Mu2e : Tracker & Calorimeter Study in MARS

(with focus on geometry and simulation)

Christina Ann Nelson
Fermilab 16409N
August 6, 2014

University of Hawai'i Mānoa

Outline

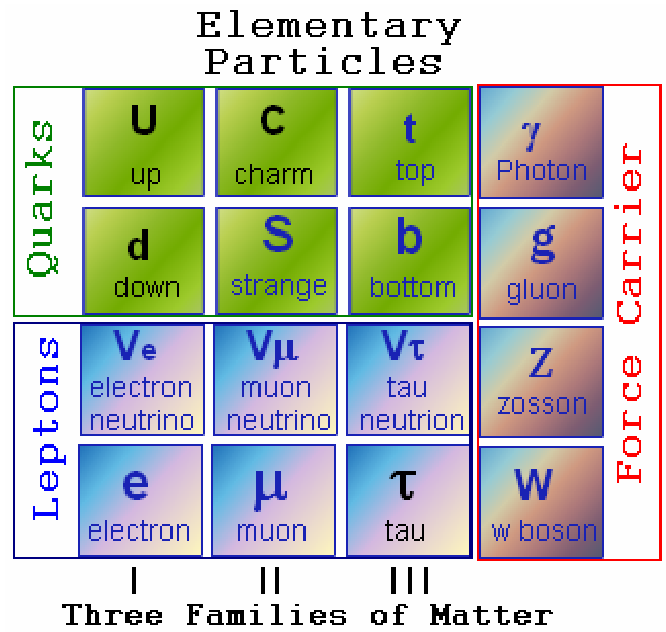
- Mu2e overview (brief)
- Building tracker for MARS model
- Building calorimeter for MARS model
- Implementation in MARS
- Energy Limits
- Dose rates
- Conclusion

Intro Brief

- $\mu^- N \rightarrow e^- N$
- Rate $\propto (\Delta m_{ij}/M_W)^4$
- Standard Model

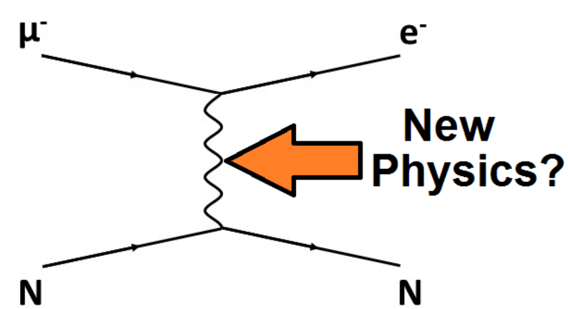
$$\mathcal{B}(\mu \rightarrow e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{i1}}{M^2_W}\right|^2 \sim 10^{-54},$$

- (Marciano et al. 2008)



- CLFV is not predicted in the SM
- Theories such as SUSY, Heavy neutrino, double Higgs etc…predict CLFV to happen at a rate of 10^{-17}.

  Observation of CLFV would be a clear sign of NP



What Mu2e will measure:

- $\boldsymbol{R}_{\mu e} = \Gamma(\mu^- + (\boldsymbol{A}, \boldsymbol{Z}) \rightarrow e^- + (\boldsymbol{A}, \boldsymbol{Z})) \ / \ \Gamma(\mu^- + (\boldsymbol{A}, \boldsymbol{Z}) \rightarrow \mu + (\boldsymbol{A}, \boldsymbol{Z} - 1))$

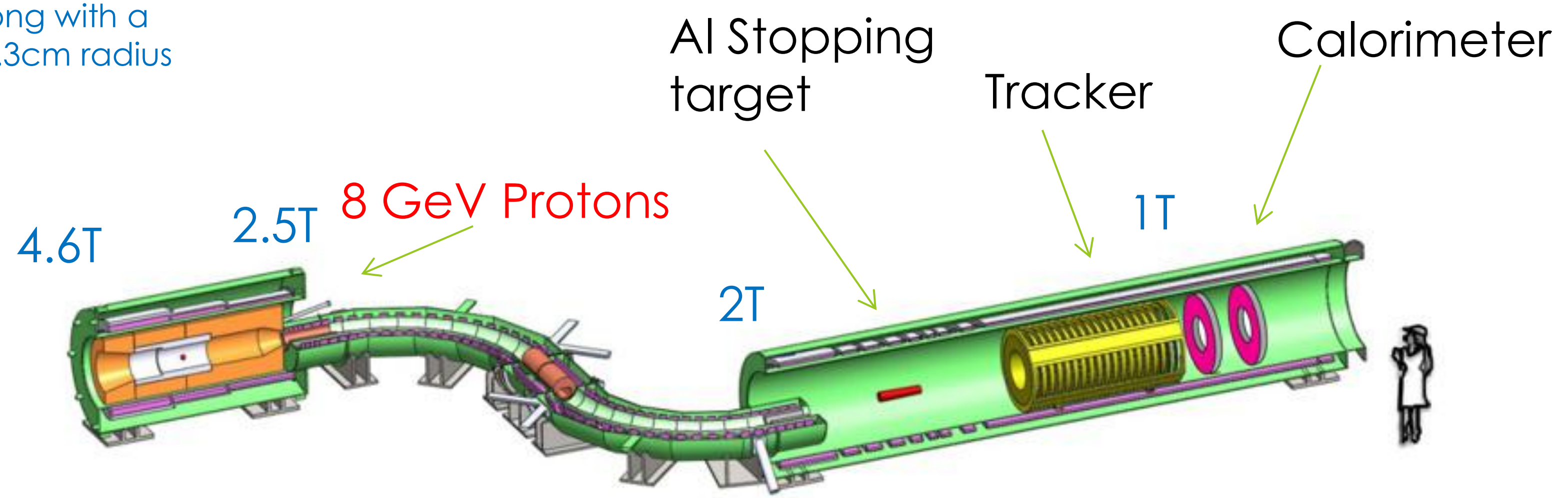
- **Ratio of muon to electron conversions to the number of muon captures by the Al nuclei**

- Goal : $\boldsymbol{R}_{\mu e} < 6$ e-17 *limit at 90% CL*
- *For Al target:* $E_e = 104.96$ *MeV*

Experimental set up

Muons stop on Al target, creating backgrounds

Tungsten target rod is 16cm long with a 0.3cm radius



<u>Production Solenoid</u>

Produces, collects, & Transports particles

<u>Transport Solenoid</u>

Design selects negative particles, collimator selects desired momenta particles

<u>Detector Solenoid</u>

Uniform magnetic field of 1 Tesla through DS

Some Dominant Background sources of focus

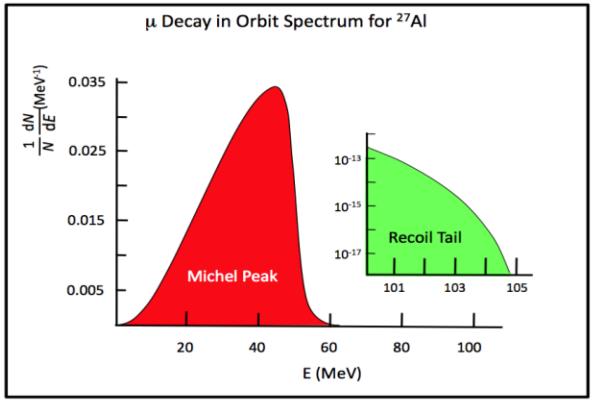
- Muons after hitting the Al stopping target produce muonic atoms that:
- 1.) Decay in orbit (DIO)
  via the weak interaction

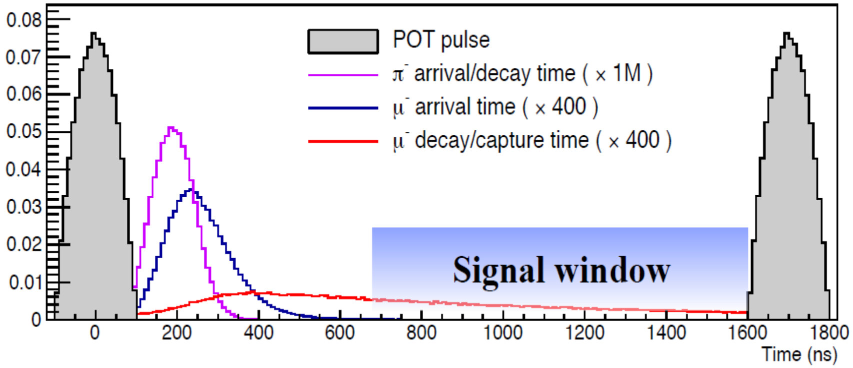
  $$\mu^- \rightarrow e^- \bar{\nu}_e \nu_\mu$$

- 2.) Radiative Muon capture (RMC)
  and undergo nuclear breakup

  $$\mu^- N \rightarrow \gamma \nu N'$$

- 3.) Decay in Flight (DIF) from the beam flash this is mitigated by setting up time working window





Building of the Tracker & calorimeter in MARS

- Developed code in **root** for geometry

1.) toy MARS model to study single particles, 2.) full MARS model to study full simulation run

to investigate if the inner radius of 380 mm is positioned to ignore electrons with less than the conversion energy

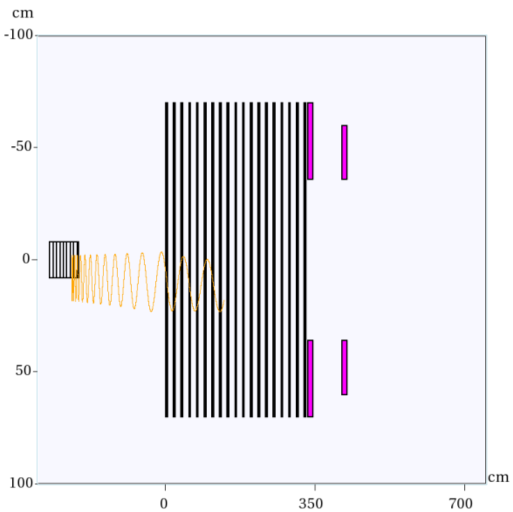
- Study B field to implement in toy model

to prove input in MARS from B field map is uniform of 1 Tesla through out the tracker and calorimeter.

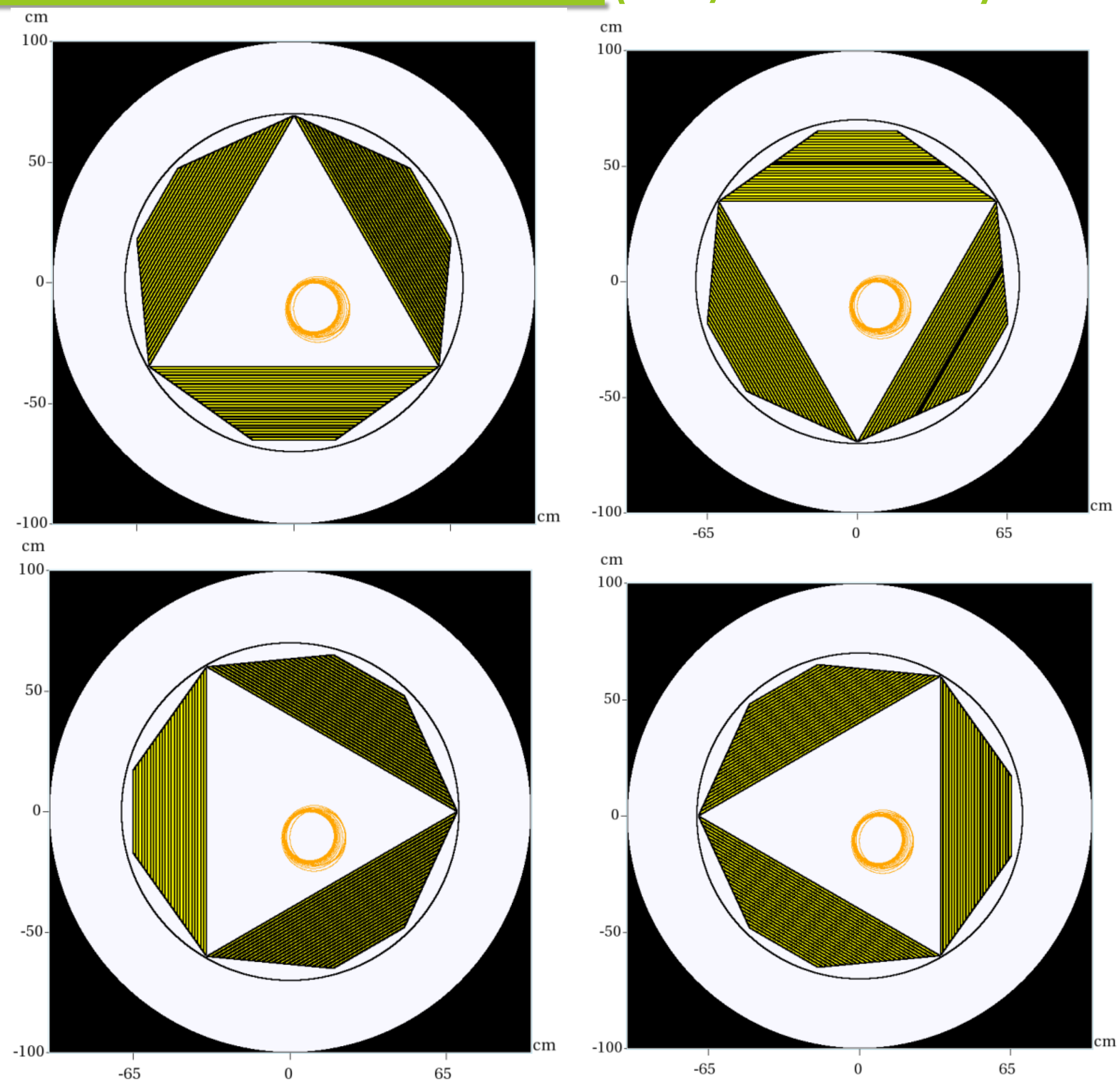
- Inputted materials in MARS by calculating density fractions from material composition
  materials need to detect conversion electron & must be durable at least for 3 years of experiment running time.

MARS model Tracker (toy model)

44 MeV electron

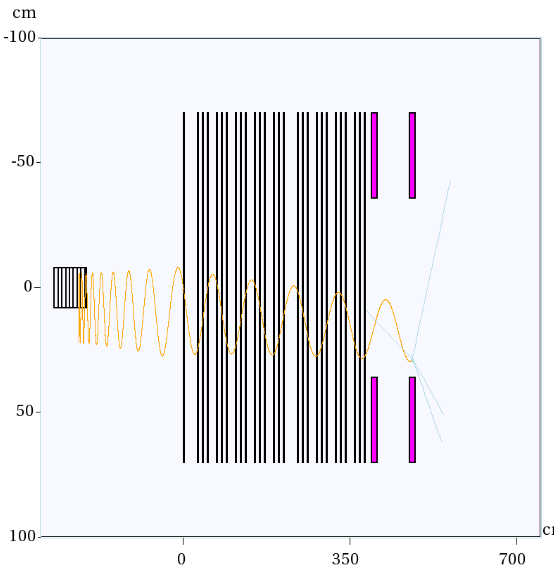


The electron does not interact with tracker or calorimeter

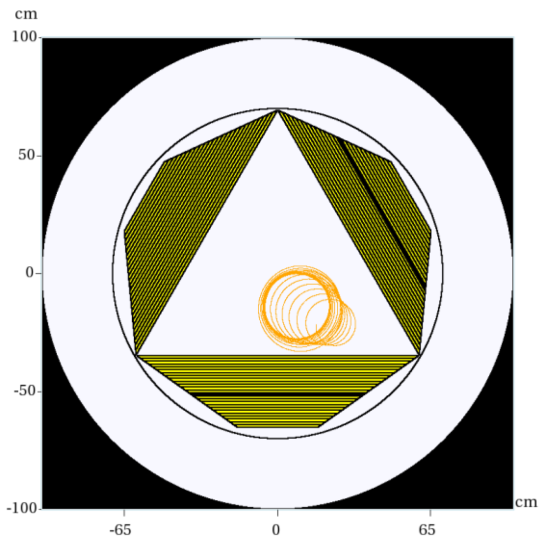


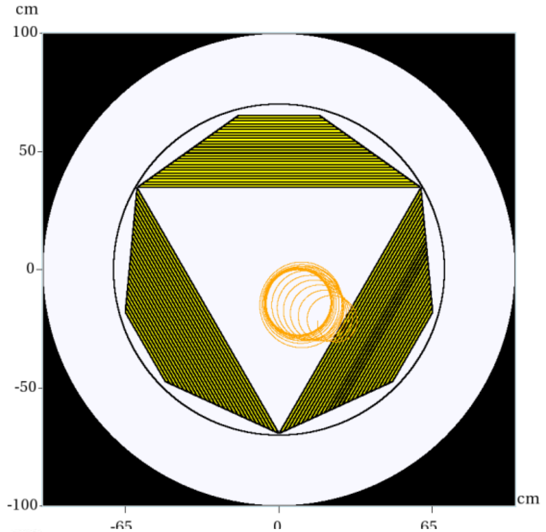
MARS model tracker (toy model)

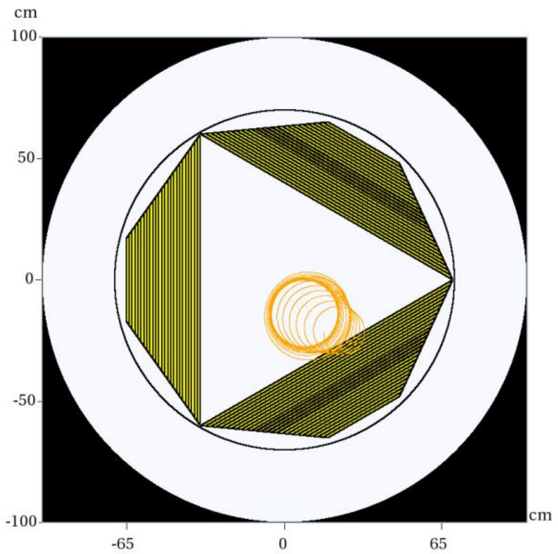
60 MeV electron

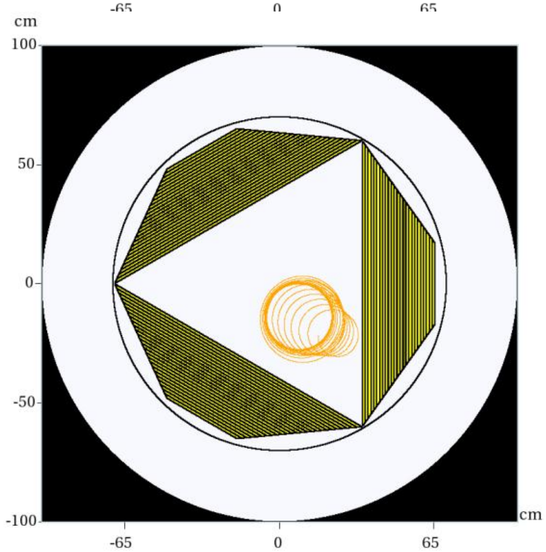


The 60 MeV electron ejects a photon as it reaches second calorimeter, undergoing possibly RMC



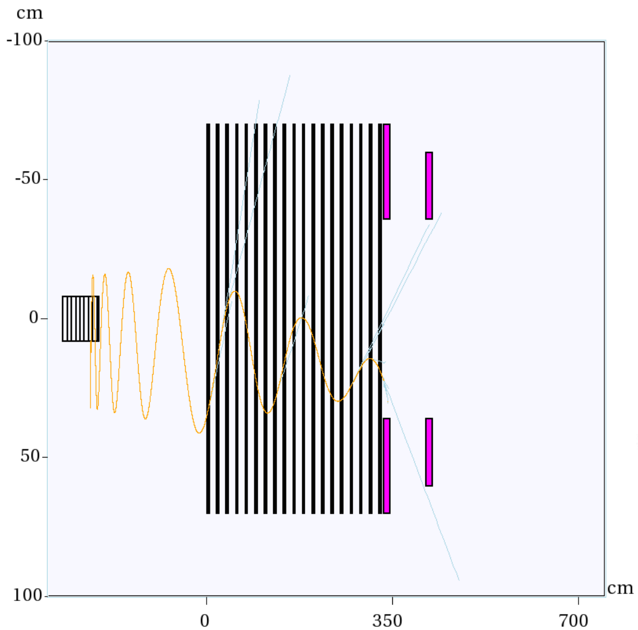


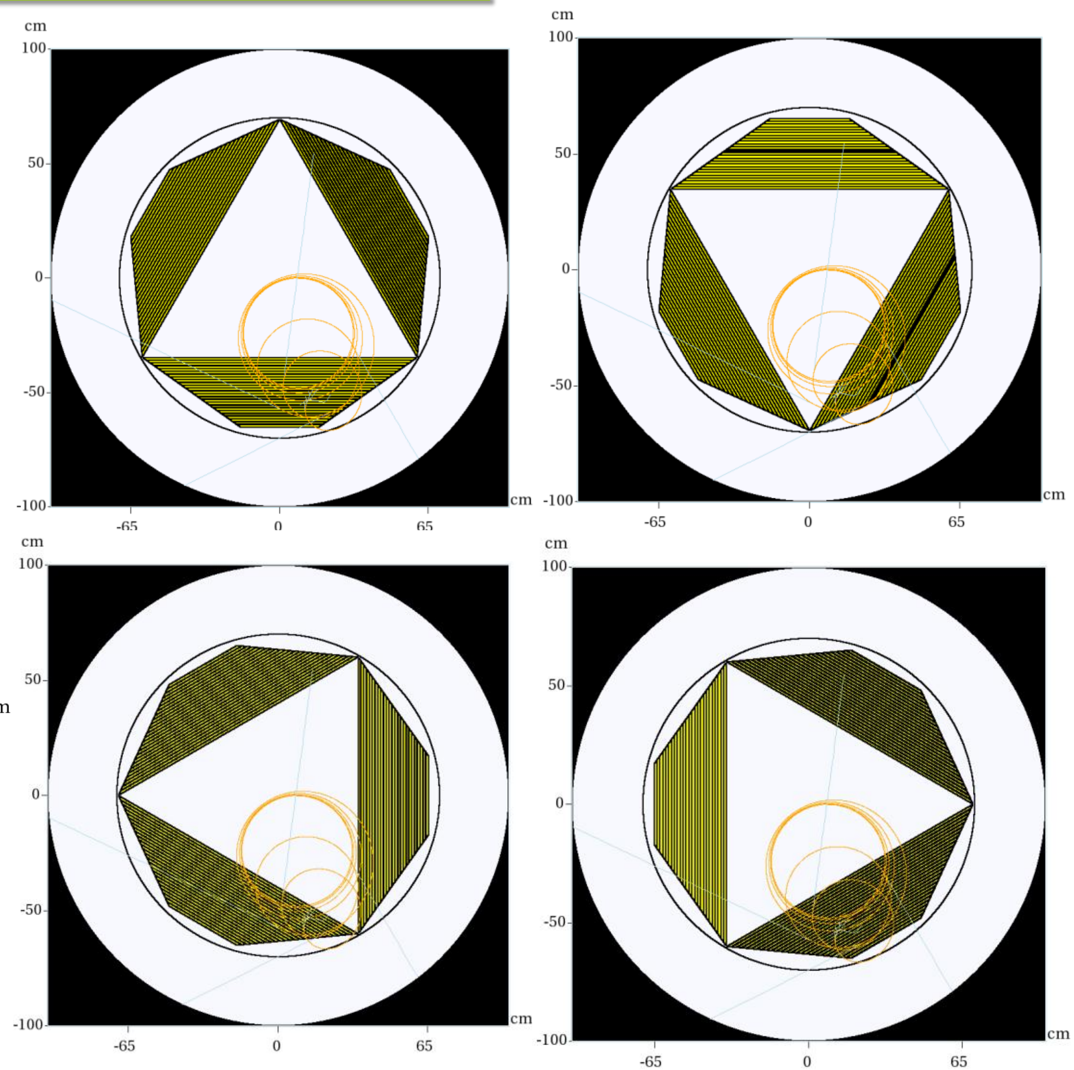




MARS model tracker (toy model)

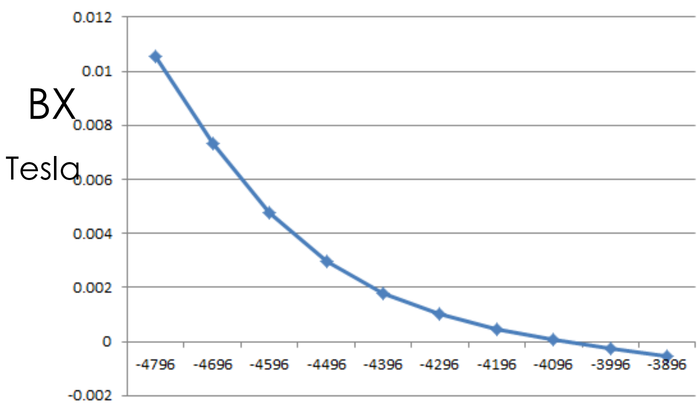
105 MeV electron



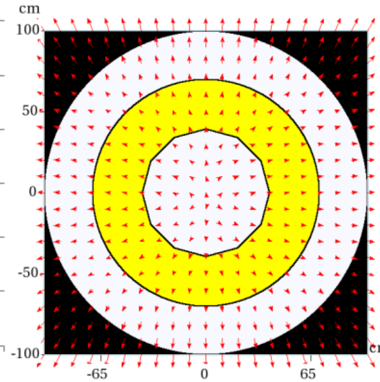


The 105 MeV electron intersects many times directly with the tracker releasing 4 photons that release beyond the tracker and one that initializes a shower in the tracker panel.

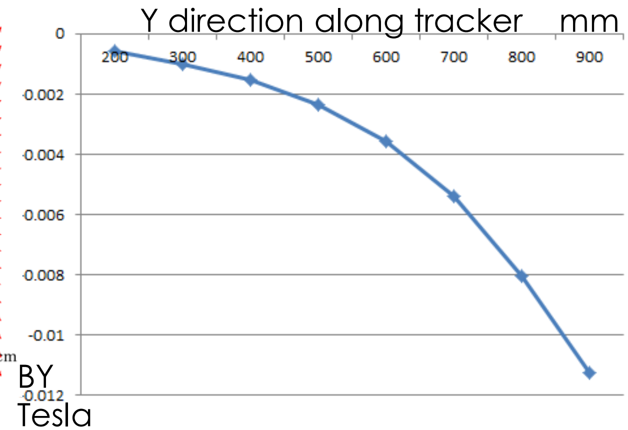
Magnetic field study in MARS

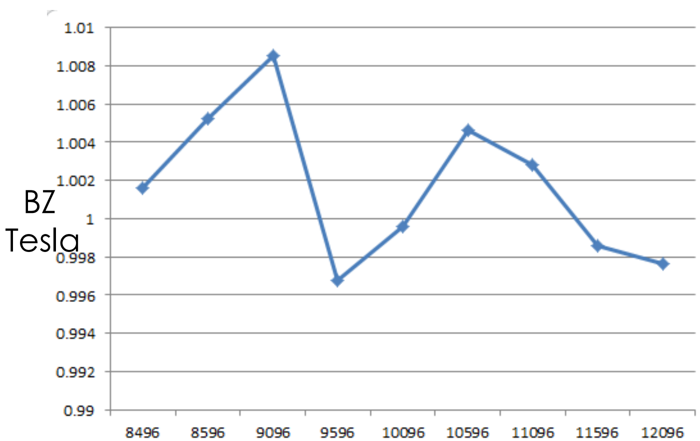


X direction along tracker mm



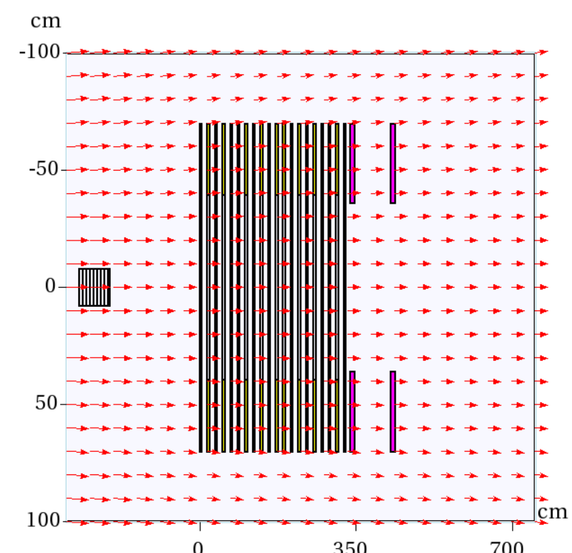
XY direction of tracker MARS model





Z direction along tracker mm

B field studied from field map in MARS, notice X & Y fields begin to diverge as moving out on the radius. And there are some non linear observations in the Z direction. The oscillation is on order .005 T above and below 1T.



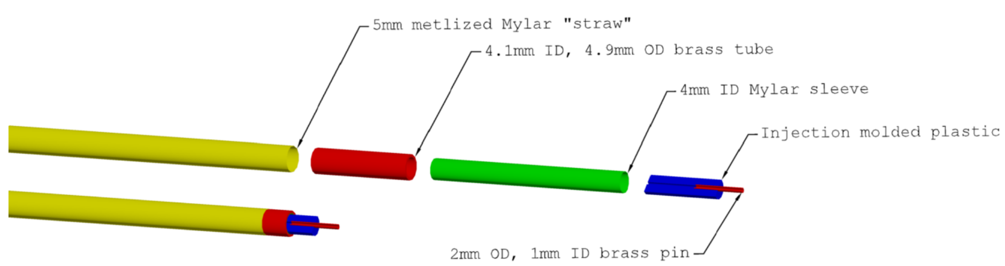
YZ direction of Stopping target, Tracker, & Calorimeter in MARS model

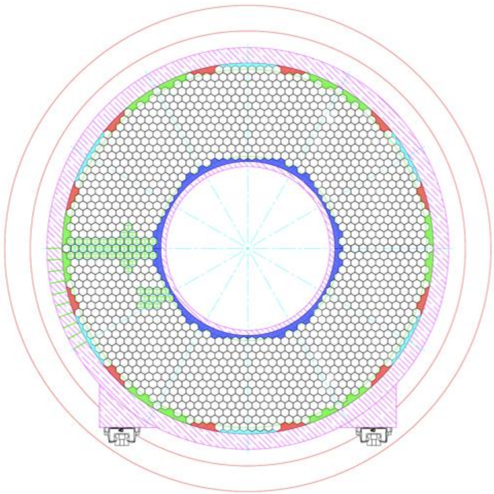
Material input in MARS model for mars tracker & calorimeter

- MARS tracker: Low density 6 μm Mylar (2 layers), and other materials such as sense wire, etc… The heaviest elements are the drift gas: Argon & $C0_2$ (80 : 20)

- LYSO: lutetium-yttrium oxyorthosilicate

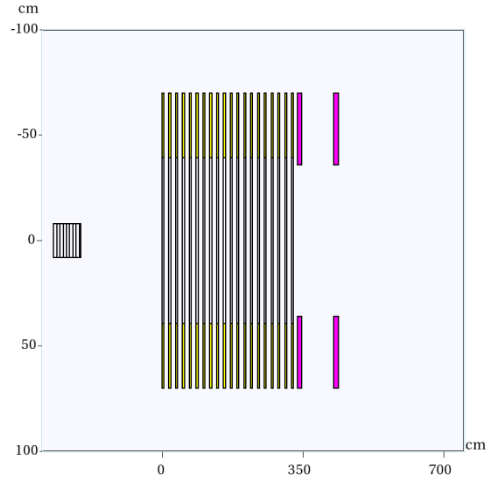
- Needs to withstand beam over 3 year period

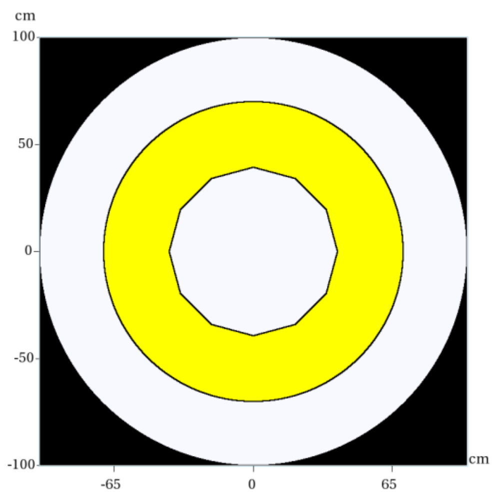


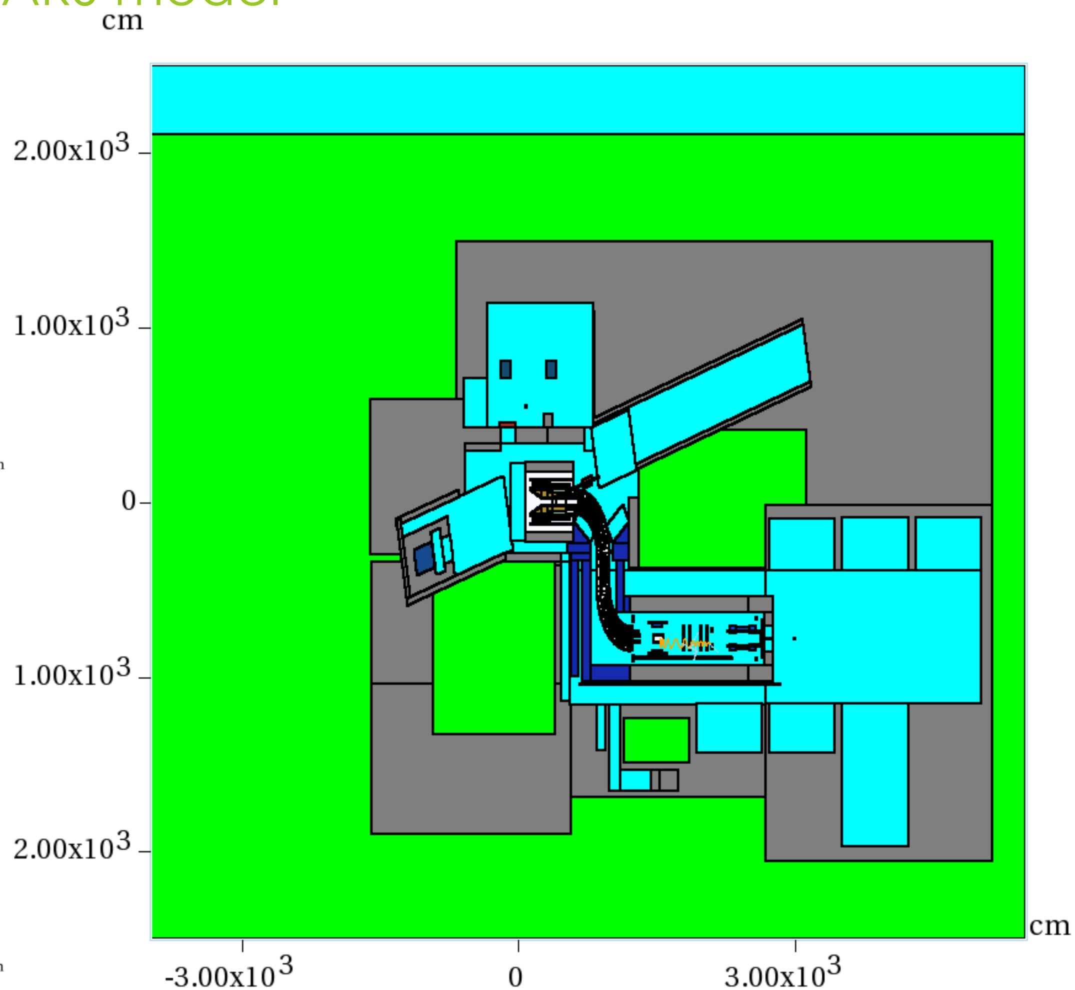


Tracker & Calorimeter

implemented in MARS model







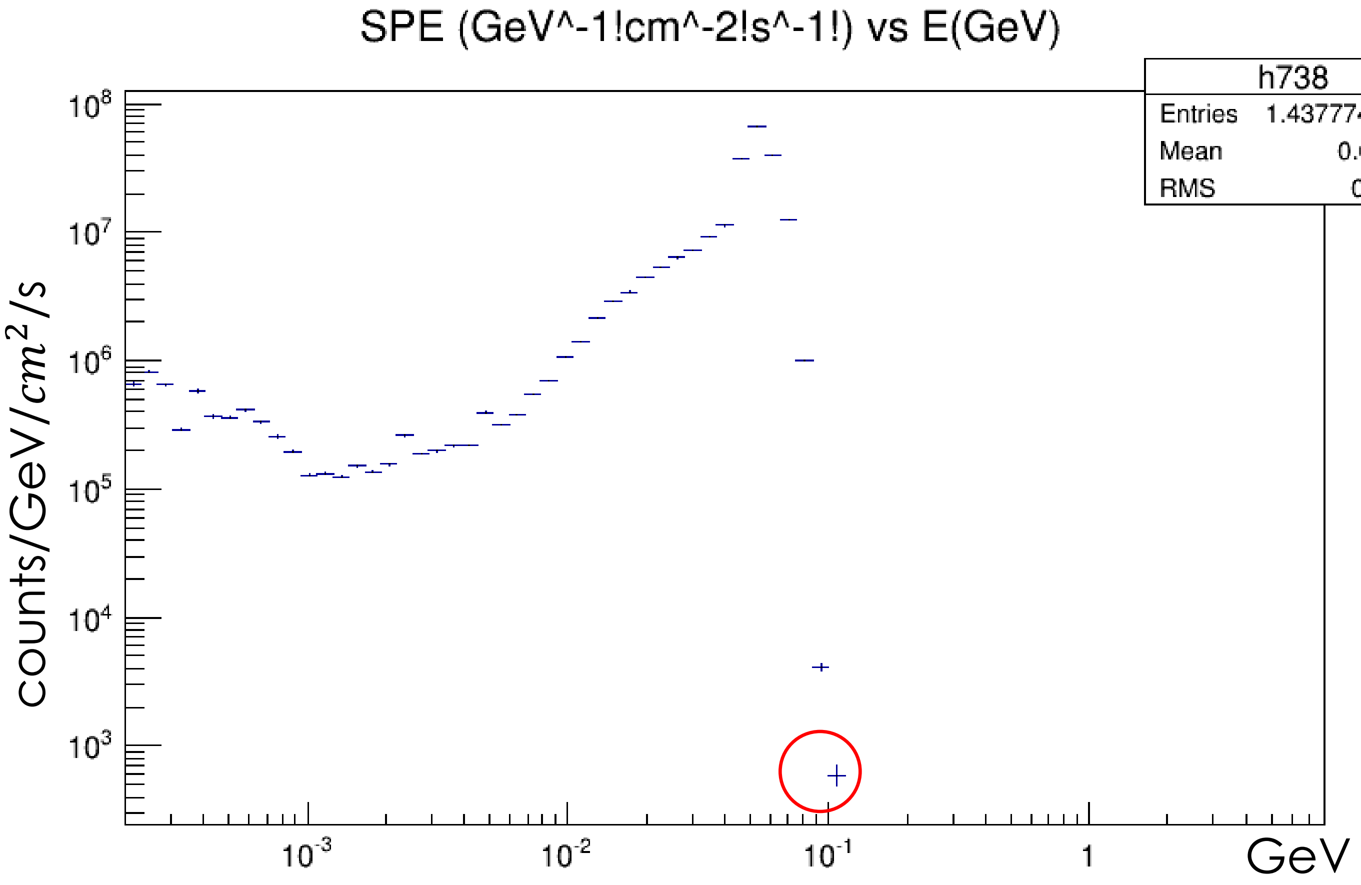
Full Simulation of models developed in MARS

- 1000 events / job
- 2500 jobs at Fermigrid
- Total protons on target (POT) = $2.5 * 10^6$

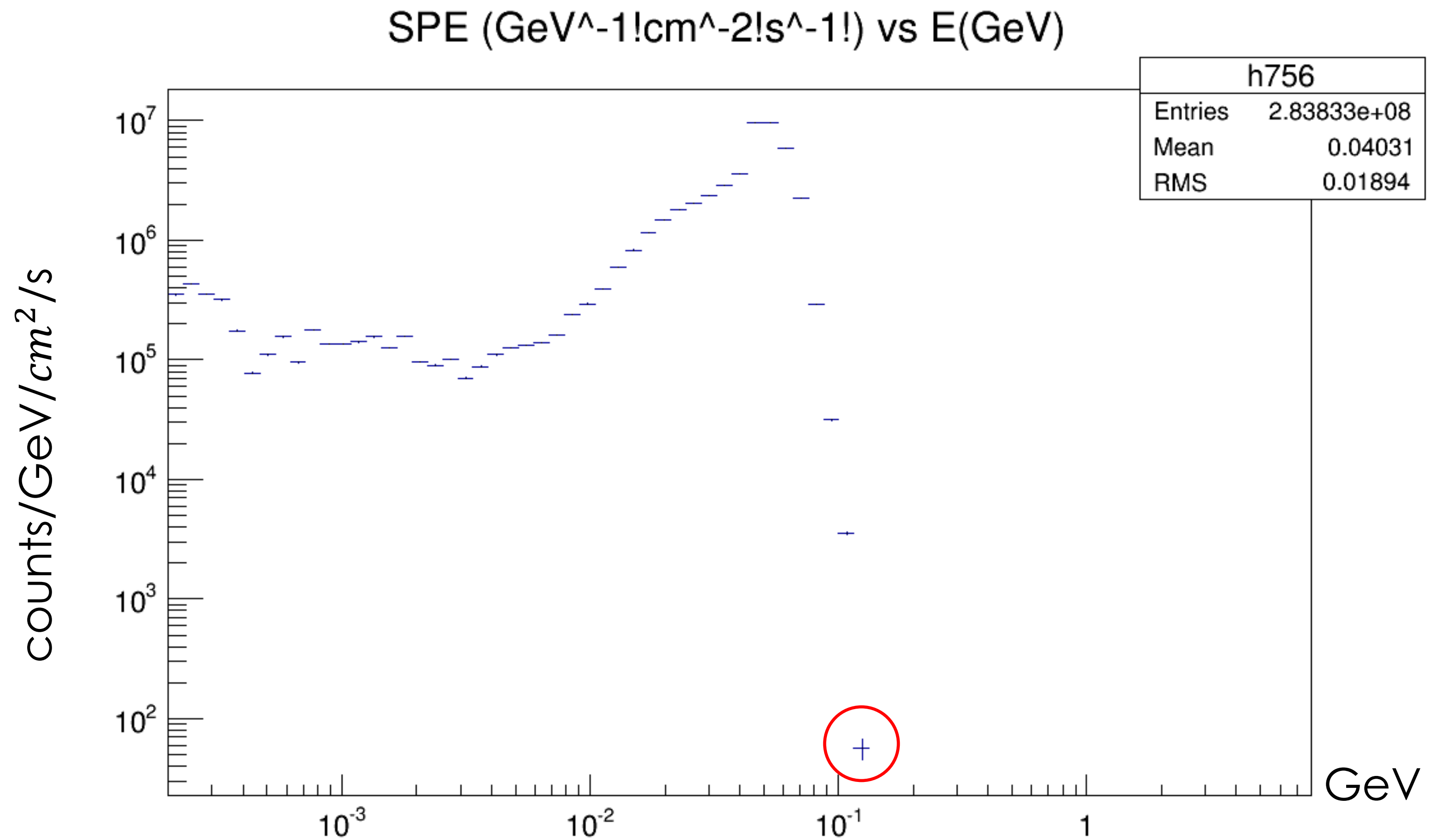
- Note that Mu2e experiment needs
  POT = $3.6 * 10^{20}$

(more study will need to be done in MARS)

Results from MARS simulation with the code I produced

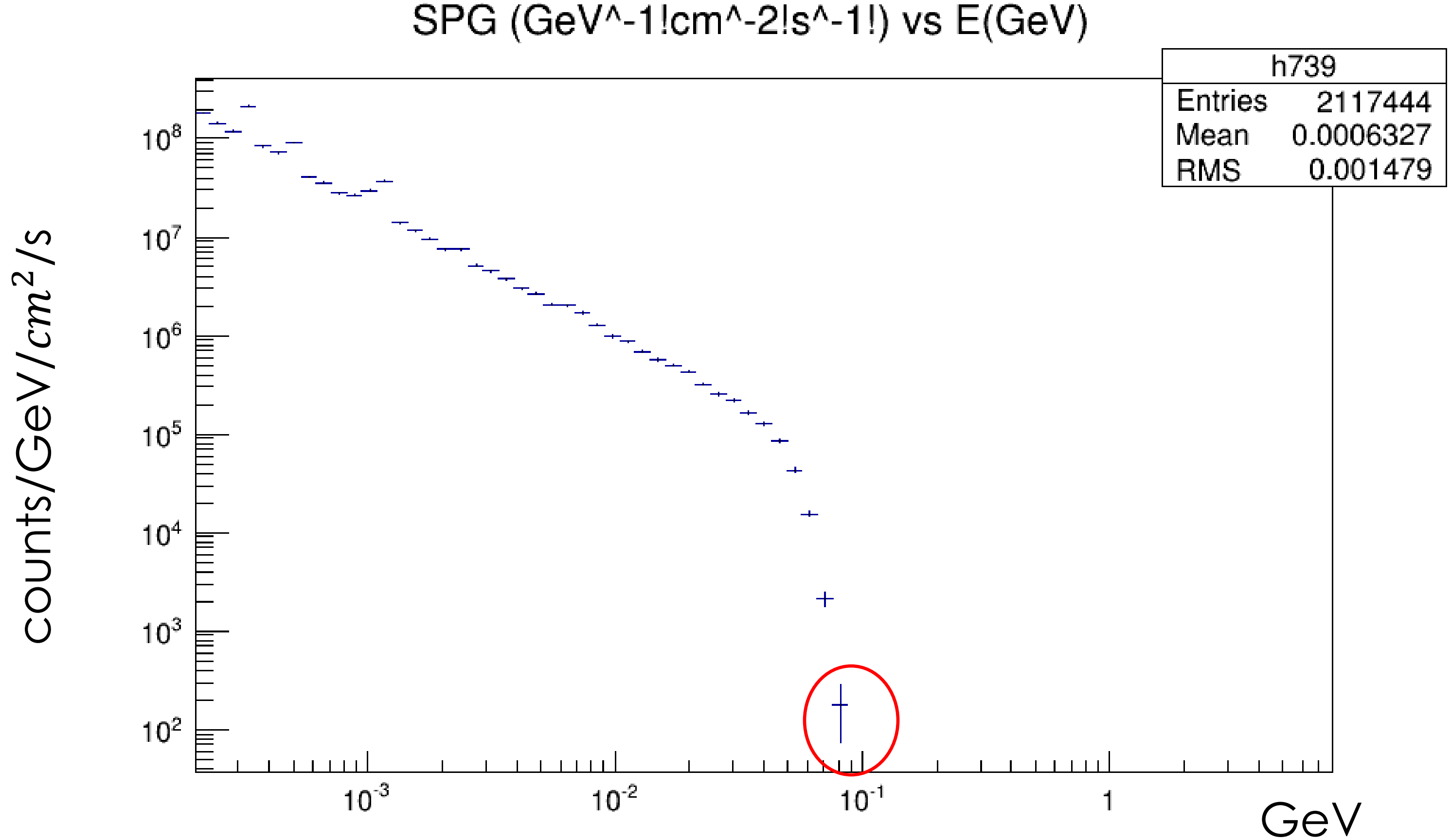


Energy Limit for an electron before entering tracker:
107.6 MeV, 587.9 particles
This is DIO background



Energy Limit for electron between tracker and calorimeter (after calorimeter, essentially the reading is the same) :
123.9 MeV, 56 particles.
This is due to DIF because the time window was not set up.
(cal1 = 125.23 MeV, cal2 = 125.23 MeV)

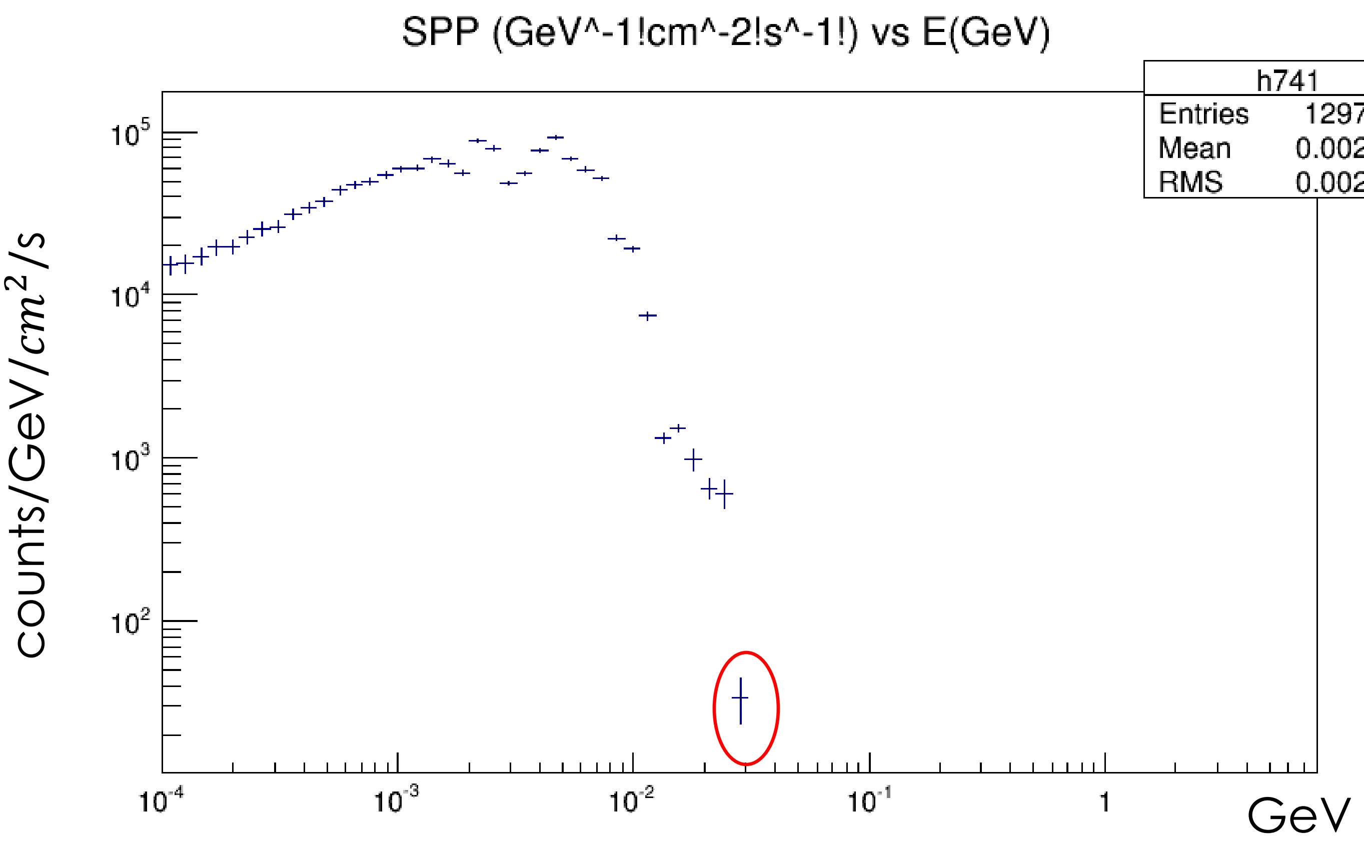
Results from MARS simulation with the code I produced



Energy limit for photon Before the entrance to the tracker

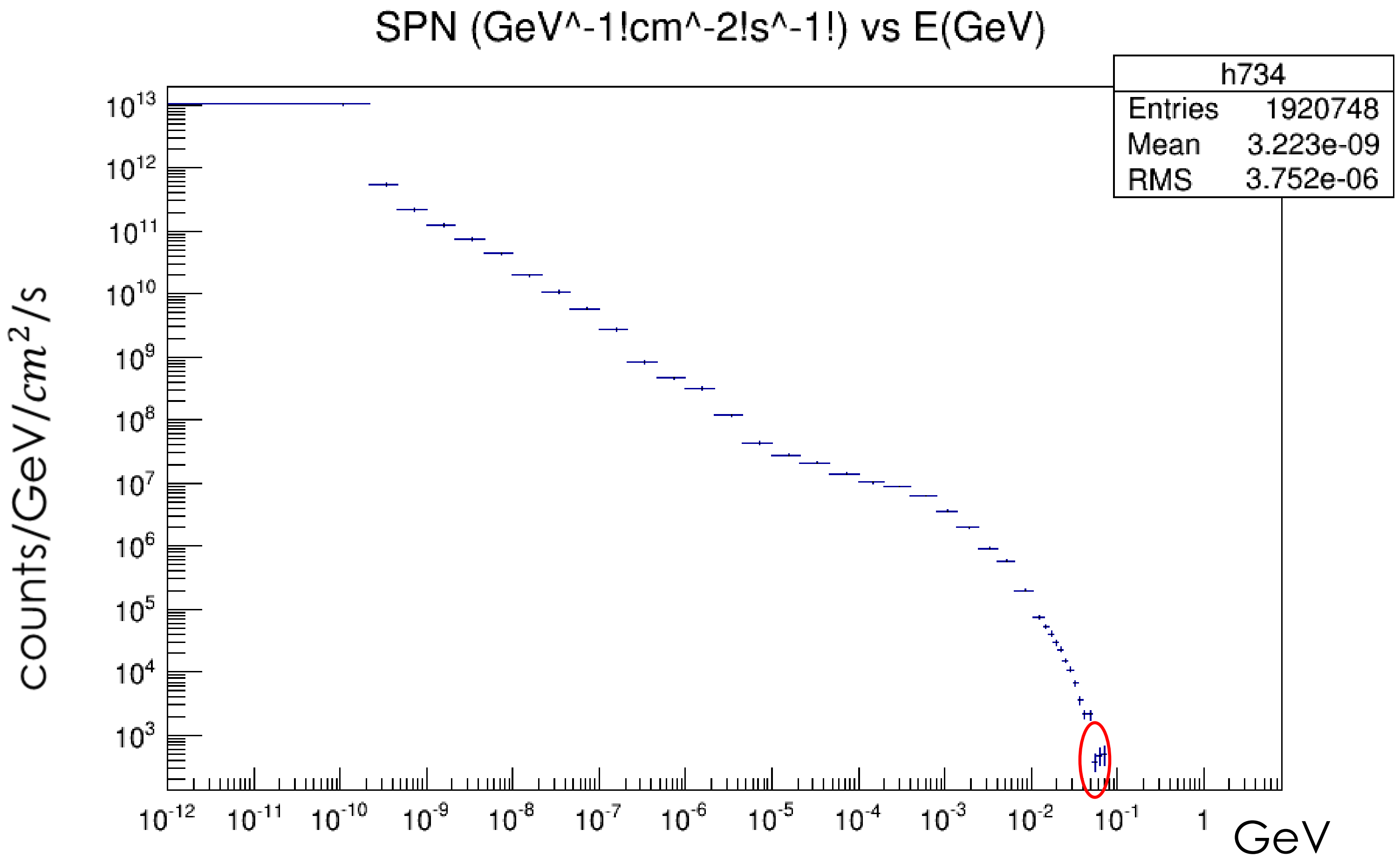
$\gamma = 82.7$ **MeV**

Results from MARS simulation with the code I produced



Energy Limit for protons Before entrance to tracker:
P = 28.9 MeV
(between tracker and cal1 = 28.8 MeV)

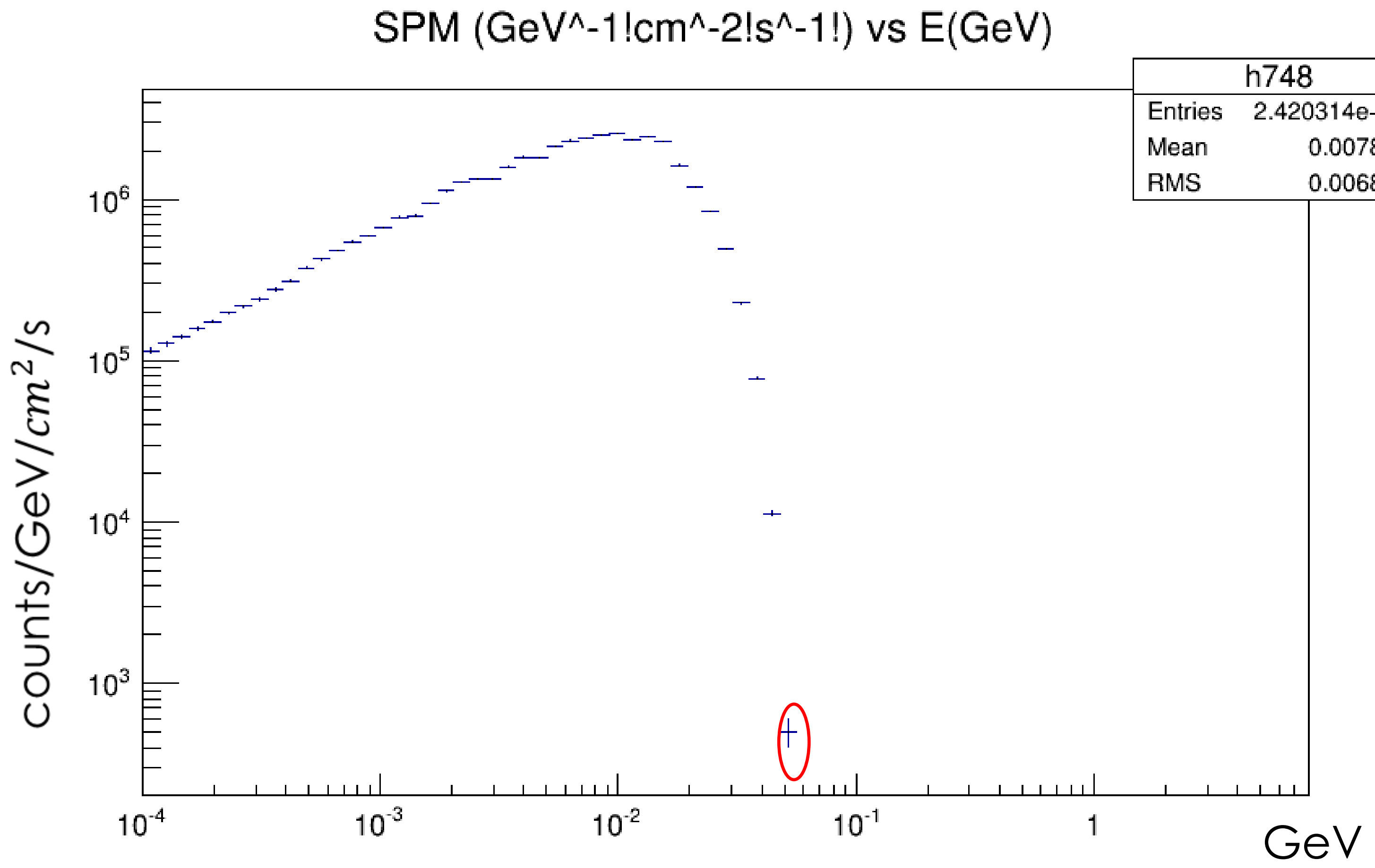
Results from MARS simulation with the code I produced



Energy Limit for neutrons Before entrance to tracker

N = 71.2 MeV (After tracker N = 71.2, After calorimeter N = 39.5 MeV)

Results from MARS simulation with the code I produced

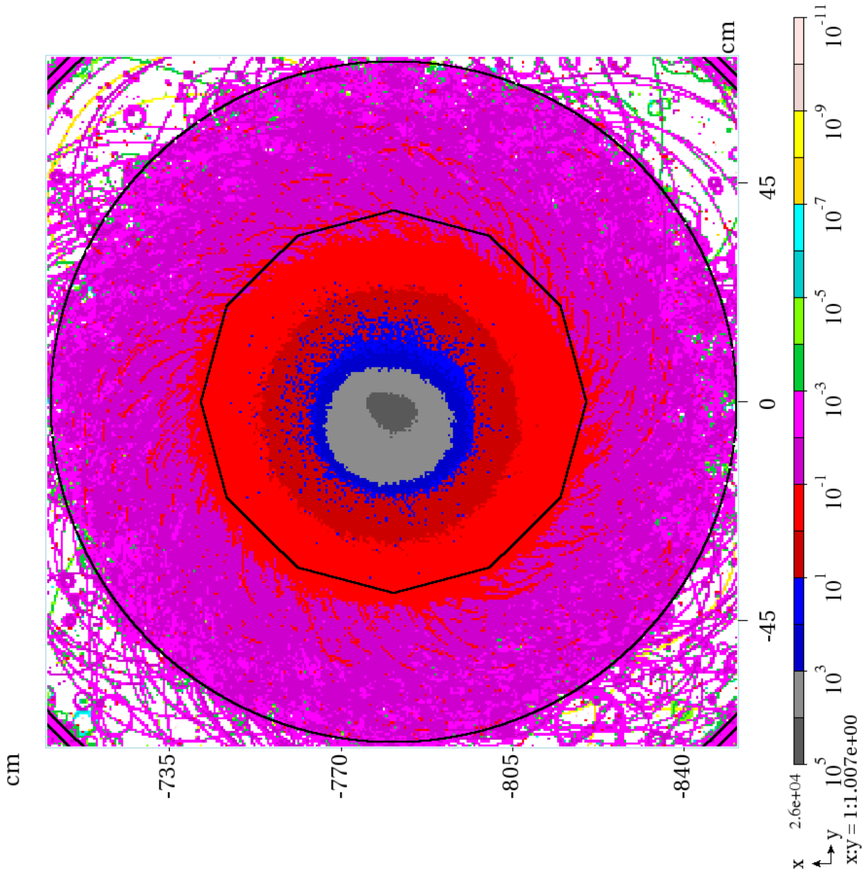


Energy Limit for muons before entering the tracker is **μ = 51.9 MeV**

Proof of Concept

- The Energy Limits found in the simulation are less than the conversion energy of 105 MeV which proves optimal for rejecting some of the backgrounds mentioned previously such as DIO, RMC, the photo electric effect, etc…

Power Deposition in Tracker: (PDT) in MARS with implemented model



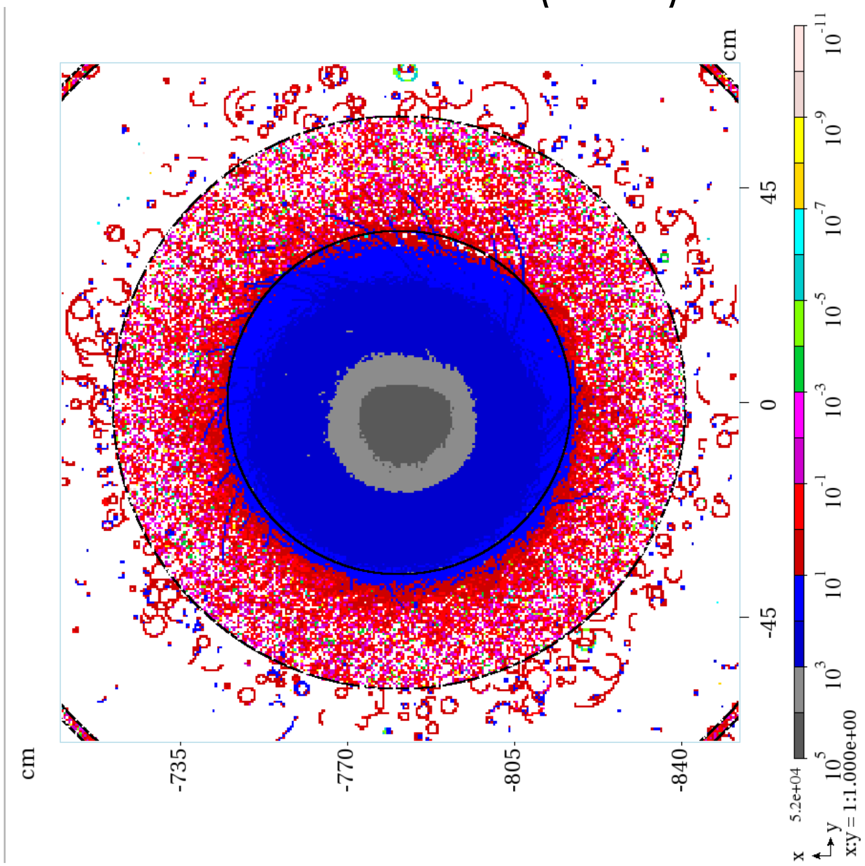
Most contribution to Power Density Total by electrons

Average rate: 3.97 kRad/yr
Peak dose: 25 kRad/yr

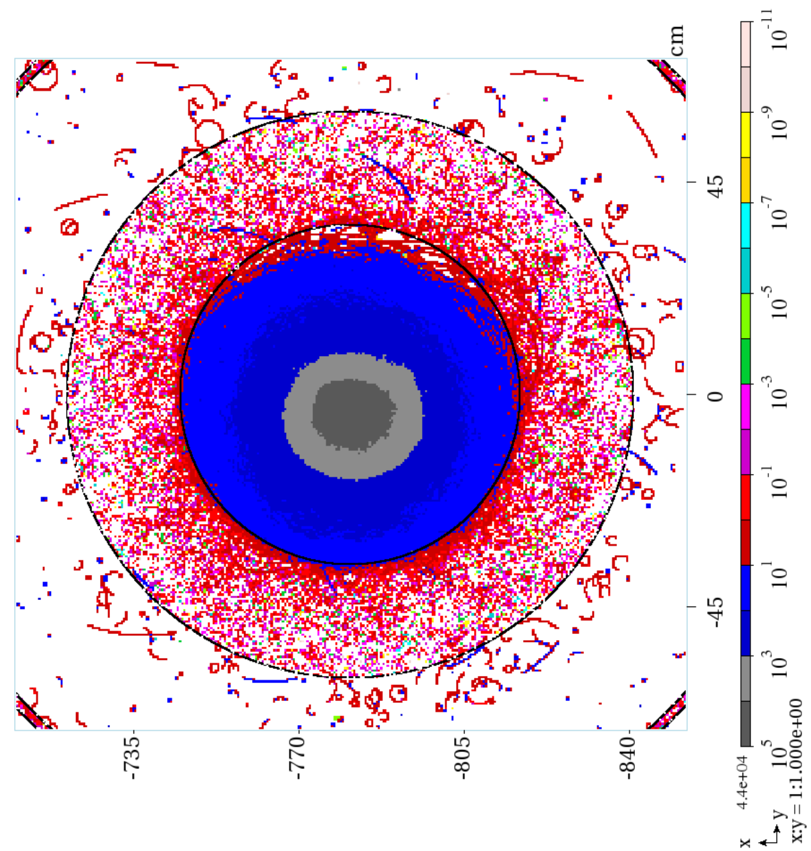
DIO and DIF(from beam flash)

Power Deposition Total (PDT) Dose in kRad / year : LYSO from MARS simulation with implemented model

Calorimeter disk1 (Front)



Calorimeter disk2 (Back)

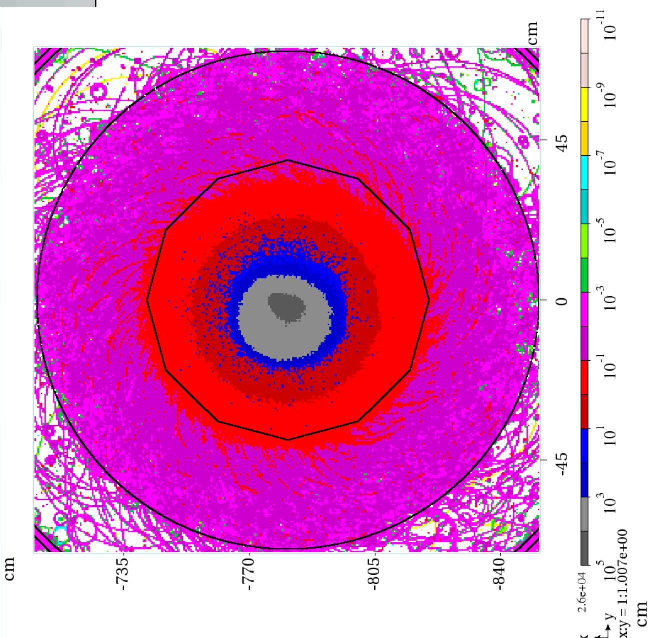


Disk1→ **average dose= 2.55 kRad/yr**
Peak dose = 22 kRad/yr

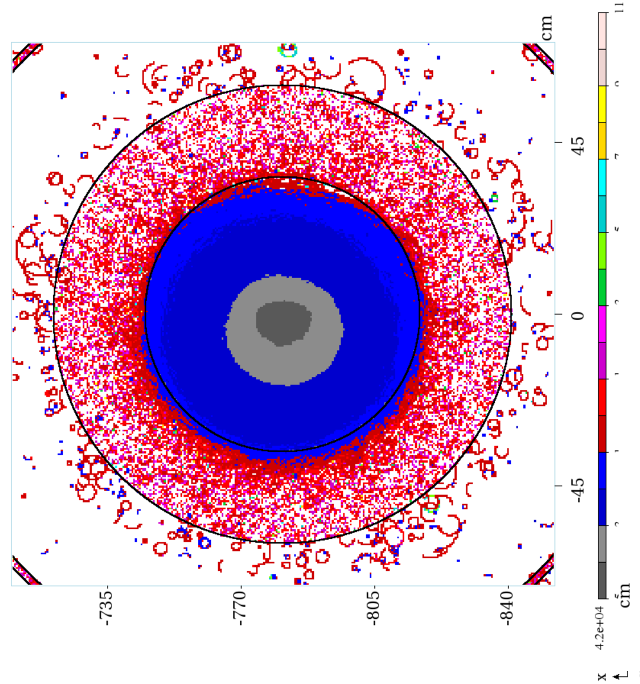
Disk2→ **average dose = 1.31 kRad/yr**
Peak dose = 18 kRad/yr

Electron Peak Dose (PDE) in MARS of implemented Tracker and Calorimeter

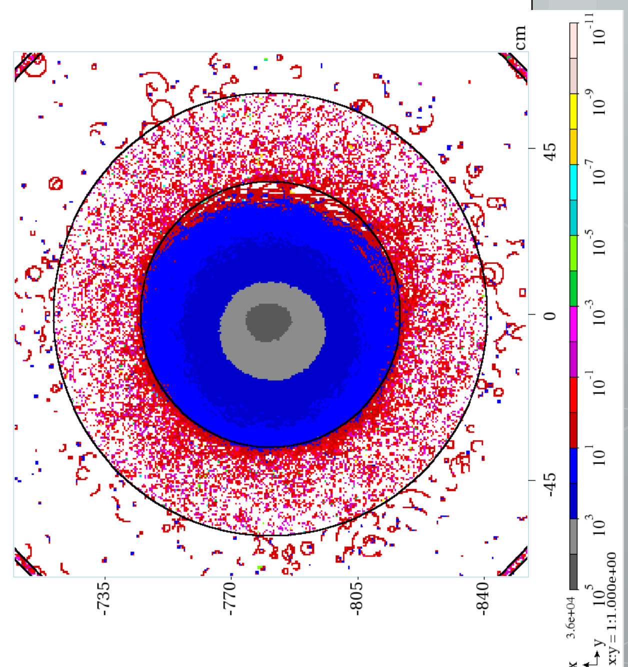
T : PDE



C1: PDE



C2: PDE



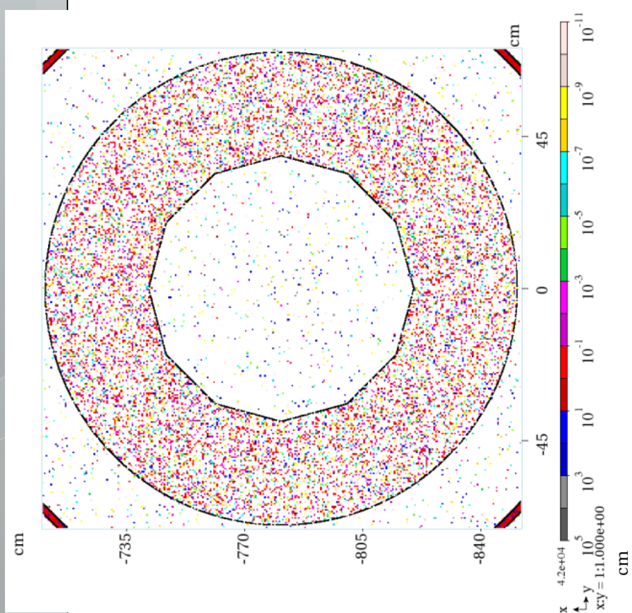
Peak Dose
T = 17 kRad/yr

Peak Dose
C1 = 15 kRad/yr

Peak Dose
C2 = 11 kRad/yr

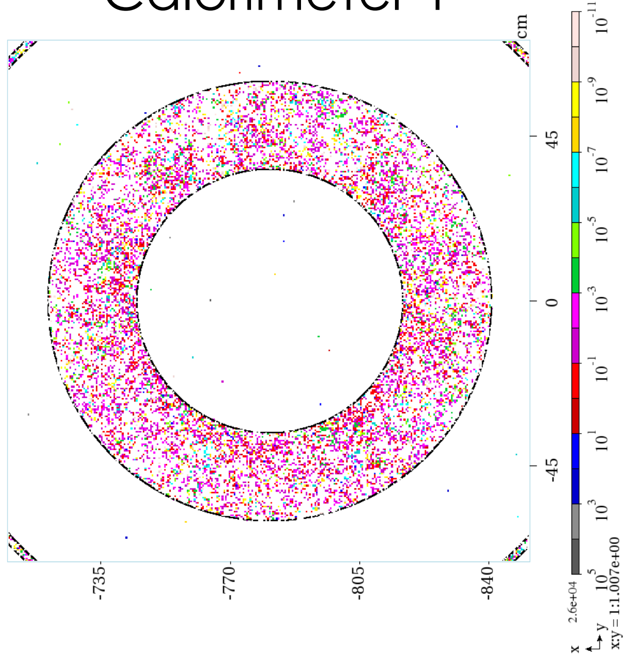
Neutron peak dose (PDN) in MARS of implemented Tracker & Calorimeter

Tracker



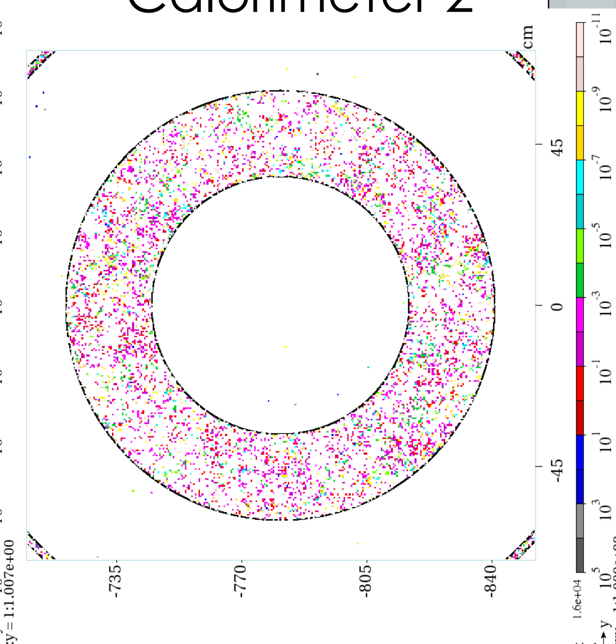
Peak dose
T = 6.3 kRad/yr

Calorimeter 1



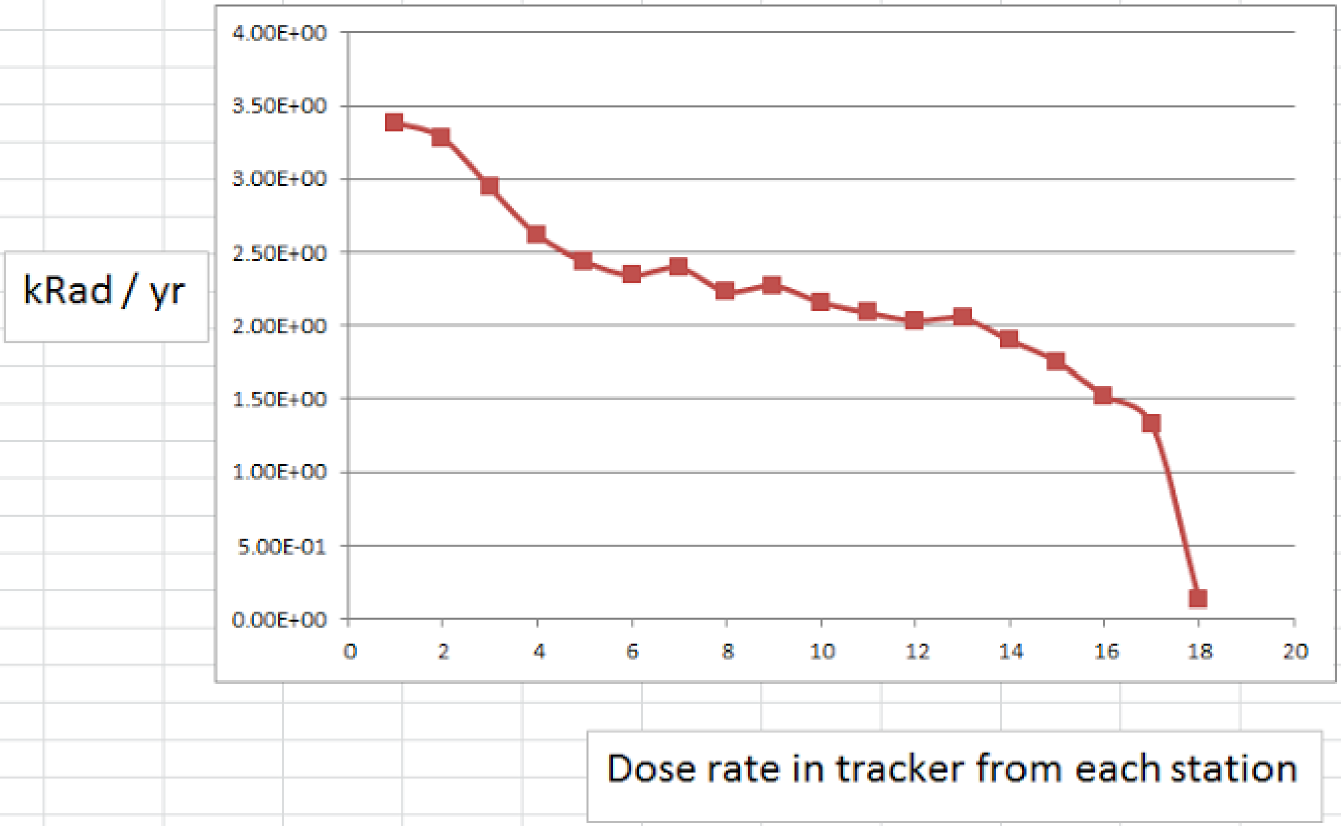
Peak dose
C1 = 4.8 kRad/yr

Calorimeter 2



Peak dose
C2 = 1.1 kRad/yr

Average PDT on each station of the tracker MARS with implemented model



Conclusion from simulation in MARS with implemented tracker & calorimeter model

Direct simulations in MARS are successfully used with the model I built of the tracker and calorimeter based upon the CDR.

The 60 MeV electrons are found to sometimes interact with the tracker and calorimeter contributing to background

The calorimeter has an average rate of **2.55 kRad/yr front** disk and **1.31kRad/yr back** disk. Comparable to study by B.Echenard and G.Pezullo average dose: **3 kRad/yr front**, **0.5 kRad/yr back**. There is a difference due to the model used.

We can see by comparing Peak Dose rate (which is a rough approximation because I used the GUI) **electrons contribute ~68% to total PDT** and **Neutrons contribute ~15.6% to PDT**.

Thank you to Vitaly Pronskih, Nikolai Mokhov, SULI, Mu2e Collaboration, & Fermilab