$\mu \to e\gamma$ detector using $\gamma \to ee$ conversion

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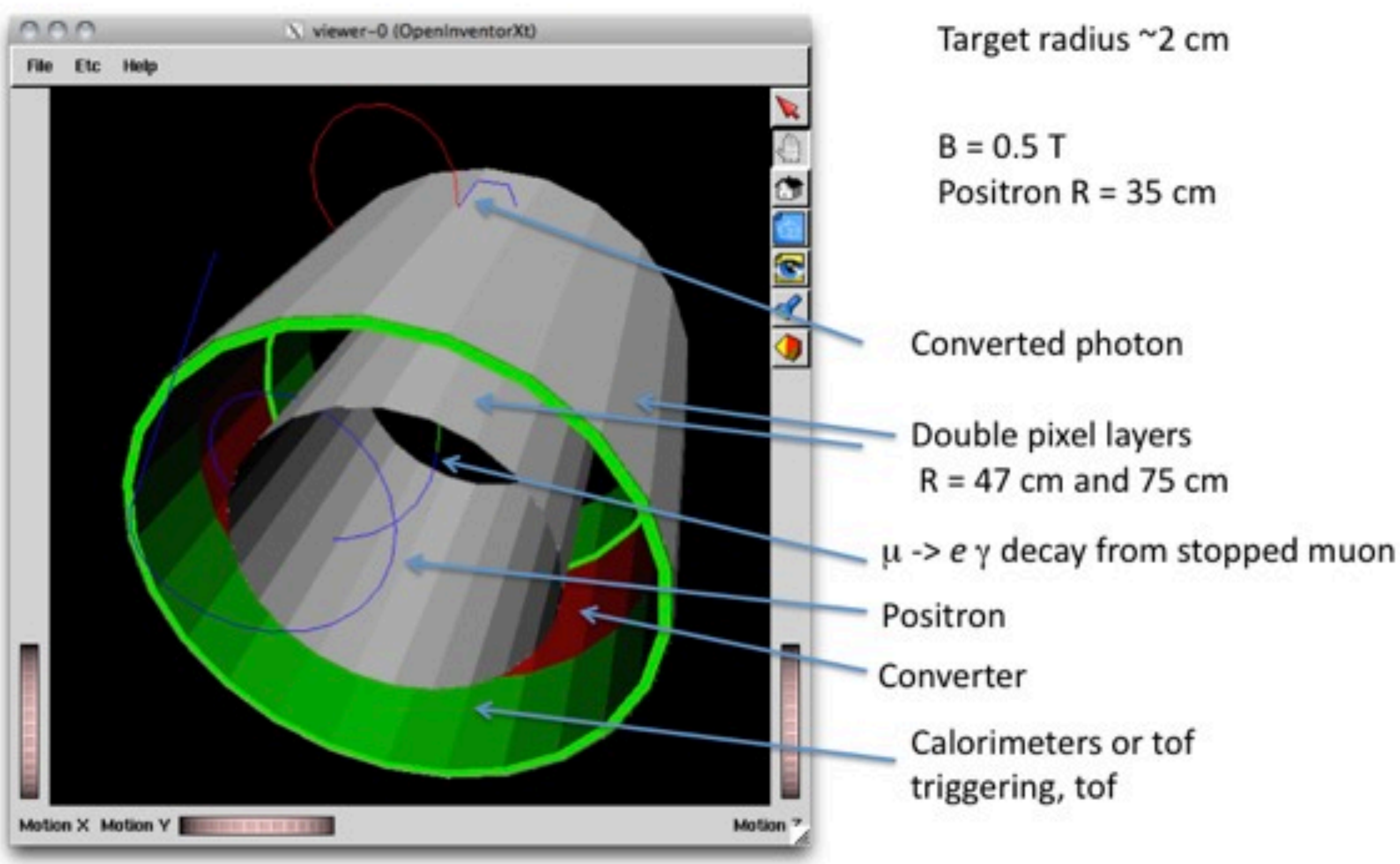
Motivation

- A limiting factor of $\mu \to e\gamma$ search is the photon energy resolution in calorimeter. A possible solution is to reconstruct converted e^+e^- pair tracks, trading efficiency for better photon energy resolution.
- Motivated by Fritz DeJongh's talk at 2012 summer study, we thought we can use the Super*B* FastSim framework to take a look.

The simple minded geometry seems to work. Needs many m² pixel tracking



FastSim

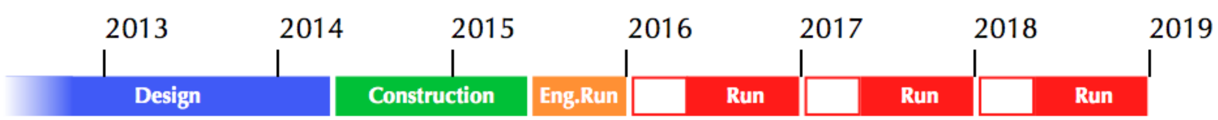
- Born from *BABAR* offline software framework.
- Developed primarily for Super*B*; extensively used for physics studies and detector optimization.
- Detectors are modeled with 2D shells of cylinders, planes, and cones; configured by xml files, very easy and quick to modify.
- Event 4-momenta are generated by EvtGen
- Particle scattering, energy loss, secondary particles, etc. (Compton, Bremsstrahlung, conversion, EM/hadron showers), are simulated at the intersection of particle at each shell.
- Tracks are reconstructed with a Kalman filter into piece-wise trajectories. No pattern recognition, but can artificially confuse hits to mimic inefficiencies.
- High level physics candidates are built and analyzed with *BABAR* framework.

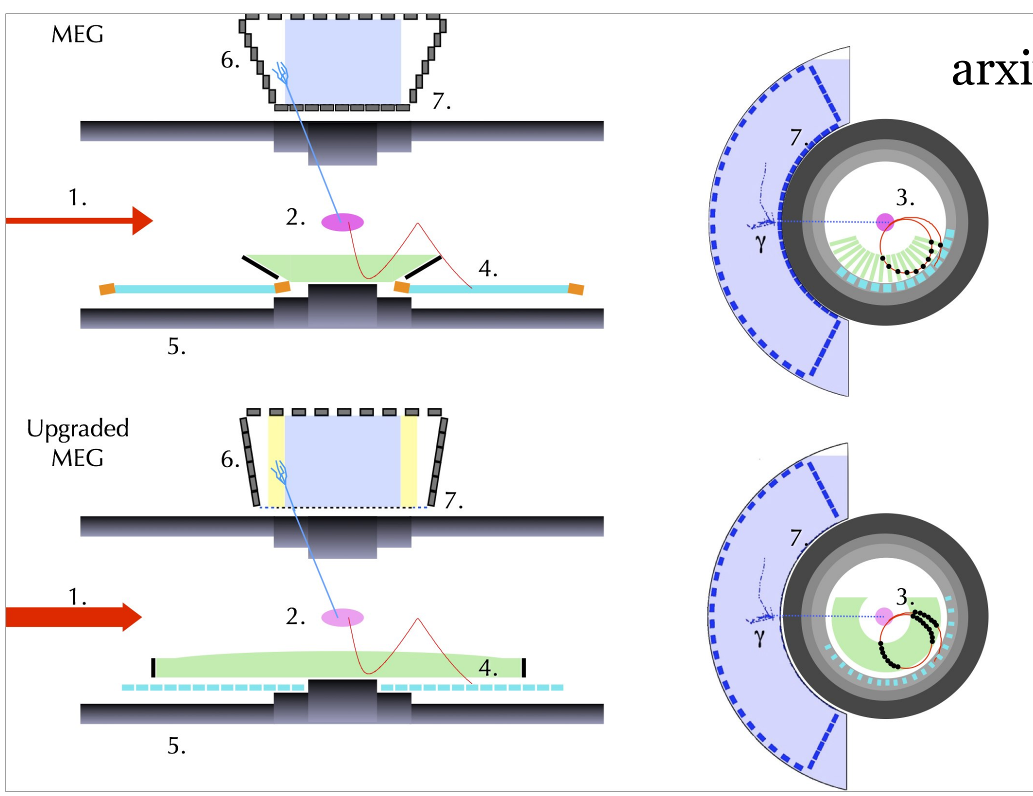
MEG

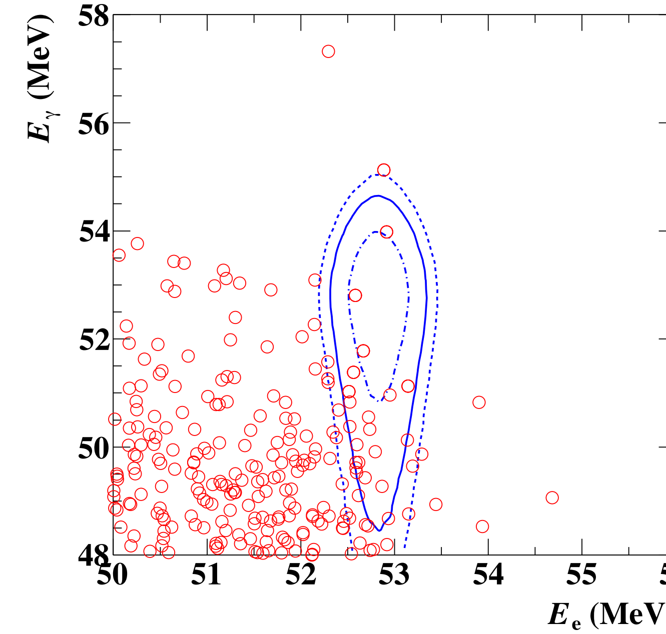
- Current limit: $\mathcal{B}(\mu^+ \to e^+\gamma) < 5.7 \times 10^{-13}$ using 3.6×10^{14} stopped muons.
- Background is dominated by accidentals.

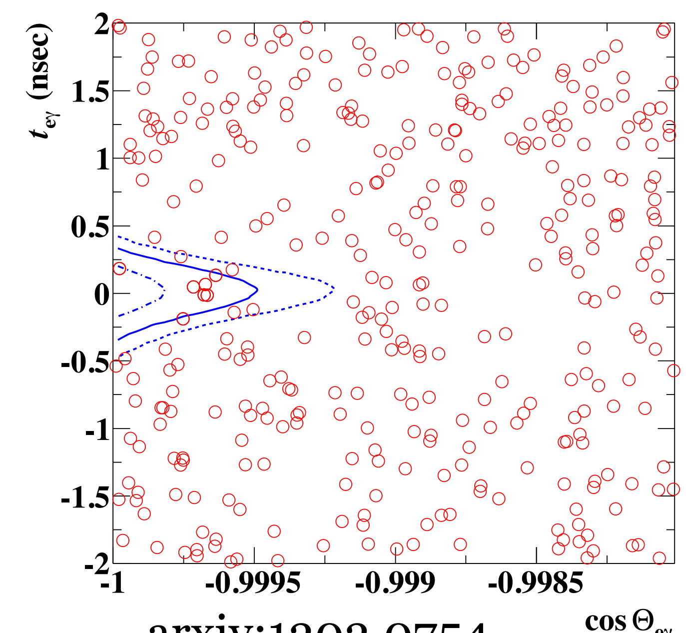
$$N_{\rm acc} \propto R_\mu^2 \times \Delta E_\gamma{}^2 \times \Delta P_{\rm e} \times \Delta\Theta_{e\gamma}^2 \times \Delta t_{e\gamma} \times T$$

- Upgrade: target sensitivity ~ 6×10^{-14} based on ~ 3.3×10^{15} stopped muons.







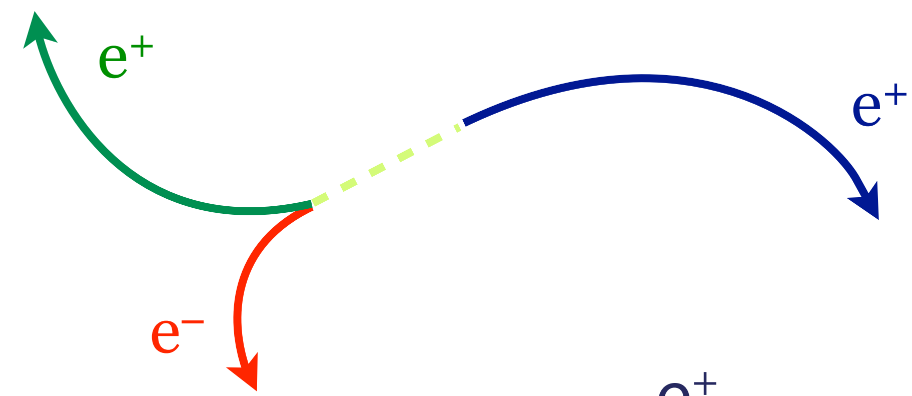


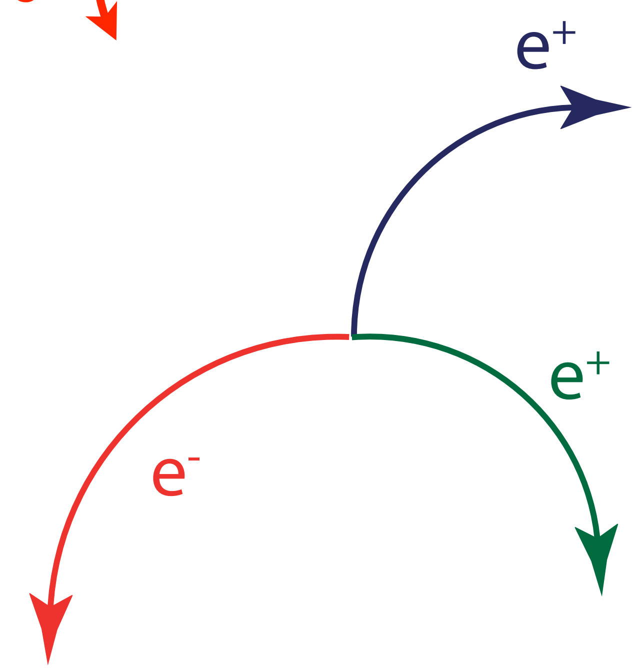
arxiv:1303.0754

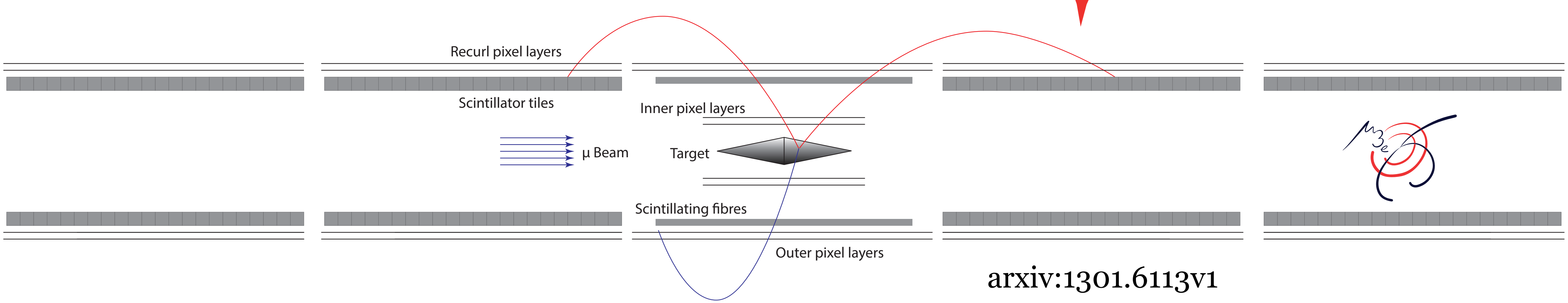
Detector geometry

- Take note from Mu3e proposal.
  - ✦ Similar event topology
- Cylinders of thin silicon sensors
- Thin cone-shape target
- Scintillator timing devices.

- We need to add a thick material to convert photons.

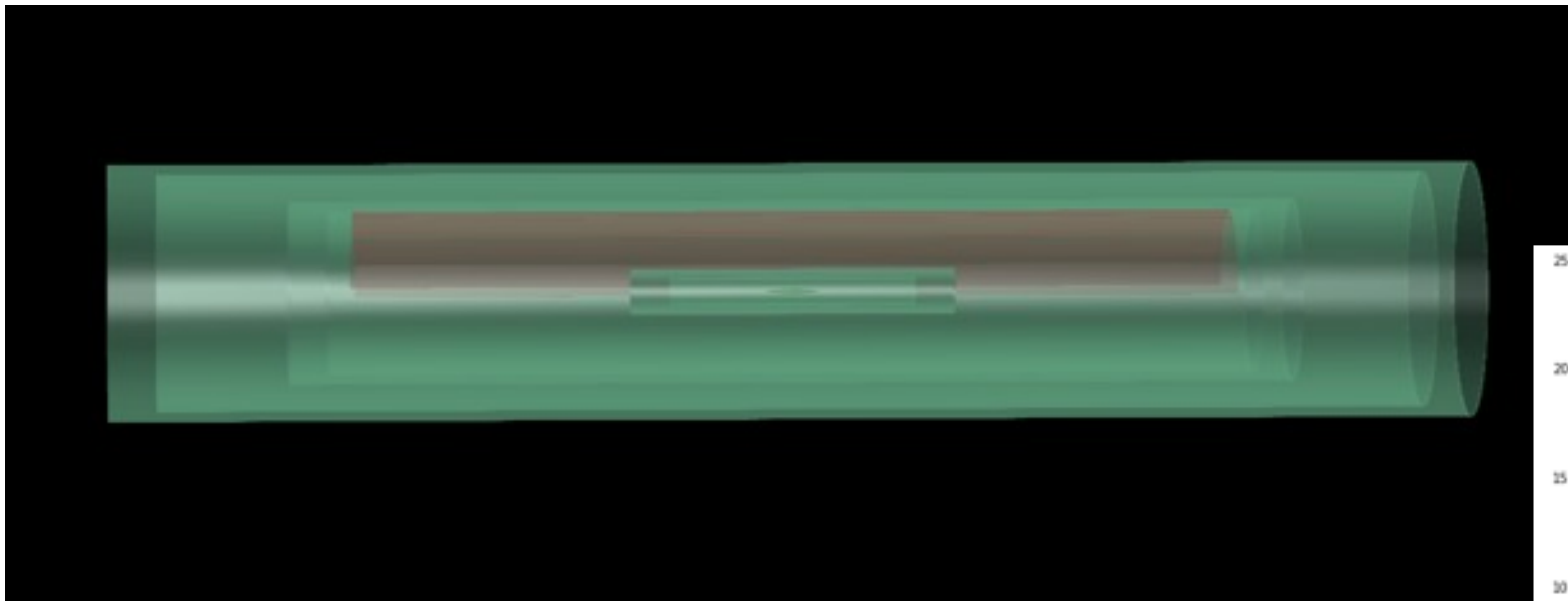


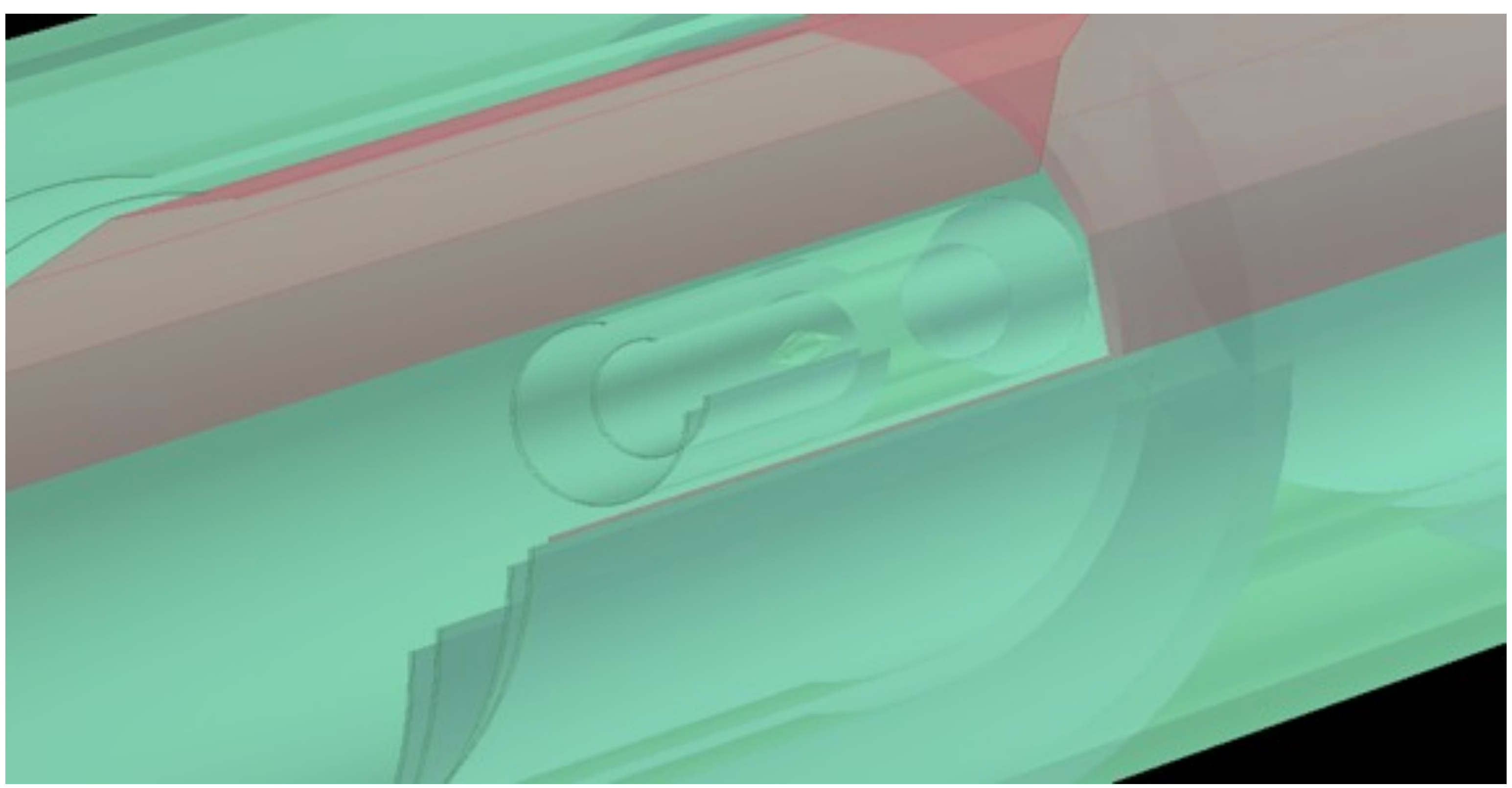


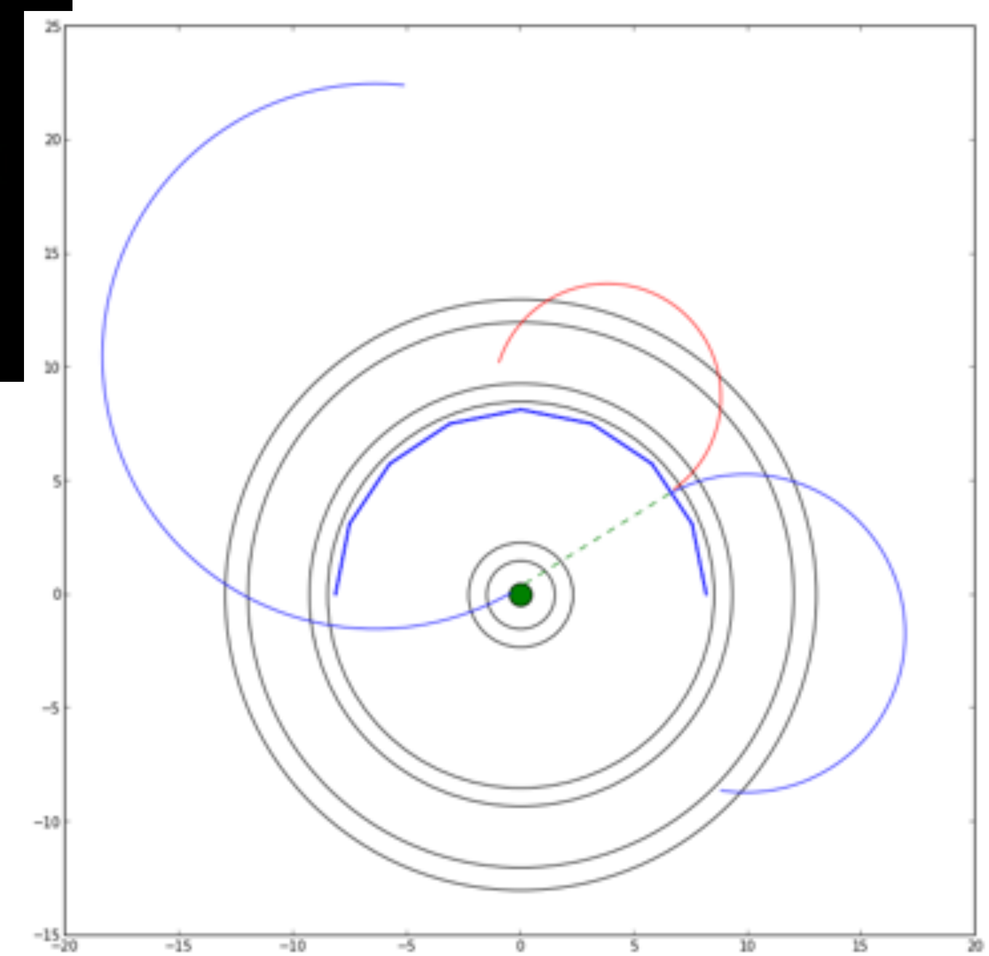


arxiv:1301.6113v1

FastSim geometry



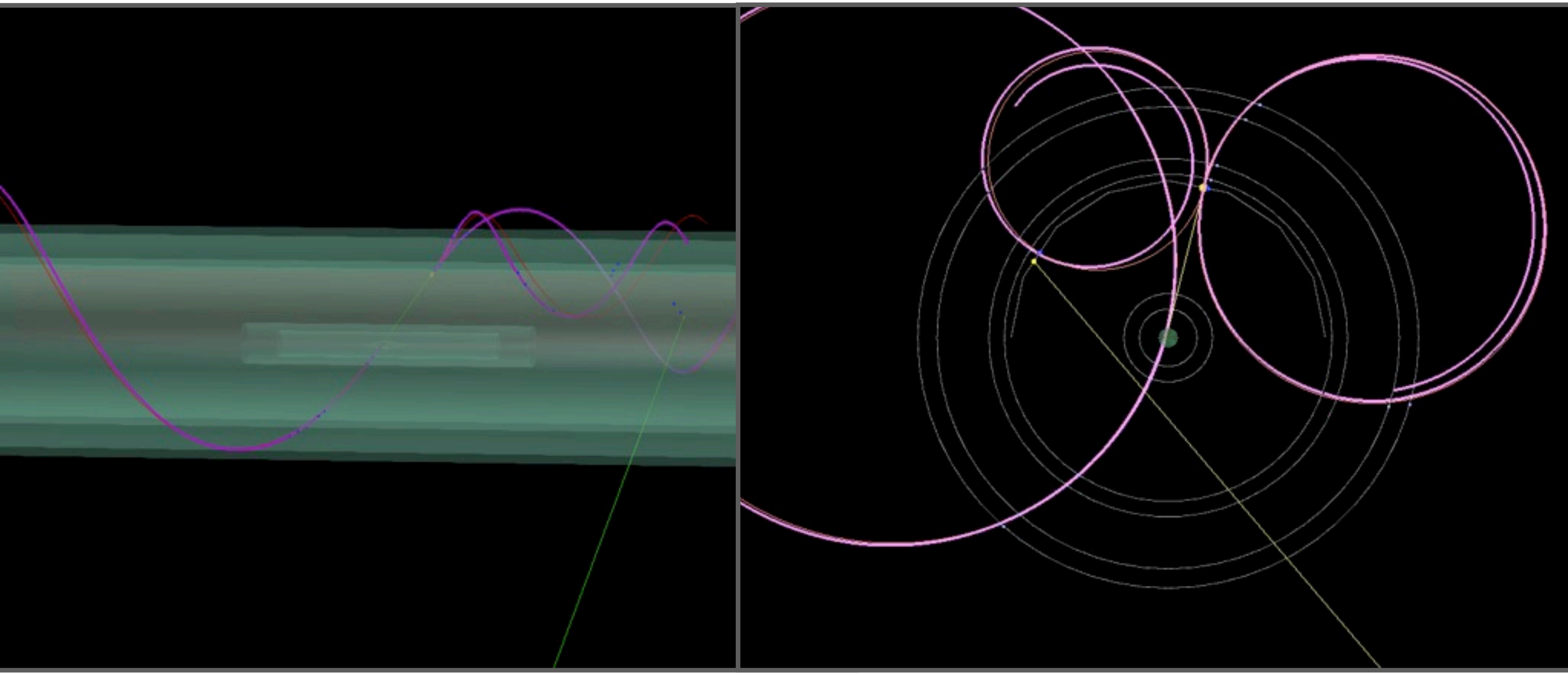




FastSim

- 6 layers: R= 1.5, 2.3, 8.5, 9.3, 12.0, 13.0 cm
- Si thickness= 50 μm, plus 50 μm kapton.
- Pb photon converter, 0.56 mm thick (10% X_0) at R=8.0 cm.
- "Target", double-cone Aluminum. Z vertices at ±3cm; R=0.5 cm at z=0; thickness= 50 μm, to simulate the effect of target.
  - Muons decay just inside the surface of the target.
- Polar angle coverage: [0.2, π–0.2] rad
- B Field= 1.0 T
- Silicon layers are modeled after Super*B* double-sided striplets.
  - Hit resolution: 8 μm, plus some fraction of a 20 μm tail.
  - Hit efficiency: 99%.

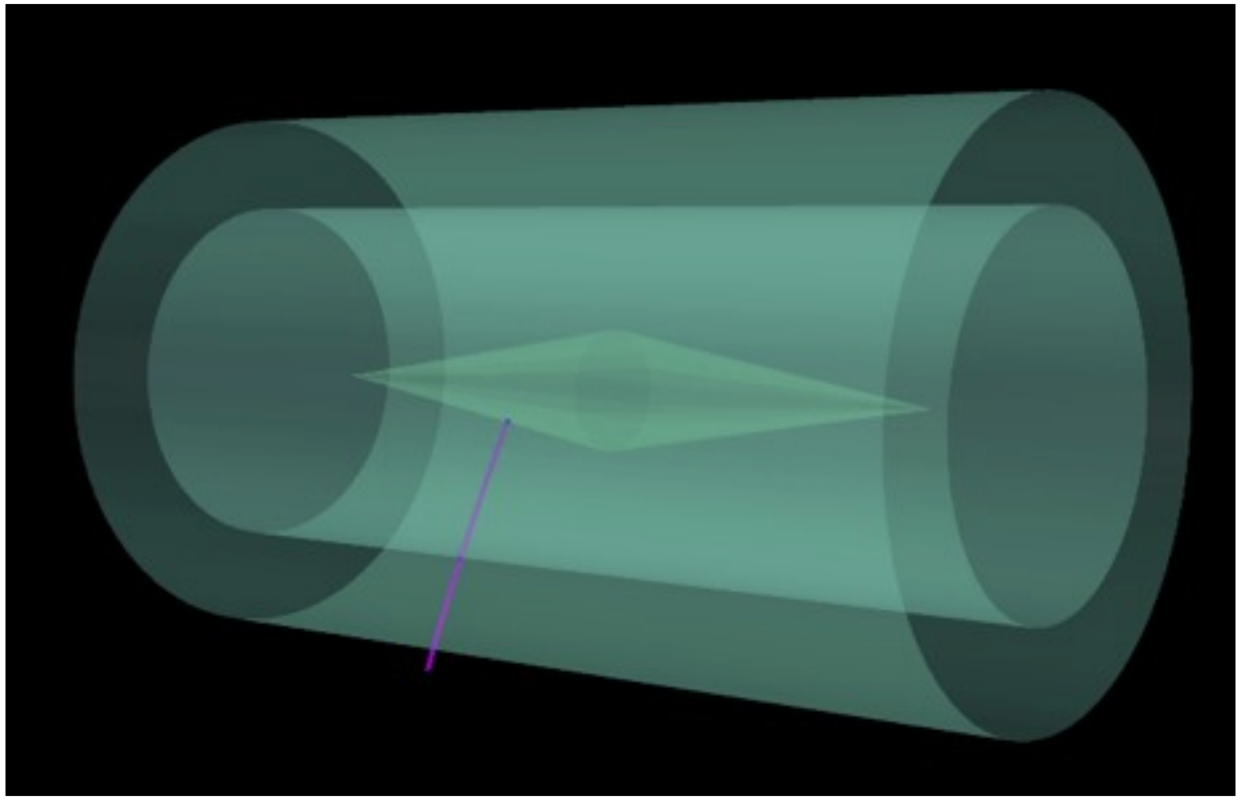
Event display

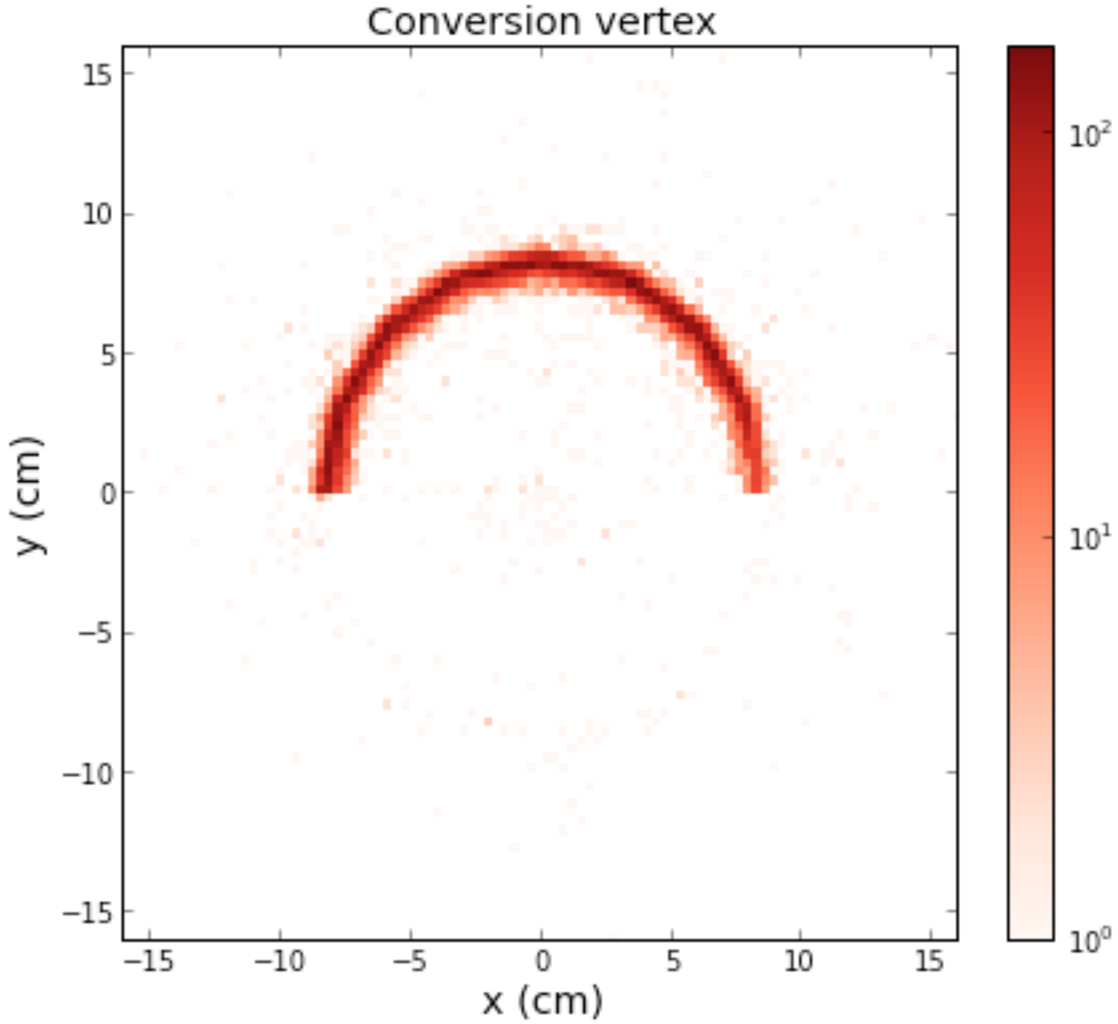


Thin red curves: generated helices; magenta curves: fitted trajectories

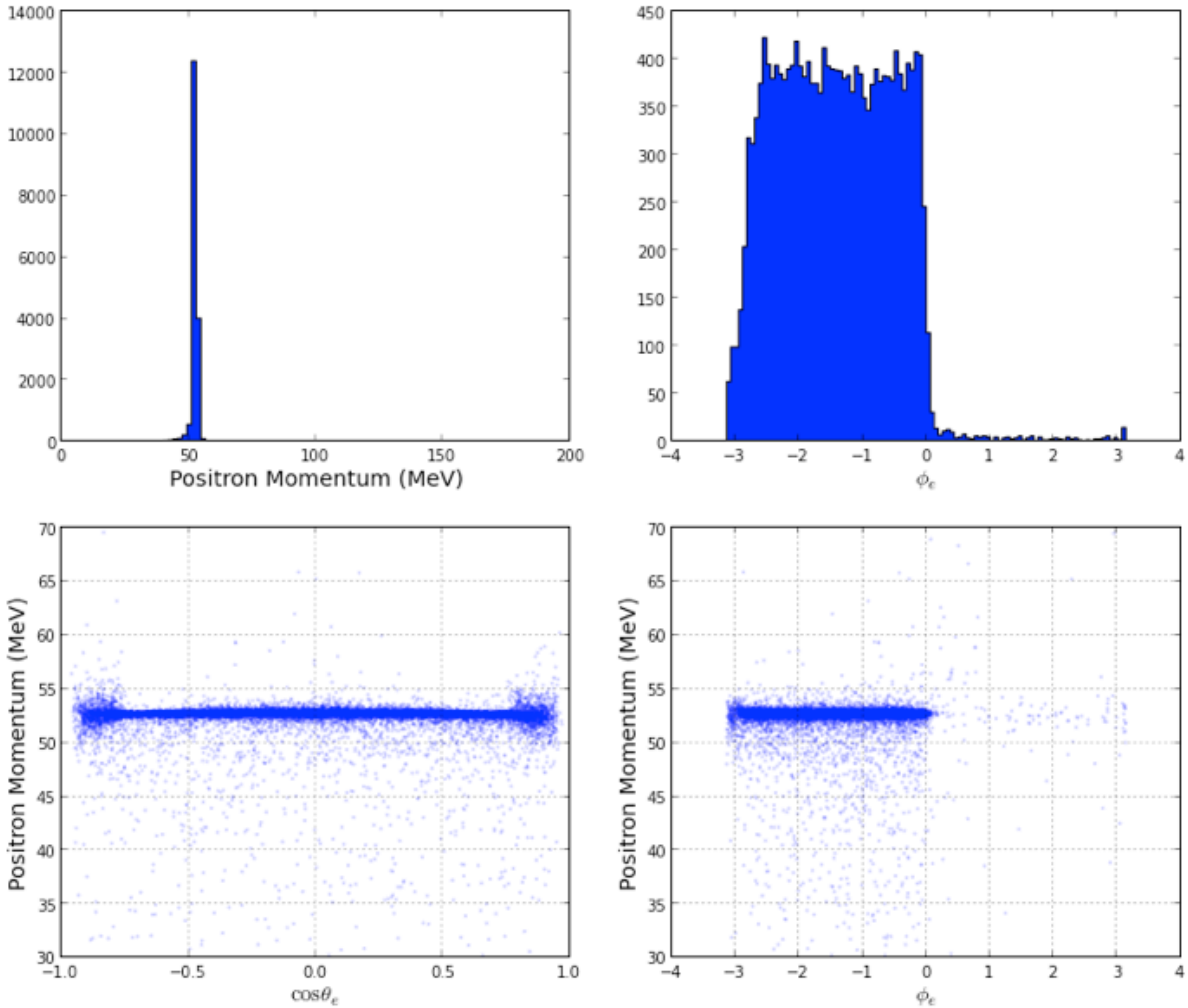
Analysis

- Generate 10^6 $\mu^+ \rightarrow e^+ \gamma$ uniformly under the surface of target.
- *BABAR* algorithm to find/vertex converted $\gamma \rightarrow e^+ e^-$ pairs.
- Extrapolate primary e+ onto the target surface; use the intersection to constrain the muon candidate decay vertex.
- ~1.8% are reconstructed.

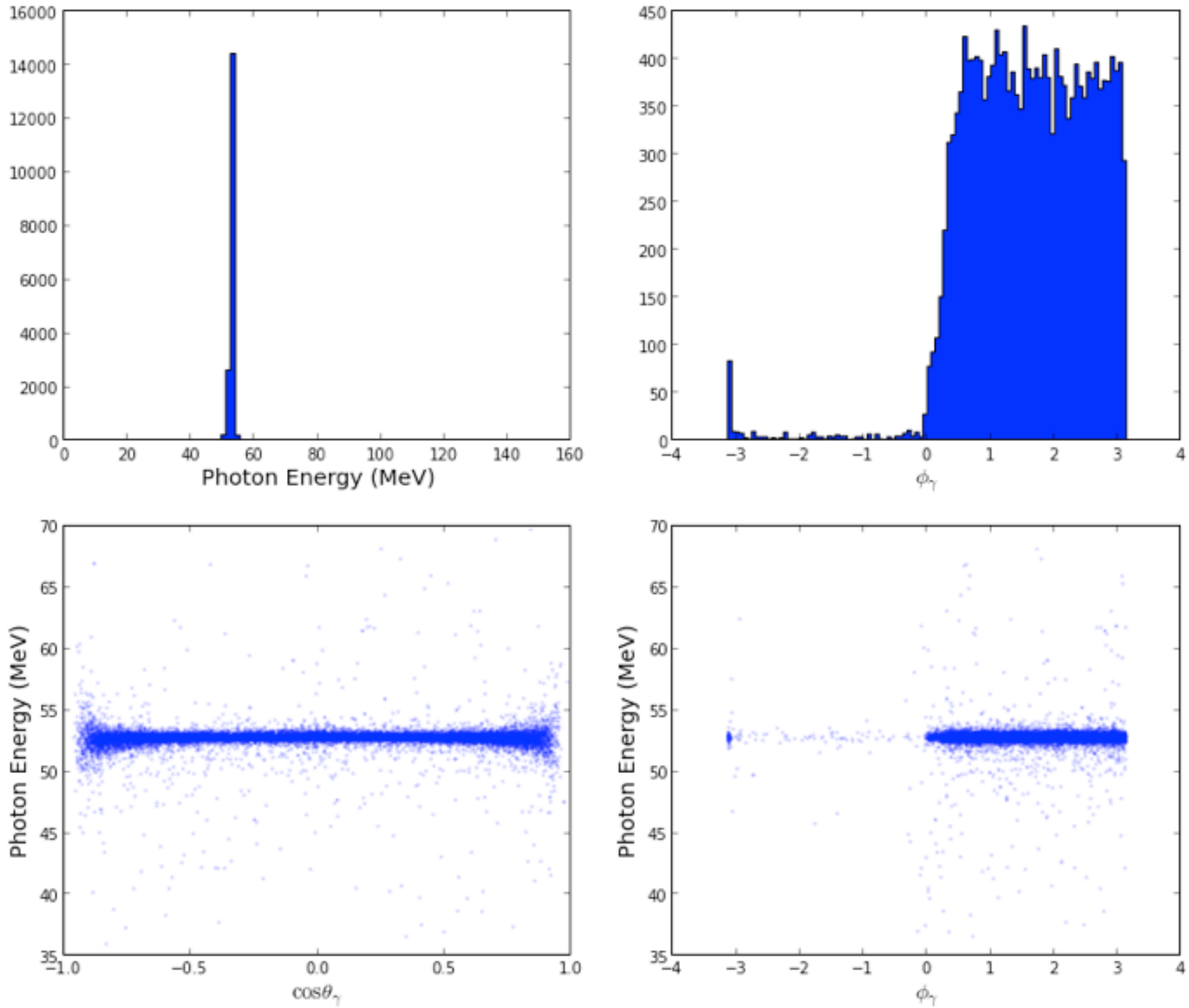




Positron momentum

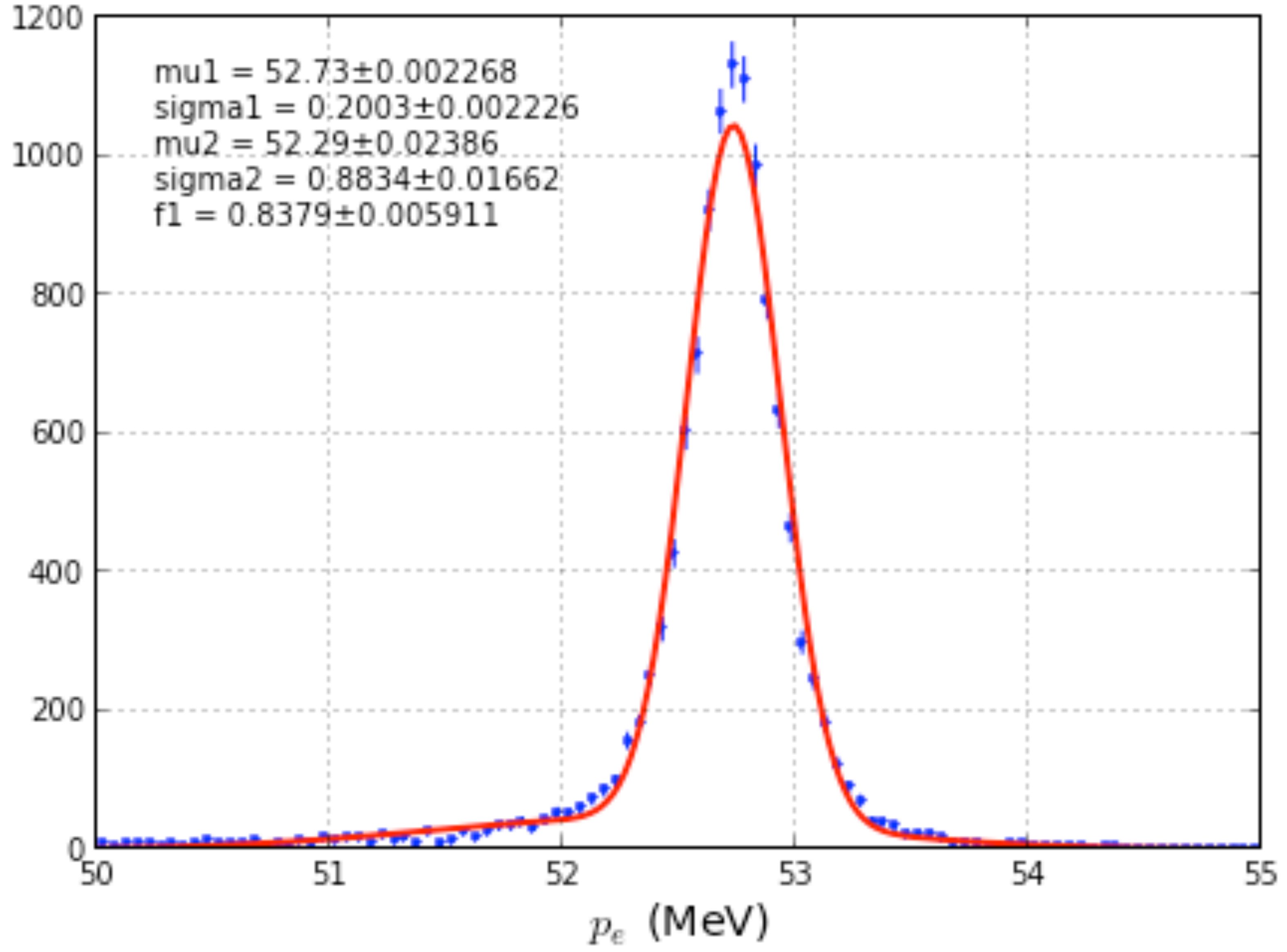


Photon energy

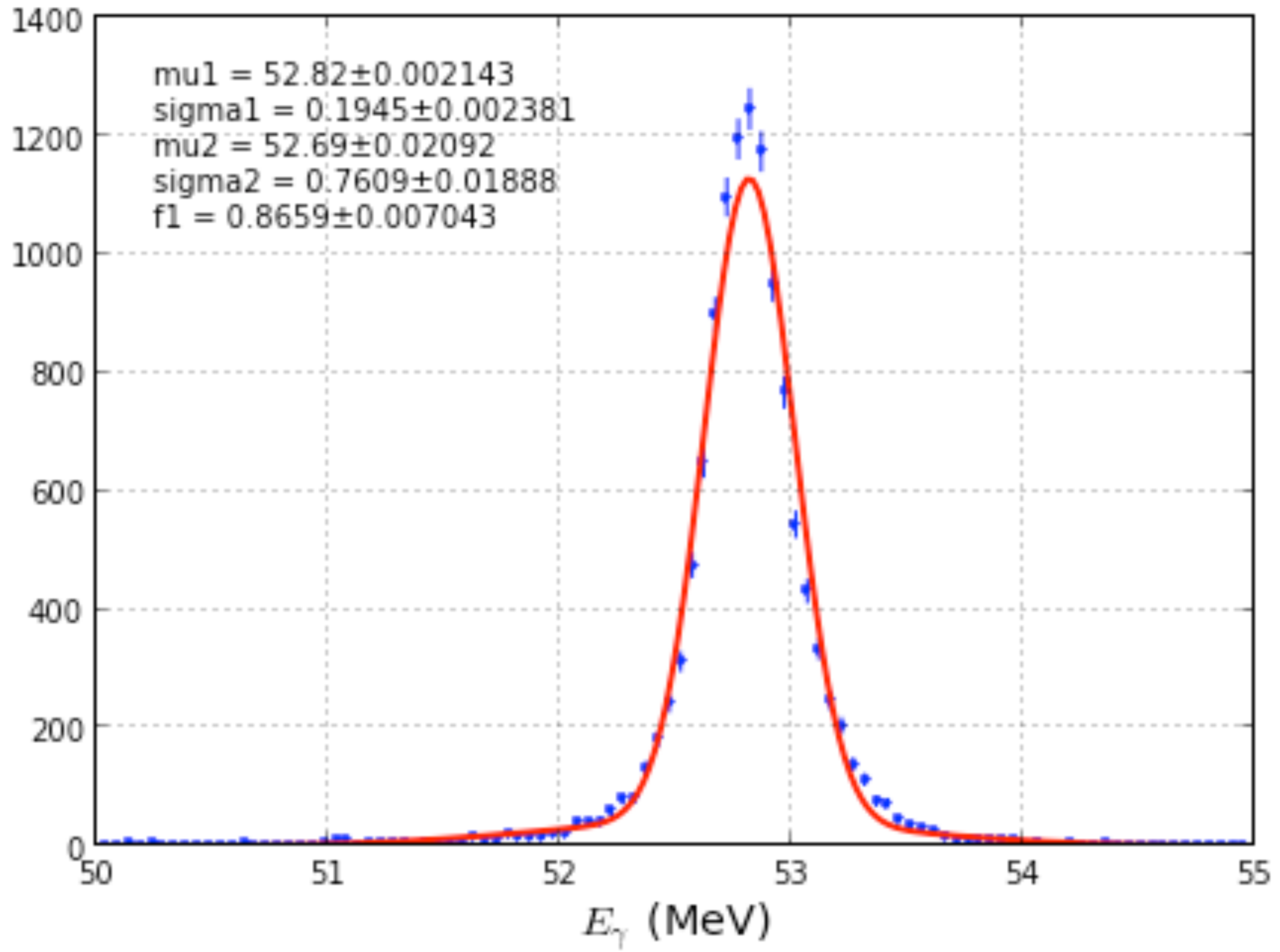


Positron momentum resolution

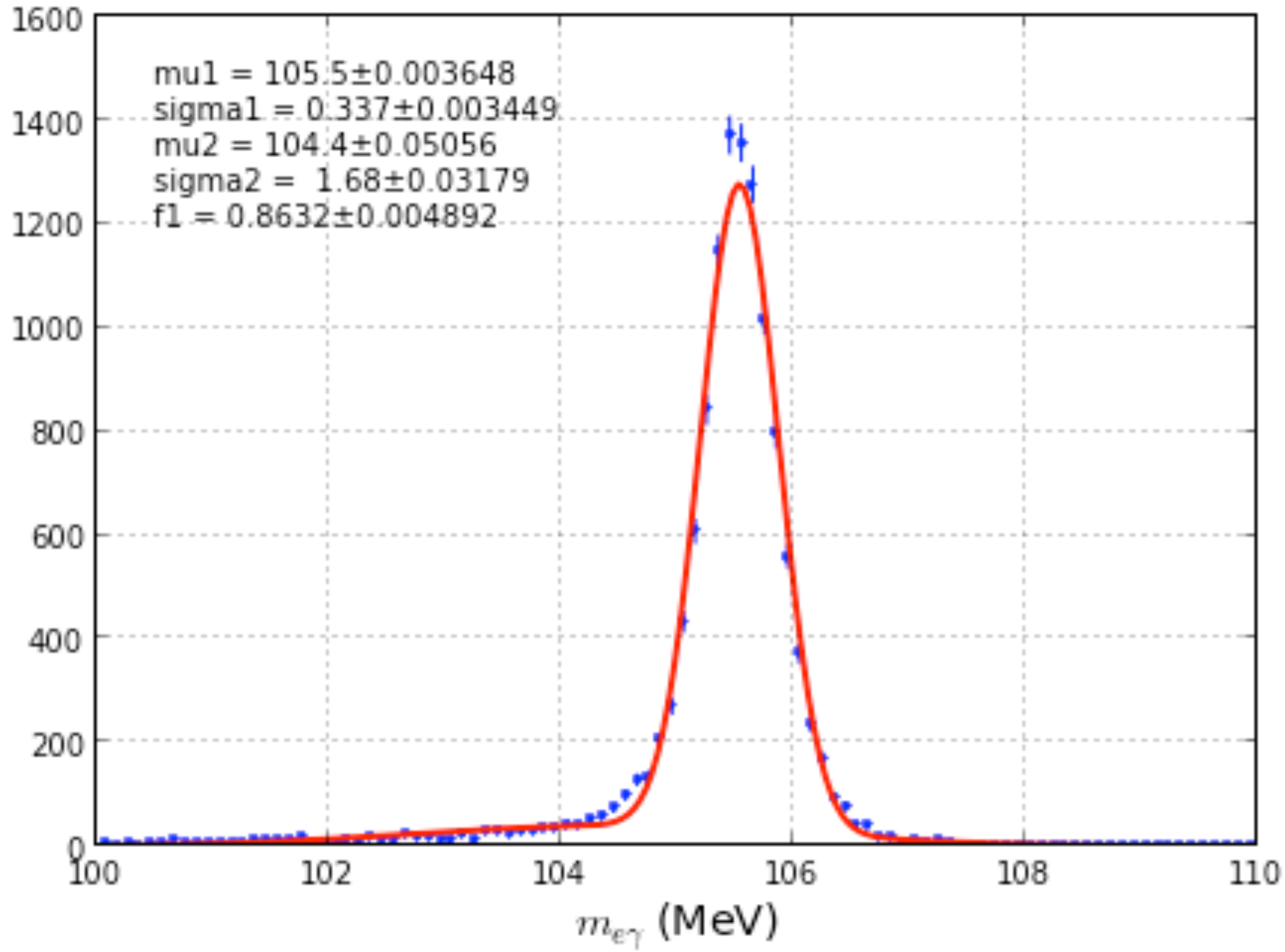
- Selection: $|\cos\theta_e|<0.7$; $|\cos\theta_\gamma|<0.7$; $-3<\phi_e<0$; $\phi_\gamma>0$
- Efficiency ~ 1.25%.



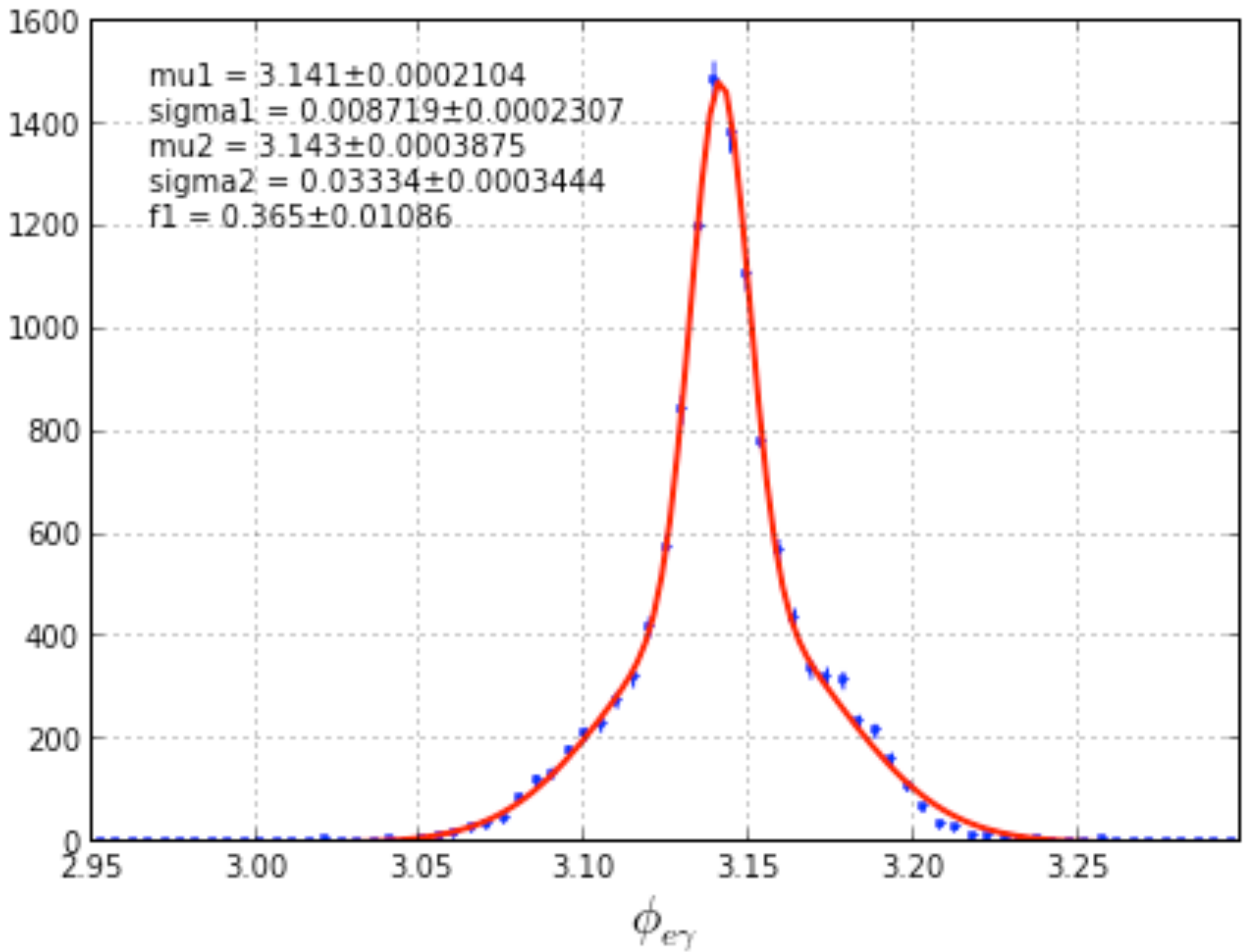
Photon energy resolution

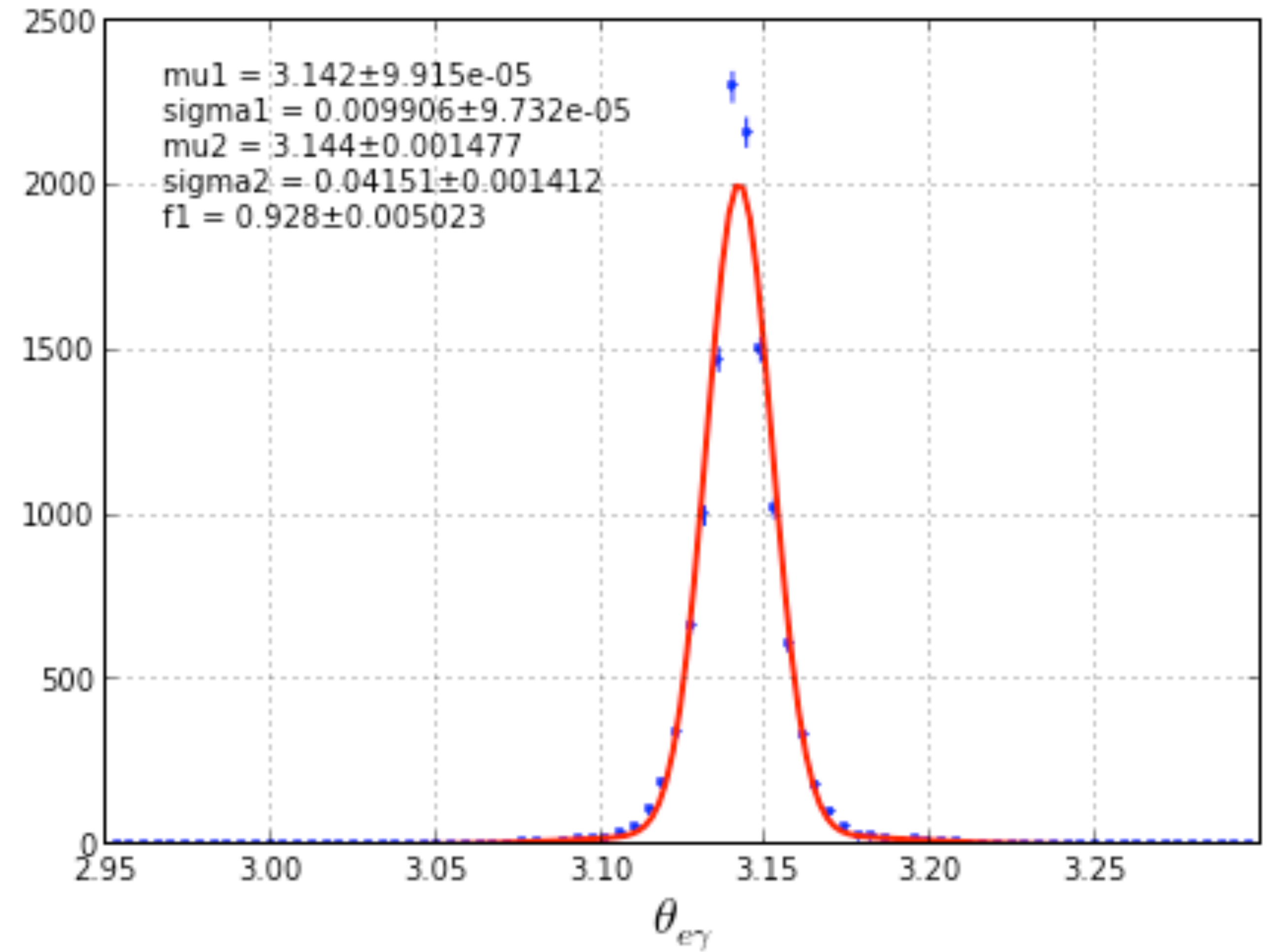


Muon mass resolution



Angular resolution





- Large $\phi_{e\gamma}$ resolution may be due to confusion of muon vertex constraint; there are two intersection on the target for each track.

Summary

- We use Super*B* FastSim and *BABAR* framework to study a conceptual design of a detector for $\mu^+ \to e^+\gamma$ ($\to e^+e^-$)

- Comparison with MEG, MEG upgrade and Mu3e.

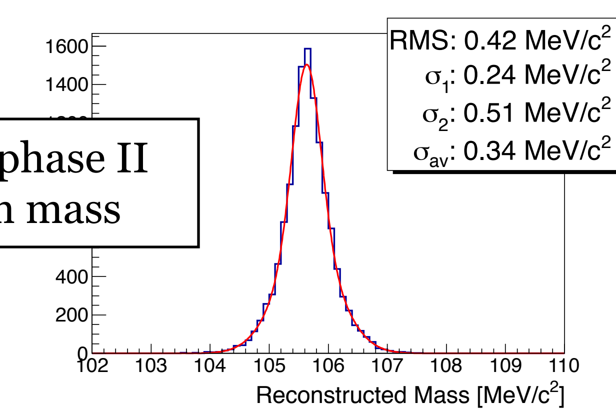
	This work	MEG
p_e	200 keV	305 keV
E_γ	0.37%	1.7–2.4 %
$m_{e\gamma}$	340 keV	
$\phi_{e\gamma}$	9/33 mrad	9 mrad
$\theta_{e\gamma}$	10 mrad	16 mrad
efficiency	1.25%	

TABLE XI: Resolution (Gaussian σ) and efficiencies for MEG upgrade

PDF parameters	Present MEG	Upgrade scenario
e^+ energy (keV)	306 (core)	130
e^+ θ (mrad)	9.4	5.3
e^+ ϕ (mrad)	8.7	3.7
e^+ vertex (mm) Z/Y(core)	2.4 / 1.2	1.6 / 0.7
γ energy (%) (w <2 cm)/(w >2 cm)	2.4 / 1.7	1.1 / 1.0
γ position (mm) $u/v/w$	5 / 5 / 6	2.6 / 2.2 / 5
γ-e^+ timing (ps)	122	84
Efficiency (%)		
trigger	≈ 99	≈ 99
γ	63	69
e^+	40	88

arxiv:1301.7225v2

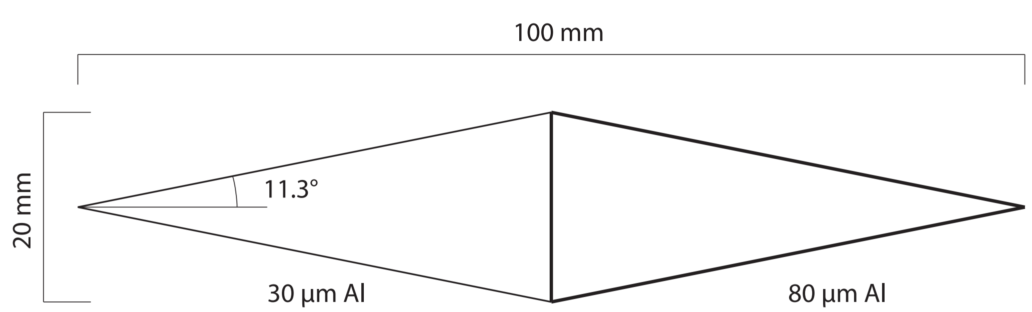
Mu3e phase II
muon mass



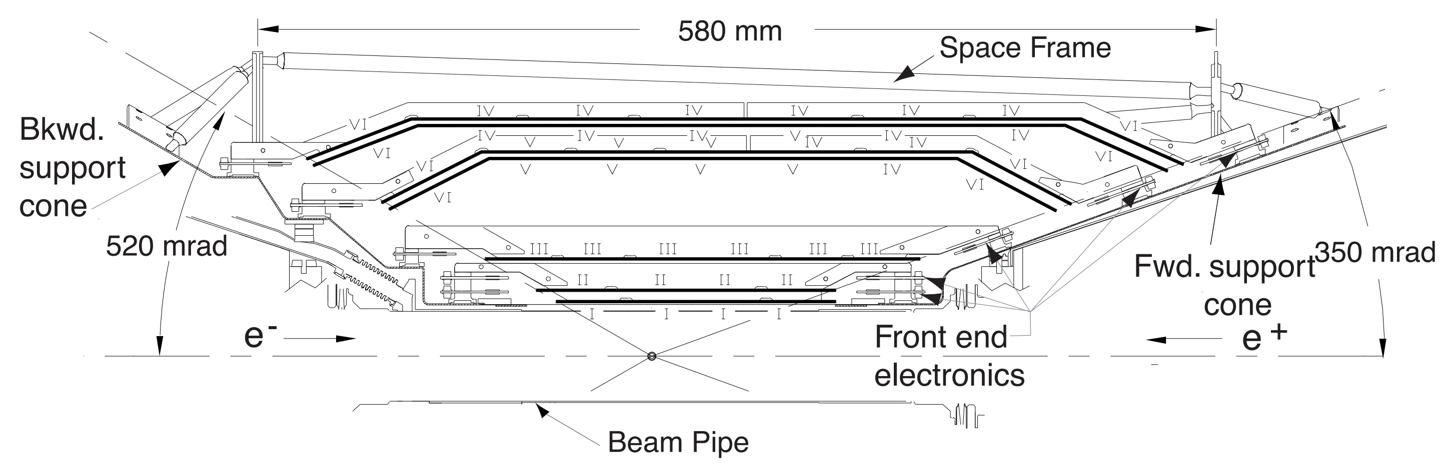
arxiv:1301.7225v2

To do

- Add timing devices (scintillator).
- Model/generate background (accidentals, radiative muon decays, etc.)
- Optimize target shape (longer, narrower, other geometries).
- Tune tracking/reconstruction algorithms (*BABAR* tracking is optimized for higher momentum and non-loopers)
- Explore active target options.
- Optimize geometry (arch to reduce multiple scattering?)



Mu3e target arxiv:1301.7225v2



BABAR SVT