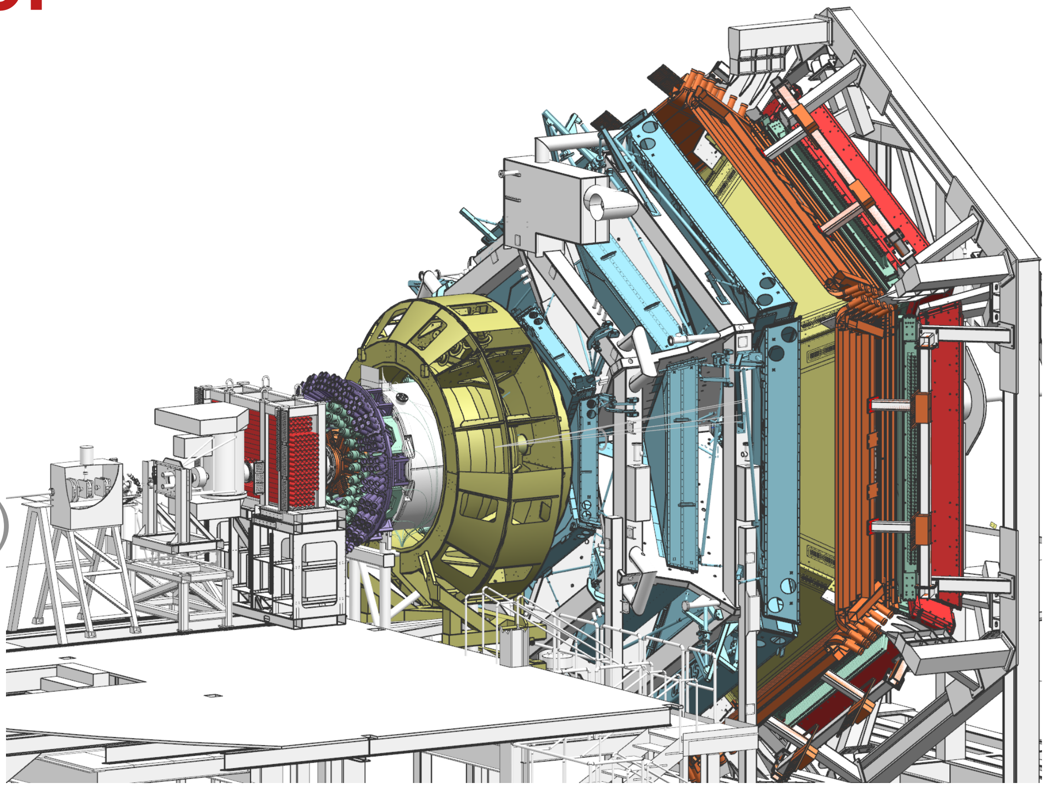
Simulation studies of beam-related background: what we have learned from CLAS12



Raffaella De Vita (Jefferson Lab)
and the CLAS Collaboration

Beam background simulations

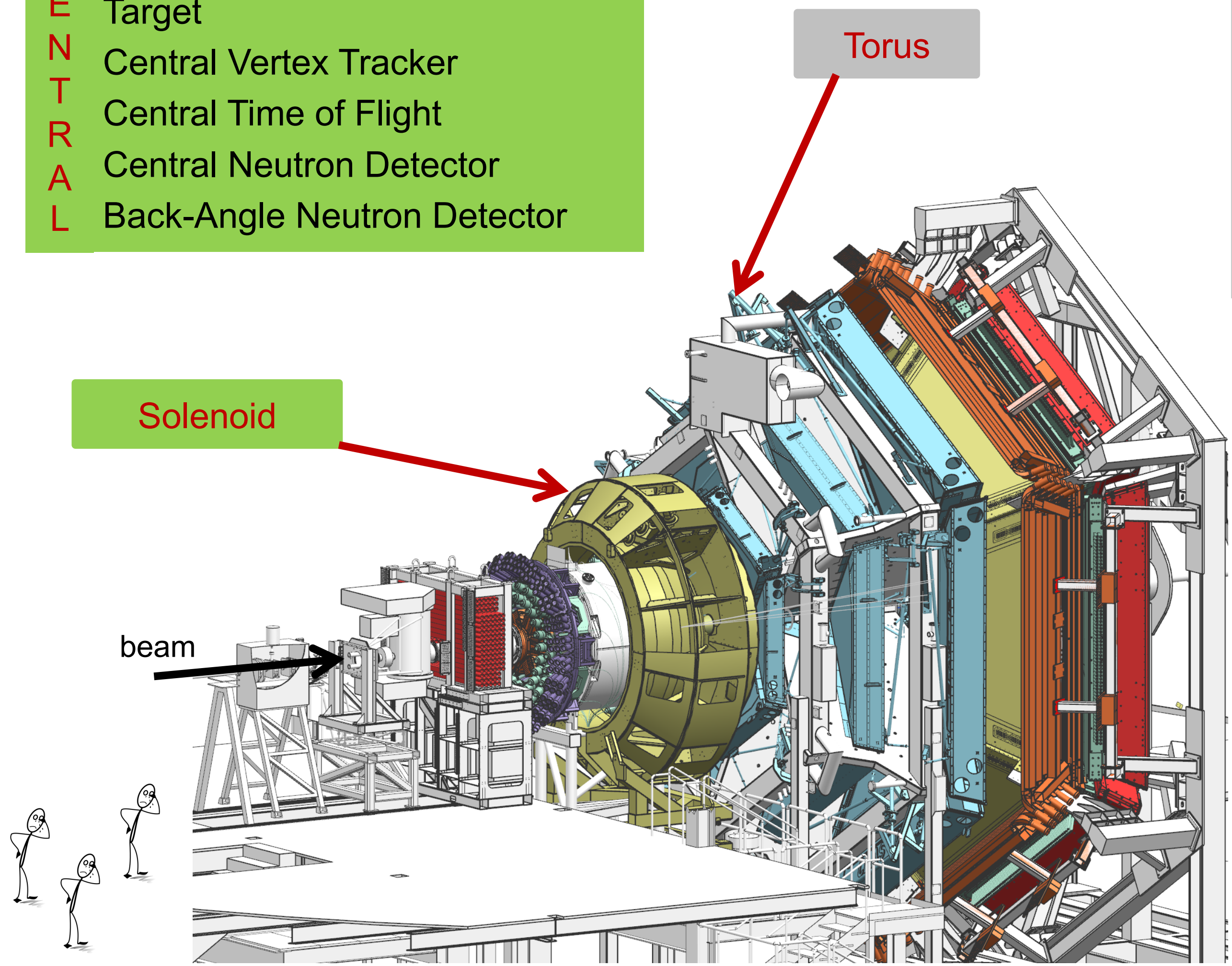
- Simulation studies of beam-related background can be performed with GEANT4
- Single beam particle simulation can be used to:
  - Estimate background particle rates:
    - Per process
    - Per particle type
    - …
  - Identify where background is created
  - Estimate radiation doses
  - Estimate detector hit rates, PMT rates, etc.
- Simulations of multiple beam particles in the detector readout window can be used to:
  - Estimate the impact of background on the “true” signals:
    - Pile-up
    - Dead-time
  - Estimate the impact on reconstruction efficiency and resolution

Such kind of studies have been done simulating the electron beam in CLAS12 to optimize the detector design and configuration

CLAS12

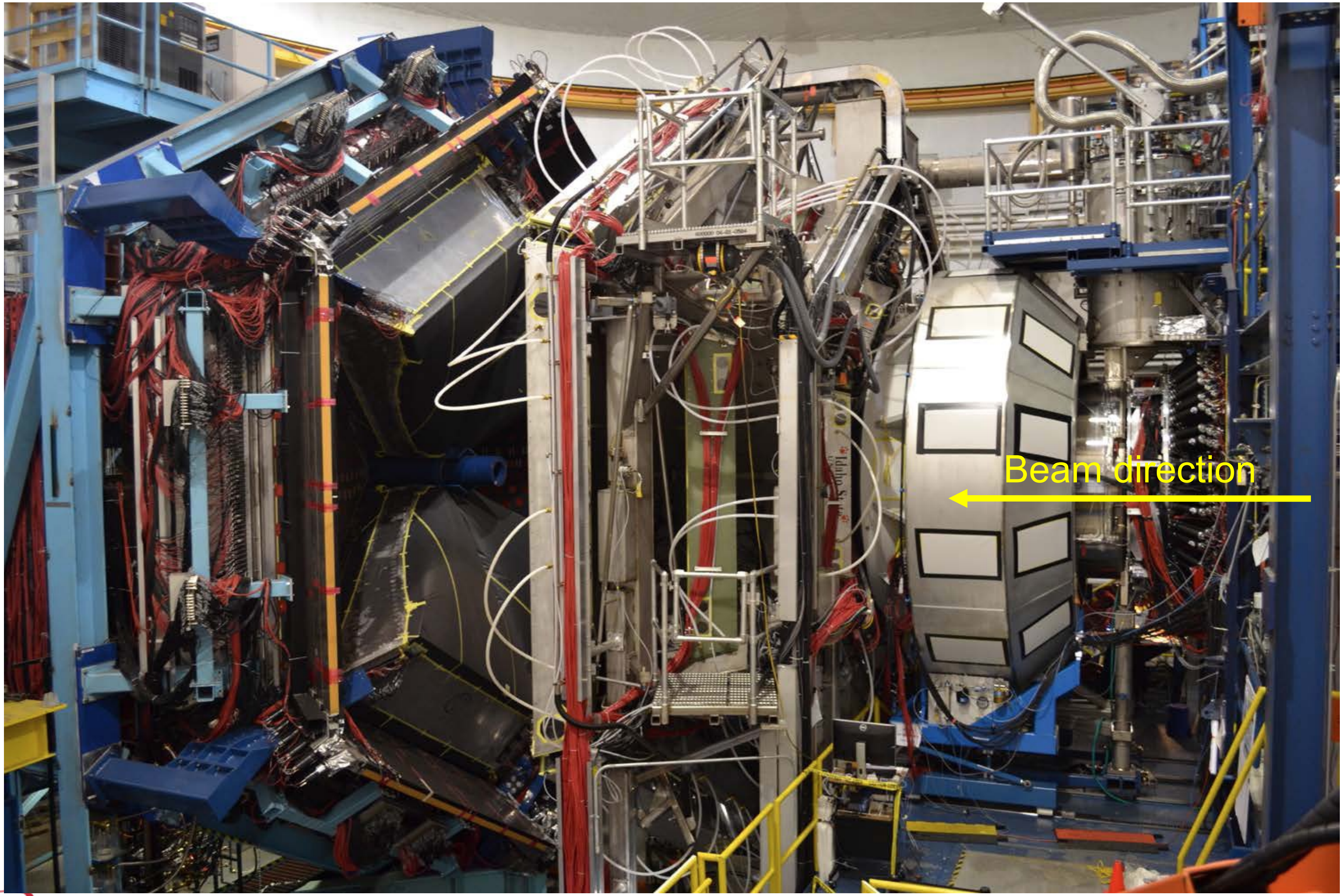
C E N T R A L	Beamline Target Central Vertex Tracker Central Time of Flight Central Neutron Detector Back-Angle Neutron Detector

F O R W A R D	High Threshold Cherenkov Forward Tagger Drift Chambers Low Threshold Cherenkov Ring Imaging Cherenkov Forward Time of Flight EM Calorimeter

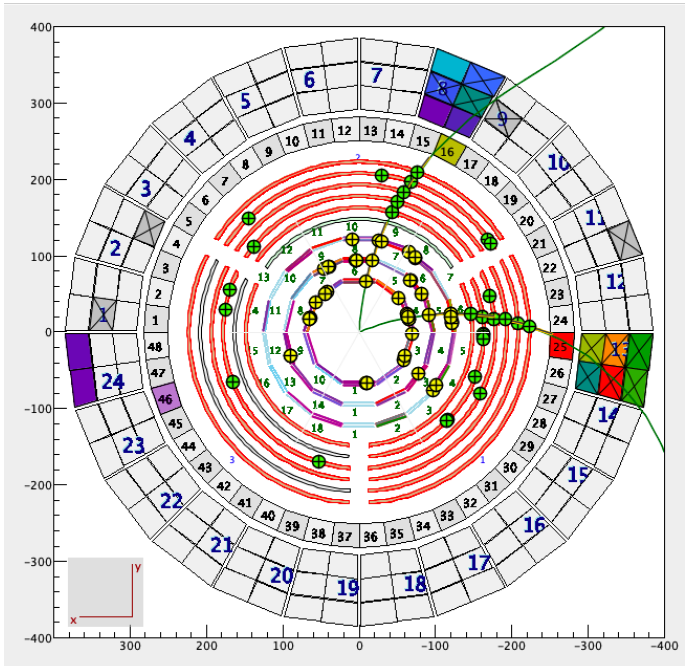


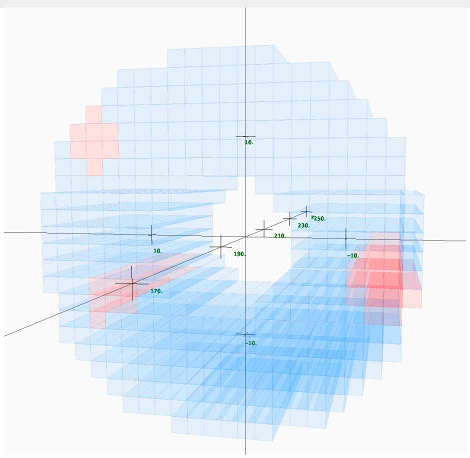
	Forward	Central
Angular coverage	5° – 35°	35° – 135°
Momentum resolution	dp/p < 1%	dp/p < 5%
θ resolution	1 mrad	5 – 10 mrad
ϕ resolution	1 mrad/sinθ	5 mrad/sinθ

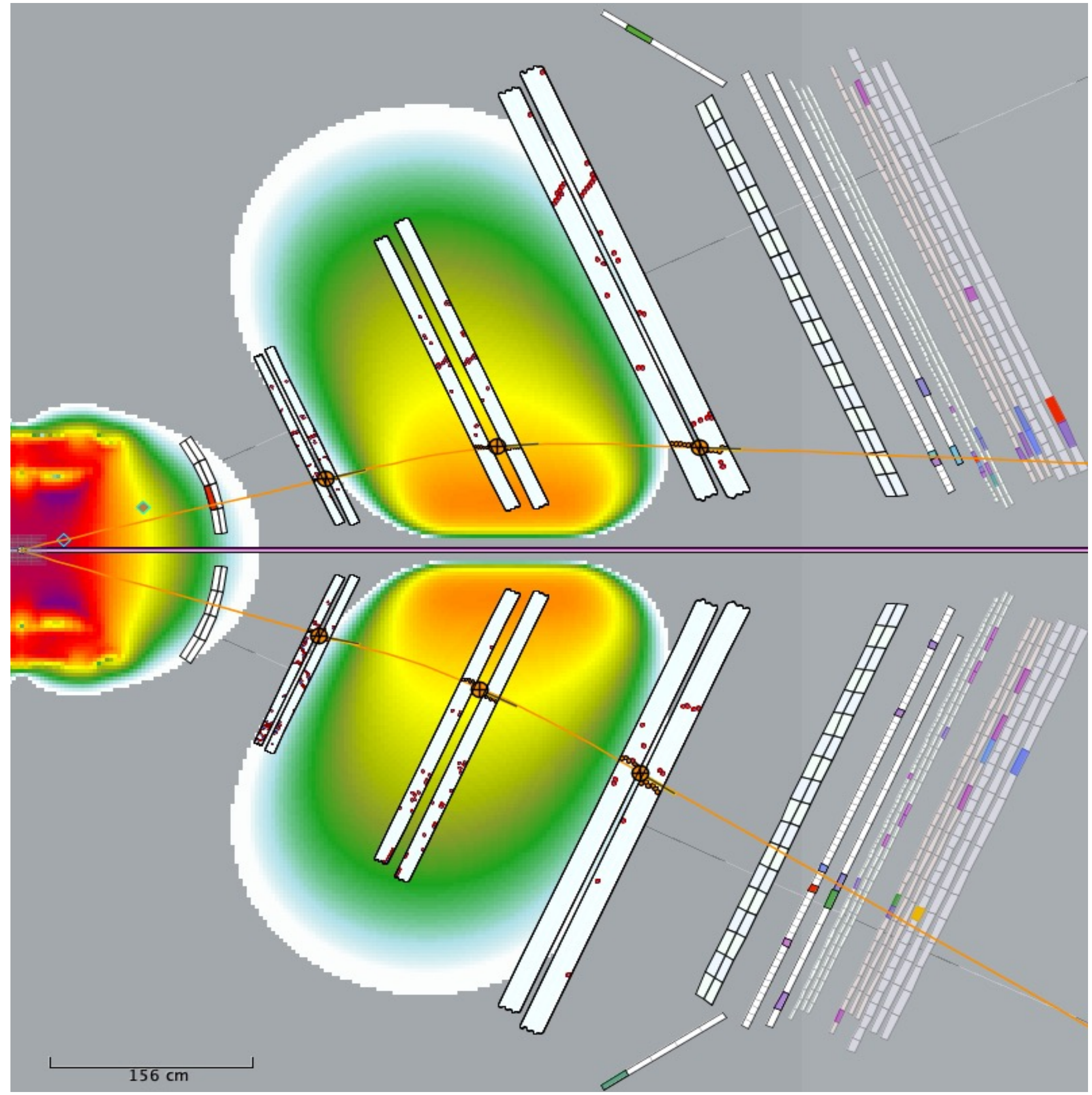
CLAS12 in Hall B



CLAS12 Event Display



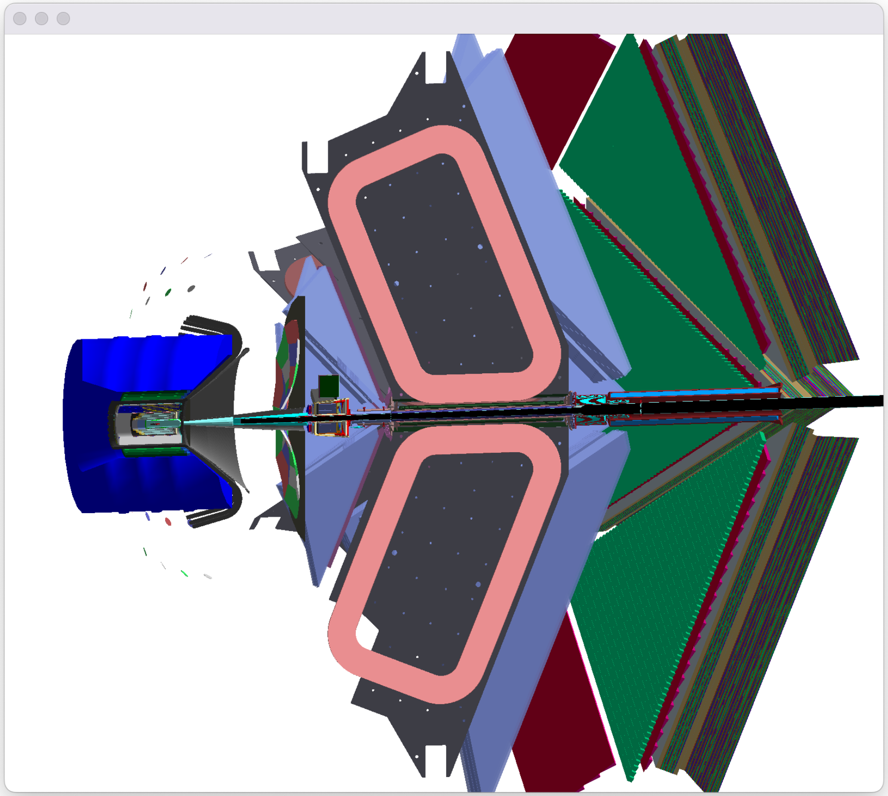




Background simulations

- Simulations performed with GEMC (GEANT4 Monte Carlo), developed by M. Ungaro, see http://gemc.jlab.org

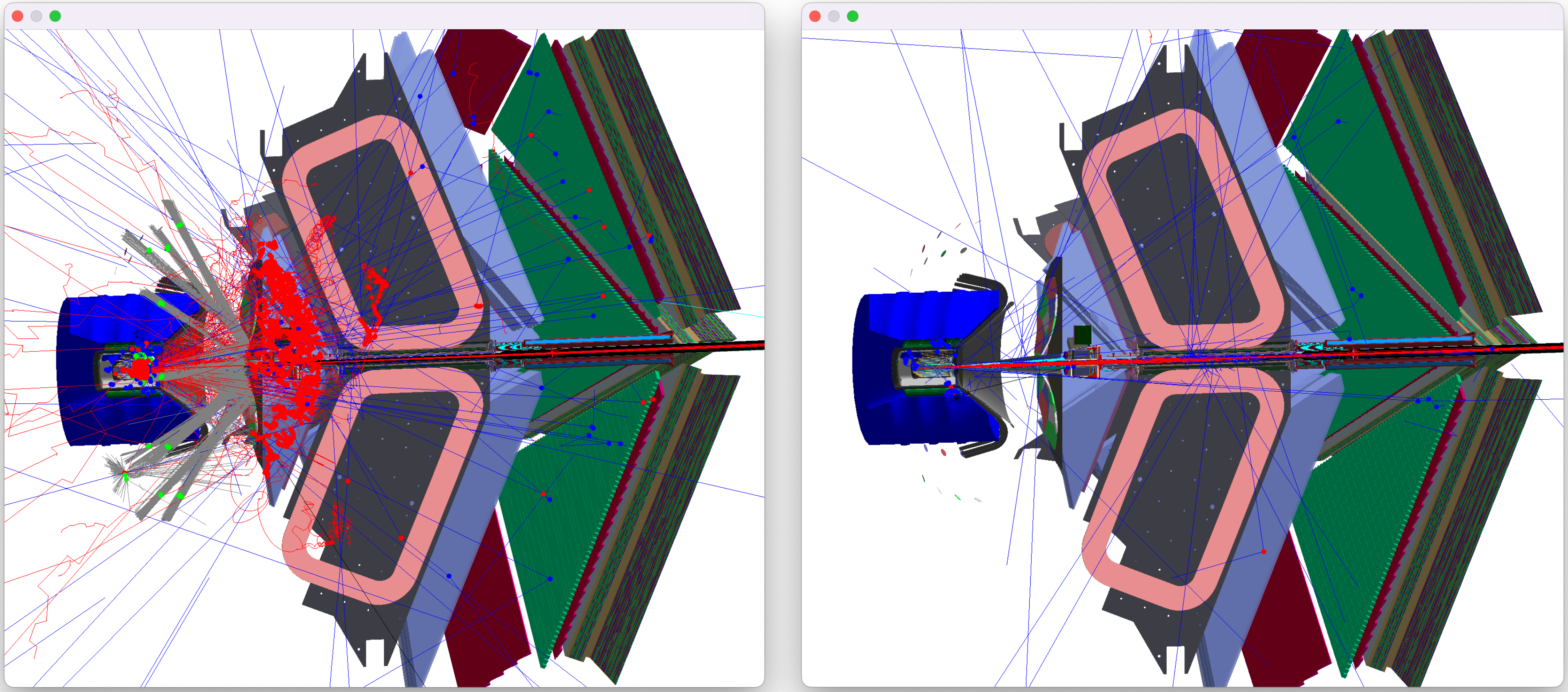
- Supports simulations of “signal” particles and “beam”, where the user can select:
  - Number of beam particles
  - Type of beam particles
  - Particle energy and vertex
  - Time window in which the beam particles are distributed
  - Time structure
- Beam is generated upstream the CLAS12 target and the primary background is generated by the particle interaction within the target and other materials
- Most of the background is due to electromagnetic processes (Moller scattering and Bremsstrahlung for the electron beam)
- Contributions from nuclear and hadronic processes are smaller but can be critical for specific cases such as neutron fluxes



GEMC rendering of CLAS12

Active and passive shield in CLAS12

- Moller electrons produced at the target are focussed in the forward detector by the 5 Tesla solenoid field and absorbed by “thick” beamline components



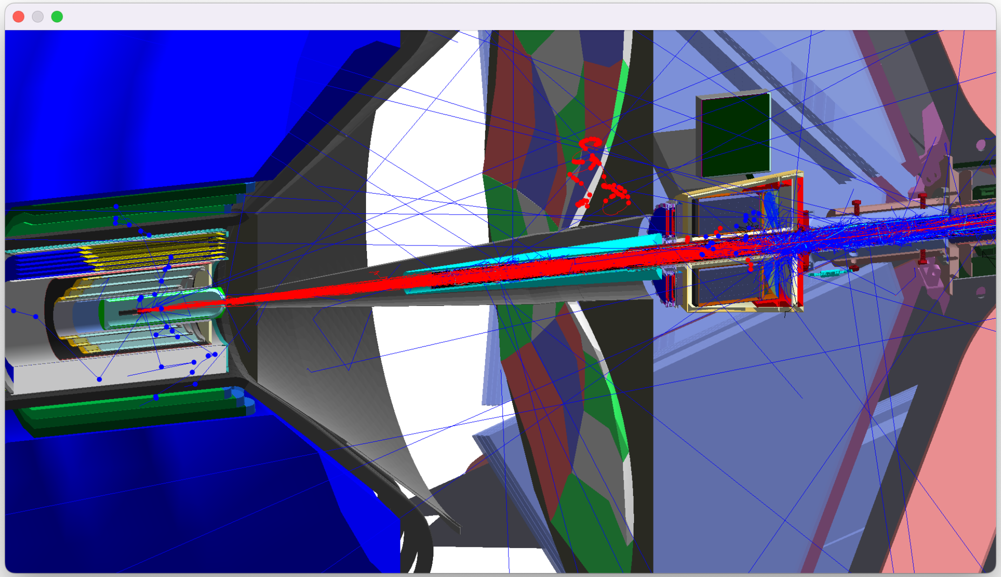
10k 10-GeV electrons with no field and with 5T field

Jefferson Lab

clas

Passive shield design

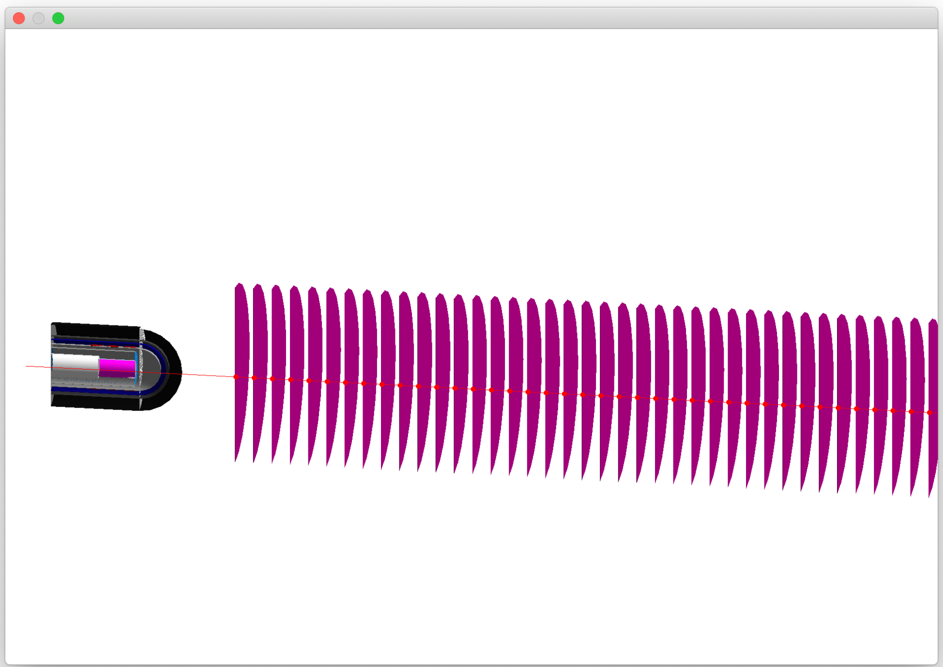
- The main absorber is a tungsten cone surrounding the vacuum pipe downstream of the target



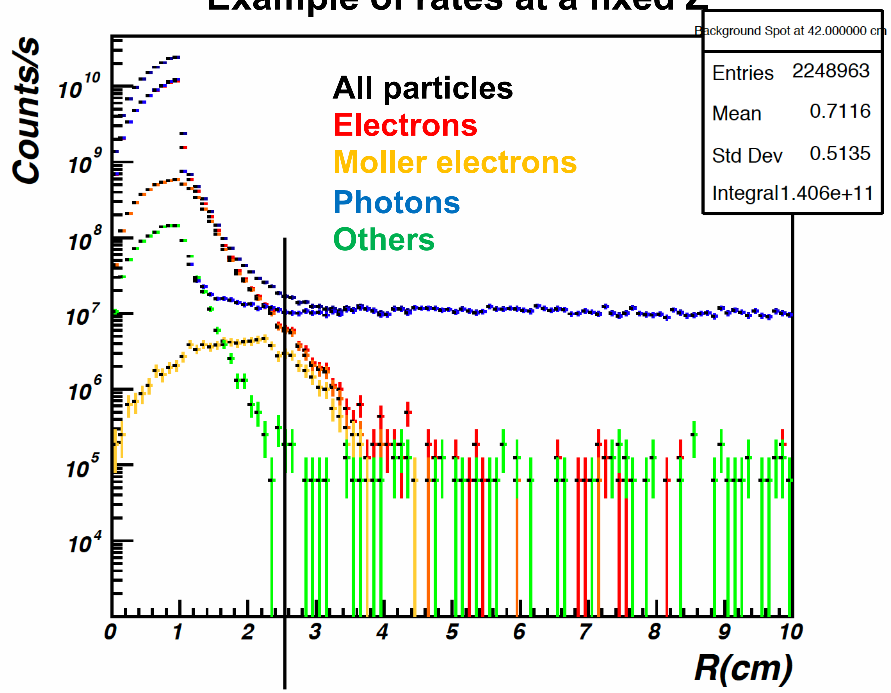
- The optimal shape of the cone (inner radius, angle, z position) depends on the desired acceptance, beam size, target thickness, and position, and determines the maximum operating luminosity for the forward detector
- Most challenging configuration simulated so far is the rastered beam used in polarized target experiments (RG-C)

Beam profile sampling

- Use "flux detectors" to sample particles passing through vertical planes at different z along the beamline
  - Record particle type, energy, coordinates, …
- Determine particle rates as a function of R and Z

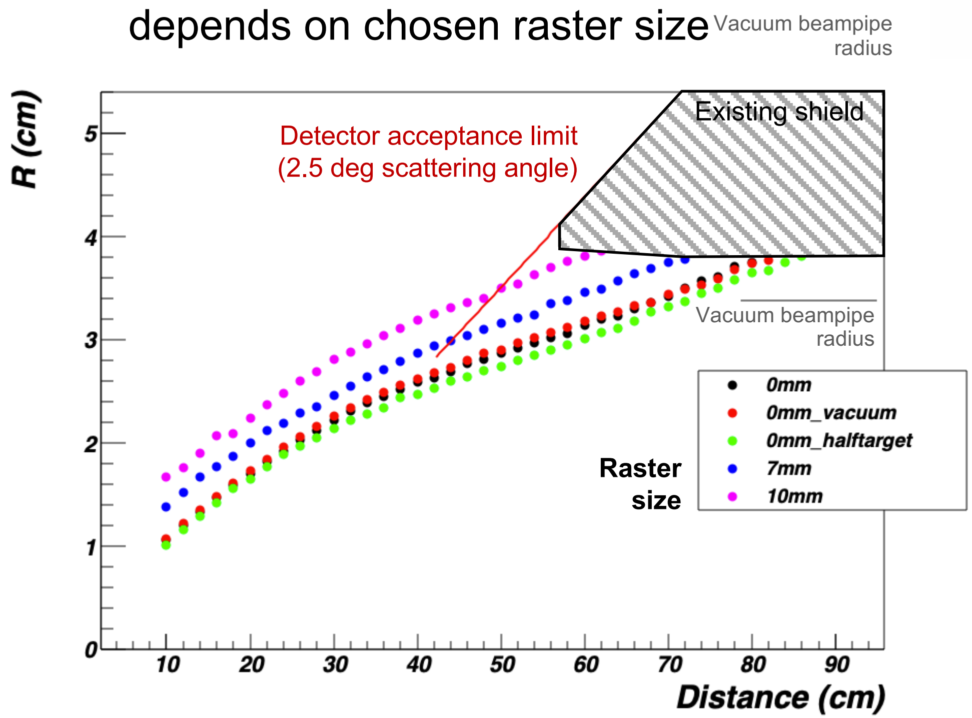


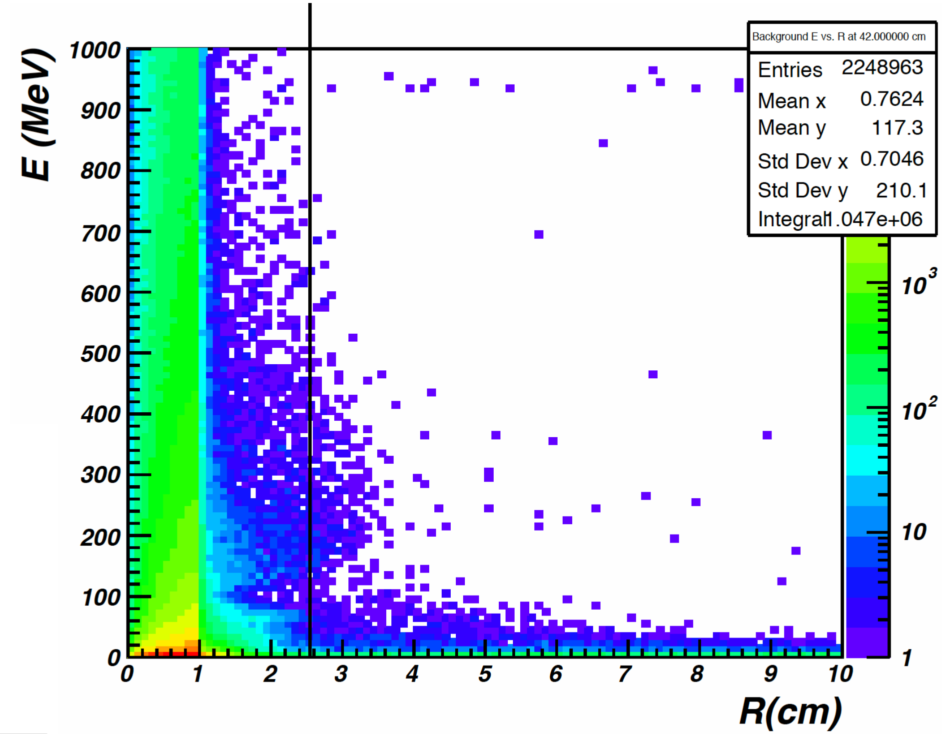
Example of rates at a fixed Z



Moller spot size

- Radius of Moller electrons' spot size is determined by the trajectory of Moller electrons with energy of 200-300 MeV that spiralize in the solenoid field
- Spot size increases slowly with z and depends on chosen raster size

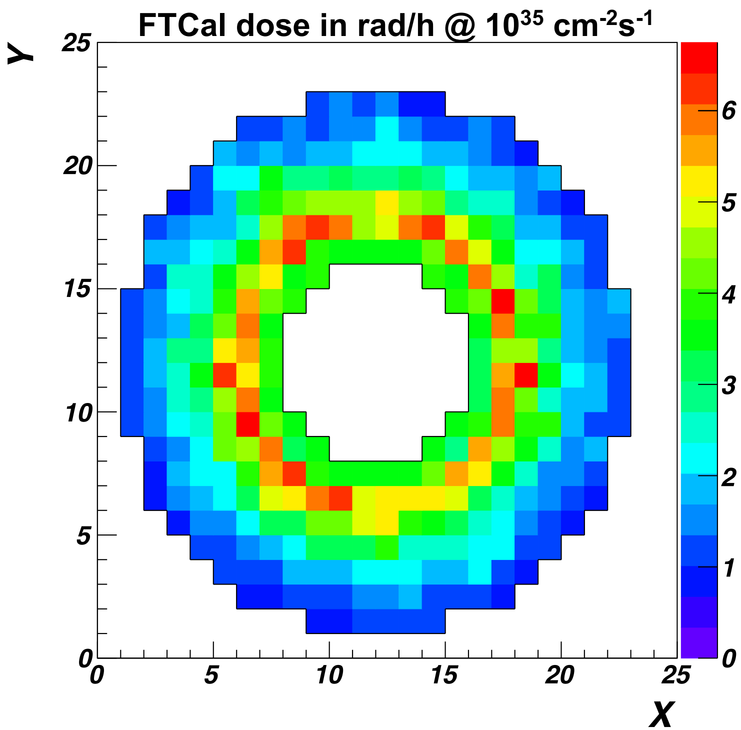


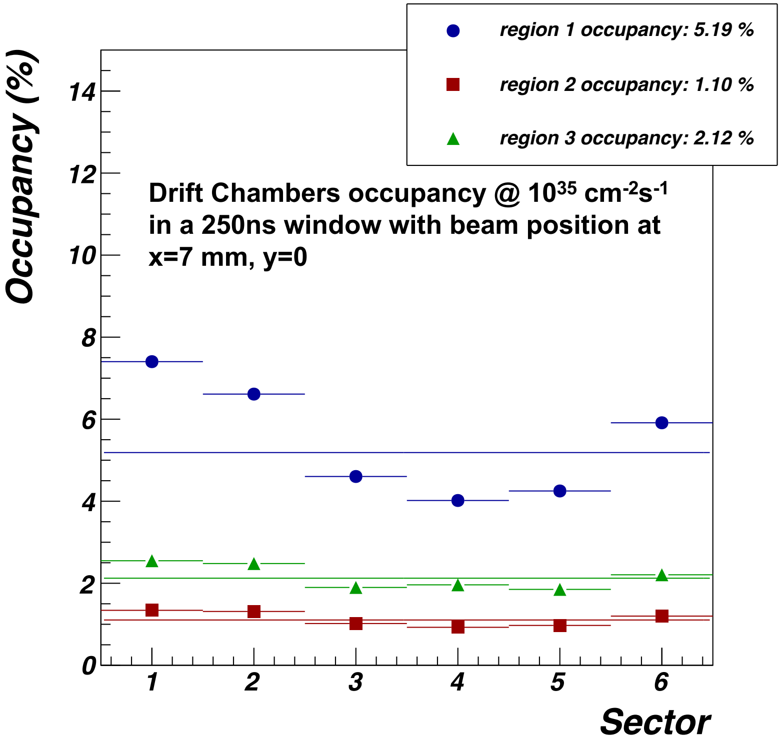


- Maximum raster size estimated to be less than 10 mm, more likely of the order of 7 mm
- The actual raster size used by the experiment was in the end 6 mm because of a misalignment of the target cell

Detector rates, occupancy, dose

- For each given shield configuration, detector rates, occupancy, and rates can be estimated as a function of raster size and/or beam position and luminosity



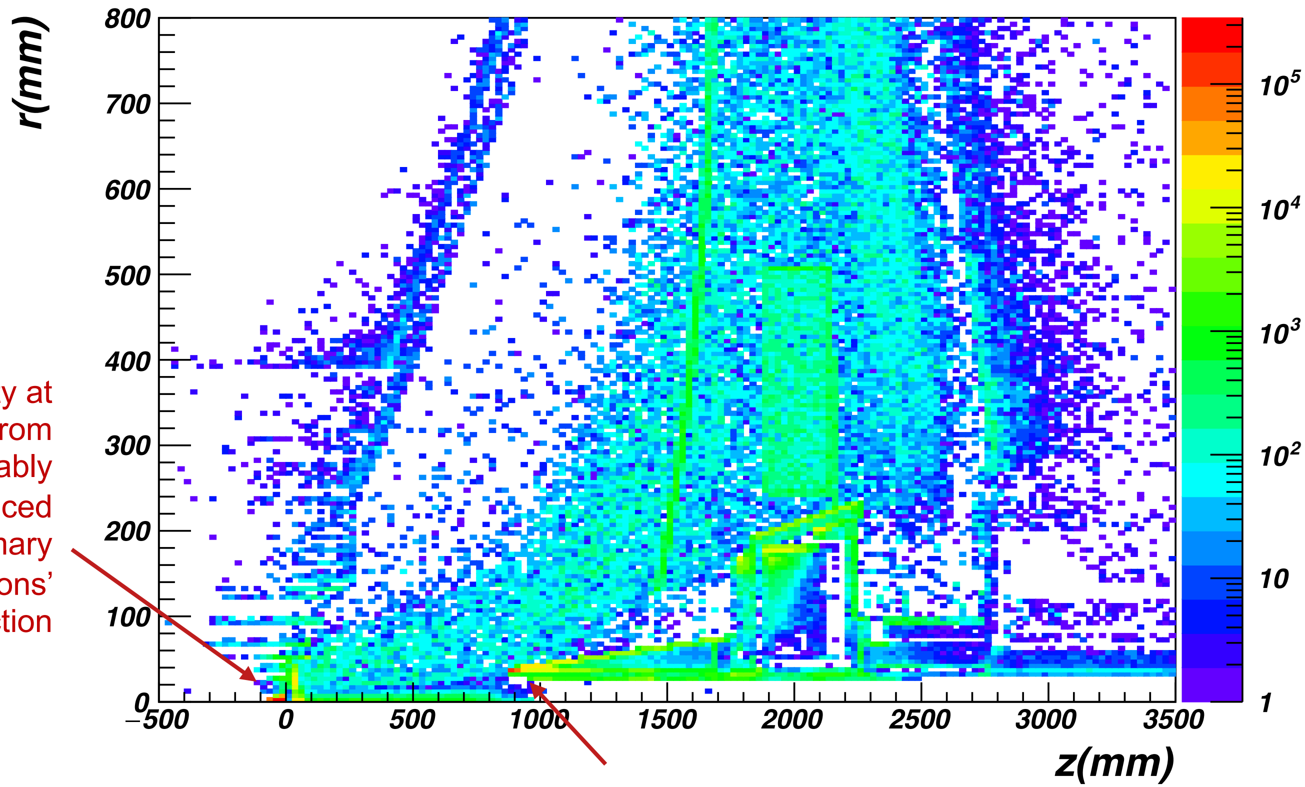


- Operating luminosity with 7 mm rastered beam was set to 0.5 x 1035cm-2s-1 based on:
  - Estimated FTCal dose rate and corresponding light loss due to radiation damage
  - DC average occupancy and dependence on beam position

Background origin

- Origin of detected background hits can be studied by recording their "mother" particles and keeping track of production of secondaries throughout the GEANT4 processing:
  - Useful for finding hot spots
  - Can be produced per particle type etc.

Origin of particles creating hits in Drift-Chamber Region 1



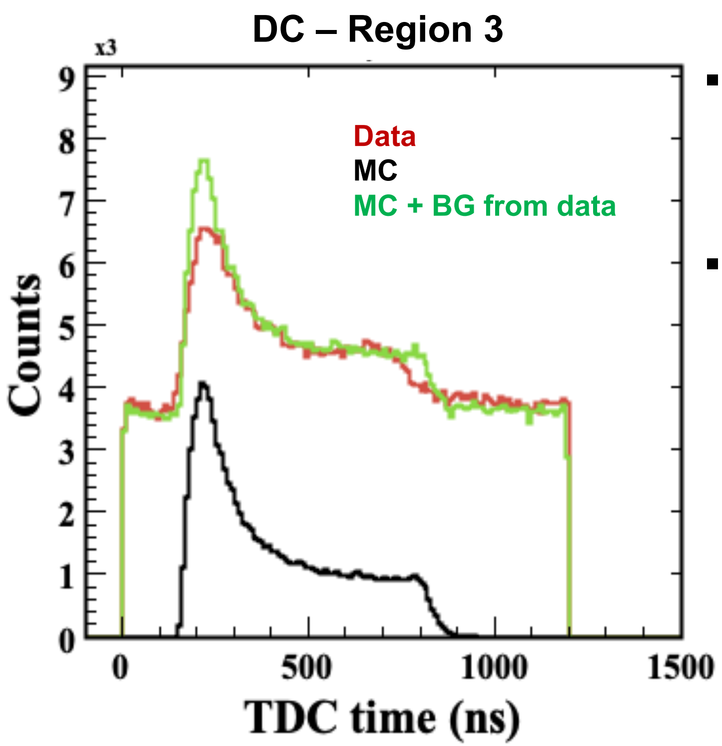
Highest intensity at the target, i.e. from particles, probably photons, produced from the primary beam electrons' interaction

Second highest intensity from the cone entrance

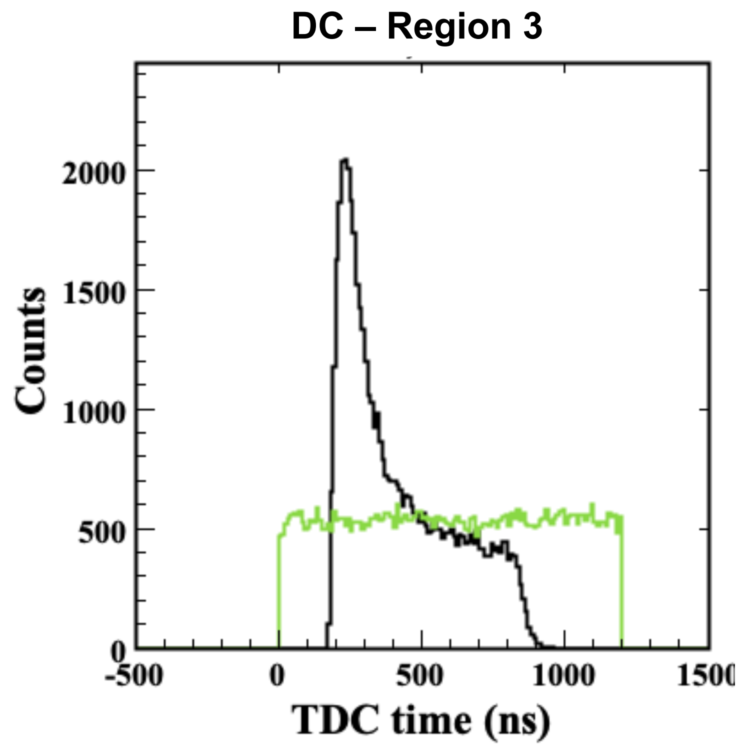
Detector response

- Background hits can be turned into detector signals using the same “digitization” algorithms used for the true hits:
  - Study impact on detection of the true hits and ultimately on particle reconstruction
  - Study pile-up, dead-time effects, …

Need to account for the detector response vs. time, readout windows, and readout electronics behavior



- Background hits contribute with a “flat” pedestal being uniformly distributed in time
- To obtain the same distribution from simulations, it is necessary to simulate beam particles:
  - From –Δt to + Δt, with Δt being the detector readout window,
  - With the correct multiplicity for the chosen luminosity



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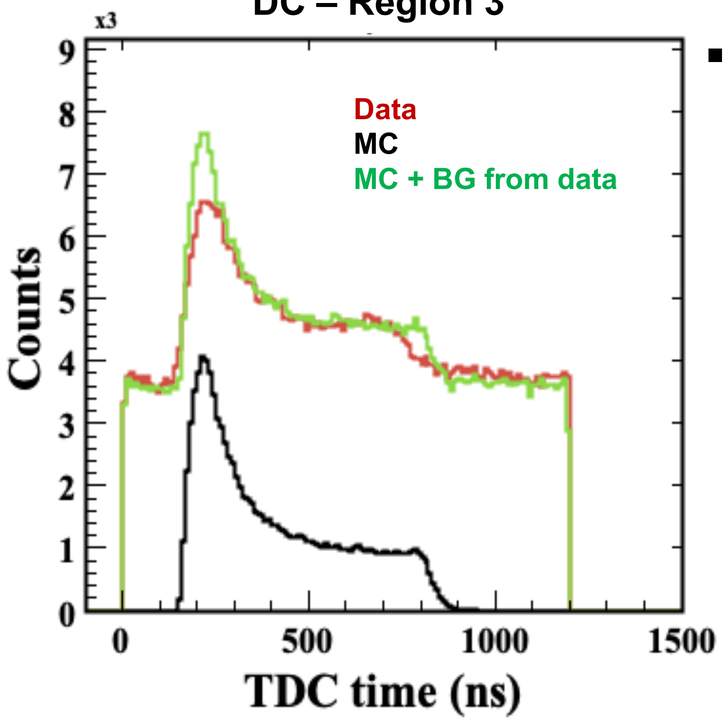
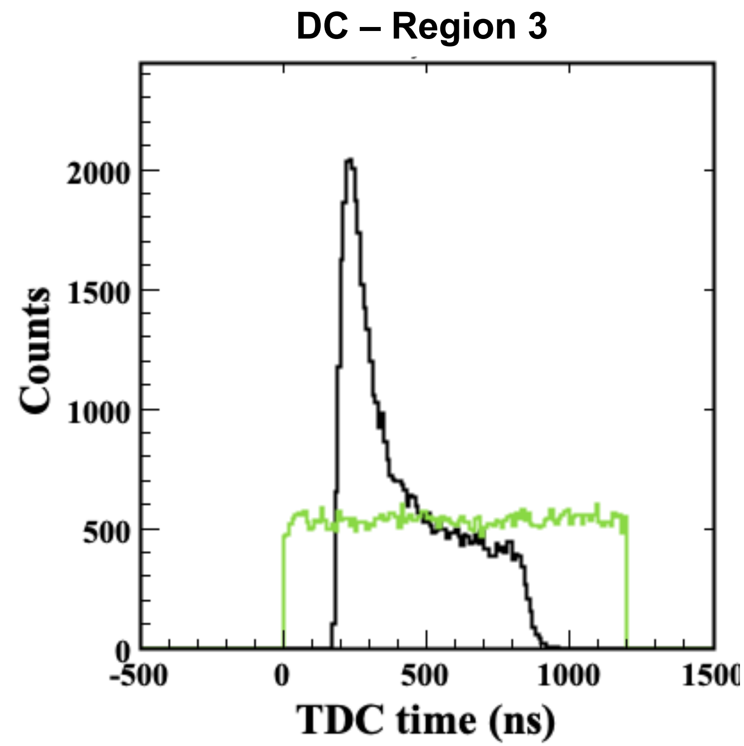


- If occupancies are high, it is necessary to account for pile-up between true and background hits
  - How the measured detector signal is affected
  - How the readout electronics behave with multiple hits



Summary

- Detailed beam background simulations for CLAS12 were performed with GEANT4 to:
  - Design shielding
  - Optimize the detector configuration
  - Determine limiting factors to the maximum luminosity
  - Estimate background rates, occupancies, and radiation doses
  - Estimate the impact on the “true” signal detection and particle reconstruction efficiency and resolution
- Results have been shown to match reality quite well
- These studies have become quite standard for planning future data taking in new configurations
- Currently being done for the CLAS12 high-luminosity upgrade