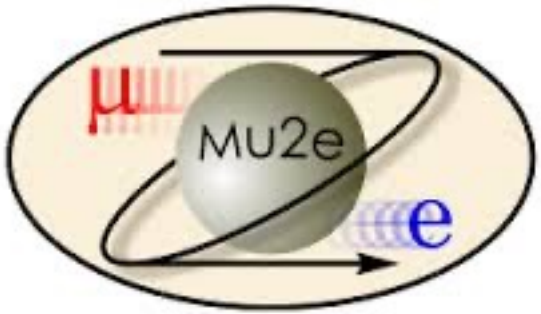
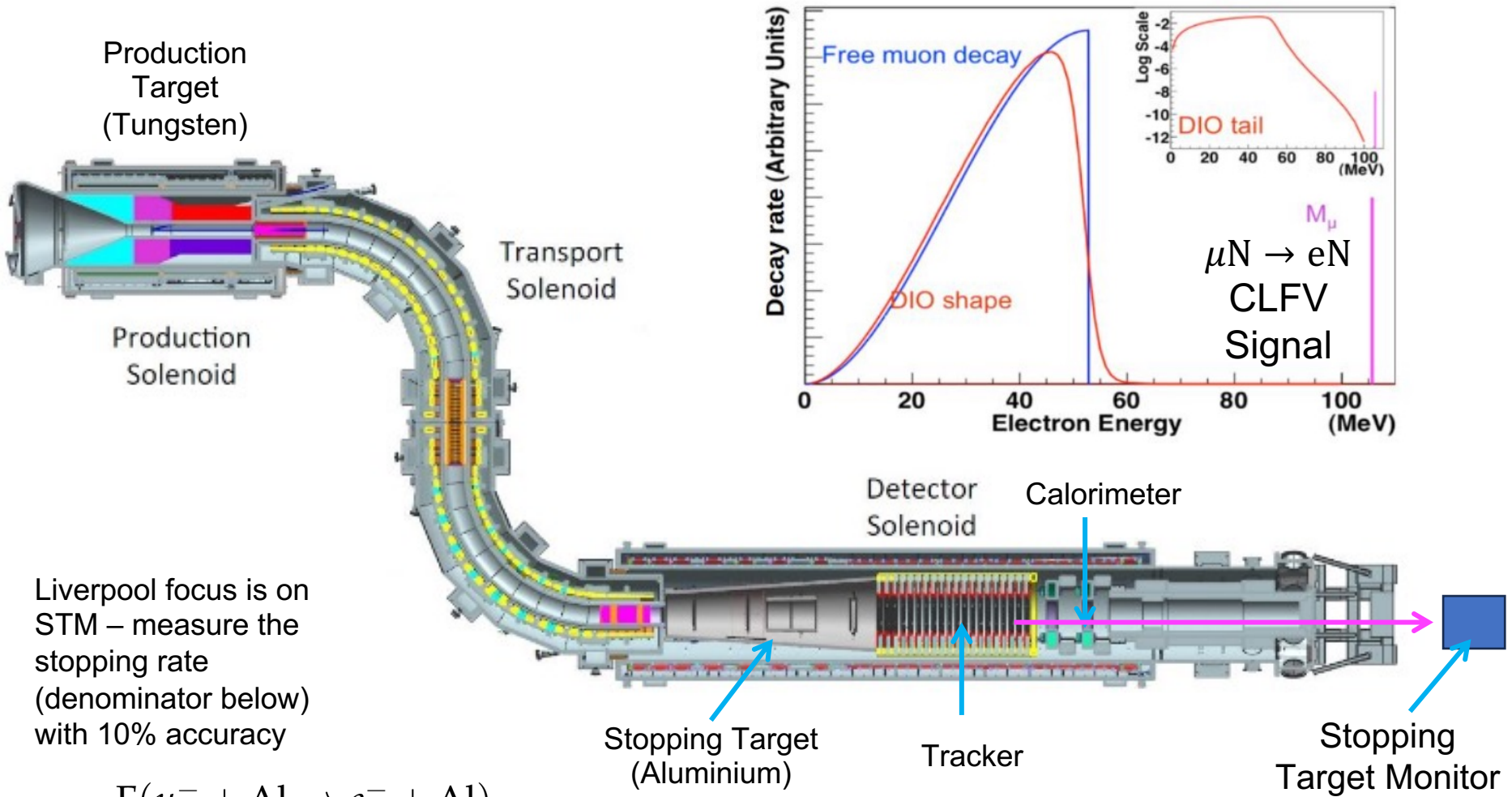


Mu2e + muon EDM measurements

Joe Price, Dominika Vasilkova (Mu2e slides)

Mu2e overview



Liverpool focus is on STM – measure the stopping rate (denominator below) with 10% accuracy

$$R_{\mu e} = \frac{\Gamma(\mu^- + \mathrm{Al} \rightarrow e^- + \mathrm{Al})}{\Gamma(\mu^- + \mathrm{Al} \rightarrow \nu_\mu + \mathrm{Mg})}$$

Mu2e: Solenoid Status

- **Production solenoid (PS)** and **transport solenoid (TS)** installed in Mu2e hall – leak checked.
- Currently undergoing quench protection and power supply testing, plan to cool down and power this summer.
- **Detector solenoid (DS)** still with manufacturer – undergoing cooling and leak tests after sealing.
- DS delivery expected in July 2026, then ~ 1 year to commission.

Mu2e: Sub-system Status

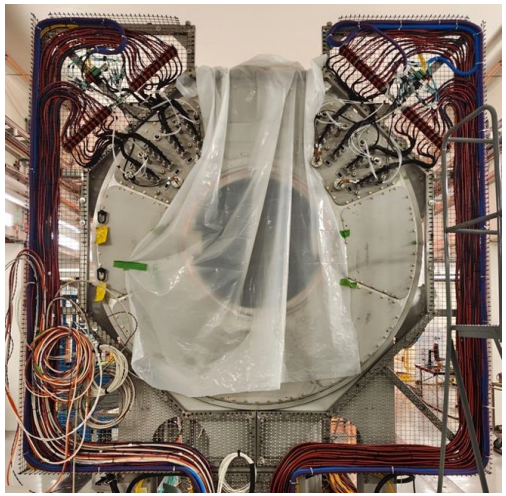
- **CRV, calo, tracker, STM are all in the hall in some capacity:**
- **CRV** has all modules complete and delivered to FNAL – 8 are installed in the hall for cosmics running.
  - Tests with cosmics show they are meeting the ~ 99.9% efficiency requirement.
  - Successful DAQ runs with STM, calo and tracker paired individually.

CRV modules in storage

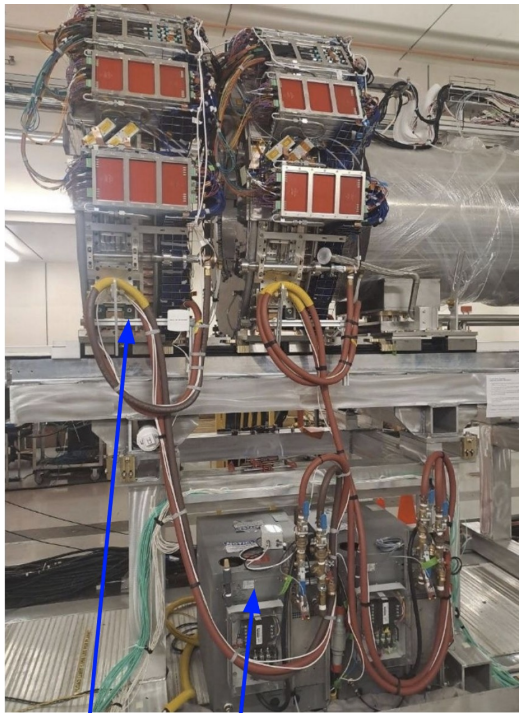
CRV installed above tracker and calorimeter

Mu2e: Sub-system Status

- **CRV, calo, tracker, STM are all in the hall in some capacity:**
- **Calorimeter i**nstalled in the mu2e hall last September, now fully cabled up and connected to chillers (lower box in photo).
  - Work ongoing to finish mapping readout + integrate with Mu2e's OTSDAQ
- Successfully running with cosmics to test general functionality as well as laser/source calibration systems.



Cabling for both sides is now complete.



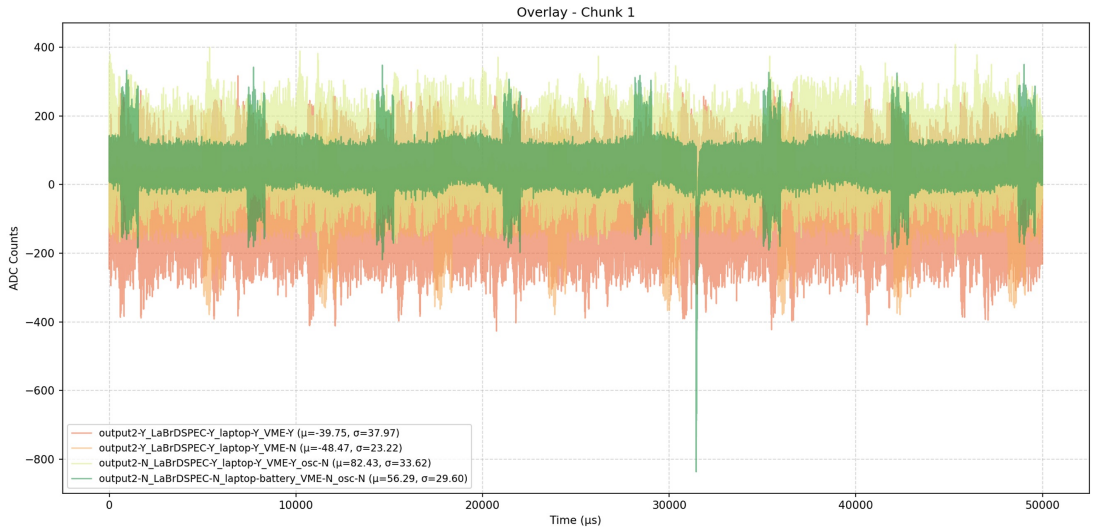
Calo side view showing chiller

Mu2e: Sub-system Status

- **CRV, calo, tracker, STM are all in the hall in some capacity:**
- **Tracker** has all stations connected to cooling and powered in the hall, 3 of them also have HV, so data ready.
- Currently undergoing gas flow and leak testing in the hall, alongside alignment studies and moving the stations to their ‘final’ kinematic mounts (rather than the current temporary ones).

Mu2e: Sub-system Status

- **CRV, calo, tracker, STM are all in the hall in some capacity:**
- **STM** set up in a ‘temporary’ position at the back of the hall (both HPGe and LaBr) one in lead shielding depending on requirements.
- Past month has focussed on understanding and reducing noise seen in HPGe, and integrating DAQ with OTSDAQ and other subsystems.



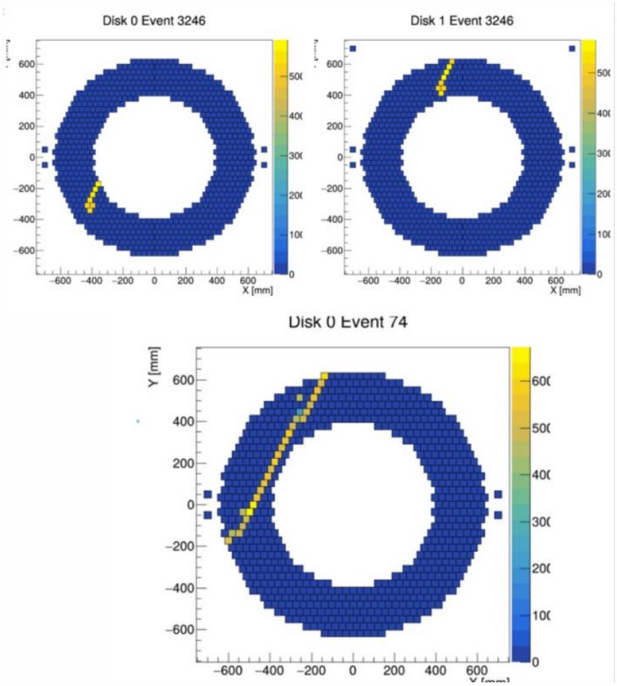
STM noise with different components removed.

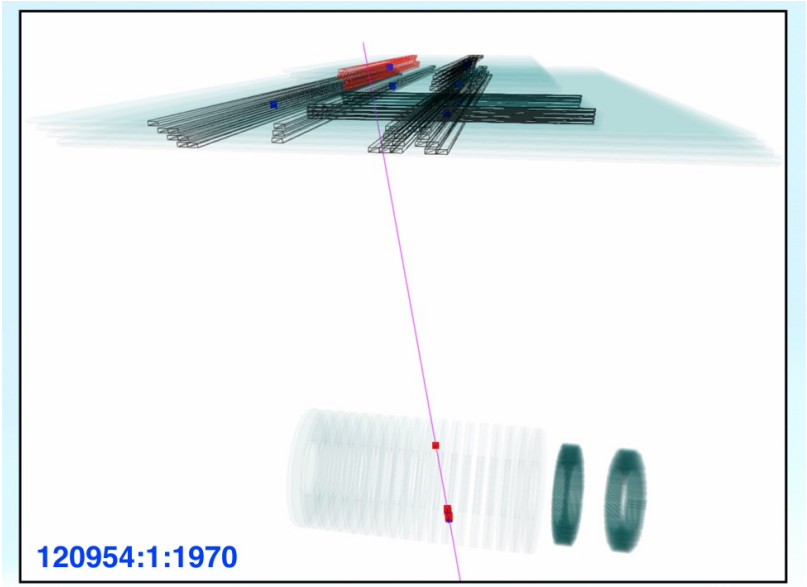
STM rack with HPGe in shielding.

Mu2e: Towards experimental operations

- Mu2e Project milestone of ‘key performance parameters’ (KPP) for CRV, tracker and calorimeter:
  - Each subsystem needs to be fully powered and able to measure cosmics.
  - All 3 subsystems close to achieving full KPP – successful paired runs of CRV + other systems:

Calo half disk KPP + coincidence plot for calo/CRV:





Event display and z-position coincidence plot with tracker/CRV

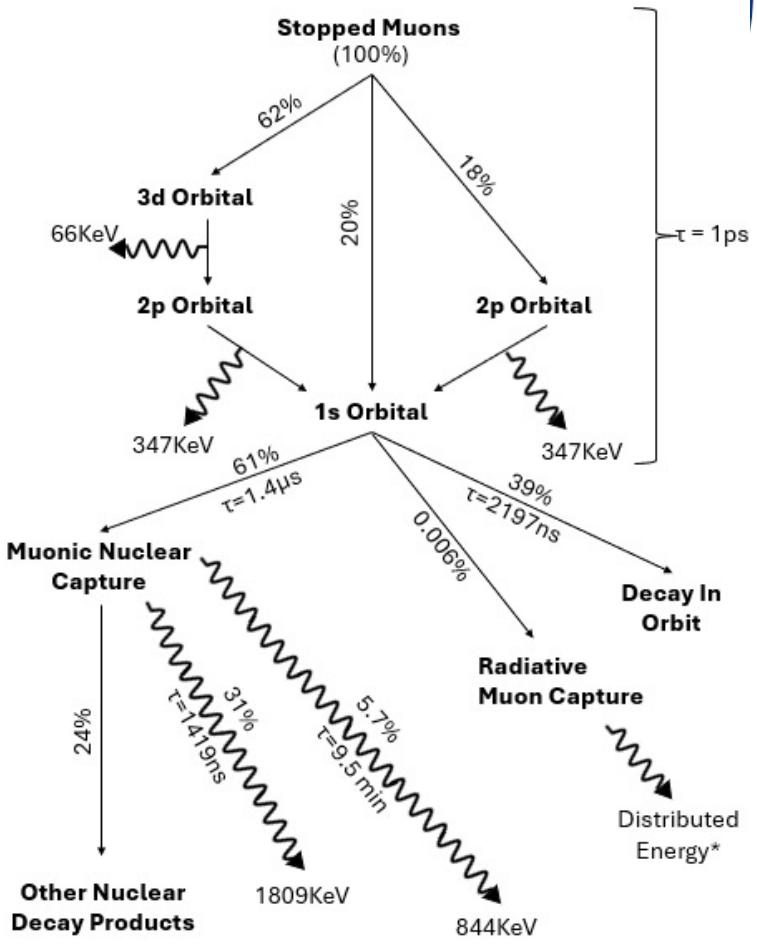
Mu2e: Towards experimental operations, shifters

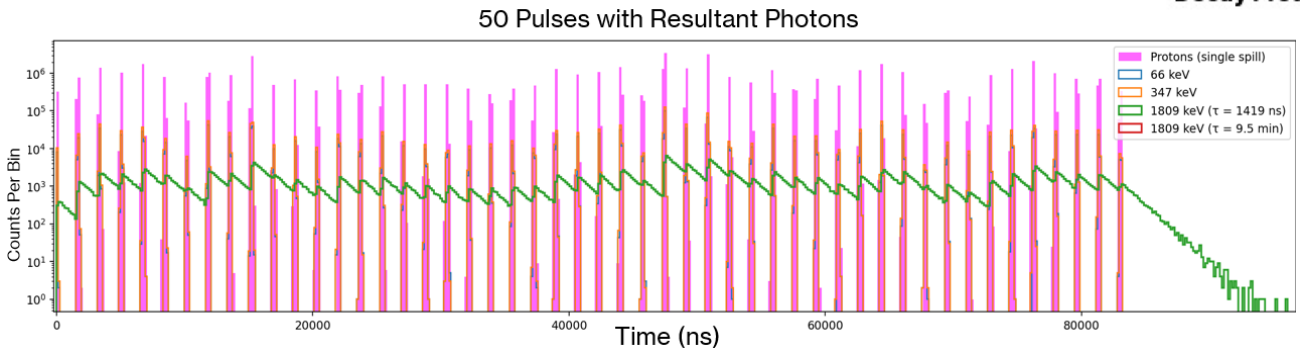
- **‘Cosmic ray run’ planned for later this year with all subsystems turned on.**
  - Requires all subsystems fully operational + continuous data taking
  - Planned ‘shifter runs’ every few weeks to test (and fix issues with) stability of subsystems and their DAQs + non-expert controls.

- **Shifter run 1 (29th/30th Apr): joint running with STM and CRV**
  - Complications from power outages and recovery from them.
  - Both subsystems able to run together for a short period of time.
  - Shifter controls and monitoring successful!
- **Shifter run 2 planned for 26th/27th May: STM + CRV + Calo**
  - UK group will be actively participating remotely as needed.

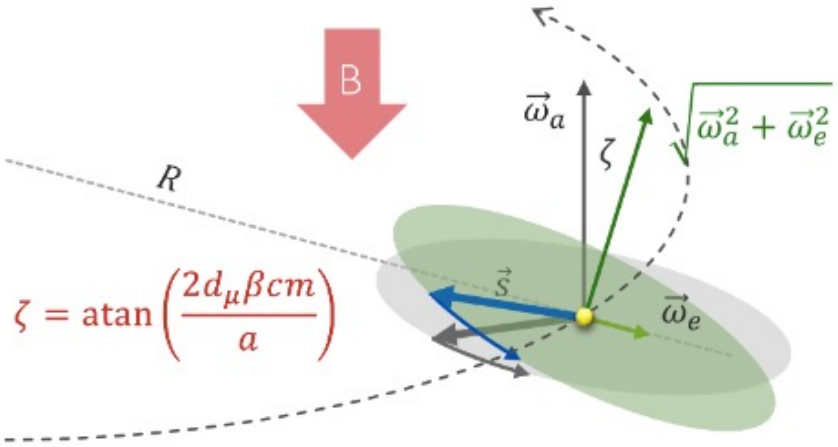
Mu2e status - summary

- **Detector Solenoid** sets schedule for data taking before PIP-II shutdown in early 2028
- With installation in ~2 months need 1 year to fully install and energise DS magnet
- Allows for ~6 months of running in late 2027
- All magnets fully powered, subsystems in with partial CRV (just the top), no DS shielding
- Aiming to improve on SINDRUM II's limit by a factor of ~ 30.
- Contingency plans in place, all involve STM

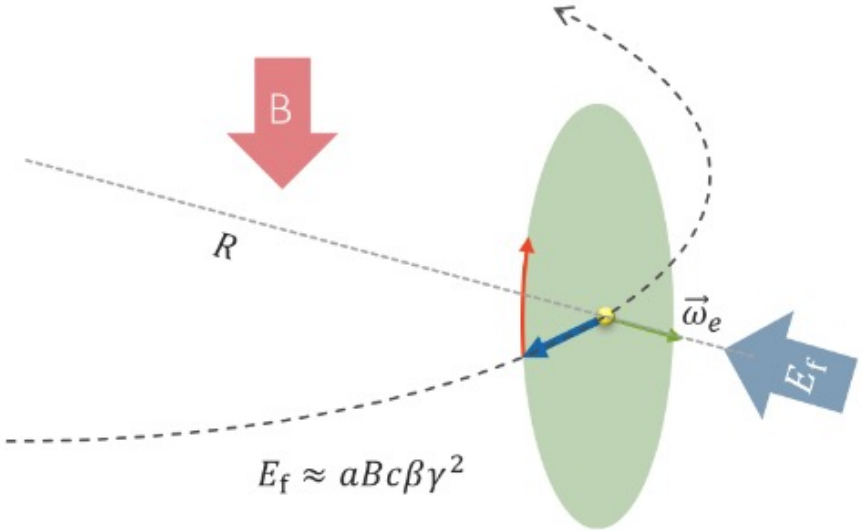




EDM measurements - visual



- Without frozen spin condition an EDM tilts the precession plane
- This is **Fermilab-style** EDM search



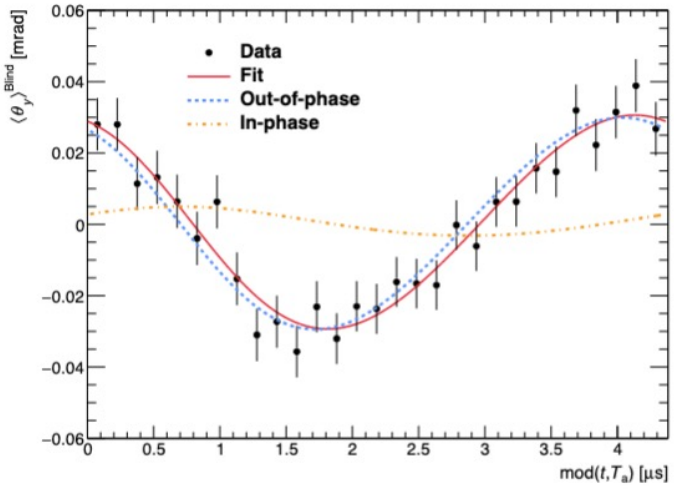
- With frozen spin condition an EDM is the only cause of the precession
- This is **PSI-style** EDM search
- **Advantage of frozen spin:** Every positron is useful!

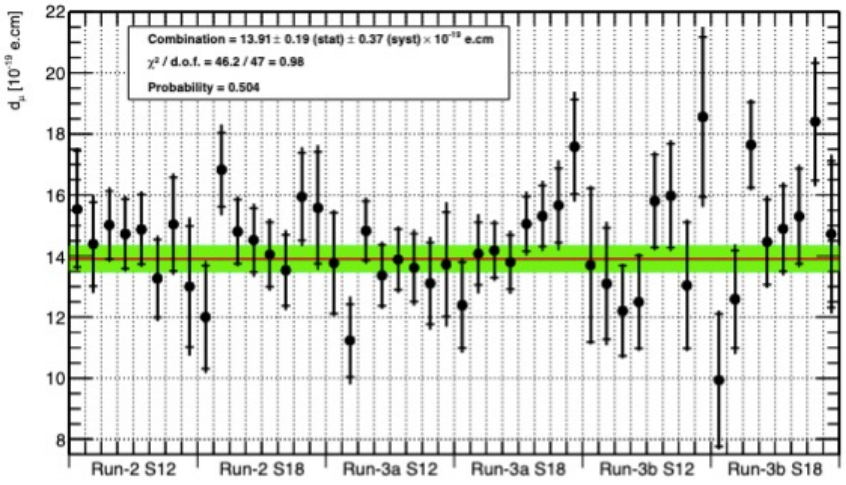
Fermilab: muon EDM measurement

- Blinded analysis using vertical angle of tracks in run 2+3, in final stage of review

$$\langle\theta_y\rangle(t) = \frac{A_{g-2}\cos(\omega_a t + \phi_a) + A_{EDM}\sin(\omega_a t + \phi_a)}{[1 + A_N\cos(\omega_a t + \phi_a^p)][1 + A_{CBO}\cos(\omega_{CBO} t + \phi_{CBO}^p)]} + C$$

- Fit each tracker separately in different momentum bins, for different beam conditions. 48 measurements in total

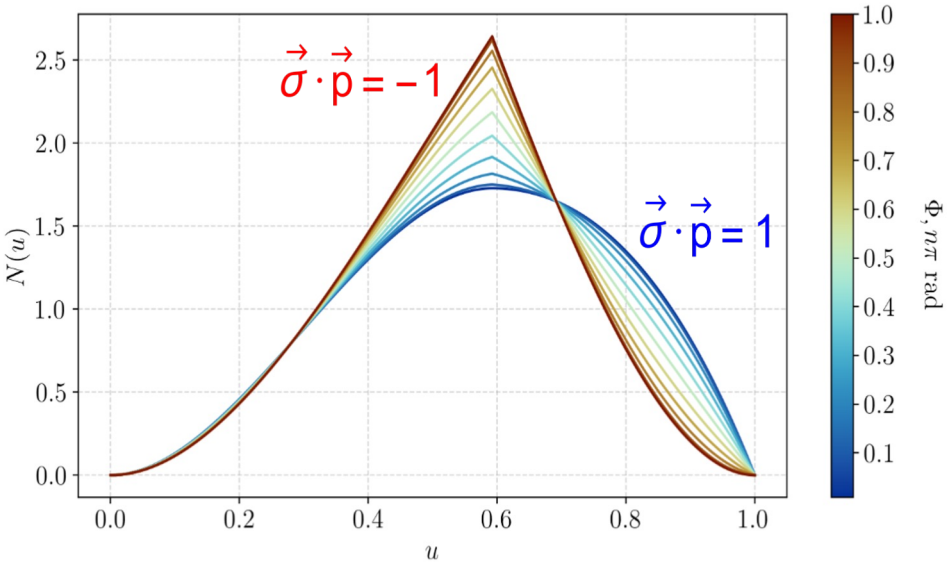


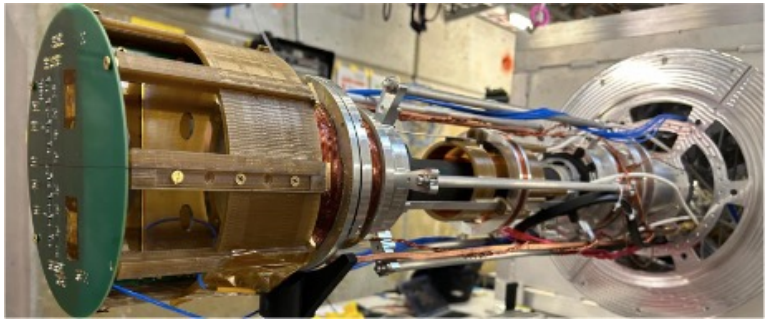


- In absence of a signal will be world's most precise muon EDM measurement
- Syst limited, full dataset (4 × stats) analysis requires extra sim campaign
- Current limit from BNL $|d_\mu| < 1.8\times10^{-19}$e.cm @ 95% C.L.

MuEDM @ PSI

- Next generation of muon EDM measurements requires frozen spin method





- Spin can be frozen aligned, and anti aligned – changes momentum dependence
- Liverpool- simulation for positron momentum and longitudinal angle weighting, maximising sensitivity
- Phase I: $d_\mu < 3\times10^{-21}$e.cm
- Phase II: $d_\mu < 6\times10^{-23}$e.cm

- Undergraduate student summer internship @PSI to measure magnetic field
- Turn this into 4th year project
- Demonstration of frozen spin this year!