Measuring jet properties from $\pi^{\pm}$ — h correlation in dAu and pp

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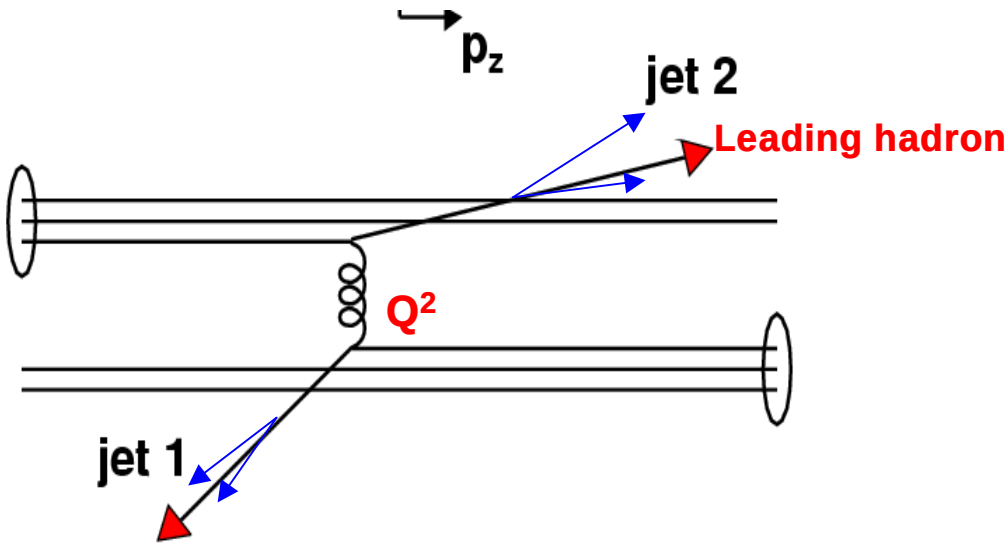
For the PHENIX Collaborations

- Introduction
- study of jet shape
- study of fragmentation function
- conclusion

Hard-scattering and Jet fragmentation



- Properties of di-jet system
  - **The spread of the hadrons around the jet axis and relative orientation of the two jets – jT, kT, Pout**
  - **The multiplicity of hadrons – fragmentation function D(z)**
- They can be accessed with two particle correlation in $\Delta\phi$.
  - We present the result for leading $\pi^{\pm}$ — h correlation from dAu and pp collisions

$\pi^{\pm}$ — h azimuthal distribution

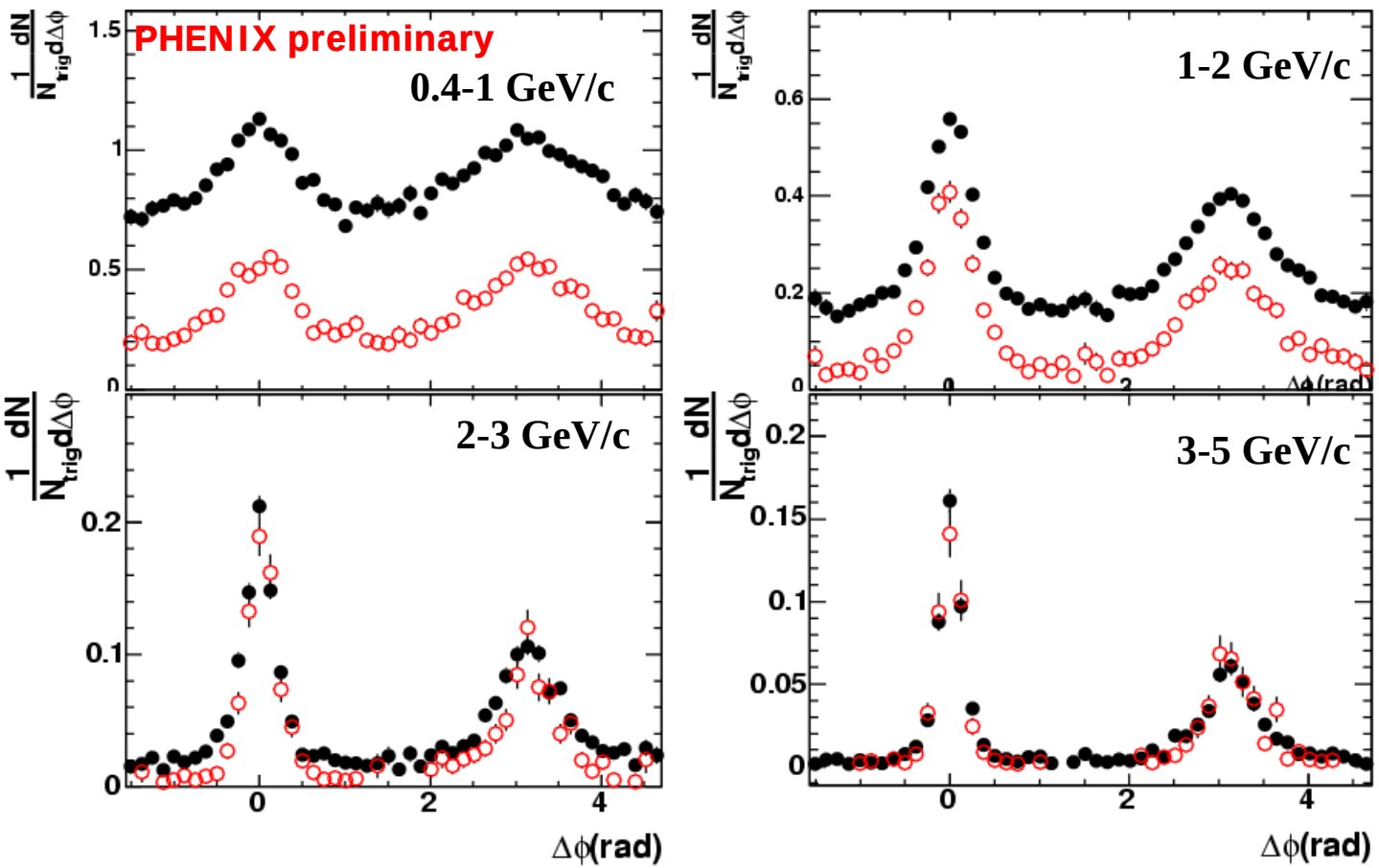
PHENIX identify $\pi^{\pm}$ at p_T> 4.7 GeV/c

Trigger pion 5-10 GeV/c

dAu pp

Jet shape jT, kT is given by the near side and far side width

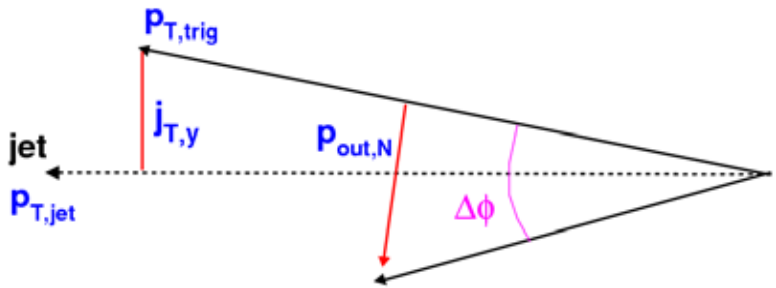
Jet multiplicity is given by the area under the peak



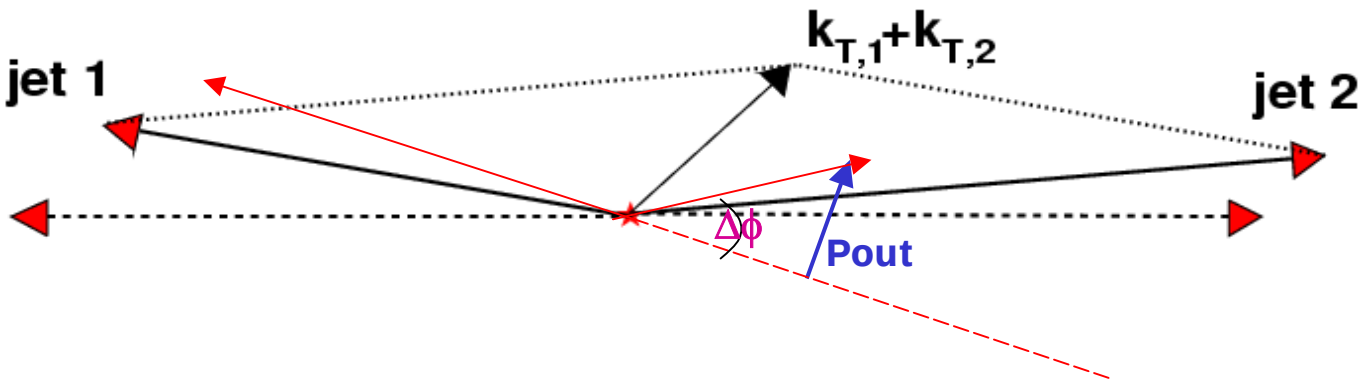
Jet shape

- Near side correlation

j_T is fragmentation momentum



- Far side correlation



k_T is parton initial momentum

$$\vec{p}_{T,jet1} + \vec{p}_{T,jet2} = \vec{k}_{T,1} + \vec{k}_{T,2}$$

RMS of jT kT can be extracted from the jet width
More direct way is via the projection of assoc to trigger : Pout

$P_{out} = p_{T,assoc} \sin(\Delta\phi)$

Relation jT and kT to Pout

Near side Pout depends on jT $\left\langle p_{out}^2 \right\rangle \approx \left\langle j_T^2 \right\rangle + x_E^2 \left\langle j_T^2 \right\rangle$

$$x_E = \frac{p_{T,asso}\cos(\Delta\phi)}{p_{T,trig}}$$

Far side Pout also depends on kT $\left\langle p_{out}^2 \right\rangle \approx \left\langle j_T^2 \right\rangle + x_E^2 \left(\left\langle j_T^2 \right\rangle + 2z^2 \left\langle k_T^2 \right\rangle \right)$

$$\langle k_\perp{}^2 \rangle_{\mathrm{dA}} = \langle k_\perp{}^2 \rangle_{\mathrm{Intrisic}} + \langle k_\perp{}^2 \rangle_{\mathrm{Radiation}} + \langle k_\perp{}^2 \rangle_{\mathrm{Cold\ nucl}}$$

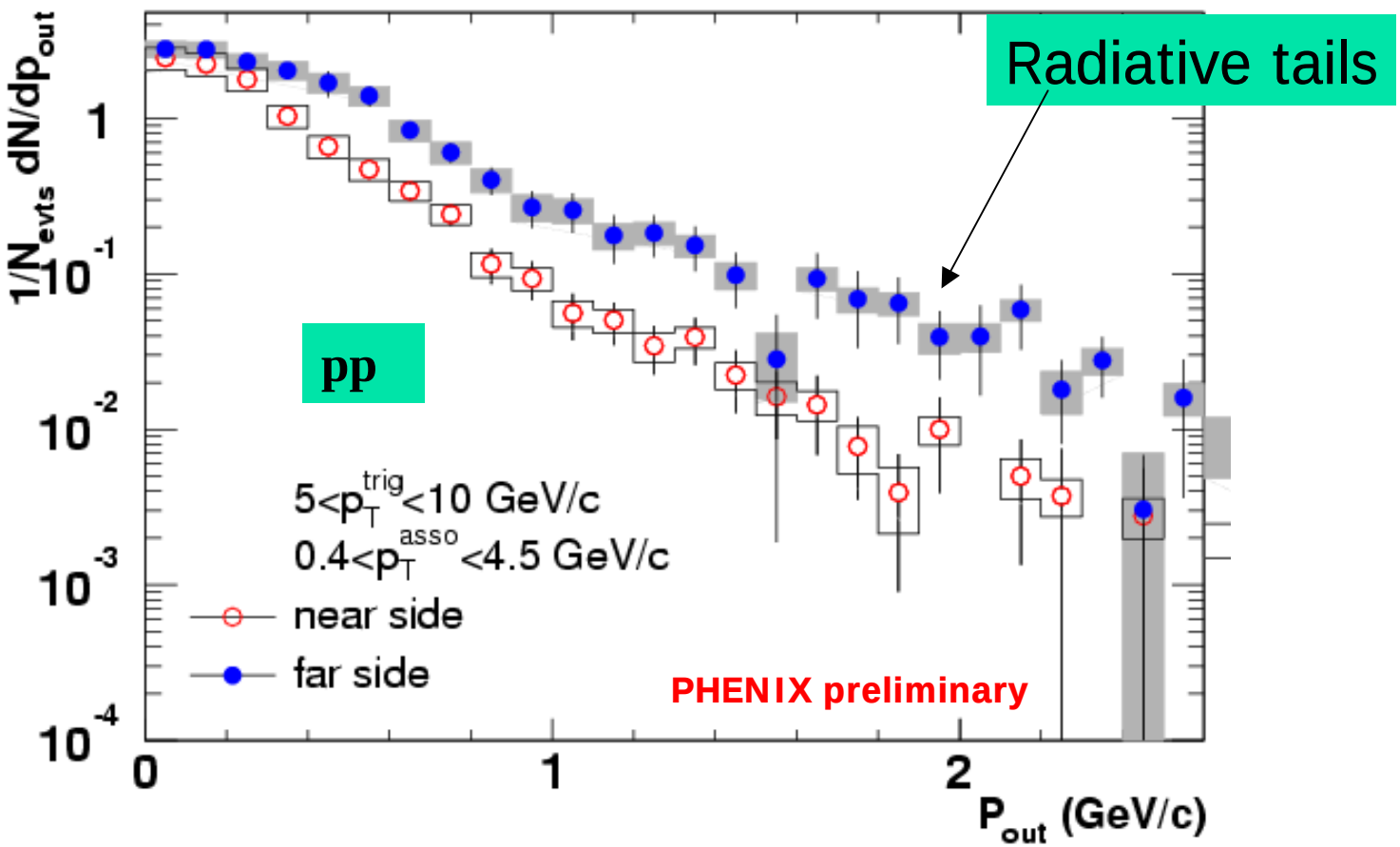
p+p p+p d+A

Multiple scattering in dAu would broaden the Pout distribution

Pout distribution

Pout distribution carries more information than just RMS of jT, kT.

Far side Pout is broader than near side due to kT



Pout dAu central vs pp

- No sensitivity to broadening?

$$\langle k_T^2 \rangle_{pA} = \langle k_T^2 \rangle_{pp} + C \cdot h_{pA}(b) \ .$$

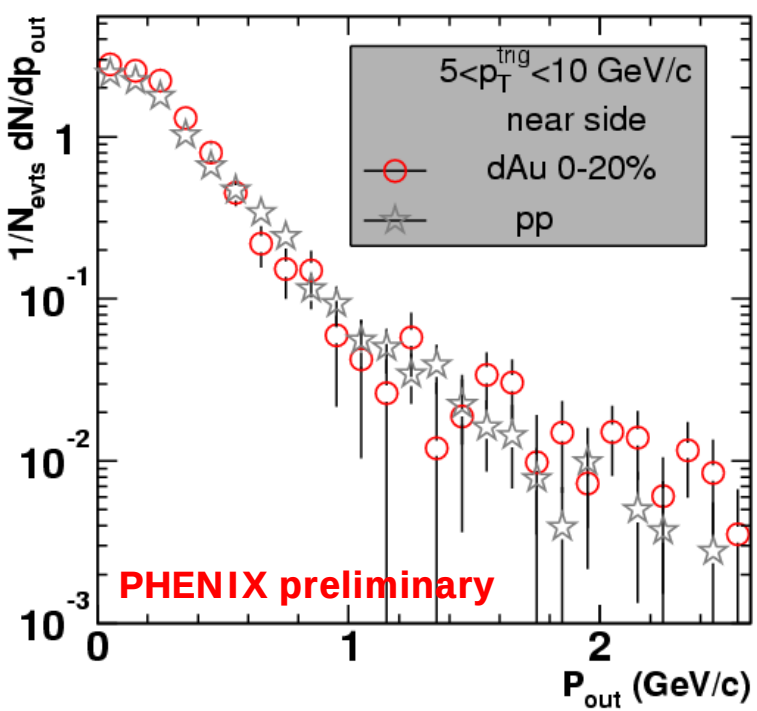
C~ 0.2-0.4

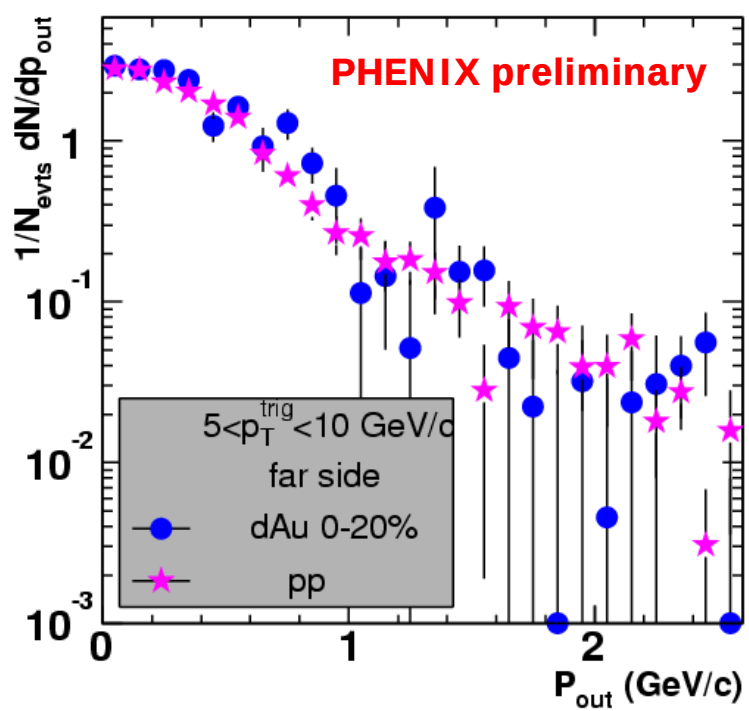
0.8-1.6 $(GeV/c)^2$
in central collisions

$$\langle k_\perp{}^2 \rangle_{pA} = \langle k_\perp{}^2 \rangle_{Intrisic} + \langle k_\perp{}^2 \rangle_{Radiation} + \langle k_\perp{}^2 \rangle_{Cold\ nucl}$$

$<1(GeV/c)^2$ **$\approx 7(GeV/c)^2$** **$\approx 1(GeV/c)^2$**

W.Volgelsang, hep-ph/0312320





Jet multiplicity ↔ Conditional yield

Fragmentation function $$D(z) = \frac{1}{N_{jet}} \frac{dN_h}{dz}$$

Correlation method give per trigger yield

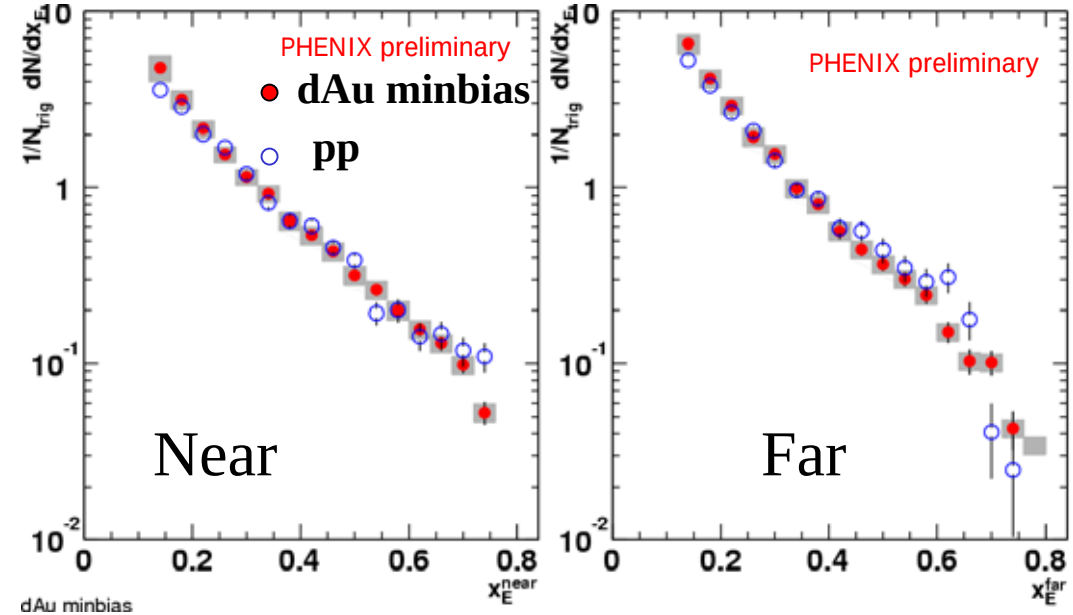
$$CY(x_E) = \frac{1}{N_{trig}} \frac{dN_h}{dx_E} \approx z_{trig} D(z)$$

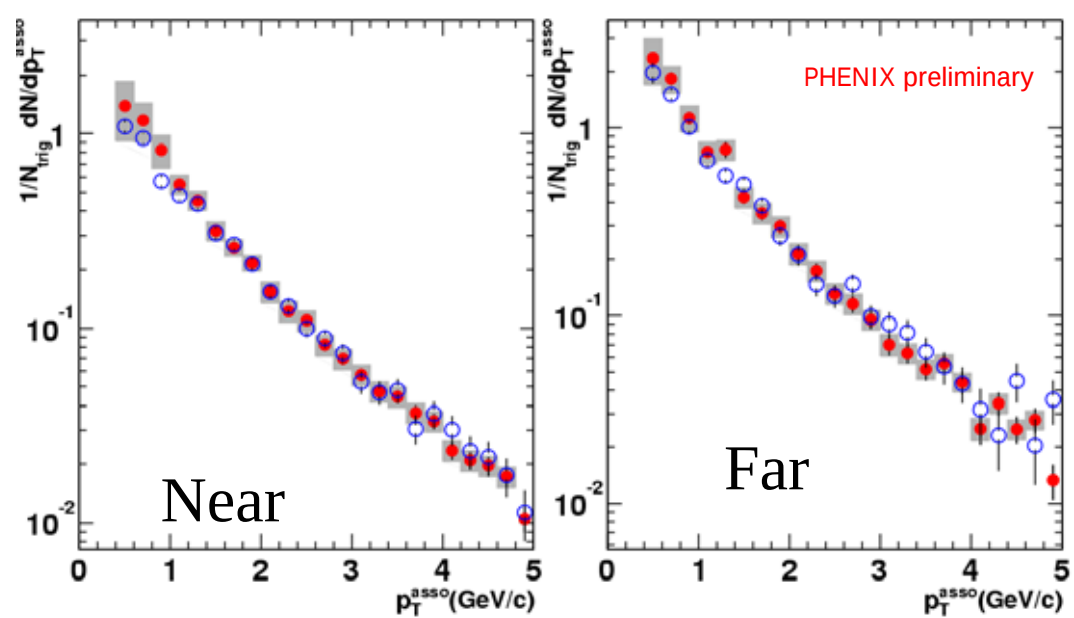
$$\langle z_{trig} \rangle \approx 0.7$$

- Study any modification of jet multiplicity in dAu
  - Multiple scattering, modification of PDF, etc..

Jet Yield

- $1/N_{trig}\ dN_h/dx_E$
  - x_E from 0.1-0.7
- Near side yield is related to di-hadron fragmentation function.
- Far side is closer to single fragmentation function.
- No difference between dAu and pp within errors
- $1/N_{trig}\ dN_h/dp_T$
  - p_T from 0.4-5 GeV/c.

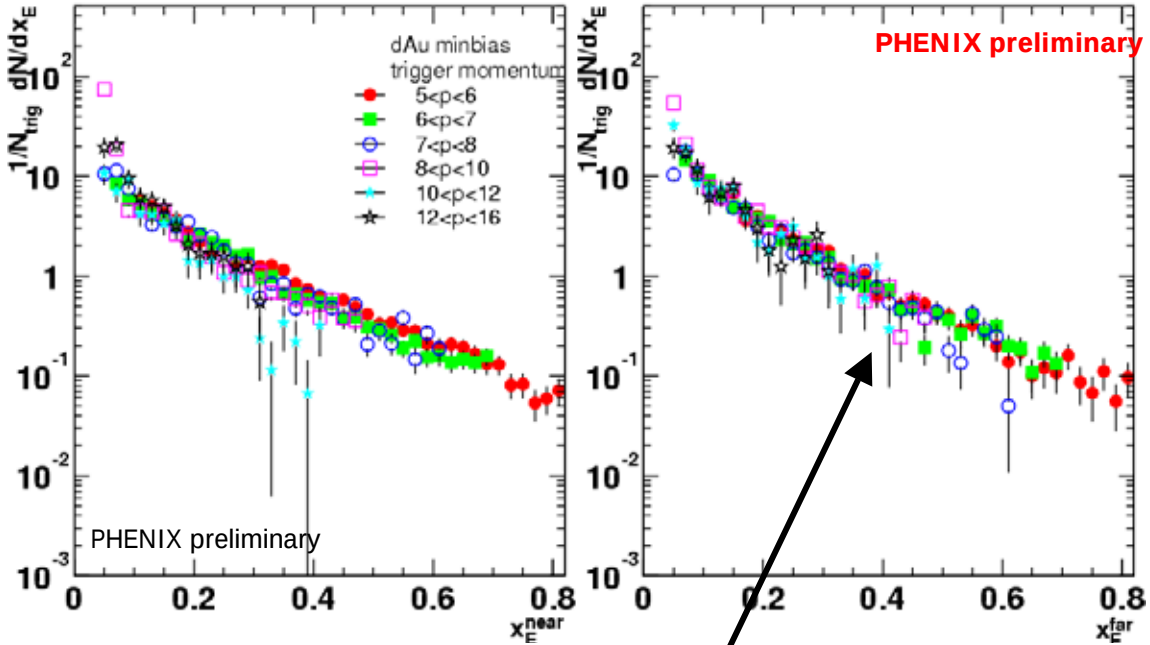


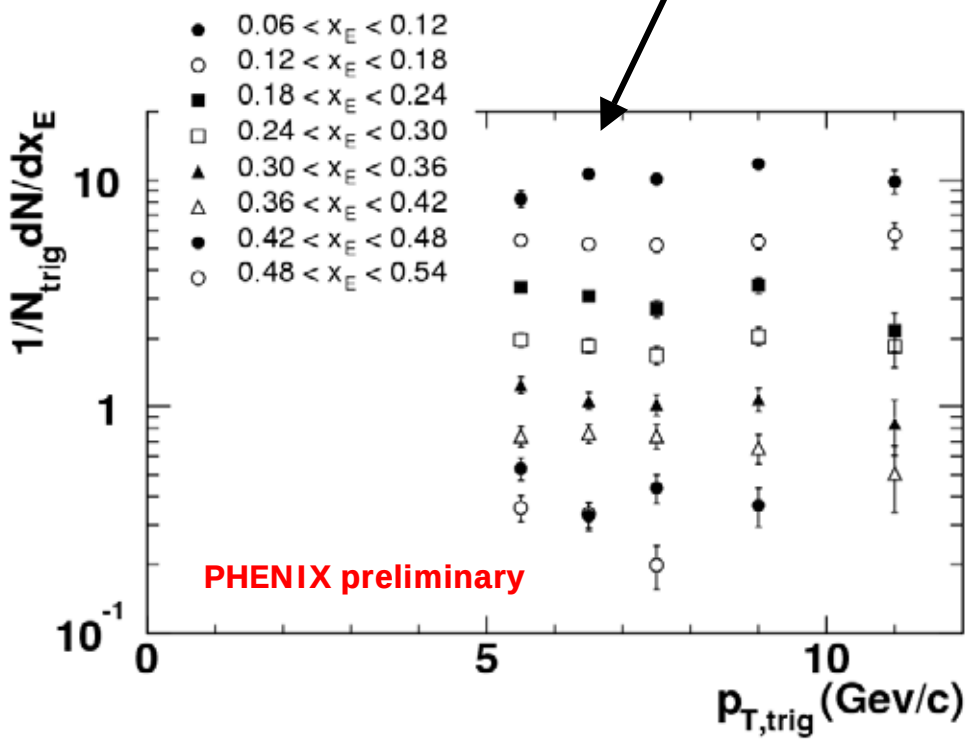


Scale dependence

- Study the CY as function of trigger pT (thus the Q^2)

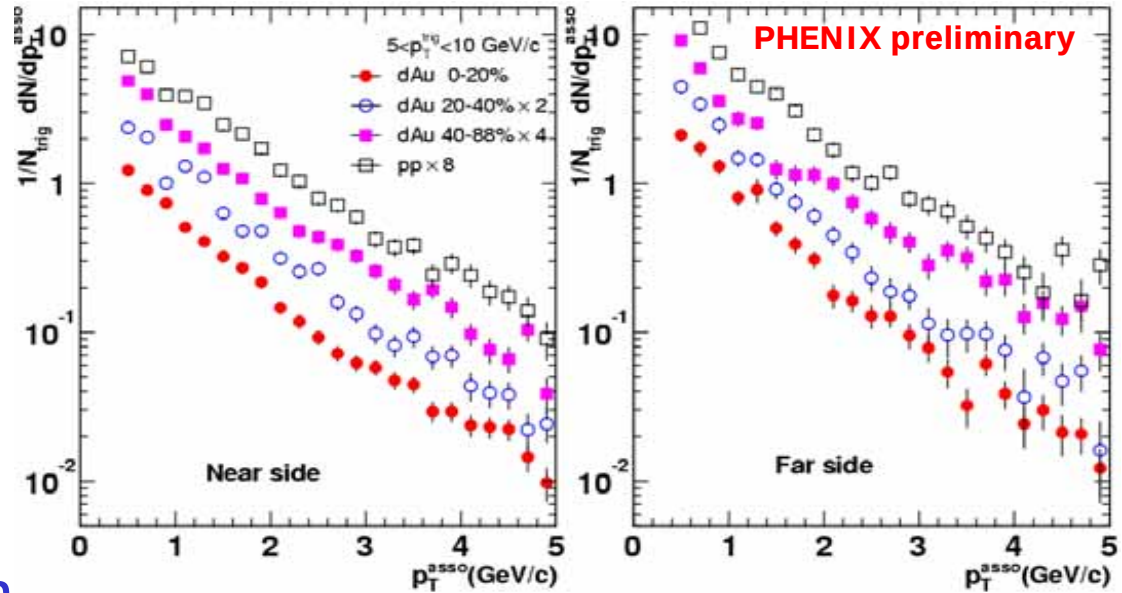
- Plot the far side CY for fixed xE ranges.
  - No apparent scale dependence.

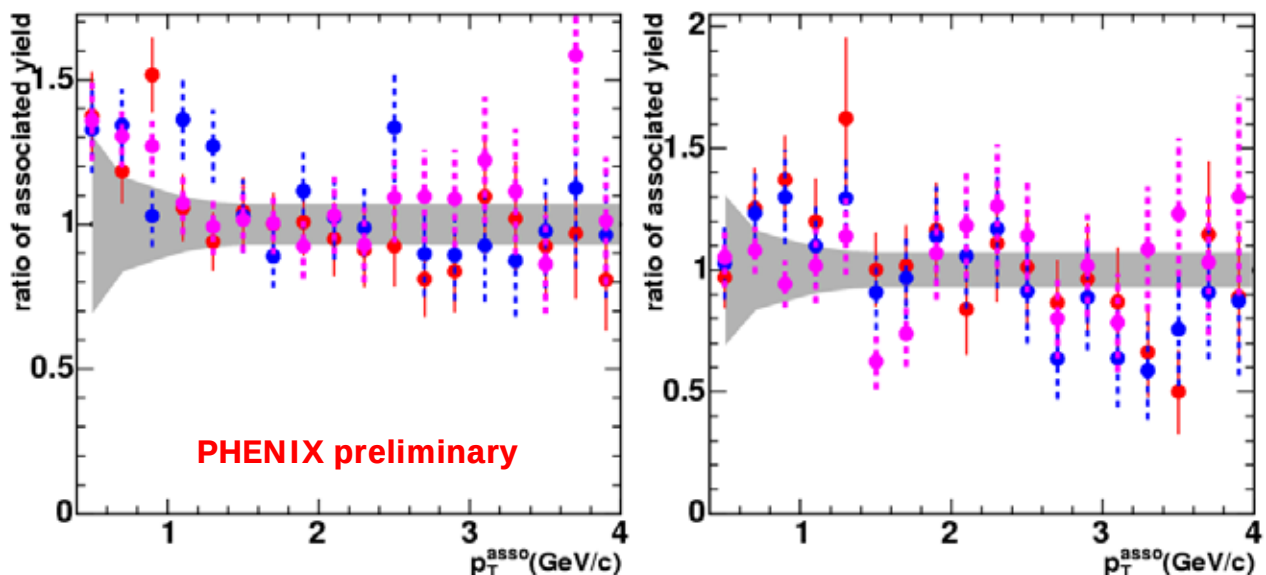




Jet multiplicity: centrality dependence

- $1/N_{trig}\ dN_h/dp_T$
  - p_T from 0.4-5 GeV/c.
  - as function of centrality and compare with pp
  - Modification of jet multiplicity in dAu
- No change in jet multiplicity is seen within errors





Conclusion

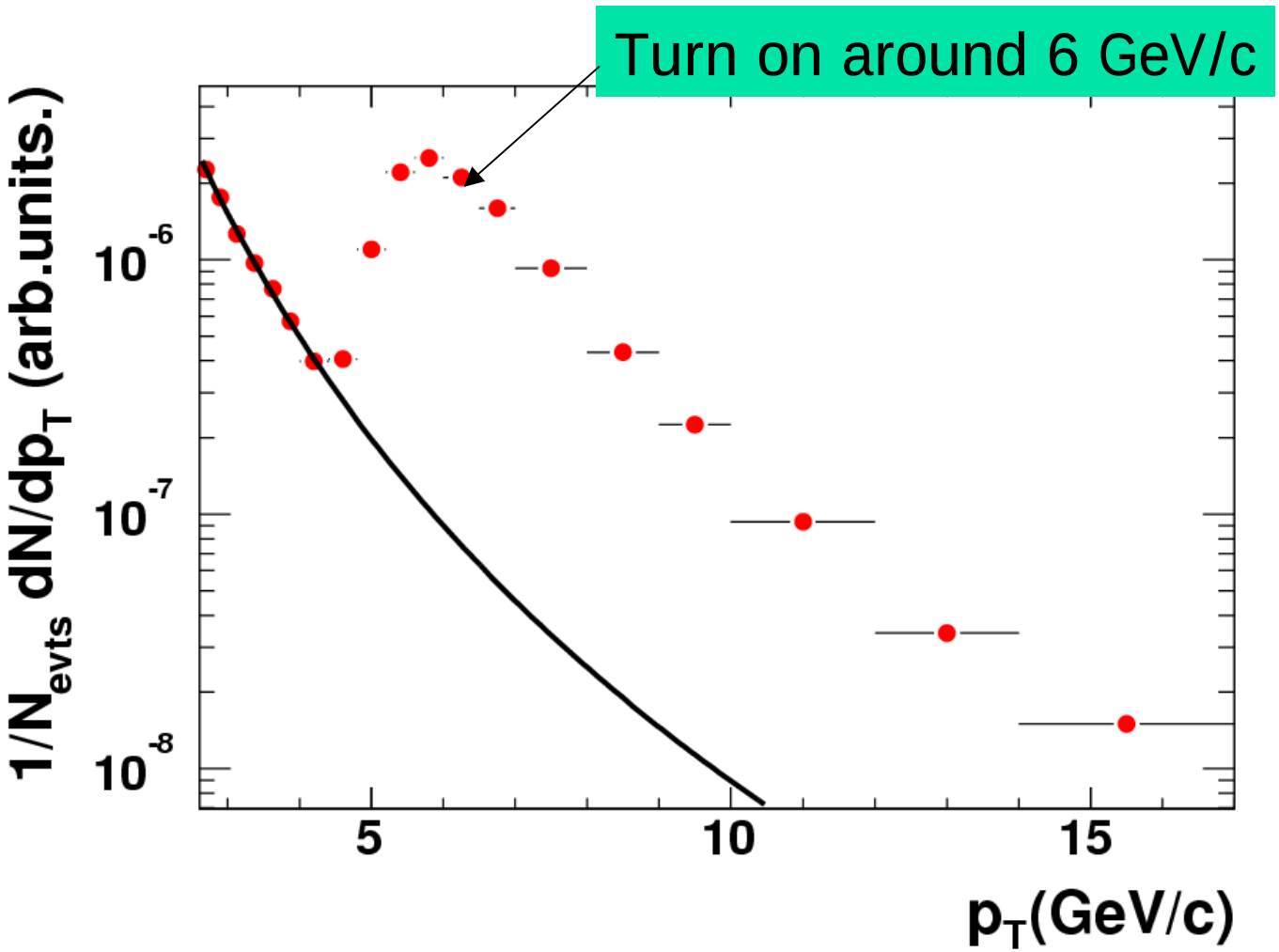
- The di-jet decay kinematics are studied with $\pi^{\pm}$ — h correlation
- Pout distribution are very similar between dAu and pp, indicating no significant broadening in cold nuclear medium
- CY distribution are also similar between dAu and pp, indicating no significant increase in jet multiplicity in dAu relative to pp.

$\pi^{\pm}$ identification

RICH detects $\pi^{\pm}$ at p_T> 4.7 GeV/c

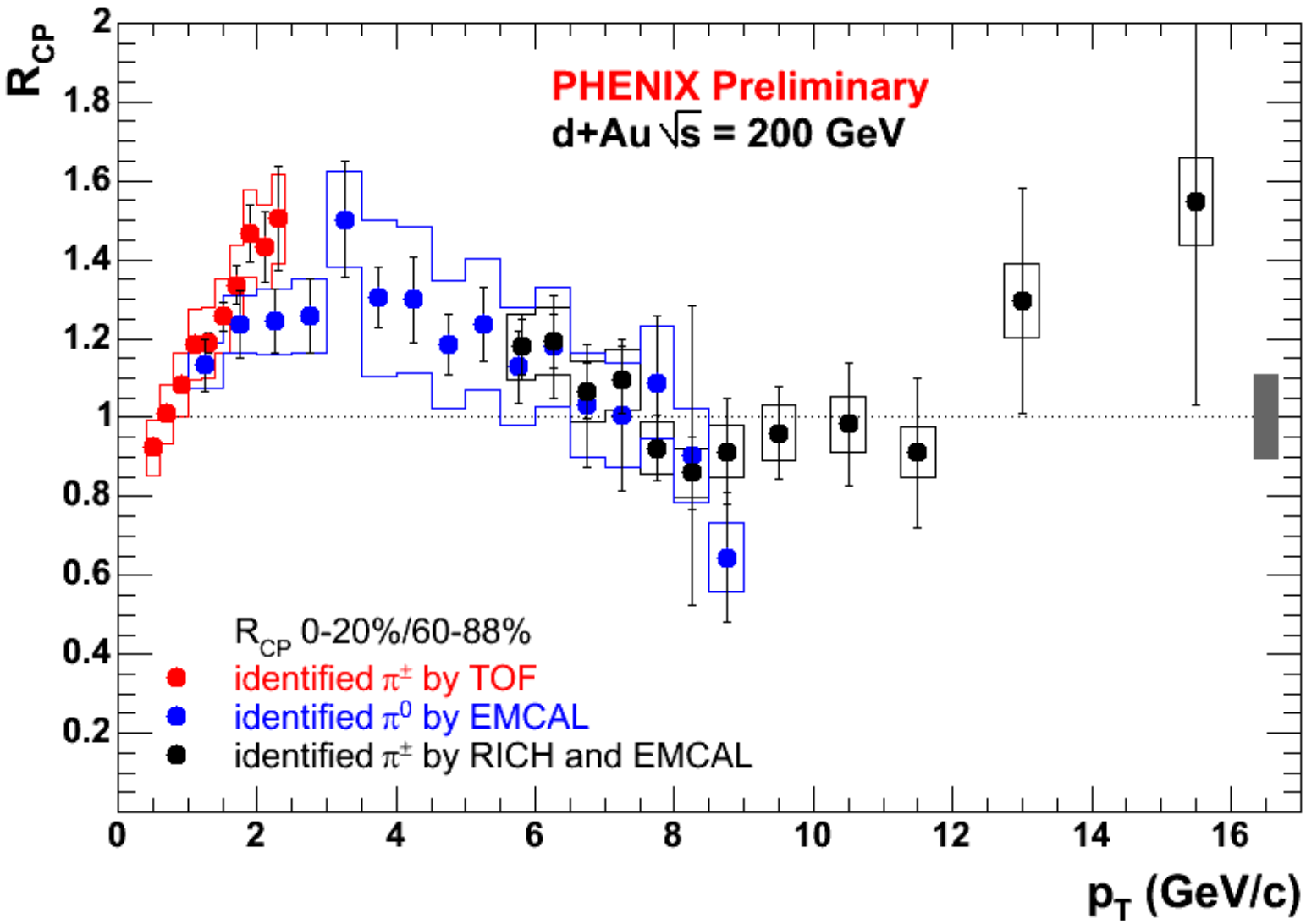
EMCal is used to reject high pT background from conversion

Remaining background is less than 5%.



$\pi^{\pm}$ Rcp

Up to 16 GeV/c



Two particle azimuth correlation method

- In ideal acceptance, real pair distribution is

$$dN_0^{real} / d\Delta\phi d\Delta\eta = \lambda + jet(\Delta\phi, \Delta\eta)$$

- Real distribution is modulated by pair acceptance function $Acc(\Delta\phi, \Delta\eta)$.

$$dN^{real} / d\Delta\phi d\Delta\eta = Acc(\Delta\phi, \Delta\eta)(\lambda + jet(\Delta\phi, \Delta\eta))$$

- Pair acceptance function can be determined from event mixing technique

$$dN^{mix} / d\Delta\phi d\Delta\eta \propto Acc(\Delta\phi, \Delta\eta)$$

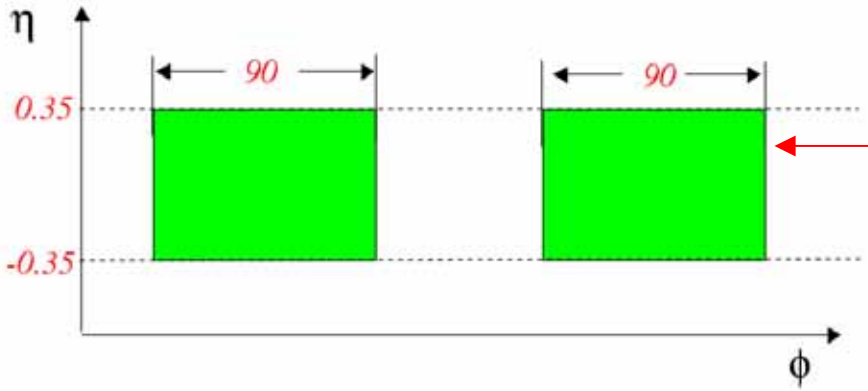
- Real/mix gives the acceptance corrected CY (modulo constant background λ).

$$\frac{1}{N_{Trig}^0} \frac{dN_0^{real}}{d\Delta\phi d\Delta\eta} \propto \frac{dN^{real} / d\Delta\phi d\Delta\eta}{dN^{mix} / d\Delta\phi d\Delta\eta} \propto \lambda + jet(\Delta\phi, \Delta\eta)$$

- Fit with a double gauss + constant to extract the Near side and far side yield.

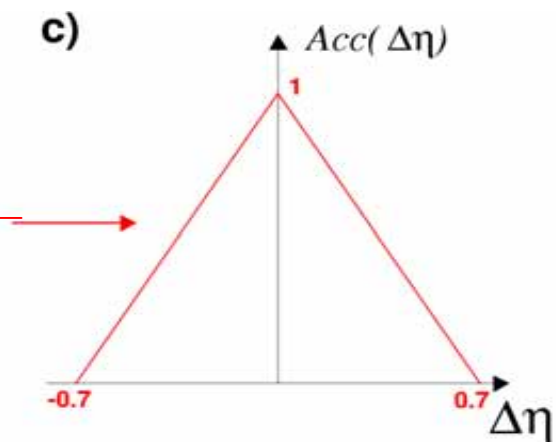
$$\frac{1}{N_{trig}^0} \frac{dN_0}{d\Delta\phi} = \lambda + \frac{Yield_{Near}}{\sqrt{2\pi}\sigma_N} e^{\frac{-\Delta\phi^2}{2\sigma_N^2}} + \frac{Yield_{Far}}{\sqrt{2\pi}\sigma_F} e^{\frac{-(\Delta\phi-\pi)^2}{2\sigma_F^2}}.$$

Pair acceptance function ACC in PHENIX



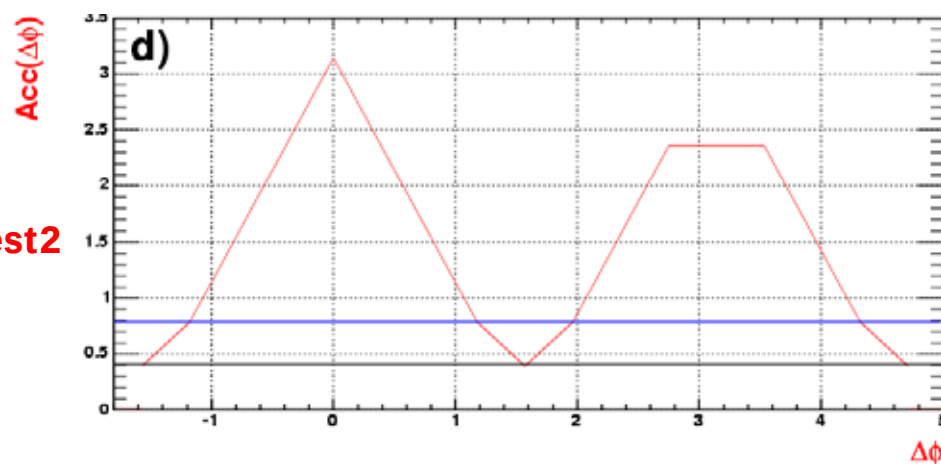
Single particle acceptance

Pair acceptance in $\Delta\eta$



Triangle results from convoluting two flat distribution

Pair acceptance in $\Delta\phi$



Shape from overlapping four triangles:

west1-west2, east1-east2, west1-east2, east1-west2

effi is 100% at $\Delta\phi=0$, $\Delta\eta=0$
Average is 25%

The corrections

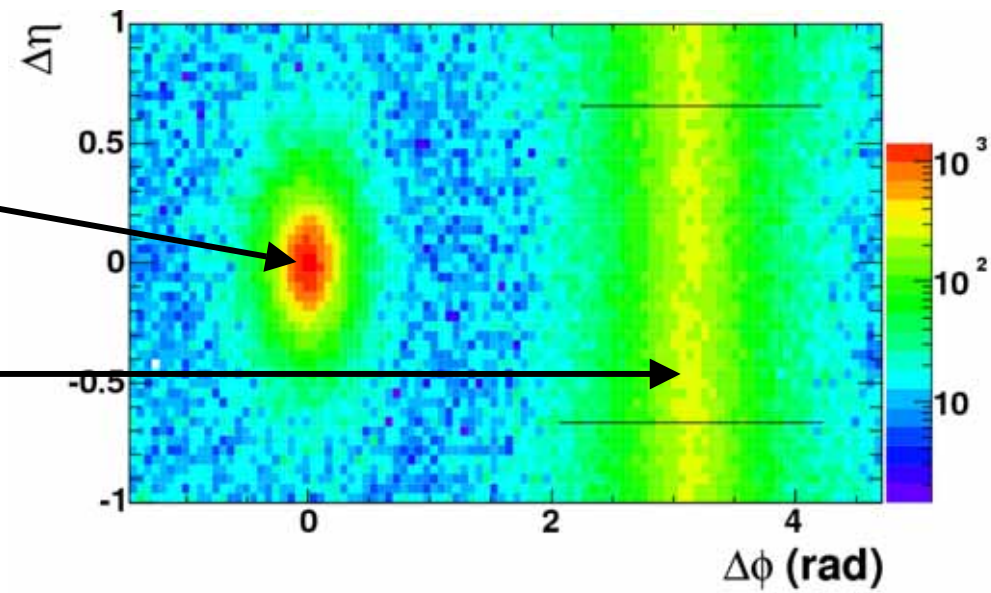
- The mathematical framework is detailed in nucl-ex/0409024

$$\frac{1}{N_{Trig}^{0}}\left(\frac{dN_{0}^{real}}{d\Delta\phi}-\lambda\frac{dN_{0}^{mix}}{d\Delta\phi}\right)=\frac{1}{N_{Trig}\varepsilon}\frac{dN^{real}/d\Delta\phi-\lambda dN^{mix}/d\Delta\phi}{\frac{2\pi\, dN^{mix}/d\Delta\phi}{\int d\Delta\phi dN^{mix}/d\Delta\phi}}$$

  - The normalization factor can be determined experimentally.

The near side peaks in both $\Delta\phi$ and $\Delta\eta$.

Far side is very broad in $\Delta\eta$ (almost flat in $|\Delta\eta|<1$)



- Correct near side jet yield to full jet yield $|\Delta\eta|<\infty$
- Correct far side jet yield to yield in $|\Delta\eta|<0.7$
- Procedure has been verified with MC simulation

Normalization for 2D and 1D CY

- 2D CY

Detected triggers

$$\frac{1}{N^{0}_{Trig}}\frac{dN^{real}_{0}}{d\Delta\phi d\Delta\eta}=\frac{1}{N_{Trig}}\frac{N^{0}_{asso}}{N_{asso}}\frac{dN^{real}/d\Delta\phi d\Delta\eta}{\frac{2\pi\times 1.7\times dN^{mix}/d\Delta\phi d\Delta\eta}{\iint d\Delta\phi d\Delta\eta dN^{mix}/d\Delta\phi d\Delta\eta}}$$

Underling triggers

Acceptance+ efficiency

Mix normalized to pair phase space

- 1D CY can be obtained by integrating out $\Delta\eta$.

$$\frac{1}{N^{0}_{Trig}}\left(\frac{dN^{real}_{0}}{d\Delta\phi}-\lambda\frac{dN^{mix}_{0}}{d\Delta\phi}\right)=\frac{1}{N_{Trig}\varepsilon}\frac{dN^{real}/d\Delta\phi-\lambda dN^{mix}/d\Delta\phi}{\frac{2\pi\times dN^{mix}/d\Delta\phi}{\int d\Delta\phi dN^{mix}/d\Delta\phi}}$$

Single particle efficiency in full azimuth and 1 unit η

$$\varepsilon=\frac{\varepsilon_{single}R_{\Delta\eta}}{0.7}\frac{k^{real}(\Delta\phi)}{k^{mix}(\Delta\phi)/K^{mix}}$$

Pair cuts and two track resolution

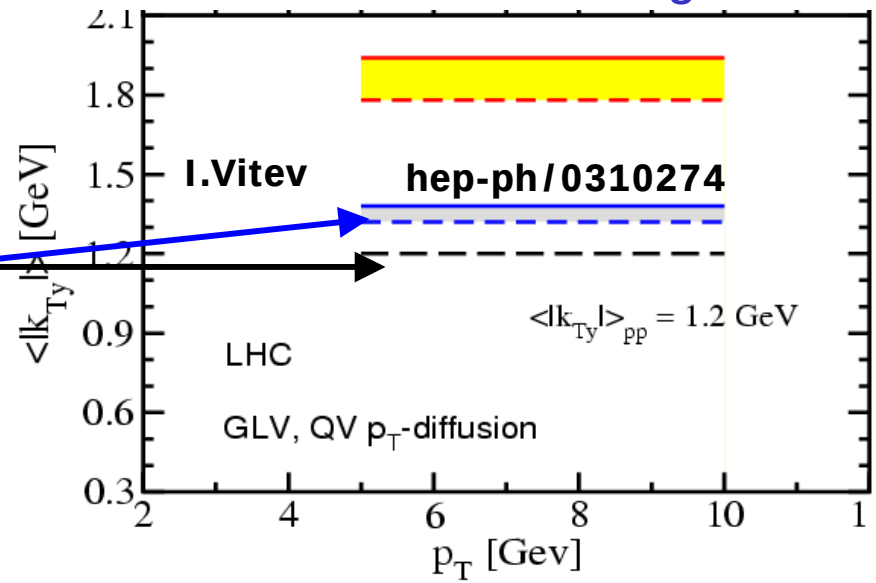
Fraction of jet yield falls in η acceptance
Can be calculated analytically assuming Gauss shape

$$R_{\Delta\eta}=\frac{\int_{-\infty}^{+\infty}d\Delta\eta\, jet(\Delta\eta)Acc(\Delta\eta)}{\int_{-\infty}^{+\infty}d\Delta\eta\, jet(\Delta\eta)}$$

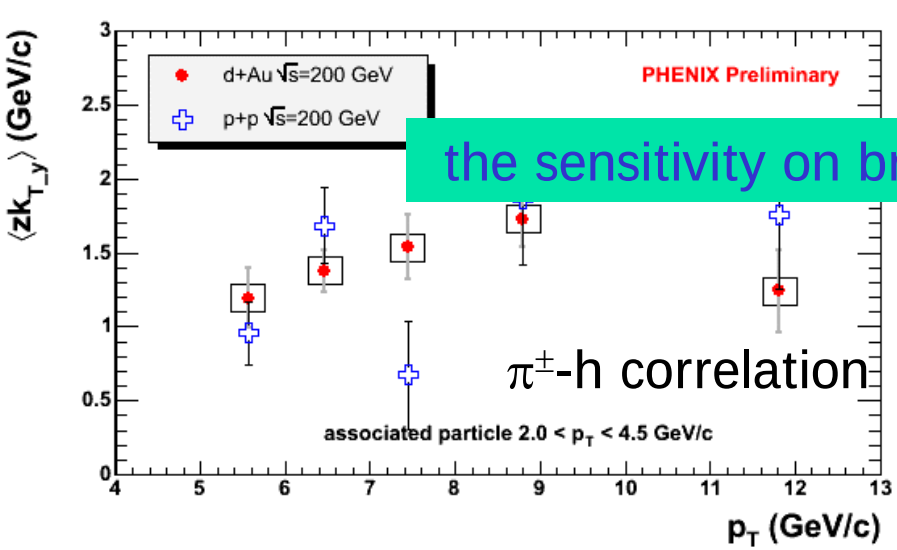
Is kT in dAu sensitive to broadening?

- Seems radiation contribution dominate over the broadening

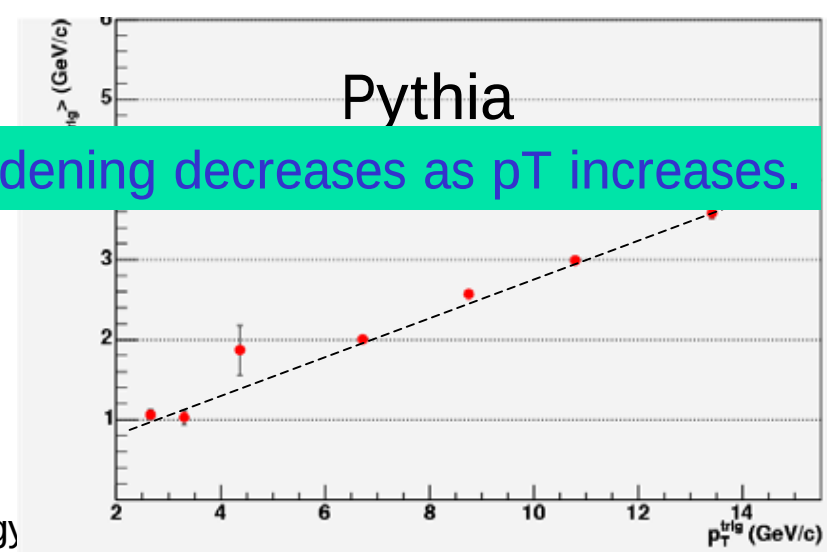
10% difference between dAu and pp for 4.5 GeV trigger



- Radiation contribution is even stronger at higher pT



the sensitivity on broadening decreases as pT increases.



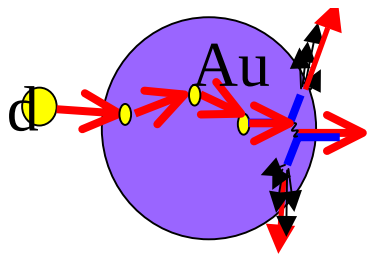
kT Broadening in dAu

- Presence of cold medium can broaden the jet kT

$$\langle k_T^2 \rangle_{pA} = \langle k_T^2 \rangle_{pp} + C \cdot h_{pA}(b) \ .$$

C~ 0.2-0.4

0.8-1.6 $(GeV/c)^2$ in central collisions



$$\langle k_\perp{}^2 \rangle_{pA} = \langle k_\perp{}^2 \rangle_{\text{Intrisic}} + \langle k_\perp{}^2 \rangle_{\text{Radiation}} + \langle k_\perp{}^2 \rangle_{\text{Cold nucl}}$$

0.9$(GeV/c)^2$ 7$(GeV/c)^2$ 1$(GeV/c)^2$

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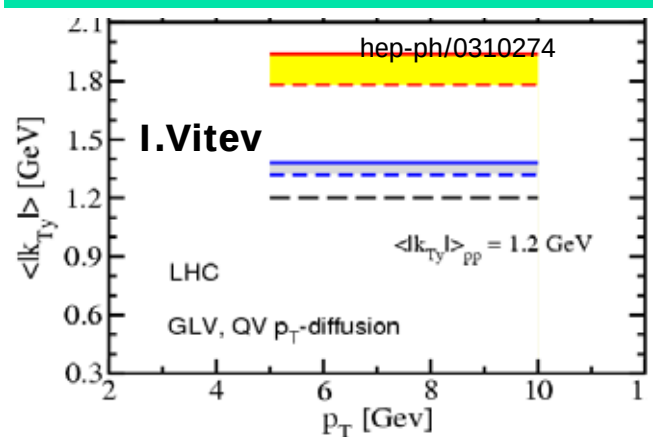
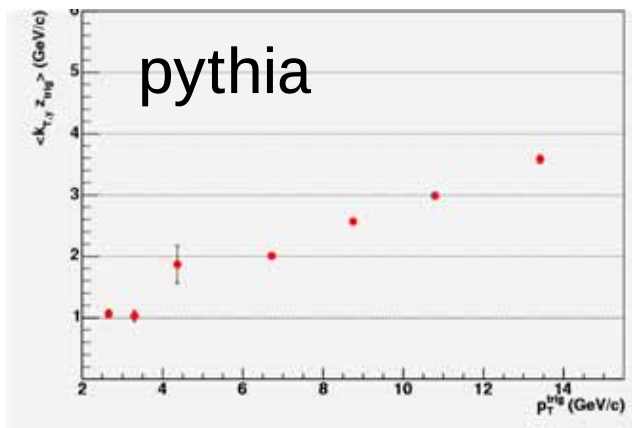
- However, radiation contribution seems dominate over broadening

Small difference between dAu and pp

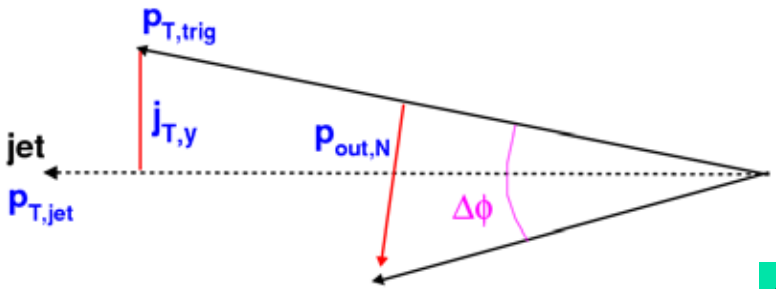




the sensitivity on broadening decreases as pT increases.

Jet shape

- Near side correlation



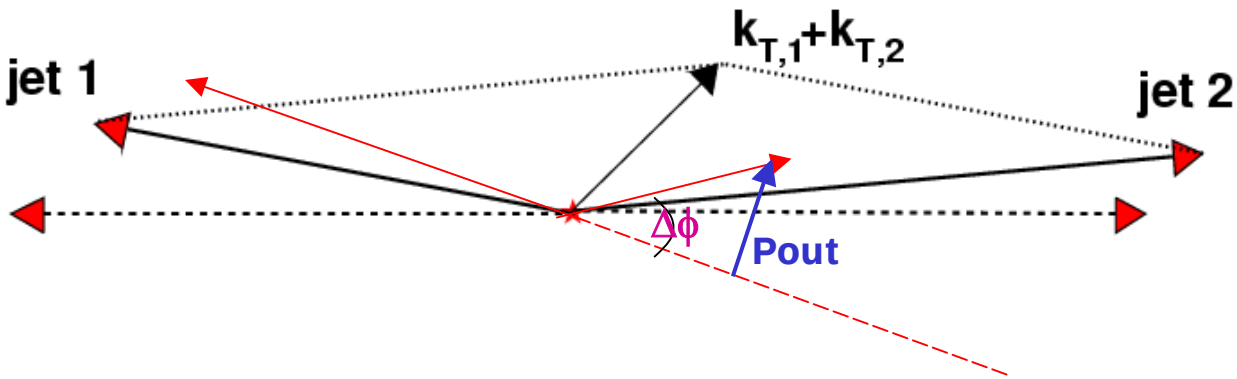
- j_T is fragmentation momentum
- Pout is projection of assoc to trigger

$$P_{out} = p_{T,assoc} \sin(\Delta\phi)$$

$$\left\langle p_{out}^2 \right\rangle \approx \left\langle j_T^2 \right\rangle + x_E^2 \left\langle j_T^2 \right\rangle$$

$$x_E = \frac{p_{T,asso} \cos(\Delta\phi)}{p_{T,trig}}$$

- Far side correlation



jets have intrinsic pT

$$\vec{p}_{T,jet1} + \vec{p}_{T,jet2} = k_{T,1} + k_{T,2}$$

p+p p+A

$$\langle k_\perp{}^2 \rangle_{pA} = \langle k_\perp{}^2 \rangle_{Intrisic} + \langle k_\perp{}^2 \rangle_{Radiation} + \langle k_\perp{}^2 \rangle_{Cold\ nucl}$$

$$\left\langle p_{out}^2 \right\rangle \approx \left\langle j_T^2 \right\rangle + x_E^2 \left(\left\langle j_T^2 \right\rangle + 2z^2 \left\langle k_T^2 \right\rangle \right)$$