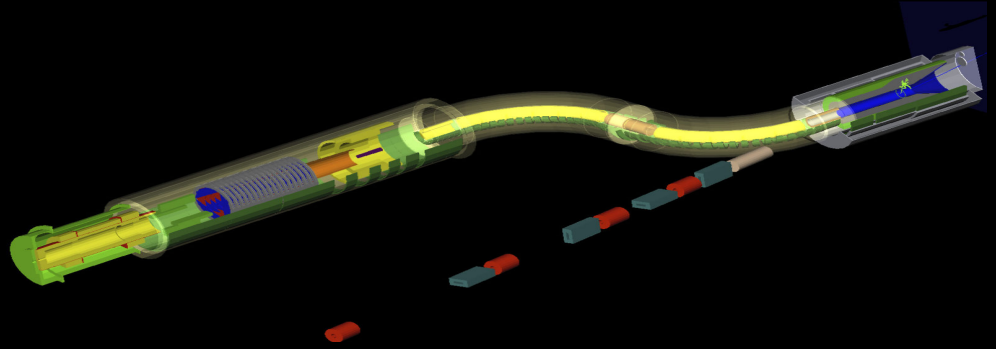
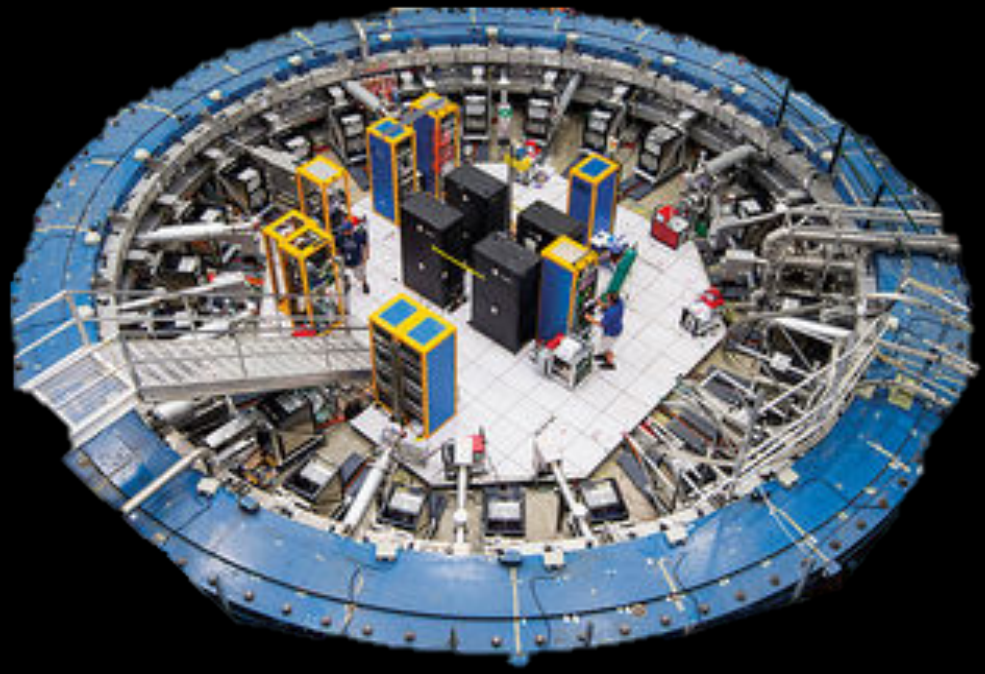
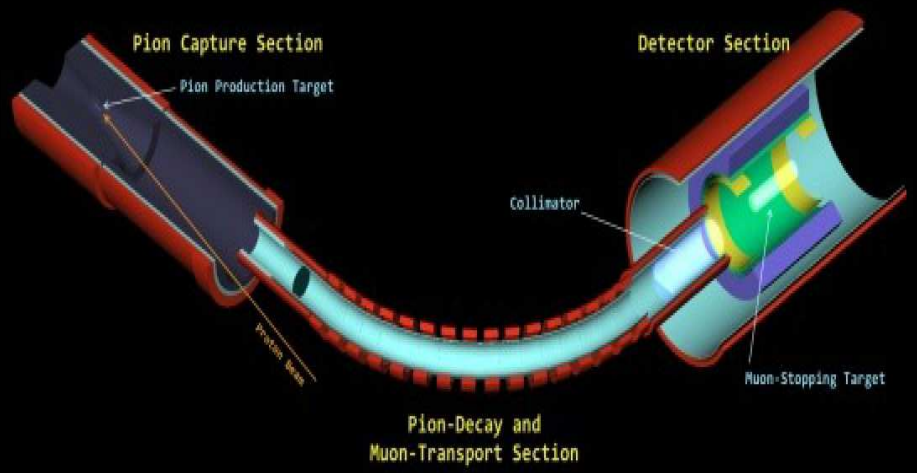
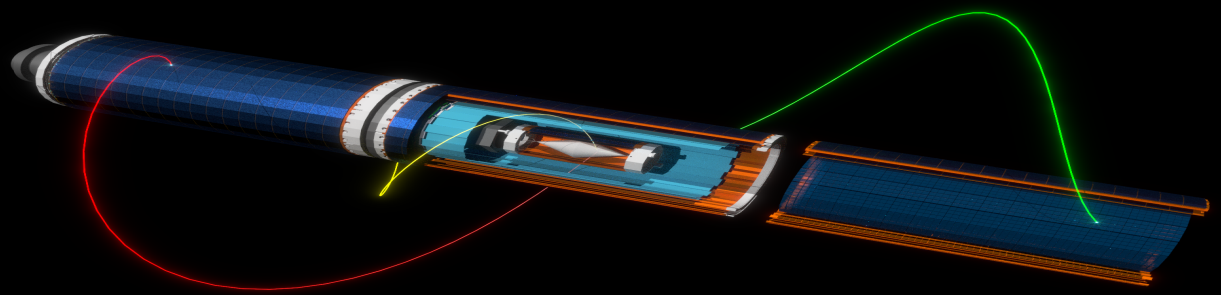




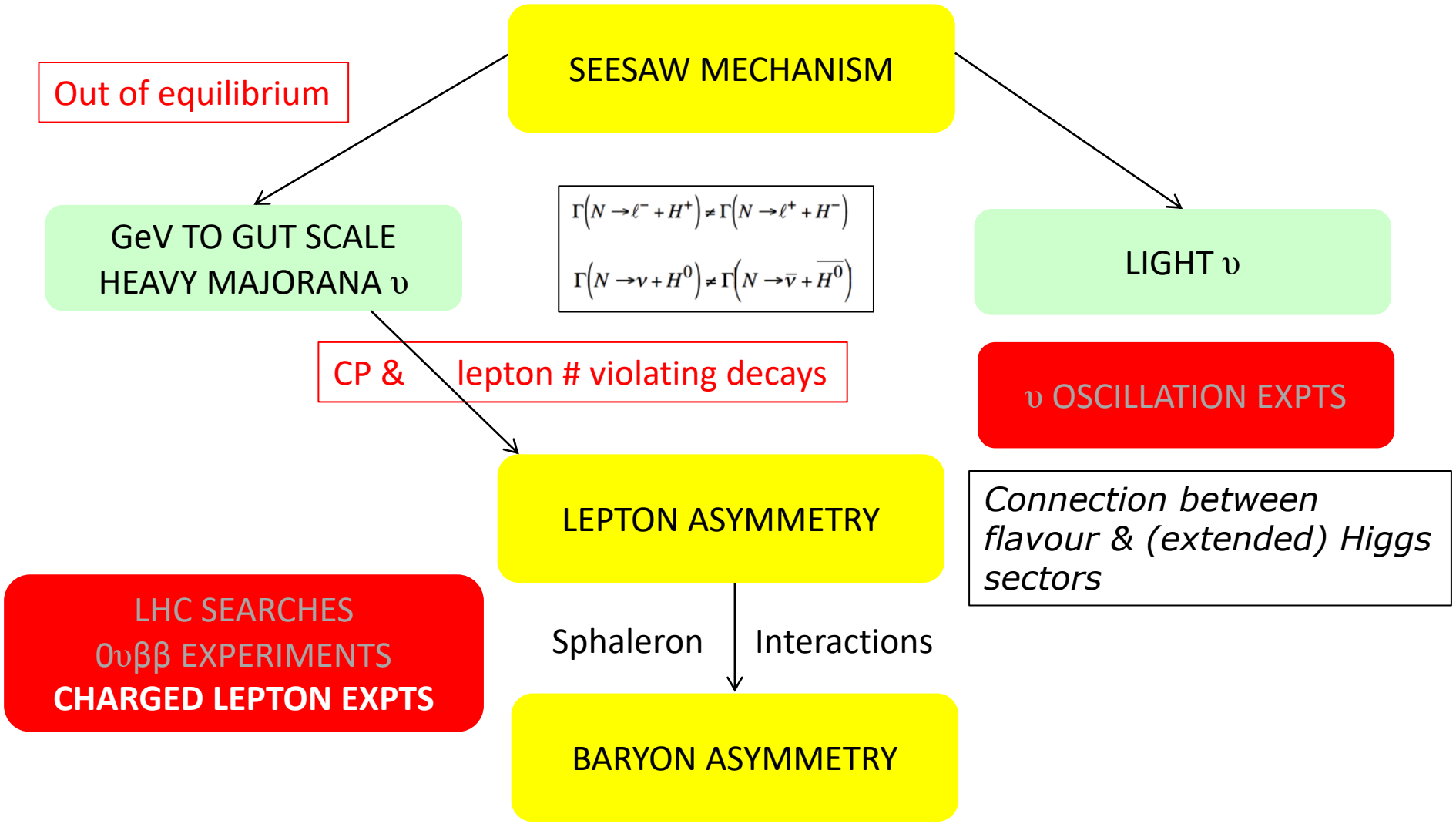
Muon g-2, cLFV and EDMs

Mark Lancaster



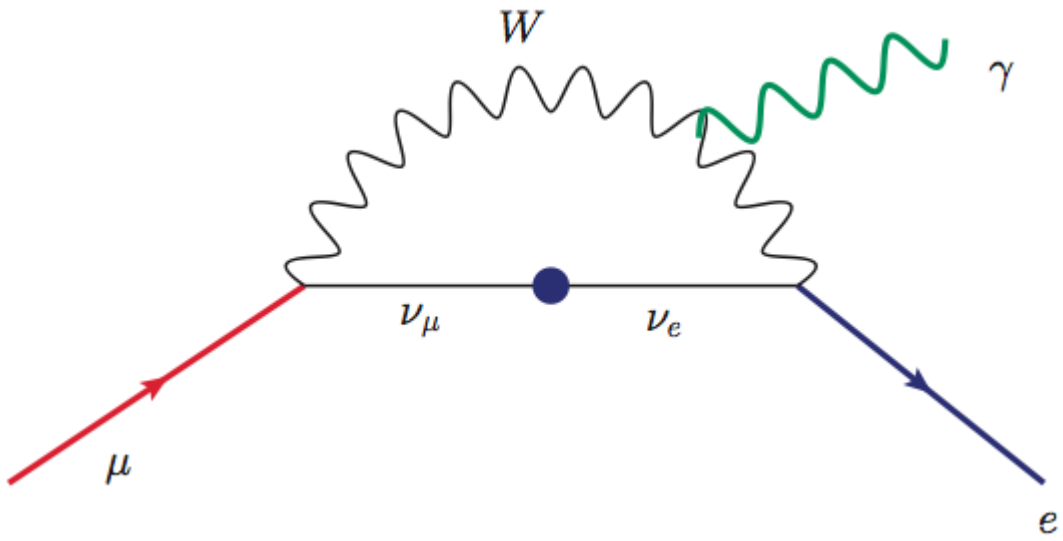


Motivation : leptogenesis



Motivation : extended Higgs sector

In SM: neutrino oscillations (masses) are intimately connected with charged lepton flavour violation



Mu2e/COMET sensitive to BR ($h \rightarrow \mu e$) of 10^{-10} (vs $O(10^{-4})$ at LHC)

Proton EDM experiment sensitive to CP violating h interactions in 1st generation: 2 orders of magnitude beyond other experiments

and also in BSM: $\nu_{RH} \rightarrow l^- H^+$

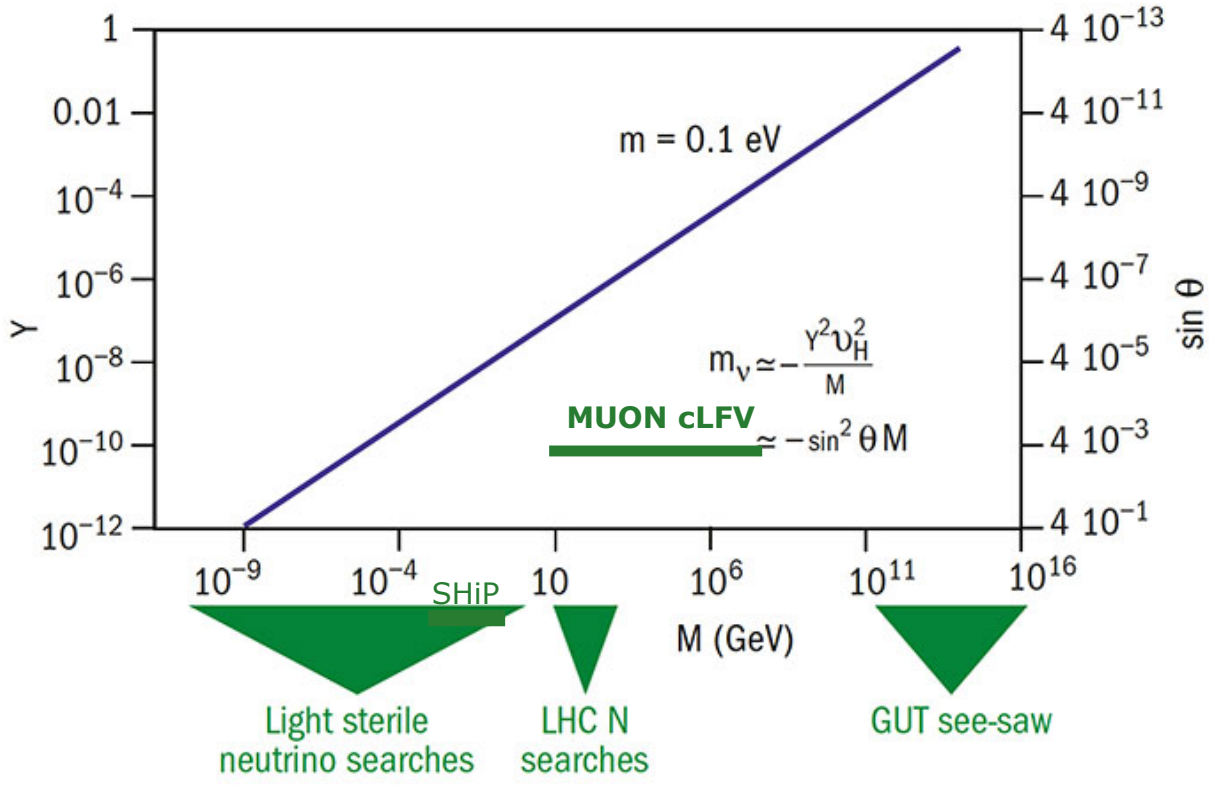
And thus to **extensions to the Higgs sector.**

Motivation : origin of neutrino mass

Requires new degrees of freedom and new interactions

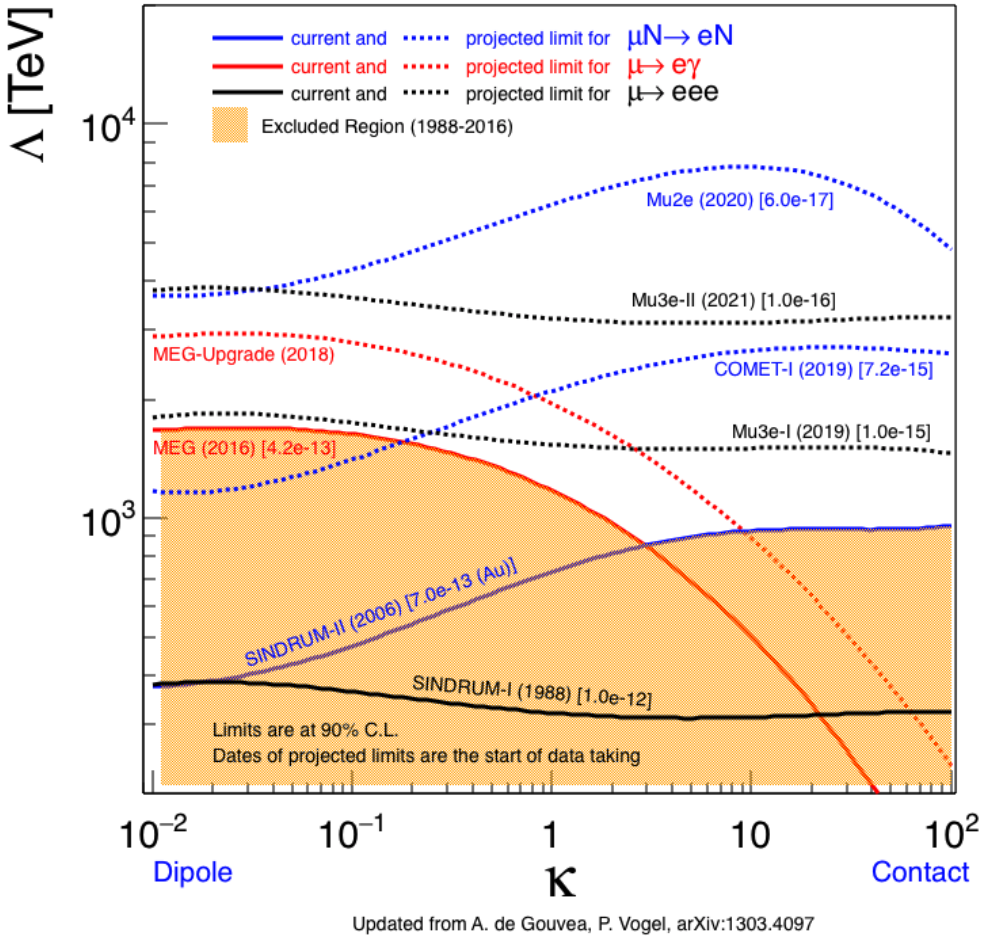
Avoid fine-tuning in Yukawa coupling by:

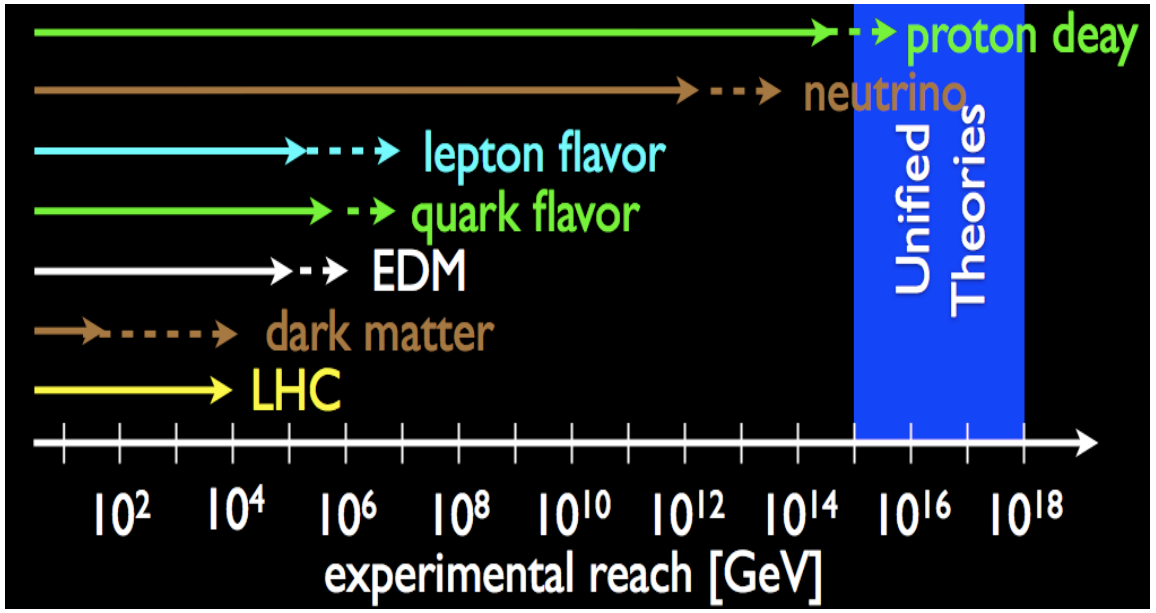
- adding heavy RH Majorana neutrinos, fermion/scalar triplets & Seesaw mechanisms
- radiative & R-parity violating SUSY interactions



Very wide range in possible RH neutrino masses

Motivation : access to mass scales beyond ATLAS/CMS





Scales of up to 8000 TeV for unity coupling

Observations being undertaken are

- lepton flavour violation (LFV)
- lepton number violation (LNV)
- lepton universality violation
- CP-violation : EDM

Muon Expts

$$\mu \to e\gamma$$
$$R_P\ (\mu \text{ vs } e)$$
$$\text{HFS}$$
$$\mu N \to eN$$
$$\mu \to 3e$$
$$(g-2)_\mu$$

LHCb/BaBar/Belle

$$\tau \to e\gamma, \mu\gamma, 3\mu, \ldots$$
$$D \to \tau\nu / D \to \mu\nu$$

Kaon/Pion Expts

$$K \to \pi\mu e,\ \pi ee,\ \pi\mu\mu$$
$$\pi/K \to e\nu/\mu\nu$$

LHC GPD Expts

$$h \to \mu\tau, e\tau$$
$$Z \to e\mu, \mu\tau, e\tau$$
$$pp \to lljj$$

0νββ Expts

$$N \to ee$$

UK role: Bristol, Imperial, Lancaster/CI, Liverpool, Manchester, Oxford, RAL-TD, UCL

Landscape : O($1B) of experiments

PSI

MEG
Mu3e
CREMA
MUSE

FNAL

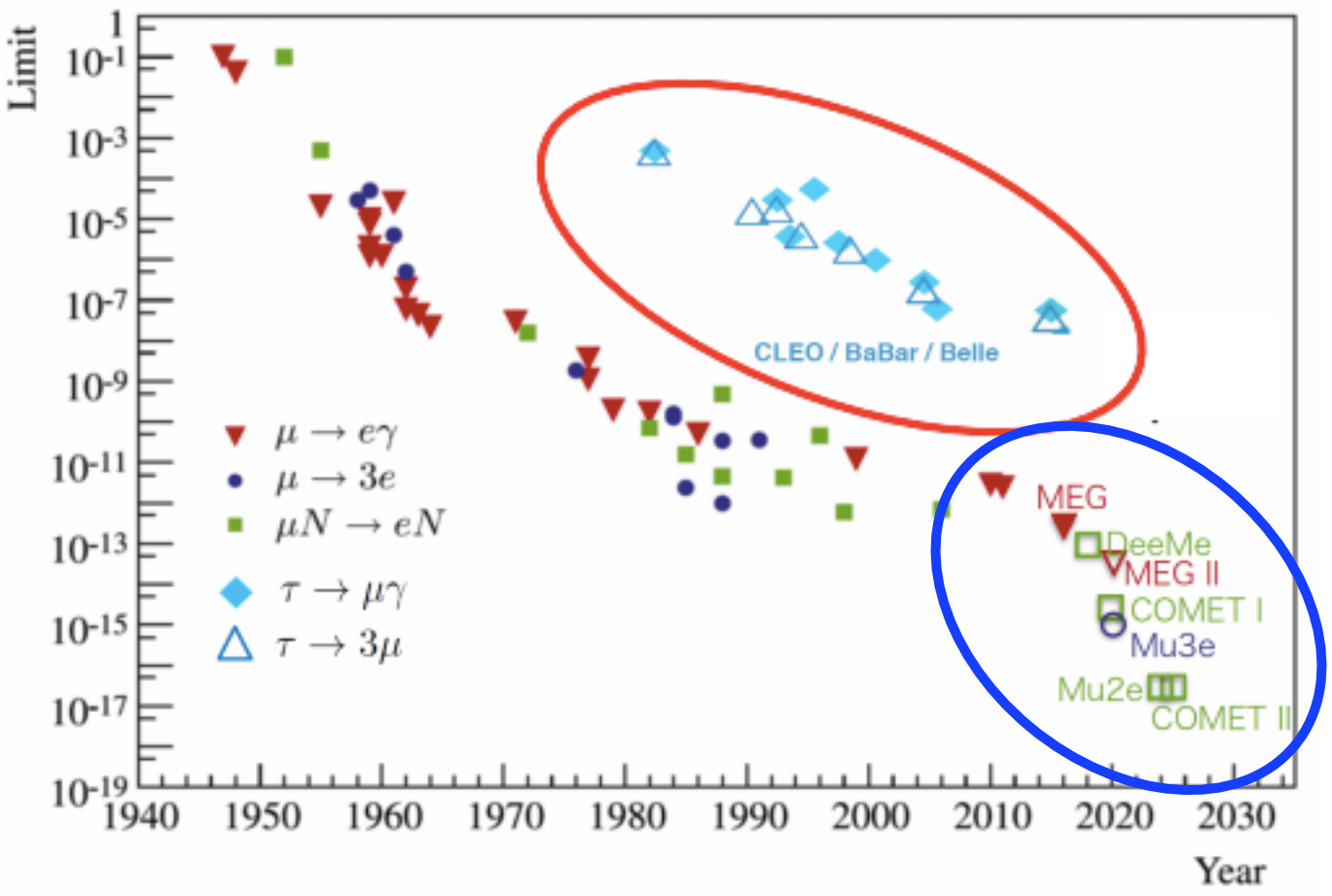
g-2
Mu2e

J-PARC

COMET
g-2
DeeMe
Museum

DC Beam
Pulsed Beam

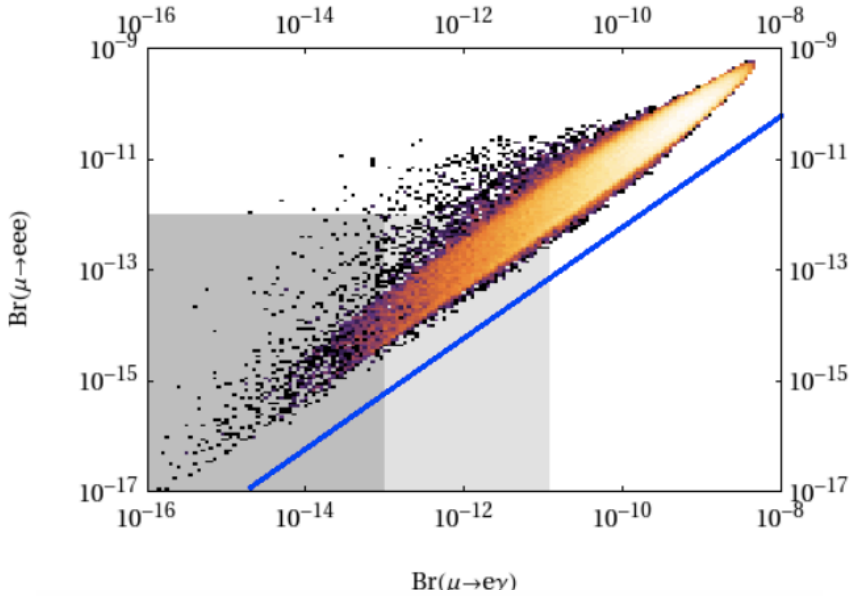
Need variety of experiments

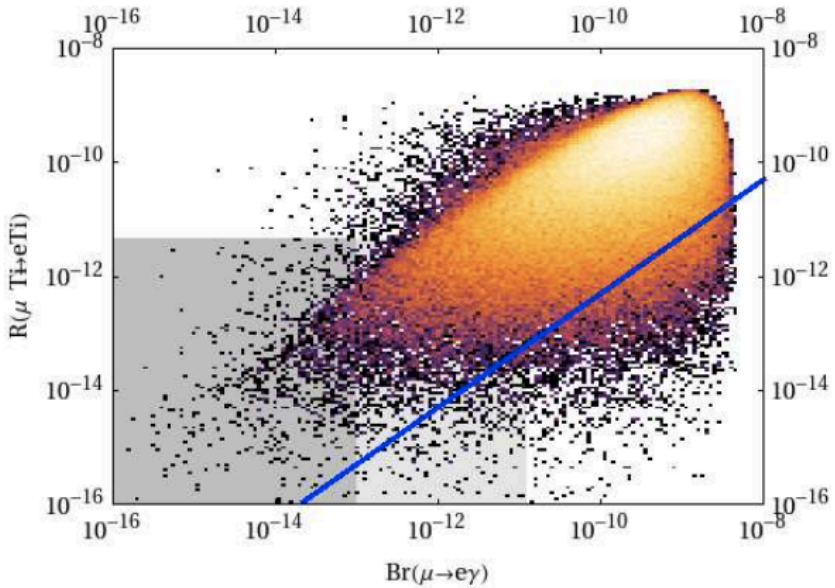


Important to make measurements across all channels and both μ and τ

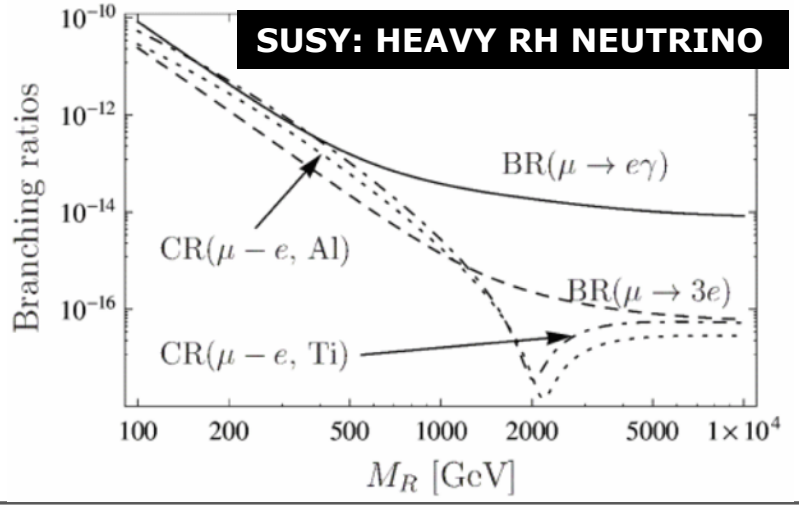
Resolve model degeneracy

LITTLE HIGGS MODEL

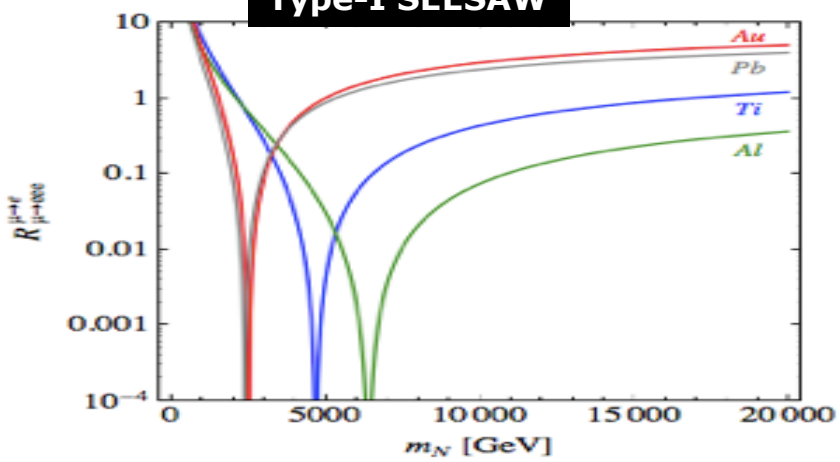




SUSY: HEAVY RH NEUTRINO



Type-I SEESAW



Synergy across programme in US/Europe/Asia

Joint submission to European Strategy

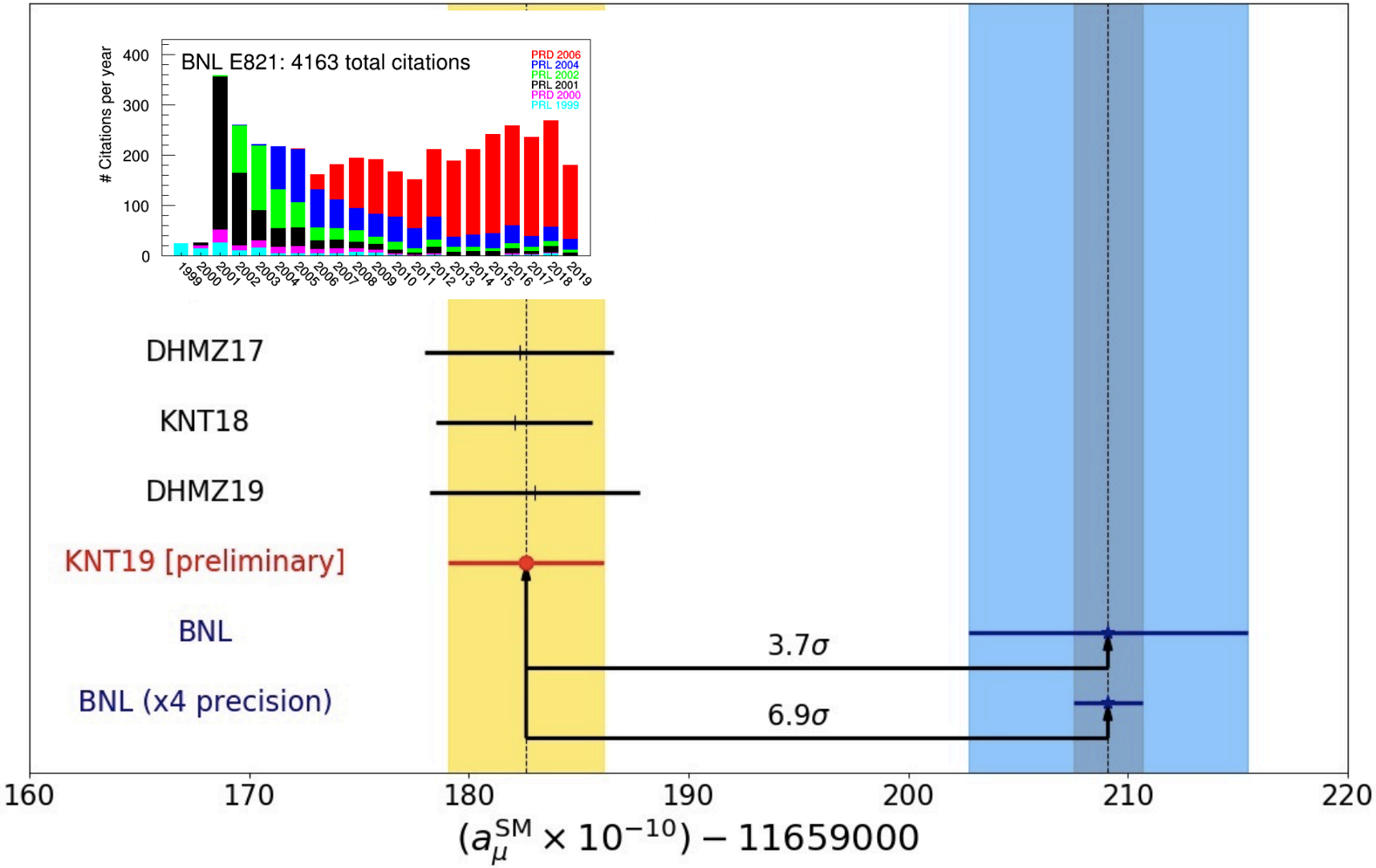
Charged Lepton Flavour Violation using Intense Muon Beams at Future Facilities

A. Baldini, D. Glenzinski, F. Kapusta, Y. Kuno, M. Lancaster,
J. Miller, S. Miscetti, T. Mori, A. Papa, A. Schöning, Y. Uchida

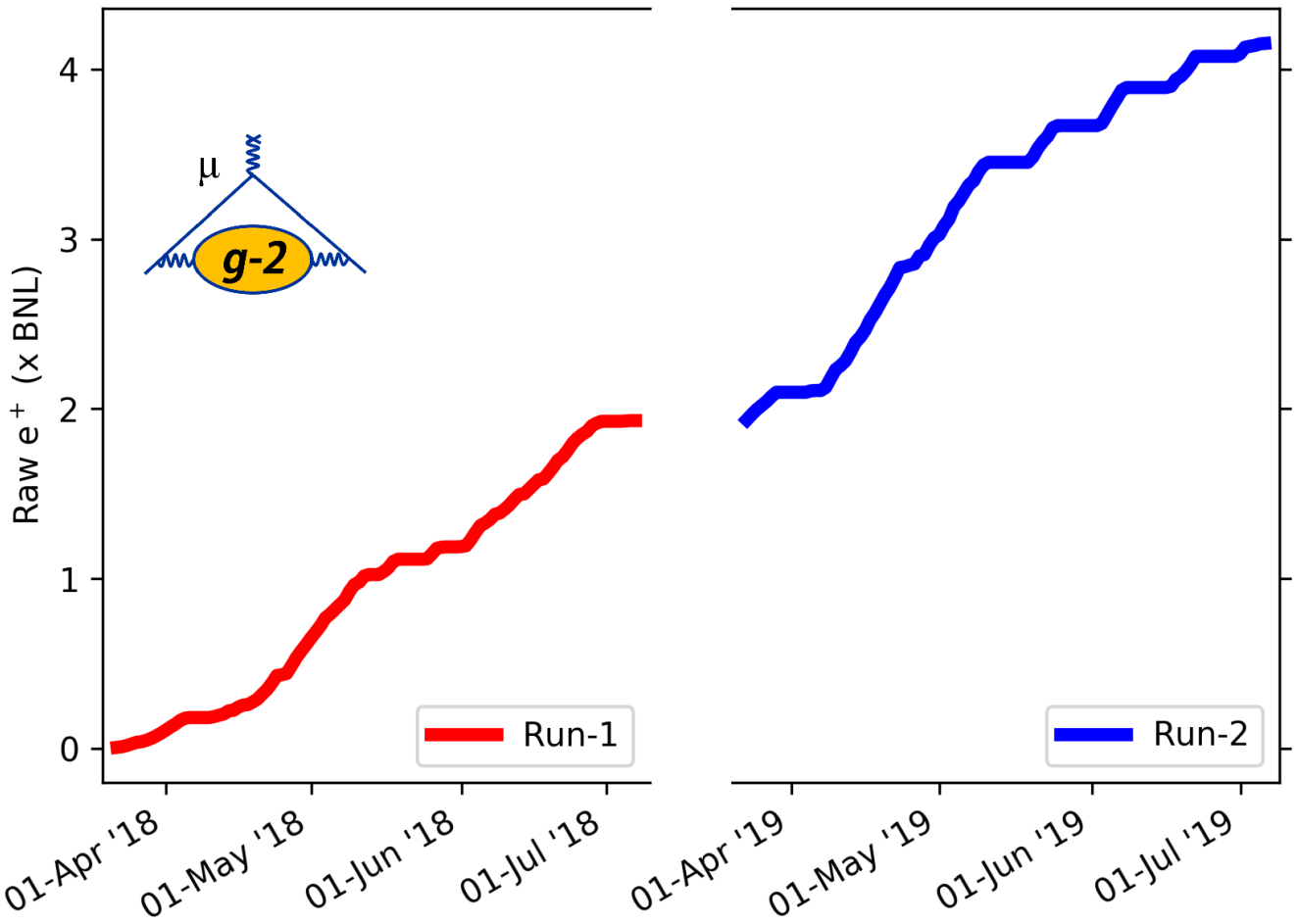
A submission to the 2020 update of the European Strategy for Particle Physics on behalf of the COMET, MEG, Mu2e and Mu3e collaborations.

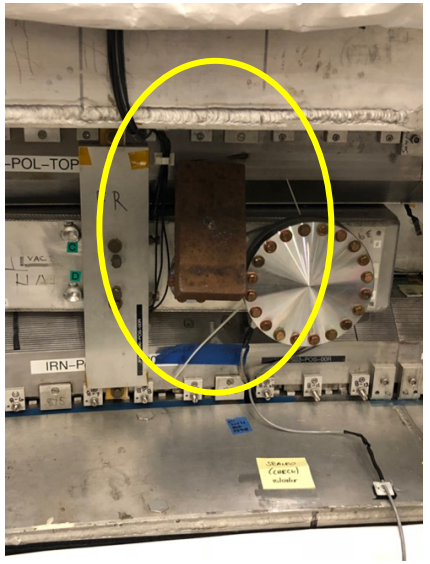
Is there new physics lurking in muon interactions

Proton radius puzzle remains unsolved



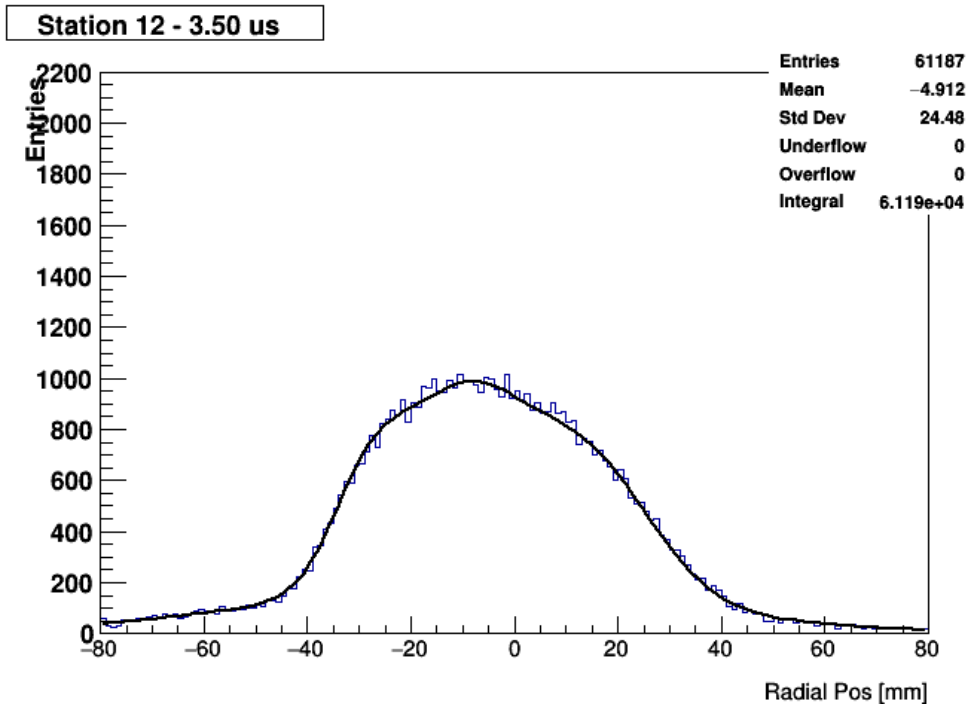
Fermilab Muon g-2

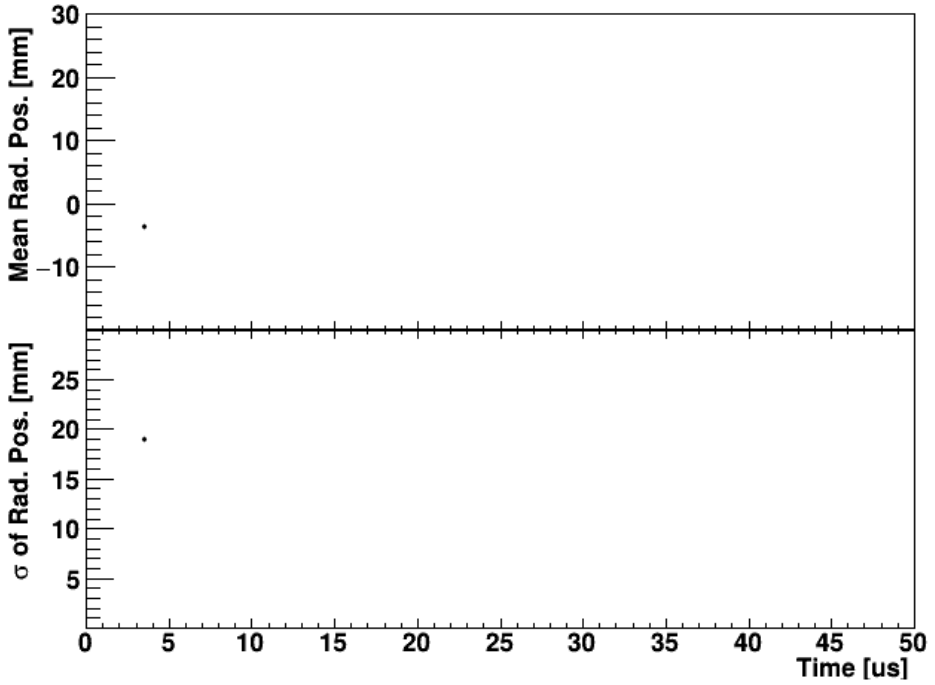




0.0023318xxx

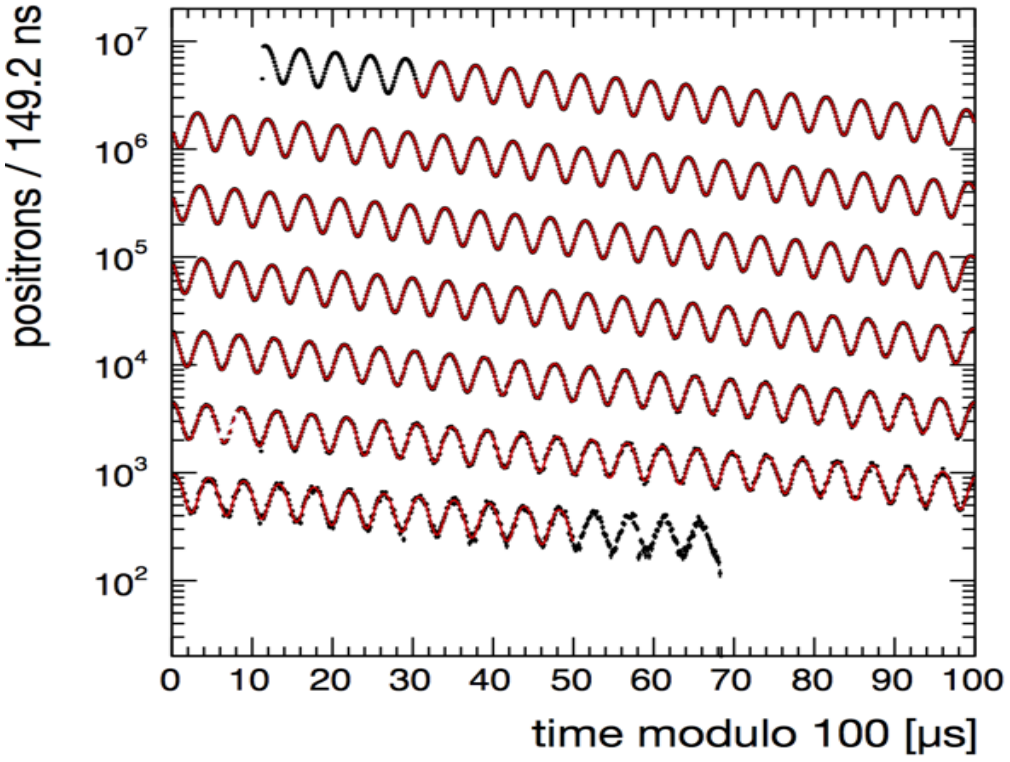
Everything is SHM....

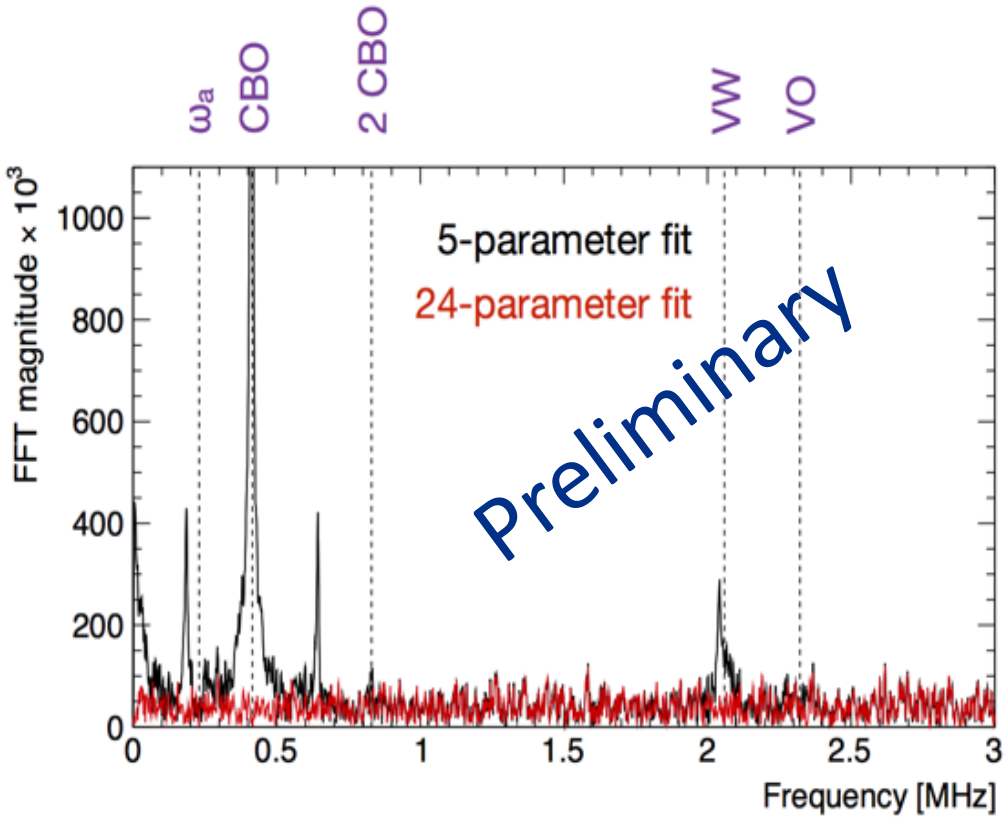




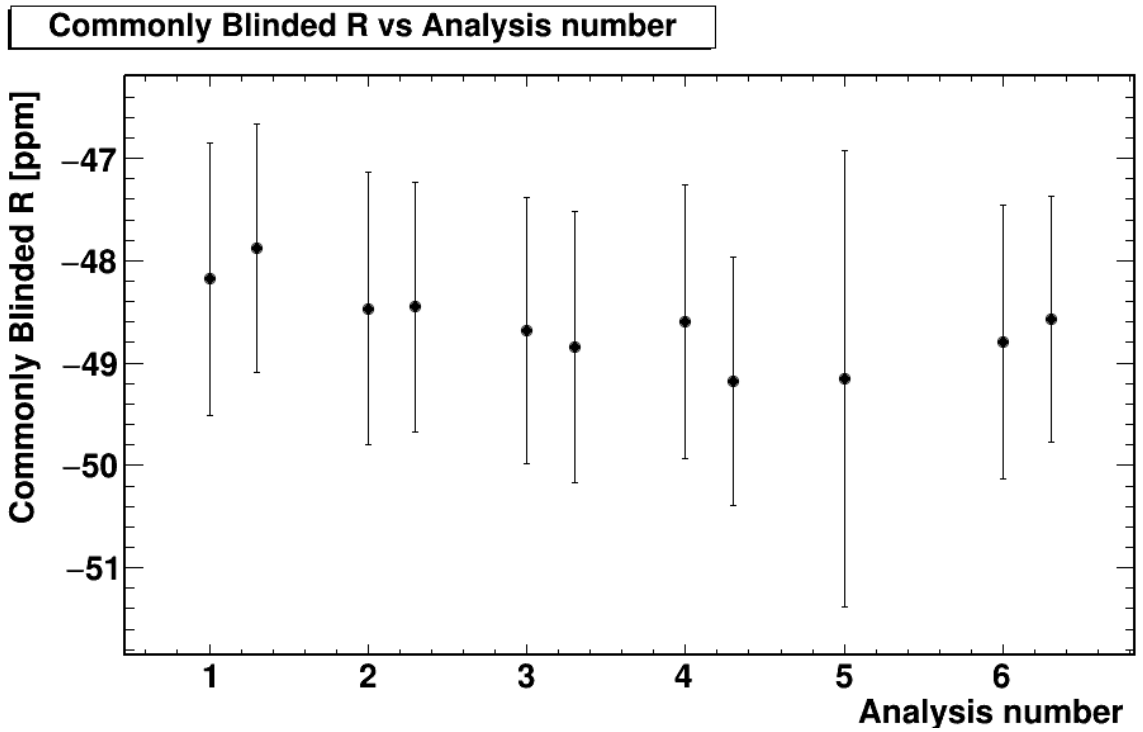
Account for beam motion with 24-parameter fit

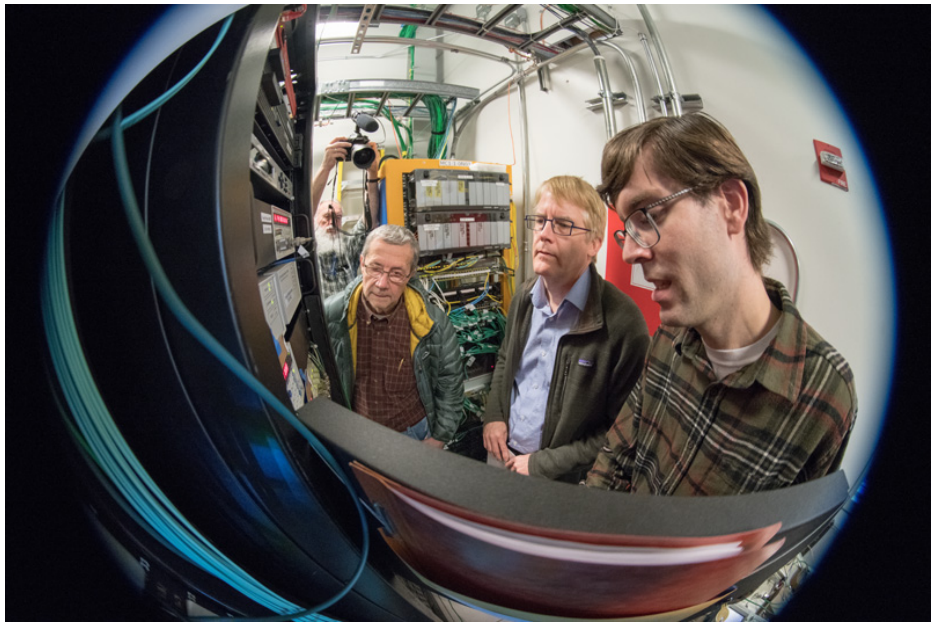
$$N(t) = N_0 \cdot \Lambda(t) \cdot N_{1\mathrm{CBO}}(t) \cdot N_{2\mathrm{CBO}}(t) \cdot N_{VW}(t) \cdot N_{VO}(t)$$
$$\cdot e^{-t/\tau} \left[1 + A_0 \cdot A_{1\mathrm{CBO}}(t) \cdot \cos(\omega_a(R) \cdot t + \phi_0 + \phi_{1\mathrm{CBO}}(t))\right]$$





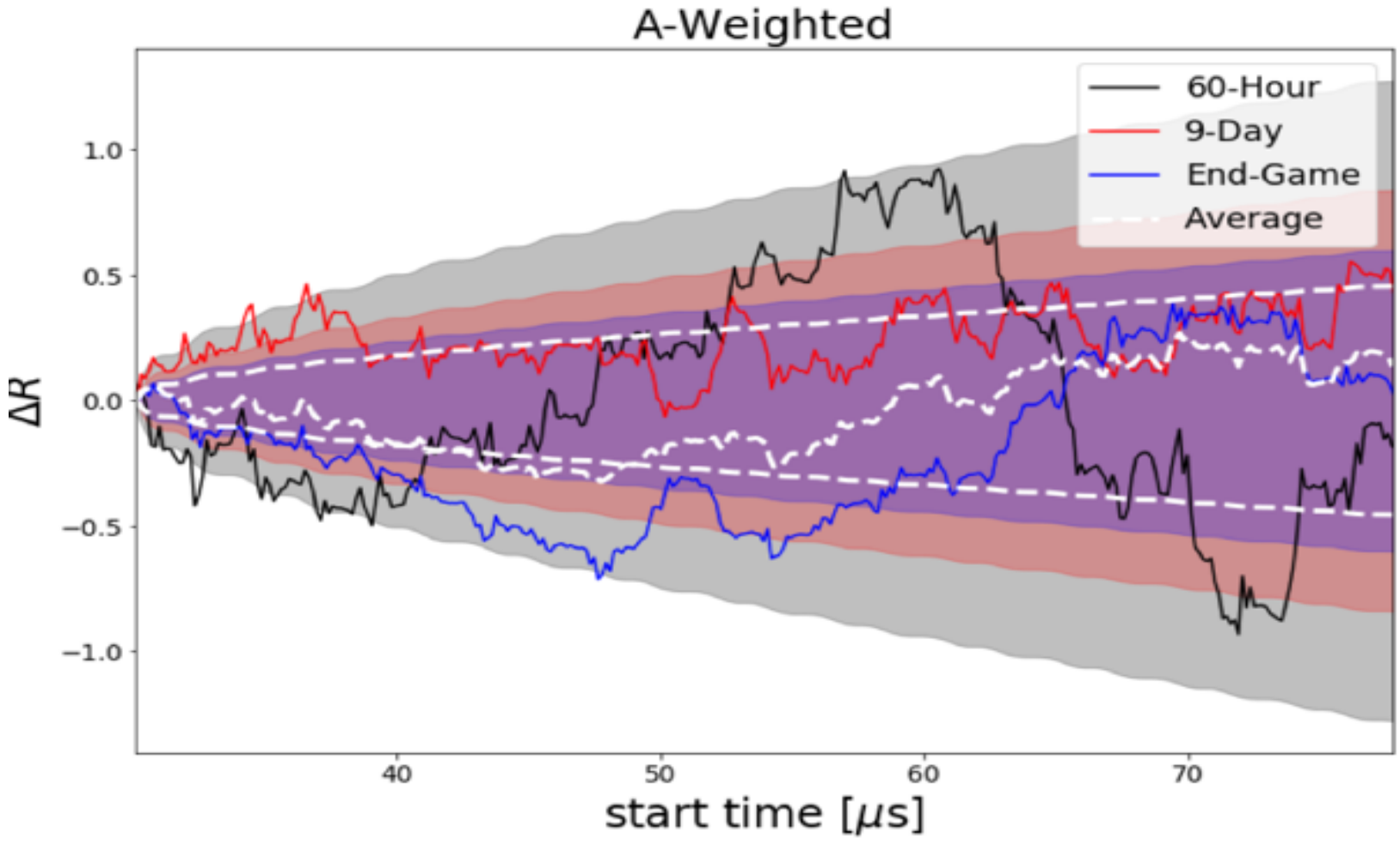
Value is hardware and software blinded





Hardware blinding : x10 size of the BNL discrepancy wrt SM

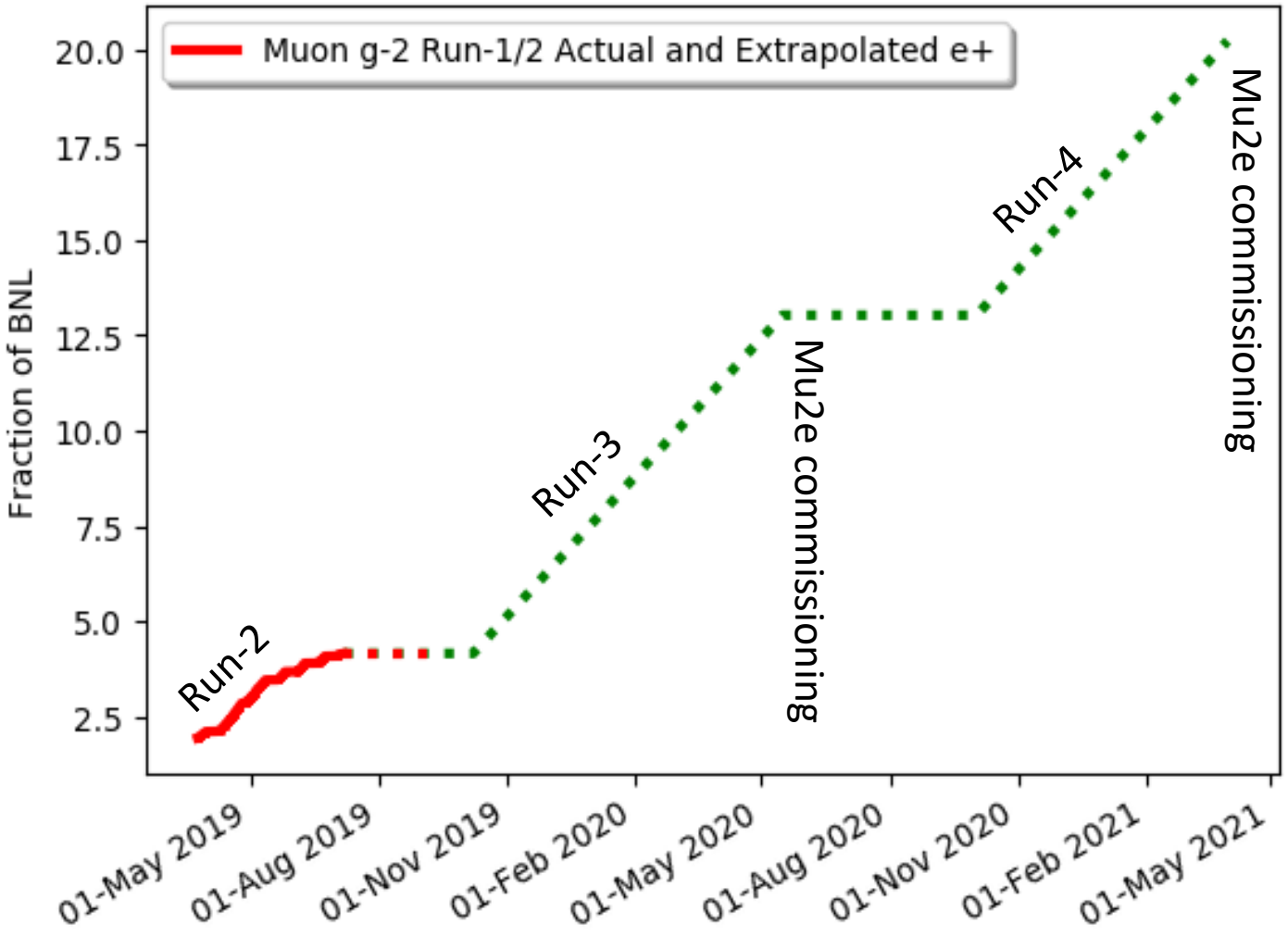
Present datasets have stat. uncertainty ~ ½ that of BNL



410 ppb (stat) Run-1 vs 460 ppb (BNL).

With Run-2 data approach half the BNL stat. uncertainty

Future running



Run-4 could alternatively accumulate x8.5 the BNL μ- sample
e.g. if becomes systematics limited with μ+ or μ+ result > 5σ

$(g\text{-}2)_e$ vs $(g\text{-}2)_\mu$

arXiv.org > hep-ph > arXiv:1908.03607

High Energy Physics – Phenomenology

Explanation of electron and muon g−2 anomalies in the MSSM

Marcin Badziak, Kazuki Sakurai

(Submitted on 9 Aug 2019)

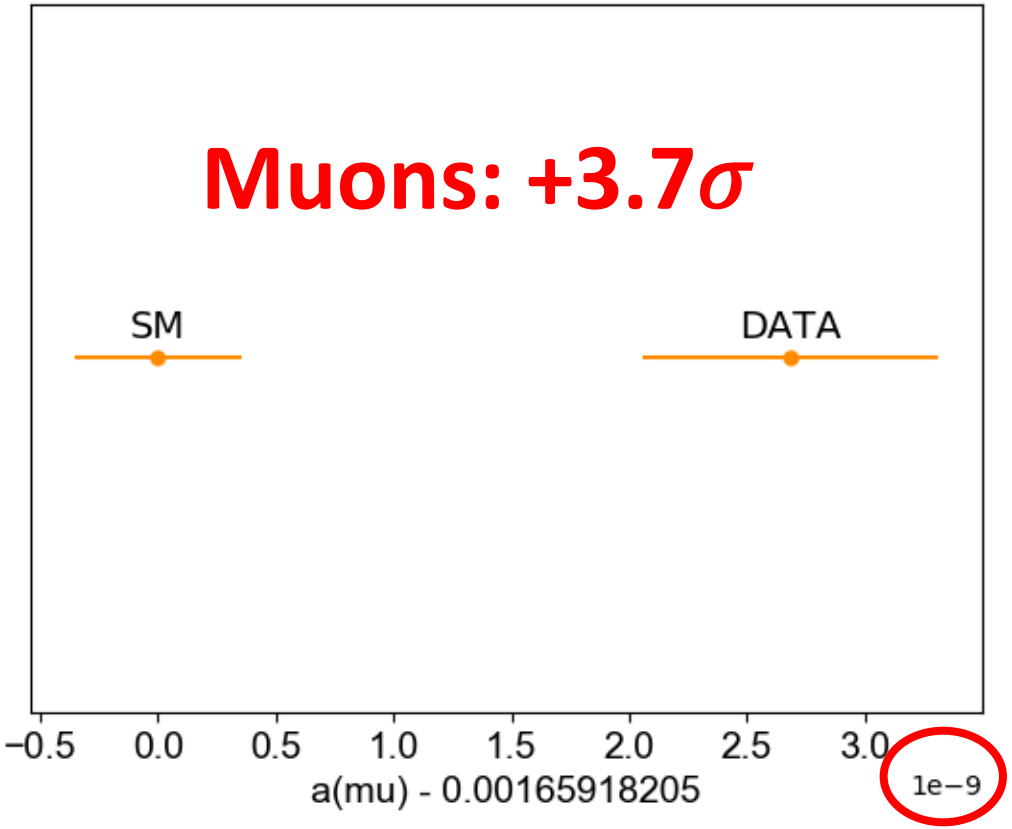
arXiv.org > hep-ph > arXiv:1907.08109

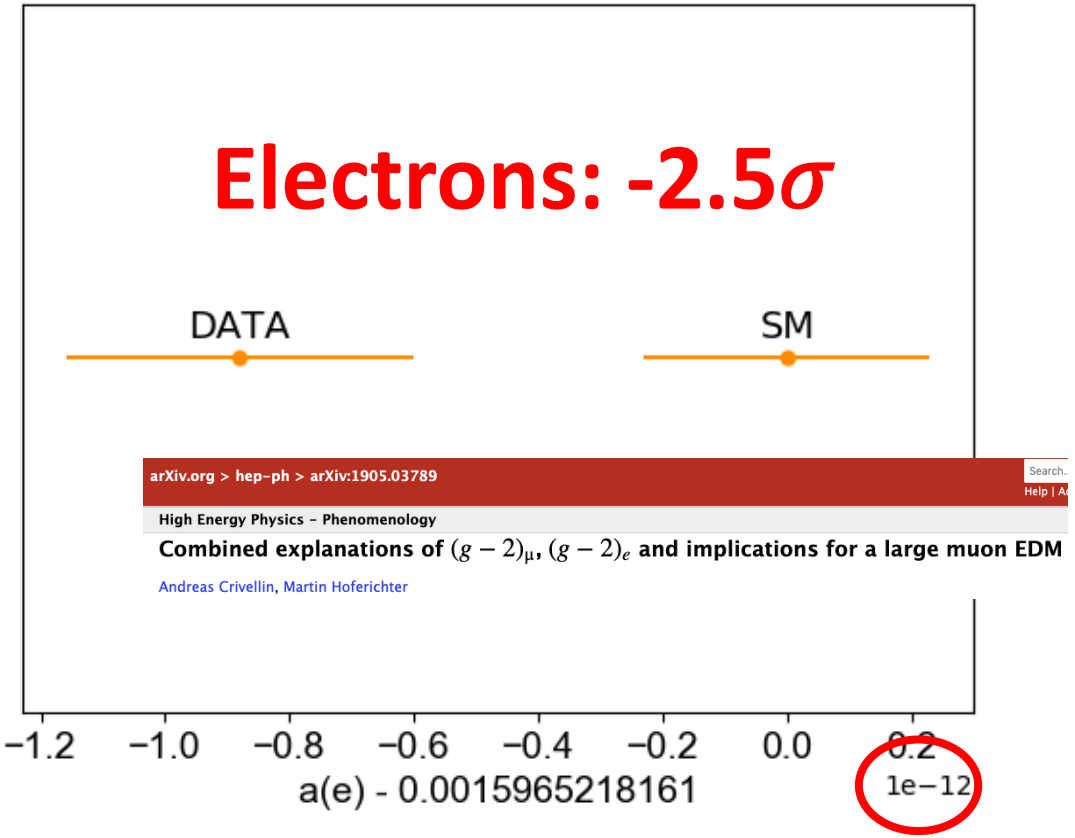
High Energy Physics – Phenomenology

$(g-2)_{\mu,e}$ and the ANITA anomalous events in a three-loop neutrino mass model

Mohammad Abdullah, Bhaskar Dutta, Sumit Ghosh, Tianjun Li

(Submitted on 18 Jul 2019)





arXiv.org > hep-ph > arXiv:1905.03789

High Energy Physics – Phenomenology

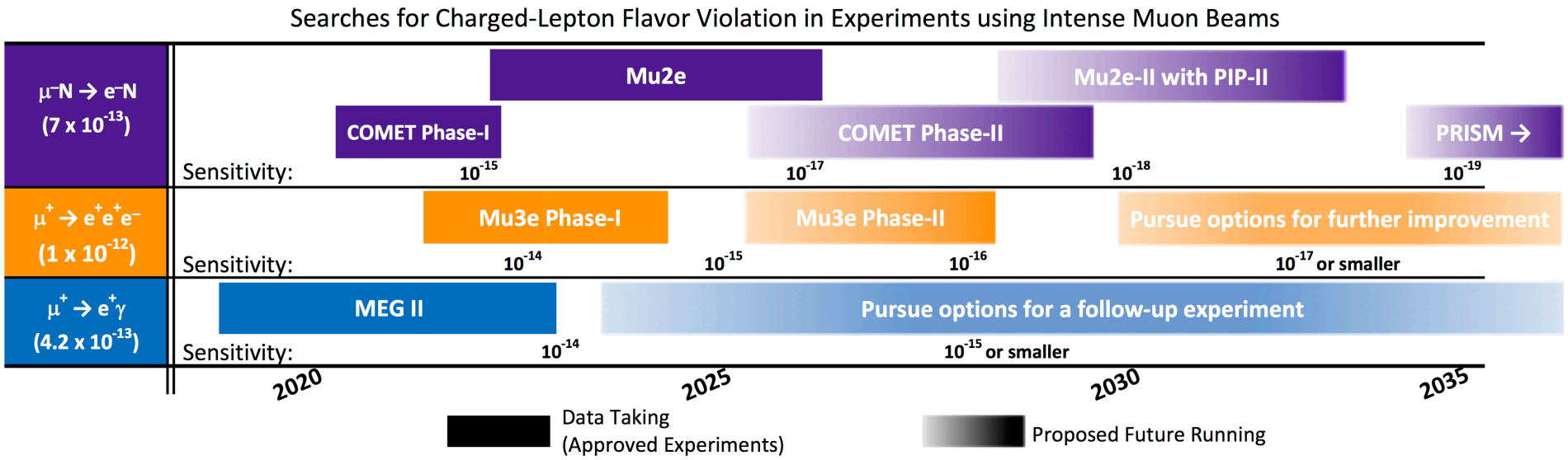
Combined explanations of $(g-2)_\mu$, $(g-2)_e$ and implications for a large muon EDM

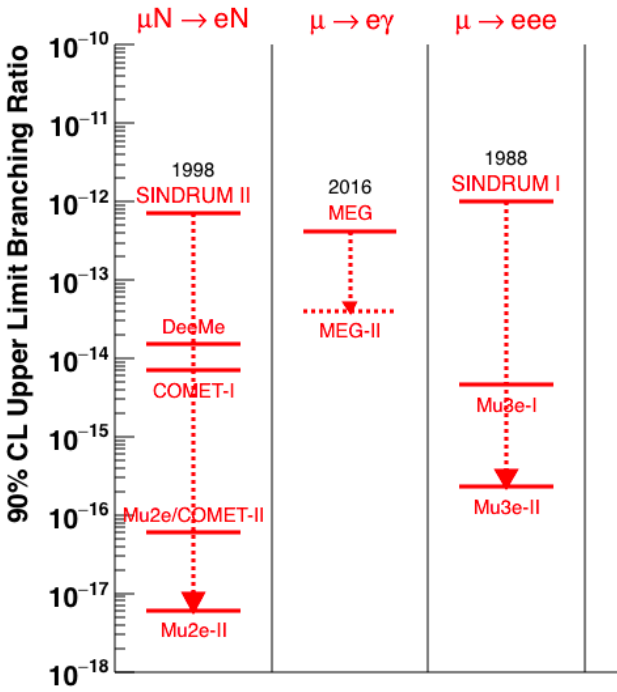
Andreas Crivellin, Martin Hoferichter

Muon cLFV

The University of Manchester

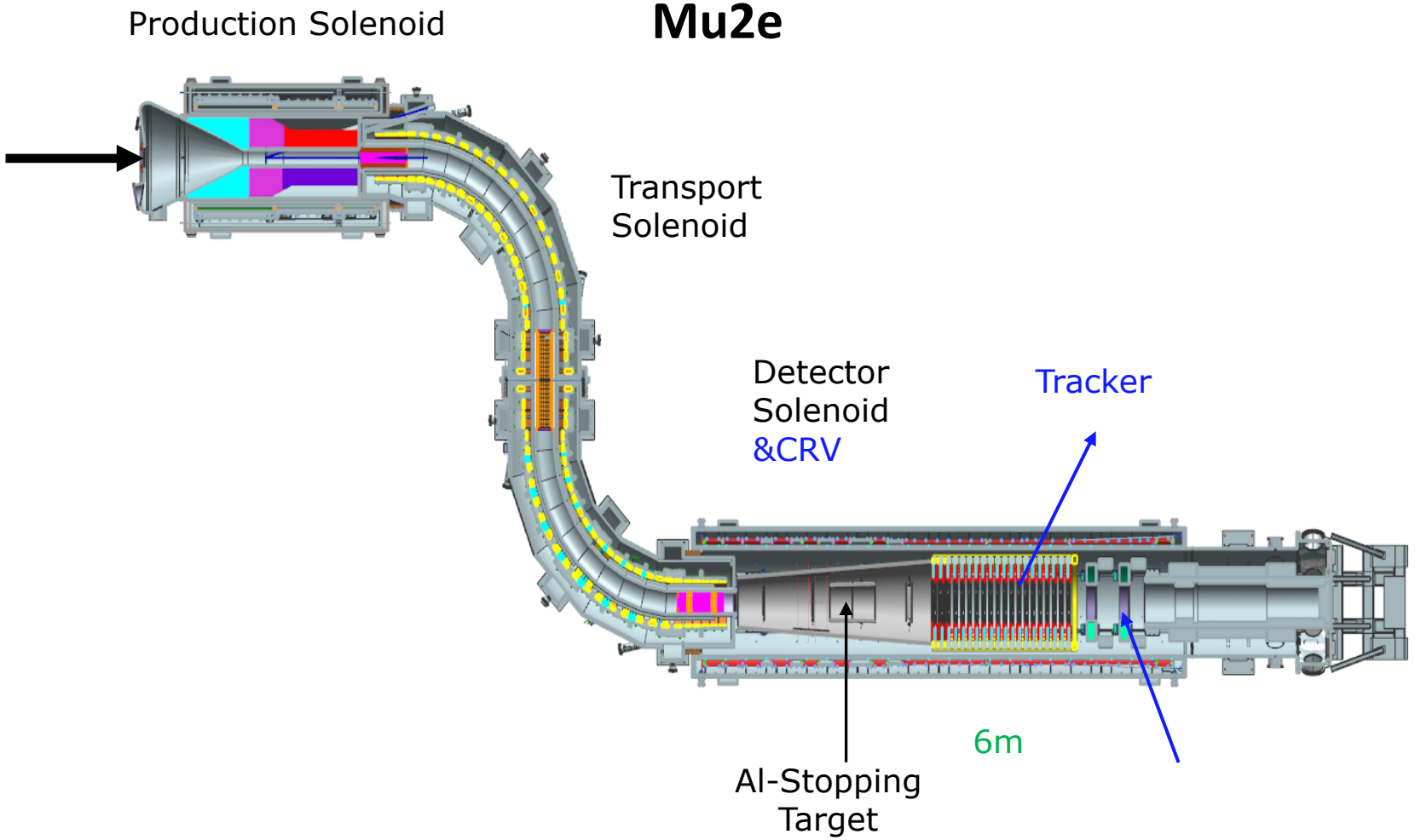
Factors of 1 – 10^5 improvements in sensitivity across 3 channels



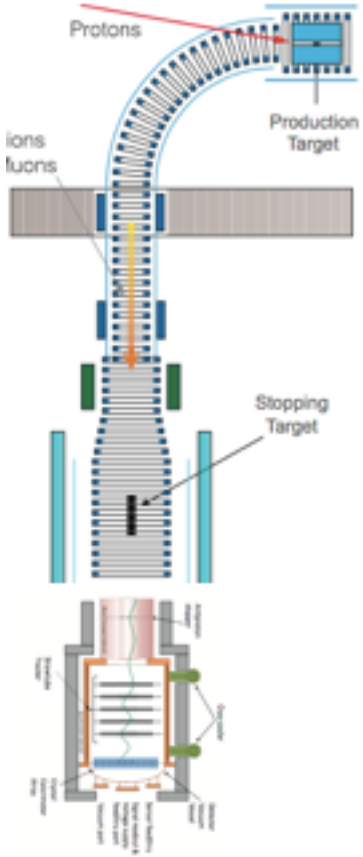


COMET and Mu2e

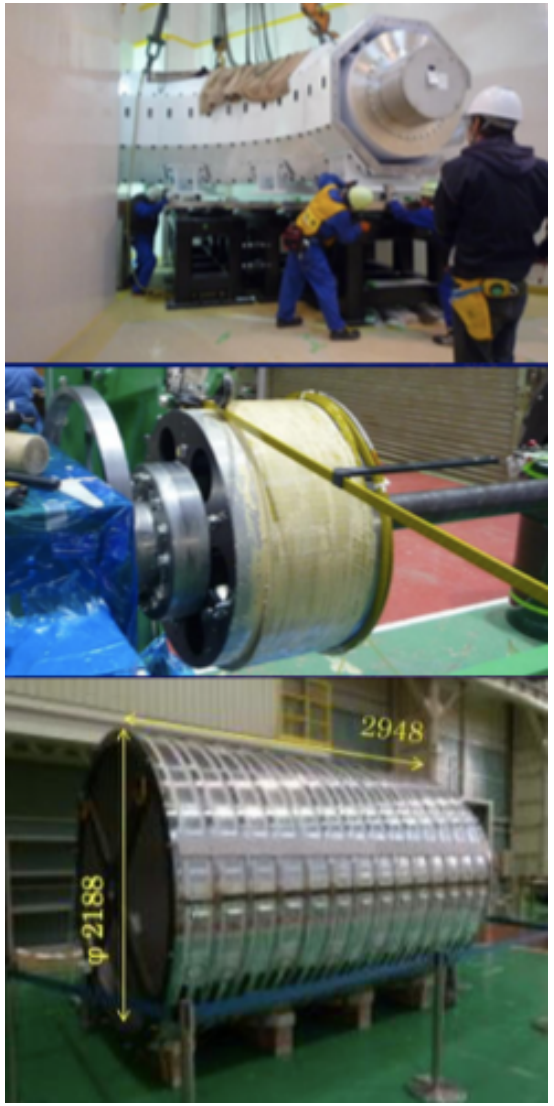
Mu2e

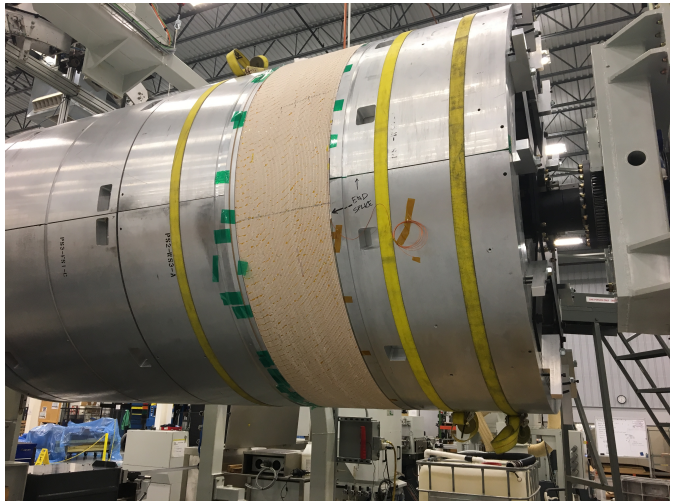


COMET-I



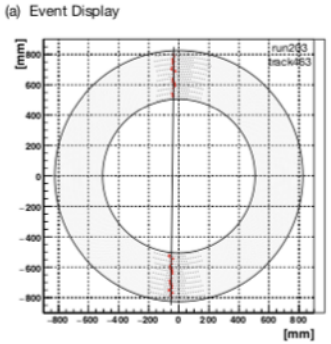
COMET and Mu2e solenoid production

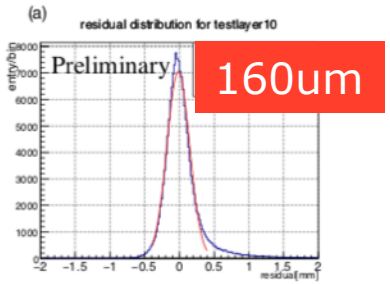


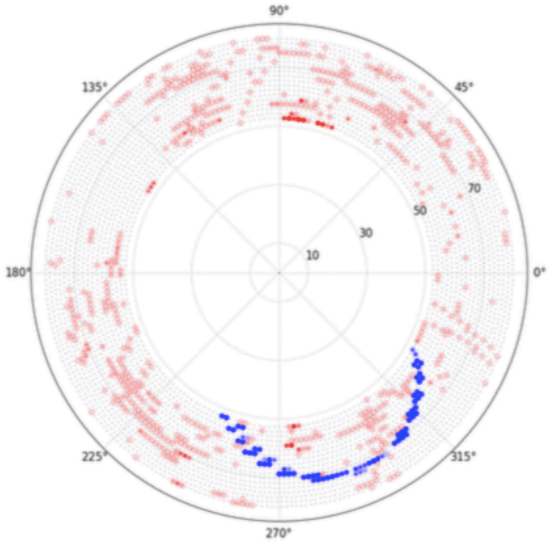


COMET and Mu2e Detectors

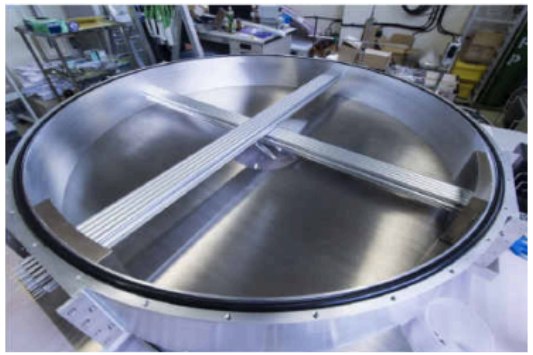
CDC cosmic-ray test is ongoing in KEK.
Good performance was obtained.

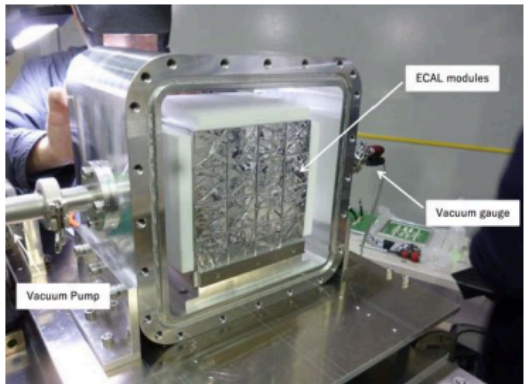


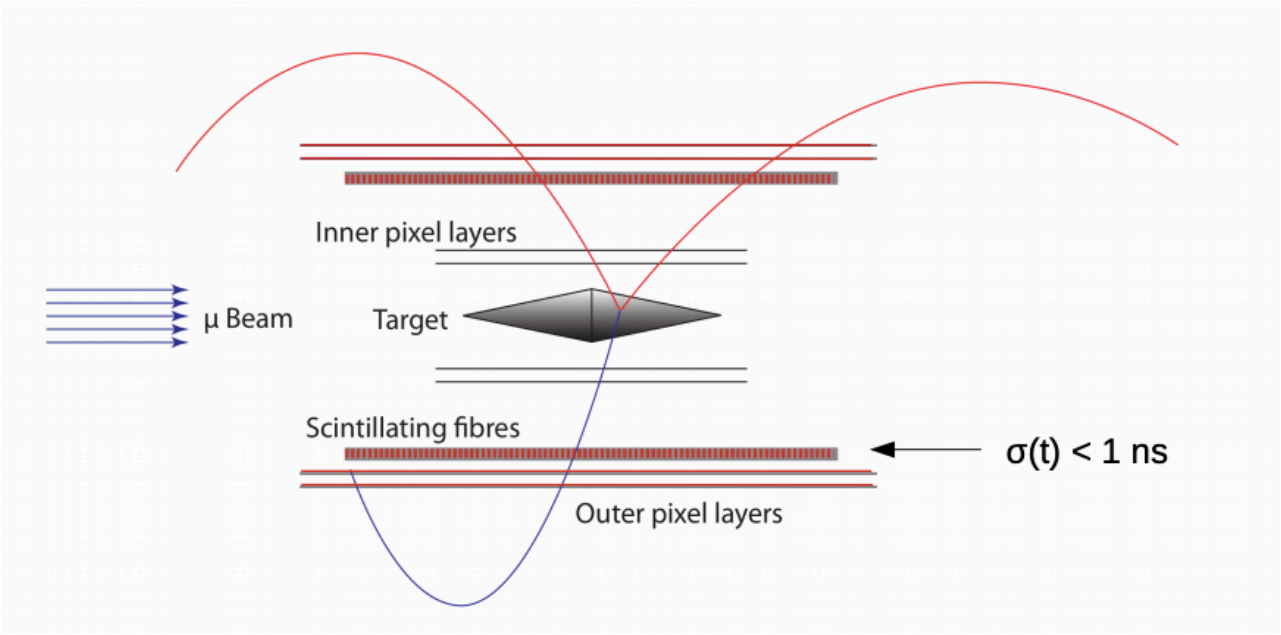




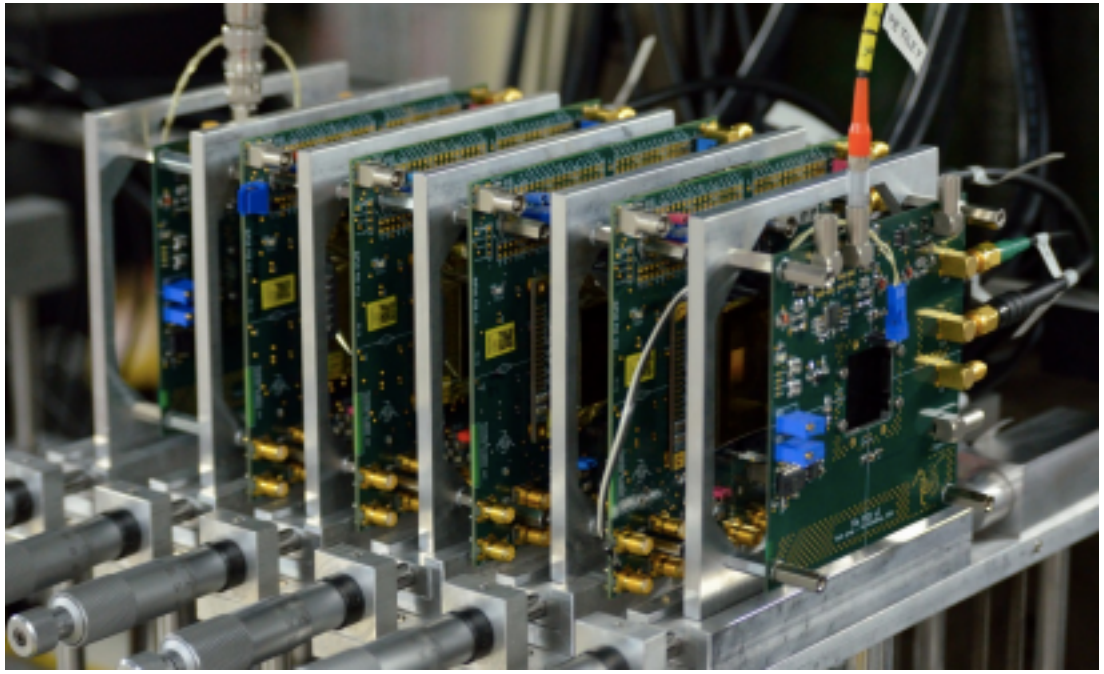
COMET-I commissioning 2020
Mu2e commissioning 2021







Detector commissioning 2020/2021



180nm HV-CMOS.
MuPix design evolving → MuPix11

Future Projects

”Big Ideas”

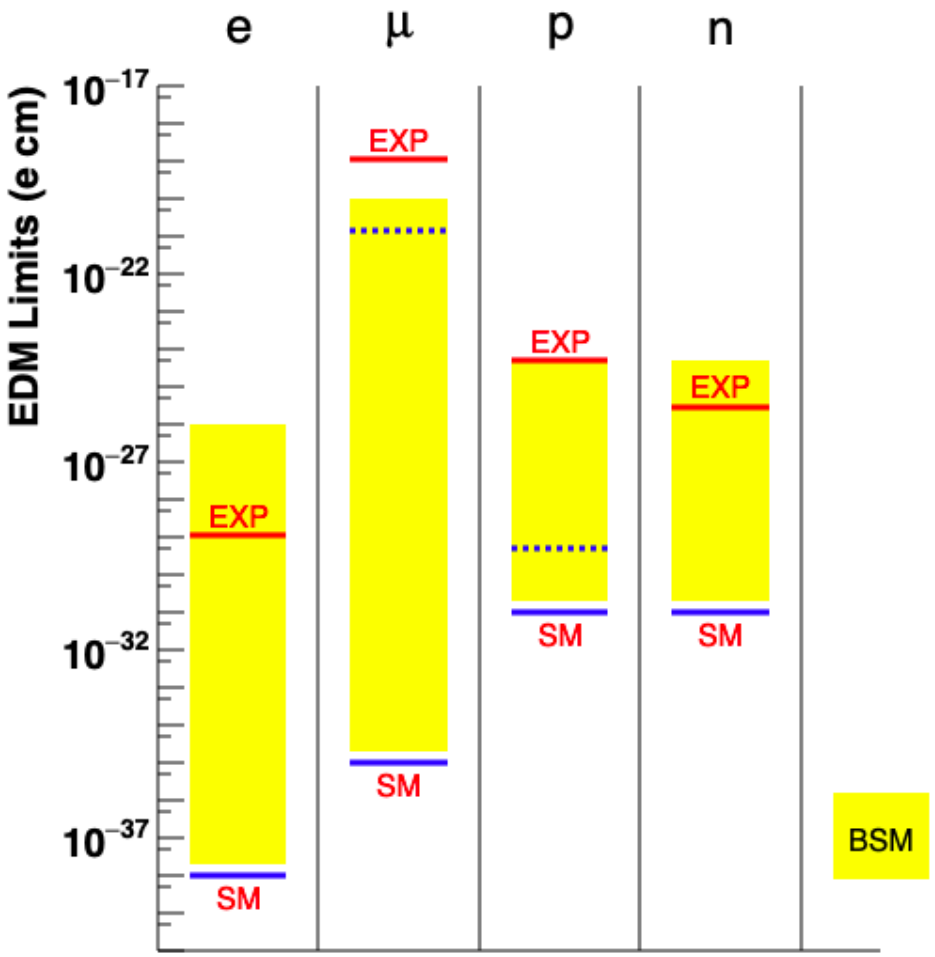
SoI for a future storage-ring-EDM and CLFV programme

T. Bowcock (Liverpool), J. Goldstein (Bristol), G. Hesketh (UCL),
M. Lancaster (UCL/Manchester), J. Vossebeld (Liverpool), G. Wilkinson (Oxford)

- Increase muon CLFV by factor of 10: Mu2e-II and COMET-FFAG
- Increase tau CLFV by factor of 10-100: tauFV@CERN
- Proton EDM : improve by a factor of 10^5
- Muon EDM: improve by a factor for 10.
- Cross-check g-2 theory with dedicated me scattering experiment : MuonE

Much of this is underpinned by need for very low-mass/high-resolution tracking : HV-CMOS.

EDMs

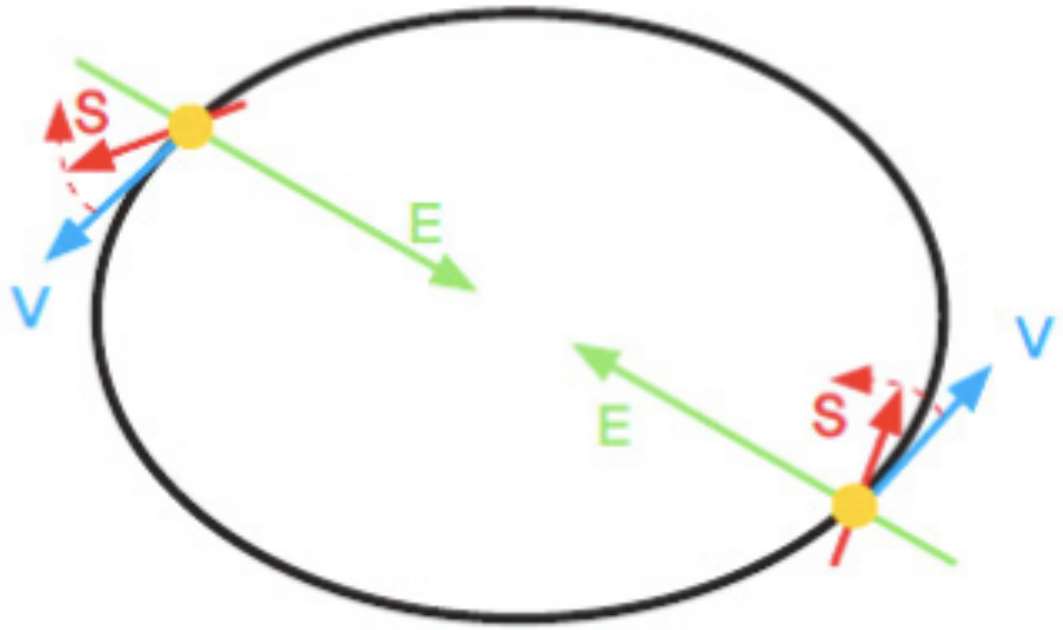


Muon EDM: add Si trackers to g-2

Dedicated experiment at PSI with 1m storage ring.
- workshop Feb 2020

Proton EDM
- prototype of techniques using deuterons at COSY
- potential to be realised at CERN (PBC, SPSC)

Storage Ring Proton EDM

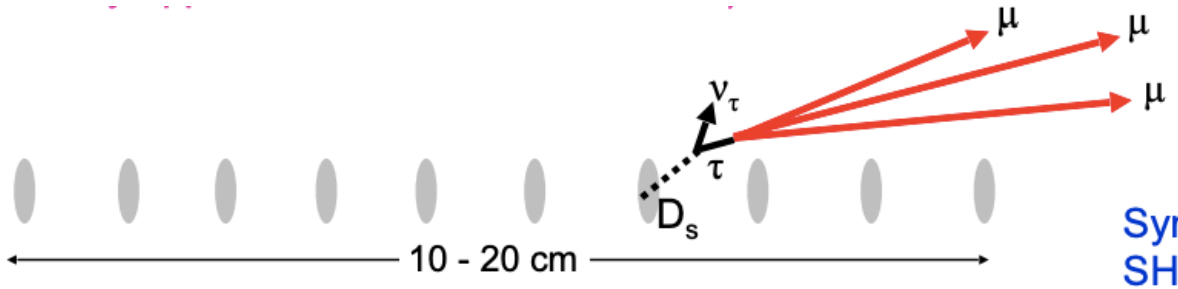


All electric storage ring similar to g-2.
Protons at 700 MeV

If there is an EDM spin precession plane develops a vertical component.

140 members in JEDI collaboration based around COSY

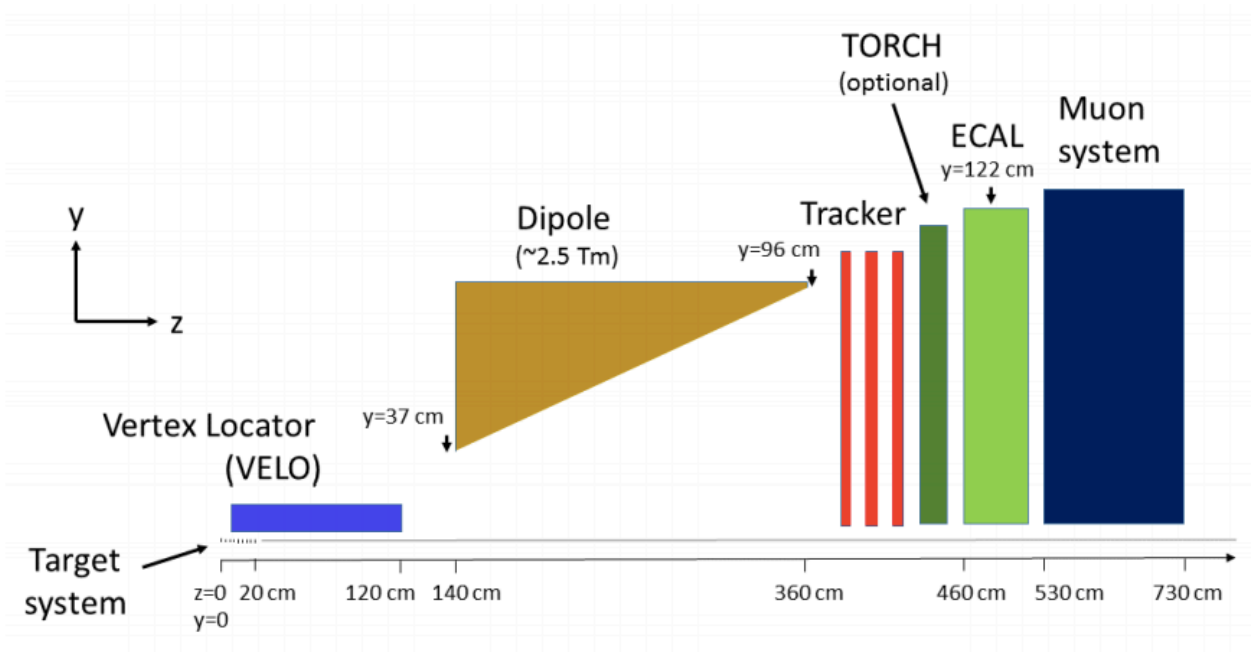
10^{14} Ds in 5 years. Extend Belle-II reach by a further factor of 10

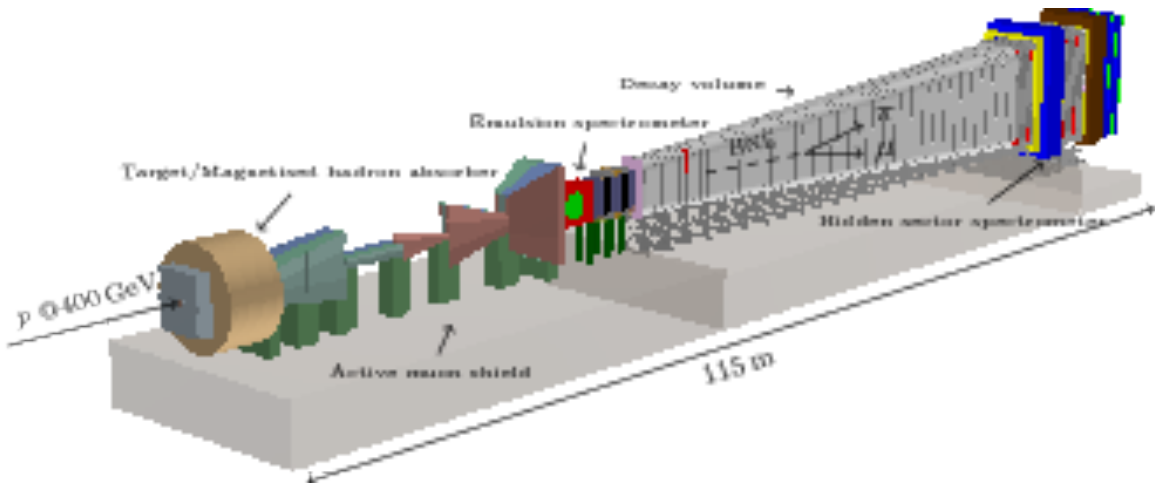


Synergetic with SHiP operation !

Technology challenge is FE ASIC

Depends on SHIP
Could be installed in LS4 (2030)





Summary

Ten years ago UK had essentially no involvement in the muon physics programme

Now playing a significant role in Muon g-2, COMET, Mu2e and Mu3e

We're all looking for similar things:
- Anomalous/extended Higgs properties
- Clues on origin of neutrino mass / leptogenesis
- A source of CP violation
- A "dark" particle

And I think we should cast the net wide.

There are plenty of opportunities for relatively cheap new experiments with challenging technology : storage-ring muon, proton EDMs, tauFV, Mu2e-II, COMET-FFAG for the 2030s.