MOLLER Simulation: Review and Future Plans

Dustin McNulty
Idaho State University
mcnulty@jlab.org

Thanks to: Juliette, Mark, Luis, Klaus, and Nevin

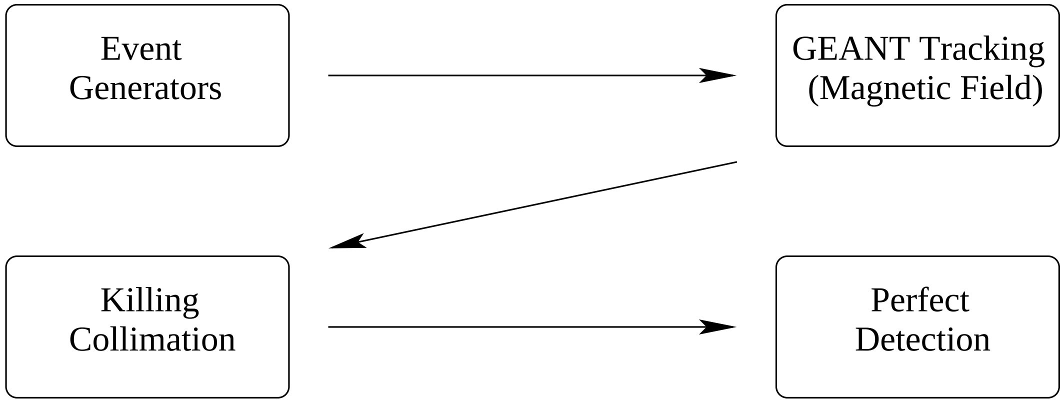
December 4, 2010

MOLLER Simulation: Review and Future Plans

Outline

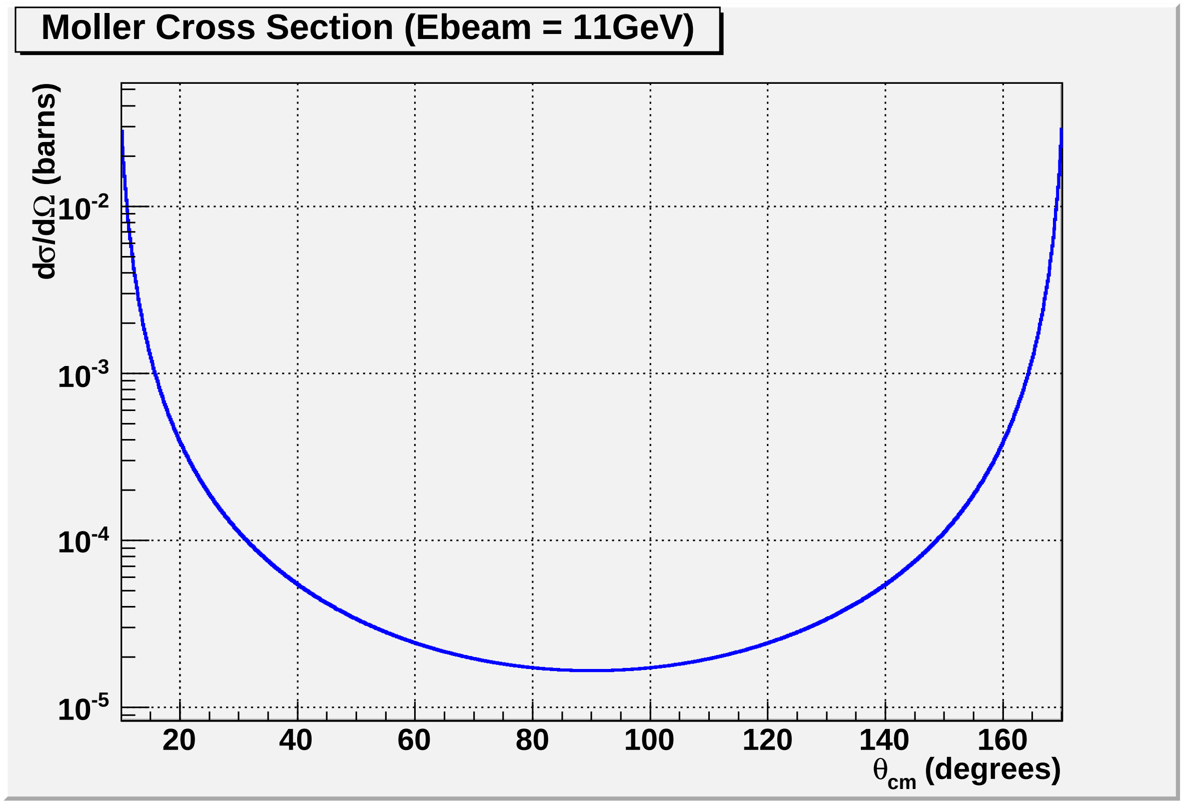
- Simulation Framework
- Physics Generators: Moller, elastic and inelastic ep
- Backgrounds:
  - –Photons and Collimation
  - –Correcting for Inelastic ep's
- Recent Results with new TOSCA Fieldmaps
- Near Future Plans

Simulation Framework



- GEANT 4 framework based on a distribution example
- Initial proposal (idealized) spectrometer design based on UVA in-house code
- Updated (buildable) spectrometer design based on TOSCA
- Mag. field incorporated using QWeak interpolation code of the fieldmap
- Collimators kill all particles, no showering, no rescattering
- Detectors perfectly detect position and all energy

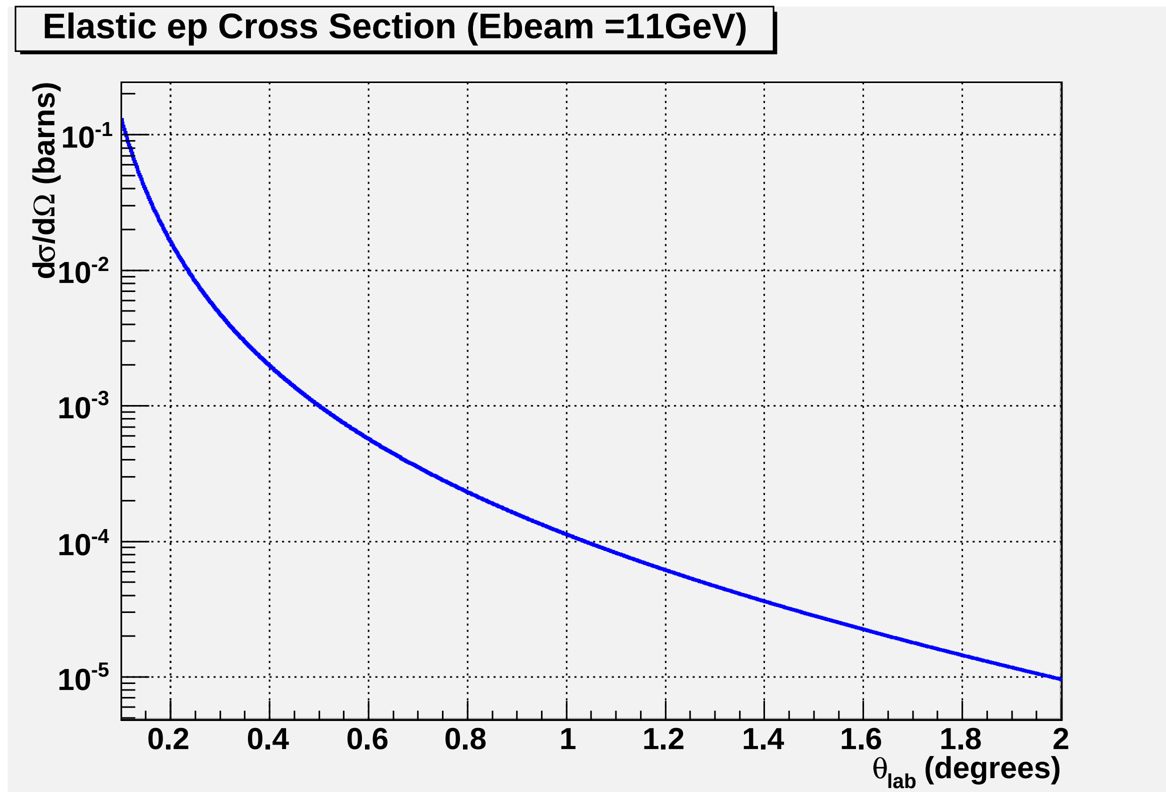
Møller Event Generator



$$\frac{d\sigma}{d\Omega^{cm}} = \frac{4\alpha^2}{s}\left[\frac{\zeta}{\sin^4\theta_{cm}} + \frac{(1-\frac{3}{4}\zeta)}{\sin^2\theta_{cm}} + \frac{1}{4}\right] \qquad (1)$$

$$\text{where} \quad \zeta = \frac{(2\xi-1)^2}{(\xi-1)^2}, \quad \xi = \frac{s}{4m^2}, \quad s = 2m^2 + 2mE^{lab}_{vertex} \qquad (2)$$

Elastic ep Event Generator



$$\frac{d\sigma}{d\Omega} = \frac{\alpha^2}{4{P_0}^2\sin^4(\frac{\theta}{2})} \frac{\cos^2(\frac{\theta}{2})}{1+2\frac{P_0}{m_p}\sin^2(\frac{\theta}{2})} \left[\frac{G_{Ep}^2+\tau G_{Mp}^2}{1+\tau} + \frac{\tau^2 G_{Mp}^2\sin^2(\frac{\theta}{2})}{\cos^2(\frac{\theta}{2})}\right] \quad (3)$$

$$\text{where} \quad \tau = \frac{Q^2}{4{m_p}^2}, \quad G_{Ep} = \frac{1}{(1+\frac{Q^2}{0.71})^2}, \quad G_{Mp} = \mu_p G_{Ep} \quad (4)$$

Inelastic ep Event Generator (from P.Bosted)

$$\frac{d\sigma}{d\Omega dE'} = \frac{5.2\times 10^{-9}}{(E\sin^2(\frac{\theta}{2}))^2}\left[\frac{\cos^2(\frac{\theta}{2})F_2}{\nu} + \frac{2\sin^2(\frac{\theta}{2})F_1}{m_p}\right] \quad (5)$$

$$F_1 = (\nu - \frac{Q^2}{2m_p})\frac{m_p\sigma_T}{4\pi^2\alpha(0.389)}, \quad (6)$$

$$F_2 = \frac{F_1}{(1+\frac{2(m_p x)^2}{Q^2})2x(1+Q^2)}, \quad (7)$$

$$Q^2 = 4EE'\sin^2(\frac{\theta}{2}), \quad x = \frac{Q^2}{2m_p(E-E')}, \quad \nu = \frac{Q^2}{2m_p x} \quad (8)$$

$$\sigma_T \equiv \text{total photoabsorption cross section (use table from PB)} \quad (9)$$

$$W^2 = {m_p}^2 + 2m_p(E-E') - Q^2 \quad (10)$$

Inelastic ep Event Generator: Coding Stradegy

- Generate angular distribution in same fashion as for Møller and elastic ep–using event-by-event generated normalized XS table...
- Since we have double differential XS, we must also sample the event inelasticity (E - E'), where $E = E_{vertex}$
- Choose upper E' sampling limit such that $W = m_p + m_\pi = 1.0779$ and $Q^2 = 0 \longrightarrow E'_{max} = \text{Evertex} - 0.150$
- Choose lower E' sampling limit such that $W = 4.5 \longrightarrow E'_{min} = \text{Evertex} - 10.3219$

Radiative Effects

- Radiative correction algorithm taken from genercone
- Only incoming (pre-vertex) bremsstrahlung handled; outgoing effects taken care of entirely by GEANT

Beam Effects

- Uniformly rastered beam 5 x 5 mm^2, centered on the target cell

Other Details

- z-target vertex uniformly sampled; realistic vertex distribution obtained by cross section weighting events

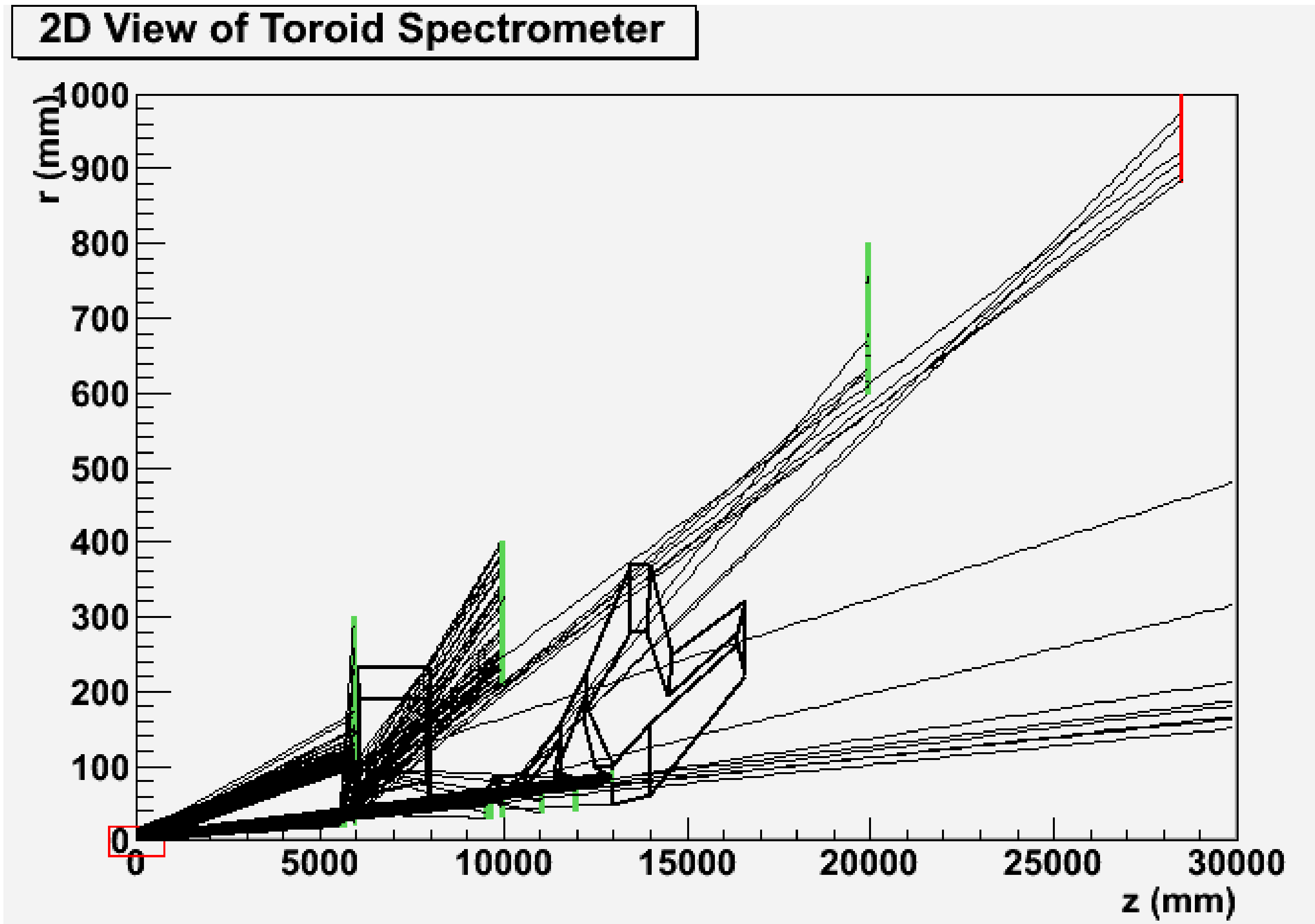
What's still needed...

- 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
-

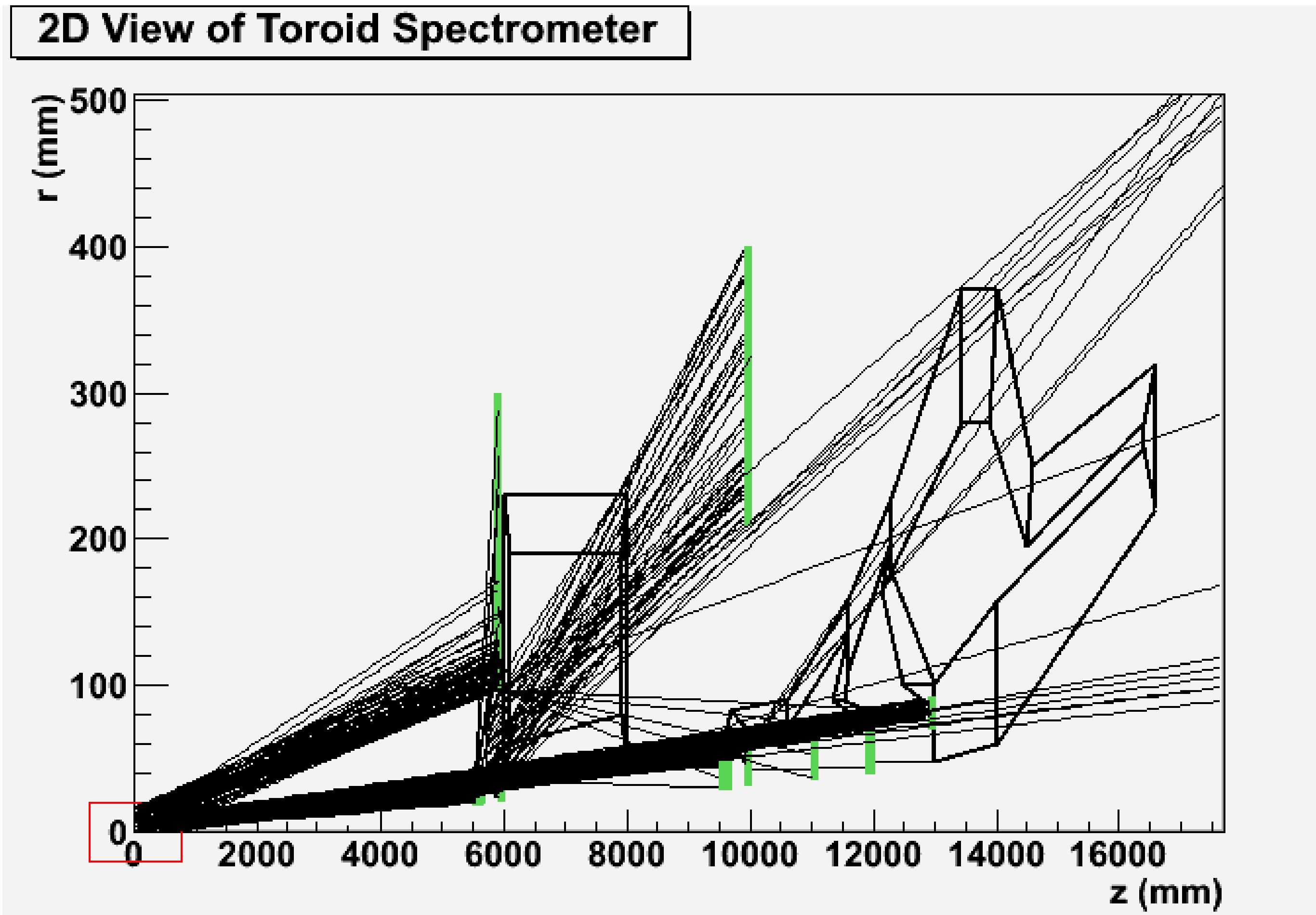
Backgrounds: Photons and Collimation

–Note that 1M Watt of beam on target produces 150k Watts of γ's

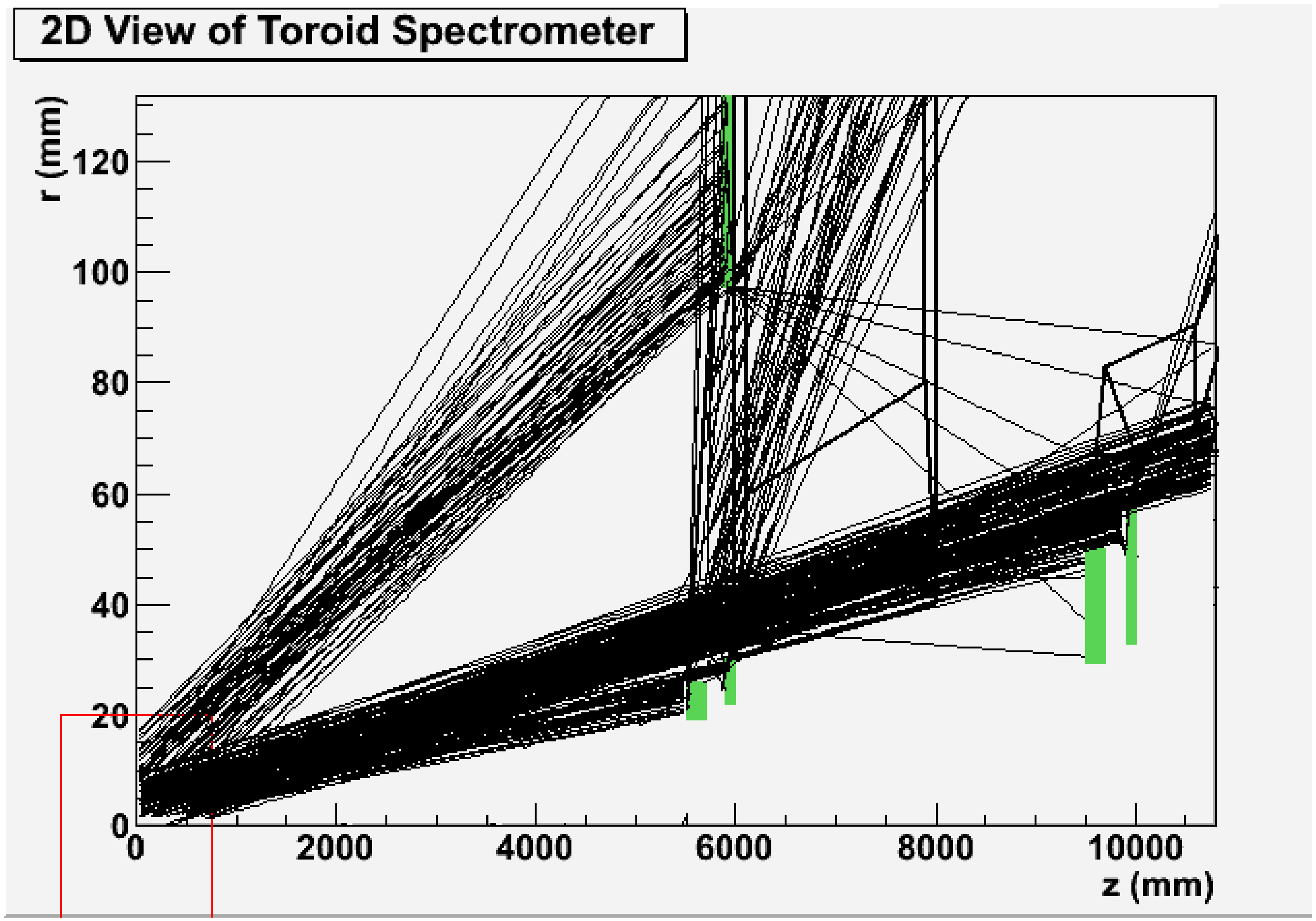
Photon Trajectories (1000 Møller Events Generated)



Photon Trajectories (1000 Møller Events Generated)



Photon Trajectories (1000 Møller Events Generated)



GEANT Photon Summary
(Note: 100MeV Energy cut applied here)

1000 Moller events generated

- Out of 1000 Moller events generated, about 70% hit the detector.
- Only 6 photons get through the collimators.
- Photon energies are mostly a few hundred MeV.

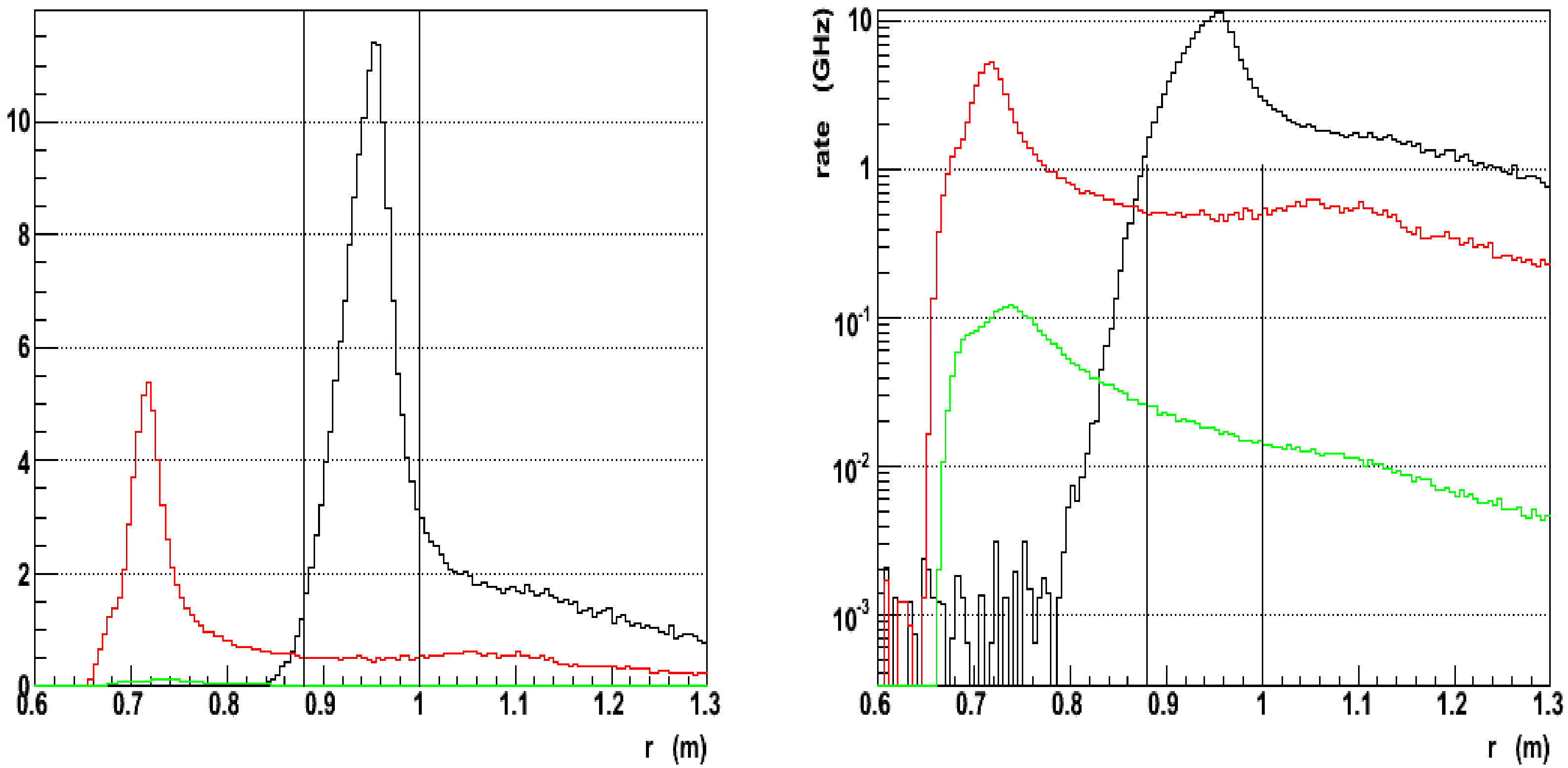
Power Dumped in 1st Collimator (preliminary)

- Threw 100,000 beam electrons through target
- These generated 820 GeV total integrated energy absorbed in 1st collimator
- For 75μA beam current, this gives **620 Watts**
- This is for 20cm thick collimator centered at z=5.6m from target center, with inner radius of 2.3 cm and outer radius of 3.1 cm

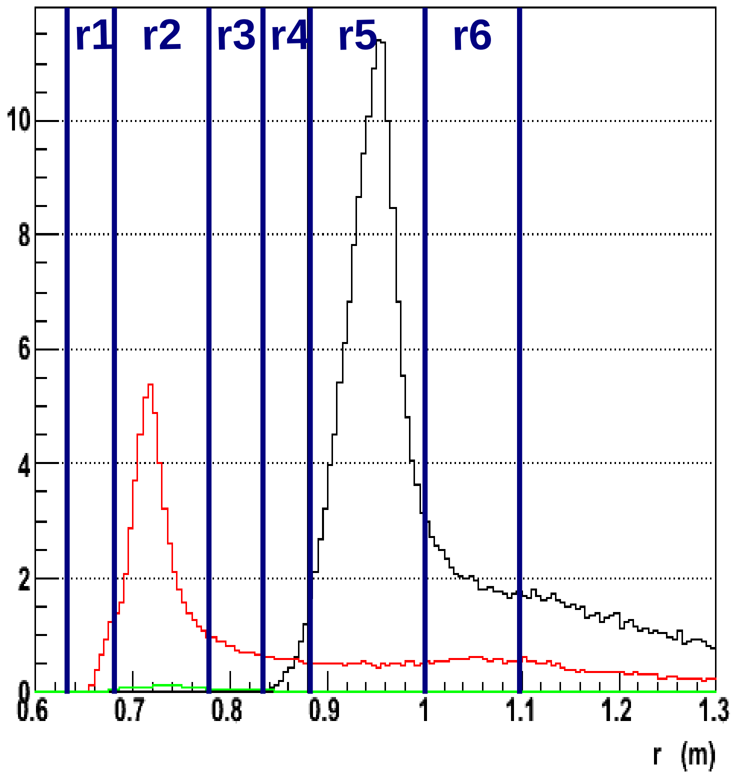
Møller Signal Background Corrections

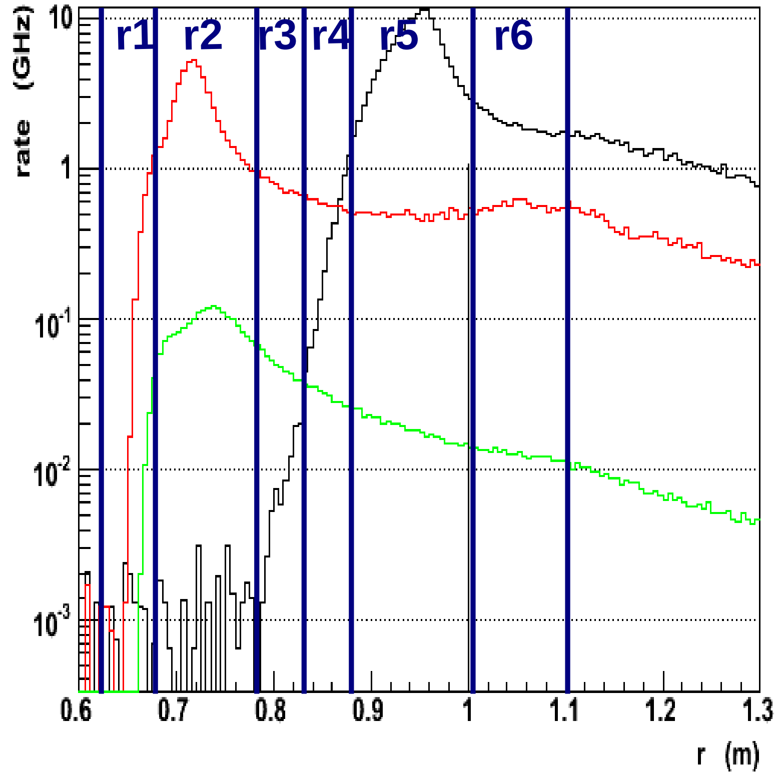
- Systematic corrections resulting from radiative tails of elastic and inelastic ep processes under the measured Møller signal
- For elastic ep ($\sim$ 8% of signal) , the PV asymmetry is well known and can be modeled and measured quite easily
- From proposal, with $< Q^2 >= 0.004$ GeV^2 for the elastic ep's, assuming 4% uncertainty in Q_W^p leads to a 0.3% systematic
- For inelastic ep's ($\lesssim$ 0.5% of signal), the PV asym is significantly ($\sim 20\times$) larger than for Møller and $\sim 12\times$ larger than for elastics – but is not well known
- The idea is to measure the inelastic asymmetry in a radial region where it dominates, and use simulation to scale this measurement to the Møller signal contamination (using Q^2-weighted W^2 to characterize)

Radial Rates

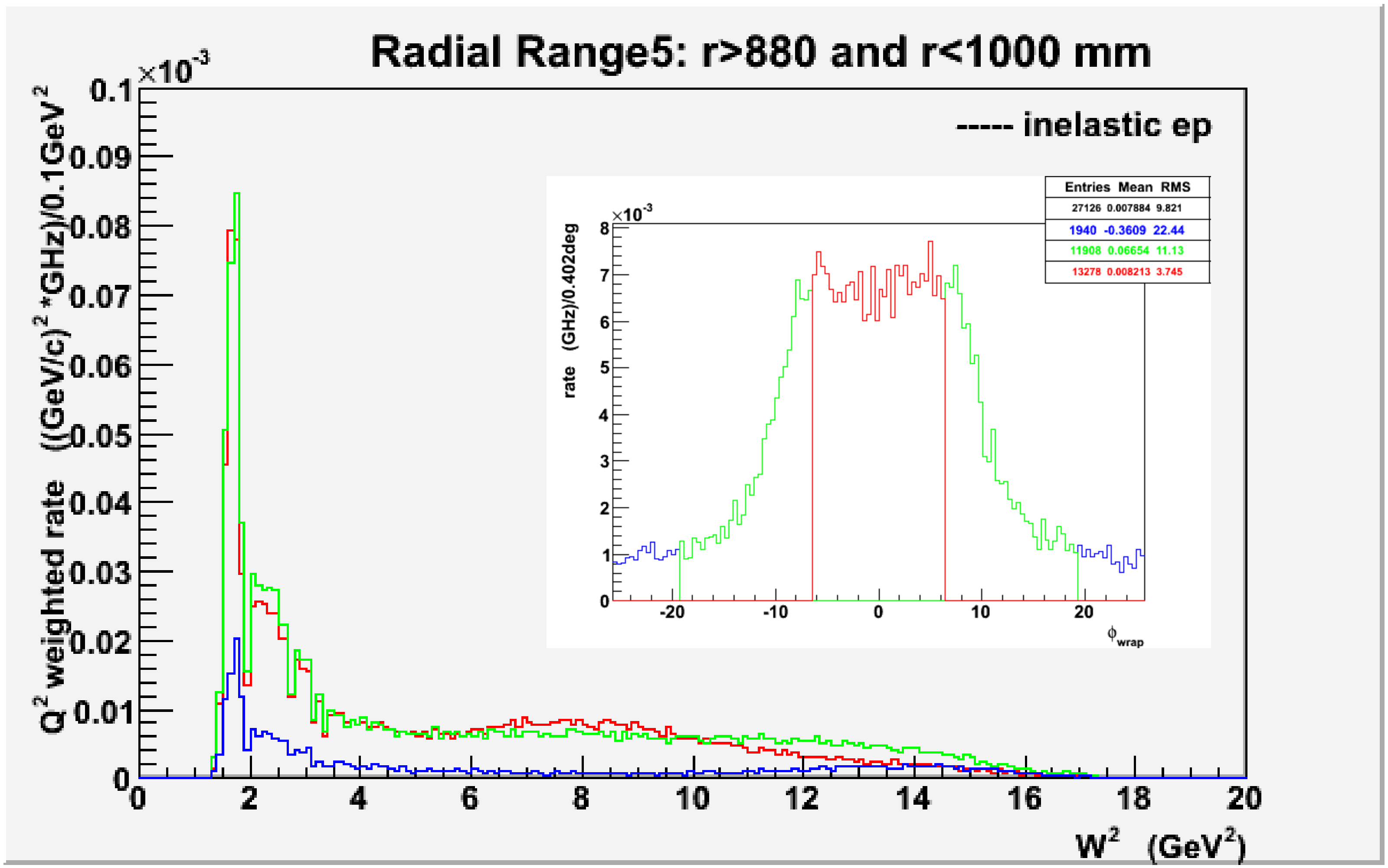


Radial Rates with Auxiliary Detector Regions

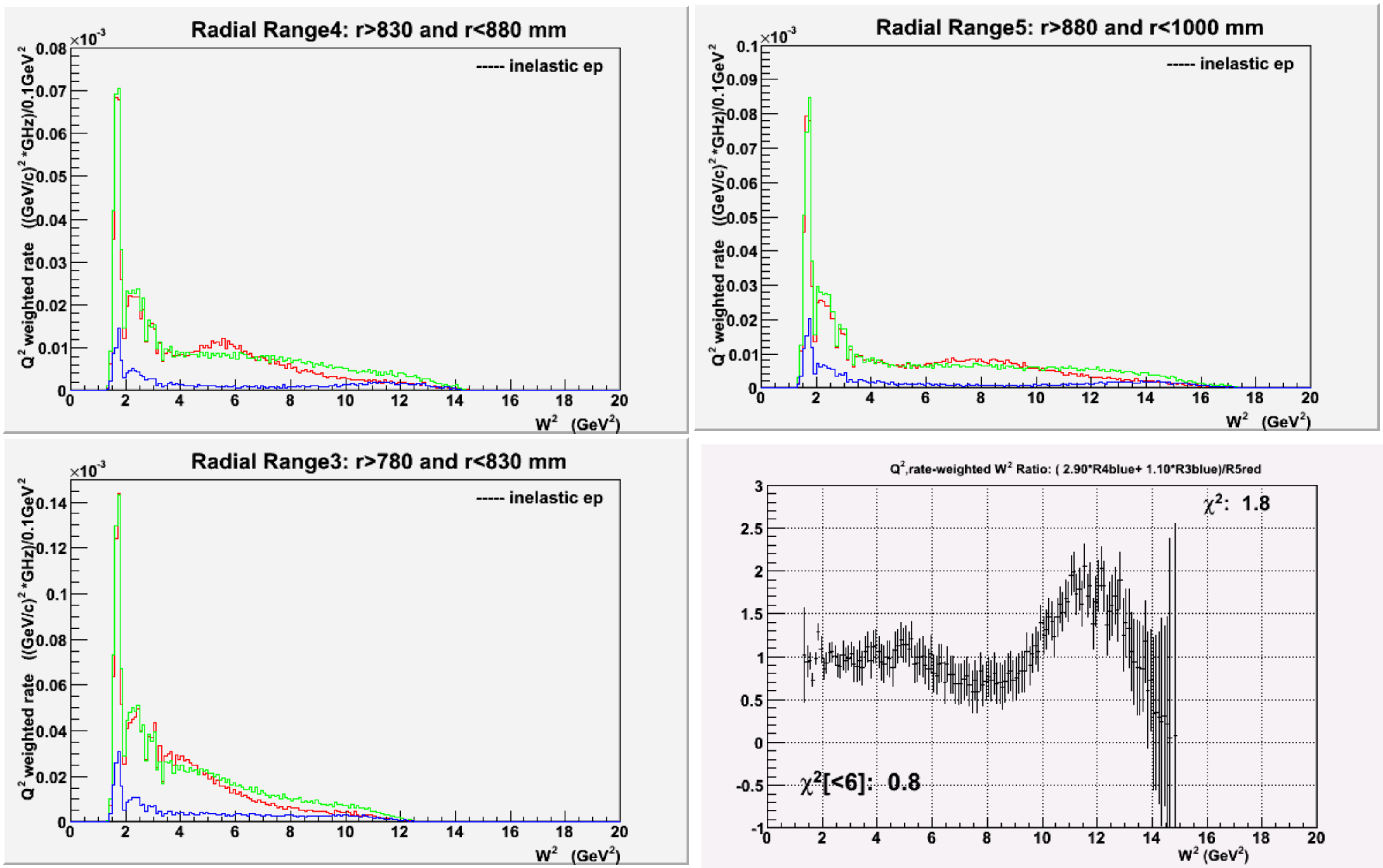




W^2 Signature of Inelastic ep Contamination
(in Møller Det. Ring: $880 < r < 1000$ mm)



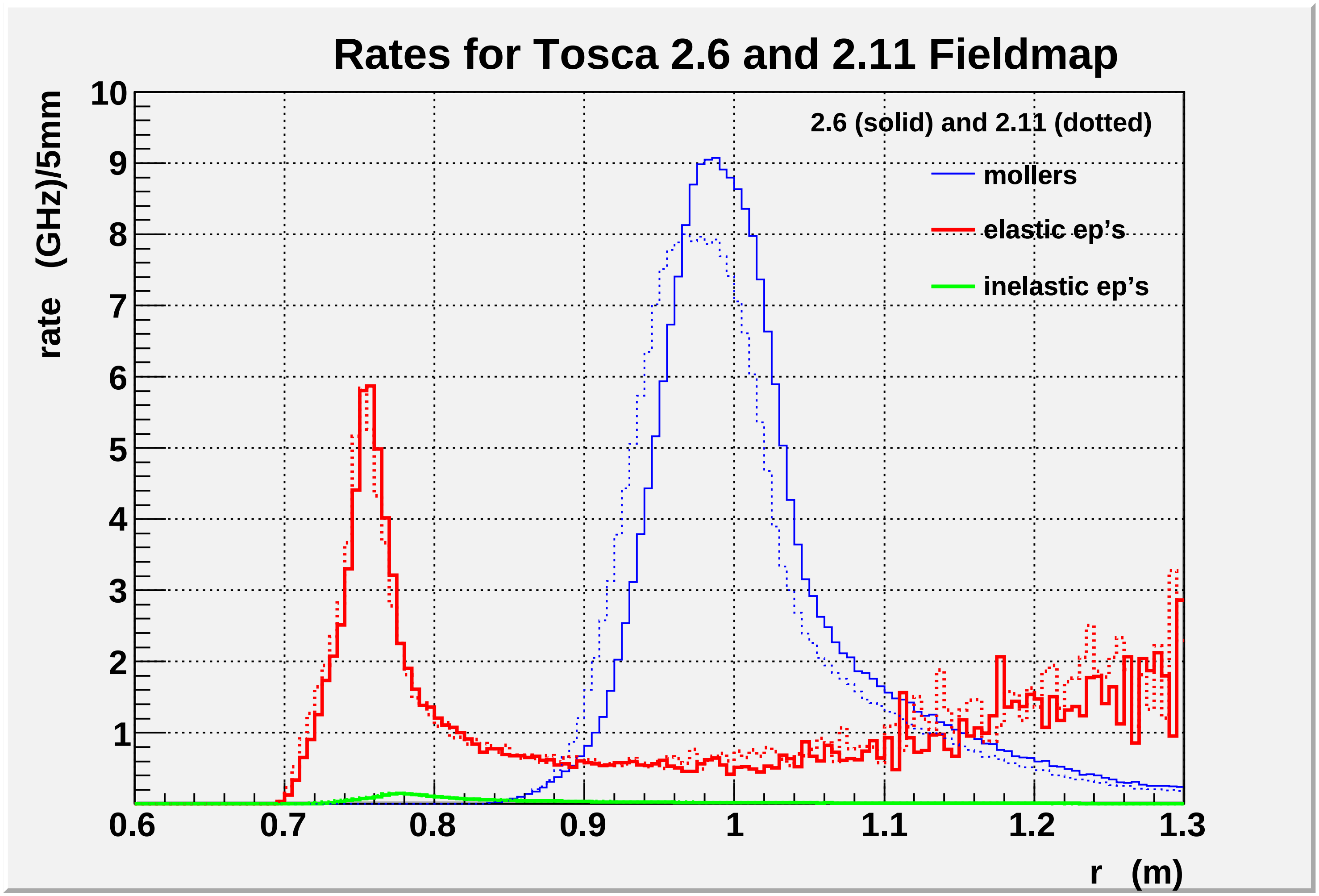
Matching W^2 of Regions 3 and 4 with Region 5



Background Summary and Future Work

- Outlook for inelastic correction is promising. Additional radial focusing of Møller signal can further improve situation. Work ongoing.
- Photon backgrounds are very preliminary and additional work in collimation design will ramp-up soon to ensure a $\geq$2-bounce system.
- Will also need to study weak decay backgrounds using a 4th physics generator.

Rate comparisons between Juliette's recent fieldmaps



Comparison Summary

Fieldmap Name [det width]	Rates (GHz)		
	Moller	Elastic ep	Inelastic ep
BA2.6 [920 - 1060mm]	169	15.8 (9.3%)	0.58 (0.3%)
BA2.11 [900 - 1060mm]	169	20.6 (12%)	0.74 (0.4%)

Table 1: Rate Summary

- Nearly all simulation results for the realistic spectrometer design are remarkably similar to those of idealized proposal design
- BA2.6 together with upstream toroid field increased by 25% give best results so far...better peak separation and better S/N; uses $\sim$14cm main detector ring

Near Future Plans: General Remarks

- Need to establish larger coding community involving students, postdocs, and faculty responsible for simulation and analysis
- Need to maintain detailed **documentation** which is tedious but pays off in many ways:
  - –student leaves project => have to reinvent the wheel
  - –stating facts, assumptions, procedures...(quality control)
  - –easier to lure new collaborator into coding (simulation/analysis)
- Need framework **expansions** to allow flexibilty in handling configuration changes...
- Need to establish and maintain good **version control** habits...

Near Future Plans: Documentation

- Low level online documentation: DOxygen
  - –DOxygen is a tool to convert your C++ comments into publishable HTML

- High level software documentation:
  - –MediaWiki
  - –PMWiki
  - –Simply a Latex Document

Documenting must become a habit!

Near Future Plans: Expansions

- Use **Geant4 Messenger** functionality for steering simulation configuration through external macro file(s) w/o changing the simulation code
  - –turning off/on various physical reactions
  - –changing target charateristics...length, position, windows
  - –changing collimator/detector sizes, positions etc.
- Stand alone event generators: Produce rootfiles read-in by GEANT 4
- Clever track storage parameters – contain info about a track's previous interaction points–very useful for understanding and minimizing n-bounce detector hits
- Use an **OpenGL viewer**: Coin3D, OpenInventor – allows interactive 3D scene visualization
- Use external CAD file, **convert to GDML**, and import into GEANT 4 – for geometry/materials description

Summary

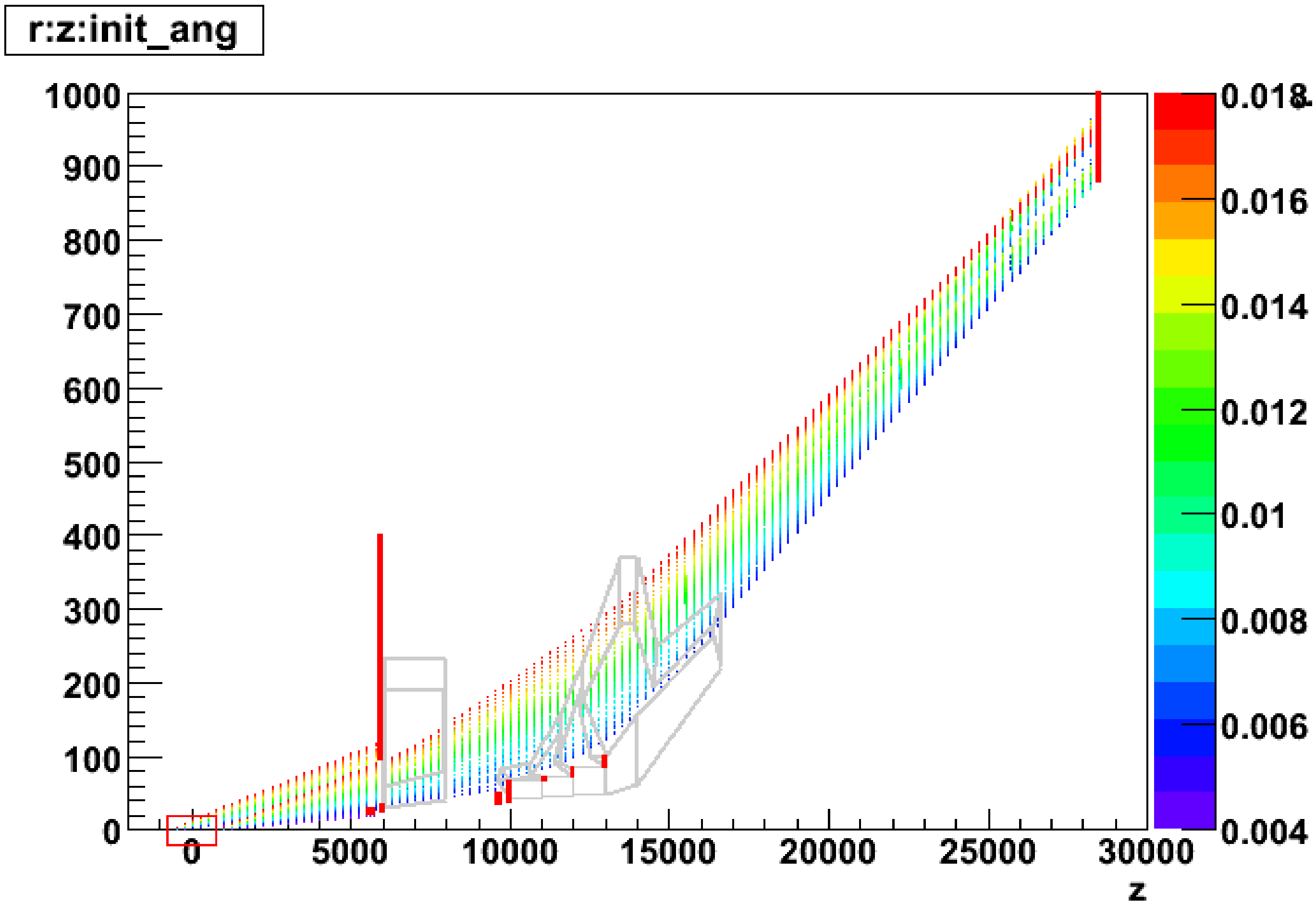
- Initial simulation framework appropriate for producing proposal (in a short time frame)
- Framework is general enough to be used as starting position for near future full simulation effort
- We will start to have regular meetings and all are welcome

Extra Slides

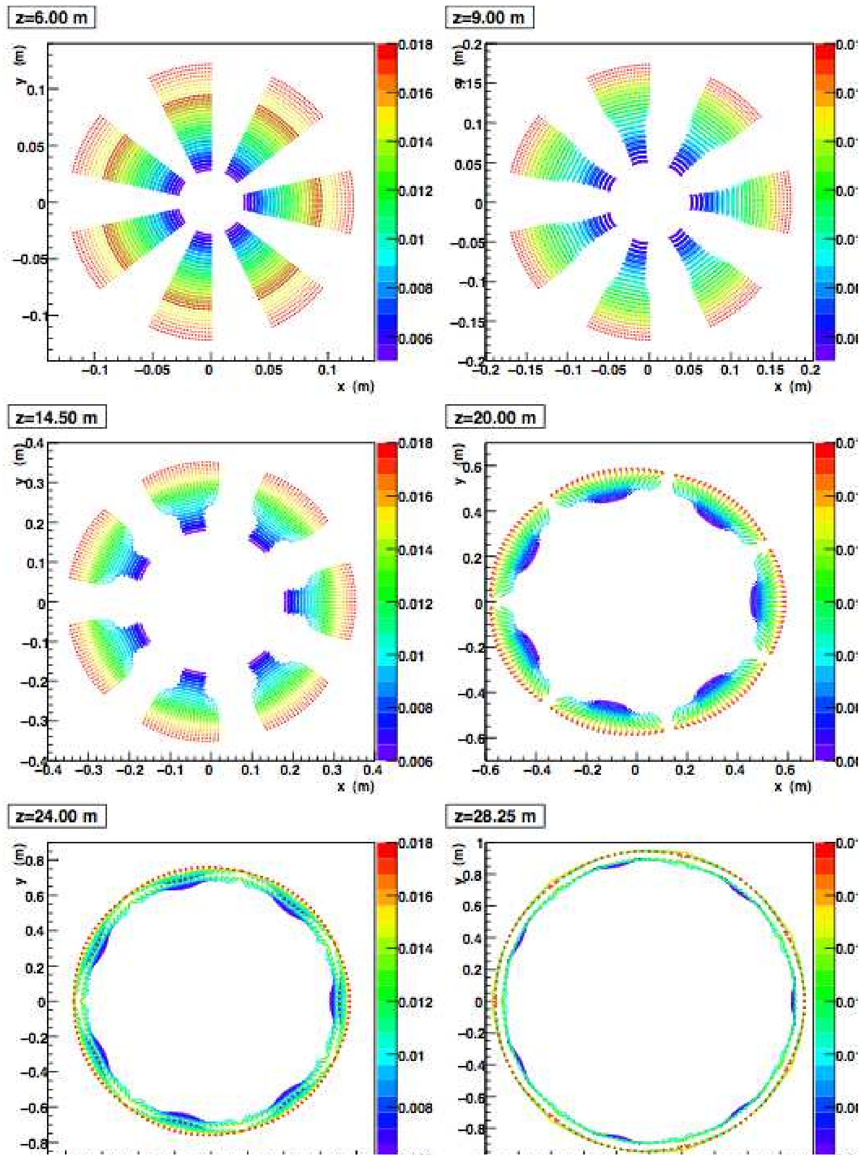
Møller Event Generator: Coding Stradegy

- Generate differential cross section (XS) table as function of θ_{cm}
- Integrate XS and redefine table as running integral sum normalized to total XS. Now table values run from [0,1] as function of θ_{cm}
- To choose θ_{cm} for each thrown event: Pick random number (r1) between [0,1], find the two table indices closest to condition r1 = normXS, and then do linear interpolation between the indices to get the precise angle. This gives proper angular distribution
- To choose ϕ_{cm} for each event: Uniformly sample between $[0,2\pi]$
- Calculate kinematics in CM and then transform to the lab frame

Møller Trajectories



Møller Trajectories



Event Fractions for Different W^2, ϕ, r regions

Range3 780 < r < 830:

phi	0 - 2	2 - 3	3 - 4	4 - 6	6 - 8	8 -10	10-12	12-14	14-20
red:	0.212	0.221	0.166	0.221	0.097	0.053	0.028	0.002	0.000
green:	0.205	0.206	0.131	0.200	0.125	0.082	0.047	0.004	0.000
blue:	0.205	0.186	0.102	0.154	0.133	0.119	0.089	0.010	0.000

Range4: 830 < r < 880:

phi	0 - 2	2 - 3	3 - 4	4 - 6	6 - 8	8 -10	10-12	12-14	14-20
red:	0.205	0.186	0.103	0.200	0.153	0.080	0.046	0.025	0.002
green:	0.203	0.181	0.096	0.149	0.137	0.110	0.077	0.045	0.003
blue:	0.199	0.176	0.082	0.099	0.080	0.096	0.152	0.107	0.008

Range5: 880 < r < 1000:

phi	0 - 2	2 - 3	3 - 4	4 - 6	6 - 8	8 -10	10-12	12-14	14-20
red:	0.208	0.180	0.088	0.117	0.132	0.123	0.077	0.045	0.029
green:	0.206	0.184	0.084	0.107	0.102	0.096	0.089	0.077	0.054
blue:	0.217	0.191	0.086	0.090	0.060	0.052	0.069	0.111	0.124