
Analysis report:
Neutral pions in D-meson decays

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ECAL Upgrade II Workshop

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Physics case

- Discovered CP violation in two body charm decays:

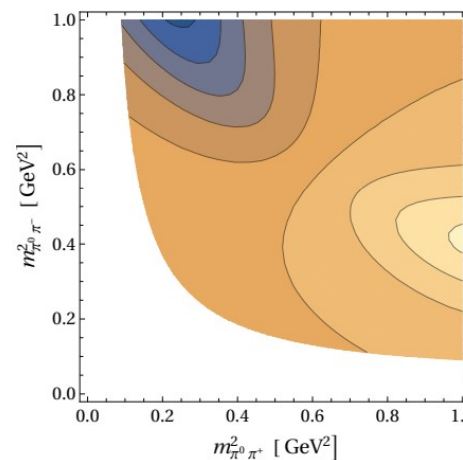
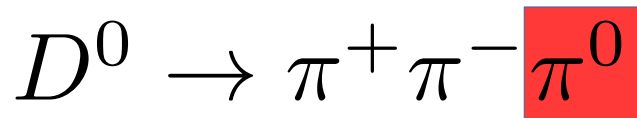
$$\Delta A_{CP} = A_{CP}(D^0 \rightarrow K^+ K^-) - A_{CP}(D^0 \rightarrow \pi^+ \pi^-)$$

$$\Delta A_{CP} = (-15.4 \pm 2.9) \times 10^{-4}$$

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- Hard to interpret result due to unknown strong phases.
- Multi-body decays allow to disentangle strong and weak phases as strong phases vary over the Dalitz plot.

- Local CP asymmetry in



Per mille level variations

(b) $\tilde{R}^{P_1 V_2} = \exp(i\pi/2)$, $\tilde{R}^{P_2 V_1} = \exp(i\pi/3)$

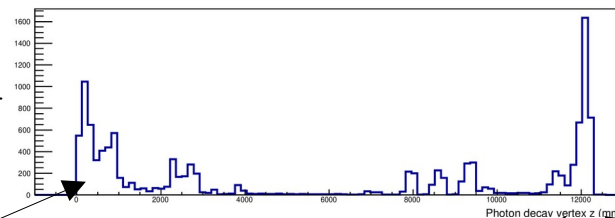
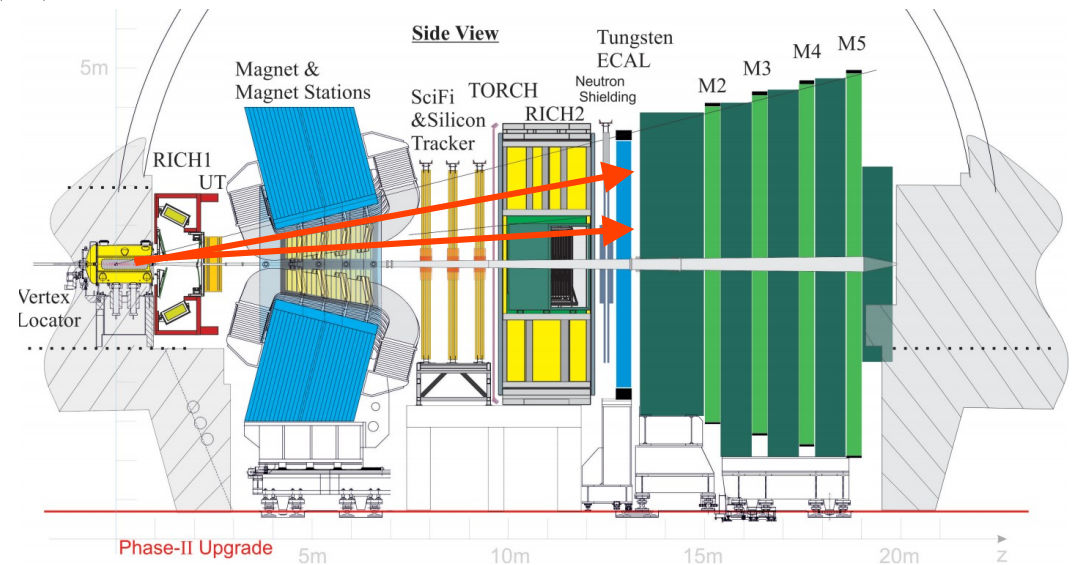
S. Schacht et al <https://arxiv.org/pdf/2101.02560.pdf>

Stating the (not so) obvious

- Neutral pions predominantly decay instantaneously to two photons (98%) $\pi^0 \rightarrow \gamma\gamma$

- Reconstructed with 2 or 1 clusters in the ECAL (momentum dependent)

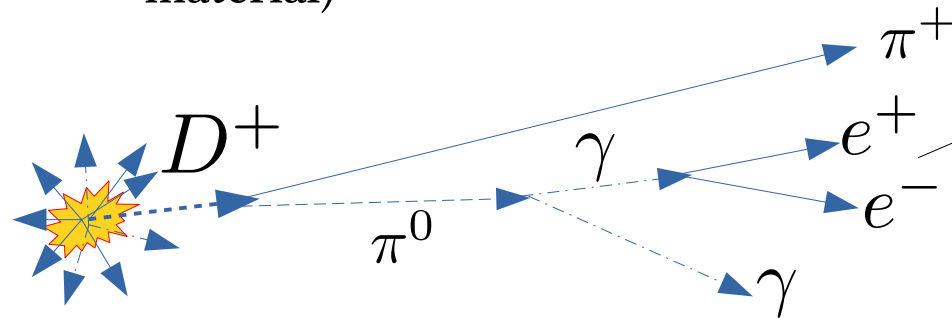
- Not covered today:
 $\pi^0 \rightarrow e^+e^-\gamma$ (suppressed decay) or
 $\pi^0 \rightarrow \gamma(\rightarrow e^+e^-)\gamma$ (conversion in material)



Photons from pi0 from D decays interacting before ECAL

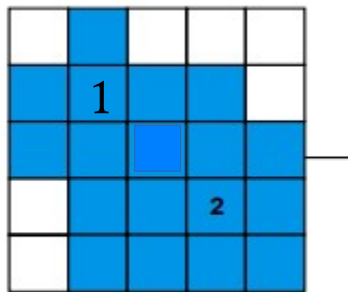
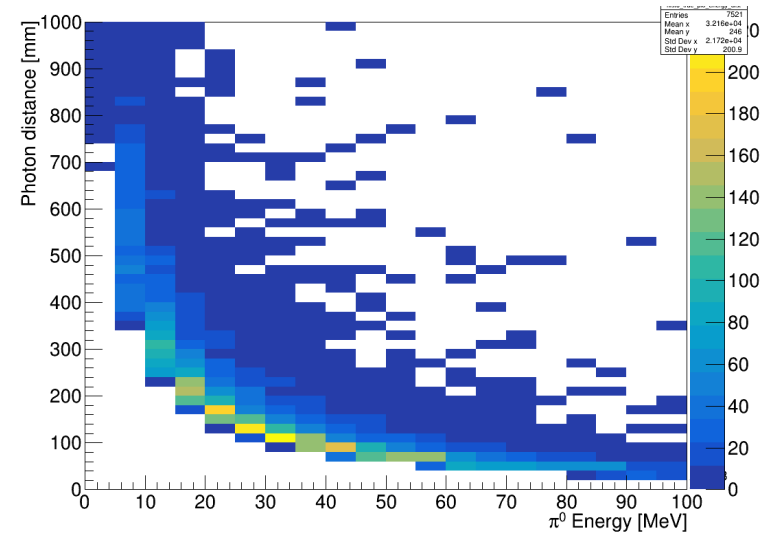
(Have to check their reconstruction efficiency)

Neutron shield

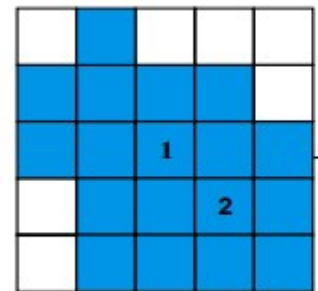


π^0 reconstruction

- Reminder: Clusters (3x3) can be separated if there is at least one cell between two local maxima (seed cells).
- Two cases:
 - Resolved $\pi^0 \rightarrow$ each photon creates one cluster
 - Merged $\pi^0 \rightarrow$ one cluster for both photons

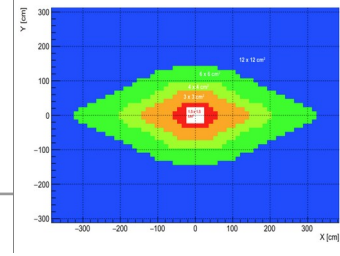


Two clusters

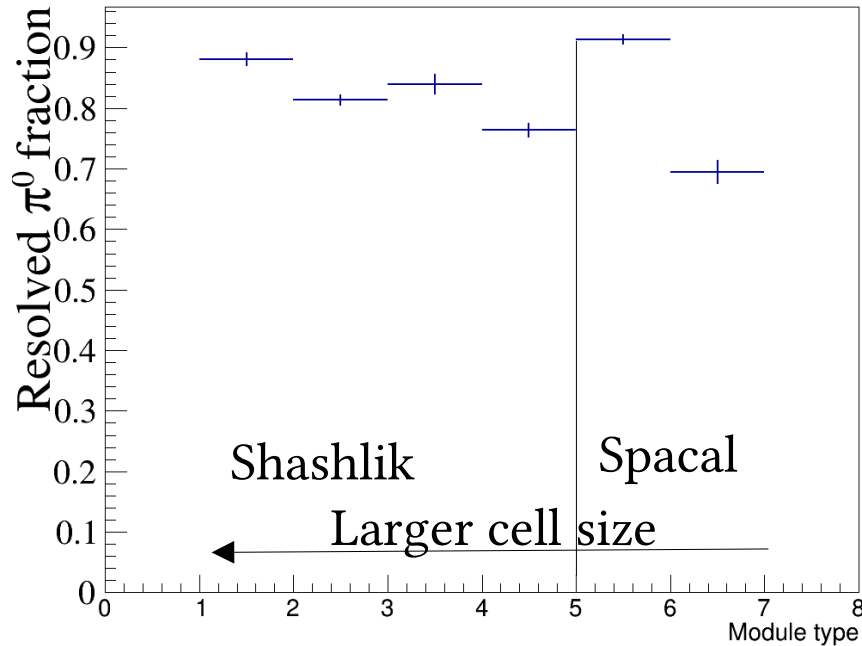


Single cluster

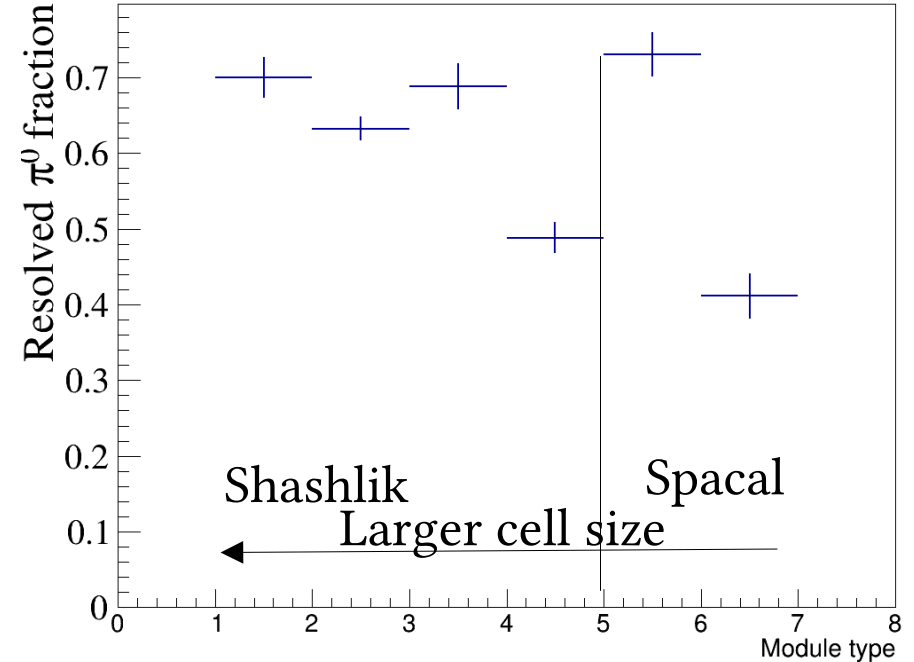
Fraction resolved versus merged



Upgrade 2 baseline



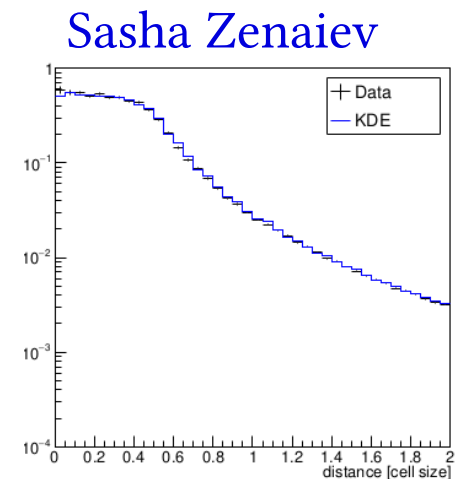
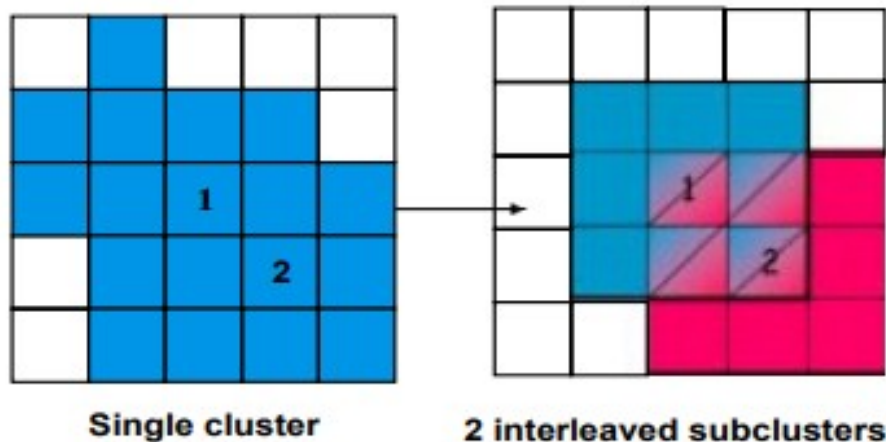
π^0 $P_T > 3.5$ GeV, π^0 $P > 5$ GeV



- π^0 from D have lower momenta than from B \rightarrow more resolved
- Resolved π^0 have much more background due to lower momentum photons \rightarrow Most analyses use both types and sometimes only merged π^0 .

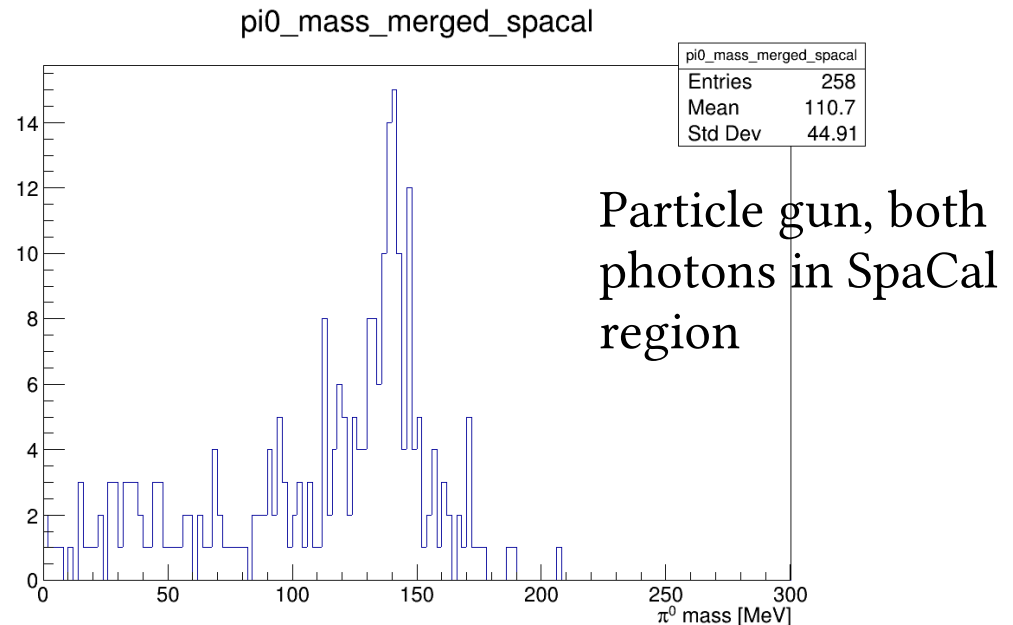
(Classical) merged π^0 reconstruction

- Follow approach from Run1/2 <https://cds.cern.ch/record/691634> and use input from Sasha Zenaiev's studies.
- Algorithm:
 - 1. Take 3x3 cluster and look for cell with second highest energy
 - 2. Define two subclusters, first identical with original, second 3x3 around second seed.
 - 3. Distribute energy in each cell among subclusters:
 - Use expected transverse showershape to assign fraction per subcluster
 - Recalculate position and energy of each subcluster and repeat until energies stay constant



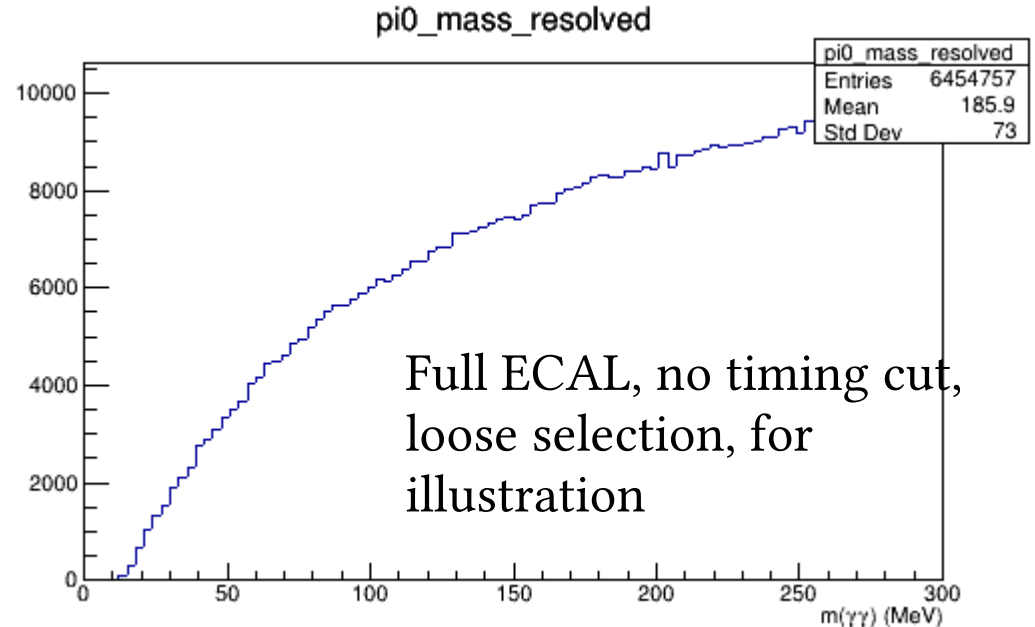
(Example) merged π^0 reconstruction

- Implemented procedure in reconstruction of standalone simulation of ECAL.
- Assume photons coming from (0,0,0)
→ calculate invariant mass
- Basic reconstruction working but room for improvements
 - See also next talks
 - Use of timing
 - Machine learning



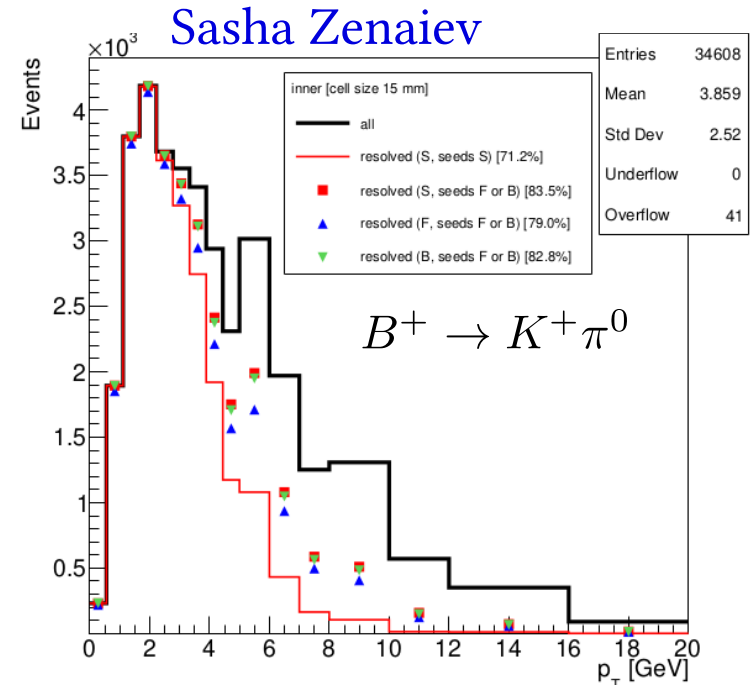
TODO: Run 4 studies

- Next step is to do studies with signal and background for Run 4 configuration
 - Simulation running but started too late for this workshop.
- How much does timing in the inner region reduce backgrounds on overall scale?



TODO: Run 5 studies

- Start studies with rotated modules for this channel.
- Include timing and segmentation in π^0 reconstruction for merged and resolved π^0 s.
 - For example seeding clusters with front and back separately, increases fraction of resolved π^0 s



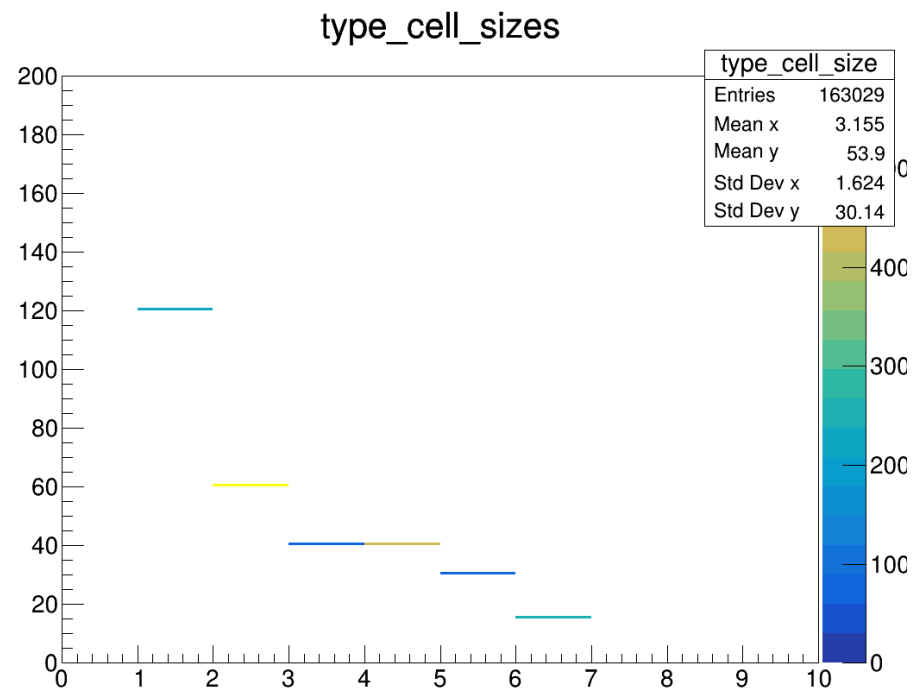
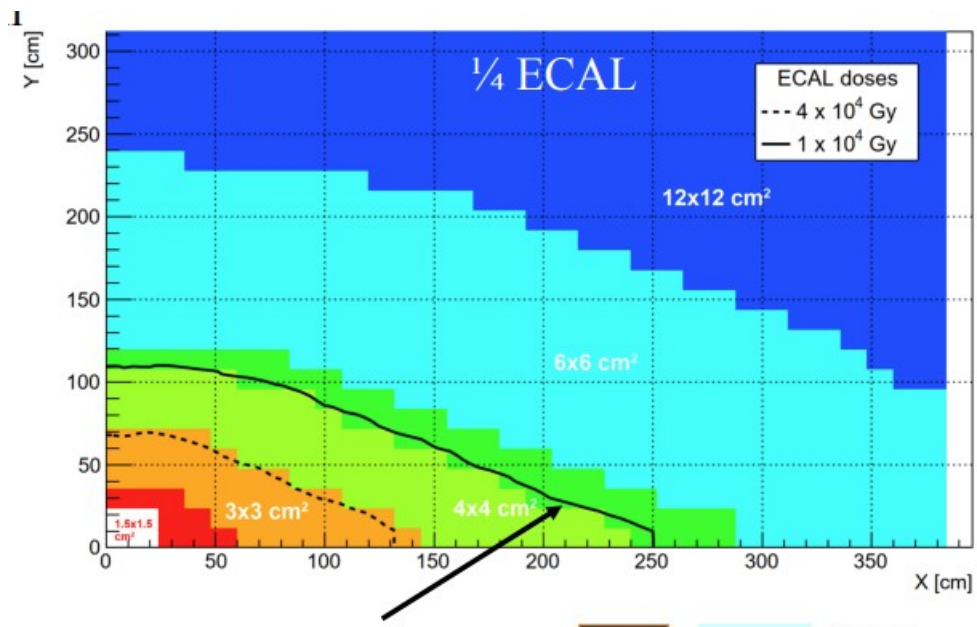
- Integrate with Velo+Calo setup \rightarrow see Laurent's talk.
 - Allows to have more realistic cuts on time at decay vertex and Calo.

Conclusion

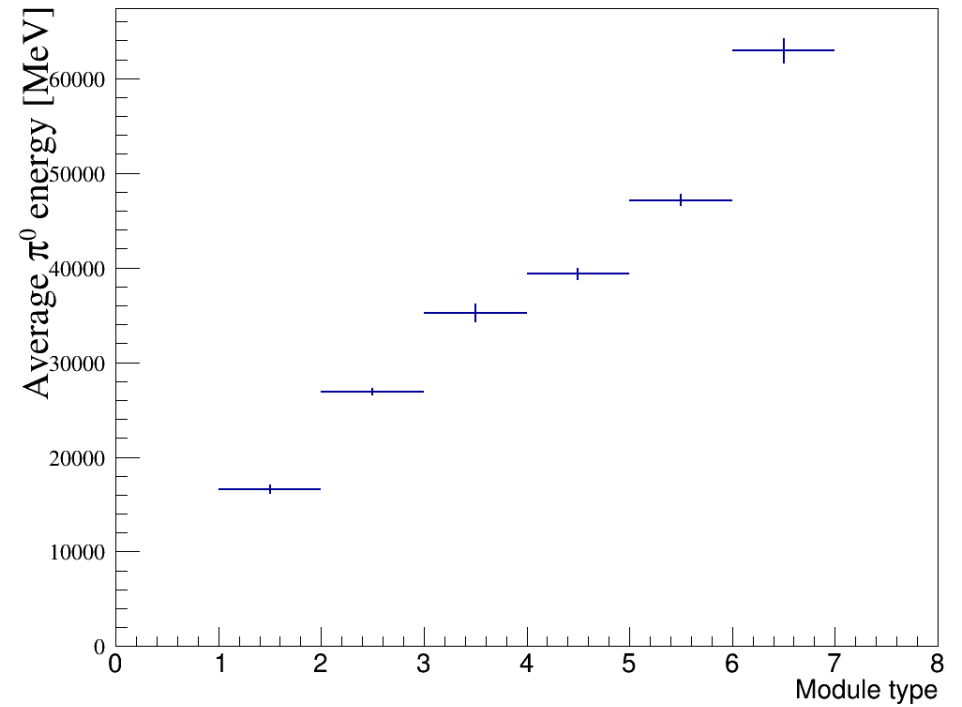
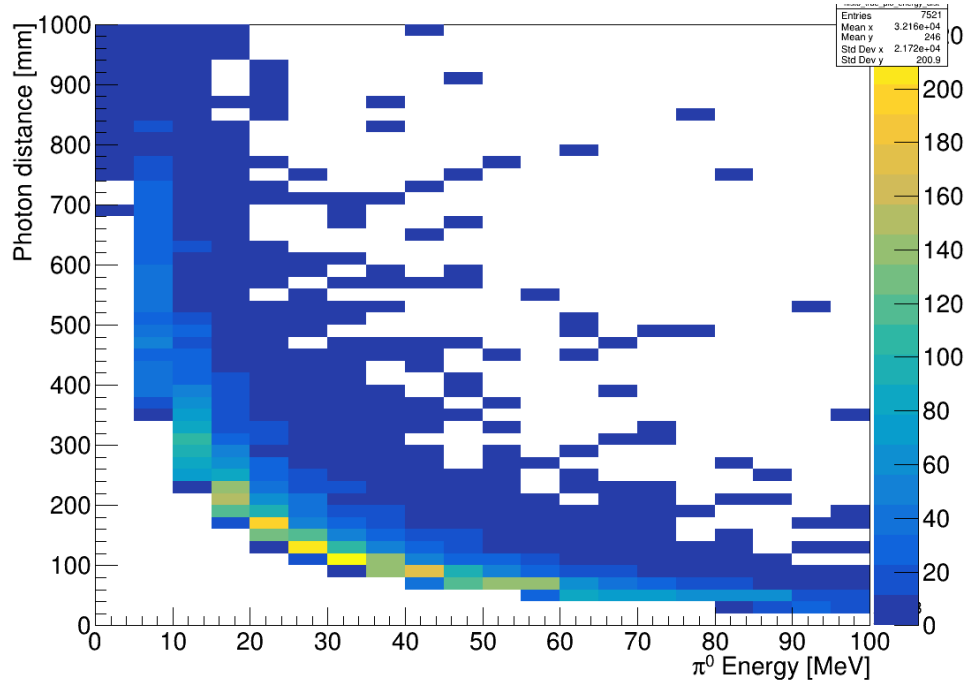
- Have to learn how to use improved detector for π^0 reconstruction.
 - See next two talks for examples but more to do.
- More people working on π^0 identification and reconstruction are welcome (already interesting for Run 3).

Backup

Module types

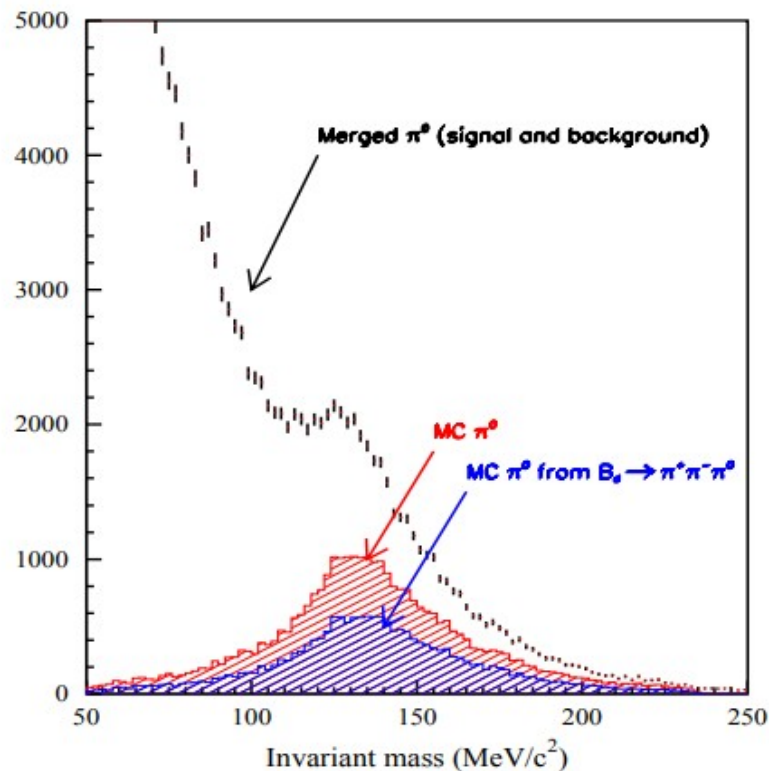


Some plots



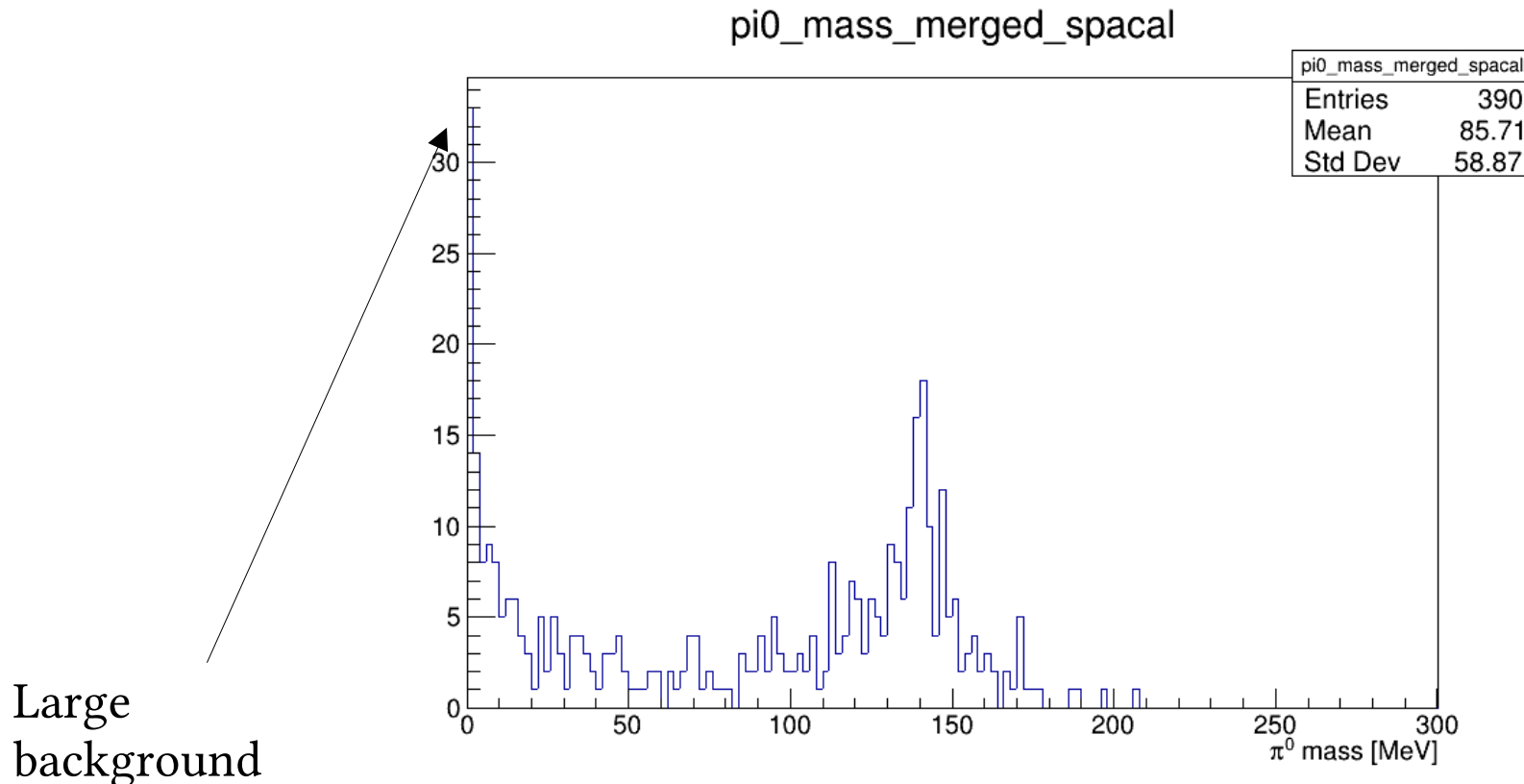
Merged π^0 reconstruction

- Invariant mass calculated from cluster positions and energies assuming both photons come from 0,0,0.
- Plot from old note



Merged π^0 reconstruction, SpaCal

- Energy sharing also a problem for resolved π^0 so Sasha had fitted the energy fraction as function of distance for the SpaCal region \rightarrow Took the same function to get weights.
- Shashlik region todo.

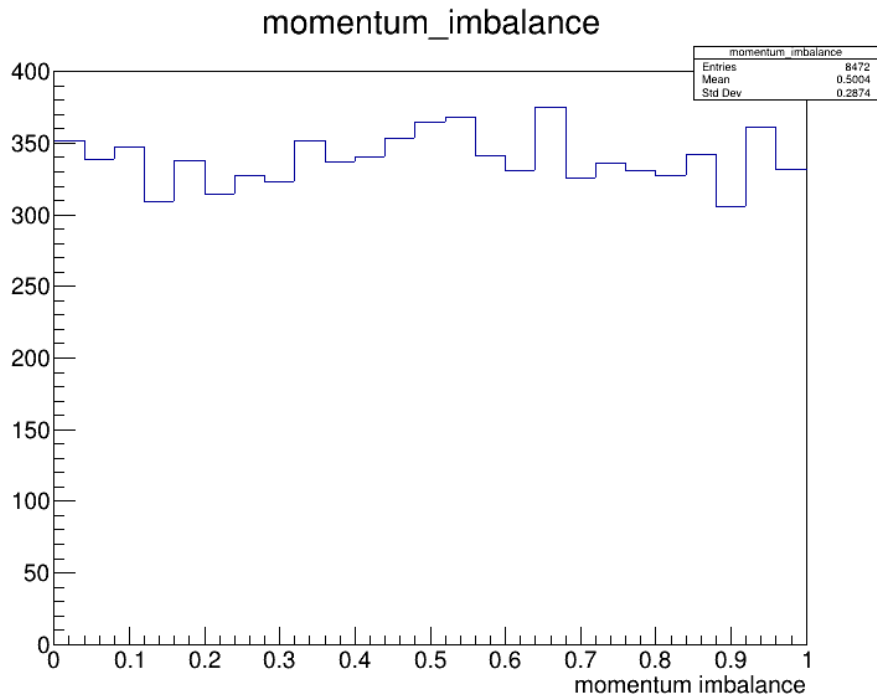


More plots

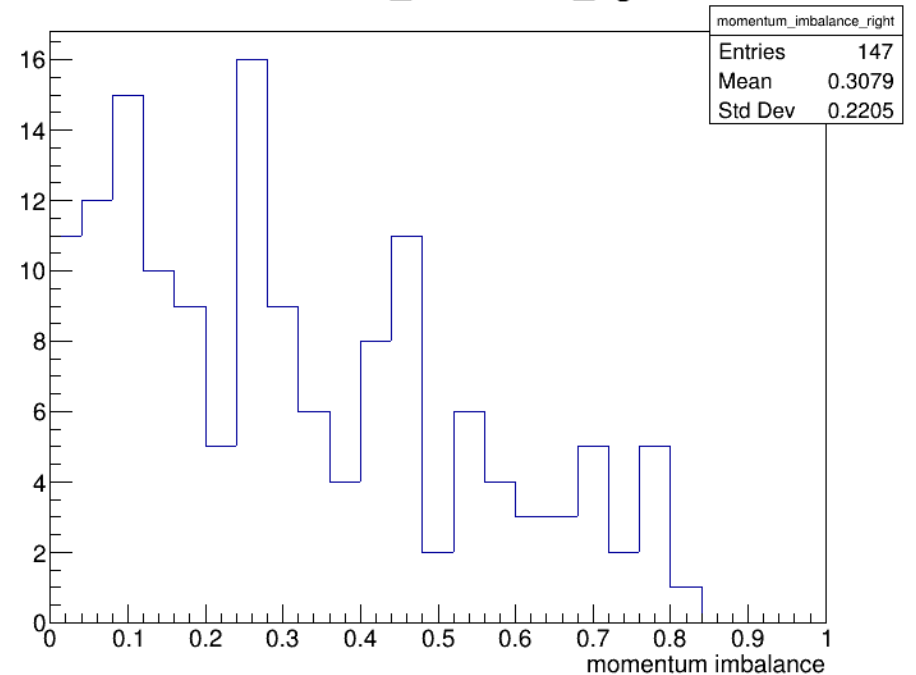
- Look at momentum imbalance of photons

$$\frac{p_1 - p_2}{p_1 + p_2}, p_1 > p_2$$

All pi0:



Merged pi0 with
correct mass:
momentum_imbalance_right



Redistributing energy probably
doesn't work well.

Next steps

- Implement something working for Shashlik region.
 - Start with functions from Run 2.
 - Study with backgrounds.
 - Try using timing and segmentation.
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- Project: How about using machine learning for merged π^0 identification?