Mu3e experiment - filter farm and camera alignment system

By

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European Commission

“Intense Monthly Meeting”

Intense

H2020 MSCA ITN
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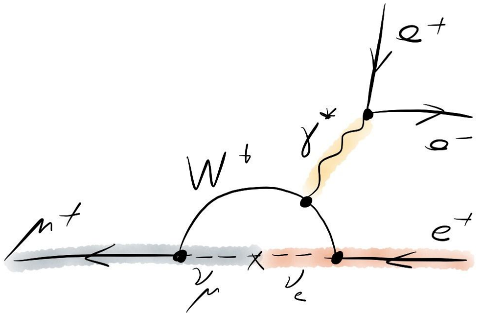
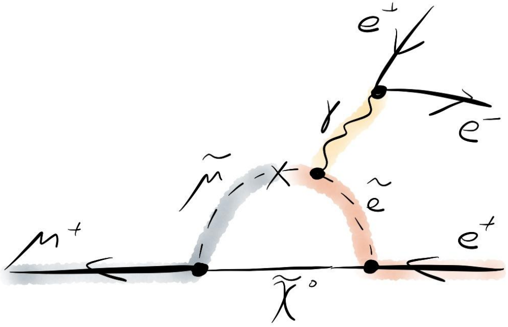
November, 2022

Overview

- Introduction
- Data Acquisition System
- Camera Alignment System
- Things to do

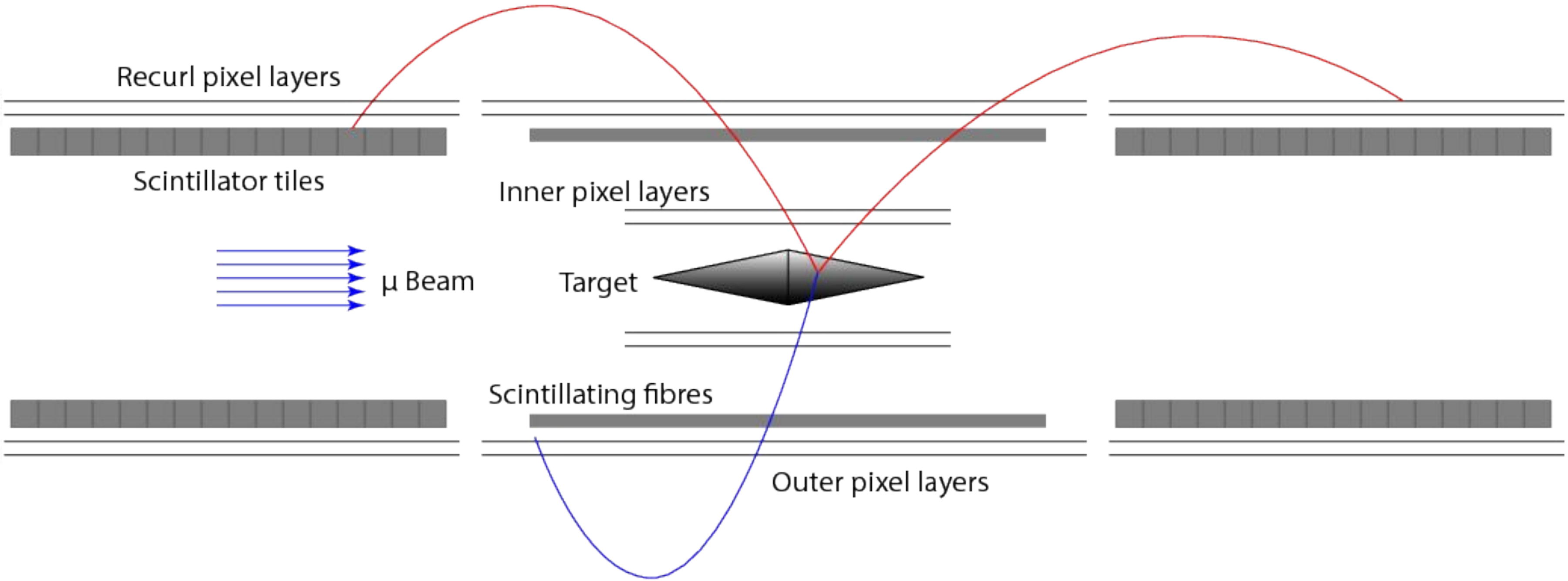
Mu3e Experiment





- The Mu3e experiment searches to observe or exclude the decay of a positive muon to two positrons and an electron.
- Such an observation would be a violation of the lepton flavour conservation and indicate for Physics Beyond the Standard Model of particle physics.
- In standard model, the lepton flavour violating decay is possible via neutrino mixing but suppressed to a branching ratio Br < 10^{-54}.
- SINDRUM achieved Br < 10^{-12} (1988) PSI.
- The Mu3e experiment will observe more than > 10^{16} muon decays in order to probe existence of new physics beyond the standard model in the Br > 10^{-16}.

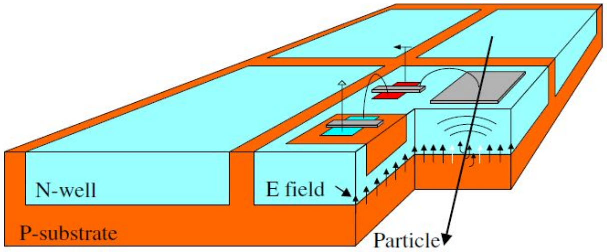
Mu3e Detector



Schematic diagram of Mu3e detector.

Detector Subsystems

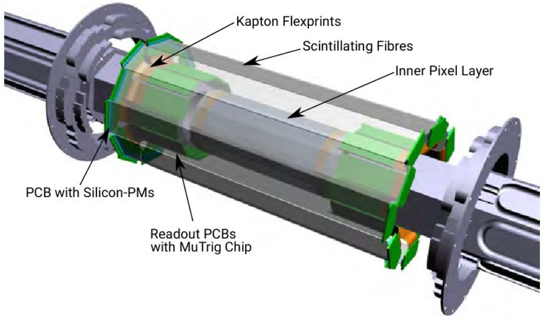
Tracking detector



- A pixel sensor consists of junctions of p-doped and n-doped semiconductor material.

- Any particles interacting in this depletion zone will form electron-hole pairs and lead to a measurable current through the p-n-junction, which can be measured by readout electronics of the pixel detector.

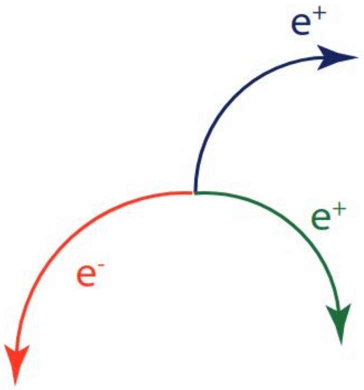
Timing detector



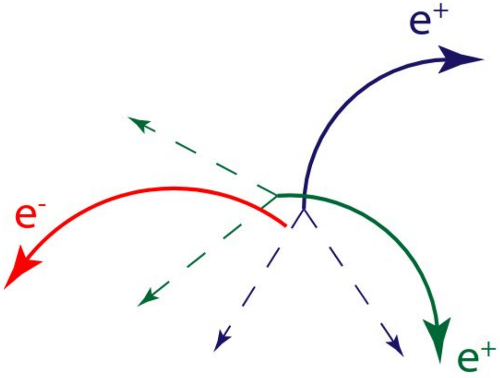
- The scintillating fibres are responsible for the timing measurement in the central station. They consist of a scintillator material, which gets excited into a higher energy level by the interaction of ionising radiation.

- The tile detector is also scintillating material. It is located in the inner-most layer of the upstream and downstream recurl stations.

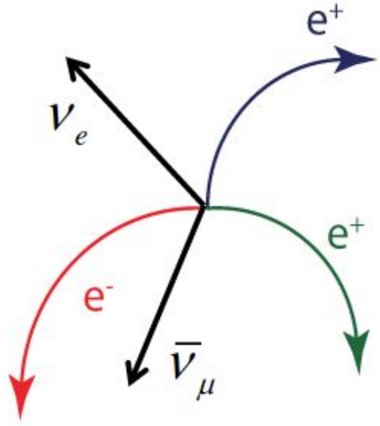
Signal and Background processes



Signal

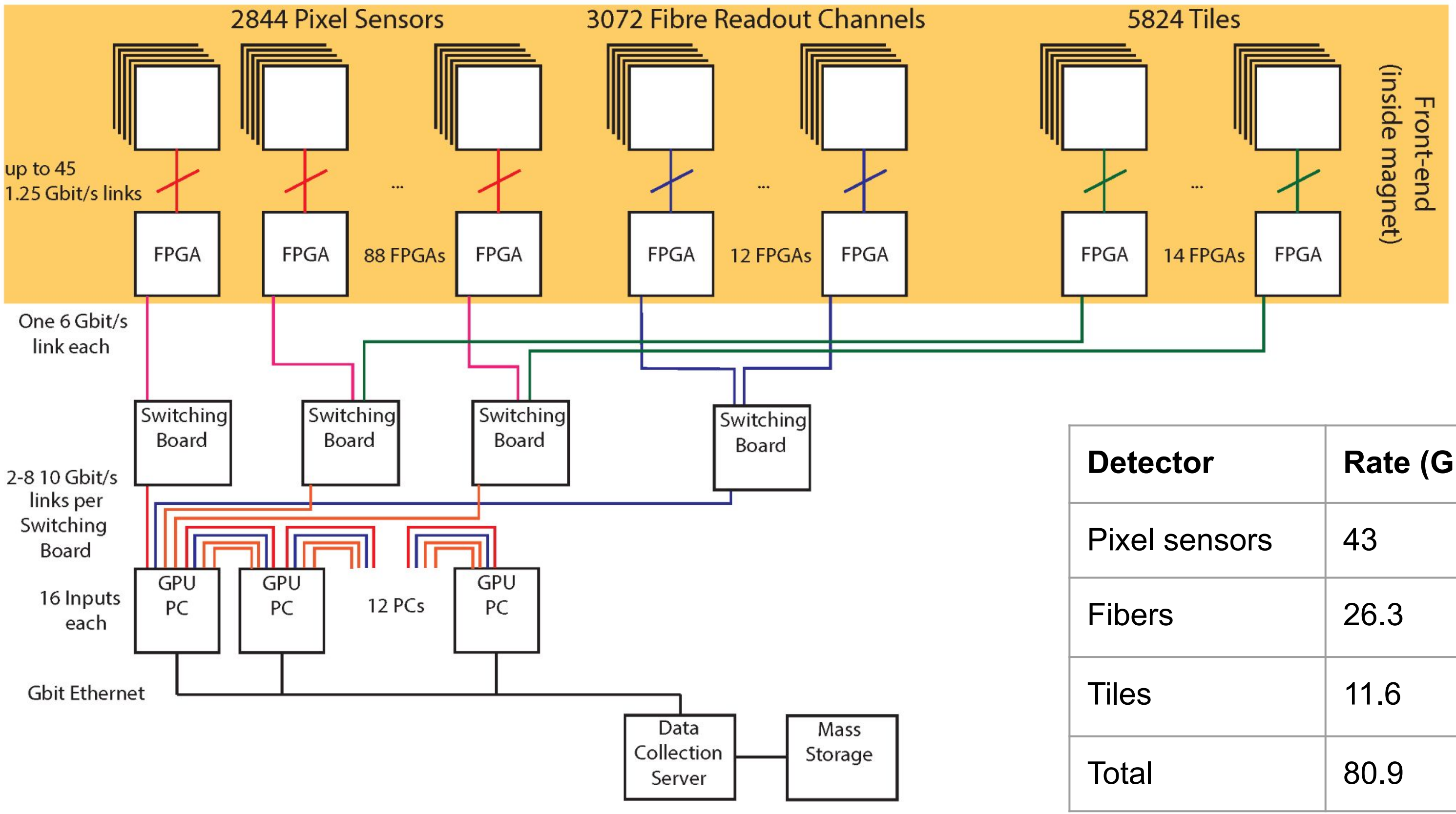


Combinatorial Background



Internal photon conversion
(Br = 3.4×10^{-5})

DAQ Readout System



Detector	Rate (Gbit/s)
Pixel sensors	43
Fibers	26.3
Tiles	11.6
Total	80.9

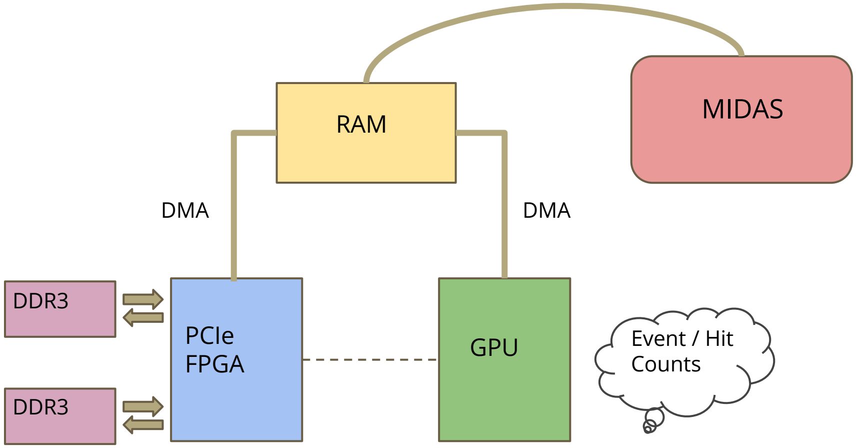
Filter Farm

- Objective of the Filter Farm is to select signal candidate events by reconstruction of tracks and vertices. The data rate is decreased by over a factor of 100, reducing it to below 100 MB/s, which can be written to disk.

- Currently, we have procured two Asus ESC4000A-E10 Servers: Powered by AMD EPYC™ 7002 processor with 64 cores, 128 threads.

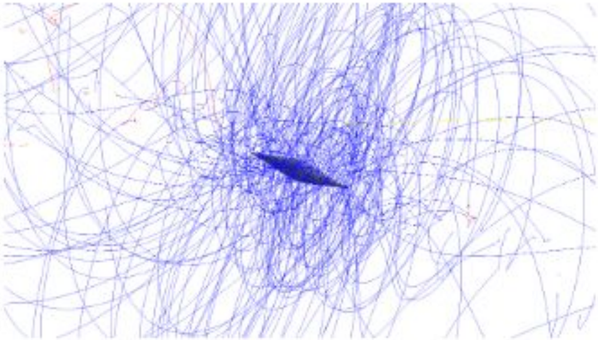
- GPU-optimized design allows four double-slot or eight single-slot GPUs. NVIDIA GeForce RTX 3080 Ti.

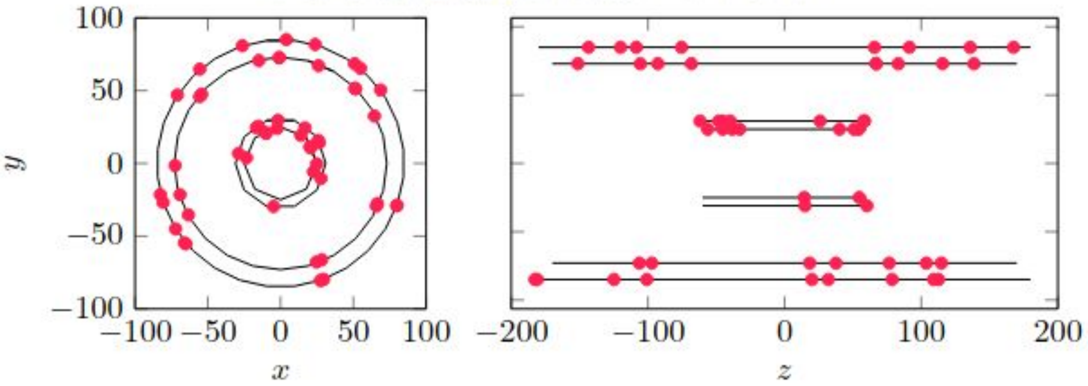
- Up to eleven PCIe® 4.0 slots enables higher bandwidth and improved data transfer rates.



Online Event Selection

- Selection Cuts: A simple geometrical filter cutting away most hit combinations before the actual track reconstruction.
- Track Reconstruction: A hit triplet-based reconstruction and classification of particle tracks.
- Vertex Reconstruction: A simplified reconstruction of possible event vertices. e^+, e^+, e^- track combinations are examined for a possible event vertex fulfilling the signal characteristics.
- Each frame is a snapshot of hits detected in a timeframe of 64ns.





Selection Cuts

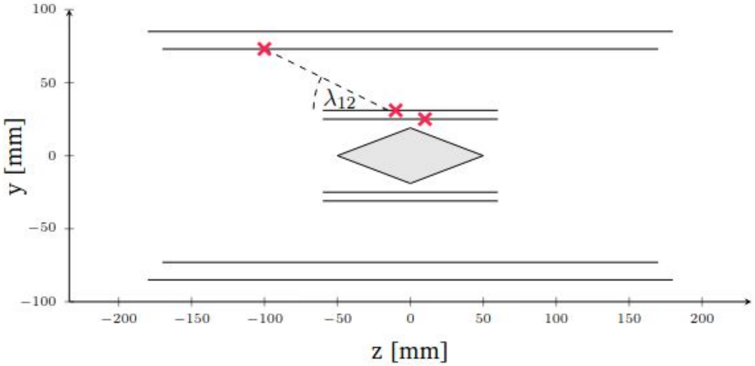
- Slope difference Δz between the slopes of consecutive layer hits in the longitudinal plane.

$$\tan \lambda_{ij} = \frac{z_j - z_i}{h_{t,j} - h_{t,i}},$$

$$\Delta\lambda = \tan \lambda_{12} - \tan \lambda_{01}.$$

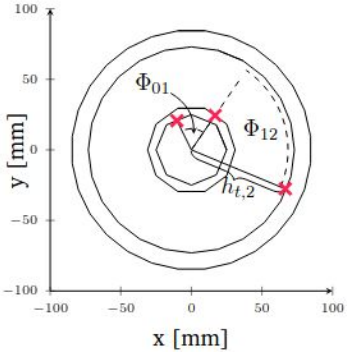
- In transverse plane we observe the angle Φ_{ij} between hits of two consecutive layers in relation the the origin:

$$\cos \Phi_{ij} = \frac{\mathbf{h}_{t,i} \cdot \mathbf{h}_{t,j}}{h_{t,i} h_{t,j}},$$

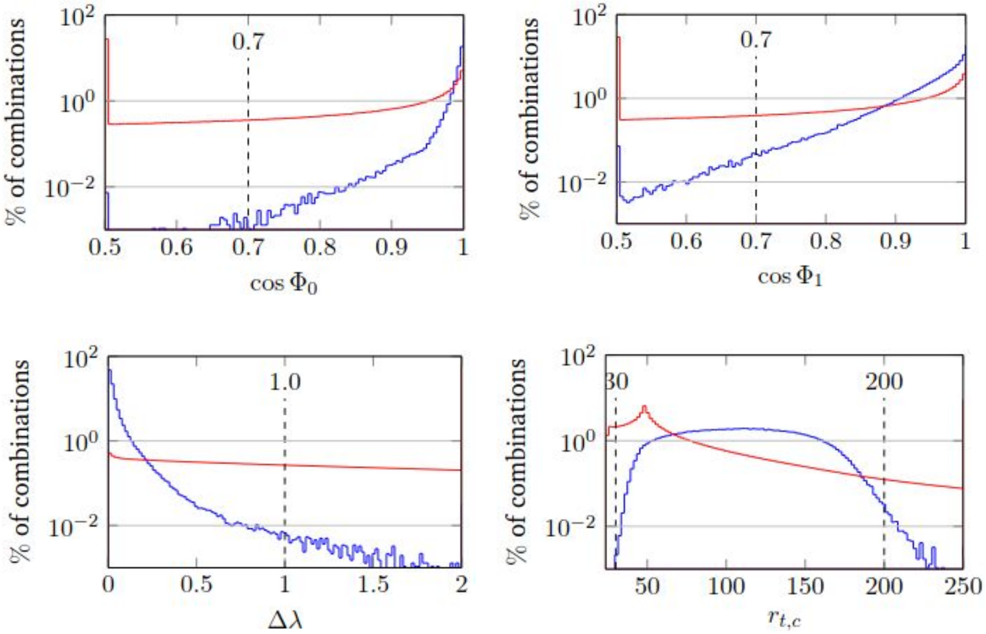


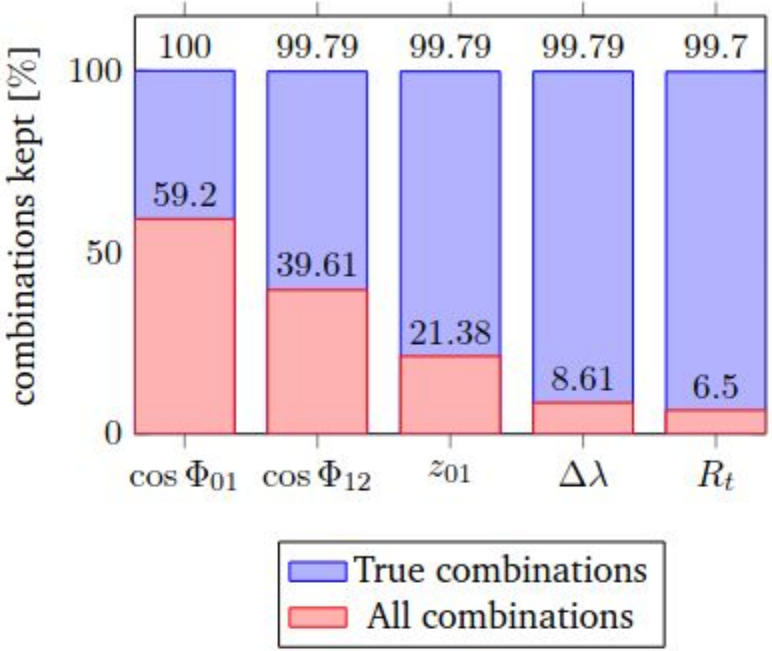
- $z_0 - z_1 < 30$ mm
- The transverse radius of the circle going through all three hits

$$r_{t,c} = \frac{d_{01} d_{12} d_{20}}{2[(\mathbf{h}_0 - \mathbf{h}_1) \times (\mathbf{h}_2 - \mathbf{h}_1)]_z},$$



Selected Hits





Track Reconstruction

- For reconstruction Triplet fit is used.

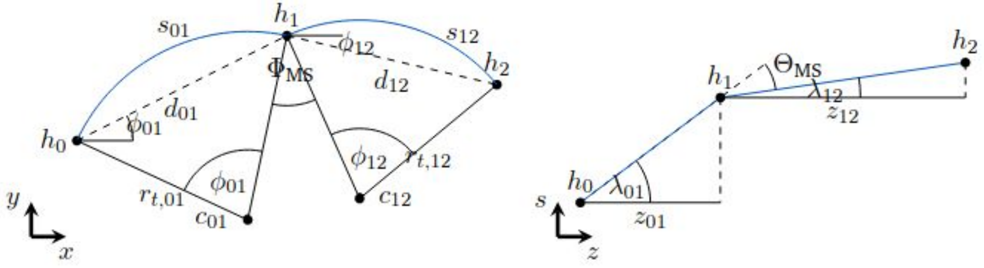
- We search for the track minimizing the objective function. Assuming no momentum loss and thus a constant curvature k.

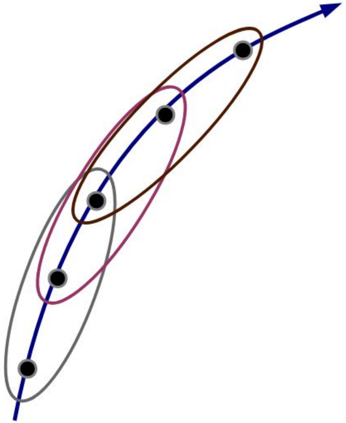
$$\chi^2(\kappa) = \frac{\Phi_{MS}(\kappa)^2}{\sigma_\Phi^2} + \frac{\Theta_{MS}(\kappa)^2}{\sigma_\Theta^2}.$$

- More than three hits for a full track fit requires to accommodate for multiple triplets.

$$\chi^2_{global}(\kappa) = \sum_t^{n_{triplets}} \chi_t^2(\kappa).$$

- A global curvature is found for all triplet combinations minimising the MS angles for each triplet.





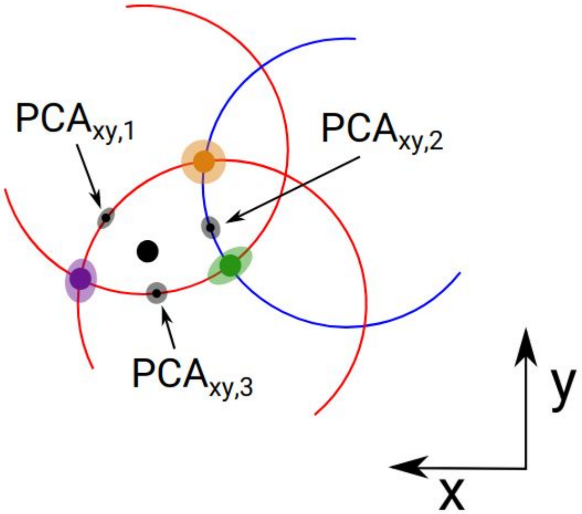
Vertex Fit

- All combinations of two positrons and one electron are considered within each time slice. We calculate the total energy of all particles in the triplet using their curvature κ.

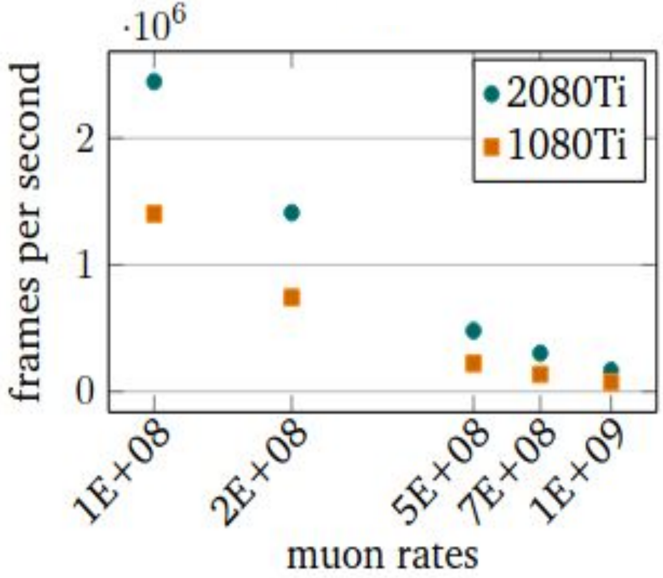
- The total energy of all particles, must match the muons rest energy.

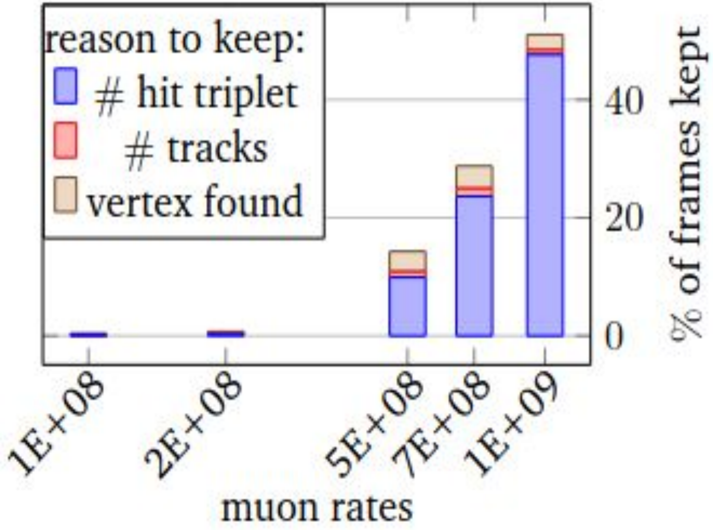
- The weighted mean is calculated only if all three reconstructed tracks intersect and it is calculated for all combinations of three intersections from three tracks.

- The χ^2 for a vertex estimate is computed from the differences between the point of closest approach and the weighted mean both in the transverse plane and in the z-coordinate.



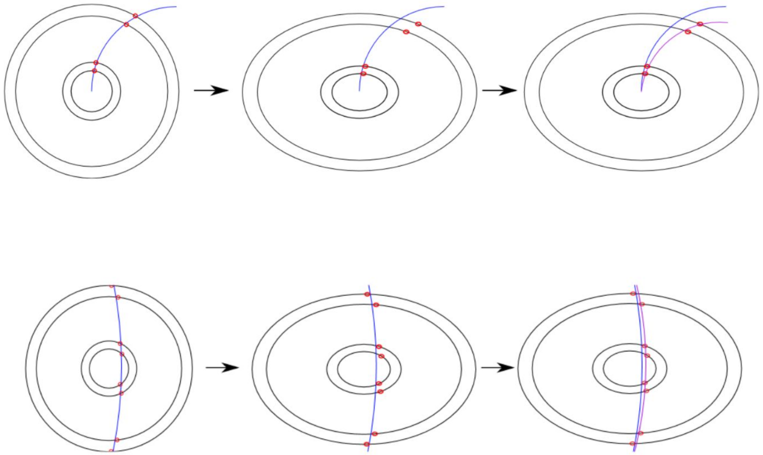
Performance





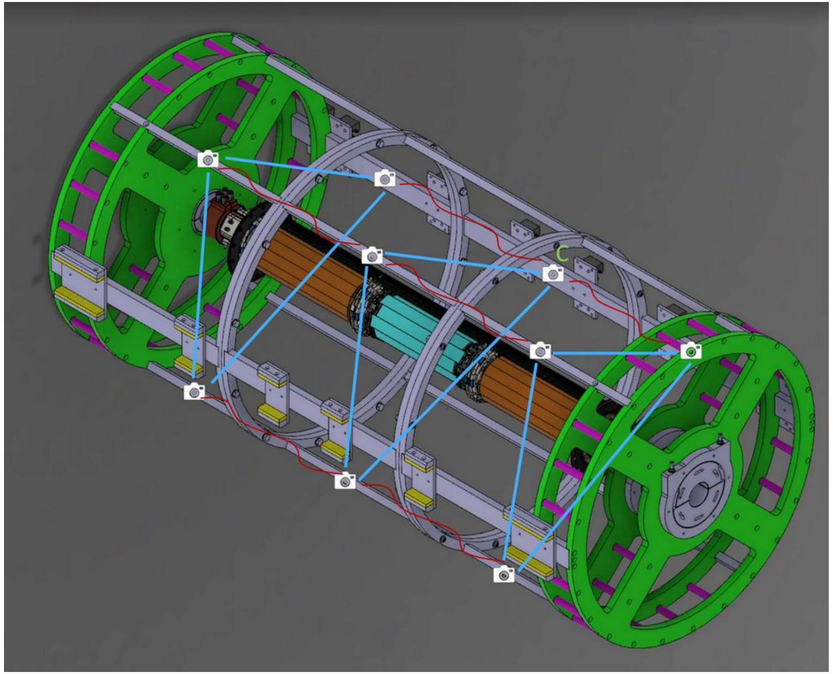
Misalignments

- The misalignment in the position of the Mu3e detector system affects the precision of track reconstruction.
- Weak modes of the detector misalignment causes track-based alignment software to fit deformed tracks.
- Cosmic muons offer insight into detector deformation by connecting detector parts that would otherwise not be connected by the tracks coming from decay of muon beam.
- Precise position measurement of the detector segments using camera system would provide additional information regarding the detector geometry.

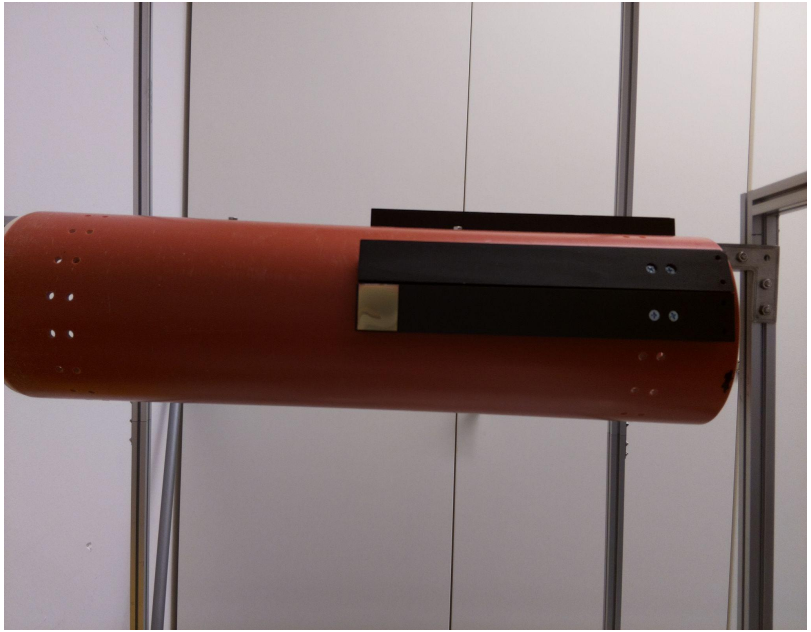


Camera Alignment System

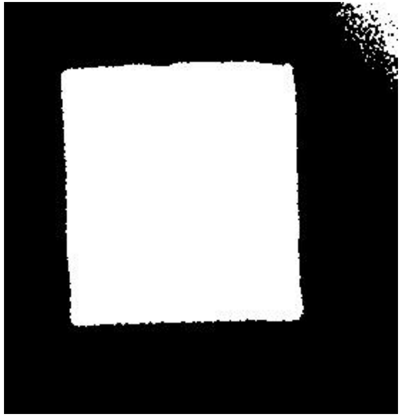
- The main goal is to drive the camera measurement precision to be comparable to the individual tracking detector pixels, which is at 80 μm.
- The detector system is viewed as 3 individual detector components.
- Camera system with 3 cameras at the middle of each component.
- LEDs are mounted on the camera to triangulate the position measurements of individual cameras.



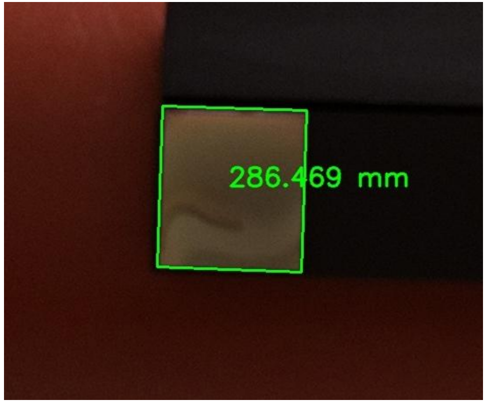
Chip Detection

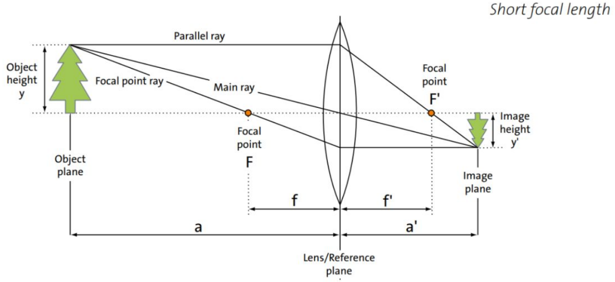


- To detect the chip. Image taken from the central camera shows the chip on the model of the mu3e detector.
- The images is then converted to grayscale. This gives a contour of the chip.
- Area of the contour that matches with the chip is selected and it's pixel coordinates on the image are obtained.



Distance Measurement





- To estimate the actual distance of the chip from the camera. The pixel coordinates of the chip is transformed into the lab coordinates with the camera position fixed as the origin.
- The dimension of the chip is (20 x 20) mm and the focal length of the camera is 2.92 mm.
- Using these known parameters and with help of the magnification formula, the distance between the chip and the camera is estimated.
- The distance estimation matches well with actual measurement.

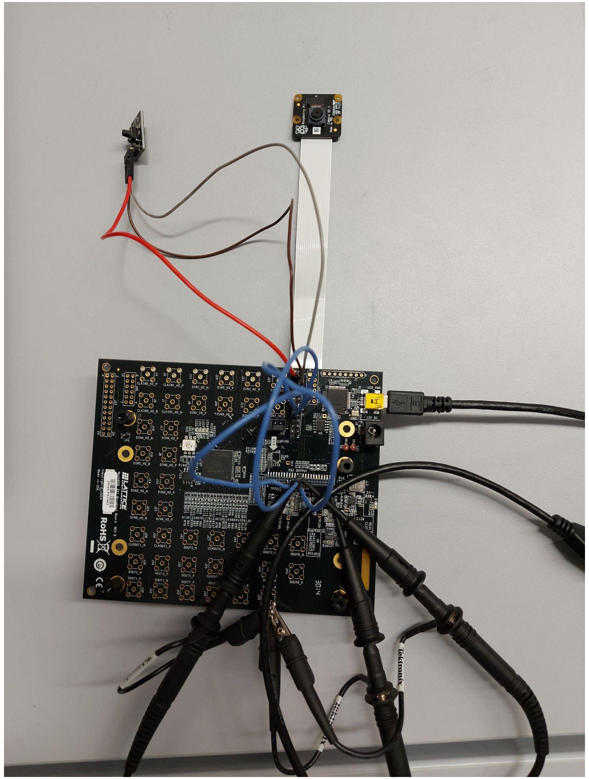
$$\frac{y'}{y} = M = \frac{f}{f-a}$$

Camera-FPGA interface

- The initial iteration of the camera system is controlled using a raspberry pi.

- Ethernet connection has to be replaced because of the magnetic properties of the connector (optical fibers as an alternative).

- Therefore, we are developing firmware to communicate with the camera via FPGA to capture images and send them via optic fiber cables.



Things to do:

- Develop firmware for the GPU selection in the filter farm.
- Integrate multiple Farm PCs for the commissioning of the Mu3e Filter Farm.
- Online Reconstruction of Tracks in the GPU filter farm using real data from Mupix chips.
- Pattern recognition to detect the misalignment in the position of the chips.
- Need to answer the question of if it would be precise enough to identify misalignments at the pixel level.

PhD Requirements:

- Took the teaching assistantship of Advanced Practical course on Balmer series for the winter semester, 2022.

Workshops and Conferences

- “DPG Conference”, (Heidelberg, March 21-25, 2022) held online and organized by Deutsche Physikalische Gesellschaft e.V.;
- “Mu3e Collaboration Meeting”, (Villigen, April 28-29, 2022) workshop held at Paul Scherrer Institute;
- “EPT Summer Camp for Physics TAs”, (Zuoz, August 12-14, 2022) engaging physics tutoring summer camp organised by ETH Zürich;
- “Paul Scherrer Institute Particle Physics Summer School – Vision and Precision”, (Zuoz, August 14-20, 2022) lectures and talks organised by Paul Scherrer Institute.
- “PRISMA+ Cluster of Excellence” (Geisenheim, September 19-21, 2022) gave a talk about my dissertation.

Thank You