Active Targets for Stopped Muon CLFV Experiments

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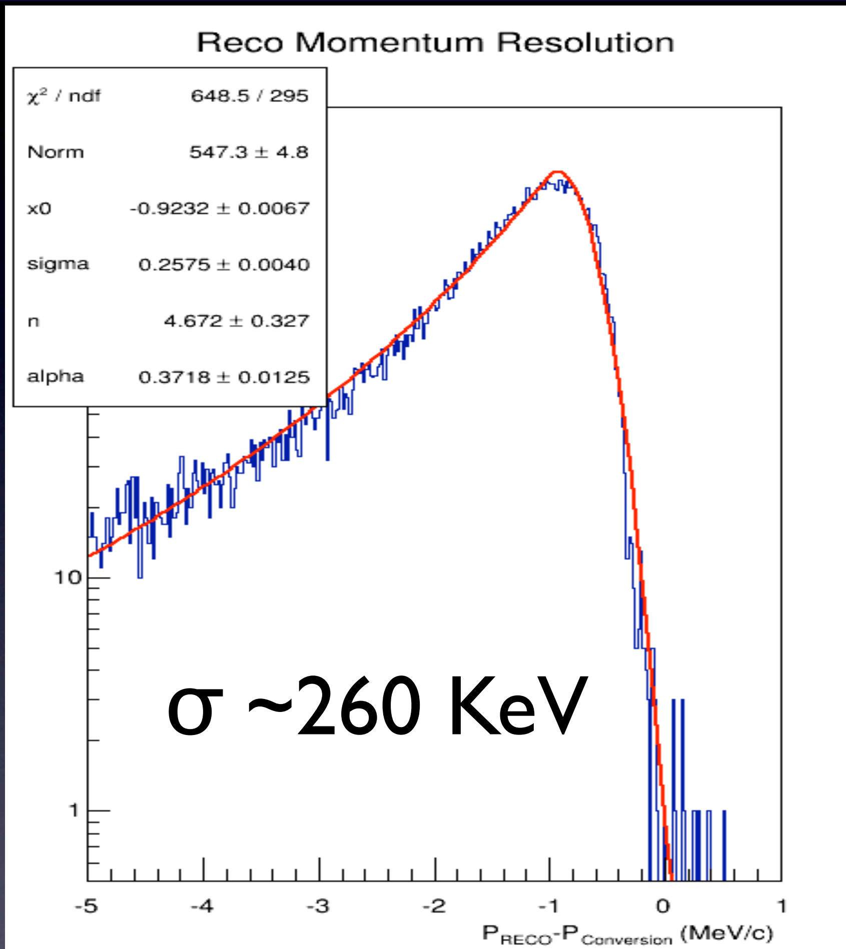
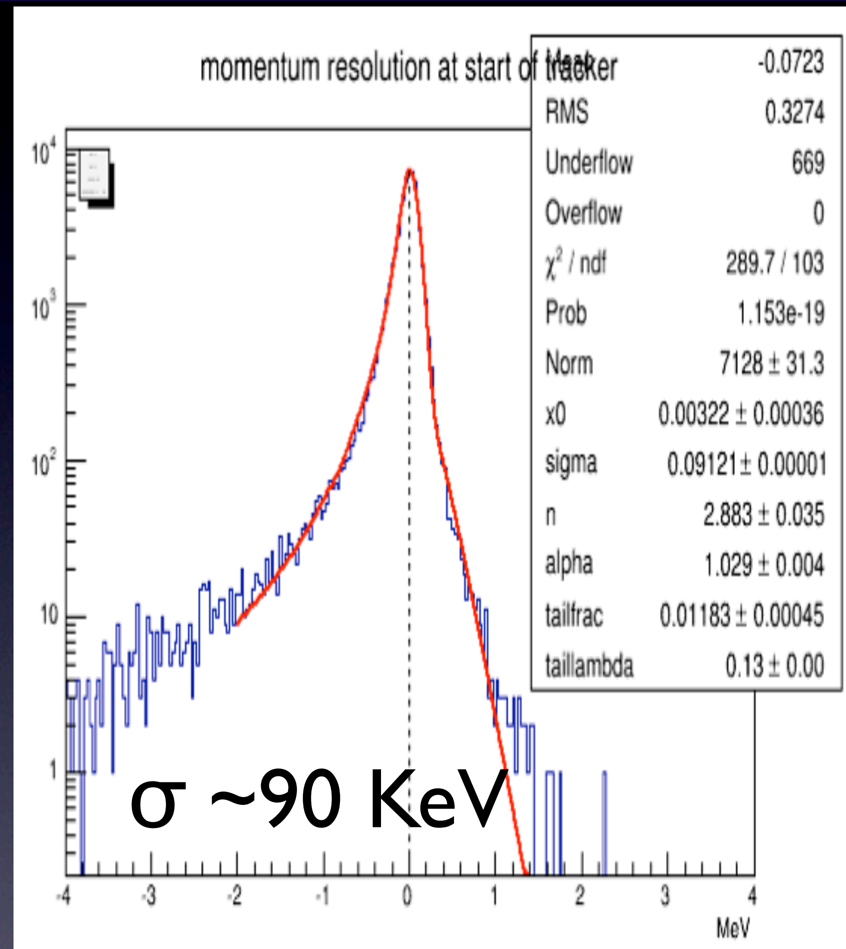
Argonne IF workshop
CL group

Stopping Targets

- μ CLFV experiments require a stopping target
  - Material to slow, stop and (possibly) capture muons
  - Stopping rate ~ proportional to the mass
- Targets also degrade the muon decay particles (e^-)
  - scattering and energy loss, ~ proportional to the mass
  - can limit the experimental resolution
- Can an active target recover (some) of the lost resolution?
- What features does an active target require?
- What technologies might make sense?
- What experiments would benefit?

Mu2e Momentum Resolution





- Experimental resolution is dominated by material effects, not measurement error

(Potential) Active Target Features

- Segmentation
  - Allow separation of signals
  - Creates ambiguity in extrapolation association
- Position information
  - Allows association with track extrapolation position
  - Can be used to improve track fit
- Time information
  - Allows association with track extrapolation time
  - Provides precise decay time
- Energy information
  - Distinguish signal from backgrounds
  - Can be used to recover straggling information (?)

Using an Active Target

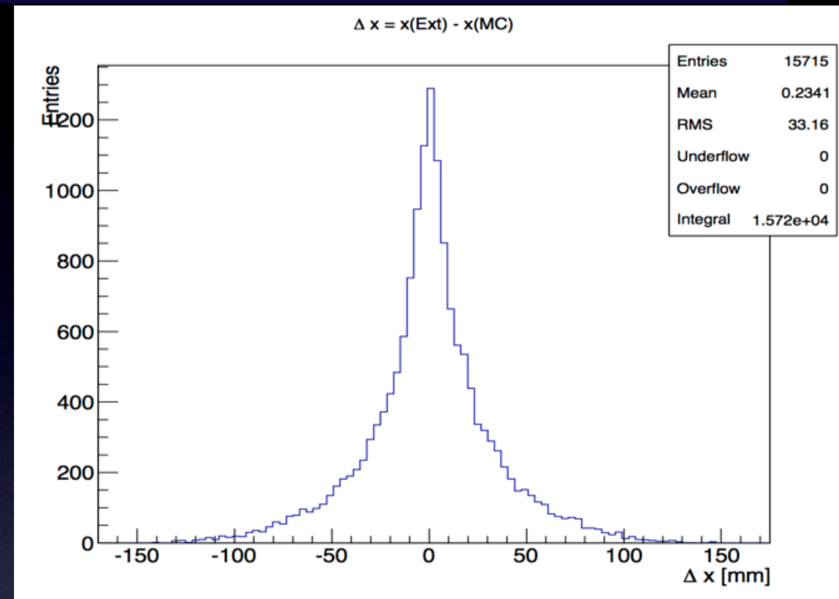
- Assume primary detector is a tracker
  - Measures e^- time and trajectory
- Extrapolate track from tracker to target
  - Provides time and position ‘footprint’ at target(s)
    - footprint given by reconstruction resolution
    - multiple targets creates ambiguities
    - Extrapolation can add large errors (i.e. scattering)
- Associate target hits to track
  - Need an effective occupancy $\ll$1.0
- Refit track using target information
  - improved pointing, momentum, timing, ...

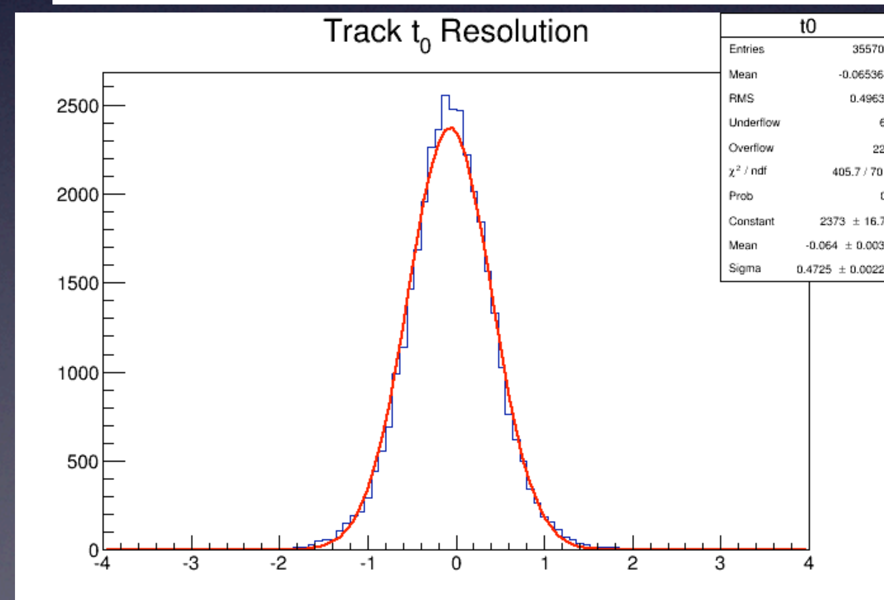
Backgrounds

- Pulsed beam
  - Wait for beam-induced backgrounds to die off
  - Primary backgrounds from other muons decaying
- Continuous beam
  - beam-induced signals are primary background
    - lower instantaneous rate

Mu2e (Pulsed) Association

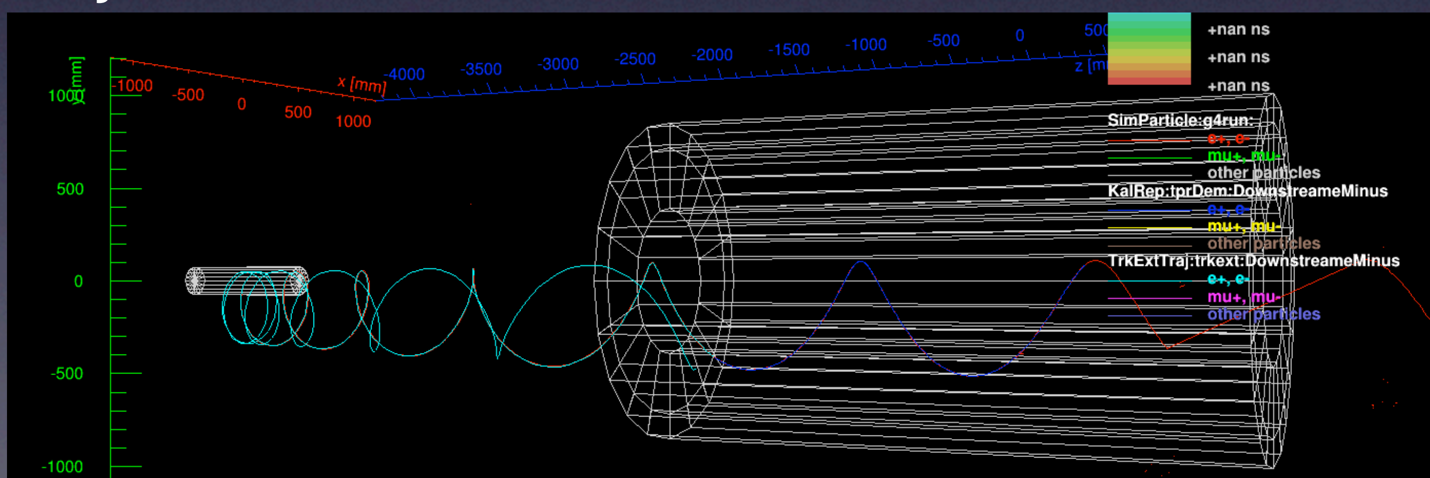
- μ stoping rate = 4×10^{10} s^{-1}
- beam profile σ ~ 40 mm
- 17 foils
- Flux (F) = 1.5×10^{6} $mm^{-2}s^{-1}$
- Extrapolated resolution
  - σ_{space} ~ 30 mm
  - $\sigma_{time} = 0.5\times10^{-9}$ s
- Association Occupancy
  - $O = F \times \sigma^2_s \times \sigma_t$ = ~ 0.5
  - Not usable





A Usable Mu2e Active Target

- Move target to middle of tracker
  - extrapolation distance ~ 0.5 meter (was ~3 meters)
  - constant field region: easier propagation
- Extrapolation spatial precision: $\sigma_s \sim 1$mm
  - Current Mu2e rate: O < 10^{-3} : useable
  - Project X rates: ~ few 10^{-3} : useable

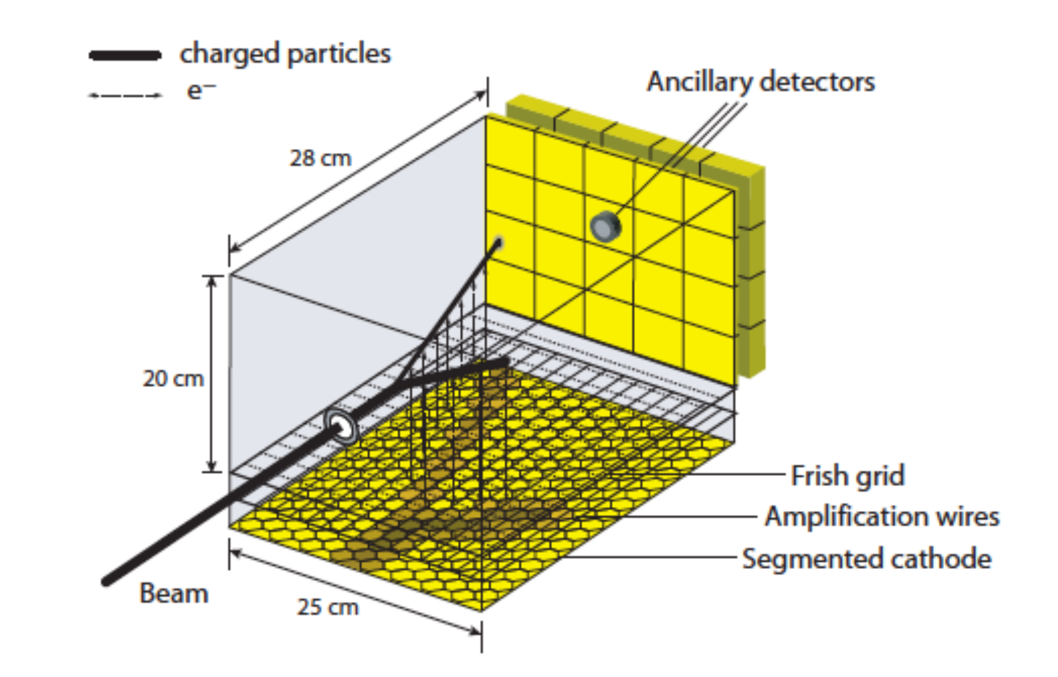


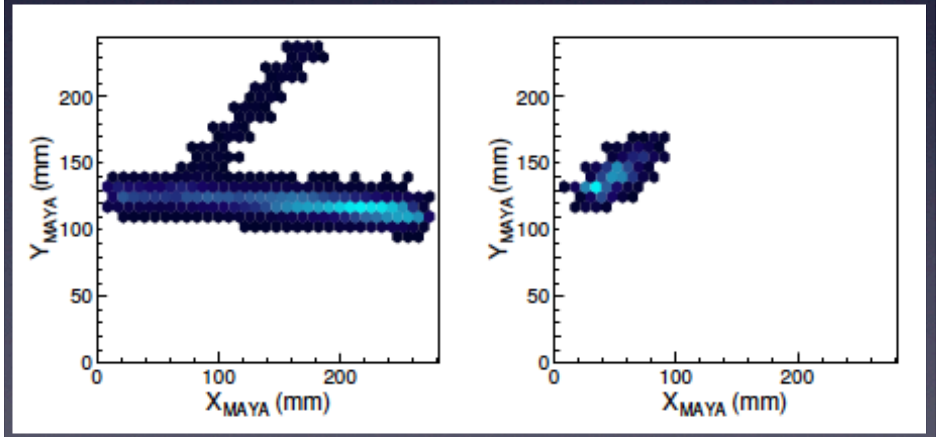
Possible Active Target Technologies

- gaseous
  - TPC
- SciFi
  - MEG upgrade (?)
- Semiconductor (Si, Ge)
- Advantages/disadvantages to each

MAYA Target TPC

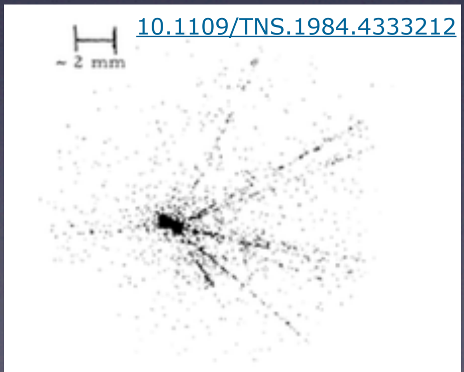
- Used in nuclear x-section measurement (NIM-A 573 (145) 2007)
- 3-D spatial resolution $\sigma_s \sim$ few mm
- Drift time ~ few μ sec
- Not practical at current/future CLFV experiment rates





SciFi

- Long history in nuclear, particle physics
- Readout is 2-dimensional: stereo layers required for space point
  - additional combinatorics in overlap
- Timing resolution can be very good
  - compensates for 2-D readout
- Readout outside target region
- Material choices
  - glass (SiO_2 , ...)
  - organic (hydrocarbon)



MEG Upgrade Option

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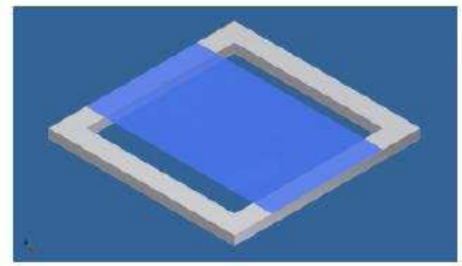
New Muon Target

- MEG baseline solution: 140 μm thick target, 15° inclination angle
- alternative concept: active target

> - A $\mu \Rightarrow e\gamma$ decay event is identified by four observables: **ΔE_γ, ΔE_e, $\Delta t_{e\gamma}$, $\Delta \Theta_{e\gamma}$**
> - The positron momentum and direction are measured by the spectrometer after that the particle has left the target and has flown towards the detector: an additional measured point on the target plane can help the positron track fit
> - **If emerging positron is detected on the target:**
>   - **improvements in both positron momentum and photon/positron angle resolutions**
> - **If the muons ranging in the target are counted: (*<<large signal compared to the positron, even if not time-correlated>>*):**
>   - **beam monitoring ("absolute normalization")**
>
> A.Papa, MEG Review 2013



- single fibre array
- 250 μm fibres, double cladding
- short fibre length, SiPM readout

→ challenge: to detect m.i.p. with expected energy deposit of ~30 keV

- „first" prototype: 8 fibres array

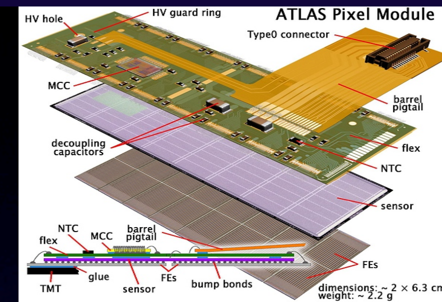
Semiconductor Detectors

- '3D' readout (2-D pixels, thin wafers)
- Relatively pure materials
  - dopants, conductor + passivation layers may be contaminants
- Can be thinned (< 50 μm)
  - Requires tension or support to hold thin wafers flat
- Readout electronics can be ~> 50% of mass
- Si is a natural choice for μ^+, what about μ^-?
  - Coresponding ^{A}Al have higher mass than natural ^{A}Si isotopes
  - Could be used in μ^- (capture)
- Ge could be a (higher-Z) alternative

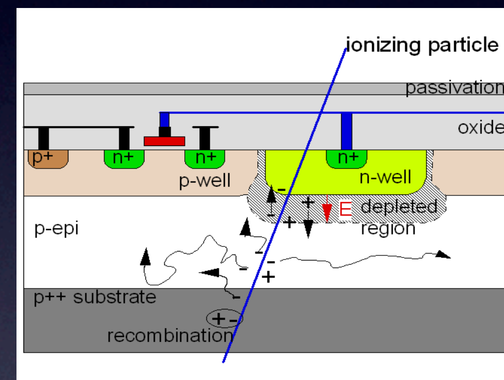
Si Detector Energy Measurement

- Energy deposition in an active Si target might measure straggling
  - Must minimize inert material
    - Fully-depleted detector
    - Integrated readout
- However, Energy loss ≠ Energy deposition
  - hard bremsstrahlung would clearly escape
  - soft radiation might be (partially) captured
- R&D to compare Energy Loss vs Energy deposition is needed to see if this is viable

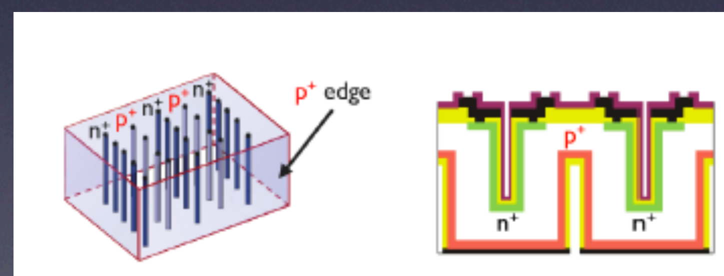
Possible Solid-State Detectors



- Hybrid Pixel detectors
  - ATLAS
  - thick sensors, + equally thick readout chip



- MAPS
  - STAR pixel detector
  - can be thinned to ~40 μm
  - charge collection by diffusion



- 3-D Si
  - i.e. arXiv:1101.4203
  - Vertical implants, horizontal drift, fully-depleted
    - Integrated readout possible

Conclusions

- Active targets can help measure muon rates
  - beam, capture, decay, ...
- Active targets can refine reconstruction in stopped muon experiments
  - extrapolated position and time resolution must be adequate to correctly associate hits
- Solid state technologies seem best suited
  - SciFi (multi-layer?), Semiconductor
- Energy deposition measurement could reduce resolution due to straggling
  - requires R&D on material effects, readout