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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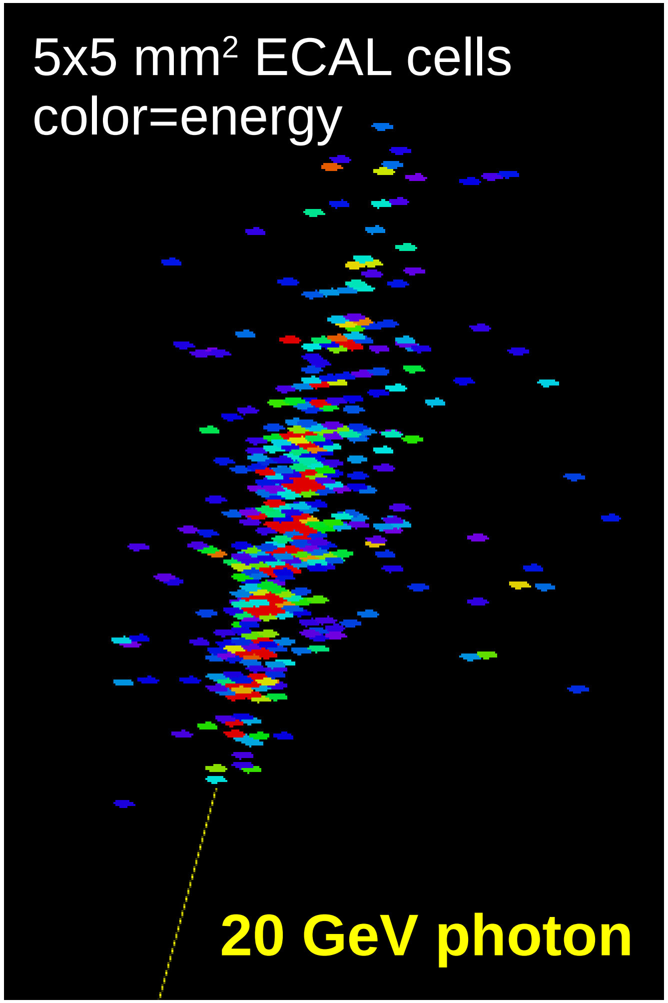
GARLIC photon reconstruction algorithm

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

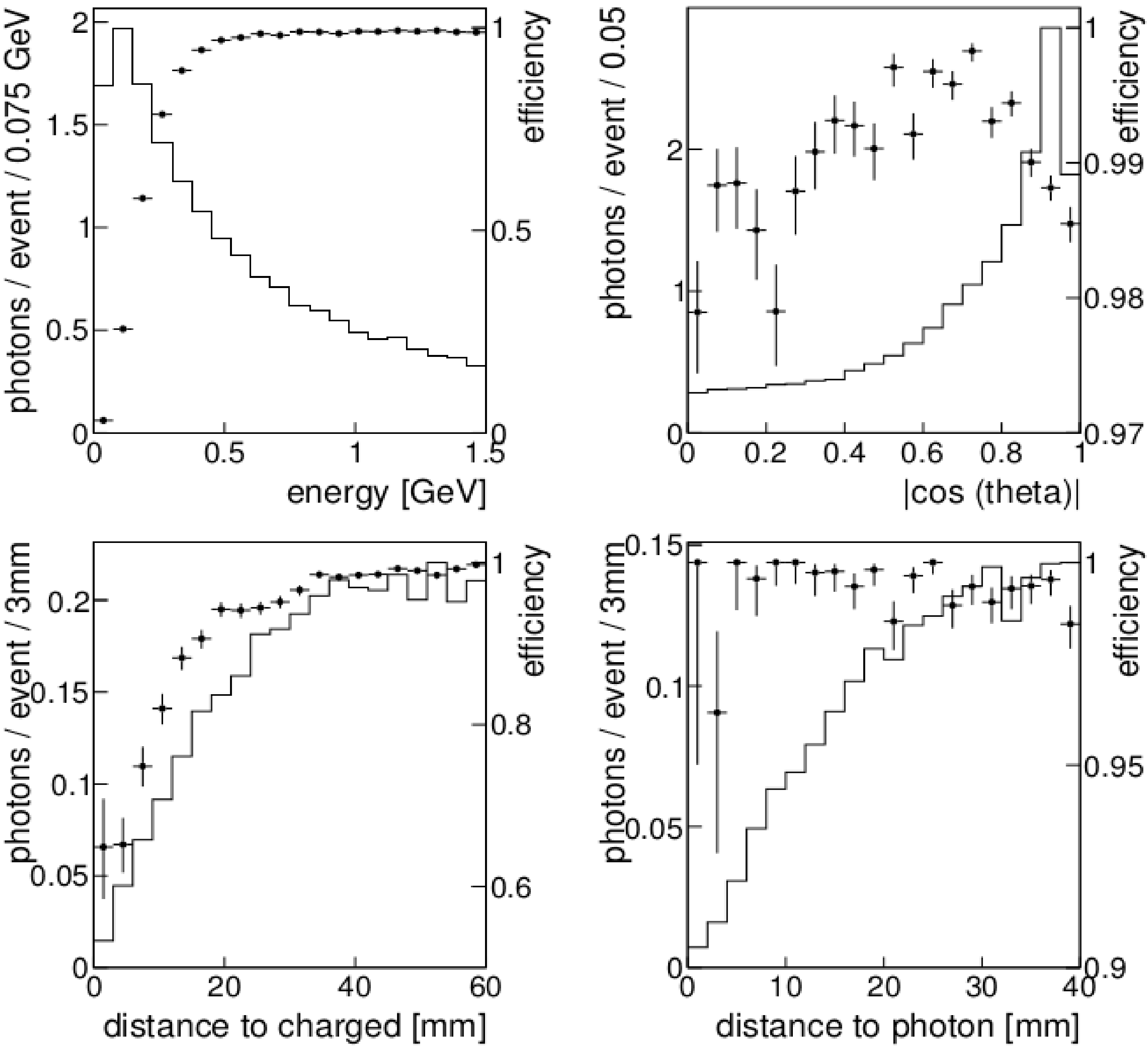
Decide if resulting cluster looks like photon
(old) Neural Network trained using jet events

(new) photon multi-var likelihood for
combining nearby clusters
selecting photon-like clusters

(now testing) simpler cut-based approach

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

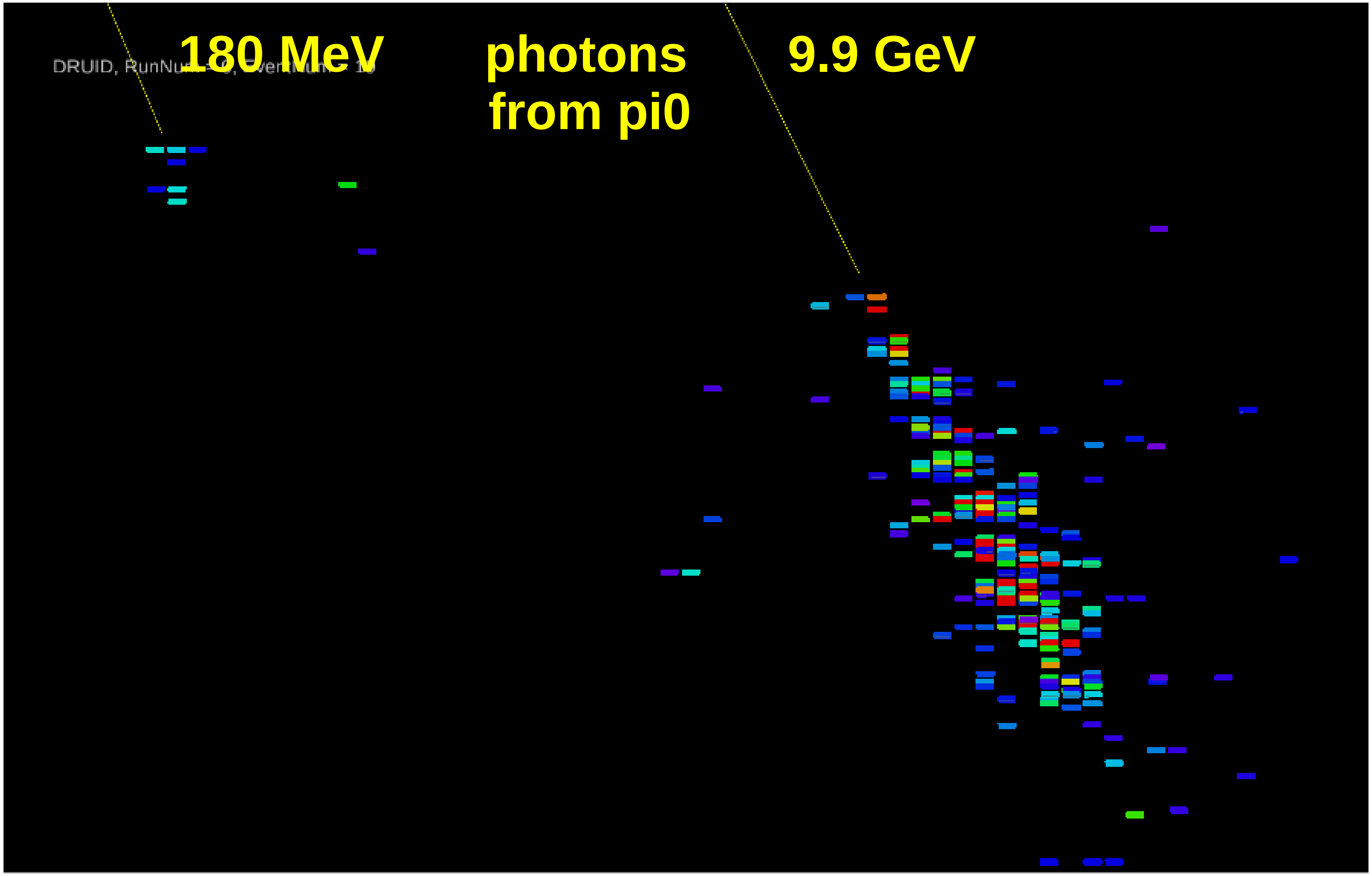
“Original” GARLIC performance in jets



“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



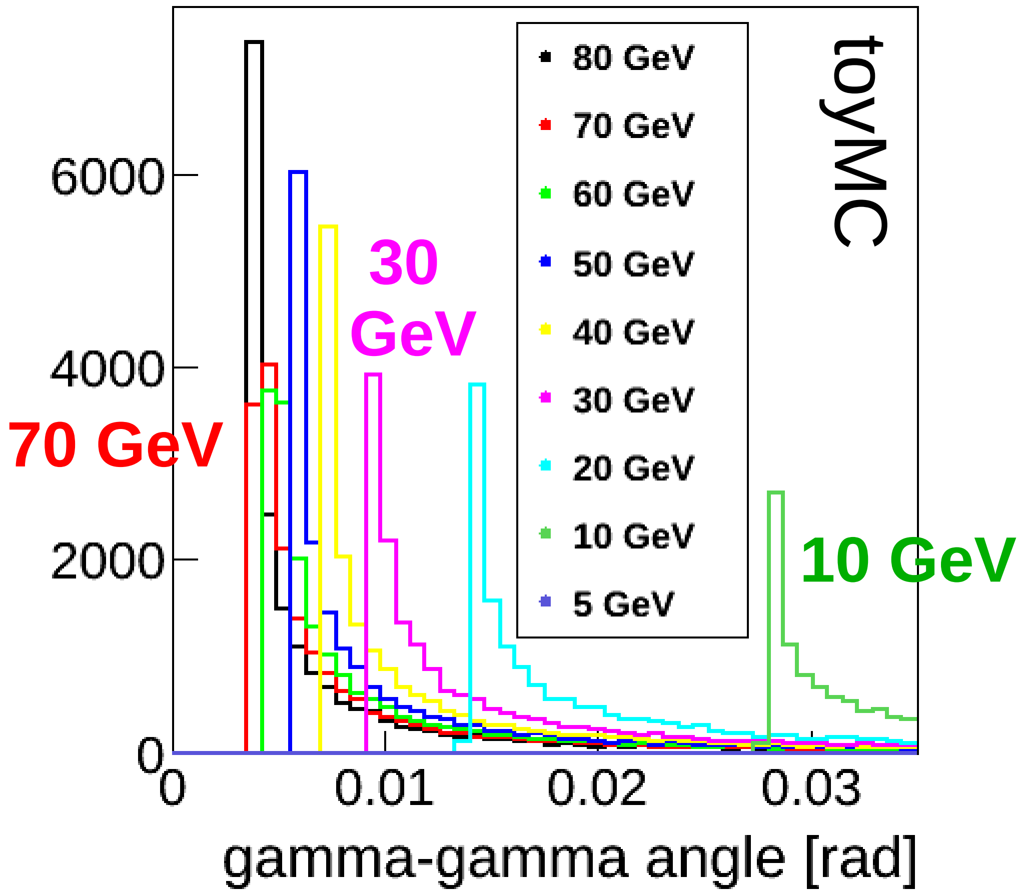
Recent work with view to:

- 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...)

Still “in progress”

Introductory motivation:

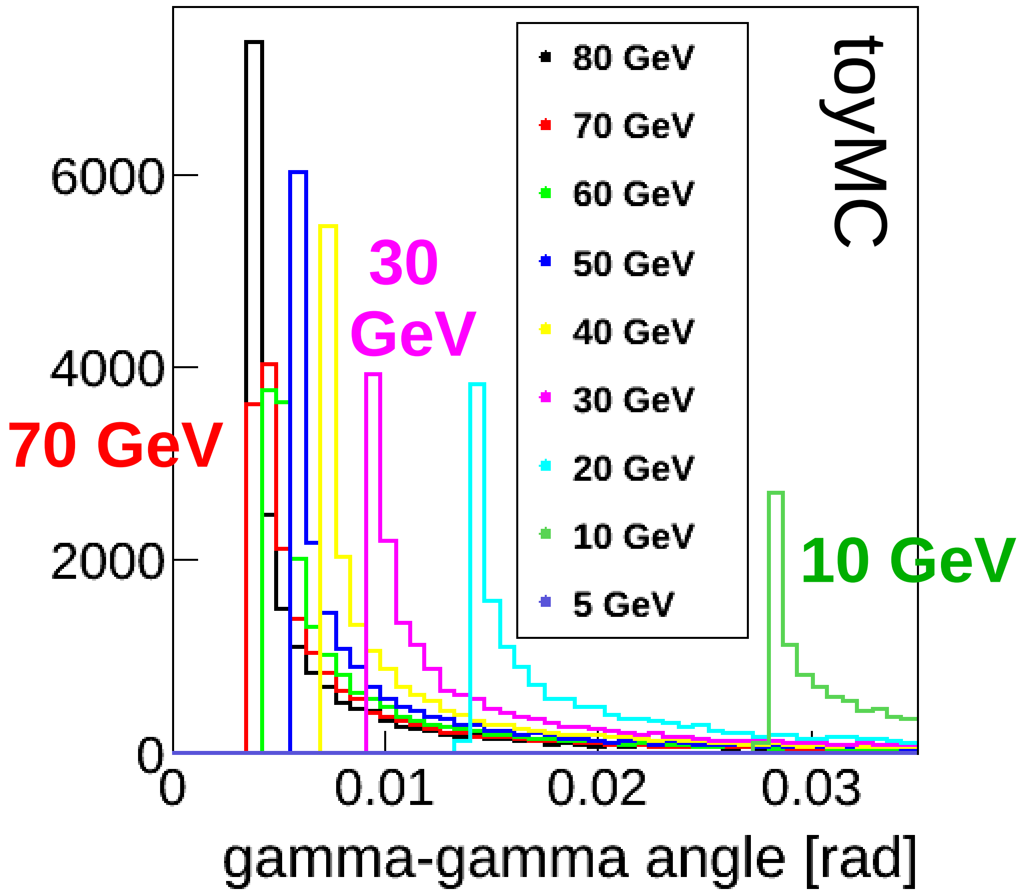
angle between photons at different π^0 energies



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

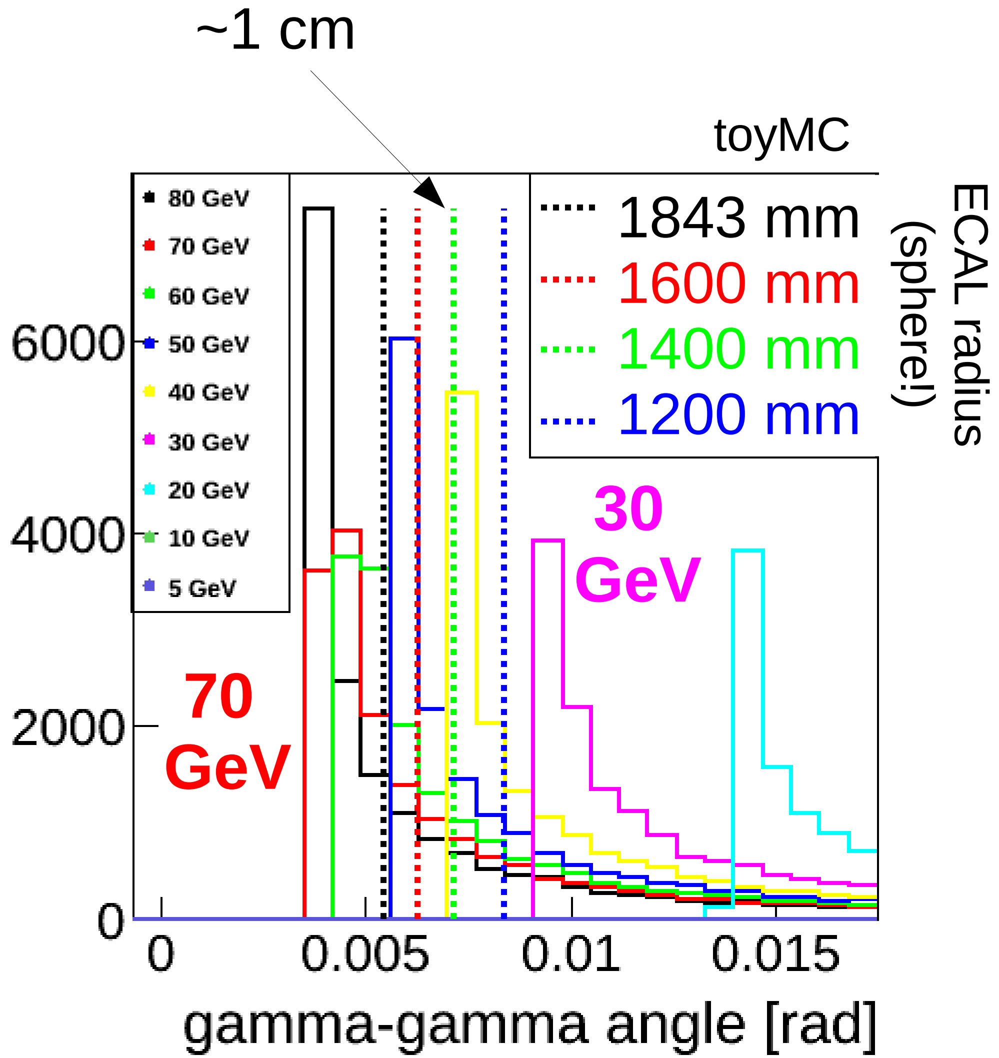
Introductory motivation:

angle between photons at different π^0 energies



Identification of pi0 in tau decays from H is (probably) important for measurement of Higgs CP properties

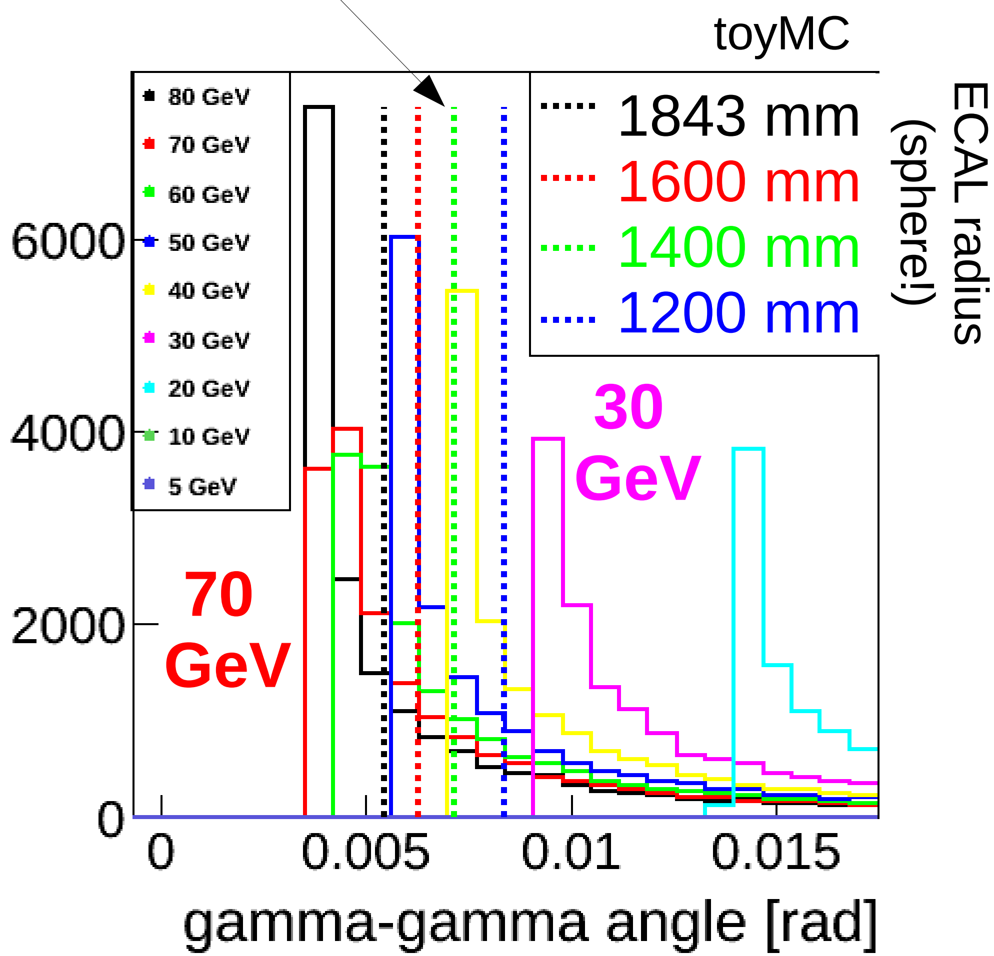
Angle subtended by 0.5*Moliere radius at different ECAL radii



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
~1 cm



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
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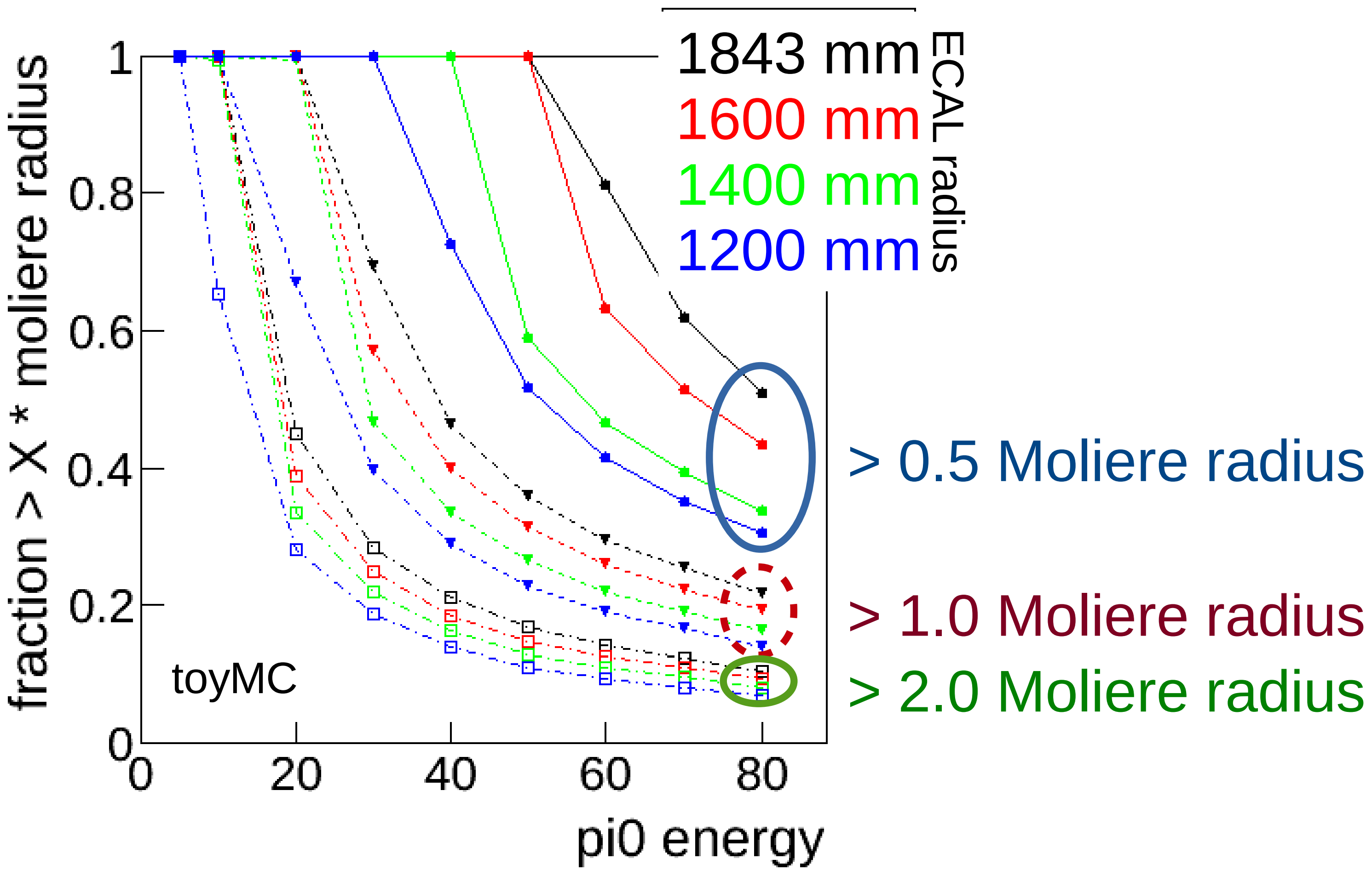
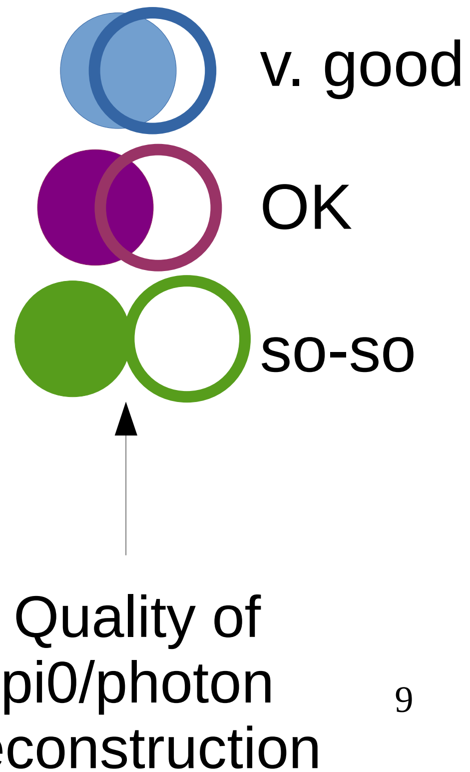
π^0 of 80 GeV look difficult

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





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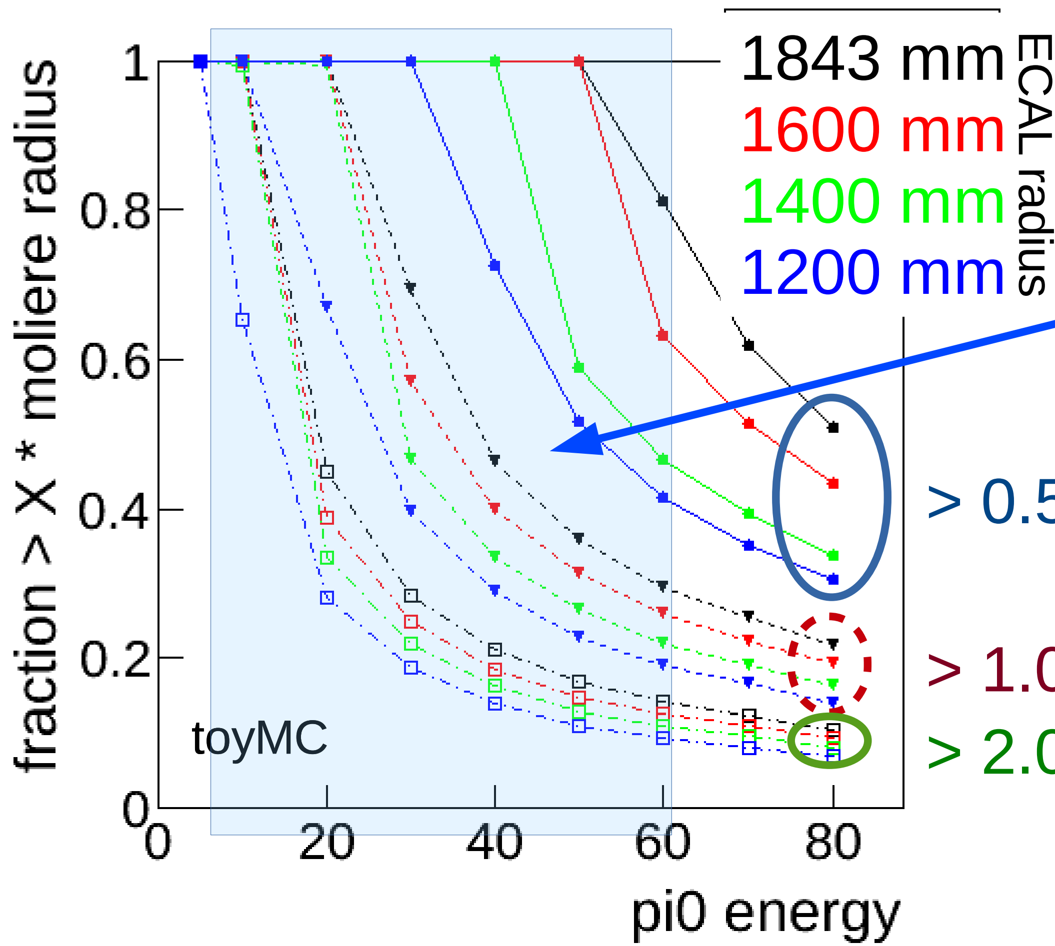

n.b.
pi0 produced in
tau decays from
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have energy
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average ~20 GeV

> 0.5 Moliere radius

> 1.0 Moliere radius

> 2.0 Moliere radius

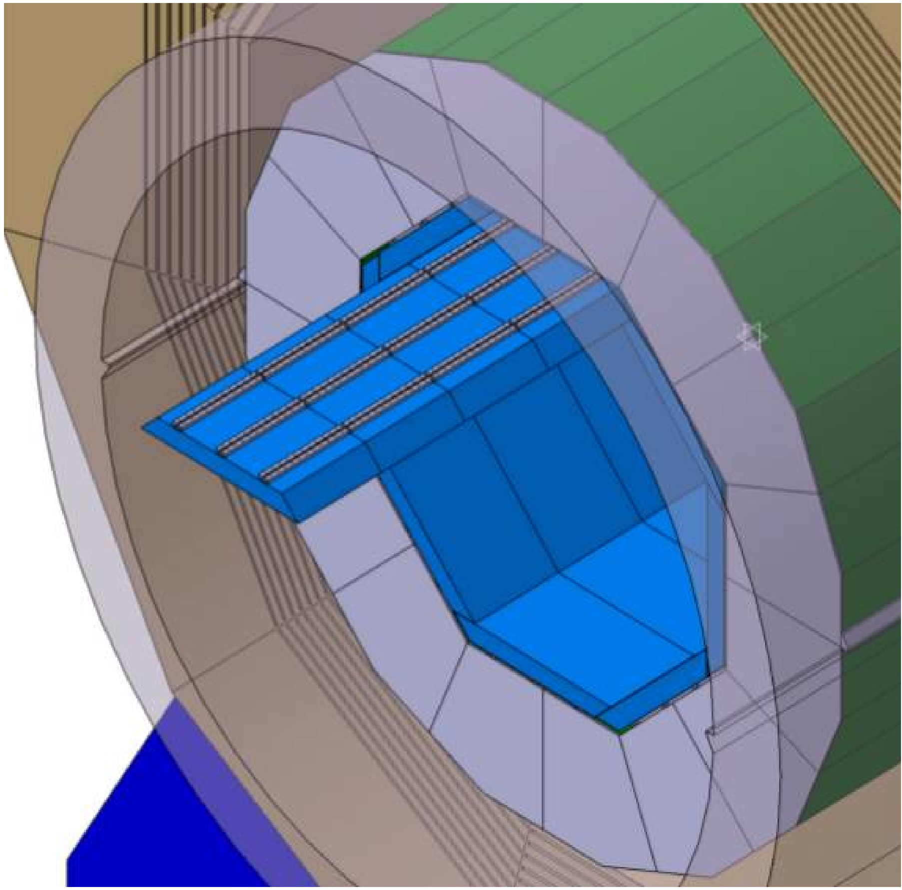
We may expect reconstruction of
π^0 of a few 10s of GeV
to depend strongly on:
- ECAL radius
- Quality of π^0 reconstruction algorithm

Quality of
pi0/photon
reconstruction

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

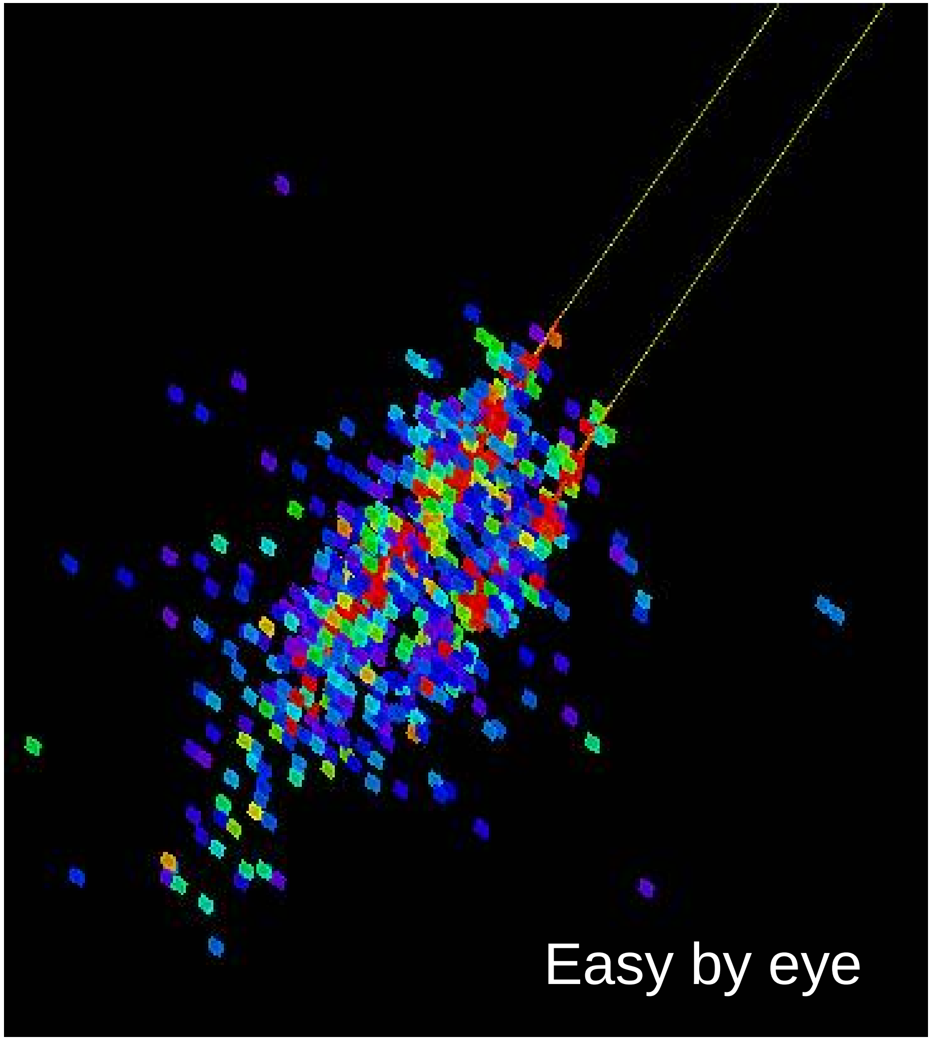


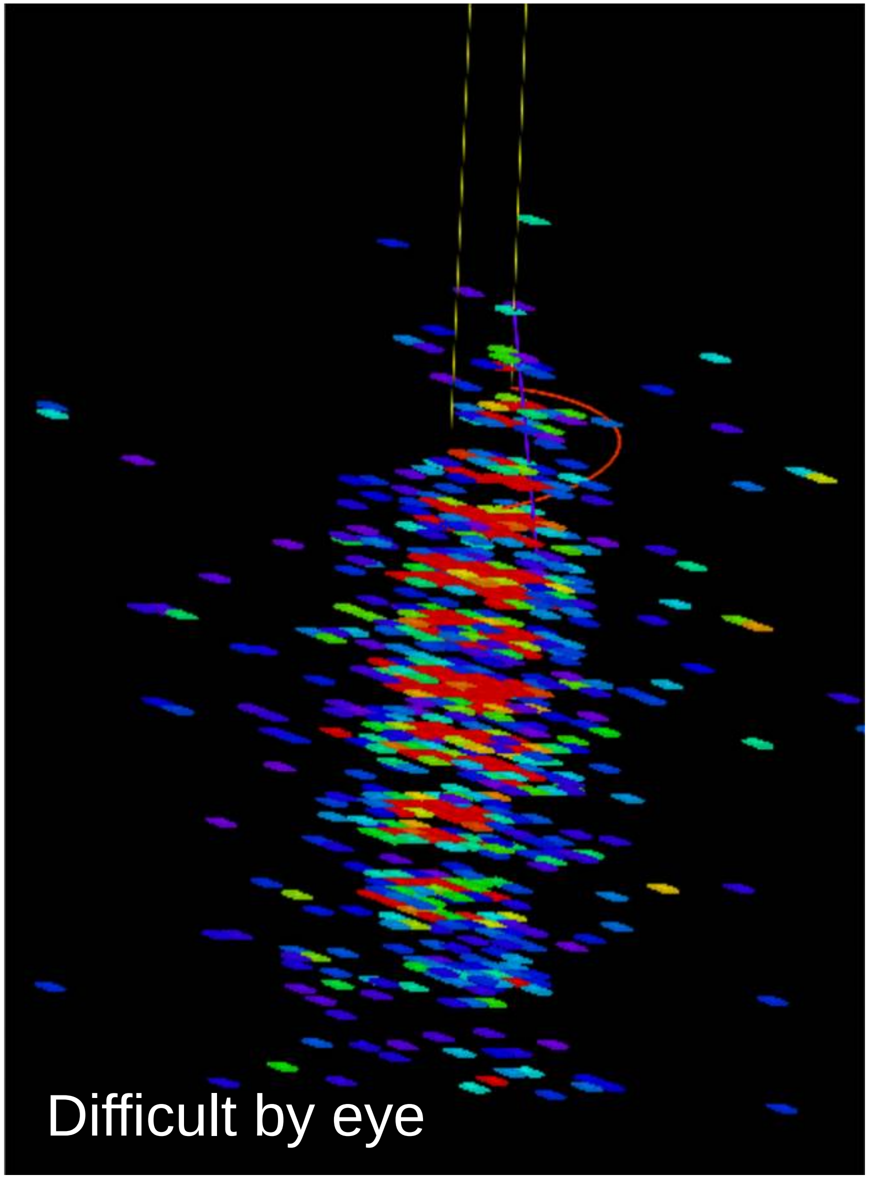
ILD

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

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

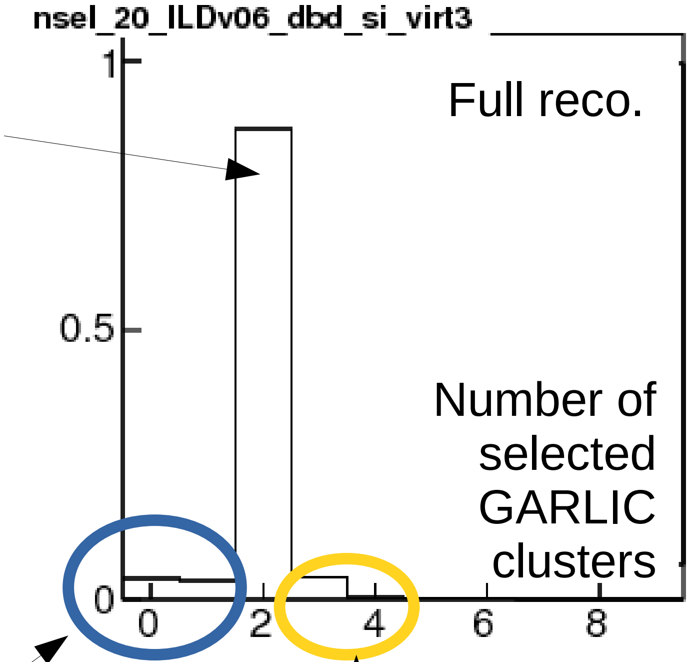
30 GeV pi0 50 GeV

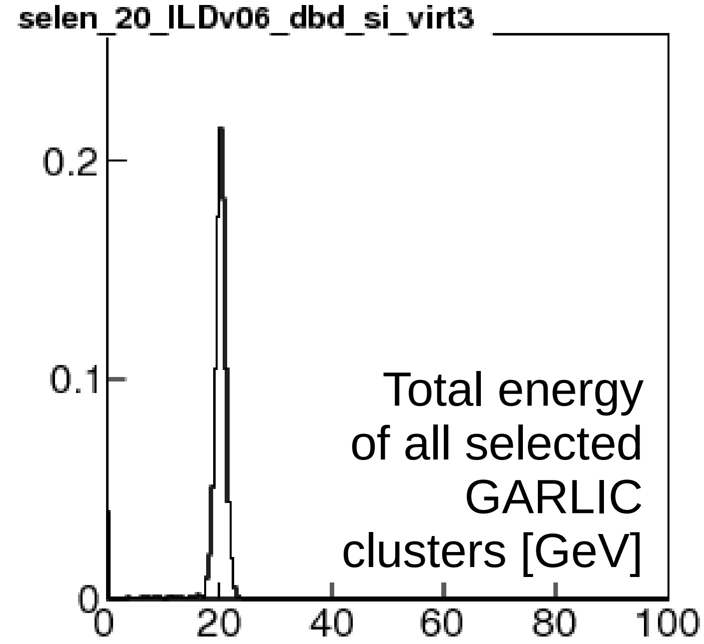




DBD-sized si-ECAL

Well reconstructed

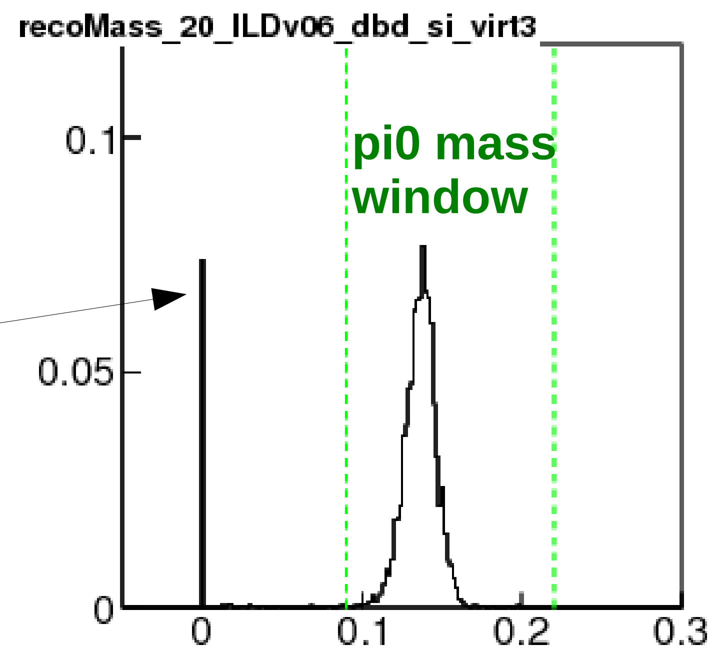




Photon identification inefficiency &
Cluster merging

Cluster splitting

<2 selected GARLIC clusters

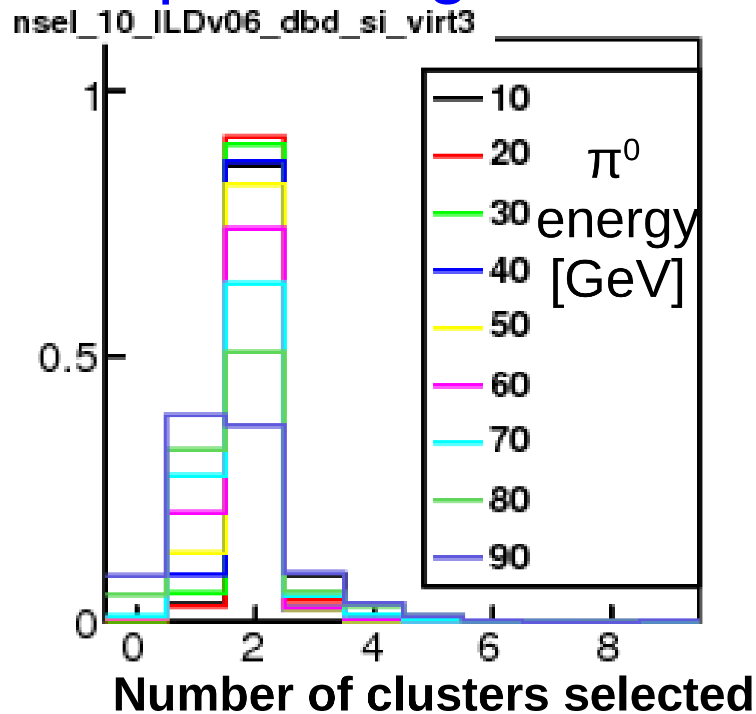


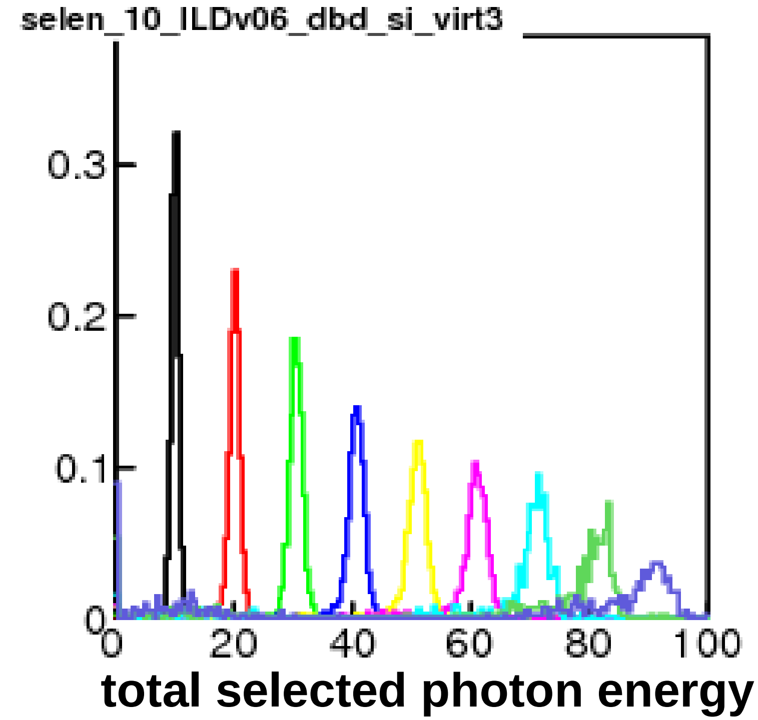
Invariant mass of 2 highest energy GARLIC clusters [GeV]

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

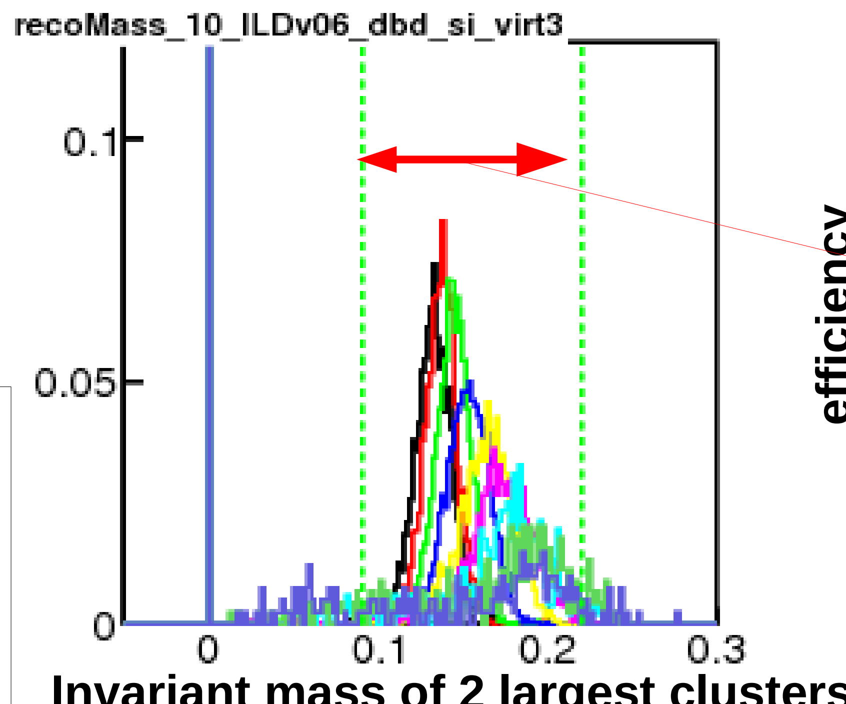
Compare different pi0 energies

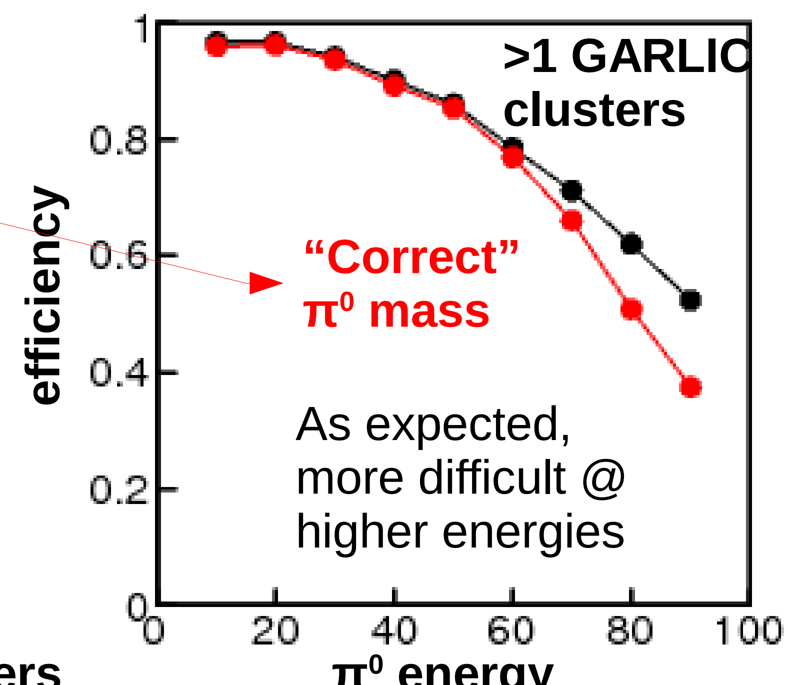
Standard ILD size (1843 mm ECAL radius)





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

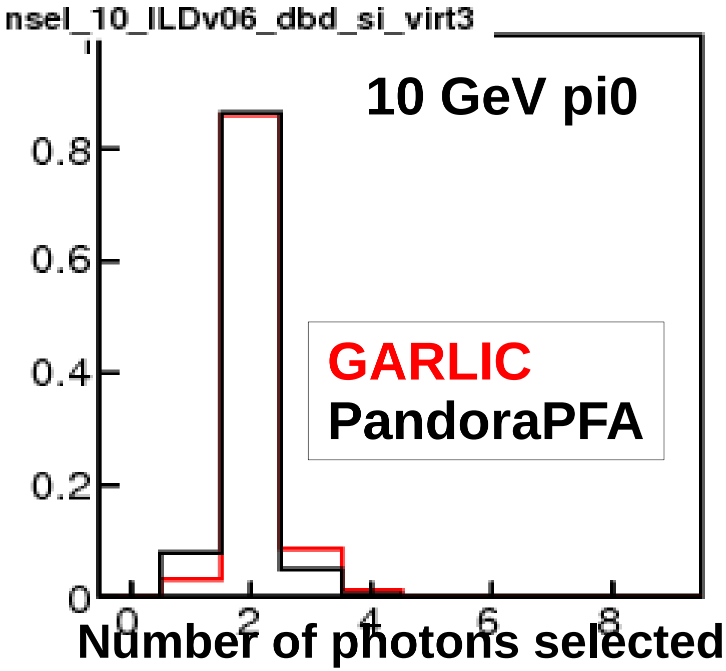
This GARLIC version tuned to separate nearby photons

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

Using "DBD" version of Pandora

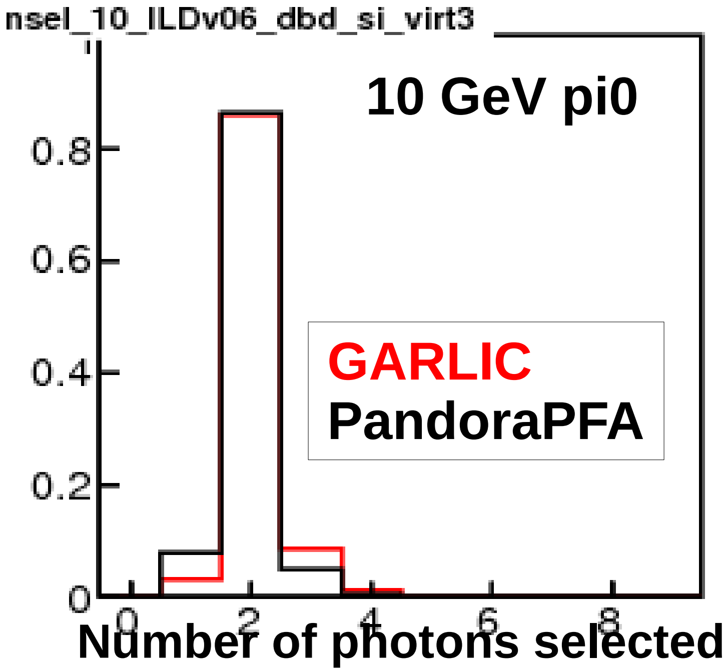
- I know there are photon clustering improvements in the latest Pandora version (already committed to svn, I believe)

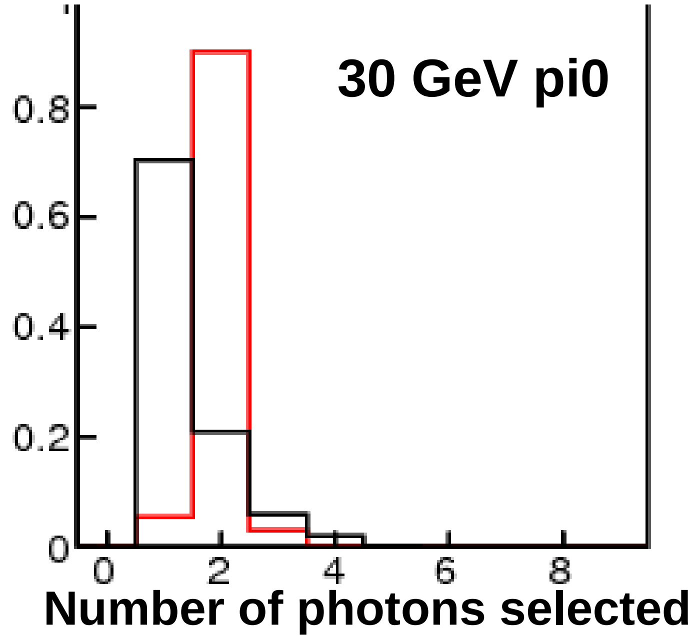
Comparison of GARLIC and PandoraPFA algorithms for π^0 reconstruction



DBD detector, SiECAL

Comparison of GARLIC and PandoraPFA algorithms for π^0 reconstruction





DBD detector,
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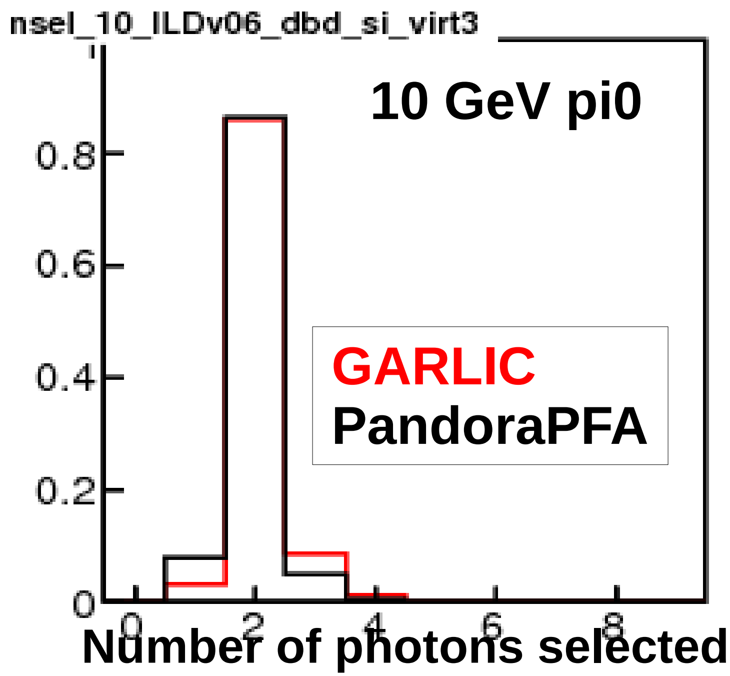
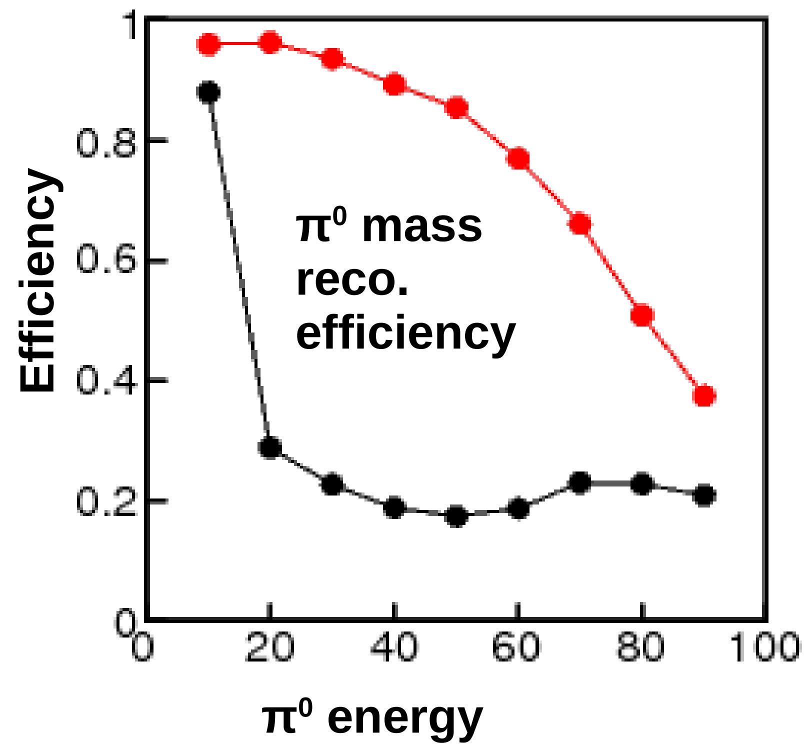
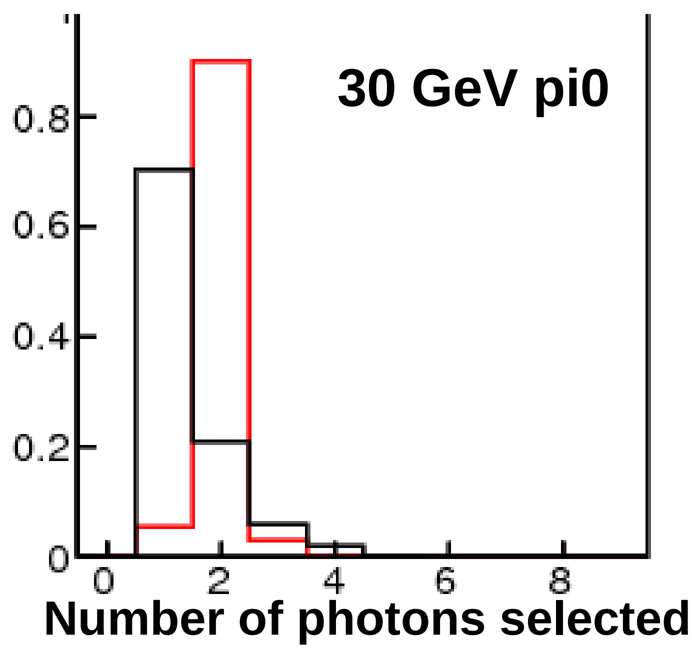


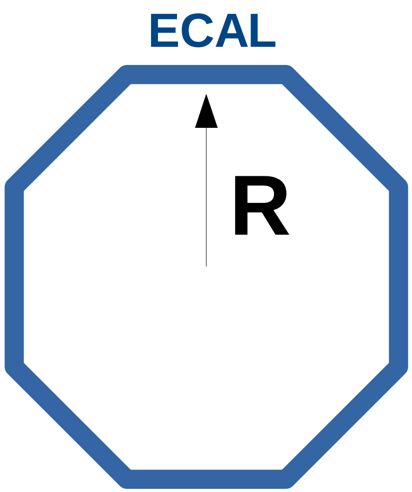




GARLIC reconstructs π^0 significantly better than PandoraPFA for pi0 energies>10 GeV

DBD detector, SiECAL

Compare π^0 reconstruction in detectors with different ECAL radius

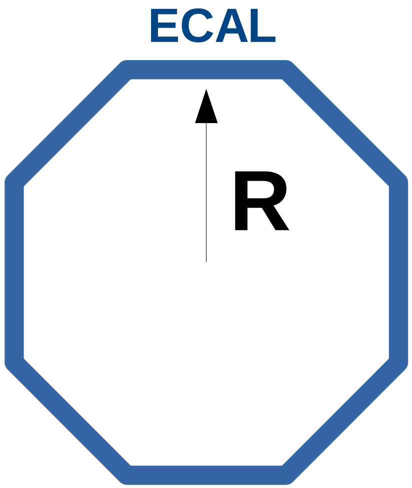


Attractive from a cost perspective,

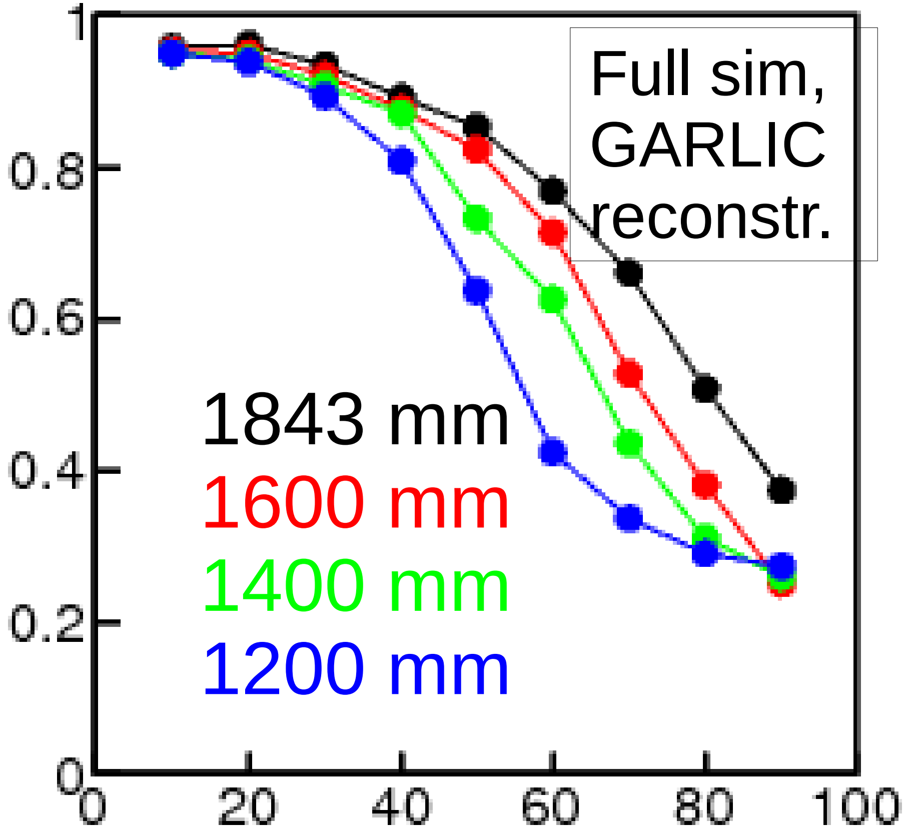
however

distance between photons at the ECAL $\propto$ radius

Compare π^0 reconstruction in detectors with different ECAL radius



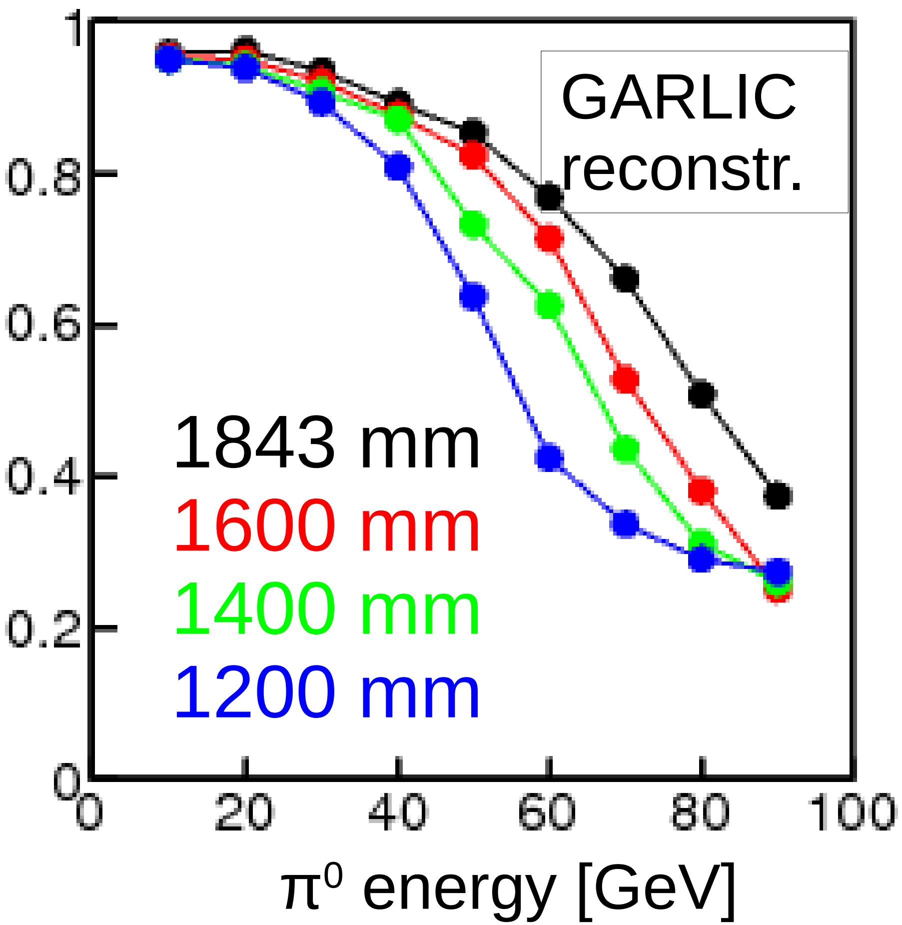
π^0 mass reco. efficiency



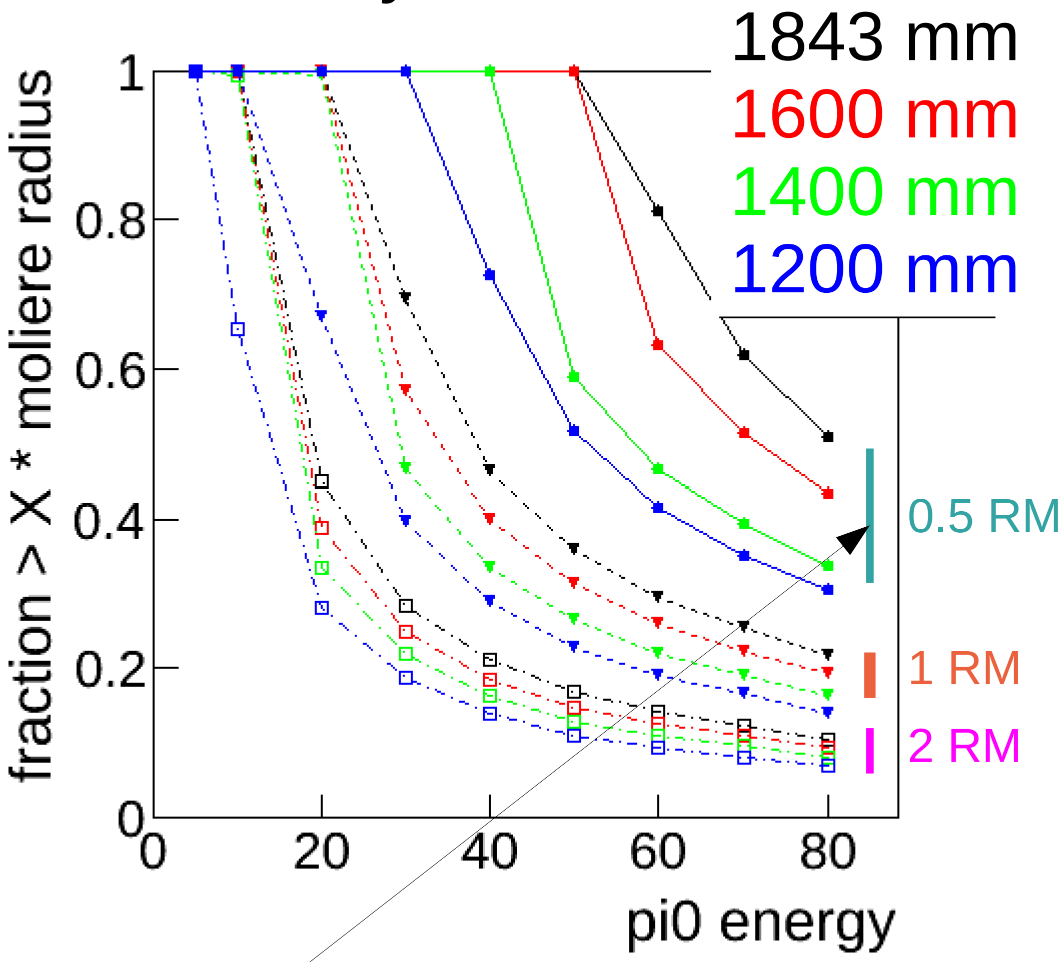
π^0 energy [GeV]

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

Full reconstruction



Toy MC



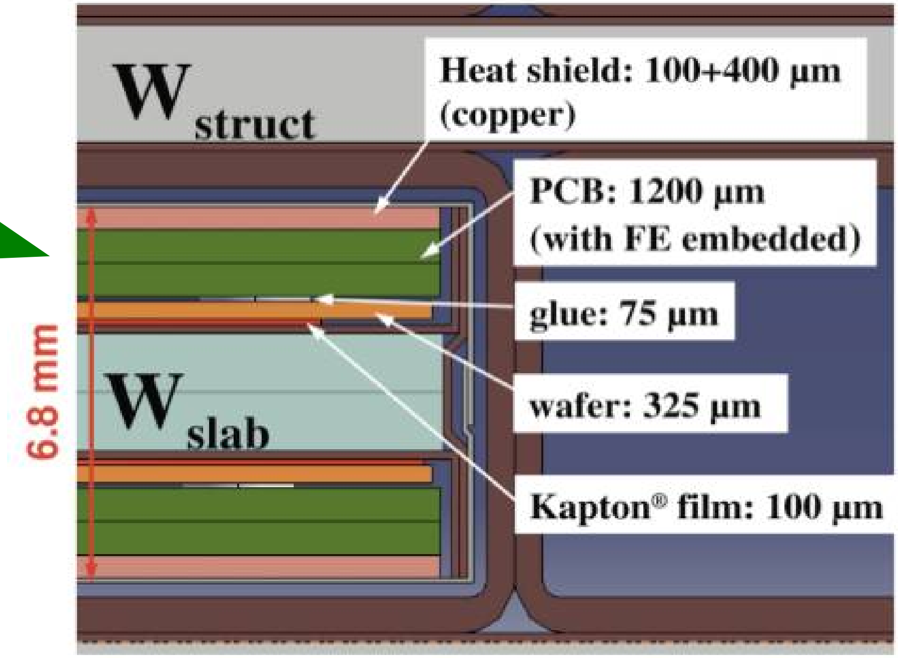
Rather similar dependecy:

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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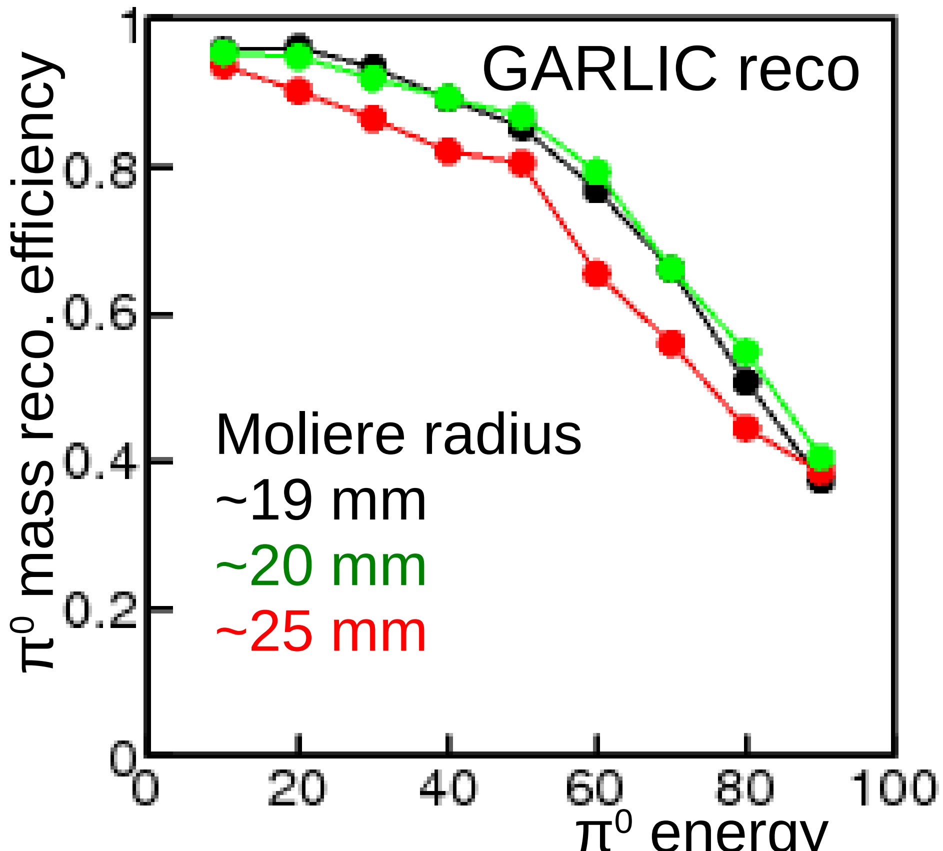

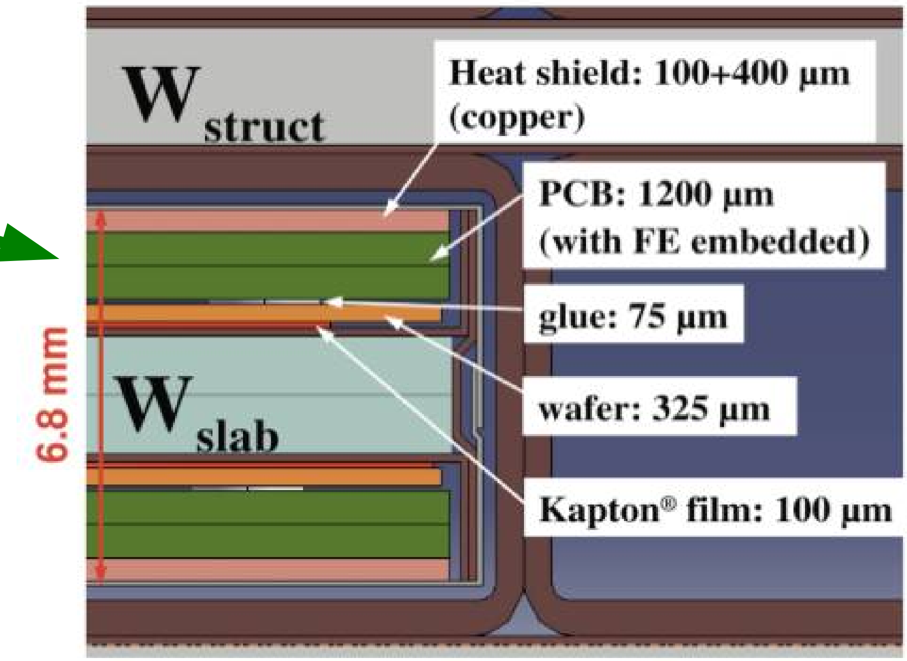

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Some modest degradation for thickest PCB design

Current activities:

Further improvements in GARLIC:

- now working on hadronic fragment rejection
- low energy photons

Apply GARLIC to tau decays

- Quantify impact of radius, cell size on
  - tau decay mode reconstruction

Apply to Higgs CP measurement in tau decay mode

Summary

Snapshot of GARLIC performance
- further developments in the pipeline

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

Moliere radius seems less critical
- (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 -> $\gamma\gamma$
    such rare processes are not a top priority @ ILC
    LHC usually does this better, thanks to high luminosity

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:

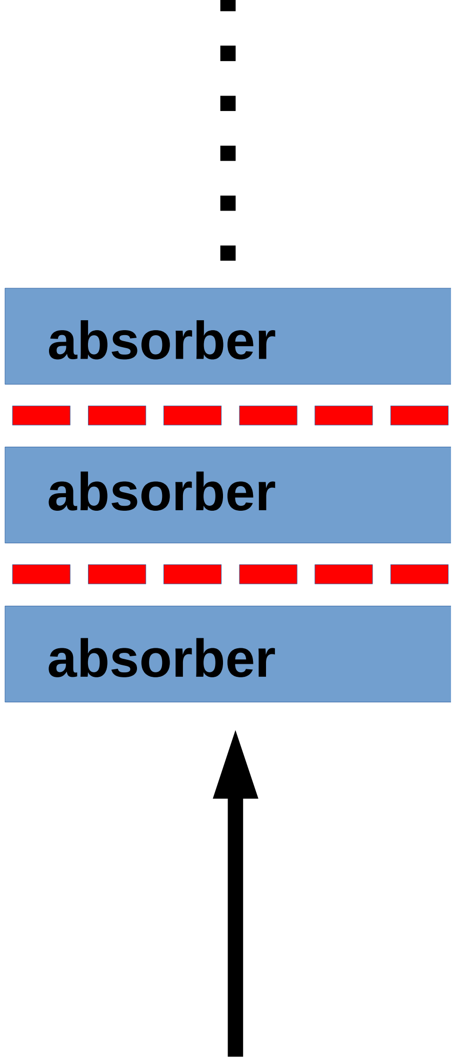
motivates:

use of tungsten

and

thin readout gap between absorber layers

Moliere radius ~20mm in ILD ECAL



ECAL is most expensive sub-detector

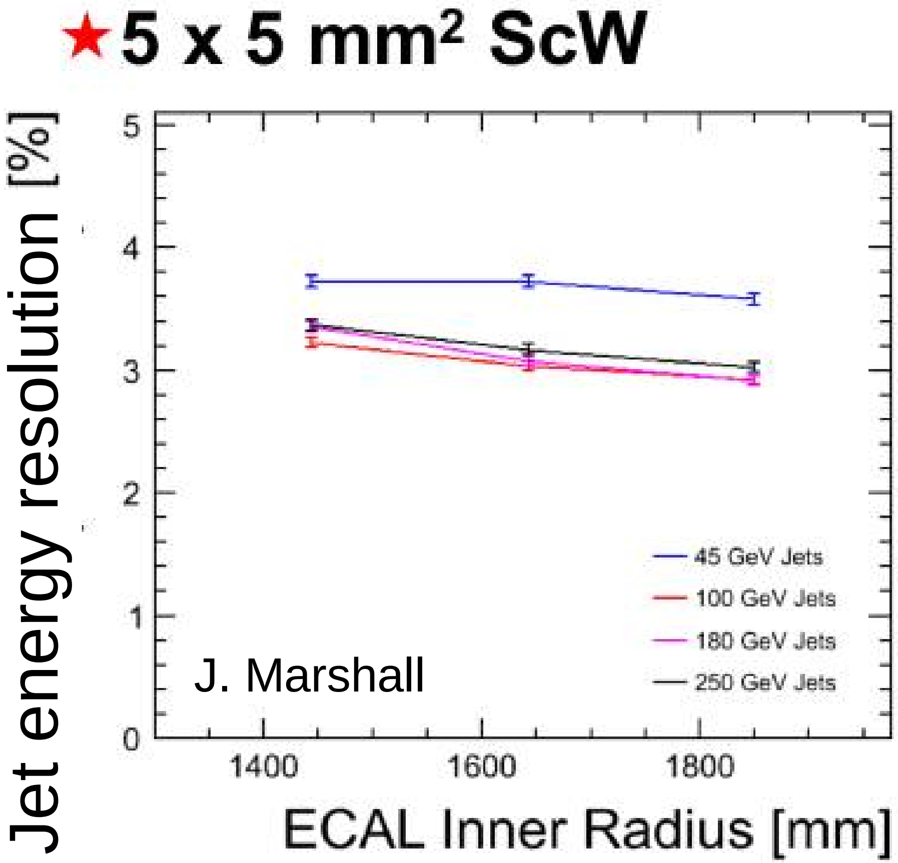
- large active area
- 10-100M readout channels
- expensive readout technology (silicon detectors, SiPM)

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

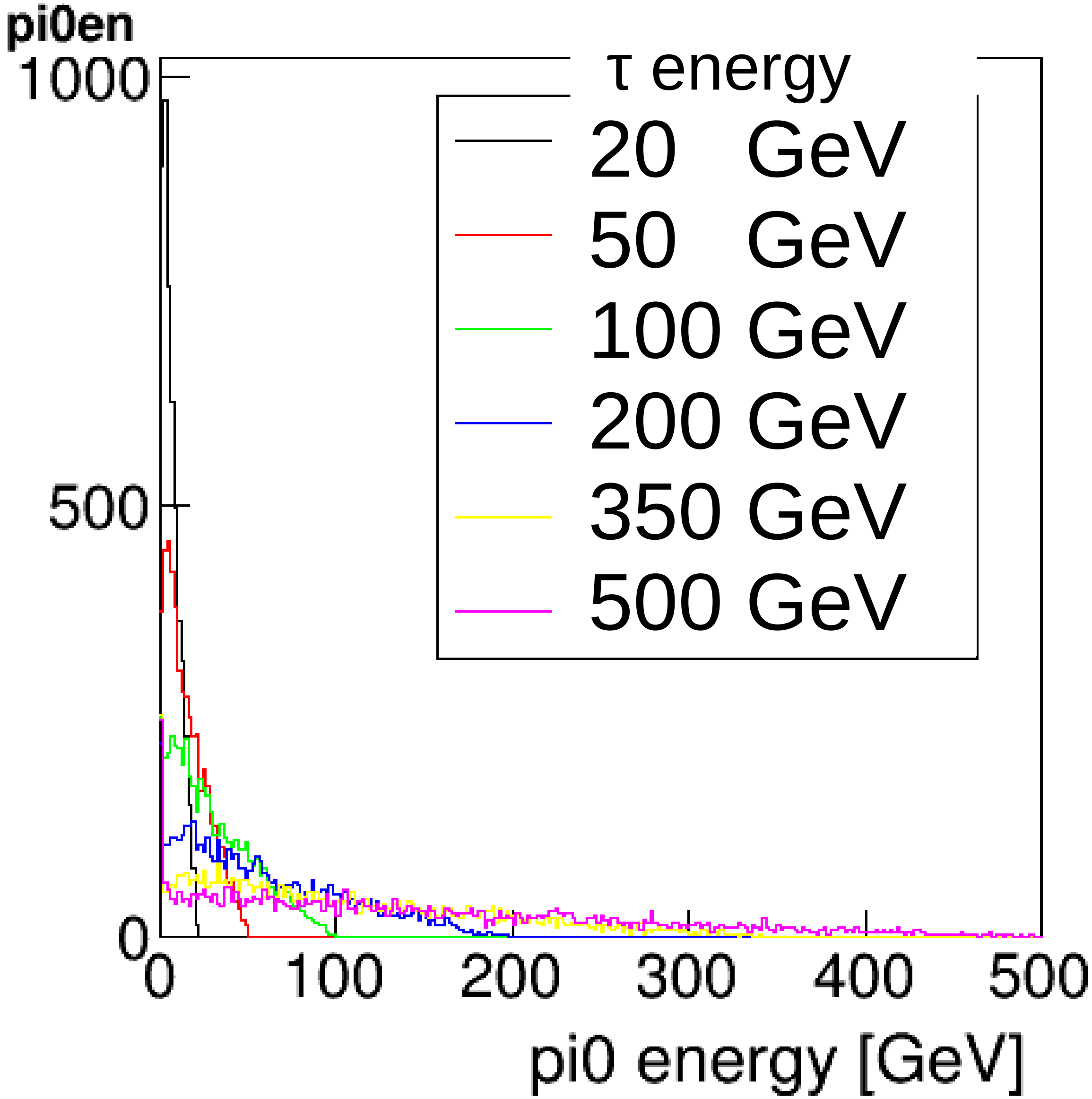
τ spin ---> spin properties of τ parent

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



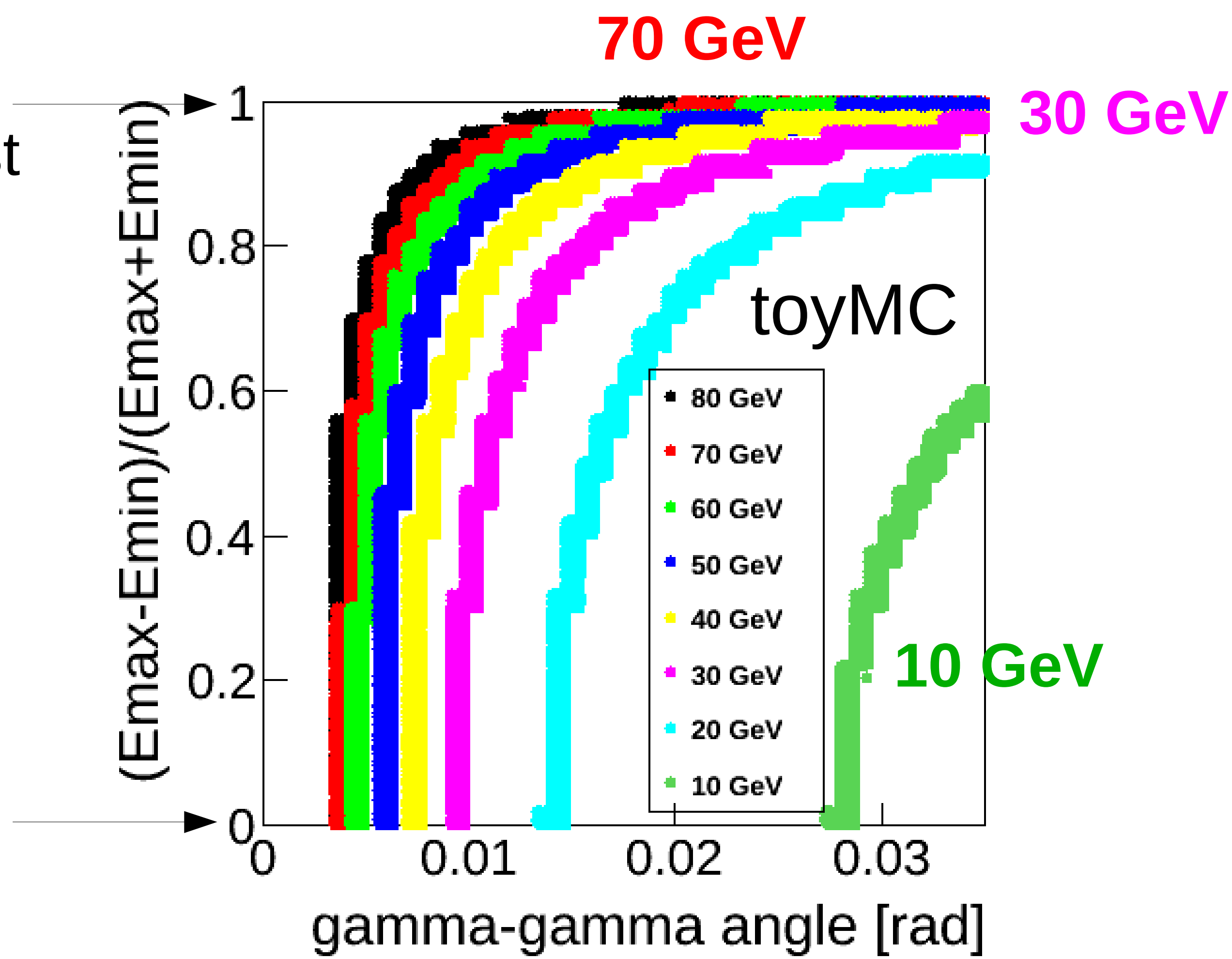
τ produced in Higgs decays near the e+e- -> ZH threshold
are strongest motivation for reconstruction of τ decay modes

---> 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