Discussing an AMF Tracker

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Future Muon Program at Fermilab Workshop

Cal Tech, Pasadena, CA

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***Possible Advanced Muon Facility design logo**
Not associated with American Machine and Foundry (and bowling)

Goal of this talk

The goal of this talk is NOT to pick a tracker we will use for AMF.

It is to outline the environment and to discussion what R&D people are interested in.

Discussing what we want to optimize for given environmental parameters.

There are plenty of people in the audience with more experience building a wider range of trackers than myself and people from the Mu2e-II tracker breakouts are likely tired of me talking…

so the more we are discussing and the less I'm talking the better.

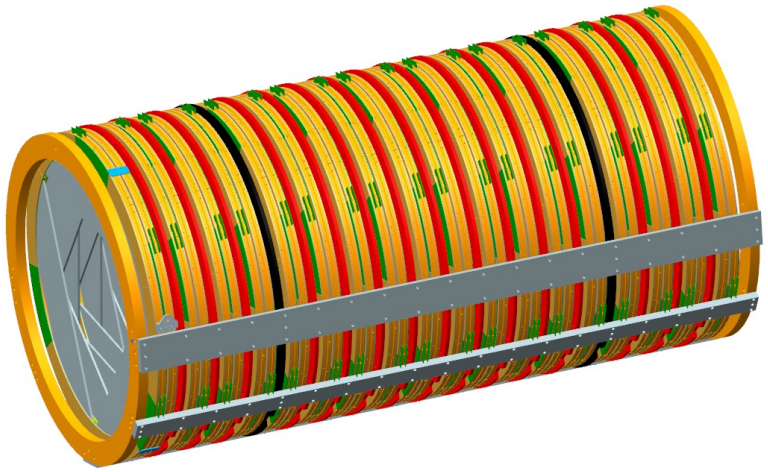
AI Generated Pictural Representation of Available Tracker Design Space

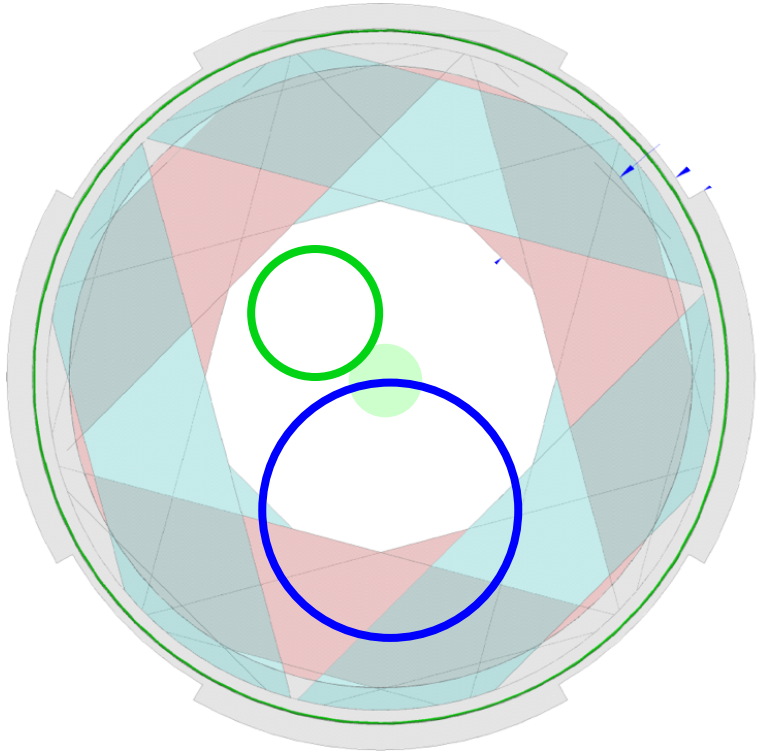
*Midjourney

Mu2e-II Environment

AMF Environment

Mu2e Tracker Environment



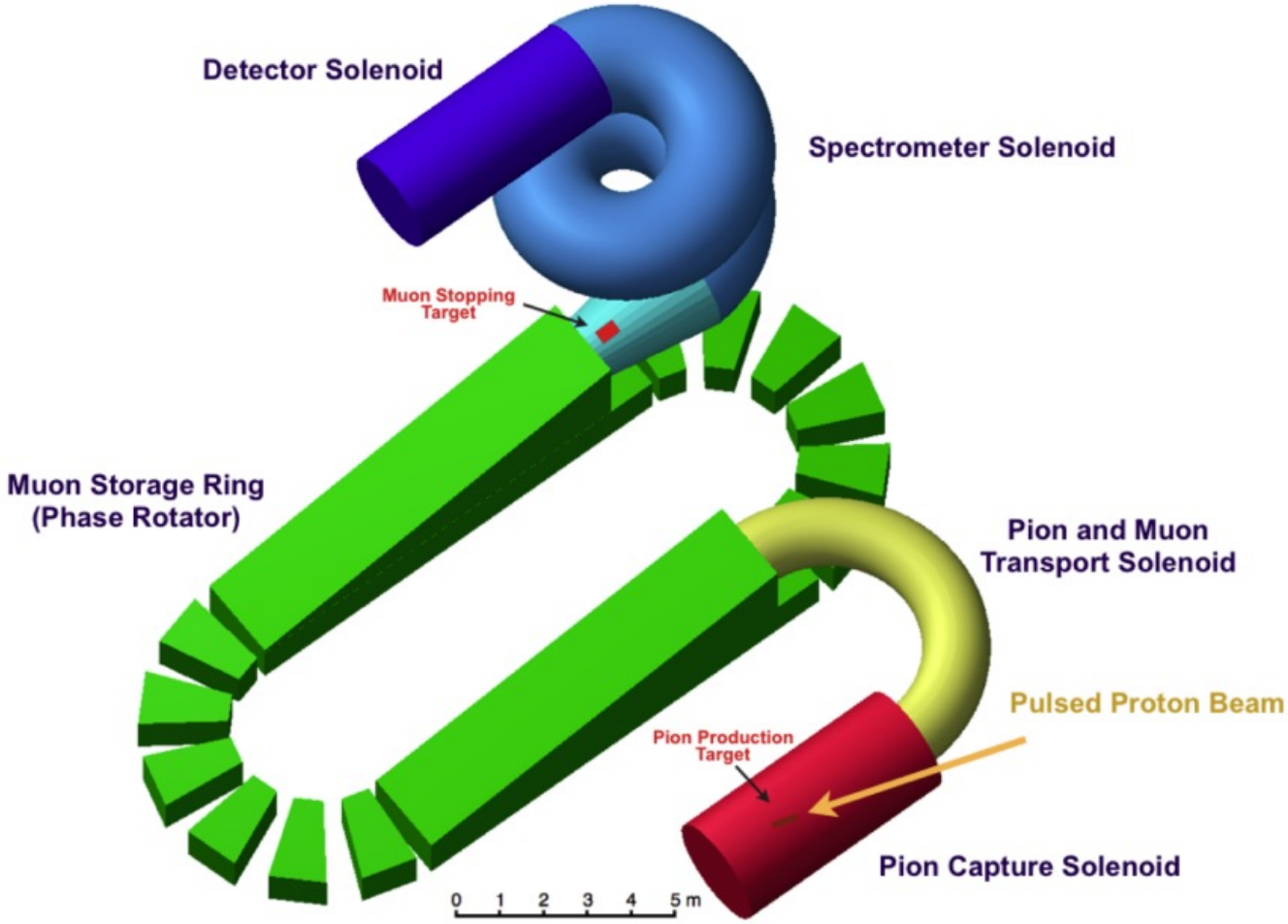


Beam's-eye view of Tracker

- **No mass r < 38 cm, Low mass 38 cm < r < 70 cm**
- **Electron momentum resolution: < 180 keV/c at 105 MeV/c**
- **Efficiency for acceptance and reconstruction of 105 MeV/c electron tracks: >20%**
- **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**

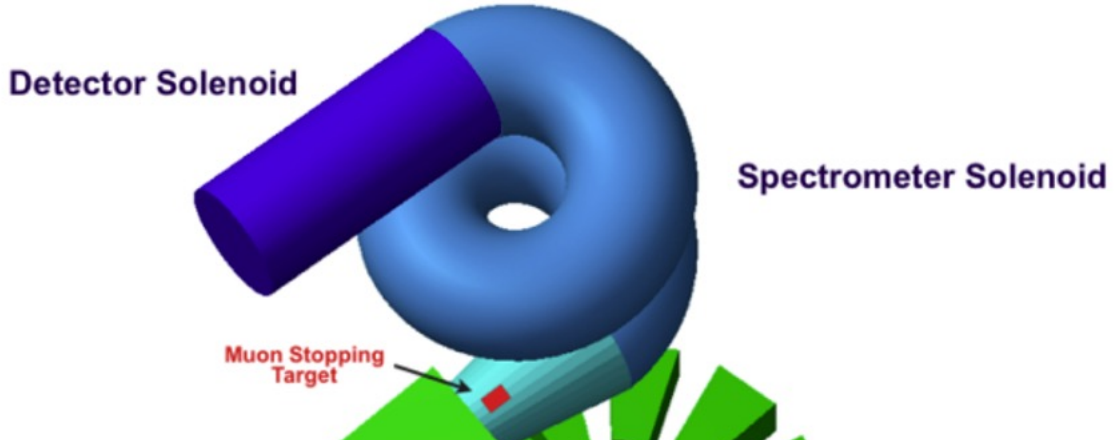
AMF Tracker Environment

- Designed to remove the beam flash background and radiation
- Can be shielded from most Muon capture neutrons and photons
- Solenoid curvature selects for electron momentum
  - This does create the e^+/e^- asymmetry
- Tracker is mostly indifferent to muon stopping target material



Prism Concept
arXiv:2203.08278

Evolution of Requirements

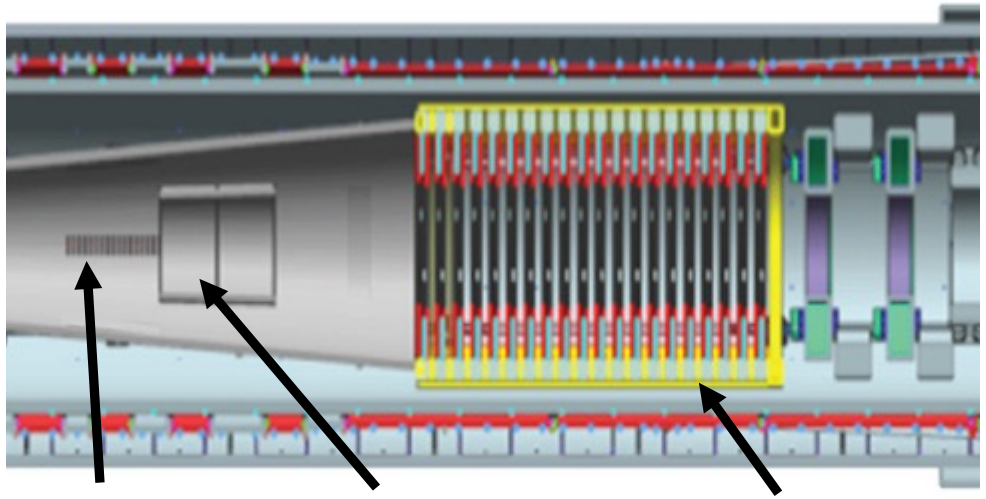


Mu2e's Requirements

- **No mass r < 38 cm, Low mass 38 cm < r < 70 cm** → No longer relevant
- **Electron momentum resolution: < 180 keV/c at 105 MeV/c** → Optimize for resolution, Needs improvement for DIO discrimination. Sub 100 keV/c range
- **Efficiency for acceptance and reconstruction of 105 MeV/c electron tracks: >20%** — This is more dependent on optimizing the spectrometer solenoid. Expect high efficiency of electrons that enter tracker.
- **Outgassing rate :< 6 sccm** → Leak rate is an issue but wider range of technology available
- **Hit rate: > 5MHz/channel, 500 ns after proton bunch hits production target** — No beam flash, significantly less radiation, more room for shielding. Spectrometer solenoid curates the electron spectrum.
- **Access : < once per year**
- **Operation time: > 10 yrs** → Possibly harder to access with more shielding in place.

System Intrinsic Momentum Resolution

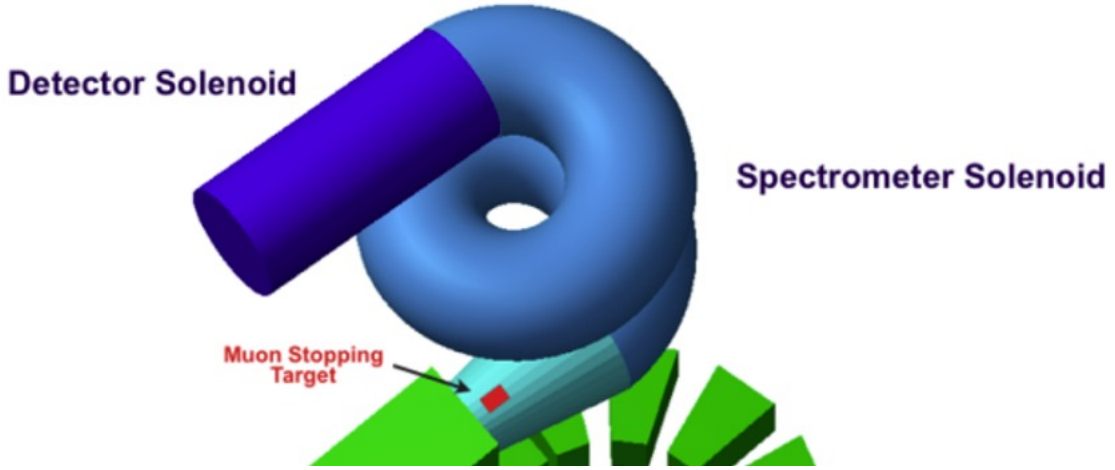
Mu2e Detector Solenoid



Muon Stopping Target

Inner Proton Absorber

Tracker



Mu2e Material in CE path :
Stopping Target
Inner Proton Absorber
Tracker
10^{-4} Torr Vacuum

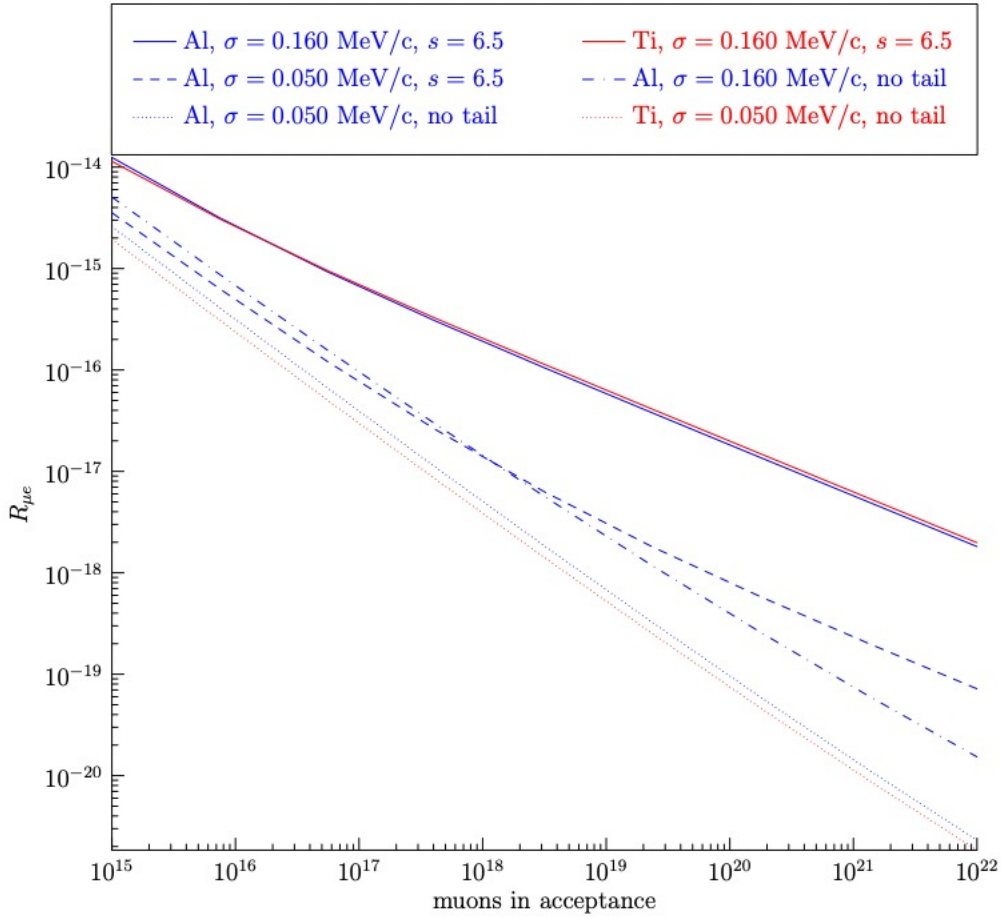
AMF Material in CE path :
Stopping Target
Tracker
Vacuum

Stopping target mass and geometric design will also be critical to possible momentum resolution.
Slower muon beam -> less stopping target mass needed -> better intrinsic momentum resolution.
High Z target -> higher mass ->Worse intrinsic momentum resolution

Effect of Resolution on Discovery Sensitivity

"Median 5σ discovery sensitivity scaling with stopped muon statistics for different experimental resolutions: "Mu2e-like" solid lines with core resolution of 0.160 MeV/c (Landau FWHM of 0.377 MeV/c) and high side power tail (p − ptail) −s with s = 6.5, improved core resolution or eliminated power tail, and both improved core resolution and eliminated power tail"

This was shown in the previous talk. Here to reference the importance of improving resolution.



A. Gaponenko, "Momentum resolution requirement for muon-to-electron conversion searches," FERMILAB-PUB-22-117-PPD (2022).

Track to the Drawing Board

Straw Tube Proportional Tracker	Multi-wire Proportional Chamber Tracker	Gas Electron Multiplier (GEM) Tracker	Newer Technologies
Pros: Highly segmented Good intrinsic momentum resolution A lot of experience on hand Cons: Many small gas volumes and surfaces to leak Hard to manufacture	Pros: Less intrinsic mass -Helium? One large gas volume Easier to manufacture Plenty of experience on hand Cons : Less segmented than straws	Pros: Very easy to manufacture Variable geometry One large gas volume Cons: Limited experience on hand(?) Intrinsic Mass(?)	"Novel Sensors for Particle Tracking: A Contribution to the Snowmass Community Planning Exercise of 2021" https://arxiv.org/pdf/2202.11828.pdf We have time to do some R&D

"low-mass silicon sensors, such as HVMaps or micro-pattern gas detectors proposed for the Belle-II tracking TPC"

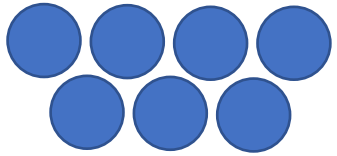
Summary

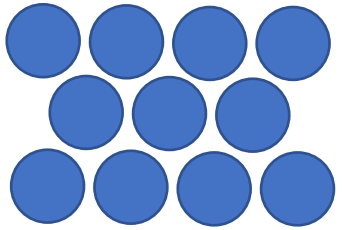
- Wide open design space of new/improved tracking technology
- Challenging but likely doable momentum resolution goal
- Radiation and occupancy amounts should be easier than Mu2e-II

Discussion/Questions

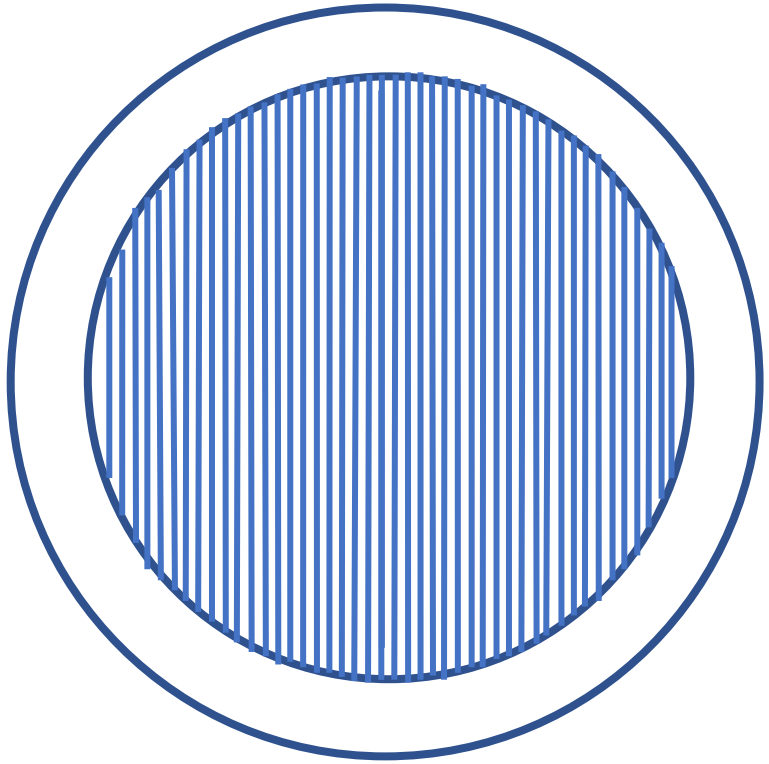
- Pros and Cons of the different tracker types
- Is there a new tracking technology people are interested in?

Straw Tube Proportional Chamber

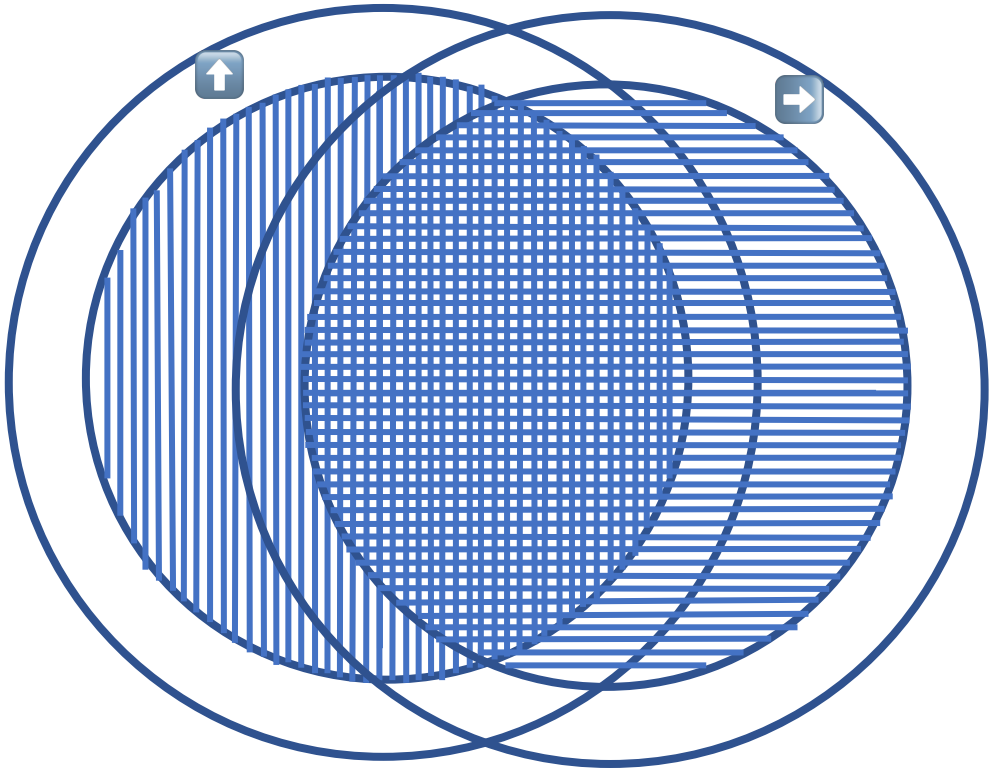




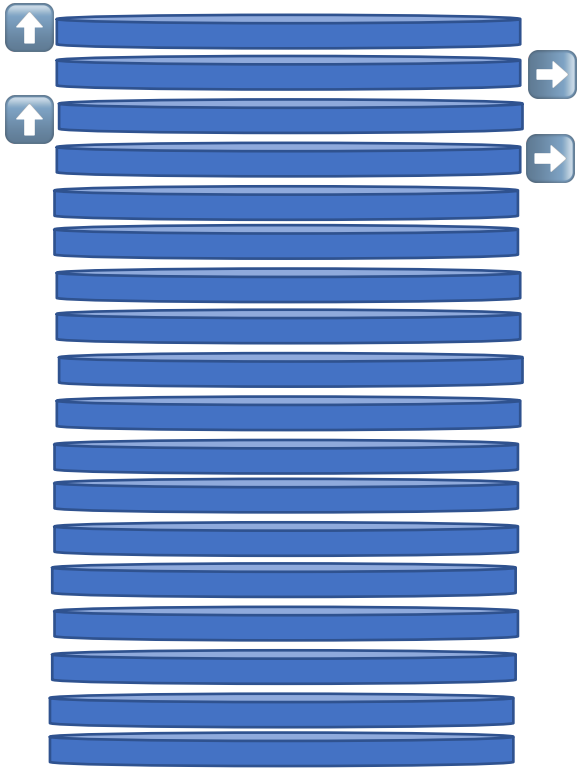
Double verses triple layer of straws



Plane

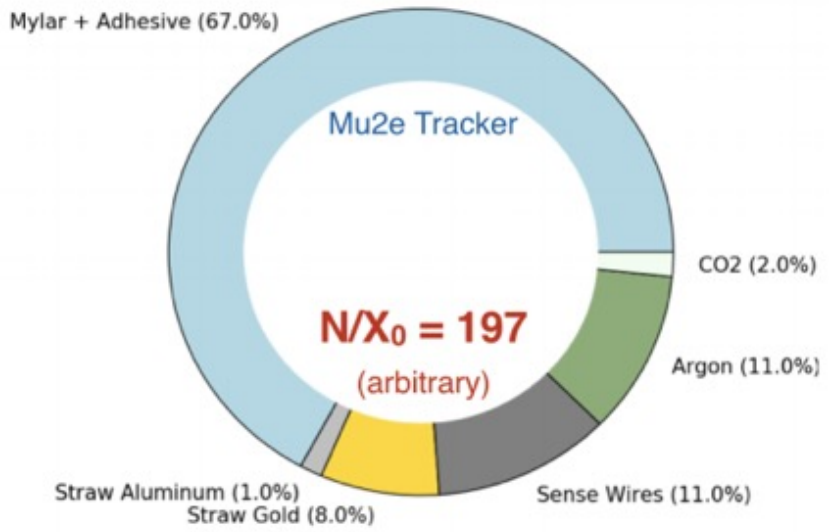


Stereo grid



Stack of planes

Mu2e Tracker compisition



Jason Bono

Component	Key Dimension		Density (g/cm^3)	Cross section (cm^2)	X_0 (g/cm^2)	$L\rho/X_0$	Fraction of Total
Mylar	15	μm	1.4	2.36E-03	40.00	1.32E-04	67.1%
Aluminum	1000	Å	2.699	1.57E-05	24.01	2.83E-06	1.4%
Gold	200	Å	19.3	3.14E-06	6.46	1.50E-05	7.6%
W (25μm)	25	μm	19.3	4.91E-06	6.76	2.24E-05	11.4%
Argon	80%		0.00133	1.96E-01	19.55	2.13E-05	10.8%
CO_2	20%		0.00037	1.96E-01	36.20	3.19E-06	1.6%
Total (one straw)						1.97E-04	

Table 1. Composition of a straw.

From Mu2e Tracker Geometry Docdb#888