Searches for Lepton Flavor Violation

An Experimental Review

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BLV17
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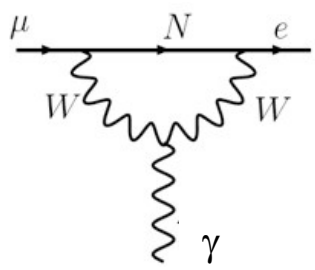
Charged lepton flavor violation

- The existence of neutrino oscillations is proof of the violation of lepton flavor conservation in the ν sector, as well as evidence for BSM physics (*e.g.,* see-saw)
- Is there also observable charged lepton flavor violation (CLFV) ?
  - In the Standard Model (+ heavy neutrinos), CLFV is very small, *e.g.*,

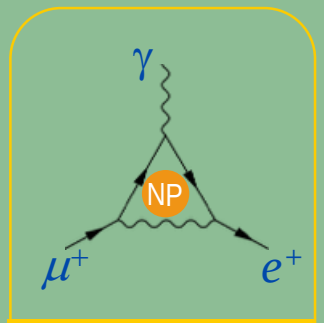


$$\mathcal{B}(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{1i}}{M^2_W}\right|^2 < 10^{-54}$$

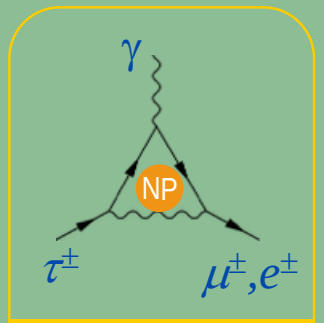
  - Thus CLFV searches are a clean probe of new physics
  - Many models predict CLFV processes to occur in an observable regime
  - Sensitivity to CLFV in loop processes can exceed that in direct production
    - There are many distinct experimental probes and a rich phenomenology, leading to a robust experimental scene
    - The form of the CLFV Yukawa coupling matrix is model-dependent, *e.g.,* it could be PMNS-like or CKM-like?
    - Different theories predict distinct correlations between CLFV processes Should, for example, $\mu \to e\gamma$ decay be observed, it is important to understand the rate of μ to e conversion or $\tau \to \mu\gamma$ decay

CLFV Processes

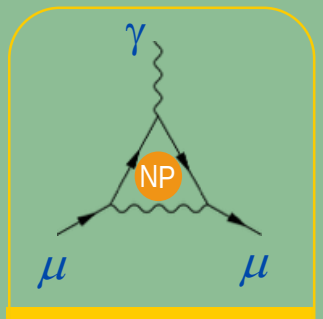
- Low energy probes: rare μ, τ and h decays, $\mu \to e$ conversion, CLFV in meson decay



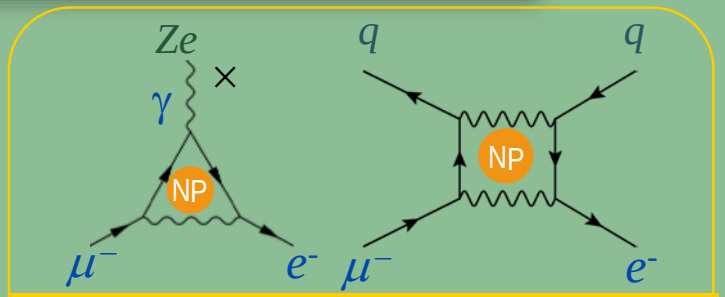
$\mu^+ \to e^+\gamma$



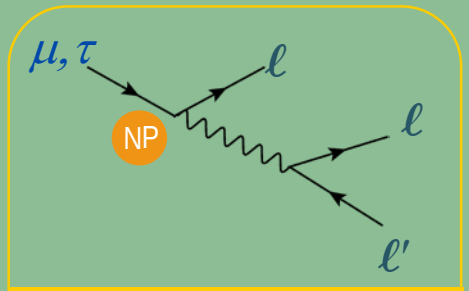
$\tau \to \mu\gamma$, eγ



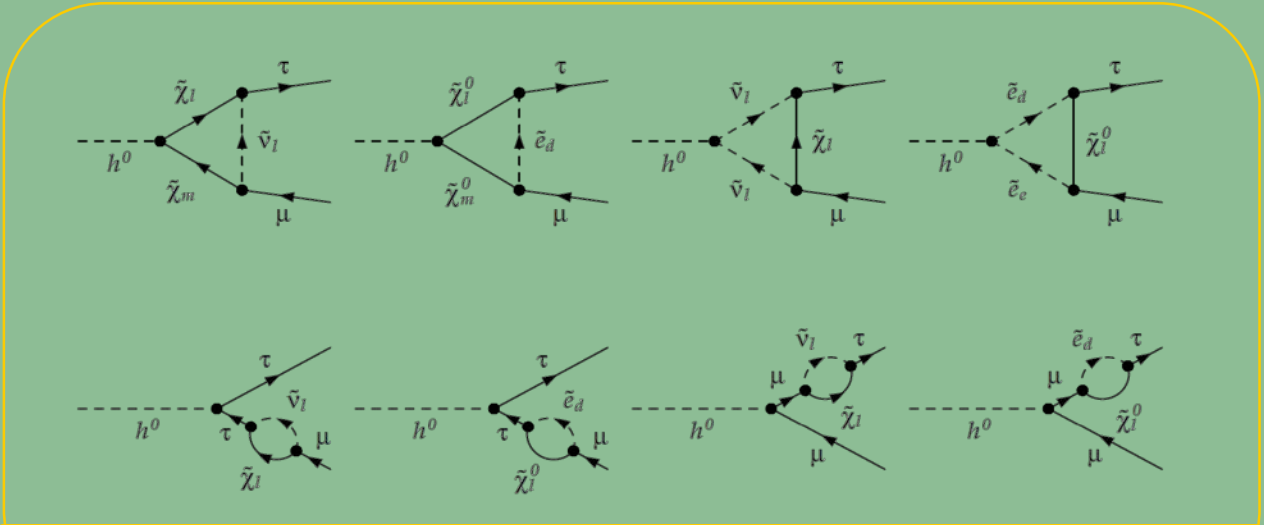
$(g\text{-}2)_\mu$



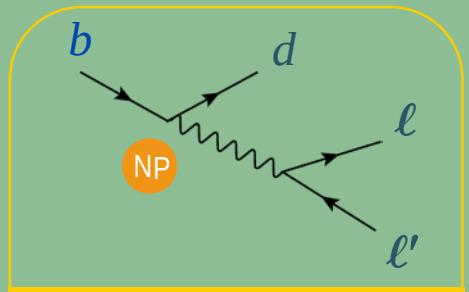
$\mu^- \mathrm{N} \to e^- \mathrm{N}$



$\mu, \tau \to 3\ell$



Higgs decay: $h^0 \to \tau\,\mu$ (also $\tau\,e$, $\mu\,e$)

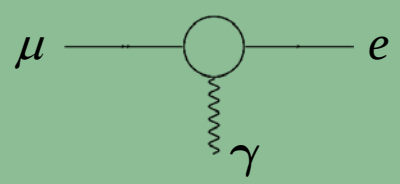


$B \to \ell\ell'$

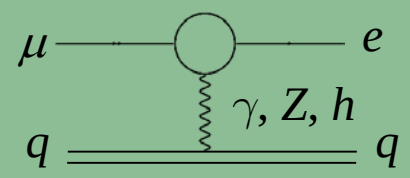
$B \to X_s \ell\ell'$

The new CLFV physics NP

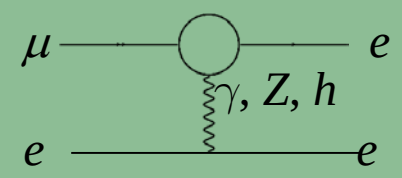
$\mu^+ \to e^+\gamma$

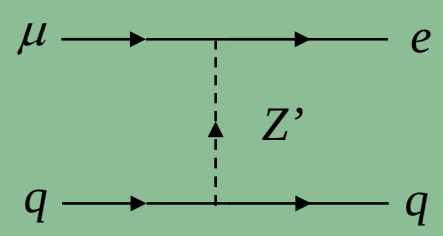


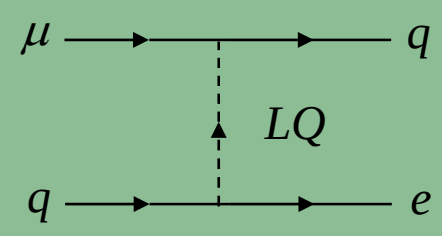
$\mu^- \mathrm{N} \to e^- \mathrm{N}$



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







+ analagous τ decay processes

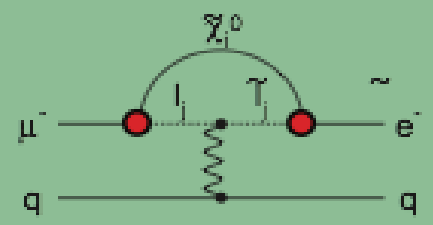
CLFV rates and ratios are sensitive probes of underlying model

New Physics contributions to $\mu \to e$ conversion

$\mu N \to eN$ is sensitive to a wide variety of New Physics models, *e.g.*, SUSY, 2HDM, Extra Dimensions, LeptoQuarks, GUTs, LHT,…

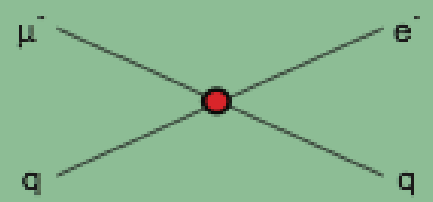
Supersymmetry

rate ~ 10^{-15}



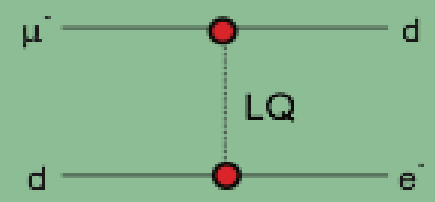
Compositeness

Λ_c ~ 3000 TeV



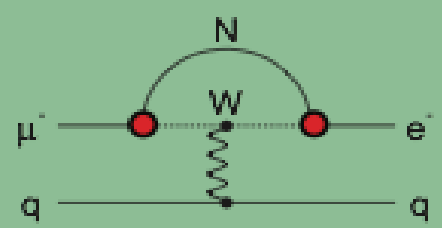
Leptoquark

M_{LQ} = 3000 $(\lambda_{\mu d}\lambda_{ed})^{1/2}$ TeV/c^2



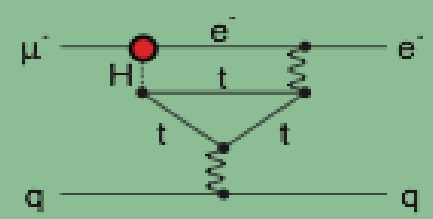
Heavy Neutrinos

$|U_{\mu N}U_{eN}|^2$ ~ 8×10^{-13}



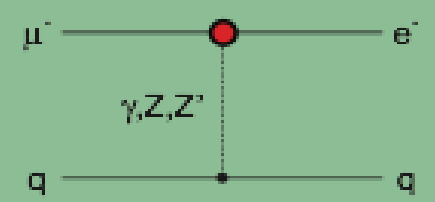
Second Higgs Doublet

$g(H_{\mu e})$ ~ $10^{-4} g(H_{\mu\mu})$



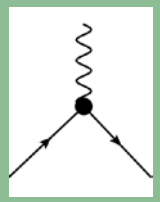
Heavy Z' Anomal. Z Coupling

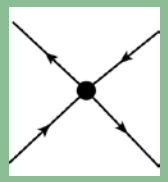
$M_{Z'}$ = 3000 TeV/c^2



Model-independent Effective Lagrangian

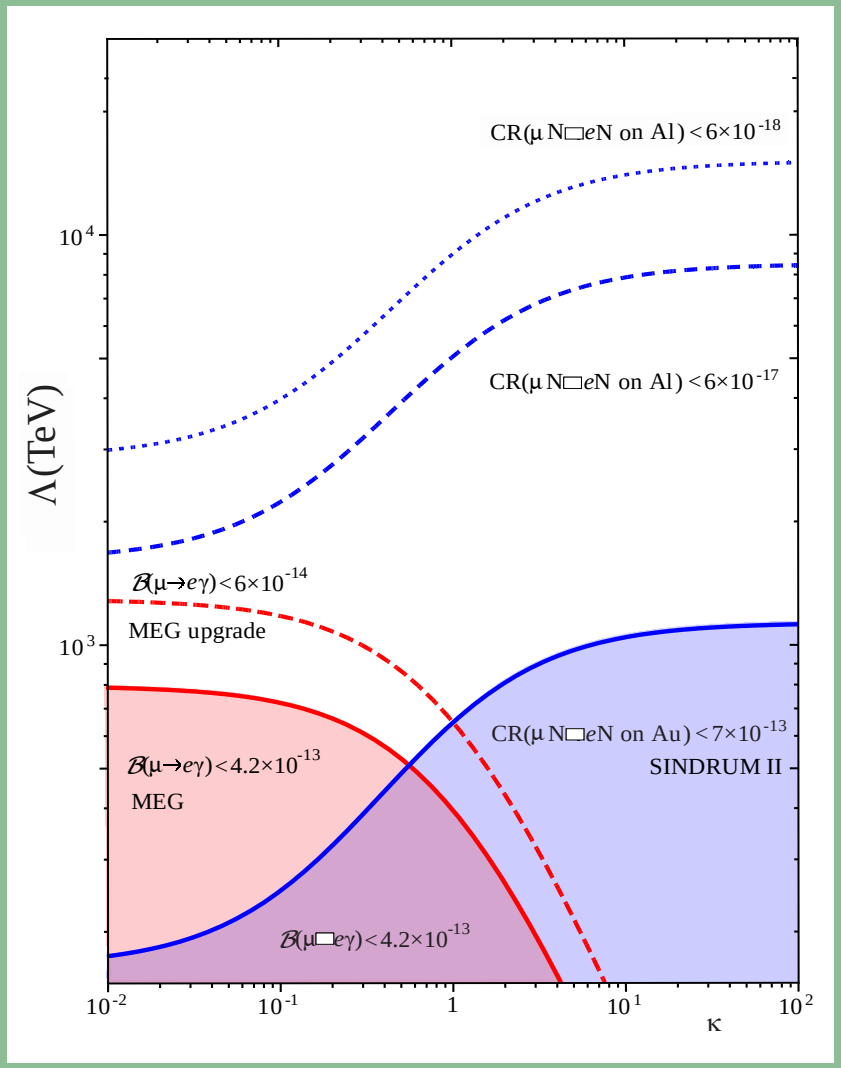
$$\mathcal{L}_{\mathrm{CLFV}} = \frac{m_\mu}{(1+\kappa)\Lambda^2}\bar{\mu}_R \sigma_{\mu\nu} e_L F^{\mu\nu} + \frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L \gamma_\mu e_L (\bar{u}_L \gamma_\mu u_L + \bar{d}_L \gamma_\mu d_L) + h.c.$$





Dipole (SUSY, ……)	Contact (Z', leptoquarks, …
$\mu \to e\gamma$	[$\mu \to eee$] $\mu - e$ conversion

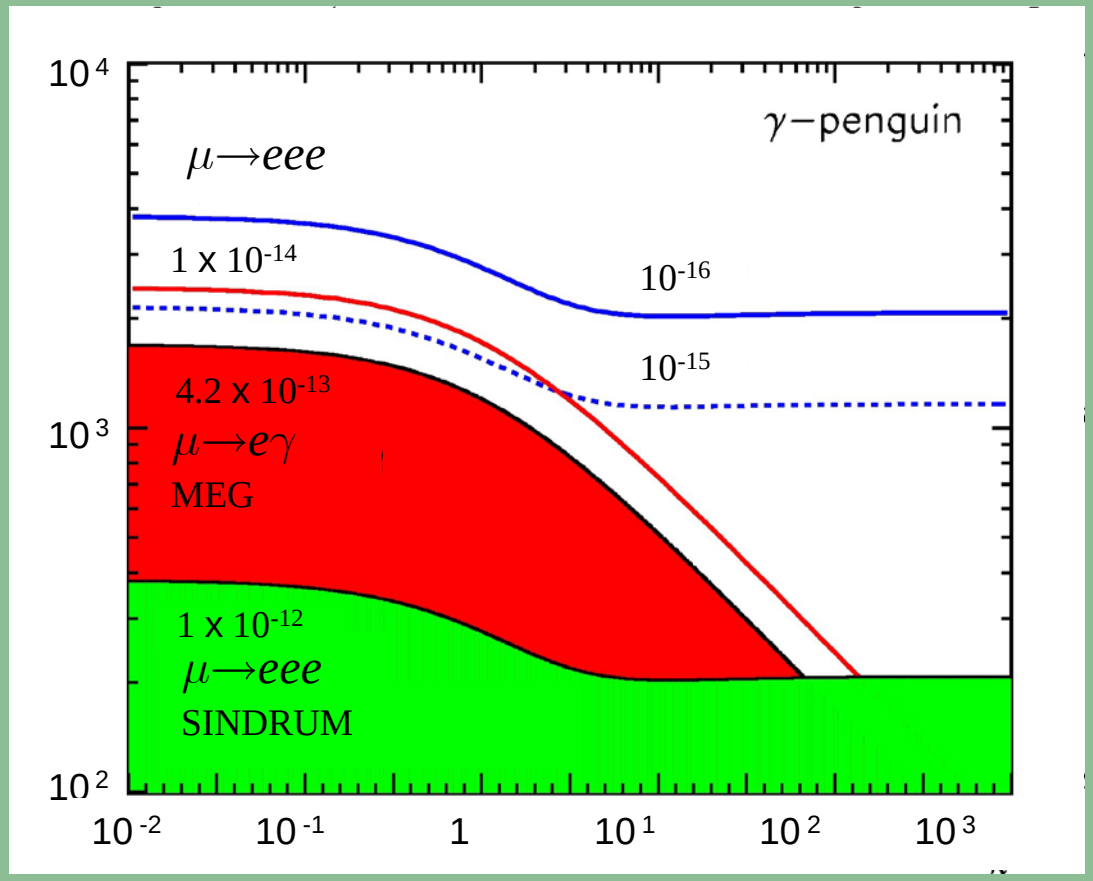
CLFV processes have unique sensitivity to New Physics at high mass scales

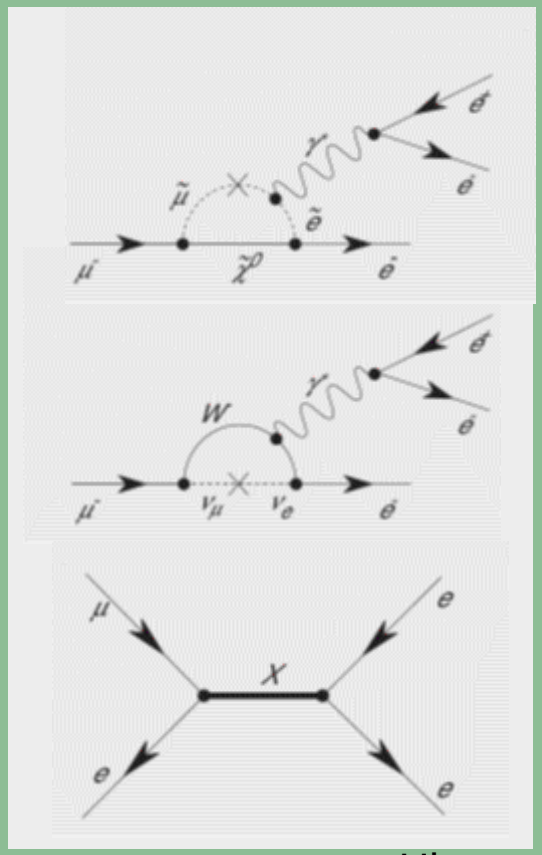


Derived from A. de Gouvêa, P. Vogel, Prog.Part.Nucl.Phys 71, 75 (2013)

Purely leptonic case: $\mu \to e\gamma$, $\mu \to 3e$

$$\mathcal{L}_{\mathrm{CLFV}} = \frac{m_\mu}{(1+\kappa)\Lambda^2}\bar{\mu}_R \sigma_{\mu\nu} e_L F^{\mu\nu} + \frac{\kappa}{(1+\kappa)\Lambda^2}\bar{\mu}_L \gamma_\mu e_L (\bar{e}_L \gamma_\mu e_L) + h.c.$$





Hisano

Bounds on Higgs exchange models

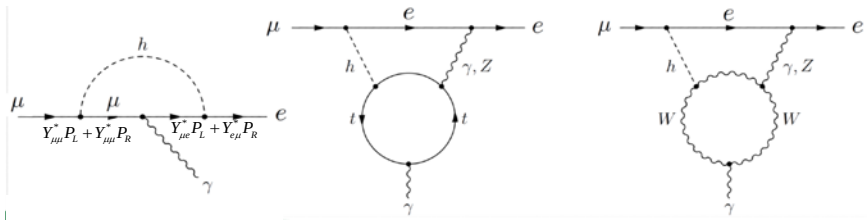
$$\begin{pmatrix} Y_{ee} & Y_{e\mu} & Y_{e\tau} \\ Y_{\mu e} & Y_{\mu\mu} & Y_{\mu\tau} \\ Y_{\tau e} & Y_{e\mu} & Y_{\tau\tau} \end{pmatrix}$$

- Bounds on CLFV couplings to the Higgs can be derived from LHC limits as well as conventional leptonic processes

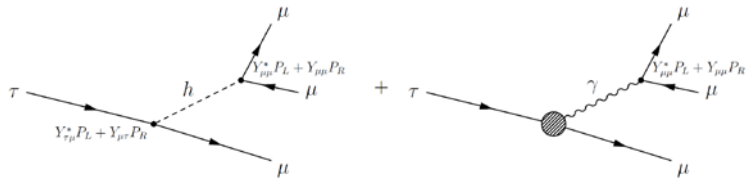
$$\mathcal{L}_Y \supset -Y_{e\mu}\bar{e}_L\mu_R h - Y_{\mu e}\bar{\mu}_L e_R h - Y_{e\tau}\bar{e}_L\tau_R h - Y_{\tau e}\bar{\tau}_L e_R h - Y_{\mu\tau}\bar{\mu}_L\tau_R h - Y_{\tau\mu}\bar{\tau}_L\mu_R h + h.c..$$

CLFV Higgs decay $\Gamma(h \to \ell^\alpha \ell^\beta) = \frac{m_h}{8\pi}\left(|Y_{\ell^\beta \ell^\alpha}|^2 + |Y_{\ell^\alpha \ell^\beta}|^2\right)$

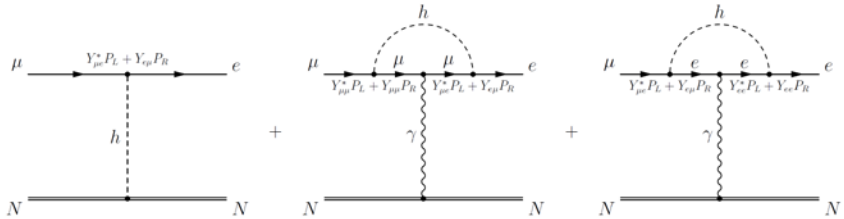
$\mu \to e\gamma \;\; (\tau \to \mu\gamma)$



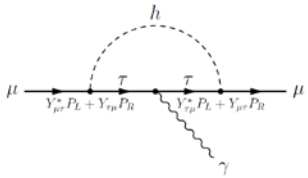
$\mu \to 3e \;\; (\tau \to \ell'\ell\ell)$



$\mu N \to eN$



g-2



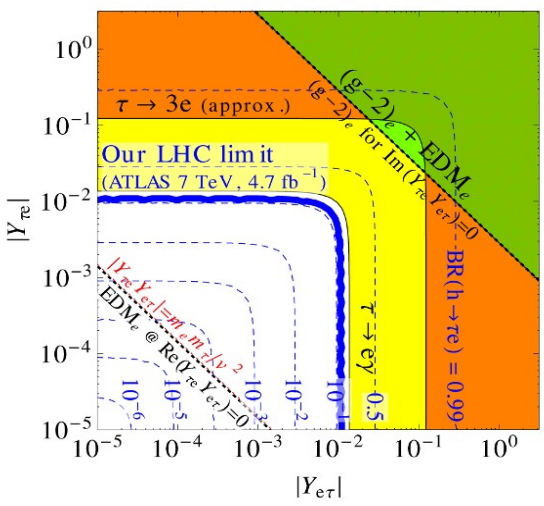
Current CLFV limits

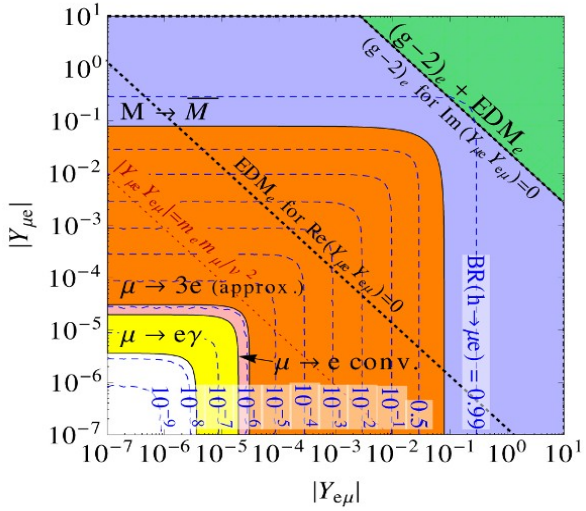
Process	Current Limit	Next Generation exp
$\tau \to \mu\eta$	BR < 6.5 x 10^{-8}	
$\tau \to \mu\gamma$	BR < 6.8 x 10^{-8}	10^{-9} - 10^{-10} (Belle II)
$\tau \to \mu\mu\mu$	BR < 3.2 x 10^{-8}	
$\tau \to eee$	BR < 3.6 x 10^{-8}	
$K_L \to e\mu$	BR < 4.7 x 10^{-12}	
$K^+ \to \pi^+ e^- \mu^+$	BR < 1.3 x 10^{-11}	
$B^0 \to e\mu$	BR < 7.8 x 10^{-8}	
$B^+ \to K^+ e\mu$	BR < 9.1 x 10^{-8}	
$\mu^+ \to e^+\gamma$	BR < 4.2 x x 10^{-13}	10^{-14} (MEG Upgrade)
$\mu^+ \to e^+e^+e^-$	BR < 1.0 x 10^{-12}	10^{-16} (Mu3e)
$\mu N \to eN$	$R_{\mu e}$ < 7.0 x 10^{-13}	10^{-17} (Mu2e, COMET)

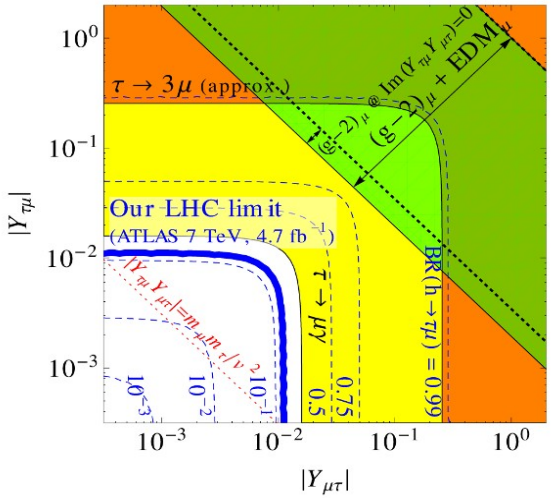
Limits on Higgs CLFV couplings

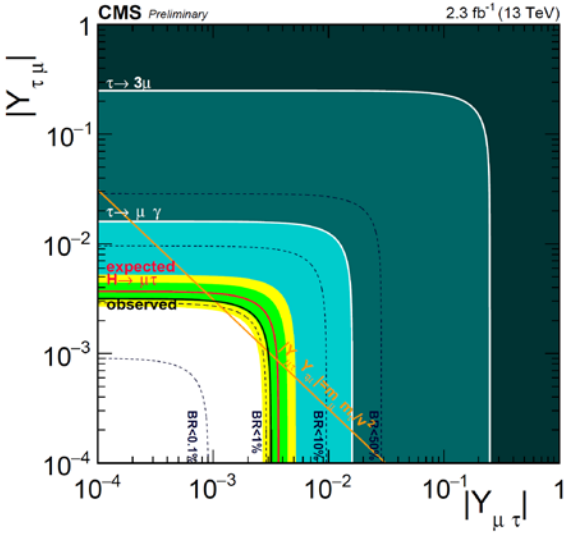
Channel	Coupling	Bound
$\mu \to e\gamma$	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	$< 3.6 \times 10^{-6}$
$\mu \to 3e$	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	< 0.31
electron $g-2$	$\mathrm{Re}(Y_{e\mu} Y_{\mu e})$	$-0.019 \ldots 0.026$
electron EDM	$\lvert\mathrm{Im}(Y_{e\mu} Y_{\mu e})\rvert$	$< 9.8 \times 10^{-8}$
$\mu \to e$ conversion	$\sqrt{\lvert Y_{\mu e}\rvert^2 + \lvert Y_{e\mu}\rvert^2}$	$< 4.6 \times 10^{-5}$
M-$\bar{M}$ oscillations	$\lvert Y_{\mu e} + Y^*_{e\mu}\rvert$	< 0.079
$\tau \to e\gamma$	$\sqrt{\lvert Y_{\tau e}\rvert^2 + \lvert Y_{e\tau}\rvert^2}$	< 0.014
$\tau \to e\mu\mu$	$\sqrt{\lvert Y_{\tau e}\rvert^2 + \lvert Y_{e\tau}\rvert^2}$	< 0.66
electron $g-2$	$\mathrm{Re}(Y_{e\tau} Y_{\tau e})$	$[-2.1 \ldots 2.9] \times 10^{-3}$
electron EDM	$\lvert\mathrm{Im}(Y_{e\tau} Y_{\tau e})\rvert$	$< 1.1 \times 10^{-8}$
$\tau \to \mu\gamma$	$\sqrt{\lvert Y_{\tau\mu}\rvert^2 + \lvert Y_{\mu\tau}\rvert^2}$	$< 3.16 \times 10^{-3}$
$\tau \to 3\mu$	$\sqrt{\lvert Y^2_{\tau\mu} + \lvert Y_{\mu\tau}\rvert^2}$	< 0.52
muon $g-2$	$\mathrm{Re}(Y_{\mu\tau} Y_{\tau\mu})$	$(2.7 \pm 0.75) \times 10^{-3}$
muon EDM	$\mathrm{Im}(Y_{\mu\tau} Y_{\tau\mu})$	$-0.8 \ldots 1.0$
$\mu \to e\gamma$	$\left(\lvert Y_{\tau\mu} Y_{\tau e}\rvert^2 + \lvert Y_{\mu\tau} Y_{e\tau}\rvert^2\right)^{1/4}$	$< 3.4 \times 10^{-4}$

Higgs Yukawa coupling limits

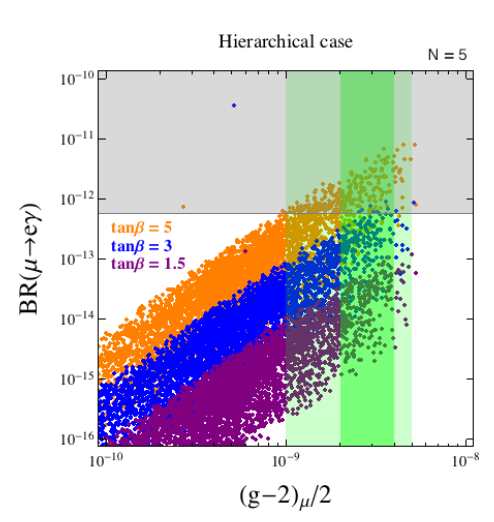




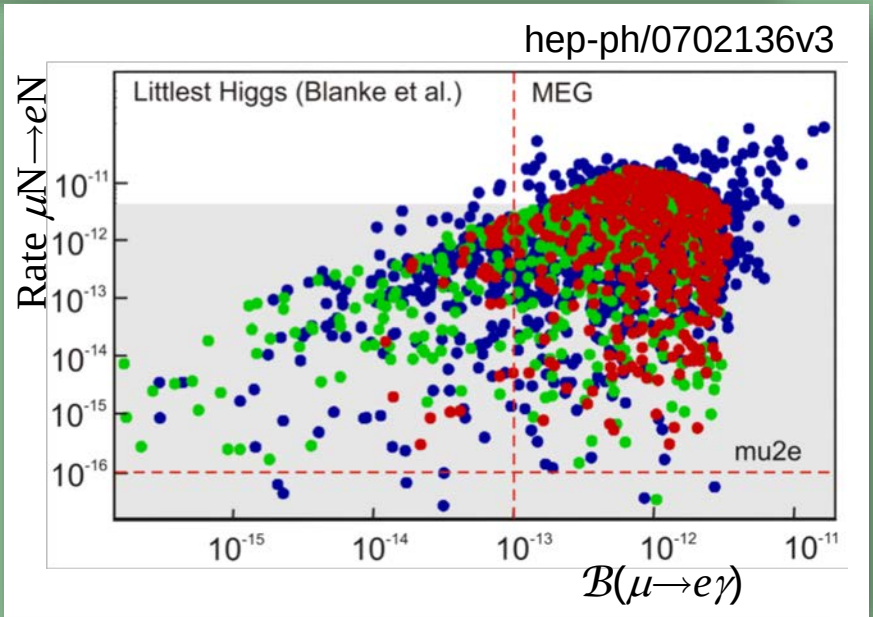




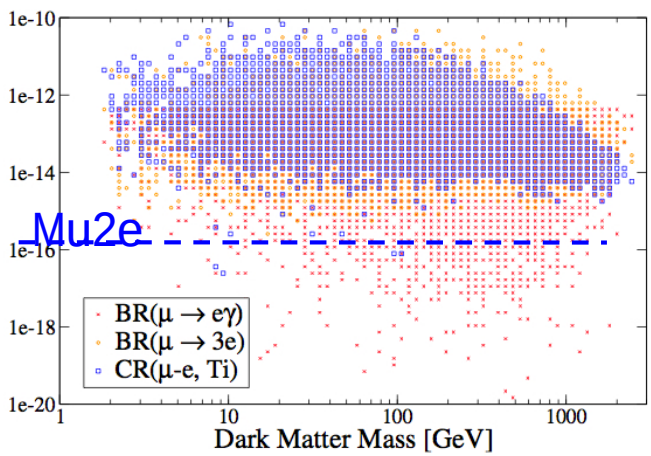
Model discrimination through correlations

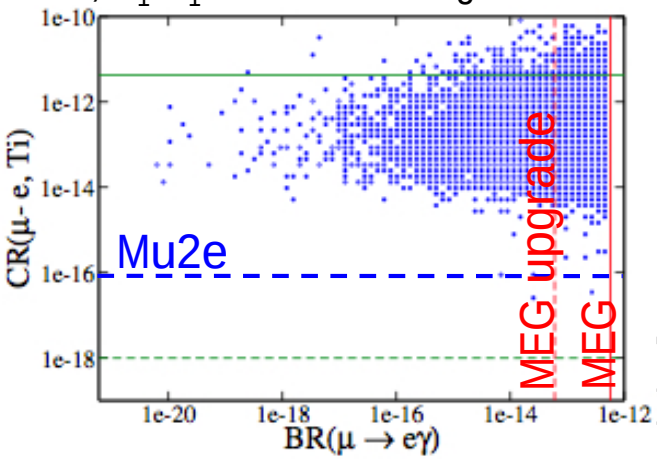


Calibbi et al *1408.0754*



A. Vicente & C.E. Yaguna – Scotogenic model, N_1-N_1 annihilation region

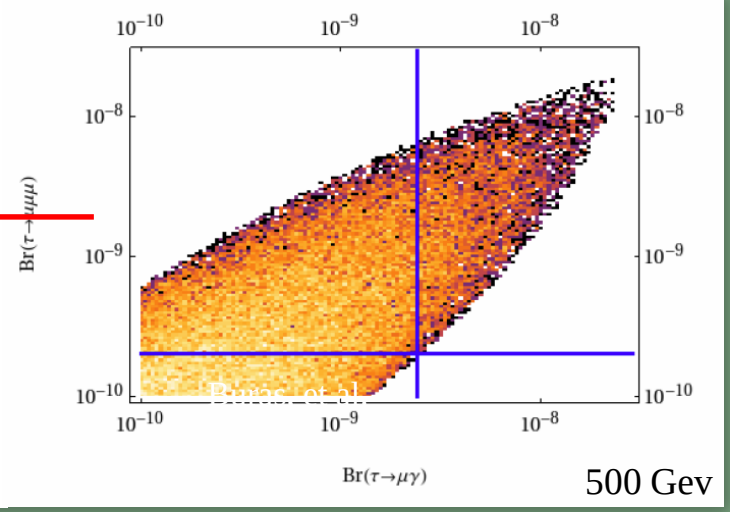




arXiv: 1412.2545 [hep-ph]

Model discrimination through correlations

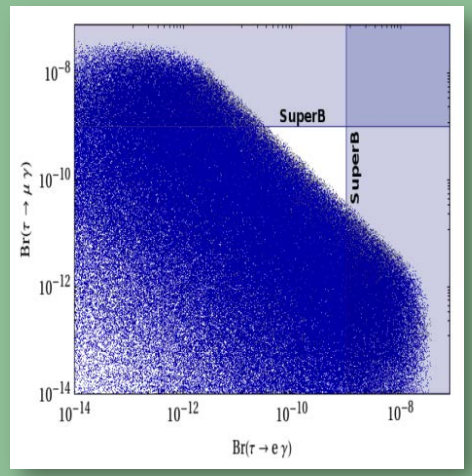
ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{Br(\mu^- \to e^- e^+ e^-)}{Br(\mu \to e\gamma)}$	$0.02\ldots1$	$\sim 6\cdot10^{-3}$	$\sim 6\cdot10^{-3}$
$\frac{Br(\tau^- \to e^- e^+ e^-)}{Br(\tau \to e\gamma)}$	$0.04\ldots0.4$	$\sim 1\cdot10^{-2}$	$\sim 1\cdot10^{-2}$
$\frac{Br(\tau^- \to \mu^- \mu^+ \mu^-)}{Br(\tau \to \mu\gamma)}$	$0.04\ldots0.4$	$\sim 2\cdot10^{-3}$	$0.06\ldots0.1$
$\frac{Br(\tau^- \to e^- \mu^+ \mu^-)}{Br(\tau \to e\gamma)}$	$0.04\ldots0.3$	$\sim 2\cdot10^{-3}$	$0.02\ldots0.04$
$\frac{Br(\tau^- \to \mu^- e^+ e^-)}{Br(\tau \to \mu\gamma)}$	$0.04\ldots0.3$	$\sim 1\cdot10^{-2}$	$\sim 1\cdot10^{-2}$
$\frac{Br(\tau^- \to e^- e^+ e^-)}{Br(\tau^- \to e^- \mu^+ \mu^-)}$	$0.8\ldots2.0$	~ 5	$0.3\ldots0.5$
$\frac{Br(\tau^- \to \mu^- \mu^+ \mu^-)}{Br(\tau^- \to \mu^- e^+ e^-)}$	$0.7\ldots1.6$	~ 0.2	$5\ldots10$
$\frac{R(\mu\mathrm{Ti} \to e\mathrm{Ti})}{Br(\mu \to e\gamma)}$	$10^{-3}\ldots10^{2}$	$\sim 5\cdot10^{-3}$	$0.08\ldots0.15$



There are correlations in the $\tau \to \mu\gamma$ and $\ell\ell\ell$ branching fractions

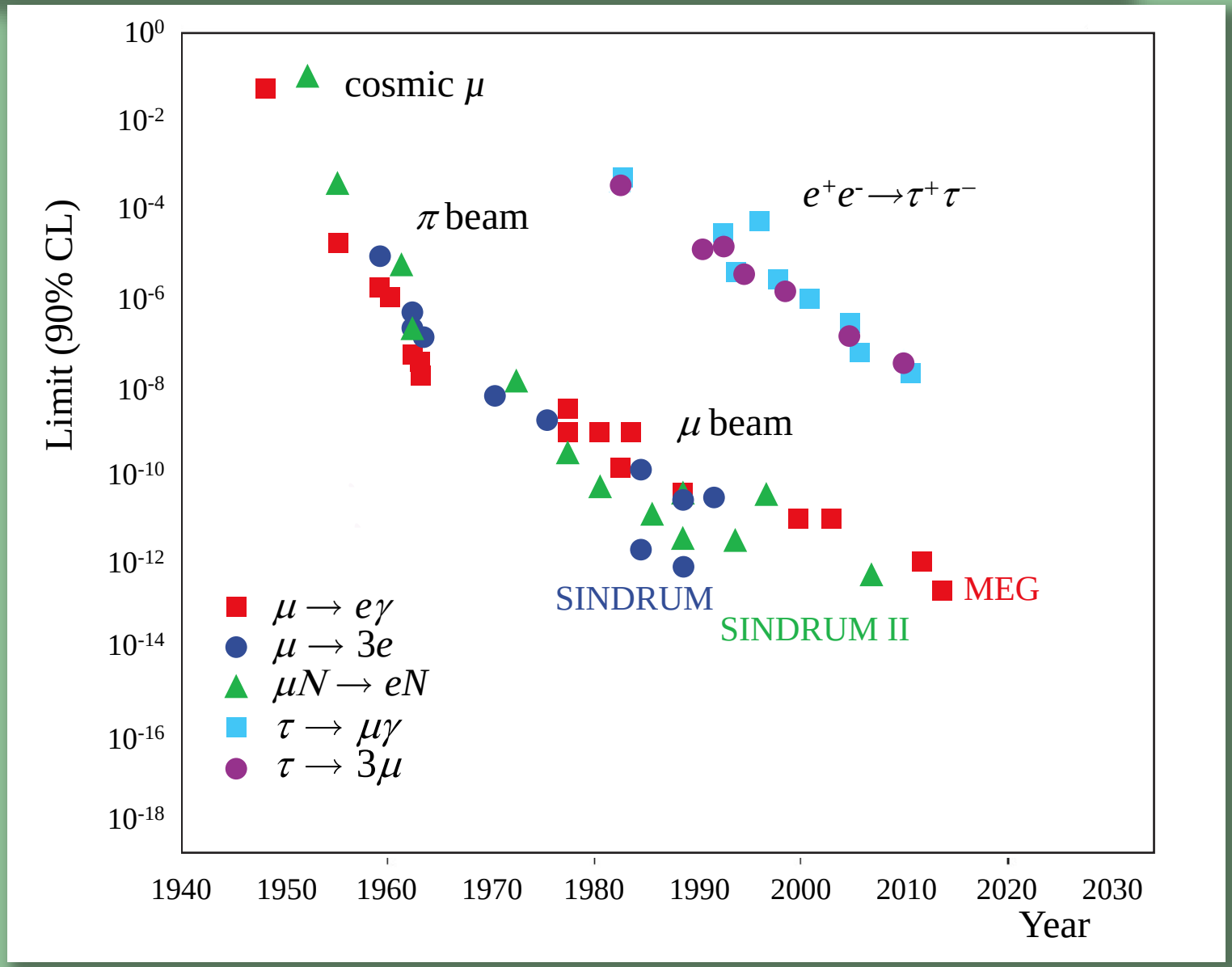
Blanke, Buras, Duling, Recksiegel & Tarantino, Acta Phys. Polon. B41, 657 (2010)

$\mathcal{B}(\tau \to \mu\gamma)$ vs. $\mathcal{B}(\tau \to e\gamma)$ in a general fourth generation scenario (Buras)

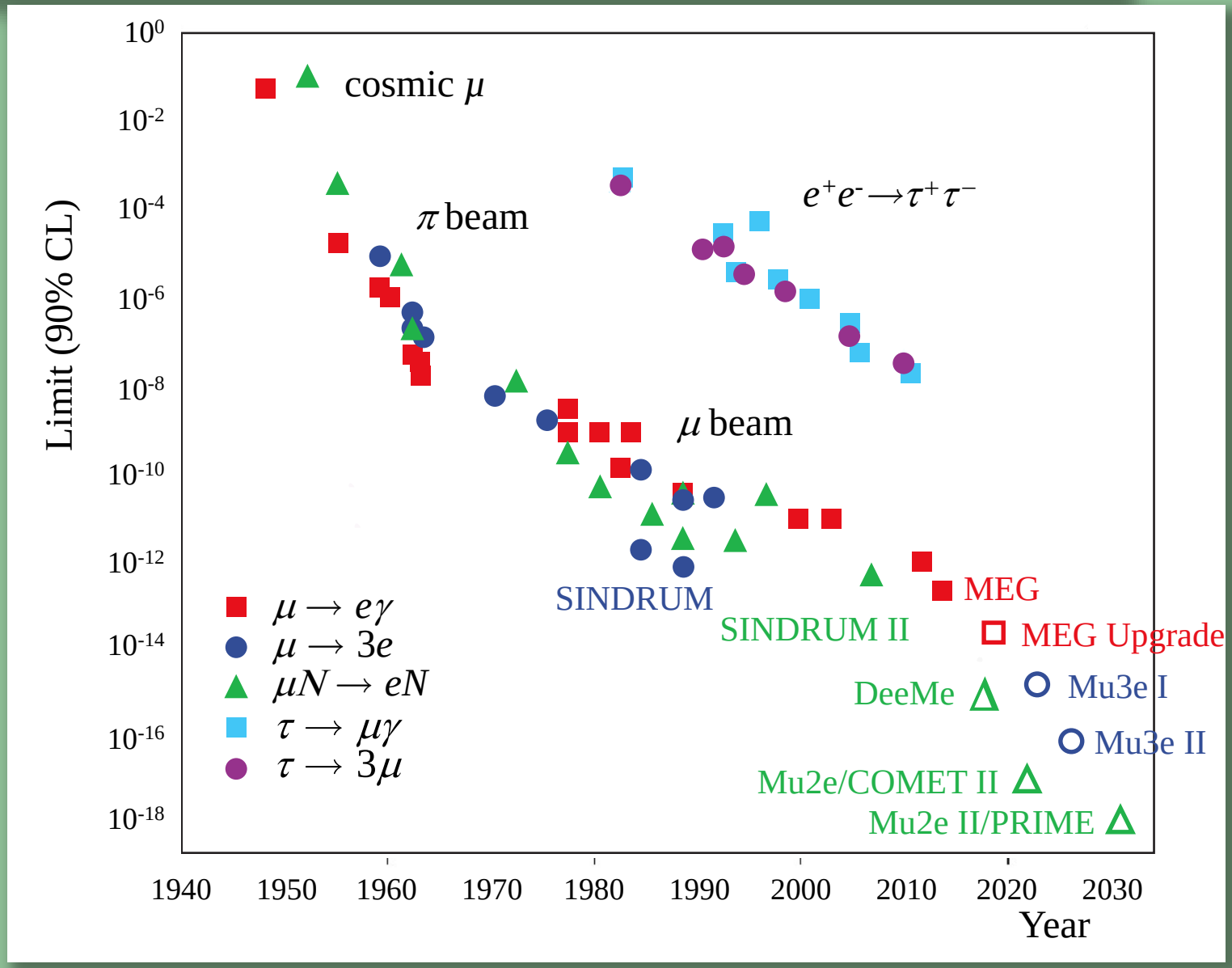


$\mathcal{B}(\tau \to \mu\gamma)$ vs. $\mathcal{B}(\tau \to e\gamma)$ are anticorrelated.
Seeing both modes would be evidence against a fourth generation

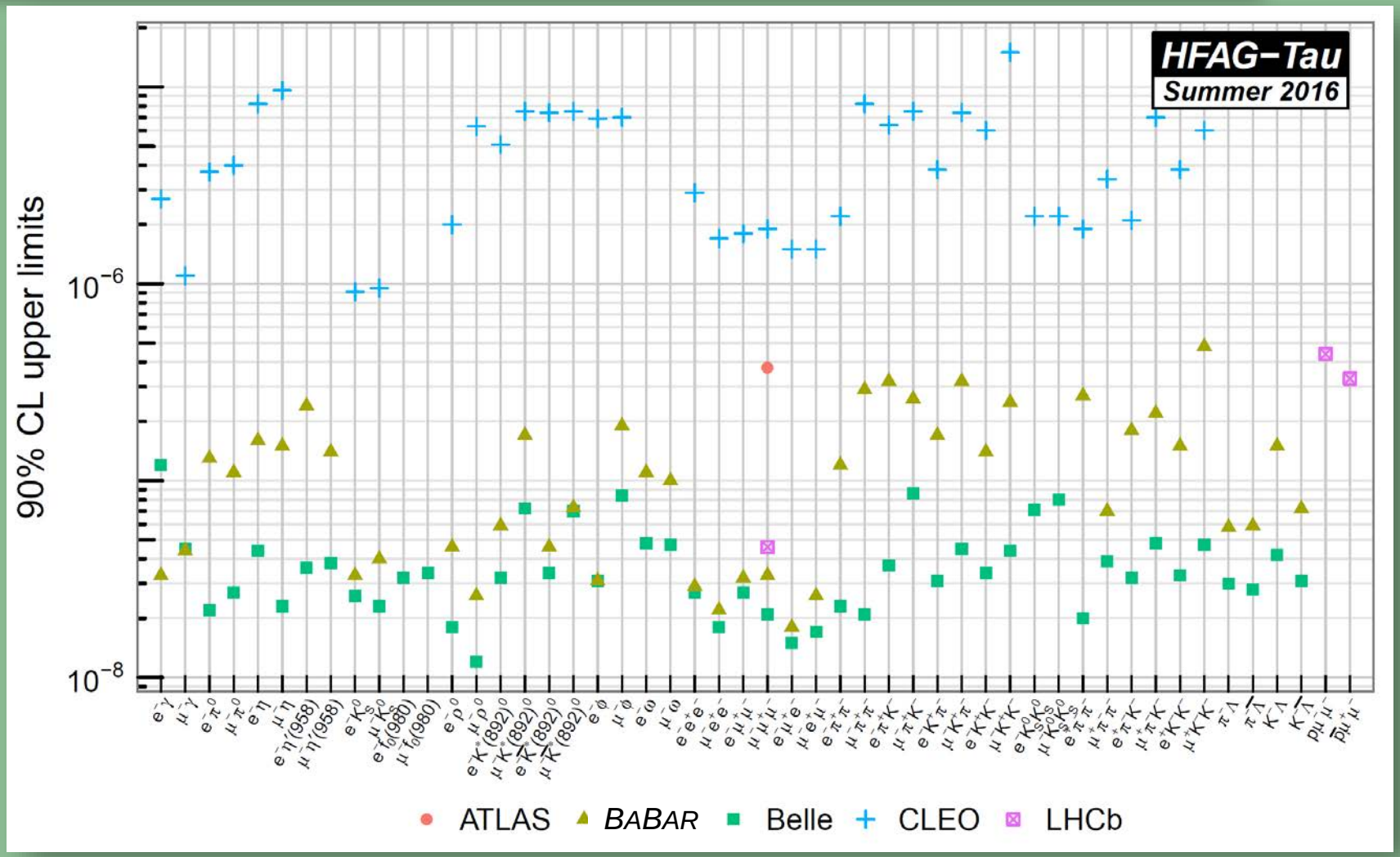
Chronology of μ and τ CLFV searches



Chronology of μ and τ CLFV searches



Limits on CLFV τ decays

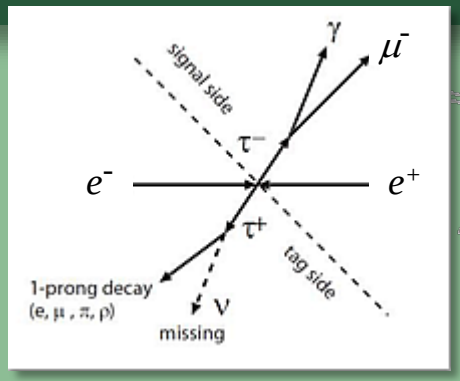


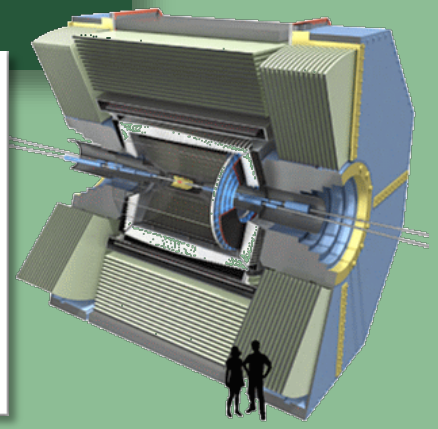
Backgrounds: the name of the game

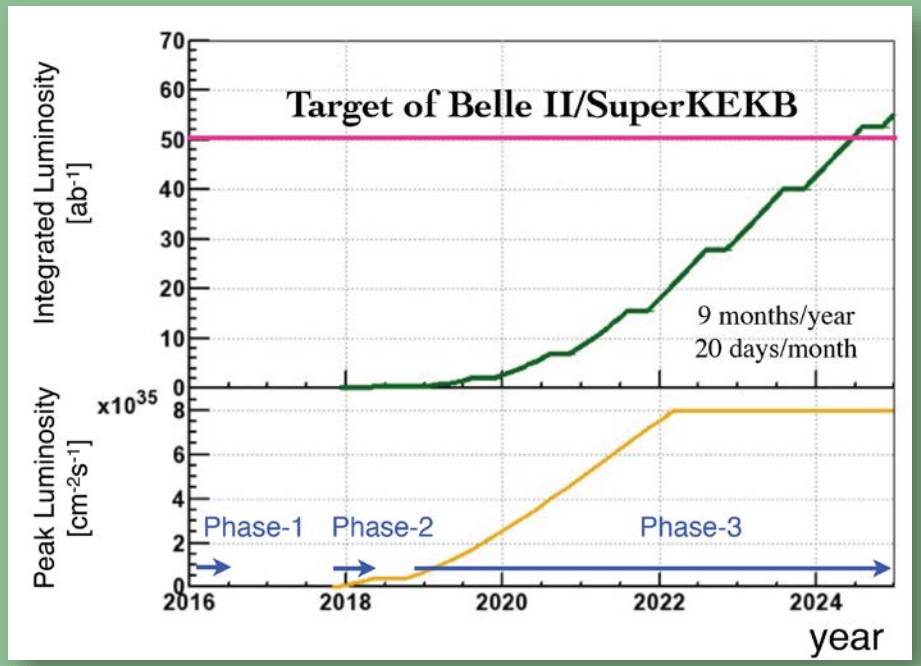
- At the sensitivities required to advance the state of the art in both τ decays and muon experiments, the primary issue is control of backgrounds in a high rate environment
  - Irreducible backgrounds
  - Accidental backgrounds
- Problematic backgrounds are specific to the type of experiment
- Handles on background control are
  - Charged particle energy resolution
  - Neutral energy resolution
  - Time resolution
  - Particle identification
  - Prompt beam particle rejection
  - Cosmic ray rejection
- New muon experiments
  - MEG upgrade
  - Mu3e
  - DeeMe, Mu2e, COMET
- New τ decay experiments
  Belle II
  LHCb

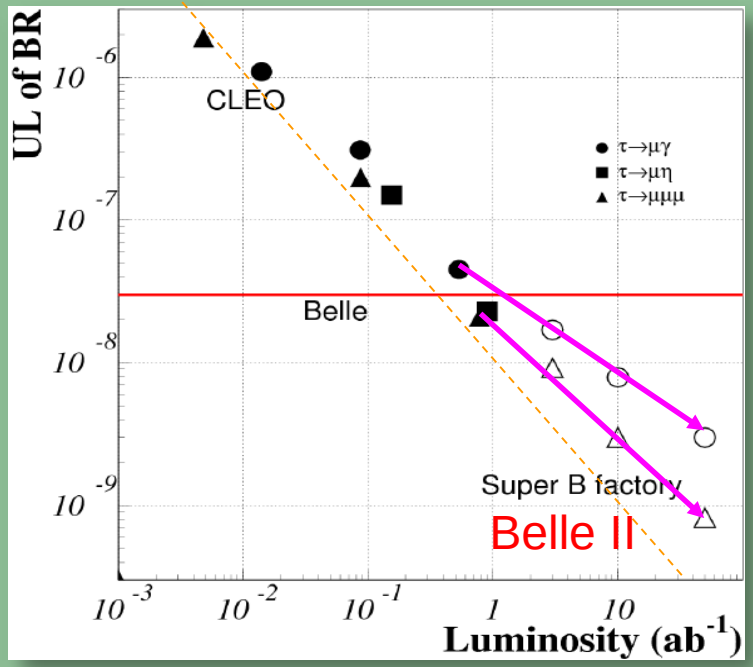
Belle II τ CLFV limits

- The target integrated luminosity of 50 ab^{-1} (~5x10^{10} $\tau\bar{\tau}$) will be reached in ~2025
- The improvement in sensitivity to CLFV τ decays depends on whether or not a particular mode has backgrounds
  - *e.g.*, limits on $\mathcal{B}(\tau\to\ell\ell\ell)$ improve as $1/\int\mathcal{L}dt$ if there is no background, but more slowly, as ~ $(1/\int\mathcal{L}dt)^{1/2}$, if there is background



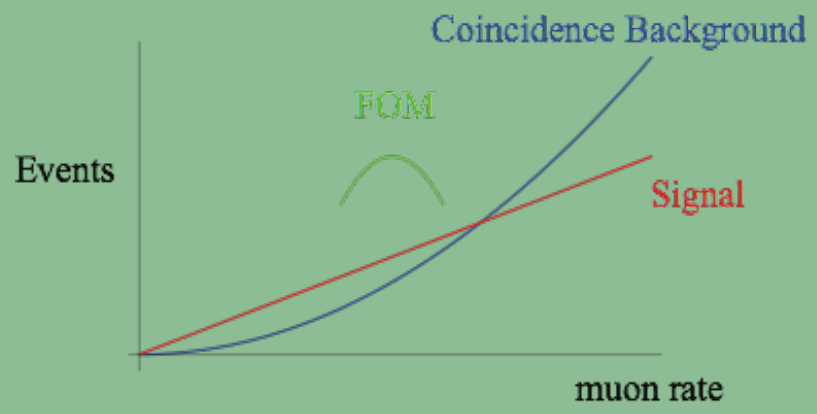






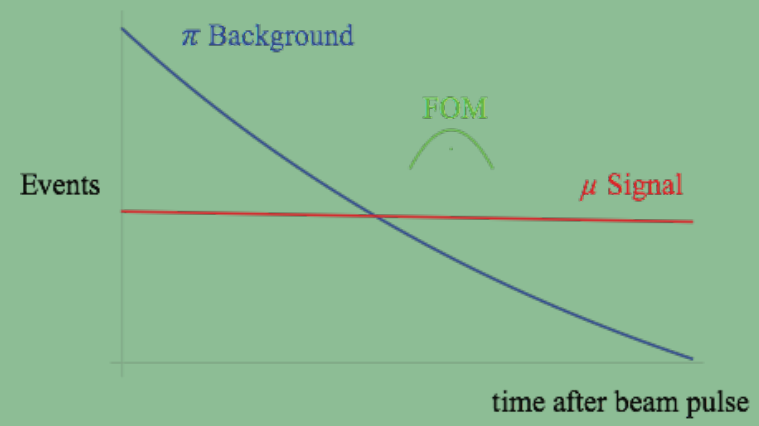
Muon experiments: CW *vs* pulsed beams

- Muon decay experiments $\mu \to e\gamma$, $\mu \to eee$ need a continuous μ^+ beam, such as the PSI synchrocyclotron surface muon beam
- The dominant backgrounds come from accidental coincidences of two decays
  - bkg $\propto$ (rate)^2
  - signal $\propto$ rate



CW operation optimizes the S/N

- $\mu \to e$ conversion experiments ned a pulsed μ^- beam, such as FNAL or J-PARC
  - many (prompt) pion-induced backgrounds immediately after the proton pulse
  - Use the muon/pion lifetime difference to reduce background



Pulsed operation optimizes the S/N

Muon experiments: CW *vs* pulsed beams

- Muon decay experiments $\mu \to e\gamma$, $\mu \to eee$ need a continuous μ^+ beam, such as the PSI synchrocyclotron surface muon beam
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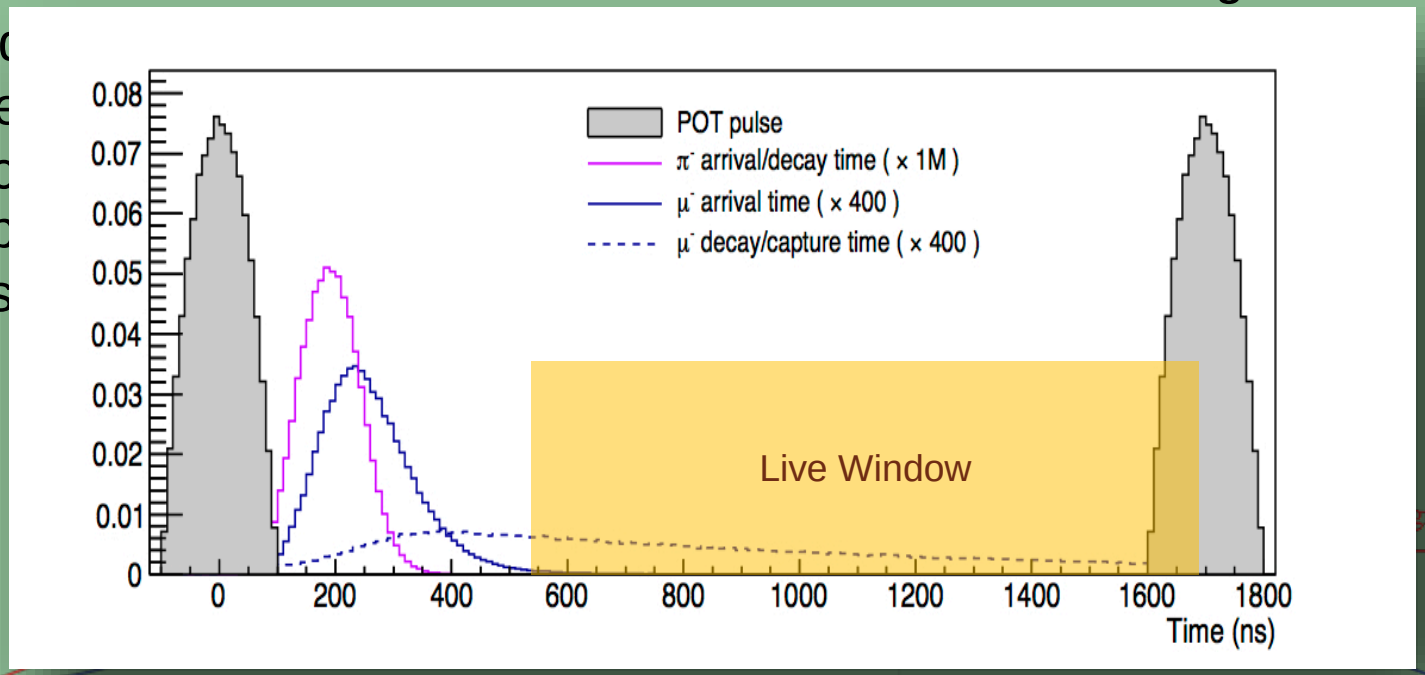
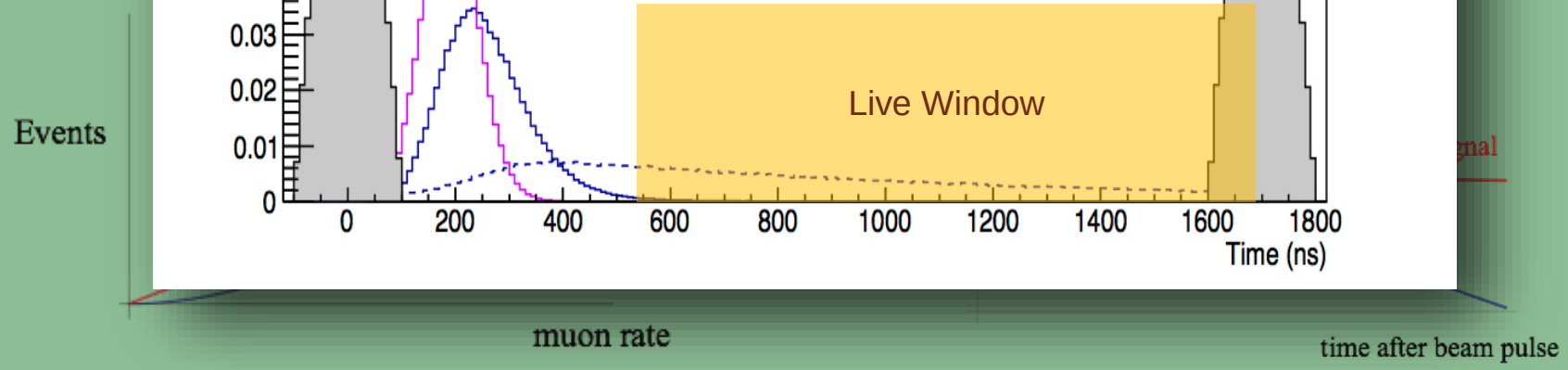
- $\mu \to e$ conversion experiments ned a pulsed μ^- beam, such as FNAL or J-PARC
  - many (prompt) pion-induced backgrounds

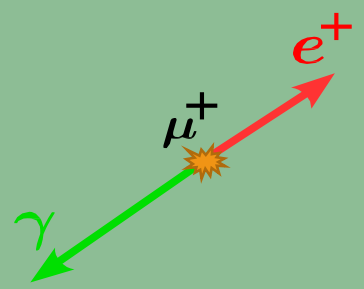




CW operation optimizes the S/N

Pulsed operation optimizes the S/N

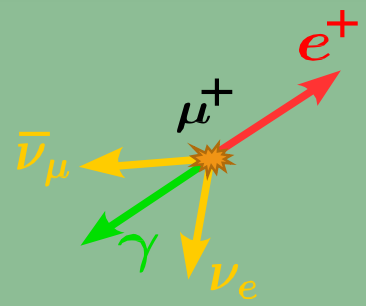
MEG upgrade signal and backgrounds



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

CLFV signal

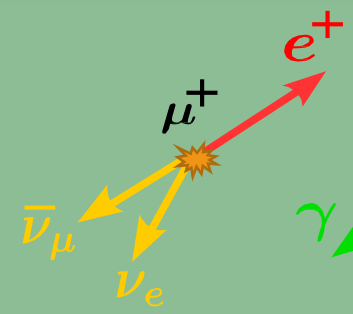
$\propto R_\mu$



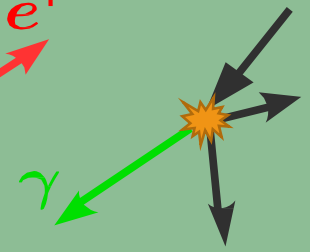
$\mu^+ \to e^+\bar{\nu}_\mu\nu_e\gamma$

Radiative muon decay

correlated $\propto R_\mu$



$\mu^+ \to e^+\bar{\nu}_\mu\nu_e$



$\mu^+ \to e^+\bar{\nu}_\mu\nu_e\gamma$

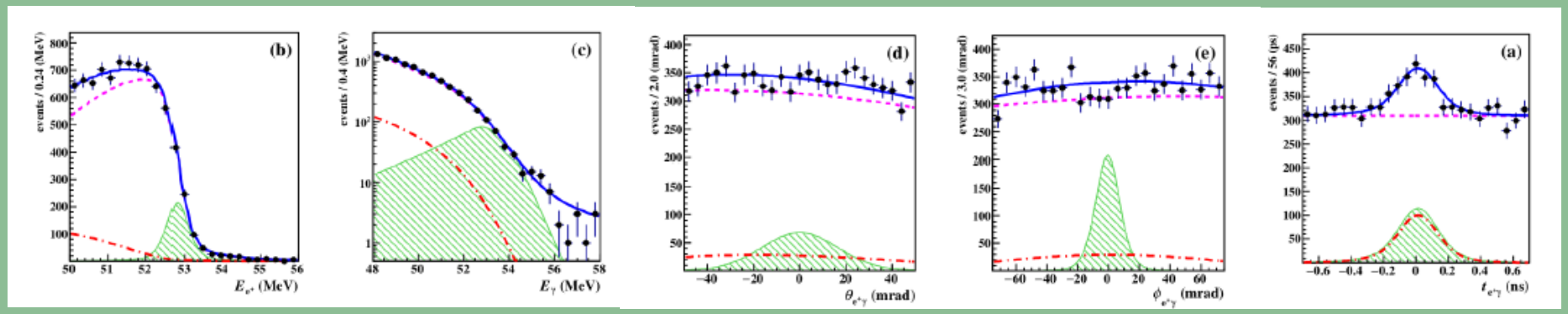
$e^+e^- \to \gamma\gamma$

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

Accidental background

uncorrelated $\propto R_\mu^2$

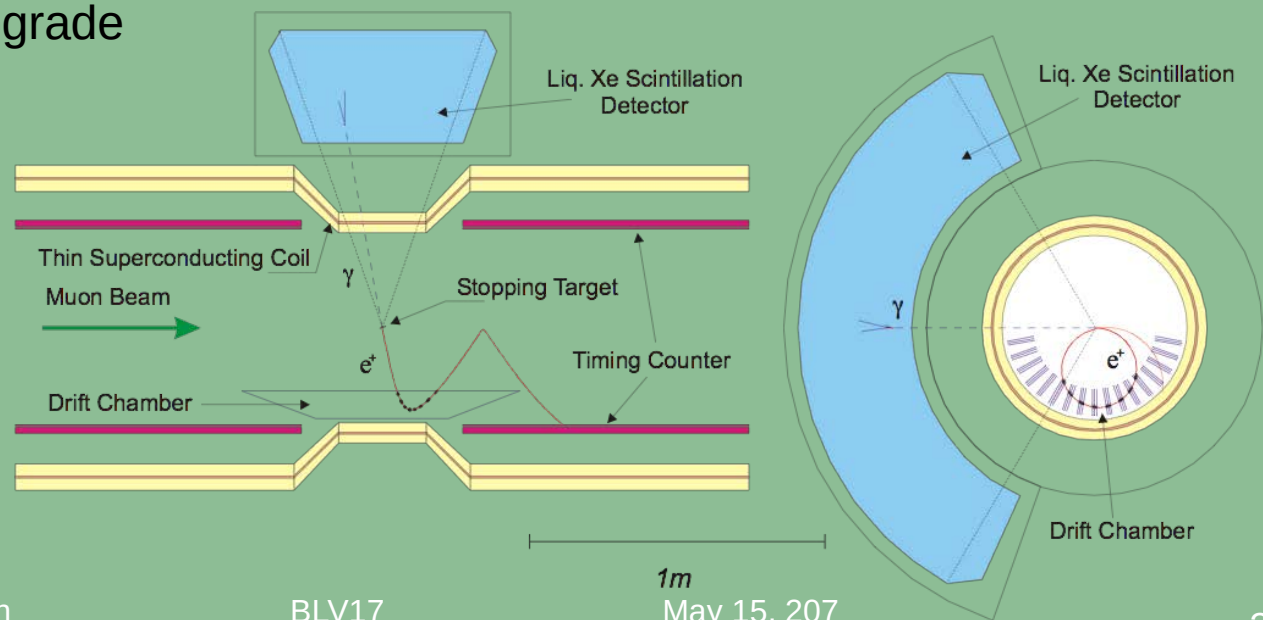
Events are described by five variables: $E_\gamma, E_e, t_{e\gamma}, \theta_{e\gamma}, \phi_{e\gamma}$



MEG backgrounds

- Backgrounds are proportional to: $\left(\frac{R_\mu}{D}\right)\left(\Delta t_{e\gamma}\right)\left(\frac{\Delta E_e}{m_\mu/2}\right)\left(\frac{\Delta E_\gamma}{15m_\mu/2}\right)^2\left(\frac{\Delta\theta_{e\gamma}}{2}\right)^2$
  - uncorrelated backgrounds $\propto$ instantaneous rate
  - electron-photon time resolution
  - electron momentum resolution
  - square of photon energy resolution, since backround due to integral of photon spectrum of $\mu \to e\nu\nu\gamma \sim (1-2E_\gamma/m_\mu)$
  - Square of electron-photon angular resolution
- These considerations dictated original MEG design and the improvements incorporated in the upgrade

Stop 10^7 muons/sec in 150μ kapton target

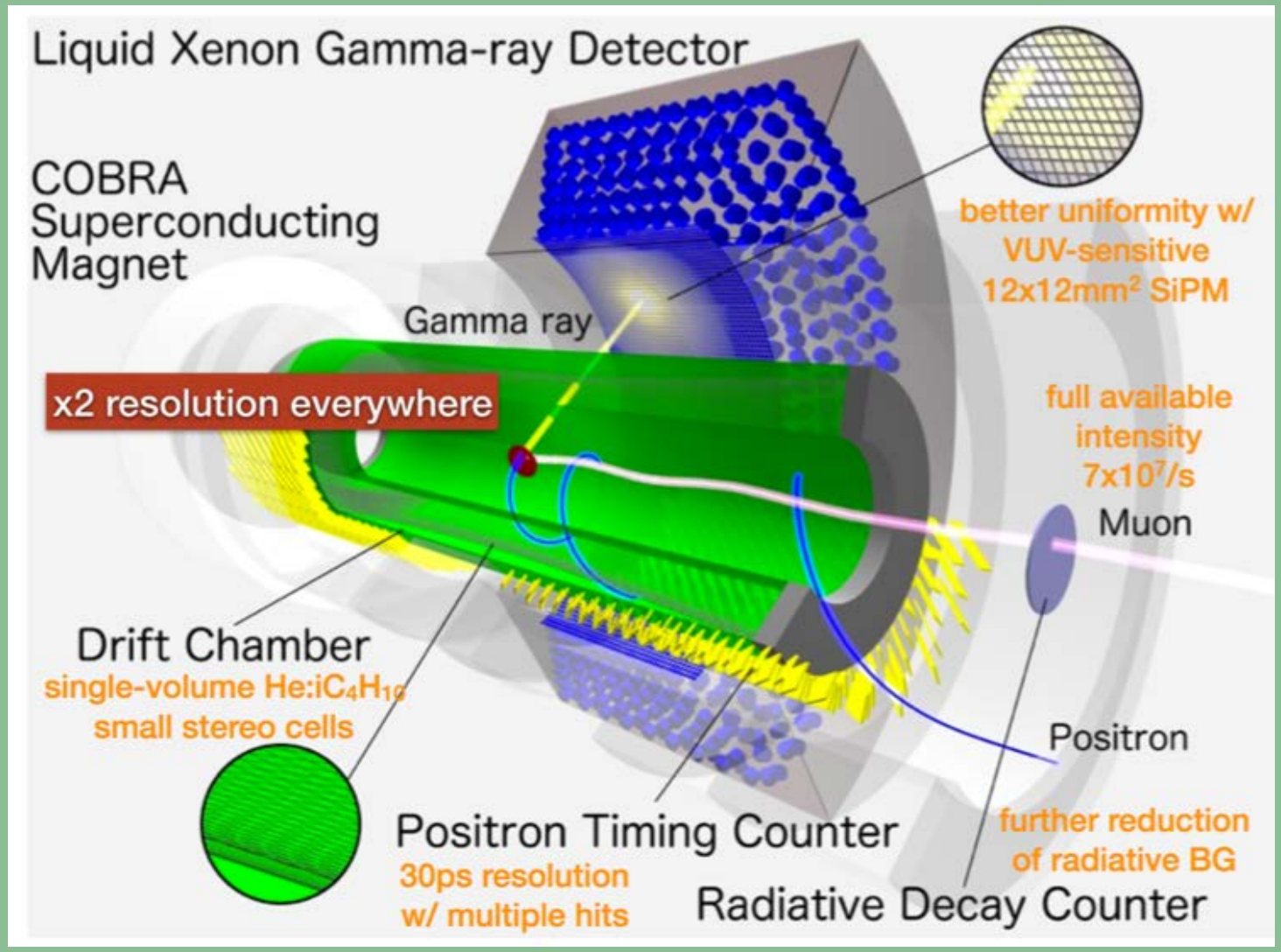


MEG result and upgrade goal

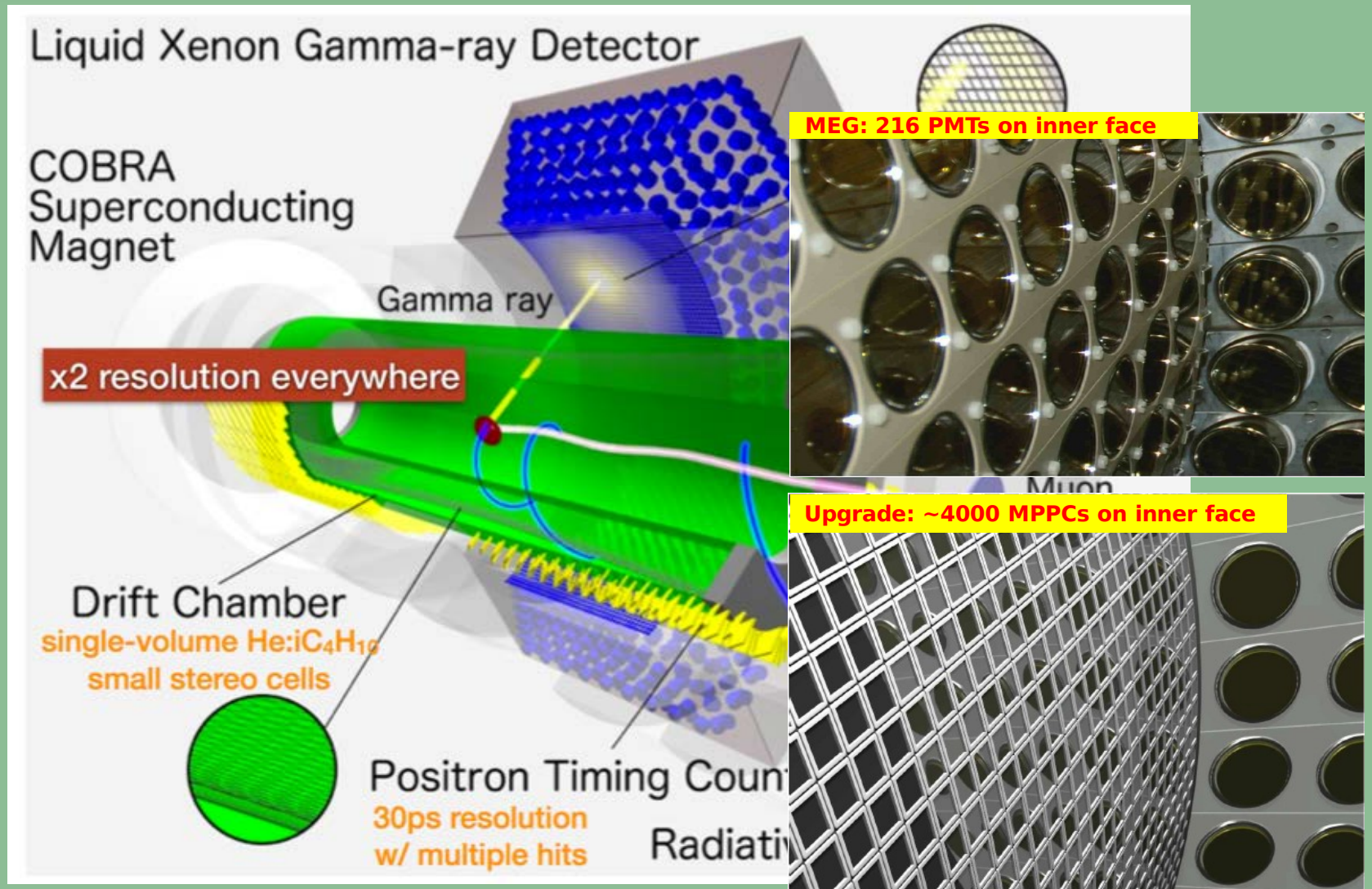
- MEG has the best current limit on $\mathcal{B}(\mu^+ \rightarrow e^+ \gamma)$
- Uses a surface muon beam: DC, $|p_\mu|$ 28 Mev/c, 10^8 μ/s
- With a total of 7.5×10^{14} stopped muons, gathered in runs from 2009 through 2013, they set a 90% CL limit of $< 4.2 \times 10^{-13}$ (Baldini *et al*., Eur.Phys.J. C76434, 2016)
- The MEG Upgrade will improve the detector to achieve a 90% CL limit of $< 5 \times 10^{-14}$ in a three year run

- Upgrade schedule
  - Engineering Run 2017 to test LXe modifications and timing
  - Full Engineering Run July 2018
  - Data Fall 2018
  - Upgrades to PSI to modify the surface beam target station

MEG upgrade


Liquid Xenon Gamma-ray Detector
COBRA Superconducting Magnet
better uniformity w/ VUV-sensitive 12x12mm² SiPM
Gamma ray
x2 resolution everywhere
full available intensity 7x10⁷/s
Muon
Drift Chamber
single-volume He:iC₄H₁₀
small stereo cells
Positron
Positron Timing Counter
30ps resolution w/ multiple hits
further reduction of radiative BG
Radiative Decay Counter

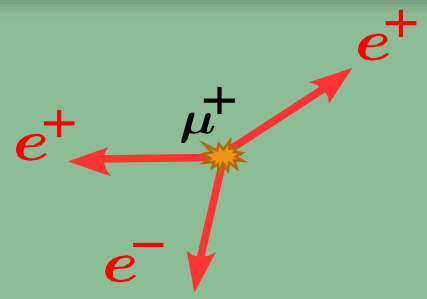
MEG upgrade


Liquid Xenon Gamma-ray Detector
COBRA
Superconducting
Magnet
Gamma ray
x2 resolution everywhere
Drift Chamber
single-volume He:iC4H10
small stereo cells
Positron Timing Coun
30ps resolution
w/ multiple hits
Radiati
MEG: 216 PMTs on inner face
Upgrade: ~4000 MPPCs on inner face

Mu3e

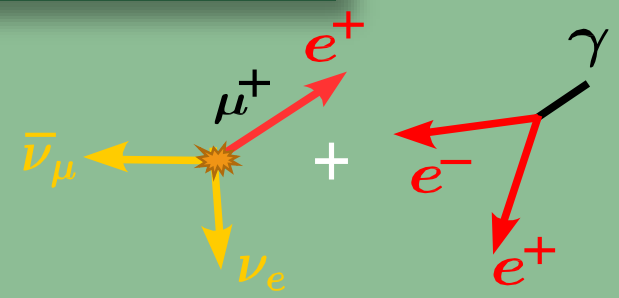
Signal

$E = m_\mu$
$\Sigma p_i = 0$
Vertex

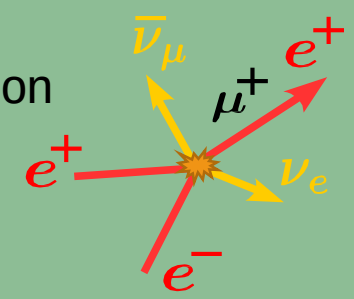


Background

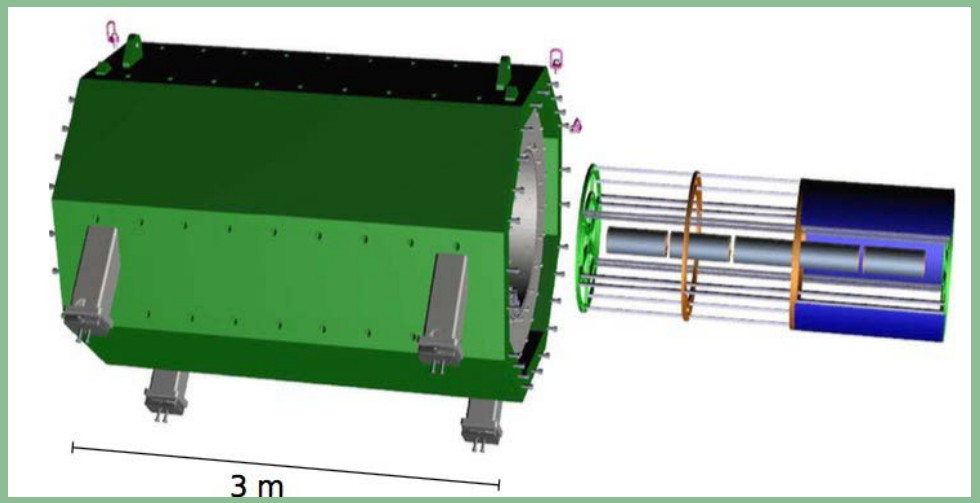
Accidentals



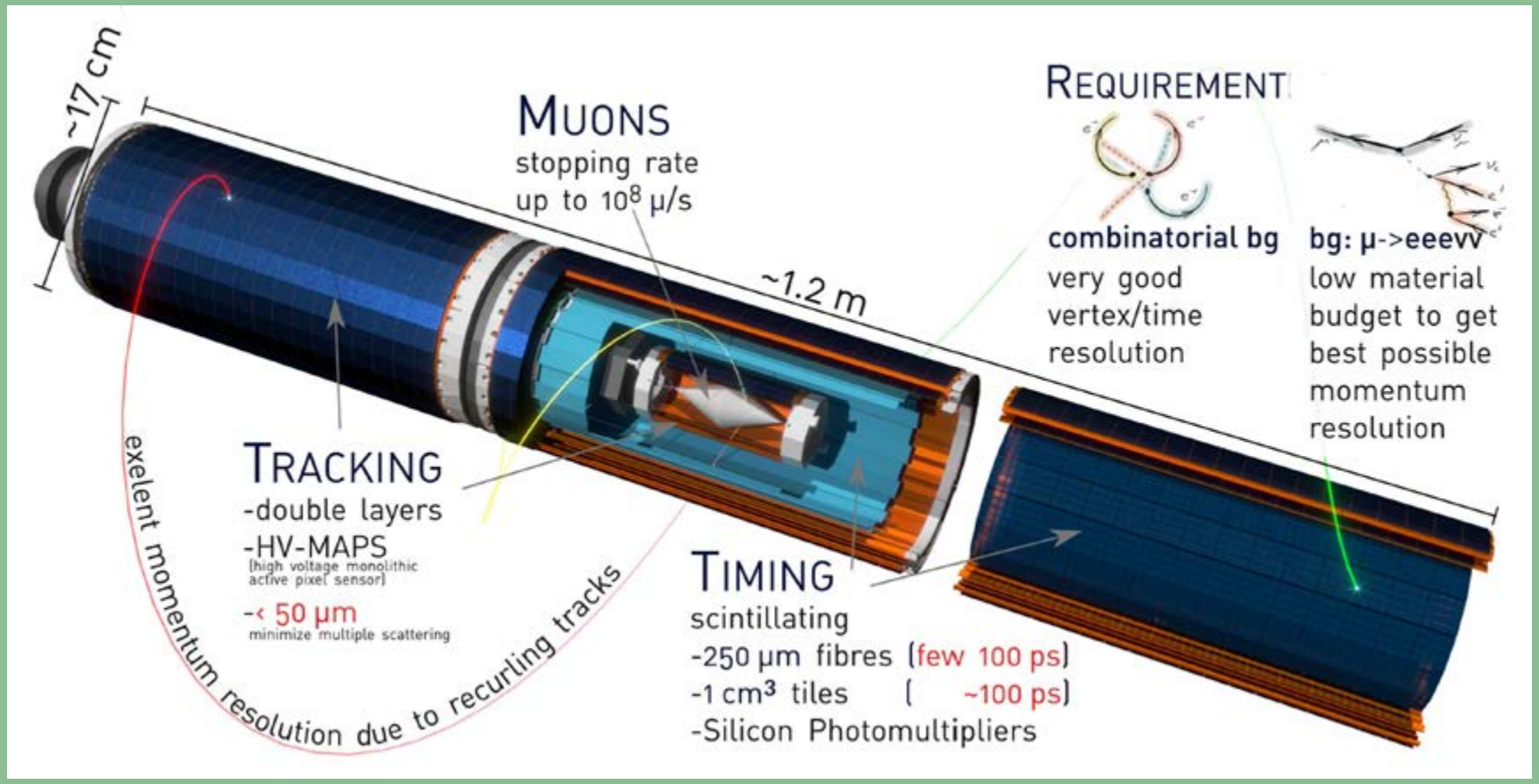
Radiative decay
w internal conversion



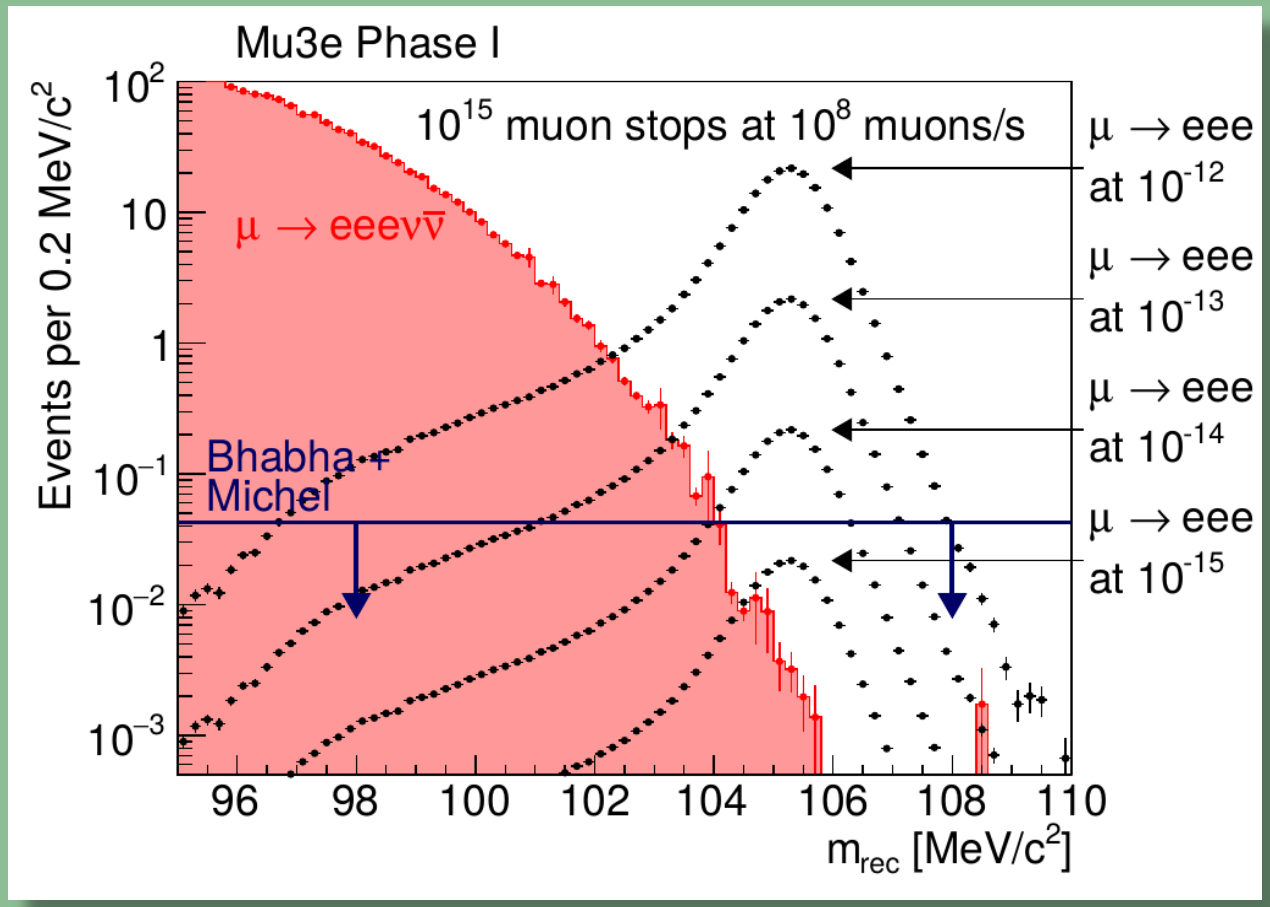
- **Current limit:** 1.0×10^{-12} (SINDRUM at PSI, 1988)
- Mu3e at PSI will provide substantial improvement
  - Phase I 2018 - πE5 beamline 10^8 μ^+/s
    - Sensitivity 10^{-15}
  - Phase II - HIMB 10^9 μ^+/s
    - Sensitivity 10^{-16}



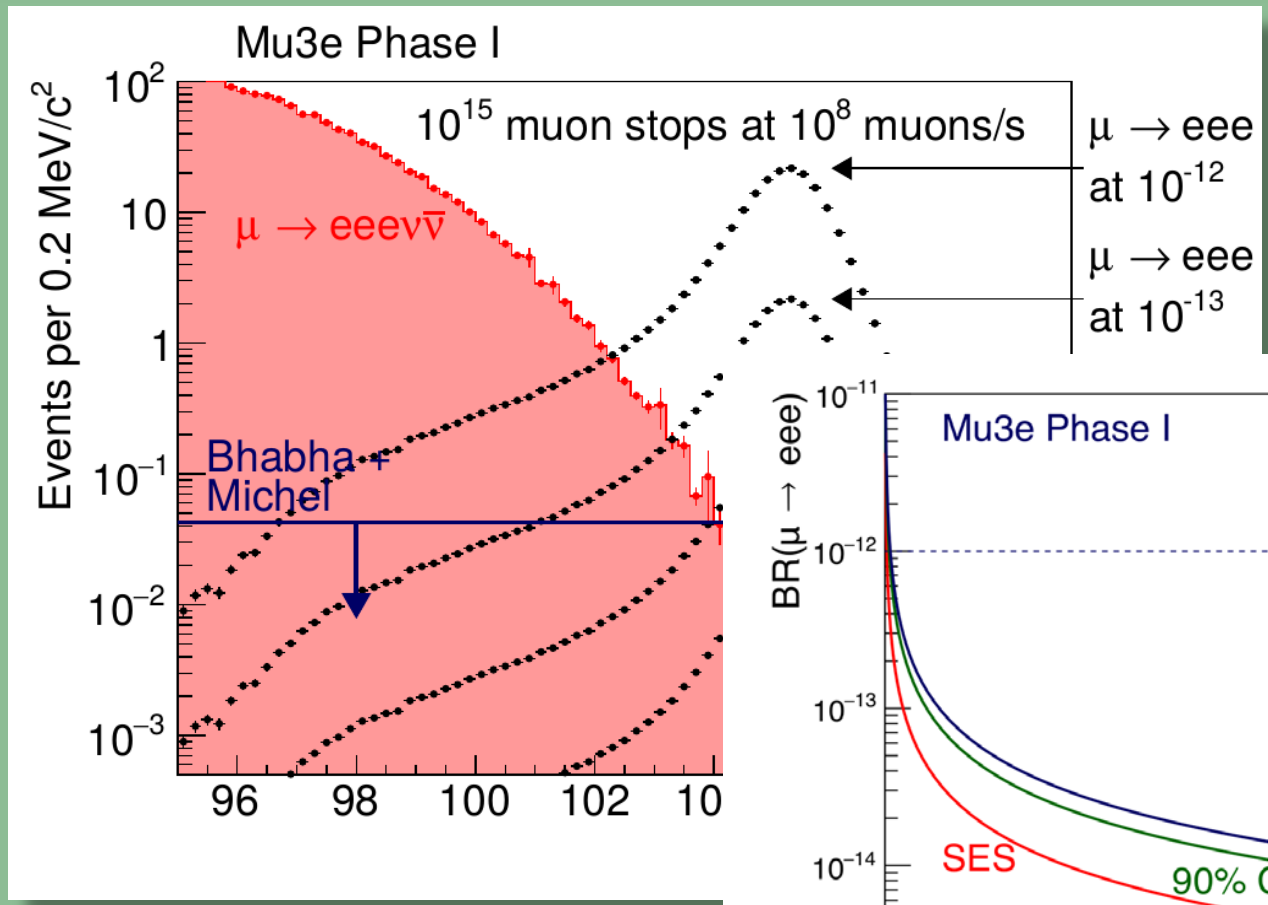
Mu3e detail

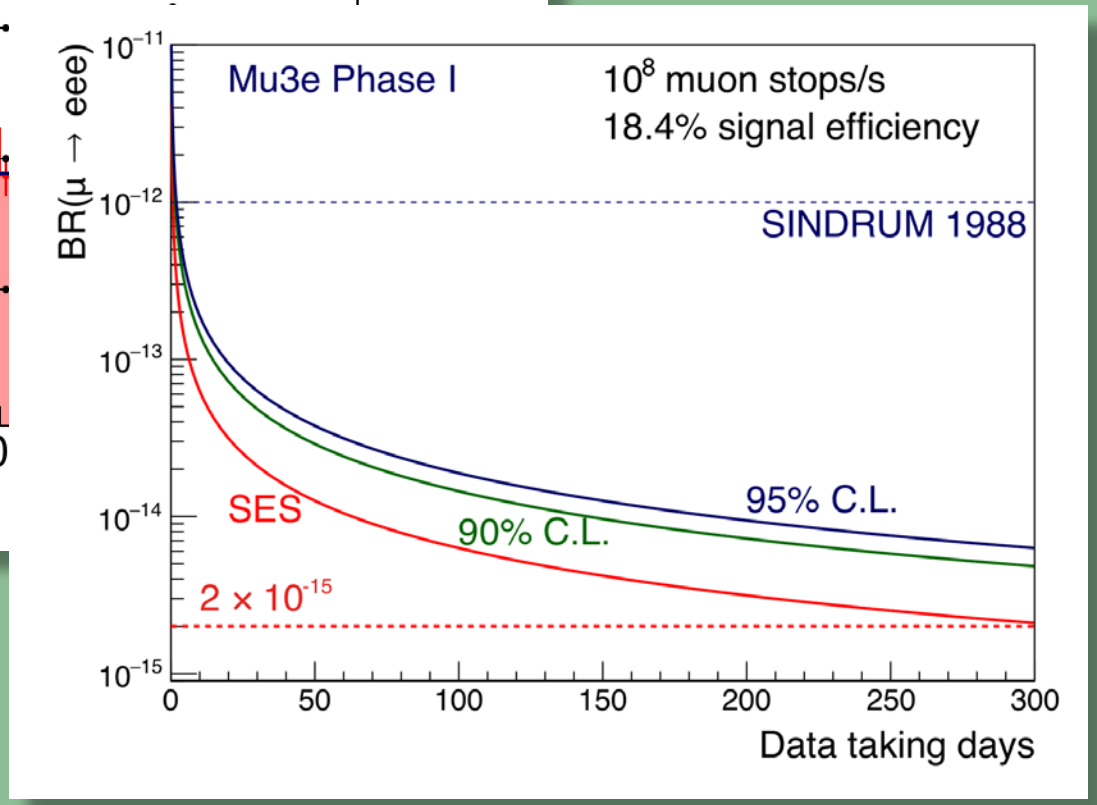

~17 cm
MUONS
stopping rate
up to 10^8 μ/s
~1.2 m
REQUIREMENT
combinatorial bg
very good
vertex/time
resolution
bg: μ->eeeνν
low material
budget to get
best possible
momentum
resolution
TRACKING
-double layers
-HV-MAPS
[high voltage monolithic
active pixel sensor]
-< 50 μm
minimize multiple scattering
exelent momentum resolution due to recurling tracks
TIMING
scintillating
-250 μm fibres (few 100 ps)
-1 cm³ tiles (~100 ps)
-Silicon Photomultipliers

Mu3e sensitivity



Mu3e sensitivity

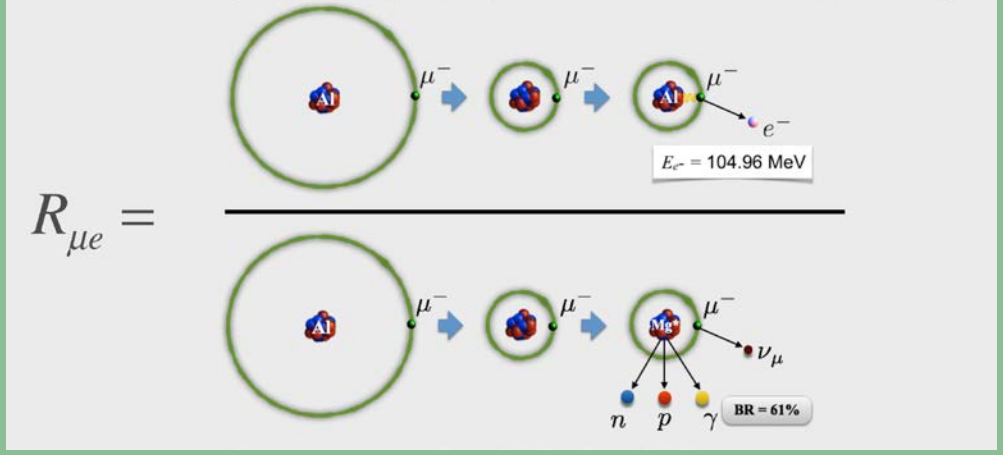




μ to e conversion experiments

- Signal is a single monoenergetic electron
- If N = Al, E_e ~105 MeV
  - electron energy depends on Z, due to atomic binding energy
- Coherent nuclear recoil

$$R_{\mu e} = \frac{\Gamma(\mu^- + N(A,Z) \rightarrow e^- + N(A,Z))}{\Gamma(\mu^- + N(A,Z) \rightarrow \text{all muon captures})}$$

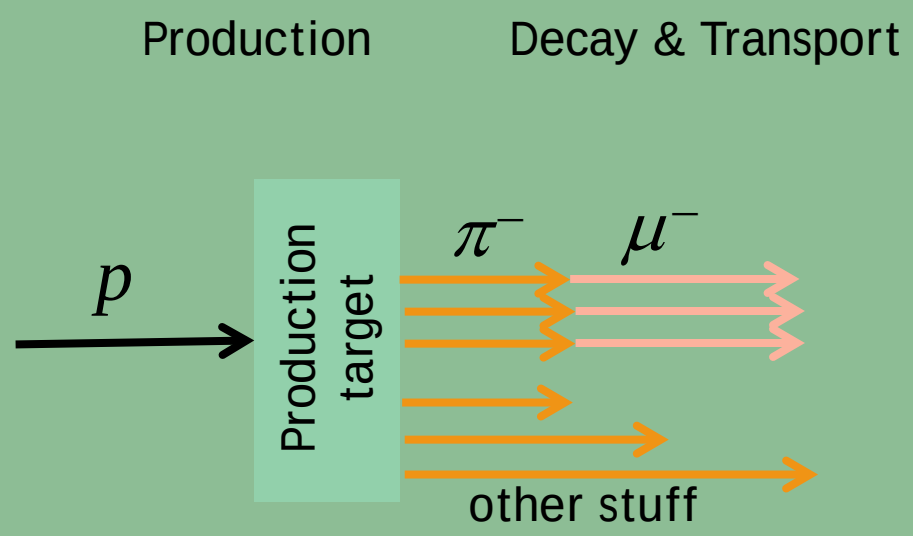


- There are four experiments in various stages of preparation
  - DeeMe
  - COMET Phase I and Phase II
  - Mu2e
  - PRISM/Prime

  } Origins trace to MELC and MECO proposals

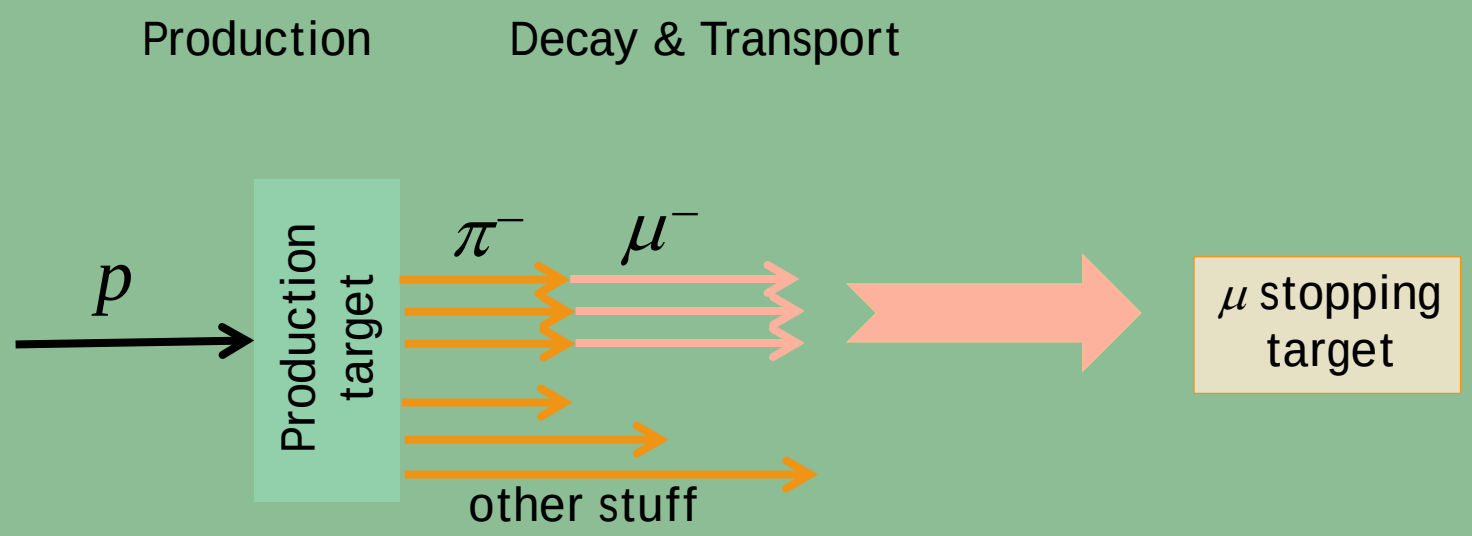
  - All face similar challenges, addressed in specific ways
    - High rates to achieve required sensitivity
    - Prompt and delayed beam-related backgrounds
    - Cosmic ray backgrounds

$\mu \rightarrow e$ experiment schematic



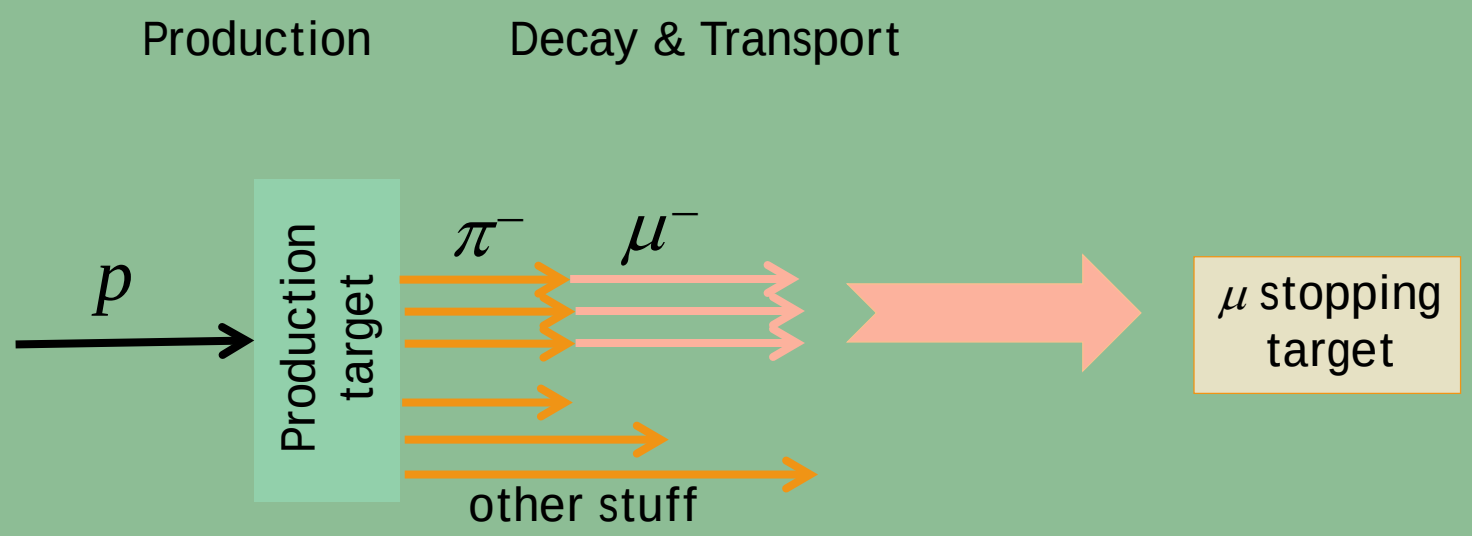
1) Generate a beam of low momentum muons

$\mu \rightarrow e$ experiment schematic



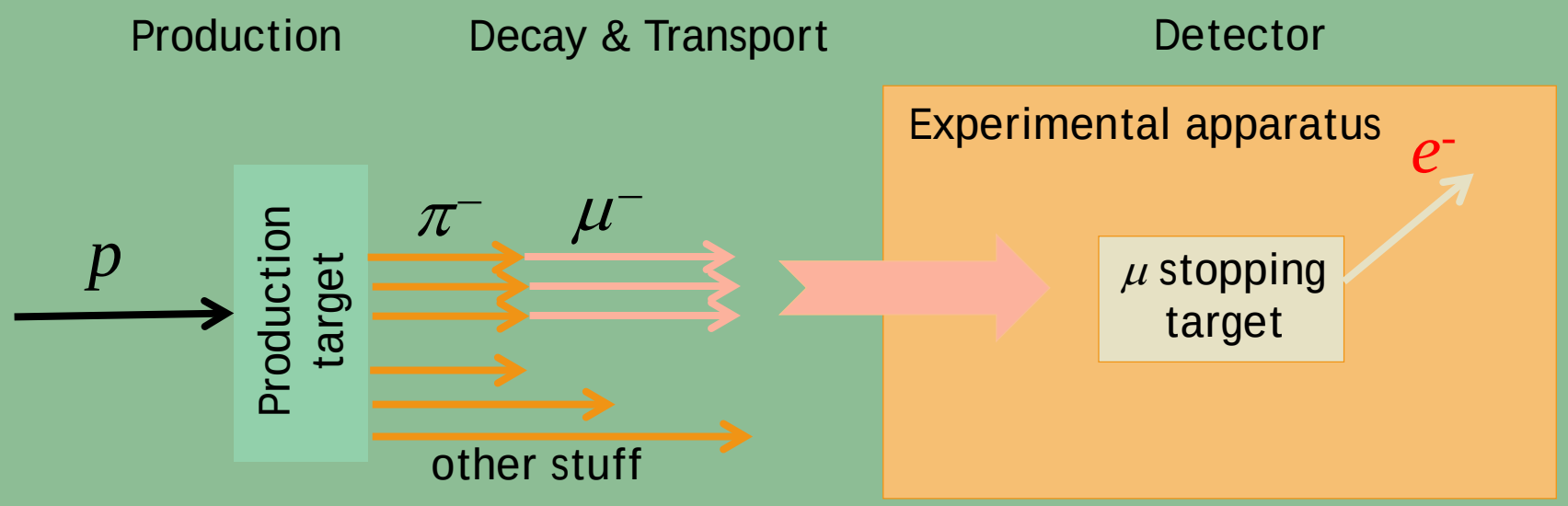
1) Generate a beam of low momentum muons
2) Stop the muons in a target (C, SiC, Al, Ti, …..)

$\mu \rightarrow e$ experiment schematic



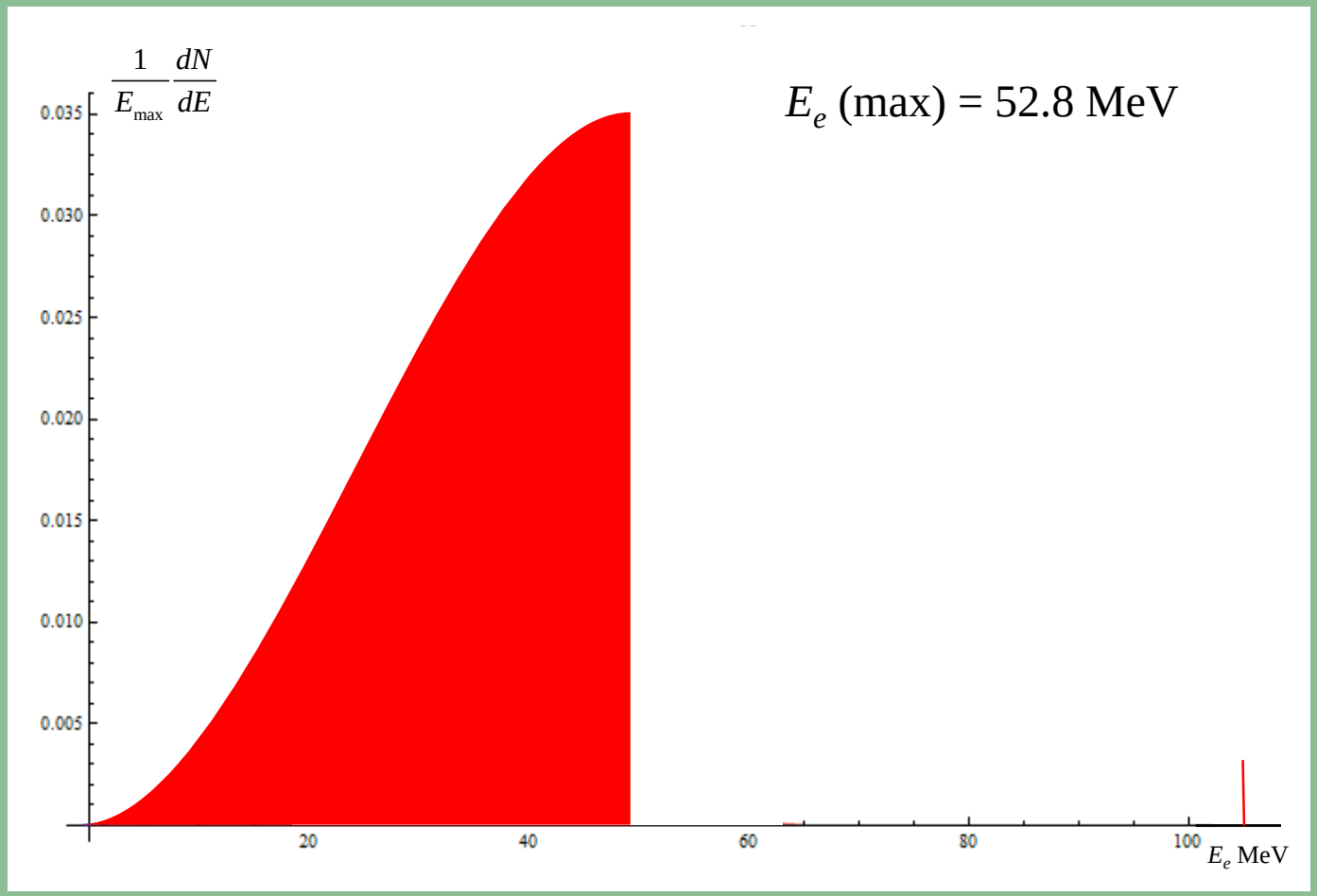
1) Generate a beam of low momentum muons
2) Stop the muons in a target (C, SiC, Al, Ti, …..)
   - In orbit around nucleus: τ_μ^{Al} = 864 ns
   - Large τ_μ^{N} is important for discriminating background

$\mu \rightarrow e$ experiment schematic

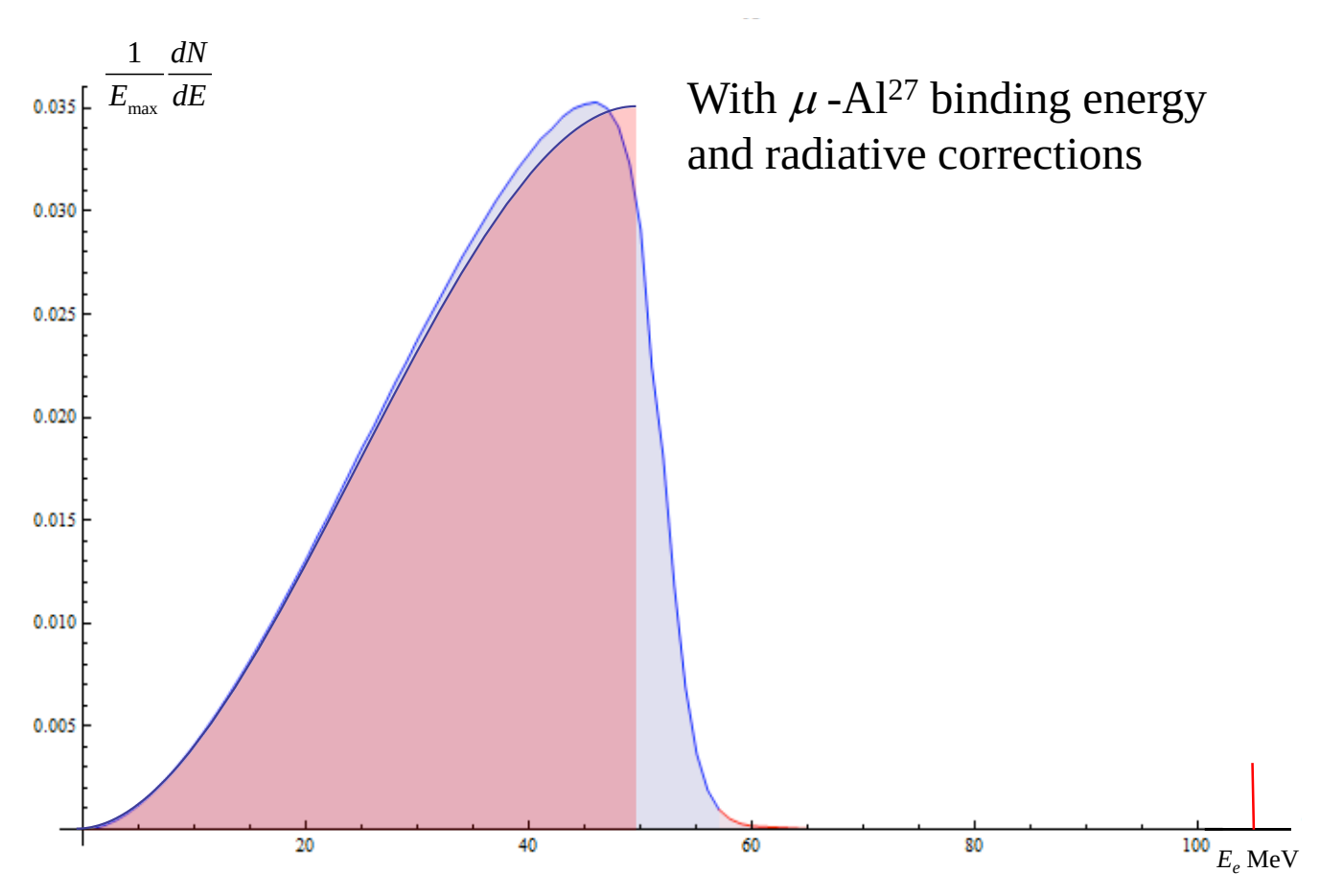


1) Generate a beam of low momentum muons
2) Stop the muons in a target (C, SiC, Al, Ti, …..)
3) Search for events consistent with $\mu N \rightarrow eN$
4) Discriminate against backgrounds from pion decays and interactions, muon decays in orbit (DIOs), radiative decays and cosmic rays

Decay-in-Orbit Shape

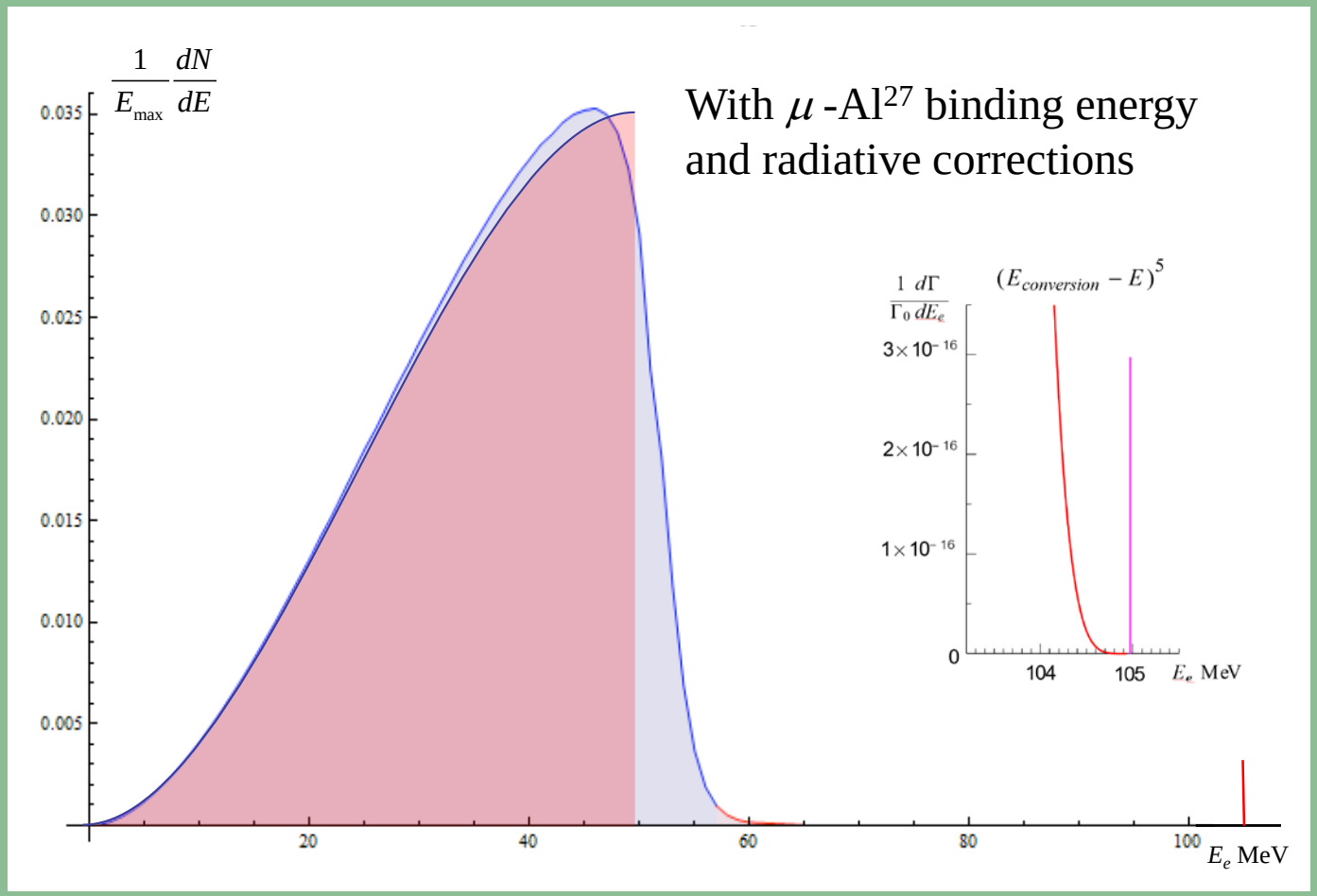


Decay-in-Orbit Shape



Czarnecki
Szafron

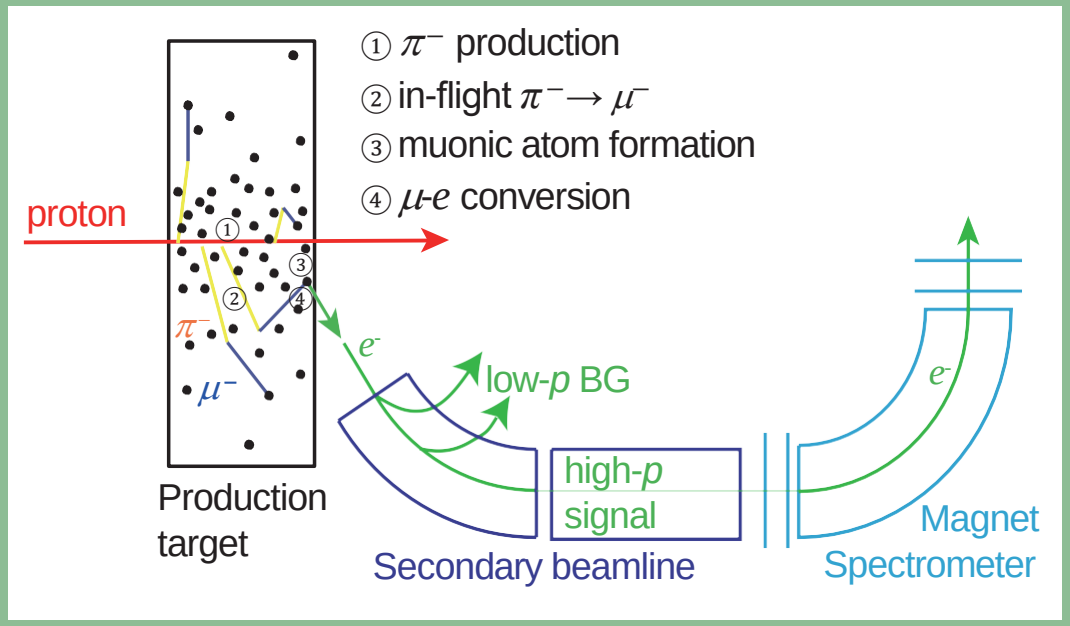
Decay-in-Orbit Shape

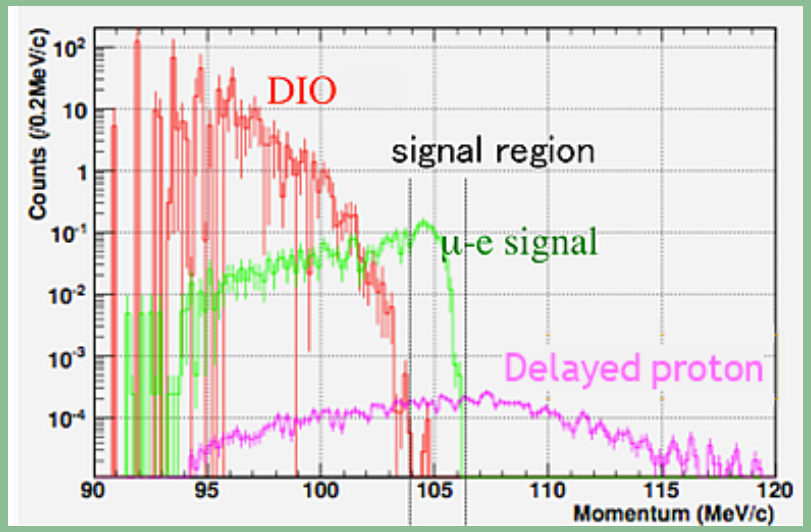


Czarnecki
Szafron

DeeMe

- Directly search for $\mu \rightarrow e$ conversion in a high power target
  - High power, high purity proton beam from MLF at J-PARC
  - initially a graphite target, then a rotating SiC target
  - production and conversion target are the same



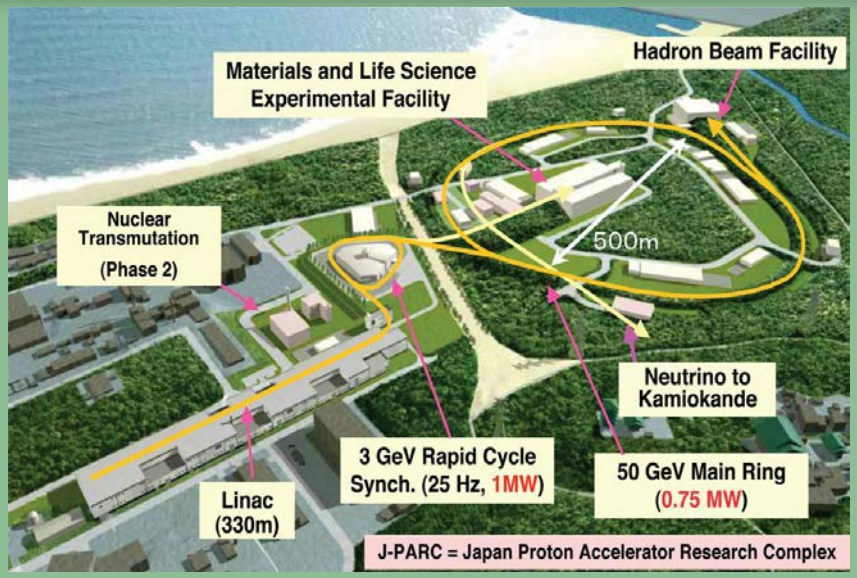


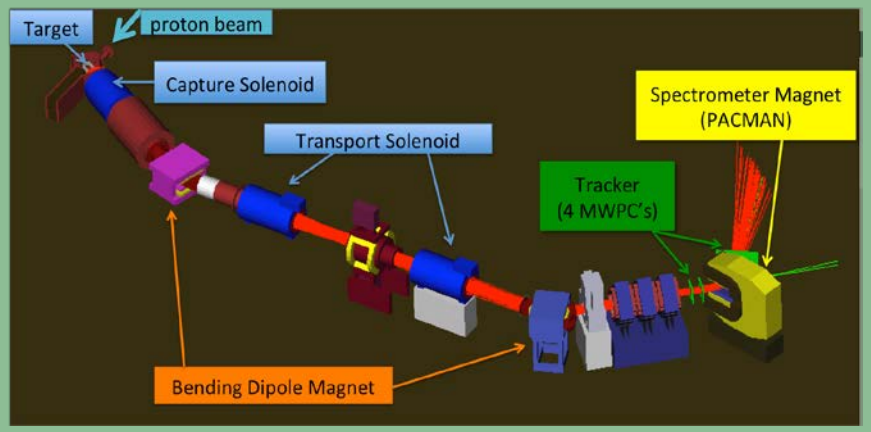
- Single event sensitivity (1 year = 2×10^7 sec) with 1MW beam
  - 1.2×10^{-13}
  - 2.5×10^{-14} (4 years)

Upgrade to SiC

  - 2.1×10^{-14}
  - 5×10^{-15} (4 years)

DeeMe status

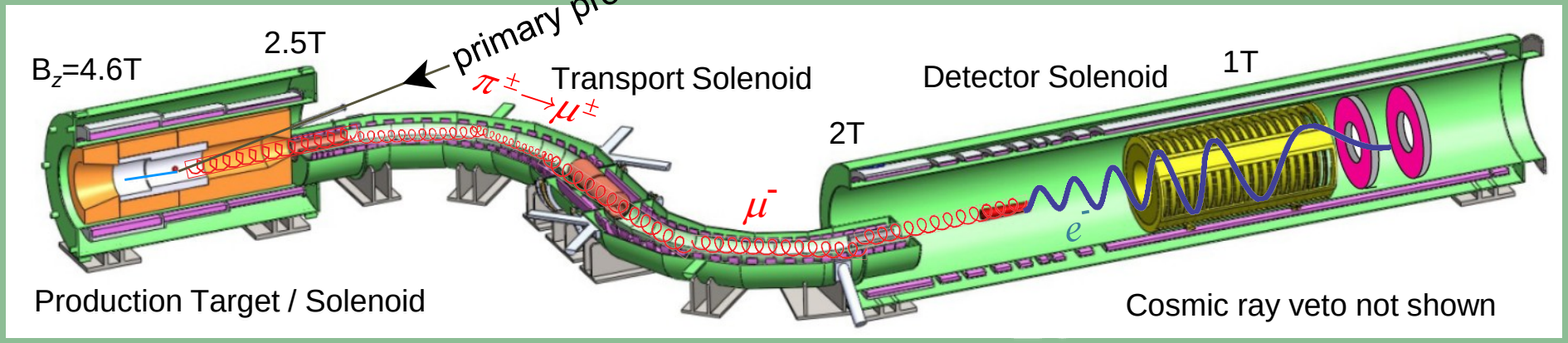




- Will start with graphite target
- Detector components built
- Beamline (to be shared with other experiemnts such as g-2 scheduled for 2018
- PACMAN spectrometer magnett moved from TRIUMF

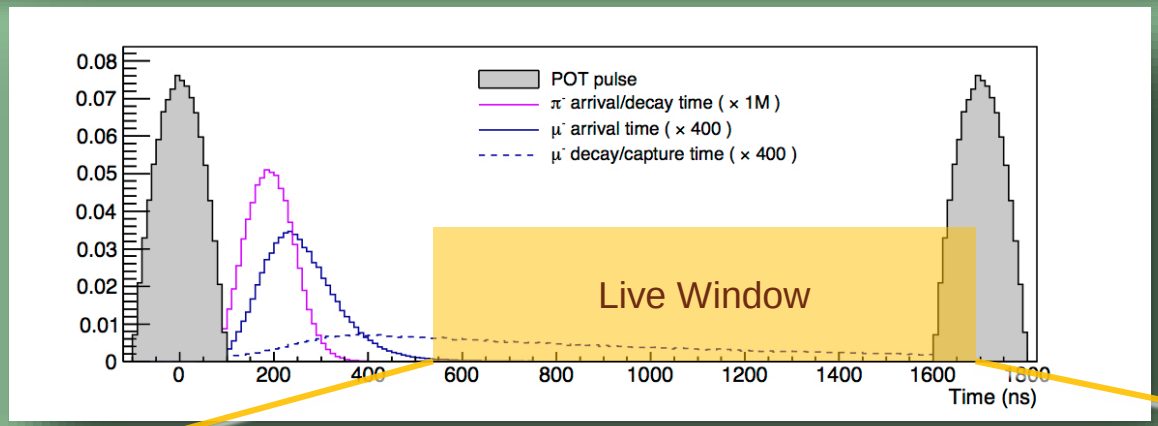
Mu2e

- The Mu2e sensitivity goal 2.6 x 10^{-17} demands a total of ~ 6x10^{17} stopped muons in a 3 year run of ~ 6x10^{7} sec
- This requires a muon stopping rate of 10^{10}/sec



- Experimental design
  - Pulsed proton beam produce pions, which are captured in the backward direction
  - Transport muons from pion decay, with momentum and sign selection
  - Since electron backgrounds are at lower momentum than the sought conversion electrons, confine lower momentum particles to smaller helical radii in a solenoid and a provide hole in tracker and calorimeter for them to pass through
  - Reject cosmic ray events

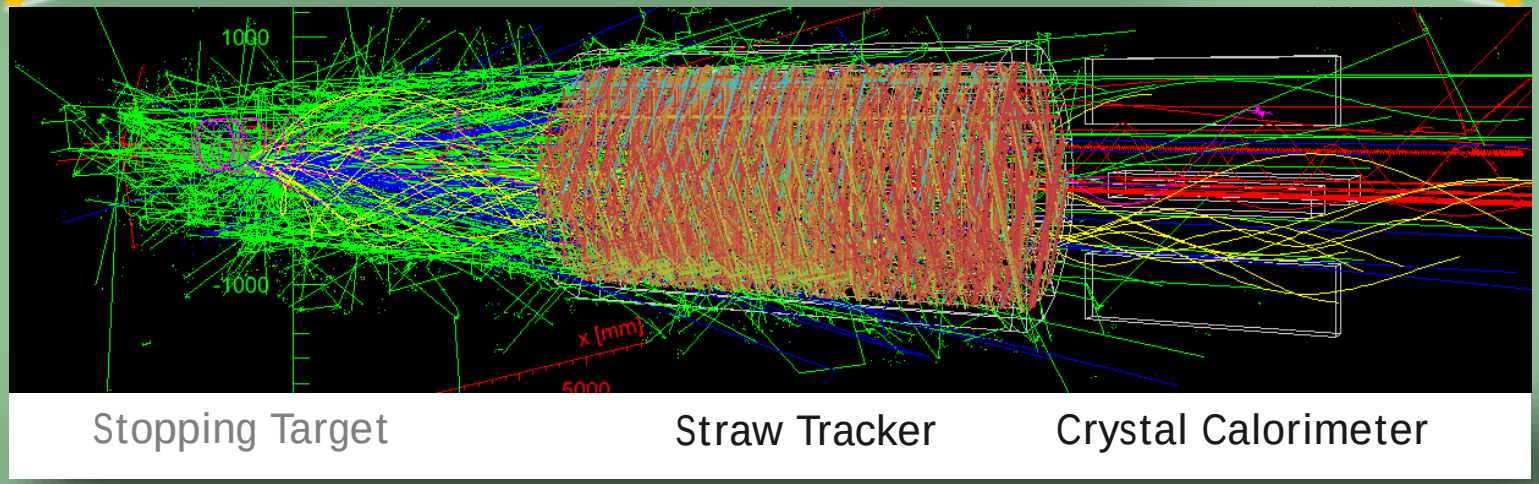
What happens during a microbunch ?



Use of pulsed proton beam and a delayed live gate allows suppression of prompt backgrounds by many orders of magnitude

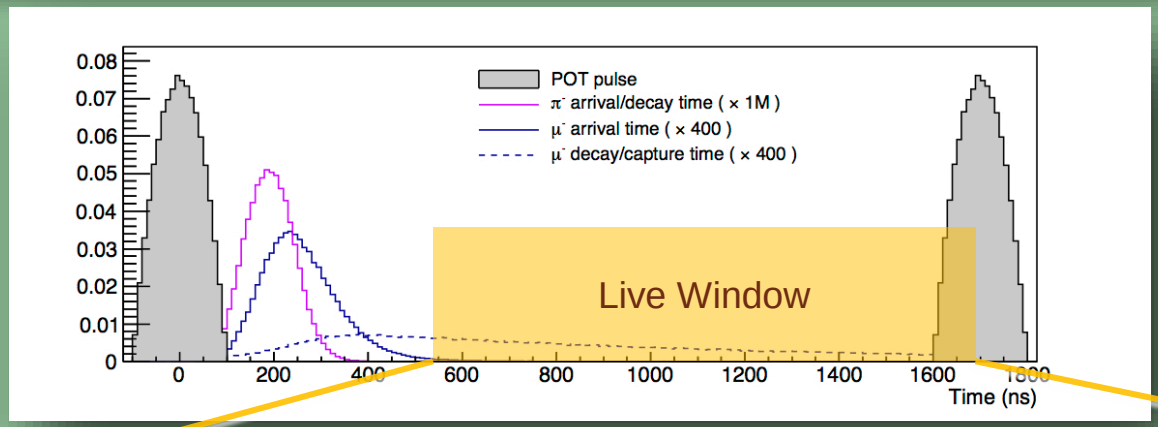
Proton pulses must be narrow

Out-of-time protons must be suppressed by $\mathcal{O}(10^{10})$



- Simulations encompass a full ~1μs, including all the background overlays from the beam flash, μ capture products, neutrons, *etc*. and properly accounts for contributions from previous bunches.

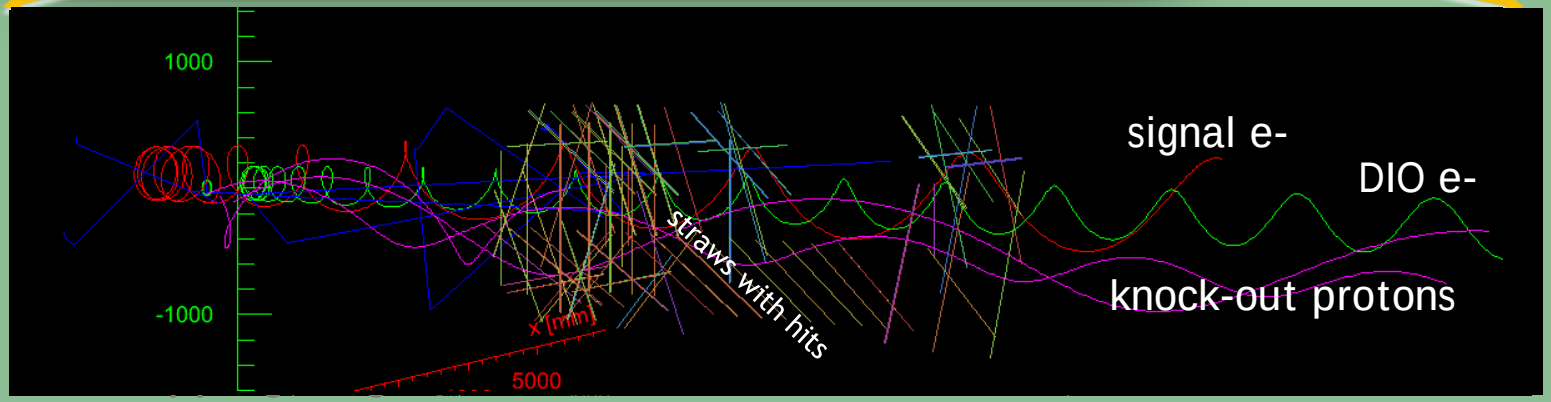
What happens during a microbunch ?



Use of pulsed proton beam and a delayed live gate allows suppression of prompt backgrounds by many orders of magnitude

Proton pulses must be narrow

Out-of-time protons must be suppressed by $\mathcal{O}(10^{10})$

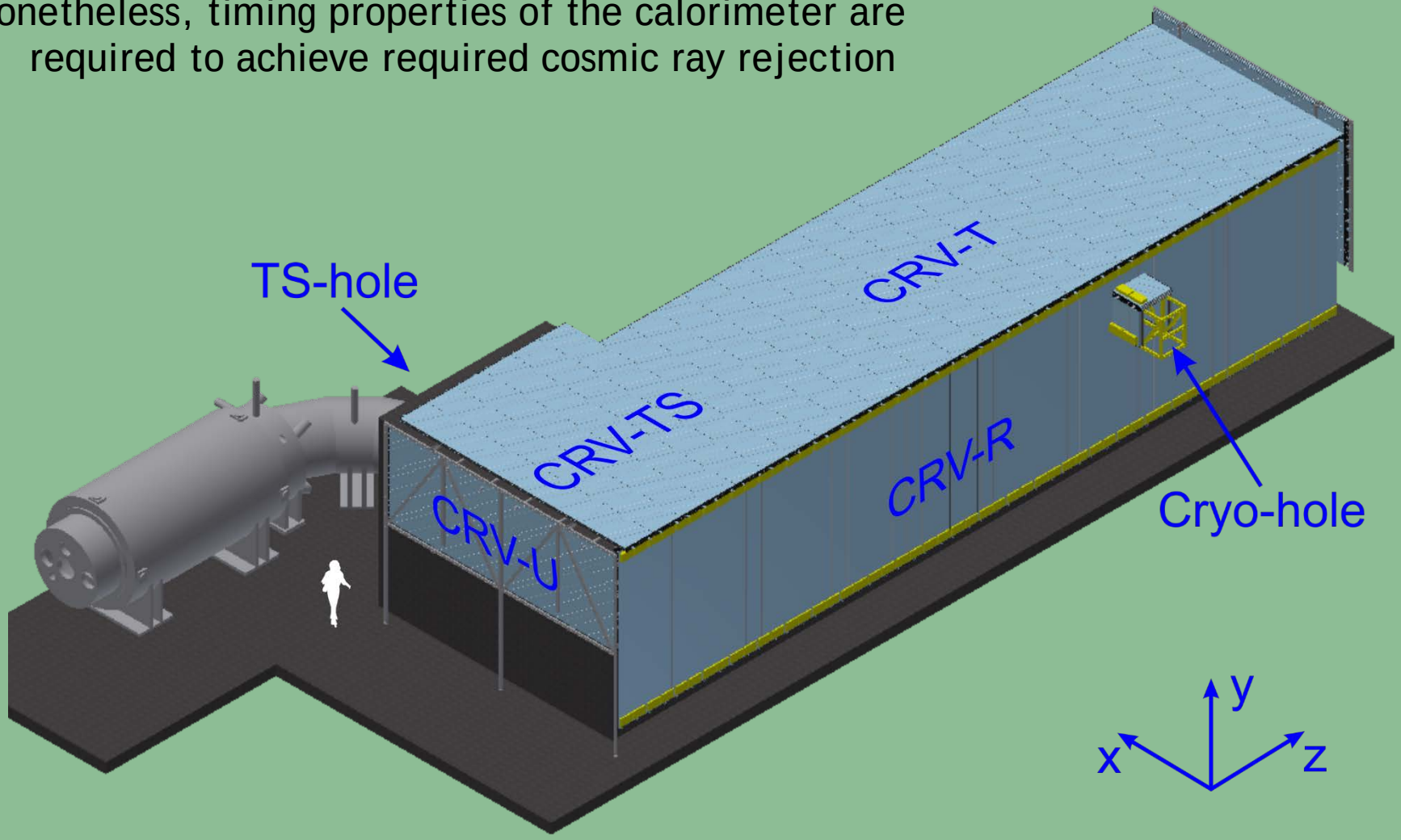


(particles with hits within +/-40 ns of signal electron t_{mean})

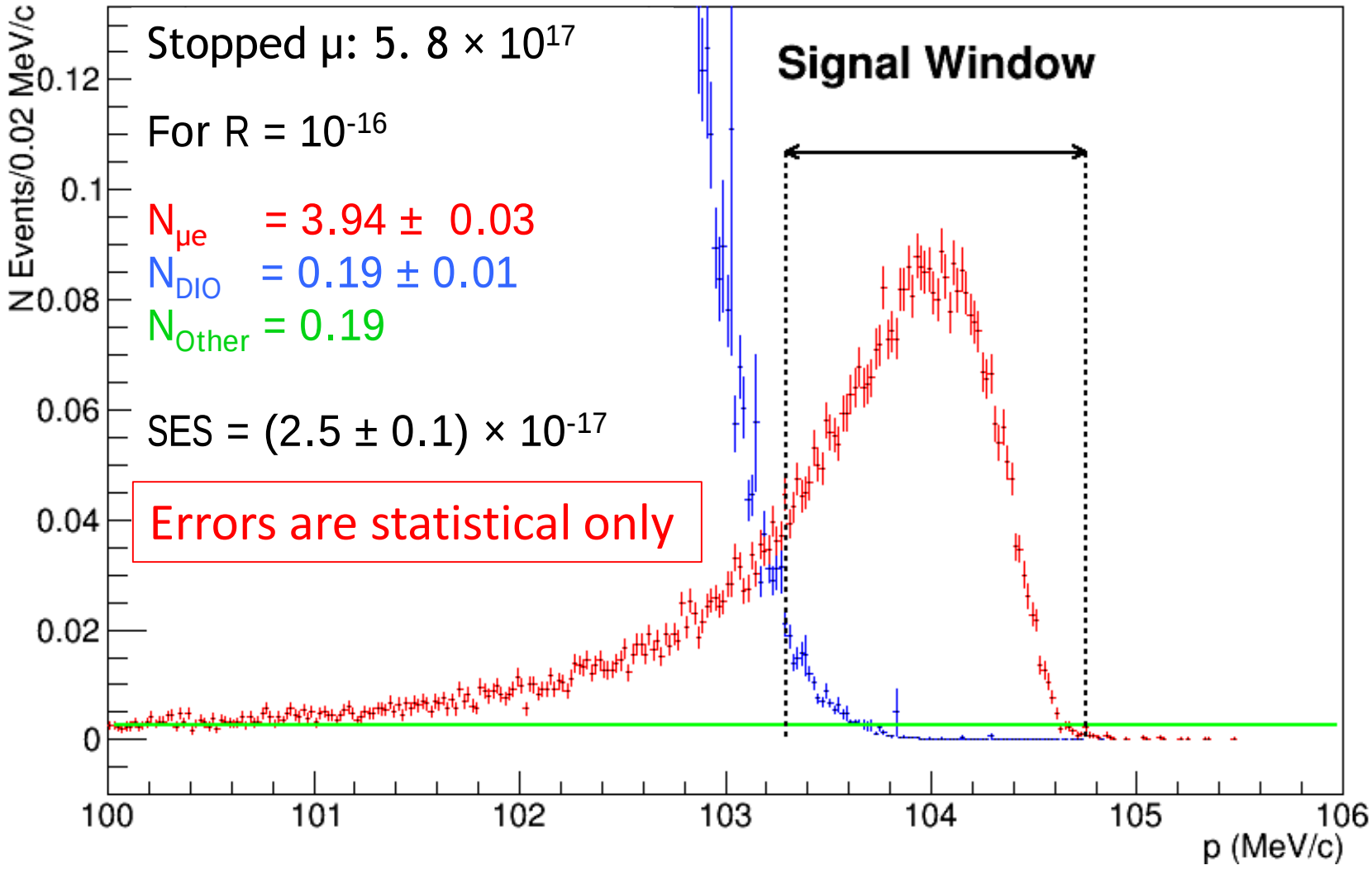
- Simulations encompass a full ~1μs, including all the background overlays from the beam flash, μ capture products, neutrons, *etc*. and properly accounts for contributions from previous bunches.

Cosmic ray veto (four layers)

Covers as much of the transport and detector solenoids as possible
Nonetheless, timing properties of the calorimeter are
required to achieve required cosmic ray rejection

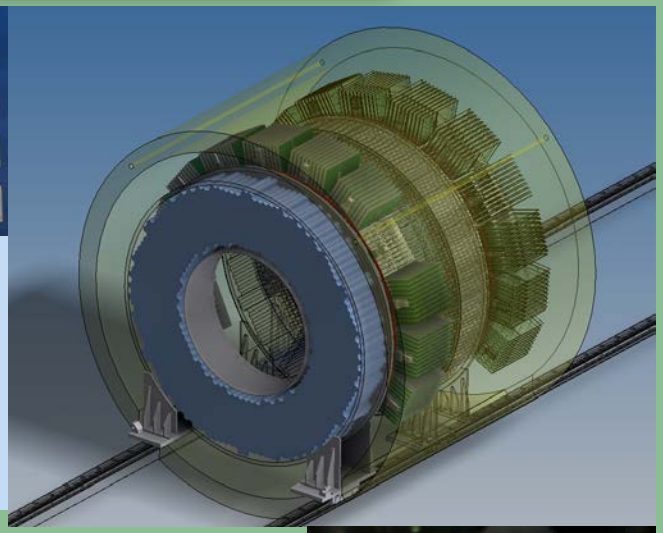


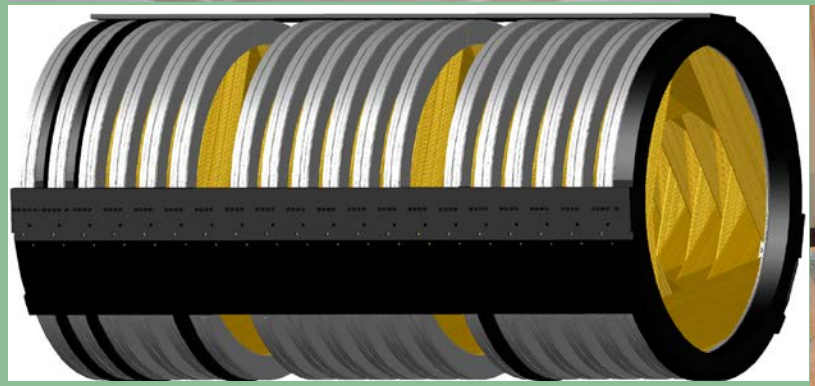
Signal sensitivity for a three year run



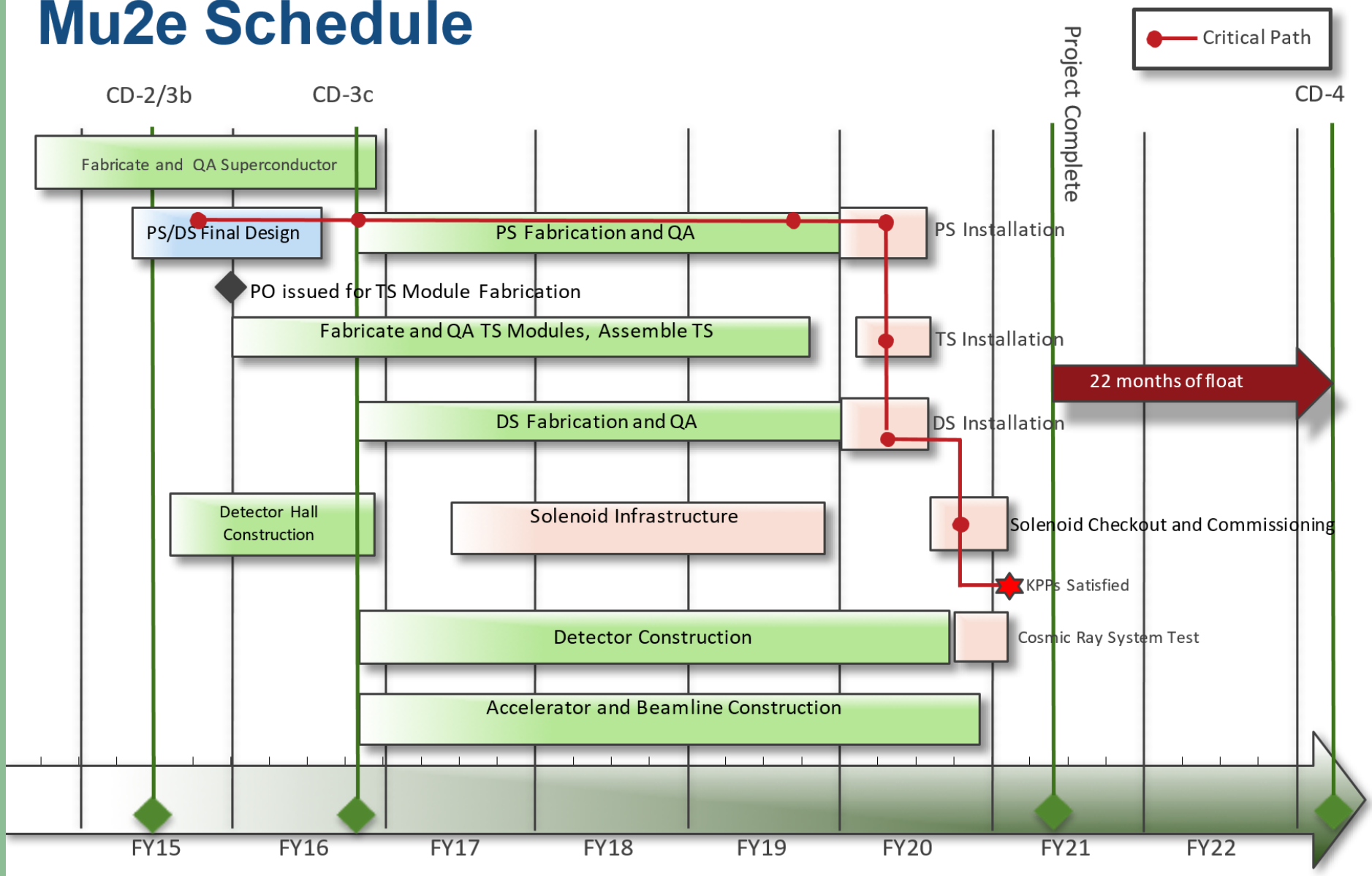
Reconstructed e^- momentum

Mu2e progress

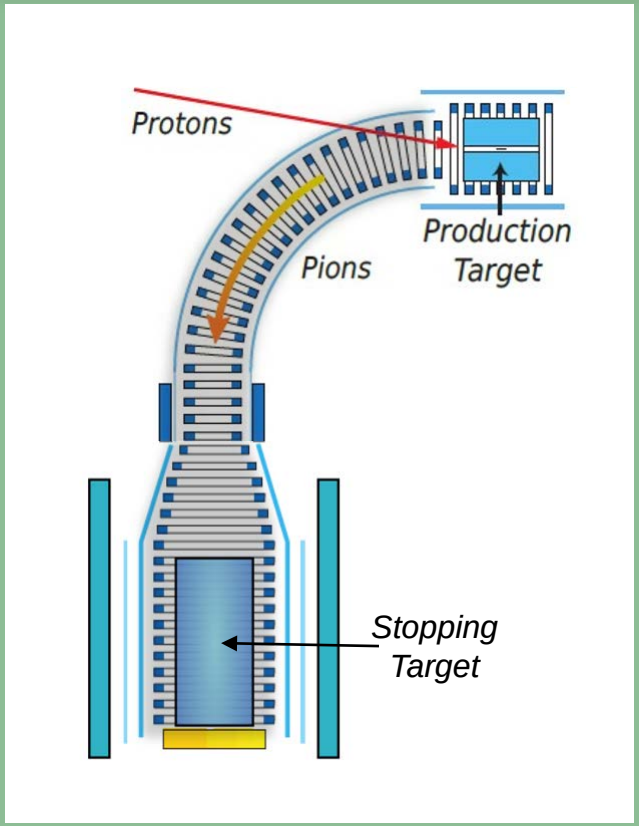




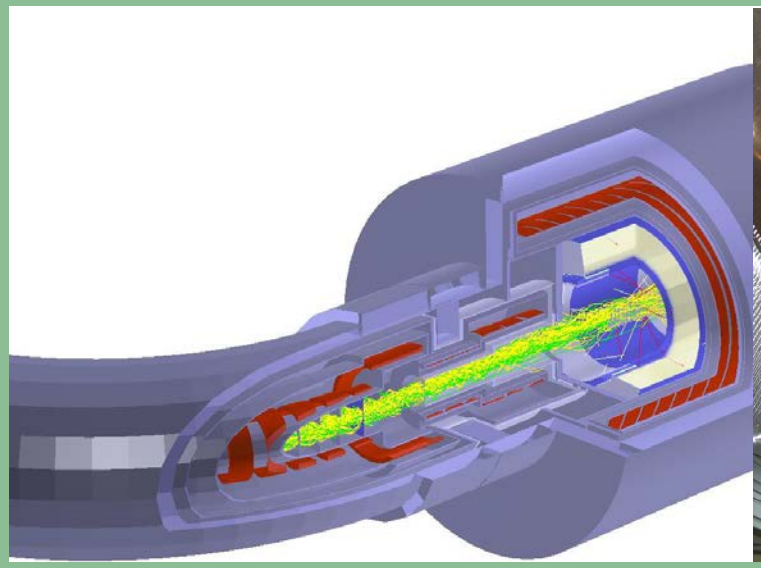
Mu2e Schedule



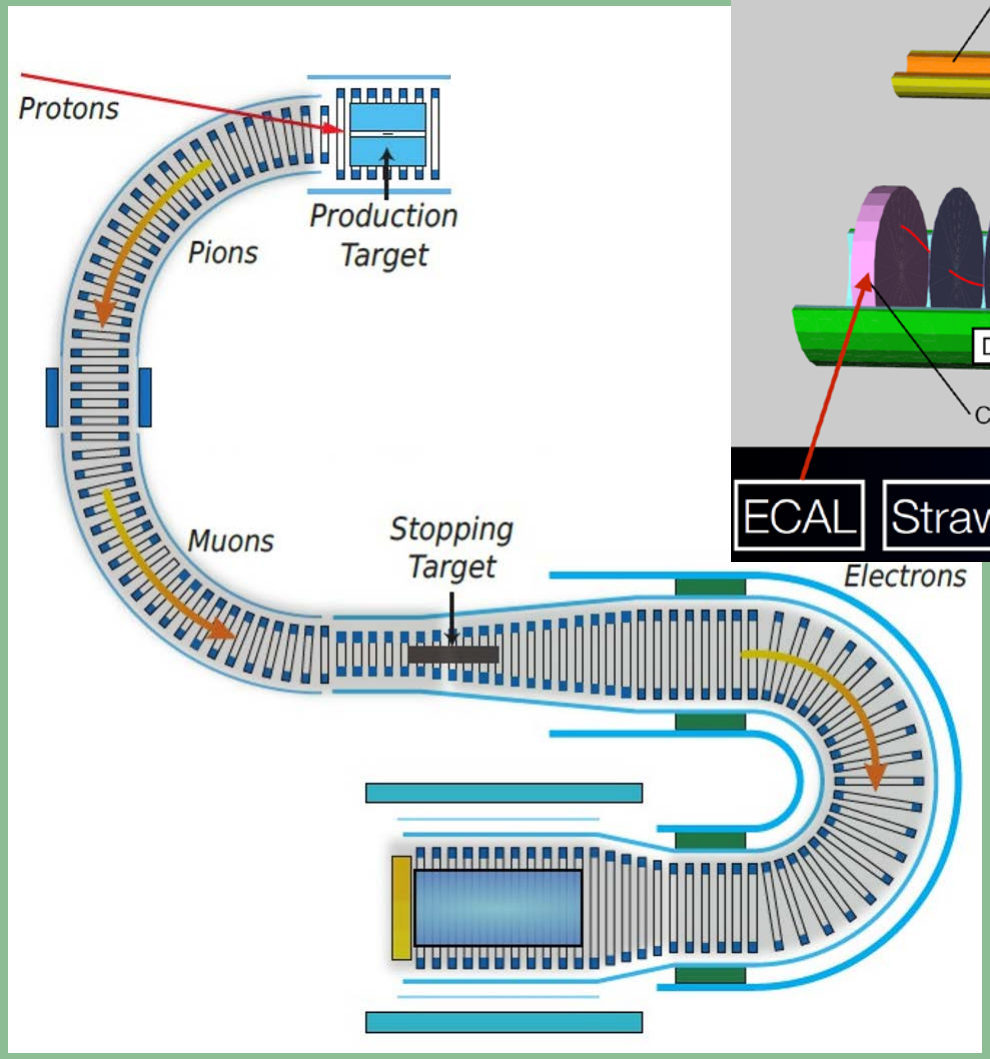
COMET Phase I

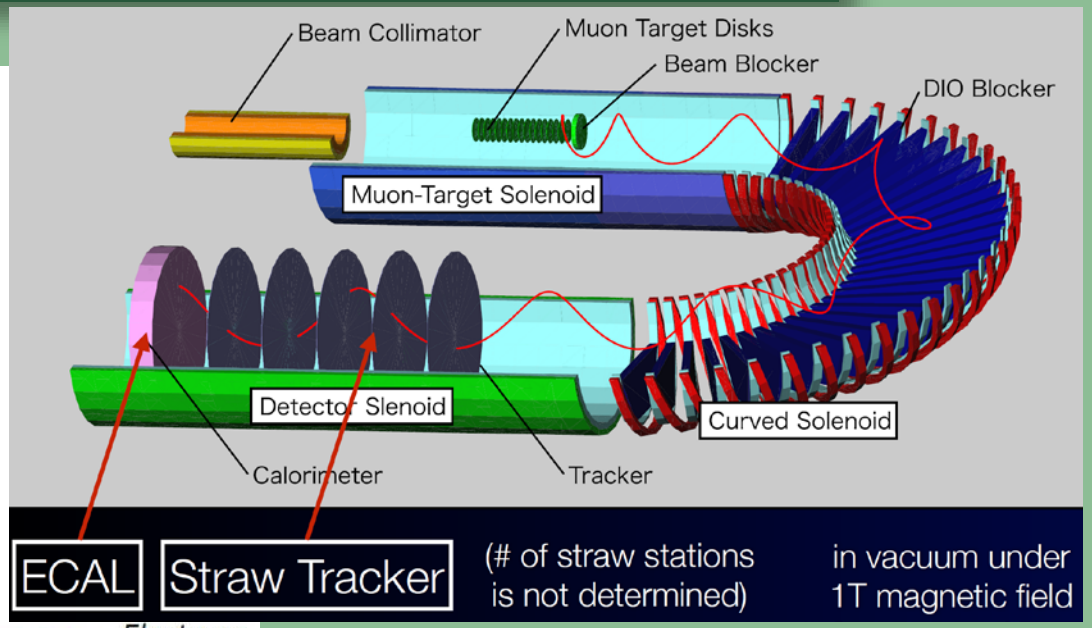


SES 3×10^{-15}
or $< 6 \times 10^{-15}$ @ 90% CL
for 150 days at 3.2 kW



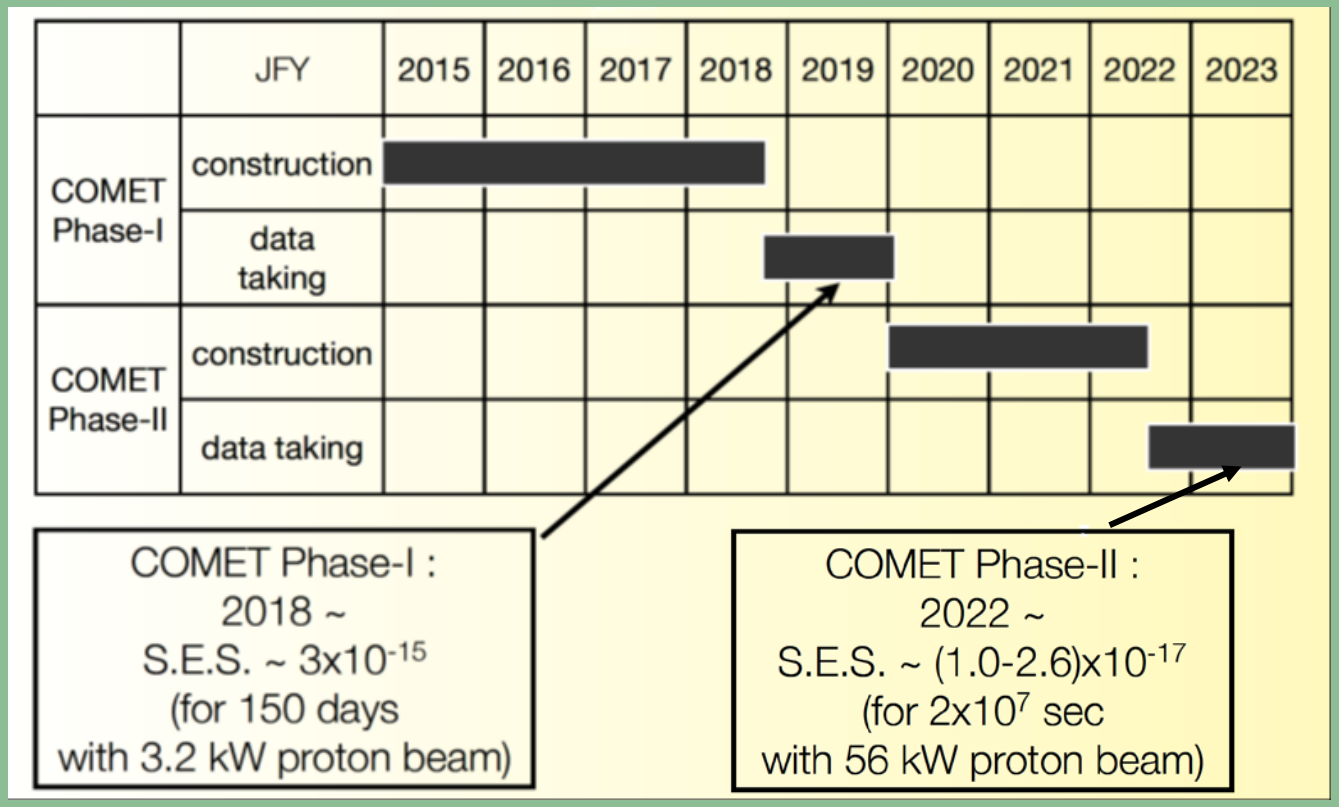
COMET Phase II



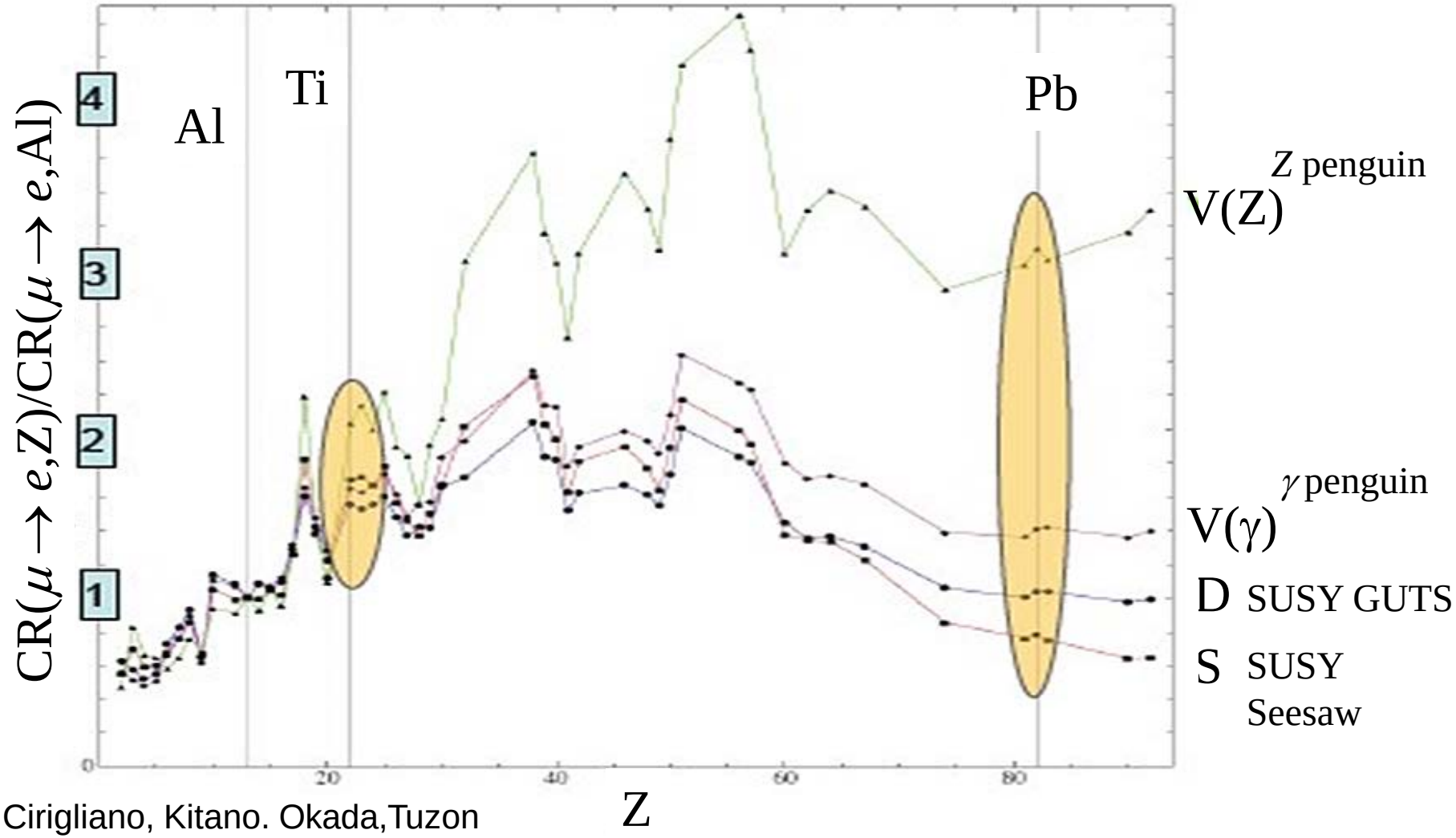


SES (1.0 – 2.6) x 10^{-17}
for 2 x 10^{7} s at 56kW

COMET schedule



Z dependence of mu to e conversion



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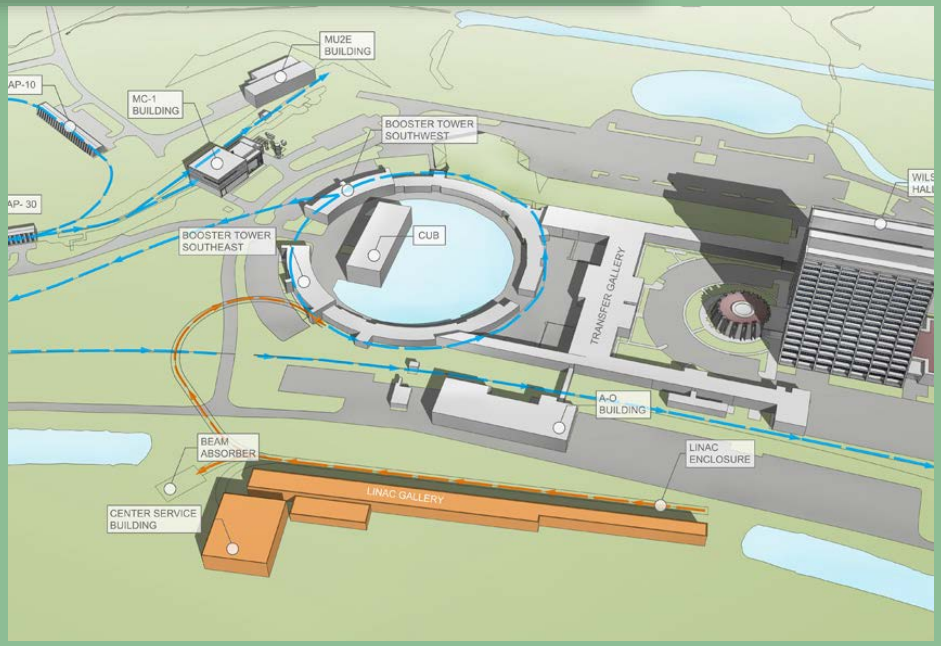
PIP2/Mu2e II

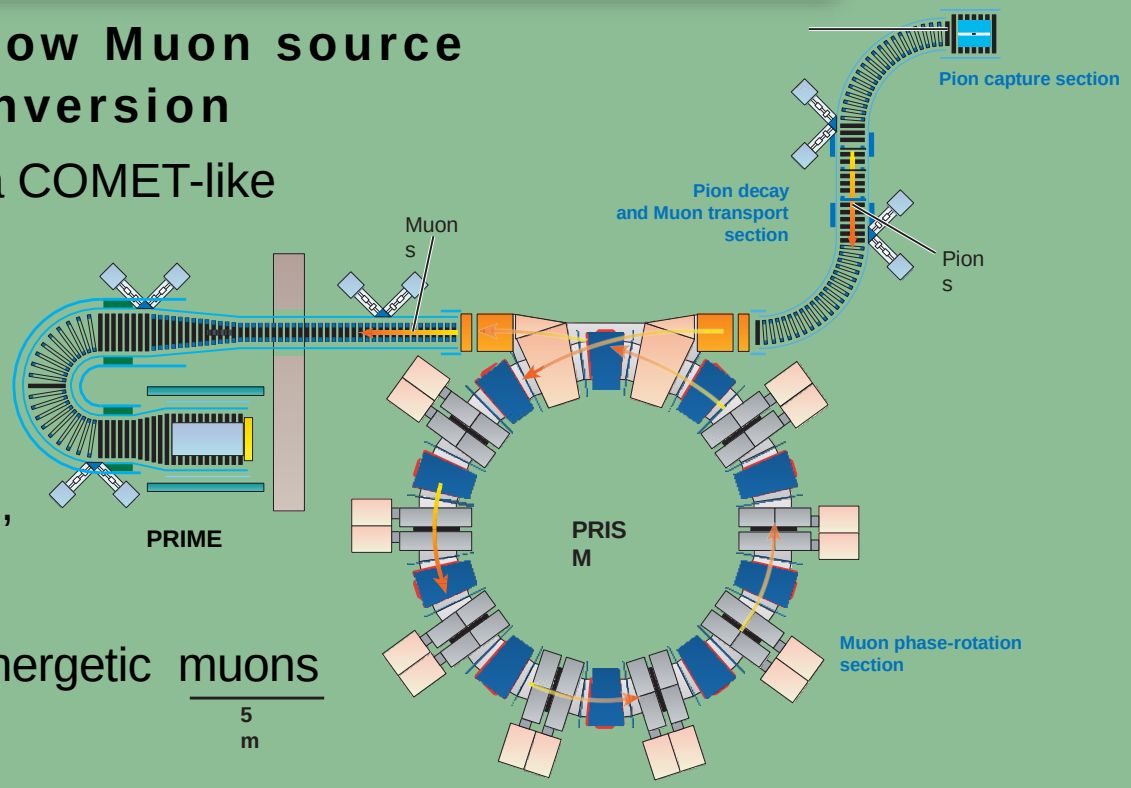


- PIP2 is an 800 MeV, 120 kW superconducting linac for LBNF and the muon campus
  - Currently under design
- There is also an active study of an upgrade of Mu2e
  - An order of magnitude increase in muon stops, but only a x3-5 increase in instantaneous rate
  - Detector systems must be upgraded
- Goals:
  - If $\mu \rightarrow e$ conversion has been found, use heavier targets to ascertain the (A, Z)-dependence of conversion rate
  - If conversion is not seen, improve sensitivity by an order of magnitude

Prism/PRIME

Phase Rotated Intense Slow Muon source
PRISM Muon Electron conversion

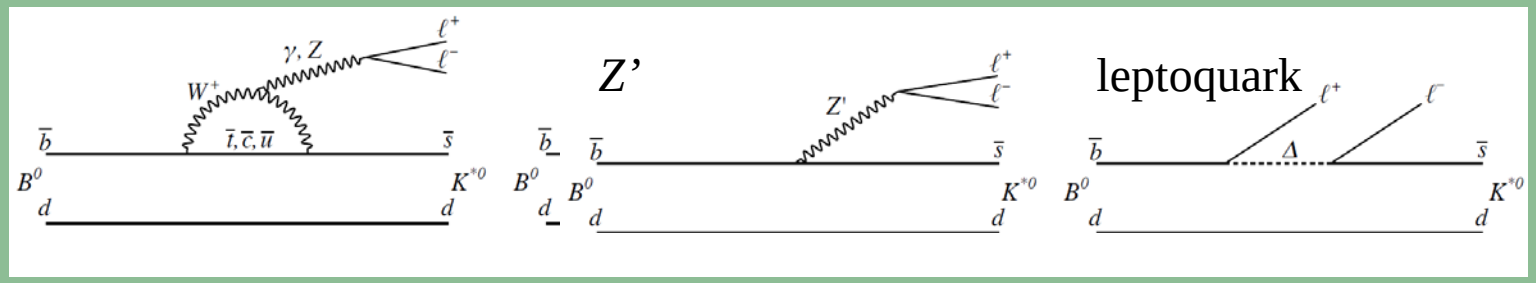
- A muon storage ring, feeding a COMET-like channel and detector
- High muon intensity:
- (10^{11}-10^{12} μ^-/s):
  large 6D acceptance (FFAG),
- Pulsed beam >100 Hz,
- Low momentum, quasi-monoenergetic muons
- Pion contamination <10^{-18}
- Requires a multi-GeV 1-4 MeV proton driver
- Aims for SES- 3×10^{-19}
- Time scale beyond 2030

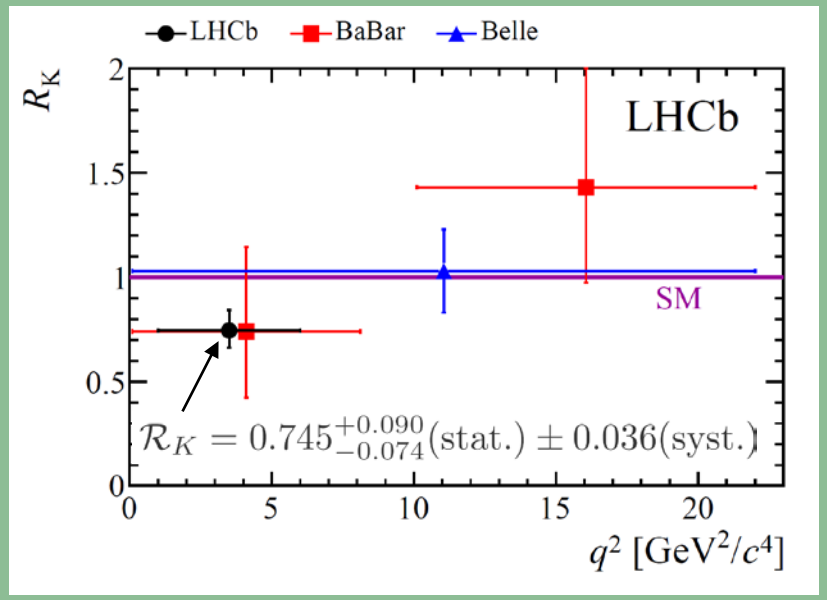


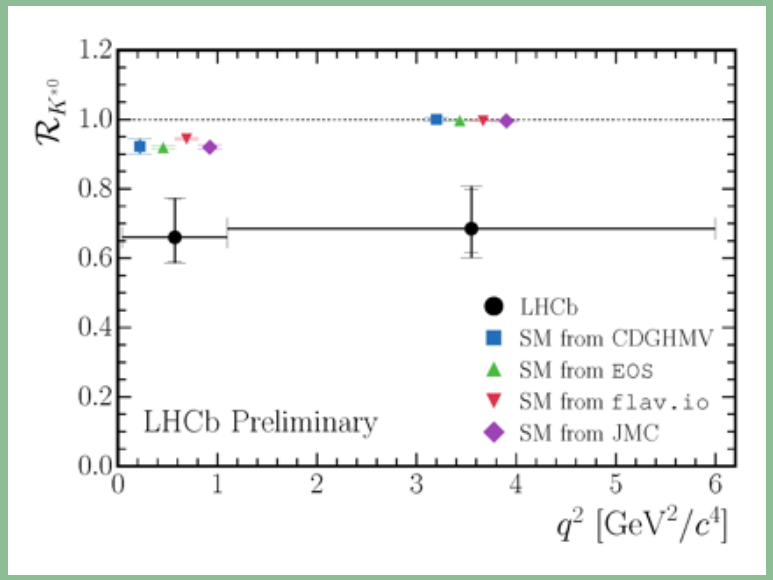
R_K and R_{K*}

$$R_K = \frac{\int_{q^2_{\min}}^{q^2_{\max}} \frac{d\Gamma[B^+ \to K^+\mu^+\mu^-]}{dq^2} dq^2}{\int_{q^2_{\min}}^{q^2_{\max}} \frac{d\Gamma[B^+ \to K^+e^+e^-]}{dq^2} dq^2}$$

also R_{K*}, with $B^0 \to K^{*0}\ell^+\ell^-$







Outlook

- Current limits on charged lepton flavor violation provide useful constraints on New Physics models
- Over the next decade, improved τ decay, μ decay, leptonic and semileptonic meson decay and $\mu \to e$ conversion experiments will have the sensitivity to probe the regime predicted by many New Physics models
  - Sensitivities reach beyond what is possible in direct production of new particles at the LHC
  - Should evidence for CLFV be found, comparison of branching ratios and conversion rates would be diagnostic of specific models