Signal Performance

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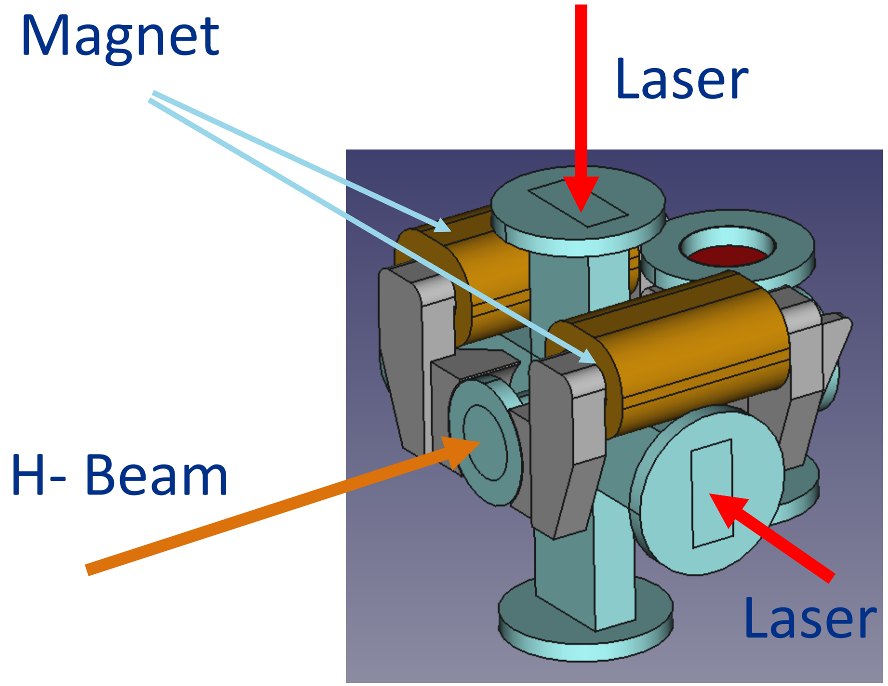
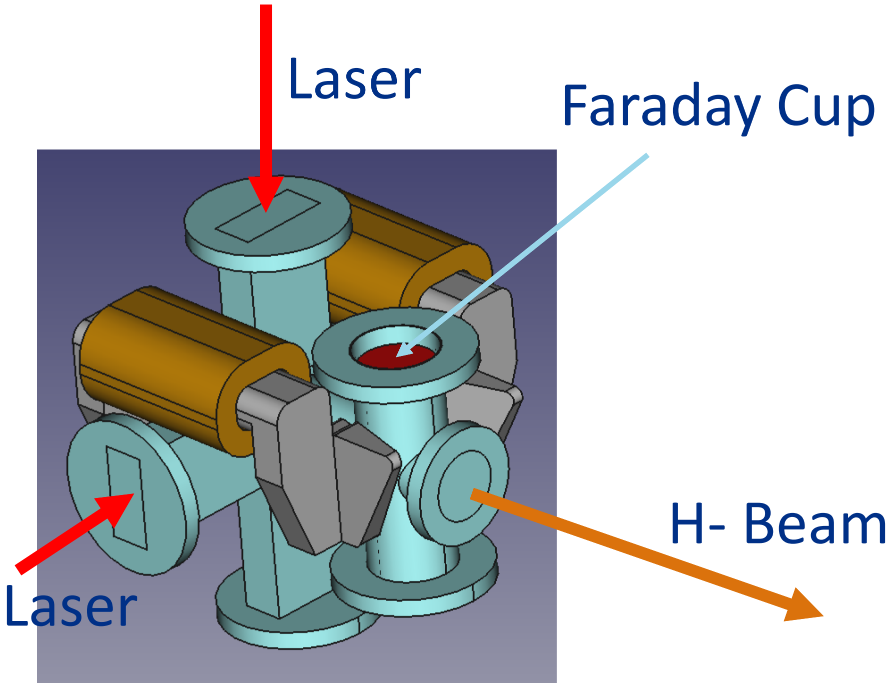
PIP2 Laserwire Final Design Review
May 2, 2024

A Partnership of:
- US/DOE
- India/DAE
- Italy/INFN
- UK/STFC-UKRI
- France/CEA, CNRS/IN2P3
- Poland/WUST

Signal Collection

- Stripped electrons are bent by magnetic field and 'collected' by faraday cup
- Magnet has two pole pairs
  - One downstream to collect the electrons
  - One upstream to correct the field for the H- beam





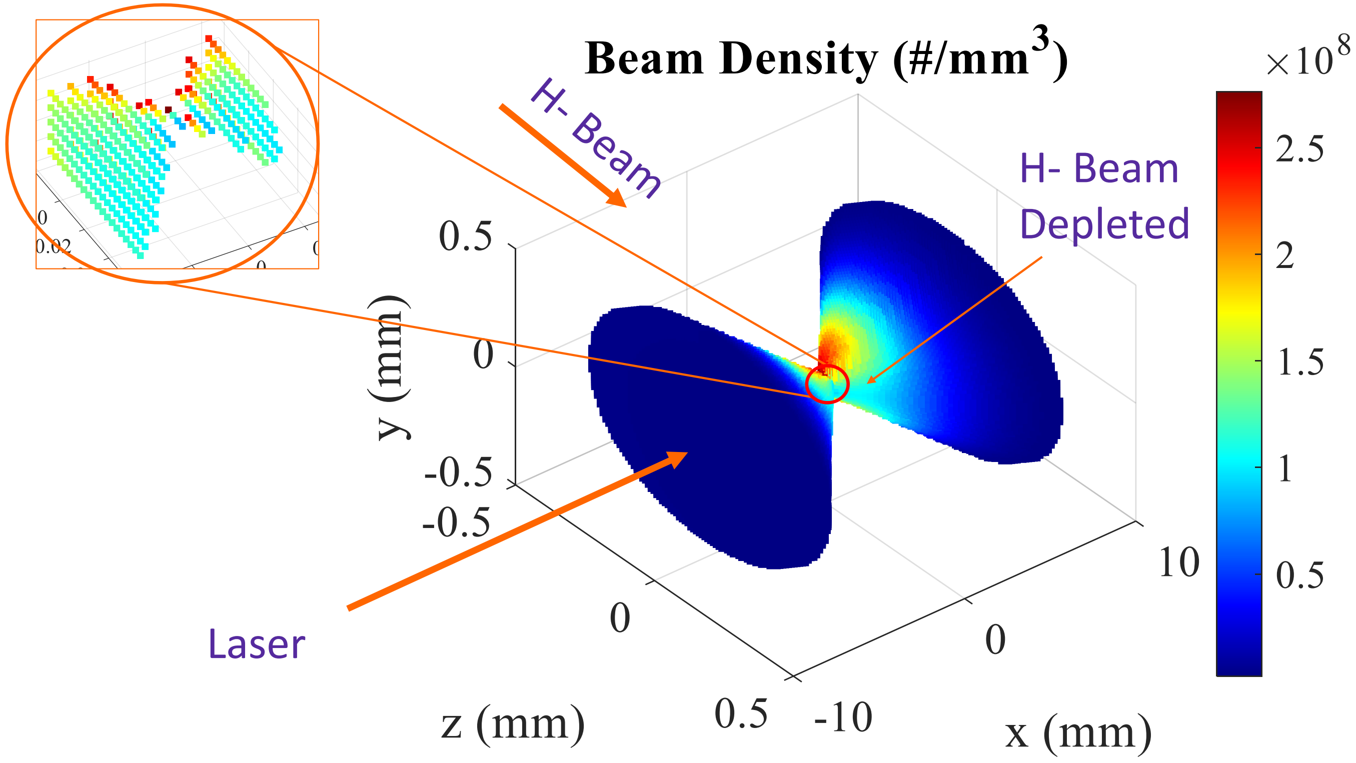
Simulations

- We have used a mix of Matlab, CST, and GEANT4 to accomplish most of the simulation features needed
- H- Stripping calculation (Matlab)
  - Overlaps the laser with the H- beam
    - Laser and H- beam are fully specified in 6-d phase space (some constraints with laser)
  - Time evolution of stripping within fixed voxel space around interaction region
    - Depletion of H- beam is included
      - Laser is not depleted as laser has significantly higher density than H- beam
  - Stripping cross section used in each voxel
    - Number of stripped electrons in each voxel at each time step are stored
- Stripped electron tracking (Matlab + CST)
  - Full relativistic 3-d tracking of particles in arbitrary **E** and **B** fields using adaptive 4th order Runge-Kutta solver
  - **E** and **B** fields of H- bunch generated separately and given time dependence during tracking
    - No transverse motion of bunch
  - **E** and **B** fields of external sources typically generated with CST model
- Tracking to and through faraday cup with GEANT4 to determine impacts to the signal such as secondary emission and backscattering of the primary electrons

Electron Generation

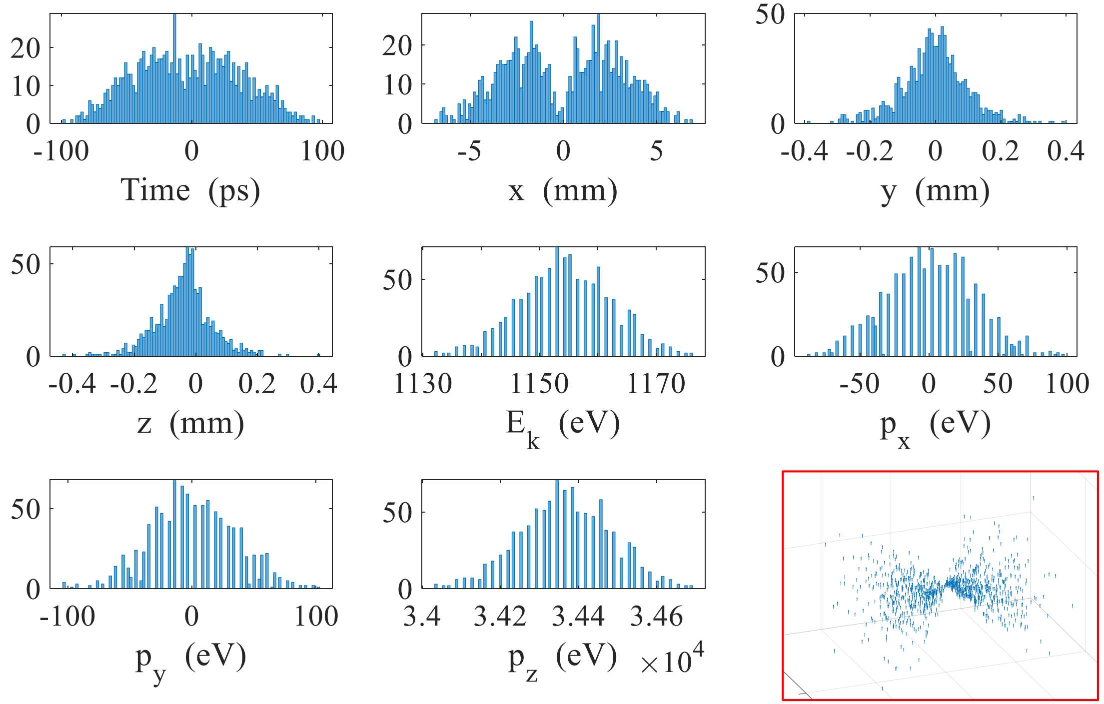
- Particles generated via Matlab code and tracked via Matlab code through the CST-generated magnetic field

Simulated Stripping



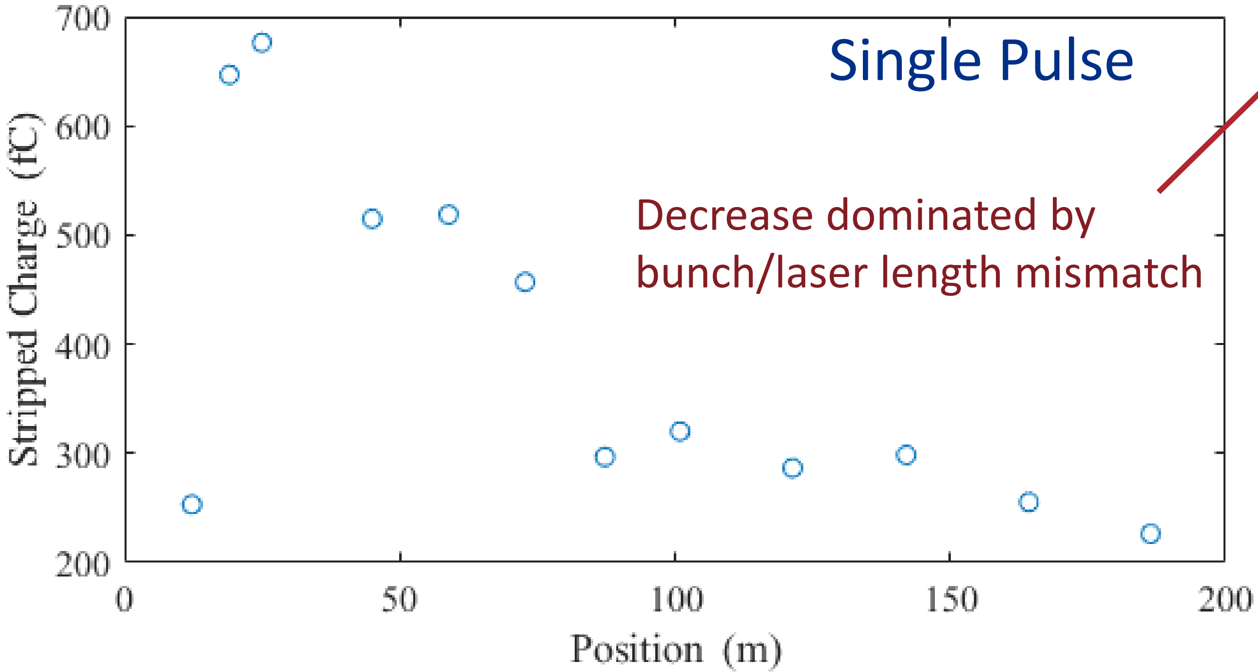
Generated Electron Distributions

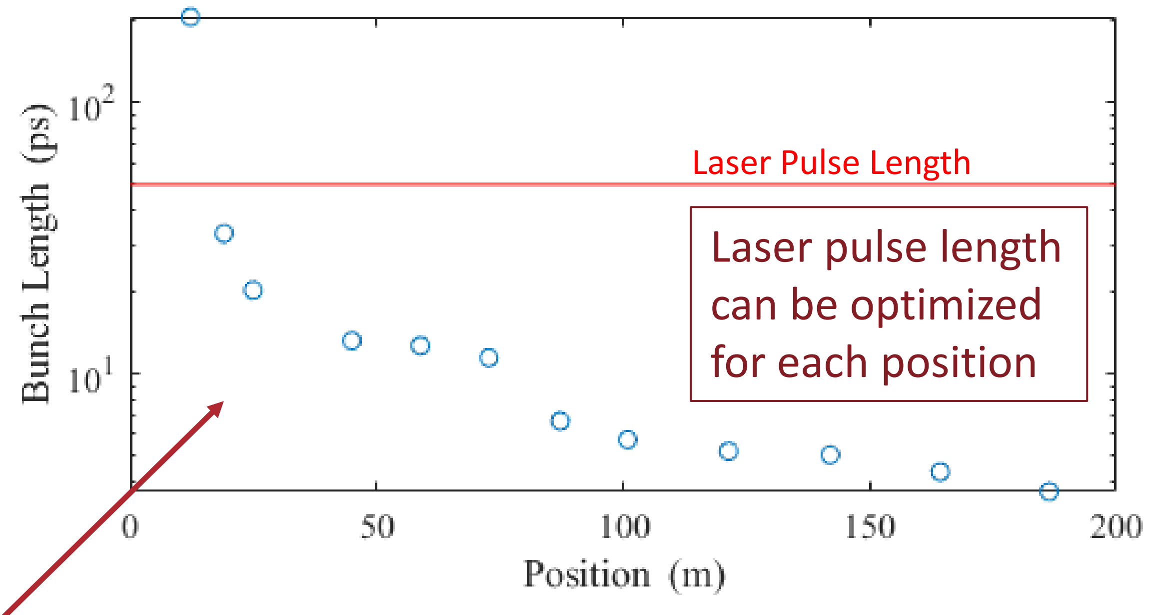
(taken from H- distributions)

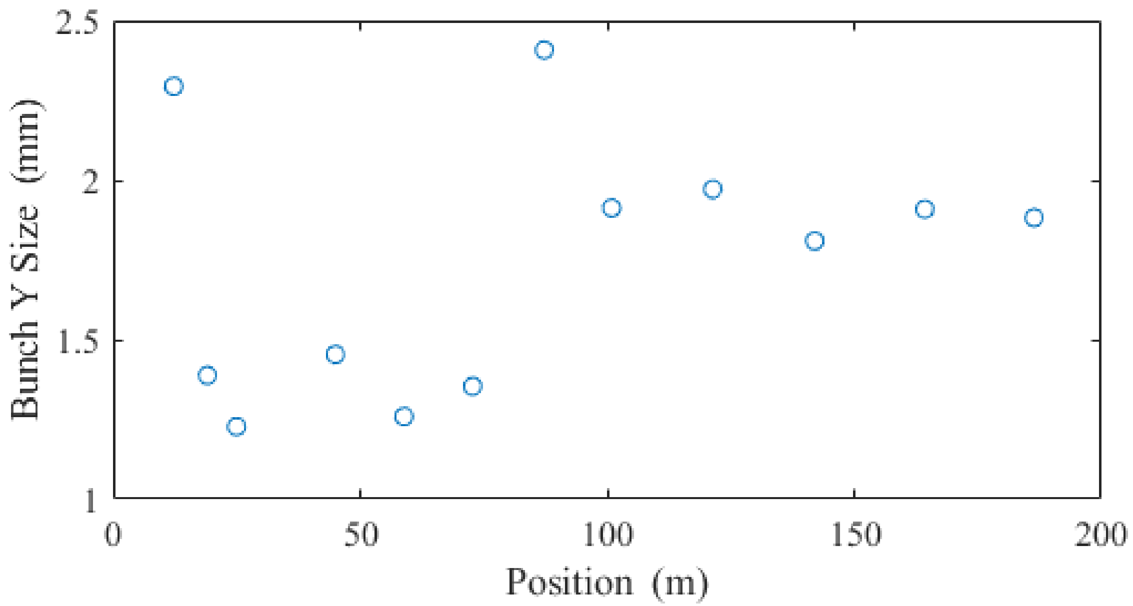


Electron Generation

- Stripped charge is function of time and space overlap of laser and bunch
  - Laser pulse length is 50 ps rms (this simulation)
  - Bunch length goes from 200 ps to 5 ps rms
- Here are plots of signal for each laserwire with laser along X and relevant bunch sizes

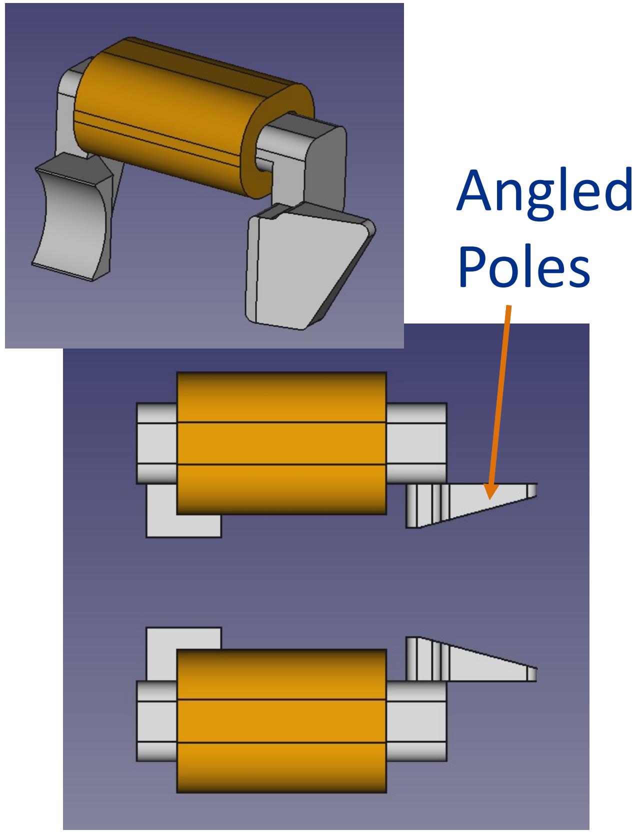


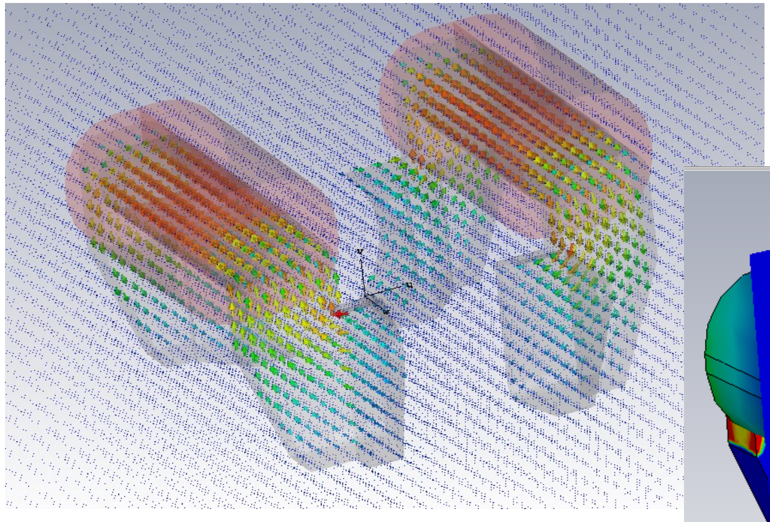


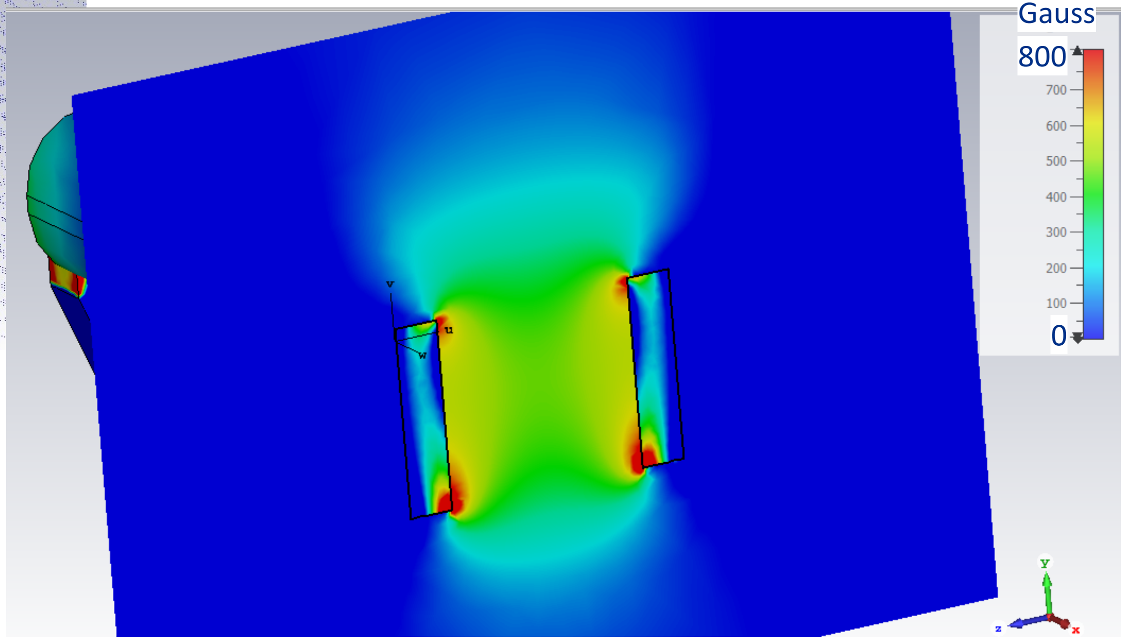


Magnet Design

- Magnet was modeled in CST
- Angled pole pieces intended to produce quadrupole field to keep electrons from spreading transversely

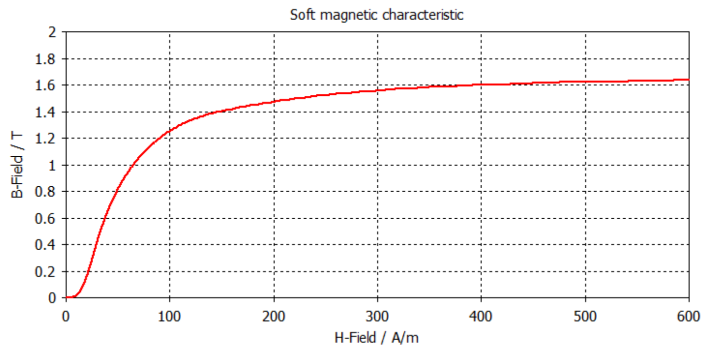


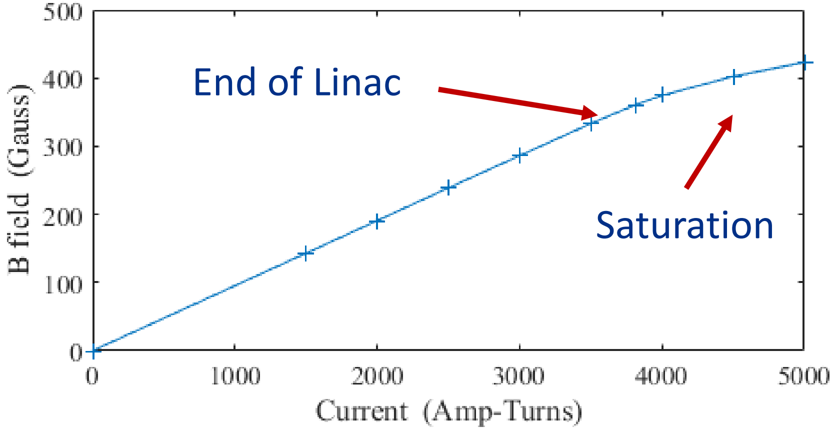


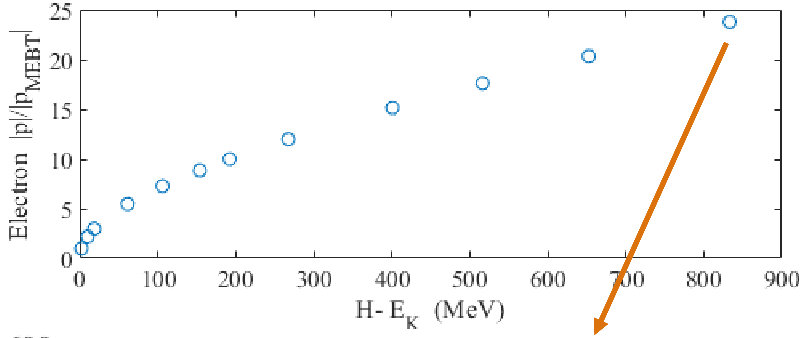


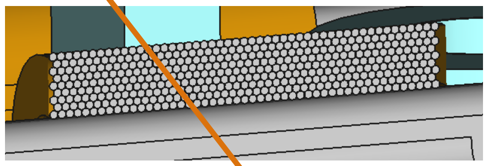
Magnet Design

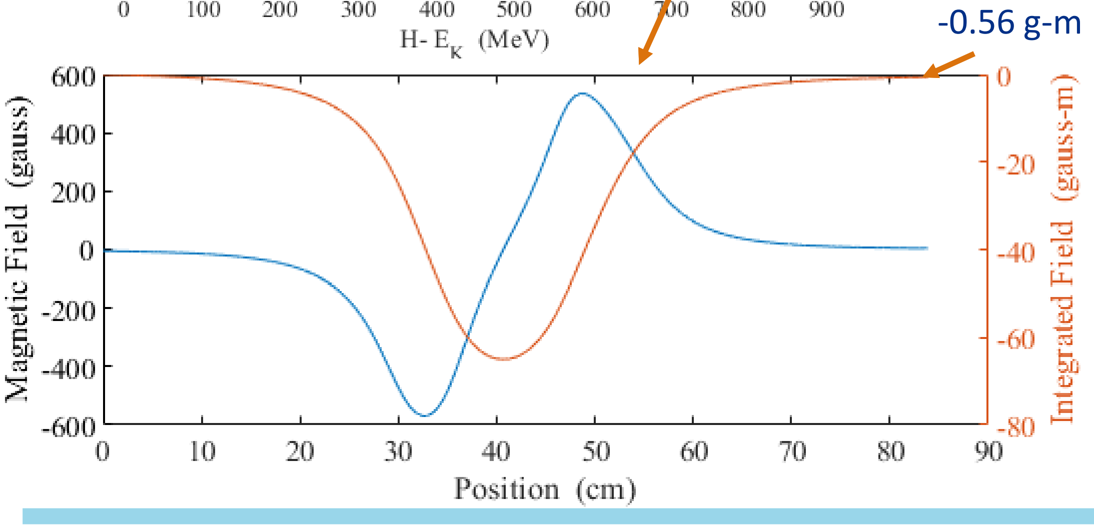
- Maximize field (avoiding saturation)
- Minimize current (and thus heating)
- Fit in available space
- Provide correction field for H-

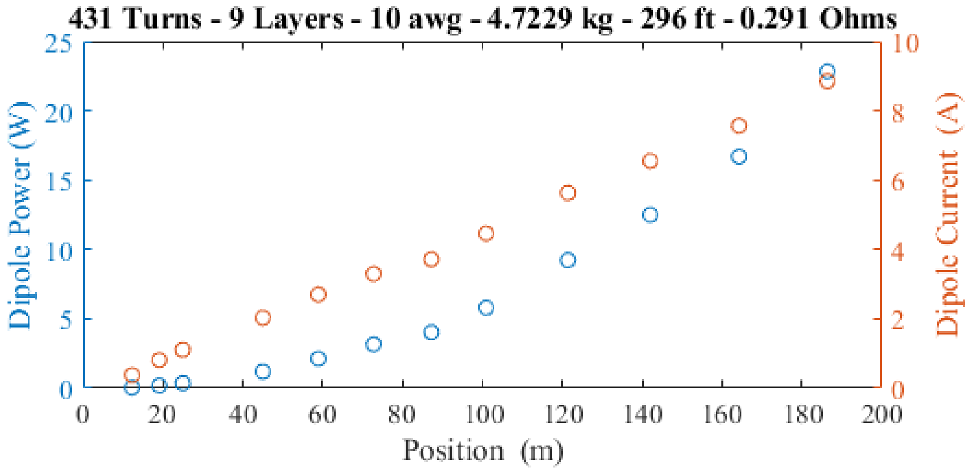








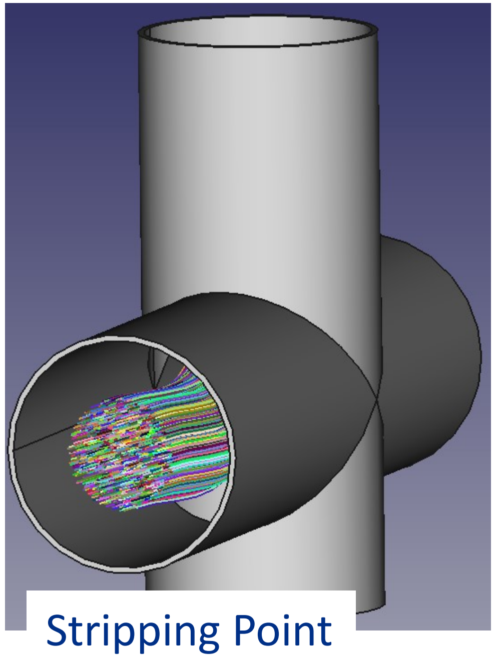


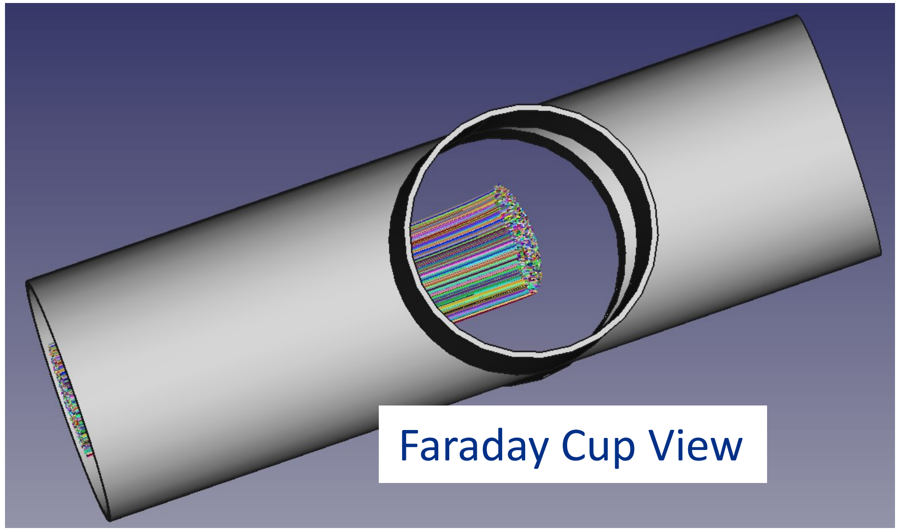


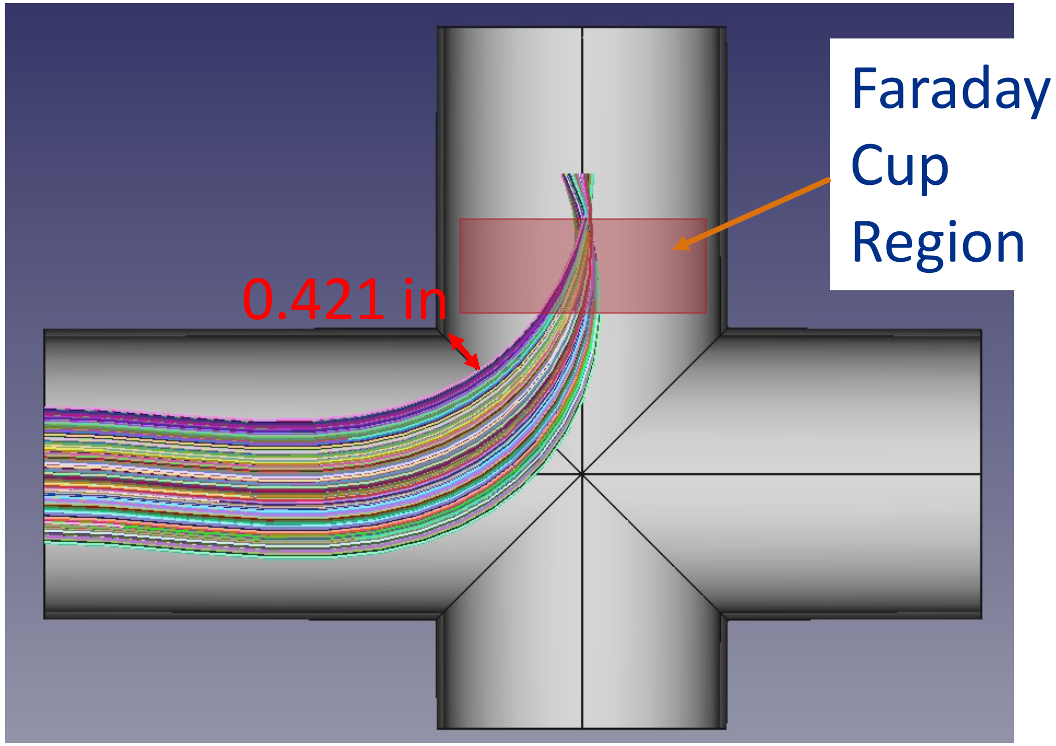
Electron Trajectories

- Check for clearance throughout design range of laserwire = ±15 mm

End of Linac: HB650-4



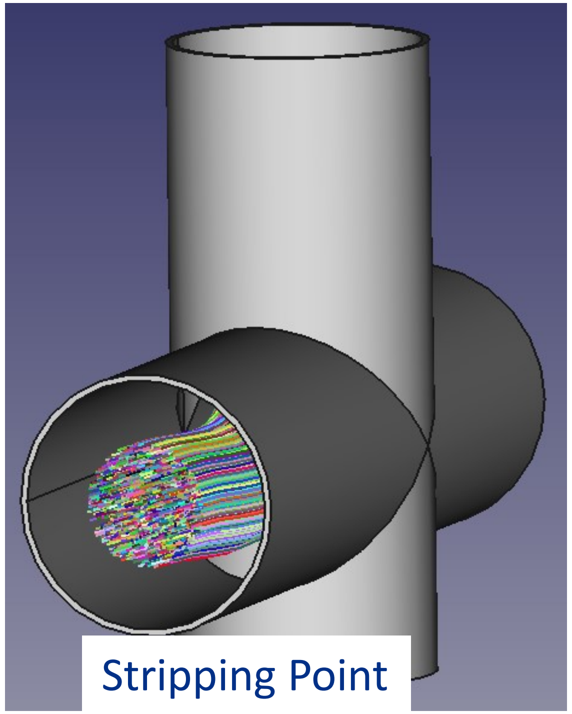


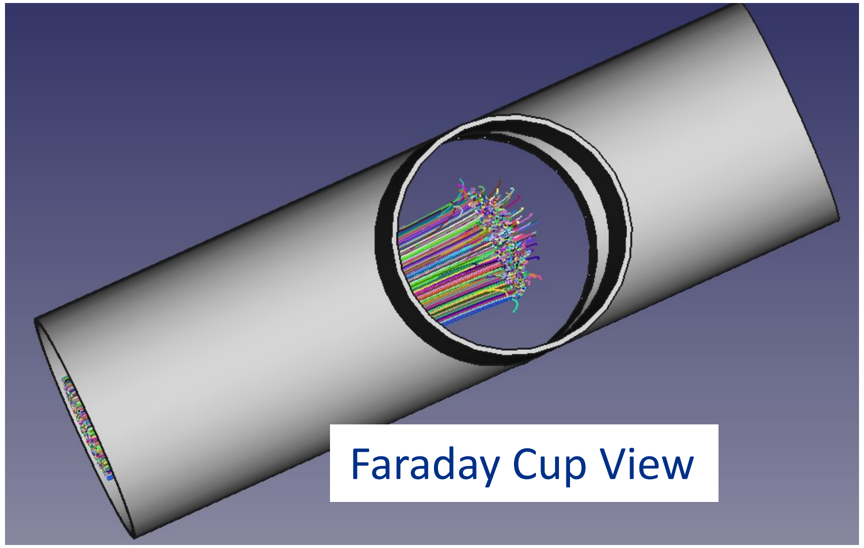


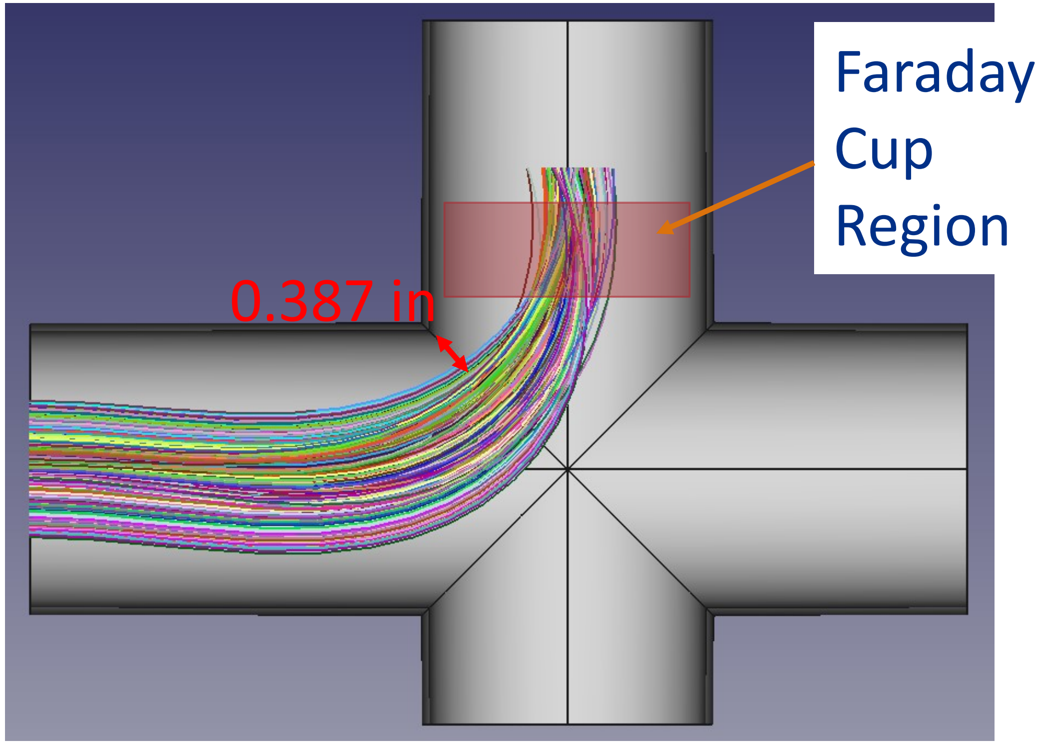
Electron Trajectories

- Check for clearance throughout design range of laserwire = ±15 mm

After HWR (first cryomodule)





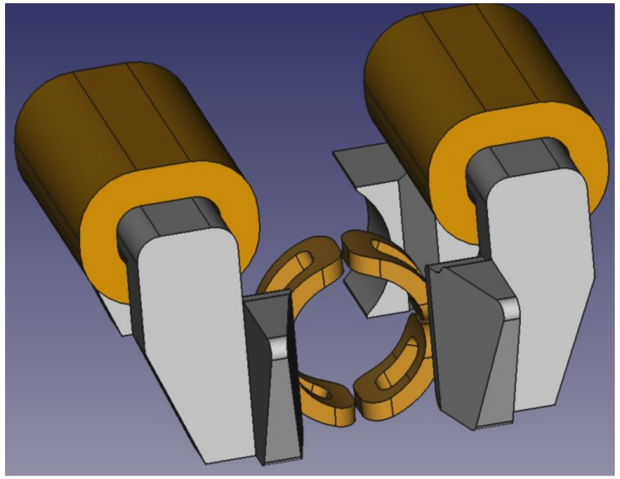


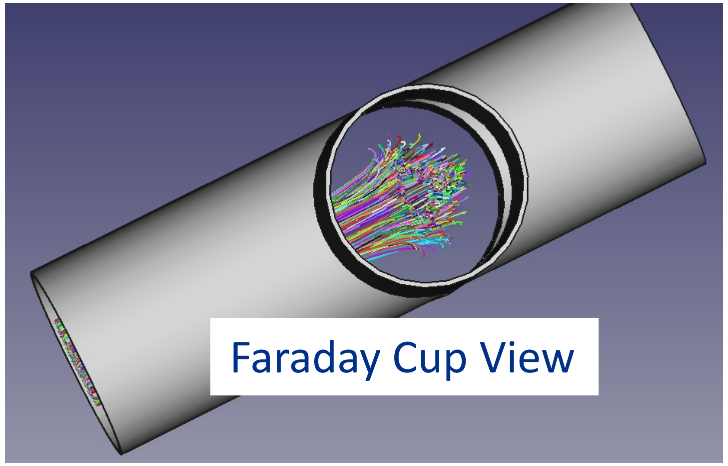
Electron Trajectories

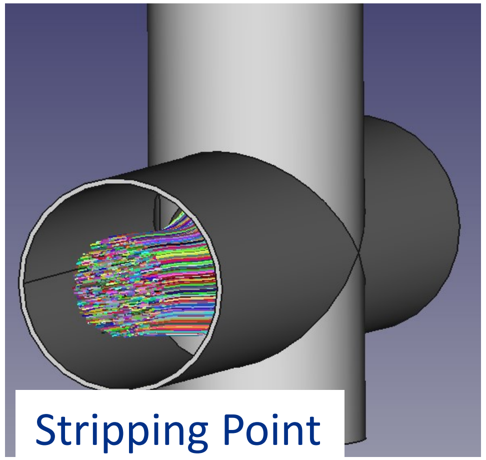
- Check for clearance throughout design range of laserwire = ±15 mm

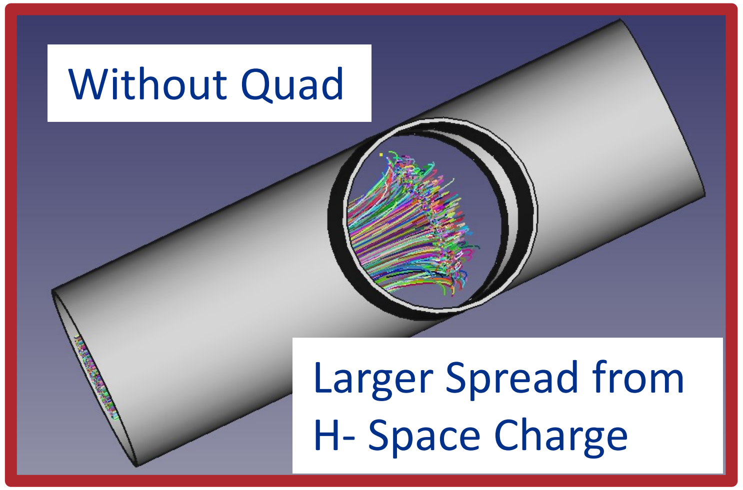
MEBT with additional Quadrupole (not yet in CAD model)

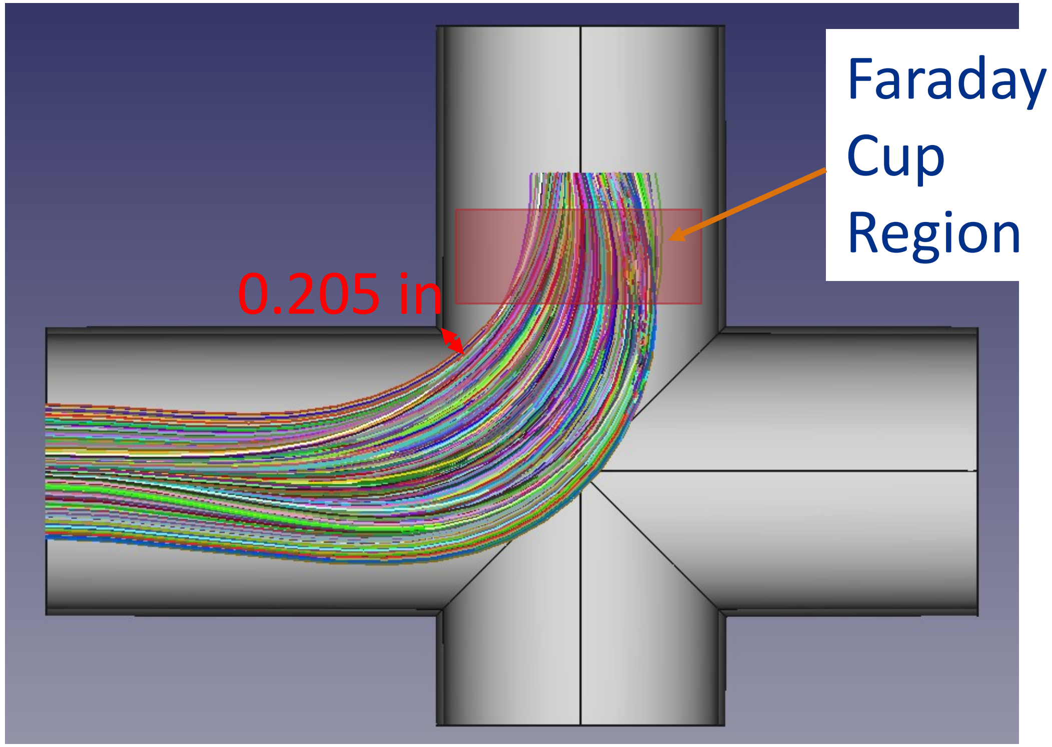
Quad Power Requirements:
1.5 A and 0.04 W







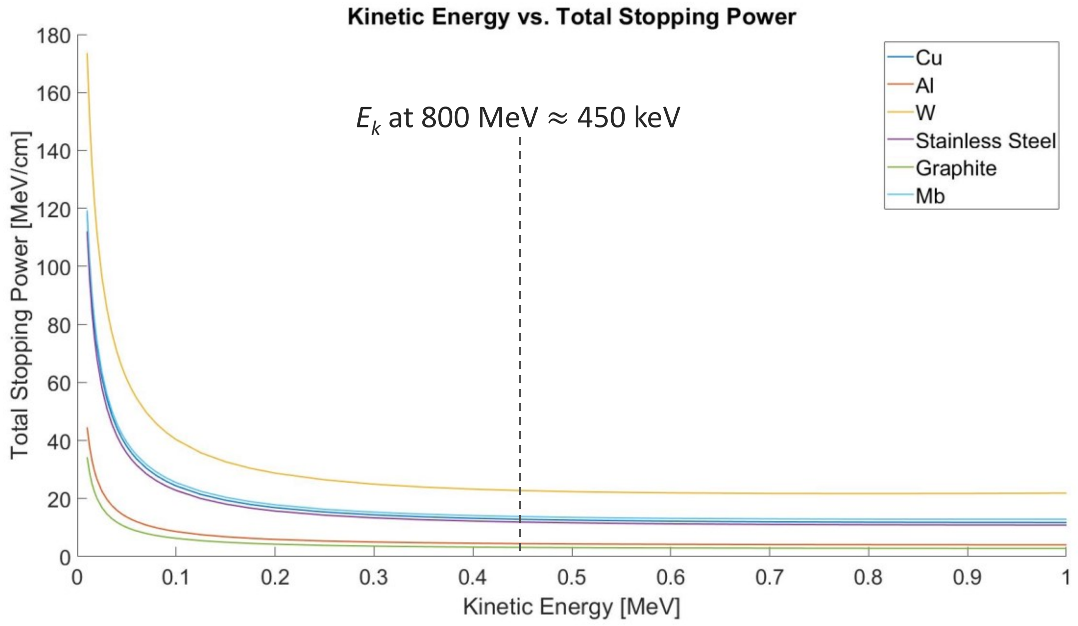


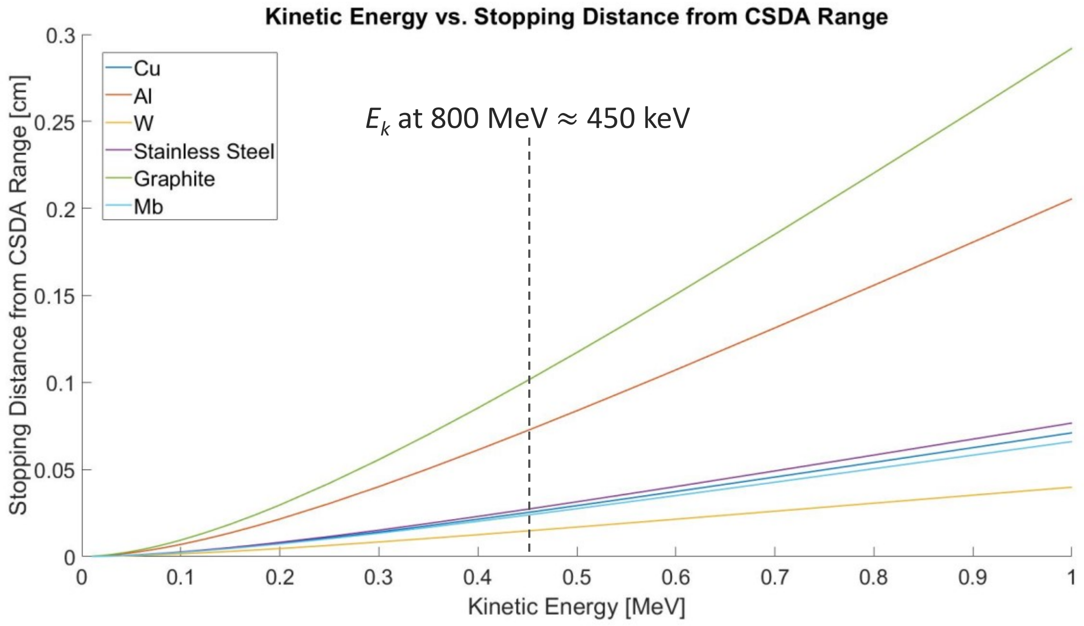


FARADAY CUP STUDIES

Electron Tracking

- H^- beam energy at 1st laser wire scanner ~ 2.1 MeV, γ = 1.00226 ⟶ E_k of the releasing electrons ≈ 1 keV
- H^- beam energy at last laser wire scanner ~ 800 MeV, γ = 1.8868 ⟶ E_k of the releasing electrons ≈ 450 keV

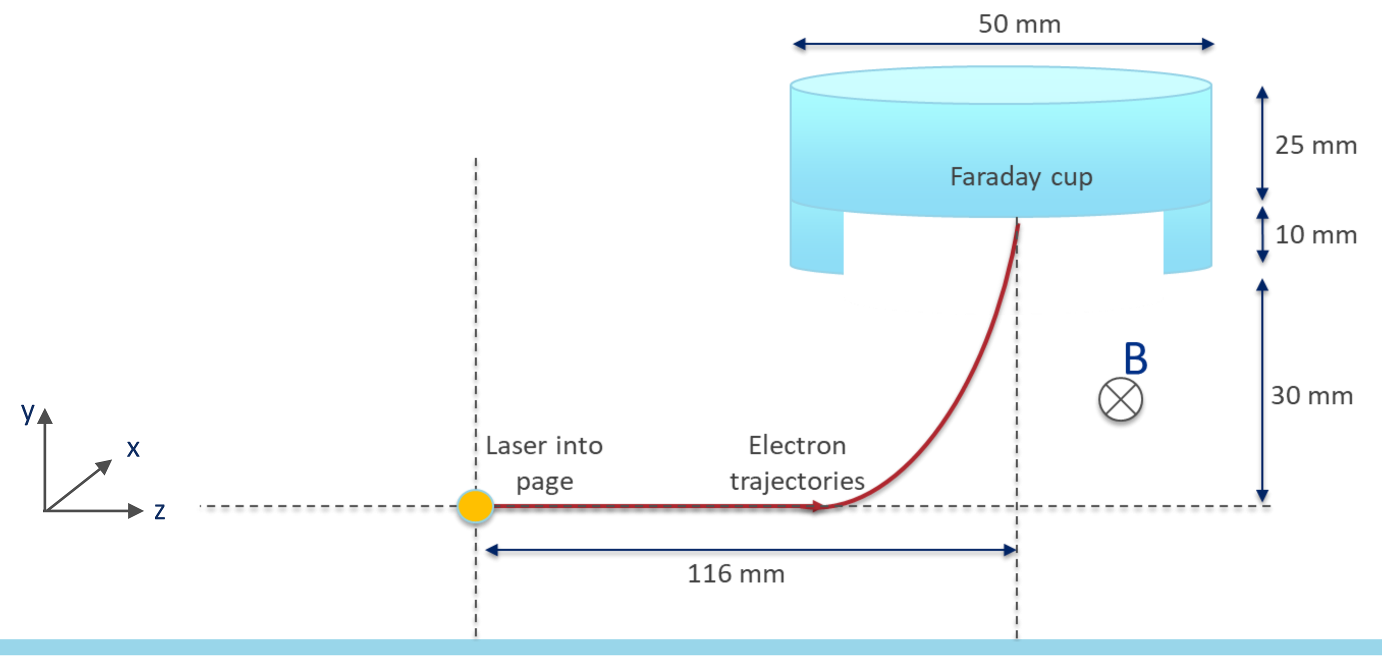


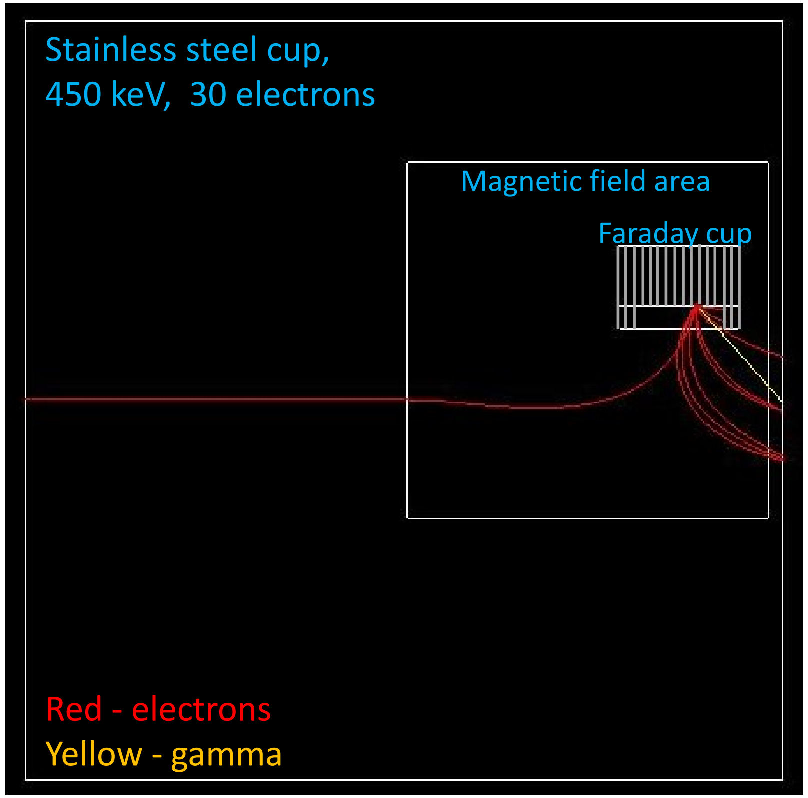


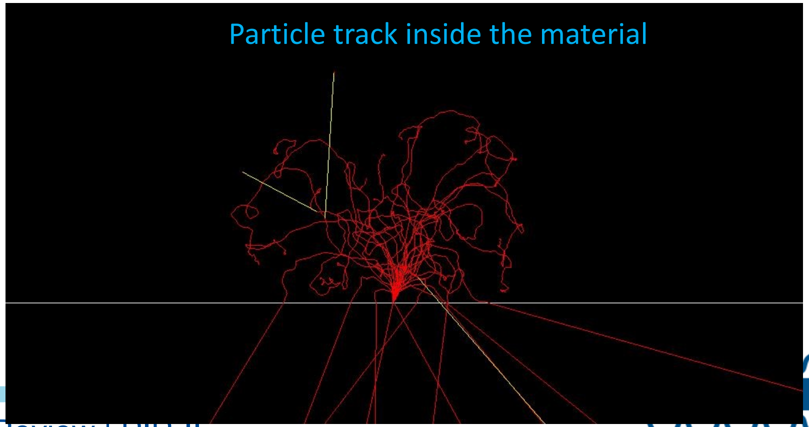
At E_k = 450 keV, the electron stopping distance for Stainless steel is ~ 0.25 mm.

Geant4: Advanced Monte Carlo Simulation Toolkit

- Geant4 is an object-oriented toolkit designed for simulating the complex interactions of particles with matter
- It offers a wide range of physics models organized into physics lists
- For electromagnetic (EM) physics, it supports both standard EM processes (above 1 keV) and low-energy EM processes (down to ~250 eV for electrons and gamma rays)
- This study utilizes "G4EmStandardPhysics_option4," which incorporates a comprehensive set of models for key interactions such as bremsstrahlung, pair production, Compton scattering, and ionization
- This option strikes a balance between precision and computational efficiency

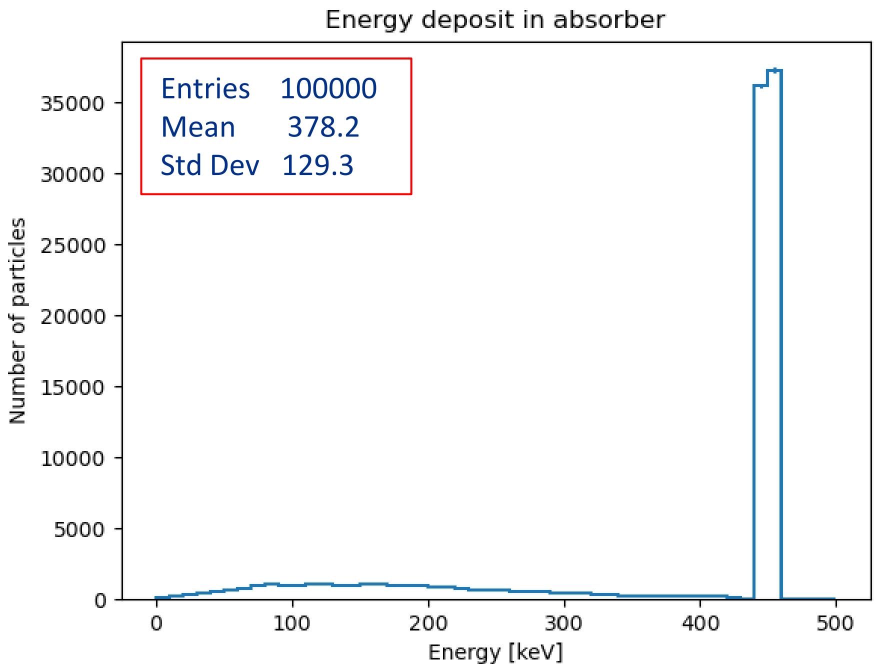






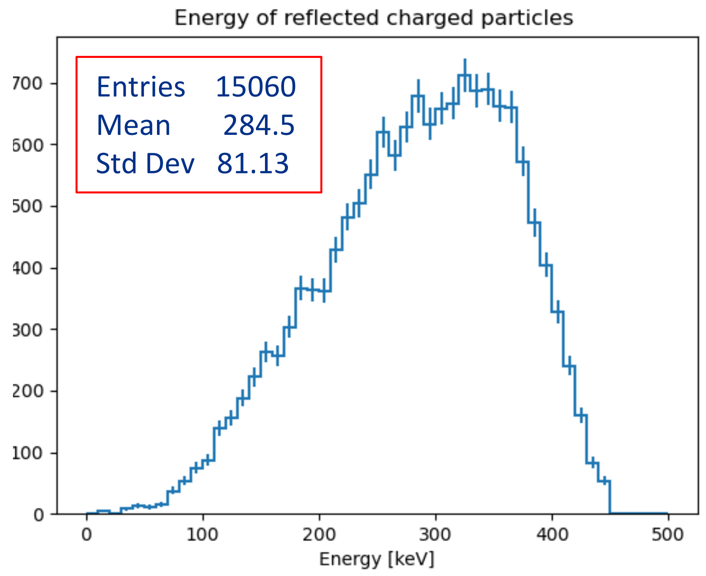
Electron Tracking for 450 keV electrons

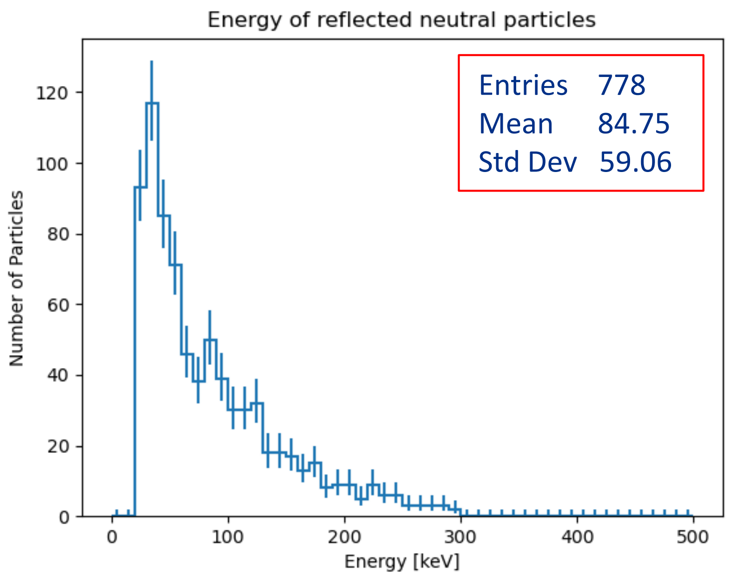
Impacted

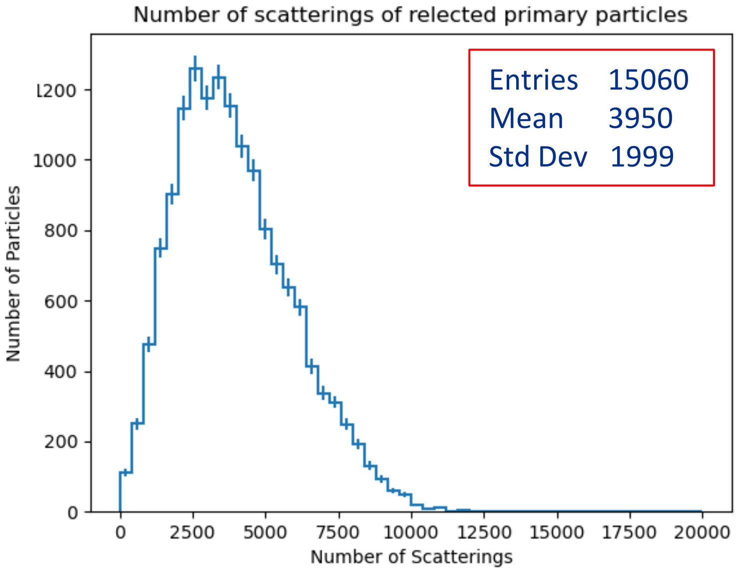


- All the particles were impacted
- None of the particles transmitted through the cup

Reflected

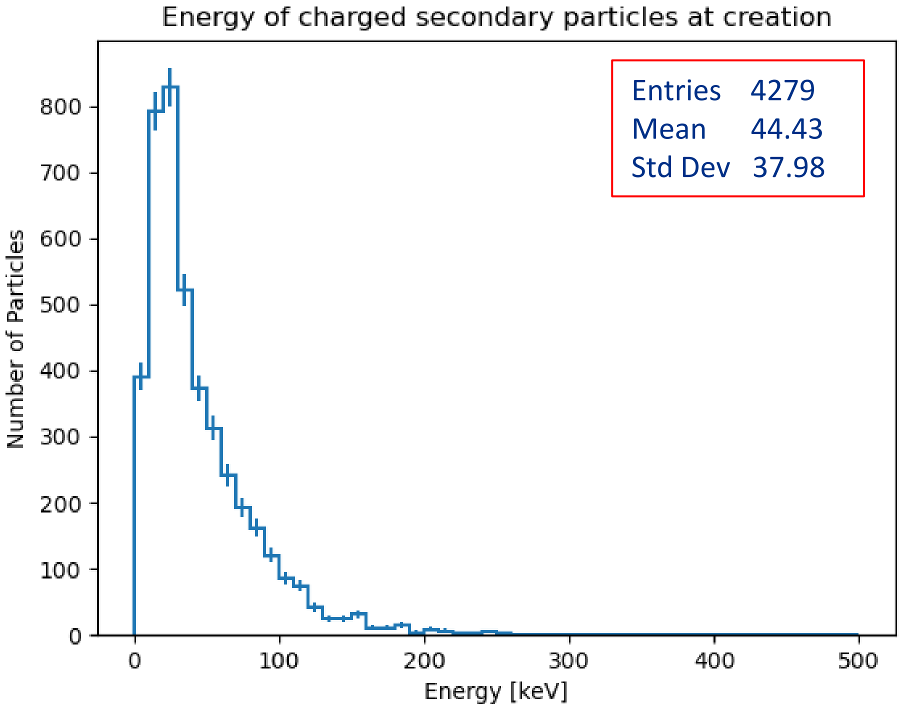


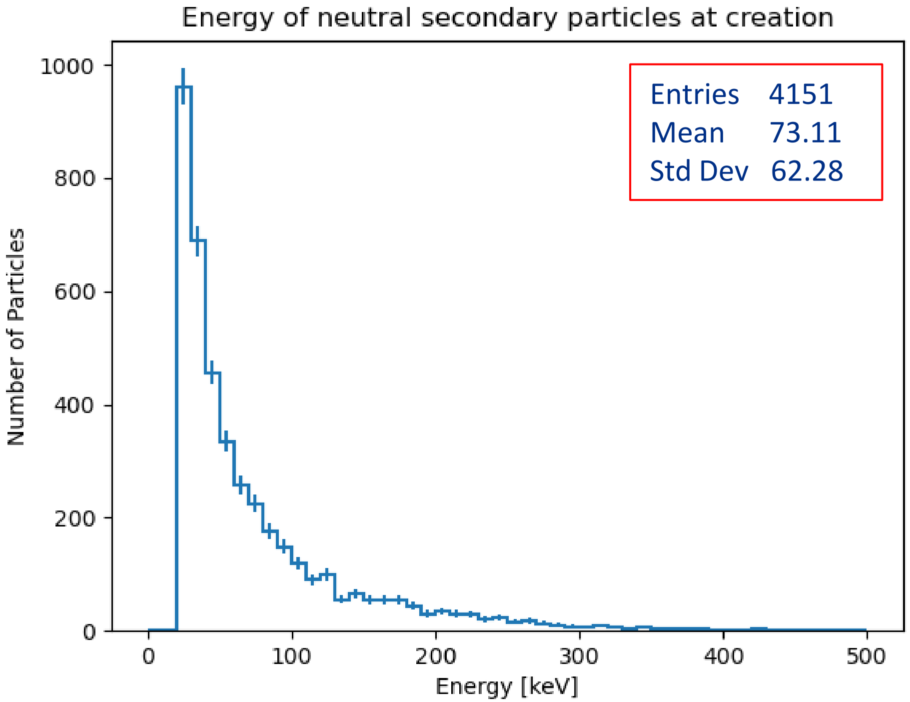




- All the reflected particles are primary particles
- Backscattering coefficient is ~15%

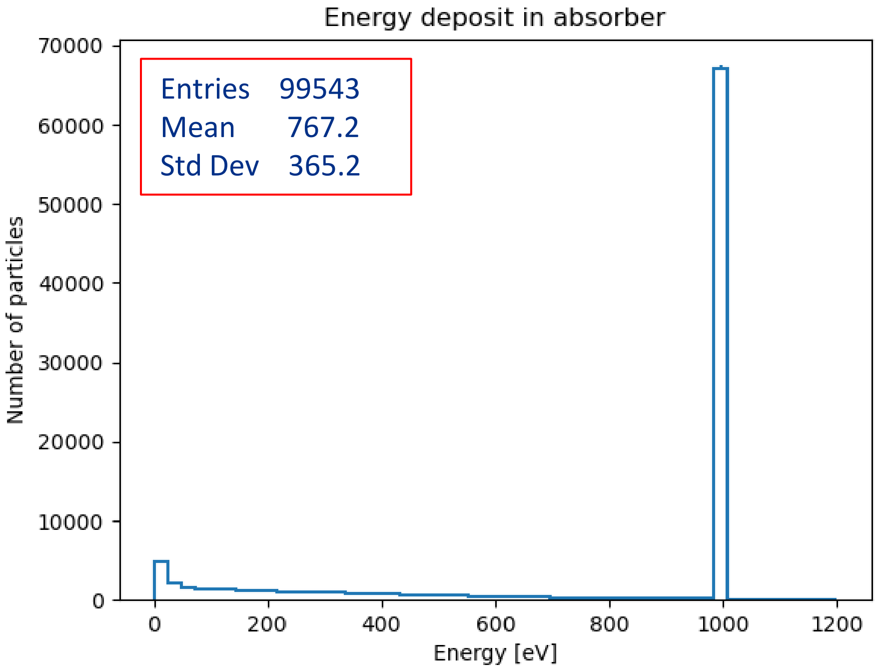
Electron Tracking for 450 keV electrons





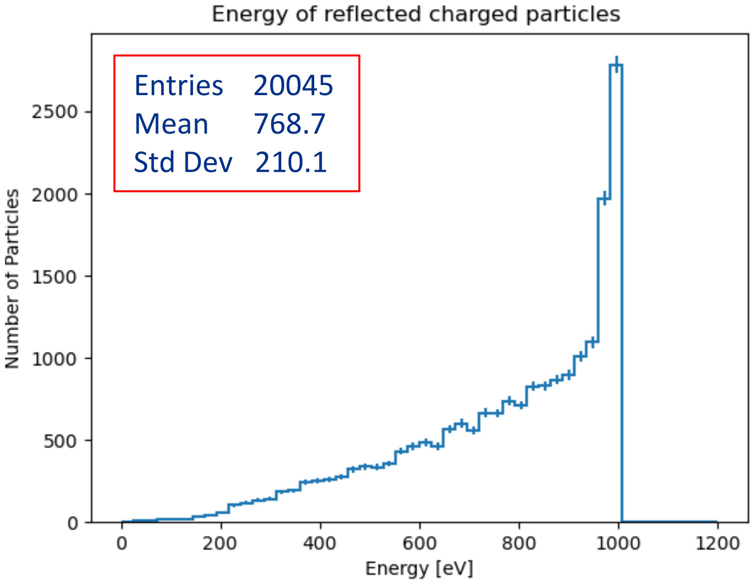
Electron Tracking for 1 keV electrons

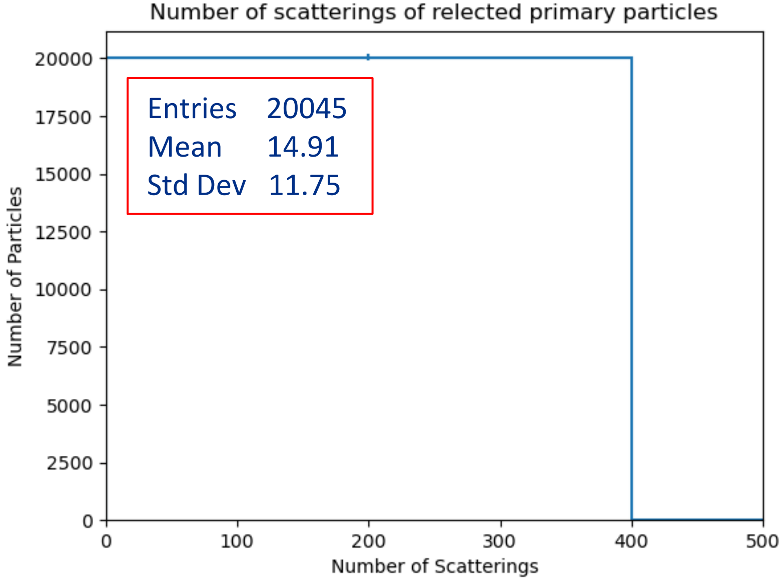
Impacted



- None of the particles transmitted through the cup
- No secondary particles created

Reflected

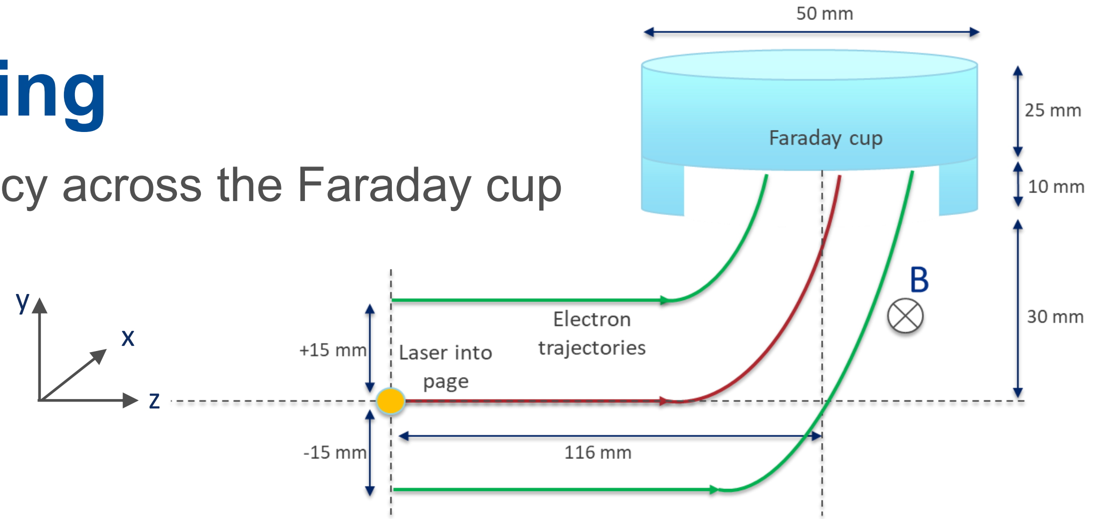


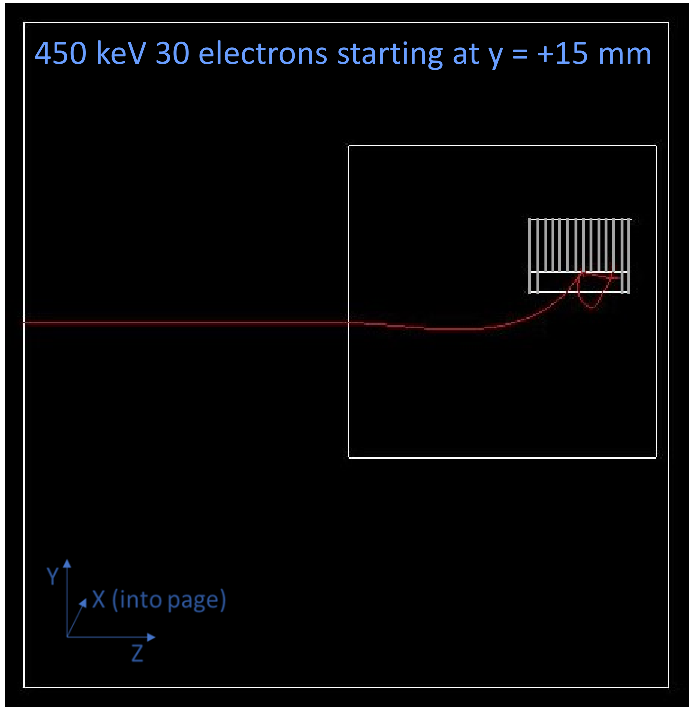


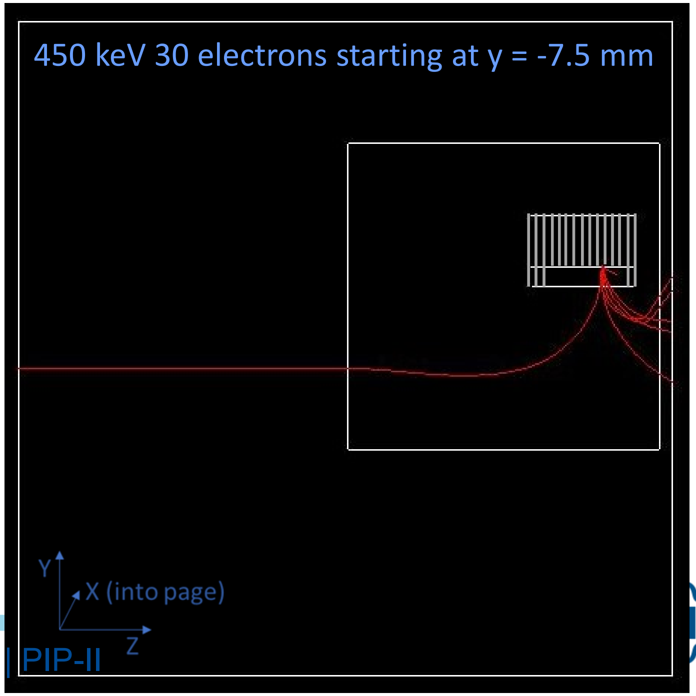
- All the reflected particles are primary particles
- Backscattering coefficient is ~20%
- None of the neutral particles got reflected

Electron Tracking

Electron collection efficiency across the Faraday cup







Electron beam position [mm]	450 keV		1 keV	
	Impacted [%]	Reflected [%]	Impacted [%]	Reflected [%]
-7.5	100	15.58±2.53	99.49	21.08±2.18
-5	100	14.98±2.58	99.48	20.47±2.21
-2.5	100	14.98±2.58	99.47	19.86±2.24
0	100	14.88±2.59	99.46	19.47±2.27
+2.5	100	14.63±2.61	99.58	19.10±2.28
+5	100	14.76±2.60	99.65	19.39±2.27
+7.5	100	14.58±2.62	99.65	18.78±2.31
+10	100	14.61±2.62	99.56	17.96±2.36
+12.5	100	14.72±2.63	99.66	17.88±2.36
+15	100	14.77±2.60	99.58	16.74±2.44

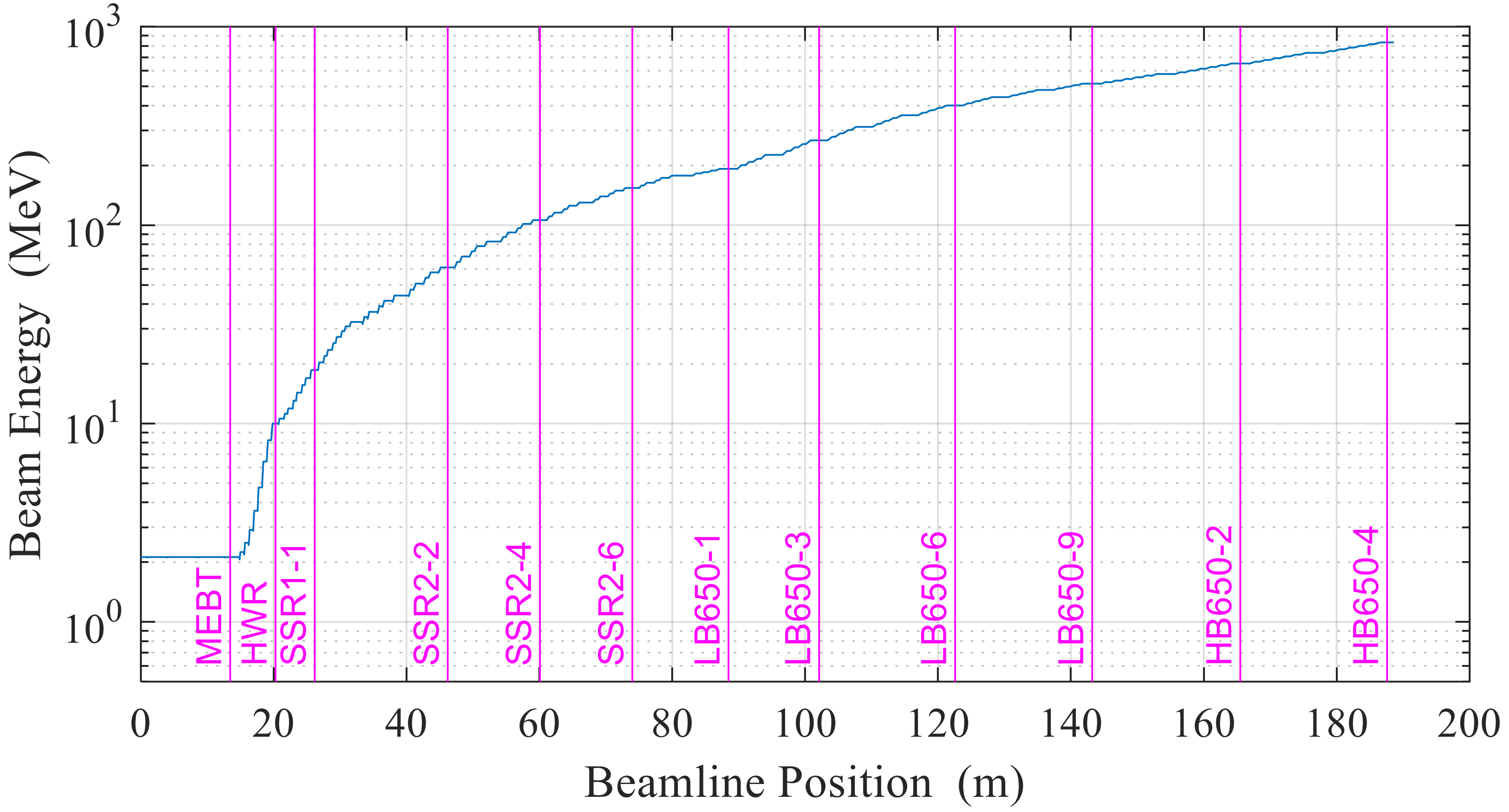
Summary

- We have simulated the generation and collection of electrons using multiple simulation techniques
- Under various space constraints, we have attempted to optimize the vacuum chamber and the magnets to intercept all the electrons over a transverse laser interaction range of ±15 mm
- We are utilizing GEANT4 to determine the collection efficiency of the intercepted electrons as a function of energy and source position

Backup Slides

Laserwire Locations

- Twelve + one laserwire stations in the PIP2 Linac proper (last not shown below)
- The laser room is upstream of the H- source which is at 0 m



Electron Generation

- PIP2IT vs PIP2

Total # of stripped electrons = 7.699607e+02
Fraction of stripped electrons = 4.0092e-06
Energy/bunch @ lens (CW / Beam On / Single Pulse / Single Bunch) = 0.57693 / 5.7693e-05 / 2.8847e-06 / 3.5503e-09 J/cm^2
Energy/bunch @ window (CW / Beam On / Single Pulse / Single Bunch) = 2.3077 / 0.00023077 / 1.1539e-05 / 1.4201e-08 J/cm^2

Total # of stripped electrons = 1.415507e+06
Fraction of stripped electrons = 0.0073707
Energy/bunch @ lens (CW / Beam On / Single Pulse / Single Bunch) = 9457.882 / 0.94579 / 0.047289 / 5.8202e-05 J/cm^2
Energy/bunch @ window (CW / Beam On / Single Pulse / Single Bunch) = 37831.4297 / 3.7831 / 0.18916 / 0.00023281 J/cm^2

Electron Generation