Photon Production

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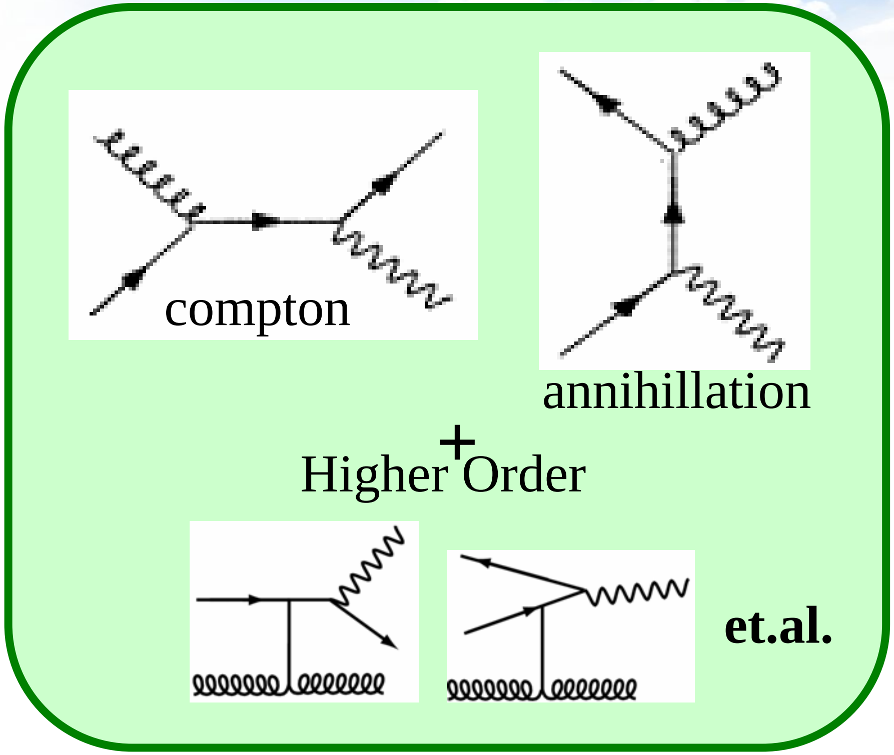
Outlines

- 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.



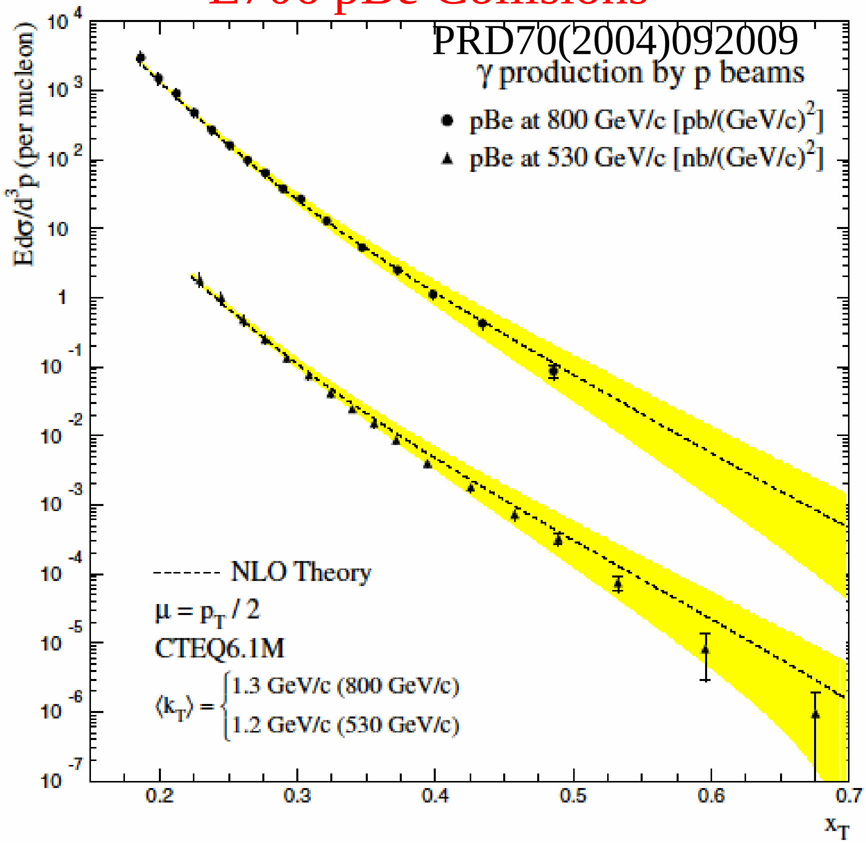
Photon in p+p is
a testing ground of pQCD

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



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

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

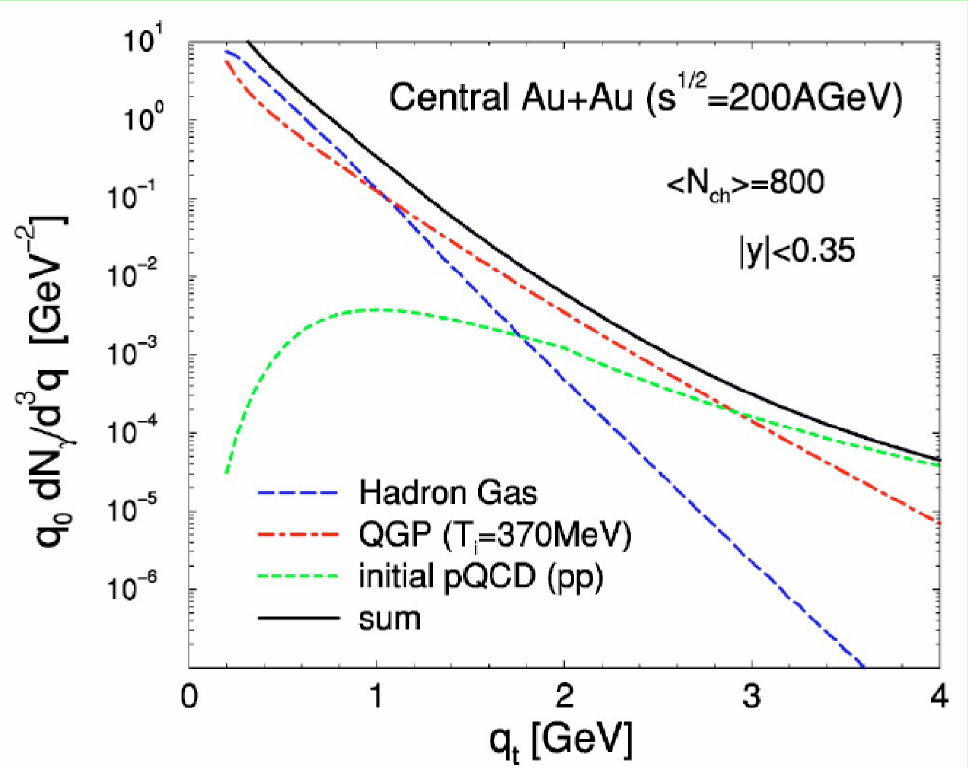
Why Photon (Au+Au)?

- 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

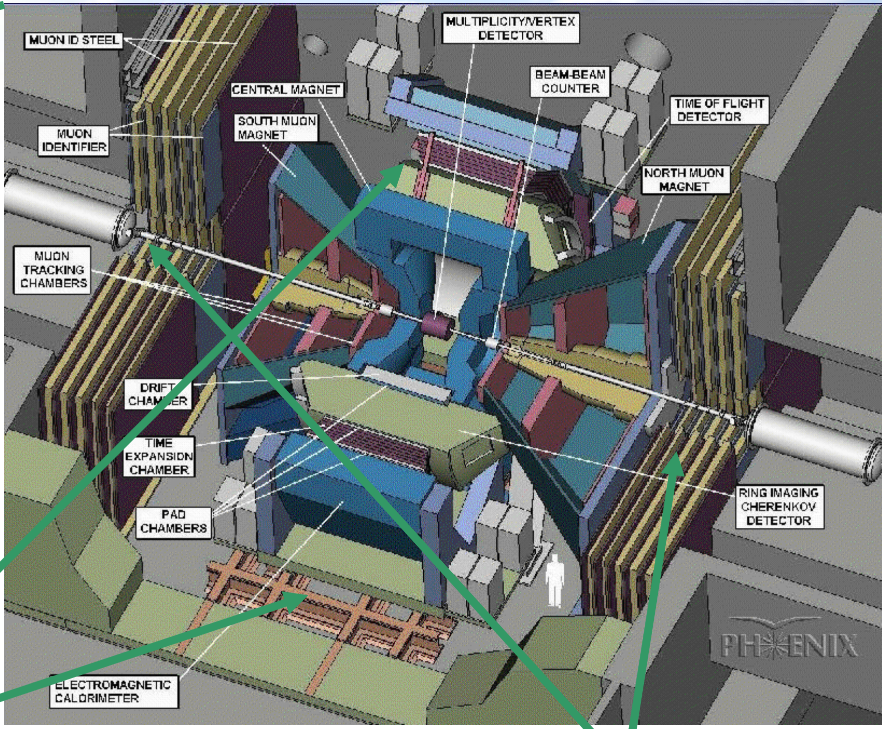
➔ Target 1-3GeV

Realistic Calculation



PRC69(2004)014903, Turbide, Rapp, Gale

PHENIX



2 central Spectrometers

2 forward Spectrometers

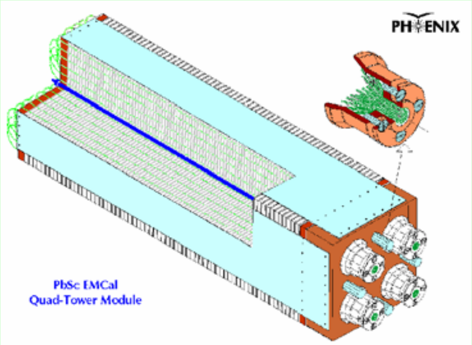
- 3.8km with 2 rings
  - 120bunch/ring
  - 106ns crossing time
- Maximum energy
  - 250GeV for p(polarized)
  - 100GeV/nucleon for Au
- Luminosity
  - Au-Au : 2 x 10^{26}cm^{-2}s^{-2}
  - p-p : 2 x 10^{32}cm^{-2}s^{-2}
- 6 Crossing points

- 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

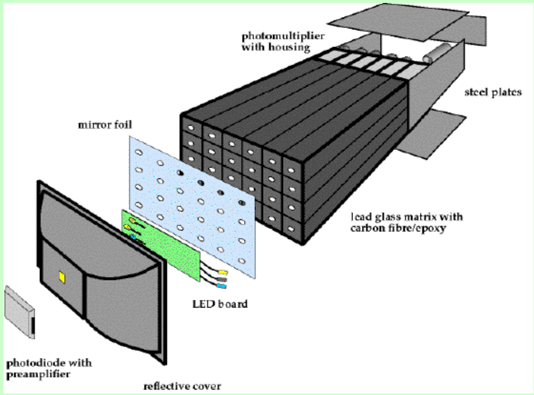
Lead Scintillator (PbSc)

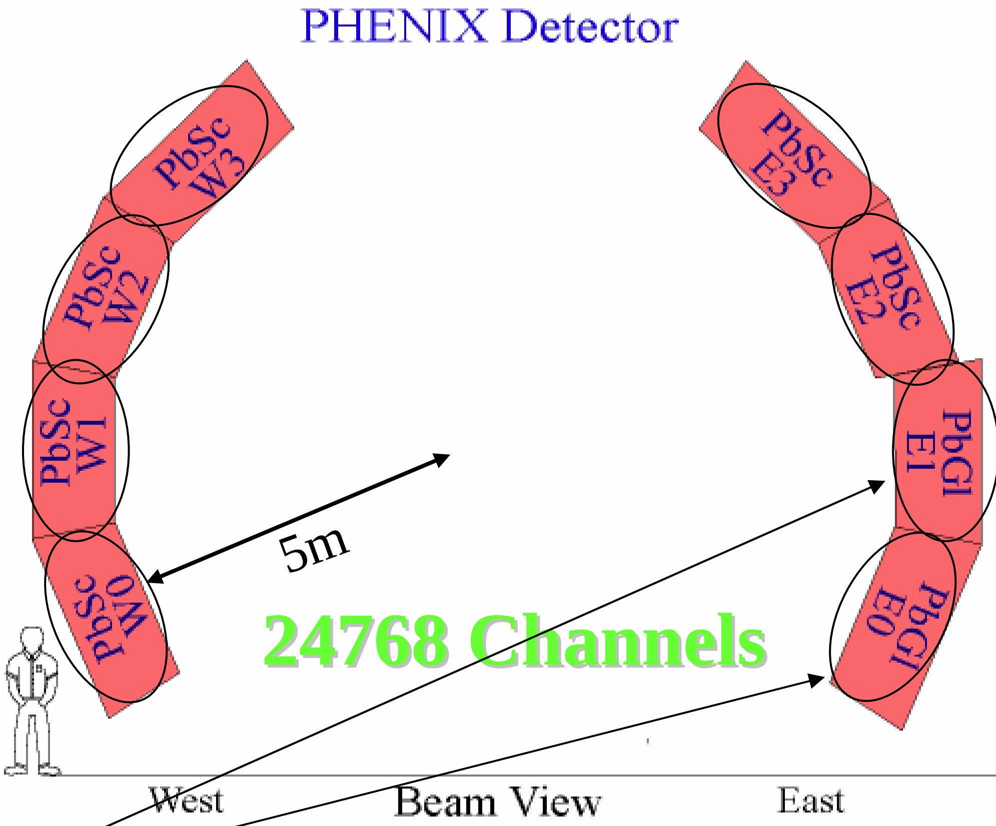
- Sandwich type calorimeter
  - Lead and scintillation plate
  - Shish-kebab type readout



Lead Glass (PbGl)

- Total reflection calorimeter





Coverage $|\eta|<0.38$ $\phi = 180°$

Fine segmented calorimeter.

distinguish two photons from $\pi0$ photons pT~25GeV/c

p+p

Prompt Photon Production

Prompt photon production consists of two processes

$$\sigma = \sigma_{dir} + \sigma_{frag} = \sum_{i,j,k} \int dx_i dx_j \times \boxed{f_1^i(x_i, \mu) \cdot f_2^j(x_j, \mu)}$$

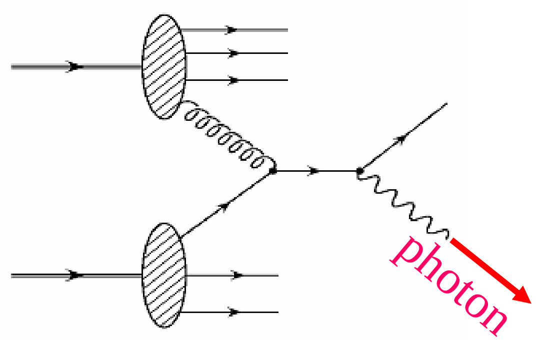
parton distribution function(PDF)

fragmentation function(FF)

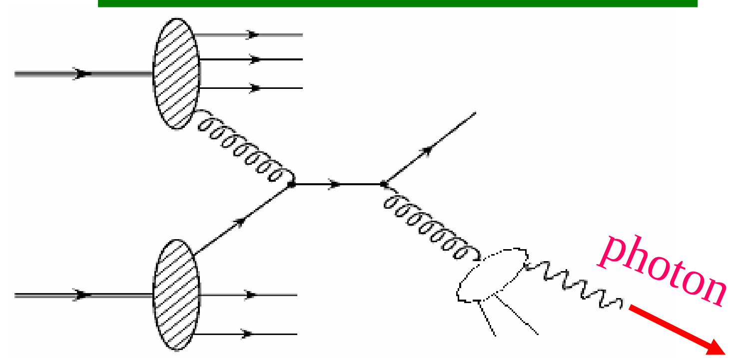
$$\times \left\{ \boxed{\sigma(i + j \to \gamma)} + \int dz \boxed{\sigma(i + j \to k)} \times \boxed{D_k^3(z_k, \mu_F)} \right\}$$

Direct Process

Bremsstrahlung Process

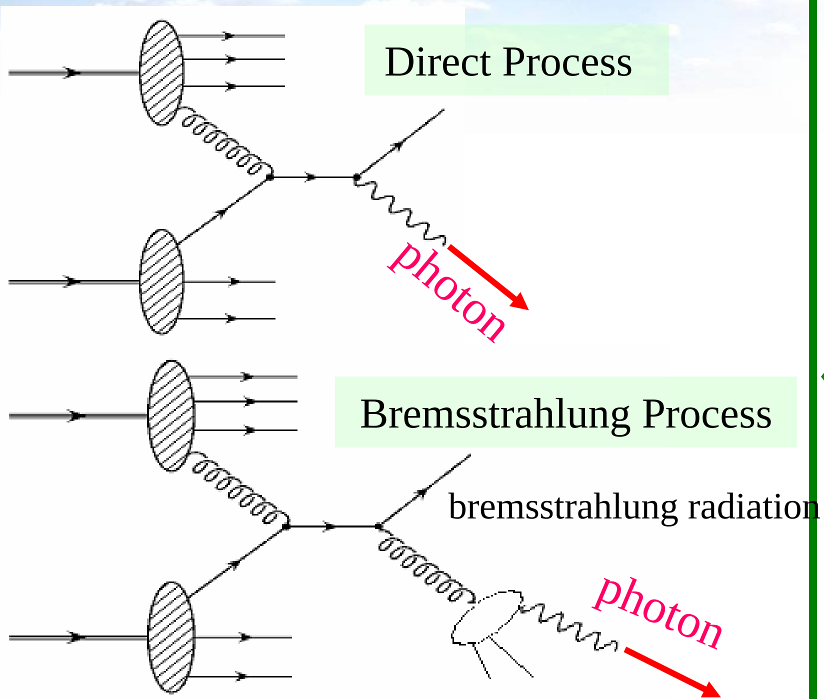


Compton/Annihilation process



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.

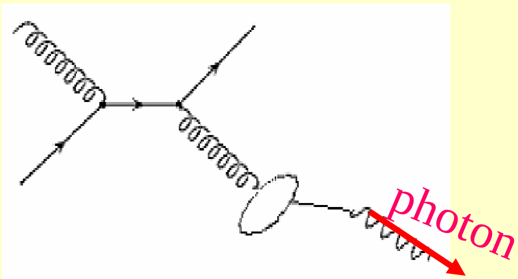
Background

Non-vertex Photon

Neutral hadron contribution

Noise in the detector

Hadron(π^0,η,ω..) decay

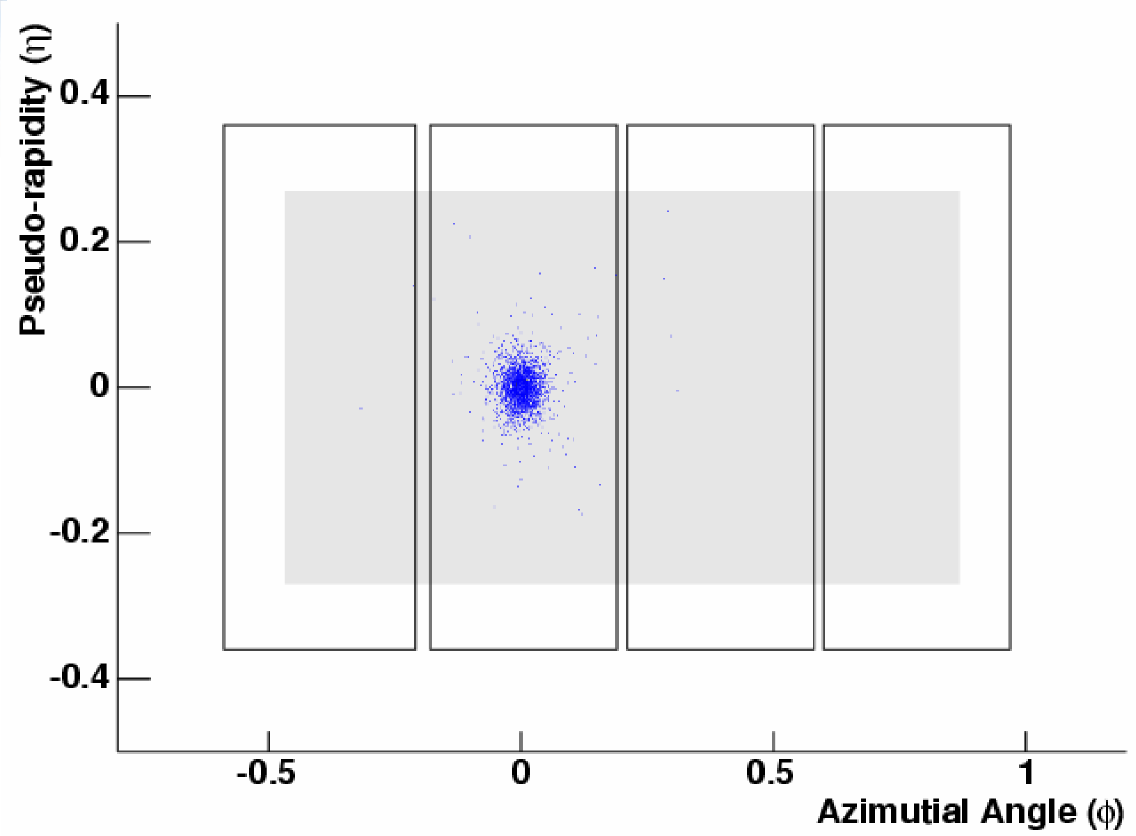


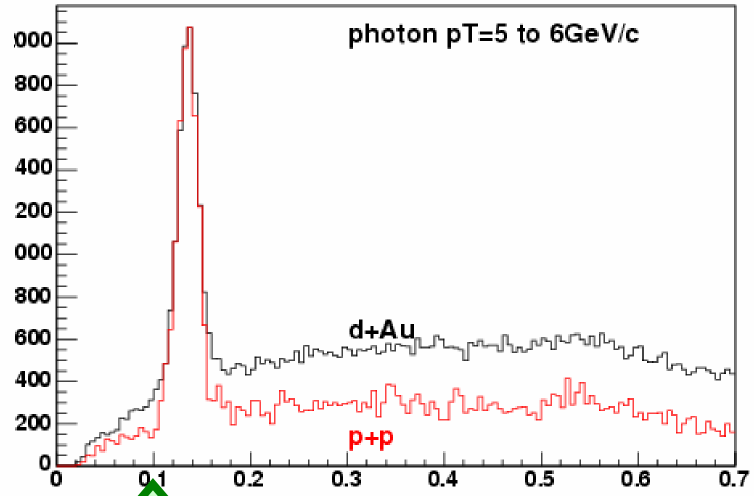
Estimate all backgrounds

After subtracting all backgrounds,

the remained photons are the signals.

Background from π^0





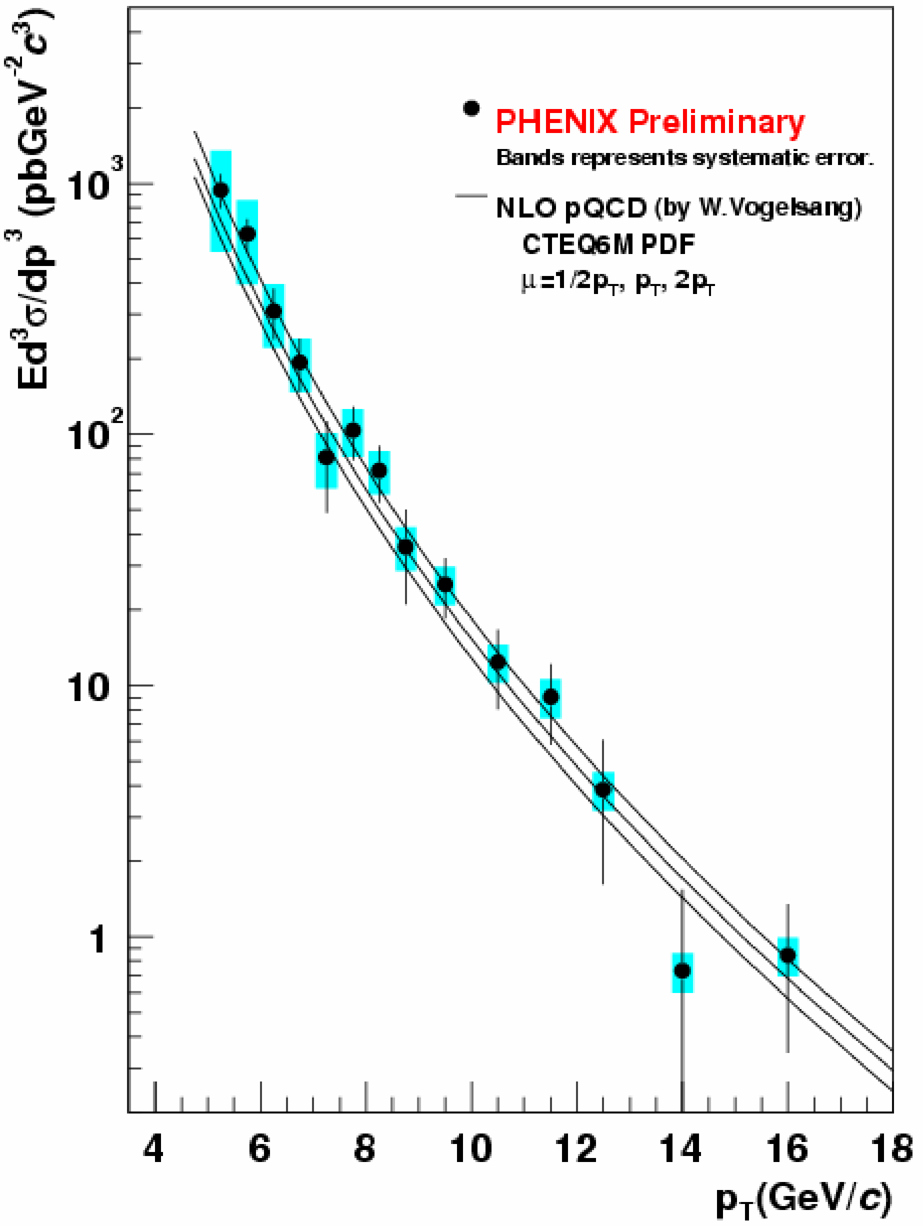
By taking all combination between the target photon and the surrounding photons, we can know the photon from pi0 decay.

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

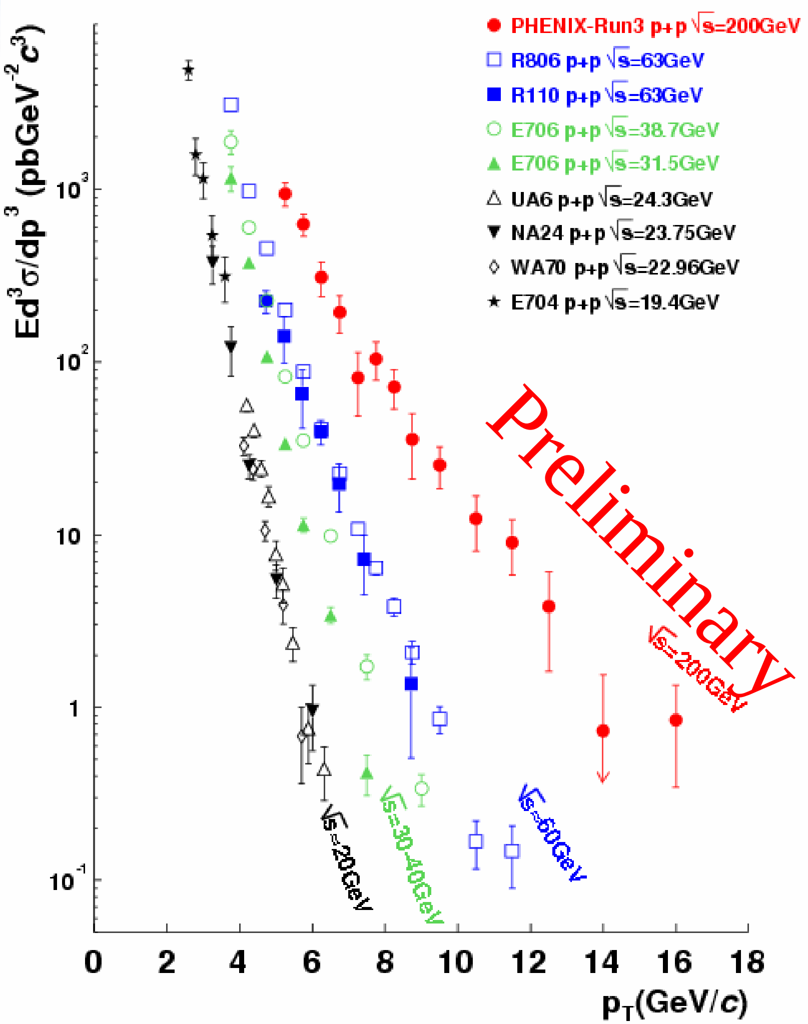
Result

- 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

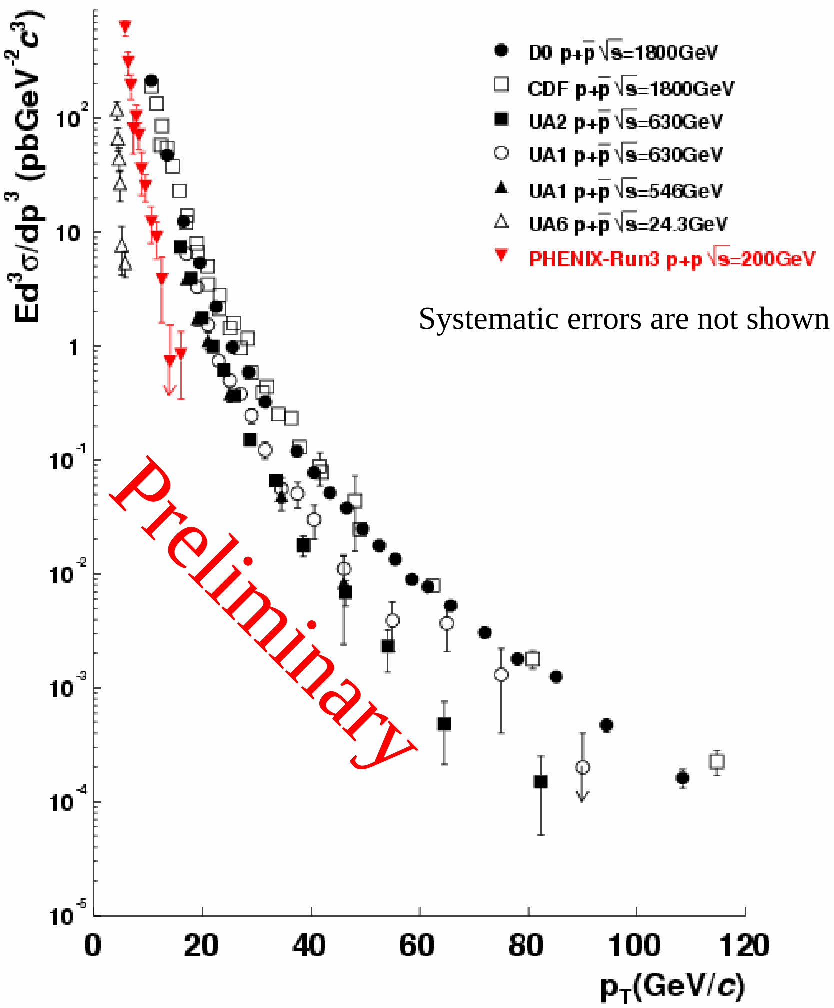
pQCD calculation can describe our result very well.



Comparison with Other Experiment



proton-proton collisions



proton-antiproton collisions

x_T Scaling

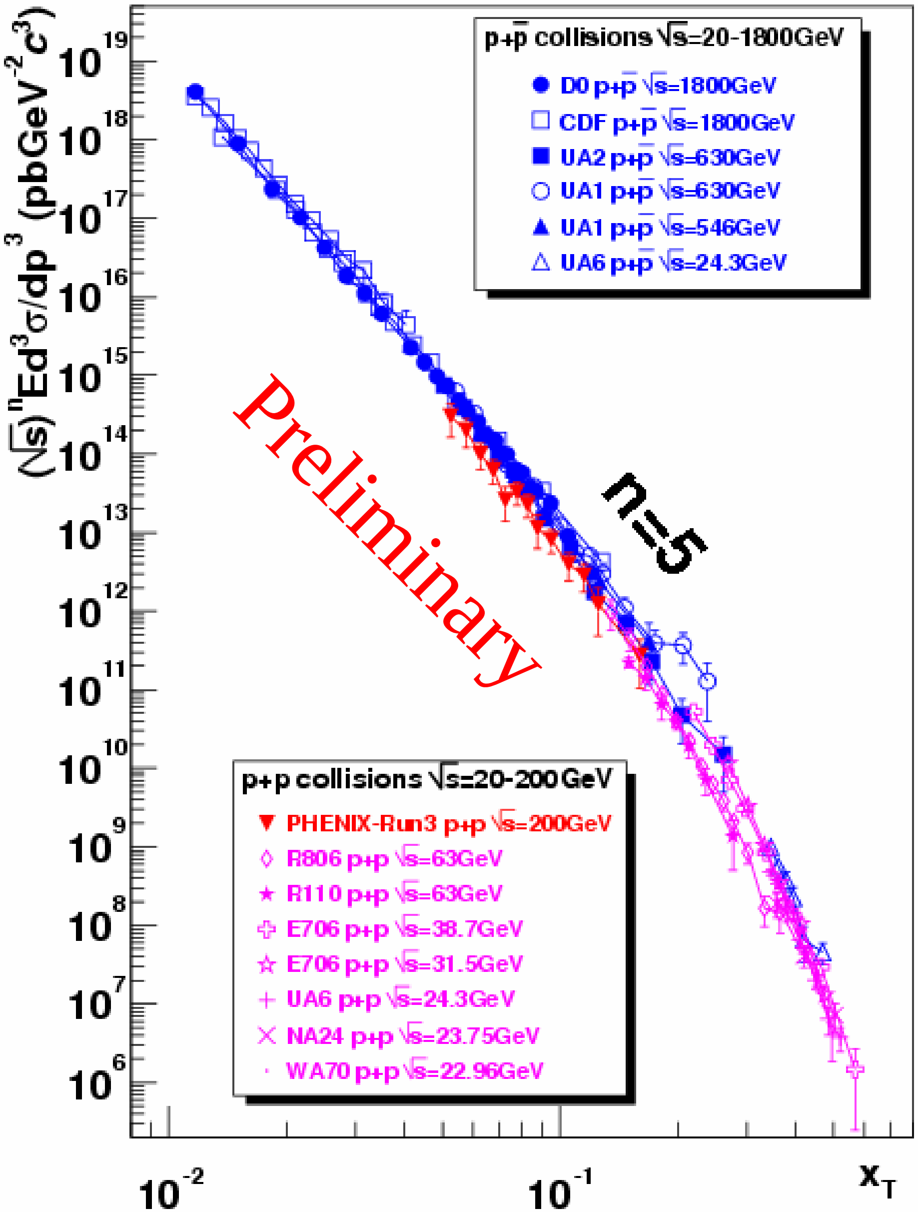
- From QCD, if
  - Q^2-Scaling of PDF,FF
  - No running coupling constant(α_s)

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

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

$\boxed{x_T\text{-Scaling } n=\sim 5}$

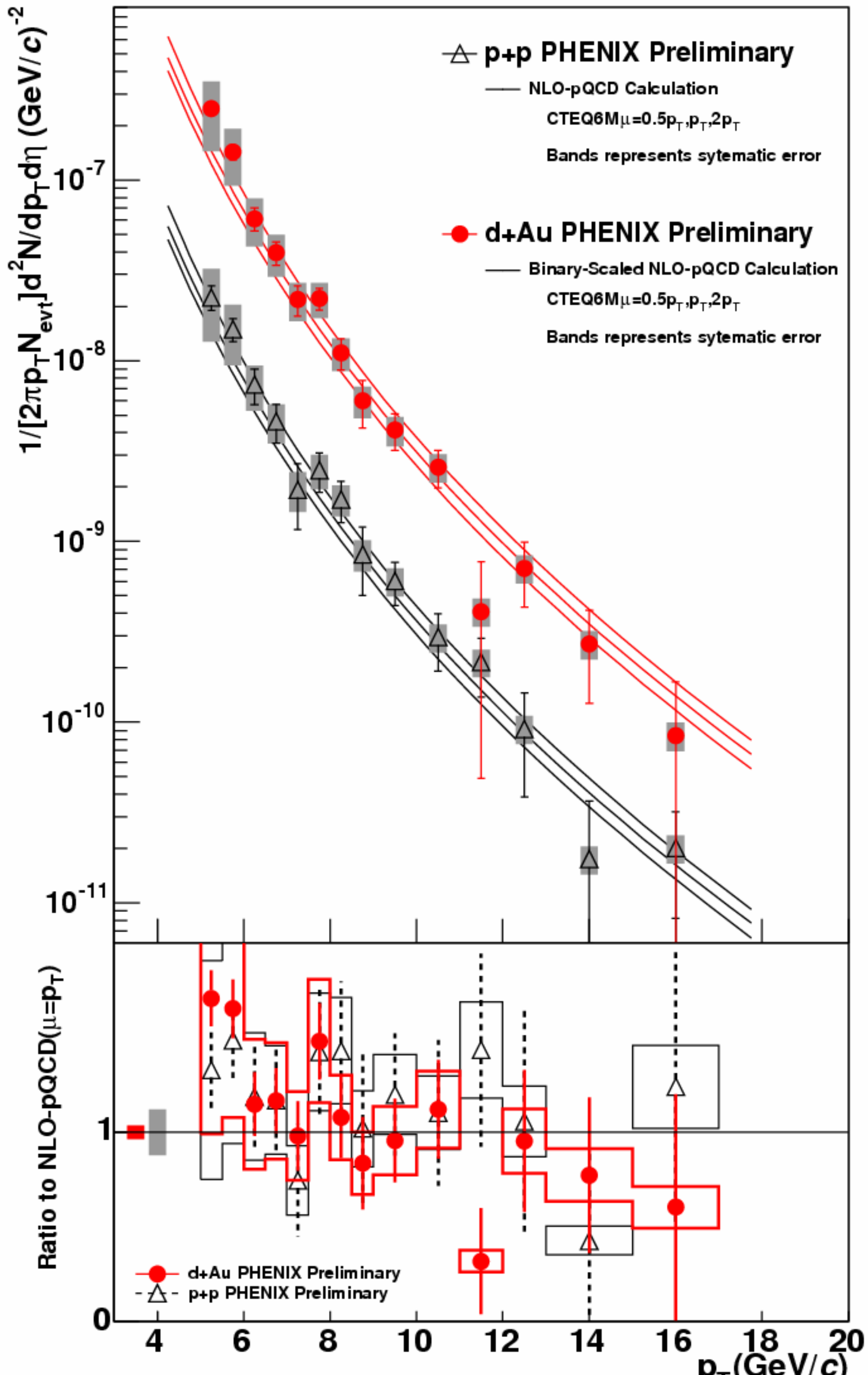


d+Au

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.

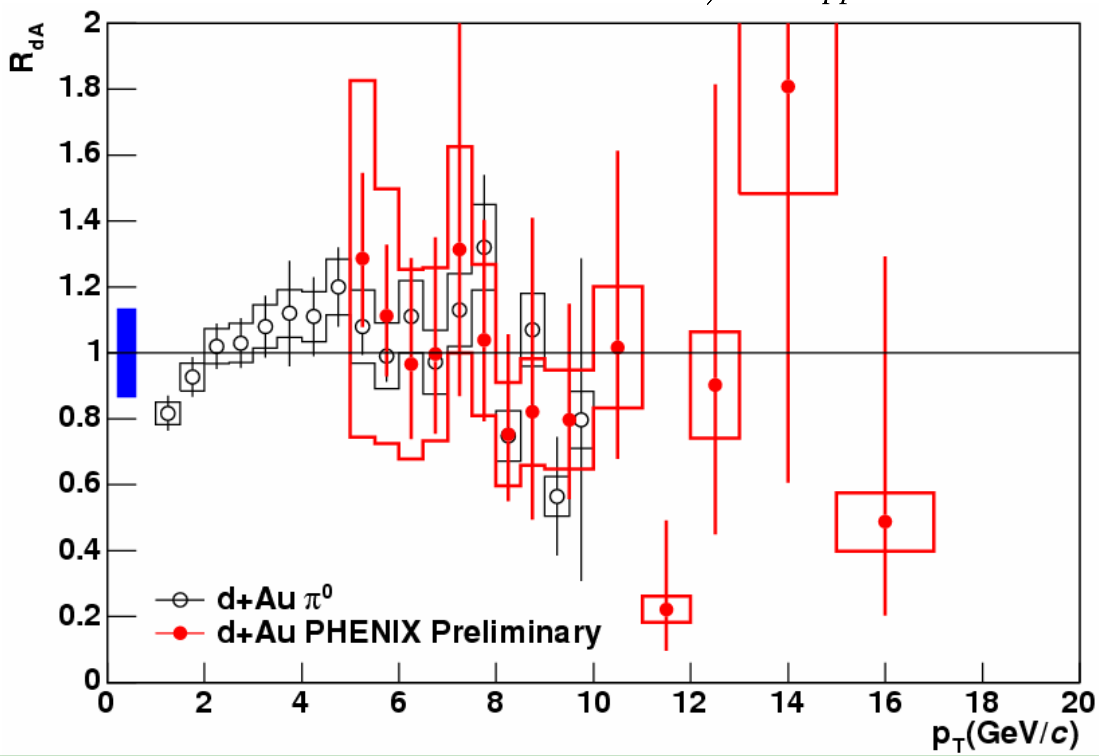
Result is consistent with the binary – scaled NLO-pQCD calculation



Result

Nuclear Modification Factor

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



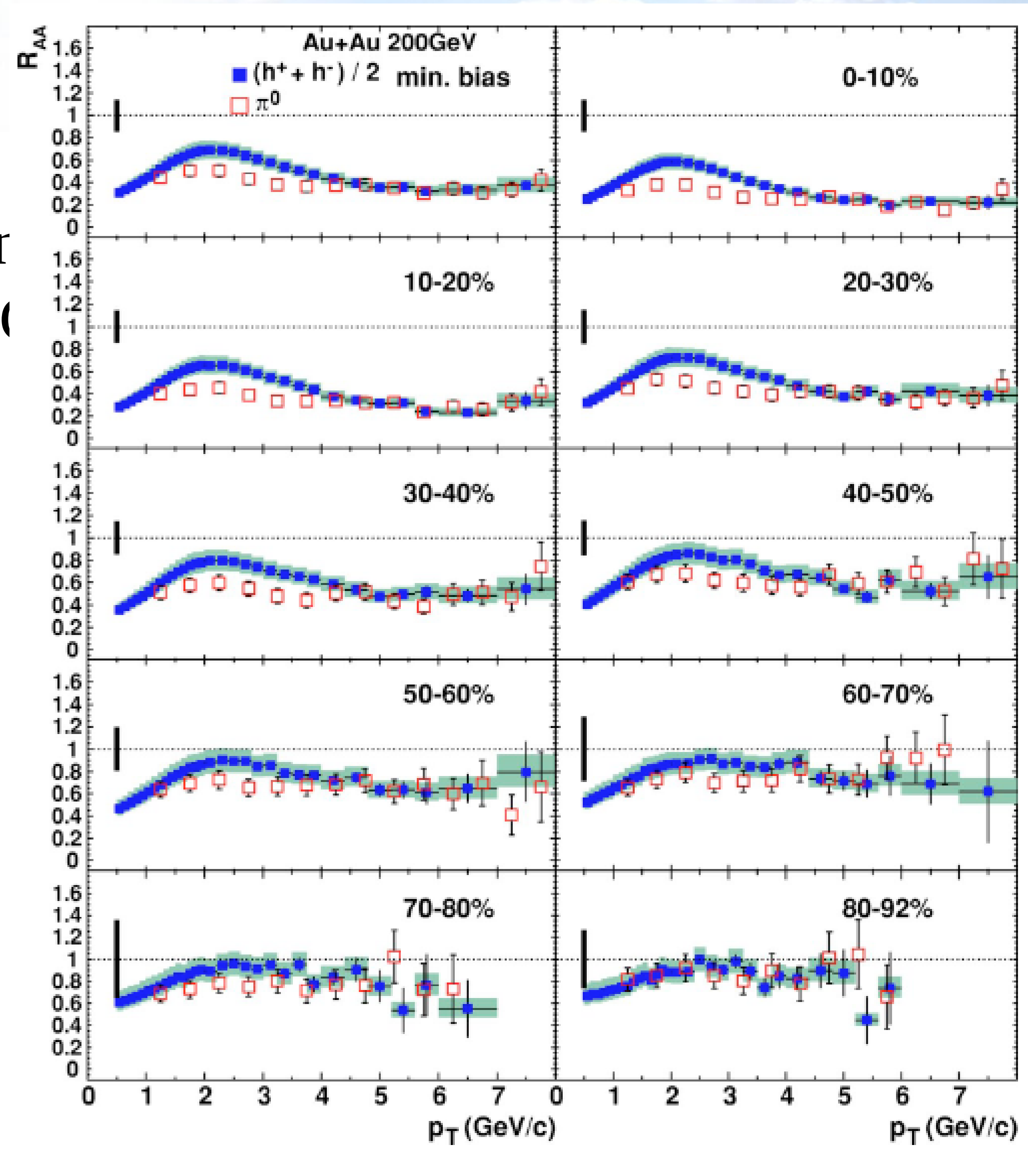
Consistent with 1 ➔ No modification within the error

This is consistent with what we measured in π^0

Au+Au

Background Photons

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



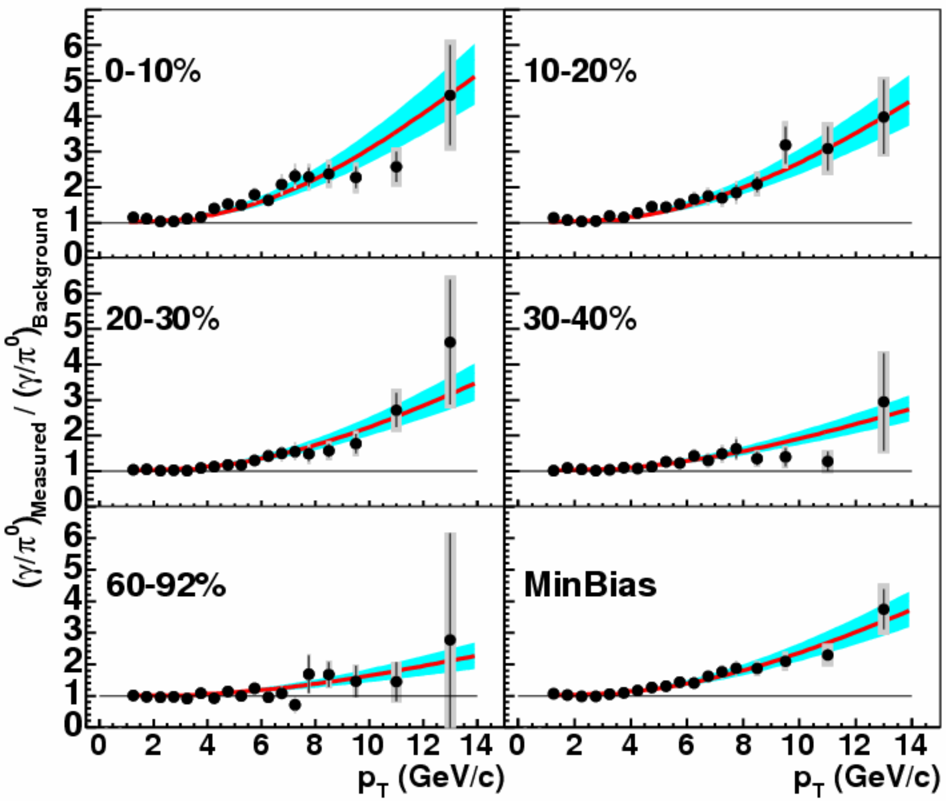
π^0 suppression help to reduce photon background

Cancel Systematic Error

- Direct photon yield

  = Excess from bg photons

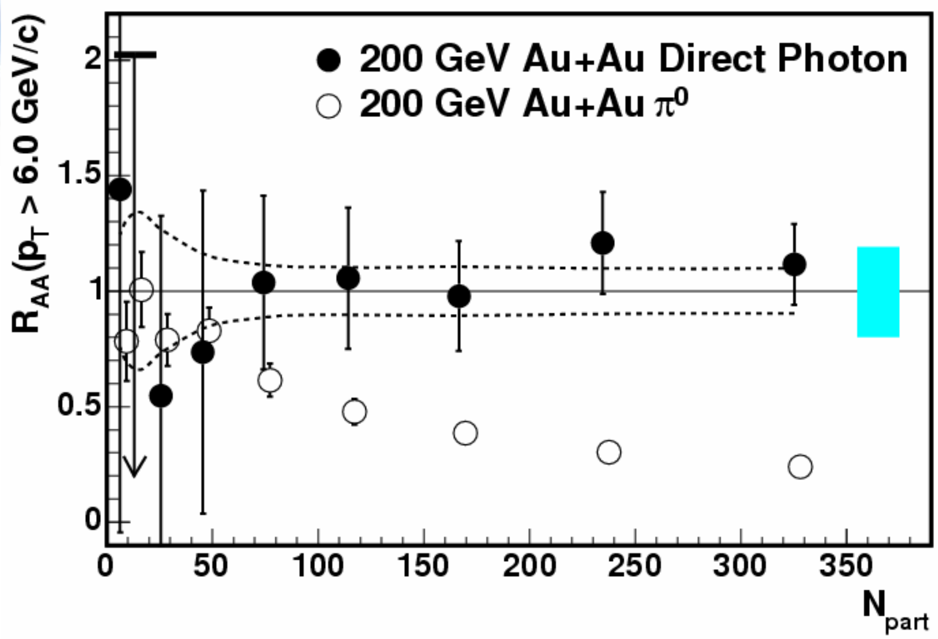
$$R = \frac{\left(\gamma/\pi^0\right)_{measured}}{\left(\gamma/\pi^0\right)_{calculated}} = \frac{\gamma_{measured}}{\gamma_{background}}$$



- 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

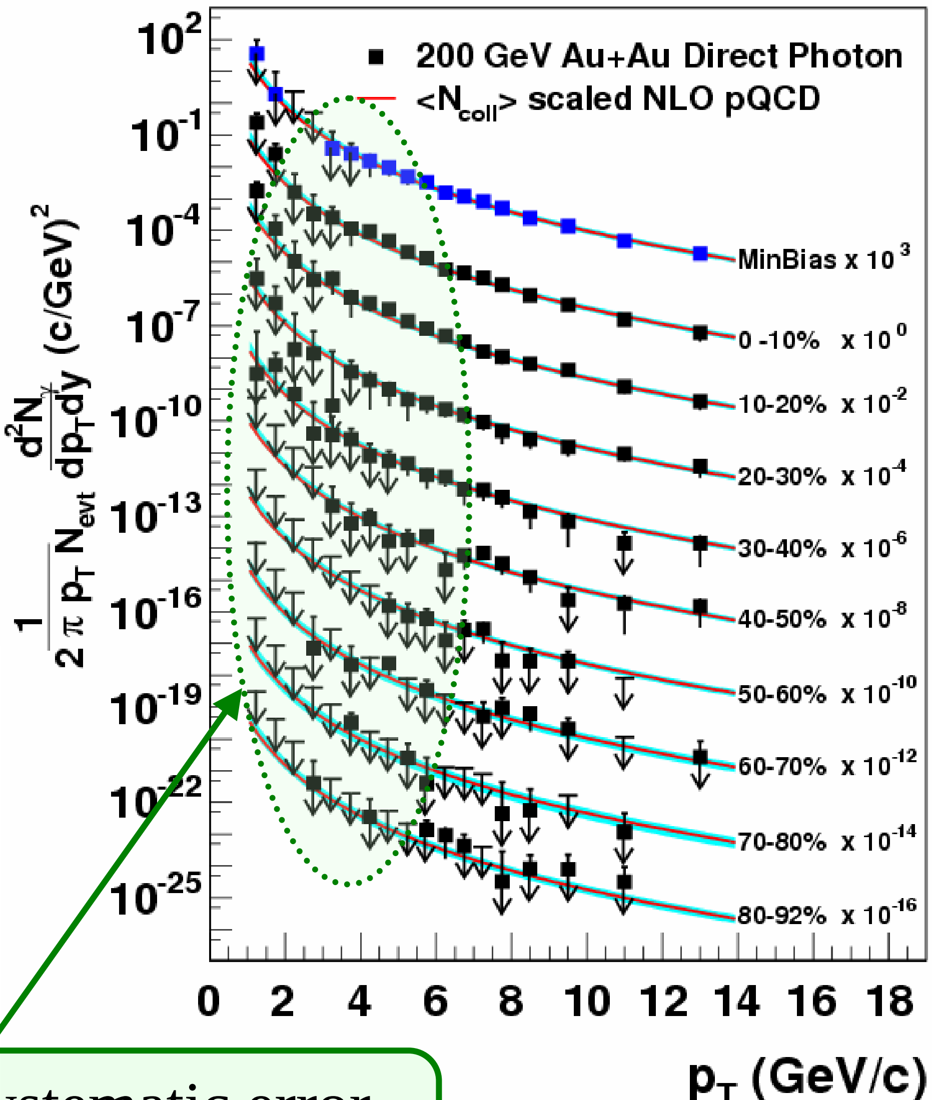
Results



consistent

Jet Quenching Scenario

(π^0 suppression)



Need to reduce the systematic error for thermal photon measurement

PRD94(2005)232301

Conclusion

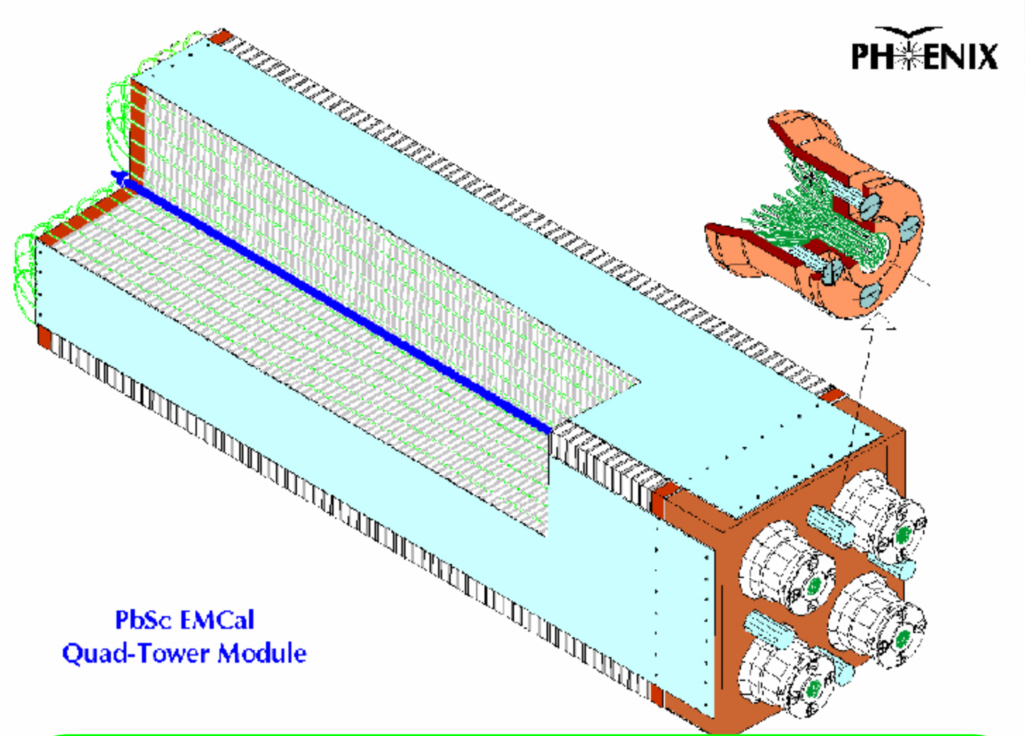
- p+p collisions
  - NLO pQCD calculation can describe our data
    - Sum of direct part and fragmentation part.
  - Fit in xT scaling with other experiment
- d+Au collisions
  - comparison with NLO-pQCD
    - Result in d+Au collisions is consistent with the binary-scaled NLO-pQCD calculation.
  - Nuclear 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

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

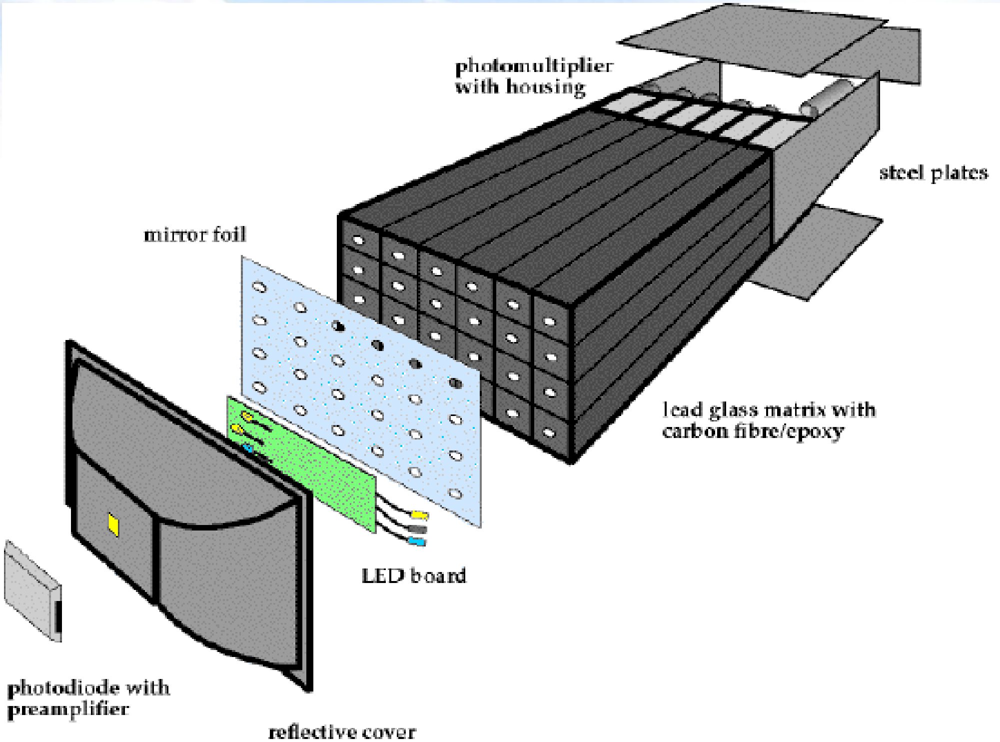
2 x 2 towers = 1 module

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

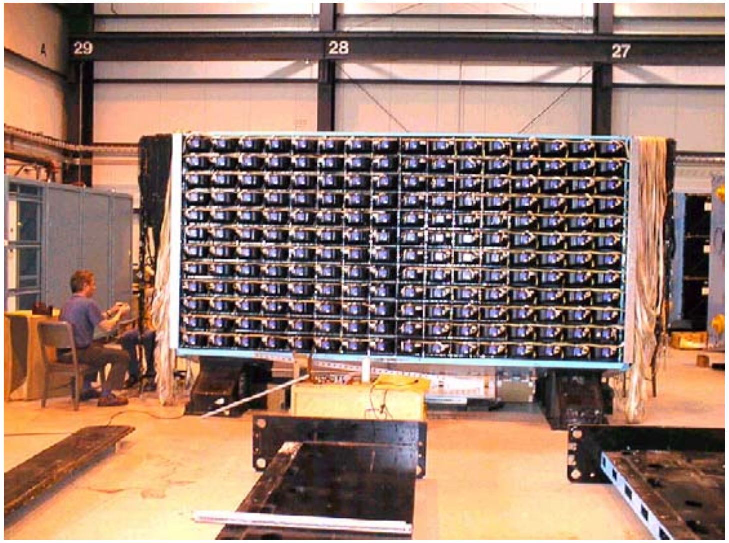
Lead Glass calorimeter

Lead Glass 40x40x400mm

used at WA98 exp.

4x6 towers = 1 super module

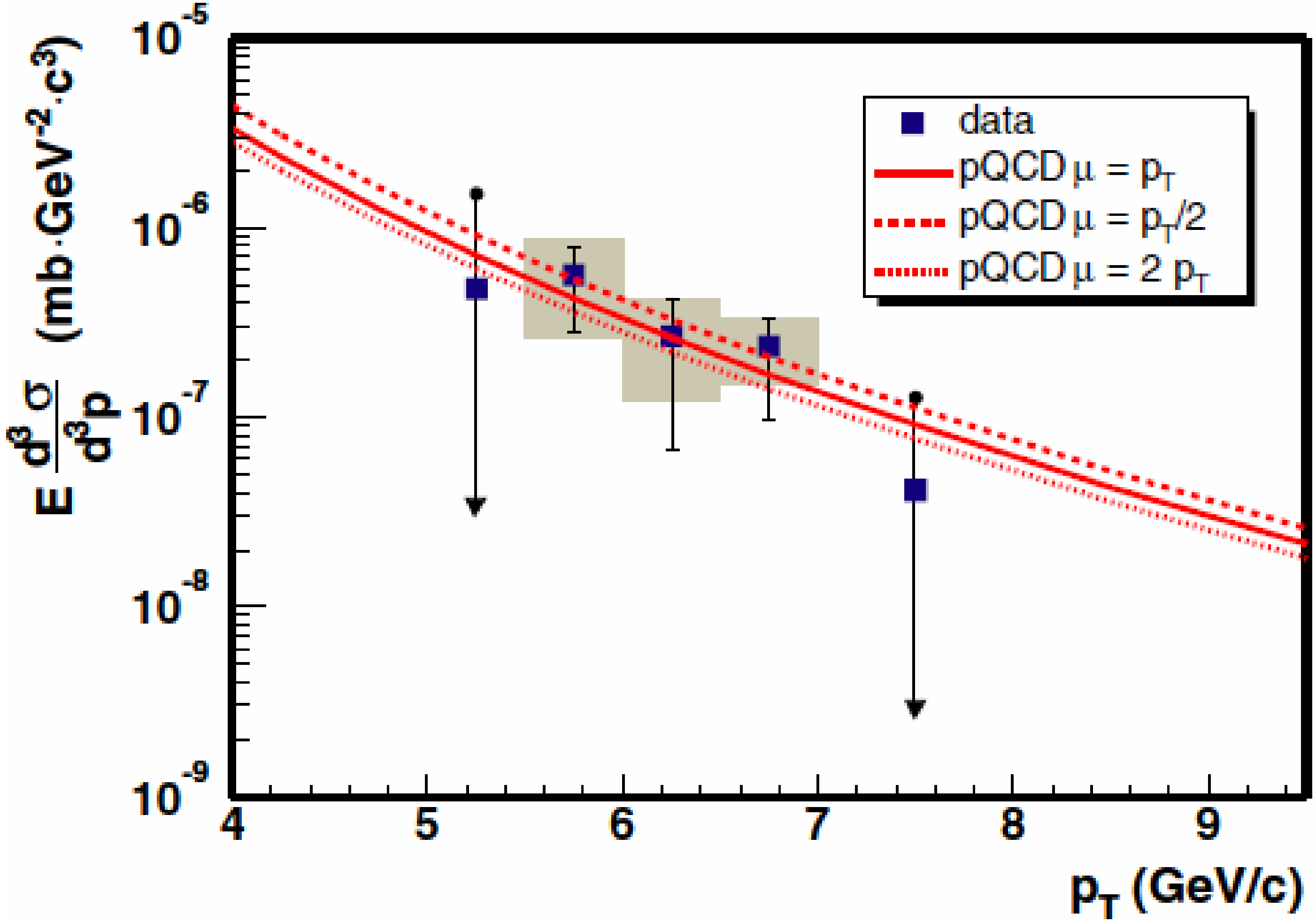
15*12 super module = 1 sector



PbGl sector 2.1m x 3.9m

Photon from run2 p+p

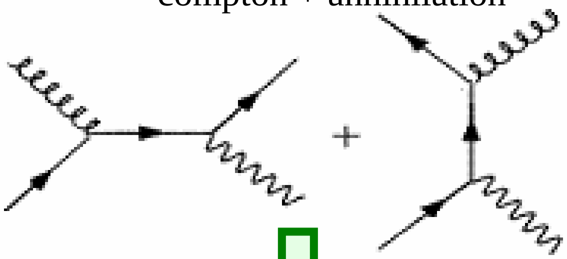
PHYSICAL REVIEW D **71**, 071102 (2005)

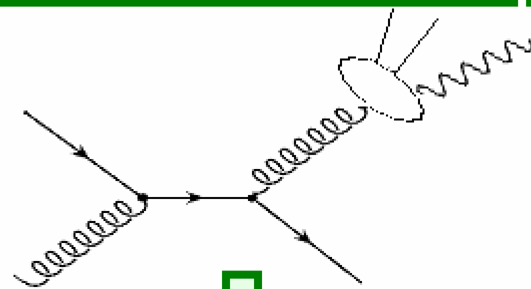


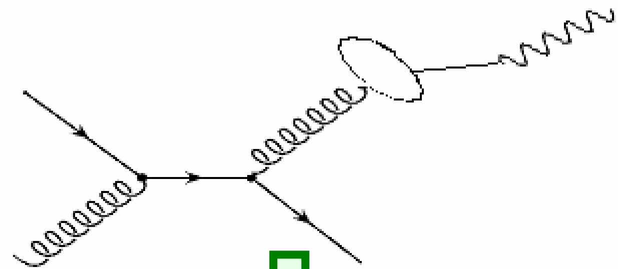
Strategy of Isolation Method

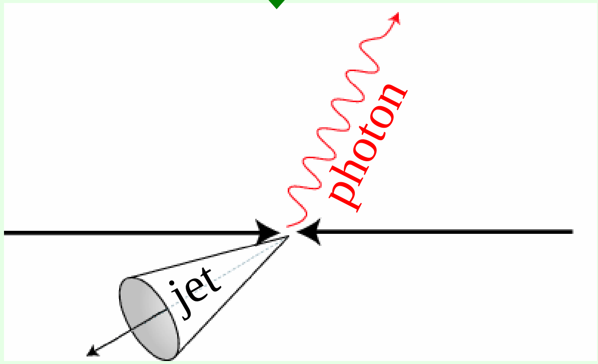
(1)Signal(direct)	(2)Signal(fragmentation)	(3)Background(hadron decay)

compton + annihilation

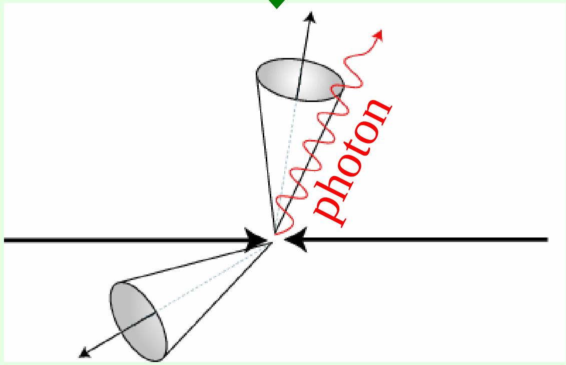




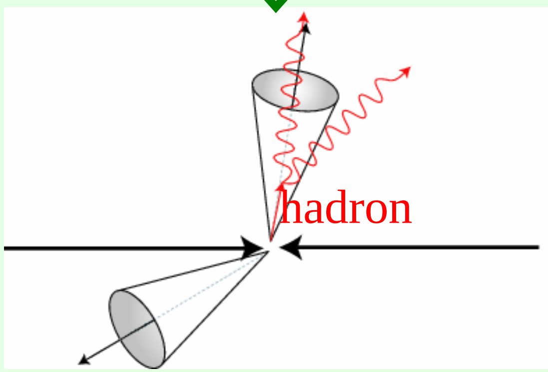




約30%@10GeV



約10%@10GeV

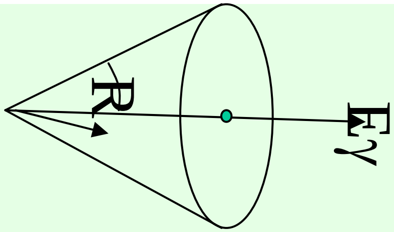


約60%@10GeV

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)