Intensity Frontier Experiments

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Intensity Frontier ?

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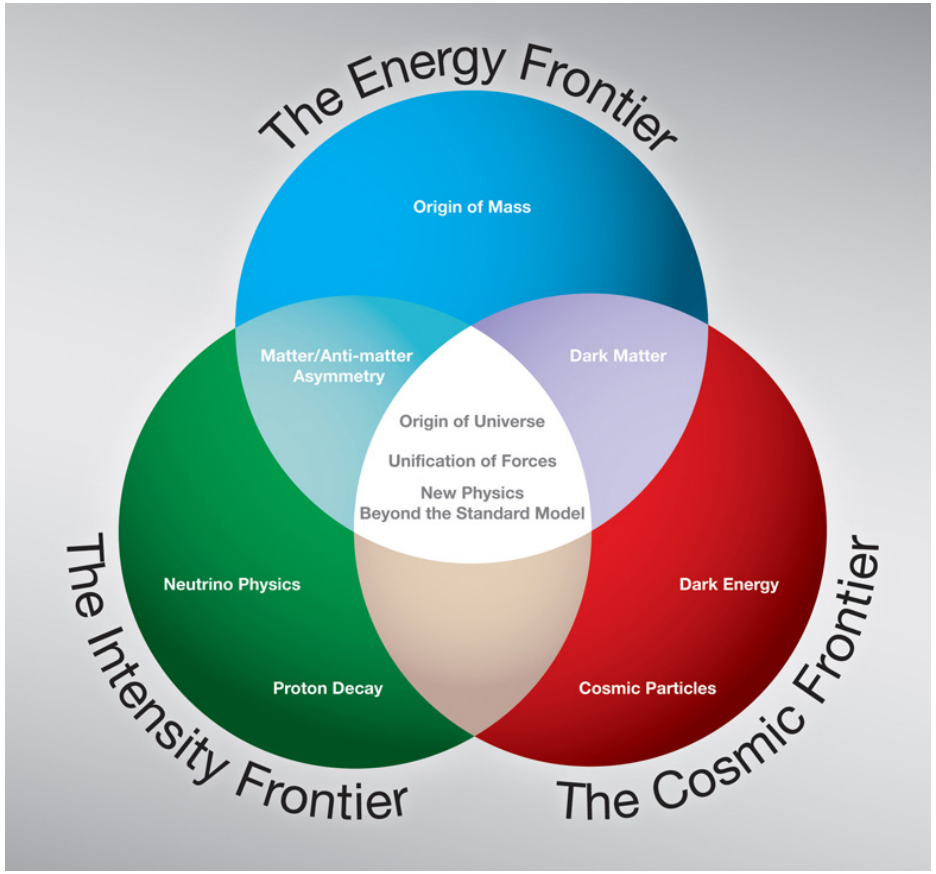
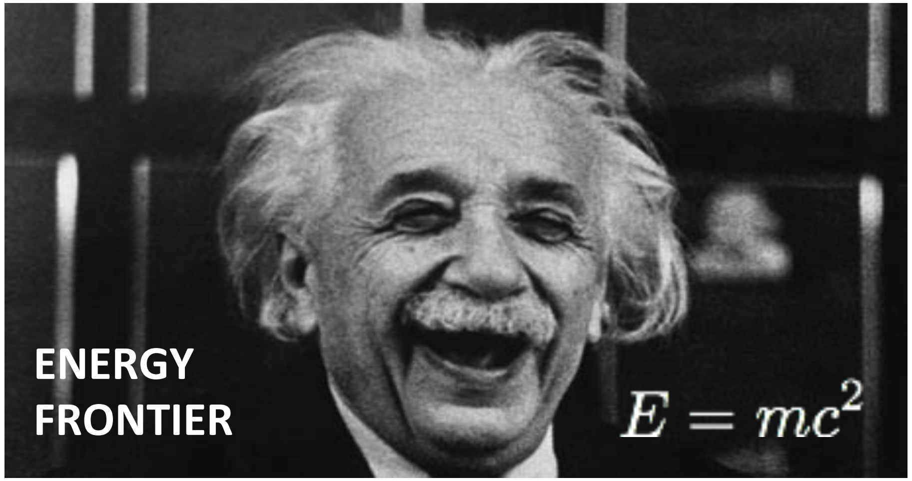


1. Probe processes that have very low rates / forbidden in SM e.g. $\mu \to e\gamma, \ K \to \pi\nu\bar{\nu}$

2. Measure tiny deviations from SM e.g. muon (g-2)

Requires intense beams and large/bespoke detectors.

Intensity vs Energy Frontier

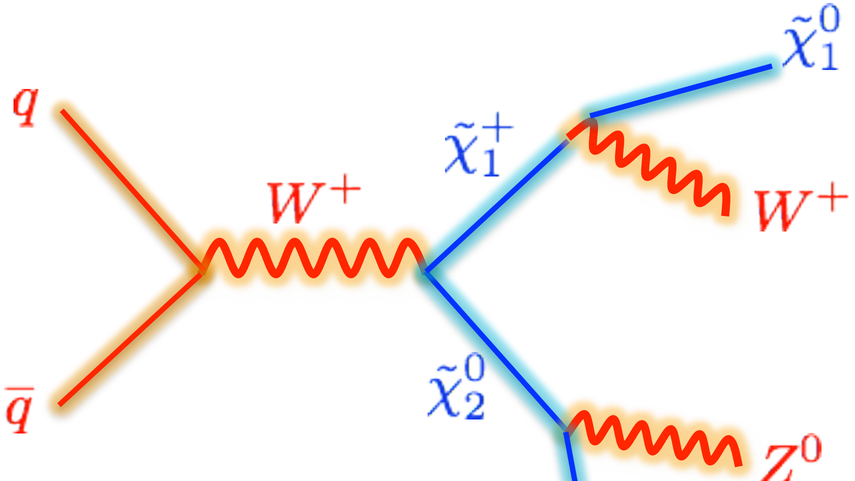


ENERGY FRONTIER

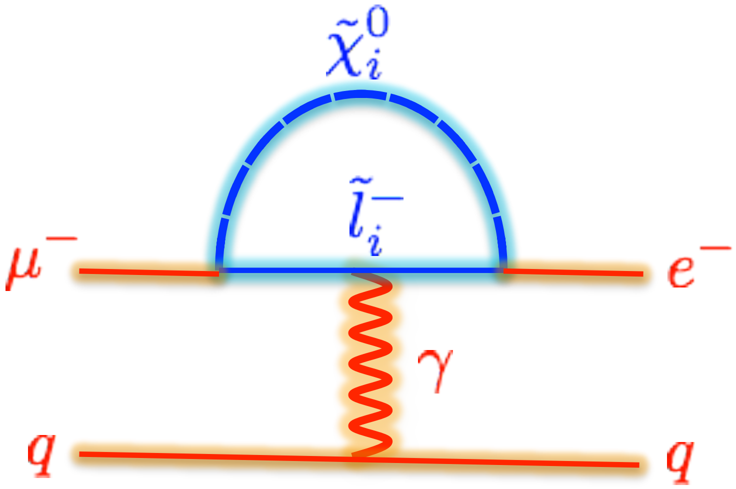
$E = mc^2$

INTENSITY FRONTIER

$\Delta E \Delta t \geq \frac{1}{2}\hbar$

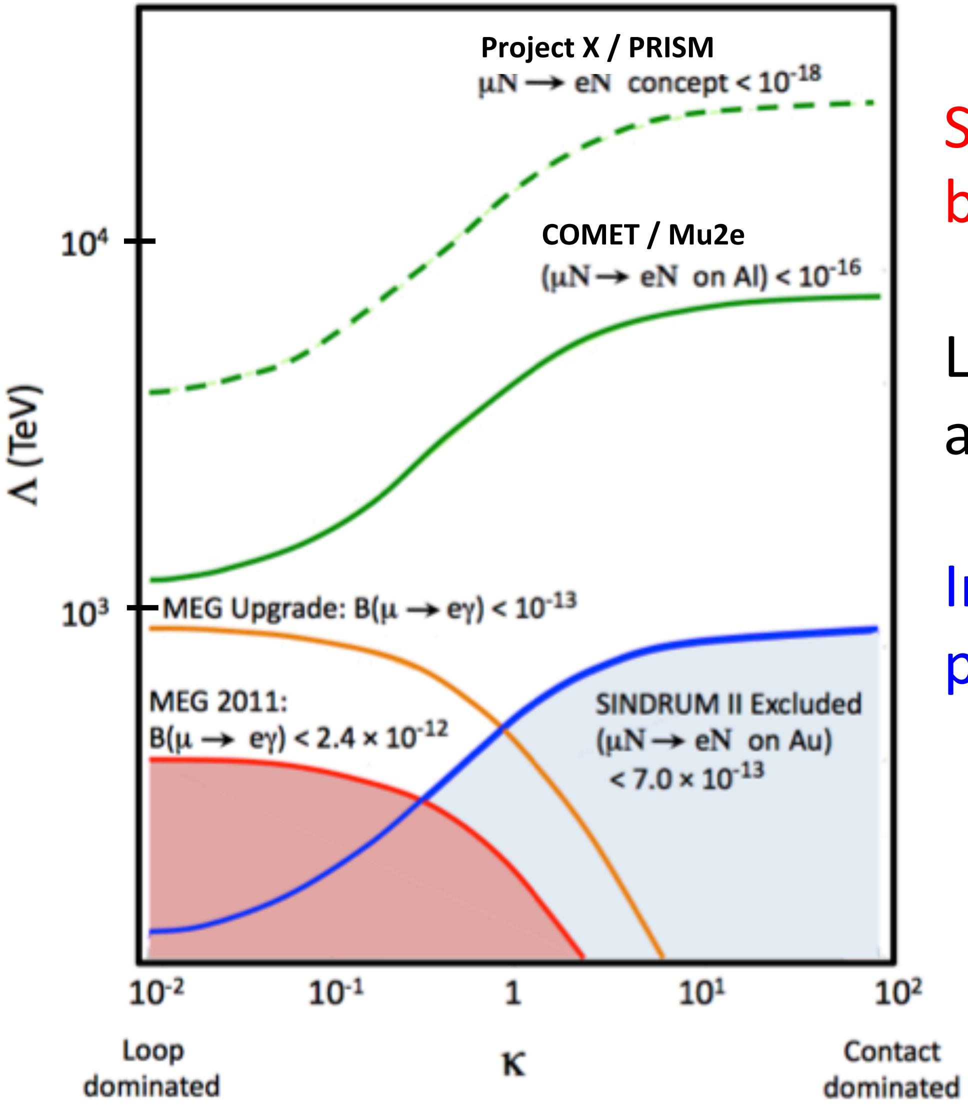


SM Backgrounds



$\mathcal{O}(10^{-50})$ in SM

Why Intensity ?



Sensitivity to physics at scales beyond the LHC.

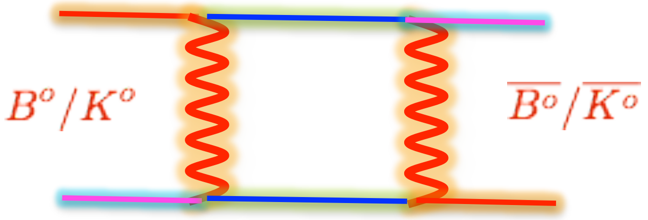
Likely that not all BSM physics is at the LHC TeV-scale.

Interpretation of any LHC BSM physics will require other inputs.

Why Intensity ?

Historically small deviations have been as insightful as new particles in developing a self-consistent (Standard) model.

1. Precise measurement of Kaon-mixing : **prediction of charm quark.**



2. Rare Kaon decays : **first observation of CP-violation**

: **requirement of CKM and a 3rd generation of quarks**

- *first input into explaining universe's baryon asymmetry.*

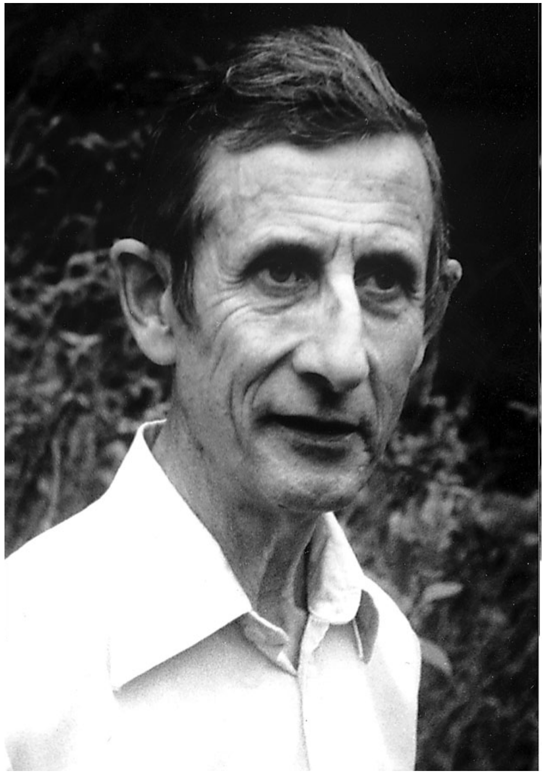
3. Precise measurement of B-mixing **: prediction of large top mass.**

Outside of HEP : tiny deviations in Mercury's orbit : vindication of General Relativity.

Why Rarity Frontier ?

"The results of my survey are then as follows: four discoveries on the energy frontier, four on the rarity frontier, eight on the accuracy frontier. *Only a quarter of the discoveries were made on the energy frontier, while half of them were made on the accuracy frontier*. For making important discoveries, high accuracy was more useful than high energy."

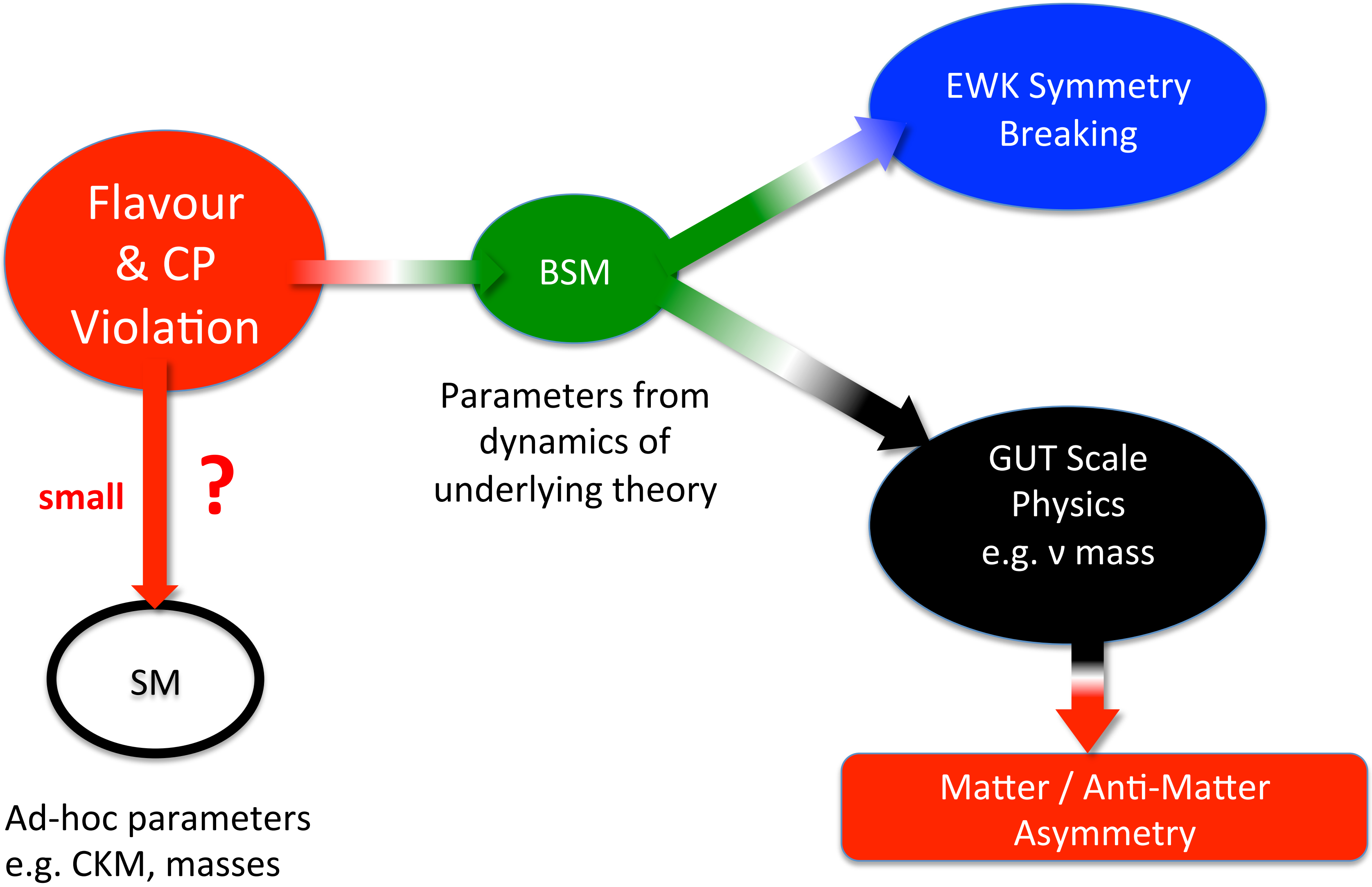
Freeman Dyson



"Limits on the neutron EDM have killed more theories than any other measurement"

Mike Pendlebury

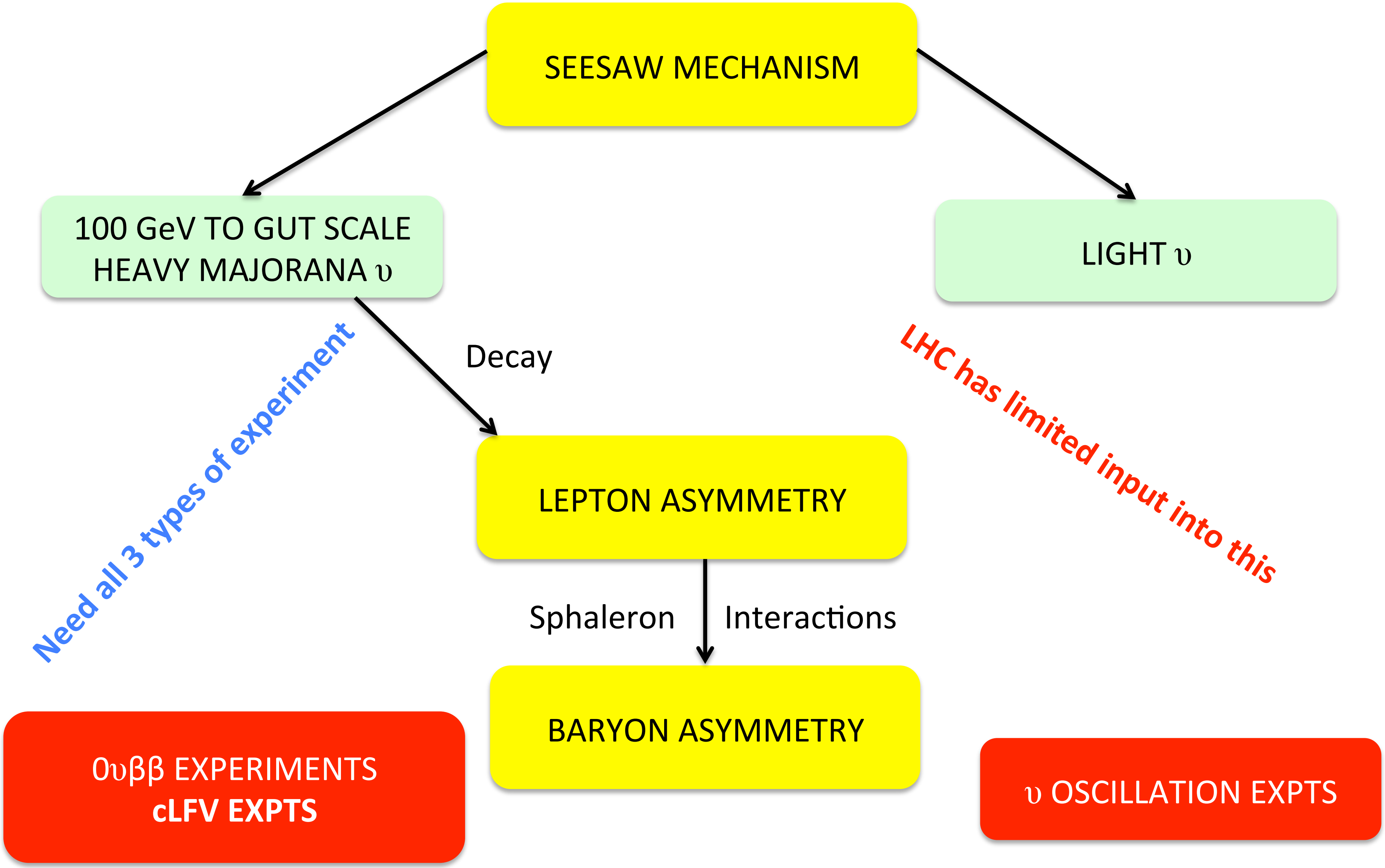
The path to new physics



Parameters from dynamics of underlying theory

Ad-hoc parameters
e.g. CKM, masses

Matter Anti-Matter / Neutrino Synergy



SEESAW MECHANISM

100 GeV TO GUT SCALE
HEAVY MAJORANA υ

LIGHT υ

Decay

LEPTON ASYMMETRY

Sphaleron Interactions

BARYON ASYMMETRY

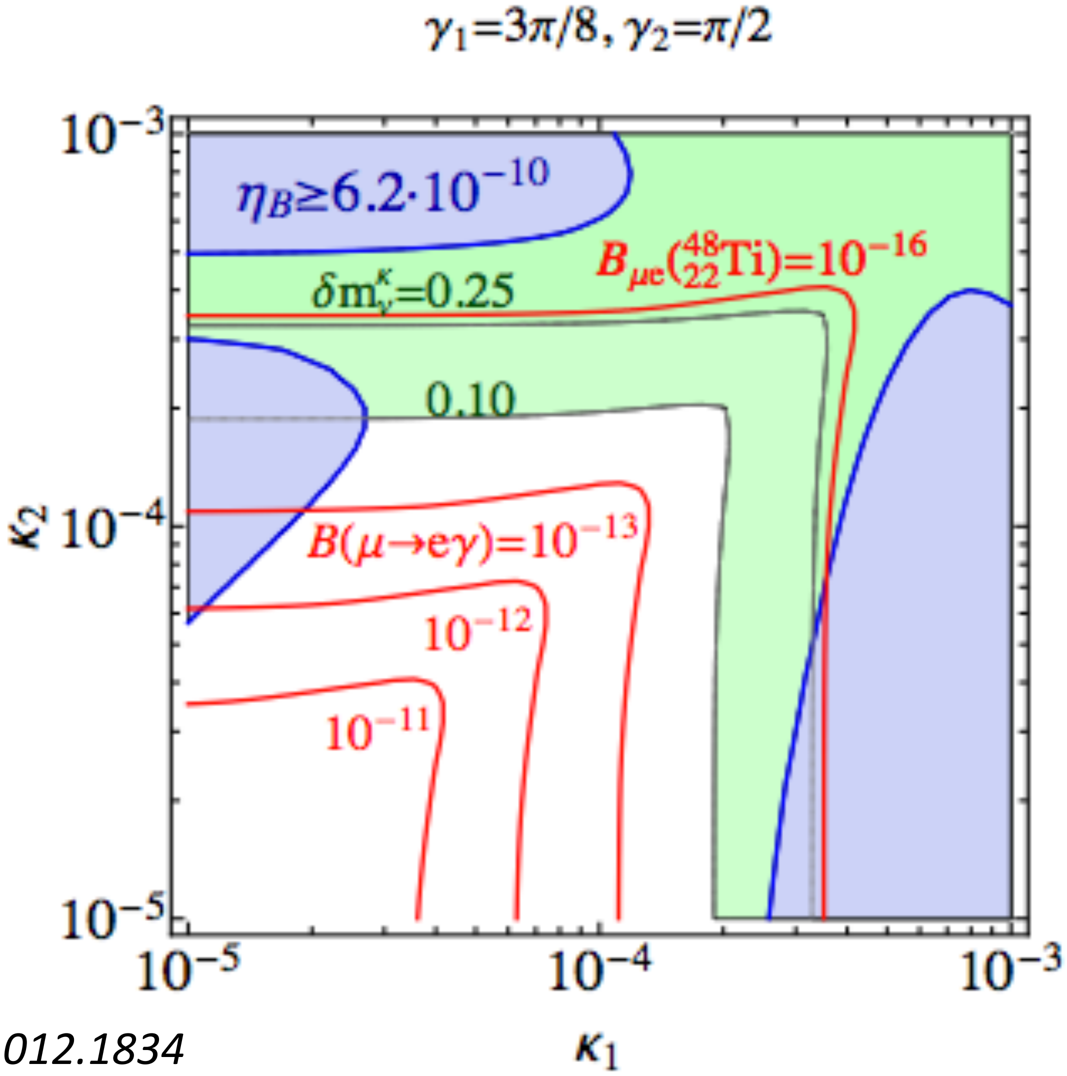
Need all 3 types of experiment

LHC has limited input into this

0υββ EXPERIMENTS
cLFV EXPTS

υ OSCILLATION EXPTS

Lepton Flavour Violation / Baryongenesis



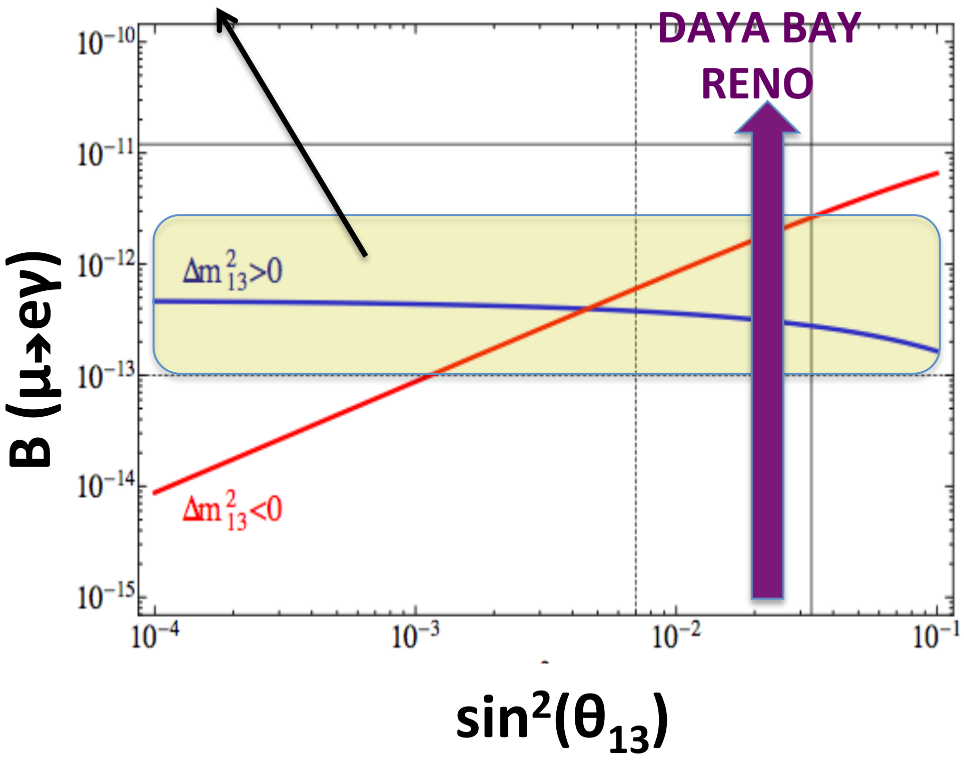
arxiV:1012.1834

$\kappa_1, \kappa_2, \gamma_1, \gamma_2$ symmetry breaking parameters

Complementary

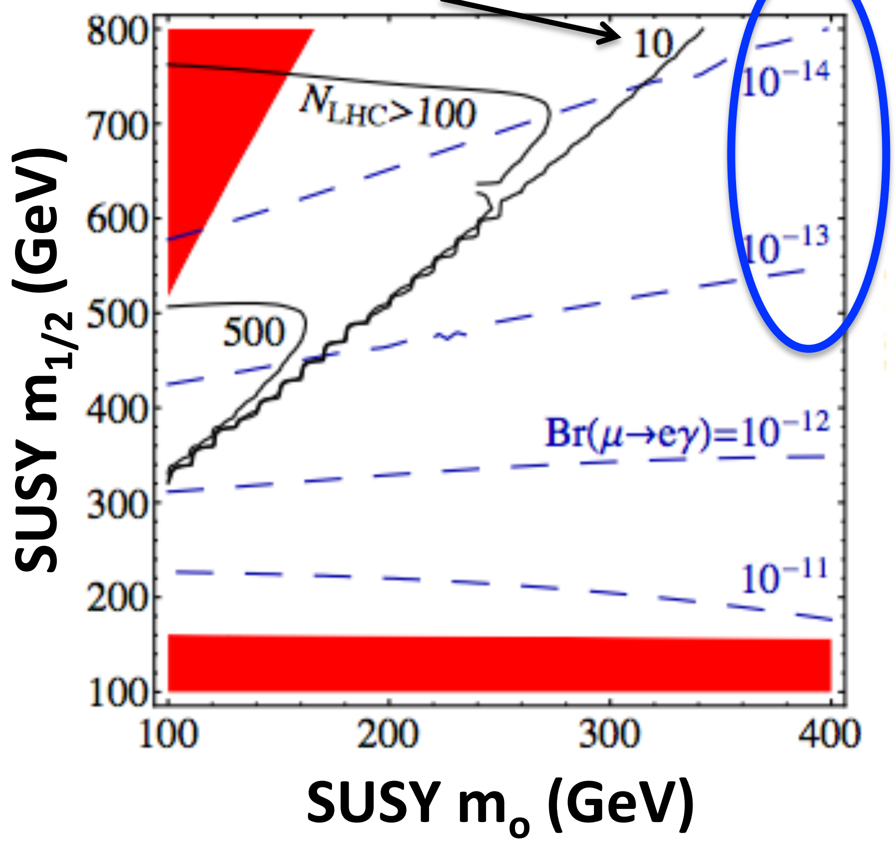
To neutrino & LHC programme

Region to be probed by MEG in next 1-4 years



arxiV:1012.1834

 # LFV events at 100/fb LHC



arxiV:1011.1404

Intensity / Rarity Frontier Programme

Intensity

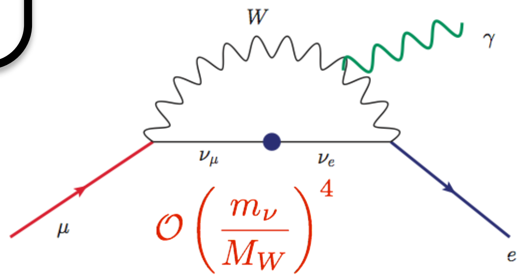
Rare B decays → **Nick Brook**

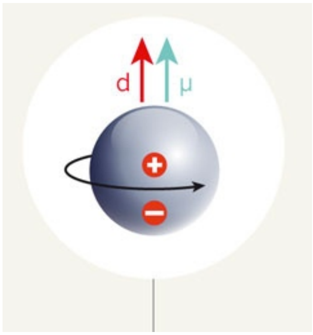
Neutrino oscillations → **Jenny Thomas**

Rare kaon / muon / tau decays

Rogue dipole moments

THIS TALK



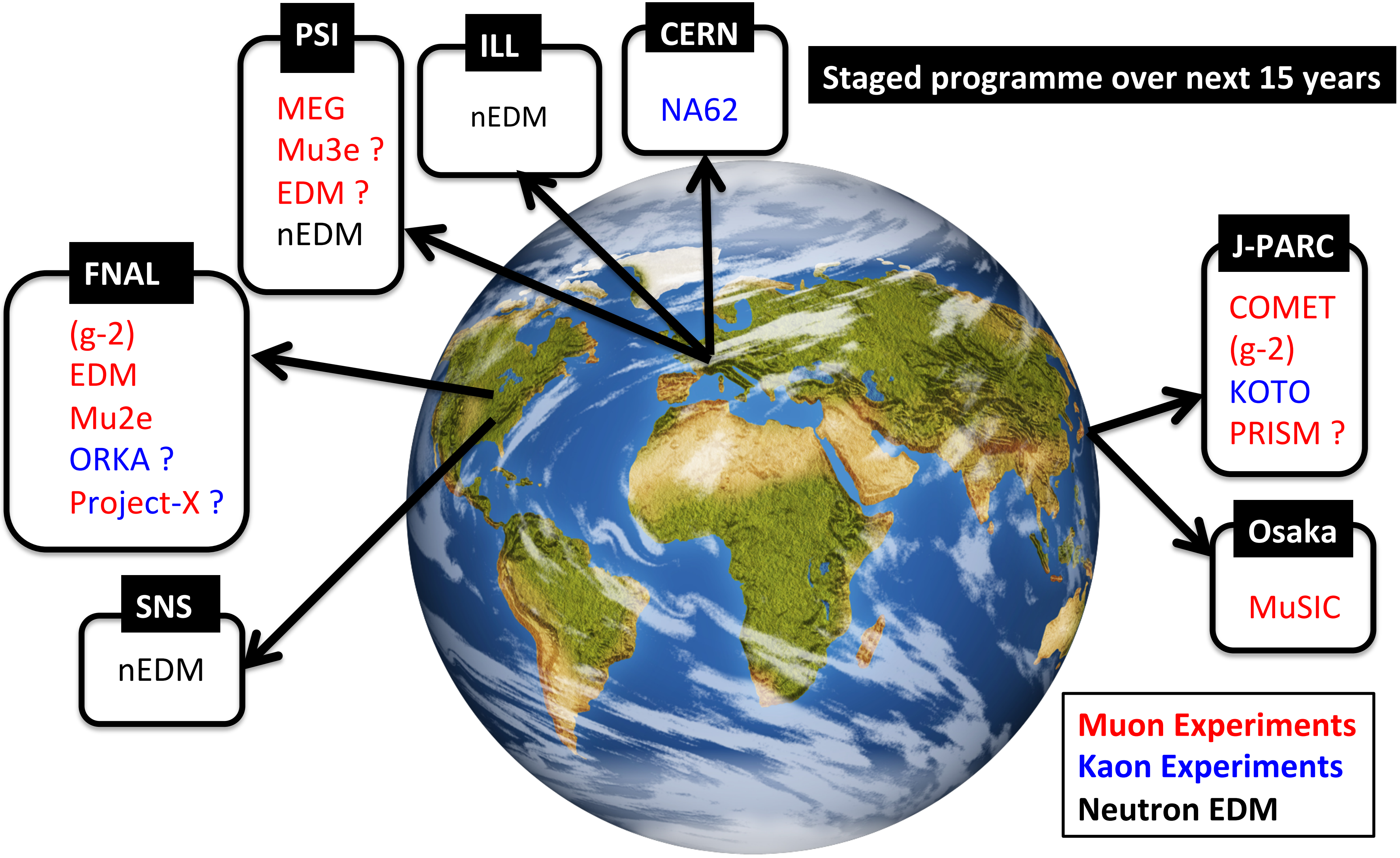


Rarity

0νββ decay → **Simon Peeters**

Dark Matter → **Jocelyn Monroe**

Where ?



Staged programme over next 15 years

PSI
MEG
Mu3e ?
EDM ?
nEDM

ILL
nEDM

CERN
NA62

FNAL
(g-2)
EDM
Mu2e
ORKA ?
Project-X ?

SNS
nEDM

J-PARC
COMET
(g-2)
KOTO
PRISM ?

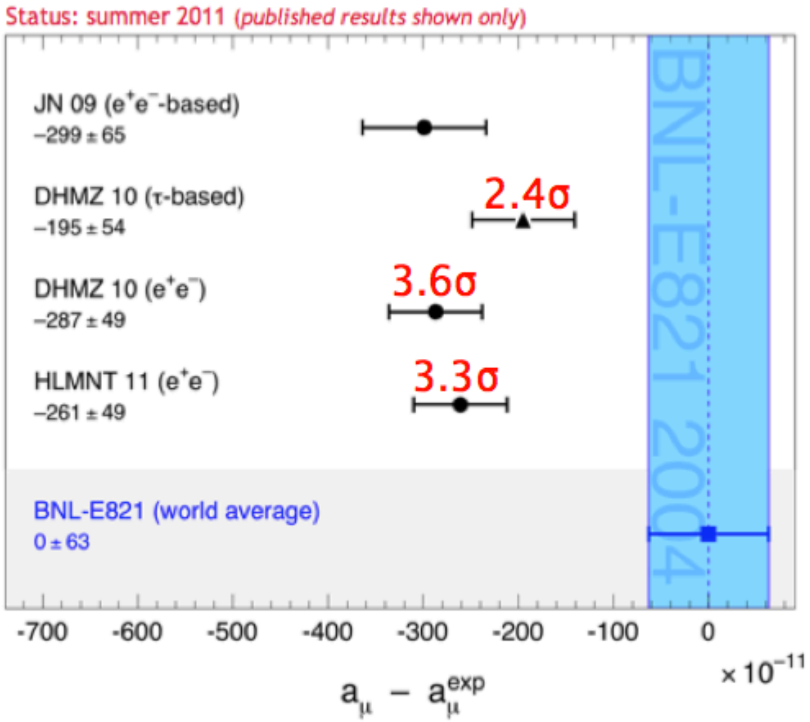
Osaka
MuSIC

Muon Experiments
Kaon Experiments
Neutron EDM

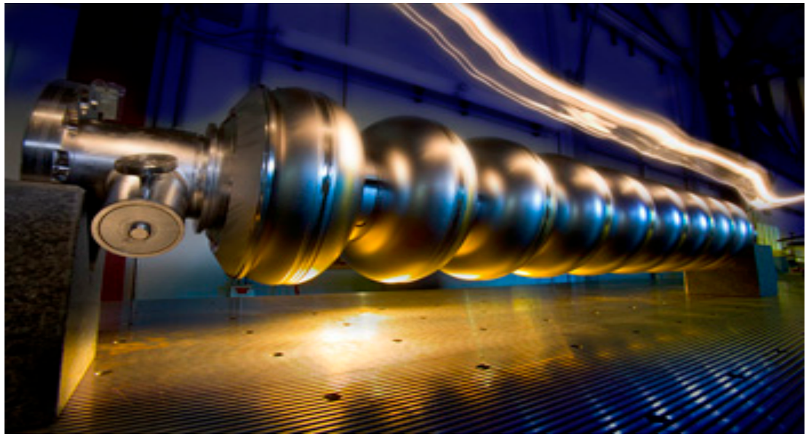
Why Now ?

Neutrino oscillations tell us that lepton flavour is not sacrosanct.

Hints of new physics in the muon (g-2) .

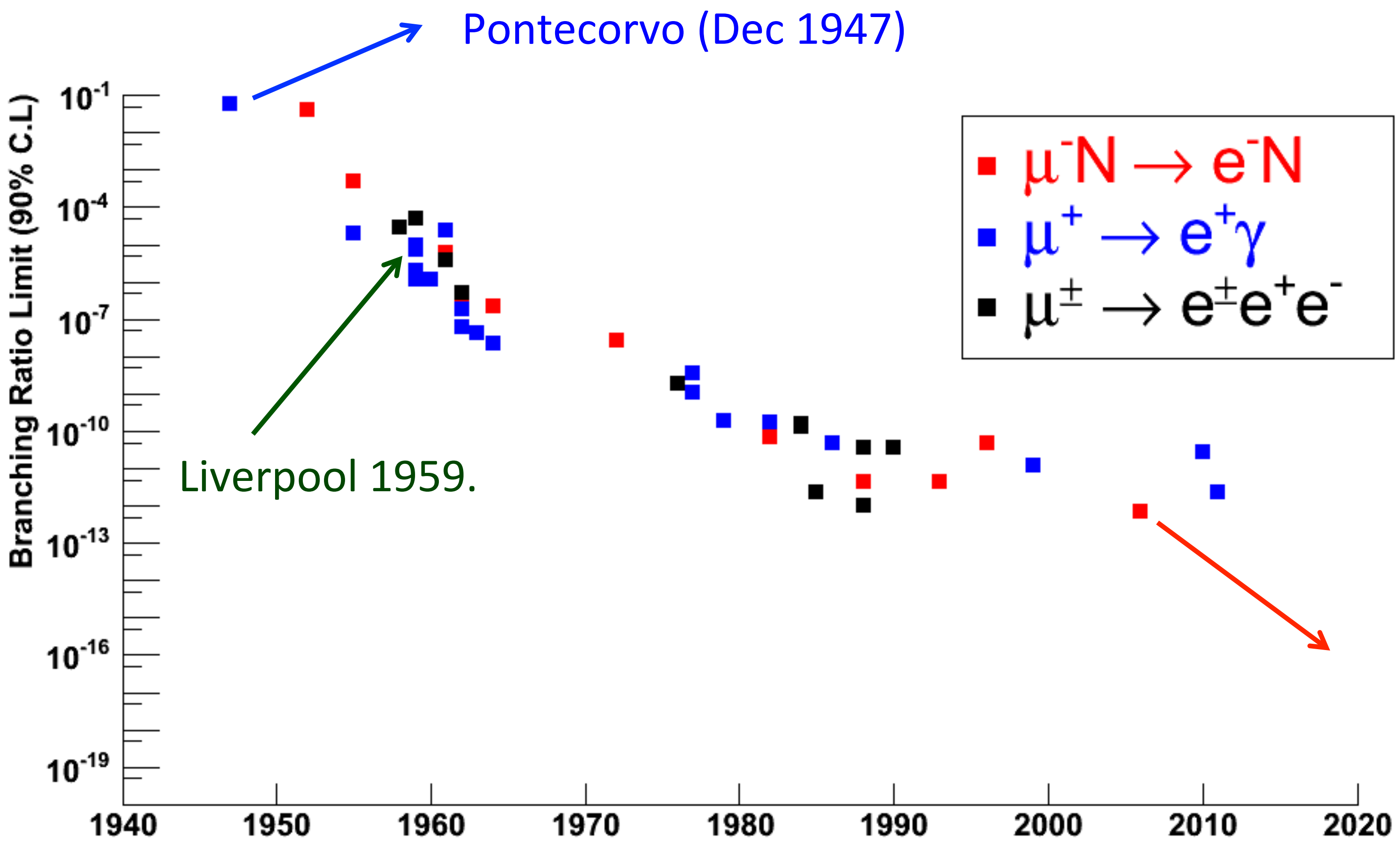


Accelerator advances now allow O(MW) proton beams and for sufficient # μ, K to probe the theoretically interesting regions e.g. that defined by new LHC physics.



Expedited by synergy with neutrino-factory and muon collider R&D.

Why Now ?



Pontecorvo (Dec 1947)

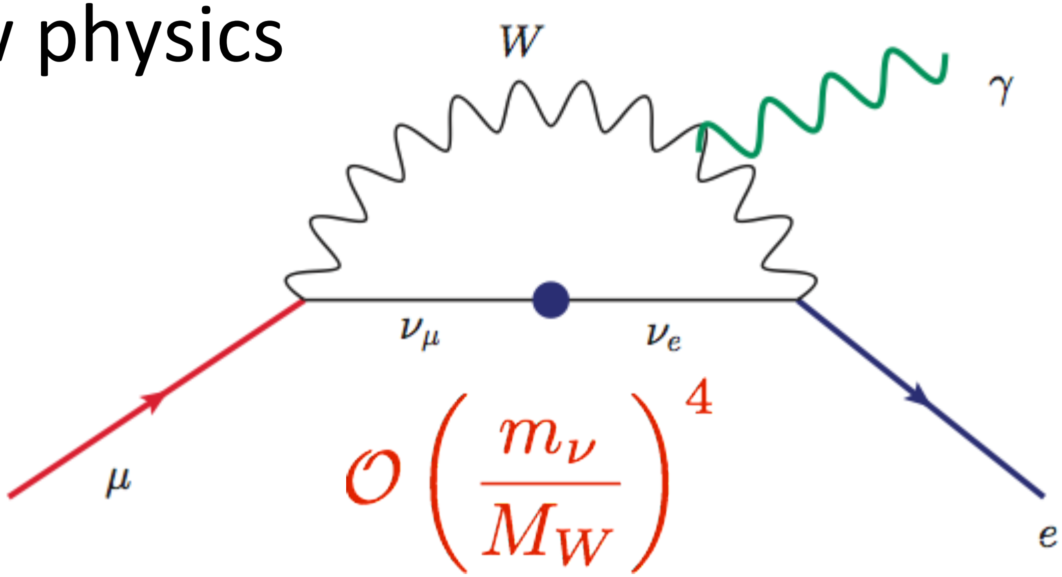
Liverpool 1959.

Factor of 10-10,000 improvements in sensitivity in near future.

Muon / Tau LFV

SM is O(10^{-50})

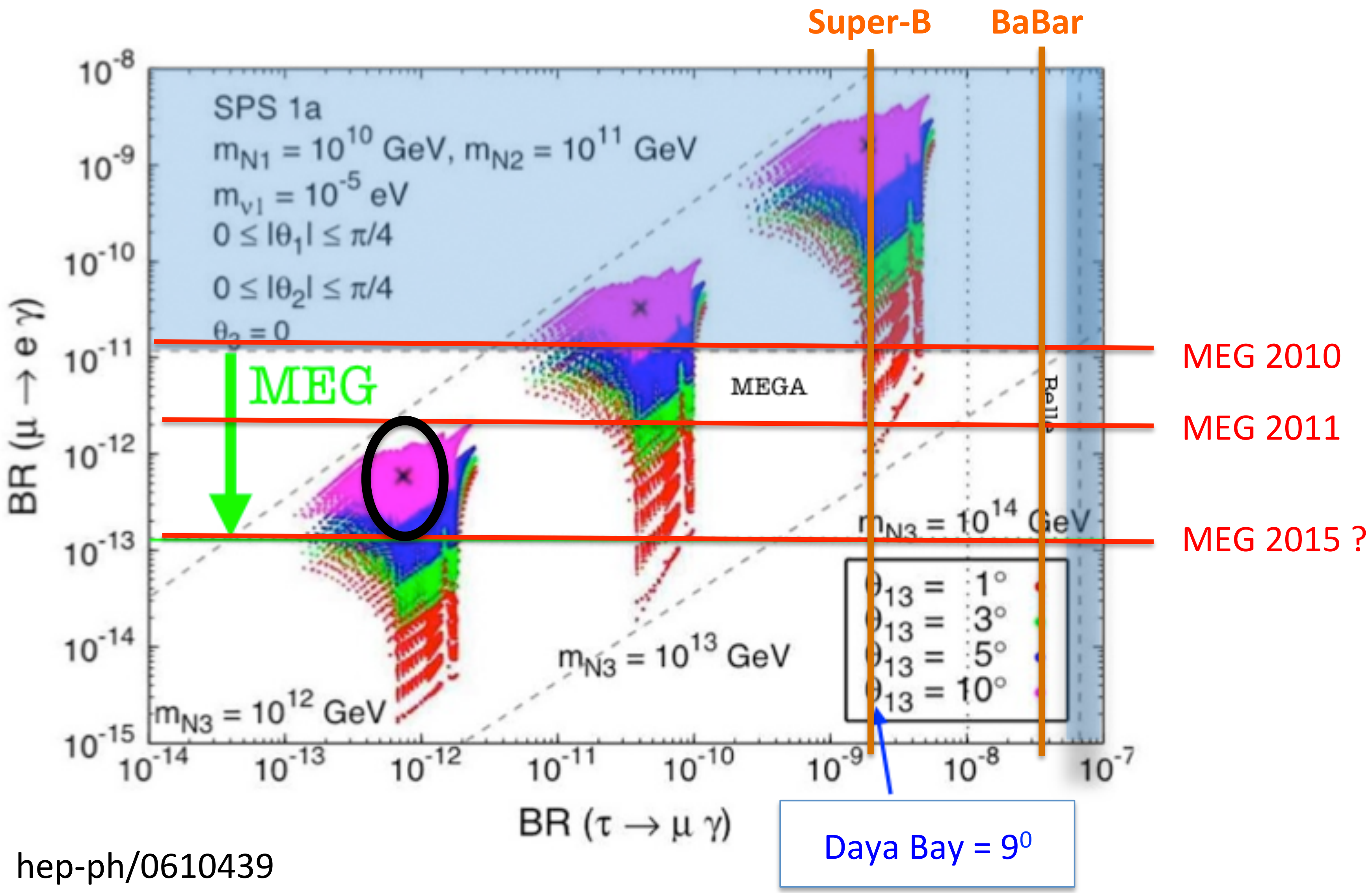
Observation **IS** new physics



No SM theory systematic

How far we can probe is limited by experiment

Sensitive to heavy neutrinos



hep-ph/0610439

Muon LFV

Sensitivity to widest variety of BSM models.

	AC	RVV2	AKM	δLL	FBMSSM	LHT	RS
$D^0 - \bar{D}^0$	★★★	★	★	★	★	★★★	?
ϵ_K	★	★★★	★★★	★	★	★★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★	?
$A_{CP}(B \to X_s\gamma)$	★	★	★	★★★	★★★	★	?
$A_{7,8}(B \to K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★★	?
$A_9(B \to K^*\mu^+\mu^-)$	★	★	★	★	★	★	?
$B \to K^{(*)}\nu\bar{\nu}$	★	★	★	★	★	★	★
$B_s \to \mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★	★
$K^+ \to \pi^+\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$K_L \to \pi^0\nu\bar{\nu}$	★	★	★	★	★	★★★	★★★
$\mu \to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
$\tau \to \mu\gamma$	★★★	★★★	★	★★★	★★★	★★★	★★★
$\mu + N \to e + N$	★★★	★★★	★★★	★★★	★★★	★★★	★★★
d_n	★★★	★★★	★★★	★★	★★★	★	★★★
d_e	★★★	★★★	★★	★	★★★	★	★★★
$(g-2)_\mu$	★★★	★★★	★★	★★★	★★★	★	?

W. Altmannshofer, et al Nucl. Phys. B 830 17 (2010)

Different **SUSY** and **non-SUSY** BSM models.

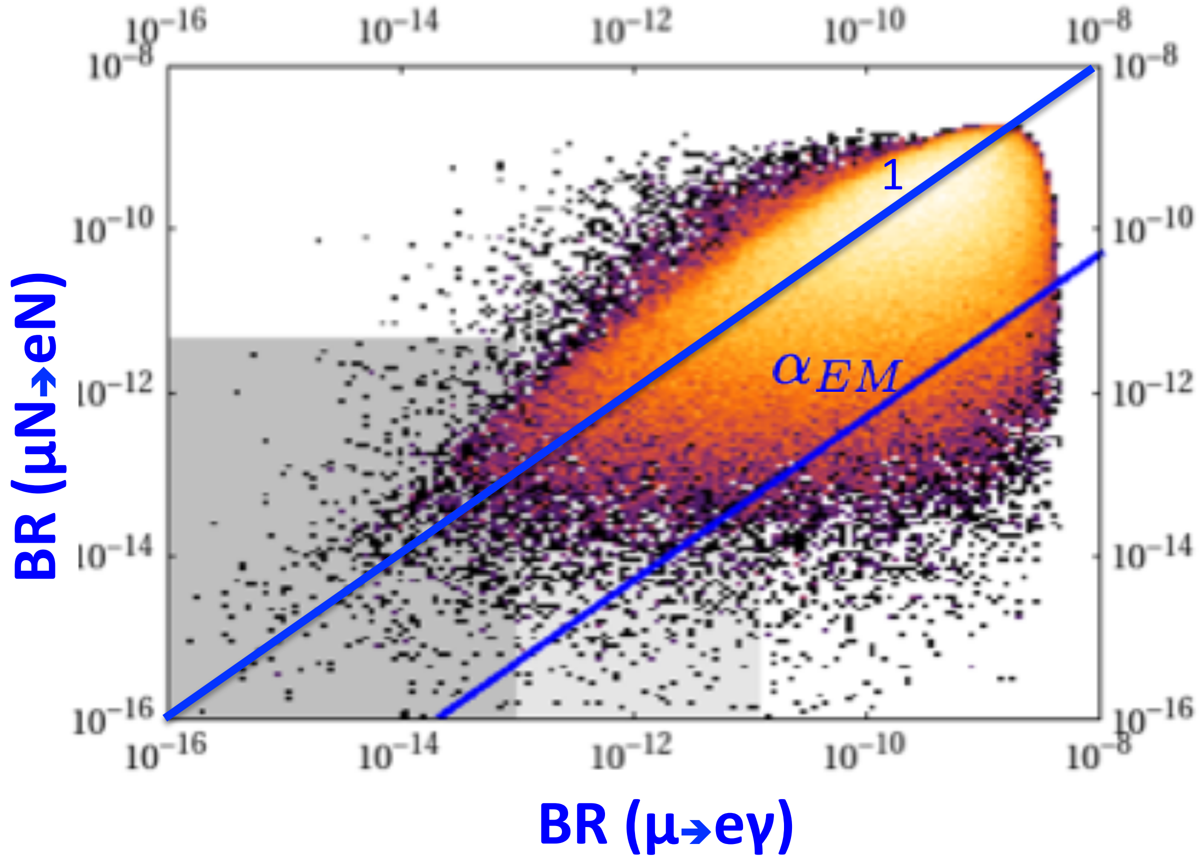
★★★ **Large effects**

★★ **Visible but small**

★ **No sizeable effect**

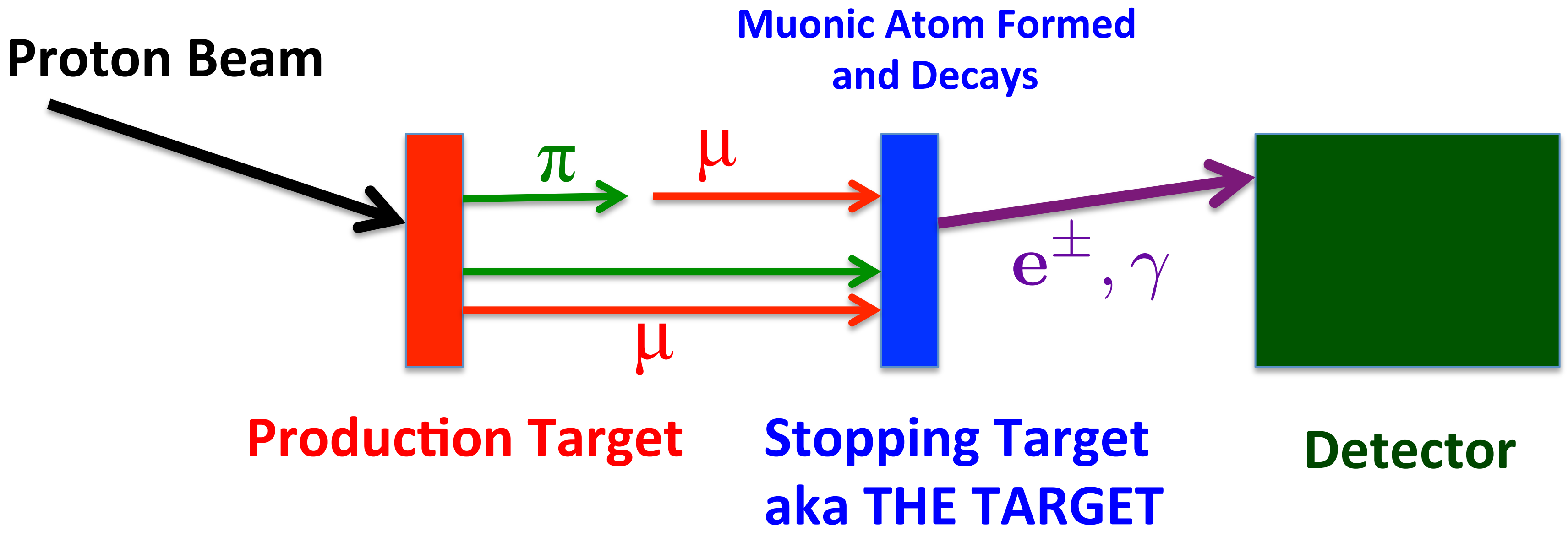
Process Ratios are Model Dependent

In general in BSM models $\frac{BR(\mu N \to eN)}{BR(\mu \to e\gamma)} = \mathcal{O}(\alpha_{EM})$ but not always…



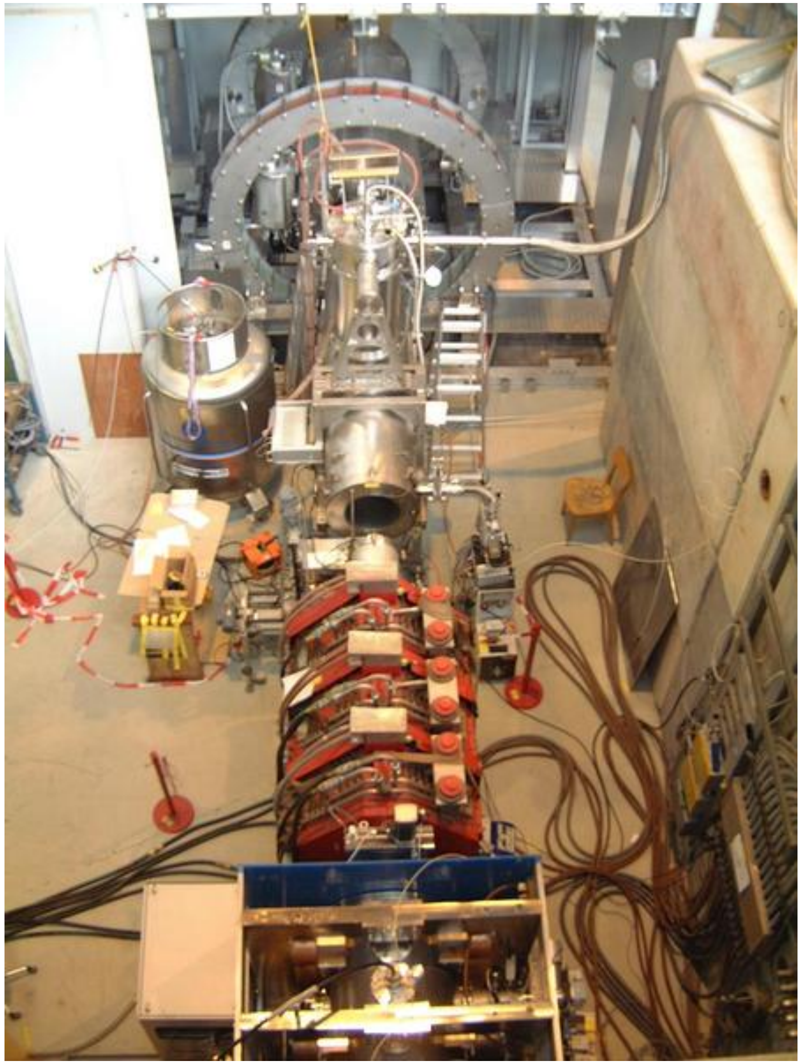
e.g. "Littlest Higgs model" with T-parity (LHT) *Blanke et al, Acta Phys.Polon.B41:657,2010*

Experimental Technique



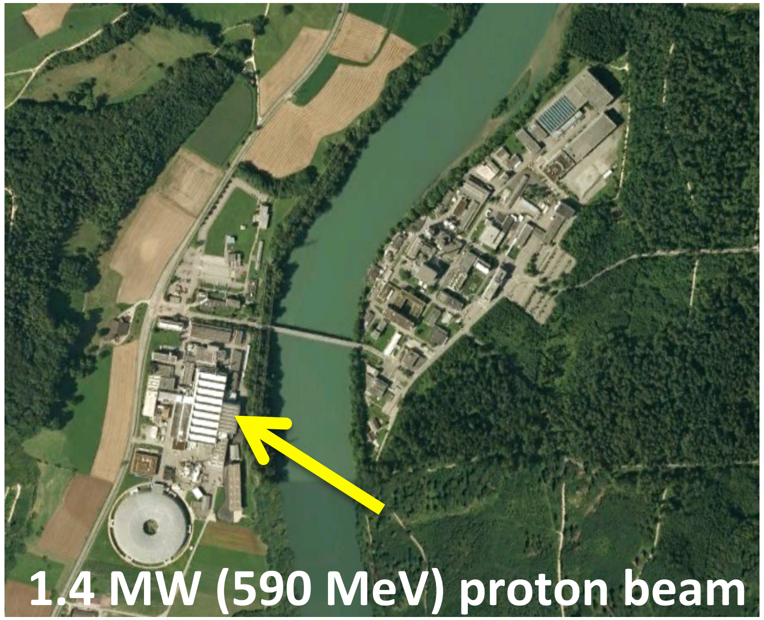
Apply symmetries, translations, rotations, …..

Current State of The Art



PSI (Zurich/Switzerland) Facility

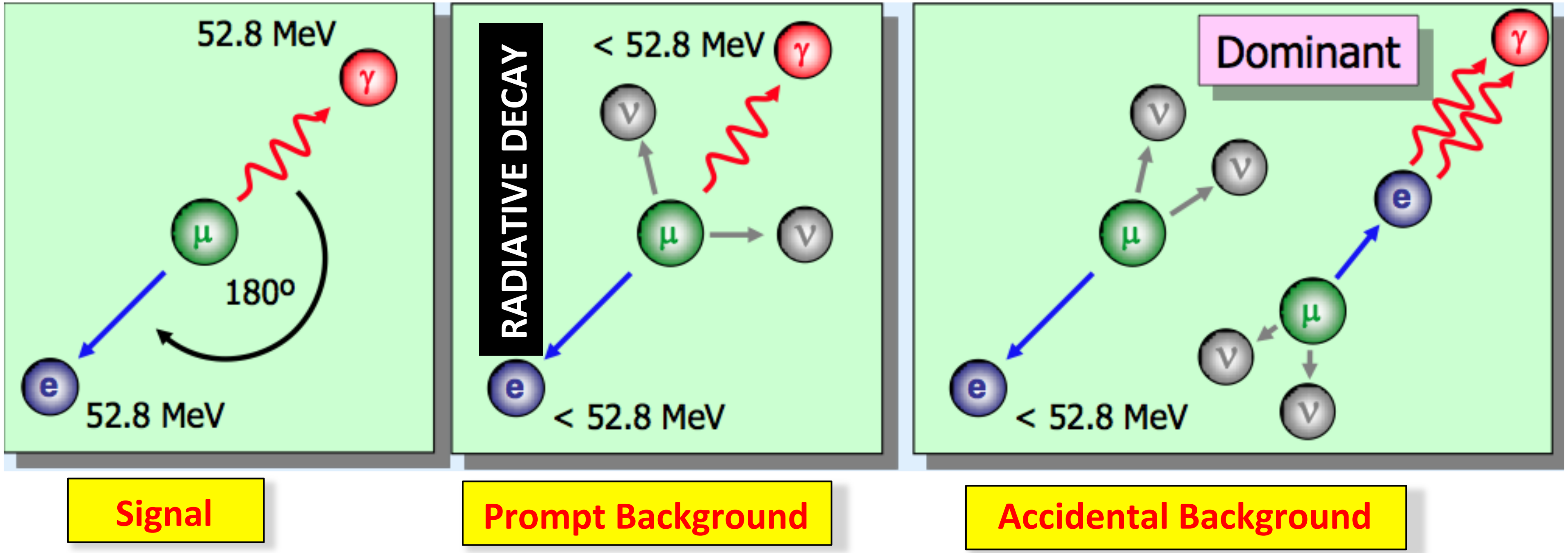
3x10^7 "stopped" **μ+**/sec



1.4 MW (590 MeV) proton beam

MEG Experiment

MEG present limit on μ→eγ is 2.4×10^{-12}. It is aiming to get to 1×10^{-13}

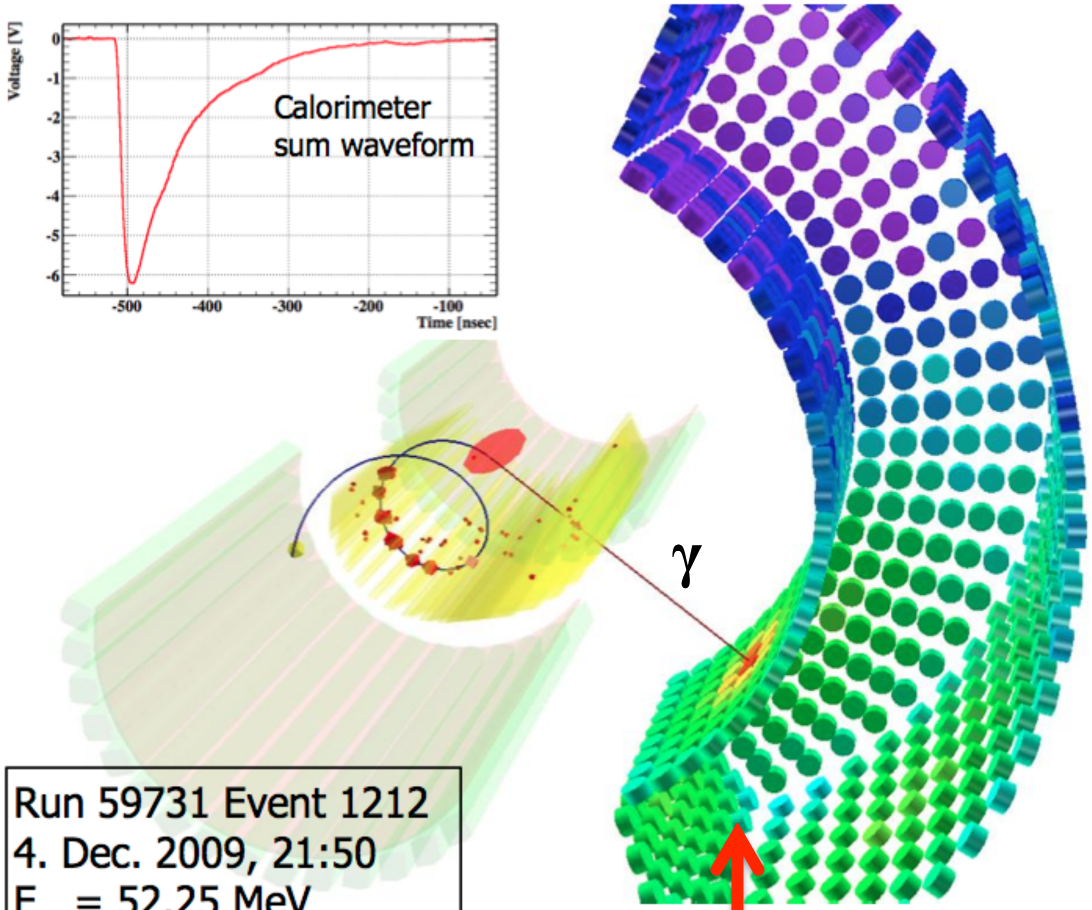


$E_\gamma = E_{e+}$ = 52.8 MeV

$\theta_{\gamma e} = 180^0$

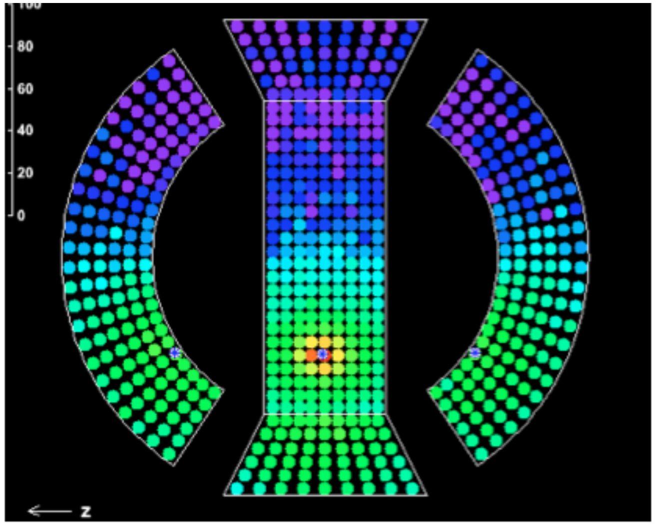
γ and e^+ in time

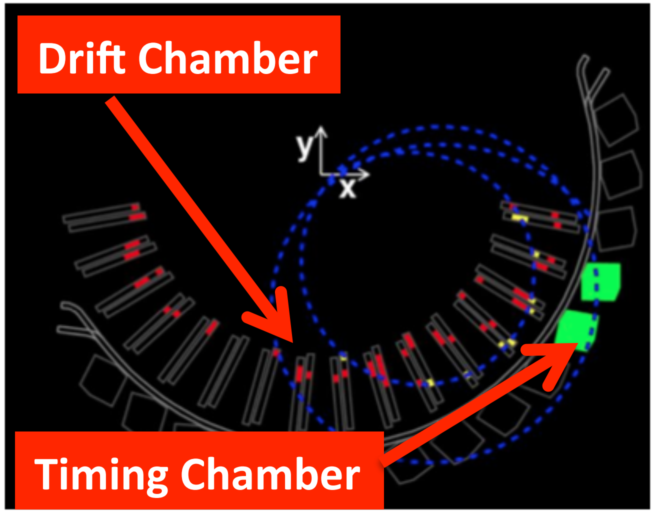
MEG Experiment



Run 59731 Event 1212
4. Dec. 2009, 21:50
E_γ = 52.25 MeV
E_{e+} = 52.84 MeV
$\Delta\theta_{e+g}$ = 178.8 degrees
$\Delta T_{e\gamma}$ = 26.8 ps

Liquid Xe calorimeter





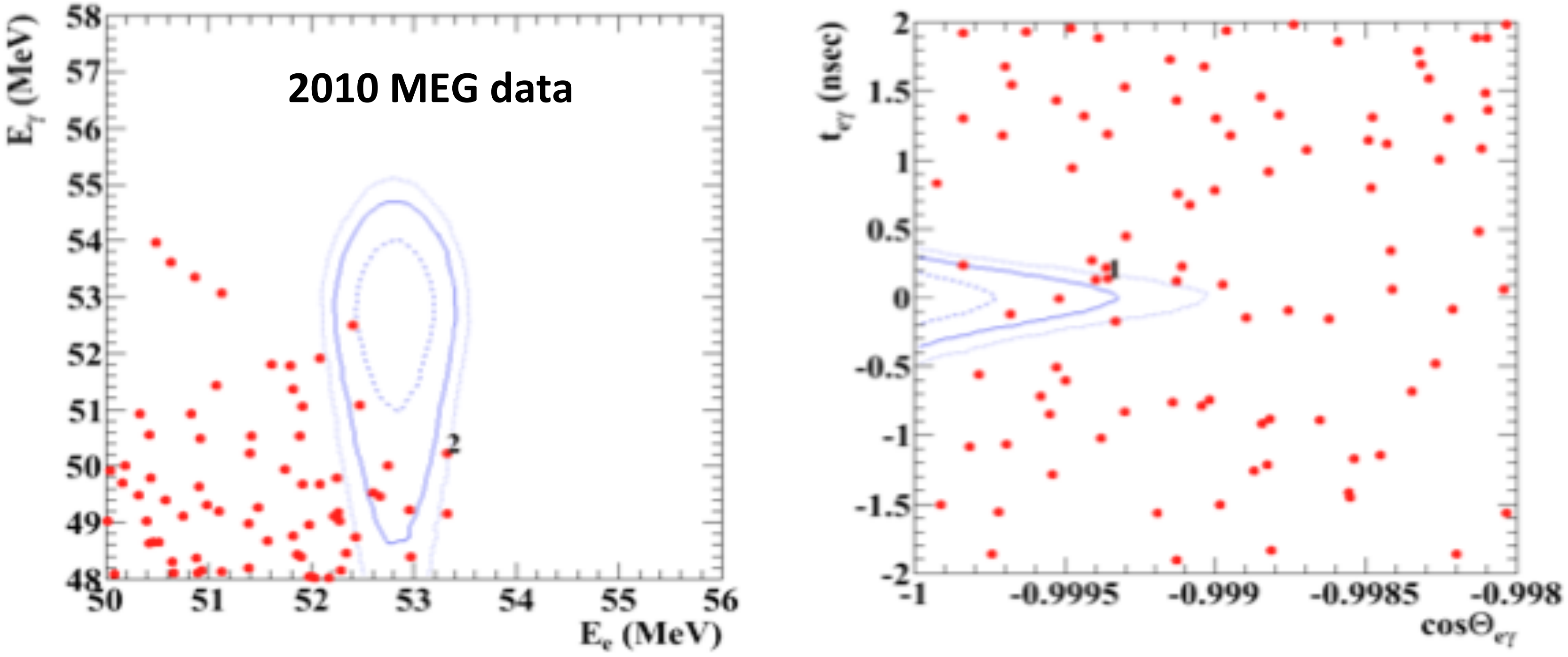
Drift Chamber

Timing Chamber

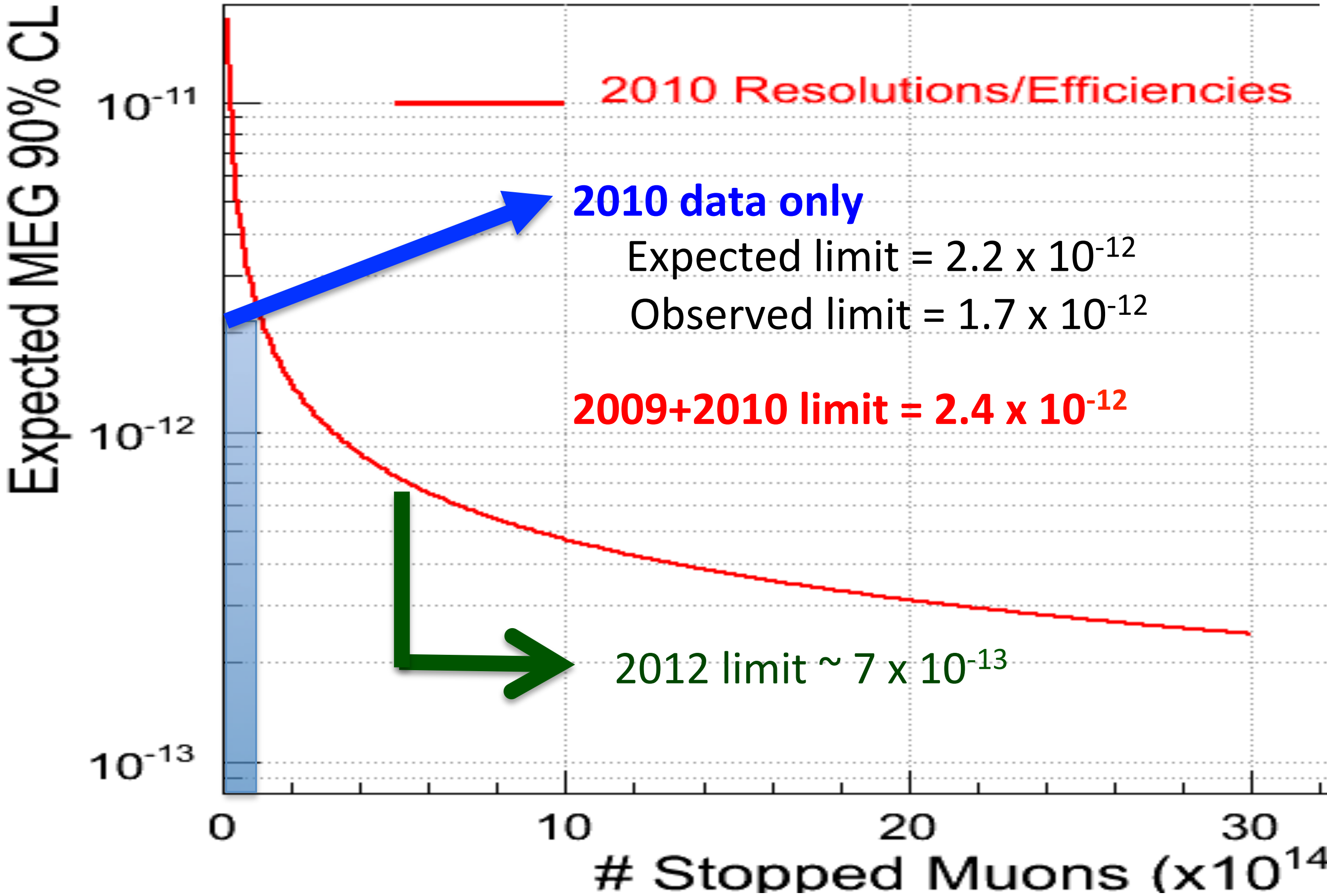
MEG Sensitivity Determined By

- # of stopped muons : accelerator driven (2010 : 2.3 x 10^7/s)

- Resolution in e^+ and photon energy and angle, time between them



MEG Sensitivity



2010 data only

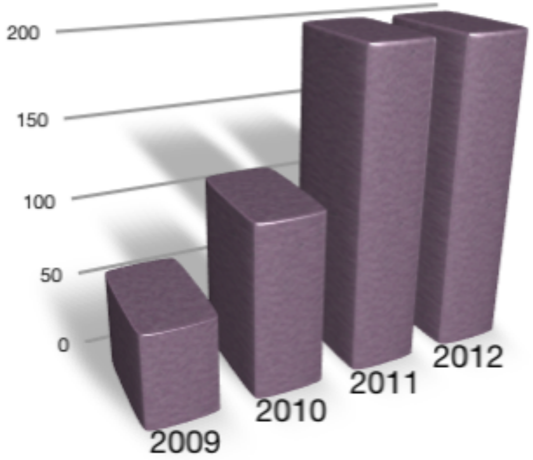
Expected limit = 2.2×10^{-12}

Observed limit = 1.7×10^{-12}

2009+2010 limit = 2.4×10^{-12}

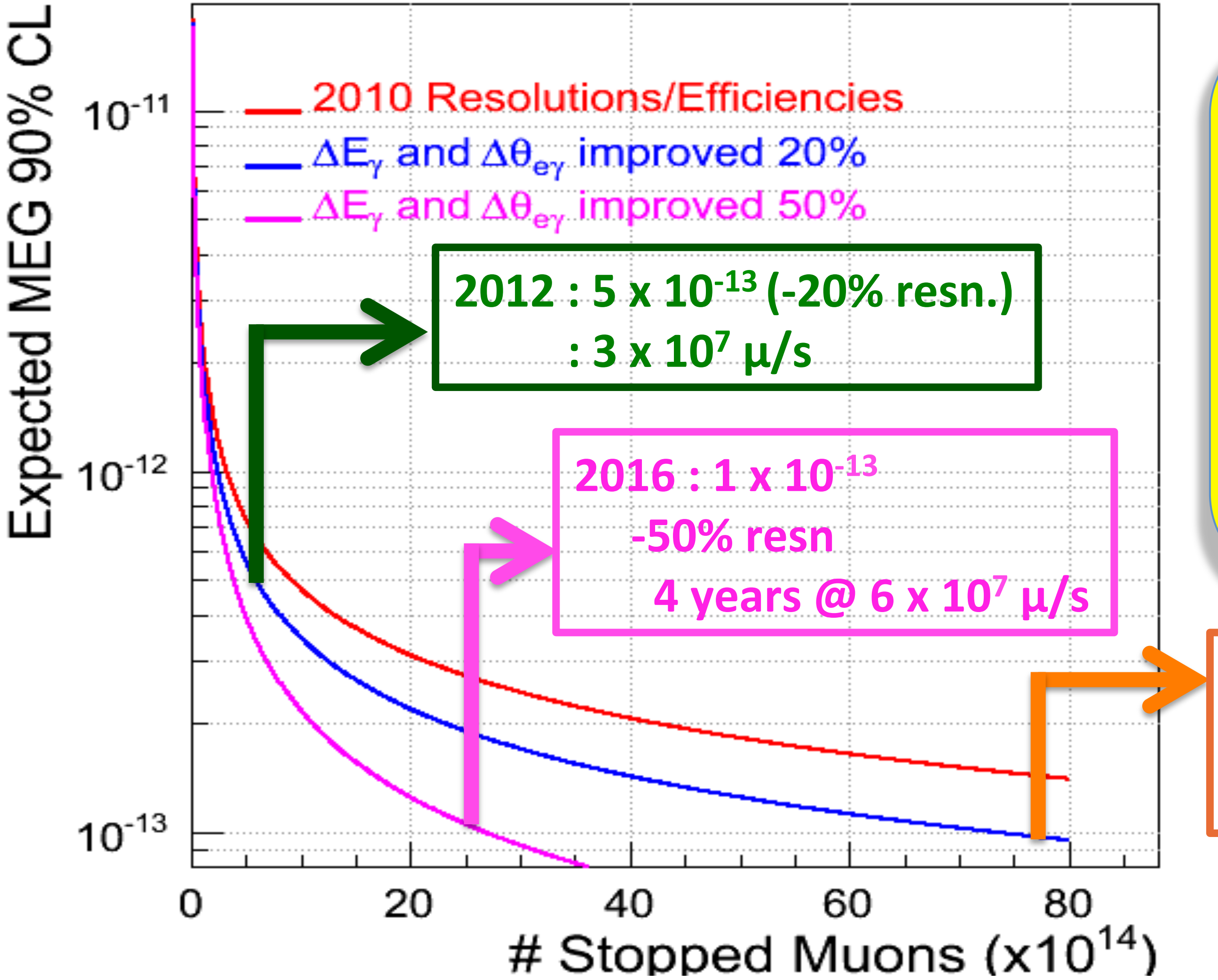
2012 limit ~ 7×10^{-13}

μ on Target x 10^{12}



MEG : 2013-2016

Assume 10^7 sec running per year for 2013-2016.



2012 : 5 x 10^{-13} (-20% resn.)
: 3 x 10^7 μ/s

2016 : 1 x 10^{-13}
-50% resn
4 years @ 6 x 10^7 μ/s

2016 : 1 x 10^{-13}
-20% resn.
PSI @ 2 x 10^8 μ/s

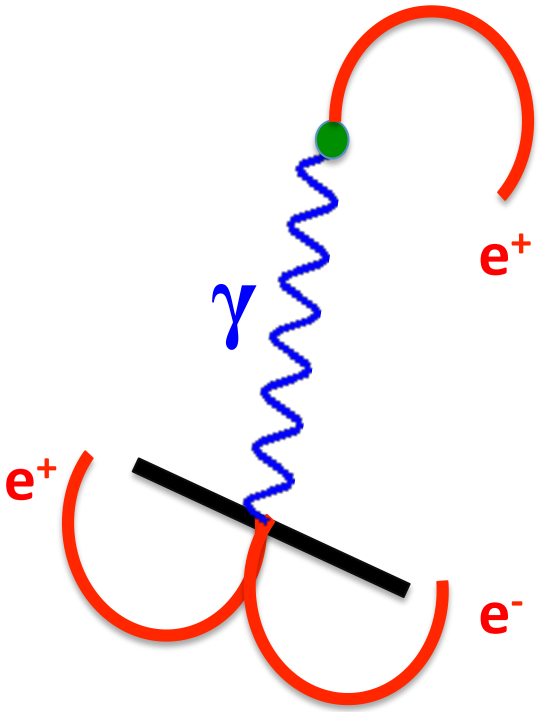
PSI already providing ~ 10^8/sec.

MEG will increase its e^+ detection efficiency + some detector improvements.

~ 10^{-13} achievable.

Below 10^{-13} needs new detector

- E_γ, $\Theta_{e\gamma}$ resolution and pile-up are limiting factors particularly at high μ intensities
- Another option to achieve reduced sensitivity is to have a "track-only" analysis.



Conversion point and event vertex defined by precision tracking.

Optimise material thickness to optimise rate reduction vs resolution degradation.

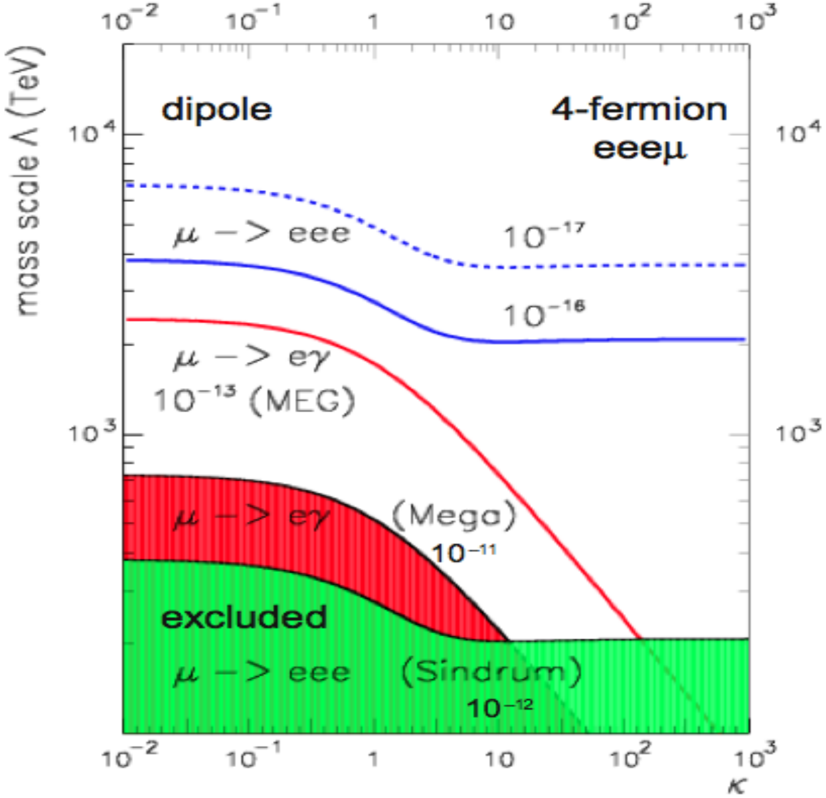
MEGA (LANL:1990s) used this approach & achieved

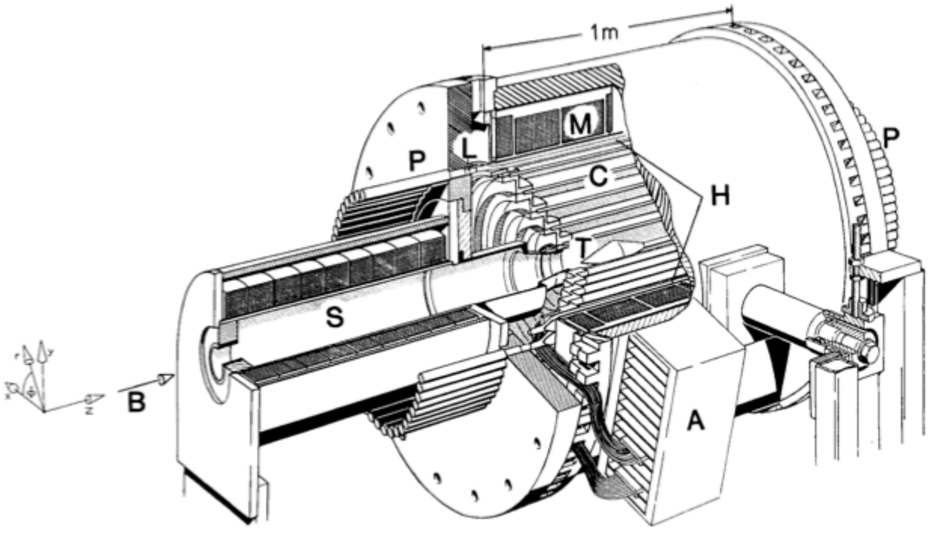
$\Delta\theta e\gamma$ = 33 mrad vs 52 mrad in MEG and
$\Delta E\gamma$ = 1.7 - 3% vs 4.5 - 5.6% (MEG).

However these resolutions need to achieved in high pile-up environment.

μ→eee

Current state of the art is 1988 with **limit @ 10^{-12}**





Sindrum-I @ PSI

Given MEG results (@ 10^{-13}) this only begins to get interesting at 10^{-14} (e.g LHT models) BUT ideally would like to get to 10^{-16}

μ→eee

Same issues as μ→eγ

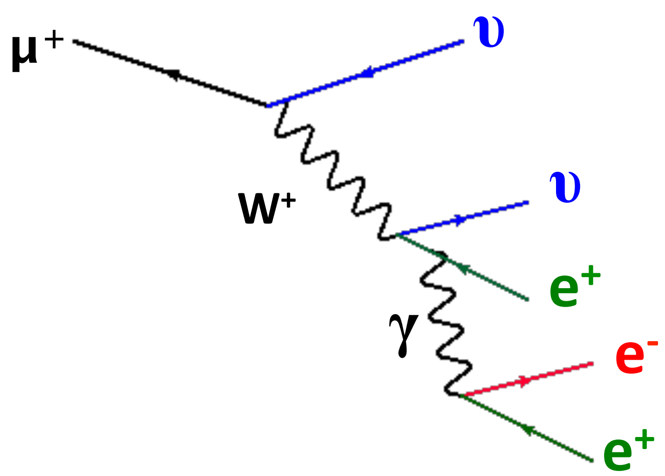
- accidental/pile-up backgrounds : $(R\mu/D)^2$ – so DC beam required.

Issue as go to v. high rates

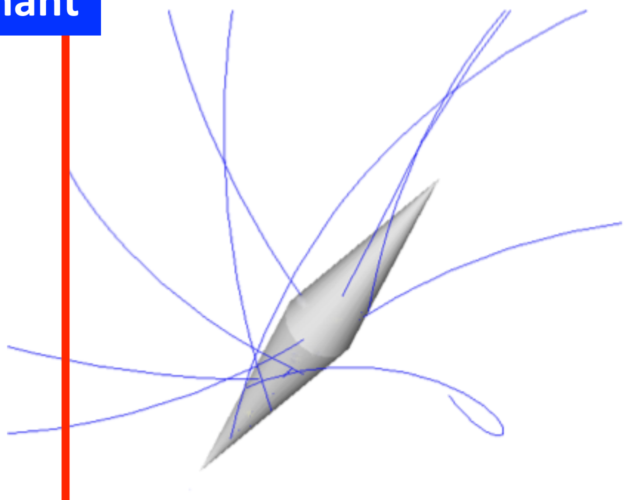
Two μ+ decays and fake e- (Bhaba scattering, γ conversion)

- irreducible background : Rμ

Dominant



BR = 3×10^{-5}

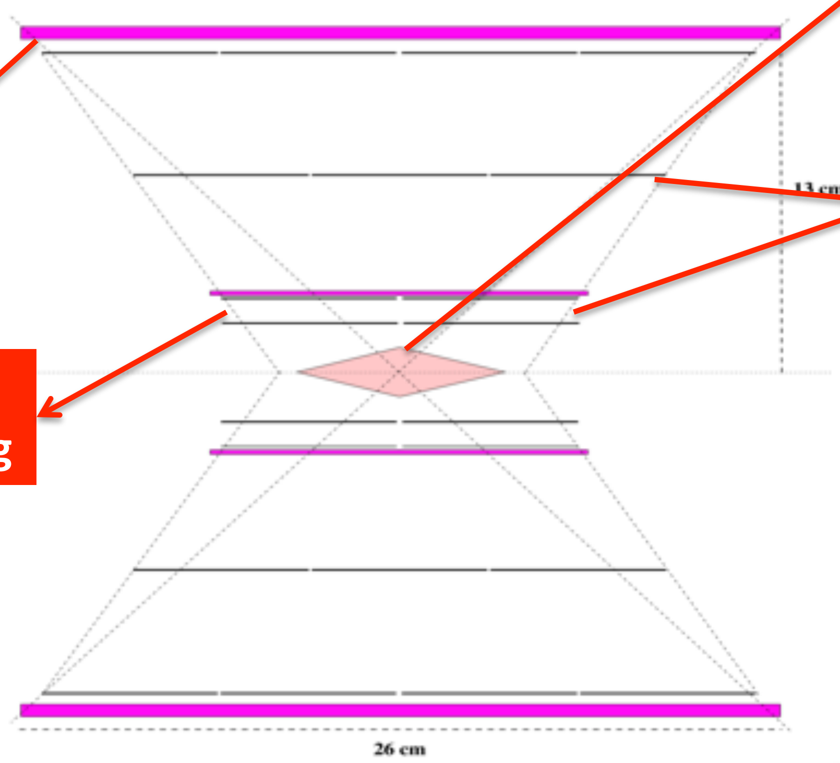


As with μ→eγ the solution is resolution, resolution, resolution…

Mu3e Proposal at PSI

Improve MS-resolution by using v. thin (~ 40µm) HV-MAPS pixel silicon layers

$\sigma(\theta)_{MS}$ = 5 mrad (c.f. SINDRUM-I : 28 mrad)

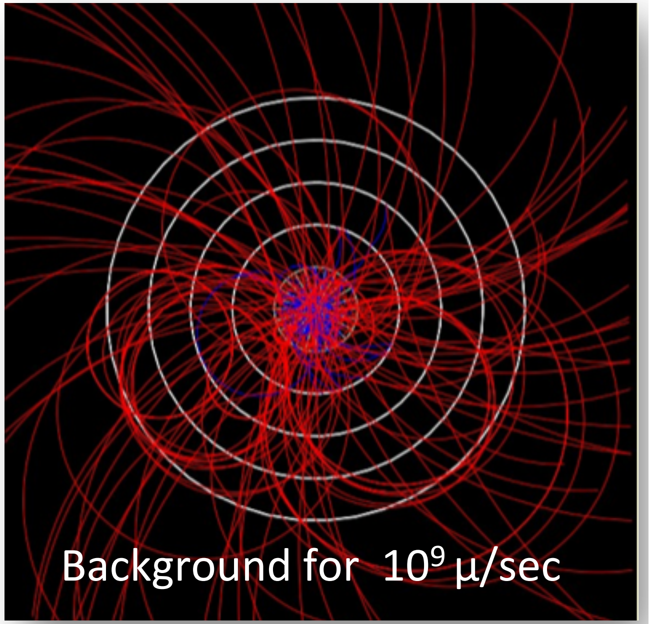


Hollow double cone target

Very thin silicon sensors for precision momentum and vertexing

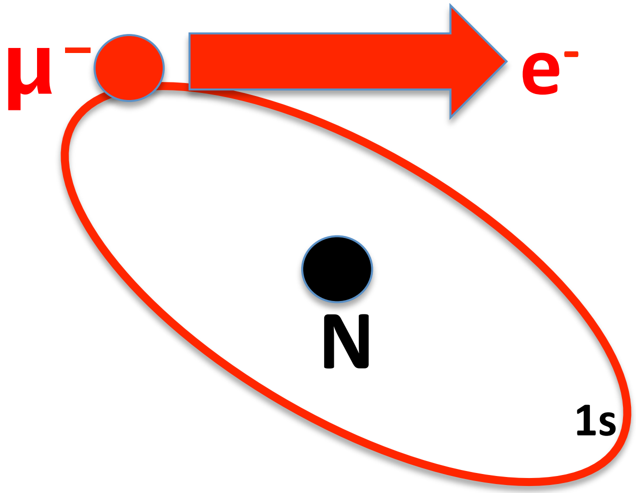
Scintillating Fibers for precision timing

Aiming to achieve 10^{-16}



Background for 10^9 µ/sec

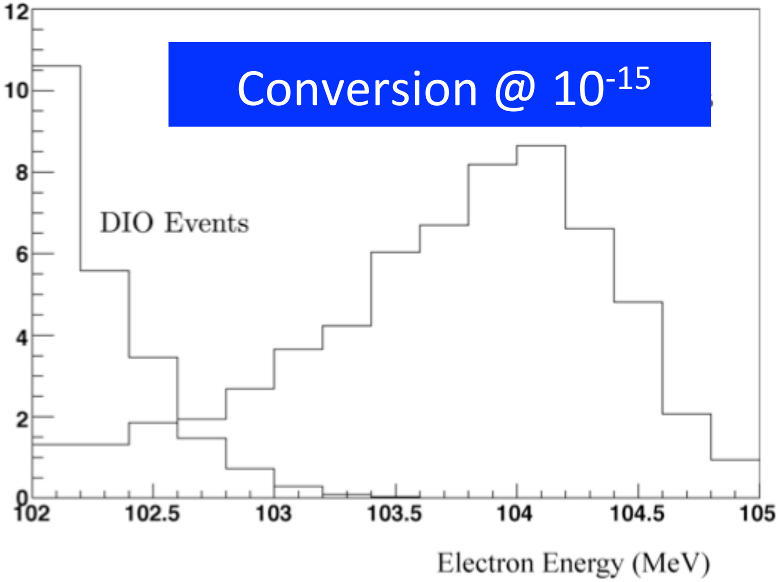
Muon to Electron Conversion



Processes considered so far suffer, at the highest rates, from accidental backgrounds that scale as $R(\mu)^2$

$$\mu^+ \rightarrow e^+\gamma$$

$$\mu^+ \rightarrow e^+e^-e^+$$



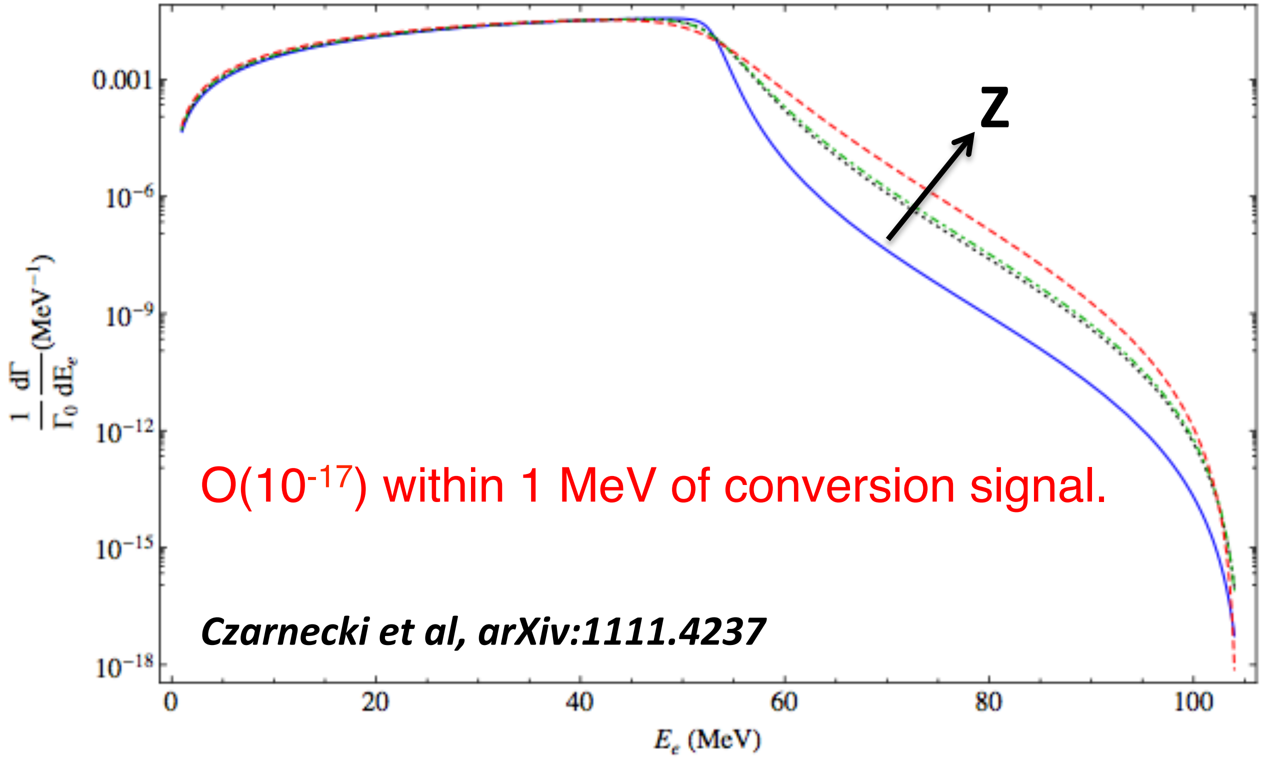
The "conversion process" has a simple one particle signature. Ee ~ m_μ
(>> Ee from free muon decay).

Arguably best route to highest sensitivity at high muon rates.

$\mu N \rightarrow eN$ Backgrounds

Two pertinent backgrounds

1. Decay in orbit (**DIO**) of stopped muon. In atom gives electrons beyond the free-muon 53 MeV end-point.



O(10^{-17}) within 1 MeV of conversion signal.

Czarnecki et al, arXiv:1111.4237

Controlled by detector resolution AND energy loss prior to detector.

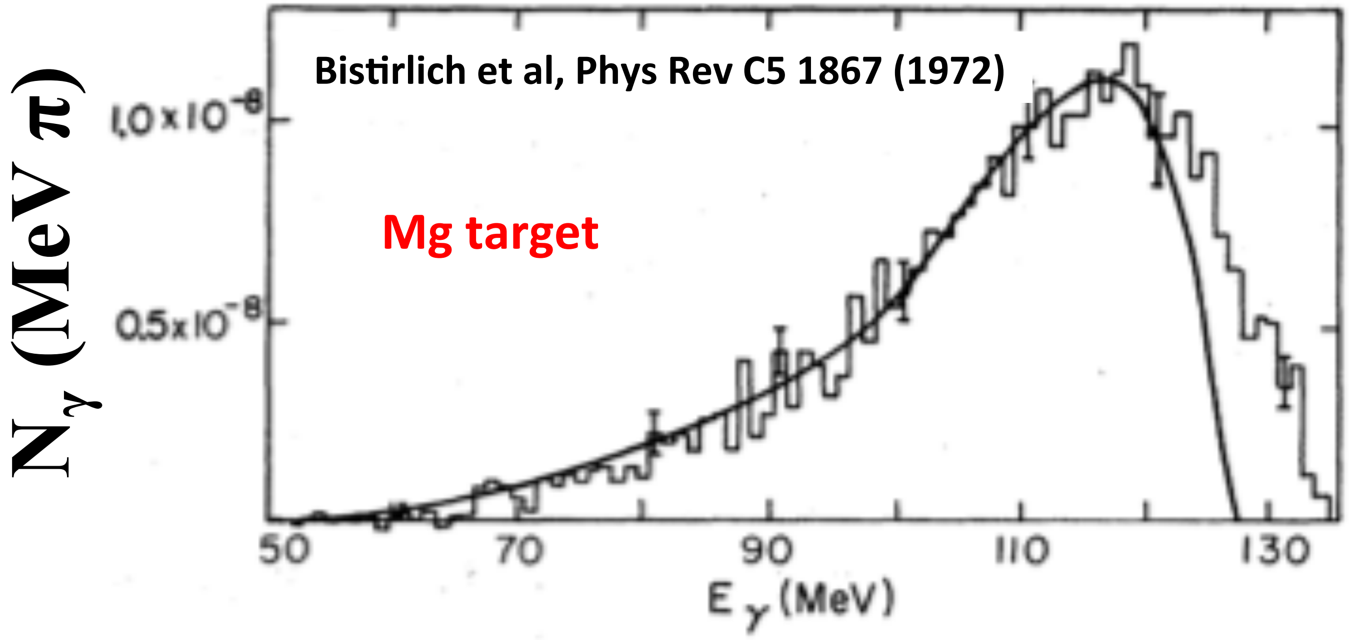
Need FWHM < 1 MeV

μN→eN Backgrounds

2. Radiative Pion Capture (RPC)

$\pi^- N \rightarrow \gamma N^*$ and $\gamma \rightarrow e^+ e^-$ External conversion

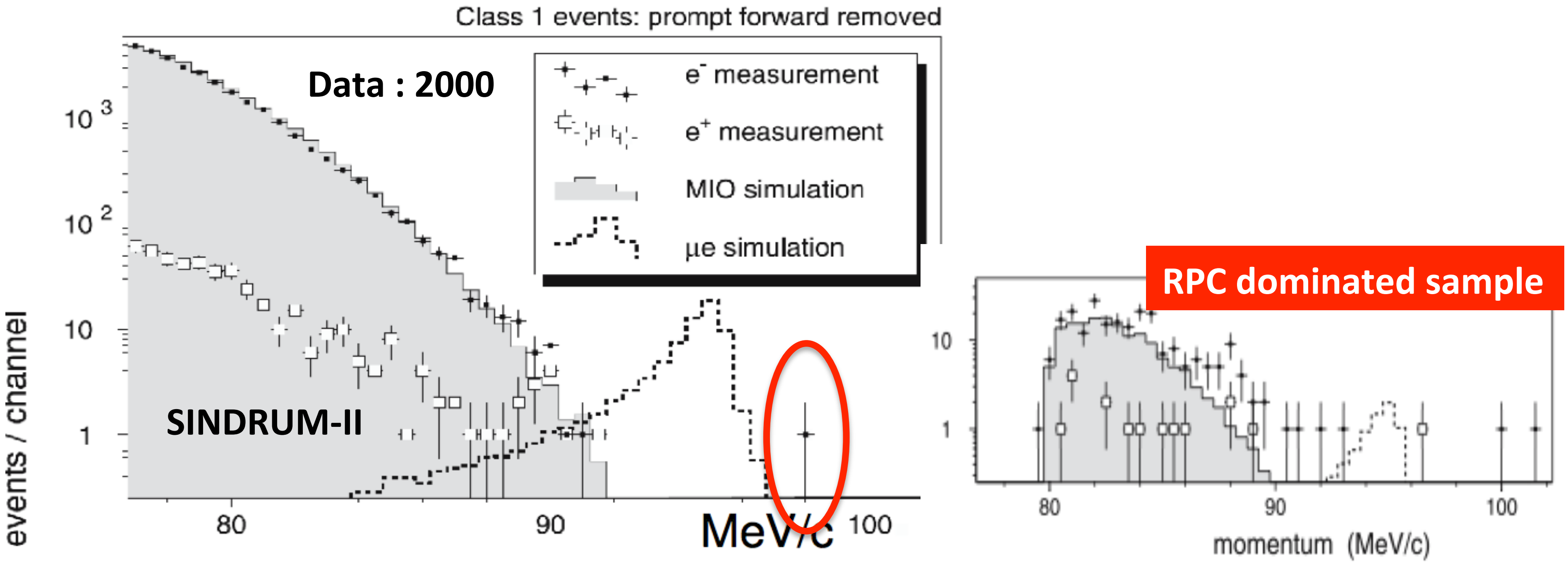
$\pi^- \mathrm{N} \rightarrow e^+ e^- N$ Internal conversion



Suppress by reducing # pions on target : wait, stop them, veto them
- beamline and accelerator are the constraint.

Muon to Electron Conversion

Current best measurement (SINDRUM-II @ PSI) used 8mm of CH_2 to reduce pion (RPC) contamination to 1 in 10^9 π reaching target



Limit : 7 x 10^{-13} (Gold target).

Next Generation

Going beyond SINDRUM requires

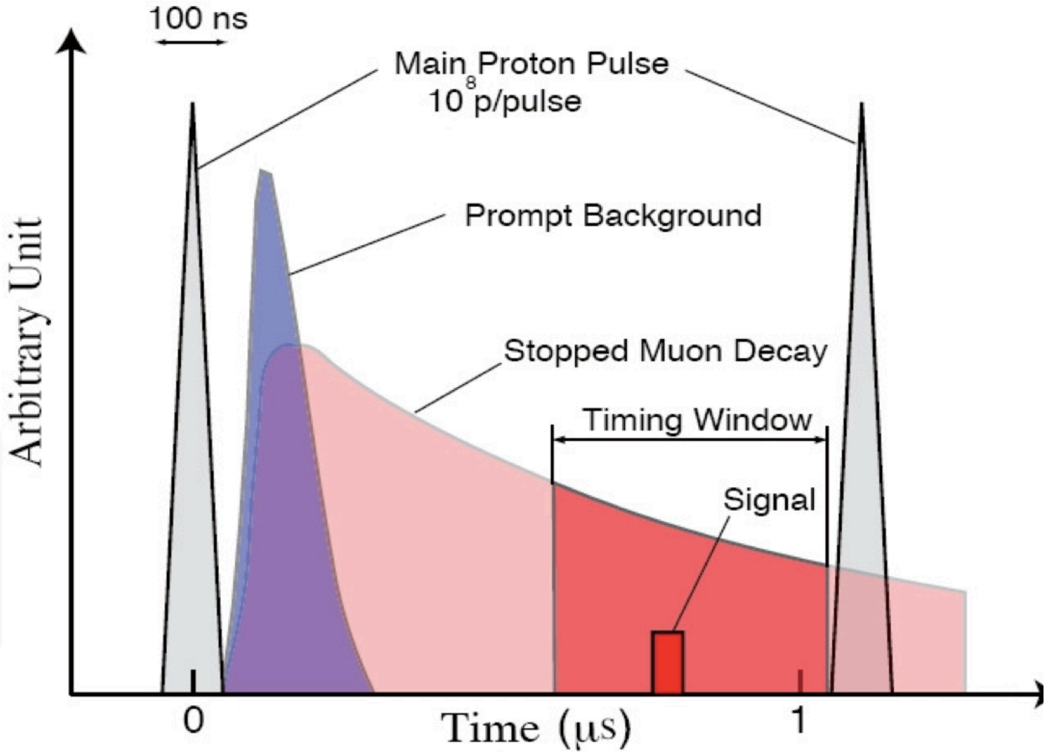
- Rate of stopped muons to be ~ O(5x10^{10})/s

- High resolution (< 1 MeV) e- momentum measurement to control DIO.

- Control of energy loss/straggling in stopping target

- Mechanism to reduce # pions at target and veto prompt backgrounds.

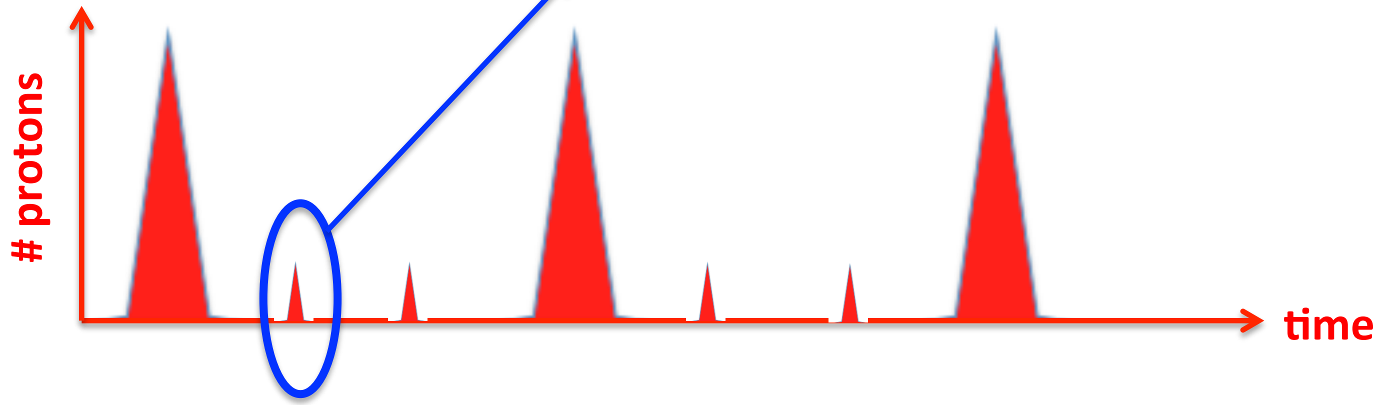
All proposed experiments use pulsed beam & only "measure" after prompt background subsided



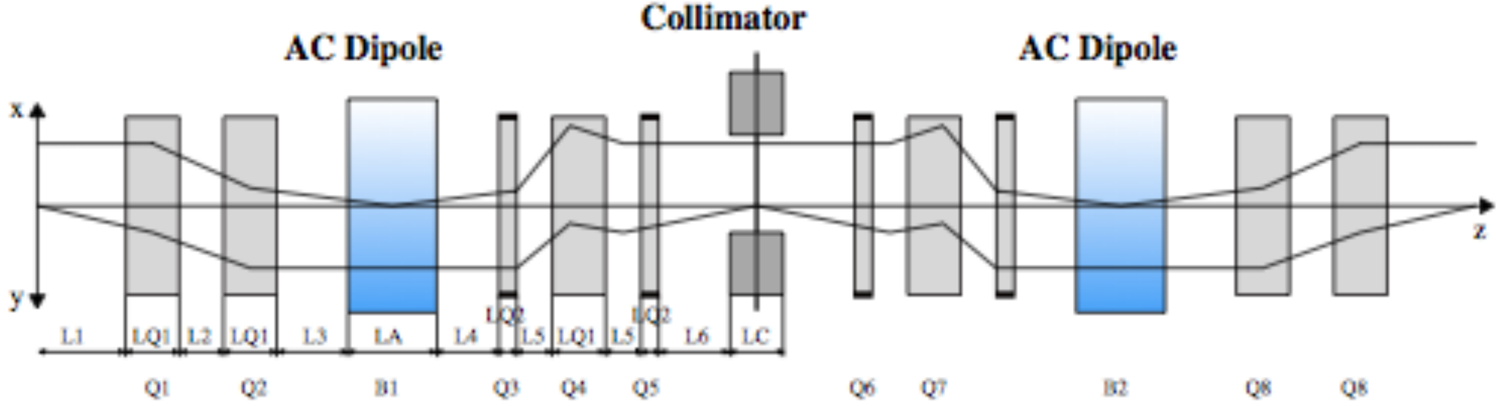
Challenges : Proton Extinction / ”After protons”

Require that between proton pulses there are no rogue proton pules that could produce a “prompt” background e.g. RPC in the timing window

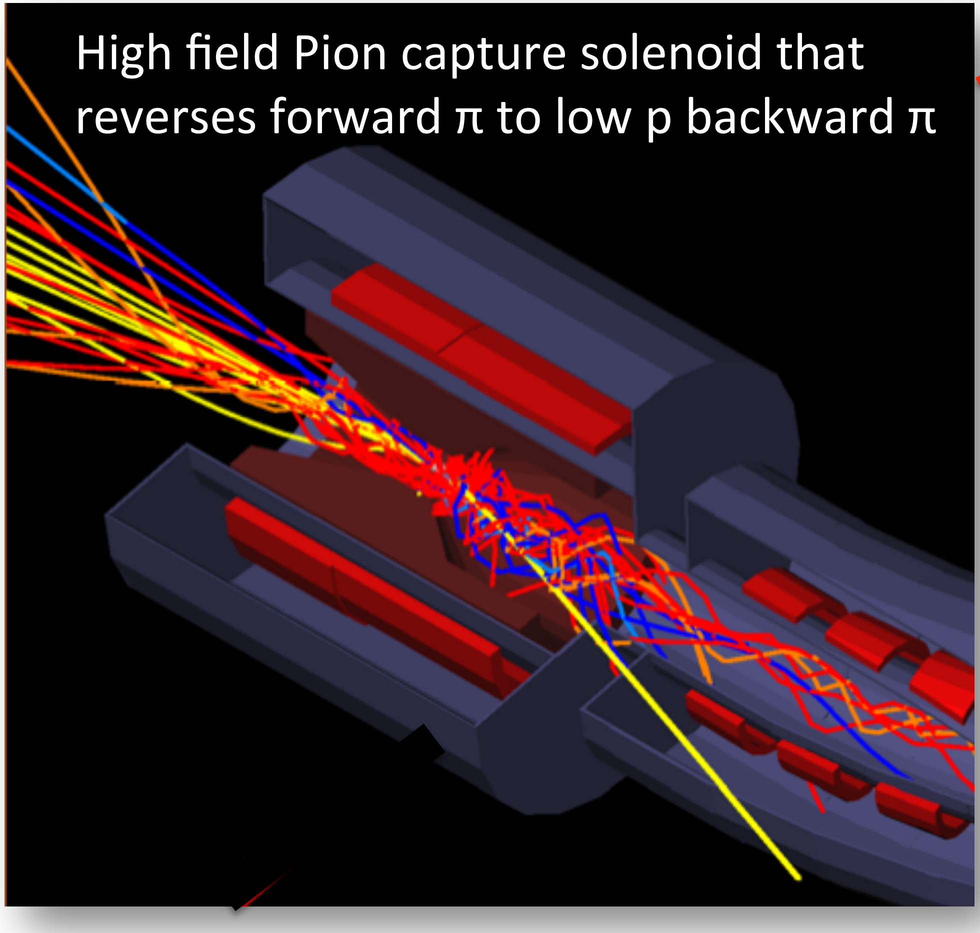
Requirement (mue2/COMET) that < 10^{-9} of primary pulse



AC dipole/collimator system kicks out the out-of-time particles



Challenges : Stopped Muon Yield



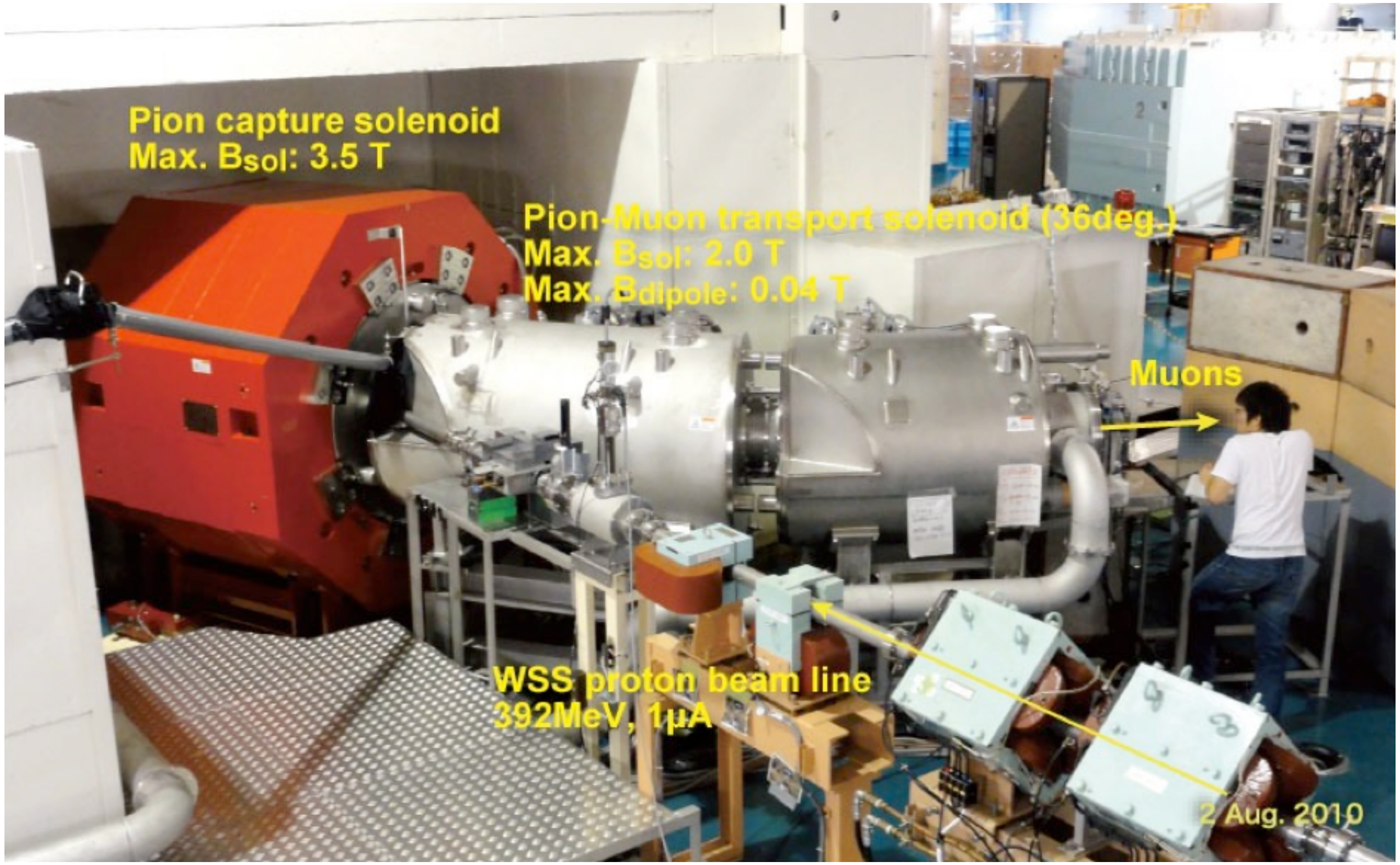
High field Pion capture solenoid that reverses forward π to low p backward π

Increases yield by O(1000) - method successfully demonstrated at MUSIC in Osaka in 2010

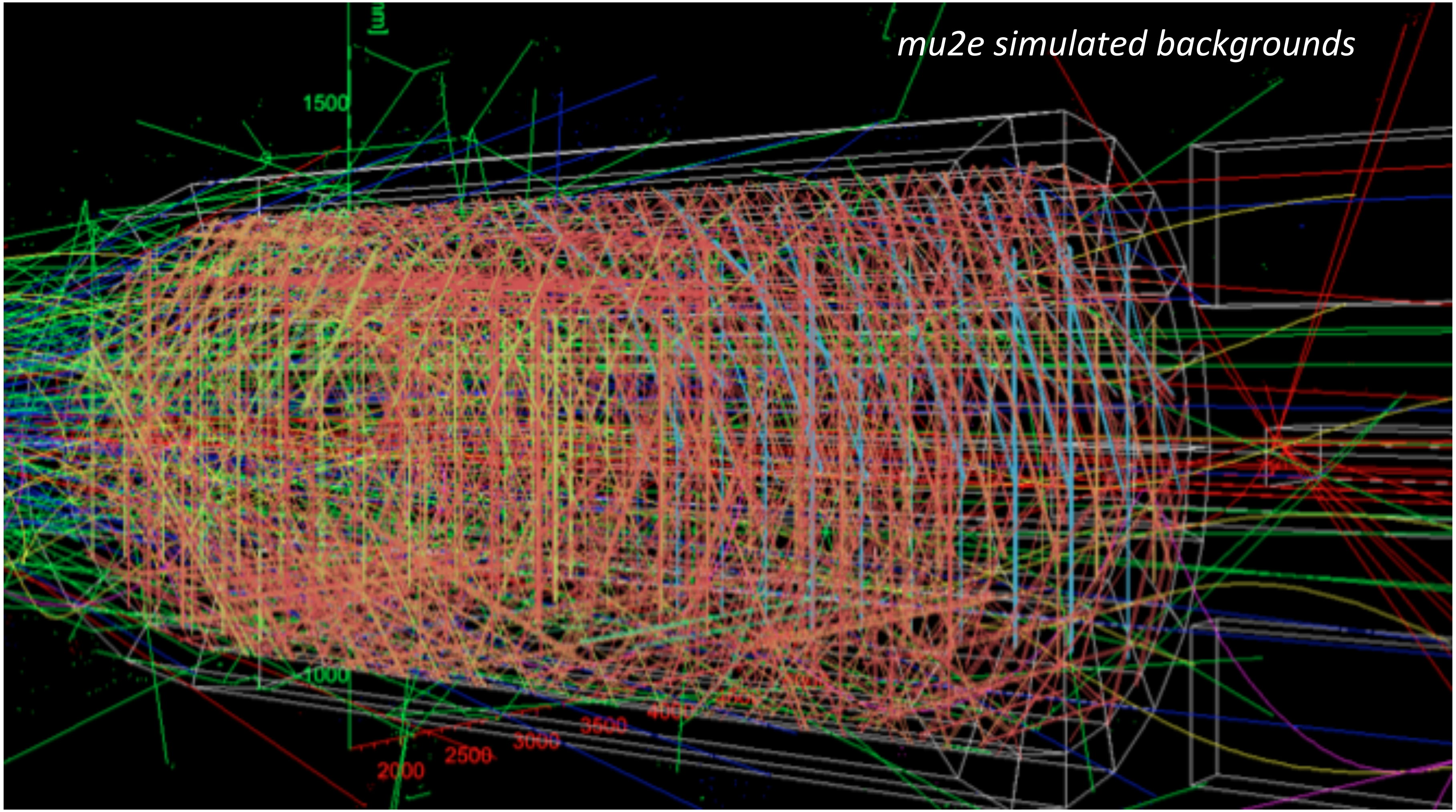
Transport solenoids that select low p (< 50 MeV) muons and reject high p particles **before** the stopping target.

MUSIC @ Osaka

Utilising prototype pion production environment for COMET



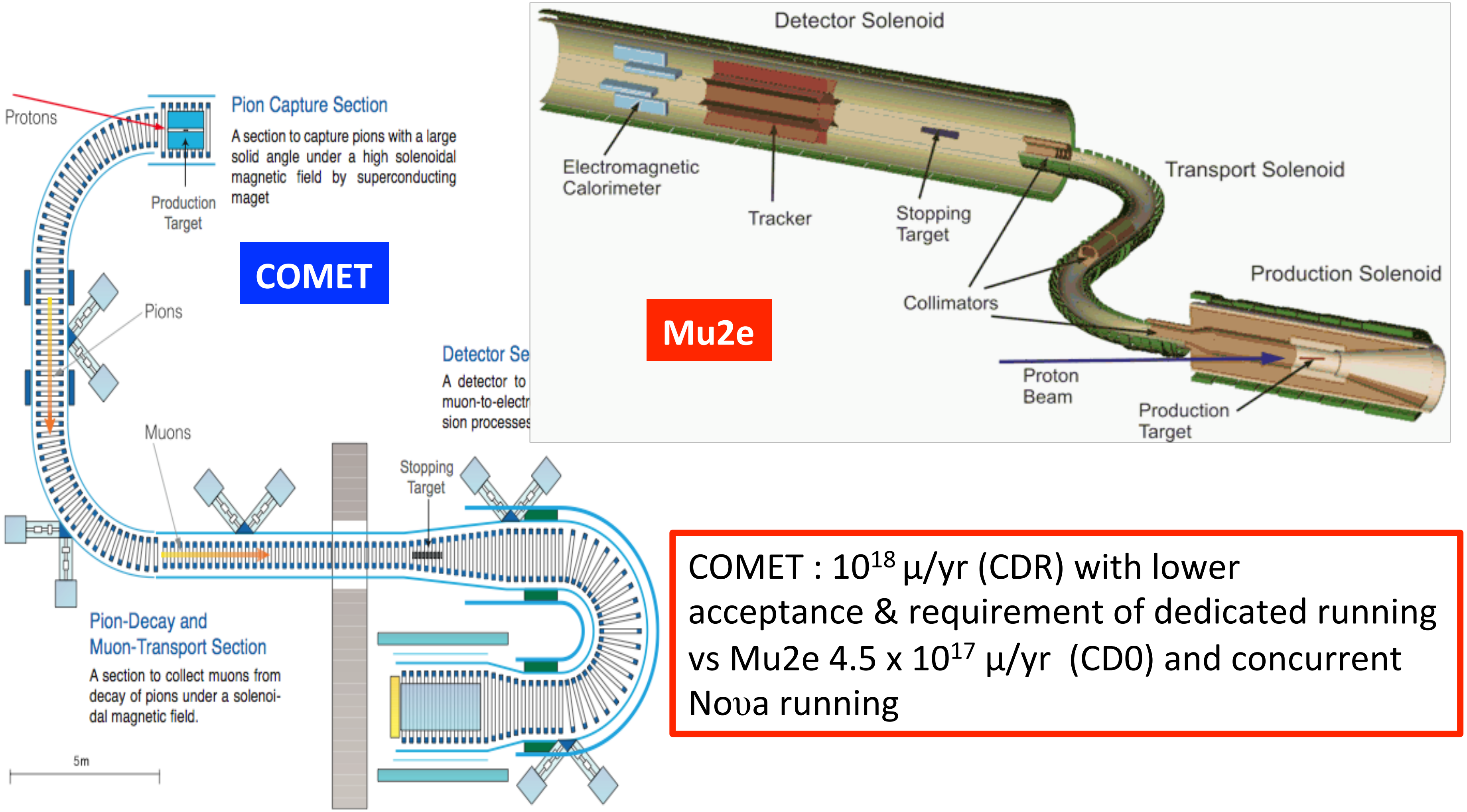
Challenges : High Rates in Detector



mu2e simulated backgrounds

COMET/Mu2e : 6x10^{-17}

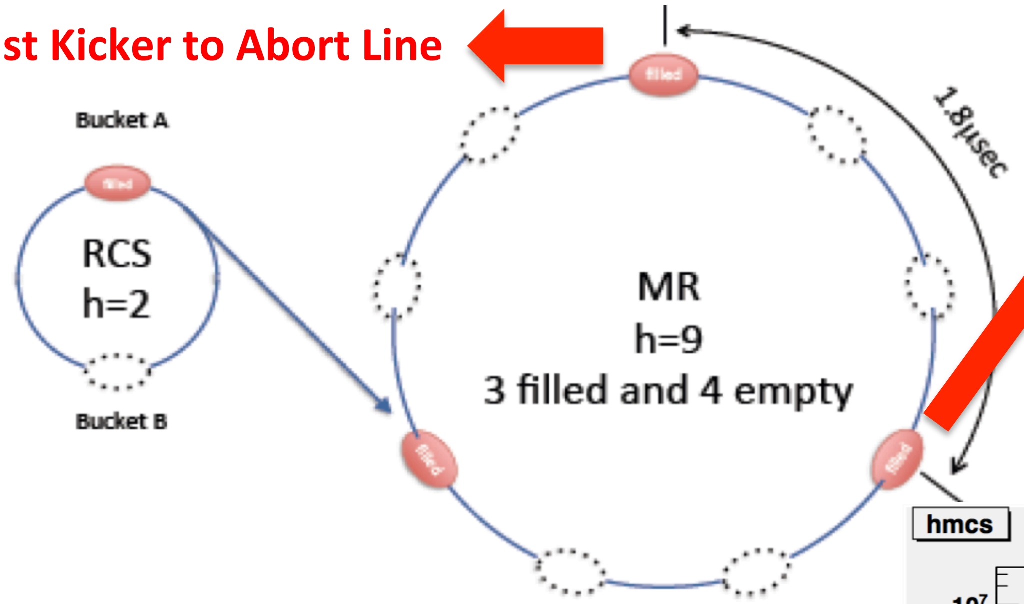
Sensitivity reach physics wise is at least x10 that of upgraded MEG.



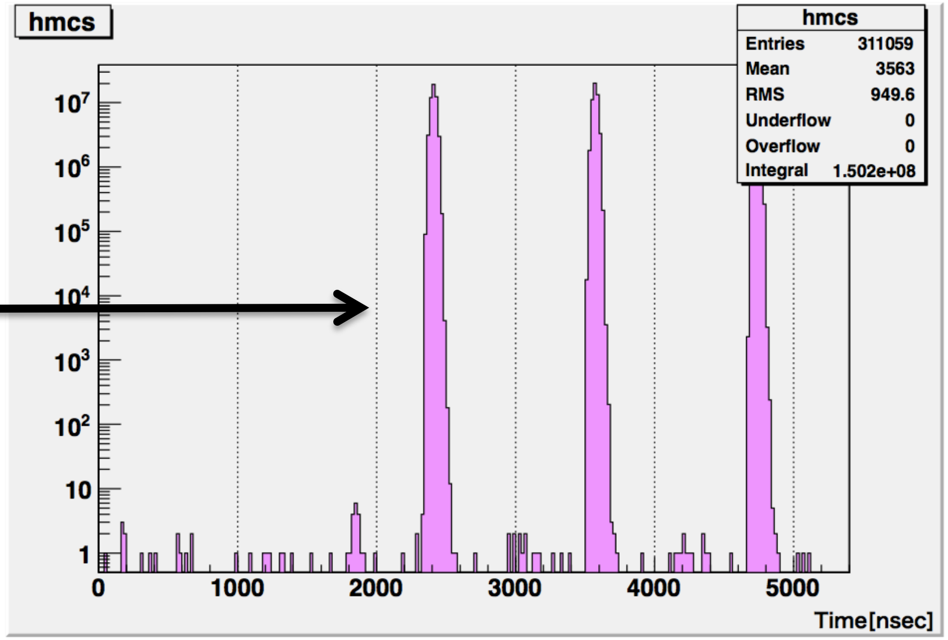
COMET : 10^{18} μ/yr (CDR) with lower acceptance & requirement of dedicated running vs Mu2e 4.5 x 10^{17} μ/yr (CD0) and concurrent Noυa running

COMET : Extinction Studies

Fast Kicker to Abort Line



Bunched slow extraction using ESS to dedicated target/ secondary beamline



Extinction level of **$(5.4 \pm 0.6) \times 10^{-7}$** measured at secondary J-PARC beam line and $O(10^{-7})$ at abort line

And additional $O(10^{-6})$ from double kick injection into MR

Beyond COMET/Mu2E

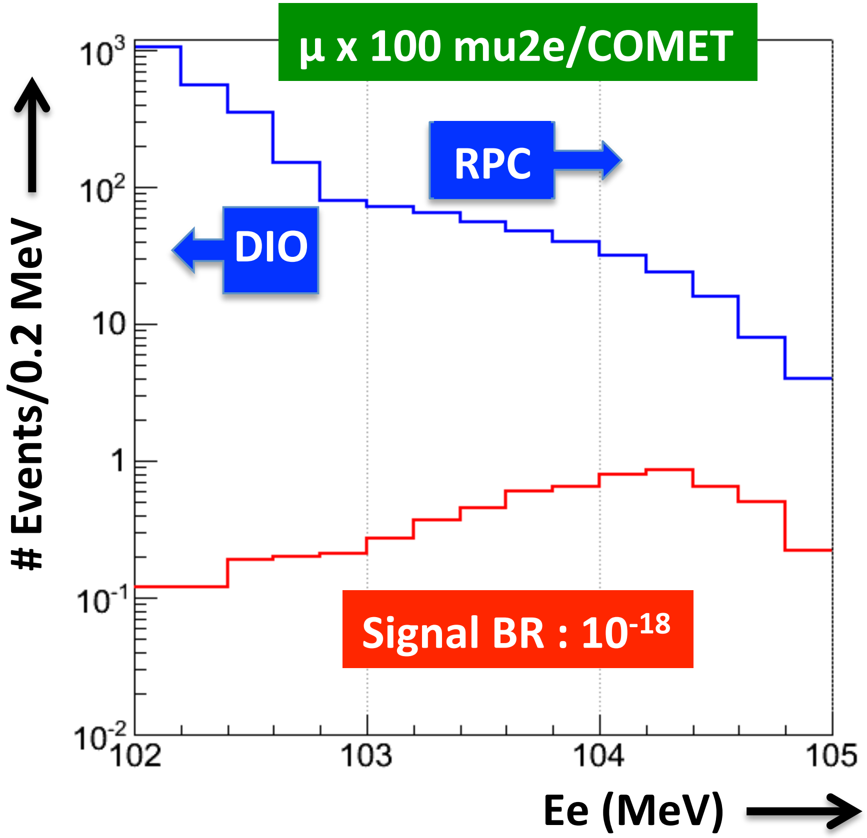
Strategy depends somewhat on whether signal is seen or not.

If signal is seen

- run with high-Z target to elucidate the underlying physics

If no signal seen

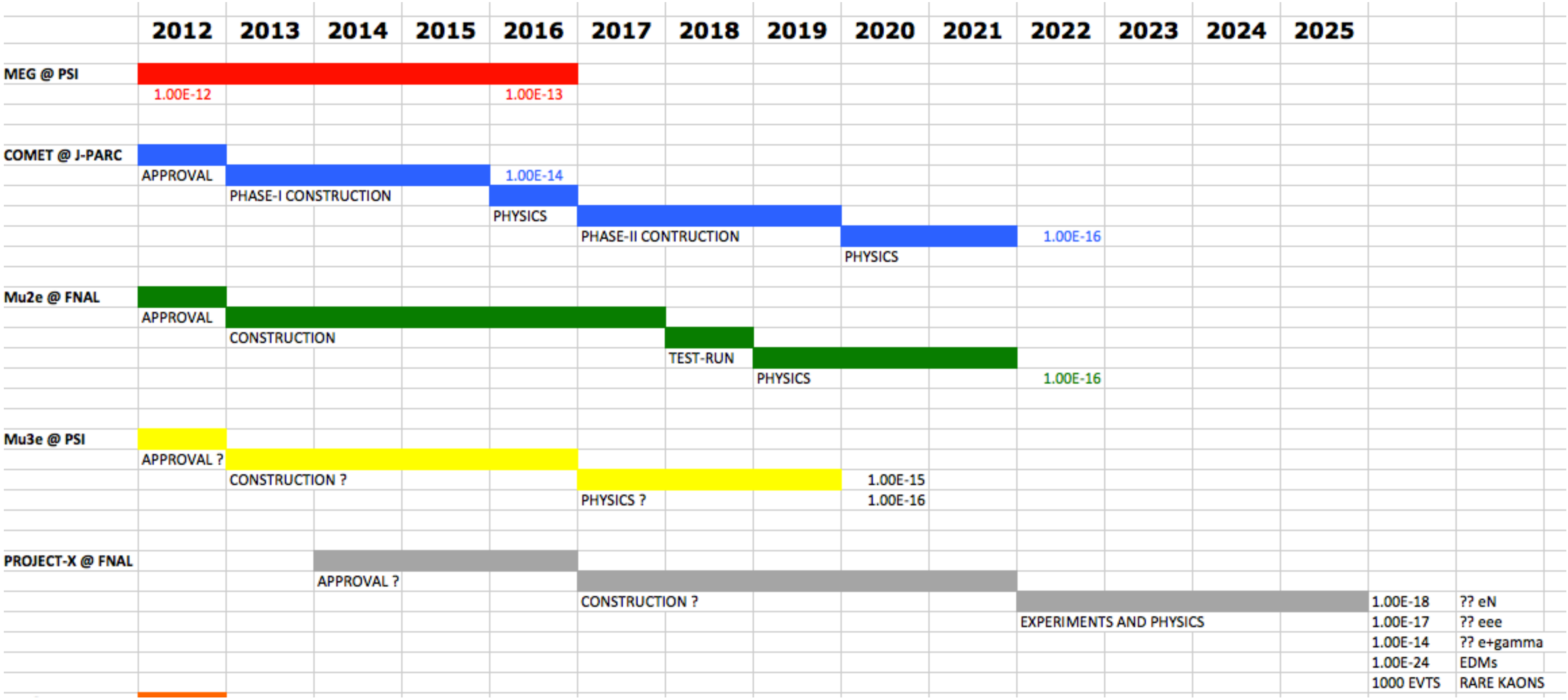
- push sensitivity down to O(10^{-18})



Very challenging requires many of the ideas being explored for NF/muon collider.

- muon momentum selection
- muon cooling (FFAG/helical channel)

Where are we now / timescales ?



COMET unlike Mu2e will be constructed in two phases with 1st data in 2016/17.

COMET Phase-I

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University of Houston, USA

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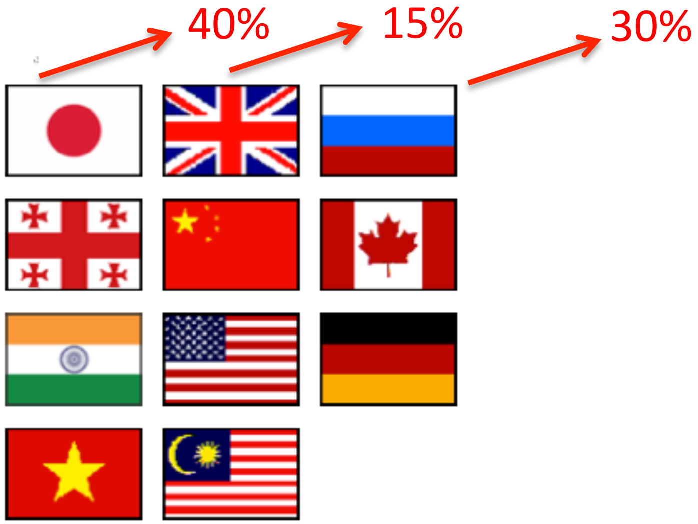
University of Manchester, UK

F. Azfar
University of Oxford, UK

Md. Imam Hossain
University Technology Malaysia

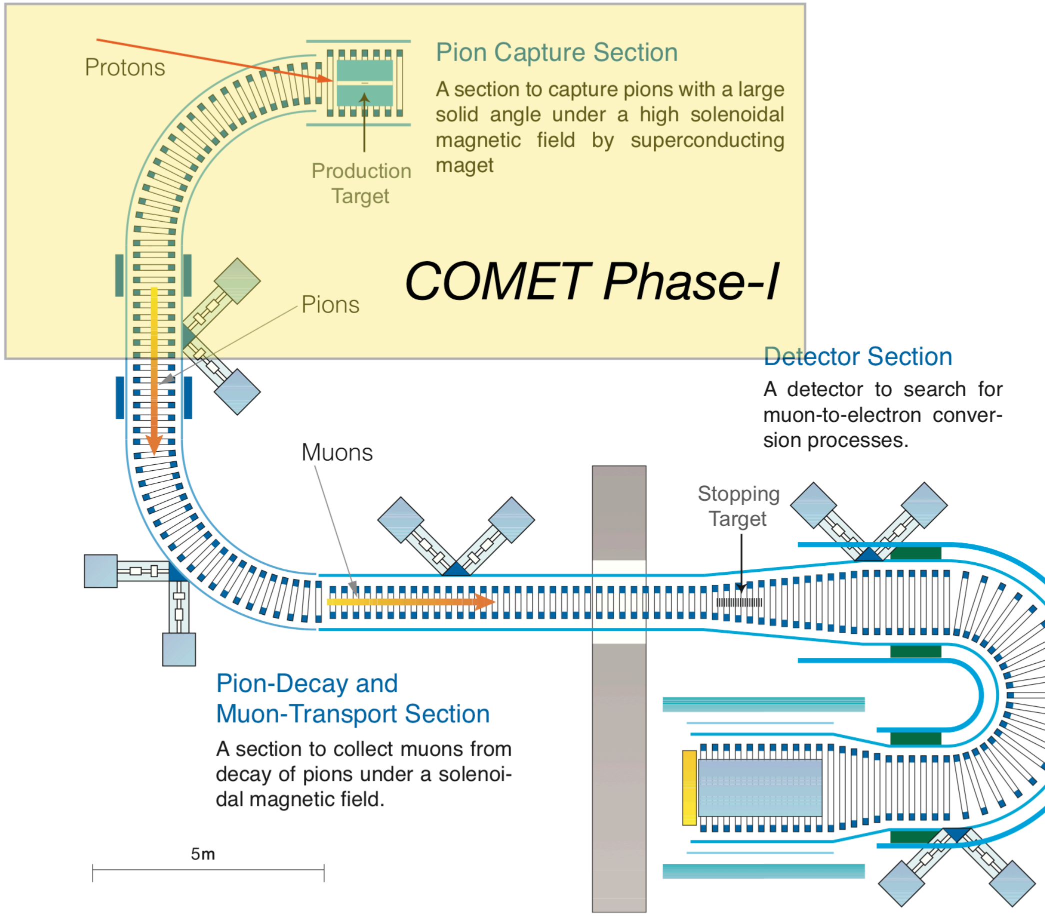
T. Numao
TRIUMF, Canada

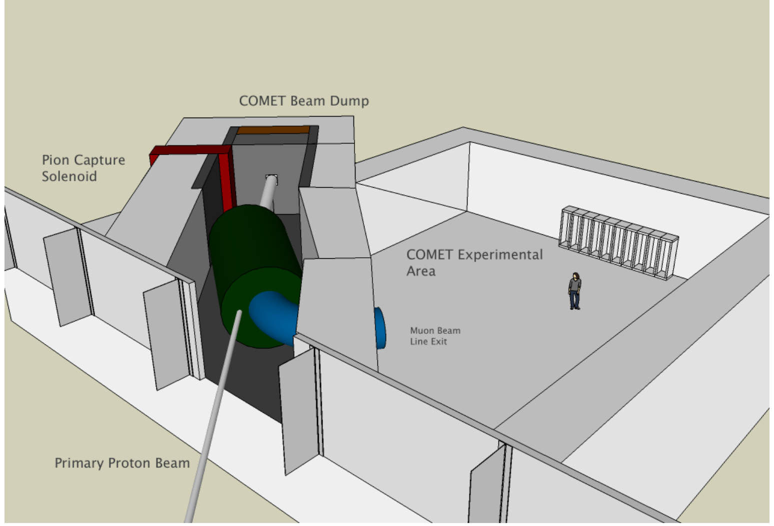


- 107 collaborators
- 25 institutes
- 11 countries

Imperial, UCL and v. recently Manchester, Oxford

COMET Phase-I



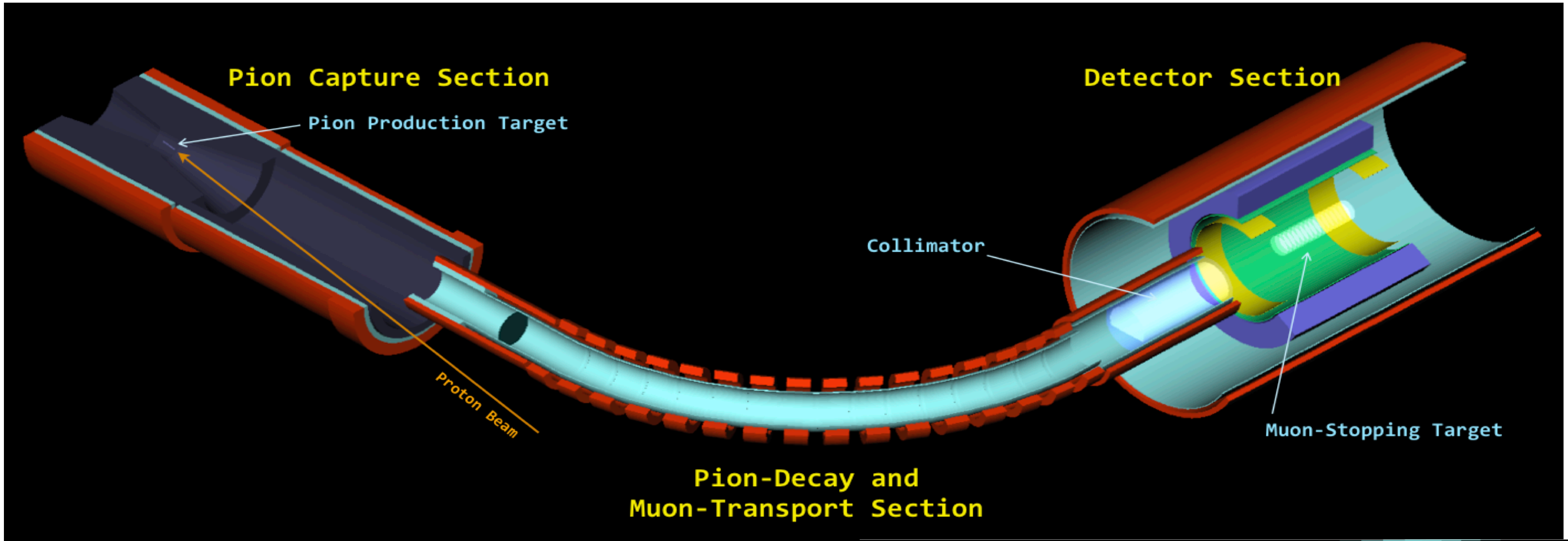


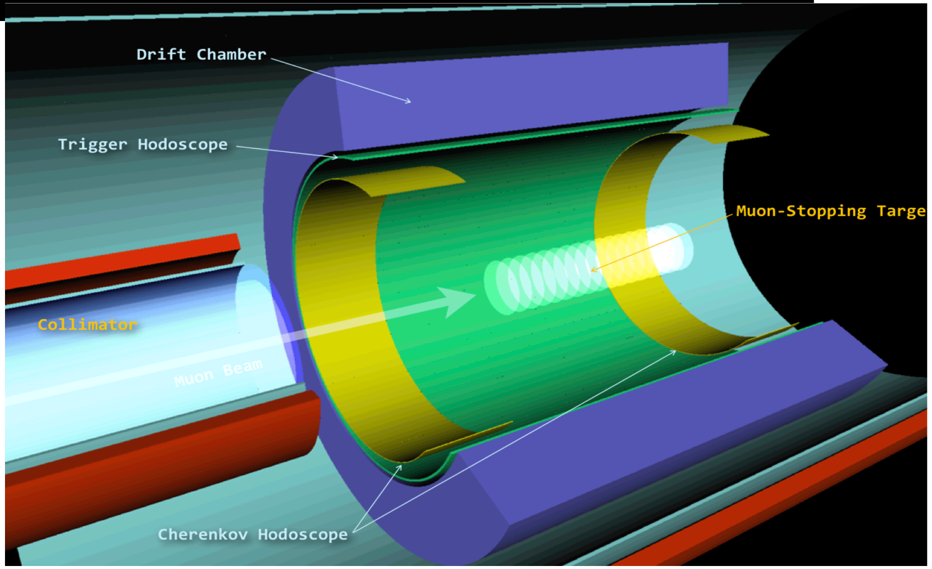
Phase-1
$30M : beamline
$15M : detector/DAQ etc

Phase-2
$45M

c.f. Mu2e : $240M

COMET Phase-I





Cylindrical detector (AMY solenoid) has higher acceptance but poorer resolution compared to transverse/phase-II detector

COMET Phase-I : Aims

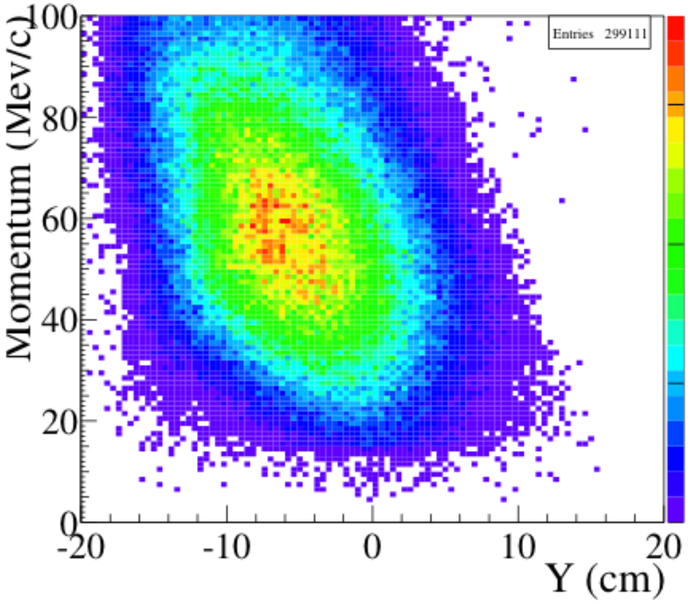
Current Mu2e/COMET sensitivity estimates of BR < 10^{-16} extrapolate current background knowledge over 4 orders of magnitude…

1. Demonstrate that beam extinction of 10^{-9} can be achieved

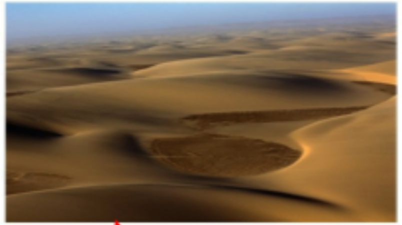
2. Measure in-situ backgrounds : neutrons, anti-p, nuclear capture products and so refine/optimise the simulation.

3. Test final/prototype detectors

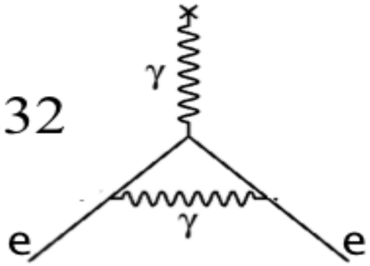
4. Measure conversion process with sensitivity **x100 that of SINDRUM-II** ie go below 10^{-14} :
physics-wise comparable to the MEG (2013) limit.



Muon Magnetic Moment (“g-2”)

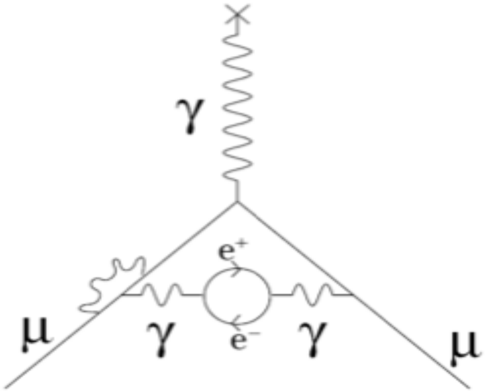


$$\frac{\alpha}{2\pi} = 0.00232$$



$$g_\mu^{exp} = \underbrace{2.}\underbrace{002}\underbrace{2\ 3}\boxed{31}\ 841\ 78\ (126)$$

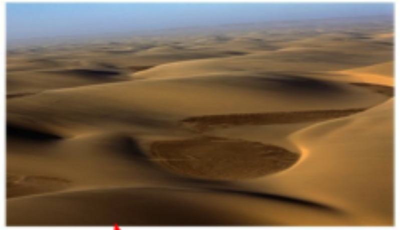
$$2\ 3\boxed{31}\ 694\ 36\ (0)$$



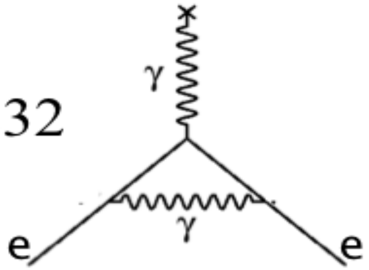
QED

* QED calculation for electron now out to 10th order (12672 diagrams)

Muon Magnetic Moment ("g-2")



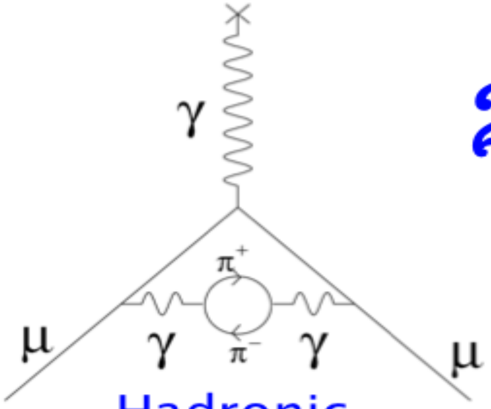
$$\frac{\alpha}{2\pi} = 0.00232$$



$$g_\mu^{exp} = 2.002\ 331\ 841\ 78\ (126)$$

$$2\ 331\ 694\ 36\ (0)$$

$$138\ 60\ (98)$$

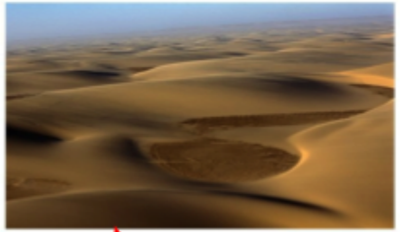


Hadronic

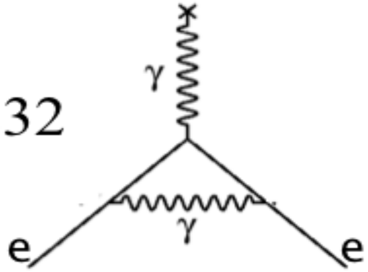
$$\lambda_{sens} \propto \left(\frac{m_\mu}{m_e}\right)^2 \approx 40,000$$

* Hadronic corrections for the electron g-2 don't show up until the 12th decimal

Muon Magnetic Moment (“g-2”)



$$\frac{\alpha}{2\pi} = 0.00232$$

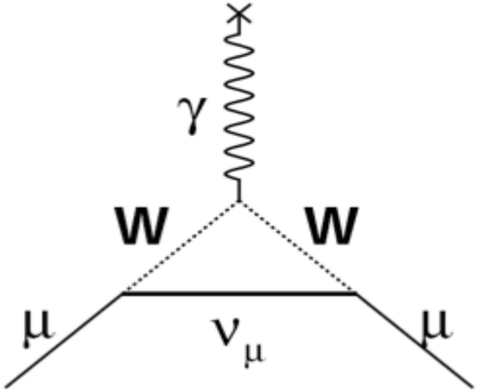


$$g_\mu^{exp} = 2.002\ 331\ 841\ 78\ (126)$$

$$2\ 331\ 694\ 36\ (0)$$

$$1\ 38\ 60\ (98)$$

$$3\ 08\ (4)$$



Electroweak

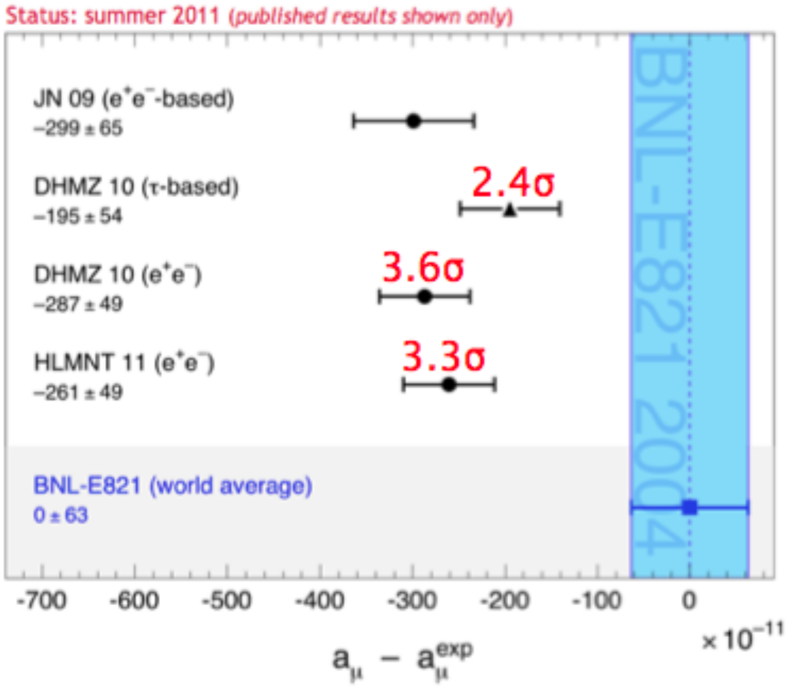
Muon Magnetic Dipole Moment ("g-2")

$$a_\mu^{exp} = 116\,592\,089\ (63) \times 10^{-11}$$

$$a_\mu^{thy} = 116\,591\,802\ (49) \times 10^{-11}$$

$$\boxed{a_\mu = \frac{g-2}{2}}$$

$$a_\mu^{exp} - a_\mu^{thy} = 287\ (80) \times 10^{-11}$$



3.6σ

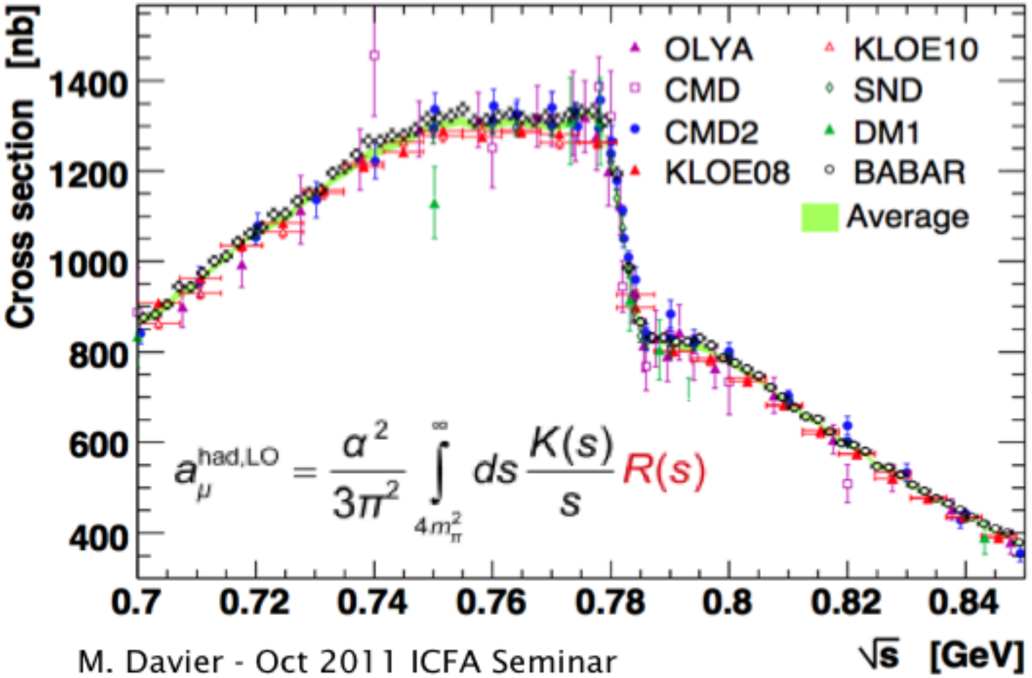
BNL measurement : statistics limited

Muon Magnetic Dipole Moment ("g-2")

$$a_\mu^{exp} - a_\mu^{thy} = 287\ (80) \times 10^{-11}$$

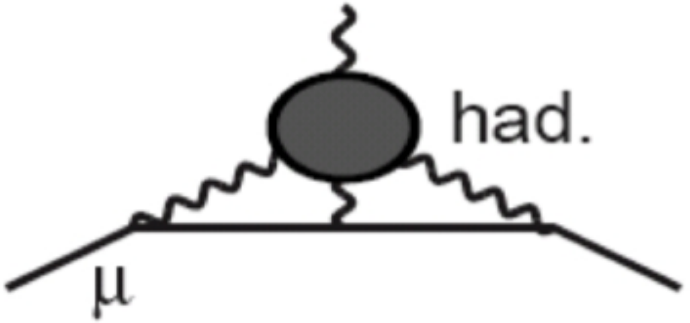
3.6 σ

$$a_\mu^{LOHVP} = 6\,903\ \ (42) \times 10^{-11}$$



M. Davier - Oct 2011 ICFA Seminar

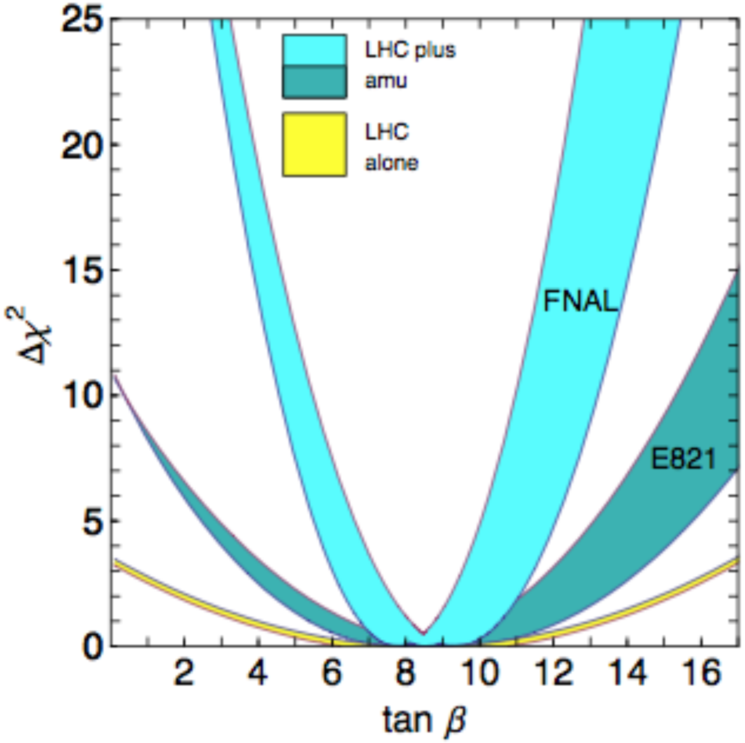
$$a_\mu^{HLBL} = 105\ \ (26) \times 10^{-11}$$

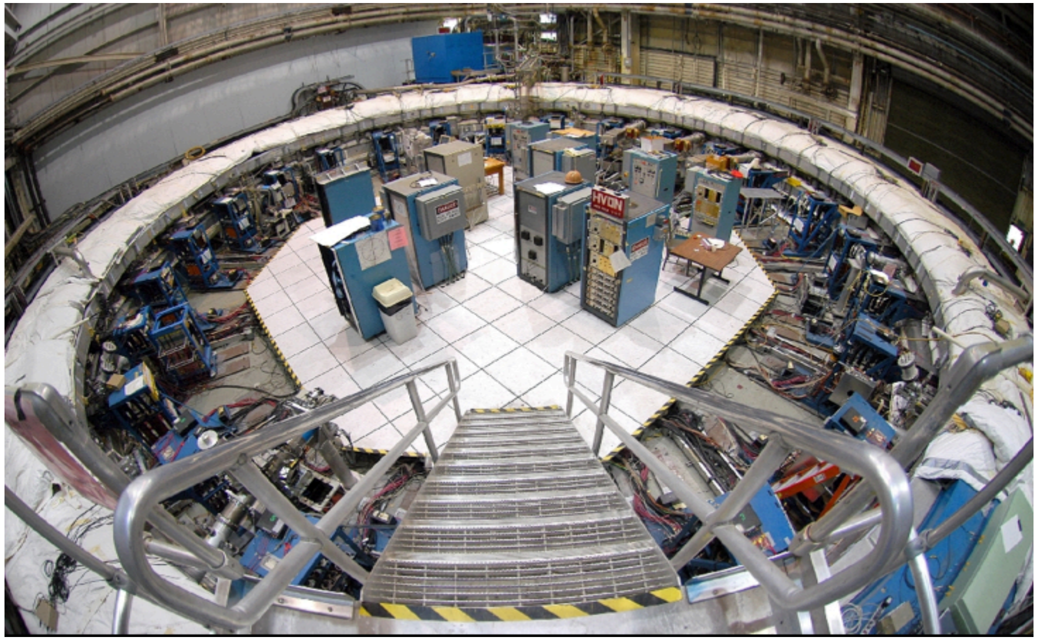


Expect theory error to be further reduced in next 5-years (e.g. lattice QCD)

FNAL Muon g-2

New FNAL experiment will re-use BNL magnets but with x20 stats and reduced systematics.





Aiming for x4 improvement in a_μ uncertainty to be 0.1ppm (16×10^{-11}) measurement

Without theory improvement : 3.6 σ → 5 σ, with theory : 7.5 σ.

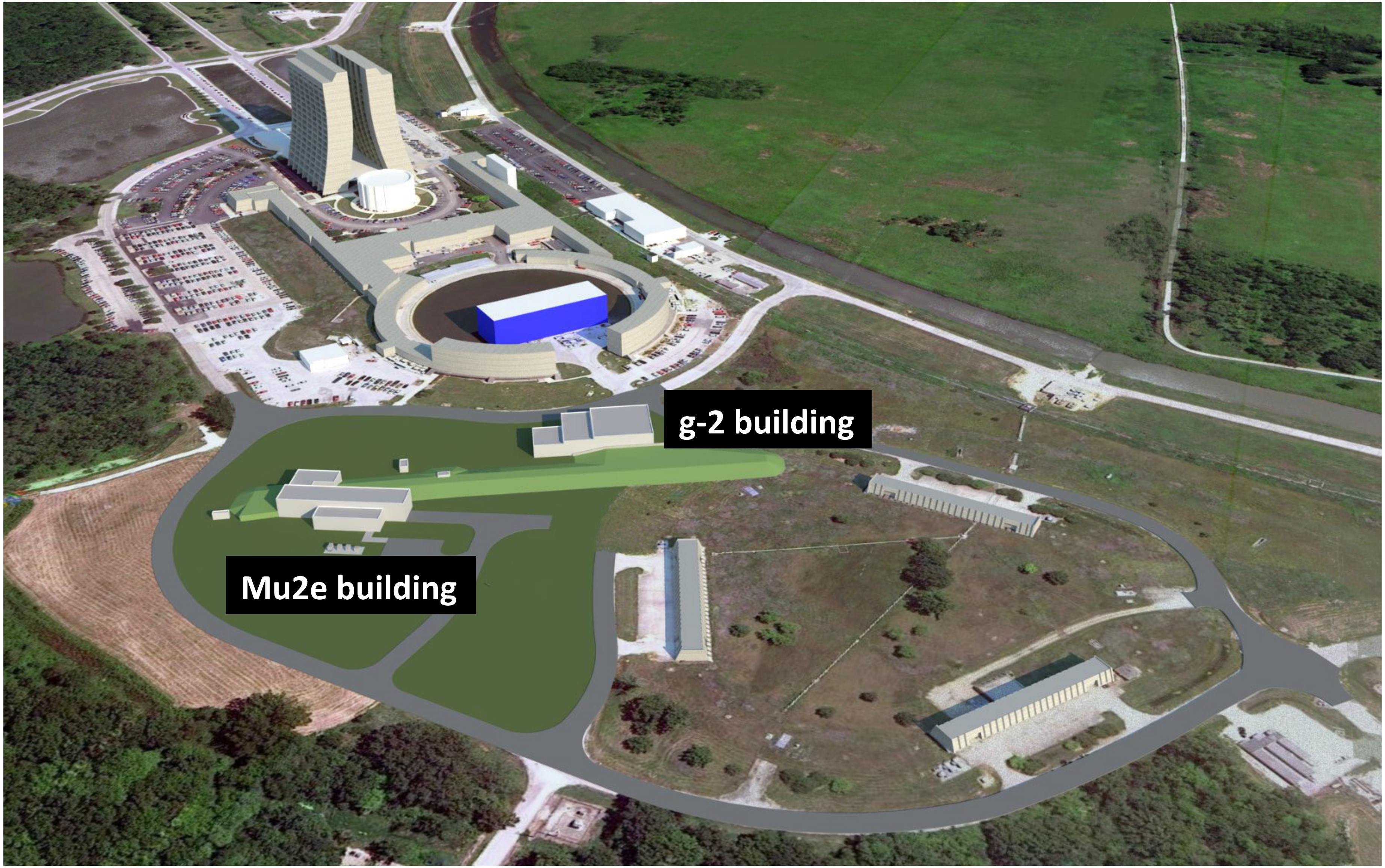
FNAL Muon g-2

Expect CD1 DOE approval ~ one year from now.
Next year FNAL spending $20M.

Will share much of the Mu2e infrastructure.

Data in 2016/17. **They are welcoming UK involvement.**

FNAL Muon Campus



J-PARC Muon g-2

$$\vec{\omega}_a = \omega_S - \omega_C$$

average over muons

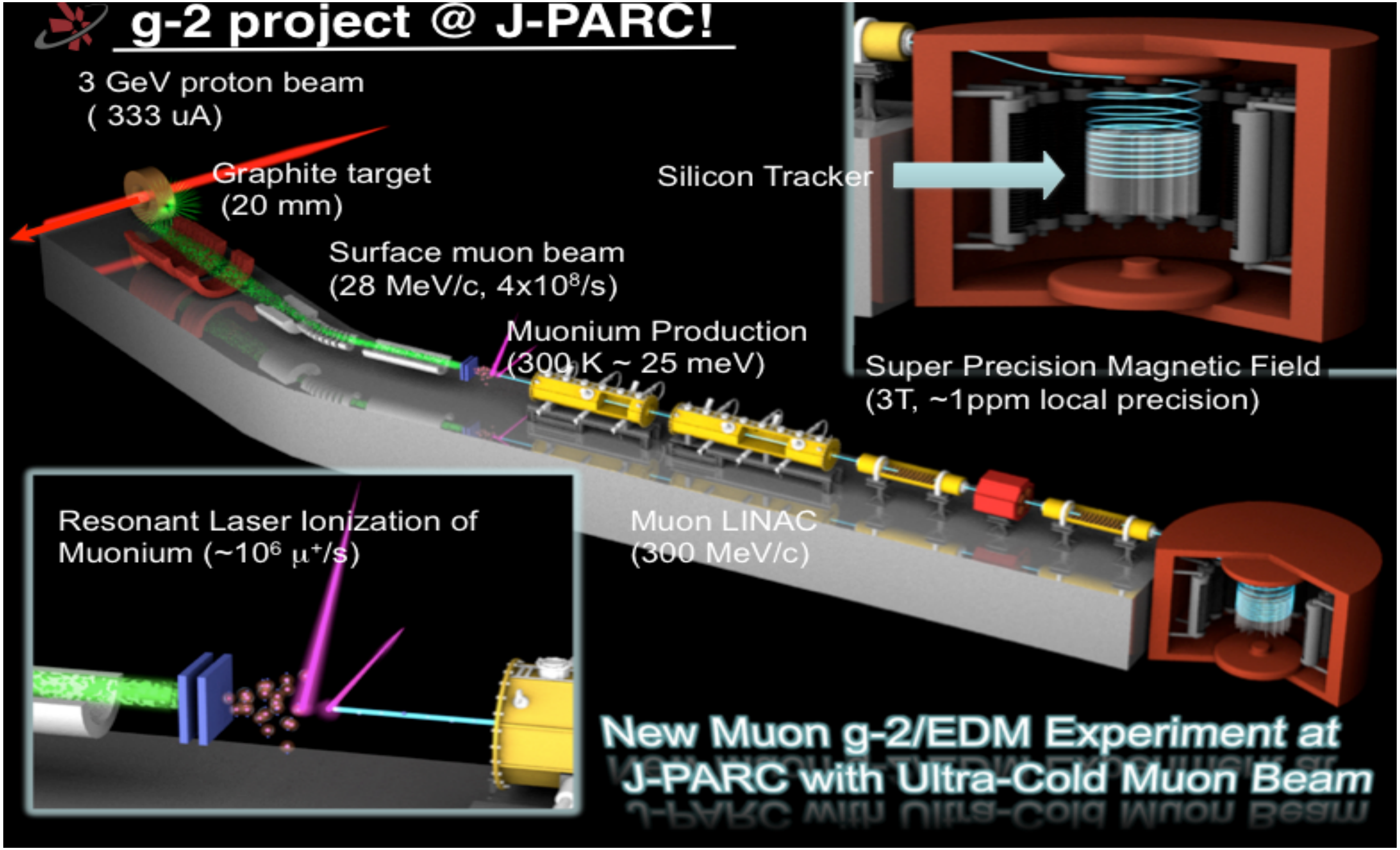
$$= -\frac{e}{m}\left[a_\mu \boxed{\vec{B}} - \cancelto{0}{\left(a_\mu - \frac{1}{\gamma^2 - 1}\right)\frac{\vec{\beta}\times\vec{E}}{c}}\right]$$

$$\gamma_{\text{magic}} = 29.3$$

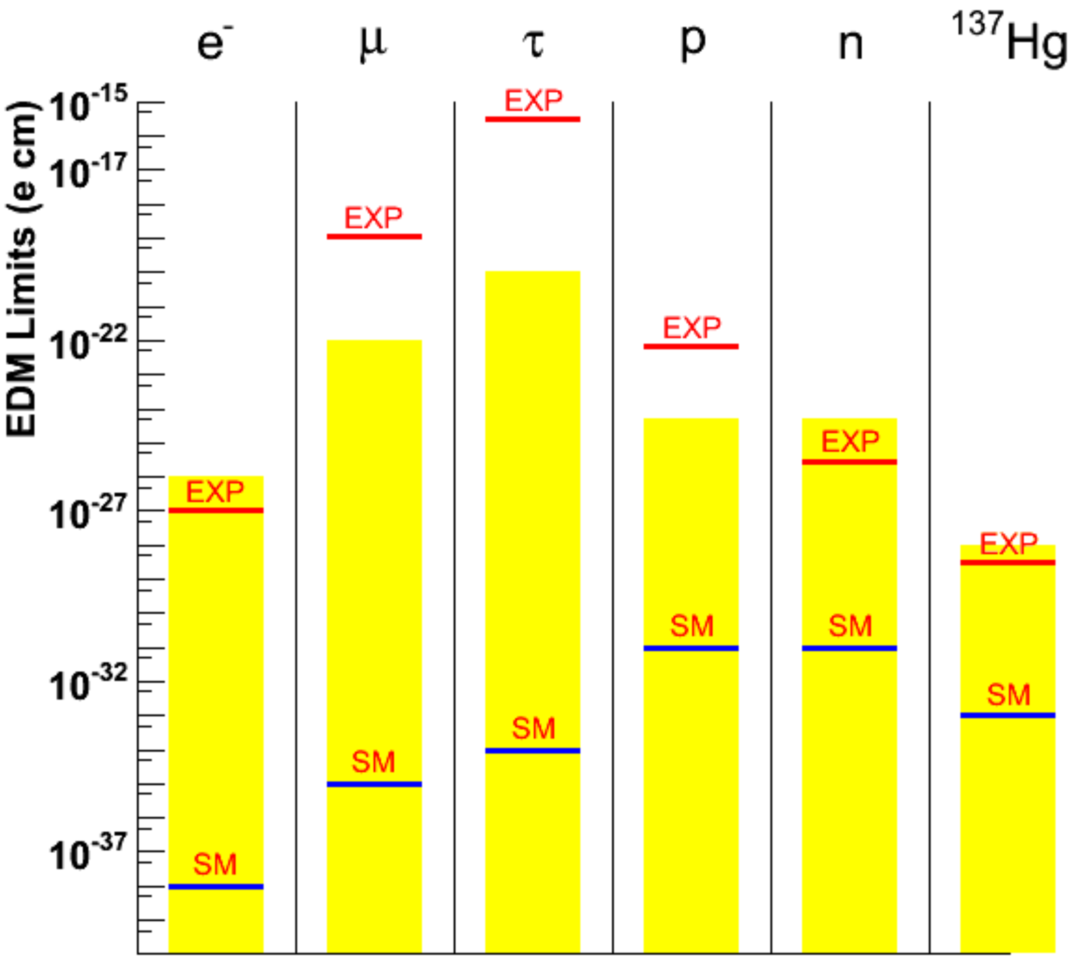
Or

1. No vertical E focussing E field and v. small vertical beam divergence ($\Delta p_T/p_T = 10^{-5}$)
2. $\beta \sim 0$ by using ultra cold muons
3. Very large and uniform B (using MRI magnets)

J-PARC Muon g-2



EDMs



BSM

Neutron EDM is one nearest to reaching SM prediction while also being in the “BSM” region.

Muon EDM is 2nd generation and free of nuclear/molecular complications.

Like flavour violation, since SM is heavily suppressed any observation is new physics.

Neutron EDM

UK presently has world's best limit @ 2.9 x 10^{-26} (also for e^{-})

27 orders of magnitude

10^{27}

Observation would violate both P and T.

Limits / observation : strong constraints on strong-CP phase in SM (now < 10^{-10})

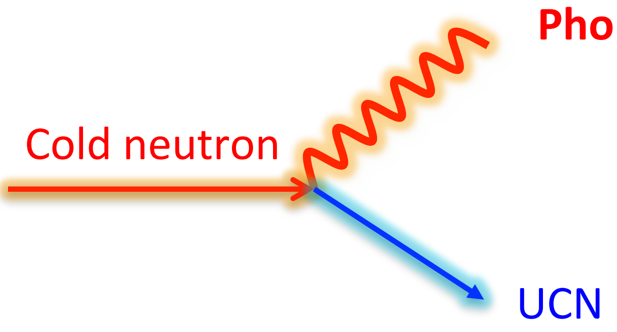
If EDMS are driven by strong-CP phase then expect dn >> de.

Neutron EDM

2006 ILL nEDM result limited by systematic of additional fields from neutron (and earth's) motion.

Solution : ultra cold neutrons (UCN)

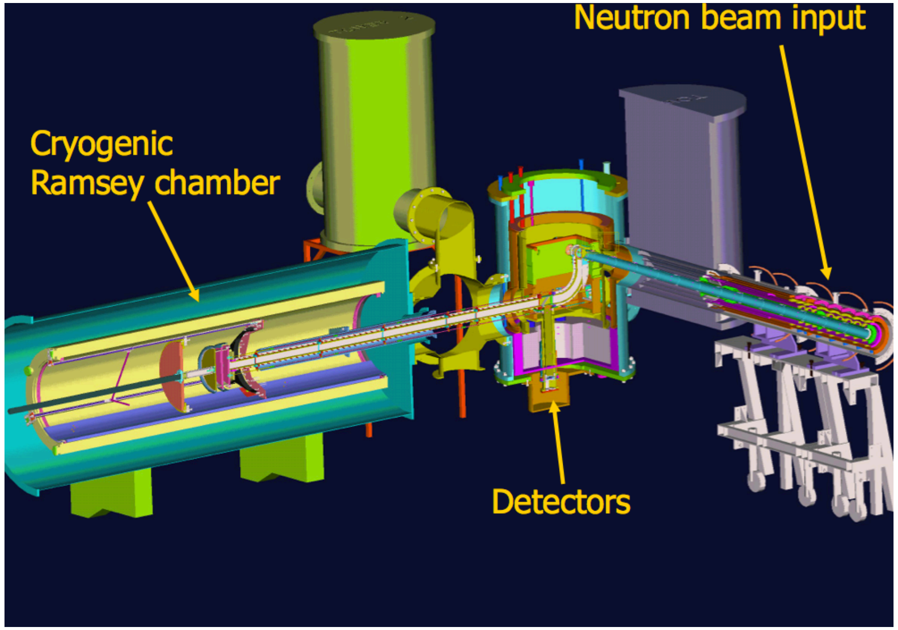
11K n down-scatter from 0.5K He



And

- increase E field (30 kV/cm)
- increase # neutrons & polarisation time

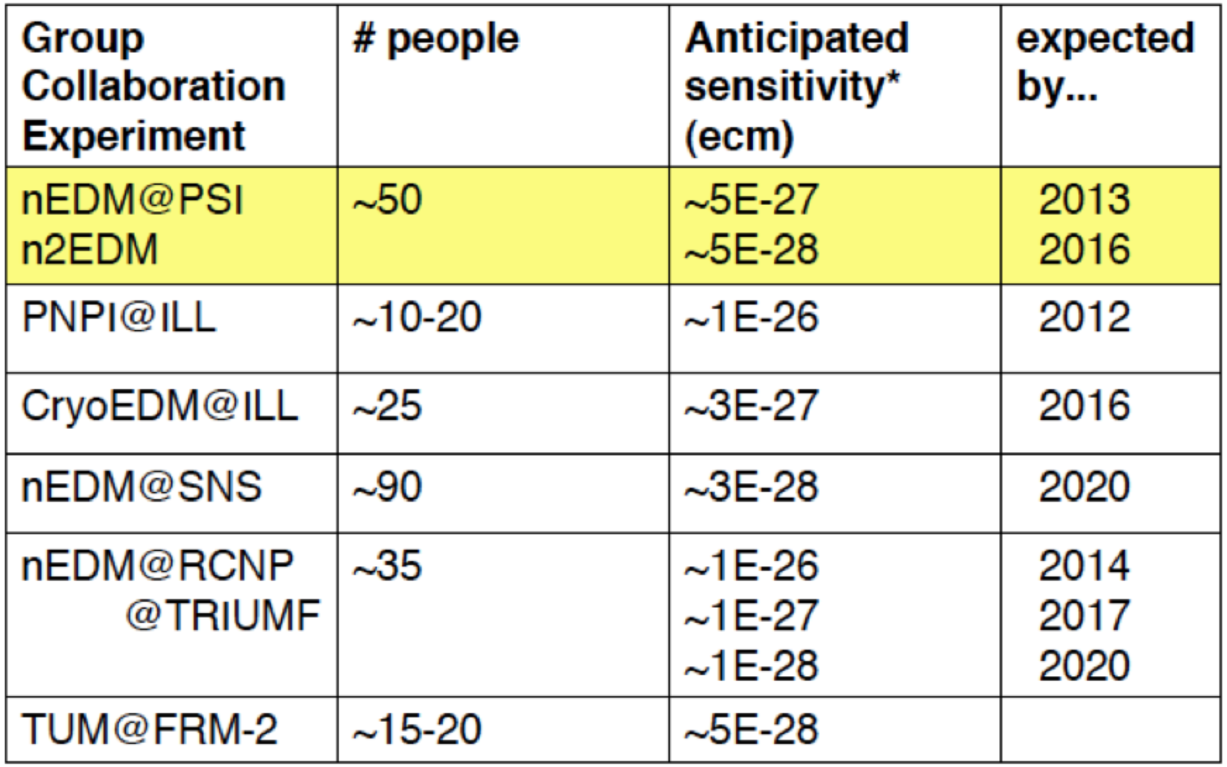
CryoEDM Expt : x10 sensitivity



Competition

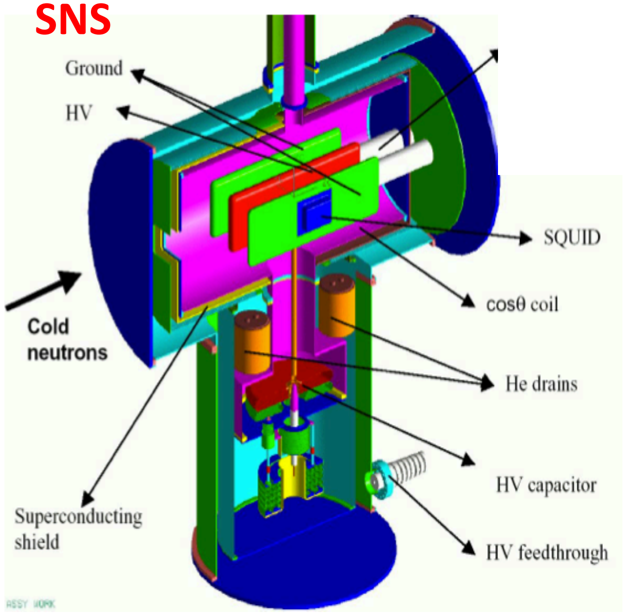
US at SNS using spallation neutrons also with cryo-design.

PSI using old nEDM apparatus but with greater neutron flux from spallation moderated by D_2O



Group Collaboration Experiment	# people	Anticipated sensitivity* (ecm)	expected by...
nEDM@PSI n2EDM	~50	~5E-27 ~5E-28	2013 2016
PNPI@ILL	~10-20	~1E-26	2012
CryoEDM@ILL	~25	~3E-27	2016
nEDM@SNS	~90	~3E-28	2020
nEDM@RCNP @TRIUMF	~35	~1E-26 ~1E-27 ~1E-28	2014 2017 2020
TUM@FRM-2	~15-20	~5E-28	

SNS

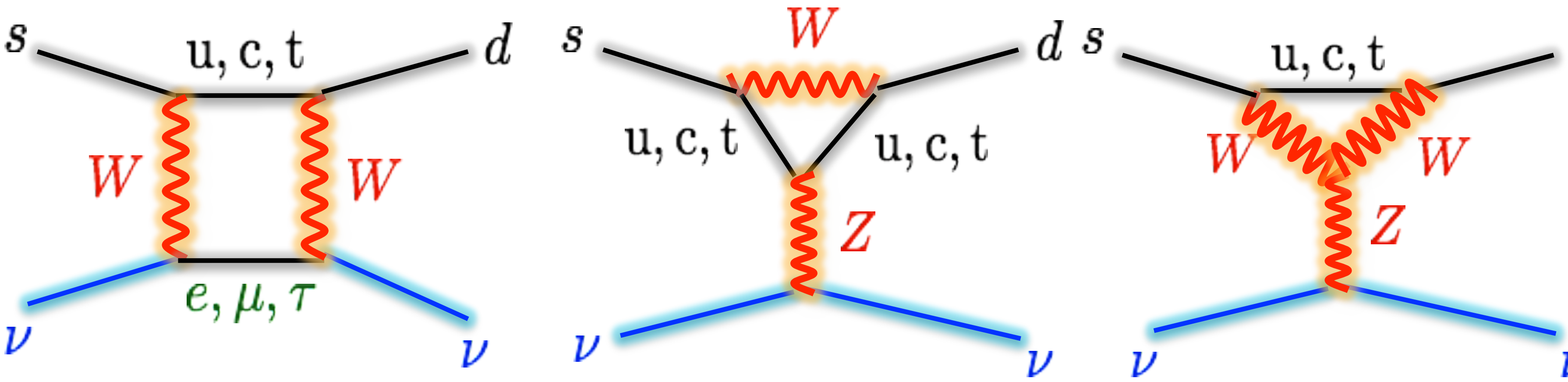


Kaons

Focus is on the two rare FCNC decays that have the most precise prediction in the SM for such decay.

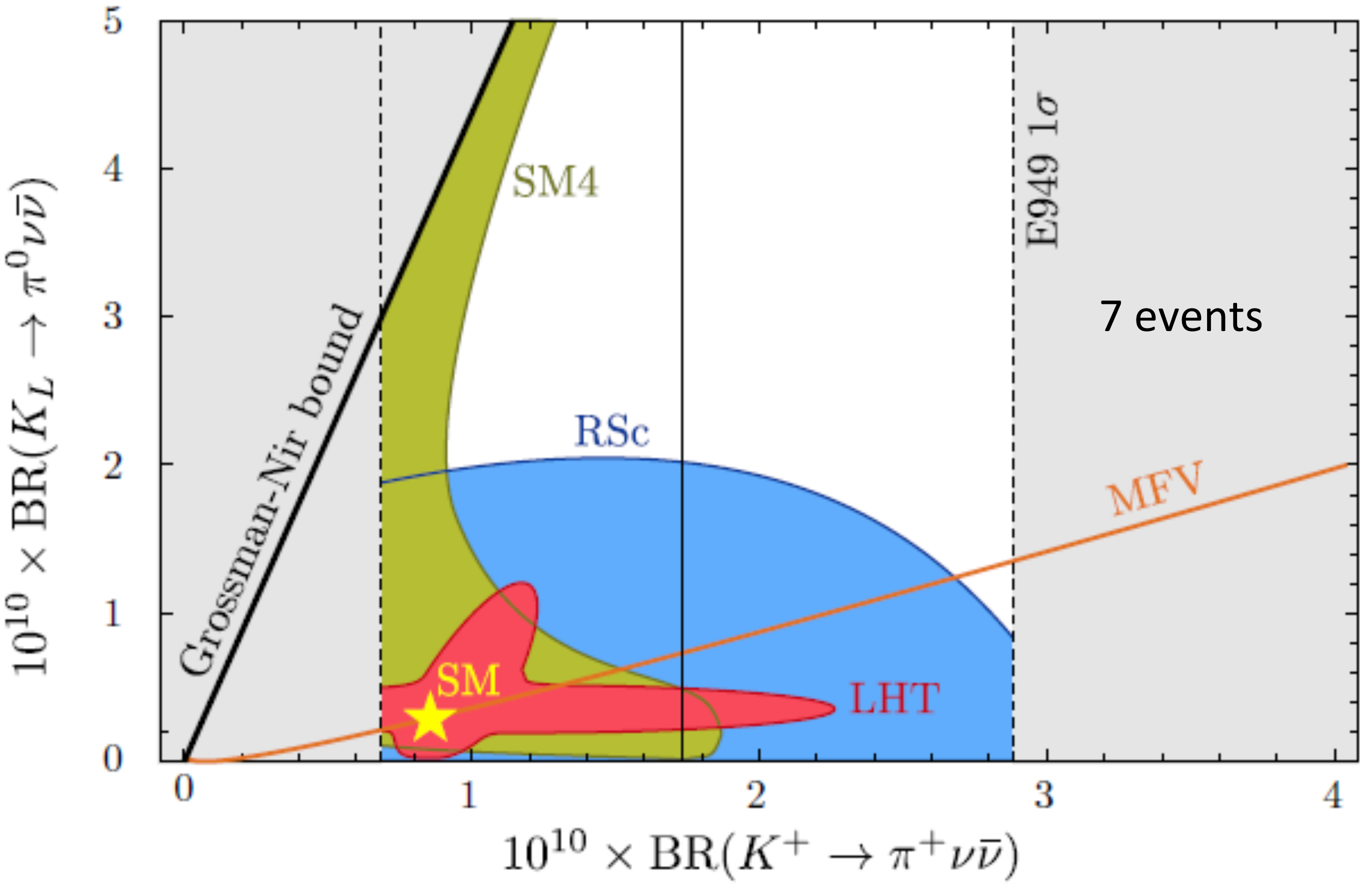
$$K^+ \to \pi^+ \nu\bar{\nu} \qquad \text{SM} = (7.8 \pm 0.8) \times 10^{-11}$$

$$K^0_L \to \pi^0 \nu\bar{\nu} \qquad \text{SM} = (2.8 \pm 0.4) \times 10^{-11}$$



Kaons

Small but measurable window for new physics



arXiv:1012.3893

Expts @ CERN, FNAL, J-PARC

$$K^+ \rightarrow \pi^+ \nu \overline{\nu}$$

NA62/CERN : 2014 : O(50)/yr → 200 (2017)

ORKA/FNAL : 2017 : O(200)/yr → 1000 (2020)

PROJECT-X/FNAL : 202x – 202y : > 1000 events

NA62 and ORKA complementary
NA62 – decay in flight K
ORKA – decay from stopped target

$$K_L^0 \rightarrow \pi^0 \nu \overline{\nu}$$

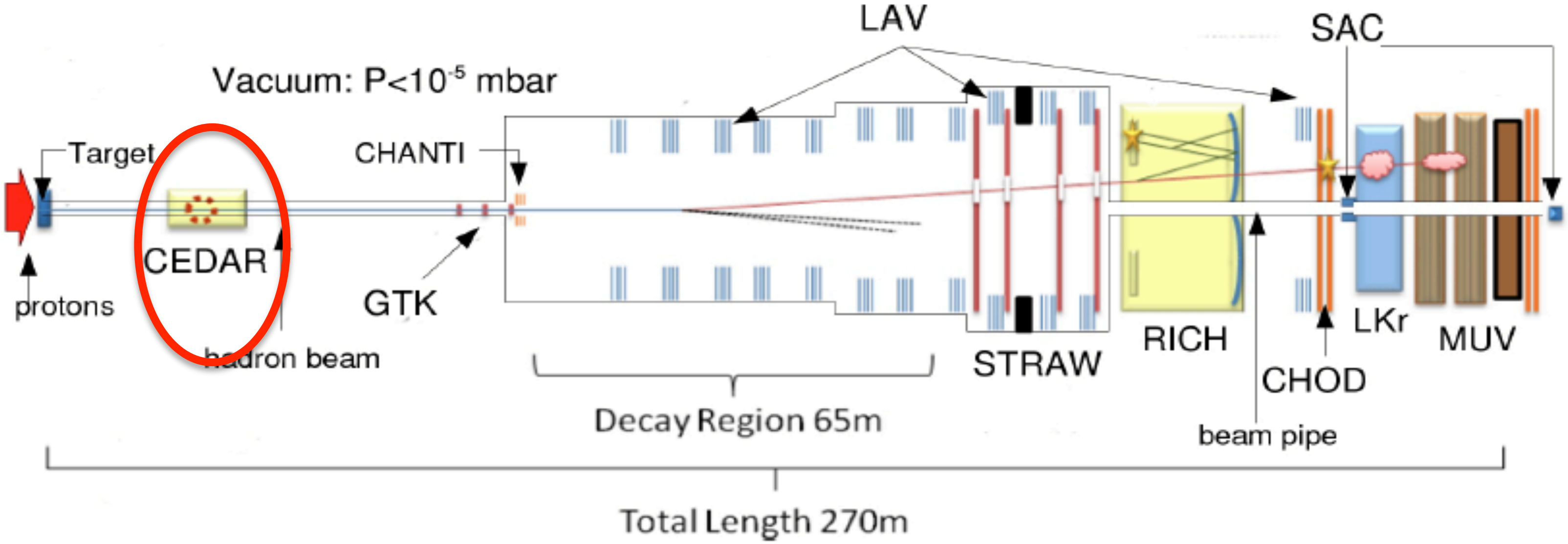
KOTO-I/J-PARC : 2012 – 2017 : O(1-10) ie SM signal

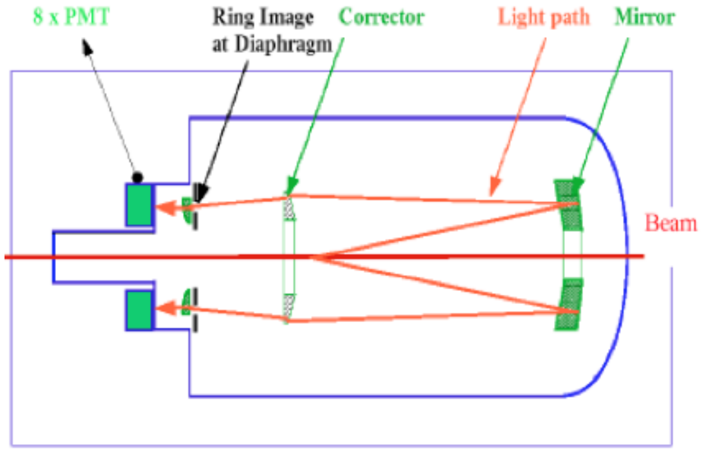
KOTO-II/J-PARC : 2017 – 2020 : O(100)

PROJECT-X/FNAL : 202x – 202y : > 1000 events

NA62 : UK role

Bristol, Birmingham, Liverpool, Glasgow





Differential Cerenkov counter to identify Kaons in the 800 MHz beam…

50 years after The Summer of Love

2017

Final results from MEG
(@ 10^{-13} sensitivity)

Results from g-2 @ FNAL
(will the 3.6 σ become 5^{+} σ?)

PSI & ILL neutron
EDM @ (0.5 – 3) x 10^{-27}

Results from KOTO (@ SM)
& NA62 (@ O(100) events)

Results from COMET Phase-I
@ J-PARC (@ 10^{-14} sensitivity)

Start of 2nd generation experiments

J-PARC g-2
ORKA
Mu2e construction
COMET Phase-II construction

UK Involvement

Presently rather modest : NA62, COMET, nEDM.

Many opportunities for UK to develop leadership roles.

- g-2 are actively soliciting UK collaborators
- COMET Phase-I needs more
- nEDM has ½ people compared to PSI / SNS.
- Mu2e/COMET Phase-II

Data on all these in 2012-2017

Your Muons Need You

Summary

There is life outside the LHC !

Rarity / Intensity Frontier has a host of experiments in next 2-20 years.

Provide a clean and complementary probe of BSM physics to the LHC to energy scales beyond LHC direct searches.

Win-Win

- ✓ If the LHC throws up nothing – this is the best game in town.
- ✓ If the LHC discovers new physics then this will elucidate the theory.