Geant4 Simulation Studies for the MOLLER Experiment

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On behalf of the MOLLER Collaboration

Winter Hall A Collaboration Meeting
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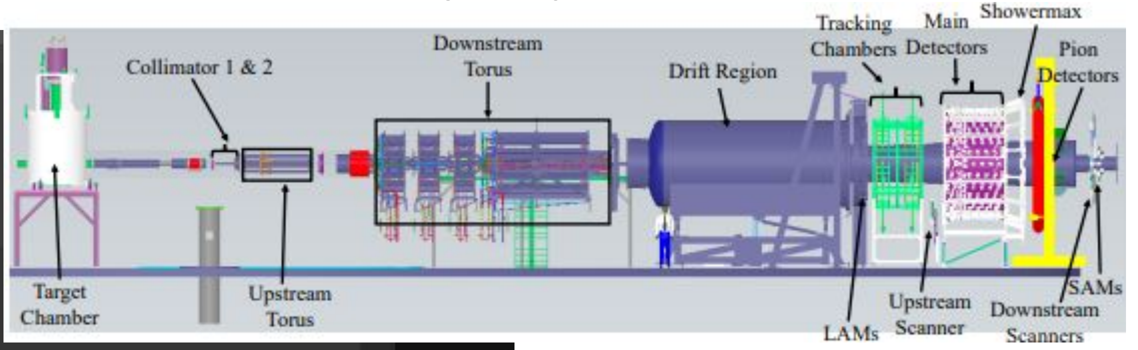
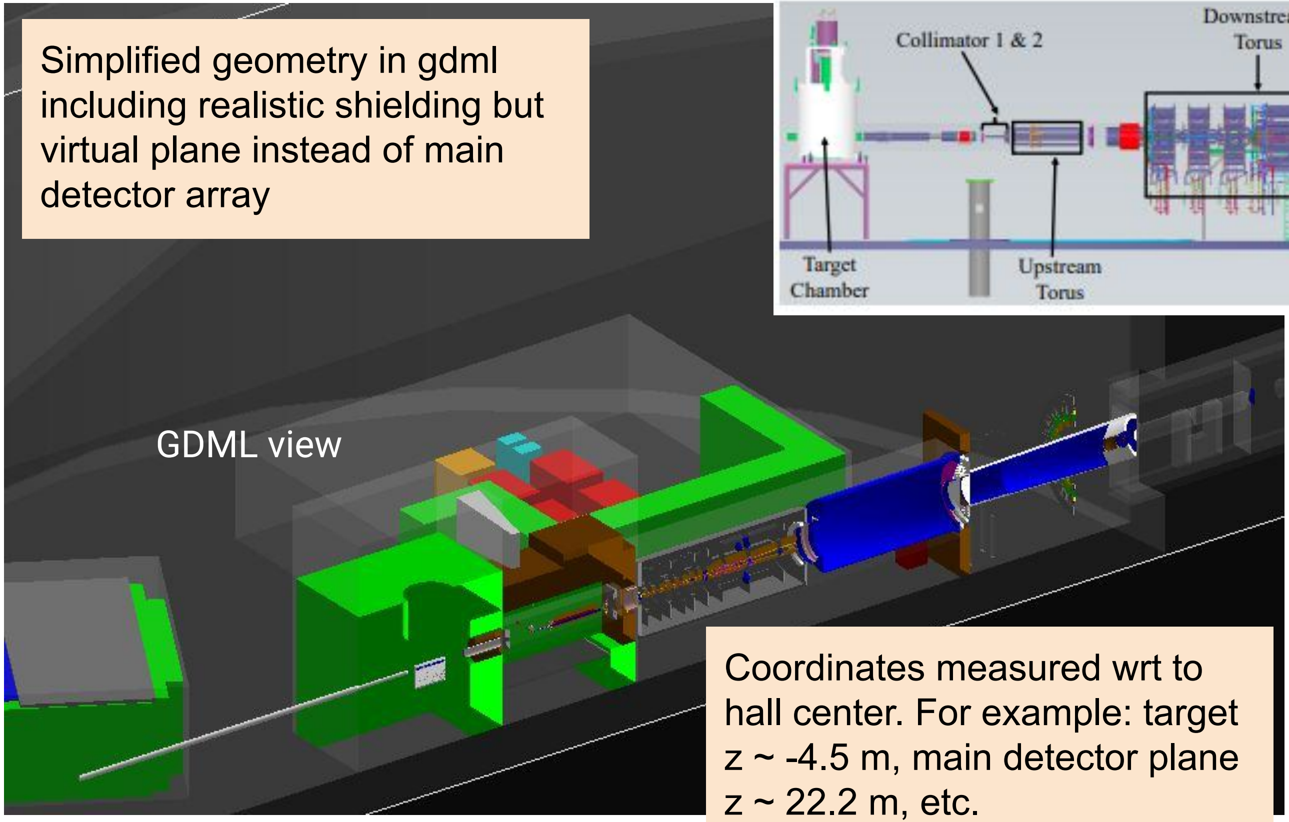
Outline

1) Simulation Framework
    a) Geometry
    b) C++ core (Physics Generators)
    c) Benchmark plots
2) Shielding studies
    a) Hall site boundary dose
    b) Dose inside electronics and magnet power supply bunkers and detector regions
3) Spectrometer Studies
    a) Clean transport of central beam to dump
    b) Dose in spectrometer insulation
4) Ferrous Material Studies
5) Detector Studies
    a) Main detector tile optimization and deconvolution Analysis
    b) Dedicated optical simulations to tune light guide parameters
6) Conclusion and Upcoming Studies

Remoll Simulation Framework - GDML Geometry

CAD view





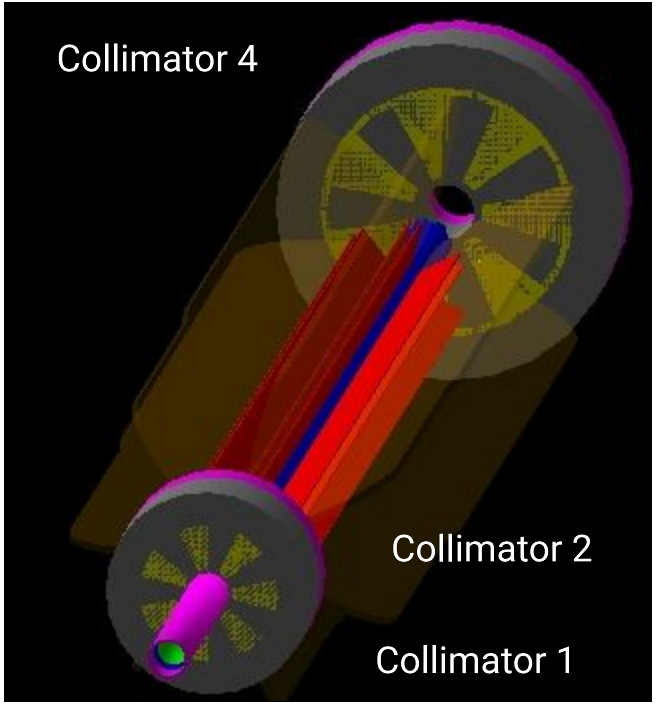
Simplified geometry in gdml including realistic shielding but virtual plane instead of main detector array

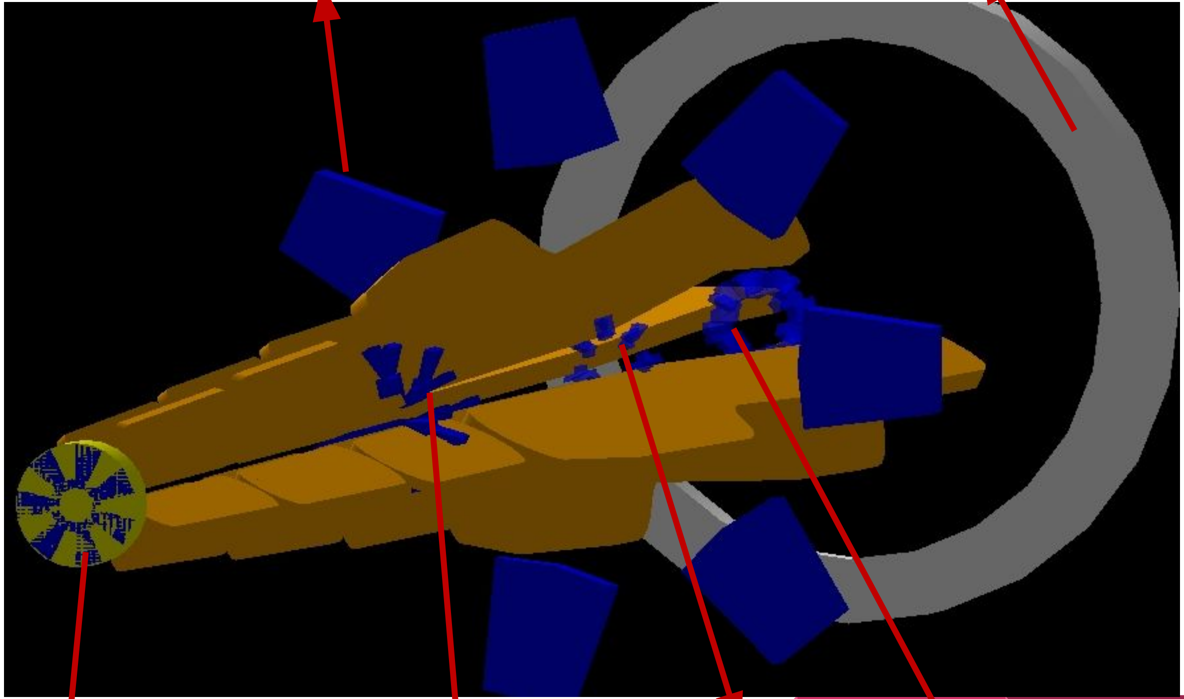
GDML view

Coordinates measured wrt to hall center. For example: target z ~ -4.5 m, main detector plane z ~ 22.2 m, etc.

GDML interface used to keep geometry development independent from simulation core.

GDML geometry



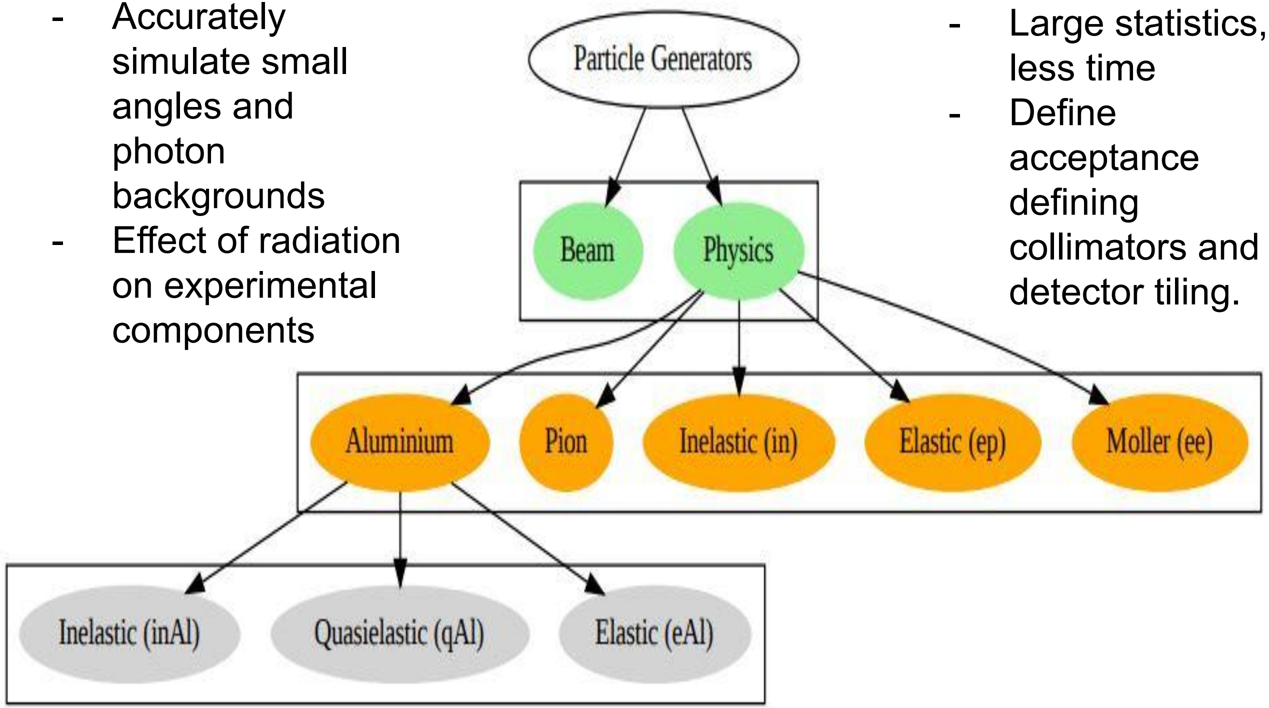


Collimators - CW90, some Cu in 2 and 4
Lintels and Collars - Lead

Remoll Simulation Framework - C++ Core

Beam generators:

- Accurately simulate small angles and photon backgrounds
- Effect of radiation on experimental components



Physics generators:

- Large statistics, less time
- Define acceptance defining collimators and detector tiling.

QGSP_BERT_HP used as physics list (accurately simulate neutrons upto low energies)

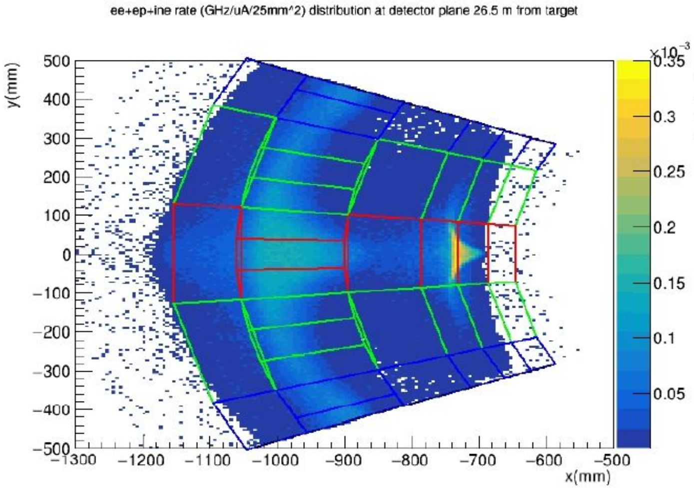
Magnetic field maps developed by TOSCA

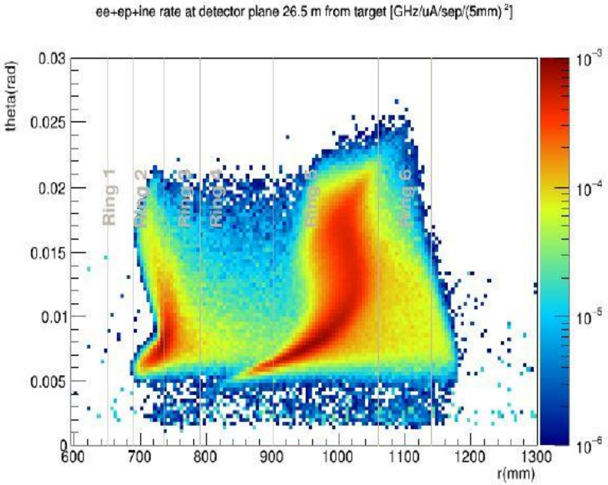
Geant 4.10.6 and 4.10.7 used for all studies

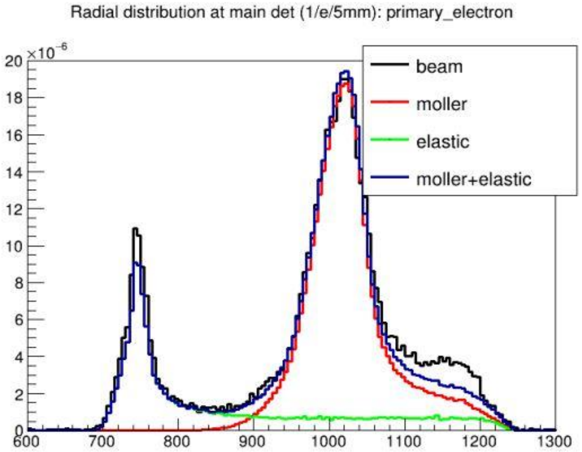
100 M events for beam generator and 10-20 M events for physics generators are required for most studies

Remoll used for all simulation studies except for dedicated detector optical simulations

Remoll Simulation Framework - Benchmark Plots







Clean separation of moller signal peak from backgrounds at the main detector plane provided by spectrometer magnets

Moller peak - ring 5
Elastic peak - ring 2 and 3

Default angular ranges for physics generators:

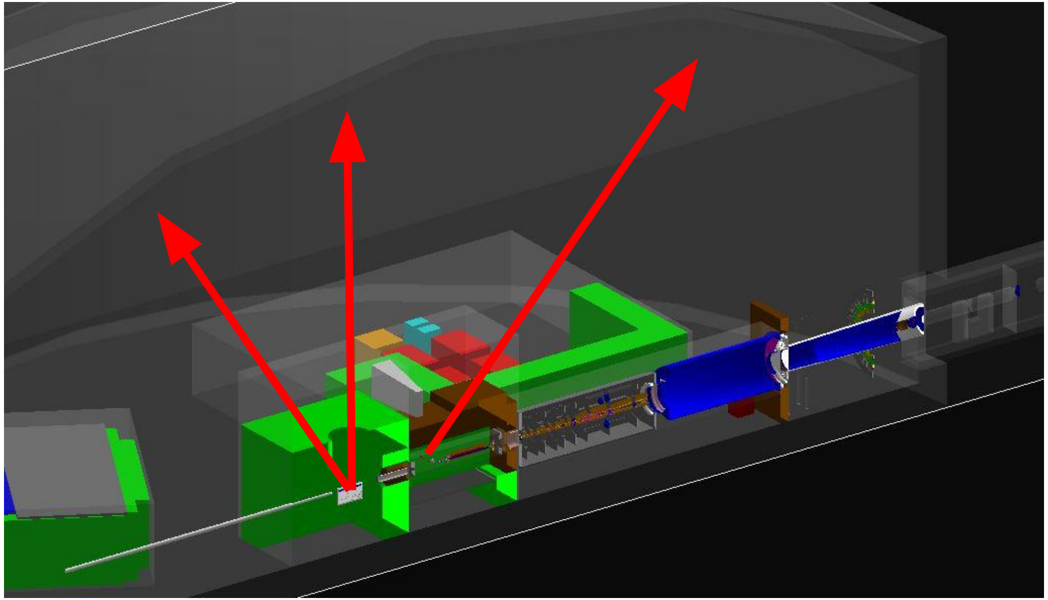
1) *Moller : 30-150 deg in COM*
2) *Elastic: 0.1-2 deg in lab*
3) *Inelastic: 0.1-5 deg in lab*

Physics generators combined match beam generator radial distribution at main detector for primary particles within acceptance

Hall Boundary Radiation Dose

High current, high energy => Need to carefully consider prompt radiation dose rate measured with radiation monitors around hall perimeter.

Target and collimator-1 => Greatest sources



Focus on >=30 MeV neutrons reaching the roof of the hall => Greatest shower probability

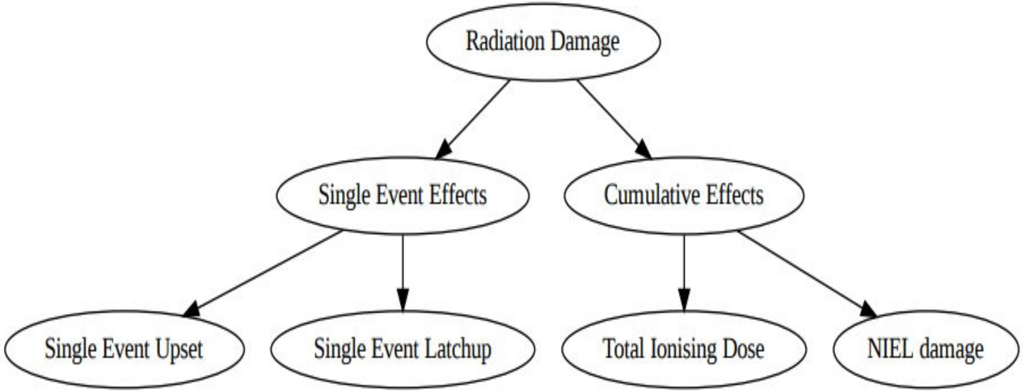
Estimated PREX-2 dose: 0.9-2.2 mrem/yr
Measured dose: 953 MeV energy, ~70 uA current, 114 C charge on Pb-208 target => 1.24 mrem/yr

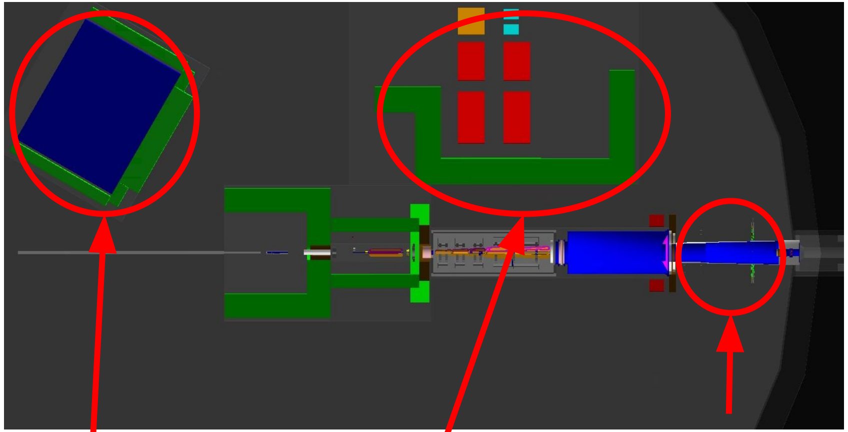
MOLLER estimate: 11 GeV energy, 65uA current and ~660 C charge on LH2

Method	Estimated Dose Rate (mrem/yr)
Geant4	5.6 +/- 3.0
Fluka	6.3 +/- 1.1

Estimated hall boundary dose rate well under DOE/JLAB prescribed limits of 100/10 mrem/yr.

Radiation effects on electronics





Detector Region

Radiation sensitive components => PMTs, bases, GEM electronics

Single event effects not a concern based on experience with similar flux in the past

PMT TID ~ 60 kRad, a factor of 5 below safety limit for degradation and **NIEL dose ~ 1e12 n 1MeV eq**

Magnet Power Supply Bunker (Concrete)

Houses spectrometer magnet power supplies and miscellaneous electronics

Radiation level inside bunker ~ 15 kRad satisfies engineering controls

SBS Bunker (Iron/Steele)

Houses DAQ electronics

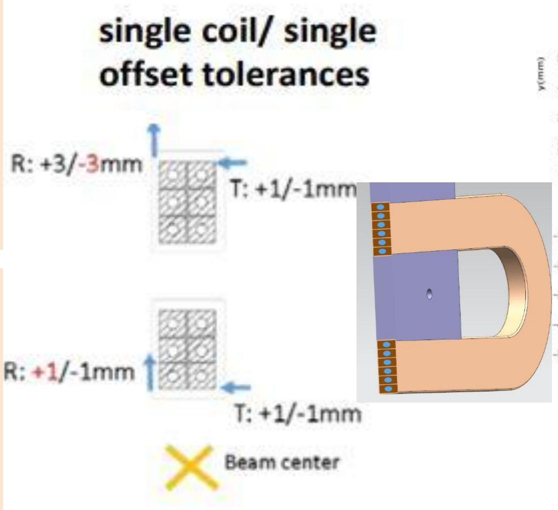
NIEL dose inside bunker ~ 2.2e9 n 1MeV eq

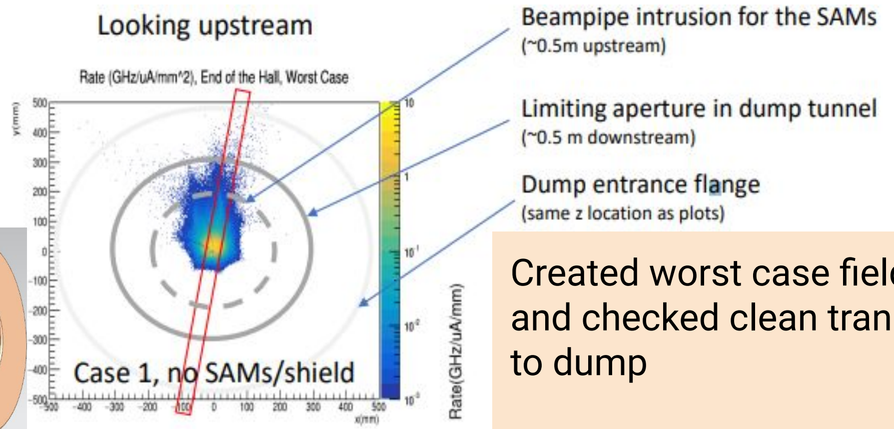
TID under control in sensitive areas and NIEL dose well below commercial electronics safety limit 1e13 n 1MeV eq

Spectrometer Magnet Radiation Studies

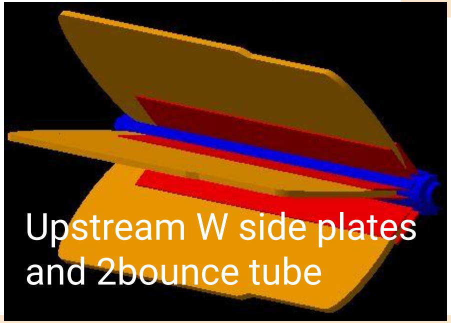
Single coil offset position tolerances = Allowed change in asymmetry/slope

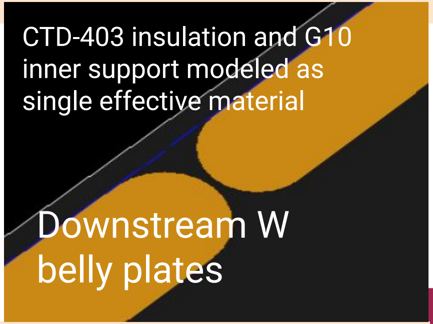
Consider geometric constraints and clearance from particle envelopes

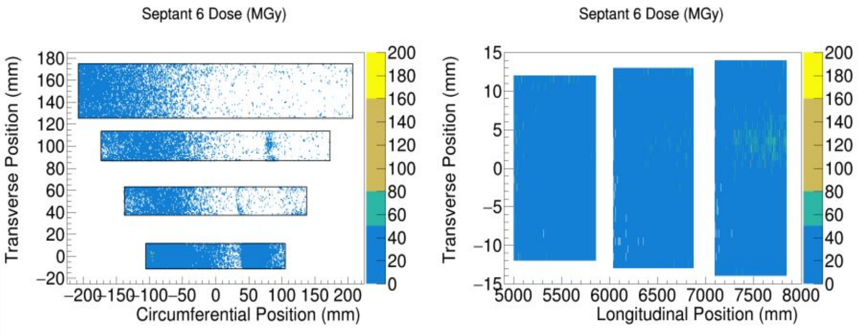




Created worst case field maps and checked clean transport to dump







3 mm W does the trick everywhere.

Optimized shielding on spectrometer coils for worst case configs. Maximum dose at most spots contained under ~100 MGy for both upstream and downstream spectrometer coils

Effect of Ferrous Materials

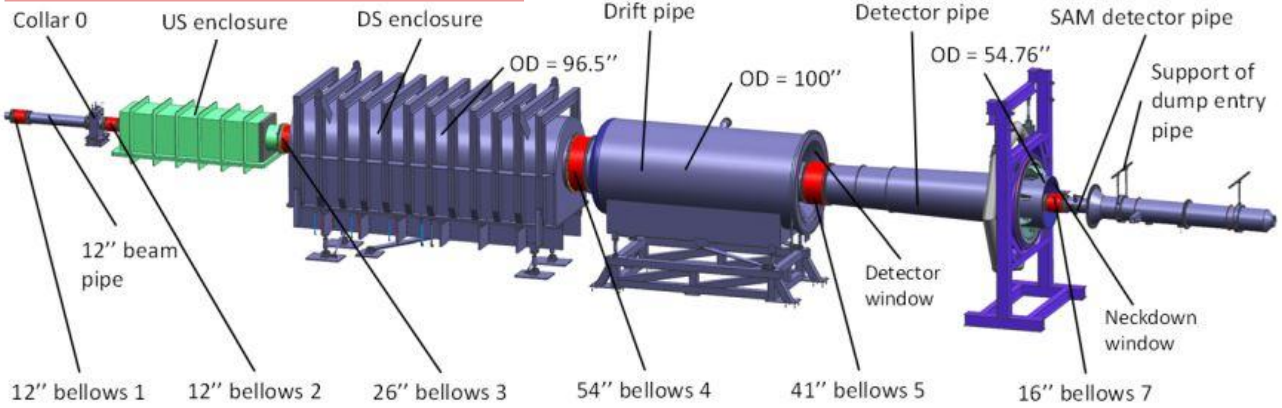
Source of high asymmetry backgrounds

Ferrous
Stainless steel needed for some bellows, some support and service components.
Ferrous steel in other locations, including small components in support structures and motion mechanisms.

Non-Ferrous
Most components from aluminum, bellows near target use Inconel625.

"Biased" simulation to show limits (depending on material) of 10^{-6}-10^{-13} events per beam e^-

1) Virtual planes in possible location of Ferrous materials
2) Run many (~100M) beam events for population on those materials
3) Run secondary simulation of that population, into ferrous component. Measure signal at main detector.



Minimized ferrous materials in high flux regions.

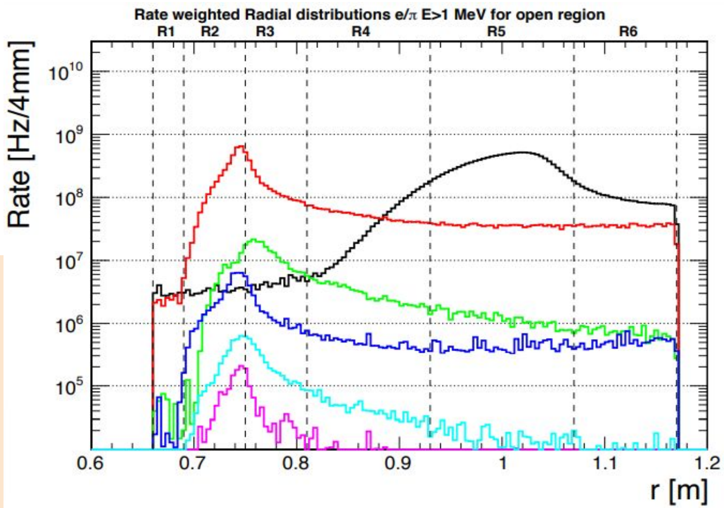
Ferrous material backgrounds at detector planes under control.

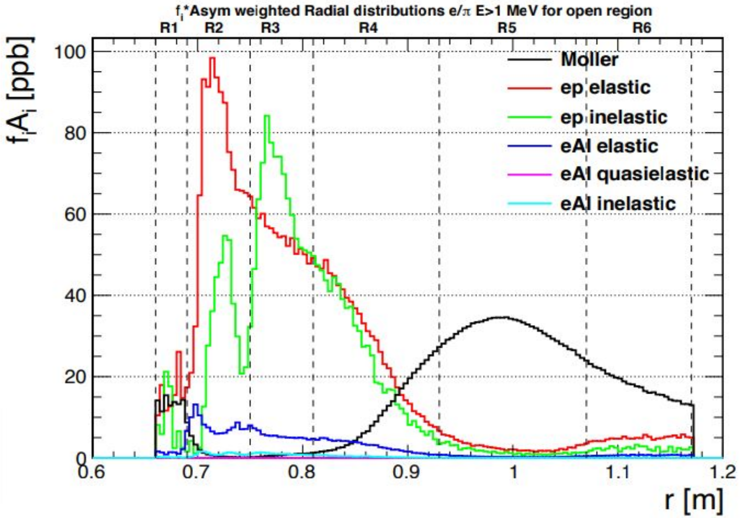
Detector Tile Optimization and Deconvolution Analysis

Analysis based on virtual detector plane at 22.2 m from hall center

Main detector tile dimensions initially guessed from dilution*asymmetry plots that help to distinguish kinematic regimes

Can recover simulated asymmetry with desired relative uncertainty based on 5 process deconvolution analysis



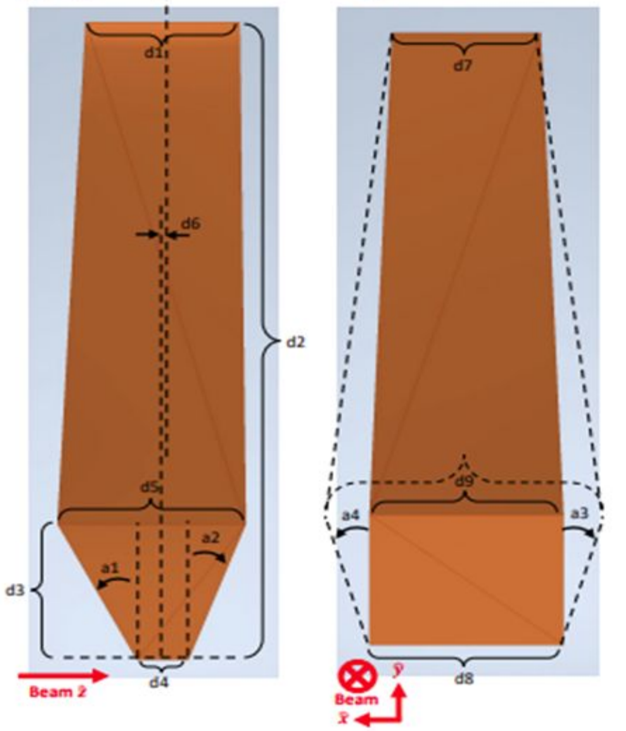


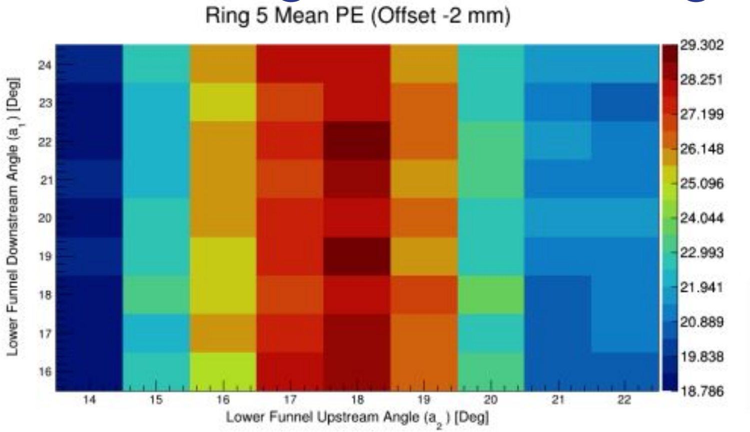
Overall			
Name	Asymmetry	uncert[ppb]	relative uncer
moller	-34.72	0.72	2.09%
ep Elastic	-29.05	1.58	5.45%
ep Inelastic W1	-523.36	77.23	14.76%
ep Inelastic W2	-532.61	51.86	9.74%
ep Inelastic W3	-439.16	98.80	22.50%

Optical Simulations for Tuning Detector Lightguide

Simulated 8 GeV electrons incident perpendicularly on quartz and light guide sections separately

Light guide parameters and possible variations





Simulation benchmarked with beam tests at Mainz and cosmic tests for Ring 5 and 6

Ring	d4 (mm)	a1 (mm)	a2 (mm)	d6 (mm)	d3 (mm)	SS (mm)	Mean PE	Excess noise (%)
2	20	18	22	-2	75	400	22	10
3	20	18	22	-2	75	300	22	10
4	20	17	22	3	75	200	22	10
5	15	18	19	-2	75	0	25	3.5
6	20	17	20	0	83	90	19	10

Conclusion

Geant4 simulation studies play an important role in ensuring efficiency and safety of equipment concerned with spectrometer magnets, detectors, and shielding.

Completed significant studies

1) Hall boundary dose under control
2) Spectrometer magnet coils well shielded
3) Background levels at detector under control
4) Ferrous materials minimized in high flux areas
5) Detector tiling dimension and positioning optimized
6) Deconvolution analysis performed to show robustness of analysis
7) Dedicated optical sims to tune lightguides

Upcoming studies

1) Improve details in GDML geometry (real detectors instead of virtual plane) and look at cross-talk.
2) For spectrometer dose, implement detailed conductor cross-section for high dose absorbing segment. Compare against stress analysis from CTD403 irradiation studies.

etc….

Acknowledgement

Remoll Simulation Framework Maintenance and Development: Rakitha Beminiwattha and Wouter Deconinck

Shielding and deconvolution studies: Ciprian Gal, Zuhal Demiroglu, and Sakib Rahman

Collimator design and particle envelope creation: Chandan Ghosh

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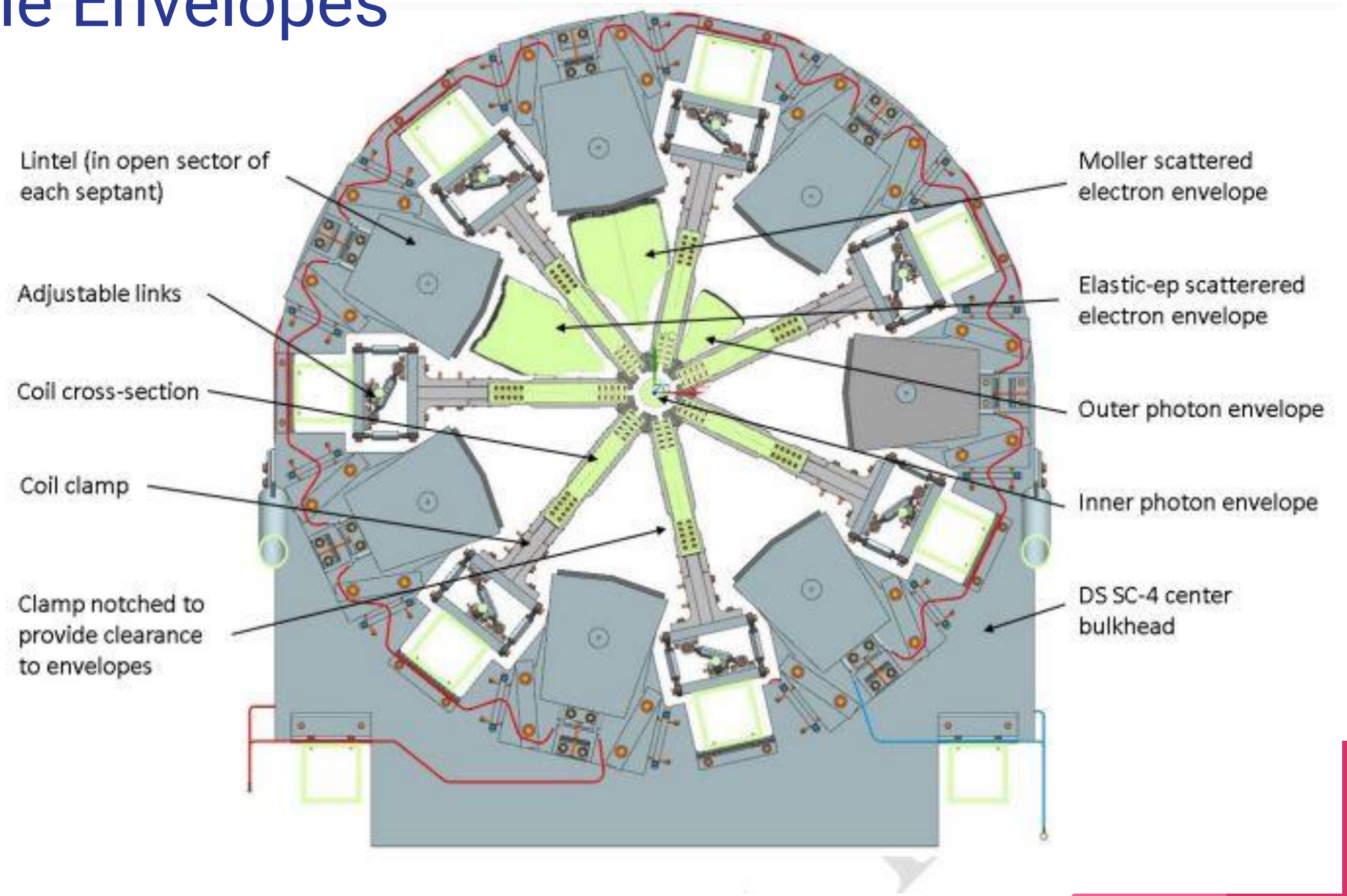
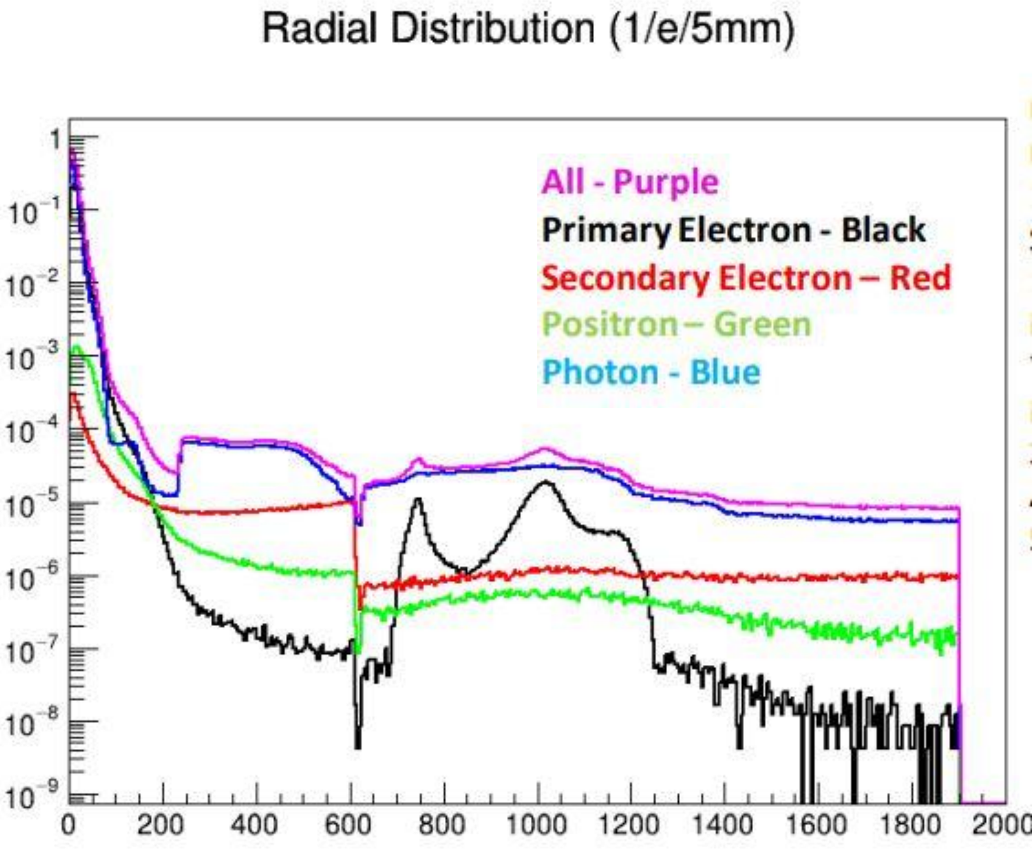
Backup Slide

Particle Envelopes



Photon Backgrounds at Main Detector Plane (z=22.2m)



Raw photon background rate relatively high compared to signal at detector plane but effect mitigated by comparatively low PE response (1/500) of Cerenkov detectors for photons relative to signal electrons