Photon Production

PHENIX

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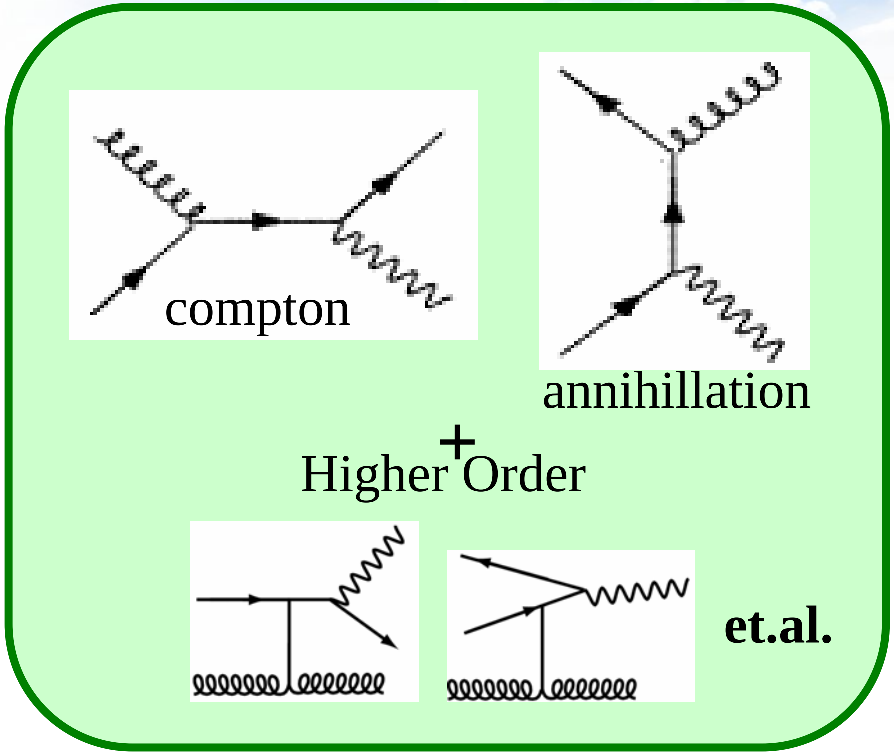
Outlines

- Introduction
  - Why photon? in p+p d+Au Au+Au
- Experiment
  - Electro Magnetic Calorimeter
- Analysis and Results
  - p+p , d+Au , and Au+Au
- Conclusion

Why Photon (p+p) ?

- Photon in p+p is a good probe for the parton structure.
    - Leading process
    - Higher order
    - Bremsstrahlung Process
- Why RHIC?
    - RHIC provides the highest energy as p+p collisions.
        - Very unique
        - As a basic for gluon spin measurement in the future.
        - A reference for d+Au and Au+Au.



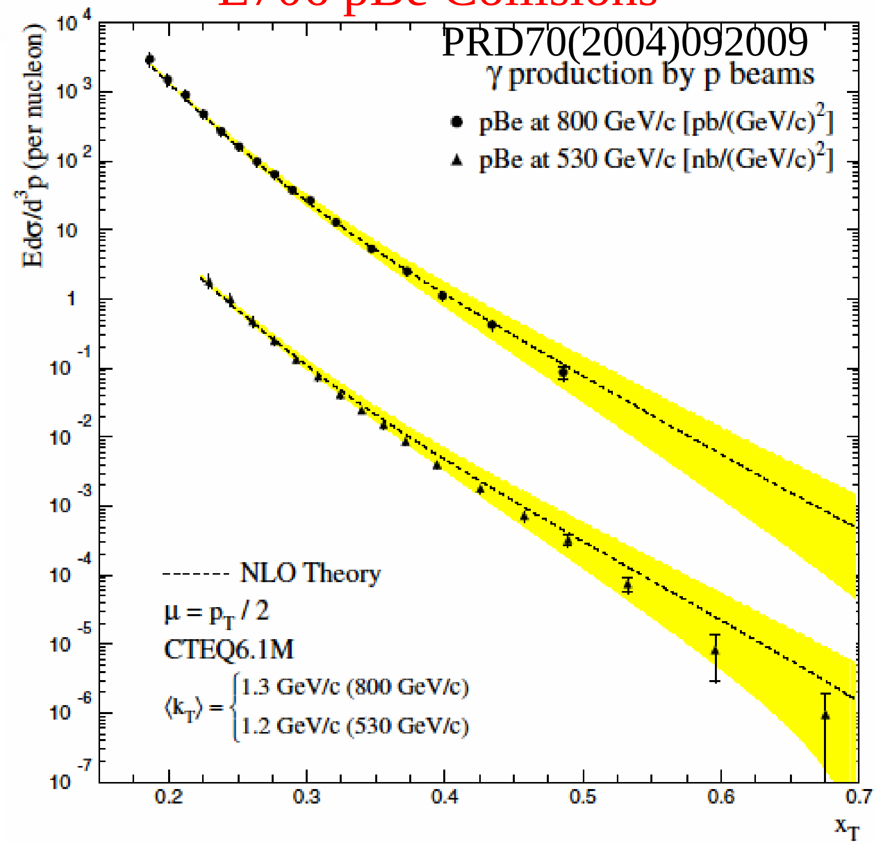
Photon in p+p is

a testing ground of pQCD

Why Photon (d+Au)?

- Nuclear Effect
  - Initial Parton Distribution
    - kT
    - (EMC effect)
    - (Shadowing, anti-shadowing)
    - (color glass condensate)
  - Final Parton Interaction
    - Multiple Scattering
    - Jet Quenching
    - ➔ Photon is less sensitive.

E706 pBe Collisions



Photon in d+Au is a good probe for modification of initial distribution

FNAL-E706 concluded kT=~1.3GeV/c in pBe collisions

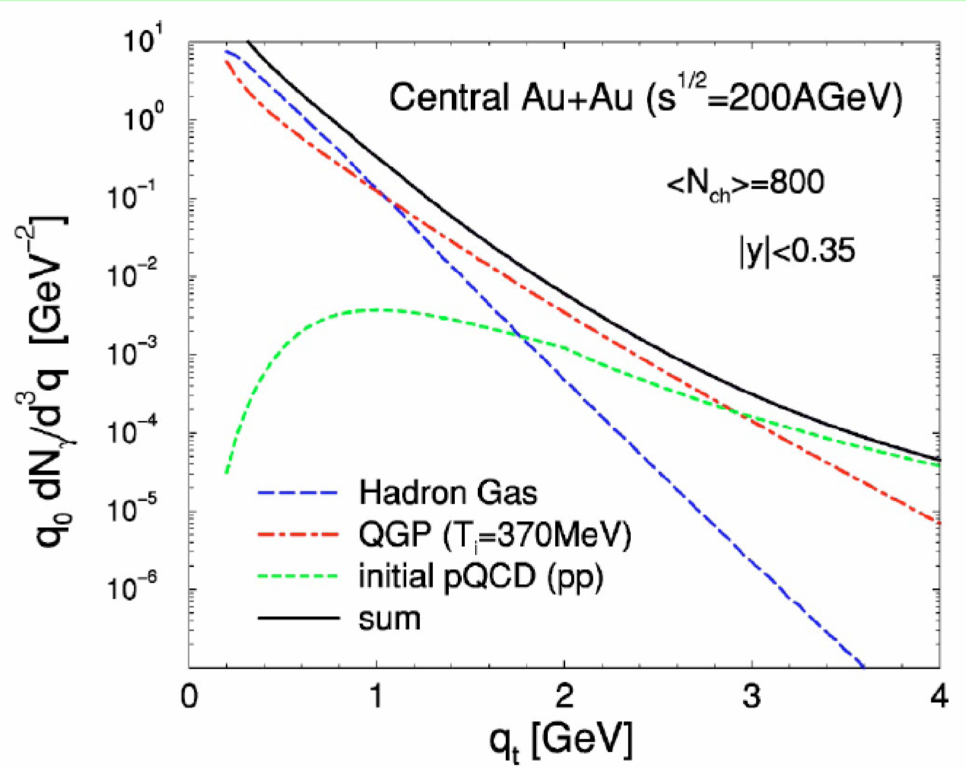
Why Photon (Au+Au)?

- Photon source
  - pQCD photons
    - Compton
    - Annihilation
    - Bremsstrahlung
  - Photons from jet quenching
  - Thermal photons
    - From hadron GAS
    - From QGP

Thermal photon is a good probe for QGP temperature

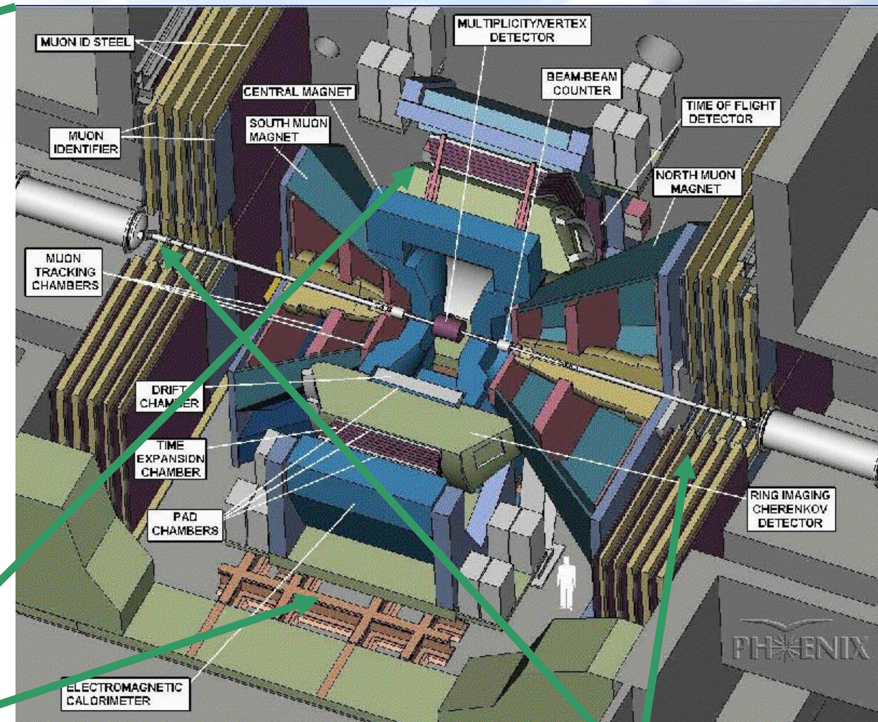
➔ Target 1-3GeV

Realistic Calculation



PRC69(2004)014903, Turbide, Rapp, Gale

PHENIX



2 central Spectrometers

2 forward Spectrometers

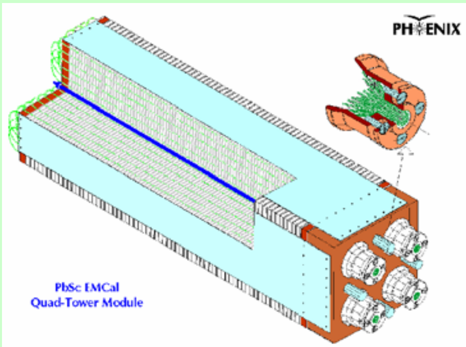
- 3.8km with 2 rings
  - 120bunch/ring
  - 106ns crossing time
- Maximum energy
  - 250GeV for p(polarized)
  - 100GeV/nucleon for Au
- Luminosity
  - Au-Au : 2 x $10^{26}cm^{-2}s^{-2}$
  - p-p : 2 x $10^{32}cm^{-2}s^{-2}$
- 6 Crossing points

- 3 detectors to measure the collision point, the luminosity, and the multiplicity.
  - Beam Beam Counter(BBC)
  - Zero Degree Calorimeter(ZDC)
  - Multiplicity and Vertex Detector(MVD)

Electro-Magnetic Calorimeter

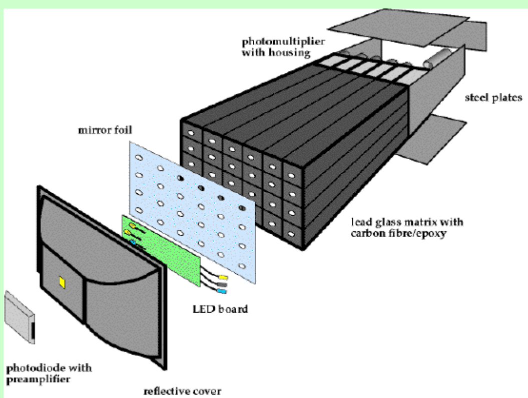
Lead Scintillator (PbSc)

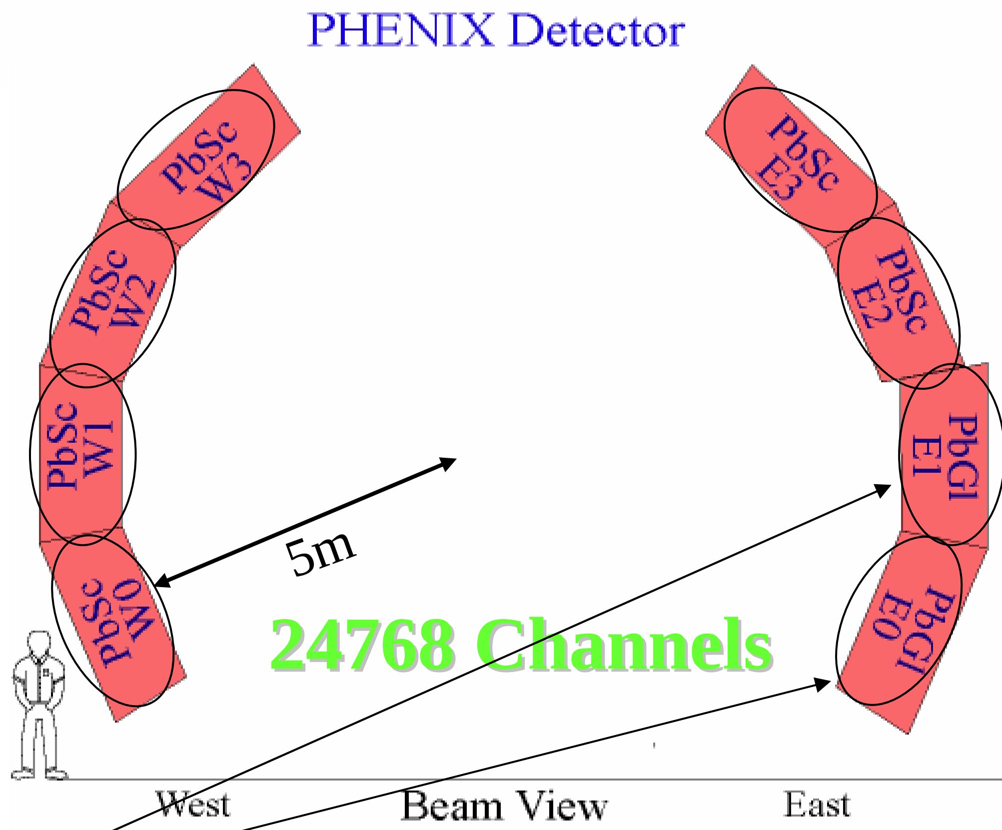
- Sandwich type calorimeter
  - Lead and scintillation plate
  - Shish-kebab type readout



Lead Glass (PbGl)

- Total reflection calorimeter





Coverage |η|<0.38 ϕ = 180°

Fine segmented calorimeter.

distinguish two photons from π0 photons pT~25GeV/c

p+p

Prompt Photon Production

Prompt photon production consists of two processes

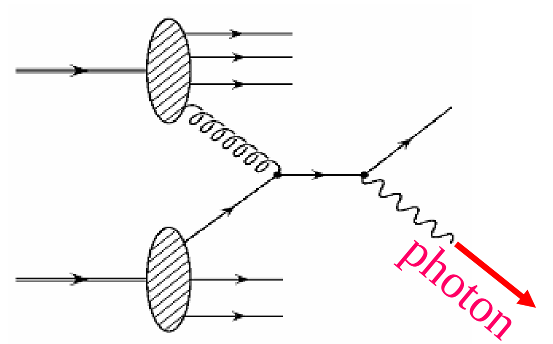
$$\sigma = \sigma_{dir} + \sigma_{frag} = \sum_{i,j,k} \int dx_i dx_j \times f_1^i(x_i, \mu) \cdot f_2^j(x_j, \mu) \times \left\{ \sigma(i + j \to \gamma) + \int dz\, \sigma(i + j \to k) \times D_k^3(z_k, \mu_F) \right\}$$

parton distribution function(PDF)

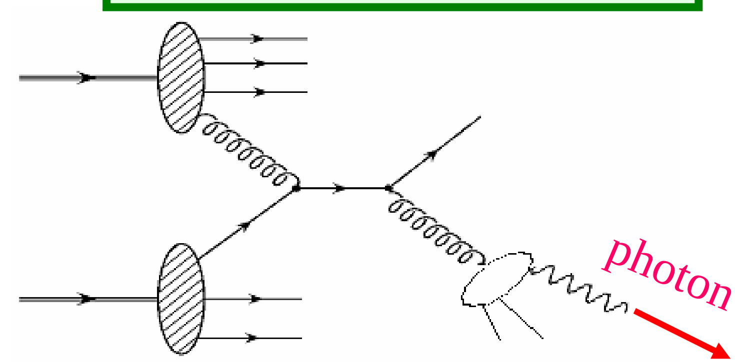
fragmentation function(FF)

Direct Process

Bremsstrahlung Process

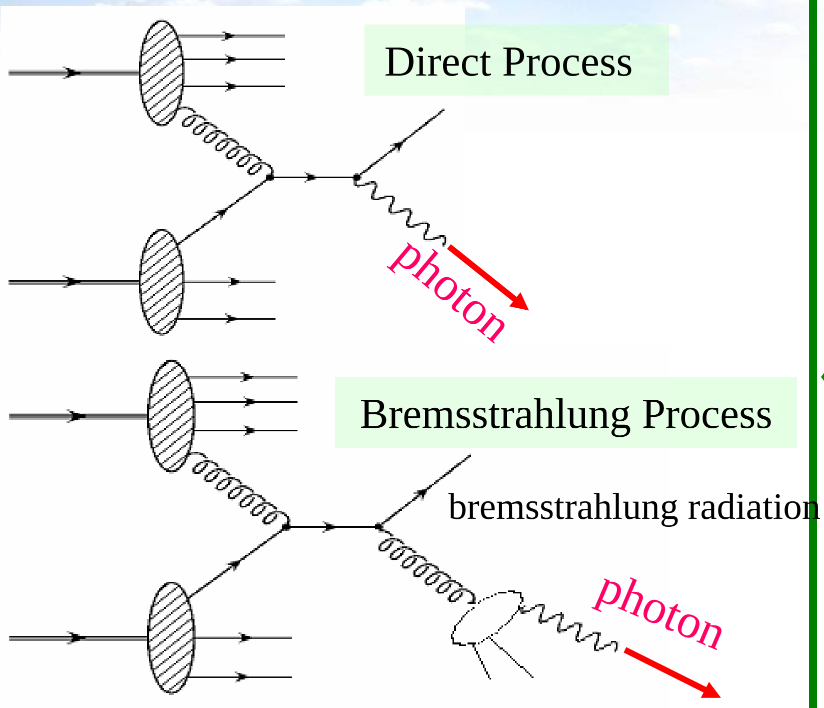


Compton/Annihilation process



In this talk, we compare our result with next-to-leading order(NLO) pQCD calculation

How to Measure?



No one know which photon from what.

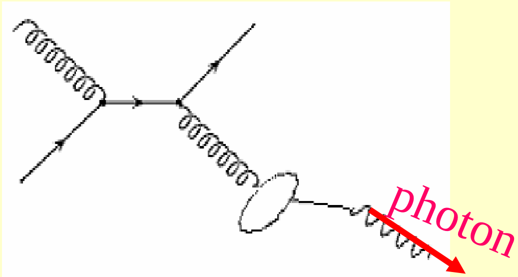
Background

Non-vertex Photon

Neutral hadron contribution

Noise in the detector

Hadron(π^0,η,ω..) decay

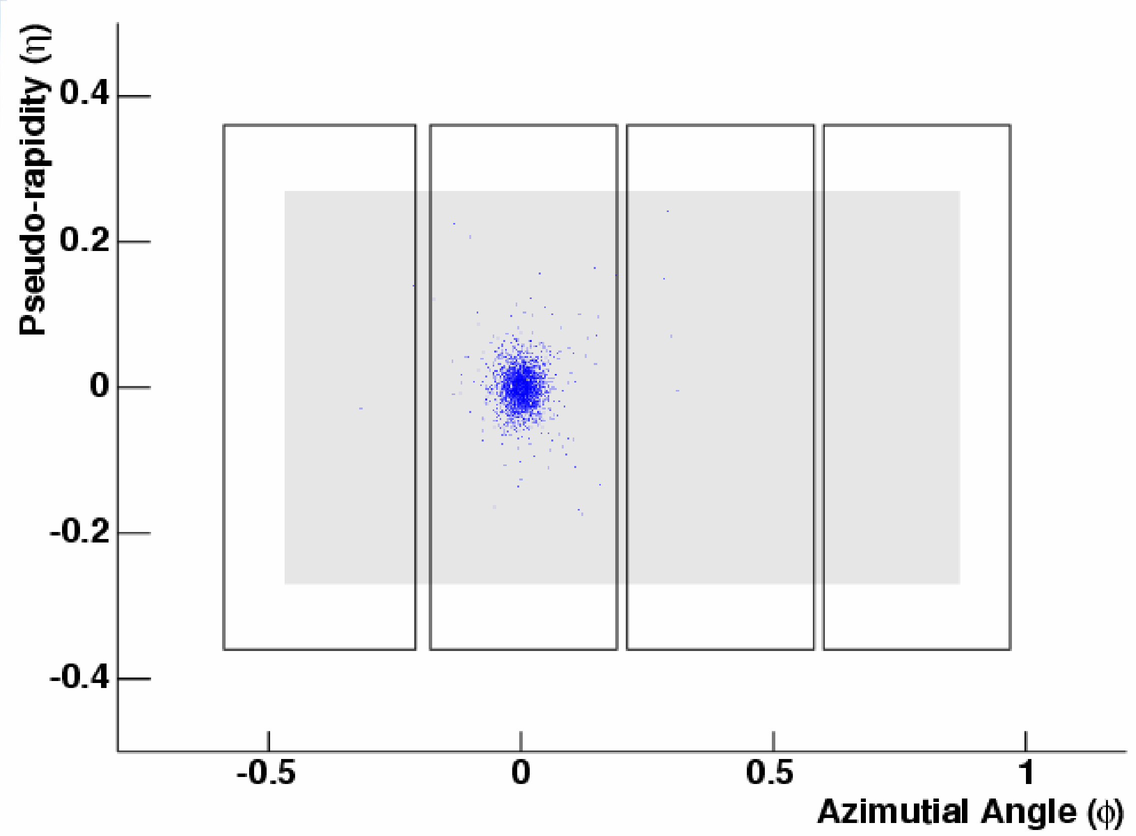


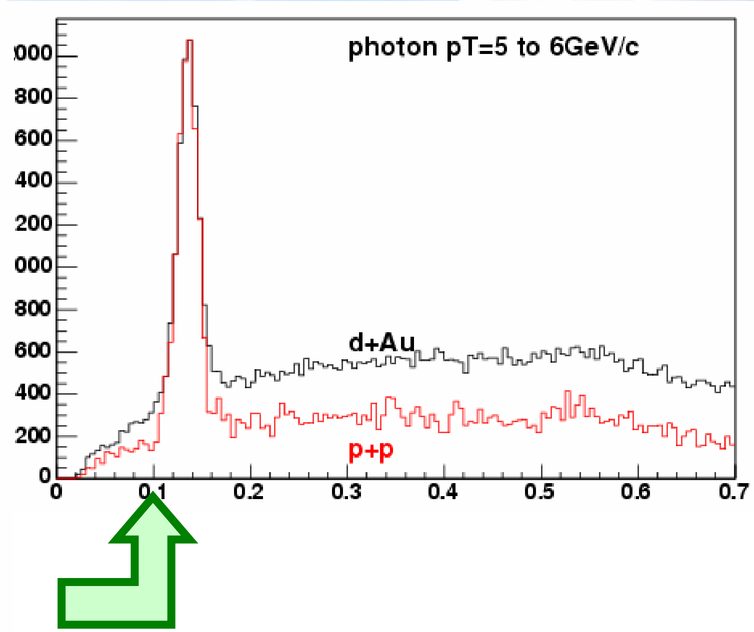
Estimate all backgrounds

After subtracting all backgrounds,

the remained photons are the signals.

Background from π^0



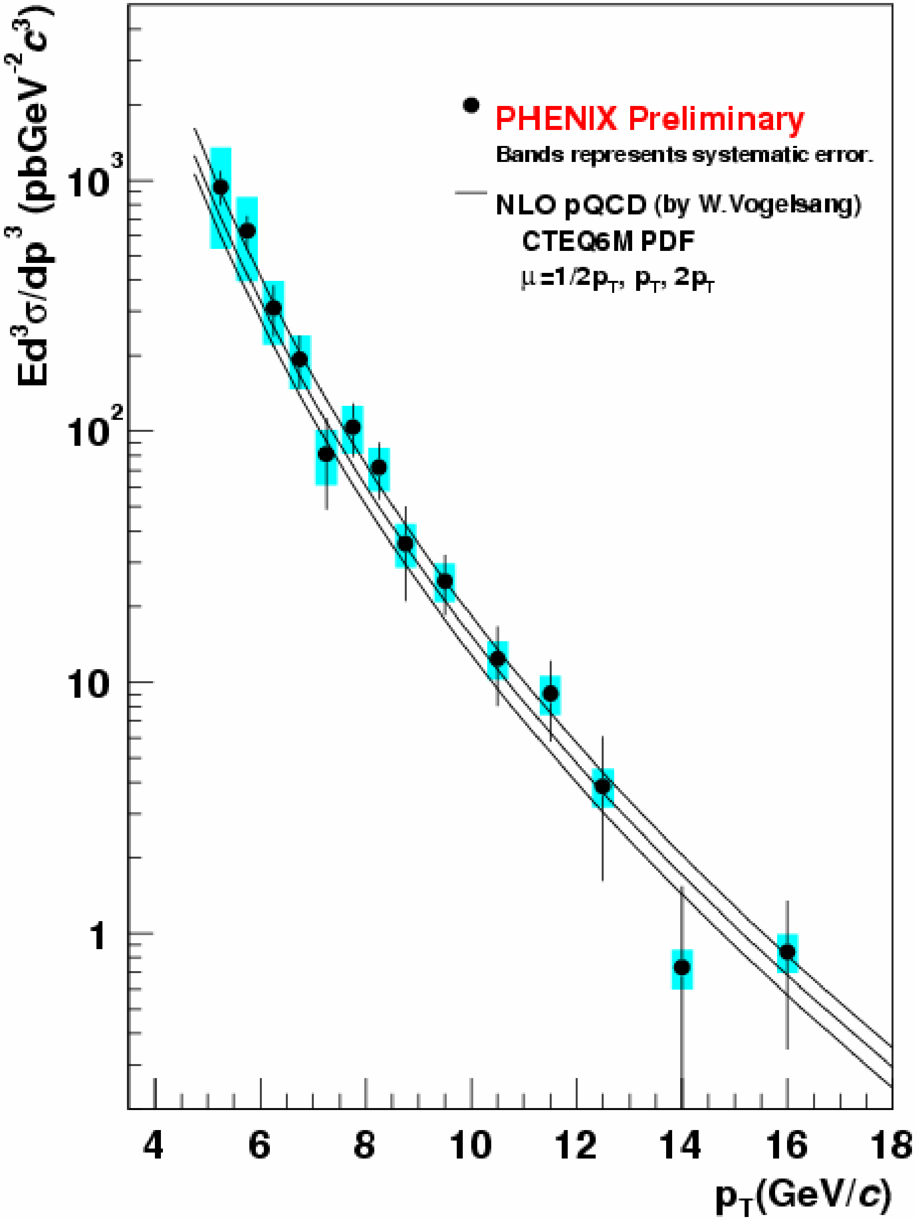


By taking all combination between the target photon and the surrounding photons, we can know the photon from pi0 decay.

➔ 70% of pi0 decay can be identified from the mass distribution

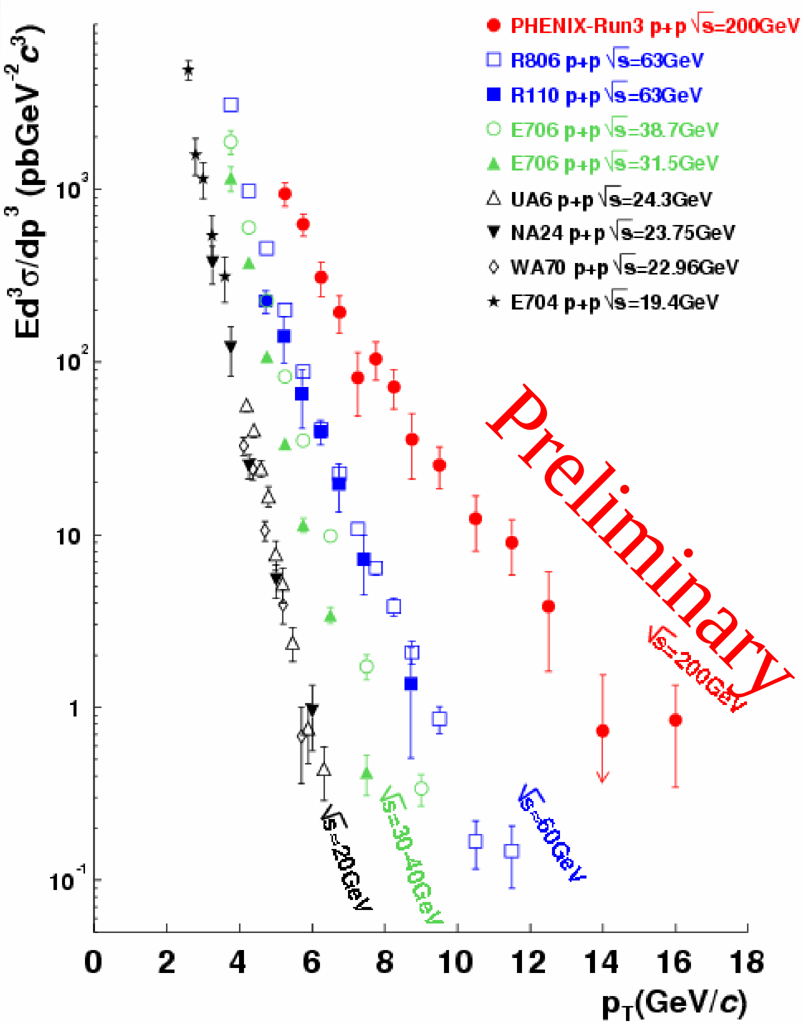
Result

- PHENIX preliminary result.
- NLO-pQCD calculation
  - Private communication with W.Vogelsang
  - CTEQ6M PDF.
  - Sum of direct photon bremsstrhlung photon
  - 3 scales (1/2pT,1pT,2 pT)
    - For renormalization scale factorization scale

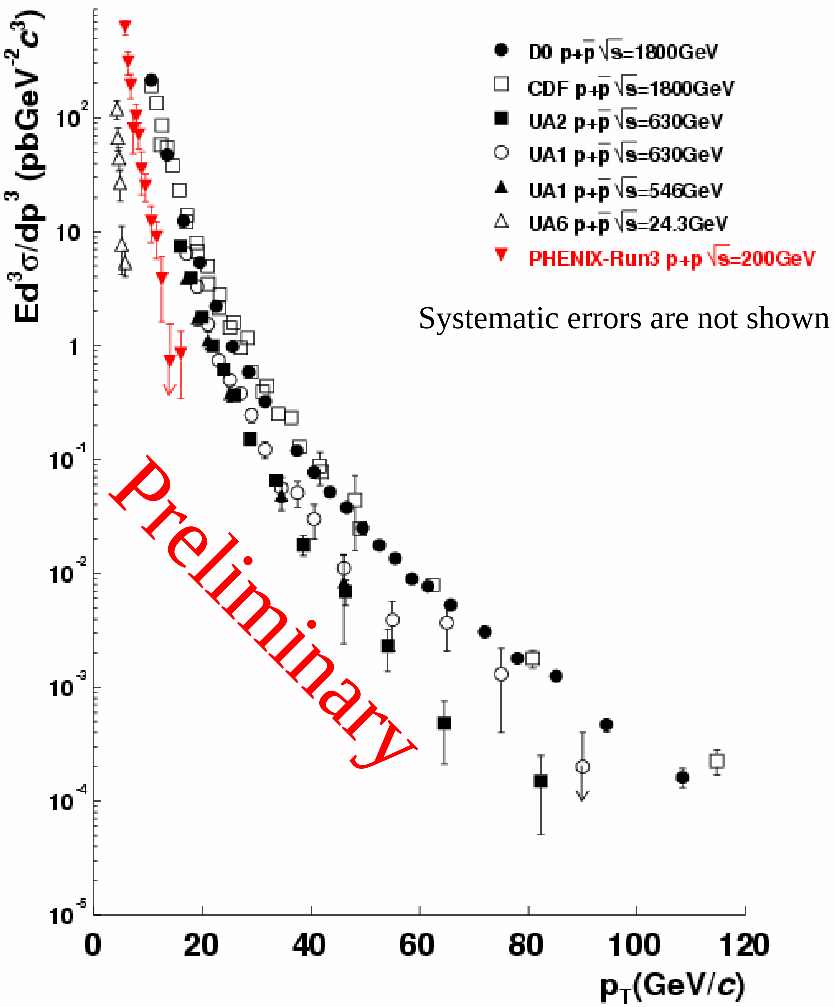


pQCD calculation can describe our result very well.

Comparison with Other Experiment



proton-proton collisions



proton-antiproton collisions

x_T Scaling

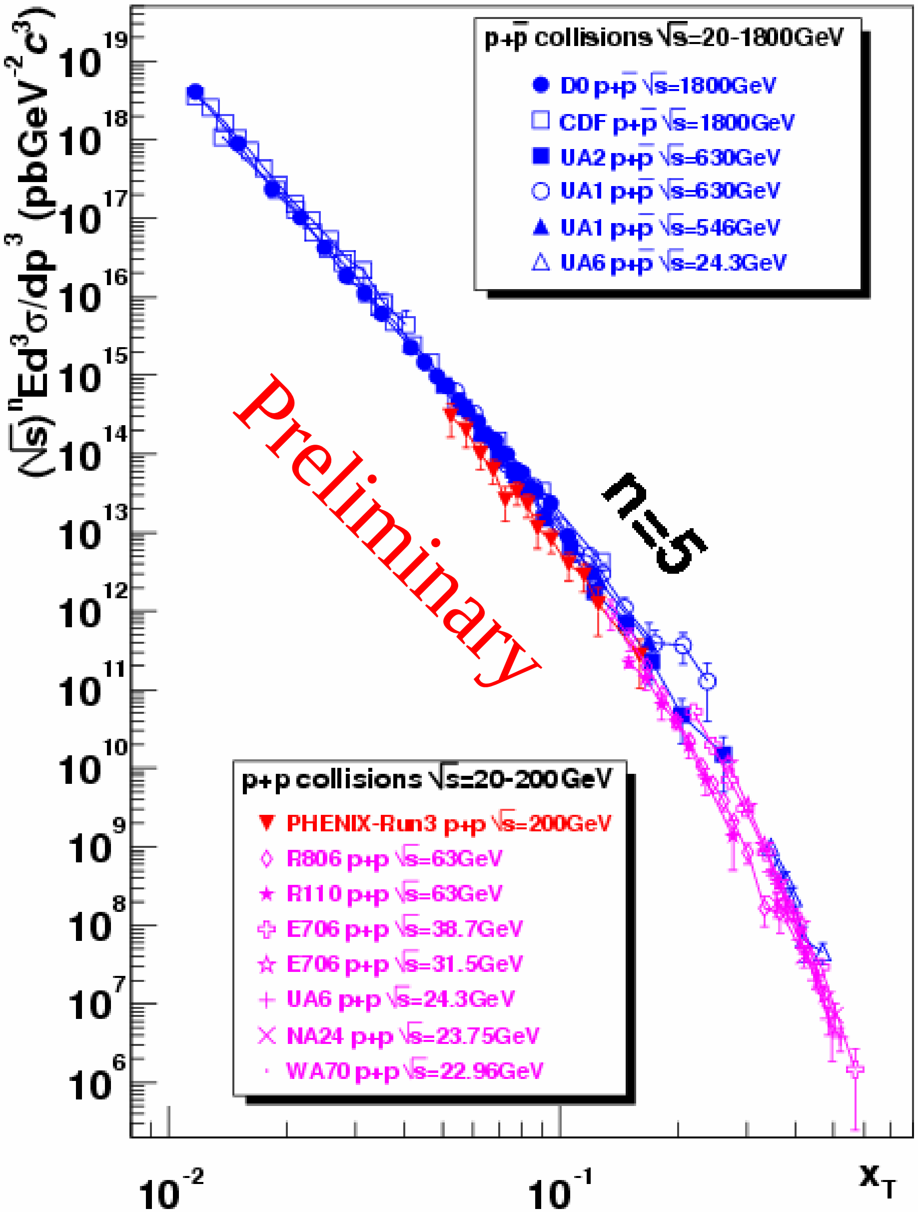
- From QCD, if
  - Q^2-Scaling of PDF,FF
  - No running coupling constant(α_s)

$$\sigma = \left(\sqrt{s}\right)^{-n} \times F\left(x_T\right)$$

n=constant。 $x_T=2p_T/\sqrt{s}$

  - Can be express as two terms
    - Interaction
    - Structure
  - If leading order n=4
    - Next-to-leading order: n=4+α

x_T-Scaling n=~5

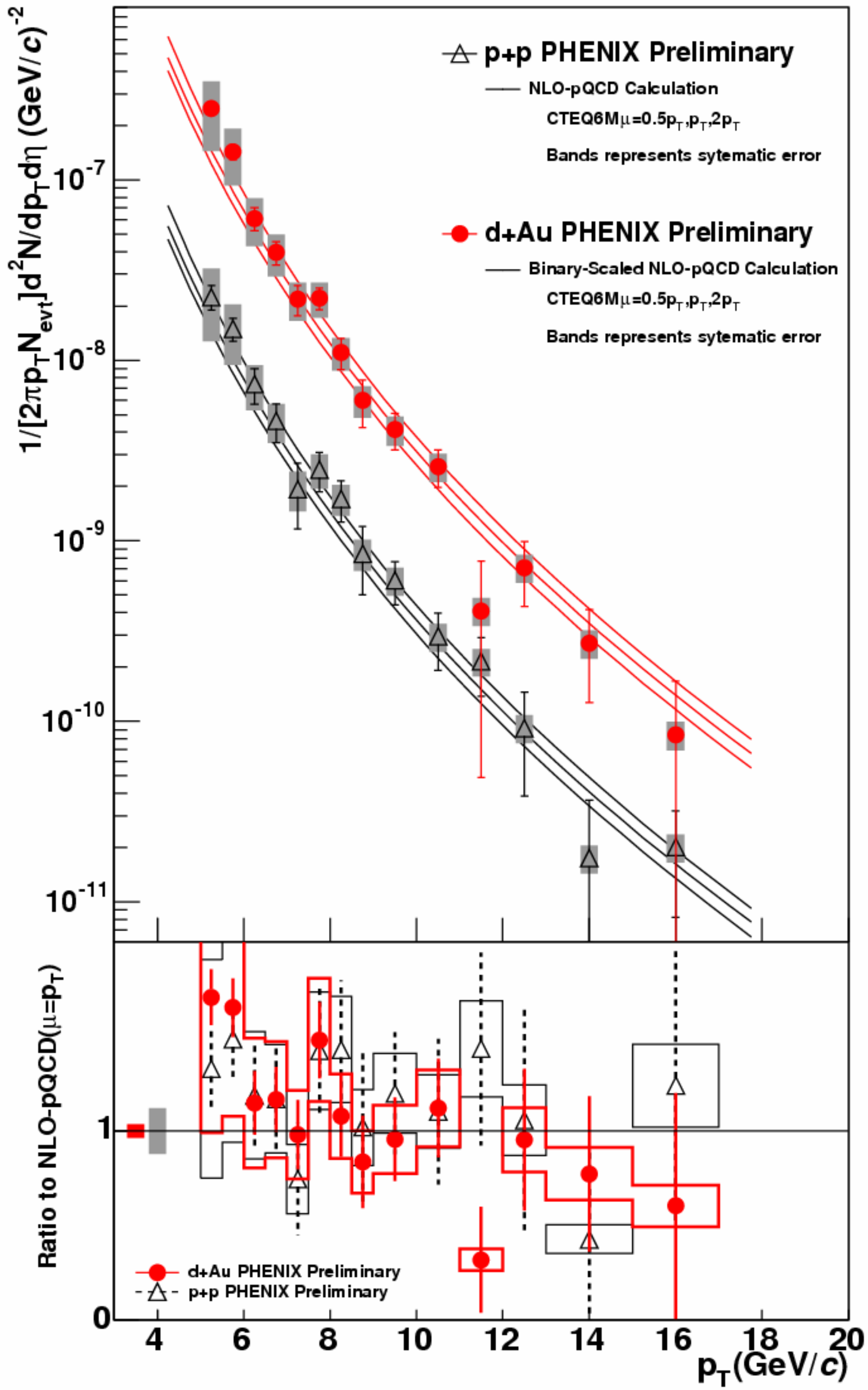


d+Au

Result

- The analysis method is similar to p+p
- NLO pQCD Calculation
  - p+p collisions
  - Calculated by W.Vogelsang
  - CTEQ6M
  - Scale(renormalization and factorization scale) 0.5,1.0,2.0pT
- In comparison with d+Au
  - Averaged number of collisions (8.42) from the Glauber model was multiplied to the calculation.

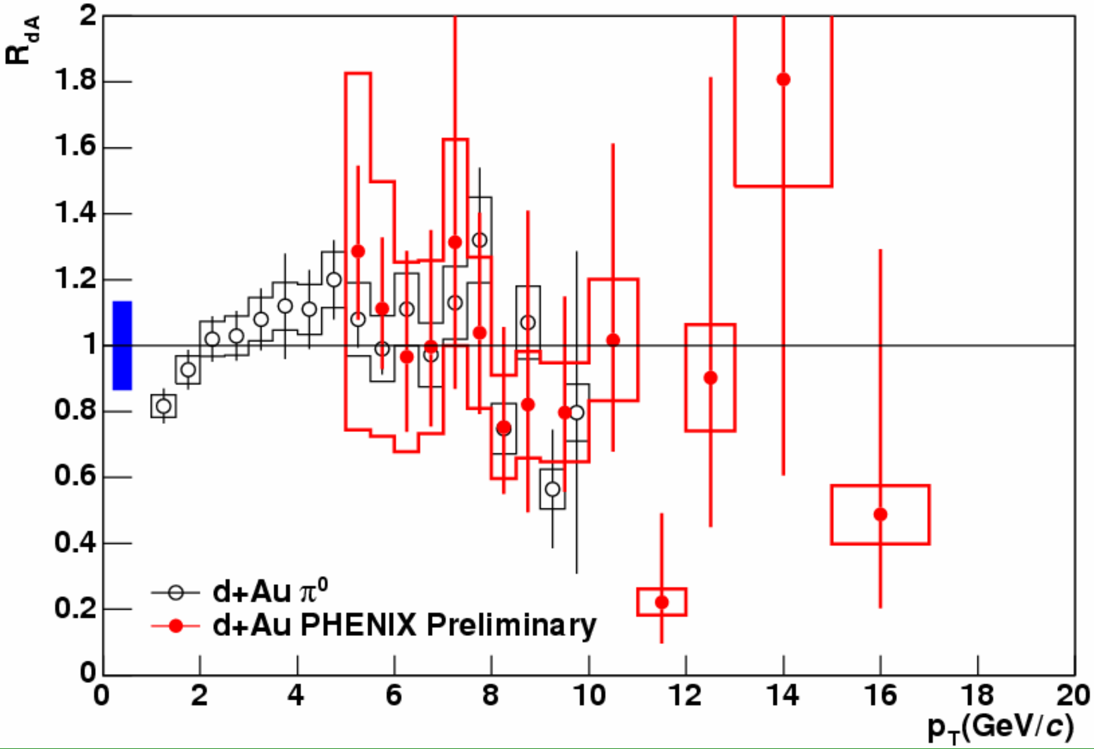
Result is consistent with the binary – scaled NLO-pQCD calculation



Result

Nuclear Modification Factor

$$R_{dA} = \frac{\left[d^2 N_{dA} / dp_T d\eta dN_{evt} \right]}{\langle N_{coll} \rangle / \sigma_{pp}^{inel} \times \left[d^2 \sigma_{pp} / dp_T d\eta \right]}$$



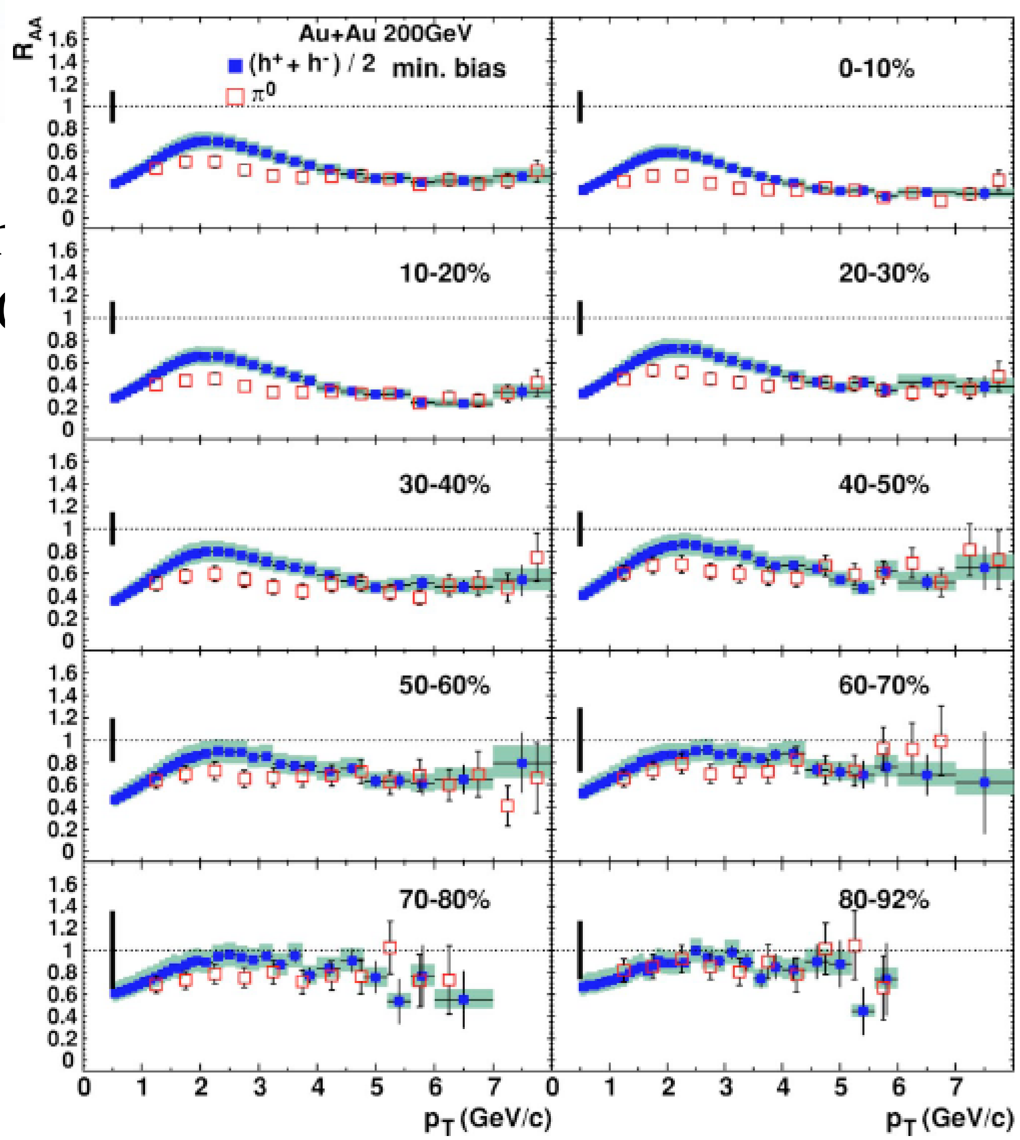
Consistent with 1 ➔ No modification within the error

This is consistent with what we measured in π^0

Au+Au

Background Photons

- The main source of background is π0
- Thanks to large suppressio (factor~5) of 0 yield at RHI energy, we have an advantage to pick up the direct photon.



π^0 suppression help to reduce photon background

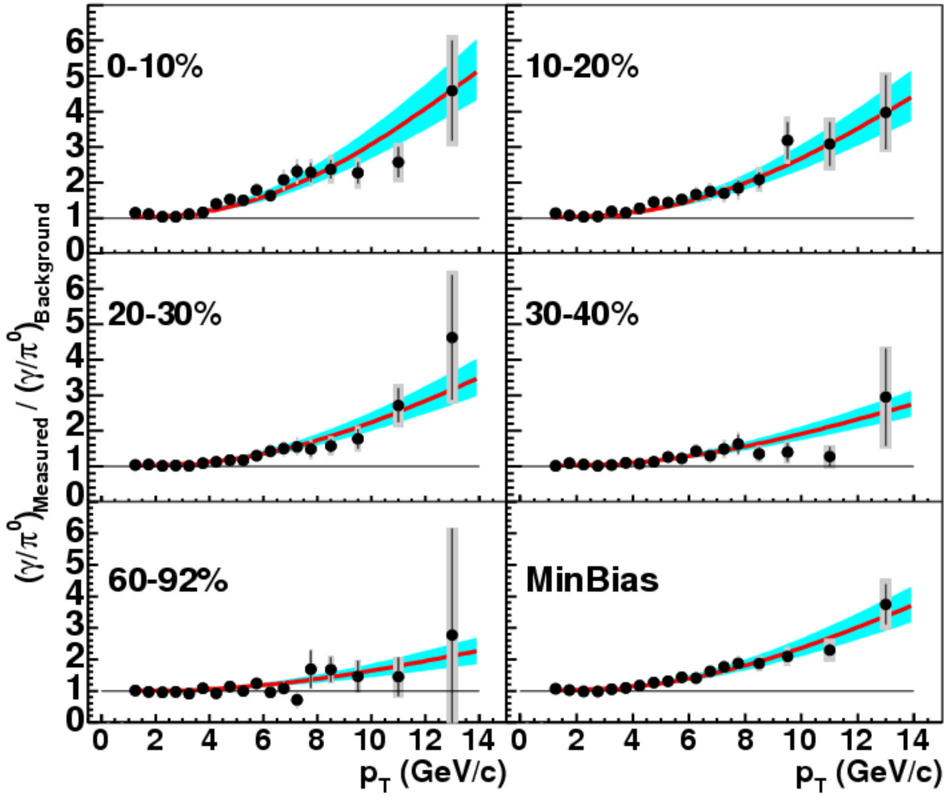
Cancel Systematic Error

- Direct photon yield

  = Excess from bg photons

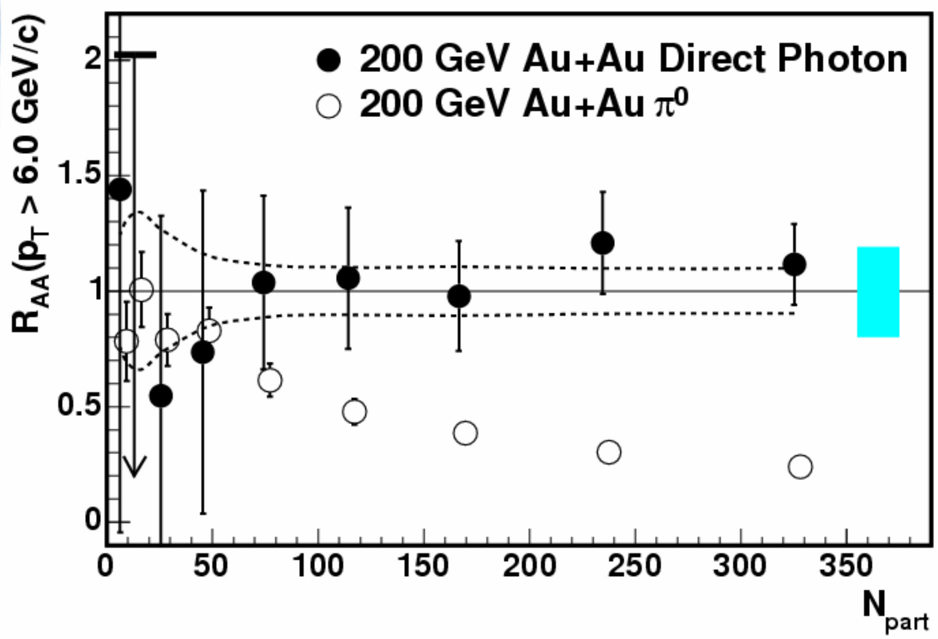
$$R = \frac{\left(\gamma/\pi^0\right)_{measured}}{\left(\gamma/\pi^0\right)_{calculated}} = \frac{\gamma_{measured}}{\gamma_{background}}$$

- Double ratio has an advantage
  - because in the ratio of the actual point by point π^0 and inclusive γ measurements will cancel many systematics



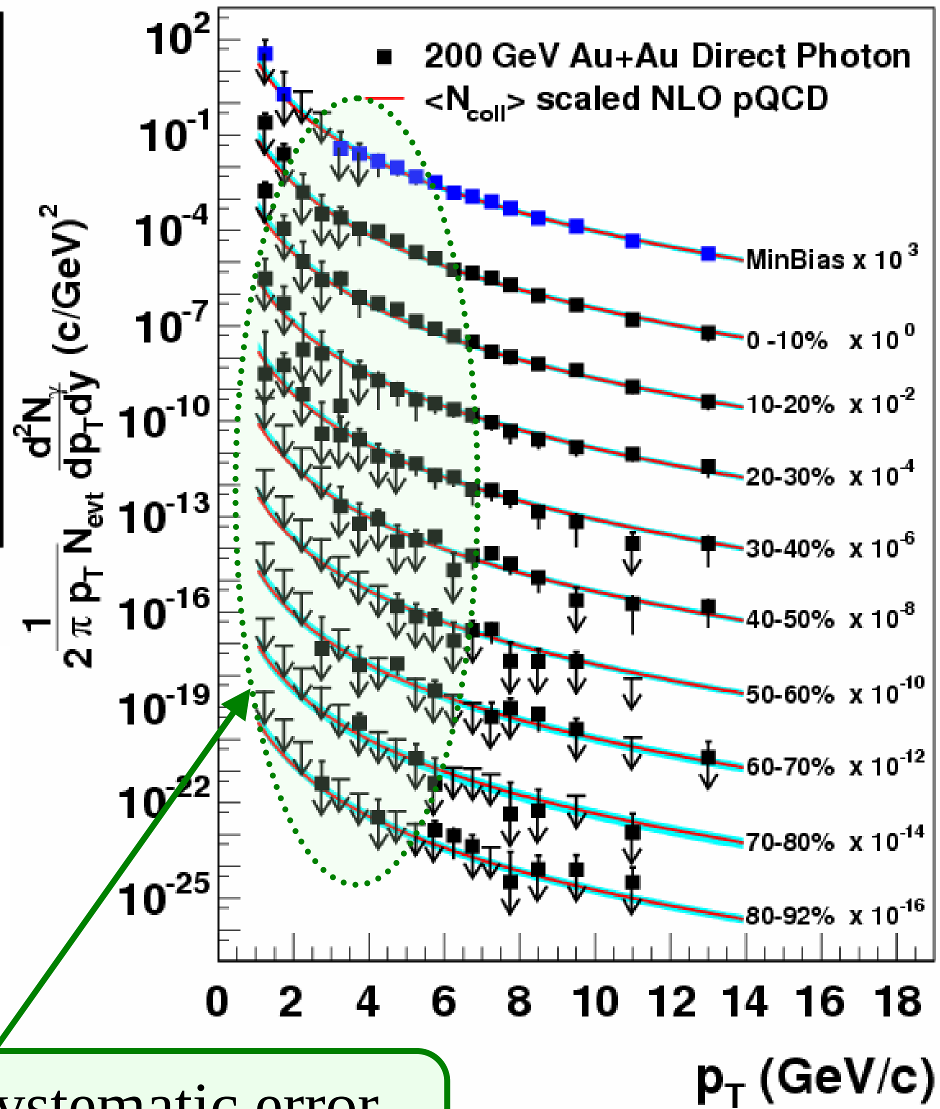
➔ Direct photon = Excess above 1

Results



consistent

Jet Quenching Scenario
(π^0 suppression)



Need to reduce the systematic error for thermal photon measurement

PRD94(2005)232301

Conclusion

- p+p collisions
  - NLO pQCD calculation can describe our data
    - Sum of direct part and fragmentation part.
  - Fit in xT scaling with other experiment
- d+Au collisions
  - comparison with NLO-pQCD
    - Result in d+Au collisions is consistent with the binary-scaled NLO-pQCD calculation.
  - Nuclear Modification Factor
    - Consistent with 1 ➔ No modification within the errors
    - Prompt photon production in d+Au can be described as binary scaling
    - Result is consistent with $\pi 0$

Conclusion

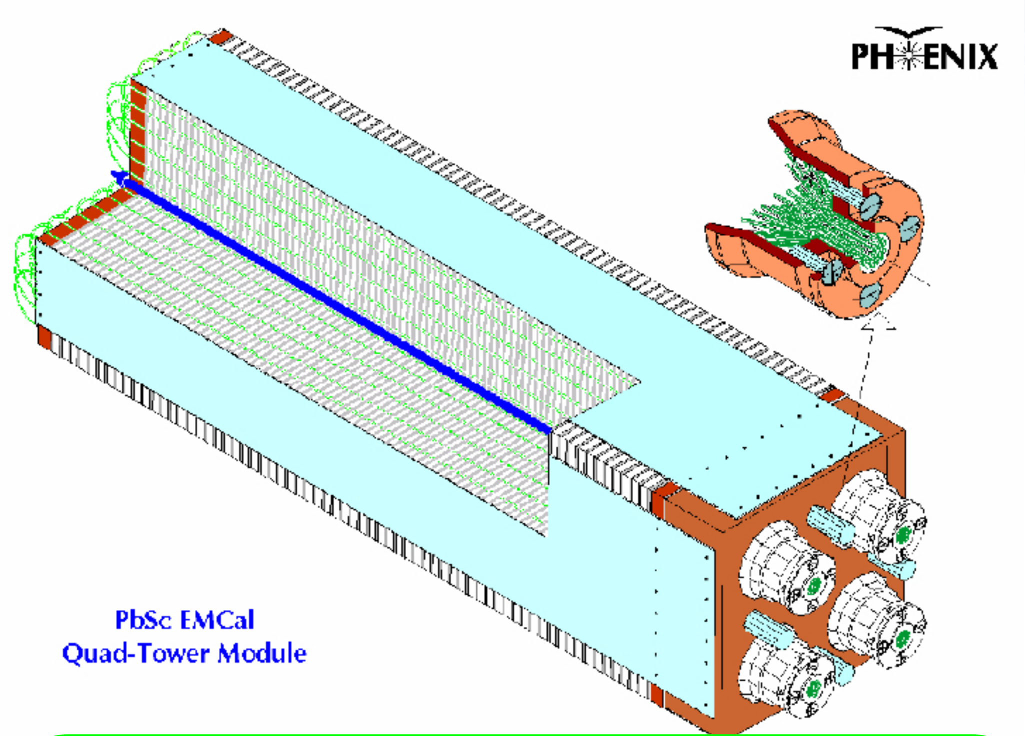
- Au+Au collisions.
  - High pT photon
    - Binary Scaling and pQCD calculation
  - Consistent with 1
    - No modification within the errors
    - Support jet quenching scenario observed as pion suppression
  - No thermal photon signal yet.
    - We're analyzing the run4 Au+Au data. Plan to have the preliminary result.

Backup slide

Data Set

Run	Year	Species	$s^{1/2}$ [GeV]	$\int Ldt$	N_{tot}	p-p Equivalent	Data Size
01	2000	Au+Au	130	1 μb^{-1}	10M	0.04 pb^{-1}	3 TB
02	2001/2002	Au+Au	200	24 μb^{-1}	170M	1.0 pb^{-1}	10 TB
		p+p	200	0.15 pb^{-1}	3.7G	0.15 pb^{-1}	20 TB
03	2002/2003	d+Au	200	2.74 nb^{-1}	5.5G	1.1 pb^{-1}	46 TB
		p+p	200	0.35 pb^{-1}	6.6G	0.35 pb^{-1}	35 TB
04	2003/2004	Au+Au	200	241 μb^{-1}	1.5G	10.0 pb^{-1}	270 TB
		Au+Au	62	9 μb^{-1}	58M	0.36 pb^{-1}	10 TB

PbSc EM Calorimeter



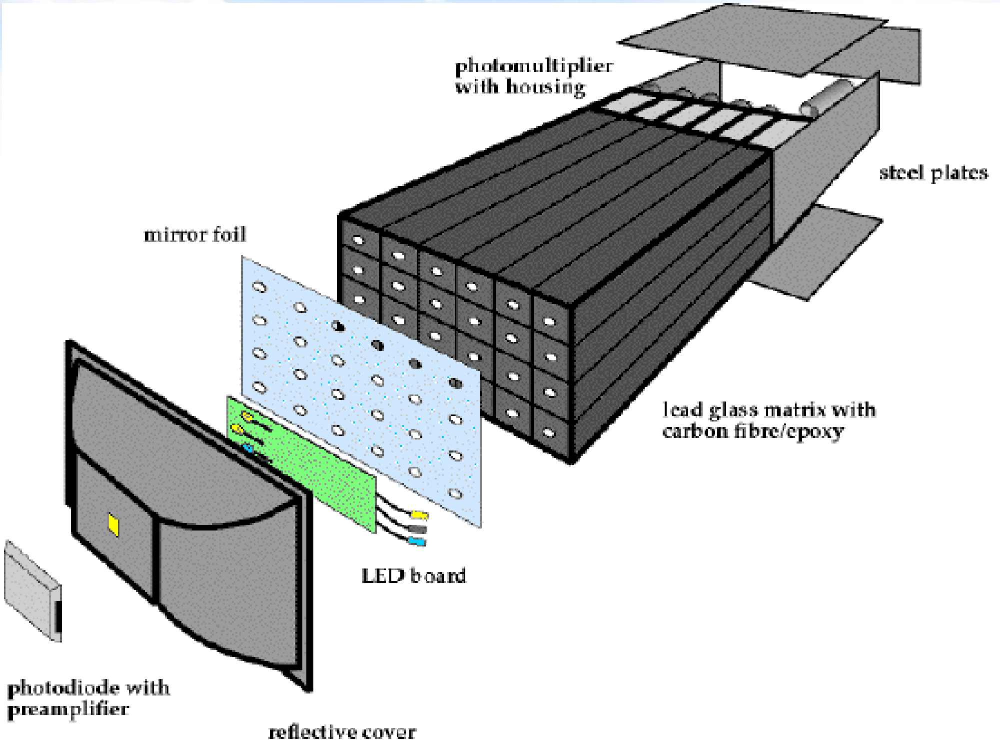
	PbSc
Size(cm x cm)	5.52 x 5.52
Depth(cm)	37.5
Number of towers	15552
Sampling fraction	~ 20%
η cov.	0.7
ϕ cov.	90+45deg
η/mod	0.011
ϕ/mod	0.011
X_0	18
Molière Radius	~ 3cm

Sandwich type calorimeter
- Lead plates 55.2x55.2x1.5mm
- Scintillator plates 110.4x110.4x4mm

Shish-kebab geometry wave shifter fiber readout
- 6x6 fibers → 1 PMT = 1 tower
- 2 x 2 towers = 1 module
- 6 x 6 module = 1 super module
- 6 x 3 super module = 1 sector

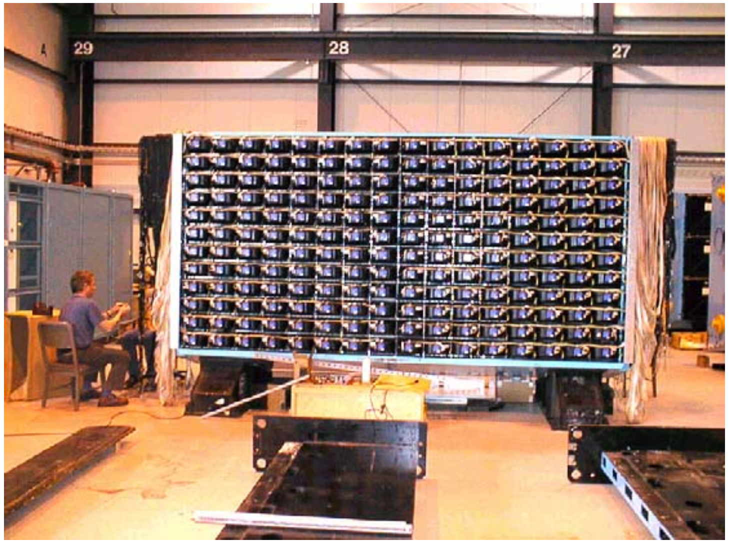
PbSc sector 2.0m x 4.0m

PbGl EM Calorimeter



	PbGl
Size(cm x cm)	4.0 x 4.0
Depth(cm)	40
Number of towers	9216
Sampling fraction	100%
η cov.	0.7
ϕ cov.	45deg
η/mod	0.008
ϕ/mod	0.008
X_0	14.4
Molière Radius	3.68cm

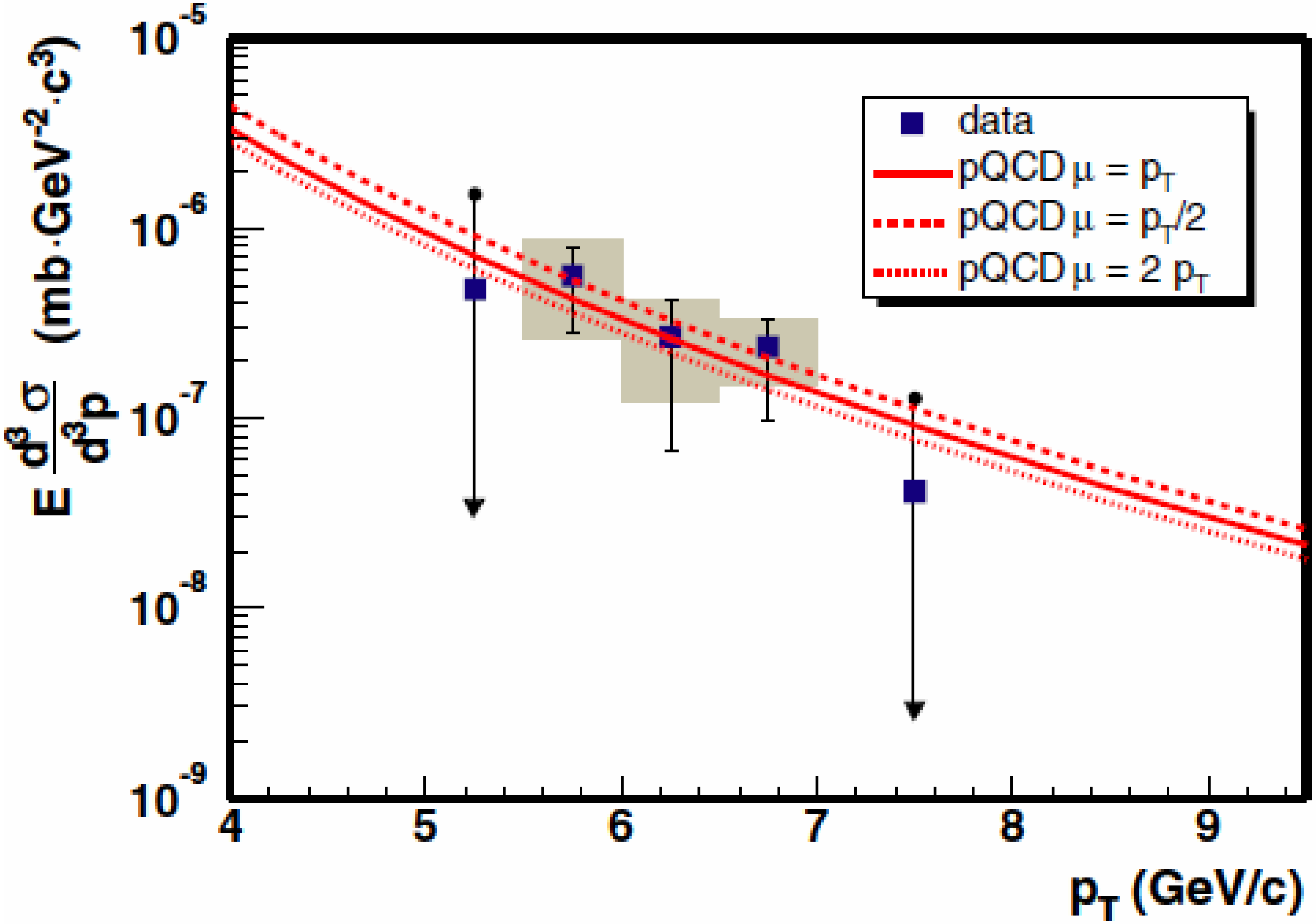
Lead Glass calorimeter
Lead Glass 40x40x400mm
used at WA98 exp.
4x6 towers = 1 super module
15*12 super module = 1 sector



PbGl sector 2.1m x 3.9m

Photon from run2 p+p

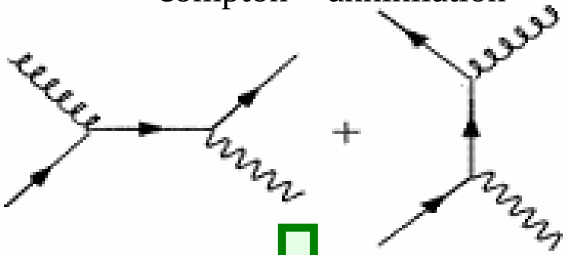
PHYSICAL REVIEW D 71, 071102 (2005)

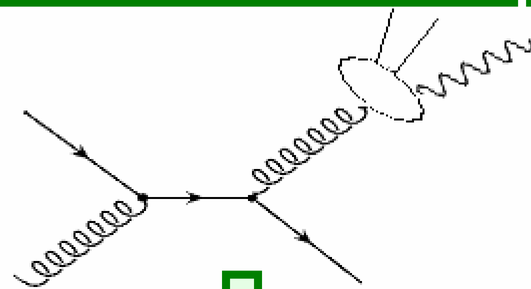


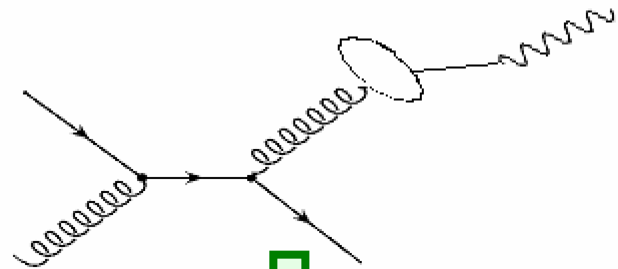
Strategy of Isolation Method

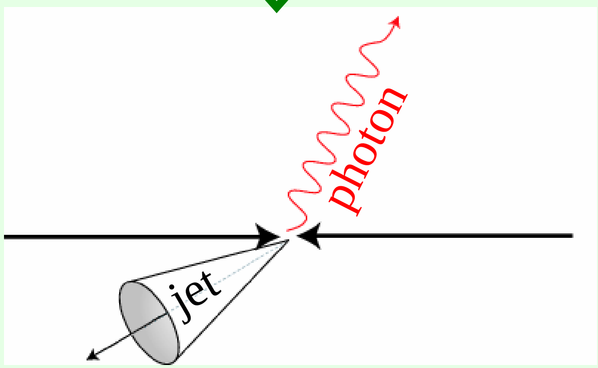
(1)Signal(direct)	(2)Signal(fragmentation)	(3)Background(hadron decay)

compton + annihilation

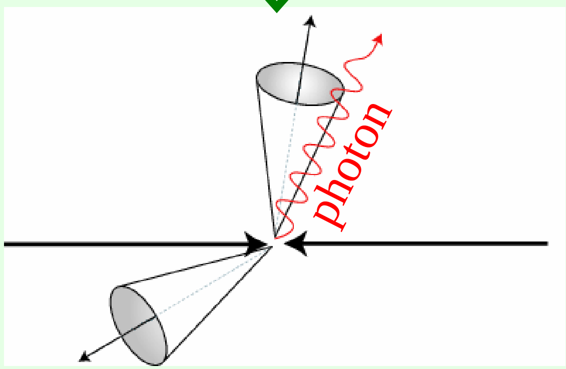




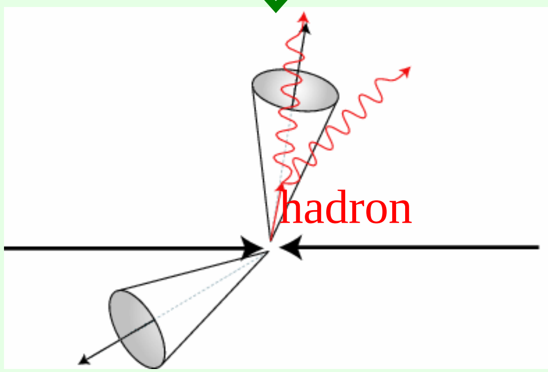




約30%@10GeV



約10%@10GeV

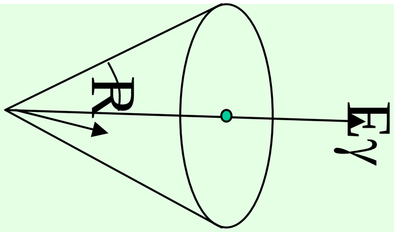


約60%@10GeV

Isolation cut to reduce background

$$R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.5$$

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



What is the efficiency by this cut for signal 1)&2)➔Next slide

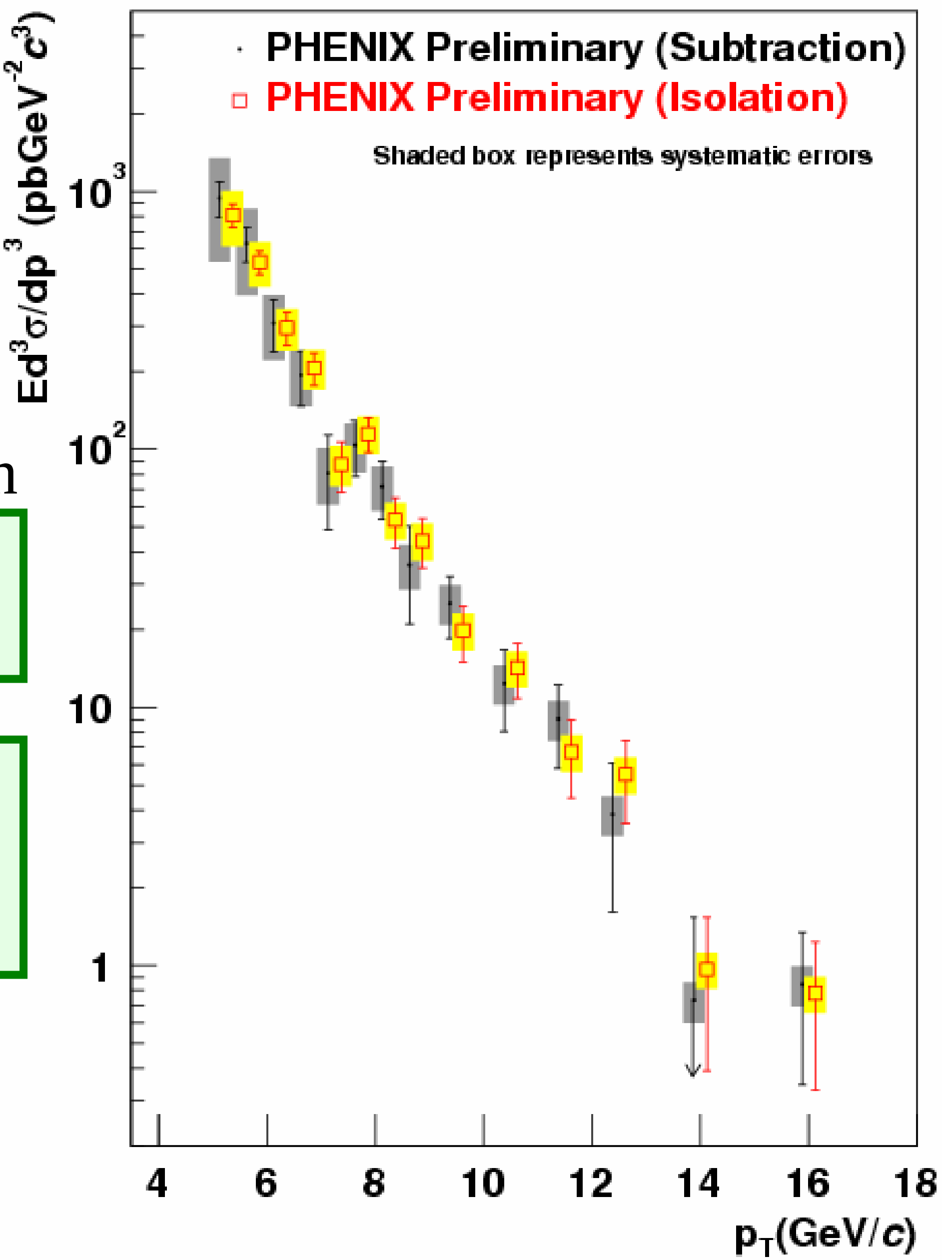
Result

- Two methods
  - Subtraction method
  - isolation method
    - To be smaller by 20-40%
- They are not different as we expected from pQCD calculation

Rjection for fragmentation photon
Is not perfect

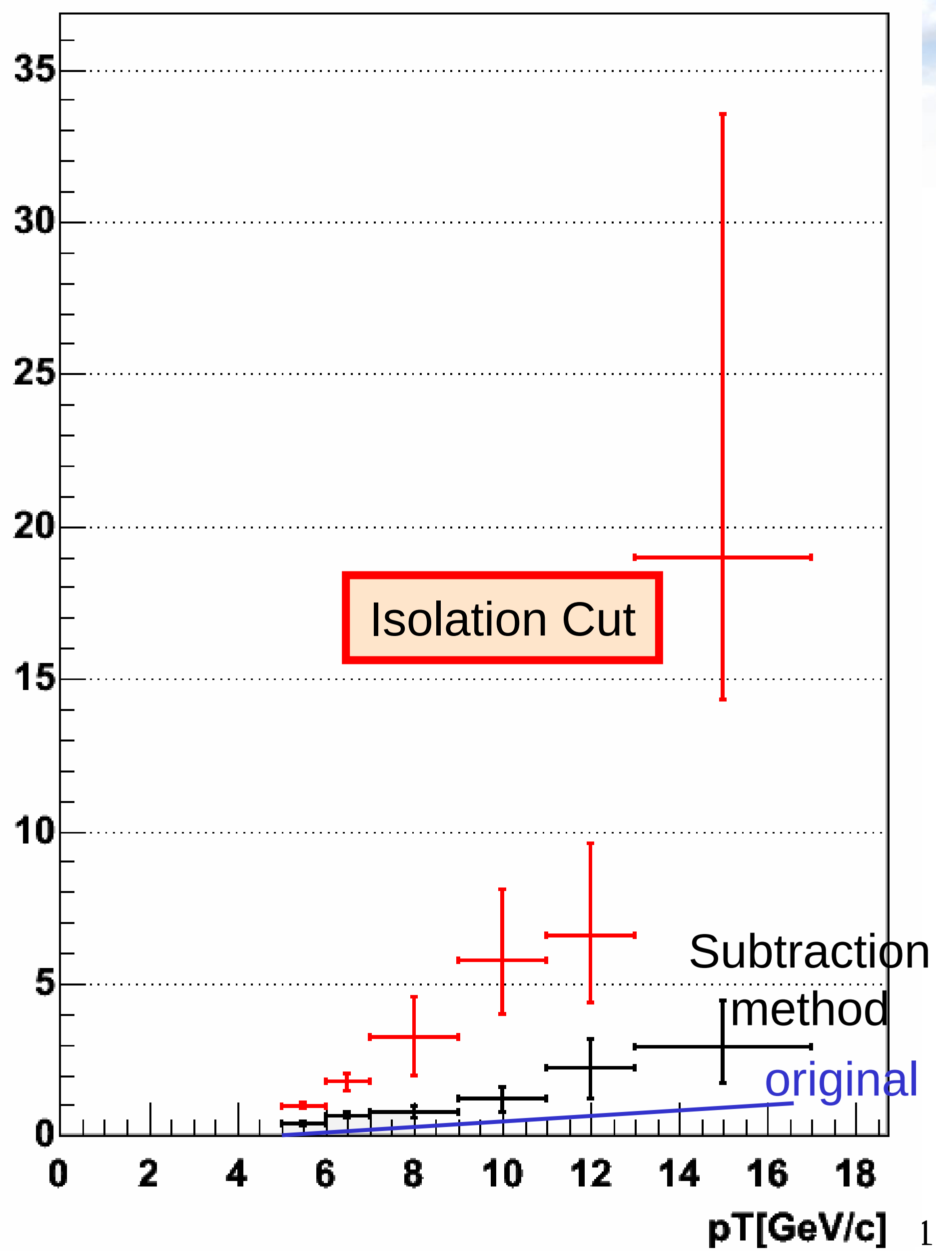
or

Most of measured photon are
From direct process
(compton, annihilation, or NLO)



S/N Ratio with Isolation Cut

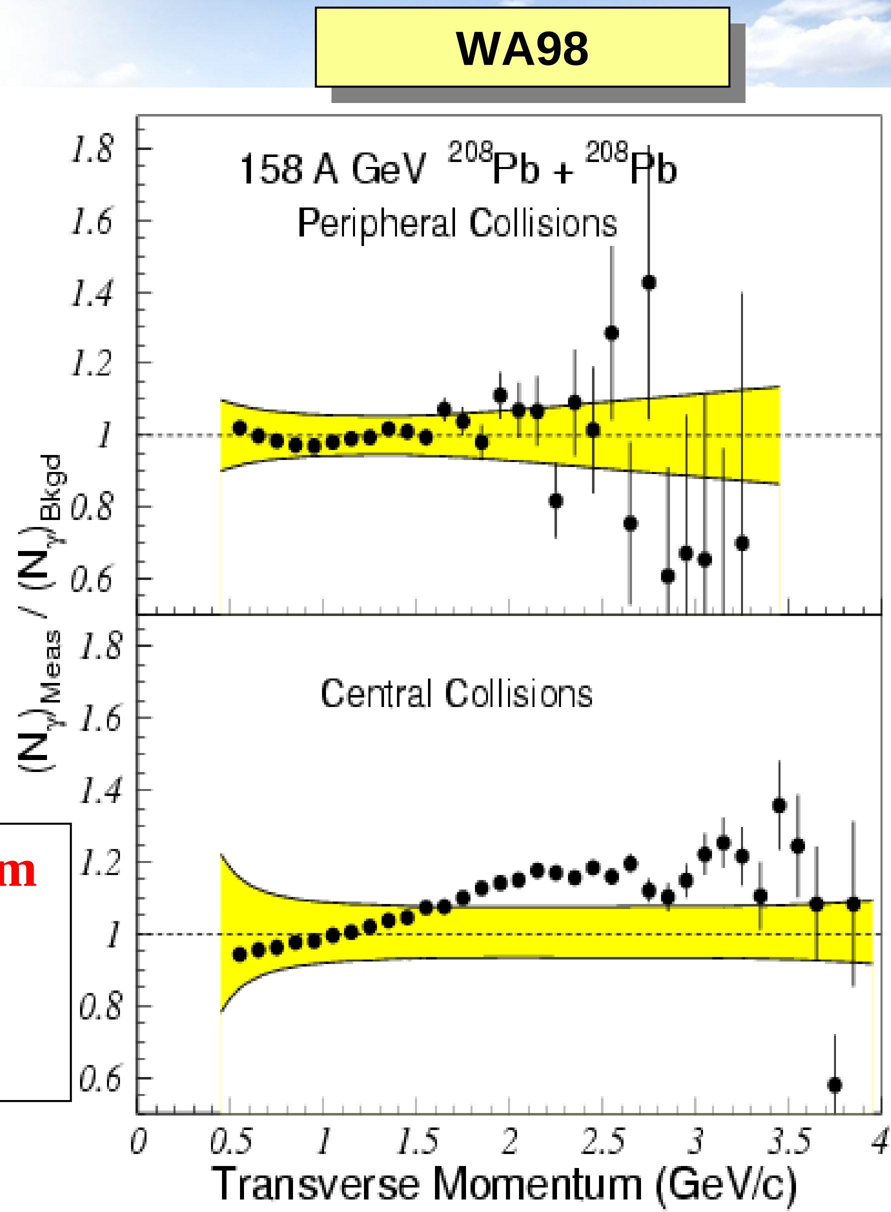
- S/N ratio
  - S = 直接光子
  - N = 検出できなかったπ^0からくる寄与
- Isolation cutを掛けることにより、S/N ratioが改善。
  - Subtraction method(岡田さんトーク)と比較して約5倍。
  - 将来予定している直接光子を用いた陽子中グルーオン偏極量の測定に有効。
- 測定レンジ
  - p_T = 5-17GeV/c



Direct Photons at the SPS

- **Evidence for direct photons in central Pb-Pb collisions?**

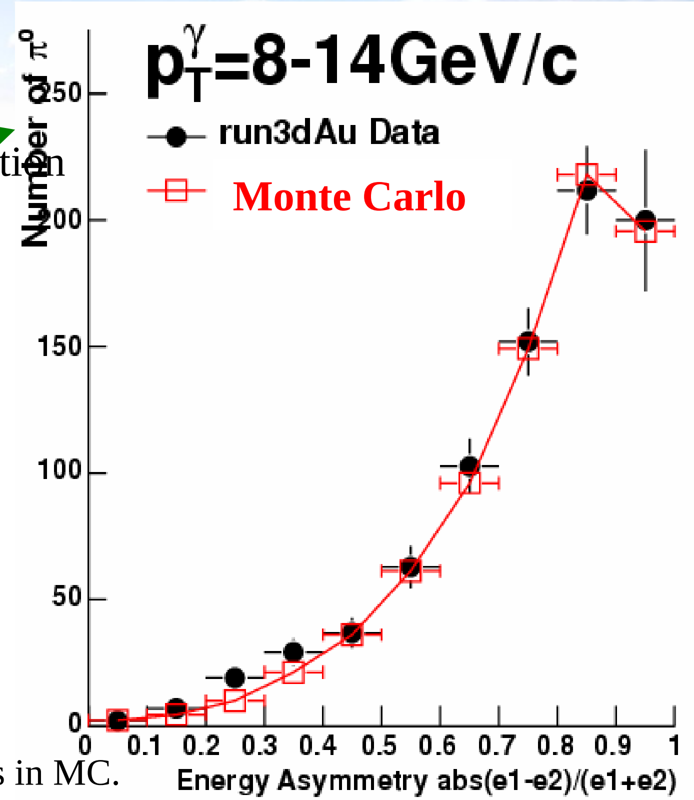
10-20% excess but 1σ effect only



- **Comparison to scaled pA: similar spectrum but factor of ~2 enhanced yield in Pb-Pb, again ~1σ effect.**
- **pQCD underpredicts direct photon yield**

Background from π^0

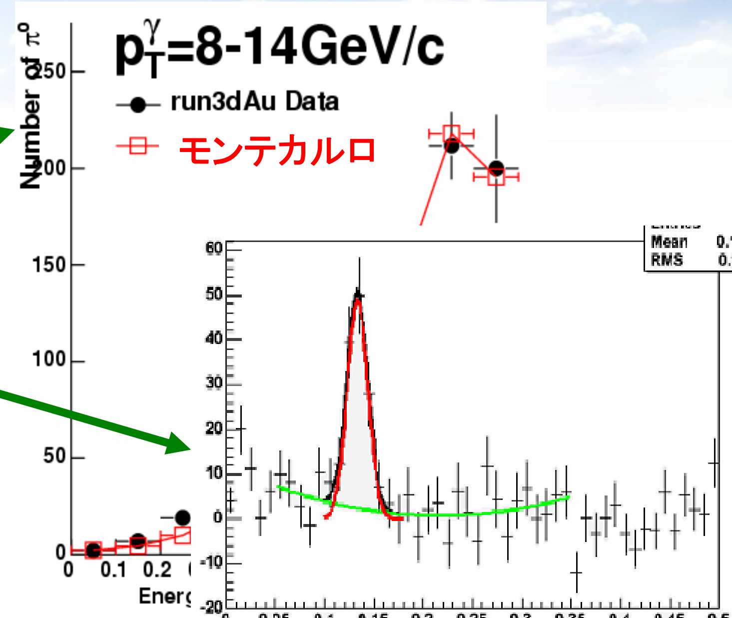
- Identified π 0 decay(~70%)
  - Check measured π0
    - Peak position and width is consistent with the expectation
    - Energy asymmetry is consistent with the expectation
  - All channels of EMCal are working.
    - We confirmed all channels are working properly.
    - No-Position dependence
  - Systematic uncertainty due to the combinatorial bg.
- Un-identified π0 (~30%)
  - Corrected by a Monte Carlo simulation
    - The main loss is due to the geometrical acceptance.
    - Systematic error on the Monte Carlo
      - Was estimated from the possible miss-tuned parameters in MC.
- Other Hadron
  - PHENIX measured η
  - ω and other hadron was estimated by assuming m_T scaling
- Other souce
  - Neutral/charged hadron and non-vertex photon was estimated by the GEANT simulation and data itself.



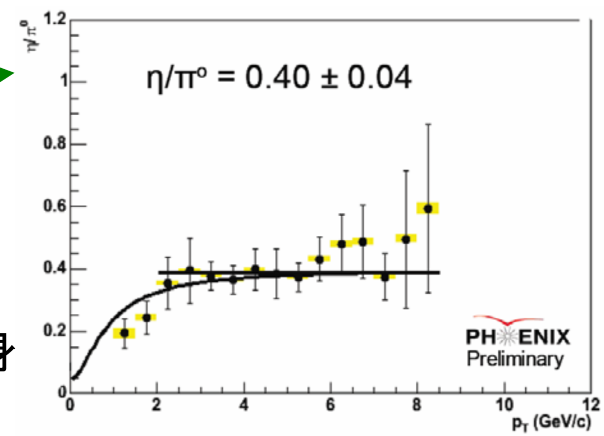
モンテカルロ自体は過去のテスト実験等で測定してきたEMCalの性能を再現するように調整済み。

バックグランド同定

- 同定できたπ^0粒子からの光子
  - π^0質量分布
    - ピーク位置や幅が正しく再現する。
    - π^0のenergy asymmetryが正しく再現する。
  - すべてのEMCalのチャンネルが正しく動作。
    - 一つもπ^0を見落としていないことを確認。
    - 場所依存性が無い。
  - Combinatorialの見積もりから来る系統誤差3%。
- 同定できなかったπ^0粒子からの光子
  - モンテカルロ計算で補正
    - おもに、検出器間の隙間によって起こる
    - モンテカルロ計算の系統誤差
      - 系統誤差はあらゆる可能性を考慮して誤差を評価。
- 他のハドロン崩壊からの光子
  - PHENIXにおけるη粒子の測定結果ならびにm_Tスケーリング則を仮定して、ω等を見積もる。
- その他もろもろ
  - 中性・荷電ハドロン、衝突以外からの光子等はデータ自身ならびにGeantモンテカルロを用いて見積もる。



モンテカルロ計算は過去のテスト実験等で得られたEMCalの性能を再現するように調整



Isolation Cutの効率

- なにが原因で効率/非効率を生み出すのか?
  - イベント構造によるもの
    - fragmentation photon は近くにジェットを伴うため効率は低いと予想される。
  - PHENIX検出器のアクセプタンスは完全ではない。
  - Underlying eventによるもの。
- Isolation cut による検出効率をMonte Carlo計算により見積もる。
  - モデル依存の計算である。
  - PYTHIA simulationによる見積もり。
    - Signal(direct photon) : >90% for pT>5GeV/c
    - Signal(fragmentation photon)に関しては研究を進めている最中である。

T.Horaguchi and K.Nakano are working for these items.

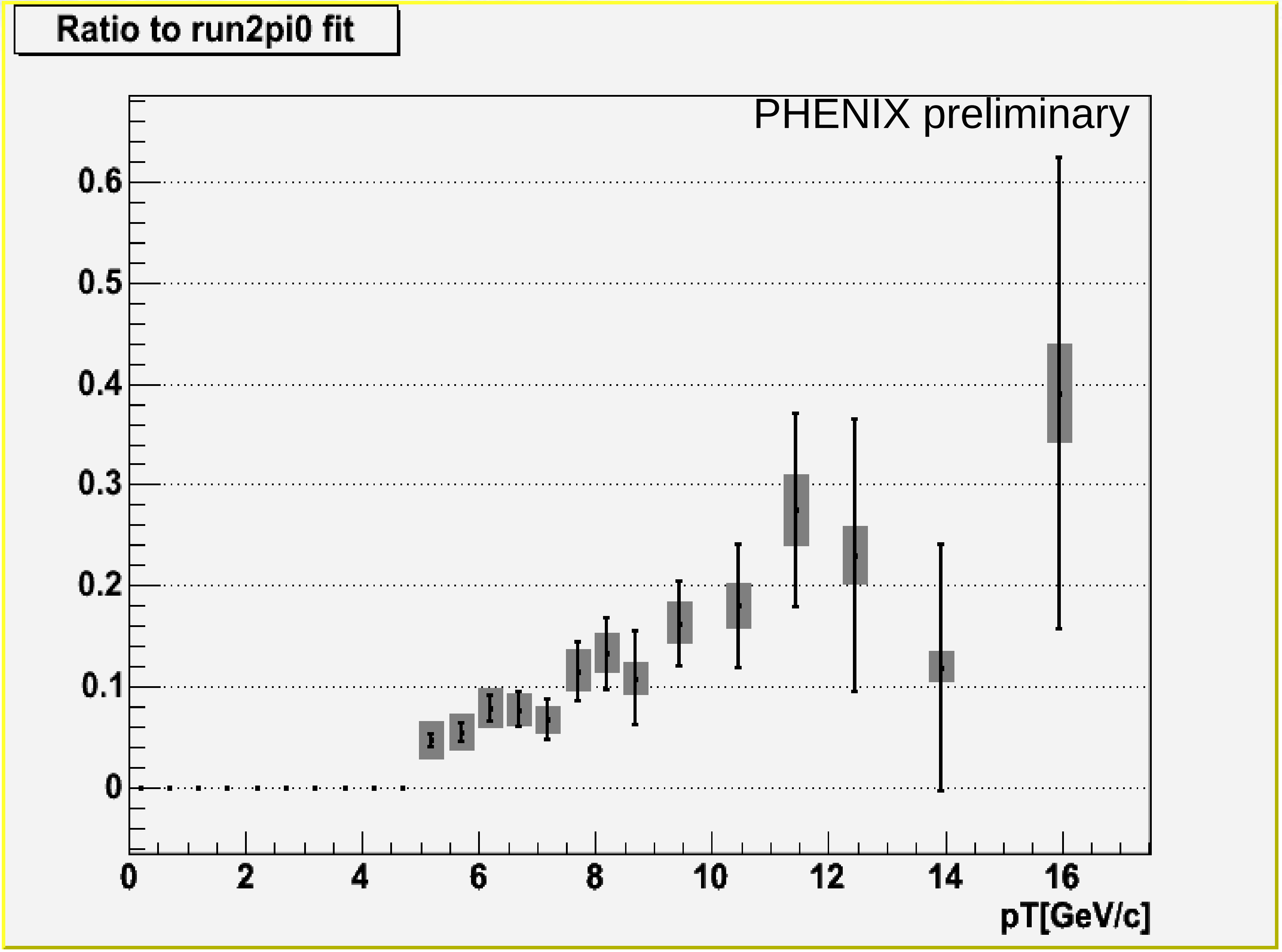
- この発表ではisolation cutによる効率の補正なしで、isolation methodで得られた結果をsubtraction method (前の岡田さん発表)の結果と比較してみる。
  - この比較により、direct/fragmentation photonの成分を分けることができないだろうか、ということを念頭に。

Event Selection and Analysis

- Event Selection
  - データはRHIC-run3 p+p データ（2003/Apr – May）
    - 陽子ビームは longitudinally polarized at PHENIX. 偏極平均での測定。
  - 今回解析したデータは、ERTトリガー($E\gamma$>1.5GeV/c)にて取得。
    - 266pb^{-1} 相当。
- Analysis procedure
  - 光子の選択
    - EM shower is photon-like
    - No charge hit on chambers in front of EMCal.
    - Isolation cut .
  - π^0からくる(上の選択を通り抜けた)光子の寄与はデータ自身から見積もる。
    - ただし、検出器にて検出できなかったπ^0からくる寄与ならびに他のハドロン(ω、η 他)からくる寄与は
      - 過去の実験からの推定
      - 我々PHENIXでの測定(π^0, η)
      - モンテカルロ計算
- Cross section calculation

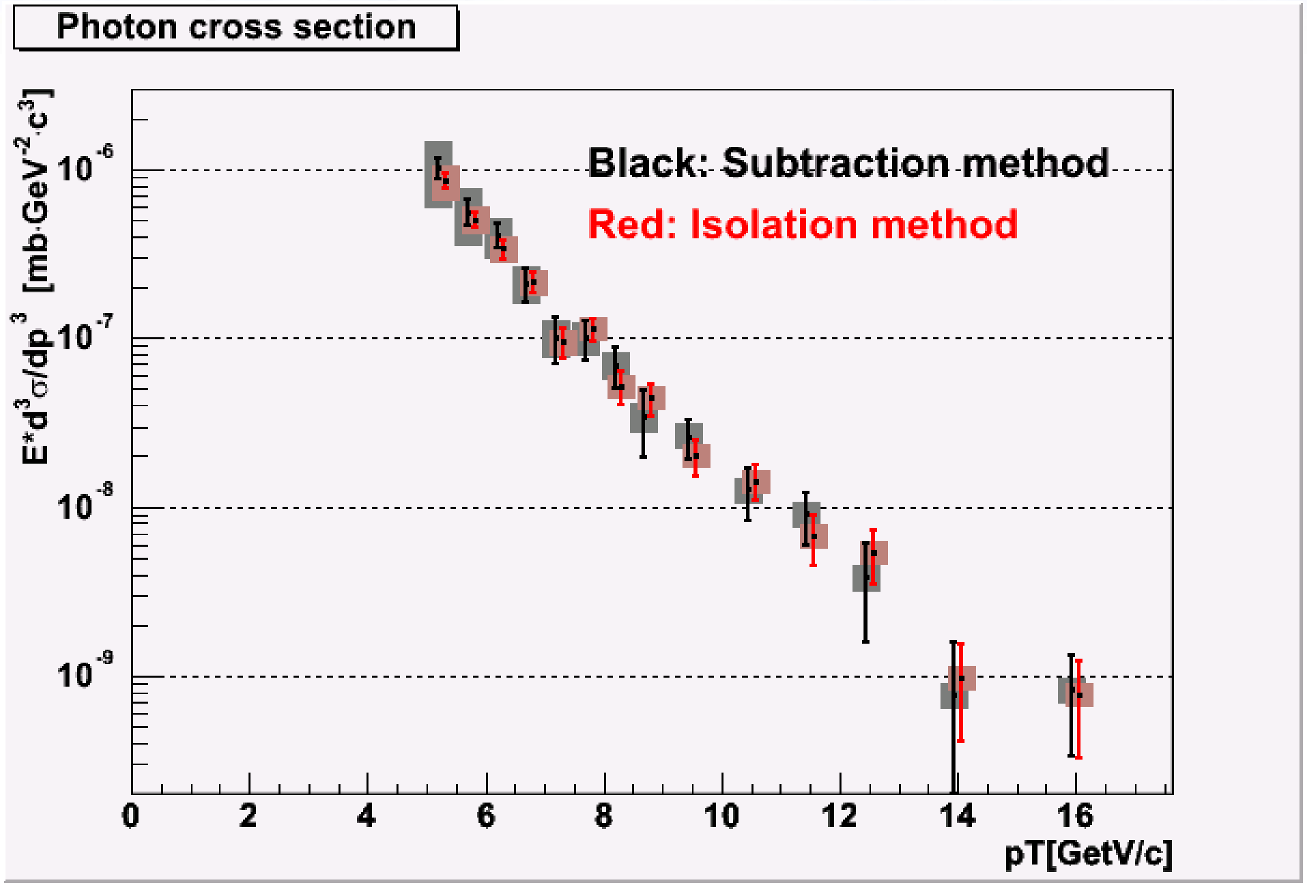
$$E\frac{d^3\sigma}{dp^3} = \frac{1}{L} \times \frac{1}{2\pi p_T} \times \frac{N_{photon}}{\varepsilon_{eff} \times \varepsilon_{acc} \times \varepsilon_{triggerbias}}$$

photon/π^0 ratio



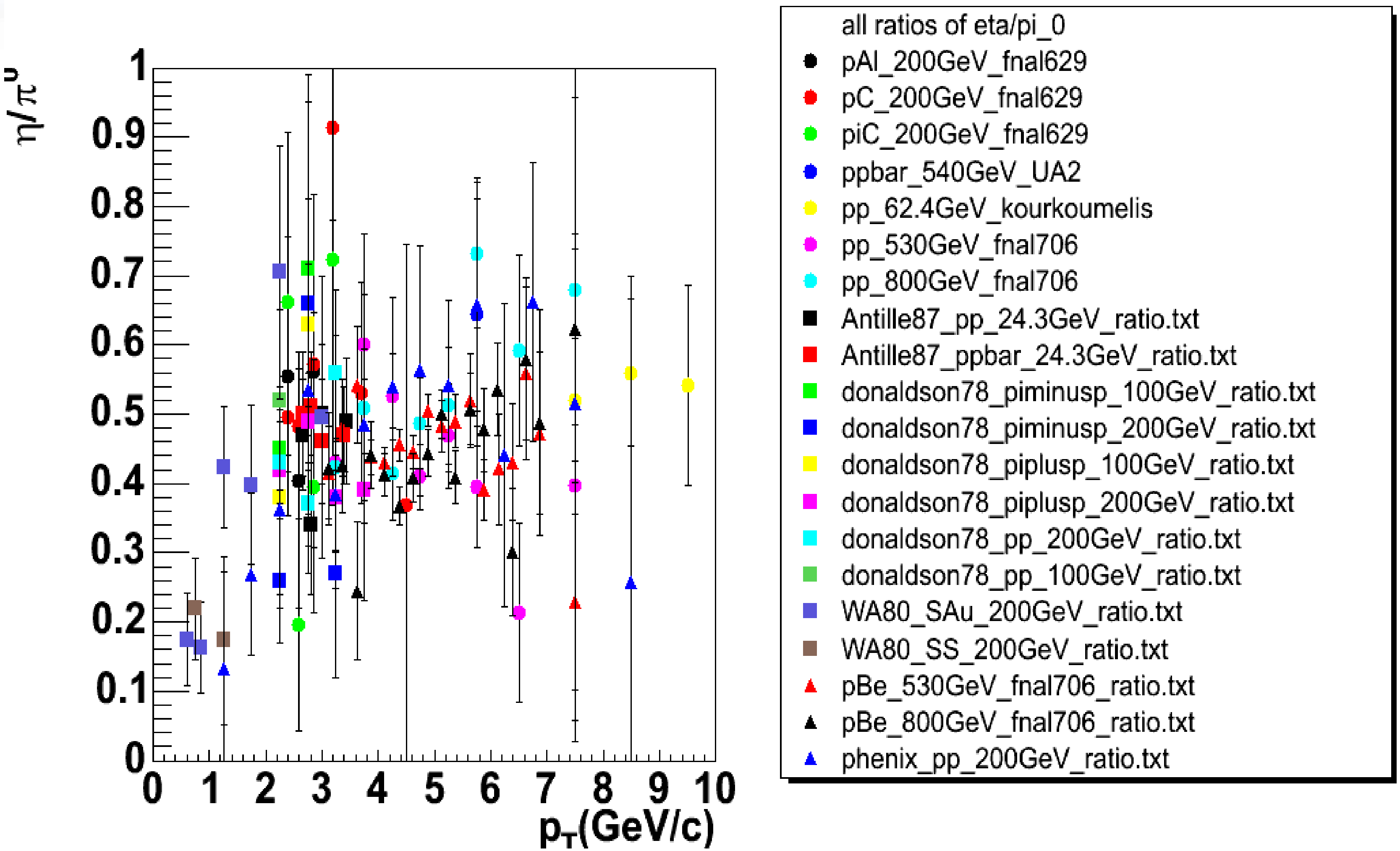
Plot (1)

PHENIX Preliminary

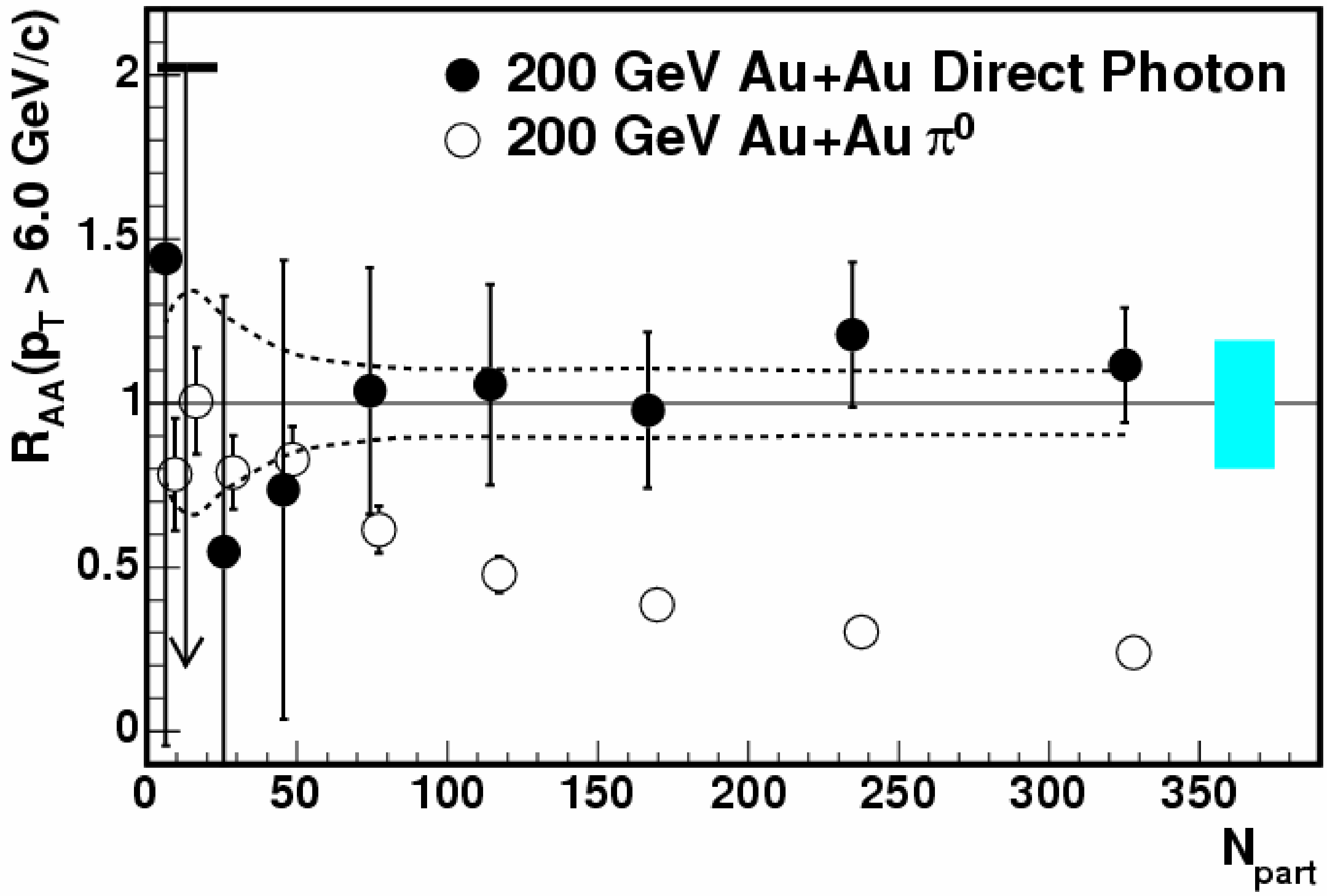


Vertical bin shift correction has been applied (3-4%)

Eta/pi0 ratio



Results



200 GeV Au+Au Direct Photon
200 GeV Au+Au π^0
$R_{AA}(p_T > 6.0$ GeV/c)
2
1.5
1
0.5
0
0
50
100
150
200
250
300
350
N_{part}