# $\mu$-> e $\gamma$ with converted $\gamma$: Tracking needs

Fritz DeJongh

- Goal: Path to $10^{-16}$ sensitivity using
  - Intense stopped muons beams from Project-X
  - Monolithic pixel detectors
  - Time of flight
- What's next toward Snowmass?

# Existing Branching Ratio Limits

MEGA: $< 1.2 \times 10^{-11}$ (1999)

Using converted photons

converter: 9% radiation length (in each of 3 layers)

6% duty cycle

$1.5 \times 10^{7}$ stopped muons/sec

MEG: $< 2.4 \times 10^{-12}$ (2010)

Using LXe calorimeter

Expects to reach few $\times 10^{-13}$

Moving forward with the converted photon approach:

- Use project X to increase $R\mu$ (the rate of stopped muons) and signal rate
- Problem: Accidental coincidence rate increases as $R\mu^2$ (instantaneous)
- Need
  - 100% duty cycle
  - Thin converter
  - Thin detectors
    - Resolution limited only by energy loss and multiple scattering

# Sensitivity goals and Project X cold muon beams

1 event at BR = $10^{-16}$ with S/N = 1

- Will need 3 x $10^{11}$ stopped muons/sec
  - Mu2e: 5 x $10^{10}$ with 8 KW proton power
- However, need it with small, thin target
  - A challenge for Project X, but seems plausible

What if we discover BR = $10^{-14}$?

Can increase $R\mu$ by 100 and have S/N = 1

Would obtain $10^4$ events and precision BR!

- Need 3 x $10^{13}$ stopped muons/sec
  - Advanced muon cooling at a high project X stage #

# Accidental Coincidences: "Effective Branching Ratio" of Background

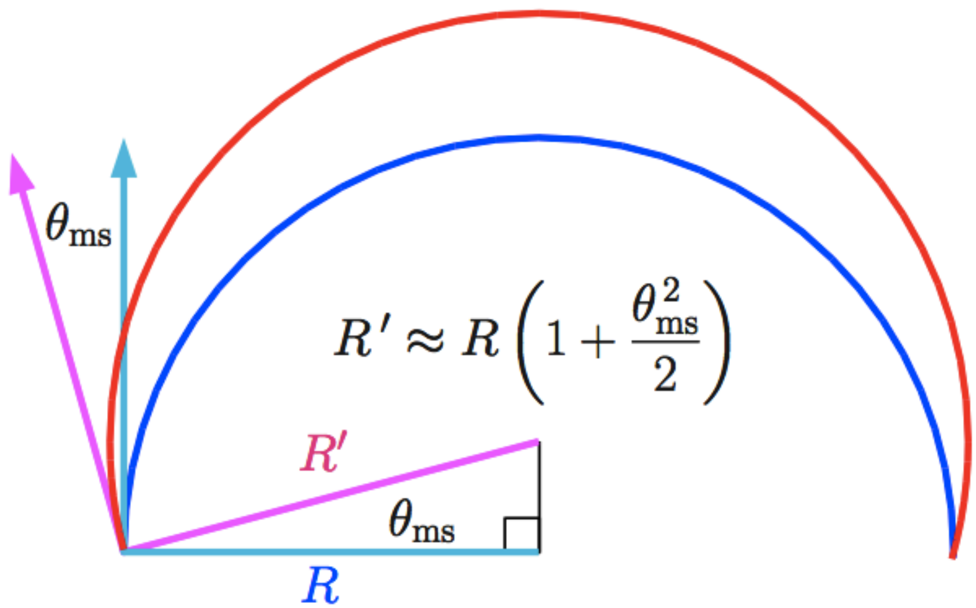
$$
\begin{aligned}
B_{acc} = \quad & \left(\frac{R_\mu}{d}\delta t_{e\gamma}\right) && \text{timing, duty cycle} \\
& (\delta x) && e^+ \text{ energy resolution} \\
& \left(\frac{\delta y}{15}\right)^2 && \gamma \text{ energy resolution} \\
& \left(\frac{\delta\theta^2_{e\gamma}}{4}\right) && \text{opening angle} \\
& \left(\frac{(2\delta\theta_z L_{\gamma T})^2}{A_T}\right) && \text{traceback angle}
\end{aligned}
$$

Timing:
External tof,
Or gigatracker style pixels?

Kuno, Okada, RMP73,151 (2001)
MEGA Collaboration, PRD65,112002 (2002)

# Measuring electron and positron energies

Use double pixel layers to measure position and direction at points on the helix trajectory of a track in a B field




Geometry: Try to arrange to obtain measurements 180º apart on the circle

If successful:

- Multiple scattering affects resolution only at 2nd order
- Energy loss in pixels becomes the limitation

# Projections: Scale from MEGA
# Calculate resolutions based on dE/dx and multiple scattering

Assume detector with:

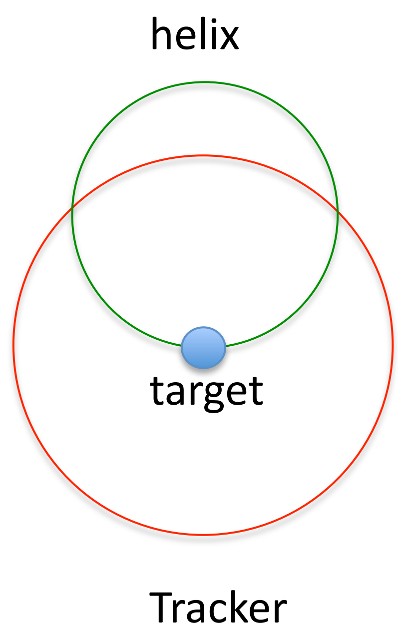
- •100% duty cycle (vs. 6% for MEGA)
- •Run-time 4 x $10^7$ sec (5x MEGA)
- •Increase factor $2\times10^4$ for $R_\mu$ (3 x $10^{11}$ / sec)
- •Same coverage as MEGA (30% of $4\pi$)
- •Monolithic pixels, 100 $\mu$m thick
- •converter thickness 1% of rad. length
- •160 psec FWHM tof res. (10x better)

1-event sensitivity: 2 x $10^{-16}$

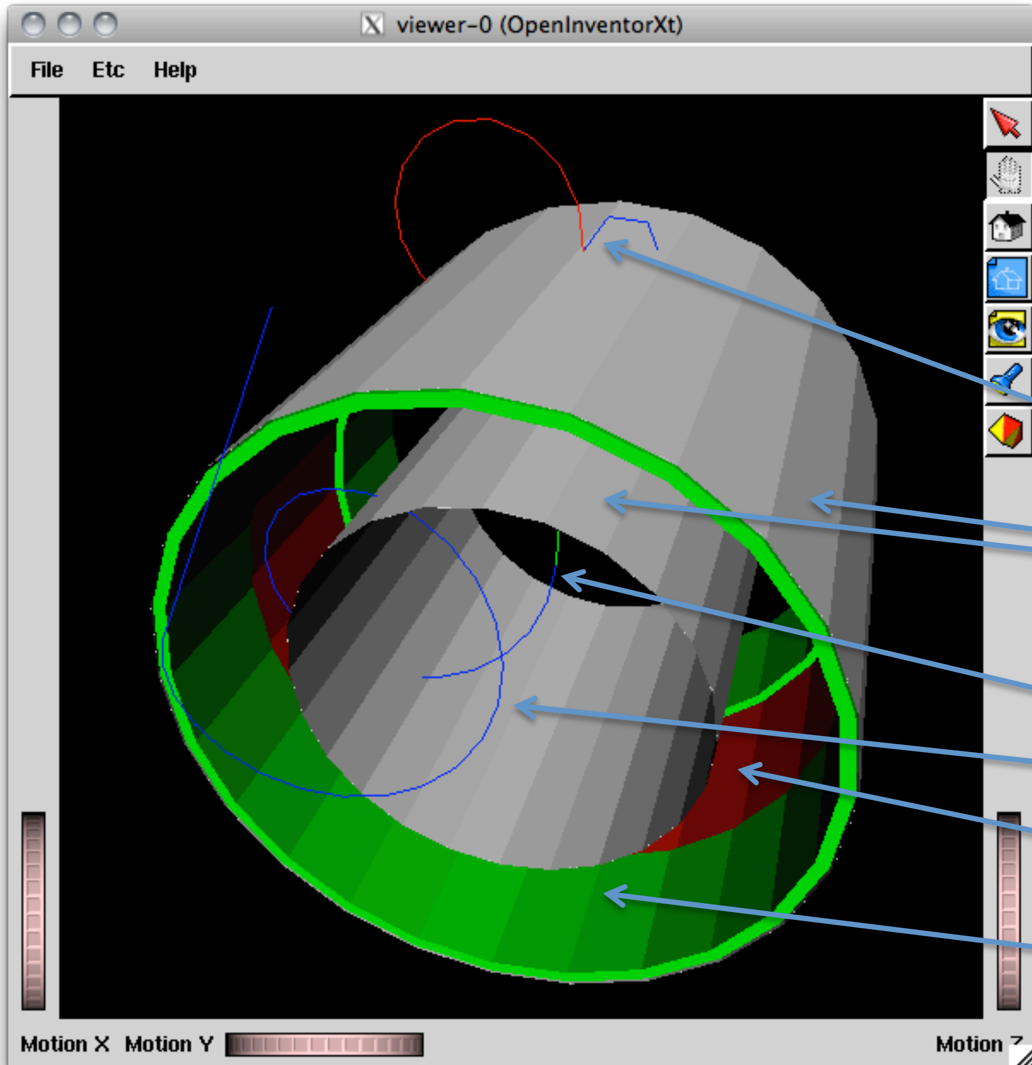
$B_{acc}$ : 2 x $10^{-16}$

Relative Resolutions for

- •Positron: $2\times10^{-4}$
- •Gamma: $4\times10^{-4}$


helix
target
Tracker

The simple minded geometry seems to work. Needs many $m^2$ pixel tracking




Target radius ~2 cm

B = 0.5 T

Positron R = 35 cm

Converted photon

Double pixel layers
R = 47 cm and 75 cm

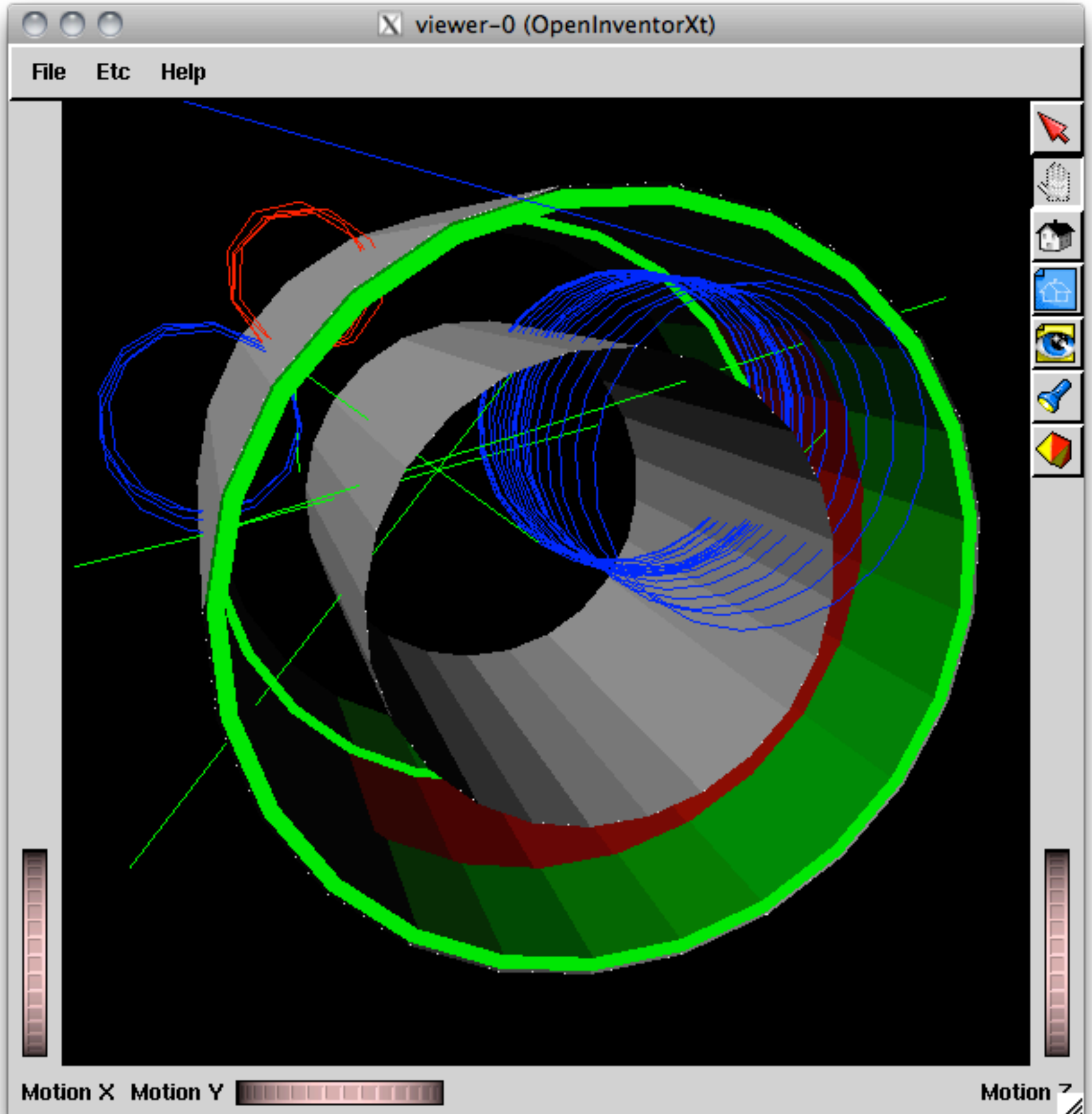
$\mu \rightarrow e\,\gamma$ decay from stopped muon

Positron

Converter

Calorimeters or tof
triggering, tof

Transverse geometry is nice theoretically but has some problems…




Other problem:

Need target extended in z (~150 cm) since gamma is pointing in from so far out.

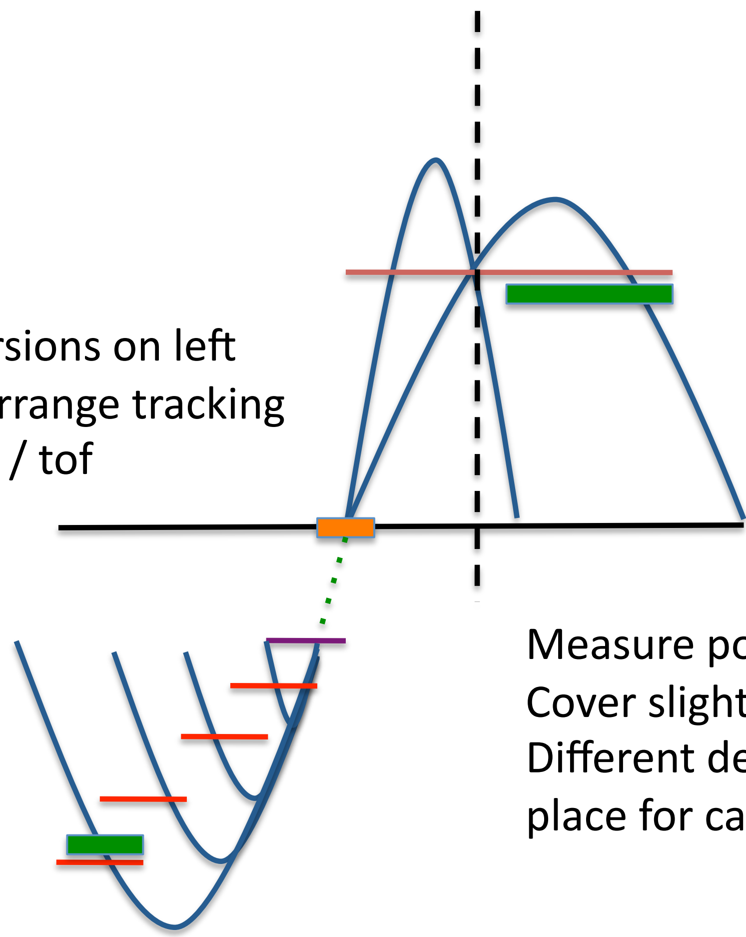
Putting calorimetry / tof On sides doesn’t work…

They could go inside converter if they’re not too thick

Is there a small target solution?  Requires moving converter way in (so gamma can point to a given fraction of the target)
Trickier geometry, occupancy issues, etc.

r-z view

Measure conversions on left
Try to cleverly arrange tracking
and calorimetry / tof

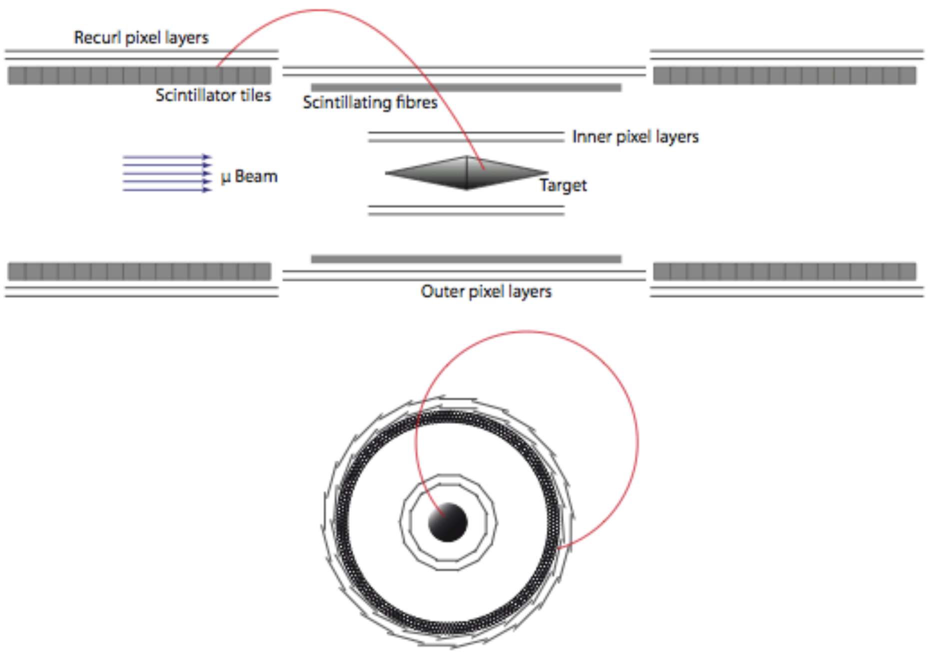


Can we use an active pixel target?

Measure positrons on right
Cover slightly higher pitch angle range
Different detectors measure 1$^{st}$ and 2$^{nd}$ hits
place for calorimetry / tof

Use internal
conversions?

Comments on $\mu \to e^+ e^+ e^-$: PSI LOI aims to use $10^9$ $\mu$/sec
Ultimate sensitivity goal: $\alpha \times 10^{-14}$
How could we exploit higher muon stopping rate to do better?




PSI μ3e LOI

Some things to try:

Optimize resolution, keeping events with best geometry
•Smaller acceptance
•Smaller target
•Lower mass- remove scintillating fibers, with tof in pixels or on side.

If accidental backgrounds are an issue:
•Focus on 3-body (rather than $e^+ \gamma^*$) rejecting e- accompanied by possible e+

# Toward Snowmass

- Challenging parameters (depends on geometry choice):
  - Thickness
  - Time of flight
  - Area
  - Triggering, readout
  - Cooling, mechanical
  - Less so on hit resolution, coverage
- Would like to start designing a more realistic layout for $10^{-14}$ sensitivity
- Test beam with low energy electrons: Resolution, tails, tune Geant.