## Simulation

### Calorimeter optimization

The baseline calorimeter geometry design (henceforth disk geometry) for Mu2e consists of two annular disks separated by approximately half a wavelength. This configuration presents minimal area for the interception of backgrounds to particles entering the Detector Solenoid and originating in the muon-stopping target or the beam dump while keeping excellent signal efficiency. We selected hexagonal faced crystals to tessellate the annular disk, as they provide a more natural tiling and offer a better coverage than square crystals. Hexagonal crystals also offer superior light collection efficiency and better approximate the shape of electromagnetic showers. In optimizing the disk design, we considered the inner and outer radii of the disks, their placement and relative separation, and the dimensions of the crystals.

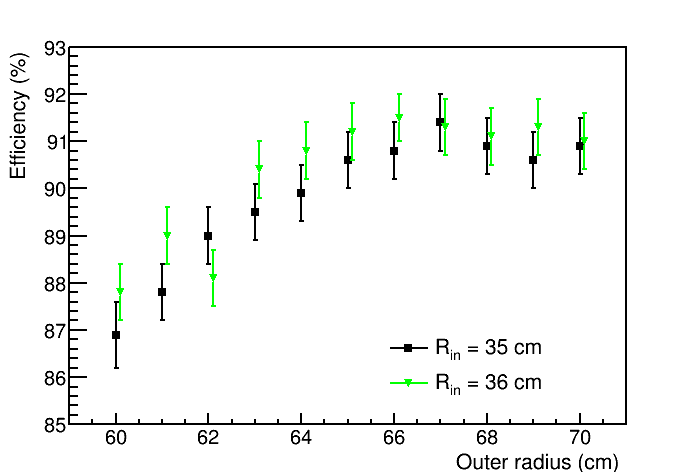
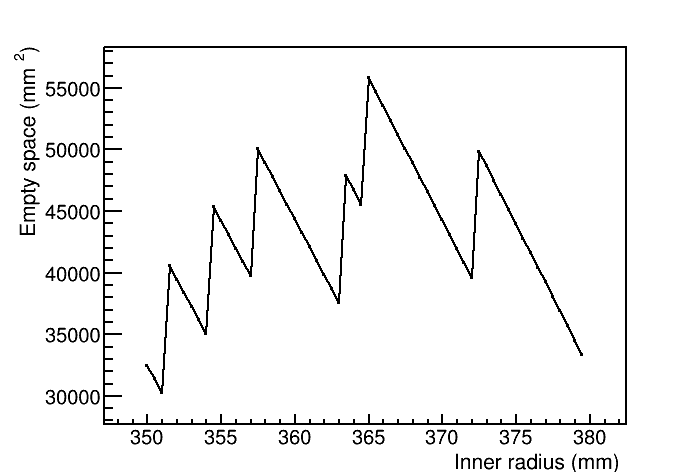
The dimensions of the disks are the first to be addressed. Figure XX shows the efficiency for detecting in the calorimeter a good signal electron found by the tracker as a function of the disk inner and outer radii. We consider only cluster with a deposited energy above 60 MeV. The separation between the disks is set to 70 cm, corresponding approximately to half a wavelength, and the crystal size is taken to be 32 mm across flats. The efficiency reaches a maximum at an outer radius close to 67 cm for both an inner radius of 35 cm and 36 cm. A similar conclusion holds for considering disks with different outer radii. We refine the optimization by minimizing the empty space between the crystals and the disk boundaries as a function of the crystal size and the disk radii. Figure XX shows for example the empty space as a function of the disk inner radius for a crystal dimension of 33 mm across flats. Several possible configurations are detailed in Table XX. We selected a crystal size of 33 mm across flats with disk radii of 351 mm and 660 mm, respectively. This choice ensures sufficient space to mount the readout at the back of the crystal while maintaining efficiency and limiting the number of readout channels. The crystal layout is shown in Figure xx.

We finally optimize the separation between the disks. As shown in Figure XX, a separation of 70 cm is optimal, independent of the energy deposited in the calorimeter. The position of the disk w.r.t the tracker has a negligible impact on the efficiency, as expected from translational invariance.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Crystal size  (mm) | Disk Radii  in / out (cm) | # crystals | Empty volume  in / out (mm3) | Crystal  volume (cm3) | Efficiency  (%) |
| 31 | 359.1 / 643 | 966 | 28772.2 / 54288.1 | 168830 | 90.5 ± 0.6 |
| 31 | 359.1 / 672.3 | 1110 | 28772.2 / 54508.3 | 193998 | 90.4 ± 0.6 |
| 32 | 340.1 / 663.5 | 1044 | 29098.3 / 57184.3 | 194424 | 92.2 ± 0.6 |
| 32 | 371 / 663.5 | 966 | 29801.2 / 57184.3 | 179898 | 90.2 ± 0.6 |
| 33 | 351 / 660 | 930 | 30243.4 / 67178.5 | 184188 | 92.2 ± 0.6 |
| 34 | 361.2 / 647.3 | 798 | 32992.5 / 68438.1 | 167769 | 90.4 ± 0.6 |

Table xx.xx: Characteristics of the disks and crystals for some of the configurations optimizing the empty volume between the crystal and the disk boundaries.

Figure Left: The cumulative efficiency for detection in the calorimeter of good signal tracks first found in the tracker, as a function of the disk outer radius for different values of inner radius. Right: Empty space between the crystals and the disk inner bo



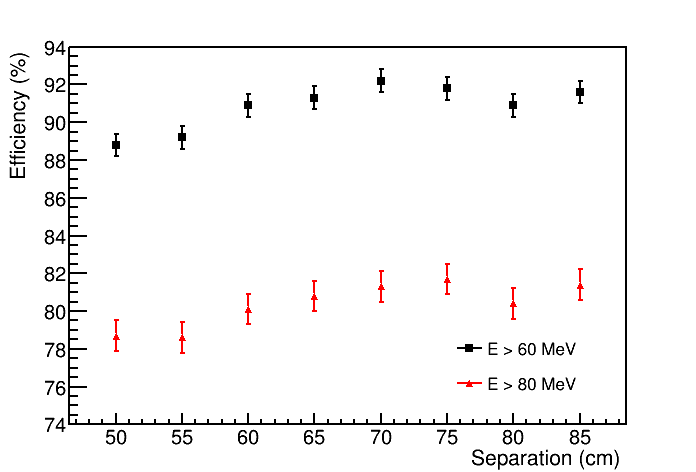


Figure The cumulative efficiency for detection in the calorimeter of good signal tracks first found in the tracker, as a function of the separation between the disks, for two thresholds of the energy deposited in the calorimeter.

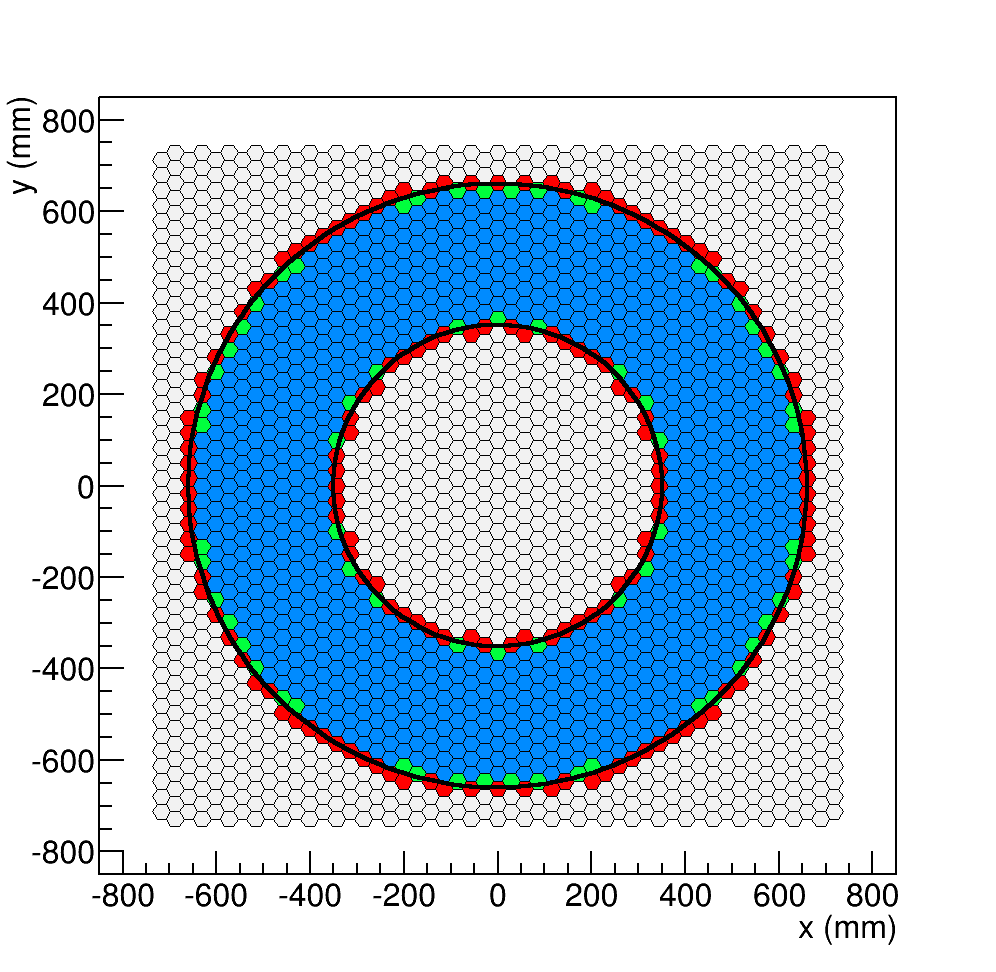
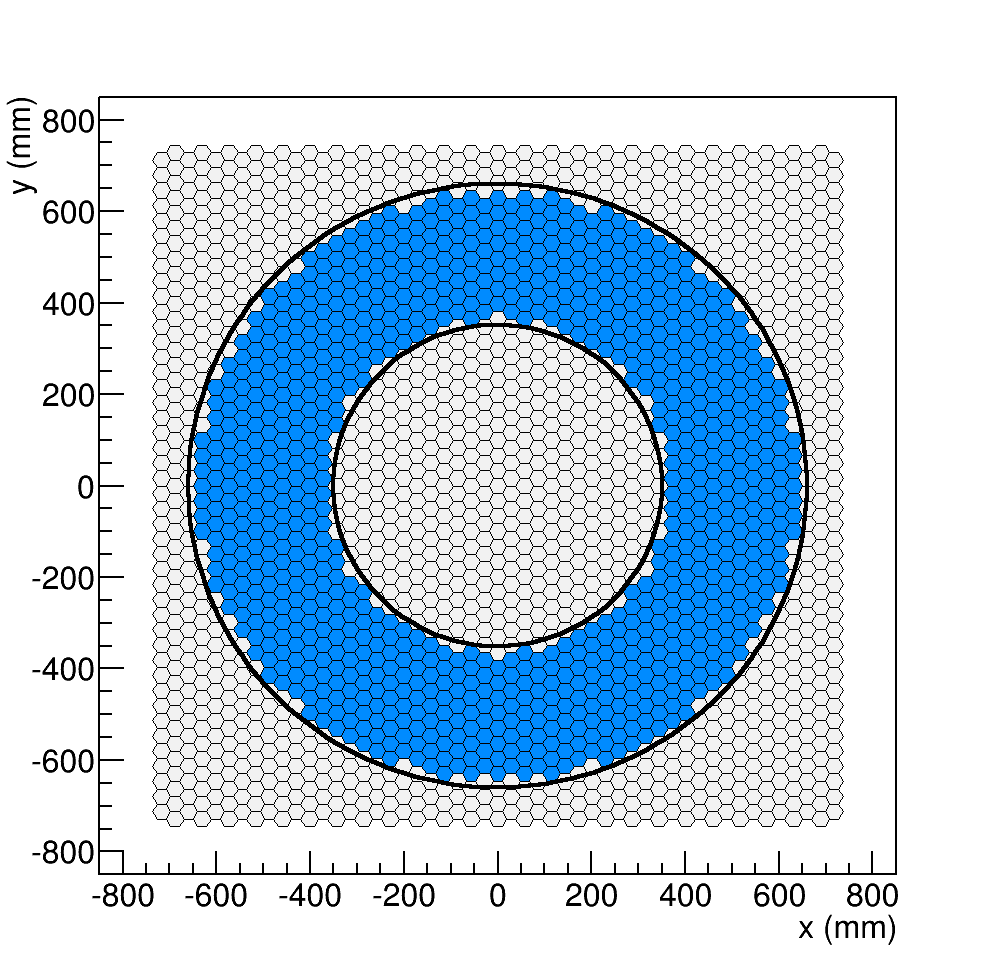


Figure 3. Left:: Crystal layout for a crystal size of 33 mm across flats with disk radii of 351 mm and 660 mm. The crystals in the disk are colored in blue. Right: Similar layout, together with crystal intersecting the disk boundaries colored in green (blue) if their center lie inside (outside ) the disk boundaries.

### Calorimeter Resolution

Tracks enter the calorimeter in the direction not normally to its surface but at an angle close to 45 degrees. As the interaction depth is not known, the distance Y = Ytrack-Ycluster depends on the track direction as well as on the interaction depth. To get rid of this dependence, we calculate track to cluster residuals in the direction orthogonal to the track, the corresponding distribution is shown in Figure 4. The coordinate resolution of about 1cm can be achieved,

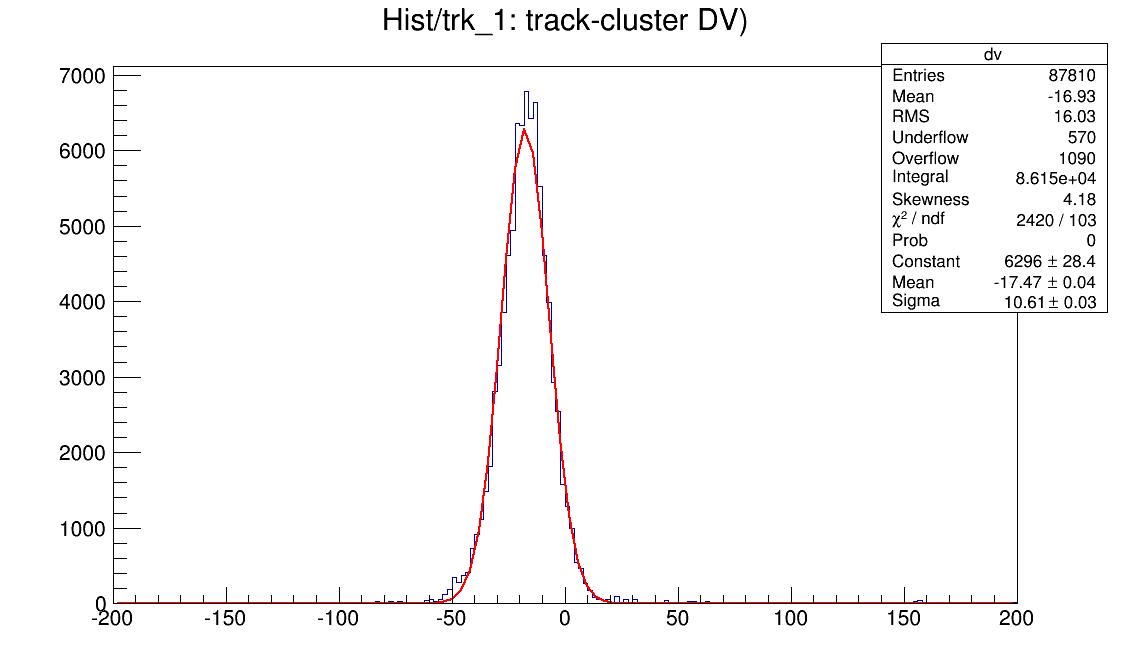
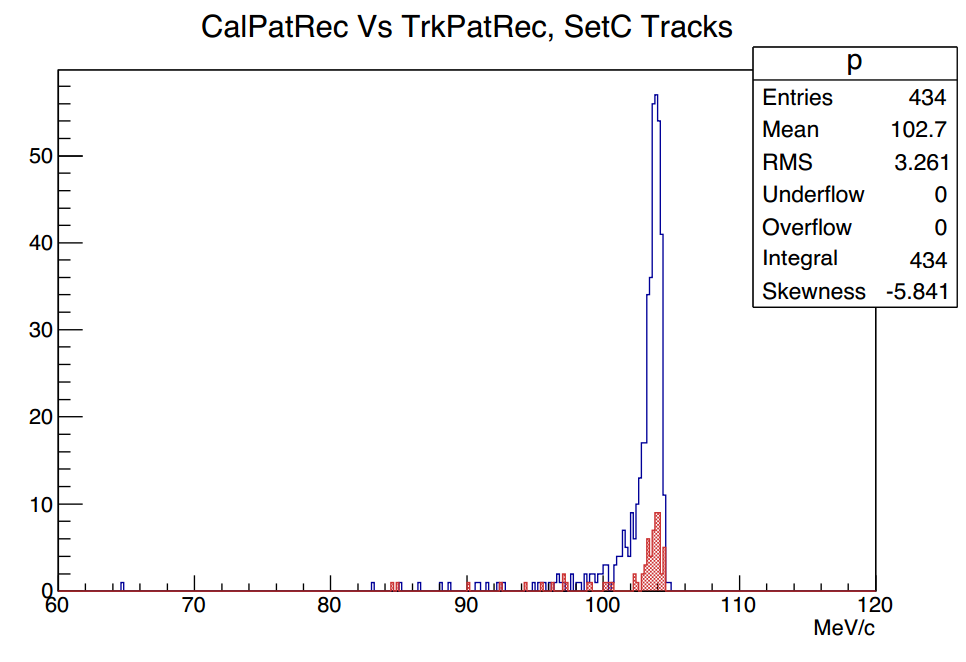


Figure 4: Distribution in the residuals between the reconstructed track and the calorimeter cluster. Residuals are calculated in the direction orthogonal to the track. **Label the axes**.

### Calorimeter-Driven Track Finding

In addition to improved background rejection, the calorimeter provides a robust approach to track reconstruction. Mu2e doesn’t have an “event time”, therefore all straw hits reconstructed within a micro-bunch have to be considered by the track finding algorithm and the track time is a reconstructed as a track fit parameter. The standalone Mu2e track reconstruction attempts to find within a micro-bunch a time slice of about 100 ns wide with maximal number of hits in it and use those hits to find a track. In presence of the correlated in time background produced by -electrons, such an approach strongly relies on the -electron hits being identified and excluded before the track reconstruction begins. Currently, a neural network-based, procedure has been developed for that. In case a cluster produced by a track in the calorimeter has been reconstructed, it can be used as a seed for the track finding instead.. Figure XX shows the momentum distributions for tracks found by the standalone track finding algorithm and for tracks, missed by the standalone algorithm, but reconstructed starting from the calorimeter clusters. One finds, that the calorimeter-driven track finding improves the overall track finding efficiency by 15%.



### Particle Identification and Muon Rejection

work in progress

### Energy resolution

The event reconstruction of the calorimeter information proceeds in several stages. The interaction of particle with the crystals is first simulated by Geant4, recording the energy, position and time of each step. Each energy deposit is converted into photons, taking into account corrections from non-linearities in the light production and non-uniformities in the longitudinal response. The response of each APD is then simulated, including the XXX and electronic noise. At this point, the signal digitization and pile-up identification remains to be implemented. To simulate these effects, we group together hits within a time window of xx ns are together to form crystal hits.

The crystal hits are finally used to form calorimeter clusters. The clustering algorithm start by taking the crystal hit with the largest energy as seed, and adds all simply connected hits within a time window of ± 10 ns. Hits are defined as simply connected if they can be reached through a series of adjacent hits. The procedure is repeated until all crystals hits are assigned to clusters. Additional low-energy deposits disconnected from the main cluster are recovered by dedicated algorithms. These fragments are usually produced by the shower, or low-energy photons emitted by incident particles. As shown in Fig.XX, recovering these split-off deposits significantly improve the energy resolution.

We estimate the energy resolution by simulating conversion electrons distributed at random in the target foils, together with the expected neutron, photon and DIO backgrounds. The distribution of the difference between the cluster energy and the signal electron energy is plotted in Figure XX, accounting for the energy lost by the electron before hitting the calorimeter. The low-side tail is due to background pile-up with the cluster. We fit the distribution with a Crystal Ball function to extract the resolution. A full width at half maximum of XXX is observed. The fraction of pile-up background for cluster energies between XX and XX MeV is found to be XX%. The contribution of pile-up is shown in Figure XX.