GEANT4 Simulation of MOLLER Experiment

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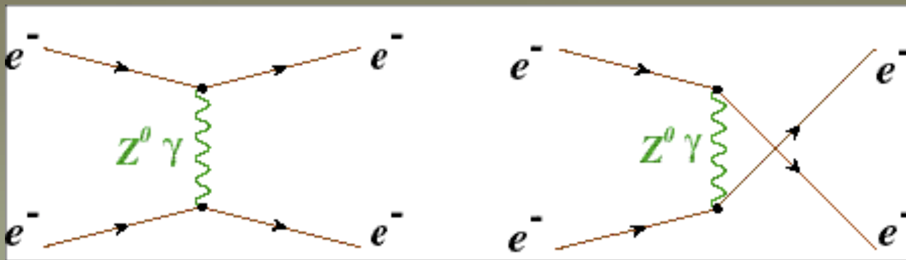
UVa

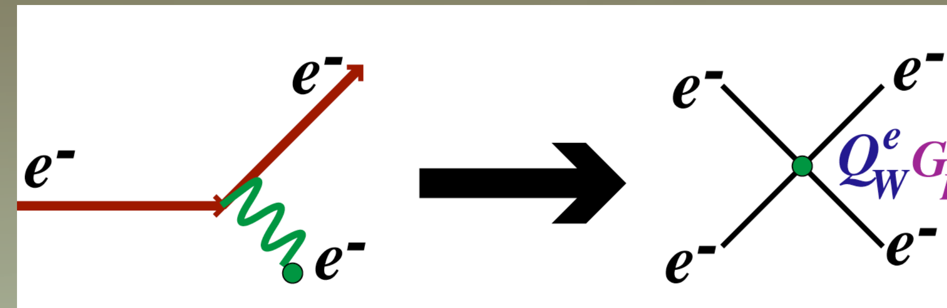
(for Dustin McNulty, Luis Mercado and the MOLLER Collaboration)

Outline

- Introduction to the MOLLER experiment
- Simulation Overview
- Spectrometer Design
- Generators
- Collimation

Møller Scattering





Purely leptonic reaction

$$\mathbf{A_{PV} = -mE\frac{G_F}{\sqrt{2}\pi\alpha}\frac{16\sin^2\Theta}{(3+\cos^2\Theta)^2}Q^e_W}$$

Derman and Marciano (1978)

$$A_{PV} \propto m_e E_{lab}(1-4\sin^2\vartheta_W)$$

Small, well-understood dilution

$$\frac{\delta(\sin^2\vartheta_W)}{\sin^2\vartheta_W} \cong 0.05\frac{\delta(A_{PV})}{A_{PV}}$$

$$\sigma \propto \frac{1}{E_{lab}}$$ ⇒ ***Figure of Merit rises linearly with E_{lab}***

SLAC: Highest beam energy with moderate polarized luminosity

JLab 11 GeV: Moderate beam energy with LARGE polarized luminosity

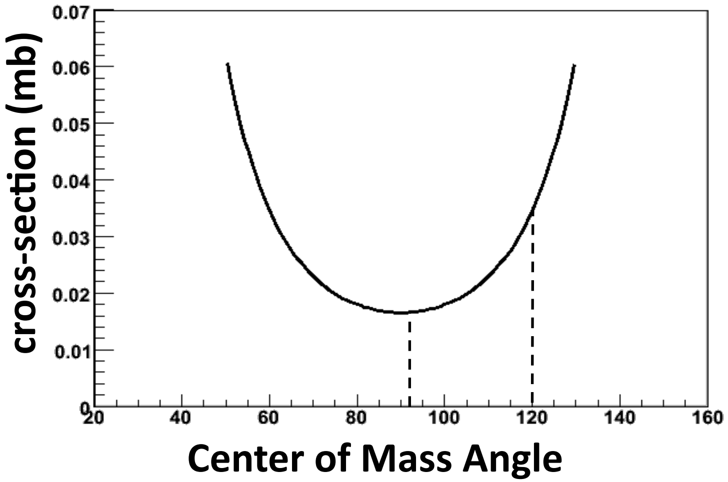
Slide: K Kumar

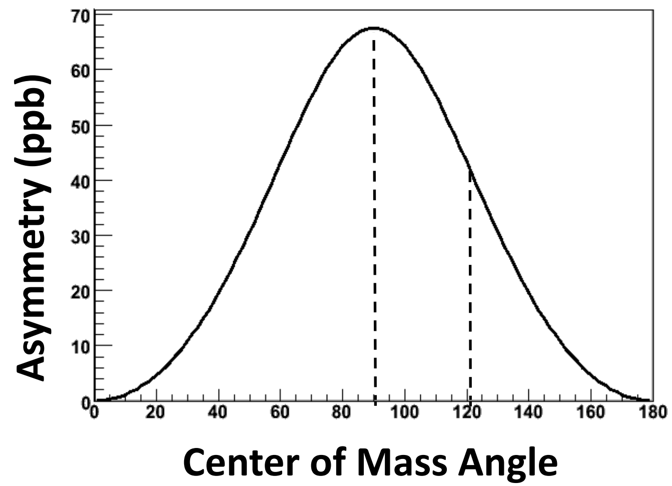
MOLLER Experiment

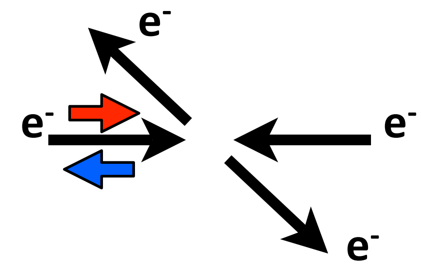
Measurement Of Lepton-Lepton Electroweak Reaction

- E_{beam} = 11 GeV
- A_{PV} = 35.6 ppb
- $\delta(A_{PV})$ = 0.73 ppb
- $\delta(Q^e_W)$ = ± 2.1 (stat.) ± 1.0 (syst.) %
- 75 µA 80% polarized
- $\delta(\sin^2\theta_W)$ = ± 0.00026 (stat.) ± 0.00012 (syst.) ~ 0.1%
- ~ 38 weeks (~ 2 yrs)

Spectrometer Concept

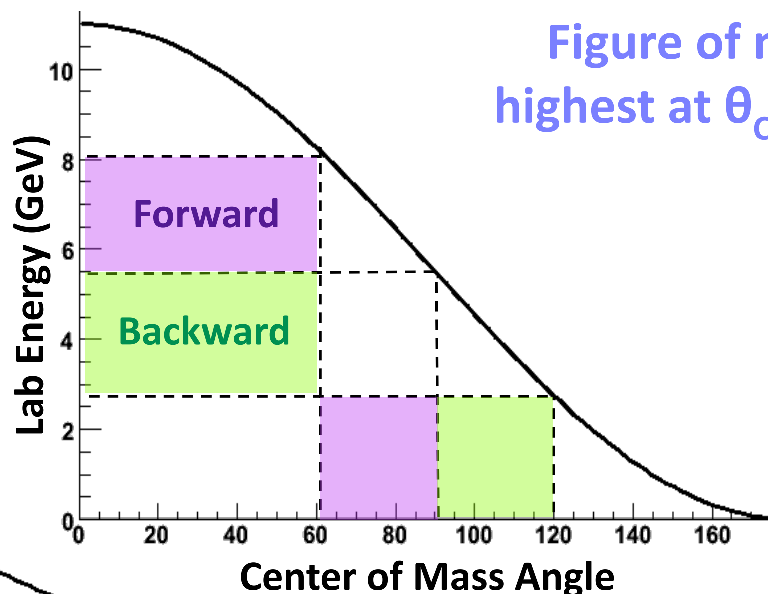






identical particles

Highly boosted lab frame



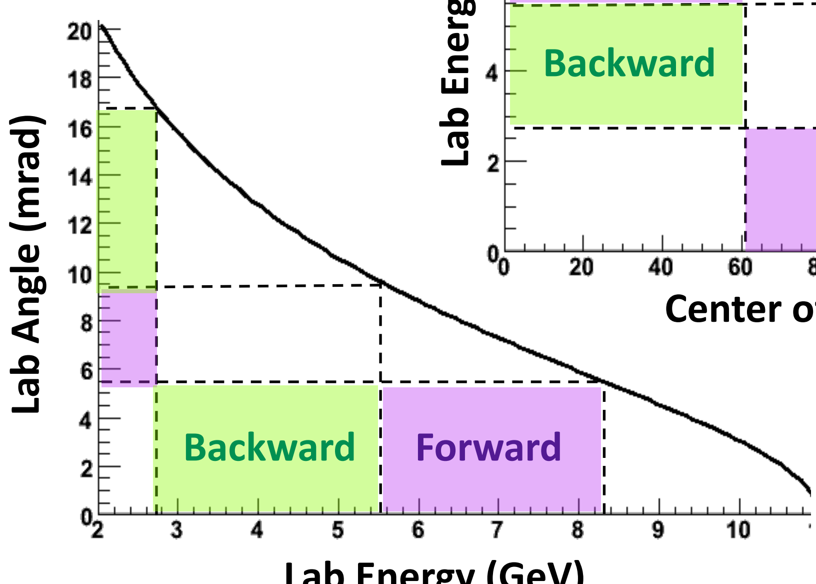
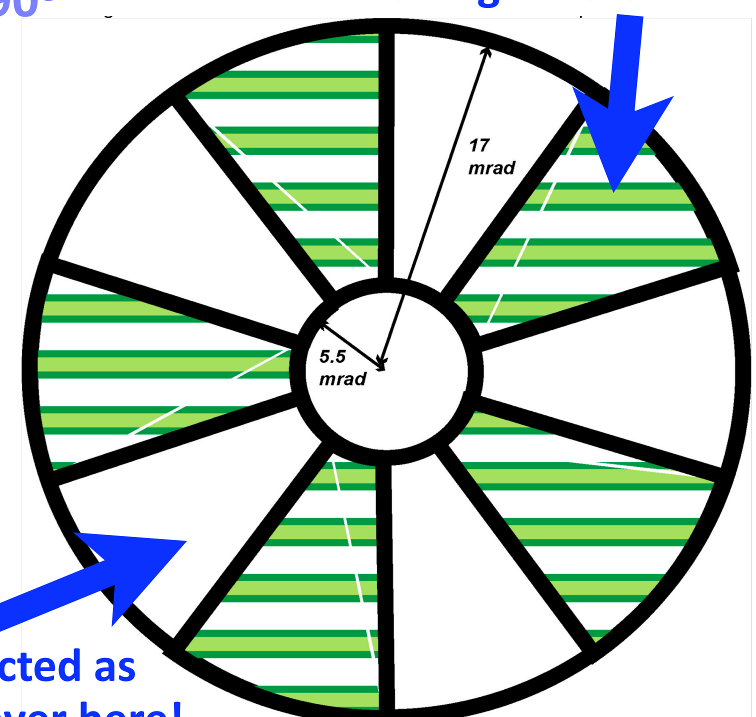


Figure of merit highest at θ_{CM} = 90°

All of those rays of θ_{CM}=[90,120] that you don't get here...

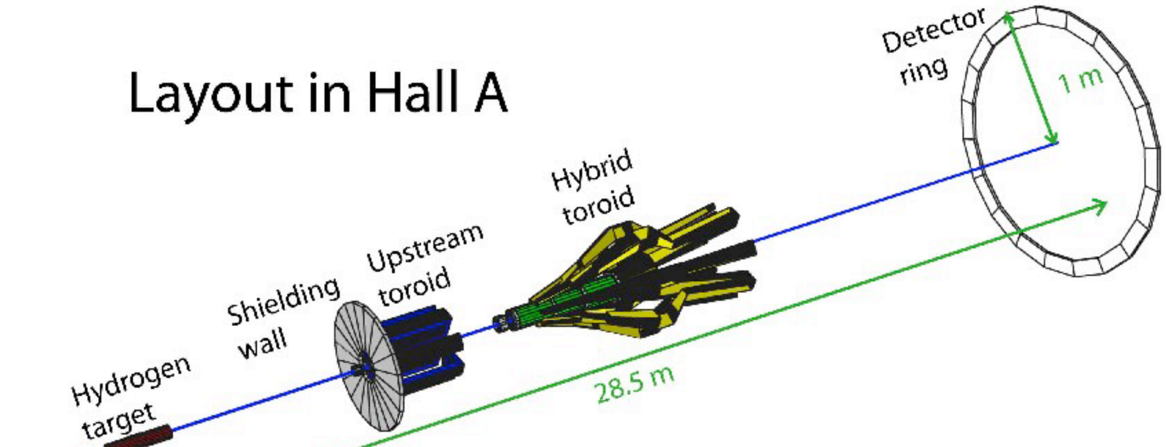


... are collected as θ_{CM}=[60,90] over here!

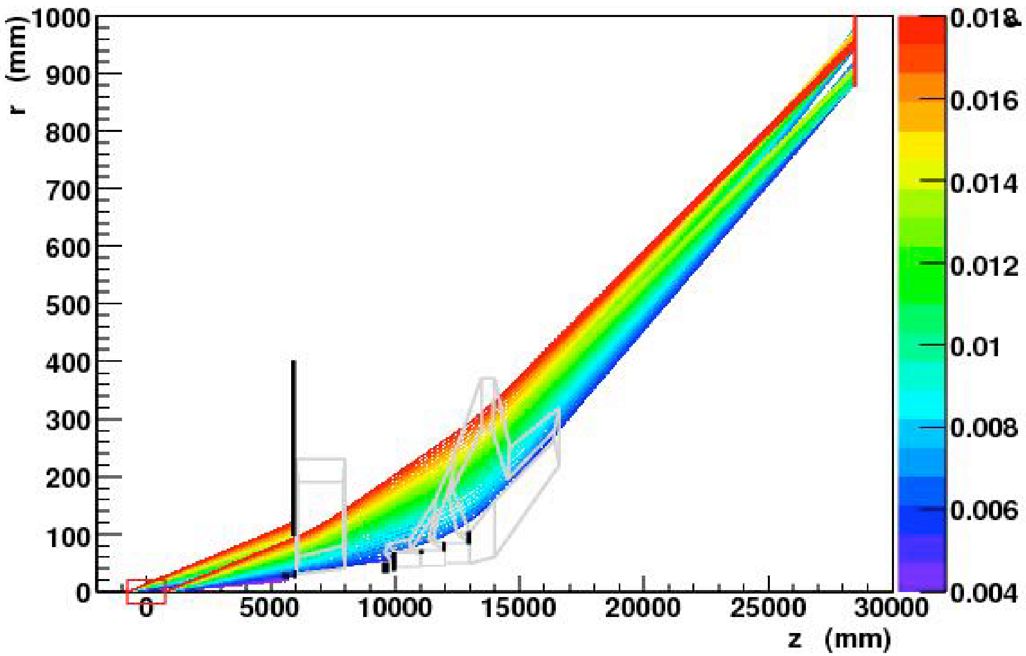
Slide: K Paschke

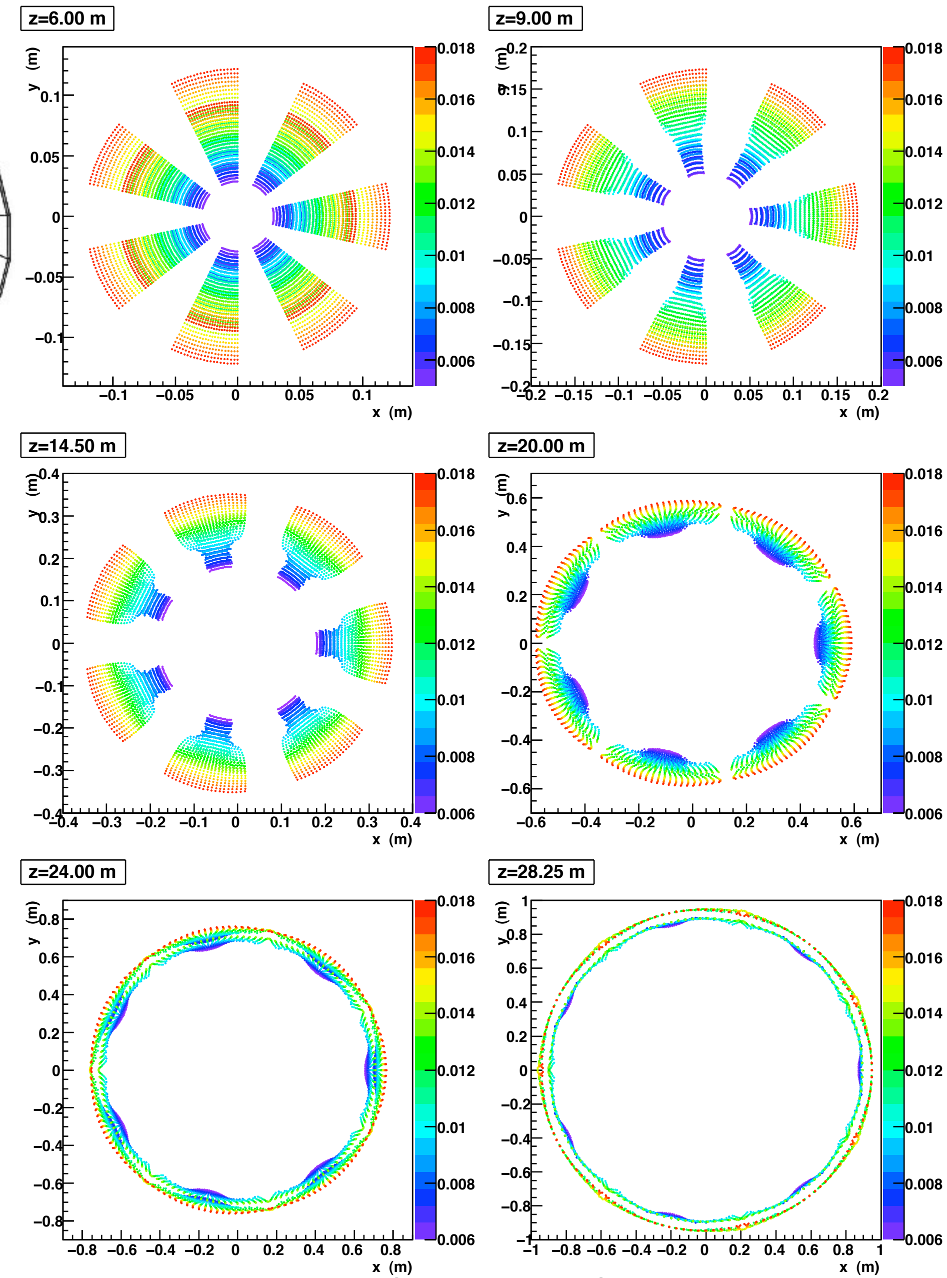
Two Toroid Spectrometer

Layout in Hall A



1 meter radial focus, 30 meters from target
Clean separation from backgrounds



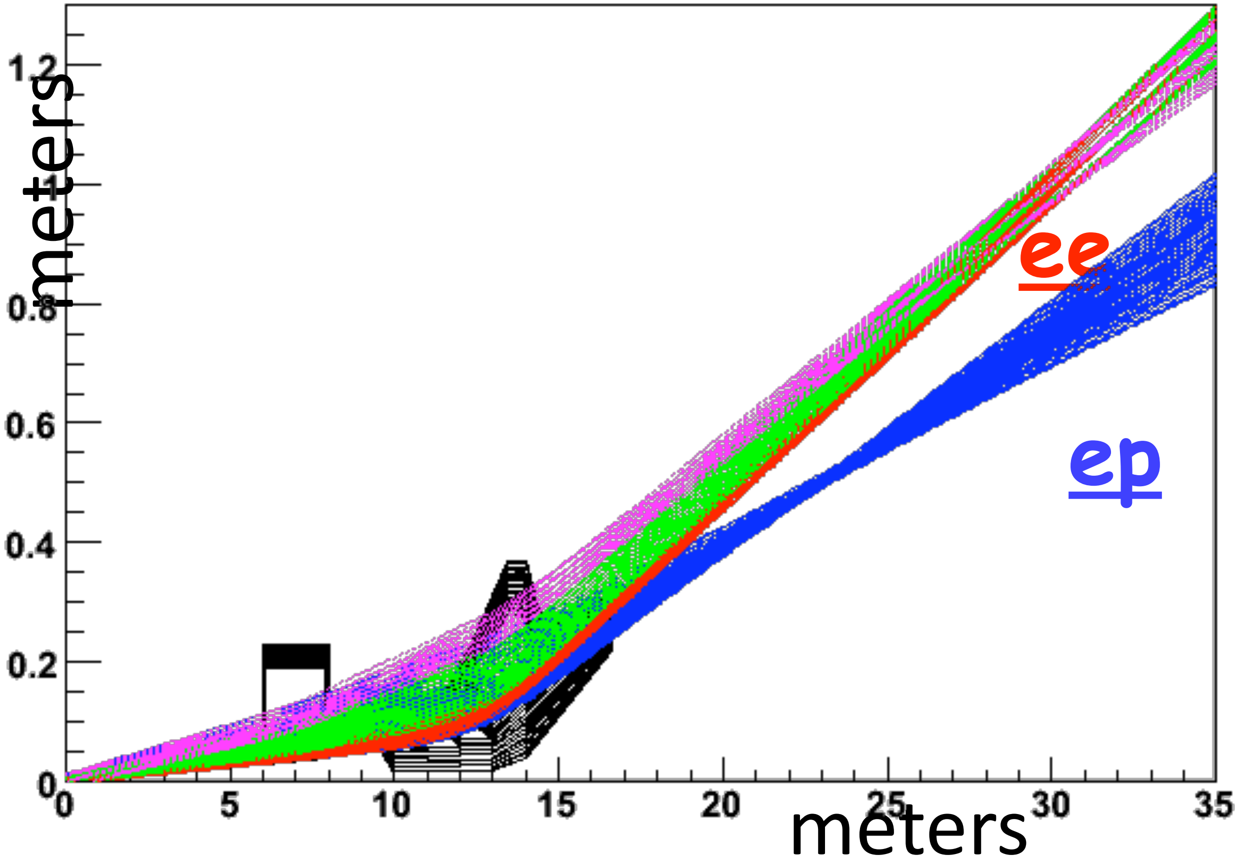


Designed by UVa (Clayton Davis)

Radial Fields (edge effect) creates azimuthal defocussing which populates the full ring at the detector

Slide: K Paschke

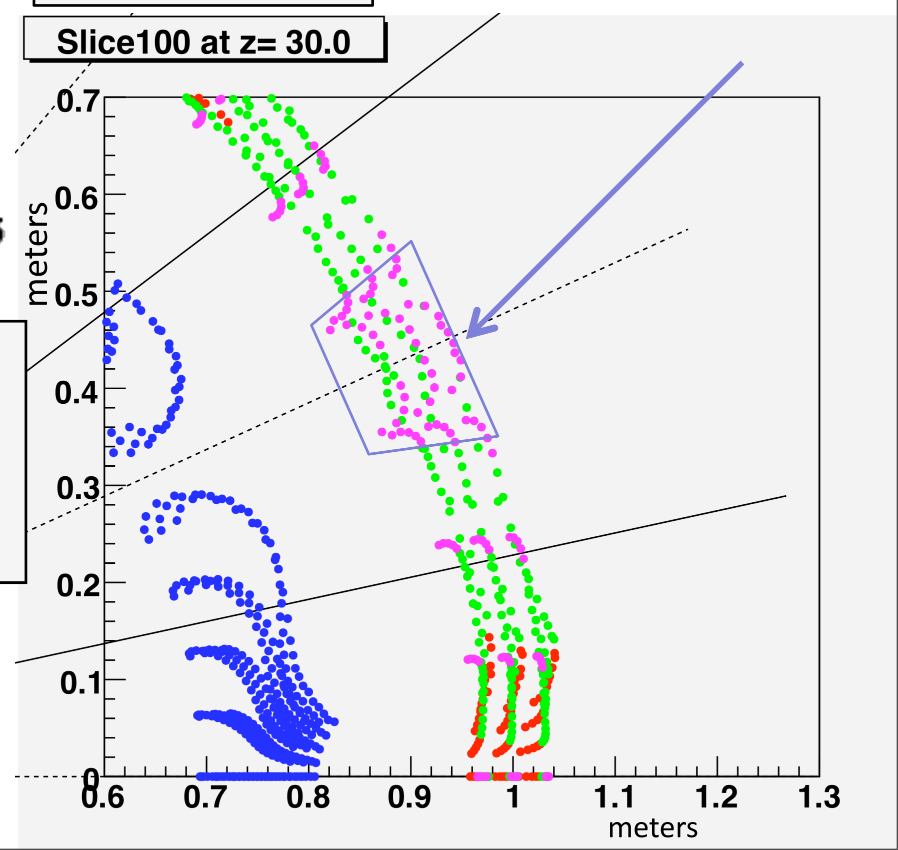
Toroid design concept



- More complicated magnet geometry used to control integral Bdl without extensive defocusing
- Pre-bender magnet pushes highest angle tracks above high field region, and focuses other tracks

Focus at ~32.5 meters

Overlap between neighboring sectors



- ep
- ee, 60°-75°
- ee, 75°-105°
- ee, 105°-120°

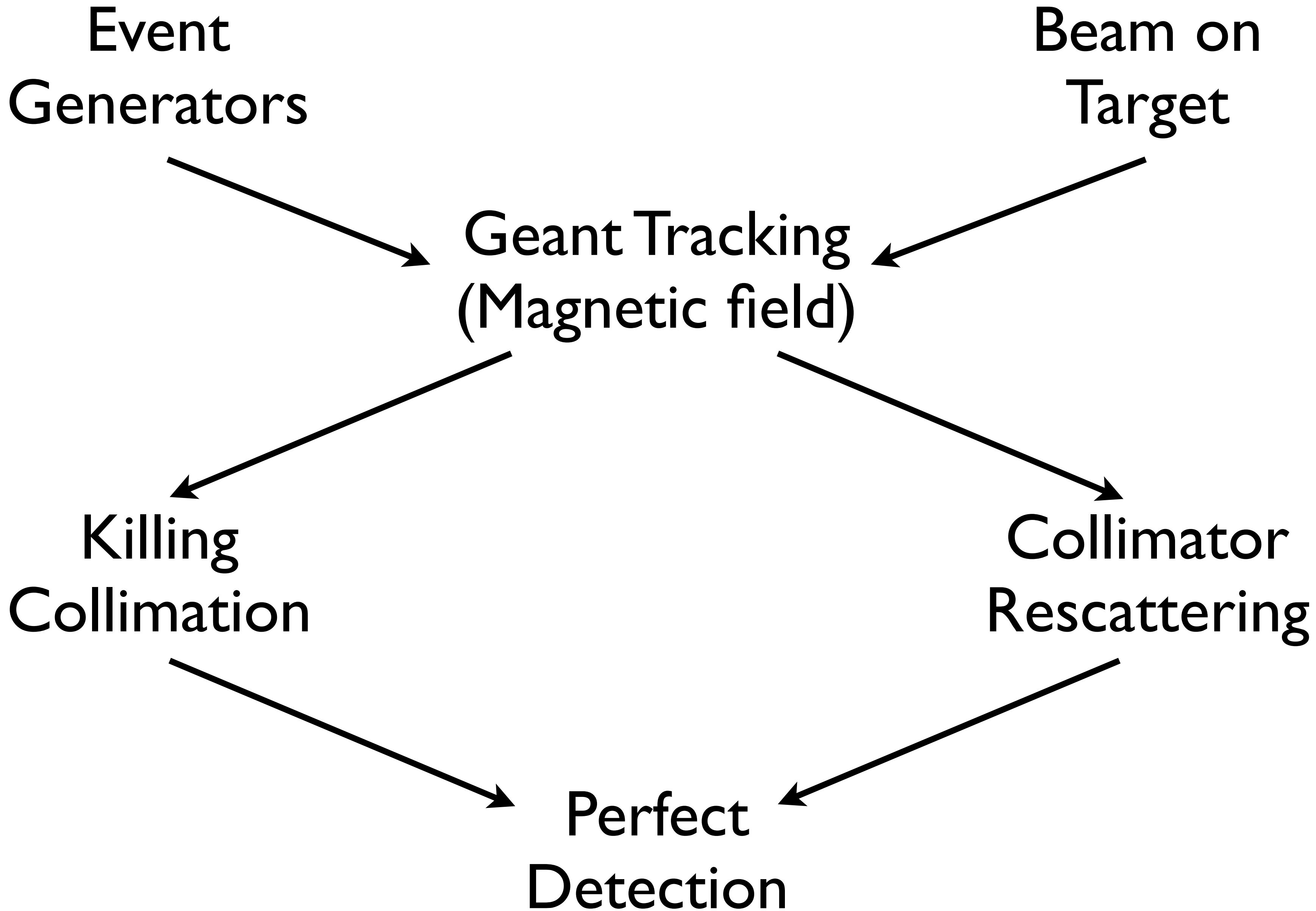
1.5 meter target, full range of theta and phi

Slide: K Paschke

Simulation Overview

- Proposal level (proof of principle) simulation
- Geant4 used for tracking, calculation of acceptance and collimation planning
- A work in progress

Simulation Schematic



Specifics

- Geant 4 framework based on a distribution example
- Developed spectrometer design based on UVa in-house code.
- Magnetic field incorporated using QWeak interpolation code of the fieldmap.
- Collimators kill all particles, no showering, rescattering.
- Detectors perfectly detect all energy.

Spectrometer Design

(written/used by Clayton Davis, UVa)

3-D Biot-Savart calculation using current segments.

Text file defined straight current paths of finite extent. Parameters prescribed density of current segments used to model each current section.

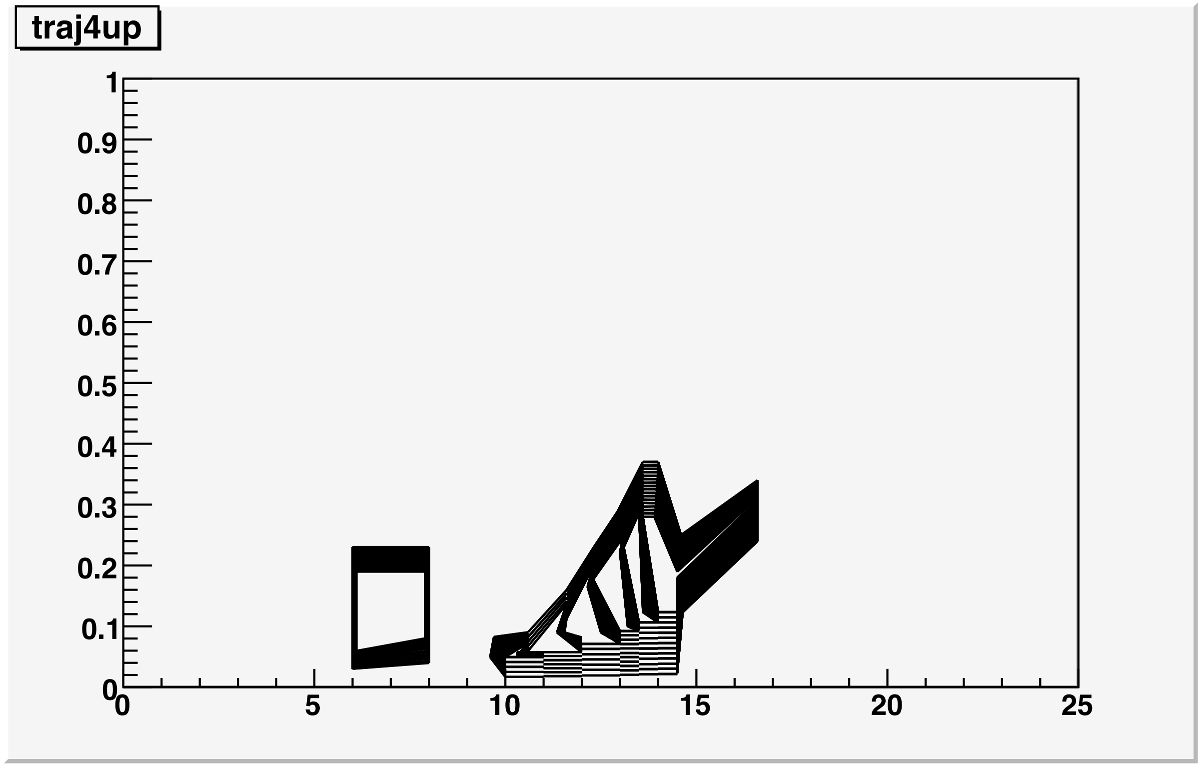
Calculation for single coil, with all seven added after appropriate rotation/translation.

3-D Ray tracing

"optics" rays are tracked through the system (Runge-Kutte). Step-size and coil granularity errors are estimated through additional calculations. Simpler to use (and faster?) than GEANT.

3-D Field Map

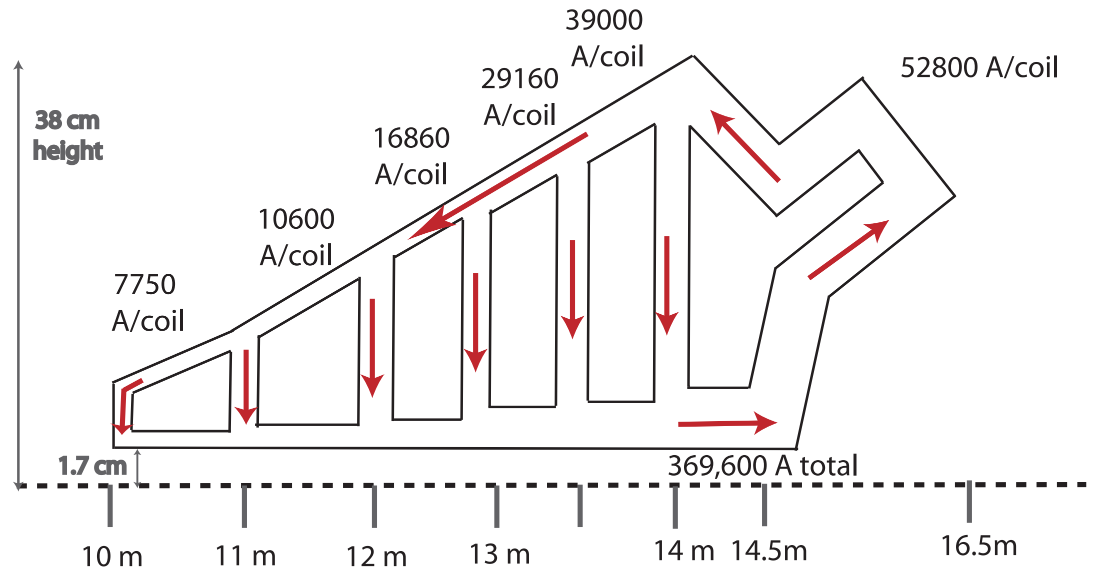
Field map output used for GEANT MC code. Optics agrees between GEANT and home-built tracking. (Field map takes as long to generate as the ray traces do.)



“Nested” toroidal coils

7 coils returning current to central “line current”

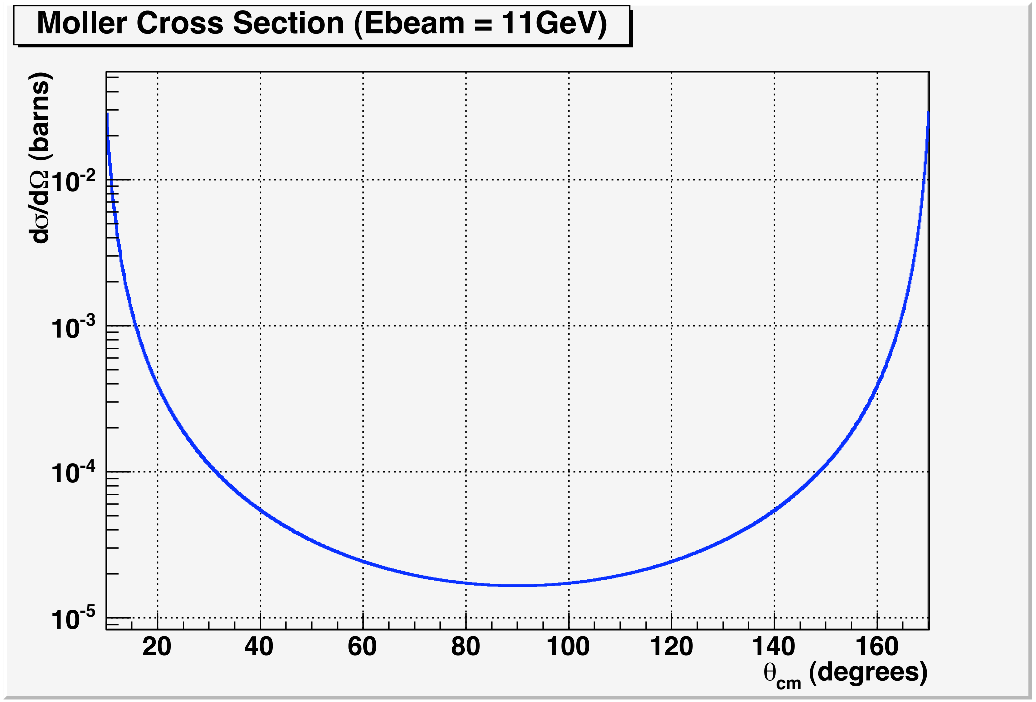
100% azimuth “line current” near beamline
14-17 degree azimuthal fill for coil limbs



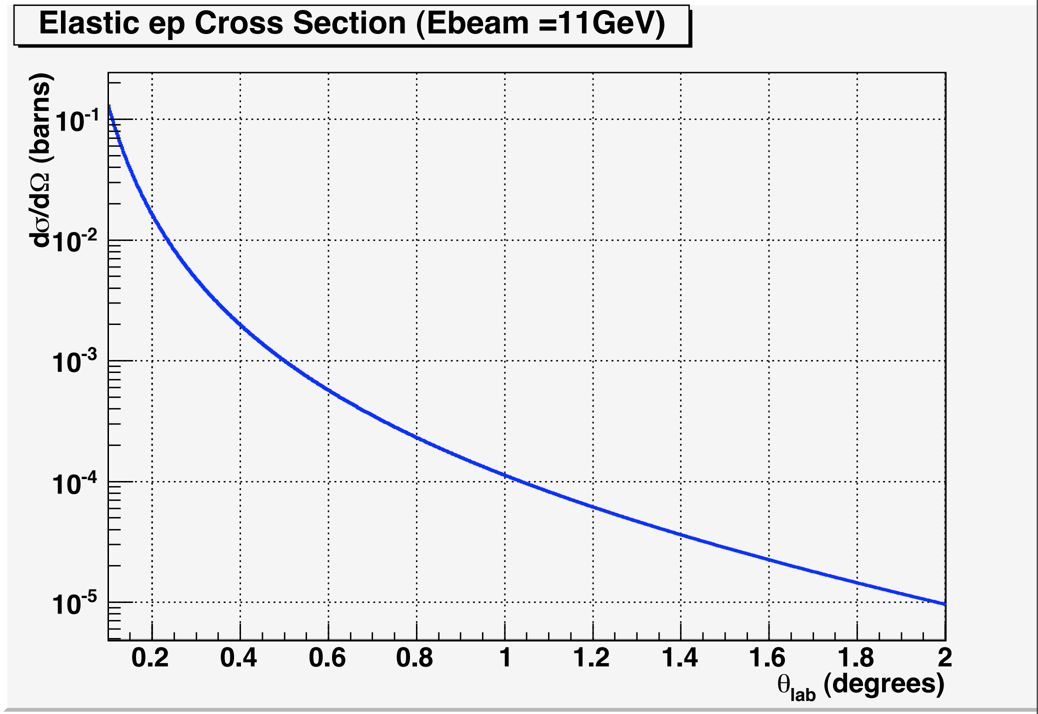
Generators

Implemented by Dustin McNulty

Møller Event Generator



Elastic ep Event Generator

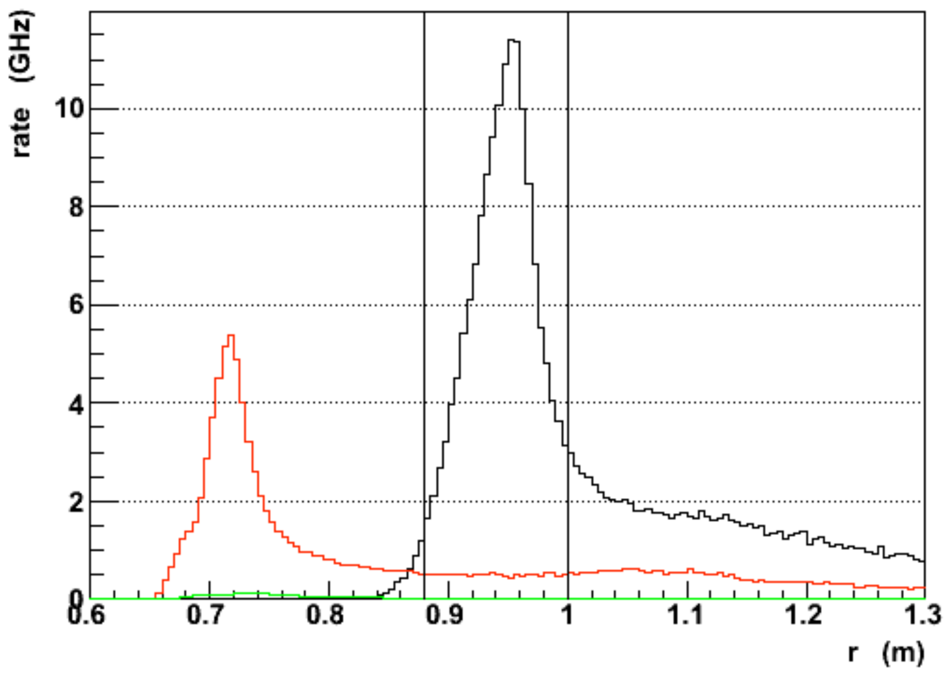


Inelastic ep cross section based on tables from Peter Bosted.

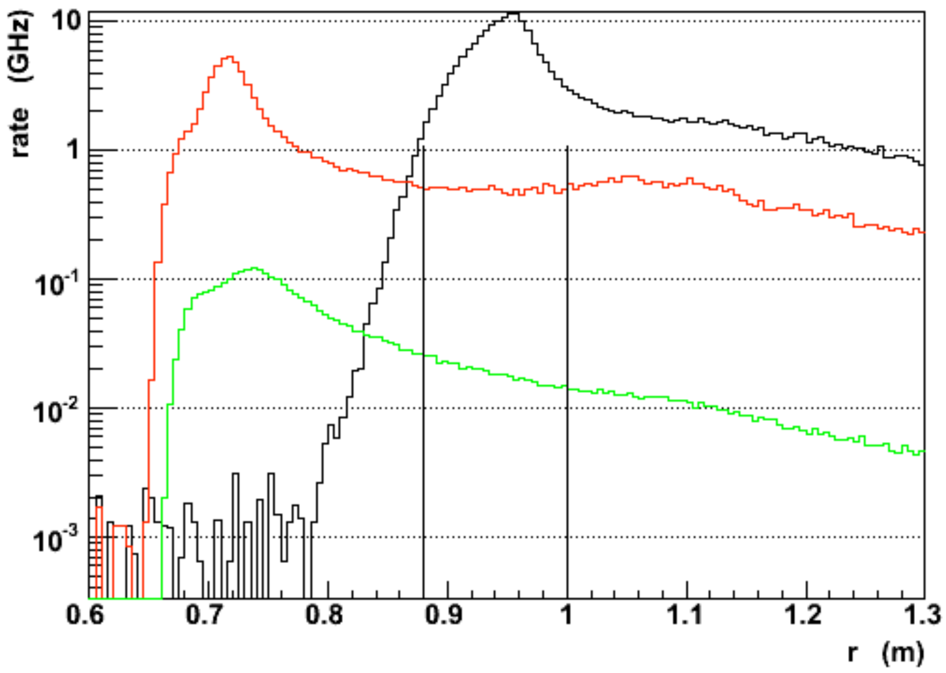
Additional details

- Incoming radiation done in generator with genercone
- Outgoing radiation done in Geant4
- Uniformly rastered beam 5 x 5 mm
- z-target vertex uniformly sampled; realistic vertex distribution obtained by cross section weighting events

Acceptance



rate (GHz)
10
8
6
4
2
0
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
r (m)



rate (GHz)
10
1
10^{-1}
10^{-2}
10^{-3}
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
r (m)

Future developments

- Aluminum Target window scattering
- Realistic beam angle and offset at the target
- Realistic target z-vertex sampling
- Multiple scattering for incoming (pre-vertex) beam
- Internal radiative vertex correction
- Beam - target - spectrometer misalignments

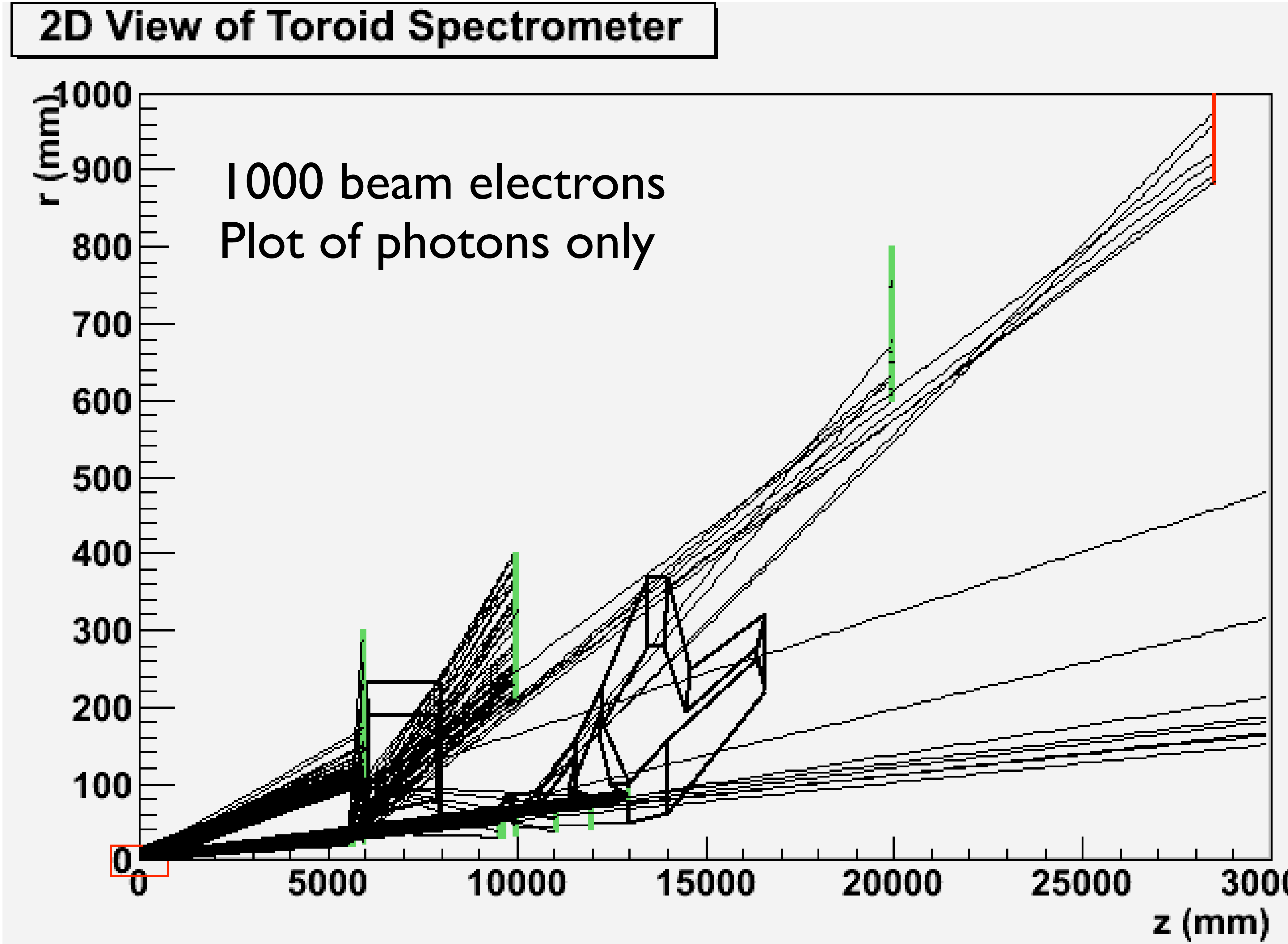
Collimation

Studies by Luis Mercado

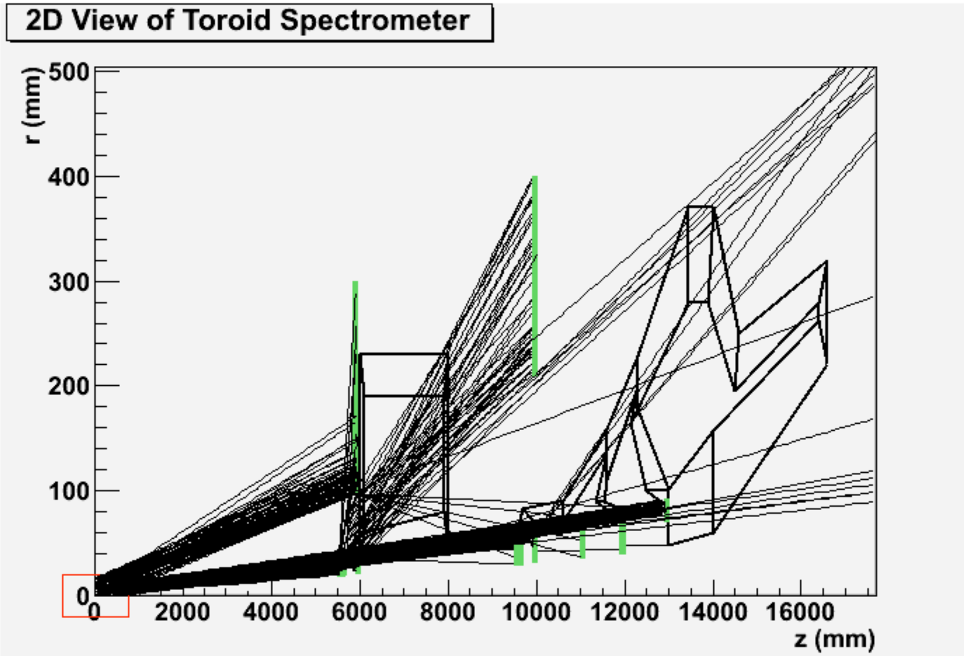
- Block line-of-sight photons.
- Done with main collimator at 6 meters and several sequential collimators to block one-bounce photons.
- Avoid blocking the signal.
- Estimate heating in collimation elemets.

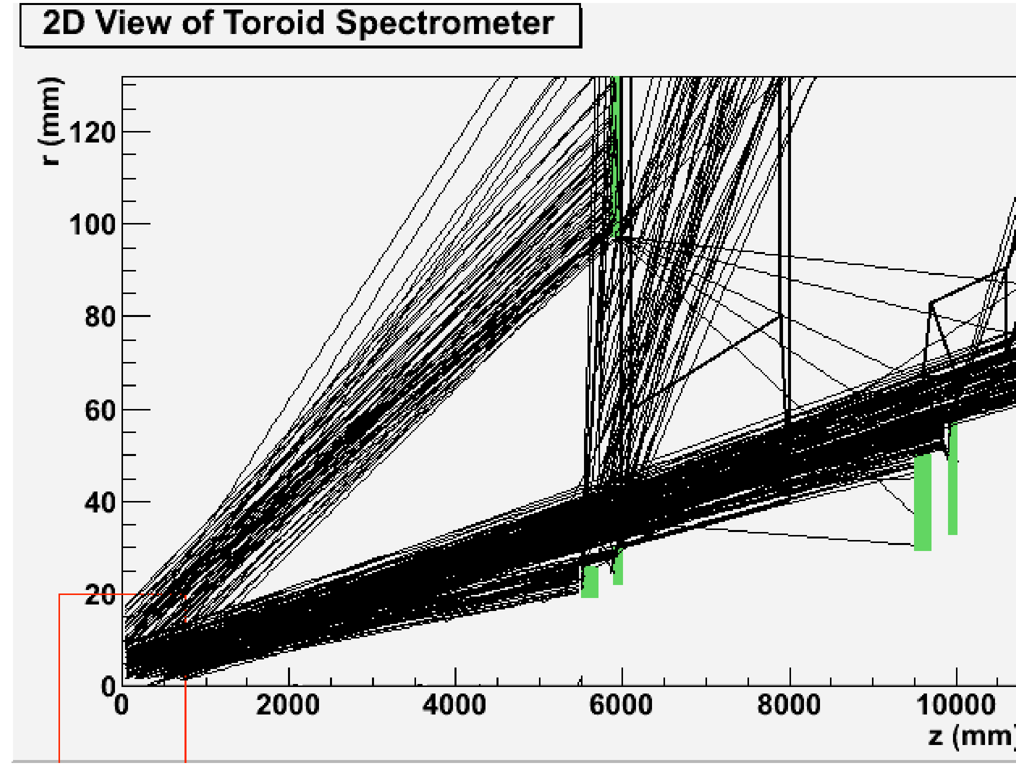
Collimation

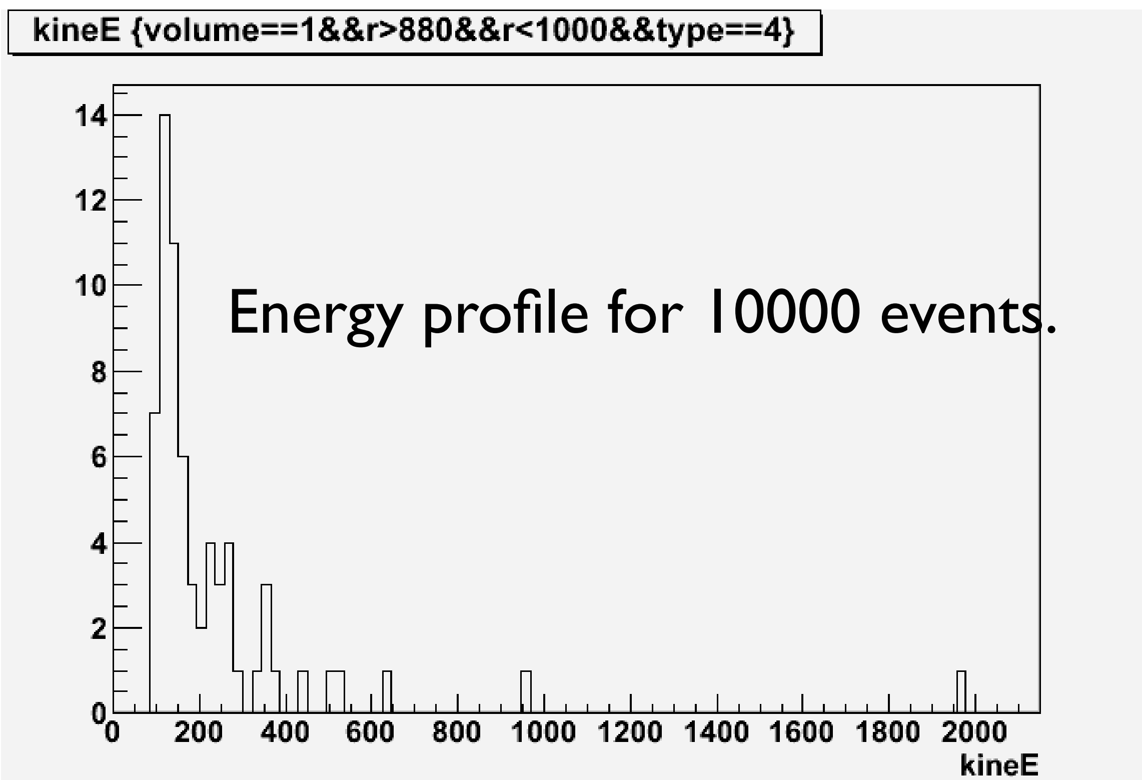
- Simulation done with internal Geant cross sections using beam and target approach.
- Only 300 Moller events per 1M beam electrons.
- Out of 1000 Moller events generated, about 70% hit the detector.
- 6 photons get through the collimators.
- Photon energies are mostly a few hundred MeV.



2D View of Toroid Spectrometer
1000 beam electrons
Plot of photons only
r (mm)
1000
900
800
700
600
500
400
300
200
100
0
0
5000
10000
15000
20000
25000
3000
z (mm)







Energy profile for 10000 events.

Summary

- Simulation used to produce proposal.
- Work is ongoing, additional collaborators welcome and encouraged.