Jet properties from di-hadron correlation in pp and dAu

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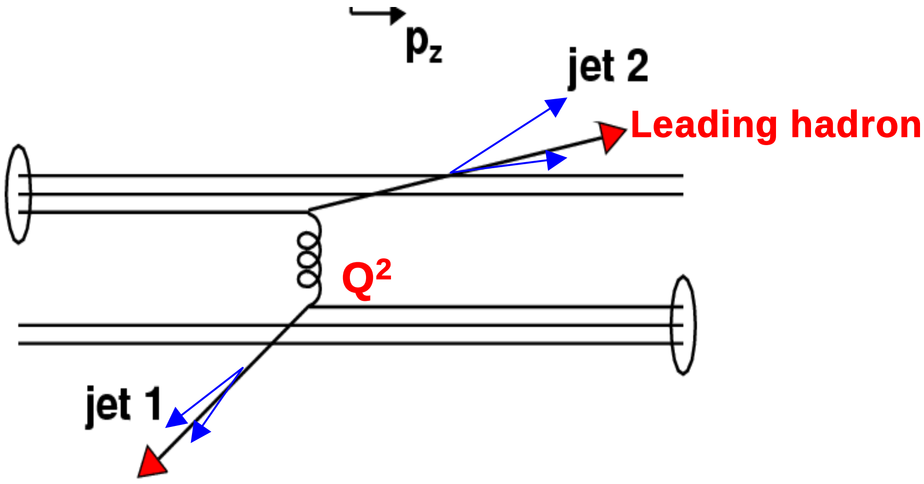
For the PHENIX Collaborations

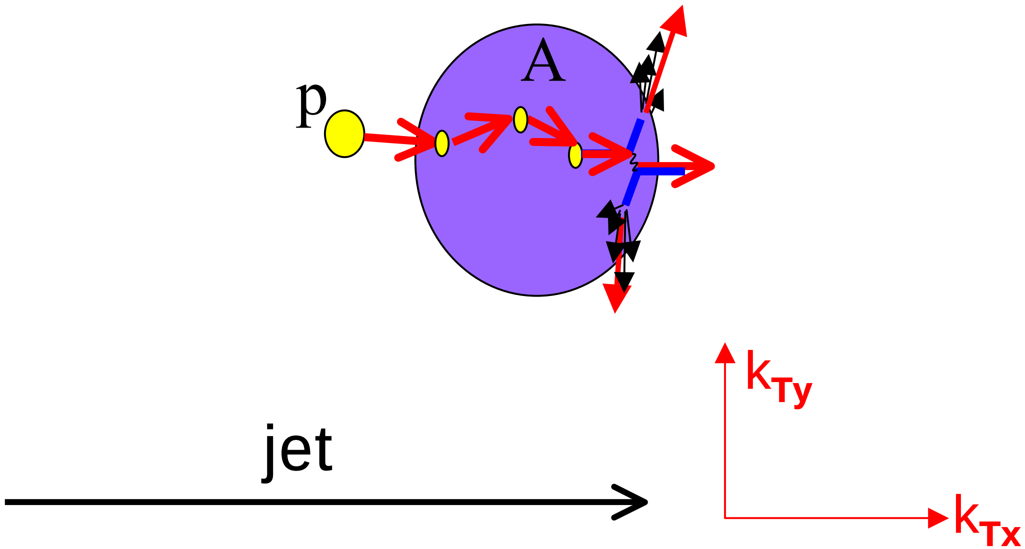
- Introduction
- study of jet shape
- study of jet fragmentation function
- comment on underlying event
- summary

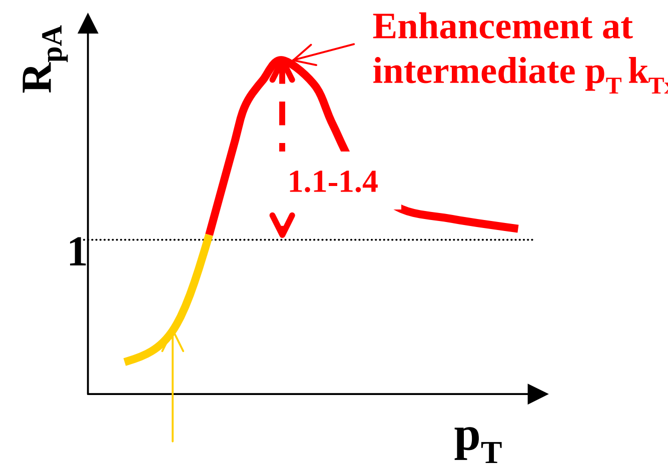
Hard-scattering and Jet fragmentation



- Properties of di-jet system
  - **The spread of the hadrons around the jet axis and relative orientation of the two jets – width, jT, kT**
  - **The multiplicity of hadrons – fragmentation function D(z)**
  - **Initial/final radiation contributions: underlying event**
- They can be accessed with two particle correlation in $\Delta\phi$.

Probing the cold nuclear medium (p+A)

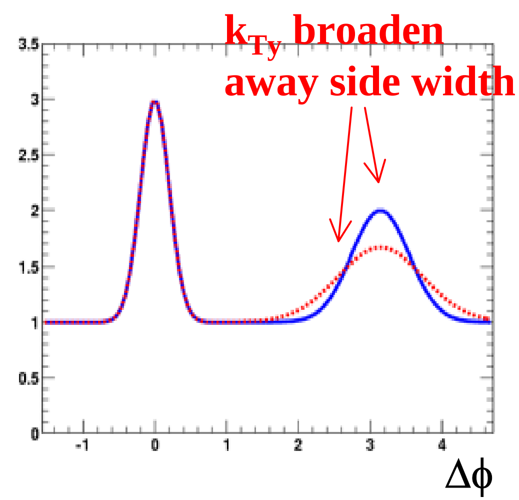




<u>Multiple scattering</u>

- Cronin effect
- Broadening of the back-to-back correlation

d+Au at RHIC

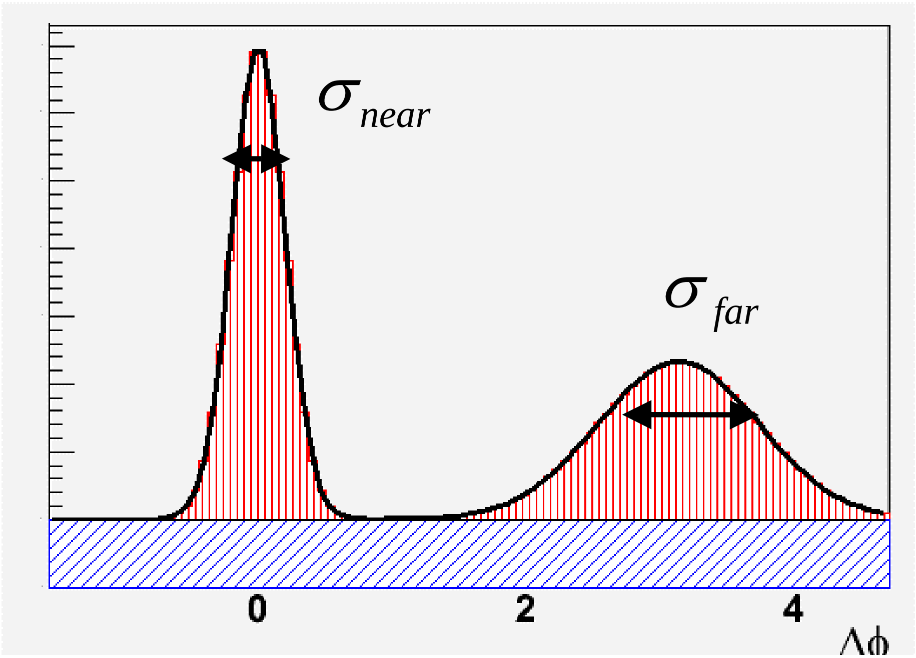


Two particle correlation

- Leading hadron – associated hadron correlation in $\Delta\phi$
- Leading hadron tagging one jet: per-trigger-yield <-> per-jet-yield
- Fit per-trigger-yield with a double gauss + constant

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

Underlying event | Near side jet | Far side jet



1) Jet shape
2) Jet Yield
3) Underlying event

Why two particle correlation?

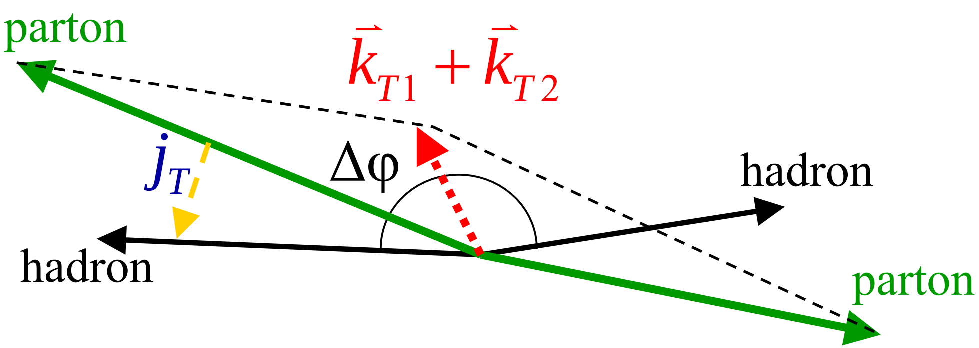
Jet correlation		Jet reconstruction
Measured statistically	↔	event by event
Access down to pT<5 GeV/c	↔	>~ 5-10 GeV/c
Relatively insensitive to multiplicity (Heavy-ion)		
Minimize the acceptance effect (event mixing)	↔	jet cone contained in the acceptance
Biased by the trigger particles	↔	unbiased jet tagging

Jet correlation is the only method for jet measurement in Heavy-Ion collisions at RHIC ($\sqrt{s}$ =200 GeV)

Method described in nucl-ex/0409024

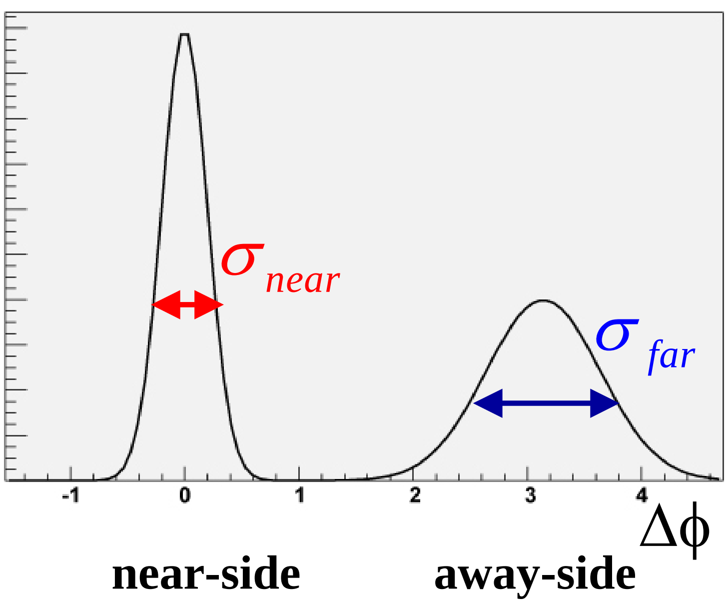
Di-jet shape

Di-hadron Fragmentation



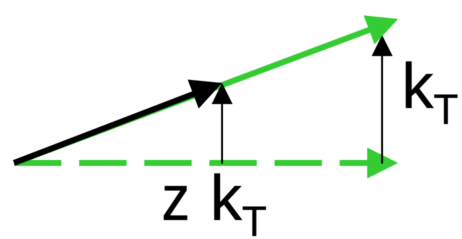
k_{Ty} : parton pair $p_T \perp$ jet axis

j_{Ty} : p_T of hadron $\perp$ to jet axis



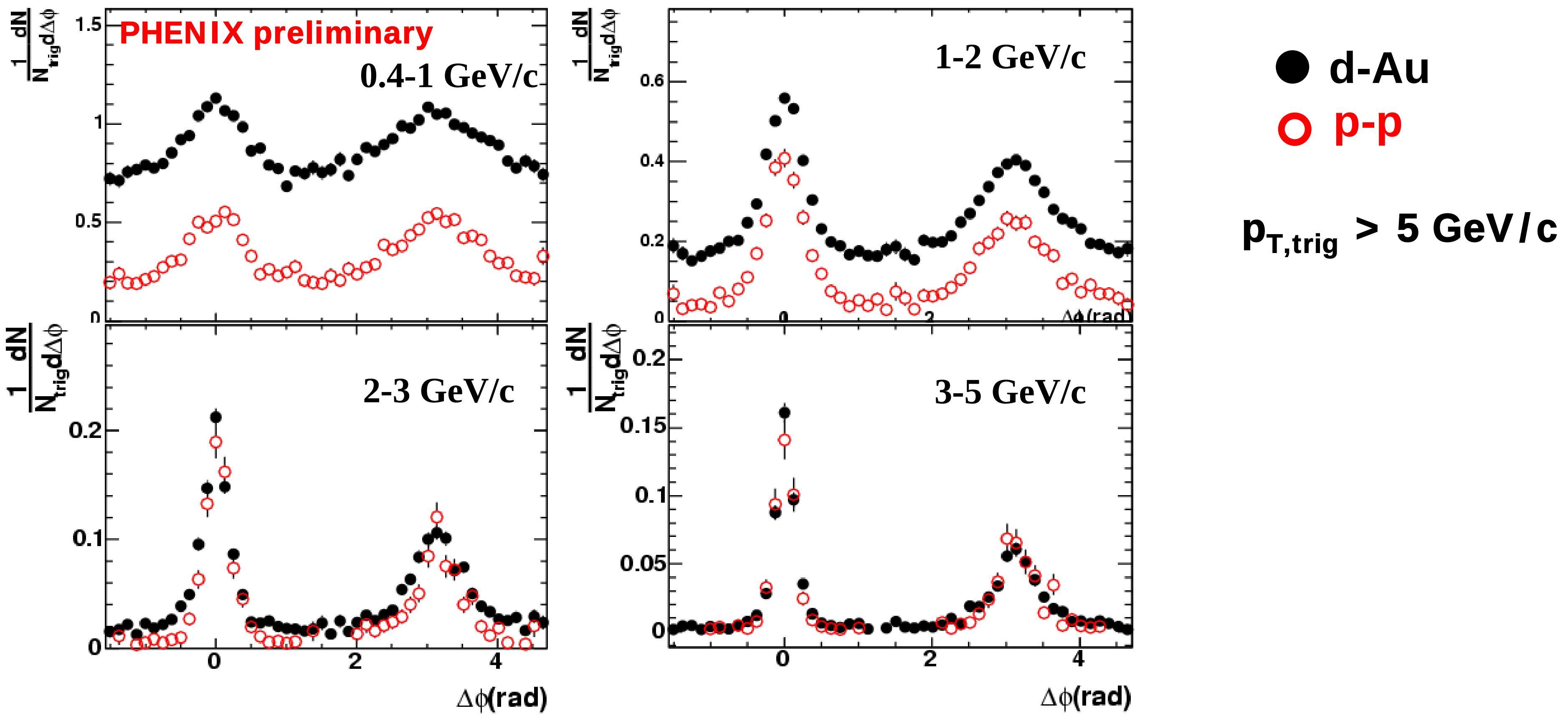
$$j_{Ty} \approx p_T \sigma_{near}$$ **Jet "width"**

$$k_{Ty} \propto p_T \sqrt{\sigma_{far}^2 - \sigma_{near}^2}$$ **Jet-coplanarity**



$$z_{assoc} k_{Ty} \approx p_T \sqrt{\sigma_{far}^2 - \sigma_{near}^2}$$

d-Au/p-p, $\pi^{\pm}$ - h, $\Delta\phi$ Correlations



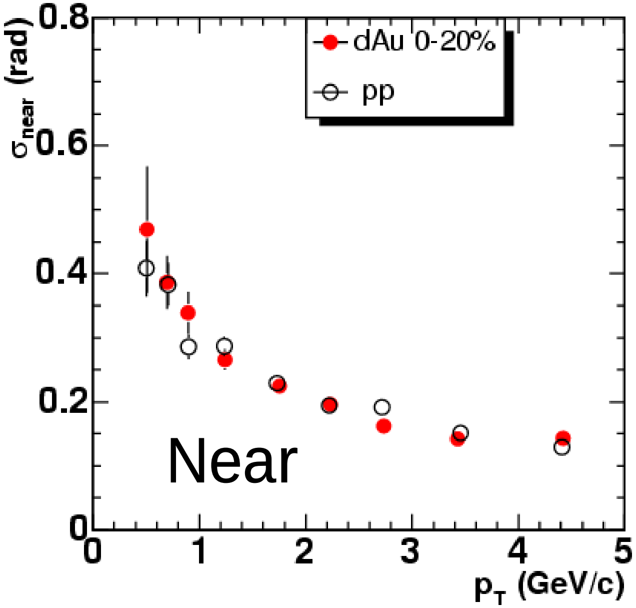
Jet width narrows with increasing $p_{T,assoc}$

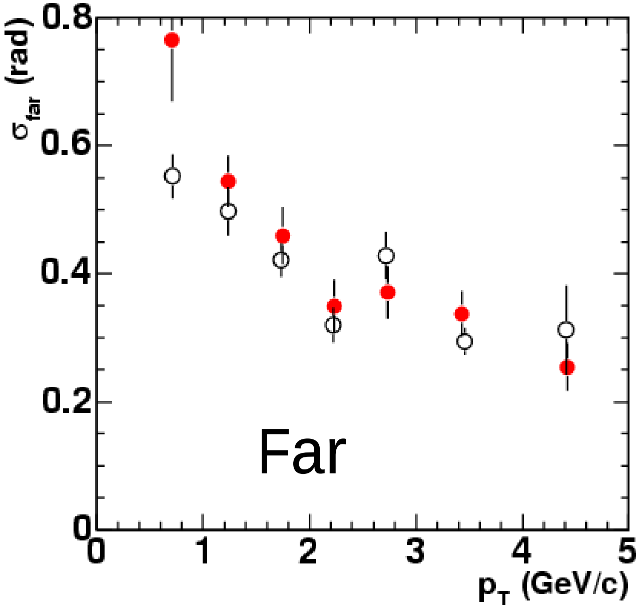
For events with a 5 GeV/c trigger

Significant jet contribution down to lowest pT (0.4-1 GeV/c)

Underlying event yield drops quickly, negligible >2 GeV/c

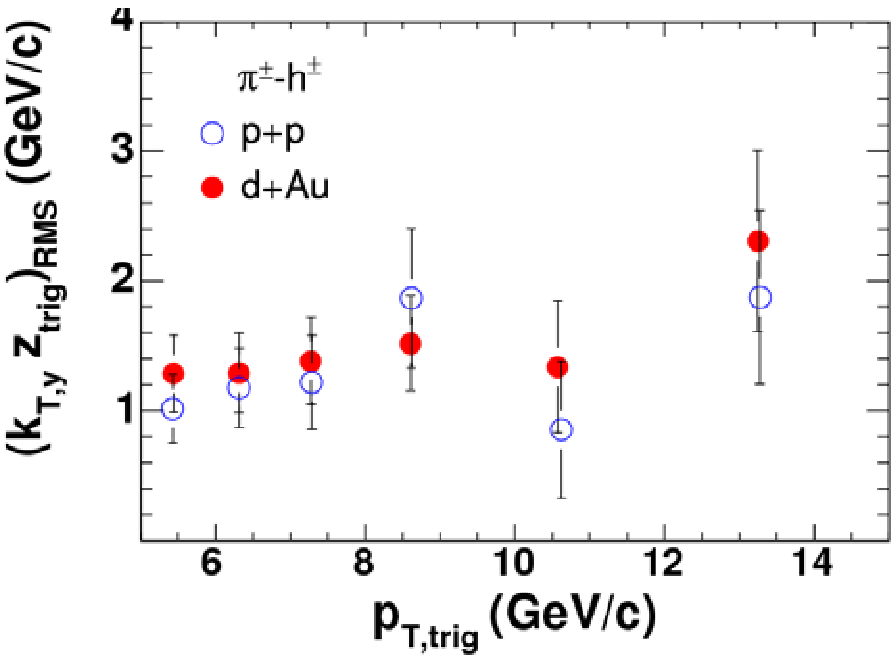
Jet width in $\Delta\phi$





- Width obtained from gauss fits
- Far width > Near width, kT
- Consistent between pp and central dAu

kT broadening in dAu?



z kT consistent between pp and dAu

$$\Delta\langle k_T^2\rangle = \langle k_T^2\rangle_{p+A} - \langle k_T^2\rangle_{p+p}$$

$$\Delta\left\langle\left(k_T z_{trig}\right)^2\right\rangle = 0.64 \pm 0.78 \pm 0.42\ (\mathrm{GeV/c})^2$$

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

No apparent indication of increased k_T.

No sensitivity to multiple scattering?

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

C~ 0.2-0.4

0.8-1.6 $(\mathrm{GeV/c})^2$
in central collisions

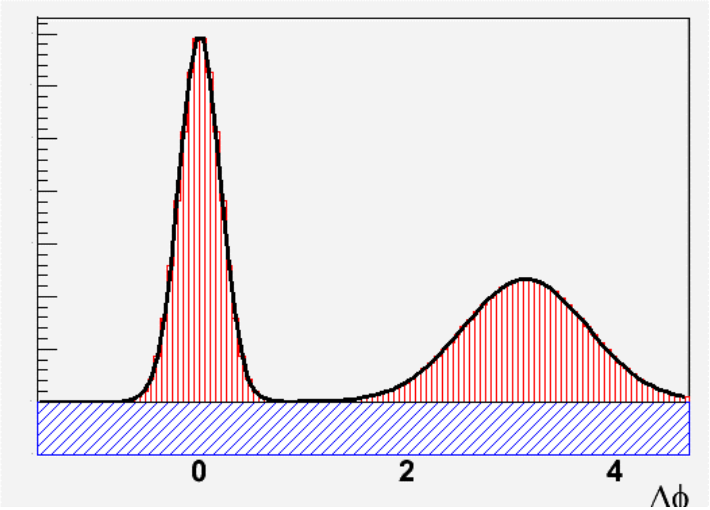
$$\langle k_\perp^{\ 2}\rangle_{pA} = \langle k_\perp^{\ 2}\rangle_{\mathrm{Intrisic}} + \langle k_\perp^{\ 2}\rangle_{\mathrm{Radiation}} + \langle k_\perp^{\ 2}\rangle_{\mathrm{multi\text{-}scatter}}$$

$<1(\mathrm{GeV/c})^2$ $\approx 7(\mathrm{GeV/c})^2$ $\approx 1(\mathrm{GeV/c})^2$

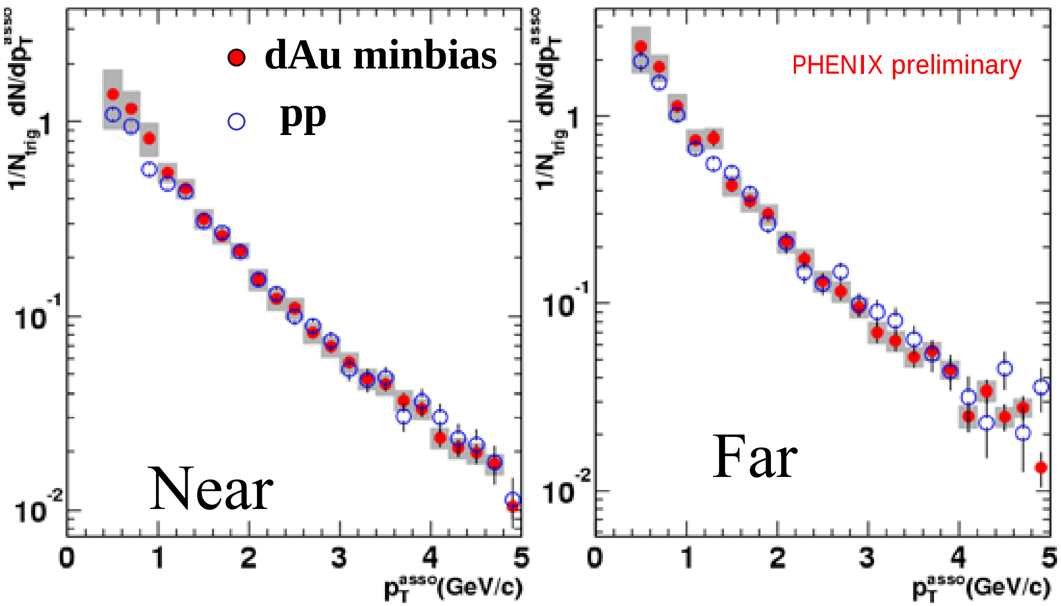
W.Volgelsang, hep-ph/0312320

I.Vitev, Phys.Lett.B570:161,2003.

Jet Yield

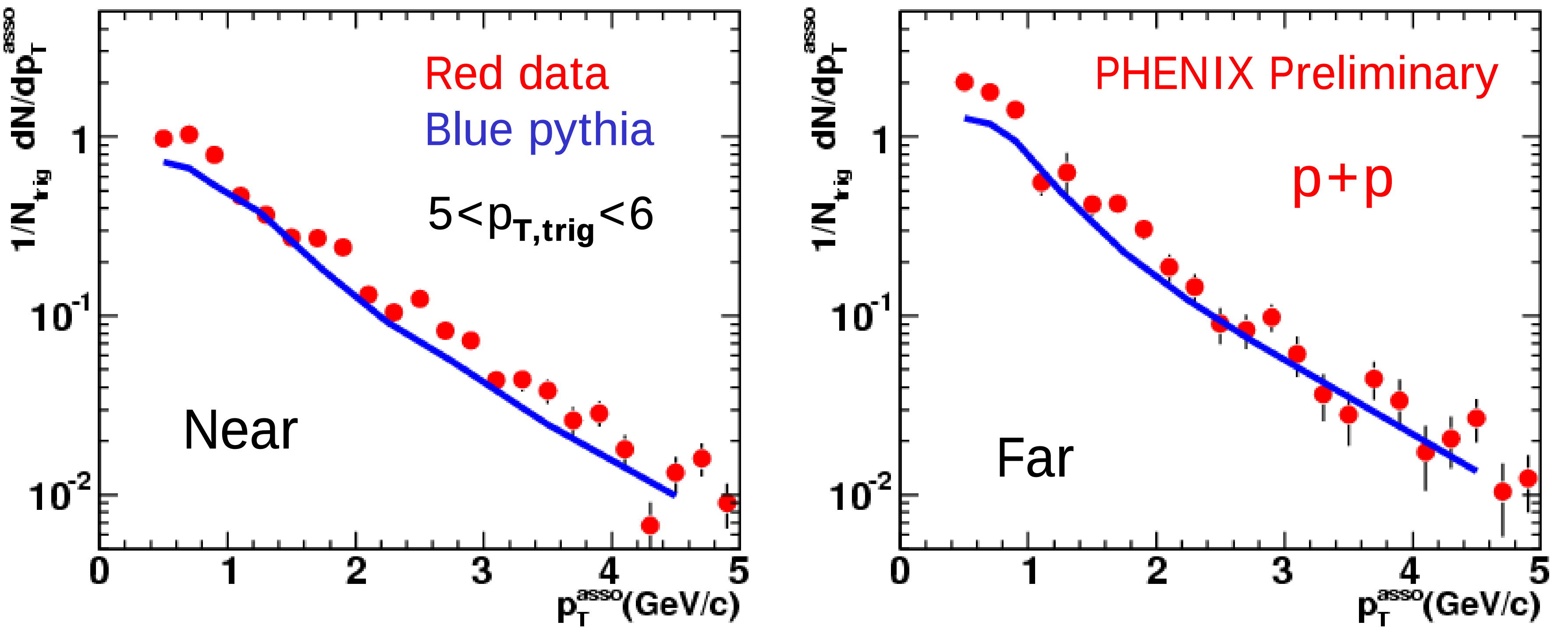


Compare Yield pp and dAu



- $1/N_{trig}\ dN_h/dp_T$
  - p_T from 0.4-5 GeV/c.
- No difference between dAu and pp within errors.
  parton recombination effect not important for these high pT jets

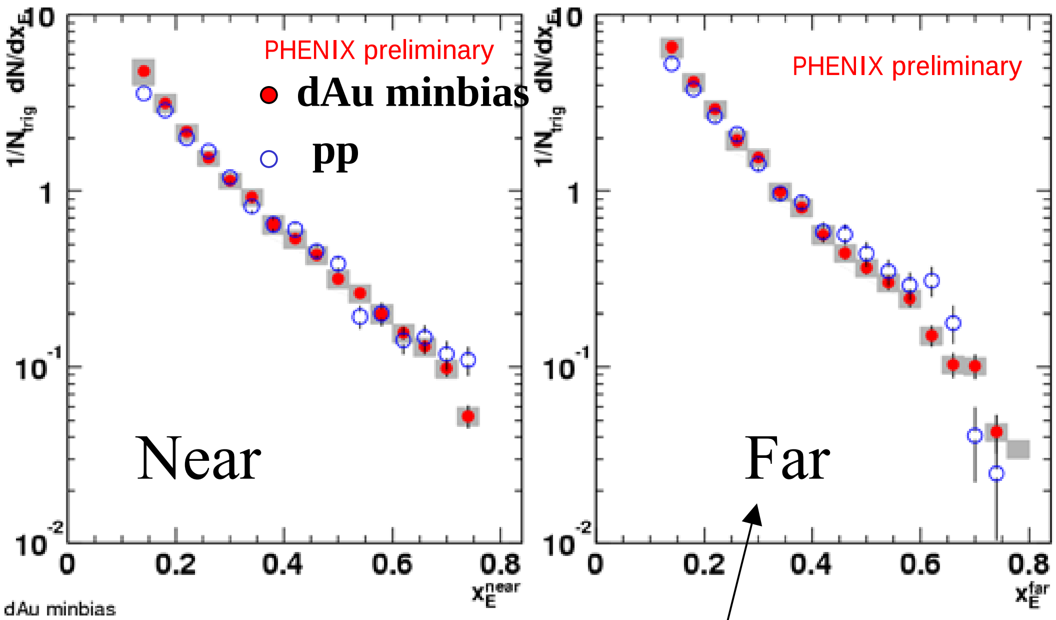
Compare pp yield with Pythia 6.131



We checked the Pythia high pT hadron yield, it’s shape is consistent with PHENIX measurement
Thus the shape of parton pT spectra is same between data and pythia

xE distribution in pp and dAu

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



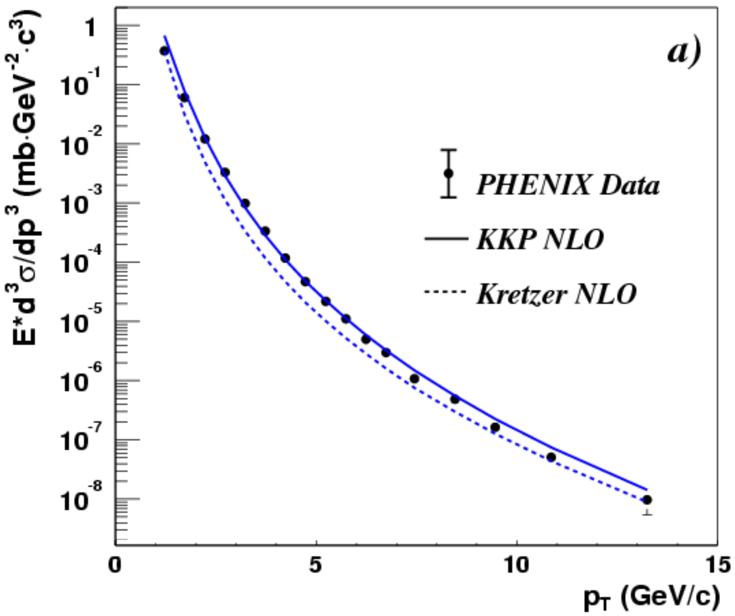
Our focus

- $1/N_{trig}\ dN_h/dx_E$
  - 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.

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

- No difference between dAu and pp within errors.

Connection to Fragmentation function(far side)



$$\frac{1}{p_T}\frac{d\sigma_{\pi 0}}{dp_T} = \frac{C}{p_T^{\ N}} \propto f_q(\hat{p}_T)\otimes D(z) \Rightarrow f_q(\hat{p}_T) \propto \frac{CD_N}{\hat{p}_T^{\ N}}$$

$$D_N = \int dz z^{N-1} D(z)$$

dN/dxE related to di-jet fragmentation:

$$\frac{d^2N}{dp_t dp_a} \propto f_t(\hat{p}_T)\otimes D(z_t)\otimes f_a(\hat{p}_T)\otimes D(z_a)$$

$$dp_t dp_a = \frac{dp_t dx_E}{p_t}$$

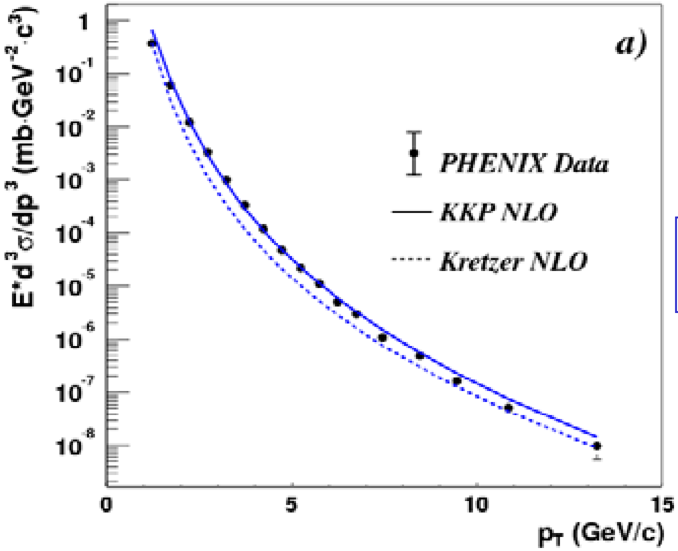
$f_t(\hat{p}_T) = f_a(\hat{p}_T)$ Ignoring initial kT

D(z) can be obtained by inverting away side dN/dxE distribution (fix p_t)

Or for a given D(z) form we can fit dN/dxE to constrain the parameters:

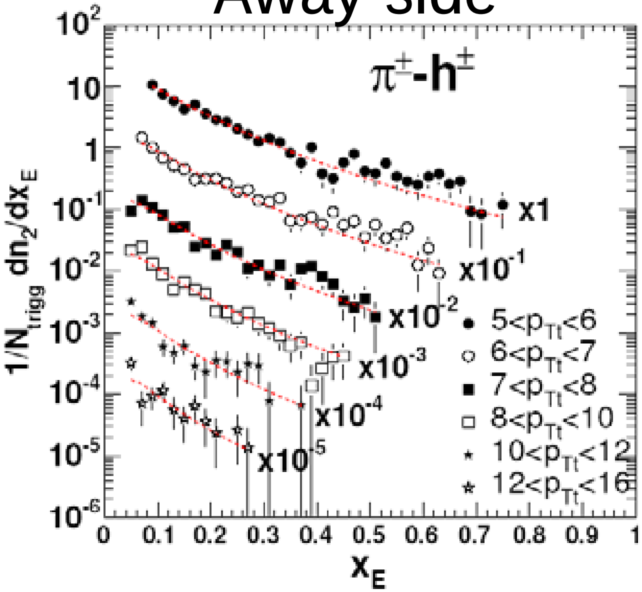
$$D(z) = z^{\alpha}\cdot(1-z)^{\beta}\cdot(1+z)^{\gamma}$$

$$\frac{1}{N_{trig}}\frac{dN}{dx_E} \propto \frac{f(\hat{p}_T)\otimes D(z_t)\otimes D(z_a)}{f(\hat{p}_T)\otimes D(z_t)}$$



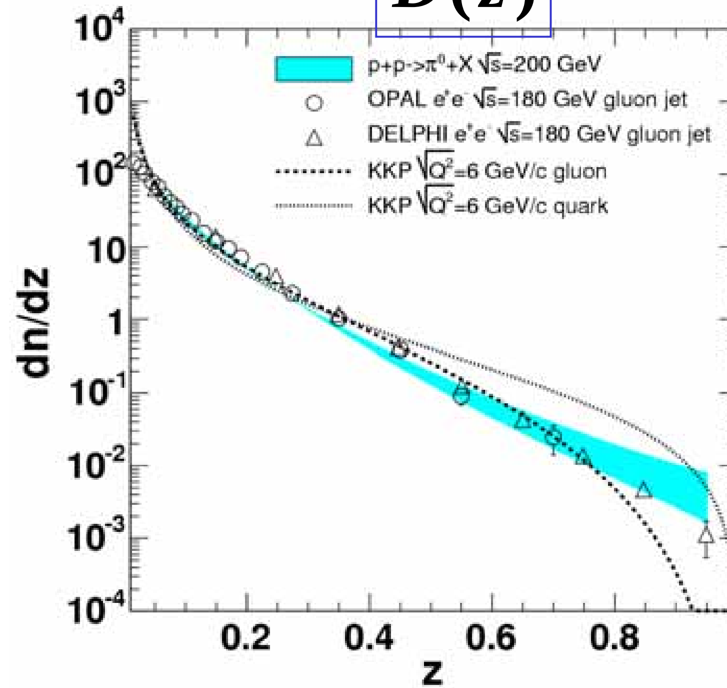
$f(\hat{p}_T)$

Away side



$\frac{1}{N_{trig}}\frac{dN}{dx_E}$

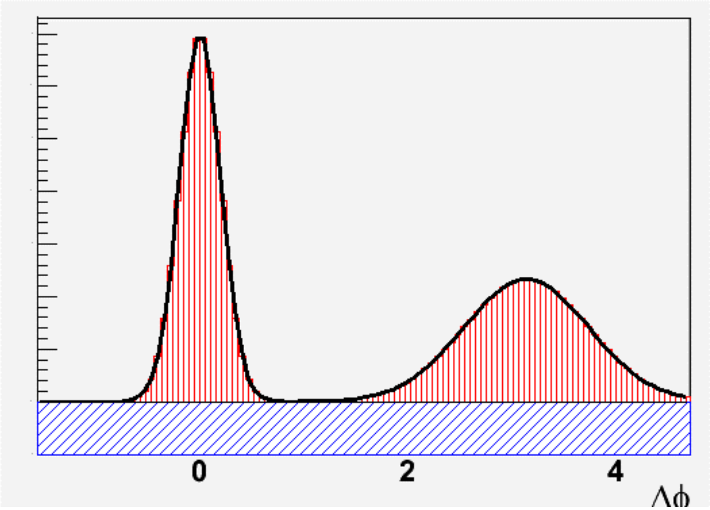
$D(z)$



Normalization is arbitrary

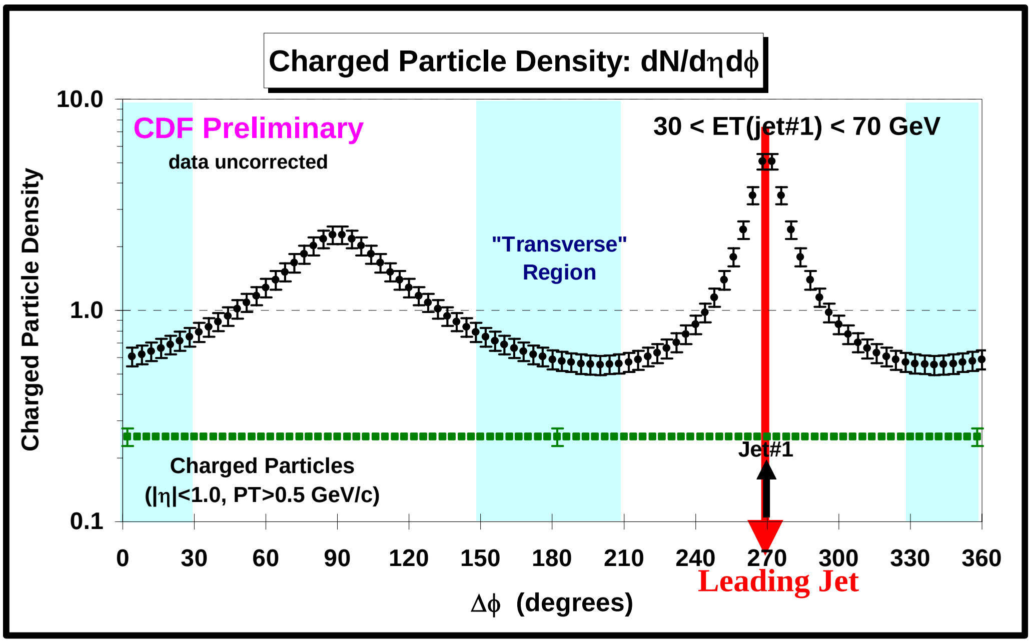
Not finalized yet

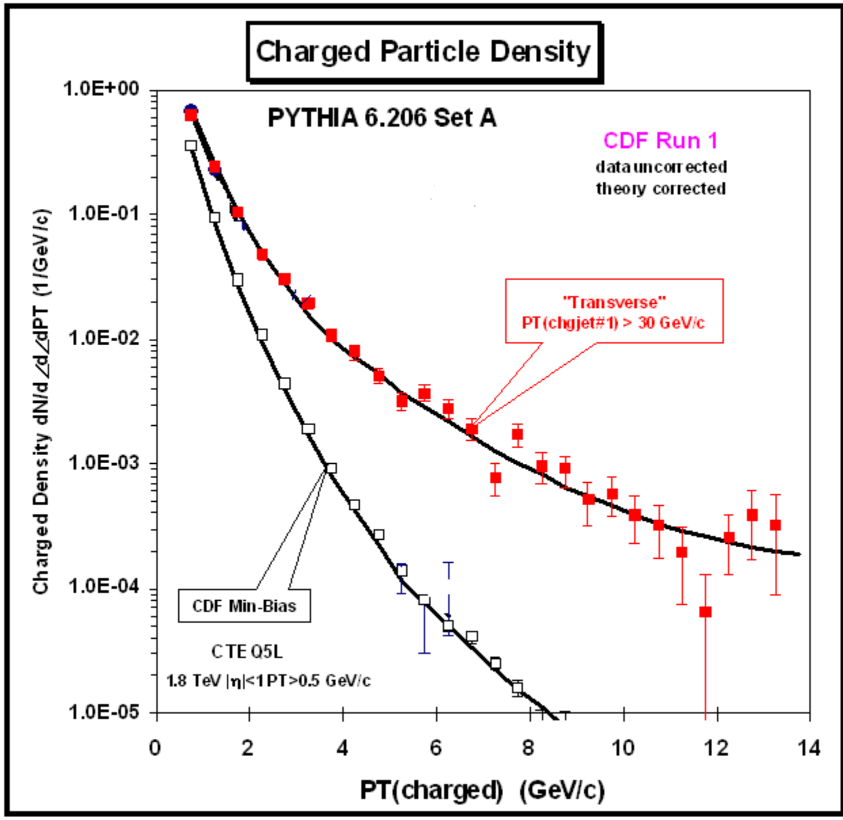
Underlying event



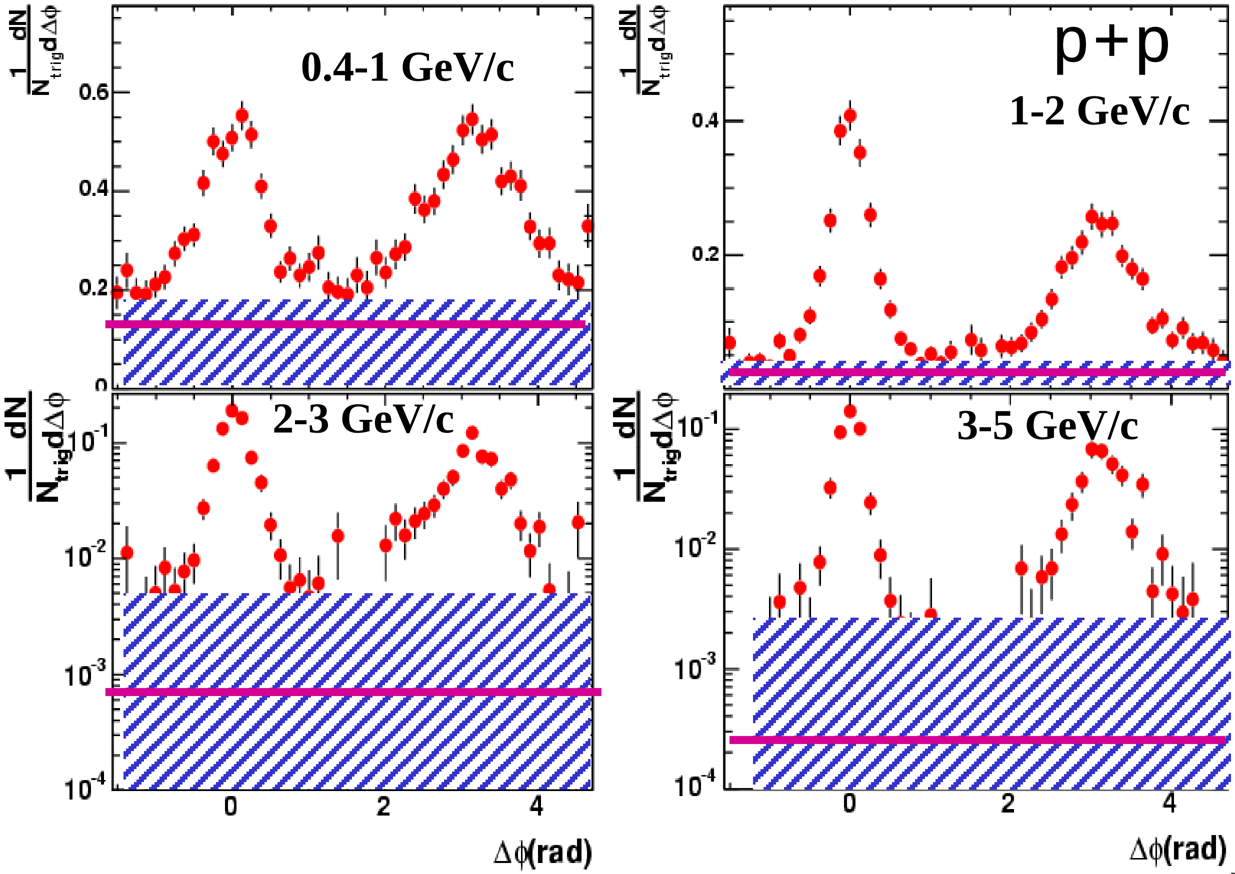
Underlying event study from CDF

From Rick Field, ISMD2004





Underlying event at RHIC



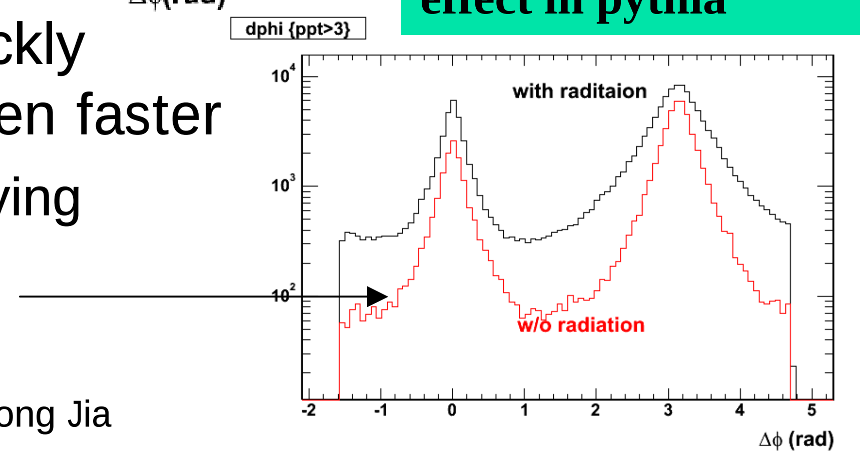
PHENIX preliminary

Linear scale

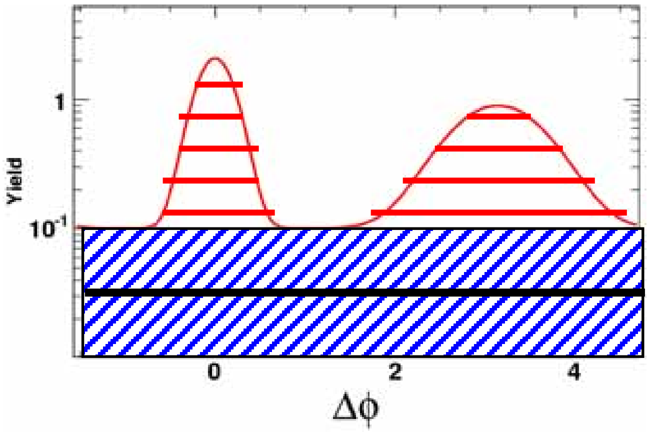
Log scale

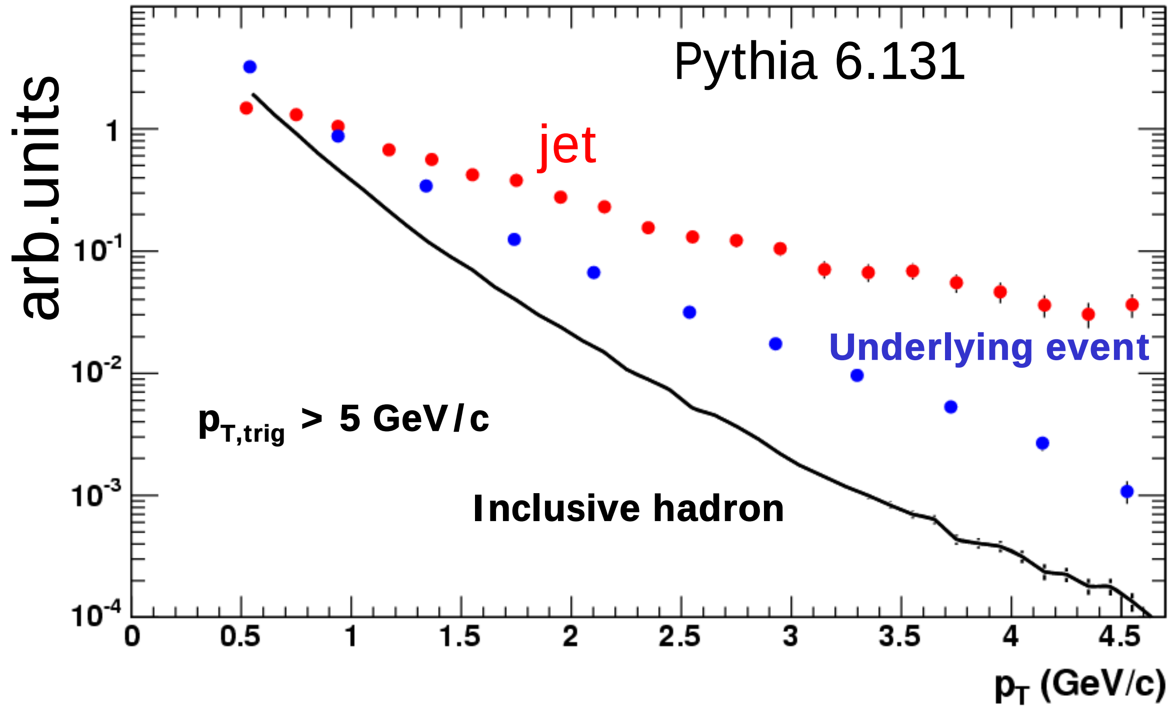
Initial/final radiation effect in pythia

- Underlying event yield drops quickly
- But minimum bias level drops even faster
- Pythia indicates most of the underlying event is from radiative tails



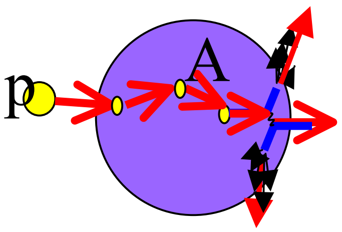
What do we expect?





The underlying event is harder than the inclusive!

pp Underlying event dominated by one hard-scattering,
p+A should scale as : C(A-1) + pp_level.



Summary

- The di-jet decay kinematics are studied with two particle correlation in pp and dAu.
- Width, kT distributions are very similar between dAu and pp, indicating no significant broadening in cold nuclear medium.
- Jet yield distribution in xE and $p_{T,assoc}$ are also similar between dAu and pp, indicating no significant increase in jet multiplicity in dAu relative to pp. D(z) can be derived from single spectra + xE distribution.
- The underlying event yield for triggered events is harder than inclusive yield.

Back Up

Two particle correlation in PHENIX

1) In ideal acceptance, real pair distribution in $\Delta\phi$, $\Delta\eta$ is

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

2) It is modulated by PHENIX pair acceptance function **$Acc(\Delta\phi, \Delta\eta)$**.

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

3) Pair acceptance function can be determined from event mixing technique

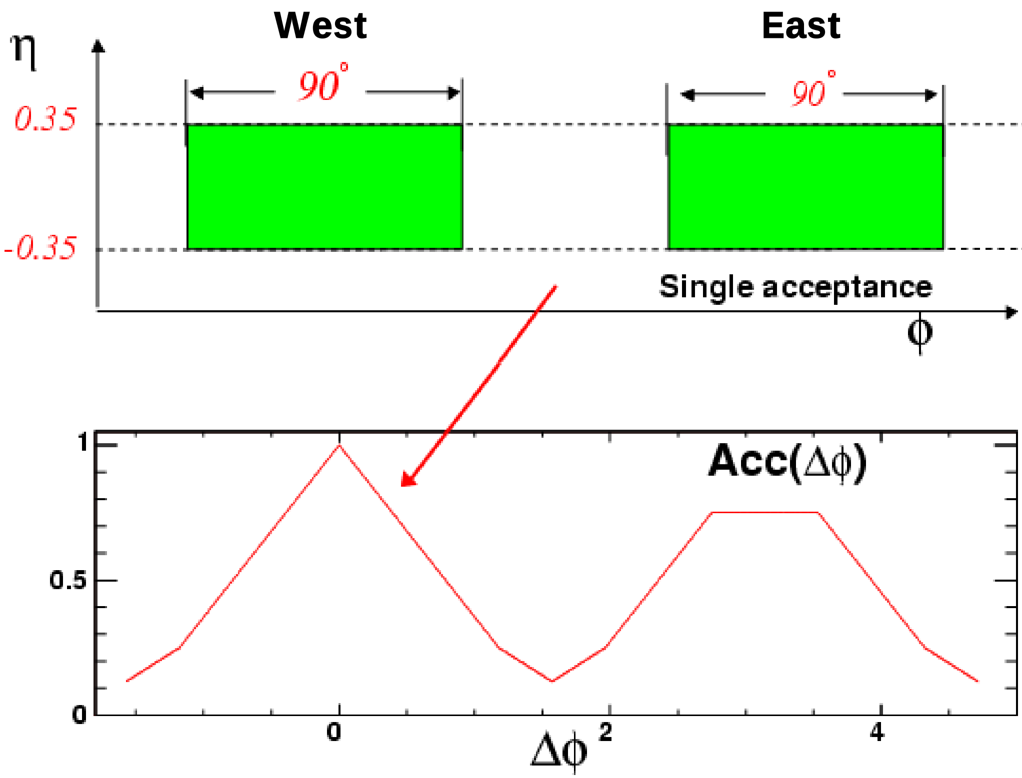
$$dN^{mix} / d\Delta\phi d\Delta\eta \propto Acc(\Delta\phi, \Delta\eta)$$

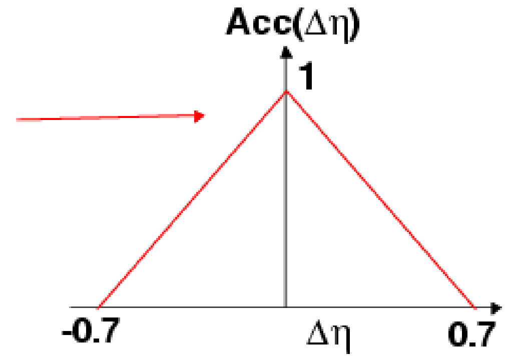
4) Real/mix gives the acceptance corrected CY.

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

1D correlation function: $dN/\Delta\phi$ or $dN/d\Delta\eta$.

Pair acceptance function in PHENIX





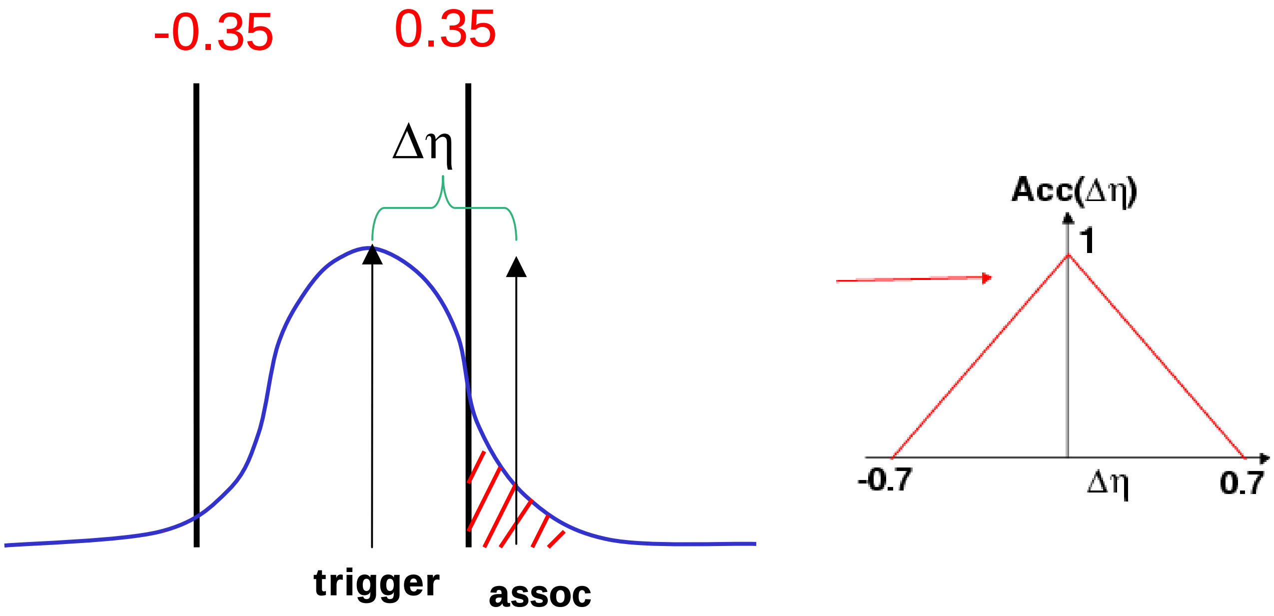
nucl-ex/0409024

Shape from overlapping four triangles:

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

Pair effi is 100% at $\Delta\phi=0$, $\Delta\eta=0$. average is 25%

The correction in Δη



Pair acceptance is limited by single acceptance: |η|<0.35 =>|Δη|<0.7

- If we know the jet shape in Δη, we can correct back to true yield in |Δη|<0.7

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

Convoluted with pair acceptance

- In pp/dAu collisions, jet shape is the same in Δϕ and Δη. (AuAu is different!)

Extracting jet properties

- Correlation function in $\Delta\phi$: per-trigger-yield

  correct for pair acceptance , efficiency and $\Delta\eta$.

$$\frac{1}{N^0_{trig}}\frac{dN^0}{d\Delta\phi} = \frac{1}{N_{trig}}\frac{N_{corr}(\Delta\phi)}{2\pi N_{mix}(\Delta\phi)\Big/\int d\Delta\phi\, N_{mix}(\Delta\phi)}\frac{R_{\Delta\eta}}{\varepsilon}$$

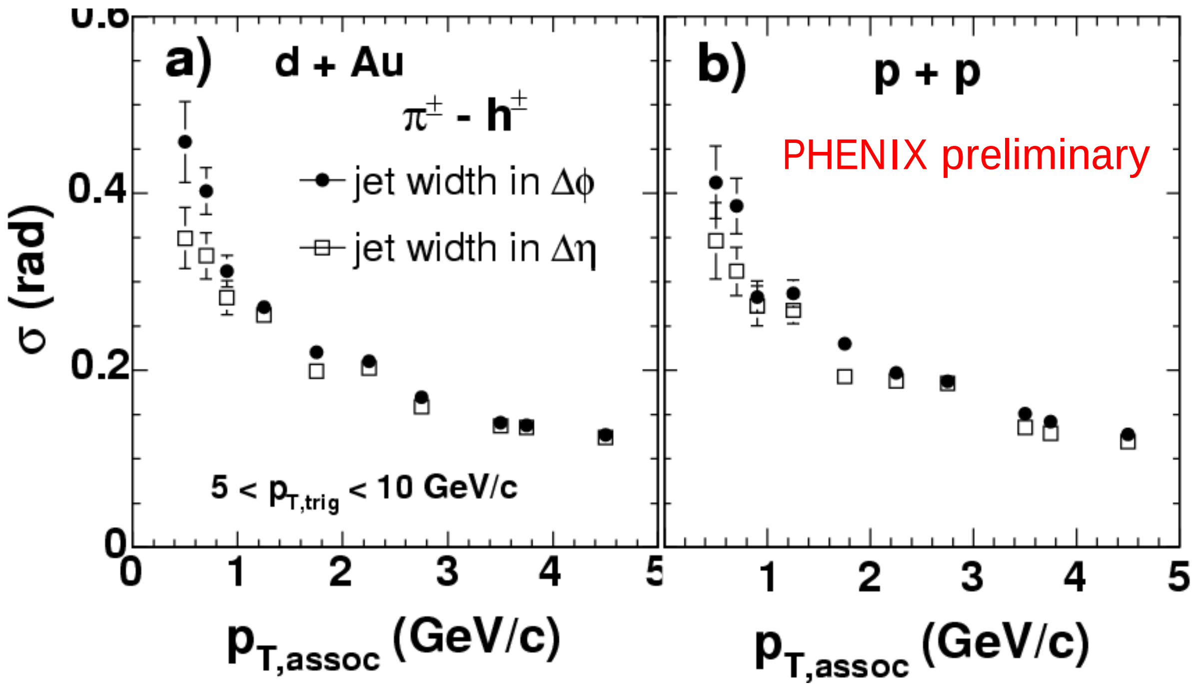
- Fit per-trigger-yield with a double gauss + constant

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

Underlying event — Near side jet — Far side jet

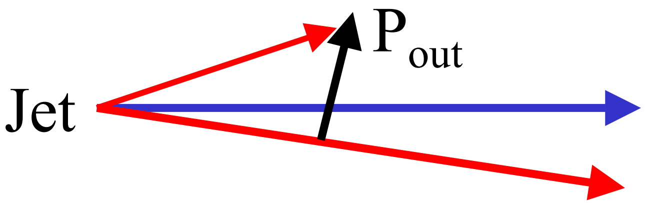
Near side width in $\Delta\eta$ compared with $\Delta\phi$

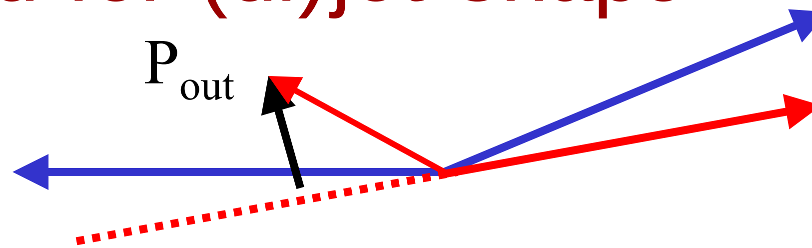
$|\Delta\eta|<0.7$



- Near side jet width are consistent in $\Delta\phi$ and $\Delta\eta$ for both dAu and pp

Alternative Method for (di)jet Shape

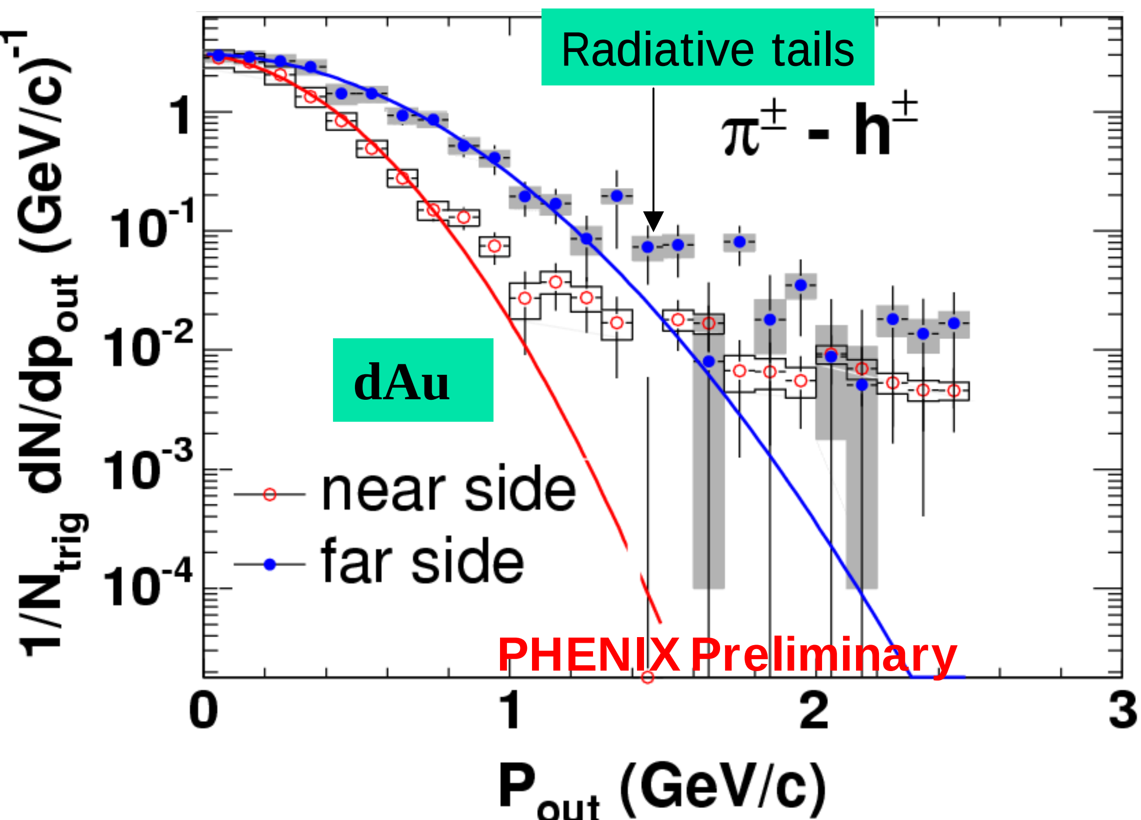




$$\langle p_{out}^2 \rangle \approx \langle j_T^2 \rangle + x_E^2 \langle j_T^2 \rangle \approx \langle j_T^2 \rangle$$

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

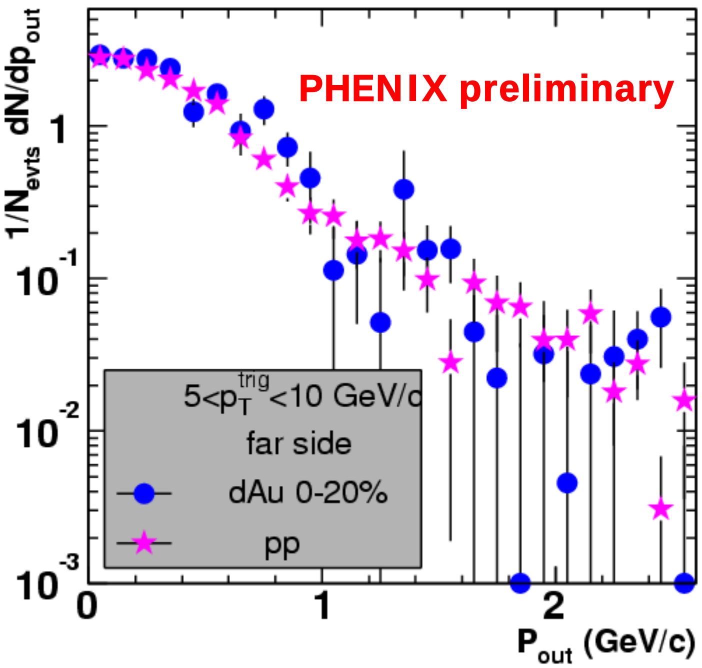
$$2 x_E^2 z^2 \langle k_T^2 \rangle \approx \langle p_{out,far}^2 \rangle - \langle p_{out,near}^2 \rangle$$

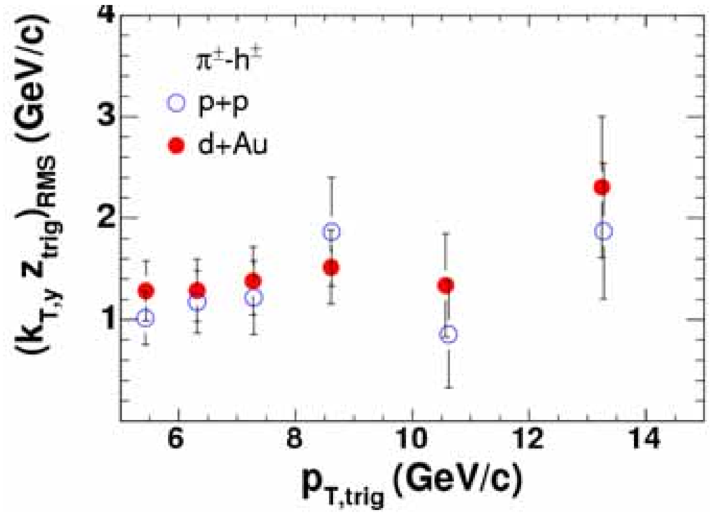


- By measuring pout pair-by-pair, more directly see the shape of the j_T/k_T dist's.
- See non-Gaussian tails – expected due to hard radiation.

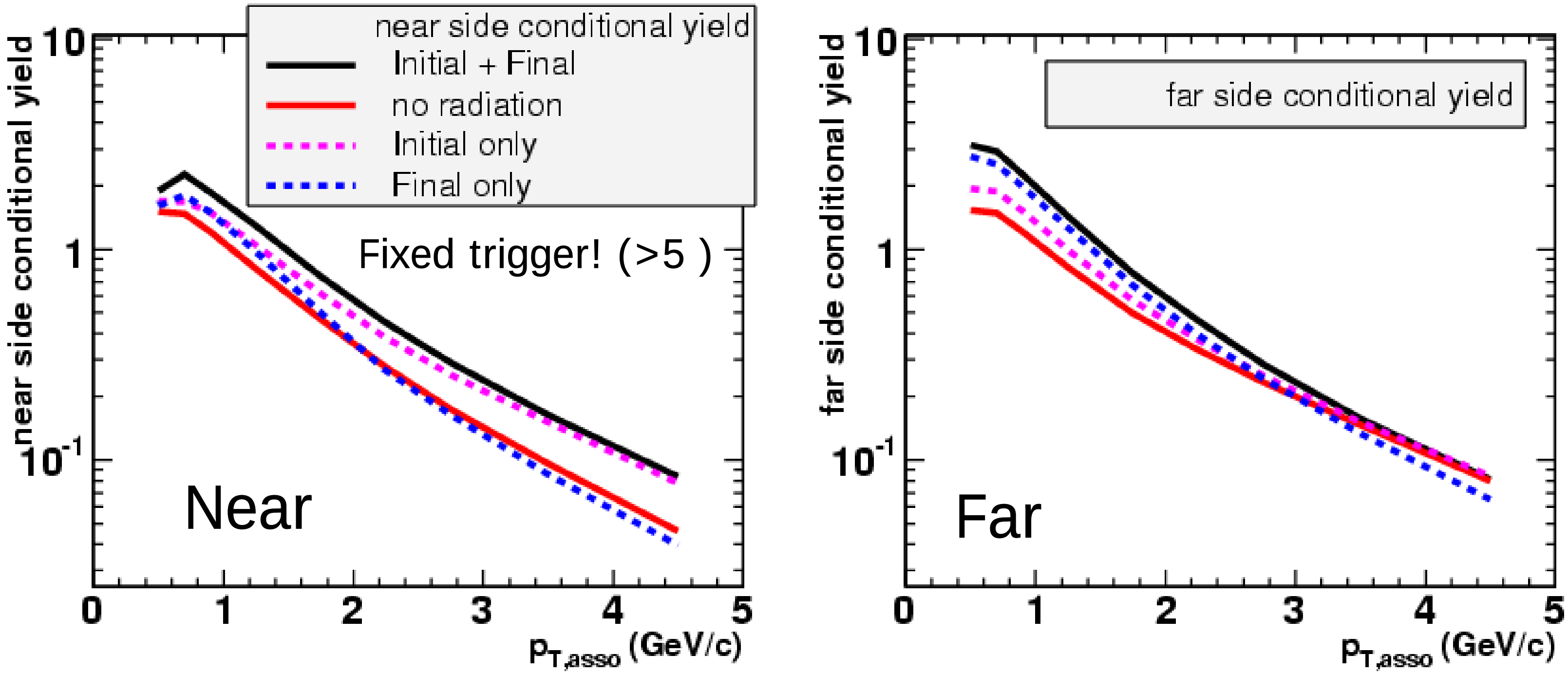
dAu central vs pp

- Away side Pout distributions are similar between pp and dAu
  - Consistent with the kT results





Initial/ final state radiation from Pythia



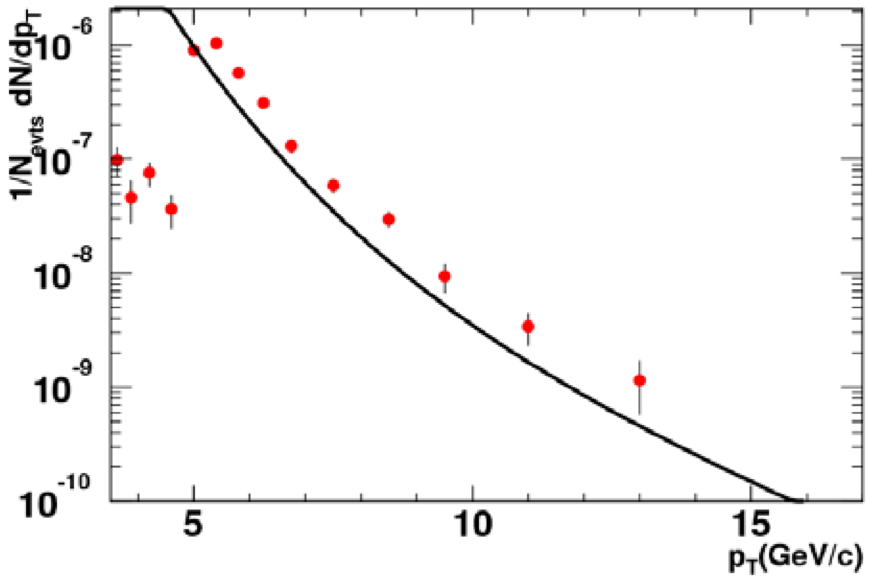
$$\frac{d^2N}{dp_t dp_a} \propto f(x) \otimes F(k_T) \otimes D(z)$$

- Initial radiation:
  - Near side: enhanced yield at large $p_{T,assoc}$
  - Far side: small change

  Due to initial kT + trigger bias effect? z_{trig} decrease, and z_{assoc} increase
- Final radiation :
  - Near side: small change. Energy available: $(1-z_{Trig})E_{Jet}$
  - Far side: enhanced yield at low $p_{T,assoc}$. Full jet energy available: E_{Jet}

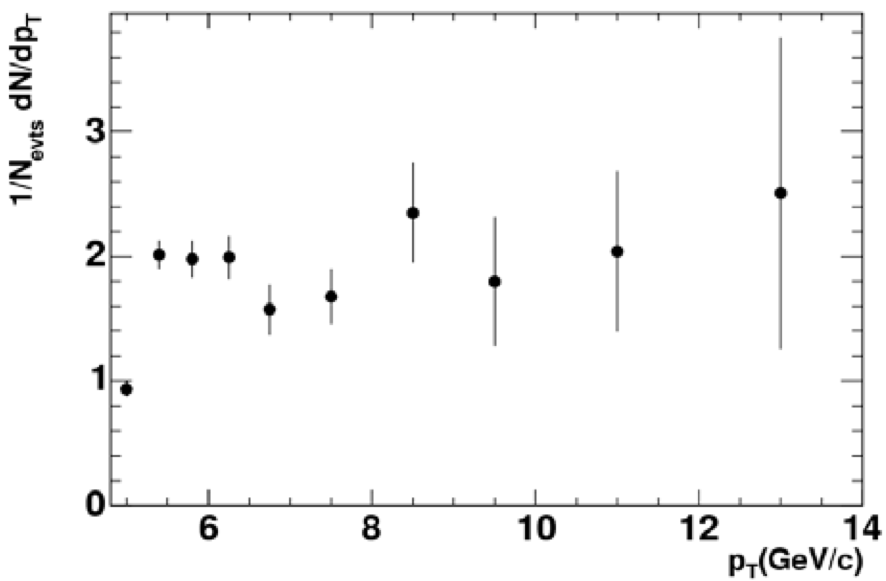
Pythia Pion yield compared with data

- Line is fit to data
- Red point is pythia pi0 yield



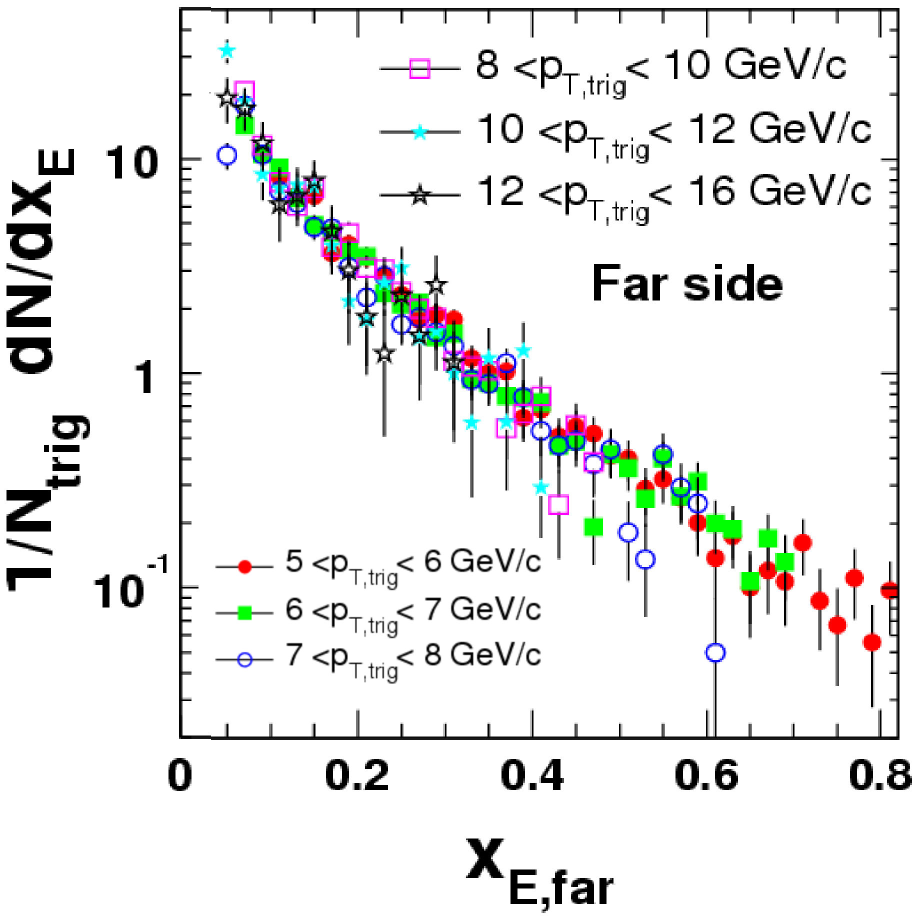
- has the same shape
- Which means that the parton spectra are the same!

$$\frac{dN}{p_T\,dp_T} = \int_{x_T}^{1} D(z)\, f\left(\frac{p_T}{z}\right)\frac{dz}{z^2}$$



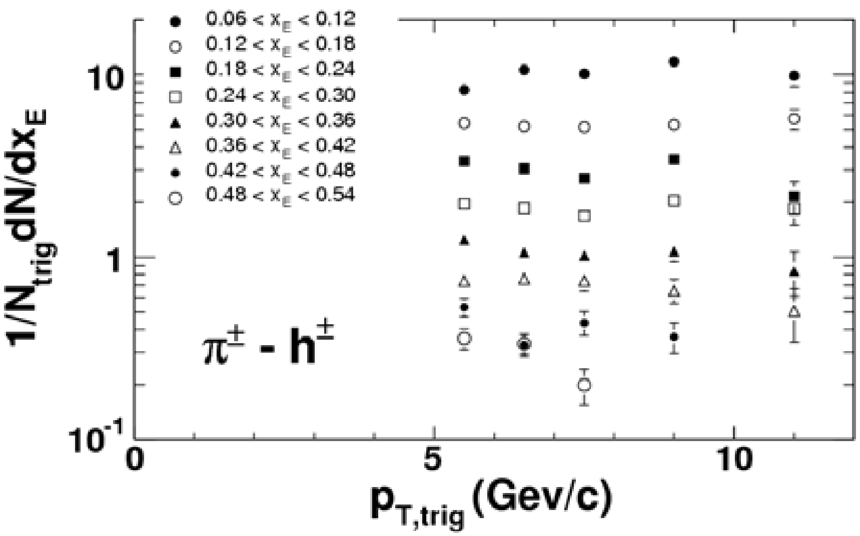
dN/dx_E:dependence on trigger pT

- x_E distributions for several different trigger ranges
- Overlap of data consistent with fragmentation being independent of parton momentum.
  - Note $<z_{trig}>$ only weakly depends on $p_{T,trig}$

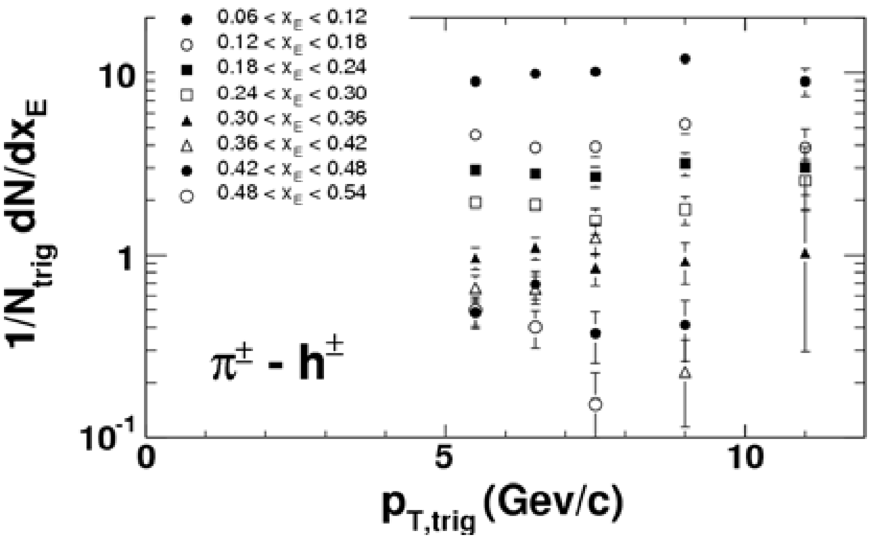


Scaling of dN/dx_E

d+Au Min Bias



p+p



Scaling with p_{Ttrig}

Scaling holds for p+p and d+Au at RHIC.

Jet multiplicity: centrality dependence

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