

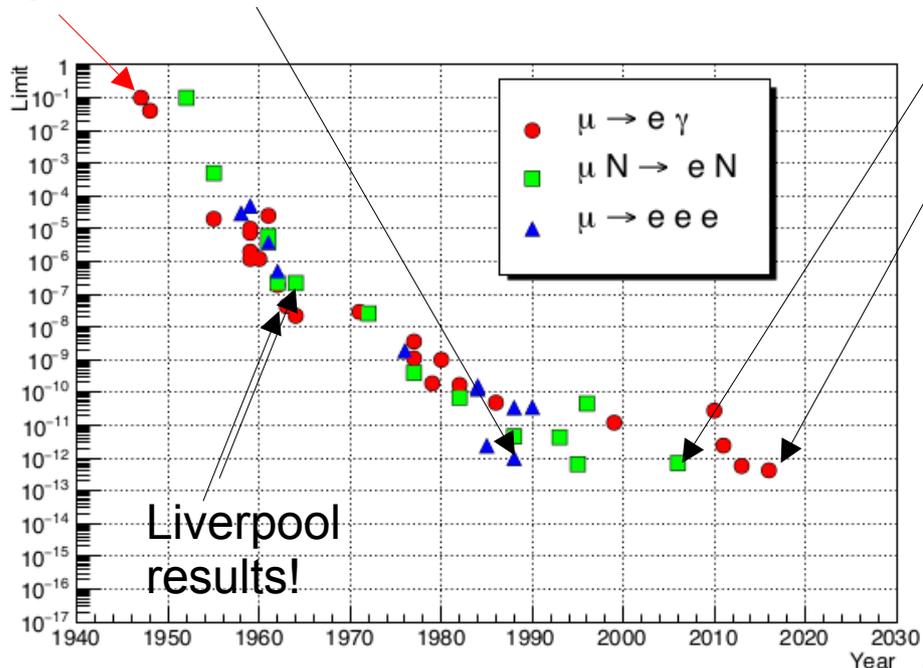
# Overview of Mu3e, Mu2e & Muon EDM experiments

Nikolaos Rompotis (Liverpool)

# Charged Lepton Flavour Violation

- Muons have been the experimental workhorse for charged lepton flavour violation
- For the last 70 years there has been a continuum of searches for
  - $\mu \rightarrow e\gamma$
  - $\mu N \rightarrow eN$  **In this talk**
  - $\mu \rightarrow eee$

1947 Best  $\mu \rightarrow eee$  result: SINDRUM (1988)  $BR < 10^{-12}$



Best  $\mu N \rightarrow eN$  result: SINDRUM II (2006)  $BR < 10^{-13}$

Best  $\mu \rightarrow e\gamma$  result: MEG (2016)  $BR < 10^{-13}$

Complementarity in theoretical models among the three usually studied muon LFV decays

Model	$\mu \rightarrow eee$	$\mu N \rightarrow eN$	$\frac{BR(\mu \rightarrow eee)}{BR(\mu \rightarrow e\gamma)}$	$\frac{CR(\mu N \rightarrow eN)}{BR(\mu \rightarrow e\gamma)}$
MSSM	Loop	Loop	$\approx 6 \times 10^{-3}$	$10^{-3} - 10^{-2}$
Type-I seesaw	Loop*	Loop*	$3 \times 10^{-3} - 0.3$	0.1 - 10
Type-II seesaw	Tree	Loop	$(0.1 - 3) \times 10^3$	$\mathcal{O}(10^{-2})$
Type-III seesaw	Tree	Tree	$\approx 10^3$	$\mathcal{O}(10^3)$
LFV Higgs	Loop <sup>†</sup>	Loop* <sup>†</sup>	$\approx 10^{-2}$	$\mathcal{O}(0.1)$
Composite Higgs	Loop*	Loop*	0.05 - 0.5	2 - 20



# Mu3e Experiment (PSI)

- **Liverpool mu3e experiment team**

<https://www.psi.ch/en/mu3e>

## Staff members:

Joost Vossebeld (head of the Mu3e group, **Pixel Detector coordinator** )

Helen Hayward

Nikos Rompotis

Paolo Beltrame (**Data & MC Manager**)

Mark Wang

Matthew Brown (technician)

*Andrea Loreti (till Feb 2024; now staff at Culham)*

*Carlos Chavez Barajas (till 2023; Data & MC Manager; now DUNE at Daresbury)*

## PhD students:

*Sean Hughes (graduated 2023, now post-doc @ LZ)*

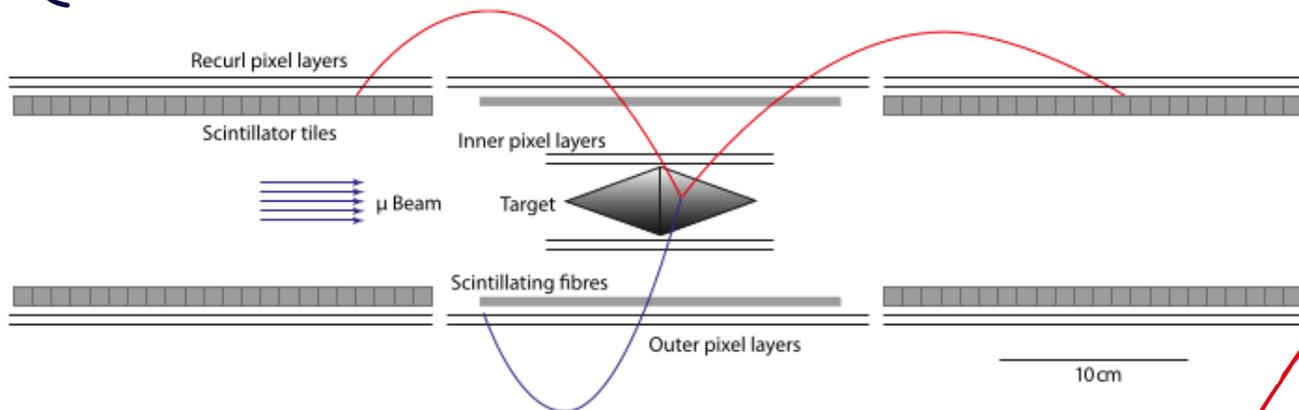
Charles Kinsman

Jak Woodford (incoming PhD student - Oct 2024)

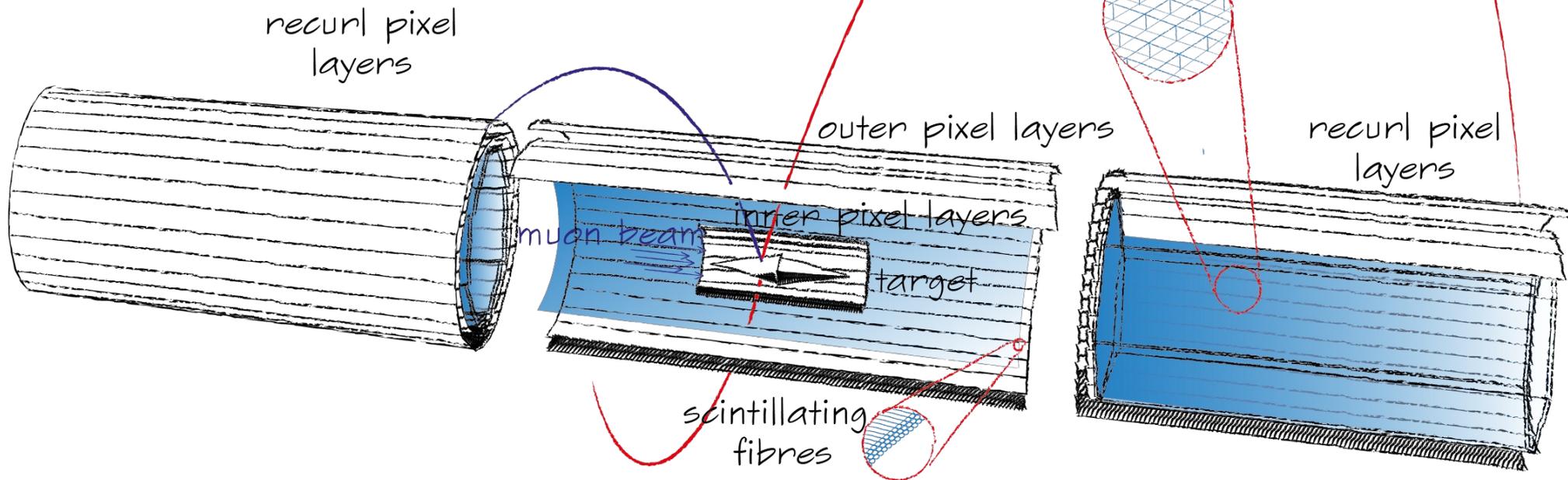
**Official Collaboration roles in red**  
**Recently joined/new members in blue**



# Mu3e Detector



Immersed in 1 T magnetic field from a solenoid

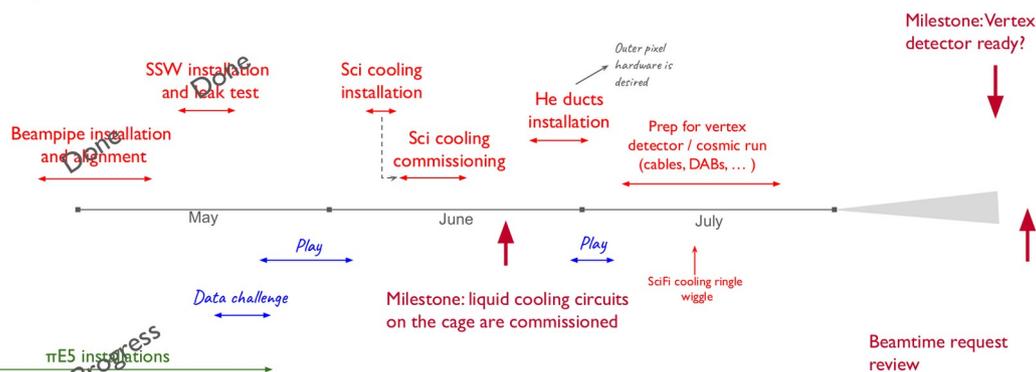


Silicon for tracking  
Fibre + tiles for timing

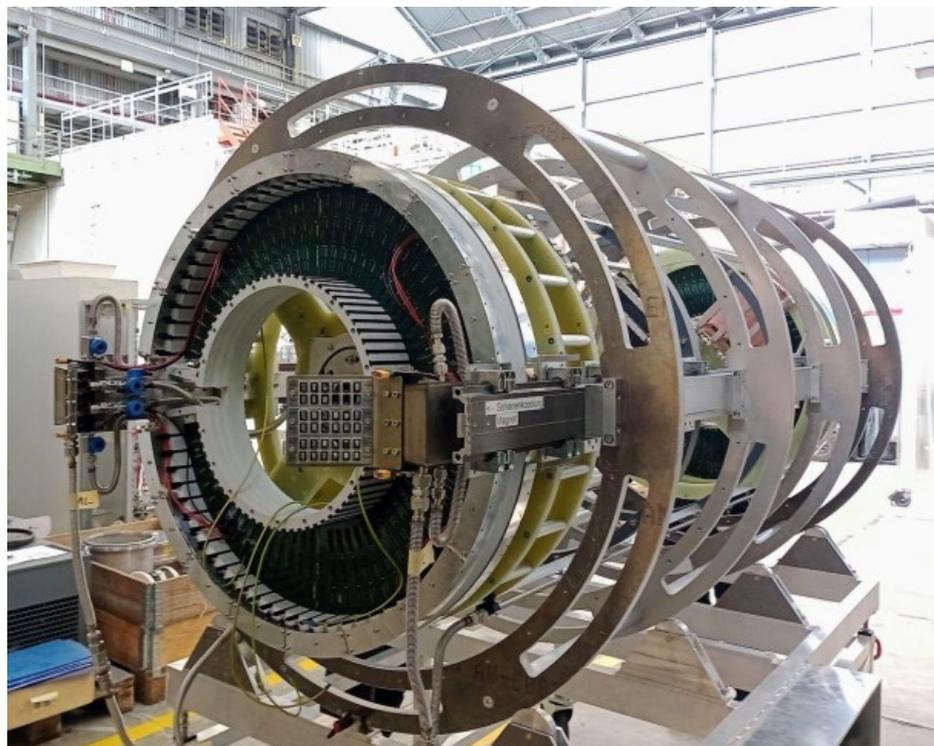


# Detector construction status

Aiming to have the installation of the central station ready by the end of the year

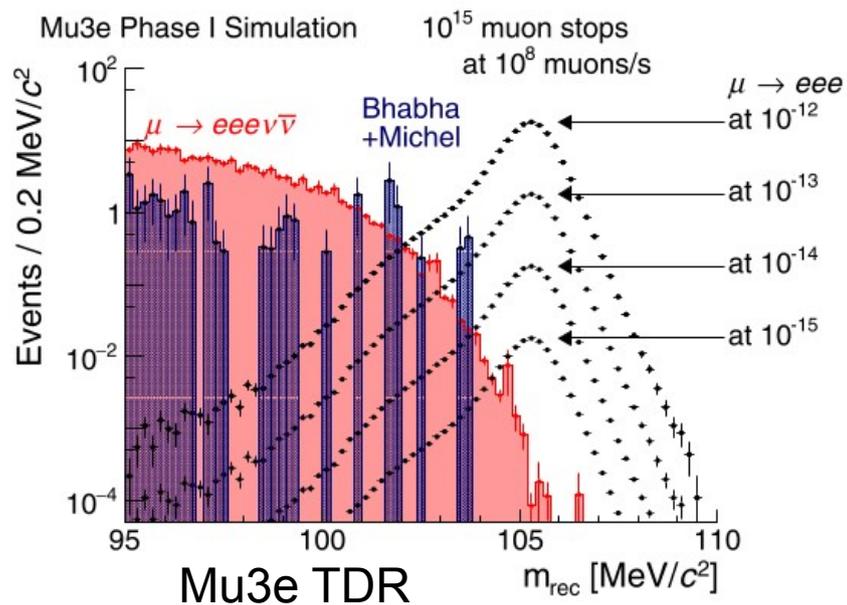


Mu3e cage and beampipe in PSI

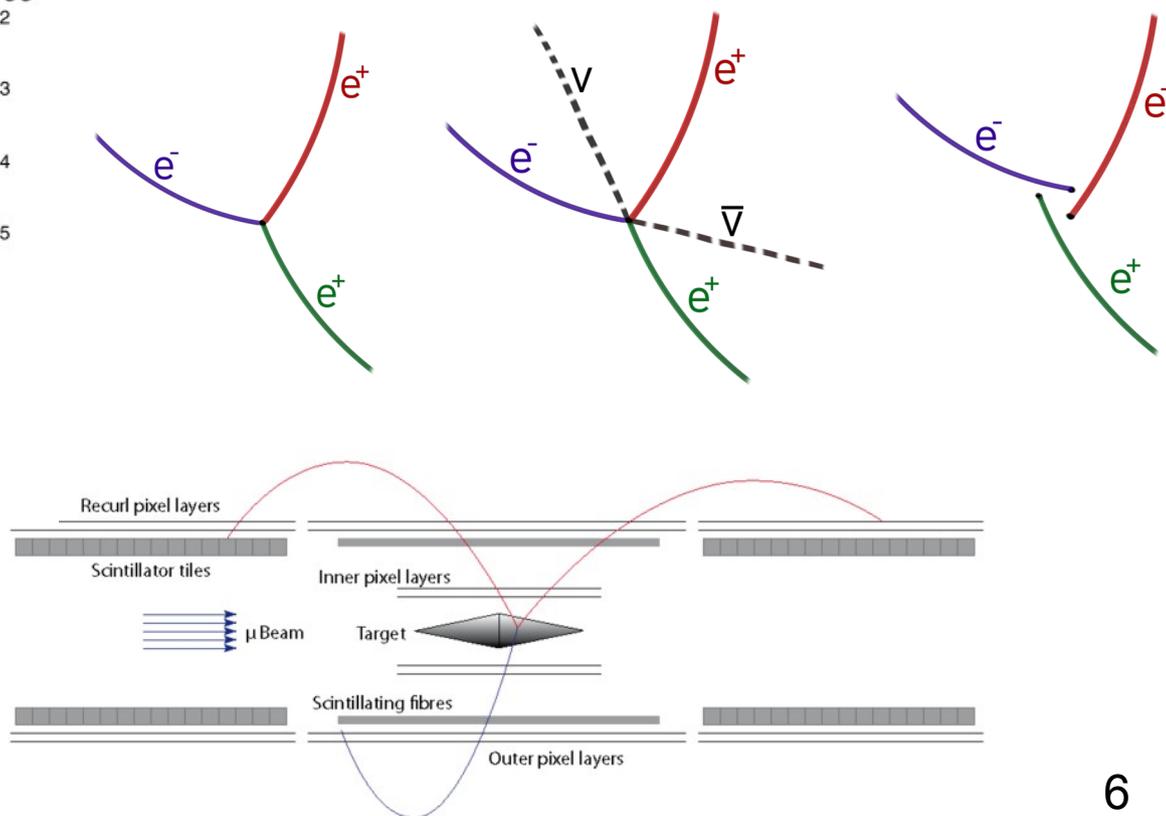


# Tracking & Vertexing

- The experiment relies on precise
  - **Momentum reconstruction**: to see the signal in the tail of  $\mu \rightarrow eee\nu$
  - **Vertexing + timing**: 3 tracks emanating from the same point at the same time against accidental overlaps



Multiple scattering is one of the main constraints



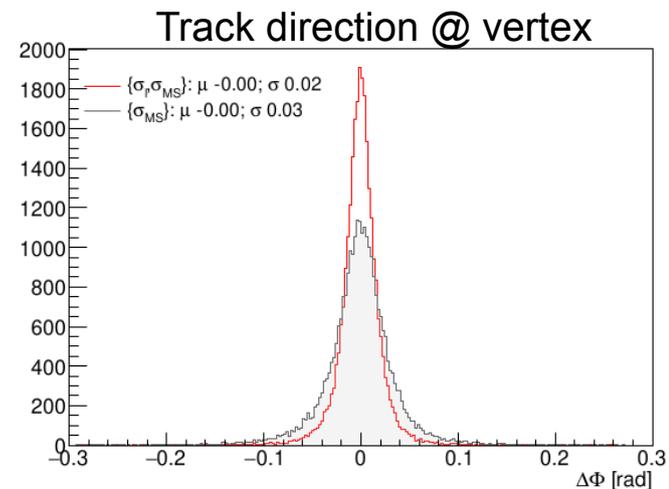
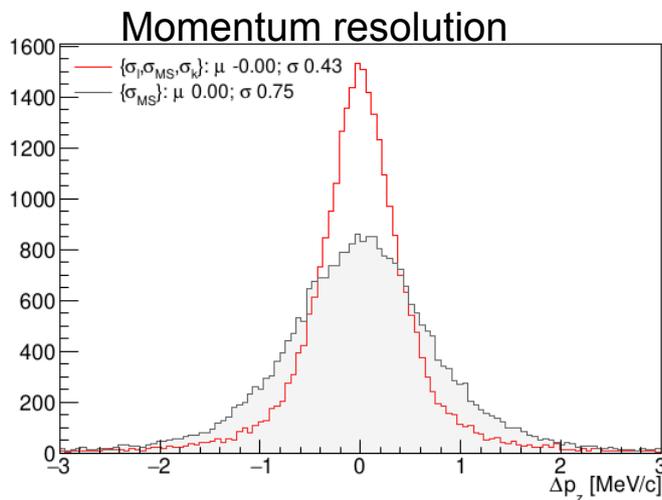


# Vertex and Tracking

- New Vertex fitting**

Andrea Loreti     arXiv:2401.13538

Implements pixel position resolution and energy losses in silicon (previously only multiple scattering)

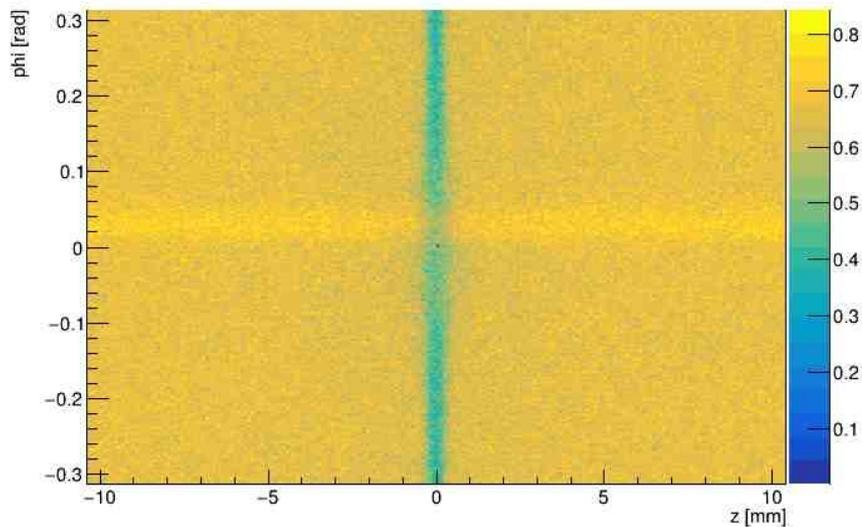


- Measuring silicon hit efficiency from data**

Charlie Kinsman

Tag and probe:

- tag: track reconstructed with an alternative tracking algorithm that does reco with one hit less
- probe: the track from the normal reco algorithm



75% hit efficiency measurement test

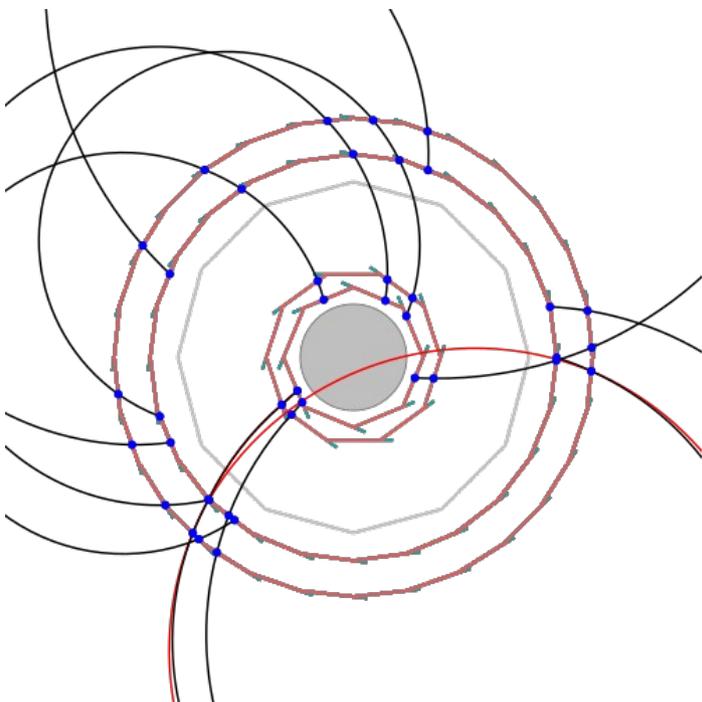


# Tracking

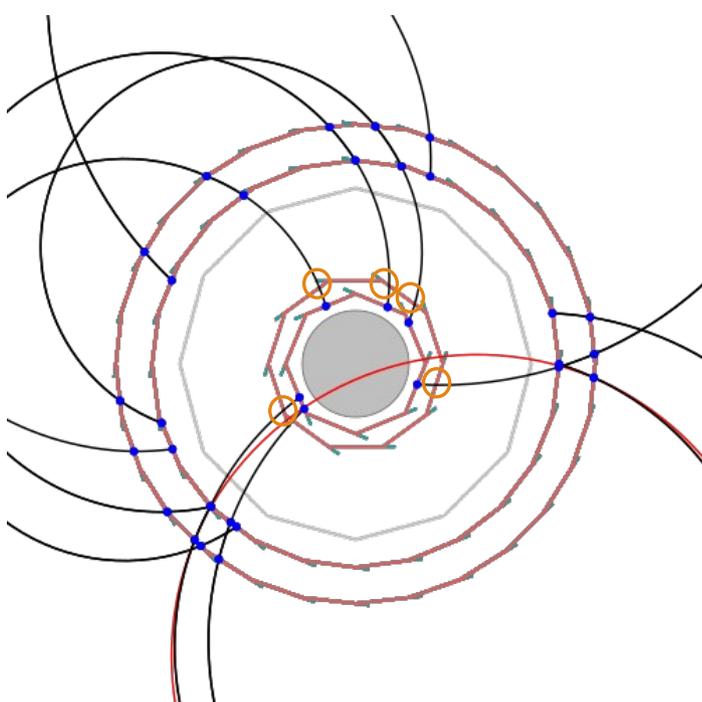
- Alternative tracking algorithm

Charlie Kinsman

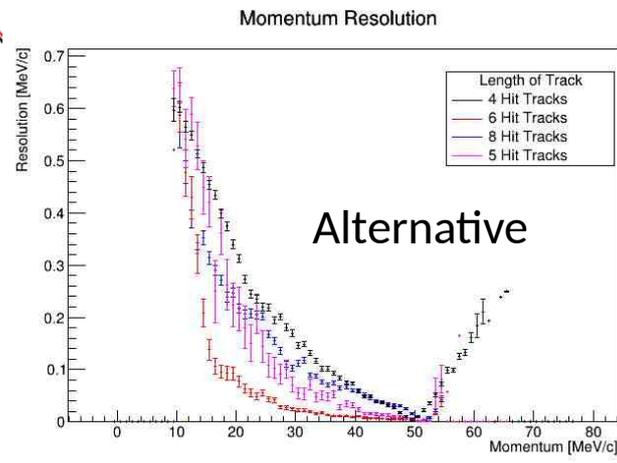
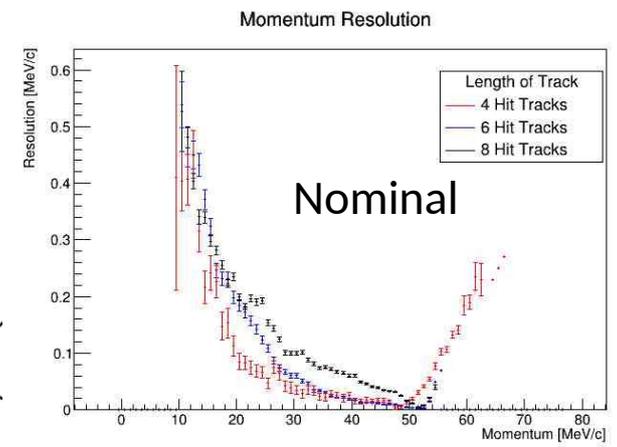
The alternative tracking algorithm was developed from scratch by Charlie but eventually it is deemed useful also for other things as well



Nominal



Alternative

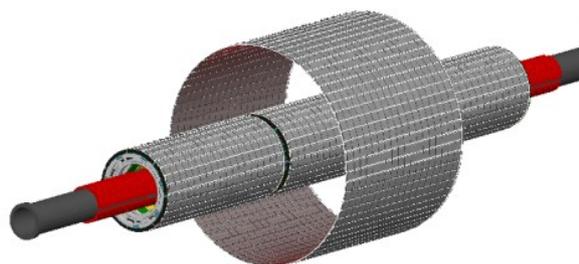




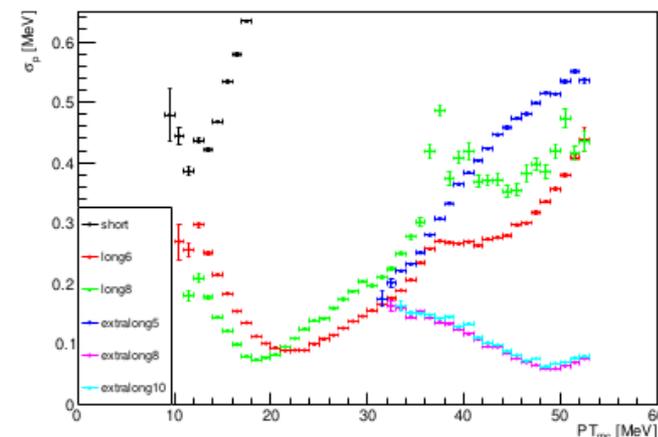
# Upgrade and Physics Studies

Sean Hughes thesis

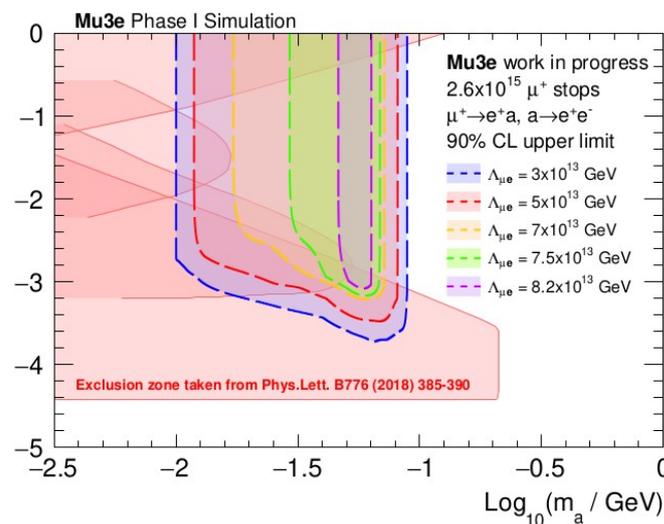
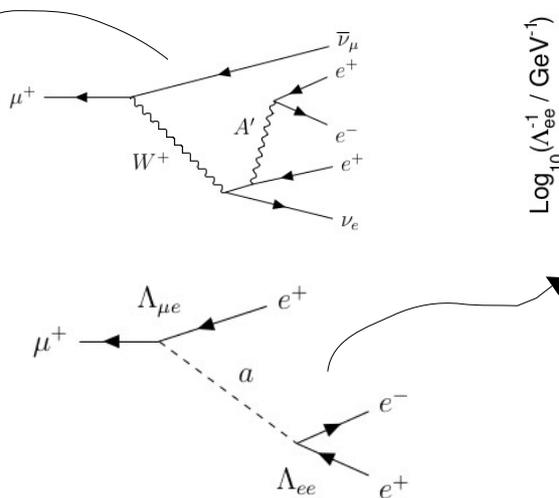
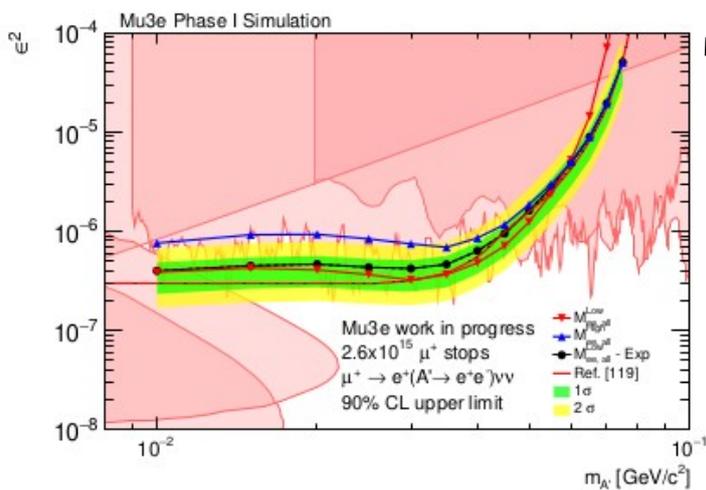
- Upgrade studies



Examining the effect in momentum resolution with an additional silicon layer



- Searching for dark photons and axion-like particles

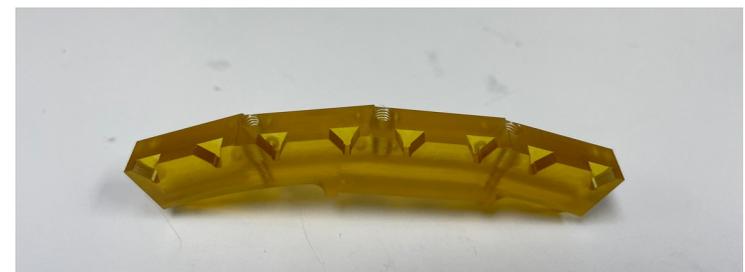
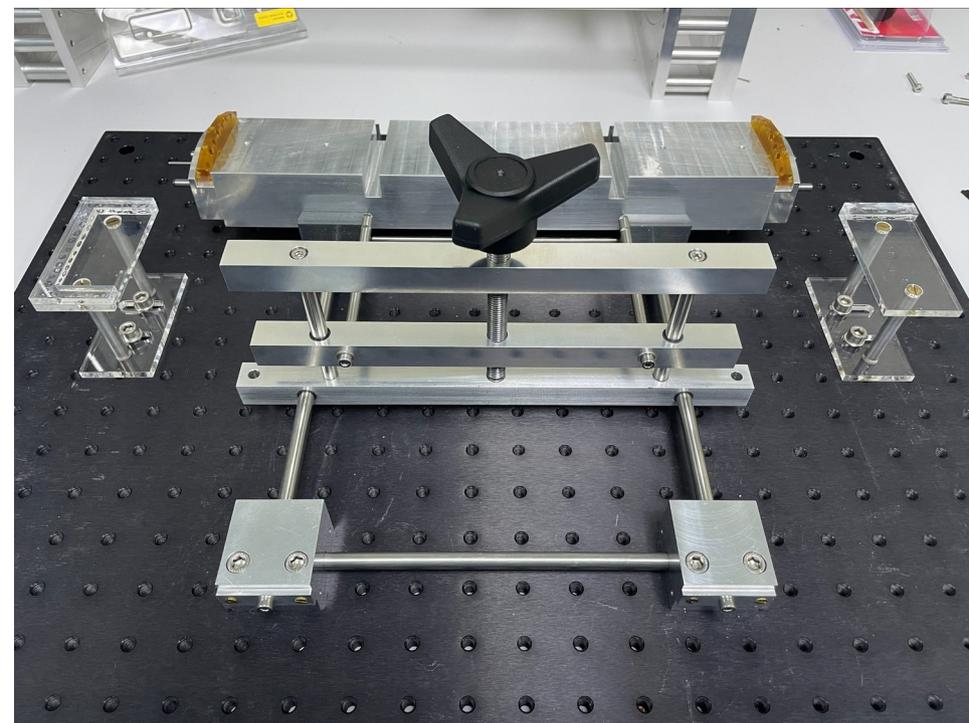
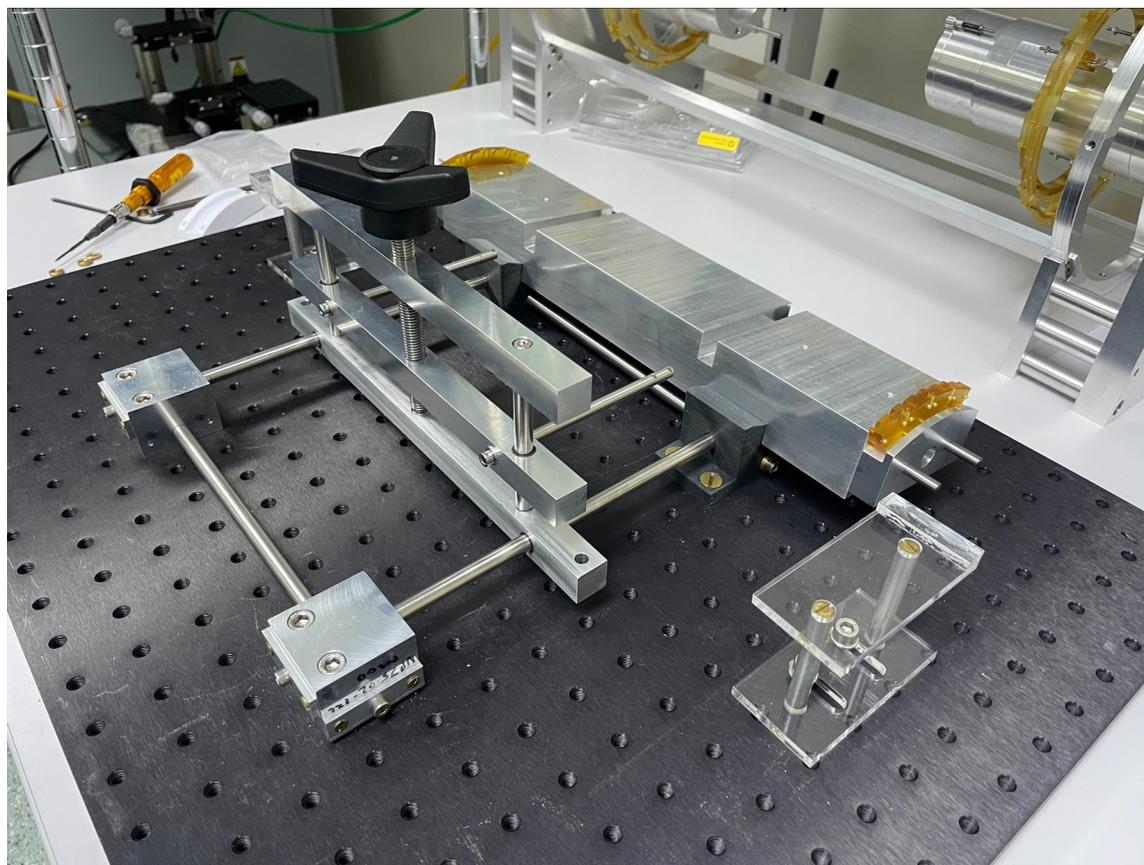




# Pixel Activities at Liverpool

Pics from Matthew Brown

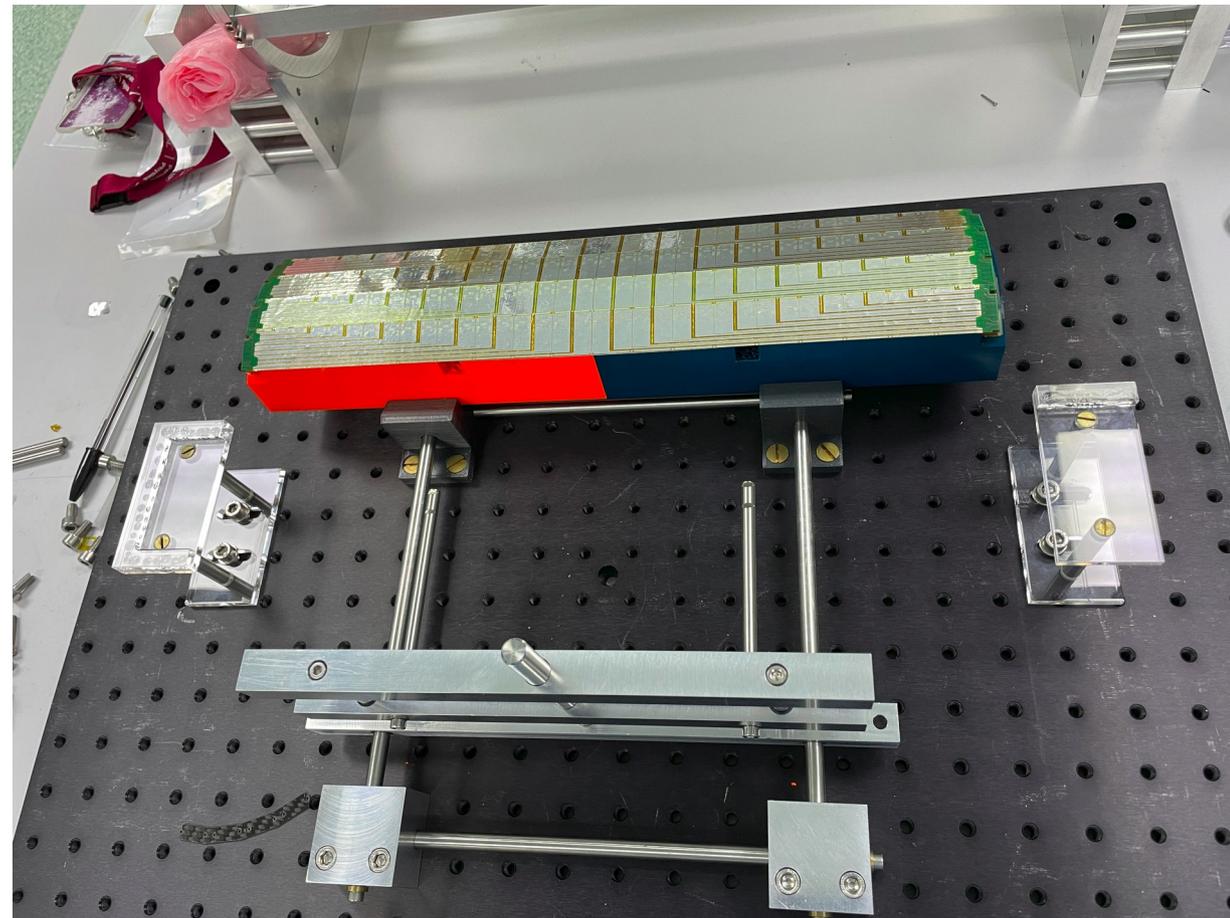
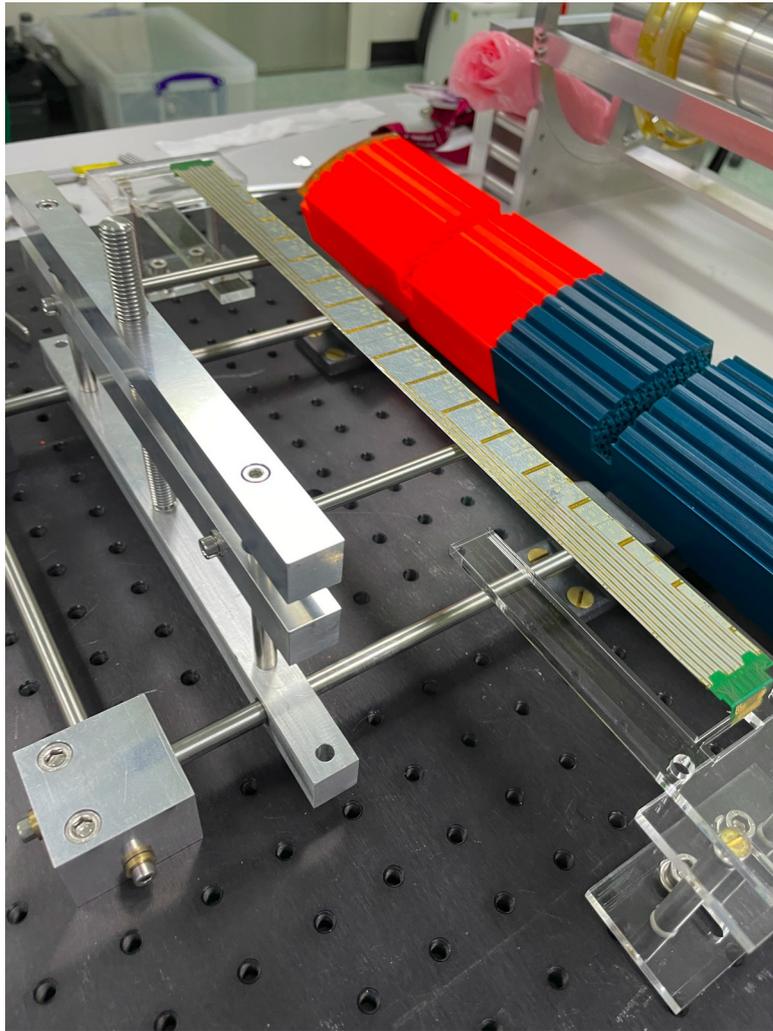
Our setup in the workshop for module production and ladder assembly

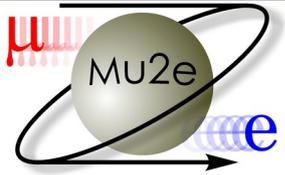


# Pixel Activities at Liverpool

Pics from Matthew Brown

The setup with the ladders being assembled





# Mu2e Experiment (Fermilab)

<https://mu2e.fnal.gov/>

- Liverpool mu2e experiment team

## Staff members:

Themis Bowcock

Joe Price (**STM operation, Tracking**)

Laura Harkness-Brennan

Dan Judson

Saskia Charity

## PhD students:

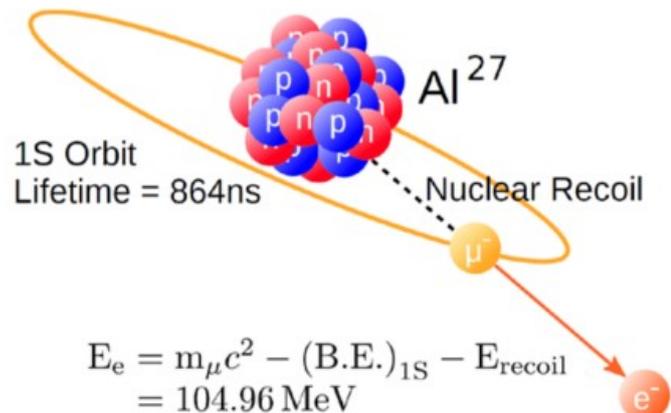
*Steven Tickle (graduated 2024)*

Thanks to Joe Price for  
providing the slides for mu2e



# Mu2e physics

- Search for  $\mu$  to  $e$  conversion in the field of a nucleus



muon to electron conversion

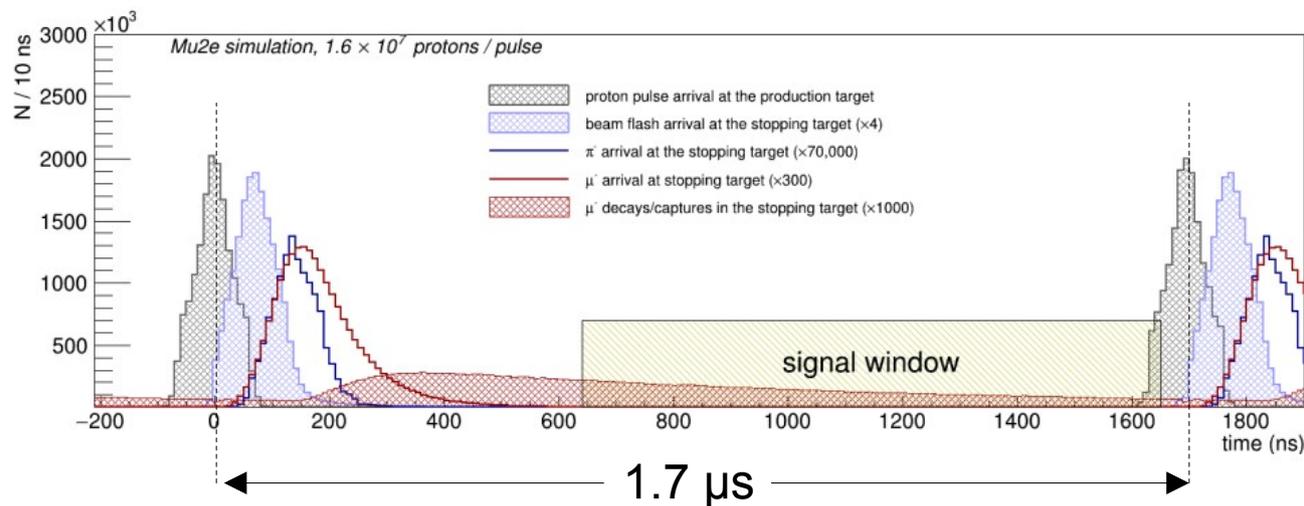
$$R_{\mu e} = \frac{\mu^- + A(Z, N) \rightarrow e^- + A(Z, N)}{\mu^- + A(Z, N) \rightarrow \nu_\mu + A(Z-1, N)}$$

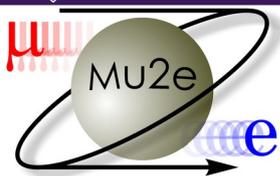
muon capture on the nucleus

Signal: a mono-energetic electron

Requirements:

- High intensity (stop  $10^{18}$ ) muons
- $\ll 1$  background event



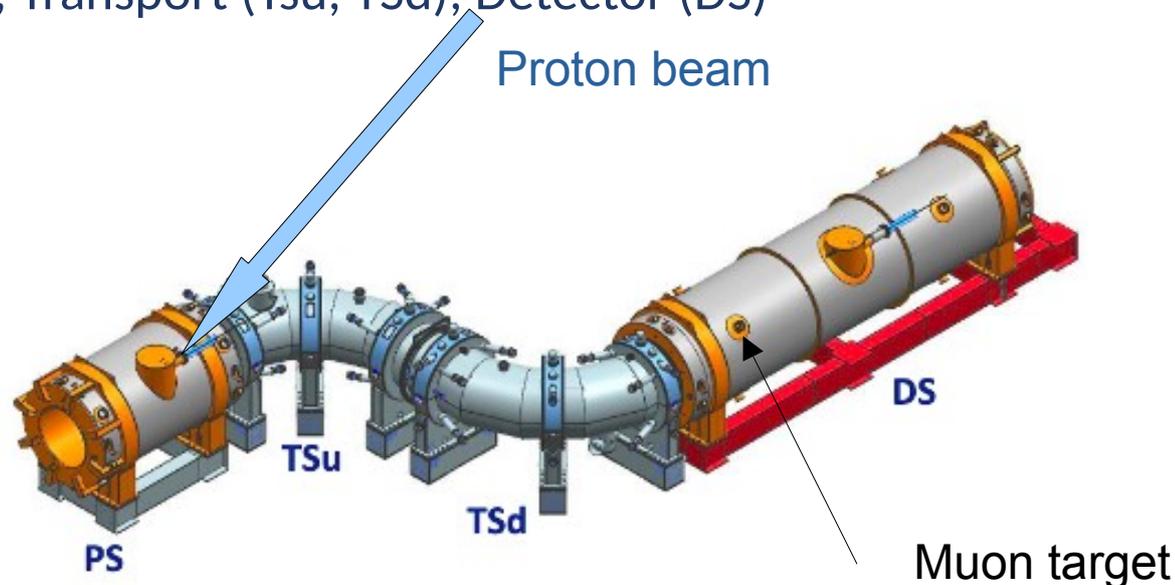


# Mu2e system highlights

3 Solenoids - Production (PS), Transport (Tsu, TSd), Detector (DS)

Proton beam

- PS has been transported from Tupelo (Texas) to Mu2e hall at FNAL (650 miles)
- TSu and TSd were moved from HAB to Mu2e hall (0.7 miles)
- DS to be completed ~Nov 24



PS in the Mu2e hall

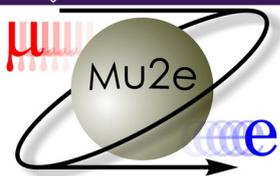


TSu (and TSd) transported to Mu2e hall



TSd in final position



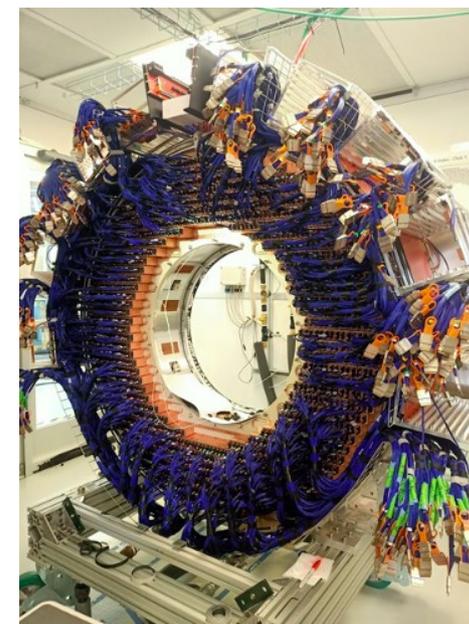


# Mu2e detector status

Calorimeter – cabled and awaiting move to Mu2e hall

Detectors being installed in Mu2e hall

- STM (=Stopping Target Monitor): first detector to be installed in Mu2e hall!
- Cosmic Ray Veto (CRV): completed June 23, installed Spring 24
- Calorimeter: fully cabled, laser system being calibrated, awaiting installation
- Tracker assembly ongoing (33 out of 36 planes constructed)

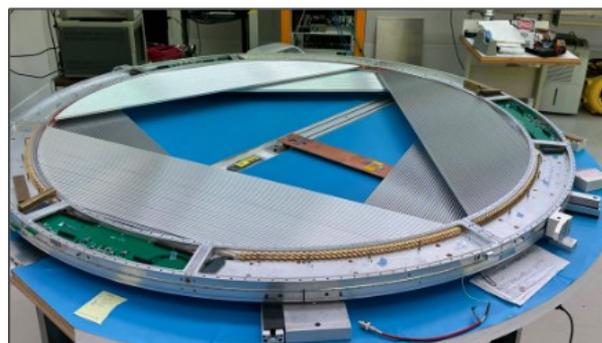


HV tests of tracker panels



## TRACKERS

Plane assembly – contains 6 panels



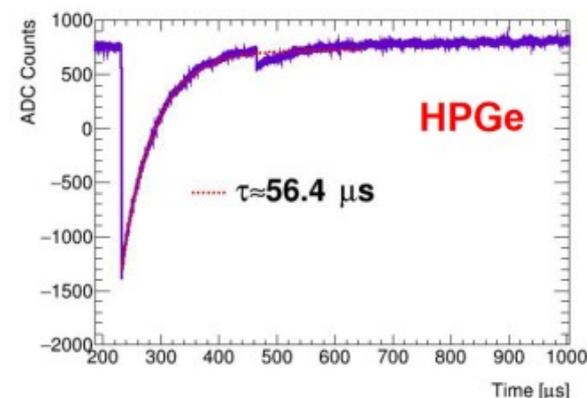
Long term leak tests of 25 full planes





# Liverpool contribution: STM

- Stopping Target Monitor (STM) provided by Liverpool
- STM determines the overall rate for normalisation ( $N_{\text{captures}}$ )
- Count characteristic  $\gamma$ - and X-rays
- UK leads the Stopping Target Monitor (STM) detector group
- Org chart roles in operations and commissioning of STM
- STM at Fermilab: ready for integration with other detectors and main DAQ
- UK leading role in DAQ integration for full experiment
  - Successful DAQ “dry run” completed early 2024





# Muon EDM experiment (PSI)

<https://www.psi.ch/en/ltp/muedm-experiment>

## • Liverpool involvement

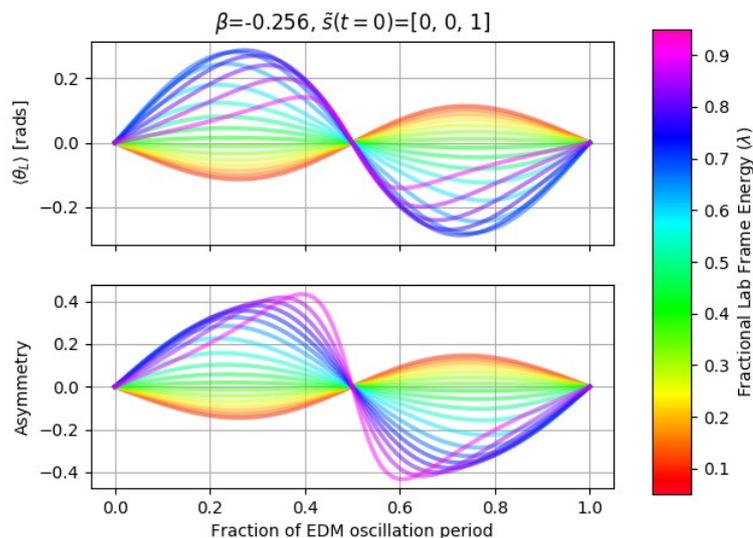
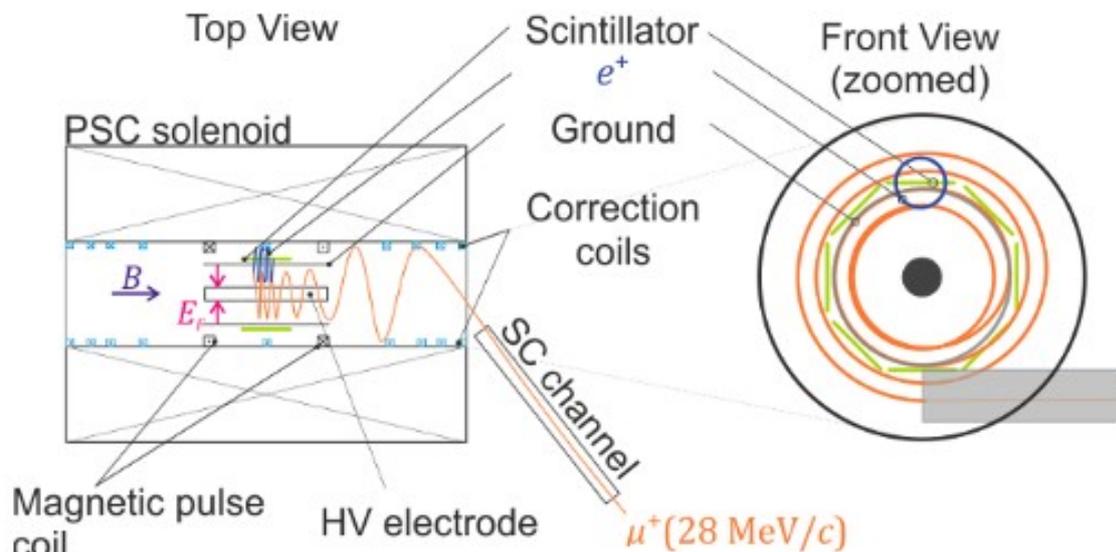
### Staff members:

Themis Bowcock

Joost Vossebeld

Joe Price (Simulation coordinator)

Dominka Vasilikova



- Store muons one at a time, and employ frozen spin technique
- Observe change in polarisation vector due to muon EDM by measuring positrons
- Liverpool team has been focusing on simulation and how to optimize the analysis for different starting conditions



# Final words

