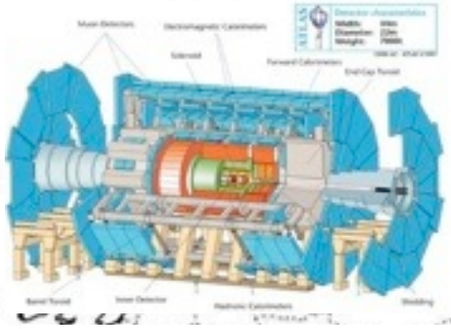
Prospects for CLFV experiments

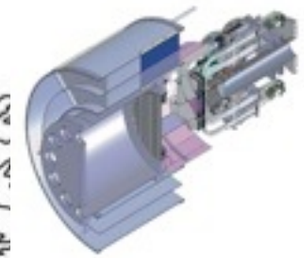
Satoshi MIHARA
KEK, Japan

CLFV and Related Programs

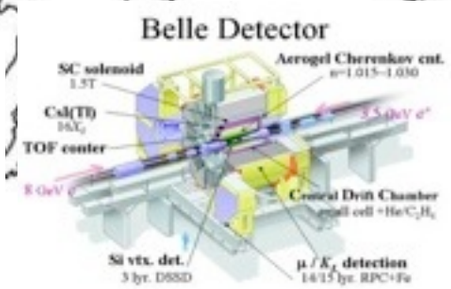


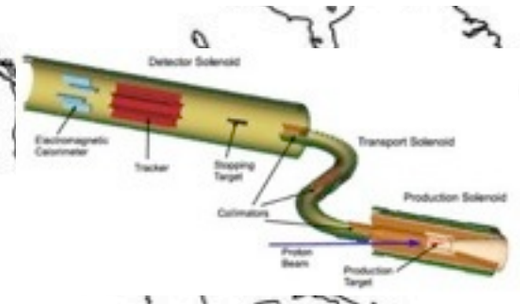
LHC: SUSY Search

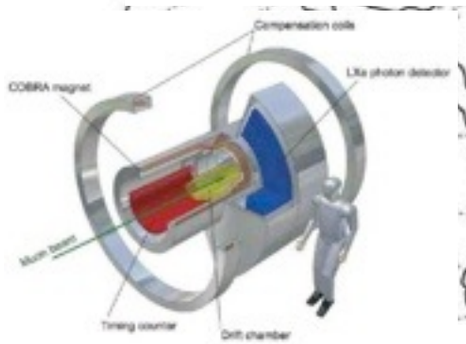
$B_s \rightarrow \mu^+\mu^-, B_s \rightarrow \tau\mu, \tau \rightarrow \mu\mu\mu$



TRIUMF: PIENU







KEKB: $\tau \rightarrow e(\mu)\,\gamma, \tau \rightarrow e(\mu)\,\eta$ ...

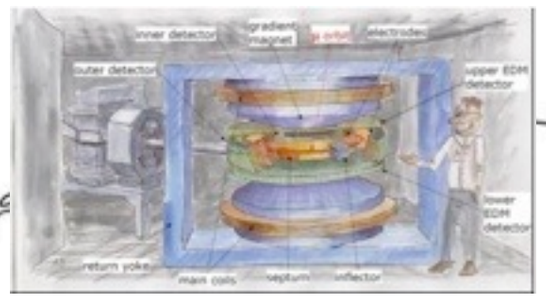
$BR < 10^{-8}$

FNAL: $BR(\mu^- N \rightarrow e^- N) < 10^{-16}$

FNAL: μ g-2 < 0.1 ppm

PSI/MEG: $BR(\mu \rightarrow e\,\gamma) < 10^{-13}$

$\mu \rightarrow eee$ in future



PSI: μ EDM

J-PARC: $BR(\mu^- N \rightarrow e^- N) < 10^{-14}, 10^{-16}$

J-PARC: $K_{e2}/K_{\mu 2}$

J-PARC: μ g-2 < 0.1 ppm

J-PARC: μ EDM

BNL: μ g-2 < 0.5 ppm

>3-σ off from SM

Outline

- Introduction
- MEG
- COMET, Mu2e and other Experiments
- Summary

ν oscillation and cLFV

- cLFV searches play a key role to understand the origin of neutrino mass
  - Scale of neutrino mass generation

  - Scale of EW Symmetry breaking (TeV)
- Verification of new physics existence

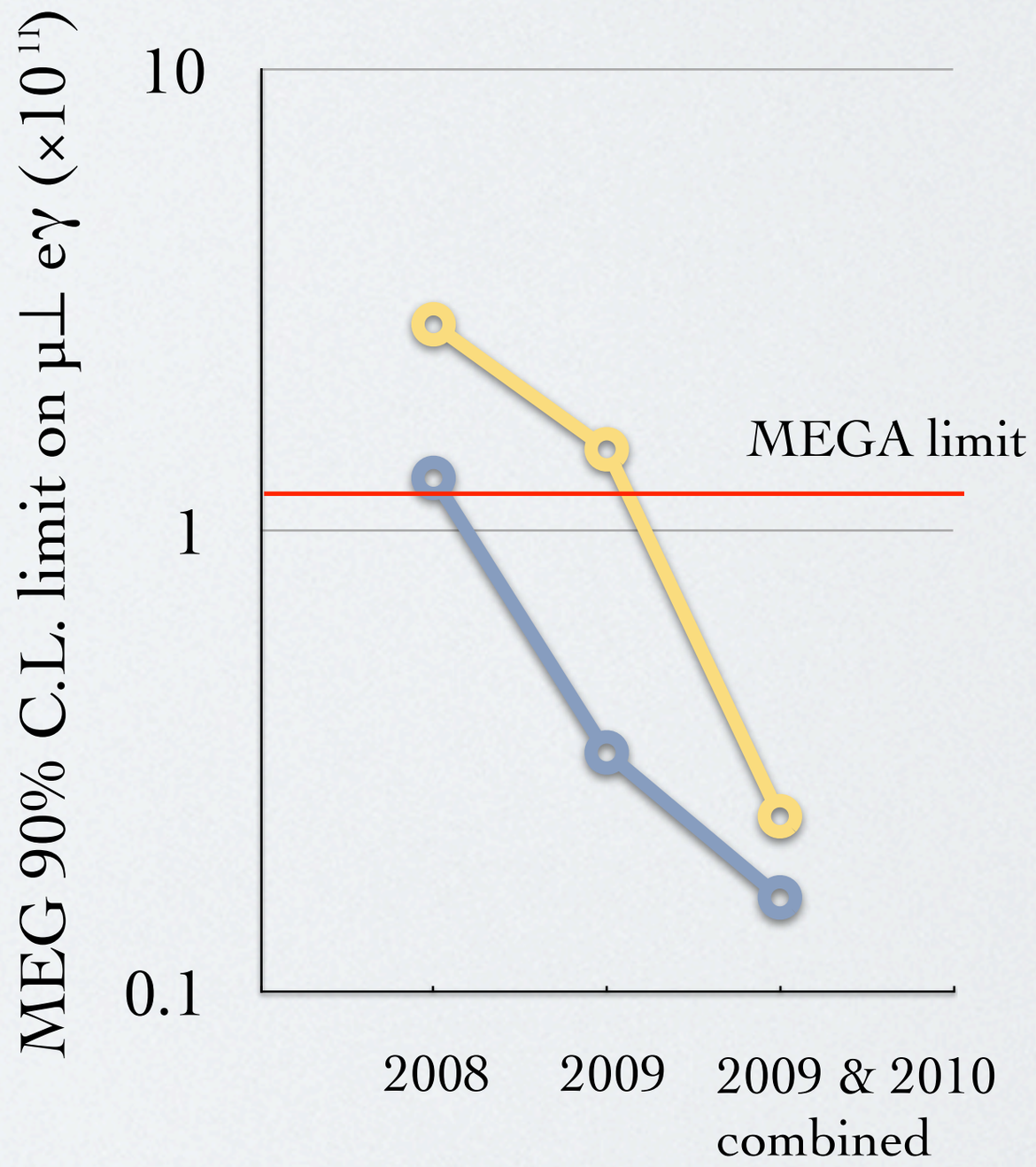
MEG

Recent Result

Donato Nicolò's talk Today afternoon WG4

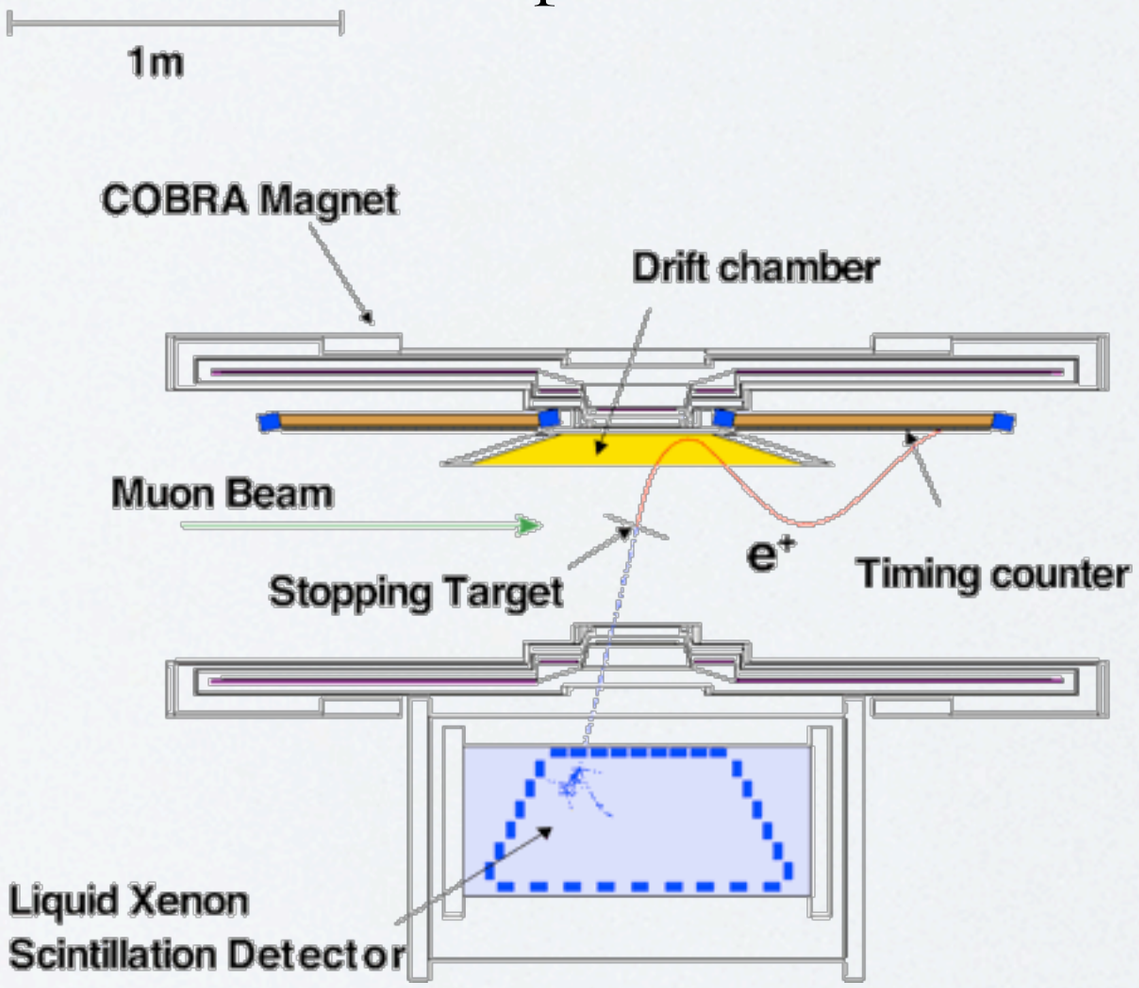
MEG Result before this Summer

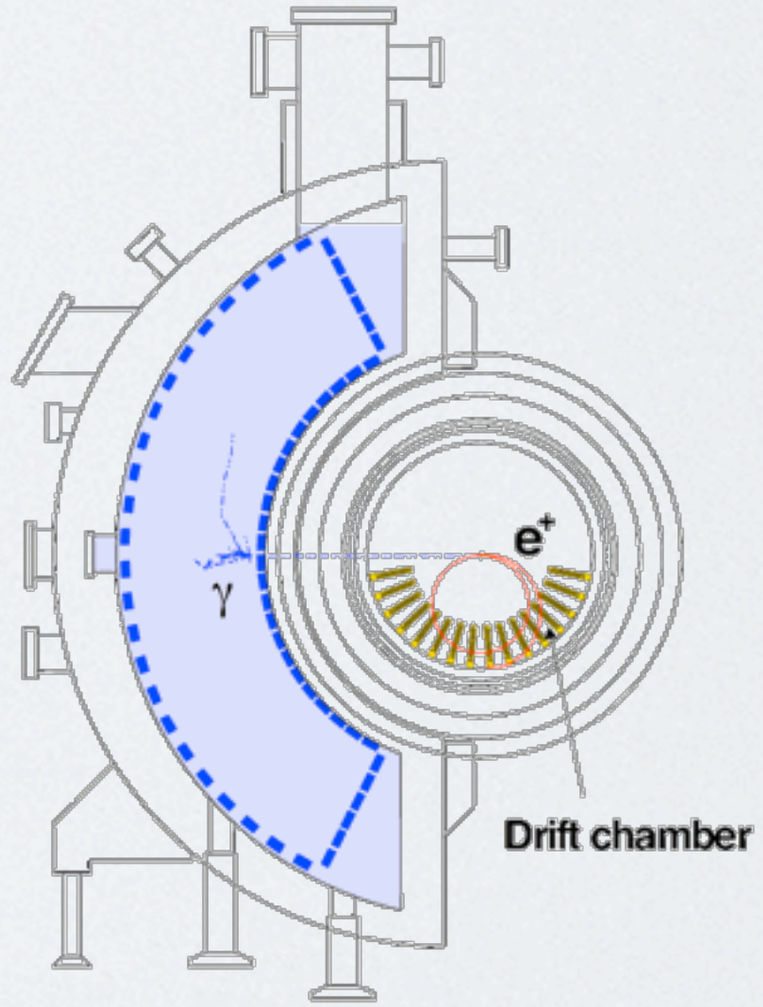
- 2008 data
  - $<2.8\times10^{-11}$ @ 90% C.L.
    - NP B834(2010) 1-12
- 2009 data
  - $<1.5\times10^{-11}$ @ 90%C.L.
    - Preliminary, shown at ICHEP 2010



MEG Detector

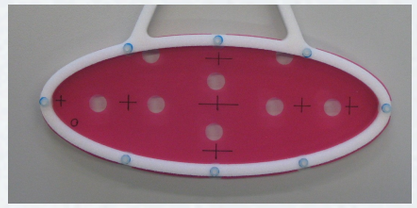
- Beam Transport System - PSI PiE5 beam line 3×10^7 /sec
- Liquid Xenon Gamma-ray Detector
- Positron Spectrometer

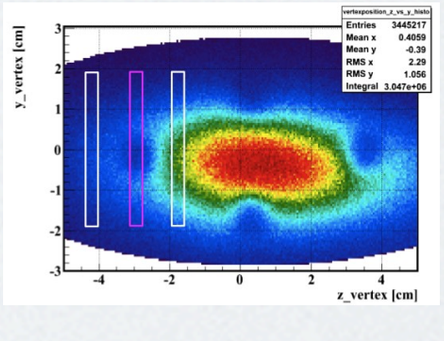


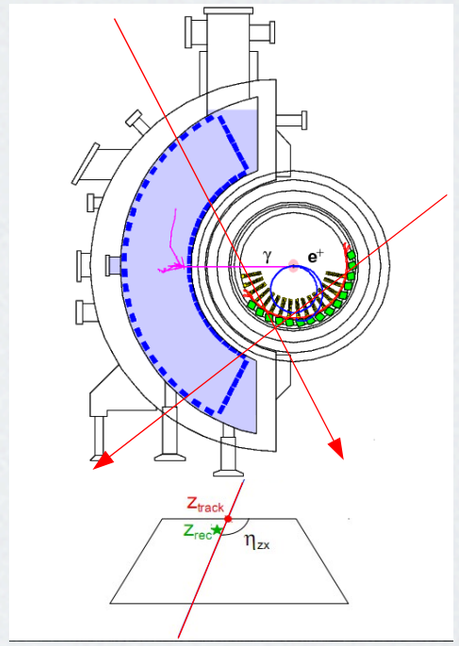


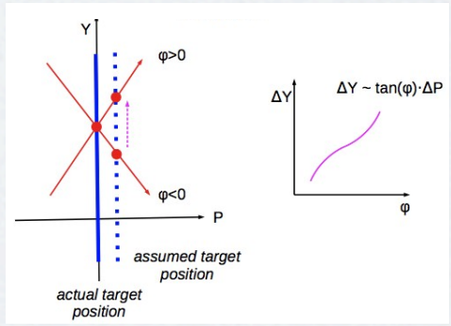
Analysis Update

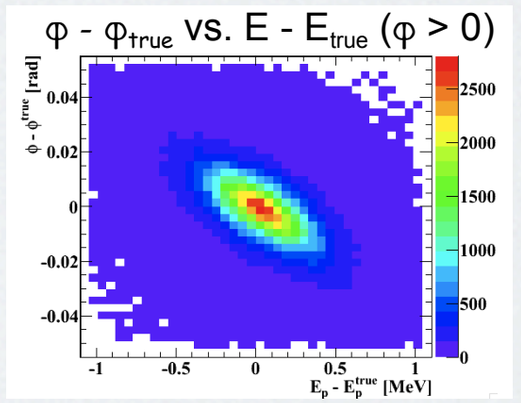
- After ICHEP 2010 presentation
- More work on the major systematics
  - Alignments (DC-B-target-LXe)
  - B field reconstruction refinement using measured Bz
  - Detailed implementation of positron observable correlations
- Data analysis cross check
  - Two likelihood analysis implementation

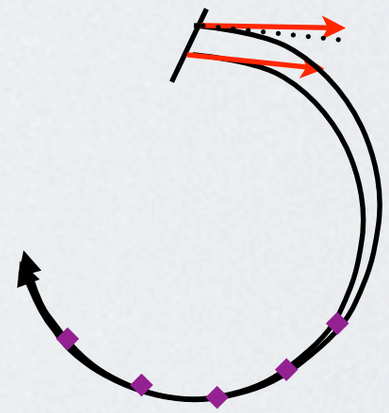






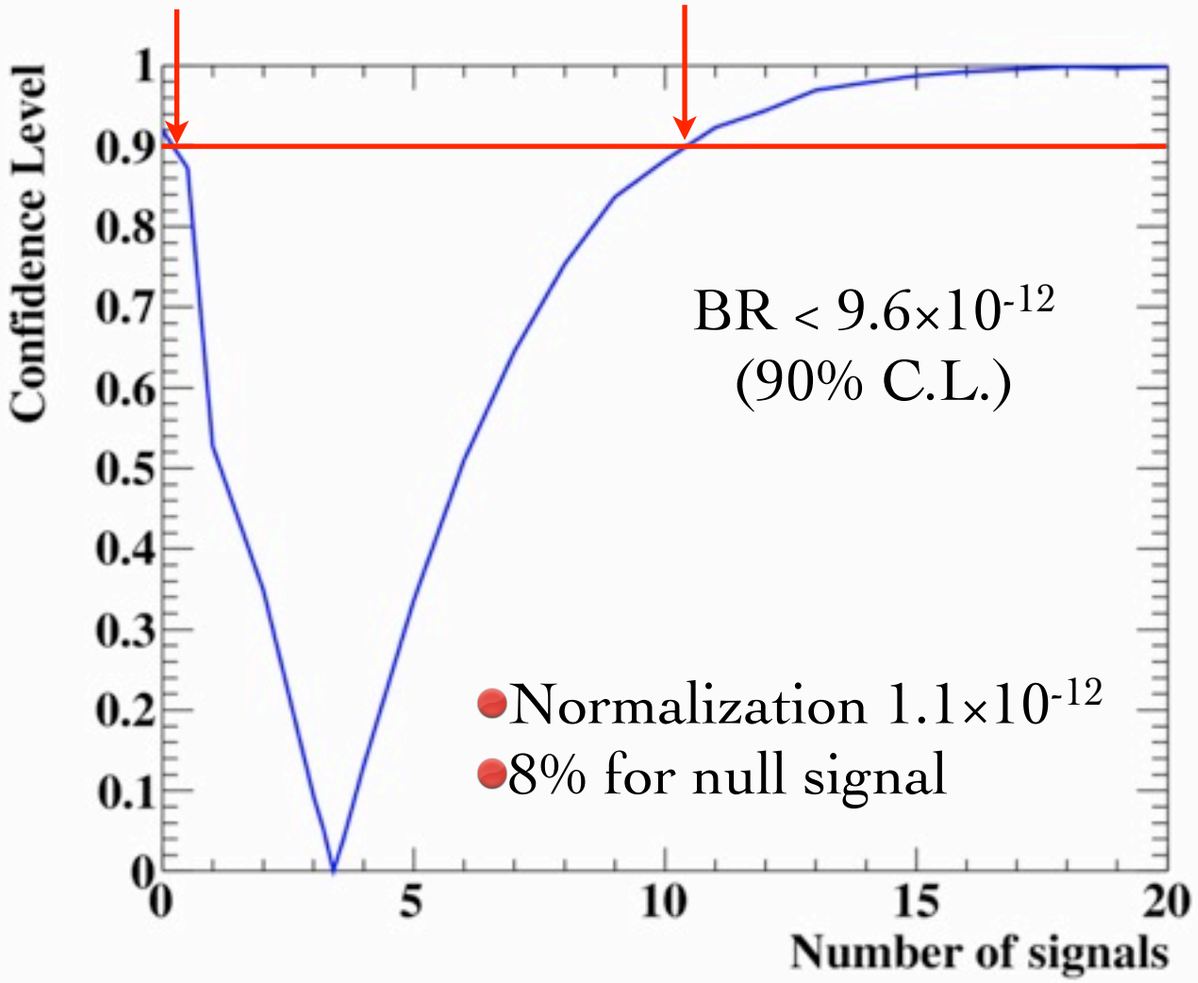




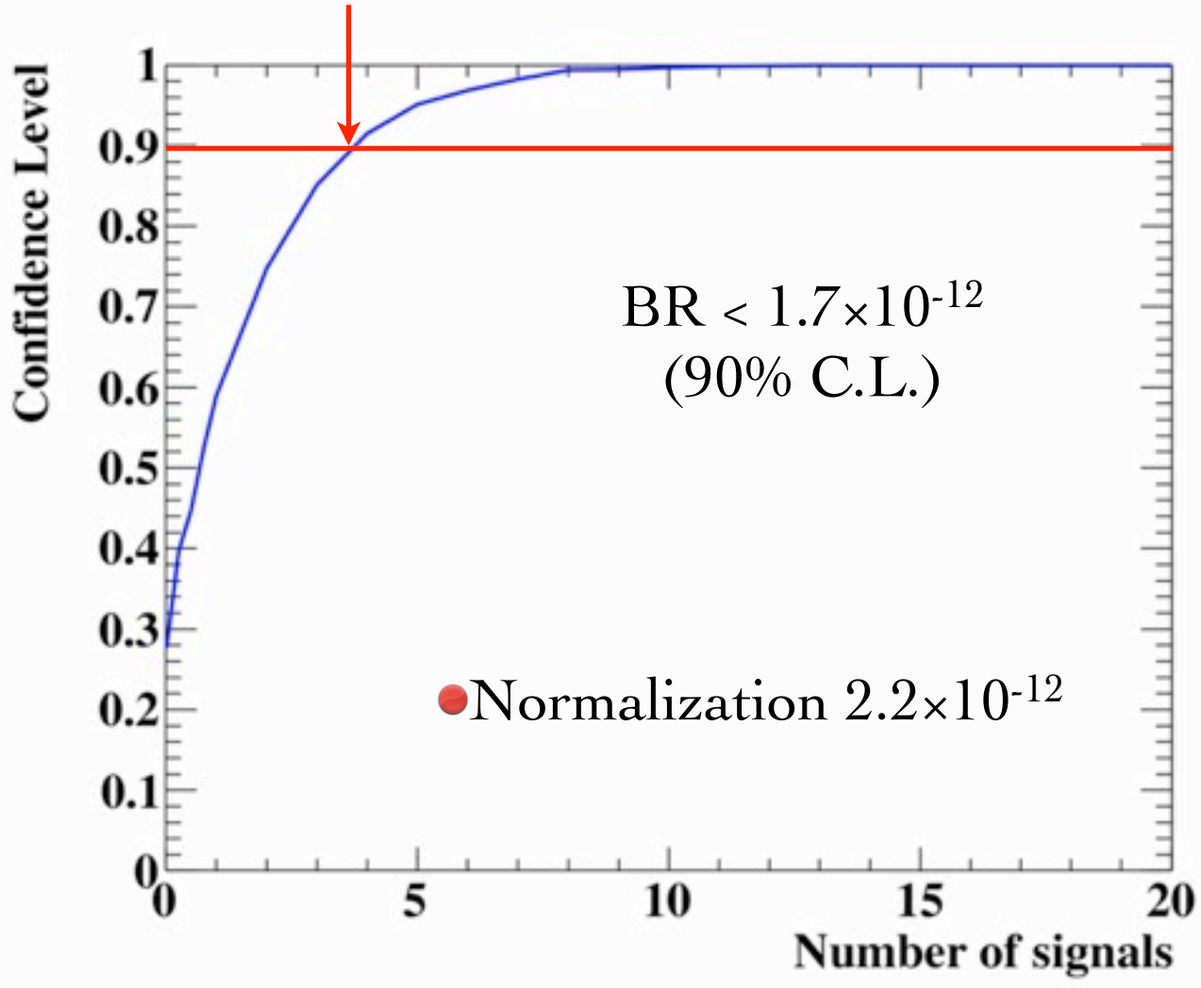


Likelihood

2009



2010



2009 & 2010 Combined Result

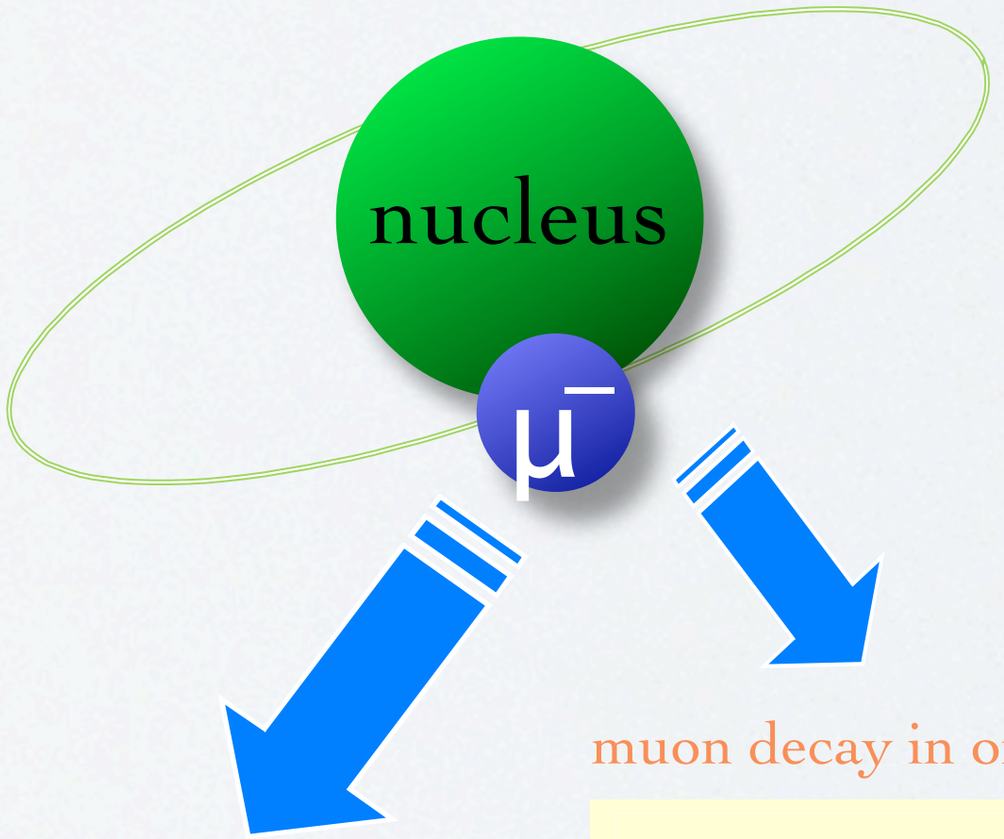
Data	B_{fit}	LL	UL
2009	3.2×10^{-12}	1.7×10^{-13}	9.6×10^{-12}
2010	-9.9×10^{-13}	-	1.7×10^{-12}
2009+2010	-1.5×10^{-13}	-	2.4×10^{-12}

- Systematic error (total 2.2%) included
  - Data fitted 100 times, with changing PDF using its uncertainty
  - RMS of the unconstrained best fit and the UL is calculated
- More data in 2011 and 2012
- Detector upgrade under discussion

Future Experiments

What is mu-e Conversion ?

1s state in a muonic atom



muon decay in orbit

$$\mu^- \rightarrow e^- \bar{\nu} \nu$$

nuclear muon capture

$$\mu^- + (A,Z) \rightarrow \nu_\mu + (A,Z-1)$$

Neutrino-less muon nuclear capture (=μ-e conversion)

$$\mu^- + (A,Z) \rightarrow e^- + (A,Z)$$

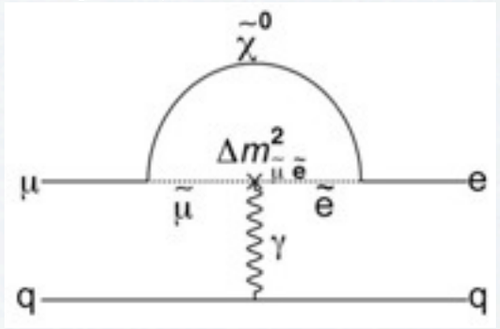
lepton flavours changes by one unit

- $E_{\mu e} \sim m_\mu - B_\mu$
  - B_μ: binding energy of the 1s muonic atom

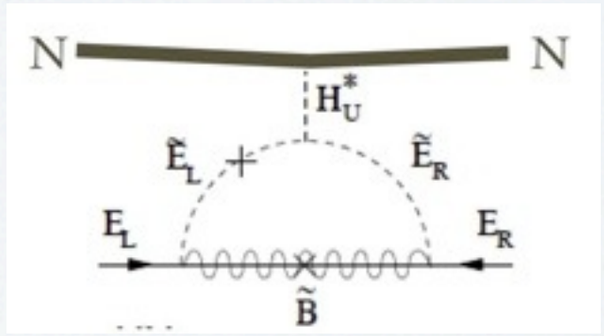
$$B(\mu^- N \rightarrow e^- N) = \frac{\Gamma(\mu^- N \rightarrow e^- N)}{\Gamma(\mu^- N \rightarrow \nu N')}$$

Theoretical Models

- SUSY-GUT, SUSY-seesaw (Gauge Mediated process)
  - BR = 10^{-14} = BR($\mu \rightarrow e\gamma$) × O(α)
  - $\tau \rightarrow l\gamma$

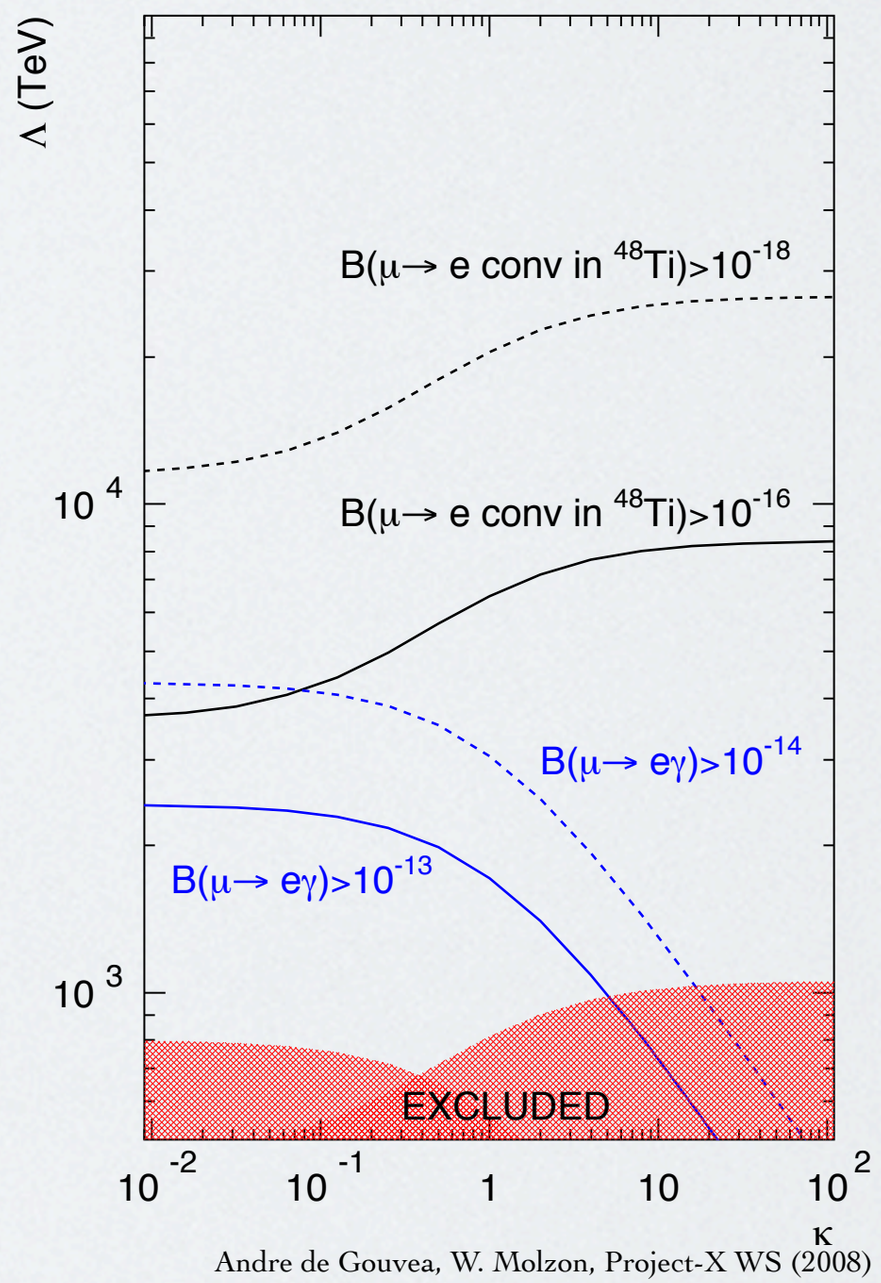


- SUSY-seesaw (Higgs Mediated process)
  - BR = 10^{-12}~10^{-15}
  - $\tau \rightarrow l\eta$



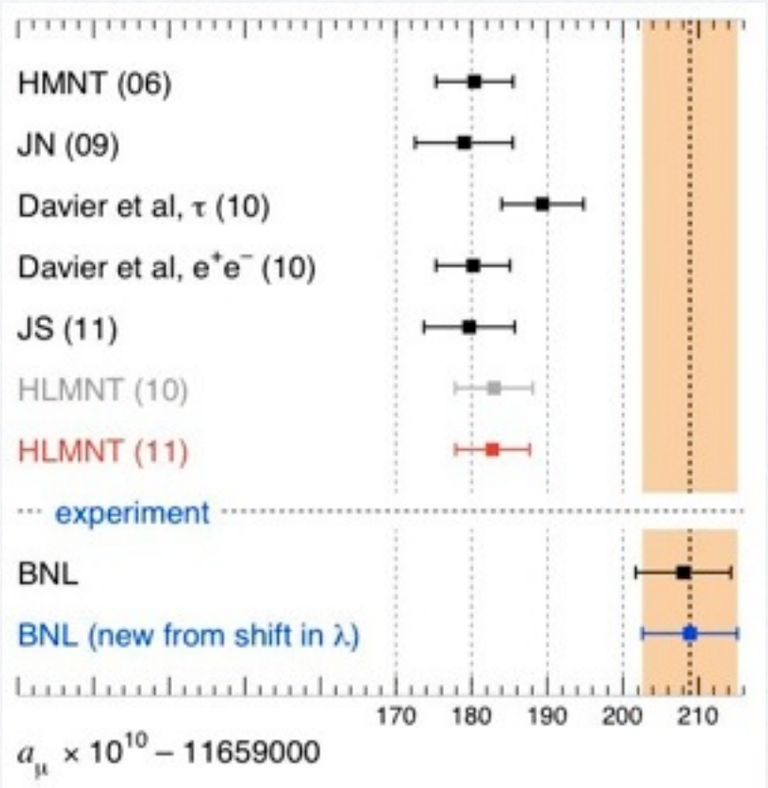
- Doubly Charged Higgs Boson (LRS *etc.*)
  - Logarithmic enhancement in a loop diagram for $\mu^- N \rightarrow e^- N$, not for $\mu \rightarrow e\,\gamma$
    - M. Raidal and A. Santamaria, PLB 421 (1998) 250
- and many others

$$L_{\mathrm{CLFV}} = \frac{m_\mu}{(\kappa+1)\Lambda^2}\bar{\mu}_R\sigma_{\mu\nu}e_L F^{\mu\nu} + \frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L\gamma_\mu e_L\left(\bar{u}_L\gamma^\mu u_L + \bar{d}_L\gamma^\mu d_L\right)$$

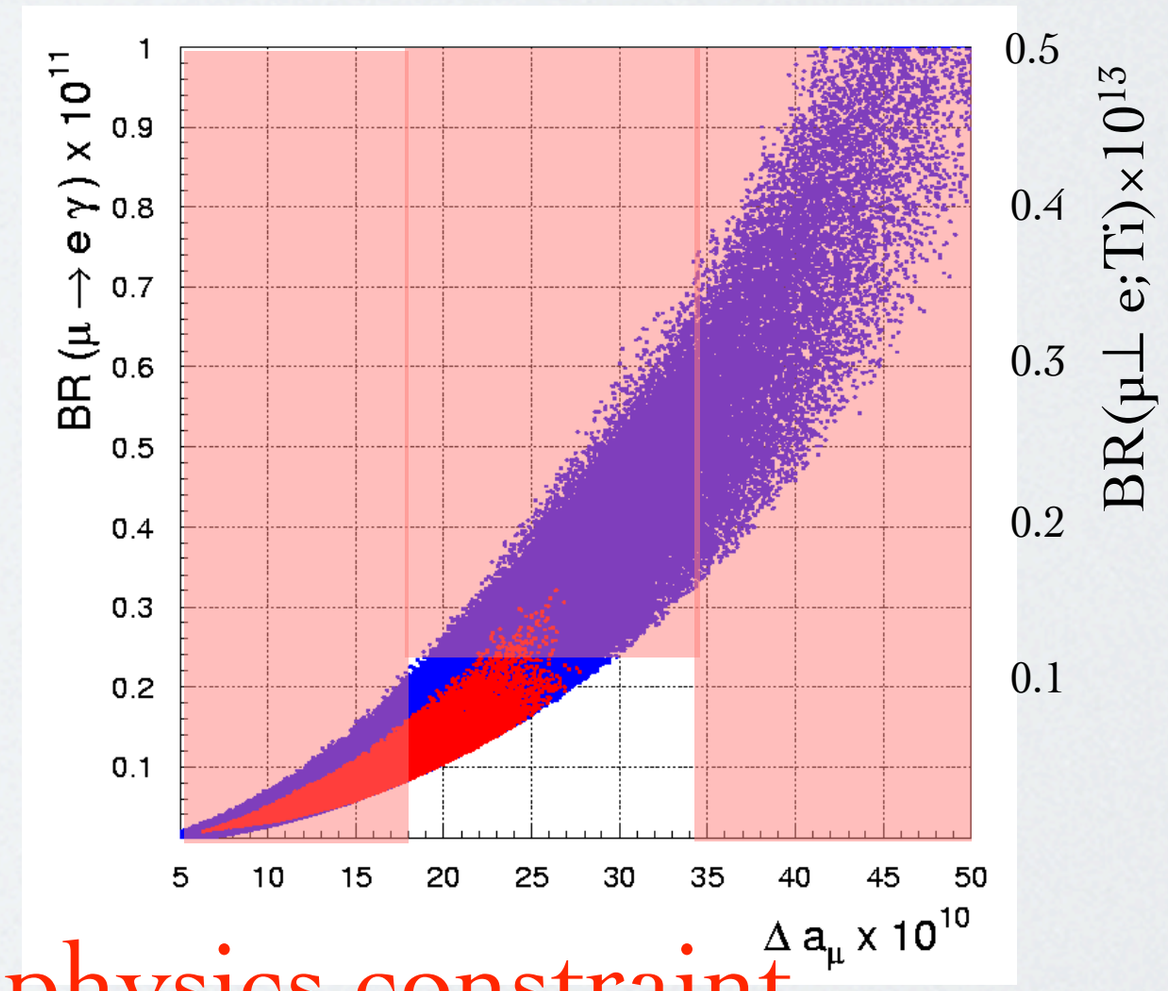


Andre de Gouvea, W. Molzon, Project-X WS (2008)

mu-e & g-2

- muon g-2
  - 

G. Ishidori *et al.*, PRD 75 (2007) 115019



- μ ⊥ e γ (MEG)
  - 2009-2010
    BR < 2.4 × 10^{-12} (90%C.L.)

B physics constraint

Recent Upper Limits

SINDRUM-II: BR[μ^- + Au ⊥ e^- + Au] < 7 × 10^{-13}

SINDRUM-II: BR[μ^- + Ti ⊥ e^- + Ti] < 4.3 × 10^{-12}

TRIUMF: BR[μ^- + Ti ⊥ e^- + Ti] < 4.6 × 10^{-12}

Principle of Measurement

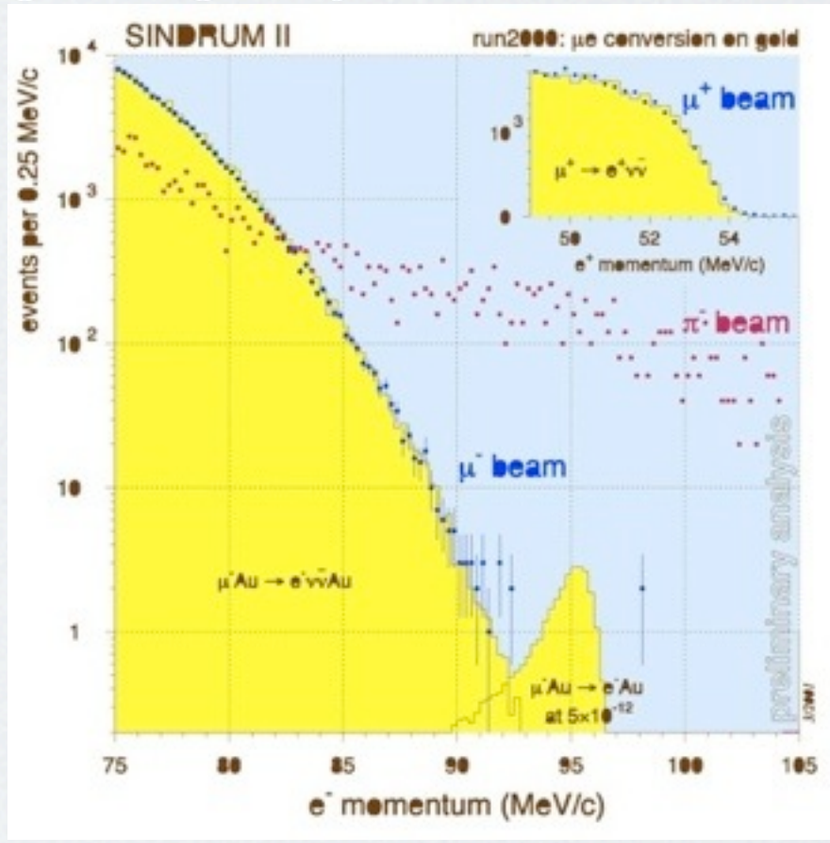
- Process : $\mu^- + (A,Z) \rightarrow e^- + (A,Z)$
  - A single mono-energetic electron
    - $E_{\mu e} \sim m_\mu - B_\mu$:105 MeV
    - Delayed : ~1μS

- No accidental backgrounds
- Physics backgrounds
  - Muon Decay in Orbit (DIO)
    - $E_e > 102.5$ MeV (BR:10^{-14})
    - $E_e > 103.5$ MeV (BR:10^{-16})
  - Beam Pion Capture
    - $\pi^+ + (A,Z) \rightarrow (A,Z-1)^* \rightarrow \gamma + (A,Z-1)$
      $\gamma \rightarrow e^+ e^-$

SINDRUM II

BR[$\mu^- + Au \perp e^- + Au$]

$< 7 \times 10^{-13}$



1-2μs

$$R_{ext} = \frac{\text{number of proton between pulses}}{\text{number of proton in a pulse}}$$

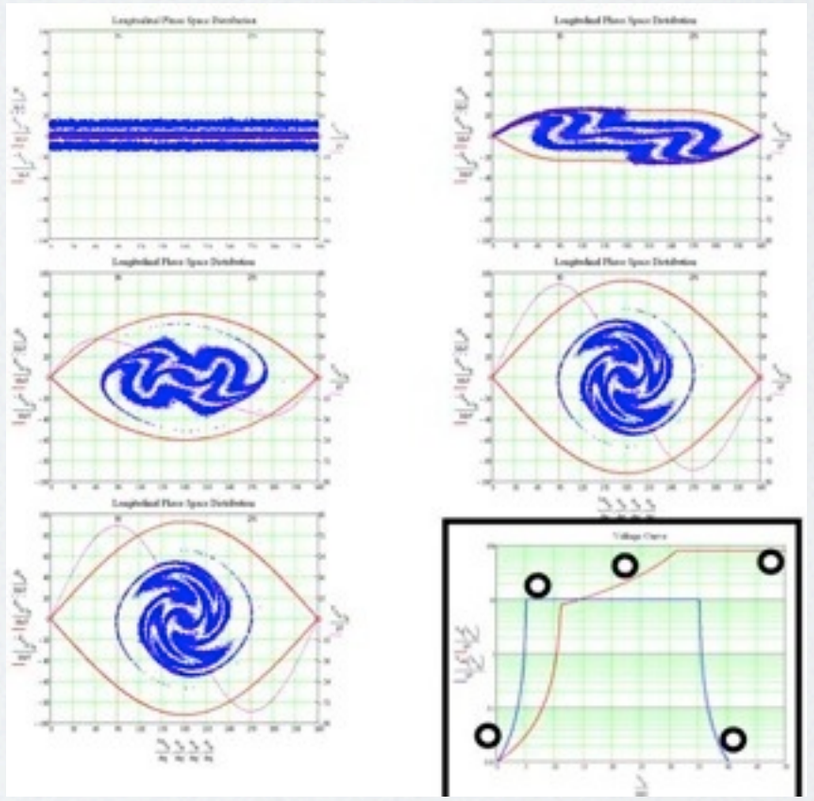
mu-e conversion search

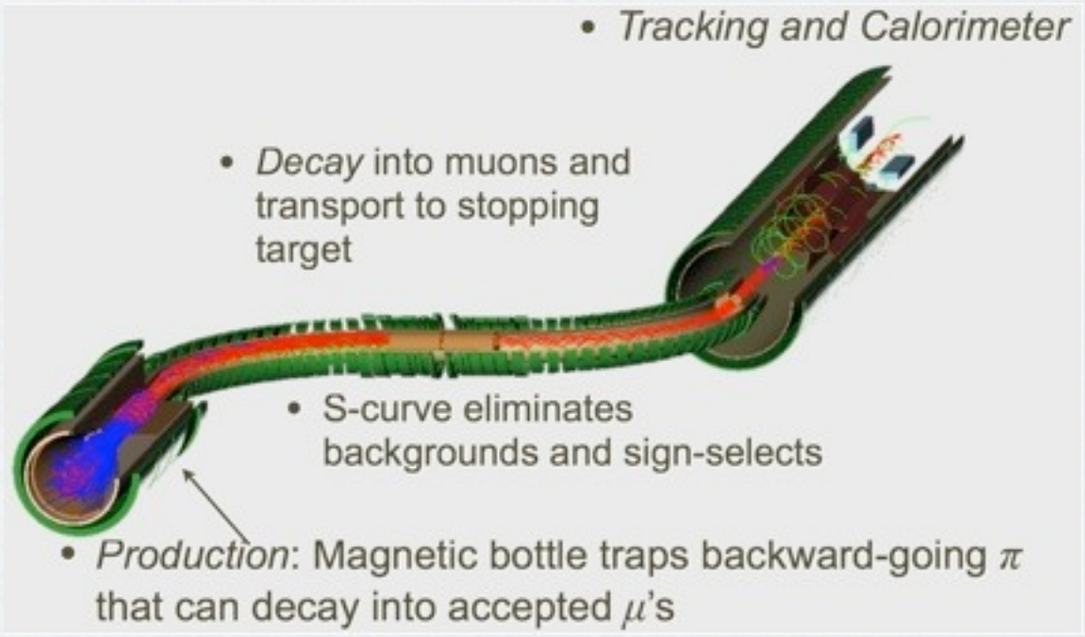
- Mu2e at FNAL
- COMET at J-PARC

MELC experiment at Moscow Meson Factory

Mu2e Experiment at FNAL

- Target S.E.S. 2×10^{-17}
- uses the antiproton accumulator/ debuncher rings to manipulate proton beam bunches
- No interference with NOvA experiment
    - Mu2e uses beam NOvA can't
- pion production target in a solenoid magnet
- S-shape muon transport to eliminate BG and sign-select
- Tracker and calorimeter to measure electrons

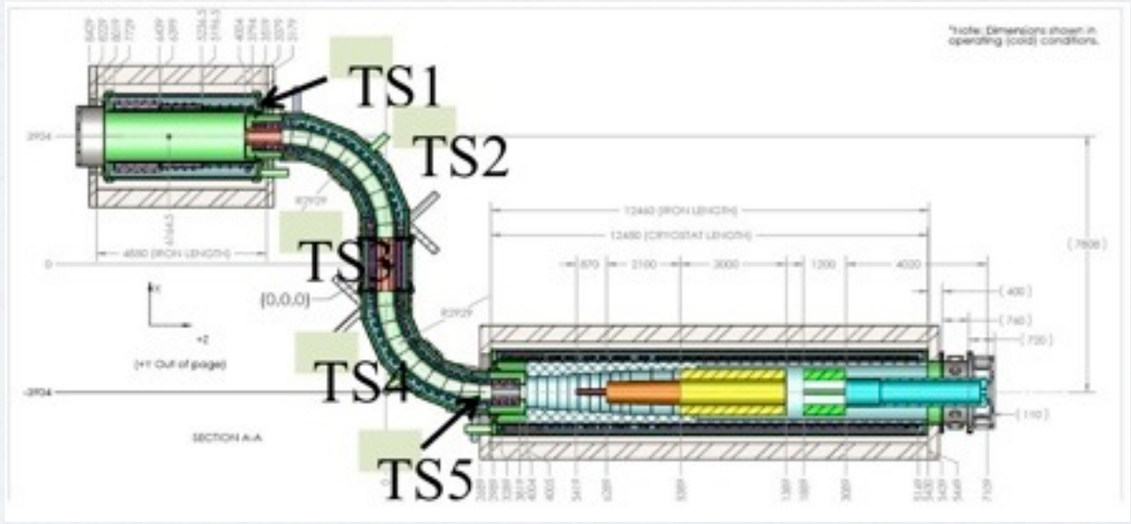




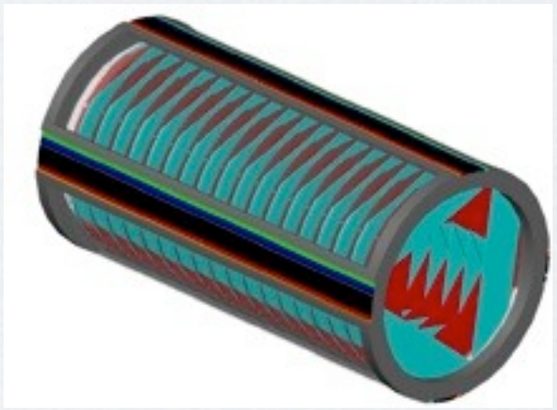
R. Bernstein WG4 Monday

Mu2e R&D Status

- Solenoid system design
- Advanced modeling of the primary beam
- civil and building design as well
- Detector R&D
  - Straw tracker in vacuum

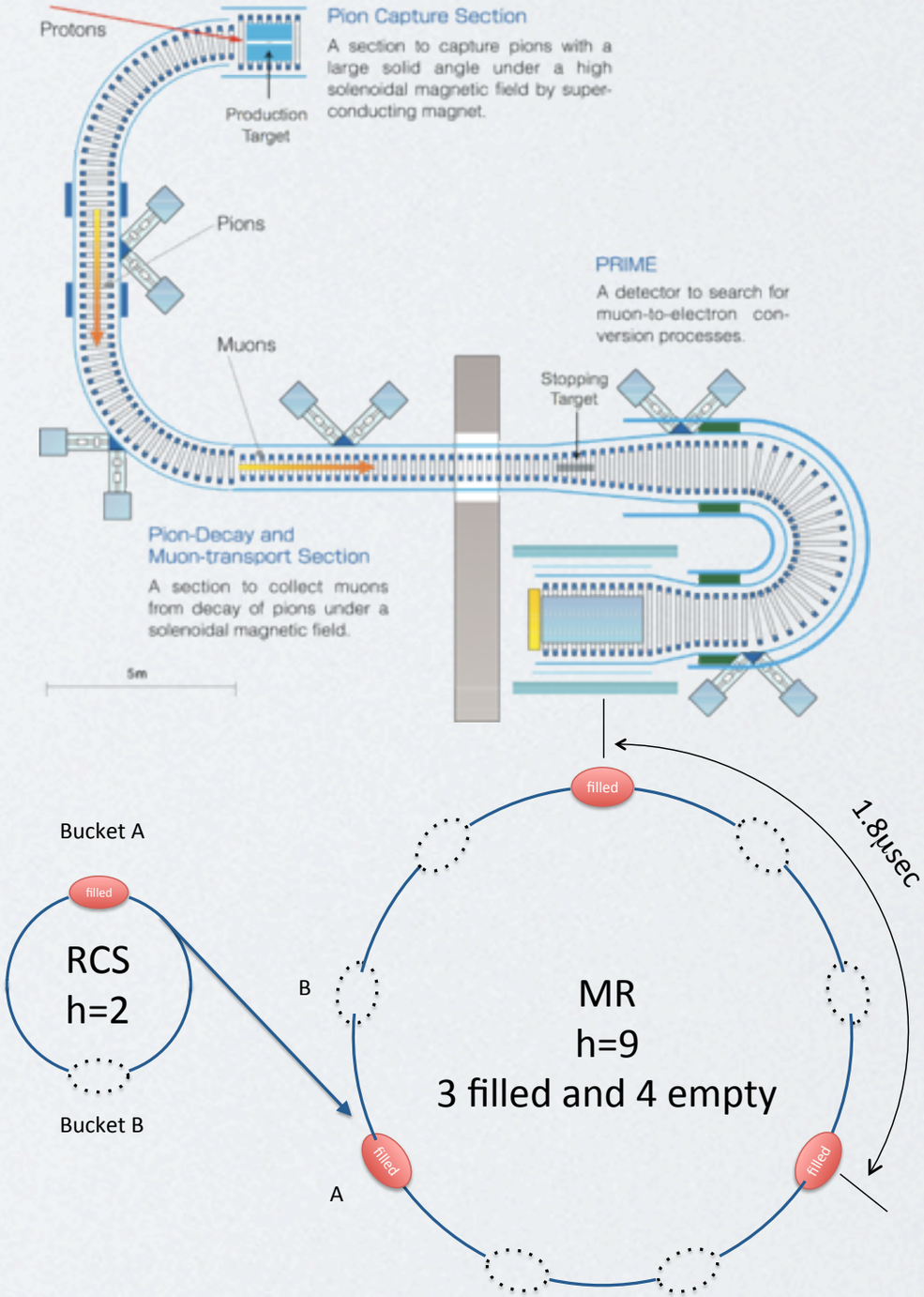


- DOE CD-1 this autumn
  - CD-2/3a about a year later



COMET Experiment at J-PARC

- Target S.E.S. 2.6×10^{-17}
- Pulsed proton beam at J-PARC
  - Insert empty buckets for necessary pulse-pulse width
  - bunched-slow extraction
- pion production target in a solenoid magnet
- Muon transport & electron momentum analysis using C-shape solenoids
  - smaller detector hit rate
  - need compensating vertical field
- Tracker and calorimeter to measure electrons

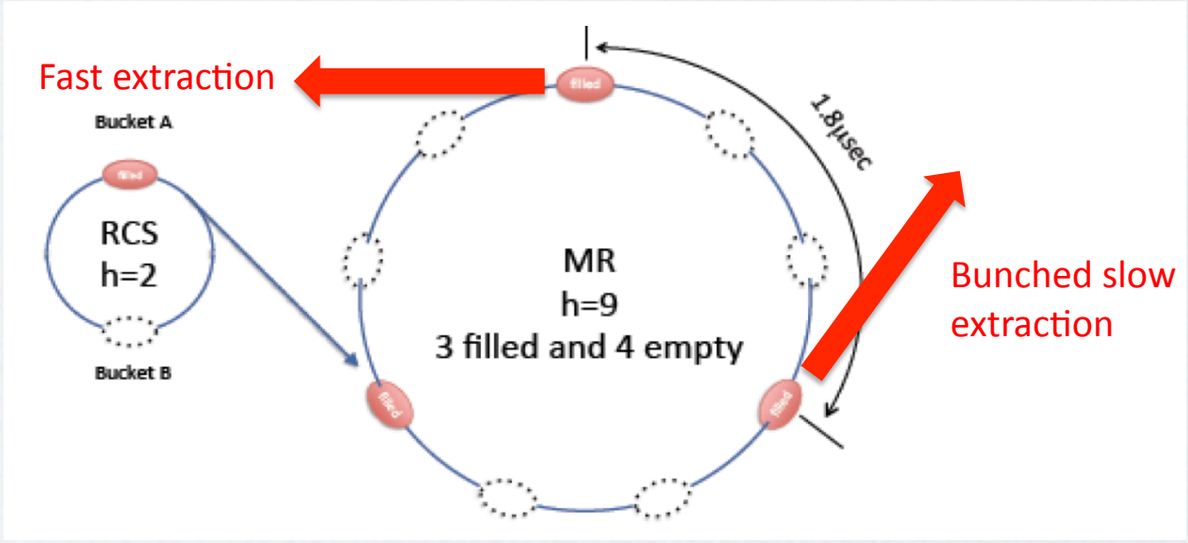


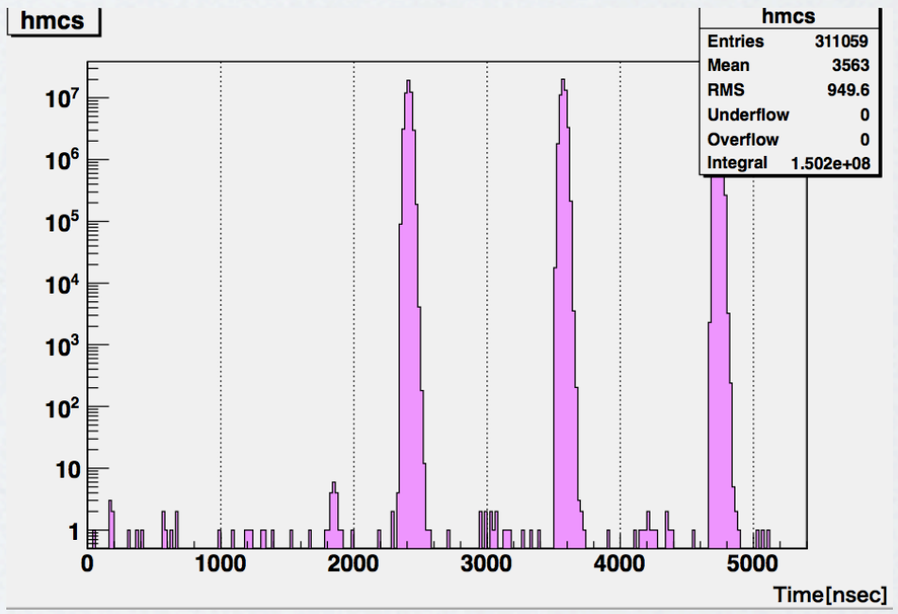
R. D'Arcy WG4 Monday

COMET R&D Status

proton beam

- Proton beam study (Extinction Measurement)
- Measurement at MR abort line (Fast Extraction) and Secondary beam line (Slow Extraction)
  - Both provided consistent result
  - Extinction: $(5.4 \pm 0.6)\times10^{-7}$
- Further improvement expected (O(10^{-6})) by double injection kicking
- External extinction device improves even more (O(10^{-3}))
  - US-Japan cooperative research program

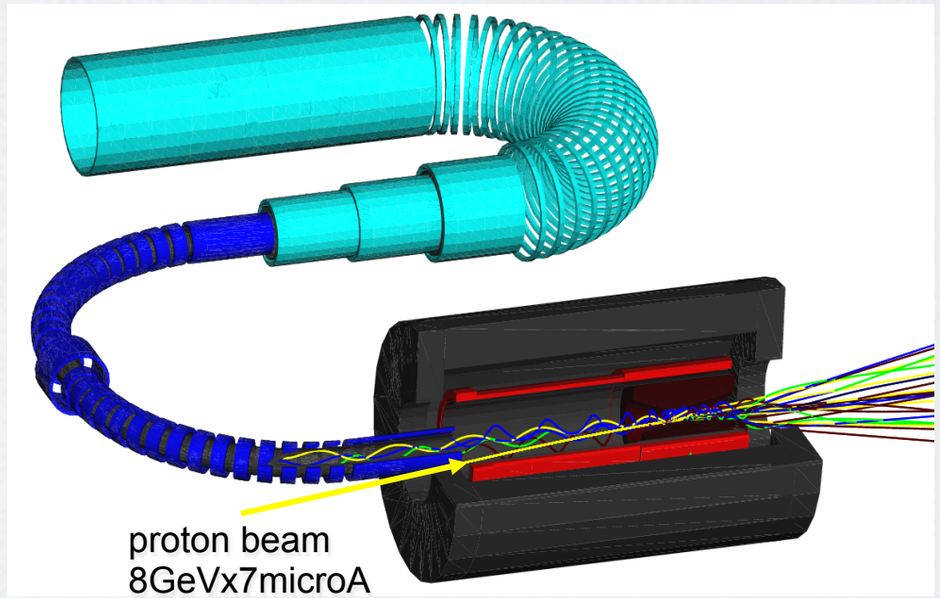


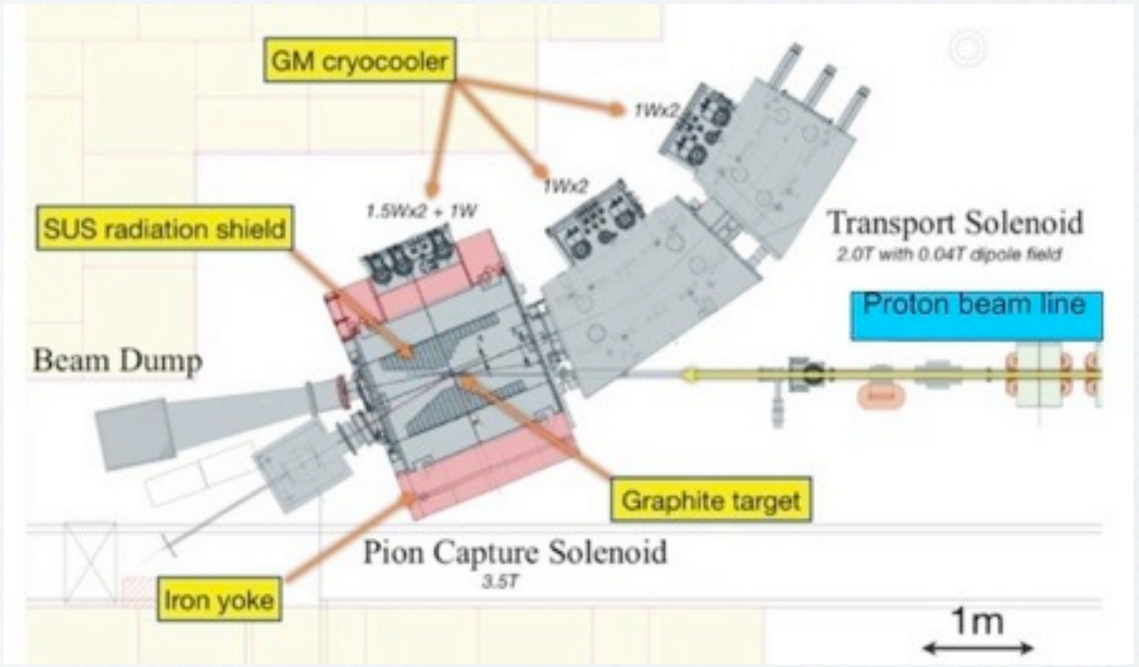


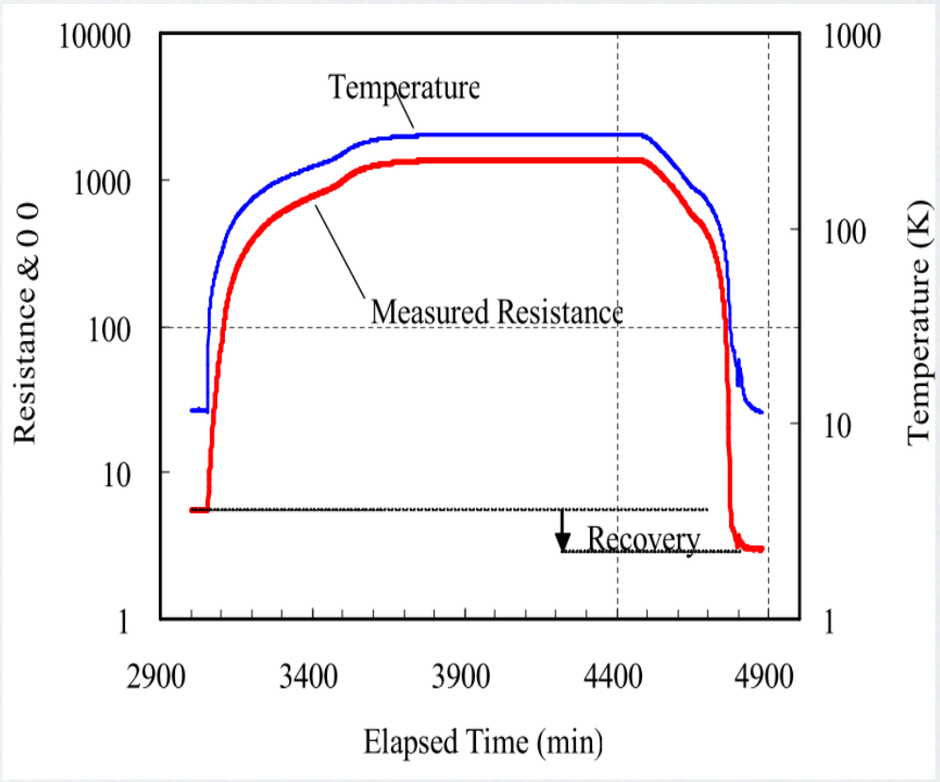
COMET R&D Status

pion capture solenoid

- Intensive studies of SC wire and solenoid magnet
- Irradiation test of SC wire at Kyoto Univ. research reactor
  - Deterioration after irradiation and recovery after thermal cycle confirmed

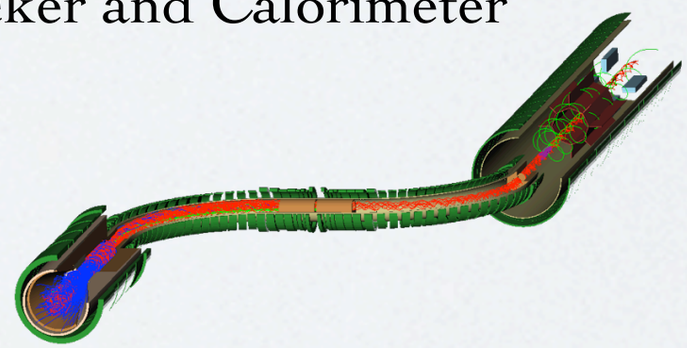
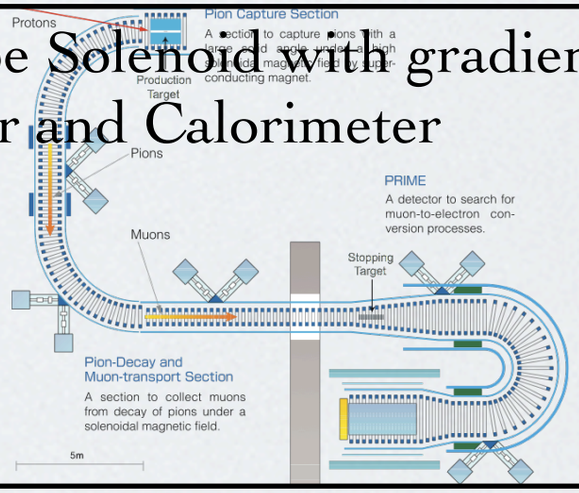






M. Yoshida WG3&4 Thursday
S. Cook WG3&4 Thursday

Comparison between Mu2e and COMET

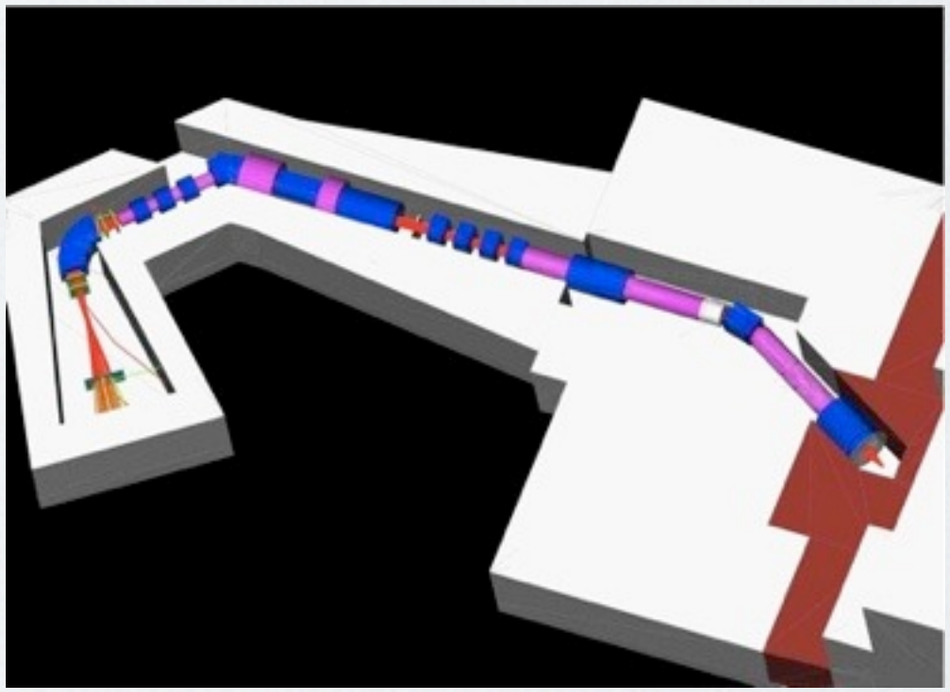
	Mu2e	COMET
Proton Beam	8GeV, 20kW bunch-bunch spacing 1.69 μsec rebunching Extinction: < 10^{-10}	8GeV, 50kW bunch-bunch spacing 1.18-1.76 μsec empty buckets Extinction: < 10^{-9}
Muon Transport	S-shape Solenoid	C-shape solenoid
Detector	Straight Solenoid with gradient field Tracker and Calorimeter 	C-shape Solenoid with gradient field Tracker and Calorimeter 
Sensitivity	SES: 2×10^{-17} 90% CL UL: 6×10^{-17}	SES: 2.6×10^{-17} 90% CL UL: 6×10^{-17}

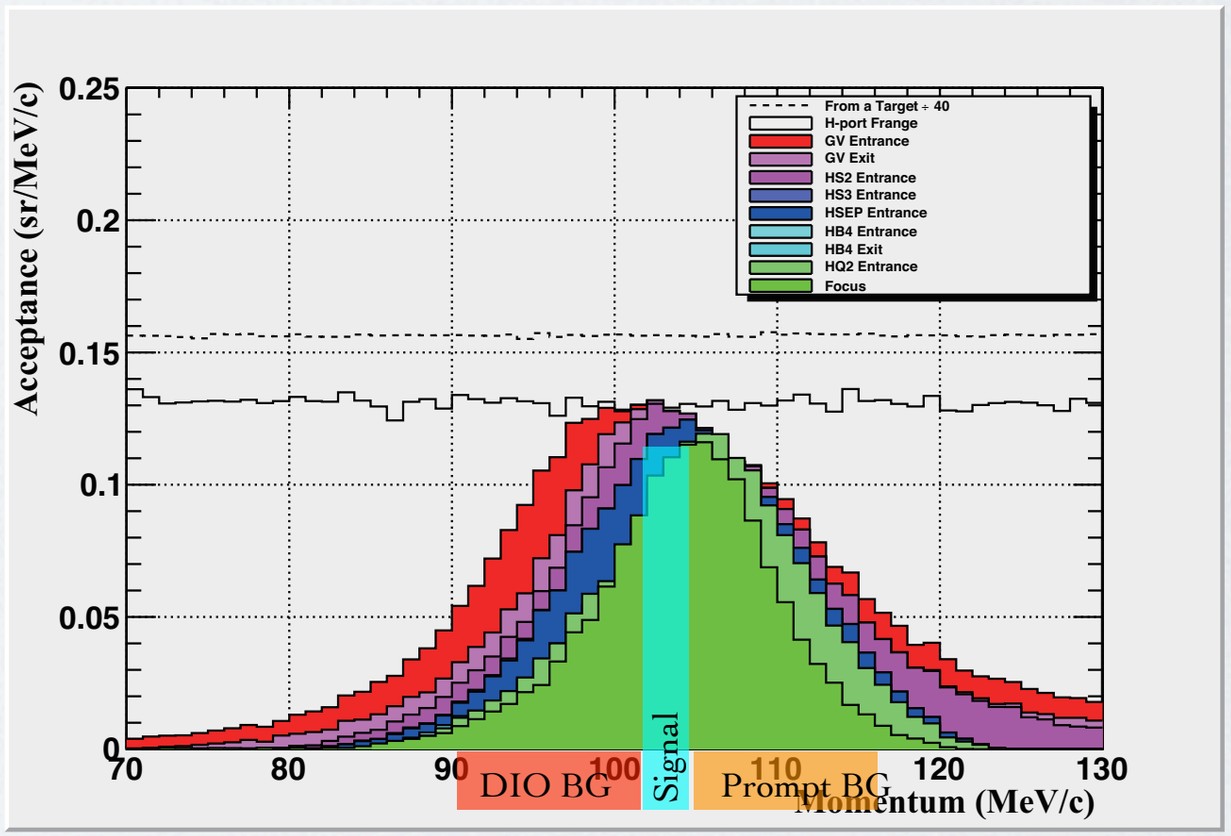
Other cLFV Experiments

- DeeMe
  - Another mu-e conversion search proposal at J-PARC
- μ⊥ eee search plan at PSI
- cLFV search using τ lepton at Belle/Belle II

DeeMe at J-PARC

- mu-e conversion search at J-PARC with a S.E.S. of 10^{-14}
- Primary proton beam from RCS
  - 3GeV, 1MW
  - Pion production target as a muon stopping target
  - Beam line as a spectrometer
    - Kicker magnets to remove prompt background
  - Multi-purpose beam line for DeeMe, HFS, g-2/EDM is under construction

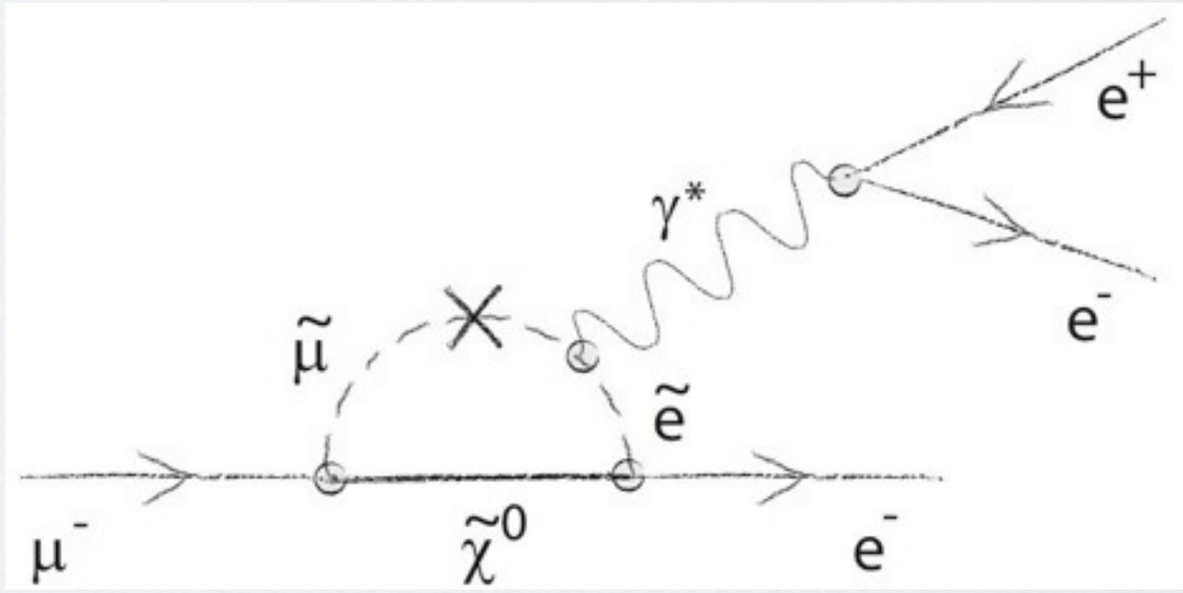


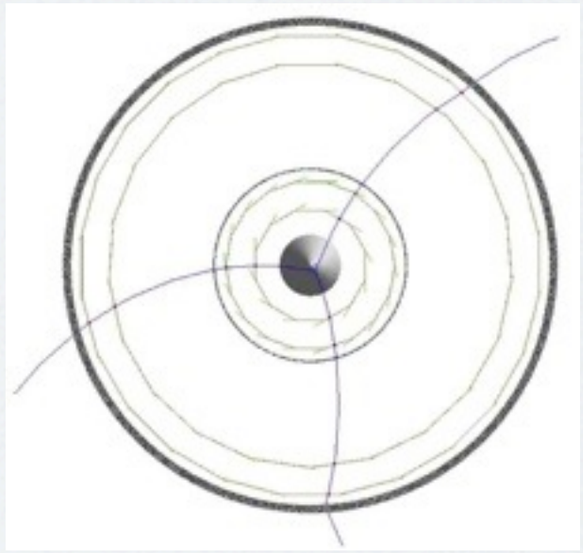


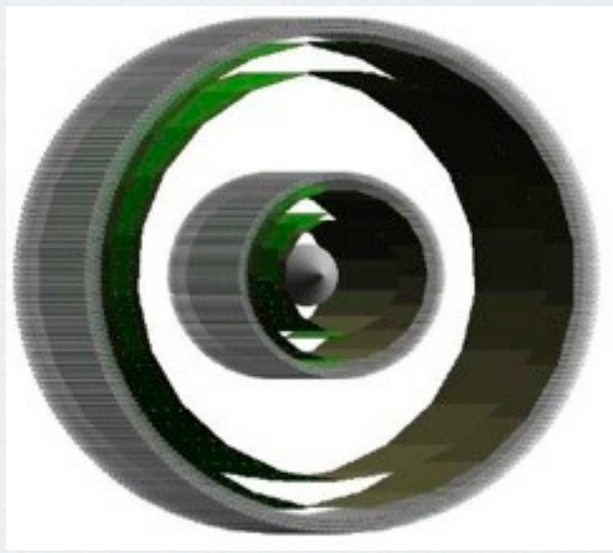
SM WG4 Tuesday

μ⊥ eee search

- Plan to search for μ⊥ eee using PSI muon beam
  - SINDRUM limit in 1988 1.0×10^{-12}
- Thin pixel silicon tracker and scintillating fiber timing counter
- LoI planned in 2011

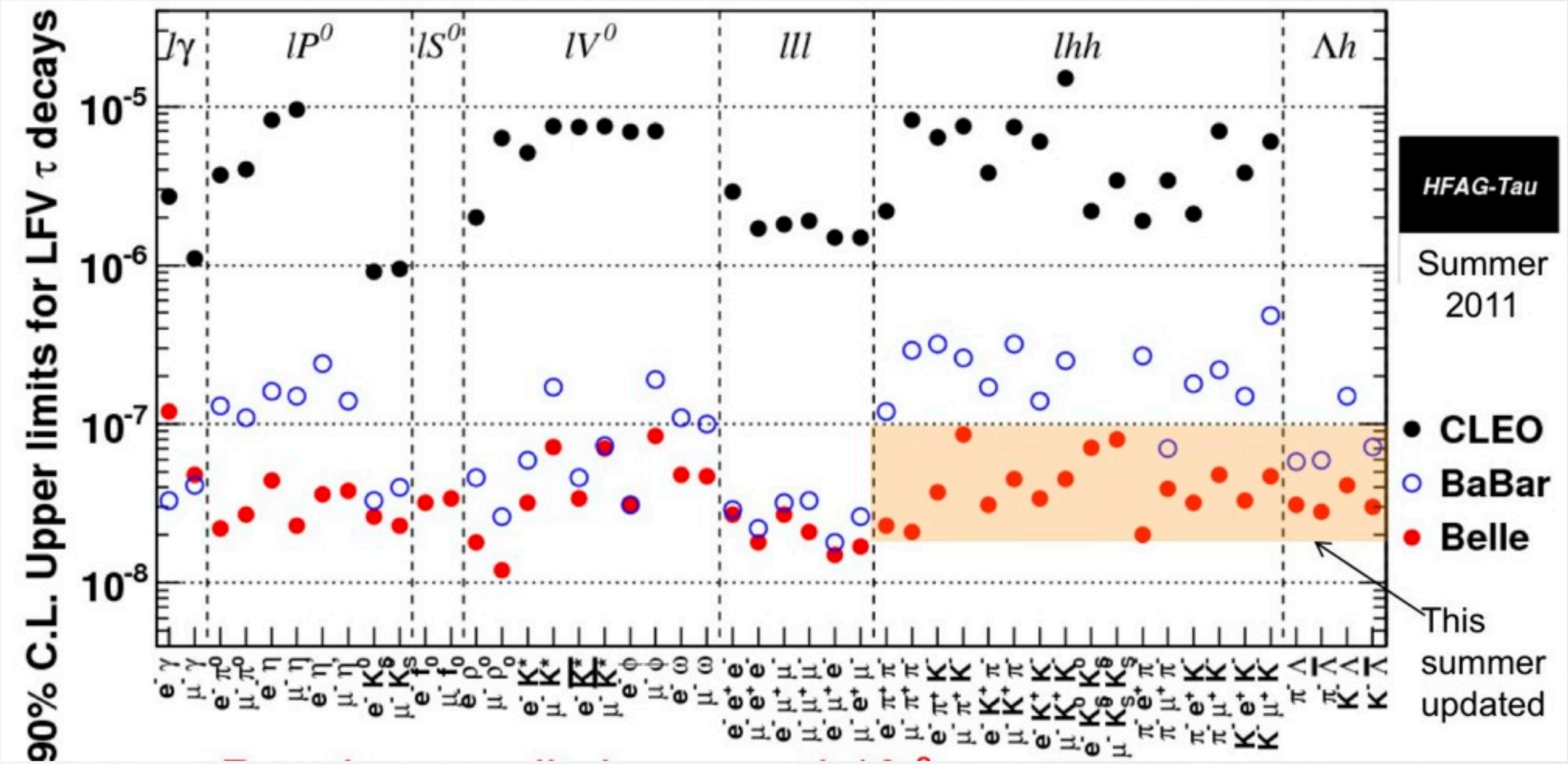






N. Berger WG4 Tuesday

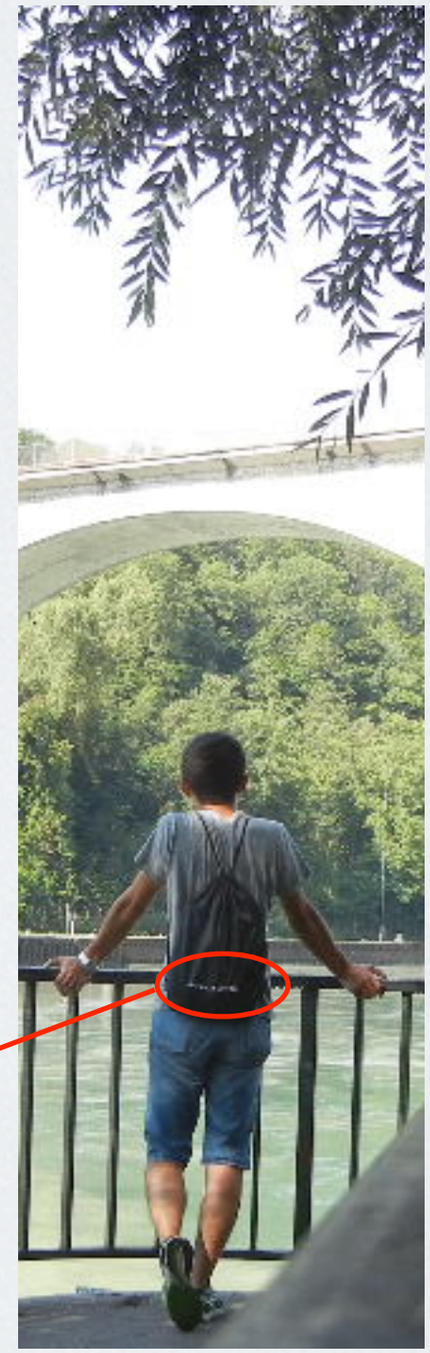
cLFV search using τ lepton



K. Hayasaka WG4 Tuesday

Summary

- cLFV search activities in the world
- MEG improved the limit of $\mu \rightarrow e\gamma$
  - 2.4×10^{-12} at 90% C.L.
  - Further improvement expected
- COMET, DeeMe and Mu2e
  - intensive R&D for realization of experiments
- τ LFV at Belle, $\mu \rightarrow eee$ at PSI



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