Photon-Hadron Correlations in p-p Collisions with the PHENIX Detector

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DNP Fall Meeting

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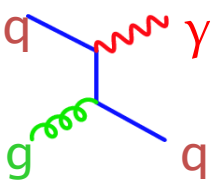
Motivation

Why study γ-jet?
HI Collisions – Energy loss in QGP
Polarized p+p – Polarized Gluon PDF
Unpolarized p+p – Baseline Measurement



LO Compton Scattering

'Leading Order' picture of γ-jet

$$\longrightarrow \quad p_\gamma \approx p_{jet}$$

Fragmentation Functions:

$$D_q^h(z) \propto dN_h / dz \qquad z \equiv p_h / p_{jet}$$

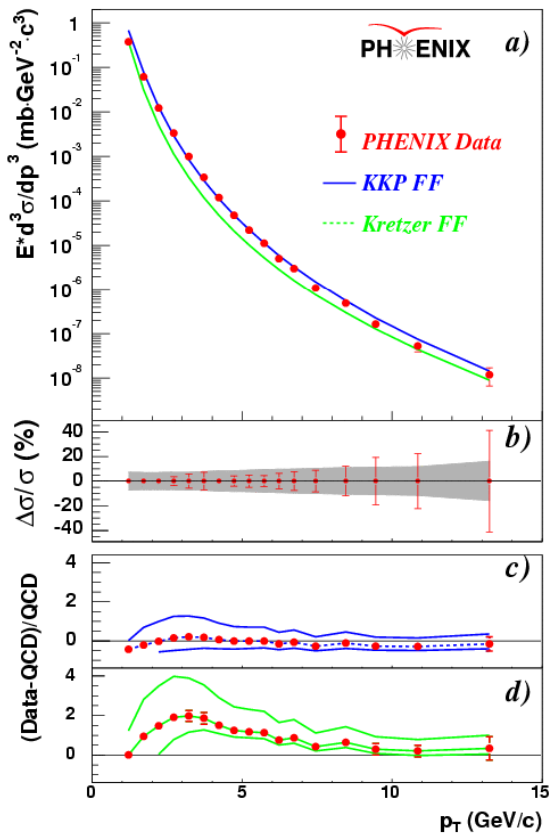
Directly measurable by γ-h correlations

$$x_E \equiv \frac{p_T^h}{p_T^\gamma}\cos\Delta\phi \approx z \qquad \therefore \frac{dN}{dx_E} \approx D_h^q$$

Interpretation of spin asymmetries relies on FF's
Can γ-h correlations further constrain FFs?

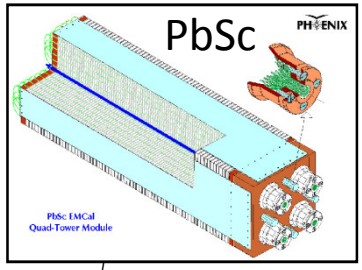
Single Inclusive Production:

$$E_h \frac{d^3\sigma}{dp_h^3} = \sum_{a,b,c} f_a \otimes f_b \otimes d\hat{\sigma}_{ab}^c \otimes D_c^h$$



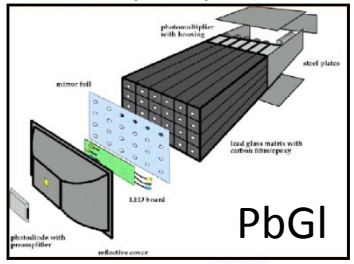
γ-h Correlations PHENIX

Electromagnetic Calorimeters

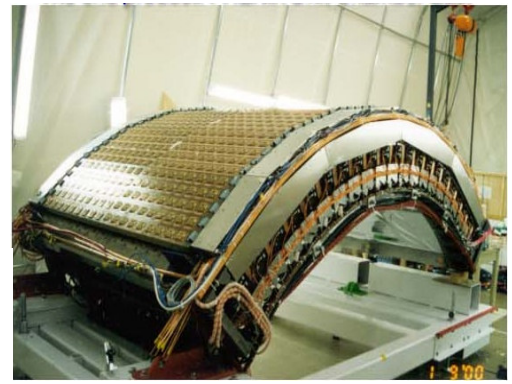


8.1/√E(GeV) ⊕ 2.1 %

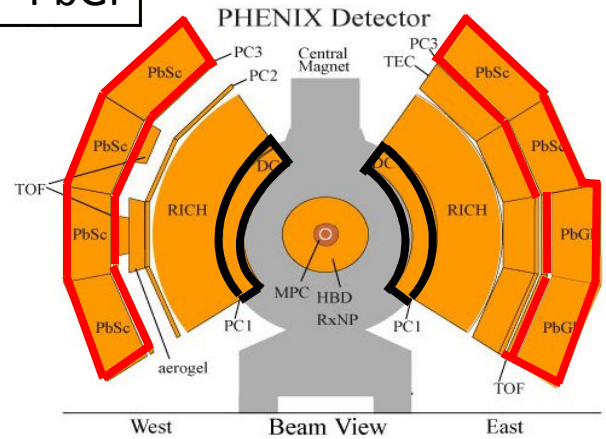
5.9/√E(GeV) ⊕ 0.8 %



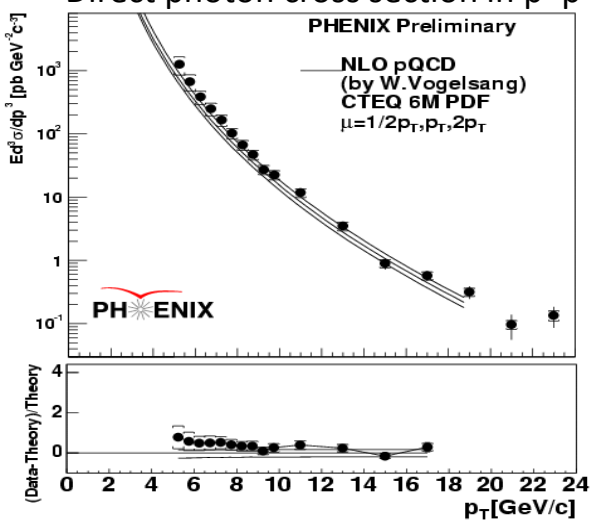
Drift Chamber



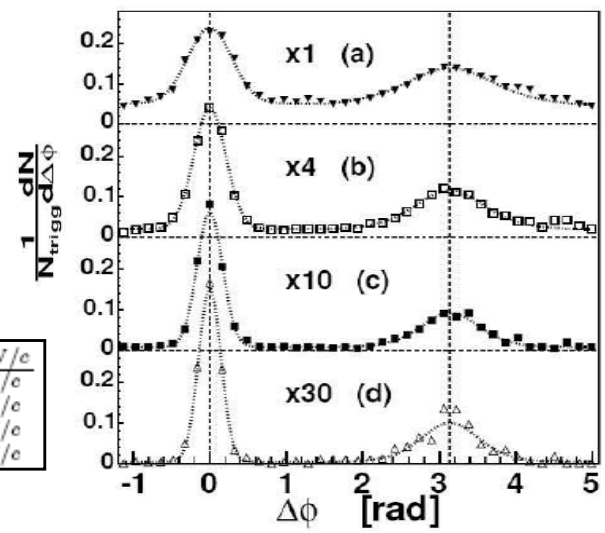
$dp/p \approx 0.7 \otimes 1.0\% p\,(\mathrm{GeV/c})$



Direct photon cross section in p+p



h-h Correlations in p+p



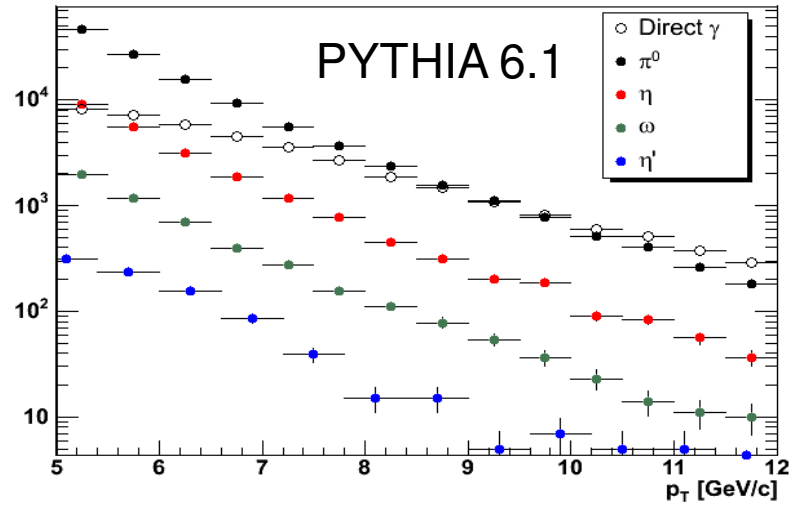
$3.0 < p_{T\,t} < 10.0$ GeV/c
(a) $1.7 < p_{T\,a} < 2.0$ GeV/c
(b) $2.0 < p_{T\,a} < 2.5$ GeV/c
(c) $2.5 < p_{T\,a} < 3.0$ GeV/c
(d) $3.0 < p_{T\,a} < 3.5$ GeV/c

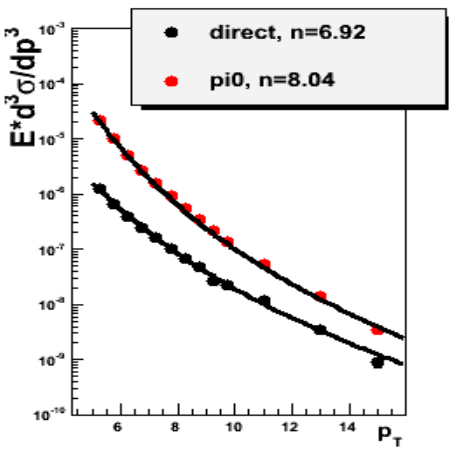
γ-h – Statistical Subtraction Method

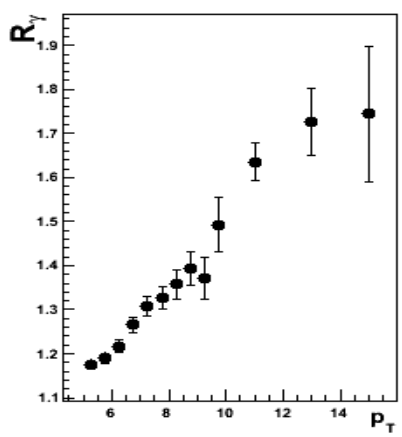
- Large background from meson decay
- R_γ = *N(inclusive) / N(decay)*
- π^0-h, η-h decayed via MC to get decay γ-h
- Can perform a ***statistical subtraction*** of per-trigger yields:

$$Y^{direct} = \frac{R_\gamma}{R_\gamma - 1} Y^{inclusive} - \frac{1}{R_\gamma - 1} Y^{decay}$$

Where Y = # hadrons per photon



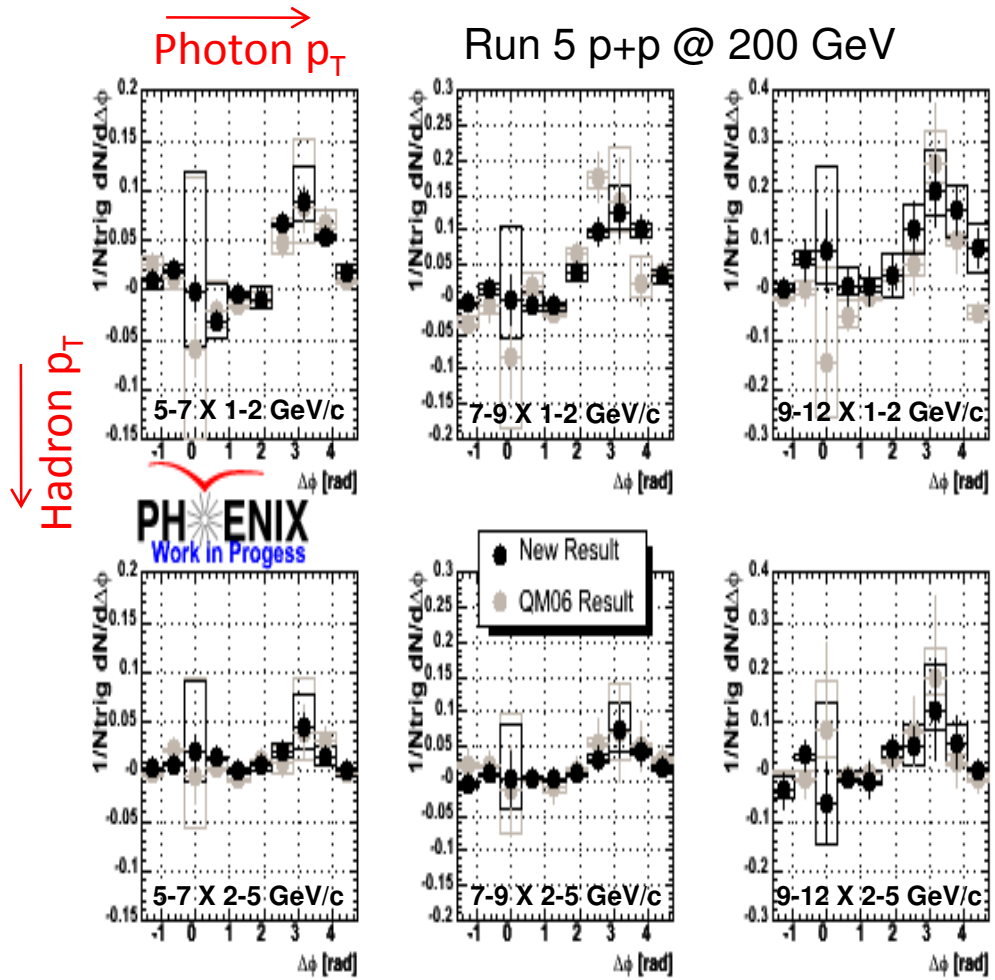




- Method well-suited for high multiplicity environment (A+A)
- Isolation cuts will improve precision
- Dominant systematic is uncertainty in R_γ

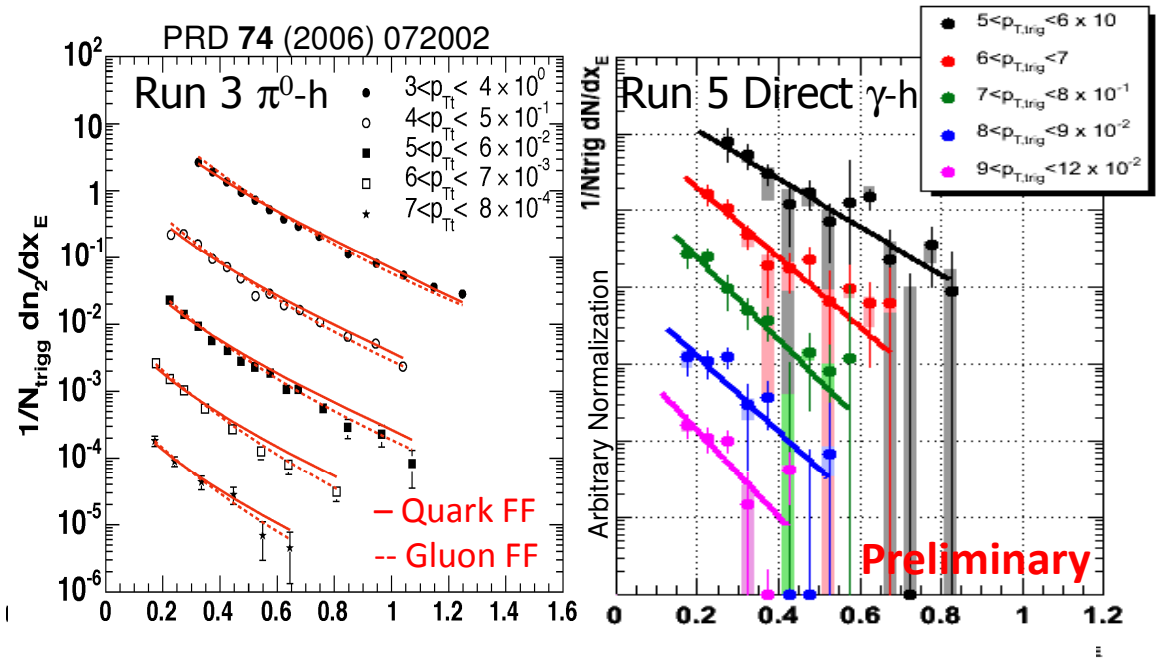
γ-h Yields

- Δϕ distributions show away-side jet structure
- Near-side peak consistent with zero but with large uncertainty
- Systematic Errors still being estimated conservatively – Final Results coming soon
- Adding Run 6 data will reduce statistical errors
- Recent Improvement – Include correction due to η contribution to decay yield



Towards the Fragmentation Function

p+p @ 200 GeV

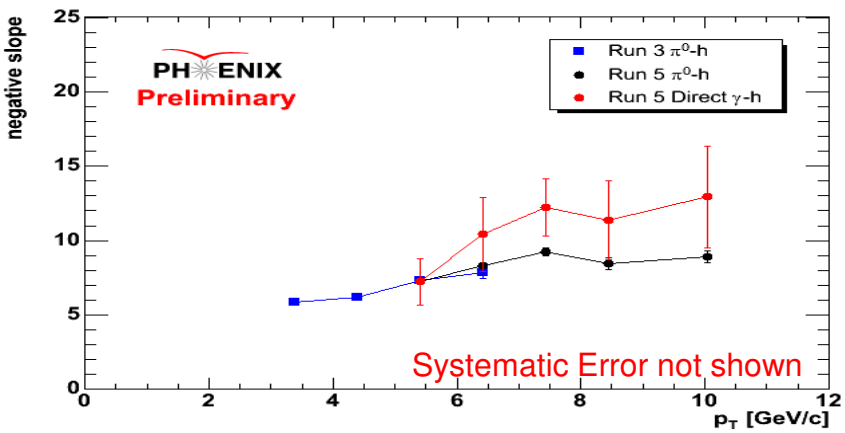


$$x_E \equiv \frac{p_T^h}{p_T^\gamma}\cos\Delta\phi \approx z$$

- π^0-h x_E distributions were shown to poorly discriminate between quark* and gluon+ fragmentation due to π^0 trigger bias (z<1)

  * DELPHI, Eur. Phys. J. C13,543, (1996)
  + OPAL Z.Phys. C 69, 543 (1996)

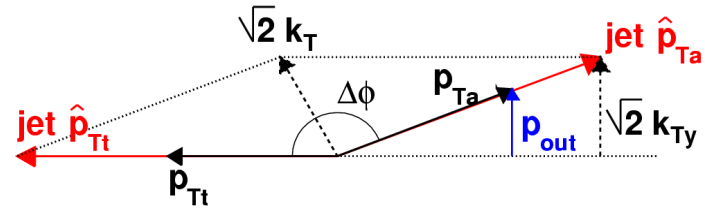
- Direct photon x_E distributions Should be sensitive to underlying fragmentation function



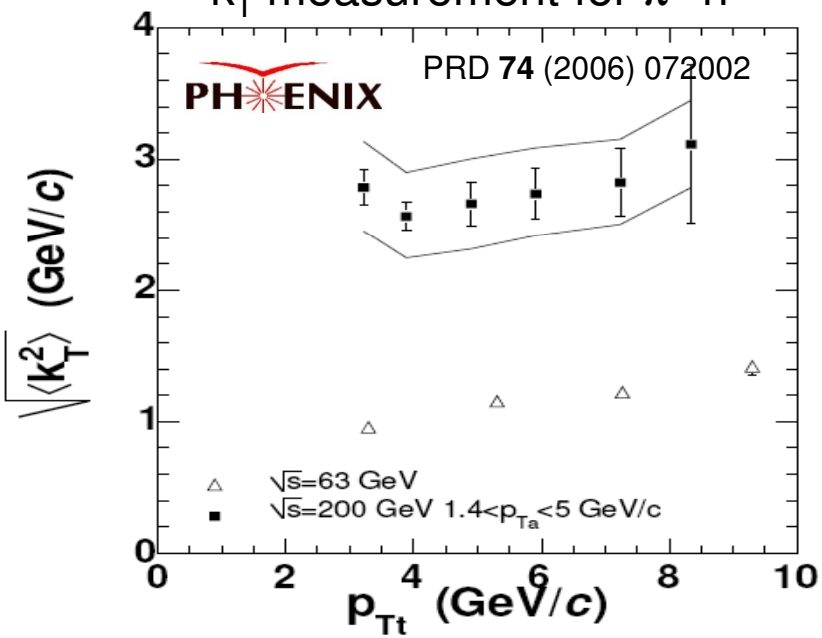
- Fragmentation Functions should scale with photon p_T
- However γ-h x_E distributions hint at non-scaling
- Non-zero k_T could give rise to a p_T dependence

k_T Effect

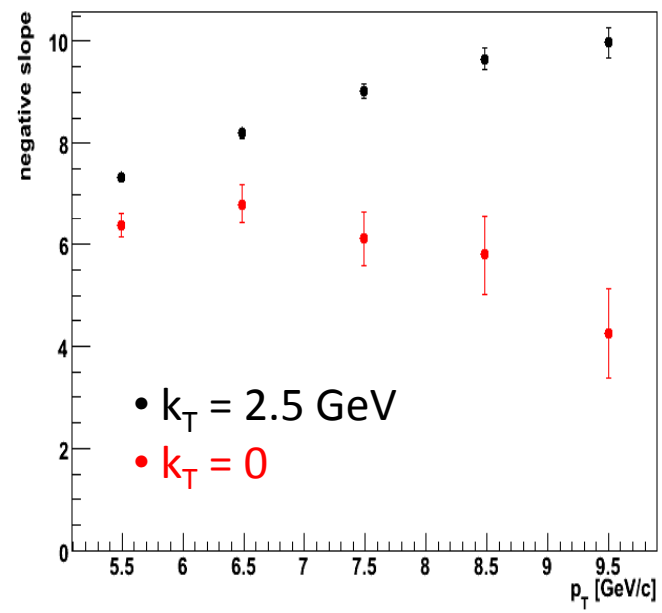
k_T Effect: Net momentum of di-jets (and γ-jets) due to initial state radiation



k_T measurement for π^0-h



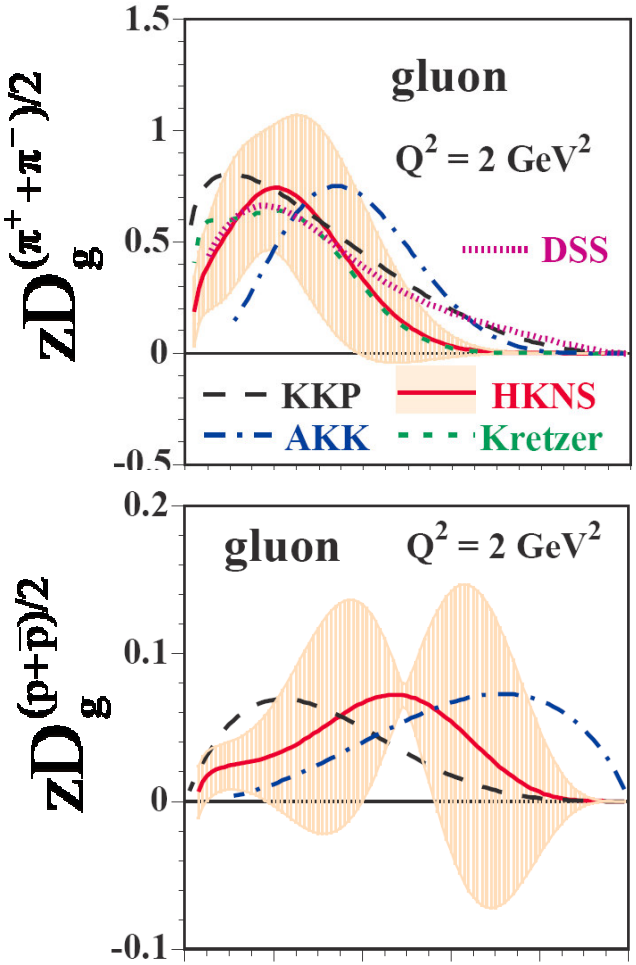
x_E slopes for γ-h from PYTHIA



k_T measurements the di-jet channel show a large effect -- 2.5 – 3.0 GeV

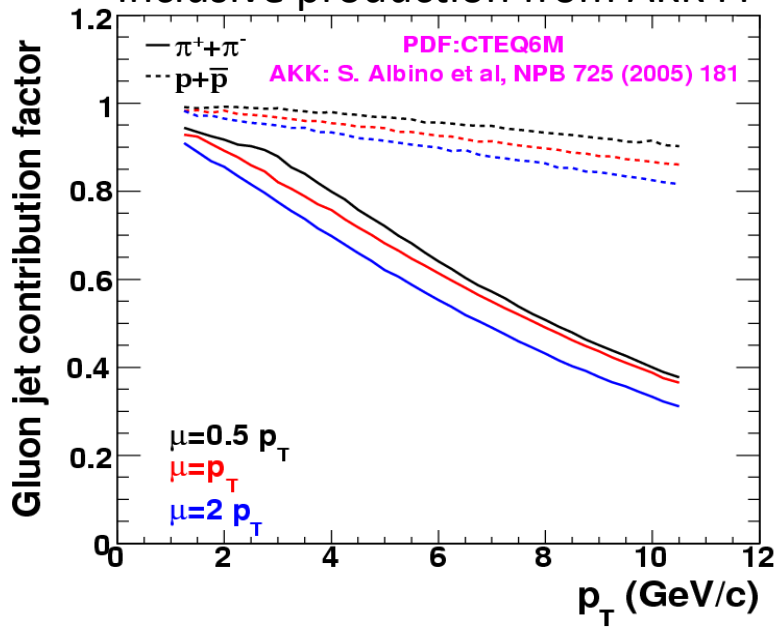
PYTHIA shows that k_T changes the x_E distribution significantly
k_T measurement in γ-h is needed

Gluon Fragmentation Functions



Compilation by Hirai et al.
Phys Rev D75 (2007) 94009

Inclusive production from AKK FF



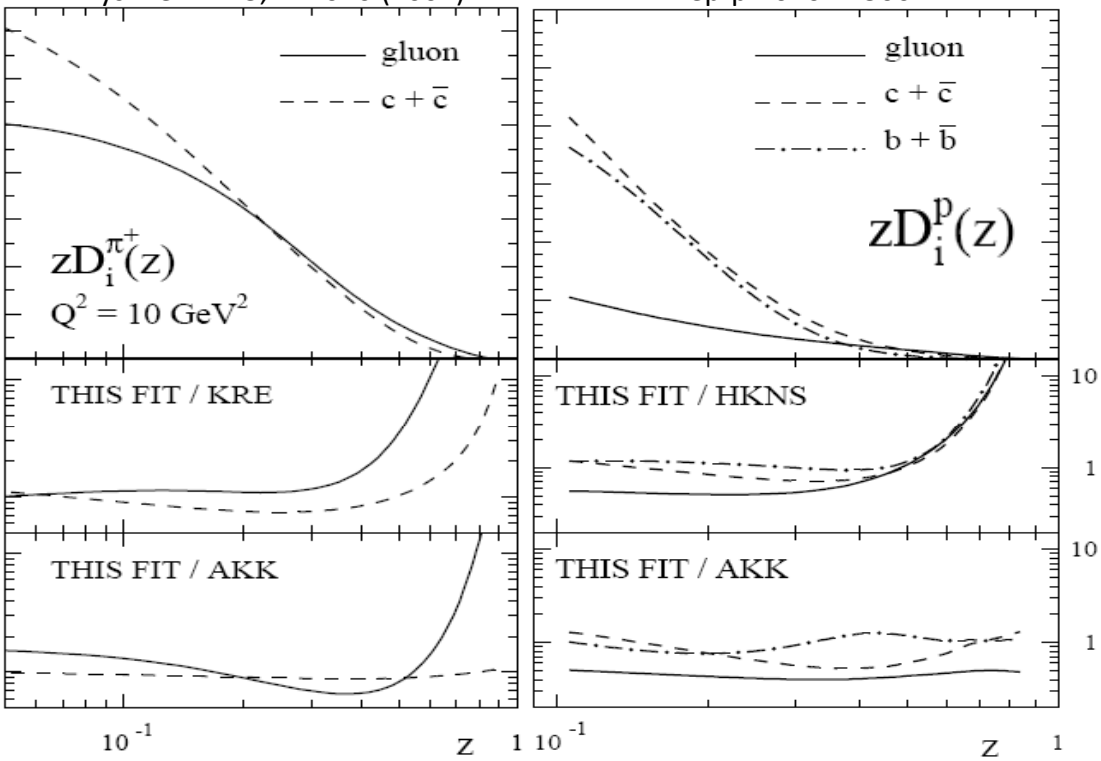
- Gluons contribute significantly to single inclusive measurements at RHIC
- However different parameterizations give divergent estimations of gluon contribution
- e.g., AKK FF's indicate much higher gluon contribution than previous fits

Using p+p data in FF's

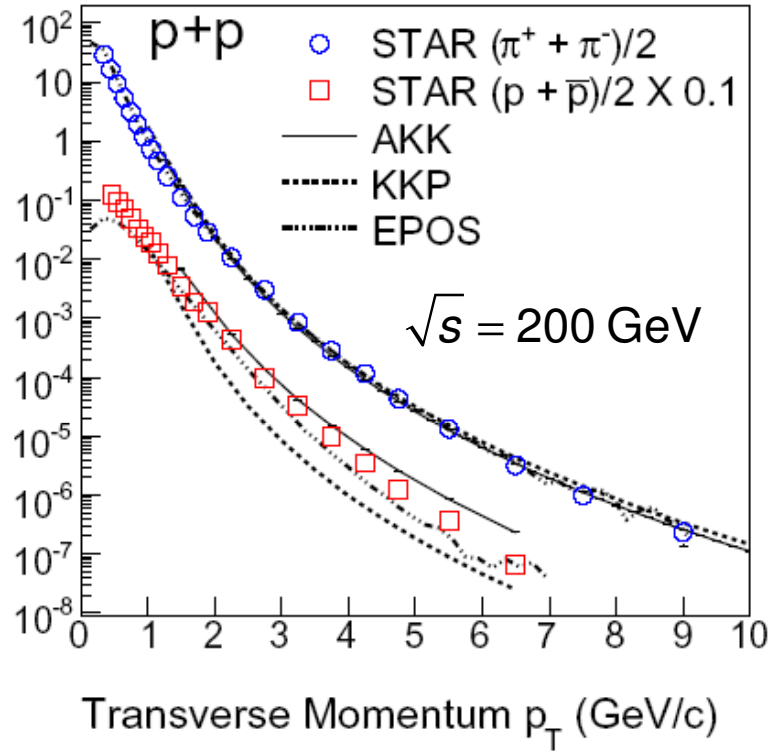
De Florian, Sassot, Stratmann

Phys. Rev. D75, 114010 (2007).

hep-ph:0707.1506



STAR, Phys Lett B, 637 (2006) 161



New set of fragmentation functions include p+p (and DIS) data and obtain very different parameterizations of the gluon FF's

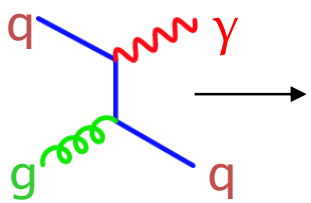
STAR identified hadron spectra constrain the gluon FF at large z
Use two particle correlations to constrain g→ p at all z?

Identified Hadron Correlations

- γ recoil jets more likely to be a quark jet than π^0 recoil jets
- Quark and gluon jets may have different particle content

→ p/π on the away-side of γ vs. π^0 recoil sensitive the FF's

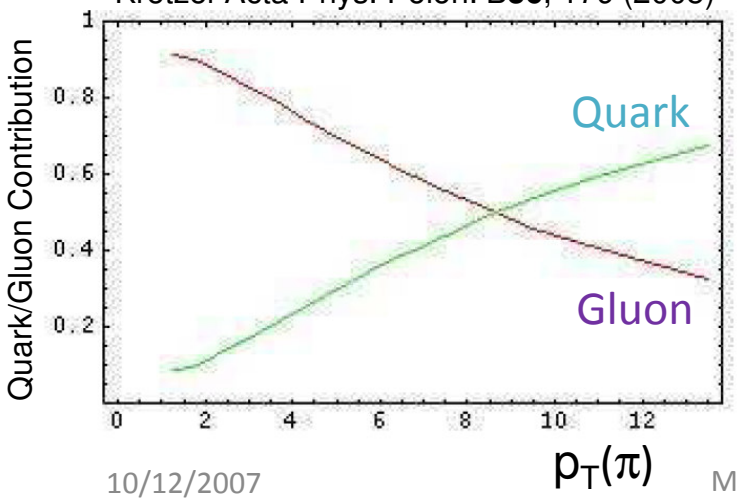
A concrete example,
For definiteness assume:



$$\longrightarrow \quad D(\gamma \text{ recoil}) \approx D_q$$

& $D(\pi^0 \text{ recoil}) \approx 1/2 D_q + 1/2 D_g$

Kretzer Acta Phys. Polon. B**36**, 179 (2005)



In this simplified picture particle ratios can be written in terms of FF's:

$$\frac{p/\pi\,(\pi^0 \text{ recoil})}{p/\pi\,(\gamma \text{ recoil})} \approx \frac{1/2\, D_q^p / D_q^\pi + 1/2\, D_g^p / D_g^\pi}{D_q^p / D_q^\pi}$$

$$\rightarrow D_g^p / D_g^\pi = 2\, D_q^p / D_q^\pi \, \frac{p/\pi(\pi^0 \text{ recoil})}{p/\pi(\gamma \text{ recoil})} - 1$$

Well constrained from e+e-

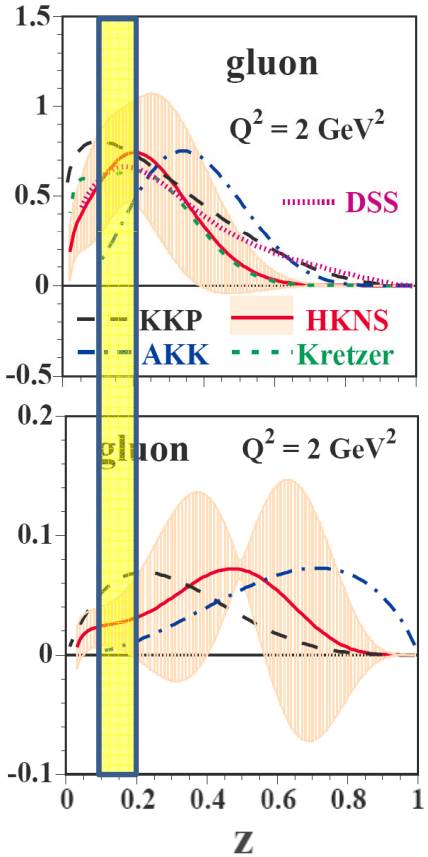
Double ratio gives partial cancellation of systematics due to particle identification and direct photon subtraction

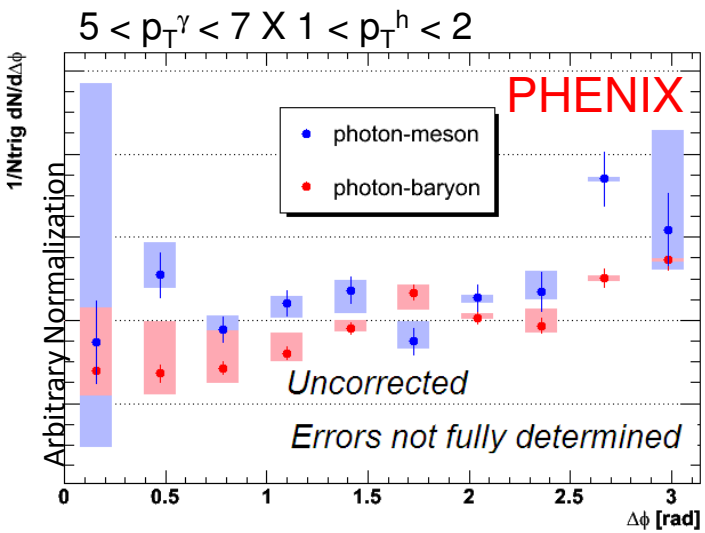
γ-Identified h Results (Under Construction)

γ- identified hadron correlations can be performed in the range

$5 < p_T^{\gamma} < 12$ X $1 < p_T^{h} < 2$

This corresponds to about $0.1 < z < 0.2$





- Hadron efficiencies not finalized
- Systematic errors are large but will most cancel in ratio
- So far run 5 only
- Run 5 + 6 should enable a significant measurement (integrated over away-side)

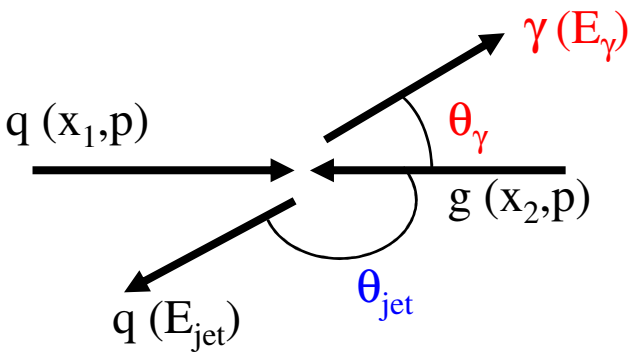
Conclusions

- γ-h Correlations in p+p which are a baseline measurement for both heavy-ion and spin phyiscs and are reaching a mature stage
- Fragmentation Functions should be further constrained to interpret spin asymmetries from single inclusive measurements
- Direct γ triggers fix the energy of the recoil quark jet and thus may be useful for constraining fragmentation functions

From γ-h to γ-jet

Yuji Goto, RHIC-AGS User's Meeting

jet reconstruction with VTX



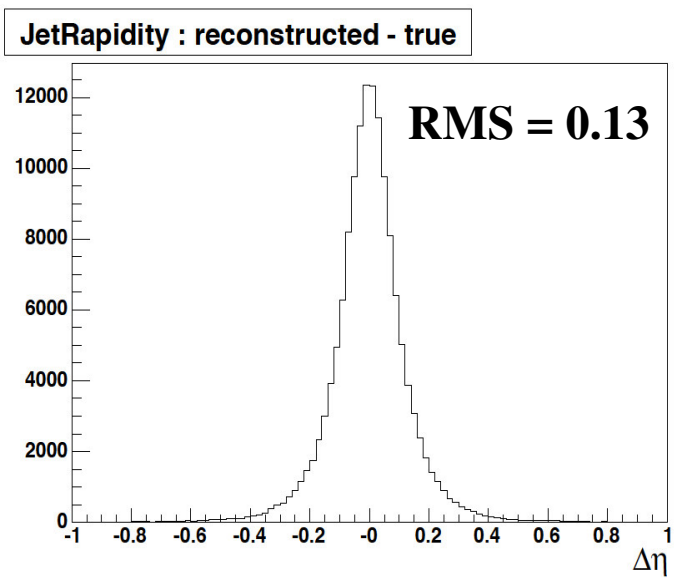
θ_{jet} : reconstructed by charged particles using Cone algorithm.

***Assuming that the p_T of the prompt photon and recoil jet are balanced.**

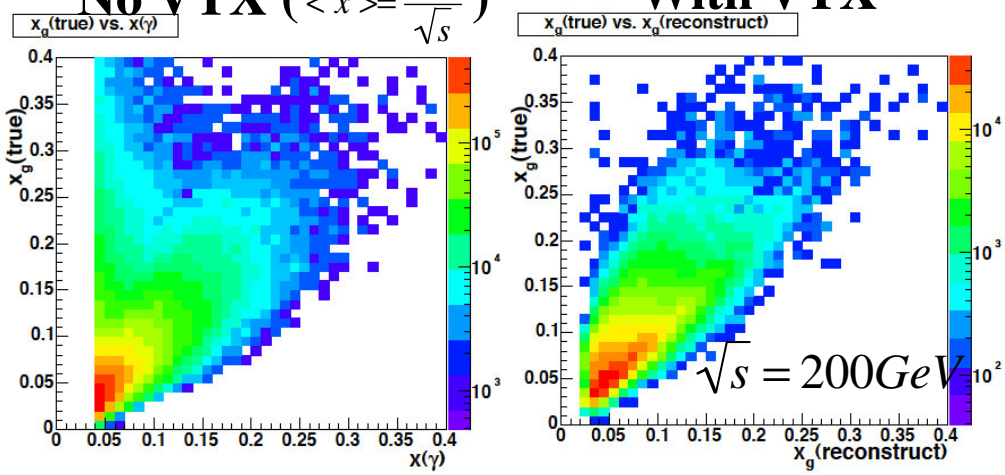
$$x_1 = \frac{p_T}{\sqrt{s}}\left(e^{\eta_{jet}} + e^{\eta_\gamma}\right) \quad x_2 = \frac{p_T}{\sqrt{s}}\left(e^{-\eta_{jet}} + e^{-\eta_\gamma}\right)$$

***Assuming that $x_g < x_q$**

$$x_g = min(x_1, x_2) \quad x_q = \max(x_1, x_2)$$



No VTX ($< x > = \frac{2p_T}{\sqrt{s}}$) **With VTX**



Also forward photons with NCC
Sensitive to gluon PDF at low x!

ISR Results

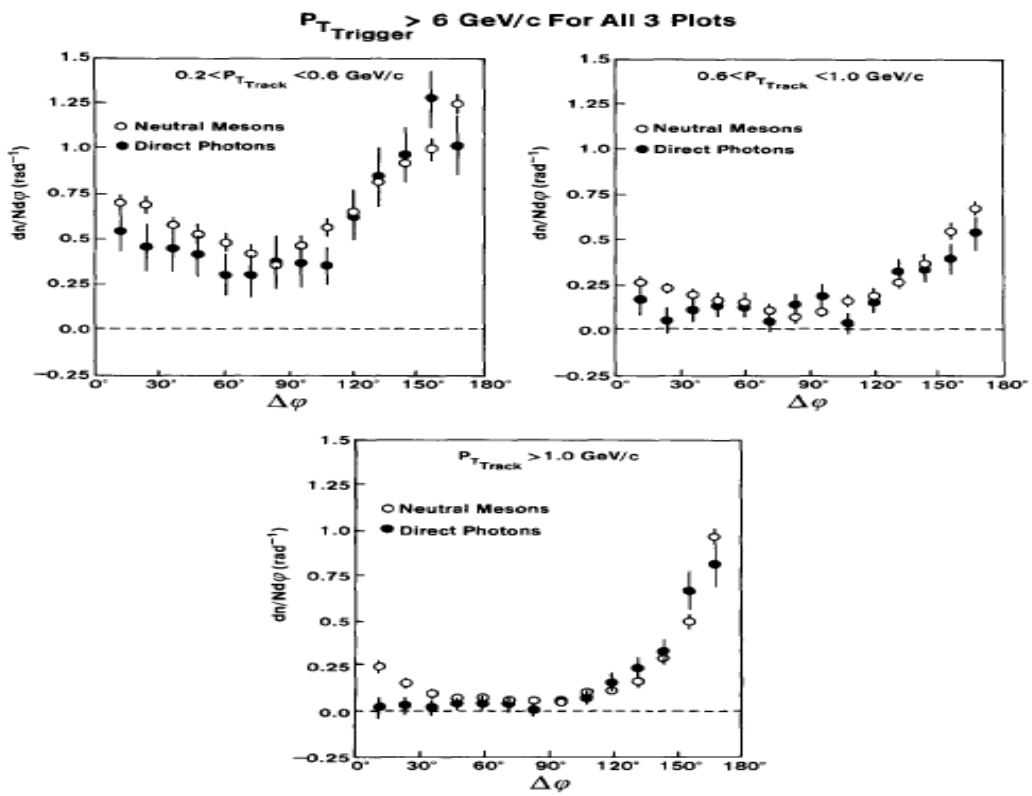


Fig. 15. Azimuthal distributions of charged associated particles for the direct photon and neutral meson samples (after background extraction) for $p_{T\,trigger}$ greater than 6.0 GeV/c and for three different $p_{T\,track}$ ranges.

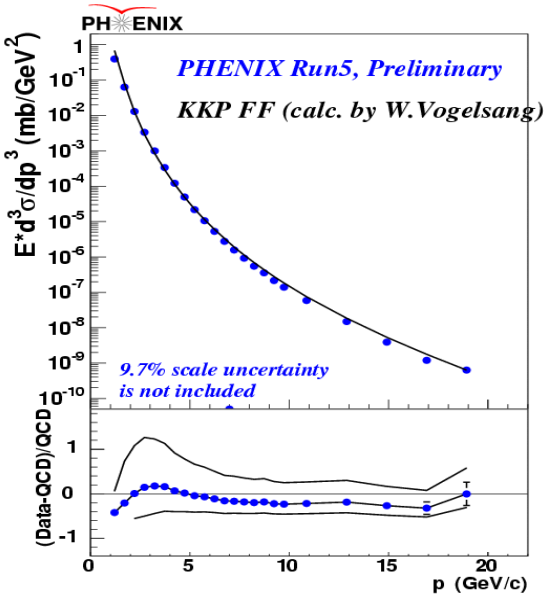
Rγ from p+p Collisions

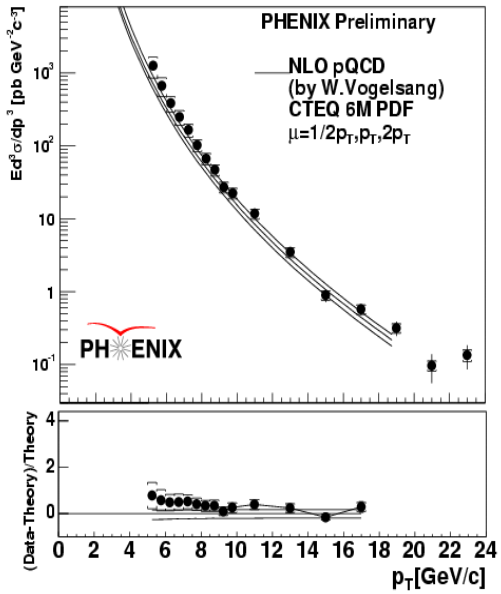
In p+p there is no published Rγ but deriveable from π^0 and γ spectra

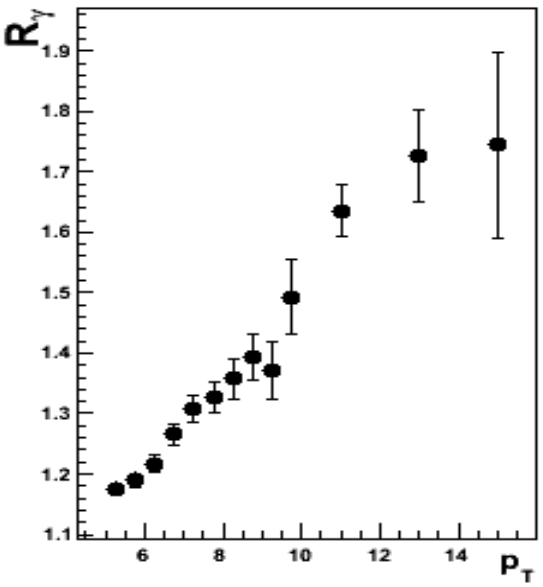
For pure power law: $N(\pi^0)/N(\gamma) = (n-1)/2$; n = π^0 slope parameter

Quoted from γ x-sec analysis

$$R\gamma = 1 + \frac{n-1}{2} \frac{\pi^0}{\text{total decay}} \frac{dN(\gamma)/dp_T}{dN(\pi^0)/dp_T}$$

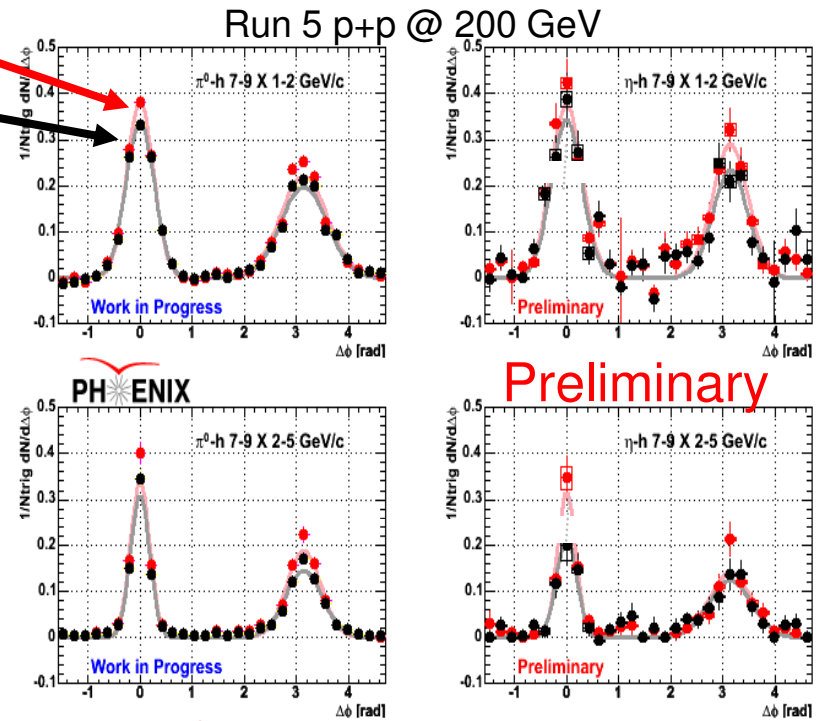




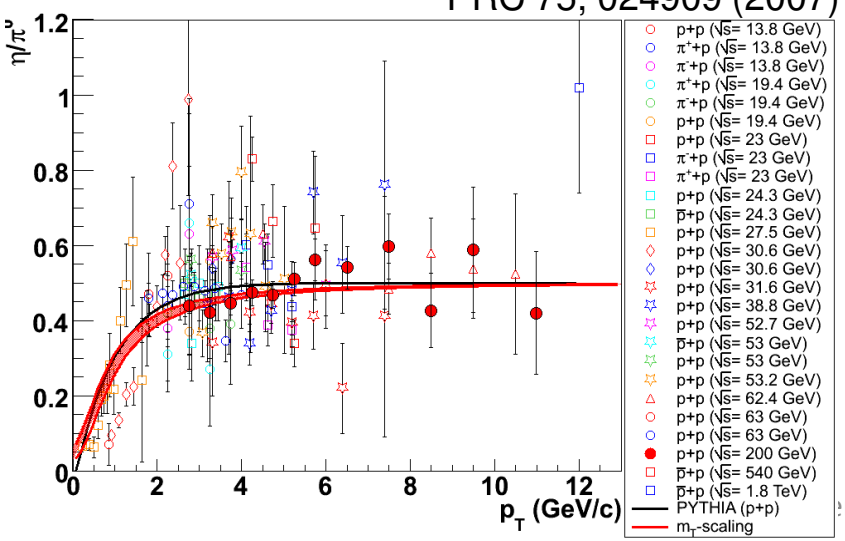


η-h Correlations

- First measurement of η-h correlations at RHIC!
- γ(η)-h Yields generated by same procedure as γ(π^0)-h
- Combinatorial background under h peak subtracted using a sideband procedure



PRC 75, 024909 (2007)



- η/π^0 measured in PHENIX – consistent with world data and m_T scaling
- η, π^0 account for ~ 95% of the decay background

Constructing the Decay Background

- To start: Construct $\gamma(\pi^0)$ - h from π^0-h
- Problem is that tagging the π^0's introduces a bias

  $\langle p_T \rangle$ tagged = $\langle p_T \rangle$ true
- Developed a *pair-by-pair* correction procedure

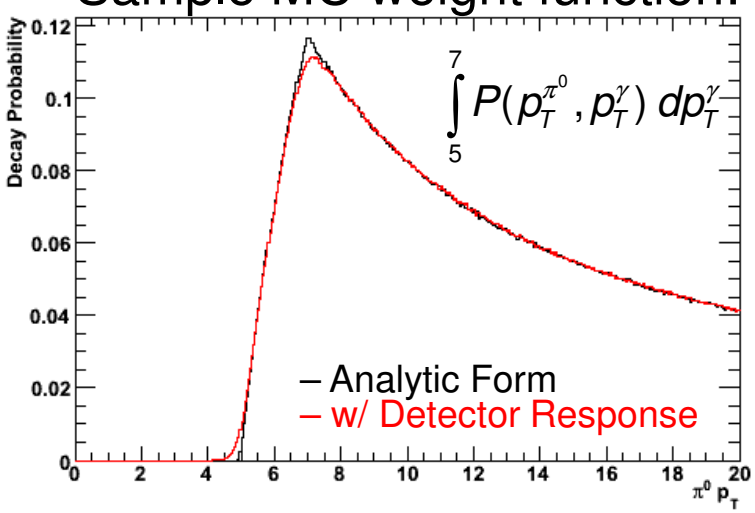
Correction Procedure:

$$\text{Tagged}\ \frac{dN(\pi^0)}{dp_T} \rightarrow \text{True}\ \frac{dN(\pi^0)}{dp_T} \rightarrow \frac{dN(\gamma^{\pi^0})}{dp_T}$$

Per-Trigger Yield from $\gamma(\pi^0)$:

$$Y_{\gamma(\pi^0)}\left(p_T^{\gamma}, p_T^{h}\right) = \int P\left(p_T^{\pi^0}, p_T^{\gamma}\right) \varepsilon\left(p_T^{\pi^0}\right) Y_{\pi^0}\left(p_T^{\pi^0}, p_T^{h}\right) \mathrm{d}p_T^{\pi^0}$$

Sample MC weight function:



- Decay kinematics reproduced by Monte Carlo include energy resolution effects and acceptance (*P*)
- This is just for π^0's, What about contributions from other mesons? → This approach implicitly assumes they have the same associated yield

Why Direct Photons Correlations?

- p+p: Direct Photon Correlations measure the Fragmentation Function (FF) of quarks:

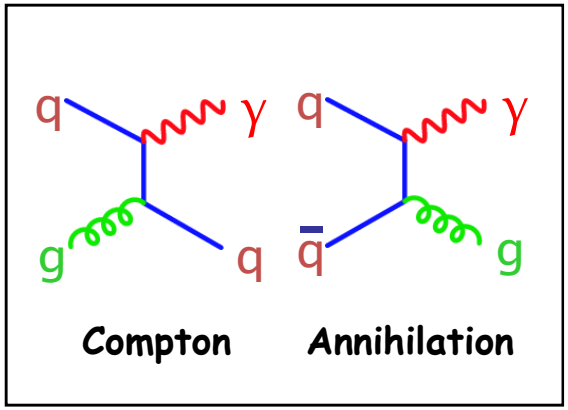
$$D(z) \equiv dN/dz; \quad z = p(fragment)/p(jet)$$

- A+A:
  - Modified Jet Fragmentation

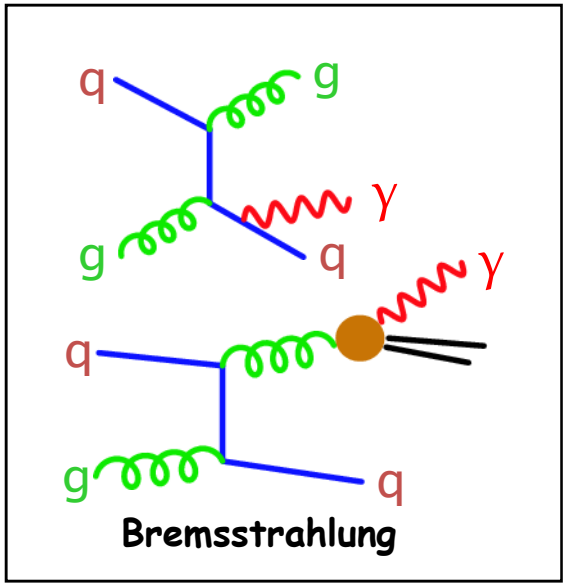
$$\tilde{D}(z) \approx \frac{1}{1-1/\Delta E} D\left(\frac{z}{1-\Delta E/E}\right)$$

Wang, X.N., Nucl. Phys. A, 702 (1) 2002

  - The Golden Channel?
- Beyond Leading Order (the fine print)
  - Fragmentation plays a role
  - FF for photons not very well constrained
  - Initial state effects (k_T)

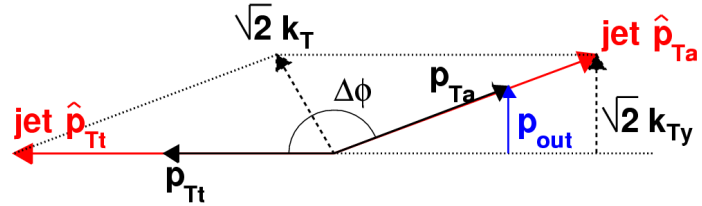


Direct Photon Processes



Trigger Biases and the k_T effect

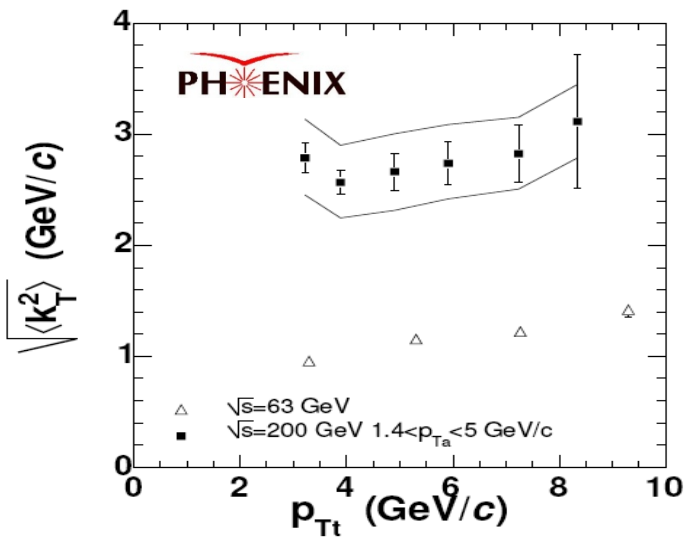
Insensitivity of dN/dx_E to true FF is the interplay of two trigger biases:



k_T Effect: Acoplanarity of di-jets (and γ-jets) due to initial state radiation

Trigger Bias #1: Trigger requirement biases the near side FF to high z

- Does not affect away-side jet
- Absent in g-h



k_T measurement for di-jets

Trigger Bias #2: Longitudinal component of k_T biases jet CM in direction of the trigger for p_T,t > p_T,a

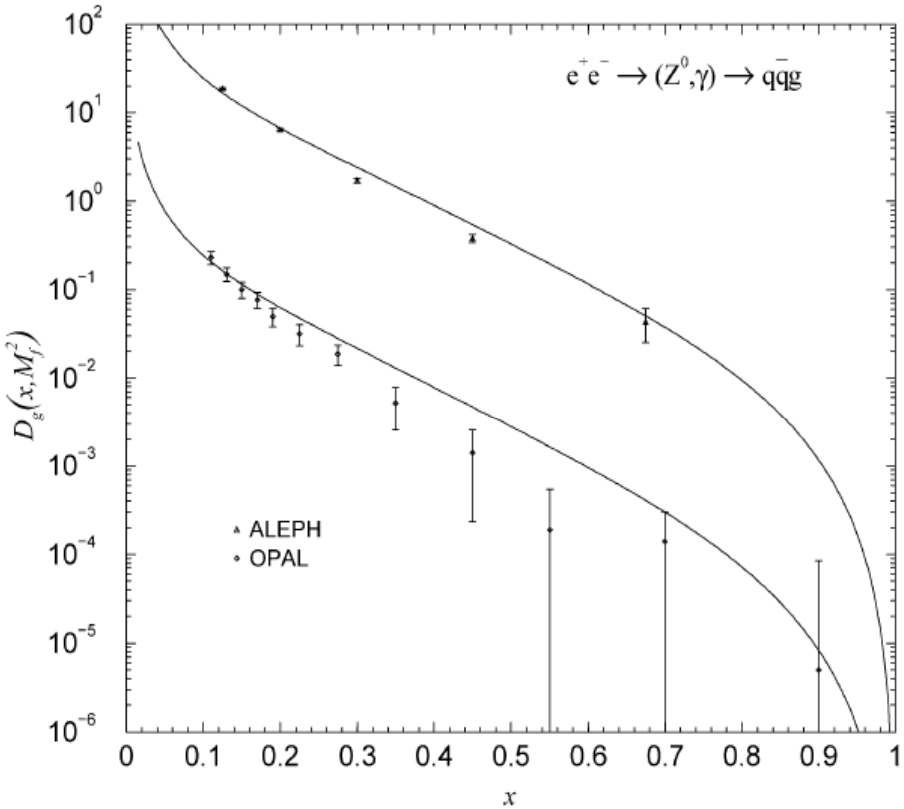
- Does affect the away-side jet
- Present in γ-h

k_T effect affects:

–away-side jet width
–Inclusive high p_T x-sections
–Recoil spectra (dN/dx_E)

k_T described by NLO,
Why do we need to measure it?

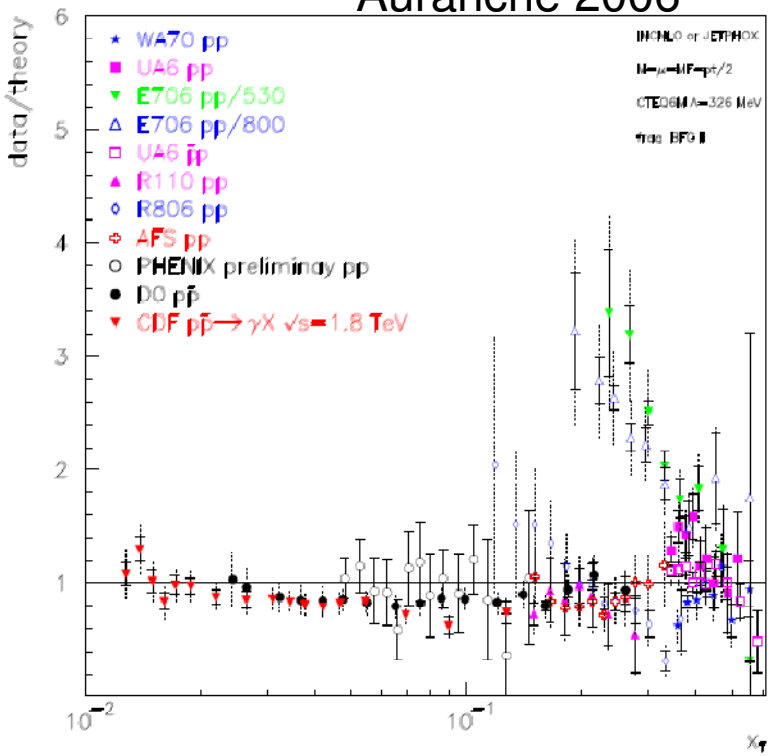
Gluon Fragmentation

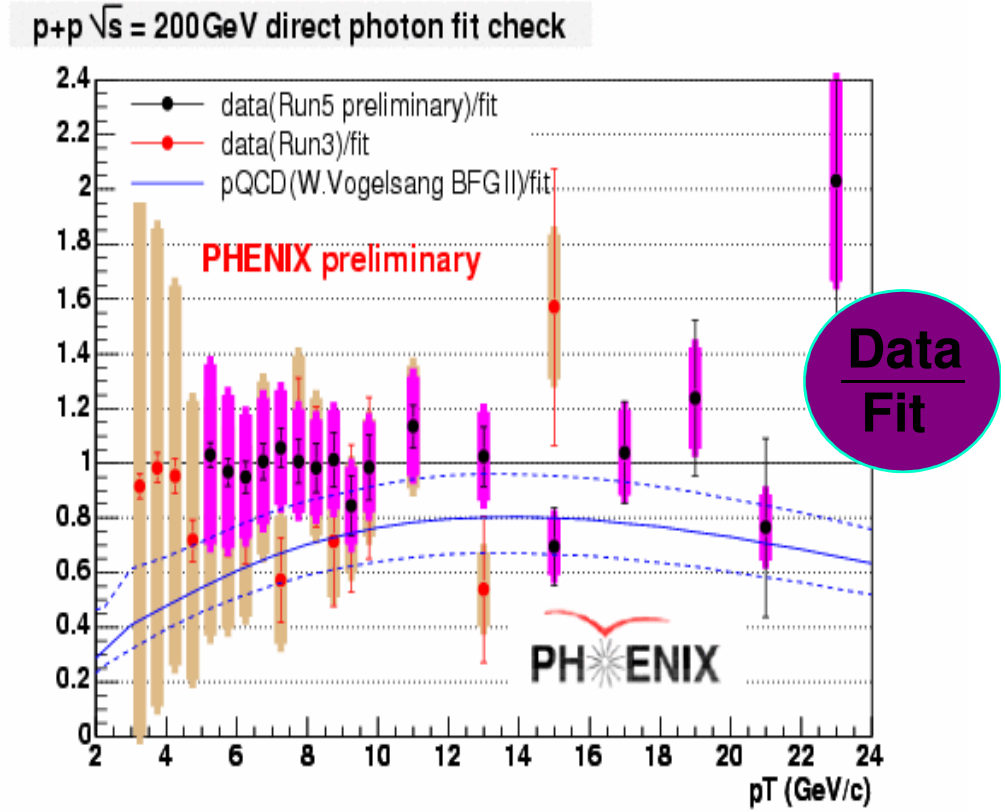


The gluon fragmentation function has large uncertainties!
Is there an independent test of g→p?

pQCD Limitations

Auranche 2006



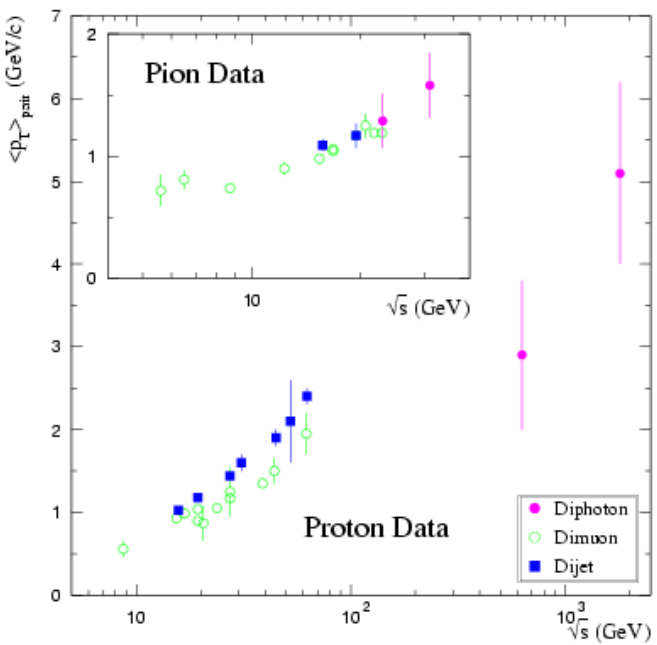


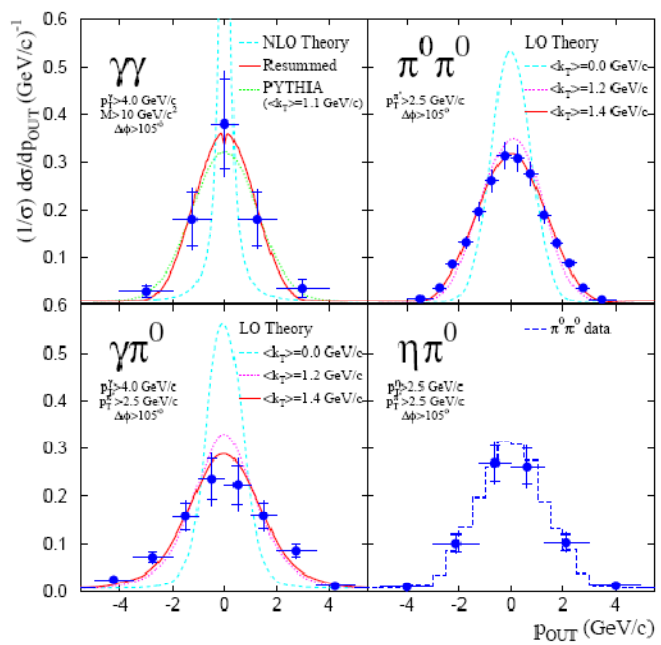
Agreement w/ data is remarkable!
Better than jet cross-sections

Closer: Agreement only 20%
Not good enough to constrain k_T

k_T in the γ-jet channel

M. Begel, Nucl. Phys. B **79**, 244 1999;
Ph.d thesis (1998)





$k_T \propto \sqrt{s}$ Independent of process

Measurement for γ-π^0 at lower $\sqrt{s}$

Experience from h-h correlations

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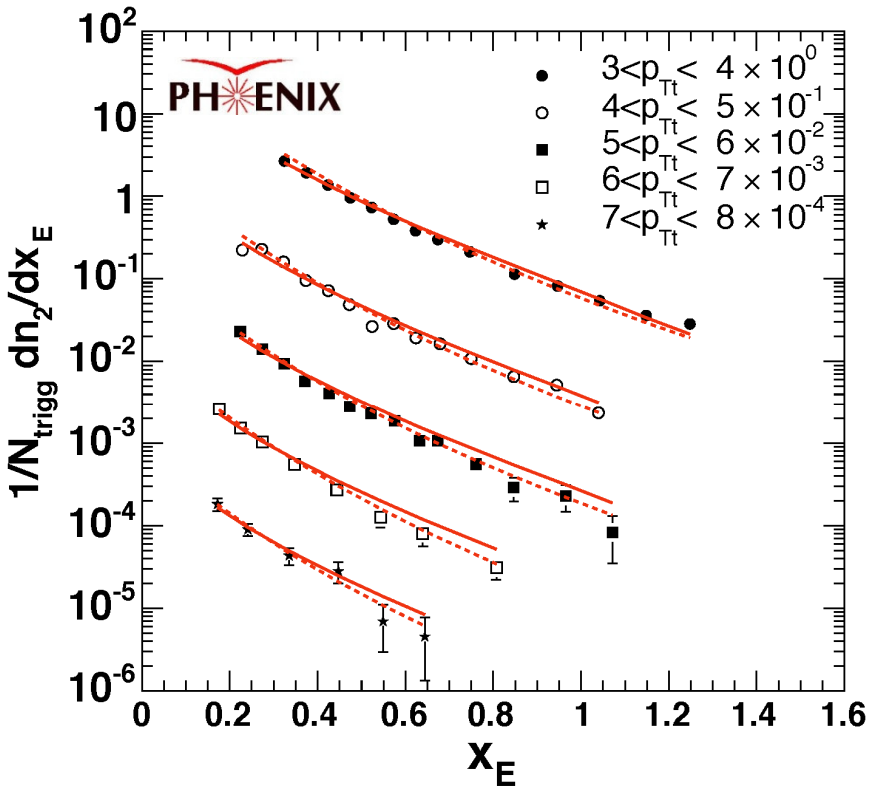
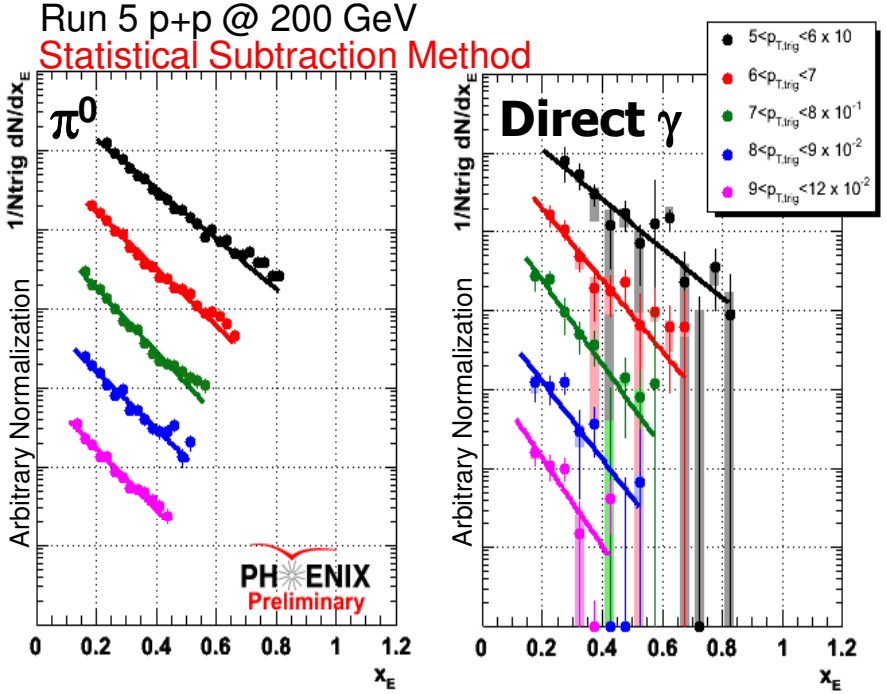


dN/dx_E for h-h correlations was long thought to be sensitive to FF's

When we input different the gluon and quark FF's turned out to be false

Towards Fragmentation Functions

Run 5 p+p @ 200 GeV
Statistical Subtraction Method



Naively one expects that dN/dx_E Measures the fragmentation function

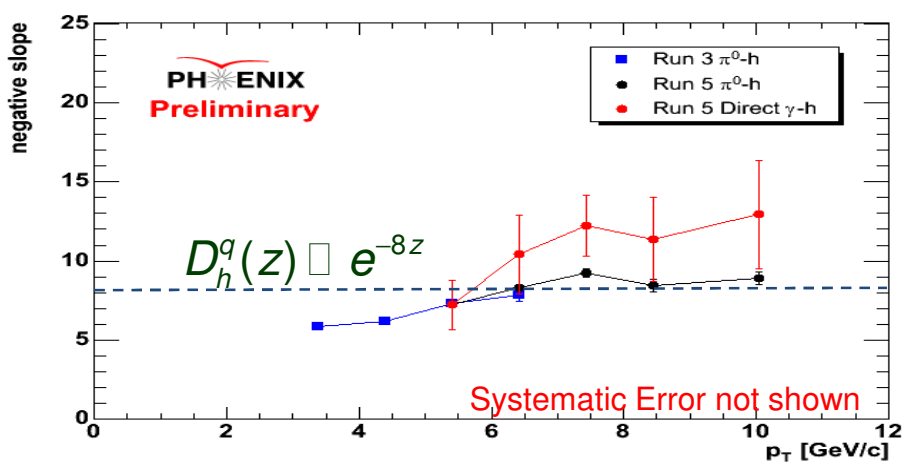
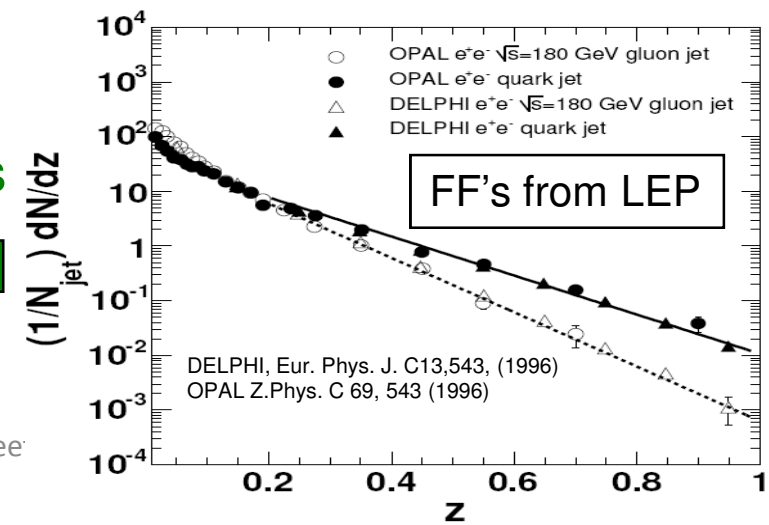
γ-h: $p_T\gamma = p_T$jet

$$x_E = \frac{\vec{p}_T^{\gamma} \cdot \vec{p}_T^{h}}{\left|\vec{p}_T^{\gamma}\right|^2} = \frac{\left|p_T^h\right|}{\left|p_T^{\gamma}\right|}\cos(\Delta\phi) \approx \frac{\left|p^h\right|}{\left|p^{jet}\right|} = z$$

$$\boxed{\therefore \left.\frac{dN}{dx_E}\right|_{p_T^{\gamma}} \approx D_h^q(z)}$$

LEP data tell us that:

$$D_{quark}(z) \propto e^{-8z} \quad D_{gluon}(z) \propto e^{-11z}$$



predicts