

SESSION 1 • 13:00 – 14:00

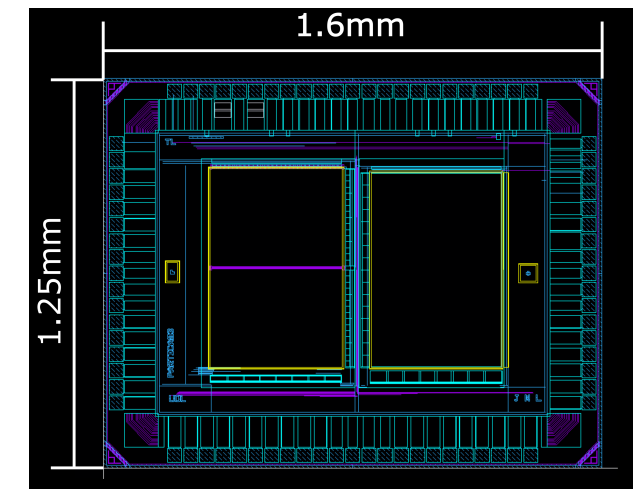
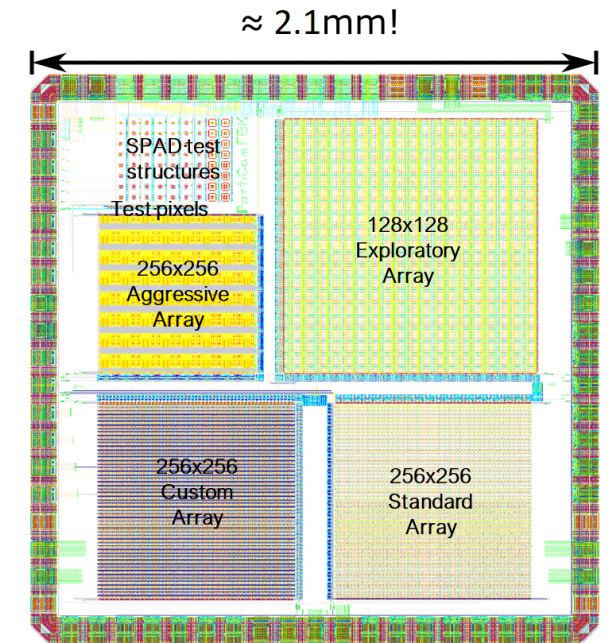
PDRA contributions

Who you are and what you work on

2

minutes each

- Generic R&D project together with Fondazione Bruno Kessler (FBK)
- The aim is to make monolithic pixel sensors with the smallest possible pitch
- Abandon analogue information for full binary (hit/no hit)
- First prototype ($2\text{ }\mu\text{m}$ to $6.5\text{ }\mu\text{m}$ pitch) not so good for particles but currently exploring application as laser sensor with the atom interferometry group
- Submitted new prototype ($3.25\text{ }\mu\text{m}$ and $6.5\text{ }\mu\text{m}$ pitch) in a 22 nm (!) process end of September
- Also still involved in the HV-CMOS/RadPix/LHCb activities



Triangulations and friezes

This is a demonstration of the connections between triangulated polygons, paths in the Farey graph, Conway–Coxeter friezes, and cluster variables. For the background information on this, see [our research](#) and references therein.

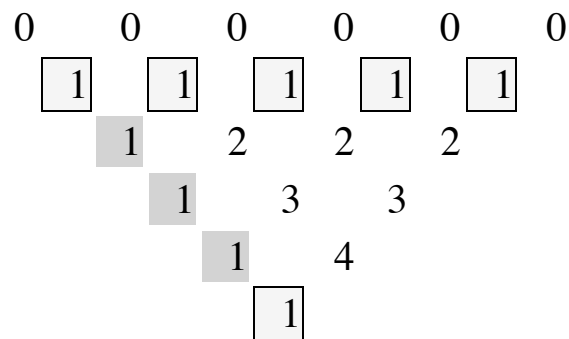
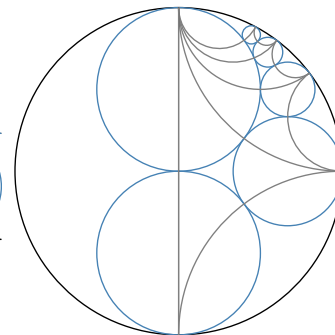
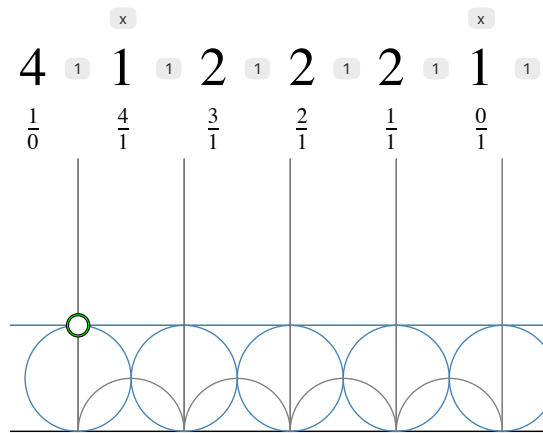
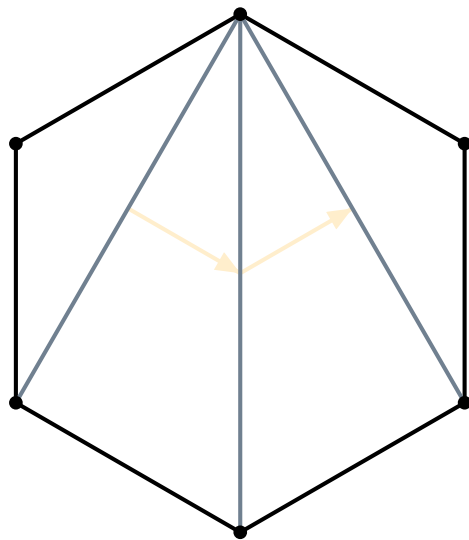
The picture shows a polygon dissected into triangles, i.e. a triangulation. There are two ways to modify the triangulation: the first is by left-clicking on a diagonal to flip it; the second is using the itinerary.

The itinerary of the corresponding path in the Farey graph, i.e. the counts of the triangles at each vertex, is shown to the right of the picture. Click on a **1** button to insert a 1 into the itinerary, which corresponds to attaching a triangle to a side of the triangulation, or click on a **x** button to remove a 1 from the itinerary, which corresponds to removing an external triangle from the triangulation. One possible choice of the vertices of the path in the Farey graph is shown below the corresponding itinerary entries.

That path in the Farey graph together with the edges in its interior is shown as the sequence of hyperbolic lines in the upper half-plane model of the hyperbolic plane. Superimposed are the corresponding Ford circles. When the path has even length, the circles' radii can be alternately multiplied by a positive factor preserving their tangencies; move the slider to see this. If the slider has a thin green ring, double-click it to do a multifold.

There is a tame integer frieze corresponding to the triangulation. The fundamental domain of that frieze under the action of its glide reflection symmetry is shown. Every entry in the frieze corresponds to a pair of vertices in the triangulation, hover or tap to highlight the corresponding diagonal. The entries corresponding to the diagonals in the triangulation (all equal to 1) have shaded background; these entries also correspond to the initial cluster variables, see below. The quiddity of the frieze (i.e. the row right below the row of 1s) is equal to the itinerary of the triangulation.

Every pair of vertices in the triangulated n -gon also corresponds to a cluster variable in the cluster algebra of type A_{n-3} . The triangulation defines a particular choice of initial cluster variables. All cluster variables are shown in the bottom part of the page. The corresponding quiver is shown with faint orange arrows. Again, the corresponding diagonal in the picture is highlighted upon hover or tap, and the list of the initial cluster variables x_i is additionally given for convenience. The entries of the frieze are obtained by evaluating the corresponding cluster variables at $x_i = 1$, so the entire frieze can be restored from these values only.



$$\begin{array}{c}
 x_1, x_2, x_3 \\
 x_1 \quad \frac{1+x_2}{x_1} \quad \frac{x_3+x_1}{x_2} \quad \frac{1+x_2}{x_3} \\
 x_2 \quad \frac{x_1+x_3+x_2x_3}{x_1x_2} \quad \frac{x_3+x_1+x_1x_2}{x_2x_3} \\
 x_3 \quad \frac{x_1x_2+x_1+x_3+x_2x_3}{x_1x_2x_3}
 \end{array}$$

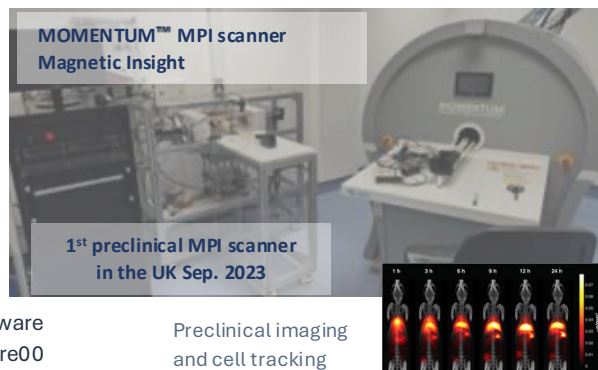
Magnetic Particle Imaging (MPI)

MPI technology, tracer development and standardisation

What is MPI?

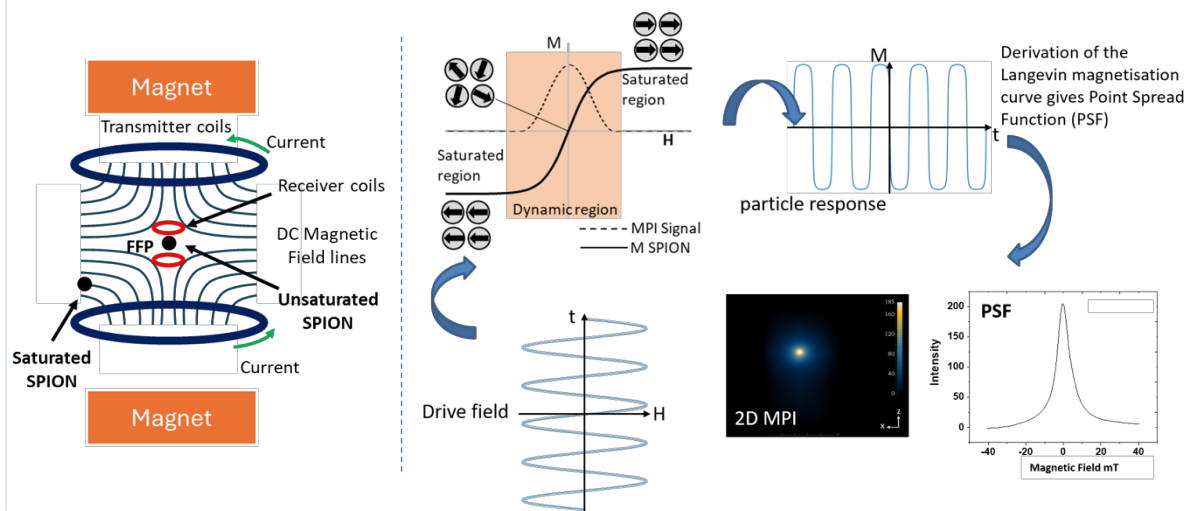
A non-invasive imaging technique that detects the magnetic response of superparamagnetic iron oxide nanoparticles (SPIONs).

- MOMENTUM MPI scanner
- HYPER - Focused Magnetic Fluid Hyperthermia
- RELAX - Tracer Optimization & Relaxometry software
- MOMENTUM SDK - Image reconstruction software00



How is the MPI signal generated?

Bauer et al., J. Phys. Chem. Lett., 6, 2509–2517 (2015)
 Gleich & Weizenecker, Nature, 435, 1214–1217 (2005)

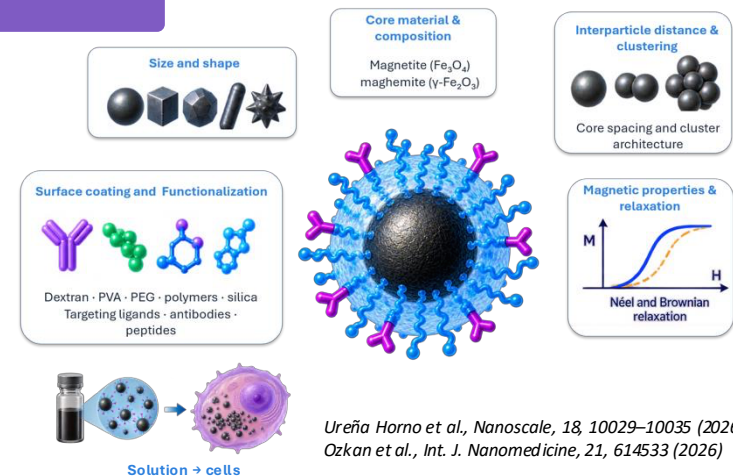


Magnetic fields → tracer response → signal detection → image reconstruction

Designing MPI tracers

Key design parameters

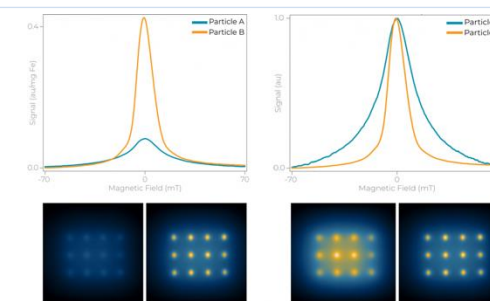
- Core composition
- Size and shape
- Interparticle distance / clustering
- Surface chemistry and coating
- Functionalisation
- Magnetic properties and relaxation



Ureña Horno et al., Nanoscale, 18, 10029–10035 (2026)
 Ozkan et al., Int. J. Nanomedicine, 21, 614533 (2026)

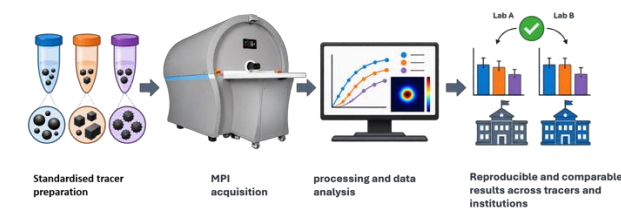
Why do tracers matter?

- They determine the signal intensity and spatial resolution
- Their magnetic properties control how they respond to the MPI drive field
- They need to be stable, biocompatible and effective in biological environment (e.g. inside cells)



Towards MPI standardisation

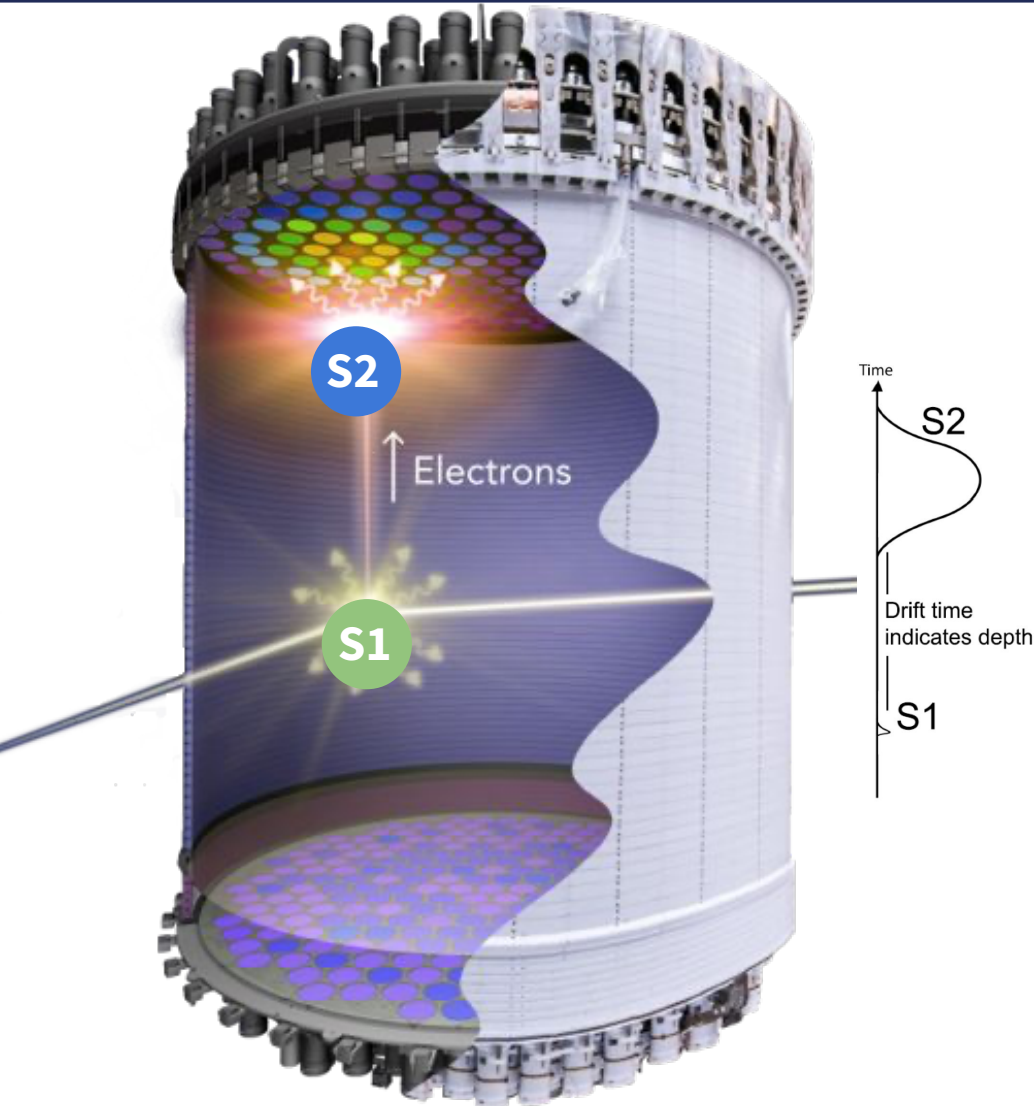
- Developing reproducible protocols for sample preparation, image acquisition, data collection, processing and calibration.
- The goal: to enable reliable comparisons across tracers, biological settings and institutions.



Ureña Horno et al., Nanoscale, 17, 24060–24071 (2025)

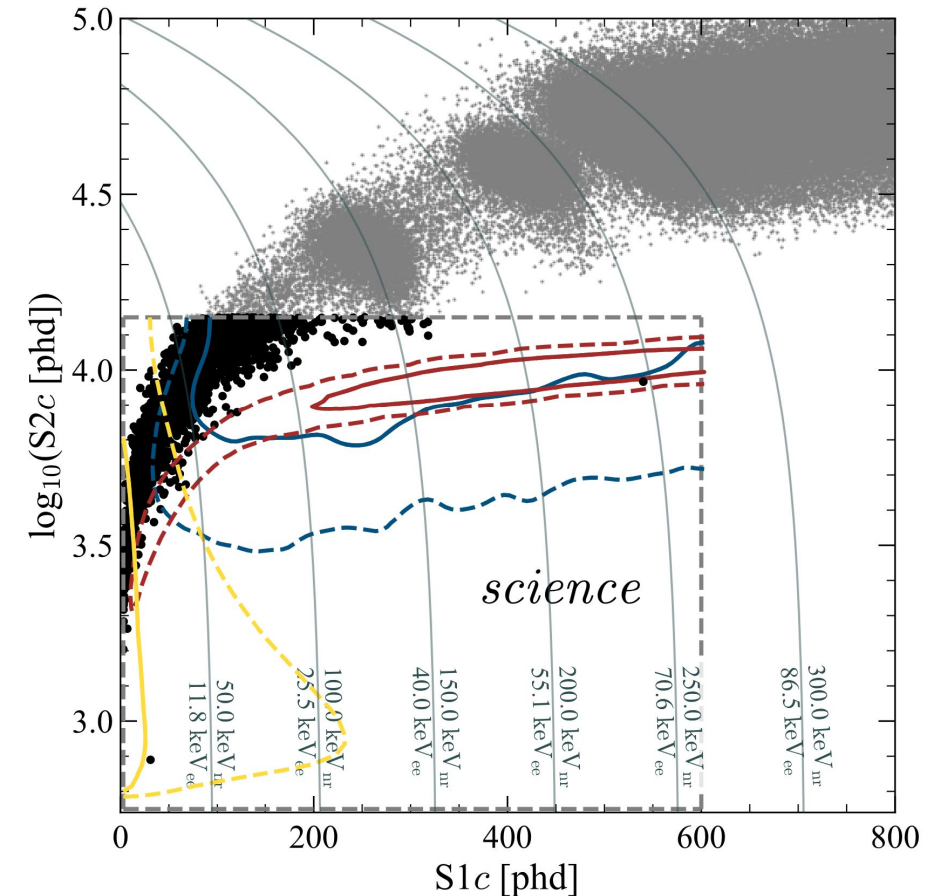
LUX-ZEPLIN: WIMP Search via Direct Detection

High Energy Nuclear Recoil Search 2024



LZ Cartoon

Currently, Data Quality Coordinator
Previously, Vetoes Coordinator



Event of interest Occurred on **16 June 2023 (LZ230616)**

□ $248 \pm 23_{\text{stat}} \pm 23_{\text{sys}}$ keV compatible with nuclear recoil

Background Model: 0.0106 ± 0.0008 (sys) counts

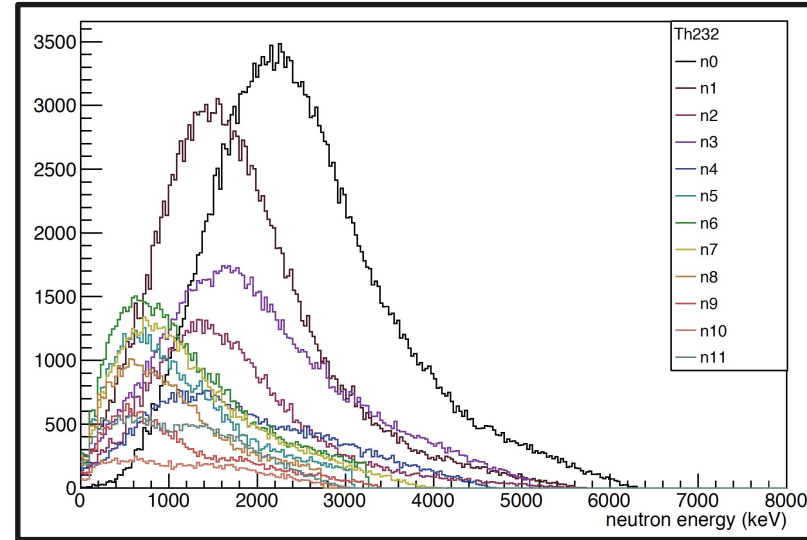
□ Global significance 2.6σ

LUX-ZEPLIN: Background Modelling



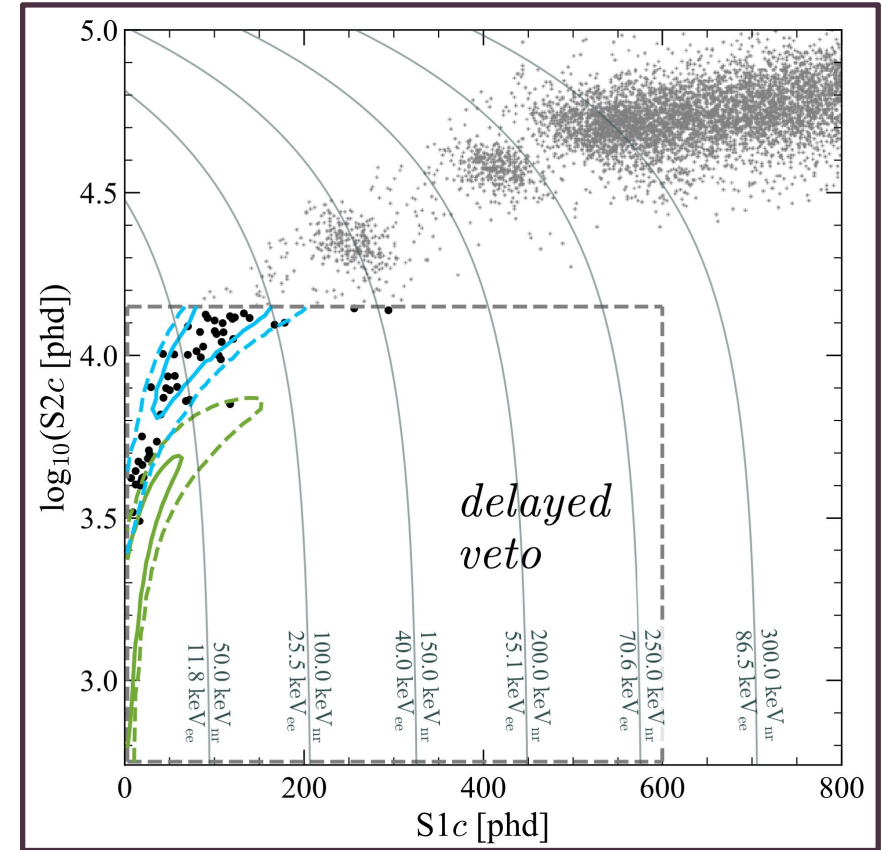
Figure 3: (l-r) Lumpsey, Chaloner, and Lunehead, the three detectors of BUGS. The small pre-screening detector (Wilton) can be seen to the right of Lunehead in a taller, cylindrical shield.

HPGe detectors at Boulby
Underground Laboratory
[Astro. Phys. V. 97 2018 P. 160-173](#)



Neutron spectra for daughter
excited states
 $\alpha + {}^{19}\text{F} \rightarrow {}^{22}\text{Na} + n$

[Nuclear Data Sheets, ISSN: 0090-3752, Vol: 112, Issue: 12, Page: 2887-2996](#)



HENR2024 Delayed-Veto tagged events
<https://arxiv.org/abs/2609.02823>

**Radioassay &
Radio-Cleanliness**



**Background Model
& Predictions**



Sideband Analysis

Ex-situ activity measurements

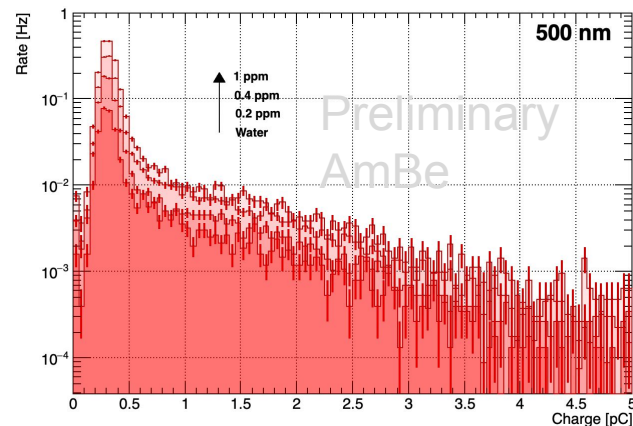
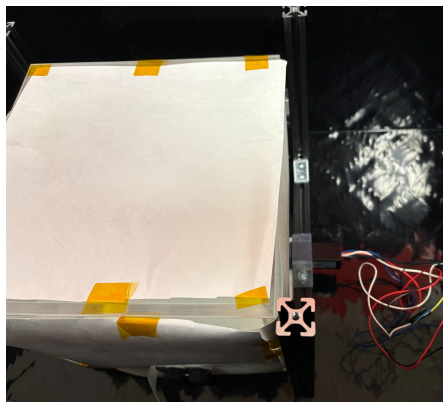
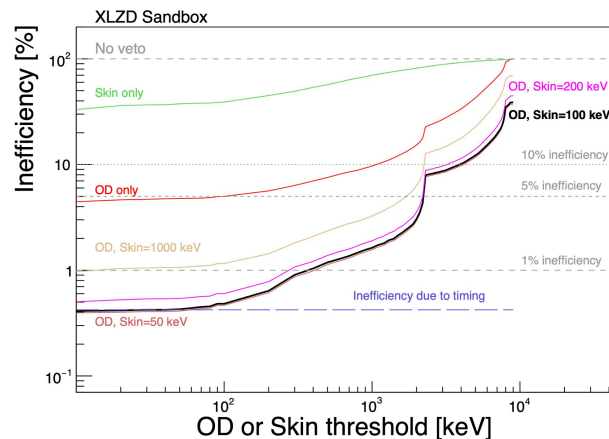
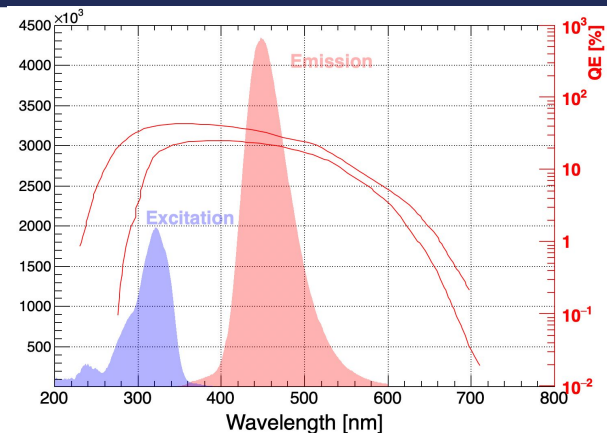
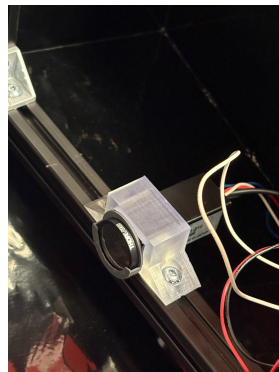
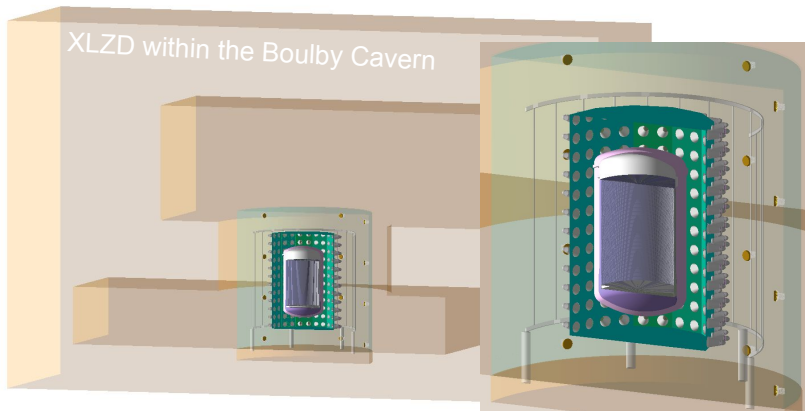
In-situ activity measurements

XLZD (XENONnT, LUX-ZEPLIN, DARWIN)

The next generation Liquid Xenon Observatory
for Dark Matter & neutrino Physics



XLZD (XENONnT, LUX-ZEPLIN, DARWIN)



Cosmological correlators

Kajal Singh

Why do we care? [Maldacena, 2003]

Primordial fluctuations leave observable patterns in the **CMB and large-scale structure**.

We describe their statistics through equal-time correlation functions:

$$\left\langle \zeta_{\mathbf{k}_1}(\eta) \cdots \zeta_{\mathbf{k}_n}(\eta) \right\rangle.$$

Two-point function: the amplitude and scale dependence of fluctuations.

Higher-point functions: non-Gaussianity and primordial interactions.

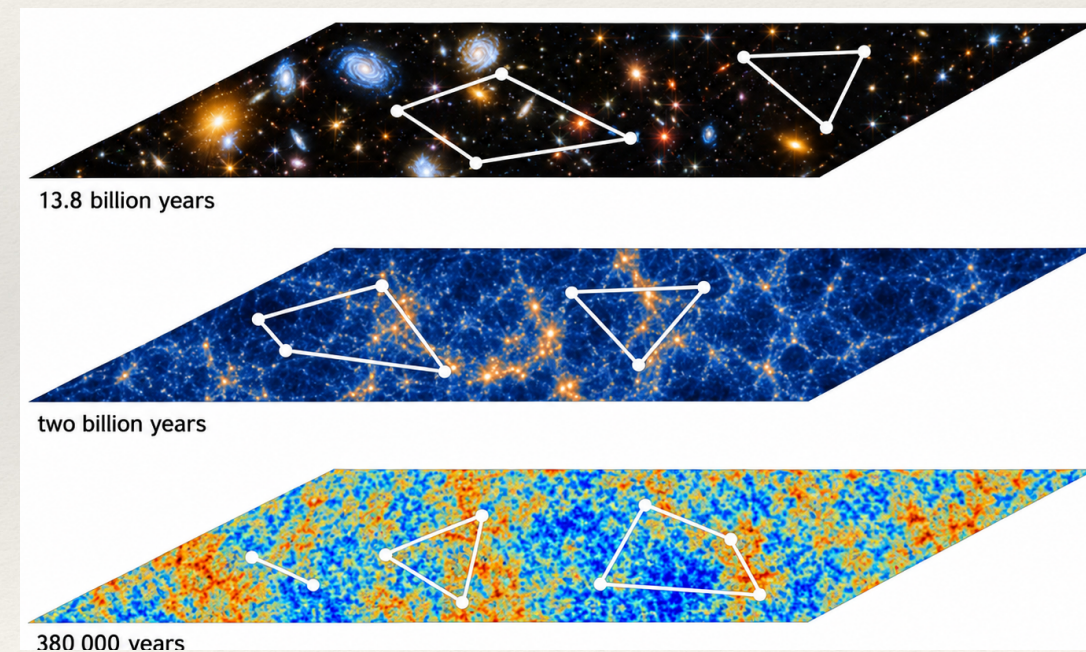


Image: [Baumann, 2021]

How do we compute?

The **in-in formalism**: evolve an initial state forward to the observation time, insert the operator, and evolve back.

[Weinberg, 2005]

$$\langle O(\eta) \rangle = \left\langle \bar{T} \exp \left(i \int_{\eta_0}^{\eta} d\eta' H_I(\eta') \right) O_I(\eta) T \exp \left(-i \int_{\eta_0}^{\eta} d\eta' H_I(\eta') \right) \right\rangle_0$$

Choose an initial state, usually **Bunch–Davies**, with the appropriate $i\epsilon$ prescription.

Expand perturbatively. At first order:

$$\langle O(\eta) \rangle = \langle O_I(\eta) \rangle_0 + i \int_{\eta_0}^{\eta} d\eta' \langle [H_I(\eta'), O_I(\eta)] \rangle_0 + \dots$$

The difficulty: higher orders introduce many diagrams and nested time integrals.

Hidden simplicity: can we bootstrap the answer?

Complicated intermediate expressions can combine into a much simpler answer. [Arkani-Hamed et al., 2020]

Scattering amplitudes show how symmetry, locality and unitarity constrain physical quantities.

Cosmological correlators also have a constrained singularity structure.

Total-energy singularity encodes the corresponding flat-space scattering amplitude:

$$\psi_n \underset{E_T \rightarrow 0}{\sim} \frac{\mathcal{A}_n}{E_T}, \quad E_T = \sum_i |\mathbf{k}_i|,$$

Partial-energy singularities constrain how exchange contributions factorise into simpler building blocks.

Current and future directions: develop recursion relations for cosmological correlators and extend bootstrap methods to spinning fields and loop corrections.



Muon g-2 at Fermilab

Most of my career has been spent on the **Muon g-2 experiment at Fermilab**.



Long Term Gain correction

Developed it, based on a state-of-the-art laser system.



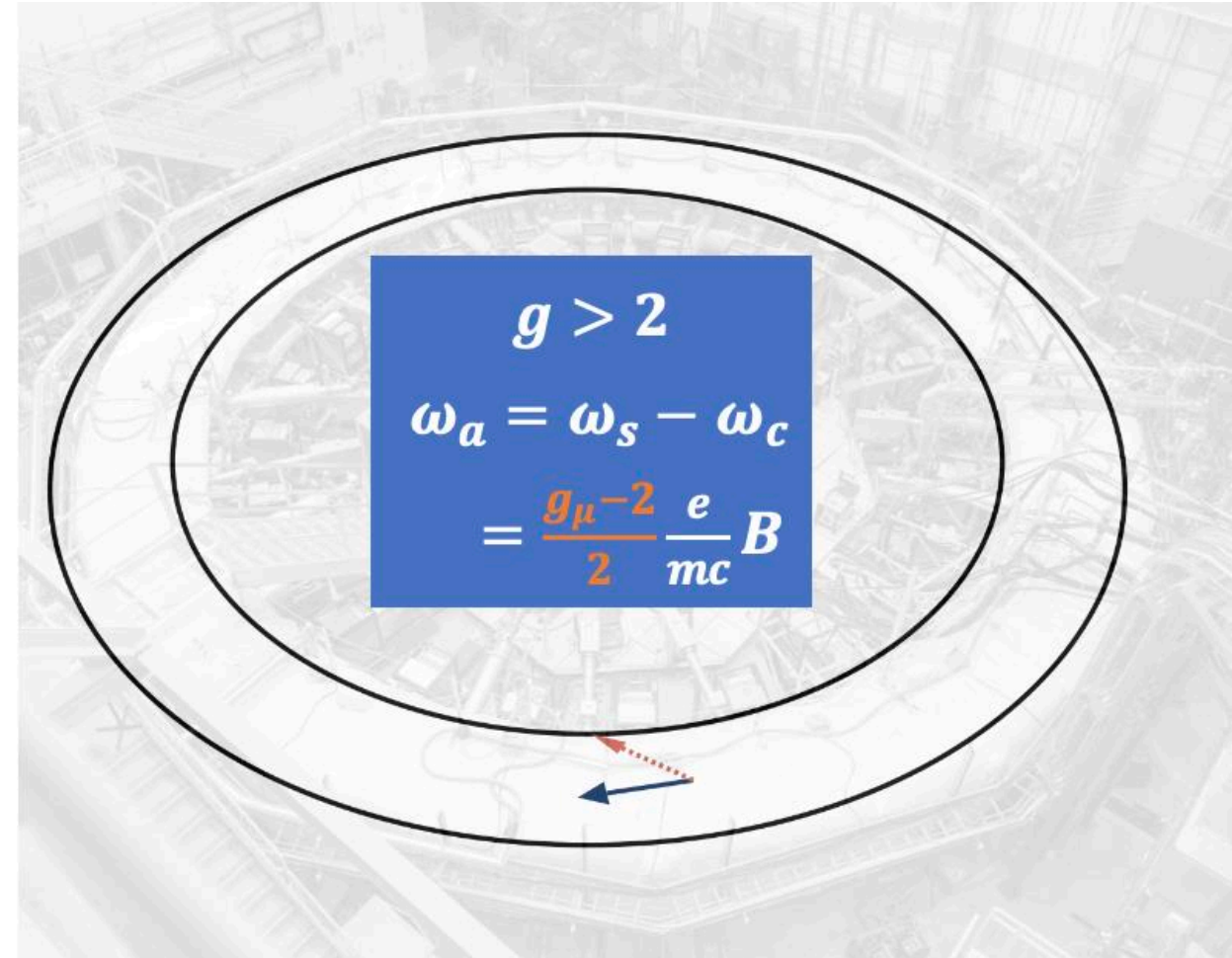
A new systematic effect

Investigated an effect that heavily impacted the Run-1 results.



In the past 3 years

Data–simulation agreement · led the analysis of 2 beam-dynamics corrections · **analysis coordinator** of the beam-dynamics analysis.



An open puzzle: why MUonE and J-PARC

The current situation is **very confusing!**

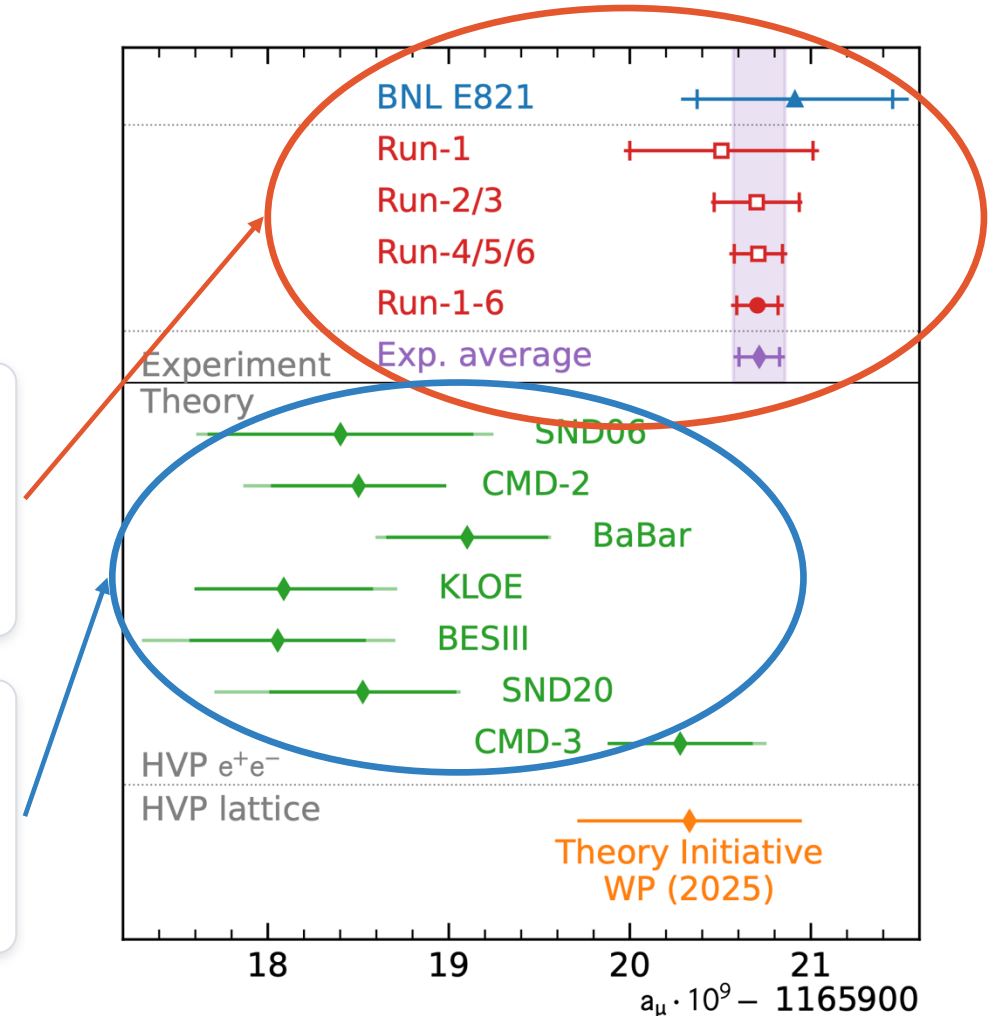
That's why, during the last year, I focused on two other experiments:

J-PARC

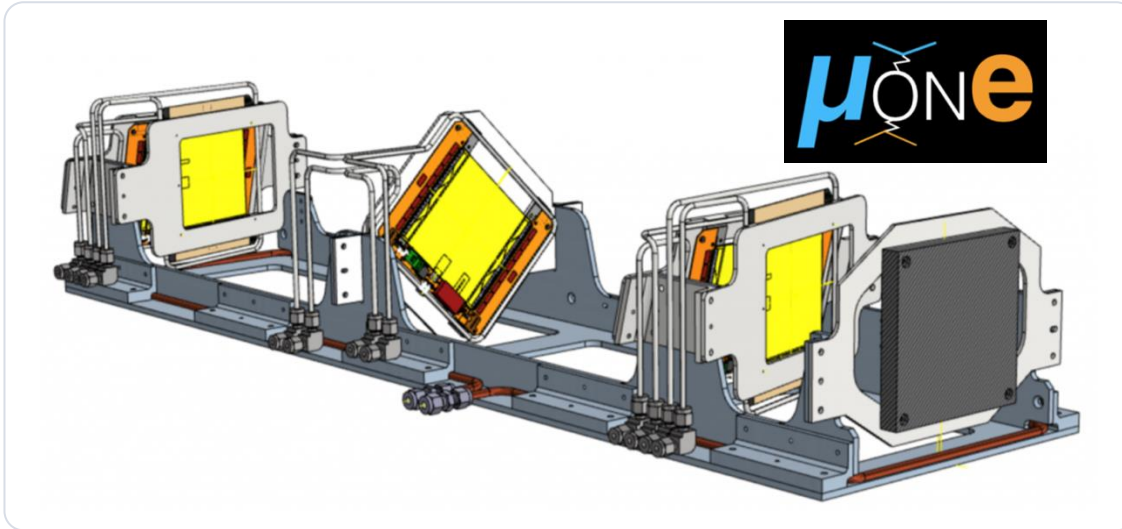
An **independent measurement of a_μ** to compare with the Fermilab result.

MUonE

A measurement of the **hadronic contribution to a_μ** .



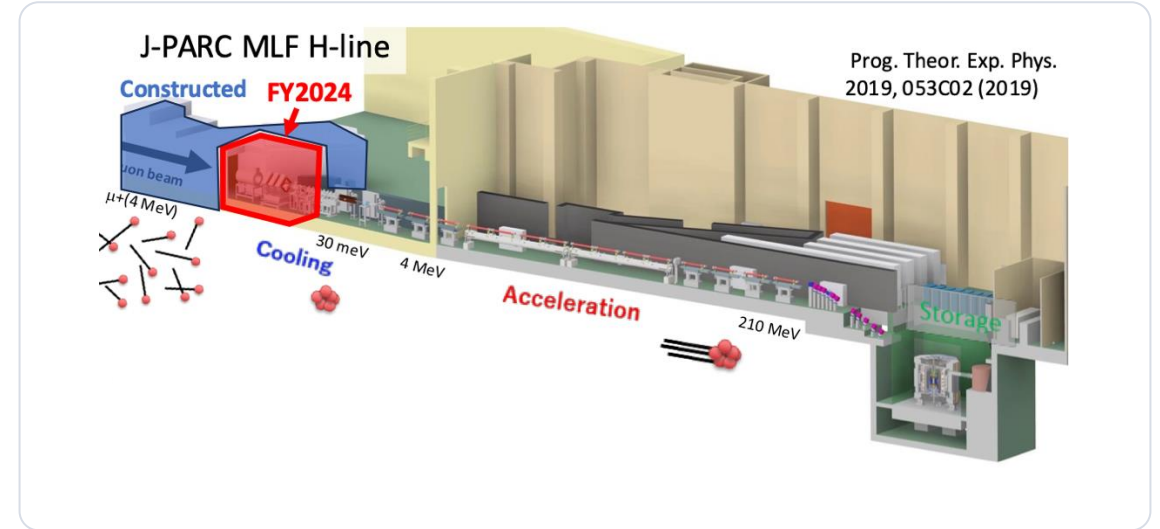
In the last year: MUonE and J-PARC



MUonE

Goal: Measure a_{μ}^{HLO} (hadronic LO contribution) with **0.3 % statistical precision**.

My role: Helped develop the **tracker detector simulation** and coordinate the **analysis of the Liverpool group**.



Muon g-2/EDM at J-PARC

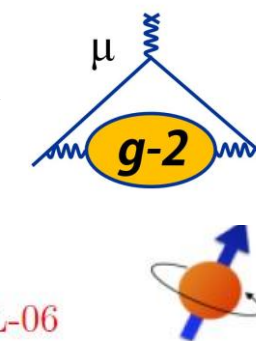
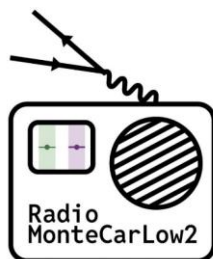
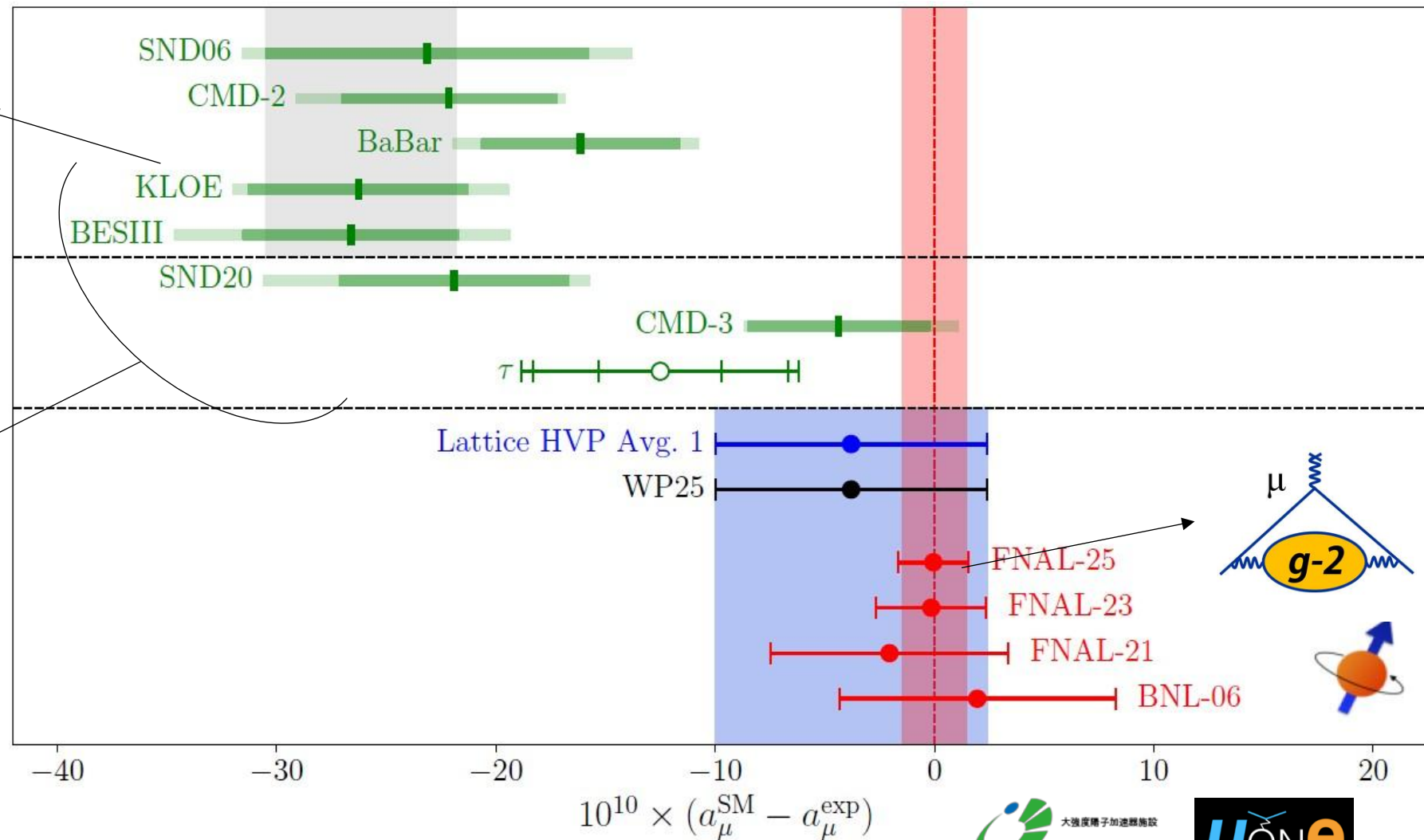
Goal: Measure g-2 with a **precision similar to the Fermilab** experiment.

My role: New design of the **acceleration cavities**, to reach the higher final momentum needed for the statistical goal.



PDRA @ Liverpool since 2024

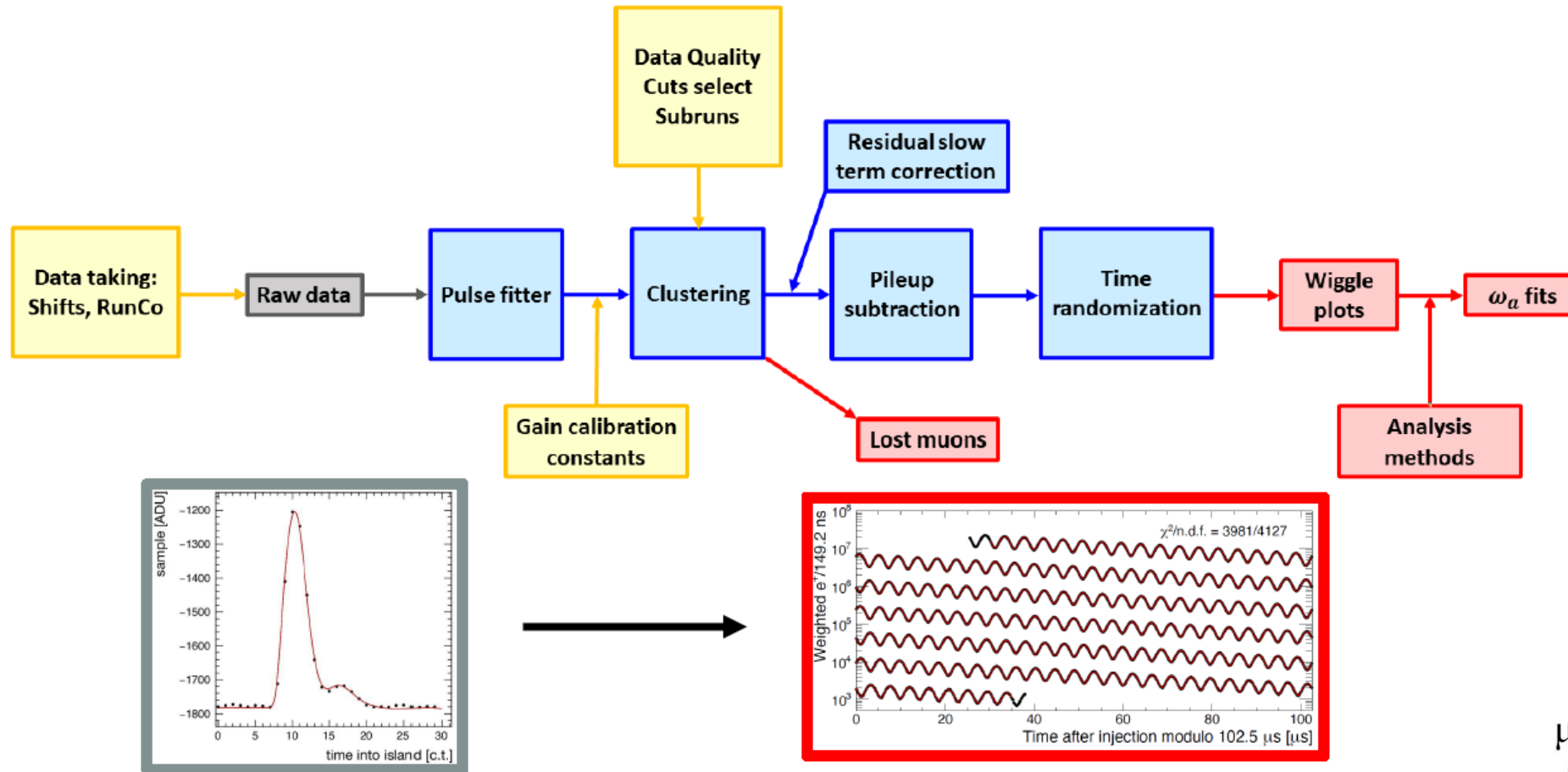
Muon Physics group under Graziano Venanzoni's Leverhulme Grant



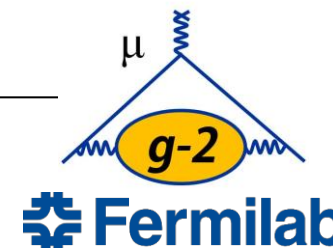
Fermilab

Contribution to Muon g-2 @Fermilab

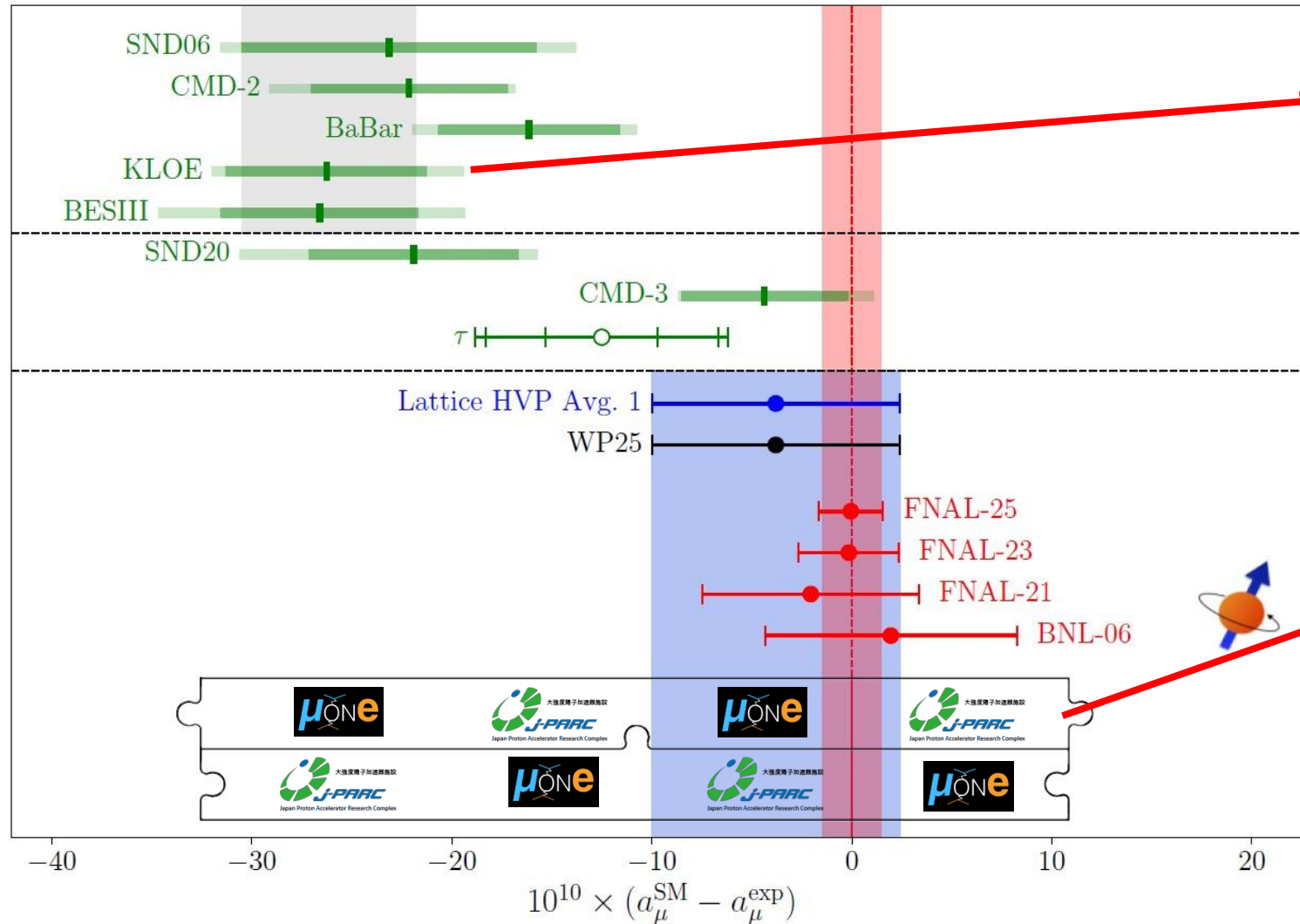
ω_a analysis flowchart



Led the Liverpool contributions to the ω_a analysis for the final 2025 result, with Cedric



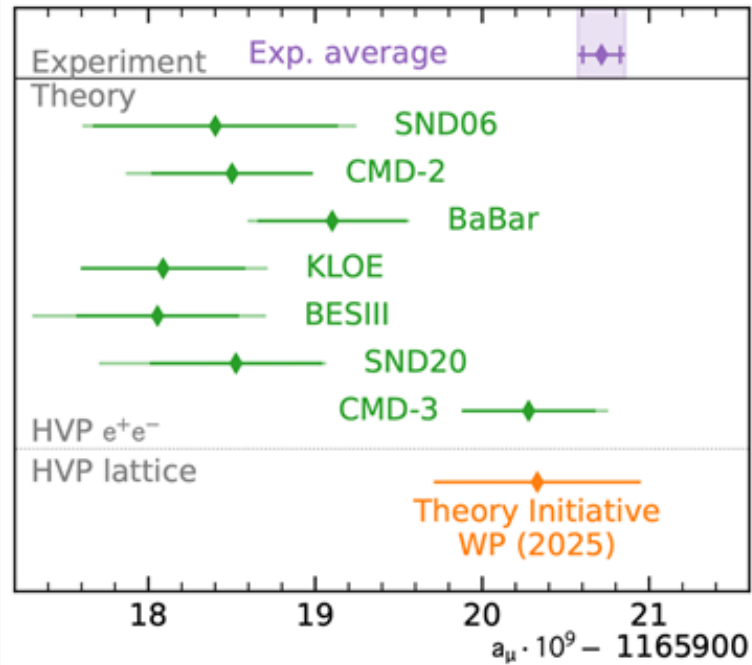
Future of the Muon g-2 puzzle



New KLOE HVP analysis, led by Liverpool: co-chair of weekly group meetings, with Estifa'a

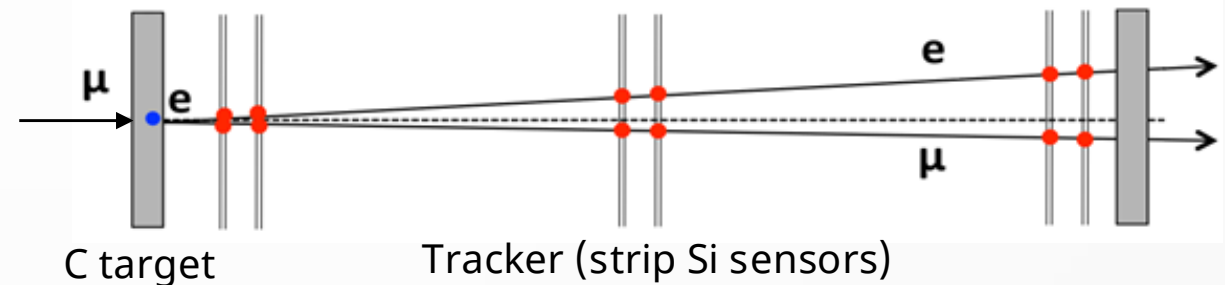
Member of J-PARC Muon g-2/EDM: I will attend a test beam later this year thanks to School's Development Awards

The MUonE experiment at CERN



- Muon: heavier cousin of the electron, very sensitive probe to New Physics
- Muon g-2: how muons interact with magnetic fields. Provides indirect sensitivity to the existence of new unknown particles
- Discrepancies in the theoretical calculation of the muon g-2 using different methods: unclear comparison with the experimental value

- **MUonE**: new method to compute the muon g-2 by probing muon-electron interactions at unprecedented precision (10 parts-per-million)



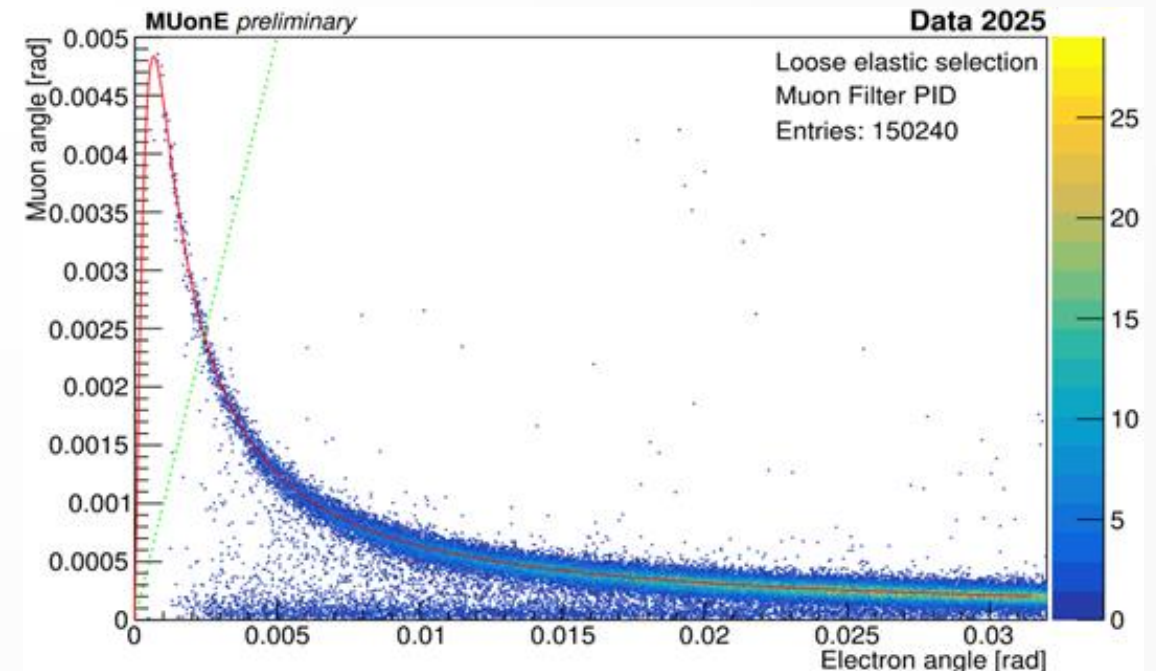
The MUonE experiment at CERN

LEVERHULME
TRUST

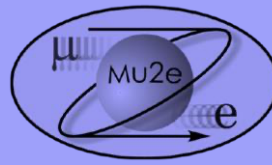


Personal contributions:

- Detector alignment
- Tracking detector performance
- Analysis of muon-electron interactions
- Coordination of the installation and analysis of a new detector built at UoL to measure the muon beam energy



Searching for New Physics with Muons

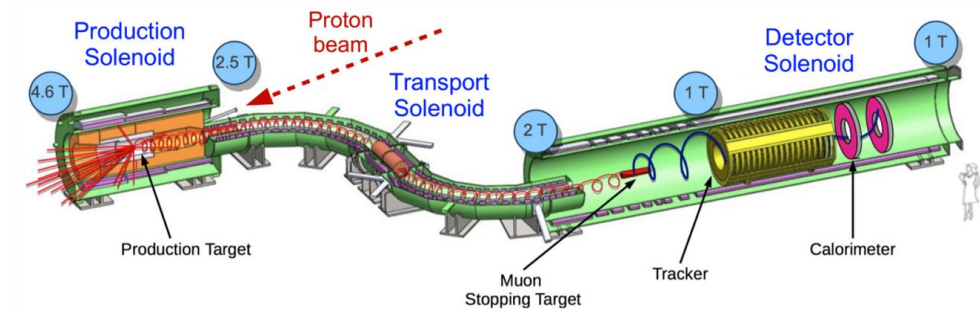


- Particle physics' Standard Model (SM): all that we know about the building blocks of the Universe.
 - It's very good – predicted new particles like the Higgs Boson – but it's not perfect!
 - Always trying to find more cracks in the SM to better explain the ones we know about.

- My work focuses on investigating two potential areas where such a 'crack' could be found:

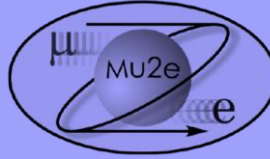
1. Muon-to-electron conversion – extremely low rates predicted (ratio of this process/muon decay is $< 10^{-54}$).

- Process violates a fundamental conservation law in the SM, so higher rates = new physics.
- Mu2e experiment at Fermilab: designed to improve the current world limit by 4 orders of magnitude.
 - Trap muons in aluminium – wait and look for emitted electron of exactly 104.97 MeV.



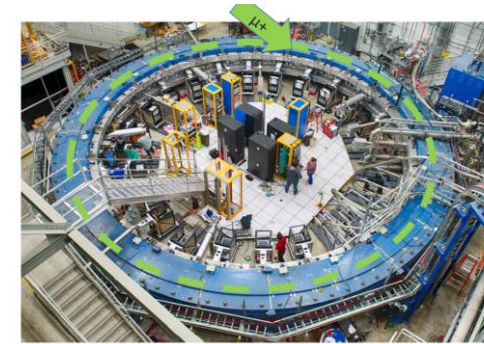
(I work on the Stopping Target Monitor (STM) detector, which is ~ 10m to the right!)

Searching for New Physics with Muons

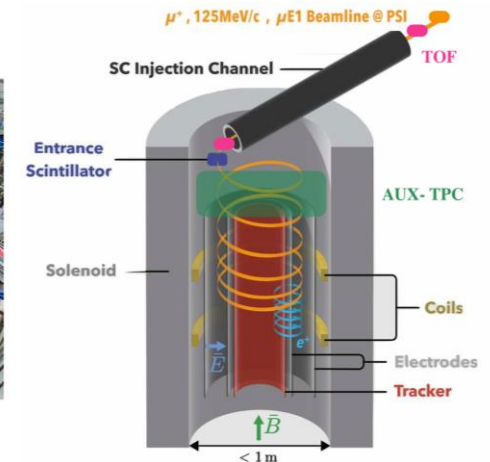


2. Muon electric dipole moments (EDMs) – so tiny in the SM that we shouldn't be able to measure them.

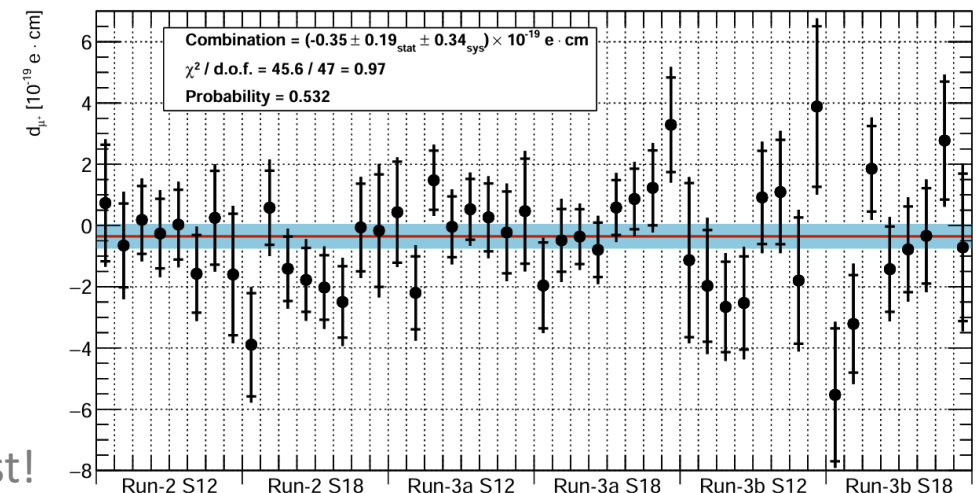
- Electron EDM is well known – need CP violation to get a large muon EDM.
 - Could help better explain why we had matter/antimatter asymmetry in the early Universe...
 - Or maybe electrons/muons/taus don't behave the same!
-
- Two experiments: Muon g-2 @ FNAL + muEDM @ PSI.
 - Put muons in a magnetic/electric field, measure the angle the decay electron comes off at.
 - Muon g-2: check if there's a vertical wobble.
 - MuEDM: look for a vertical asymmetry increasing with time.
 - We set the current world limit: $|d_\mu| < 1.10 \times 10^{-19} \text{ e} \cdot \text{cm}$.



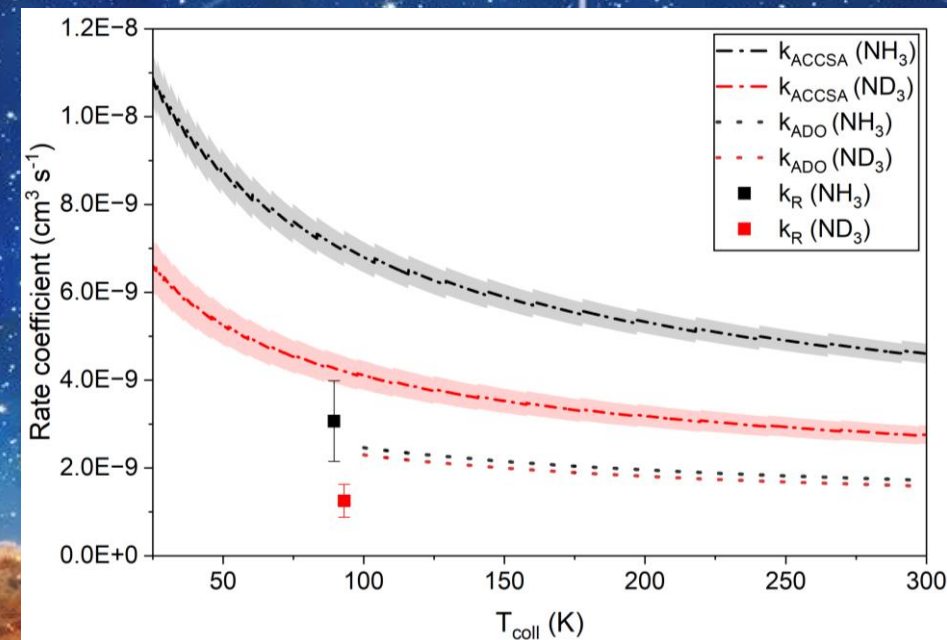
Muon g-2 @ FNAL



MuEDM @ PSI



Plot from our paper in August!



OPEN ACCESS

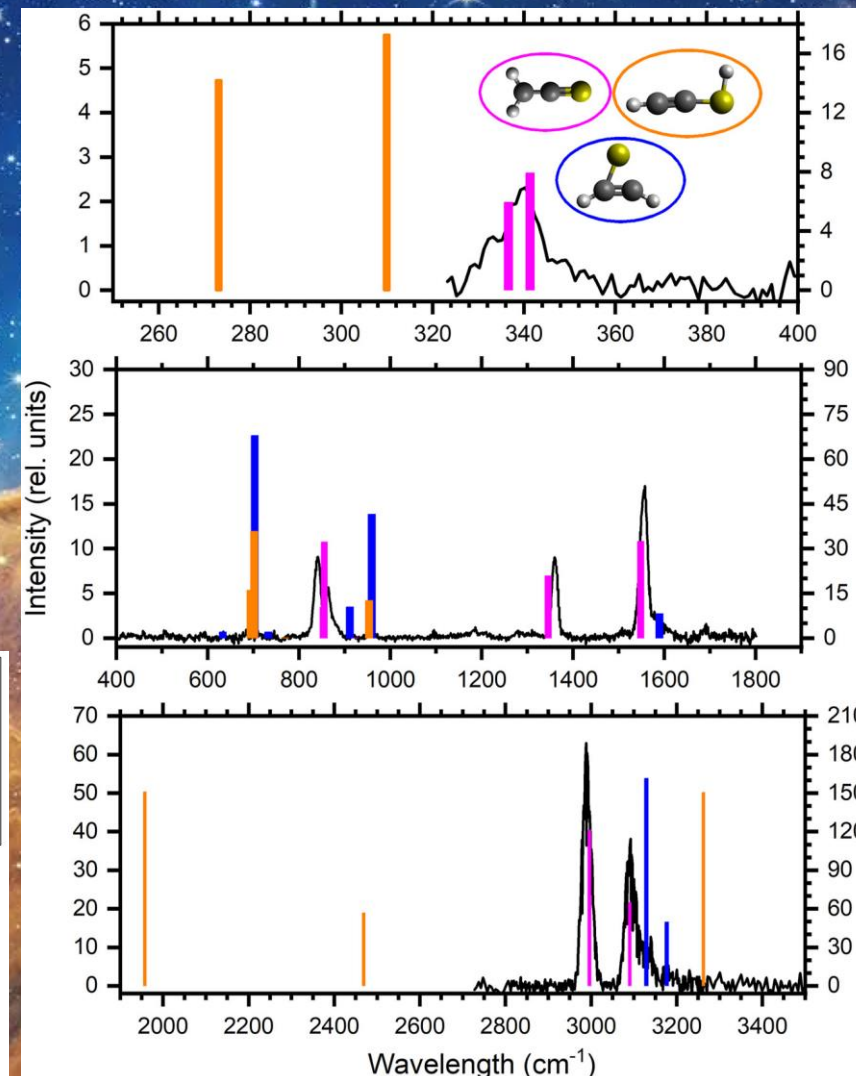
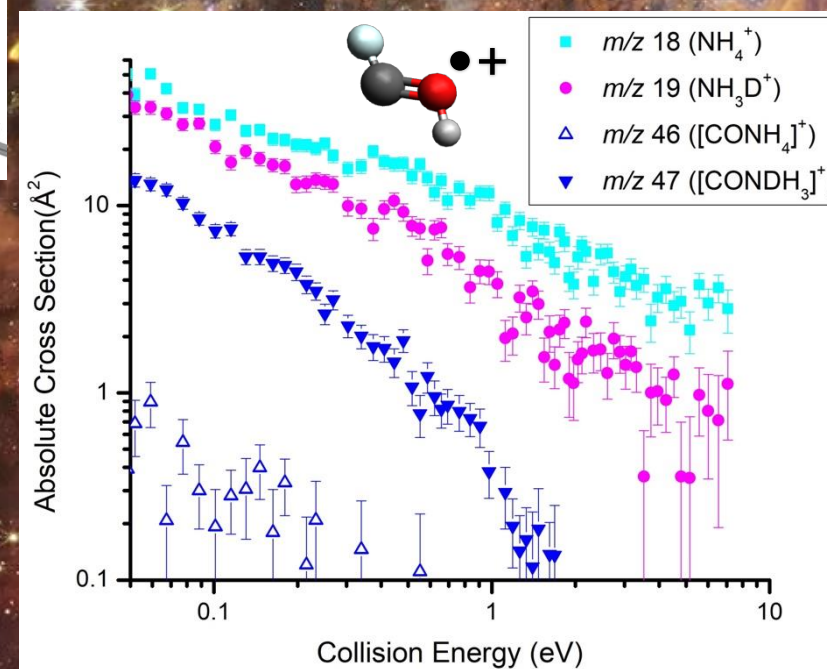
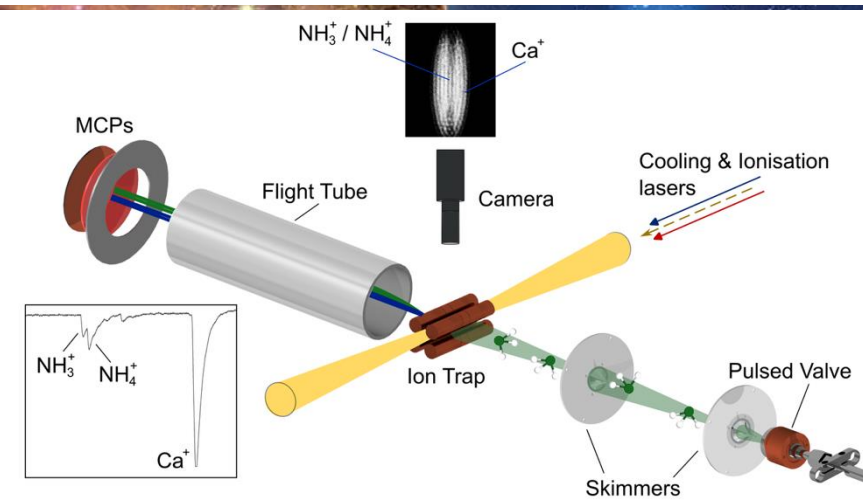
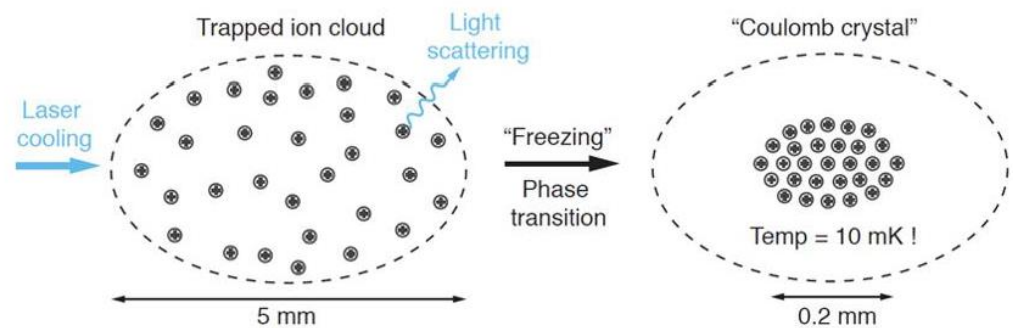
New Constraints on DMS and DMDS in the Atmosphere of K2-18 b from JWST MIRI

Nikku Madhusudhan, Savvas Constantinou, Måns Holmberg, Subhajt Sarkar, Anjali A. A. Piette, and Julianne I. Moses

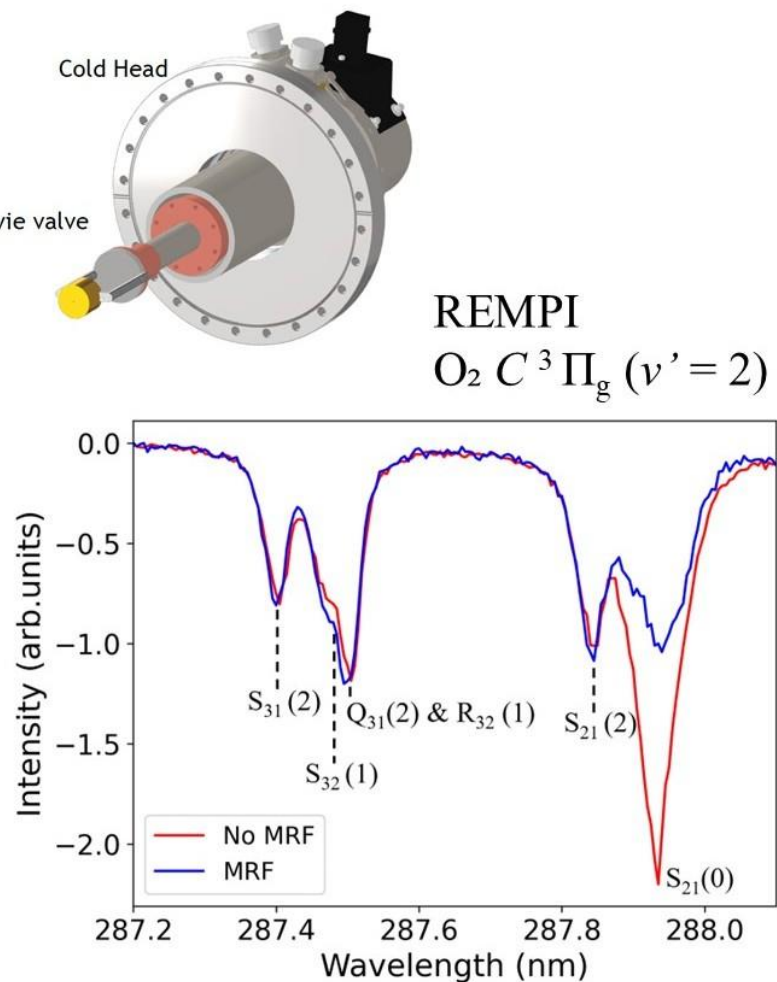
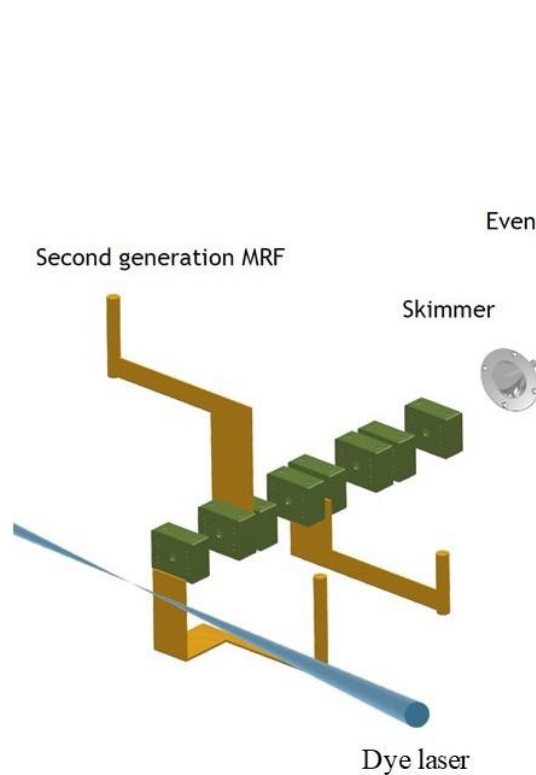
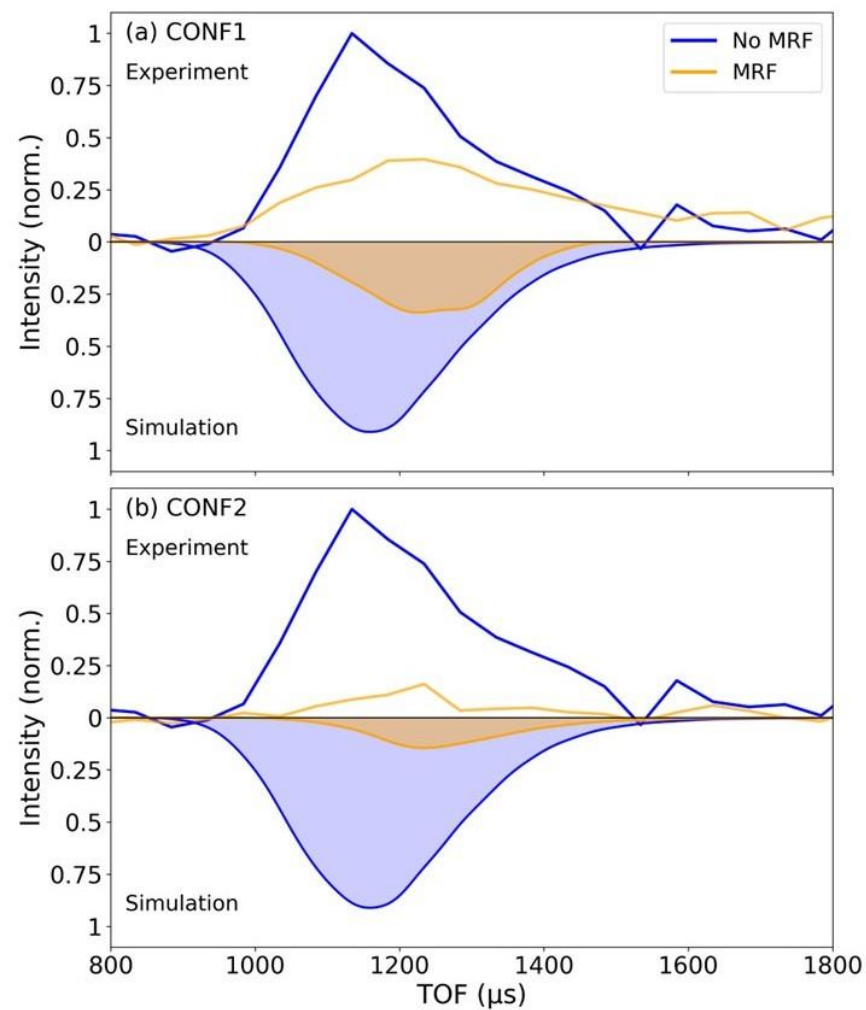
Published 2025 April 17 • © 2025. The Author(s). Published by the American Astronomical Society.

[The Astrophysical Journal Letters](#), Volume 983, Number 2

Citation Nikku Madhusudhan *et al* 2025 *ApJL* 983 L40



Magnetic control of supersonic beams of radicals



Mu3e: searching for $\mu^+ \rightarrow e^+e^+e^-$

This decay is forbidden in the Standard Model, so seeing it would mean new physics. Mu3e aims at branching ratios down to 10^{-16} , using the world's most intense muon beam.

50 μm

thin HV-MAPS
sensors

0.1% X_0

per tracking layer

23 μm

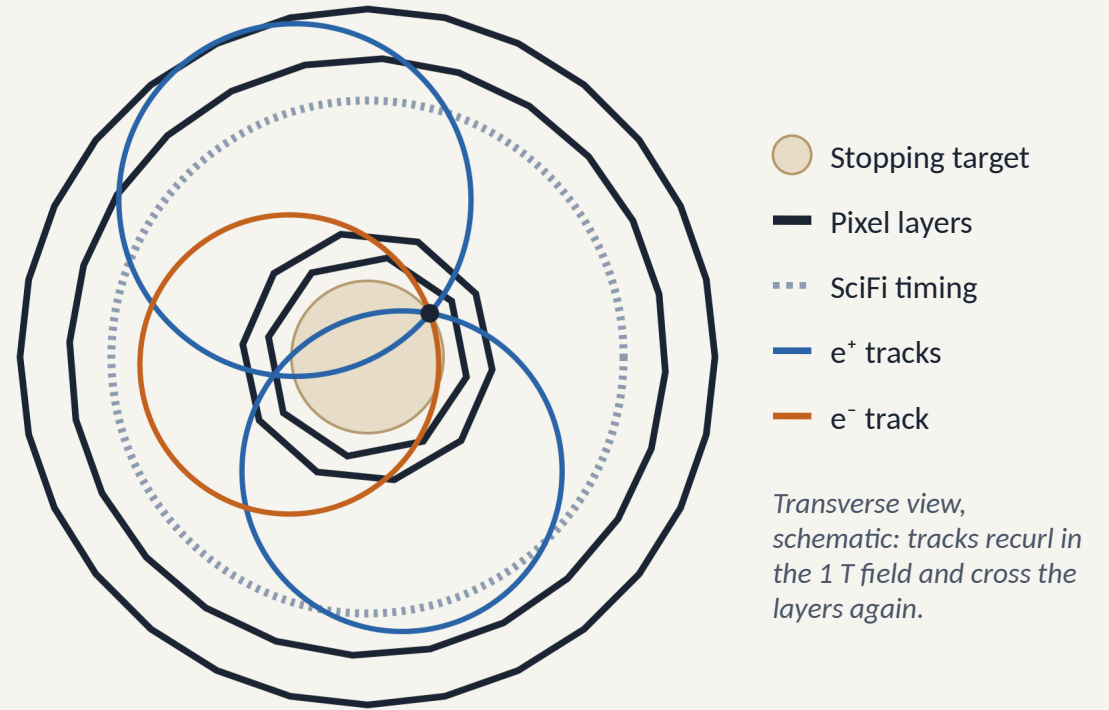
hit resolution

1 T

solenoid field

My work on the pixel tracker

- PixelQC test bench for MuPix (HV-MAPS) chips
- MIDAS DAQ, slow control and temperature monitoring
- FPGA high-speed serial links and their diagnostics

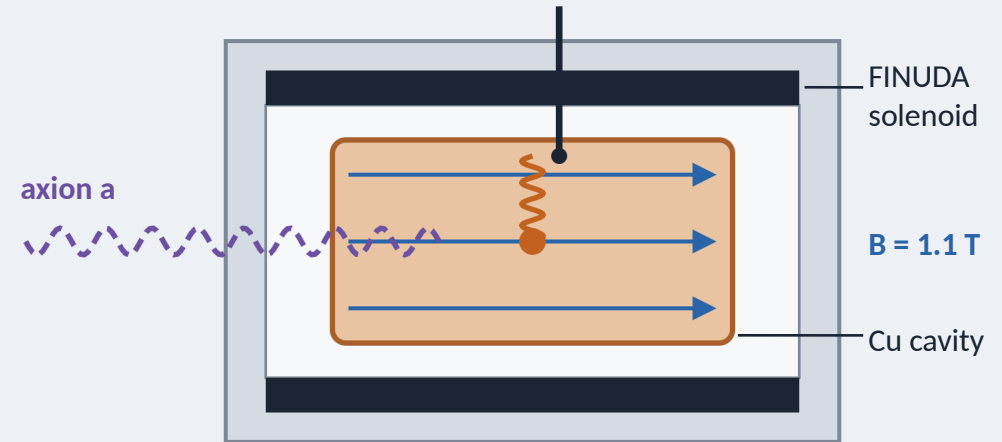


FLASH: a 1.1 T haloscope for light axions

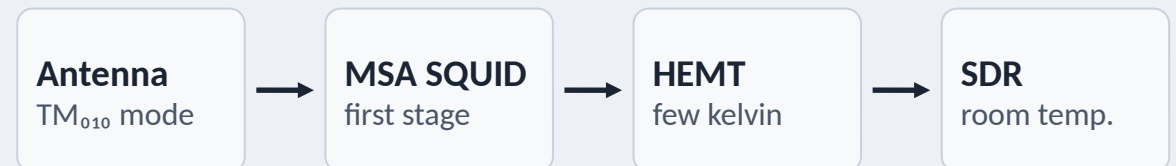
Axion mass	0.49–1.49 μeV
Cavity frequency	117–360 MHz
Axion–photon coupling	$\sim 10^{-16} \text{ GeV}^{-1}$
HF gravitational waves	100–300 MHz
Cavity volume	$\approx 4.15 \text{ m}^3$
Magnet (ex-FINUDA)	1.1 T, 1.4 m bore radius

My role

- Co-proposer and technical co-lead of FLASH
- Cryogenic readout R&D and data analysis
- MPhys students: ALPs and HF gravitational waves



Schematic: in the 1.1 T field an axion converts to a photon in the cavity ($a \rightarrow \gamma$), picked up by an antenna.



What does a precision measurement tell us?

Muon $g-2$

Book chapter and review paper on what a_μ tells us: virtual particles, precision, inference to the best explanation.

Quantum foundations

Axiomatic Hilbert-space quantum mechanics: spectral measures and the Born rule, entanglement, Bell inequalities.

Science and religion

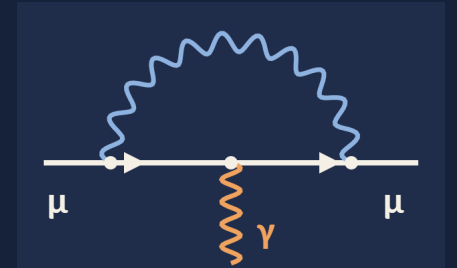
Public dialogue between science and religion, and Integral Ecology and the Pontifical University of Rome

The common thread: what do the fundamental laws of physics really tell us?

Nature of reality. Do our best theories describe what exists, or only what we can predict?

Status of laws. Are they necessities, regularities, or expressions of symmetry?

Limits of precision. What can an anomaly, or a null result, reveal about the world?



Leading QED loop: $a_\mu = \alpha/2\pi + \dots$

PDRA & ECR AWAY DAY

Thank you

To all our speakers, and to everyone who joined us