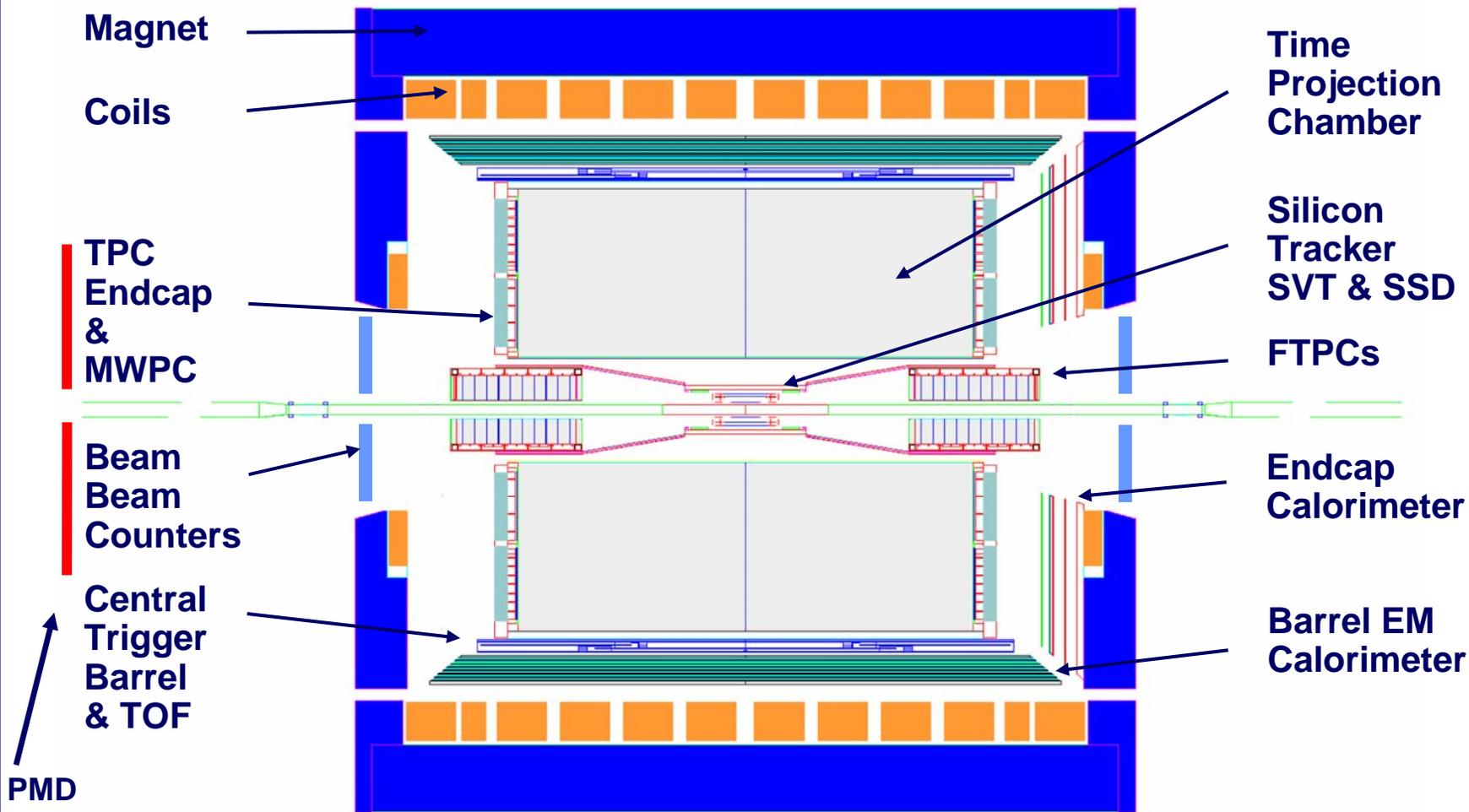


# Photons @ RHIC: Results from STAR

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for the STAR Collaboration*

# STAR Experiment At RHIC



# Introduction

## Photons in A+A collisions

- Mainly, from  $\pi^0$ ,  $\eta$  decays
  - Important probe in many aspects
  - In STAR, allow better statistics to higher  $p_T$  than charged pions
- Direct photons
  - Main advantage – large mean free path in the created matter
  - Produced in all stages of the collision
    - thermal photons – access to temperature (initial, hadronization)
    - High  $p_T$  photons to investigate hadron suppression in A+A collisions
- Extraction of direct photon production is harder due to large hadronic decay background  $\rightarrow \pi^0$  ( $\eta$ ) measurements very important

Direct  $\gamma$  production

$$q + \bar{q} \rightarrow g + \gamma$$

$$q + g \rightarrow q + \gamma$$

*Bremsstrahlung*

# Inclusive $\gamma$ and $\pi^0$ from the STAR TPC

Measurement obtained from  $\gamma$  conversion in TPC

Material used as  $\gamma$  converter:

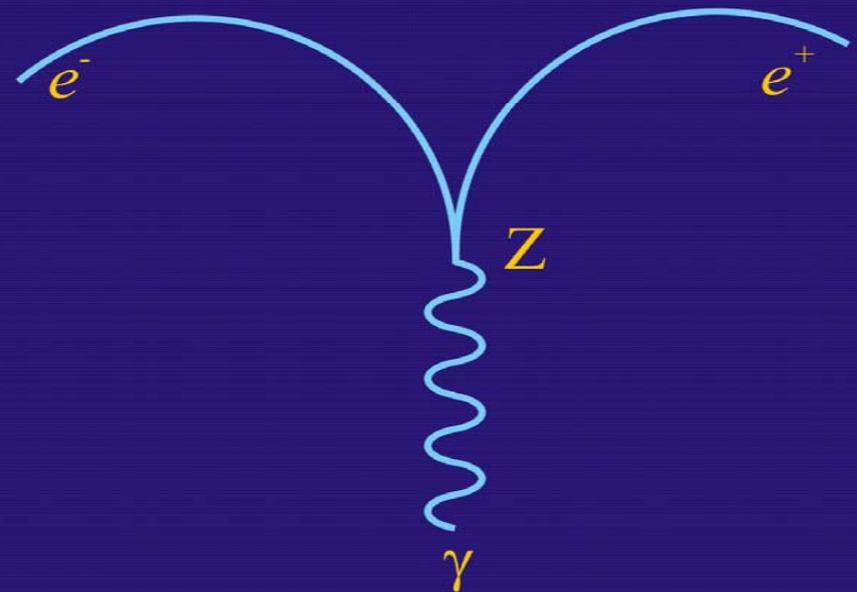
- Beampipe
- SVT
- SSD
- Inner field cage
- TPC gas

Efficiency

- $\gamma \sim 2\%$
- $\pi^0 \sim 0.04\%$

# $\gamma$ reconstruction

- $e^+$  and  $e^-$  are selected through  $dE/dx$ 
  - loose cuts are applied
  - low  $p_T$  accepted only if they do not come from collision vertex
- For the pairs, it is required a small opening angle and conversion vertex different from collision vertex
- Trajectory of reconstructed  $\gamma$  points back to collision vertex



# Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV - $\gamma$ spectra

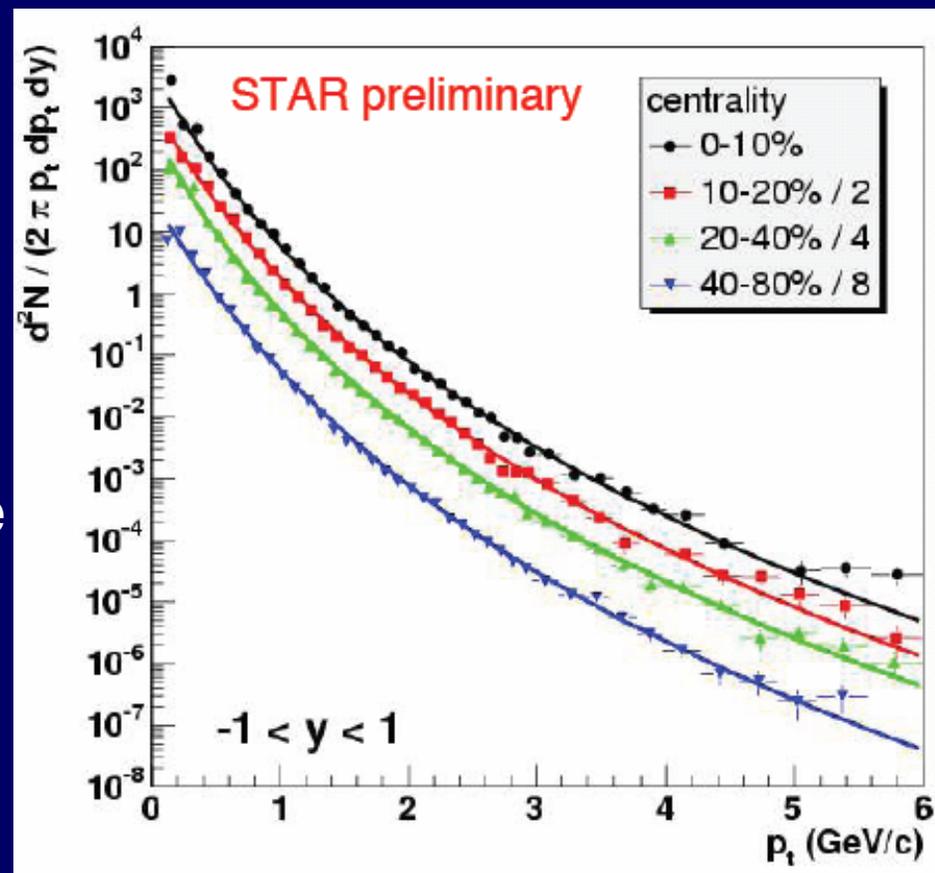
$\gamma$  and  $\pi^0$  – Au+Au at 130 GeV

J. Adams *et al.*, Phys. Rev. C **70** (2004) 044902

- Error bars: statistical only
- Systematic uncertainty: 20%
- Combinatorial background has been subtracted
- Other contributions, such as  $\Lambda$  decays, were verified to be negligible

## Centrality dependence

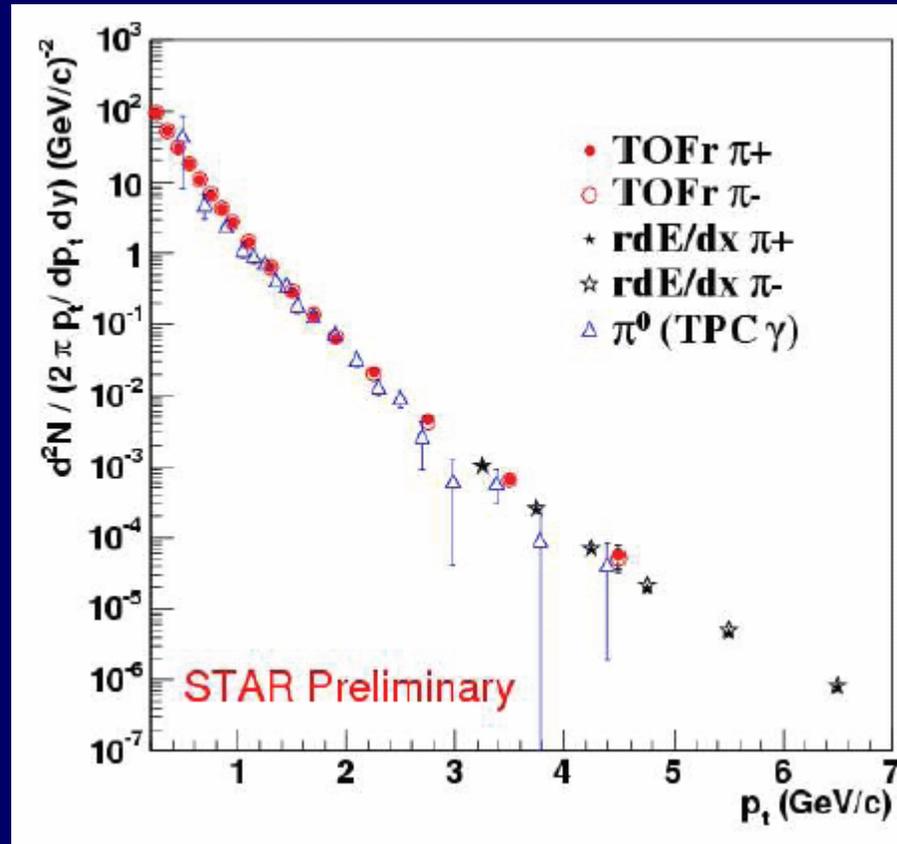
- Curves are power law fits



# Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV - $\pi^0$ spectrum

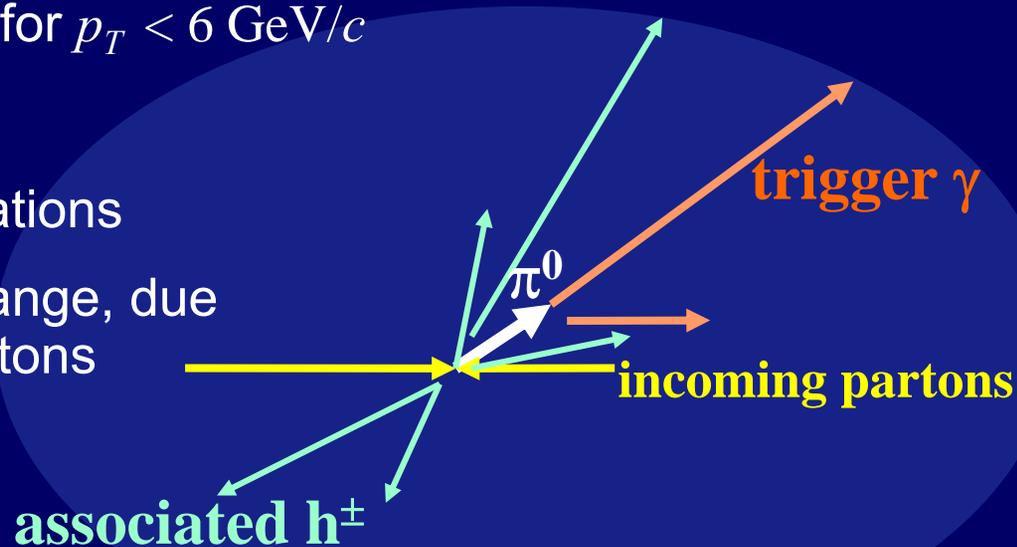
- Each point is the gaussian fit of the  $2\gamma$  invariant mass distribution for a given  $p_T$
- $\sim 10$  MeV width, depending on  $p_T$
- Systematic uncertainty of 30%

Comparison of  $\pi^0$  to  $\pi^+$  and  $\pi^-$  from STAR TPC  $dE/dx$  and TOFr shows good agreement.



# Correlation of large $E_T$ photons with charged particles

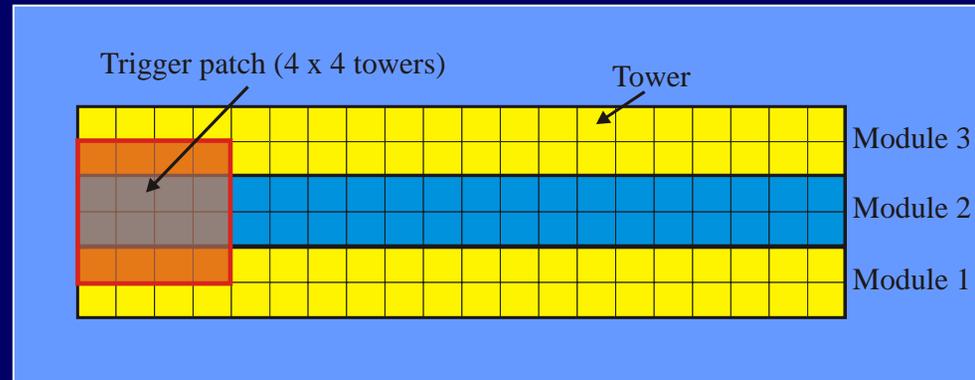
- Jet studies allow further investigation of parton energy loss mechanism
- 2 particle correlations
  - probe of intra-jet (same side) and back-to-back jet (away side)
- Previous studies
  - charged particle correlations for  $p_T < 6 \text{ GeV}/c$
- This Analysis
  - $\gamma$  (mostly from  $\pi^0$ ) –  $h^\pm$  correlations
  - Extends correlation energy range, due to EMC measurement of photons



# d+Au collisions at $\sqrt{s_{NN}}=200$ GeV

## Data set

- 3.9 M High Tower triggered events
  - EMC patch - 4 x 4 towers
  - High tower trigger - tower in a patch with the highest energy above threshold

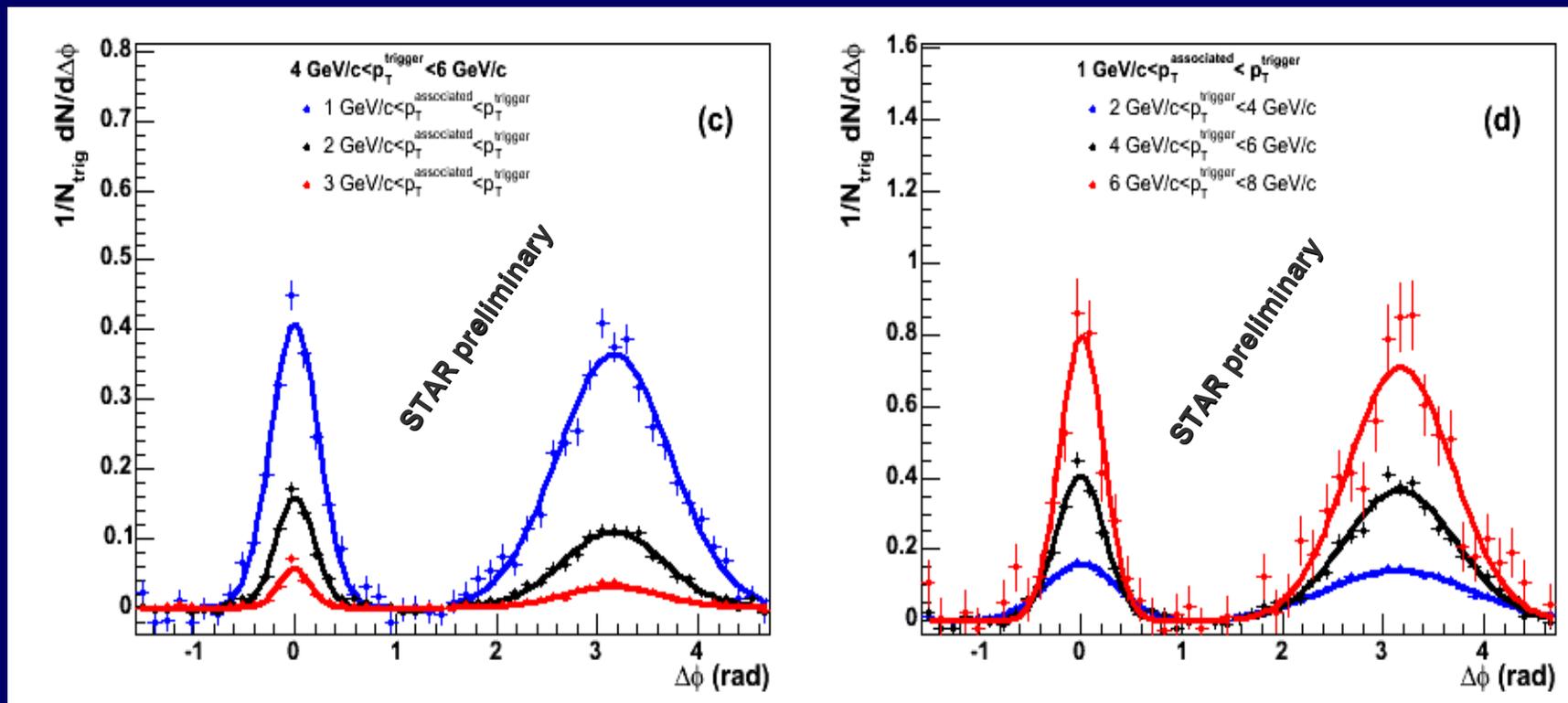


EMC Tower  $\rightarrow \delta\eta \times \delta\phi = 0.05 \times 0.05$

## Selections and Cuts

- Highest tower energy selected
- Isolation cut
  - No track pointing in a 3 x 3 tower patch around main tower
- Associated track – basic selection criterium used in many STAR analysis

# d+Au correlations

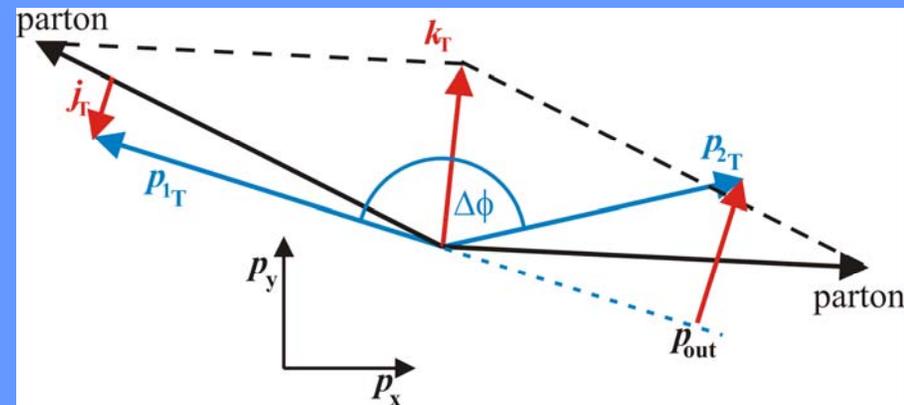


$p_T^{\text{associated}}$  dependence

$E_{\text{trig}}$  dependence

# Jet properties – $\langle j_T \rangle$ and $\sqrt{\langle k_T^{rms} \rangle}$

- $j_T$  - transverse momentum component of jet from jet axis
- $k_T$  - transverse momentum component of initial parton



## Correlation (Gaussian) widths

- $\sigma_N \rightarrow$  near side
- $\sigma_F \rightarrow$  far side

- $E_T \rightarrow E_{trig}$ ,
- $p_T \rightarrow p_T^{associated}$
- $\langle z \rangle \rightarrow$  fragmentation function of trigger photon (0.6~0.8)

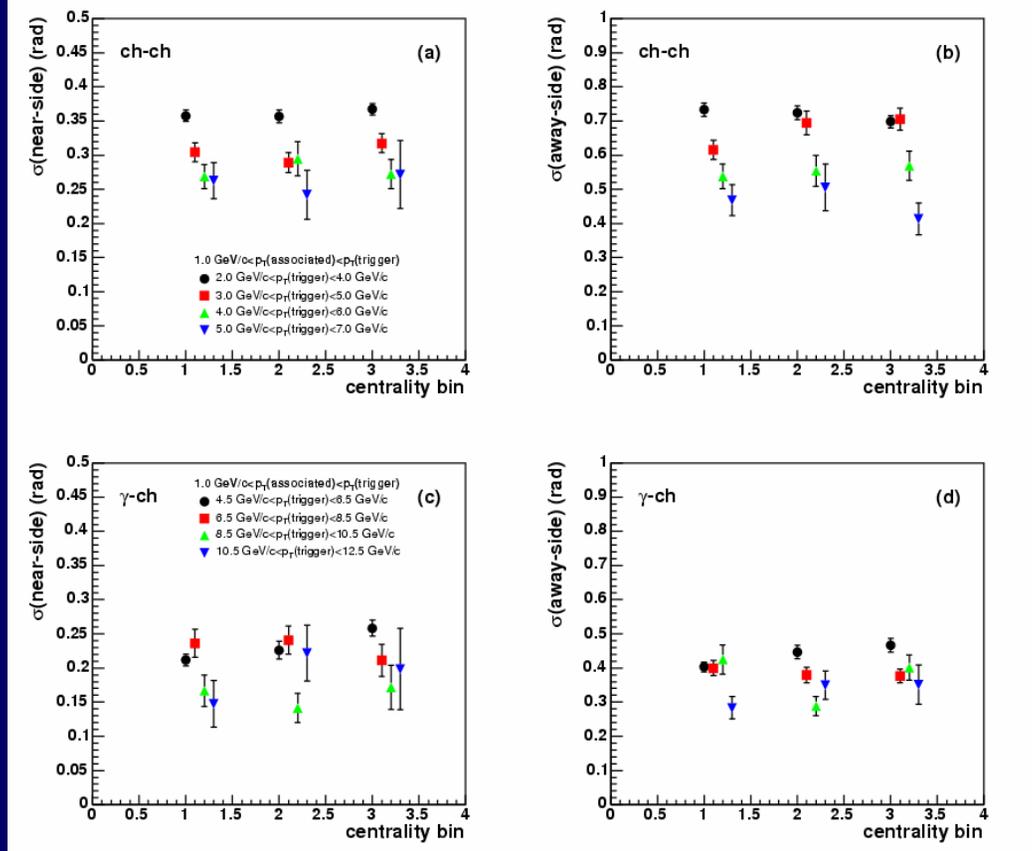
$$\sigma_N^2 \approx \frac{\langle E_T^2 \rangle + \langle p_T^2 \rangle}{2 \langle E_T \rangle \langle p_T \rangle} \langle j_T^2 \rangle$$

$$\langle j_T \rangle = \frac{\sqrt{\pi}}{2} \langle j_T^2 \rangle$$

$$\sqrt{\langle k_T^2 \rangle} \approx \frac{\langle E_T \rangle}{\langle z \rangle} \sqrt{\sigma_F^2 + \sigma_N^2}$$

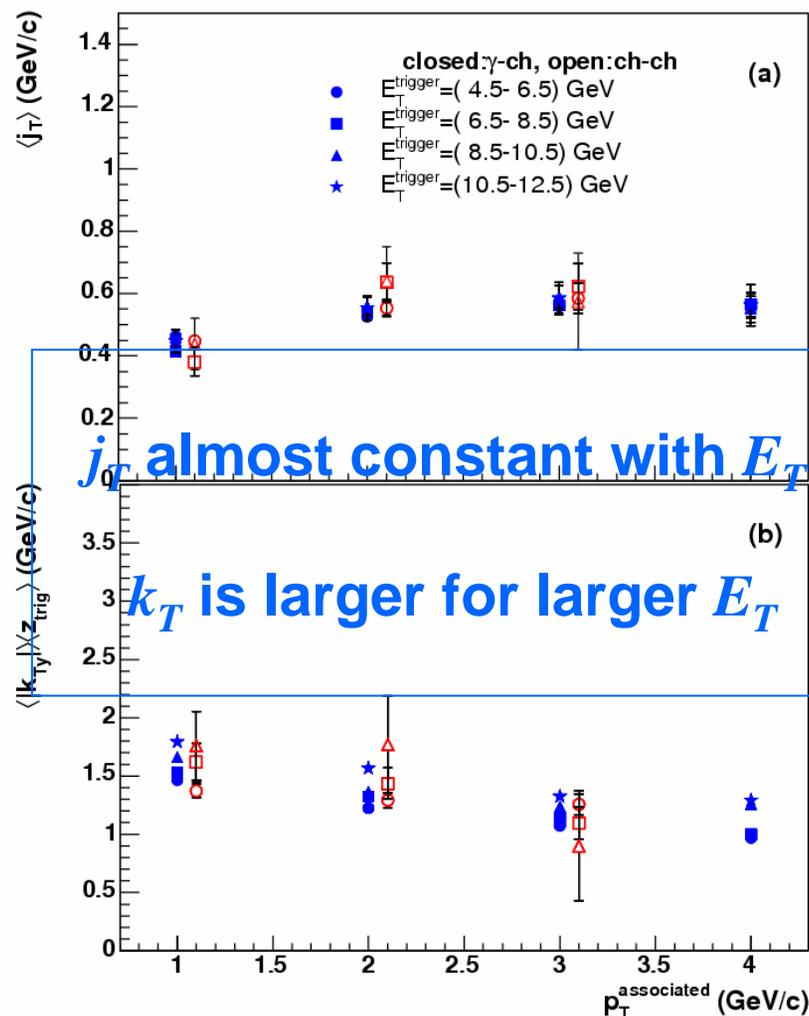
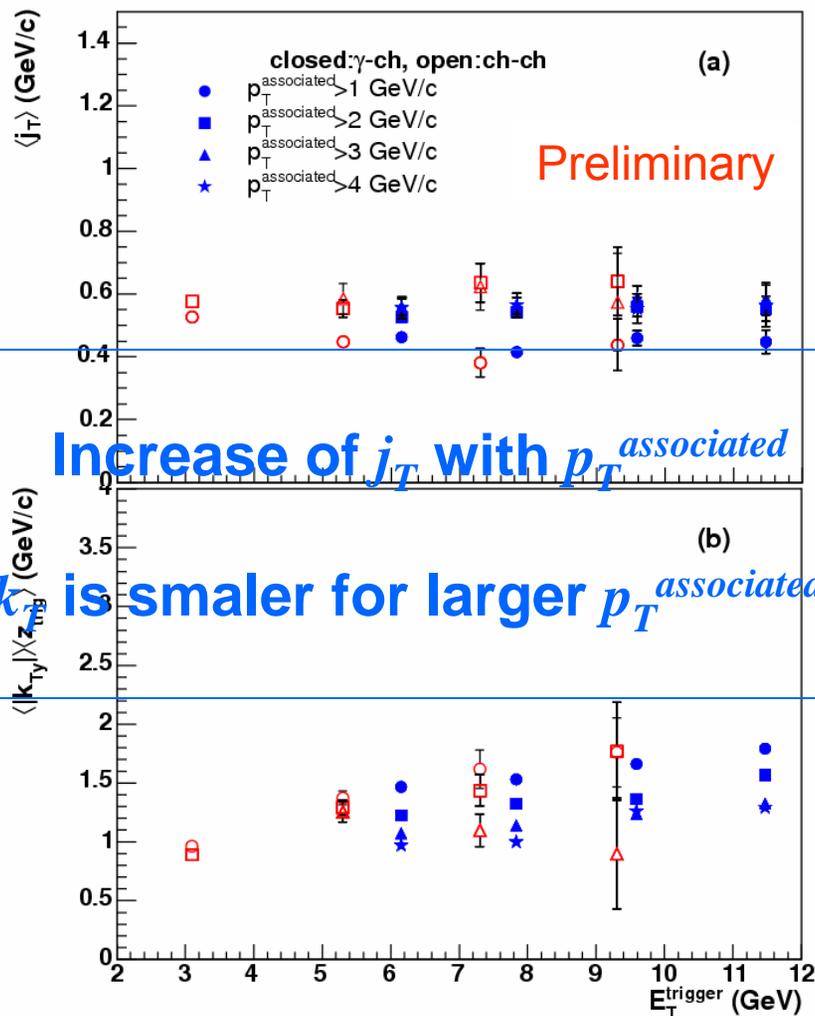
# Centrality dependence of $\sigma_N$ and $\sigma_F$

Preliminary

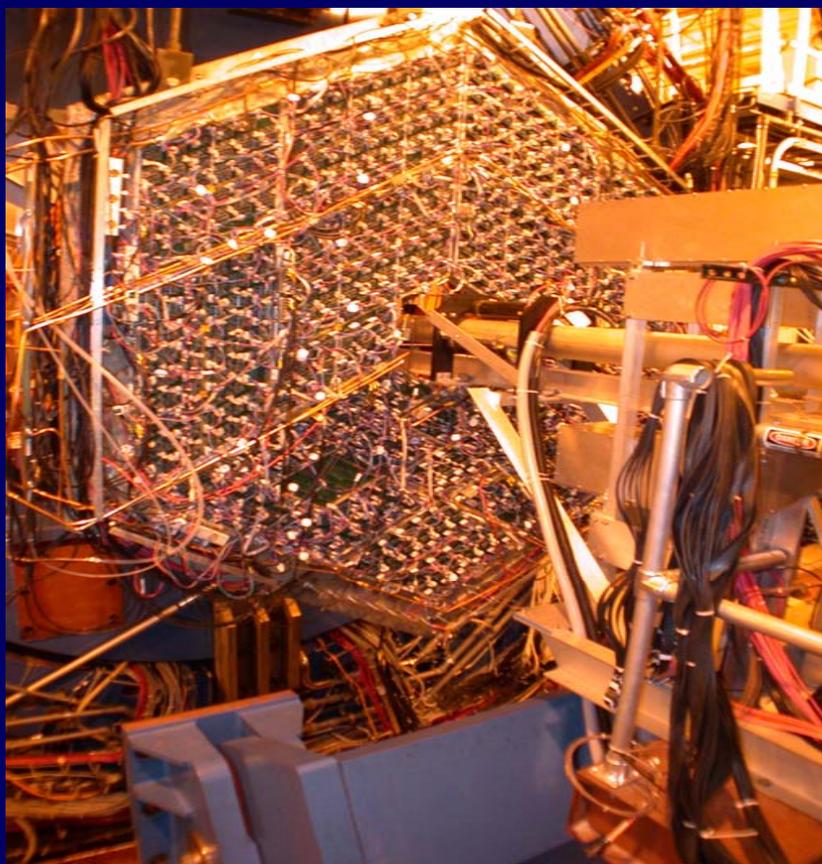


No strong centrality dependence of either near and far side widths within errors

# $\langle j_T \rangle$ and $\sqrt{\langle k_T^{rms} \rangle}$ dependences



# First Results from Photon Multiplicity Detector

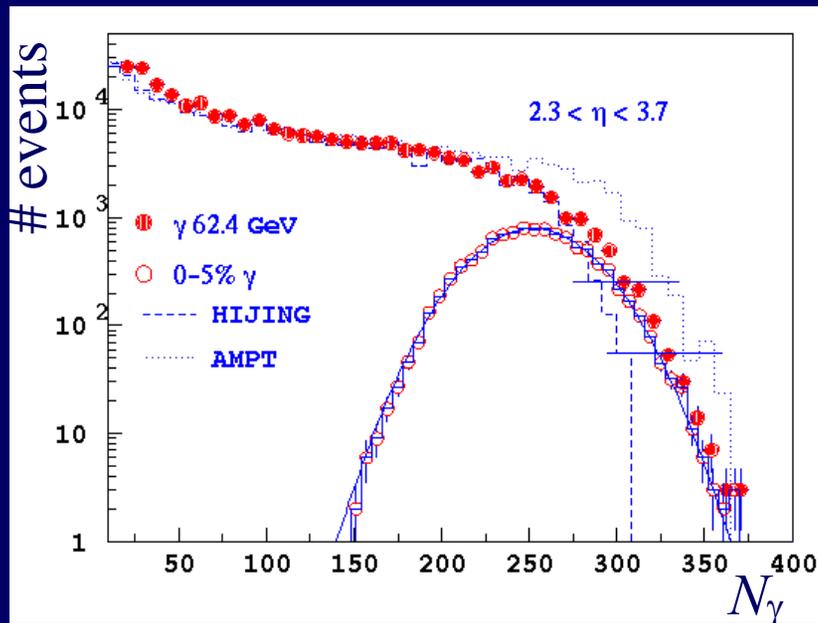


- Two planes CPV+Pre-shower
- Gas (Ar+CO<sub>2</sub>) detector of 82944 hexagonal cells
- Detector area: 4.2 m<sup>2</sup>
- Distance from vertex: 5.4 m
- $-3.8 < \eta < -2.3$  and full azimuthal coverage

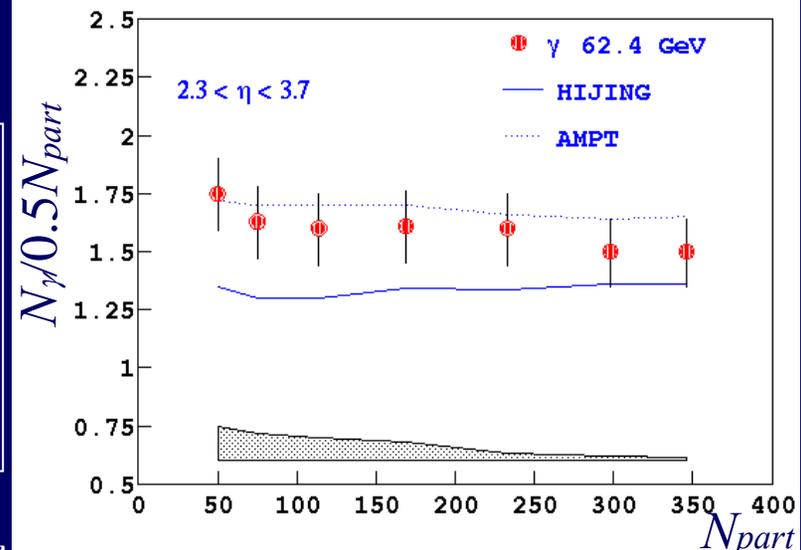
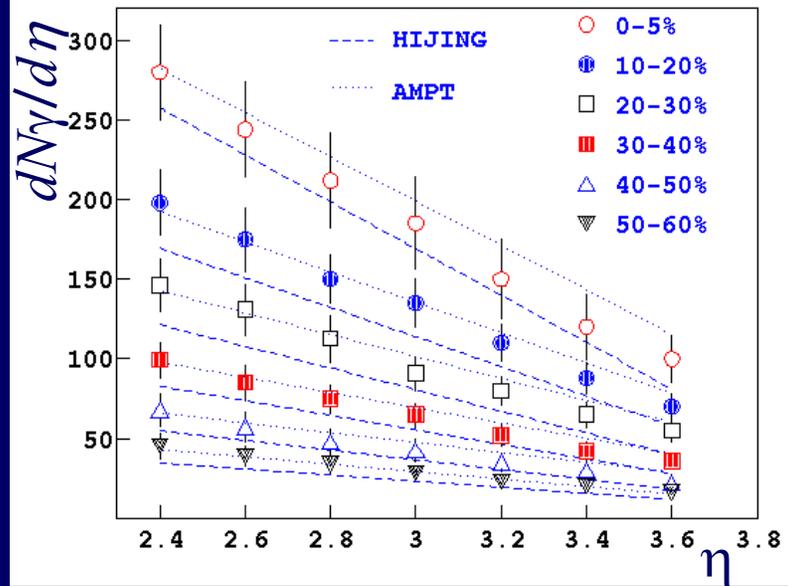
The CPV plane was not in present analysis

# Photon Multiplicity Distribution

Minimum Bias Au+Au @ 62.4 GeV

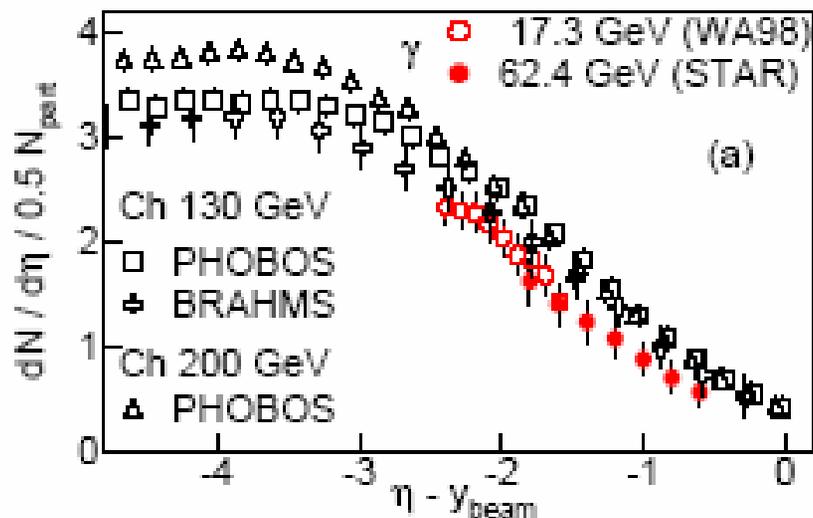


- $N_\gamma$  at forward rapidities scales with  $N_{part}$
- Better agreement to data of AMPT model than HIJING

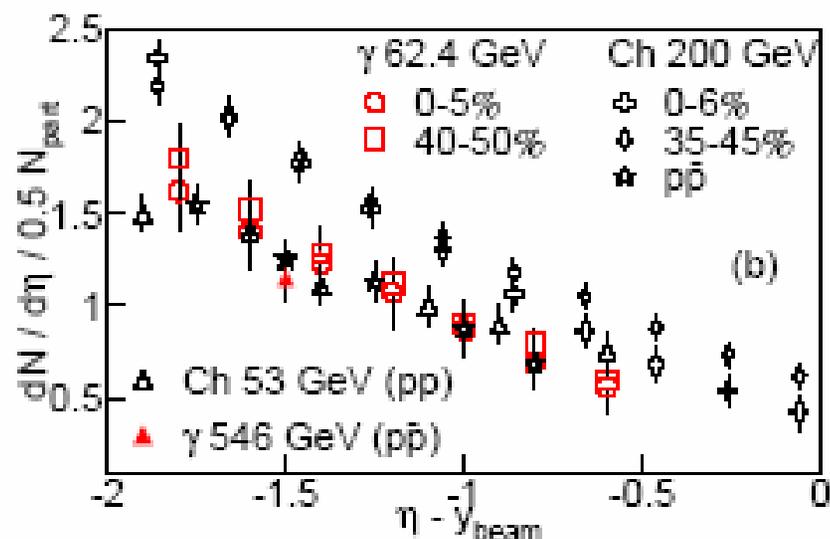


# Limiting Fragmentation trend

## Energy dependence



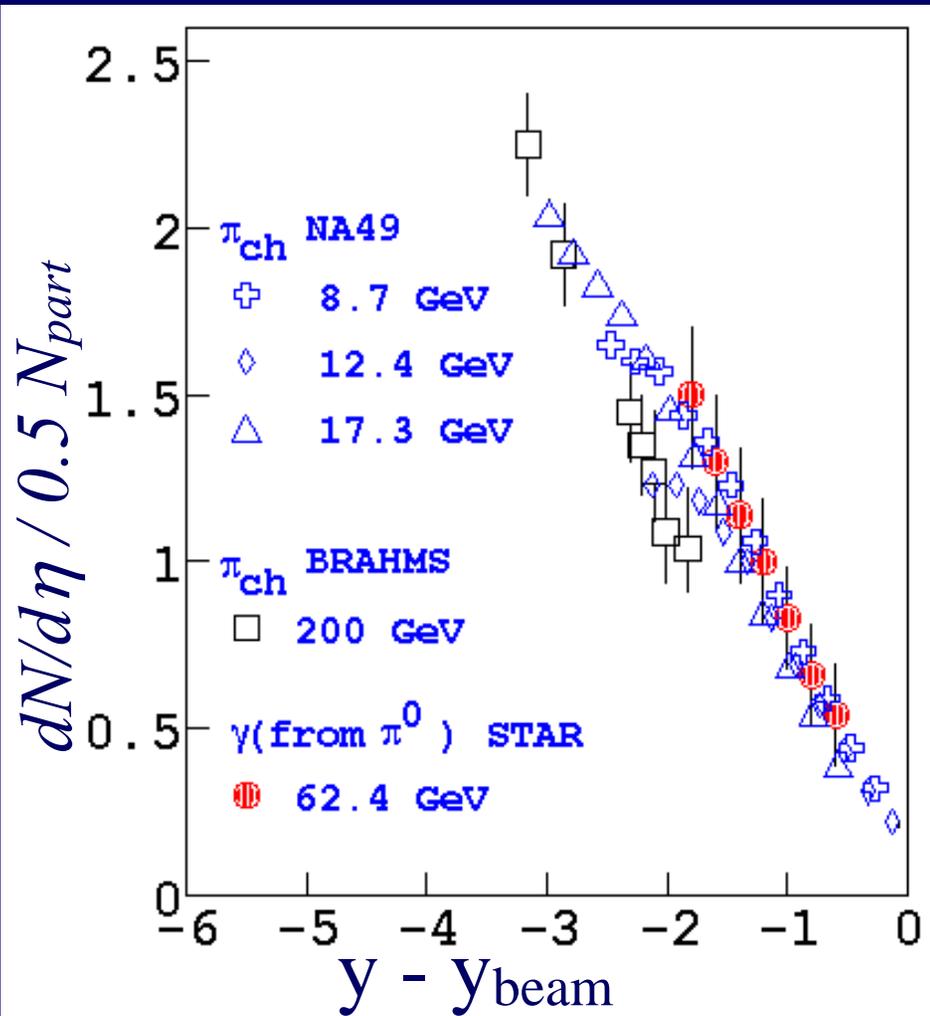
## Centrality dependence



- Photons undergo limiting fragmentation

- No centrality dependence of limiting fragmentation for photons, unlike for charged particles

# Limiting Fragmentation Scenario for $\pi$ and $\gamma$



- $\pi$  production follows the LF scenario
- Photon production is scaled down by about 7% to reflect the contribution from  $\pi^0$

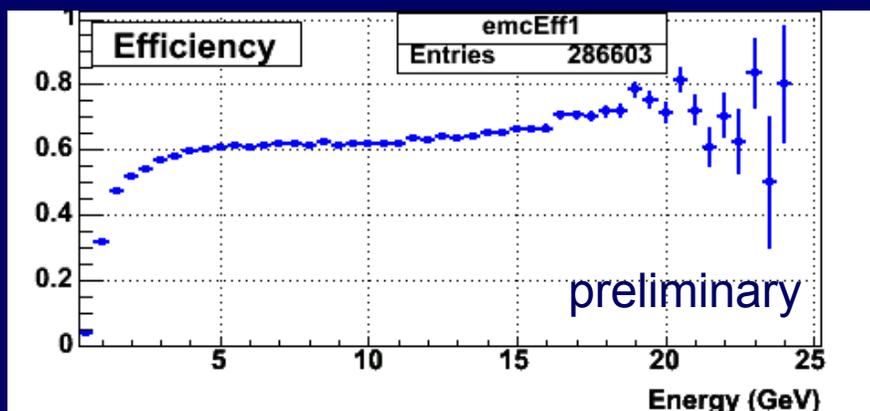
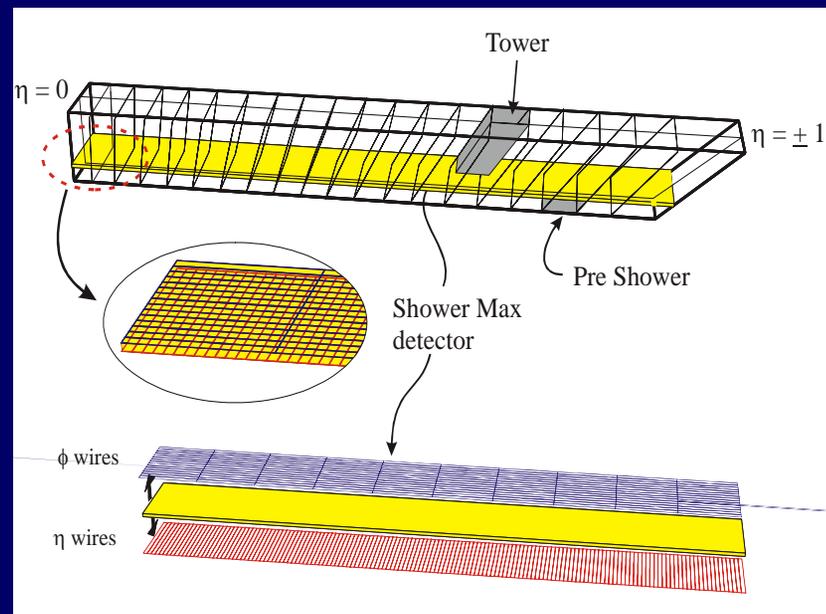
*nucl-ex/0502008 - Submitted to PRL*

# Direct Photon measurements for p+p and d+Au

- EMC measurements
  - Tower + SMD + pre-shower
- p+p and d+Au, towards Au+Au
- Direct photon spectra
  - Subtraction of background and contamination from inclusive spectra
    - $\pi^0$ ,  $\eta$  photon decays
    - other neutral contribution (n,  $K^0$ )
    - Contamination from charged hadrons
  - Acceptance/Efficiency corrections

# Direct Photon Analysis Status

- Systematic studies of BEMC/BSMD
- Shower properties studies on BSMD
  - Cluster size, energy
  - Development of cluster algorithm
- Acceptance/efficiency
  - d+Au  $\pi^0$  embedded data



## ■ EMC module

### □ Tower

- $(\Delta\eta, \Delta\phi) = (0.05, 0.05)$
- $\delta E/E \sim 16\%/\sqrt{E}(\text{GeV})$

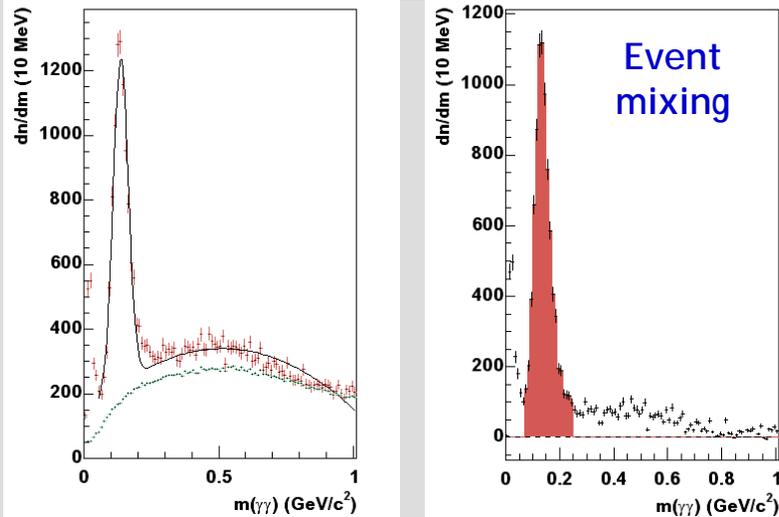
### □ BSMD

- $(\Delta\eta, \Delta\phi) \text{ strip} = (0.007, 0.007)$
- $\sigma_\eta = 2.4 \text{ mm} + 5.6 \text{ mm}/\sqrt{E}(\text{GeV})$
- $\sigma_\phi = 3.2 \text{ mm} + 5.8 \text{ mm}/\sqrt{E}(\text{GeV})$

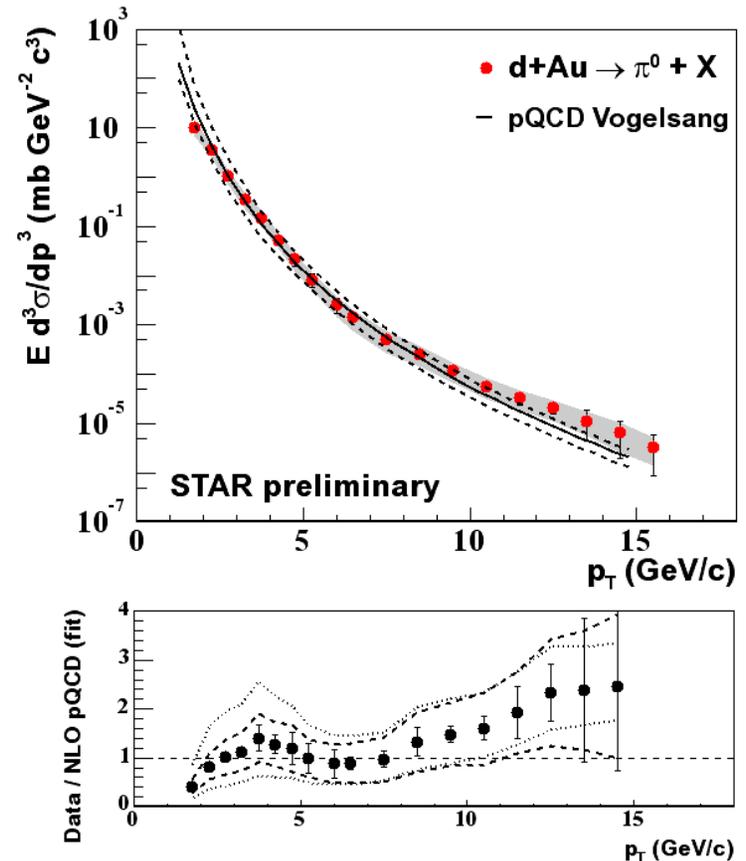
# $\pi^0$ spectrum for d+Au collisions

## From EMC measurements

Mass =  $135 \pm 1$  MeV  
Width =  $28 \pm 0.6$  MeV



*nucl-ex/0412045 – to be published in Eur. Phys. J. C.*

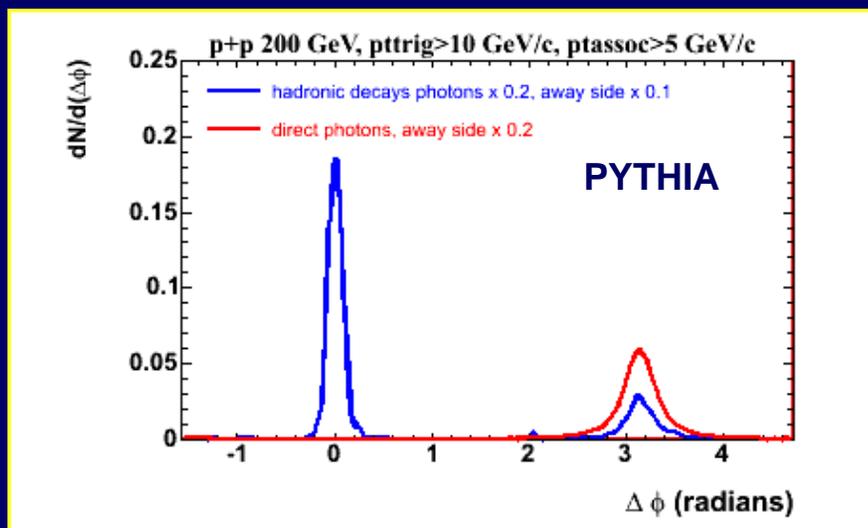


- Reasonable agreement with pQCD calculations within errors

# More to come...

## ■ Photon HBT (*Jack Sandweiss* talk)

- Analysis of  $q_{\text{invariant}}$  photon pairs distribution
- HBT peak produced by direct photons
- Investigation of spatial and temporal dimensions of QGP phase



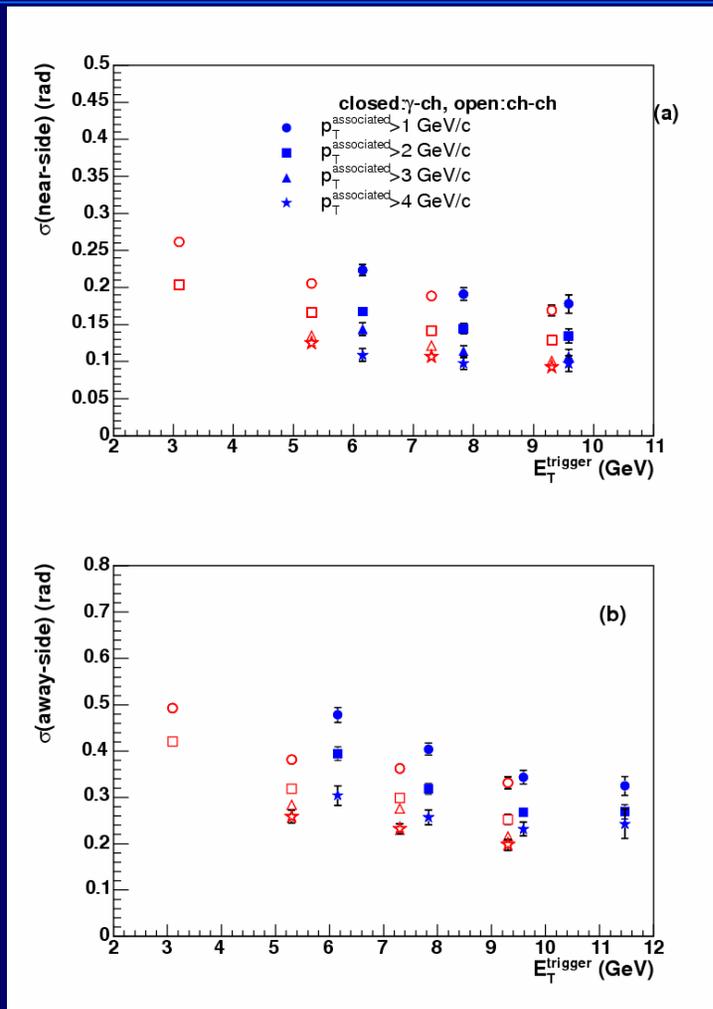
## ■ $\gamma$ -charged correlations in Au+Au

- Potential observation of away-side correlation from direct photons due to hadron ( $\pi^0$ ) suppression
- Investigation of parton energy loss

Back up slides

# Near and Far side widths

Decrease with increasing  $E_{\text{trig}}$



Decrease with increasing  $p_T^{\text{associated}}$

