Design and studies for the Mu2e-II tracker

https://mu2eiiwiki.fnal.gov/wiki/Mu2e-II

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on Behalf of Mu2e-II Collaboration

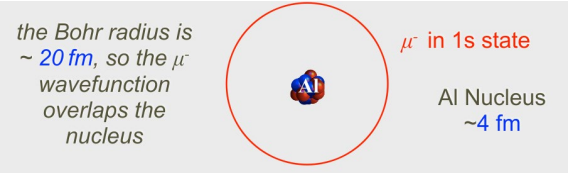
Outline

- Brief Overview of Mu2e Experiment
- Low Mass Drift Tube (Straw) Mu2e Tracker
- Mu2e-II Experiment and Tracker Requirements
- Even thinner walled straw prototypes
- Other Possible Designs

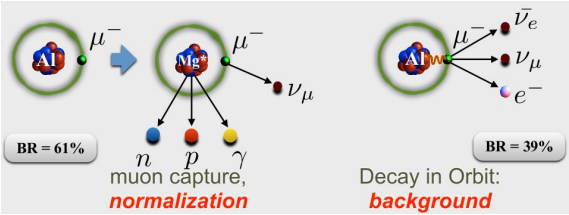
The concept of Mu2e(-II) measurement

- Use pulsed beam of low momentum μ^-
- Stop muons in thin foils and form muonic atoms
- Wait for them to decay
  - Decay-in-orbit (DIO): 40%
    - Continuous E_e spectrum.
  - Muon capture on nucleus: 60%
    - Nuclear breakup: p, n, γ
  - Neutrino-less $\mu \rightarrow e$ conversion

For Al: Lifetime 864 ns, E_e=104.97 MeV



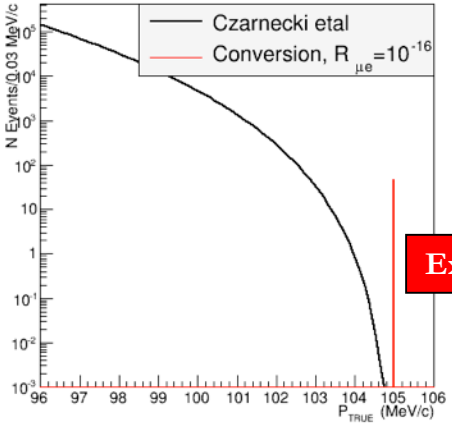
backgrounds



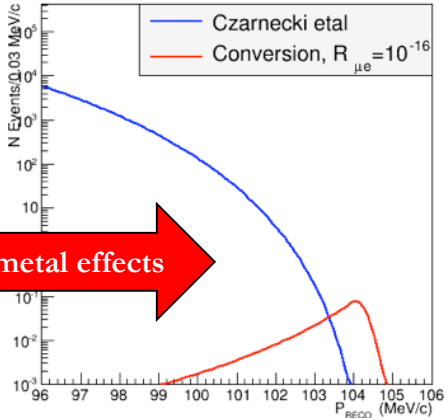
m.e. Standard Model ($m_\nu \neq 0$) rate is ~10^{-52}

Mu2e goal: SES ~$3 \cdot 10^{-17}$ x 10^4 previous result

Mu2e-II goal: SES ~10^{-18} x 10 more



Experimetal effects



Mu2e Apparatus

The entire system must be evacuated to 10^{-4} Torr

Cosmic Ray Veto and Stopping Target Monitor not shown

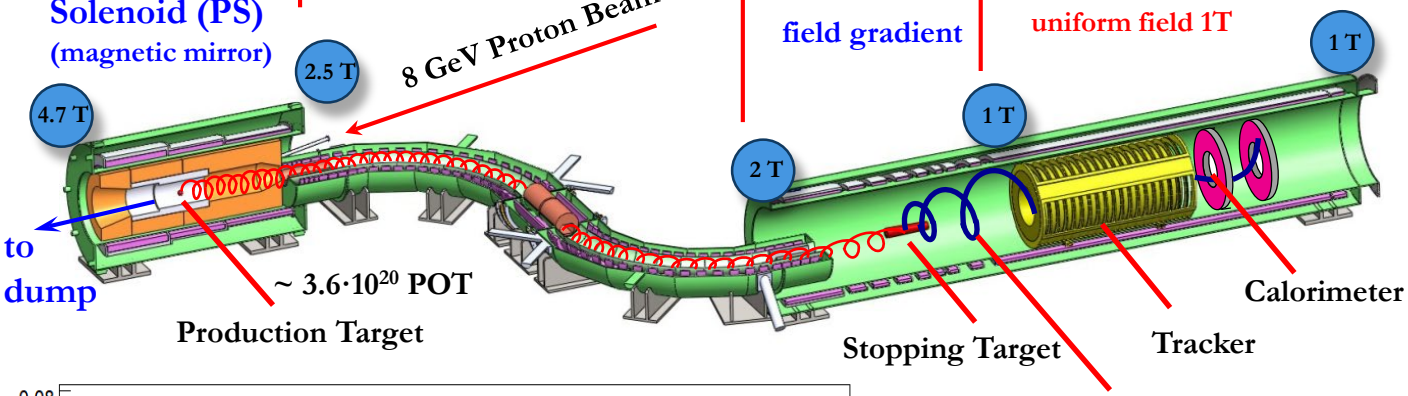
Production Solenoid (PS)
(magnetic mirror)

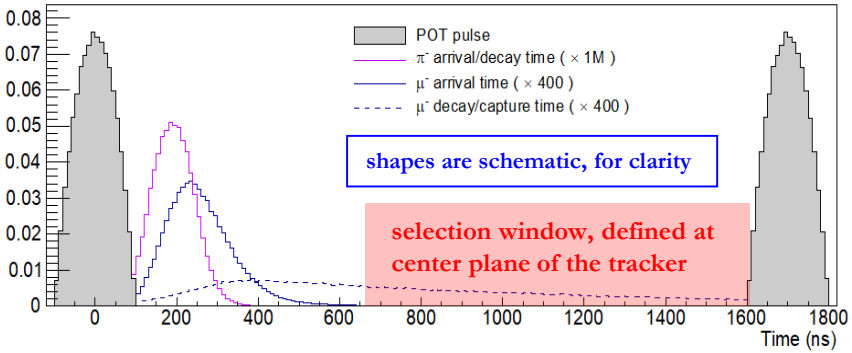
Transport Solenoid (TS)

Detector Solenoid (DS)

field gradient

uniform field 1T





- **μ are accompanied by e-, e+, π, $\overline{p}$**
  - these create prompt backgrounds
  - strategy: wait for them to decay
- **extinction = (# protons between bunches)/(protons per bunch)**
  - requirement: extinction < 10^{-10}

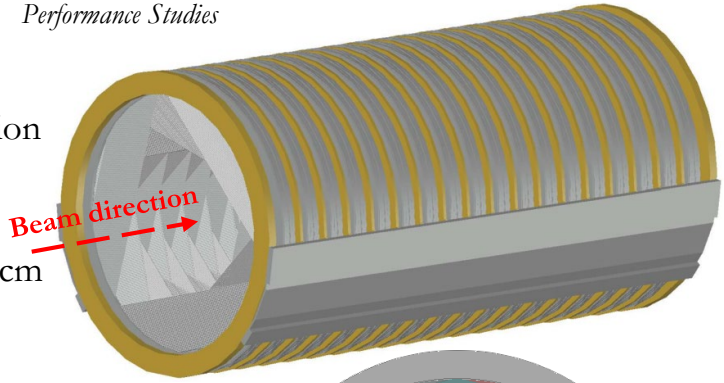
Mu2e Tracker Requirements

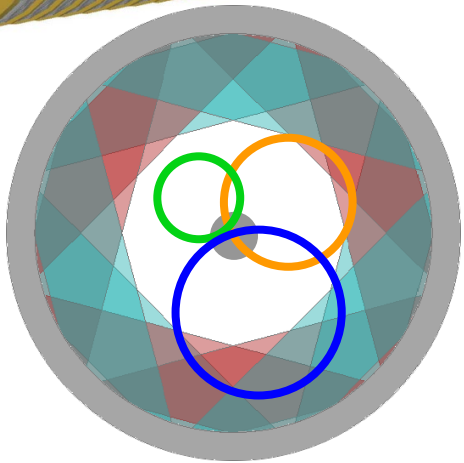
More details in (talk at this conference):
Mu2e Straw Tube Tracker Pre-Production Panel Performance Studies

- Electron momentum resolution: < 180 keV/c at 105 MeV/c
- Efficiency for acceptance and reconstruction of 105 MeV/c electron tracks: >20%
- Work in vaccum: operation limits for outgassing rate :< 6 sccm (standard cubic cm per minute)
- Hit rate: > 5MHz/channel, 500 ns after proton bunch hits production target
- Access : < once per year
- Operation time: > 10 yrs

Solution: Straw drift tubes measure track curvature through a 1 T magnetic field.

- Segmentation to minimize occupancy
- Thin walls minimize multiple scattering
- No support structure in tracking region
- High radiation survival (structure & electronics)



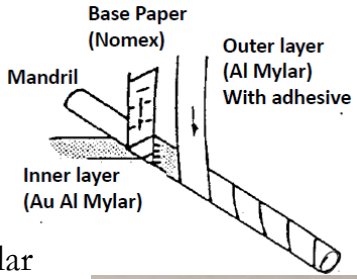


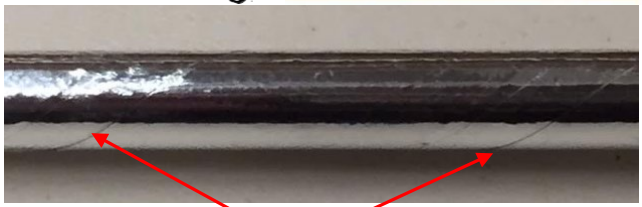
beam's-eye view of the tracker

Mu2e Tracker Components: Straw Drift Tubes

Two layers of Mylar wound to produce straws

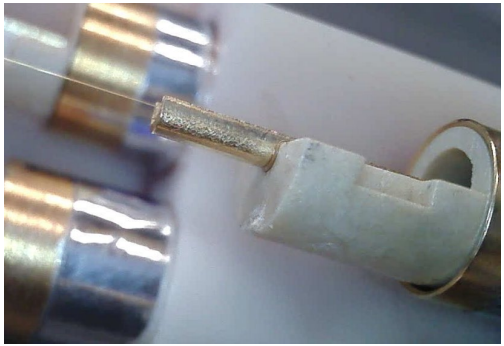
- 20,736 5 mm diameter straws
- Lengths: 45 to 120 cm
- 6 μm Mylar + 3 μm adhesive + 6 μm Mylar double helical wrap
- Outer wall coating: 0.05 μm Al
- Inner wall coating: 0.05 μm Al + 0.02 μm Au
- Sense Wire: 25 μm diameter Au plated W





Spiral wrap seams

inside



Mu2e-II Experiment

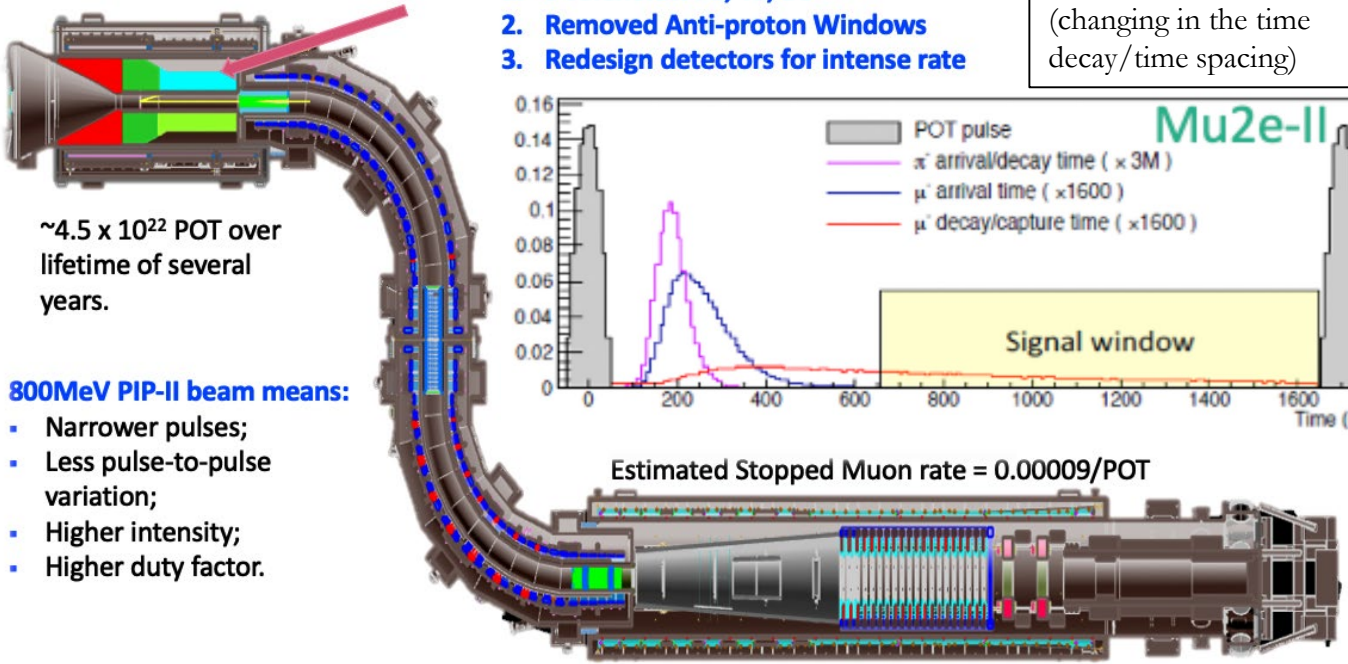
- >10x measurement sensitivity increase (10^{-18} level)
- Possible different material for the stopping target (Titanium)
- Reuse most of the Mu2e infrastructure

Mu2e-II Beam

Mu2e-II will have similar design to Mu2e:

1. **3 solenoids: PS, TS, DS**
2. **Removed Anti-proton Windows**
3. **Redesign detectors for intense rate**

Possibility to use different stopping material (as Ti) (changing in the time decay/time spacing)



~4.5 x 10^{22} POT over lifetime of several years.

800MeV PIP-II beam means:

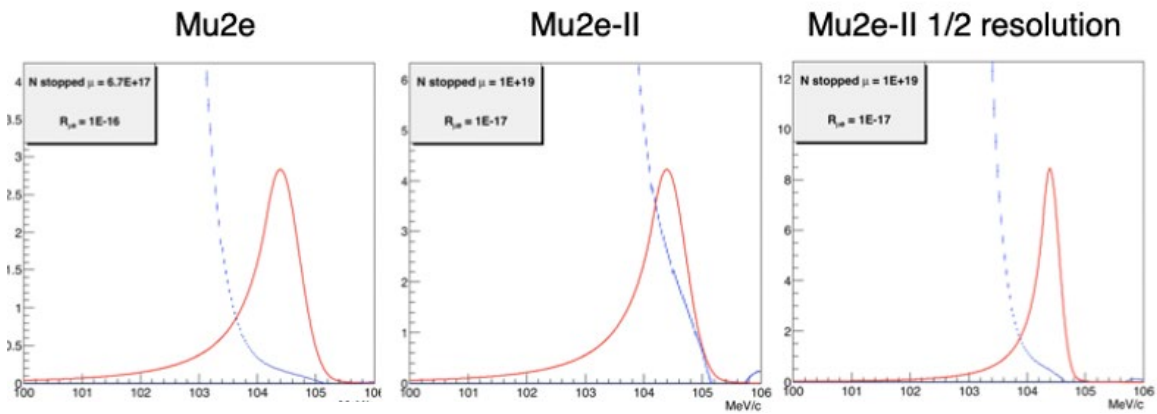
- Narrower pulses;
- Less pulse-to-pulse variation;
- Higher intensity;
- Higher duty factor.

Estimated Stopped Muon rate = 0.00009/POT

Mu2e-II Tracker Requirements

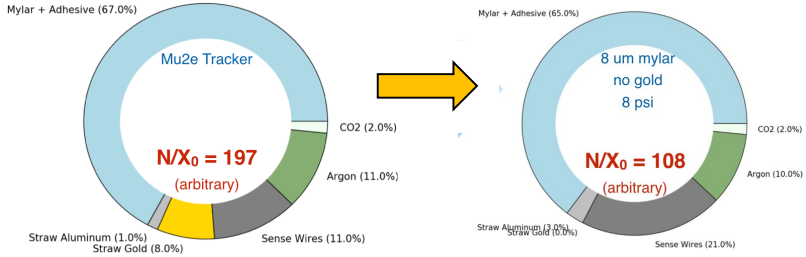
Resolution effects, toy MC study:

- ~ ½ momentum resolution
- Dominated by energy straggling (Stopping targets; Inner Proton Absorber, Tracker material)

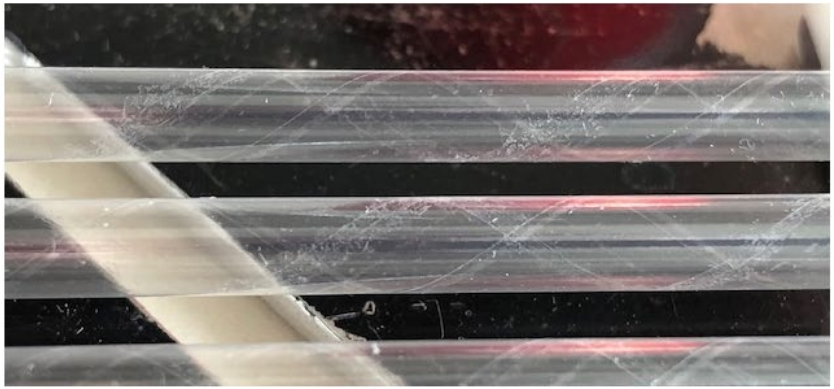


To increase electron momentum resolution tracker:

- needs to have less material
- Thinner walled straws
- Different tracker technology
- Different gas



How thin can you make straws?



Pressurized 8 μm Mylar Straws

8 μm Mylar Straw

Test structure: 3.5 µm Mylar + 1 µm adhesive + 3.5 µm Mylar double helical wrap straws

Made by same drinking straw company that made Mu2e straws

These straws held 15 PSI for multiple days and 400 g Tension without visible distortion. Looking into what the needed initial tension to limit sag an acceptable distance (< .3 mm).

B.Casey, Fermilab LDRD

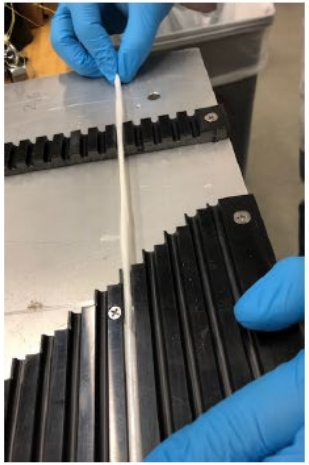
Handling Prototype Straws

Without internal support, the 8 μm wall thickness straws collapse.

Straws inflated to an internal 1 atm force show no damage.

Possible techniques of keeping straws supported throughout installation.

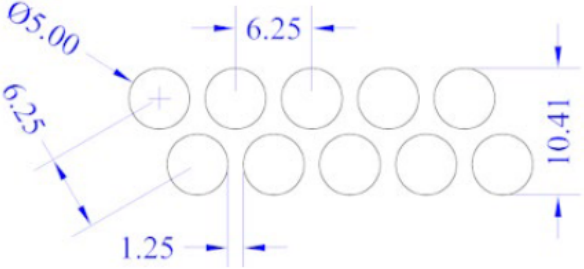
- **Straws are kept inflated during construction**
- **Winding paper left inside during assembly**



A possible alternative to Straws

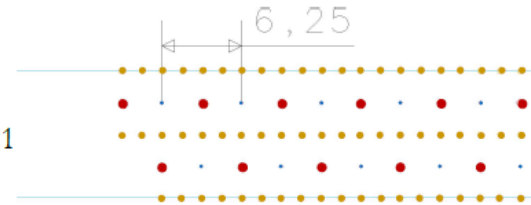
Assumption:
- 20 μm W wires
- 50 μm Al wires
- 40 μm Al wires
- 2.5 μm Mylar with 500 Å Al

Instead of using straws for the cathodes use:
- all thin wires (conf. 1)
- thin metalized Maylar foils and thin wires (conf. 2/3)



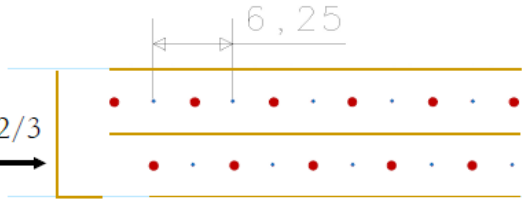
or

conf. 1



Option: use unique foil to be gas-tight

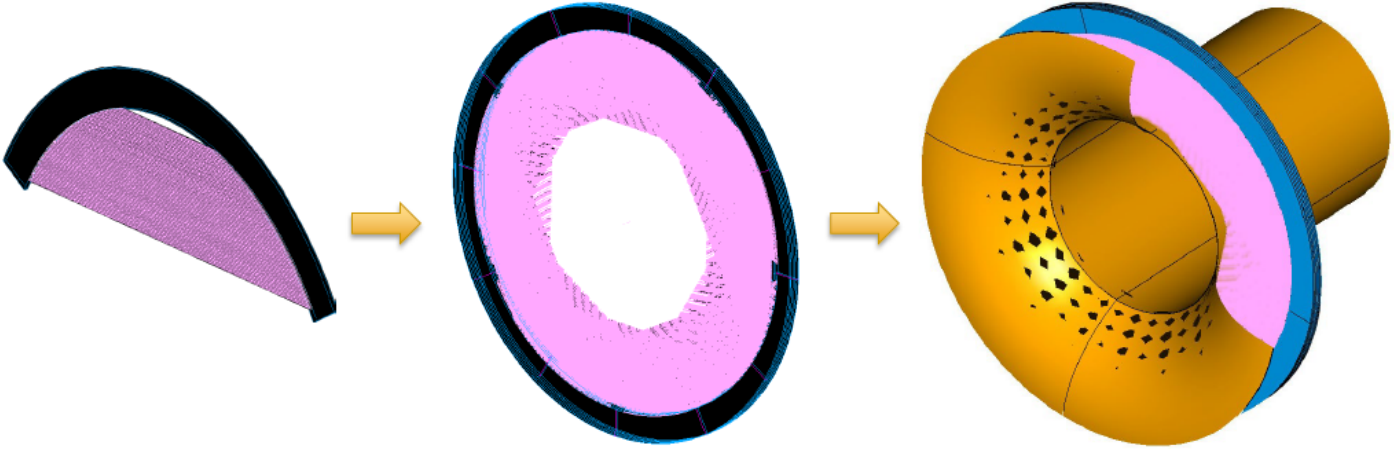
conf. 2/3



Simple construction (as used for MEG-II drift chamber):
- with a wiring robot, build 3 layers of cathode wires (or use 3 foils)
- build 2 layers of anode and cathode wires
- machine 4 planar spacer layers
- stack the wire layers and the spacer layers (in the right sequence) on a support frame.
- use dowel pins and screws to align and to lock (no glue, apart from conf. 3).

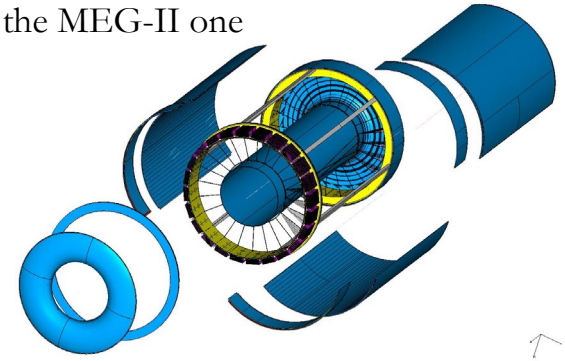
A “minimal” possible tracker alternative

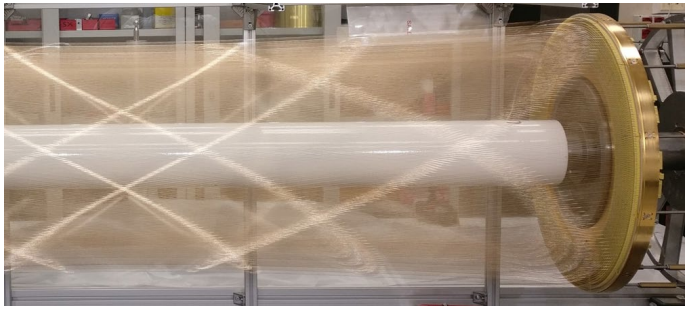
- Keep the same panel overall layout
- Keep the same cell pitch
- The panel can be made (simpler) using wires or thin metalized foils for the cathodes
- Keep plain layout
- keep stations layout
- Insert the stations in a light gas vessel



Other possible tracker alternatives

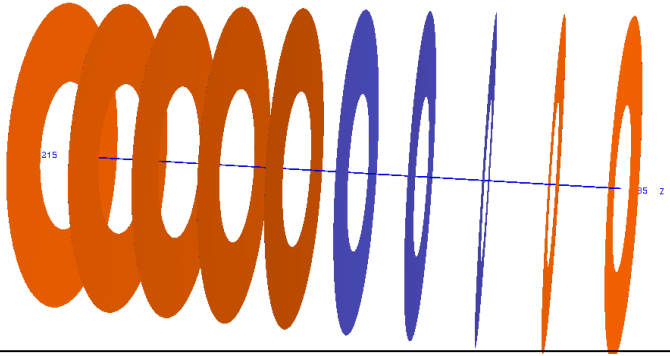
A Drift Chamber based on the MEG-II one





Consider other technologies: light Si or MPGD:

- disk geometry
- radial TPC



Summary

- Simulations to study the expected performance and to evaluate different options in ongoing:
  - Using Geant-4 simulation looking into different tracker geometries
  - Toy MC being developed to estimate electron energy resolution based on parameters of the tracker, stopping target, and proton absorber.

Tracker designs being tested by simulation and building prototypes:

- Initial batch of 8 μm thin straws have passed multiple material requirements.
  - Purchase of metalized prototype batch has run into significant delays in material procurement.
  - Designed test stand for determining amount and type of metallization required of the straws
  - Material tests on the initial batch continue.
- Developing techniques in Tracker construction
  - Building a small prototype with inflated straws
  - Material testing on overlapped seam straws

Thanks for your attention

Design of tracker is open: All ideas welcome.

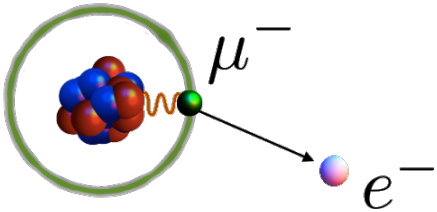
If you are interested in joining us, please contact me (giovanni.tassielli@le.infn.it),
Dan Ambrose (ambr0028@umn.edu),
or come to the workgroup meeting though the list-serve (MU2EII-TRACKER@fnal.gov)

Backup

Muon to electron conversion in the field of a nucleus

- **Initial state: muonic atom**
- **Final state:**
  - a single mono-energetic electron
    - the energy depends on Z of target
  - recoiling nucleus is not observed
    - the process is coherent: the nucleus stays intact
  - neutrino-less

$$\mu N \rightarrow eN$$



E_e~105 MeV

- Conventional Signal Normalization:

$$R_{\mu e} = \frac{\Gamma(\mu^- + N(A,Z) \rightarrow e^- + N(A,Z))}{\Gamma(\mu^- + N(A,Z) \rightarrow \text{all muon captures})}$$

- m.e. Standard Model ($m_\nu \neq 0$) rate is ~10^{-52}
- There is an observable rate in many new physics scenarios.
- Related decays: Charged Lepton Flavor Violation (CLFV):

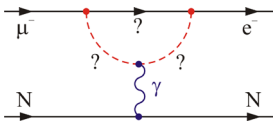
$$\mu \rightarrow e\gamma \quad \mu \rightarrow e^+e^-e^+ \quad K_L^0 \rightarrow \mu e \quad B^0 \rightarrow \mu e$$
$$\tau \rightarrow \mu\gamma \quad \tau \rightarrow \mu^+\mu^-\mu^+ \quad D^+ \rightarrow \mu^+\mu^+\mu^-$$

Sensitivity to high mass scales

$$\mathrm{L_{CLFV}} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + \frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L(\bar{u}_L\gamma^\mu u_L + \bar{d}_L\gamma^\mu d_L)$$

Loops dominate for $\kappa << 1$

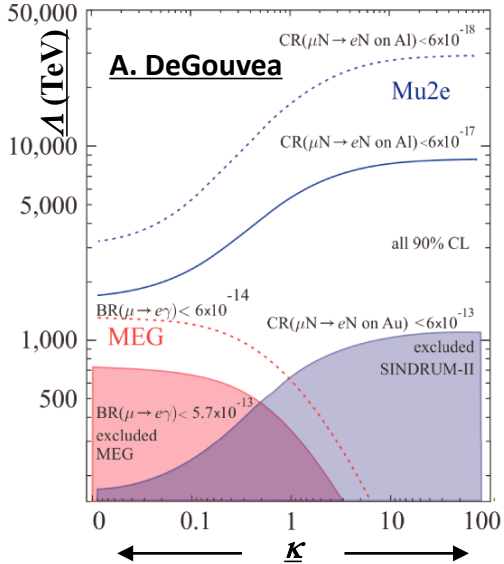
$\kappa = 0$



$\mu \to e\gamma$

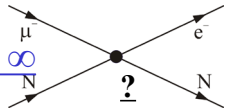
$\mu N \to eN$

$\mu \to eee$



Contact terms dominate for $\kappa >> 1$

$\kappa = \infty$



$\mu \to e\gamma$

$\mu N \to eN$

$\mu \to eee$

- **If new physics is seen at the LHC**
  Need CLFV measurements (Mu2e and others) to discriminate among interpretations
- **If new physics is not seen at the LHC**
  Mu2e has discovery reach to mass scales that are inaccessible to the the LHC

Straw Assembly Steps

Paper Removal

Conductivity Test

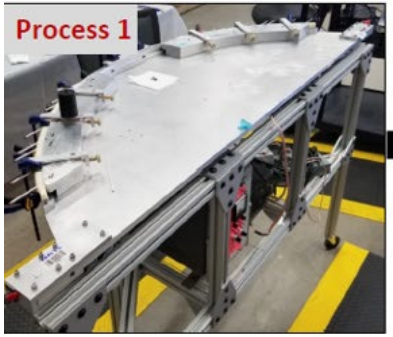
CO_2 Leak Test

Laser Cut to length

Insert Terminations

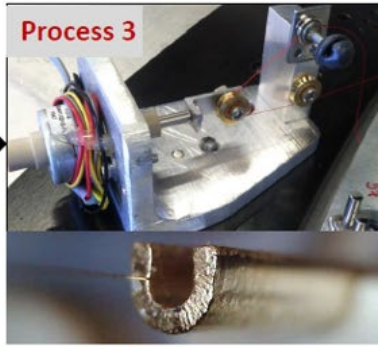
Length Verification

Panel Assembly Steps



Inner Ring Building (2 days)

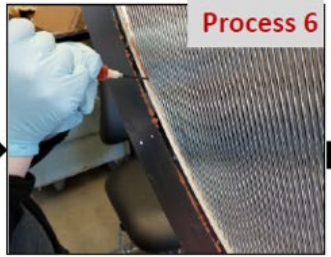
Straw Installation (1 day)



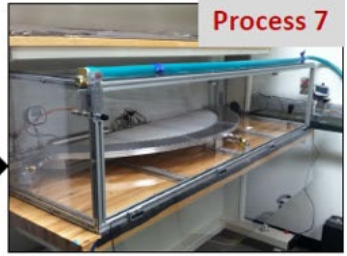
Wire Installation (3 days)

Pin Protector & Ground Clip Installation (1 day)

Manifold Installation (1 day)

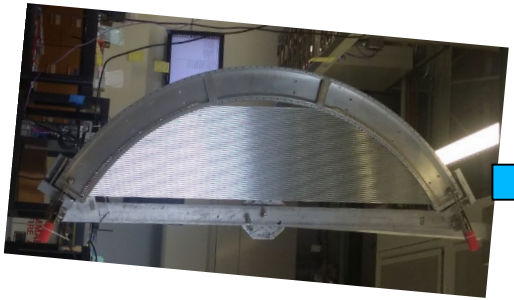


Alcohol Leak Check and Flooding (2 days)

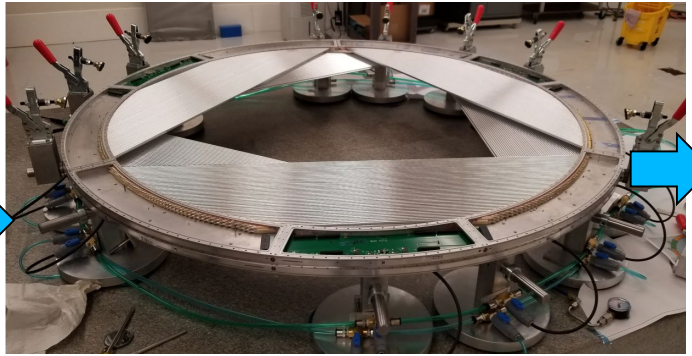


Resistance Check & Leak Test (3 days)

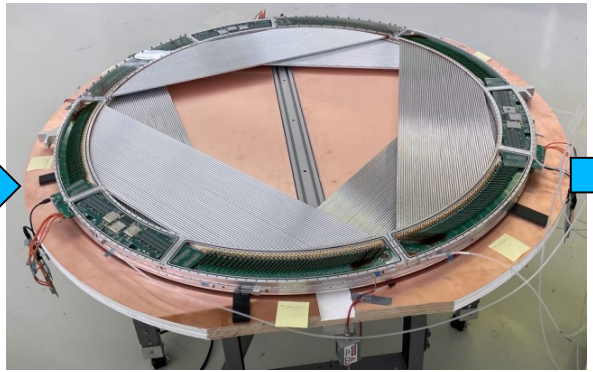
Tracker Assembly Steps



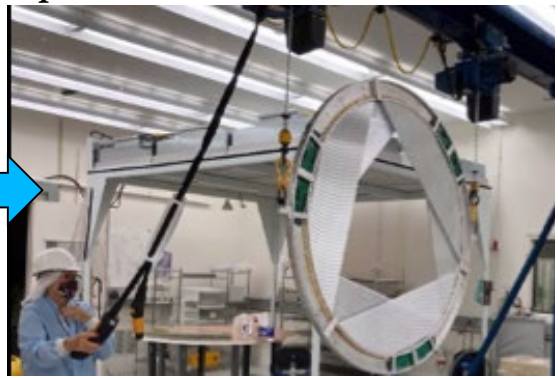
6 panels make a plane



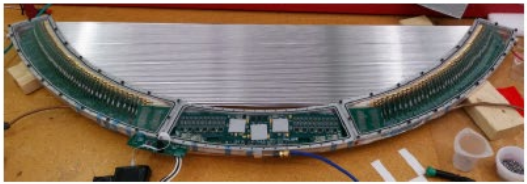
Electronics installed



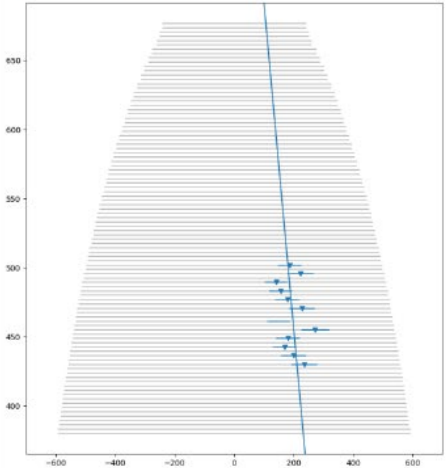
Planes installed into detector frame: 36 planes make the tracker

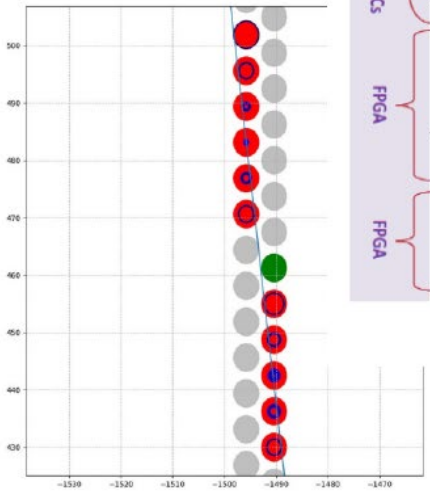


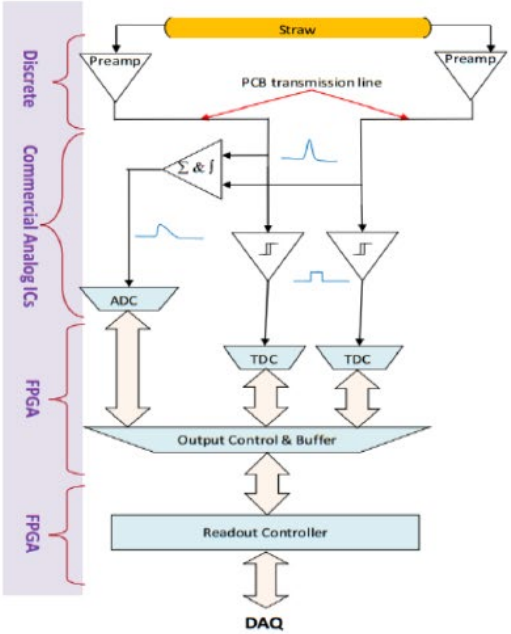
Single Panel Cosmic Ray Test



Downward cosmic ray through adjacent straws in a vertical panel.







R. Bonventre

- He - i-C_4H_{10} 90% - 10% gas mixture is assumed
- average 35 hits per track
- add the contribution of the gas in the gas vessel but outside of the panels (conf 3 assume pure He)
- add two times the inner wall of the gas vessel

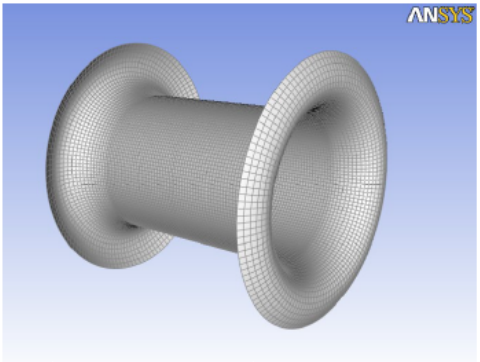
Number are in 10^{-3} X/X_0

	Mu2e	8μm straw	8μm straw no gold, 8 psi	Conf 1	Conf 2	Conf 3
Single sensitive element	0.197	0.135	0.108	0.019	0.035	0.035
additional gas				1.5	1.5	0.3
2 x inner wall				1.6	1.6	1.6
average per track	6.9	4.7	3.8	3.8	4.3	3.2

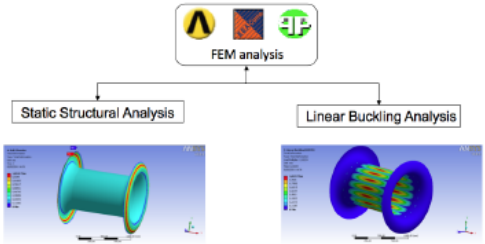
Notes: the gas vessel material (uniform) at the entrance ($<0.8\cdot10^{-3}$ X/X_0) doesn't contribute to the resolution, it should be compensated from the proton absorber. The same amount of material should be considered for the extrapolation to the calorimeter

Mu2e ITracker Gas Vessel

End-plate profile optimization and buckling instabilities well documented in previous presentations (doc-db 1421, 2316). Detailed simulations indicate as a possible solution:

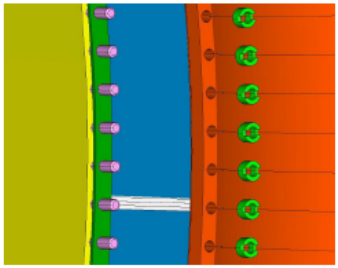


Structural response of the Drift Chamber



The external pressure can cause a buckling failure of the internal cylinder, that represent the most critical component

The inner cylinder-endcap connection was studied:



27 Mpa for 1 bar differential pressure
1 M3 screw per cm,
240 screws, 4.5 Kg each

	type	# of ply - thick	[g/cm^2]	X_0 [10^{-3}]	[Kg]
Inner Cylinder	HM M30S 30 ET443 Kapton foam (0.03) HM M30S 53 ET443	2 ply – 76 μm 5.85 mm 2 ply – 76 μm	0.007 0.017 0.007	0.80	2.25
Connect. ring	C-fiber inserts *(2x1.5%)*	5 mm 116 cm^2	0.710 **(0.021)*	16.6 **(0.63)*	1.00
End plates	HM M30S 30 ET443	4 ply – 152 μm	0.013	0.30	0.27