Jets and High-p_T (Di-hadron) Correlations in PHENIX

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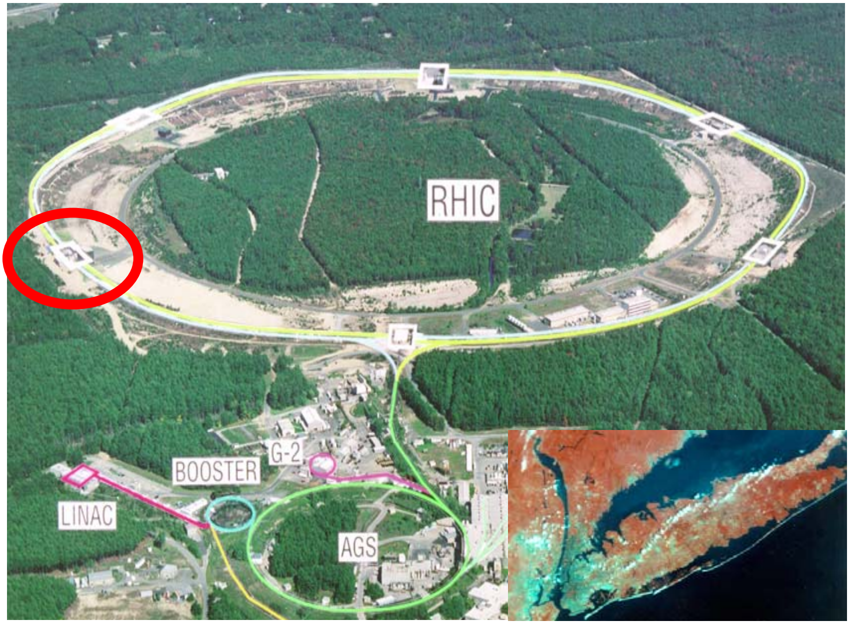
Outline

- RHIC and PHENIX
- The nuclear medium and jet modifications
  - Correlation Functions
  - Hard scattering
  - Near (Same)-side and Away-side (di-jet) correlations
- Jet modifications in Heavy-Ion Collisions
- Future measurement technique
- Summary

RHIC and PHENIX

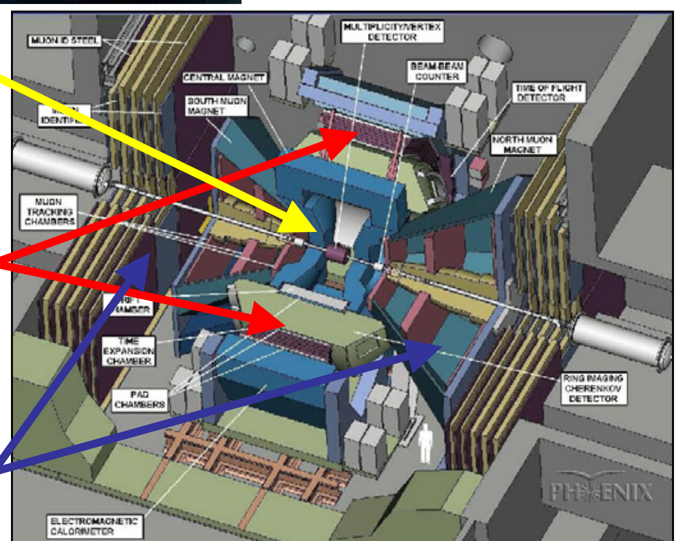


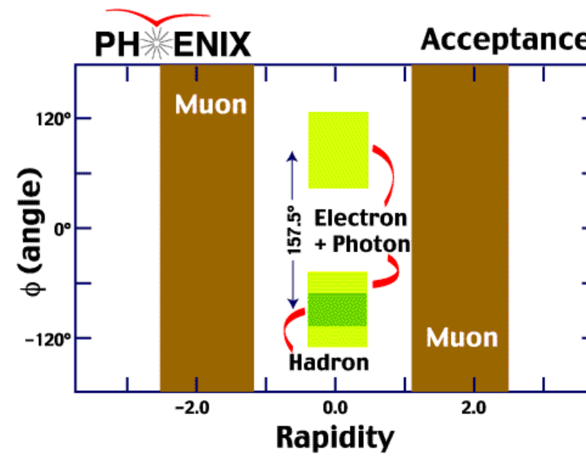
- Brookhaven National Laboratory
  - 70 mi from Manhattan
- Two rings / 3.83 km circumference
- Capable of colliding ~ any nuclear species on ~ any other species
- Energy:
  - ➡ 500 GeV for p-p
  - ➡ 200 GeV for Au-Au (per N-N collision)
- Luminosity
  - Au-Au: 2 x 10^{26} cm^{-2} s^{-1}
  - p-p : 2 x 10^{32} cm^{-2} s^{-1} (polarized)

Event characterization detectors in center

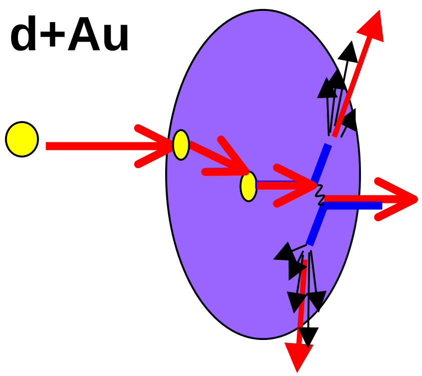
Two central arms for measuring hadrons, photons and electrons

Two forward arms for measuring muons





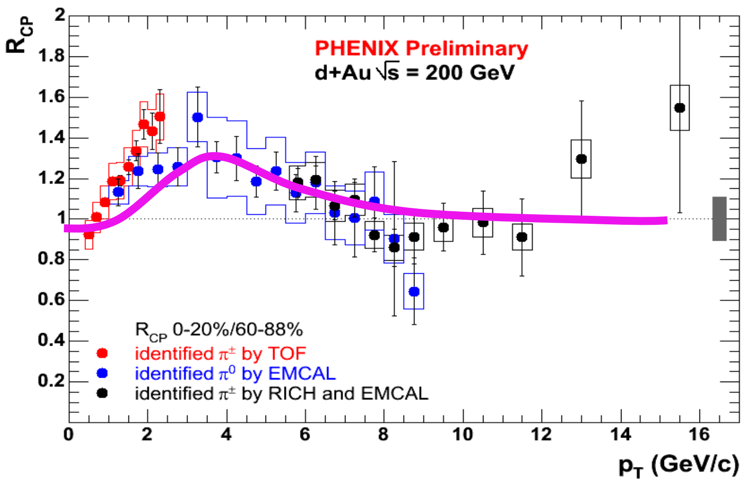
The Nuclear Medium

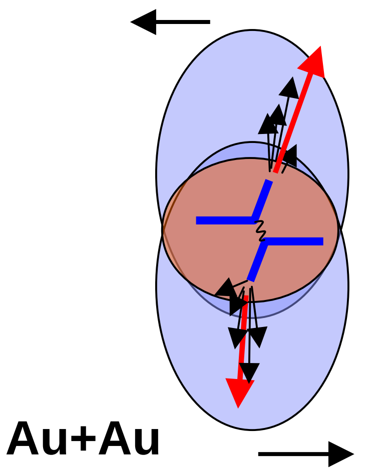


- Nuclear modification factor

$$R_{cp} = \frac{\text{Yield (Central), scaled}}{\text{Yield (Periph), scaled}}$$

- Multiple scattering in the medium results in k_T broadening
- Thought to be source of Cronin Enhancement

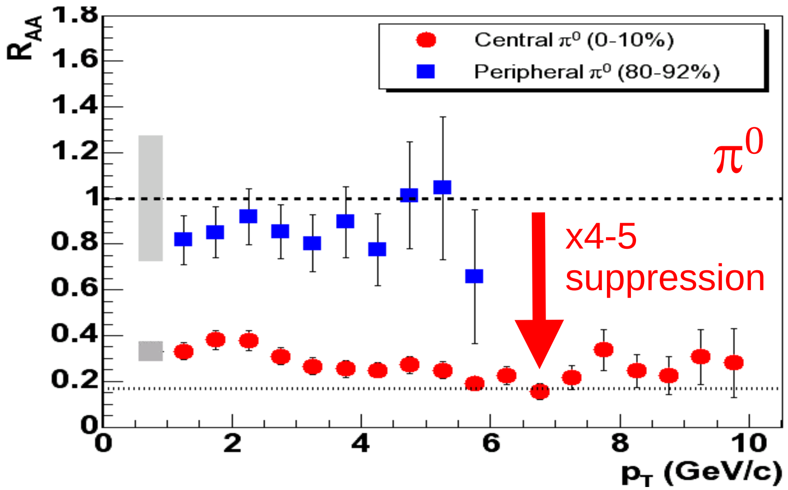




- Nuclear modification factor

$$R_{AA} = \frac{\text{Yield}(AA)\text{, scaled}}{\text{Yield}(pp)\text{, scaled}}$$

- Medium-induced energy loss?



Let's go beyond single-particle observables -- What can study of jet observables tell us?

Correlation Functions

- Azimuthal correlations are an alternative approach to jet studies where full reconstruction is impractical
- $\Delta\phi$ is ϕ between leading and associated particles
- Correlation functions typically defined as :

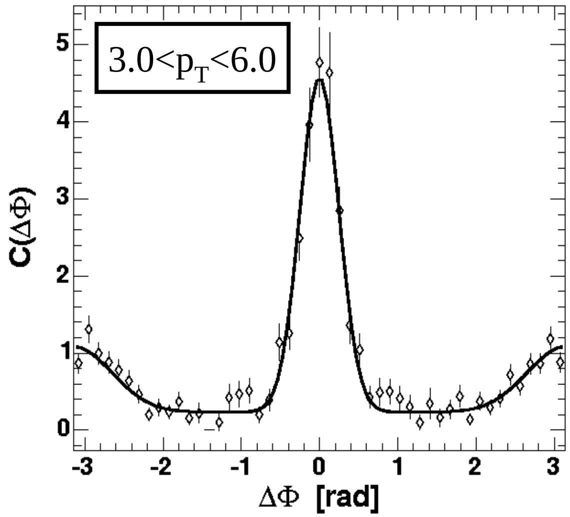
$$C(\Delta\phi) \propto \frac{N_{corr}(\Delta\phi)}{N_{mix}(\Delta\phi)}$$

→ Same-event pairs

→ Mixed-event pairs

Fit with: 2 Gaussians + Constant Bg term

p+p $h^{\pm}$ Correlation Function



- Conditional Yields can be extracted from correlation when properly normalized and corrected for acceptance and efficiency:

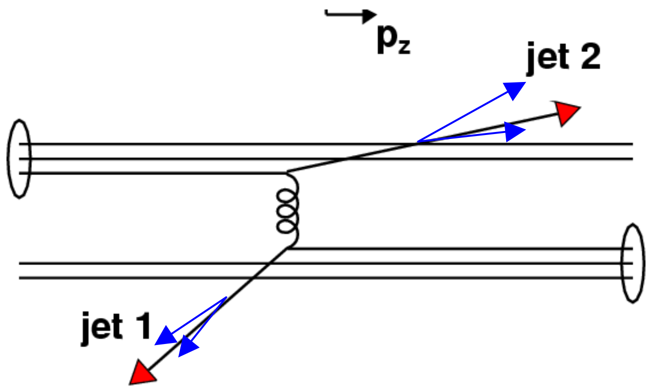
$$\frac{1}{N^0_{trig}}\frac{dN^0}{d\Delta\phi} = \frac{1}{N_{trig}}\frac{N_{corr}(\Delta\phi)}{2\pi N_{mix}(\Delta\phi)\Big/\int d\Delta\phi N_{mix}(\Delta\phi)}\frac{R_{\Delta\eta}}{\varepsilon}$$

Real yield per trigger particle

Observed yield per trigger

Correct for limited η acceptance and single-particle efficiency

Hard-scattering



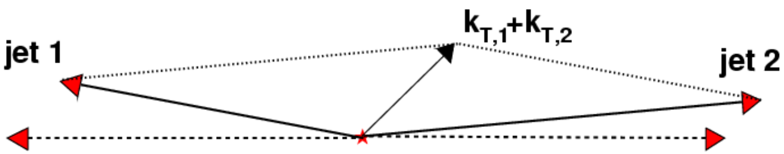
Leading hadron

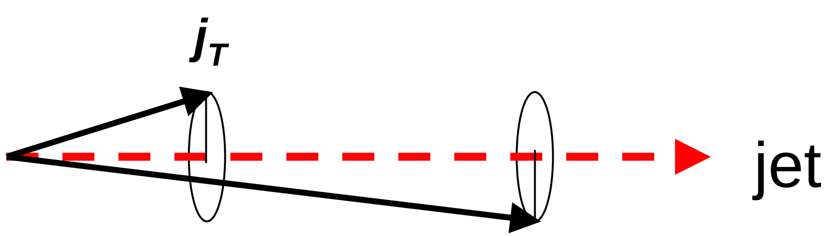
- Partons scatter with large Q^2
- Outgoing partons fragment into cone of hadrons

$$R = \sqrt{\Delta\phi^2 + \Delta\eta^2} \approx 0.7$$

- Parameters of interest
  - Spread of particles around jet axis (j_T)
  - Acoplanarity of back-to-back jets (k_T)
  - Hadronic spectrum (Frag. Func. D(z))

Transverse plane:





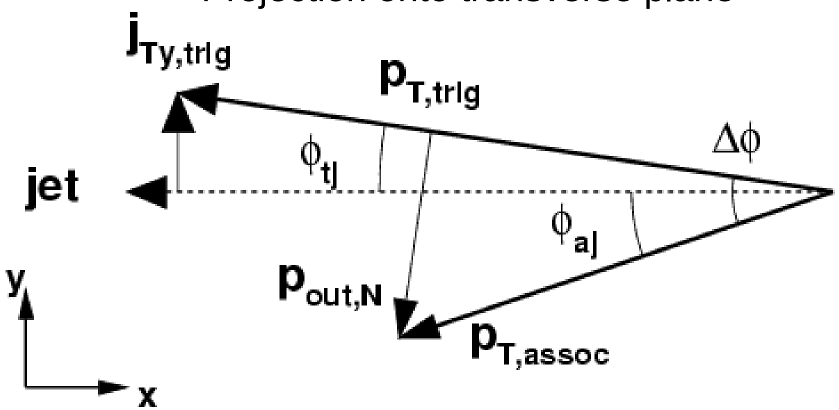
Partons have intrinsic transverse momentum k_T:

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

j_T = hadron's momentum transverse to the jet axis

Near-side Correlation

Projection onto transverse plane

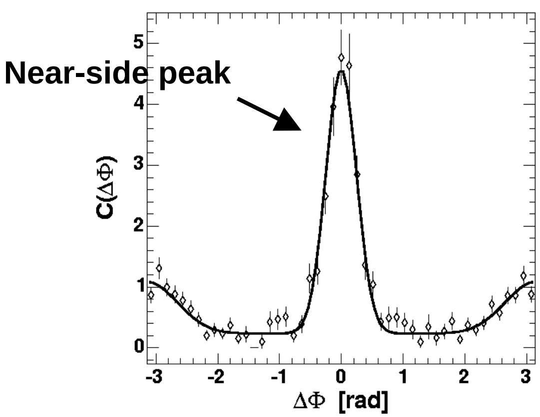


ϕ_{tj} **trigger-parton**
ϕ_{aj} **associated-parton**

$$\Delta\phi = \phi_{tj} + \phi_{aj}$$
$$= \text{Angle between Trigger \& Associated}$$

Assume angles are statistically independent

- Leading (highest p_T) "Trigger" particle used as estimator for jet axis
- "Near-Side": particles from same jet will be correlated in a peak around $\Delta\phi \sim 0$
- Simple relations can be derived (assume $p_{T,trig} >> j_{Ty}$):

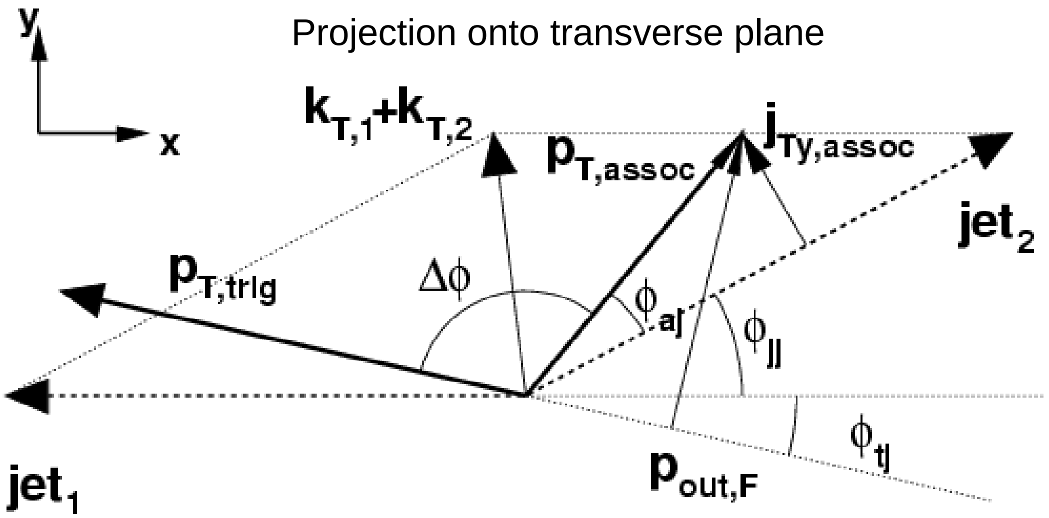


$$\left\langle p_{out,N}^2 \right\rangle = \left\langle p_{T,assoc}^2 \sin^2 \Delta\phi \right\rangle = \left\langle j_{T_y}^2 \right\rangle \left(1 + \left\langle x_h^2 \right\rangle\right), \text{ with } x_h = \frac{p_{T,assoc}}{p_{T,trig}}$$

$$\left(j_{T_y}\right)_{RMS} = \sqrt{\frac{\left\langle p_{out,N}^2 \right\rangle}{1 + \left\langle x_h^2 \right\rangle - 2\left\langle x_{j,assoc}^2 \right\rangle}} \approx \frac{\sigma_N \left\langle p_{T,assoc} \right\rangle}{\sqrt{1 + \left\langle x_h^2 \right\rangle}}$$

Note there are corrections to these expressions, but they are small
See J. Jia, nucl-ex/0409024 for further details

Away-side Correlation

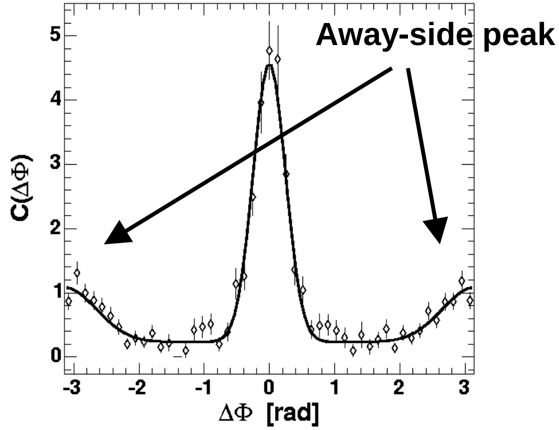


ϕ_{tj} **trigger-parton**
ϕ_{aj} **associated-parton**
ϕ_{jj} **parton-parton**

$$\Delta\phi = \pi - \left(\phi_{tj} + \phi_{aj} + \phi_{jj}\right)$$

Assume angles are statistically independent

- "Away-Side": particles from (nearly) back-back jets form a peak at $\Delta\phi \sim \pi$
- Average di-jet acoplanarity k_T can be extracted from angles btn hadrons:



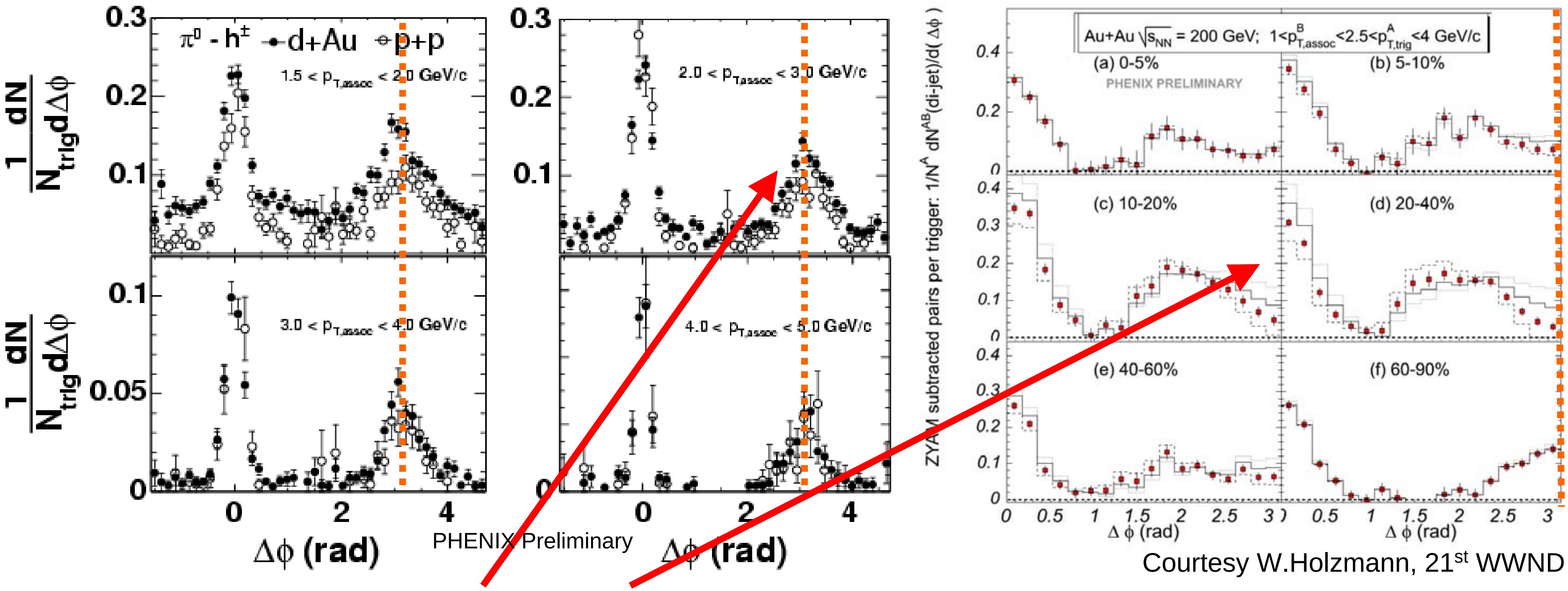
$$\left(k_{T_y} z_{trig}\right)_{RMS} \approx \frac{\left\langle p_{T,assoc}\right\rangle}{\sqrt{2\left\langle x_h^2\right\rangle}} \sqrt{\left\langle \sin^2 \sigma_F \right\rangle - \left\langle \sin^2 \sigma_N \right\rangle}$$

$$z_{trig} = \frac{p_{T,trig}}{p_{T,jet}}$$

Again, there are small corrections…
cf. nucl-ex/0409024

Jet Modifications

- One of the most exciting results at RHIC has been the behavior of the away-side peak in azimuthal correlations



Courtesy W.Holzmann, 21st WWND

There is little if any difference between p+p, d+Au away-side peak (esp. at high p_T), but the broadening of away-side peak in Au+Au is striking!

k_T comparison

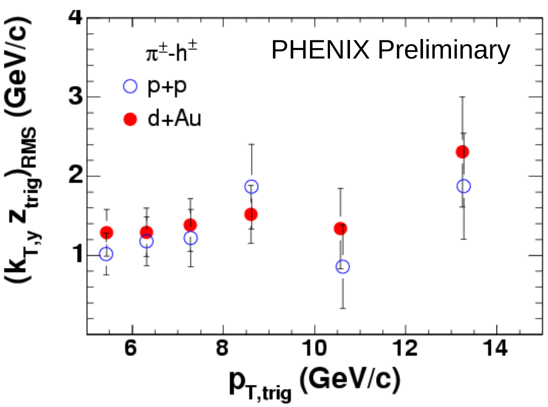
PHENIX

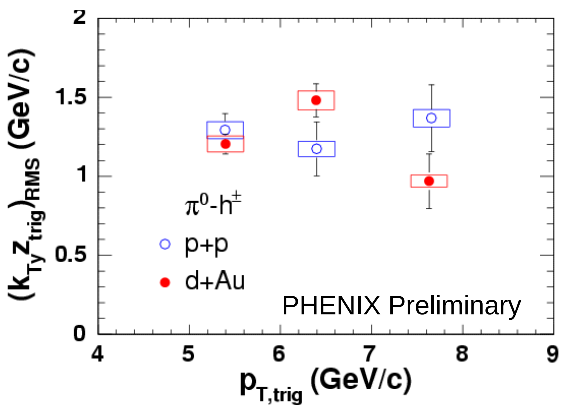
$$\langle k_\perp^{\,2}\rangle_{AA} = \langle k_\perp^{\,2}\rangle_{vac} + \langle k_\perp^{\,2}\rangle_{IS\ nucl} + \langle k_\perp^{\,2}\rangle_{FS\ nucl}$$

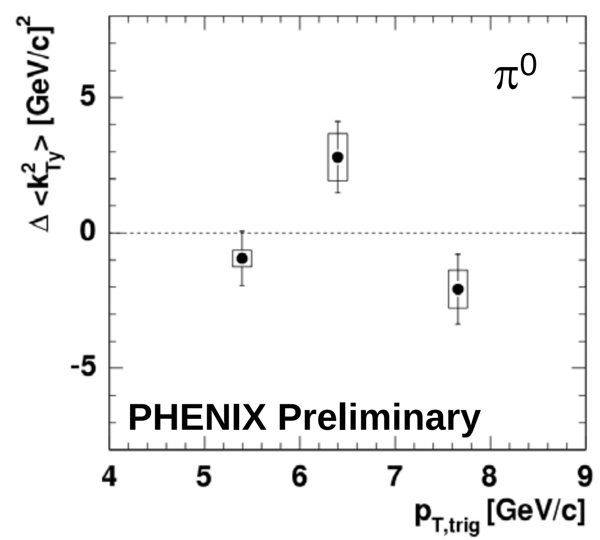
p+p p+A A+A

- Comparison of p+p/d+Au/Au+Au allows separation of medium effects
- We see little, if any, difference between k_T of p+p & d+Au
  - Disappearance of away-side in Au+Au complicates this comparison...

$$\Delta\langle k_{Ty}^2\rangle = (k_{Ty})^2_{RMS,dAu} - (k_{Ty}^2)^2_{RMS,pp}$$







1d RMS $k_T z_{trig}$ product using π^0 and $\pi^\pm$ as triggers

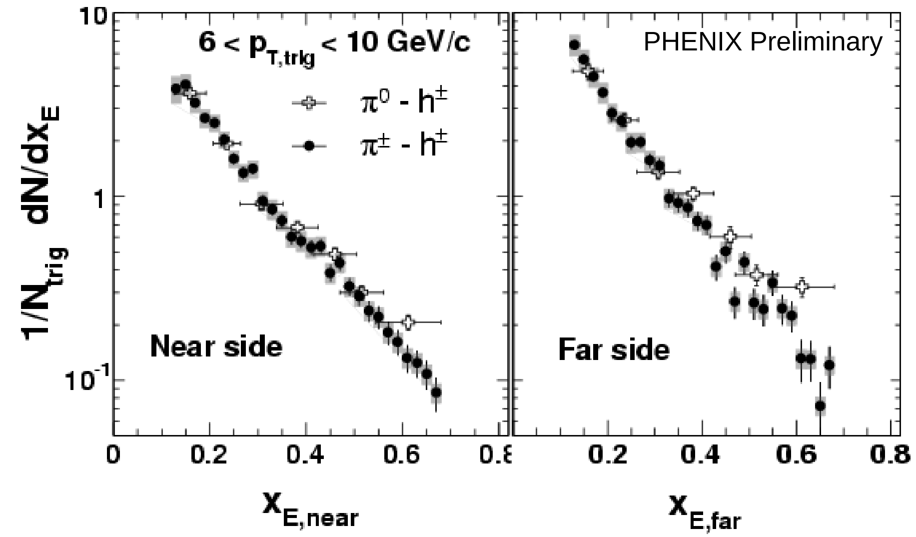
$$\Delta\langle k_{Ty}^2\rangle = -0.25 \pm 0.68(stat.) \pm 0.27(sys.)$$

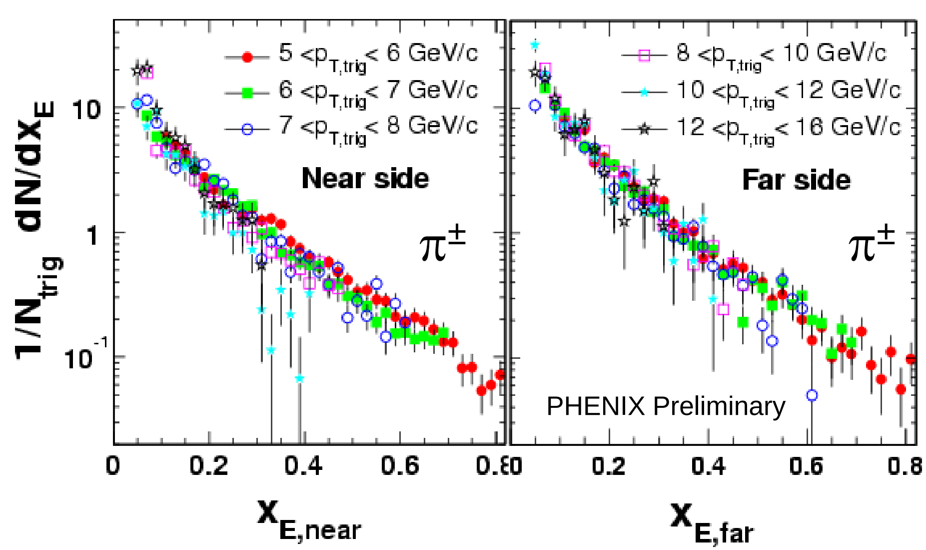
Future Measurements

- Correlation method requires rough binning in p_T
  - Observables extracted as averages within these rough bins
  - Corresponding bin widths also need to be "extracted"
- Alternatively, statistical weighting can be used to extract distributions directly
- Example:

$$x_E = \frac{\vec{p}_{T,trig} \cdot \vec{p}_{T,assoc}}{p_{T,trig}^2}$$

  - Away-side dN/dx_E sensitive to the fragmentation function (e.g.. at high-pT, slopes of dN/dx_E and D(*z*) are related)
- See upcoming d+Au Correlations paper, to be submitted to PRC





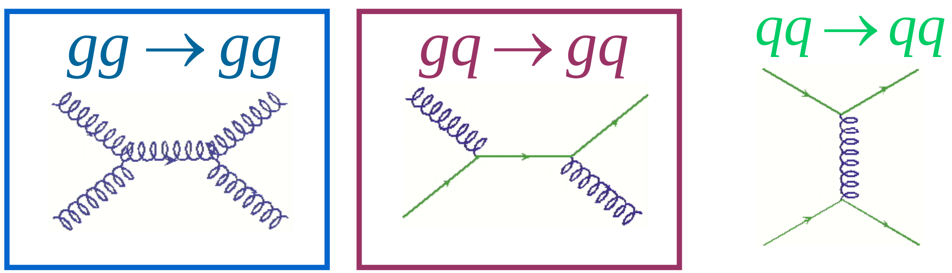
Summary

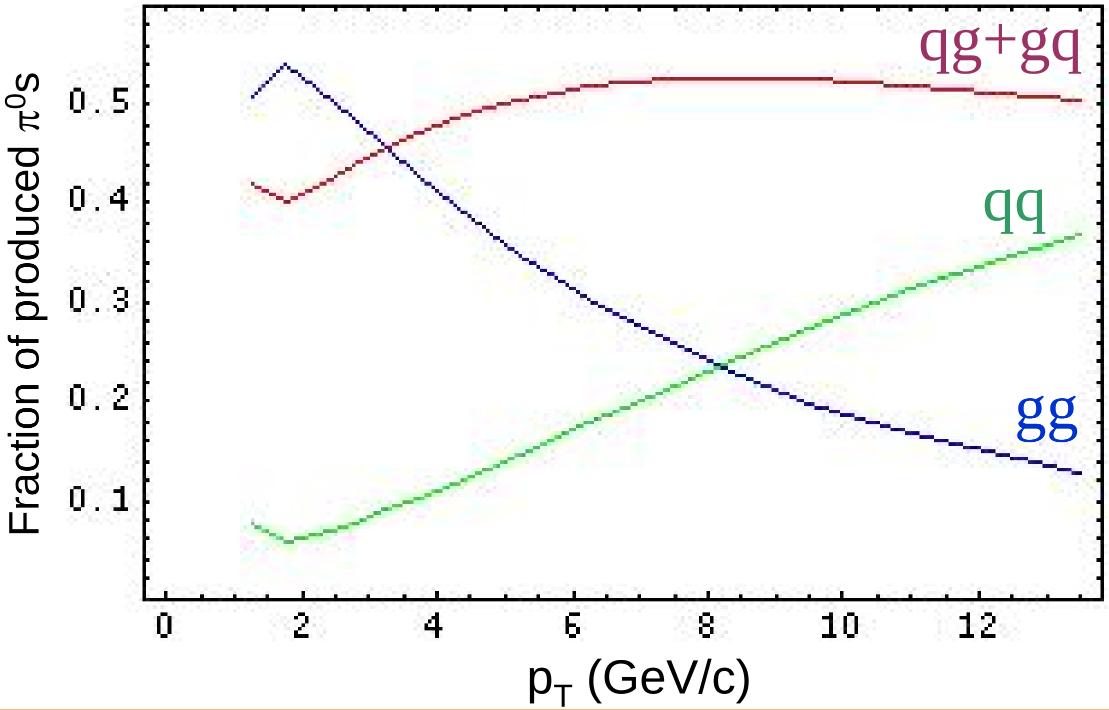
- Traditional jet-finding methods are unpractical in RHIC collisions. Azimuthal Correlations make jet studies possible this high multiplicity environment
- Study of the jet structure (j_T, k_T) allows us to distinguish between vacuum, initial-state, and final-state effects
- Evolution of jet structure from pp to AuAu collisions
  - No difference btn pp & dAu, but broadening of di-jet peak in AuAu
- Look for upcoming publications
  - (nucl-ex/0410003) “Formation of dense partonic matter in relativistic heavy-ion nucleus-nucleus collisions at RHIC: Experimental evaluation by the PHENIX collaboration”
  - (nucl-ex/0408007) “Jet Structure of Baryon Excess in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV”
  - (nucl-ex/0404024) J. Jia, HotQuarks04 proceedings
  - Jets and correlations: p+p, d+Au, and Au+Au

Backup Slides

Relative Gluon/Quark Contrib.

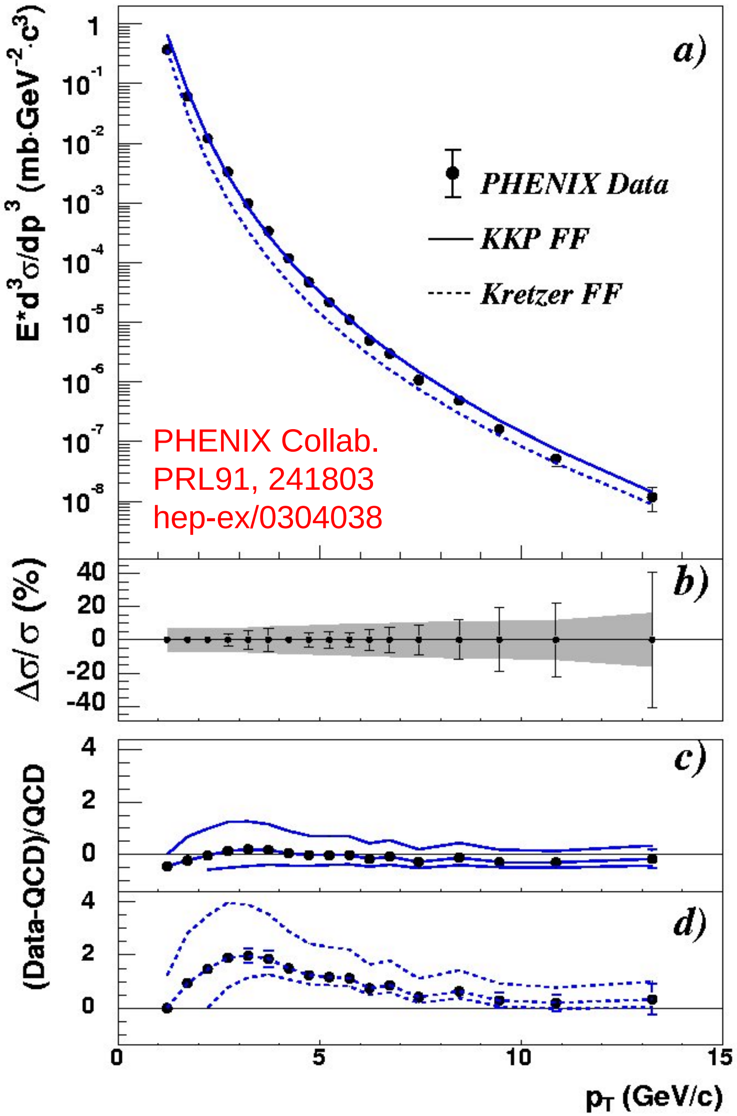
- In current measurement, π^0s mainly produced by *gg* and *qg* scattering





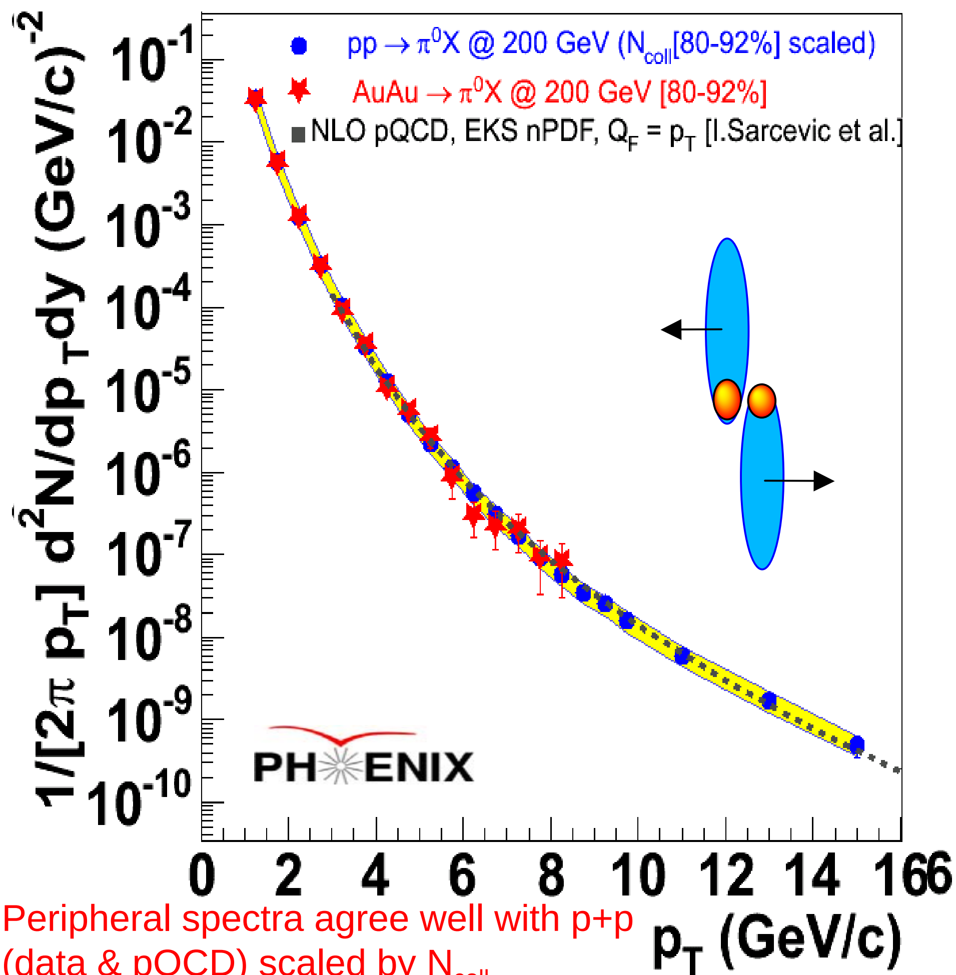
Kretzler, hep-ph/0410219

Is It Hard-scattering?



Single-particle spectrum and QCD predictions

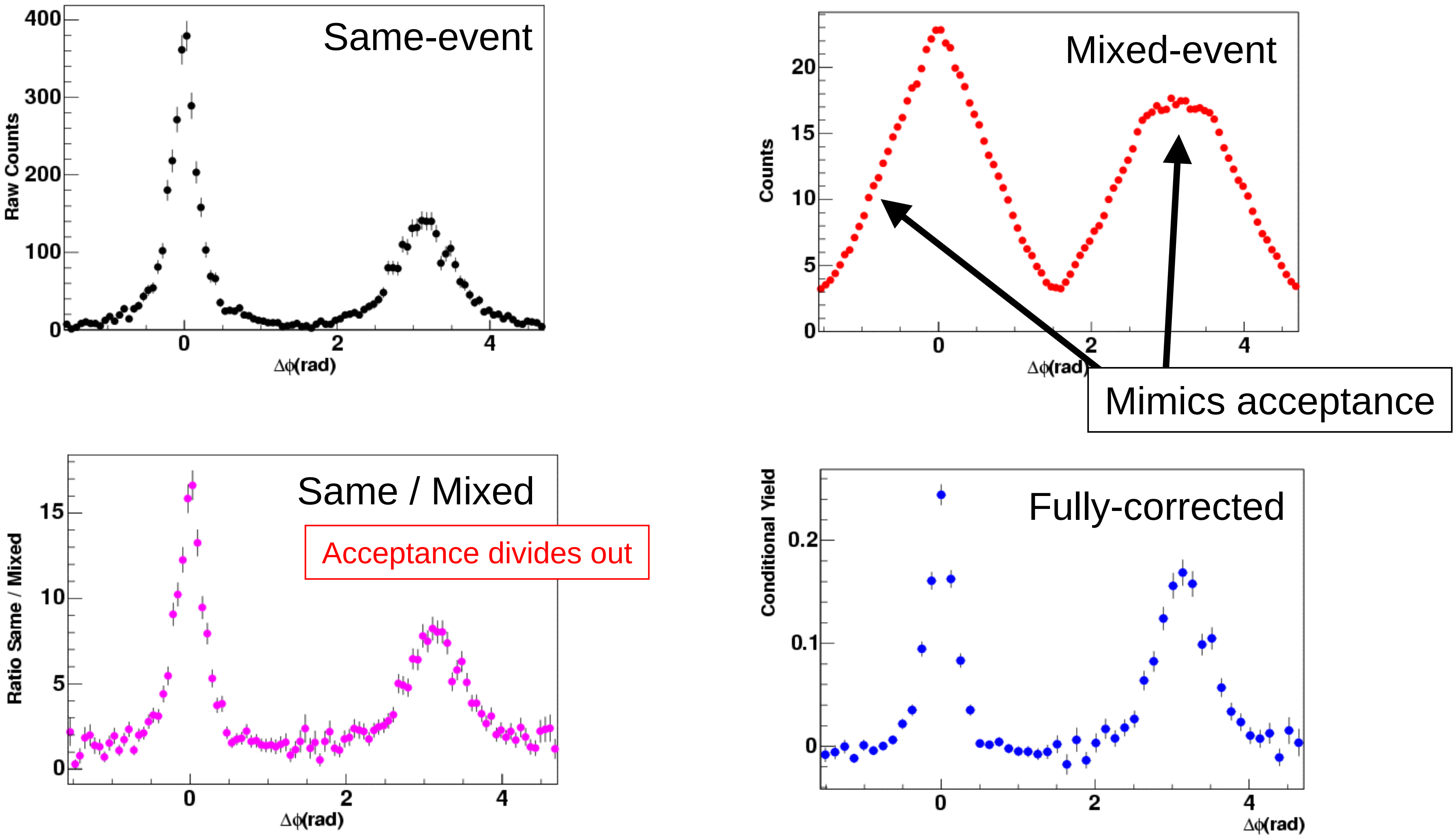
Au+Au $\rightarrow \pi^0 + X$ (peripheral)



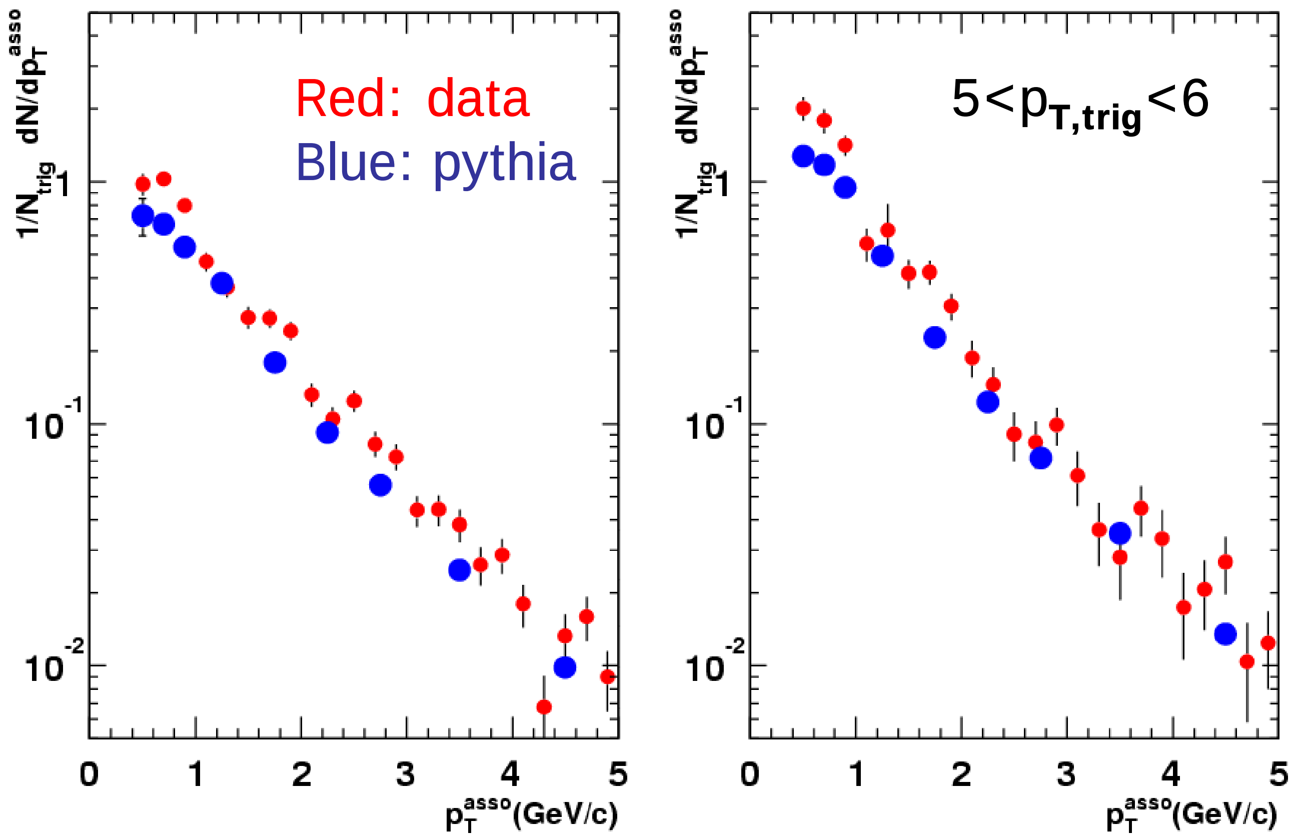
Peripheral spectra agree well with p+p (data & pQCD) scaled by N_{coll}

Correlations Example

d+Au $\sqrt{s}$=200 GeV 5<$p_{T,trig}$<10 GeV/c 2<$p_{T,assoc}$<3 GeV/c



Comparison with Pythia



p+p √s=200 GeV (Run3)
Pythia results agree within ~20%

How high is high (multiplicity)?

- Central events: N_{part} ~ 300
- $dN_{ch}/d\eta$ ~ 450
- Most particles are π's

dN/dη ~ 670