Overview of the UK Experimental Particle Physics Programme

Paul Newman (University of Birmingham)

On behalf of the STFC
Particle Physics Advisory Panel (PPAP)

Friday 7 November 2014

- Introduction to PPAP
- The UK at the Large Hadron Collider
- The UK and Long Baseline Neutrino Experiments
- Other experiments with strong UK involvement
- The UK and future colliders

(Theory, computing and accelerator science covered elsewhere)

The Particle Physics Advisory Panel

PPAP Role

- Charged with liaising with UK particle physics community, maintaining an overview of activities, continuously developing a roadmap and advising STFC as appropriate.

- Panel meets every ~2 months to exchange and review news
- Hosts an annual ~ 2 day open Community Meeting
- Hosts ad hoc grant-holders fora when relevant matters arise

Current Membership

Rob Appleby (Manchester)

Christine Davies (Glasgow)
Victoria Martin (Edinburgh)
Paul Newman (B'ham, chair)
Jonas Rademacker (Bristol)

Yorck Ramachers (Warwick)
Claire Shepherd-Themistocleous (RAL, deputy-chair)
Bill Spence (QMUL)
Morgan Wascko (ICSTM)
Matthew Wing (UCL)

Last PPAP Roadmap (Nov 2012)

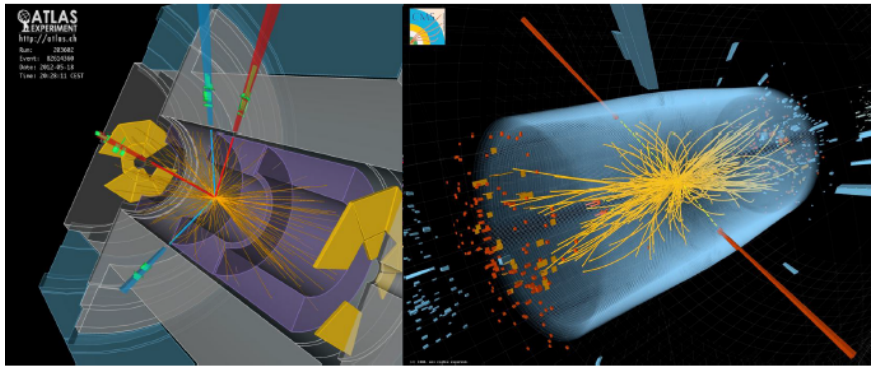
… input to 2013/4 Prog. Review

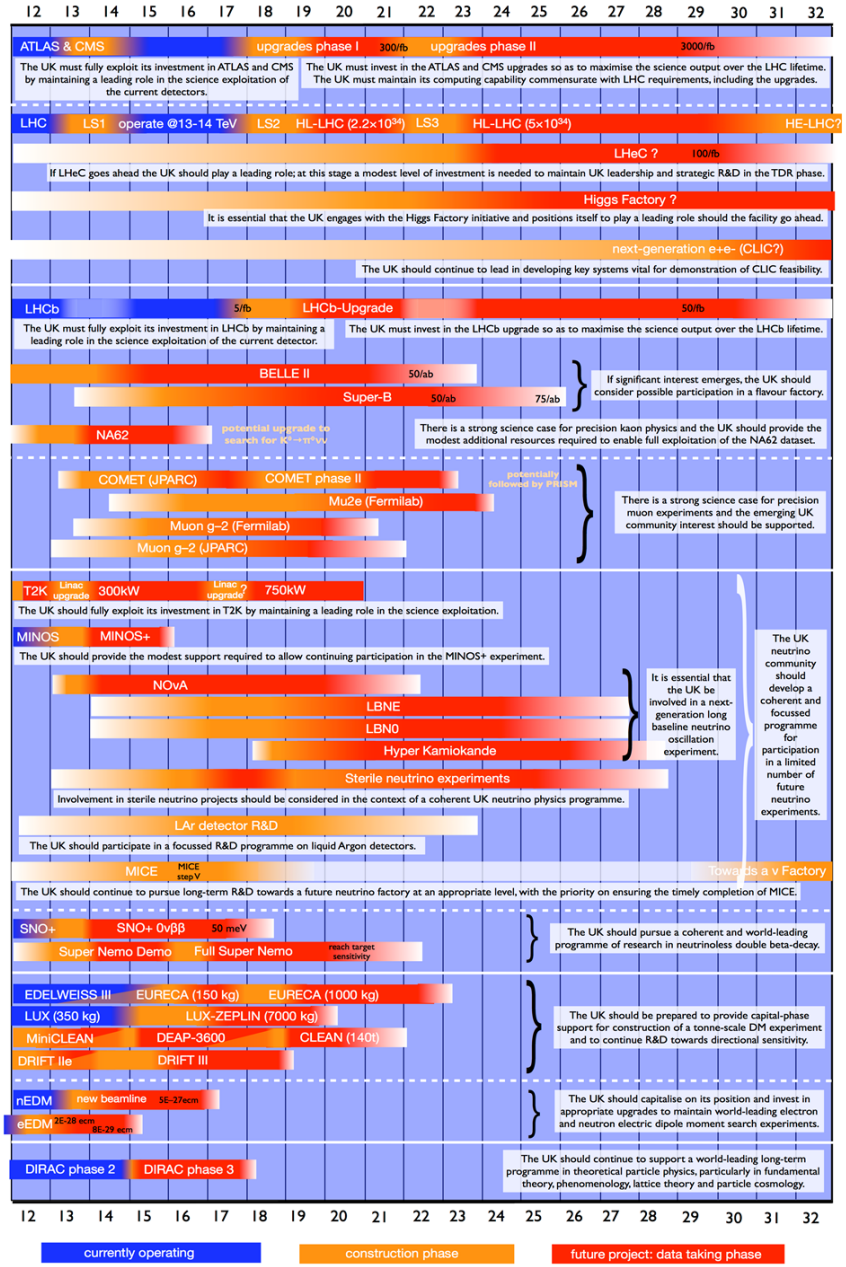
The UK Particle Physics Roadmap

Particle Physics Advisory Panel:

P. N. Burrows, C. Da Via, E. W. N. Glover, P.R. Newman, J. Rademacker, C. Shepherd-Themistocleous, W.J. Spence, M. A. Thomson and M. Wing

7/11/12





- PPAP documents and slides from community meetings are available from our web-page: http://www.stfc.ac.uk/2415.aspx

Recommended `Balanced Programme' from 2012 Roadmap

	Exploitation phase	Upgrade phase	Medium-term construction (operation within c. 10 years)	Design-stage projects; construction decision/start within c. 5 years	R&D for longer-term future projects
Energy frontier	**ATLAS+CMS**	***ATLAS+CMS phase 1 upgrades***	***ATLAS+CMS phase 2 upgrades (HL-LHC)***	*Higgs Factory* *LHeC*	*HE-LHC* *CLIC*
Flavour frontier	**LHCb** NA62	***LHCb upgrade***	*Precision lepton flavour experiment*		
Neutrino frontier	**T2K** MINOS+ SNO+		***Neutrinoless double beta decay experiment***	***Next-generation long baseline experiment*** *LAr detector*	Neutrino factory
Non-accelerator frontier	**EDM searches**		***Dark matter search experiment***		

- `Flagship elements' in bold font
- Smaller scale / other projects where UK leads in normal font
- Projects not yet approved/funded by STFC in italics

… update (not a rewrite) currently in litt.

Agenda of July 2014 Community Meeting

Monday, 21 July 2014

10:30 - 11:00 Coffee

11:00 - 11:40 Introduction and Context

- 11:00 **Introduction and Welcome** *15'*
  Speaker: Paul Newman (The University of Birmingham)
- 11:20 **Science Board and STFC news** *15'*
  Speaker: Dr. Dan Tovey (Sheffield PPPA)

11:40 - 12:30 Theory

- 11:40 **Overview** *20'*
  Speaker: Prof. Simon Hands (Swansea University)
- 12:00 **Formal theory and cosmology** *20'*
  Speaker: Daniel Litim

12:30 - 13:30 Lunch

13:30 - 14:35 Theory

- 13:30 **Phenomenology** *20'*
  Speakers: Prof. Robert Thorne (University College London), Pro London)
- 13:55 **Lattice QCD** *20'*
  Speaker: Christine Davies
- 14:20 **Discussion** *15'*

14:35 - 15:45 High Energy Frontier

- 14:35 **ATLAS - upgrades + future physics programme** *30'*
  Speaker: Phil Allport
- 15:10 **CMS - updgrades and future physics programme** *30'*
  Speaker: Geoff Hall

15:45 - 16:10 Tea

16:10 - 18:15 High Energy Frontier

- 16:10 **Grid Computing** *15'*
  Speaker: Steve Lloyd
- 16:30 **ILC and the CLIC connection** *30'*
  Speaker: Phil Burrows
- 17:05 **FCC + other Future ee/pp Circular Colliders** *20'*
  Speaker: Rob Appleby
- 17:30 **LHeC / lepton-hadron colliders** *15'*
  Speaker: Eram Rizvi
- 17:50 **New Technologies (plasmas, dielectrics, muons)** *20'*
  Speaker: Guoxing Xia

18:15 - 18:55 Discussion *40'*

Tuesday, 22 July 2014

09:30 - 10:45 Neutrinos & non-accelerator programme

- 09:30 **Long-baseline neutrino oscillation experiments** *20'*
  Speaker: Lee Thompson
- 09:55 **Reactor, SBL and PINGU** *20'*
  Speaker: Dr. Justin Evans (University of Manchester)
- 10:20 **UK Dark Matter** *20'*
  Speaker: Prof. Hans Kraus (University of Oxford)

10:45 - 11:10 Coffee

11:10 - 12:40 Neutrinos & non-accelerator programme

- 11:10 **Neutrinoless double-beta decay** *20'*
  Speaker: Prof. David Waters (UCL)
- 11:35 **e and n EDMs** *20'*
  Speaker: Prof. Philip Harris (University of Sussex)
- 12:00 **LSST** *15'*
  Speaker: Ian Shipsey
- 12:15 **Discussion** *15'*

12:40 - 13:40 Lunch

13:40 - 16:00 Flavour Physics

- 13:40 **Introduction and other news** *20'*
  Speaker: Sebastian Jaeger
- 14:00 **LHCb** *30'*
  Speaker: Matt Needham
- 14:35 **NA62 and kaon experiments** *15'*
  Speaker: Dr. Evgueni Goudzovski (University of Birmingham)
- 14:55 **SHIP** *15'*
  Speaker: Andrey Golutvin
- 15:15 **COMET / PRISM / cLFV** *20'*
  Speaker: Ajit Kurup
- 15:40 **Muon g-2** *20'*
  Speaker: Dr. Stephen Maxfield (University of Liverpool)

16:00 - 16:20 Tea

16:20 - 17:10 Discussion

Size and Distribution of UK Community:

[Academics receiving STFC Consolidated Grant Support, 2012]

- 165 Experimental Particle Physics academics from 18 groups received support in the 2012 Grants round, distributed approximately as:

ATLAS	71
CMS	15
LHCb	24
Long Baseline Neutrinos	16
$0\nu\beta\beta$	12
Other experiments	14
Detector R&D	9
Accelerator R&D	5

- Royal Society URFs / STFC Rutherford / ERC Fellows excluded
- RAL PPD excluded

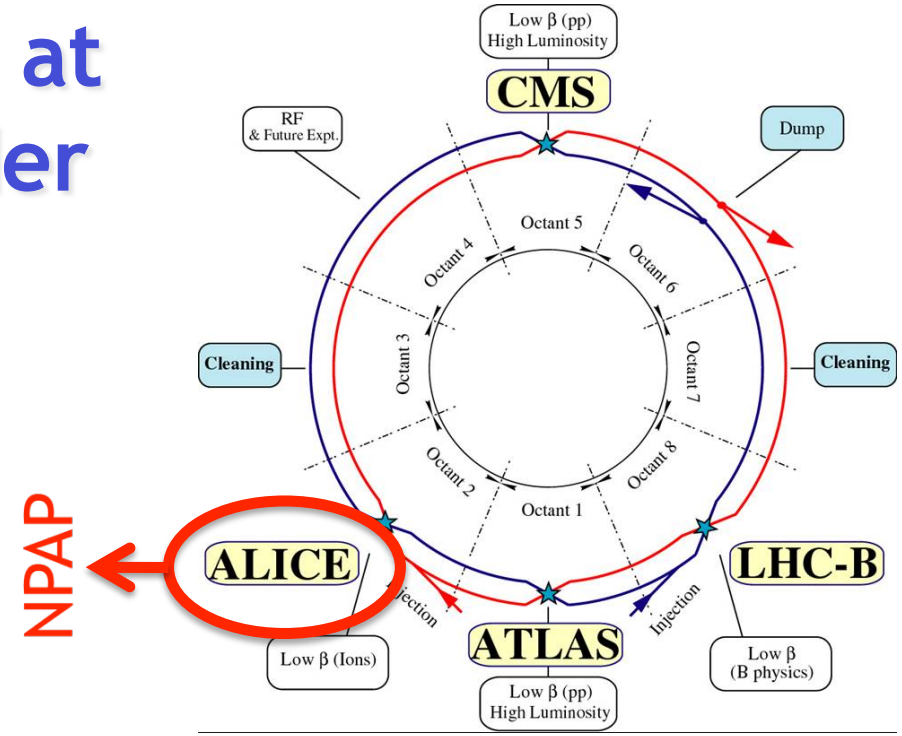
Experiments / Upgrades at the Large Hadron Collider

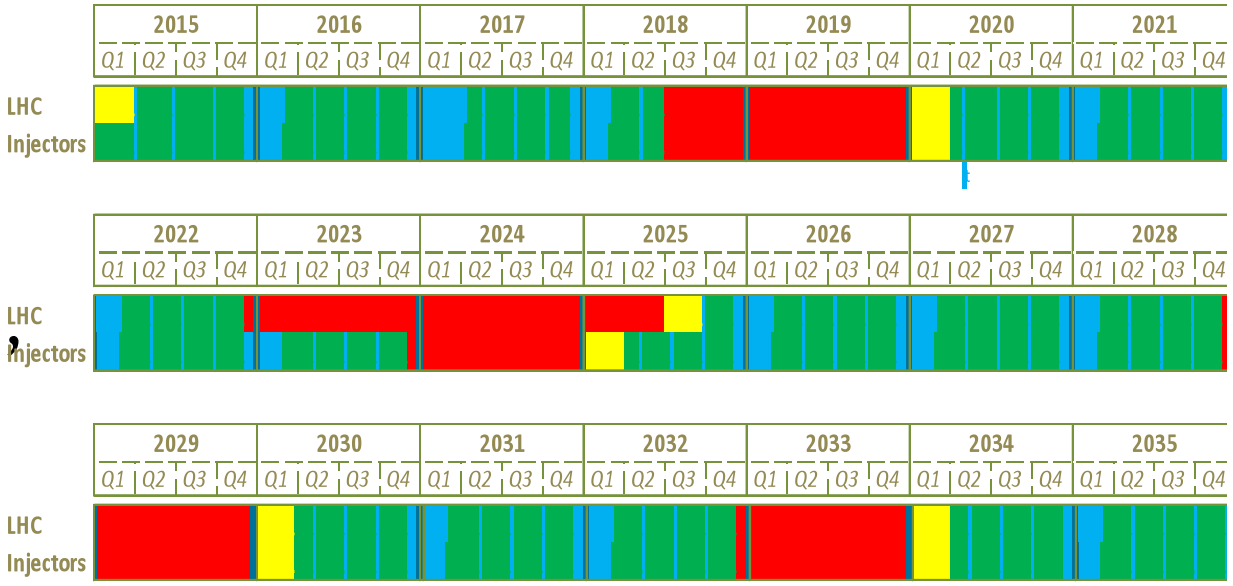
- Very strong UK coordination, technical and data analysis contributions to ATLAS, CMS, LHCb

- 20+ year programme just starting

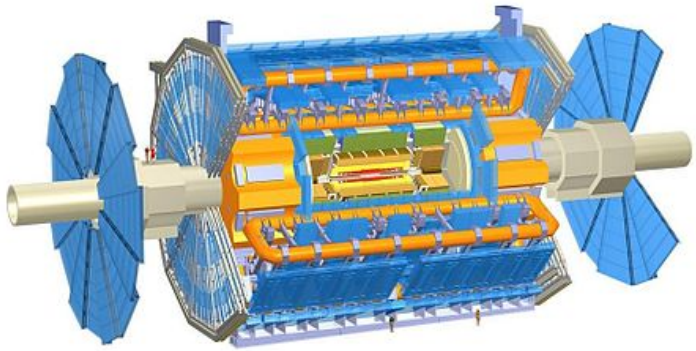
- Current detectors designed for 10 years at $10^{34}\,cm^{-2}s^{-1}$ and $<\mu>=23$.

- Still performing well beyond this specification, but have limited life and will certainly not handle HL-LHC $<\mu>=140$





ATLAS



Institutes: Birmingham, Cambridge, Edinburgh, Glasgow, Lancaster, Liverpool, QMUL, RHUL, UCL, Manchester, Oxford, RAL, Sheffield, Sussex, Warwick
[largest UK activity by some distance …
~300 authors: 10% of collaboration]

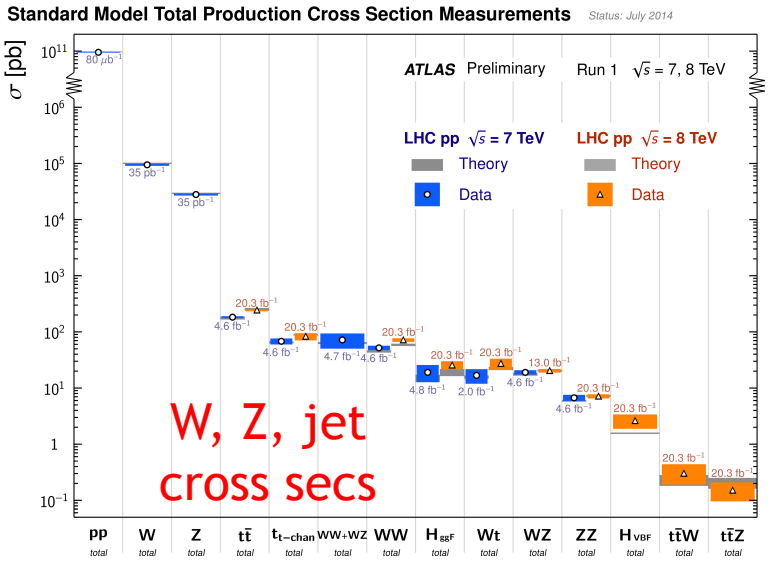
Leadership: Current spokesperson (ex deputy, physics coord), current physics coordinator, upgrade coordinator, project leaders for major detector components, working group conveners …

Main UK Responsibilities: UK delivered substantial parts of Tracking, Triggers, DAQ, Computing and Software in 2008.

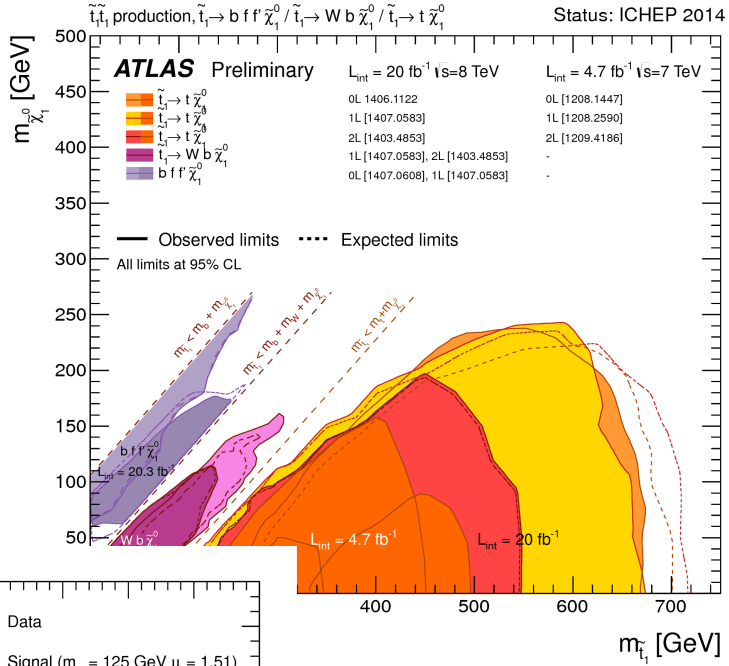
Substantial contributions in all areas since.

ATLAS Physics

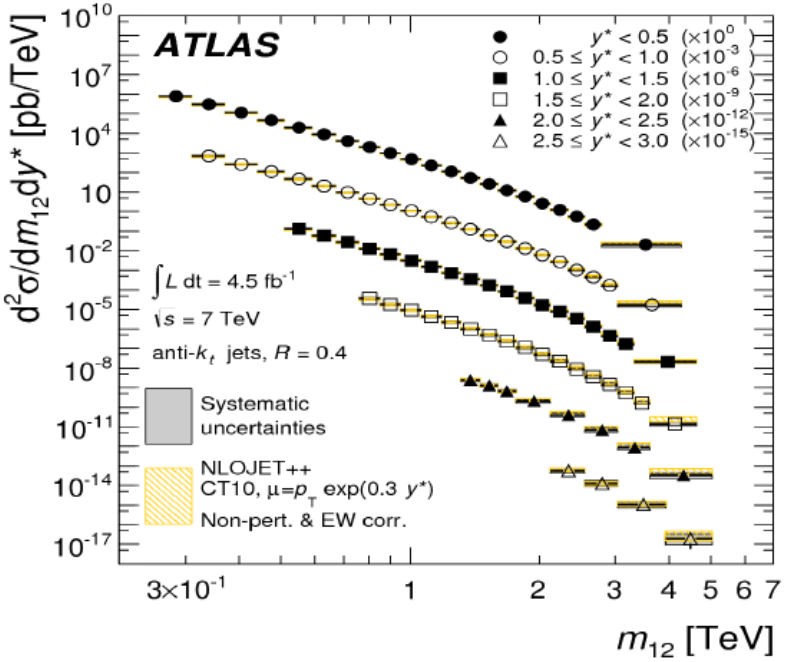
Strong UK participation in seminal physics results: from Standard Model, top & bottom, to exotics, via major roles in several Higgs channels

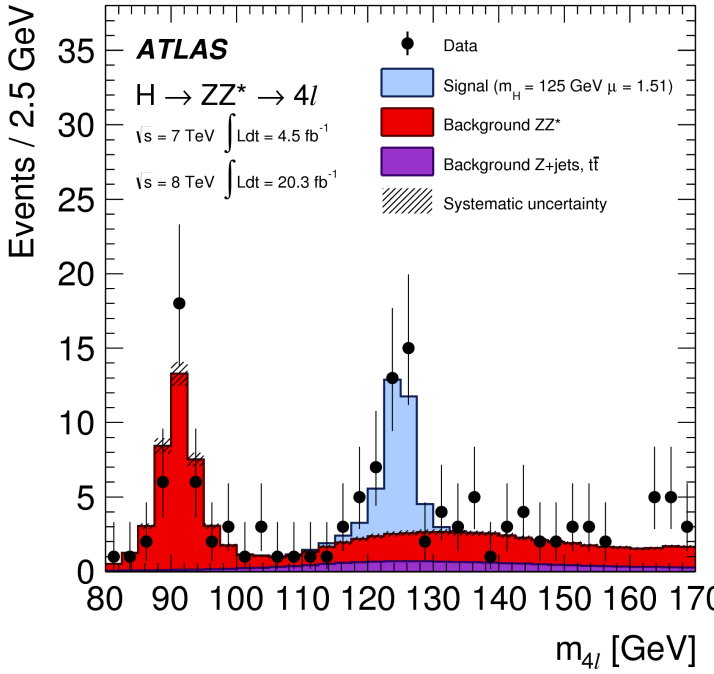


W, Z, jet cross secs



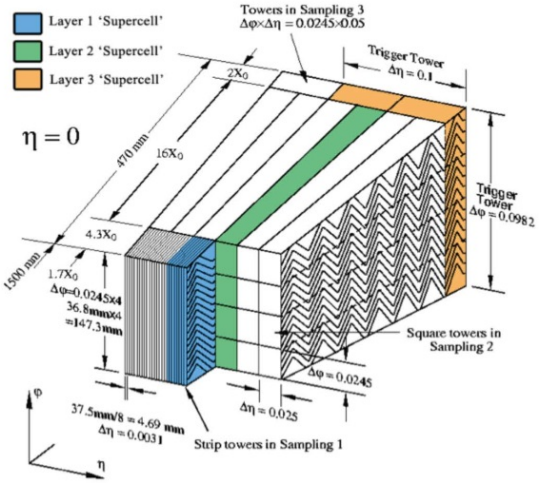
Top, SUSY

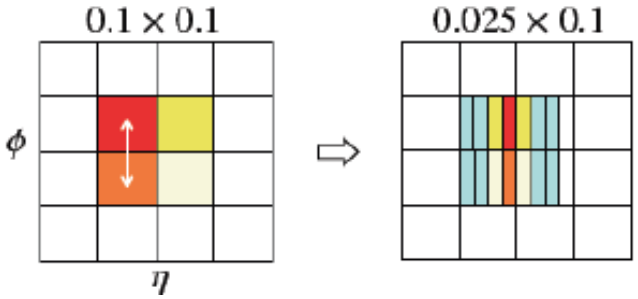




H → 4l

ATLAS 1st Level Calorimeter Trigger (Phase 1 and 2)



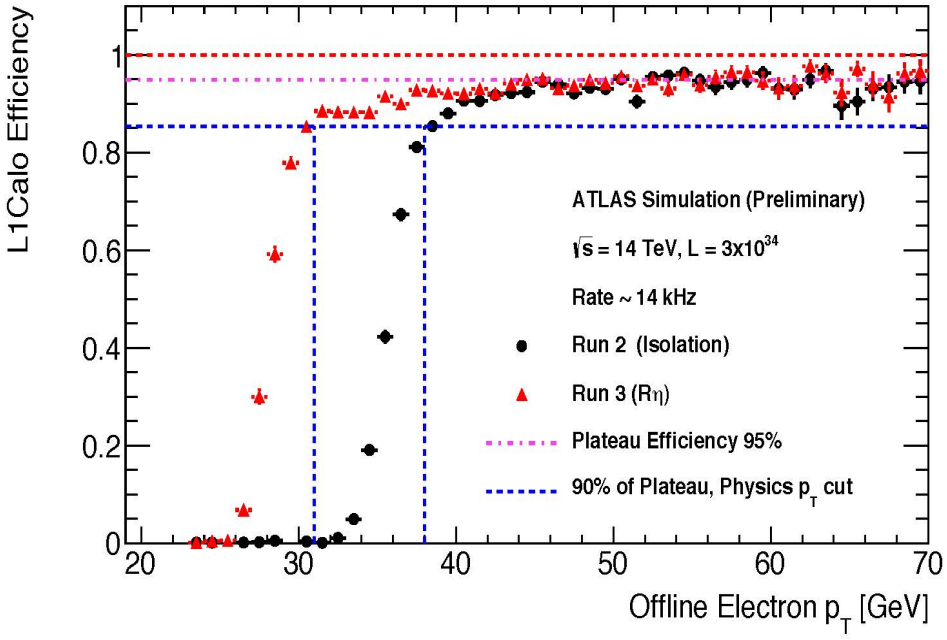


- Currently working towards phase 1 upgrade with increased granularity and topological capabilities → maintain efficiency at acceptable p_T threshold (~ 25 GeV for electrons)

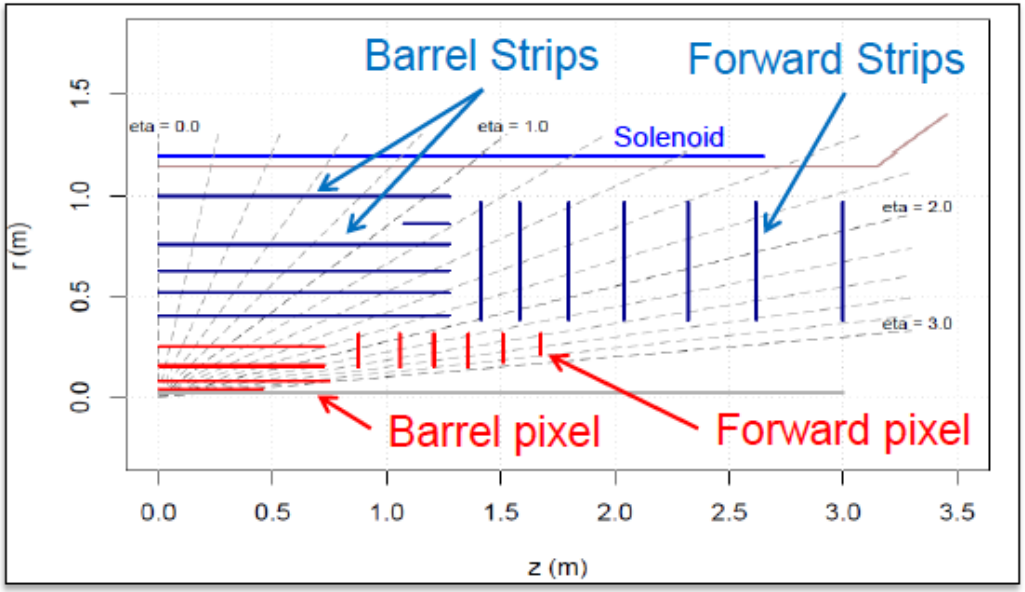
- Challenging front-end electronics and firmware

- Phase 1 L1 system designed to be capable of becoming phase 2 L0 …

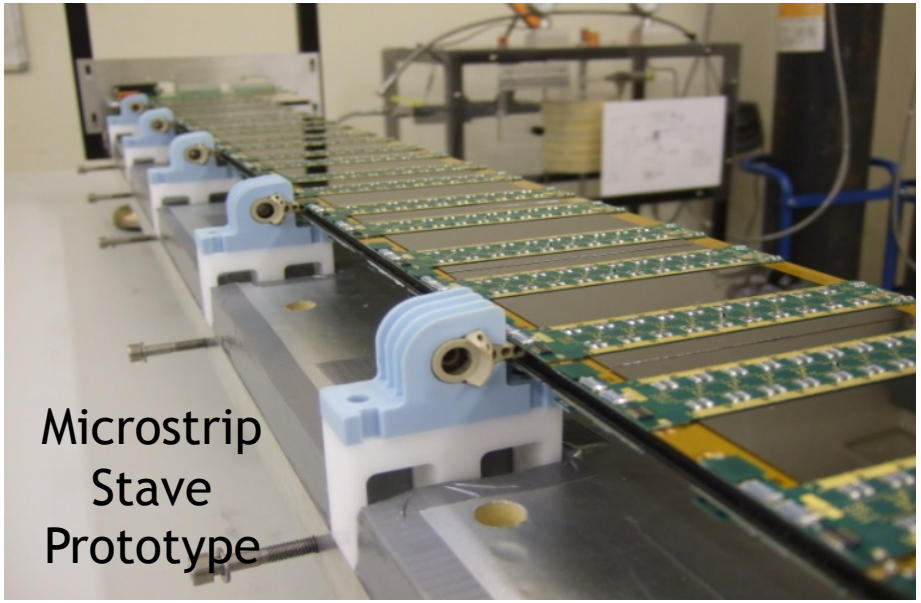
plans under discussion …

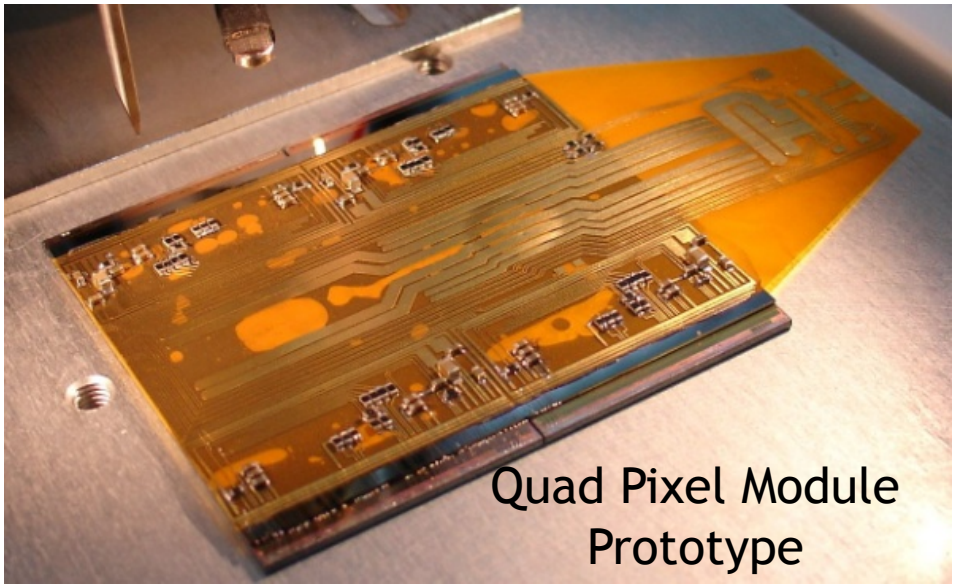


ATLAS All-Silicon Inner Tracker (Phase 2)



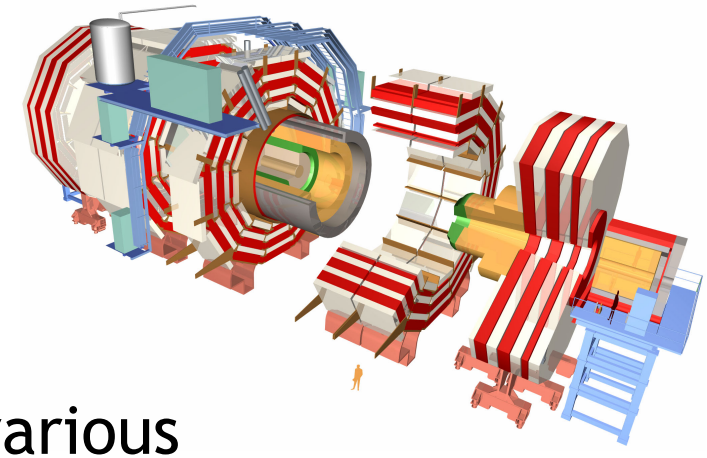
UK leading in multiple aspects of design, assembly, interfacing, radiation testing





Also active in track trigger, higher-level trigger and computing pgrades at phases 1 and 2.

CMS

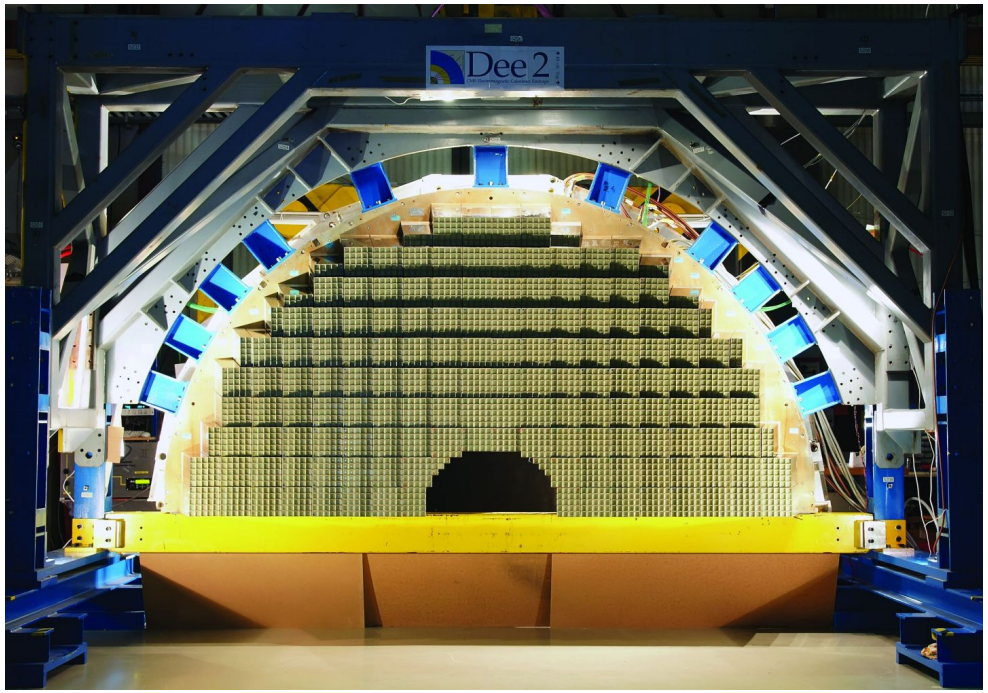


Institutes: Bristol, Brunel, ICSTM, RAL

Leadership: Ex-spokesperson / deputy, various ECAL, tracker and physics project management roles.

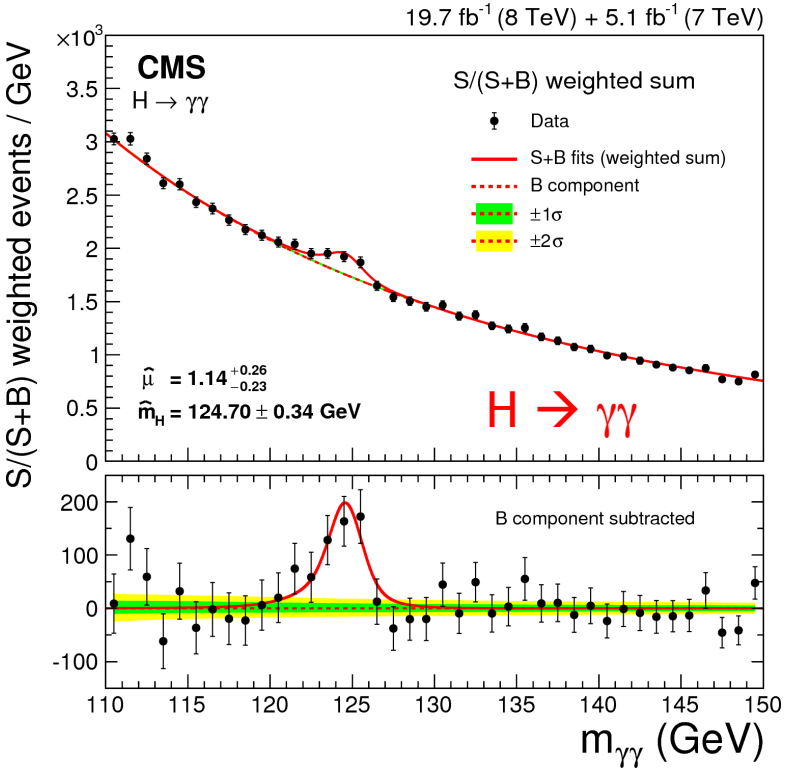
Main UK Responsibilities:

- End-cap crystal calorimeter,
- Front-end electronics for tracker and ECAL,
- Calorimeter trigger
- Software and physics

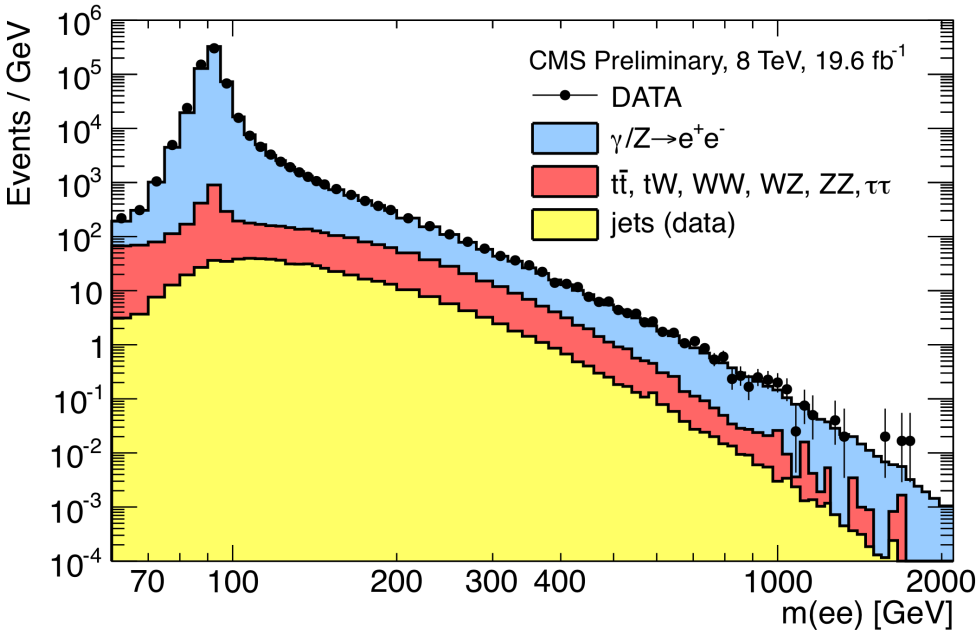


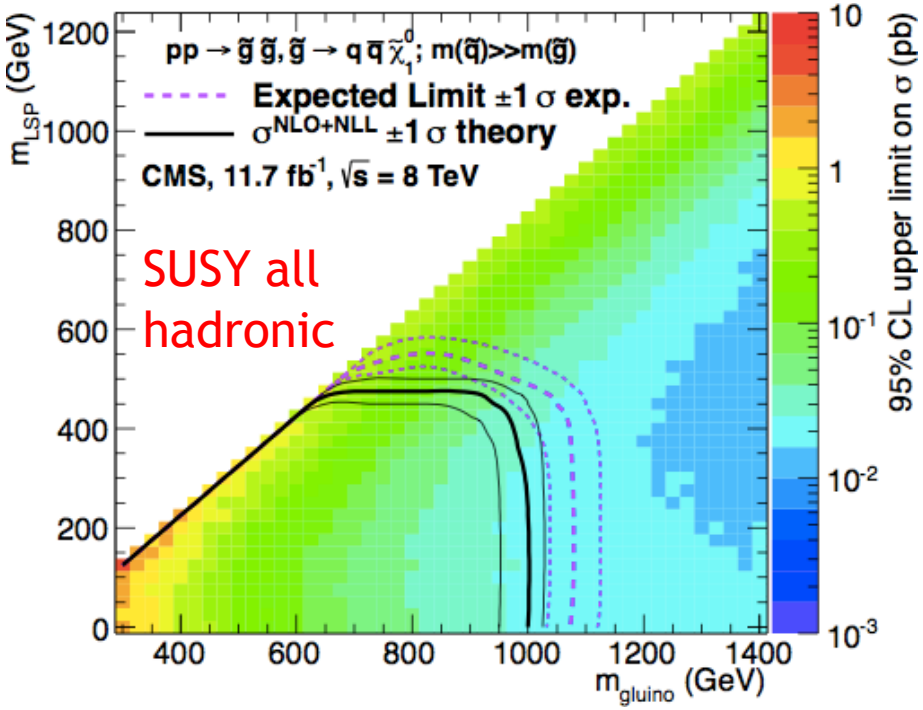
CMS Physics

Significant UK physics contributions in diverse areas (Higgs, SUSY, W', Z', exotics …)



Z' search

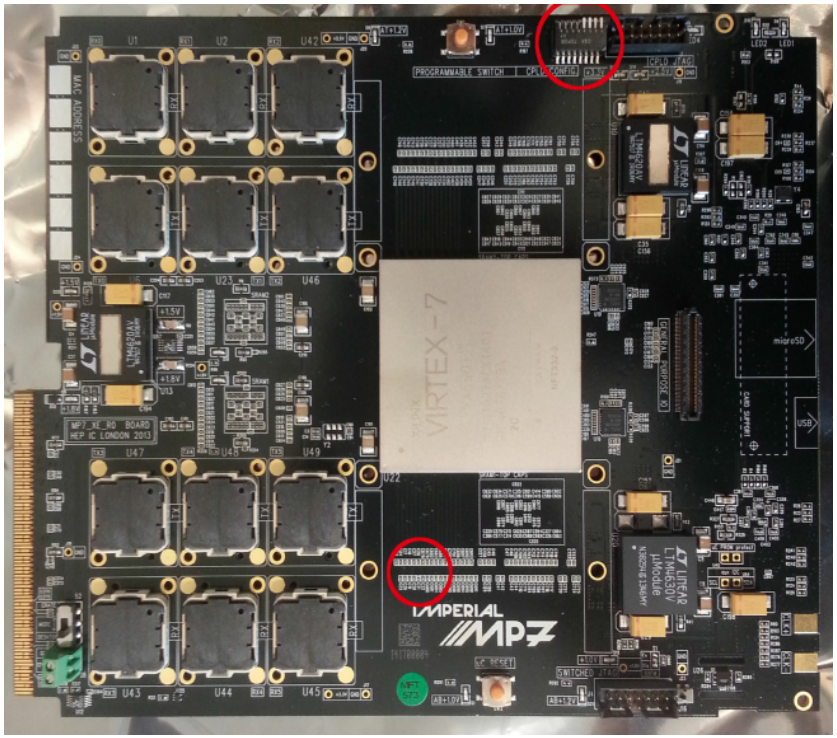




CMS Upgrades

UK has leading role in Phase 1 calorimeter trigger upgrade

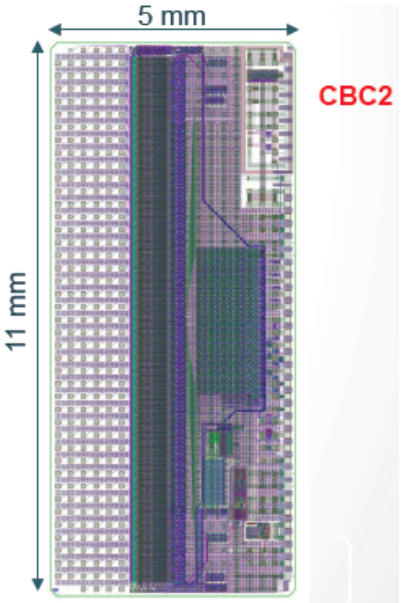
- MP7 state-of-the-art electronics processing board
- New-concept time multiplexing trigger system



- Total bandwidth >0.9Tb/s.

- Tested, Currently in production

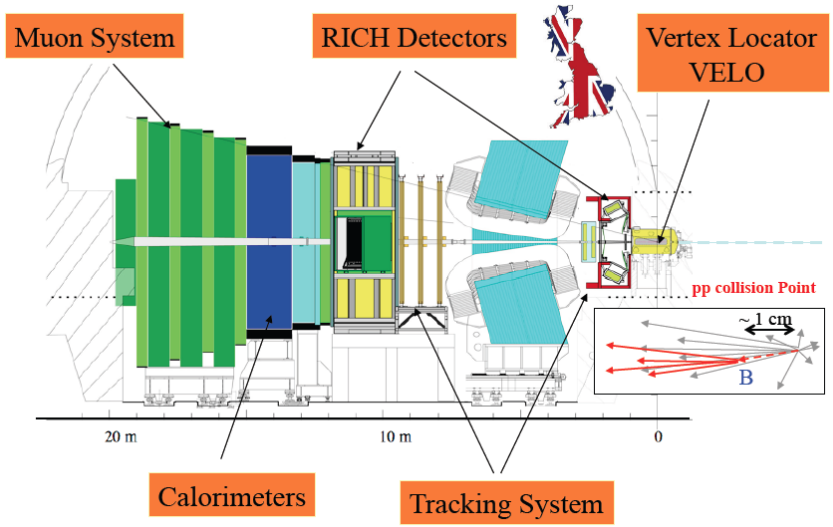
- Algorithm development well advanced



- Phase 2 upgrade R&D on trigger and tracker
  - … CBC ASIC and 2S module
  - … only phase 2 SMS ASIC in existence.

LHCb

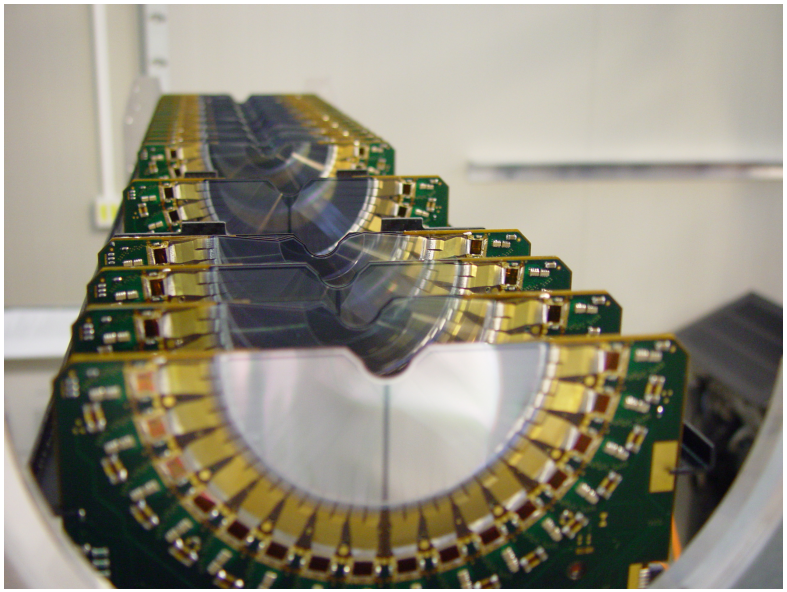
Institutes: Birmingham, Bristol, Cambridge, Edinburgh, Glasgow, ICSTM, Liverpool, Manchester, Oxford, RAL, Warwick



[UK flagship flavour physics experiment (~20% of collaboration)]

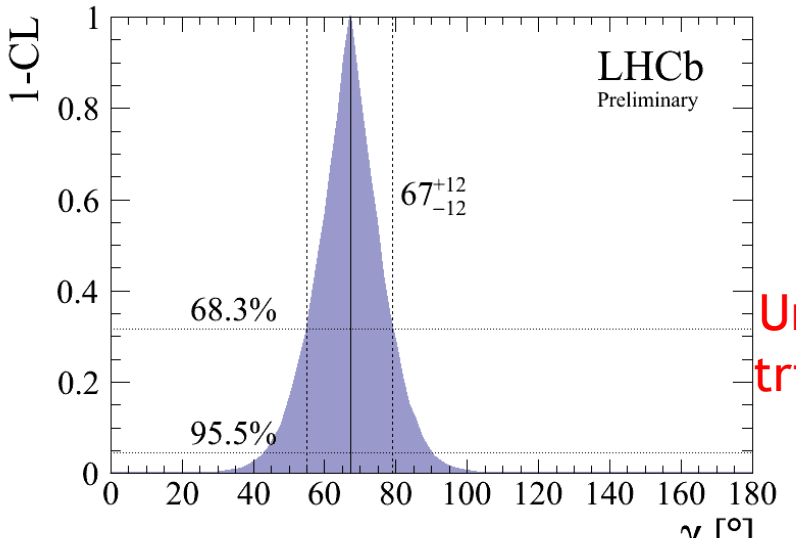
Leadership: Current and previous spokespersons, two former physics coordinators, 30% of physics group coordinators

Main UK Responsibilities: Led construction and now operation of VELO and RICH (current project leaders are from UK)



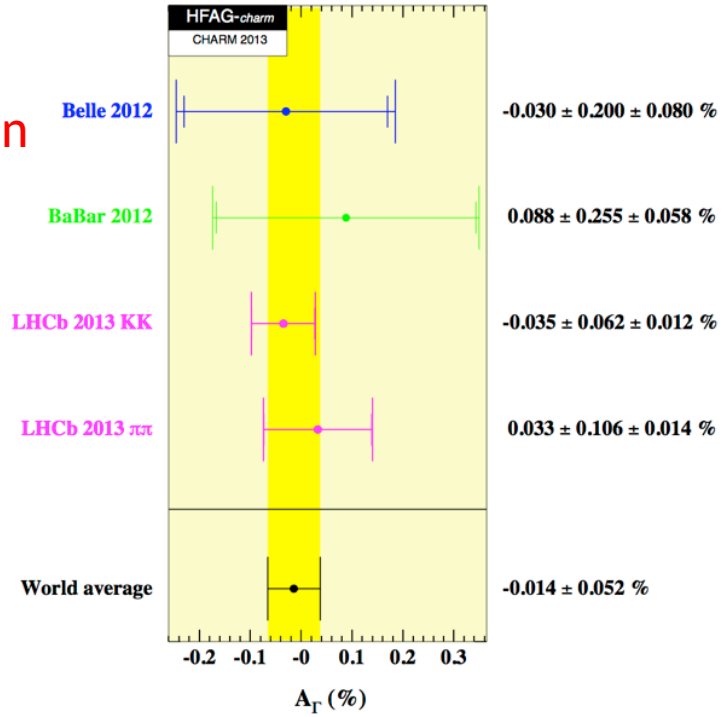
UK Contributions to LHCb Physics

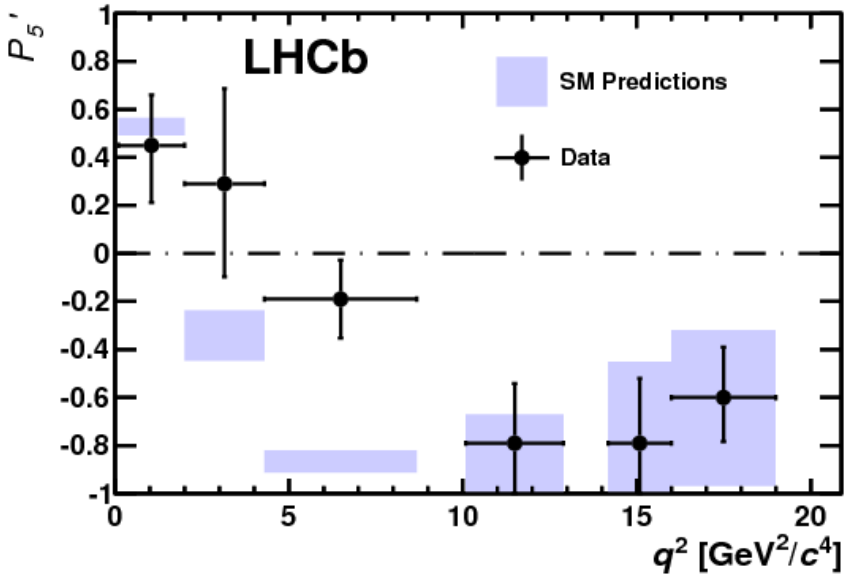
Leadership of analysis across a wide range of topics.



Unitarity triangle γ

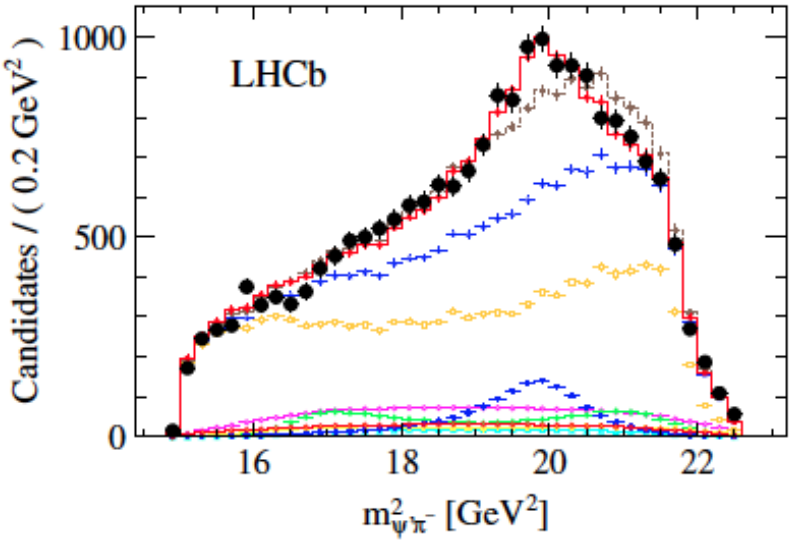
CP violation in charm sector



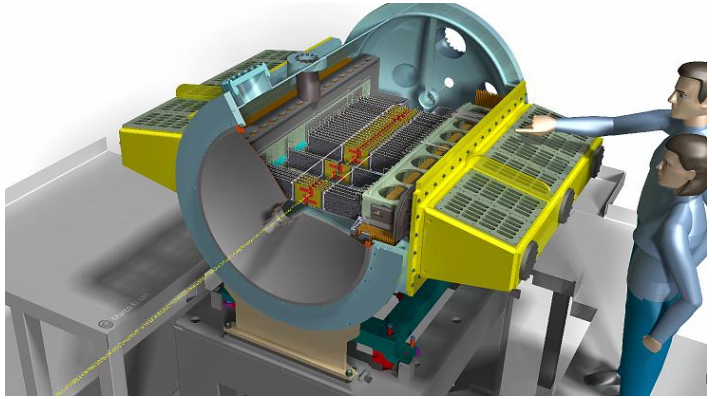


Rare decays ($K^{*0}\mu^+\mu^-$ anomaly)

Z(4430) tetraquark

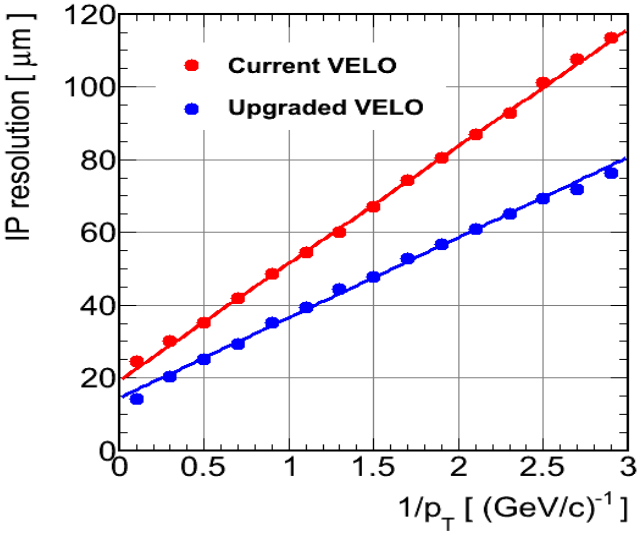


UK-Led LHCb Phase 1 Upgrades



VELO / Pixels

$(55\ \mu m)^2$ pixels,
5mm from beam
10^{16} protons/cm^2
fluence

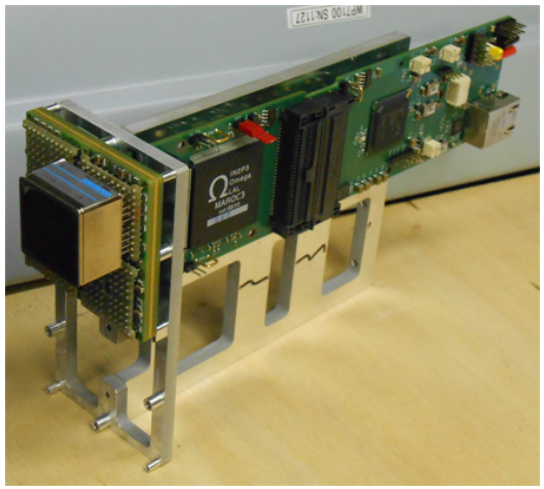


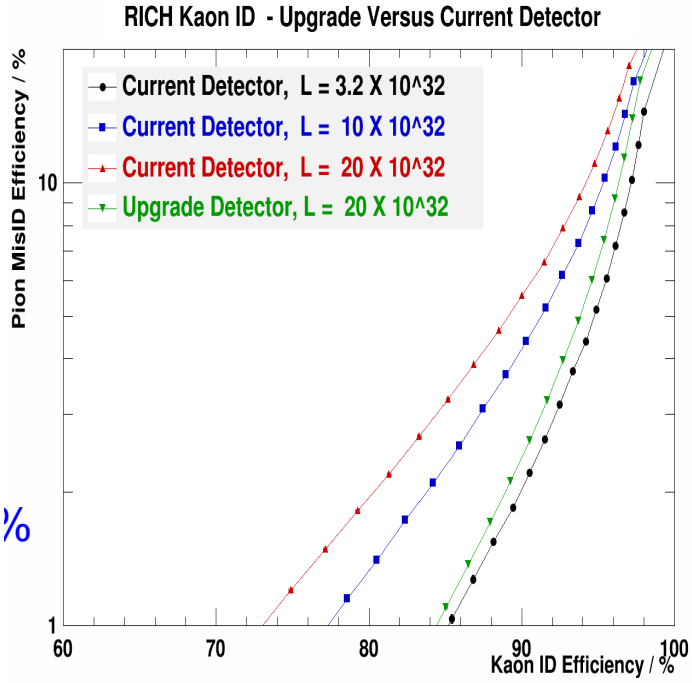
Microchannel cooling … `most advanced silicon pixel tracking detector ever'

RICH

Challenge of high occupancy …

- New mechanics / mirrors
- New photodetectors
- New readout electronics



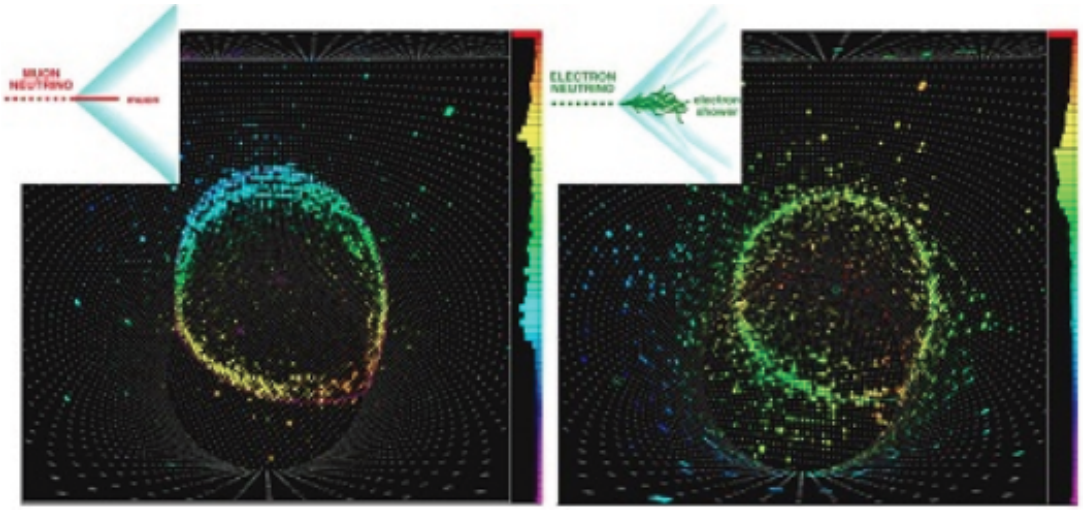


Long Baseline Neutrino Physics

A topic where the UK has a leading position, in …

- Current experiments (T2K, MINOS+)
- Possible major future facilities (Hyper-K and LBNF(E)), addressing mass hierarchy and CP violation, with start-dates ~2025,
- Development of detector technologies (e.g. CHIPS → Cerenkov detector using naturally abundant water for target / support)

CHIPS-M
Model detector



e/μ separation at SuperK

T2K

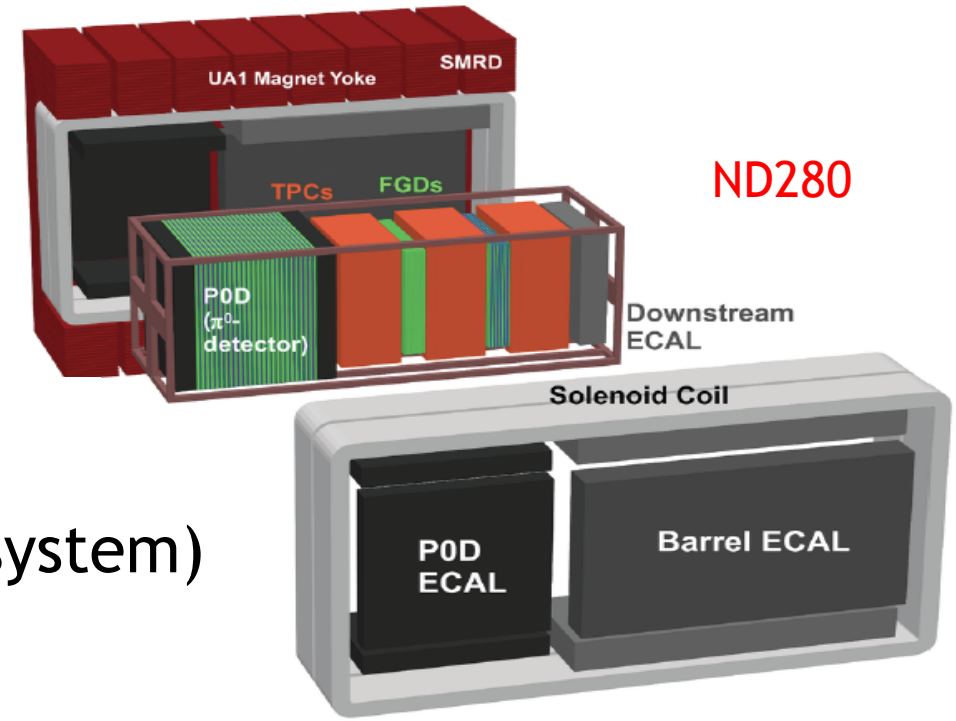
Institutes: Daresbury, ICSTM, Lancaster, Liverpool, Oxford, QMUL, Sheffield, RAL, Warwick

[Water-based far detector at Super-K, 220 → 750kW beam]

Leadership: Ex-international co-spokesperson, 17 current working group conveners ...

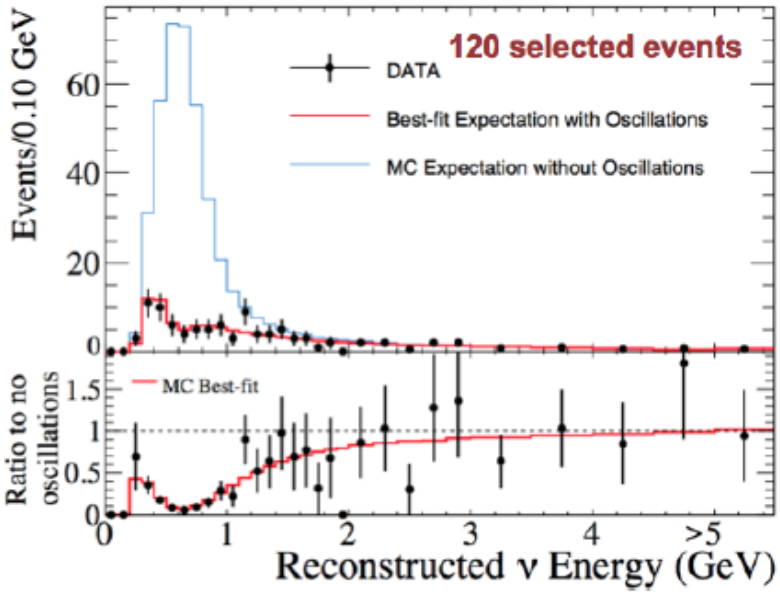
Main UK Responsibilities:

- Near detector electronics, DAQ, ECAL.
- Beamline (beam dump / target system)
- Data analysis

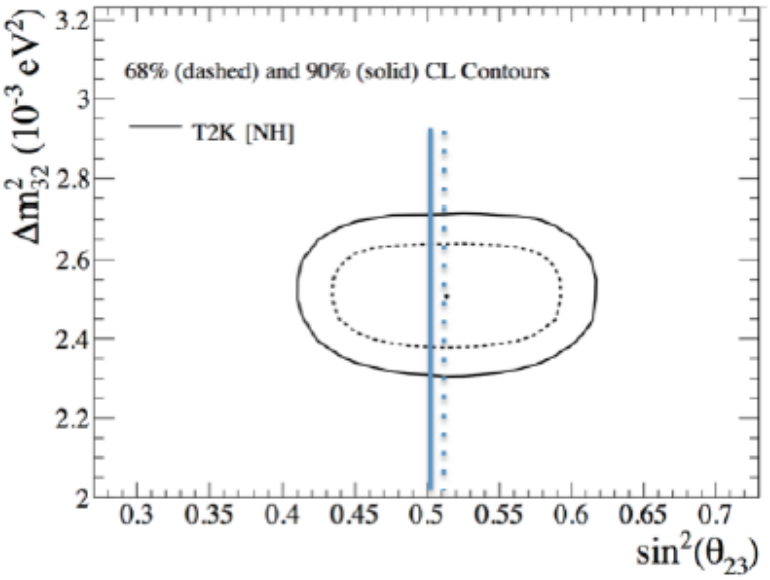


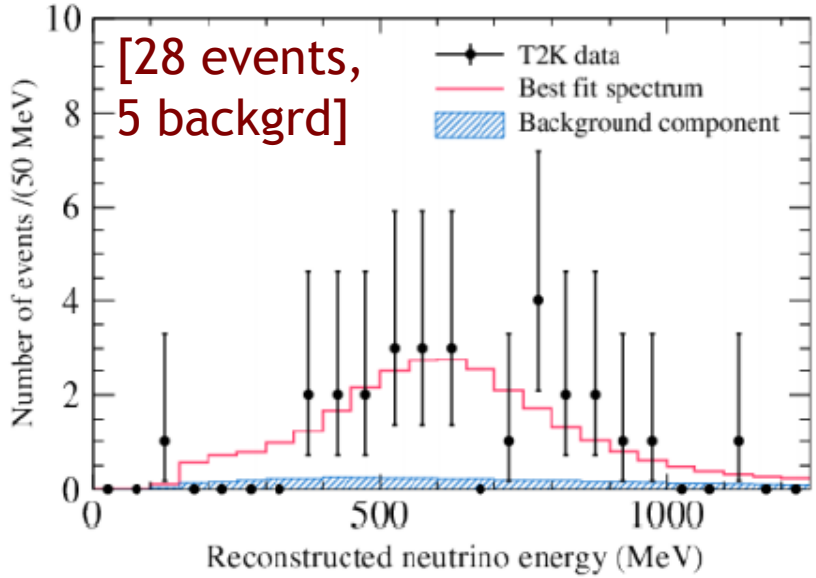
ND280

T2K Physics

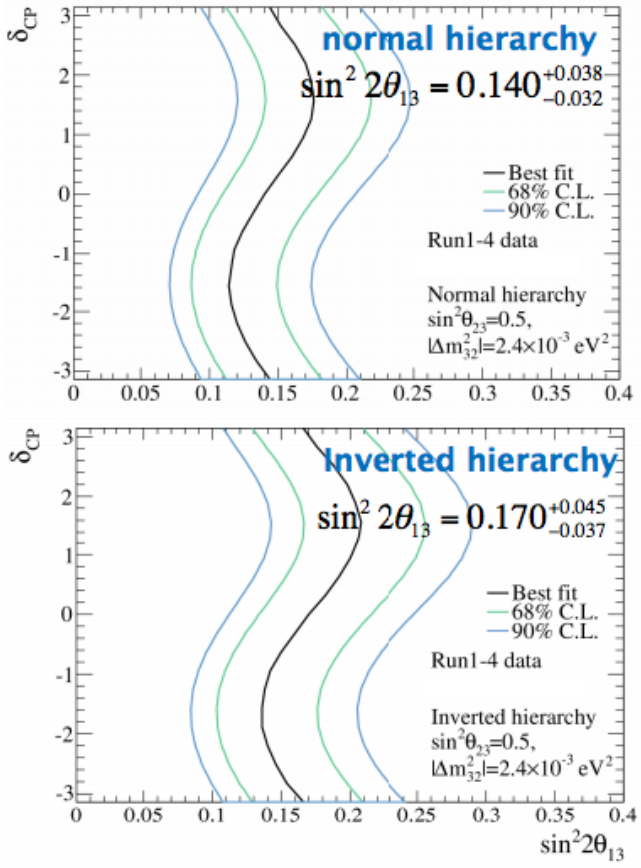


ν_μ disappearance
→ $\sin^2\theta_{23}$, Δm^2_{23}





ν_e appearance
(first such
observation)
→ $\sin^2\theta_{13}$
→ $\Delta m^2_{13} \sim \Delta m^2_{23}$
→ some δ_{CP}
sensitivity



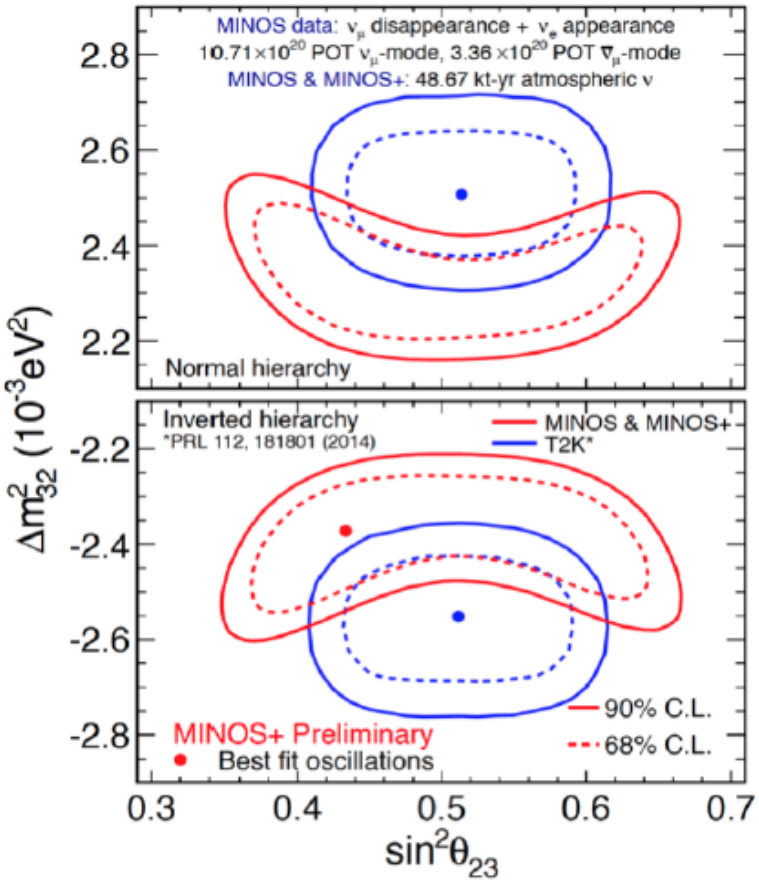
Minos / Minos+ (steel/plastic scintillator)

Institutes: Cambridge, Oxford, RAL, Sussex, UCL

Leadership: Current spokesperson

Main UK Responsibilities:
DAQ, electronics, PMT testing, light injection

Minos+ currently taking data using higher energy NUMI beam



Nova (liquid scintillator)

Institutes: Sussex

[Restarted running October 2014].

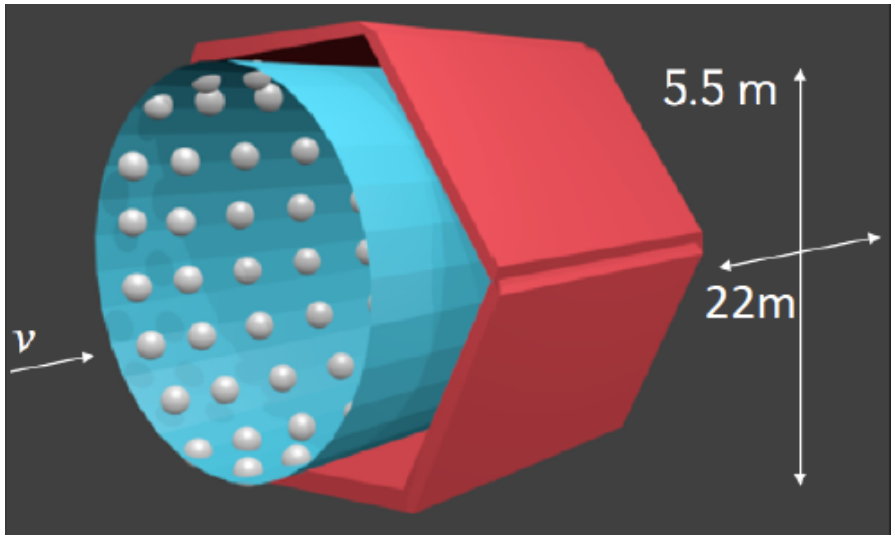
UK Responsibility: Data driven trigger, stopping muon calibration, data analysis.

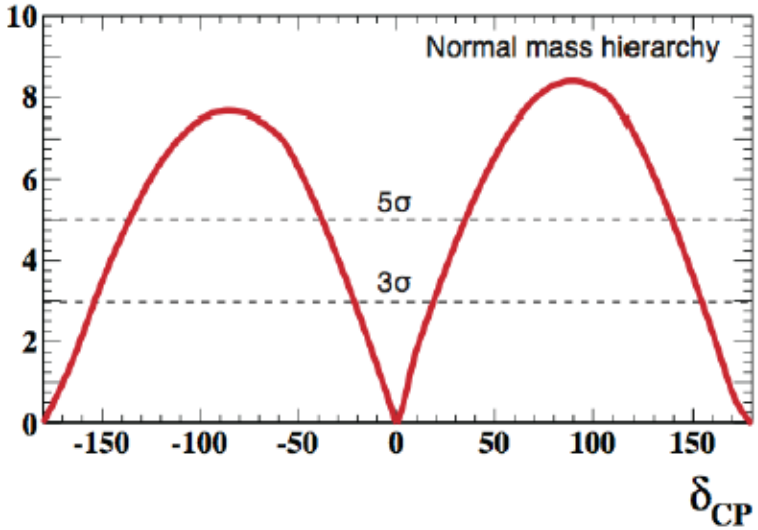
Future Long Baseline: Hyper-K

Institutes: Edinburgh, ICSTM, Lancaster, Liverpool, Oxford, QMUL, RHUL, Sheffield, RAL, Warwick

~ Mtonne far detector (water)
with current 0.75MW beam → ~3500 ν_e appearance events in 10 years

Main UK Interests:
Near detector, high pressure TPC





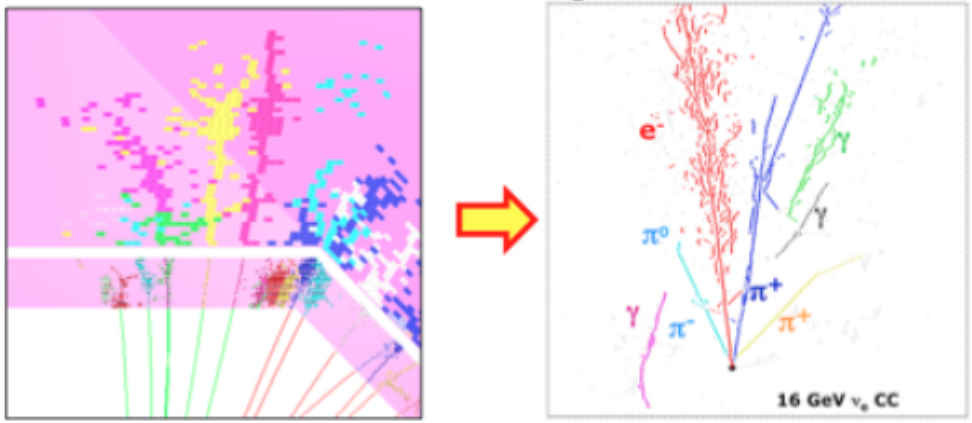
Assuming 7.5×10^7 MW sec:

- CP violation can be observed at
  - **3σ** for **76%** values of δ
  - **5σ** for **58%** values of δ
- δ can be measured with
  - 8° precision for δ = 0
  - 19° precision for δ = π/2

Future Long Baseline: LBNE(F)

Institutes: Cambridge, Lancaster, Liverpool, Manchester, Oxford, Sheffield, RAL, Sussex, UCL, Warwick

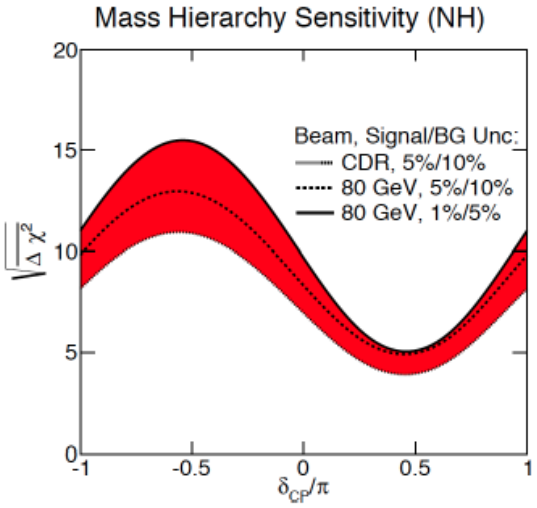
10-35 ktonne far detector (LAr TPC) with 1.2 - 2.3 MW beam

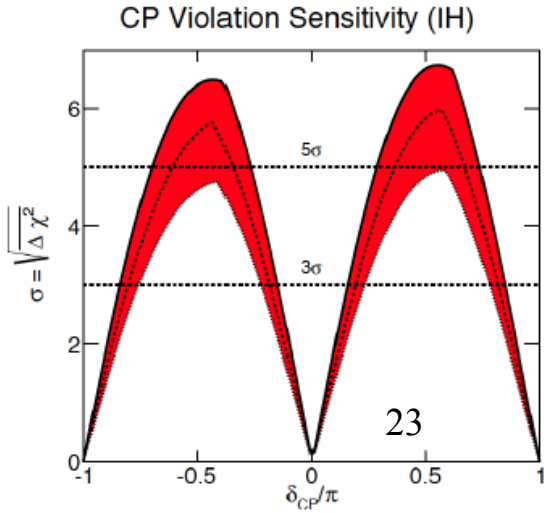


Main UK Interests:
Event reconstruction (PANDORA), DAQ, prototypes, APA/CPA frame for TPC

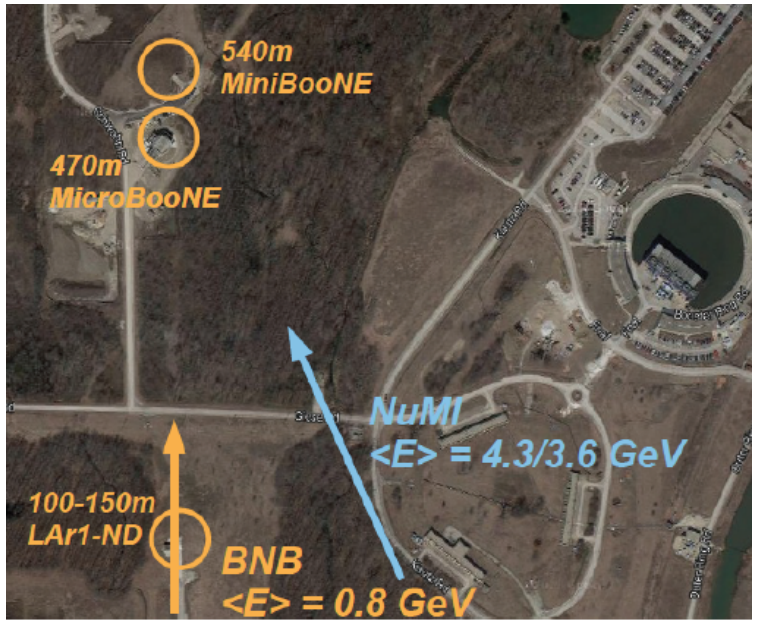
-35 tonne LAr prototype planned for 2015

- UK also involved in WA105 and LAr1-ND …





Microboone / LAr1-ND



Institutes: Cambridge, Lancaster, Liverpool, Manchester, Oxford, Sheffield, UCL

Short baseline neutrinos (470m, 100m)
→ sterile ν

LAr1-ND 82 tonne near detector is also a vital LAr TPC prototype for LBNE/F

Leadership and Responsibilities:

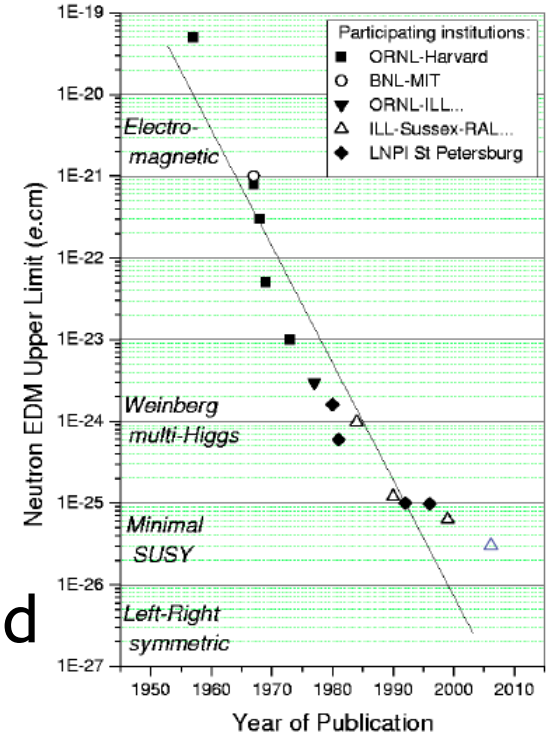
- M'boone TPC construction project manager
- Plans to build TPC for LAr1-ND.
- Also cosmic muon veto system, reconstruction software …

Other / Smaller-Scale Experiments

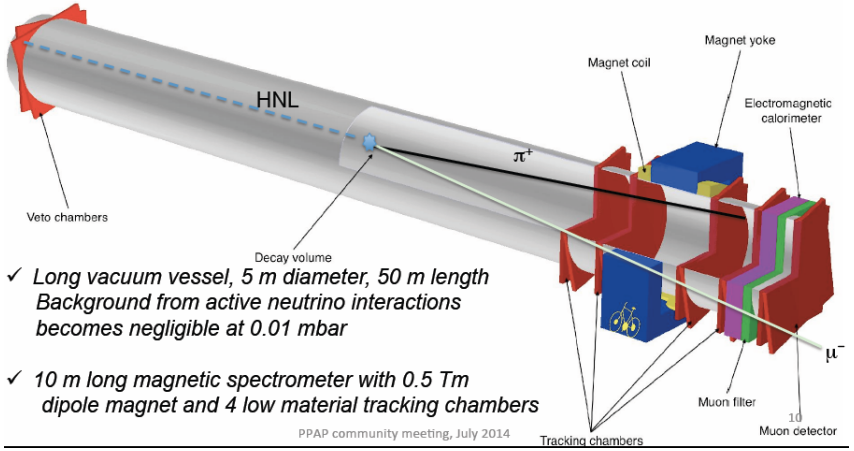
… offering high rewards at `high risk' and relatively modest cost.

PINGU: Atmospheric neutrinos with sensitivity to sterile neutrinos / neutrino mass hierarchy &
UKDM Dark Matter Searches → PAAP

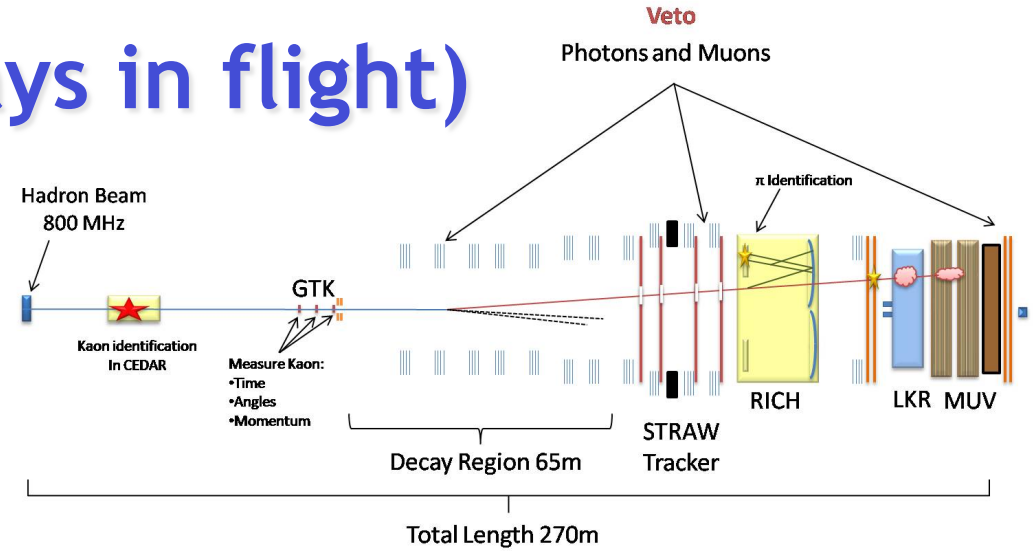
Electron and Neutron EDMs: UK has history of world-leading measurements.
- Ongoing / reorganised work in UK and abroad



SHIP: Hidden particles (eg dark photons, massive ν) in SPS beam-dump experiment.
… UK led and interest developing from several institutes…
… still to be evaluated



NA62 (Rare Kaon Decays in flight)

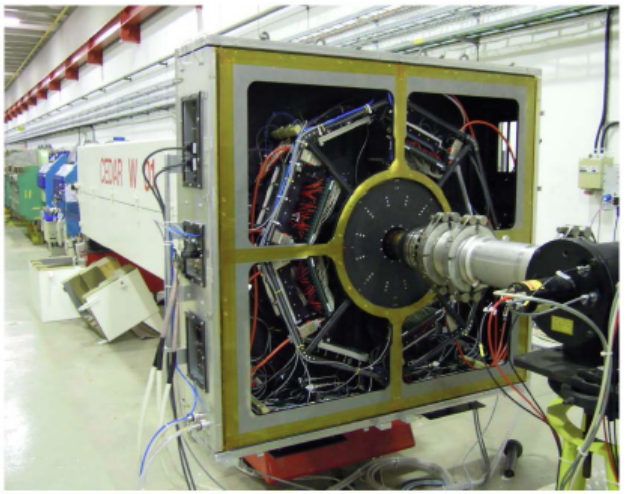


Following work on NA48 ++

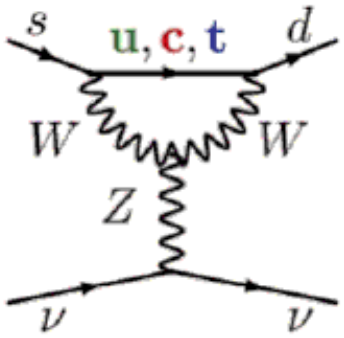
Institutes: Birmingham, Bristol, Glasgow, Liverpool

-$K \rightarrow \pi\nu\nu$ (SM BR < 10^{-10}), aiming for 100 events in 3 years, with 20% background.
- Also LFV, LFU, dark photons, heavy ν …
- Operation starting now …

CEDAR+KTAG installed in the beam line



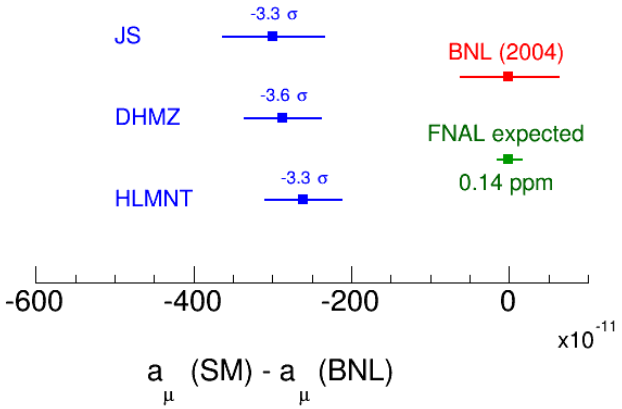
Main UK Responsibilities:
- Kaon identification detector fully UK built
- First level Muon trigger delivered
- Trigger and clock distribution
- Overall data analysis and software coordination



g-2 (polarised μ @ FNAL)

Institutes: Cockcroft, Liverpool, Oxford, UCL

- Will probe BNL a_μ anomaly with 4x better precision using 1.6×10^{11} polarised μ decays starting 2016/17



Sensitive to broad range of BSM interactions


BNL ring now in new building at FNAL


32 channel straw tracker prototype

Main UK Responsibilities:

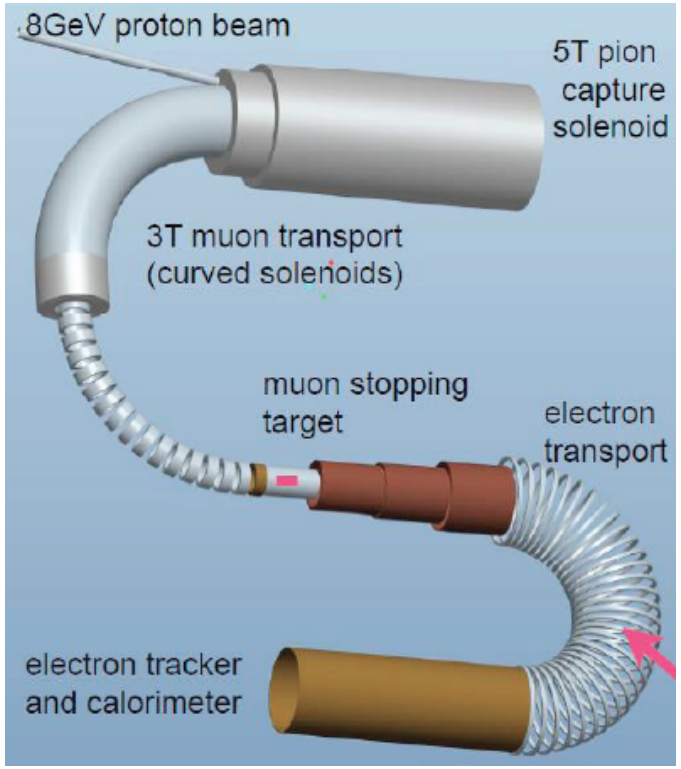
Straw trackers, BE readout, DAQ

^{3}He magnetometer → absolute B-field

Sim^n & systematics of beam dynamics

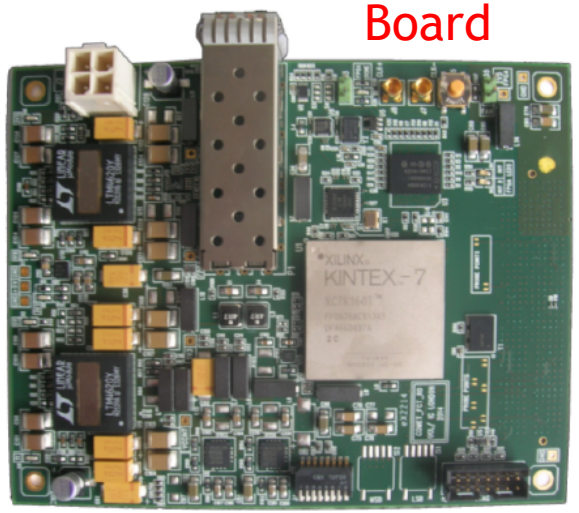
Charged Lepton Flavour Violation (COMET / PRISM @ J-PARC)

Institutes: Cockcroft, ICSTM, Manchester, RAL, UCL



- Stopped muon → electron (μ A → e A)
  - $<10^{-50}$ in standard model
  - $\sim 10^{-13}$ in some BSM theories
- Phase 1 physics runs from 2016
  - → 3.10^{-15} sensitivity in 90 days
- Phase 2 from 2020 → $<10^{-16}$ sensitivity
- R&D for PRISM in parallel.

Fast Control Board



Leadership and Responsibilities:

- CB Chair, trigger, readout, software and proton target coordinators, beamline and beam monitoring.
- Leading PRISM task force

Neutrinoless Double Beta Decay

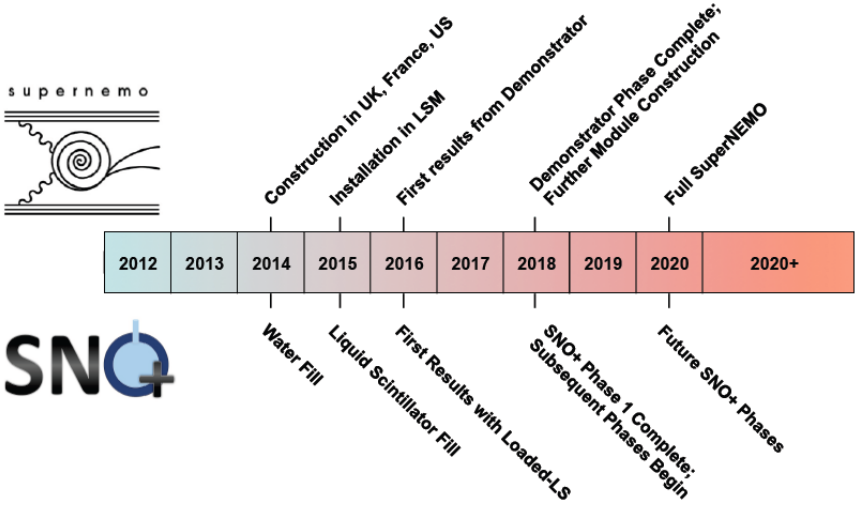
- Building on previous work: SNO, NEMO3 …

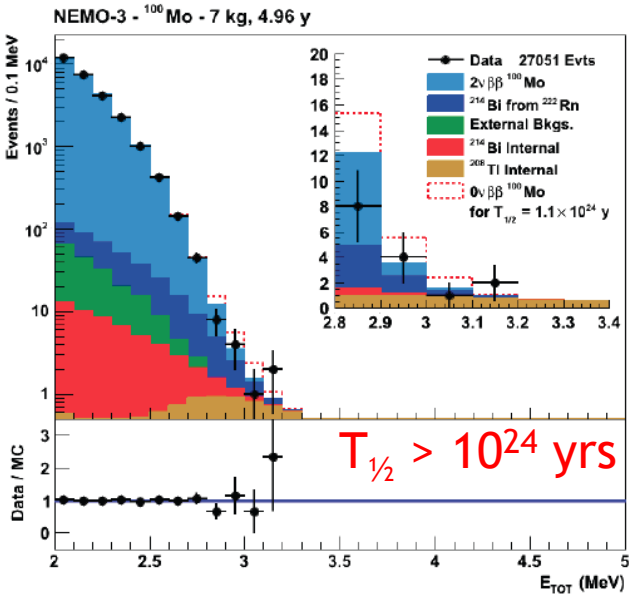
- Two complementary experiments on similar timescales:

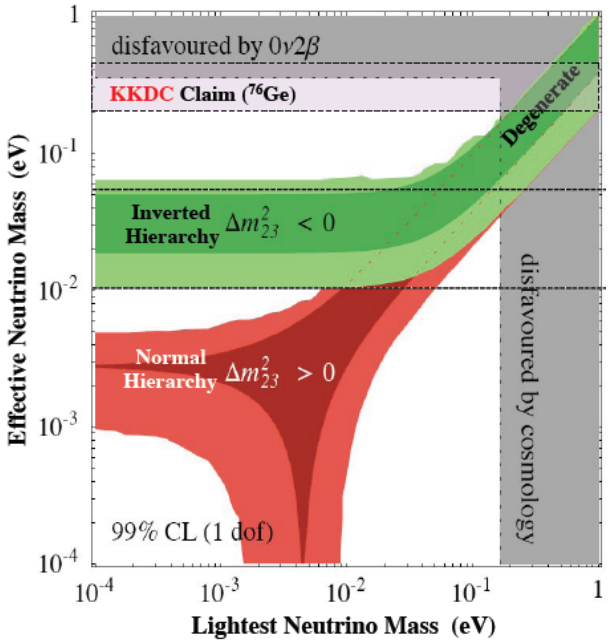
  SNO+ (largest isotope mass)

  SuperNEMO (lowest background).

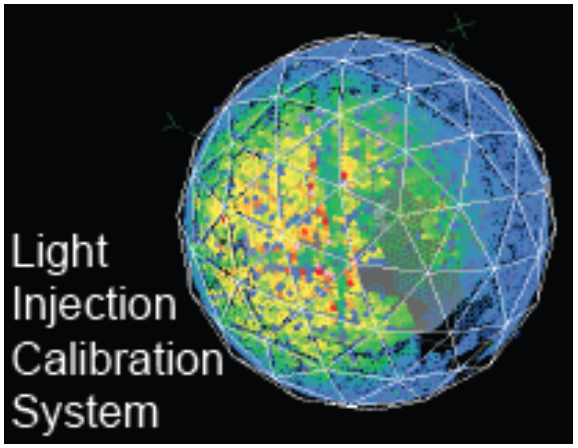
- First phase starts to explore inverted hierarchy region, future phases may cover it in full,







Neutrinoless Double Beta Decay

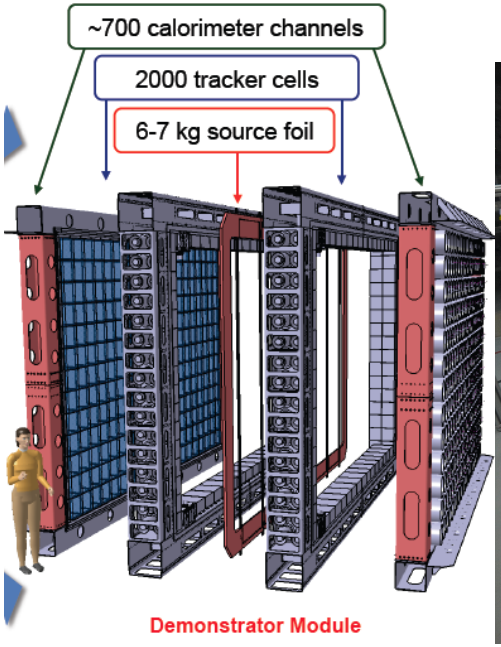


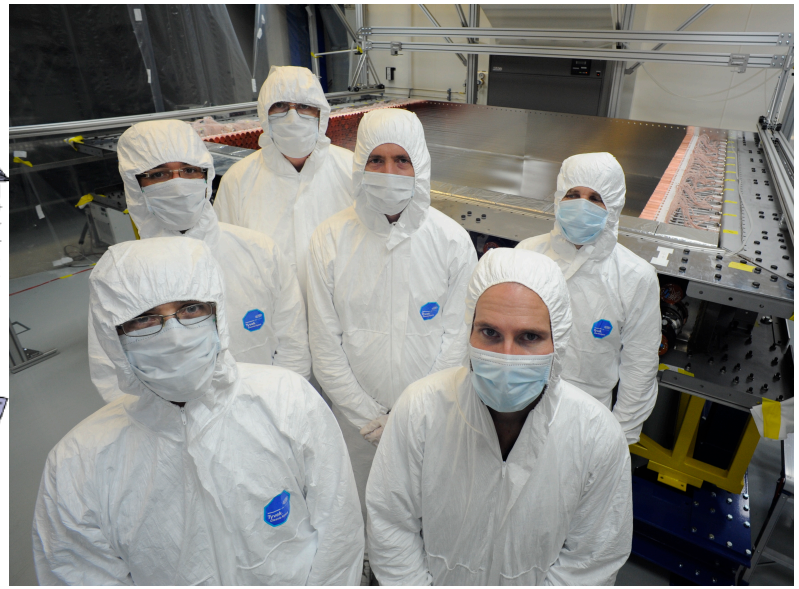
SNO+ Institutes: Liverpool, Manchester, Oxford, Sheffield, Sussex, QMUL

UK Leadership & Responsibilities:
R&D towards higher loading fractions and light injection calibration system

SuperNEMO Institutes: ICSTM, Manchester, UCL, Warwick

UK Leadership & Responsibilities:
- Co-Spokesperson
- Track detector for demonstrator module



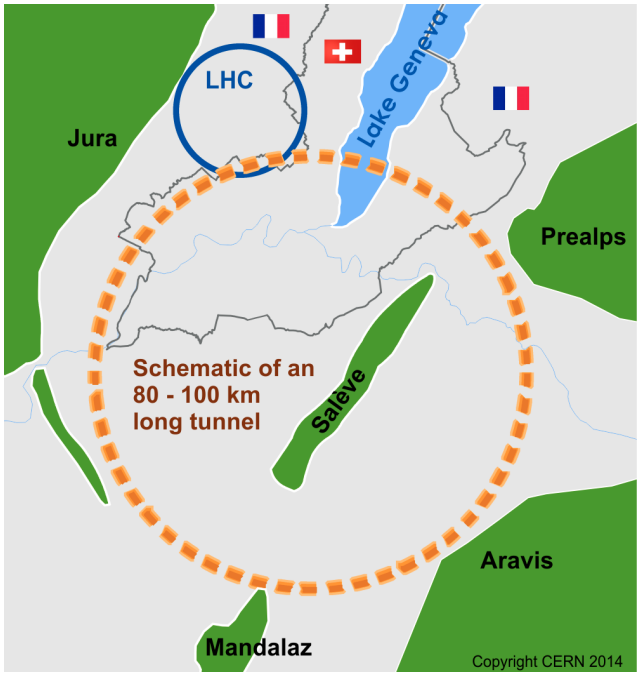


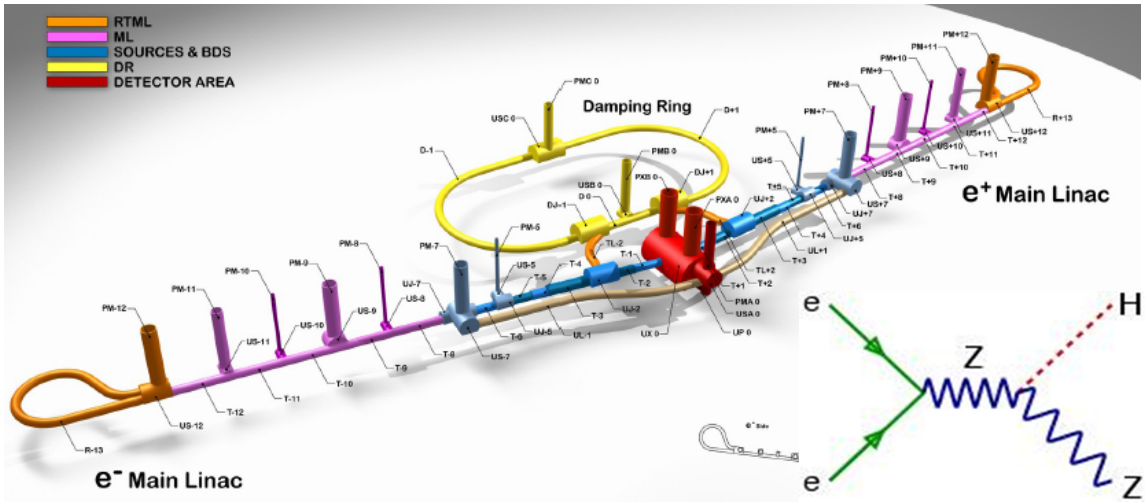
Future Colliders

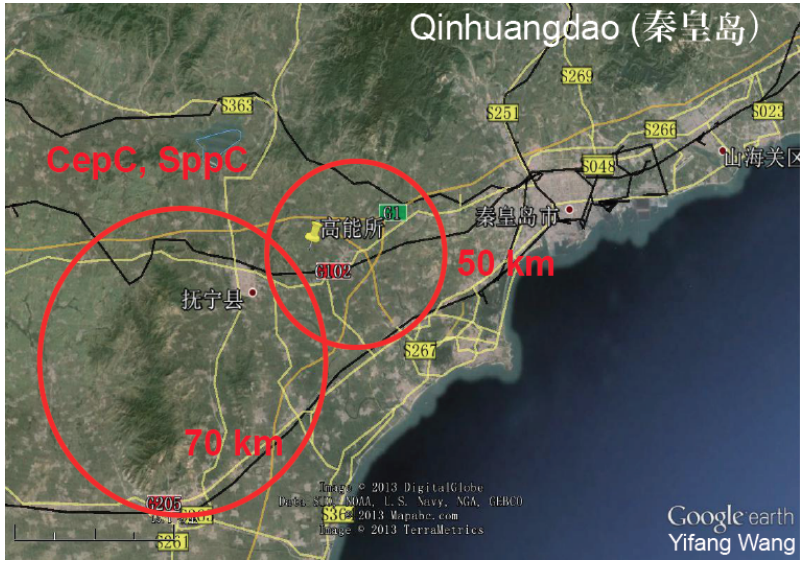
- Accelerator technologies (e.g. CLIC) covered in accelerators talk.

- UK watches international developments at the energy frontier with interest and engages directly in many ways.

→ Essential to be part of whatever emerges as the next (and/or next-but-one) generation machine(s).

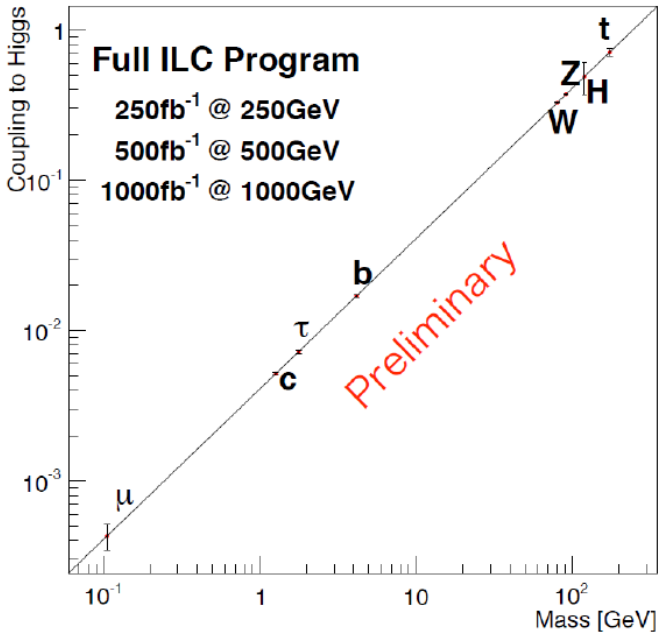






Future e+e- @ ILC / CLIC

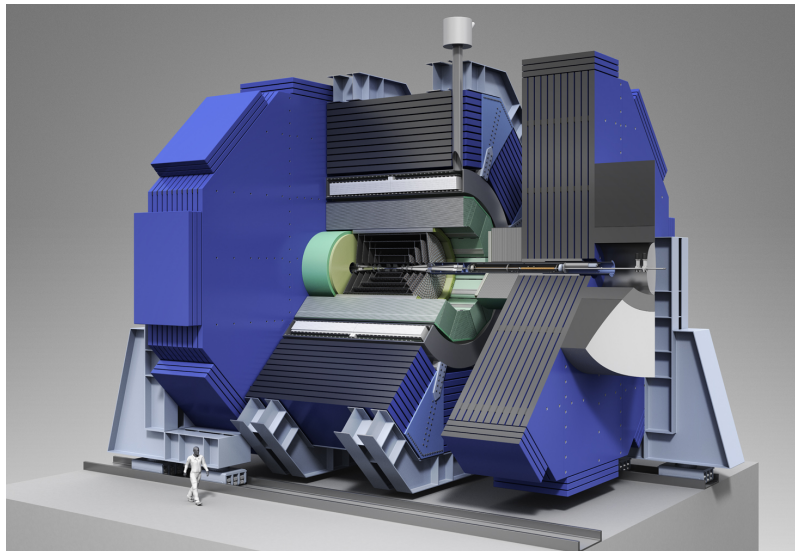
Strong historical UK interest, renewed in light of Japanese ILC initiative
… precision characterisaton of Higgs
… complementary BSM sensitivity



Institutes signing ILC LoI: B'ham, Bristol, Cambridge, Edinburgh, Glasgow, ICSTM, Lancaster, Liverpool, Manchester, Oxford, QMUL, Open U, RHUL, Sheffield, Southampton, Daresbury, RAL, Sussex, UCL, Warwick

Leadership: EU LC regional director, CLIC spokesperson, Various roles in SiD, ILC, CLIC …

UK Activities: Silicon tracking, Calorimetry (CALICE, particle flow), Trigger & DAQ, Physics studies



Future ep/eA at LHeC / FCC-he

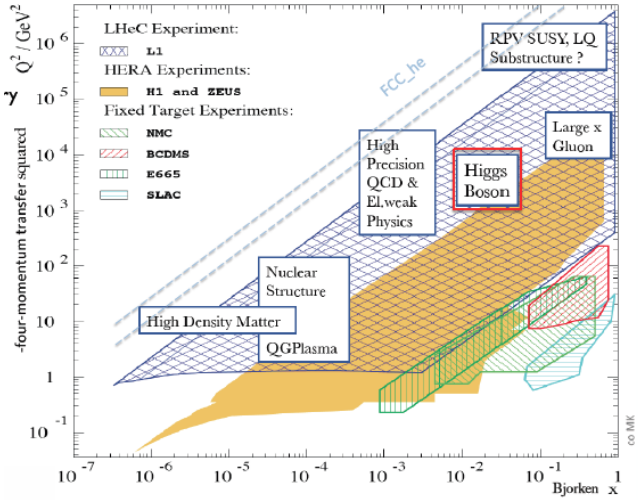
- Proposed upgrade to the LHC

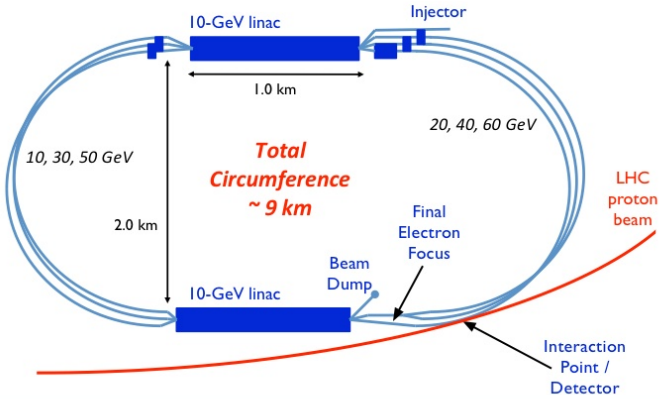
- Broad physics programme including Higgs physics at $\sqrt{s_{ep}}$ = 1.3TeV and Lumi=10^{34} $cm^{-2}s^{-1}$, precision PDFs complementing LHC, QCD …

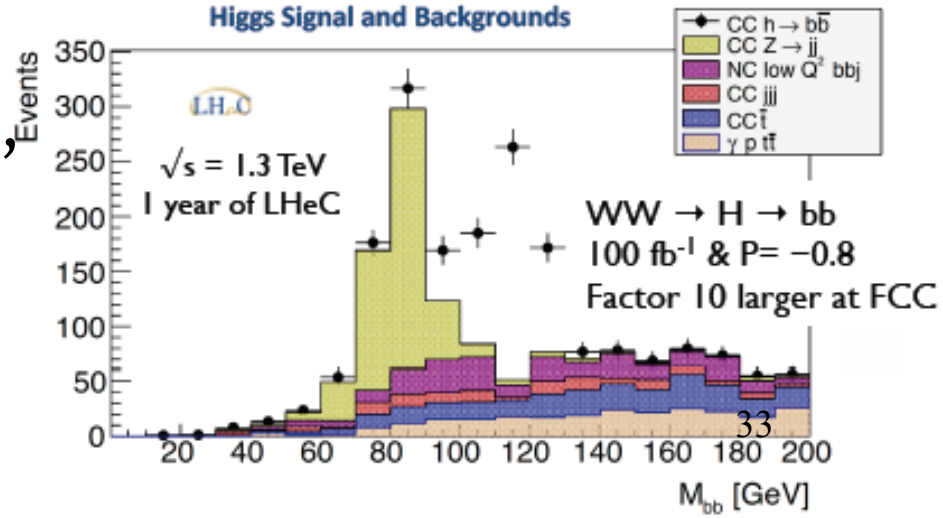
Institutes (NP and PP): Birmingham, Cockcroft, Edinburgh, Glasgow, Liverpool, Manchester, Oxford, QMUL

Leadership: Current spokesperson, Physics working group conveners

UK Interests: Silicon detectors, electron trigger, physics studies.







Summary / Final Comments

- UK PP thriving at grass-roots level, leading and delivering broad range of science, despite increasingly tight funding environment

- Main funding source is STFC. Additional contributions from ERC, Royal Society have been important to preserve breadth

- Increasingly, lost opportunities due to times of austerity

- Largest scale (energy frontier, flavour physics, neutrino) projects well aligned with Euro (& US) Strategy.

- Portfolio of smaller `high risk, high reward' experiments

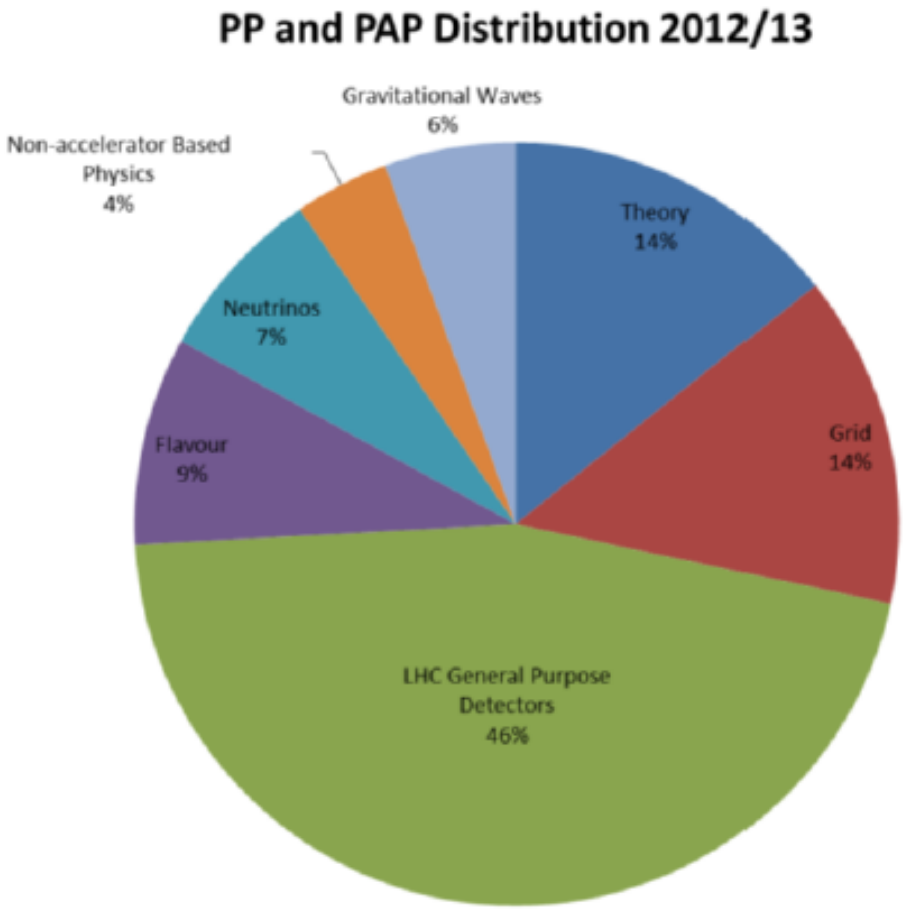
- Exploiting CERN membership, whilst also participating beyond Europe where appropriate

Thanks: P Allport, P Burrows, C Buttar, M Klein, M Lancaster, C Lazzeroni, K Nikolopoulos, C Parkes, Y Ramachers, C Shepherd-Themistocleous, L Thompson, M Wascko, A Watson, D Waters, M Wing

Back-ups

Financial Information

Figure 1a



Distribution of resources among subject areas in particle physics and particle astrophysics at time of last PPAP roadmap

[2012/13 version … not up to date].

Nov 2012 Roadmap

Fundamental Questions addressed in PPAP science, according to 2012 roadmap document …

- **What are the basic building blocks of the Universe?**
- **Can the forces between particles be understood in a unified framework?**
- **How does gravity fit in?**
- **What unknown properties of these particles and forces drove the evolution of the Universe from the Big Bang to its present state?**
- **What is the origin of the matter/antimatter asymmetry?**