Direct-Photon Production in PHENIX

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for the PHENIX Collaboration

Winter Workshop on Nuclear Dynamics 2006

What are Direct Photons?

- Definition:

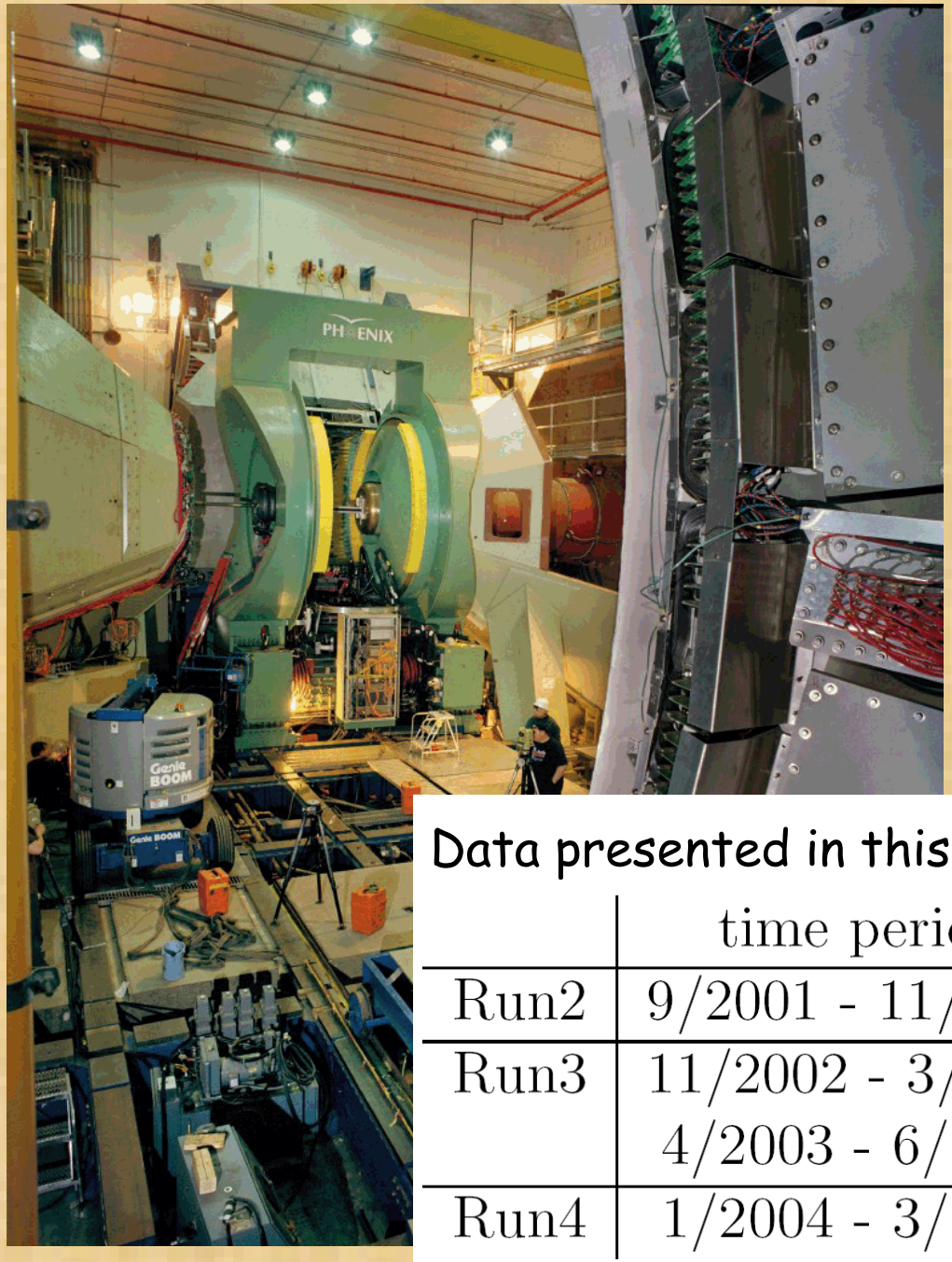
Photons that emerge directly from a particle collision

inclusive photons = decay photons + direct photons

- challenge: large background from hadronic decays

$$\pi^0 \rightarrow \gamma + \gamma$$
$$\eta \rightarrow \gamma + \gamma$$

- PHENIX measured direct-photons in various reaction systems



PHENIX Data

Data presented in this talk:

	time period	species	$\sqrt{s_{NN}}$ (GeV)
Run2	9/2001 - 11/2001	Au+Au	200
Run3	11/2002 - 3/2003	d+Au	200
	4/2003 - 6/2003	$p+p$	200
Run4	1/2004 - 3/2004	Au+Au	200

Direct Photons in p+p at $\sqrt{s}$ = 200 GeV

Why Direct Photons in p+p?

- p+p
  - test of pQCD
  - baseline for direct photons in A+A
  - constrain gluon distribution in proton (gluon contributes at LO)

Direct-Photon Production in p+p

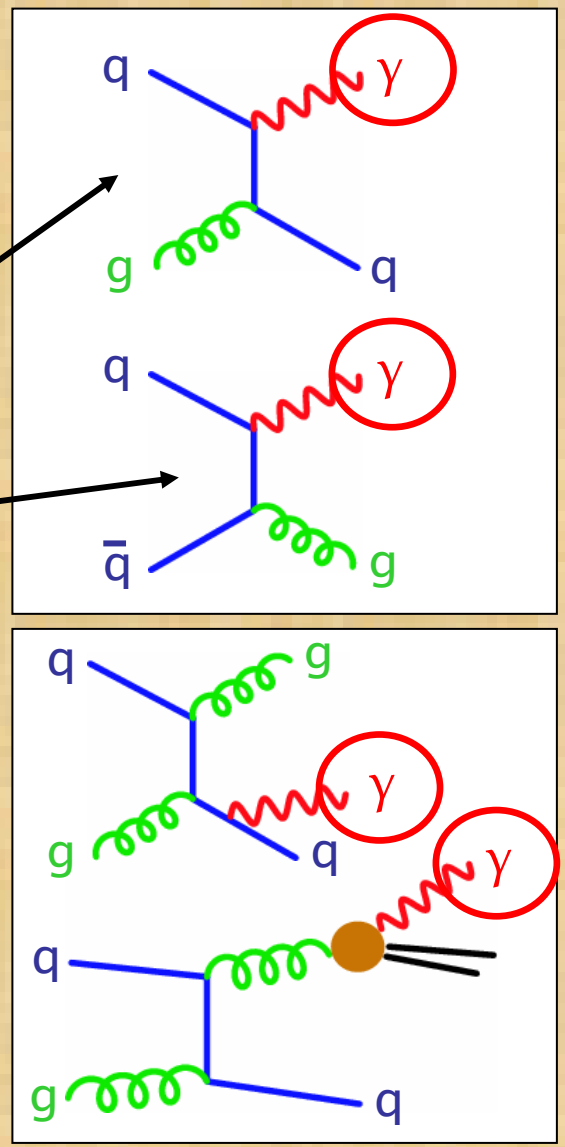
- produced in hard scatterings:
  - rates can be calculated in pQCD

prompt/pQCD photons

  - quark-gluon Compton scattering
  - quark-antiquark annihilation
  - Bremsstrahlung

direct component

fragmentation component

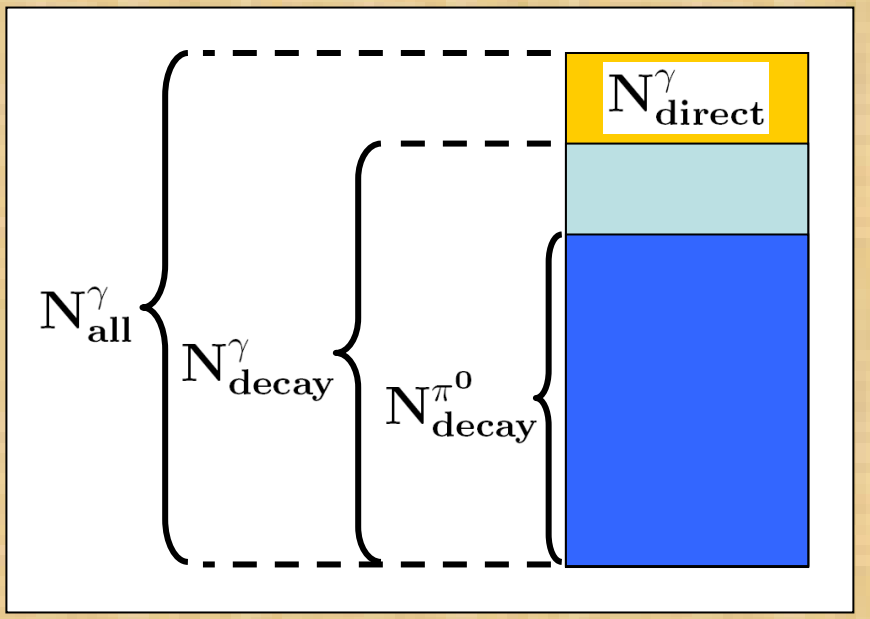


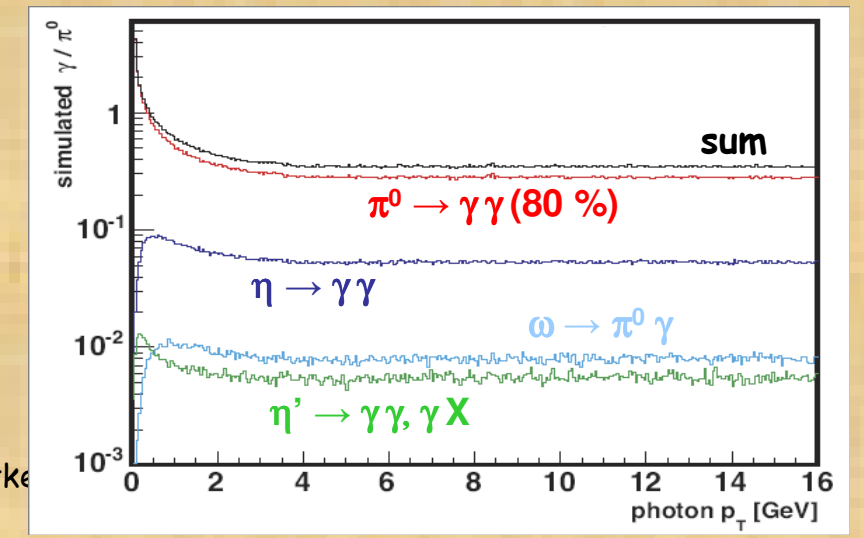
Analysis Techniques (I)

- Cocktail Method
  - start with inclusive photons

$$N^{\gamma}_{all} = N^{\gamma}_{decay} + N^{\gamma}_{direct}$$

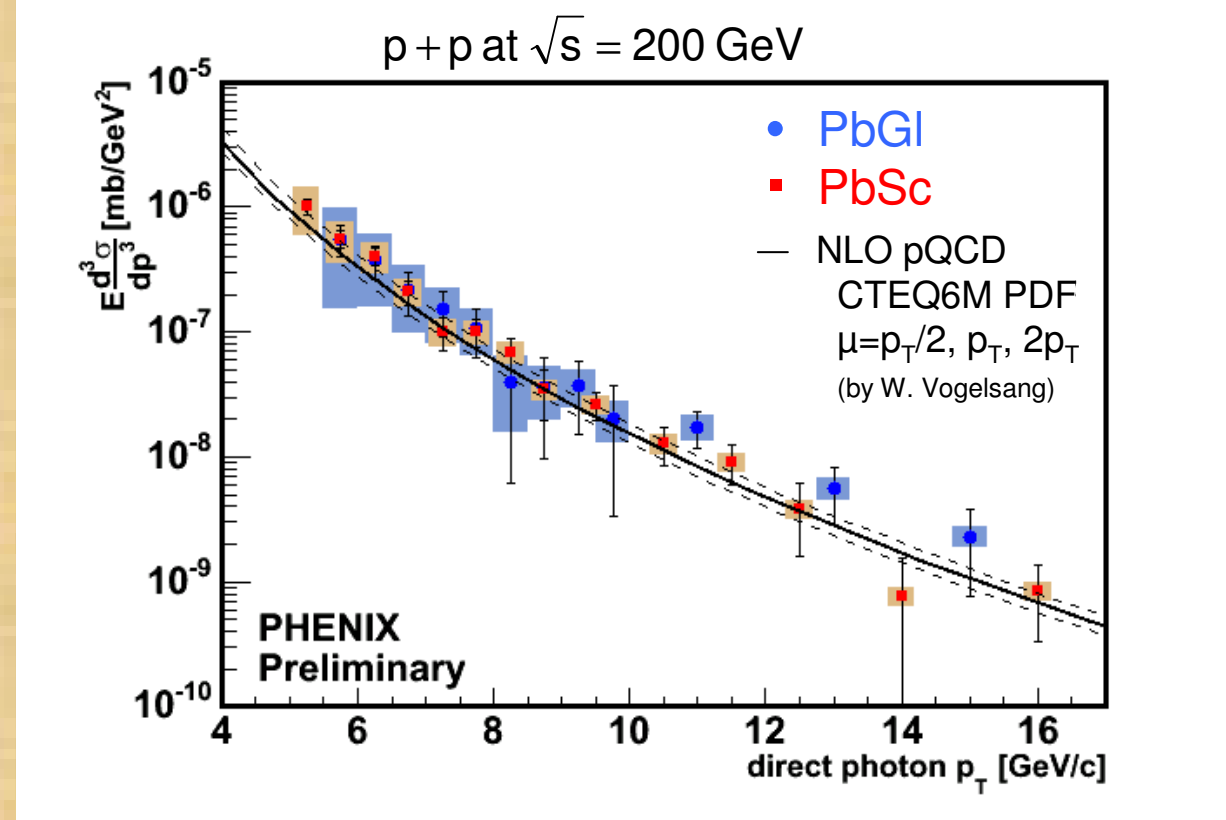
  - subtract photons from hadronic decays
    - main contribution from π^0 decays ($\pi^0 \rightarrow \gamma\gamma$)
    - spectrum of decay photons can be simulated
  - signal/background ratio very small





Results in p+p (I)

- two independent analyses
- different detectors
- measured spectra agree with each other



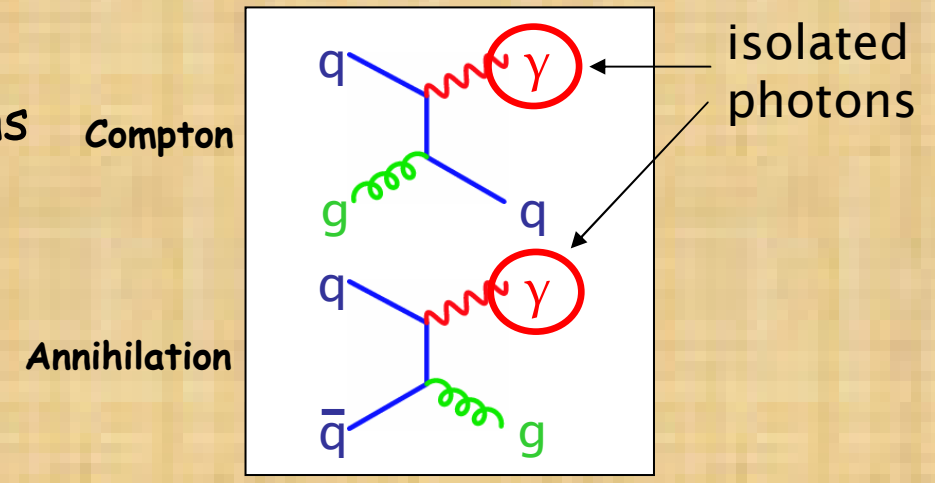
→ good agreement with NLO pQCD

→ important baseline for Au+Au measuement

Analysis Techniques (II)

Isolation Method

- What fraction of direct photons is isolated?



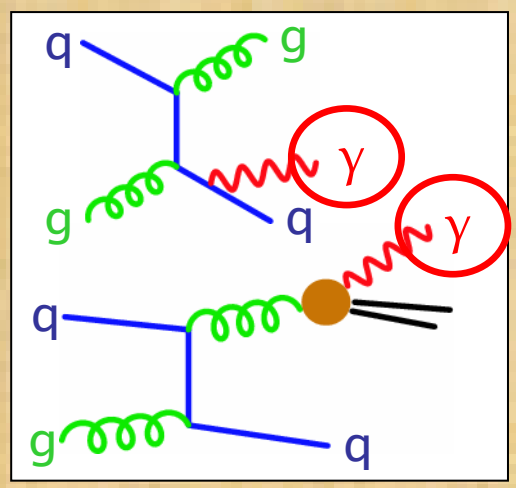
Analysis Techniques (II)

Isolation Method

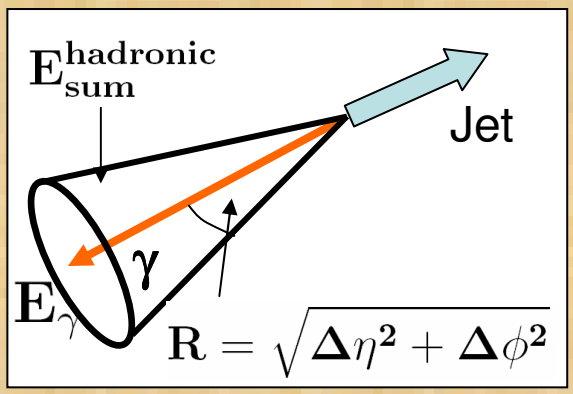
- What fraction of direct photons is isolated?

$$E_{sum}^{hadronic}(R < 0.5\ rad) < 0.1 \times E_{\gamma}$$

  - isolation cut should remove Bremsstrahlung

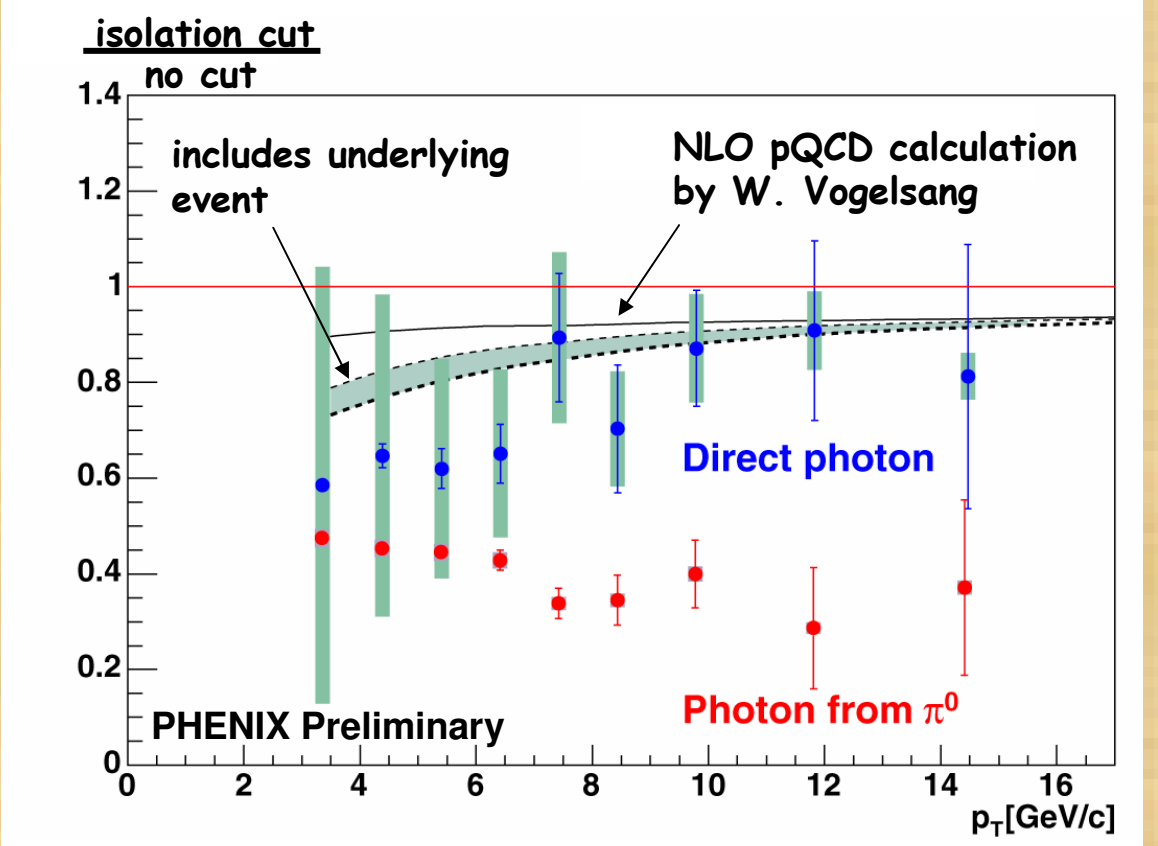


- difficult to estimate efficiency of isolation cut:
  - underlying event (soft physics)
  - limited acceptance



Results in p+p (II)

- isolation of direct photons:
  - direct photon sample with cocktail method
  - effect on π^0 decay photons



➡ data is better described by pQCD + underlying event

Direct Photons in d+Au at $\sqrt{s}$ = 200 GeV

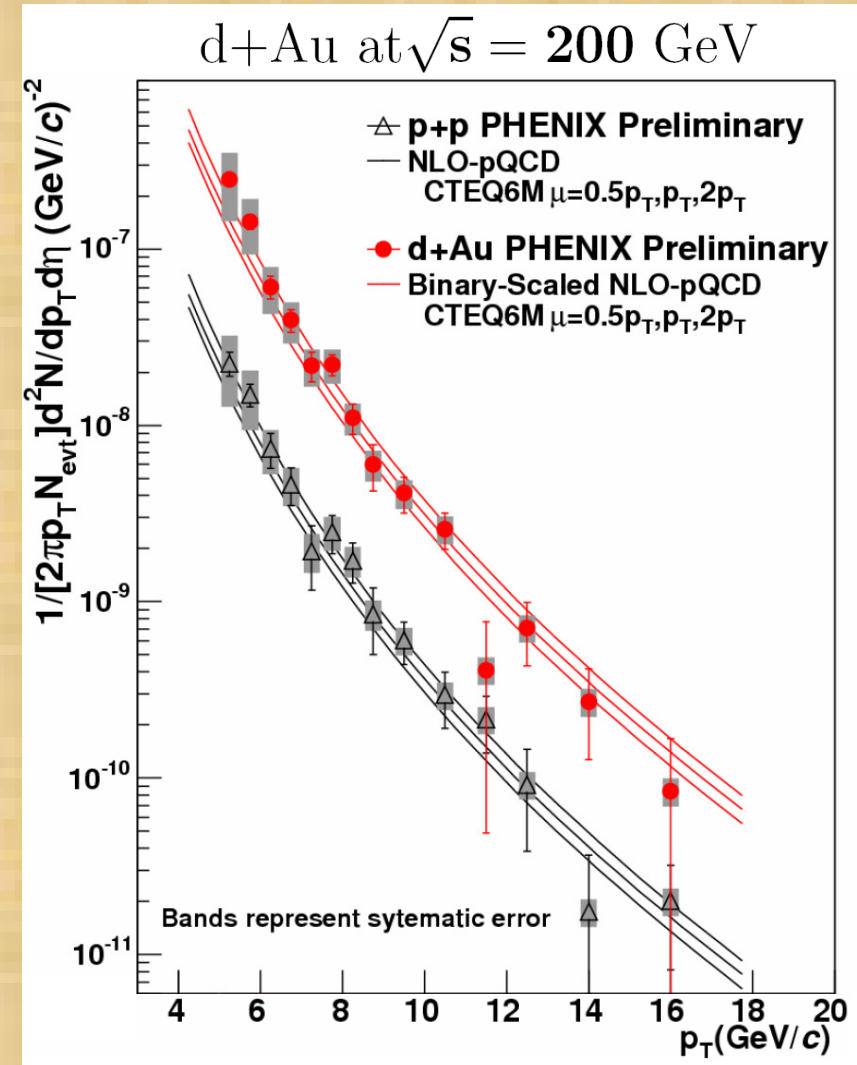
Why Direct Photons in d+Au?

- p+p
  - test of pQCD
  - baseline for direct photons in A+A
  - constrain gluon distribution in proton (gluon contributes at LO)

done

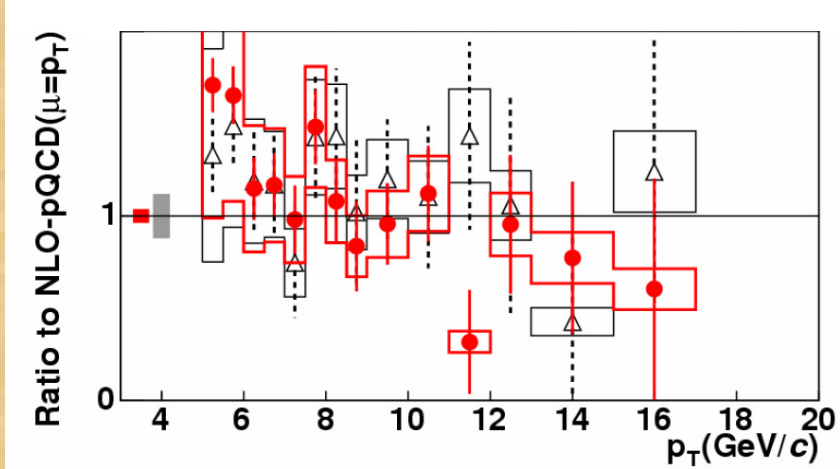
- d+Au
  - study cold nuclear matter effects
    - k_T broadening (Cronin)
    - nuclear shadowing

Results in d+Au



$$R_{AB} = \frac{dN/dp_T|_{A+B}}{\langle T_{AB}\rangle \times d\sigma/dp_T|_{p+p}}$$

$$\langle T_{AB}\rangle = \frac{\langle N_{coll}\rangle}{\sigma_{NN}}$$



- in good agreement with binary scaled pQCD
- no indication of cold nuclear matter effects ($R_{dA} \approx 1$)

Direct Photons in Au+Au at $\sqrt{s}$ = 200 GeV

Why Direct Photons in Au+Au?

- p+p
  - test of pQCD
  - baseline for direct photons in A+A
  - constrain gluon distribution in proton (gluon contributes at LO)

done

- d+Au
  - study cold nuclear matter effects
    - k_T broadening (Cronin)
    - nuclear shadowing

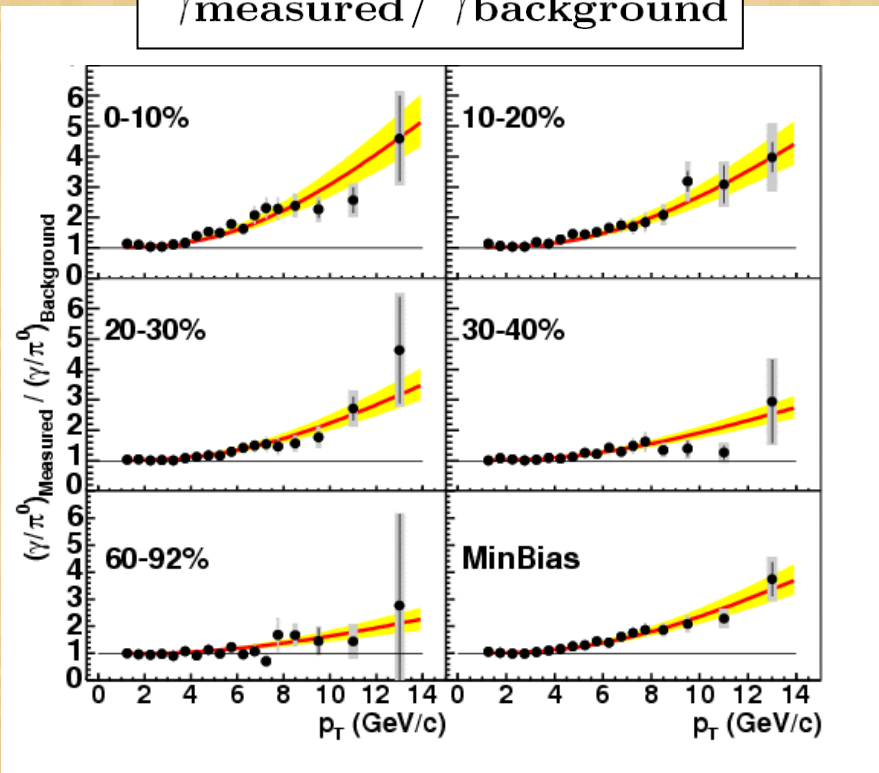
done

- Au+Au
  - photons do not interact strongly with medium
  - hard photons
    - test of binary scaling (N_{coll} scaling)
    - understand high-p_T hadron suppression
  - thermal photons
    - constrain temperature of the collision system
    - QGP signature

Hard-Scattering in Au+Au

- direct photons produced in early hard scatterings at high-p_T
  - signal should scale with number of binary collisions

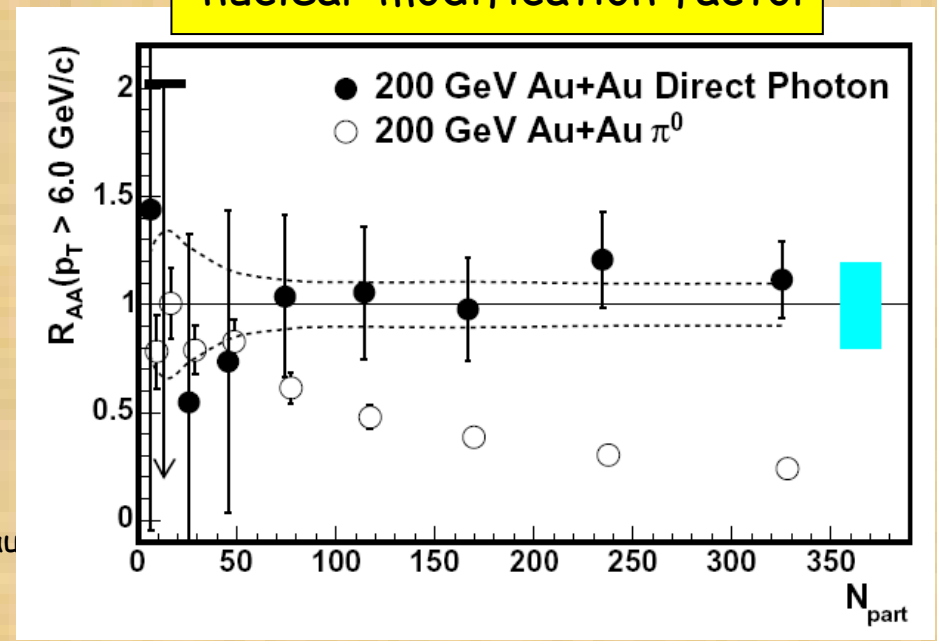
$\gamma_{\text{measured}} / \gamma_{\text{background}}$



PRL 94, 232301 (2005) (Run 2)

binary scaling holds for all centralities

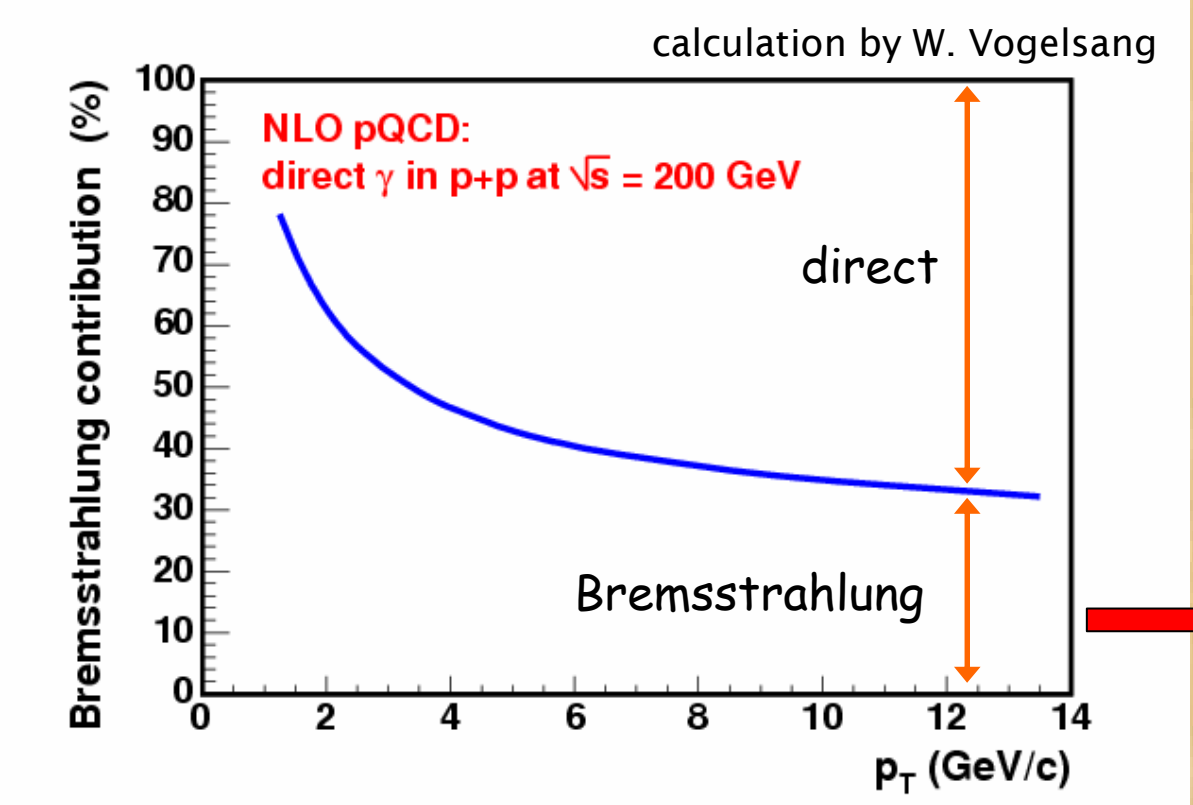
nuclear modification factor



π^0 suppression caused by parton energy loss in the medium

Contribution of Bremsstrahlung

- maybe it is not that simple:
  - is Bremsstrahlung production modified by medium?

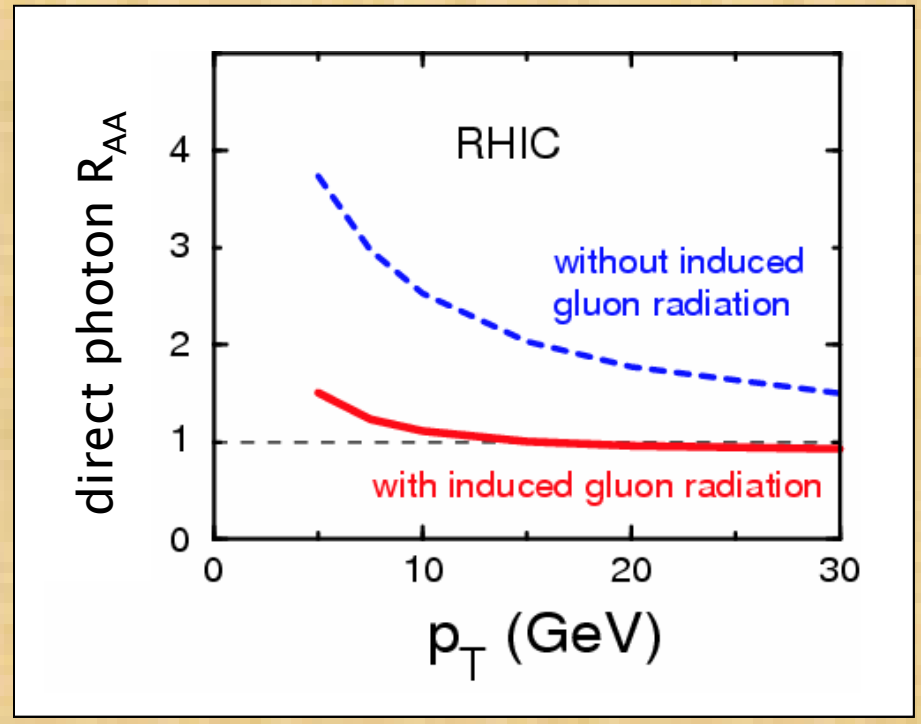


large contribution from Bremsstrahlung

Modification of Bremsstrahlung?

- is Bremsstrahlung suppressed by parton energy loss in the medium (induced gluon radiation)?
- enhancement of direct-photon production via medium induced Bremsstrahlung?
- possible net effect: $R_{AA} \approx 1$
- issue not solved yet!

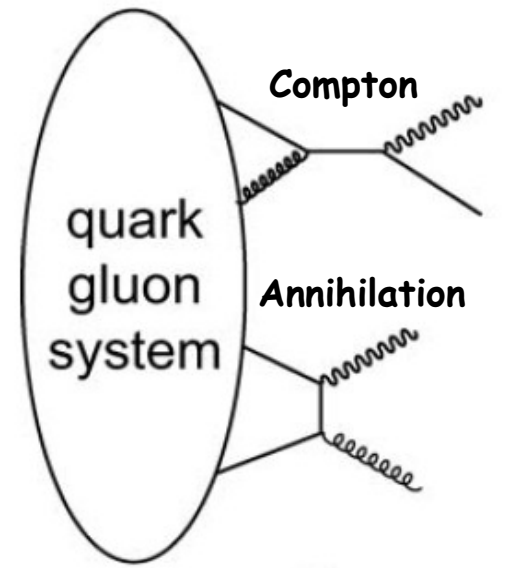
Jeon, Jalilian-Marian, Sarcevic, Zakharov, hep-ph/0405201
Zakharov, A715, 0405(2003)

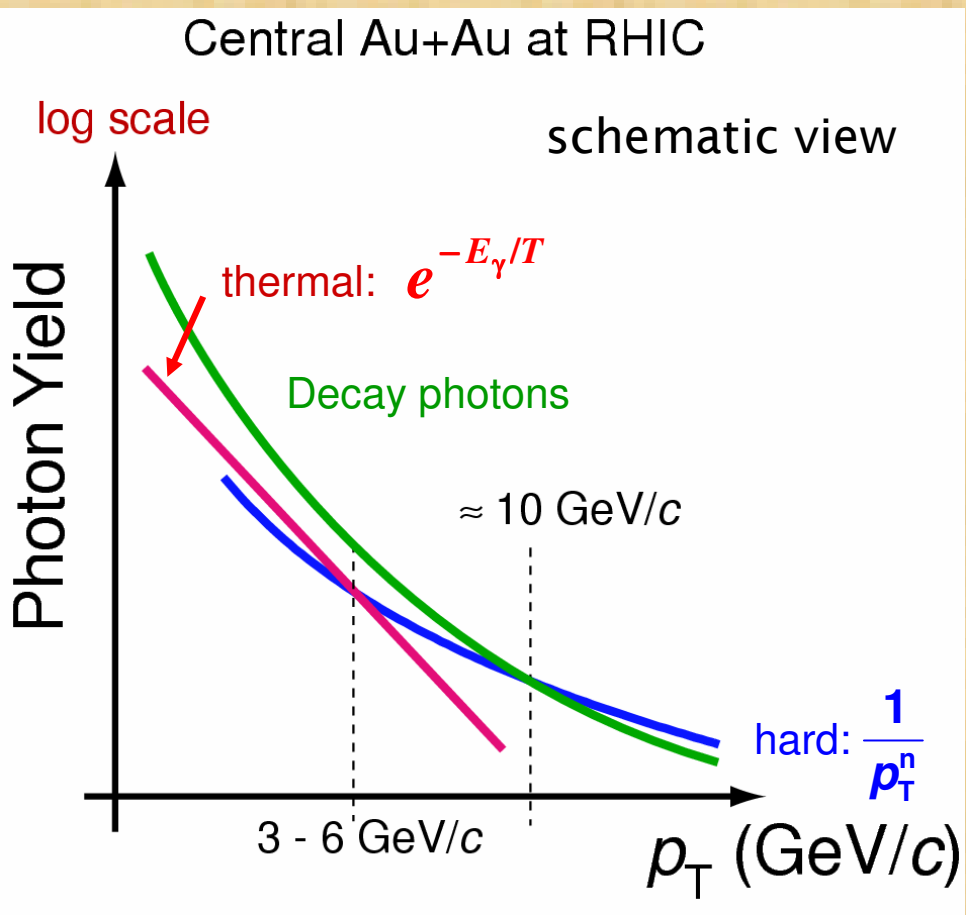


Thermal Photons in Au+Au

Photon Spectrum in Au+Au

- hot and dense medium in thermal equilibrium

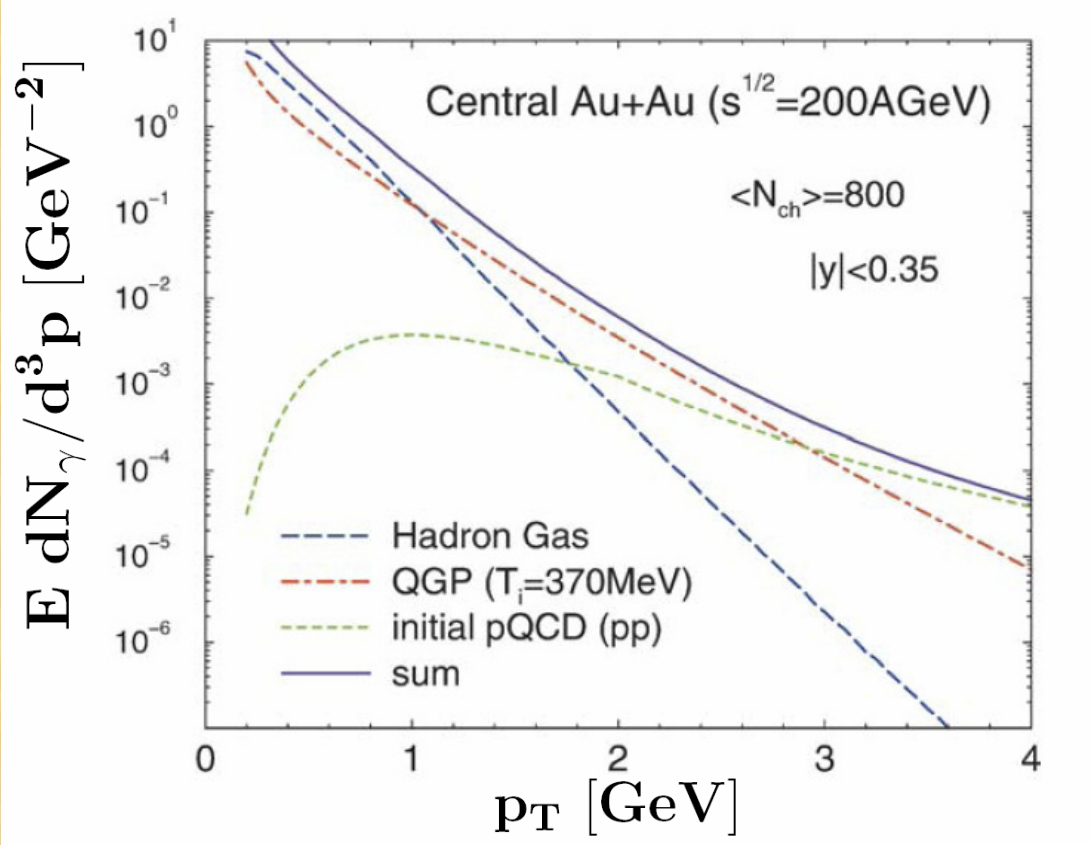




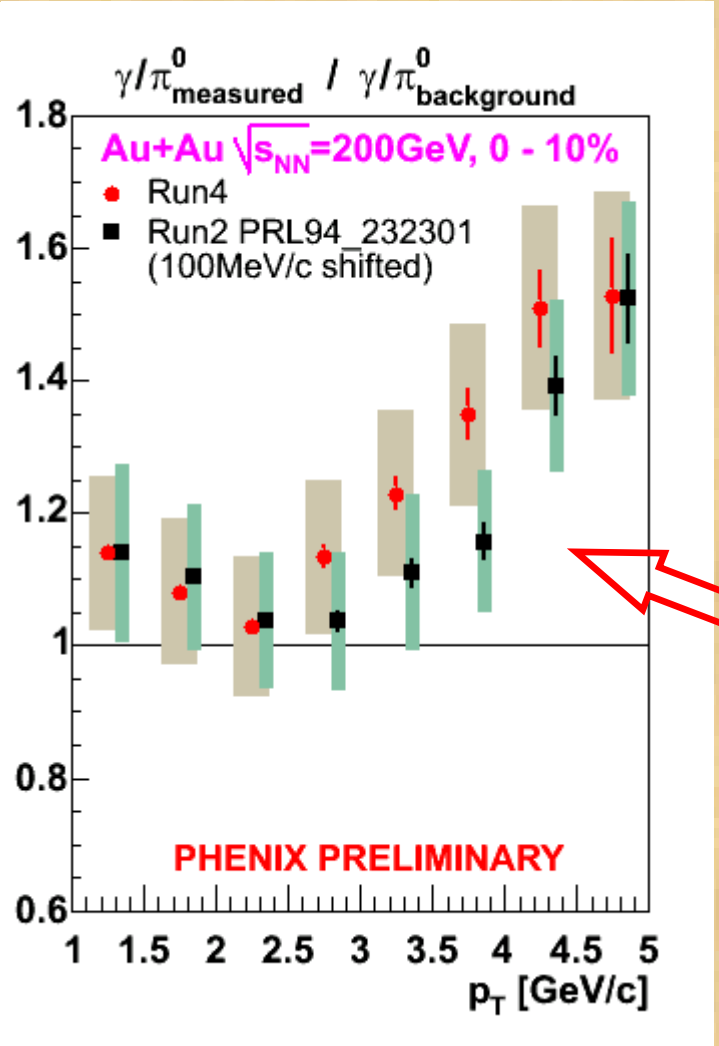
Realistic Calculation

- thermal photons from QGP dominant source in p_T range ≈1-3 GeV/c
- potential signature for QGP

Turbide, Rapp, Gale, Phys. Rev. C 69 (014902), 2004



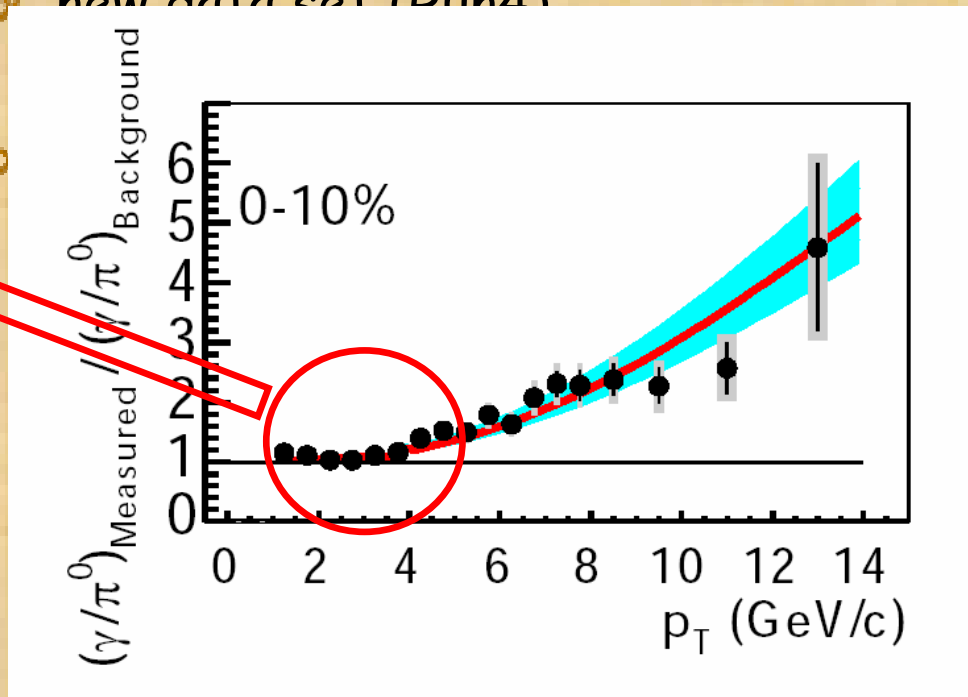
Thermal Signal?



- published spectrum

PRL 94, 232301 (2005) (Run 2)

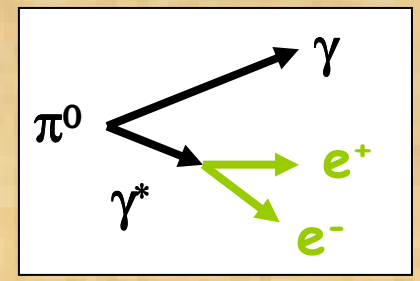
- new data set (Run4)

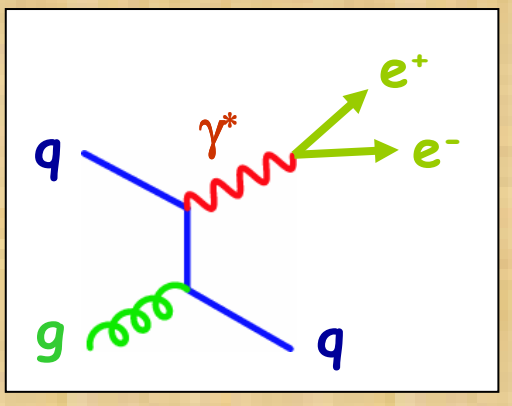


Internal Conversion (I)

A New Approach:

- direct photons via internal conversion
  - any source of real photons can emit virtual photons with very low mass (e.g. π^0 Dalitz)
  - virtual photons can subsequently decay into e^+e^- pairs
  - same is true for direct-photon production





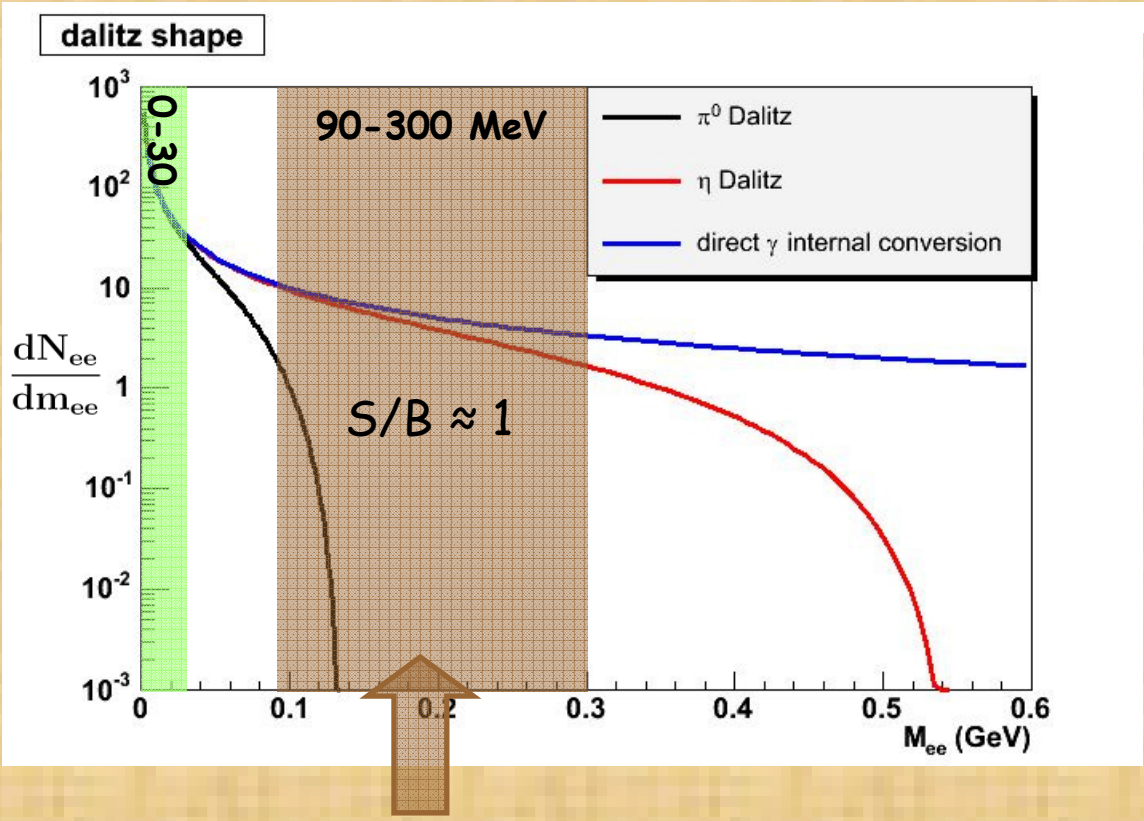
Internal Conversion (II)

- mass distribution of Dalitz pairs is given by Kroll-Wada Formula

$$\frac{1}{N_\gamma}\frac{dN_{ee}}{dm_{ee}} = \underbrace{\frac{2\alpha}{3\pi}\sqrt{1-\frac{4m_e^2}{m_{ee}^2}}\left(1+\frac{2m_e^2}{m_{ee}^2}\right)\frac{1}{m_{ee}}}_{\text{QED}}\underbrace{\cancel{\left(1-\frac{m_{ee}^2}{M^2}\right)^3}}_{\text{phase space}}\underbrace{\cancel{|F(m_{ee}^2)|^2}}_{\text{form factor}}$$

at very low mass ($m_{ee} \approx 0$) mass distribution process independent (only governed by QED part)

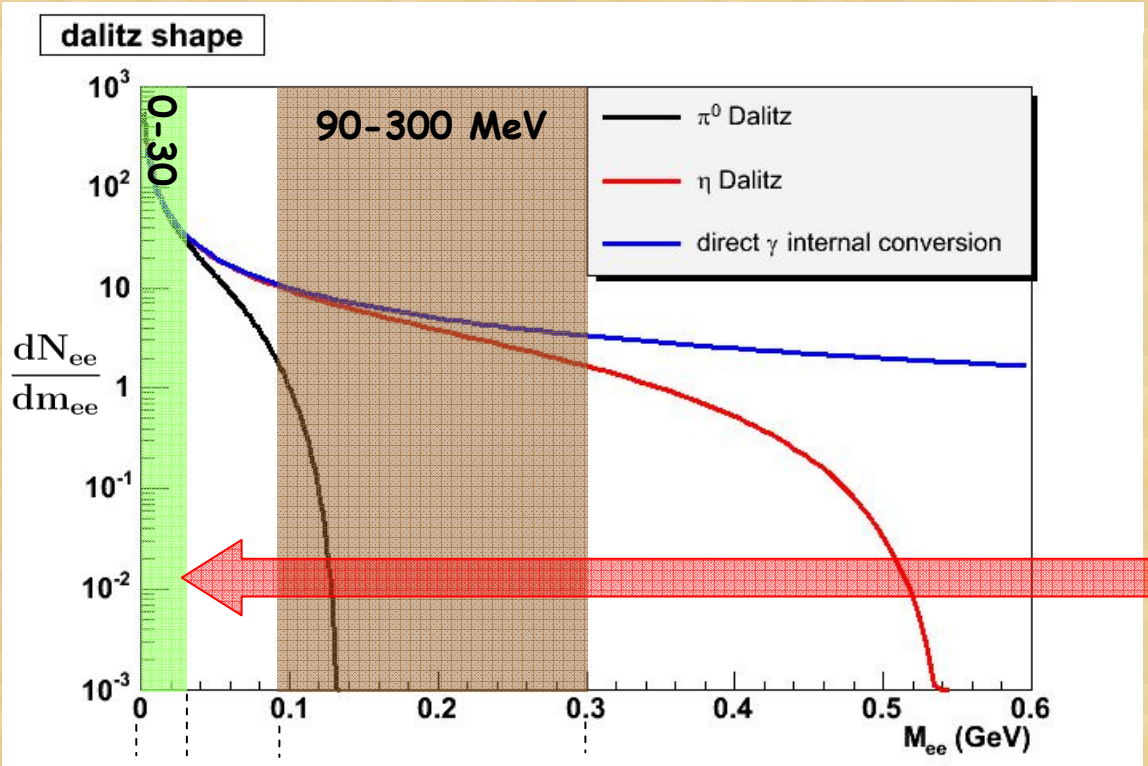
Internal Conversion (III)



π^0 Dalitz pairs highly suppressed in this mass range

- direct photons:
  - hadronic form factor becomes unity
  - no phase space limitation for photons in chosen mass range

The Method



$N^{0-30}_{\gamma^*_{all}}$ $N^{90-300}_{\gamma^*_{all}}$

÷

WWN R_{data}

- Measure ratio:

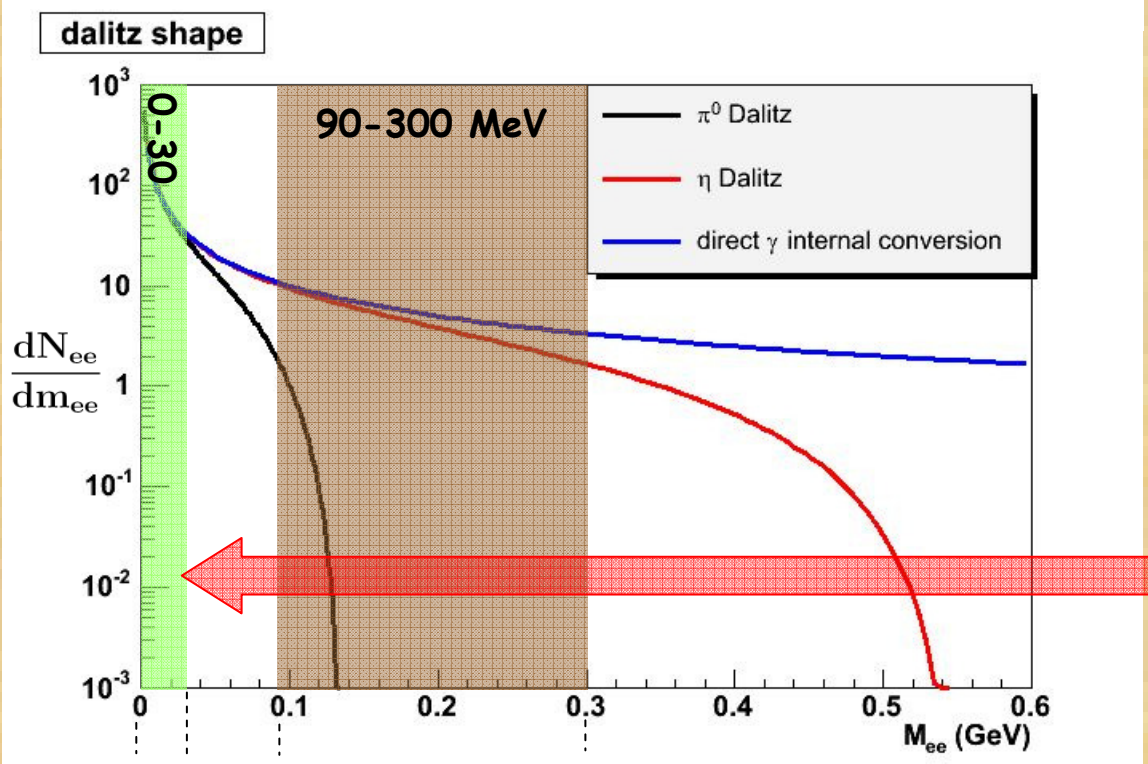
$$R_{data} = \frac{N^{90-300}_{\gamma^*_{all}}}{N^{0-30}_{\gamma^*_{all}}}$$

- Calculate:

$$\frac{N^{0-30}_{\gamma^*_{direct}}}{N^{0-30}_{\gamma^*_{all}}} = \frac{R_{data} - R_{hadron}}{R_{direct} - R_{hadron}}$$

from Kroll-Wada formula

The Method



$N^{0-30}_{\gamma^*_{all}}$ $N^{90-300}_{\gamma^*_{all}}$

÷

WWN R_{data}

- Measure ratio:

$$R_{data} = \frac{N^{90-300}_{\gamma^*_{all}}}{N^{0-30}_{\gamma^*_{all}}}$$

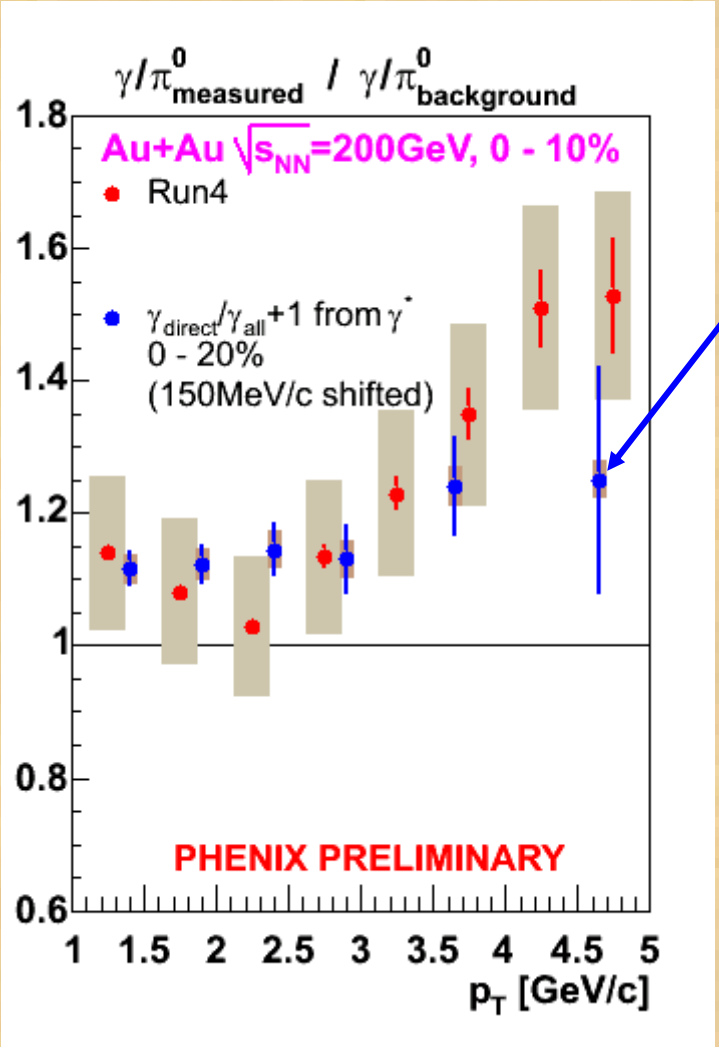
- Calculate:

$$\frac{N^{0-30}_{\gamma^*_{direct}}}{N^{0-30}_{\gamma^*_{all}}} = \frac{R_{data} - R_{hadron}}{R_{direct} - R_{hadron}}$$

$$\frac{N^{0-30}_{\gamma^*_{direct}}}{N^{0-30}_{\gamma^*_{all}}} = \frac{\gamma^*_{direct}}{\gamma^*_{all}} = \frac{\gamma_{direct}}{\gamma_{all}}$$

measured with EMCal

Comparison to Conventional Result



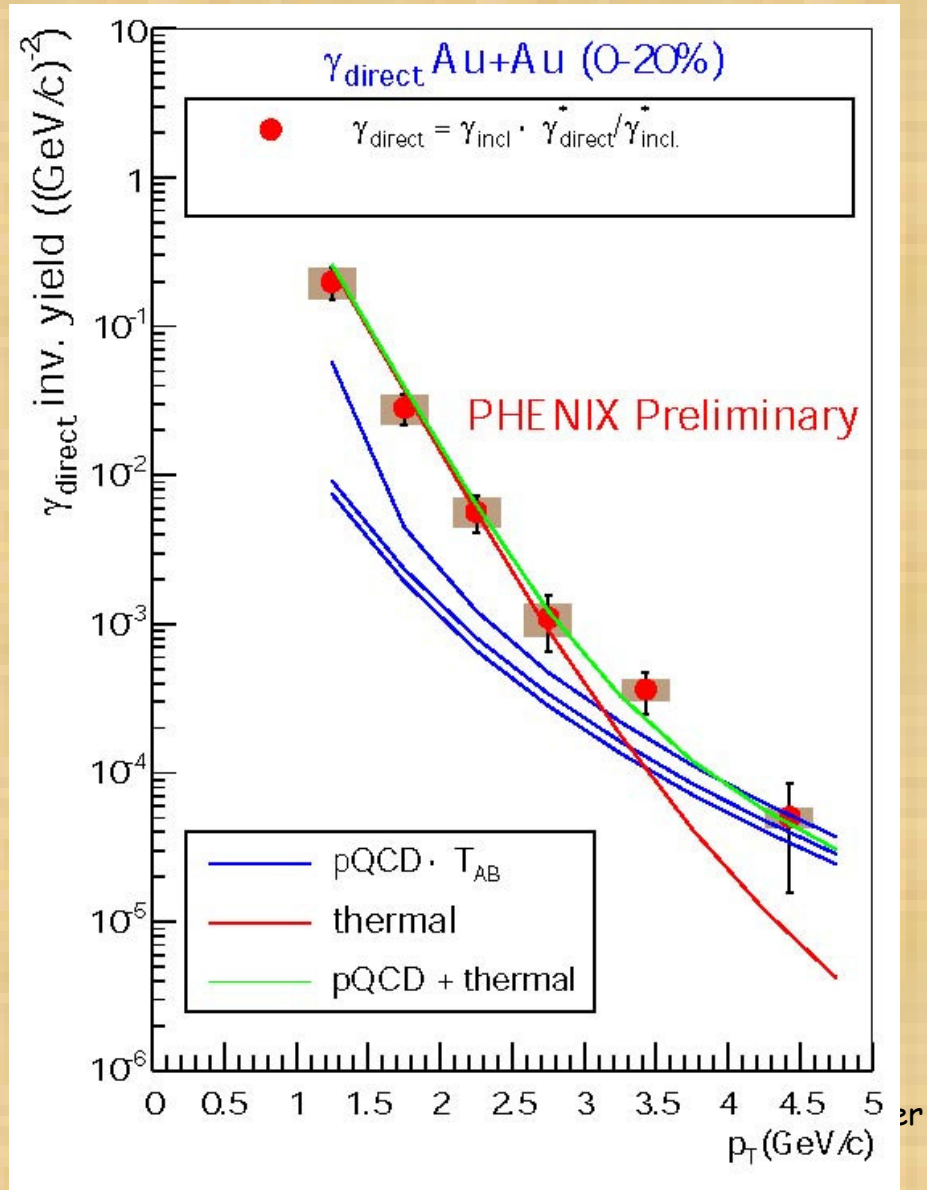
$$\frac{\gamma_{direct}}{\gamma_{all}} = \frac{\gamma^*_{direct}}{\gamma^*_{all}} = \frac{R_{data} - R_{hadron}}{R_{direct} - R_{hadron}}$$

(+1)

- significant signal below p_T = 3 GeV/c
- systematic errors:
  - ~20% measured η/π^0
  - ~10% inclusive photons
  - ~5% acceptance

~25 % total systematic error

The Direct-Photon Spectrum



- NLO pQCD

  Phys. Rev. D48, 3136 (1993)

  L.E. Gordon, W. Vogelsang

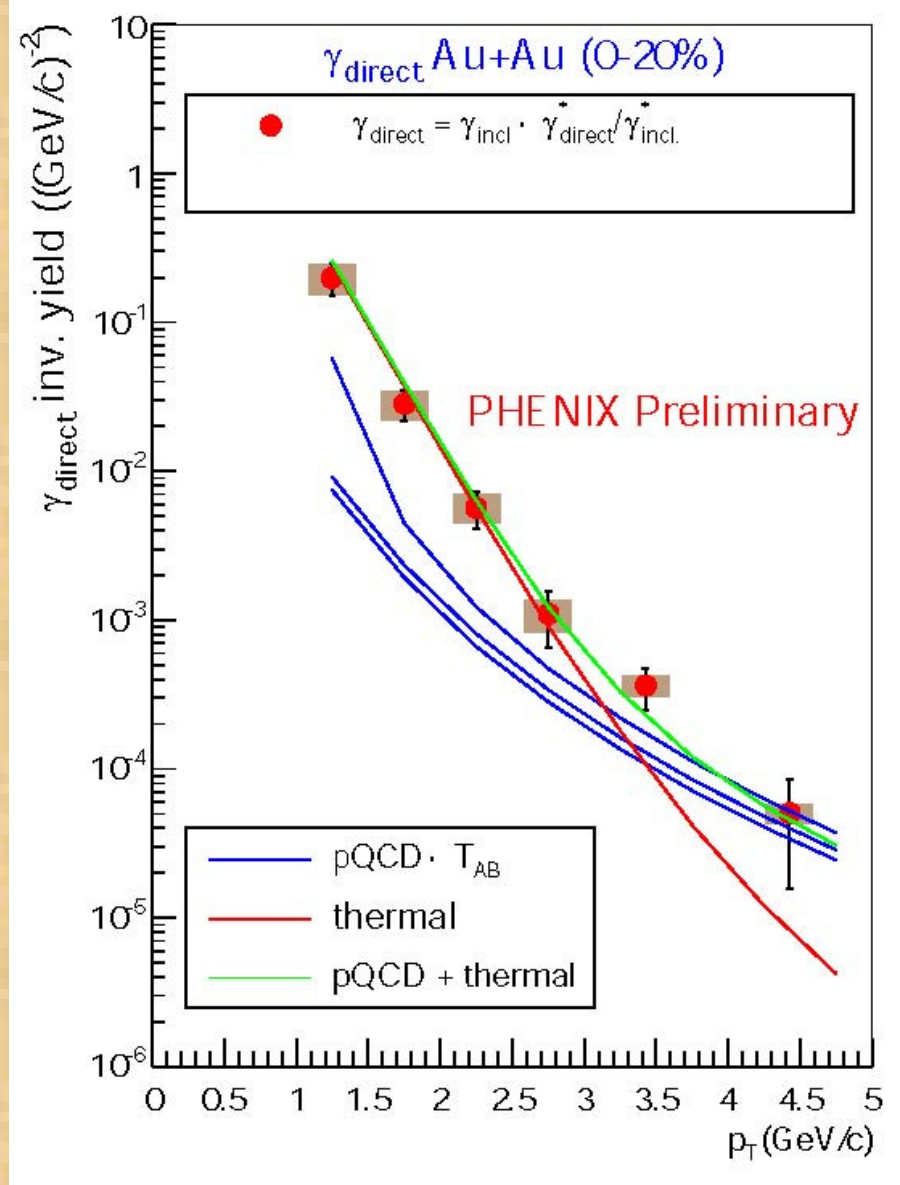
- Thermal Model
  - 2+1 hydro
  - T_0^{ave}=360 MeV(T_0^{max}=570 MeV)
  - τ_0=0.15 fm/c

  nucl-th/0503054

  D. d'Enterria, D. Perresounko

- The data are consistent with thermal + pQCD
  (only one possible interpretation!)

The Direct-Photon Spectrum



- Signal of thermal origin?
  - analysis of p+p and d+Au using the same technique is needed
  - if excess in Au+Au is of thermal origin the reference will show a much smaller effect

Summary

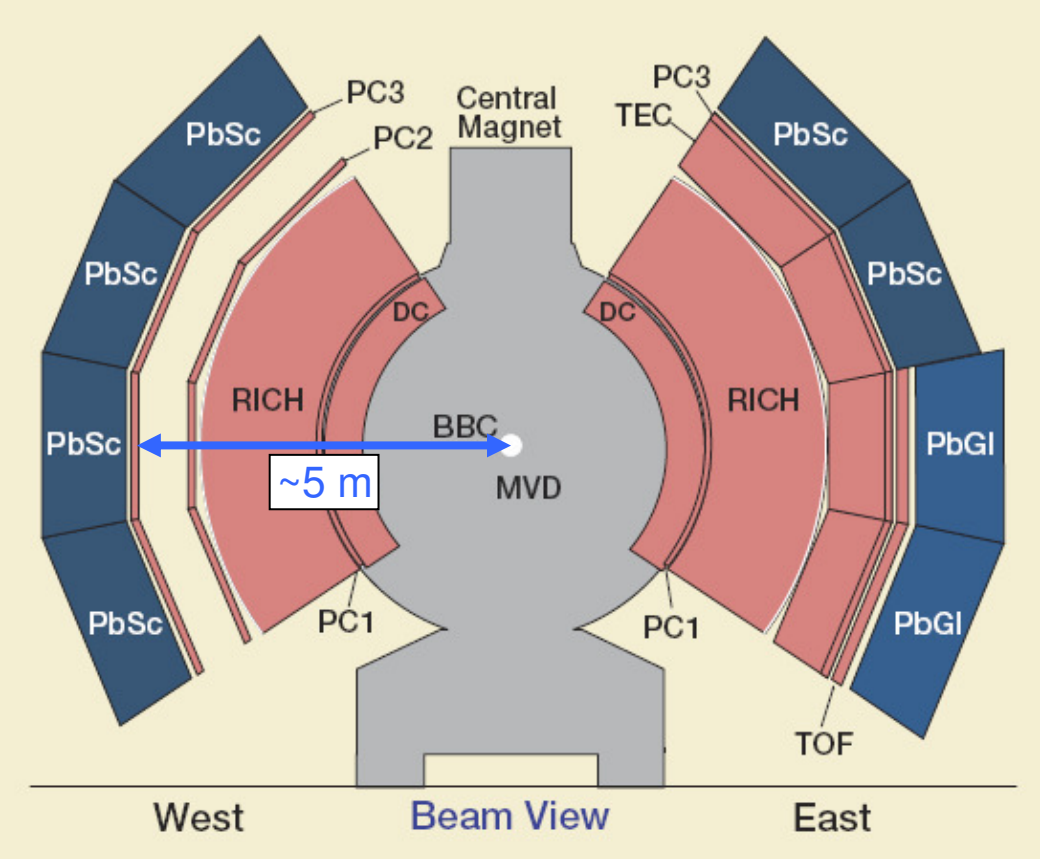
- p+p
  - direct photons show good agreement with NLO pQCD
  - isolated signal better described by pQCD + underlying event
- d+Au
  - good agreement with scaled NLO pQCD
  - no indication of cold nuclear matter effects
- Au+Au
  - hard scattering contribution (p_T>4 GeV/c) follows binary scaling for all centralities
  - significant signal obtained at low p_T (<4 GeV/c) using internal conversion
    - spectrum agrees with NLO pQCD + thermal model

PHENIX
OVER ONE BILLION SERVED

Backup

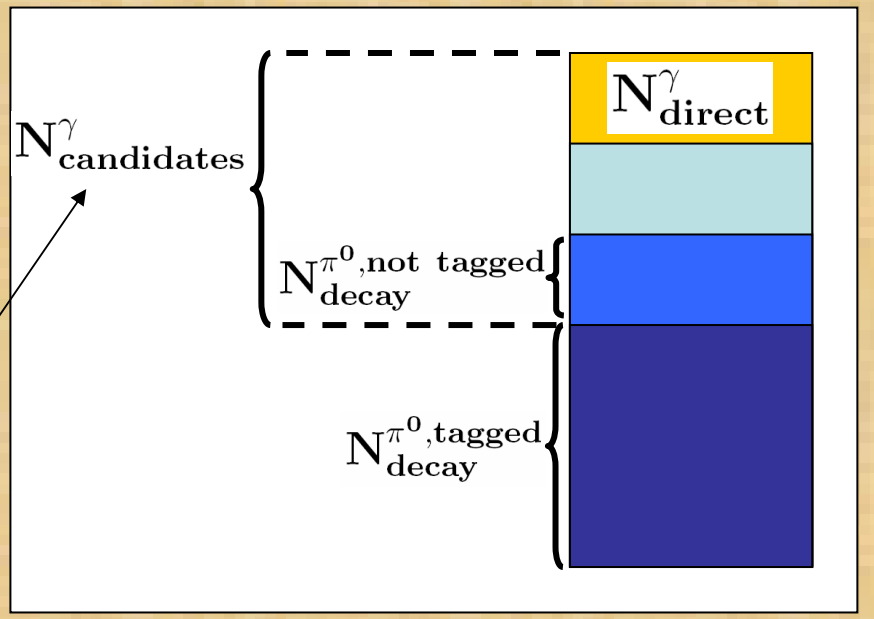
The PHENIX Experiment I

- photon measurement:
  - EMCal (PbGl, PbSc)
- electron measurement:
  - Tracking, RICH, EMCal



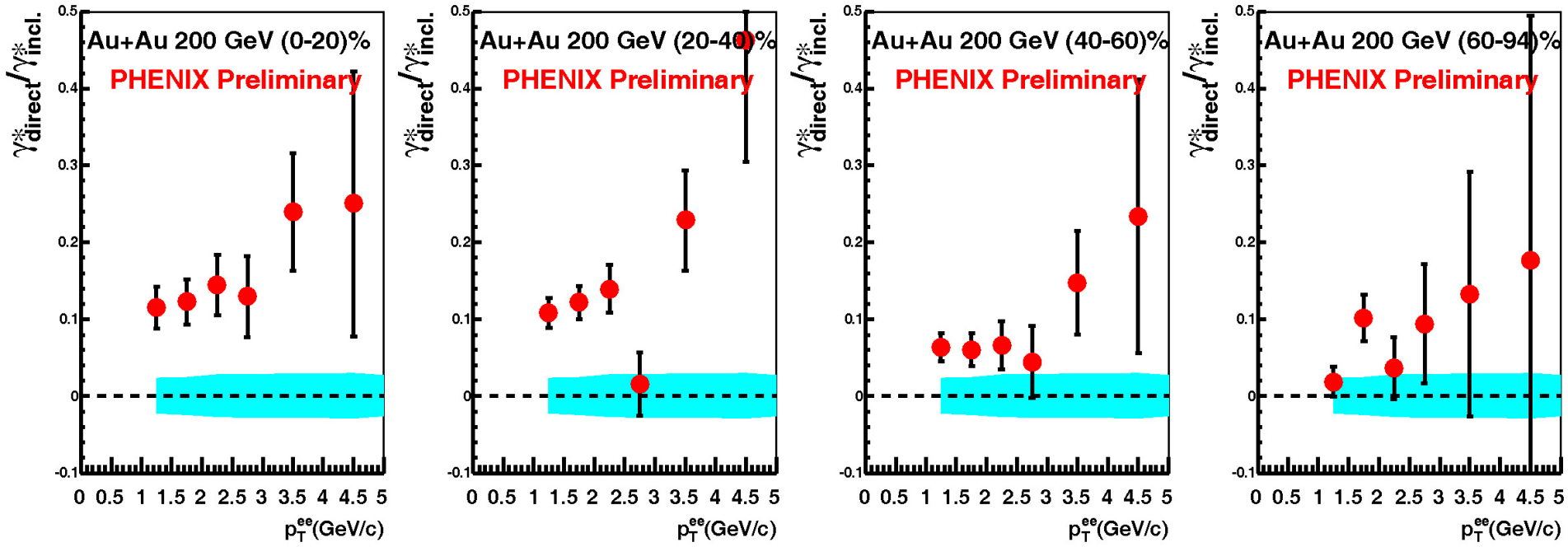
Analysis Techniques (II)

- Tagging Method
  - increase signal/background ratio by tagging π^0 photons
  - start with sample of direct photon candidates
    - tagging efficiency determind in Monte-Carlo



$$N^{\gamma}_{direct} = N^{\gamma}_{candidates} - N^{\gamma,not\ tagged}_{decay}$$

Centrality dependence



more peripheral

indication for centrality dependence