Simulation study of ECAL with precision timing for LHCb UpgradeII

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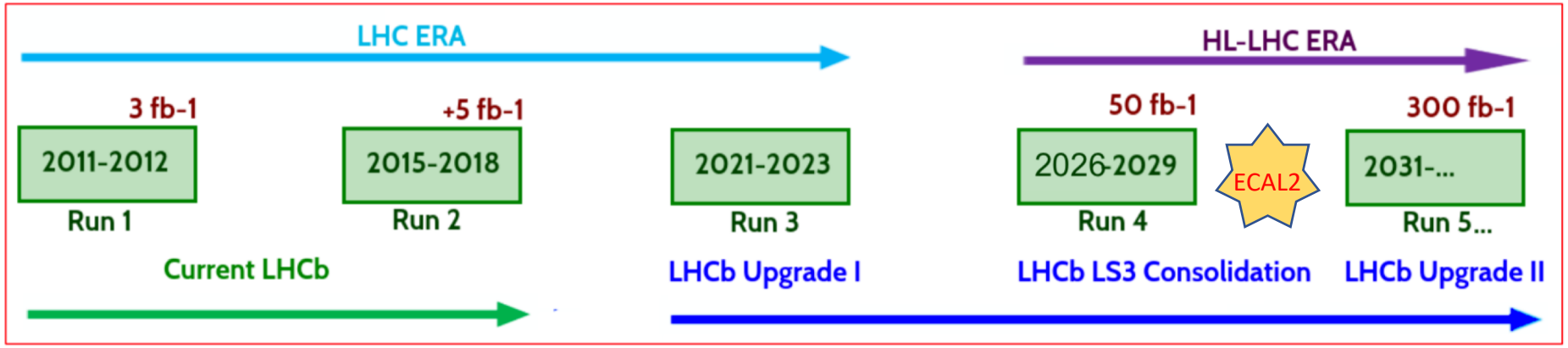
4th Workshop on LHCb UpgradeII
2019.04.09, Amsterdam

Parameterized fast simulation for ECAL



Use GAUSS event generator and DELPHES simulation framework to study:

1. High luminosity effect, e.g. pile up
2. Different intrinsic energy resolution and Moliere Radius
3. Different ECAL cell size
4. Including time information

Preliminary simulation study in this phase:

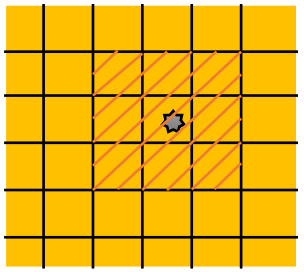
1. Test general optimization scheme
2. Naïve clustering reconstruction algorithm
3. Assuming no energy deposition by charged μ, π, K and p by now

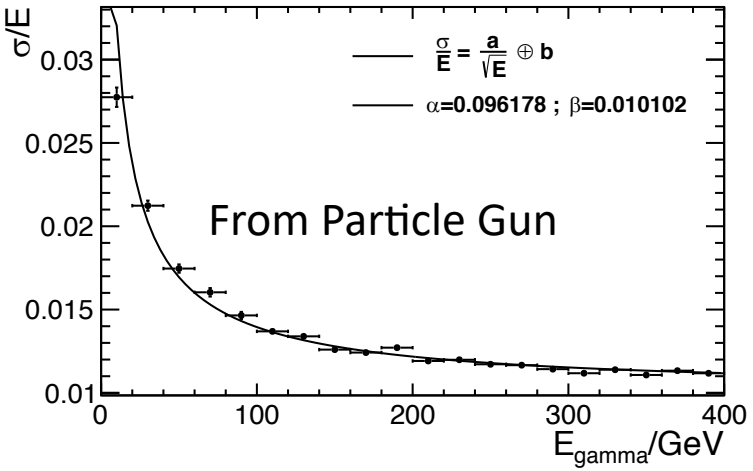
Simulation and reconstruction method

Simulation in DELPHES:
cluster transverse development added

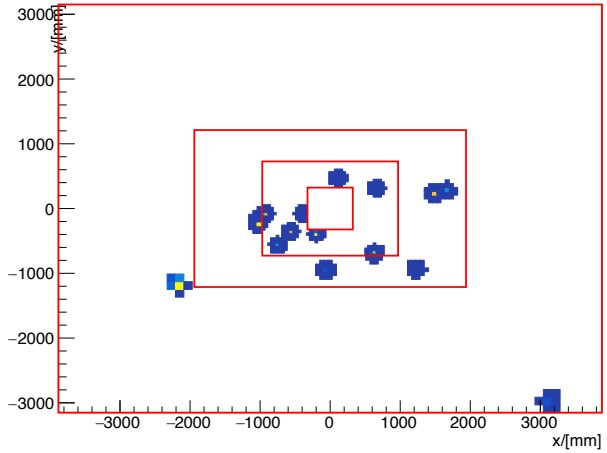
Reconstruction process:

1. Search for the seed cell (local energy maximum)
2. Reconstruct a cluster by 3×3 cells
3. Energy and position calibration
4. Matching with tracks

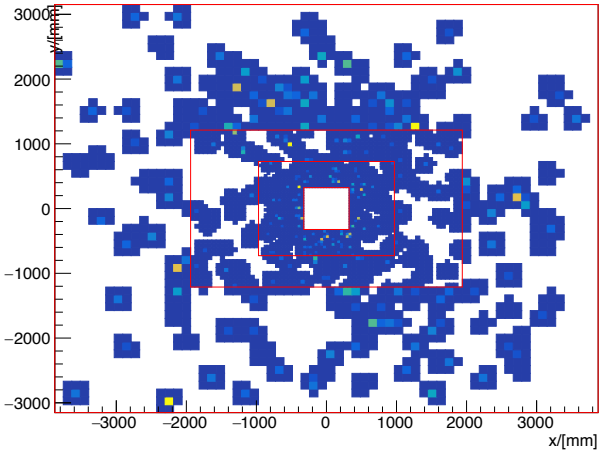




Present $L = 4\times10^{32} cm^{-2} \cdot s^{-1}$

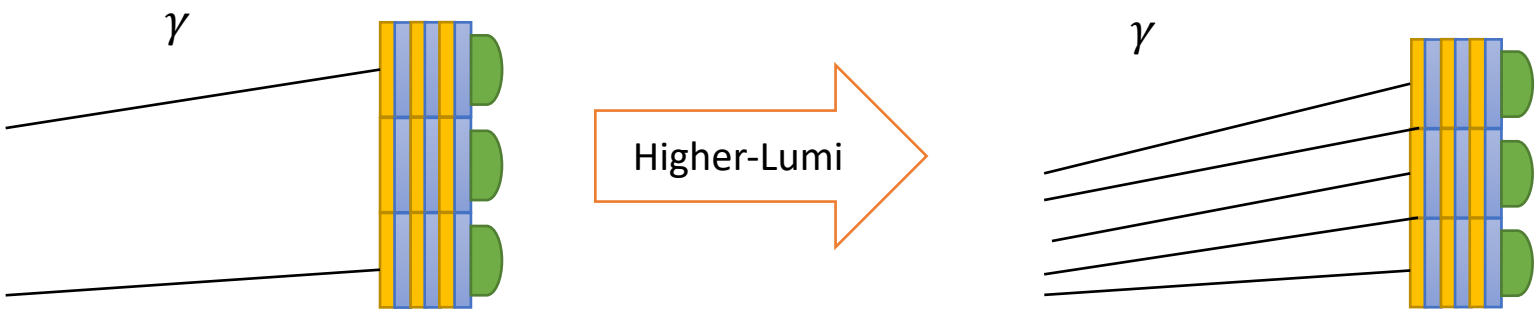


Upgrade II with $L = 1.5\times10^{34} cm^{-2} \cdot s^{-1}$



Present clusters include energy deposition of photons and electrons.

Energy resolution at different Luminosity

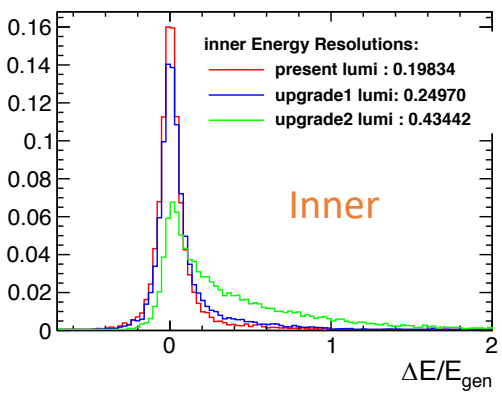


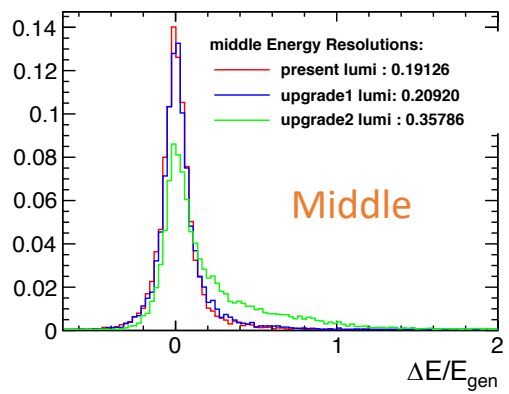
The reconstructed cluster is matched with highest energy photon that hits seed cell
Energy resolution defined as:

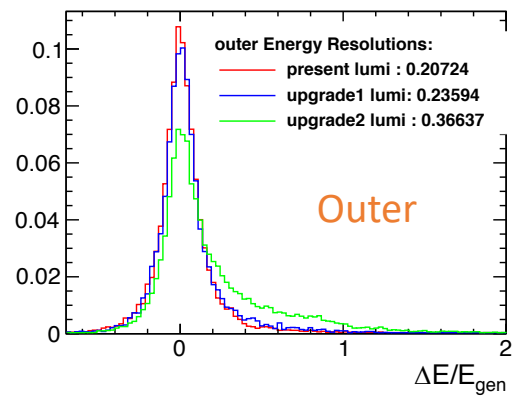
$$Res(E) = (E_{rec} - E_{gen})/E_{gen}$$

No fitting, standard deviation here:

With current ECAL configuration



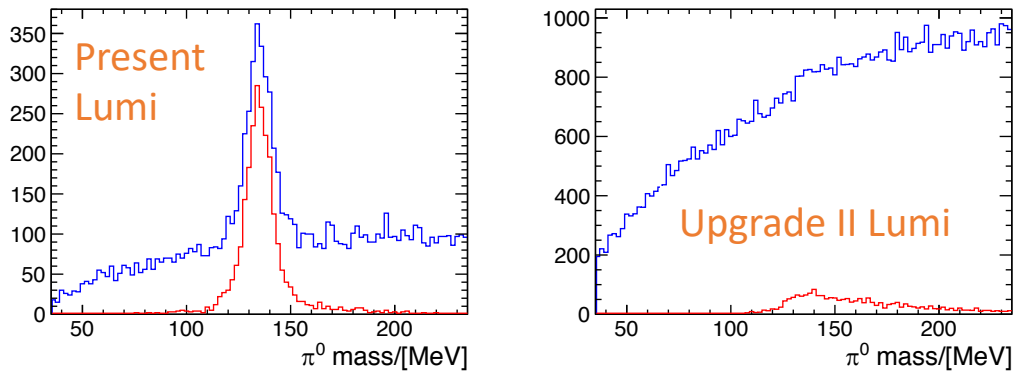




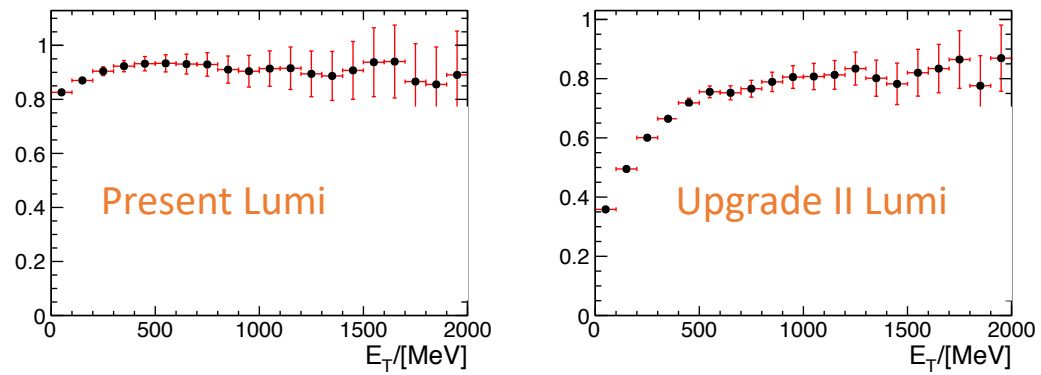
π^0 and γ performance

Reconstruct π^0 in minimum bias sample, combine two γ in one events:

1. $p_T(\gamma) > 0.2\text{GeV}$
2. $p_T(\pi^0) > 2\text{GeV}$



γ reconstruction efficiency, including matching efficiency.



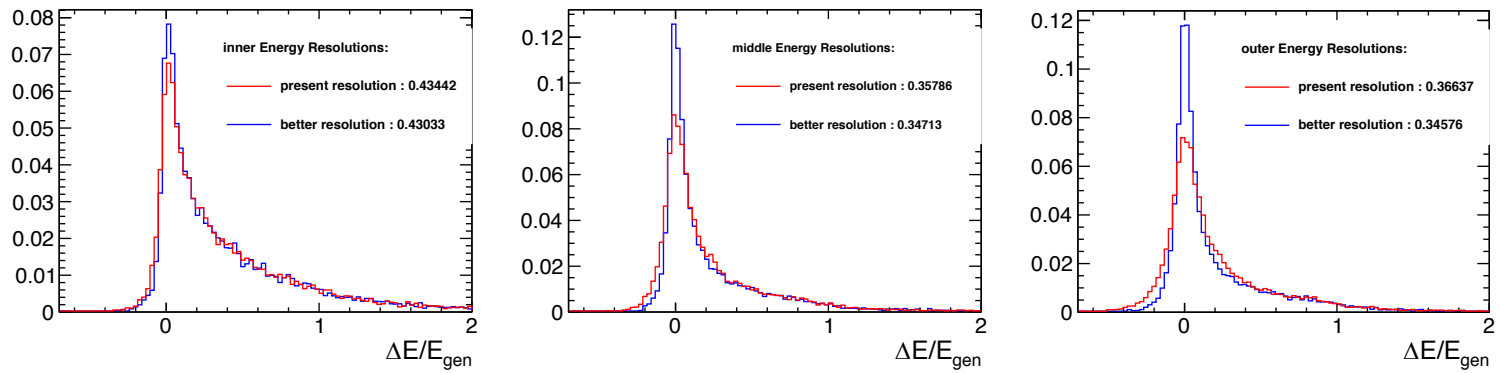
1. Higher Luminosity causes worse energy resolution.
2. More background in π^0 mass spectrum.
3. Worse π^0 mass resolution.
4. Worse photon reconstruction efficiency.

Overlapping effect is the biggest challenge with higher luminosity.

Areas of Improvement

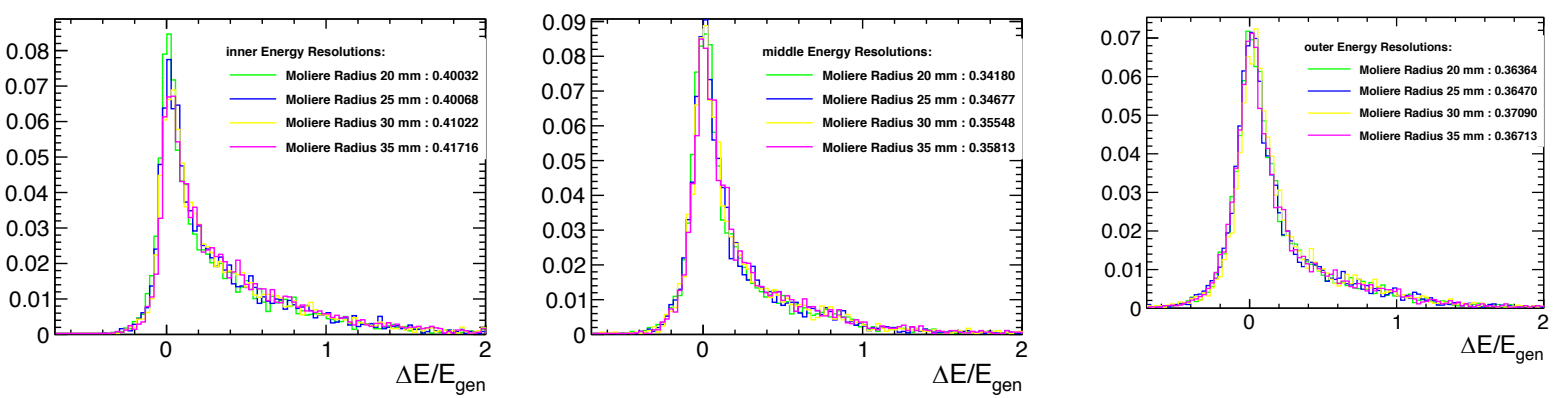
Intrinsic cell energy resolution:

$\frac{\sigma}{E} \sim \frac{\alpha}{\sqrt{E}} \oplus \beta$: change α from 10% to 5%, the improvement is small.



Moliere Radius:

Change present value $35mm$ to $15mm$, no obvious improvement.

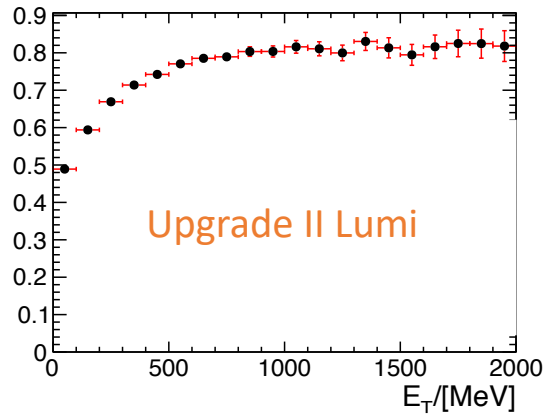


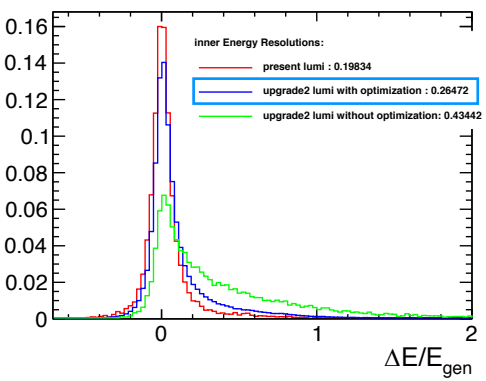
Areas of Improvement

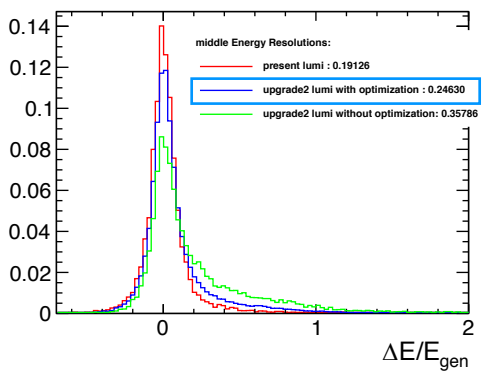
Change the cell size:

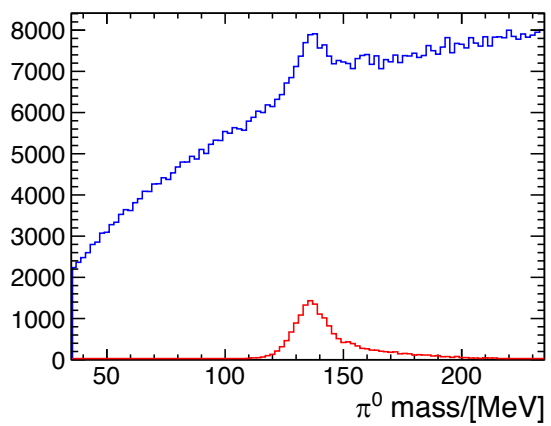
Different Region	Present size	Present Num	New size	New Num
Inner	40×40	1472	20×20	5888
Middle	60×60	1792	40×40	4032
Outer	120×120	2688	120×120	2688

1. Inner and middle section energy resolution becomes better.
2. π^0 mass resolution get better.
3. Photon efficiency becomes higher.
4. Still high level of background from π^0 mass spectrum.

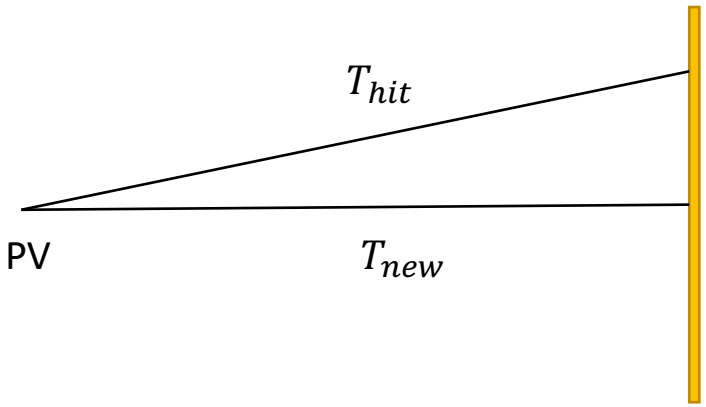


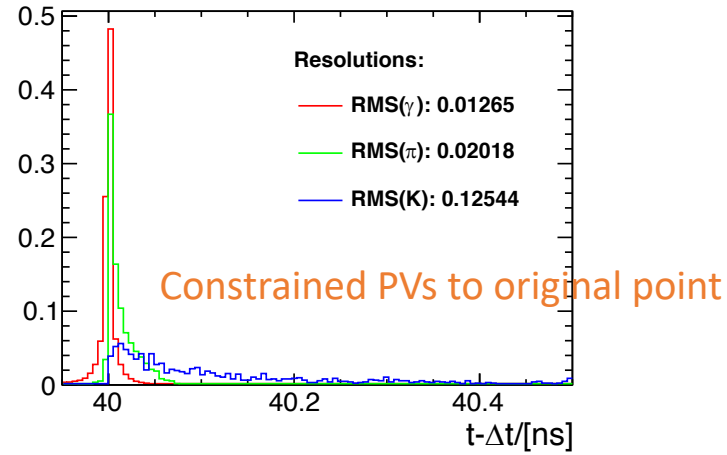






Time information



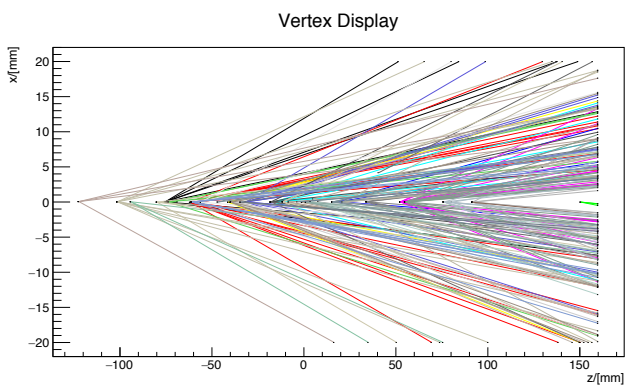


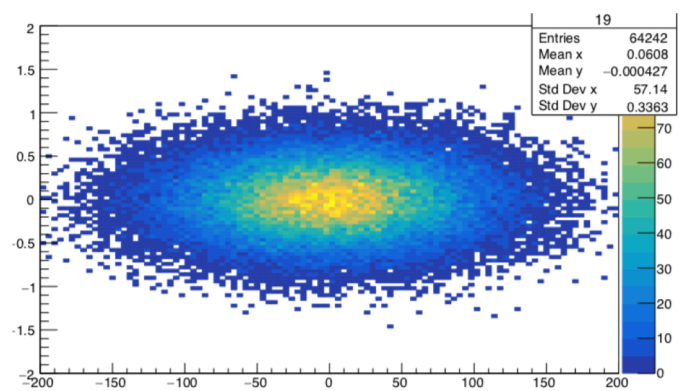
New variable: $T_{new} = T_{hit} - \Delta T(x, y)$

T_{new} is same for all photons generated from same PV, if ignore cell size effect.

Use BeamSpotMarkovChainSampleVertex Module to spread PVs.

With help from S. Easo



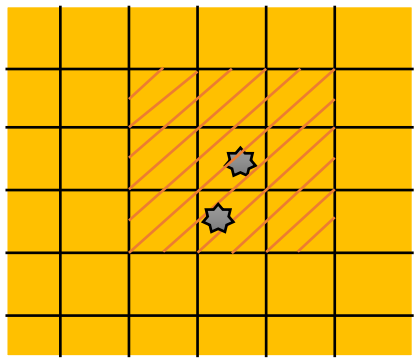


Time information

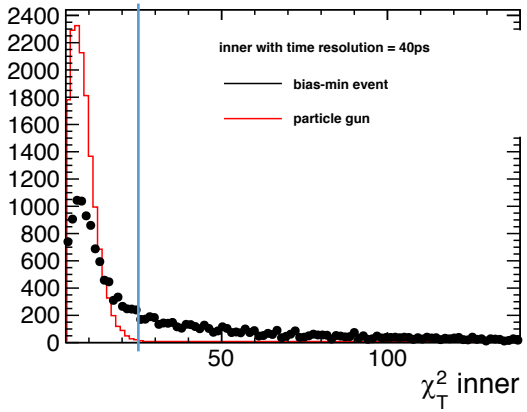
Cluster reconstruction including time information, construct a new variable to describe the time fluctuation in one cluster:

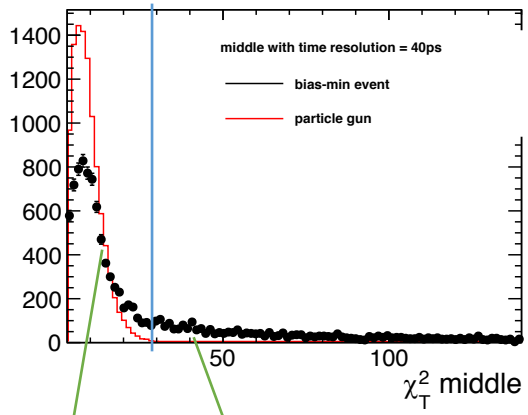
$$\chi_T^2 = \sum_i^N \frac{(T_i - \bar{T})^2}{\sigma^2\,(E_i, x_i, y_i)}$$

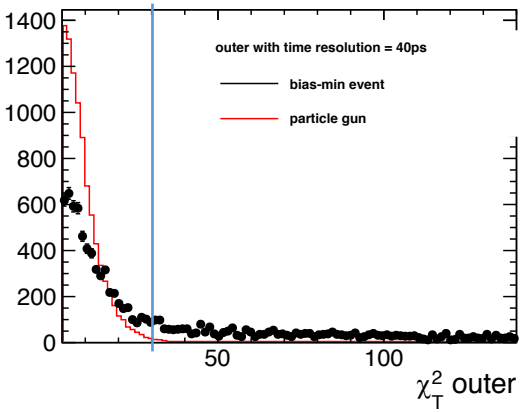
N is the total cells used in one cluster reconstruction.
In this preliminary study, we assumed σ_T is known.



The distribution of χ_T^2 with σ_T equal to $40ps$.
Red line got from particle gun, black line from minimum bias event with upgrade2 lumi.





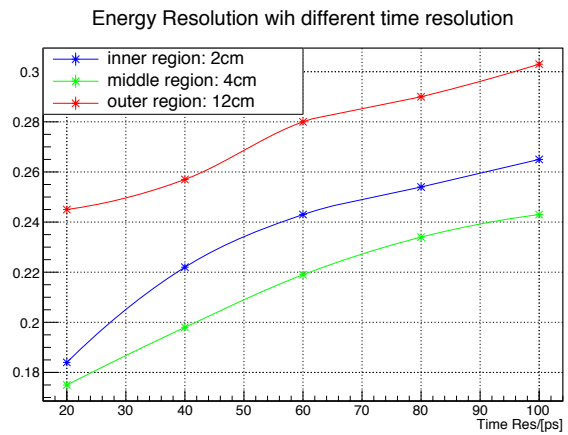


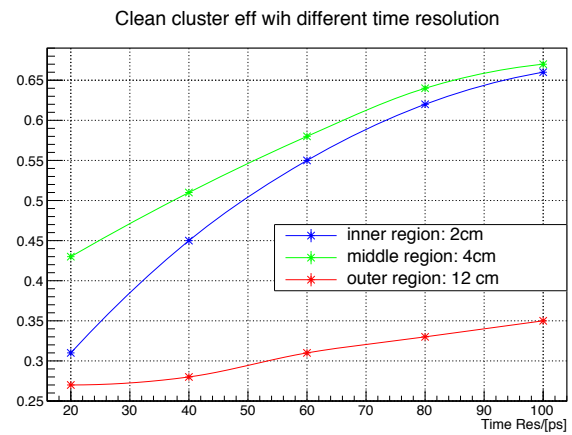
This kind of cluster contains only one photon?

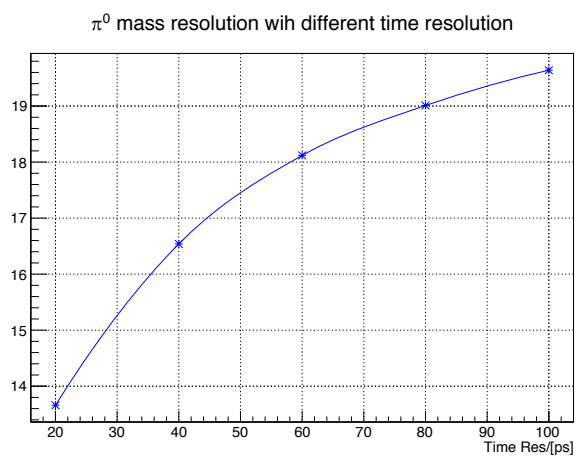
This kind of cluster contains more than one photons?

Time information

Apply a cut on χ_T^2 to choose the clean cluster.







Using time information to choose overlapping clusters:

1. Better time resolutions lead to better energy resolution.
2. Better time resolution can help to choose cleaner cluster, which bring about smaller clean cluster efficiency.
3. Better time resolution also helps to improve π^0 mass resolution.

Using energy and time distribution to separate overlapping cluster, ongoing study.

Time information for particle identification

Particle identification to reject electron hypothesis

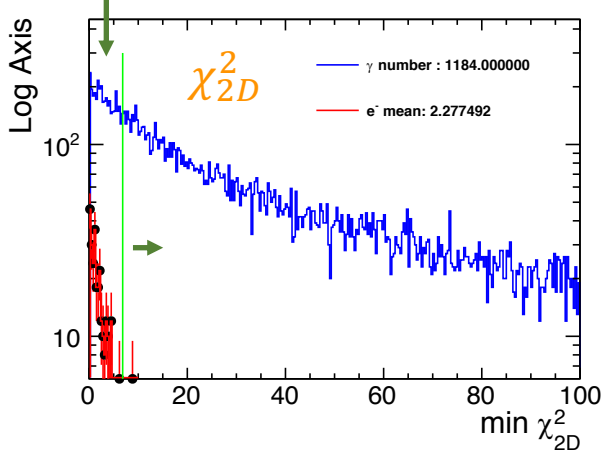
The simple form of χ^2_{2D}:

$$\chi^2_{2D} = \frac{(x_{cluster} - x_{tr})^2}{\sigma_x^2} + \frac{(y_{cluster} - y_{tr})^2}{\sigma_y^2}$$

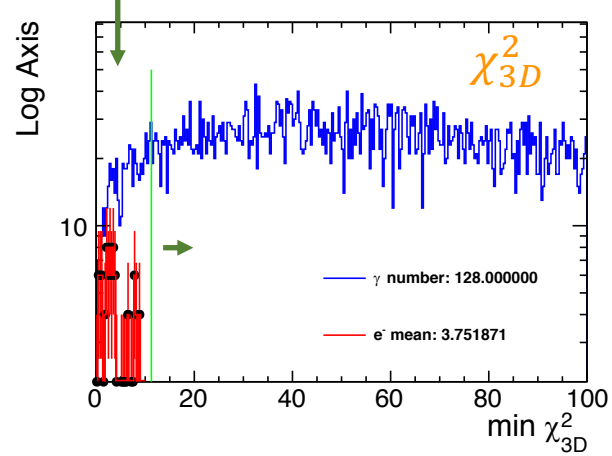
The simple form of χ^2_{3D} including time:

$$\chi^2_{3D} = \frac{(x_{cluster} - x_{tr})^2}{\sigma_x^2} + \frac{(y_{cluster} - y_{tr})^2}{\sigma_y^2} + \frac{(T_{cluster} - T_{tr})^2}{\sigma_T^2}$$

Reject 1184 photons



Reject 128 photons

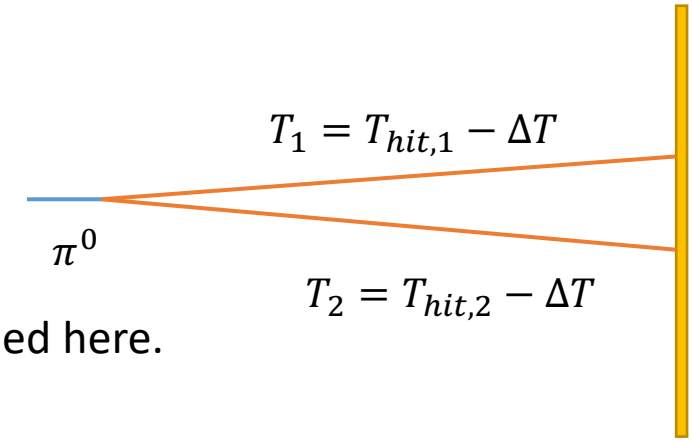


The particle identification variable has better performance including time information

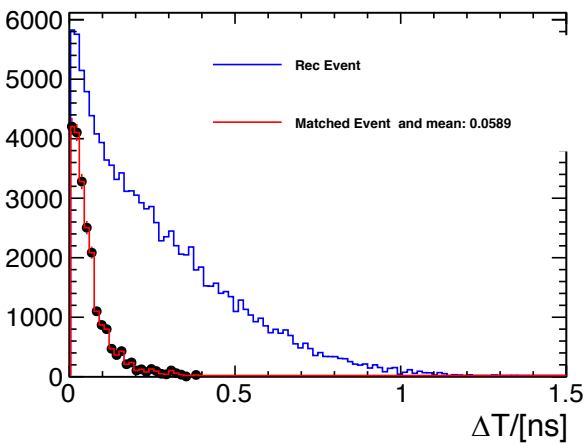
Time information to suppress combinatorics

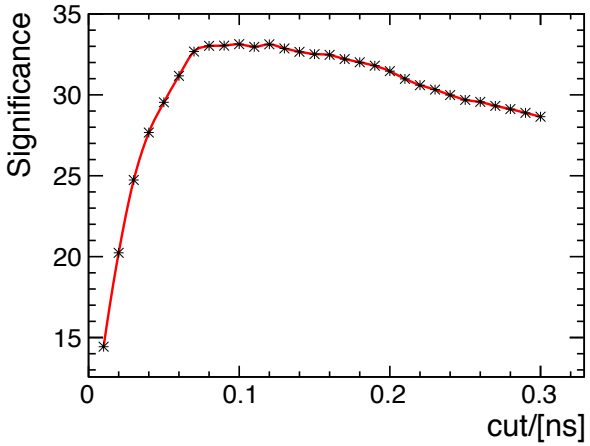
π^0 reconstruction including time:
Building new variable based on time information can help to increase the significance:

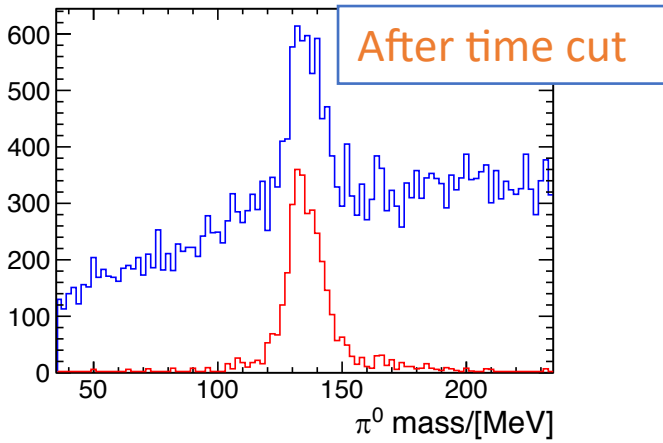
$$\Delta T_{1,2} = |T_1 - T_2|$$



T_1 and T_2 are ToA of two photons, $\Delta T_{1,2} < 0.09$ is applied here.
(Minimum bias event sample.)







1. Applying $\Delta T_{1,2}$ can help reject more background candidates.
2. If the momentum of π^0 is very large, it's difficult to estimate $\Delta T(x, y)$.

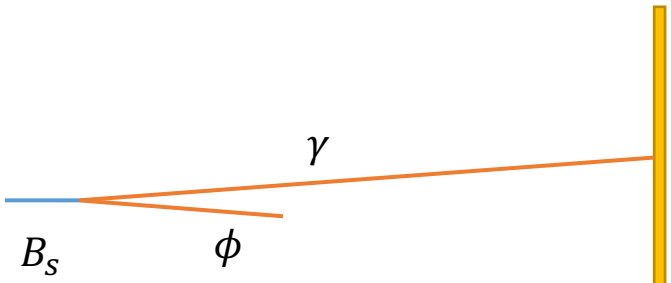
Time information

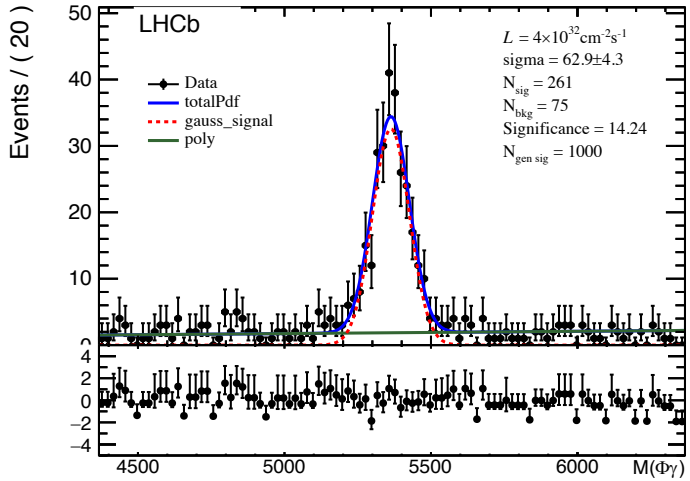
$B_s \to \phi\gamma$ reconstruction including time:

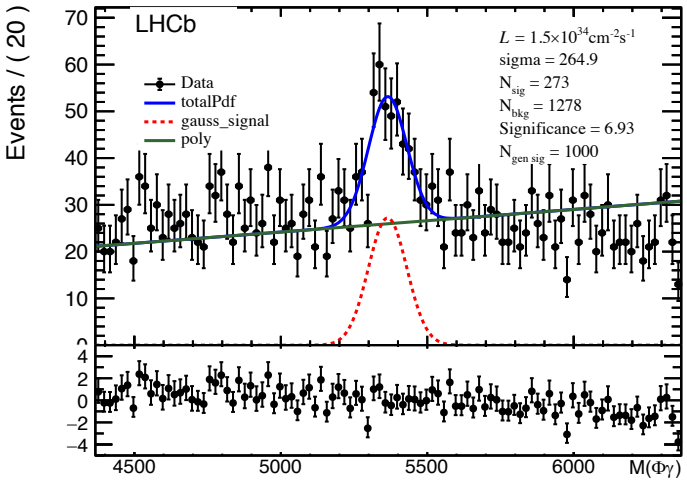
$E_T(\gamma) > 2600\text{MeV}$;

$P_T(B_s^0) > 3000\text{MeV}$;

We use the true ϕ decayed from B_s in this study.







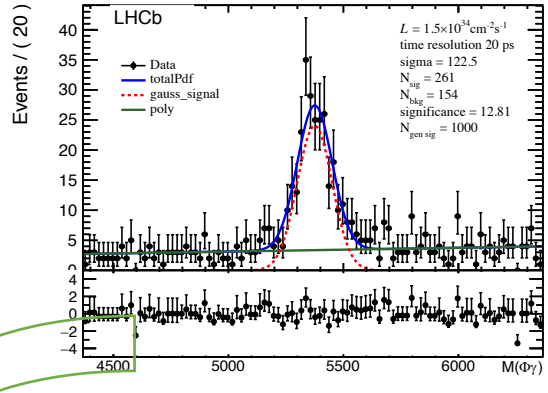
High Luminosity causes a high level background, add time coincidence to reject more background candidates.

Construct time coincidence variable:

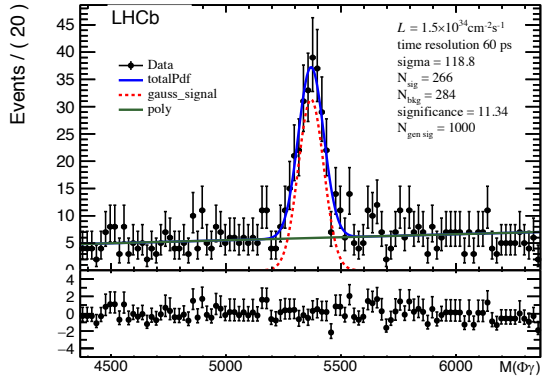
$$\Delta T = |T_\phi - T_\gamma| < criteria$$

Time information

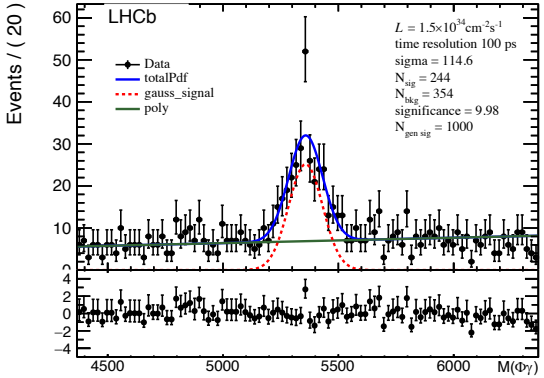
$20\ ps$



$60\ ps$

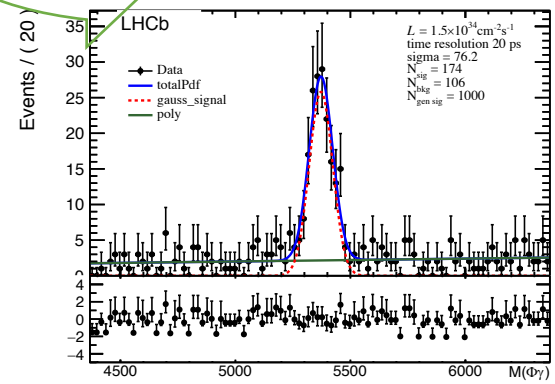


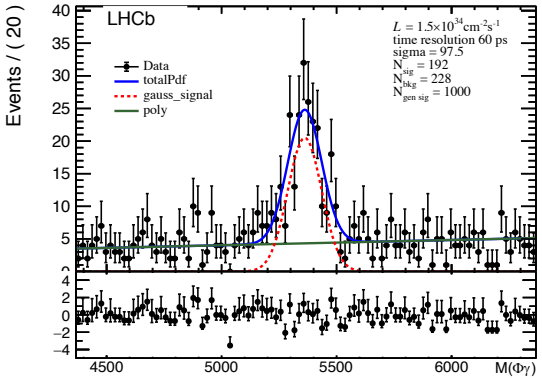
$100\ ps$

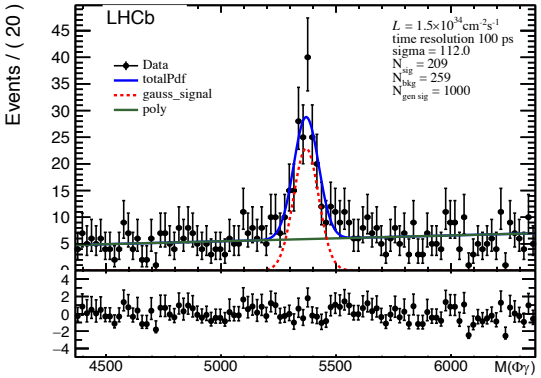


Apply χ_T^2 cut

Sigma is estimated from matched distribution.





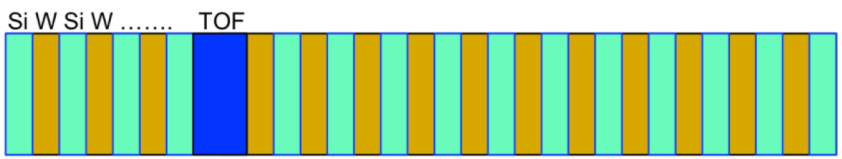


1. Time information can help to improve mass resolution.
2. Help to keep more signals and reject more background candidates at the same time.

How to measure time

How to detect time information?

1. From PMT in the shashlik or spaghetti cell. (or two PMTs)
2. Timing layer behind a pre-shower plate.
3. Insert silicon sensor in a reasonable position.



Similar to Sheldon's idea proposed before.

Insert silicon sensor in different position

PMT or Silicon Sensor?

1. We cannot expect a very good time resolution from PMT, especially if the deposited energy is small.
2. Silicon detector is very sensitive, and anti-radiation character is not very bad. But it is very expensive.

If we can afford one layer of silicon sensor detector, where to put them?

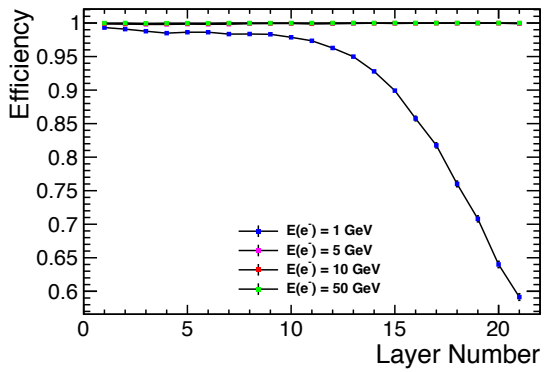
More Simulation Study

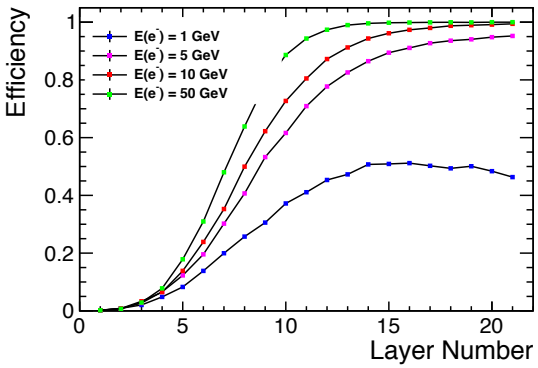
Test the silicon sensor performance in GEANT4,
Detection efficiency (>10keV):

Seed Cell

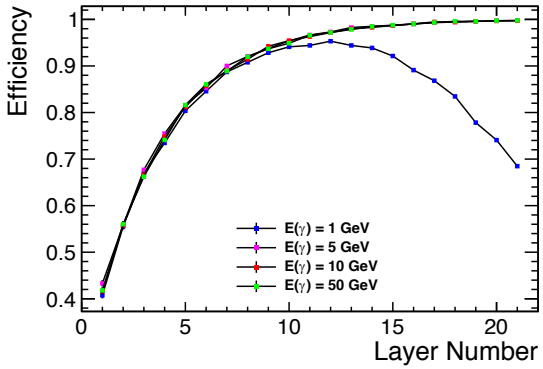
Nearby Cell

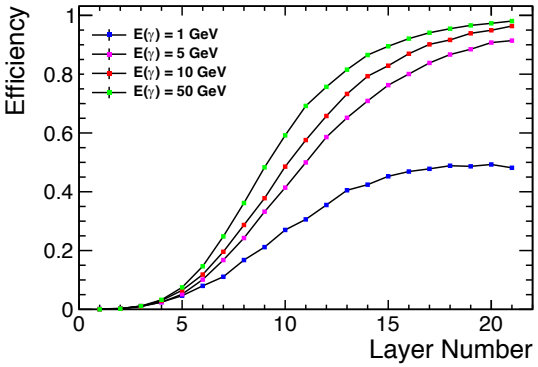
Electron Particle Gun:





Photon Particle Gun:

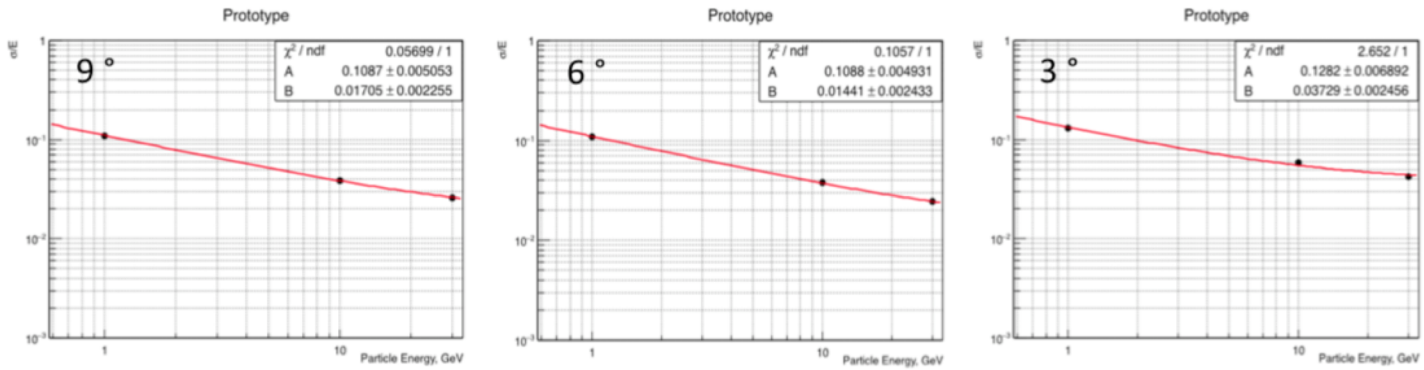




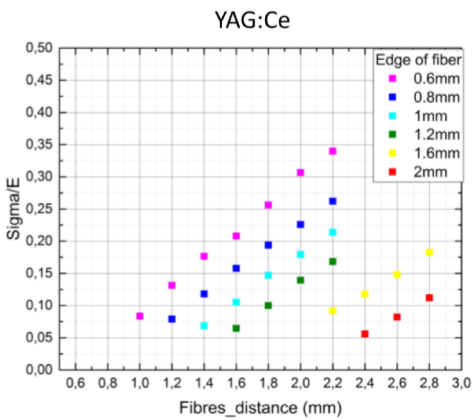
Insert silicon sensor in reasonable position, $3X_0$, might be a choice and we could reduce its thickness which also means to reduce the photon detection efficiency.
(Similar to set time layer behind pre-shower)

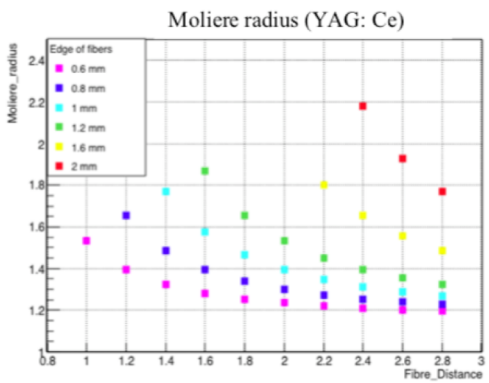
More Simulation Study

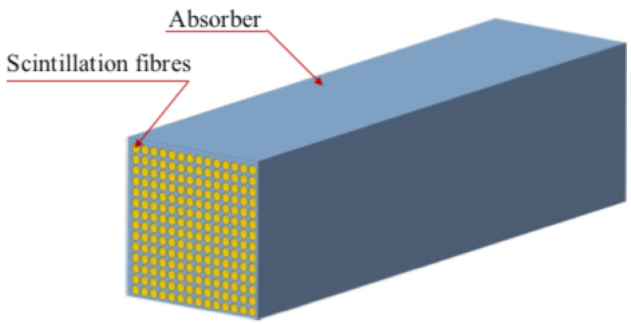
Geant4 simulations for SPACAL modules. (by S.Evgenii)



The constant term at 3° is 3.7%, goes down to 1.5% at larger angles, but no difference at 6 and 9 degrees.

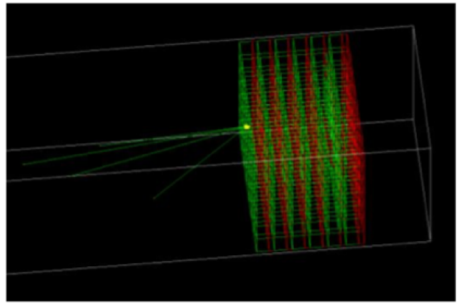




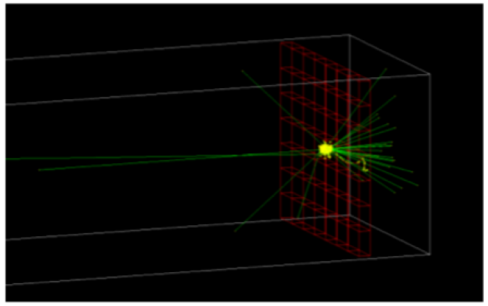


Energy resolution and Moliere Radius strongly depends on the fibre-to-fibre distance!
And the simulation results agree with beam test results!

More Simulation Study

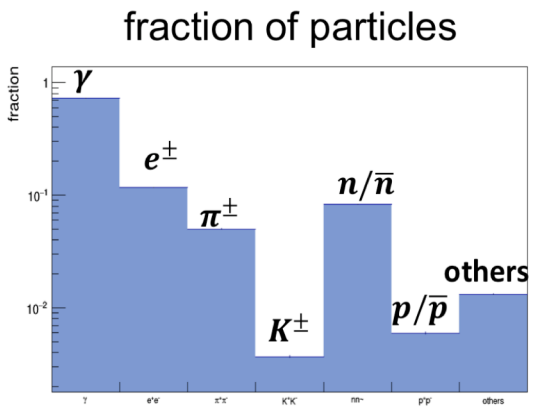


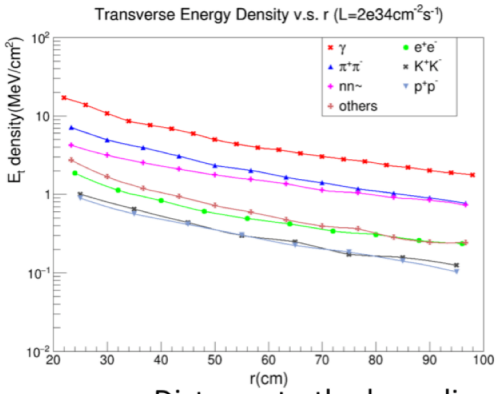
Lead (green) + GAGG (red) shashlik,
50 GeV signal photon at 5°, wo/ background



Bariumflourid single crystal modules,
100 GeV photon at 0°, wo/ backogrund

Geant4 simulations for shashlik(left) and crystal(right) modules. (by M.Röhrken)
For shashlik, tungsten is better than lead, and 60 layer has better performance than 30.





r: Distance to the beamline

Background particle simulation with high luminosity. (by Z.Shen)
Very high occupancy for the inner section of ECAL.

Summary and Plans

Summary:

1. Overlapping effect is the biggest obstacle with high-lumi for present ECAL.
2. Smaller cell size is really helpful to conquer the huge barrier.
3. Precision timing ECAL can help to optimize energy resolution and reduce background candidates.
4. Detailed simulation of SPACAL, Shashlik and Silicon have good result or ongoing.

Smaller cell and precision timing might help to handle the high luminosity challenge.

Plans:

1. Separate the overlapping cluster, by fitting energy and time distribution or using machine learning algorithm. And the photon's energy resolution reconstructed from overlapping cluster should be worse than that got from clean cluster. (We will study the detailed algorithm in full simulation framework.)
2. Construct detailed detector model, we have no much experience with time information in simulation study..

Thanks for your listening!

Backup