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

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Motivations

- **Physics meaning of prompt photon**
  - **Is a good probe of parton structure in nucleon.**
  - **One of simple processes at hadron collisions.**

- **At RHIC (a polarized proton collider capable of $\sqrt{s}$ up to 500GeV)**
  - **The highest energy available for pp→gamma+"X"**
  - **Prompt photon production can probe the gluon polarization in proton.**

Data

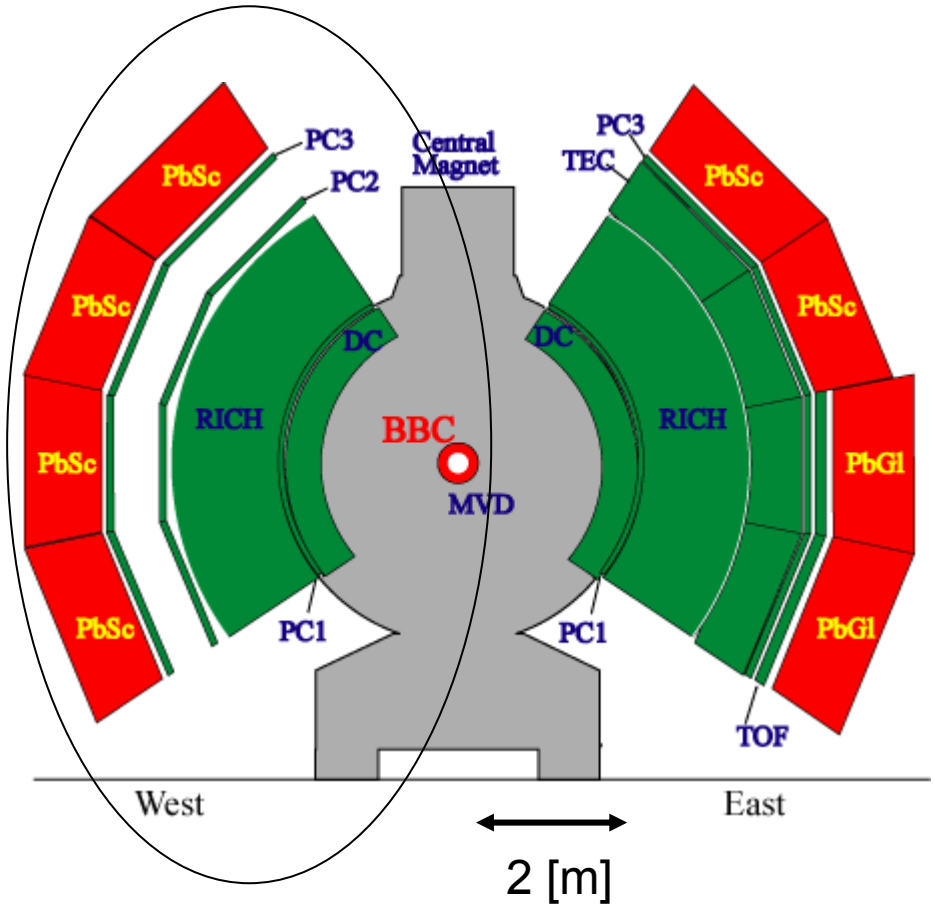
RHIC run3 p+p

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



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$\pm$5% of the total π^0 contributions
(=Production * Br(h$\rightarrow\gamma$))

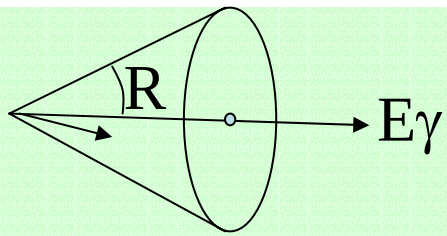
Analysis procedure (+isolation cut)

Isolation cut

in this analysis

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

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



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>.

π^0 tag

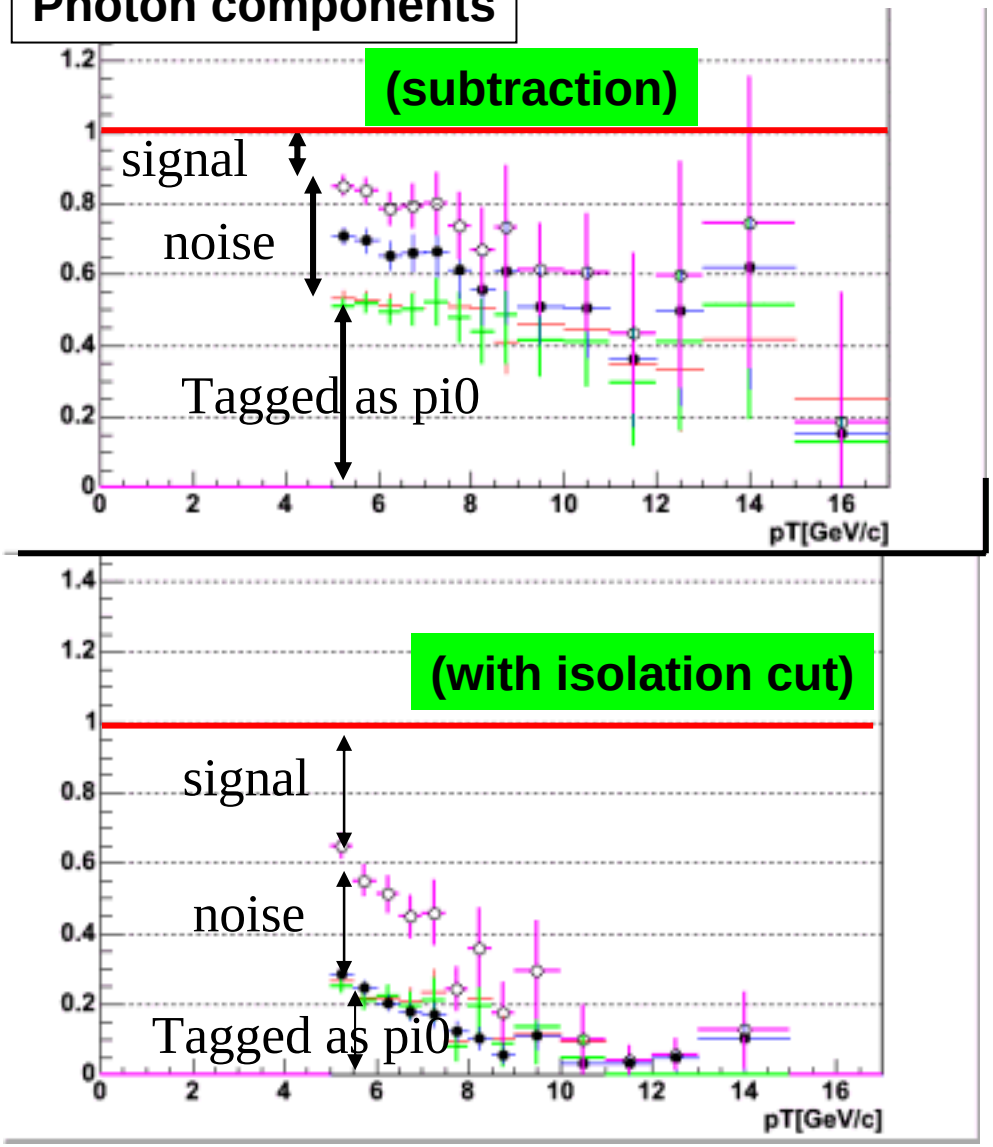
Reason to miss the partner		Our efforts to recover them
—Out of EMCal Arm	→	Assign edges only for partner search (guard veto region)
—EMCal bad area	→	Careful definition
—Less than the minimum E	→	Set E_{min} as low as possible (at 150MeV)
—Photon conversions	→	Charged veto with DC tracks, not with a detector in front of the EMCal
—Photon merging	→	In our pT region, those are rejected by the EM shower shape cut.

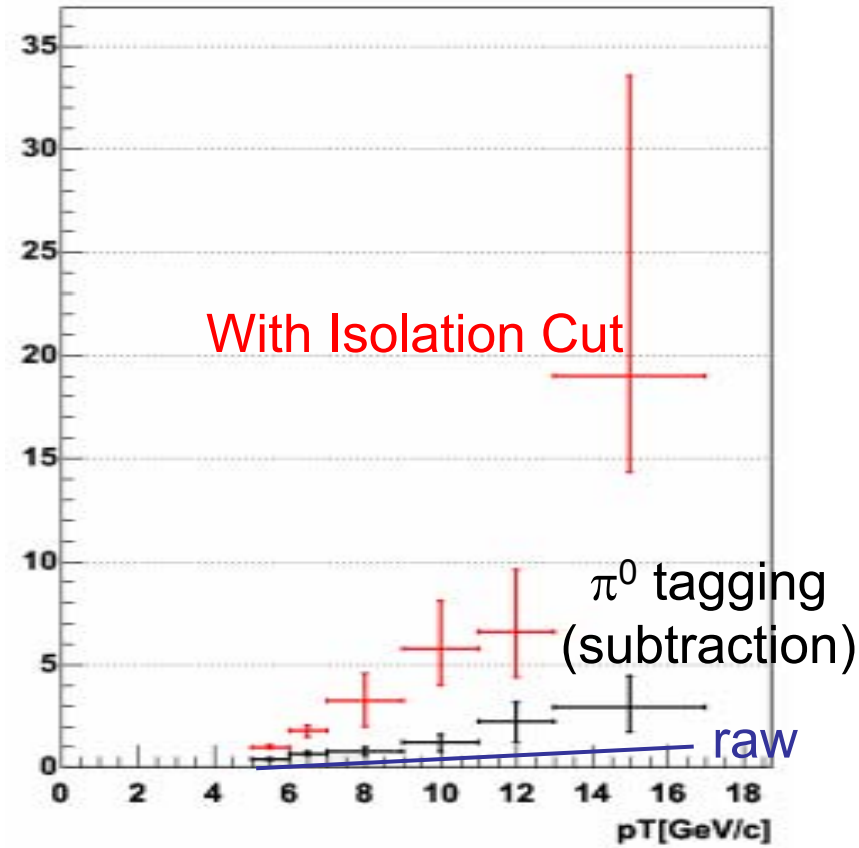
From MC,
γ from missed π^0 / from tagged π^0
= 40% @ pT=5GeV/c
= 20% @ pT=10GeV/c

<u>Now we are ready to obtain prompt photon yield.</u>

Signal to noise ratio

Photon components





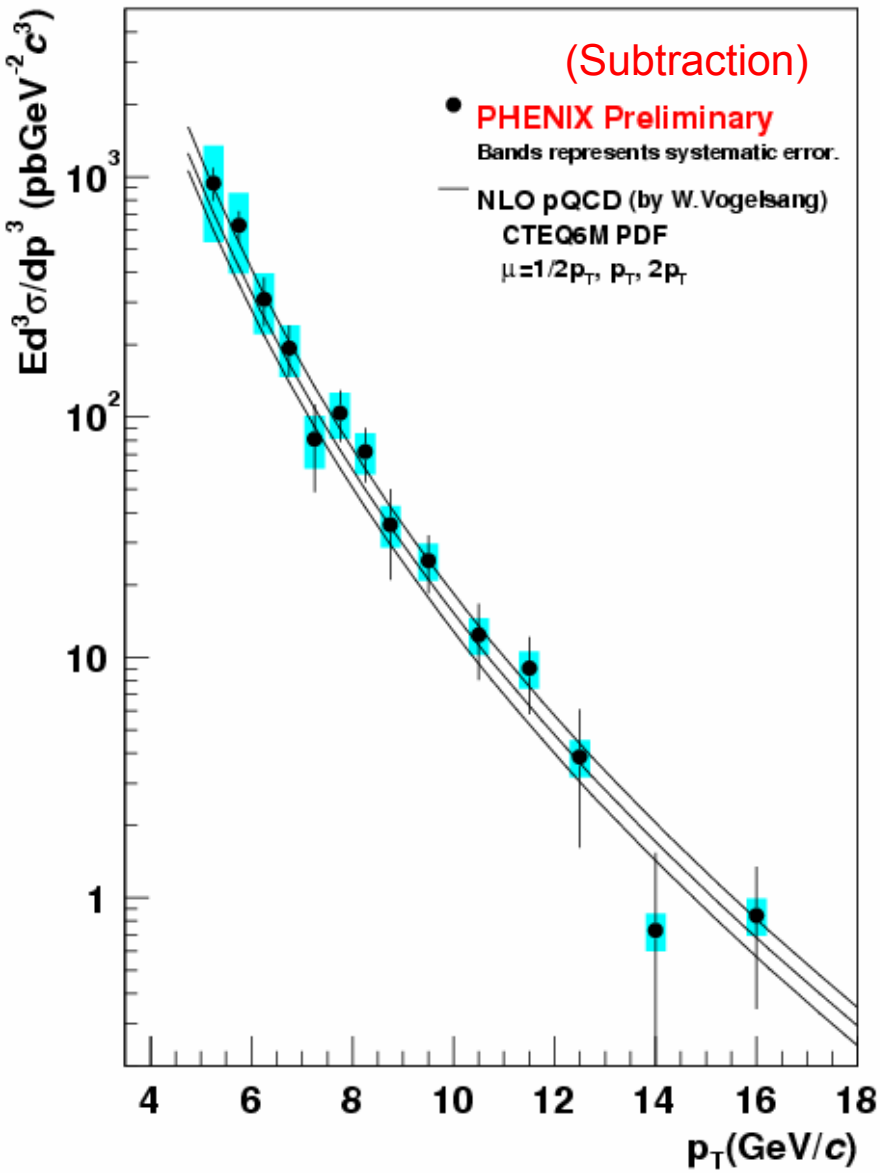
With the isolation cut,
The signal is enhanced.

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

Result with NLO pQCD calculation



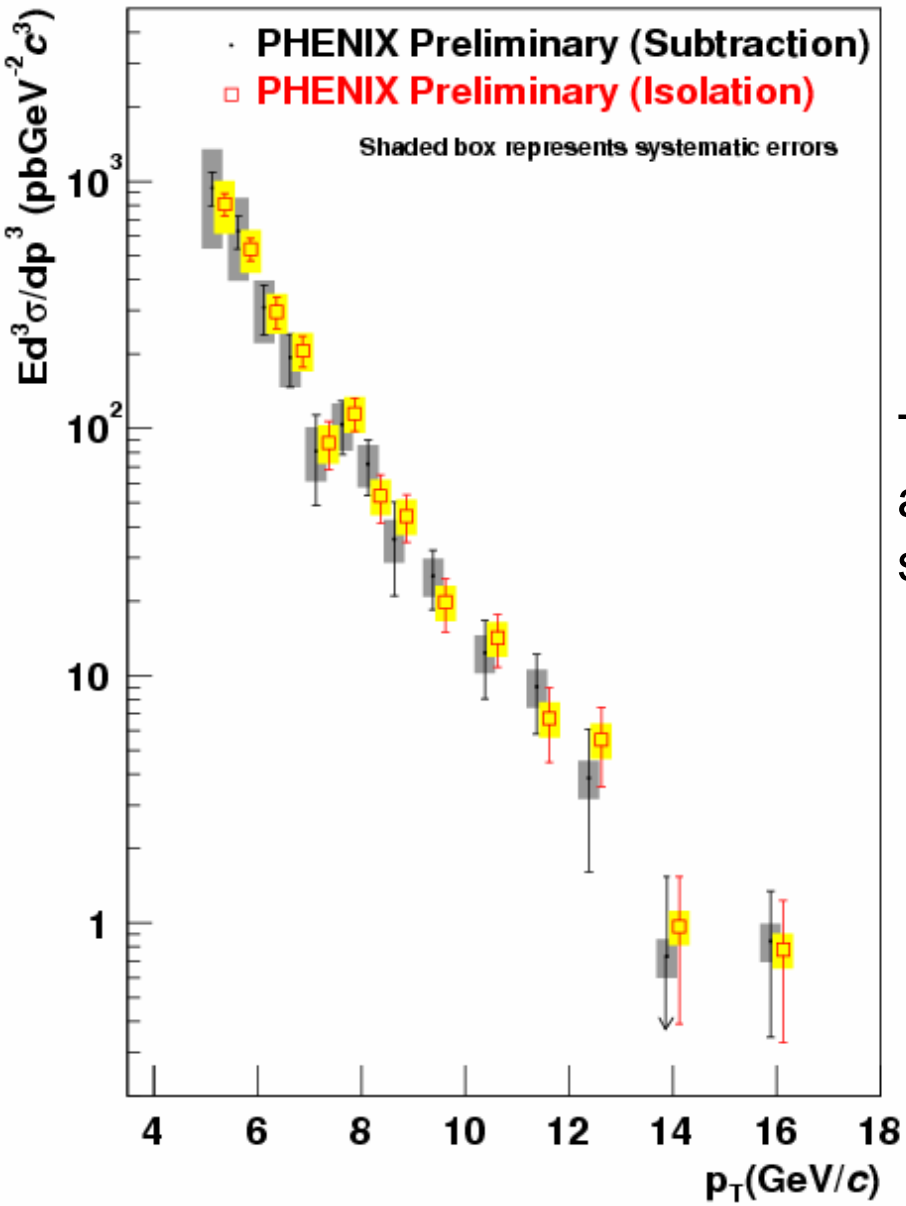
Bands represent systematic errors.

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.

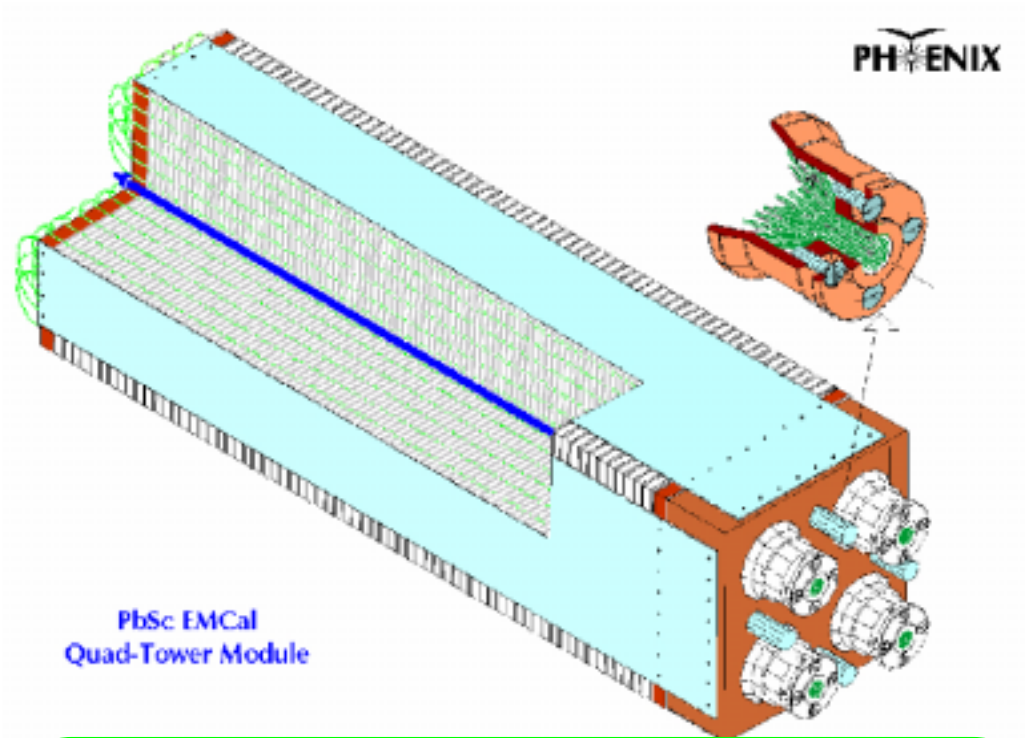
—NLO pQCD calculation agrees well with our measurement.

—The isolation cut improves the signal-to-noise ratio without significantly reducing the signal.

(It is important for future spin asymmetry measurement.)

Backup slides

EMCal (PbSc)



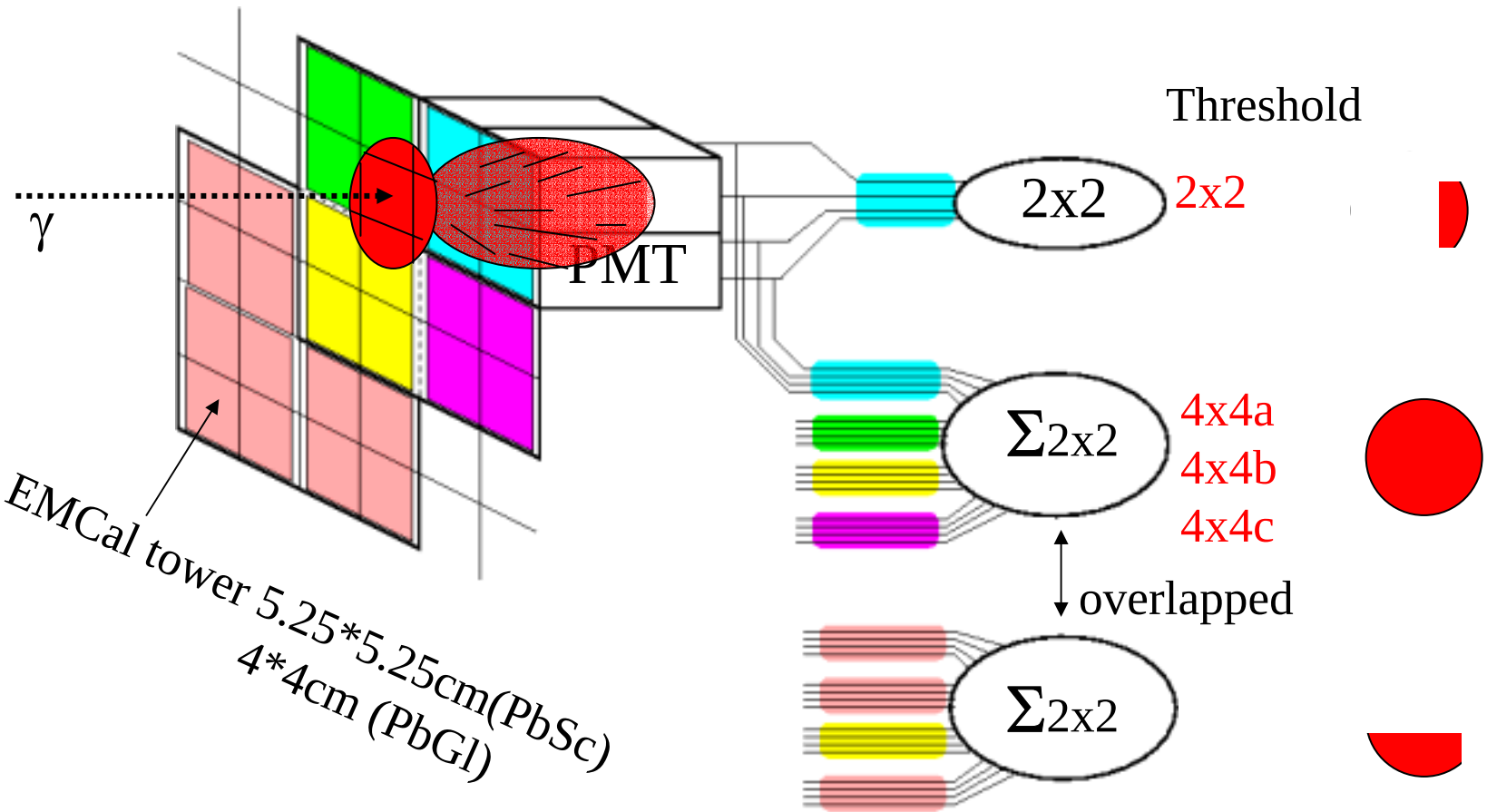
	PbSc
Size(cm x cm)	5.52 x 5.52
Depth(cm)	37.5
Number of towers	15552
Sampling fraction	~ 20%
η cov.	0.7
ϕ cov.	90+45deg
η/mod	0.011
ϕ/mod	0.011
X_0	18
Molière Radius	~ 3cm

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

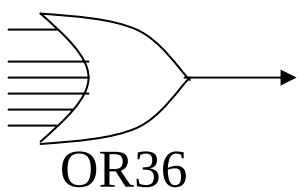
PbSc sector 2.0m x 4.0m

EMCal Trigger



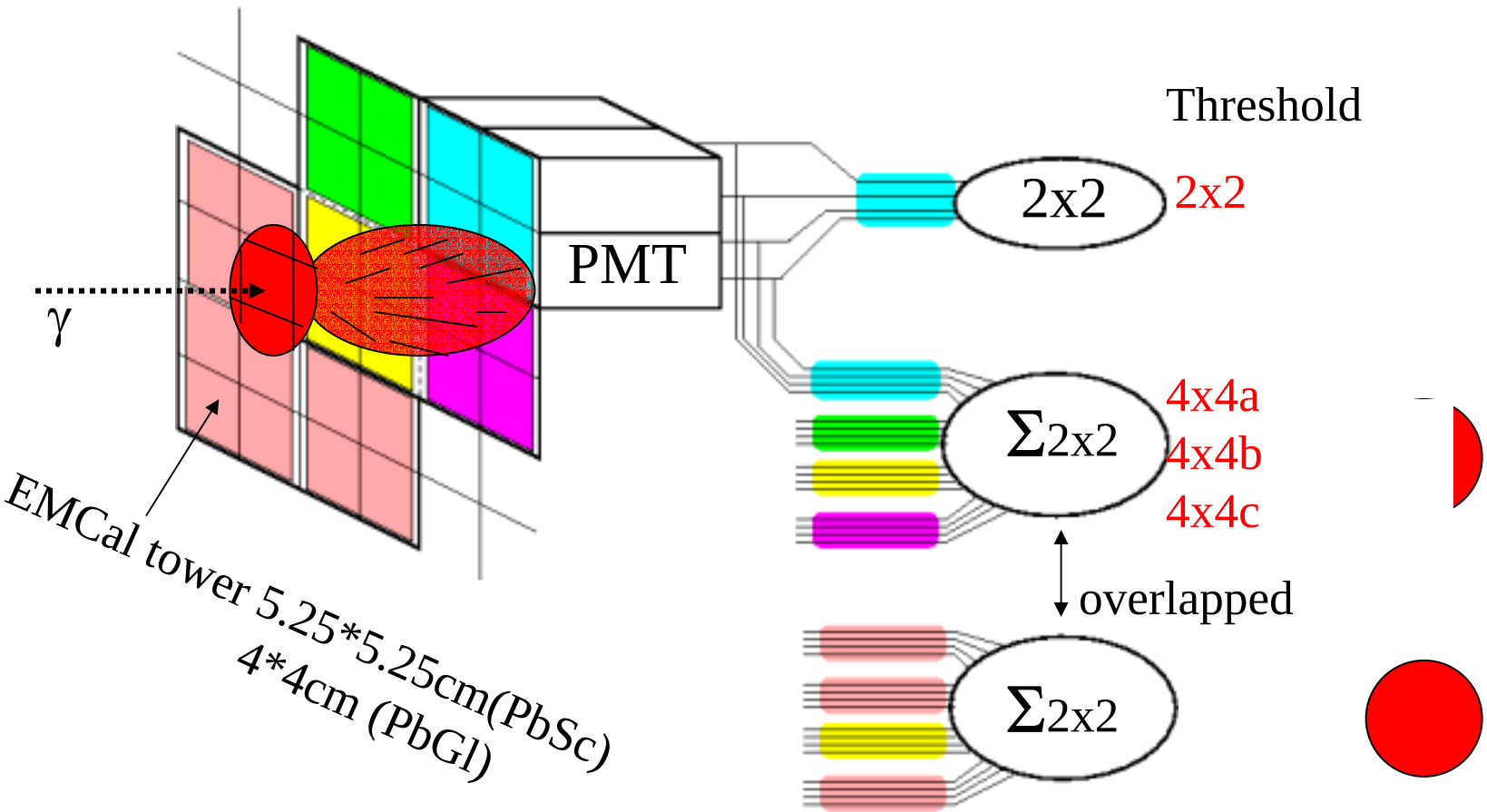
EMCal = 172 Super modules (SM)

36 tiles (~60*60cm)



1 trigger bit

EMCal Trigger



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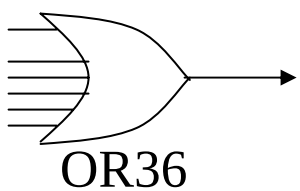
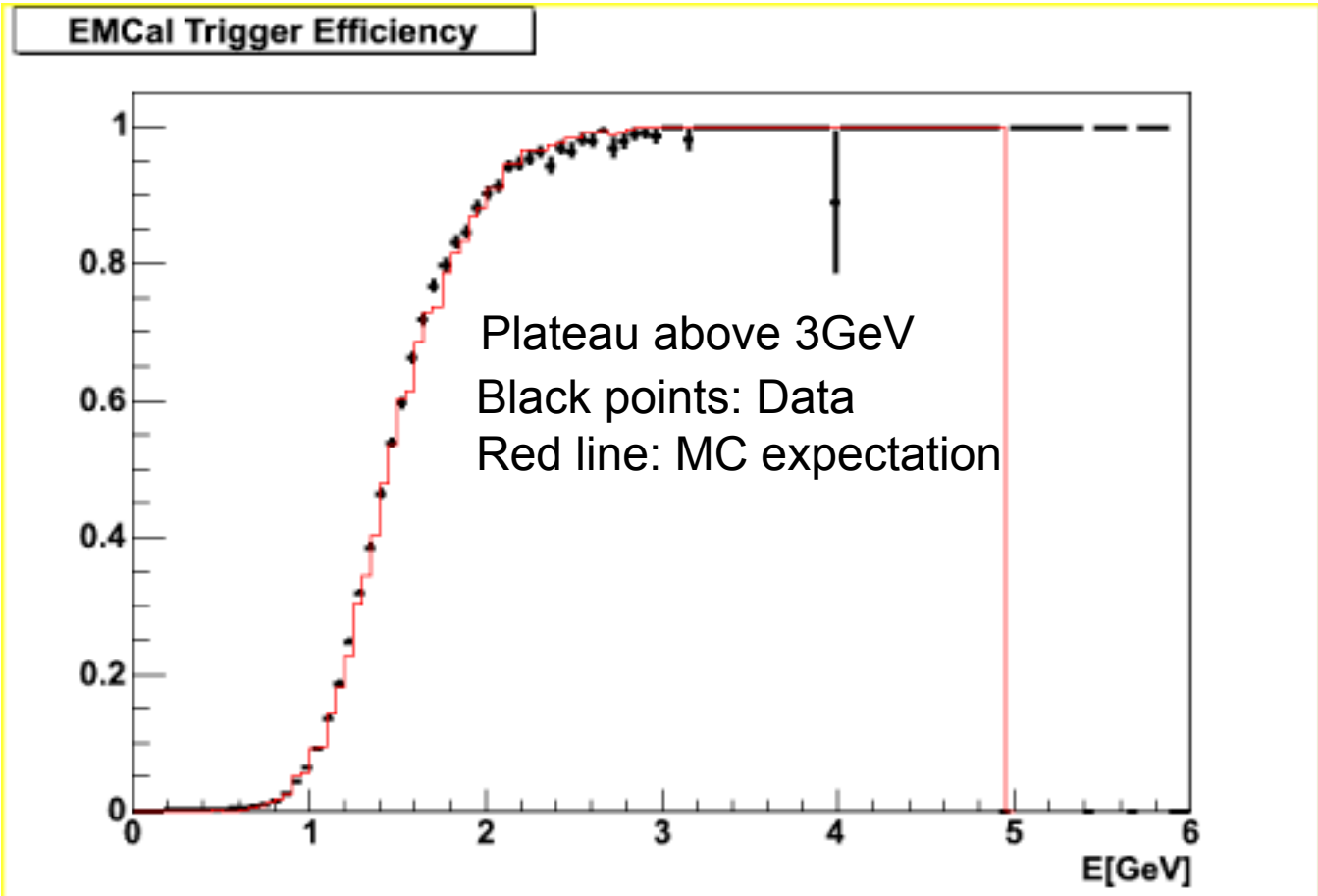


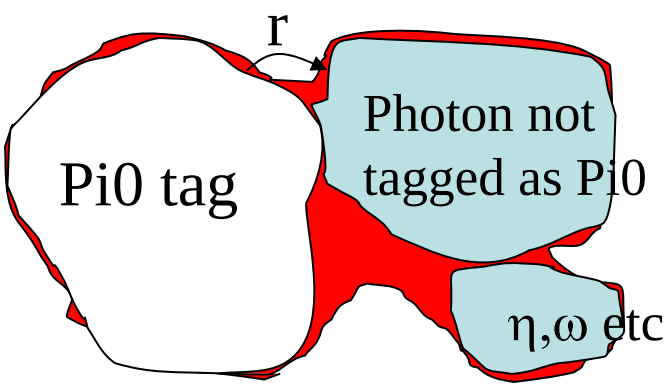
1 trigger bit

EMCal Trigger performance



Strategy 1

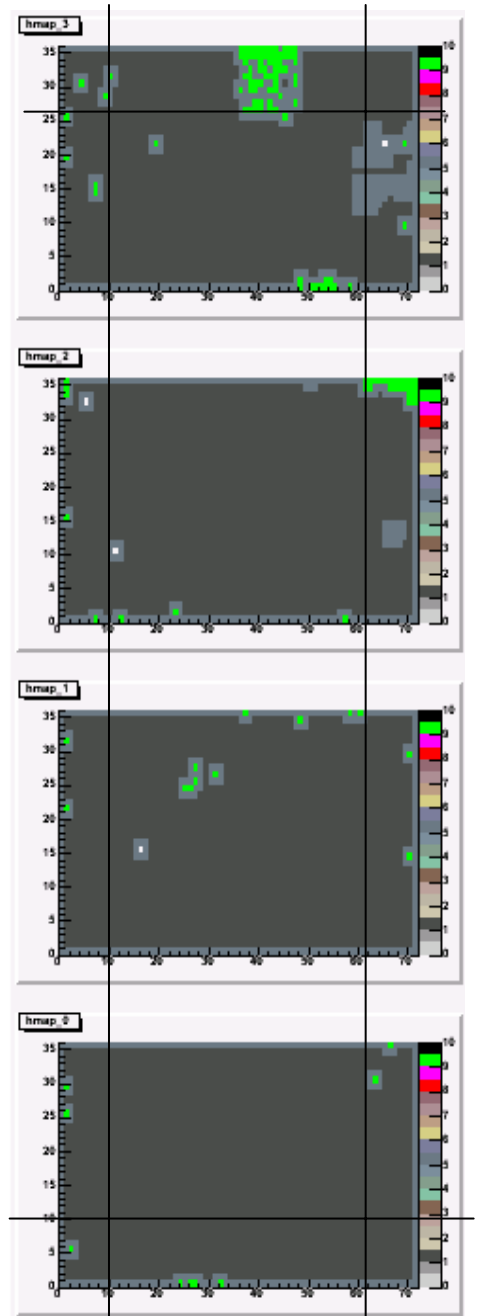
Pi0 tag and subtraction



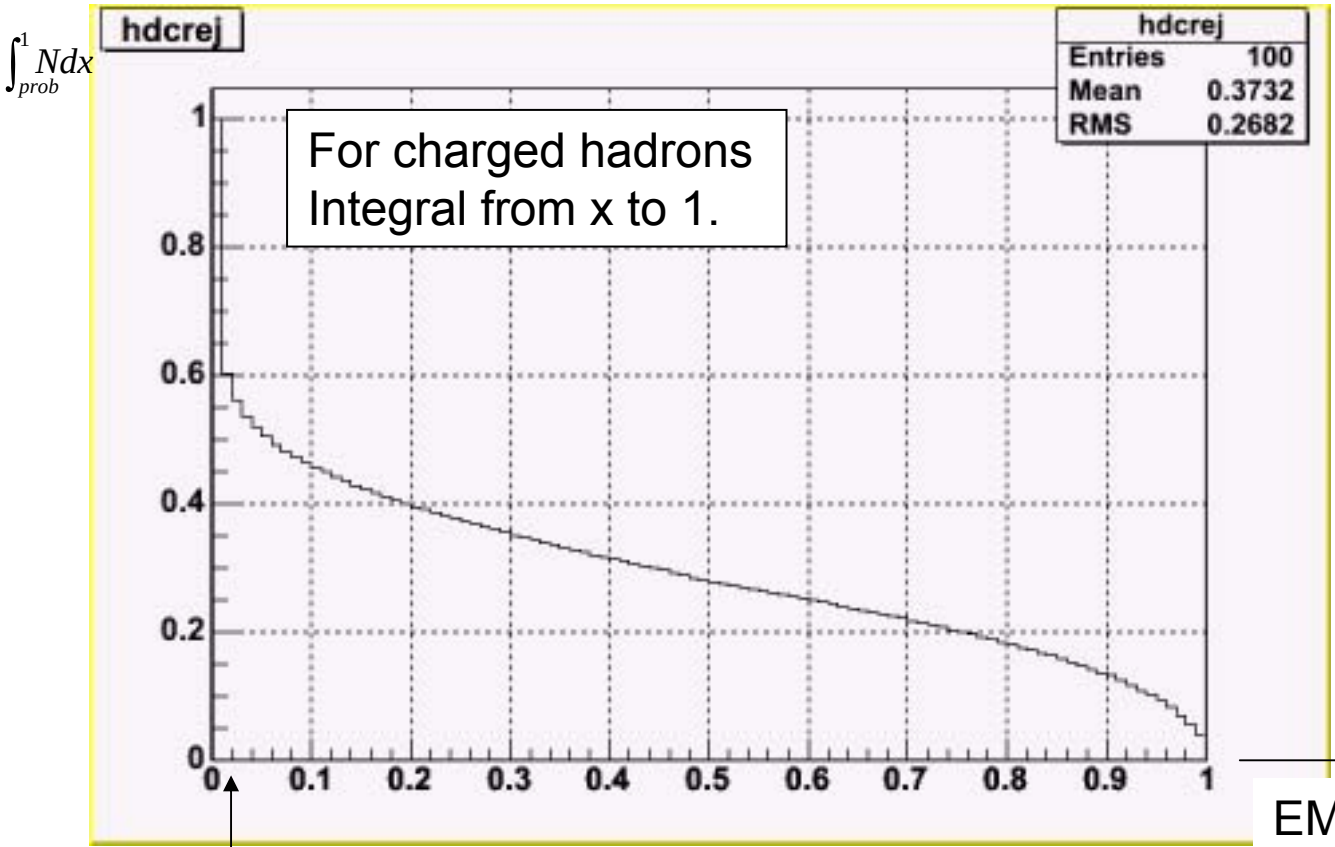
Prompt photon = all - (pi0 tag)/r *(1+non pi0)

Pi0 photons won't be tagged, since
partner's energy is below Emin
partner is in the warn map mask → MC

Guard veto (the acceptance is reduced to 67%) was applied.



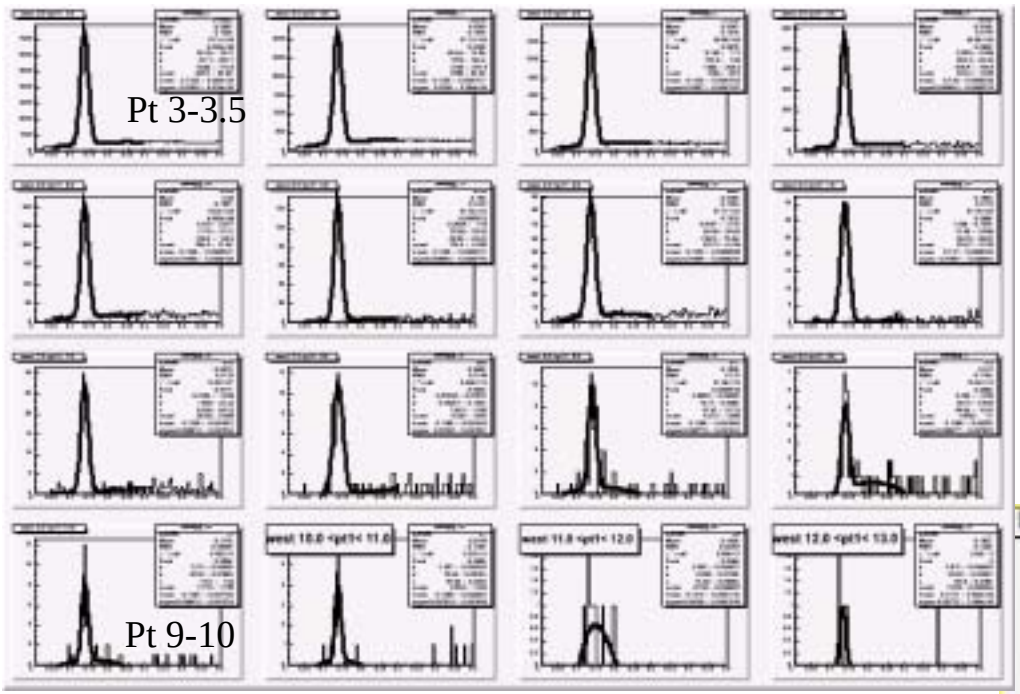
Electromagnetic shower shape cut

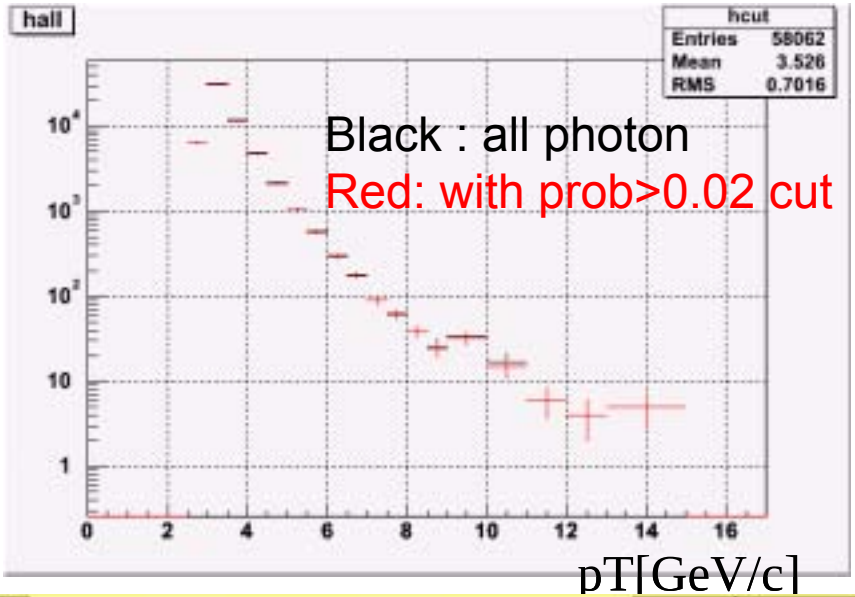


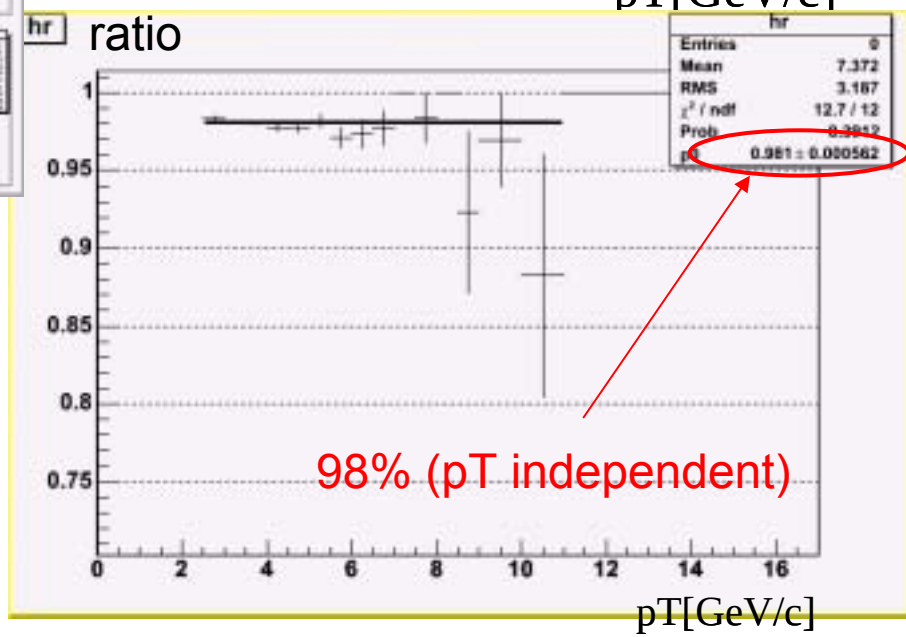
EM shower probability

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

Counts (PbSc west)

ecore>3GeV
PC3 dead area is masked off.

The difference of 3 converter runs is consistent to electron group's study.

no_cut tof prob			
all	1_1	1_2	1_3
pc3match	2_1	2_2	2_3
dcmatch	3_1	3_2	3_3
dcmatch(n0>0)	4_1	4_2	4_3
dcmatch(n0>1)	5_1	5_2	5_3

run87618-88006 40mil
#event 395M
14618 14493 13545 (92%) =1_3/1_1
2510 2491 1926 (77%) =2_3/2_1
1254 1244 770 (61%) =3_3/3_1
405 403 314 (78%) =4_3/4_1
362 361 296 (82%) =5_3/5_1

pc3match ratio : 14% =2_3/1_3
dcmatch ratio : 5.6% =3_3/1_3
electron ratio(n0>0) : 2.3% =4_3/1_3
electron ratio(n0>1) : 2.2% =5_3/1_3

electron/dcmatch(org) : 29% =5_1/3_1
electron/dcmatch : 38% =5_3/3_3
Electron/1M events : 0.75

run88825-89211 10mil
#event 841M
33879 33452 31270 (92%)
5542 5491 4238 (76%)
2630 2618 1533 (58%)
663 659 437 (66%)
565 562 403 (71%)

pc3match ratio : 14%
dcmatch ratio : 4.9%
electron ratio(n0>0) : 1.4%
electron ratio(n0>1) : 1.3%

electron/dcmatch(org) : 21%
electron/dcmatch : 26%
Electron/1M events : 0.48

Run88007-88824, 89212-92466
#event 4315M
170922 168940 157748 (92%)
26880 26666 20221 (75%)
12695 12632 7002 (55%)
2972 2960 1858 (62%)
2488 2477 1678 (67%)

pc3match ratio : 13%
dcmatch ratio : 4.4%
electron ratio(n0>0) : 1.2%
electron ratio(n0>1) : 1.1%

electron/dcmatch(org) : 20%
electron/dcmatch : 24%
Electron/1M events : 0.39

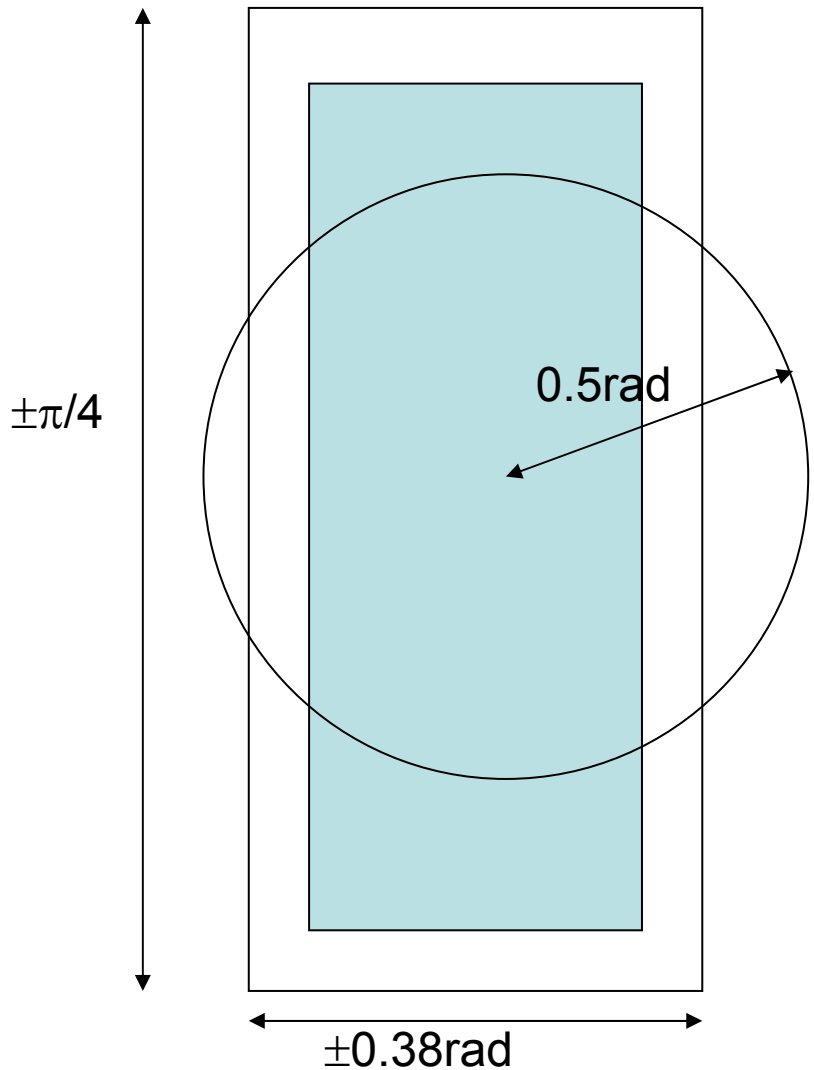
9% conversion

Counts (energy dependence)

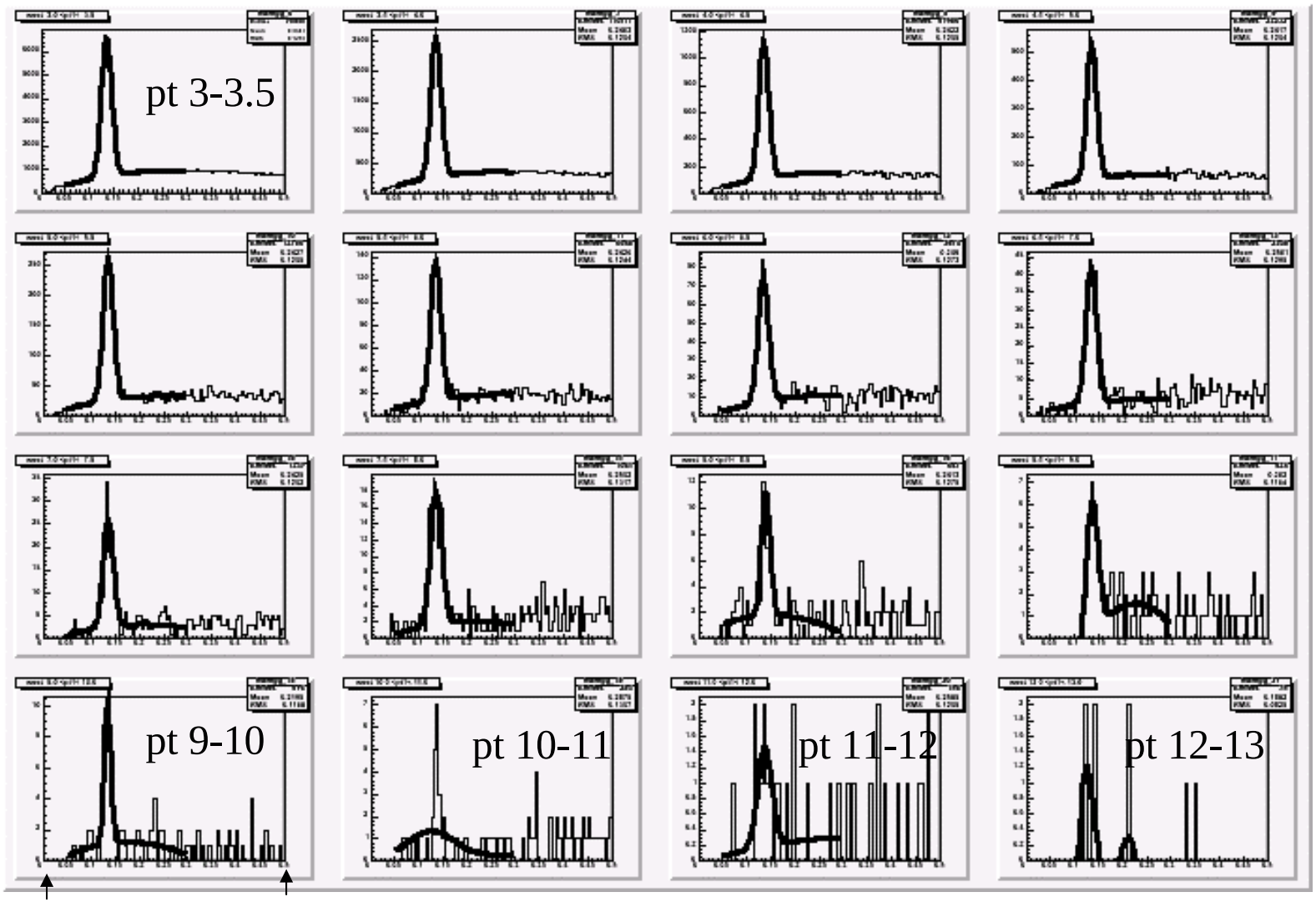
Ecore>3GeV	Ecore>5GeV	Ecore>7GeV
Run88007-88824, 89212-92466	Run88007-88824, 89212-92466	Run88007-88824, 89212-92466
#event 4315M	#event 4315M	#event 4315M
170922 168940 157748 (92%) photon 97%	8660 8372 7868 (91%) photon 97%	1279 1177 1080 (84%) photon 95%
26880 26666 20221 (75%)	1358 1330 1048 (77%)	188 181 141 (75%)
12695 12632 7002 (55%)	577 572 341 (59%)	81 79 45 (56%)
2972 2960 1858 (62%)		
2488 2477 1678 (67%)	267 265 153 (57%)	54 53 34 (63%)
pc3match ratio : 13%	pc3match ratio : 13%	pc3match ratio : 13%
dcmatch ratio : 4.4%	dcmatch ratio : 4.3%	dcmatch ratio : 4.2%
electron ratio(n0>0) : 1.2%	electron ratio(n0>0) :	electron ratio(n0>0) :
electron ratio(n0>1) : 1.1%	electron ratio(n0>1) : 1.9%	electron ratio(n0>1) : 3.1%
electron/dcmatch(org) : 20%	electron/dcmatch(org) : 46%	electron/dcmatch(org) : 67%
electron/dcmatch : 24%	electron/dcmatch : 45%	electron/dcmatch : 76%
Electron/1M events : 0.39	Electron/1M events : 0.035	Electron/1M events : 0.0079

High pT charged pion contamination can be seen in electron/dcmatch ratio.
Matching behavior looks the same.

Isolation cut cone size

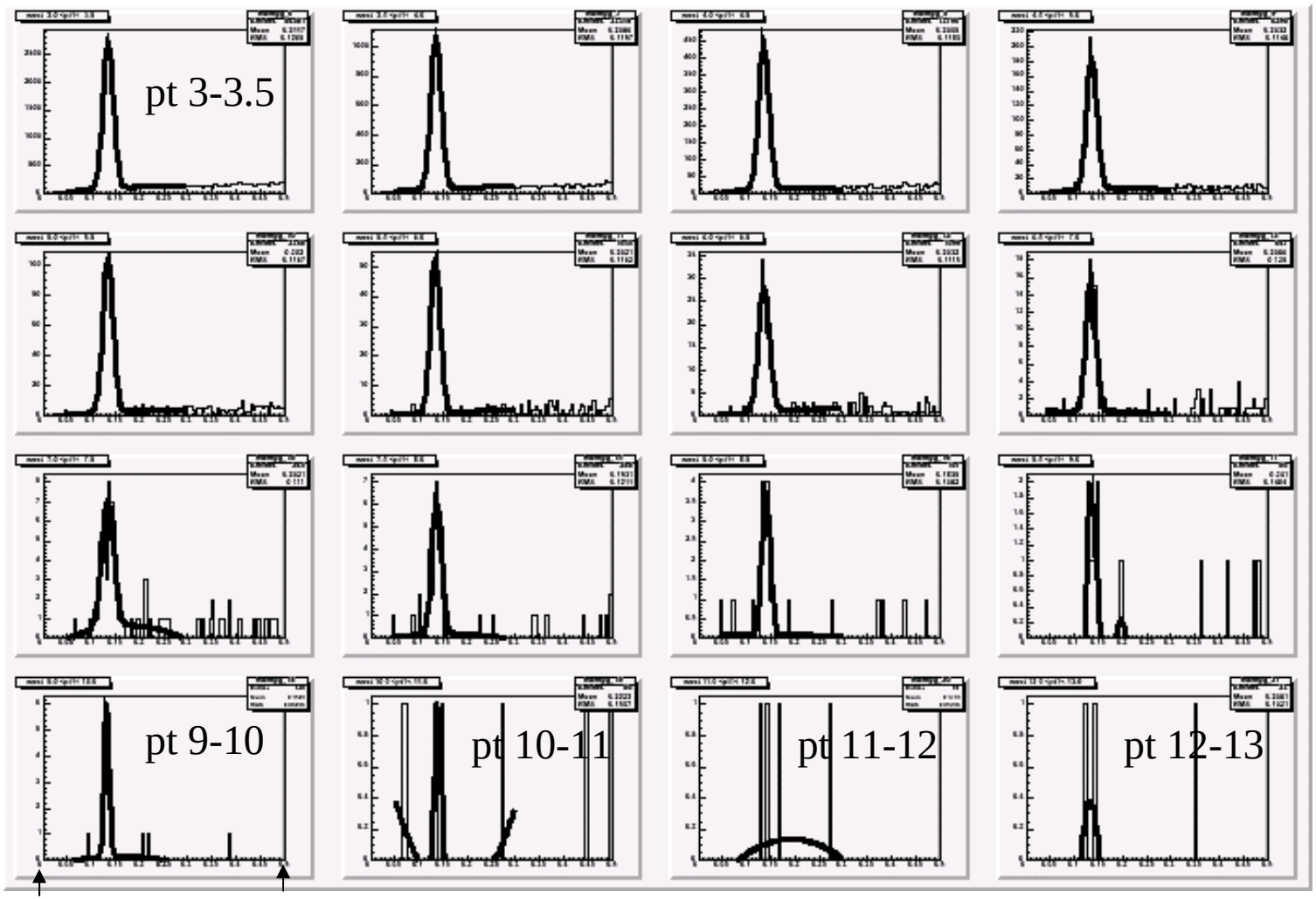


Invariant mass of two photons



Invariant mass of two photons

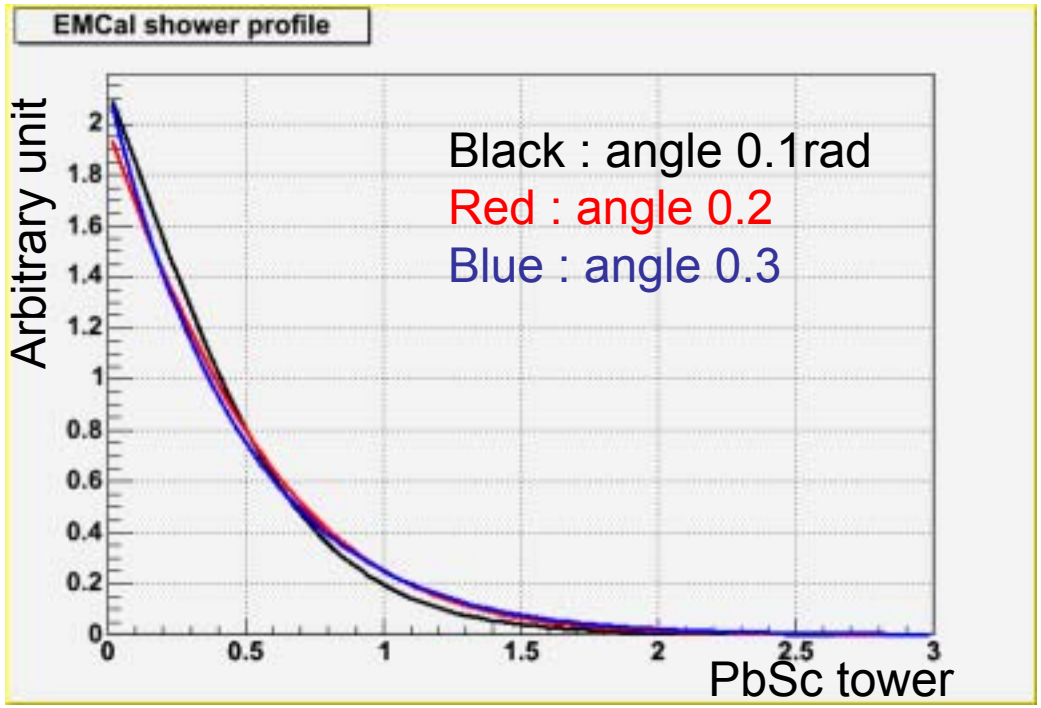
With the isolation cut



0 0.5GeV

pi0 photon merging

MC tuned with the test beam result



(second tower) / (first tower)

0.2/2 = 10% (tower center)

0.5/1.25=40% (center + 0.3unit)

Pi0 photon merging

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 is 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)

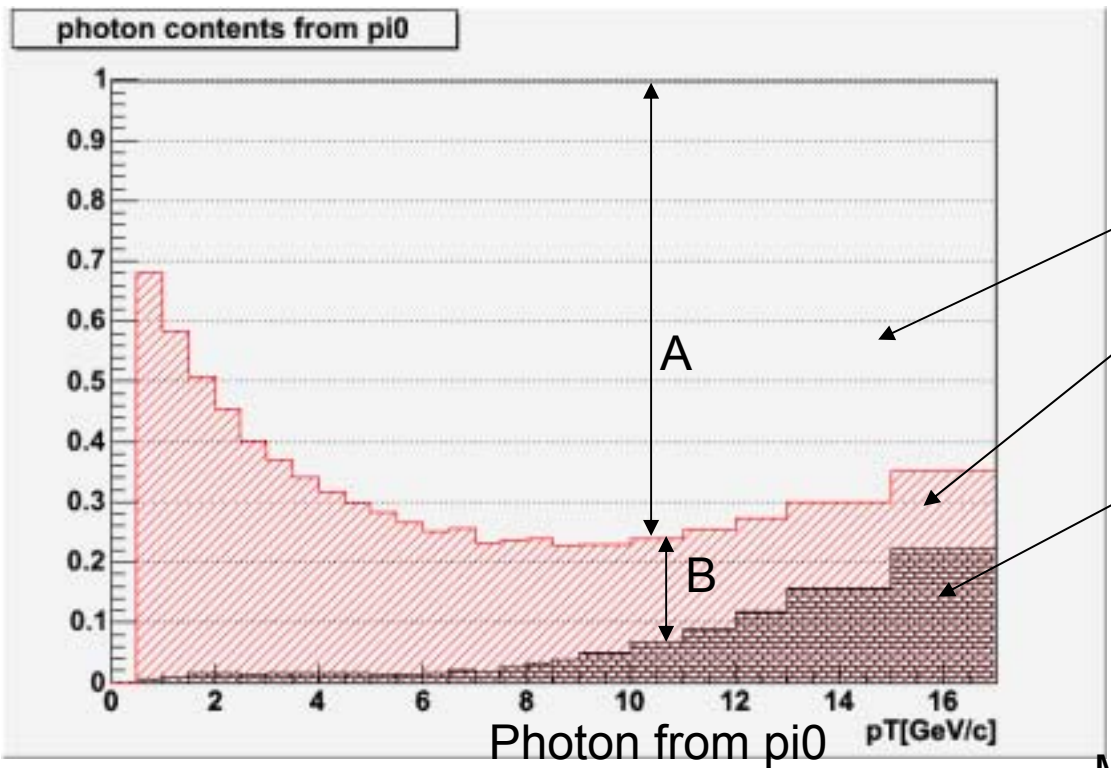
0.3	1.4	1.4	0.3	0.0
1.4	**21.7**	**21.7**	1.4	0.1
1.4	**21.7**	**21.7**	1.4	0.1
0.3	1.4	1.4	0.3	0.0
0.0	0.1	0.1	0.0	0.0

---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.



This figure shows components of photon from pi0.

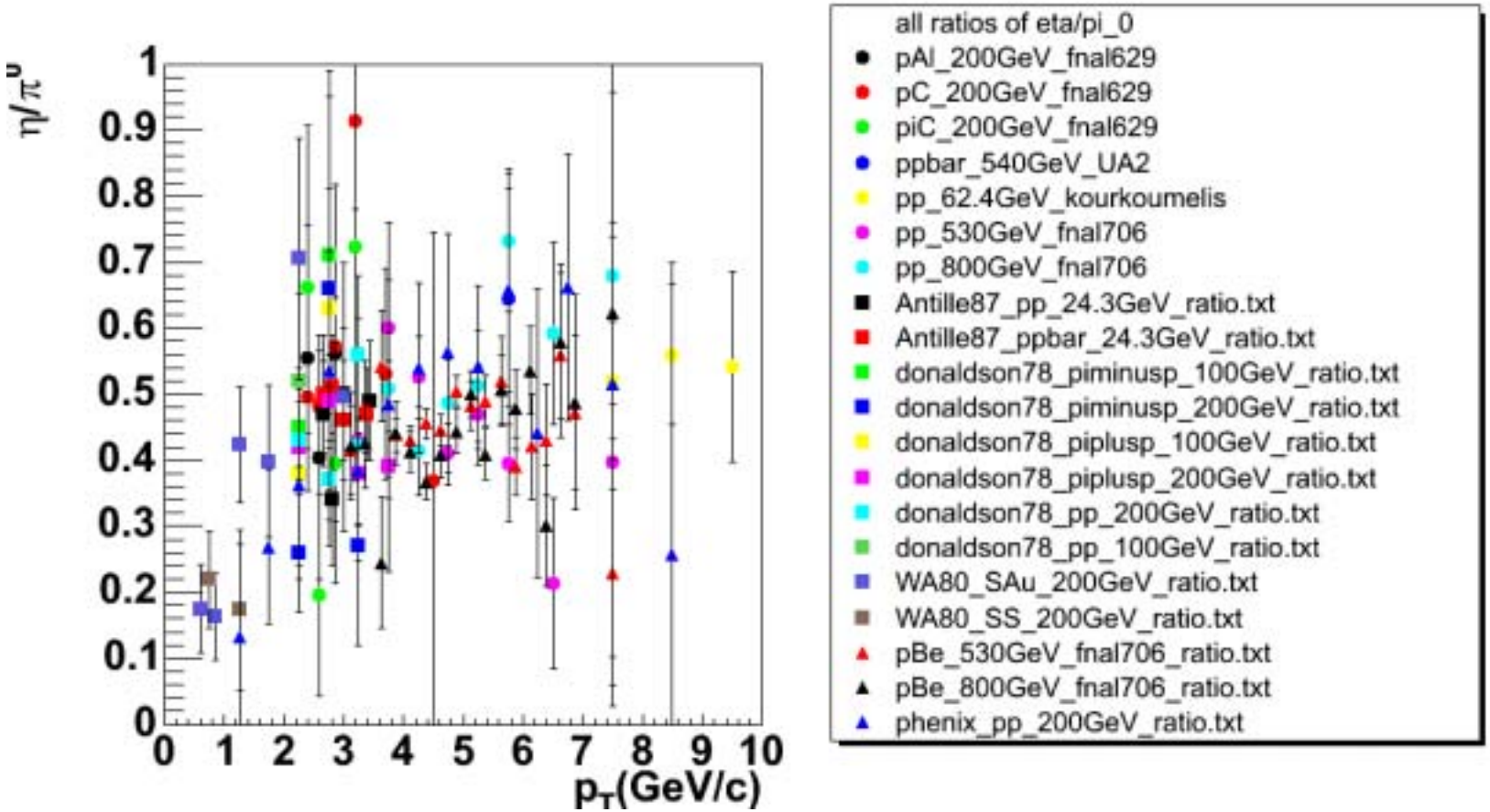
(A) 2 photons tagged as pi0

(B) 1photon (the partner missing)

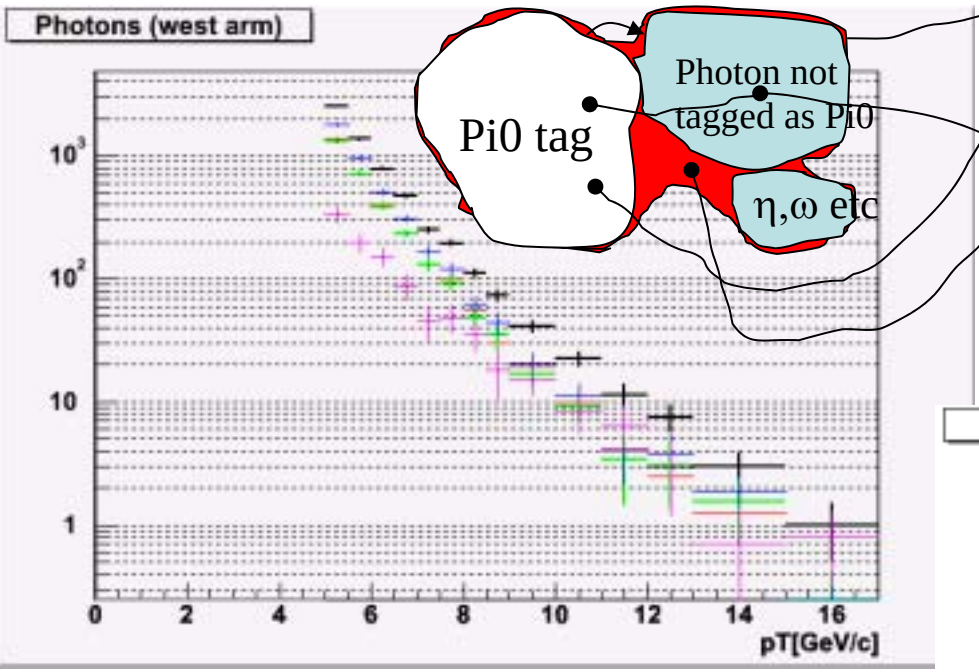
Merged photons
(to be discarded by the shower shape cut
And those have almost double energy)

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

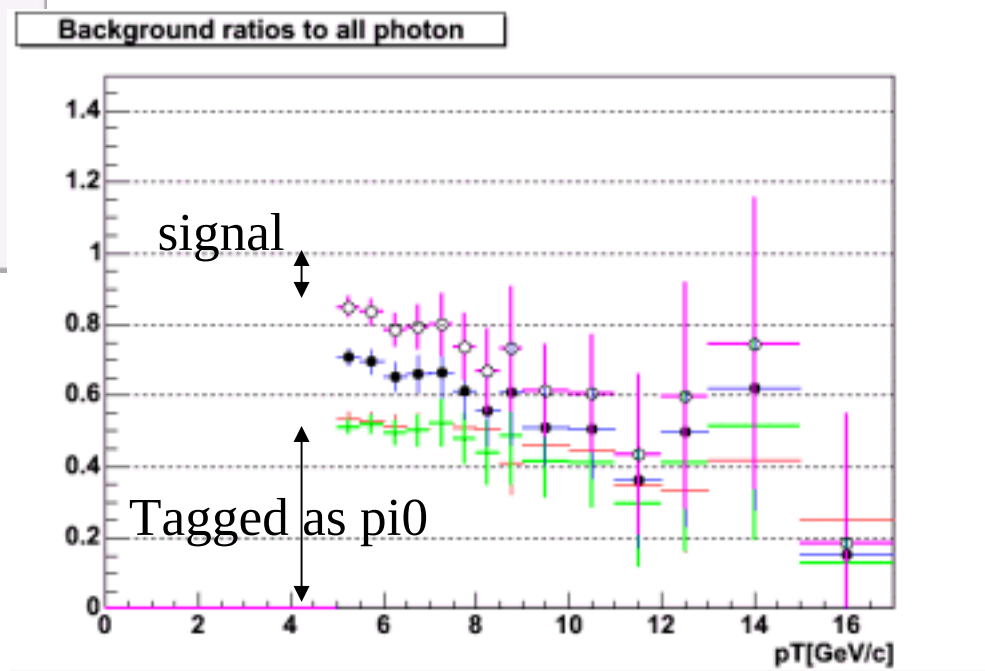
Eta/pi0 ratio



Yields (West arm)

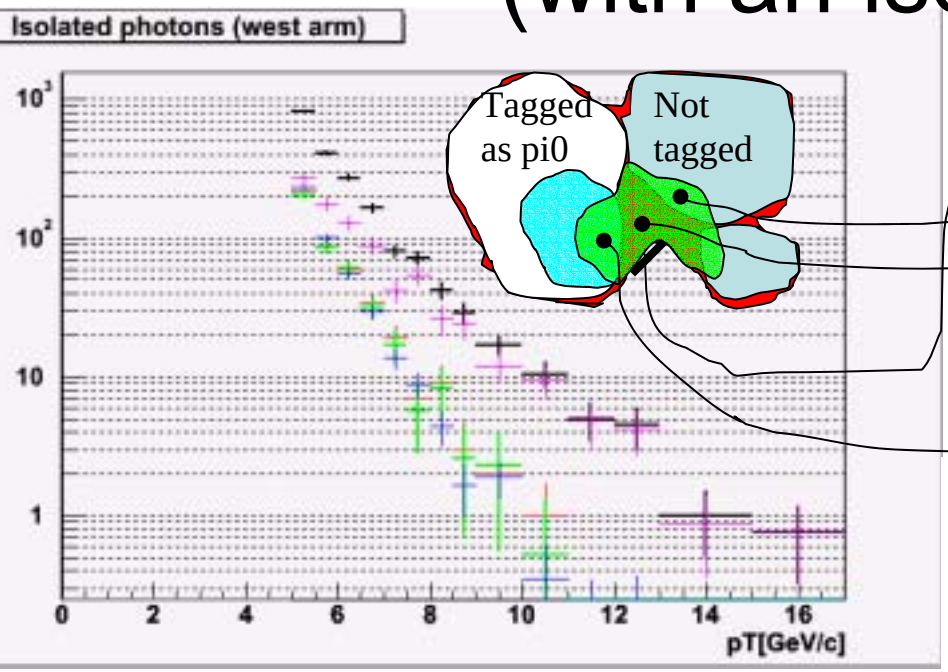


black : all photons
red : photons tagged as pi0
green : applied a combinatorial bg correction to (red)
blue : all pi0 contributions (green *(1+missing ratio))
magenta : (black)-(blue)*1.23



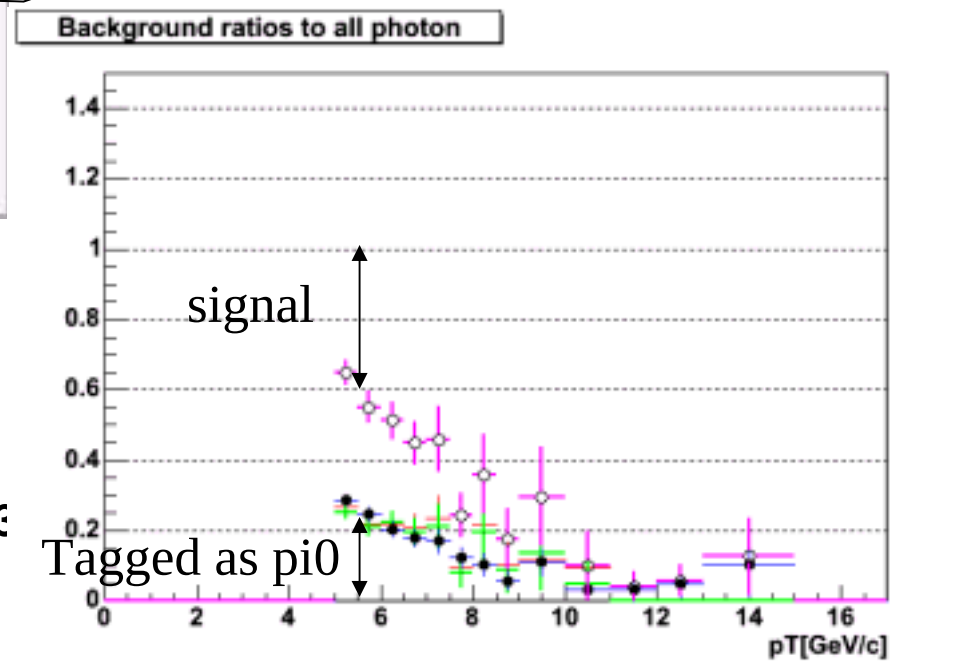
bg ratios to the total
red :
green :
blue :
magenta : all hadron contributions (blue)*1.23

Yields (west arm)
(with an isolation cut)



black : all isolated photons
red : isolated photon tagged as pi0
green : applied a combinatorial bg correction to (red)
blue : isolated photon estimated from isolated pi0s
magenta : (black)-(green+blue)*1.23

bg ratios to the total
red:
green:
blue:
magenta: all hadron contribution (green+blue)*1.23



Systematic error sources

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.

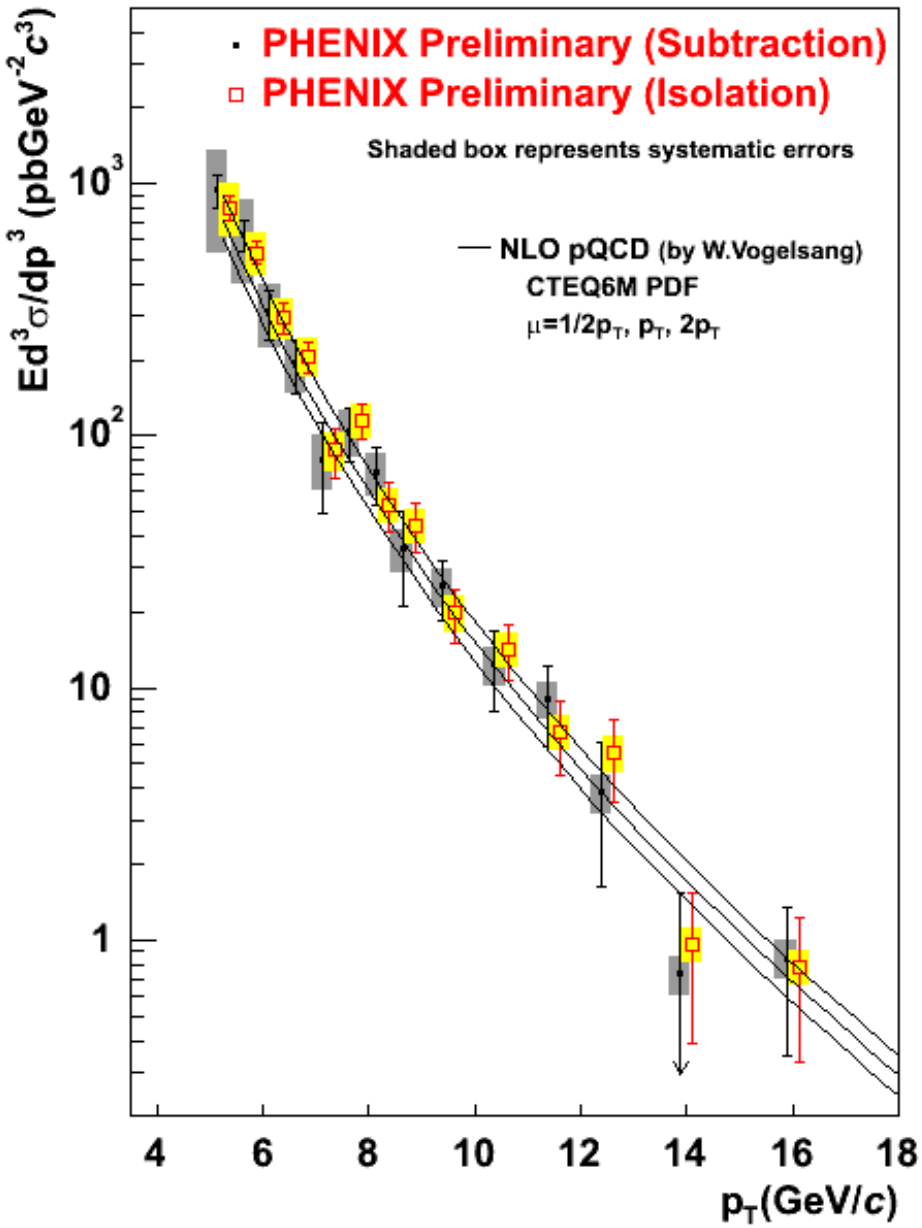
∗ With the isolation cut, those are less thanks to high S/N ratio.

Systematic error sources

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	

Comparison to NLO pQCD calculation

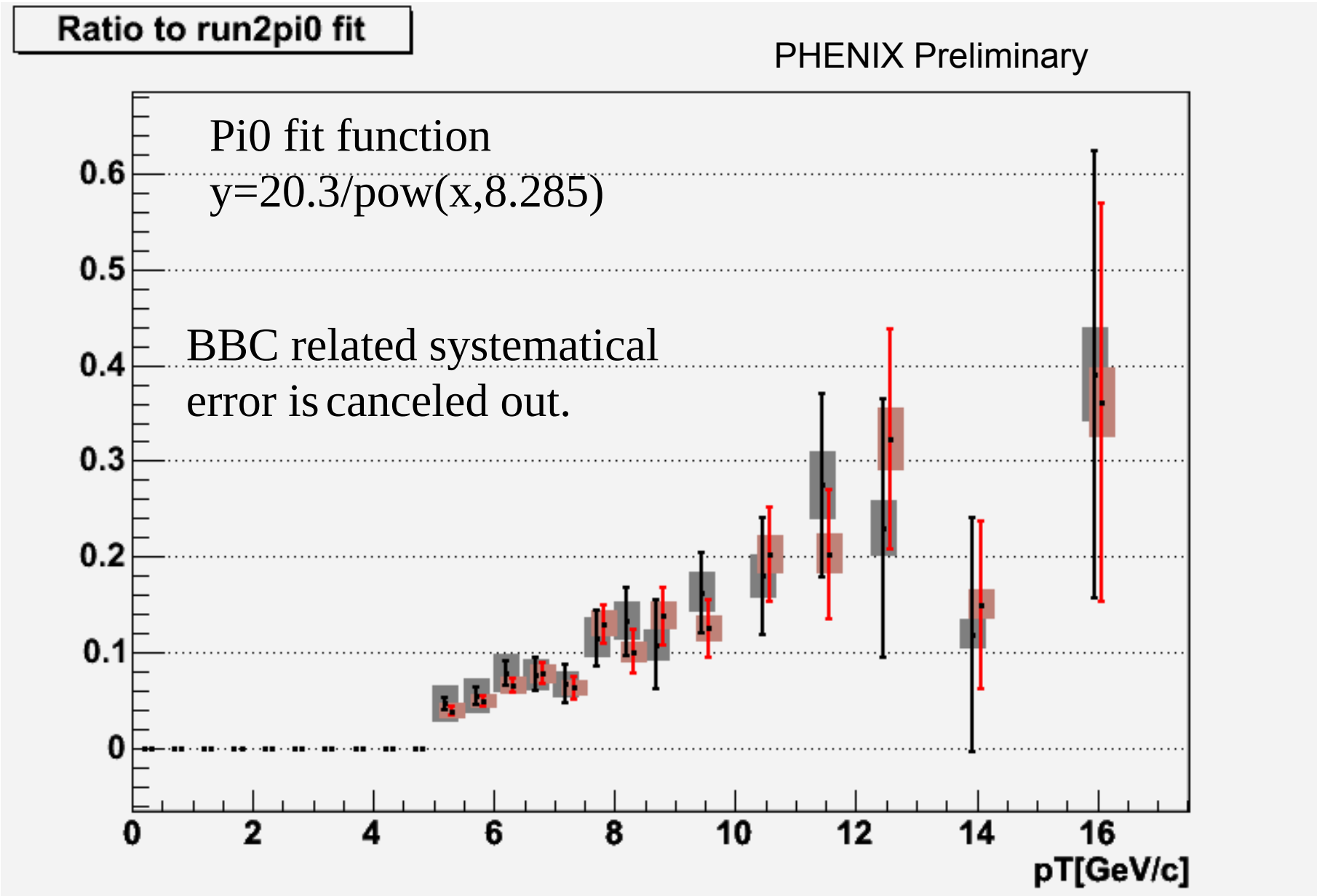


- NLO-pQCD calculation
  - Private communication with W.Vogelsang
  - CTEQ6M PDF.
  - direct photon + fragmentation photon
  - Set Renormalization scale and factorization scale pT/2,pT,2pT

The theory calculation shows a good agreement with our result.

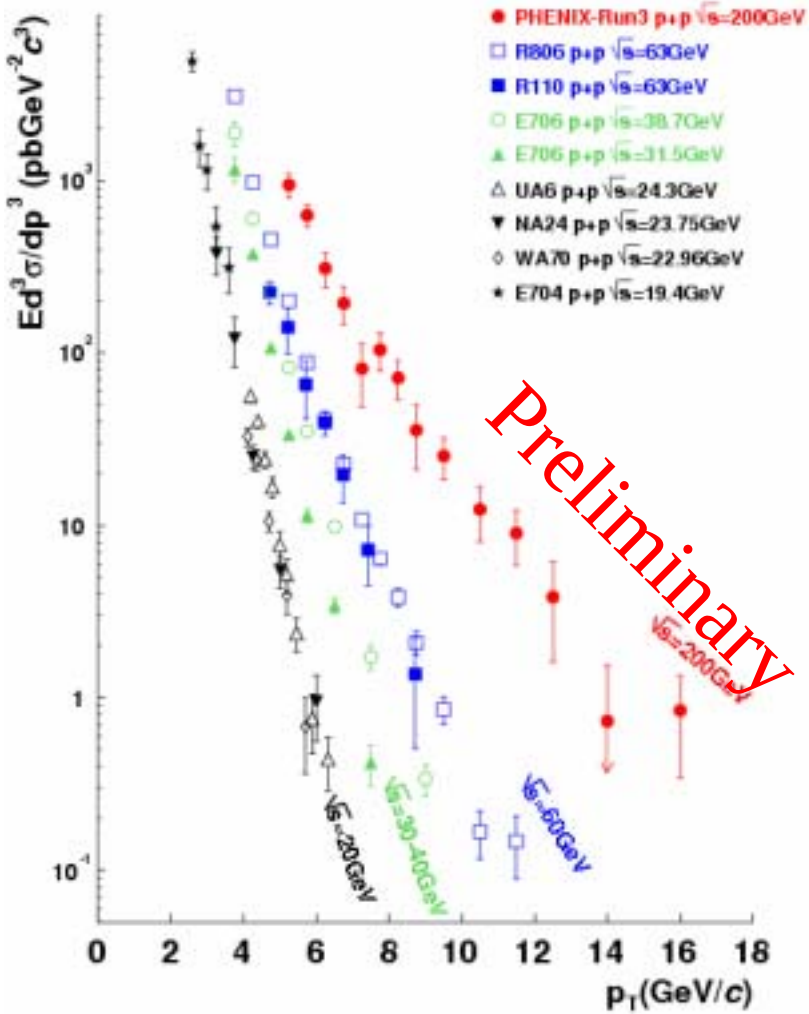
(RBRC)

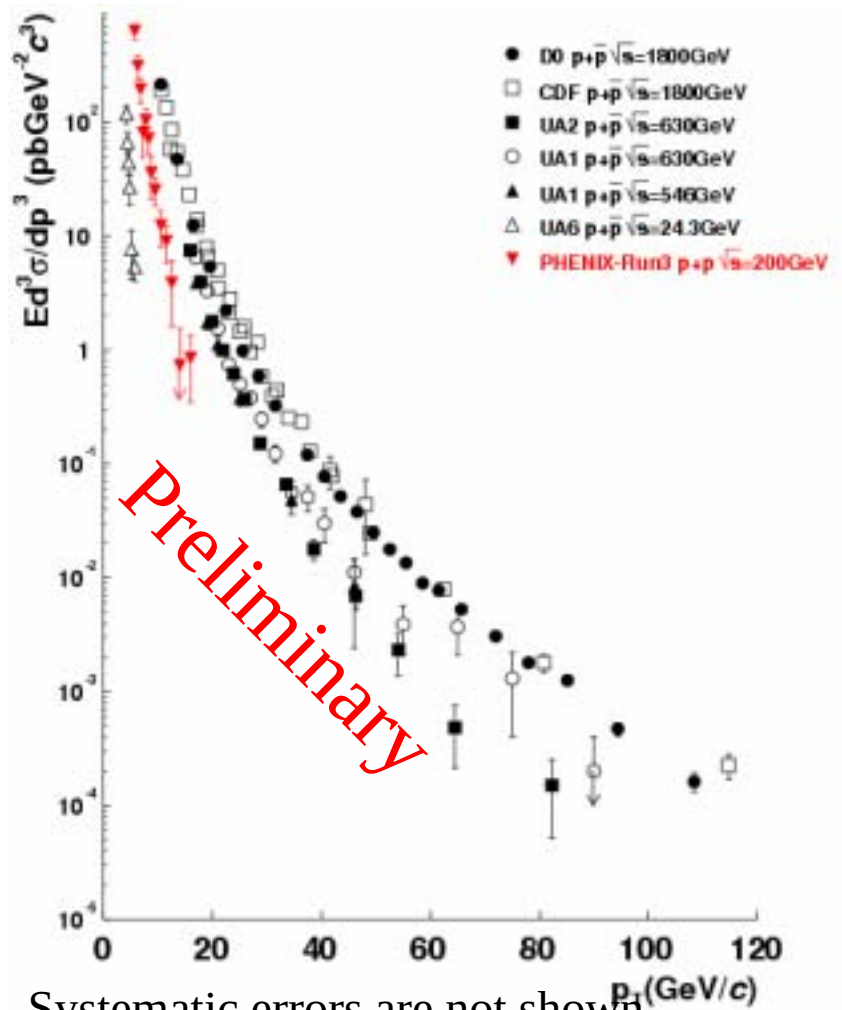
Results (gamma/pi0 ratio)



Comparison

- Comparison with existing data from p+p and p+pbar collisions
  - The cross section increases systematically as the energy increases.





Systematic errors are not shown

x_T scaling

- QCD理論によると、以下の仮定
  - PDFとFFのQ²スケーリング
  - Coupling constant(α_s)がQ²に非依存。

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

n=定数。$x_T=2p_T/\sqrt{s}$

  - 相互作用項と構造を表す項に分離

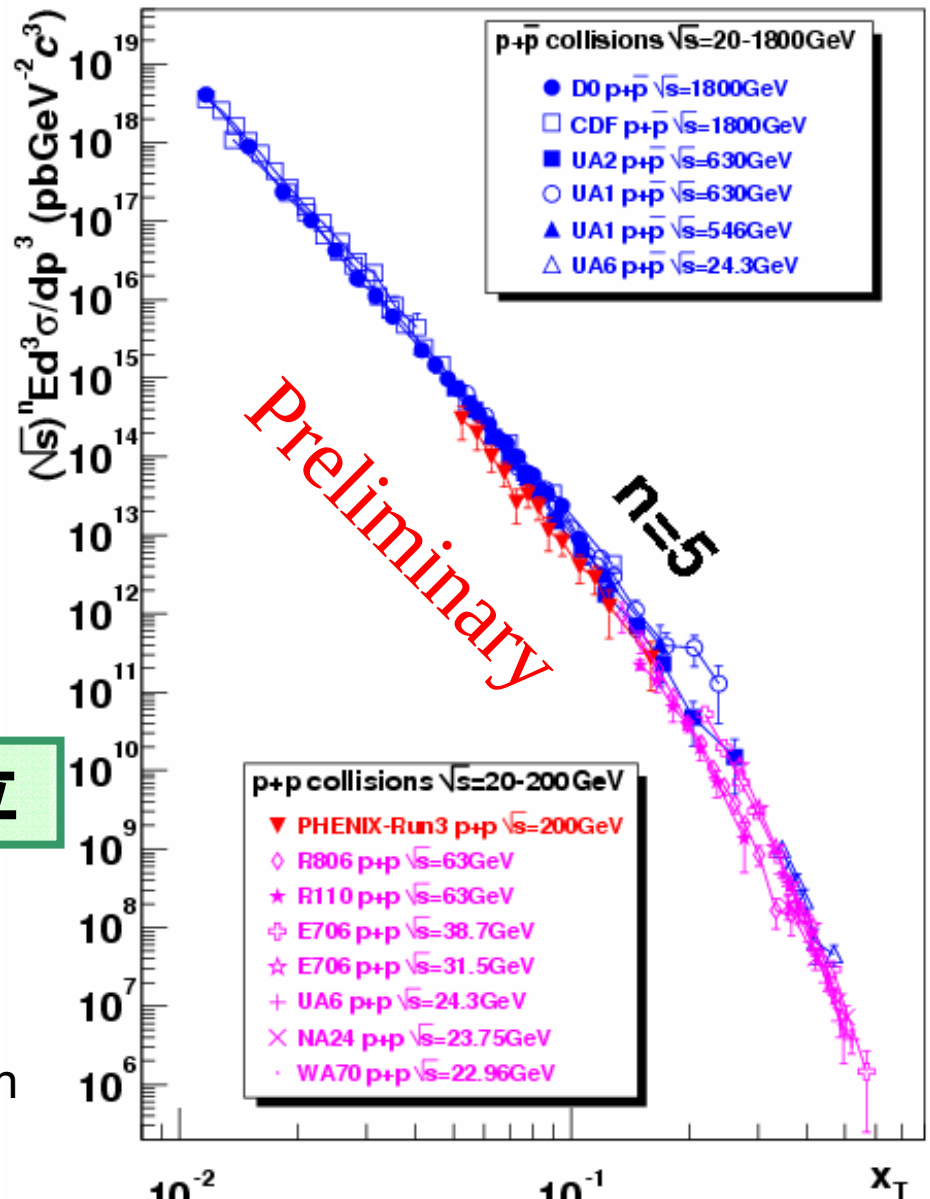
➔x_Tスケーリング

  - 定数nに対する予想
    - Leading order n=4
    - Next-to-leading order: n=4+α

x_Tスケーリング則n=5付近で成立

今回得られたデータを過去のデータ($\sqrt{s}$>20GeV)と比較して、x_Tスケーリング則がn=5付近で成り立つ

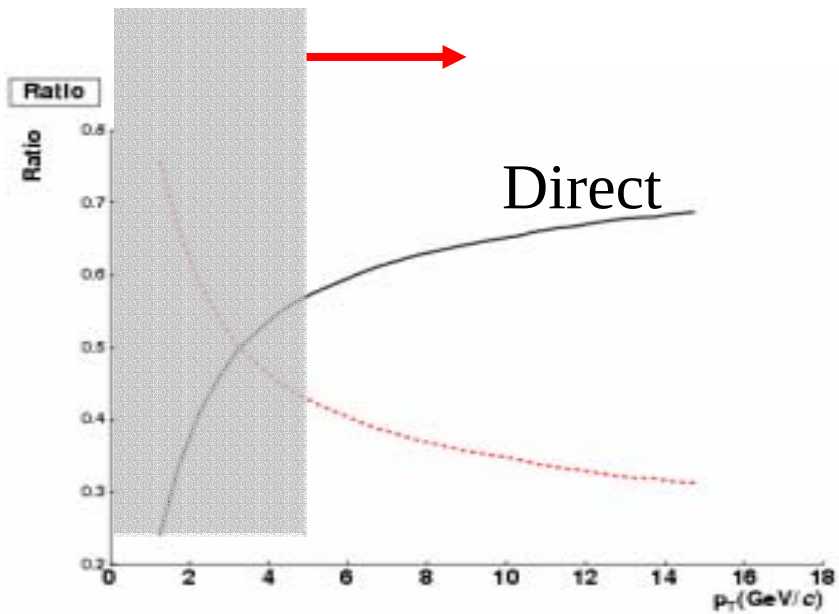
X-T scaling shows a point like interaction of the measurement.



Bias on Physics Process

- Two processes
  - Direct
  - Fragmentation

- Direct photon measurement at pT>5GeV/c is dominated by direct process.
  - The difference between two methods is small.



Private communication with W.Vogelsang

Fragmentation