Measurement of the neutral pion cross section in proton-proton collisions at $\sqrt{s}$=200 GeV with PHENIX

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Kyoto Univ.

A RIKEN BNL Research Center Workshop

"Current And Future Directions at RHIC"

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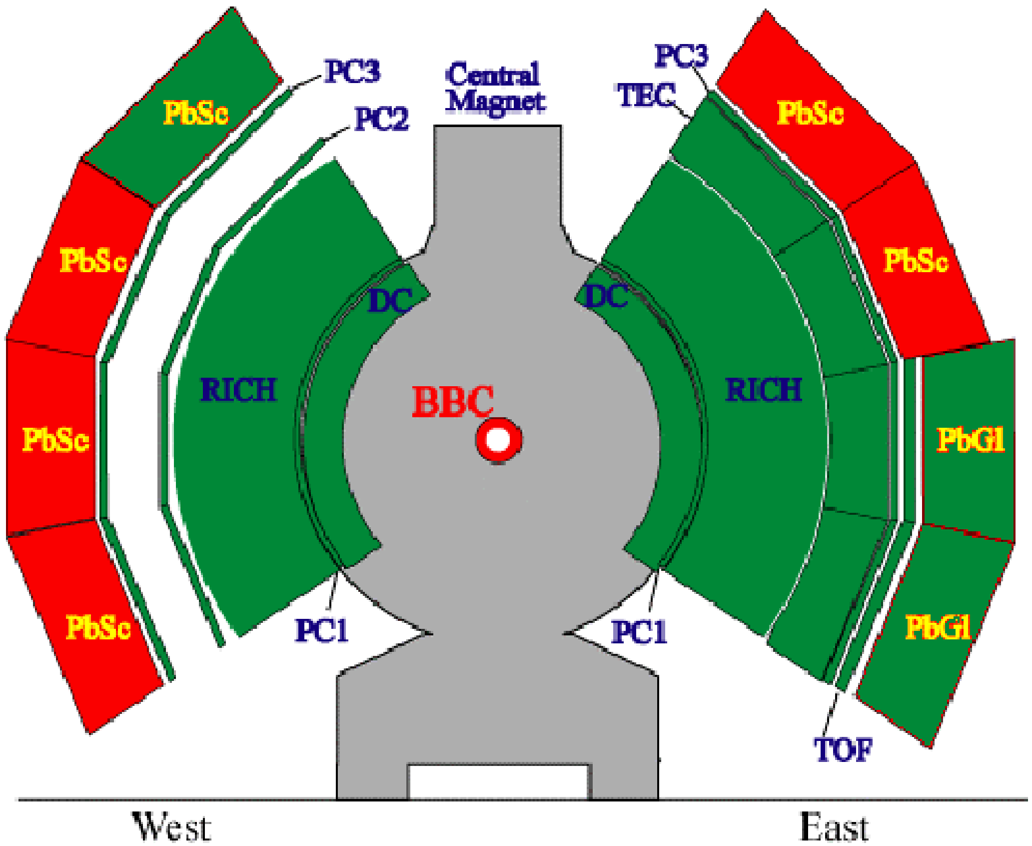
Physics Motivation

- Provide a testing ground for precision perturbative QCD
  - Baseline for future polarized pp collision analysis and asymmetry measurement
- Data baseline for high p_T heavy ion physics
  - Compare with peripheral Au+Au collisions as consistency check
  - Compare with central Au+Au collisions
    - Especially for high p_T physics in Au+Au
- In this talk, we compare the π^0 cross section with a NLO pQCD calculation and provide reliable data for heavy ion data comparison.

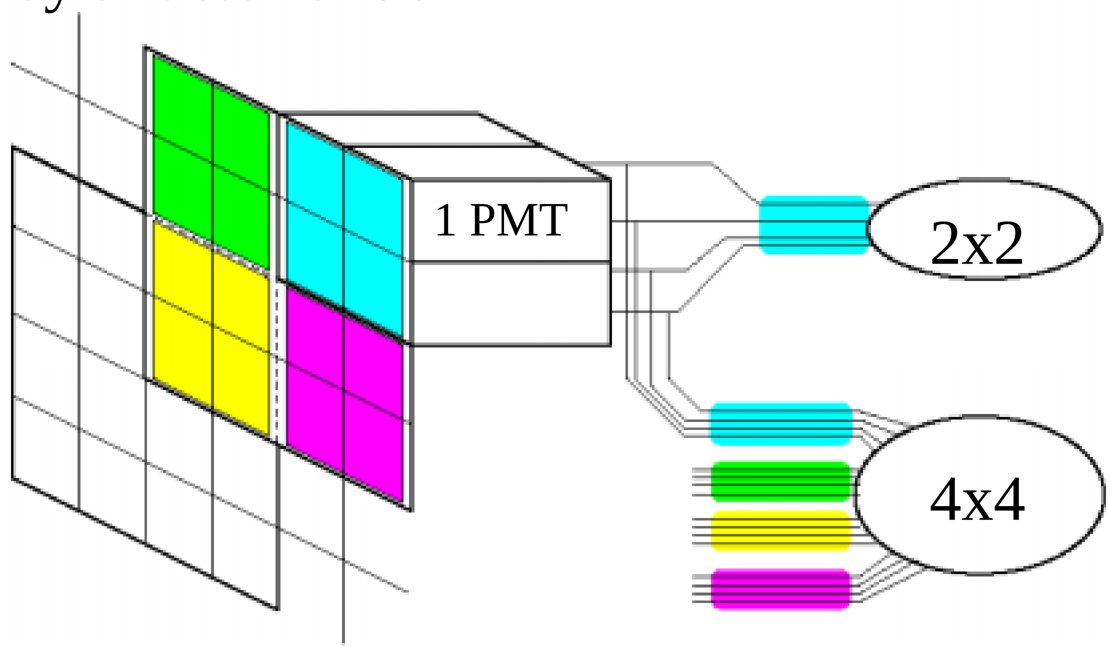
RHIC-PHENIX

- RHIC run2002 pp run
  - Integrated luminosity 0.15pb-1
  - Analyzed luminosity 0.03pb-1
    - half of runs are analyzed.
    - Vertex position cut +-30cm
    - 140M events
- EMCalorimeter
  - 2 Arm × 4 sectors
    - Lead Scintillator(PbSc)
      6 sectors(15552 channels)
    - Lead Glass (PbGl)
      2sectors (9216 channels)
  - ~5m distance from collision point
    - $|\eta|<0.38$ $\phi = 180°$
- Analysis
  - 5 sectors PbSc is used in this analysis
    - 1 PbSc/2 PbGl needs time to do fine tuning of calibration



EMCal-RICH level 1 Trigger

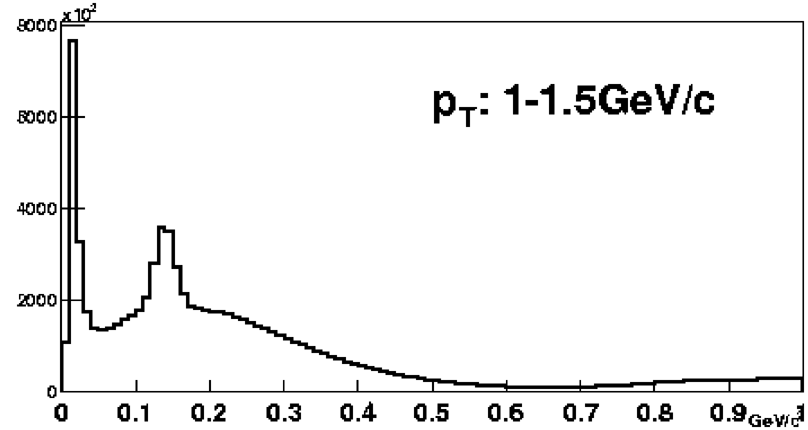
- EMCal part consists of two types of sum to collect photon shower
  - 2x2 towers non-overlapping sum (threshold=0.8GeV)
  - 4x4 towers overlapping sum (threshold=2 and 3GeV)
- π^0 measurement with **<u>2x2 trigger</u>** will be shown in this talk
  - Enhances high-p^T π^0 by a factor of 90

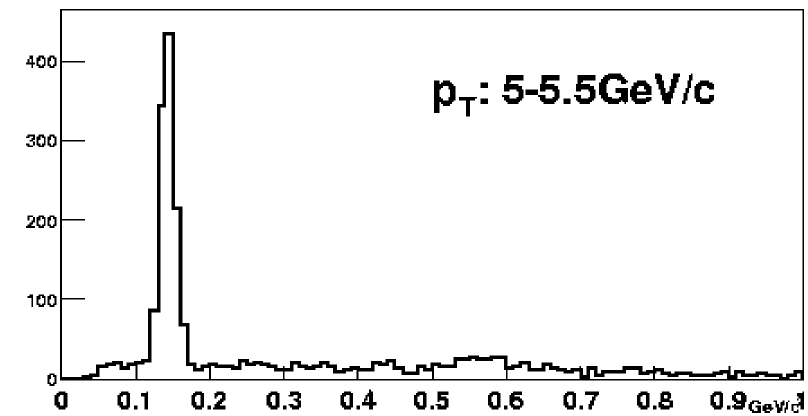


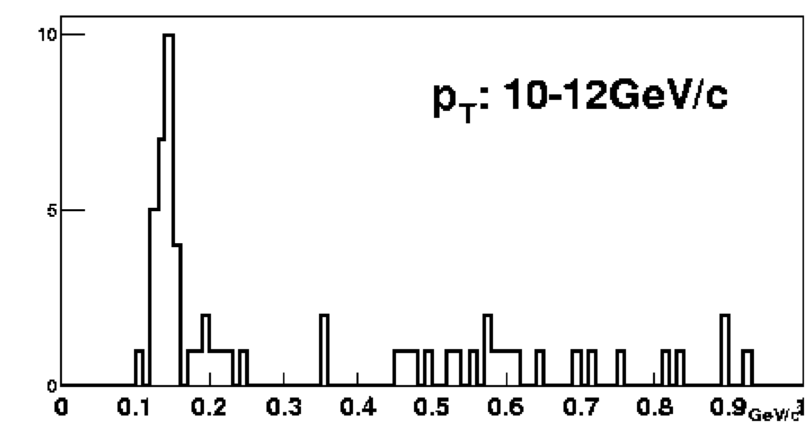
π^0 Measurement

- Invariant mass spectrum
- The background is smaller than that of heavy ion collisions
  - 1-1.5GeV/c N/S = 200%
  - p_T>5GeV/c N/S = 10%

- 2x2 trigger worked very well
  - Rejection Factor = 90
  - Measured 1-15GeV/c π^0
    - 30 π^0 at 10-12GeV/c
    - 10 π^0 at 12-15GeV/c







Analysis Procedure

$$\varepsilon^{(MB)}$$

51%

Minimum Bias(MB) Trigger efficiency

Luminosity normalization

$$\varepsilon_{\pi 0}^{(MB)}(p_T) = \frac{N_{\pi 0}^{(MB\&4\times4)}}{N_{\pi 0}^{(4\times4)}}$$

π^0 efficiency in Min. Bias trigger 75% flat

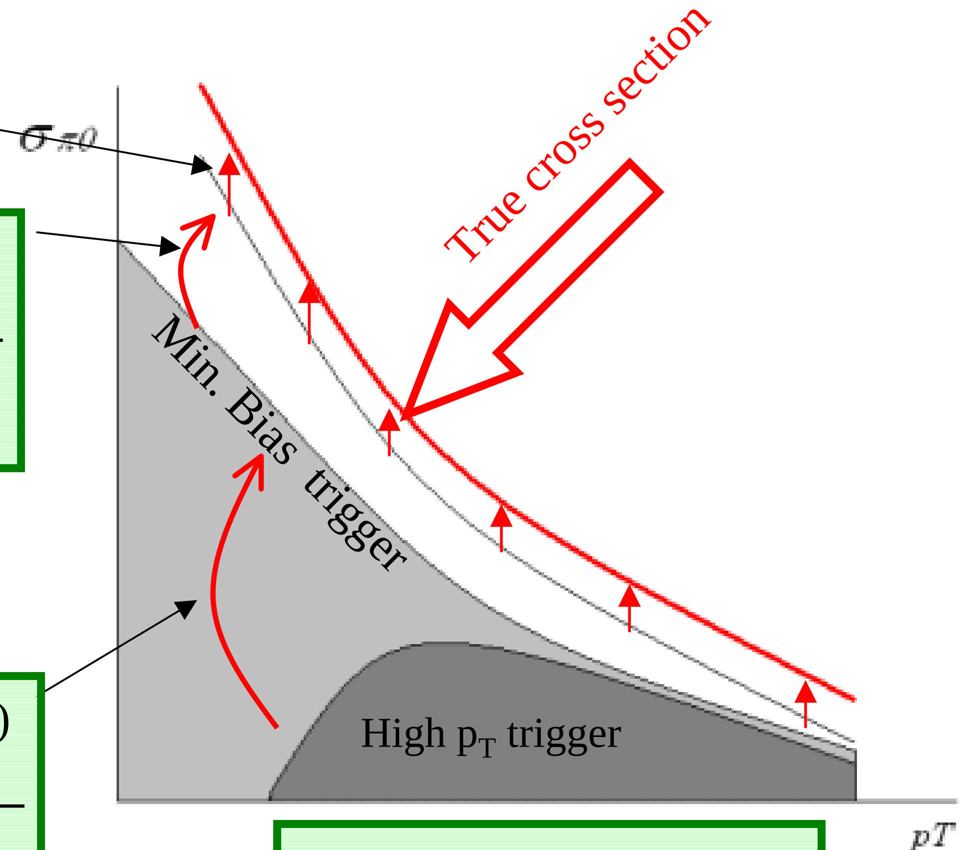
Slope correction for Min. Bias trigger

$$\varepsilon_{\pi 0}^{(High)}(p_T) = \frac{N_{\pi 0}^{(2\times2\&MB)}}{N_{\pi 0}^{(MB)}}$$

80% flat for p_T> 3GeV

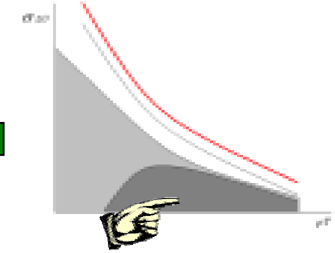
π^0 efficiency in 2x2 trigger

“turn-on” curve for trigger



$$N_{\pi 0}^{(High)} C_{\pi 0}^{reco}(p_T)$$

$C_{\pi 0}^{reco}(p_T)$: Fast MC Tuning



- Generate π^0 at given p_T,η and decay into two photon
  - π^0 p_T distribution from UA1 $(h^{+}+h^{-})/2$
- One photon makes one cluster
  - Energy resolution

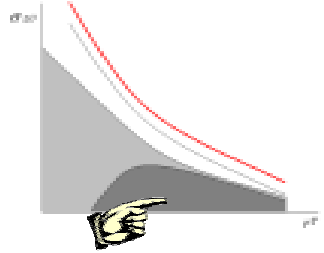
    $\sigma_E/E=8.1\%/\sqrt{E} \oplus 2.1\%$ → Tuning → $8.8\%/\sqrt{E} \oplus 4.7\%$
    - Measured by electron and tracking momentum.
  - Absolute energy

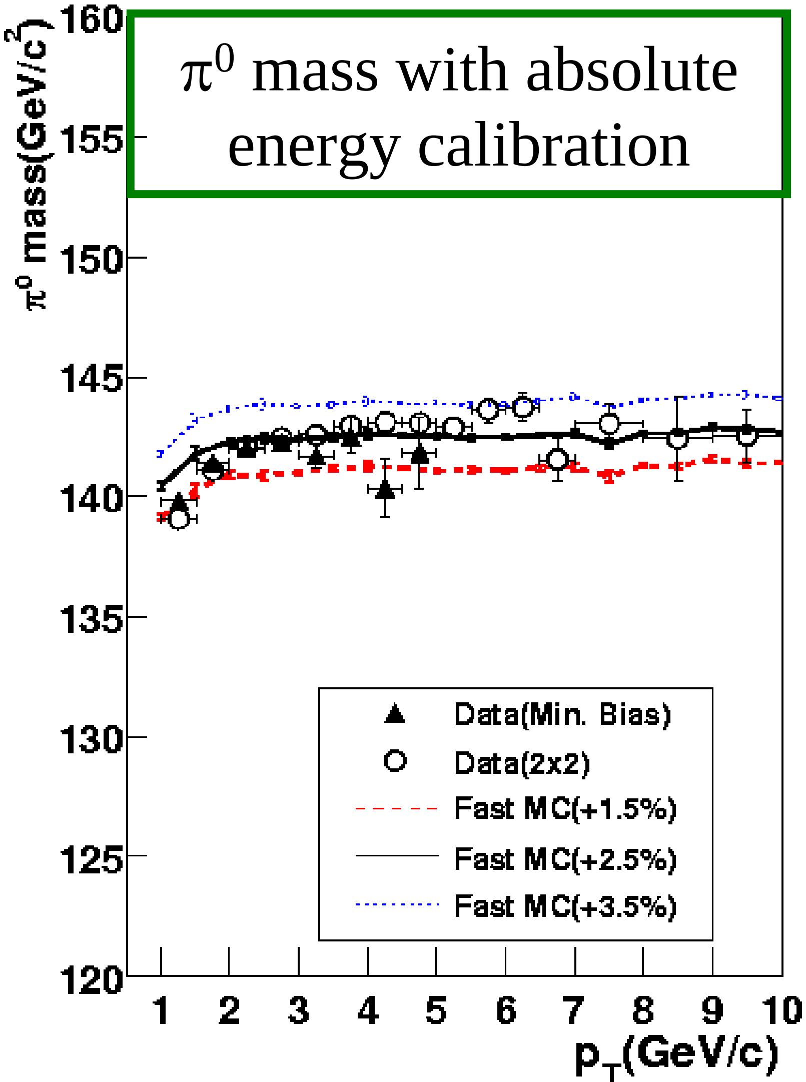
    $\Delta E/E=+2.5\%$ higher
    - Consistent with π^0 mass, Ionization energy by h^{+-}, and E/p by electron
  - Position resolution

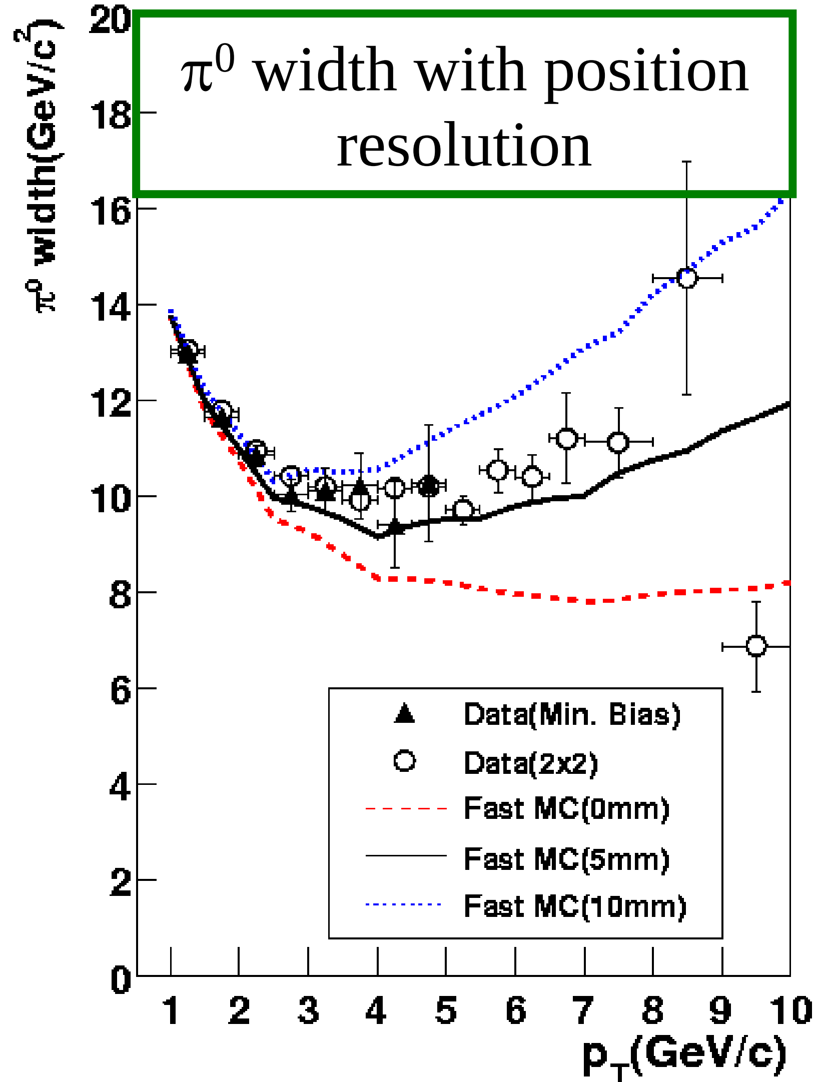
    $\sigma = (1.4\text{mm} + 5.9\text{mm}/\sqrt{E}) \oplus 20\text{mm}\times\cos(\theta)$ → Tuning →

    $(6.4\text{mm} + 5.9\text{mm}/\sqrt{E}) \oplus 20\text{mm}\times\cos(\theta)$
  - Threshold effect
    - Simulate photon shower shape and impose tower energy threshold.

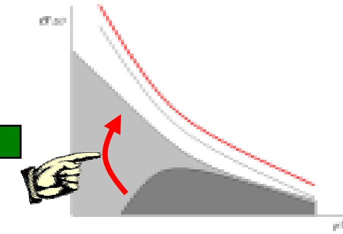
$C_{\pi 0}^{reco}(p_T)$: Example of Systematic Error Estimation





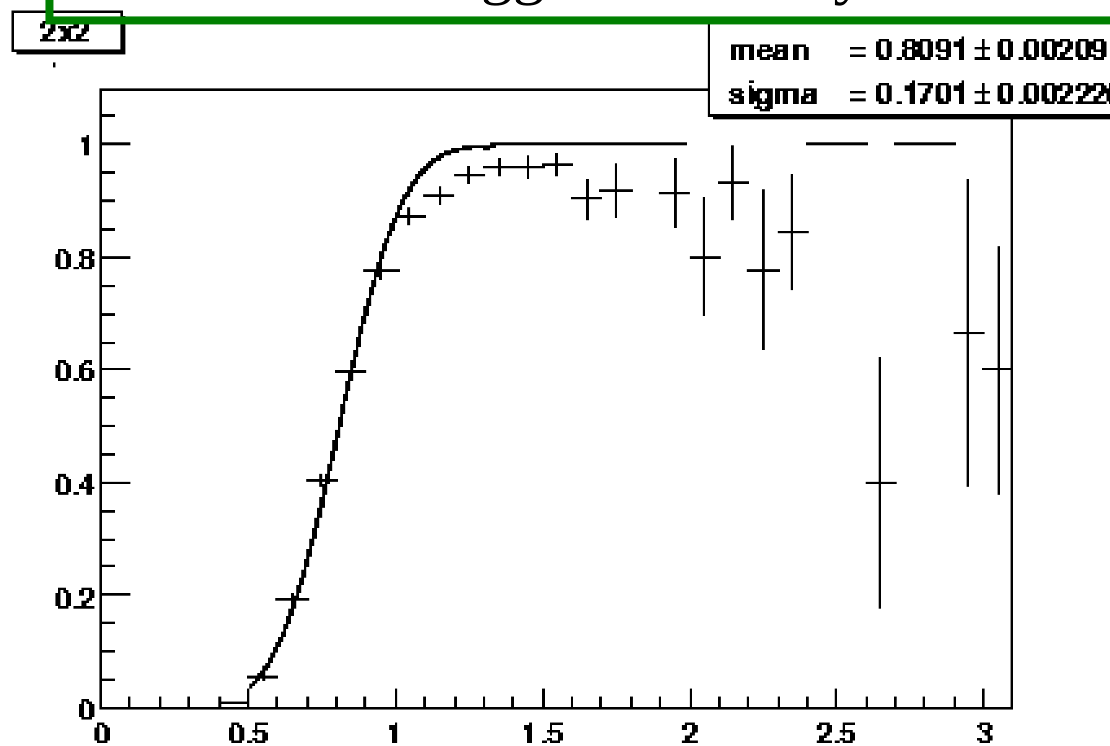


$\varepsilon_{\pi 0}^{(High)}(p_T)$: Trigger Threshold



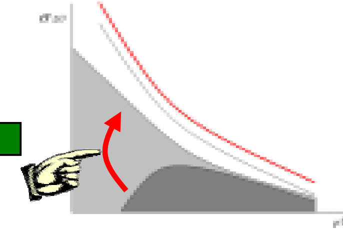
- Trigger 2x2 tile turn-on-curve
  - Measured by data
  - 0.8GeV threshold

Tile trigger efficiency

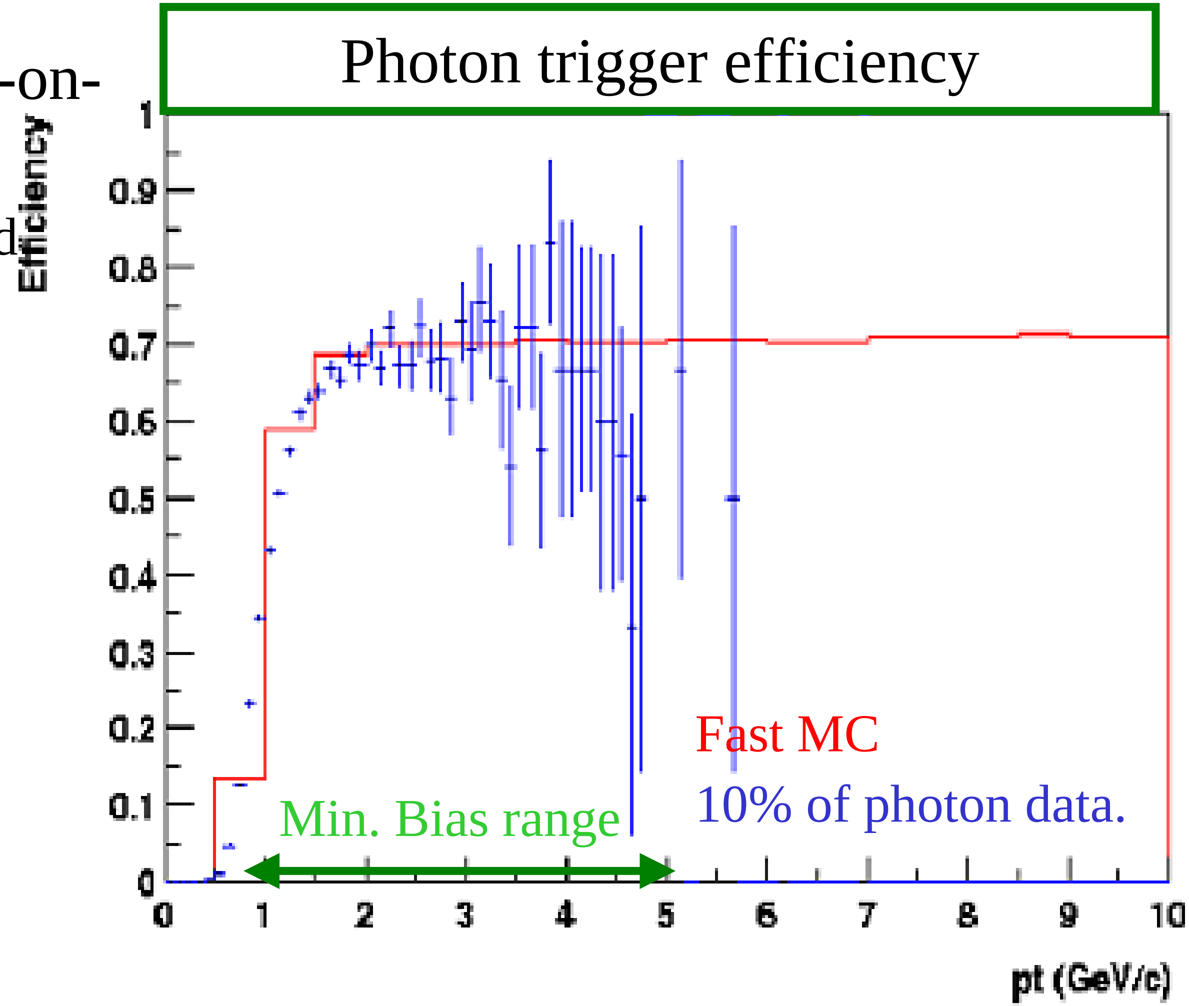


[GeV/tile]

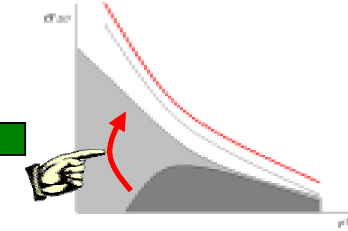
$\varepsilon_{\pi 0}^{(High)}(p_T)$: Trigger threshold



- Photon trigger efficiency
- Fast MC
  - Input trigger turn-on-curve
    - 0.8GeV threshold
    - 0.14GeV width
  - Simulate photon



$\varepsilon_{\pi 0}^{(High)}(p_T)$: Trigger threshold



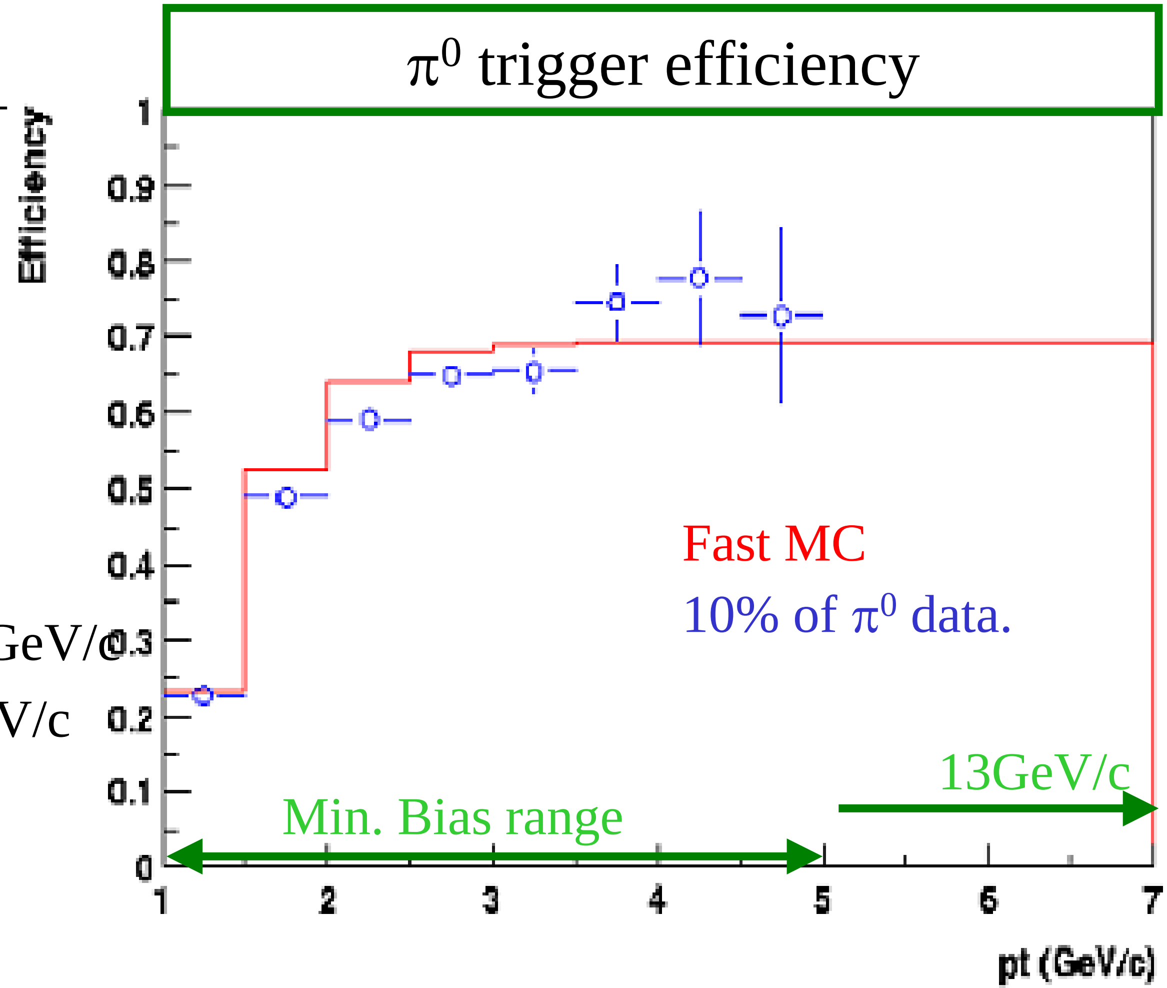
- Direct measurement

$$\varepsilon_{\pi 0}^{(High)} = \frac{N_{\pi 0}^{(2\times 2\& MB)}}{N_{\pi 0}^{(MB)}}$$

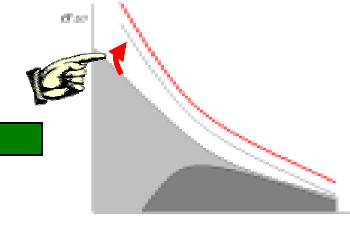
- They are consistent

<10%

- The trigger efficiency saturates at >3GeV/c
  - Min. Bias data for 1-3GeV/c
  - 2x2 trigger for 3-15GeV/c



$\varepsilon_{\pi 0}^{(MB)}(p_T)$: π^0 Efficiency in MB Trigger

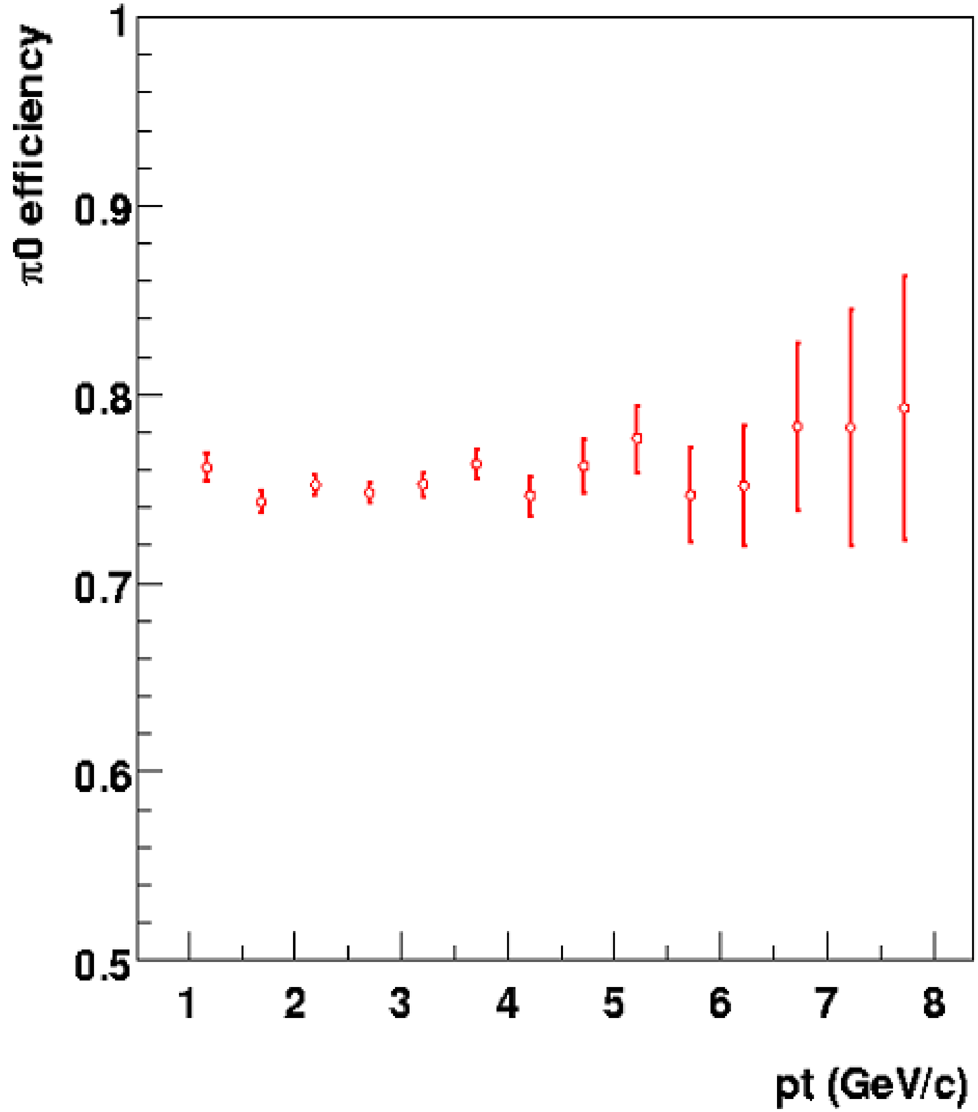


- π^0 slope correction in Min. Bias(MB) trigger

$$\varepsilon_{\pi 0}^{(MB)} = \frac{N_{\pi 0}^{(MB\&4\times 4)}}{N_{\pi 0}^{(4\times 4)}}$$

- Since the 4x4 trigger is a self trigger, systematic errors might be
  - Multiple hits
  - Beam gas/cosmic ray

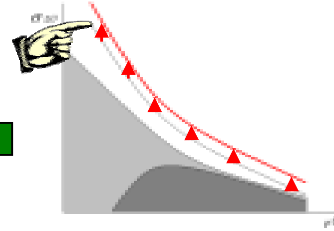
→ Small effects



p_T Dependent Systematic Error

– $N_{\pi 0}$	Run dependence	10%(Min. Bias)
		6%(2x2)
	Background subtraction	5%
	Excluded Hot/Bad towers	2-3%
– $C_{reco}(p_T)$	Energy non-linearity	0-10%
	Fast MC statistical error	1%
	Edge tower	5%
	Position resolution	0-1%
	Energy absolute calibration	3-8%
	Energy resolution constant term	<2%
	Energy resolution fluctuation term	<2%
– $\varepsilon_{\pi 0}^{2x2}(p_T)$	2x2 High p_T trigger threshold	10%

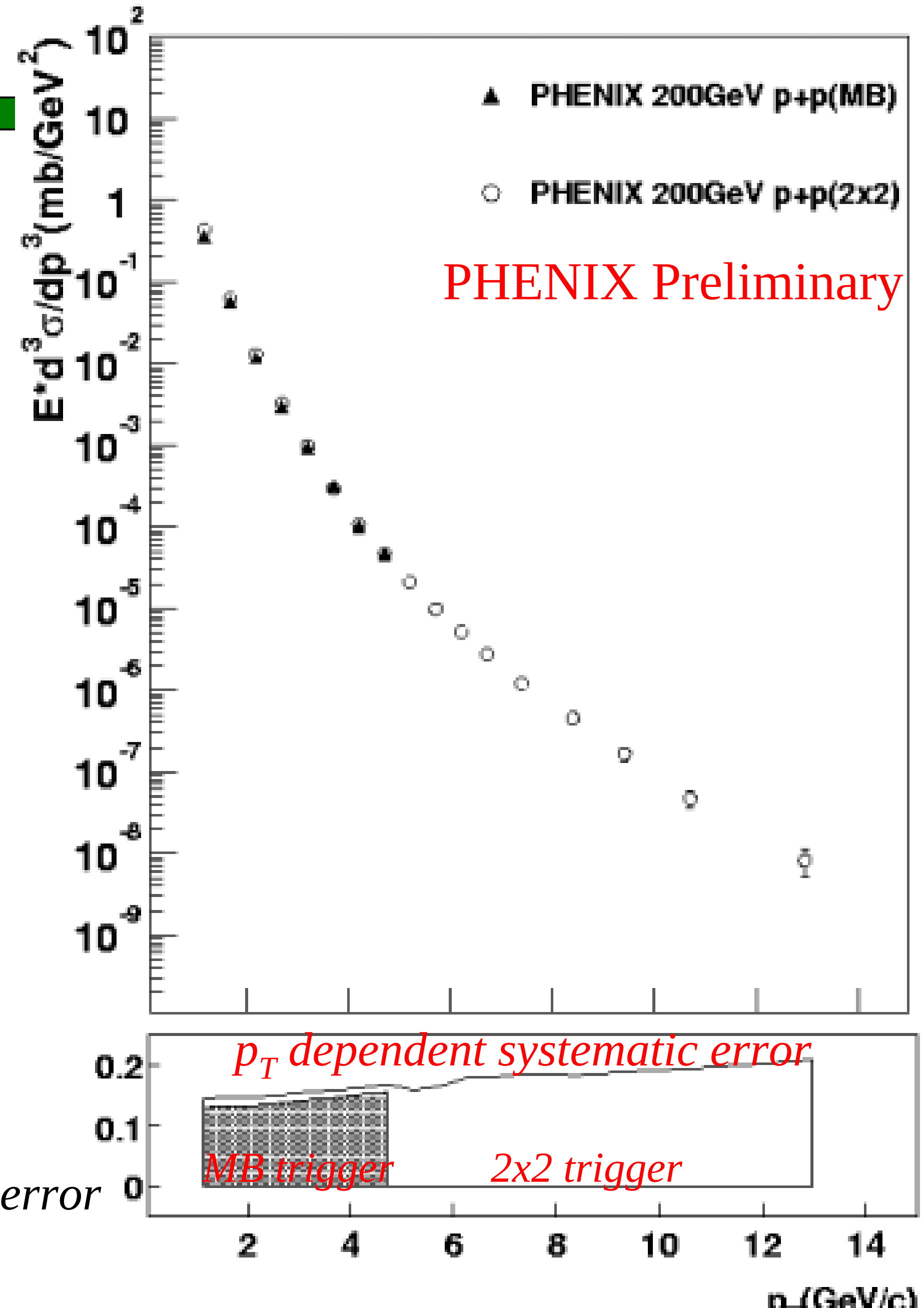
$\varepsilon_{\pi 0}^{(MB)}$: Normalization



- Two methods of luminosity measurement
  - PYTHIA/GEANT simulation
    - To estimate Min. Bias(MB) trigger efficiency
    - Luminosity $= N_{MB} / (\sigma_{pp} \times \varepsilon_{MB})$
  - van der Meer/Vernier Scan
    - Measurement of transverse size of the beam
    - By combination of beam current→ luminosity
- Comparison gauges the systematic error
- There are still some corrections which need to be finalized.
  - In this talk, we assigned 30% systematic error
    - Because 30% is maximum error for p+p cross section to reach total (inelastic + elastic) cross section

π^0 Inclusive Cross Section

- Cross section measured over 8 orders of magnitude.
  - 1-13GeV/c
- Two triggers
  - Minimum Bias(MB) trigger
  - 2x2 trigger
  - They are consistent within systematic error.
  - To minimize the systematic error
    - Min. Bias data for 1-3GeV/c
    - 2x2 trigger for 3-15GeV/c



Normalization systematic error 30% is not included here.

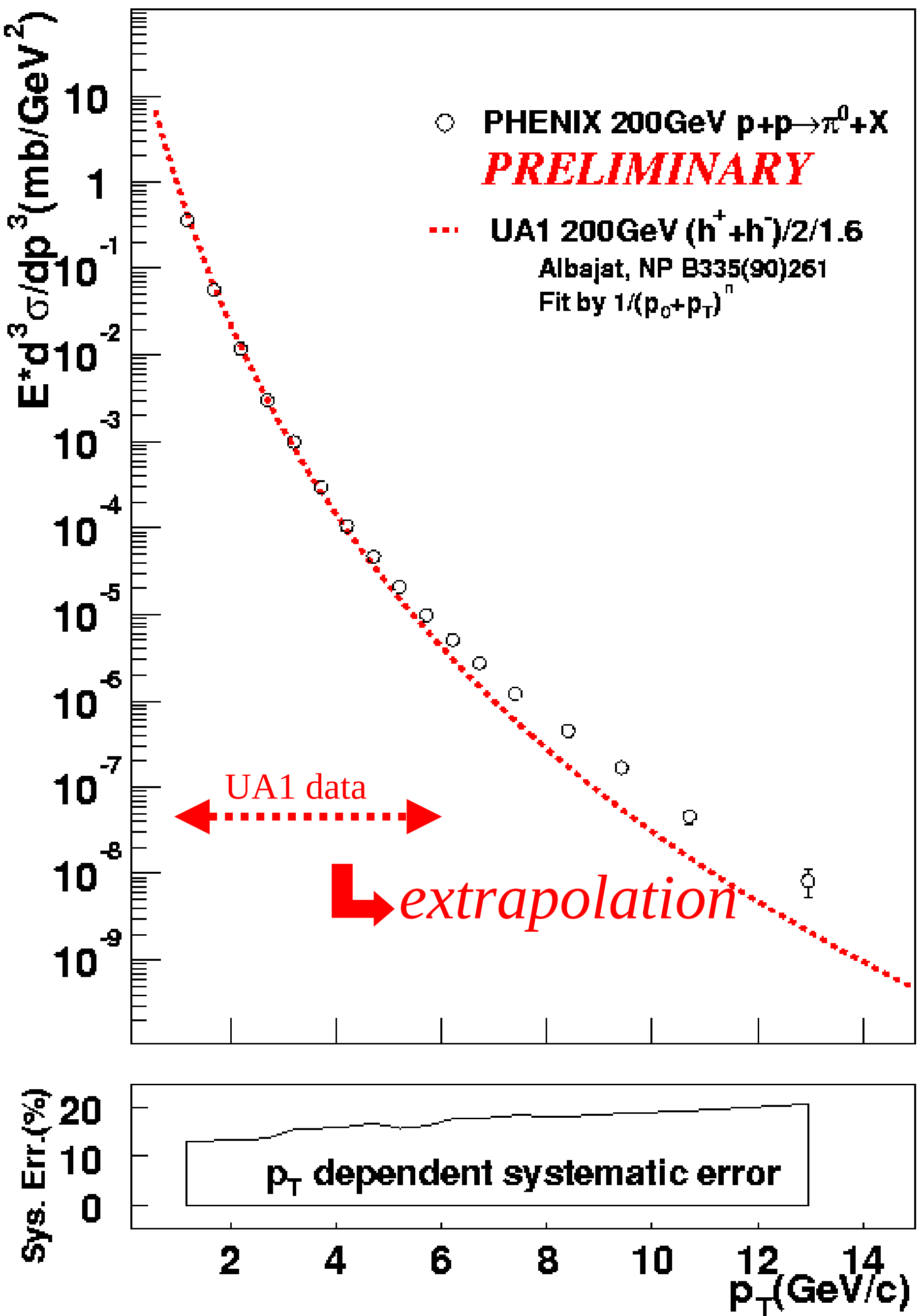
Comparison

- Comparison with existing data.
  - UA1
- Comparison with heavy ion.
  - AuAu peripheral data at 200GeV
  - AuAu central data at 200GeV
- Comparison with theory
  - NLO pQCD calculation

Comparison with UA1 Fitting

- UA1 data are only up to 6GeV/c and extrapolated to higher p_T
- The extrapolation is below our data at high p_T

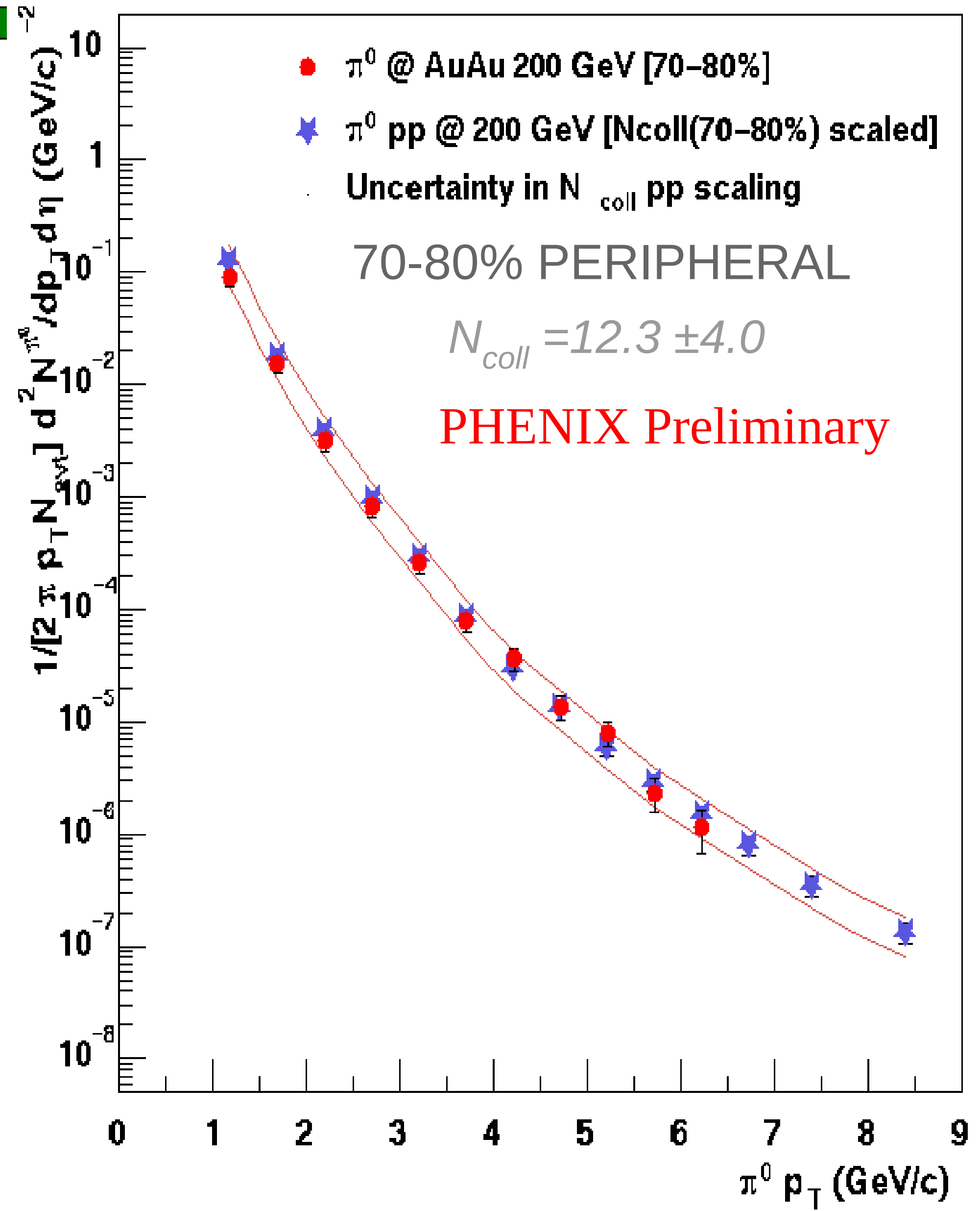
→Now we have pp data to use as important reference for Au+Au collision and jet quenching measurement.



Normalization systematic error 30% is not included here.

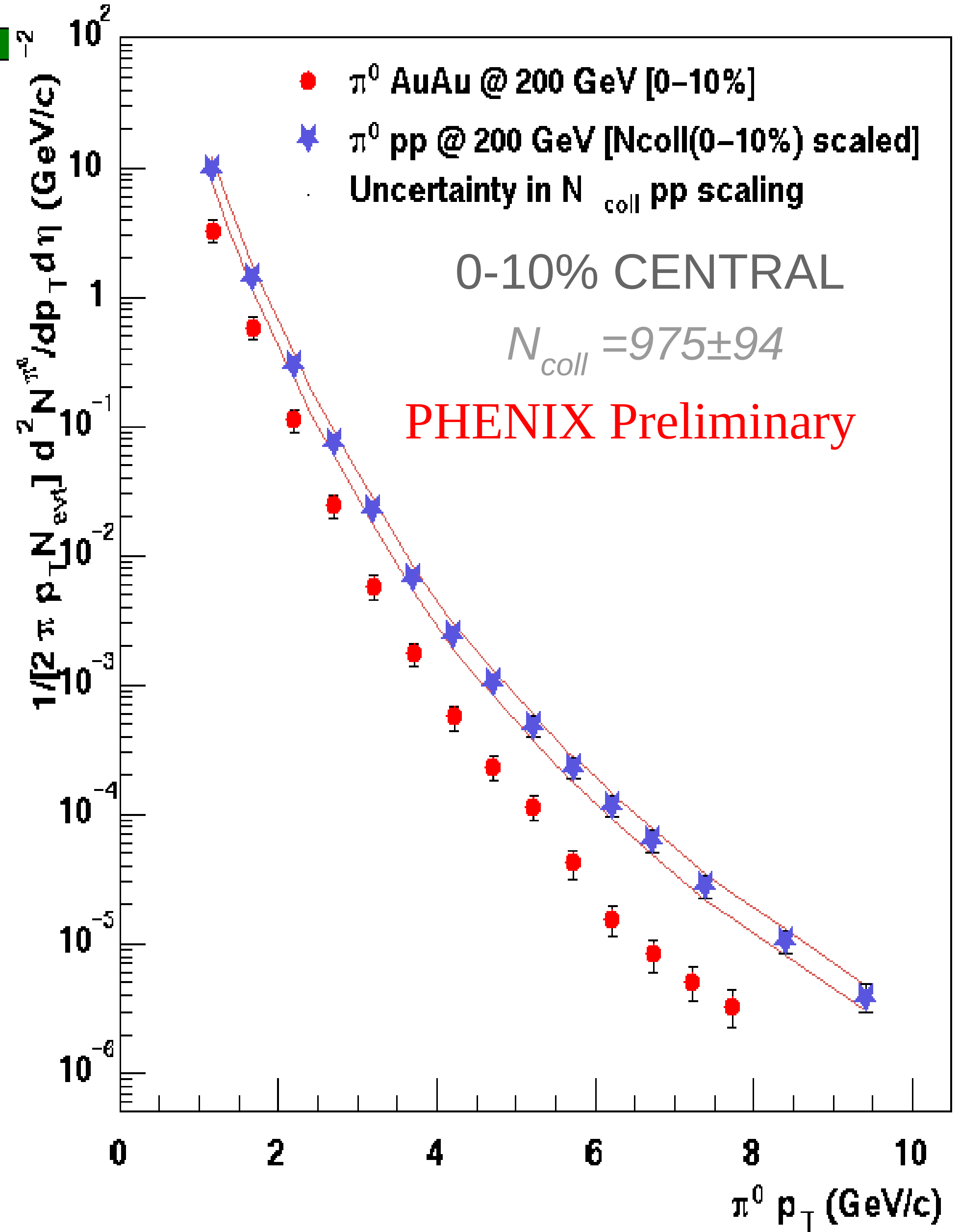
Comparison with AuAu Peripheral

- AuAu 200GeV peripheral data is up to 6GeV/c
  - The pp data is scaled up by the number of collision.
- They are consistent within Ncoll scaling



Comparison with AuAu Central

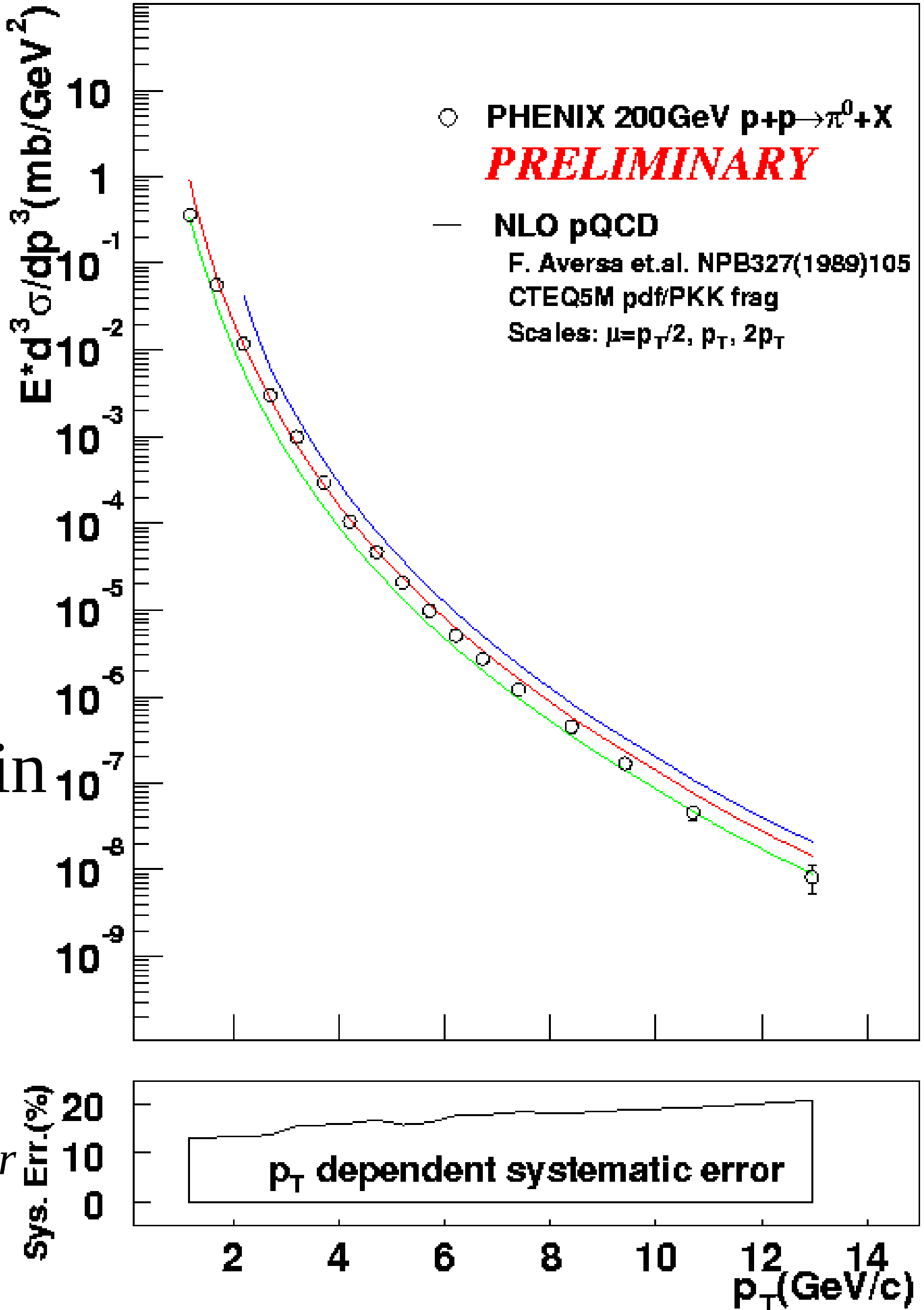
- AuAu 200GeV central data is up to 8GeV/c
  - The pp data is scaled up by the number of collision.
- AuAu data shows large suppression.
  - The suppression is dependent of pT
  - This might be understood by the jet quenching effect.



Comparison with QCD Calculation

- NLO pQCD calculation
  - CTEQ5M pdf
  - Potter-Kniehl-Kramer fragmentation function
  - $\mu = p_T/2,\ p_T,\ 2p_T$

    Thanks to W.Vogelsang
- Consistent with data within the scale dependence.



Normalization systematic error 30% is not included here.

Comparison with QCD Calculation

- The deviation of the pQCD calculation is depicted
  - The pQCD calculation with one a set of PDF/FF is consistent within the systematic error of the data and the scale selection

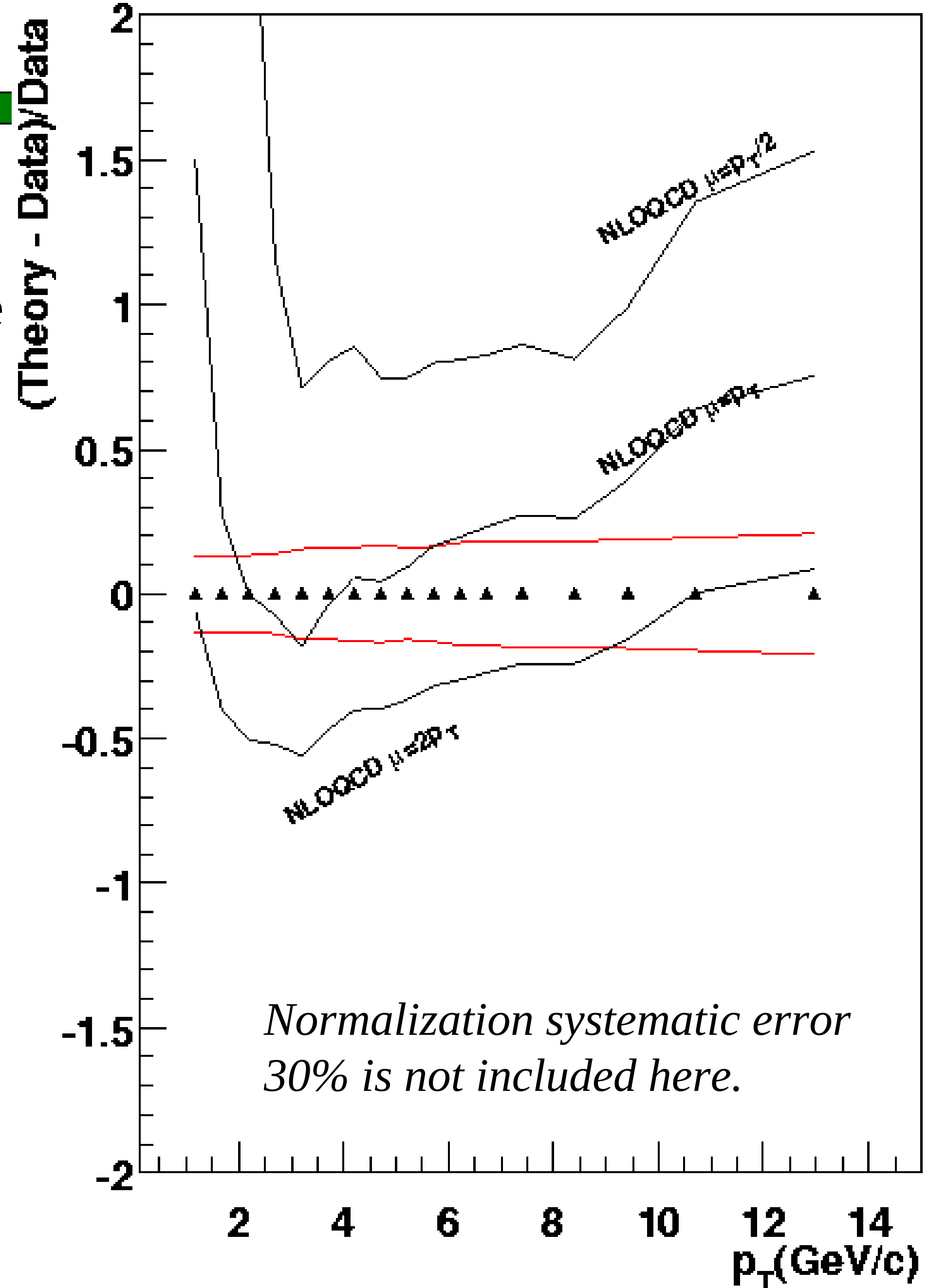
<u>O.K. So everybody is happy!!! Let's go to drink beer!!!</u>

Wait!!!!!

<u>What I want to say in this workshop is</u>

"Our data might be one more reference point for study of PDF and FF."

  - Dear all, please don't stop your head and hand !!!



Conclusion

- Measured π^0 cross section.
  - Photon trigger worked well
    - 8 orders of magnitude, 1-13GeV/c
    - Rejection factor = 90
  - Results from two triggers (Min. Bias and 2x2) are consistent within systematic error
- Comparison with UA1 extrapolation
  - Extrapolation underestimates data at high p_T
  - The data will be an important reference for A+A
- Comparison with AuAu
  - Consistent with AuAu peripheral
  - AuAu central shows large suppression
- Comparison with pQCD with NLO calculation
  - pQCD calculation agree with data

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