k_T Asymmetry in Longitudinally Polarized $p+p$ Collisions at PHENIX

October 6, 2008

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Origin of Jet k_T

Net transverse momentum of a di-hadron pair in a factorization ansatz

$$\left\langle k_T^2 \right\rangle_{di-hadron} = \left\langle k_T^2 \right\rangle_{initial} \oplus \left\langle k_T^2 \right\rangle_{hard} \oplus \left\langle k_T^2 \right\rangle_{frag}$$

- *initial* – e.g., fermi motion of the confined quarks or gluons, initial-state gluon radiation…
- *hard* – final-state radiation (three-jet)…
- *frag* – fragmentation transverse momentum j_T

Another Possibility:

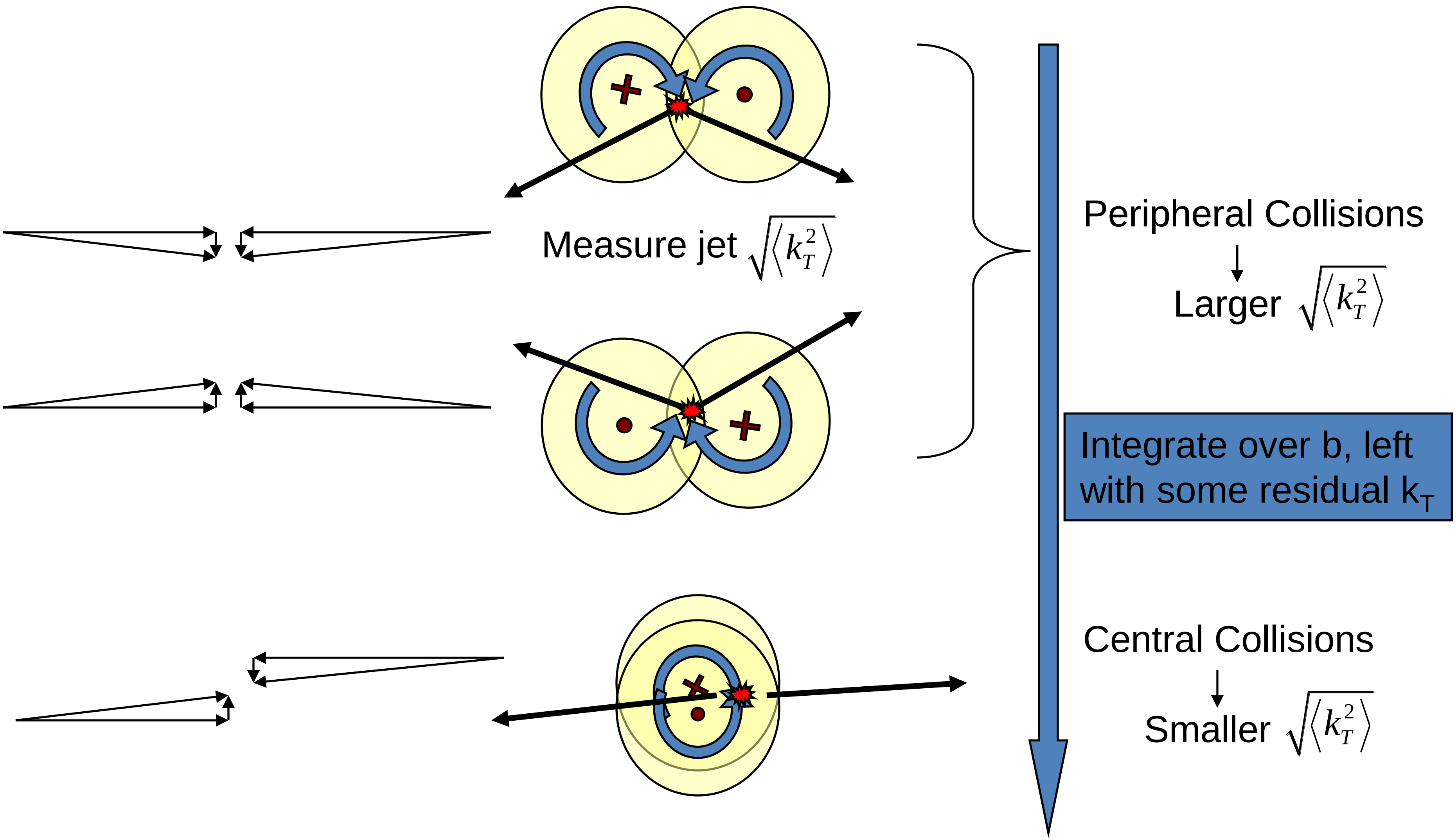
- Spin-correlated transverse momentum – partonic orbital angular momentum
- Can examine the helicity dependence of each term:

$$\Delta \left\langle k_T^2 \right\rangle_{initial} \neq 0$$

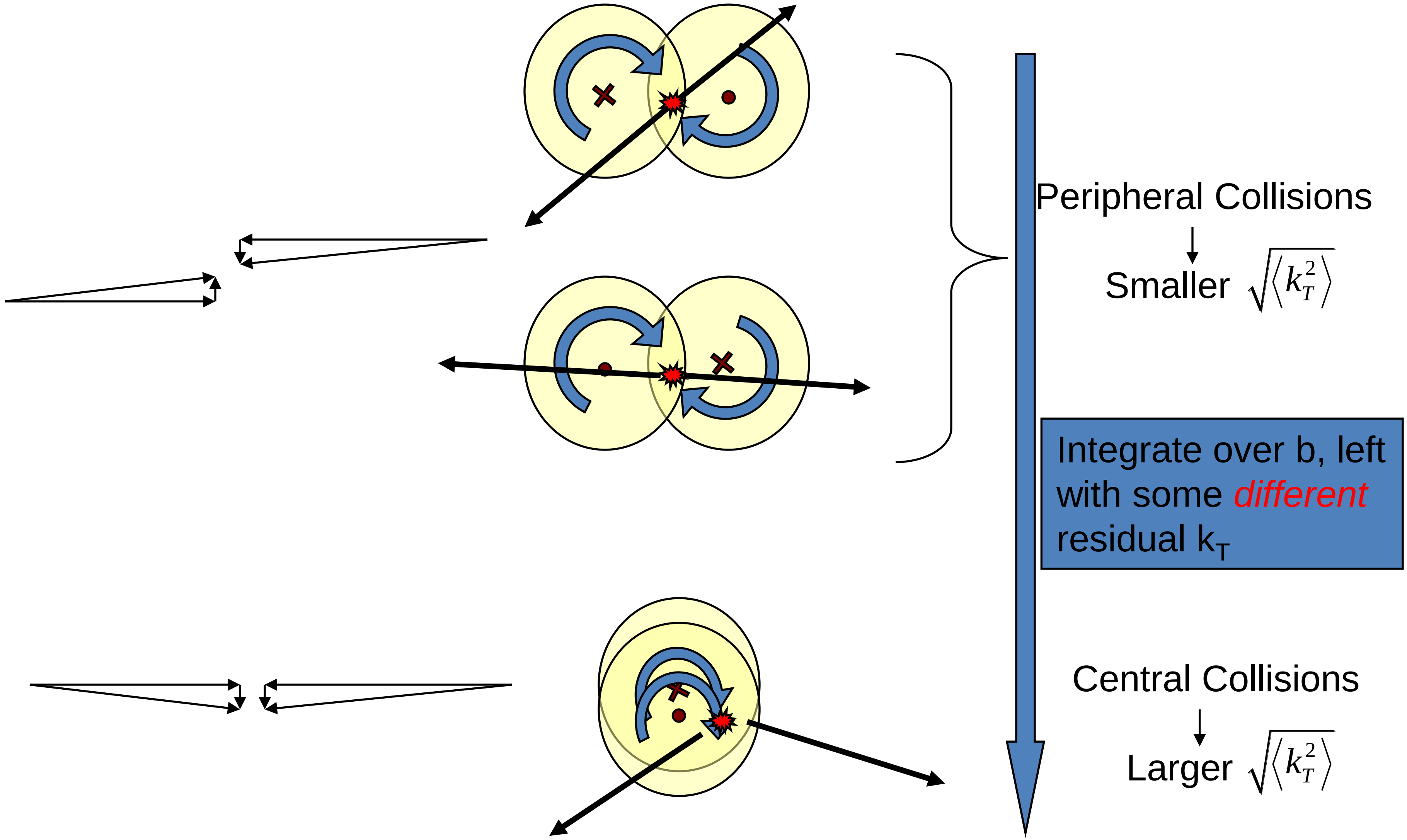
$$\Delta \left\langle k_T^2 \right\rangle_{hard} \neq 0$$

$$\Delta \left\langle k_T^2 \right\rangle_{frag} \approx \vartheta \left(\frac{1}{Q} \right)$$

Mechanism for $\Delta\left\langle k_T^2 \right\rangle_{initial} \neq 0$



Mechanism for $\Delta\langle k_T^2 \rangle_{initial} \neq 0$



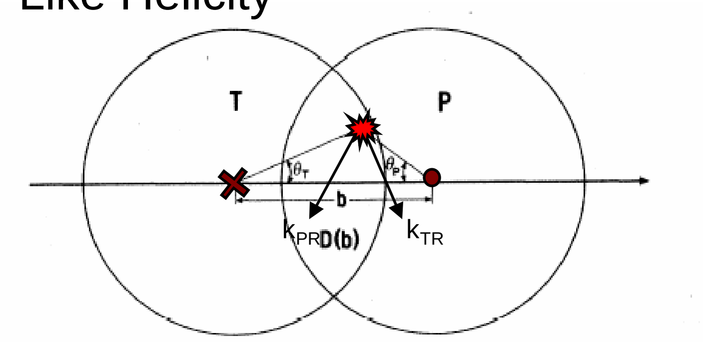
Integrating over Impact Parameter

Drell-Yan pair production in polarized *p+p* collisions.

(Meng Ta-Chung et al. Phys. Rev. D 1989)

$$p_t^2(b,\theta_P,\theta_T;\pm) = \left|\vec{k}_{PR}\right|^2 + \left|\vec{k}_{TR}\right|^2 \pm \left|\vec{k}_{PR}\right|\left|\vec{k}_{TR}\right| \cos(\theta_P + \theta_T)$$

Like Helicity

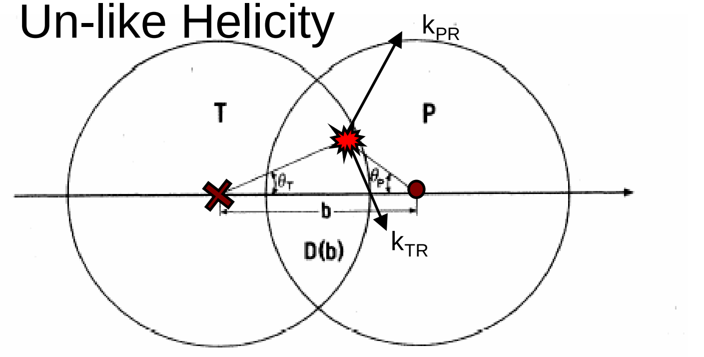


Averaging over *D(b)*:

$$\Delta\left\langle p_t^2(b)\right\rangle = \left\langle p_t^2(b,+)\right\rangle - \left\langle p_t^2(b,-)\right\rangle$$

Integrating over impact parameter *b*:

Un-like Helicity



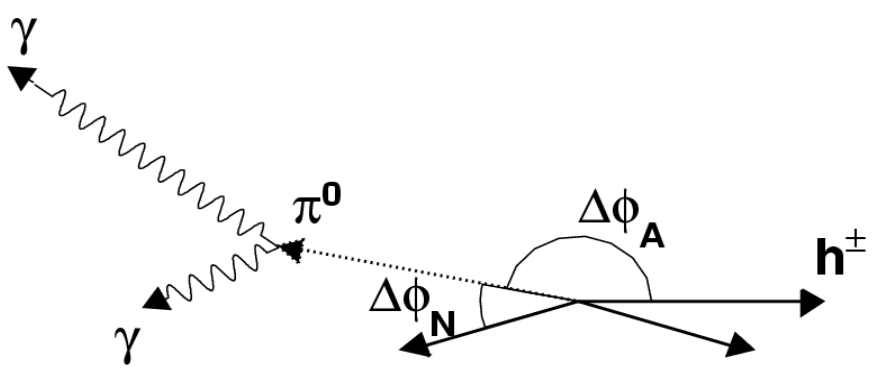
$$\Delta\left\langle p_t^2\right\rangle \approx 1.9\left\langle k_R\right\rangle^2$$

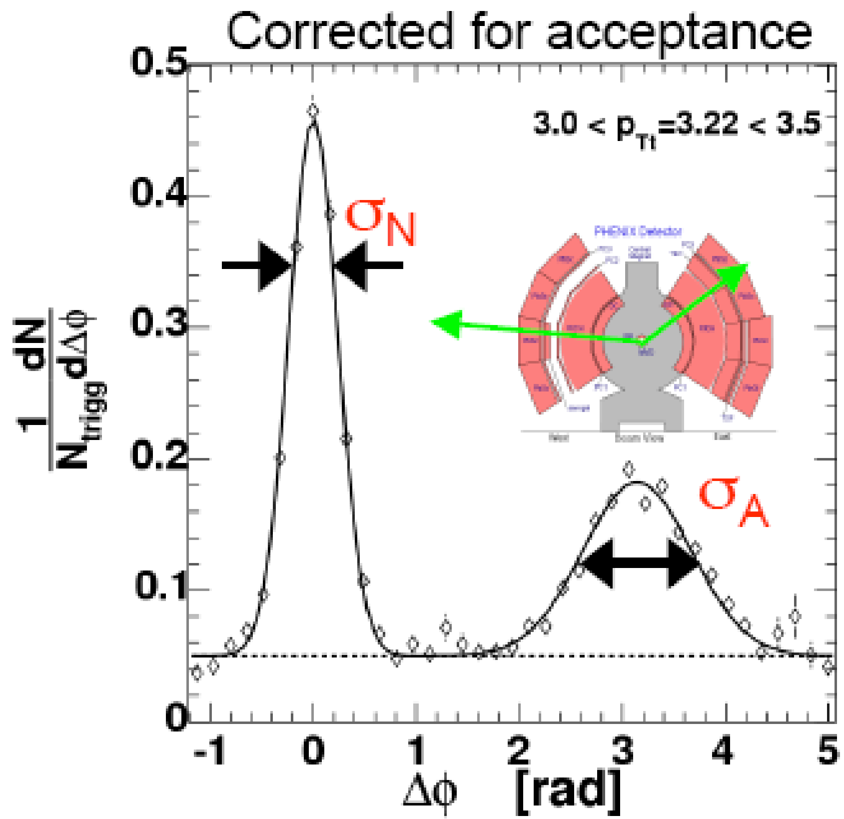
$$\left\langle k_R\right\rangle \equiv \left\langle\left|\vec{k}_{PR}\right|\right\rangle = \left\langle\left|\vec{k}_{TR}\right|\right\rangle$$

Measuring jet k_T – di-hadron correlation

π^o- $h^{\pm}$ azimuthal correlation

Trigger on a particle, e.g. π^o, with transverse momentum p_{Tt}. Measure azimuthal angular distribution *w.r.t.* the azimuth of associated (charged) particle with transverse momentum p_{Ta}. The strong ***same*** and ***away*** **side peaks** in p-p collisions indicate di-jet origin from hard scattering partons.



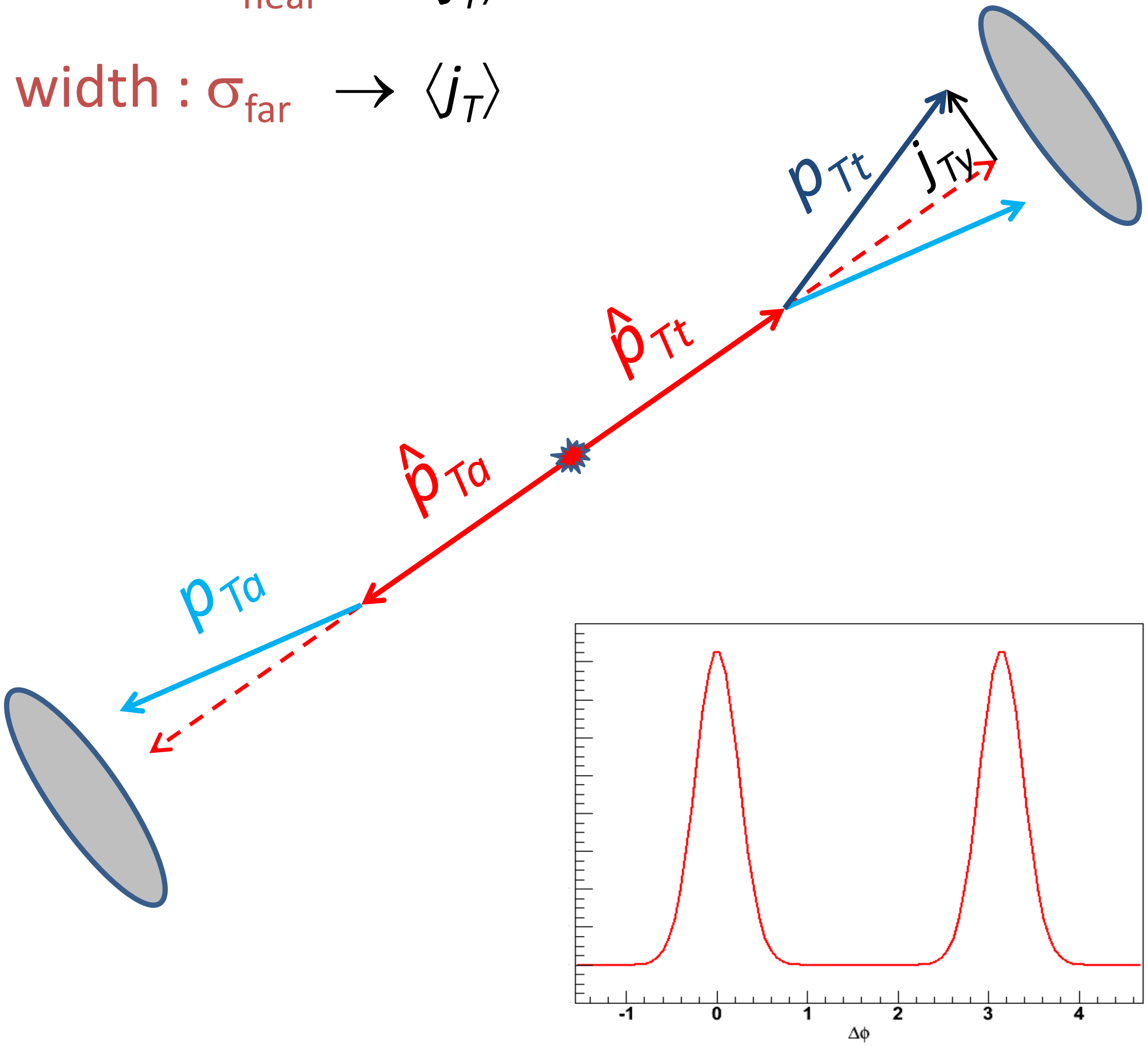


Measuring jet k_T – di-hadron correlation

Intra-jet pairs angular width : $\sigma_{near} \rightarrow \langle j_T \rangle$

Inter-jet pairs angular width : $\sigma_{far} \rightarrow \langle j_T \rangle$

- Zero k_T

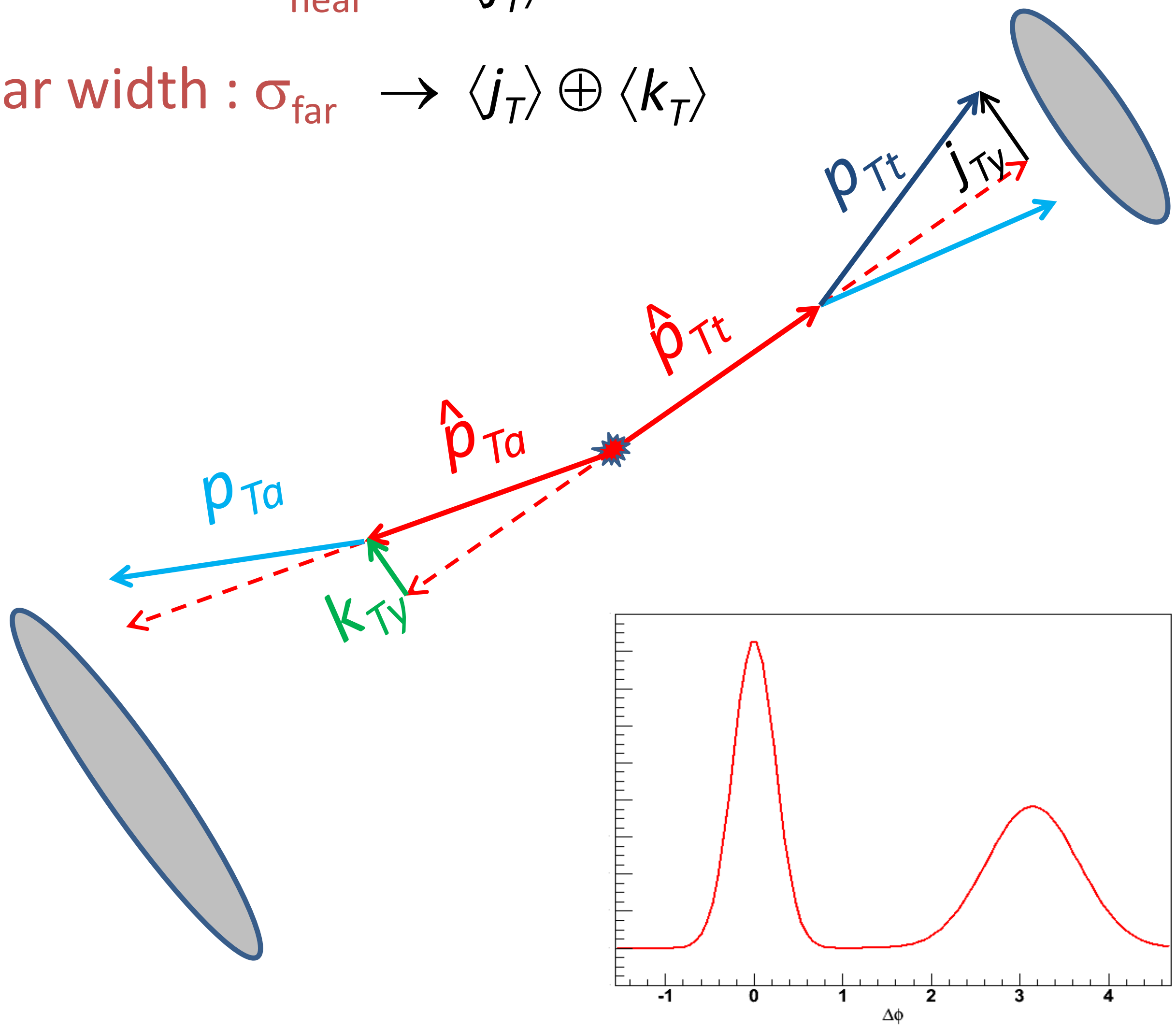


Measuring jet k_T – di-hadron correlation

Intra-jet pairs angular width : $\sigma_{near} \rightarrow \langle j_T \rangle$

Inter-jet pairs angular width : $\sigma_{far} \rightarrow \langle j_T \rangle \oplus \langle k_T \rangle$

- Non-Zero k_T



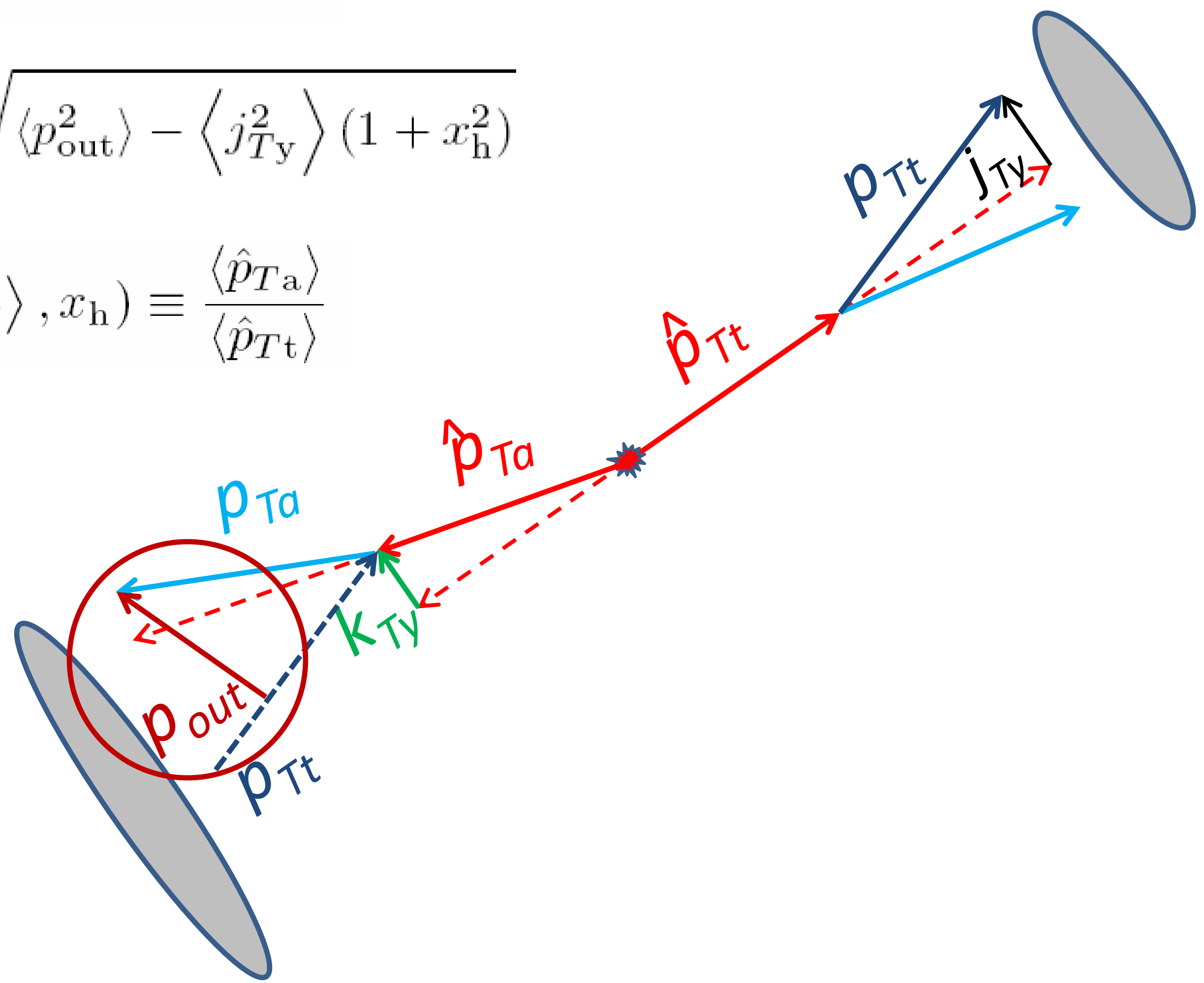
Jet Kinematics

$$\sqrt{\langle j_T^2 \rangle} = \sqrt{2 \left\langle j_{Ty}^2 \right\rangle} \simeq \sqrt{2} \frac{p_{T\mathrm{t}} \cdot p_{T\mathrm{a}}}{\sqrt{p_{T\mathrm{t}}^2 + p_{T\mathrm{a}}^2}} \sigma_{\mathrm{N}}$$

$$\frac{\langle z_{\mathrm{t}}(k_T, x_{\mathrm{h}}) \rangle \sqrt{\langle k_T^2 \rangle}}{\hat{x}_{\mathrm{h}}(k_T, x_{\mathrm{h}})} = \frac{1}{x_{\mathrm{h}}} \sqrt{\langle p_{\mathrm{out}}^2 \rangle - \left\langle j_{Ty}^2 \right\rangle (1 + x_{\mathrm{h}}^2)}$$

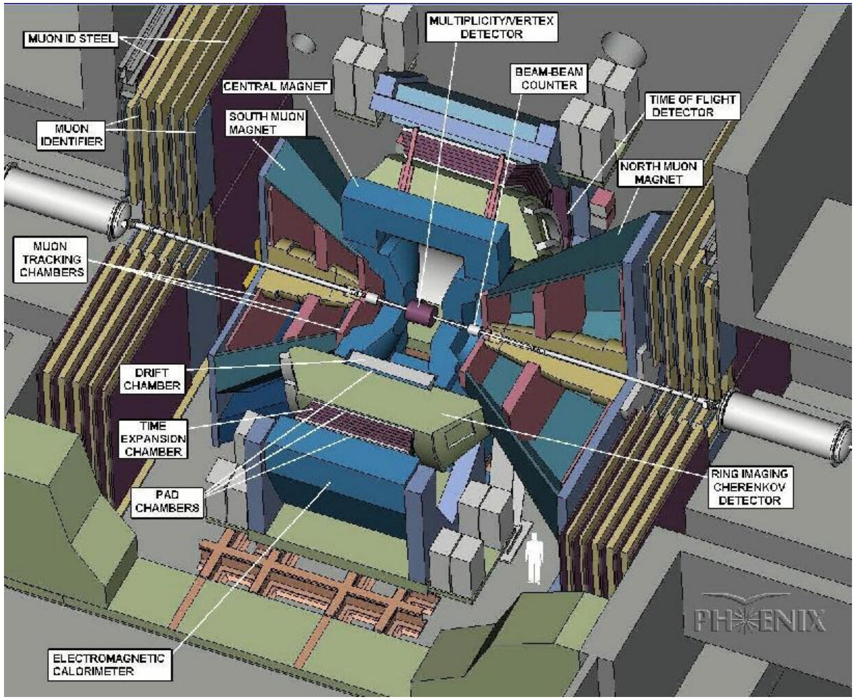
$$x_{\mathrm{h}} \equiv \frac{p_{T\mathrm{a}}}{p_{T\mathrm{t}}} \qquad \hat{x}_{\mathrm{h}} = \hat{x}_{\mathrm{h}}(\left\langle k_T^2 \right\rangle, x_{\mathrm{h}}) \equiv \frac{\langle \hat{p}_{T\mathrm{a}} \rangle}{\langle \hat{p}_{T\mathrm{t}} \rangle}$$

$$\langle z_t \rangle = \left\langle \frac{p_{Tt}}{\hat{p}_{Tt}} \right\rangle$$

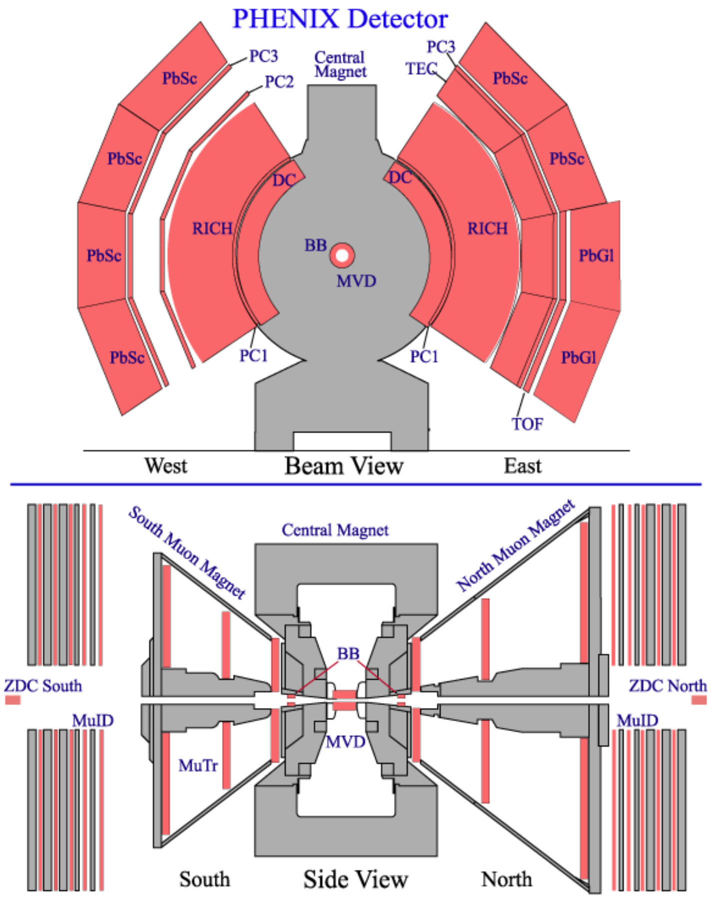


For details, see PRD 74, 072002 (2006)

PHENIX Detector



- **Philosophy:**
  - **High resolution** at the cost of acceptance
  - **High rate** capable DAQ
  - Excellent **trigger capability** for rare events



•Central Arms:
$|\eta|<0.35$, $\Delta\varphi=2\times90^0$
Charged particle ID and tracking; photon ID. EM Calorimetry.

Muon Arm:
$1.2<|\eta|<2.4$
Muon ID and tracking.

•Global Detectors
Collision trigger
Collision vertex characterization
Relative luminosity
Local Polarimetry

Data Selection

Analyzed data sample from 2005 & 2006 RHIC Runs.

- Integrated Luminosity: 2.5 pb^{-1} (Run 5) + *6.4* pb^{-1} (Run 6)
- Average beam polarization: 50% (Run 5), 57% (Run 6)
- π° transverse momentum: $2 < p_T < 10$ GeV
- $h^{\pm}$ transverse momentum: $2 < p_T < 5$ GeV
- $|\eta| < 0.35$

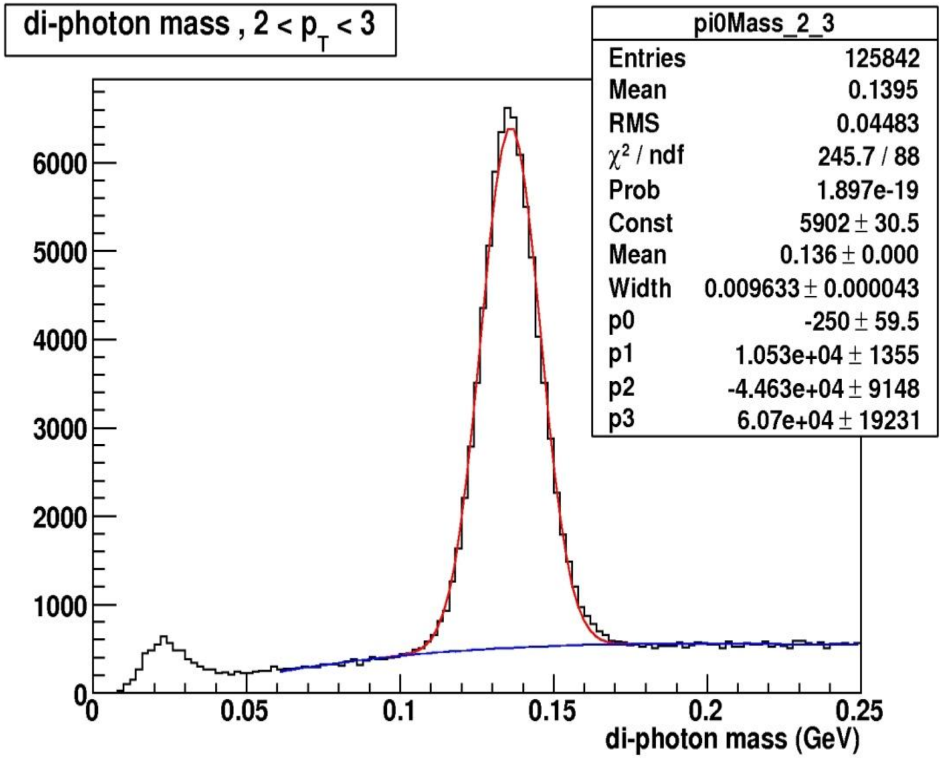
π° Identificaton

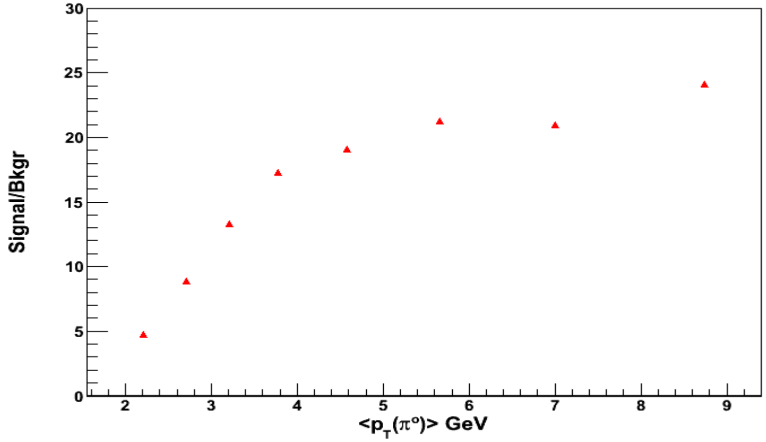
$\pi^\circ \rightarrow \gamma+\gamma$

The pions are selected within
$M_{\pi^\circ} \pm 2.0\sigma_{\pi^\circ}$

Photon trigger:
EMCal cluster energy > 1.4 GeV

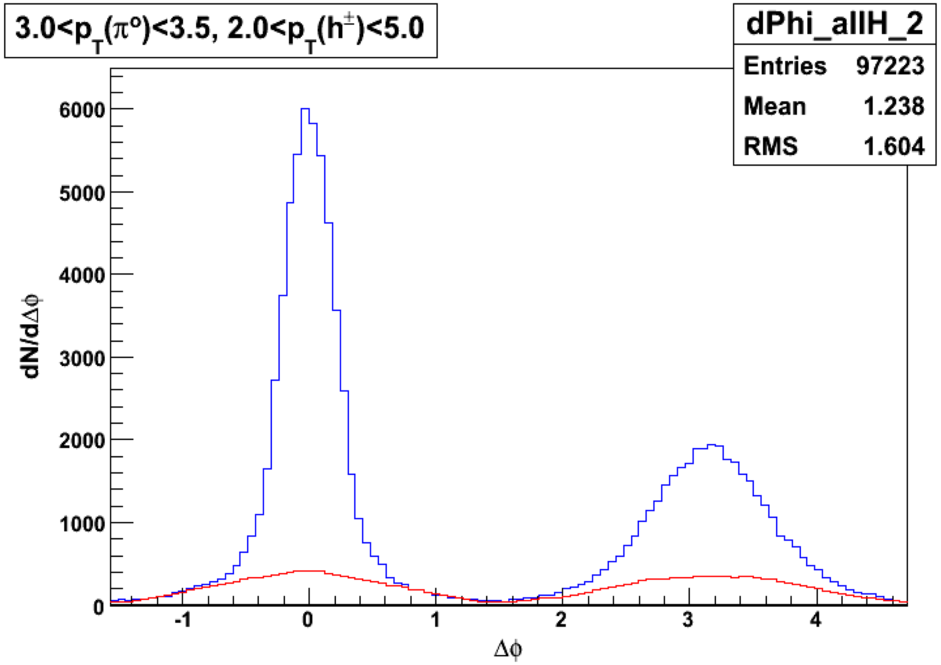
The mass, M_{π°, and the width, σ_{π°, are determined by fitting the di-photon mass spectrum with ***gaus+pol3***.

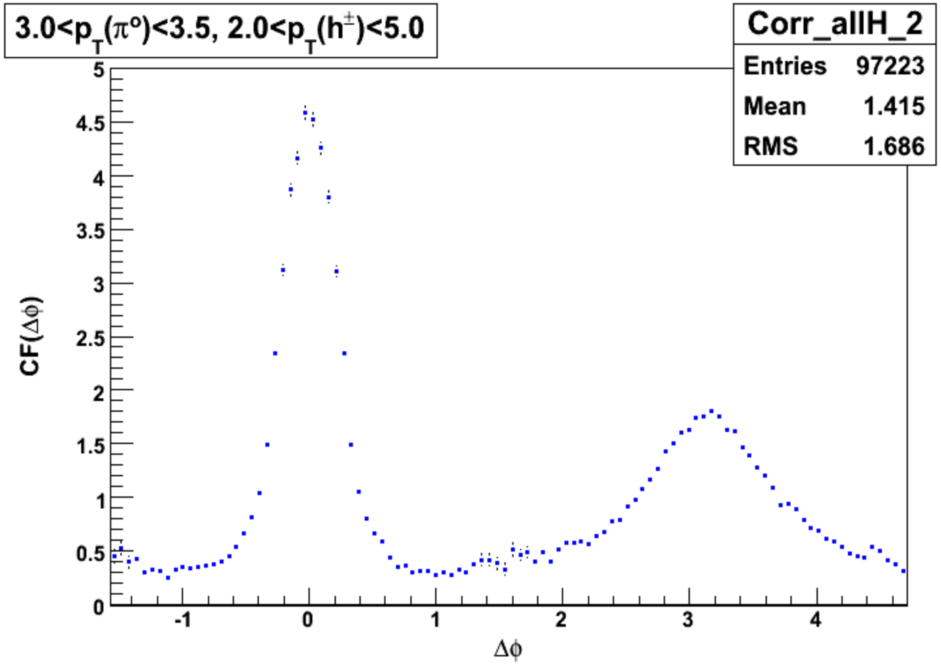




Correlation Function

- Blue – real (raw $\Delta\varphi$)
- Red – background (mixed events)



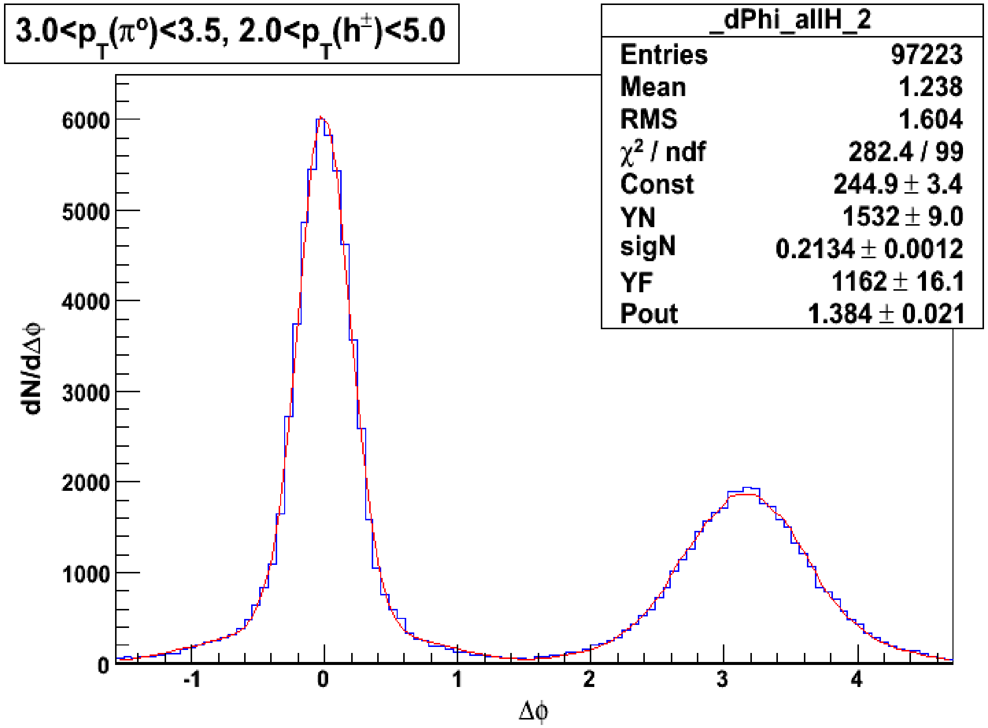


Fit Function

$$\frac{dN_{real}}{d\Delta\phi} = \frac{1}{N}\frac{dN_{mix}}{d\Delta\phi}\cdot\left(C_o + C_1 \cdot Gaus(0) + C_2 \cdot \left.\frac{dN_{away}}{d\Delta\phi}\right|_{\pi/2}^{3\pi/2}\right)$$

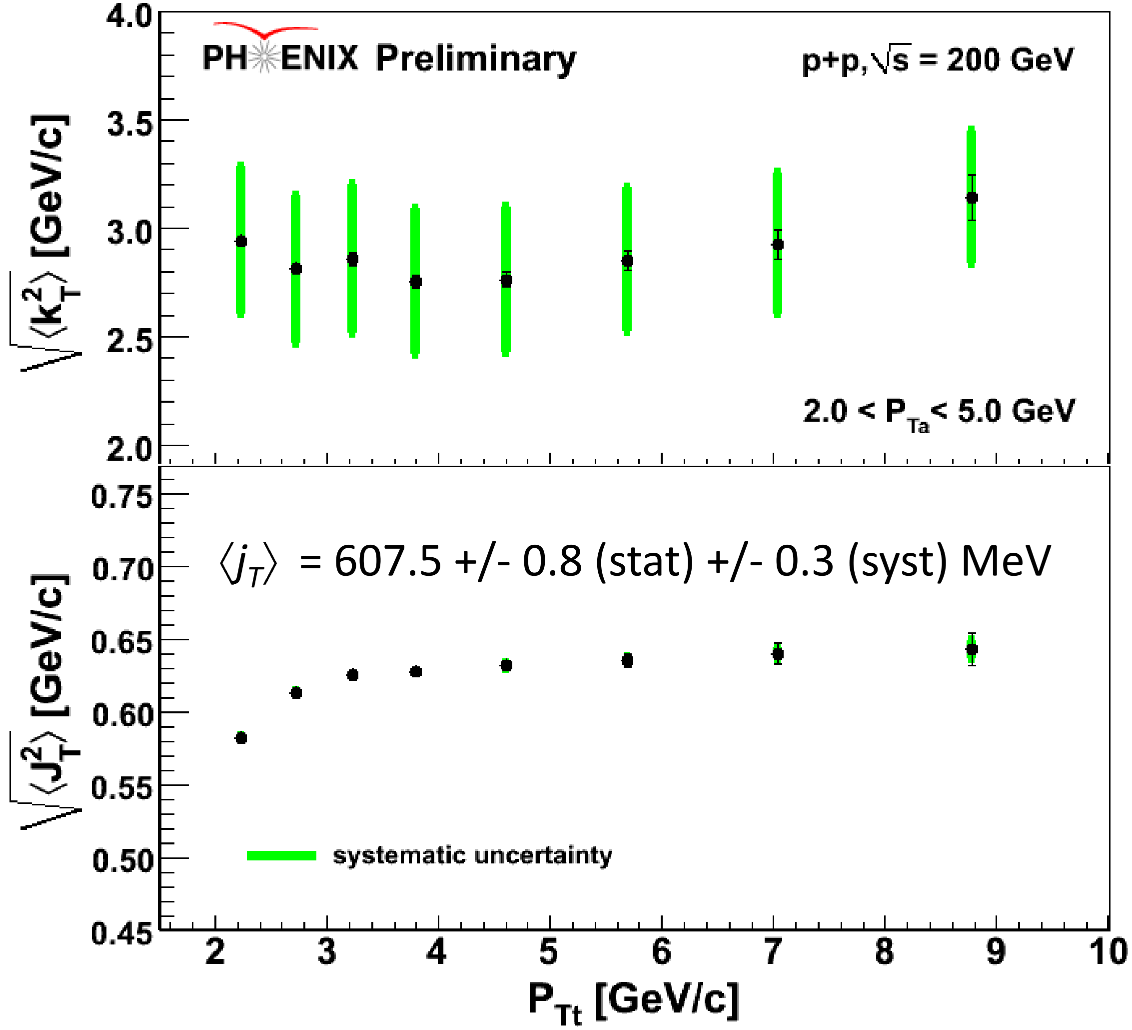
$$\left.\frac{dN_{away}}{d\Delta\phi}\right|_{\pi/2}^{3\pi/2} = \frac{-p_{Ta}\cos\Delta\phi}{\sqrt{2\pi\langle p_{out}^2\rangle}Erf\left(\sqrt{2}p_{Ta}/\sqrt{\langle p_{out}^2\rangle}\right)}\exp\left(-\frac{p_{Ta}^2\sin^2\Delta\phi}{2\langle p_{out}^2\rangle}\right)$$

- Blue – real (raw Δϕ)
- Red – Fit from above equation



k_T results for unpolarized case

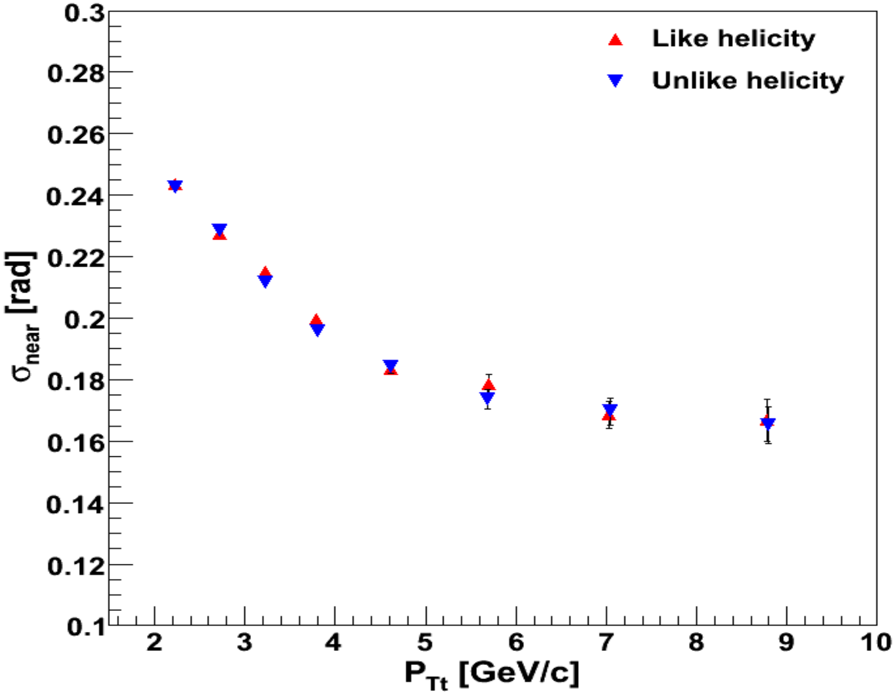
$\langle k_T \rangle$ = 2.88 +/- 0.02 (stat) +/- 0.12 (syst) GeV

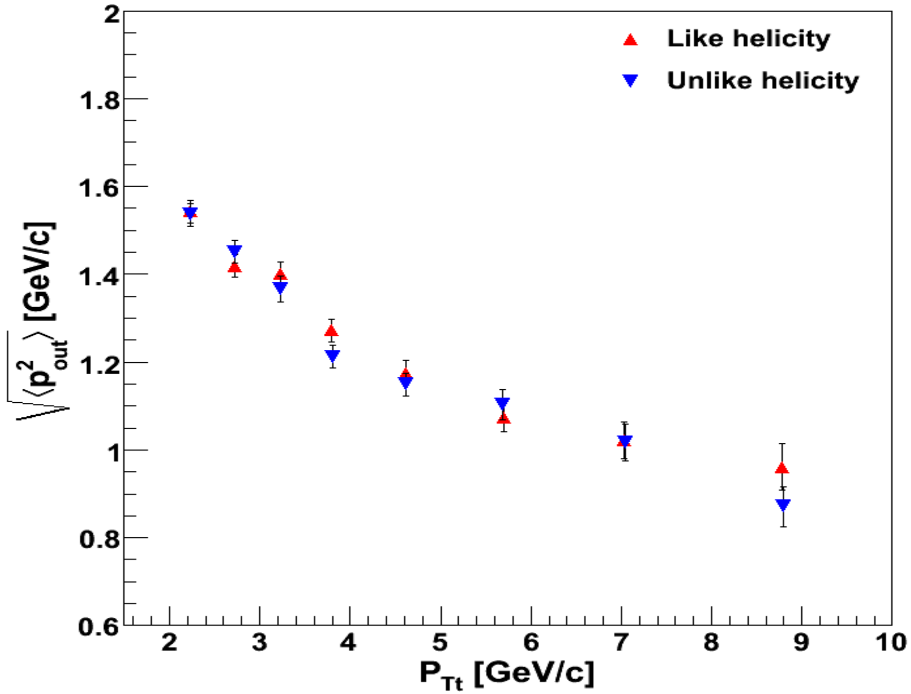


Spin sorted dihadron correlations

Fit Results

- Red ▲– Like helicity (++ & --)
- Blue ▼– Unlike helicity (+- & -+)



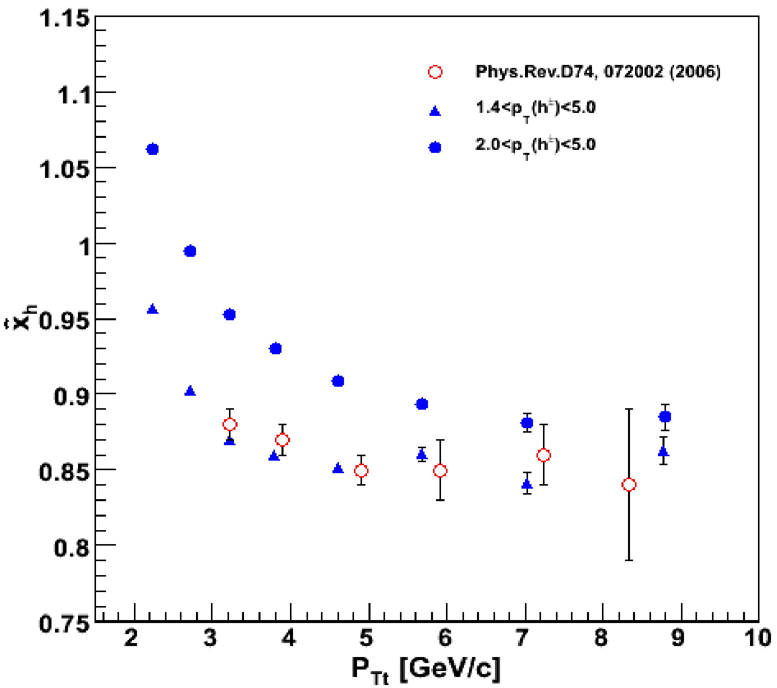


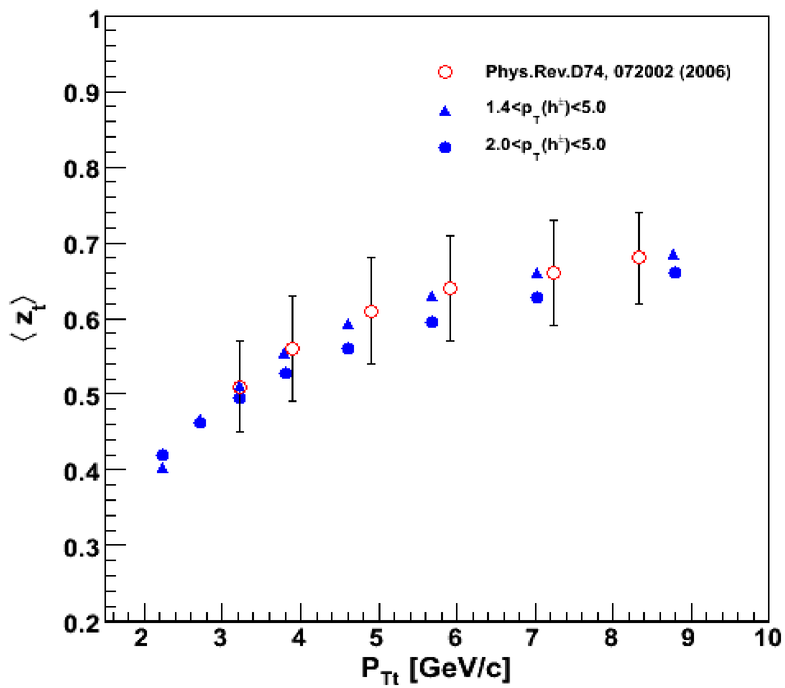
Need <z_t> and x_h

$$\frac{\langle z_{\mathrm{t}}(k_T, x_{\mathrm{h}})\rangle \sqrt{\langle k_T^2\rangle}}{\hat{x}_{\mathrm{h}}(k_T, x_{\mathrm{h}})} = \frac{1}{x_{\mathrm{h}}}\sqrt{\langle p_{\mathrm{out}}^2\rangle - \left\langle j_{T\mathrm{y}}^2\right\rangle (1 + x_{\mathrm{h}}^2)}$$

$\hat{x}_h$ and <z_t> are determined through a combined analysis of the π° inclusive cross section and using jet fragmentation function measured in e^+e^- collisions. *Ref*. PRD 74, 072002 (2006)

<k^2_T> asymmetry results are not sensitive to this $\hat{x}_h$ and <z_t> values – only needed to set the scale.

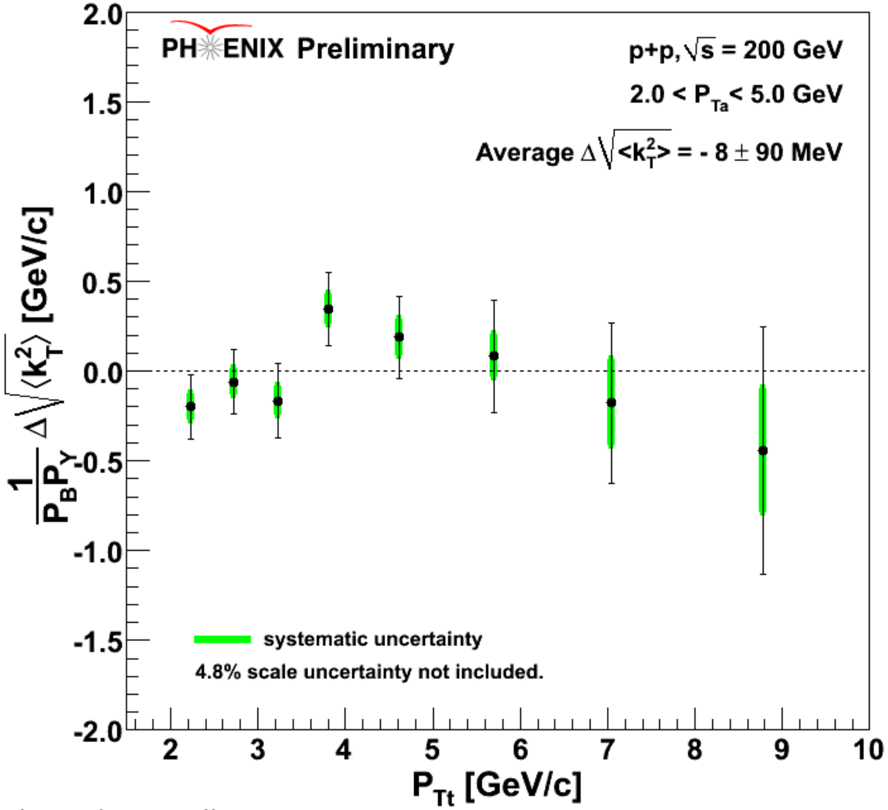




Preliminary Results

- Take the difference Like – Unlike helicities
- Normalized by beam polarizations
- $\langle j^2_T \rangle$ asymmetry small (-6 ± 6 MeV out of ~630 MeV for unpolarized)

- $\langle k^2_T \rangle$ asymmetry also small (-8 ± 90 MeV out of ~2.8 GeV for unpolarized).



Interpretation

$$\Delta\left\langle k_T^2\right\rangle_{initial} \neq 0$$

$$\Delta\left\langle k_T^2\right\rangle_{hard} \neq 0$$

$$\Delta\left\langle k_T^2\right\rangle_{frag} \approx \vartheta\left(\frac{1}{Q}\right)$$

- The small asymmetry in j_T verifies our assumption that the third term is suppressed.
- The second term can be constrained from current knowledge of the π^0 A_{LL}.

Interpretation

- The first term can be related in the “Meng conjecture” to partonic transverse momentum:

$$\Delta\left\langle k_T^2 \right\rangle_{initial} = \sum_i \sum_j c^{ij} W^{ij} \left(\left\langle \vec{k}_T^i \cdot \vec{k}_T^j \right\rangle^{++} - \left\langle \vec{k}_T^i \cdot \vec{k}_T^j \right\rangle^{+-} \right)$$

  where c^{ij} give the initial state weights and W^{ij} give the impact parameter weighting.
- Since PYTHIA studies show that the final state studied here is dominated by *gg* scattering (~50%),
- We can interpret this as a constraint on the gluon orbital angular momentum.
- Consistent with previous (Sivers) measurements, and complimentary, since one naïvely needs no initial or final state interactions.

Summary

- We have an analysis tool – di-hadron azimuthal correlations - that allows us to measure k_T.
- We are studying this in helicity-sorted collisions to see if there is a spin-dependent, coherent component of k_T.
- In our kinematic range, we find Δj_T^{RMS} = -6 ± 6 MeV, and Δk_T^{RMS} = -8 ± 90 MeV.
- While this is consistent with other measurements related to gluon OAM, the connection to parton OAM needs theoretical guidance!