Studies on energy and position resolution of SPD ECAL and reconstruction of angled electromagnetic showers

Andrei Maltsev, JINR (Dubna)

SPD Physics & MC meeting

03.03.2021

Thickness of ECAL barrel module

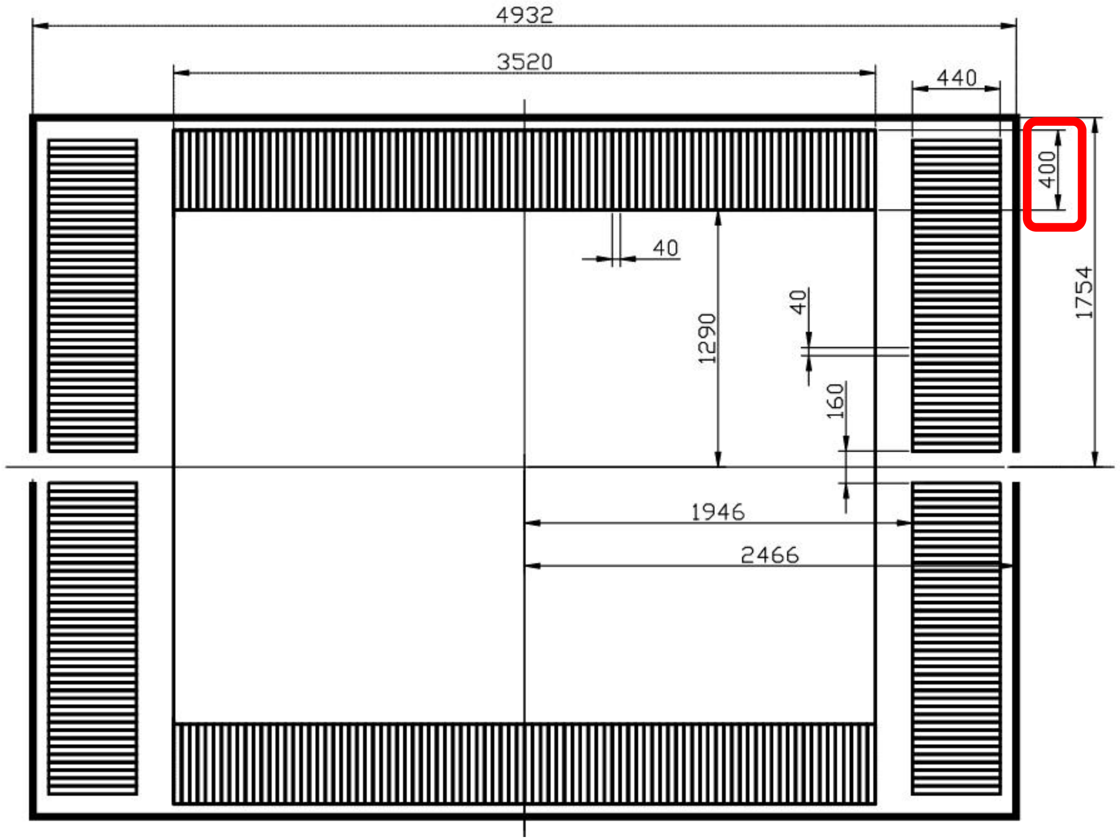
Possibly has to be shrunk from **40 cm → 36 cm**

Current setup:

200×(1.5 mm scint. **+ 0.5** mm lead)

Possible modifications:

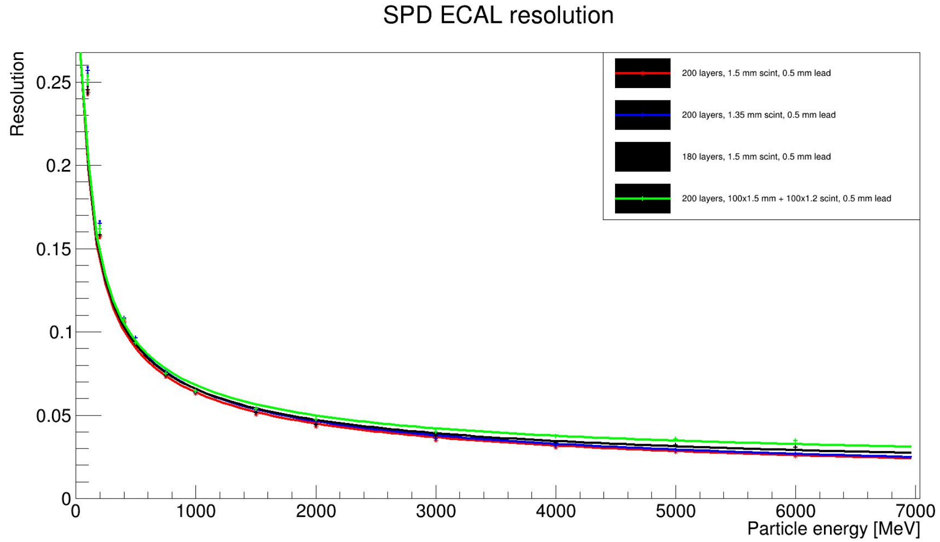
- **180×(1.5 + 0.5)**
- **200×(1.35 + 0.5)**
- **100×(1.5 + 0.5) + 100x(1.2 + 0.5)**

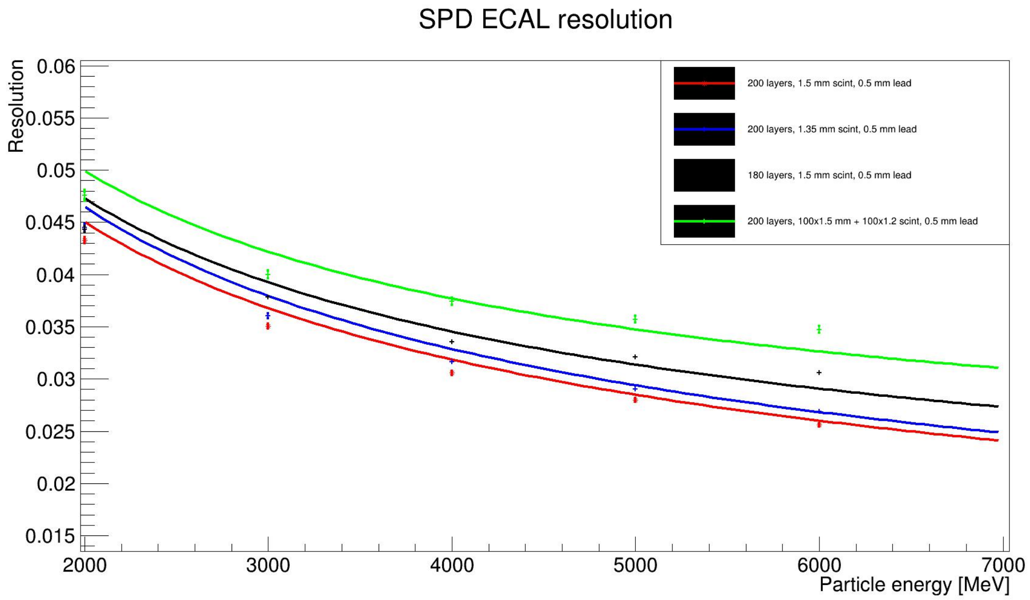


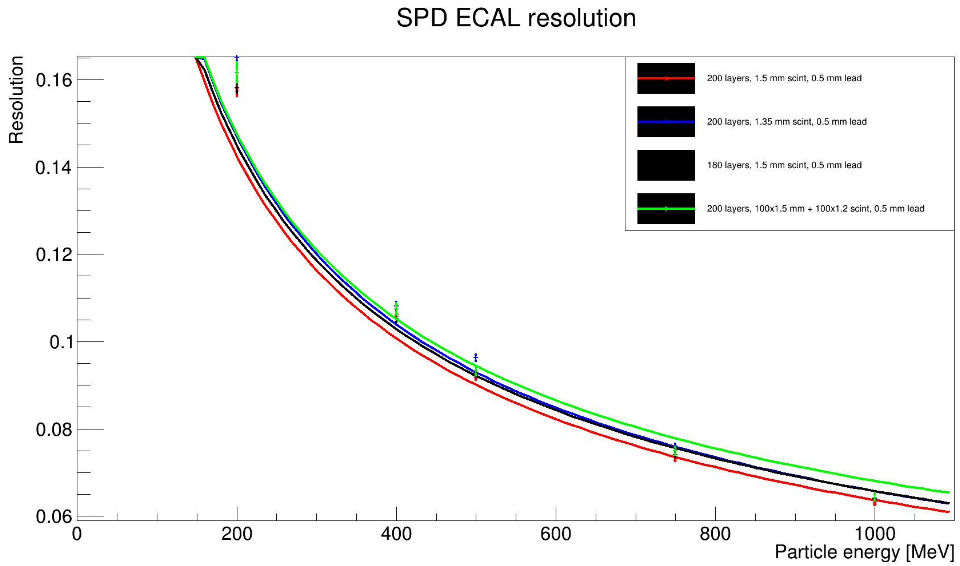
For future references:
https://git.jinr.ru/AndreiMaltsev/ecal_geant4

ECAL energy resolution for photons

Which option is better?







200×(1.5 + 0.5) - old geometry

180×(1.5 + 0.5)

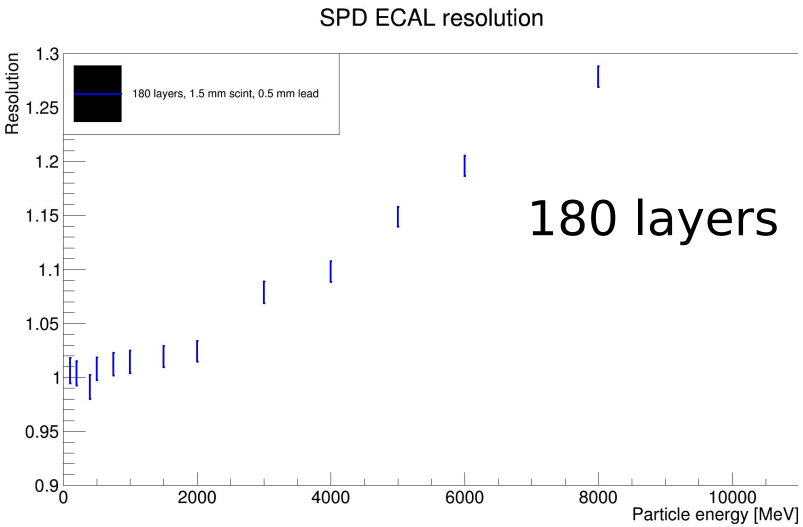
200×(1.35 + 0.5)

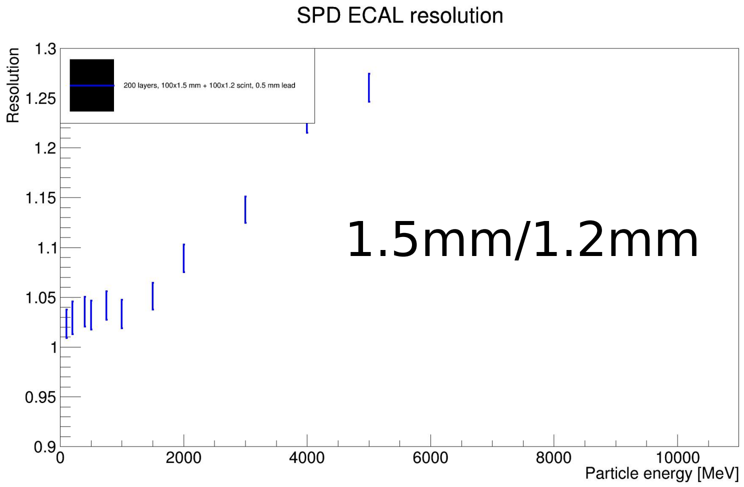
100×(1.5 + 0.5) + 100x(1.2 + 0.5)

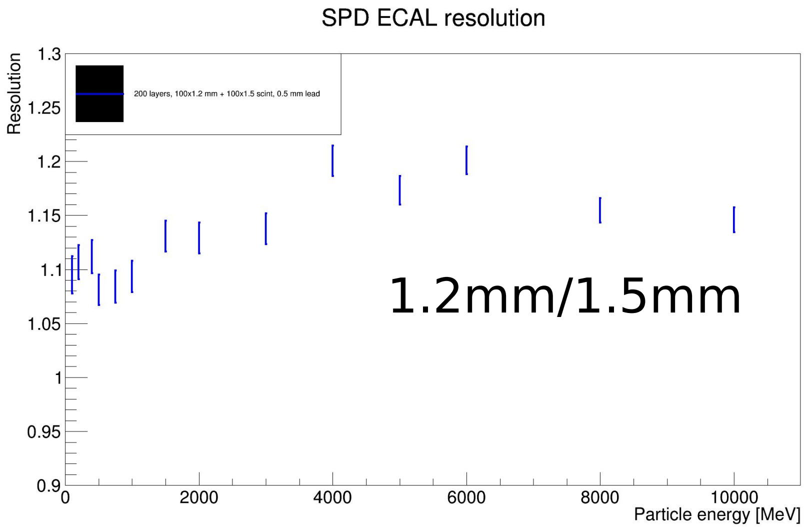
taking into account: cell energy threshold, p.e. statistics

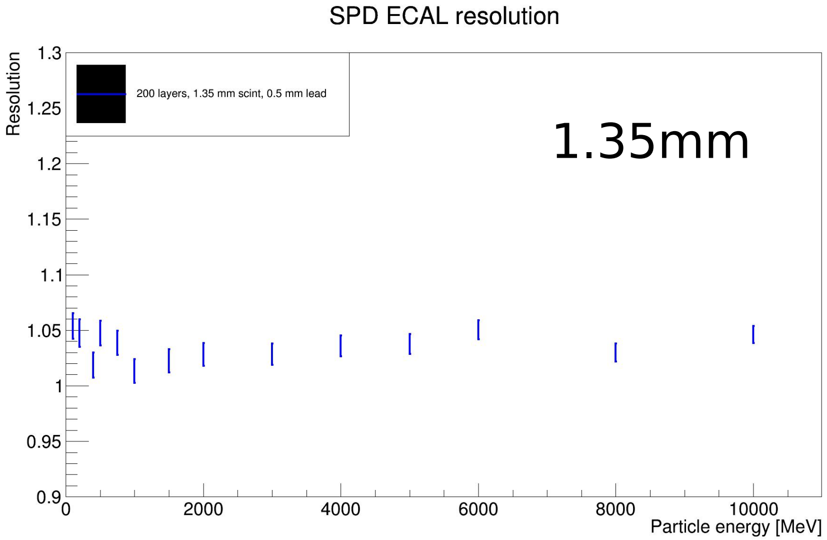
ECAL energy resolution for photons

Which option is better? ***Ratios of resolution (current geometry)/(new option)***







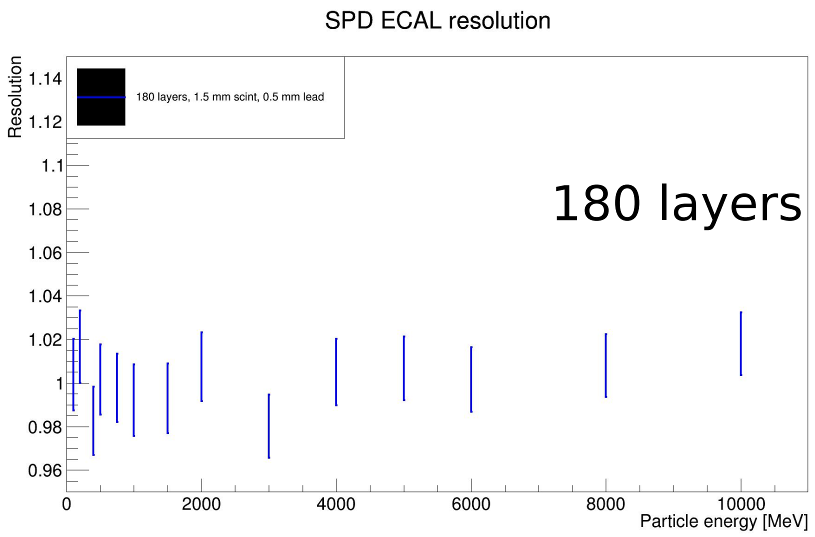


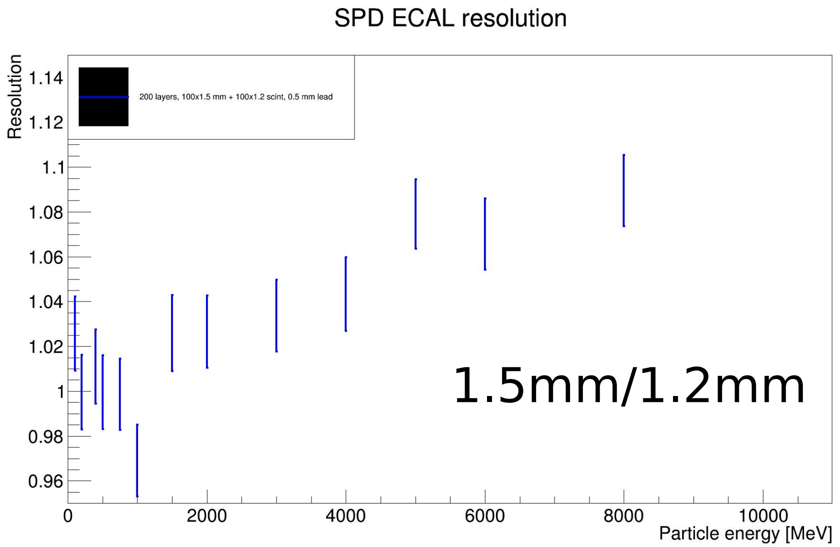
Prompt photons: need photons with high p_T:
therefore high energies with $\theta=\pi/2$
→ option with 180 layers/variable segmentation is not good?

Option with less scintillator:
only 3-5% worse resolution (relatively) in the whole range

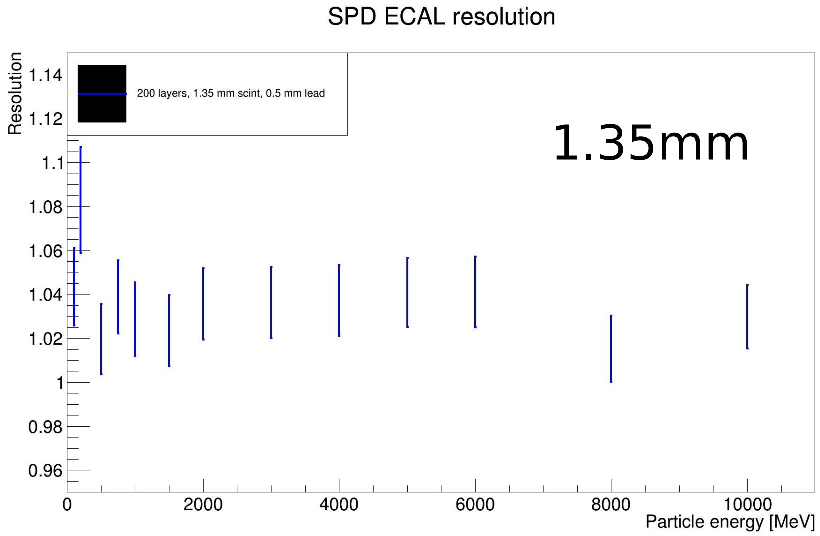
ECAL energy resolution

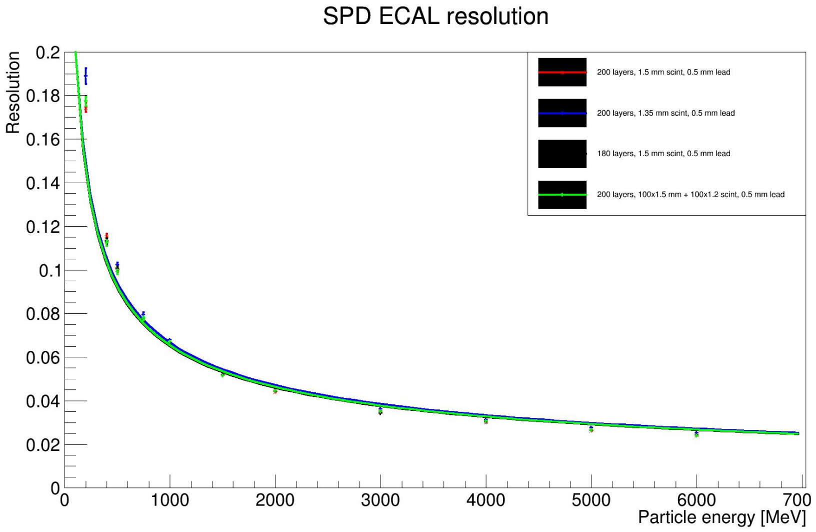
What about large angles (40°)? ***Ratios of resolution (current geometry)/(new option)***

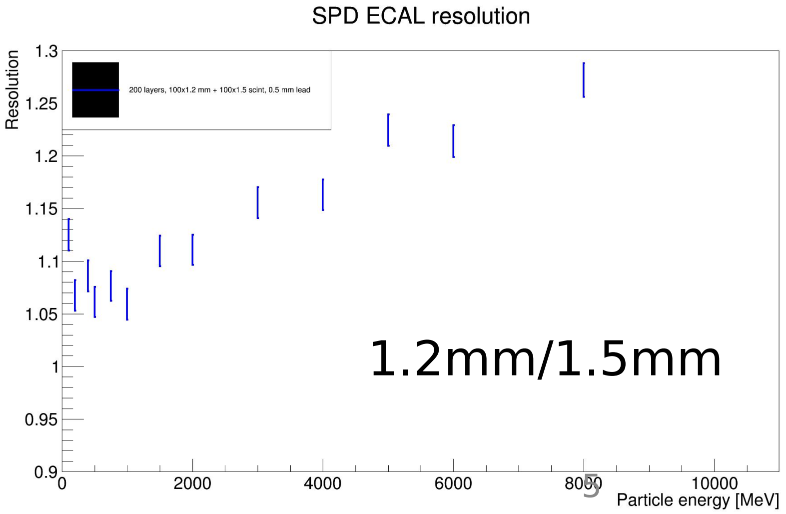




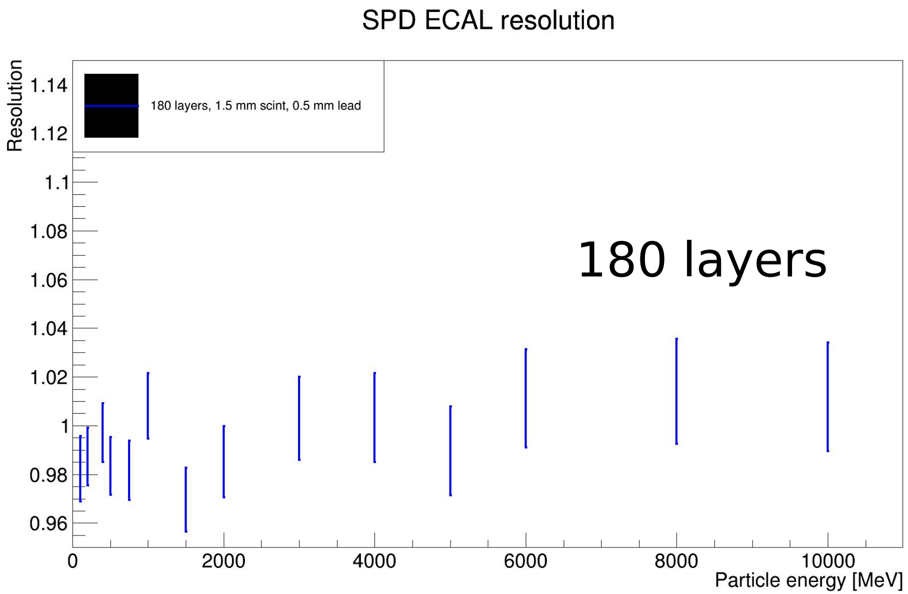
Problem with option with 180 layers gone

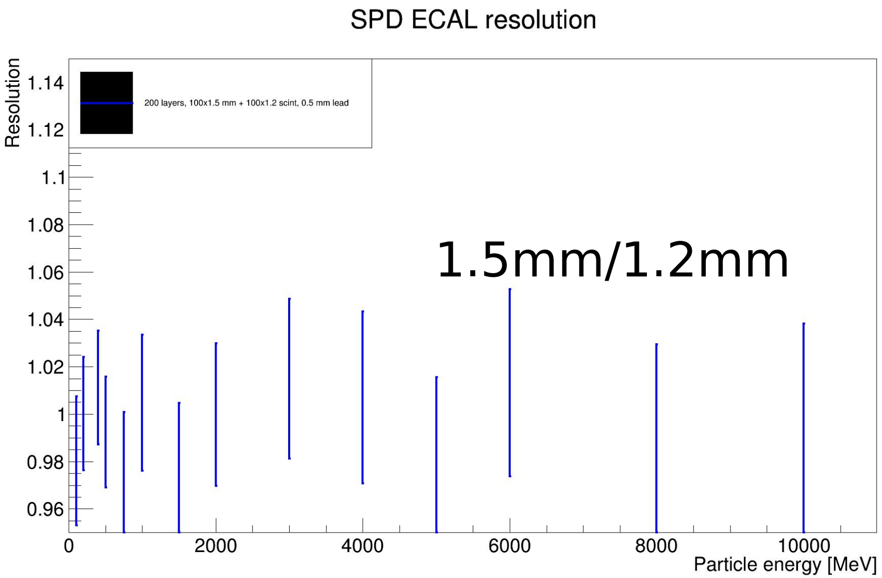






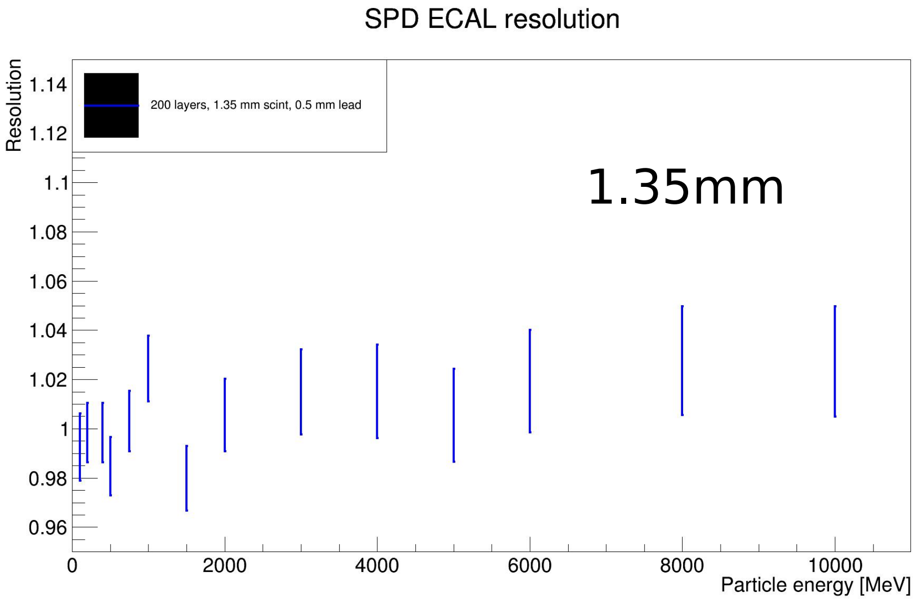
ECAL position resolution

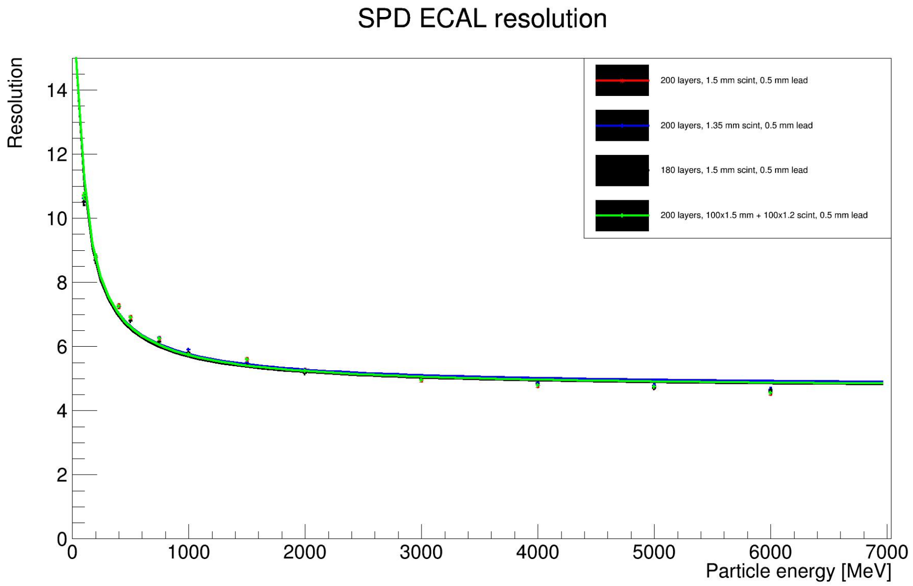




0° incidence angle

As expected, little impact on position resolution





Requirements for SPD ECAL reconstruction

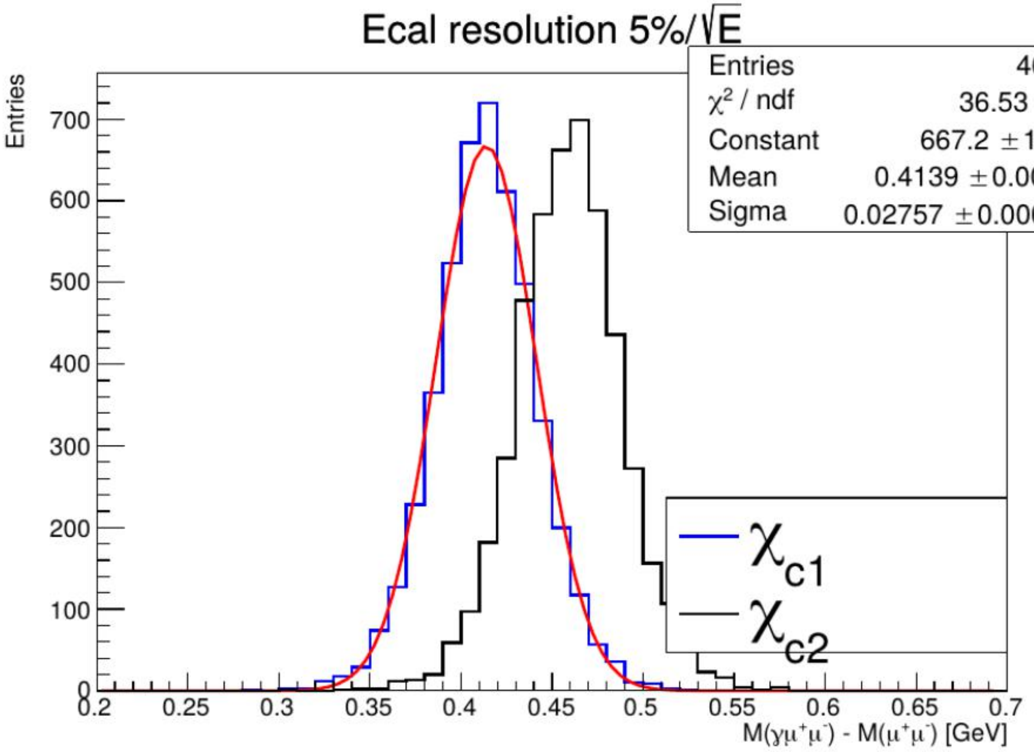
Program	Vertex detector	Straw tracker	PID system	Electromagnetic calorimeter	Beam-beam counter	Range system
Gluon content with:						
charmonia	+	++	+	++	+	+++
open charm	+++	++	++	+	+	++
prompt photons	+	+	-	+++	+	-
SSA for π and K	+	++	+++	++	+	-
Light vector meson production	+	++	-	+	+	-
Elastic scattering	+	++	-	-	+++	-
$\bar{p}$ production	+	++	+++	++	+	-
Physics with light ions	++	+++	+	++	++	+

Table from SPD CDR

- **Energy resolution for $\chi_c \rightarrow J/\psi\ \gamma$**
- **π^0 identification for prompt photons and SSA**

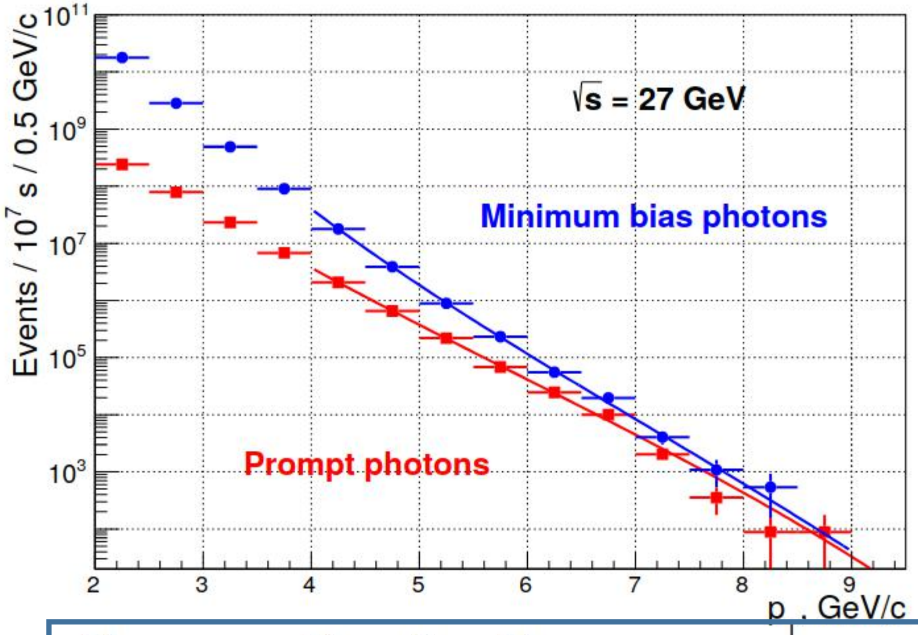
Requirements for SPD ECAL reconstruction

Energy resolution for $\chi_c \rightarrow J/\psi\ \gamma$: ~ 5%/sqrt(E)
(see Igor's talk)



Picture from talk of Igor Denisenko

π^0 identification for prompt photons:
good enough so that number of reconstructed $N_{\pi 0} \gg N_\gamma$, or at least $N_{\pi 0} \sim N_\gamma$



$$N_{prompt} = N_\gamma - k \times N_{\pi^0}$$

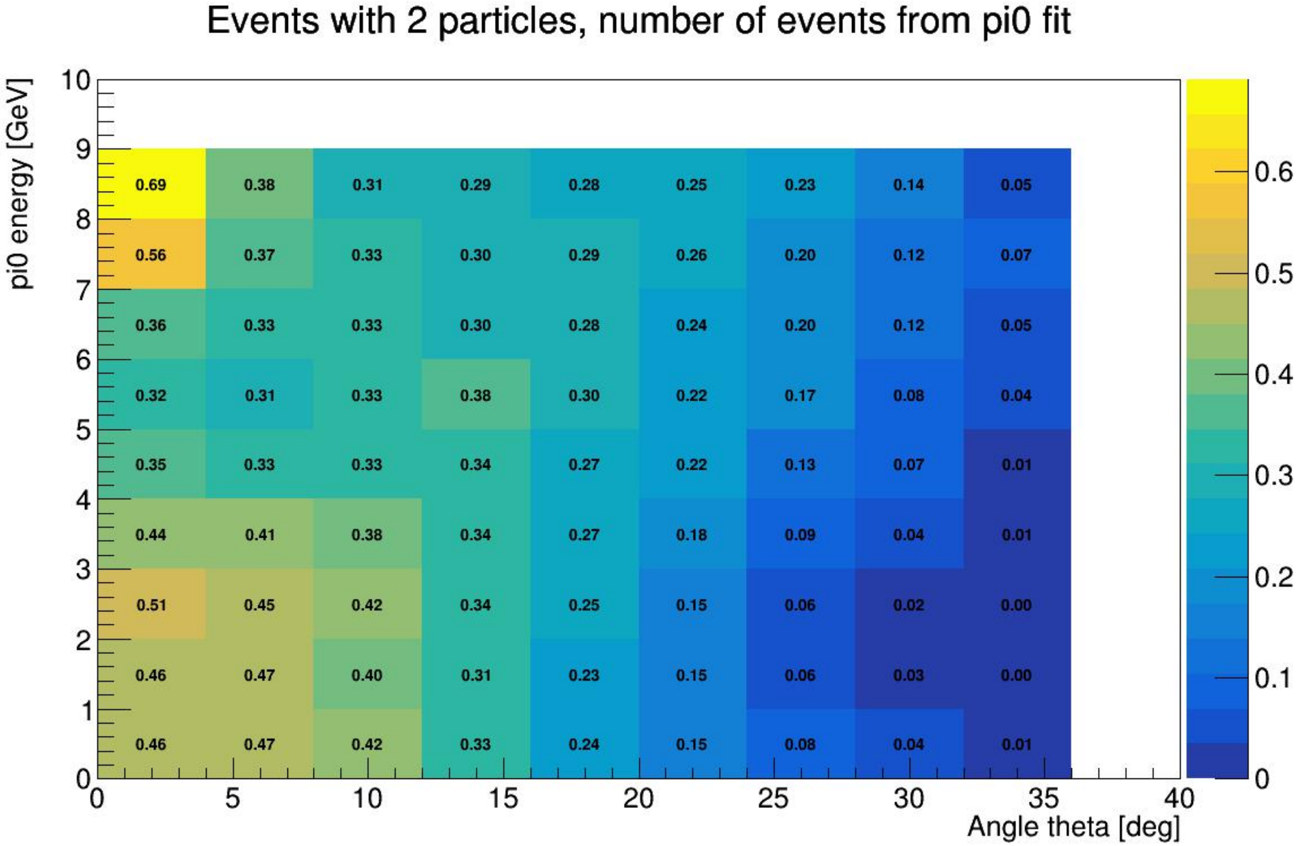
coefficient k ~ 0.3 obtained from MC

Requirements for SPD ECAL reconstruction

- So far: simple reconstruction algorithm with linear/log. weighting
- π^0/γ ID with a more sophisticated algorithm
- If π^0 can be identified, it should be reconstructed (maybe with larger errors) → use information on π^0 kinematics
- Algorithm for π^0/γ reconstruction ideally should look similar

Performance of a simple clustering/reconstruction algorithm

- Neighboring cells are combined into one cluster
- One local maxima = one shower
- BUT: if distance($cell_1$, $cell_2$)/cm < 4*GeV/sqrt(E_1,E_2), cell with lower energy is ignored



Number in each bin obtained from π^0 fit

Extremely low π^0 reconstruction efficiency at higher angles

ECAL reconstruction

- Bumping up complexity:

assuming we know energy deposition in ECAL cells for a given particle trajectory and type, fit the cluster with N=1,2,.. showers, where final Nshowers gives fit with best likelihood (COMPASS ECAL2)

- Angle = 0: analytical expression for shower shape
- Large angles: simple ML model (effectively some polynomial)

- Caveat: too slow for e.g. online π^0 reconstruction

Multi-shower fit

Cell energy deposition network:

inputs:

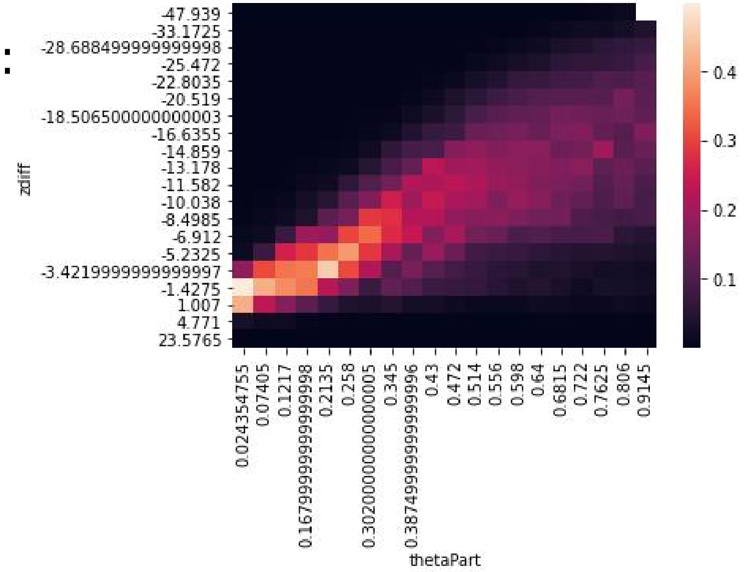
- ΔRφ of particle w.r.t cell
- ΔZ of particle w.r.t cell
- polar angle of particle
- particle energy

2 hidden layers, (8,8) neurons

output:

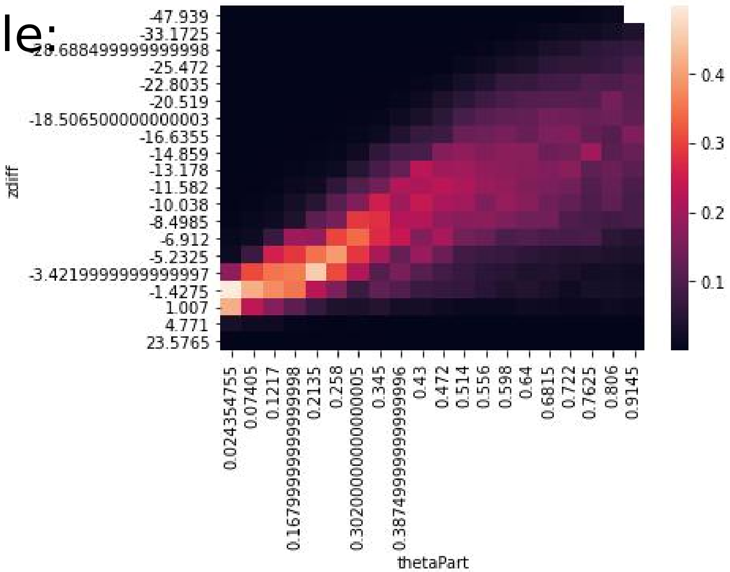
energy deposition in scintillator

train sample:
E = 4 GeV
ΔRφ = 0

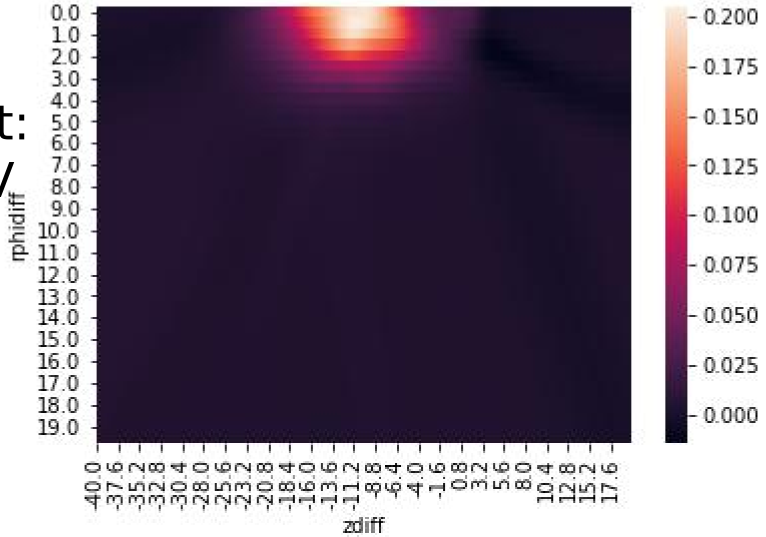


Multi-shower fit

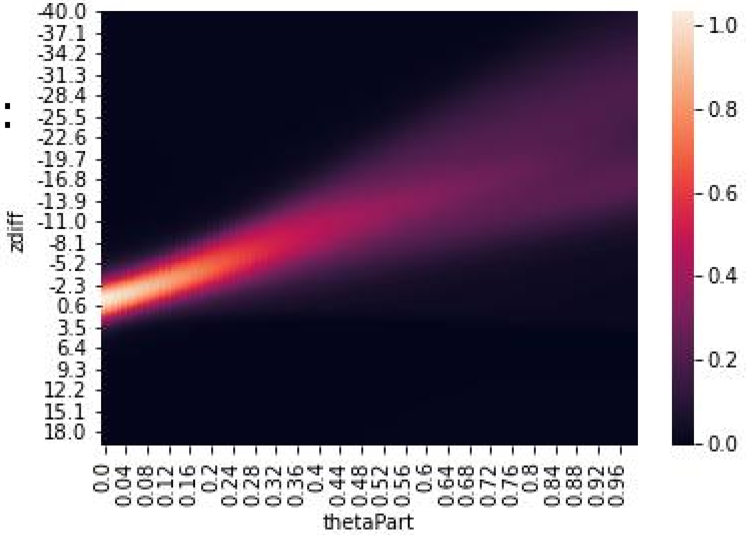
train sample:
E = 4 GeV
ΔRφ = 0



NN output:
E = 4 GeV
θ = 40°



NN output:
E = 4 GeV
ΔRφ = 0

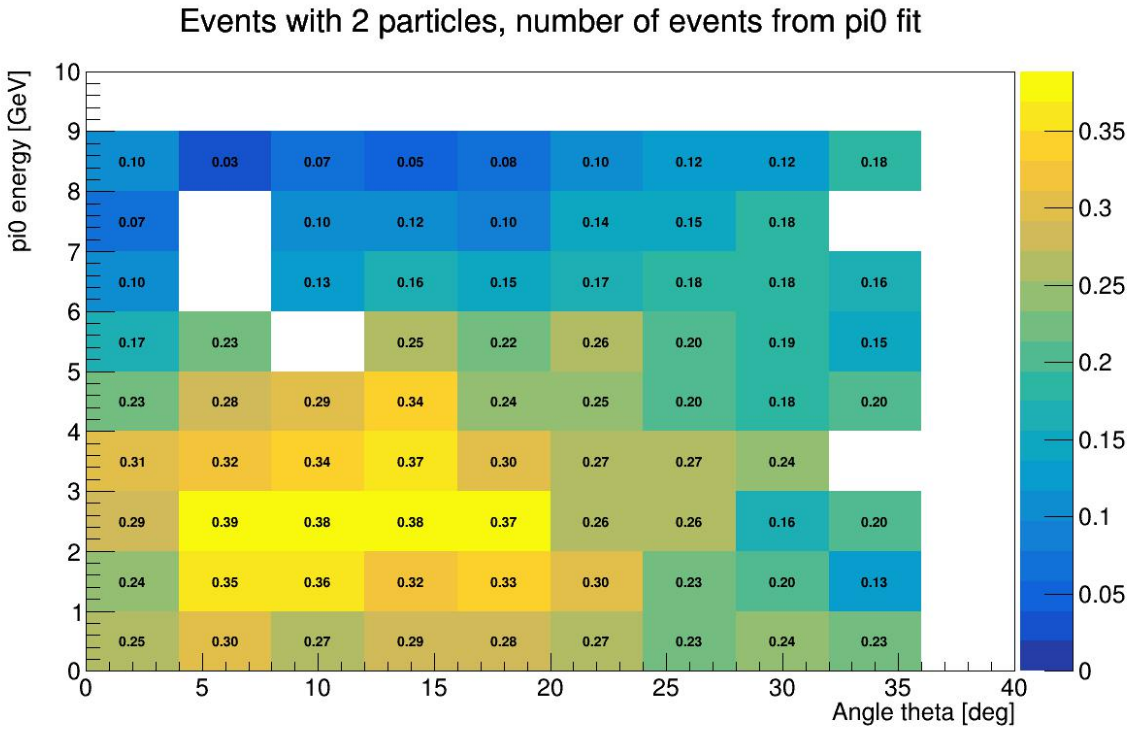


Performance of the multi-shower fit

- Using cell energy threshold of 1 MeV

(in the future: surround cluster with artificial cells)

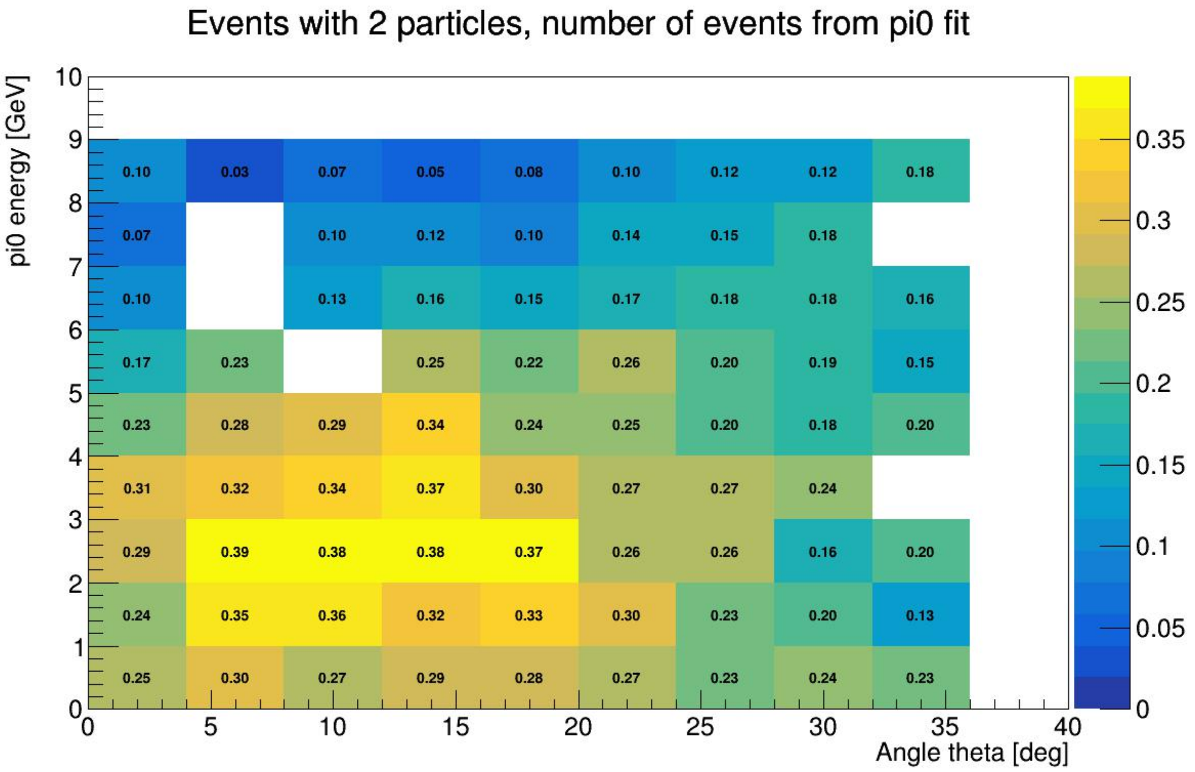
- Minimizing the likelihood function; $\log(L_{cell}) \sim (E_{pred} - E_{meas})^2/\sigma^2$, σ=3%/sqrt(E); E - energy in scintillator



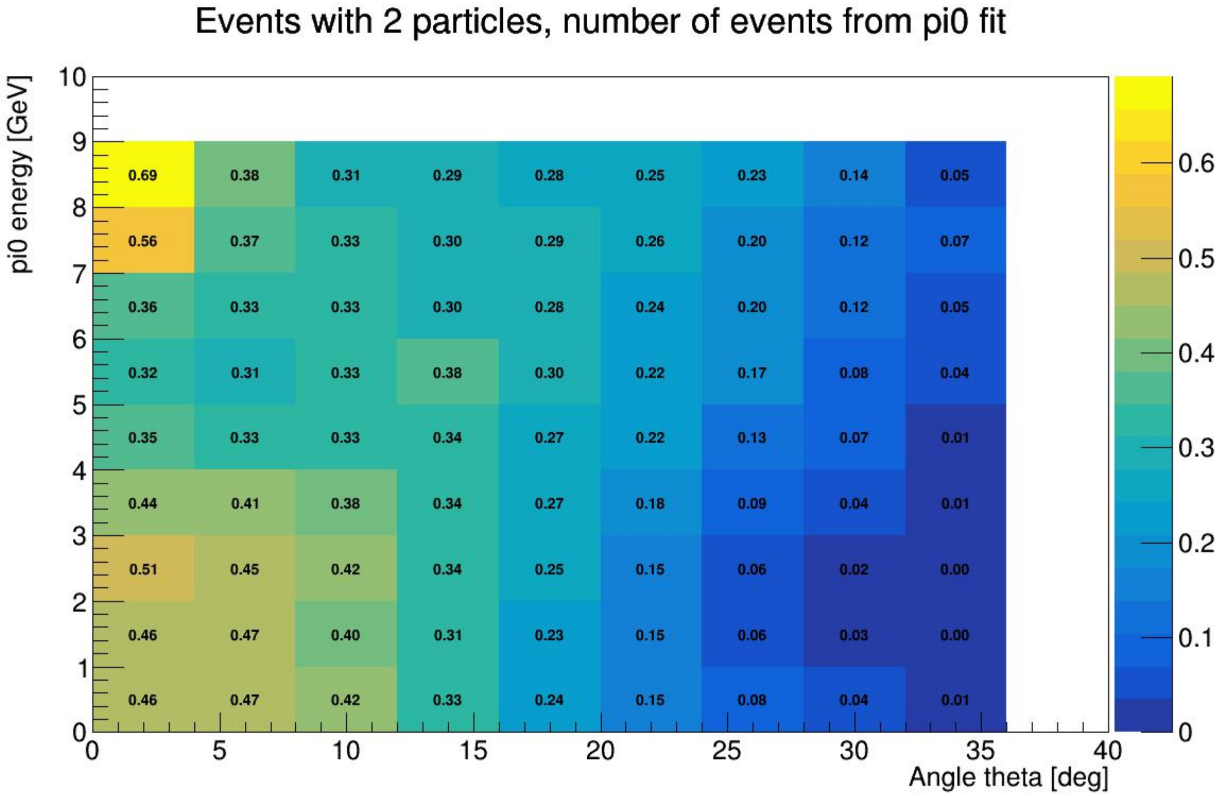
Missing bins = failed π^0 fit

Performance of the multi-shower fit

“Multi-shower”



“Simple clustering”

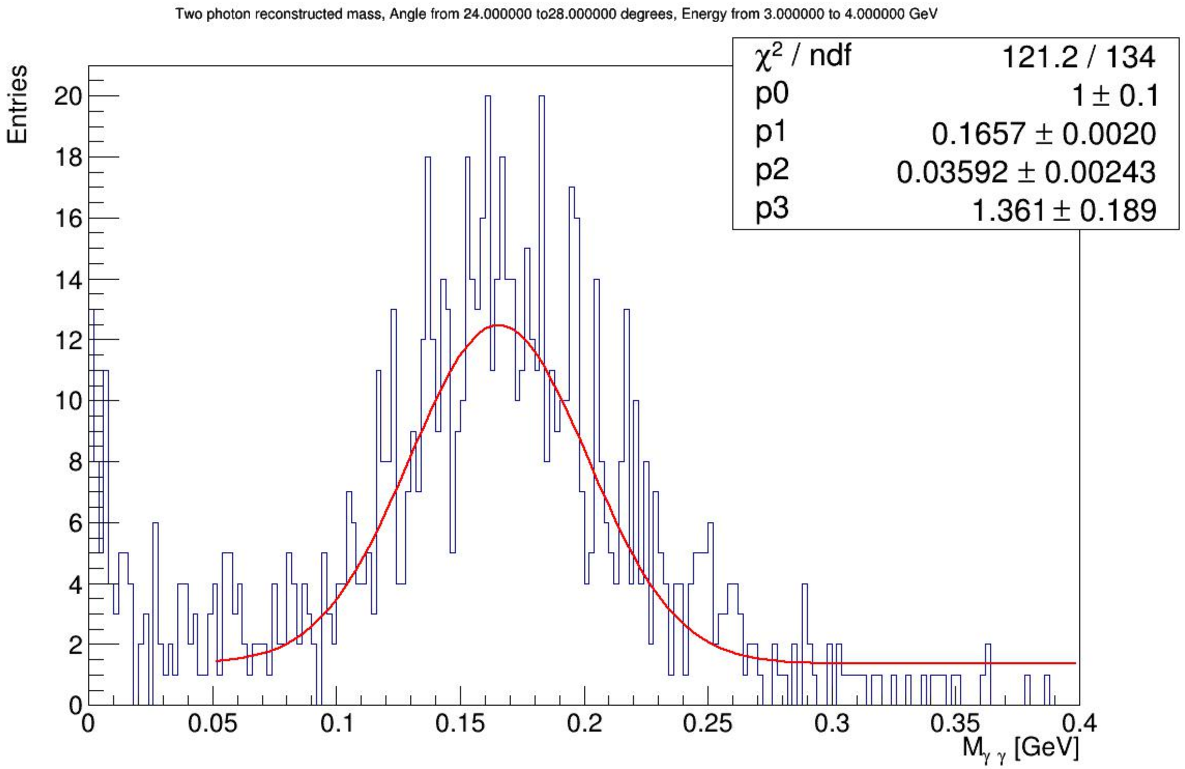


Multi-shower fit gives better π^0 reconstruction efficiency for large angles

Performance of the multi-shower fit

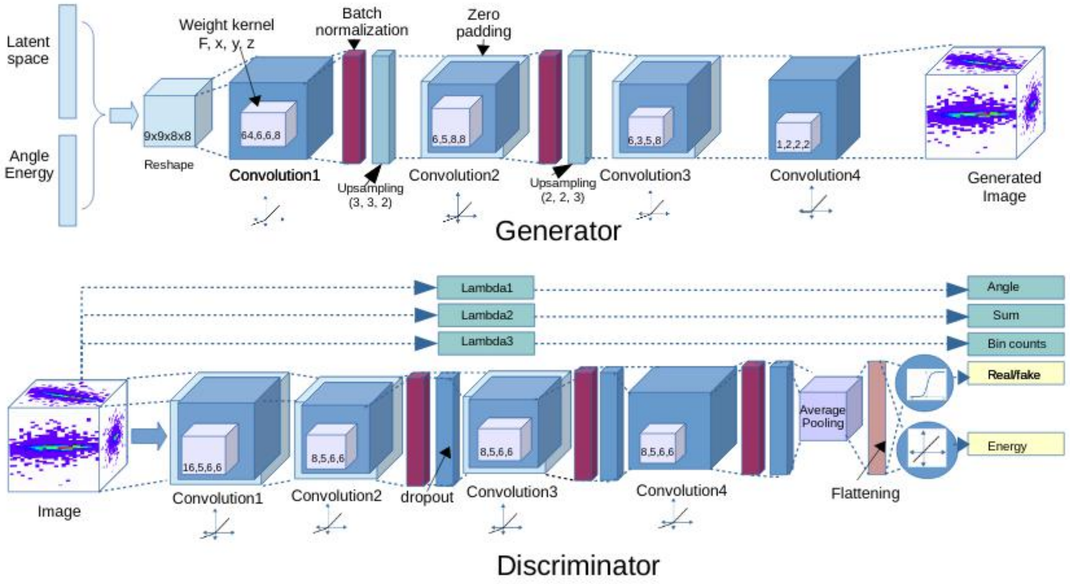
But…
Large bias in π^0 mass (165 MeV)
(energy?position of photons?)

Requires further work



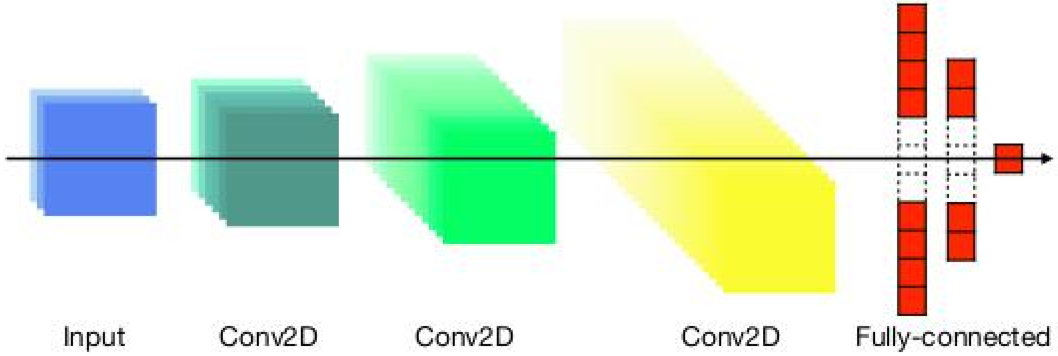
The future of ECAL reconstruction

Dawit Belayneh et al.

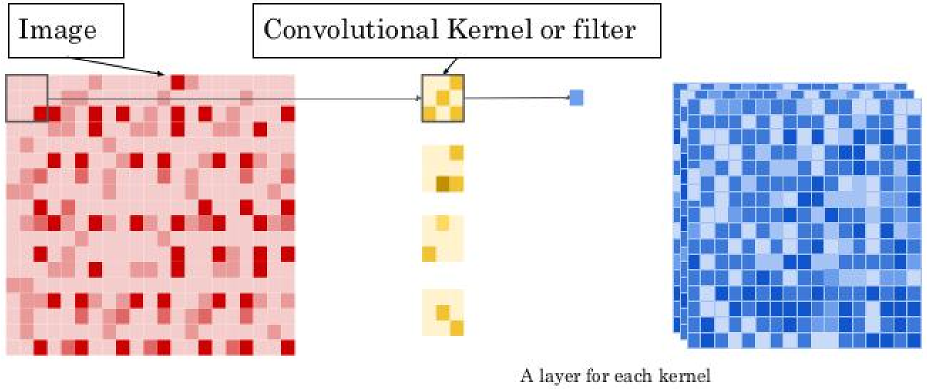


- Generative adversarial network (3D)
- Uses 3D information from calorimeters
- Typical energies 10 - 500 GeV

Fuyue Wang et al.



- MPD article
- Using waveforms as input (instead of per cell information)



Conclusions

- Among three ECAL geometry options for module size of 36 cm, **option with 1.35 mm scintillator and 200 layers** gives the best resolution over the entire energy/angles range
- For reconstruction, it is nessessary to implement algorithms which could work with angled showers; a lot of ideas can be borrowed from ML techniques
- Even a simple, crude multi-shower fit implementation gives better π^0 reconstruction efficiency at high angles than; further studies needed to estimate π^0 reconstruction efficiency
- More sophisticated ML algorithms (CNN?) will be discussed