Silicon Tracker with International Education Objective
(SiTrInEO Project)

France team

Université de Strasbourg, CNRS, IPHC

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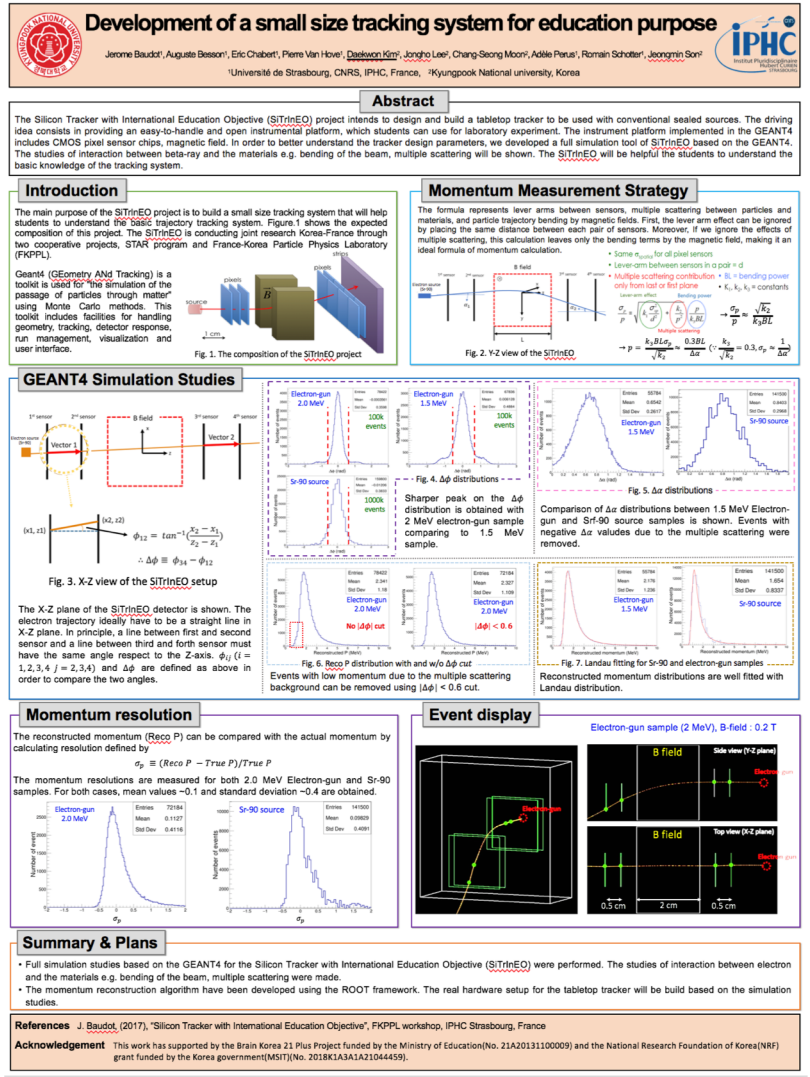
Korea team

Kyungpook National university (KNU)

Daekwon Kim, Jongho Lee, **Chang-Seong Moon**, Jeongmin Son

Outline

- Introduction
- SiTrInEO Collaboration
- GEANT4 simulation studies
  - Data analysis based on Electron gun and Sr-90 source samples
  - Measurement of electron momentum
- SiTrInEO hardware setup
- Summery & Plan



Development of a small size tracking system for education purpose

Jerome Baudot[1], Auguste Besson[1], Eric Chabert[1], Pierre Van Hove[1], Daekwon Kim[2], Jongho Lee[2], Chang-Seong Moon[2], Adèle Perus[1], Romain Schotter[1], Jeongmin Son[2]

[1]Université de Strasbourg, CNRS, IPHC, France, [2]Kyungpook National university, Korea

Abstract

The Silicon Tracker with International Education Objective (SiTrInEO) project intends to design and build a tabletop tracker to be used with conventional sealed sources. The driving idea consists in providing an easy-to-handle and open instrumental platform, which students can use for laboratory experiment. The instrument platform implemented in the GEANT4 includes CMOS pixel sensor chips, magnetic field. In order to better understand the tracker design parameters, we developed a full simulation tool of SiTrInEO based on the GEANT4. The studies of interaction between beta-ray and the materials e.g. bending of the beam, multiple scattering will be shown. The SiTrInEO will be helpful the students to understand the basic knowledge of the tracking system.

Introduction

The main purpose of the SiTrInEO project is to build a small size tracking system that will help students to understand the basic trajectory tracking system. Figure 1 shows the expected composition of this project. The SiTrInEO is conducting joint research Korea-France through two cooperative projects, STAR program and France-Korea Particle Physics Laboratory (FKPPL).

Geant4 (GEometry ANd Tracking) is a toolkit is used for "the simulation of the passage of particles through matter" using Monte Carlo methods. This toolkit includes facilities for handling geometry, tracking, detector response, run management, visualization and user interface.

Fig. 1. The composition of the SiTrInEO project

Momentum Measurement Strategy

The formula represents lever arms between sensors, multiple scattering between particles and materials, and particle trajectory bending by magnetic fields. First, the lever arm effect can be ignored by placing the same distance between each pair of sensors. Moreover, if we ignore the effects of multiple scattering, this calculation leaves only the bending terms by the magnetic field, making it an ideal formula of momentum calculation.

Fig. 2. Y-Z view of the SiTrInEO

GEANT4 Simulation Studies

Fig. 3. X-Z view of the SiTrInEO setup

The X-Z plane of the SiTrInEO detector is shown. The electron trajectory ideally have to be a straight line in X-Z plane. In principle, a line between first and second sensor and a line between third and forth sensor must have the same angle respect to the Z-axis. ϕ_{ij} (i = 1, 2, 3, 4 j = 2, 3, 4) and $\Delta\phi$ are defined as above in order to compare the two angles.

Fig. 4. $\Delta\phi$ distributions

Sharper peak on the $\Delta\phi$ distribution is obtained with 2 MeV electron-gun sample comparing to 1.5 MeV sample.

Fig. 5. $\Delta\alpha$ distributions

Comparison of $\Delta\alpha$ distributions between 1.5 MeV Electron-gun and Srf-90 source samples is shown. Events with negative $\Delta\alpha$ valudes due to the multiple scattering were removed.

Fig. 6. Reco P distribution with and w/o $\Delta\phi$ cut

Events with low momentum due to the multiple scattering background can be removed using $|\Delta\phi| < 0.6$ cut.

Fig. 7. Landau fitting for Sr-90 and electron-gun samples

Reconstructed momentum distributions are well fitted with Landau distribution.

Momentum resolution

The reconstructed momentum (Reco P) can be compared with the actual momentum by calculating resolution defined by

$$\sigma_p \equiv (Reco\ P - True\ P)/True\ P$$

The momentum resolutions are measured for both 2.0 MeV Electron-gun and Sr-90 samples. For both cases, mean values ~0.1 and standard deviation ~0.4 are obtained.

Event display

Electron-gun sample (2 MeV), B-field : 0.2 T

Summary & Plans

- Full simulation studies based on the GEANT4 for the Silicon Tracker with International Education Objective (SiTrInEO) were performed. The studies of interaction between electron and the materials e.g. bending of the beam, multiple scattering were made.
- The momentum reconstruction algorithm have been developed using the ROOT framework. The real hardware setup for the tabletop tracker will be build based on the simulation studies.

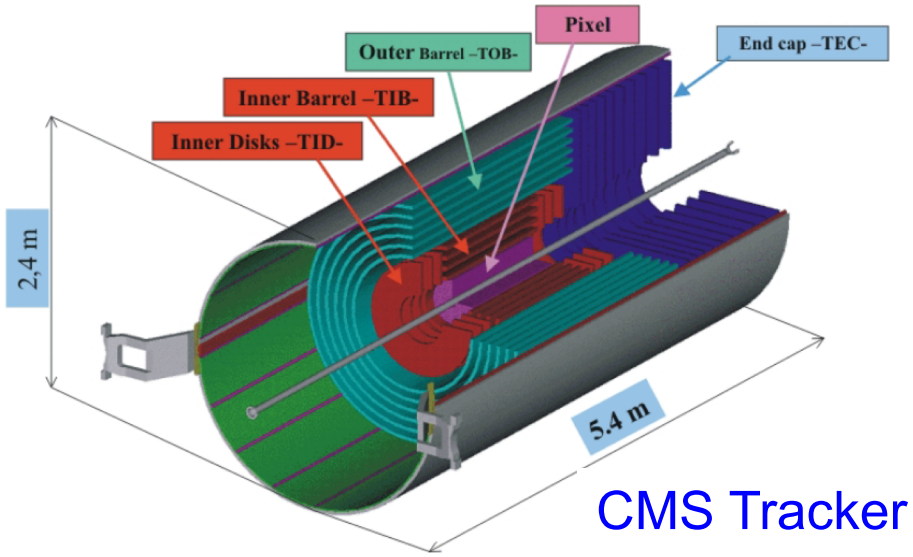
References J. Baudot, (2017), "Silicon Tracker with International Education Objective", FKPPL workshop, IPHC Strasbourg, France

Acknowledgement This work has supported by the Brain Korea 21 Plus Project funded by the Ministry of Education(No. 21A20131100009) and the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIT)(No. 2018K1A3A1A21044459).

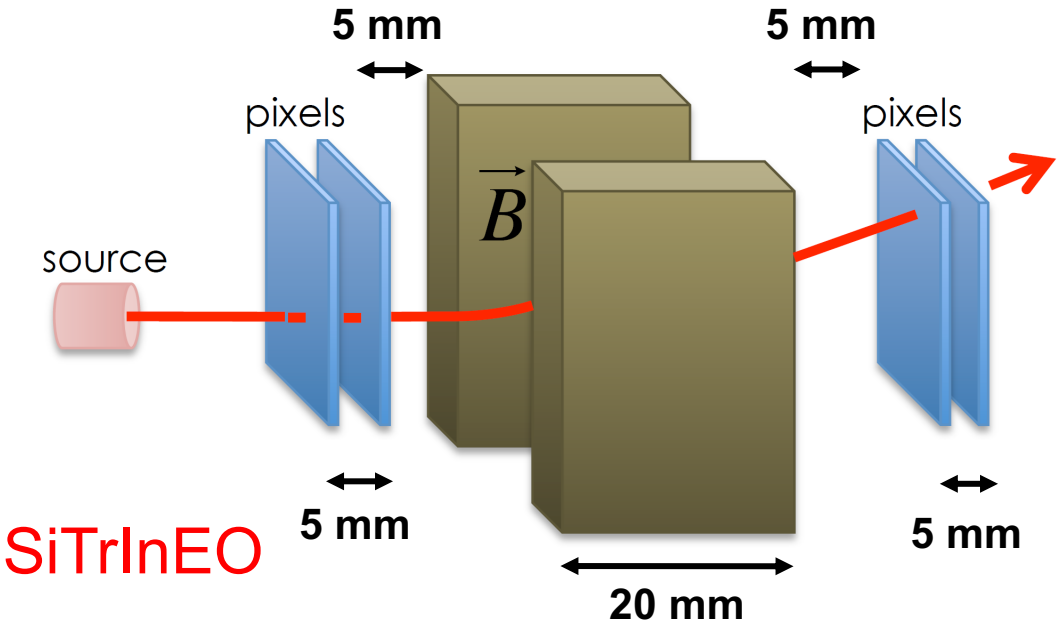
The Poster presented at Korea Physics Society (KPS) Meeting in April of 2019.

Introduction

- Motivation of the SiTrInEO project
  - High energy physics based on the accelerator uses large-scale devices and infrastructure
  - Difficult to understand for students the principles of the tracking system
- The main purpose of the SiTrInEO project
  - Help students to understand the basic tracking system
- The SiTrInEO is conducting joint research France-Korea through two cooperative projects.
  - Supported by the STAR program and FKPPL



CMS Tracker



SiTrInEO

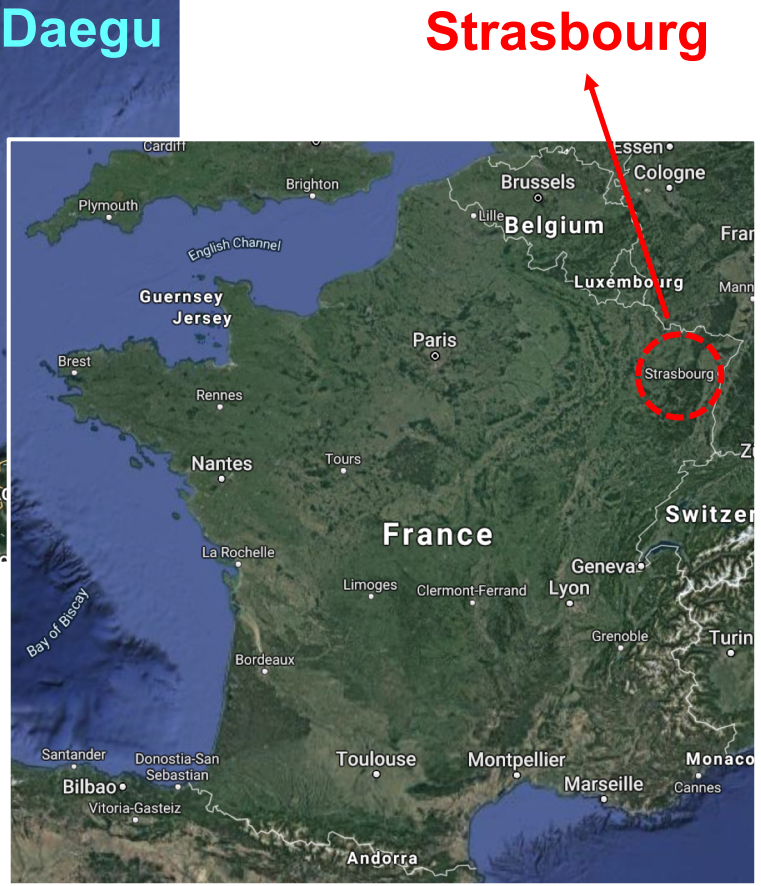
The SiTrInEO Collaboration

❑ KNU (Korea)

- CMS group
  - ➢ Staff: Chang-Seong Moon
  - ➢ Students: Jongho Lee, Daekwon Kim, Jeongmin Son

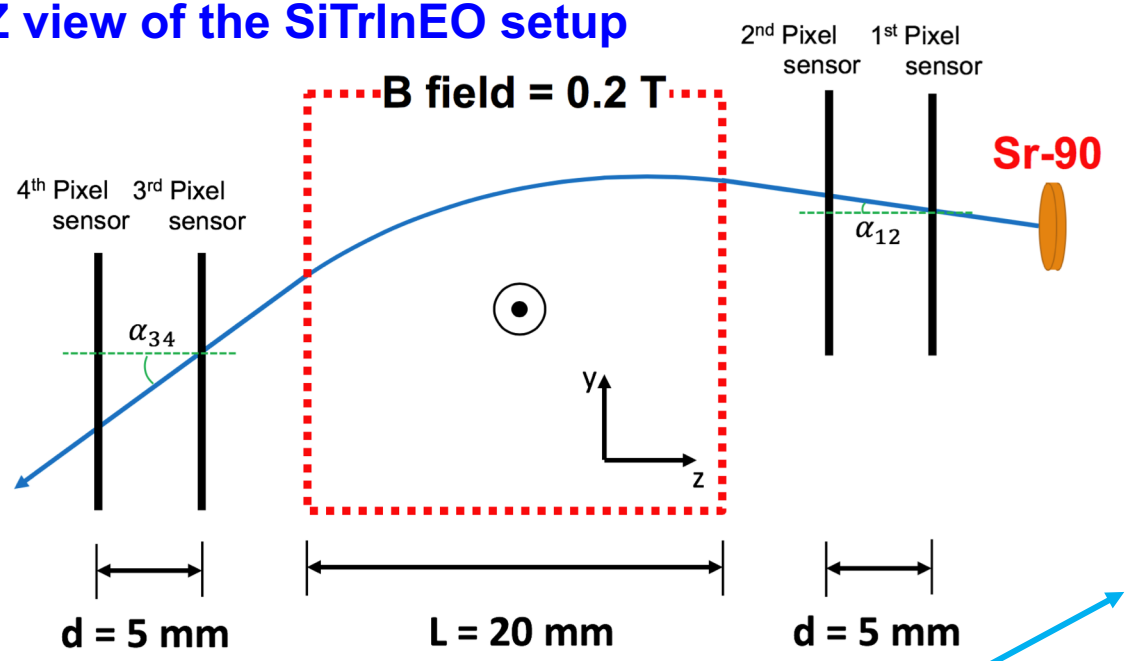
❑ IPHC (France)

- CMS group
  - ➢ Staff: Eric Chabert, Pierre Van Hove
- PICSEL group
  - ➢ Staff: Auguste Besson
- Belle II group
  - ➢ Staff: Jerome Baudot
  - ➢ Students: Adèle Perus, Romain Schotter



Momentum Measurement Strategy

Y-Z view of the SiTrInEO setup



- Same $\sigma_{spatial}$ for all pixel sensors
- Lever-arm between sensors in a pair = d
- Multiple scattering contribution only from last or first plane
- BL = bending power
- K_1, k_2, k_3 = constants

Lever-arm effect — Bending power

$$\frac{\sigma_p}{p} = \sqrt{k_1 \frac{\sigma_{sp}^2}{d^2} + \frac{k_2}{p^2}\frac{p}{k_3 BL}} \rightarrow \frac{\sigma_p}{p} \approx \frac{\sqrt{k_2}}{k_3 BL}$$

Multiple scattering

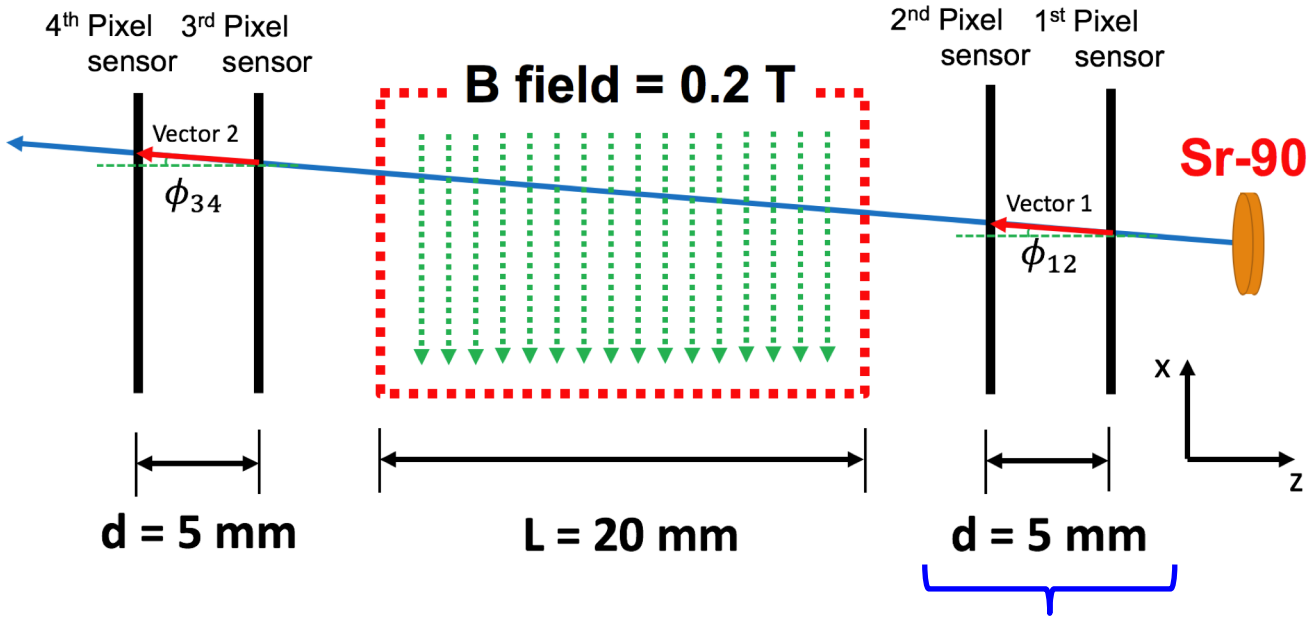
- ❑ The formula represents:
  - ➢ Lever arms **(d)** between sensors
  - ➢ Multiple scattering between particles and materials
  - ➢ Particle trajectory bending by magnetic fields **(B)**
- ❑ The lever arm effect can be ignored by placing the same distance between each pair of sensors.
- ❑ If ignoring the effects of multiple scattering:
  - ➢ Ideal formula of momentum calculation

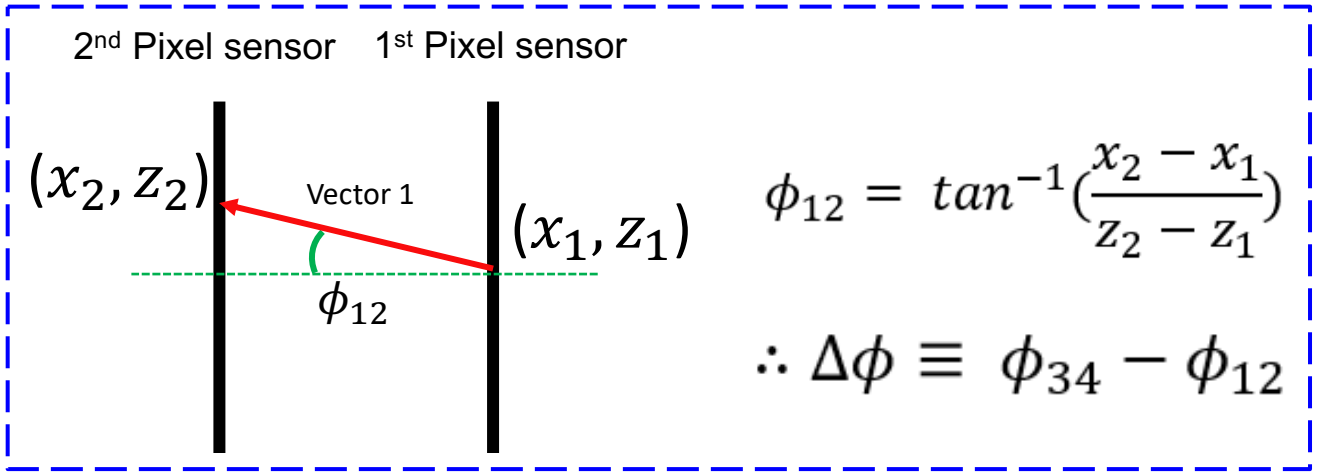
$$\rightarrow p = \frac{k_3 BL \sigma_p}{\sqrt{k_2}} \approx \frac{0.3BL}{\Delta\alpha}$$

$$\left(\because \frac{k_3}{\sqrt{k_2}} = 0.3, \sigma_p \approx \frac{1}{\Delta\alpha}\right)$$

GEANT4 Simulation Studies

x-z view of the SiTrInEO setup





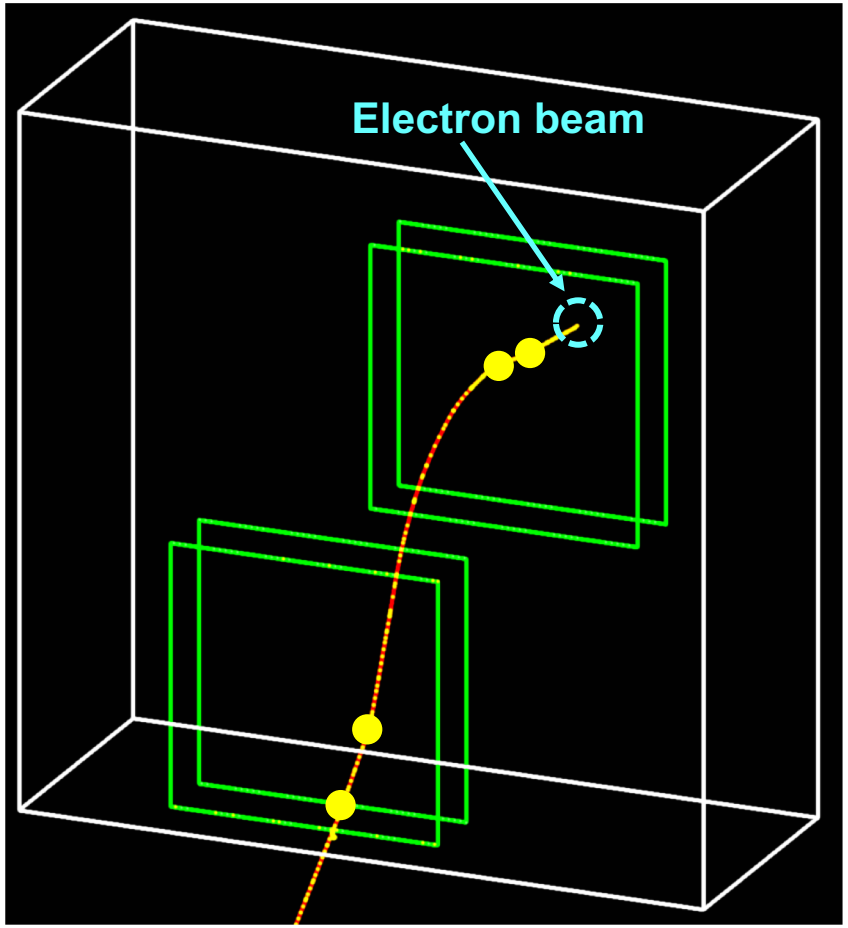
- The electron trajectory must be a straight line in x-z plane.
  - Magnetic field does not affect on electron trajectory in x-z plane.
  - The angle of Vector 1 and Vector 2 have to be the same in principle.

- ϕ_{ij} $(i = 1, 2, 3,\ j = 2, 3, 4)$ and $\Delta\phi$ are defined as in the left figure in order to compare the angles from two vectors.

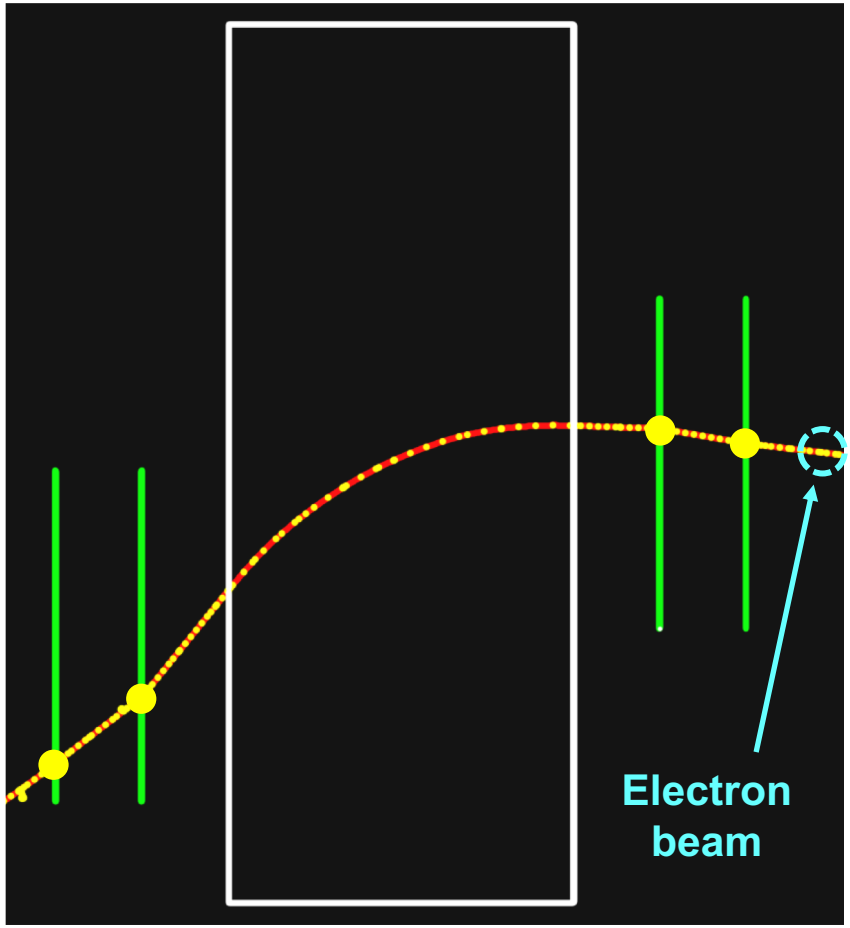
GEANT4 Simulation Studies – Event display

Based on Electron gun sample (1.5 MeV), B-field magnitude : 0.2 T

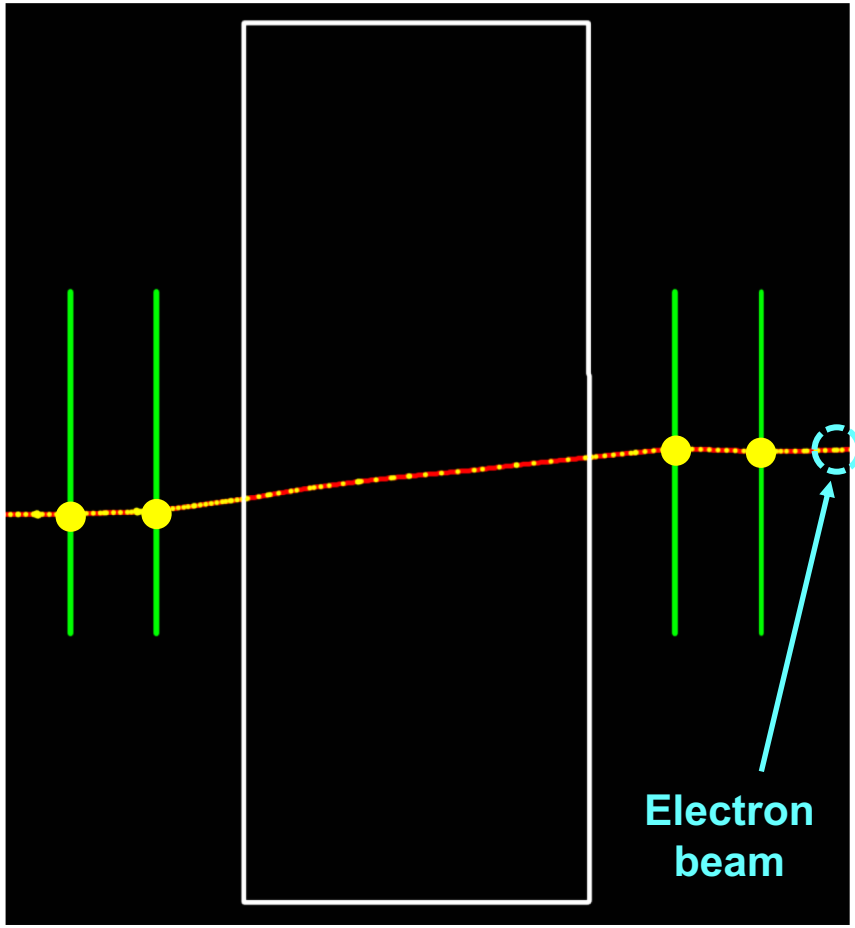
3D view



Side view (y-z plane)



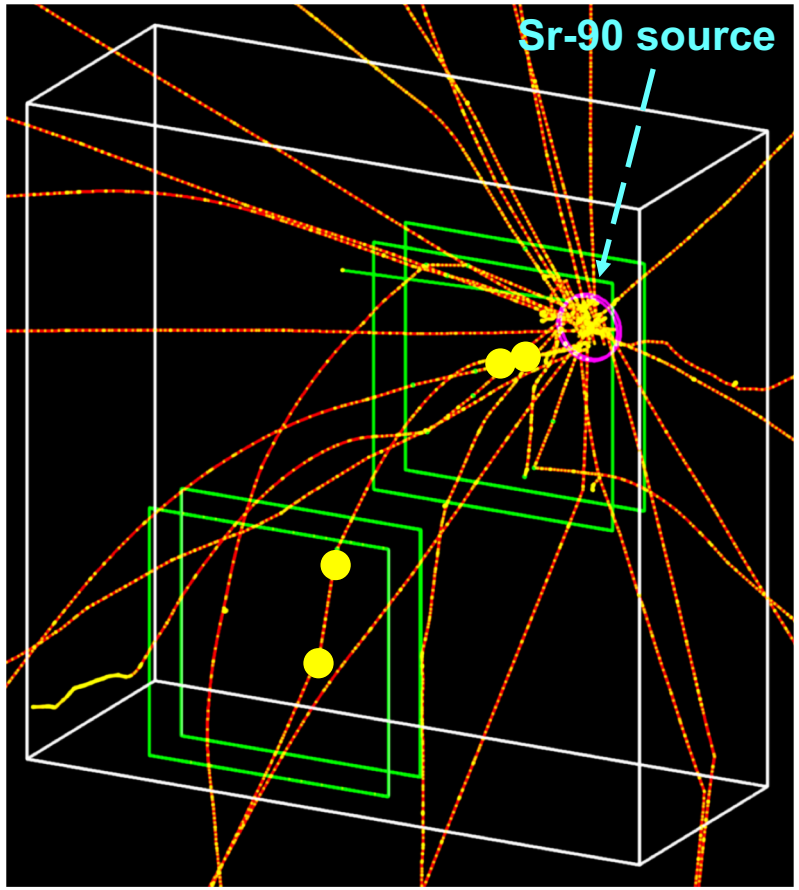
Top view (x-z plane)



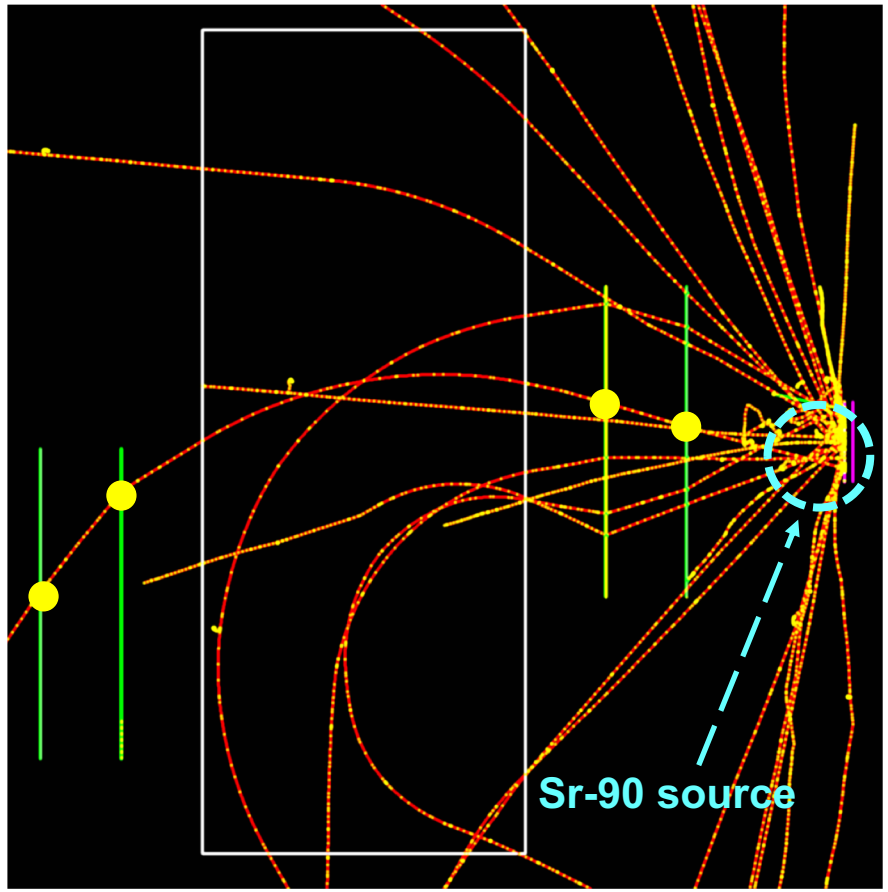
GEANT4 Simulation Studies – Event display

Based on Sr-90 source sample, B-field magnitude : 0.2 T

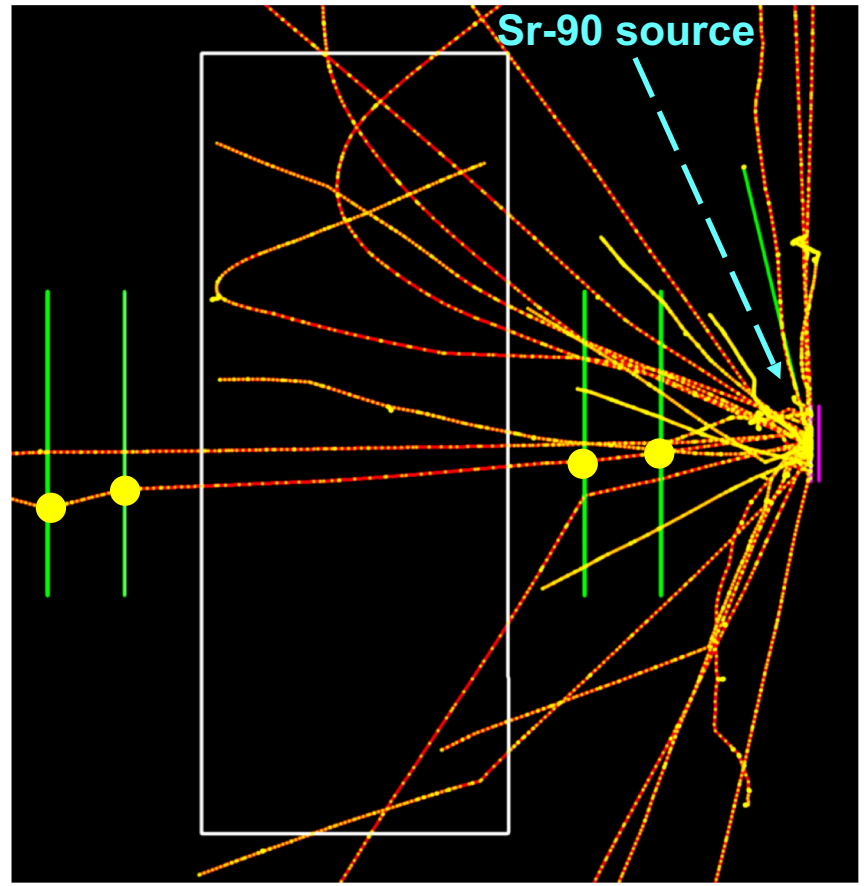
3D view



Side view (y-z plane)

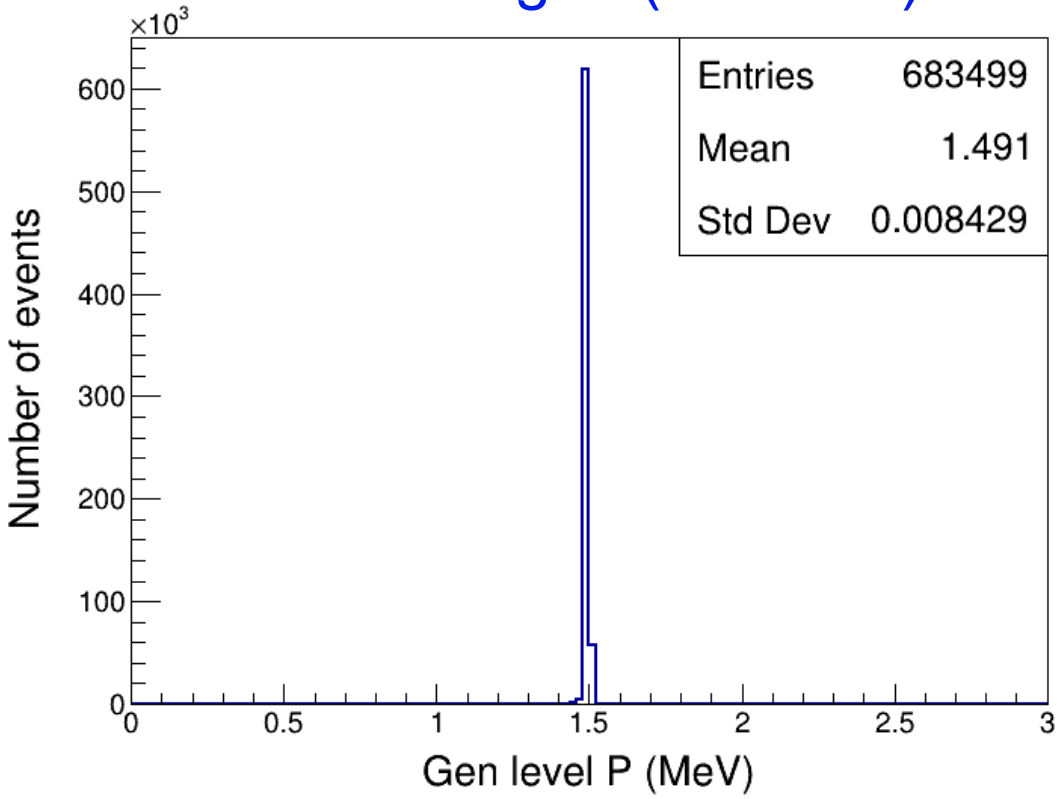


Top view (x-z plane)

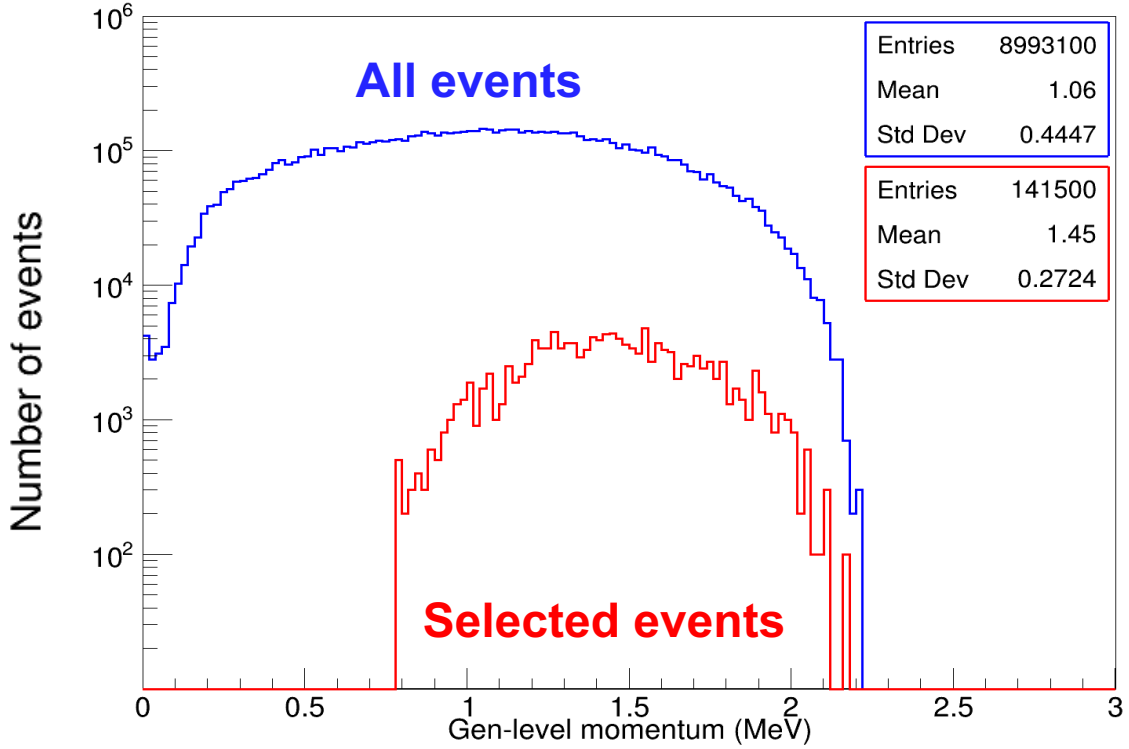


Generator level momentum distributions

Electron gun (1.5 MeV)



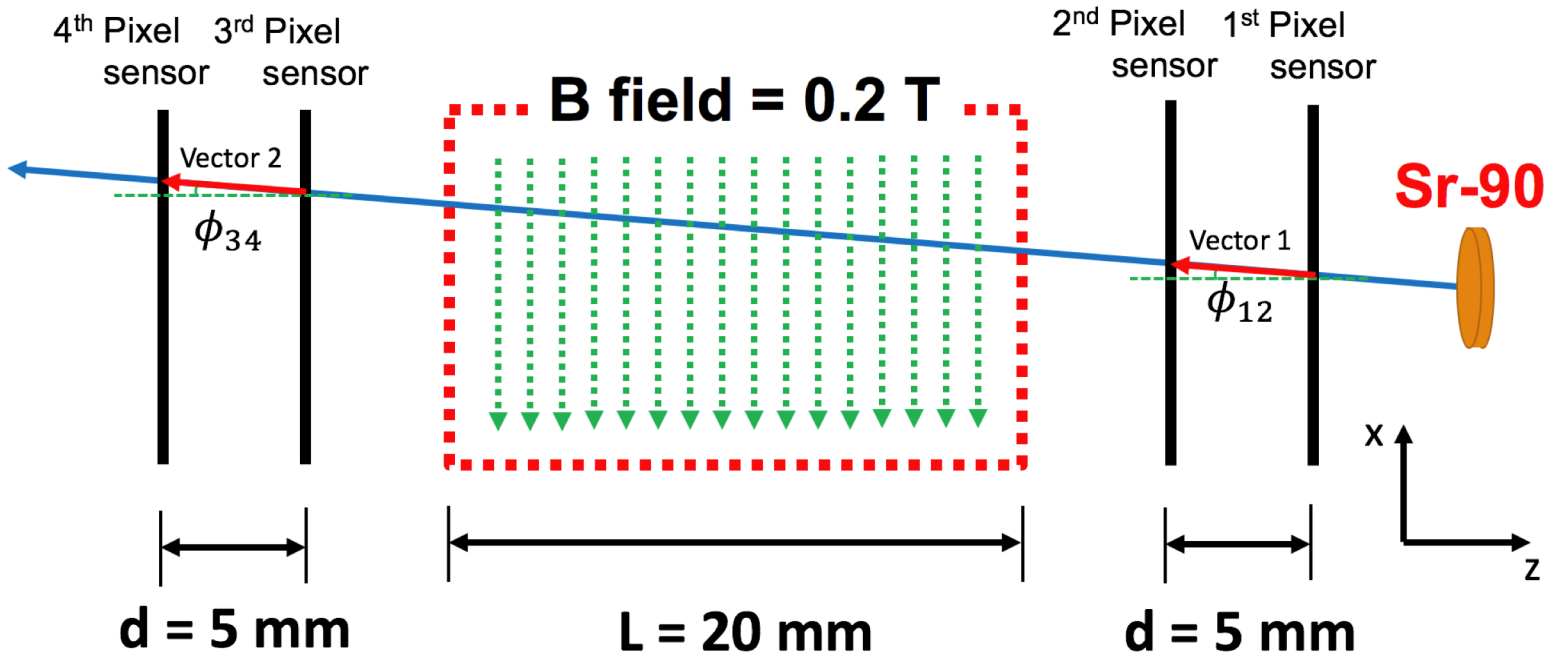
Sr-90 source



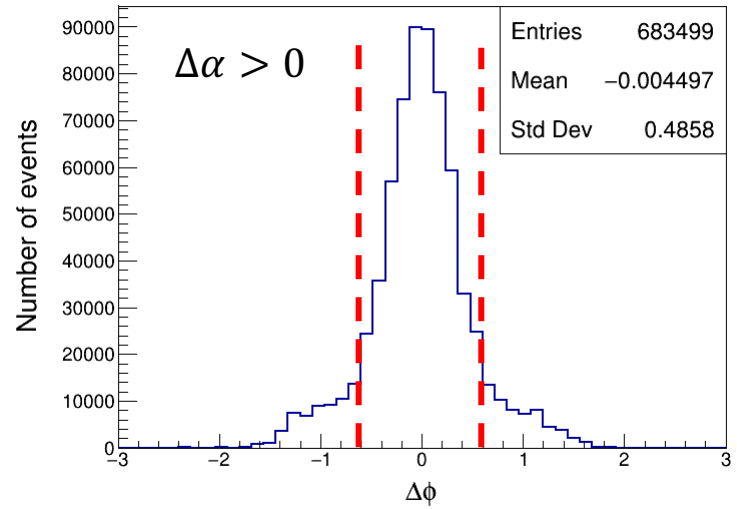
- Sharpe momentum distribution (peak: 1.5 MeV)

- Blue: All electron events from Strontium-90 source
- Red: Selected events requiring at least one hit on each pixel layer.

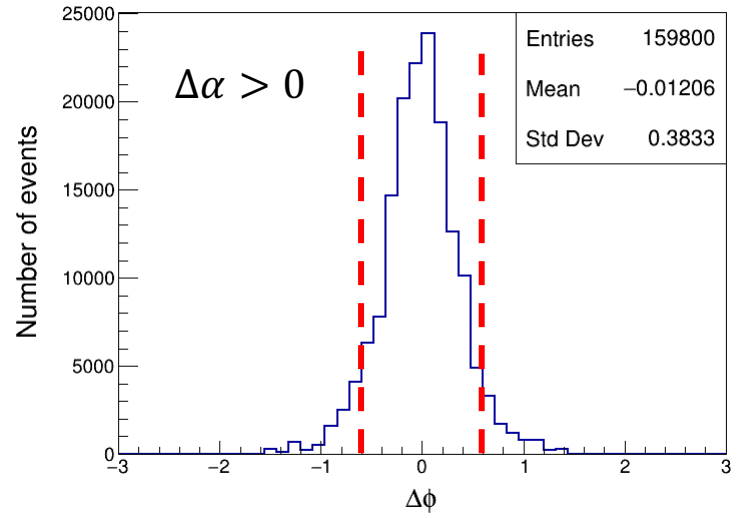
$\Delta\phi$ distribution in x-z plane



Electron gun 1.5 MeV

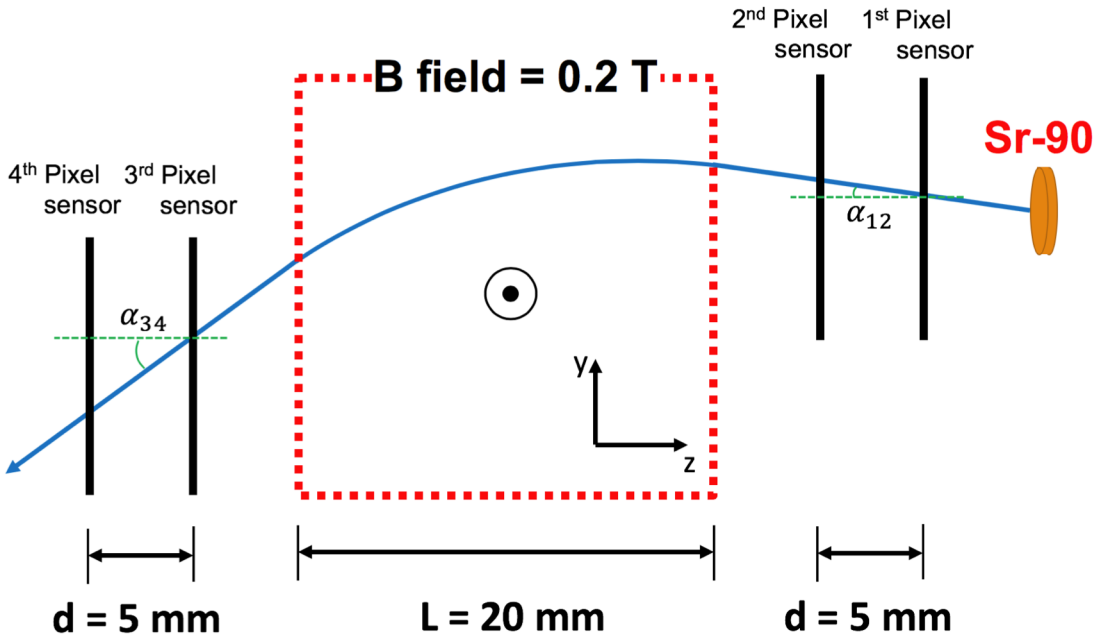


Sr-90 source



- Comparison of $\Delta\phi$ distributions between 1.5 MeV Electron gun and Sr-90 source samples
- Since ϕ_{12} and ϕ_{34} have to be same in principle, **$\Delta\phi$ has to be zero.**
  - Events out of the peak due to the multiple scattering
  - Required $|\Delta\phi| < 0.6$

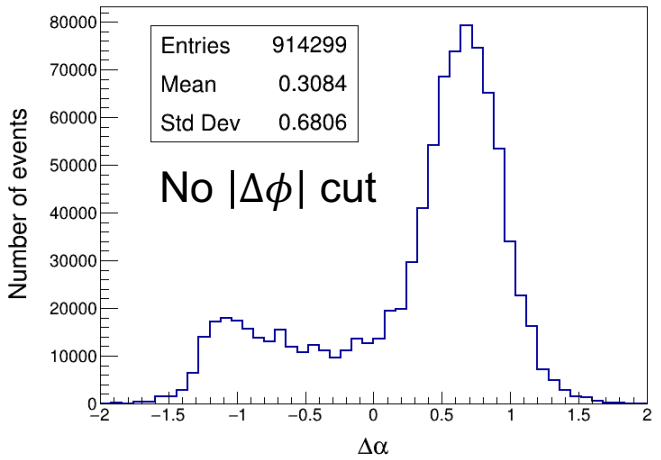
$\Delta\alpha$ distribution in y-z plane

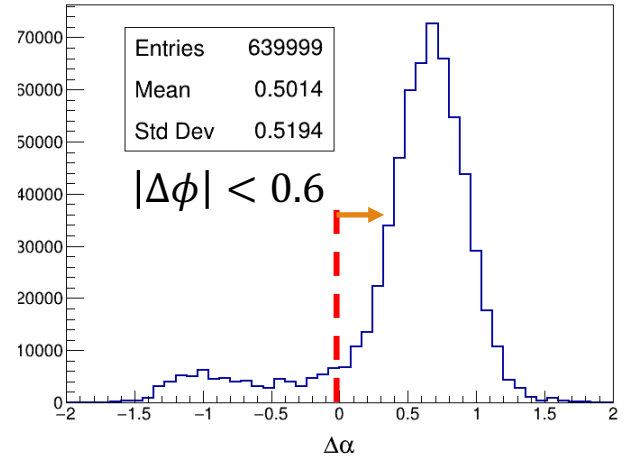


$$\Delta\alpha = a_{34} - a_{12} > 0$$

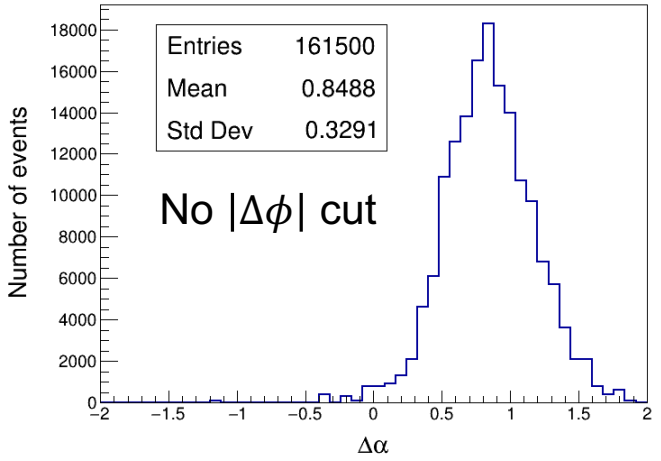
- Comparison of $\Delta\alpha$ distributions between 1.5 MeV Electron gun and Sr-90 source samples
- Basically $\Delta\alpha$ can not be smaller than zero
  - Electrons are bent in one direction by magnetic field.

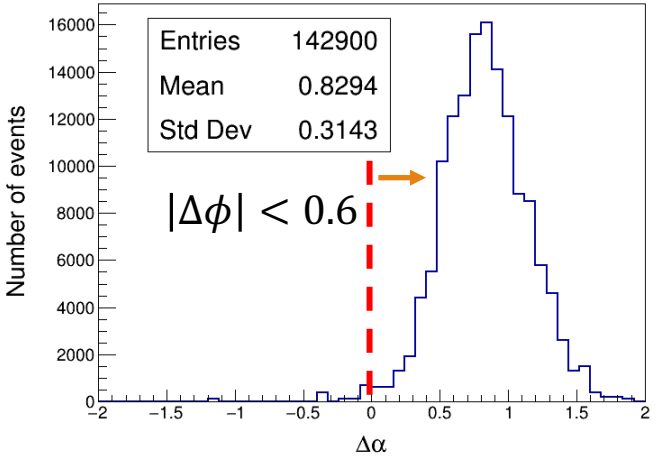
Electron gun (1.5 MeV)





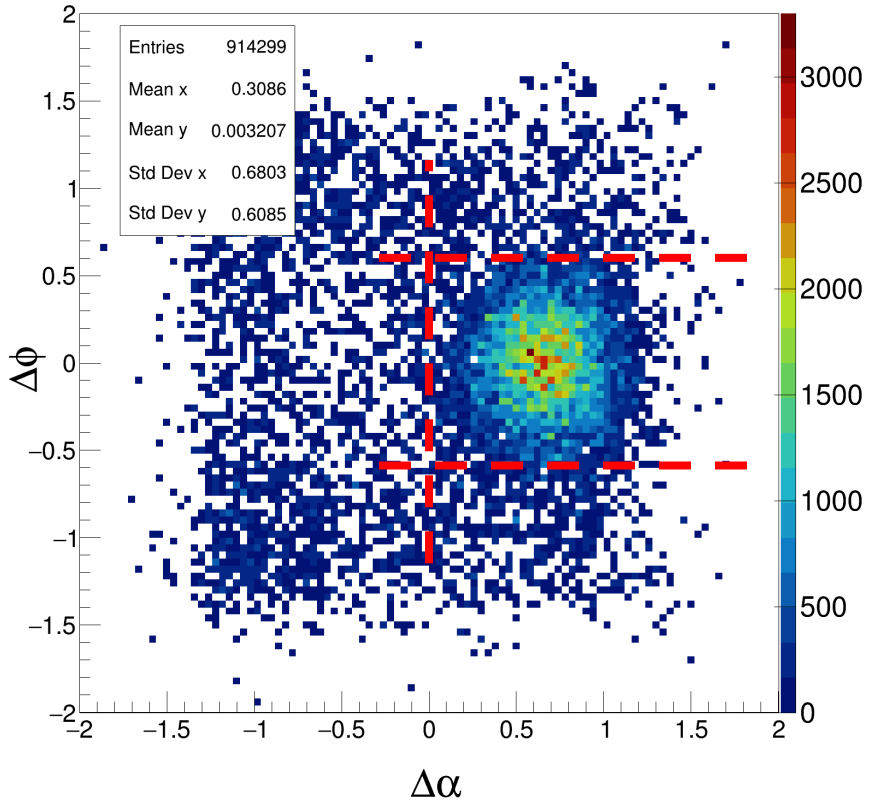
Sr-90 source



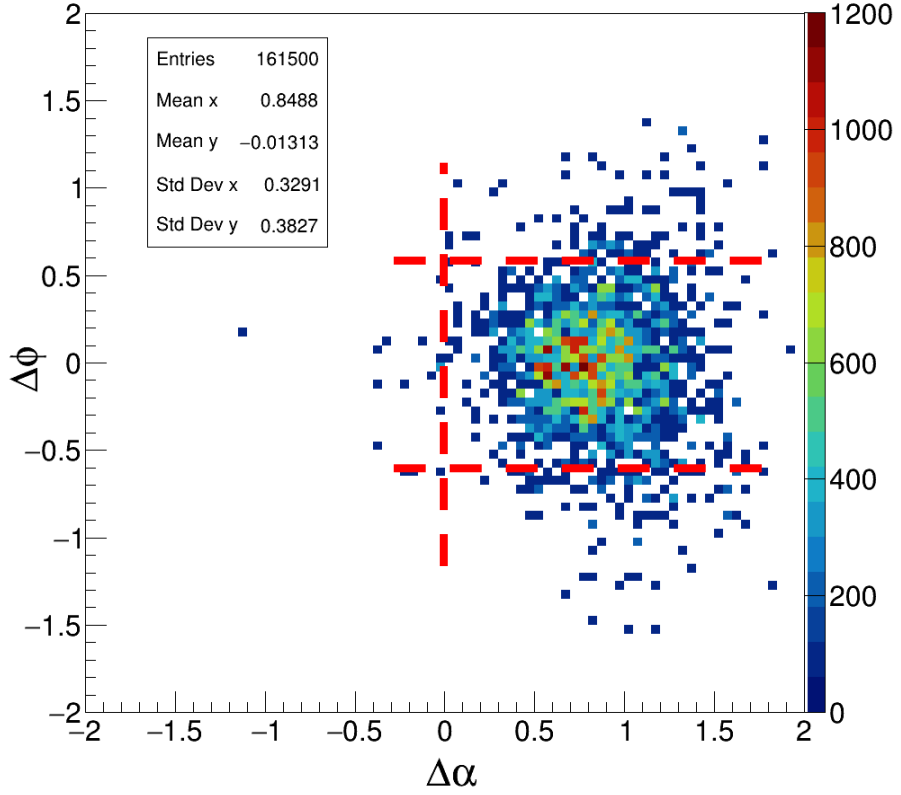


$\Delta\alpha - \Delta\phi$ scatter plots

Electron gun (1.5 MeV)

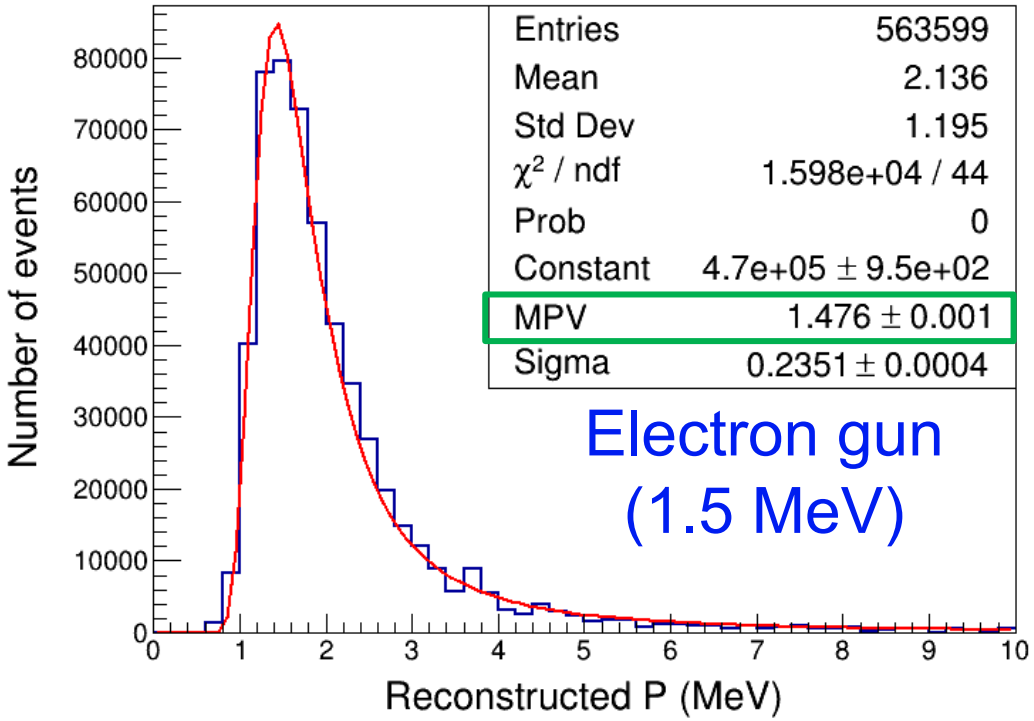


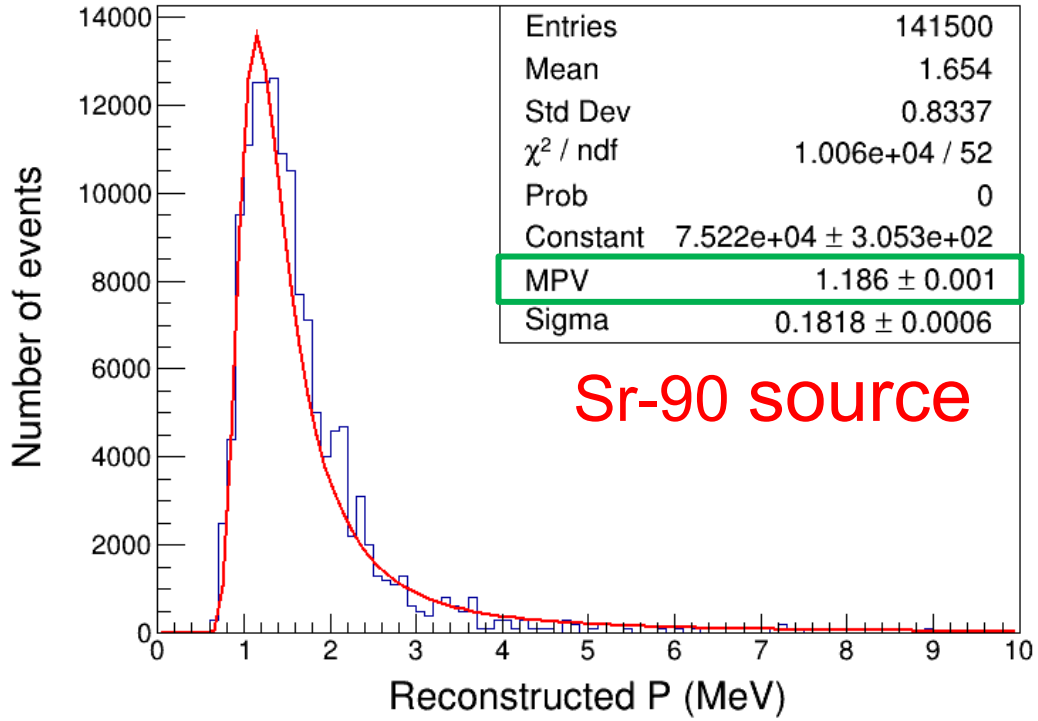
Sr-90 source



- Most events are distributed in $0.2 < \Delta\alpha < 1.2$ and $|\Delta\phi| < 0.5$ for both cases.
  - Signal region : $|\Delta\phi| < 0.6$ and $\Delta\alpha > 0$
- Events in 1.5 MeV Electron gun sample spread more broadly.

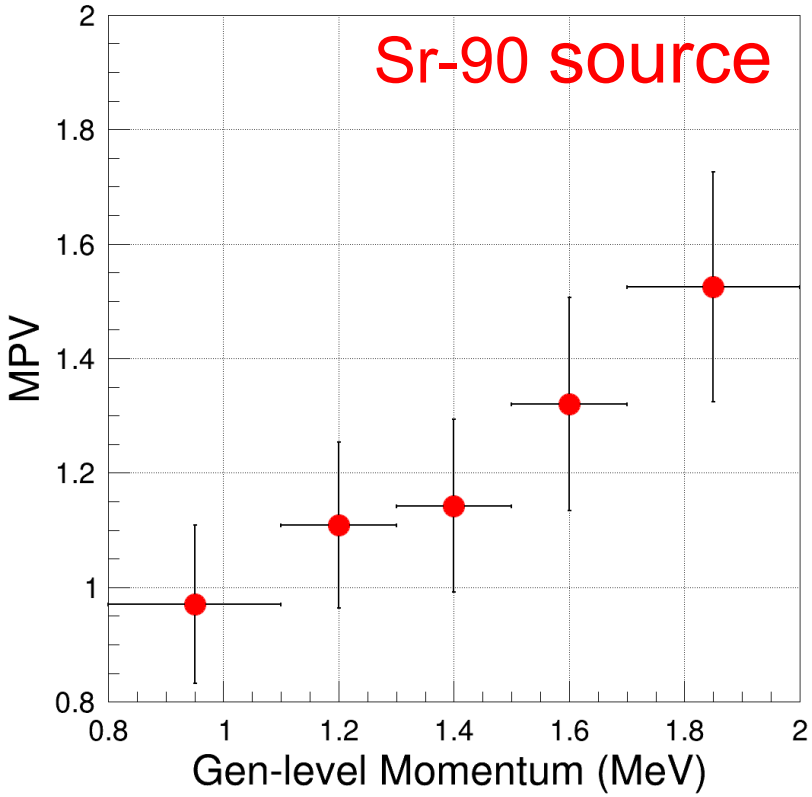
Reconstructed momentum distributions (I)

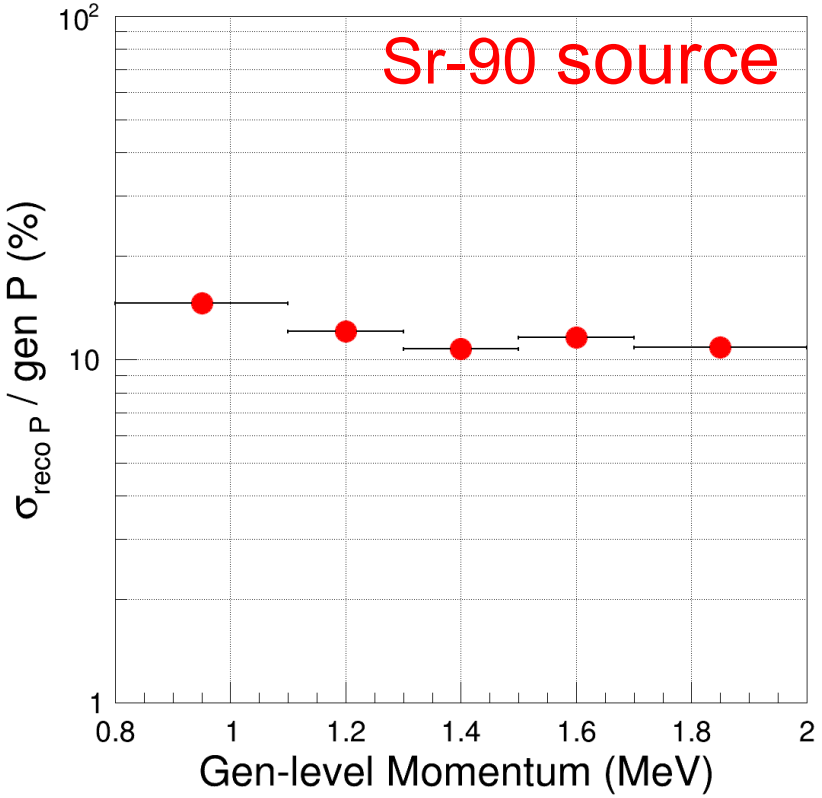




- Reconstructed momentum distributions are reasonably fitted well with Landau distribution.
- Most probable value (MPV) in both distributions:
  - Electron gun: **1.48 MeV** (Gen-level momentum: **1.5 MeV**)
  - Sr-90 source: **1.19 MeV** (Average gen-level momentum: **1.43 MeV**)
- Investigating the reason of the low reconstructed momentum in Sr-90 source sample

Reconstructed momentum distributions (II)

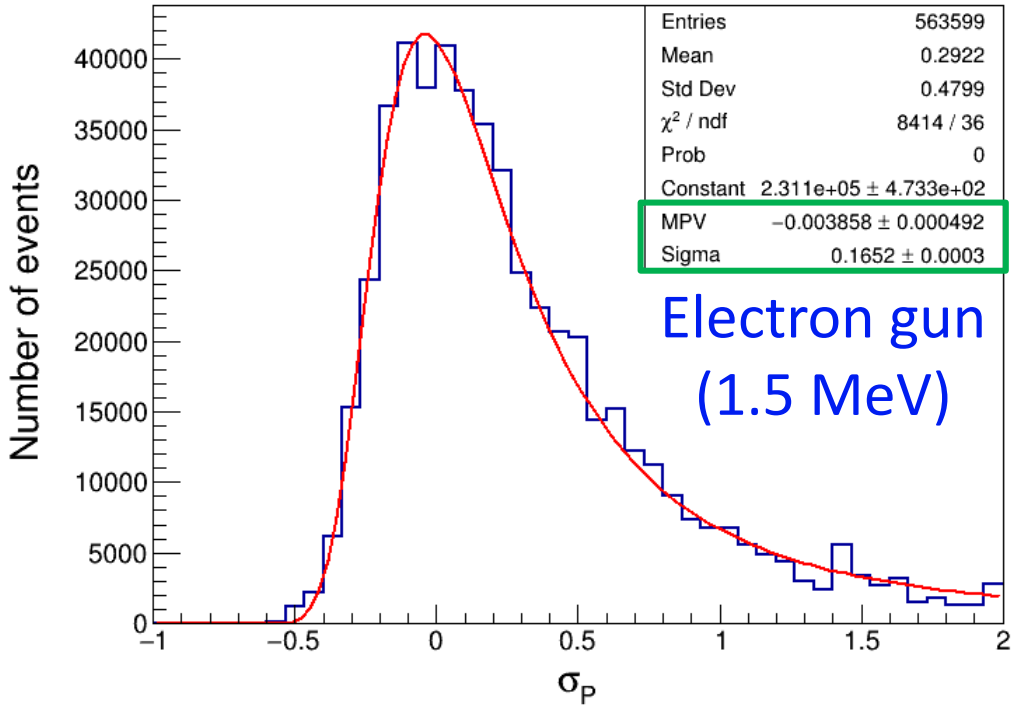


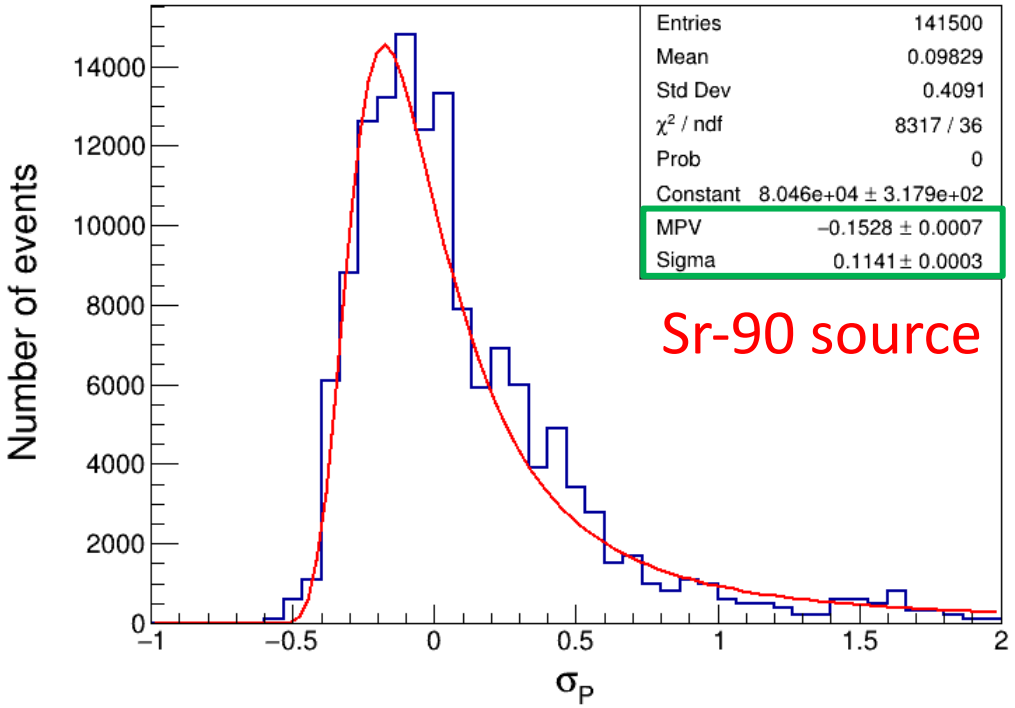


- Left: Reconstructed momentum as a function of gen-level momentum
  - Slightly lower measured the momentom w.r.t the gen-level momentum (Investigating)
- Right: Uncertainty of reconstructed momentum as a function of gen-level momentum
  - 10-15% of uncertainty measured.

Momentum resolution from simulation studies

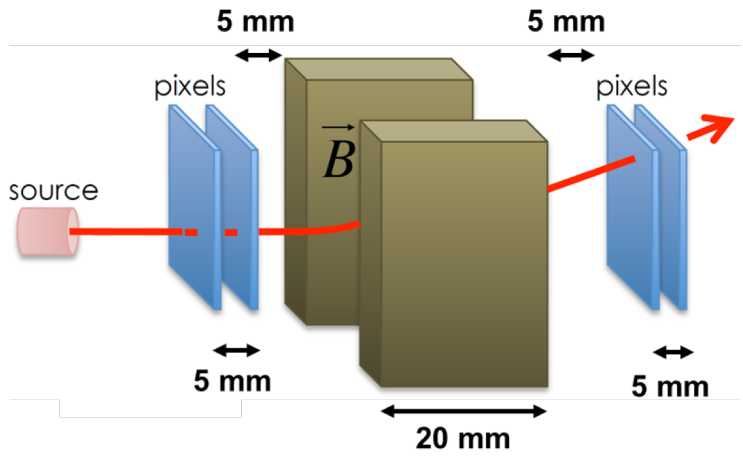
- Definition of momentum resolution:
  - $\sigma_p \equiv (Reco\ P - True\ P)\ /\ True\ P$, where P is momentum
- Momentum resolutions are measured for both 1.5 MeV Electron gun and Sr-90 samples
  - Electron gun: MPV ~ - 0.004, σ ~ 0.165
  - Sr-90 source: MPV ~ - 0.153, σ ~ 0.114



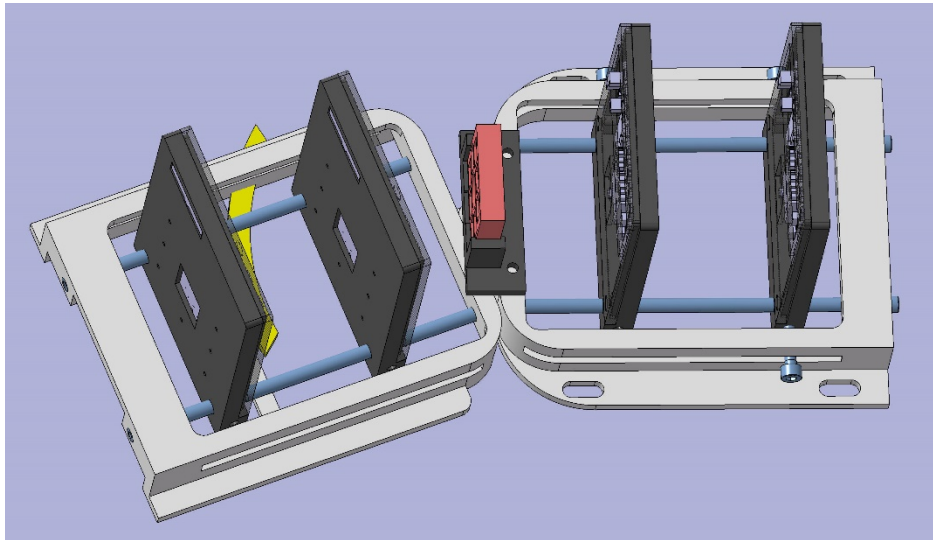


“Mockup” setup at IPHC, Strasbourg

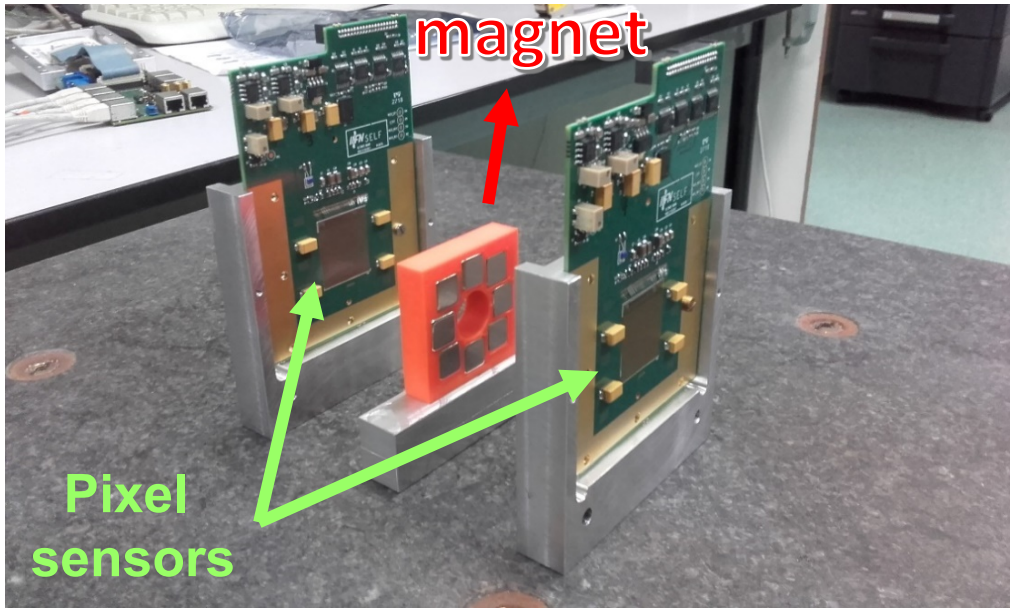
Schematic view

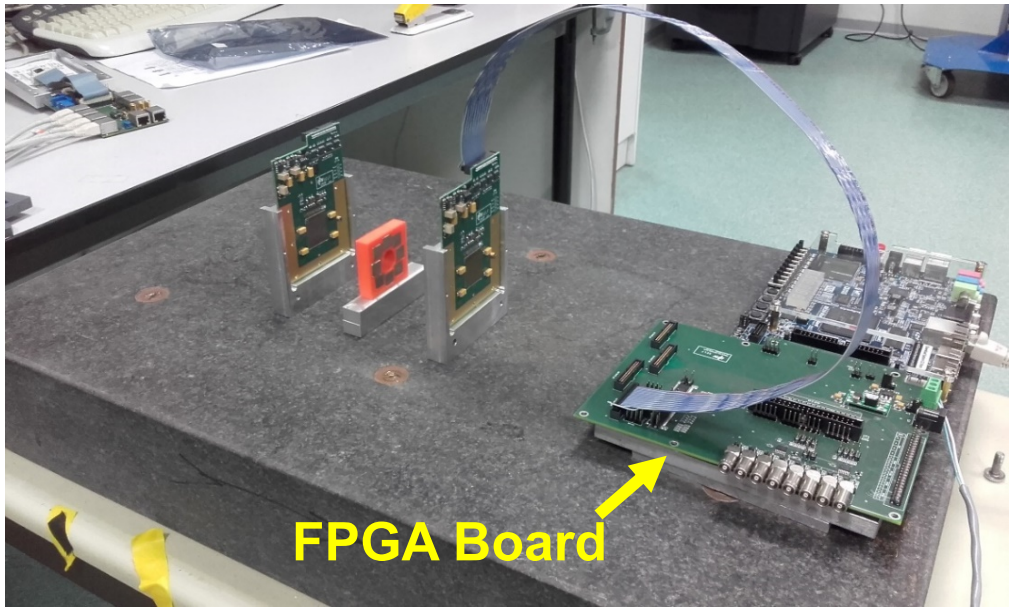


3D sketch of the first setup for SiTrInEO

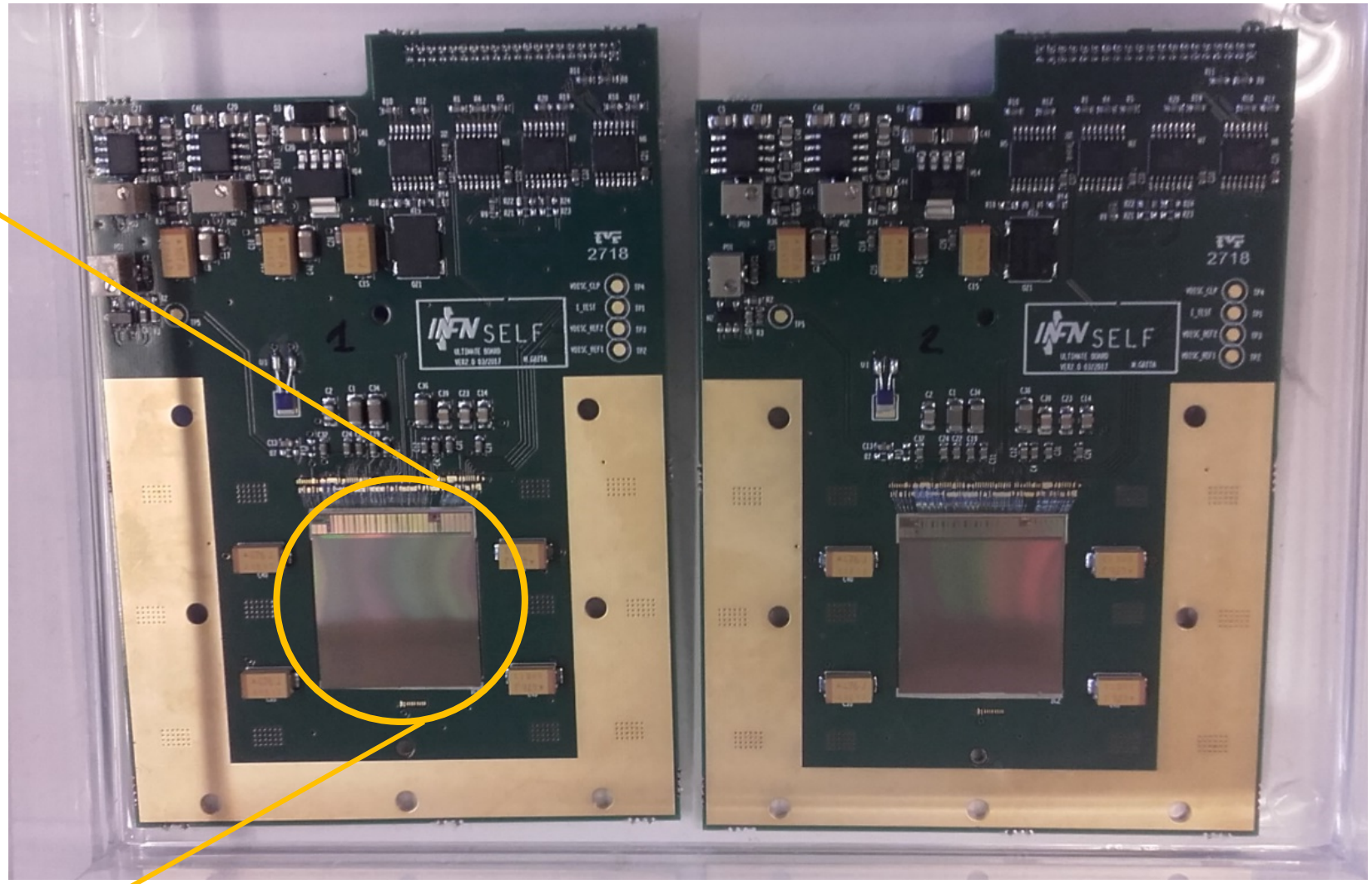


Realistic setup

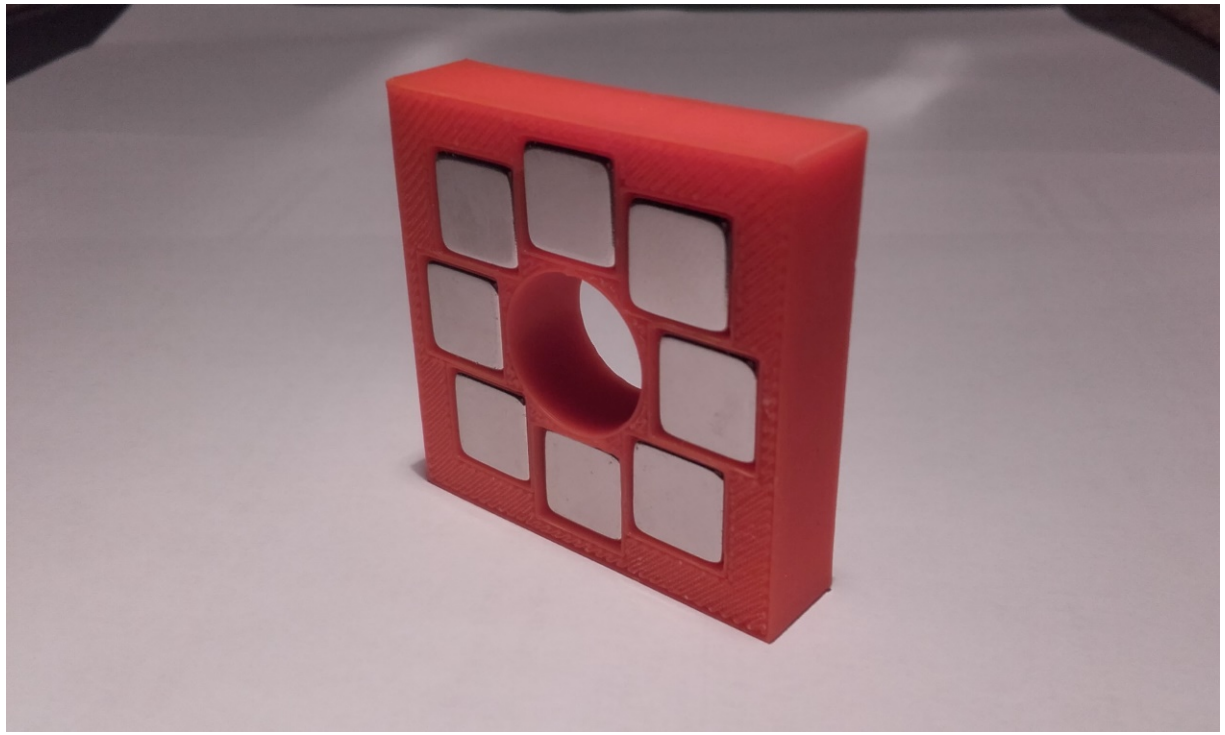


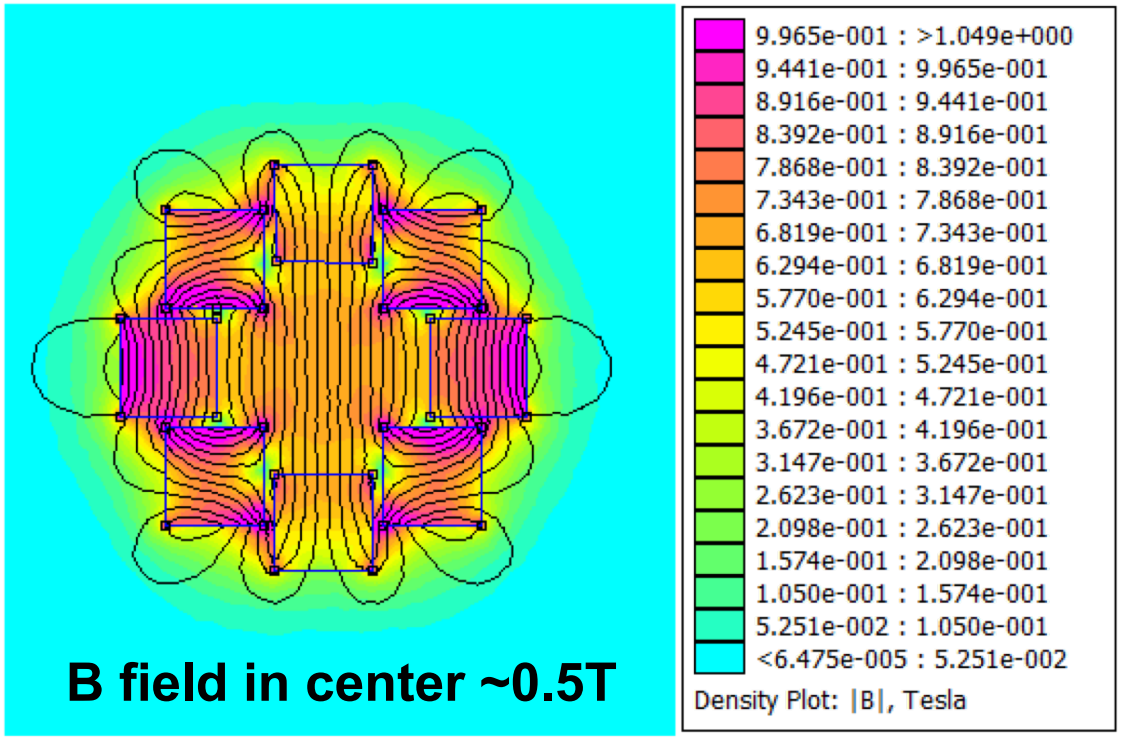


SiTrInEO pixel sensor



Halbach magnet





- Use several small magnets to:
  - Increase the field strength
  - Improve field homogeneity

Exchanging researchers

❑ From Korea to France

- ➢ Jun, 2018: Jongho (2 weeks)
- ➢ Jun, 2019: Chang-Seong (1 week)
- ➢ July, 2019: Daekwon (1 week)

❑ From France to Korea

- ➢ Dec, 2018: Jerome (1 week)
- ➢ Mar, 2019: Adèle and Romain (1 week)
- ➢ Expecting visitors in October, 2019

Summary & Plans

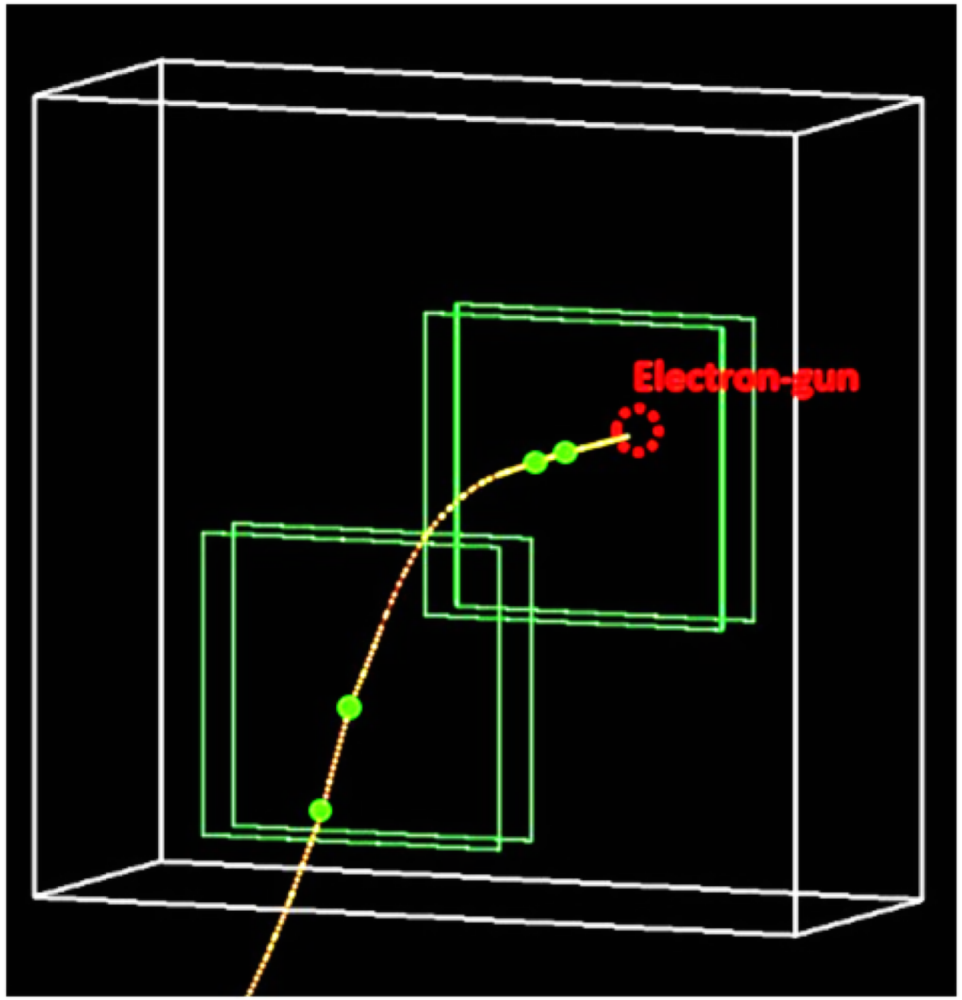
- Full simulation studies based on the GEANT4 for the SiTrInEO were performed.
  - Good agreement with generated and reconstructed electron momenta using Electron gun and Sr-90 samples
- The momentum reconstruction algorithm have been developed using the ROOT framework.
  - Optimized geometry of the pixel sensors and magnetic field to improve the algorithm performance.
- Preliminary results based on the GEANT4 simulation presented at the KPS meeting.
- The “Mockup” setup for the SiTrInEO project has been completed based on the simulation studies.
- Ready to take real data with complete setup for the SiTrInEO tracker
  - **Stay tuned!**

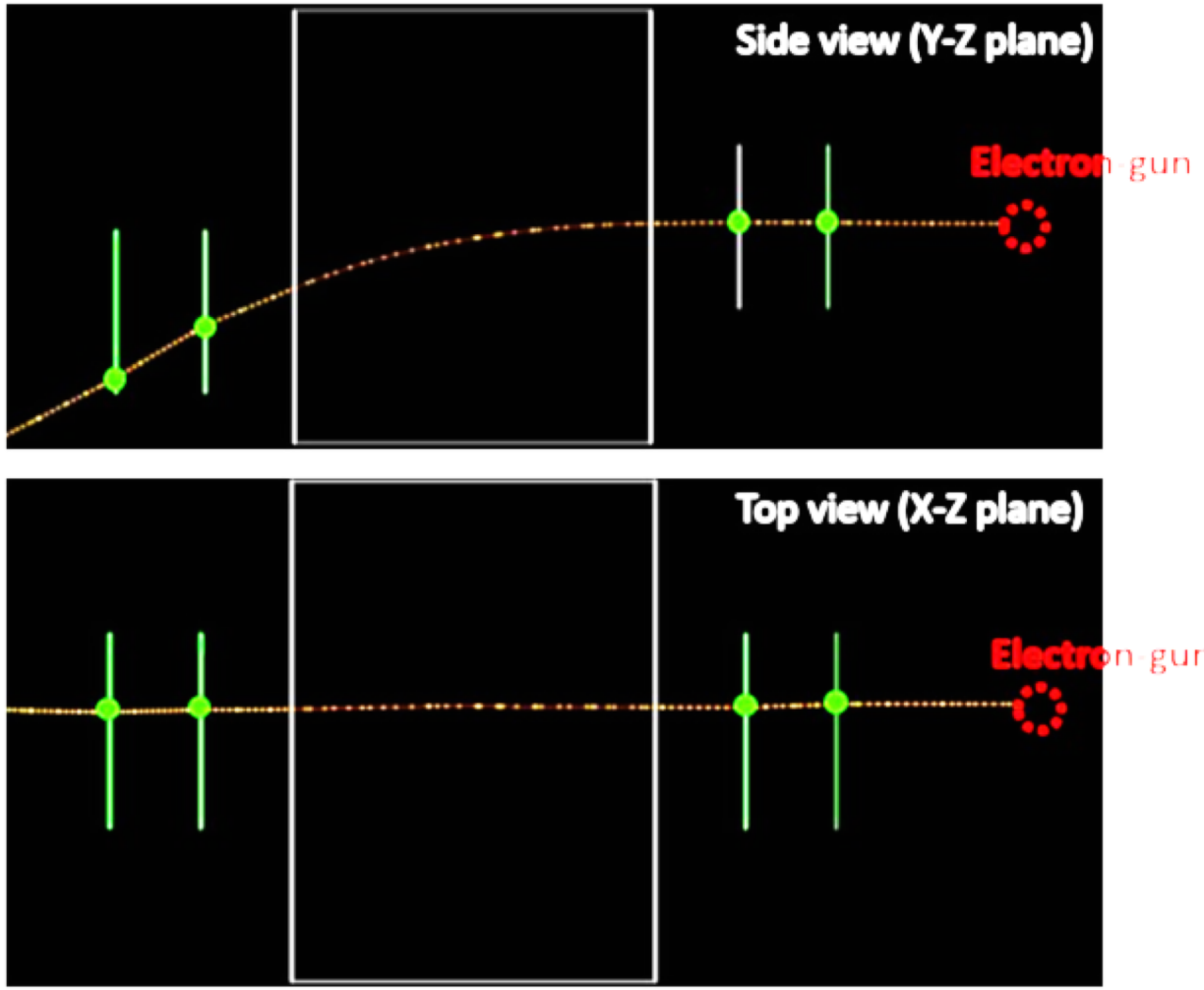
Thank you

Backup

GEANT4 Simulation Studies – Event display

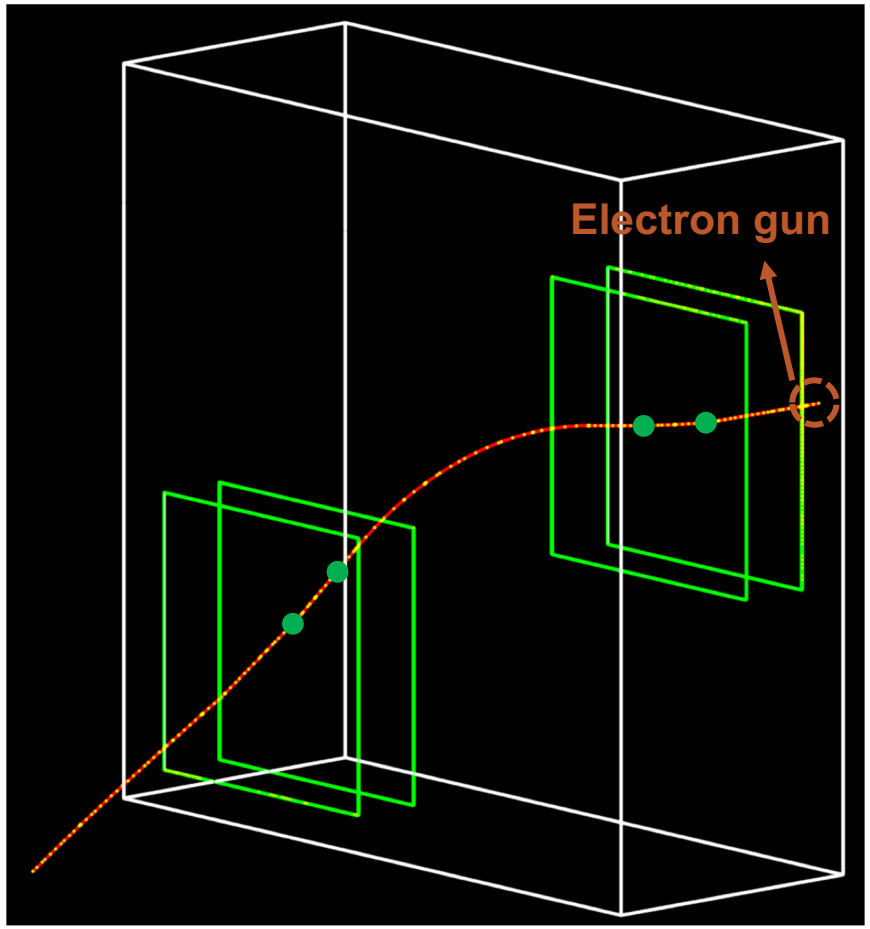
Electron gun sample (2 MeV), B-field magnitude : 0.2 T

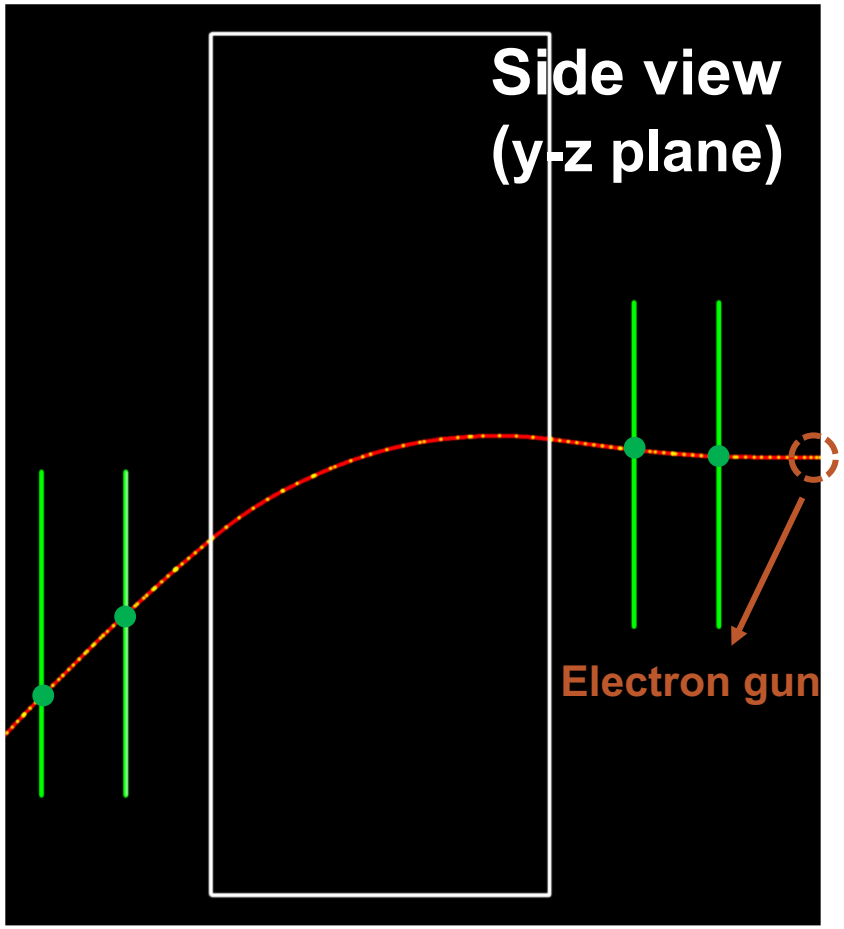


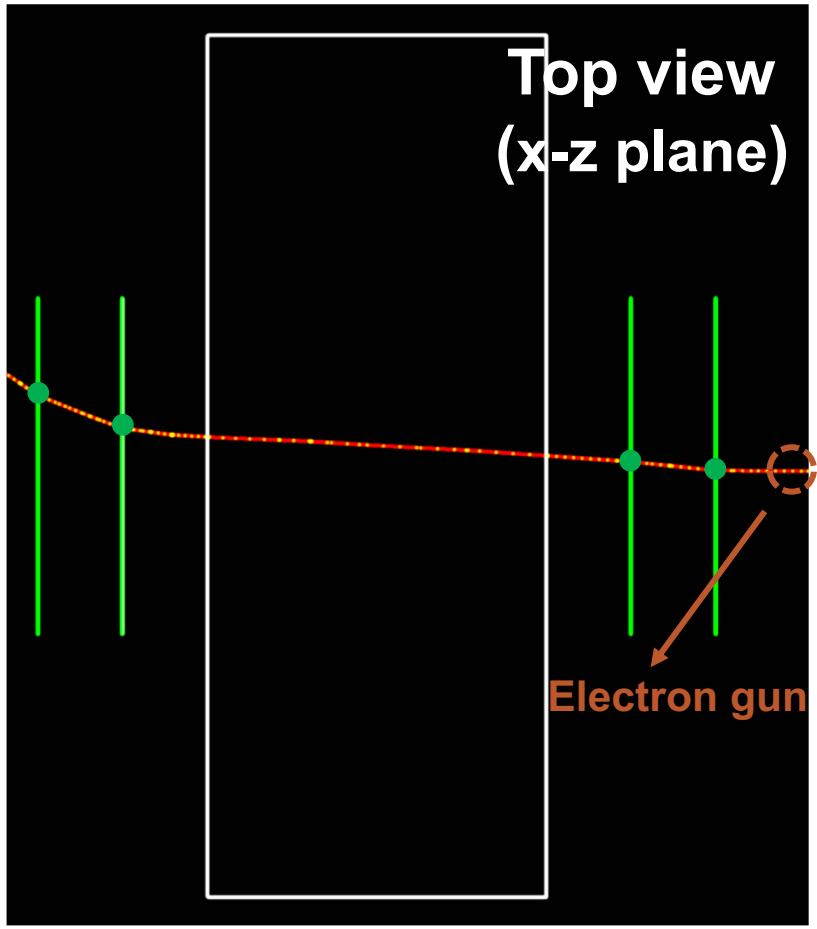


GEANT4 Simulation Studies – Event display

Electron gun sample (1.5 MeV), B-field magnitude : 0.2 T

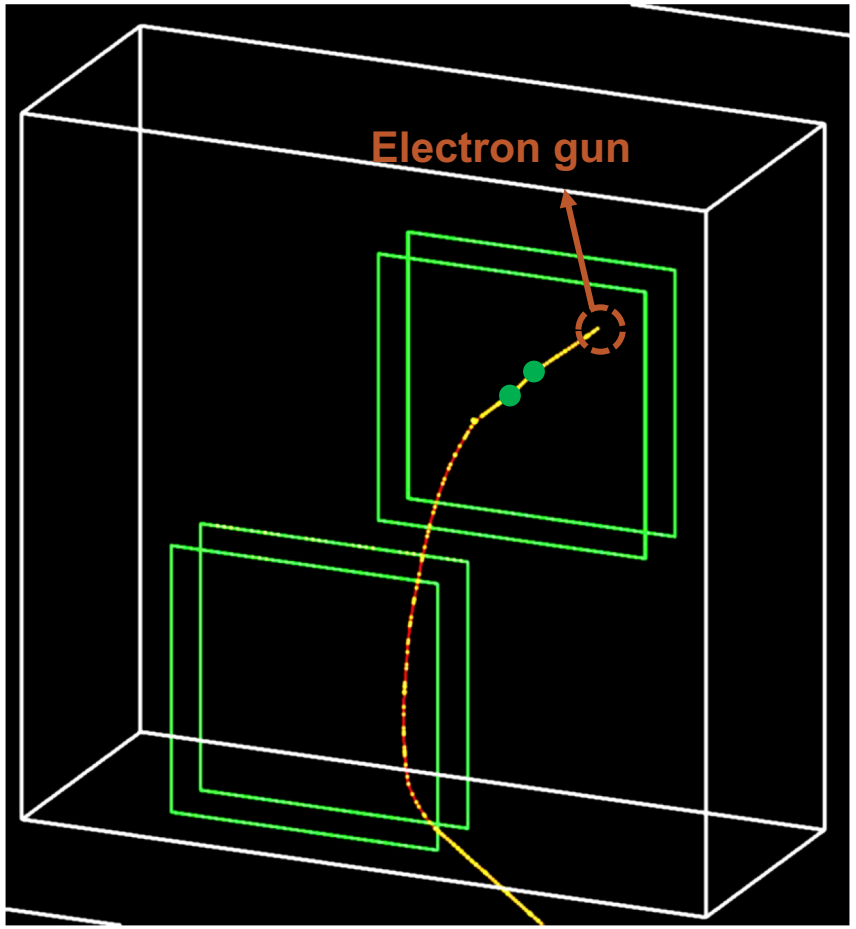


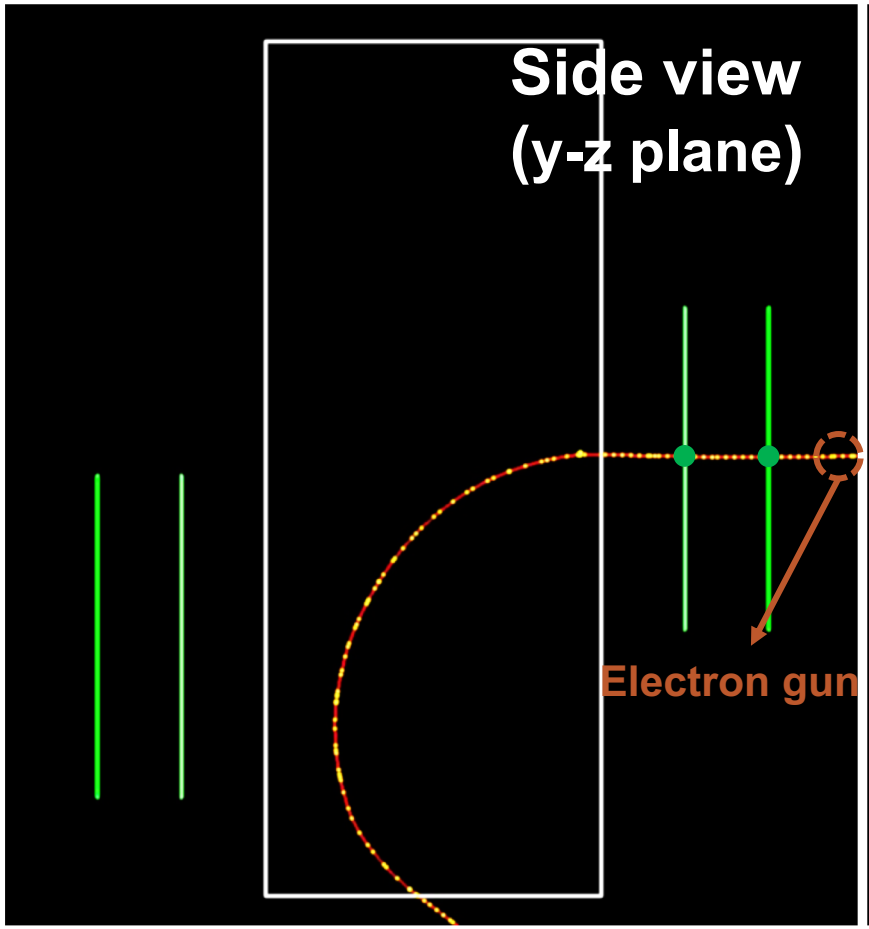


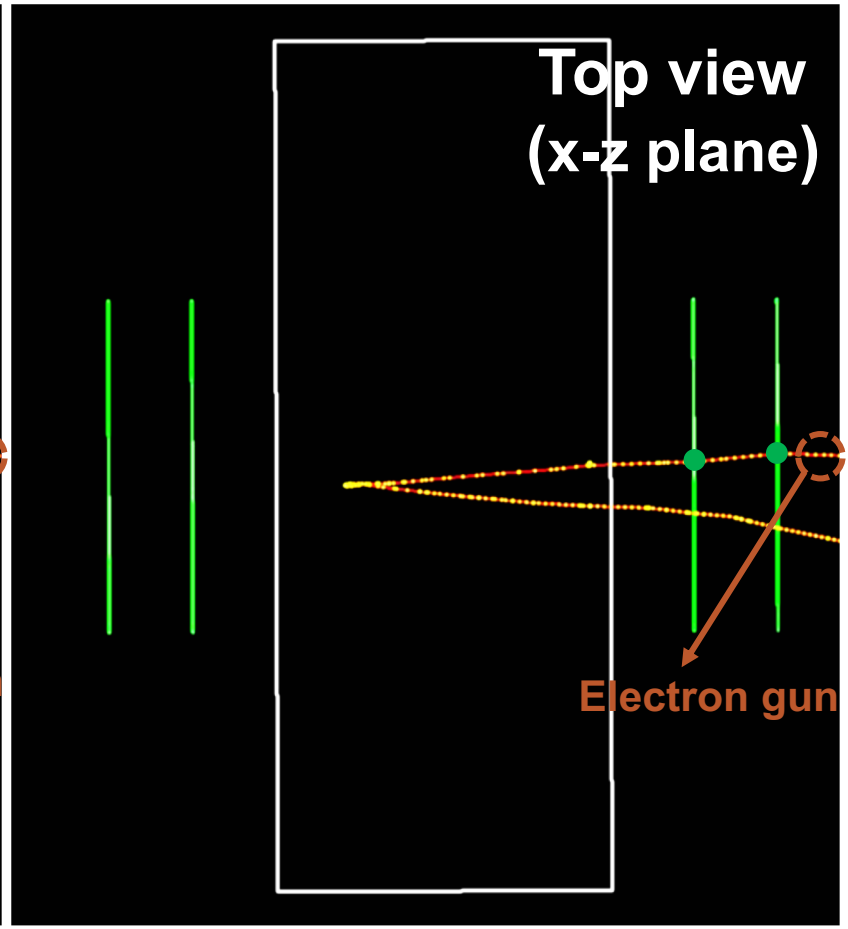


GEANT4 Simulation Studies – Event display

Electron gun sample (1.0 MeV), B-field magnitude : 0.2 T





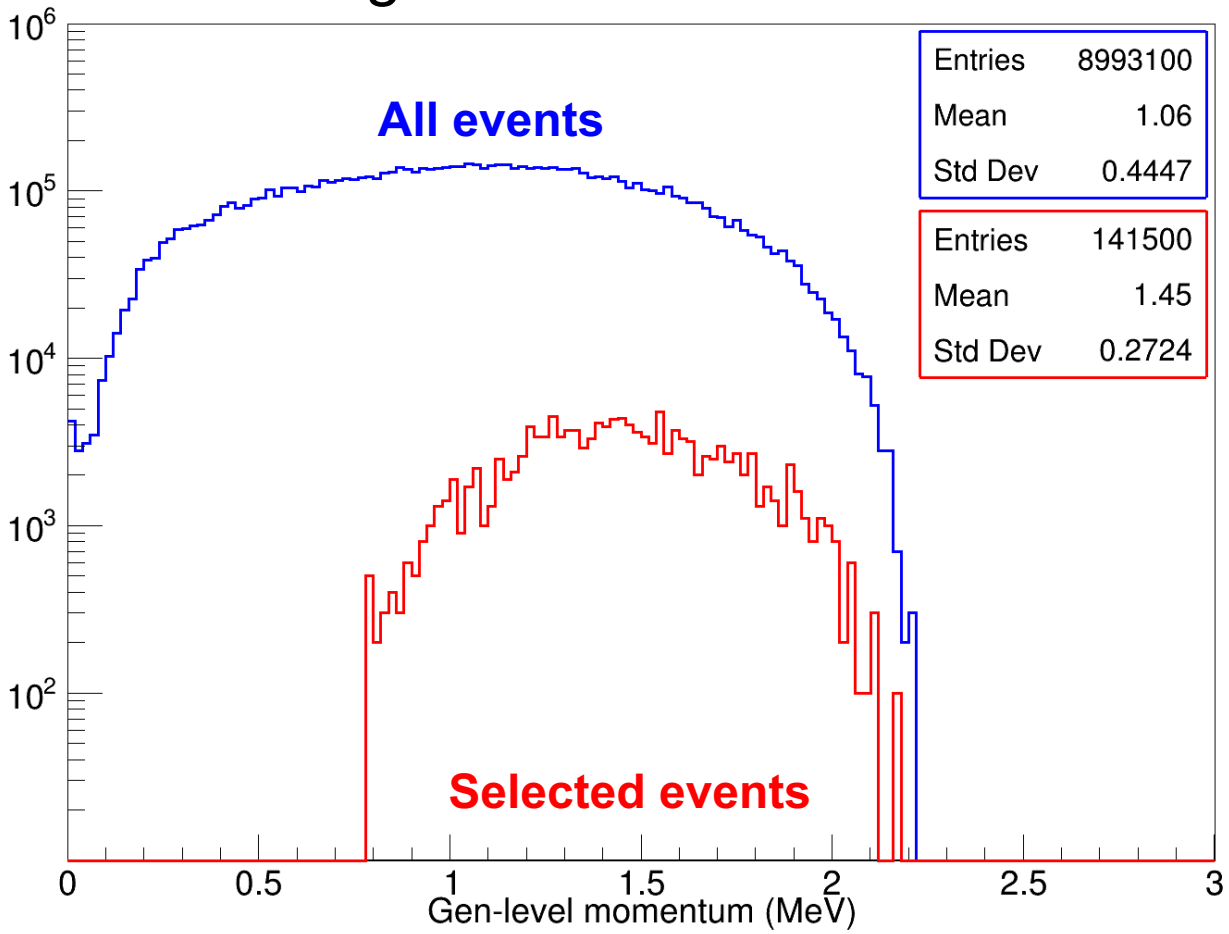


Shape comparison of momentum distributions

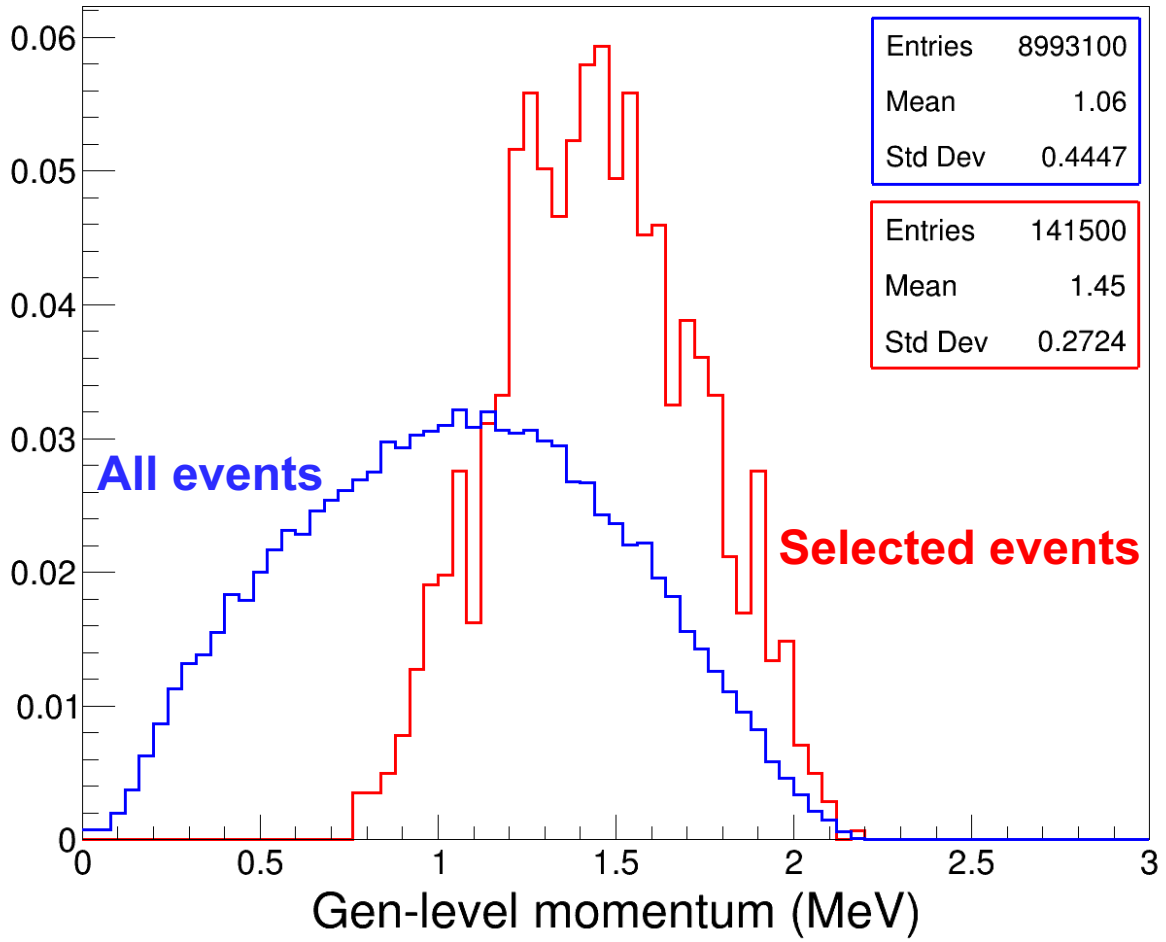
Sr-90 source sample

- Blue: All electron events from Strontium-90 source
- Red: Selected events requiring at least one hit on each pixel layer

Log scale distribution



Normalized distribution



Reconstructed momentum distributions – landau fits