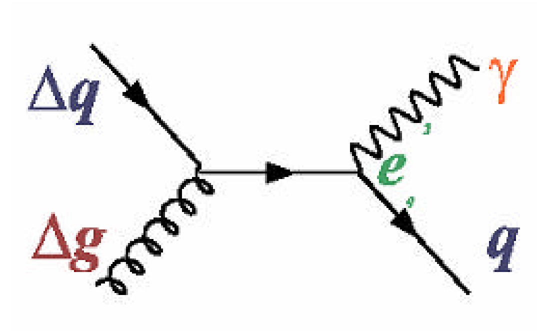
Measurement of prompt photon in $\sqrt{s}$=200GeV pp collisions

Kensuke Okada

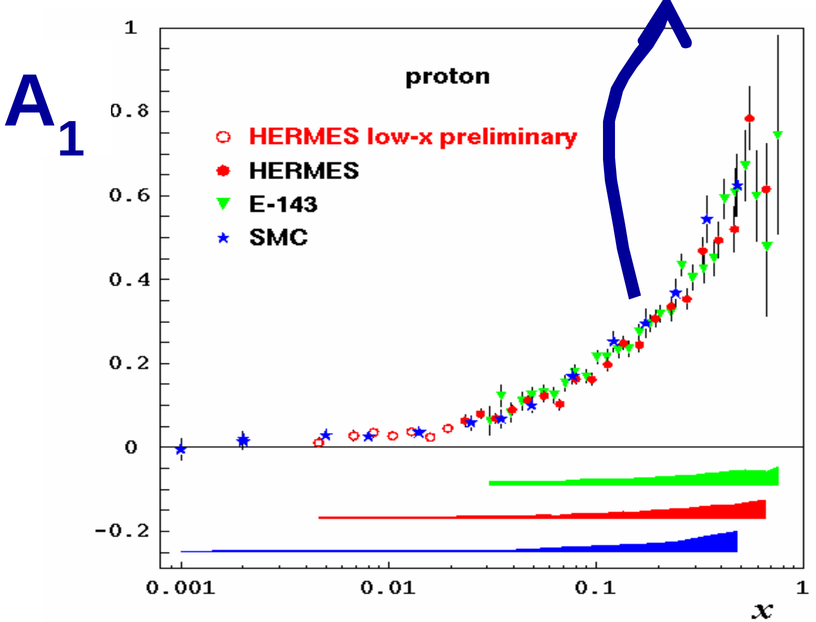
For the PHENIX collaboration

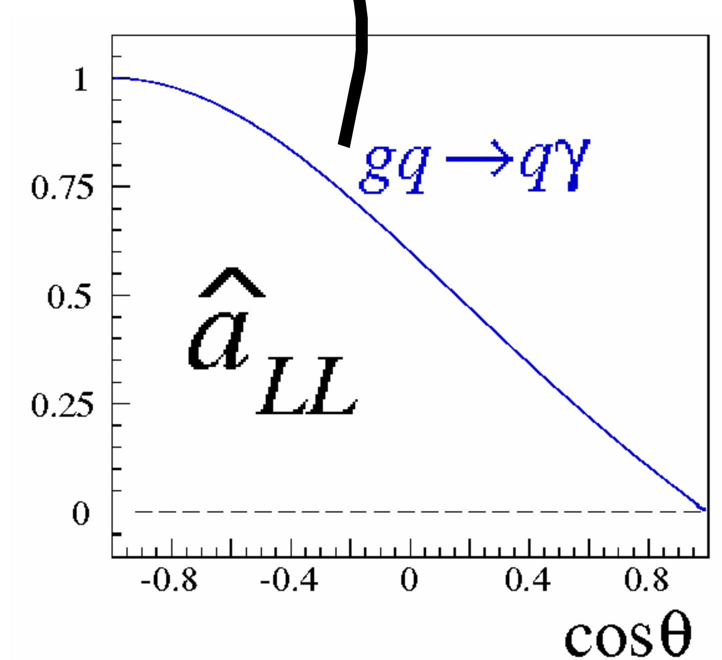
Prompt photon production

- **Gluon Compton Dominates**
  - At LO no fragmentation function
  - Small contamination from annihilation



$$A_{LL} = \frac{\Delta g(x_1)}{g(x_1)} \otimes \frac{\sum_{i=u,d,s} e_i^2 \Delta f_i(x_2)}{\sum_{i=u,d,s} e_i^2 f_i(x_2)} \otimes \hat{a}_{LL}(gq \rightarrow q\gamma)$$





Data

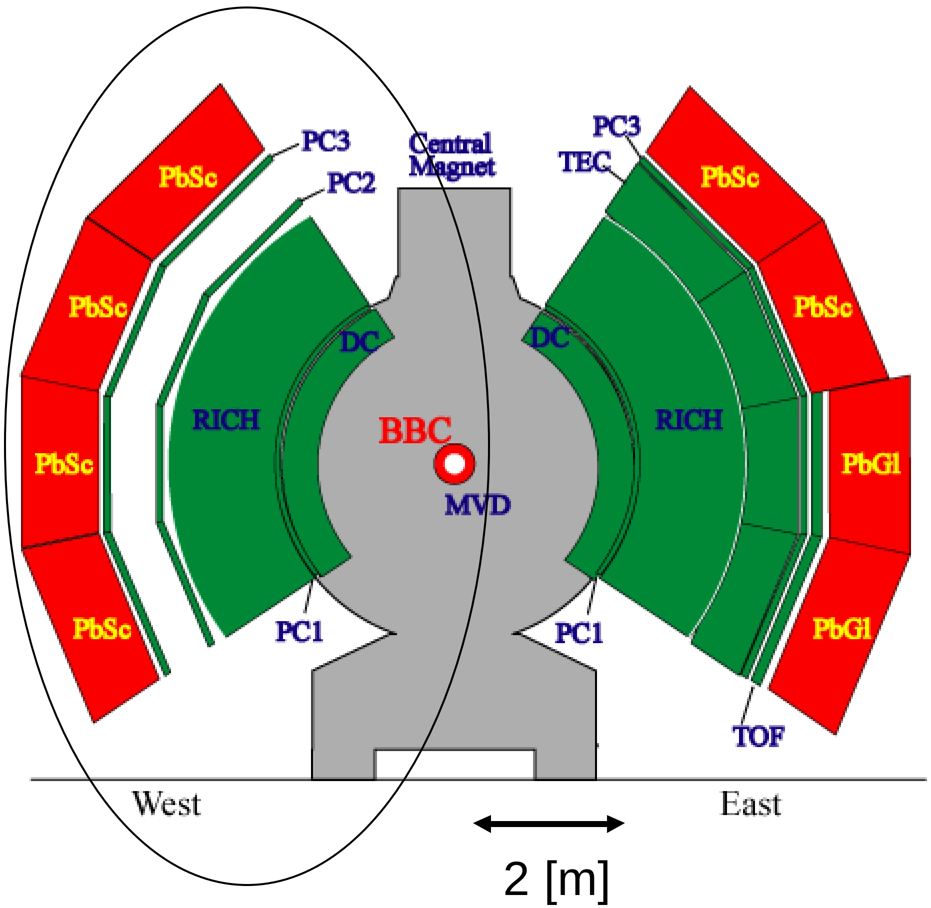
RHIC run3 p+p

2003 April-May
√s=200GeV Proton-proton collisions
Luminosity= 266nb^{-1}

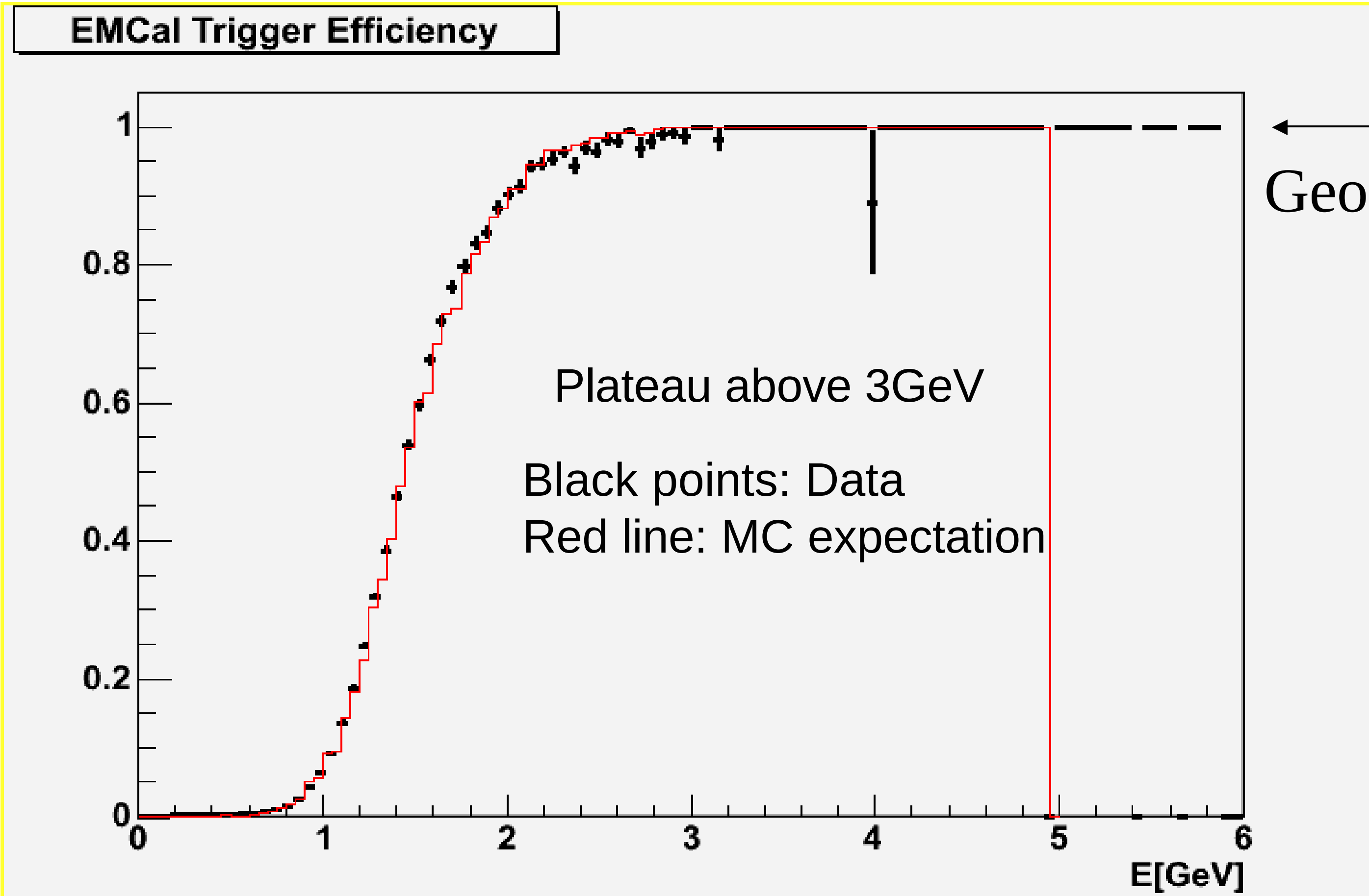
RHIC-PHENIX detector

Central Arm (West)
(Rapidity |y|<0.35)
Electromagnetic Calorimeter (EMCal)
Photon detection
High granularity (~10*10mrad^2)
Drift chamber (DC)
Charged hadron veto
Beam forward / backward
(Rapidity 3.1<|y|<3.9)
Beam-beam counter (BBC)
Triggering and vertex determination

BBC and EMCal Trigger for the data taking



EMCal Trigger



Geometrical limit

Rejection power ~ 120

Analysis procedure

Prompt photon signal = All EMCal clusters – known contributions
Signal / Noise = 0.2~1 (pT 5~17GeV/c) without π^0 tag

Non photon contributions (hadronic shower)

Electromagnetic shower shape requirement
Charged hadron veto with drift chamber tracking

Photon contributions

π^0 with both photons seen in detector
—Eliminate using a π^0 tag.
π^0 with only on photon seen in detector
—Estimate based on photon tagged as π^0
Photonic decay of η,ω etc.
—Estimate to be 23±5% of the total π^0 contributions
(=Production * Br($h\rightarrow\gamma$))

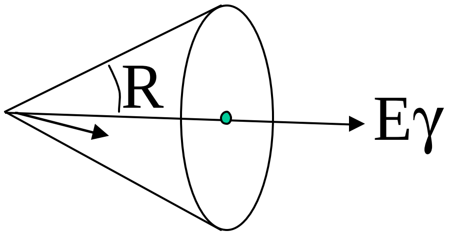
Analysis procedure (+isolation cut)

Isolation cut

in this analysis

$$R = \sqrt{\Delta h^2 + \Delta f^2} < 0.5$$

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



We expect that the isolation cut around well-identified high-pT photons reduces the background from hadronic decays (π^0, η, ω …)

In addition, the isolation cut could separate photon production processes.

Total prompt photons
= photons (gluon Compton scattering) + photons (fragmentation)

Obtained by
the subtraction method

Pass the isolation cut

Mostly eliminated by the isolation cut

Yes, it's not so simple. (cancellation of infrared divergences, underlying parton picture)
In this analysis, we compare with/without the isolation cut
<u>without efficiency correction</u>.

Analysis procedure summary

After rejecting non photon clusters

Prompt photon signal = all – (hadron decay)
= all – (all hadron/pi0)*(pi0 contribution)
= all – (all hadron/pi0)*(pi0 tagged + untagged)

Estimated using MC

Subtraction method

$$N_{signal} = N_{photon} - A(n_{pi0} + n_{pi0}R)$$

Isolation method

$$N'_{signal} = N'_{photon} - A(n'_{pi0} + N'_{iso-pi0}R)$$

A: ratio of total hadron contribution to pi0 contribution (1.23 ± 0.05)

R: ratio of photons from missing pi0 to ones from tagged pi0 (from MC)

$N'_{iso\text{-}pi0}$: photons from pi0 passing the isolation cut if the partner is missed

Contents

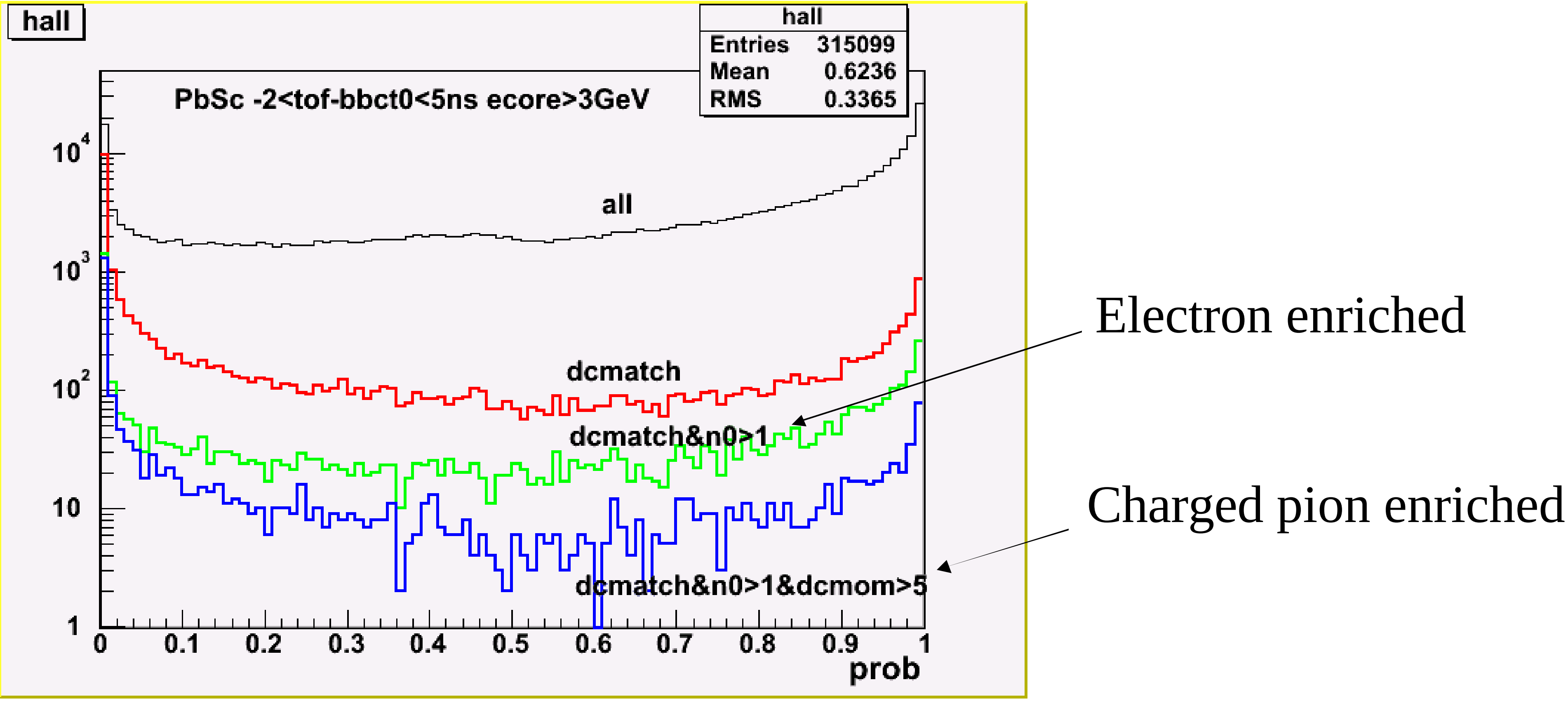
- Hadronic shower rejection
- Pi0 reconstruction
- Fast MC
- Eta, omega, etc/ pi0 ratio
- Result

Hadronic shower rejection

Keywords

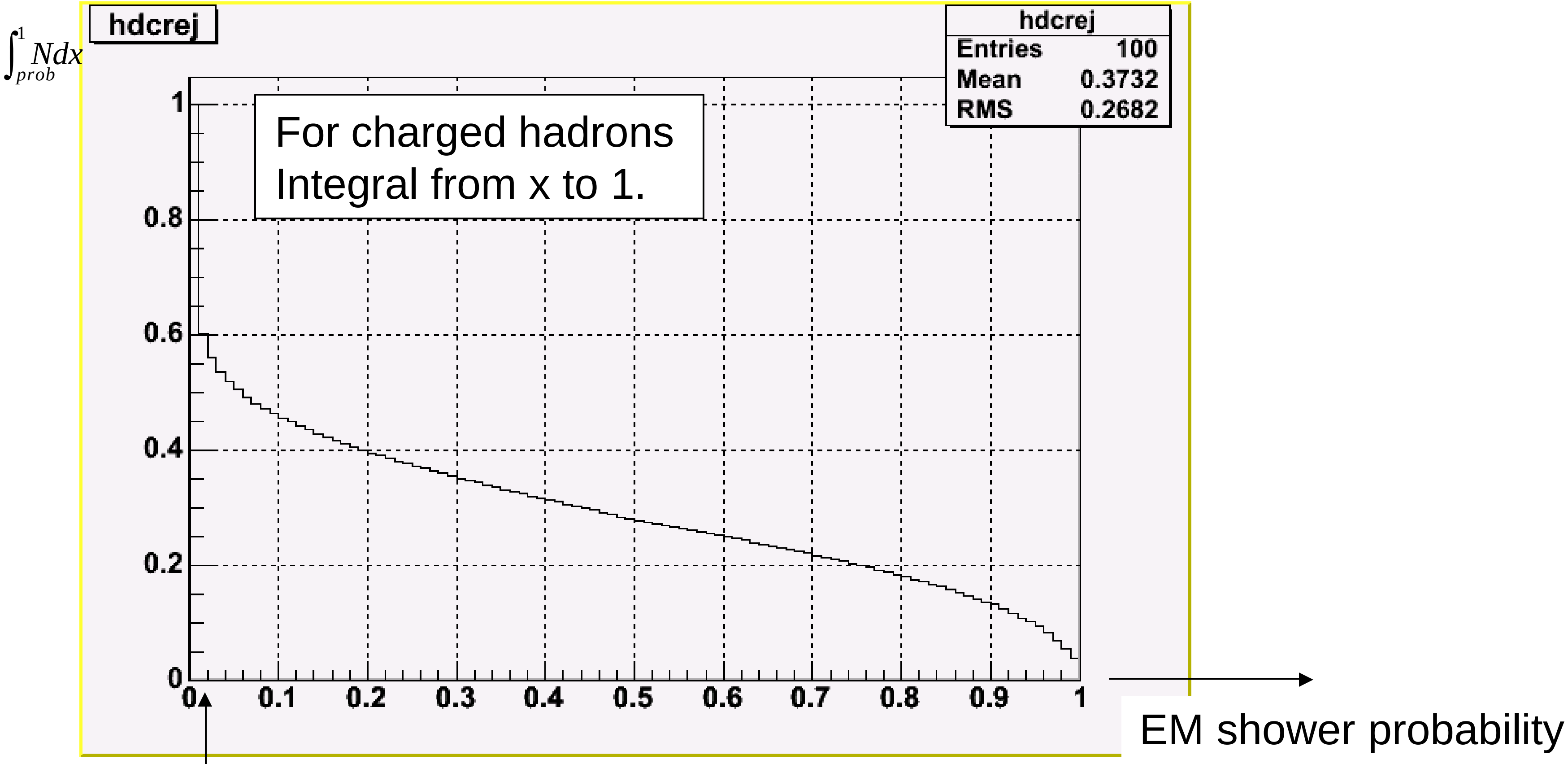
- — Electromagnetic shower probability cut
- — DC matching veto

EMCal cluster probability cut (PbSc)



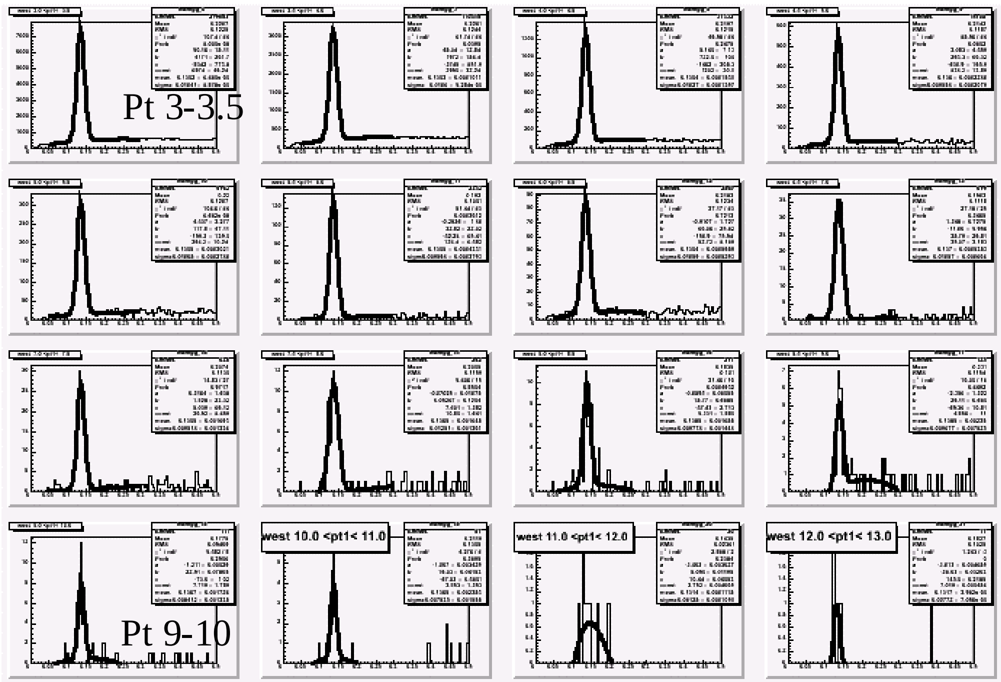
As we expected, charged hadrons (red line) have low "prob" values.

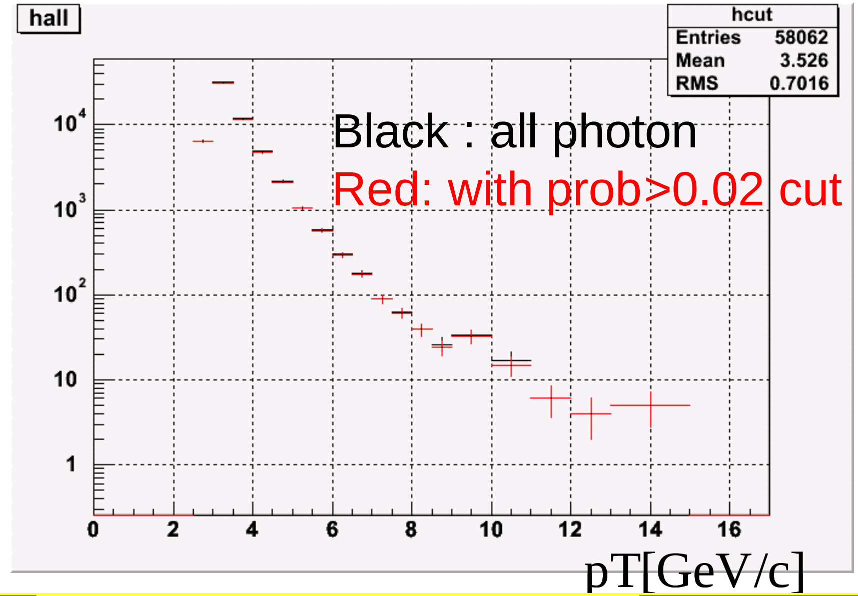
Electromagnetic shower shape cut



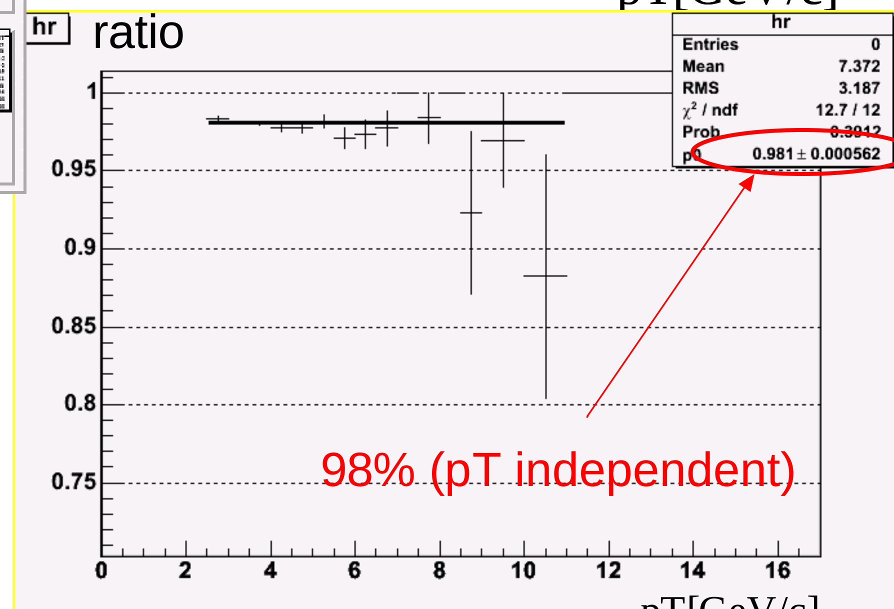
With Prob>0.02 cut
40% of hadronic shower hits are rejected
98% of photons are remained

EM shower cut (photon)



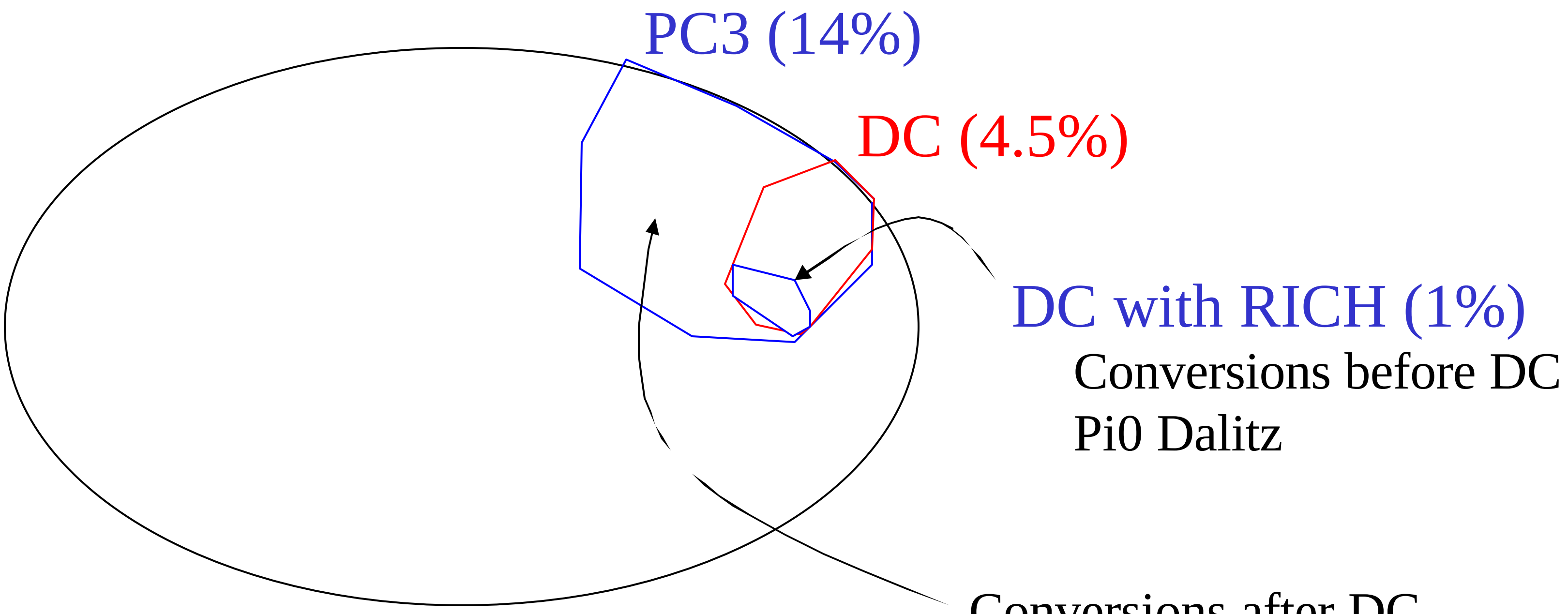


Photons are selected from pi0 mass window



A view of contents

The component of clusters with TOF,prob cut is roughly,



Summary (Hadronic shower rejection)

After tof, prob, and DC veto

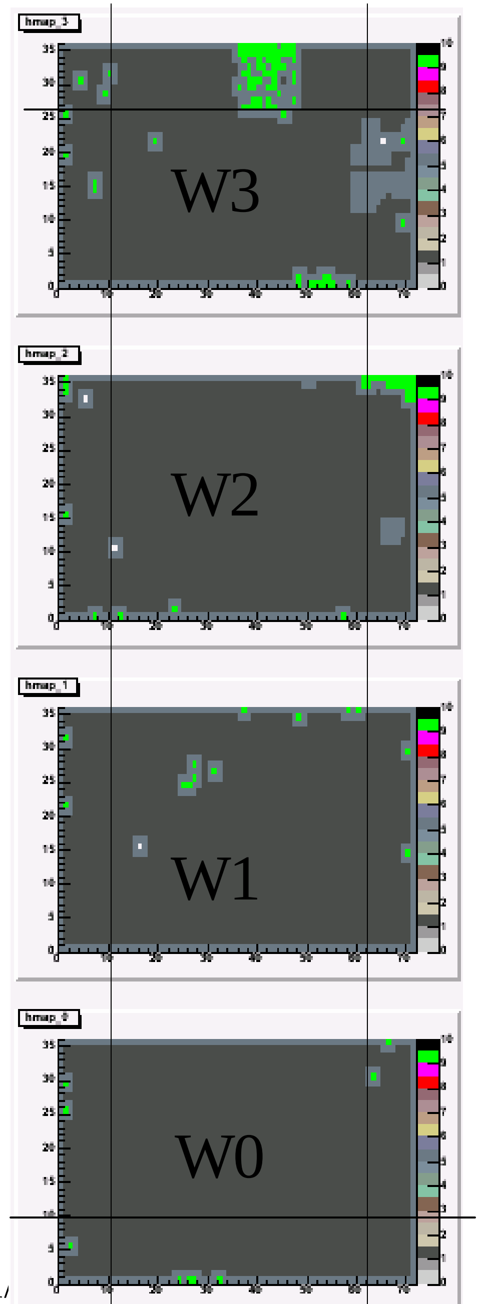
Of total photon clusters,

- Charged hadron contribution is ~0.2% due to DC dead area.
- Neutral hadron is thought to be negligible so far. (from MC).

Pi0 reconstruction

— Strategy
— Combinatorial background correction
— Partner inefficiency correction

Strategy

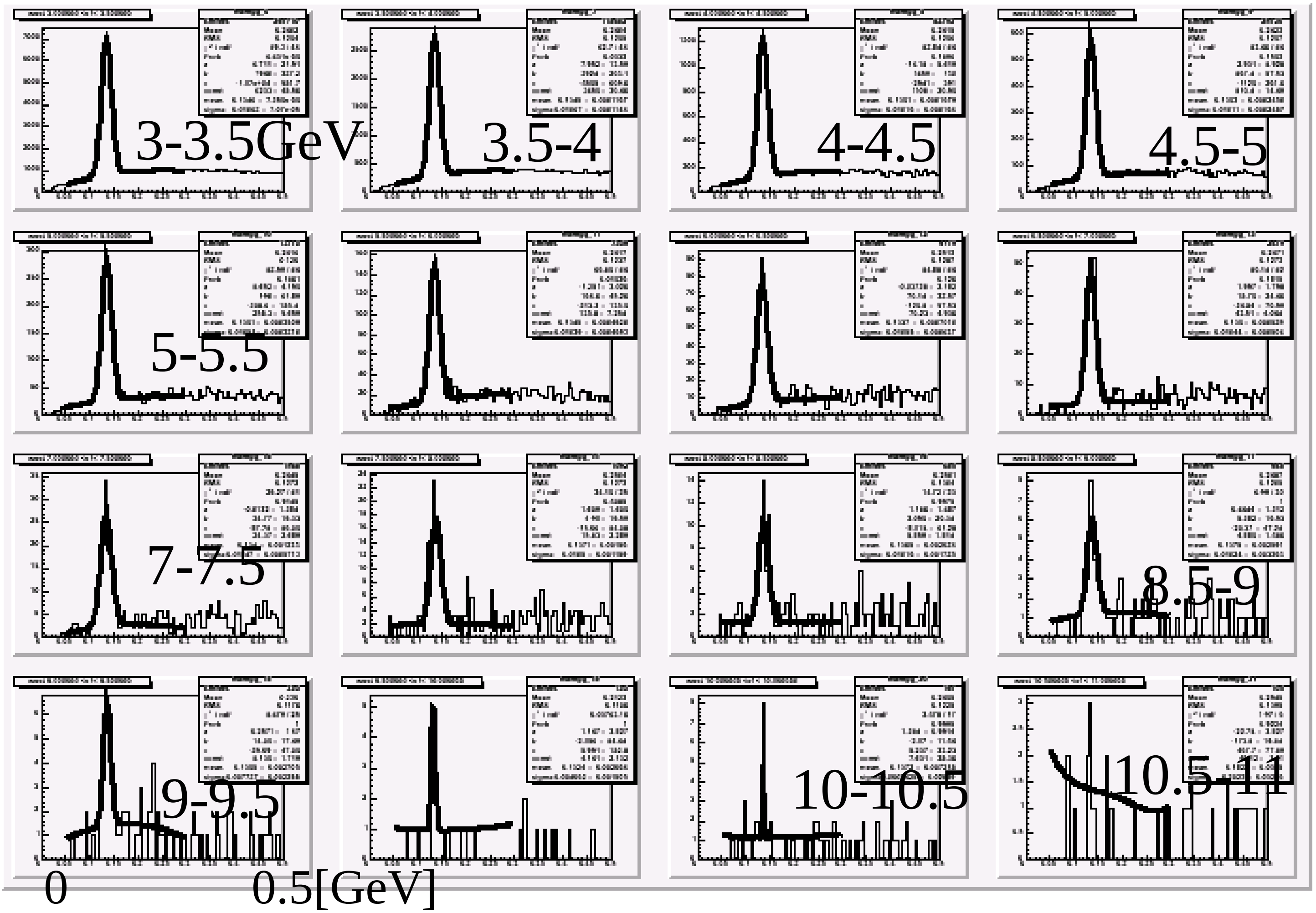


3x3 towers of dead or hot channels are rejected.

10 towers edge surrounding the arm were used as pi0 veto. (only for the partner search)
It corresponds 90% of 5GeV pi0.

Target photon : as clean as possible
(warn map,tof, prob cut, DC veto)
Pi0 partner : as many as possible
(only warn map)

$M_{\gamma\gamma}$ distribution



West arm
Guard veto (10)
ert4x4c match
-2<|tof|<5ns
Prob>0.02
DC veto

Partner
Ecore>0.15GeV

Fit: `a+bx+cx^2+const*exp(-0.5*((x-mean)/sigma)^2)`

Net γ: `cons*sqrt(2pi)*sigma*1/bin_size (bin_size=0.5e-2)`

Combinatorial background correction

Suppose there are N photons in a pT bin. There are two kinds of photons.

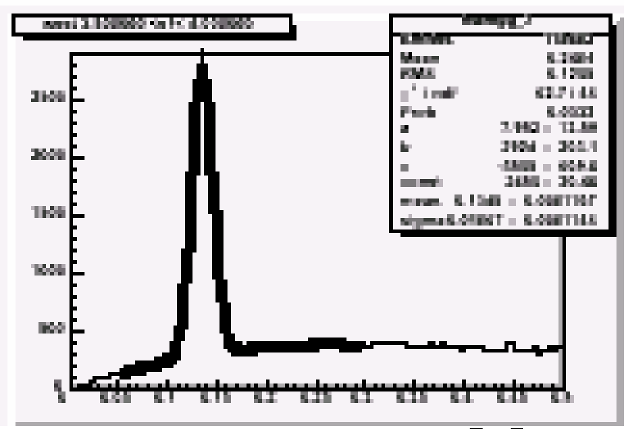
N= x + y

x: photons from pi0 should be reconstructed.

y: single photons

A) Pair based method

$x = S_p$



Mγγ

B) photon based method

From the number of photon tagged,

pi0 window region : **$N_w = x + yp$**

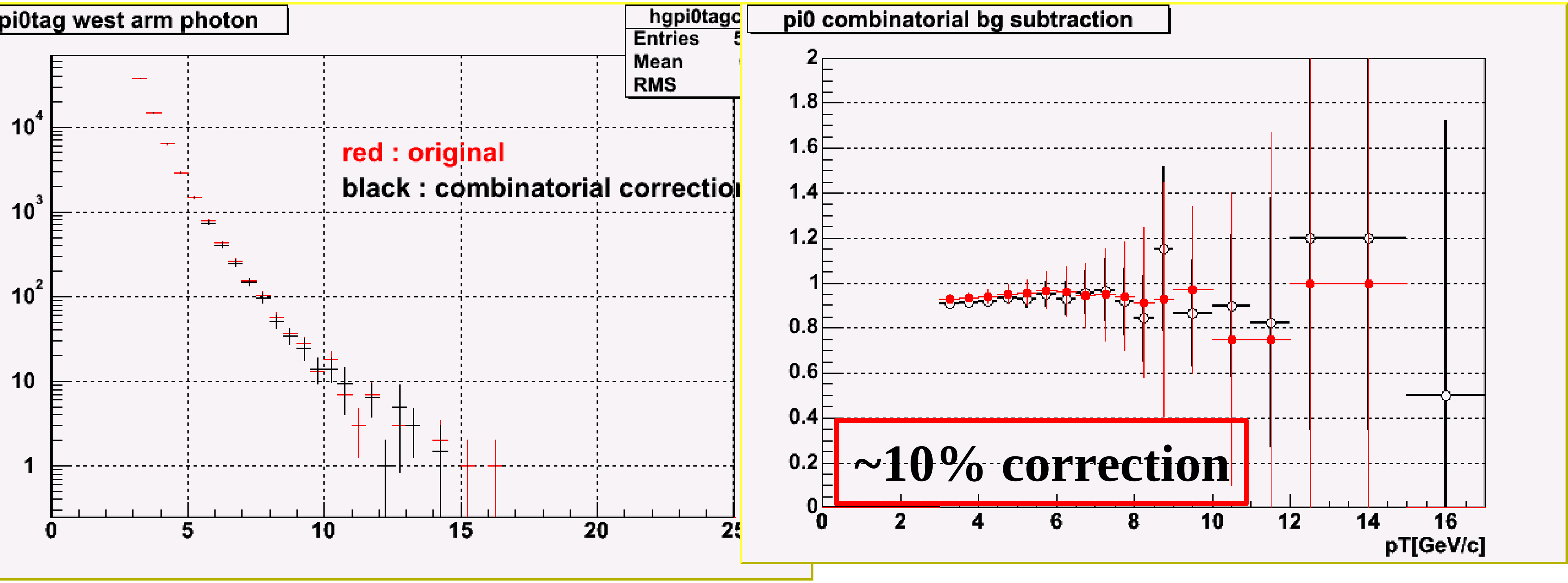
vicinity region : **$N_v = (x+y)p$**

Where **p** is combinatorial probability which can be estimated by the ratio of 2tag/1tag

Then

$x = (N_w - N_v)/(1-p)$

Photon base method



$$x = \frac{N_W - N_V / w}{1 - p} \approx (N_W - N_V / w)(1 + p)$$

$$\frac{dx}{x} = \frac{dN_W \oplus dN_V / w}{N_W - N_V / w} \oplus \frac{dp}{1 + p}$$

$$= \frac{\sqrt{N_W + N_V / w}}{N_W - N_V / w} \oplus \frac{p}{1 + p} \sqrt{\frac{1}{N_1} + \frac{1}{N_2}}$$

N_W : Photon in pi0 window

N_V : Photon in pi0 vicinity

w : Vicinity width (=2)

p : Combinatorial probability

$p \equiv N_2 / N_1$

Partner photon efficiency

Conversion before DC $\rightarrow$ Completely lost (due to magnetic field)
Conversion after DC $\rightarrow$ Partially lost

Total 3% from MC (in pi0 cross section analysis)

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fast MC

Input: EMCal warn map, pT slope

Purpose: Missing pi0 ratio
(pi0 photon merge)
Photon acceptance and smearing
(pi0 mass peak, width)

Energy Scale, Resolution

The fast MC is tuned using pi0 peak and width.

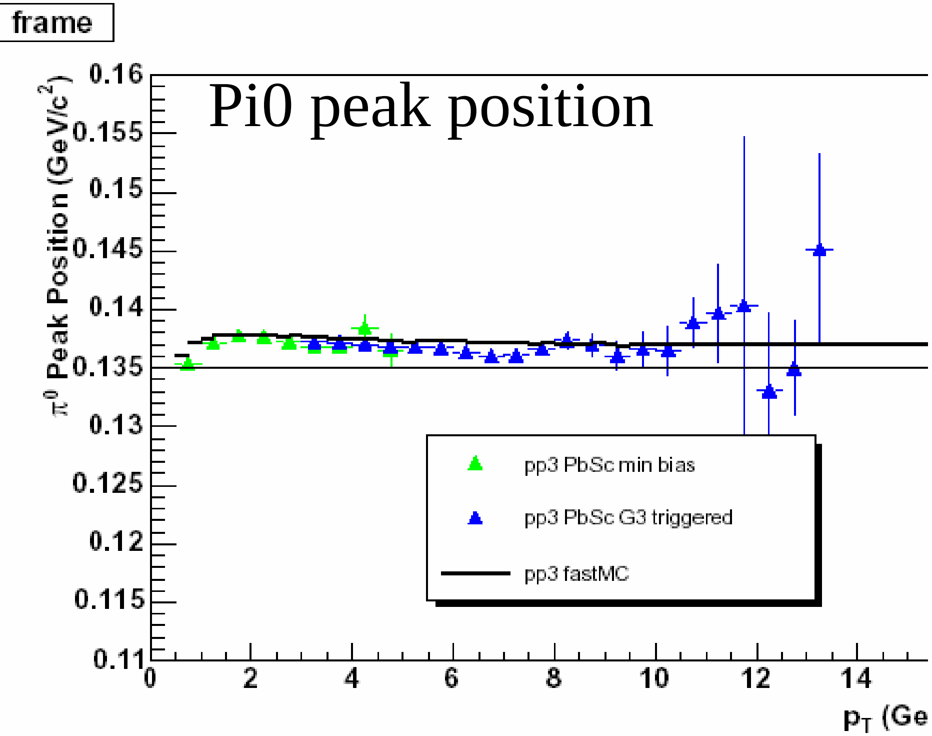


Figure 11: Comparison of the PbSc π^0-peak positions in real data and fa

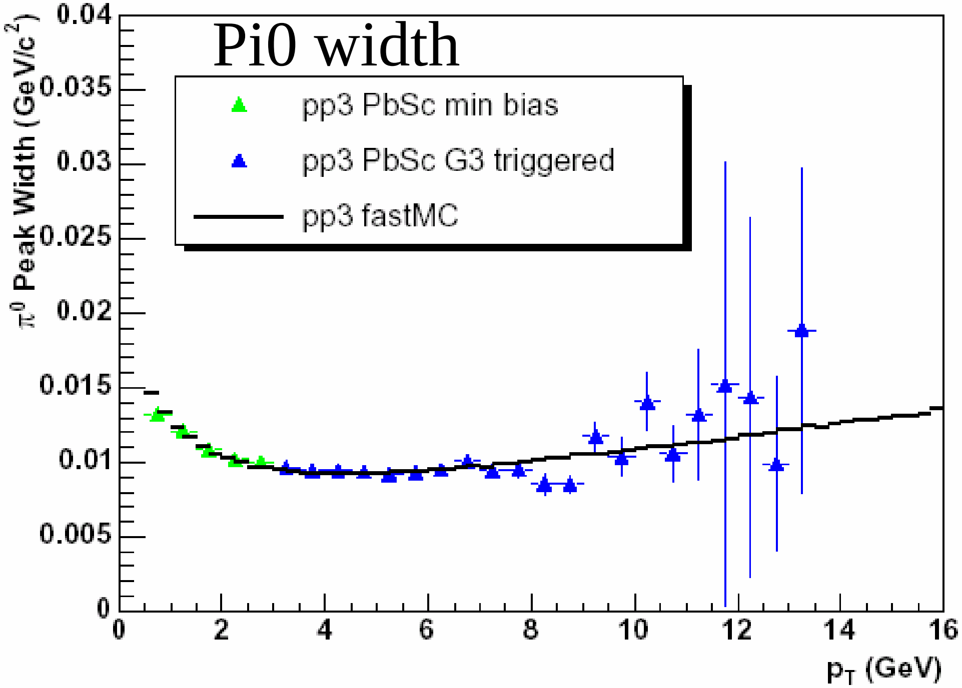
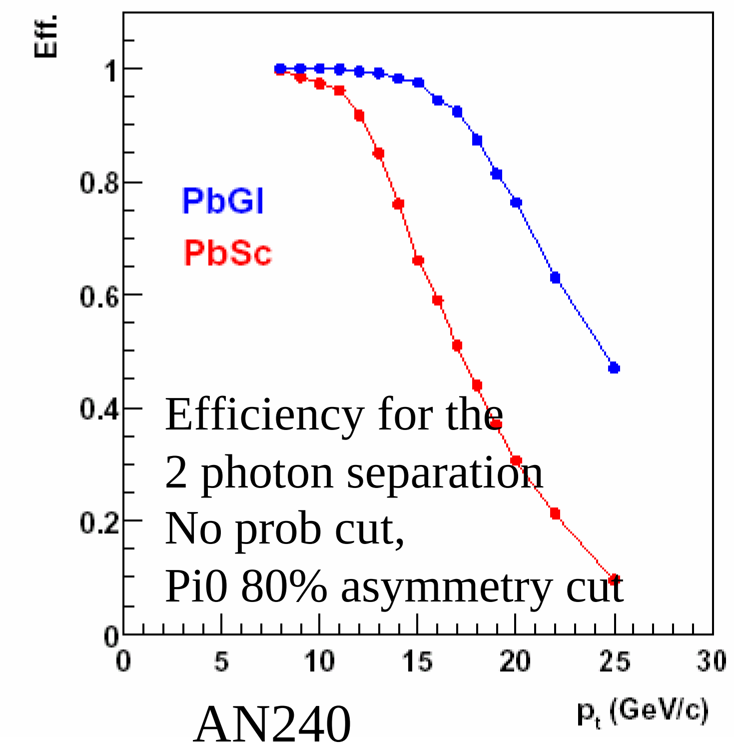


Figure 12: Comparison of the PbSc π^0-peak widths in real data and fast MC.

Study of cluster merging in PbSc

“prob” cut discards all merged photons up to 15~20 GeV.

No “prob” cut



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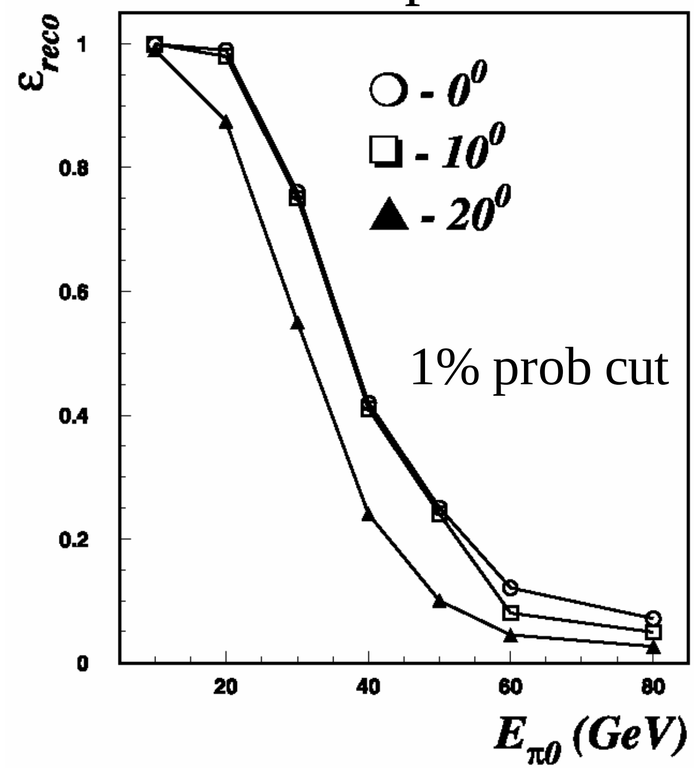
With “prob” cut



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Pi0 photon merging (example)

At 5m away, distance of 2 photons is

140cm / E_pi0[GeV]
= 25.4 towers / E_pi0[GeV]

For example, 20GeV pi0 makes 10GeV photons with 1.27towers distance.

Numbers show the deposit energy [%] of these two photon in 5x5 towers.

These are merged and will be an 20GeV cluster, but it can’t pass the EMCal shower shape criteria.

---1--- (0,0)

0.0	0.1	0.3	0.1	0.0
0.1	1.6	6.1	1.6	0.1
0.3	6.1	**66.5**	6.1	0.3
0.1	1.6	6.1	1.6	0.1
0.0	0.1	0.3	0.1	0.0

---2--- (0,1.27273)

0.0	0.0	0.1	0.3	0.2
0.0	0.1	1.1	7.0	3.7
0.0	0.2	3.3	**53.8**	17.5
0.0	0.1	1.1	7.0	3.7
0.0	0.0	0.1	0.3	0.2

---1--- (-0.5,0)

0.1	0.7	1.7	0.7	0.1
0.3	5.8	**34.4**	5.8	0.3
0.3	5.8	**34.4**	5.8	0.3
0.1	0.7	1.7	0.7	0.1
0.0	0.1	0.1	0.1	0.0

---2--- (-0.5,1.27273)

0.0	0.1	0.4	1.7	1.1
0.0	0.2	2.8	**30.8**	12.8
0.0	0.2	2.8	**30.8**	12.8
0.0	0.1	0.4	1.7	1.1
0.0	0.0	0.1	0.1	0.1

---1--- (0,-0.5)

0.1	0.3	0.3	0.1	0.0
0.7	5.8	5.8	0.7	0.1
1.7	**34.4**	**34.4**	1.7	0.1
0.7	5.8	5.8	0.7	0.1
0.1	0.3	0.3	0.1	0.0

---2--- (0,0.772727)

0.0	0.1	0.2	0.3	0.1
0.0	0.3	3.2	6.9	1.2
0.0	0.7	14.7	**56.2**	3.6
0.0	0.3	3.2	6.9	1.2
0.0	0.1	0.2	0.3	0.1

---1--- (-0.5,-0.5)

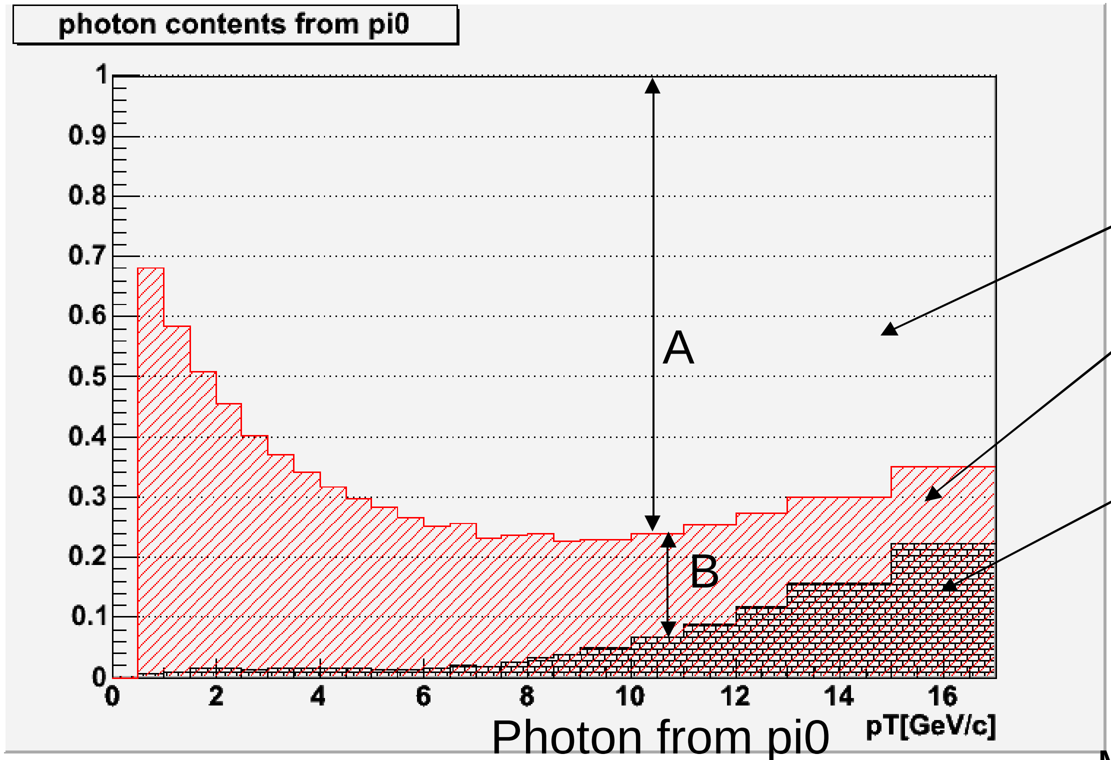
0.3	1.4	1.4	0.3	0.0
1.4	**21.7**	**21.7**	1.4	0.1
1.4	**21.7**	**21.7**	1.4	0.1
0.3	1.4	1.4	0.3	0.0
0.0	0.1	0.1	0.0	0.0

---2--- (-0.5,0.772727)

0.0	0.2	1.0	1.7	0.5
0.0	0.6	11.1	**31.6**	3.1
0.0	0.6	11.1	**31.6**	3.1
0.0	0.2	1.0	1.7	0.5
0.0	0.0	0.1	0.1	0.1

pi0 photon missing ratio (with MC)

Input: pi0 spectra, Energy resolution, Shower size from measurements
The same MC used in pi0 cross section measurement.
For the case both photon weren't lost before EMCal.



This figure shows components of photon from pi0.

(A) 2 photons tagged as pi0

(B) 1photon (the partner missing)

Merged photons
(to be discarded by the shower shape cut
And those have almost double energy)

Miss/ tag (=B/A)
40% at 5GeV/c
20% at 10GeV/c

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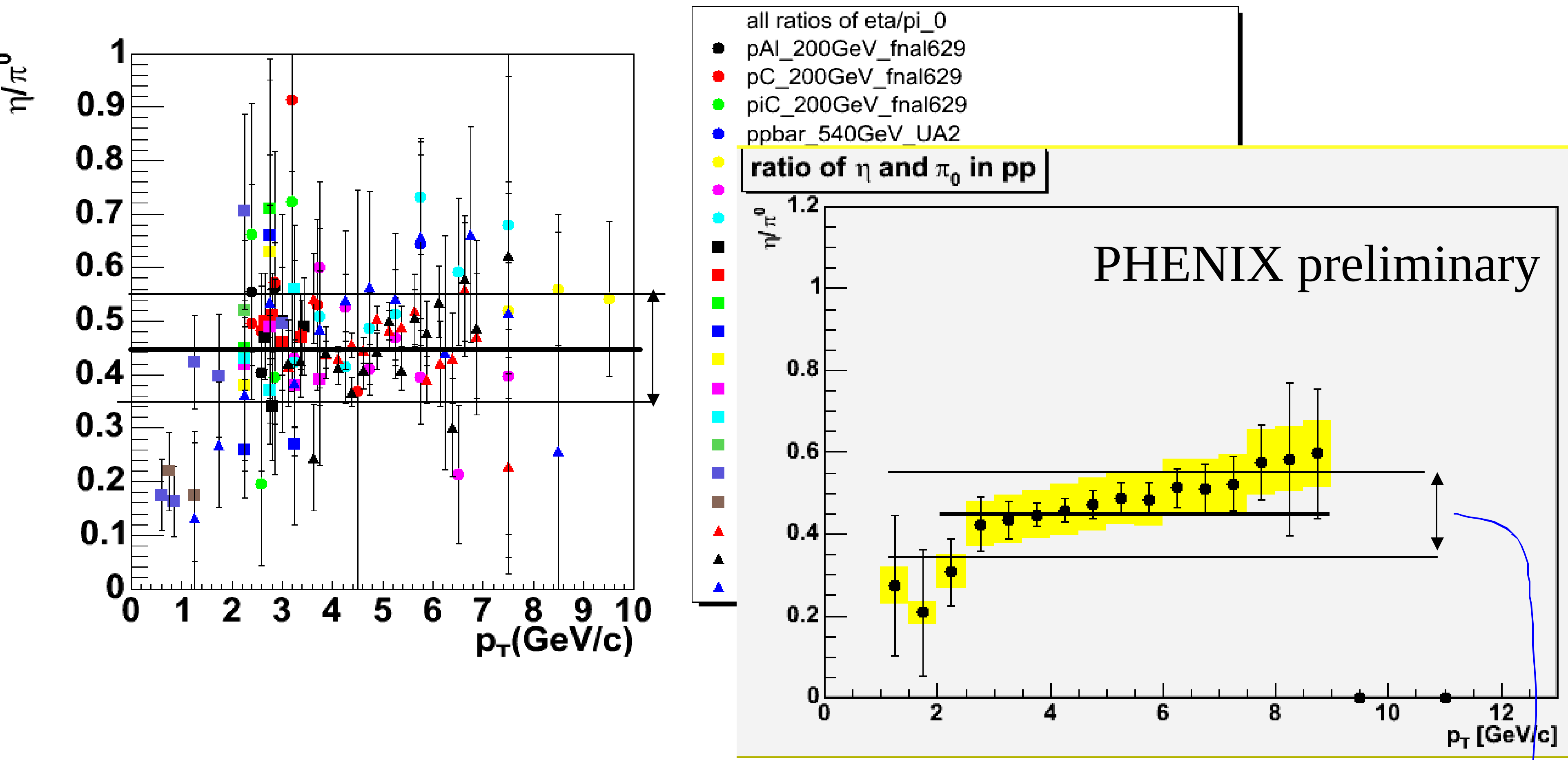
eta, omega, etc /pi0 ratio

World data, PHENIX preliminary data
Self veto effect in the isolation cut method

Eta/pi0 ratio



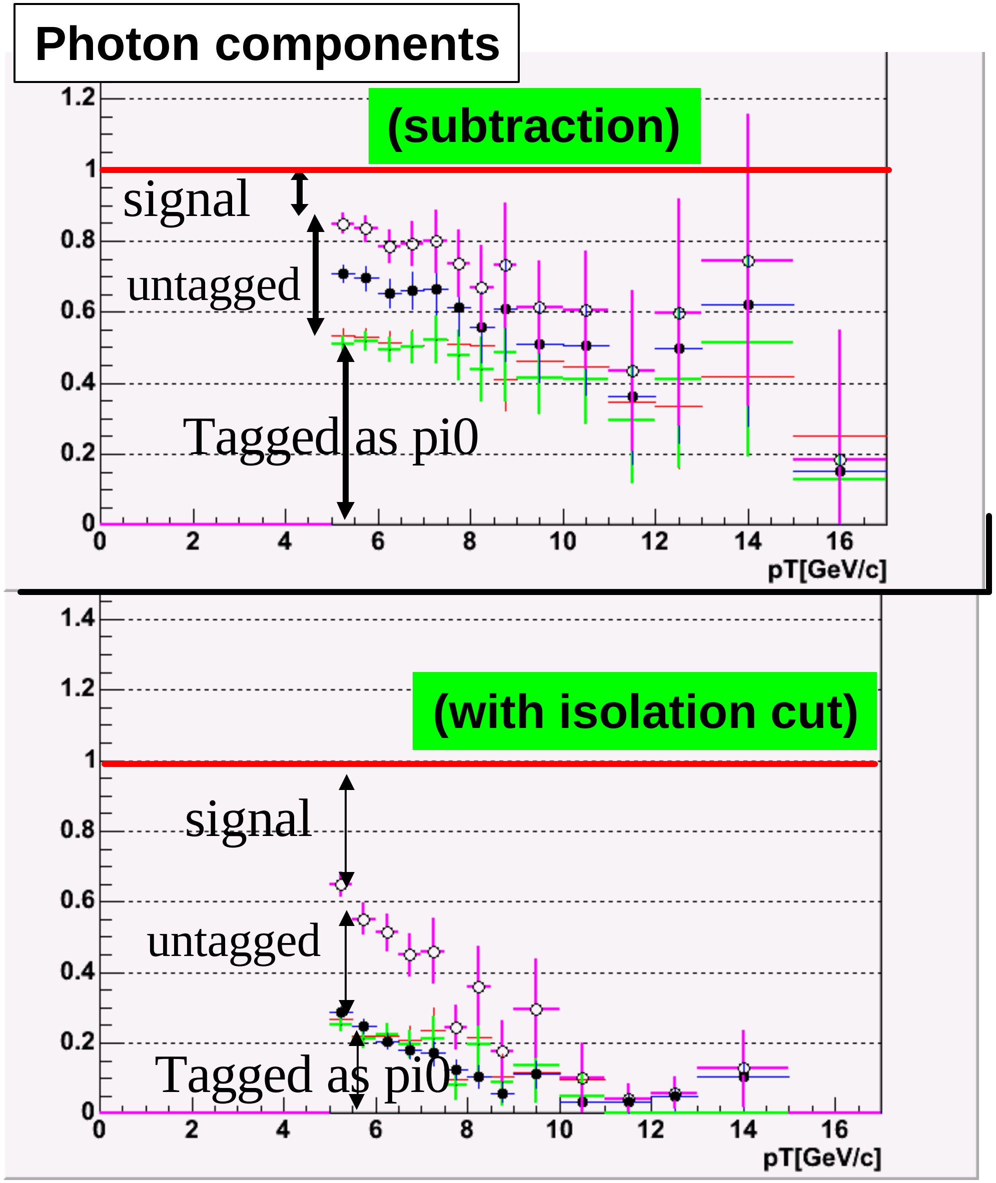
Eta/pi0 = 0.45*0.394/0.988=0.18 (assuming no pT dependence)

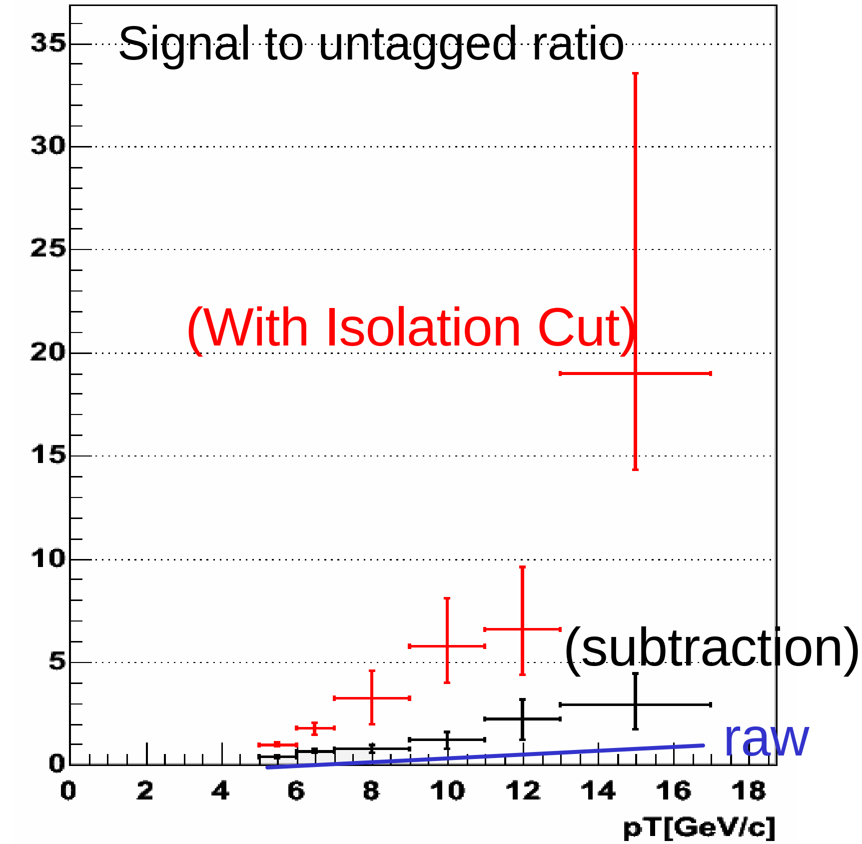
+ omega, eta',… = 0.23 ± 0.05

result

Photon components (S/N)
Systematic error
Spectra with Werner's calculation
With/without isolation cut

Prompt photon signal and photon without pi0 tag





With the isolation cut,
The signal is enhanced.

Cross section calculation

Factors

1/Luminosity: 1/266nb^{-1} (=5.450e9 events/20.5mb)
1/bbc_bias: 1/0.785
1/(acceptance+smearing): 1/0.0982
1/(shower shape cut efficiency): 1/0.98
1/(Conversion probability): 1/0.97

Systematic error sources

The followings are considered for now.

—***Pi0 photon estimation:***
combinatorial bg correction, partner inefficiency correction
missing pi0 estimation

—***Non pi0 hadron contribution:***
production ratio to pi0

—***Photon acceptance & smearing:***
energy scale ambiguity

—***Photon conversion effect:***
material, revival electron

—***Luminosity measurement:***
BBC cross section measurement by a vernier scan.

—***BBC trigger bias:***
pi0 analysis

Systematic error

For π^0 tagging (subtraction) method

	Lowest 5-5.5 [GeV/c]	Highest 15-17 [GeV/c]	
Pi0 photon estimation	30%	5	Point to point
Non pi0 hadron contribution	27	6	
Photon acceptance and smearing	10	10	
Photon conversion effect	1	1	
Luminosity measurement	12	12	global
BBC trigger bias	3	3	
Total (quadratic sum)	43%	18	

∗ Errors on the backgrounds result in enlarged errors on the signal, especially at low-pT region.

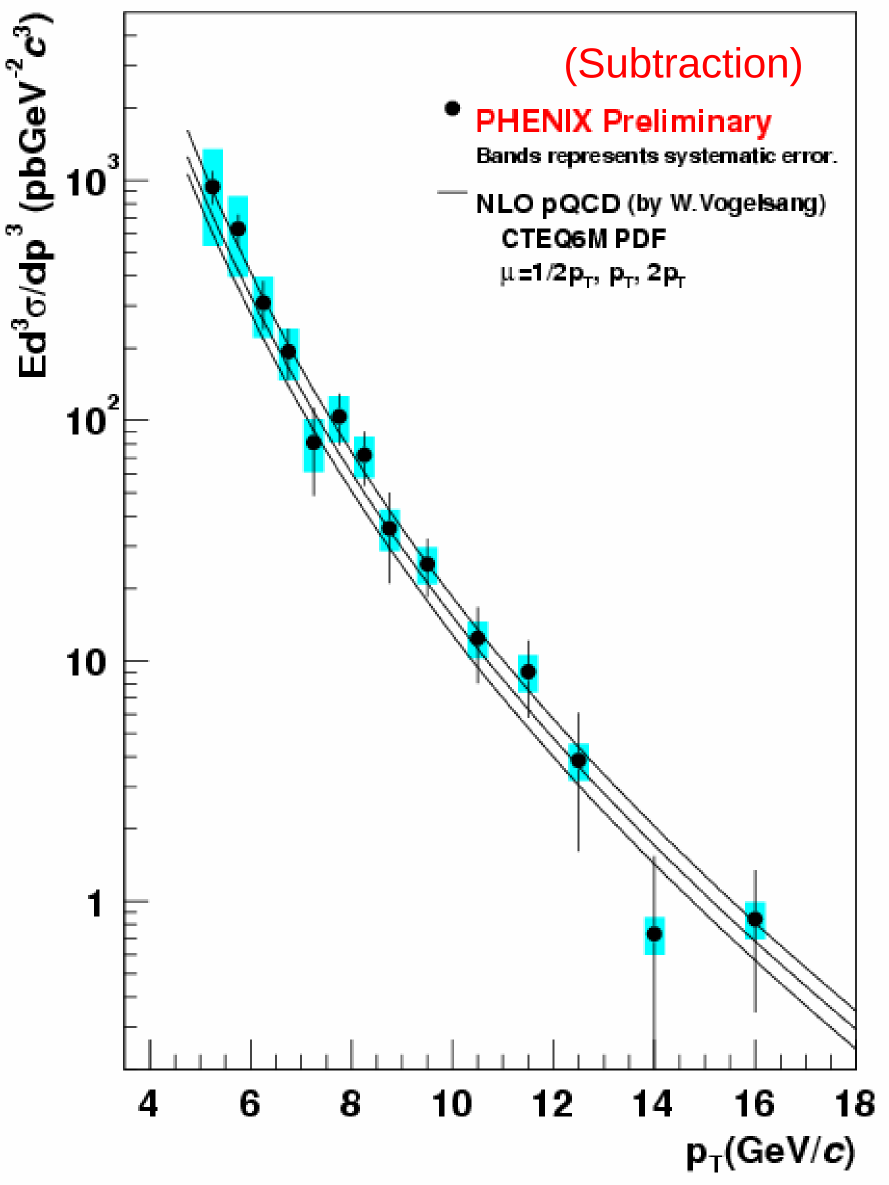
∗ With the isolation cut, those are less thanks to high S/N ratio.

Systematic error

For isolation cut method

	Lowest 5-5.5 [GeV/c]	Highest 15-17 [GeV/c]	
Pi0 photon estimation	16%	2	Point to point
Non pi0 contribution	8	1	
Photon acceptance and smearing	10	10	
Photon conversion effect	1	1	
Luminosity measurement	12	12	global
BBC trigger bias	3	3	
Total (quadratic sum)	24%	16	

Result with NLO pQCD calculation



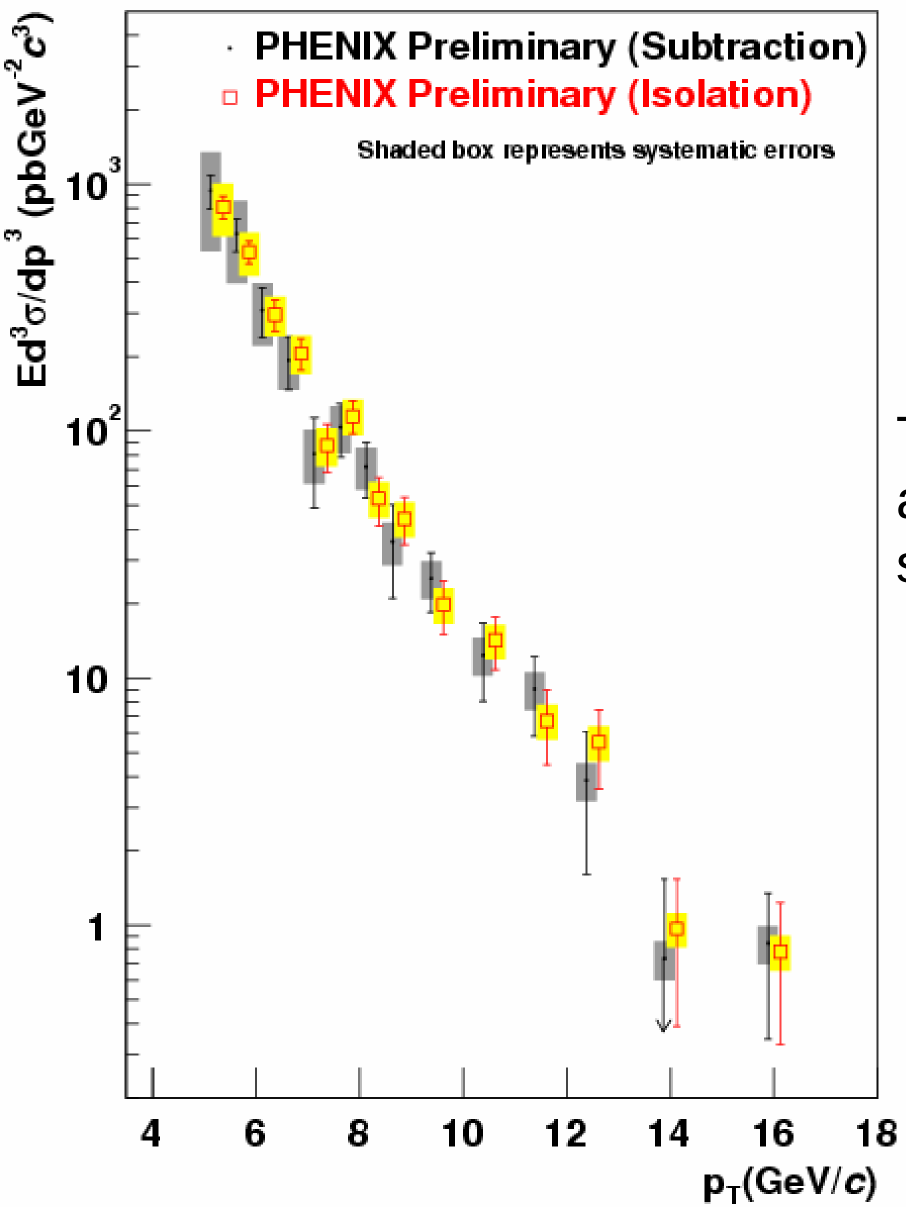
Bands represent systematic errors.

Errors on the backgrounds result in enlarged errors on the signal, especially at low-pT region.

- NLO-pQCD calculation
  - CTEQ6M PDF.
  - Gluon Compton scattering + fragmentation photon
  - Set Renormalization scale and factorization scale pT/2,pT,2pT

The theory calculation shows a good agreement with our result.

Isolation cut



<u>Without isolation cut efficiency correction</u>

The result from isolation cut method is almost identical with the result from subtraction method

It suggests
— low rejection power for the fragmentation photon contributions
or/and
— a large contribution from gluon Compton scattering

Summary

? The prompt photon cross section for 200GeV p+p collisions has been measured at PHENIX.

? In the analysis, it is important to tag π^0.

? NLO pQCD calculation agrees well with our measurement.

? The isolation cut improves the signal-to-noise ratio without significantly reducing the signal.
(It is important for future spin asymmetry measurement.)