μ-> e γ with converted γ

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- Goal: Path to 10^{-16} sensitivity using
  - Intense stopped muons beams from Project-X
  - Monolithic pixel detectors
  - Time of flight
- Outline:
  - Conceptual design based on resolution estimates
  - Some initial simulation results
  - Can we move converter closer to muon stopping target?
    - To the limit: Use internal conversions?
  - Comments on μ -> *eee*
  - What's next toward Snowmass?

Existing Branching Ratio Limits

MEGA: < 1.2×10^{-11} (1999)

Using converted photons

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

6% duty cycle

1.5×10^{7} stopped muons/sec

MEG: < 2.4×10^{-12} (2010)

Using LXe calorimeter

Expects to reach few x 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

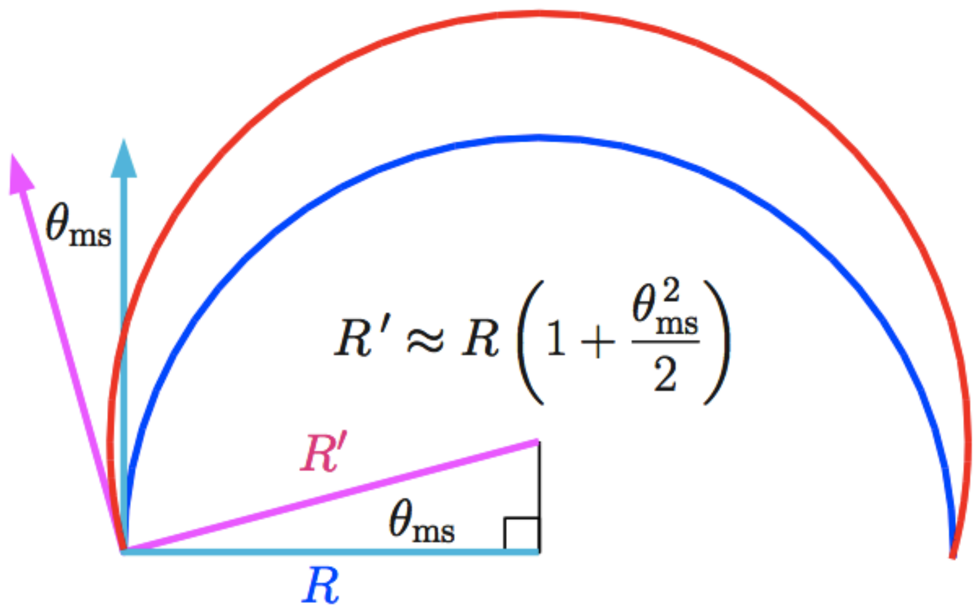
Accidental Coincidences: "Effective Branching Ratio" of Background

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

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

Measuring electron and positron energies

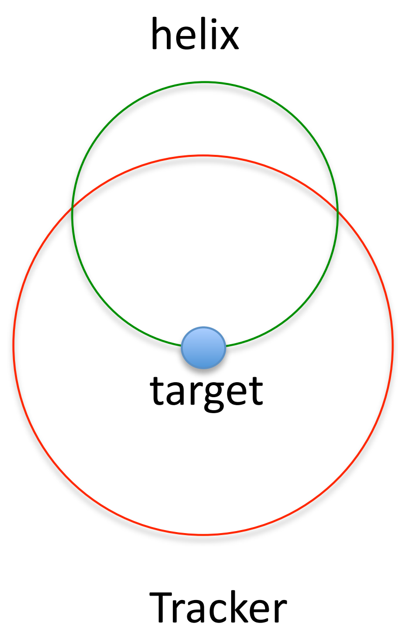
Use double pixel layers to measure position and direction at points on the helix trajectory of a track in a B field



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

If successful:

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


helix
target
Tracker

Thickness of Photon converter (*t*): A Sensitive Parameter

Signal increases as t

B_{acc} increases as t^3 since t affects
- photon energy resolution
- traceback angle resolution

If you can increase R_μ
- Do it!
- Decrease converter thickness as needed to reduce backgrounds

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 $2\text{x}10^4$ for R_μ (3 x 10^{11} / sec)
- Same coverage as MEGA (30% of 4π)
- Monolithic pixels, 100 μm 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: $2\text{x}10^{-4}$
- Gamma: $4\text{x}10^{-4}$

Should be OK for physics background if mis-reconstructions are also low

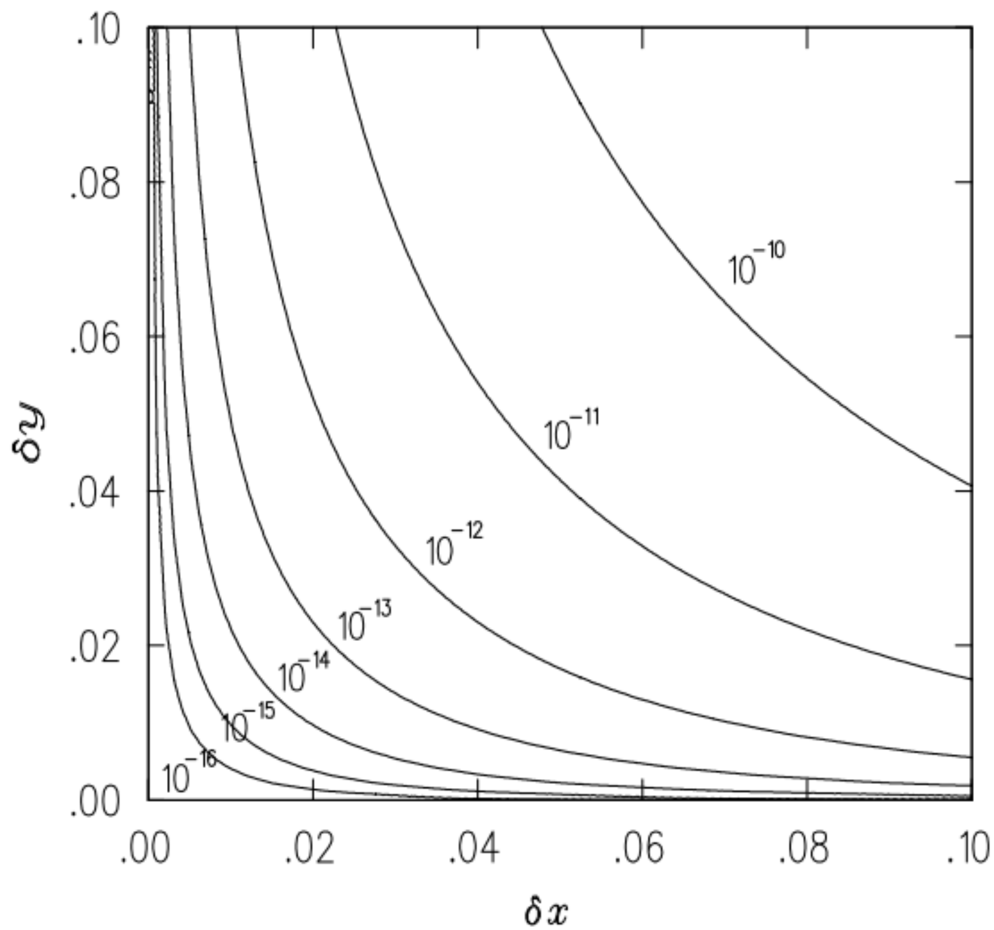
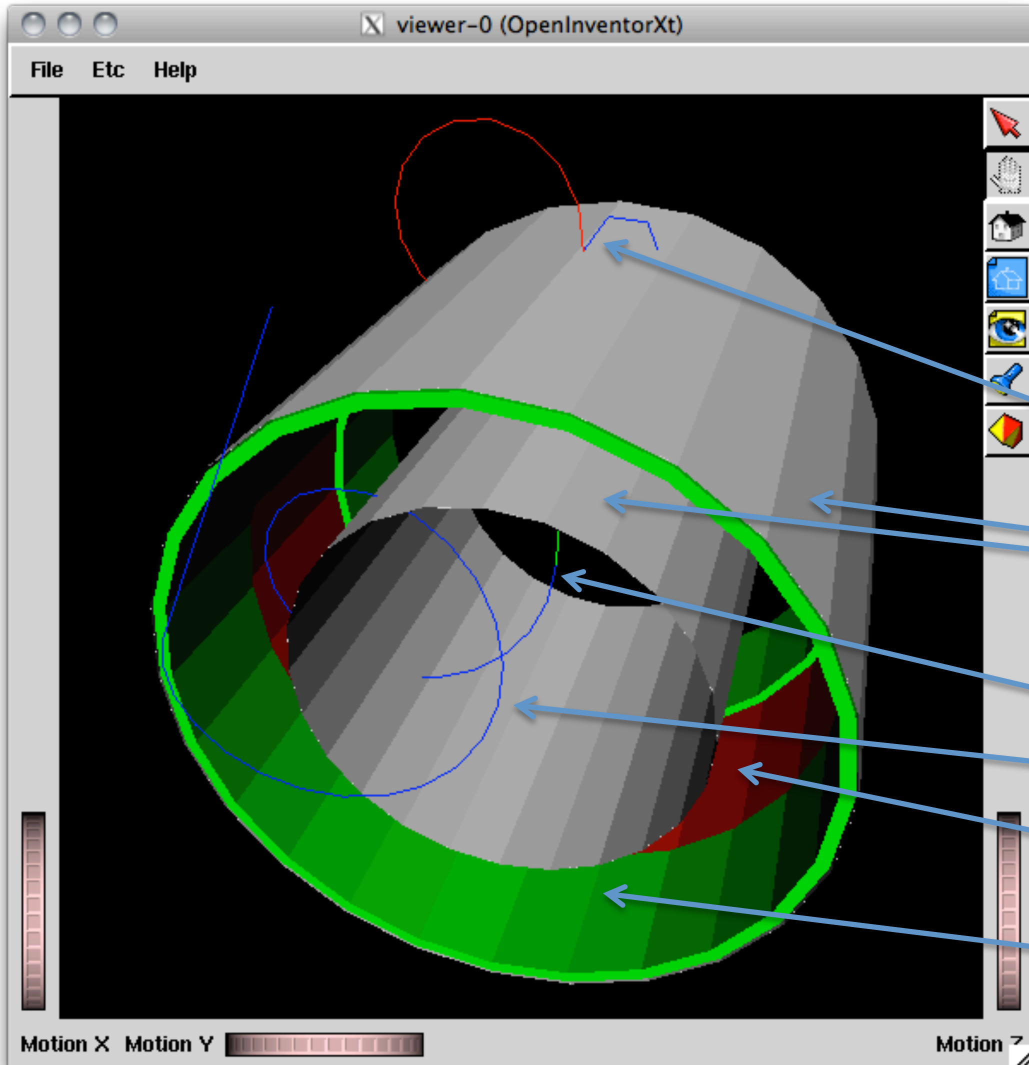


FIG. 22. Effective branching ratio of the physics background from the $\mu^+ \rightarrow e^+ \nu_e \overline{\nu}_\mu \gamma$ decay as a function of the e^+ energy resolution (δx) and photon energy resolution (δy) (after Kuno and Okada, (1996)).

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

μ -> e γ decay from stopped muon

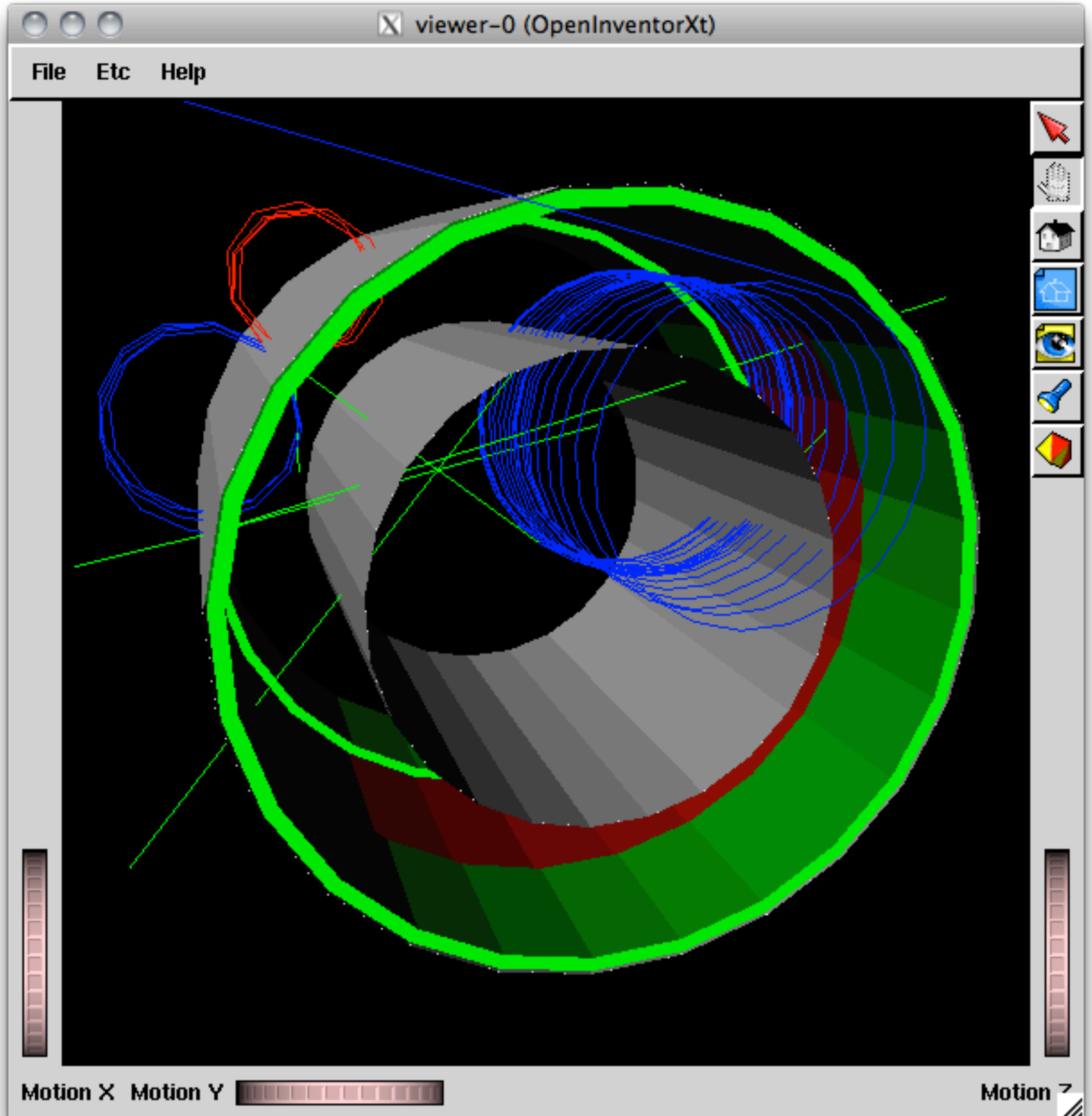
Positron

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.

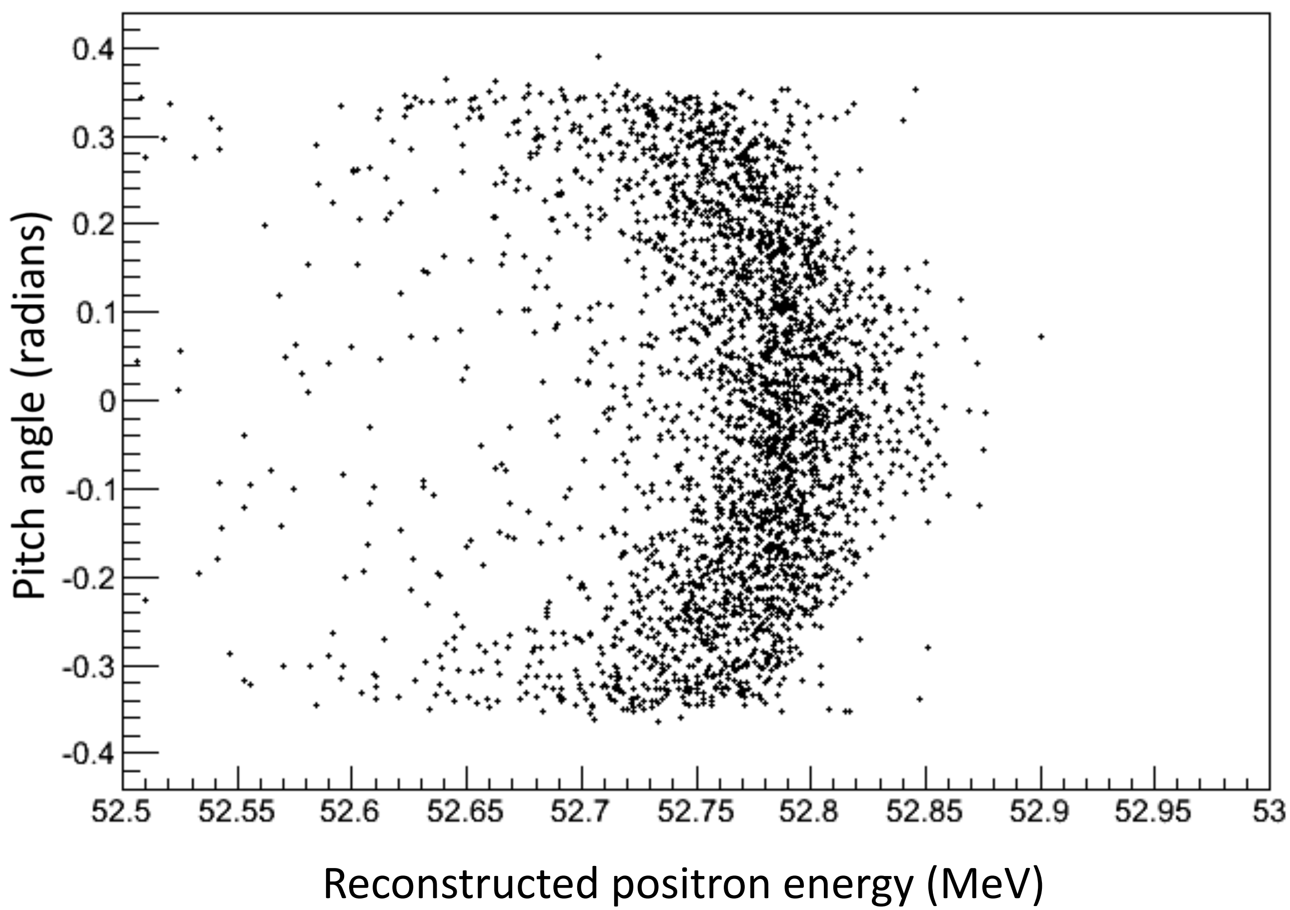
Putting calorimetry / tof On sides doesn't work…

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

Reconstruction of helix from simulated hits

Resolution not too far from expectations, with tail on low side

Dependence of reconstructed energy on helix parameters



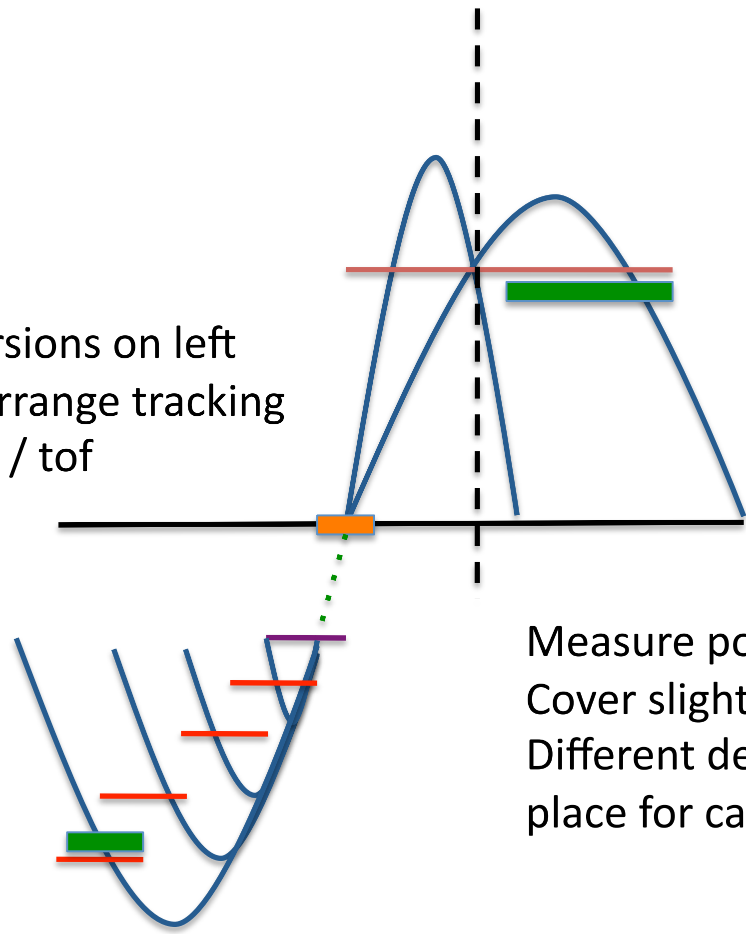
Need to improve

- Algorithm
- Energy loss corrections
- Tuning of Geant tracking precision
- Worry more about delta rays and non-gaussian tails

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

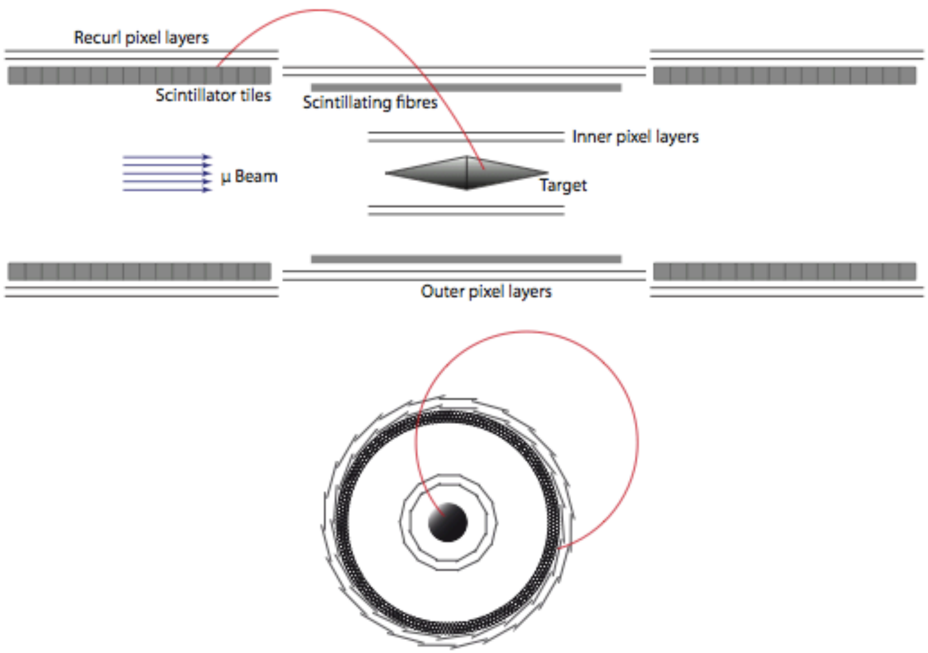


Can we use an active pixel target?

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 μ/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

- There is a way forward using improved muon beams, monolithic pixel trackers, and t.o.f., but designing the ultimate experiment is going to be very tricky.
- General considerations are pointing toward a strategy using μ -> *eee* although a converted photon approach is still a good possibility
  - Perhaps separate experiments for internal conversion and 3-body amplitudes
- Start trying to focus on realistic schemes to obtain sensitivity of $\alpha \times 10^{-14}$ that perhaps could be done even before project X stage 1
- Advocate pixel detector test beam study with low energy electrons. Try to understand resolution, tails, tune Geant simulation