Photon and pi0 identification:
recent GARLIC developments

- revisiting of algorithm

- performance in pi0 events
  as function of
    pi0 energy
    ILD size, ECAL design

- plans

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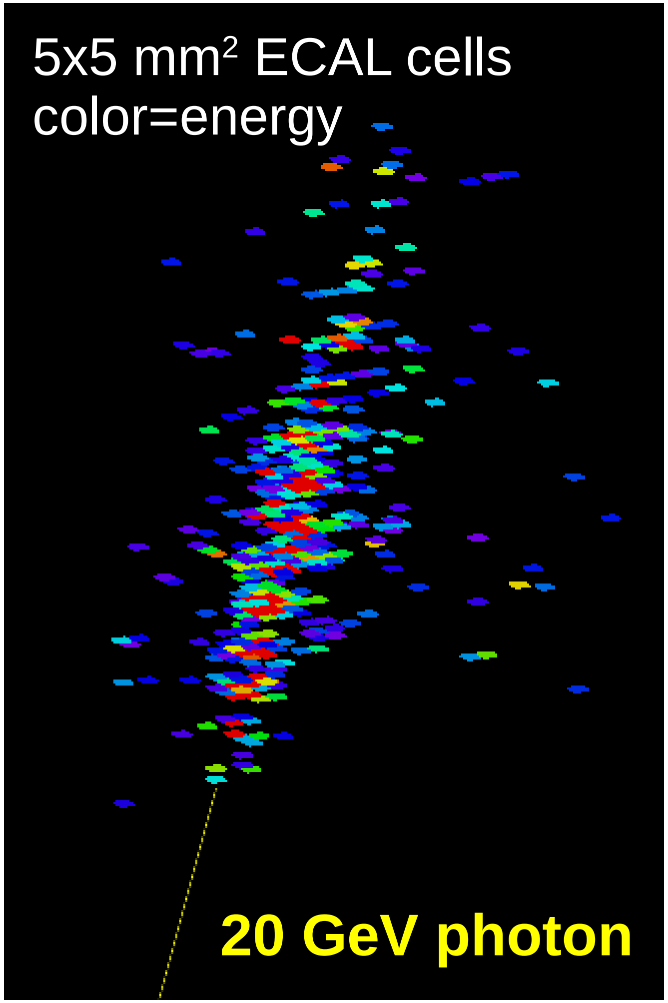
GARLIC photon reconstruction algorithm

GAmma Reconstruction at a LInear Collider experiment

(JINST 7 (2012) P06003)



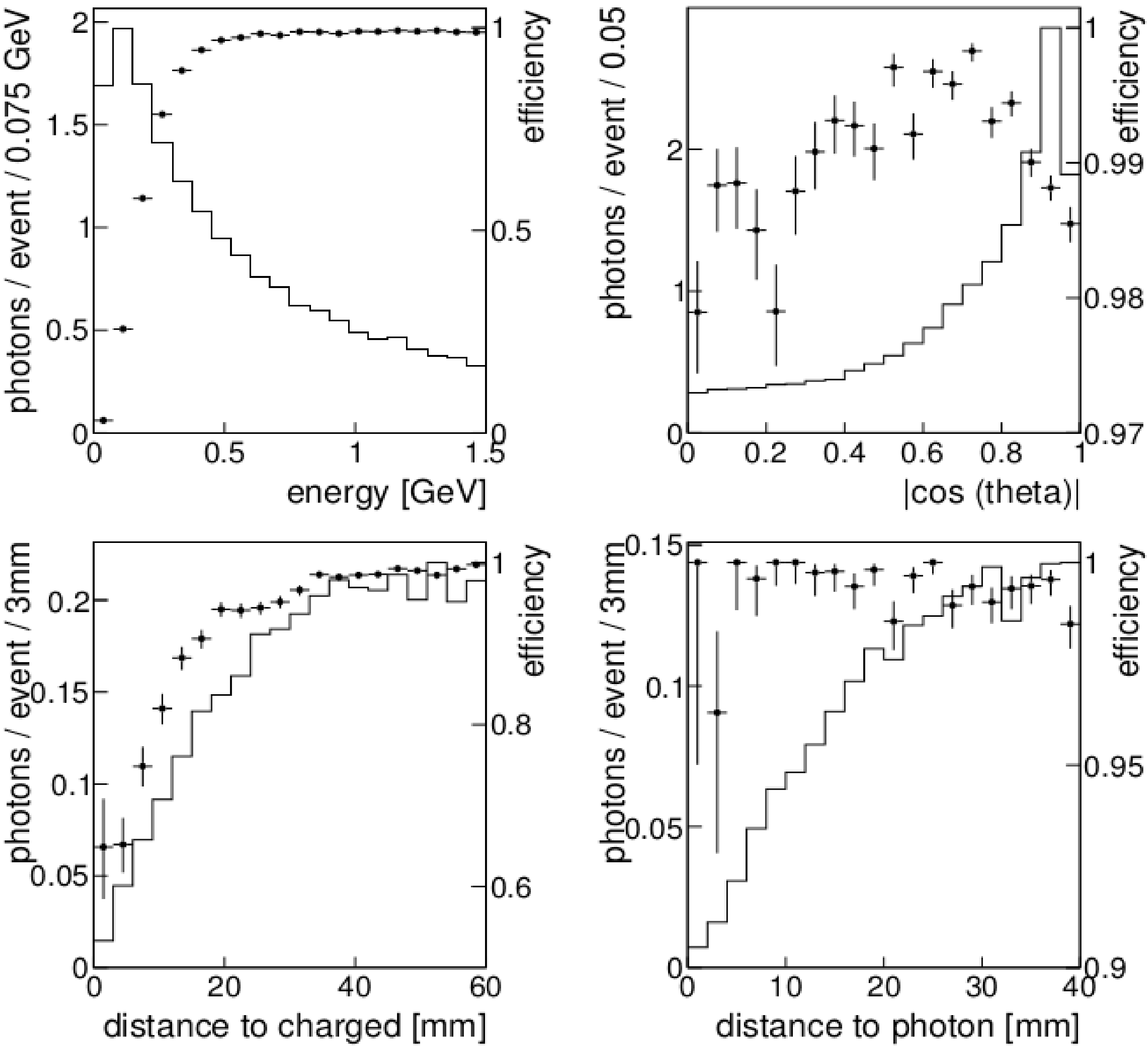
Make use of characteristic shape of EM showers,
- revealed by dense, highly segmented ECAL
- - narrow core of high energy deposit: radius ~ cell size
- - lower energy "halo": radius ~ Moliere radius ~ 20 mm
- - characteristic longitudinal profile

Algorithm outline:
- Identify electrons seeded by tracks
- Veto ECAL hits near track projections
- Project hits in first part of ECAL onto front face
- Search for peaks in projection --> "seeds"
- Project seeds through ECAL, attach hits --> "cores"
- Attach nearby hits to "cores" --> clusters

Decide if resulting cluster looks like photon
- (v2.x) Neural Network trained using jet events
- (pi0 results in this presentation)
  - photon multi-var likelihood for
    - combining nearby clusters
    - selecting photon-like clusters
- (new v3.x) simpler cut-based approach

Example observables:
- Longitudinal shower shape
- Transverse shower shape & size
- Distribution of hit energies
- Pointing to IP

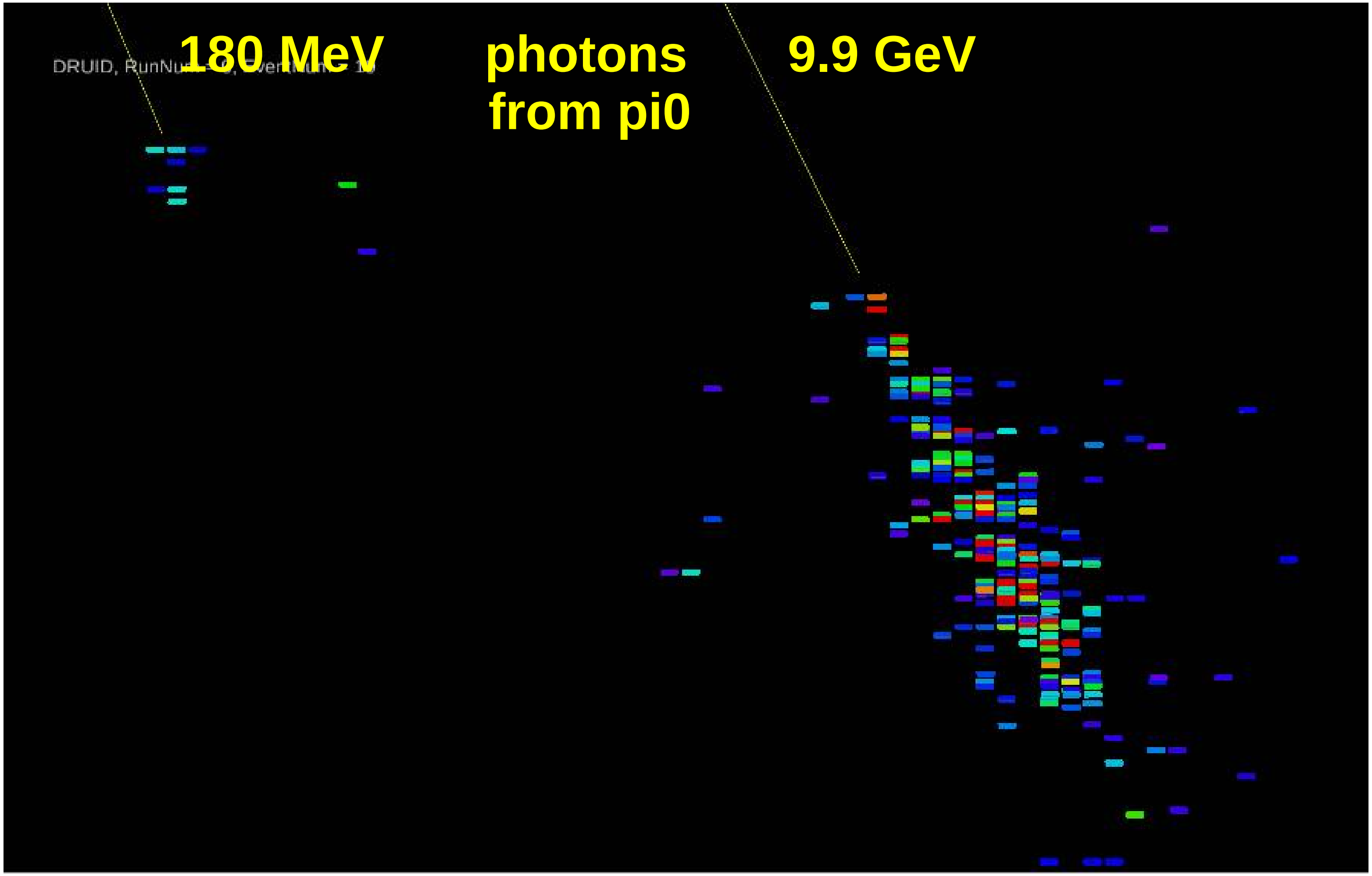
“Original” GARLIC performance in jets (v2; NN-based)



“Efficiency”
=
efficiency to collect photons into clusters

Merging nearby photons into a single cluster not penalised (~OK for Jet En Res)

Some inefficiency for energy < ~ 500 MeV



Recent work with view to:

- Better separate near-by photons: e.g. for high energy pi0 decays
- Improve efficiency for low energy photons: O (100 MeV)
- “scalable algorithm”: parameterise in terms of X0, Moliere radius, cell size
  easier to apply to different ECAL designs
- Try to simplify (no automatic MVAs if not required...)

Principal changes in GARLIC v3.0.x

Main aim was to

improve separation of nearby showers (i.e. high energy pi0s)

Simplify, in particular remove automatic MultiVariateAnalyses

in order to better understand what's going on

I have tested v3.0.x in a few scenarios: please try it in your analysis,

and give me feedback! In particular, report problems:

then we can try to fix them.

Improved electron clustering; new conversion finding.

Over-fragment showers in early stages of algorithm:

Typical region ~ cell size, rather than Moliere radius.

=> find several seeds and cores per shower

Implement more sophisticated cluster merging algorithms

- Ratio of cluster energies
- Various distances between showers
- Relative shower start points
- Does combined shower look more than a single EM shower than it's constituents?

Cut-based selection

For various cluster observables, decide “reasonable” range for EM clusters

(within central 90% -> “tight”, within central 98% -> “loose”

“train” on samples of single photons, electrons 0.1 -> 100 GeV

Parameterise “reasonable range” as fn of cluster energy

Cluster classification into Tight, Loose, VeryLoose

based on fraction of observables which fall into “reasonable ranges”

Cuts are specified in a text file, so it's easy to e.g. turn off one cut.

(just comment out the corresponding entry in the file)

Hadronic cluster fragment rejection now based on a few “by hand” cuts

A few ideas for future improvements

streamlined and improved hadron fragment rejection

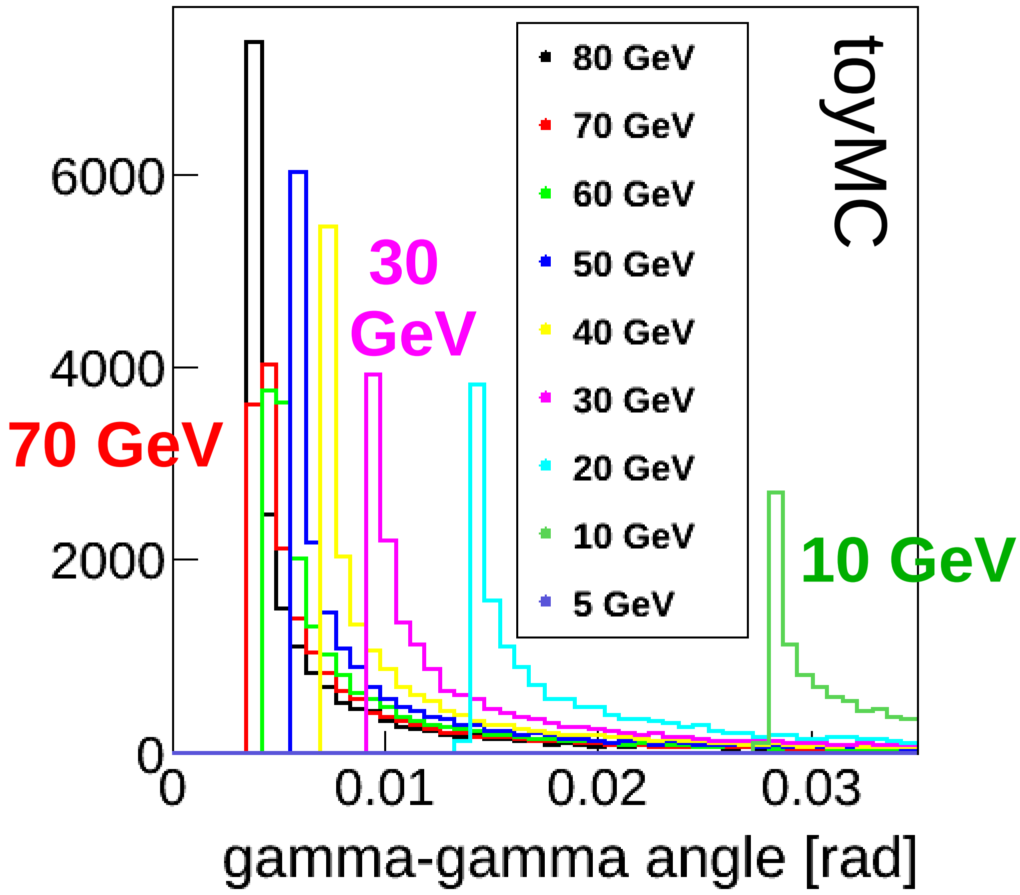
Identification of cases in which photon converts in TPC field cage/endplate, SET, ETD -> now often split into 2 clusters

Identification of bremsstrahlung photons from electrons

Look more at lower energies < 1 GeV

Hieu reports that it's too slow

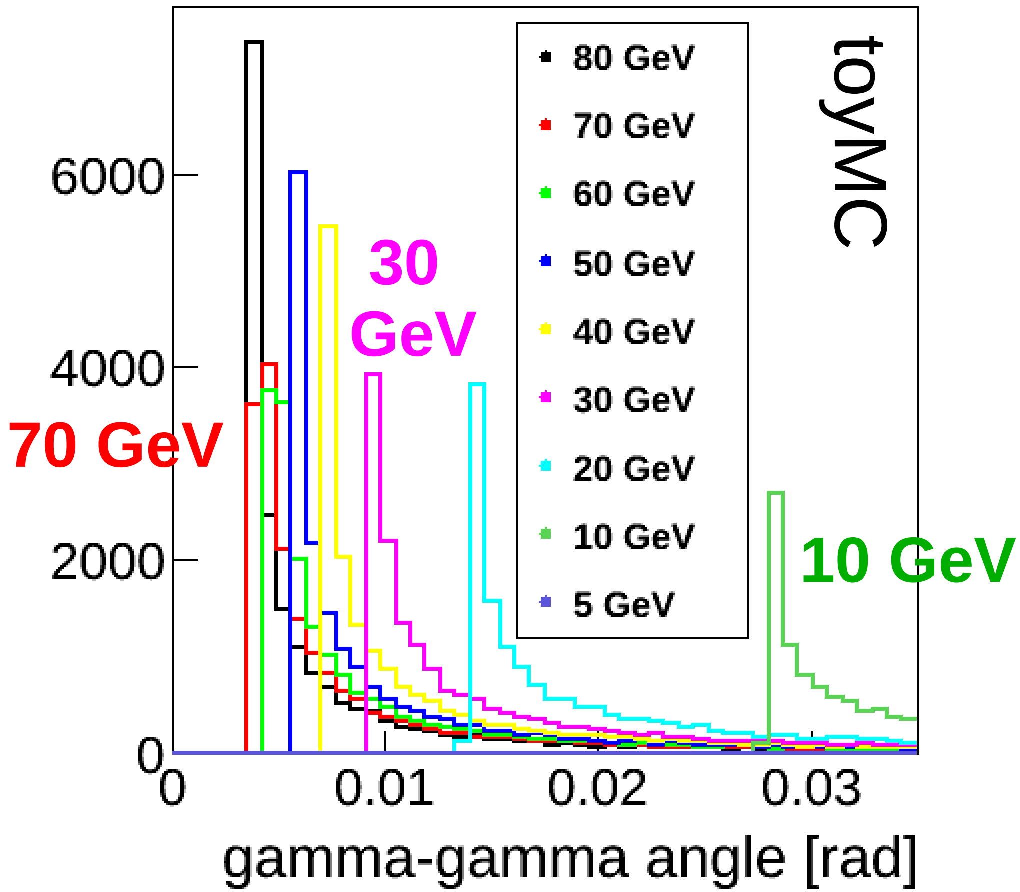
Introductory motivation:
angle between photons at different π^0 energies



n.b. “usual” PFA doesn't care if 2 photons are combined into a single reconstructed cluster
- Jet Energy Resolution is not degraded

Introductory motivation:

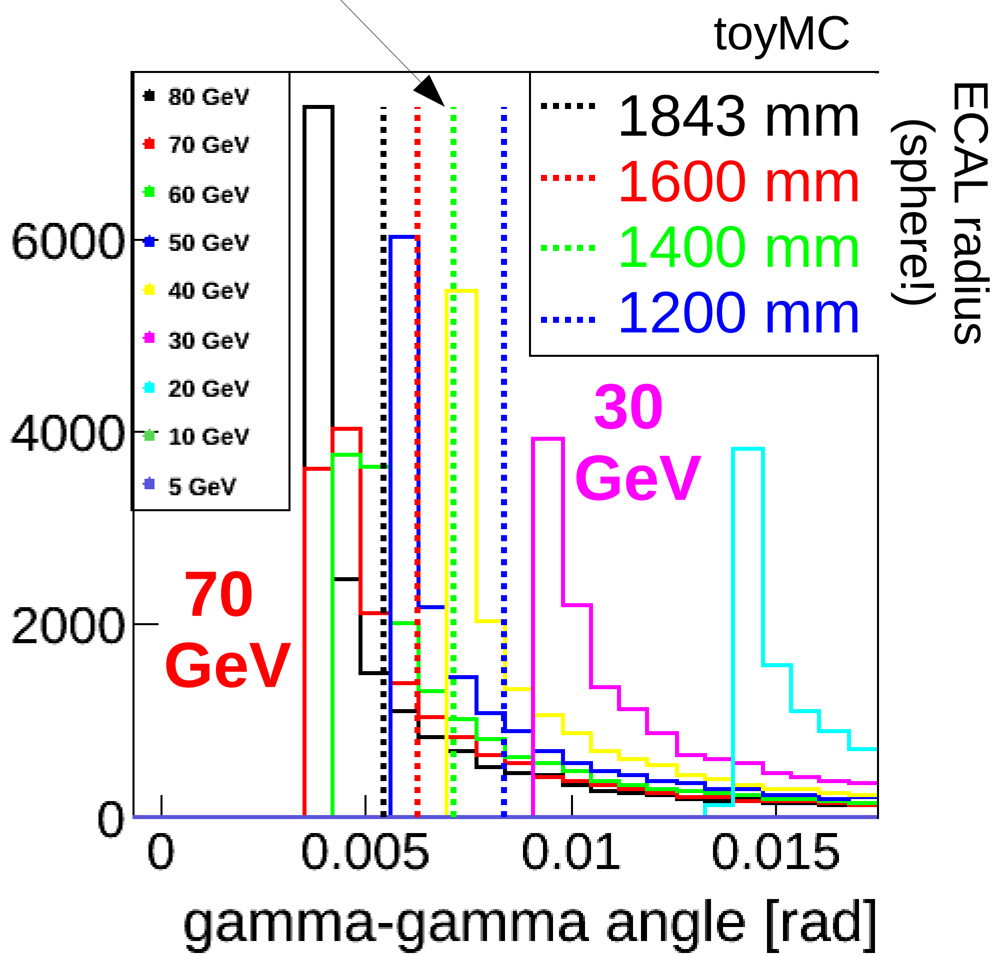
angle between photons at different π^0 energies



Identification of high energy pi0 is probably most relevant to tau decay mode identification e.g. Higgs->tau tau CP properties

Angle subtended by 0.5*Moliere radius at different ECAL radii

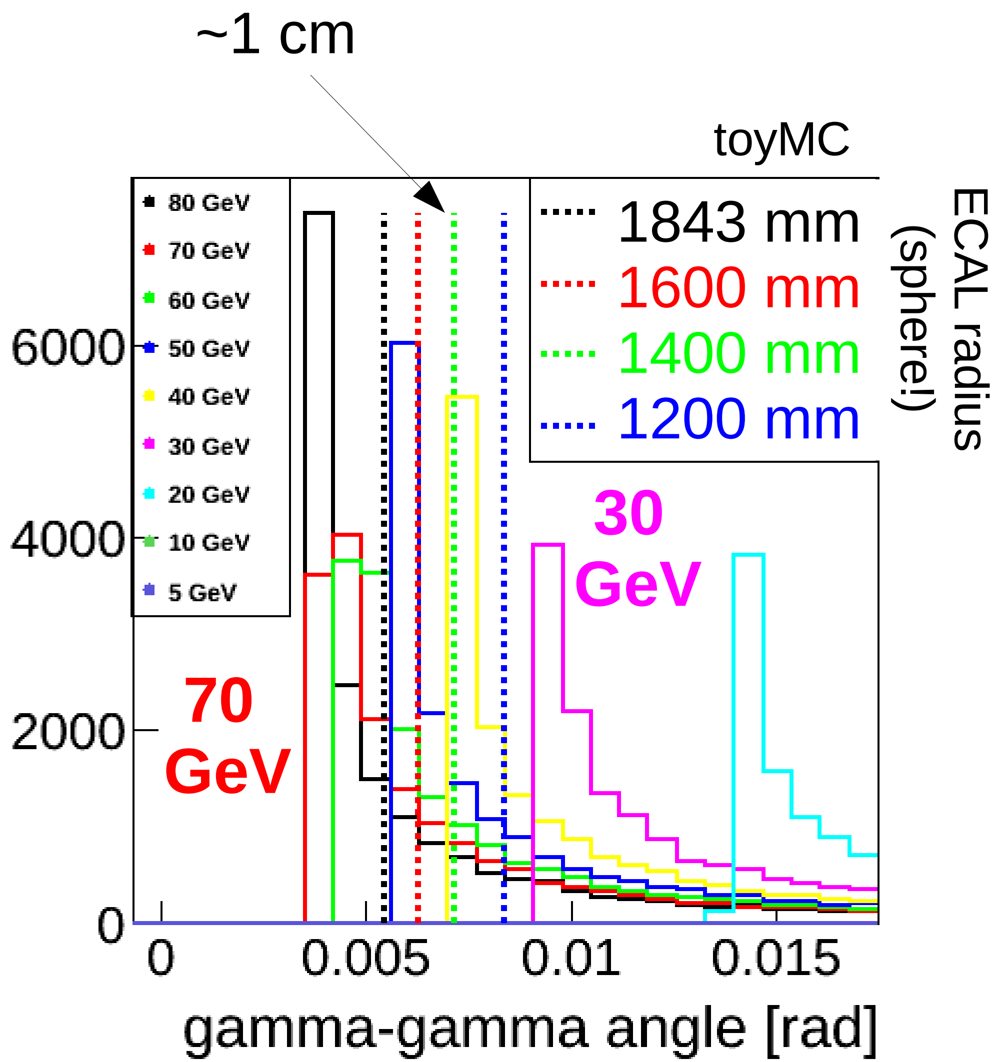
~1 cm



π^0 of 30 GeV and below should be identifiable
in a typical ILC ECAL
with a good photon separation algorithm

π^0 of 80 GeV look difficult

Angle subtended by 0.5*Moliere radius at different ECAL radii

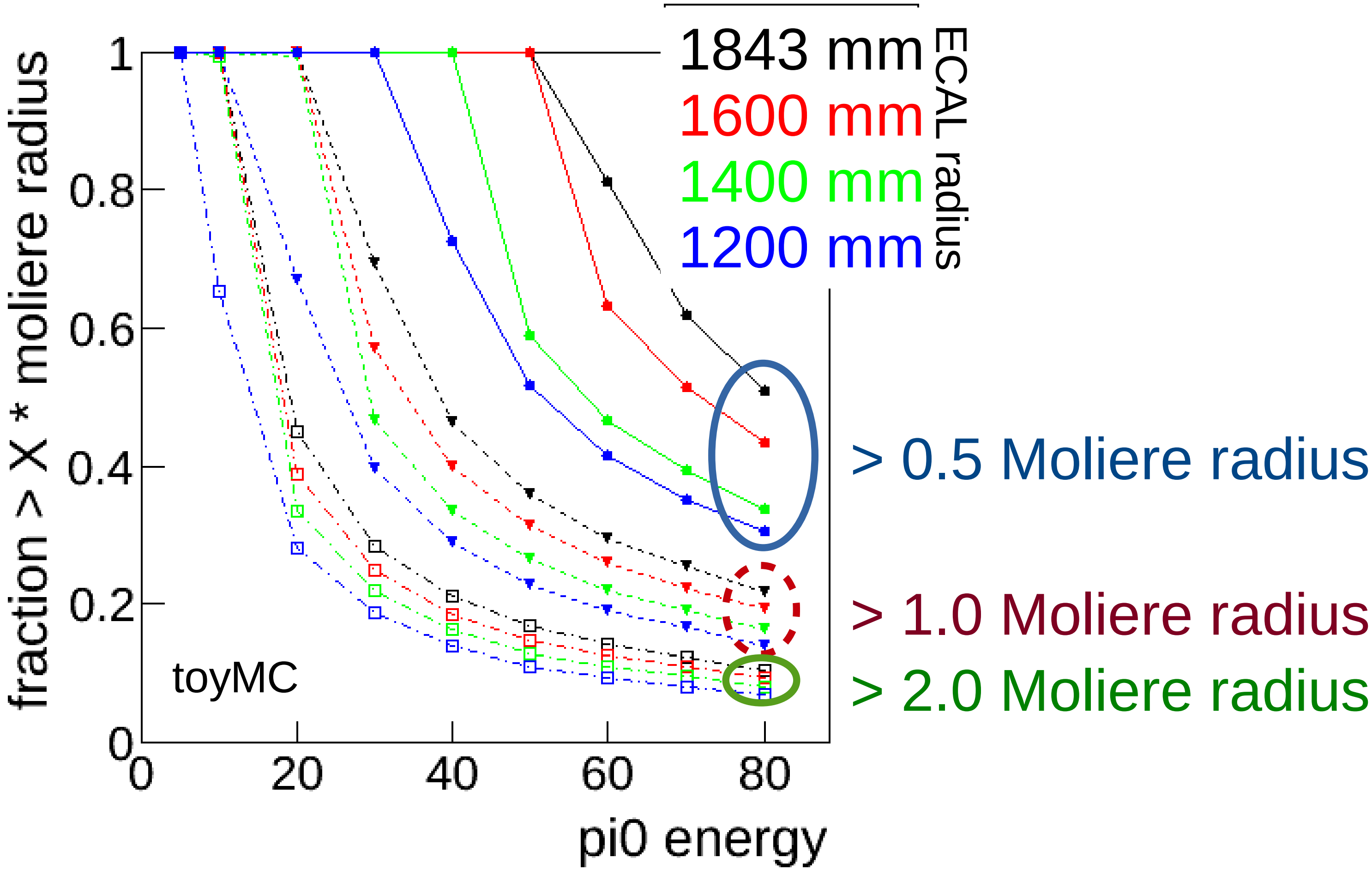


n.b.
pi0 produced in tau decays from ZH @ 250 GeV have energy up to ~60 GeV, average ~20 GeV

π^0 of 30 GeV and below should be identifiable
in a typical ILC ECAL
with a good photon separation algorithm

π^0 of 80 GeV look difficult

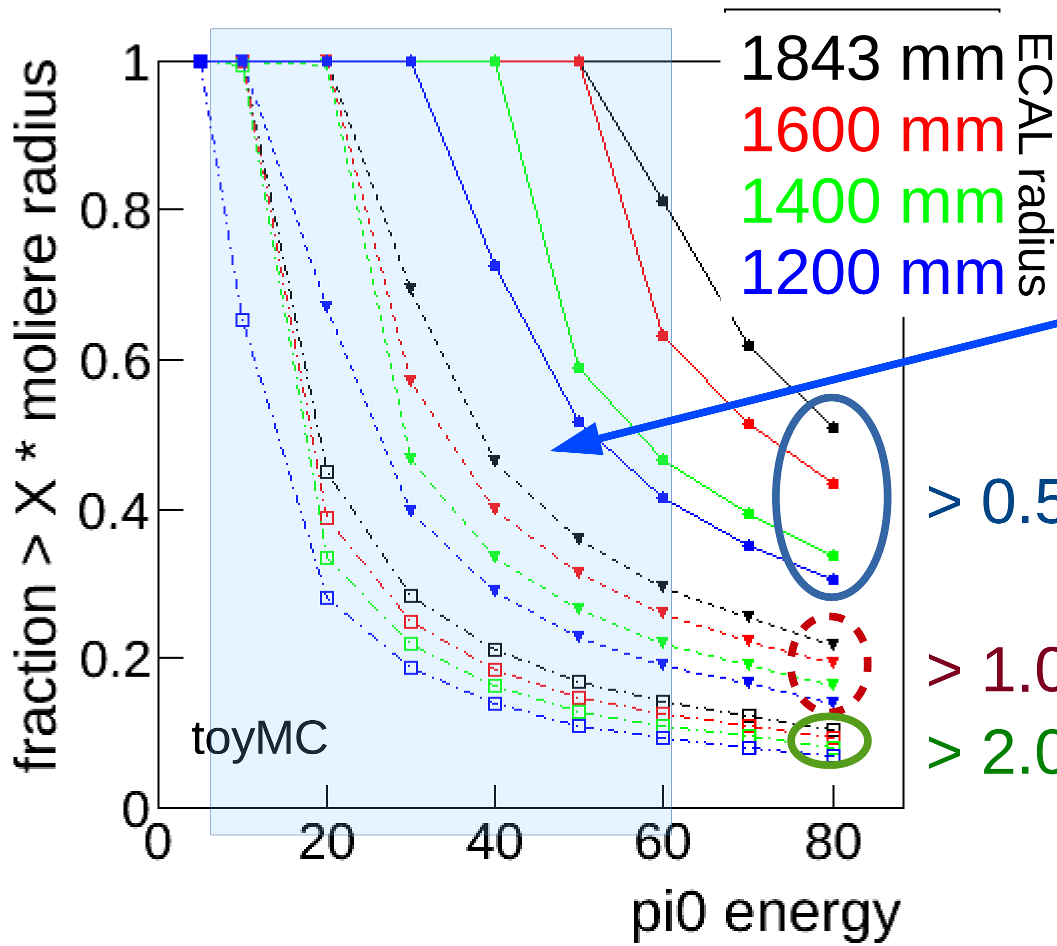
Which fraction of π^0 have
photons separated by > 2, 1, 0.5 Moliere radius
in the ECAL?



Quality of
pi0/photon
reconstruction

Unlike the case of JER, we cannot offset a smaller detector by increasing the B-field

Which fraction of π^0 have
photons separated by > 2, 1, 0.5 Moliere radius
in the ECAL?



n.b.
pi0 produced in
tau decays from
ZH @ 250 GeV
have energy
up to ~60 GeV,
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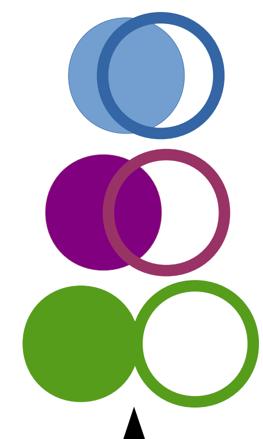
> 0.5 Moliere radius

> 1.0 Moliere radius

> 2.0 Moliere radius



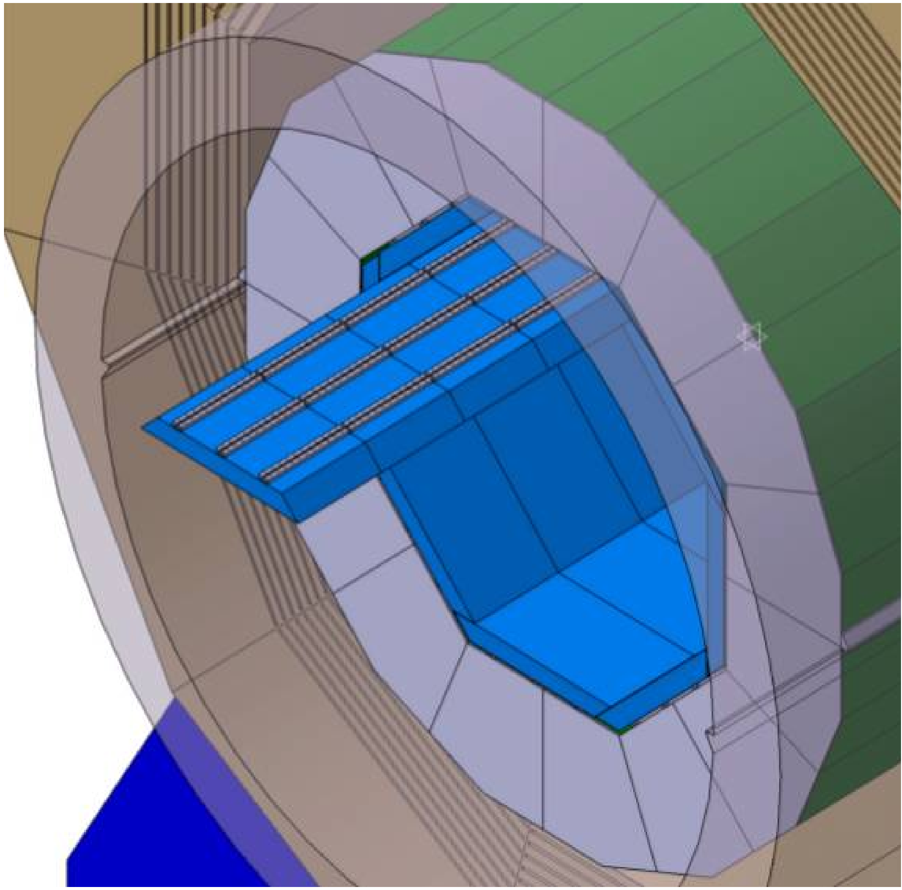
Quality of
pi0/photon
reconstruction

We may expect reconstruction of
π^0 of a few 10s of GeV
to depend strongly on:
- ECAL radius
- Quality of π^0 reconstruction algorithm

Full simulation

mono-energetic π^0 in ILD detector
from interaction point, in random direction

For now, exclude events in which:
- π^0 does not decay to 2 photons
- one or more photons:
  convert before ECAL
  very forward (|cos(theta)|>0.95)
  in barrel-endcap overlap region
- hadron has interacted in tracker

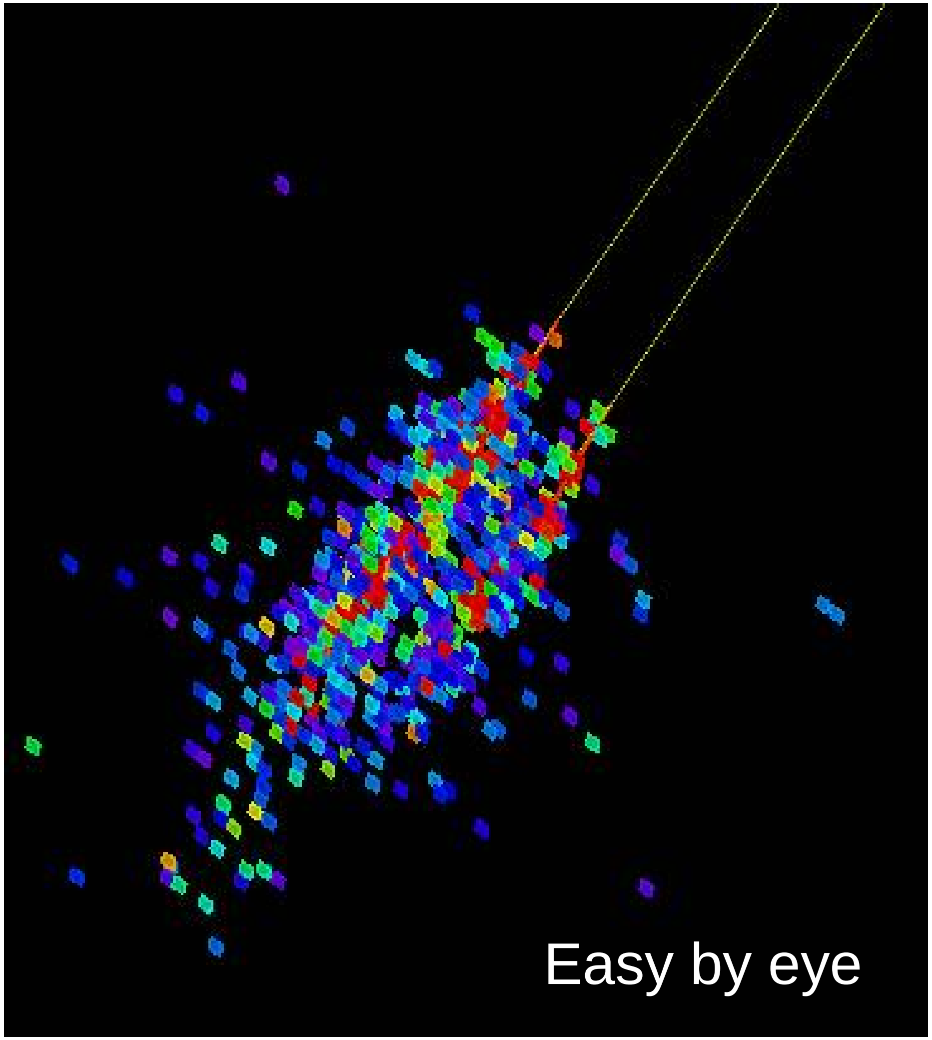


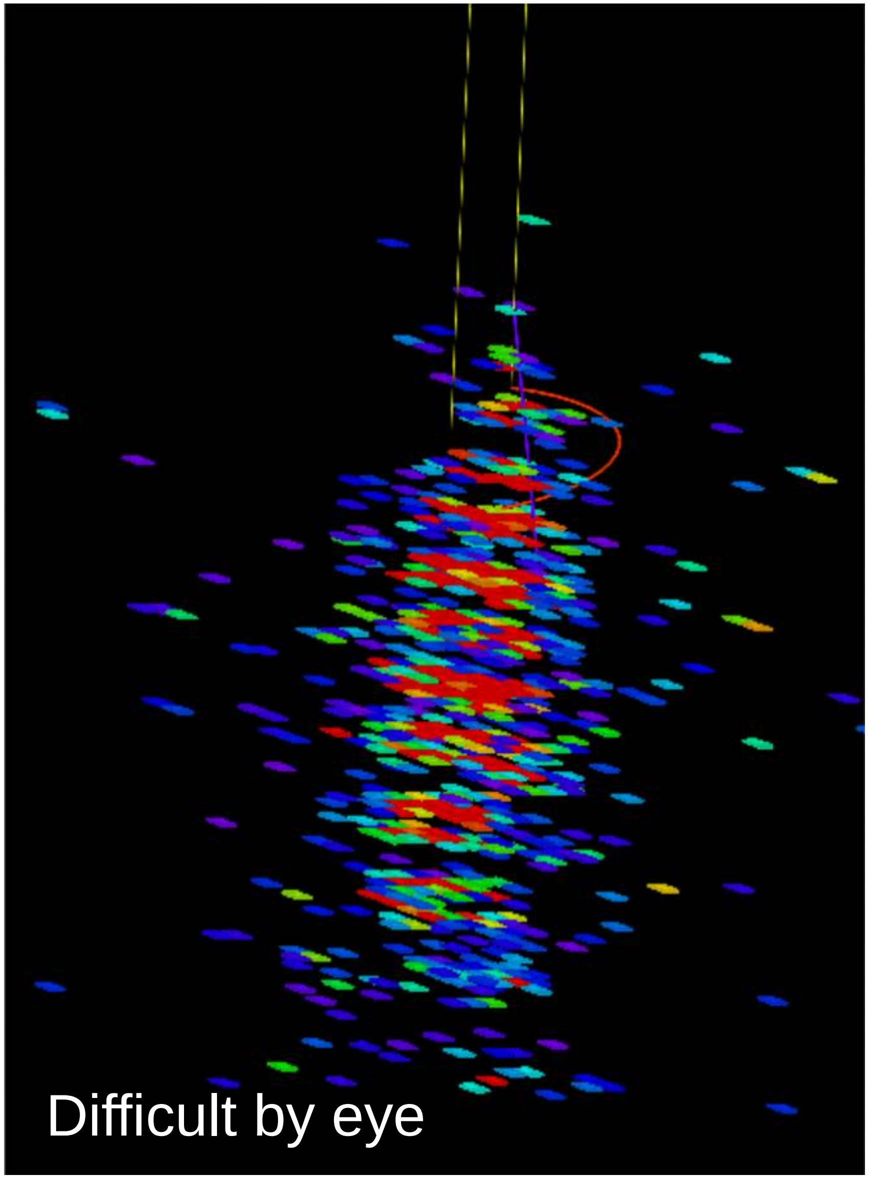
Simulate in ILD detector
Silicon ECAL, 5x5 mm^2 readout cells

Analyse events using
- GARLIC photon reconstruction algorithm
  an unstable private version...
- PandoraPFA general reconstruction algorithm
  DBD version (in ilcsoft v01-16-02)

ILD

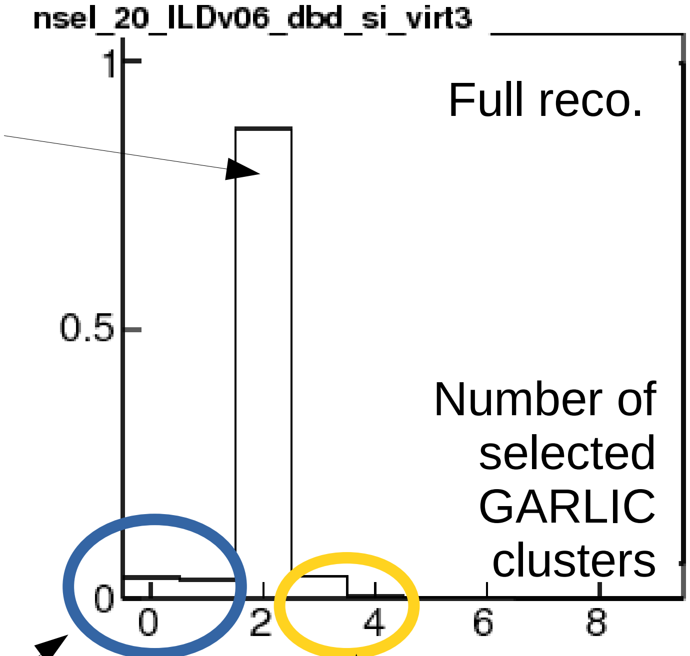
30 GeV pi0 50 GeV

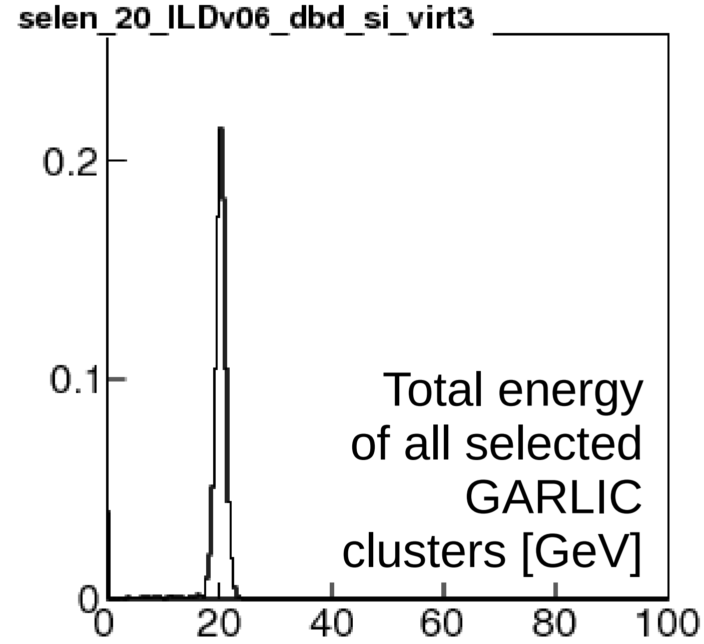




DBD-sized si-ECAL

Well reconstructed

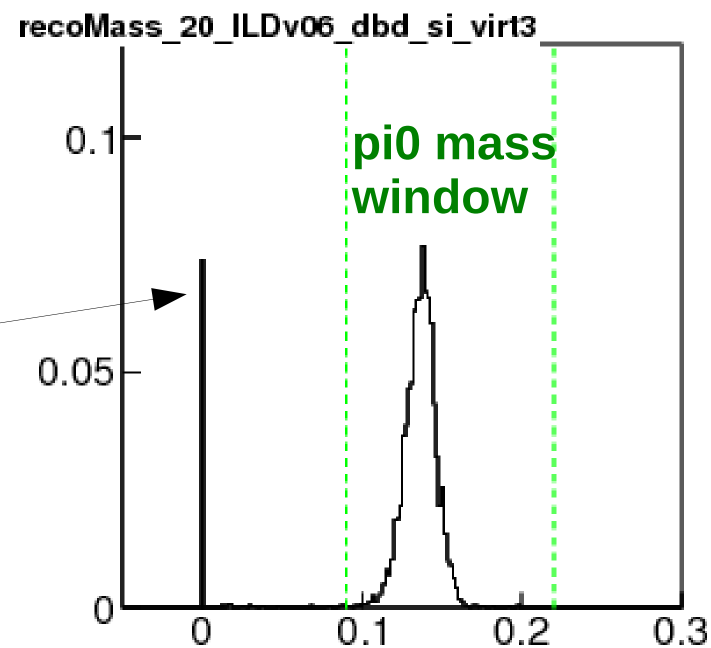




Photon identification inefficiency &
Cluster merging

Cluster splitting

<2 selected GARLIC clusters

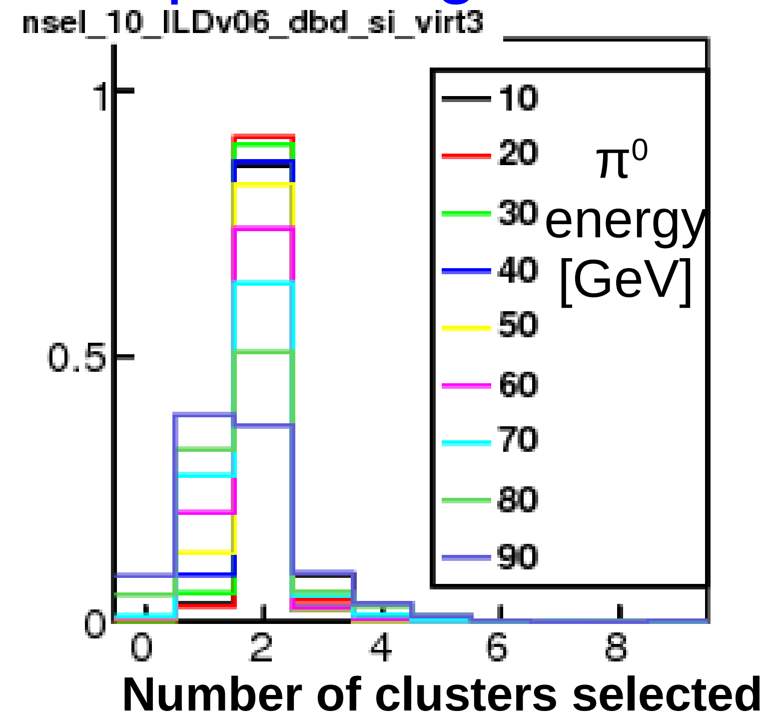


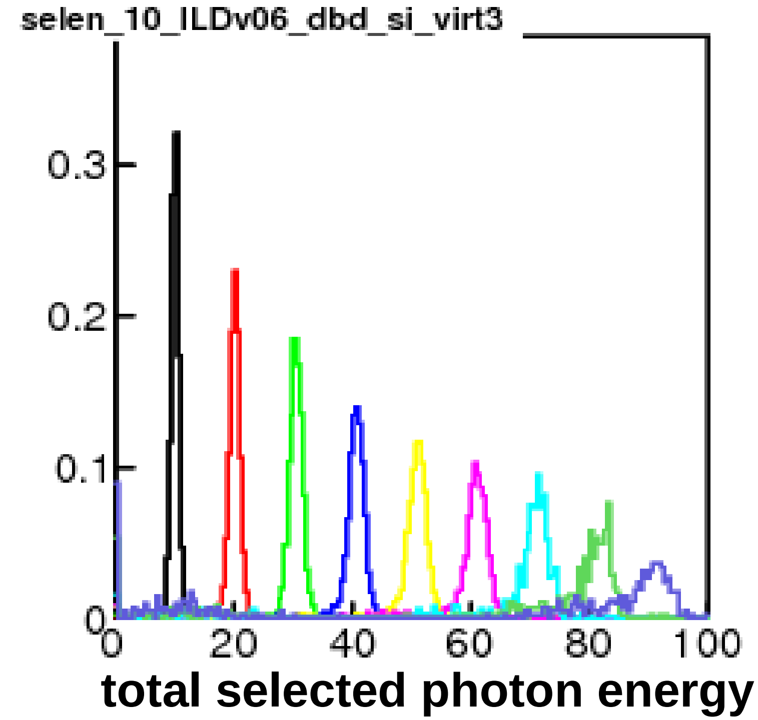
Invariant mass of 2 highest energy GARLIC clusters [GeV]

e.g.: 20 GeV pi0 in DBD si-ECAL

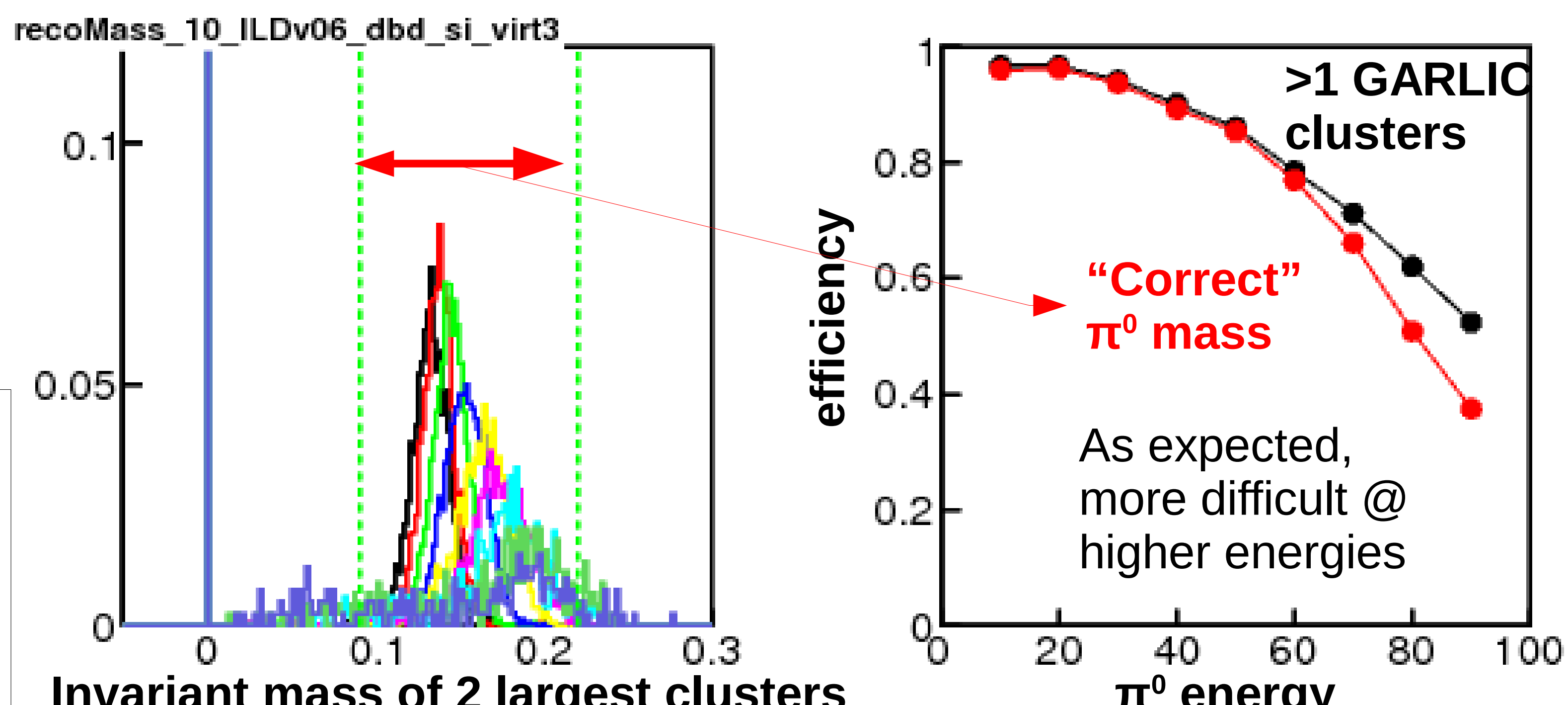
Compare different pi0 energies

Standard
ILD size
(1843 mm
ECAL radius)





Single π^0
full simulation
GARLIC reco.



Exclude:
- Conversions
- Barrel-endcap overlap
- Very forward
- Rare π^0 decays

Comparison of **GARLIC** and **PandoraPFA** algorithms for π^0 reconstruction

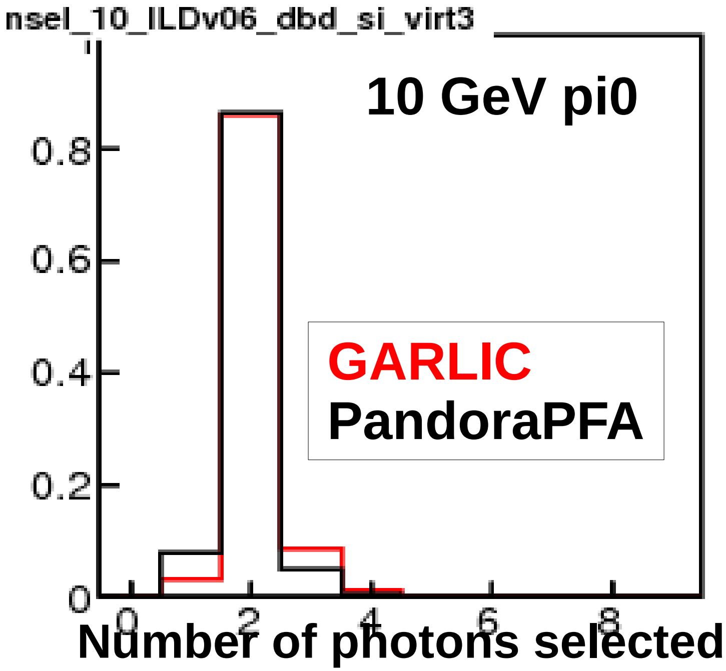
This GARLIC version tuned to separate nearby photons

2-photon separation (probably) not considered (at 1st order) in tuning/design of PandoraPFA

Using “DBD” version of Pandora

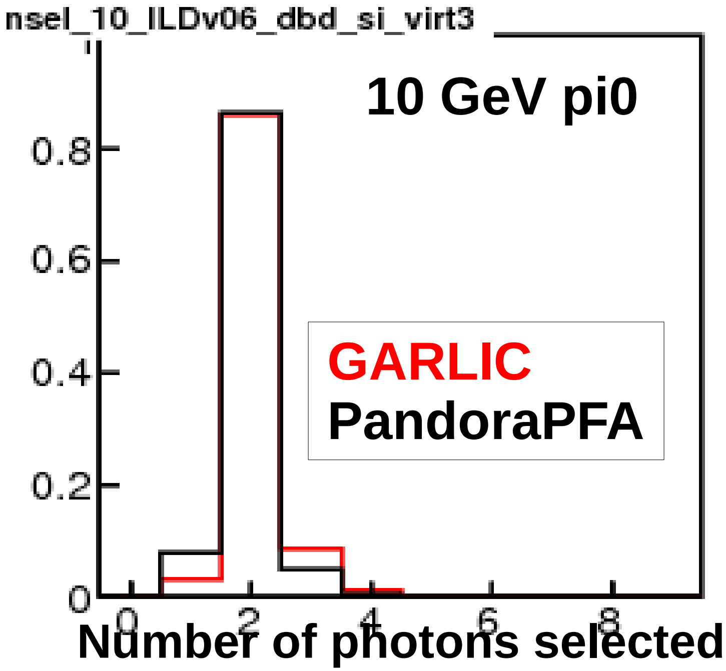
- I know there are photon clustering improvements in the latest Pandora version

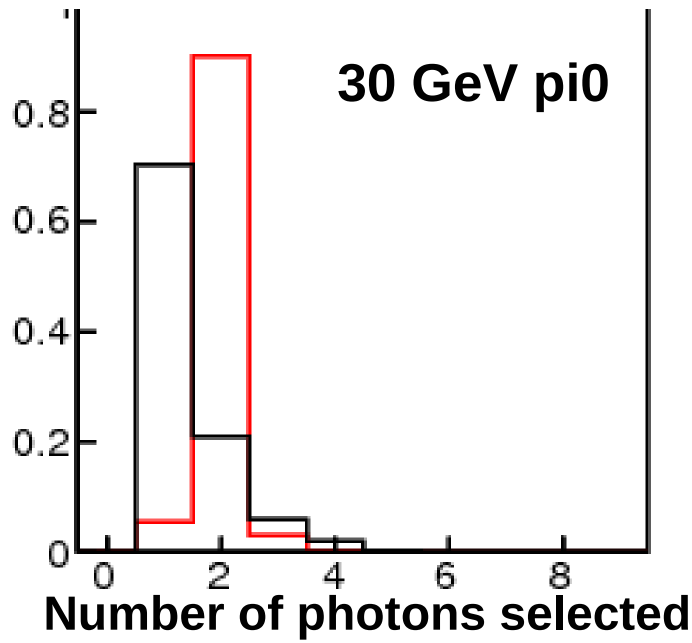
Comparison of GARLIC and PandoraPFA algorithms for π^0 reconstruction



DBD detector, SiECAL

Comparison of GARLIC and PandoraPFA algorithms for π^0 reconstruction





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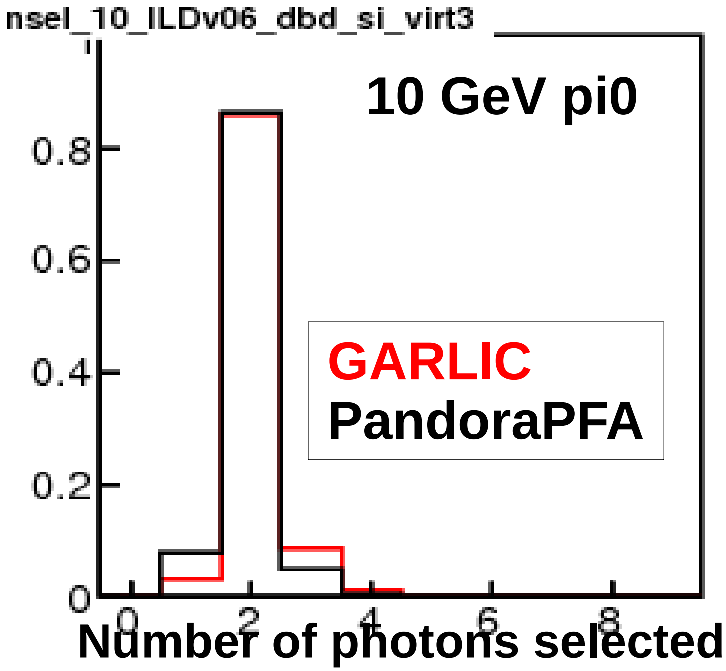
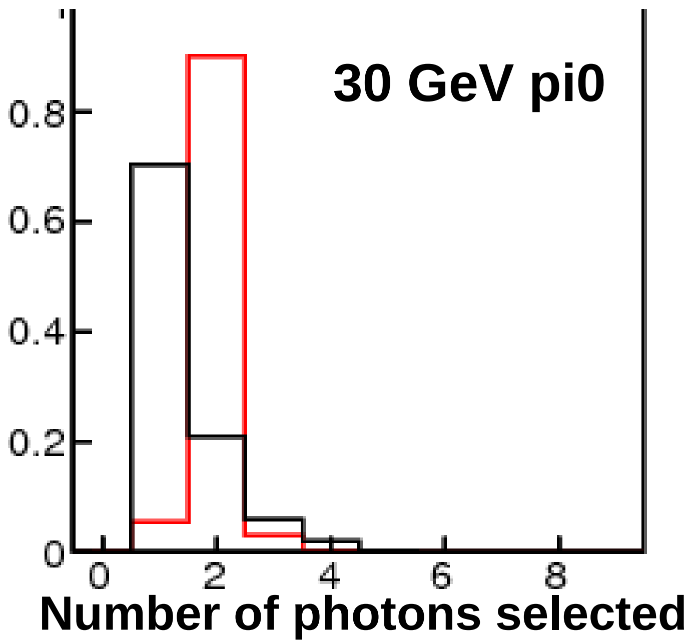
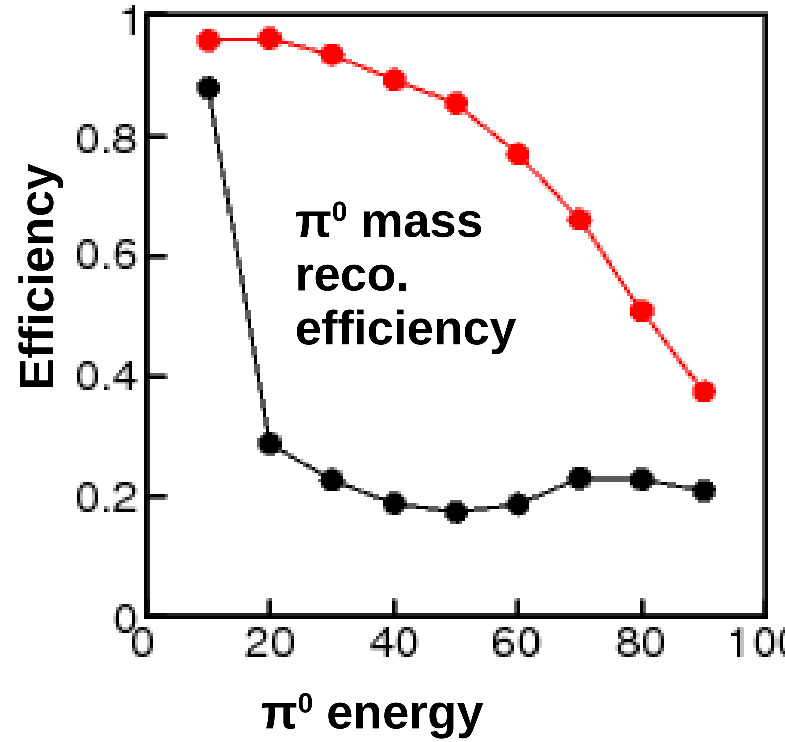


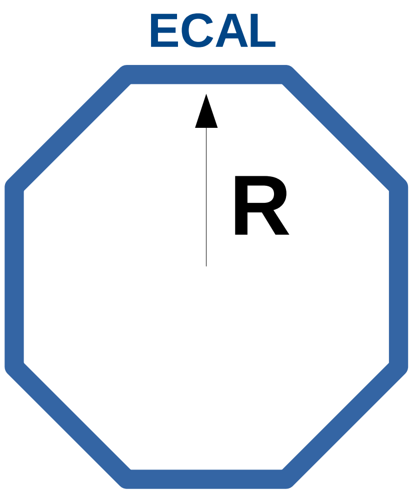




GARLIC reconstructs π^0 significantly better than PandoraPFA for pi0 energies>10 GeV

DBD detector, SiECAL

Compare π^0 reconstruction in detectors with different ECAL radius



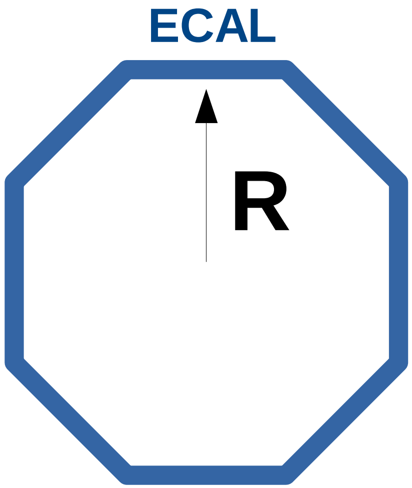
Attractive from a cost perspective,

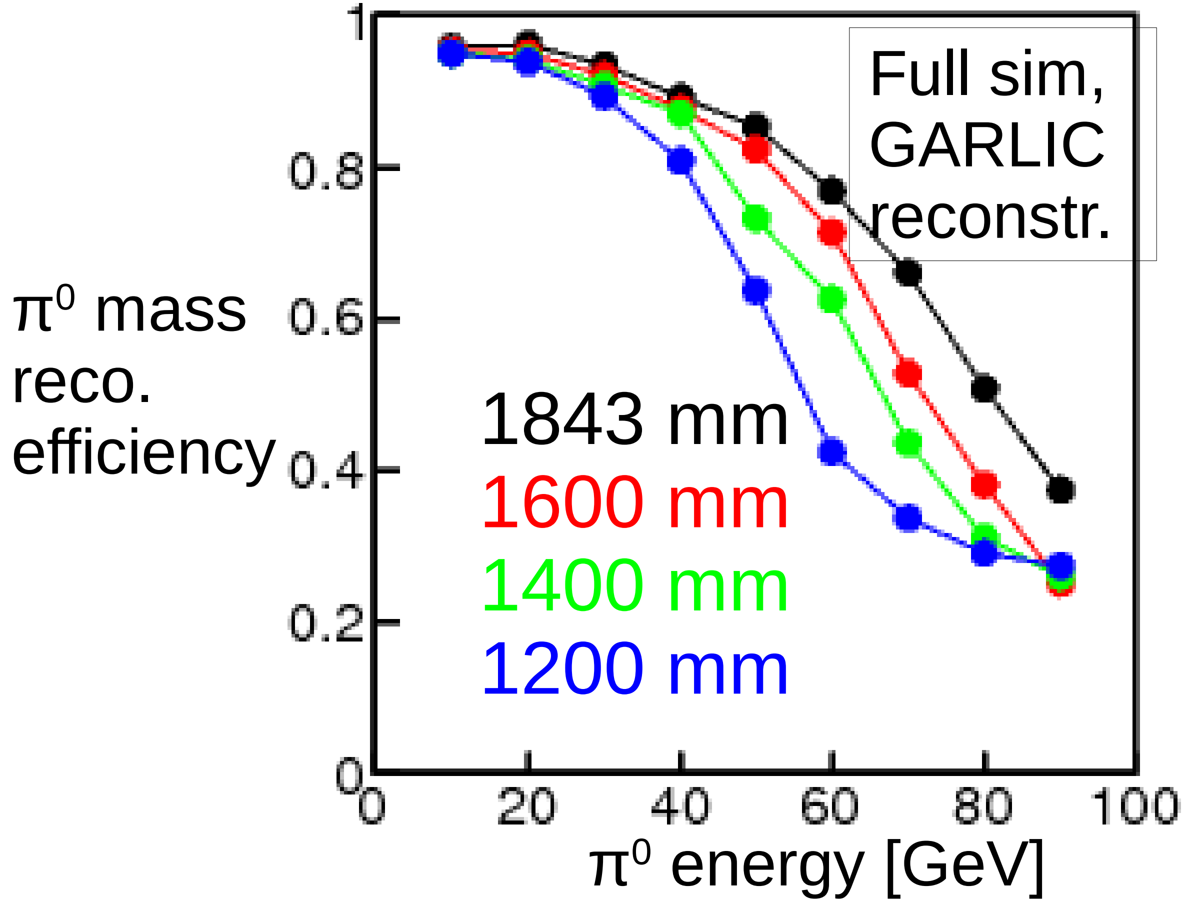
however

distance between photons at the ECAL $\propto$ radius

can't compensate by higher B

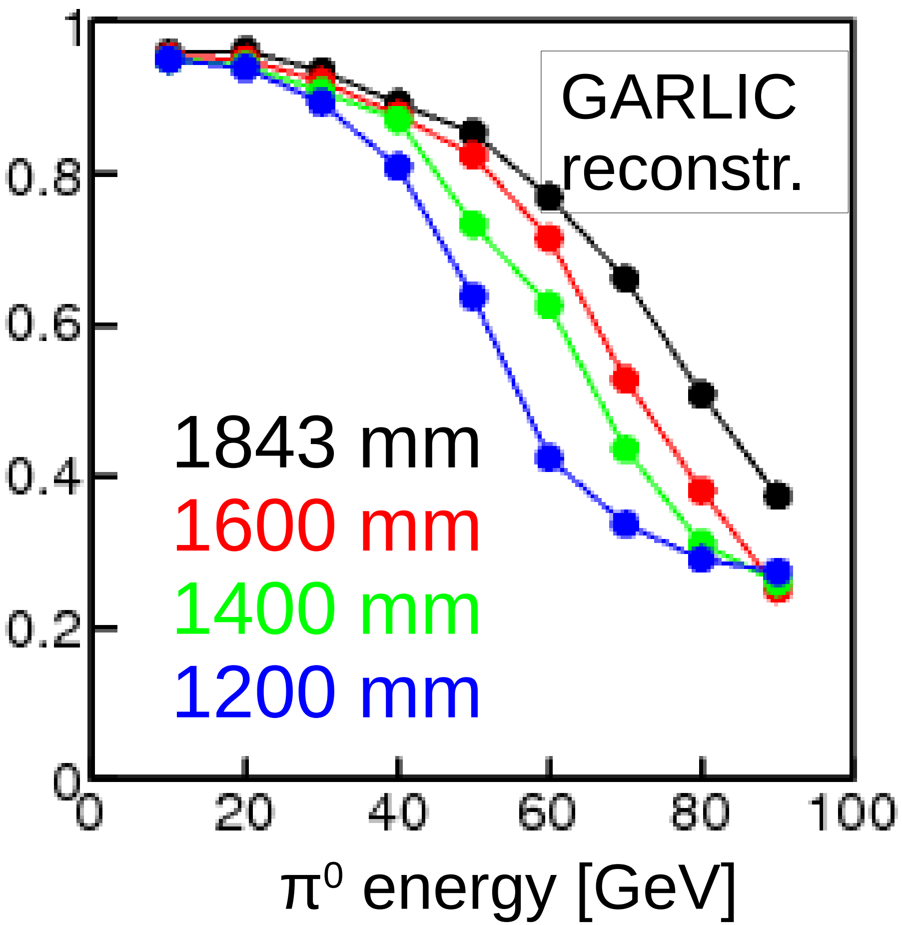
Compare π^0 reconstruction in detectors with different ECAL radius



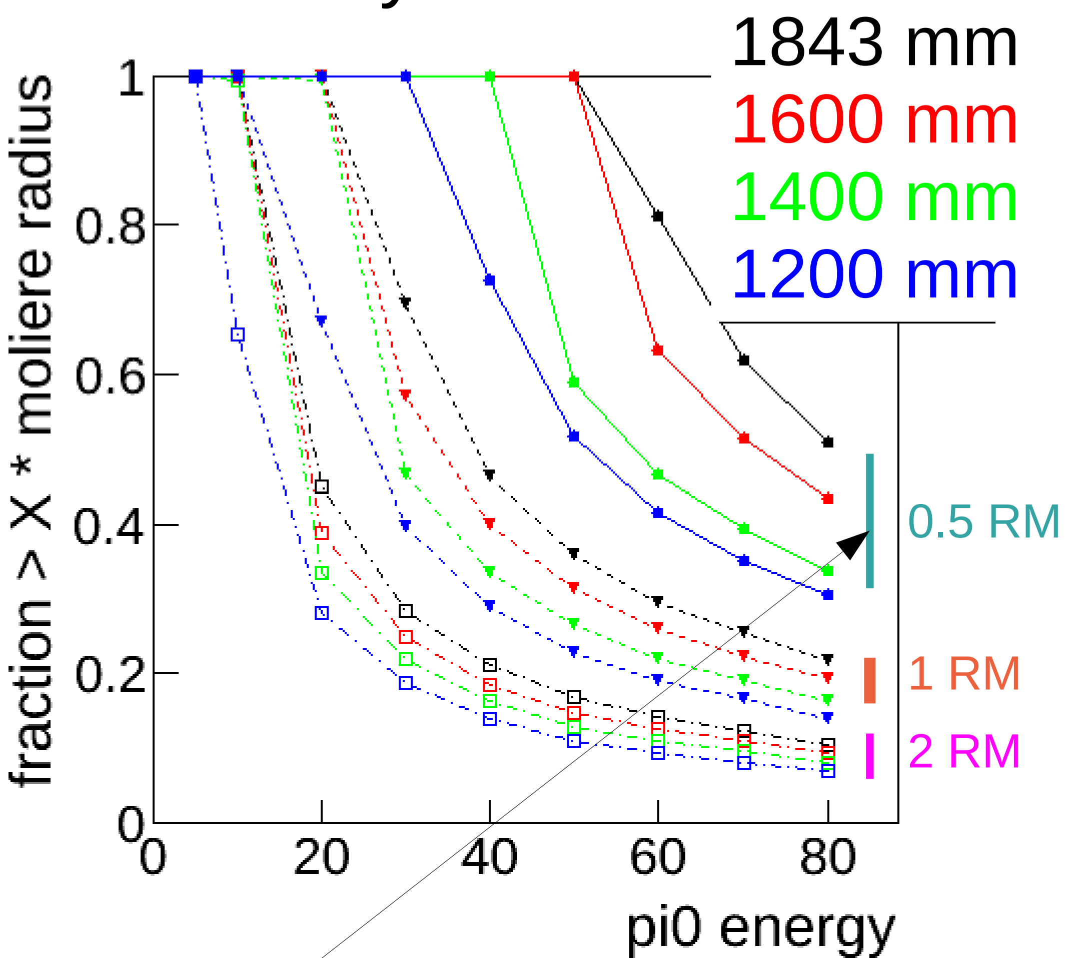


As expected, quite a strong dependence, particularly for π^0 energies 40~80 GeV

Full reconstruction



Toy MC

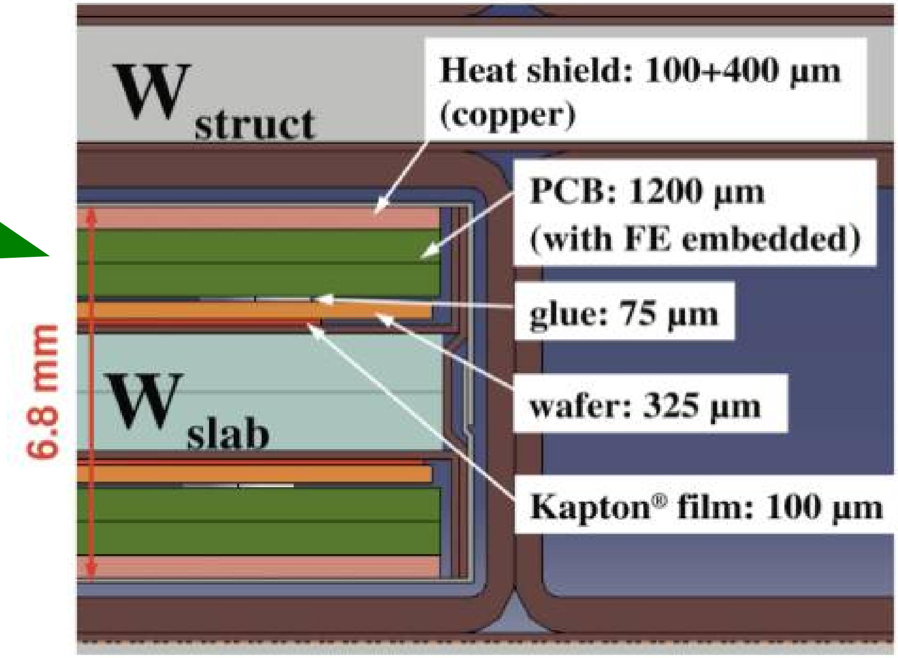


Rather similar dependecy:
GARLIC separation power ~ 0.5 Moliere radii

ECAL designs with different Moliere radius

Motivated by thickness of PCB in readout gaps

How thin must this PCB be?



PCB thickness affects effective Moliere radius

PCB thickness	R(Moliere)
0.8 mm (DBD, difficult)	~19 mm
1.2 mm (possible)	~20 mm
2.8 mm (~easy)	~25 mm

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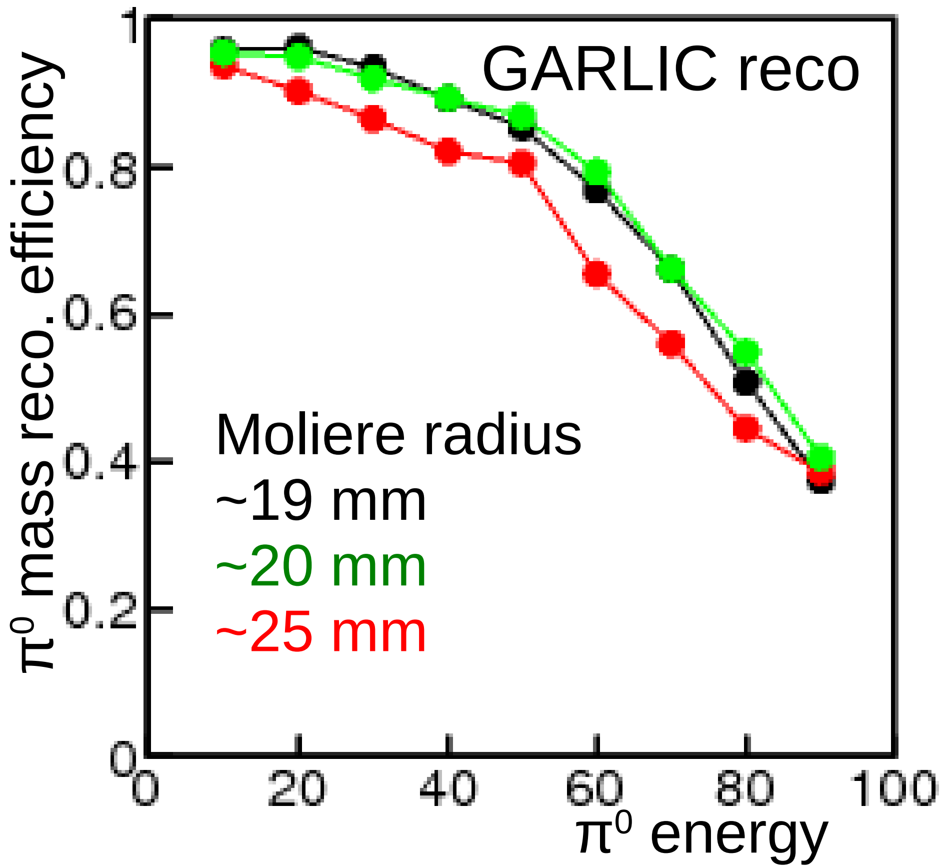

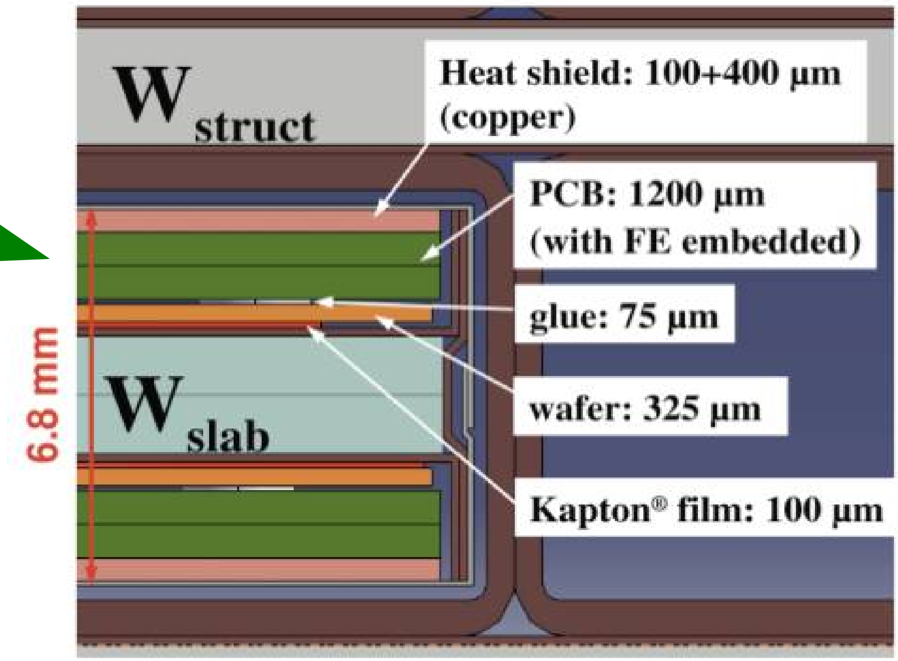

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PCB thickness	R(Moliere)
0.8 mm (DBD, difficult)	~19 mm
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Some modest degradation for thickest PCB design

Current activities:

Repeat pi0 analysis with GARLIC v3

Compare to ScECAL

Further improvements in GARLIC:

Apply GARLIC to tau decays

In particular Higgs CP measurement in tau decay mode

Summary

GARLIC v3.0 released
- Please treat it as a “beta” release and complain if it
  - doesn't work as well as you think it should

π^0 reconstruction is important for some measurements at ILC
- For example:
  - Higgs CP properties via τ decays at ZH threshold
    - π^0 of a few 10s GeV
  - Ultimate jet energy reconstruction via π^0 constrained fitting

Specialised GARLIC algorithm better than
- general purpose PandoraPFA
  - at resolving photons from high energy π^0
- ...further improvements probably possible

Radius of ECAL has a strong impact on π^0 reconstruction
- particularly in range 40-80 GeV
  - demonstrated using realistic simulation and reconstruction

Smaller effects are seen as function of Moliere radius
- (at least in technically reasonable range of variation)

BACKUP

Role of ECAL in ILC experiments

Identify photons, and measure their
    Energy, Position, Angle

Main sources of photons:
    Bhabha scattering <---- very forward: “LumiCal”
    π^0 decays in hadronic jets
    I(F)SR, bremsstrahlung

Photons often not isolated:
    require excellent pattern recognition
        to separate nearby particles

“prompt” photons are rarer: e.g. H -> γγ
    such rare processes are not a top priority @ ILC
    LHC usually does this better, thanks to large # of produced H

Layer-based sampling EM calorimeter design

natural segmentation of readout across layers

Tungsten absorber layers

20-30 layers, 0.5~1.5 X_0 thickness

Highly segmented active layers ~5x5 mm^2 granularity

silicon PIN diodes

or

scintillator strips

Transverse size of EM shower governed by Moliere radius:

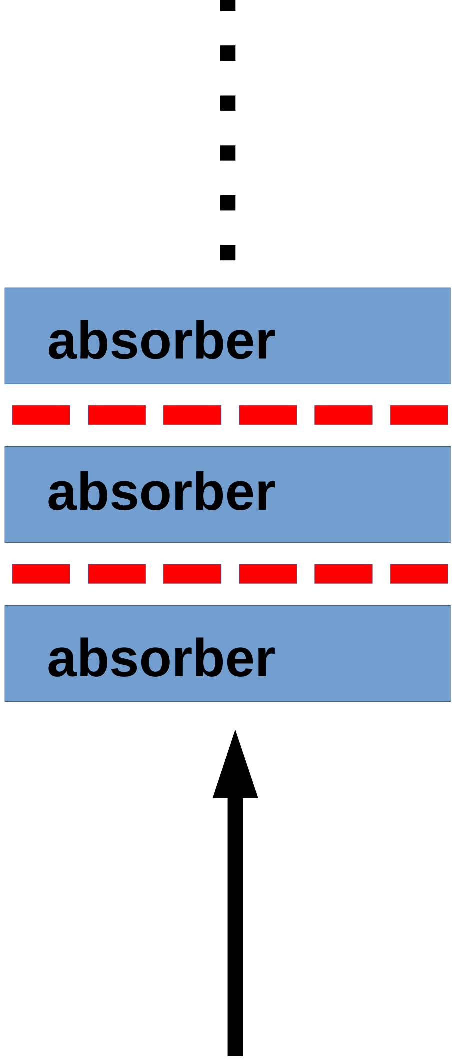
motivates:

use of tungsten

and

thin readout gap between absorber layers

Moliere radius ~20mm in ILD ECAL

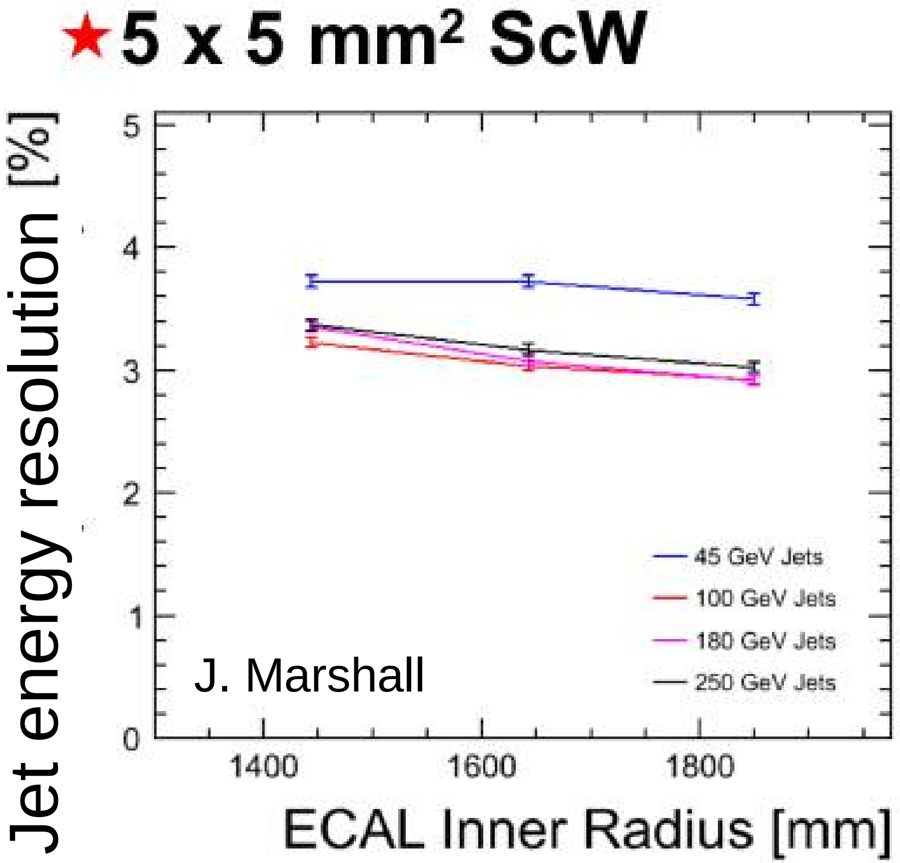


ECAL is most expensive sub-detector
- large active area
- 10-100M readout channels
- expensive readout technology (silicon detectors, SiPM)

Studies are underway to see if the ECAL cost can be reduced
without severely affecting detector performance

Cost determined by total sensor area and number of readout channels
Most sensitive parameters:
- Inner radius of ECAL <--- affects particle separation in ECAL
- Number of sensitive layers <--- affects single particle energy resolution

e.g. Reducing ECAL radius has rather little effect on Jet Energy Measurement



π^0 reconstruction

Hadronic jets: interested in the total energy deposited by photons

π^0 reconstruction not particularly relevant

(although kinematic fits of π^0 can somewhat improve jet energy resolution)

Tau lepton

Hadronic decay branching ratios

τ^- BRs	0 π^0	1 π^0	2 π^0	3 π^0
1 h^-	12%	26%	9%	1%
3 h^-	10%	4.5%	0.5%	0.1%

If the decay mode of τ can be reconstructed, can be used as polarimeter

distribution of τ decay products ---> orientation of τ spin

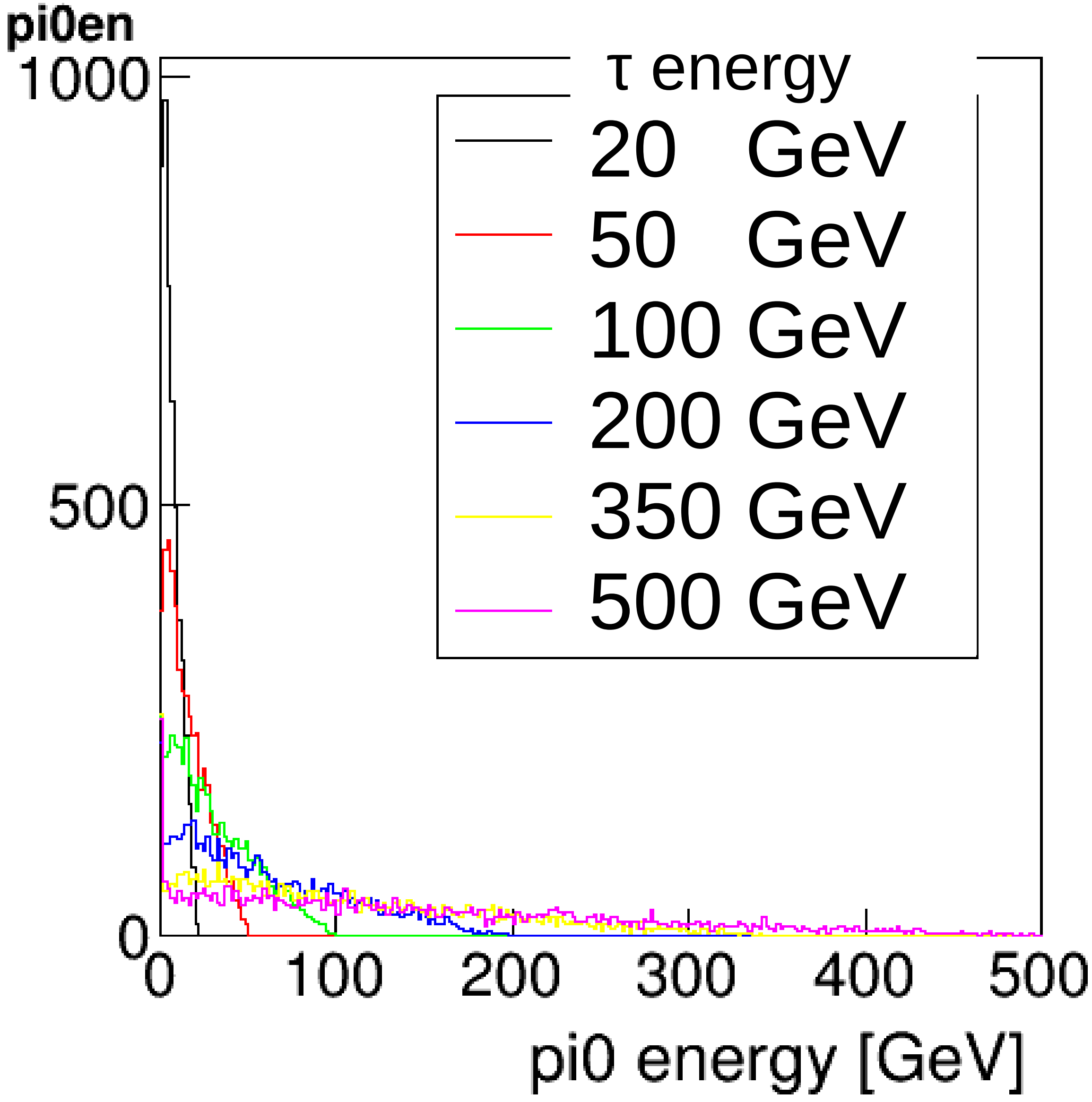
τ spin ---> spin properties of τ parent

In particular, **H --> τ τ** allows direct measurement of **Higgs CP** properties

CP mixing angle measurable to a few % @ ILC (e.g. arXiv:1308.2674)

τ decay mode must be correctly identified

Energy of π^0 produced in τ decays

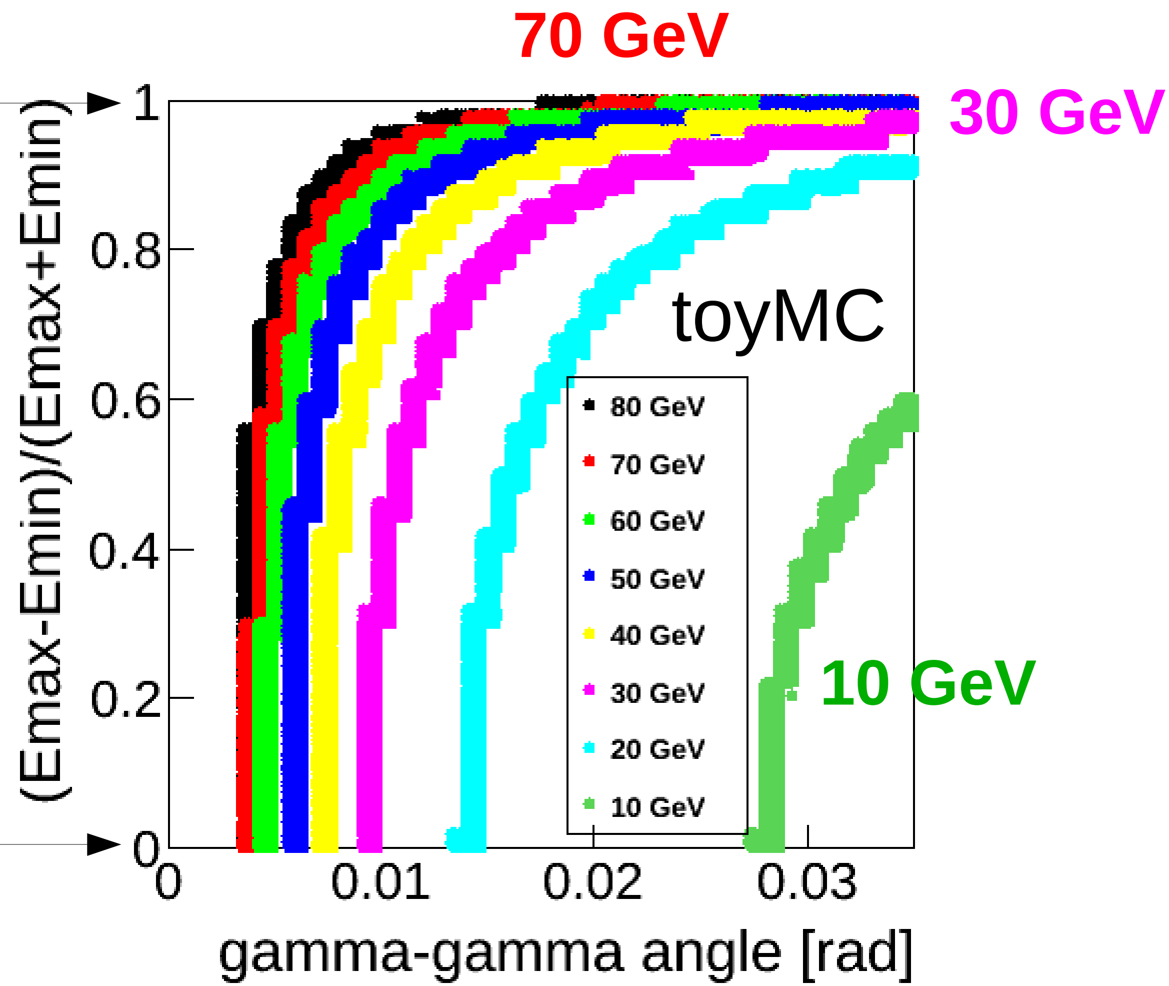


τ produced in Higgs decays near the e+e- -> ZH threshold
are strongest motivation for reconstruction of τ decay modes

---> τ energy ~ 60 GeV, π^0 energy typically few 10s of GeV

π^0 decays mostly to 2 photons

One photon carries almost all π^0 energy



Two photons have same energy

π^0 of different energies

- angle between photons
- asymmetry between photon energies

Angle subtended by 0.5*Moliere radius for different ECAL radii