Online Track Reconstruction and Calibration for the Mu3e Experiment

By

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Overview

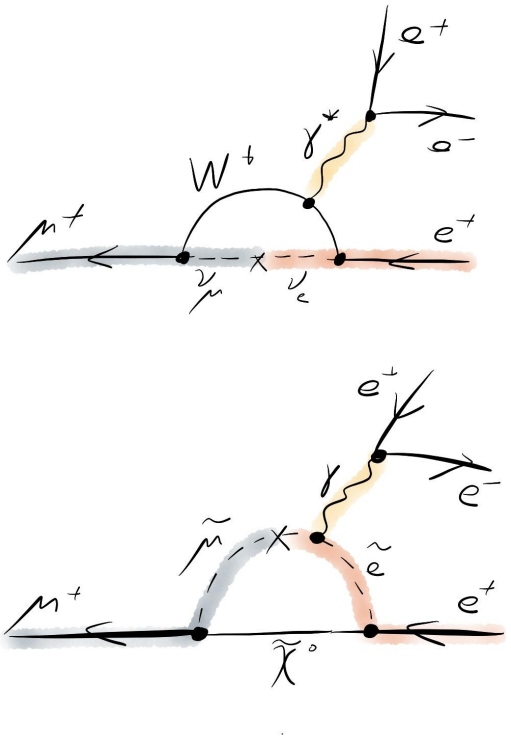
- Introduction
- Online Event Selection
- Camera Alignment System
- Things to do

Self Intro

- My name is Haris Avudaiyappan Murugan and I'm from Madurai, India.
- BS-MS dual degree (August 2016 - June 2021)
- Indian Institute of Science Education and Research (IISER), Berhampur, India.
- Master's Thesis Title: "Searches for Pentaquark States with the STAR Experiment At RHIC"
- Started as Marie Curie Early Stage Researcher (ESR) and PhD in physics at Universität Mainz in October 2021.

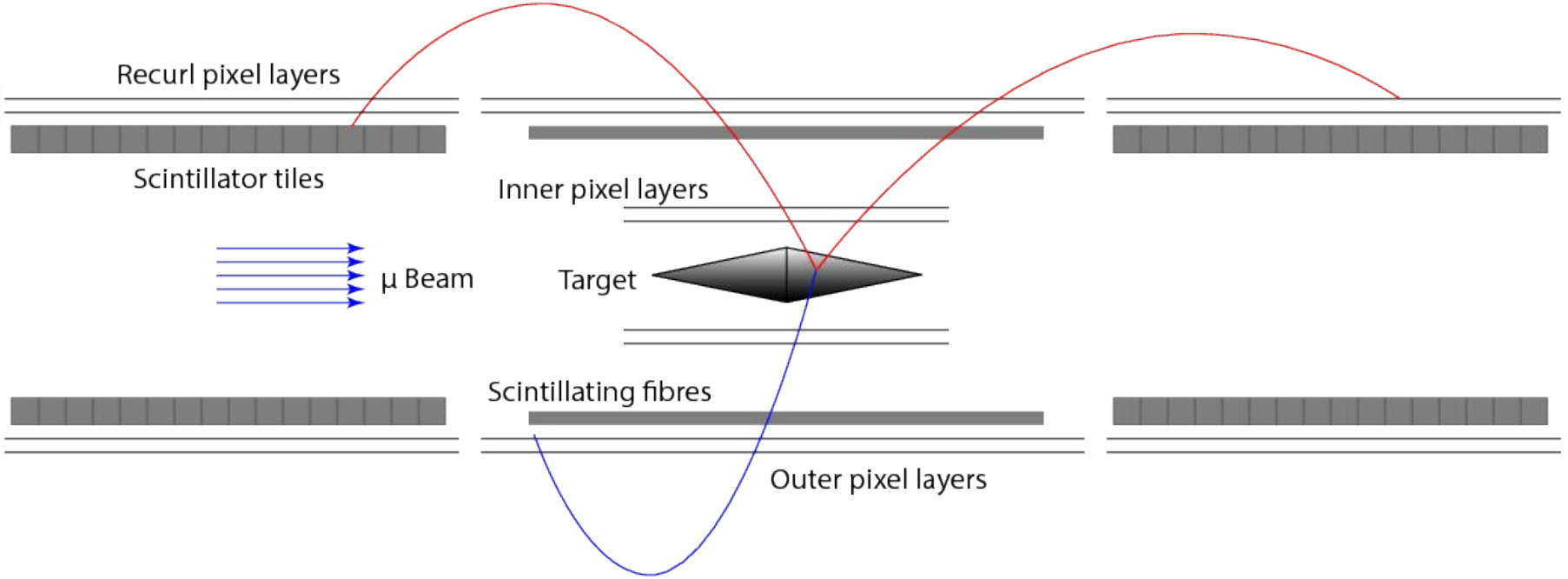
IISER BERHAMPUR

Mu3e Experiment



- We search to observe or exclude the decay of a positive muon to two positrons and an electron.
- Observation would be a violation of the lepton flavour conservation.
- In standard model, possible via neutrino mixing but suppressed to Br < 10^{-54}.
- SINDRUM achieved Br < 10^{-12} (1988) PSI.
- Phase I - muon rate of $1x10^{8}$ and Br < $2x10^{-15}$.

Mu3e Detector



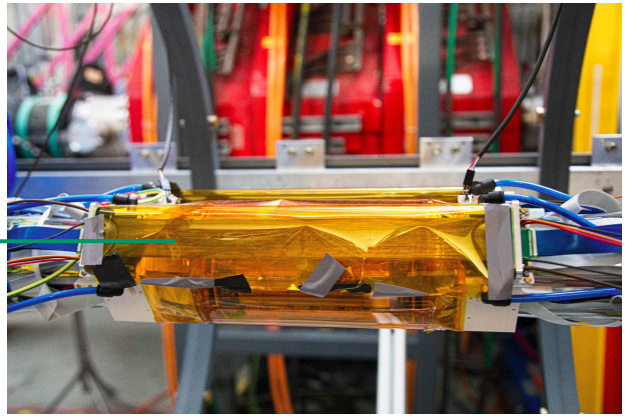
Schematic diagram of Mu3e detector.

Detector Subsystems

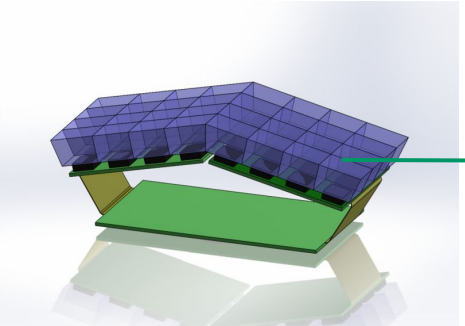
Tracking detector

MuPIX: sensor pixels and the detector electronics are integrated into the same chip

Timing detector

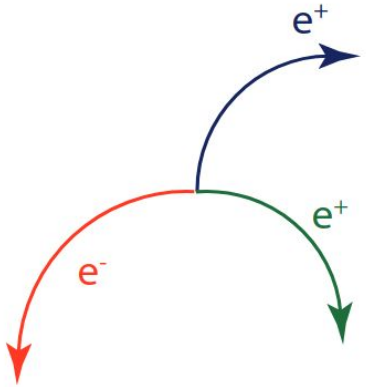


Scintillation fiber

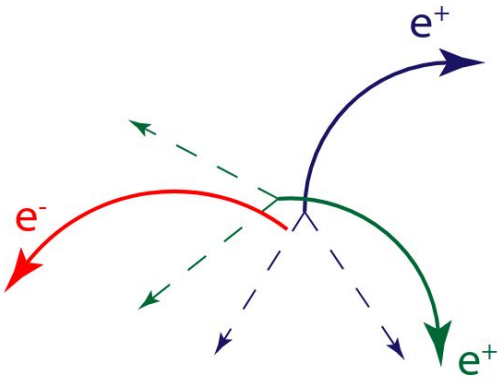


Scintillation Tiles

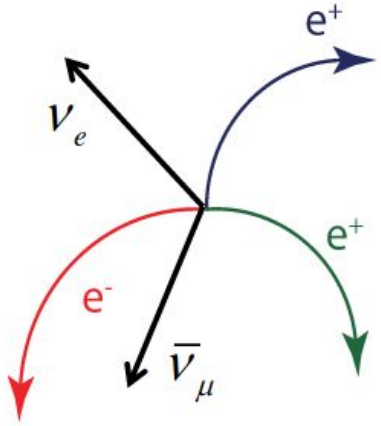
Signal and Background processes



Signal



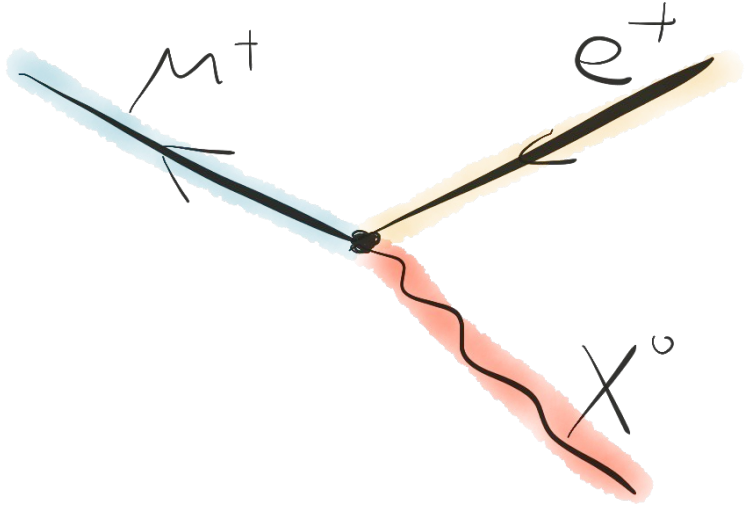
Combinatorial Background



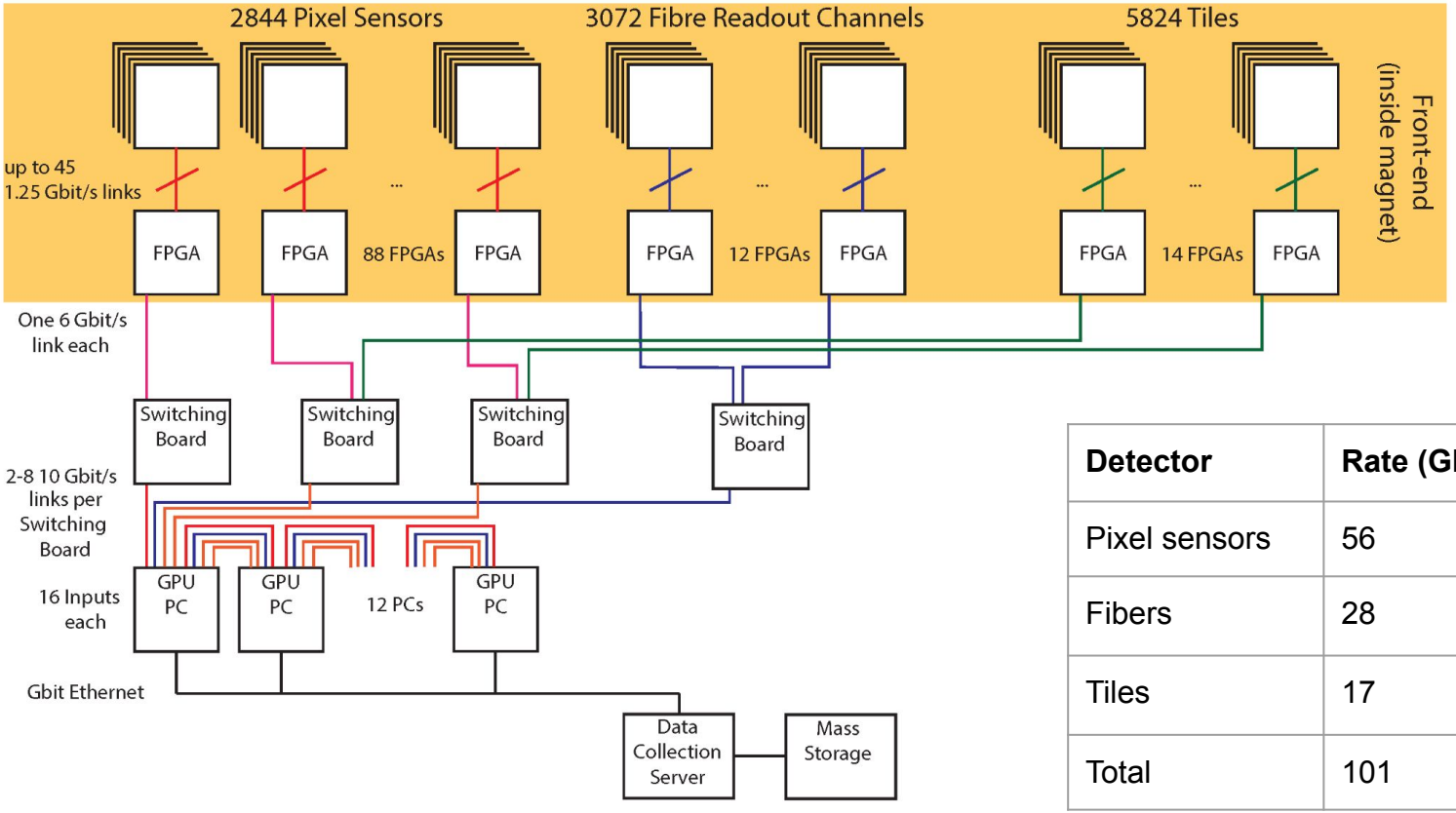
Internal photon conversion
(Br = 3.4×10^{-5})

Two body muon decay

- X can be a Familon, pseudo-Goldstone boson of a broken lepton family symmetry.
- Two body decays can only be differentiated from normal muon decays by the fixed positron momentum.
- Generate momentum histograms from GPU farm to search for such decays.
- Need precise online track reconstruction and calibration for such an analysis.



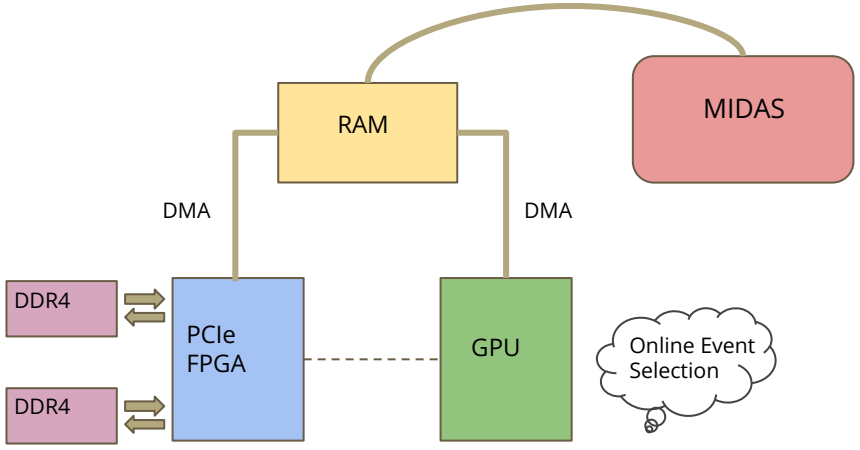
Readout System



Detector	Rate (Gbit/s)
Pixel sensors	56
Fibers	28
Tiles	17
Total	101

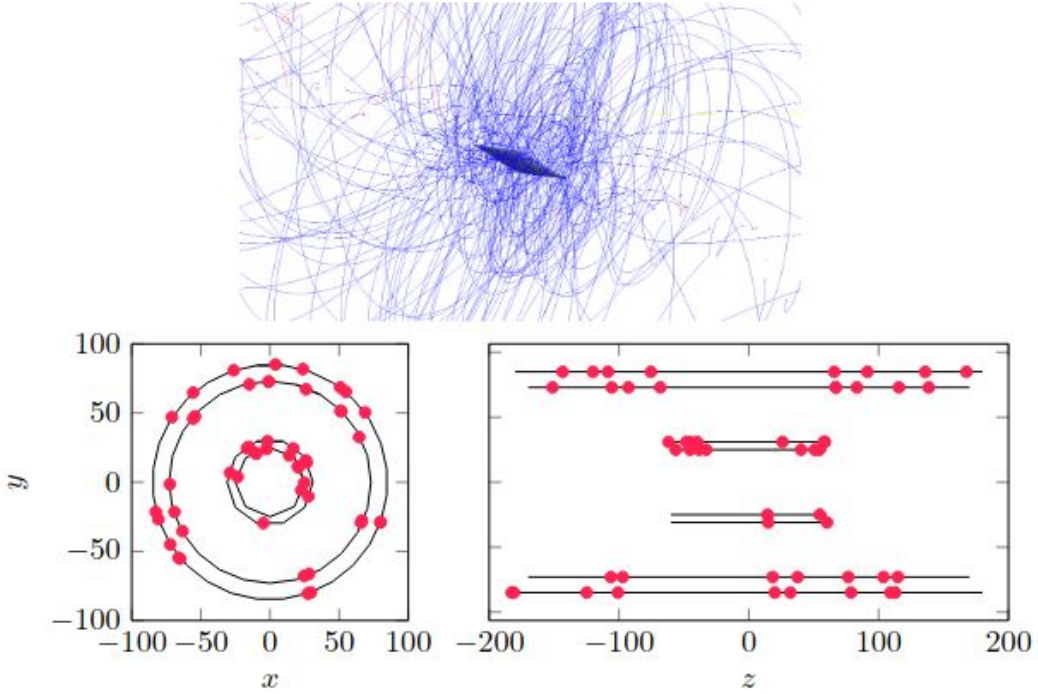
Filter Farm

- Objective - select signal candidate events by reconstruction of tracks and vertices. To reduce data rate by a factor of 100.
- 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.
- Eleven PCIe® 4.0 slots enables higher bandwidth and improved data transfer rates.

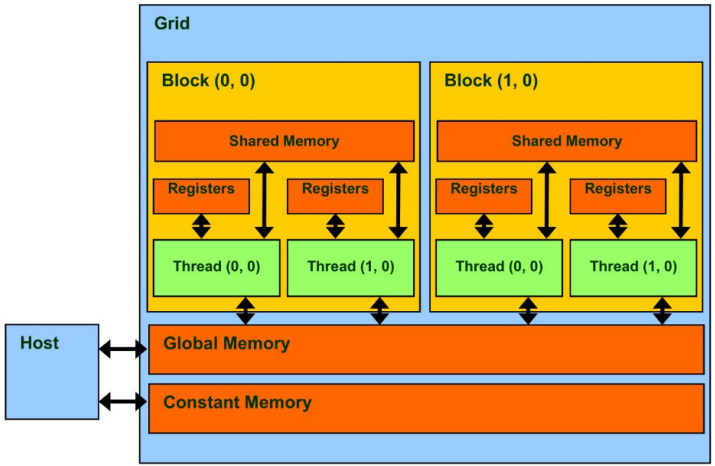


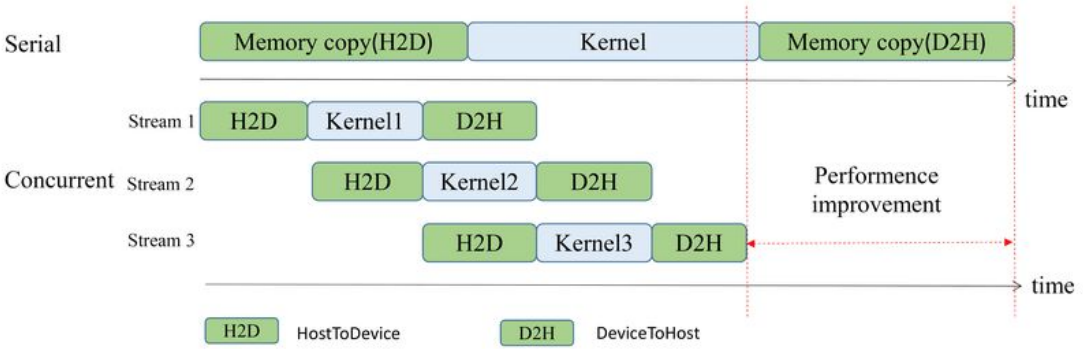
Online Event Selection

- Selection Cuts: Geometric cuts.
- Track Reconstruction: Hit triplet-based reconstruction.
- Vertex Selection: Reconstruction of possible event vertices.
- Each frame is a snapshot of 64ns.
- Threshold performance- 1.302×10^6 frames per second.

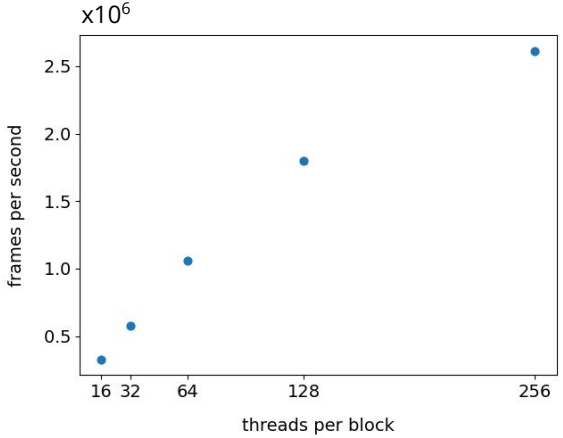


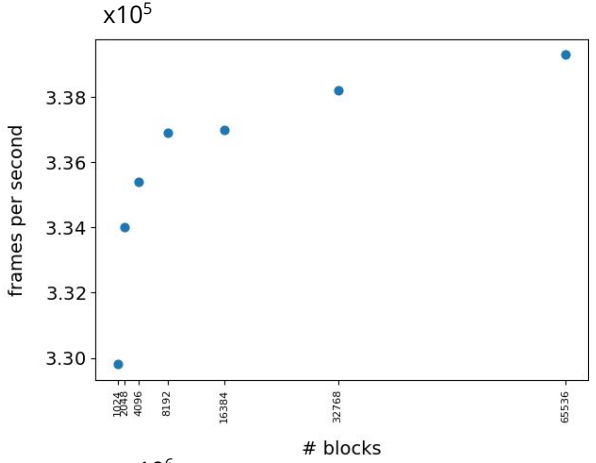
CUDA

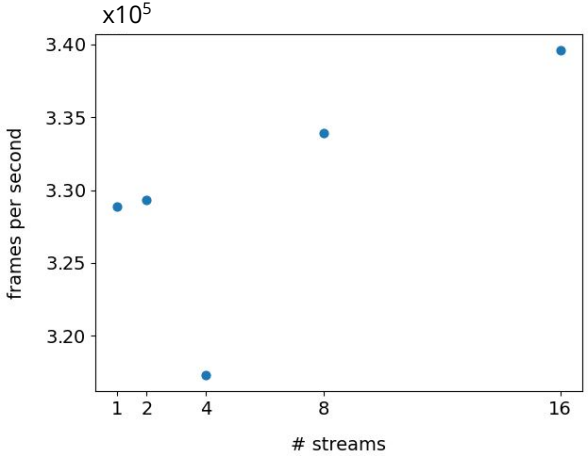

Grid
Block (0, 0)
Block (1, 0)
Shared Memory
Shared Memory
Registers
Registers
Registers
Registers
Thread (0, 0)
Thread (1, 0)
Thread (0, 0)
Thread (1, 0)
Host
Global Memory
Constant Memory

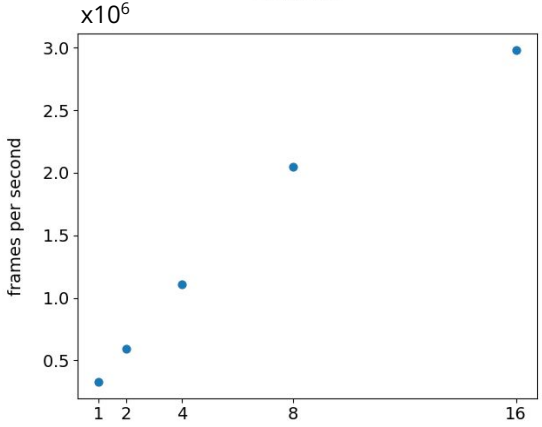

Serial
Memory copy(H2D)
Kernel
Memory copy(D2H)
time
Stream 1
H2D
Kernel1
D2H
Concurrent
Stream 2
H2D
Kernel2
D2H
Performence
improvement
Stream 3
H2D
Kernel3
D2H
time
H2D
HostToDevice
D2H
DeviceToHost

Performance - preliminary results



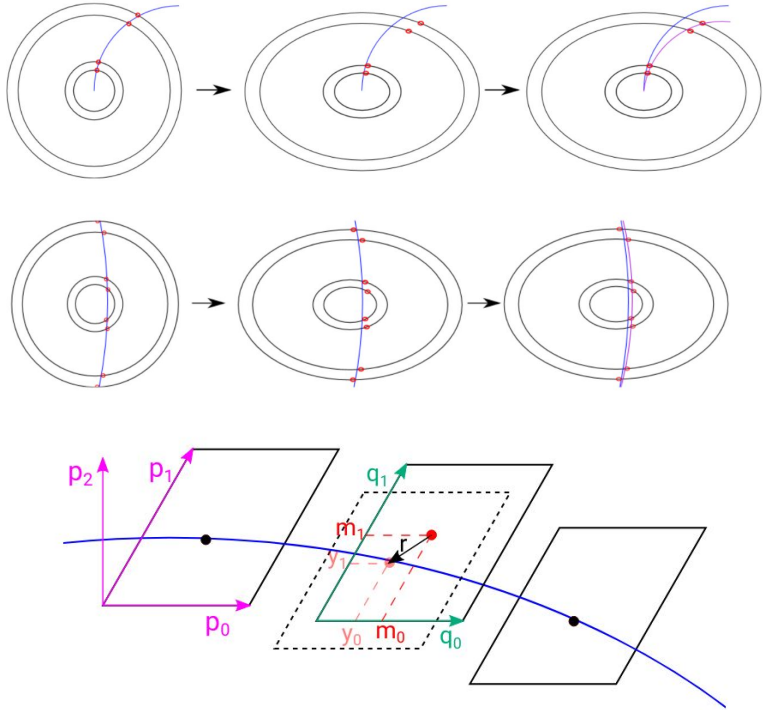




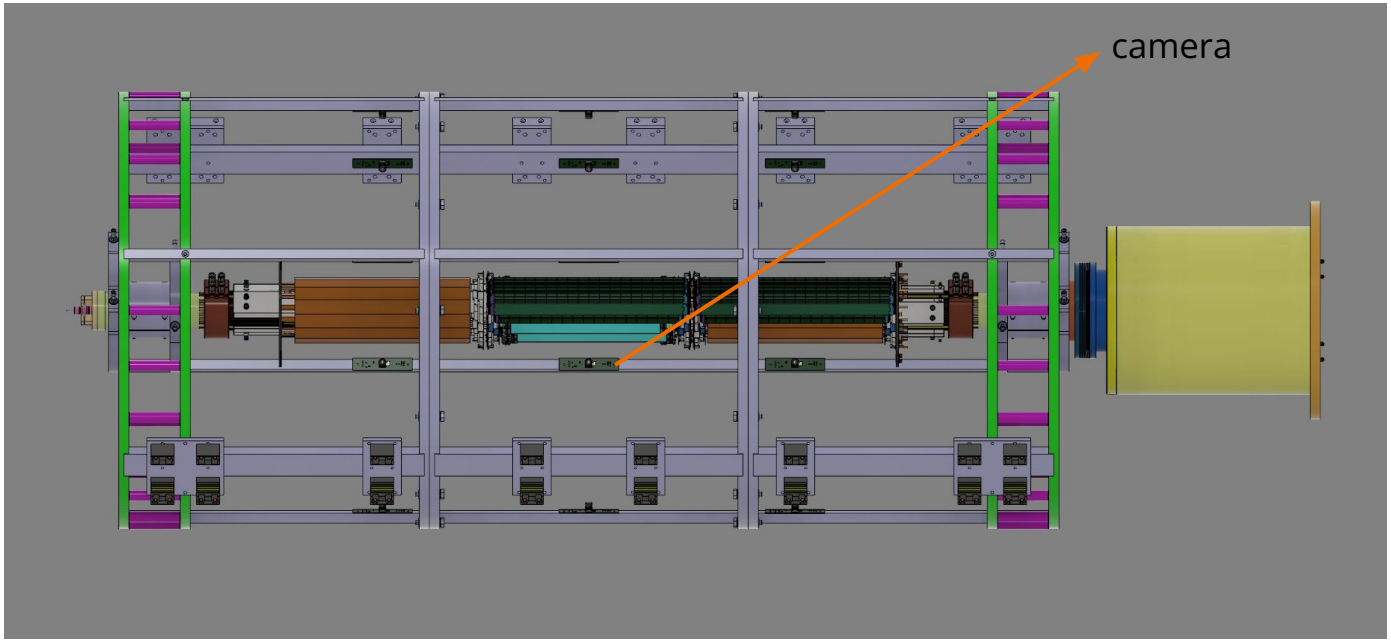


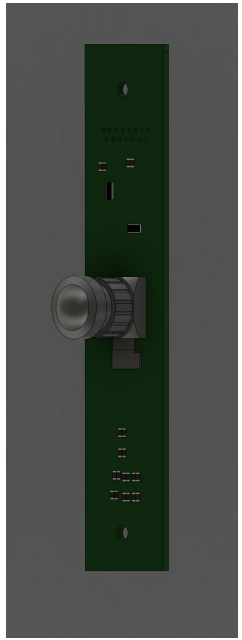
Track-based Alignment

- Misalignments affects the precision of track reconstruction.
- Weak modes of the detector misalignment causes track-based alignment software to fit deformed tracks.
- Track-based alignment needs constraints from global parameters. Which can be provided by the camera system.
- Precise position measurement of the detector segments using camera system would provide additional information regarding the detector geometry.



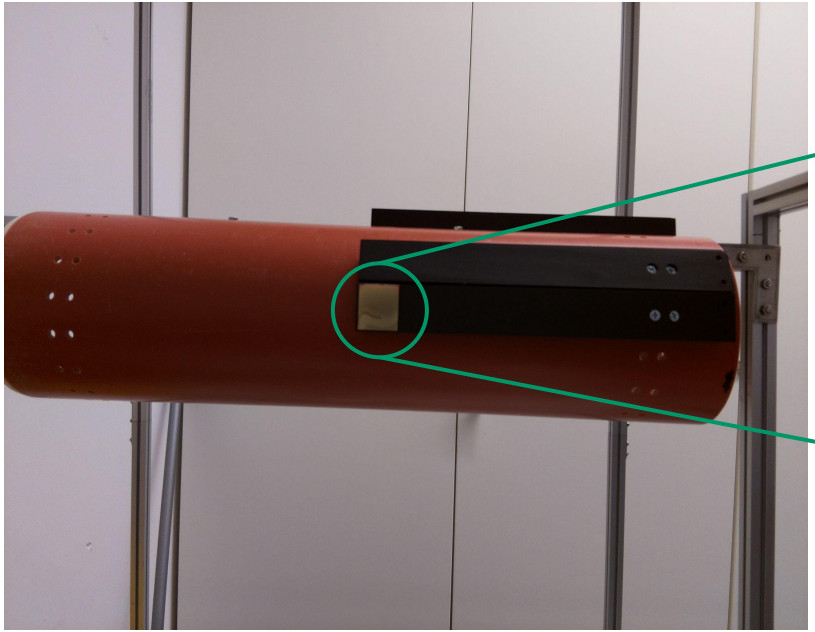
Camera Alignment System

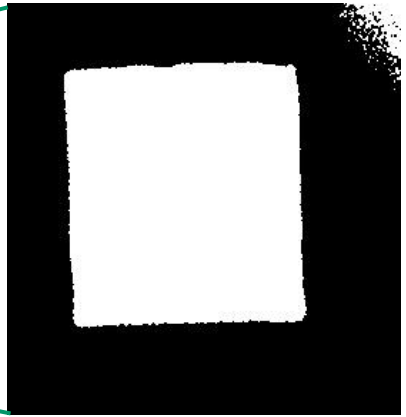




- Goal - To drive the camera measurement precision to be comparable to the individual tracking detector pixels, 80 μm.

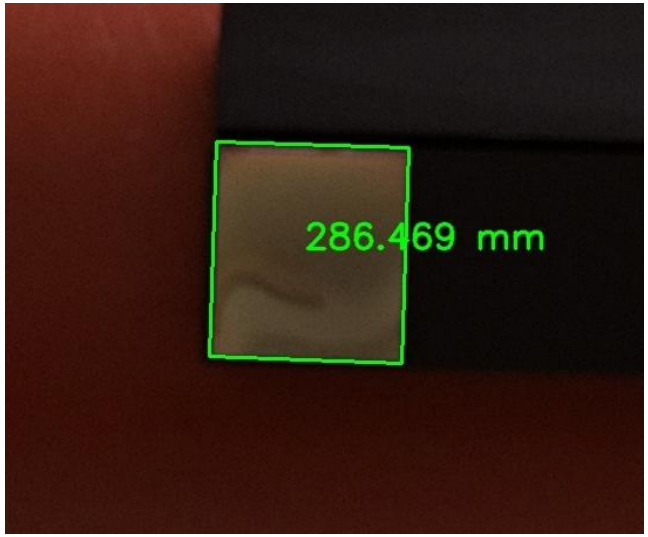
Chip Detection

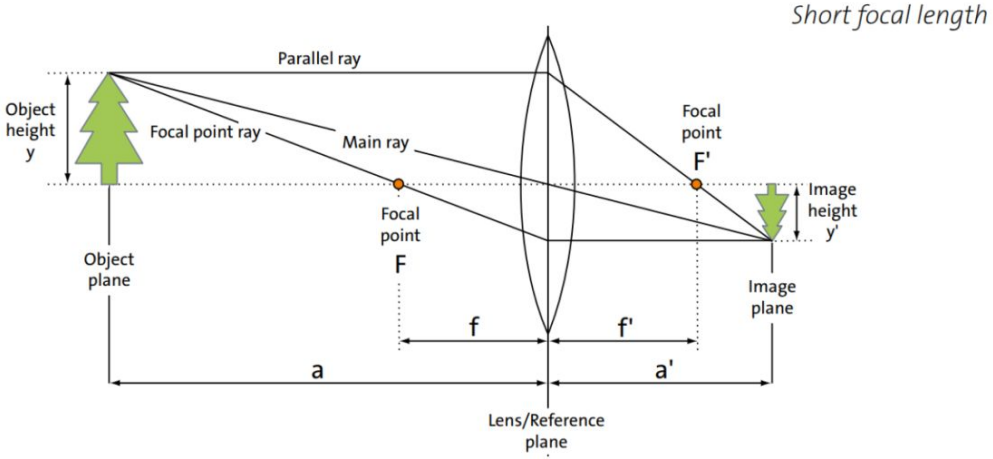




Gray scale contour

Distance Measurement





- Chip - 20 x 20 mm and Camera focal length - 2.92 mm.
- Using magnification formula, the distance between the chip and the camera is estimated.
- The distance estimation matches well with actual measurement.

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

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 position of the chips.
- Online histograming of track kinematics in the GPU.

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

Backup

Selection Cuts

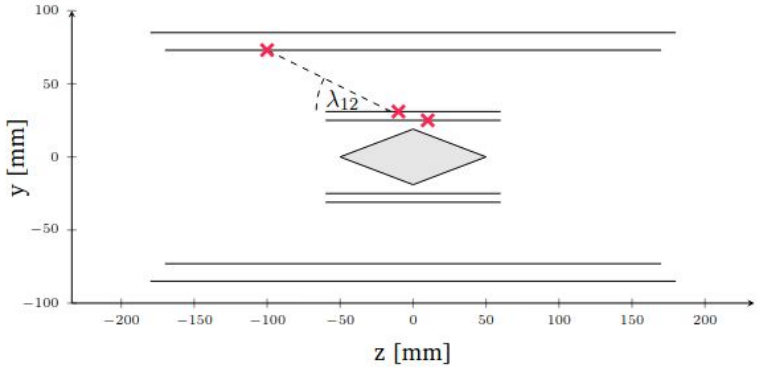
- Slope difference Δz between the slopes of consecutive layer hits in the longitudinal plane.

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

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

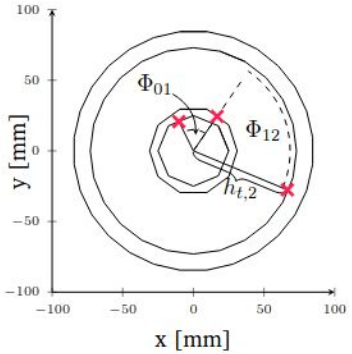
- In transverse plane we observe the angle Φ_{ij} between hits of two consecutive layers in relation the the origin:

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



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

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



Track Reconstruction

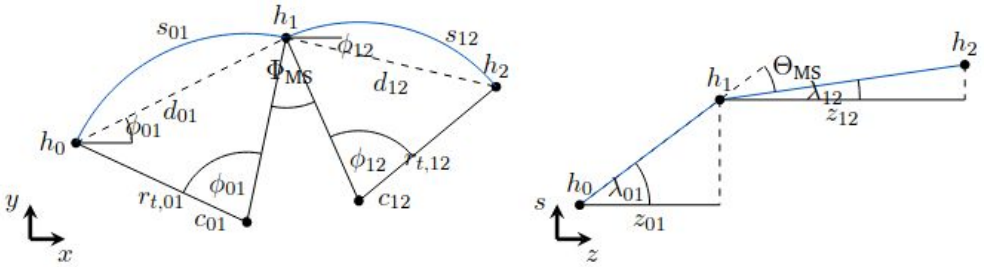
- For reconstruction Triplet fit is used.
- We search for the track minimizing the objective function. Assuming no momentum loss and thus a constant curvature k.

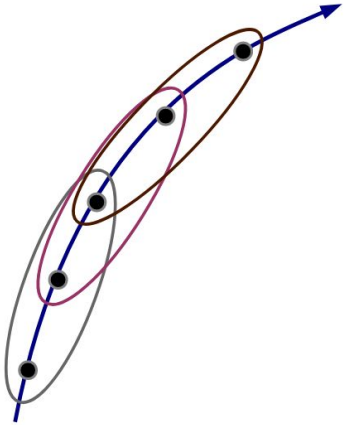
$$\chi^2(\kappa) = \frac{\Phi_{\mathrm{MS}}(\kappa)^2}{\sigma_\Phi^2} + \frac{\Theta_{\mathrm{MS}}(\kappa)^2}{\sigma_\Theta^2}.$$

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

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

- 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.