Direct photon measurements

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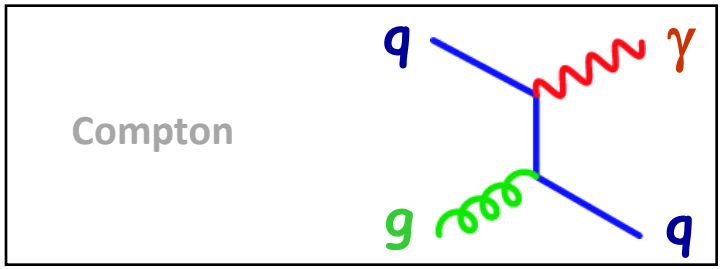
PHENIX FOCUS

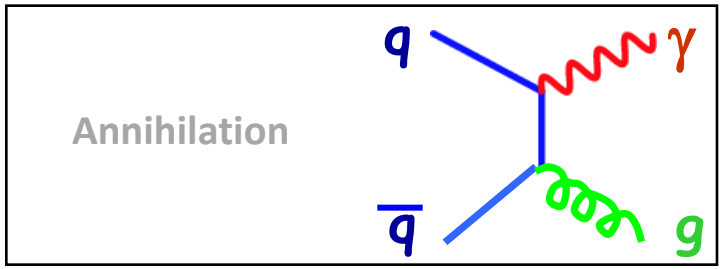
June 23, 2009

Origin

Diagrams of hard scattering



80~90%



20~10%

+ thermal, fragmentation ← Those contribution may become large in a hot and dense environment.

Applications

There are a lot of applications like iPhone.

That is why people like it.

thermometer (thermal photons)
penetrating probe (reference to hadronic probe)
(pol)PDF (basic gluon quantity of the proton)
cheap version of DY (forward photon for high x quark)
away side jet (equal to photon energy if there is no modification.)
,etc.

This talk

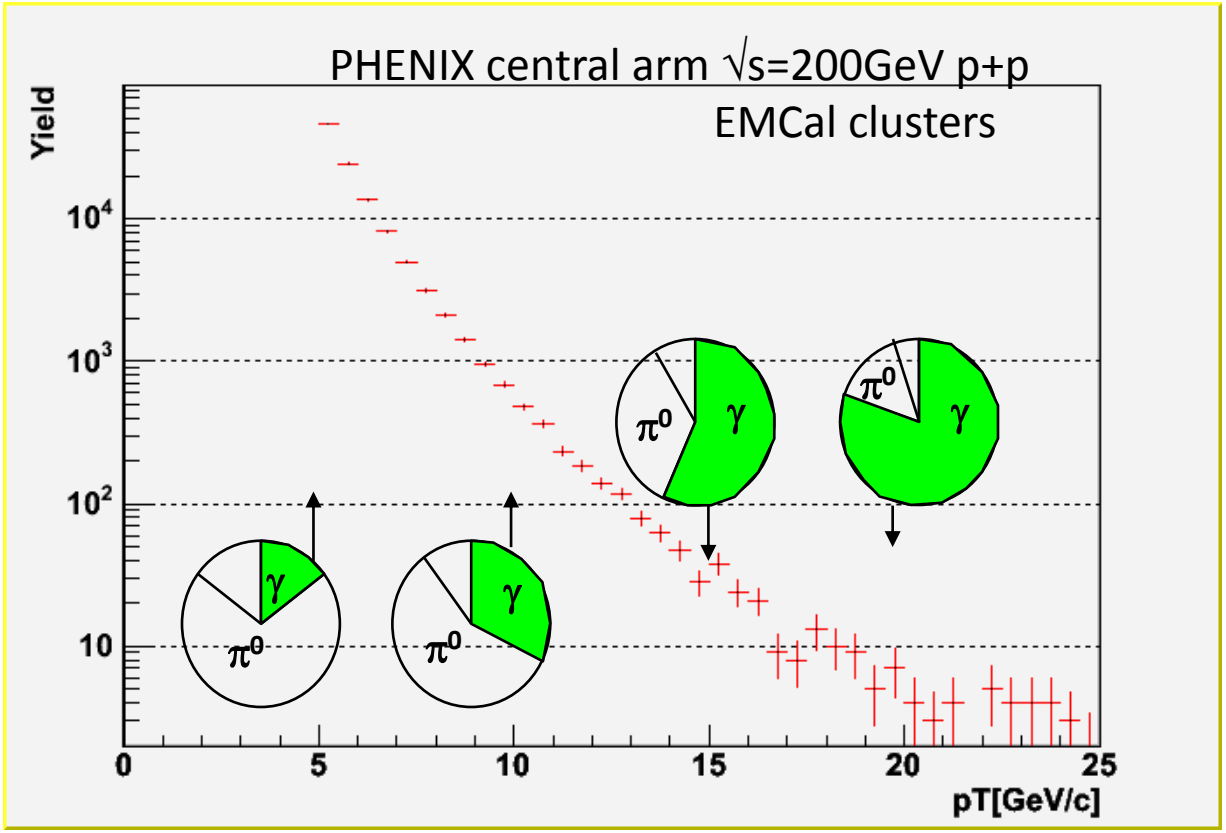
FOCUS on practical aspects

What is the problem?
How do we solve?
How can we extend?

And a little about physics

Experimental problem

Clusters from other sources (hadronic decays, albedos)



Small S/N

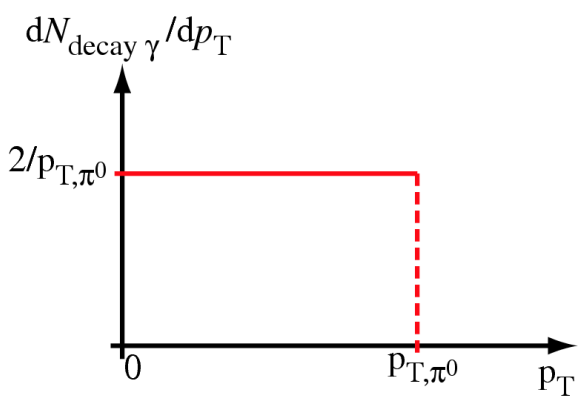
π^0 2γ into one tower

An useful formula (photons from pi0)

$$\frac{1}{p_T}\frac{dN_{\pi^0}}{dp_T} \propto 1/p_T^n$$

$$\Rightarrow \frac{\gamma_{\pi^0}^{decay}}{\pi^0} = \frac{2}{n-1} \approx 0.28 \text{ at RHIC}$$

The shape doesn't change.
To change the shape, it needs to break the conservation of number of products.
jet slope ≠ pi0 slope



Decay photon p_T distribution for π^0's with fixed p_{T,π^0}:

$$g(p_T, p_{T,\pi^0}) \approx \begin{cases} 2/p_{T,\pi^0}, & p_T < p_{T,\pi^0} \\ 0, & \text{else} \end{cases}$$

For $\frac{1}{p_T}\frac{dN_{\pi^0}}{dp_T} \propto p_T^{-n}$:

$$\left.\frac{\gamma_{\text{decay-}\pi^0}}{\pi^0}\right|_{p_T} = \frac{\int_{p_T}^{\infty} g(p_T, p_{T,\pi^0})\frac{dN_{\pi^0}}{dp_{T,\pi^0}}\, dp_{T,\pi^0}}{p_T^{-n+1}} = \frac{2\cdot\int_{p_T}^{\infty} p_{T,\pi^0}^{-n}\, dp_{T,\pi^0}}{p_T^{-n+1}} = \frac{2}{n-1}$$

Uncertainty leverage

signal(S) = inclusive photon(A) – background(N)

$$S = A - N$$

$$\frac{\delta S}{S} = \frac{\delta A}{A} \cdot W - \frac{\delta N}{N} \cdot (W - 1), W \equiv \frac{A}{S}$$

Uncertainties are enlarged by low signal ratio.

The key is to make the S/N ratio high.

What neighbors did?

Not a complete review

E706 (fixed target experiment) PRD70,092009 (2004)

beam: 515 GeV/c pi-, 530,800 GeV/c proton
target: beryllium and hydrogen

target + tracking + EMCal + muID

EMCal

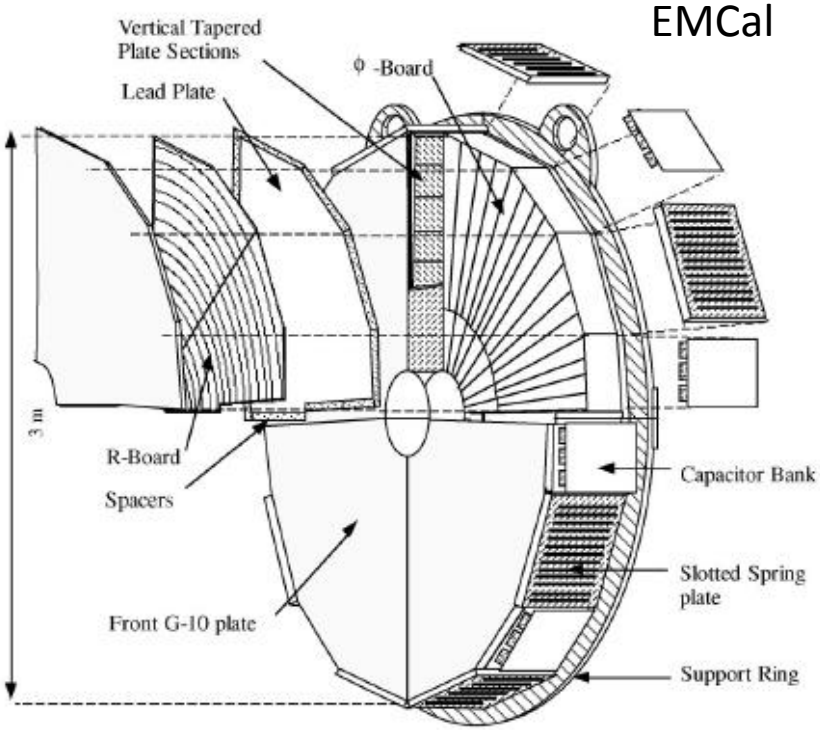
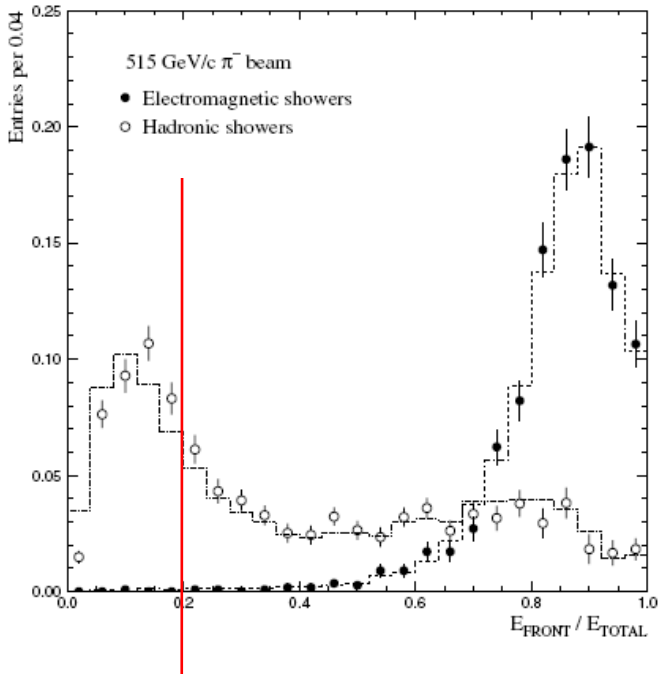


FIG. 2. A drawing of the liquid-argon electromagnetic calorimeter with some components pulled away in one quadrant to reveal a view of the internal details.

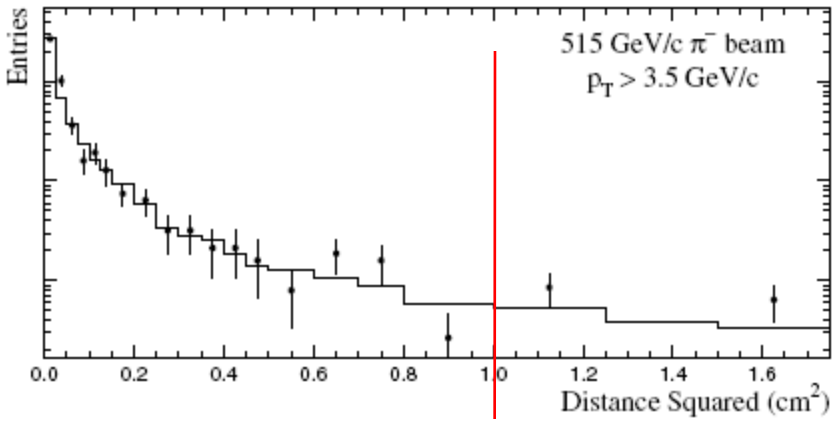
What neighbors did?

E706 (fixed target experiment)

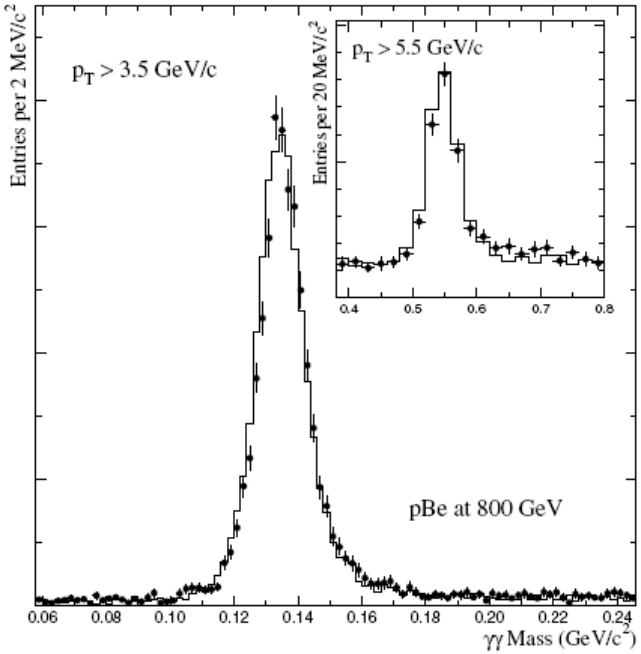
The S/N is improved by using the difference of longitudinal shower shape



Charge veto



reject photons from pi0, eta by pairing.



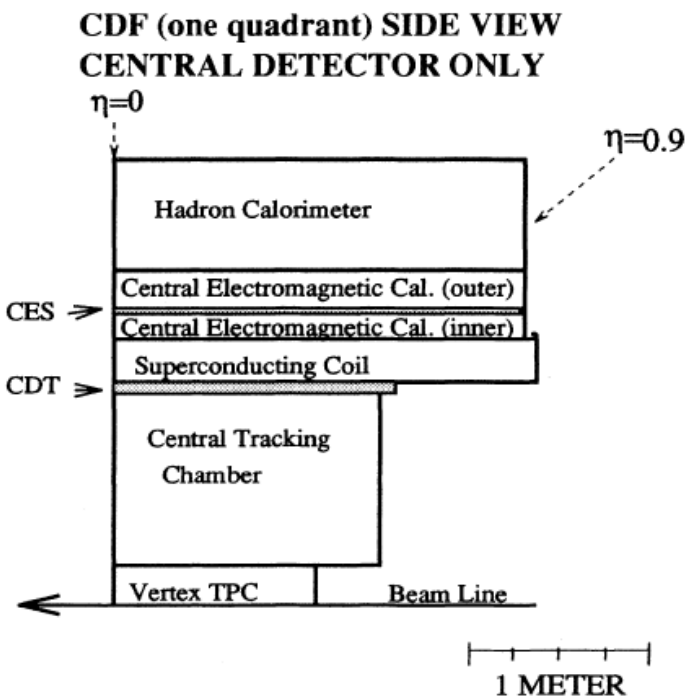
The residual background is estimated by DGS (detailed GEANT simulation)

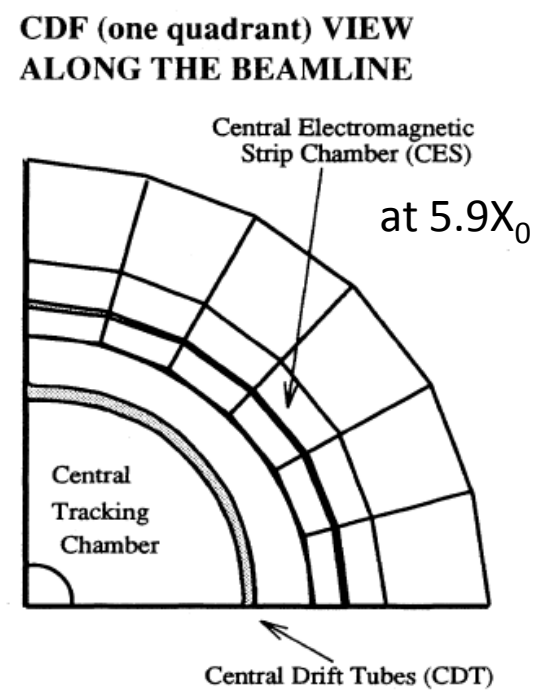
What neighbors did?

CDF (collider experiment) PRD48,2998 (1993)

EMCal
2 photons
> 50cm/pi0_pT[GeV]
because of short distance

15GeV pi0 is already difficult





Isolation cut ($E_T(R<0.7) < 2GeV$) is the largest contribution to improve S/N.

What neighbors do?

CDF (collider experiment)

—Method1 (low pT):
transverse shower profile method

—Method 2 (high pT)
The conversion method

For completely merged pi0 photons, conversion probability looks different between direct photon and pi0 clusters.

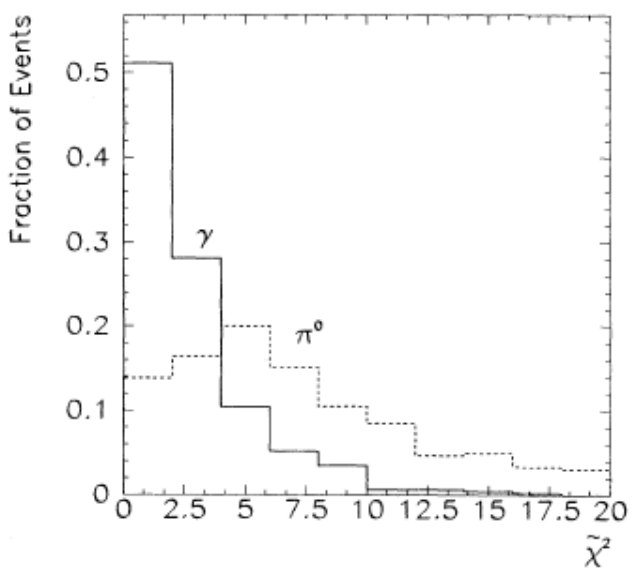


FIG. 3. Simulated $\tilde{\chi}^2$ distributions for 15 GeV/c photons (solid) and π^0's (dashed).

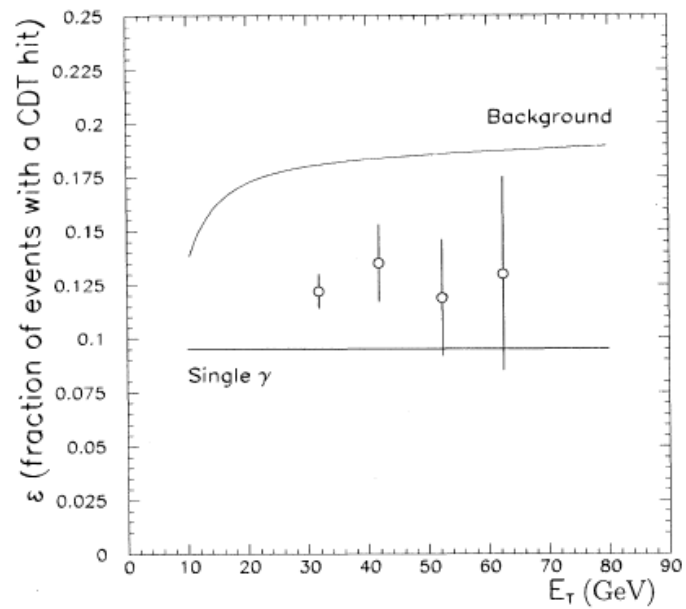
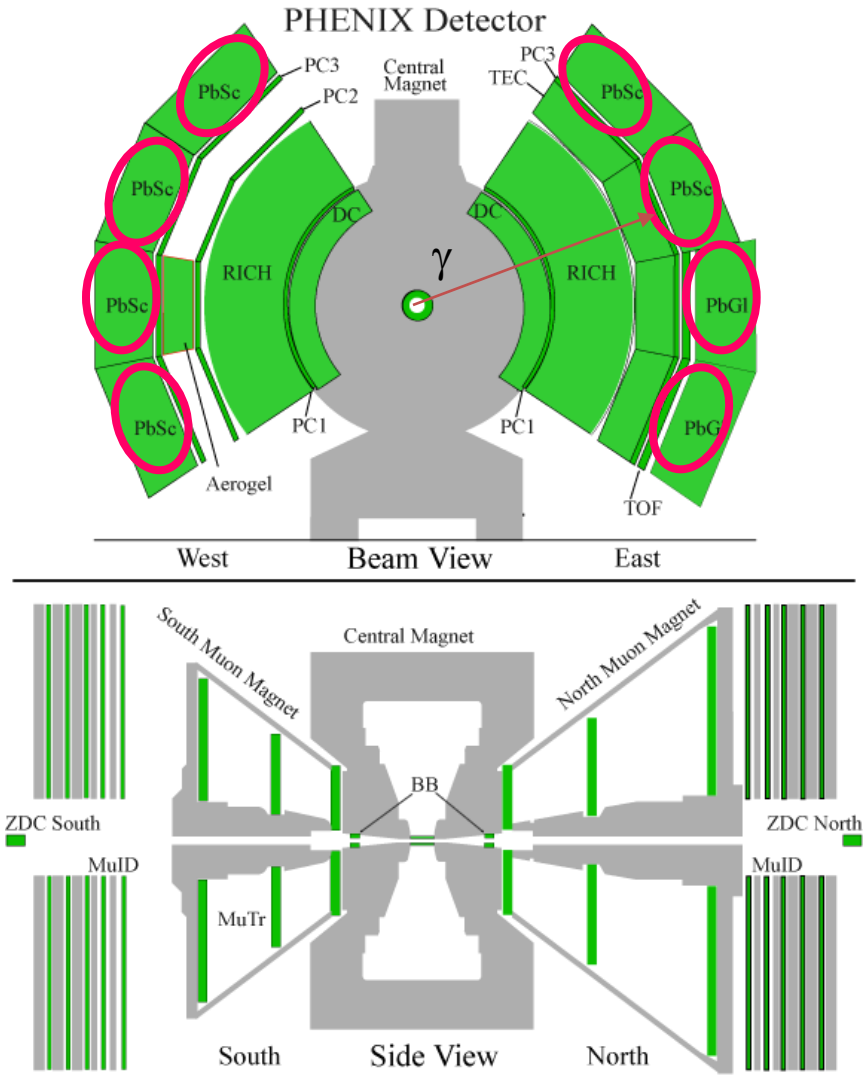


FIG. 29. The expected CDT hit rate for background and single γ events (solid lines). The data points are the observed hit rate with error bars indicating the systematic uncertainty.

The PHENIX detector

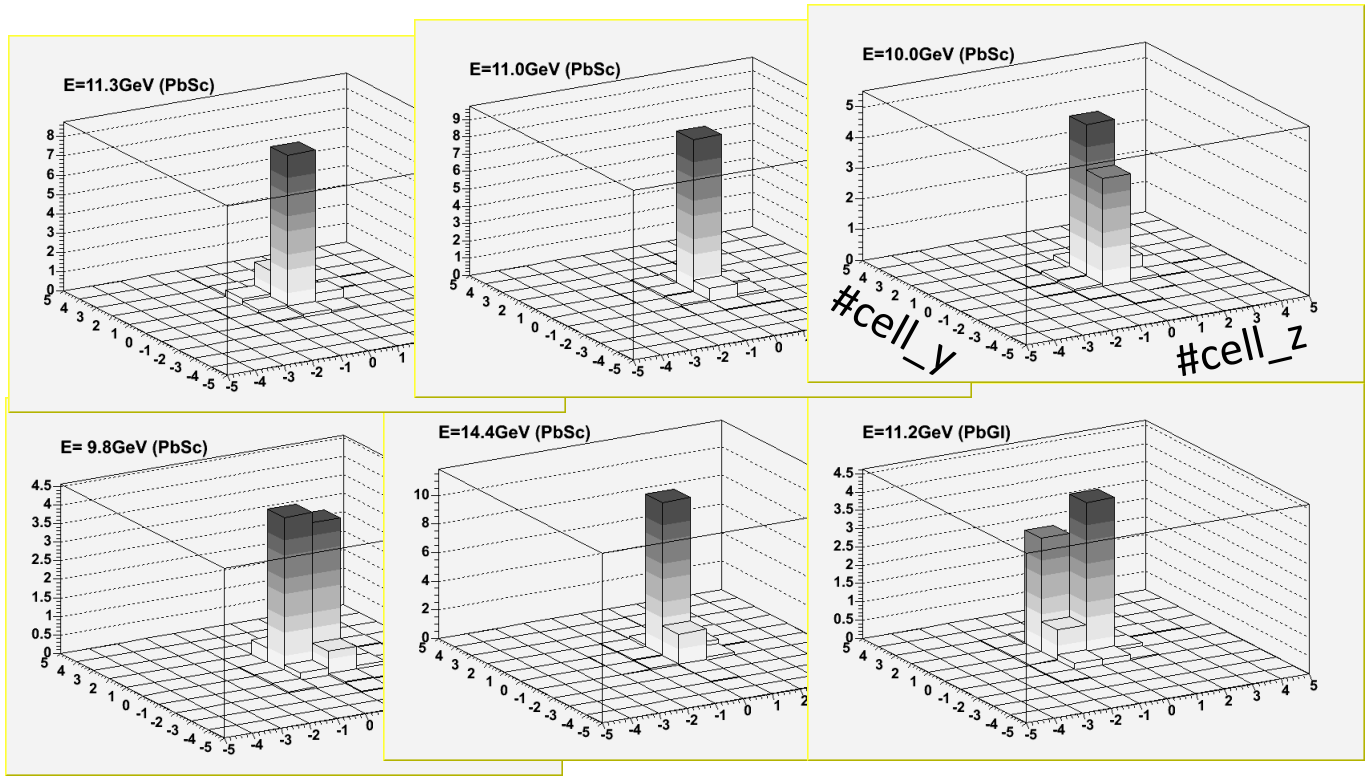
- **Electromagnetic calorimeter (EMCal)**
  - Mid-rapidity region
  - photon detection
    - coverage:
      - $0.5\pi * 0.7 * 2arms$
    - segmentation:
      - $d\phi * d\eta = 0.01*0.01$
  - no pre/post-shower counter, long distance, fine segmentation
- **Beam-beam counters (BBC)**
  - Luminosity measurement
  - Vernier scan
    - (beam size measurement)

S/N improvement
- charge track veto
- transverse shower profile



The PHENIX detector (EMCal)

- **How do ~10GeV photon clusters look like in the EMCal?**



- π^0 2gamma distance
  > 28 towers / $E\pi^0$ [GeV]

Analysis (1)

Method 1 (Cocktail) PHENIX traditional

1. Double ratio

$$r \equiv \left(\gamma/\pi^0\right)_{Measured} \Big/ \left(\gamma/\pi^0\right)_{MC}$$

shows the significance of the direct photon signal (r=1 → no direct photon signal)

2. Direct photon spectra

Need to multiply the inclusive photon spectra ($Y\gamma$)

$$Y_{direct} = \left(1 - \frac{1}{r}\right) Y_{\gamma}$$

Analysis (2)

- **Method 2 (pi0 tagging)**

  Why can't we obtain it in one step?

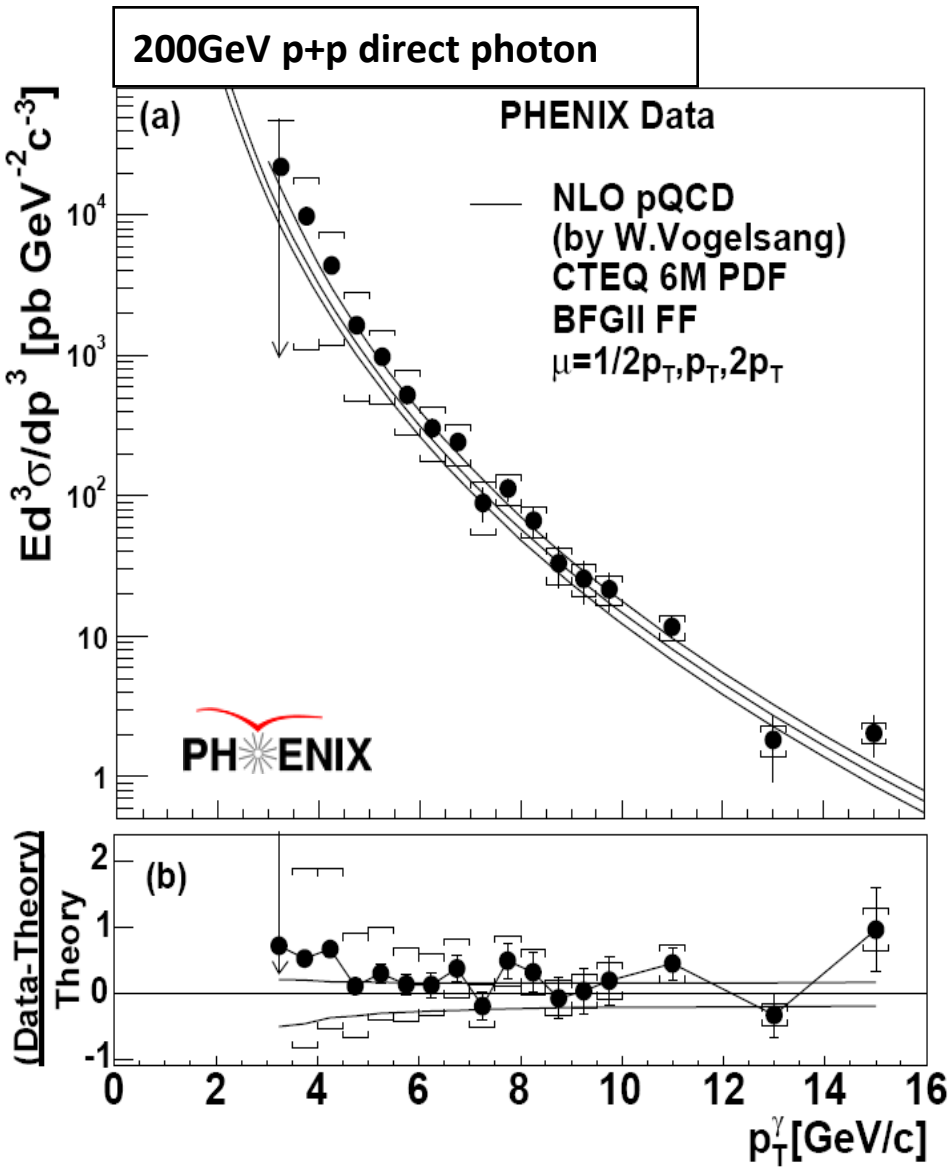
$$\boxed{Y_{direct} = Y_{\gamma} - RY_{\pi^0}}$$

We can use the same energy bin.
"R" takes care of the probability of missing pi0 photons.

- **Materials are same in the two methods.**
  pi0 tagging method is also a statistical subtraction.
  A good cross check.

  We averaged them in the final result in the Run3pp publication.

Direct photon spectra



PRL 98, 012002 (2007)

$\int Ldt = 0.24/pb$

2 methods are combined

pQCD describes the result well

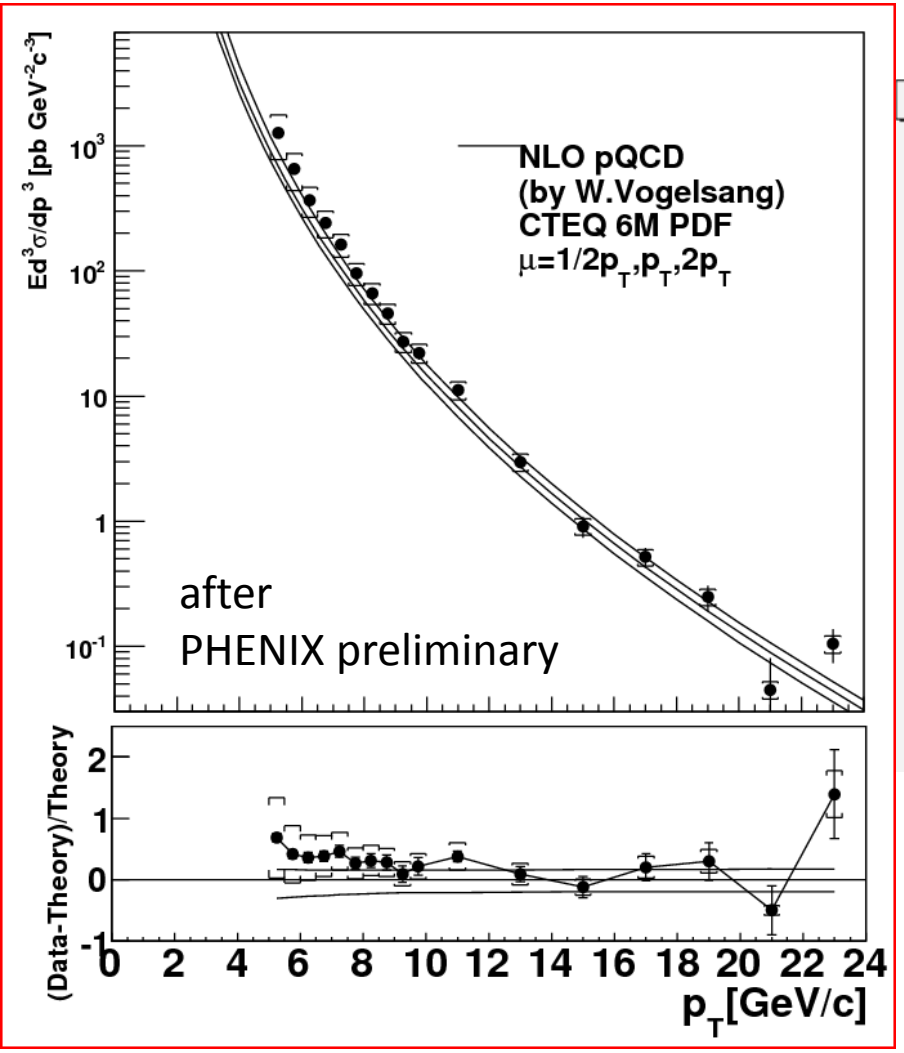
TABLE I: Relative systematic uncertainties of the direct photon spectra.

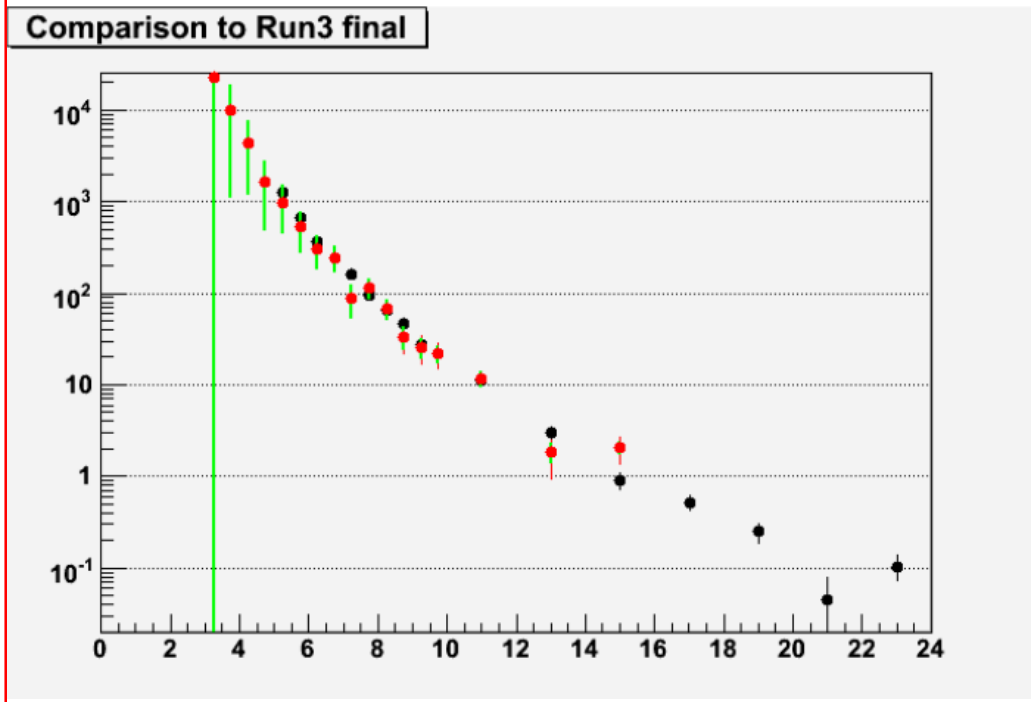
p_T [GeV/c]	4.5-5	7.5-8	10-12
Signal fraction	9%	27%	49%
(a) Global	16.8%	14.9%	14.9%
(b) Inclusive photons	12.3%	4.7%	3.1%
(c) Photons from π^0	30.1%	10.7%	6.5%
(d) Other hadrons	21.4%	6.7%	3.8%
(e) Non-linearity (+ remaining)			
(e_1) π^0 tagging	42.7%	6.8%	5.4%
(e_2) cocktail	69.5%	20.4%	13.4%
Total	71.6%	25.2%	19.8%

Updates

measurement of Run5pp data (2.5/pb)

AN734
I think it's almost final.

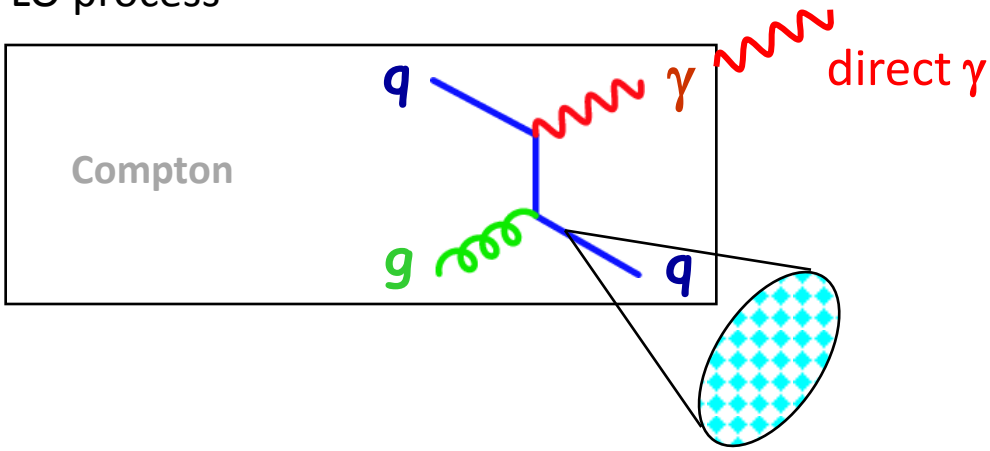




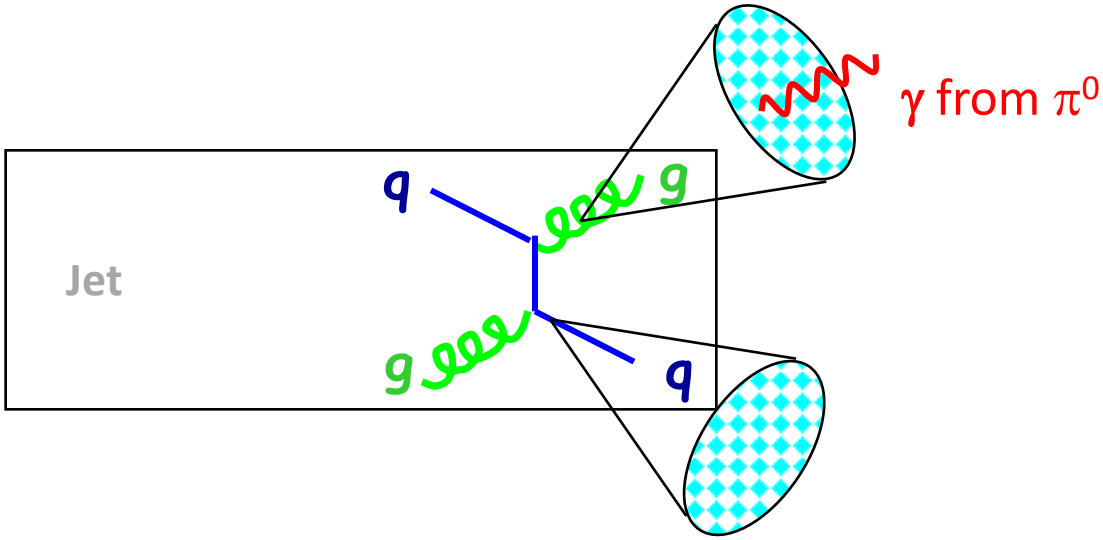
The published result is confirmed by Run5pp measurement.

Direct photon event structure

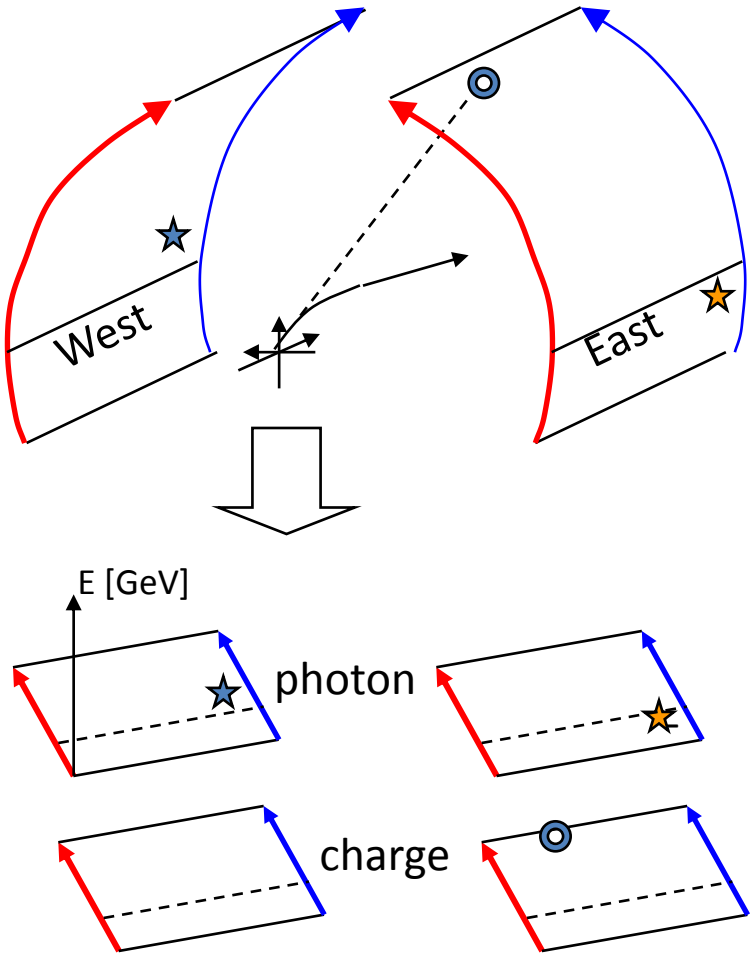
In LO process

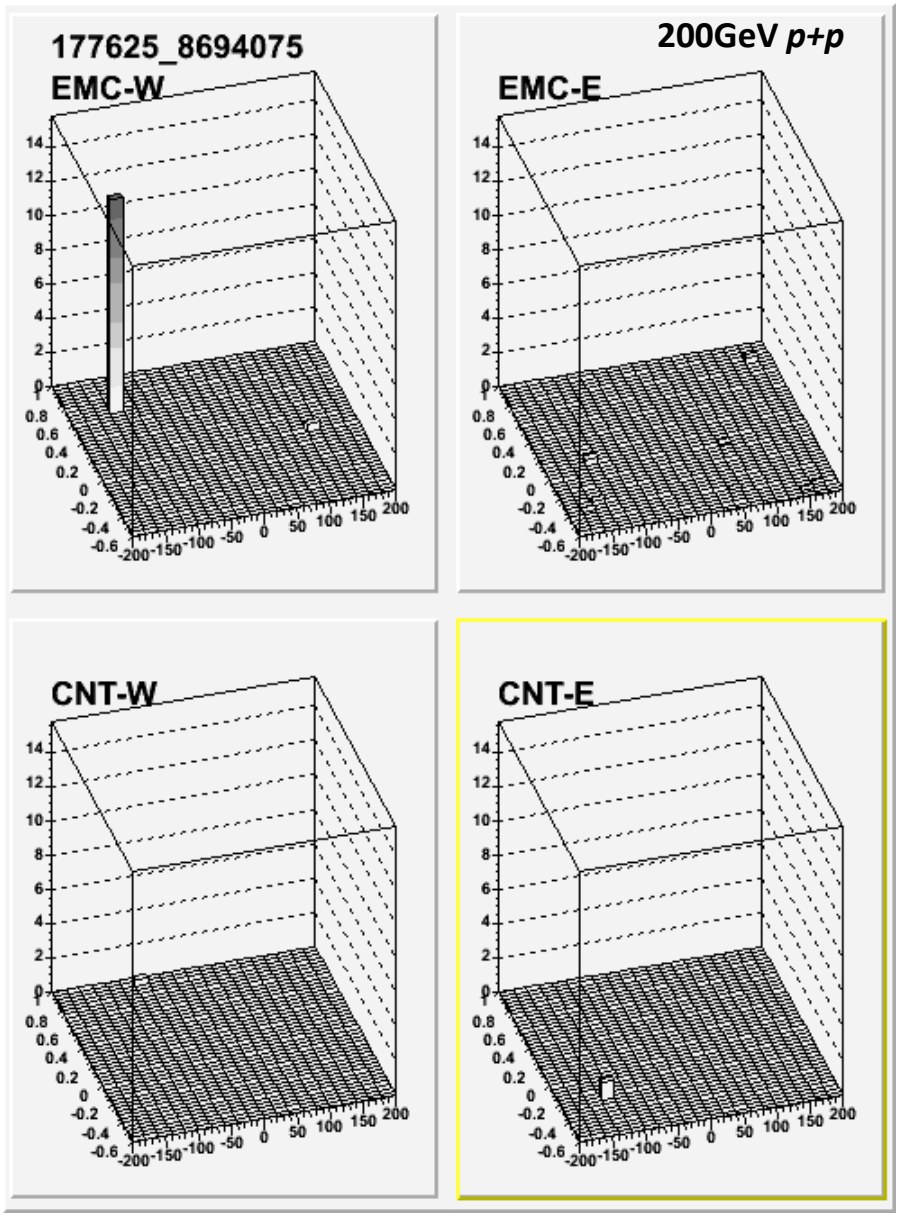


They should look different !



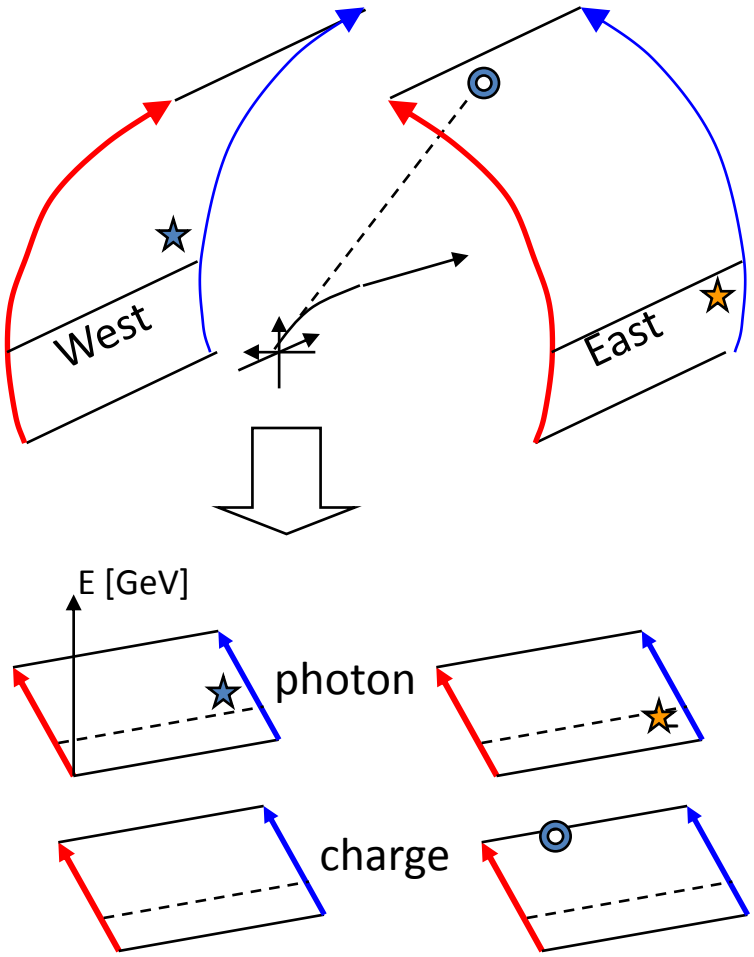
Event examples (1/4)

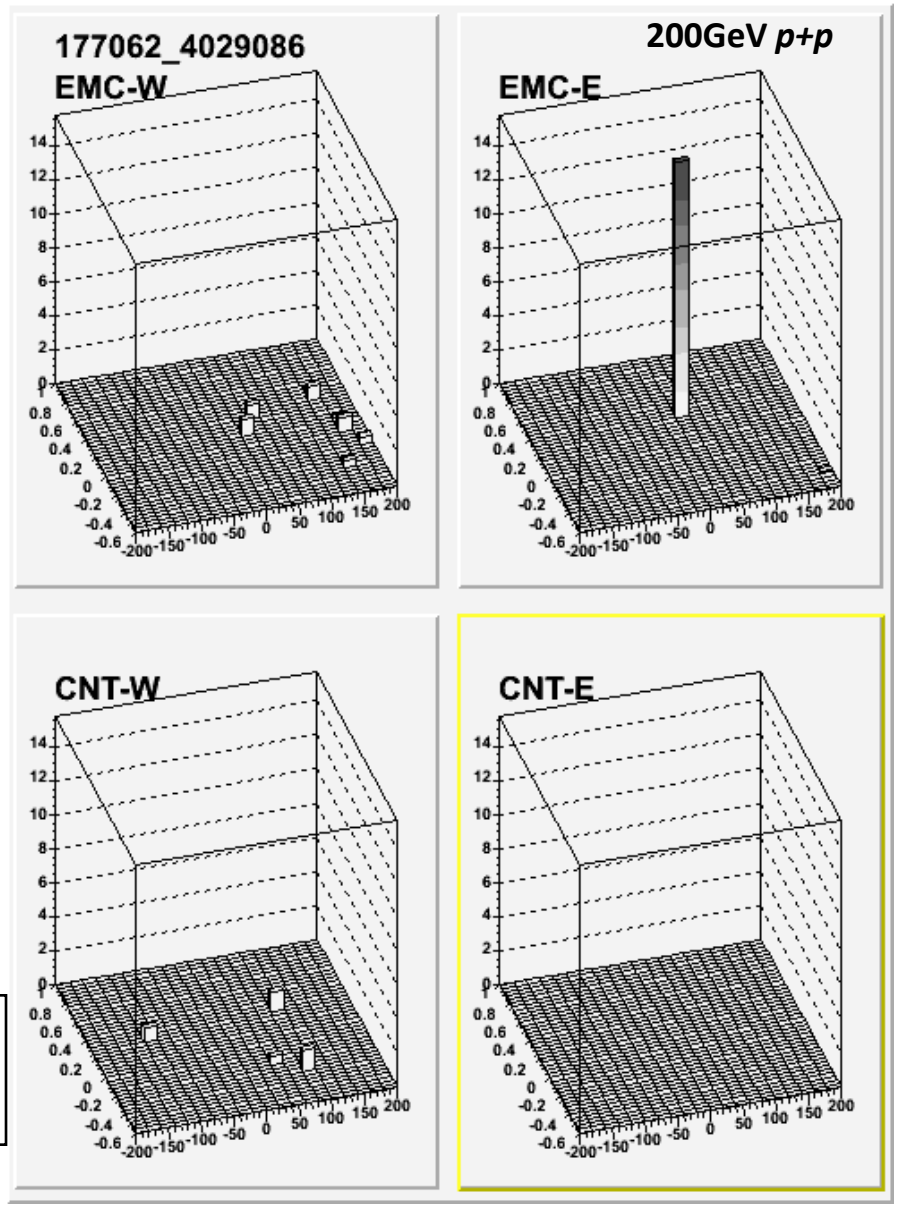




This is from *p+p* collisions, most of events are quiet.

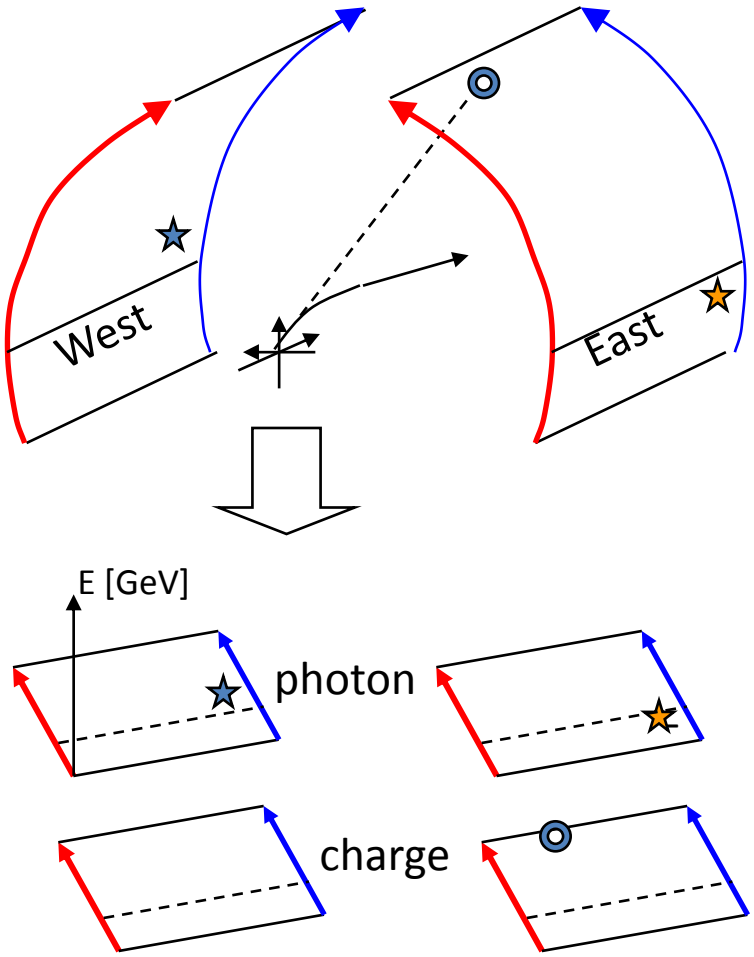
Event examples (2/4)

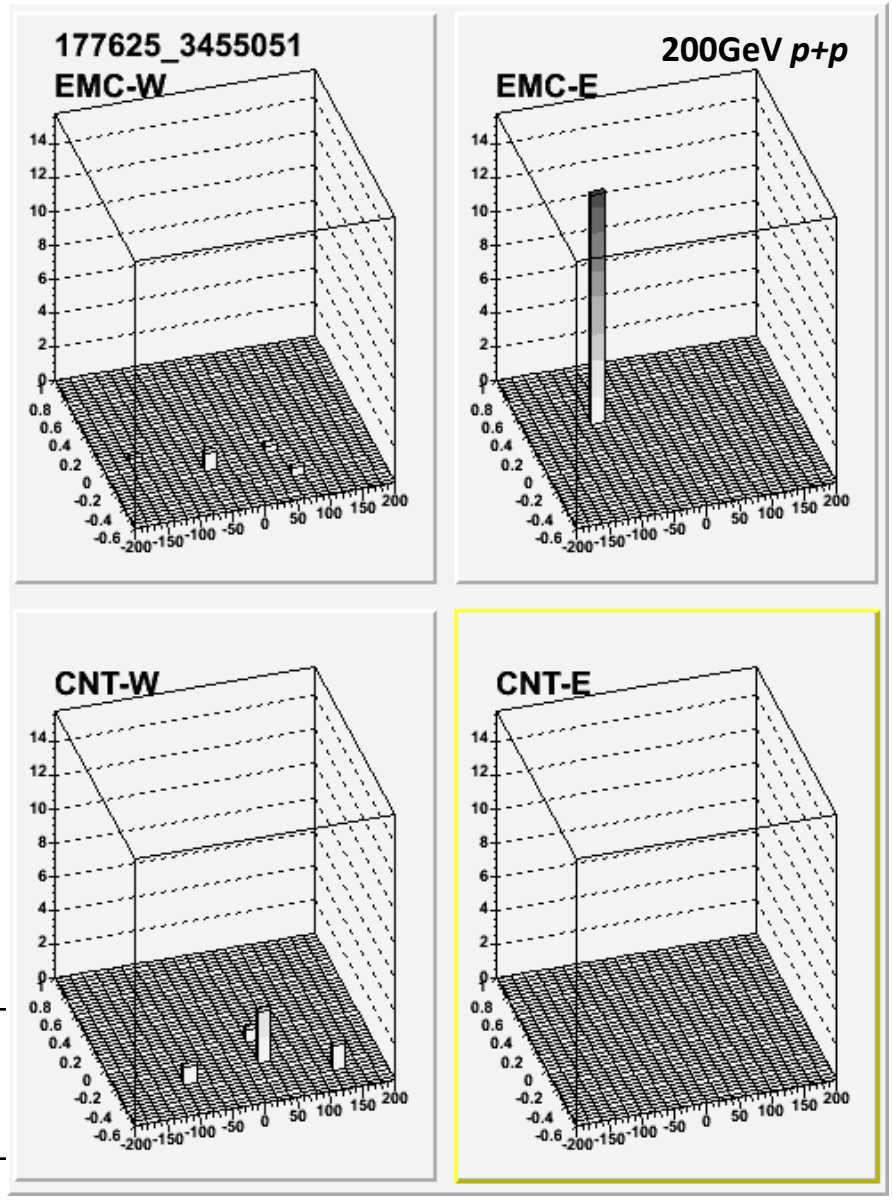




Some events have activities in the opposite side. (1)

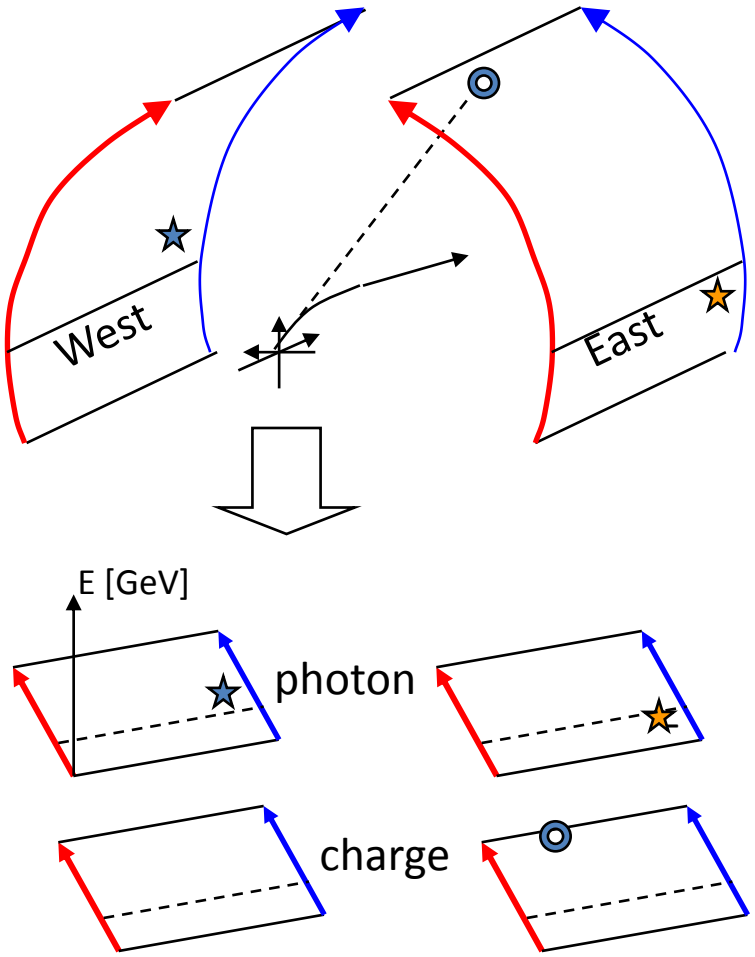
Event examples (3/4)



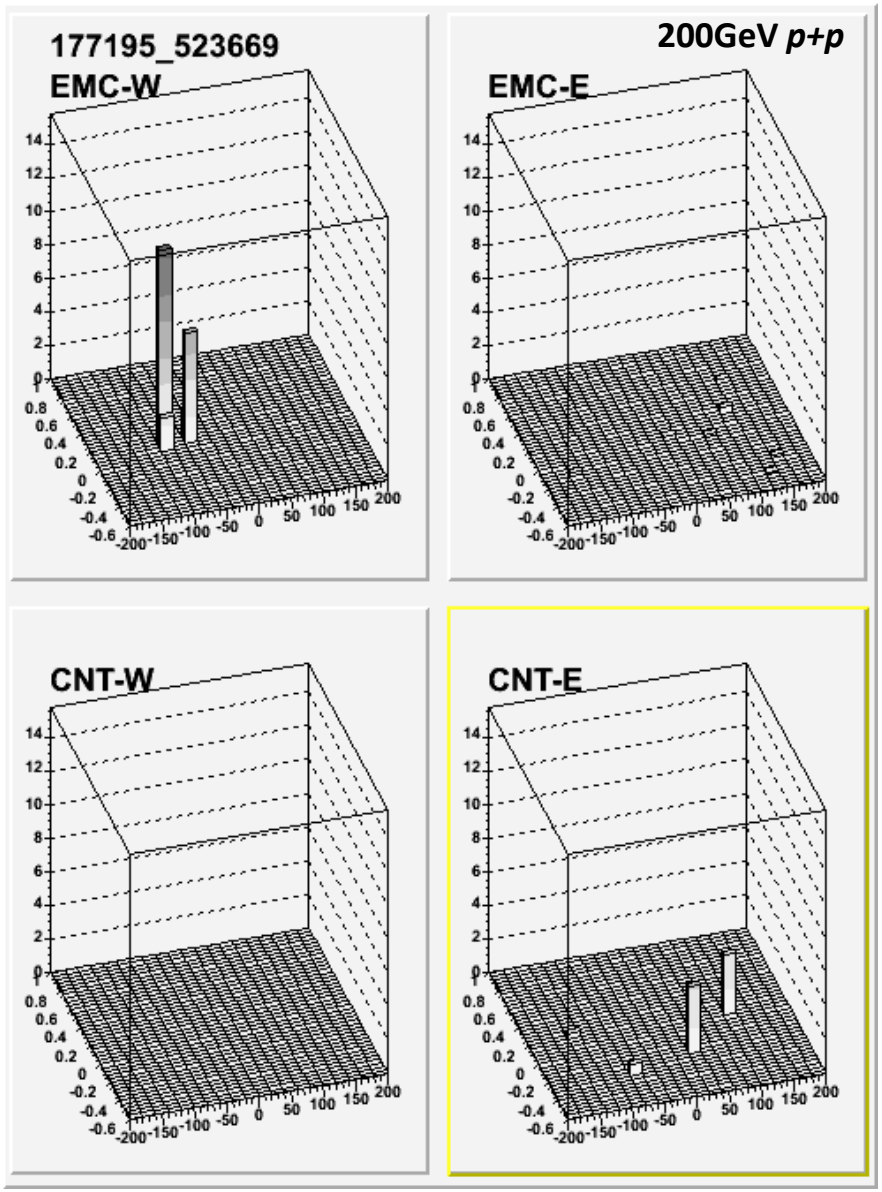


Some events have activities in the opposite side. (2)

Event examples (4/4)

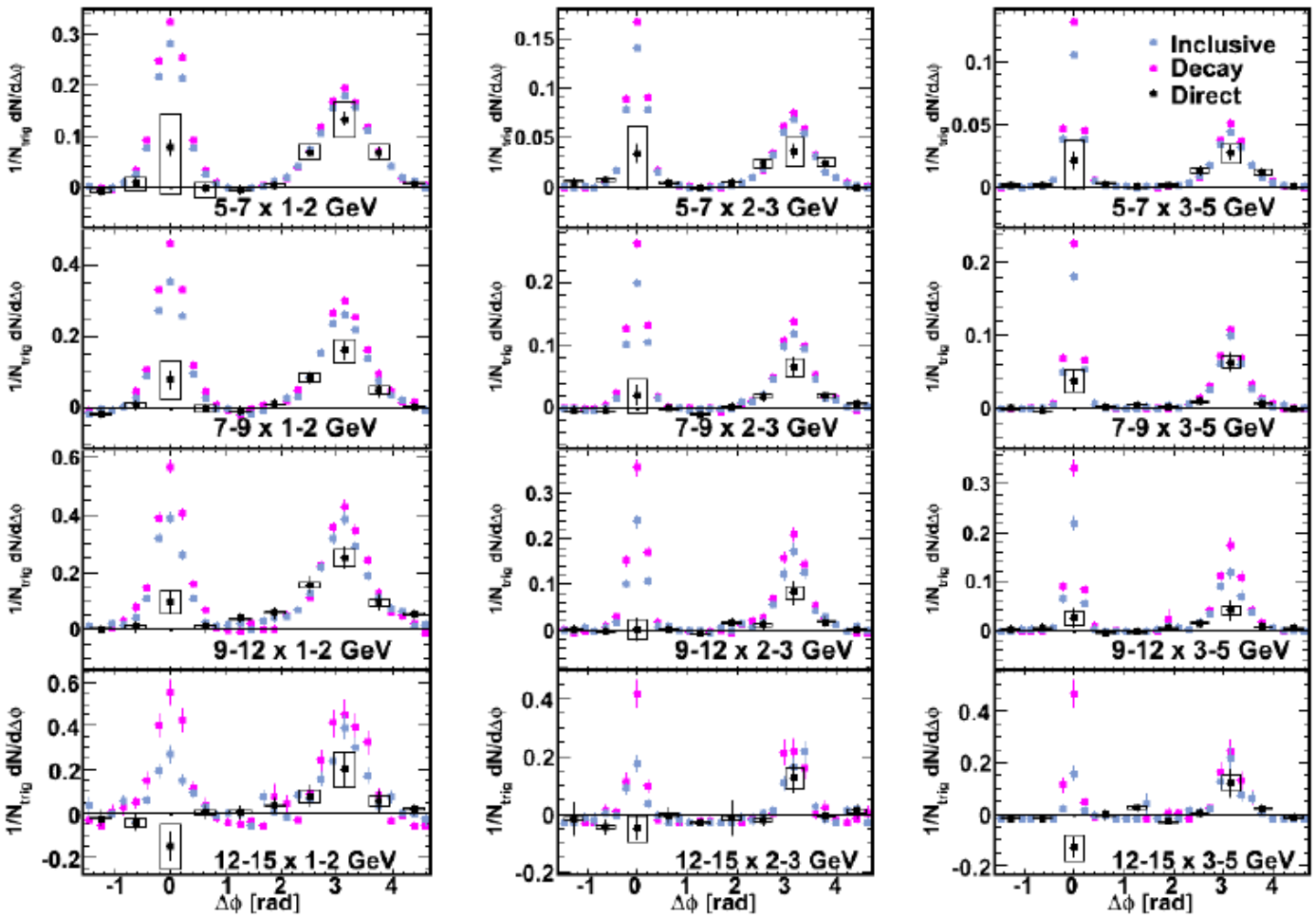


It looks like a jet event



Direct γ-h yield in *p+p*

2 particle correlation (inclusive gamma) – (decay gamma)



AN718

Matt hew Nguyen (2009 RHIC-AGS Thesis award winner)

Near side: consistent to 0
Away side: peak structure

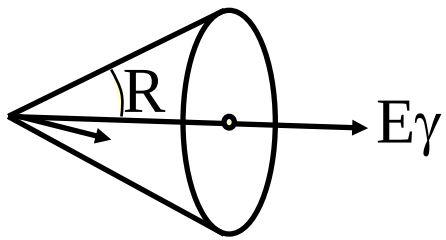
It is consistent to the feature of direct photon event.

A bonus of π^0 tagging method

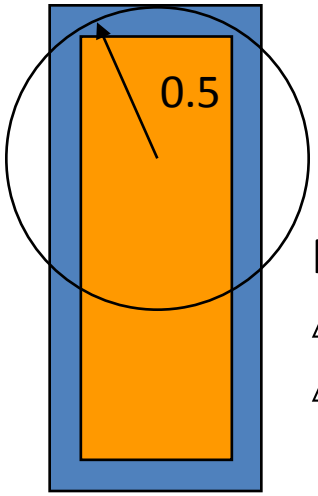
- **Photon isolation cut**

  Though our detectors aren't large enough,
  a simple isolation cut is applied. We set fringes.

$0.1E\gamma > E_{cone}$ (R=0.5rad)



E_{cone} : photon energy
+ charged particle momentum

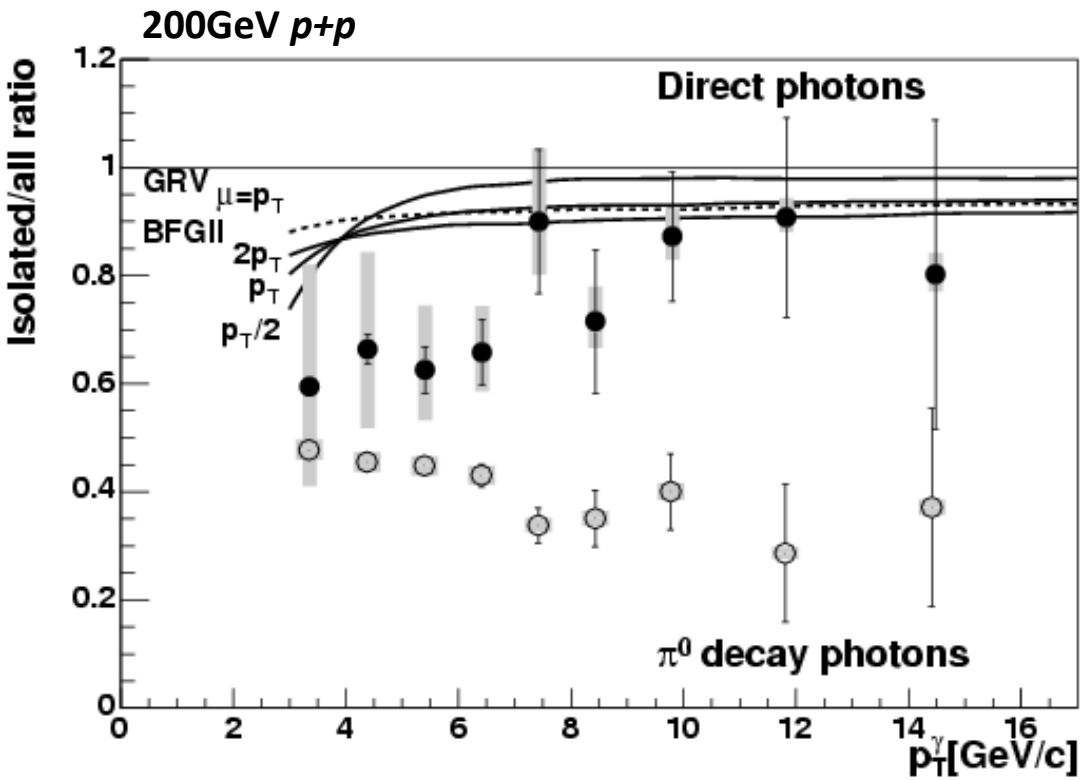


PHENIX arm
$\Delta\eta=0.7$
$\Delta\phi=\pi/2$

- **Background estimation with isolated photon pairs**

(Apply the isolation cut with ignoring the partner energy)

Fraction of Isolated to All



Included:

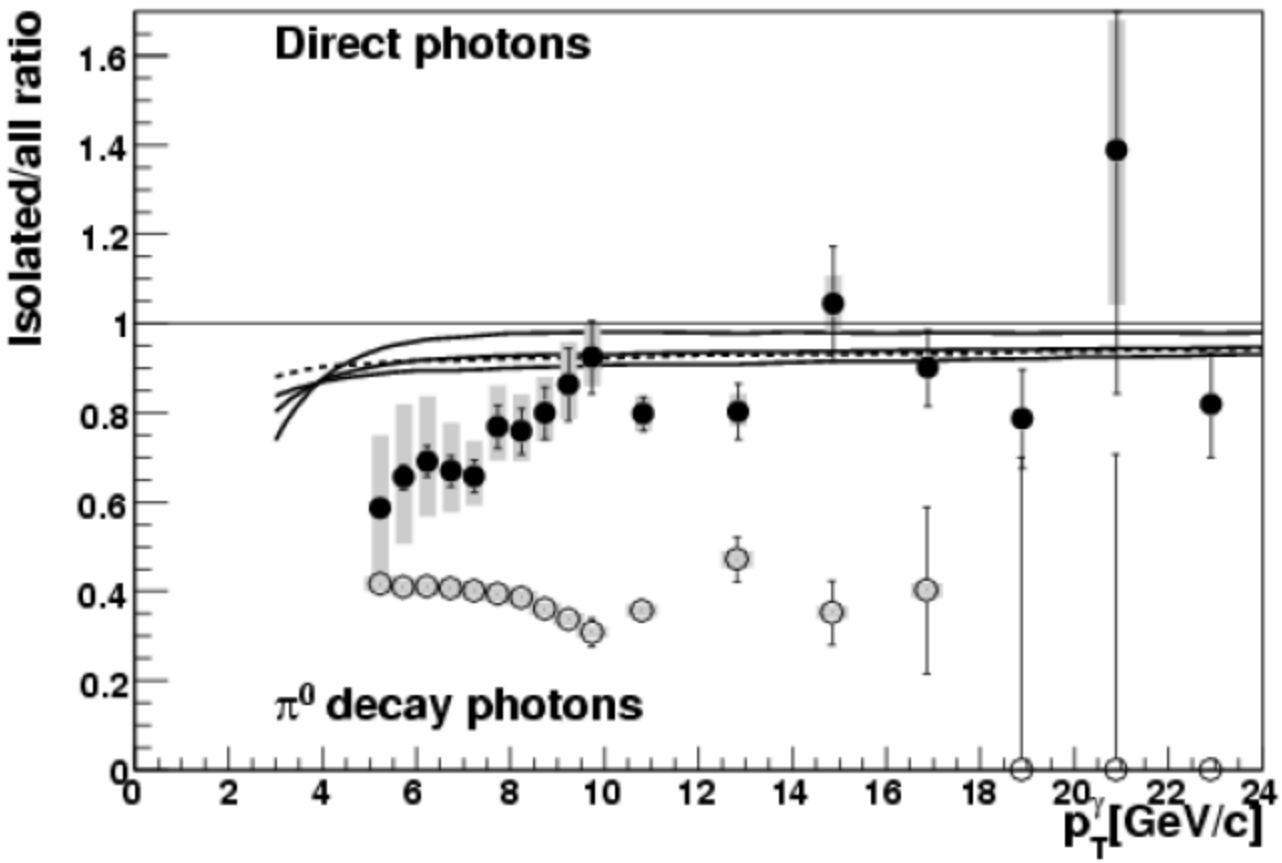
PHENIX isolation cut
(0.5rad cone,
0.1Eγ threshold
0.1rad fringe)

Not included:

Effect of Underlying event
Larger in lower p_T

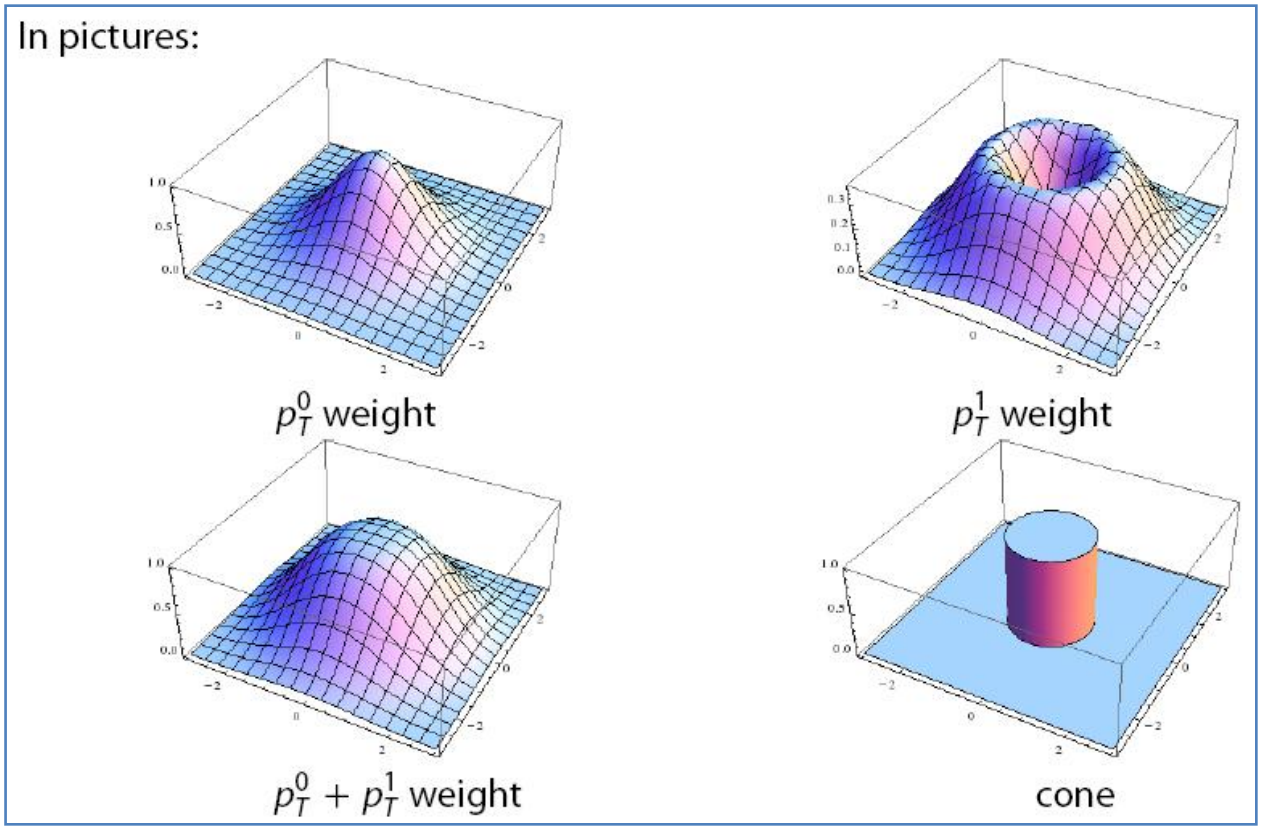
- In contrast to π^0 decay photons, direct photons are mostly isolated.
- Theory calculations agree well to the measurement at high p_T region (p_T >~7GeV/c)

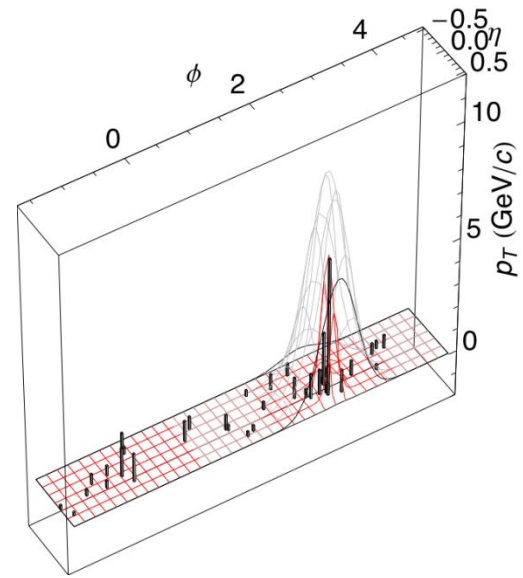
Update from Run5pp

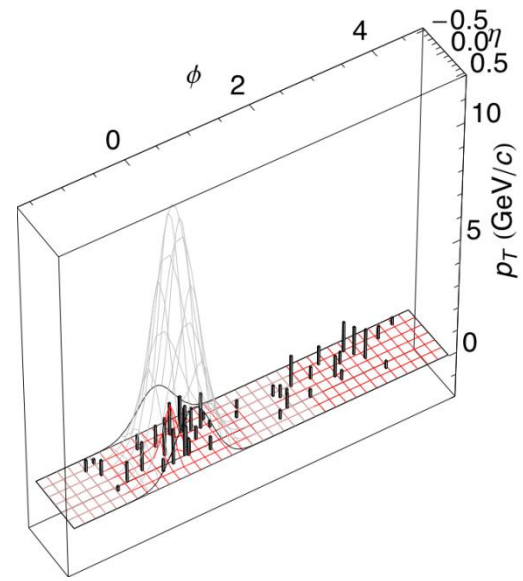


It is also consistent to the published result.

Gaussian filter method?







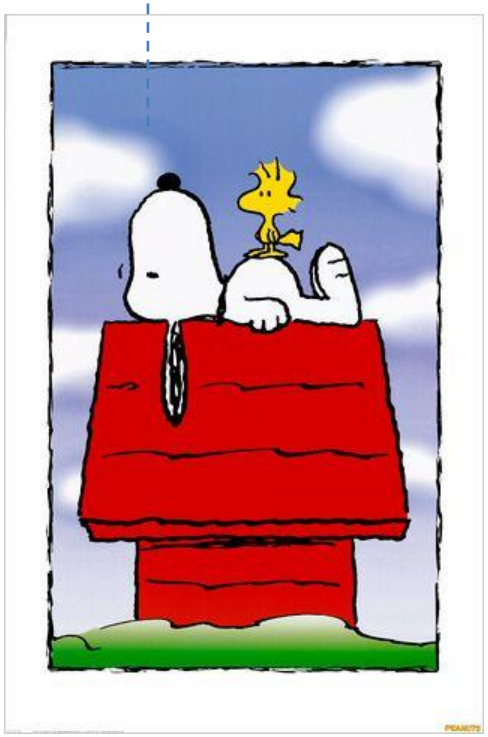
Yue Shi developed the method.
I wonder if it provides more effective isolation cut.

THE FIRST PART IS OVER.

THERE IS DEEP PHENIX WORLD.

To go higher pT

p_T > ~12GeV/c



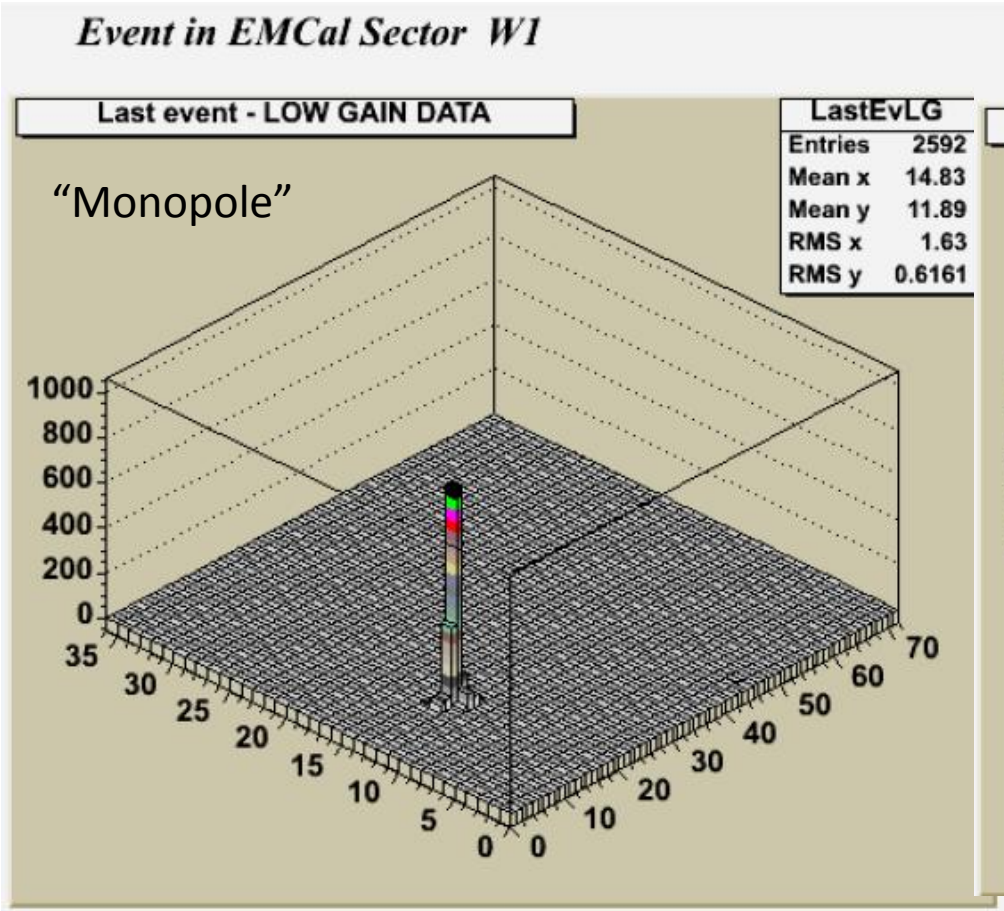
- Motivation: high x = valence region
  HI collisions : isospin, EMC effect
  spin : high x gluon

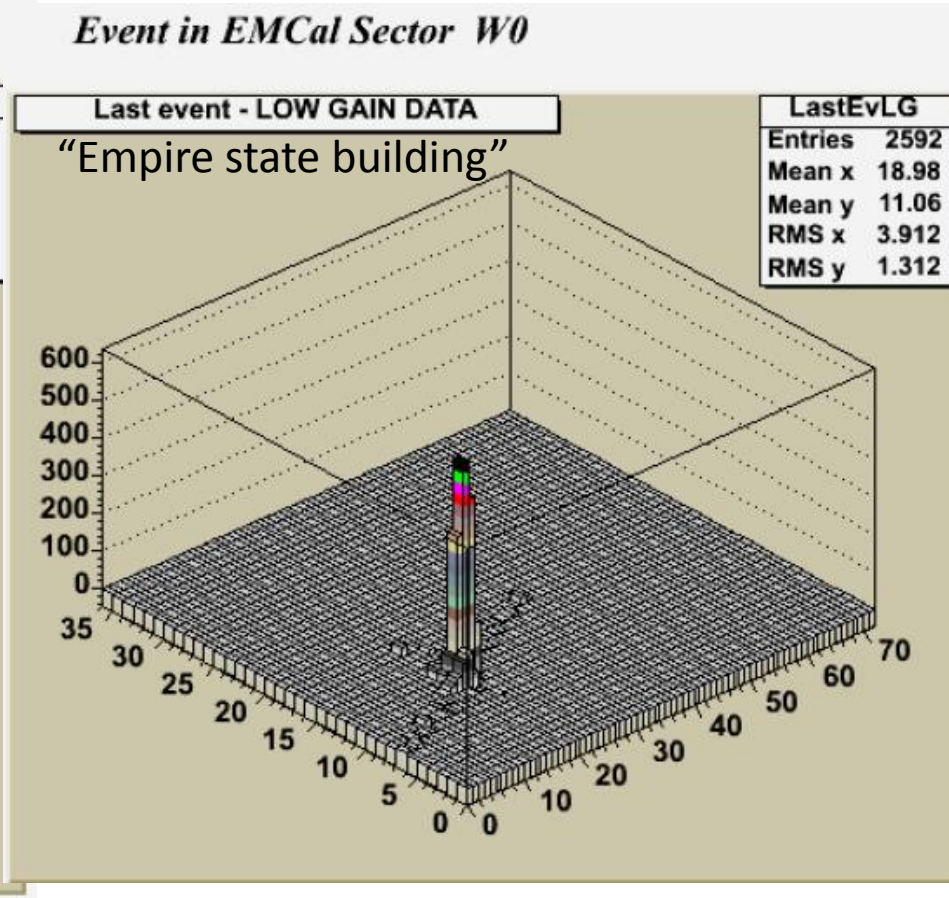
- Good: cleaner, high S/N, good EMCal resolution
- Bad: cosmic ray, electrical noise, pi0 merge

Cosmic ray run (Run7)

Comments are from Mickey. (LG: ~7MeV/ADC)

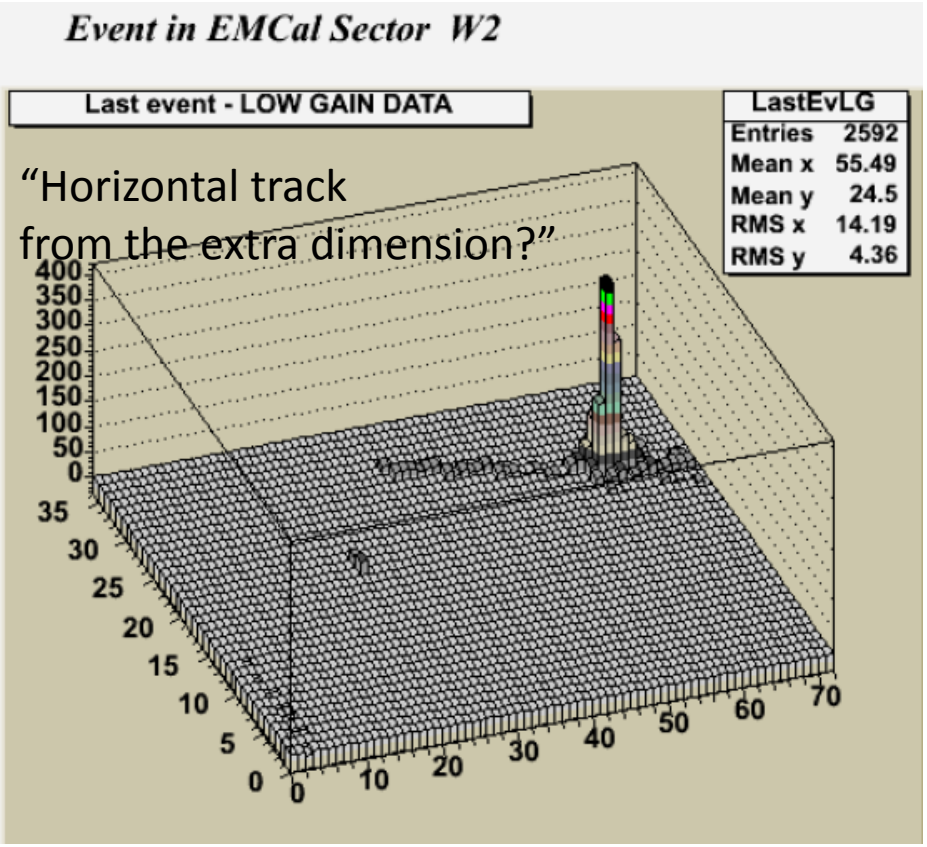
run219910
(high threshold EMCal trigger)

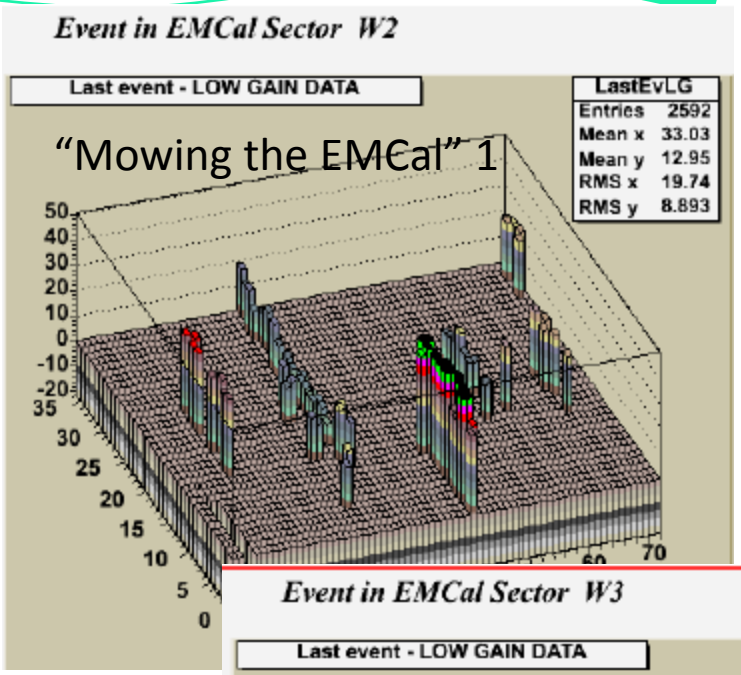


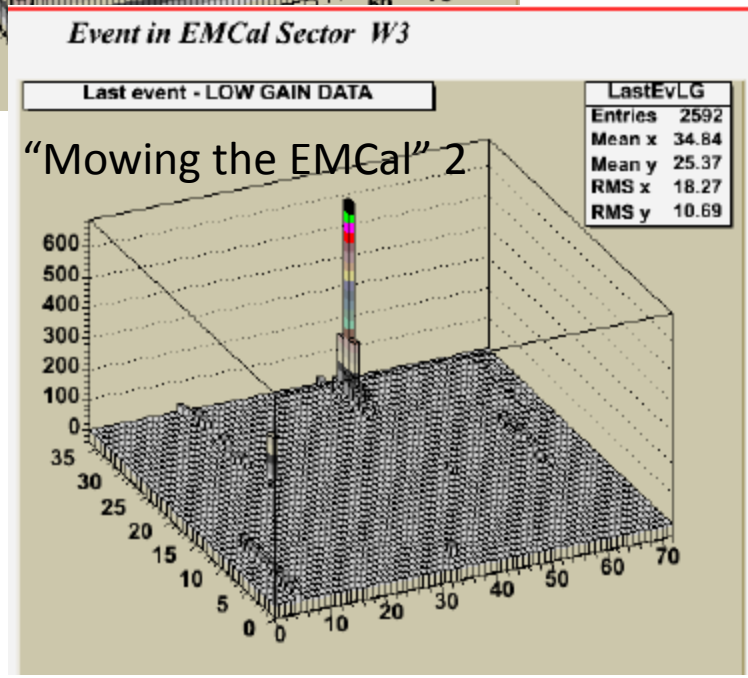


Cosmic ray run (Run7)

2/3

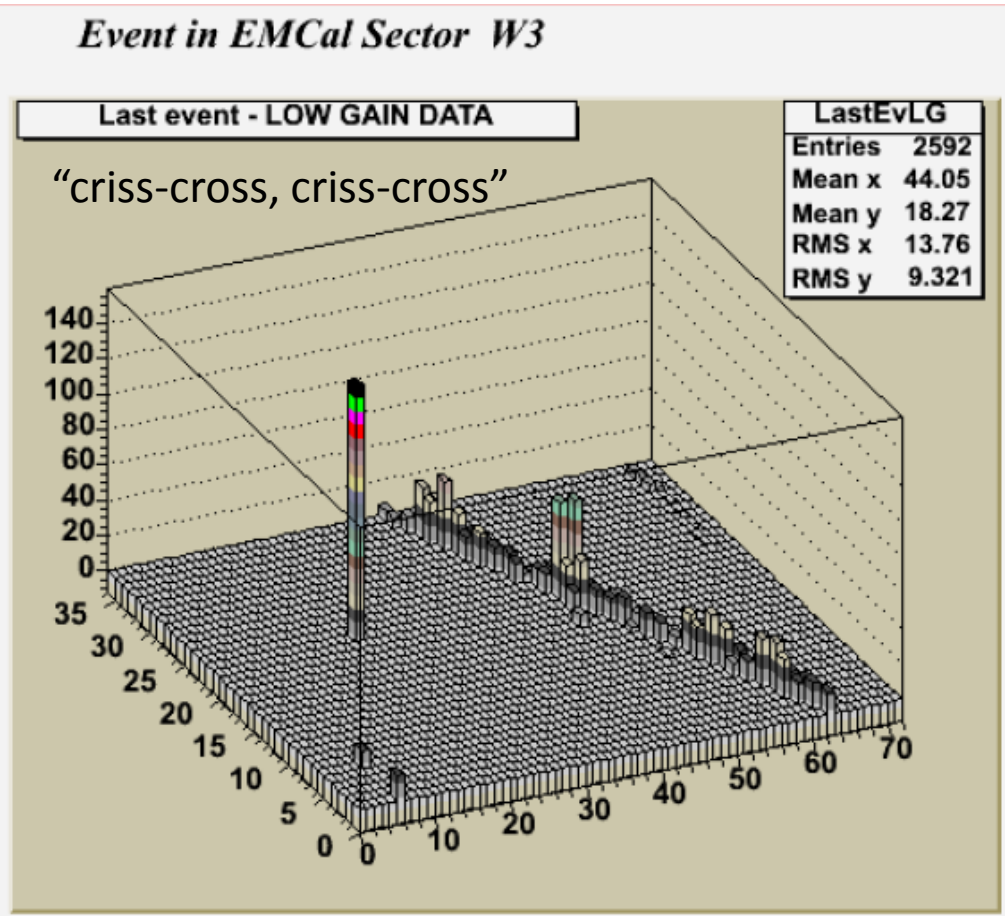


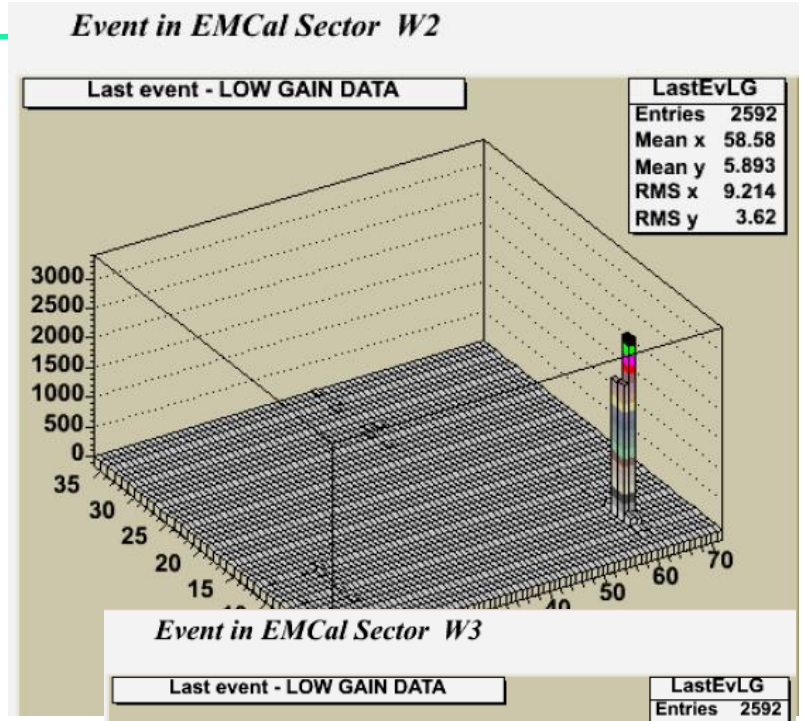


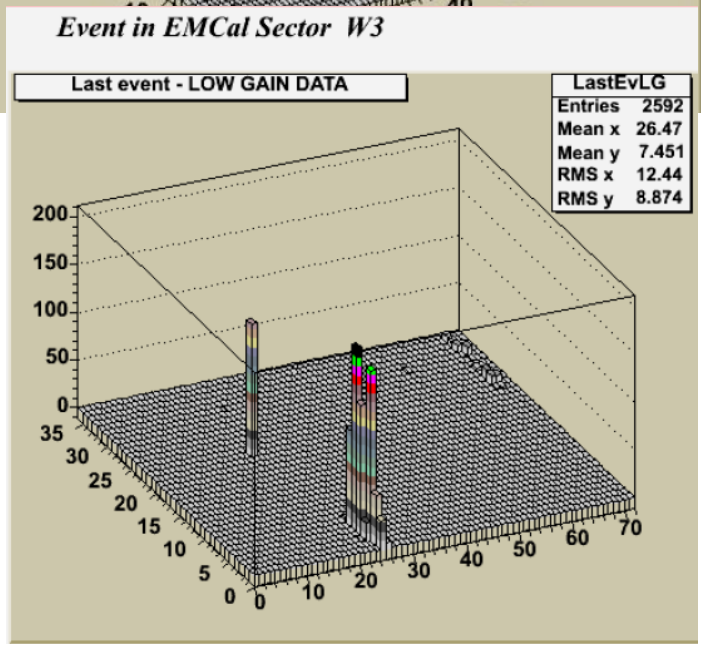


Cosmic ray run (Run7)

3/3







Why the cosmic ray is a problem?

AN714 cosmic run analysis

cosmic ray and electrical noise

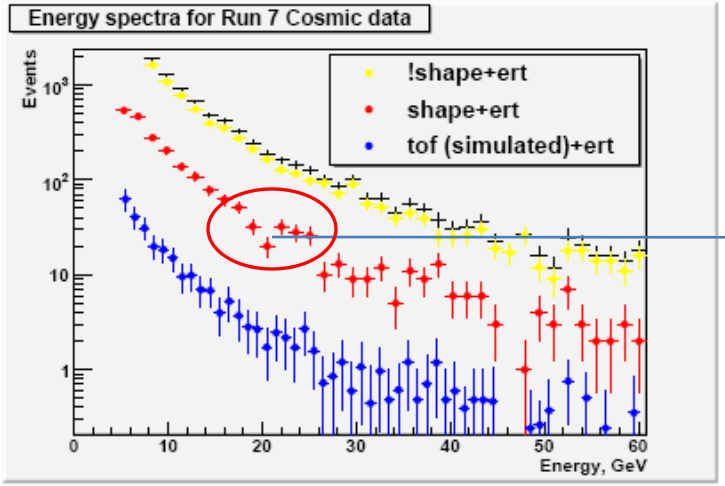


Fig. 5: *Energy spectra for cosmic data analysis.*

cosmic run
total 90e3 [s]
30 counts @ 20GeV bin

0.56 (=30*112/90*0.15/10)

period

in coincidence
with BBCLL1
(R=0.15MHz
Run6pp)

~30% of 20GeV clusters
are fake in Run6pp.

1.5

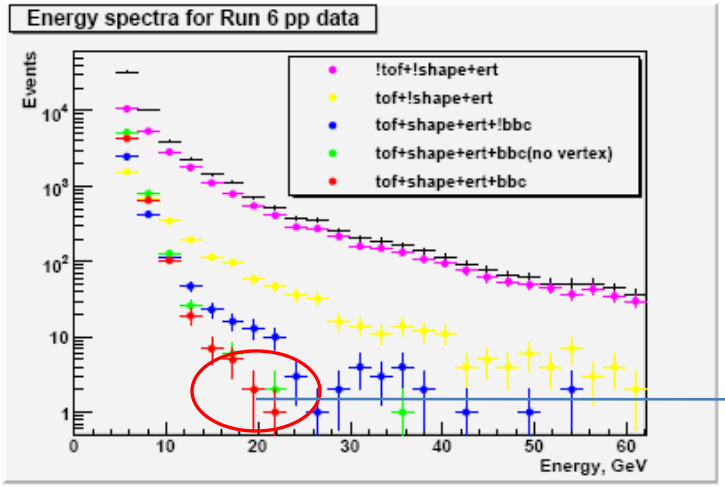
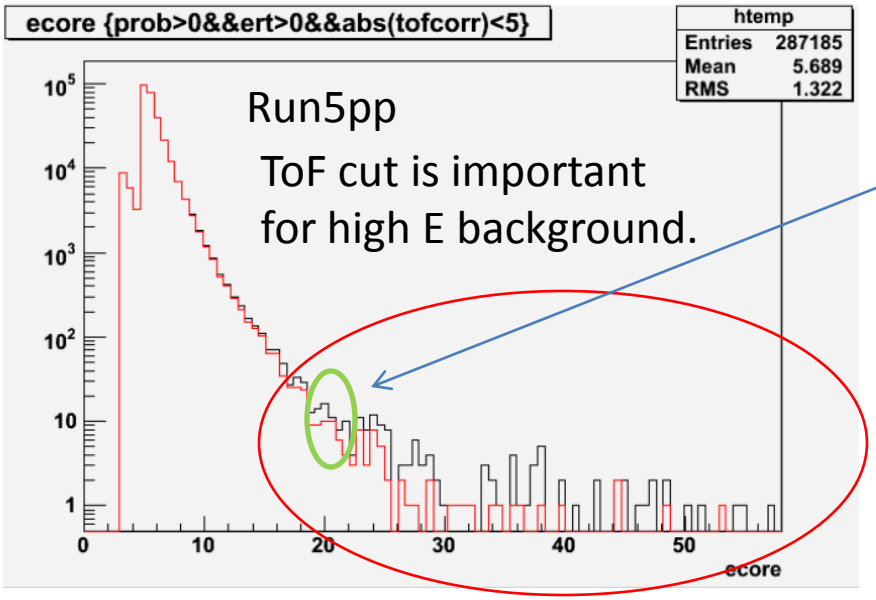


Fig. 6: *Energy spectra for Run6pp data analysis.*

Run6pp signal
total 112e3 [s]
1.5 counts @ 20GeV bin

ToF cut is important to reject CR

One order reduction with ±5ns cut (10/106ns)



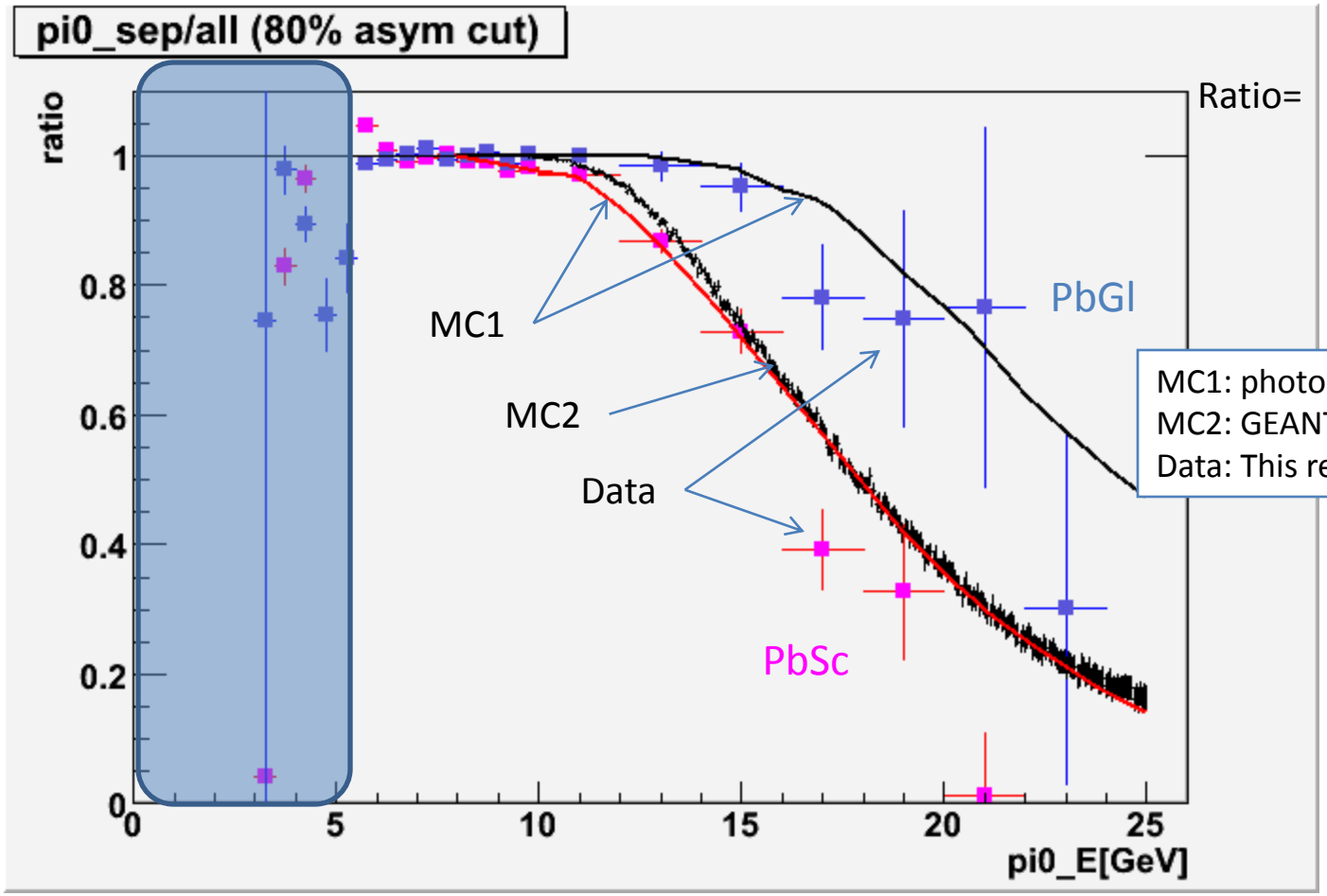
It's consistent to the Run6pp result in the previous page.

Future :

For very high rate BBC, there is no T_0, and all cosmic rays are triggered.
We have to be careful.

π^0 photons merge

For the region where the photons from π^0 do not completely overlap.
Assume bad photon probability clusters with good ToF are from pi0.



Ratio= $\frac{\text{pi0_sep (with A<80\%)}}{\text{pi0_sep+merged}}$

MC1: photon shape parameterization
MC2: GEANT (PbSc only)
Data: This result

3 independent results agree well.

pp vs HI

You may think the analysis of HI is more complicated.

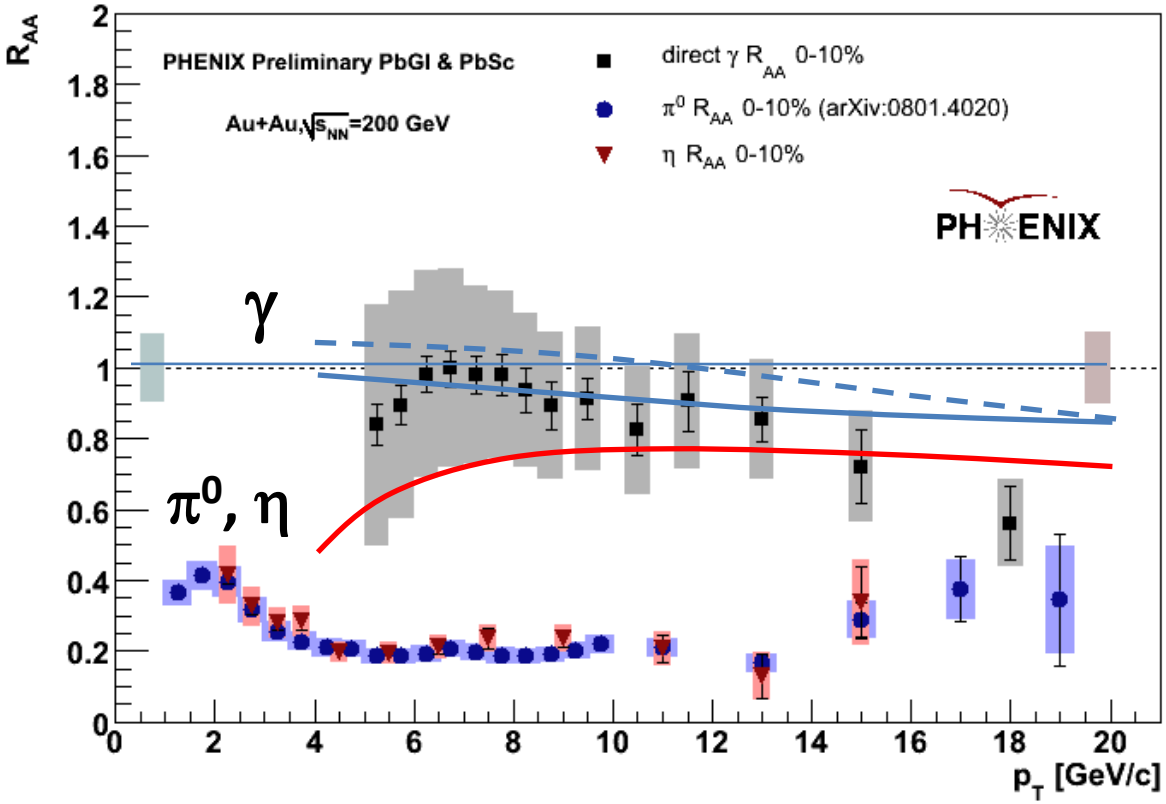
It's true for the cluster overlap.

But cosmic rays are not problem because the collision rate is low

Thanks to the jet quenching, π^0's are suppressed in the HI collisions.

Direct photon R_{AA}

R_{AA} (since QM06)



Curves : F.Arleo JHEP09(2006)015

- Isospin effect
- +cold nuclear effect (EKS)
- +energy loss $20<\omega_c<25$GeV

This plot is already shown many times as a preliminary.

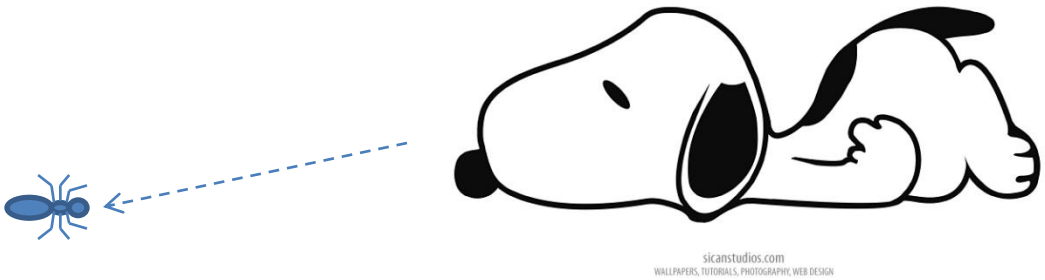
Comments
A difficulty in high pT region. (=pi0 merging, very rare.)
We need to be careful.

Various checks are done.
It is confirmed that the decrease of R_AA at high pT is real, but with a slight increase.

The final plot is coming soon!

To go lower pT

p_T < ~5GeV/c

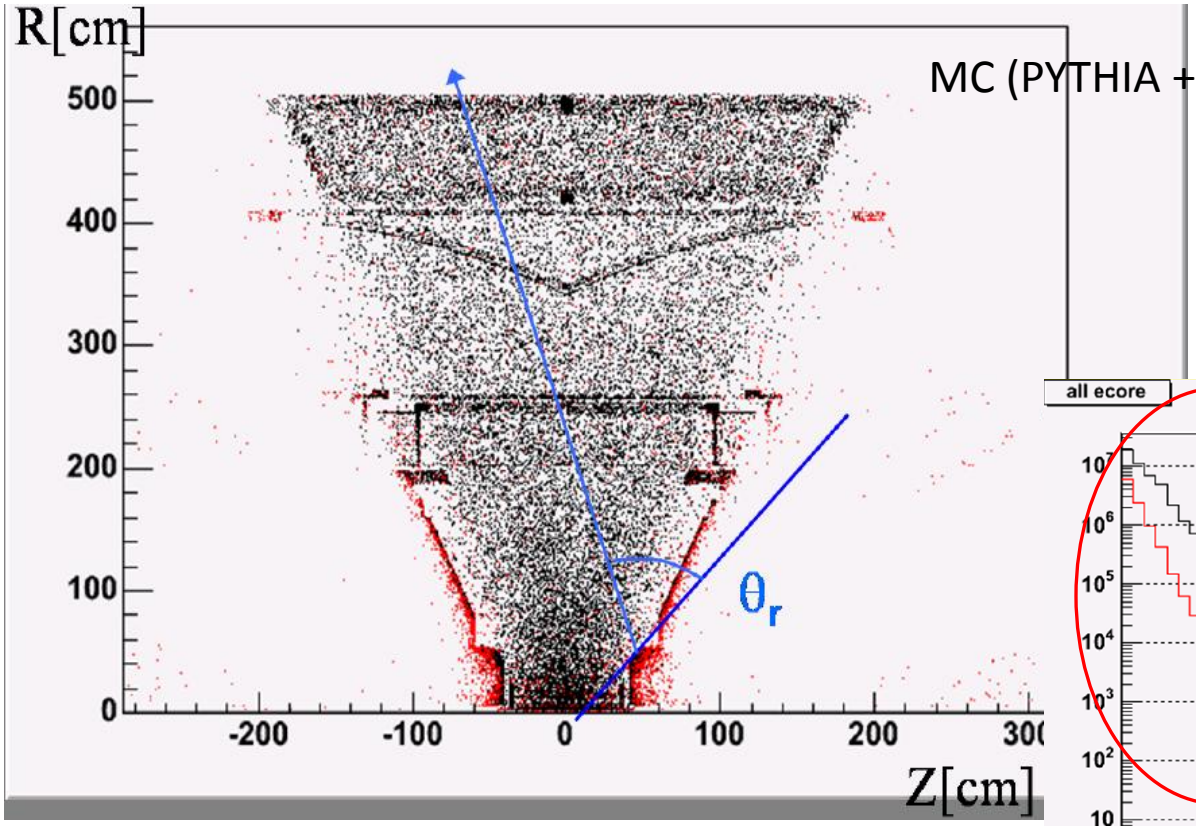


Motivation: Thermometer (sources)

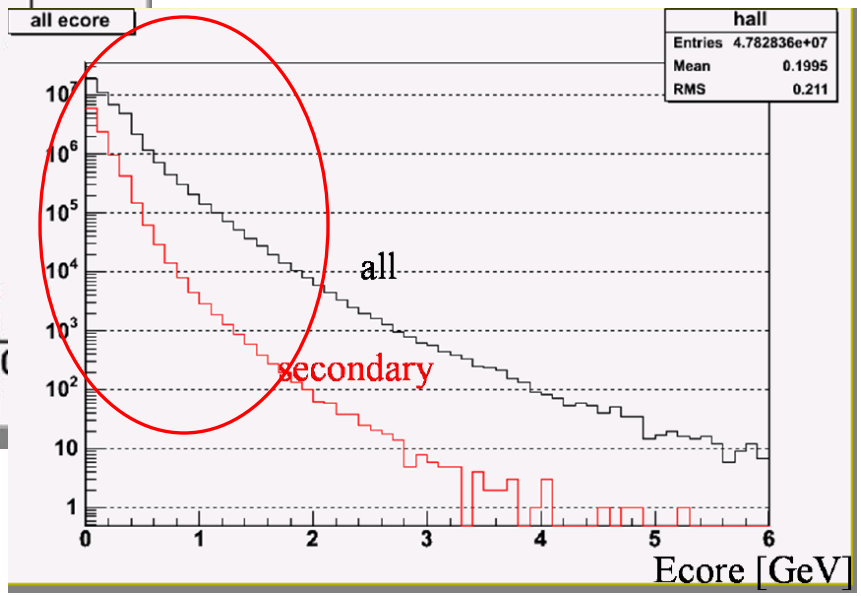
Good: a lot of statistics
Bad: low S/N, (hadron BG, albedo)

Albedo

The plot shows the origin of EMCal clusters (MC). (AN460)
Mostly from conversions, but others need to be taken care.
It is dominant in the low pT region.



MC (PYTHIA + PISA)



Hadronic interactions

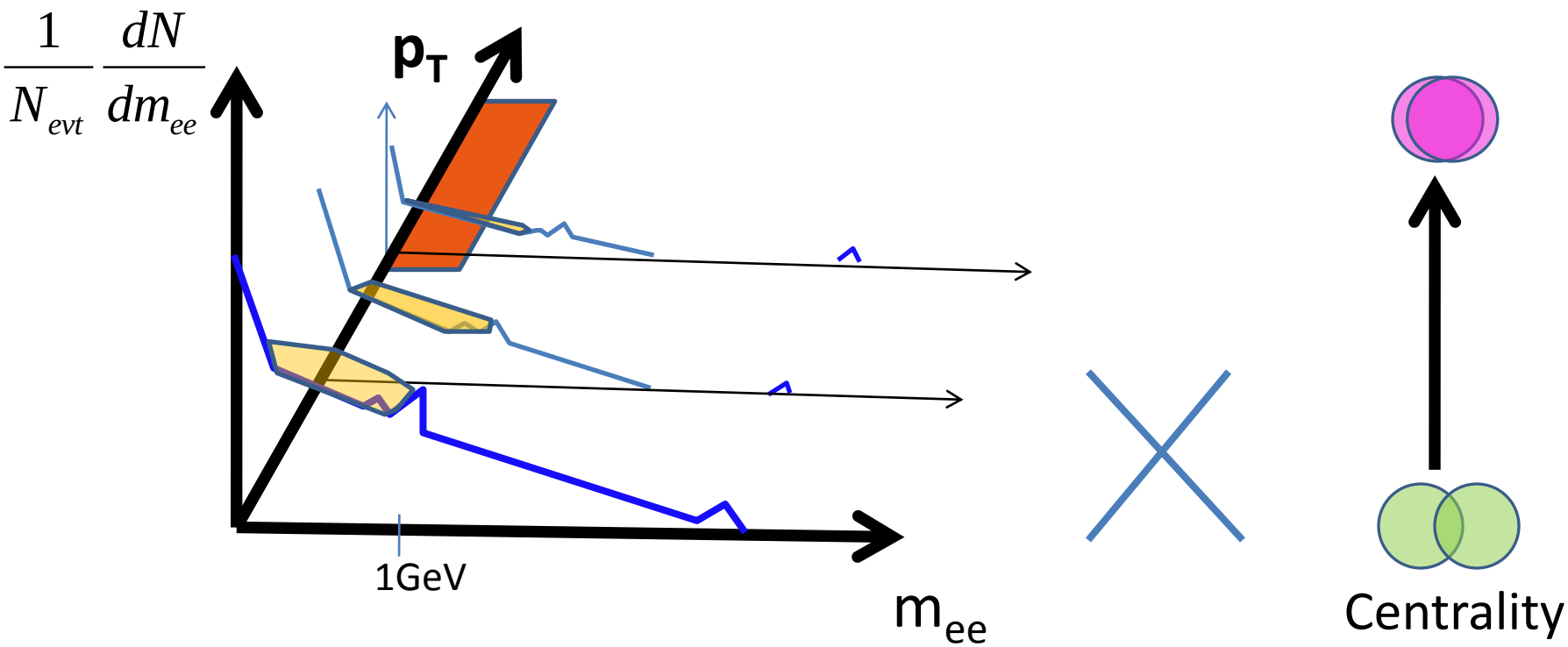
The estimation can't be without uncertainties.

Remember the uncertainties are magnified by the inverse S/N ratio.
It's too hard to get the direct photon signal based on a subtraction.

$\rightarrow$ dielectron analysis

Dielectons

There are three dimensions ; m_{ee}, pT_{ee}, Centrality.



: The low mass enhancement.

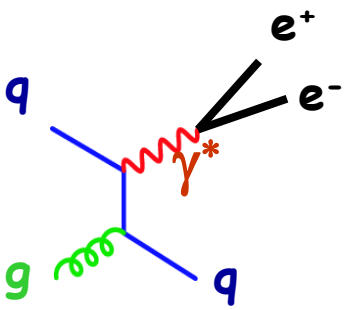
pT >1, low mass region to be attributed to direct photon production.

Dielectron = photon?

They have the same quantum number.

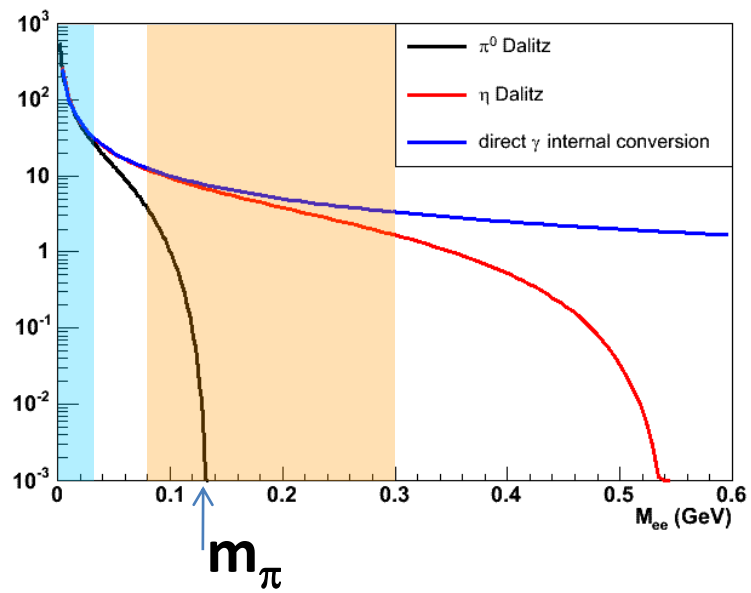
Kroll-Wada formula connects the real γ and (ee) yield.

$$\frac{d^2N}{dM_{ee}} = \frac{2\alpha}{3\pi}\sqrt{1-\frac{4m_e^2}{M_{ee}^2}}\left(1+\frac{2m_e^2}{M_{ee}^2}\right)\frac{1}{M_{ee}}SdN_\gamma$$



When $p_T^2 >> M_{ee}^2$**, S=1 for photons.**

Independent of the origin in the very low mass region (M_{ee} < ~30MeV)
Pi0 Dalitz dies out above the pi0 mass. → The key to improve the S/N ratio.
Direct photon follows $1/M_{ee}$.

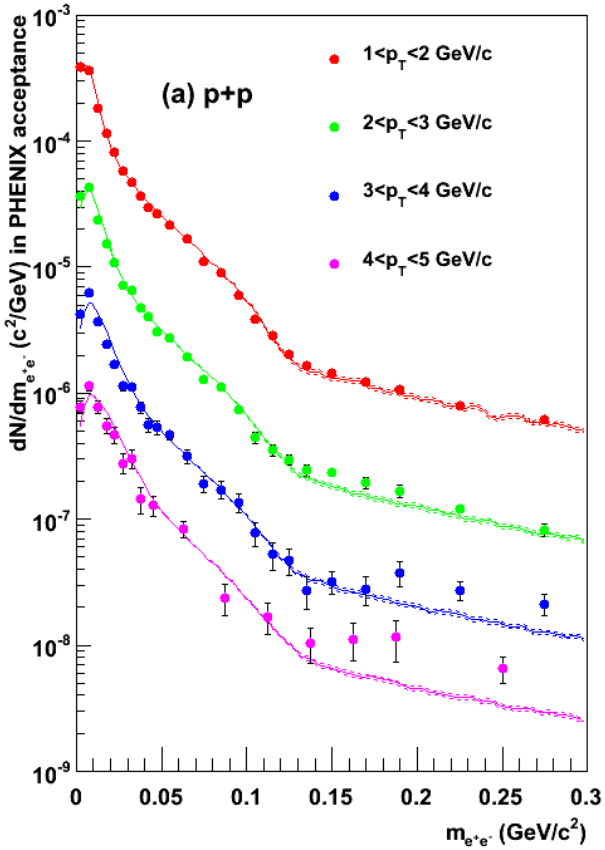


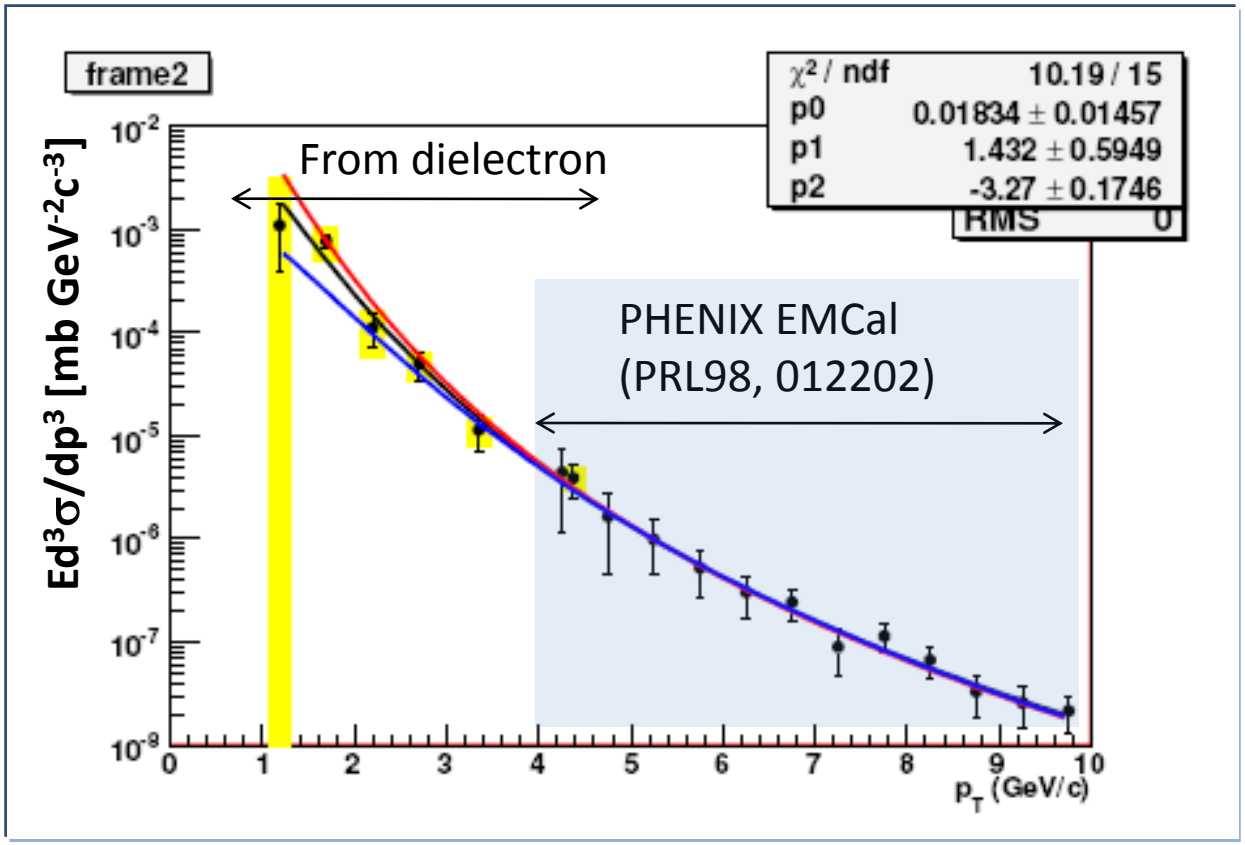
Procedure

Cocktail
Normalized in the very low mass region
Extract the direct photon component

Dielectron=photon

In p+p, the signal appears above pT=2GeV/c.
The result agrees with the EMCal result.





The first direct photon measurement below pt at 3GeV/c.
Surprisingly the pQCD calculation agrees down to ~2 Gev/c.

(the comparison is not on the plot.)

Dielectron=photon

The Au+Au result is compared to p+p.

Submitted to PRL, arXiv:0804.4168

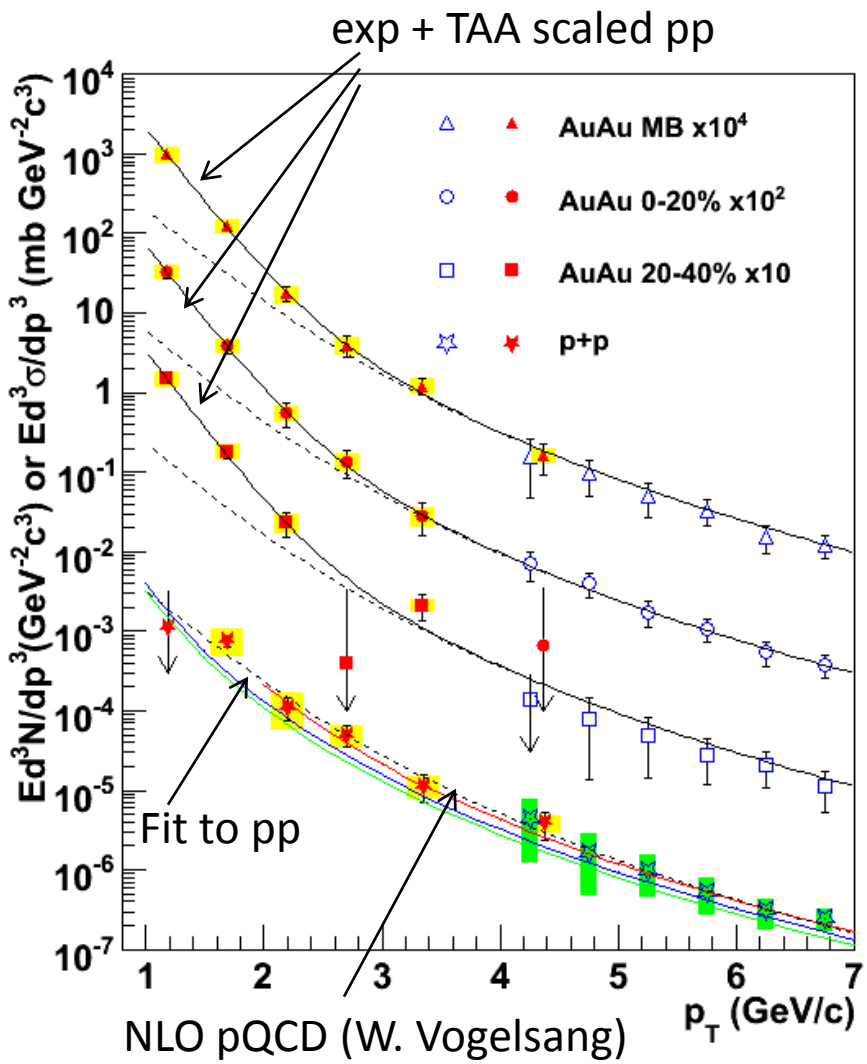


TABLE I: Summary of the fits. The first and second errors are statistical and systematical, respectively.

centrality	$dN/dy(p_T > 1\mathrm{GeV}/c)$	$T(\mathrm{MeV})$	χ^2/DOF
0-20%	$1.10 \pm 0.20 \pm 0.30$	$221 \pm 23 \pm 18$	3.6/4
20-40%	$0.52 \pm 0.08 \pm 0.14$	$214 \pm 20 \pm 15$	5.2/3
MB	$0.33 \pm 0.04 \pm 0.09$	$224 \pm 16 \pm 19$	0.9/4

- Significant yield of the exponential component (excess over the scaled p+p)
- The inverse slope is ~220MeV. (If power-law is used for the pp component, the value of T would increase by ~24MeV)
- Since it's an integration of the entire evolution, the result ~220MeV indicates the initial temperature much higher than the critical temperature.

Exit from the forest. There are 3 more slides.

Analysis opportunities

Run9 500GeVpp
challenge : pi0 (complete) merge at high pT

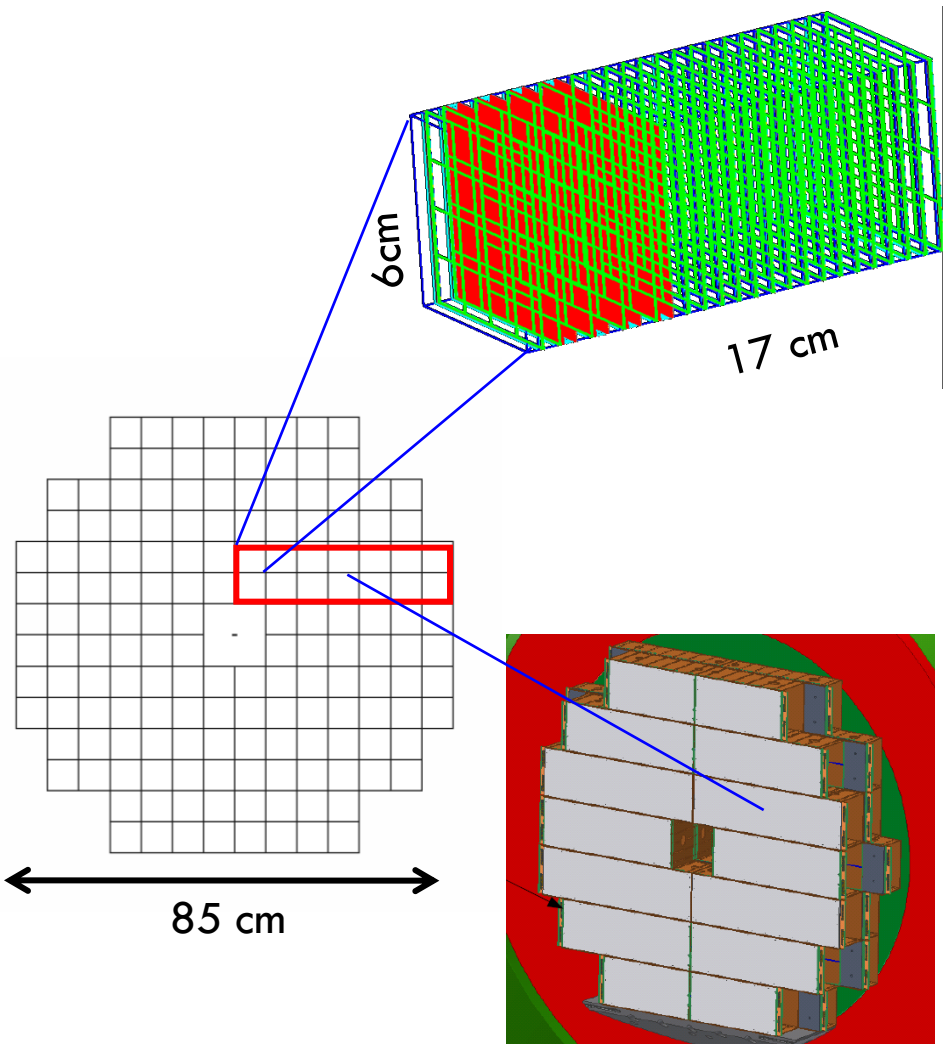
Run6 62.4GeVpp
There is a preliminary result.
The student left PHENIX without doing additional analysis. (but he got Ph.D!)

Run5,6,9 200GeVpp
Hopefully we will have another publication.

dAu, Au+Au
Gabor and his company is working.
But it might not be bad to have multiple independent analyzers to avoid mistakes.

Future

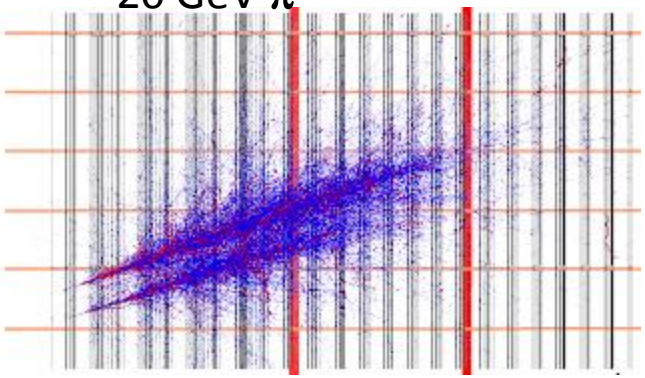
FOCAL



Forward photon, pi0.

low-x physics
combined with the central arm.

Geant simulation
20 GeV π^0



Summary

Everybody likes direct photon process.
It's from a simple diagram and a penetrating probe, hence it's a good probe of the source.

Backgrounds are the problem.
It's mainly problem in the low pT region, but there are other issues in the high pT region.

Originally I thought the analysis of p+p is much easier than the one of Au+Au.
But the p+p analysis has its own difficulties.

There are analysis opportunities and challenges.