Charged Lepton Flavor Violation Experiments

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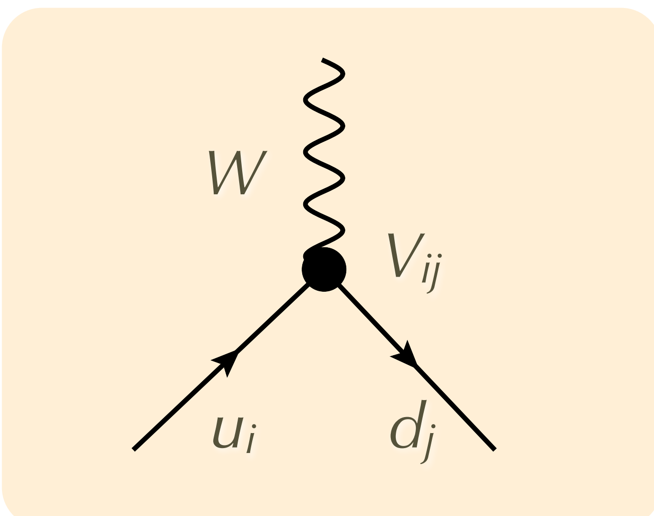
Outline

- (Charged) Lepton Flavour in the Standard Model
- Observables towards new physics
- The "classical searches"
  - $\mu \to e\gamma$
  - $\mu \to 3e$
  - $\mu N \to eN$
- Status and perspectives

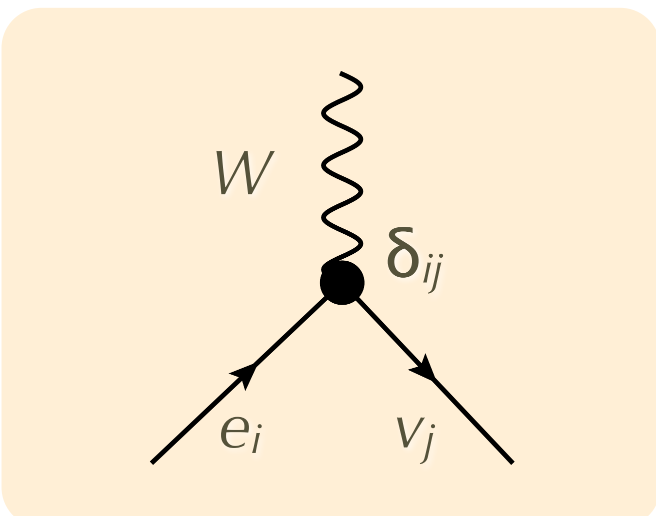
Flavor in the SM

- Unlike the quark sector, lepton flavor transitions are forbidden in the SM due to the vanishing neutrino masses
- Charged current interaction with the W field

$$J^\mu = \bar{d}'_L \gamma_\mu U^{d\,\dagger}_L U^u_L u'_L + \bar{e}'_L \gamma^\mu U^{e\,\dagger}_L \nu_L$$



V_{CKM}

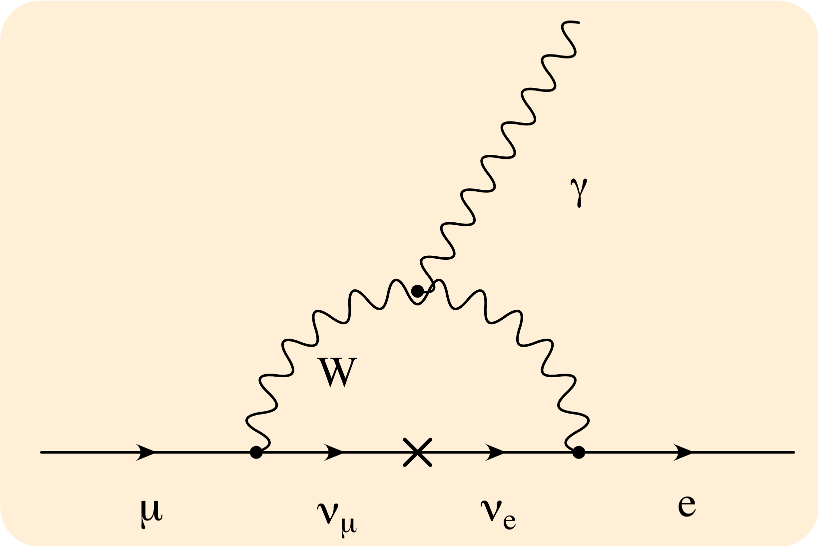


$\mathbb{1}$

- In the SM lepton flavor transition are forbidden
- Nevertheless neutrino oscillations were observed
  - Flavor transitions in the (neutral) lepton sector
  - νSM

charged Lepton Flavor Violation

- cLFV decays in the SM is radiatively induced by neutrino masses and mixings at a negligible level

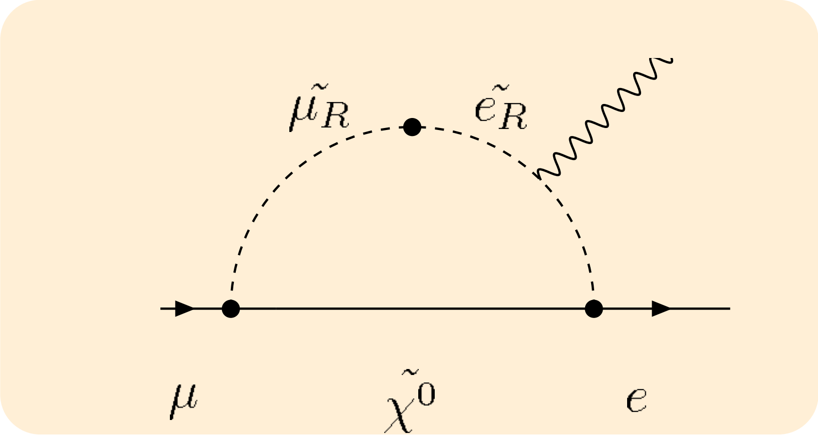


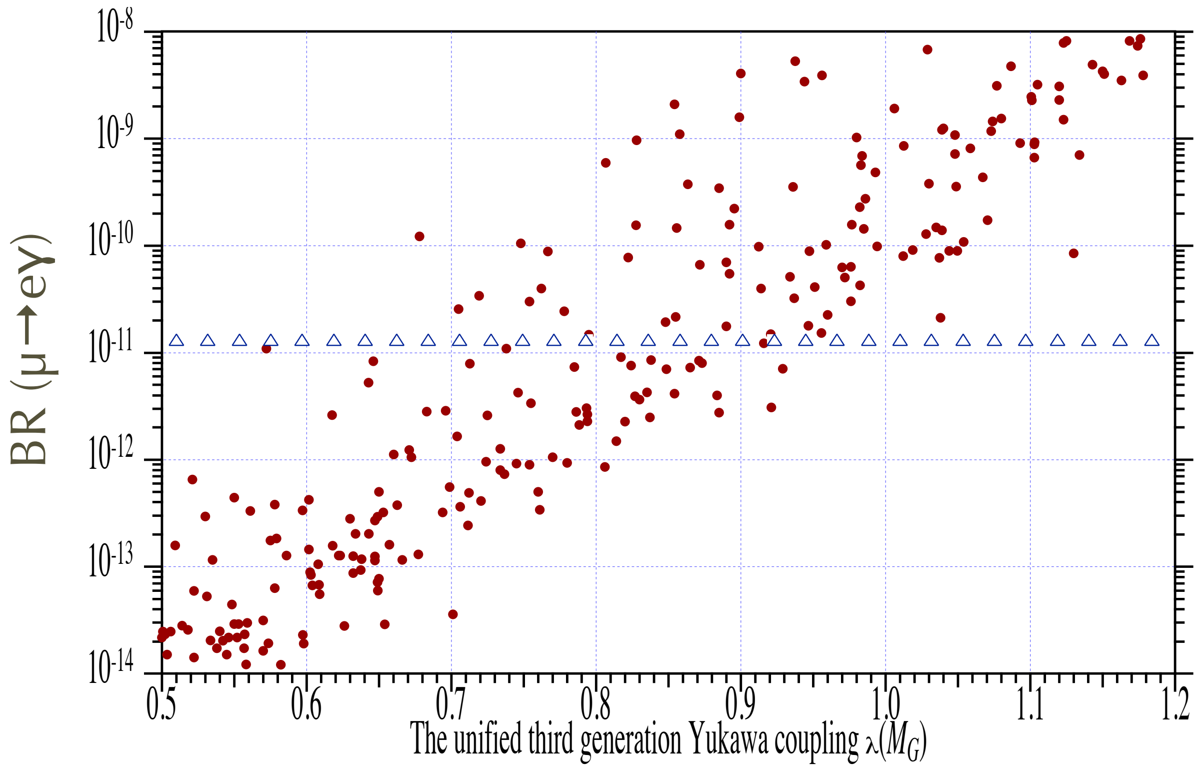
$$\Gamma(\mu \to e\gamma) \approx \underbrace{\frac{G_F^2 m_\mu^5}{192\pi^3}}_{\mu-\text{decay}} \underbrace{\left(\frac{\alpha}{2\pi}\right)}_{\gamma-\text{vertex}} \underbrace{\sin^2 2\theta \sin^2\left(\frac{1.27\Delta m^2}{M_W^2}\right)}_{\nu-\text{oscillation}}$$

$$\approx \frac{G_F^2 m_\mu^5}{192\pi^3} \frac{3\alpha}{32\pi} \left(\frac{\Delta m_{23}^2 s_{13} c_{13} s_{23}}{M_W^2}\right)^2$$

relative probability ~ 10^{-54}

- All SM extensions enhance the rate through mixing in the high energy sector of the theory (other particles in the loop...)



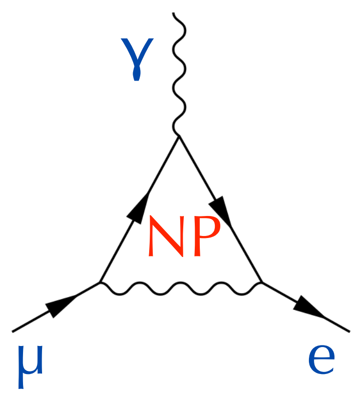


- Clear evidence for physics beyond the SM
  - background-free
- Restrict parameter space of SM extensions

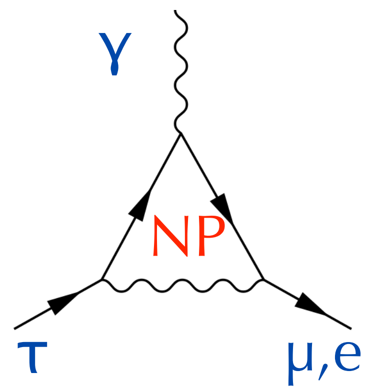
Many processes

- LFV is related to "new" lepton-lepton couplings and effective operators

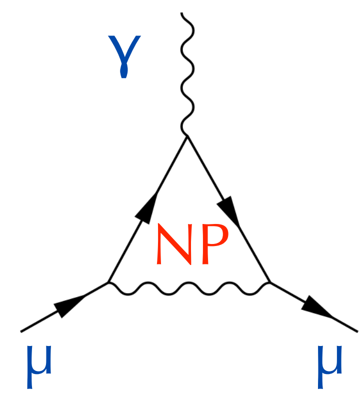
$$\frac{1}{\Lambda}\,\bar{\ell}_i\sigma_{\mu\nu}\ell_j F^{\mu\nu} \qquad\qquad \frac{1}{\Lambda^2}\,\bar{\ell}_i\gamma_\mu\ell_j(\bar{q}_k\gamma^\mu q_m + \bar{\ell}_k\gamma^\mu\ell_m)$$



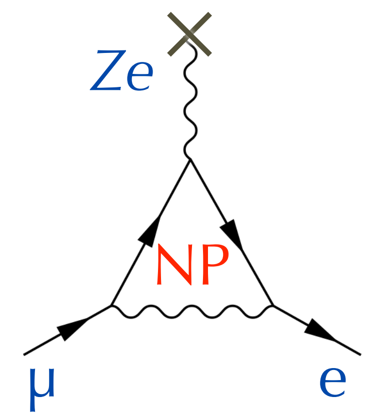
$\mu \to e\gamma$



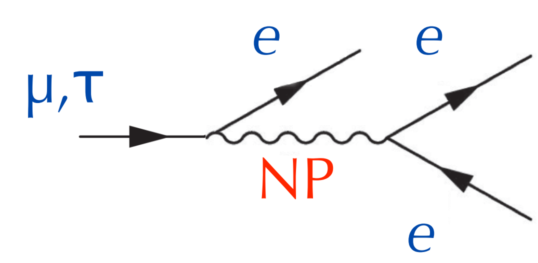
$\tau \to \mu\gamma$
$\tau \to e\gamma$



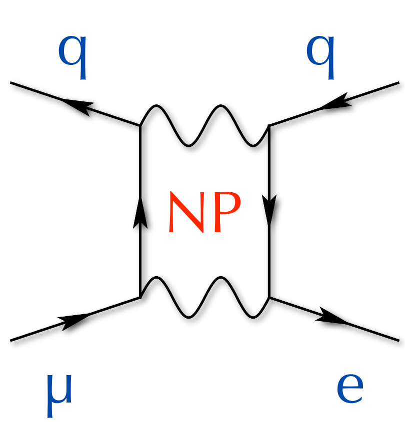
$(g-2)_\mu$

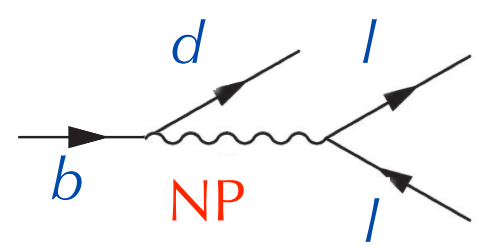


$\mu^-\mathcal{N} \to e^-\mathcal{N}$



$\mu \longrightarrow eee$



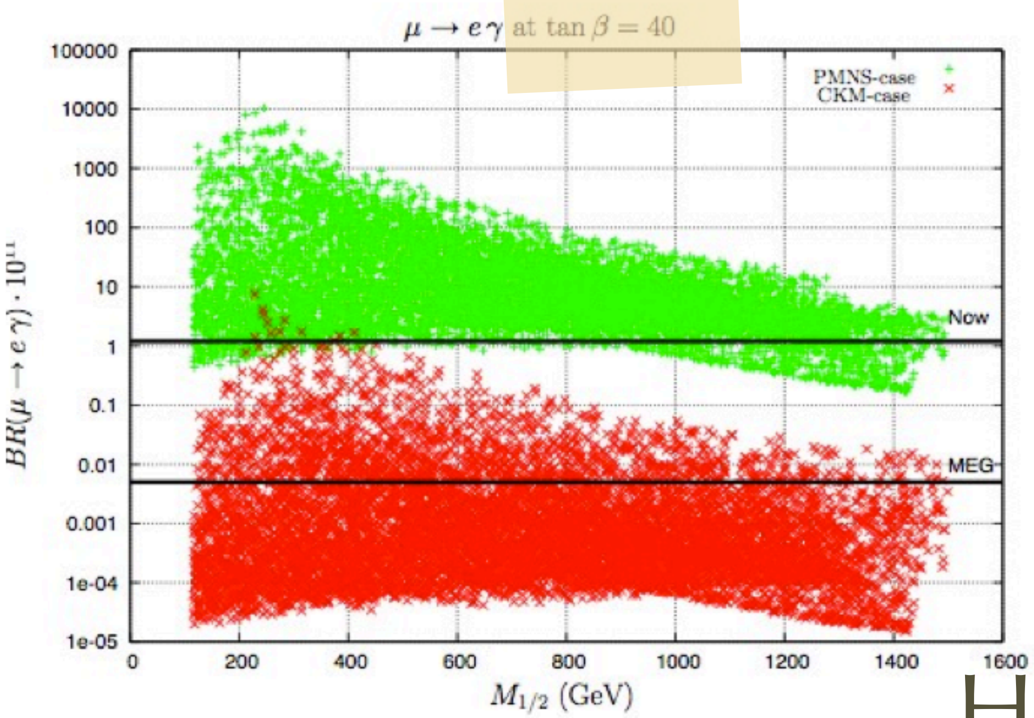


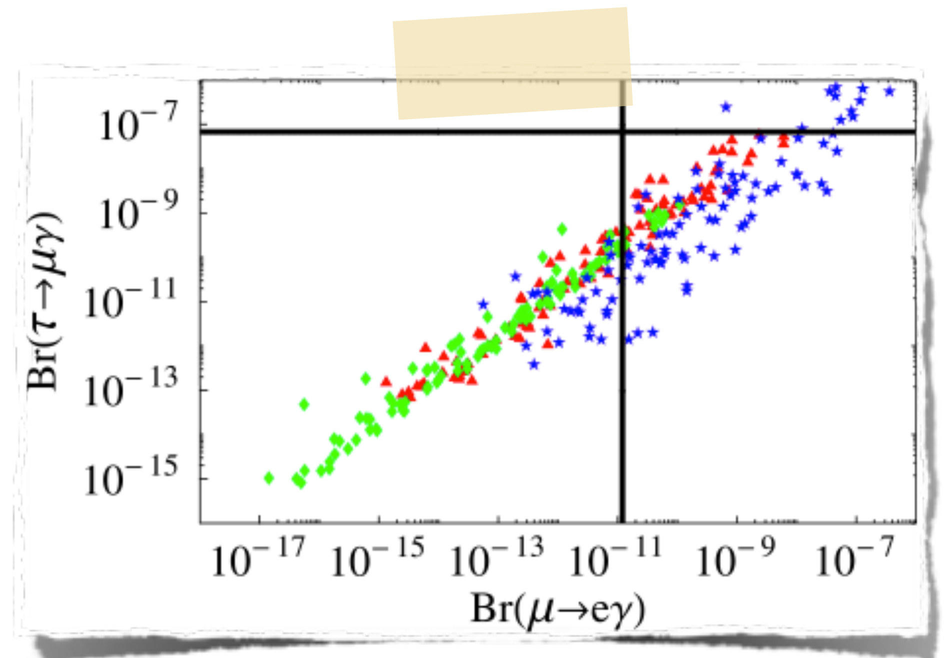
$B \to \ell\bar{\ell}'$
$B \to \ell\bar{\ell}' X_s$

- A wide field of research
  - LFV decays
  - Anomalous magnetic moment for the μ, τ
  - Muon-to-electron conversion
  - (LFV in B-meson decays)

Processes are correlated

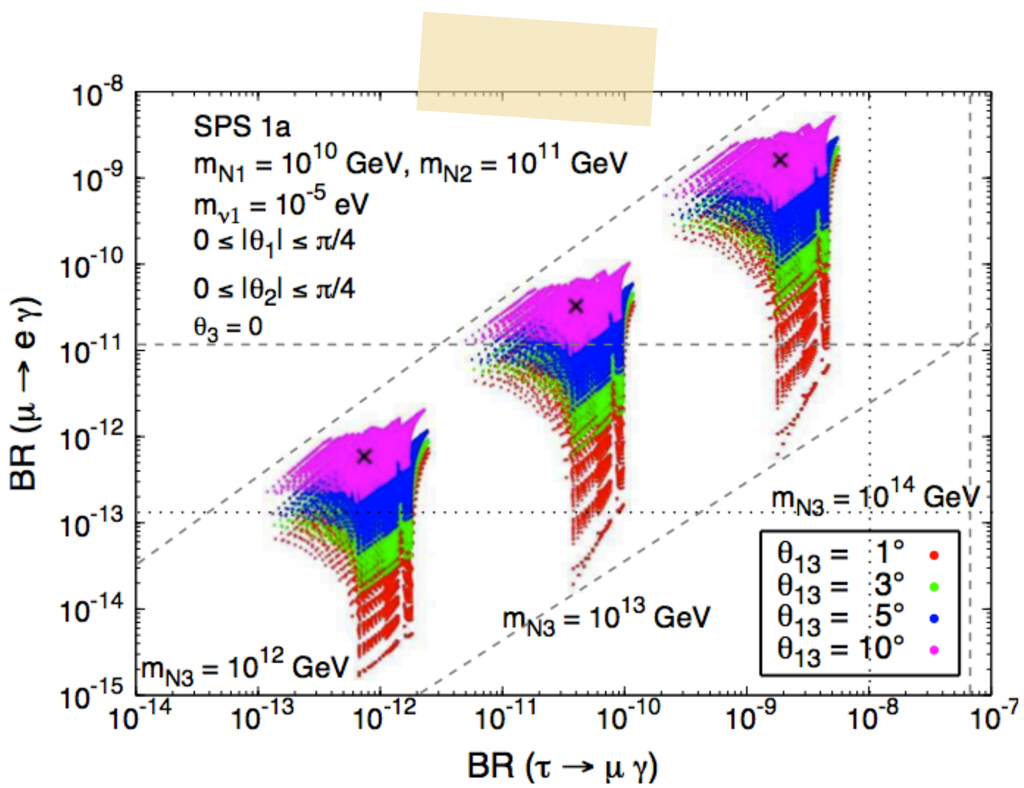
- Model-dependent correlations

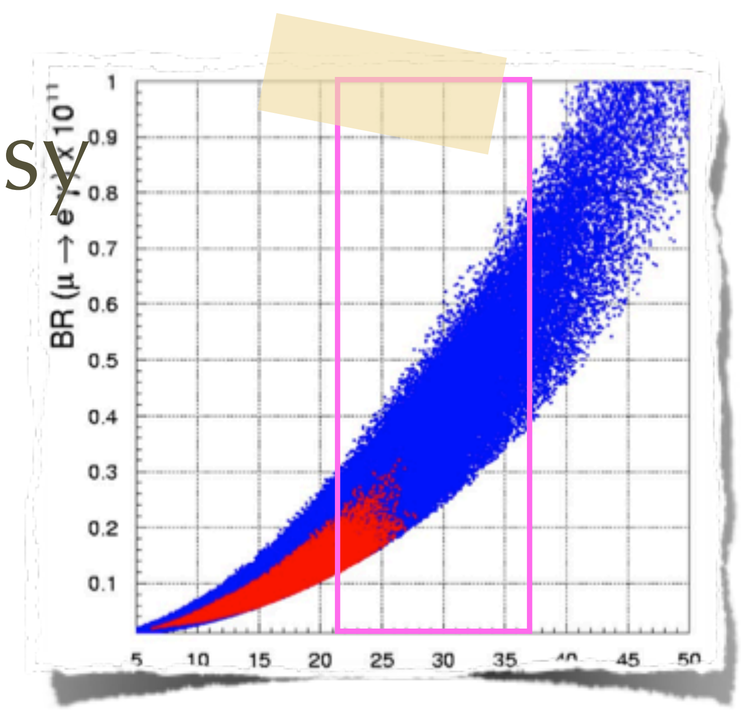




Large ϑ13

Higgs & No Susy





Barbieri *et al*,, Nucl. Phys B445 (1995) 225
Hisano *et al.*, Phys. Lett. B391 (1997) 341
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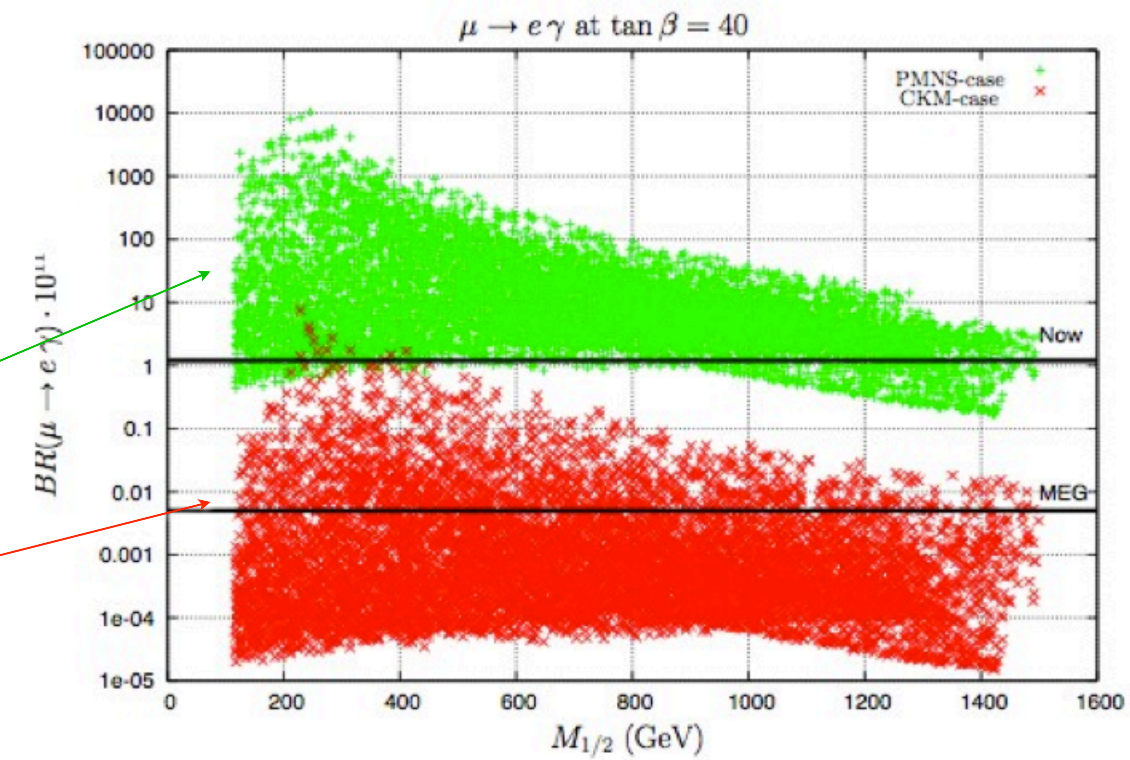
Calibbi *et al.*, Phys. Rev. D74 (2006) 116002
Isidori *et al.*, Phys. Rev. D75 (2007) 115019
...

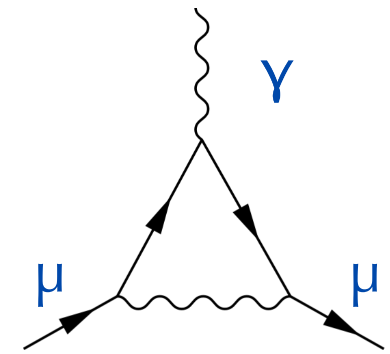
Connections

- Collider physics
  - it is Super Symmetry + Grand Unification that predicts new particles in the loop.
  - alternate search for $(E/M_{SUSY})^N$ suppressed effects

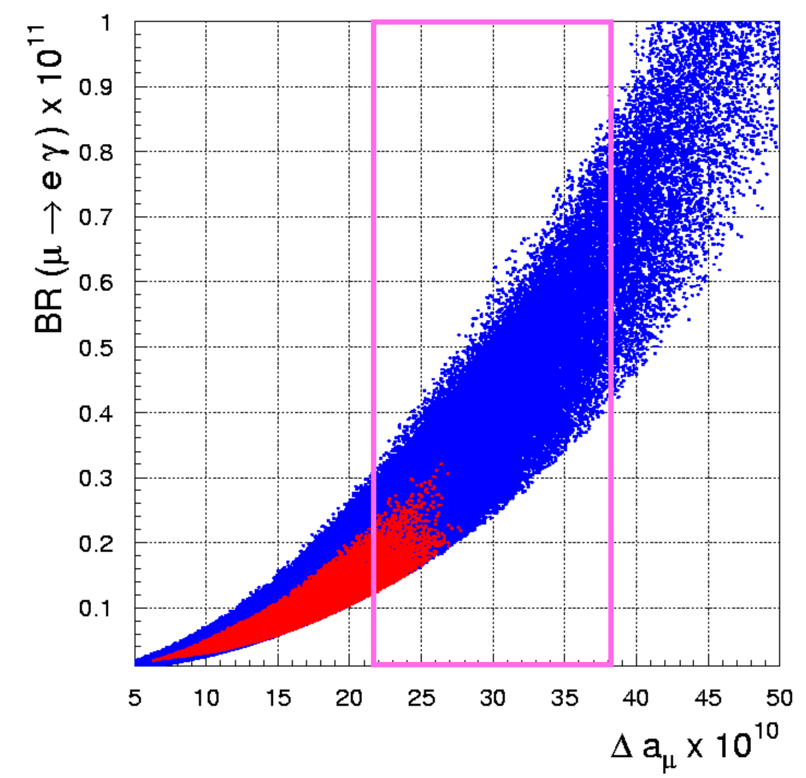


- neutrino oscillations
  - mixing matrix in charged sector can be proportional to
    - PMNS
    - CKM

- muon *g*–2
  - a_μ is the "diagonal" term
  - $\mu \to e\gamma$ diagram is the "off-diagonal"



- SUPER Flavor factory
  - Investigates LFV in the $\tau \to \mu, e\ \gamma$ decays



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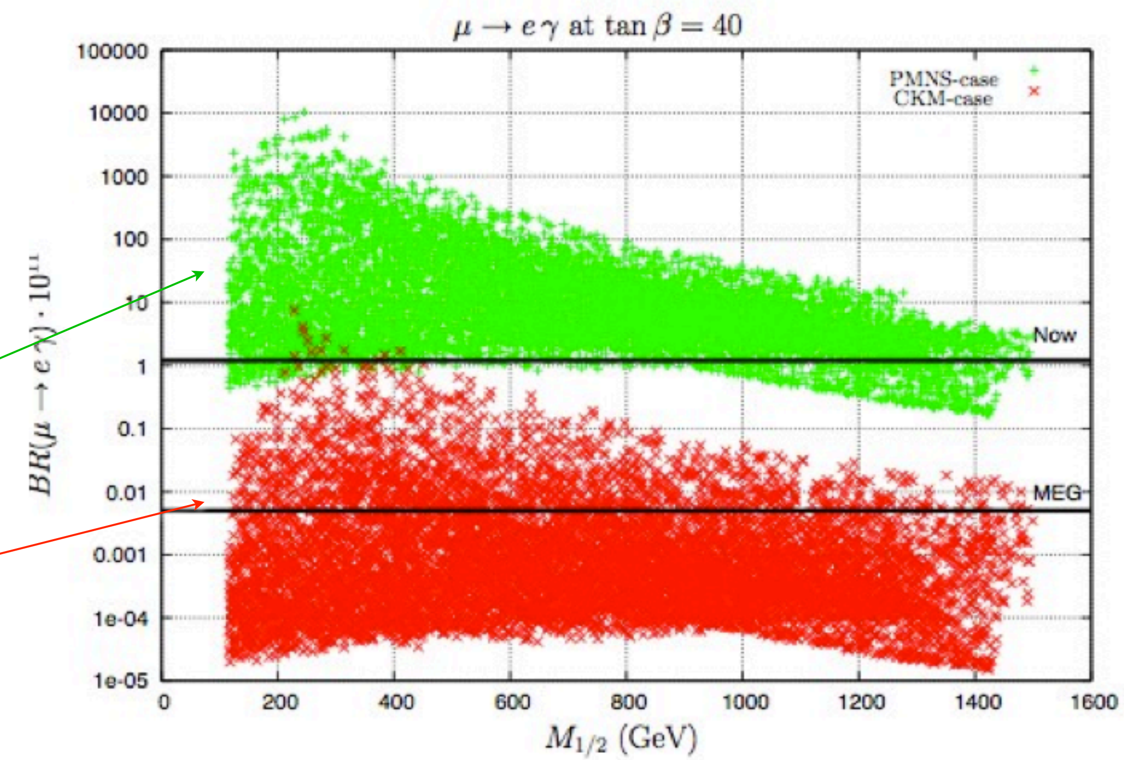

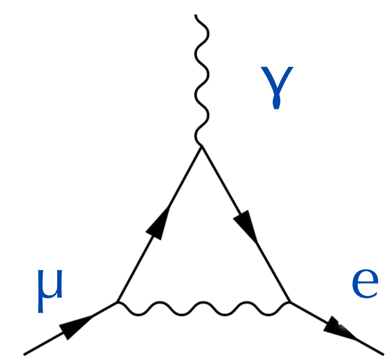

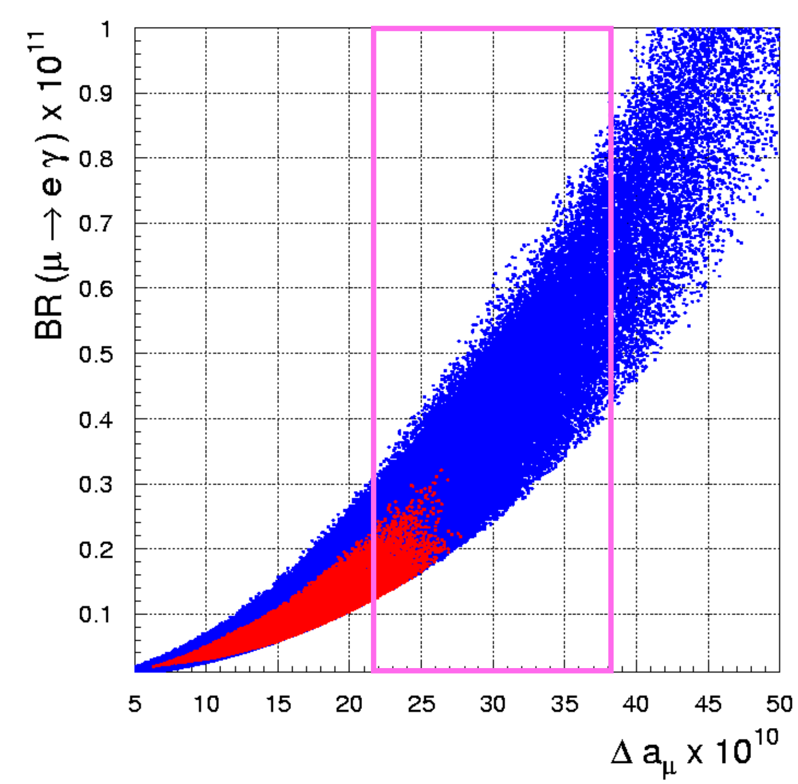

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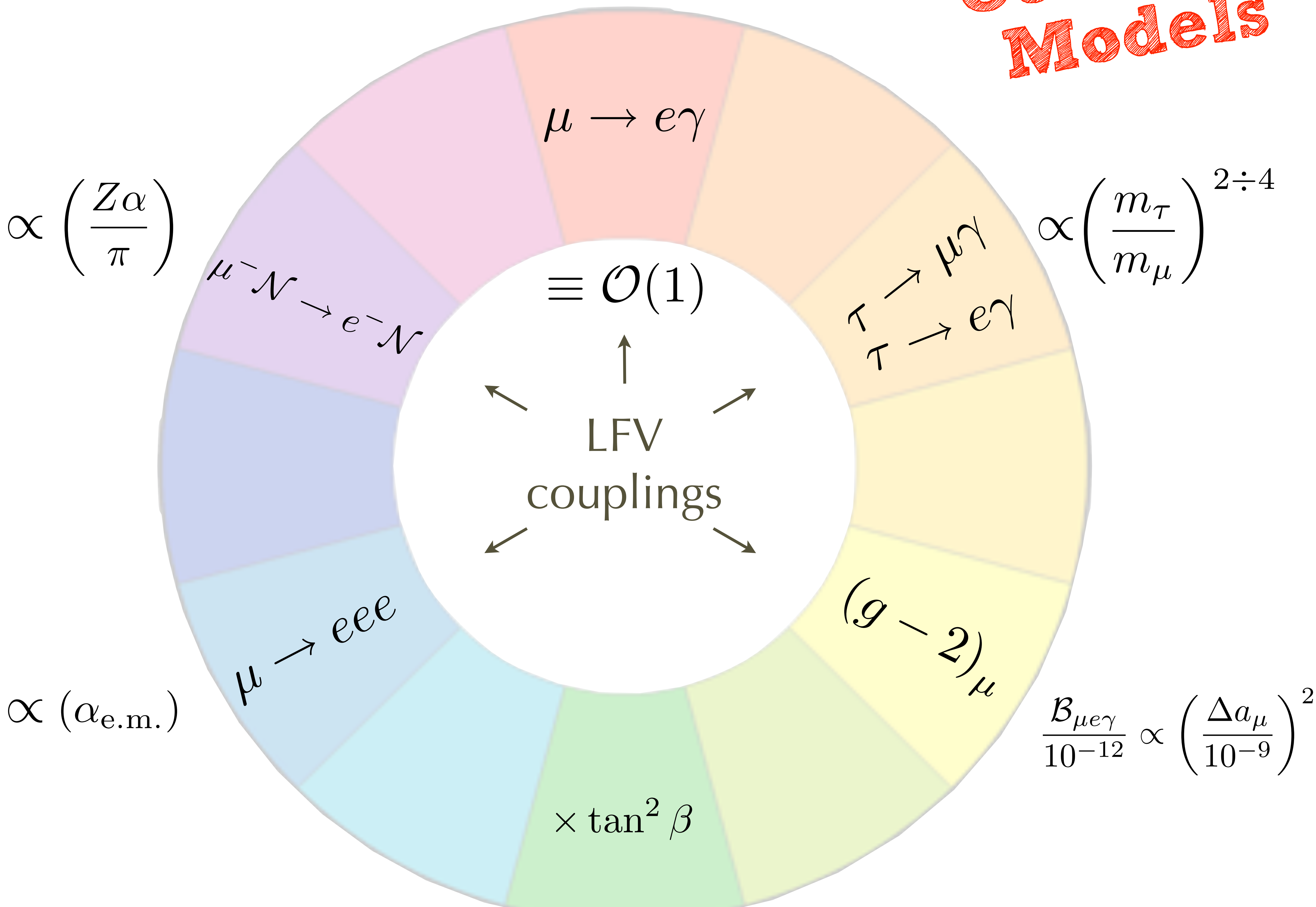
The CLFV wheel

Common Models



5.7×10^{-13}

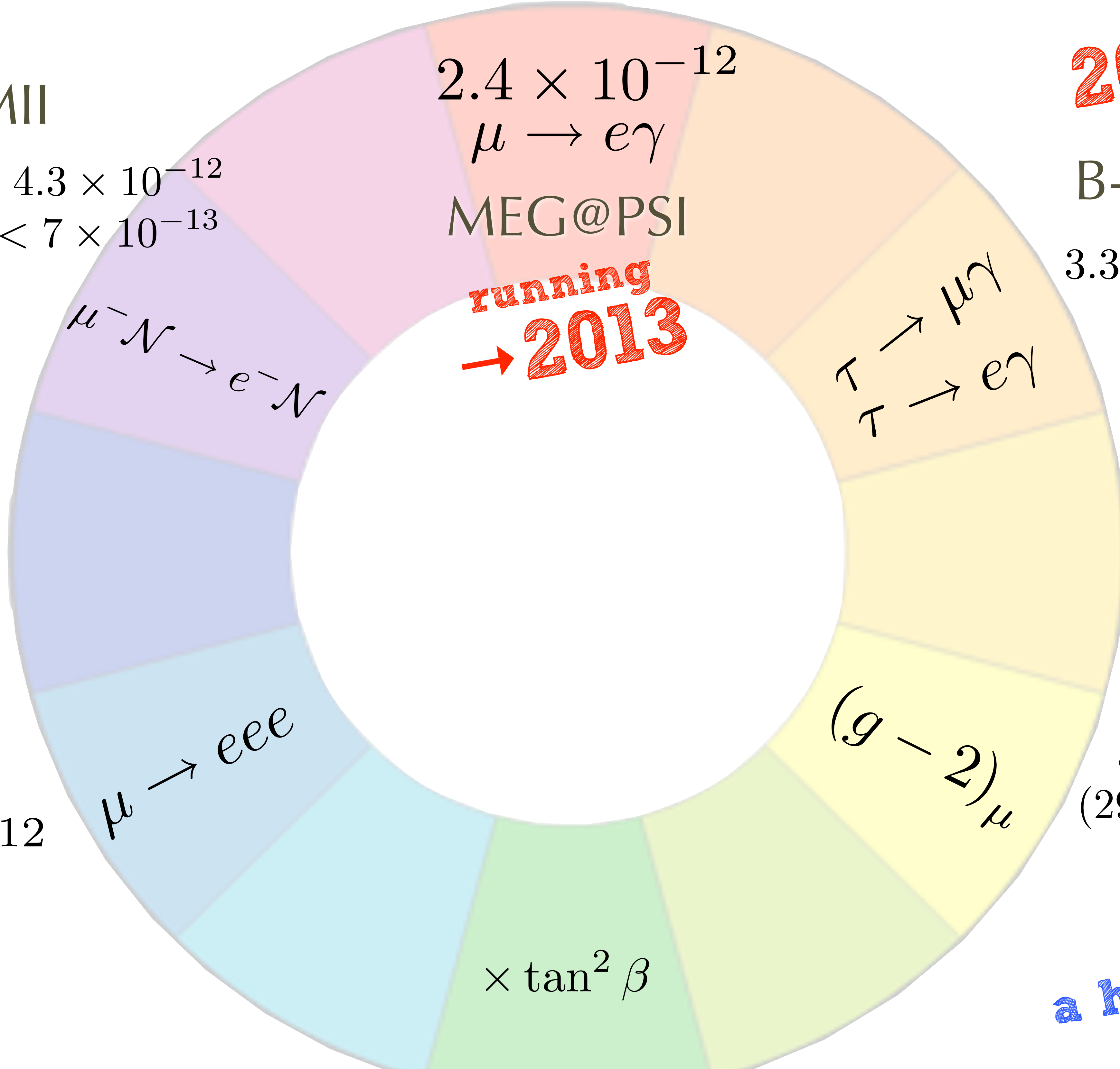
Present limits

SINDRUMII

$\mathcal{B}(\mu\text{Ti} \to e\text{Ti}) < 4.3 \times 10^{-12}$

$\mathcal{B}(\mu\text{Au} \to e\text{Au}) < 7 \times 10^{-13}$

2006



2010

B-factories

$3.3 \div 4.5 \times 10^{-8}$

SINDRUM

1×10^{-12}

1988

BNL E821

$a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (296 \pm 81) \times 10^{-11}$

2004

a hint for NP?

Experimental effort

	Dedicated experiment	Multi-purpose experiment
Exotic Searches New Physics if seen Experiment limited	$\mu \to e\gamma$ $\mu \to eee$ $\mu^- N \to e^- N$	$\tau \to \mu\gamma$ $\tau \to e\gamma$ $K_L^0 \to \mu e$ $Z' \to e\mu$ $\tau \to 3\ell$
BSM physics NP if deviations from SM Theory limited	e, μ, n edm $(g-2)_\mu$ $(g-2)_e$ $\frac{\pi^+(K^+) \to e^+\nu}{\pi^+(K^+) \to \mu^+\nu}$ $K_L^0 \to \pi^0\nu\nu$	$B \to \mu\mu$ $b \to s\gamma$ $\frac{\tau \to e\nu\nu}{\tau \to \mu\nu\nu}$ $K^+ \to \pi^+\nu\nu$

Experimental effort

	Dedicated experiment	Multi-purpose experiment
Exotic Searches New Physics if seen Experiment limited	$\mu \to e\gamma$ $\mu \to eee$ $\mu^- N \to e^- N$	$\tau \to \mu\gamma$ $\tau \to e\gamma$ $K_L^0 \to \mu e$ $Z' \to e\mu$ $\tau \to 3\ell$
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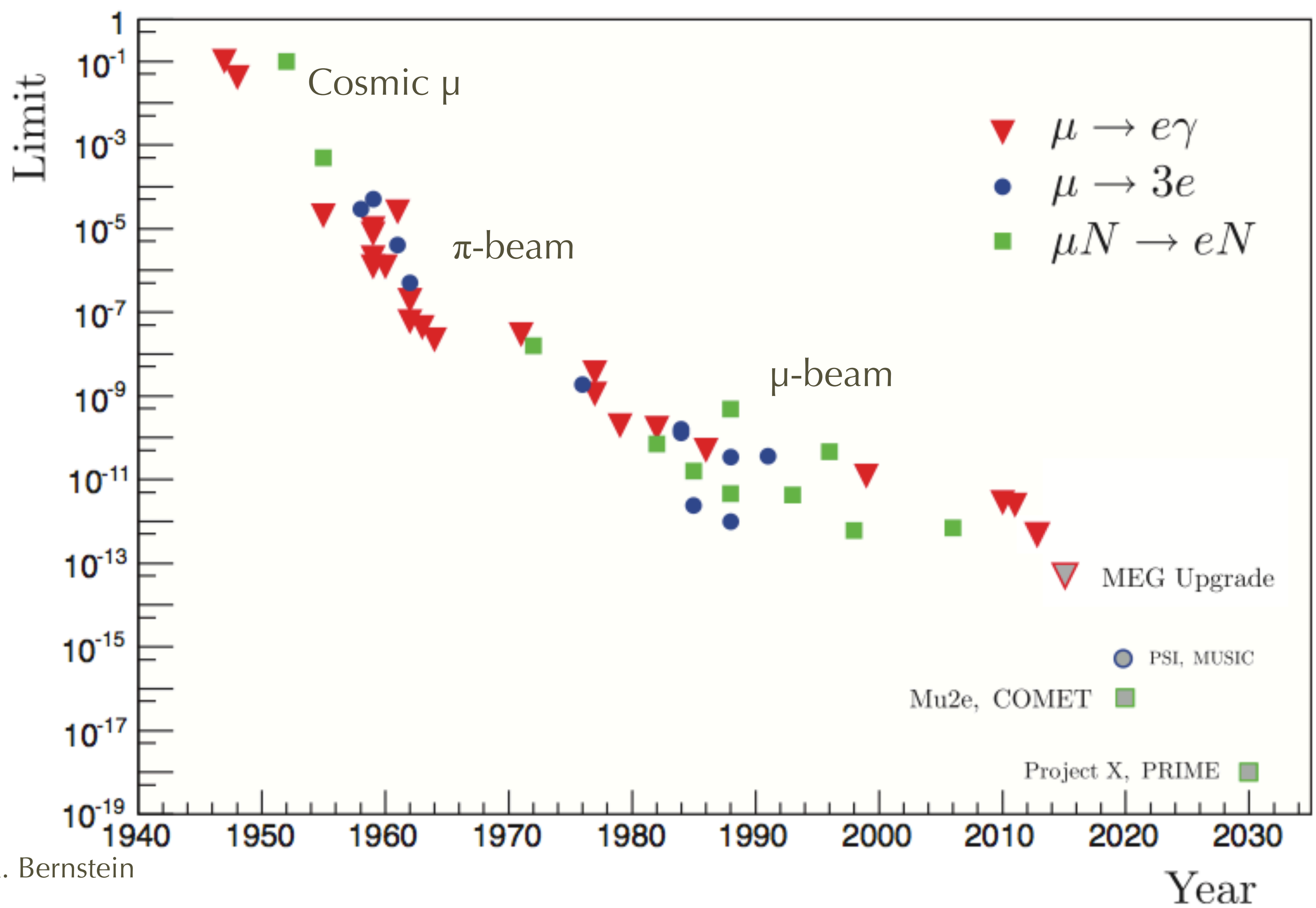
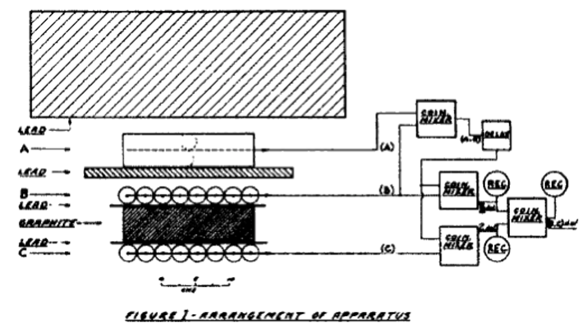
I will concentrate on the "classical" searches

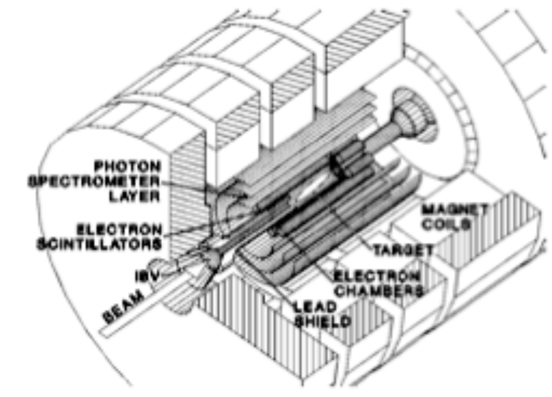
65 years of searches



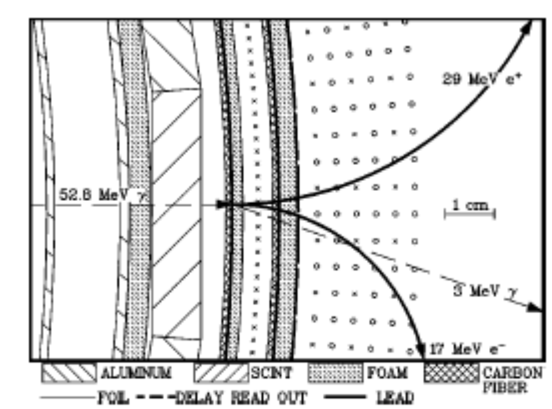
R. Bernstein

Hinks & Pontecorvo





MEGA

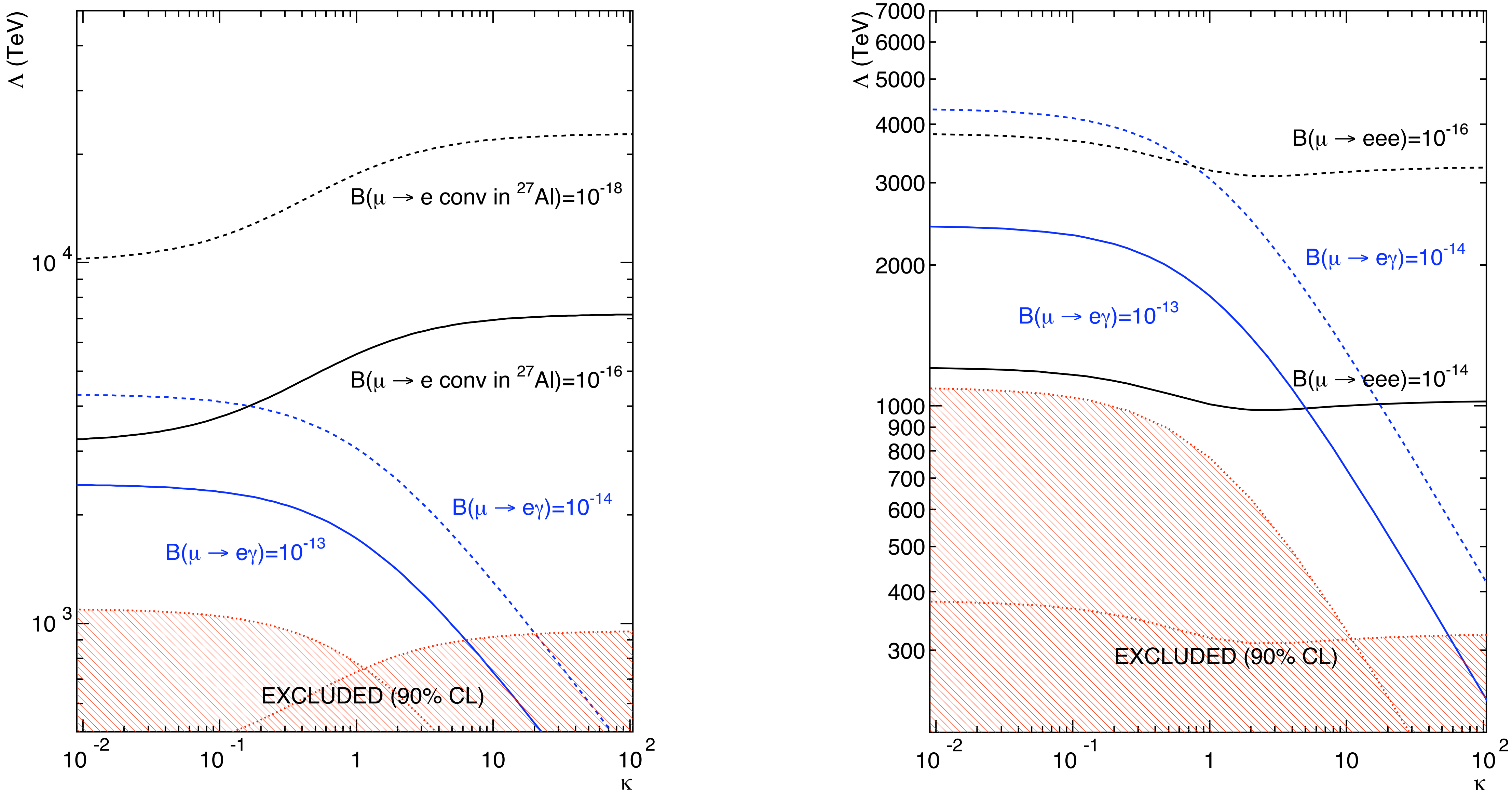


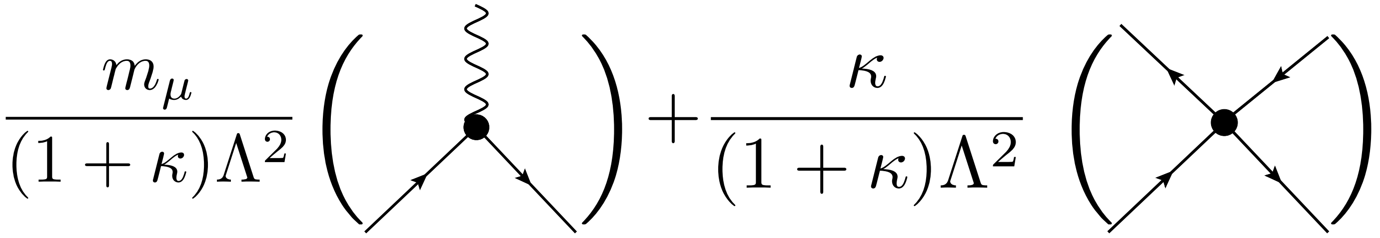
- Each improvement linked to beam and detector technology
- Trade-off between sub-detectors to achieve the best "sensitivity"

Complementarity

- Capability of different measurements to discriminate between models

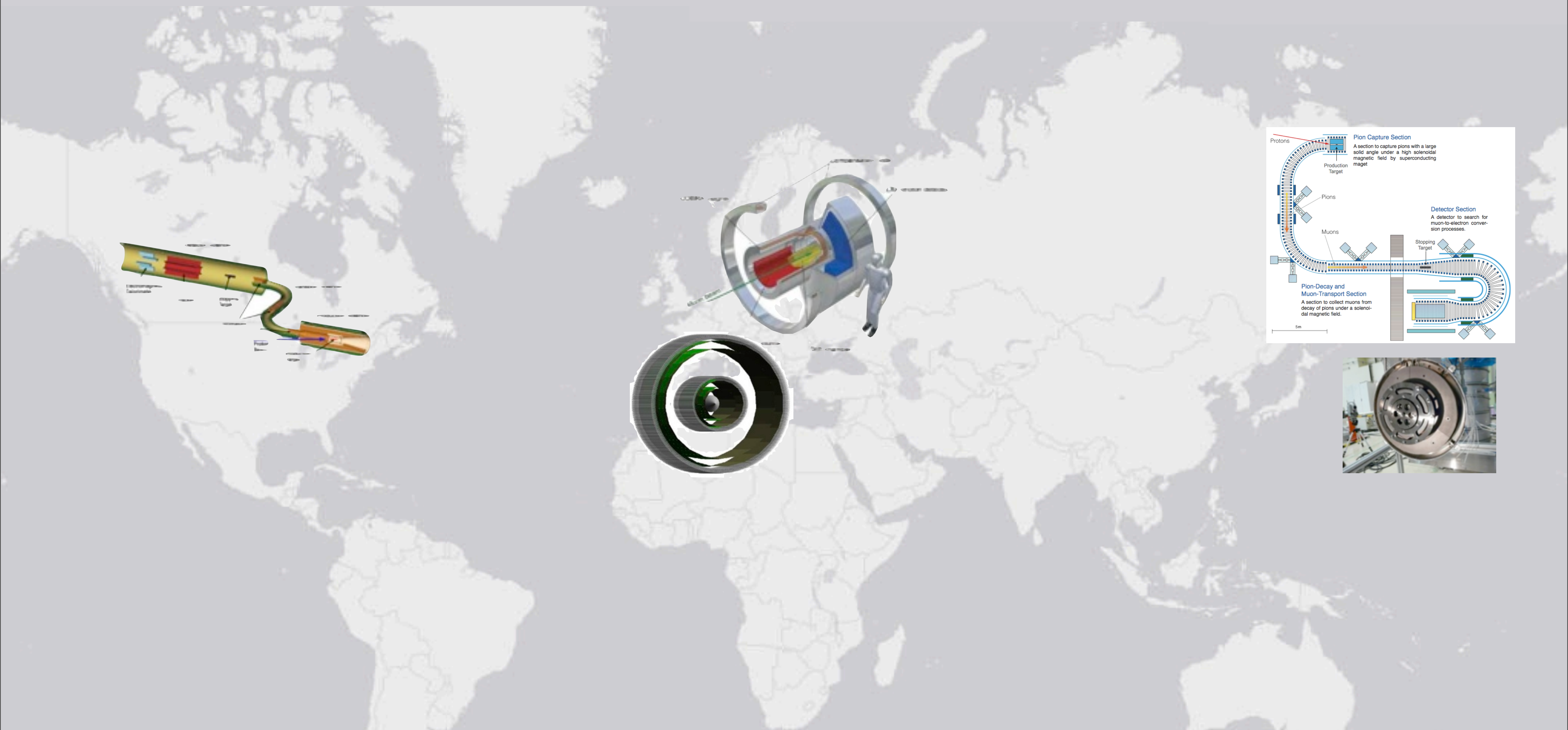
de Gouvea and Vogel, 2013





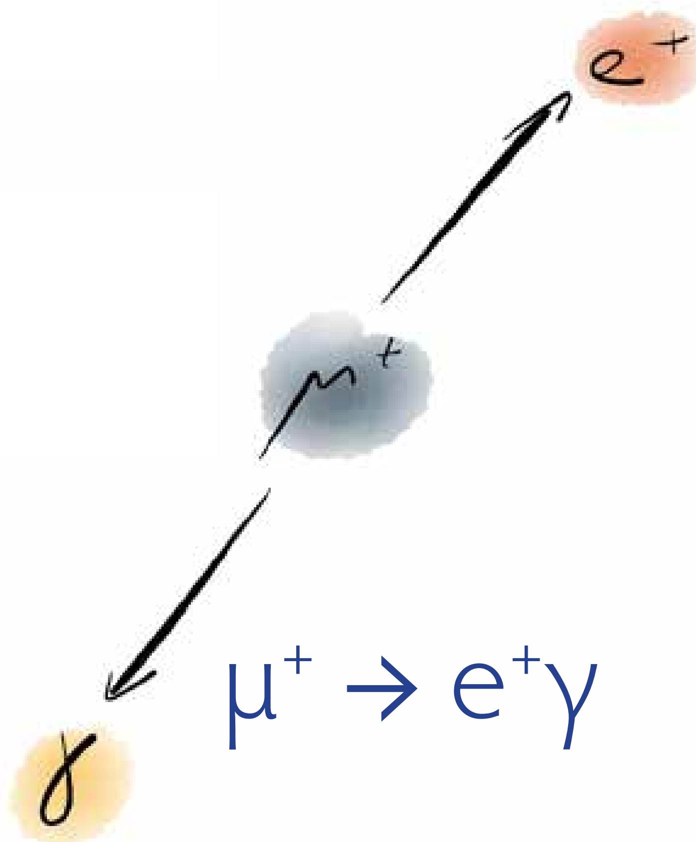
"Classical" searches

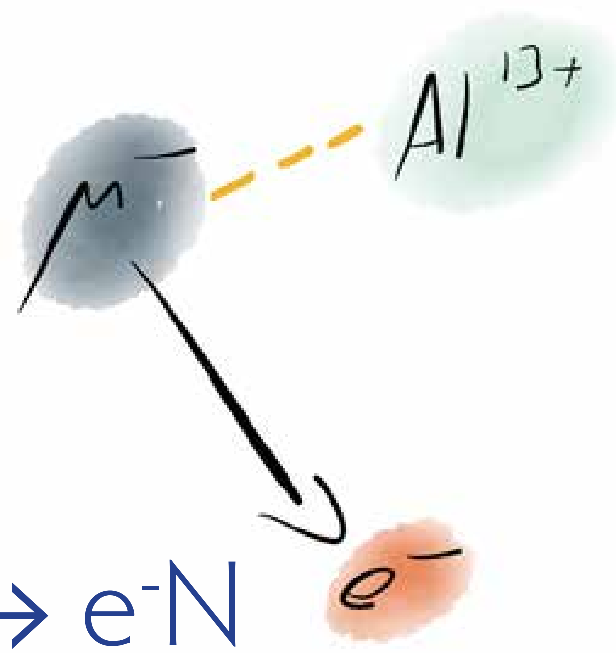
- Widespread in the world

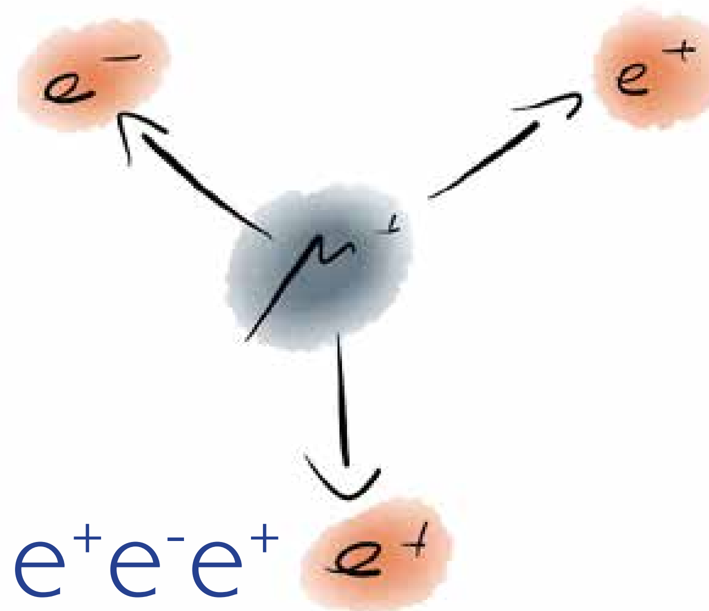


- MEG
- Mu3e
- Mu2e - Deeme - Comet Phase I - II

Kinematics







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

Kinematics

- 2-body decay
- Monoenergetic e^+, γ
- Back-to-back

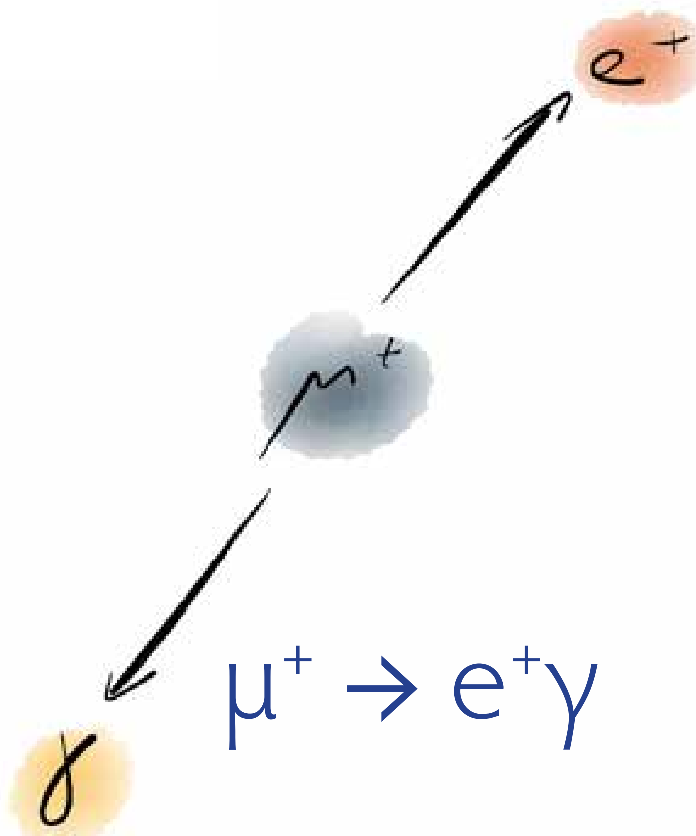
Kinematics

- Quasi 2-body decay
- Monoenergetic e^-
- Single particle detected

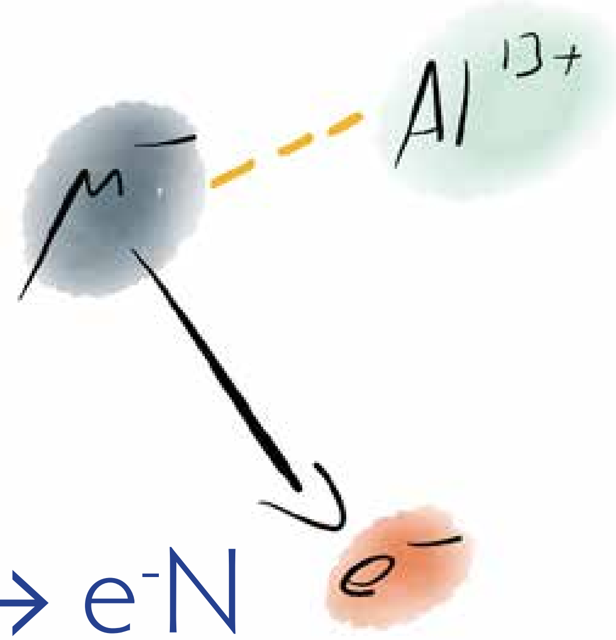
Kinematics

- 3-body decay
- Invariant mass constraint
- $\sum p_i = 0$

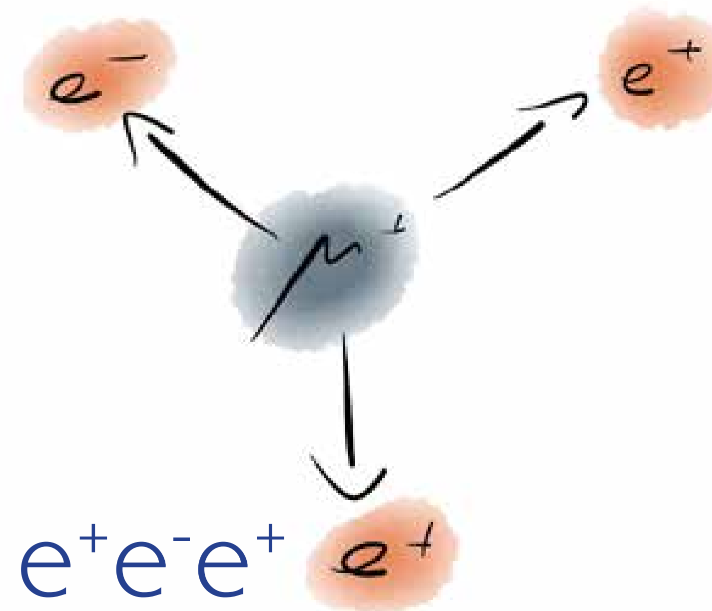
Background



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



$\mu^-N \rightarrow e^-N$



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

Kinematics

- 2-body decay
- Monoenergetic e^+, γ
- Back-to-back

Background

- Accidental background

Kinematics

- Quasi 2-body decay
- Monoenergetic e^-
- Single particle detected

Background

- Decay in orbit
- Antiprotons, pions

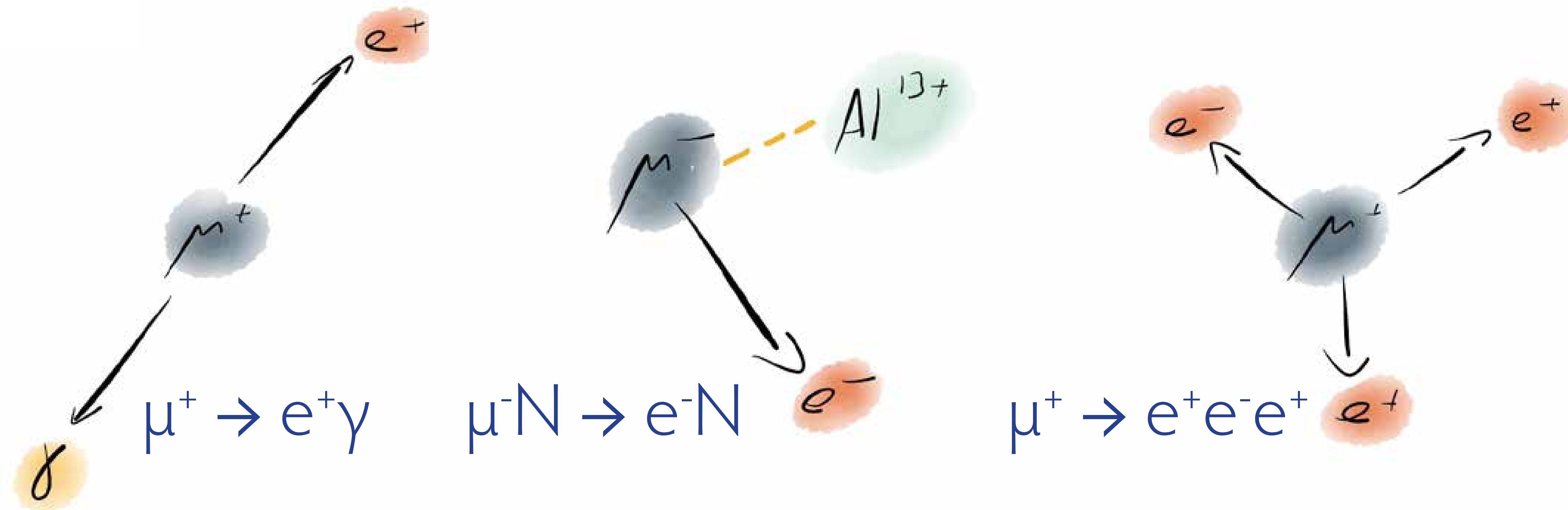
Kinematics

- 3-body decay
- Invariant mass constraint
- $\Sigma p_i = 0$

Background

- Radiative decay
- Accidental background

Beam requirements



$\mu^+ \to e^+\gamma$ $\mu^- N \to e^- N$ $\mu^+ \to e^+e^-e^+$

Continuous Beam

Kinematics

- 2-body decay
- Monoenerge
- Back-to-b

Backgro

- A al background

Pulsed Beam

Kinematics

- Quasi 2-body d
- Monoenerge
- Single pa etected

Backgro

- D orbit
- Ar protons, pions

Continuous Beam

Kinematics

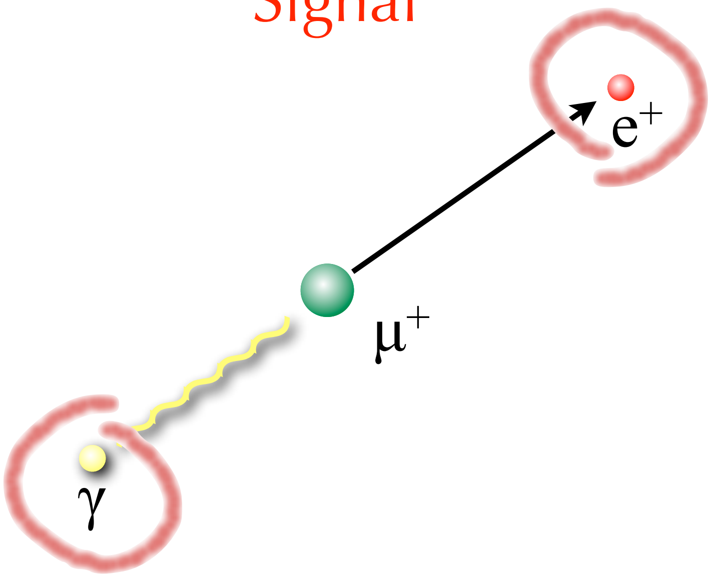
- 3-body decay
- Invariant mas aint
- $\Sigma p_i = 0$

Backgro

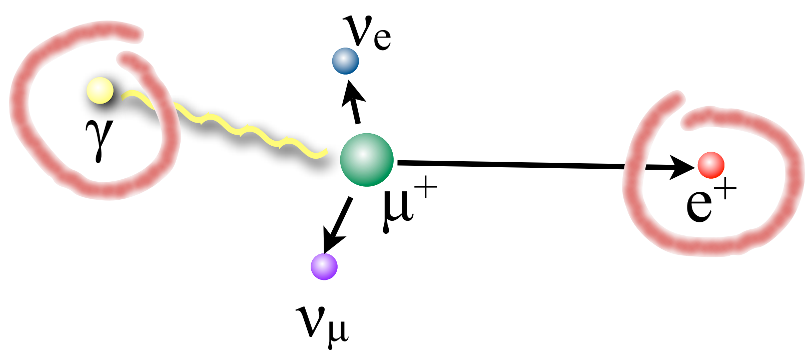
- R decay
- Ac dental background

μ→eγ signal and background

"Signal"

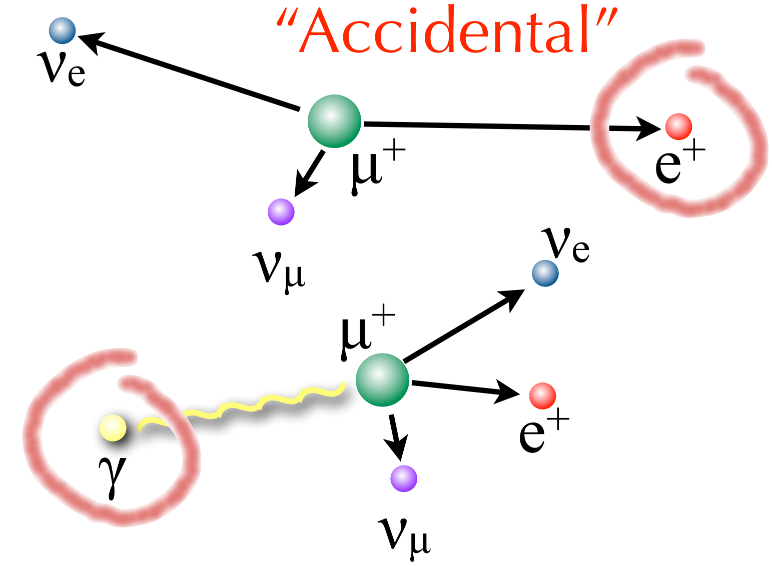


"RMD"



$\mu \to e\bar{\nu}\nu\gamma$

"Accidental"



$\mu \to e\bar{\nu}\nu\gamma$

$e\mathcal{N} \to e\mathcal{N}\gamma$

$e^+e^- \to \gamma\gamma$

$\mu \to e\bar{\nu}\nu$

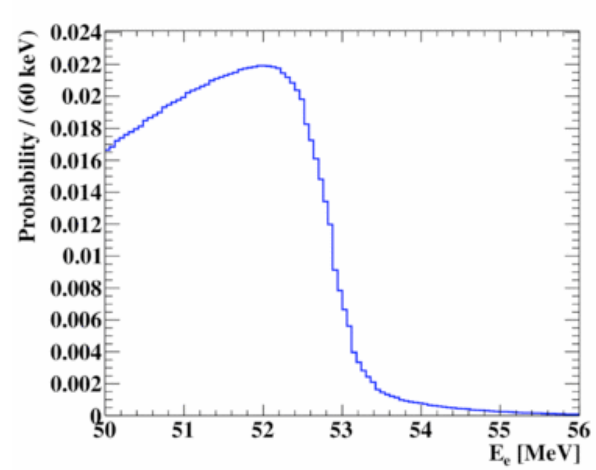
Ee = Eγ = 52.8 MeV

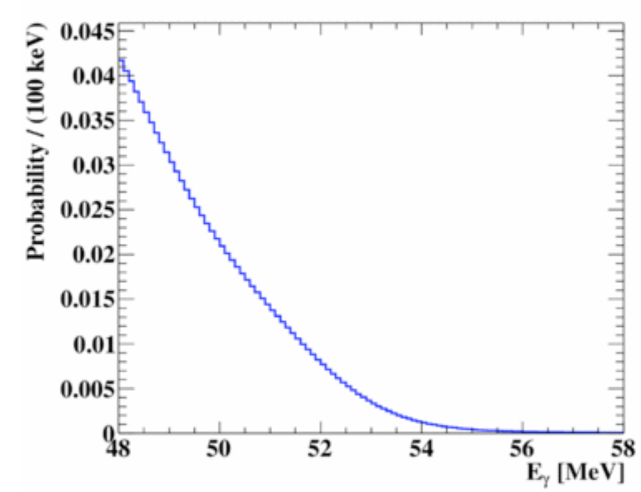
$\theta_{e\gamma}$ = 180°

$t_{e\gamma} \sim 0$

$$B_{\rm prompt} \approx 0.1 \times B_{\rm acc}$$

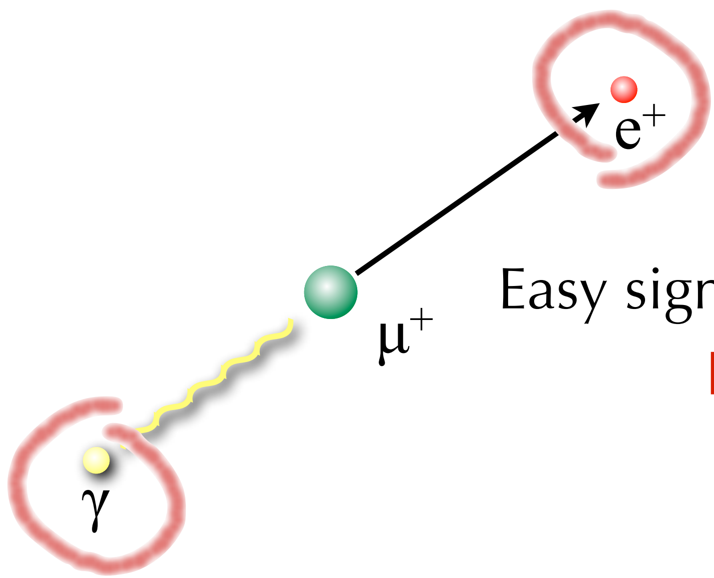
$$B_{\rm acc} \approx R_\mu \Delta E_e \Delta E_\gamma^2 \Delta\theta^2 \Delta t$$





The accidental background is dominant and it is determined by the experimental resolutions

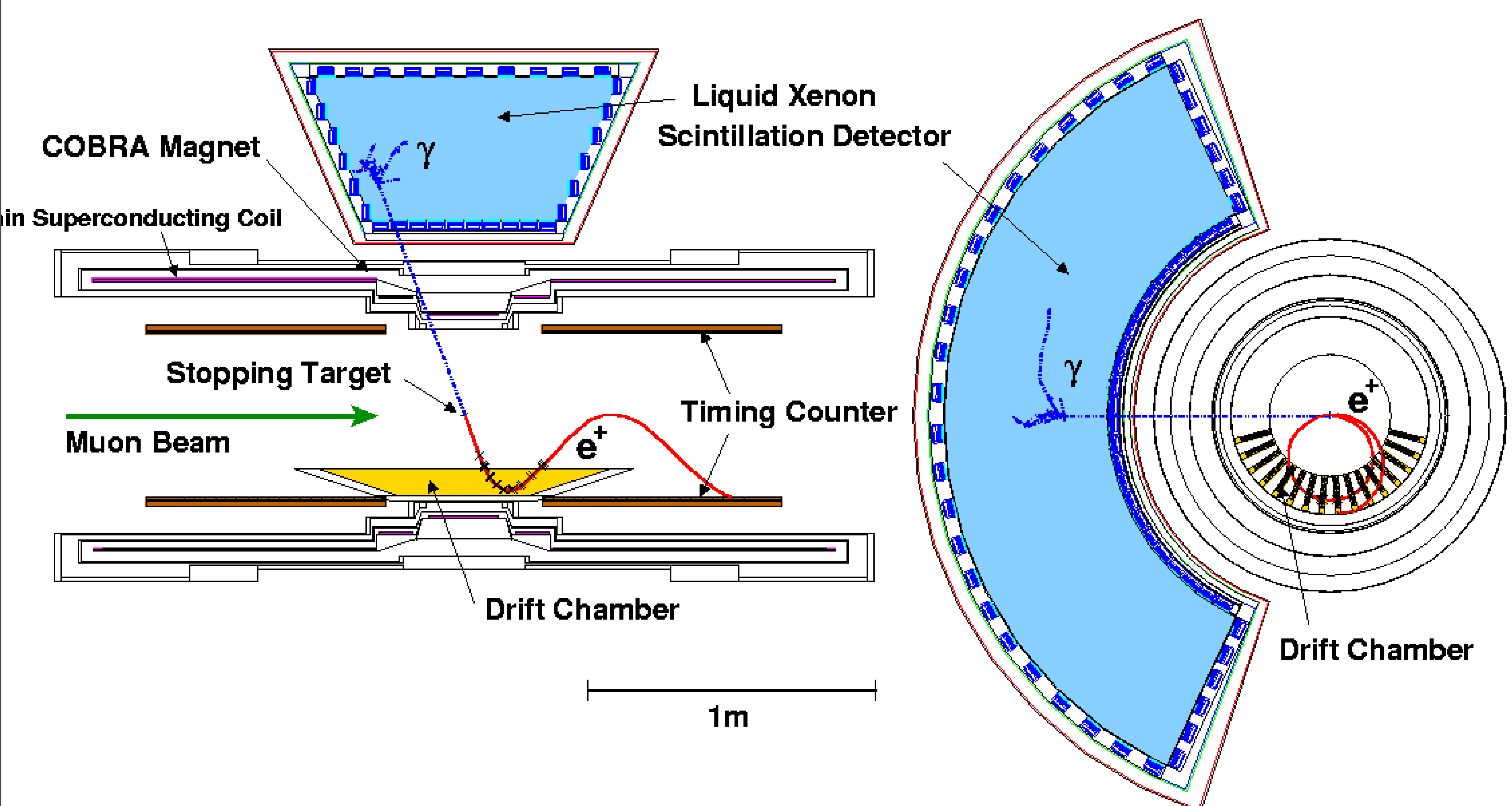
MEG experimental method



Easy signal selection with
μ+ at rest

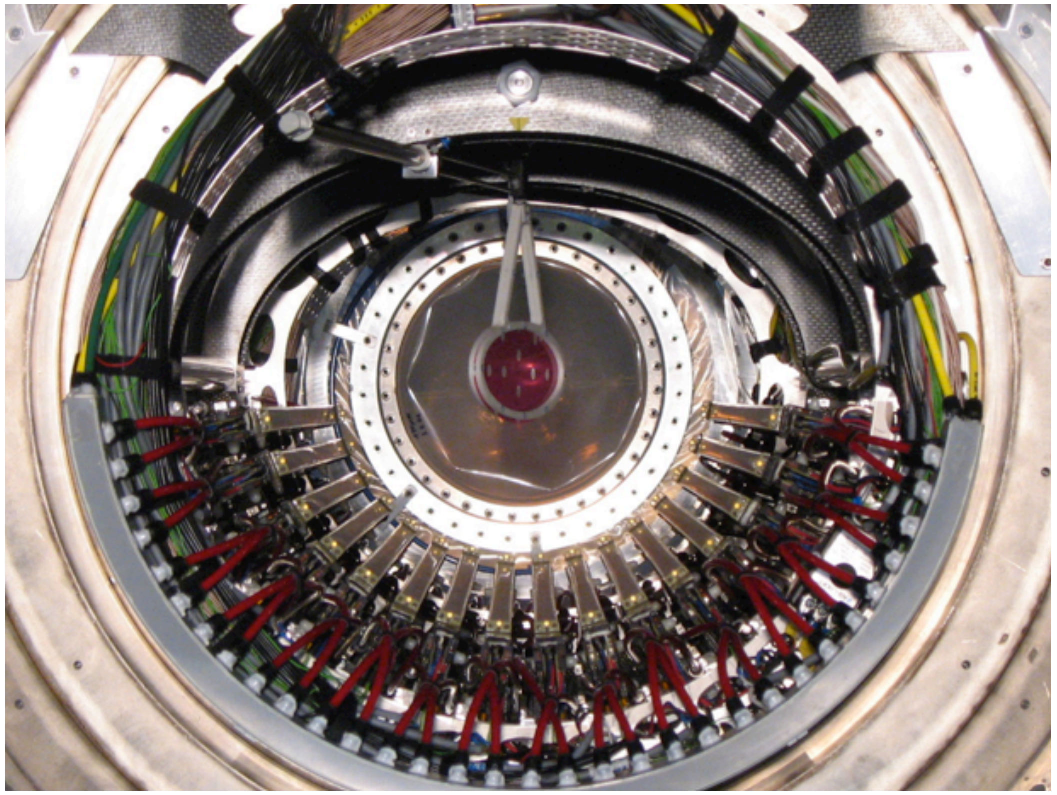
PAUL SCHERRER INSTITUT

- μ: stopped beam of 3 x 10^7 μ /sec in a 205 μm polyethylene target
  - PSI πE5 beam line: 29 MeV μ^+
- e^+ detection
  magnetic spectrometer composed by solenoidal magnet and drift chambers for momentum
  plastic counters for timing
- γ detection
  Liquid Xenon detector based on the scintillation light
  - fast: 4 / 22 / 45 ns
  - high LY: ~ 0.8 * NaI
  - short X_0: 2.77 cm



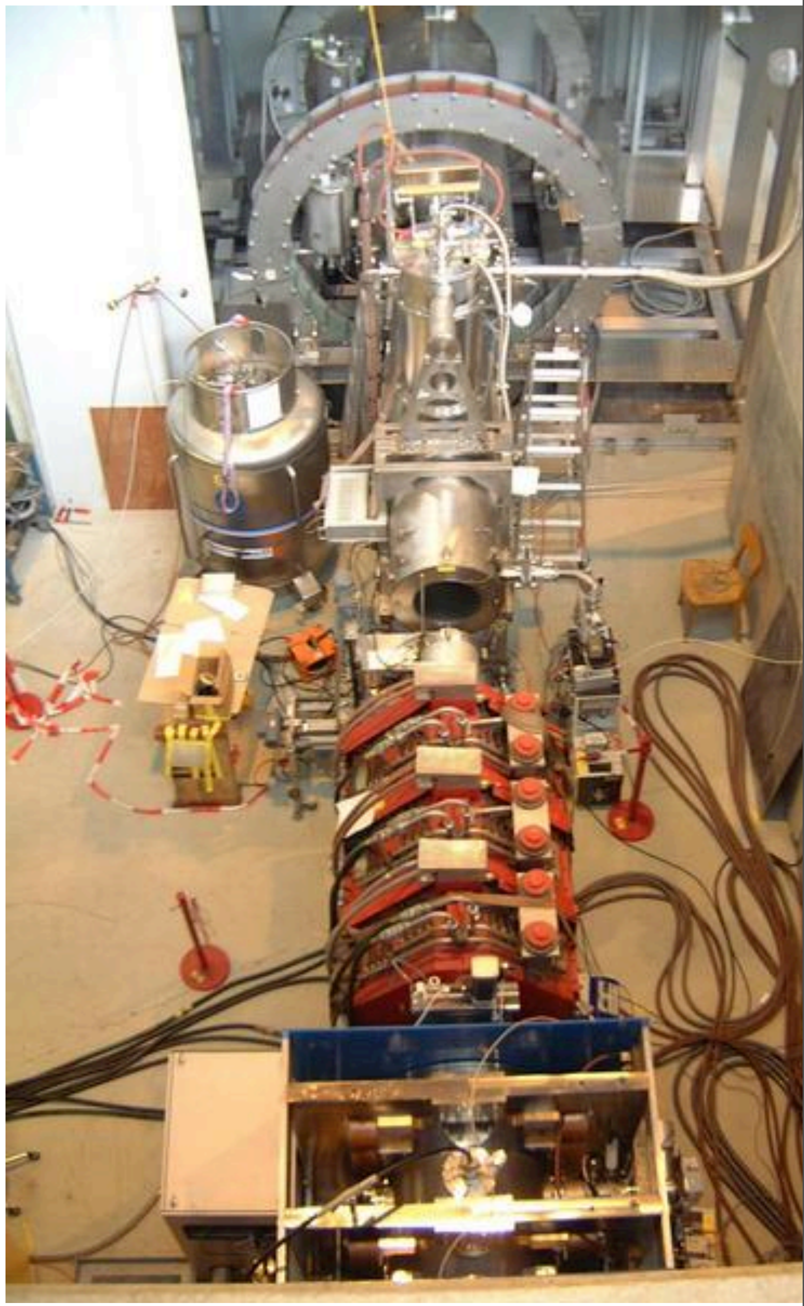
Some detector pictures

DC system



LXe detector

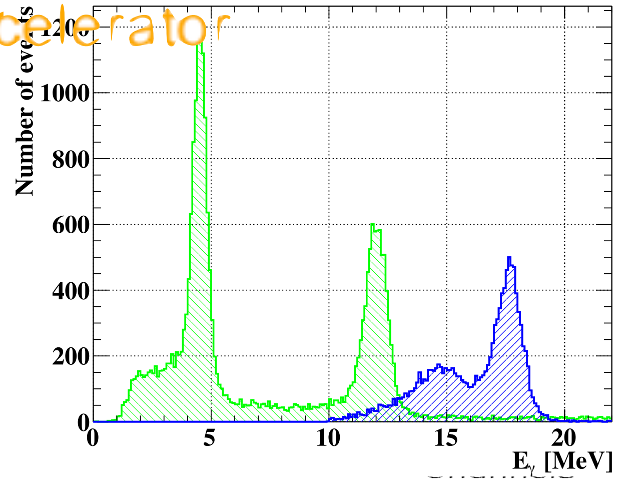
Beam Line



Calibration & Monitoring

Detector Calibration

Proton Accelerator



Li(p,γ)Be

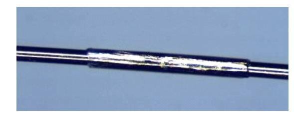
LiF target at COBRA center

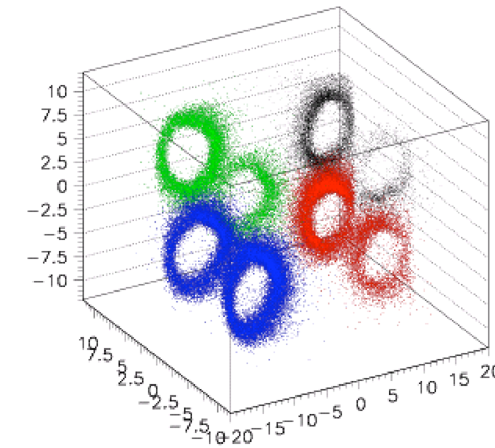
17.6MeV γ

~daily calib.

also for initial setup

Alpha on wires



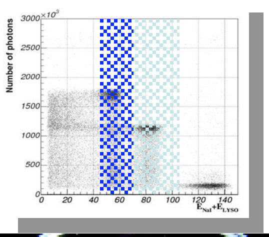


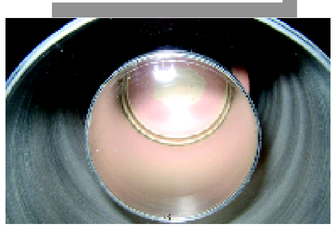
PMT QE & Att. L

Cold GXe

LXe

$\pi^0 \rightarrow \gamma\gamma$



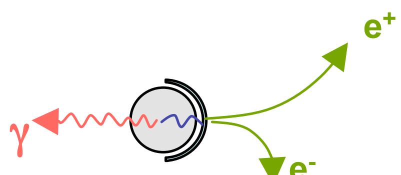


$\pi^- + p \rightarrow \pi^0 + n$

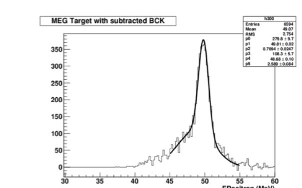
$\pi^0 \rightarrow \gamma\gamma$ (55MeV, 83MeV)

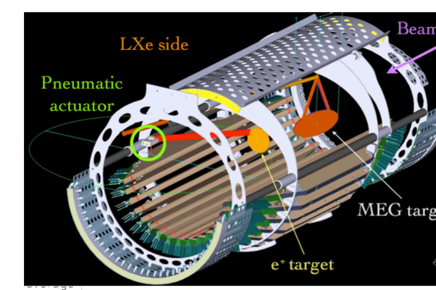
$\pi^- + p \rightarrow \gamma + n$ (129MeV)

LH_2 target

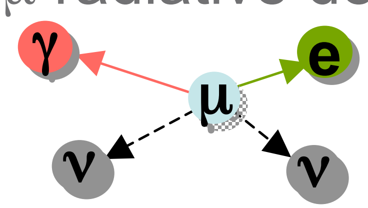


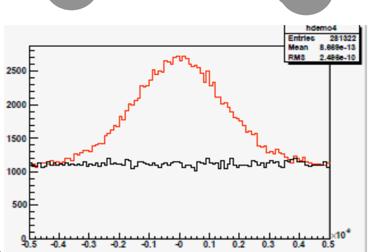
Mott e+ scattering





μ radiative decay



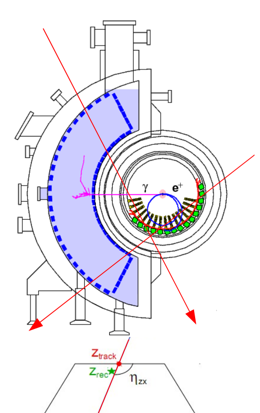


Lower beam intensity < 10^7

Is necessary to reduce pile-ups

A few days ~ 1 week to get enough statistics

Cosmic ray alignment



Nickel γ Generator

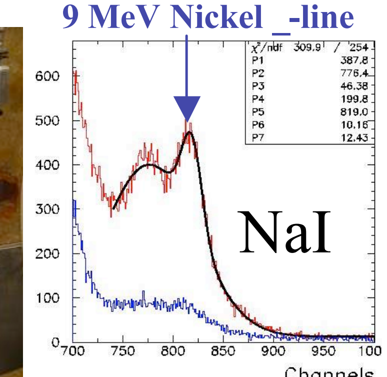
off

on

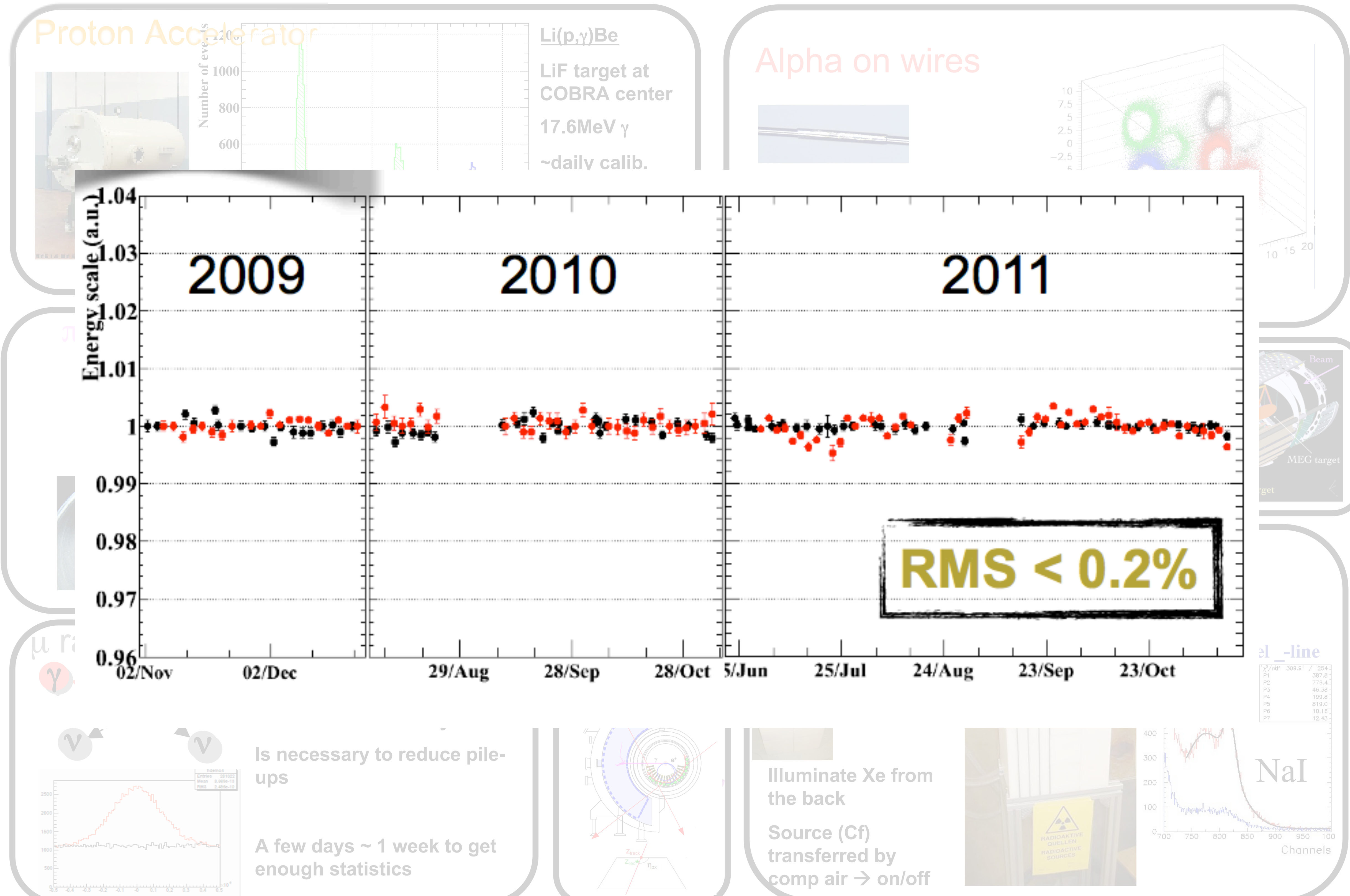
Illuminate Xe from the back

Source (Cf) transferred by comp air → on/off

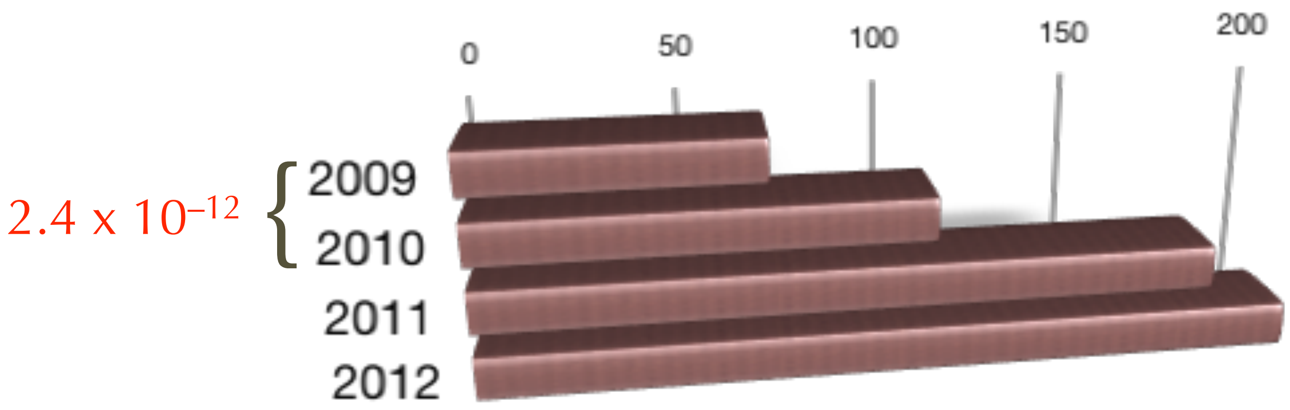
9 MeV Nickel _-line

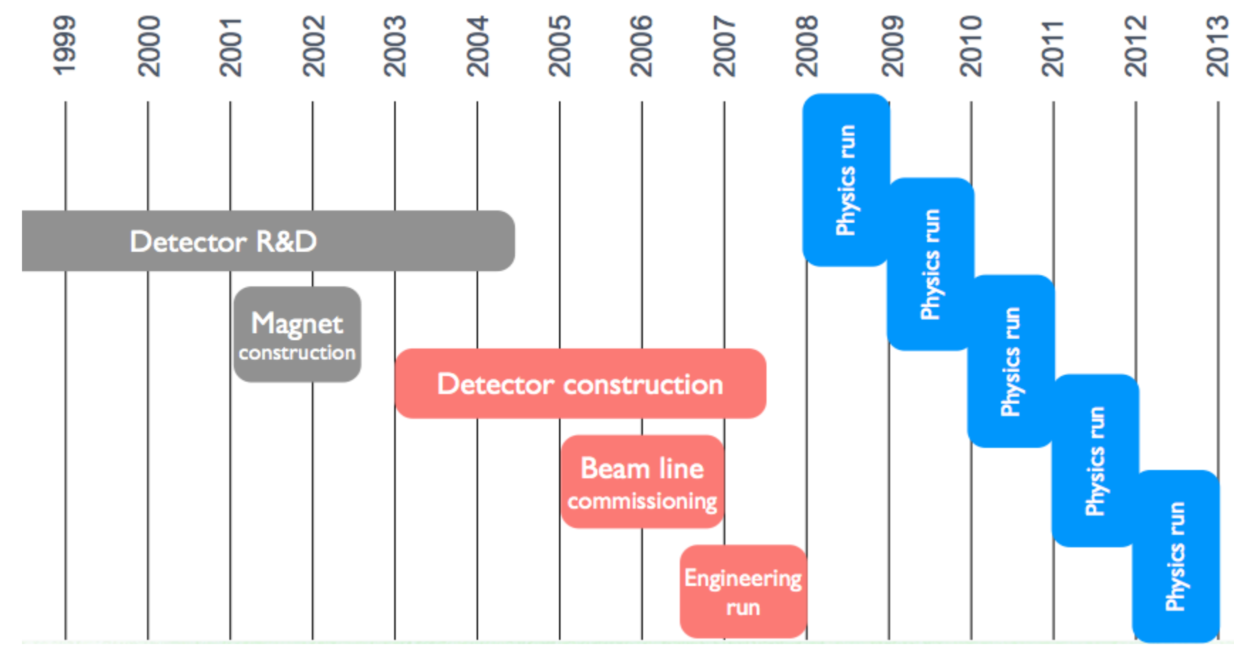


Calibration & Monitoring

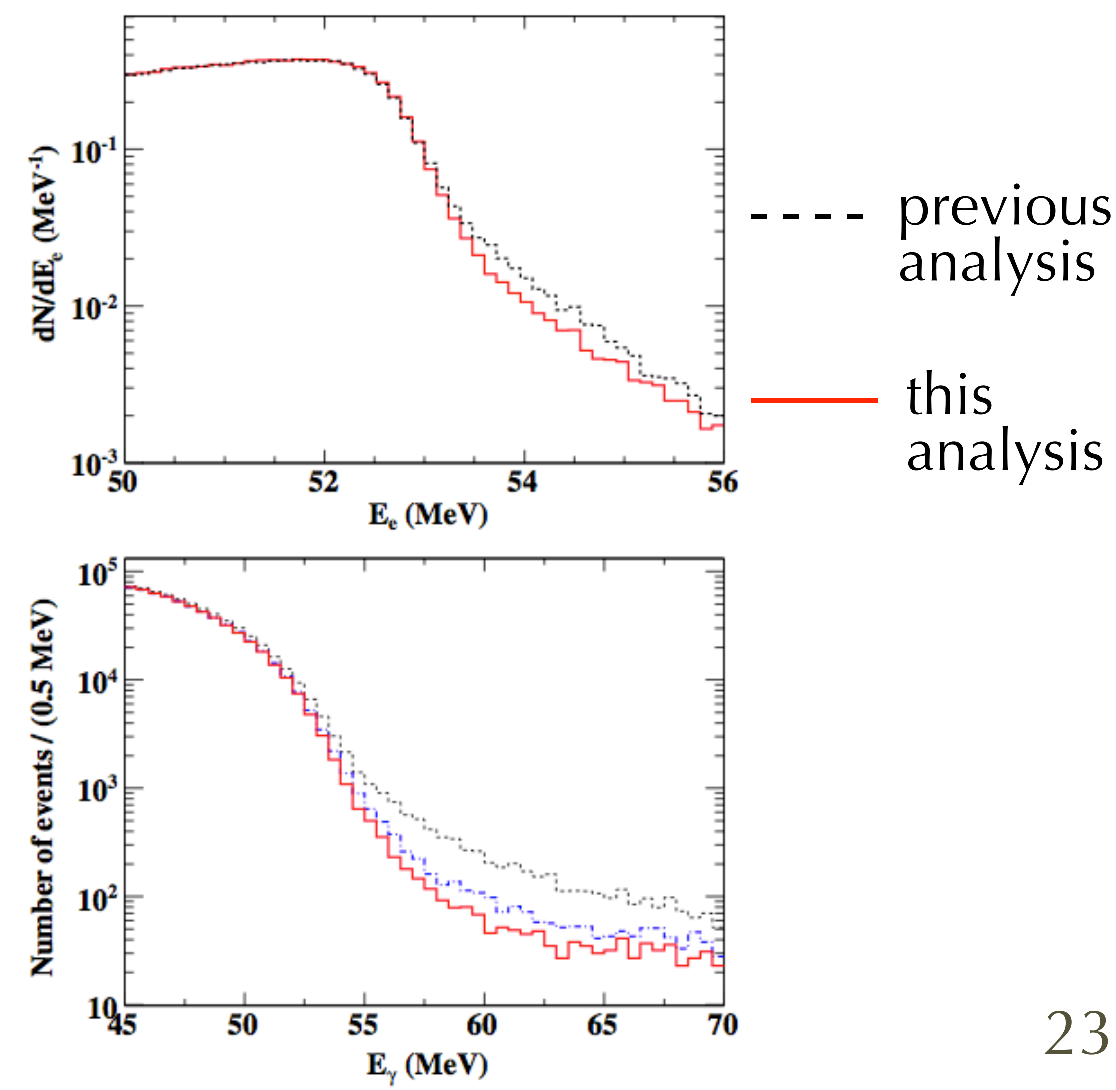


MEG schedule



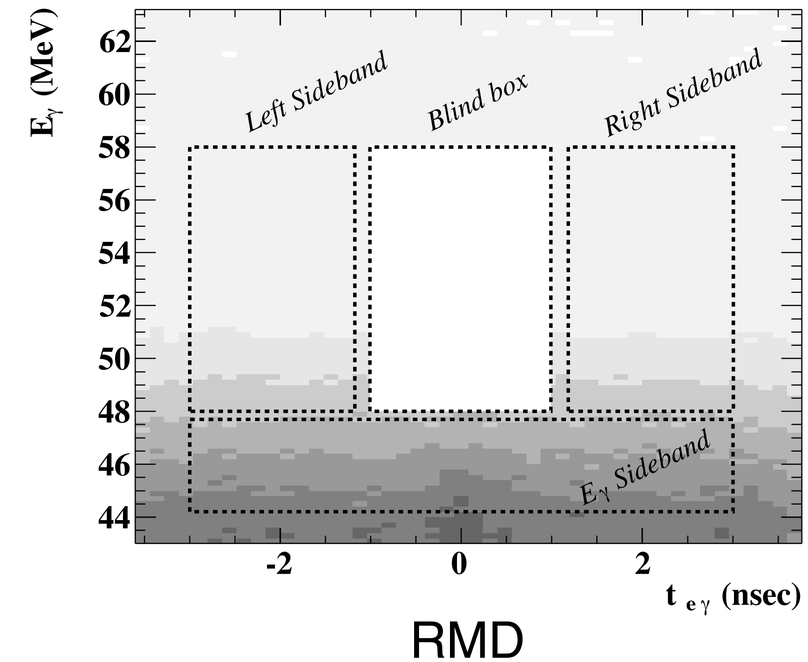


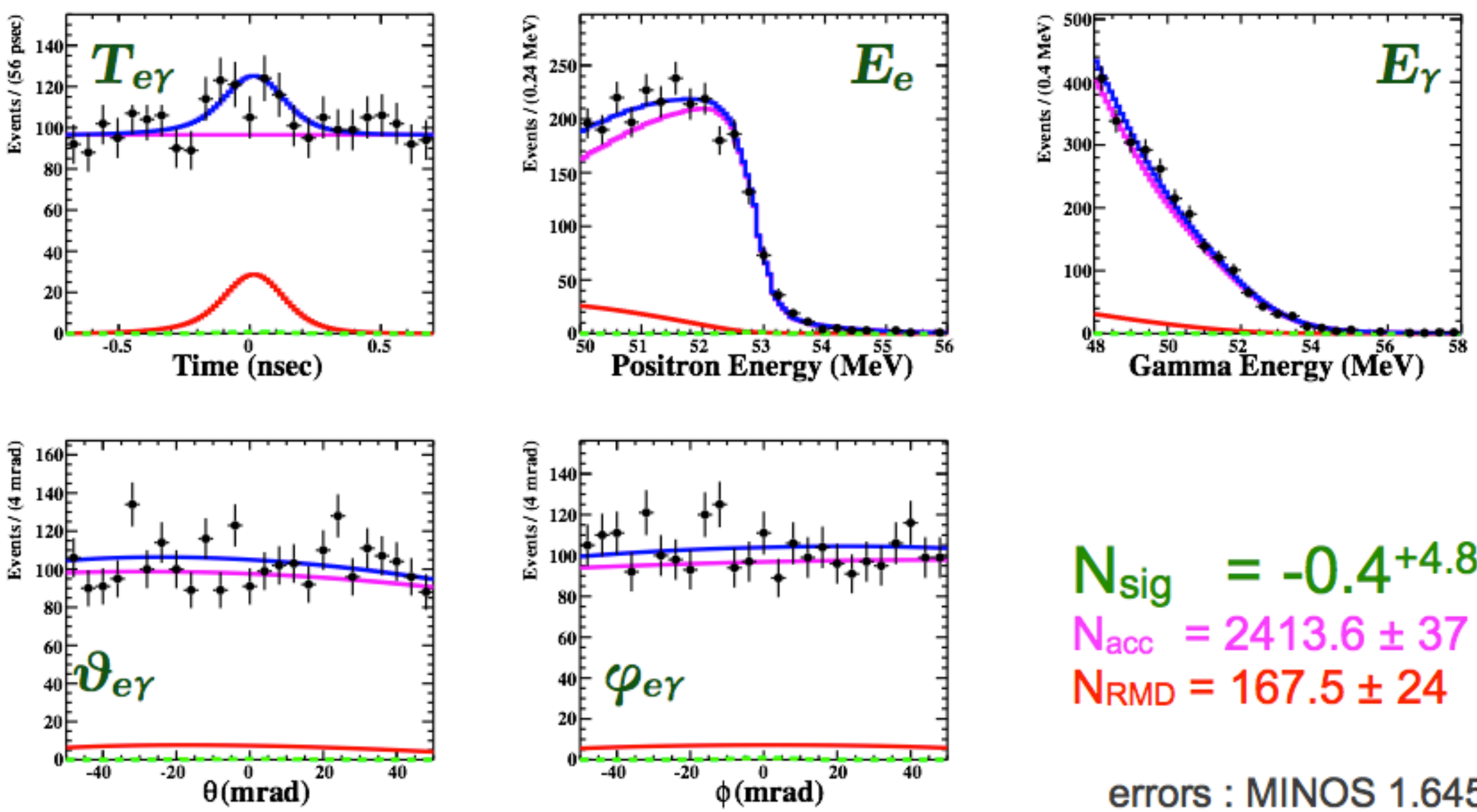
- 2009+2010 analysis: BR(μ→eγ)< 2.4 x 10^{-12} @ 90%C.L.
- 2011 data
  - Doubled the statistics
    - Improved trigger and reconstruction efficiency
  - Hardware modification
    - BGO for calibration
    - Laser tracker system for drift chamber alignment
- 2009-2011 Analysis improvements
  - Reconstruction improvements
    - γ-ray pileup unfolding
    - e^+ waveform FFT noise reduction + revised track fitter
- 2012 in progress



2009-2011 fit result

- Blind- box analysis strategy
  - off-time sideband
  - off angle sideband
- Three independent analyses
  - different *pdf* implementation
  - Fit or input N_{RMD}, N_{BG}
  - Different statistical treatment (Freq. or Bayes)
- Use of the sidebands
  - our main background comes from accidental coincidences
  - RMD can be studied in the low E_γ sideband





$N_{sig} = -0.4^{+4.8}_{-1.9}$

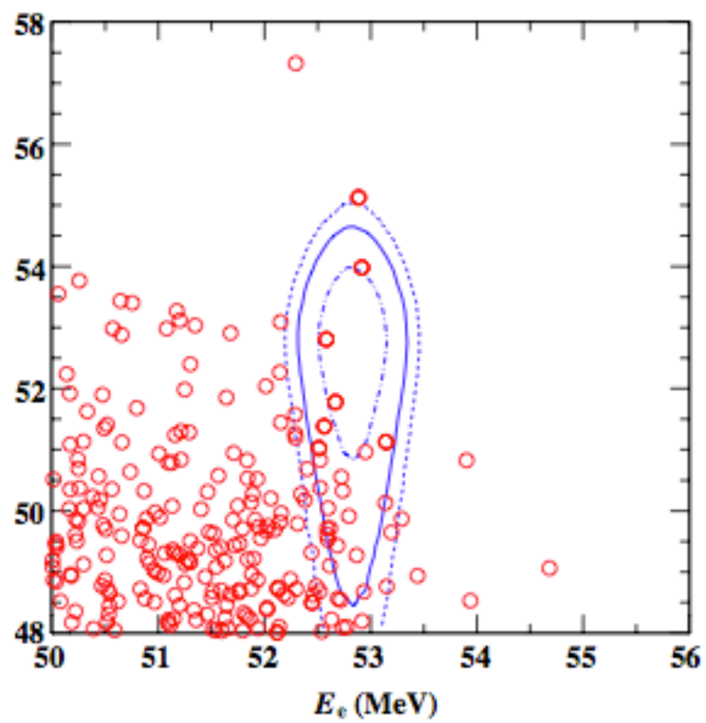
$N_{acc} = 2413.6 \pm 37$

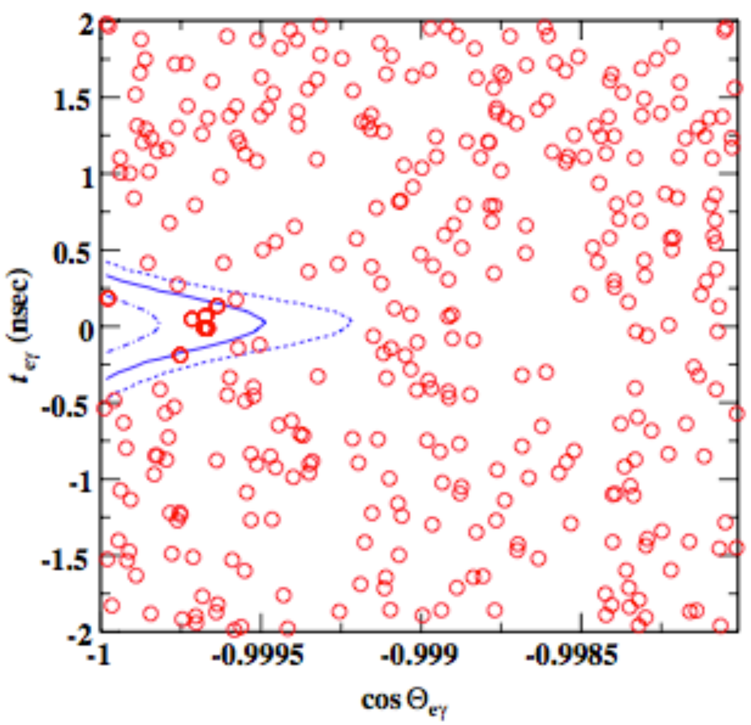
$N_{RMD} = 167.5 \pm 24$

errors : MINOS 1.645σ

Combined 2009 + 2010

2009 – 2011





Data set	$\mathcal{B}_{\text{fit}} \times 10^{12}$	$\mathcal{B}_{90} \times 10^{12}$	$\mathcal{S}_{90} \times 10^{12}$
2009–2010	0.09	1.3	1.3
2011	−0.35	0.67	1.1
2009–2011	−0.06	0.57	0.77

- 90% C.L. Feldman-Cousins upper limit
  - 8×10^{-13} expected for no signal (sensitivity)

$$\frac{\Gamma(\mu^+ \to e^+\gamma)}{\Gamma(\mu^+ \to e^+\nu\bar{\nu})} \leq 5.7 \times 10^{-13}$$

PRL **110,** 201801 (2013) PHYSICAL REVIEW LETTERS week ending 17 MAY 2013

New Constraint on the Existence of the $\mu^+ \to e^+\gamma$ Decay

J. Adam,[1,2] X. Bai,[3] A. M. Baldini,[4a] E. Baracchini,[3,5,6] C. Bemporad,[4a,4b] G. Boca,[7a,7b] P. W. Cattaneo,[7a] G. Cavoto,[8a] F. Cei,[4a,4b] C. Cerri,[4a] A. de Bari,[7a,7b] M. De Gerone,[9a,9b] T. Doke,[10] S. Dussoni,[4a] J. Egger,[1] Y. Fujii,[3] L. Galli,[1,4a] F. Gatti,[9a,9b] B. Golden,[6] M. Grassi,[4a] A. Graziosi,[8a] D. N. Grigoriev,[11,12] T. Haruyama,[5] M. Hildebrandt,[1] Y. Hisamatsu,[3] F. Ignatov,[11] T. Iwamoto,[3] D. Kaneko,[3] P.-R. Kettle,[1] B. I. Khazin,[11] N. Khomotov,[11] O. Kiselev,[1] A. Korenchenko,[13] N. Kravchuk,[13] G. Lim,[6] A. Maki,[5] S. Mihara,[5] W. Molzon,[6] T. Mori,[3] D. Mzavia,[13] R. Nardò,[7a] H. Natori,[5,3,1] D. Nicolò,[4a,4b] H. Nishiguchi,[5] Y. Nishimura,[3] W. Ootani,[3] M. Panareo,[14a,14b] A. Papa,[1] G. Piredda,[8a] A. Popov,[11] F. Renga,[8a,1] E. Ripiccini,[8a,8b] S. Ritt,[1] M. Rossella,[7a] R. Sawada,[3] F. Sergiampietri,[4a] G. Signorelli,[4a] S. Suzuki,[10] F. Tenchini,[4a,4b] C. Topchyan,[6] Y. Uchiyama,[3,1] C. Voena,[8a] F. Xiao,[6] S. Yamada,[5] A. Yamamoto,[5] S. Yamashita,[3] Z. You,[6] Yu. V. Yudin,[11] and D. Zanello[8a]

PRL 17 May 2013
20 times better than
previous limit!

Present & Future

- We have just started the 2013 data-taking (last year)
- MEG is expected to saturate its sensitivity with this year's run
- In the meanwhile an upgrade was presented and accepted by PSI laboratory

μ

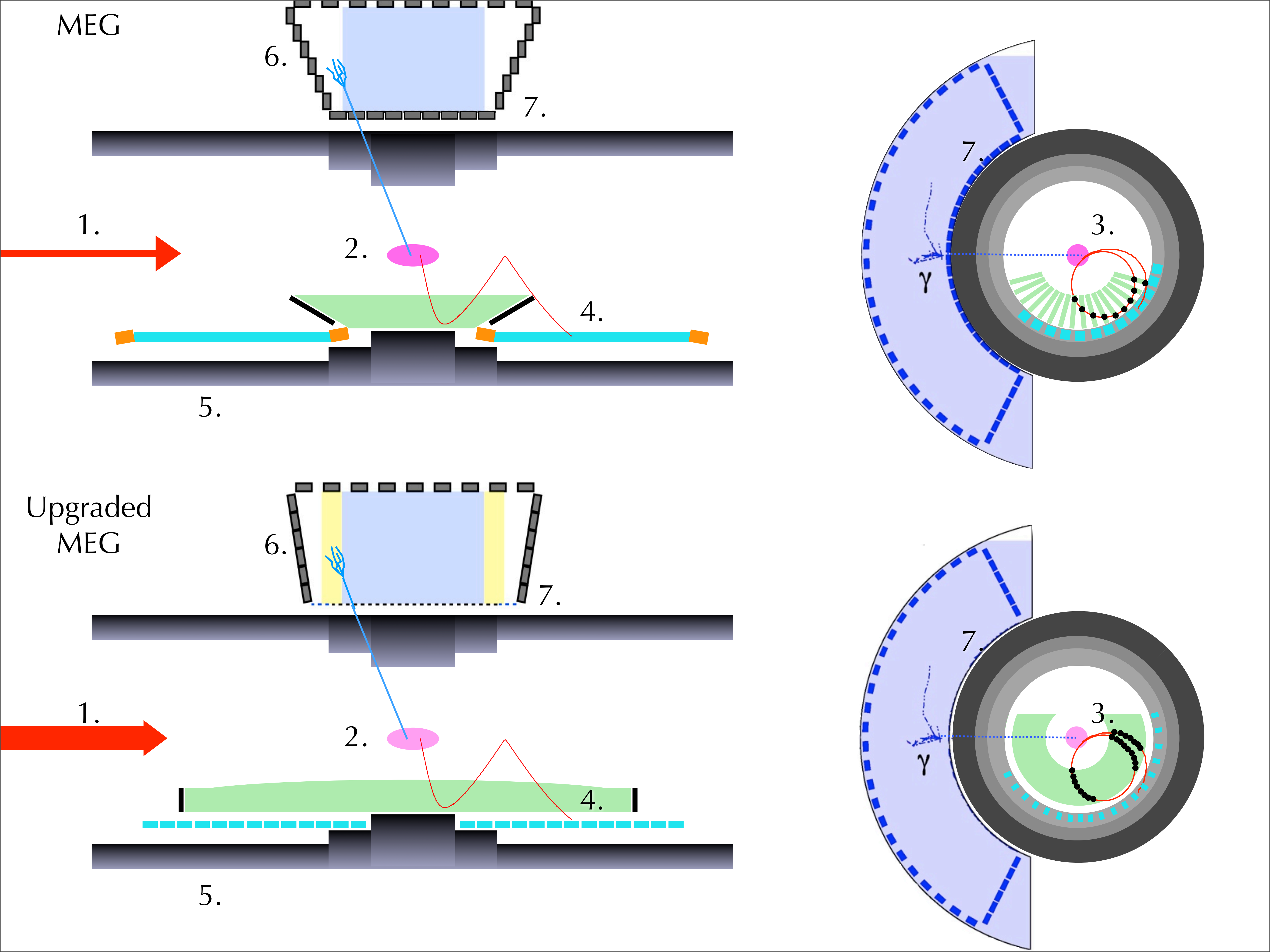
1. Increasing μ^+–stop on target
2. Reducing target thickness to minimize e+ MS & brehmsstrahlung

e

3. Replacing the e+ tracker reducing its radiation length and improving its granularity and resolutions
4. Improving the timing counter granularity for better timing and reconstruction
5. Improving the positron tracking-timing integration by measuring the e+ trajectory up to the TC interface

γ

6. Extending the γ–ray detector acceptance
7. Improving the γ-ray energy and position resolution for shallow events
8. Integrating splitter, trigger and DAQ maintaining a high bandwidth

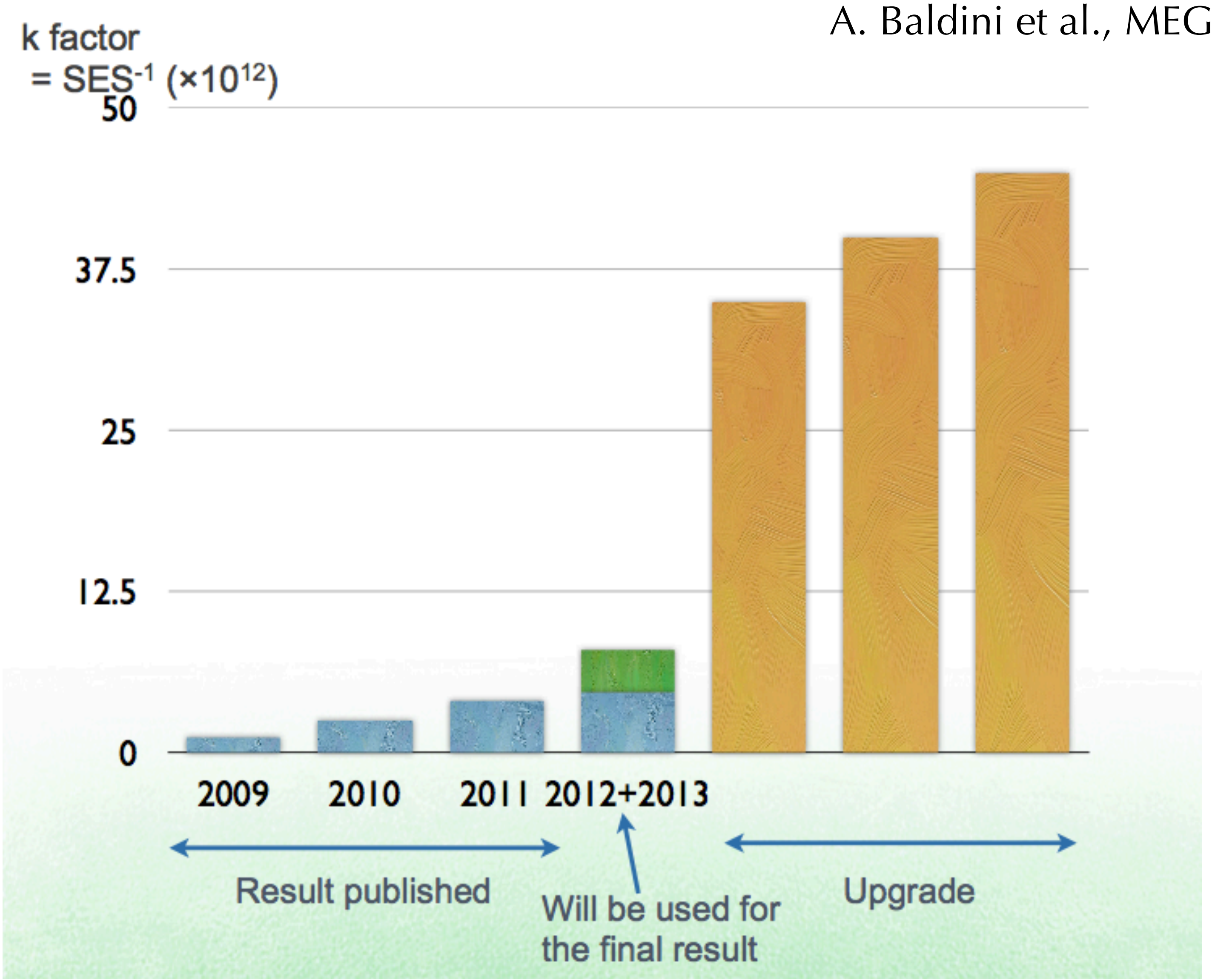


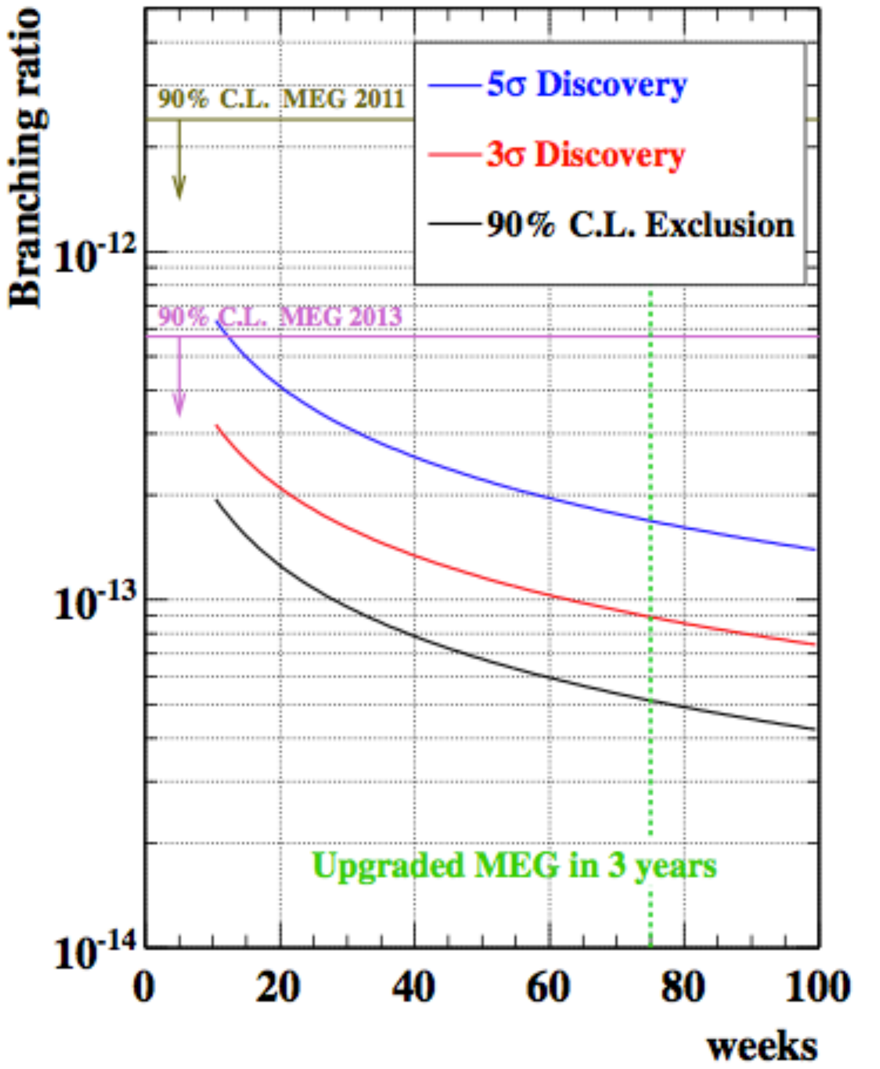
MEG
6.
7.
1.
2.
4.
5.
7.
3.
γ
Upgraded
MEG
6.
7.
1.
2.
4.
5.
7.
3.
γ

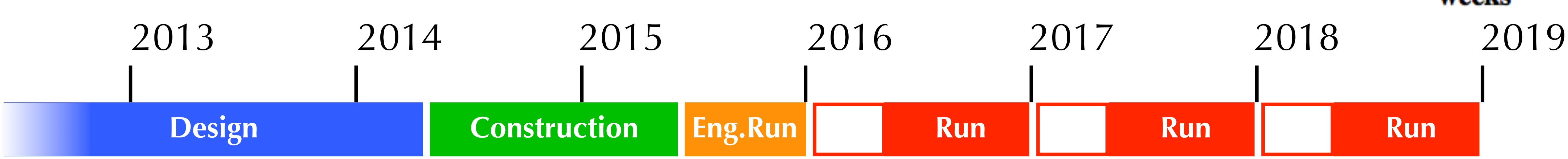
MEG^{UP} sensitivity

- Ultimate sensitivity at the few x 10^{-14} level
- Engineering run 2015
- Data taking 2016-2018

A. Baldini et al., MEG Upgrade Proposal, arXiv:1301.7225 [physics.ins-det] |

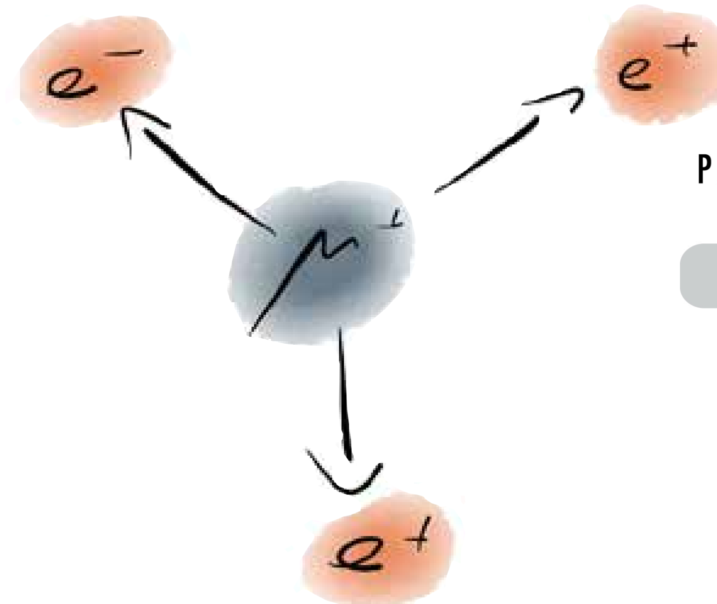


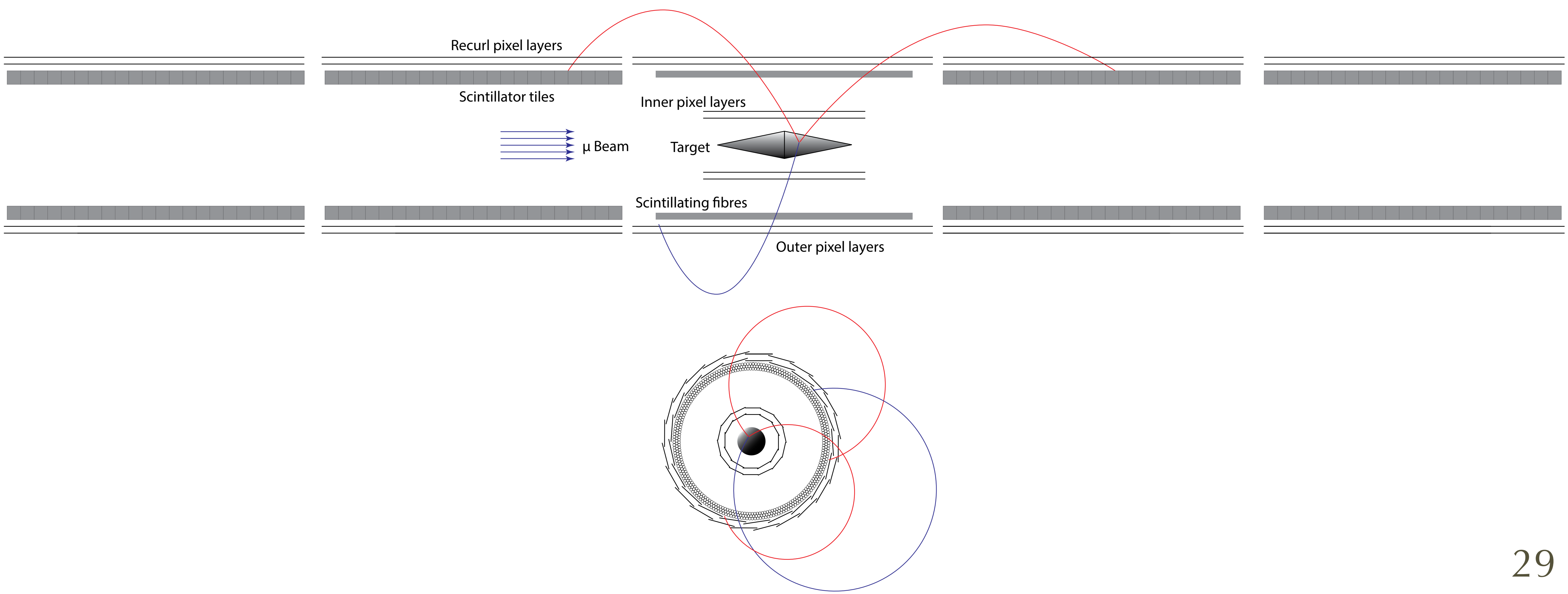




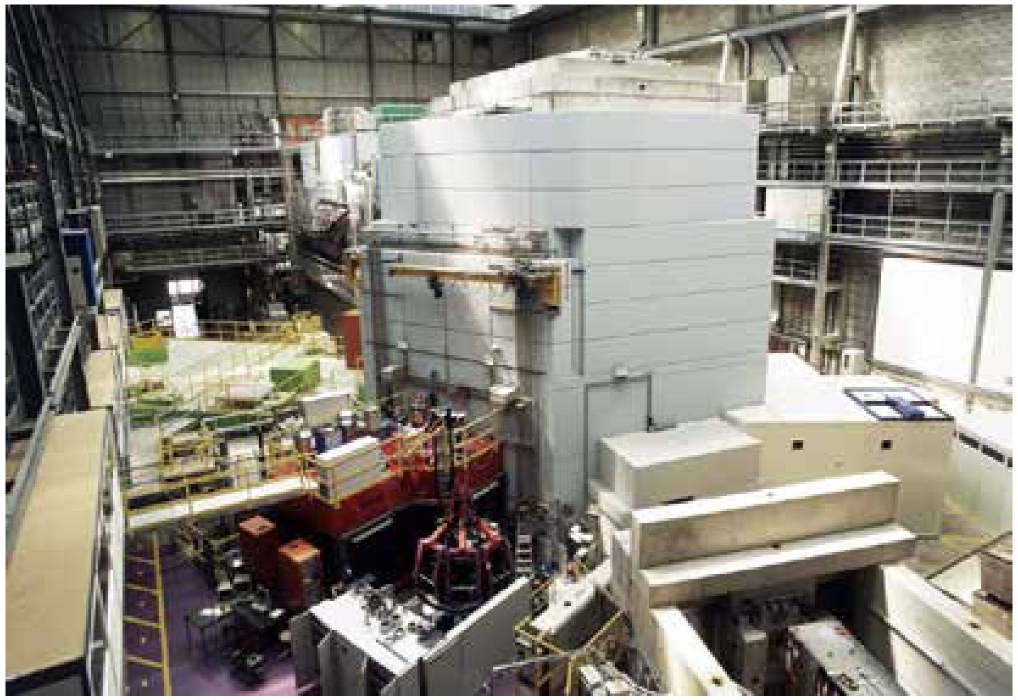
Mu3e at PSI

- Search for $\mu \rightarrow e\,e\,e$
  - 10^{-15} sensitivity in phase I
  - 10^{-16} sensitivity in phase II
- Project approved in January 2013
  - Double cone target
  - HV-MAPS ultra thin silicon detectors
  - Scintillating fibers timing counter

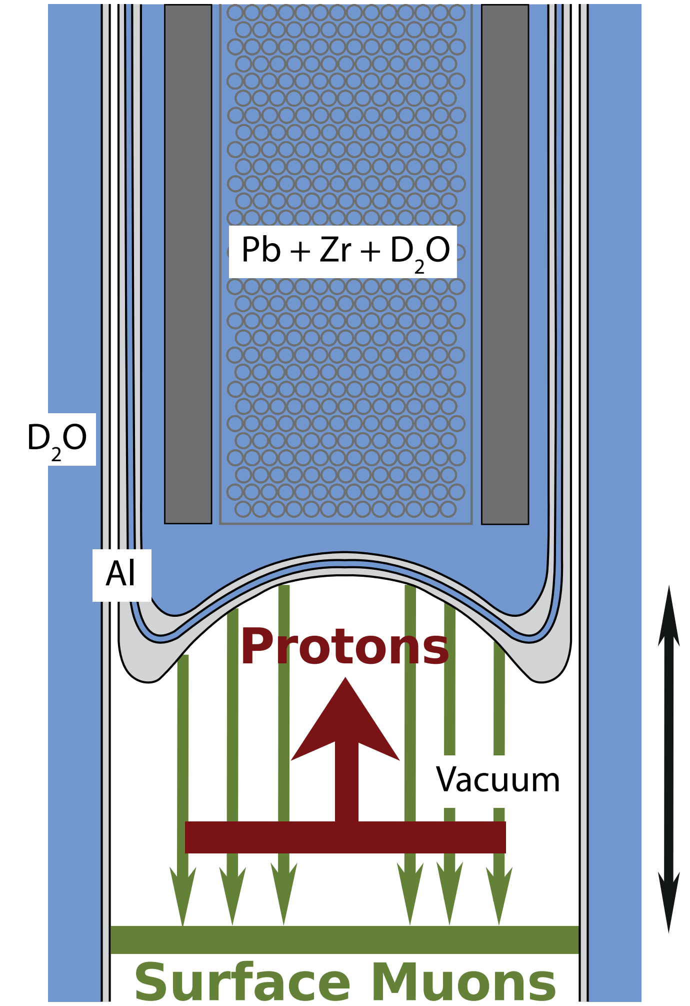


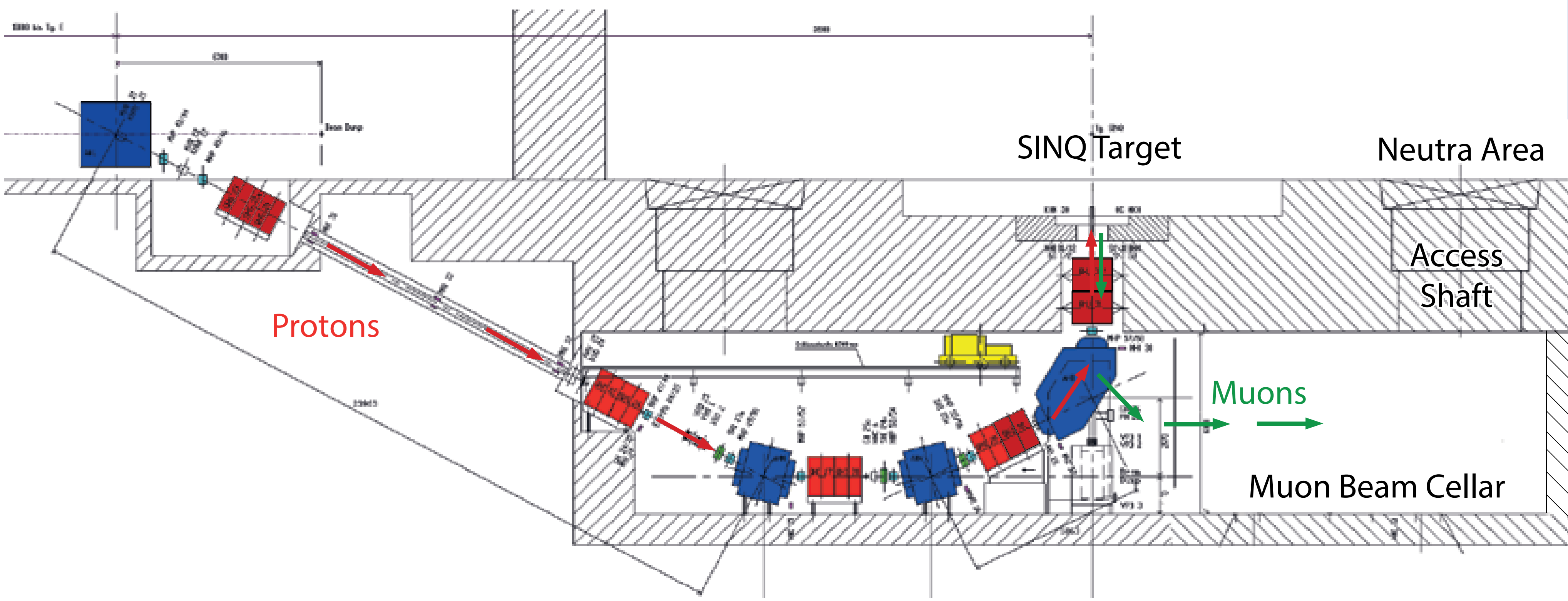


HIMB at PSI



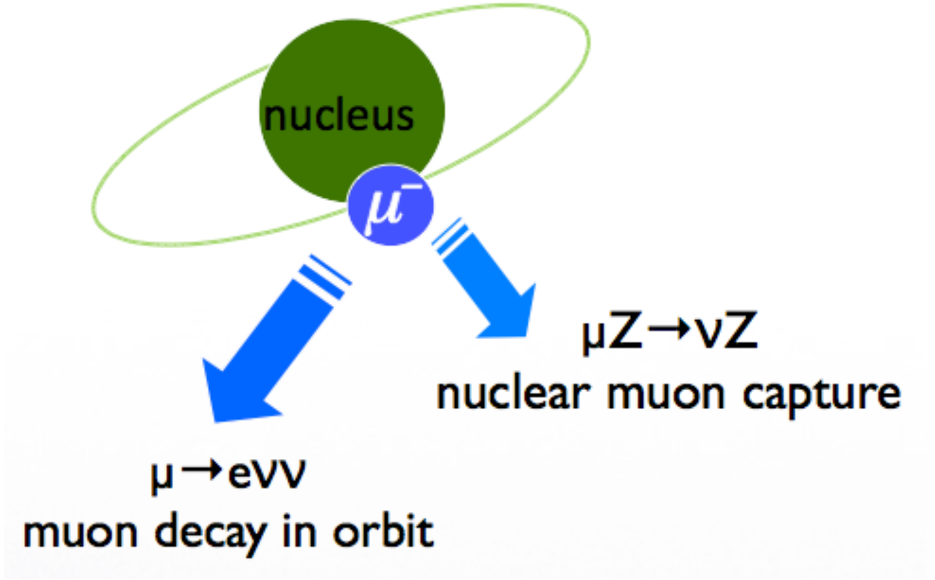
- Muon rates in excess of 10^{10}/s in acceptance
- $2 \cdot 10^{9}$/s needed for $\mu \rightarrow eee$ at 10^{-16}
- Not before 2017

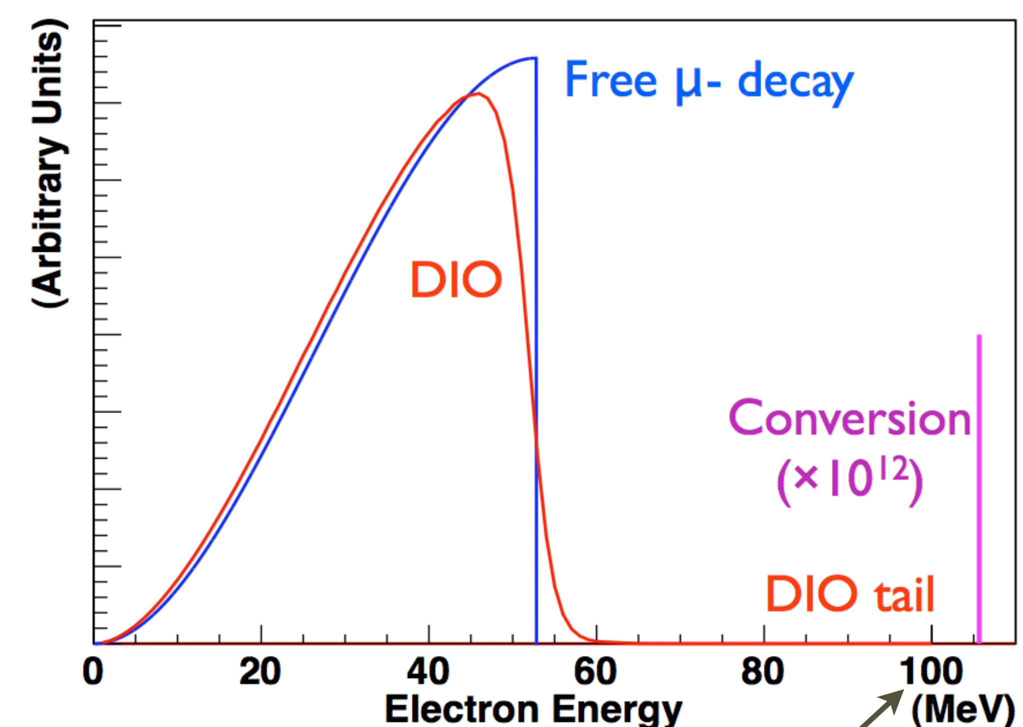




$\mu N \rightarrow eN$

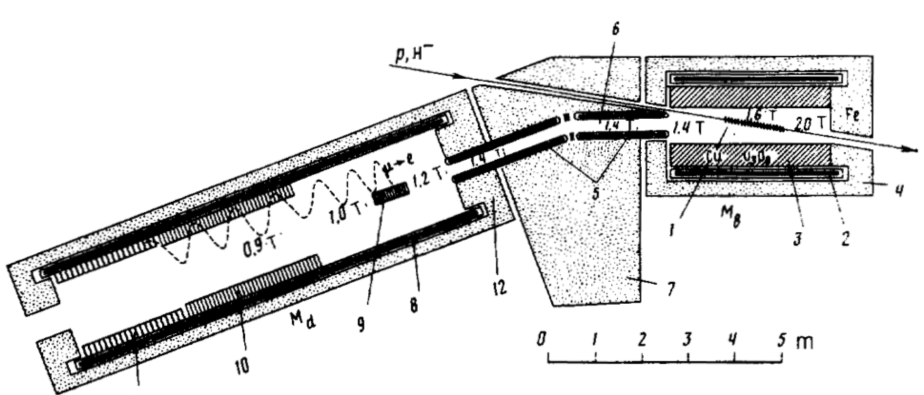
- Coherent muon capture on nucleus (Al is the candidate)
- Single mono-energetic electron
  - $E_e = m_\mu - B_\mu$ –recoil
- Only one particle in final state
  - No (accidental) background limited
  - Unlike $\mu \rightarrow e\gamma$ and $\mu \rightarrow 3e$ there is no experimental "wall" until conversion rates $O(10^{-18})$
  - It is anticipated that will provide the ultimate sensitivity to CLFV
- Background comes from
  - μ decay-in-orbit (DIO)
  - radiative muon capture
    - bkg n and γ-rays are produced
  - beam related background (π and e contaminations)
    - high purity environment
    - curved solenoid (Dzhilkibaev and Lobashev, 1989)
    - pulsed beam with challenging extinction





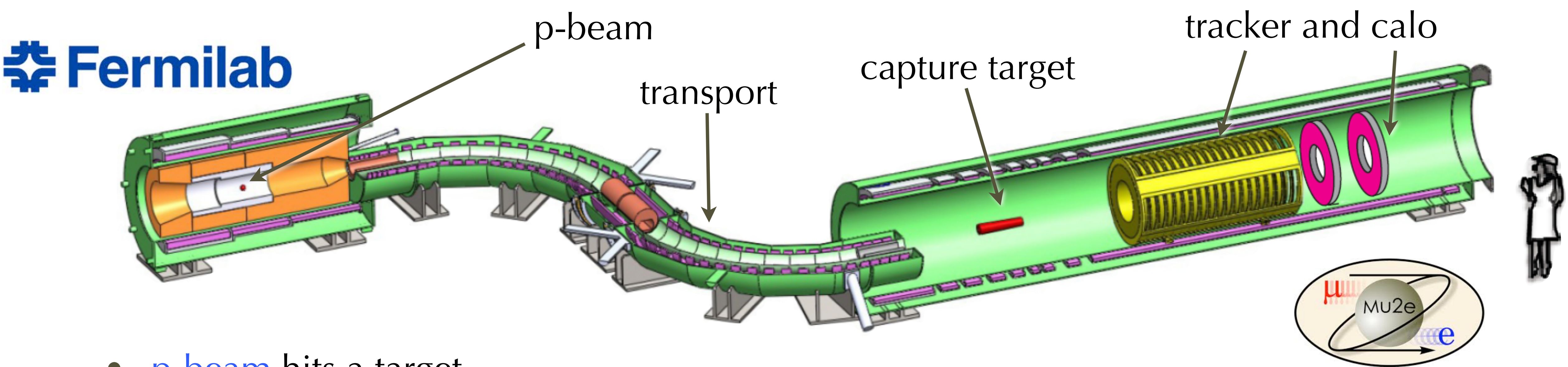
$(E_\mu - E_e)^5$

$\sim 10^{-17}$ of the spectum wihin the last MeV



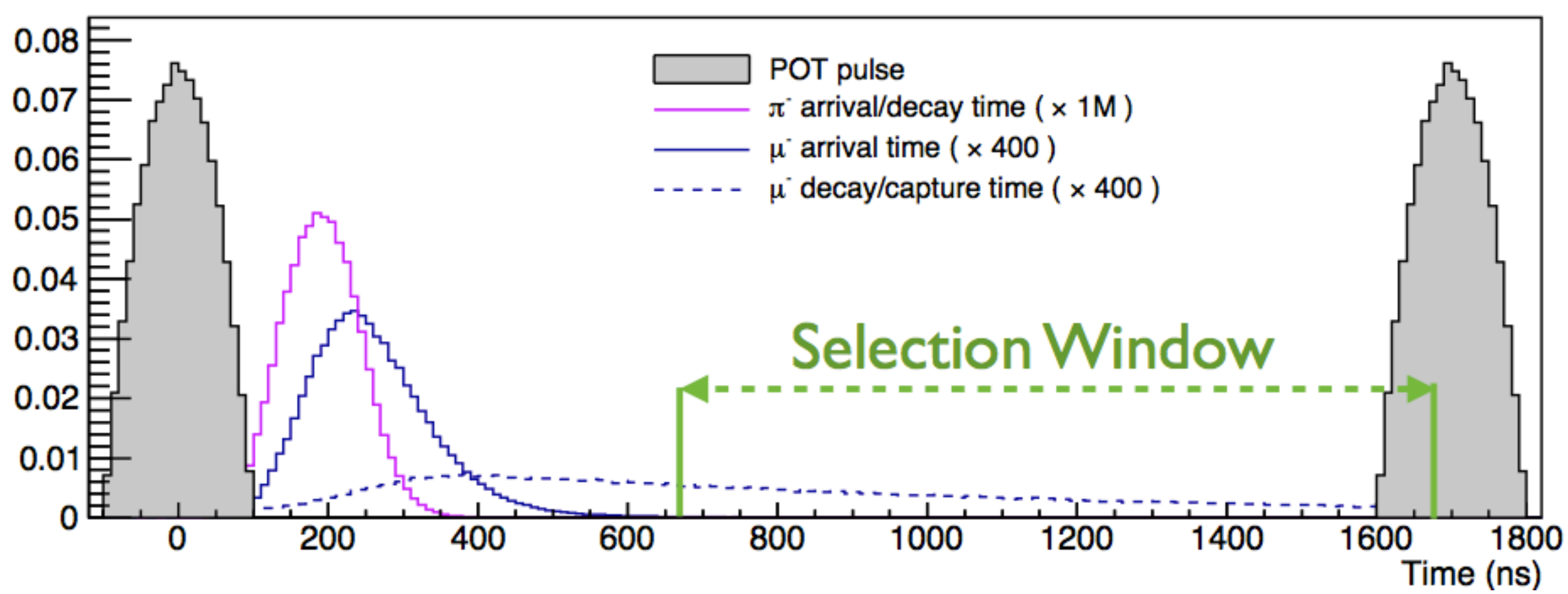
μN→eN experiments: mu2e

- Mu2e @ FNAL and COMET @ J-PARC are quite similar in the outline



- p-beam hits a target
- solenoid collects π^- and let them decay to μ^-
- μ^- are transported to the capture target
- A pulsed beam allows a time window for events ⇒ needs high extinction

Starts in 2020
Data in 2022
SES ~ 2 x 10^{-17}



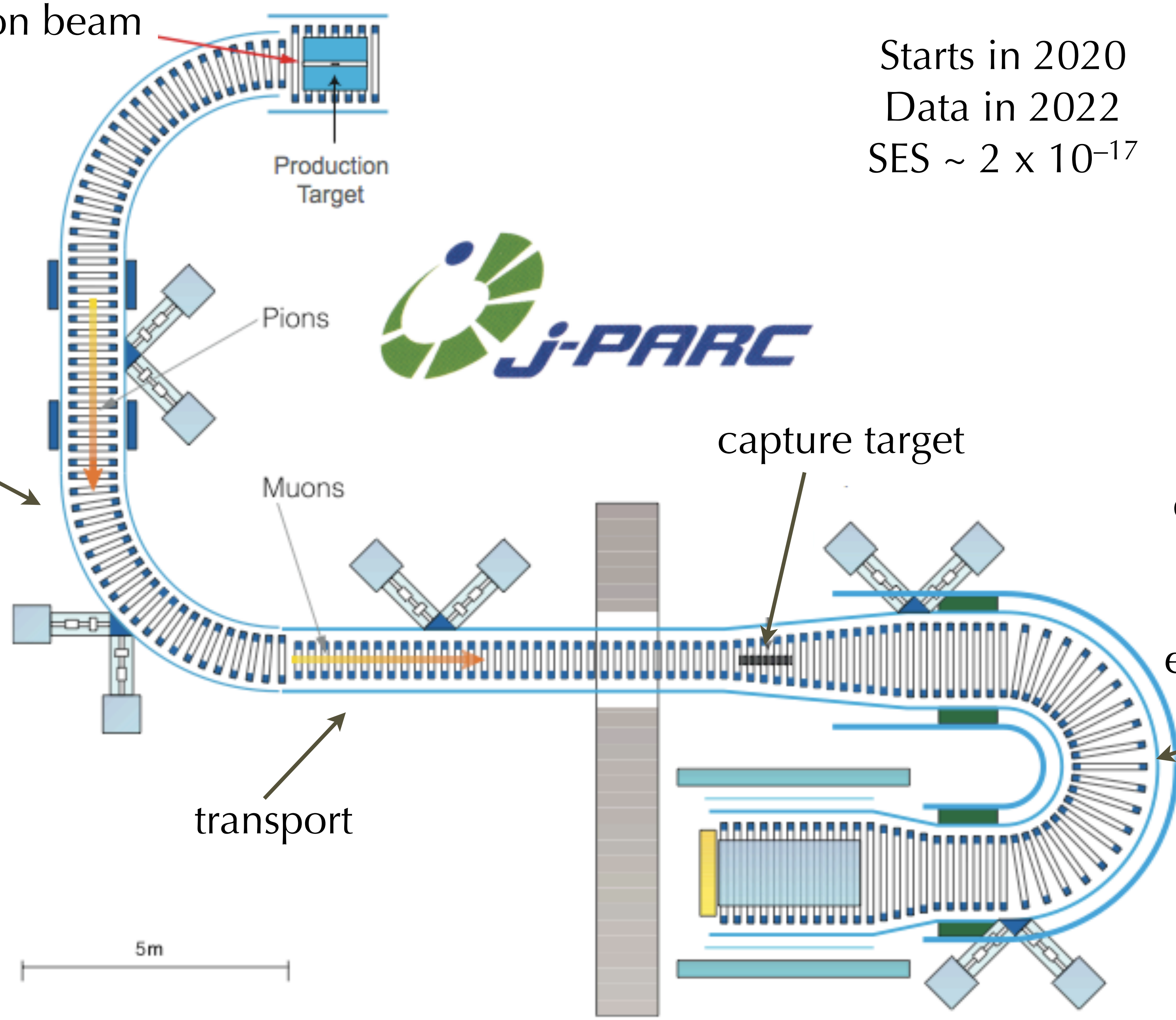
COMET: phase II

- COMET @ J-PARC has some differences

Starts in 2020
Data in 2022
SES ~ 2×10^{-17}

proton beam

S-shape instead of C-shape



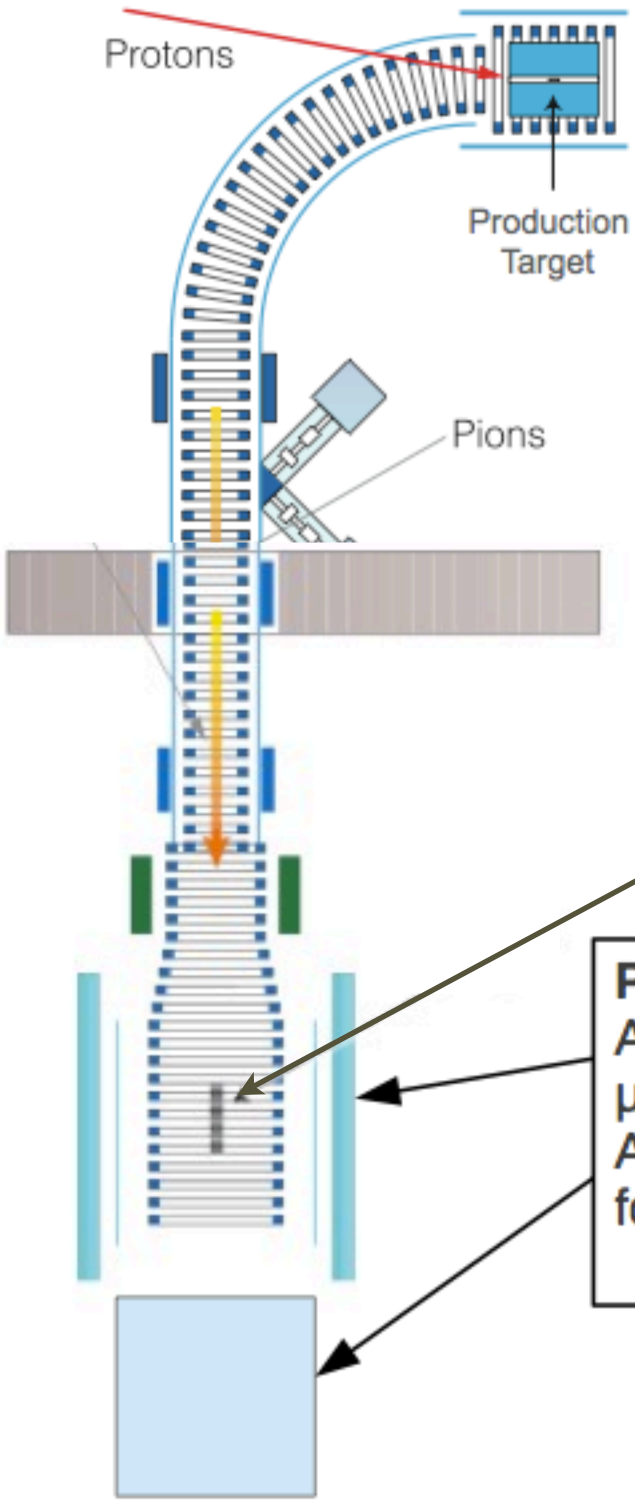
capture target

transport

detector has an extra curved magnet acting as an electron spectrometer

COMET: phase I

- COMET @ J-PARC has some differences



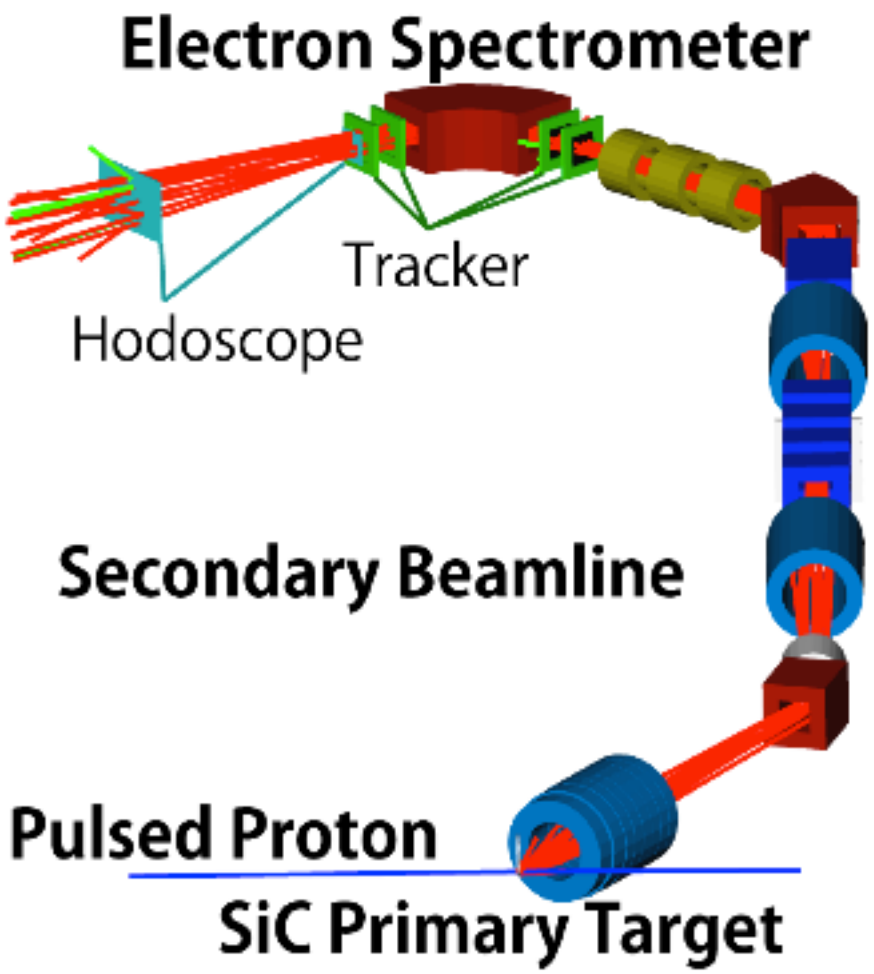
Starts in 2016
Data in 2017
SES ~ 3 x 10^{-15}

target will be placed at the center of the detector (à la Mu2e)

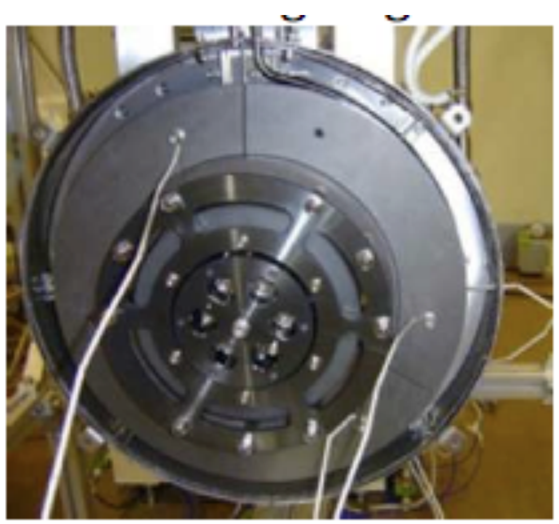
Phase-I Detector
A cylindrical drift chamber (CDC) for the μ-e conversion search
A prototype ECAL and straw tube tracker for the background studies

In the meanwhile: DeeMe

- DeeMe at J-PARC aims at searching for μN→eN with a 10^{-14} sensitivity
- production target and conversion target are the same
- rotating silicon carbide target
- physics data taking planned to start in 2015



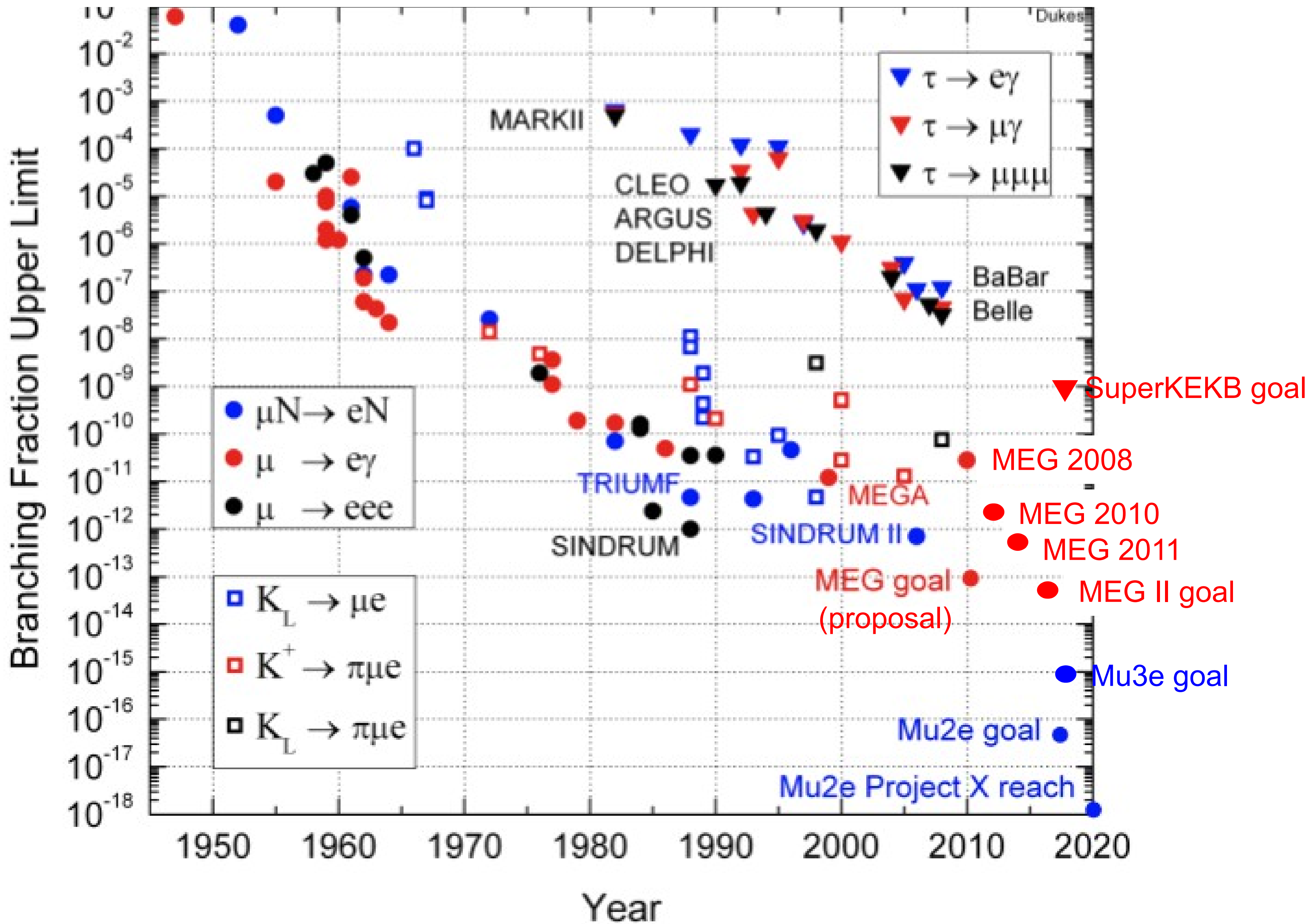
p→π→μ→e



Summary

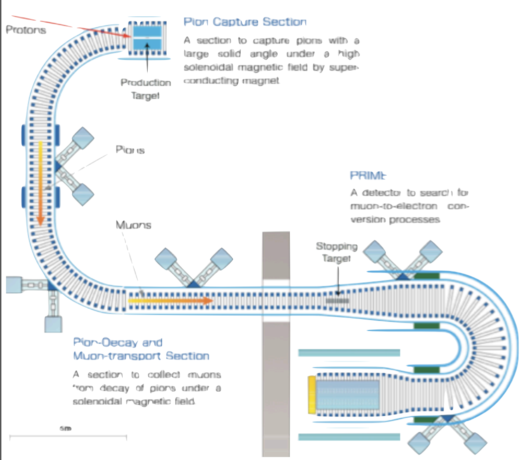
- CLFV activities in the World
- Complements flavor physics from the lepton sector
- MEG improved the limit on $\mu \to e \gamma$
  - 5.7×10^{-13} @ 90% C.L.
  - Further improvement expected
- MEG^{UP}
  - Down to 6×10^{-14}
- Mu3e @ PSI
  - Staged approach waiting for a HIMB
  - $<10^{-16}$ level
- Mu2e, DeeMe and COMET
  - intensive R&D for the realization of the experiments
  - Staged setup to test part of the techniques
  - 10^{-17} level
  - towards 10^{-18} with future muon campuses (Project-X and PRISM/PRIME)
- Complementarity with τ, meson and exotic CLFV

The future: stay tuned!



E. C. Dukes, TAU2010

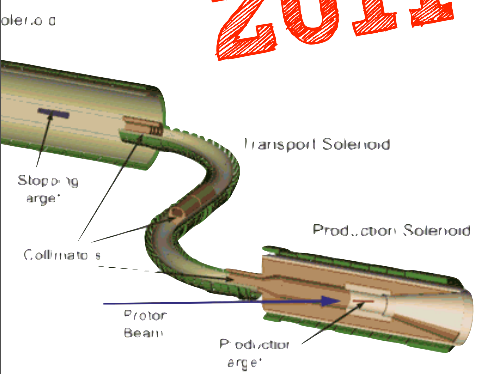
Back to the wheel



mu2e COMET

$10^{-16} \rightarrow 10^{-18}$

2017→



$\mu \rightarrow e\gamma$

MEG^{UP}

few $\times 10^{-14}$

2015→

SuperKEK

$1\div2 \times 10^{-9}$

2015→

$\tau \rightarrow \mu\gamma$

$\tau \rightarrow e\gamma$

$\mu^- \mathcal{N} \rightarrow e^- \mathcal{N}$

$\mu \rightarrow eee$

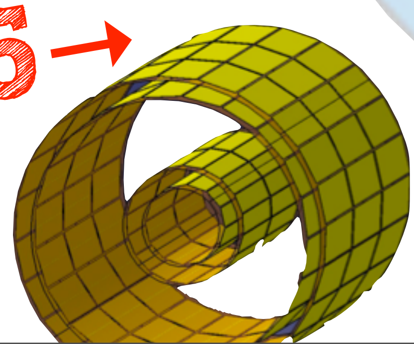
$(g-2)_\mu$

$\times \tan^2\beta$

Mu3e

$\sim 10^{-15\div16}$

2015→

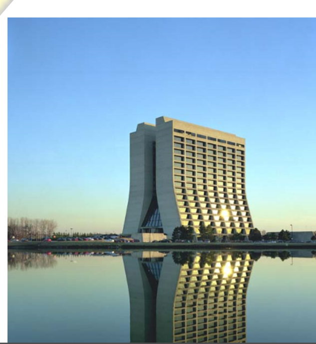


Gm2 FNAL

$\Delta a_\mu = (XXX \pm 34) \times 10^{-11}$

$3.6\sigma \rightarrow 8\sigma$

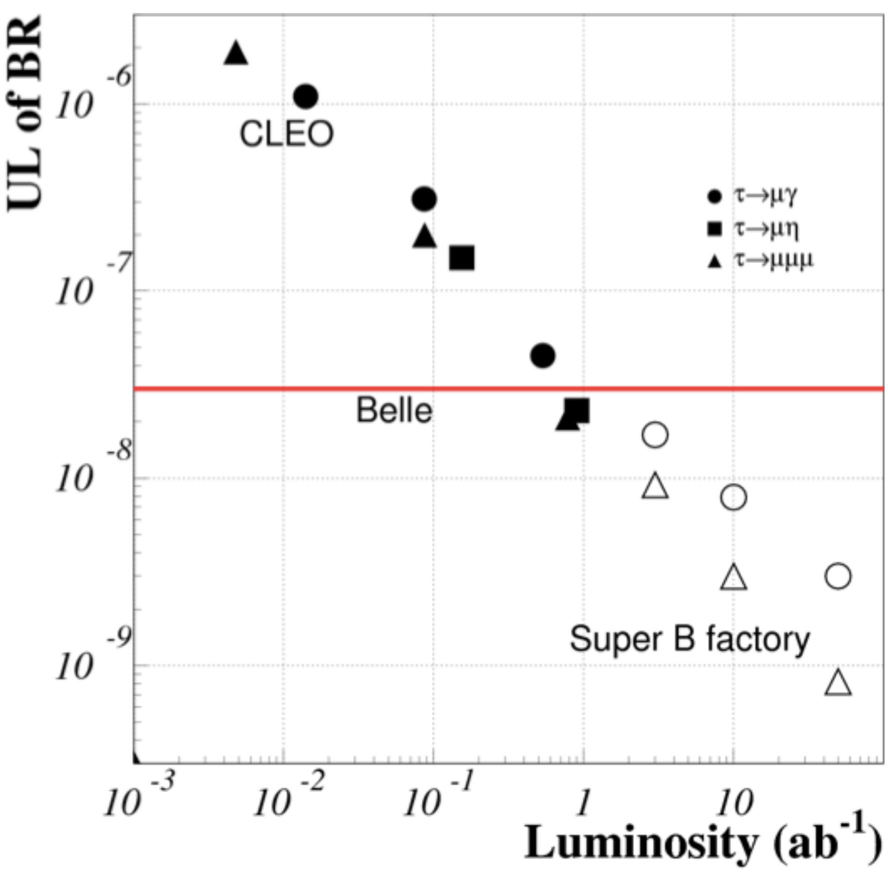
2015→



End of slides

Prospects for τ LFV at Belle II

- Belle II will collect $\sim 10^{11}$ τ-leptons (50/ab)
- Sensitivity depends on the background level
  - $\tau \to 3l$ still clean even at Belle II
  - For $\tau \to \mu\gamma$ better understanding of backgrounds, signal resolution and intelligent selections are needed



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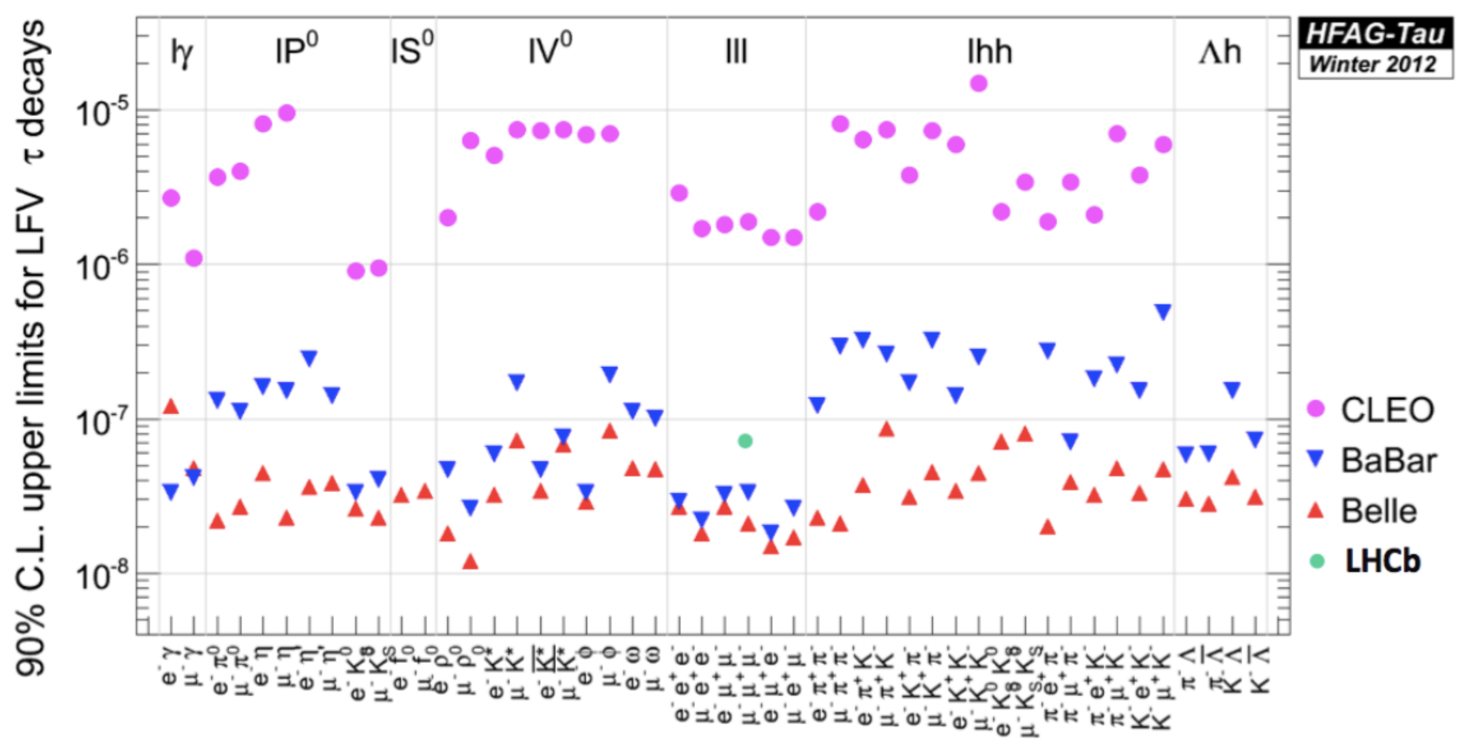
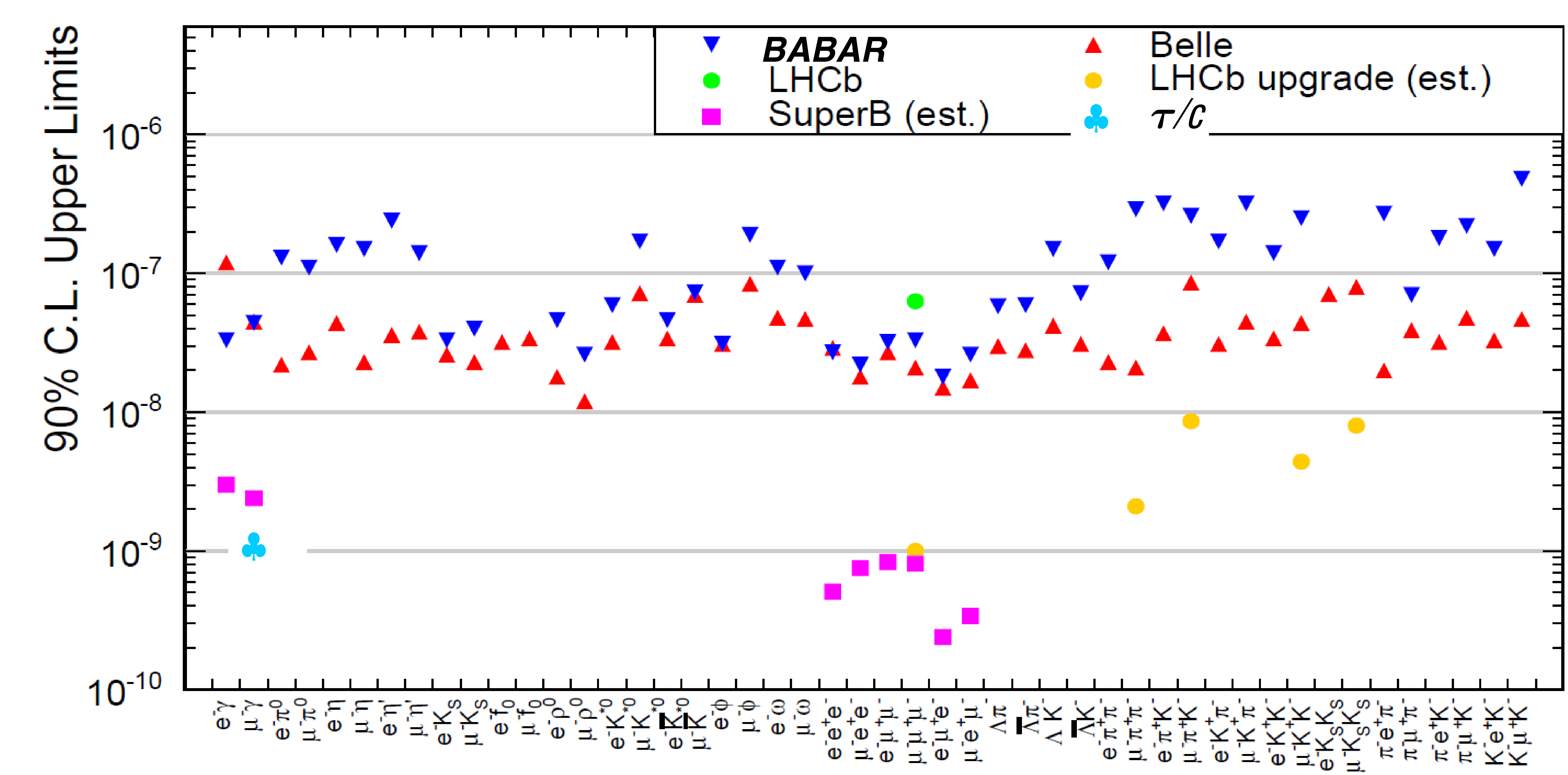
Summary Belle τ LFV results



48 modes searched for, U.L.s around ~10^{-8}

Super e^+e^- factory sensitivity directly confronts New Physics models of CLFV



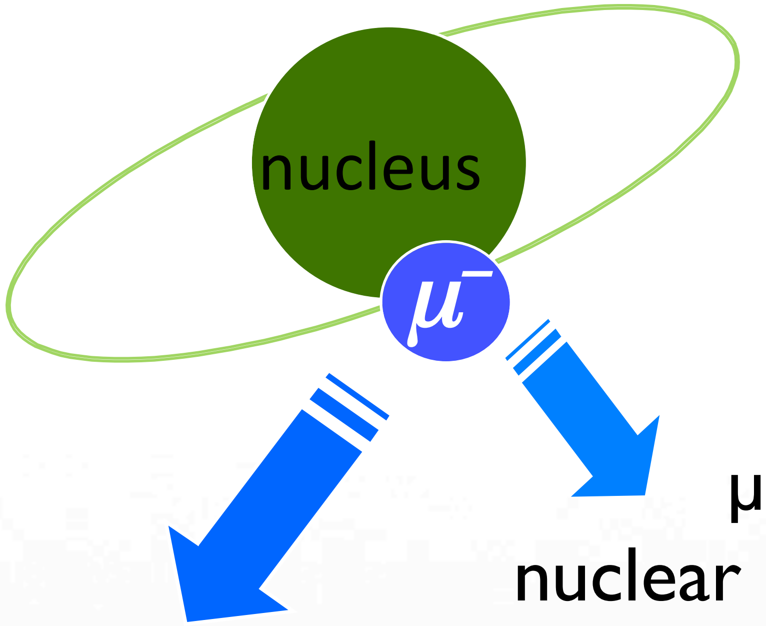
Mode	*BABAR* ($\times 10^{-8}$)	Belle ($\times 10^{-8}$)	Super*B* ($\times 10^{-8}$)
$\tau^{\pm} \to e^{\pm}\gamma$	3.3	12	0.3
$\tau^{\pm} \to \mu^{\pm}\gamma$	4.4	4.5	0.2
$\tau^{\pm} \to \mu^{\pm}\mu^{+}\mu^{-}$	3.3	2.1	0.08
$\tau^{\pm} \to e^{\pm}e^{+}e^{-}$	2.9	2.7	0.02

Summary of results in LFV searches

channel	limit		
$\mathcal{B}(B^- \to \pi^+ e^- e^-)$	$< 2.3 \times 10^{-8}$	@90 % CL	[a]
$\mathcal{B}(B^- \to K^+ e^- e^-)$	$< 3.0 \times 10^{-8}$	@90 % CL	[a]
$\mathcal{B}(B^- \to K^{*+} e^- e^-)$	$< 2.8 \times 10^{-6}$	@90 % CL	[b]
$\mathcal{B}(B^- \to \rho^+ e^- e^-)$	$< 2.6 \times 10^{-6}$	@90 % CL	[b]
$\mathcal{B}(B^- \to D^+ e^- e^-)$	$< 2.6 \times 10^{-6}$	@90 % CL	[c]
$\mathcal{B}(B^- \to D^+ e^- \mu^-)$	$< 1.8 \times 10^{-6}$	@90 % CL	[c]
$\mathcal{B}(B^- \to \pi^+ \mu^- \mu^-)$	$< 1.3 \times 10^{-8}$	@95 % CL	[d]
$\mathcal{B}(B^- \to K^+ \mu^- \mu^-)$	$< 5.4 \times 10^{-7}$	@95 % CL	[e]
$\mathcal{B}(B^- \to D^+ \mu^- \mu^-)$	$< 6.9 \times 10^{-7}$	@95 % CL	[d]
$\mathcal{B}(B^- \to D^{*+} \mu^- \mu^-)$	$< 2.4 \times 10^{-6}$	@95 % CL	[d]
$\mathcal{B}(B^- \to D_s^+ \mu^- \mu^-)$	$< 5.8 \times 10^{-7}$	@95 % CL	[d]
$\mathcal{B}(B^- \to D^0 \pi^- \mu^- \mu^-)$	$< 1.5 \times 10^{-6}$	@95 % CL	[d]

[a] BaBar, Phys. Rev. D **85**, 071103 (2012)
[b] CLEO, Phys. Rev. D **65**, 111102 (2002)
[c] Belle, Phys. Rev. D **84**, 071106(R), (2011)
[d] LHCb, Phys. Rev. D **85**,112004 (2012)
[e] LHCb, Phys. Rev. Lett. 108 101601 (2012)

$\mu Z \to eZ$



$\mu Z \to \nu Z$
nuclear muon capture

$\mu \to e\nu\nu$
muon decay in orbit

But also neutrinoless nuclear capture $\mu Z \to eZ$...

Only one particle in final state: no accidental background issue.
Background scales only linearly with beam rate → very big chance to explore extremely low BR...

Looking for single monoenergetic electron: $E_e \sim E_\mu - B_\mu$ (recoil energy negligible)

Background coming from:
- μ decay in orbit
- radiative μ capture

Beam related background:
- π and e contaminations

→

improving detector resolutions

high purity environment:
curved solenoid with gradient field
pulsed beam with challenging extinction time

μZ→eZ status

μN→eN status

Current limit by SINDRUM II:

• The current limit comes from SINDRUM II

BR(μTi→eTi)< 4.3×10^{-12}

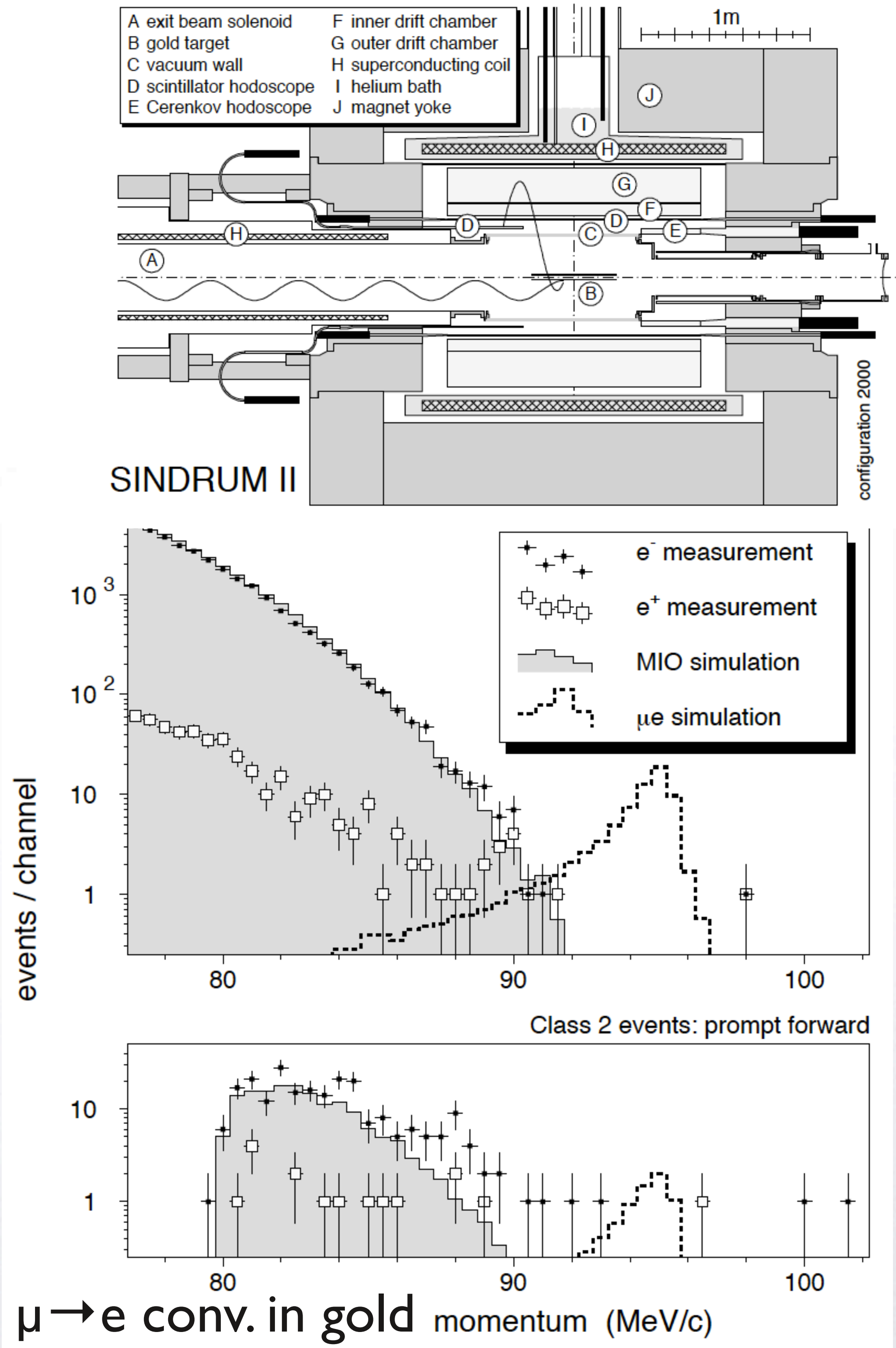
BR(μ

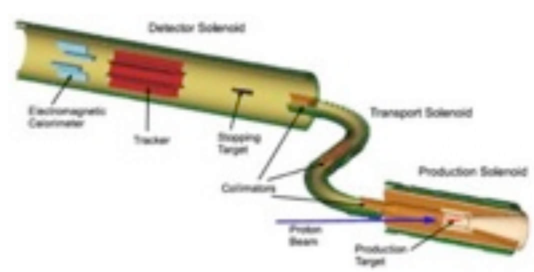
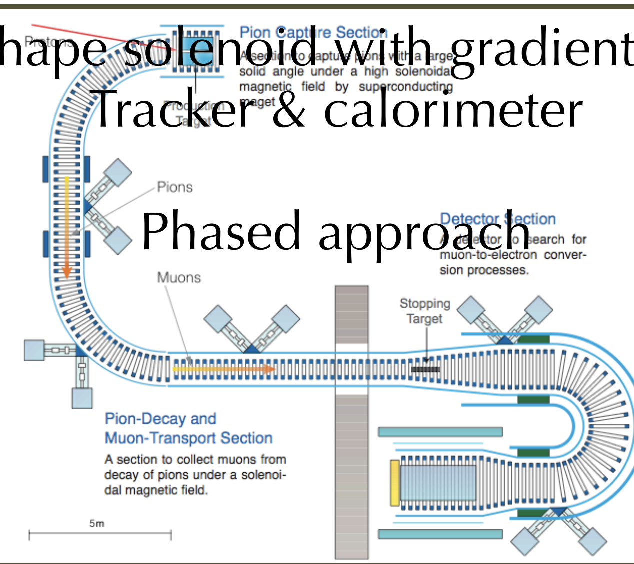
BR(μAu→eAu)< 7×10^{-13}

Beam intensity: 3×10^{7} μ/s (@PSI)

Energy of emitted electrons is measured with a cylindrical magnetic spectrometer: drift chamber and scintillators/Cerenkov hodoscope.

SINDRUM II parameters:
- beam intensity: 3×10^{7} μ/s
- μ momentum: 53 MeV/c
- magnetic field: 0.33T
- acceptance: 7%
- momentum res.: 2% FWHM
- S.E.S 3.3×10^{-13}

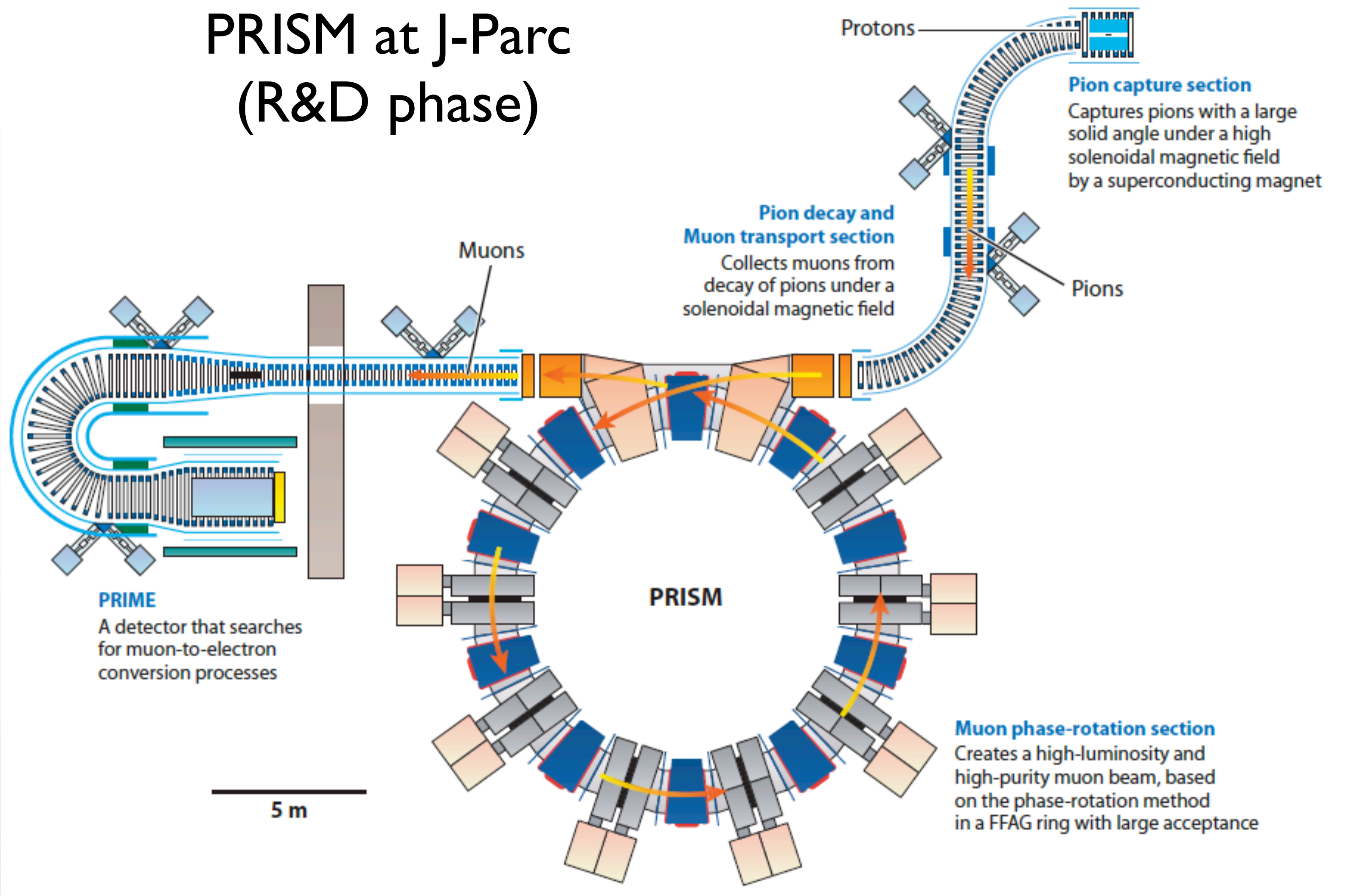


<table>
<tr><th></th><th>Mu2e</th><th>COMET</th></tr>
<tr><td>Proton Beam</td><td>8 GeV, 8kW
bunch-bunch spacing 1.69 μsec
rebunching
Extinction: < 10^{-10}</td><td>8 GeV, 50kW
bunch-bunch spacing 1.18-1.76 μsec
empty buckets
Extinction: < 10^{-9}</td></tr>
<tr><td>Muon Transport</td><td>S-shape solenoid</td><td>C-shape solenoid</td></tr>
<tr><td>Detector</td><td>Straight Solenoid w/gradient field
Tracker and Calorimeter

</td><td>C-shape solenoid with gradient field
Tracker & calorimeter
Phased approach

</td></tr>
<tr><td>Sensitivity</td><td>SES: 2 x 10^{-17}
90% CL U.L.: 6 x 10^{-17}</td><td>SES: 2.6 x 10^{-17}
90% CL U.L.: 6 x 10^{-17}</td></tr>
</table>

Aiming for a 10^{-18} search with an extreme high intensity ($10^{11} \div 10^{12}$ μ/s) beam with μ storage ring.

Fixed-field alternating gradient synchrotron perform conversion from original short-pulse beam with high momentum spread (30%) into a long pulse beam with narrow momentum spread (3%).

PRISM at J-Parc
(R&D phase)



Key elements to MEG^{UP}

μ

1. Increasing μ^+–stop on target
2. Reducing target thickness to minimize e+ MS & brehmsstrahlung

e

3. Replacing the e+ tracker reducing its radiation length and improving its granularity and resolutions
4. Improving the timing counter granularity for better timing and reconstruction
5. Improving the positron tracking-timing integration by measuring the e+ trajectory up to the TC interface

γ

6. Extending the γ–ray detector acceptance
7. Improving the γ-ray energy and position resolution for shallow events
8. Integrating splitter, trigger and DAQ maintaining a high bandwidth

CLFV Programs