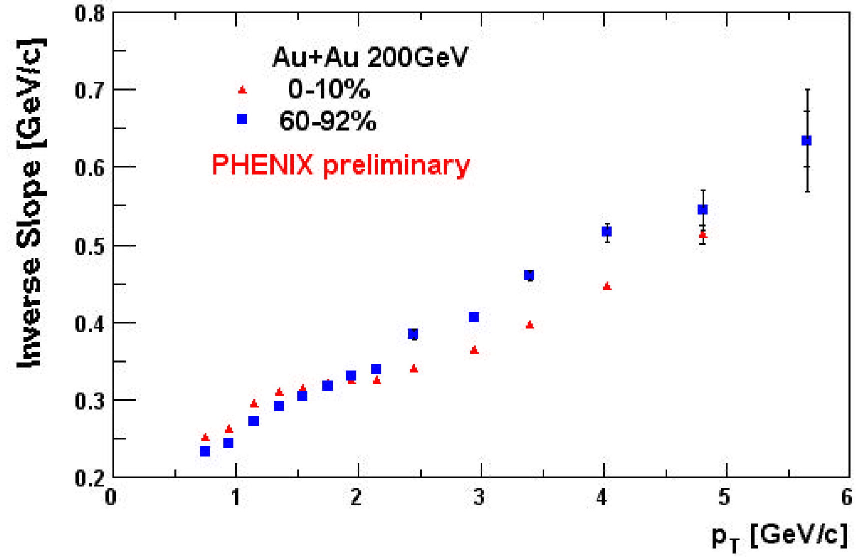




STAR measure the same and away side jet yields 4 D. Hardtke

Spectra shape at high pT

- **Inverse slope increase with pT**
  - **Spectra is more power law**
- **$<p_T^{trunc}> = \langle p_T \rangle - p_T^{min}$ as function of centrality**
  - **Nearly flat at high pT**
- **pT>4 GeV/c are jet like**



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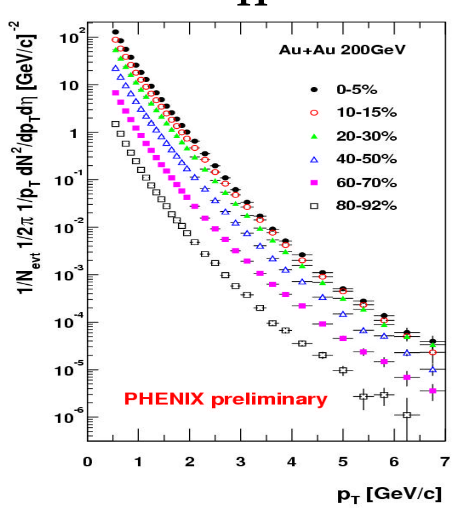
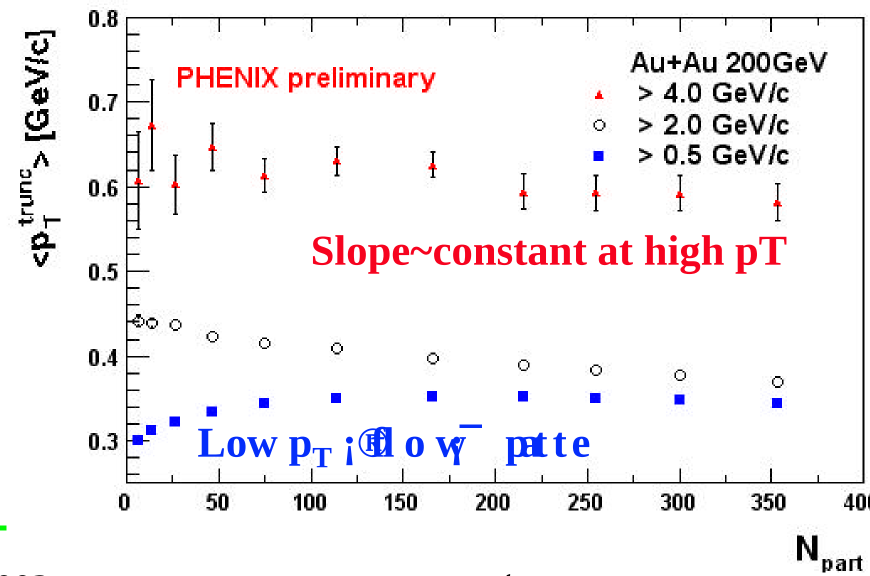
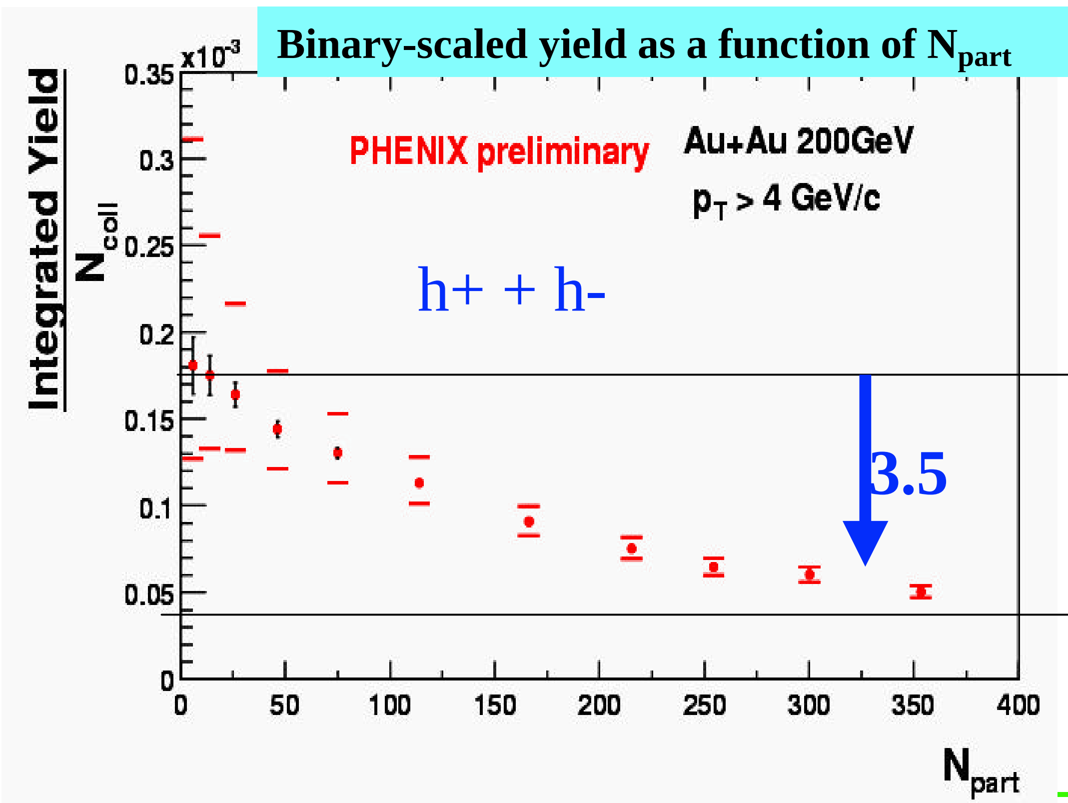
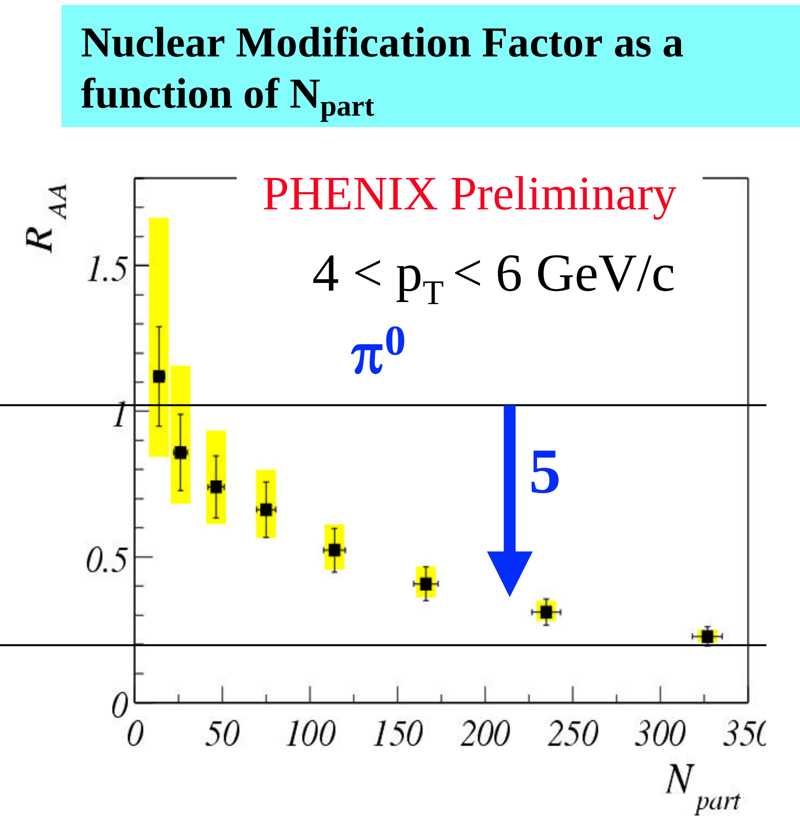




Centrality dependence of high pT suppression

- Continues decrease as function of centrality
- Charged : factor ~3.5 from peripheral to central
- π^0 : factor ~5 from peripheral to central



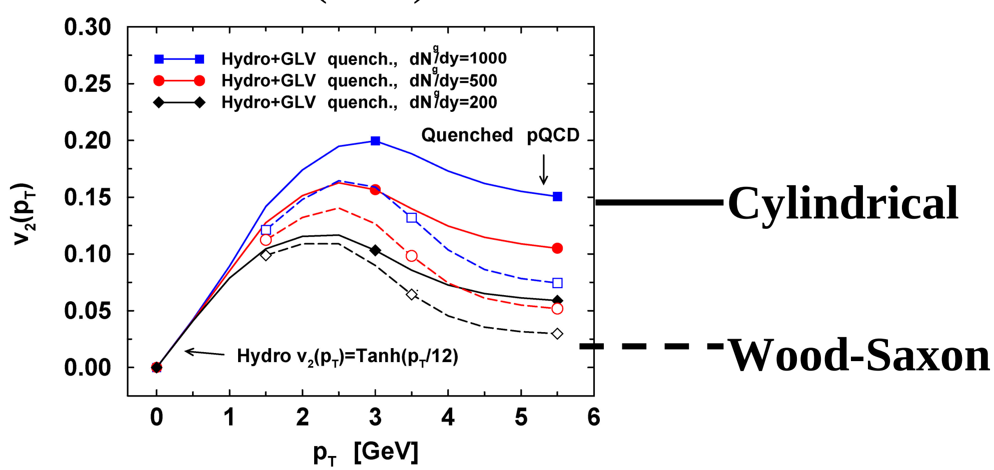


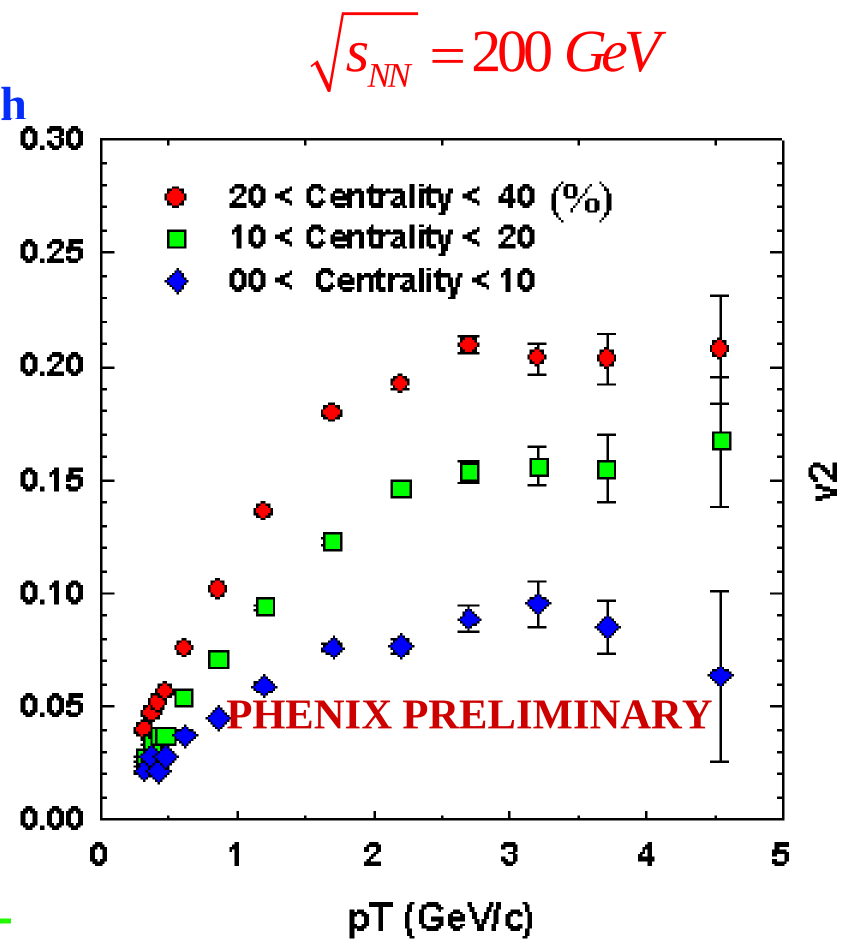
Anisotropy in momentum space = v2

- V2 saturates at high pT
- Can be described by pure energy loss?
- hydro pic: v2 created by pressure.
- Jet pic:
  - Different energy loss along different path
  - Sensitive to geometrical profile
  - Decrease with pT?

M. Gyulassy, I. Vitev and X.N. Wang

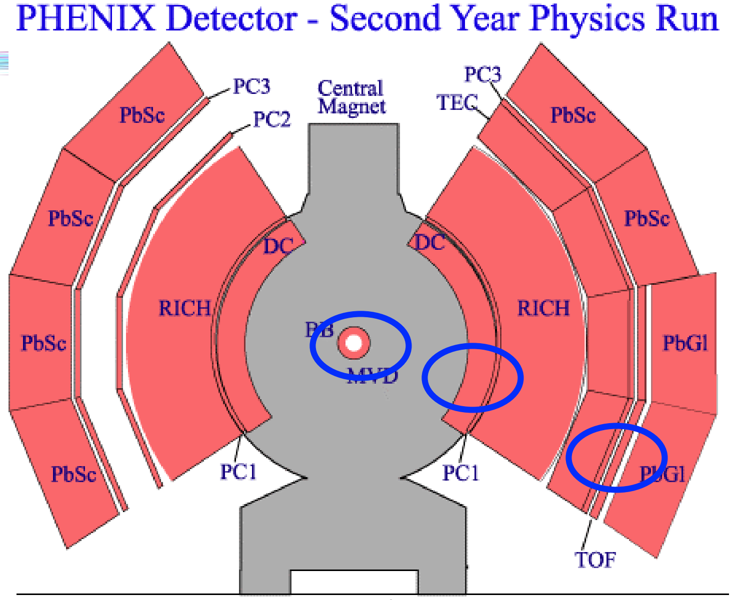
PRL 86 (2001) 2537

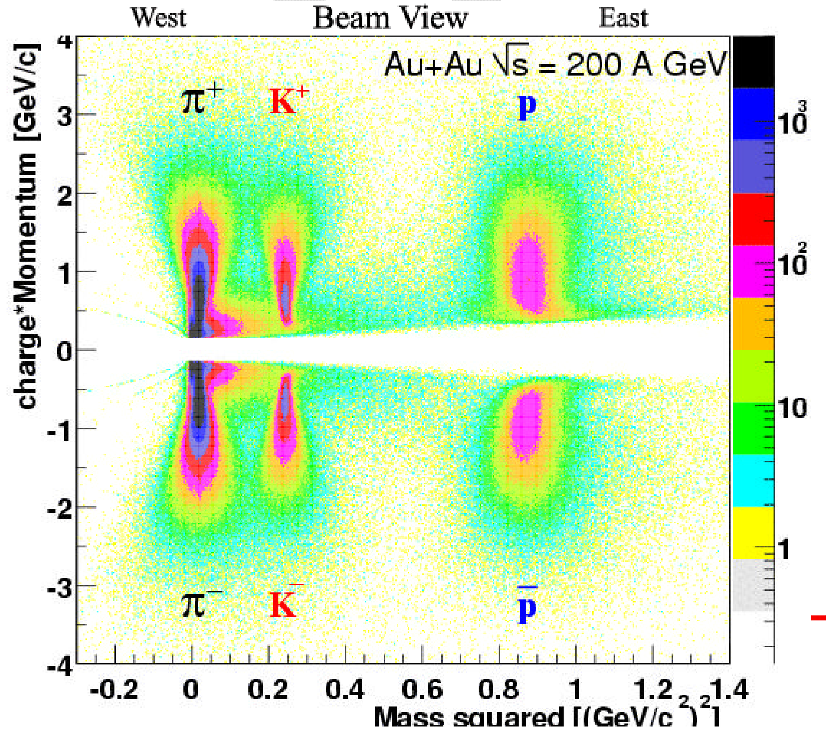




Analysis of high pT proton and antiproton

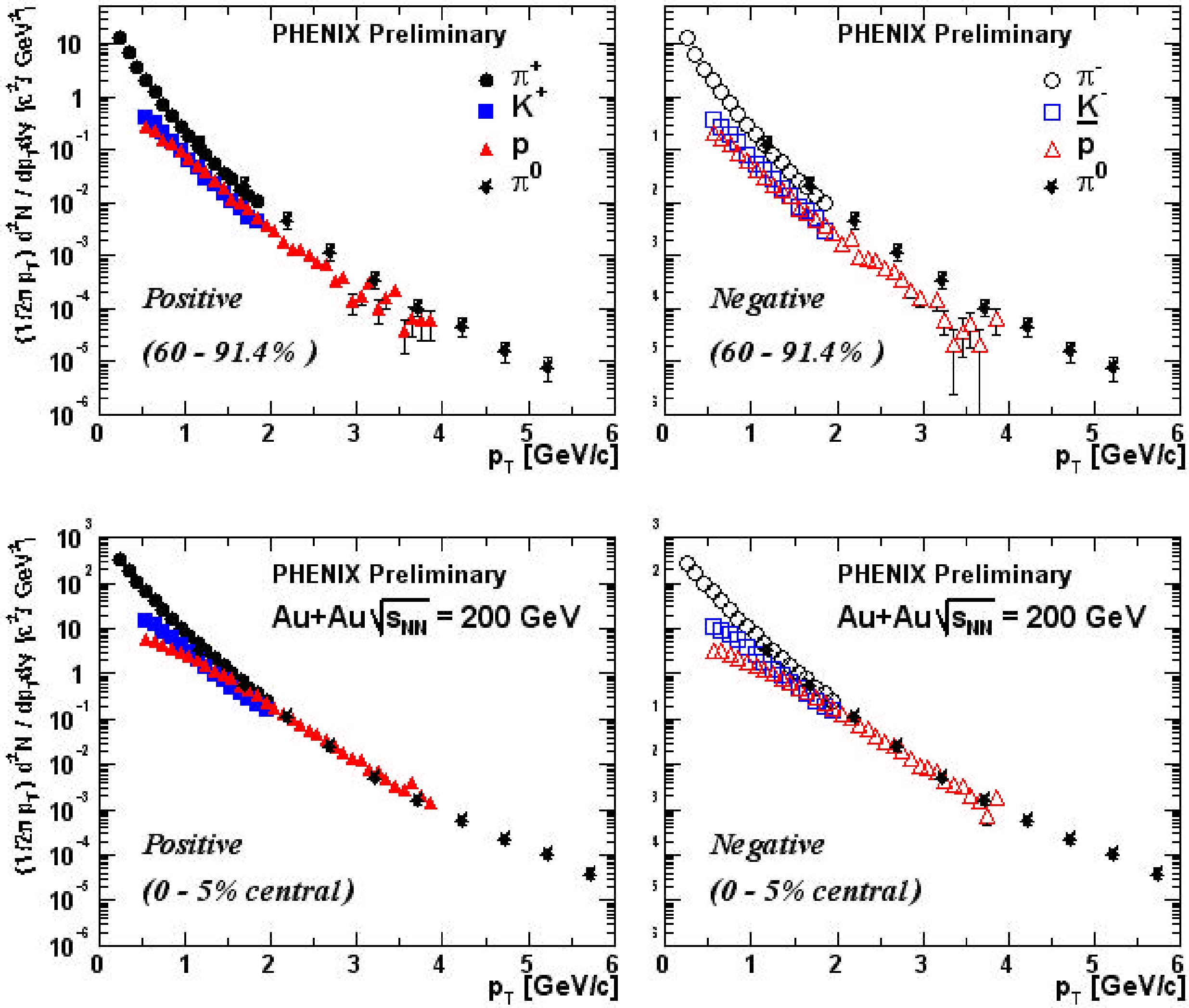
- **Using High Resolution TOF PID device and Drift Chamber.**
- **Making p_T dependent 2σ cut in squared mass**
- **Range and Systematic Error**
  - **proton, pbar: up to 4GeV/c**
  - **p_T dependent: 11%**
  - **Overall normalization:**
    Central 18%, Peripheral 16.4%





Identified hadron spectra at sqrt(s) = 200 GeV

- **Excellent agreement between charged and neutral pions**
- **anti(proton) yields increase with centrality relative to the pion yield at high pT**



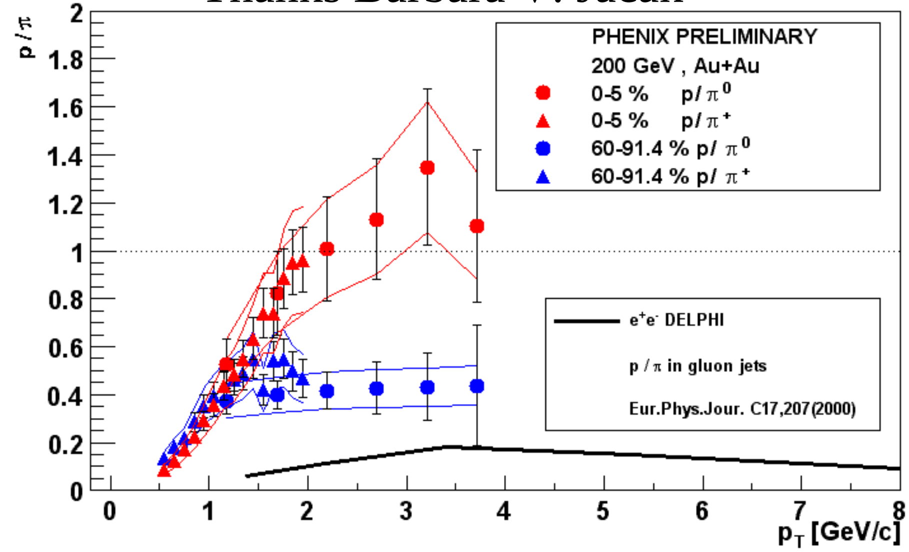
Centrality and pT dependence of p/π

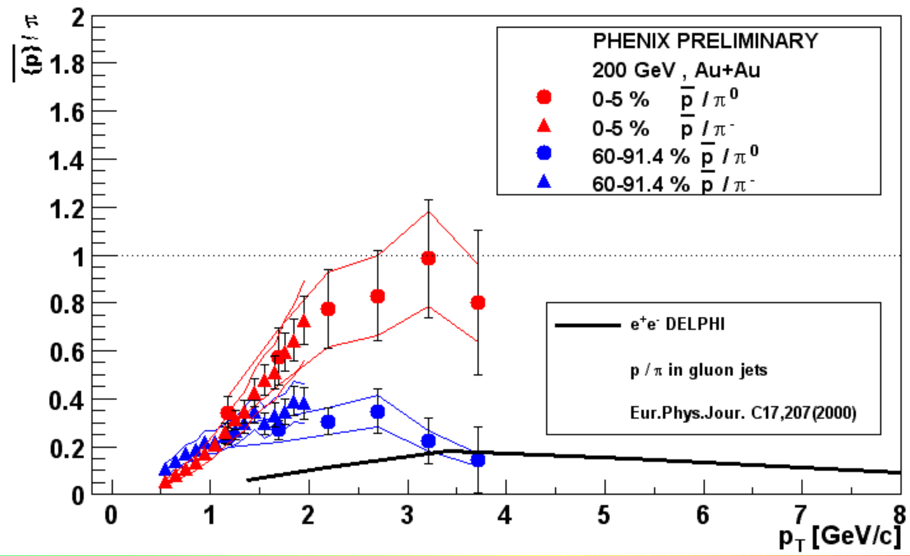
- p/π ratio for AuAu at pT>2GeV
  - ~ 1 in central collisions
  - ~ 0.4 in peripheral collisions
  - ~ 20% lower for anti-proton

  - Above gluon jet value

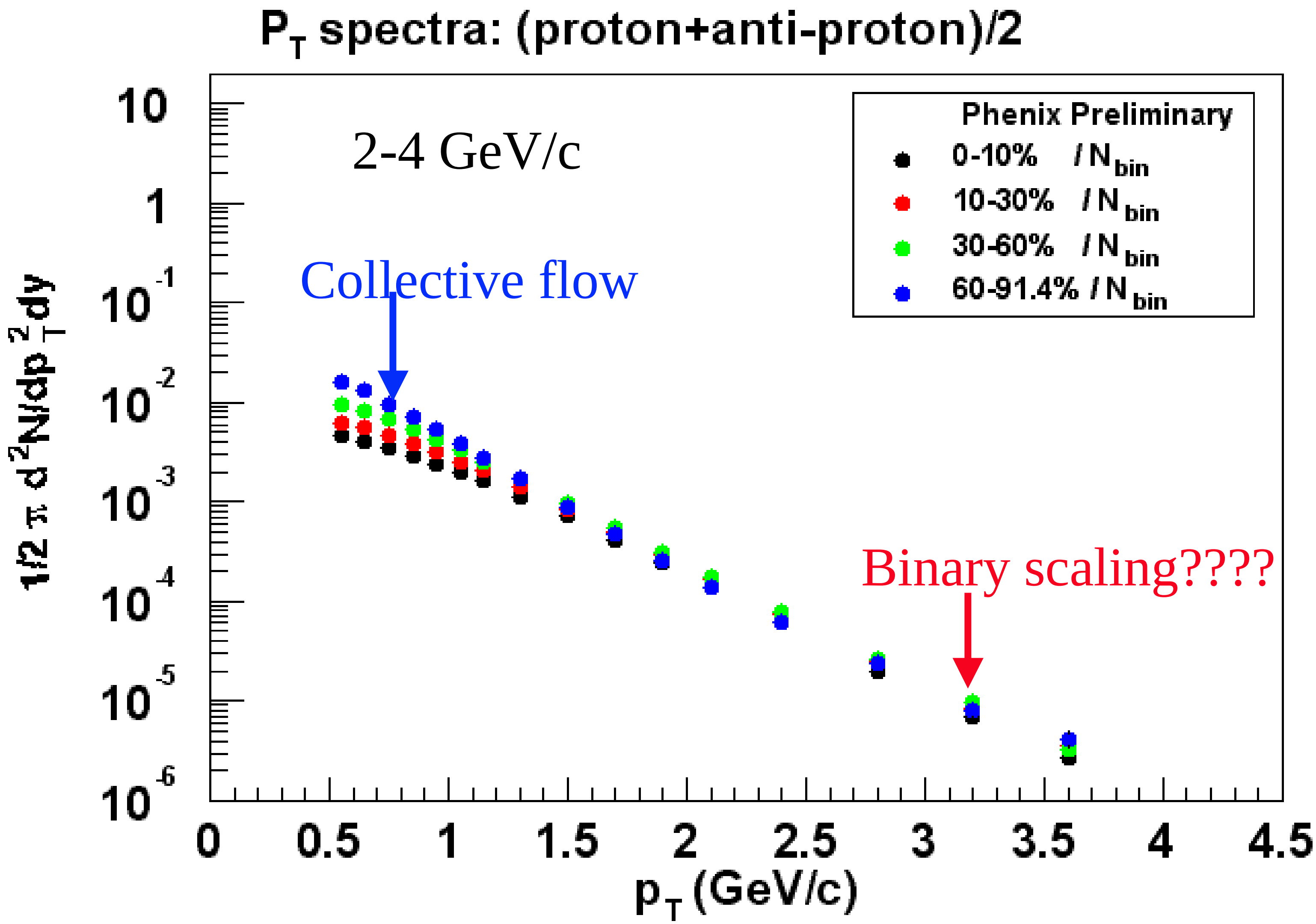
If the observed anti(proton) are from fragmentation, then it is not standard fragmentation

Thanks Barbara V. Jacak

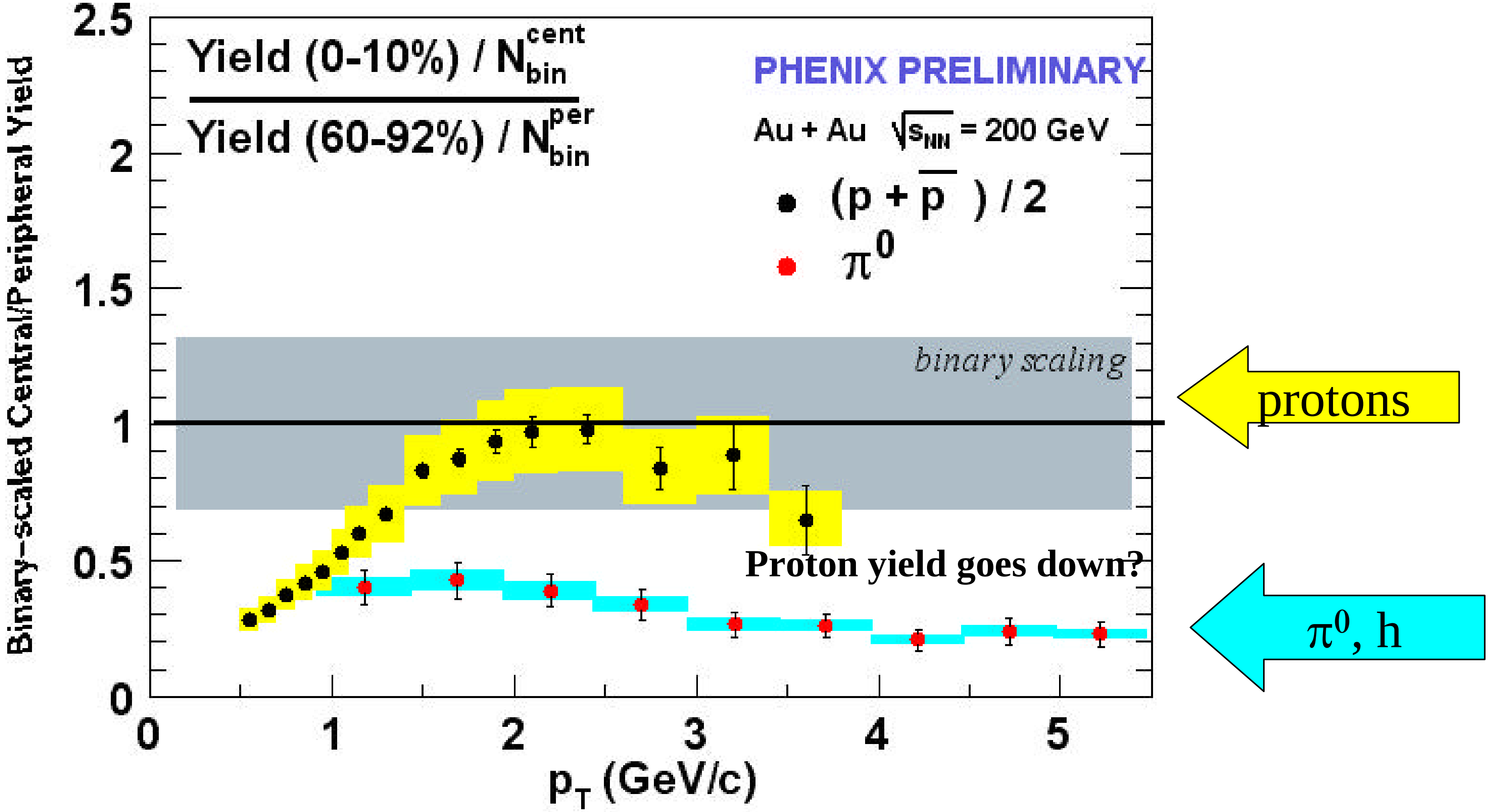




Scaling of the $\bar{p}$ p spectra

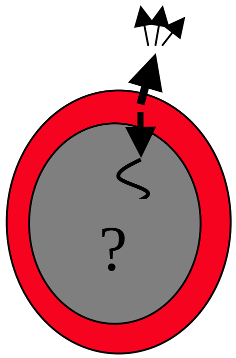


Are proton and antiproton suppressed?



What have we leaned?

- **Strong centrality dependence of suppression, v2, away side jets at high pT**
  - **Suggestive of surface emission of jets or mono-jet production?**
  - **Saturation(initial state), Jet quenching(final state)**



- **Binary scaling of protons yield between 2-4 GeV/c**
  - **Soft or hard or in between?**
  - **Baryon transport**

Inspired by E. Shuryak Phys.Rev. C66 (2002) 027902

- **Which effect can be explained by jet absorption and collision geometry?**
  - **Consistent with high pT yield and di-jet suppression.**
  - **Insufficient to describe v2**
  - **Can¡ft describe proton yield since there is no absorption**

Simple Toy Geometrical Model for Jet absorption

- **Jets are absorbed in overlap region according to**

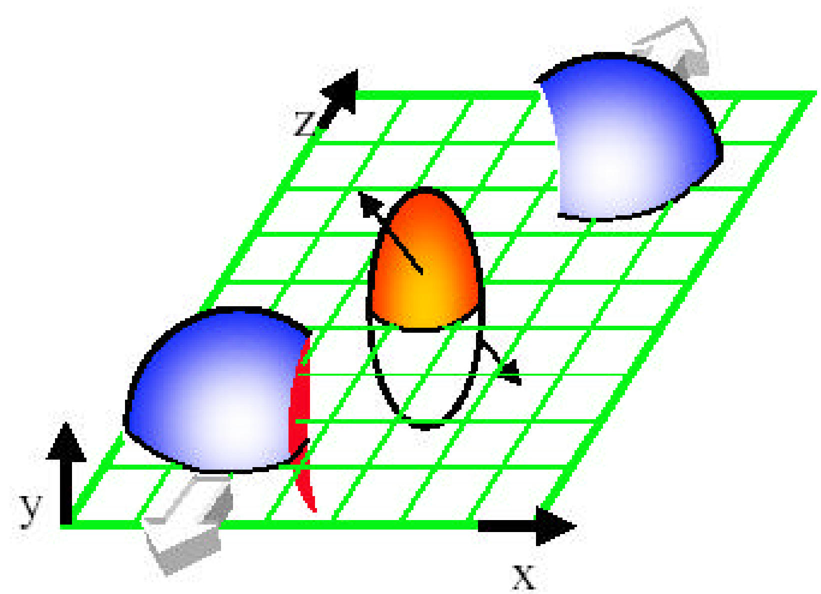
$$f = e^{-k\int \rho\, dl}$$

- **Density of matter in transverse plane determined by participant density**

$$\rho \sim \rho_{\mathbf{Npart}}$$

- **Azimuth isotropic di-jets production according to binary collision profile**

$$\rho_{\mathbf{Ncoll}}$$



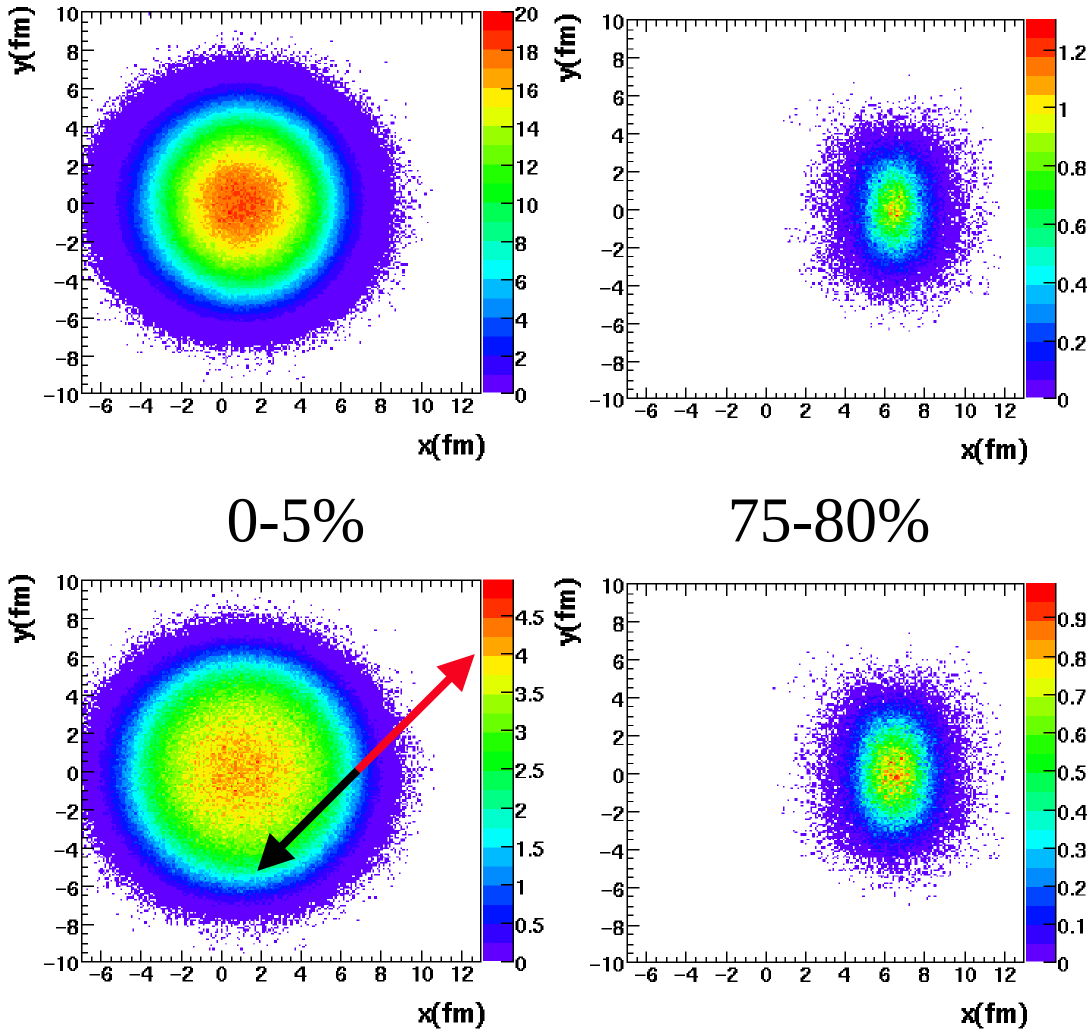
- **Hadron spectra are related to jet distribution via parton-hadron duality**

Density distribution calculated from glauber model

Wood-saxon nuclear density profile

ρ_{Npart}

ρ_{Ncoll}



Model Assumptions to Compare with Data

- **Model is simplistic and can only describes main features of geometry**
  - **Assume all particles above 4 GeV/c from jets**
  - **Assume jets are back-to-back**
  - **Ignore the fragmentation**
  - **Contains no pT and √s and flavor dependence**
  - **Try different kind of absorption :** $f = e^{-k I_i}$
  - **κ is the only free parameter**

Normal nuclear absorption

$$I_1 = \int_0^\infty dl \ \rho(x, y)$$

Energy loss style absorption

$$I_2 = \int_0^\infty dl \ l \ \rho(x, y)$$

Absorption + expansion, $l_0 \sim 0.2$ fm

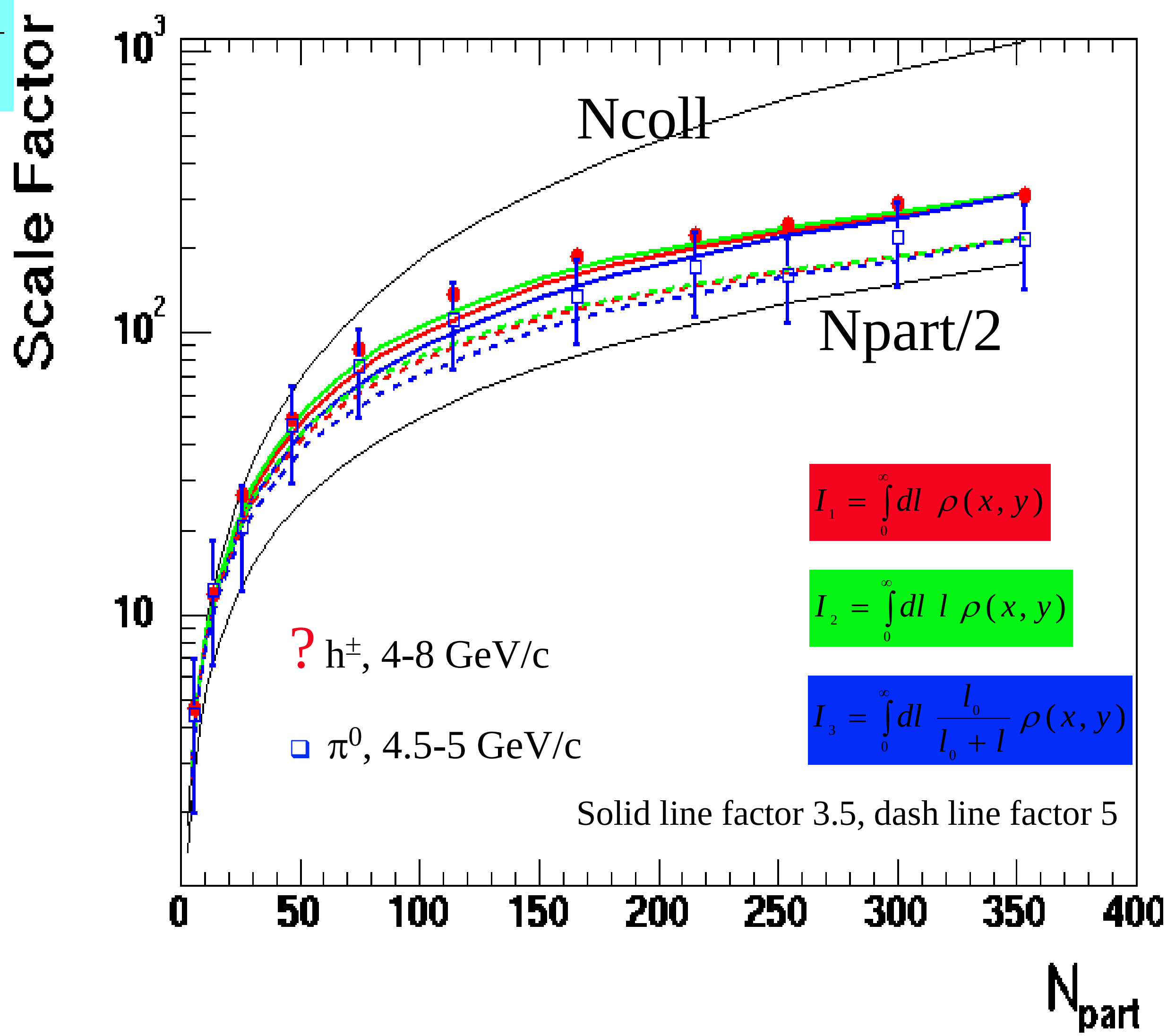
$$I_3 = \int_0^\infty dl \ \frac{l_0}{l_0 + l} \rho(x, y)$$

- **Adjust absorption strength k to reproduce suppression factor of 3.5(charged) and 5(π^0) in most central collisions.**
  - **Predict centrality dependence of yield suppression**
  - **Predict centrality dependence of di-jet suppression**
  - **Predict centrality dependence of v2**

Scaling behavior of the yields

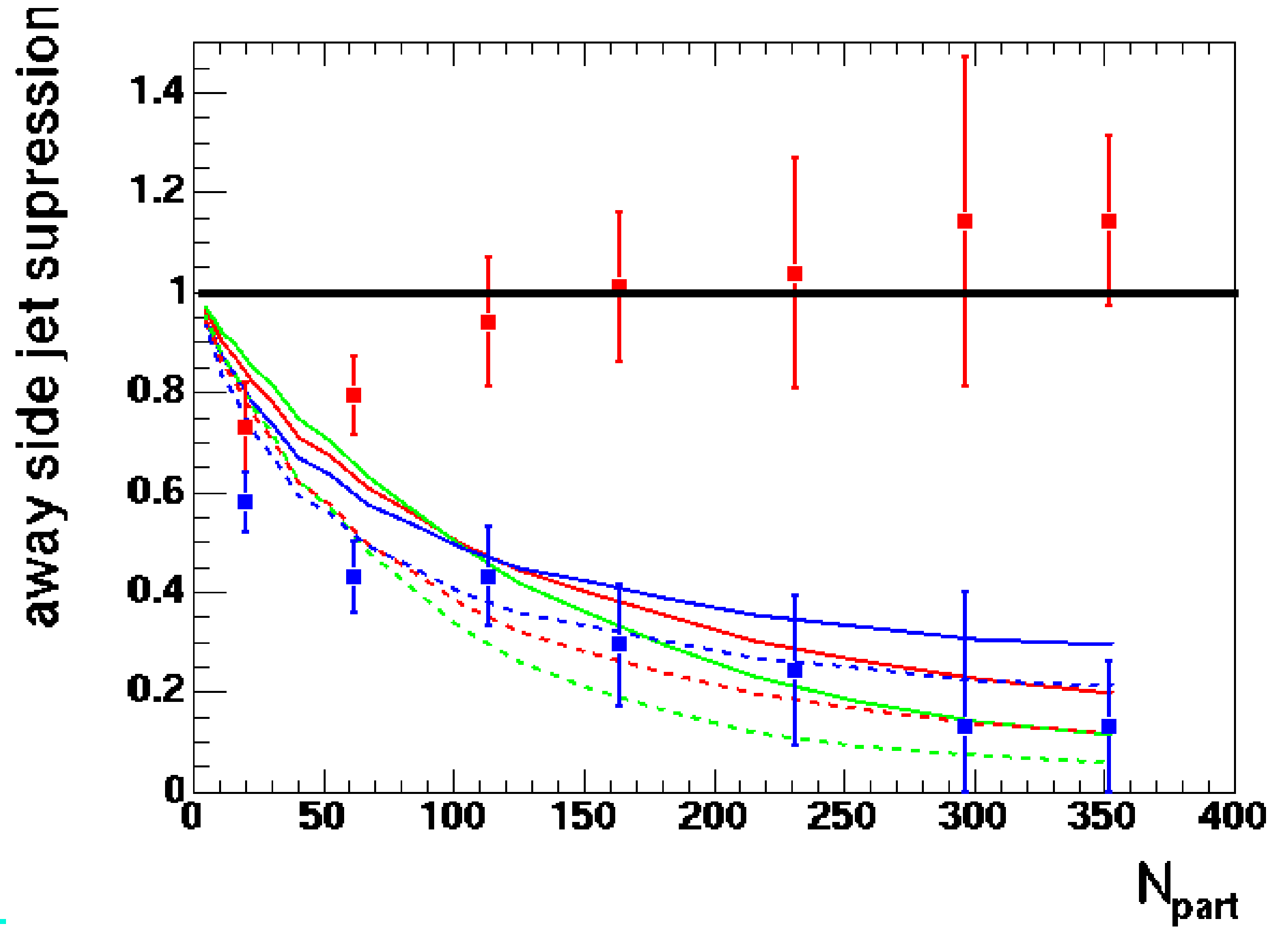
$$Sy(b) = \frac{y_{AuAu}(Npart)}{y_{AuAu}(peri)\ \textbf{or}\ y_{pp}}$$

- **Qualitatively describe the centrality dependence of the yield**
- **Not sensitive to the absorption pattern**



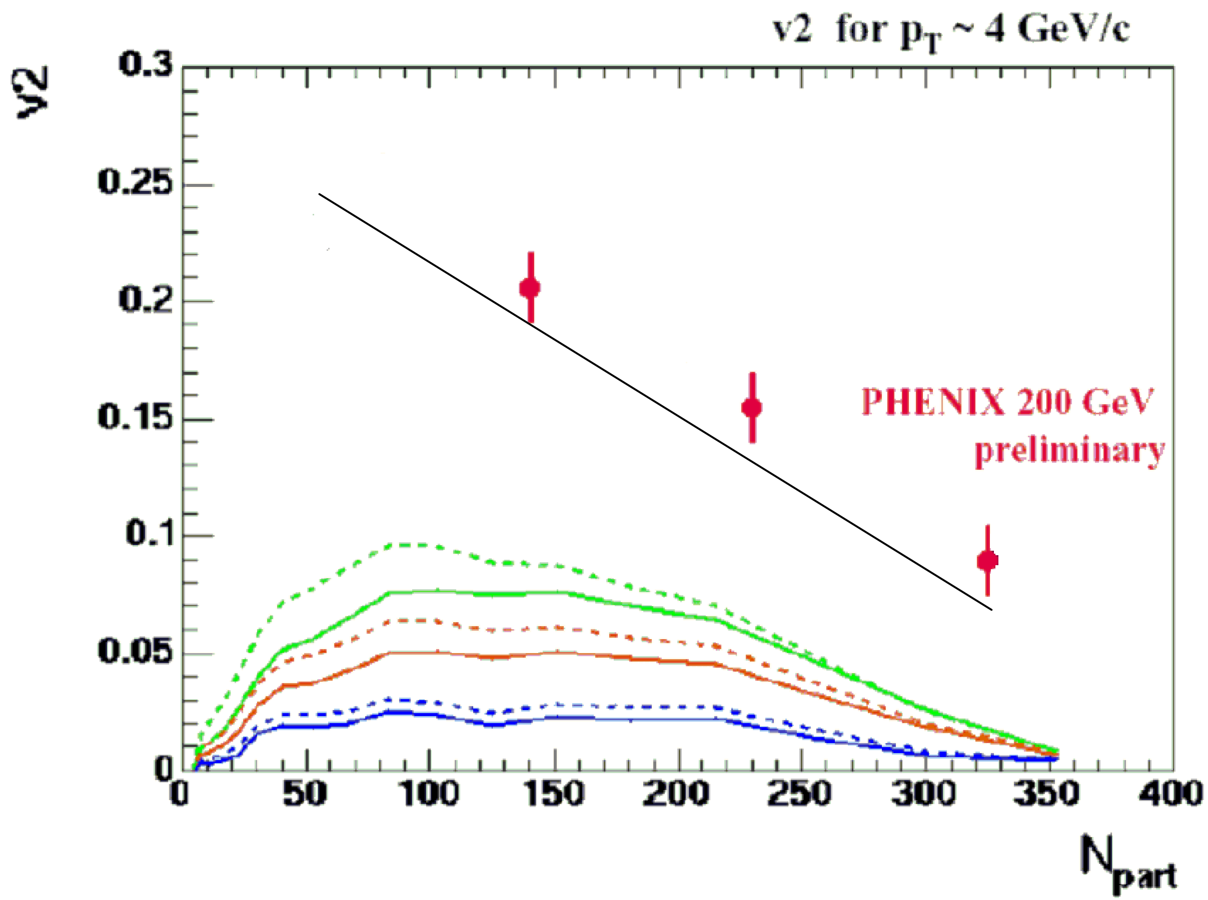
Centrality dependence of back-back jets

- **Compare STAR back-back jet measurement for 4 <pT<6 GeV/c**
  - **By construction, same side jet will always be 1**
  - **Qualitatively describe the centrality dependence of the away side**



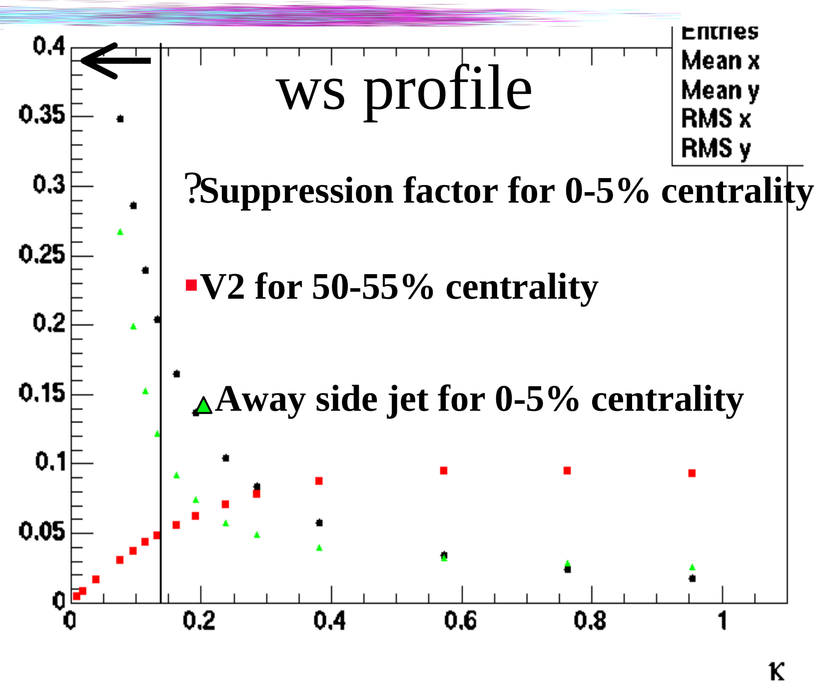
Centrality dependence of v2

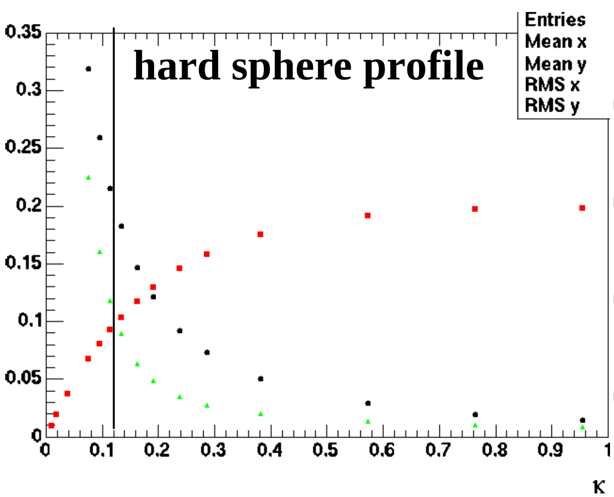
- **NB: in these models,v2 are purely geometrical origin, does not consider detailed modification of momentum distribution**
- **Geometrical anisotropy is insufficient to produce observed v2 by jet absorption**
- **V2 is sensitive to absorption model, smallest for longitudinal expanding source**
- **V2 will increase using hard sphere or cylindrical nuclear profile, but unphysical**

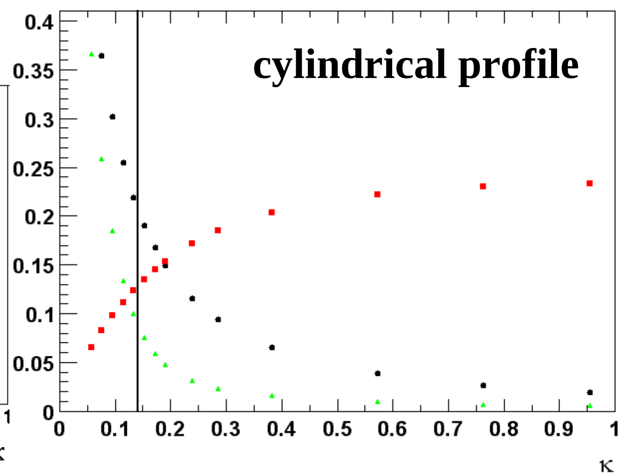


Varying κ

- Maximum v2 produce by surface.
- Different geometrical profile have different geometrical limit.
- v2 is below geometrical limit at experimental observed suppression value







For sphere, surface volume is

$$\frac{4\pi R^2 d}{4/3\pi R^3} = \frac{3d}{R} \sim 26\%$$

S. Voloshin

$$\textbf{cyl profile}: v_{\max} = \sin(2\alpha)/6\alpha$$

Conclusion

- **Exciting high pT results from 200GeV AuAu**
  - **Direct observation of jets**
  - **Strong high pT suppression**

  - **Puzzle1 : Large v2 at high pT**
  - **Puzzle2: High pT proton and antiproton**

    Binary scaling between 2-4GeV/c

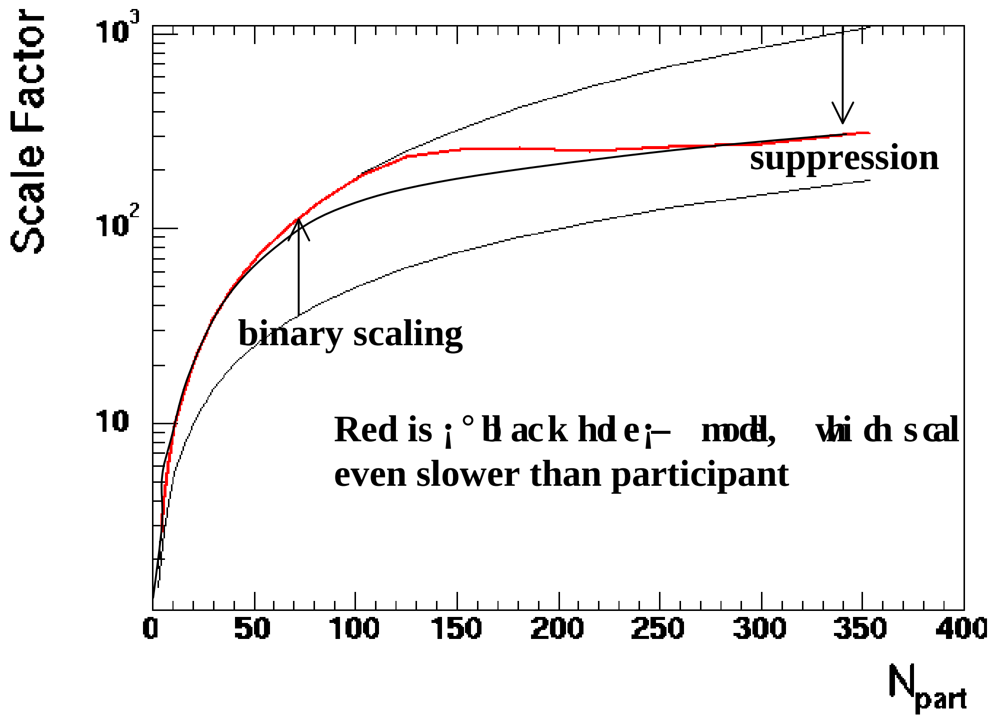
    Mysterious particle composition at high pT.

- **Jet absorption gives characteristic centrality dependence of observables**
  - **Consistent with high pT yield and di-jets suppression**
  - **Insufficient to describe v2 and proton yield**

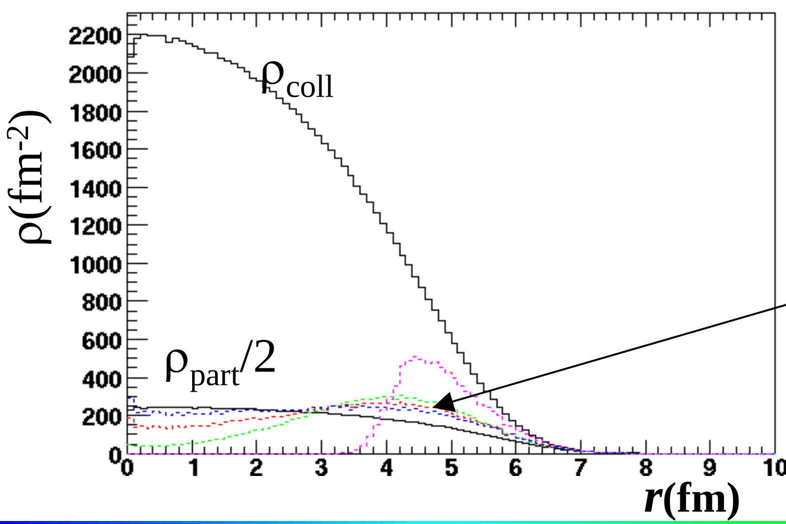
Discussion on Scaling

- **Absorption model naturally lead to stronger suppression in large ρ_{Ncoll} region**
  - **Reduce binary scaling**

$$\frac{\rho_{Ncoll}}{\rho_{Npart}} \sim \sqrt{R^2 - r^2}$$



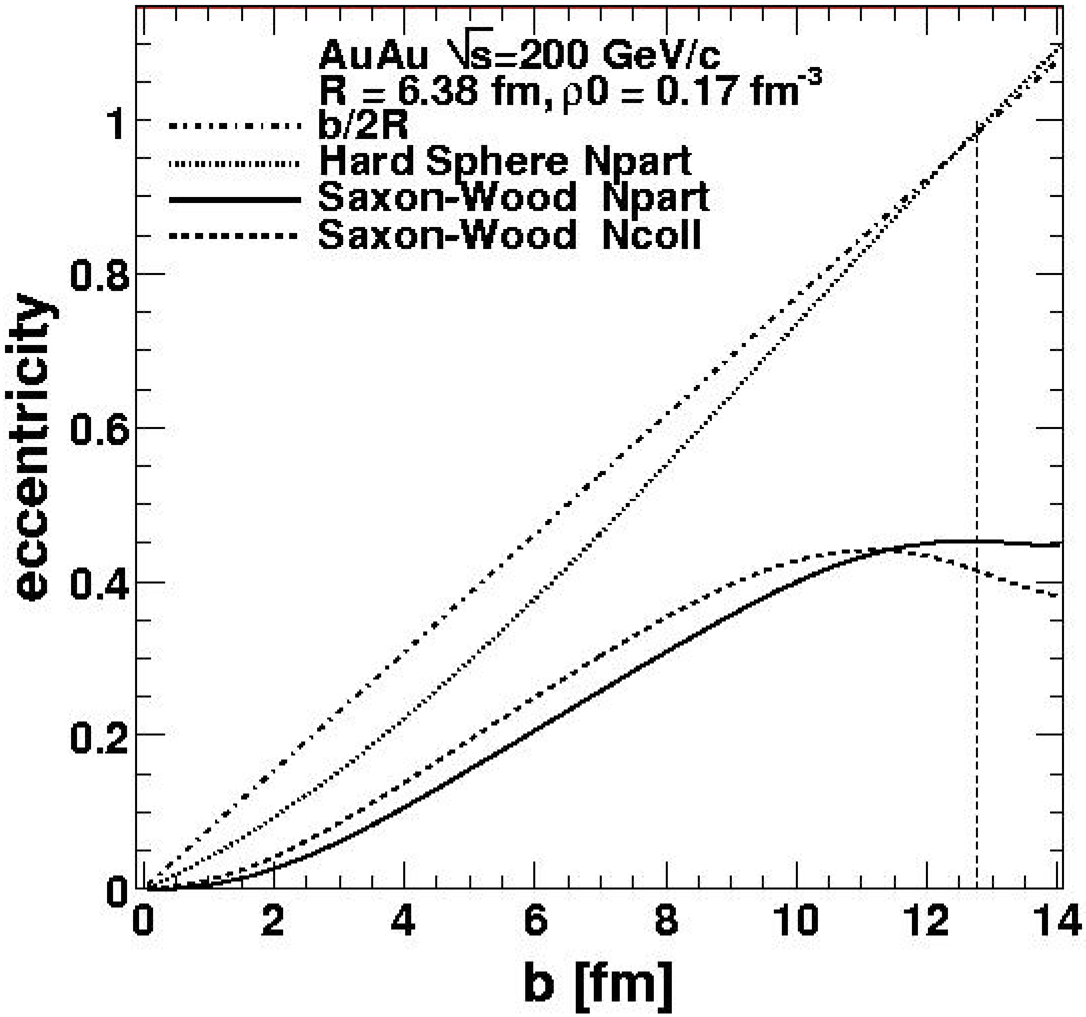
Density distribution for surviving jets (b<3fm)



Suppression can lead to Npart scaling

Hard sphere vs Saxon-Woods eccentricity

Made by Jan. Rak



$$\epsilon = \frac{< y^2 - x^2 >}{< y^2 + x^2 >}$$

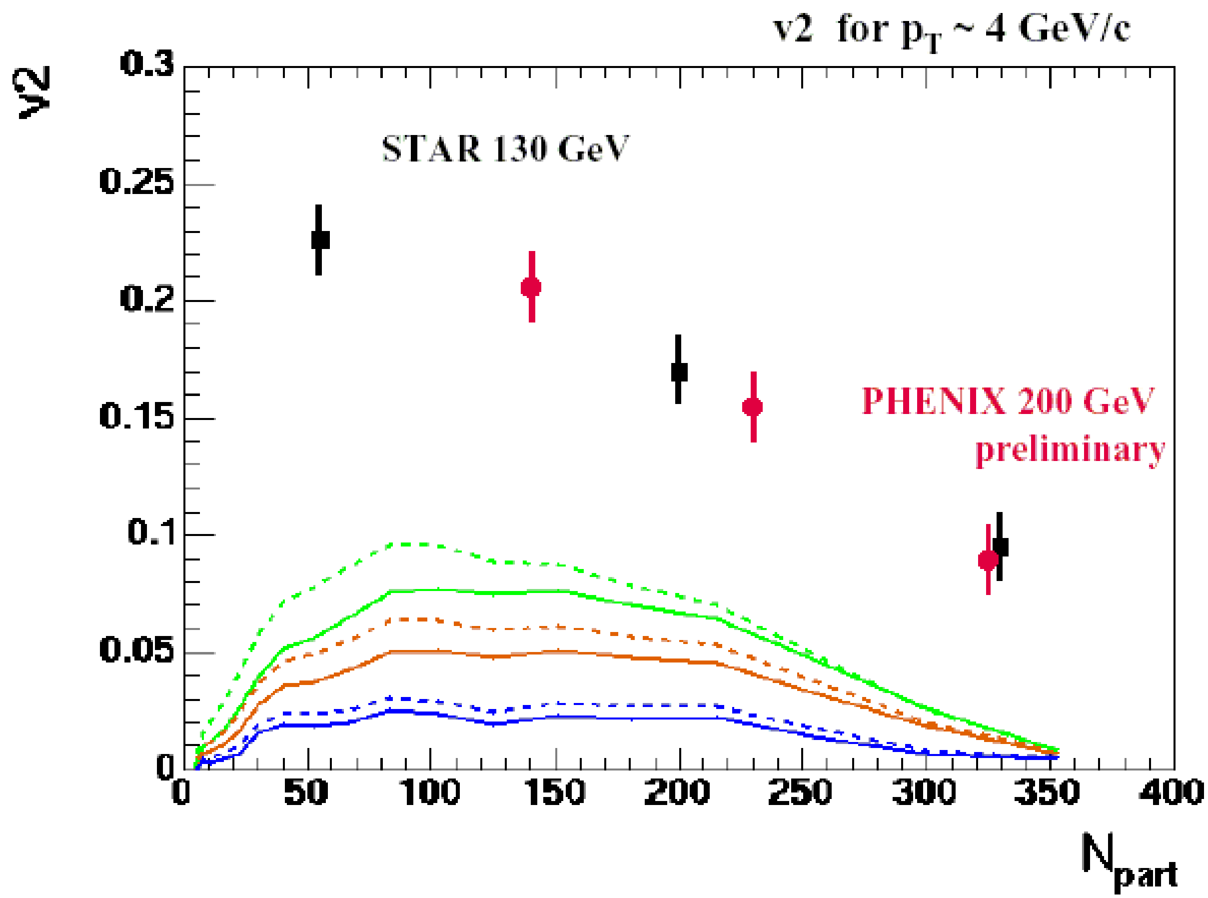
$$v_2(p_\perp) = \frac{< p_y^2 - p_x^2 >}{< p_y^2 + p_x^2 >}$$

- sheer almond $\varepsilon = b/2R$
- HS $\varepsilon \approx b/2R$
- Npart $\varepsilon \approx \sqrt{cent}/2$

HS overpredict eccentricity by factor of 2.

Any meaningful geometrical estimate has to be infered from SW

$$
\begin{aligned}
P_{esc} &= \int_0^{\infty} dh\, exp(-\rho\sigma h/\cos\theta) \;\; \propto \;\; \cos\theta|_{\sigma\to\infty} \\
v_2 &= \int d\phi\, P_{esc}\cdot\cos(2\phi) = \int_{-\alpha_m}^{\alpha_m} d\alpha \int_{-\pi/2}^{\pi/2} d\theta\cos\theta\cos 2(\theta+\alpha)\,/\,(2\cdot 2\alpha) \\
&= \frac{\sin 2\alpha}{4\alpha}\int_{-\pi/2}^{\pi/2} d\theta\cos\theta(1-2\sin^2\theta) = \frac{\sin 2\alpha}{4\alpha}(2-\frac{4}{2}) \\
&= \frac{\sin 2\alpha}{6\alpha}
\end{aligned}
$$


v2 for p_T ~ 4 GeV/c
v2
STAR 130 GeV
PHENIX 200 GeV
preliminary
0.3
0.25
0.2
0.15
0.1
0.05
0
0
50
100
150
200
250
300
350
400
N_{part}

Some Simple Mathematics

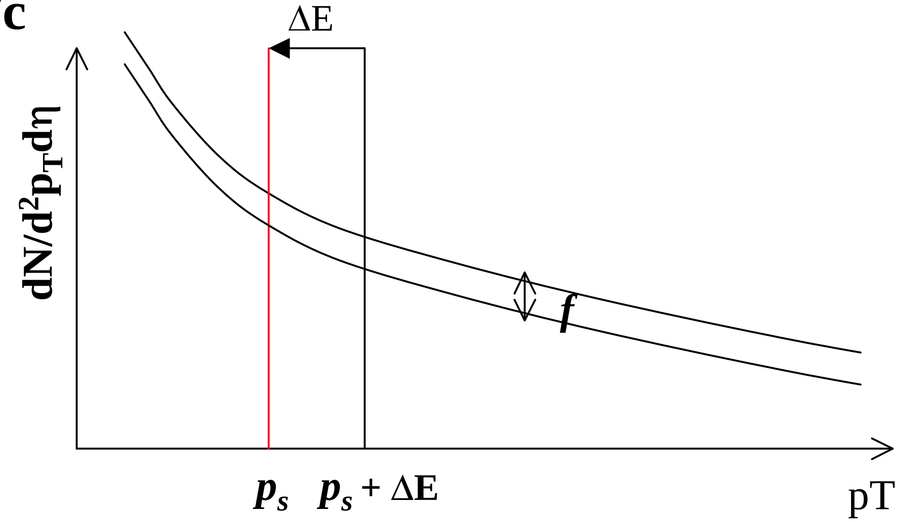
- **We look at particle yield above 4 GeV/c**
  - **Spectra have similar shape as pp**

Assume spectra is:

$$\frac{dN}{d^2 p_T d\eta} \sim e^{-p_T/T}$$

Integrated yield above $\boldsymbol{p_s}$ is:

$$I(p_s) = \frac{e^{-p_S/T}}{T}$$



Assume energy loss $\Delta E(p_T)$ is independent of pT:

$$I_1(p_s) = \frac{e^{-(p_S+\Delta E)/T}}{T} = f\ I(p_s), \text{ where } f^{-1} = e^{\Delta E/T} \text{ is } \textbf{suppression factor}$$

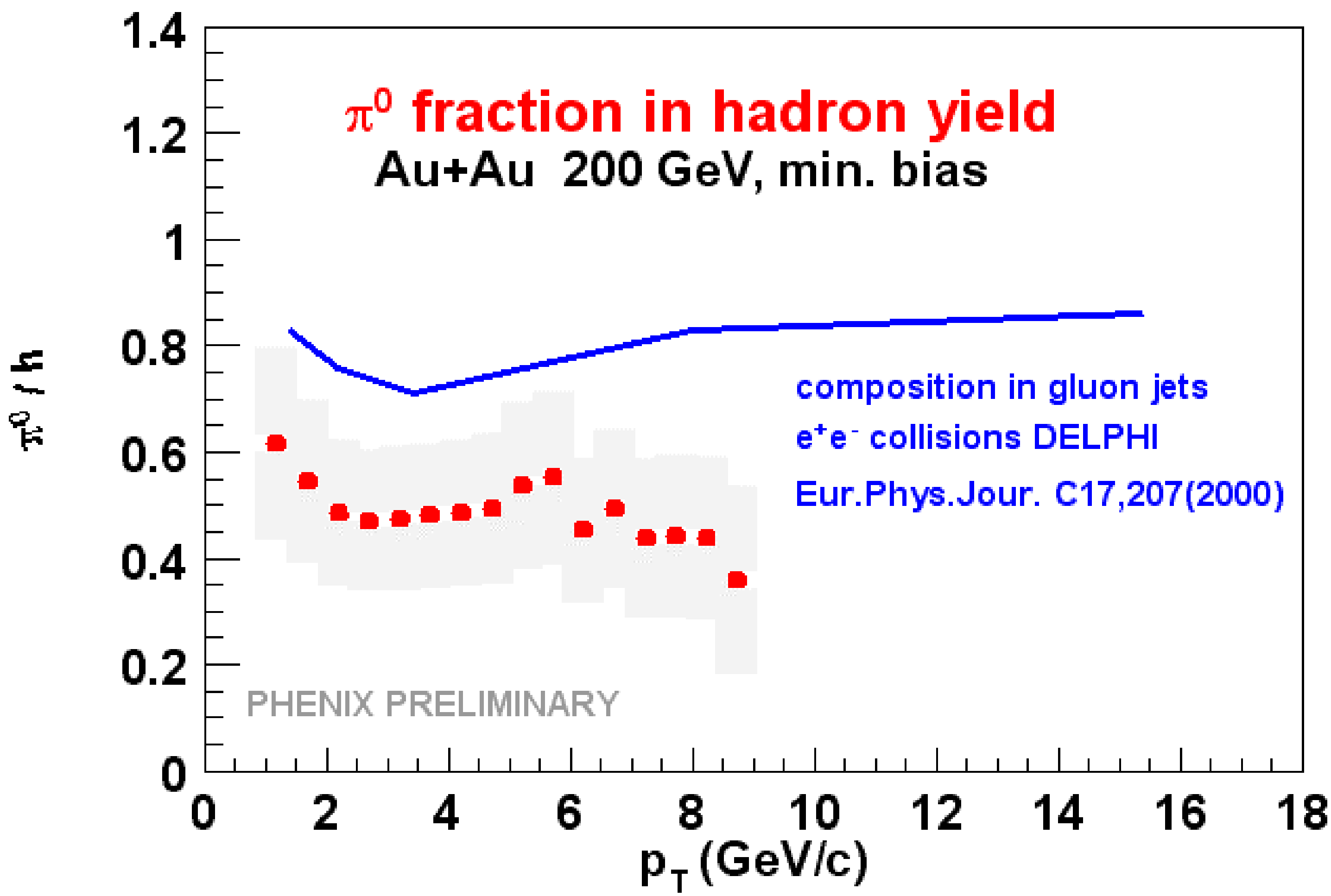
Left shift(eloss) is effectively a down shift(absorption), one can obtain the similar result

$$f = e^{-k\int \rho\, dl} \quad \textbf{E.Shuryak} \qquad \kappa \rightarrow 1/T$$

For power law shape, assumption is good for small ΔE, $\Delta E \leq 1/T \sim 1$ *GeV* **for pT=10 GeV/c**

Hadron spectra and jet spectra are related via parton-hadron duality

π/h at higher p_T



STAR yield per trigger