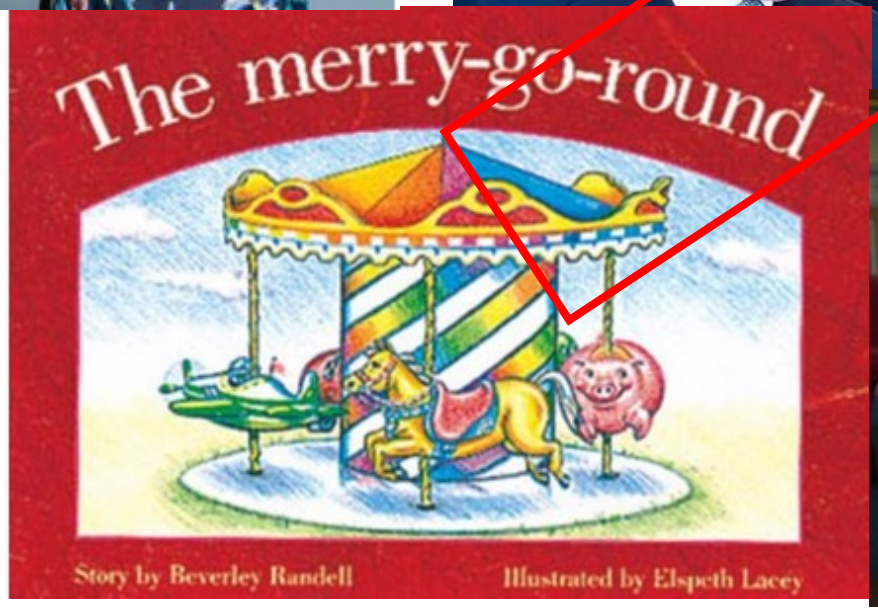
# Particle Physics: "State of the Nation"

Gavin Davies

Head of Community

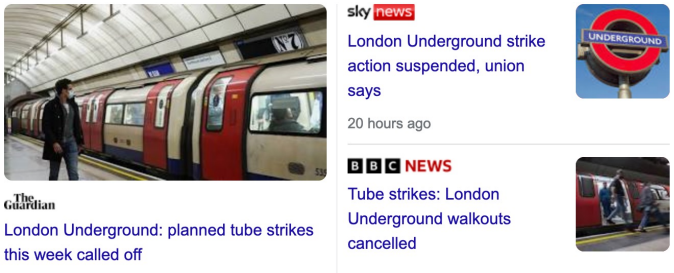
# “State of the Nation” talk

- What it’s not...


# More of a "State of the ~~Group~~" talk

- And in particular...a welcome to new-comers and a brief look at the group
- The punch line...
  - We continue to do well..
- Following past format..a brief introduction for the new people
  - The size and composition of the group
  - What we work on
  - What's "new" in the last year
  - An idea of where we are going
- And then we can socialise...but on Oct 25th

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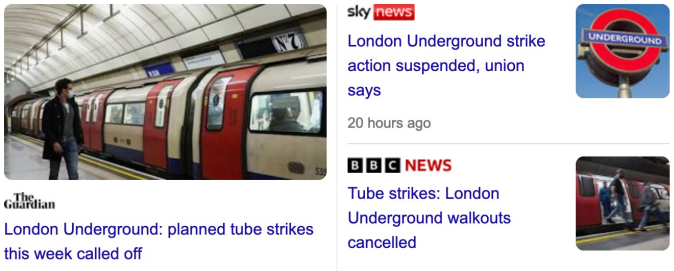



# More of a “State of the Community” talk

- https://www.imperial.ac.uk/about/covid-19/

## COVID-19, flu, and respiratory infections

*Guidance reviewed September 2023*

*Page last updated on Friday 15 September 2023*

Please protect yourself and others and:

- Stay at home if you have symptoms of respiratory disease
- Get vaccinated if you are eligible
- Cover your coughs and sneezes
- Respect personal space.

Please follow the UK government guidance for any areas not covered by College guidance.

### Stay at home if you don’t feel well

If you are displaying symptoms of respiratory disease, or have tested positive for COVID-19, don't come onto our campuses. Instead, work or study remotely if you are well enough and able to do so.

# An aside…

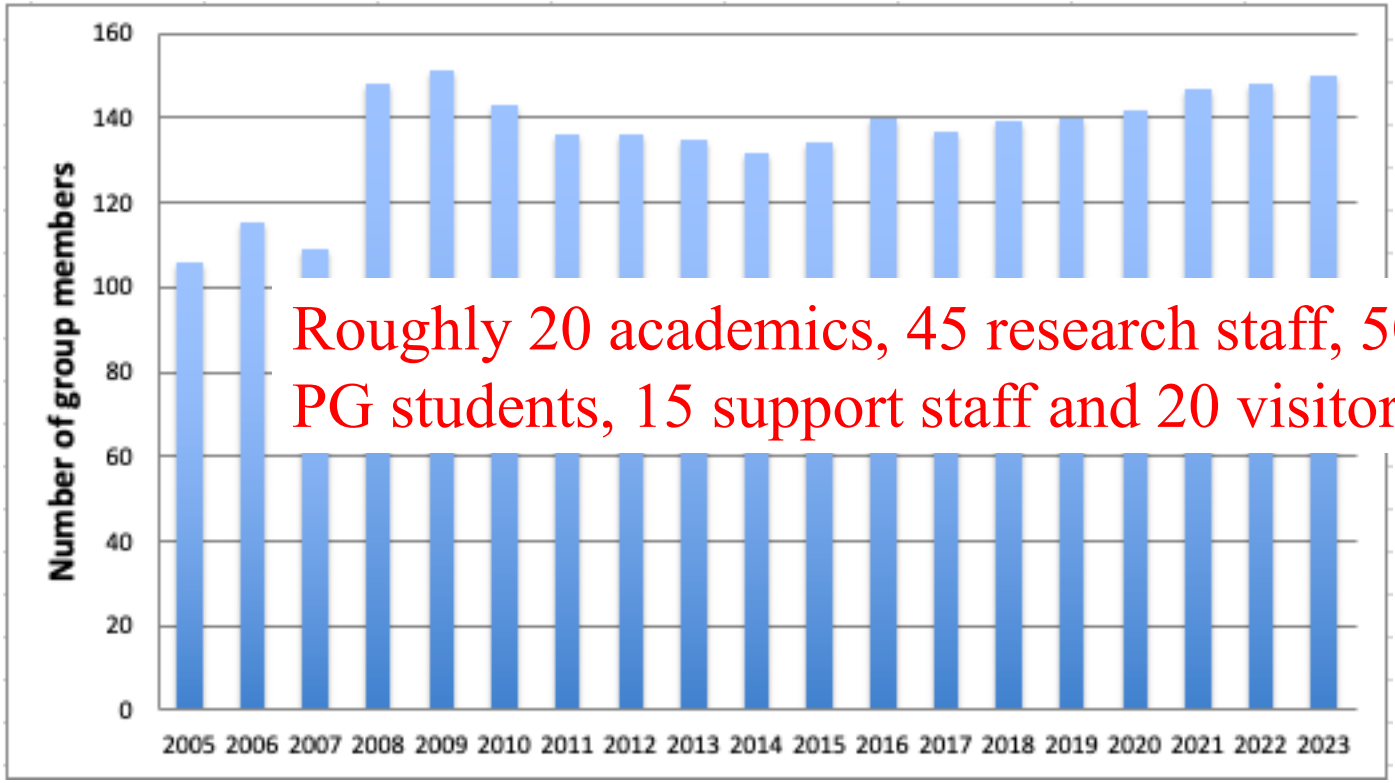
- What were we as a group?
  - A large number of people addressing similar [same] science in similar [same] way
    - Working together as a team, with real team-spirit
- Isn't that a community?
  - Yes

# What is we do & how?

- Elucidate the origins of the universe
  - Help to: Take, process & analyse data, design / build state-of-the-art instrumentation or accelerators, grid/Cloud computing, apply these concepts to societal needs, enable it to all happen, inspiring the next generation.. Team work
- Standard Model (SM) of Particle Physics
  - Our understanding of fundamental particles & forces that govern their interactions
  - Tremendously successful, but not the whole answer
    - Hierarchy problem, neutrino masses, matter-anti matter asymmetry, dark matter...
- How do we look for what's next?
  - Directly e.g. for new particles or interactions
    - e.g. AION, CMS, LZ, neutrino programme, SHiP
  - Indirectly e.g. looking for deviations from SM predictions
    - e.g. CMS, COMET, LHCb (inc LFV), neutrino programme (e.g. T2K/Hyper-K/DUNE)
  - Sometimes referred to as Energy, Precision, Flavour, Intensity Frontiers
  - Involved across the board – at different stages – Team work

# Members of the community

- Were one of the biggest groups in the Department
- ~150 members in the group list
  - Growing....[and other reasons to celebrate..]



# Welcomes and farewells over the last year

## Leavers

| |
|---|
| Roisin Armstrong |
| Lucas Borgna |
| Matt Bradley |
| Giovanni Cavallero |
| Julia Dancu |
| Titus-Stefan Dascalu |
| Matthias Dubouchet |
| David Evans |
| Shingo Hayashida |
| David Monk |
| Julia Sedgebeer |
| Antonin Vacheret |
| Morgan Wascko |
| Simon Williams |

## Arrivals

| |
|---|
| Suntia Aubeeluck |
| Matt Birch* |
| Chris Brown* |
| Indranil Das |
| Masaki Hori |
| Yuhan Hua |
| Ludo Iannizzotto Venezze |
| Kieren Joseph |
| Alice Josset |
| Jaime Leon Holgado |
| Henry Linton |
| Stavros Mallios |
| Tim Marley* |
| Andreas Mastronikolis |
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| Kang Yang |
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9 new PGs!

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A very warm welcome to all!

# What are we working on?

- Energy frontier: CMS, CMS upgrade
- Flavour physics: LHCb, LHCb upgrade, COMET, MUonE
- LB neutrinos: T2K(-II), Super-K, Hyper-K, DUNE
- Not-SM neutrinos: SuperNEMO, SoLid, SHiP
- Direct Dark Matter: LUX-Zeplin (LZ), MIGDAL
- Gravitational waves and ultra-light DM: AION
- Transformative biomedical tech.: LhARA/ITRF, NIMMS2
- Accelerators: ISIS, Linac4, PRISM, nuSTORM, MC
- Computing: GridPP, machine learning
- Phenomenology: Mastercode, QCD
- Industrial applics: Sensors, Real-time AI, “Hassard Plc”

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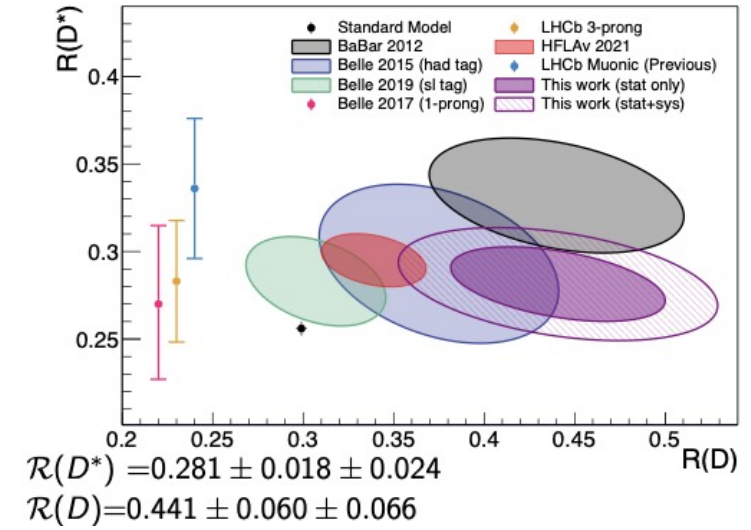
A few things I'll pick out... "2023 news"

# Flavour frontier: LHCb and Upgrade

- Some of the most exciting measurements in the field conducted in the group…
  - Angular measurements
  - Ratios between decays involving different kinds of 'leptons' e,μ,τ

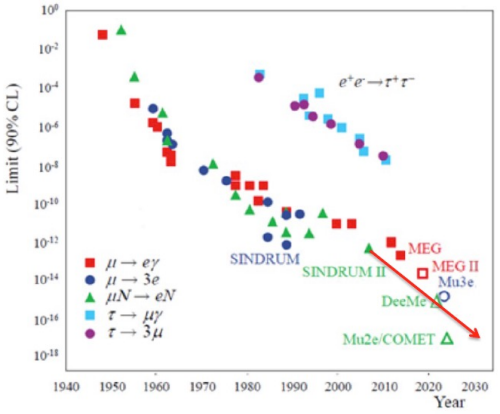
  Analysis of the data now being taken will tell us if these are the first sign of new physics!



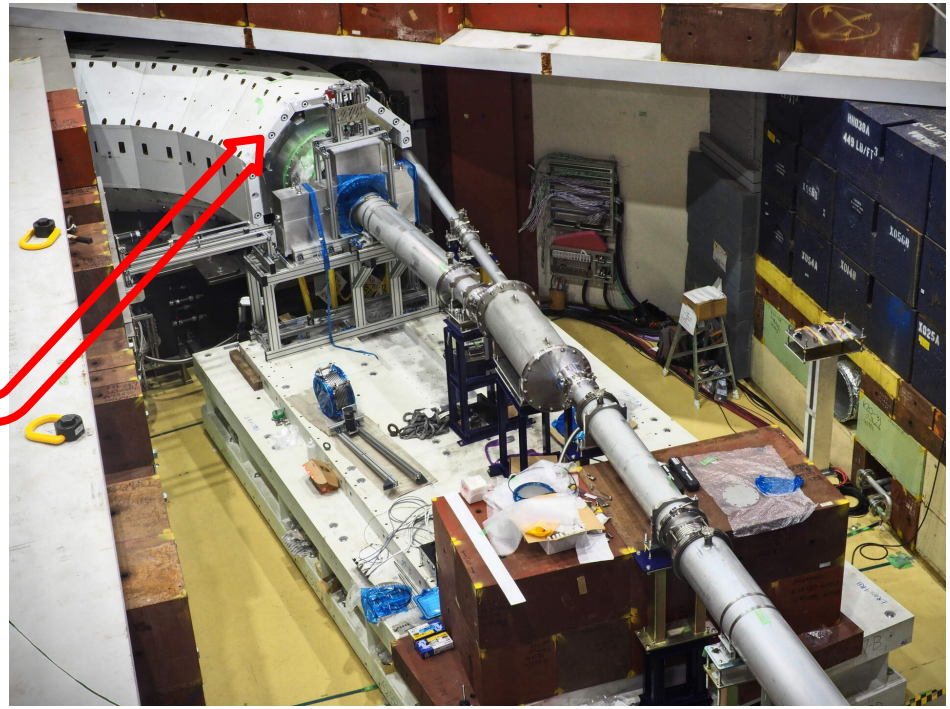

- Have also led construction and installation of a major part of the upgraded experiment
  - Led by Mike McCann, Andrey Golutvin, Mitesh Patel
  - Chris Bird, Kevin Ladhams, Dan Nardini, Trevor Savidge

# Flavour frontier: COMET

- Search for μ-e conversion at J-PARC in Japan
  - Preparing for initial Phase-α operations
  - Taking commissioning data
  - Led by Jaroslaw Pasternak, Yoshi Uchida
  - Chris Bird, Kevin Ladhams, Dan Nardini, Oliver Jeremy

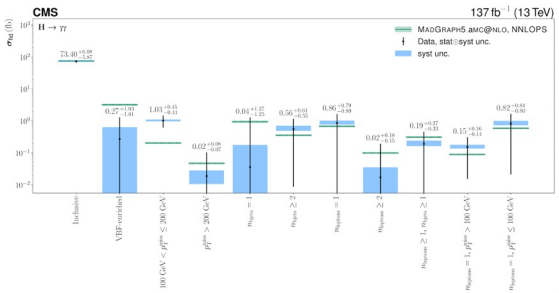


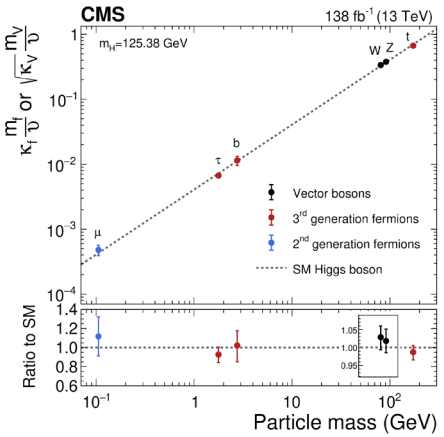

Variable beam mask designed and made here

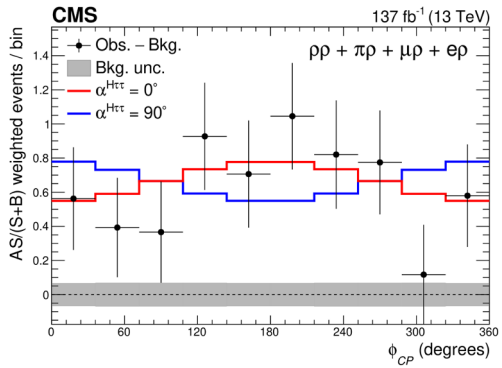


# Energy frontier: CMS Physics

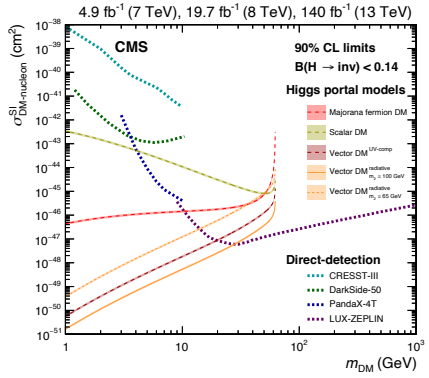
- Large activity:
  - Led by O. Buchmueller, D. Colling, P. Dauncey, G. Davies, G. Hall, N. Wardle, A. Tapper, T. Virdee
- Current: Wealth of data with more to come



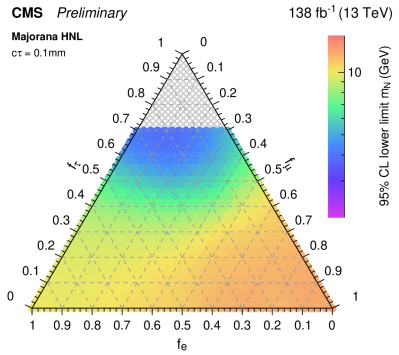



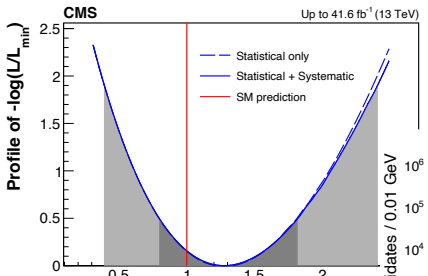



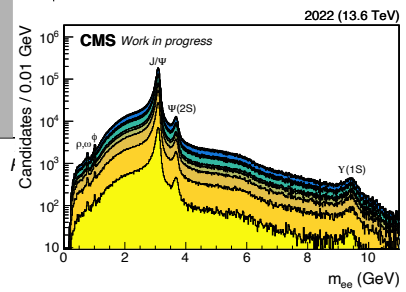

Characterising the Higgs through various decay channels – inc looking for dark matter




Heavy Neutral Leptons using particle "tagger" - advanced deep machine learning MC and LHC data



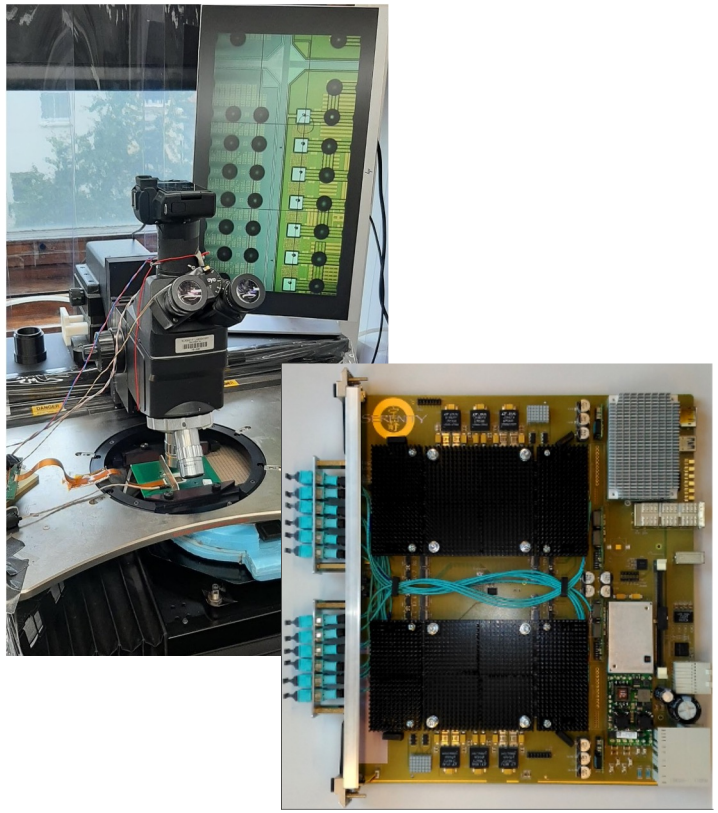

Novel "Bparked" data set of 10B unbiased B decays to probe flavour anomalies

# Energy frontier: CMS Upgrade

- Large group activity:
  - Led by D. Colling, P. Dauncey, G. Davies, G. Hall, N. Wardle, A. Tapper, T. Virdee

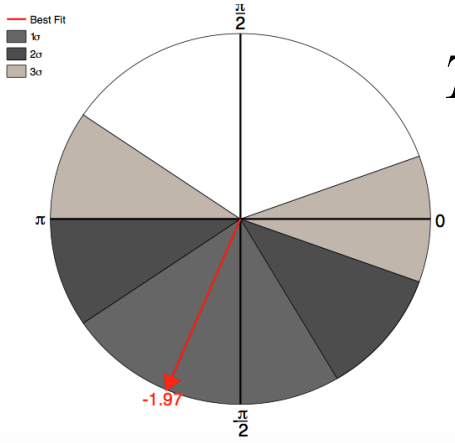
- Prepare for intense beams and rates of high-luminosity (HL) LHC
  - Will run from 2029 for around a decade
  - 6 yr construction grant started Apr 2019

- Whole CMS-UK upgrade grant based on Imperial-designed "Serenity" boards
  - Andy Rose, Duncan Parker, Mark Pesaresi and Greg Iles
  - Clear example of how a world-leading team can enable a whole research programme for UK



# Long baseline neutrinos: T2K, Hyper-K & DUNE

- Study neutrino oscillations
  - Main aim now is to determine if neutrinos violate CP = is antimatter like matter?
  - Current generation: T2K with beam from J-PARC Facility in Japan; led by Patrick Dunne, Ken Long, Jaroslaw Pasternak, Mark Scott, Yoshi Uchida
  - Beam power doubled for 2023
  - New upgraded ND280 near detector
  - Imperial leading oscillation analysis inc. joint analyses with NOvA and SK



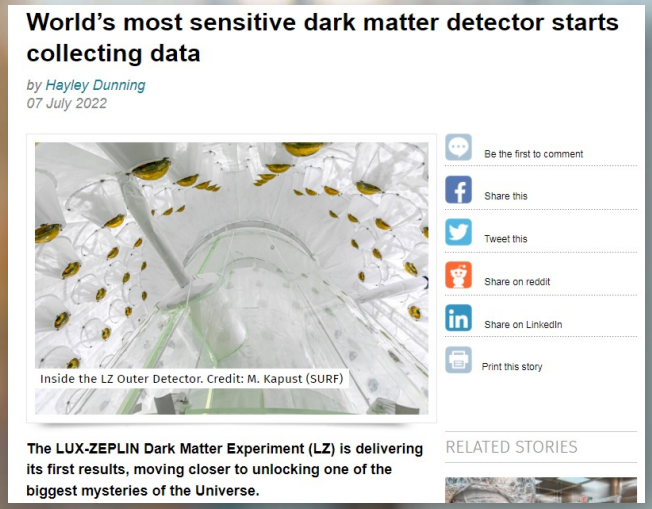

*T2K data:* $\delta_{CP}$

# Long baseline neutrinos: T2K, Hyper-K & DUNE

- Study neutrino oscillations
  - Next generation: Hyper-K & DUNE
  - HK: Beam from J-PARC; led by Ken Long, Jaroslaw Pasternak, Mark Scott, Yoshi Uchida
  - DUNE: Beam from FNAL near Chicago to Sanford Laboratory (SURF) in South Dakota; led by Patrick Dunne, Ken Long, Alex Tapper
    - Focus on DAQ readout, oscillation analyses & near detectors
  - Beam tests for DUNE and HK near detectors
    - DUNE: High-pressure gas TPC (TOAD)
    - HK: Water Cherenkov Test experiment (WCTE)

# DARK MATTER SEARCHES: LUX-ZEPLIN (LZ)

- First results at SURF (1 mile underground)
  - Established world-leading sensitivity, now moving into discovery territory
- Large mass & low background, leading sensitivity to:
  - DM particle interactions
  - Astrophysical neutrinos
  - Neutrinoless double beta decay
- Imperial plays a key role
  - LZUK project lead
  - UK Data Centre host
  - (Xenon Detector co-lead)
- **Xenon Futures / XLZD**
  - *R&D towards a global experiment*
  - *Possibility of hosting in the UK – leading this effort*



**World's most sensitive dark matter detector starts collecting data**

*by Hayley Dunning*
*07 July 2022*

Inside the LZ Outer Detector. Credit: M. Kapust (SURF)

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**The LUX-ZEPLIN Dark Matter Experiment (LZ) is delivering its first results, moving closer to unlocking one of the biggest mysteries of the Universe.**

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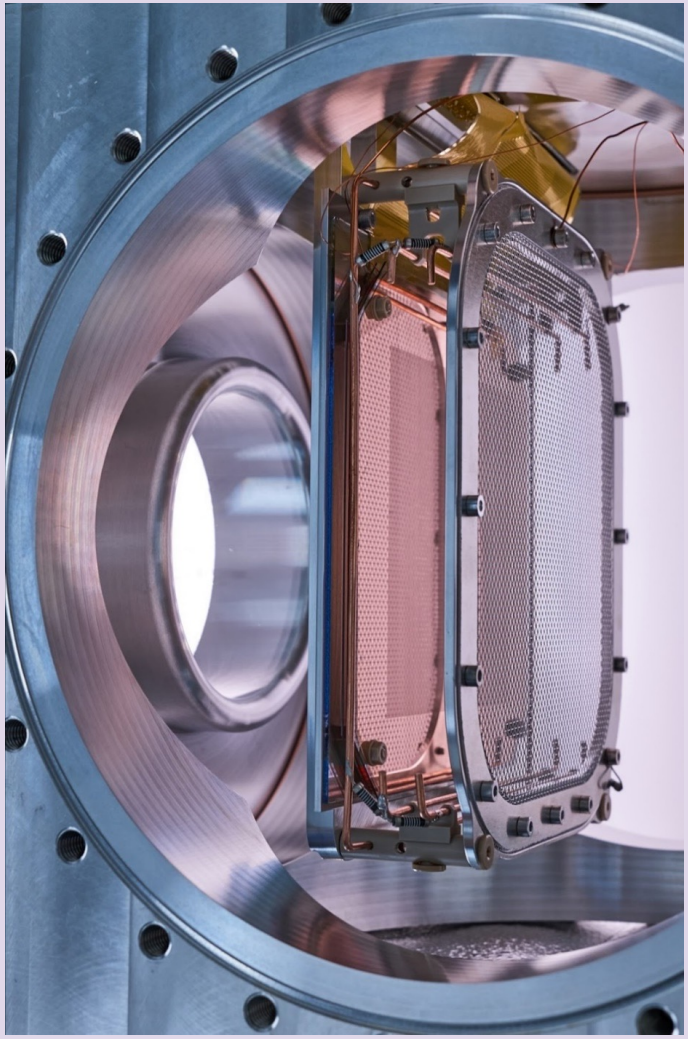
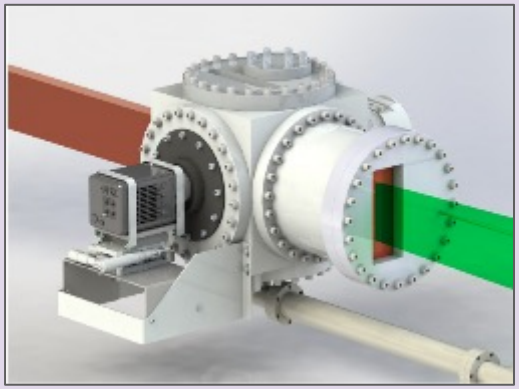
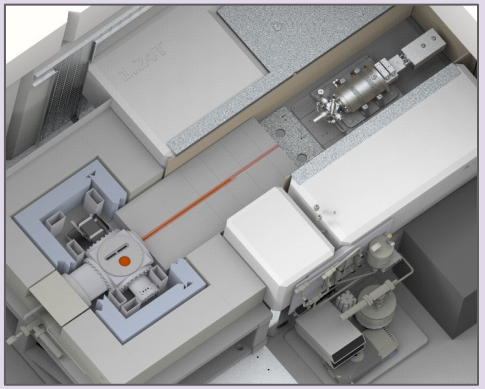
# MIGDAL EXPERIMENT

MIGDAL
Migdal In Galactic Dark mAtter expLoration



- Migdal effect: rare atomic process that is helping with the search for sub-GeV dark matter particles
- Low-pressure Optical-TPC designed to “photograph” the Migdal vertex: 1 nuclear recoil + 1 Migdal electron
- Neutron data coming in, analysis ongoing





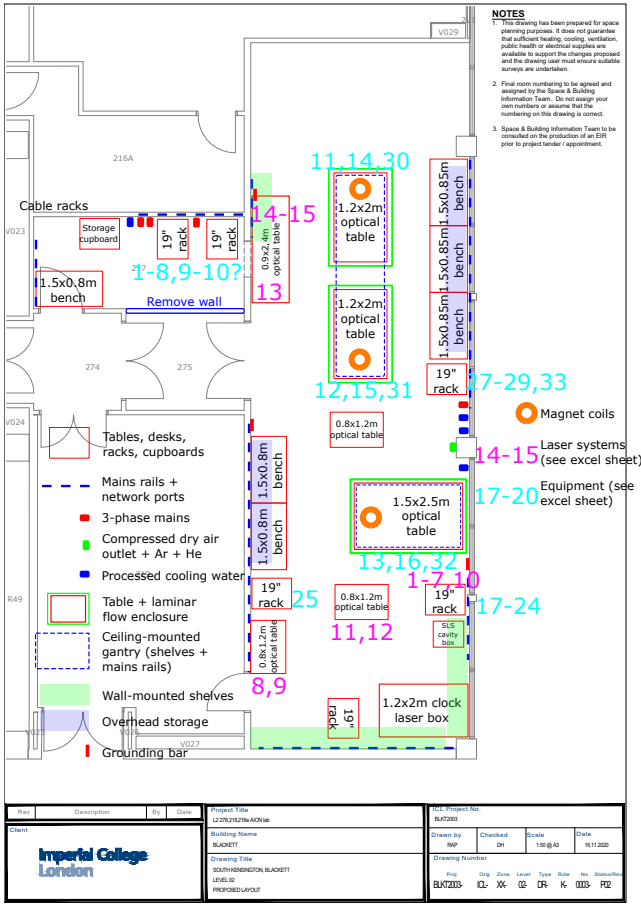
# AION: A UK Atom Interferometer Observatory &Network


- Atom interferometry with quantum sensors
  - Explore Ultra-Light Dark Matter & Mid-Frequency Gravitational Waves
  - Would need ~km long interferometer
  - Space-based opportunities


- Recently funded in the joined EPSRC & STFC Quantum Technology for Fundamental Physics (QTFP) programme
- Initial funding of ~£9M (£7.1 from QTFP) over 30 months to build Strontium based Atom Interferometry Laboratories to establish the technology & prototype a scale able Quantum Detector (10m, 100m, km-scale).
- Partners AION project with the MAGIS experiment at Fermilab
- Imperial is the lead institution (PI: Buchmueller) in a consortium of seven high-profile UK institutions
- Sr lab on Level2 complete

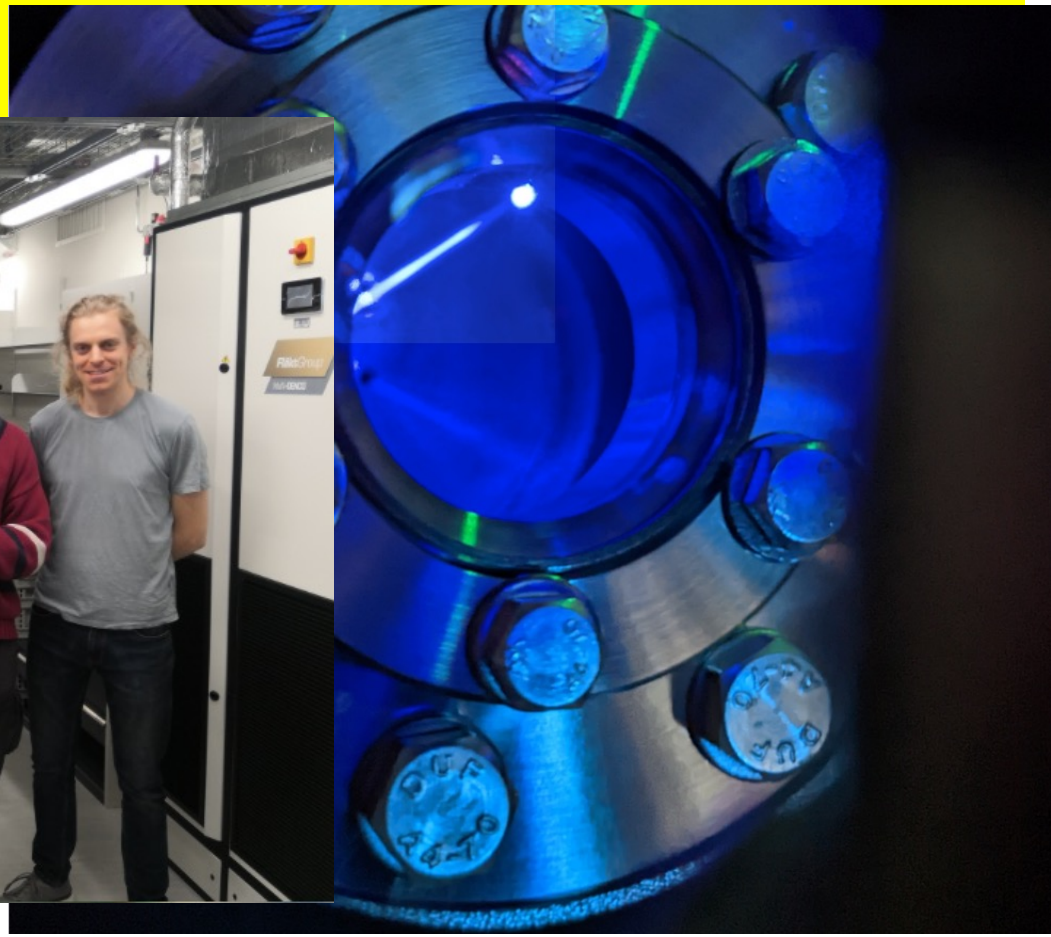
# New Ultra-Cold Strontium Laboratory at Imperial College (AION)

- In the context of the AION project, Imperial College build a **brand new Ultra-Cold Strontium Laboratory on about 100m$^2$** of high-quality real state in the Blackett Laboratory in central London.
- This Laboratory has extent significantly the already very strong Ultra-Cold Atom facilities at Imperial, exploiting strong synergies with existing laboratory space in the same building.
- The new Laboratory is **operated by world leading experts in Ultra-Cold Strontium Atomic Clocks**, and complements the already established expertise in Rb Atom Interferometry and Magneto-optical trapping and sympathetic cooling of molecules.
- **The new laboratory has been operational since the end of 2021, with ongoing extensions for Atomic Clocks, Quantum Computing, and Frequency Reference in the Physics department.**



- **The Team is growing fast:**

**C. F. A. Baynham (RF) O. Buchmüller (Prof), D. Evans (MSc) R. Hobson (RF), L. Iannizzotto-Venezze (PhD starter), A. Josset (PhD starter), E. Pasatembou (Phd 2nd), T. Walker (new PDRA), L. Hawkins (new PDRA) and CCM: M. Trabutt (Prof), B. Sauer (Prof)**



# Laser-hybrid Accelerator for Radiobiological Applications

**Ambition:**

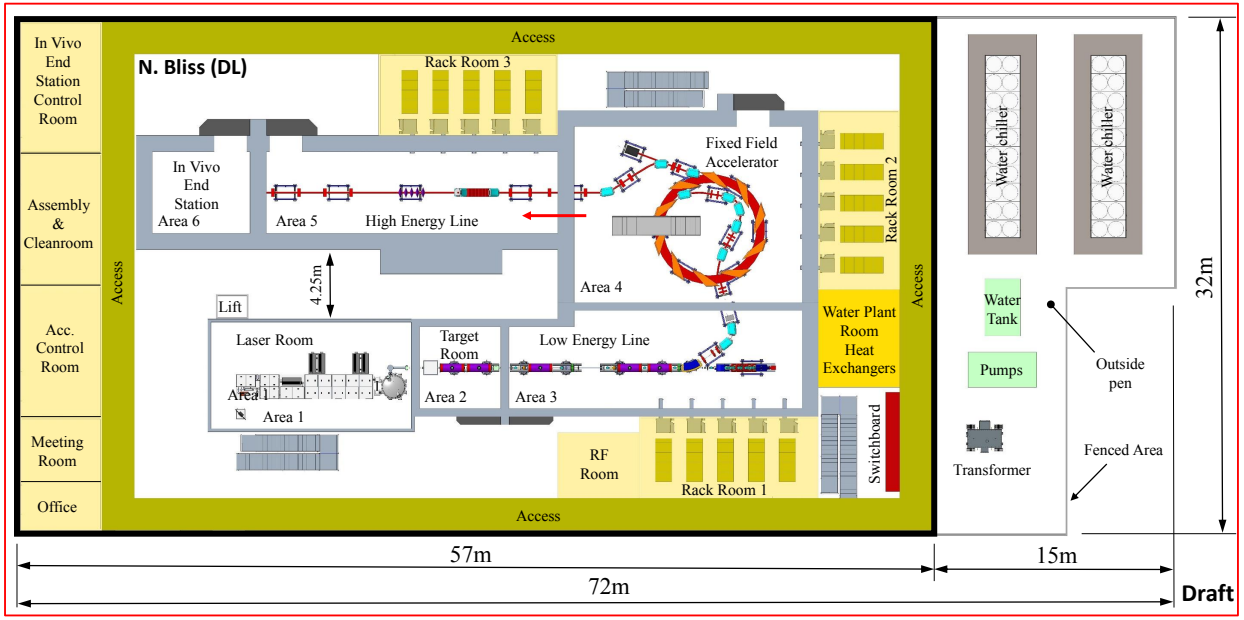
prove the principle of the techniques required to transform practice of particle-beam therapy …

…. using techniques that can be "spun back into" fundamental science

- High-flux, laser-driven proton/ion source
- Electron plasma-lens capture & focusing
- Fast, fixed-field (FFA) post acceleration
- Instrumentation and BioPoP experiment

Compact, uniquely flexible

**Funded! Through ITRF**



# Muon Collider and nuSTORM

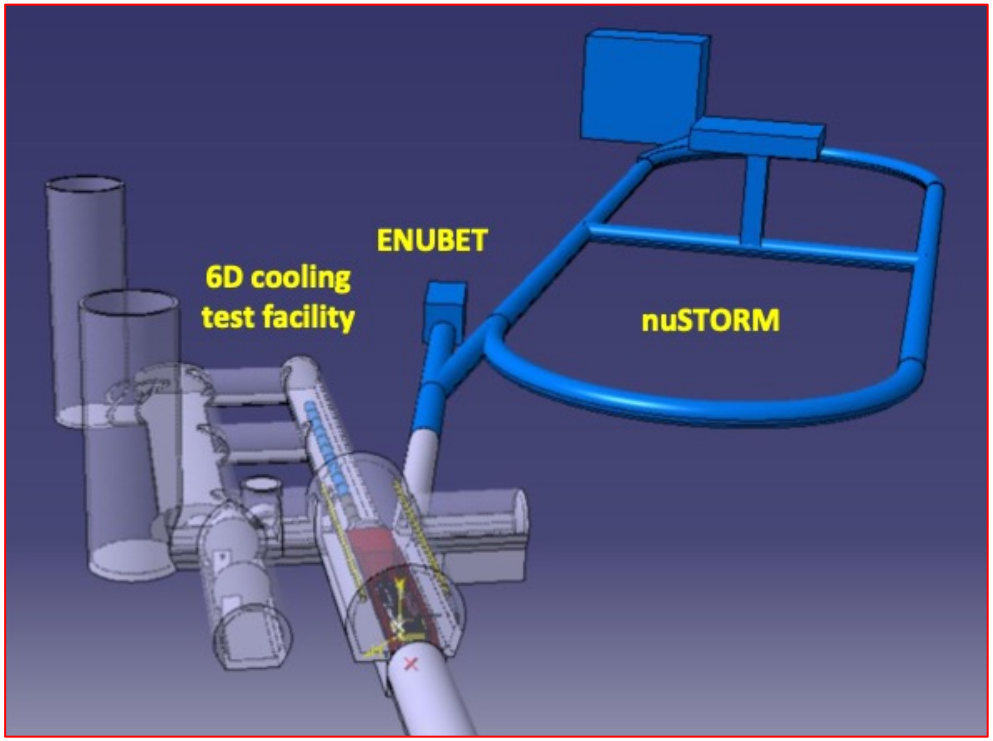
**Programme:**

Develop stored muon beams as alternative route to energy frontier

…. nuSTORM – essential way-point that *delivers unique neutrino physics*

- 6D ionisation cooling demonstrator to follow MICE
- nuSTORM: accelerator design & physics exploitation

**Funded! Through EU actions iFAST & MuCol**



# What holds the group together?


Electronics:
Sam Mansbridge
Duncan Parker
Munir Saleh

Computing:
Ray Beuselinck
Simon Fayer
Dan Whitehouse

Administration:
Sunita Aubeeluck
Paula Brown
Paula Consiglio
Louise Hayward

Mechanics:
Chris Bird
Oliver Jeremy
Kevin Ladhams
Dan Nardini
Trevor Savidge

# Who supports all this financially?

- Mainly UKRI/STFC but some funds from Imperial, EU/ERC, Royal Society and industry
- Roughly half of all the money for the group comes through the Consolidated Grants
  - Pays for: some of the staff; "running HEP experiments", i.e. CMS, LHCb, T2K, LUX-Zeplin, SuperNEMO, and a few others, i.e. COMET, SHiP
  - 'Current' Consolidated Grant runs from Oct 2022 to Sep 2025
    - Beginning preparation for next – submission in Feb 24
- The other half is from specific projects and individual awards
  - Everything else: the rest of the staff, accelerators, AION, CMS upgrade, LHCb upgrade, MICE, Hyper-K, GridPP, phenomenology, SoLid
  - There are a few smaller grants for individuals also
  - Typical grant cycle for renewal is two or three years

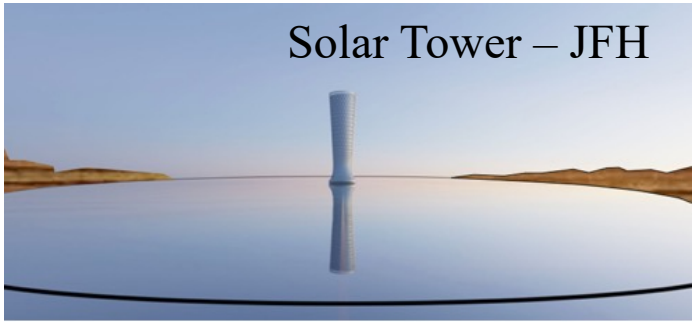
# Departmental Restructuring

- Have had historically
  - Nine research groups, 'now' of very varying size
  - Large 'management board': HoD, HoGs, Directors of Research, DUGs, DPS, Operations manager +..
- Now have
  - Five communities of ~equal size, one of which is Particle Physics
    - Each has a Head of Community and a Head of Research
  - Smaller 'management board'" 1 HoD, 5 DHoDs, Operations manager
  - Drive to promote communication within & between communities, and beyond
    - Shared seminars, social activities, strategic initiatives & themes

We are already a community, but a real opportunity for better interactions across Department & to help take forward the Department as a whole

# A New Community Initiative – HEP-X

- Context: Increased importance of societal challenges
- We are well placed [potentially] to assist
  - Via instrumentation as well as big data –AI/ML, analysis techniques
    E.g. IAA awards, ERC PoC, Misc consulting, JFH inc.
  - But [usually] a "two-step process
- Formed HEP-X to facilitate process
  - Facilitate transfer of PP research to commercial environment
    - Generation of REF Impact
    - Research and financial benefit to Group, Individual's and Department
  - Gateway for external interest & assisting internal participation and promotion of ideas
  - A co-operative, open to all
    - Managed by a Steering Board



# And later [Oct 25th].. Some refreshments...

- Enjoy…

[From summer 2019]

[From summer 2022]


- Thank you.