Mu2e tracker - an introduction

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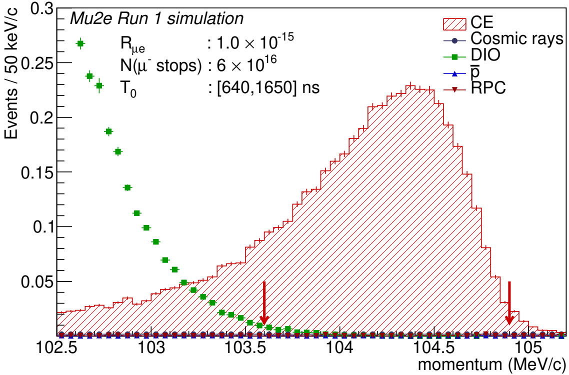
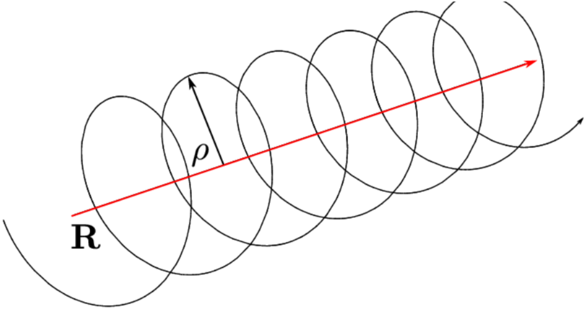
Mu2e is a tracking experiment



- search for $\mu^- \to e^-$ conversion = accurate reconstruction of the electron momentum
  - green - background from muon decays in orbit (DIO)
- currently - the momentum window $\sim$ 1.5 MeV, the resolution needs to be better than that.
- that can be done only by reconstructing the electron track momentum
- and this is why Mu2e needs a tracker

How to reconstruct the track momentum

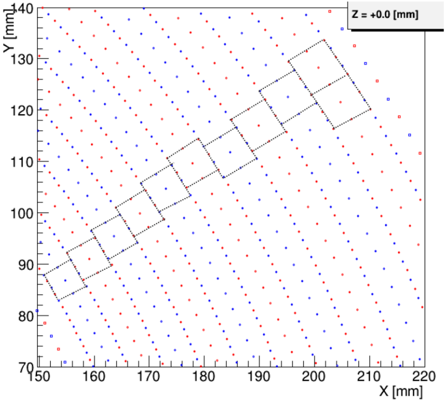


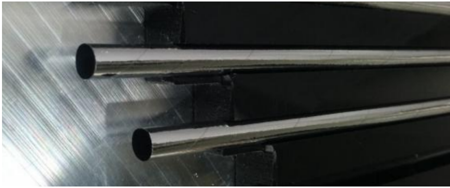
- place the detector into a magnetic field (Mu2e: superconducting solenoid, B $\sim$1 T)
- measure coordinates on the trajectory, fit the coordinates with a helix
- determine the track momentum: $R = p_T/qB$
- to reduce the energy losses and multiple scattering :
  - maintain vacuum in the tracker volume (down to 10^{-4} torr)
  - minimize the amount of material in the tracking volume

Silicon vs gas ?

- charged particle tracking is based on the measurement of ionization losses
- a particle going through the tracking sensor kicks out electrons, electrons drift and generate a signal
- in this sense, all trackers are the drift detectors, drift in silicon or in gas
- experiments with stopped muons :
  - Mu2e ($\mu^- A \rightarrow e^- A$: 100 MeV/c, straw tracker
  - MEG-II ($\mu^+ \rightarrow e\gamma$) : 50 MeV/c, single volume drift chamber (need vertexing)
  - Mu3E ($\mu + \rightarrow e^+ e - e^+$): very thin 0.1% X_L per layer silicon detector (need vertexing)
- silicon trackers provide better resolution (small strips/pixels),
  - significantly more channels, significantly more expensive , heat deposition by the electronics
- Mu2e experiment has chosen a gaseous detector

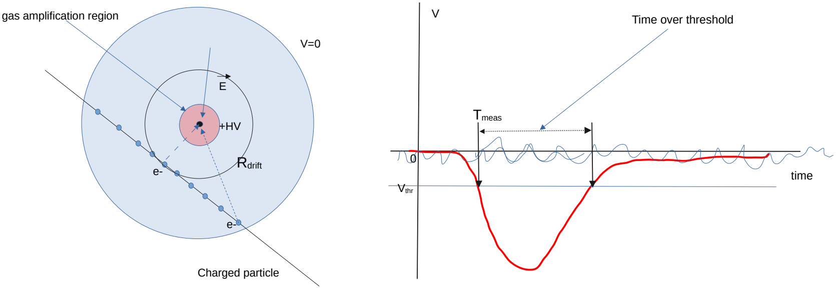
Choice of the drift technology: open volume vs straws





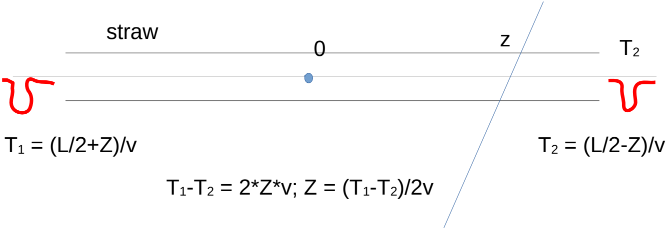
- for large tracker, can configure the drift cells in two ways
- left : a single volume tracker
- photograph on the right: drift “straws”
  - small radius tubes wound from aluminized mylar and filled with gas,
  - with a signal wire in the center, each straw is an independent drift cell
- potential advantage of an open volume chamber: less material
- but what if one of the wires breaks ? –> Mu2e choice: straw tracker

When a particle crosses a drift cell



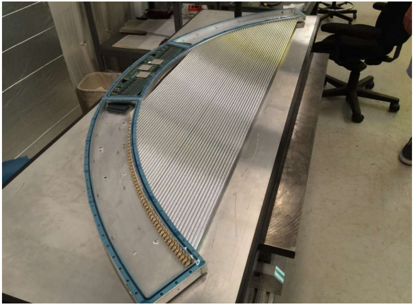
- ionization electrons drift towards wires , wires at high voltage , avalanche development, detect signal
- measure the pulse time, the time-over-threshold (TOT), and the pulse charge
- the measured time $T_{meas} = T_0 + T_{\mathrm{drift}} + T_{\mathrm{prop}}$
  - T_0 - time when the particle crossed the drift volume
  - T_{drift} - the drift time
  - T_{prop} - the signal propagation time (cables, electronics)
- for momentum reconstruction, need T_{drift}: $R = v_{drift} \times T_{drift}$
- the resolution in $R_{drift} \sim 170$ microns

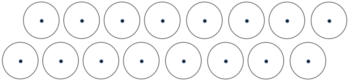
coordinate along the wire: time division



- a wire is read out from both ends
- the difference in the signal propagation times determines the hit coordinate along the wire
- resolution along the wire $\sigma_Z \sim 3.5$ cm
- the hit resolutions in two directions are significantly different

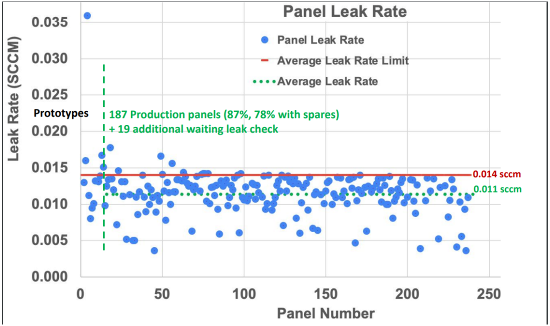
Mu2e tracker





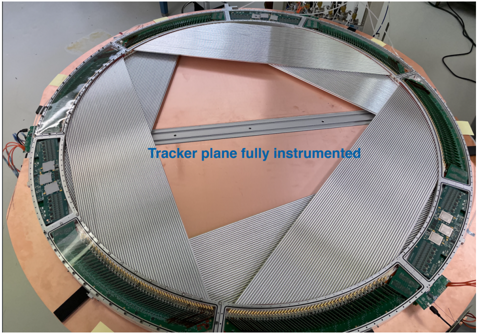
- groups from Minnesota, Duke, York, Fermilab, LBNL, Univ of Houston
- the tracker built out of straws - a panel - two layers , 96 straws in total
- D=5mm, 1.25mm gap , 2 layers , filled with Ar:Co2 (80:20)
- straws are very thin and easy to damage - the wall thickness is 15um wall
- the tracker will operate with the gas at 1 atm , vacuum outside
- the pressure differential makes the straw rigid
- control the wire tension
- a particle which crosses the panel could hit one , two , or more straws

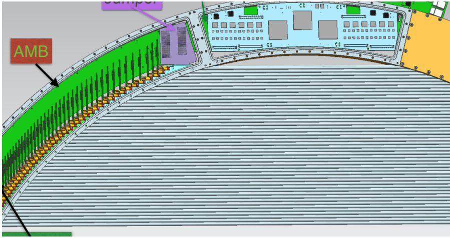
Panel leak test



- Mu2e tracker unique: the tracker in vacuum, gas (Ar:CO2) in the straws - at around 1 atm
- gas chambers always leak - there are always holes
- to maintain vacuum in the detector volume, need to keep the leak rate low
- sccm: $1\mathrm{cm}^3$ / minute

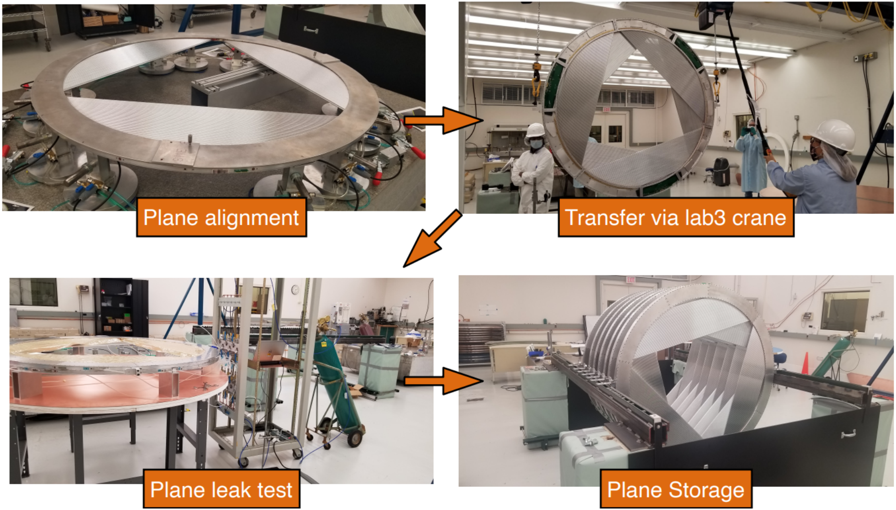
Mu2e tracker - II





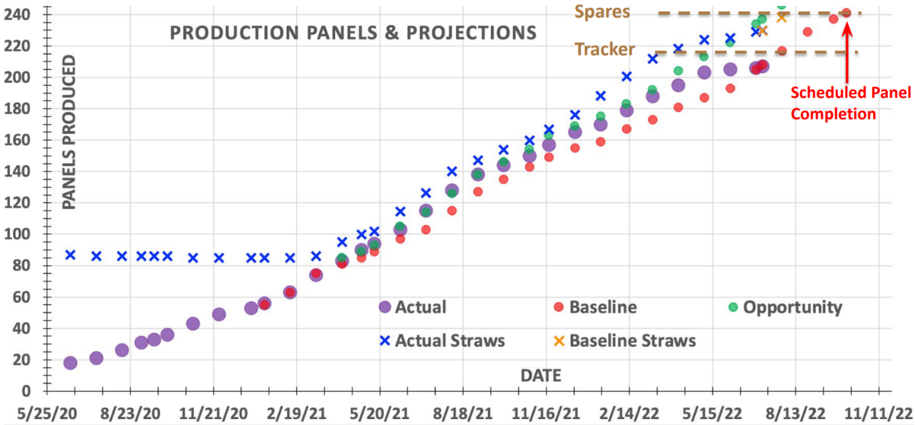
- a panel covers 120 degrees - 3 panels make a “face” - it is essentially, a tracking plane
- a face doesn’t provide a uniform coverage in ϕ, take the second face, rotate it by 30 degrees, put together. Two faces make a plane. This also adds mechanical rigidity

Mu2e tracker construction -II



- the tracker is assembled out of planes. Two planes make a station, 18 stations in total.

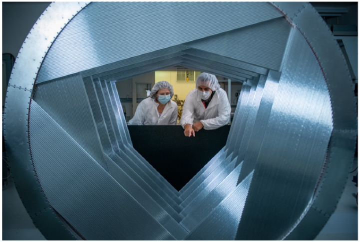
Panel production schedule



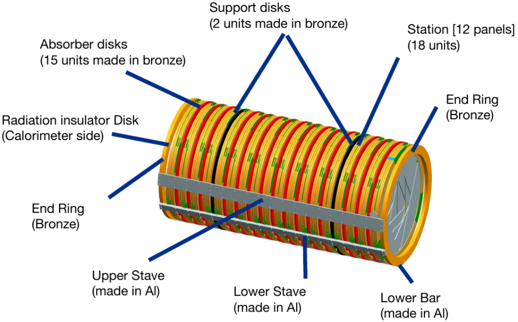
- panel production finishing in a few months

Mu2e tracker construction - IV

Tracker Overview

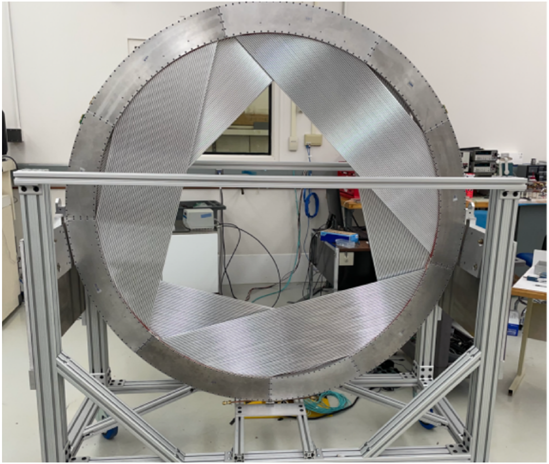


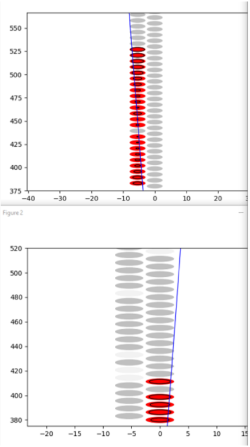
K. Byrum and M. Yucel inspecting planes in storage fixture.
R. Postel Photo



- the tracker is assembled out of planes, Two planes make a station, 18 stations in total.
- 20736 straws -> 216 panels -> 36 planes -> 18 stations,
- overall dimensions : total length $\sim$3 m , 38 < R < 70 cm
- this summer you have a chance to see the planes being built, next summer - too late!
- support / protection structure - non-magnetic (bronze)

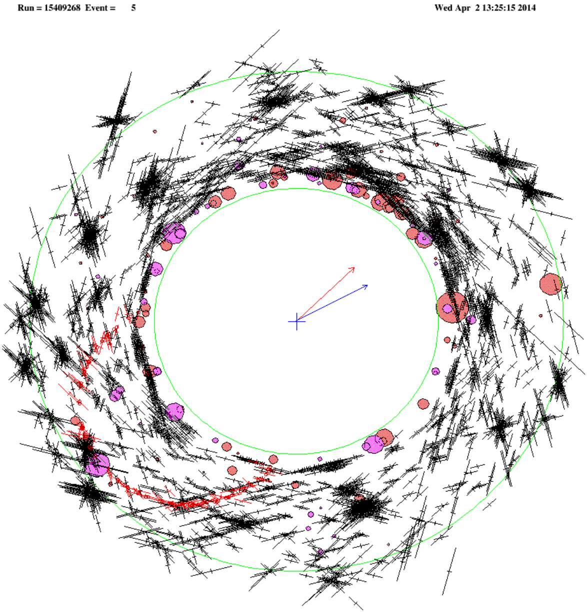
Started learning how to use the tracker



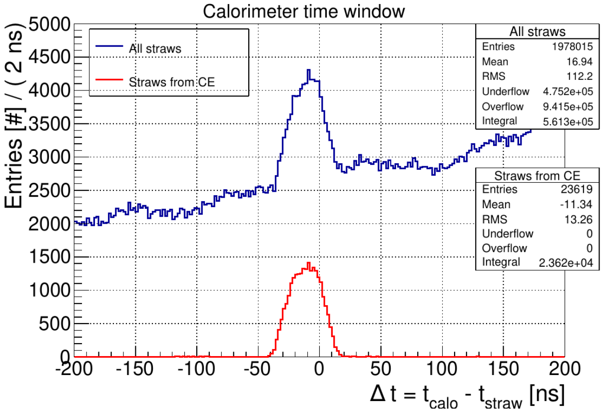


- vertical slice test (VST) - a way of learning how the tracker works
- ... and how to calibrate it
- first cosmic tracks seen

How we expect the data to look like in the tracker

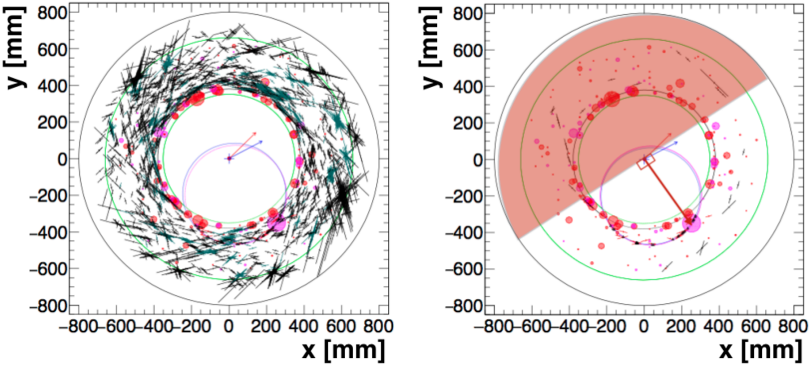


Calorimeter-seeded tracking : CE reconstruction



- use two different track finding algorithm, one is the calorimeter-seeded track search
- use calorimeter to seed the tracking
- if an electron has a calorimeter cluster, the track finding is significantly simplified
- can use only hits within $\sim$ 70 ns wide window

Calorimeter-seeded tracking

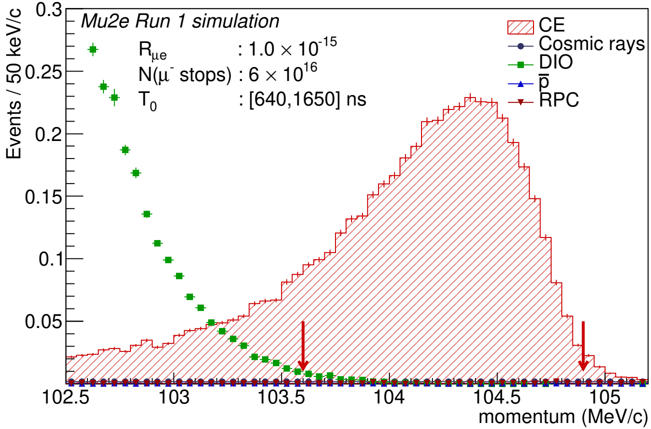


- with the calorimeter-based seeding finding a track becomes a much easier task

What is ahead

- need to finish building the tracker, produce and install the electronics
- learn what the tracker is doing, understand and calibrate its response
  - alignment
  - calibrate timing delays in the individual channels - coordinate along the wire
  - calibrate signal propagation speed along the wire
  - drift velocity or the drift time-to-distance relation
  - learn and calibrate the gas gains in the individual channels
  - calibrate the material map
- all that is a lot of work, but it has already started.
- for your pool, it is the right time frame

If we learn how to do all that



- if we learn how to operate the tracker (and the rest of the detector), we should be able to reproduce the background part of the plot
- the rest depends on the Nature. We will see.