

Full-Simulation Calorimeter Study For Energy Flow Jet reconstruction

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**In the future linear collider experiments,
many physics processes have multi jets in the final states
→ Good Jet reconstruction is essential**

Jet Reconstruction ... Energy Flow method

**We use Tracker for charged particles
Calorimeters neutral particles**

For example, in $e^+e^- \rightarrow tt$ (6jets,4jets) events,

Charged particles carry ~60% of event energy → Tracker

Photons	20%	EM Cal
Neutral hadrons	10%	HAD Cal
Neutrino	10%	cannot detect

$(E_{\text{CM}} = 500\text{GeV}, \text{Generator level})$

At first, γ reconstruction in EM CAL is important!!

In this talk, I'll report

1. Clustering algorithm
 2. GISMO vs GEANT4
 3. Photon reconstruction study
-

In this study, we use $e^+e^- \rightarrow tt$ (6jets, 4 jets) events

Generated by Pandora-Pythia

$E_{\text{CM}} = 500$ GeV, Include ISR, Beamstrahlung, Parton showering

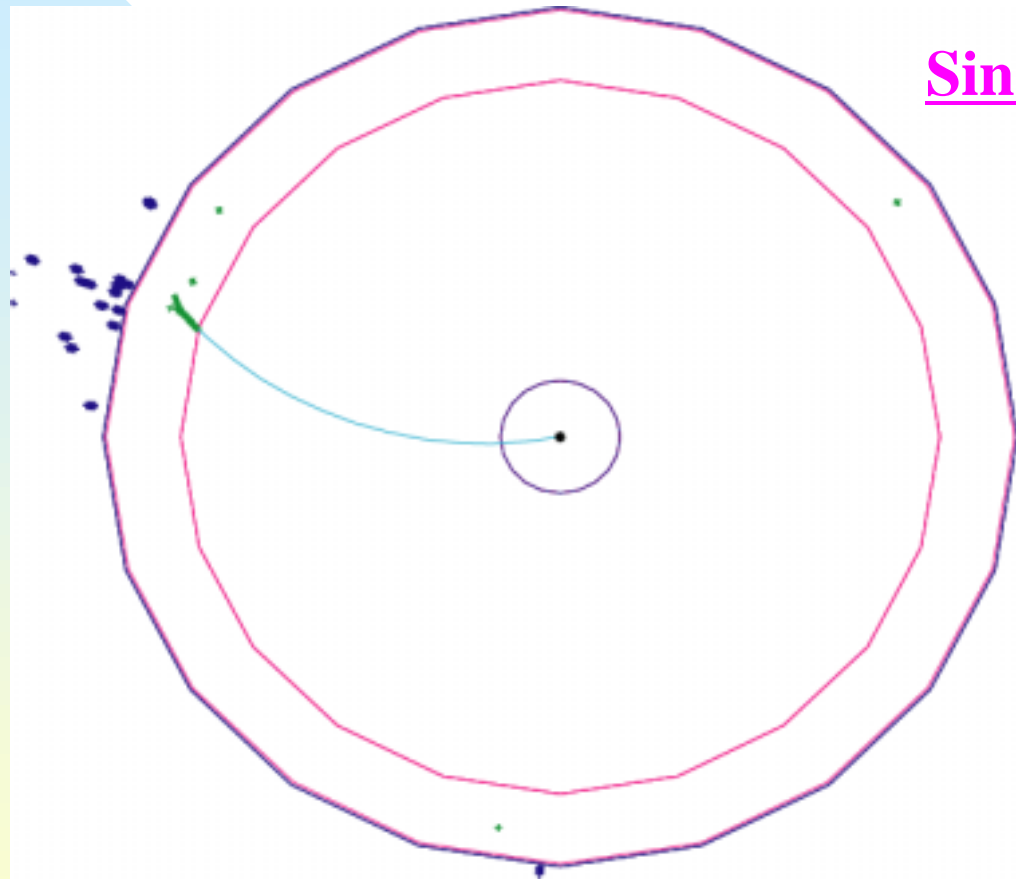
Through Full detector simulation (GISMO & GEANT4)

Assuming SDMar01 detector parameter:

W-Si EM cal	granularity	3.7 mrad (5mm segmentation)
	# layers	30 layer
	inner radius	127 cm
	B	= 5.0 Tesla

1) Clustering algorithm

So far we used **cheater algorithm** to form clusters
→ gather all CalHits associated to the same particle



Single particle generation (π)

- EMCalHit
- HADCalHit

Even there are scattering particles

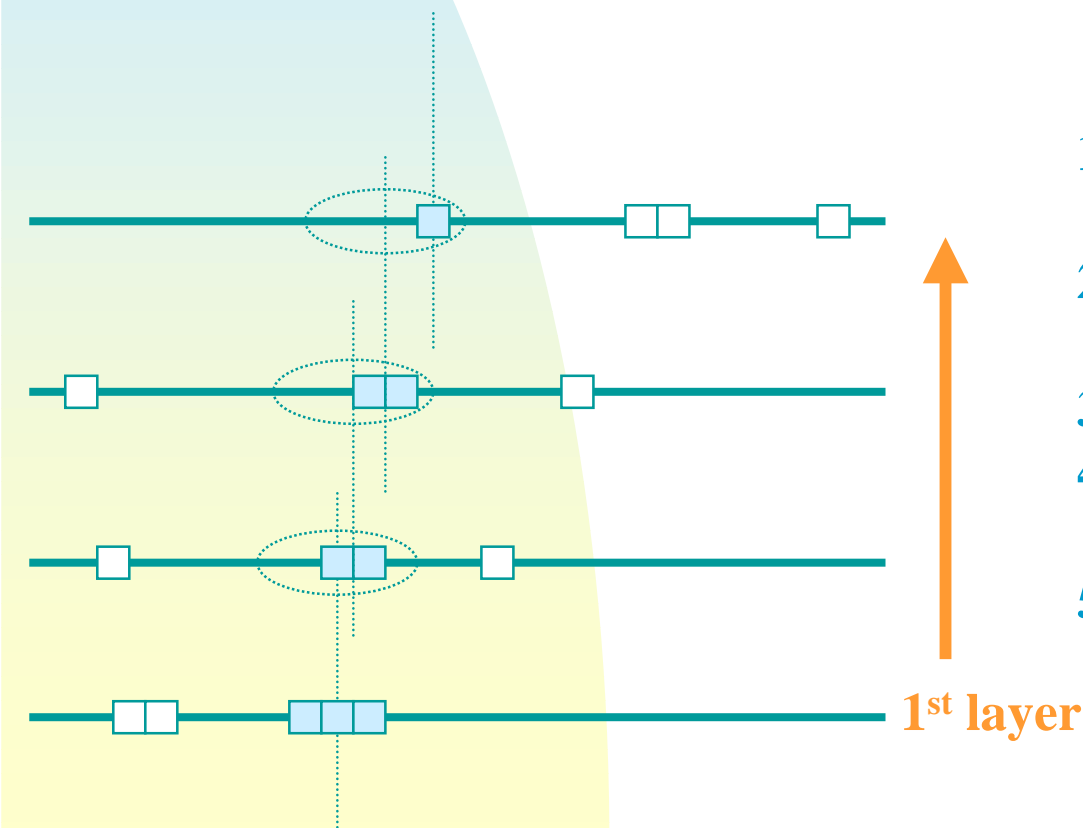
... Make **1 cluster** by gathering these CalHits

In real experiments, we cannot associate the hits from scattered particles to the original particle

→ Cheater algorithm is not a realistic clustering method

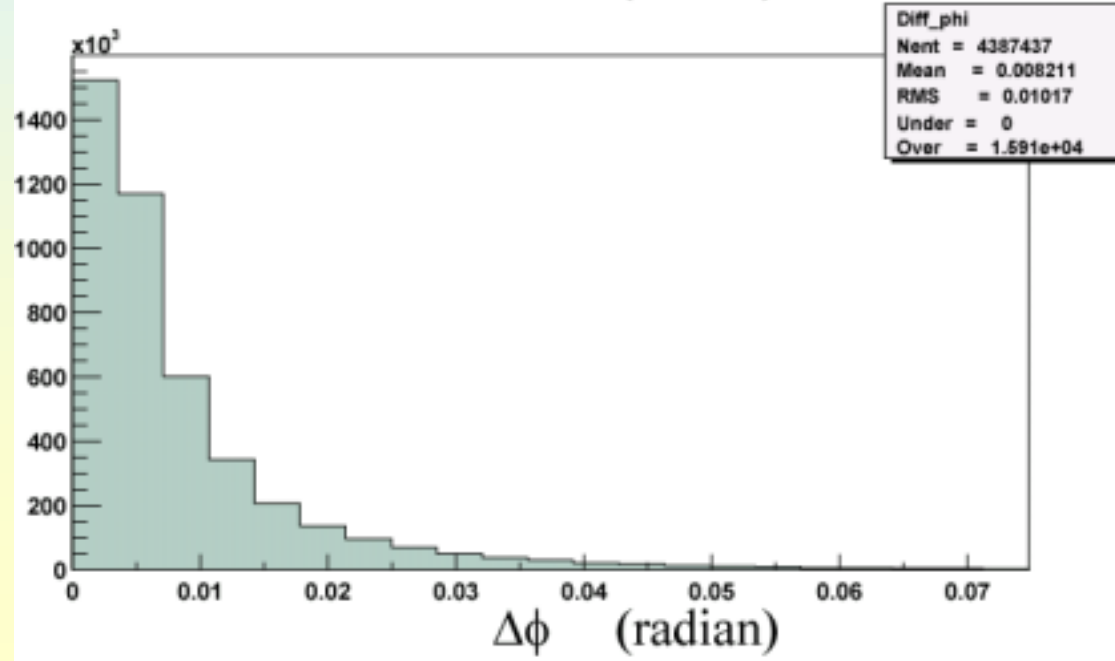
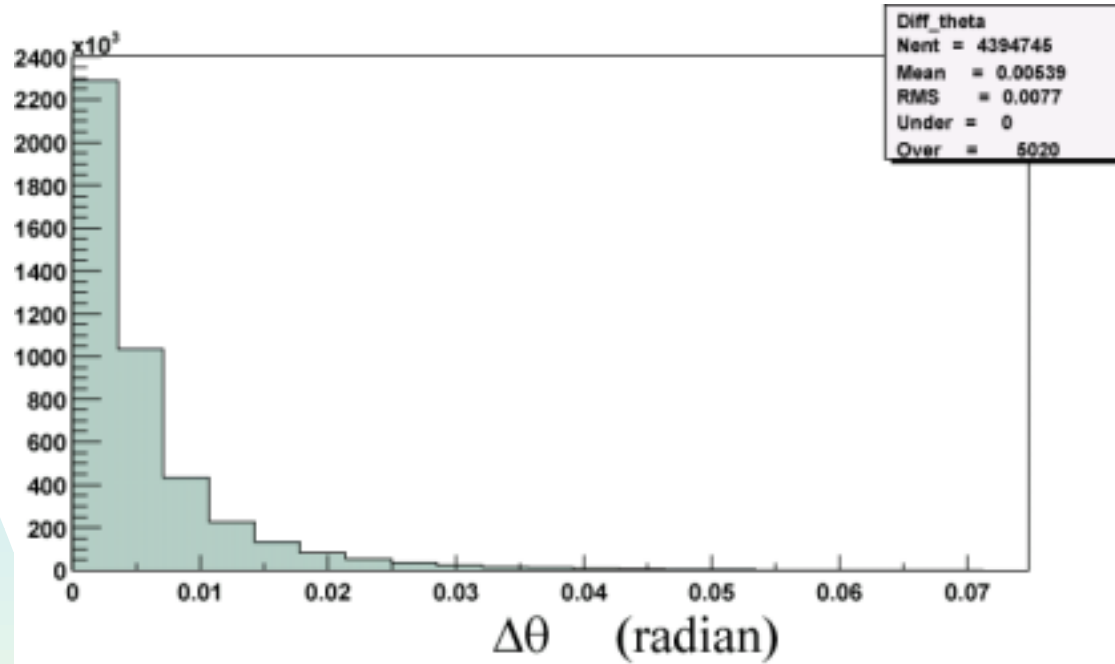
We introduce modified clustering algorithm:

- 1) Form a cluster by Cheater algorithm
- 2) Make cluster(s) from grouping CalHits

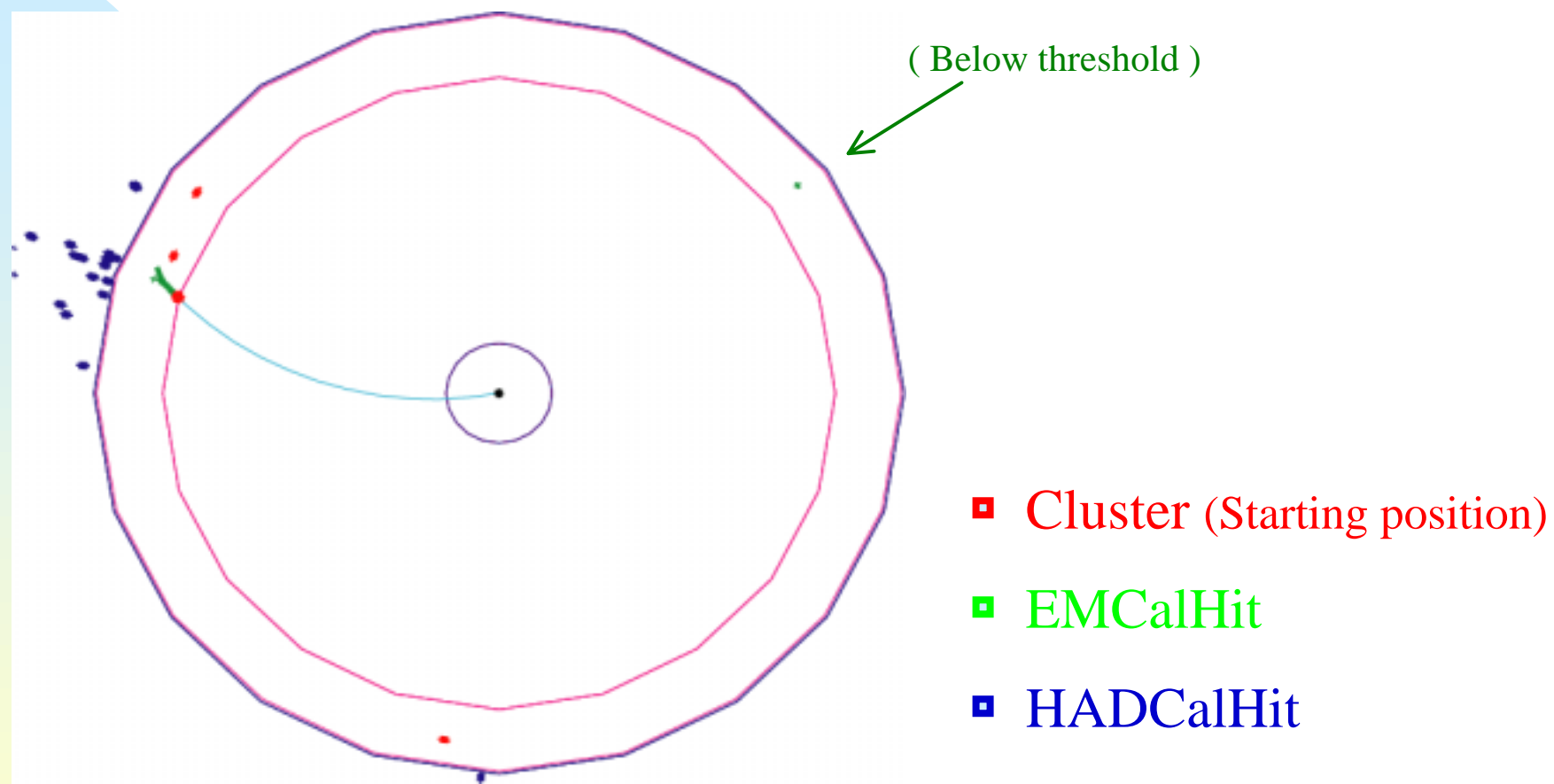


1. At 1st layer,
gather the neighboring hits
 2. Calculate energy-weight mean
← reference position
 3. Go to the next layer
 4. Gathering hits within a cone
from the reference position
 5. Repeat 2 to 4
- cone width:
 $\Delta\theta$ 20mrad $\Delta\phi$ 30mrad (SD)

$\Delta\theta$ and $\Delta\phi$ between the near calhit in the same particles

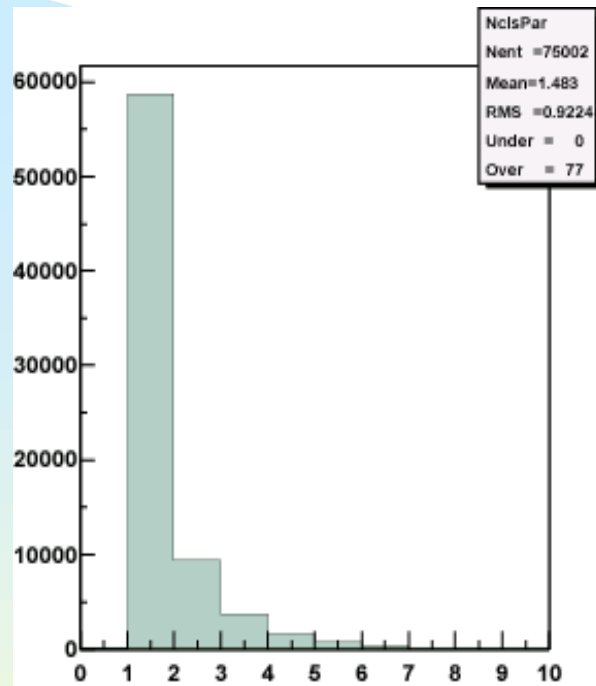


Now we have more realistic clustering

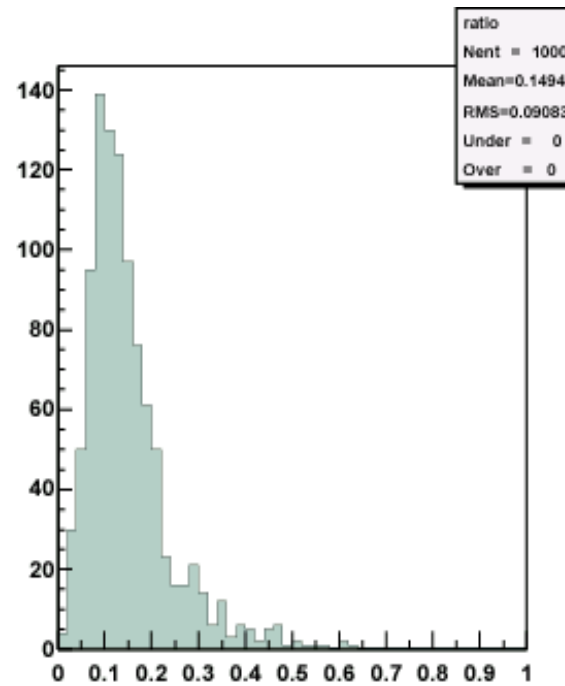


... This clustering will be available from LCDROOT V3.5

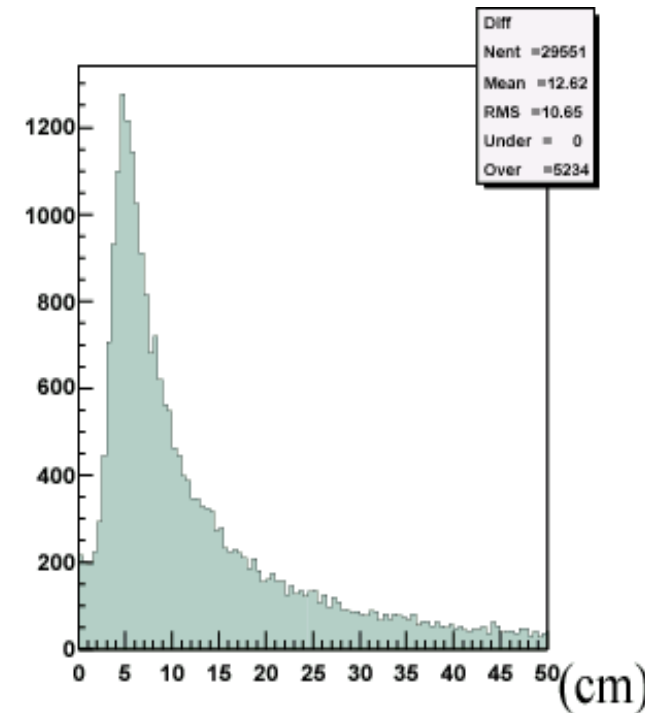
As we showed, there are one or more clusters from one particle



clusters in a particle



Escattered_cluster/Etotal



Δ (scattered cluster-particle) (cm)

(Cluster Ecls>0.1GeV, $|\cos\theta|<0.9$)

Average # of clusters in a particle ... 1.5

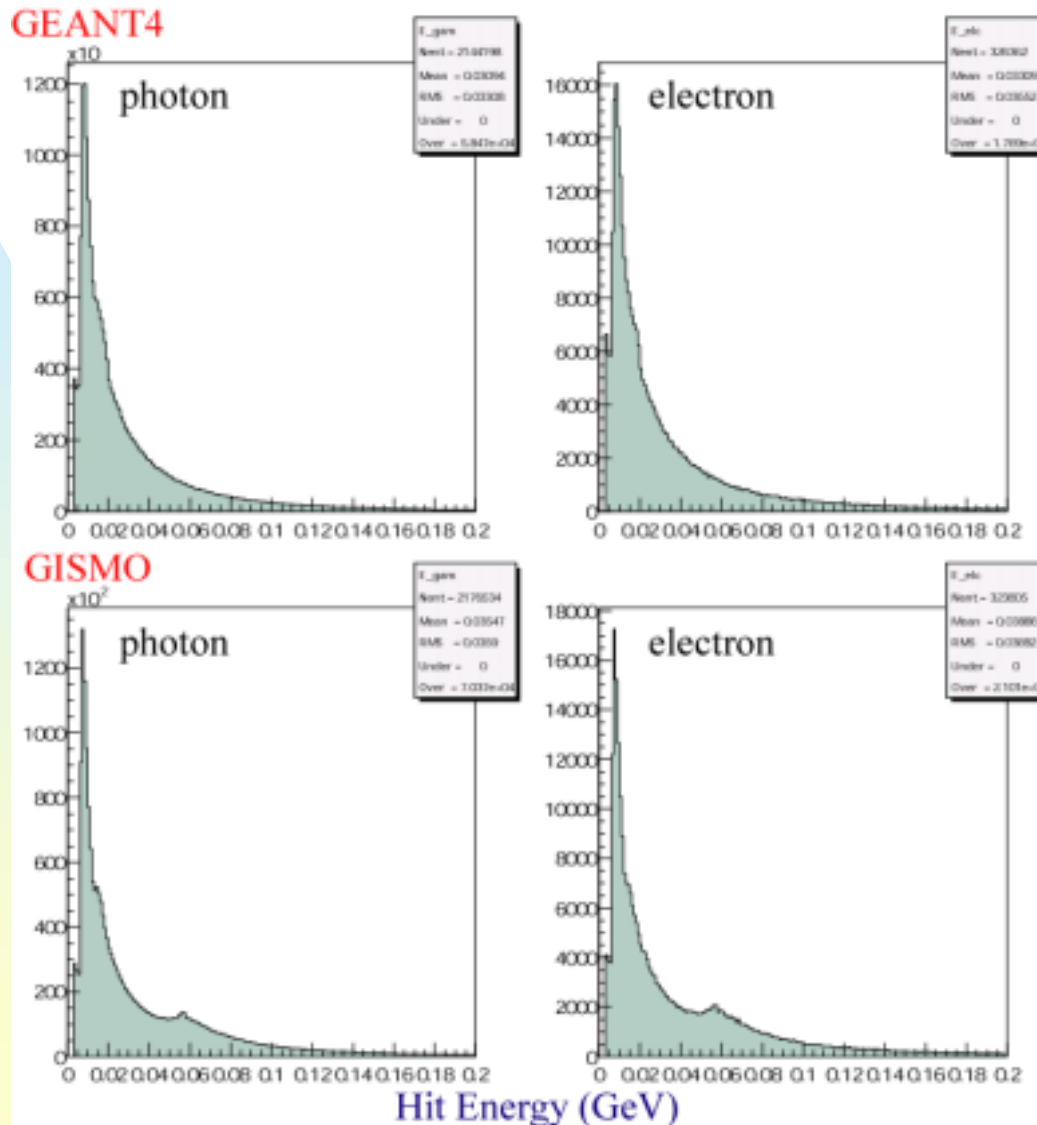
Scattered particles carry ~15% of total cluster energy sum

Scattered particle-original particle distance ... peaked around 5cm

2) GISMO vs GEANT4

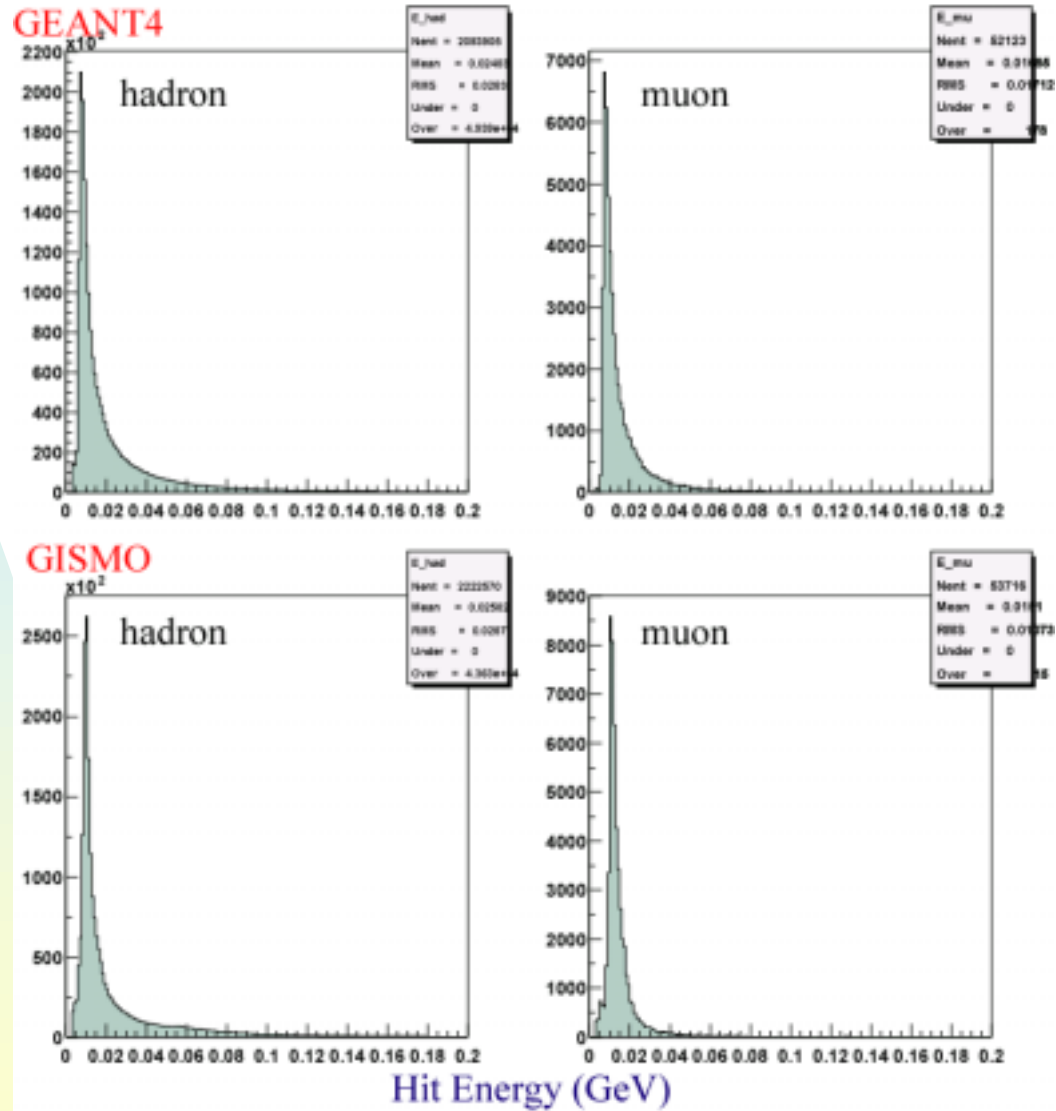
(Now GEANT4 available : See Dr. Abe's talk)

In this study, we use two simulators: GISMO & GEANT4
EMCAL hit energy distributions for EM particles



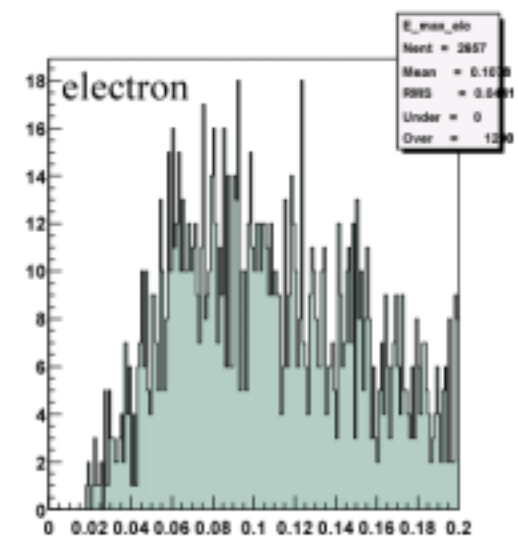
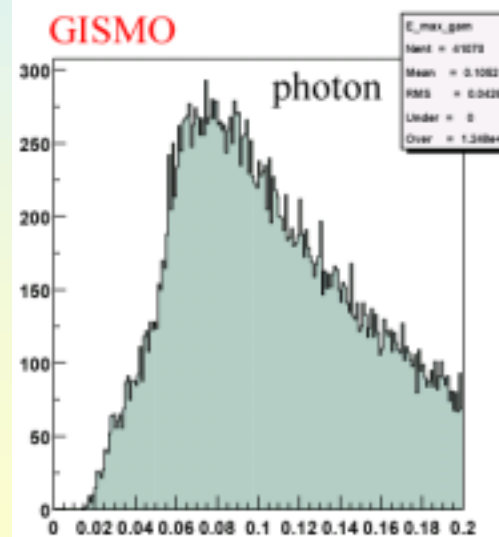
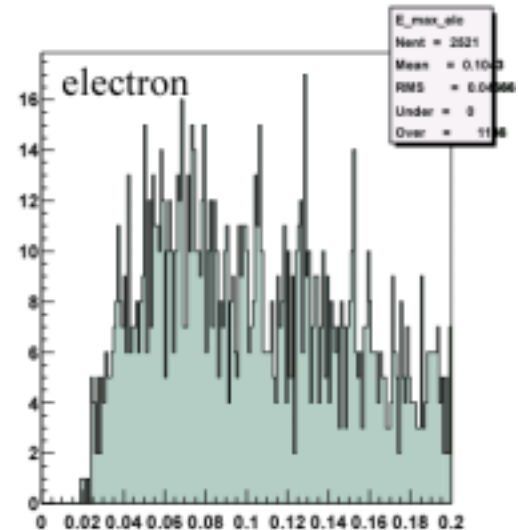
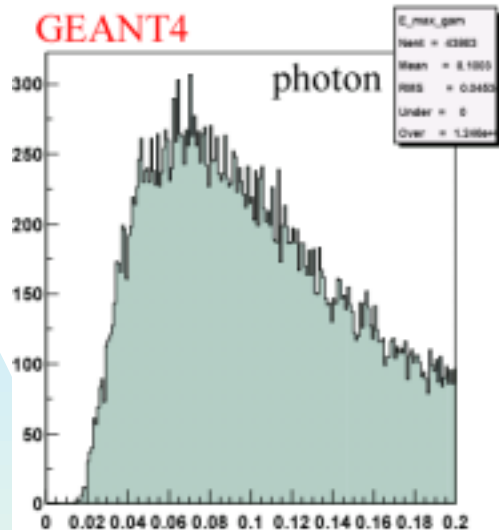
$E_{\text{GEANT4}} < E_{\text{GISMO}} (\sim 10\%)$ (Use same energy scale)

EMCAL hit energy distributions for hadrons and muons



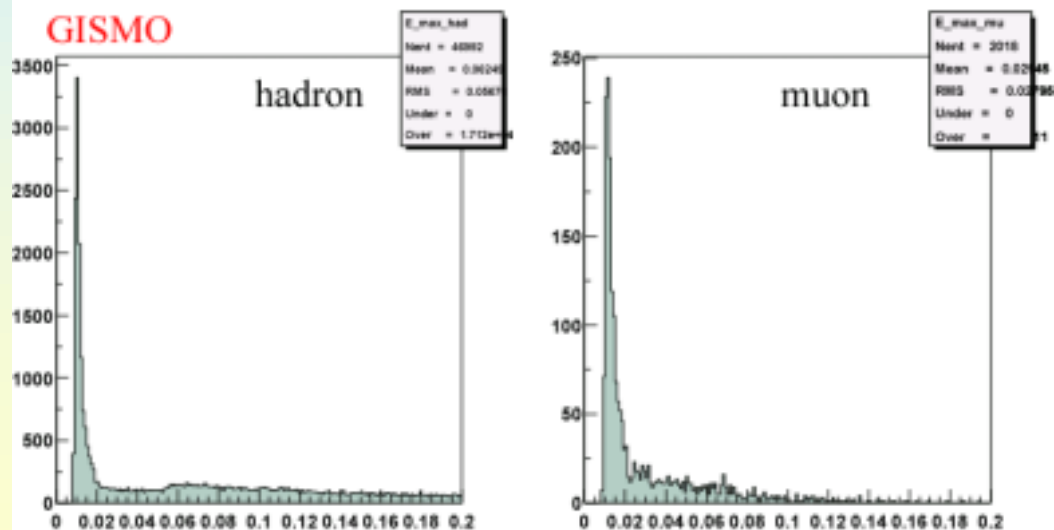
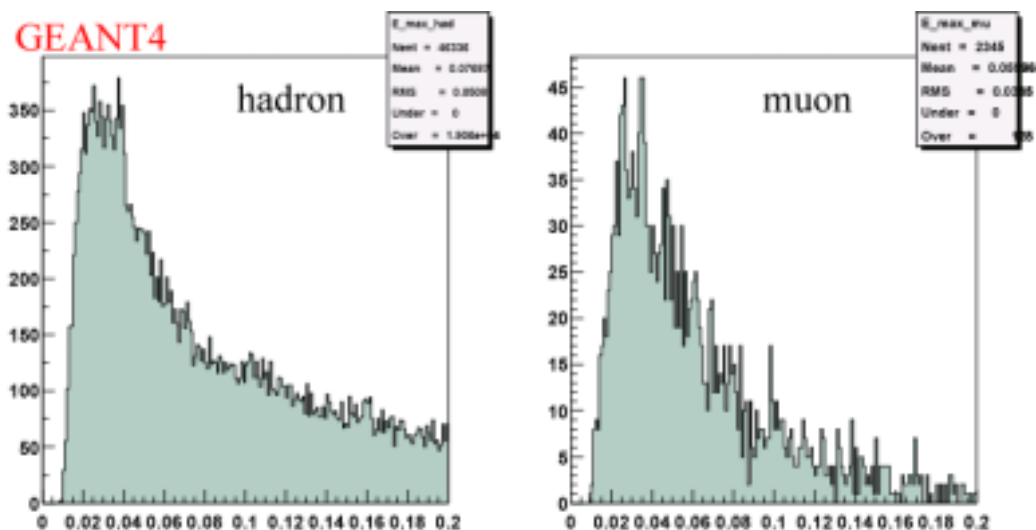
GISMO ... less high energy tail

Max hit energy in a cluster (EM particles)



Max Hit Energy (GeV)

Max hit energy in a cluster (hadron, muon)



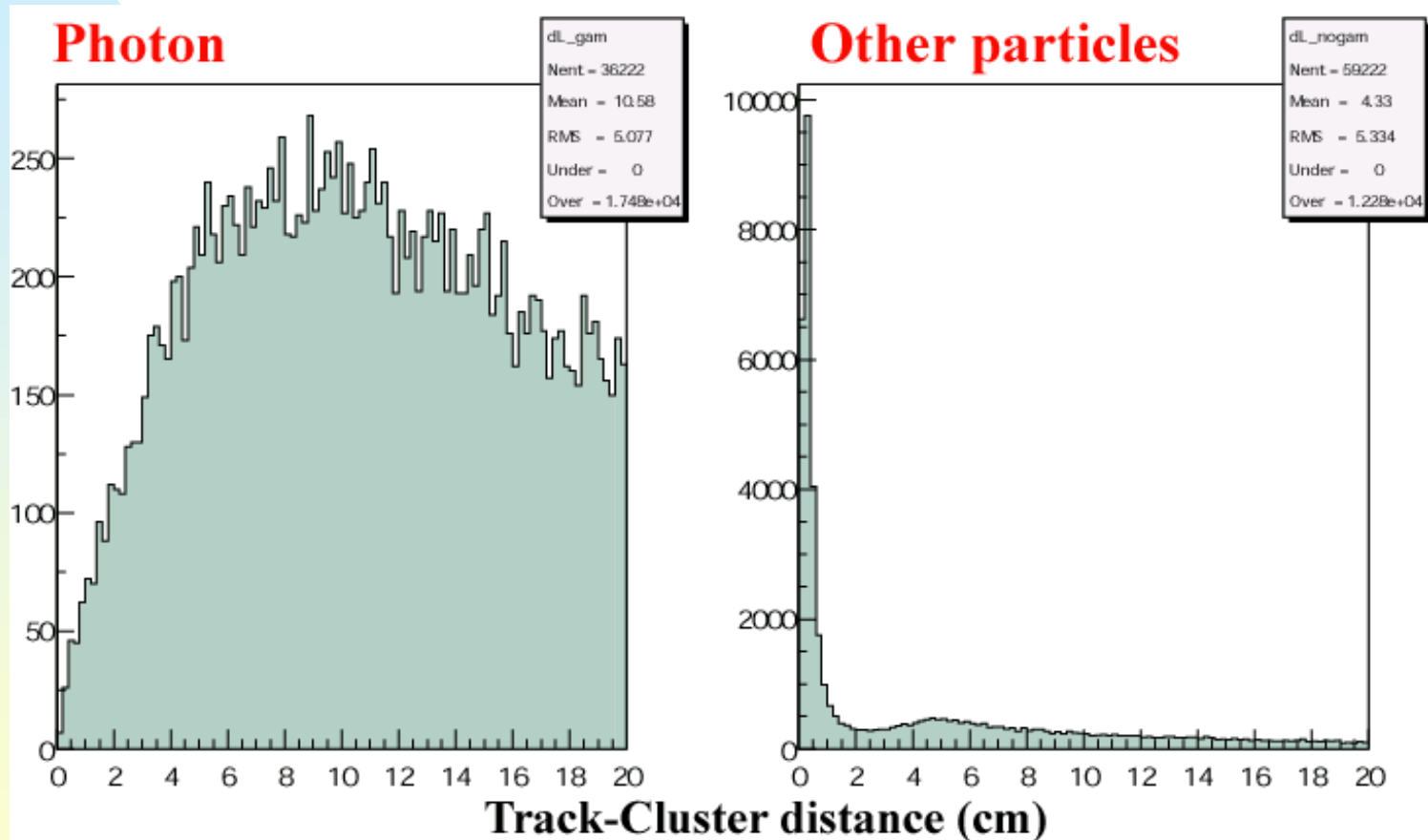
Max Hit Energy (GeV)

GISMO/GEANT4 quite different shape... need more study in future

3-1) γ selection by transverse information

To separate Charged/Neutral Clusters we see track-cluster matching

- 1) Extrapolate Charged tracks to the Cluster radius,
- 2) Associate the nearest track to the cluster



Apply a cut: Track-cluster distance > 2.5 cm

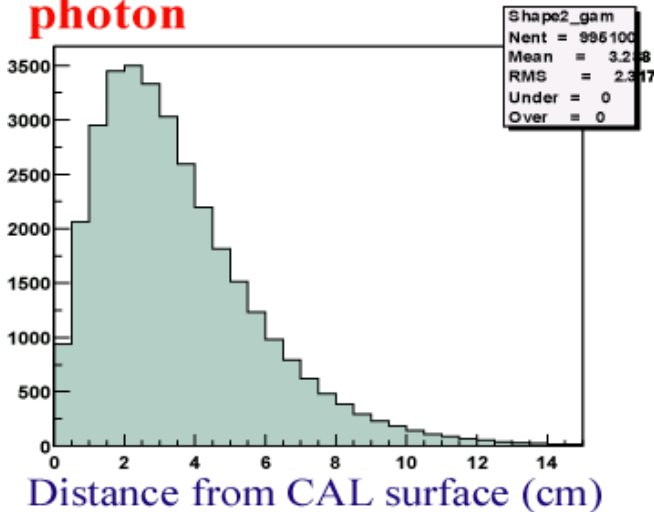
→ γ selection π 48% ε 98% (for $E_{cls} > 0.2 \text{ GeV}$ clusters: SDMar01)

3-2) γ selection by longitudinal information

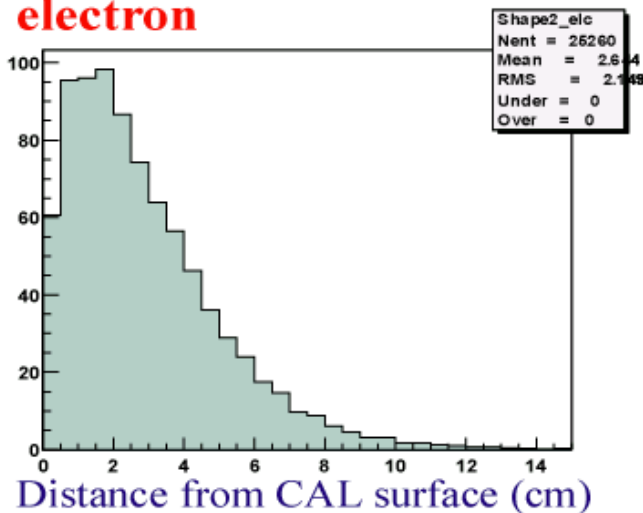
It is useful to separate EM particles / hadron
by seeing longitudinal Edeposit information

Longitudinal energy deposit shape

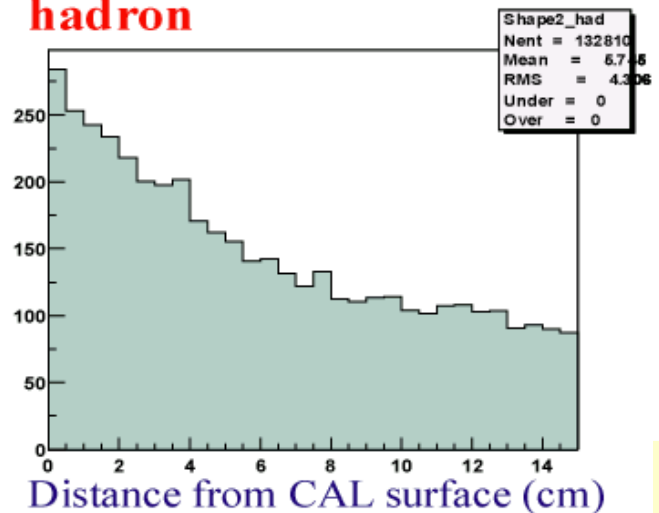
photon



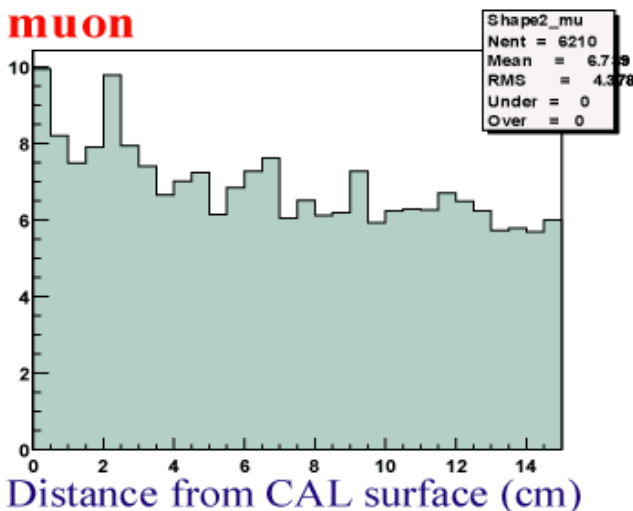
electron



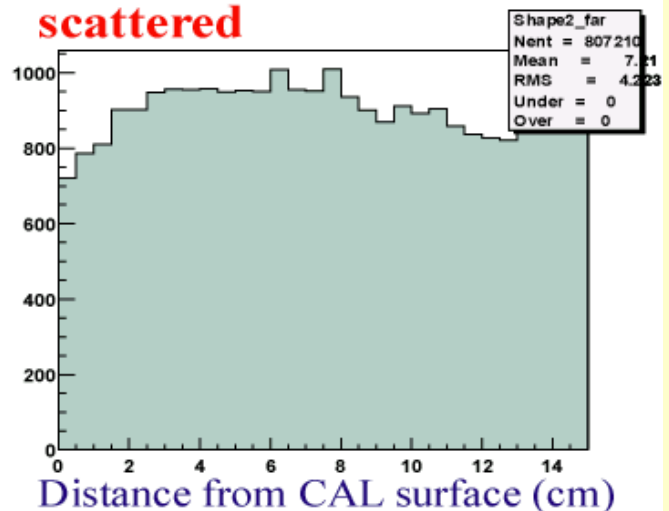
hadron



muon

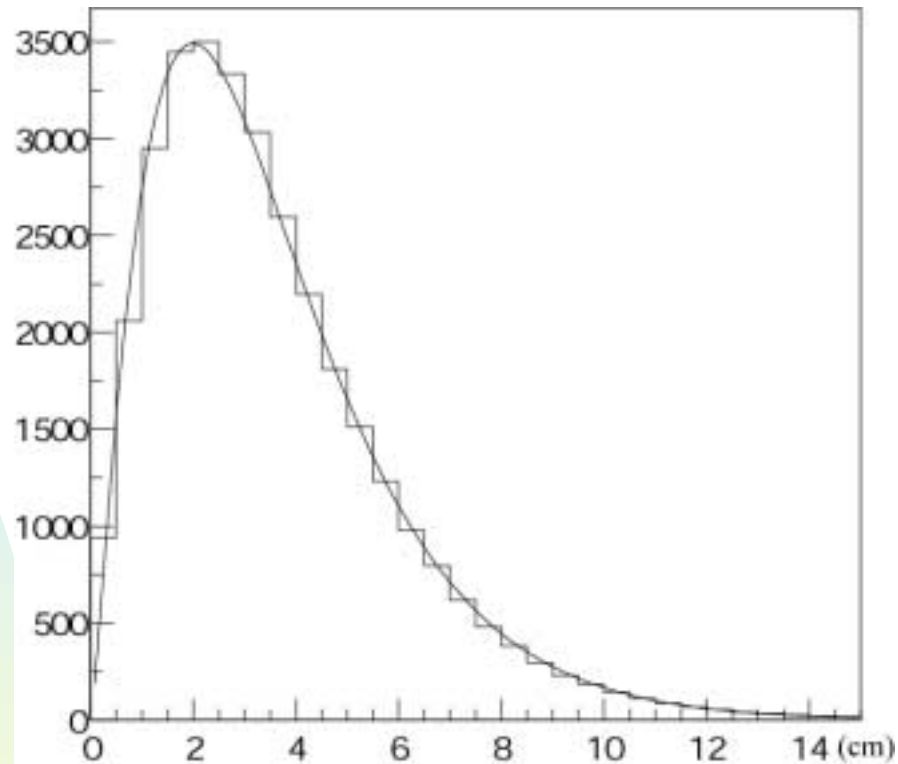


scattered



γ selection by longitudinal information

We determine the longitudinal γ shape by fitting



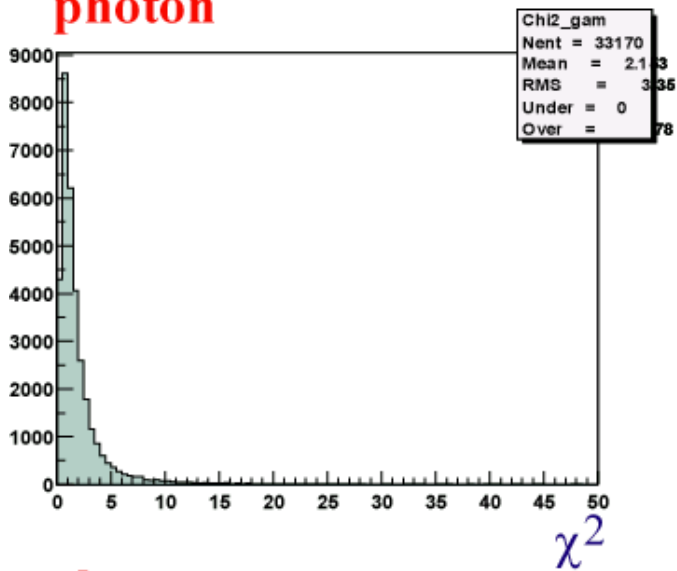
Fitting function: $p_1 \left((p_2 x)^{p_3-1} \exp(-p_2 x) \right) / \Gamma(p_3)$ x : distance (cm)

	GEANT4	GISMO
p1:	0.316	0.299
p2:	0.634	0.599
p3:	2.262	2.220

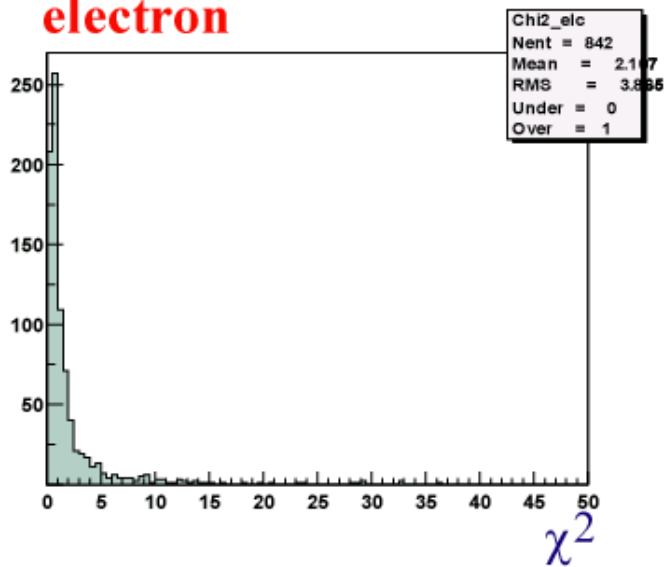
(SDMar01)

χ^2 value for the photon assumption

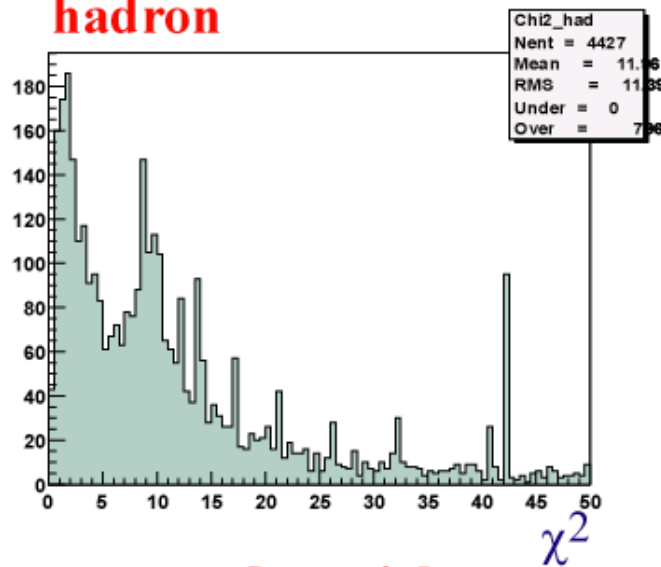
photon



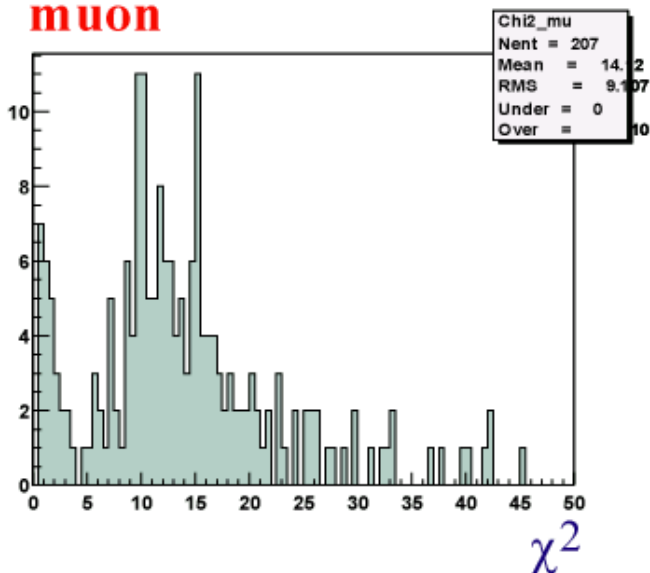
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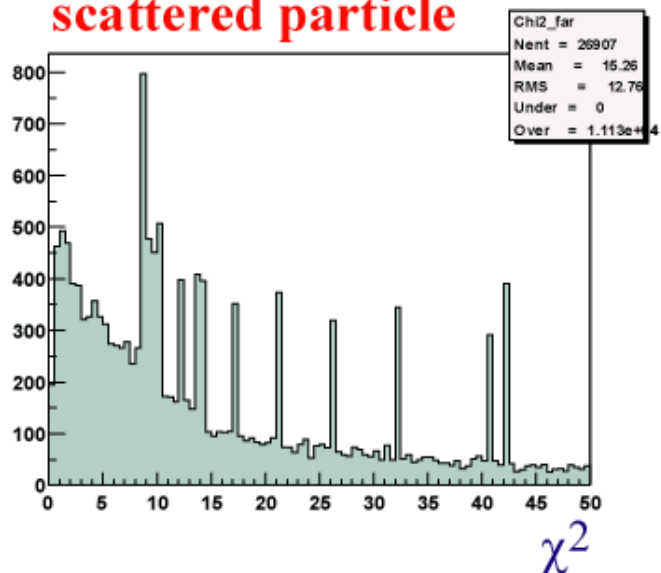
hadron



muon



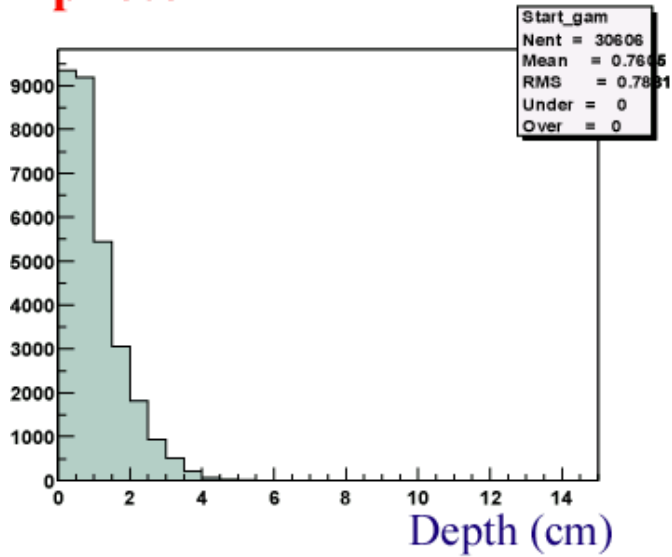
scattered particle



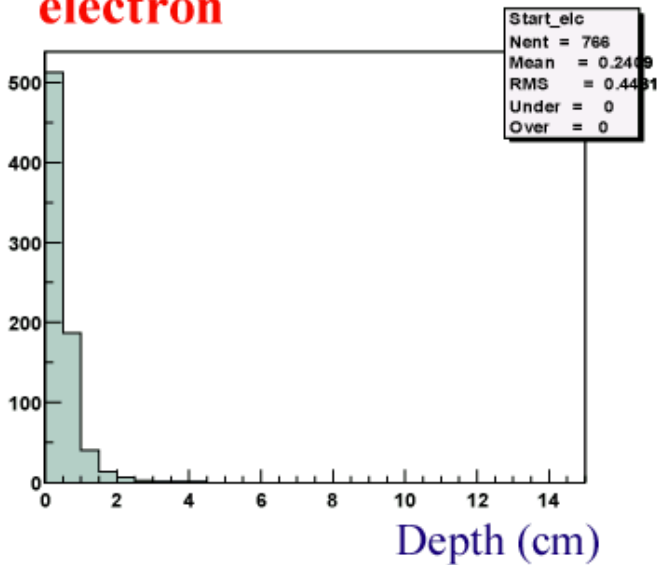
Apply a cut: $\chi^2 < 5$

Depth where CALHit Energy > min-I

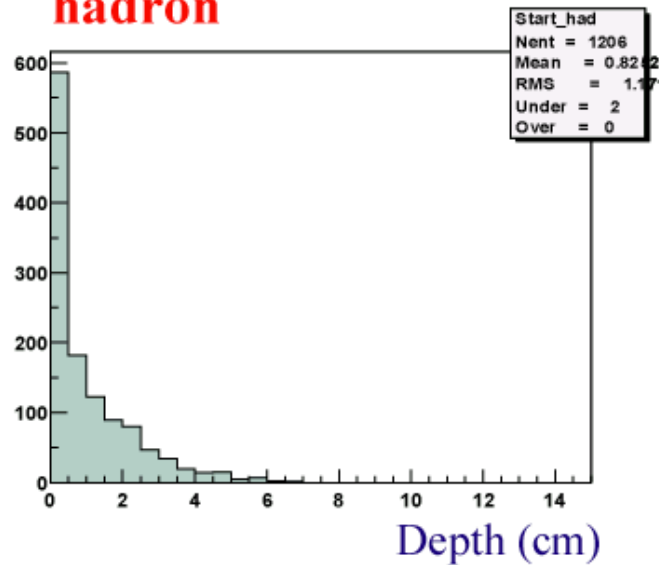
photon



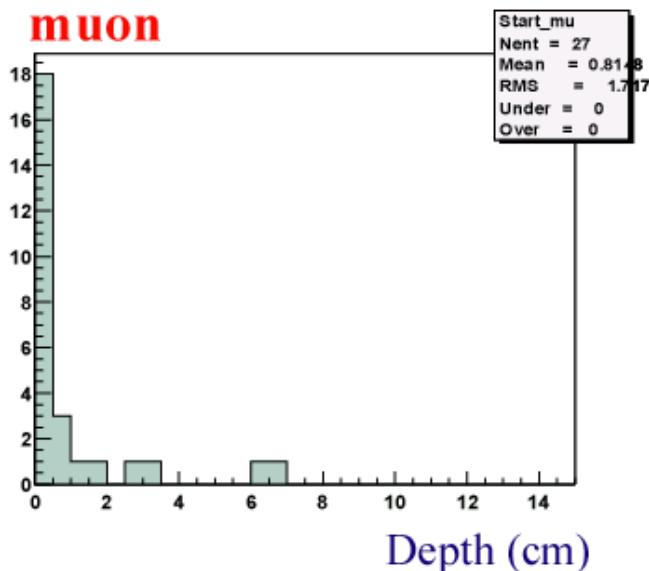
electron



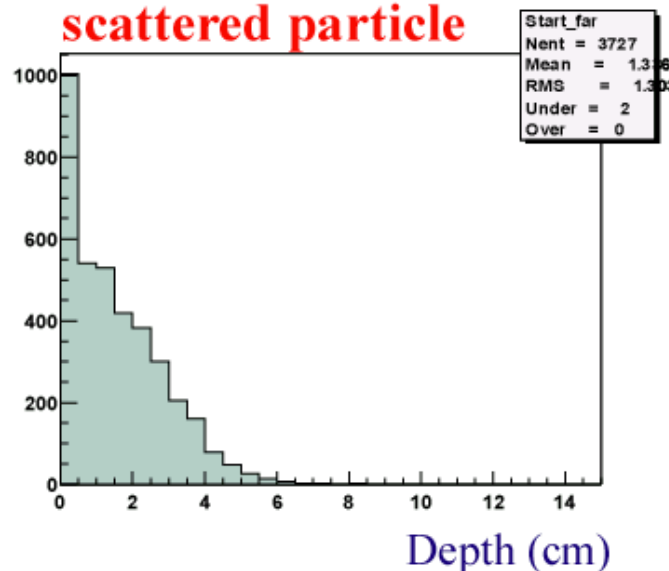
hadron



muon



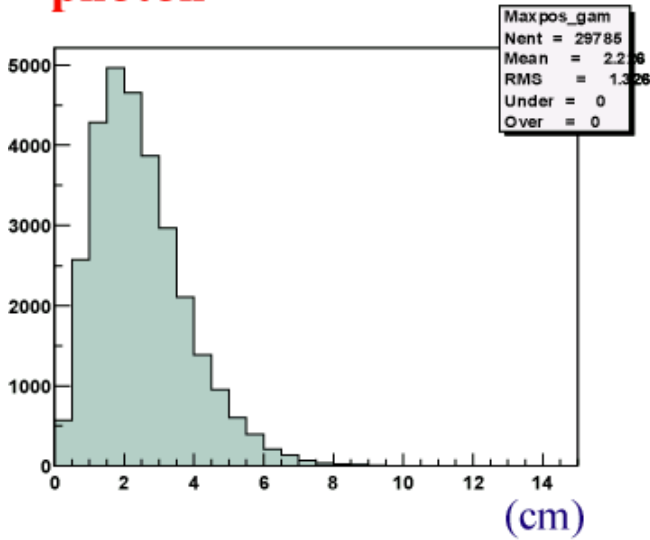
scattered particle



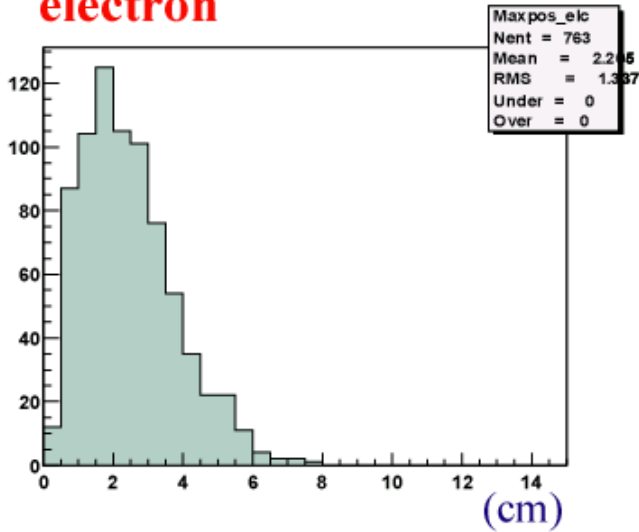
Apply a cut: depth < 2.5 cm

Cluster starting layer - max Edeposit layer distance

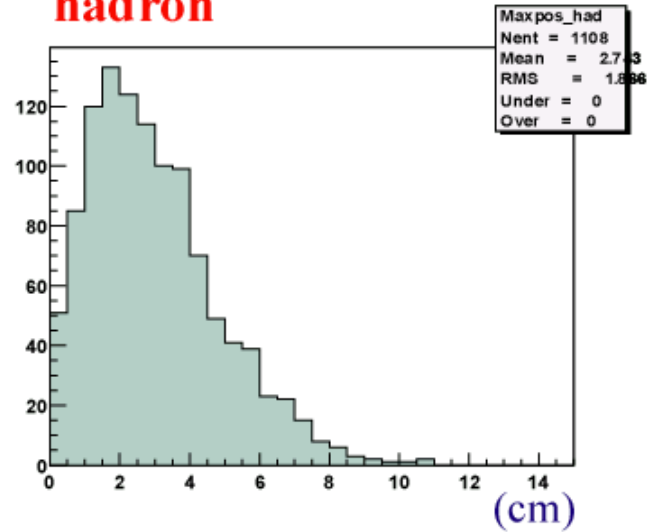
photon



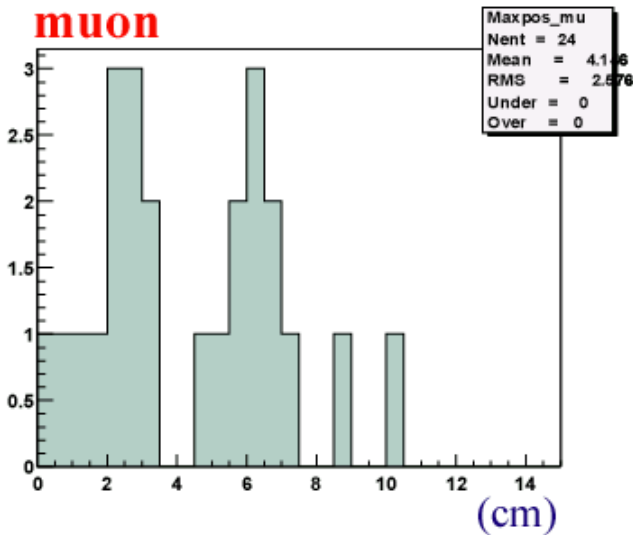
electron



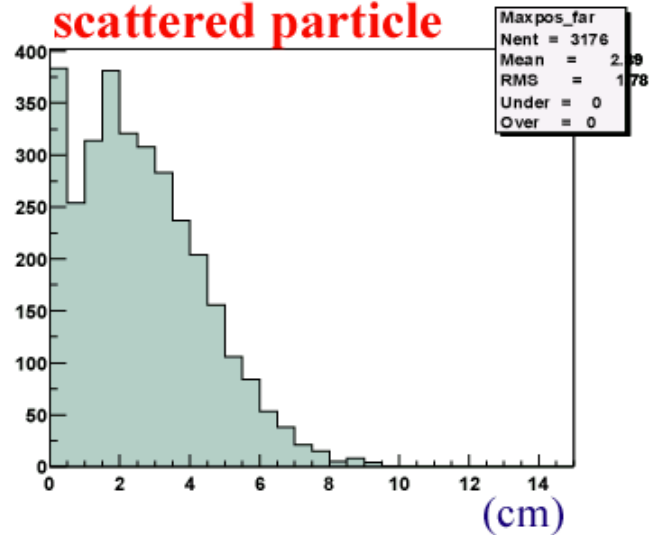
hadron



muon



scattered particle



Apply a cut: $0.5 < \text{distance} < 7 \text{ cm}$

Summary of γ selection (SDMar01 detector)

GEANT4	γ	Not γ	scattered	purity	efficiency
Ecls>0.2GeV	33974	33471	27999	36%	
Tack-cluster cut	33170	8352	26907	48%	98%
Longitudinal cuts	29148	2316	2760	85%	86%

GISMO	γ	Not γ	scattered	purity	efficiency
Ecls>0.2GeV	32552	33383	25506	36%	
Tack-cluster cut	31762	8000	24266	50%	98%
Longitudinal cuts	27586	2060	3258	84%	85%

- Transverse information is effective to reject charged particles
- Longitudinal information is effective to reject both charged and scattered clusters

Overall γ selection performance ... ~85% purity, ~85% efficiency

Mass reconstruction

Using the energy flow object (track+neutral clusters),
reconstruct W and Top-quark in $e^+e^- \rightarrow tt$ events (6jets & 4jets)

GEANT4	W mass	error	Top mass	error
Track + γ	67.1 \pm 15.9 GeV	(28%)	141.0 \pm 33.5	(24%)
Track + γ (true)	70.2 \pm 16.9	(24%)	147.0 \pm 31.7	(22%)
Track + γ (true) + h^0 (true)	77.2 \pm 15.1	(20%)	159.7 \pm 30.7	(19%)
GISMO				
Track + γ	72.2 \pm 18.6	(26%)	149.2 \pm 35.1	(24%)
Track + γ (true)	75.1 \pm 18.0	(24%)	156.5 \pm 35.9	(23%)
Track + γ (true) + h^0 (true)	84.4 \pm 16.4	(19%)	177.3 \pm 35.9	(20%)

No selection cut (Xjet cut for example) applied

True- γ /selected- γ difference ... 2~3 %

→ We get very good photon-selection performance

Adding the neutral hadron clusters at HADCAL

→ can improve mass resolution 3~4%

Summary

- 1) We update the clustering algorithm
for more realistic simulation studies
- 2) GISMO / GEANT4 comparison
now GEANT4 is ready ... Many thanks to T.Abe
significance difference in hadron and muon
→ Need mode study
- 3) Photon reconstruction in EMCAL
Using Transverse+Longitudinal information,
we get good γ reconstruction $\pi \sim 85\%$ $\epsilon \sim 85\%$
- 4) HAD Cal clusters improve 3-4% jet-mass resolution
neutral hadron reconstruction study → Future plan

**In the future linear collider experiments,
many physics processes have multi jets in the final states
→ Good Jet reconstruction is essential**

Jet reconstruction ... Energy Flow method

	Tracker	Calorimeter
Charged hadron, electron	➔	➔
Neutral hadron, photon		➔

Average momentum of charged particle ~ 2.4 GeV @ $E_{\text{CM}} = 500$ GeV
.... $\sigma_{\text{p}}(\text{Tracker})$ is better than $\sigma_{\text{E}}(\text{Calorimeter})$

Summary of γ selection (SDMar01 detector)

GEANT4

	γ	Not γ	scattered	π	ϵ
Ecls>0.2GeV	33974	33471	27999	36%	
Tack-cluster cut	33170	8352	26907	48%	98%
χ^2 for $\gamma < 5$	30606	2656	3727	83%	90%
Depth(>min-I)<2.5cm	29785	2470	3176	84%	88%
0.5 < MaxE depth < 7cm	29148	2316	2760	85%	86%

GISMO

	γ	Not γ	scattered	π	ϵ
Ecls>0.2GeV	32552	33383	25506	36%	
Tack-cluster cut	31762	8000	24266	50%	98%
χ^2 for $\gamma < 5$	29084	2634	4396	81%	89%
Depth(>min-I)<2.5cm	28237	2257	3702	83%	87%
0.5 < MaxE depth < 7cm	27586	2060	3258	84%	85%