Tracker Sessions – Lauritsen 257

Monday Afternoon (PM) PST

- 1:30-2:00 Mu2e-II Tracker Introduction & Requirements
  -Dan Ambrose, FNAL
- 2:00-2:30 Mu2e-II Tracker Intrinsic Resolution, Electronics, Readout
  -Richie Bonventre, LBLN
- 2:30-3:00 Tracker Research Topics : Identify topics for discussion
  -Jim Popp, York CUNY
- 3:00-3:30 Alternative Tracker Ideas and Discussion
  -Dave Brown

-Coffee Break 3:30-4:00

- 4:00-4:30 Vacuum Effects on Resolution and Beam Flash Radiation
  -Andy Edmonds, Boston U
- 4:30-5:00 Design Lessons Learned from Mu2e Tracker
  -Dan Ambrose, FNAL
- 5:00-5:30 Discussing Identified Research Topics

Talks have a 30 minute time slot
Goal is to have ~15 min talk +
15 min discussion/questions

Google Docs for Discussion Topics:
https://docs.google.com/document/d/1s8ZWHfrjNhCdcZ6Yd9yXkv9YNKwZ1Y8aUfJrmG-c6v0/edit?usp=sharing

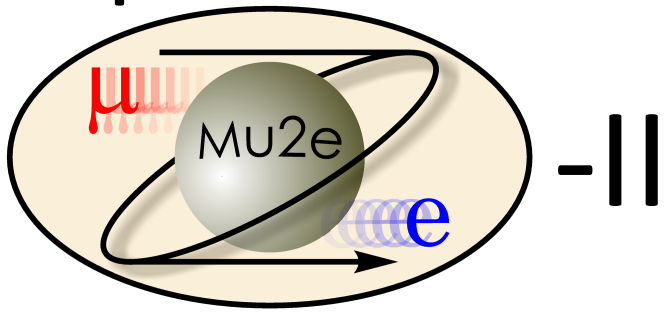
Mu2e-II Tracker : Introduction and Requirements

Dan Ambrose, Fermilab

Future Muon Program at Fermilab Workshop

Cal Tech, Pasadena, CA

3/27/23



-II

Icebreaker

We all are hoping to see a CLFV conversion event at Mu2e (and Mu2e-II) but background removal is crucial to prevent being a possible hypocrite.

A hypocrite? How so?

Well instead of a conversion event, you could have a case of "The POT causing the Kalman Track".

Mu2e/Mu2e-II Environment

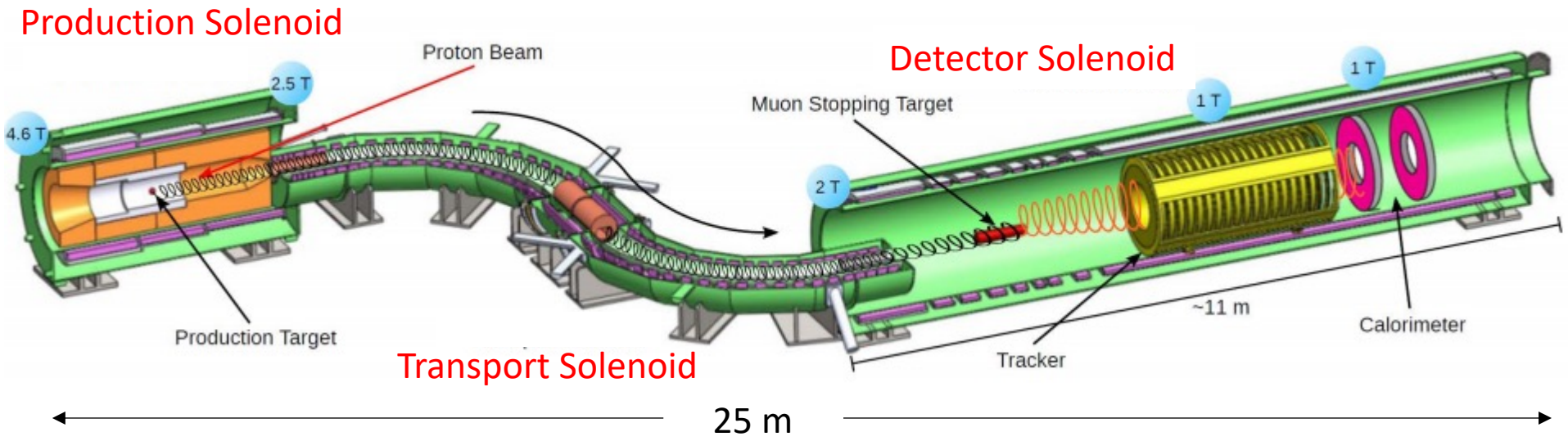


TABLE I. Selected nominal Mu2e-II quantities

Parameter	Value
Proton kinetic energy	0.8 GeV
Beam Power	100 kW
Protons/s	7.8×10^{14}
Pulse Cycle Length	1.693 μs (variable)
Extinction	$< 10^{-11}$
Stopped μ per proton	9.1×10^{-5}
Stopped μ per cycle	1.2×10^{5}
Event size	1 MB
Storage	14 PB/yr
Run period	5 yr
Single event sensitivity	3.25×10^{-18}
Total background	0.47 events
$R_{\mu e}$ (discovery)	2.3×10^{-17}
$R_{\mu e}$ (90% CL)	6.4×10^{-18}

TABLE III. Mu2e and Mu2e-II Proton beam parameters

Parameter	Mu2e	Mu2e-II	Comment
Proton source	Slow extraction from DR	PIP-II Linac	
Proton kinetic energy	8 GeV	0.8 GeV	
Beam Power for expt.	8 kW	100 kW	Mu2e-II can be increased
Protons/s	6.25×10^{12}	7.8×10^{14}	
Pulse Cycle Length	1.693 μs	1.693 μs	variable for Mu2e-II
Proton rms emittance	2.7	0.25	mm-mrad, normalized
Proton geometric emittance	0.29	0.16	mm-mrad, unnormalized
Proton Energy Spread (σ_E)	20 MeV	0.275 MeV	
$\delta p/p$	2.25×10^{-3}	2.2×10^{-4}	
Stopped μ per proton	1.59×10^{-3}	9.1×10^{-5}	
Stopped μ per cycle		1.2×10^{5}	

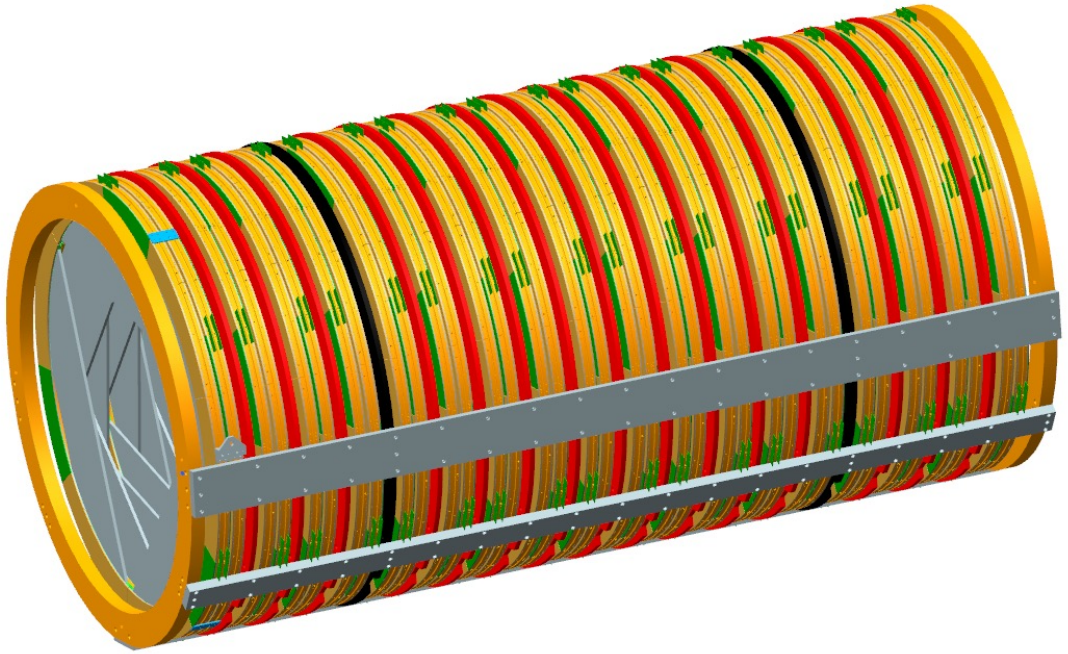
Mu2e-II's aim is an order of magnitude sensitivity increase to Mu2e.

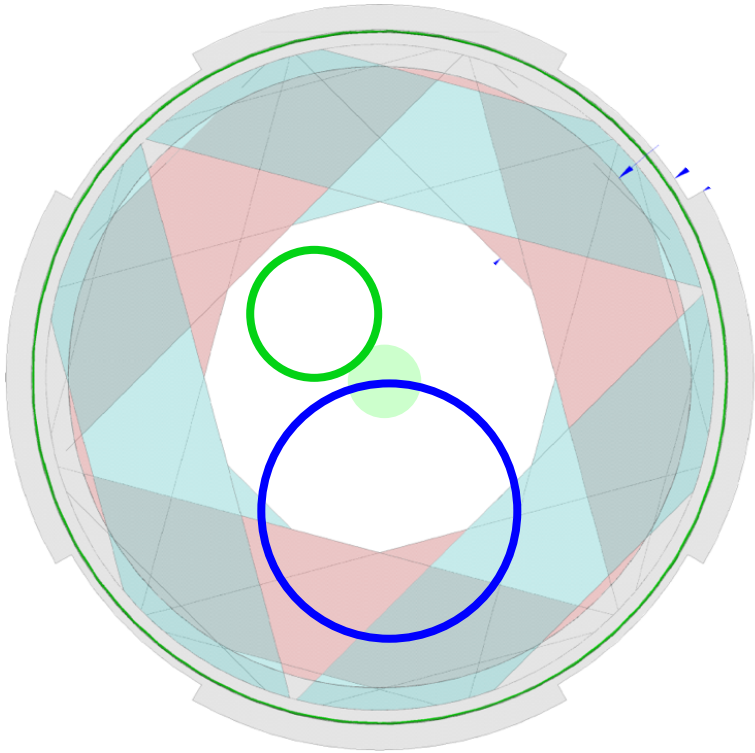
This will be made possible by the PIP-II beam upgrade.

Mu2e-II is constrained to reuse as much of Mu2e structure as possible.

For the tracker, it was determined we would need to rebuild a new tracker while reusing the detector solenoid.

Mu2e Tracker : Requirements

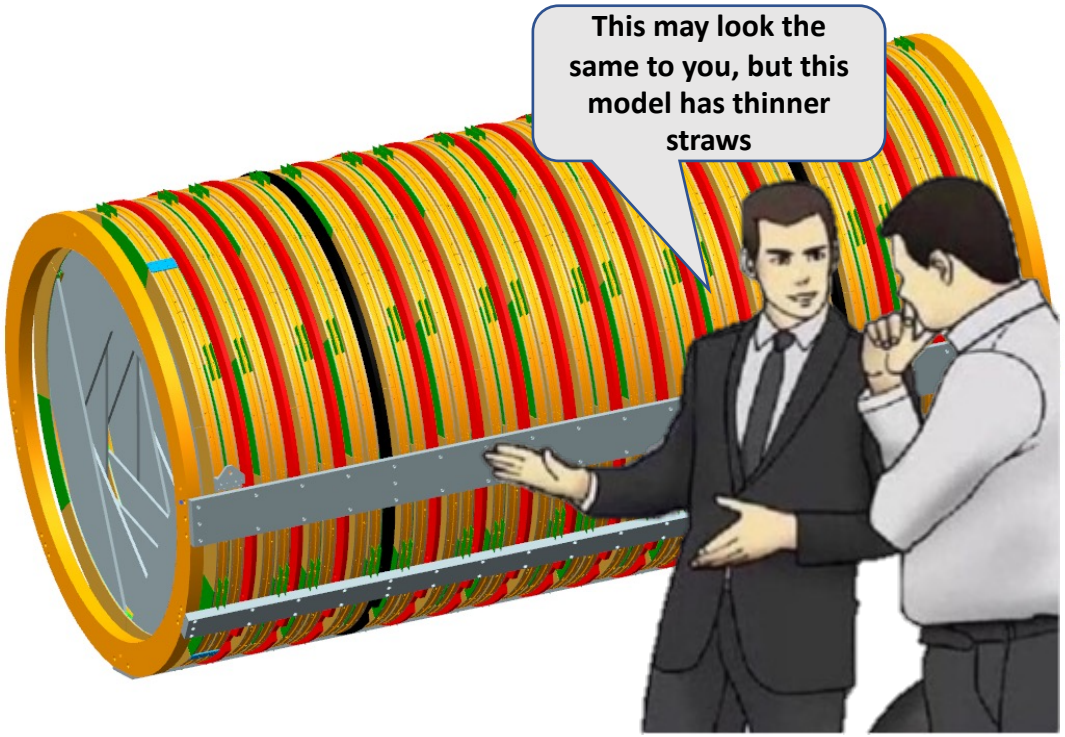


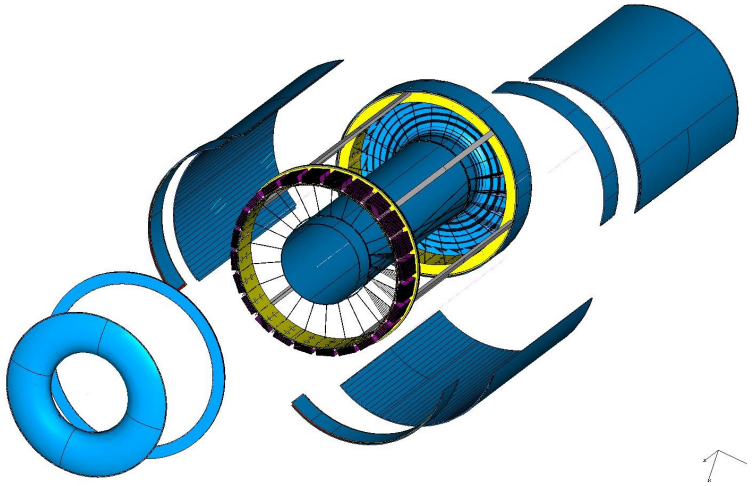


Beam's-eye view of Tracker

- **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**

Mu2e-II Tracker Baseline and additional options





Possible Mu2e-II Alternative I-Tracker Design

Mu2e-II White paper
https://arxiv.org/pdf/2203.07569.pdf

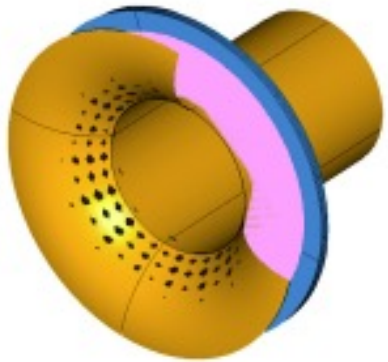


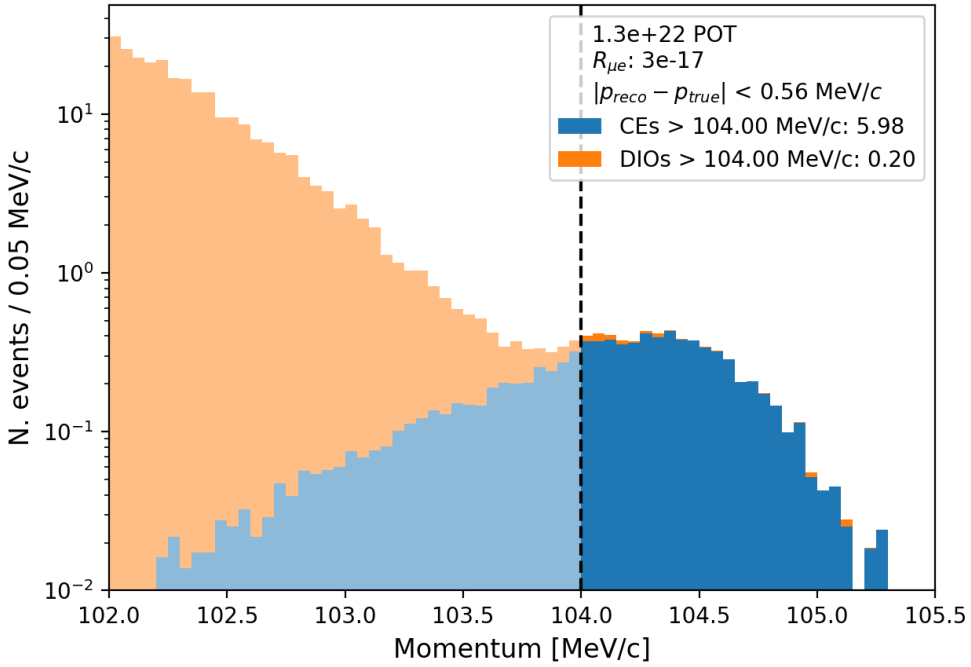
FIG. 24. Pictorial views of tracker alternative, a station of a Mu2e tracker like inserted in the C-fiber gas vessel.

For simulations, the baseline tracker is the same mu2e tracker geometry using the 8 μm straws without gold inside.
There will be design improvements to reduce leaks and address other discovered Mu2e issues but the geometry is the same.

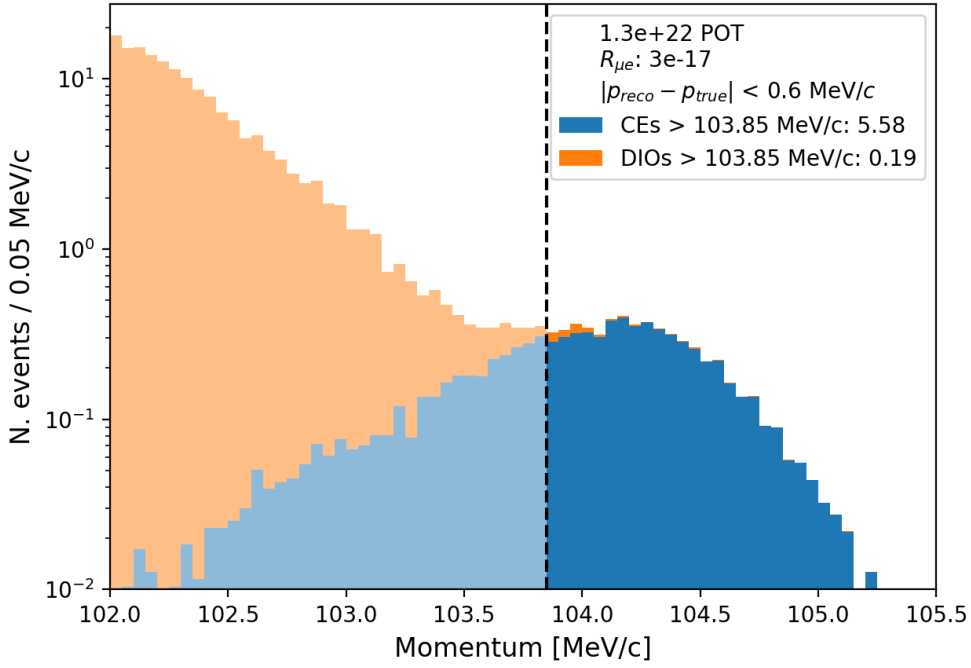
Other geometries and tracker designs have been put forward. Dave Brown will give a talk later today on Ideas for alternative tracker designs.

Baseline Tracker effect on Sensitivity

8μm Straw Tracker Simulated Reconstruction momentum



15μm Straw Tracker Simulated Reconstruction momentum



Stacked histograms of the simulated reconstructed momentum spectra for CEs (blue) and DIOs (orange), with 8μm (left) and 15 μm (right) thick straw tubes.

Less mass leads to less energy smearing in CEs and DIO.
~7% increase in signal to background in CE/DIO ratio
~12% reduction in cosmic ray background from reduced acceptance window.

Mu2e-II Tracker Challenges

Mu2e has been a difficult tracker to make, Mu2e-II tracker will be more difficult.

Mu2e-II tracker faces all the same challenges of Mu2e with additional requirements due to :

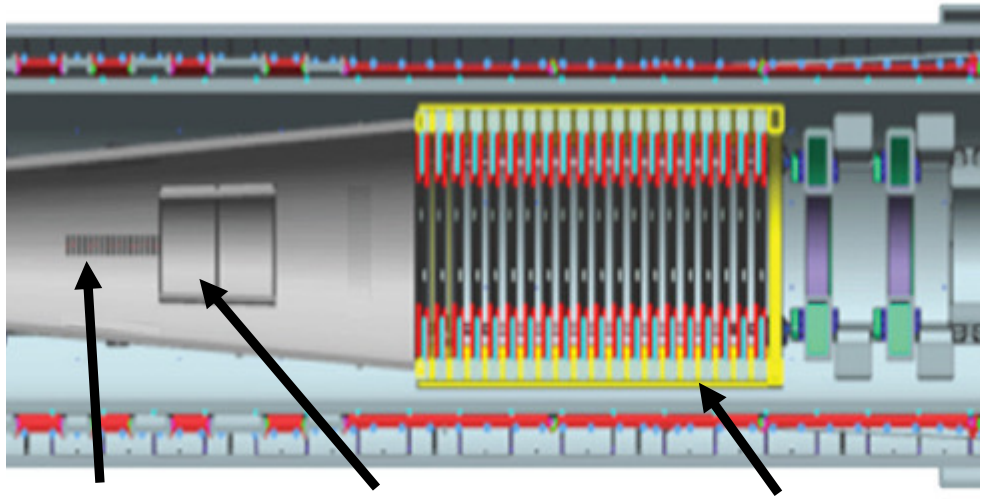
- **Increased sensitivity** → **Requires Better Momentum resolution**
- **Increased beam intensity** → **Occupancy Issues**
  → **Increased Radiation**

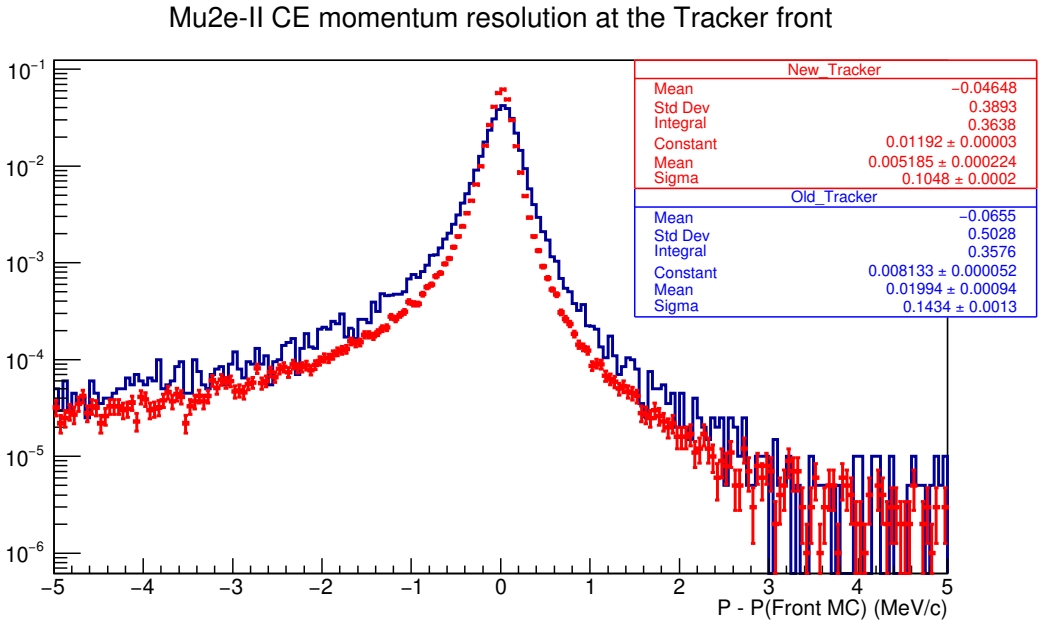
It is currently hard to make statements on the anticipated requirements for each of these issues as we must rely on future research to set our limits.

We will touch briefly on each of these topics, but Richie's talk will have more.

Momentum Resolution

Mu2e Detector Solenoid





Tracker resolution for Mu2e-II (in red) compared to the Mu2e (in blue) era tracker simulation.

Mu2e-II White paper
https://arxiv.org/pdf/2203.07569.pdf

A reduction of the tracker straw mass by 50% sees resolution improvements of ~6%.

More than half of the CE energy loss is in the stopping target and the IPA.

- **Resolution improvement relies on the whole stopping target, IPA, and tracker system**
- **Simulation studies on Stopping target and IPA mass**
- **Alternative IPA geometries could be explored**

Suggested R&D For further resolution improvement will be discussed more in Jim Popp's talk:

- **Thinner straws material studies**
- **Lower mass gas**
- **Alternative technologies and geometries for tracker**
- **Alternative geometries for Muon Stopping target and Inner Proton Absorber**

Occupancy

Mu2e-II White paper
https://arxiv.org/pdf/2203.07569.pdf

Mu2e-II faces increased occupancy due to :

- **Increased muon rate**
- **Reduced IPA shielding**
- **increased timing windows**

These could all lead to more hits, cross-talk, and dead-time in channels.

White paper simulations saw minimal differences with pileup included.

Suggested R&D to reduce effect of increased occupancy

- **Improved pattern recognition : Machine Learning studies**
- **Improve Timing resolution in electronics**
- **Use faster gas**

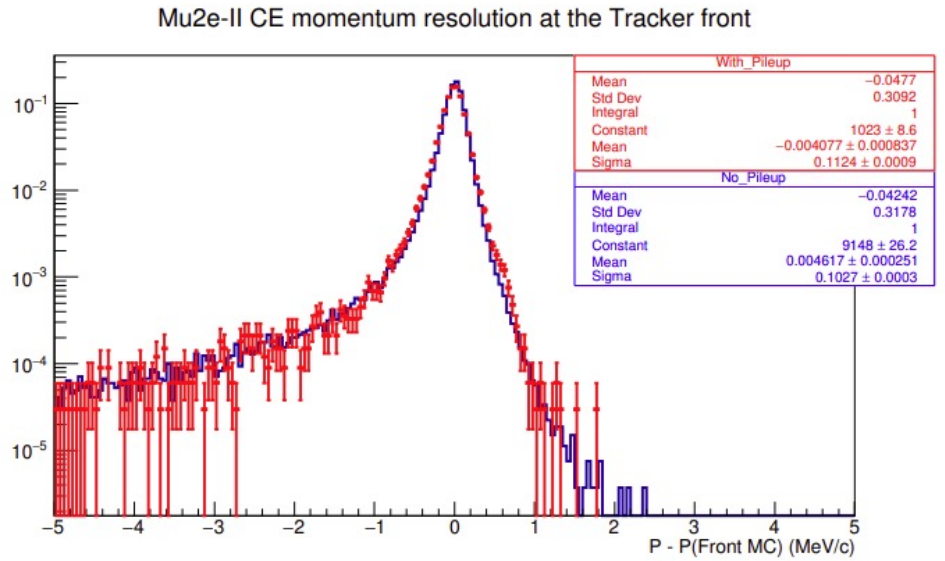


FIG. 40. Tracker resolution for the conversion electron signal at Mu2e-II before (in blue) and after (in red) the introduction of pileup. The reconstructed track momentum at the front of the tracker is compared to the MC true momentum at the front of the tracker, after selection cuts are applied. The distributions are normalized to unity.

Radiation

Increased beam intensity will lead to a larger radiation exposure and charge deposition onto the tracker material and electronics during the beam flash and over the lifetime of the experiment.

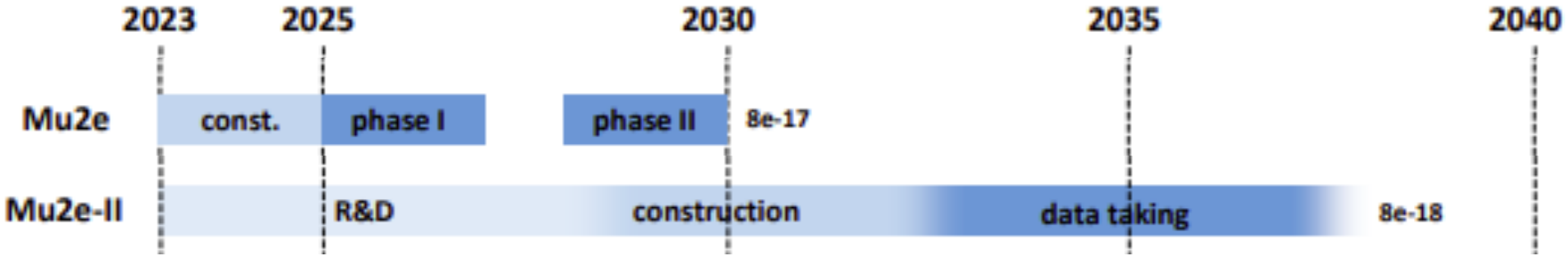
Two categories to worry about :

- Damage to the tracker components
- Damage to the electronics recording the measurements

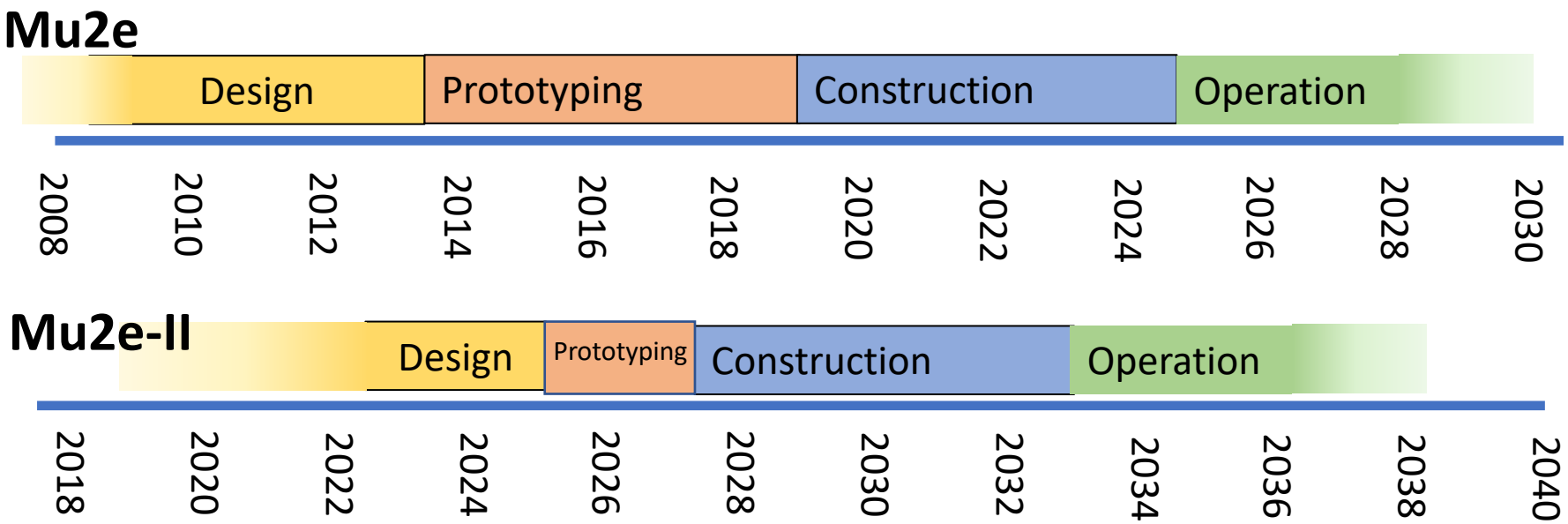
Mu2e straws showed no observable degradation in gain or cathode resistivity after a total charge deposition of 0.9 C cm^{-1}. New straws haven't been tested and will need to at larger rate.

There is no additional room to add more shielding for the electronics. Electronics need to be designed with radiation in mind. Current Mu2e electronic safety factor is x12.

Tracker Timeframe and Cost estimates



Report of the Frontier for Rare Processes and Precision Measurements
https://arxiv.org/pdf/2210.04765.pdf



The Mu2e tracker will end up costing ~$25 Million and 8 years of construction (from the first production straw to installation into the detector hall).

Mu2e-II's tracker can save a lot of time and money using research and tooling developed for Mu2e.

Rough estimate is it can be done at 70% Mu2e cost (~$18 million)

Compared to Mu2e we will have significantly less time for designing and prototyping.

If we are serious about pursuing alternative tracker designs work will need to be done soon.

Summary

- This is an introduction to the Mu2e-II tracker status
- A lot of R&D topics available
- We are open for new ideas and new people to get involved

Suggested Questions to discuss :

- What do people want to get out of this workshop?
- Which parties are interest in exploring other tracker designs?
- Anyone have plans to take on tracker research topics?

Google Docs for Discussion Topics:
https://docs.google.com/document/d/1s8ZWHfrjNhCdcZ6Yd9yXkv9YNKwZ1Y8aUfJrmG-c6v0/edit?usp=sharing