PHENIX Direct Photons in 200 GeV p+p and Au+Au Collisions:

Probing Hard Scattering Production

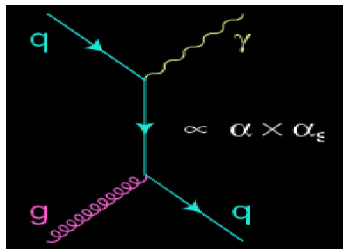
Justin Frantz

Columbia University

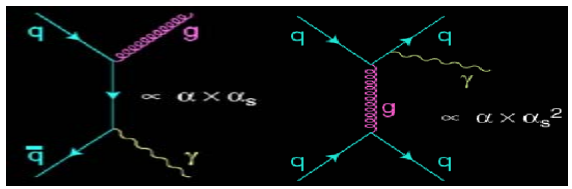
for the PHENIX Collaboration

Quark Matter 2004

Direct Photon Measurements in Particle Physics



Gluon Compton Scattering



Annihilation & Bremsstrahlung

- Interesting probe: half a di-"jet"—same collision process but γ has no fragmentation
- No measurements of direct photons at sqrt(s) = 200 GeV
- Probes x = 0.02-0.14 @ p_T = 2-14 GeV/c
- Compton scattering dominates--probes the gluon distribution – eventually do A_N, A_{LL} measurement with direct photons
- Reduces uncertainty on pQCD photons in AuAu
  - Background to thermal photons in AuAu at mid p_T?
  - Excellent control for strong modification effects–better than d-Au

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Direct Photons in AuAu

- Many sources, different p_T regions
  - Thermal Sources (p_T < 3-4 GeV)

    -Partonic (QGP!) , Hadronic Gas (new resonance diagrams → theoretical uncertainties)

    -Largest Backgrounds, **PHENIX systematics still under investigation in this momentum region**
  - Hard Scattering (p_T > 3-4GeV)

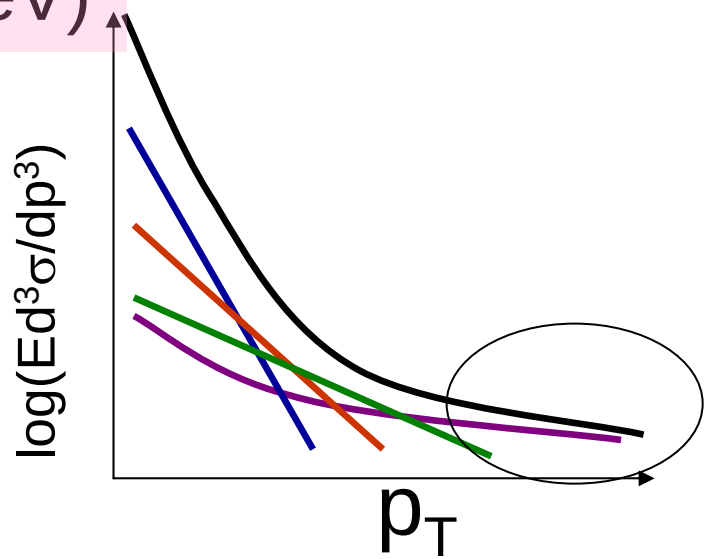
    -In central AuAu,

    π^0/meson background suppressed

    -"Cleanest" region (pQCD dominates)

    -PHENIX has good sensitivity here—

    e.g. excellent triggering capabilities.



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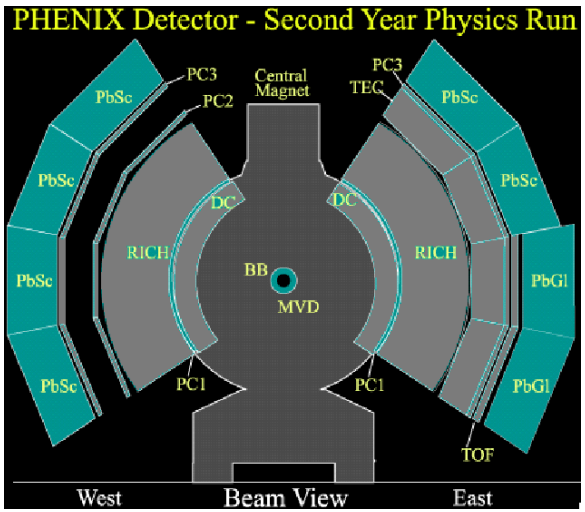
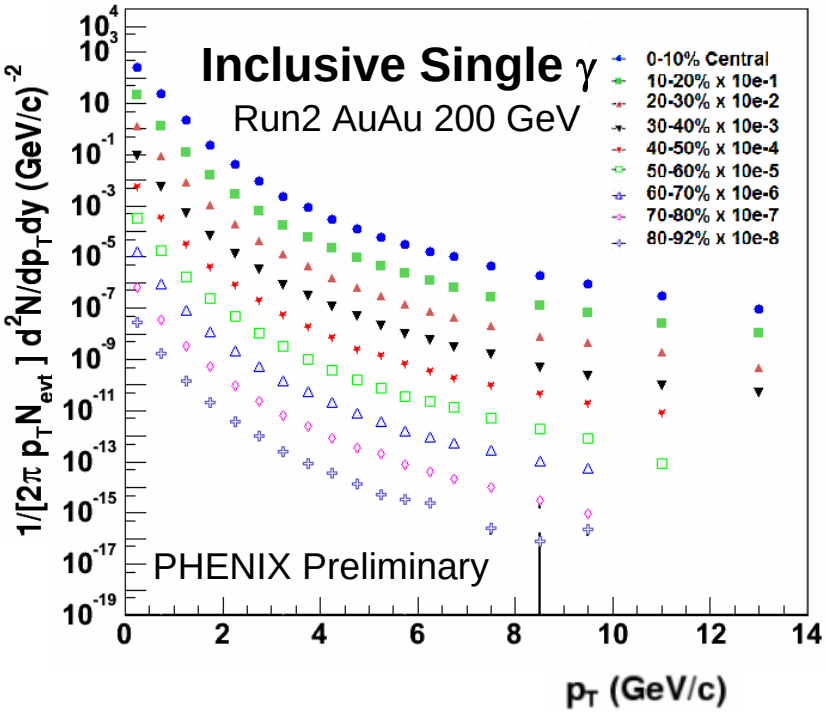
PHENIX Direct γ's: Step 1) Measure Inclusive Photon Spectrum





- Emcal Cluster Spectrum
- w/ Corrections for (*e.g.*)
  - Hadronic Shower Contamination (pp ~25-18%, AuAu 15-5%)
    (see G. David, T. Sakaguchi posters)
  - Conversions (4%)
  - In central AuAu, overlap efficiencies through embedding
  - Off-vertex background (3%)

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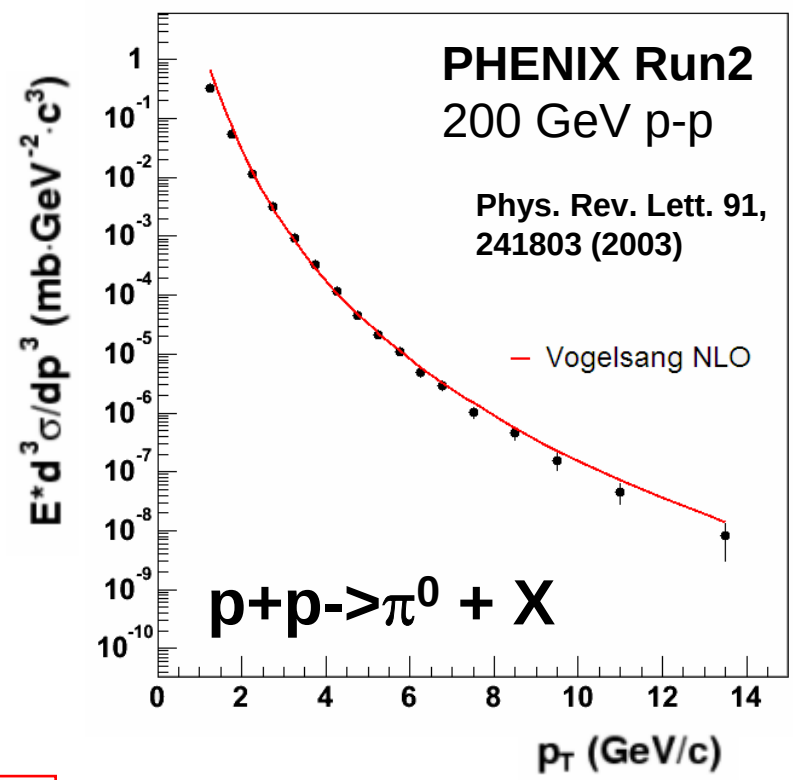
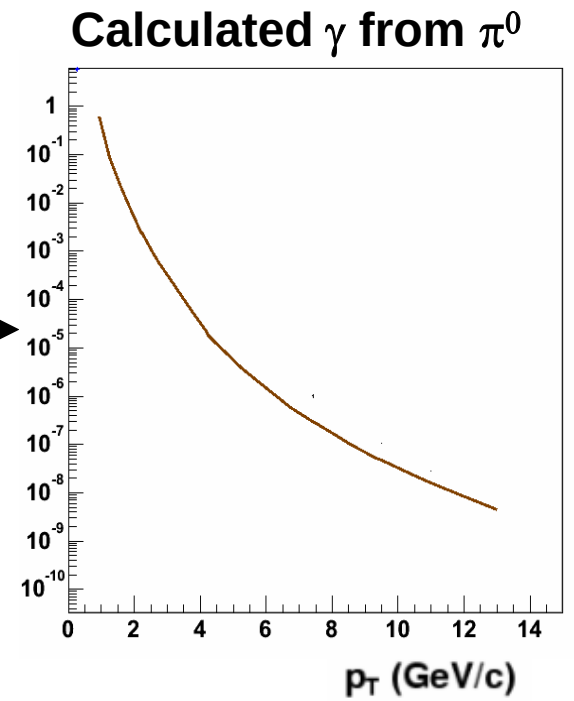
PHENIX Direct γ's: Step 0) Measure Background

- We are looking for the signal over a large background
- Requires precise knowledge of the π^0's



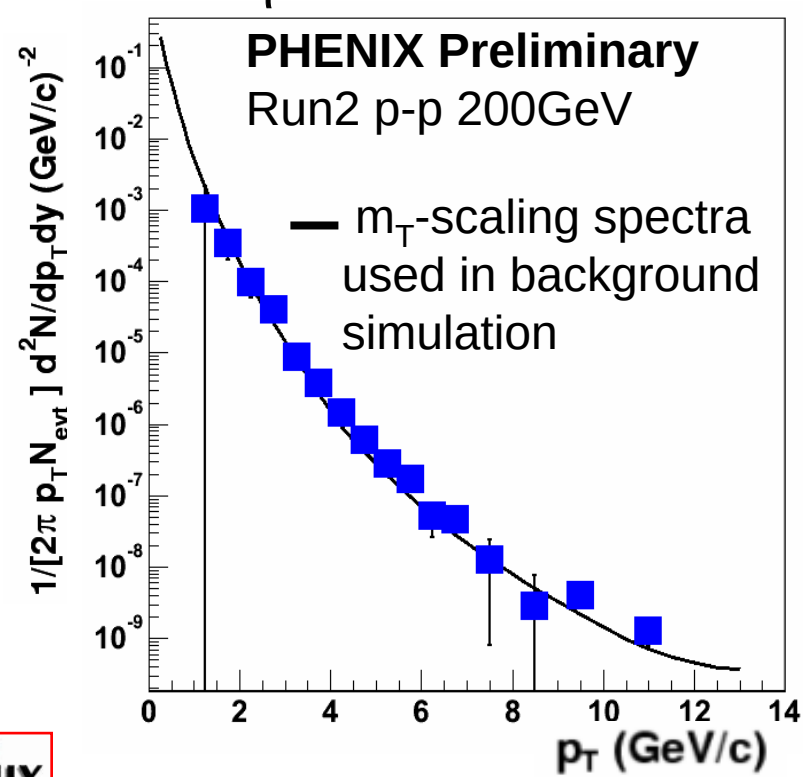


Vogelsang calculation reference: JHEP 9903 (1999) 025/ Private Comm.

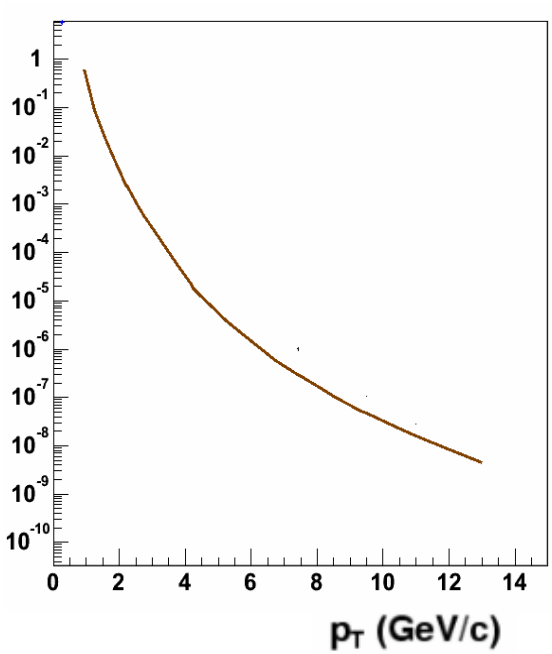
Other Background (η, η', ω,…)

- η – 18% of bkgrd: for calc., fixed by π^0 through m_T-scaling (η/π –> 0.55)
- New Preliminary pp η measurement (see H. Hiejima poster) consistent with m_T scaled calculation
- Evidence that AuAu η/π ~same as pp (see S. Mioduszewski poster)

η Invariant Yields



Calculated γ from π^0



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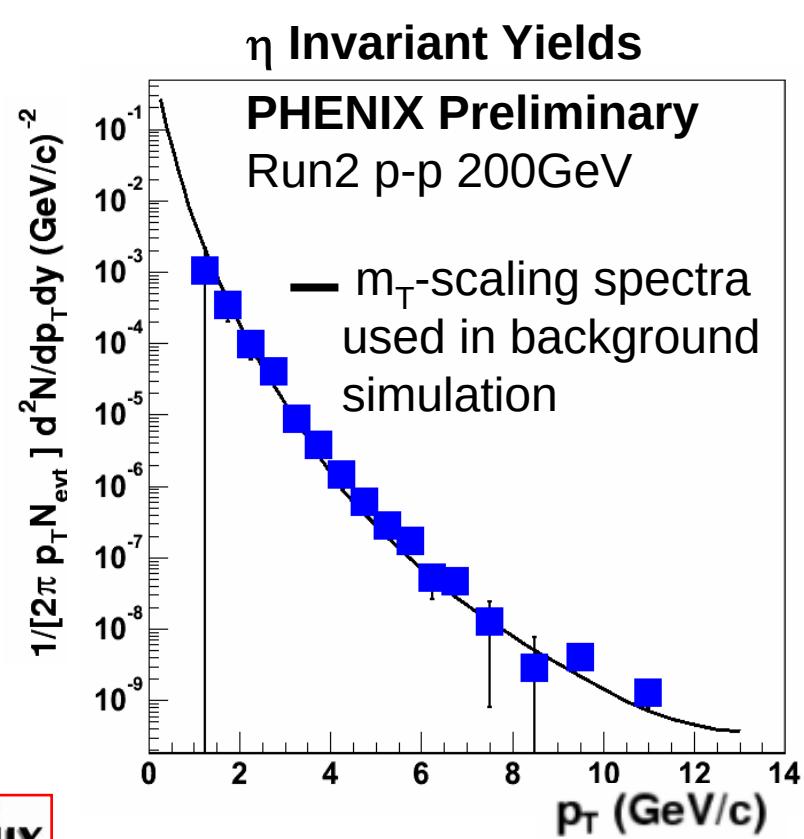
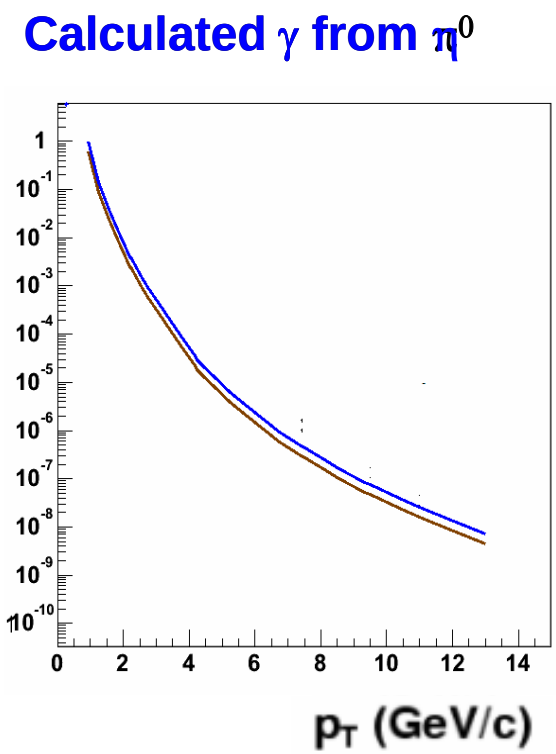
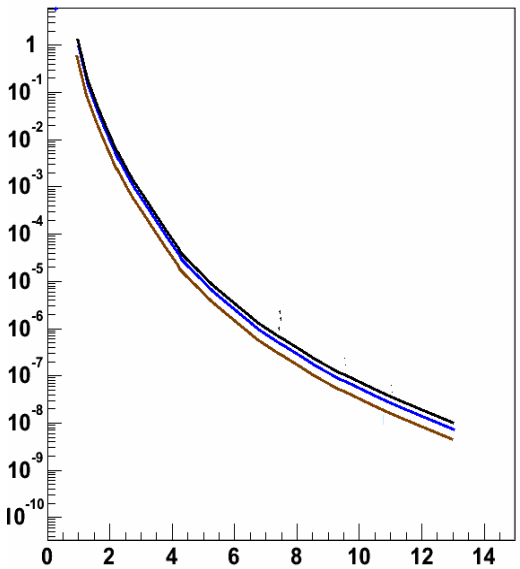




Other Background (η, η', ω,…)

- Other "cocktail" (η',ω) contributions (% level) also m_T-scaled from π^0

Calculated γ from all decays



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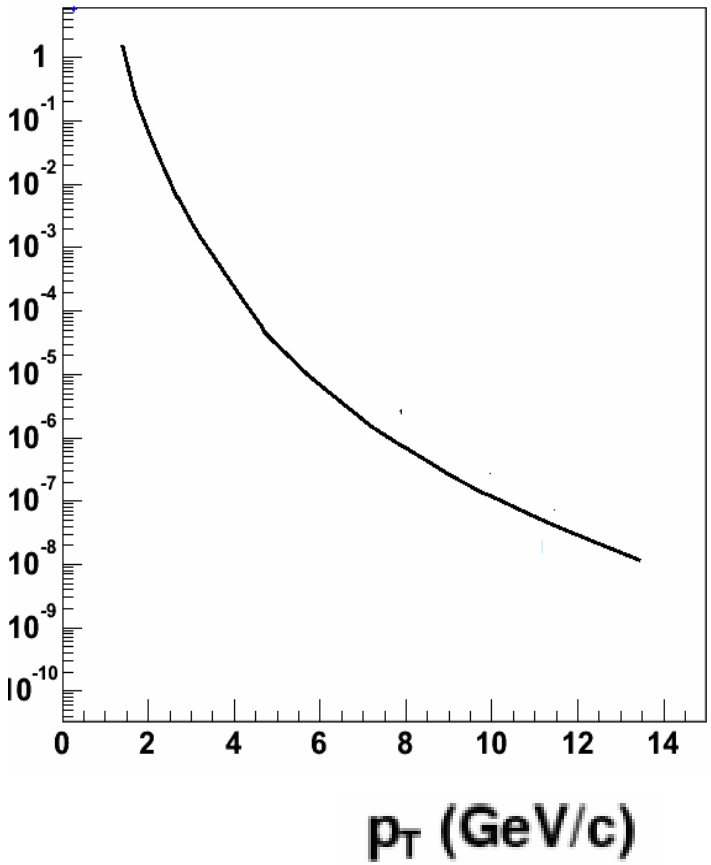
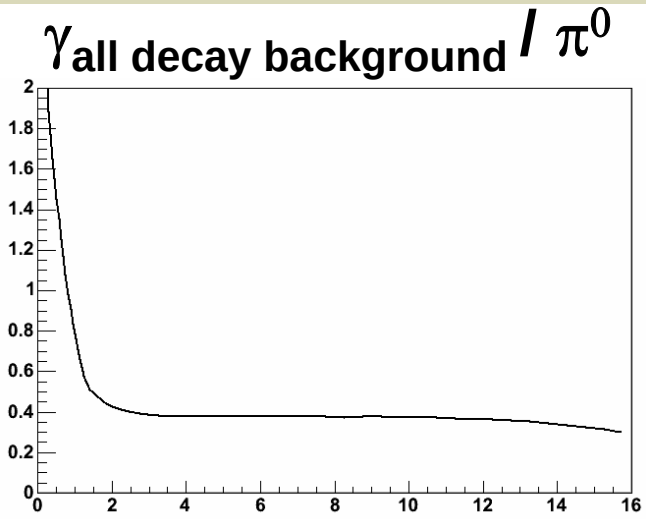


Finally, Divide By Pizero



- We do this because doing the same with the actual point by point π^0 and inclusive γ measurements will cancel many systematics
- Variations: Tagging Methods (reject γ pairs in π^0 mass window), Isolation Methods Remove inherent background so smaller $(\gamma/\pi)_{\text{expected backgrd}}$
- Then we can compare measured γ/π with background γ/π …

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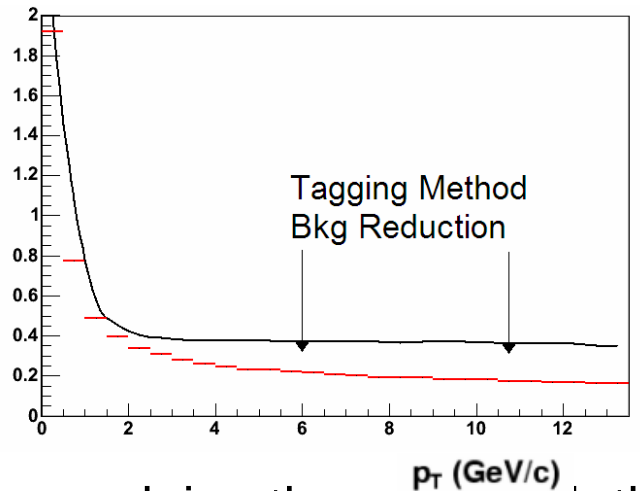

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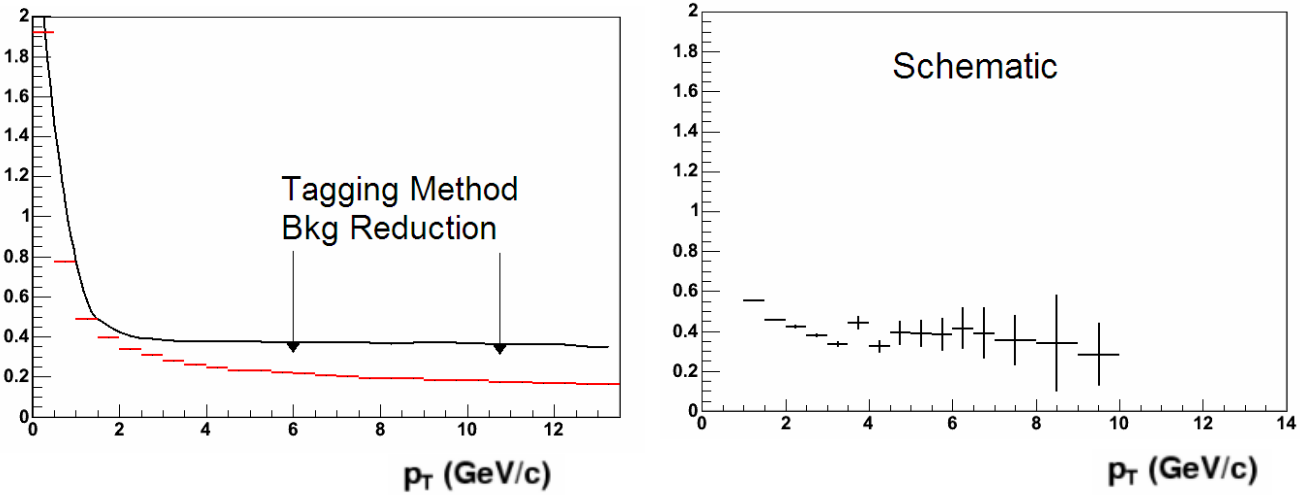
γ/π^0 Measurement



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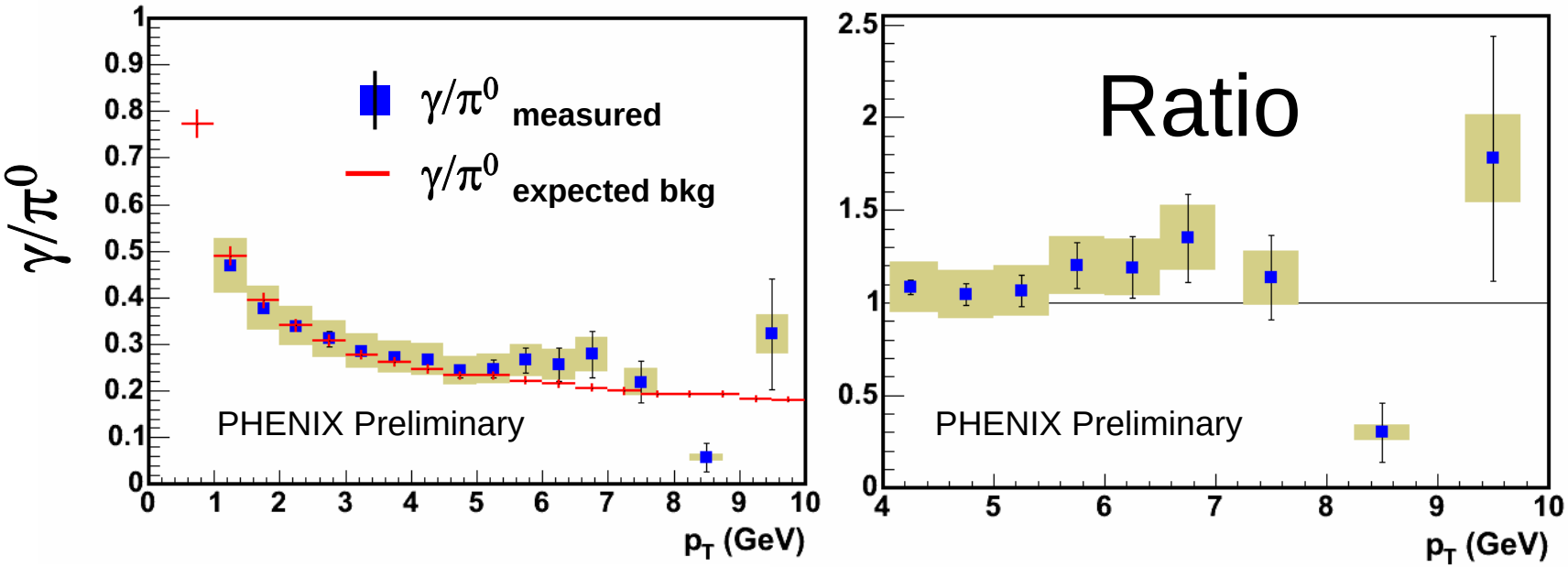
Run2 p-p Results

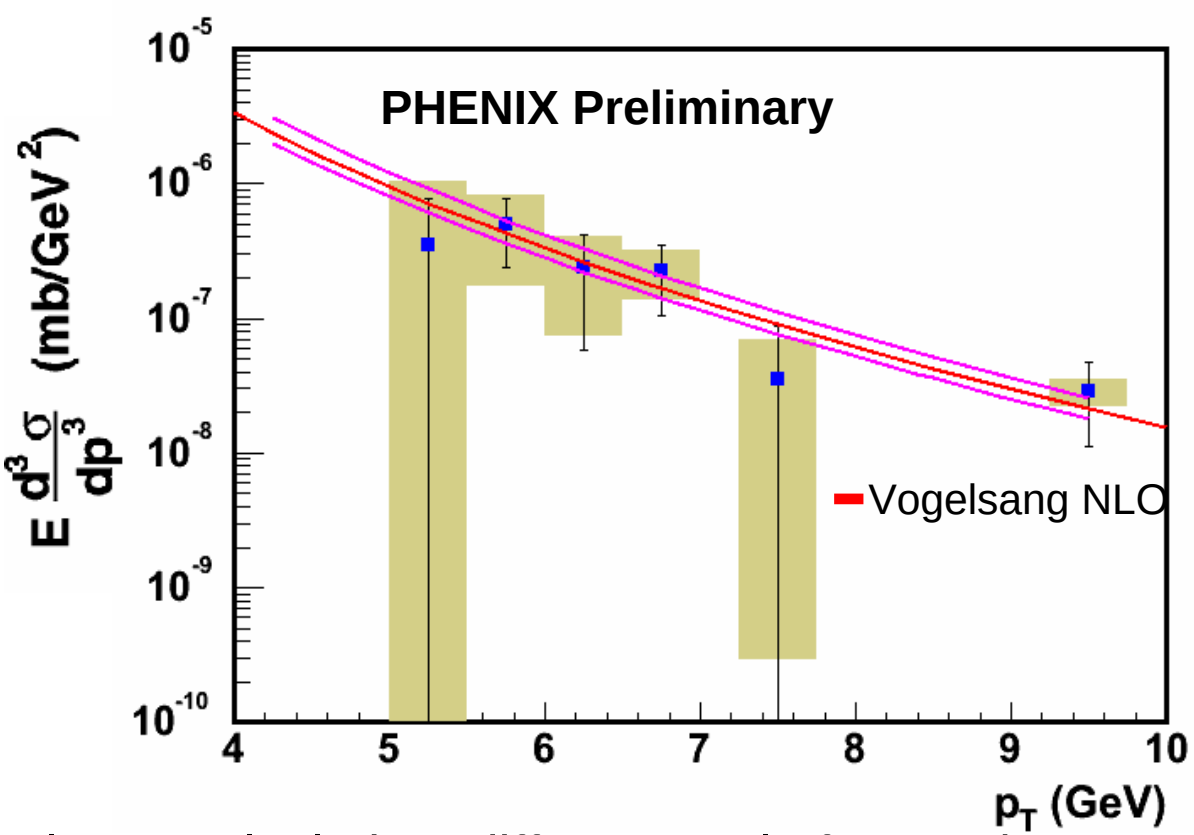


- Excess Above Background Double Ratio:

$$[\gamma/\pi]_{measured} \,/\, [\gamma/\pi]_{background} \rightarrow \gamma_{measured}/\gamma_{background}$$

- The excess above 1 is the direct photon signal
- Direct γ signal found in 200 GeV pp

PHENIX Run2 p-p Direct Photon Measurement



- Vogelsang calculation: different scale factors (0.5,**1.0**,2.0), using CTEQ6 gluon pdf: *JHEP 9903 (1999) 025/ private communication*
- See K. Reygers poster for analysis details (Tagging statistical method)

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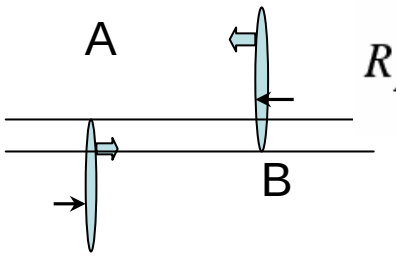
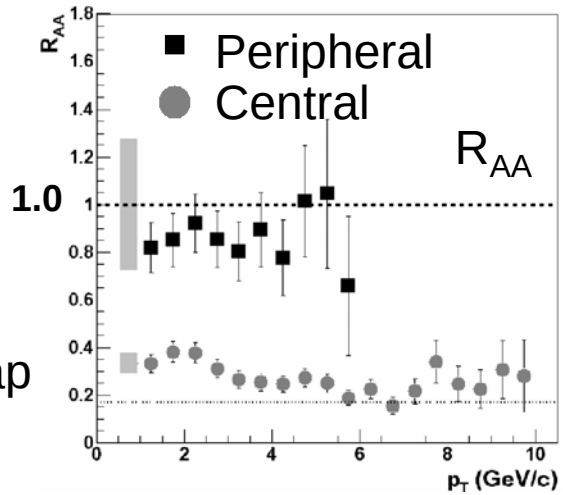
From p-p to AuAu: Binary Collision (N_{coll}) Scaling

- Look at, *e.g.*, π^0 in Peripheral AuAu:



$$R_{AB}(p_T) = \frac{(1/N_{AB}^{evt})\, d^2N_{AB}/d\eta dp_T}{\underbrace{\langle T_{AB}\rangle}\; d^2\sigma_{pp}/d\eta dp_T}$$

$\langle N_{coll}\rangle / \sigma_{pp}^{inel}$, Glauber Nucl. Overlap



- In central events, scaling broken→ suppression! Jet suppression? But the dense strong charge final state shouldn't inhibit direct γ

Neutrinos, they are very small.
They have no charge and have no mass
And do not interact at all.
The earth is just a silly ball
To them, through which they simply pass,
Like dustmaids down a drafty hall ...

-John Updike

Direct Photons, they are very small.
They have no charge and have no mass
And do not interact at all.
The QGP is just a silly fire? ball
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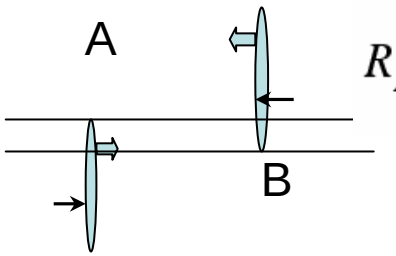

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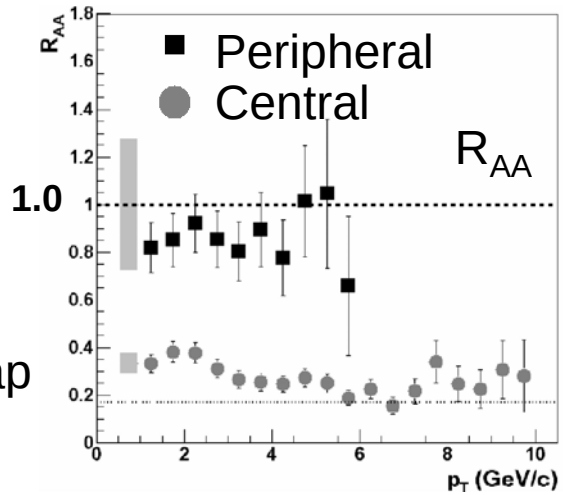

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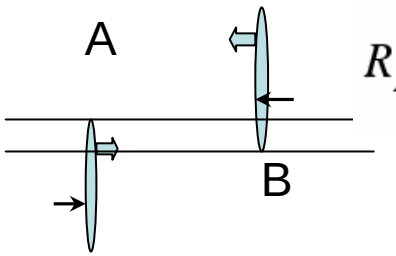

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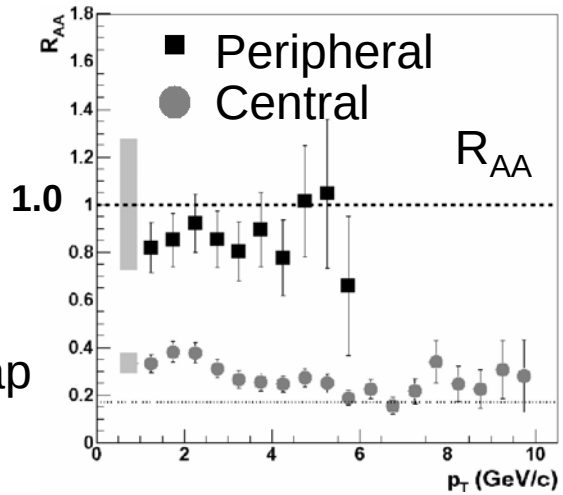
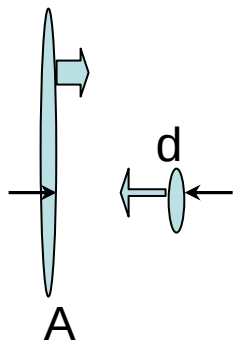
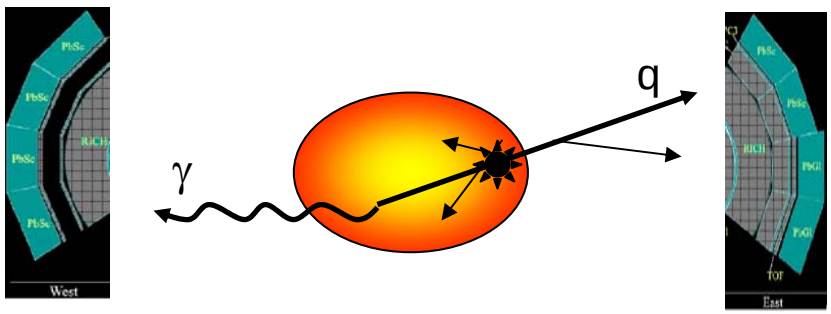


- In central events, scaling broken→ suppression! Jet suppression? But the dense strong charge final state shouldn't inhibit direct photons
- d-Au control experiment shows scaling is not affected by initial state effects but does so only at small values of N_{coll}



High p_T Direct Photons: A Better Control

- "Side by Side" at same N_{coll}
- Rates calculable in pQCD, measurable in p-p
- Less sensitive to non-perturbative QCD
- Once signal is identified, measure jet-γ correlation E_γ accurately studies E_{jet} modification
- Promising future: (no separate run)



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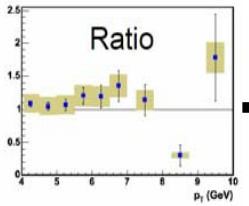
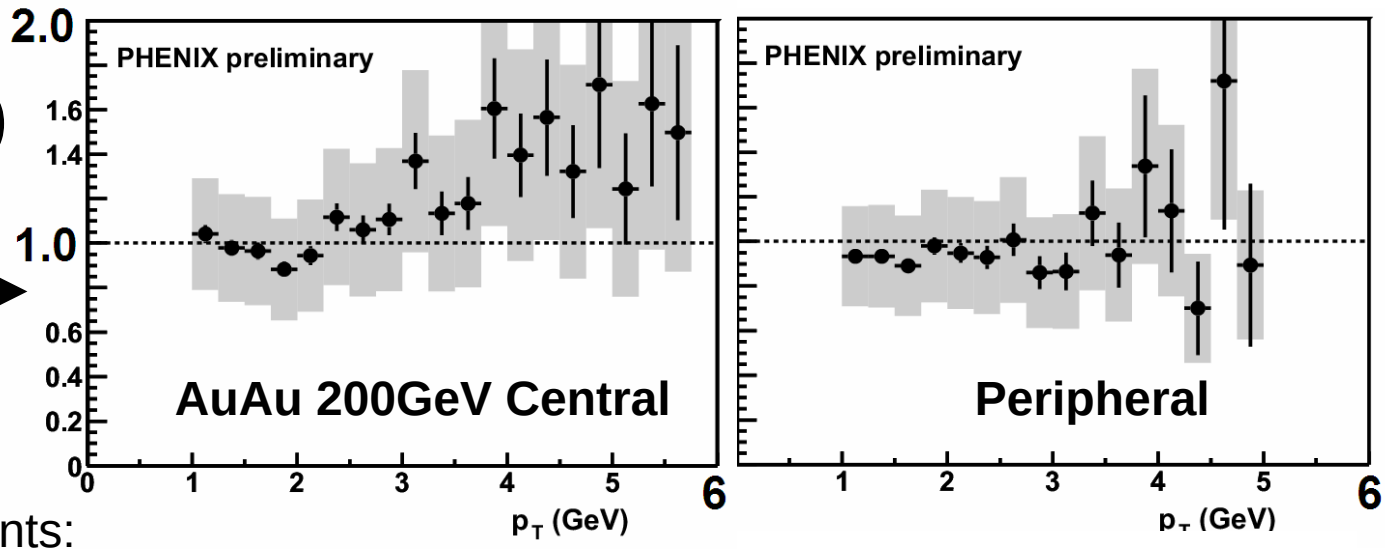
PHENIX QM'02 Preliminary Result

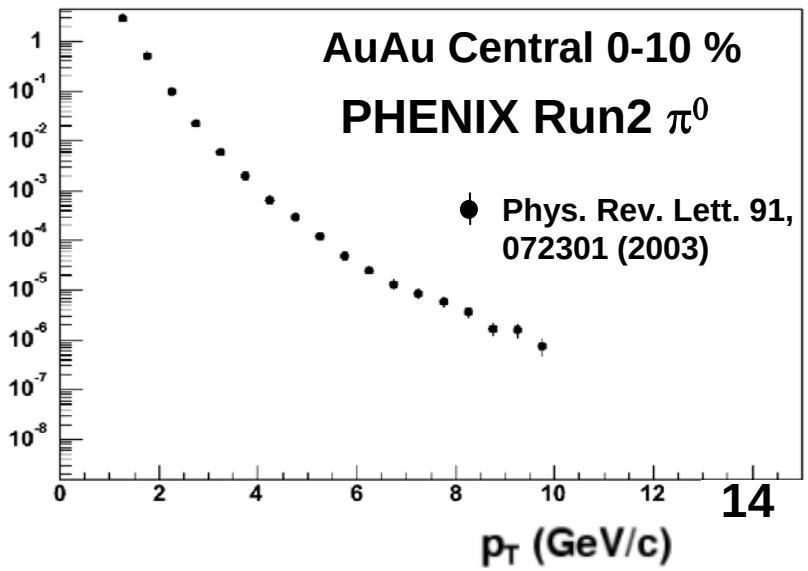
$(\gamma/\pi)\ /\ (\gamma/\pi)$





Improvements:

- **New level2 triggered data set**
- 4 more GeV of π^0's at high p_T!
- Efficiency with full embedding
- PbSc single γ systematics under control
- Multiple independent analyses



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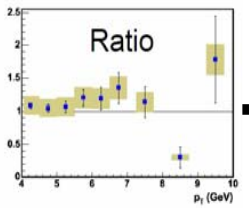

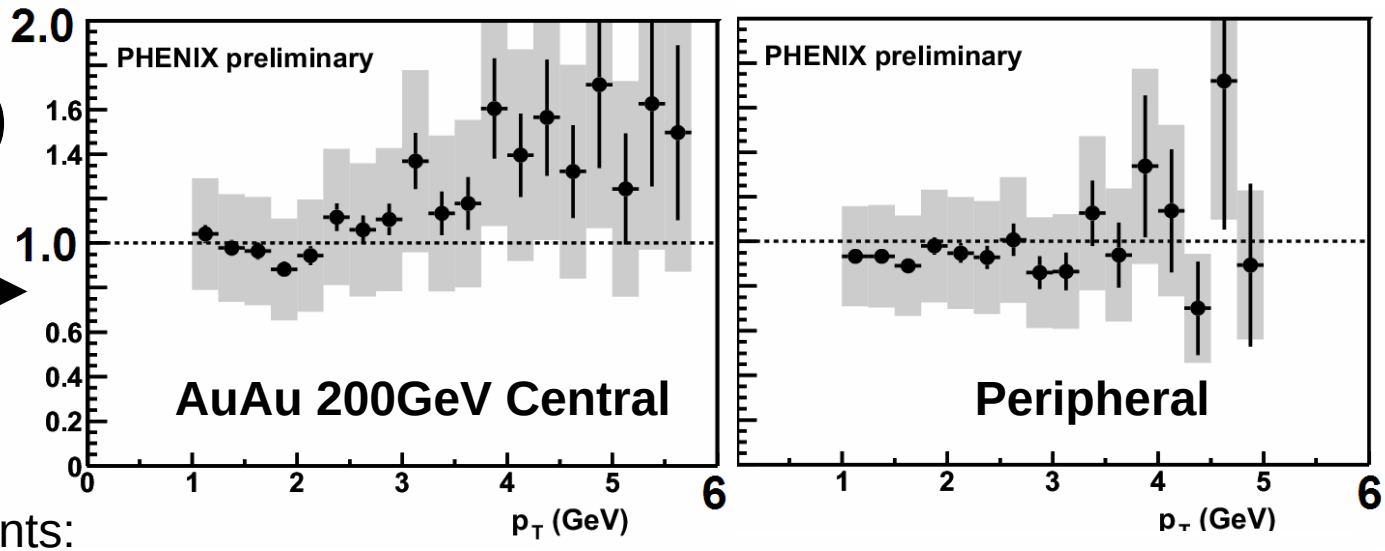

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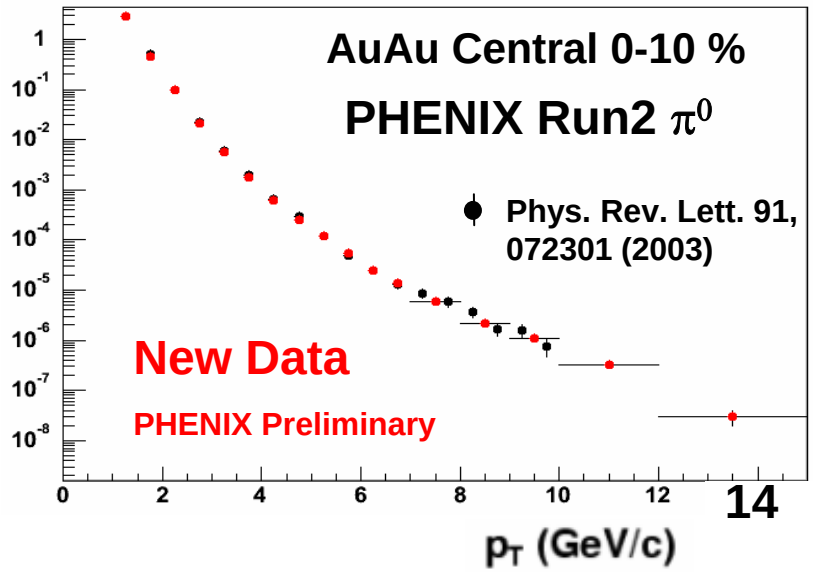
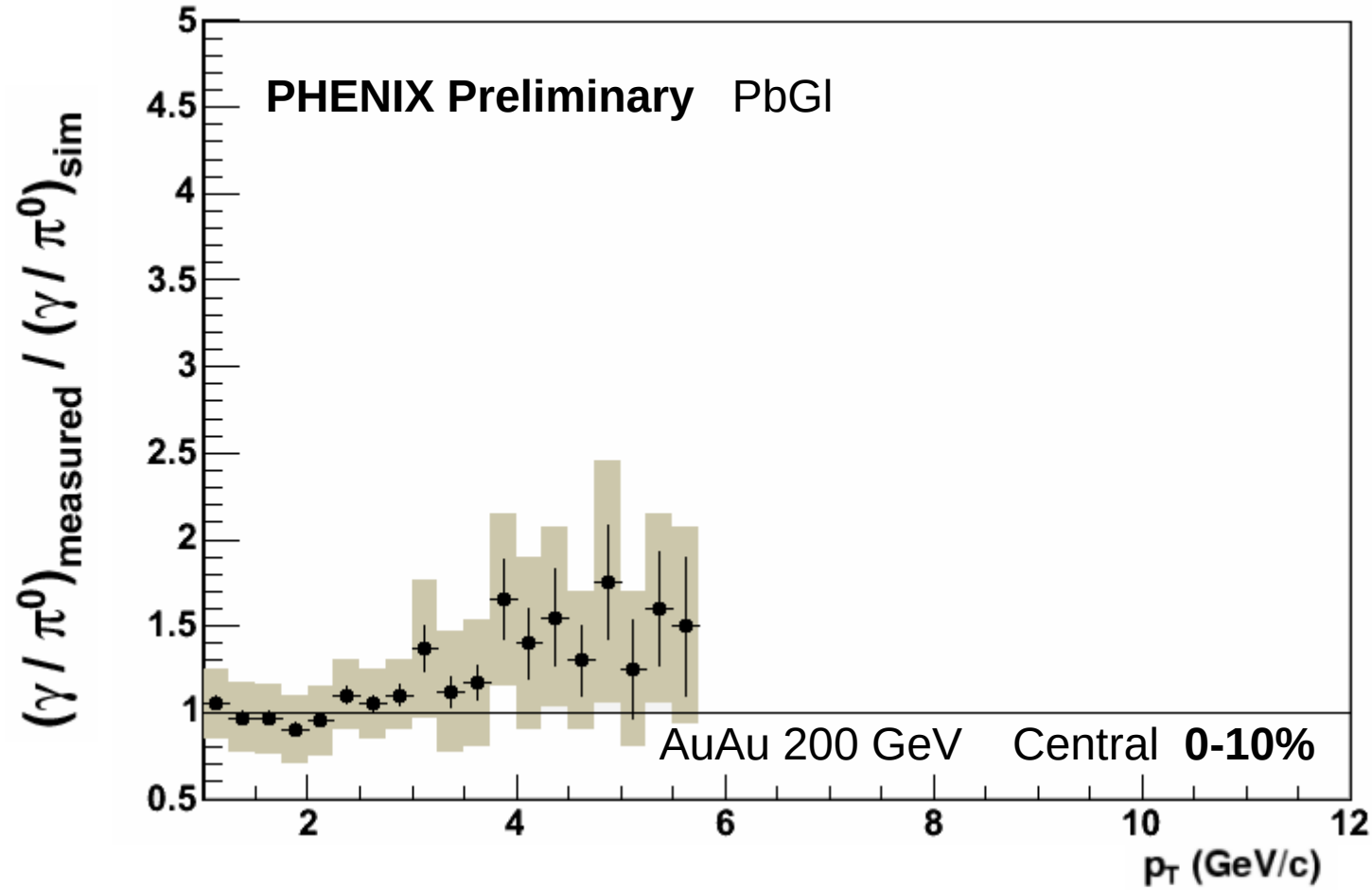


New Results Central 0-10%



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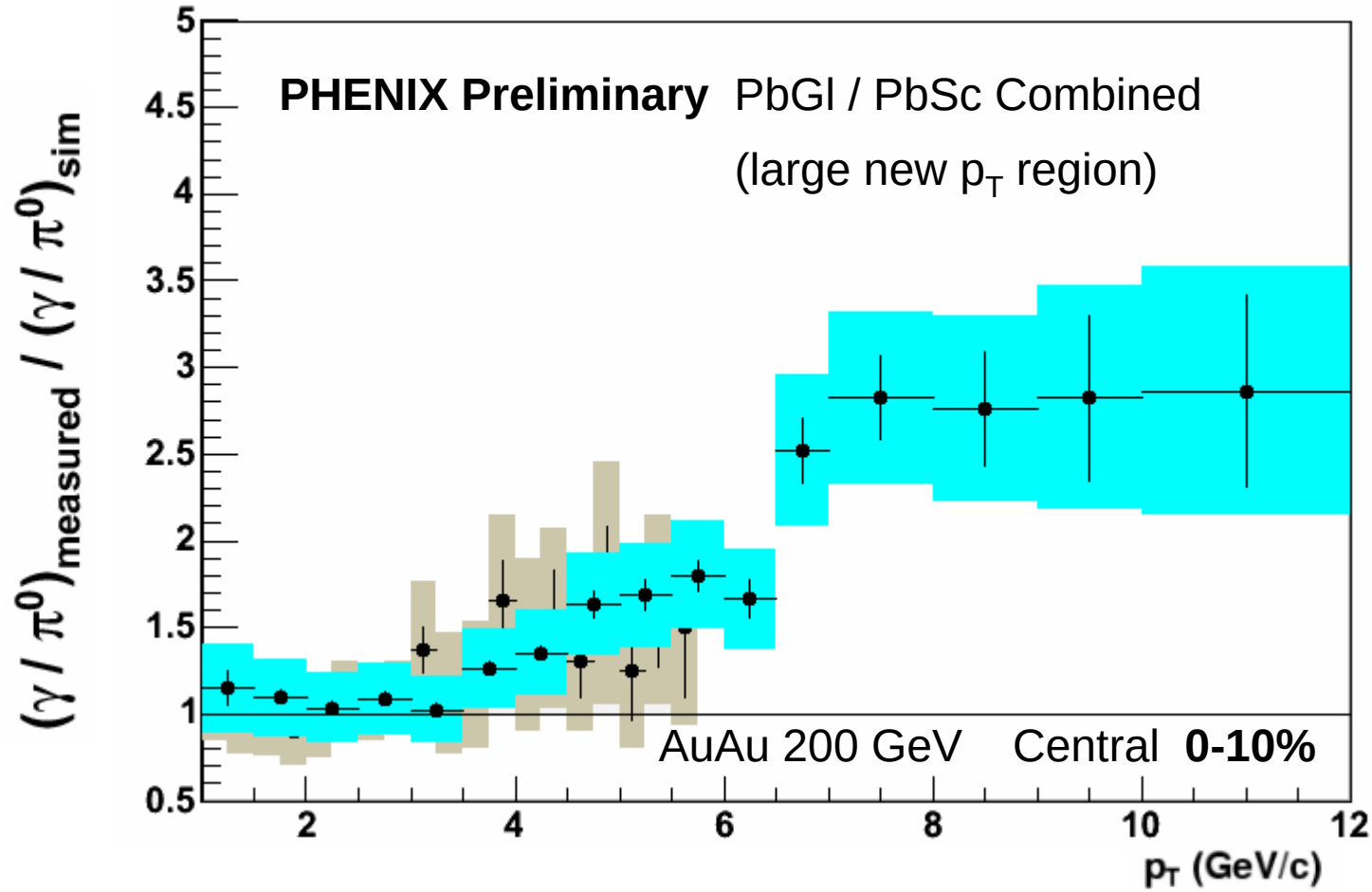

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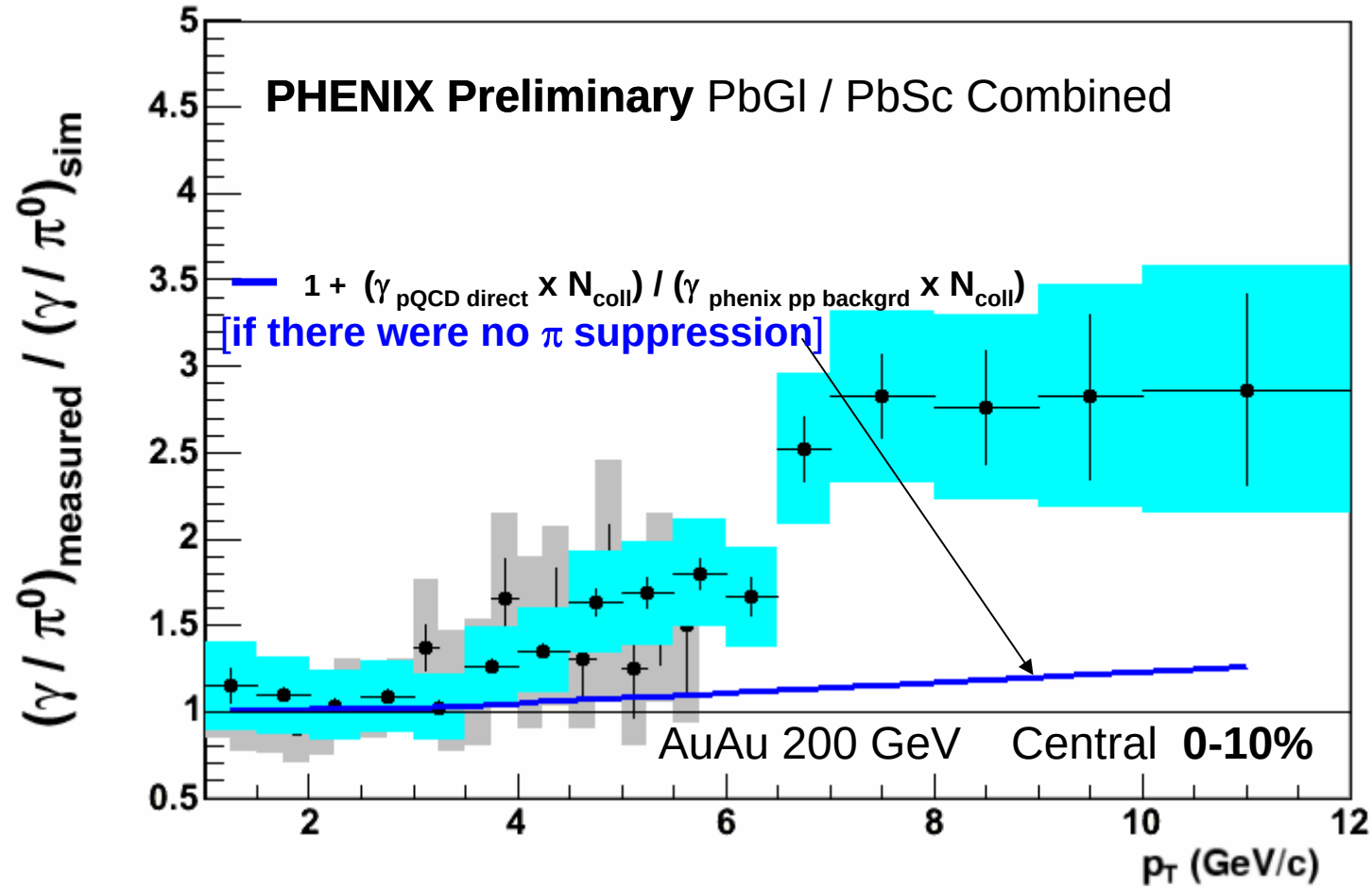

Theory curves include PHENIX $\gamma_{\text{expected background}}$ calculation based on π^0:

$$(\gamma_{\text{direct}} + \gamma_{\text{exp. bkgd.}}) / \gamma_{\text{exp. bkgd.}} = 1 + (\gamma_{\text{direct}} / \gamma_{\text{exp. bkgd.}})$$

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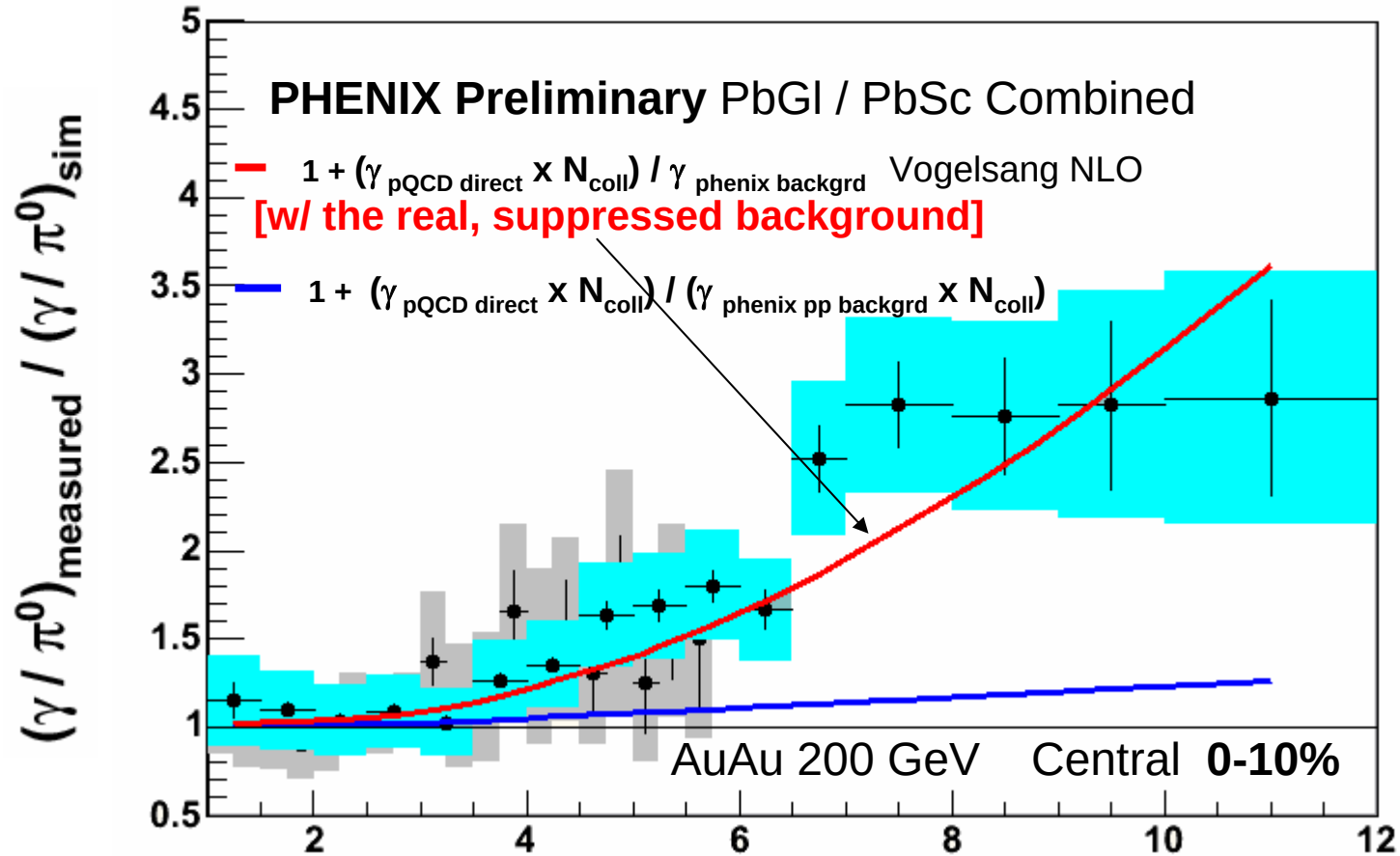

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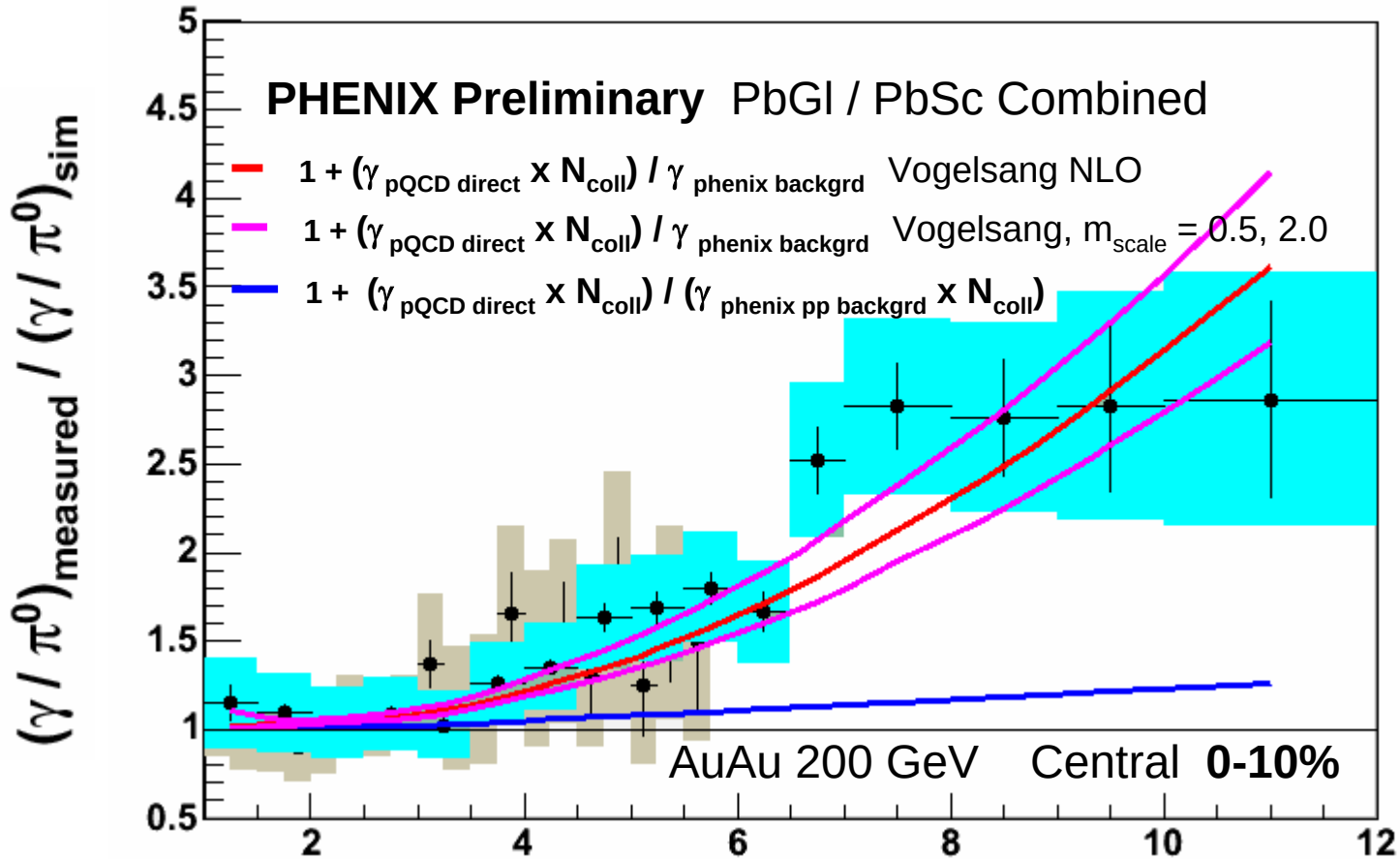

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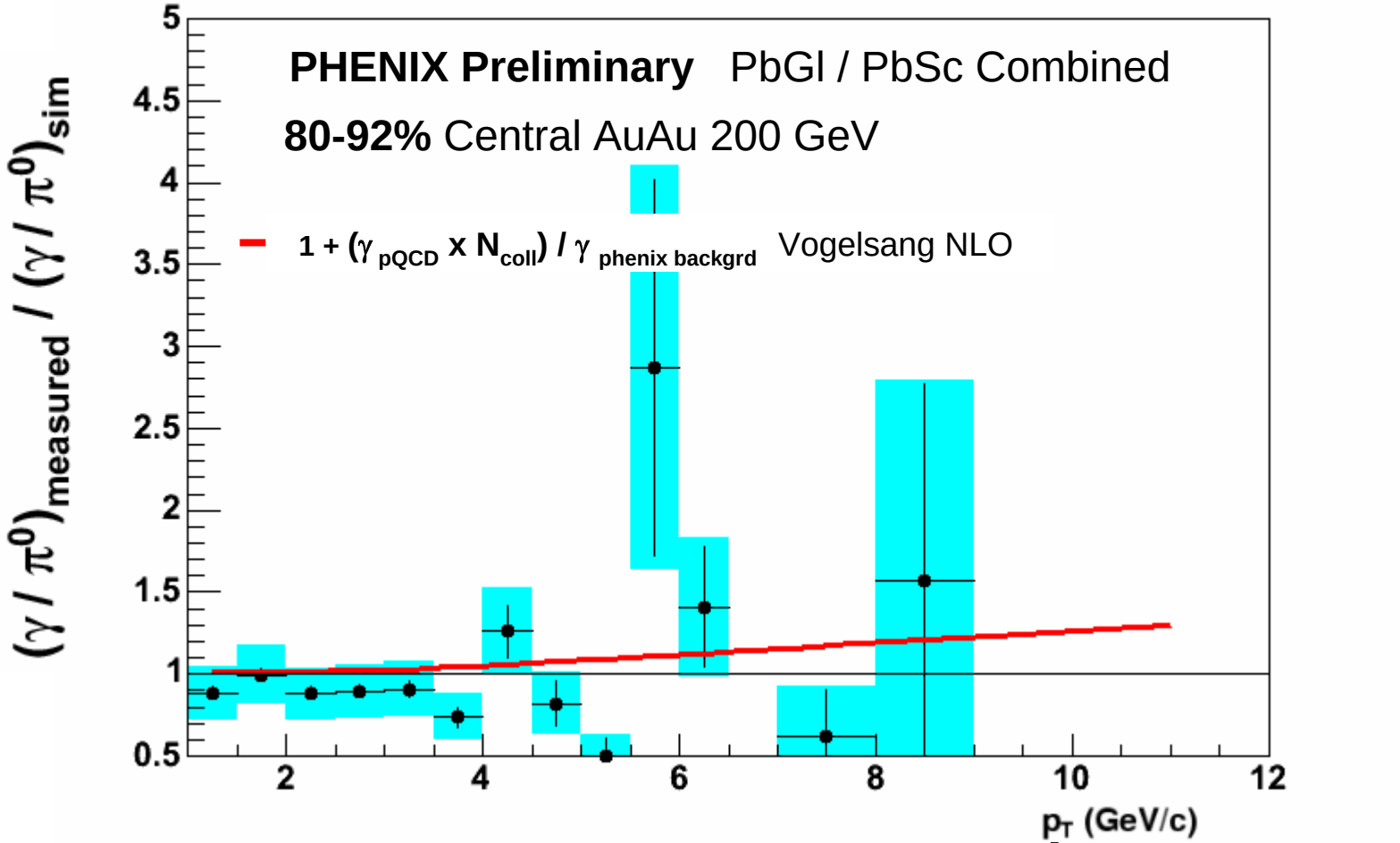
Excess Over Background Ratios, All Centralities



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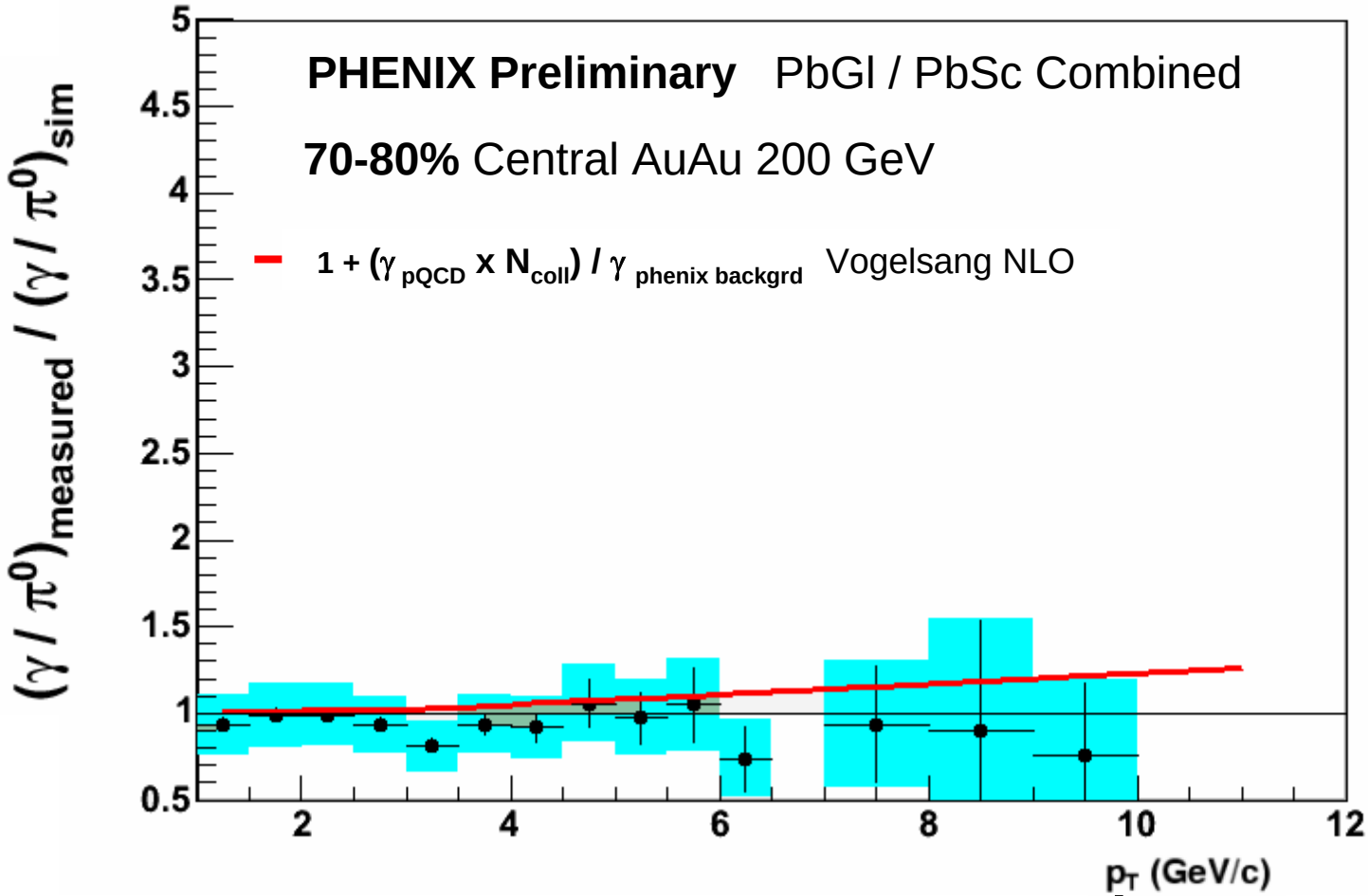

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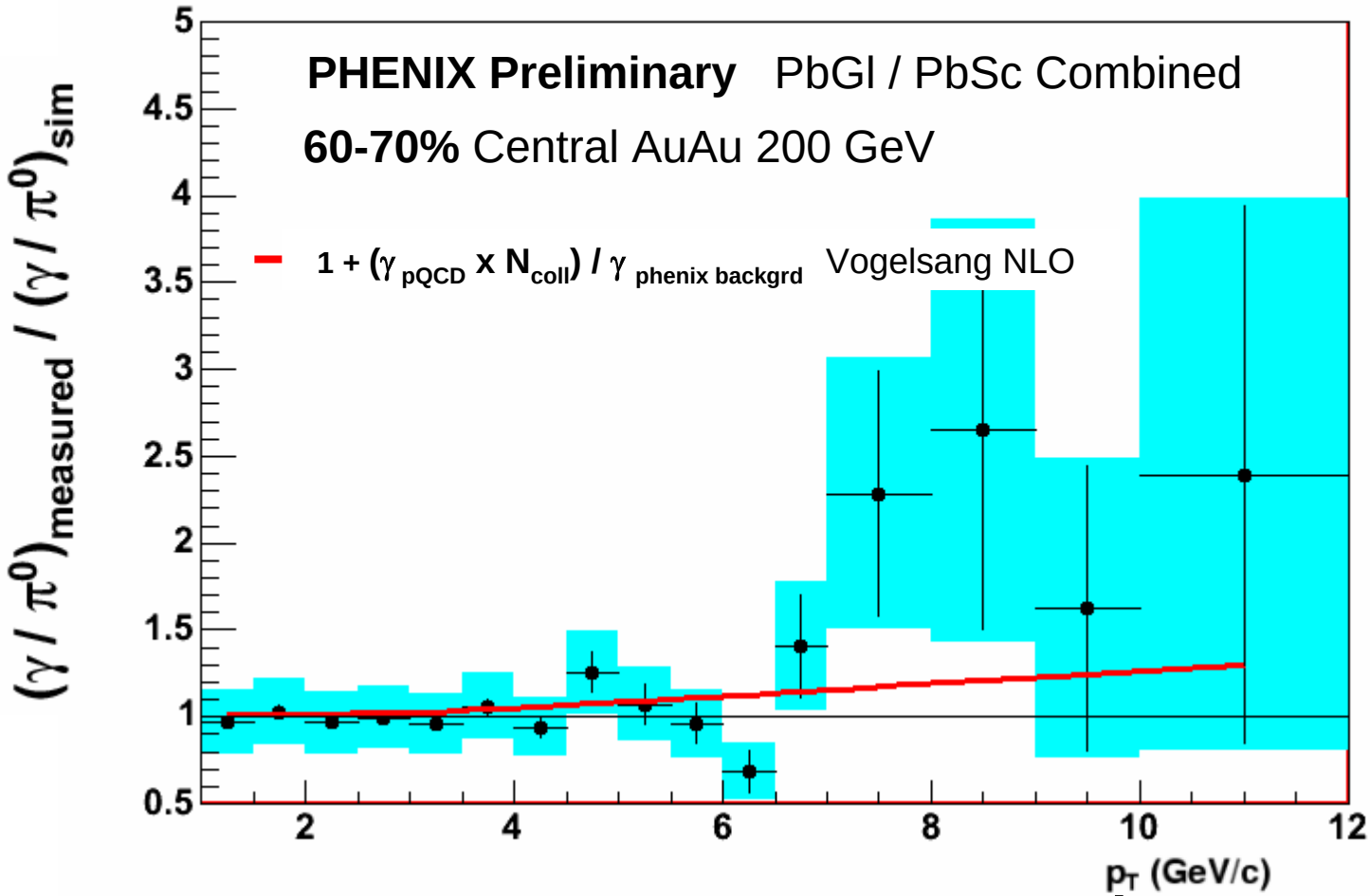

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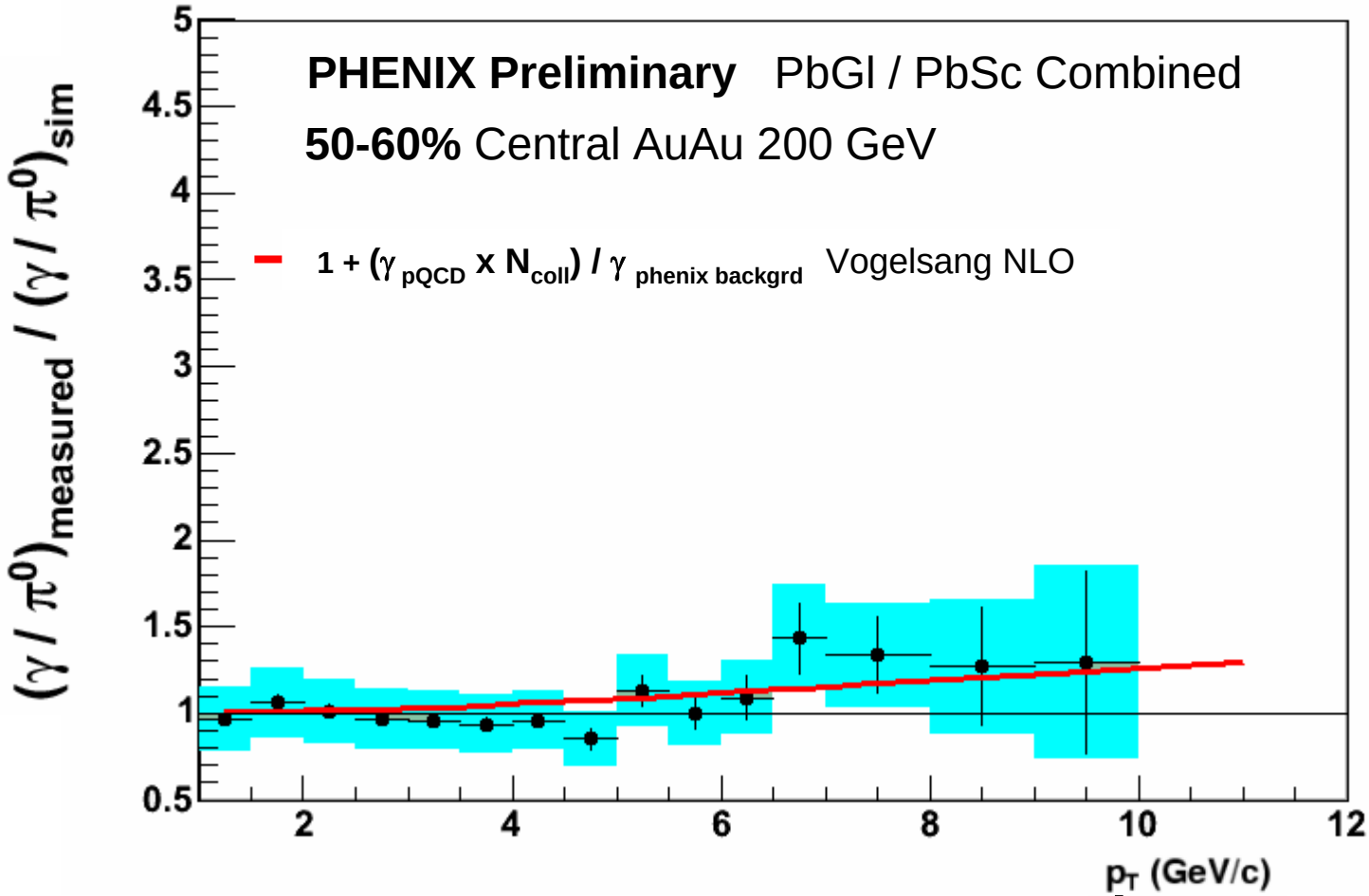

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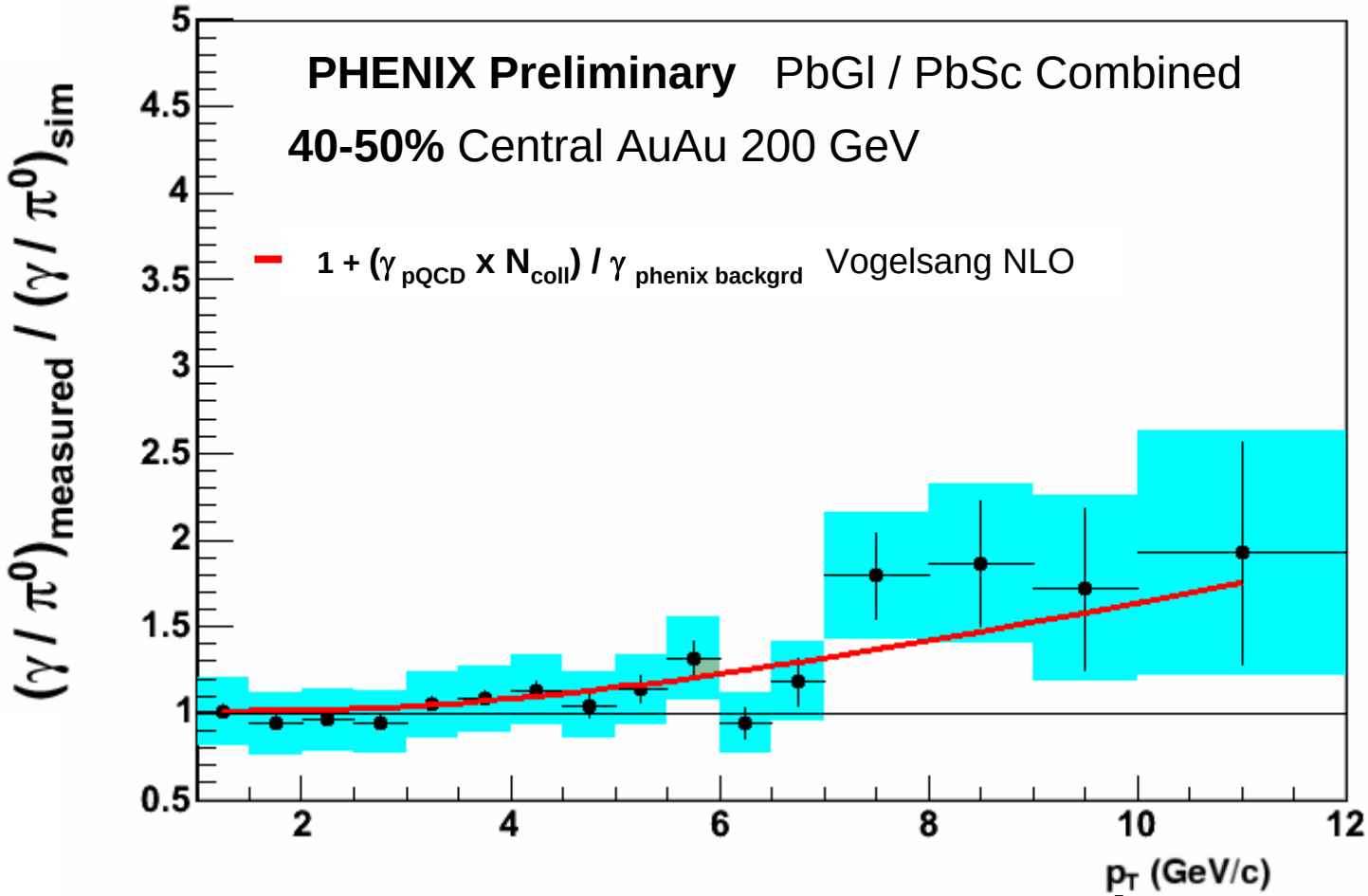
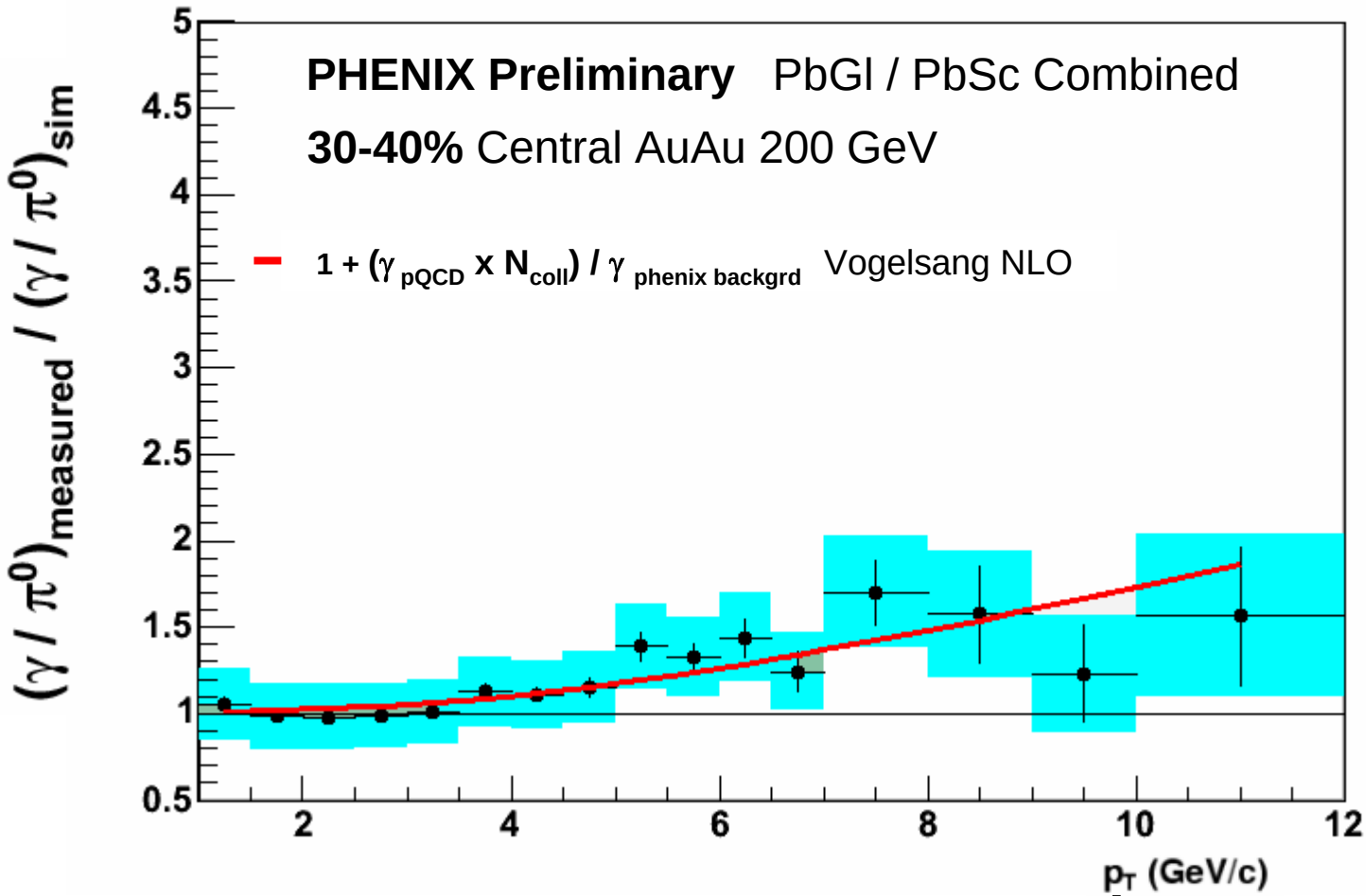
Excess Over Background Ratios, All Centralities



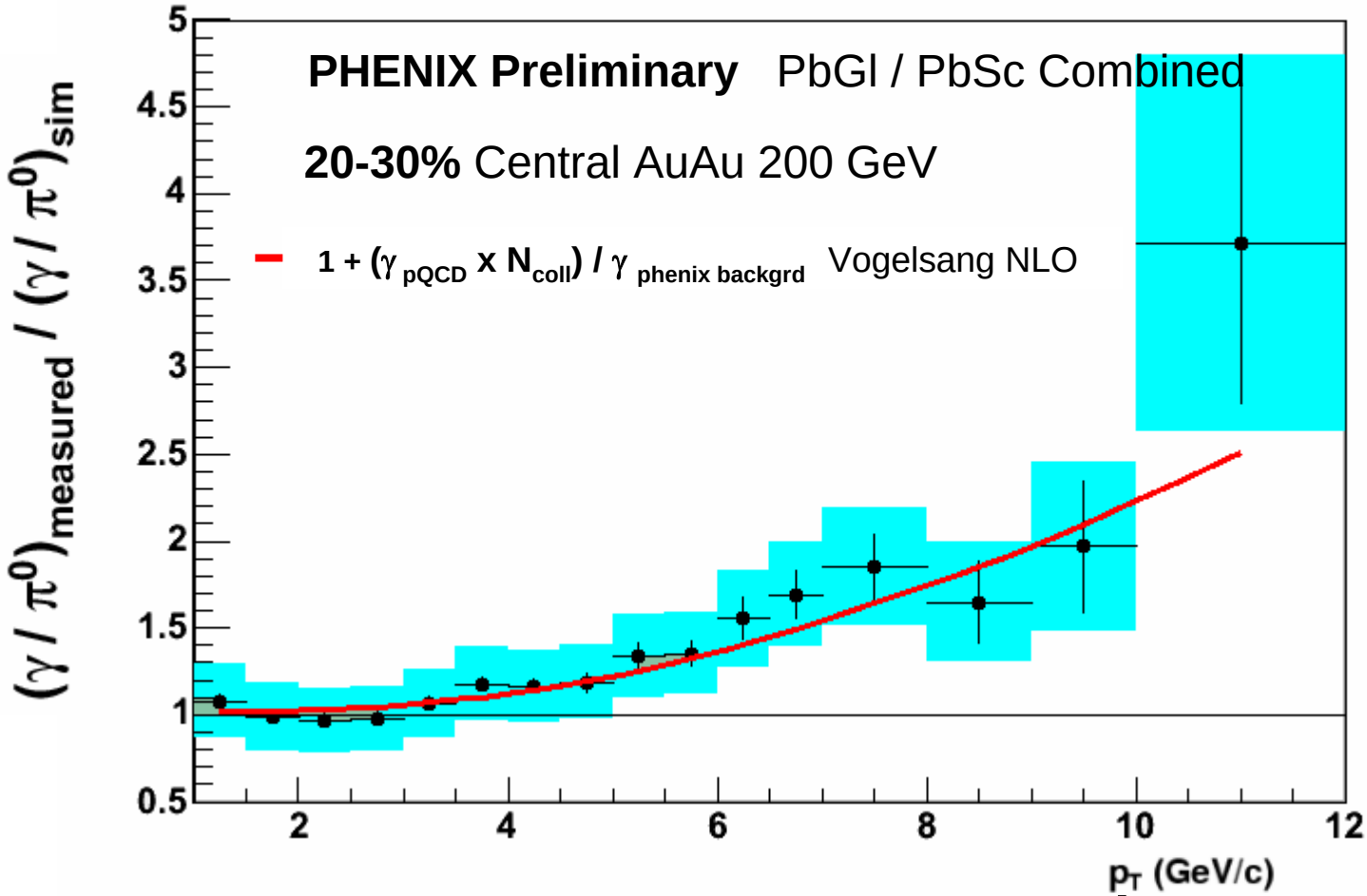
$[\gamma/\pi^0]_{measured} / [\gamma/\pi^0]_{background} = \gamma_{measured}/\gamma_{background}$

Excess Over Background Ratios, All Centralities



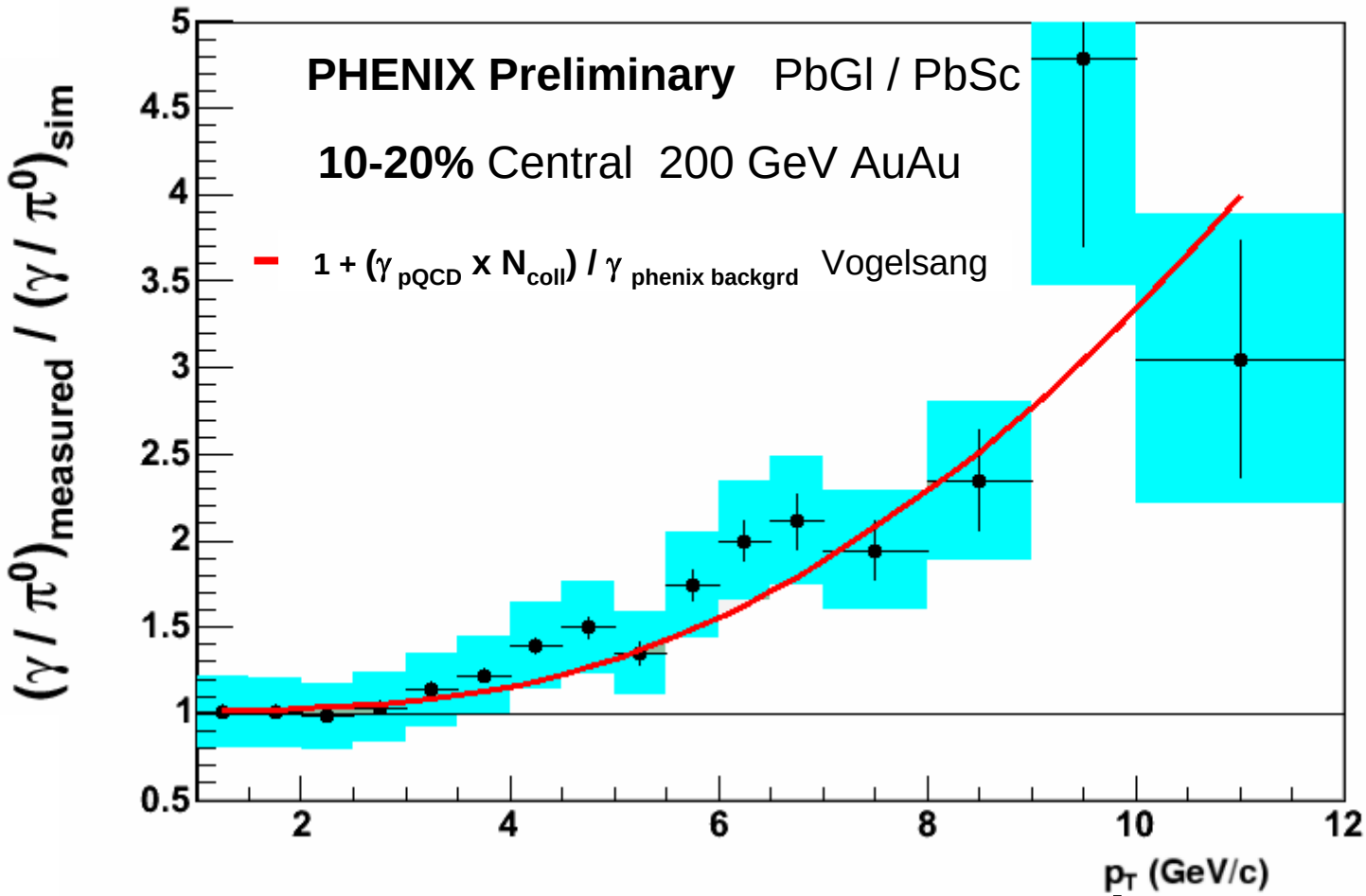
$[\gamma/\pi^0]_{measured} / [\gamma/\pi^0]_{background} = \gamma_{measured}/\gamma_{background}$

Excess Over Background Ratios, All Centralities



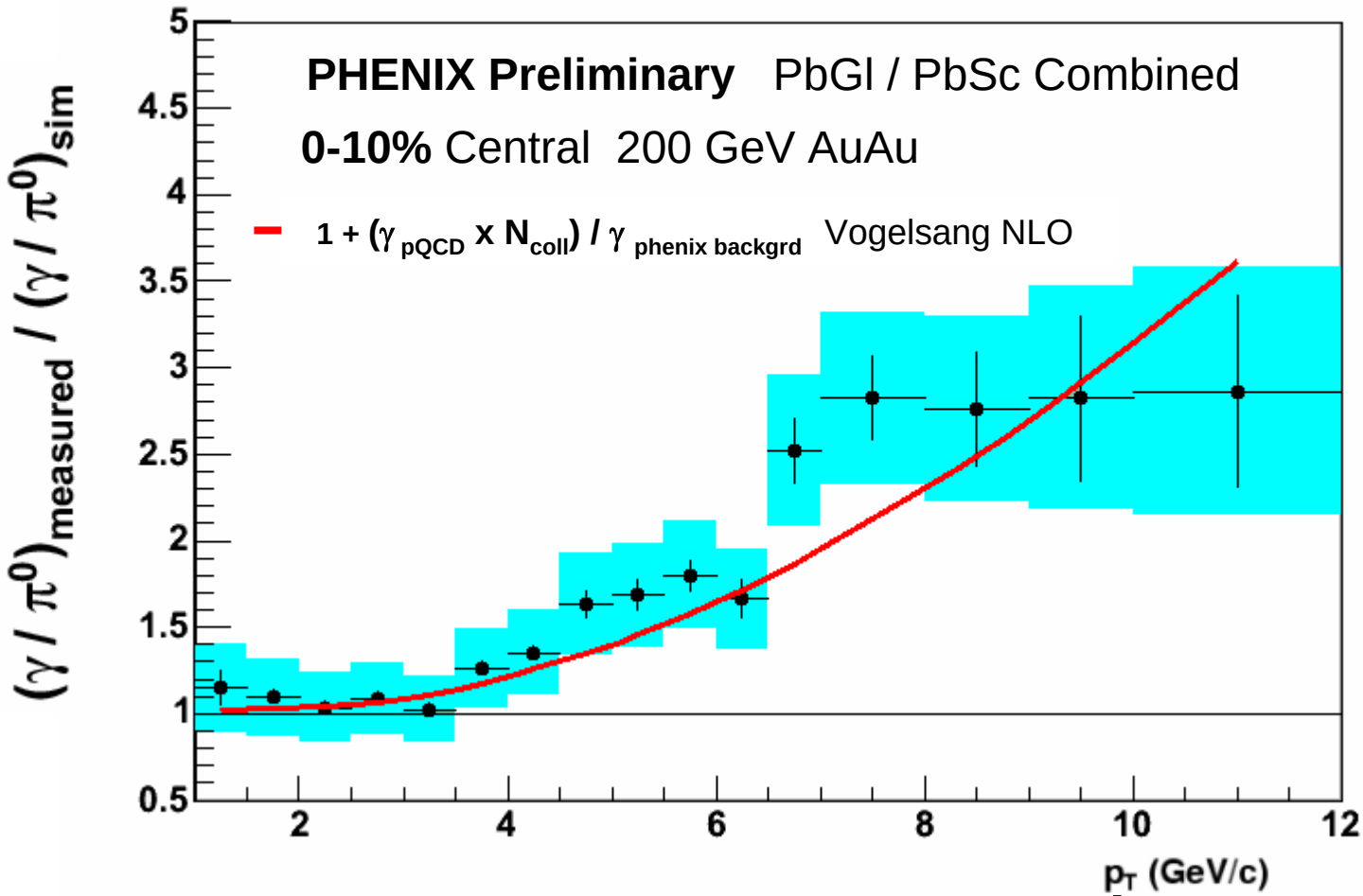
$[\gamma/\pi^0]_{measured} / [\gamma/\pi^0]_{background} = \gamma_{measured}/\gamma_{background}$

Excess Over Background Ratios, All Centralities



$[\gamma/\pi^0]_{measured} / [\gamma/\pi^0]_{background} = \gamma_{measured}/\gamma_{background}$

Excess Over Background Ratios, All Centralities



$[\gamma/\pi^0]_{measured} / [\gamma/\pi^0]_{background} = \gamma_{measured}/\gamma_{background}$

Systematic Errors

On γ/π Double Ratio (1σ in %)

	Central			Periph.	
γ/π Measured	3GeV	7	11	3GeV	7
Efficiencies	11	9	9	9	9
Acceptance	2	2	2	2	2
π0 merge to MisID γ			6.3		
energy-scale	3.6	2.4	3.3	2.8	0.5
energy-nonlinearity	3.5	0.7	0.7	3.5	0.7
Level2 trigger		1	0		1
Photon Spectra					
Central overlap eff. ε	4				
conversions	1.7	1.7	1.7	1.7	1.7
charge contam.	8.6	4	4	8.6	4
neutral had. contam.	5.8	2.8	2.8	5.8	2.8

	Central			Periph.	
π^0 ***Spectra***	3GeV	7	11	3GeV	7
acceptance fit	3	1	1	3	1
conversions	1.7	1.7	1.7	1.7	1.7
point to pt. extraction	10	8	8	8	8
γ/π Expected Background					
η/π	4	4	4	4	4
other decays	1.7	1.7	1.7	1.7	1.7
fit to π0	3	3	3	3	3
π0 pT-correllated	4	4	4	4	4
systematic errors					

Totals:	21	15	17	18	15
	3GeV	7GeV	11GeV	3GeV	7GeV
	Central			**Periph.**	

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Conclusions

- First PHENIX full measurement of direct γ made in pp.
- p-p result consistent with pQCD direct γ calc.
- In AuAu, a large photon excess above expected background is observed in central events – a very significant direct photon signal!
- In central 20%, direct γ dominate decay γ above ~7 GeV/c
- This signal gets stronger with increasing centrality.
- This behavior is consistent with the measured suppression of the π^0 along with an **unsuppressed, binary scaled** pQCD p-p prediction.
- Binary scaling holds, even at AuAu values of N_{coll} !
- With apparent continued π^0 suppression, direct γ's will be an excellent control complement to study very high p_T suppression in current Run4!

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12 Countries; 58 Institutions; 480 Participants*

Brazil	University of São Paulo, São Paulo
China	Academia Sinica, Taipei, Taiwan
	China Institute of Atomic Energy, Beijing
	Peking University, Beijing
France	LPC, University de Clermont-Ferrand, Clermont-Ferrand
	Dapnia, CEA Saclay, Gif-sur-Yvette
	IPN-Orsay, Universite Paris Sud, CNRS-IN2P3, Orsay
	LLR, Ecòle Polytechnique, CNRS-IN2P3, Palaiseau
	SUBATECH, Ecòle des Mines at Nantes, Nantes
Germany	University of Münster, Münster
Hungary	Central Research Institute for Physics (KFKI), Budapest
	Debrecen University, Debrecen
	Eötvös Loránd University (ELTE), Budapest
India	Banaras Hindu University, Banaras
	Bhabha Atomic Research Centre, Bombay
Israel	Weizmann Institute, Rehovot
Japan	Center for Nuclear Study, University of Tokyo, Tokyo
	Hiroshima University, Higashi-Hiroshima
	KEK, Institute for High Energy Physics, Tsukuba
	Kyoto University, Kyoto
	Nagasaki Institute of Applied Science, Nagasaki
	RIKEN, Institute for Physical and Chemical Research, Wako
	RIKEN-BNL Research Center, Upton, NY
	Rikkyo University, Tokyo, Japan
	Tokyo Institute of Technology, Tokyo
	University of Tsukuba, Tsukuba
	Waseda University, Tokyo
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	Korea University, Seoul
	Myong Ji University, Yongin City
	System Electronics Laboratory, Seoul Nat. University, Seoul
	Yonsei University, Seoul
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	Joint Institute for Nuclear Research, Dubna
	Kurchatov Institute, Moscow
	PNPI, St. Petersburg Nuclear Physics Institute, St. Petersburg
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	Florida Technical University, Melbourne, FL
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	University of Illinois Urbana Champaign, Urbana-Champaign, IL
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	Los Alamos National Laboratory, Los Alamos, NM
	Lawrence Livermore National Laboratory, Livermore, CA
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*as of January 2004

Backup: Rcp for Eta, Pi0