COMET実験

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Mini Workshop on
“Quarks, Lepton and Family Gauge Bosons”

Outline of My Talk

muon to electron conversion in a muonic atom

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

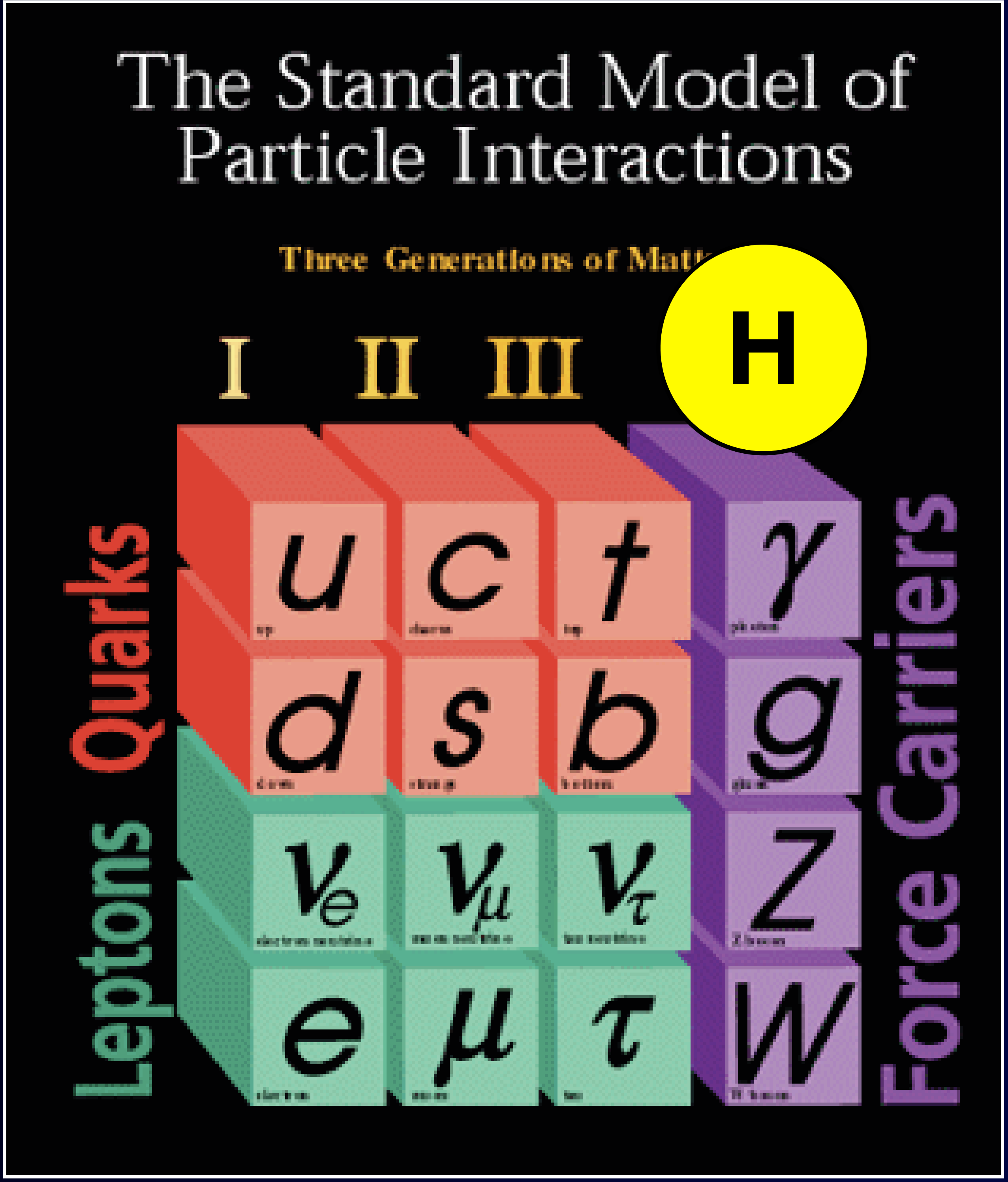
(charged lepton flavor violation)

- Flavour Physics in Particle Physics
- Physics Motivation of Charged Lepton Flavour Violation
- Muon to electron conversion
- COMET at J-PARC
- Highly intense muon beam sources
- COMET Phase-I (under experimental preparation)
- Summary

Big Picture in Particle Physics

New Physics
Beyond the Standard Model

The Standard Model is considered to be incomplete.
New Physics is needed.



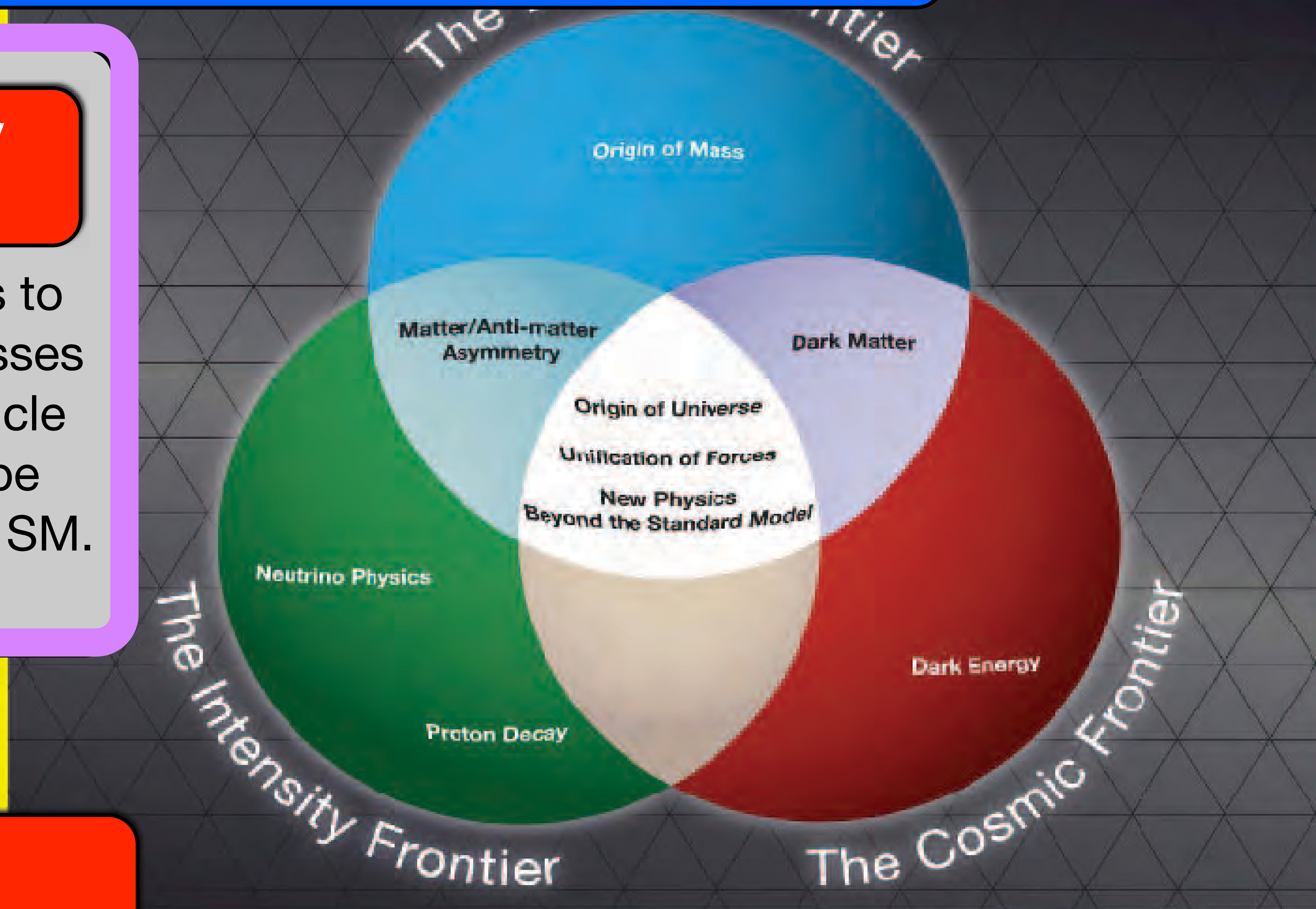
Intensity Frontiers and Rare Process

To explore new physics at high energy scale

The Intensity Frontier

use intense beams to observe rare processes and study the particle properties to probe physics beyond the SM.

Rare Decays
Flavour Physics



Why Rare Decays ?

Effective Lagrangian with New Physics

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \frac{C_{\rm NP}}{\Lambda^2} O_{ij}^{(6)}$$

dimension 6

Λ is the energy scale of new physics （∼m_{NP})

C_{NP} is the coupling constant.

New Physics could be....

very high energy scale Λ with C_{NP}~1

or

very small C_{NP} with not-high energy Λ

Effective Lagrangian with New Physics

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \frac{C_{\rm NP}}{\Lambda^2} O^{(6)}_{ij}$$

dimension 6

Λ is the energy scale of new physics （$\sim m_{NP}$)

C_{NP} is the coupling constant.

ex: Charged lepton flavour violation (CLFV), μ→eγ (B<4.2x10^{-13} from MEG(2016))

$$\frac{C_{\rm NP}}{\Lambda^2} O^{(6)}_{ij} \rightarrow \frac{C_{\mu e}}{\Lambda^2} \bar{e}_L \sigma^{\rho\nu} \mu_R \Phi F_{\rho\nu}$$

$$\Lambda > 2 \times 10^5 \ {\rm TeV} \times (C_{\mu e})^{\frac{1}{2}} \ .$$

Λ > O(10^5) TeV with $C_{\mu e}$~O(1)

or

$C_{\mu e}$~O(10^{-9}) with Λ < O(1) TeV

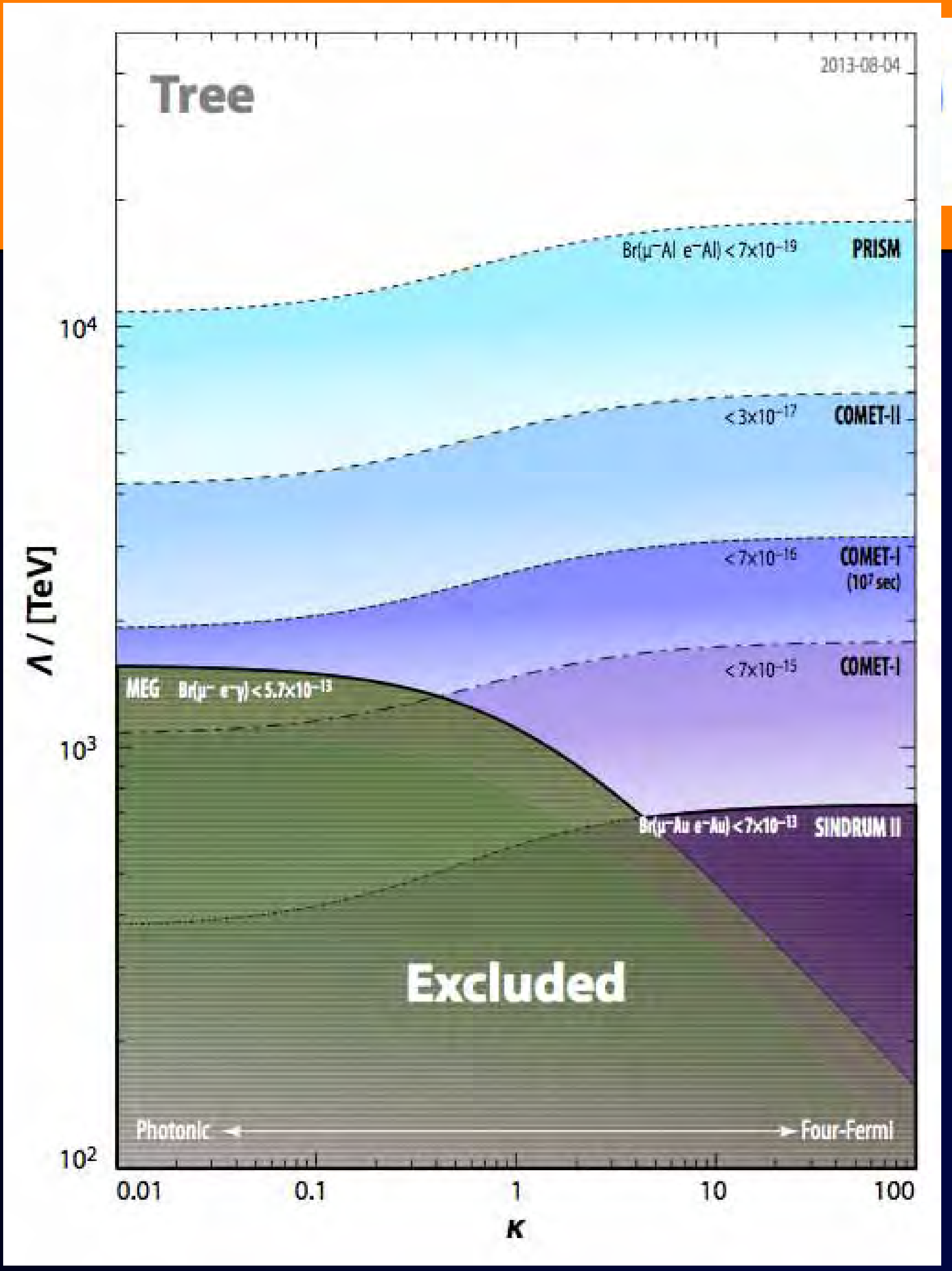
Why Rare Decays ?

Energy reach of New Physics by rare decays such as CLFV

$\Lambda > O(10^5)$TeV

(Indirect search)

It would be strategic to pursue rare decays before high energy machines (100 TeV).



Why Leptons ?

FCNC
(Flavor Changing Neutral Current)

Quark Sector
(SM suppressed)

SM + NP

Uncertainty of the SM prediction limits the sensitivity.

SM contribution has to be subtracted.

ex. B□ □□

Lepton Sector
(SM forbidden)

+ NP

Clear signature without any subtractions

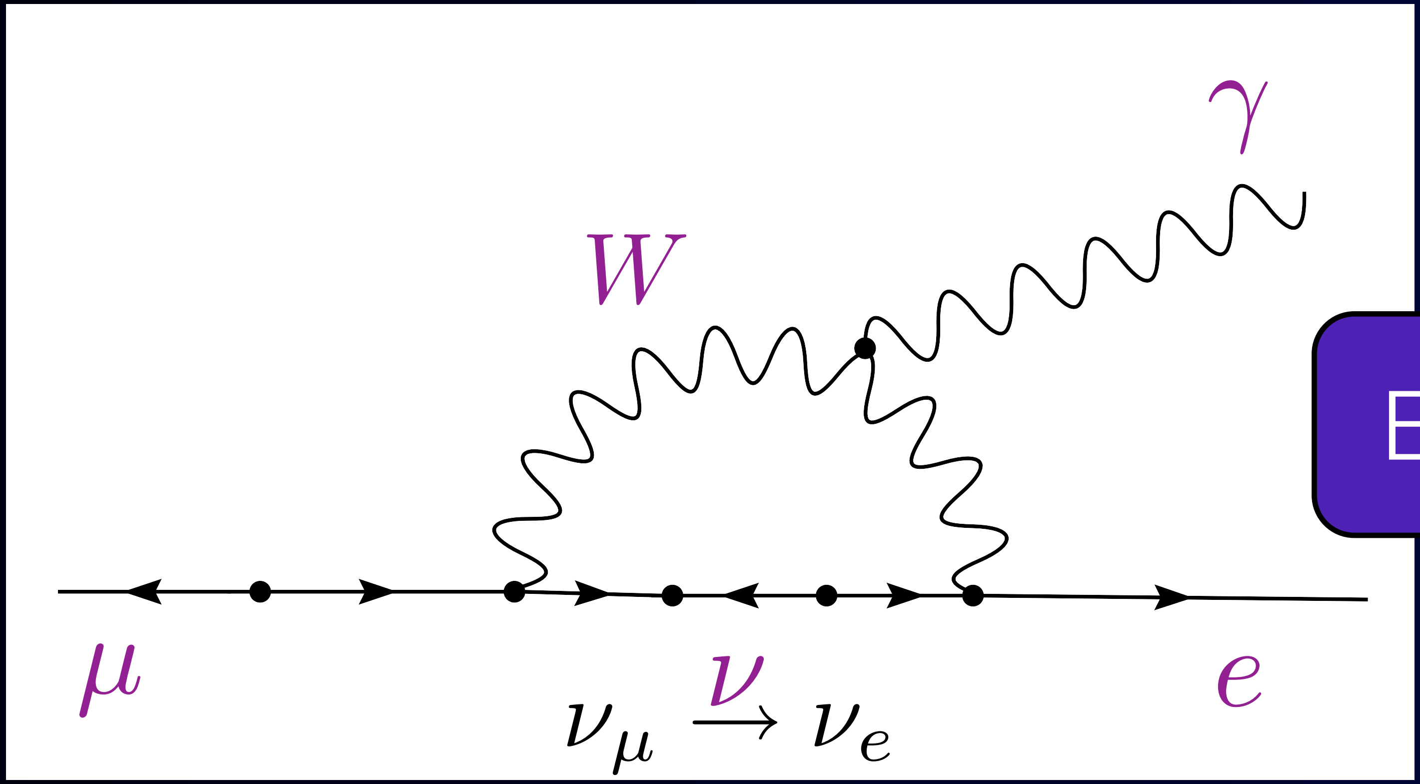
No SM contribution be subtracted.

ex. □ □ □□

Rare Process
No SM Contribution to CLFV

$$B(\mu \to e\gamma) = \frac{3\alpha}{32\pi} \left| \sum_l (V_{MNS})^*_{\mu l} (V_{MNS})_{el} \frac{m^2_{\nu_l}}{M^2_W} \right|^2$$

GIM suppression



BR~O(10^{-54})

Observation of CLFV would indicate a clear signal of physics beyond the SM with massive neutrinos.

Quarks (SM-suppressed) and Leptons (SM-forbidden)

$$|A_{SM}|^2 \pm \Delta(|A_{SM}|^2)$$

Quark (SM suppressed)

amplitude

$$|A_{\rm SM} + \varepsilon_{\rm NP}|^2 \sim |A_{\rm SM}|^2 + \underline{2Re(A_{\rm SM}\varepsilon_{\rm NP})} + |\varepsilon_{\rm N}|^2$$

subject to uncertainty of SM prediction

NP contribution ~ O(ε)

rate

Lepton (SM forbidden)

$$|A_{\rm SM} + \varepsilon_{\rm NP}|^2 \sim \cancel{|A_{\rm SM}|^2} + 2Re(\cancel{A_{\rm SM}}\varepsilon_{\rm NP}) + \underline{|\varepsilon_{\rm N}|^2}$$

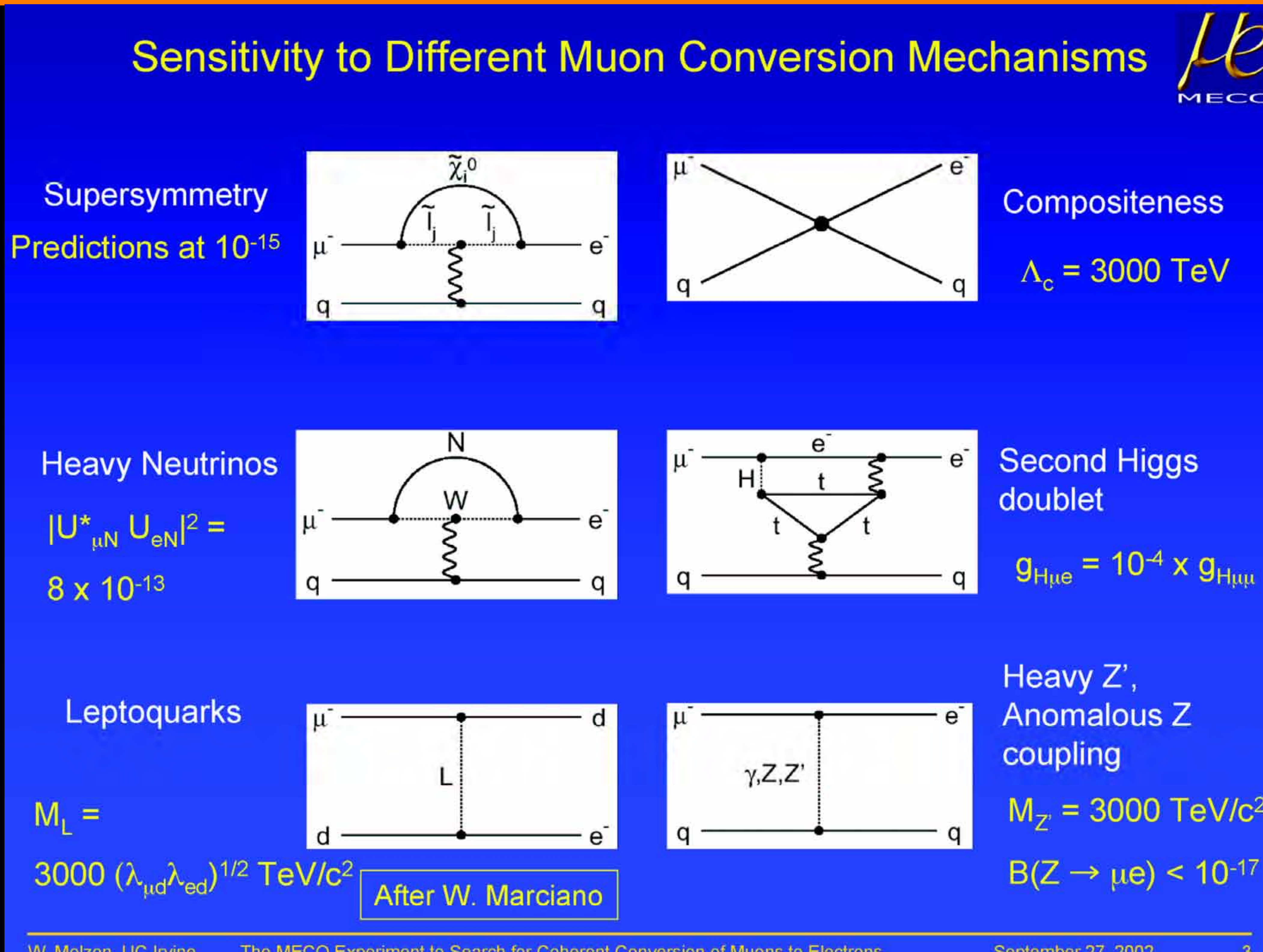
could go higher energy scale

NP contribution ~ O(ε^2)

$$R \propto \frac{1}{\Lambda^4}$$

$\Lambda \geqq$ x10 —> R $\leqq 10^{-4}$

Various Models Predict CLFV......

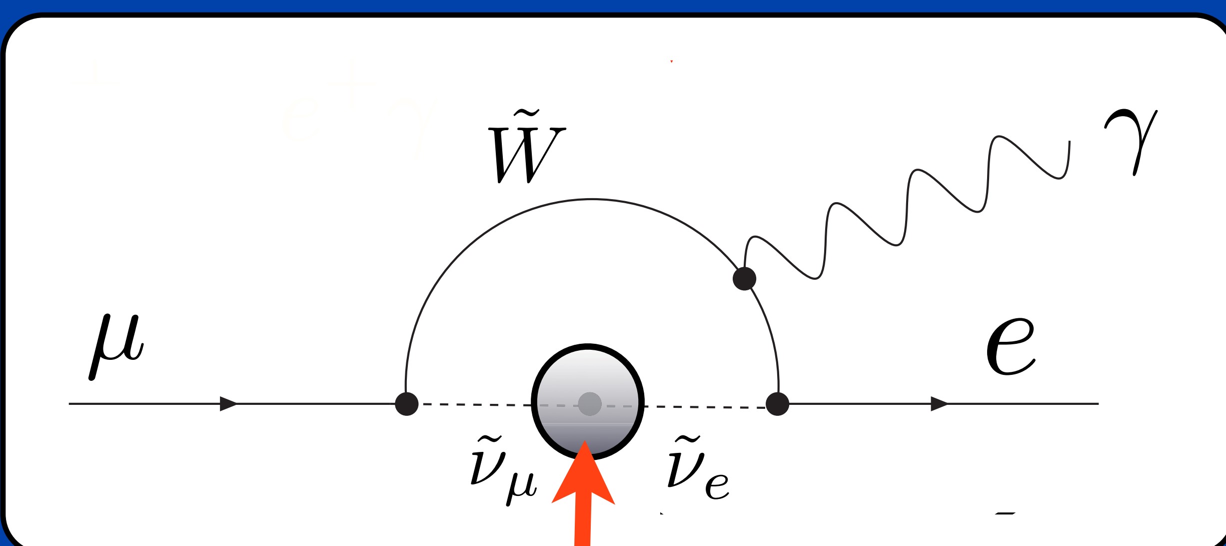


Example of Sensitivity to NP in High Energy Scale : SUSY models

- For loop diagrams,

$$\mathrm{BR}(\mu \to e\gamma) = 1 \times 10^{-11} \times \left(\frac{2\mathrm{TeV}}{\Lambda}\right)^4 \left(\frac{\theta_{\mu e}}{10^{-2}}\right)^2 \qquad y = \frac{g^2}{16\pi^2}\theta_{\mu e}$$

> sensitive to TeV energy scale with reasonable mixing



example diagram for SUSY (~TeV)

Physics at about 10^{16} GeV

slepton mixing (from RGE)

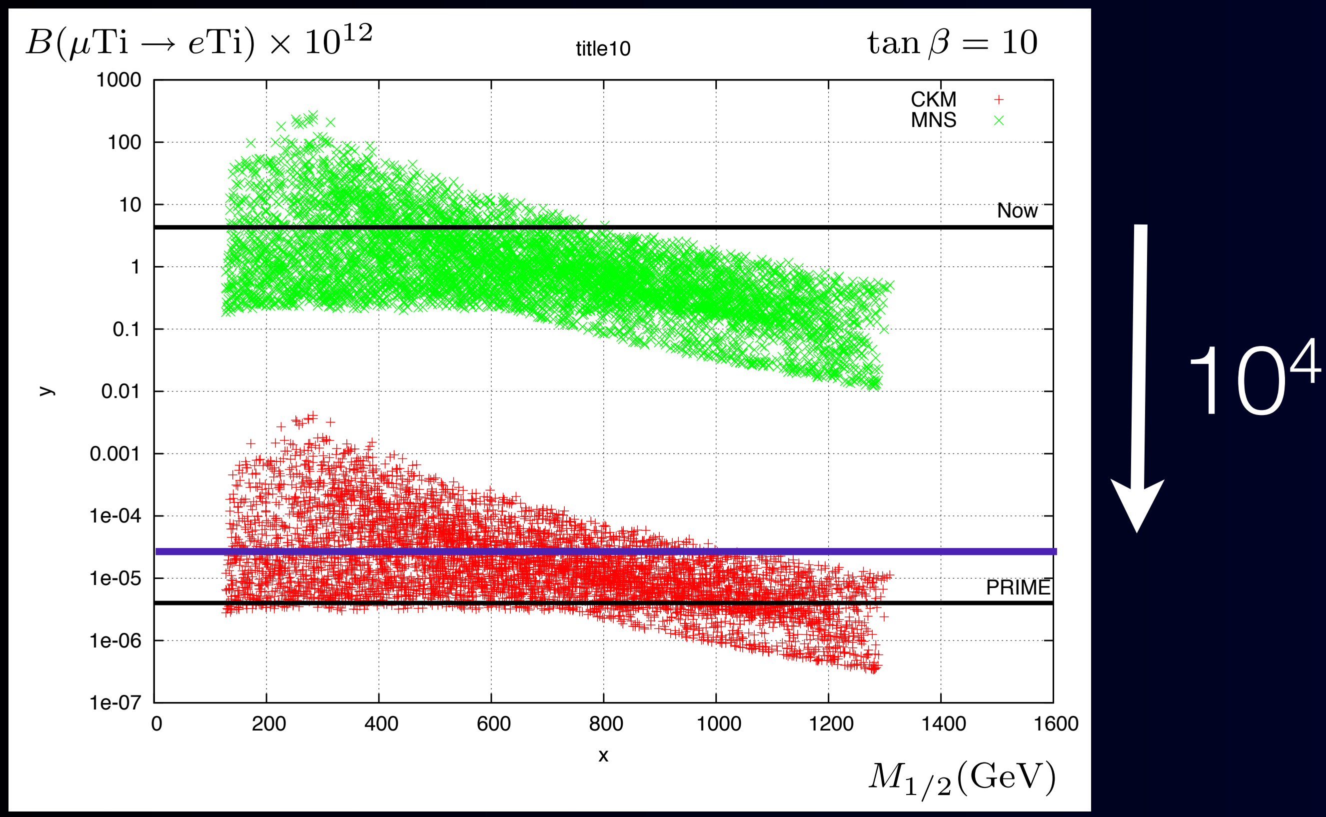
$$(m_L^2)_{21} \sim \frac{3m_0^2 + A_0^2}{8\pi^2} h_t^2 V_{td} V_{ts} \ln \frac{M_{GUT}}{M_{R_s}}$$

SUSY-GUT model

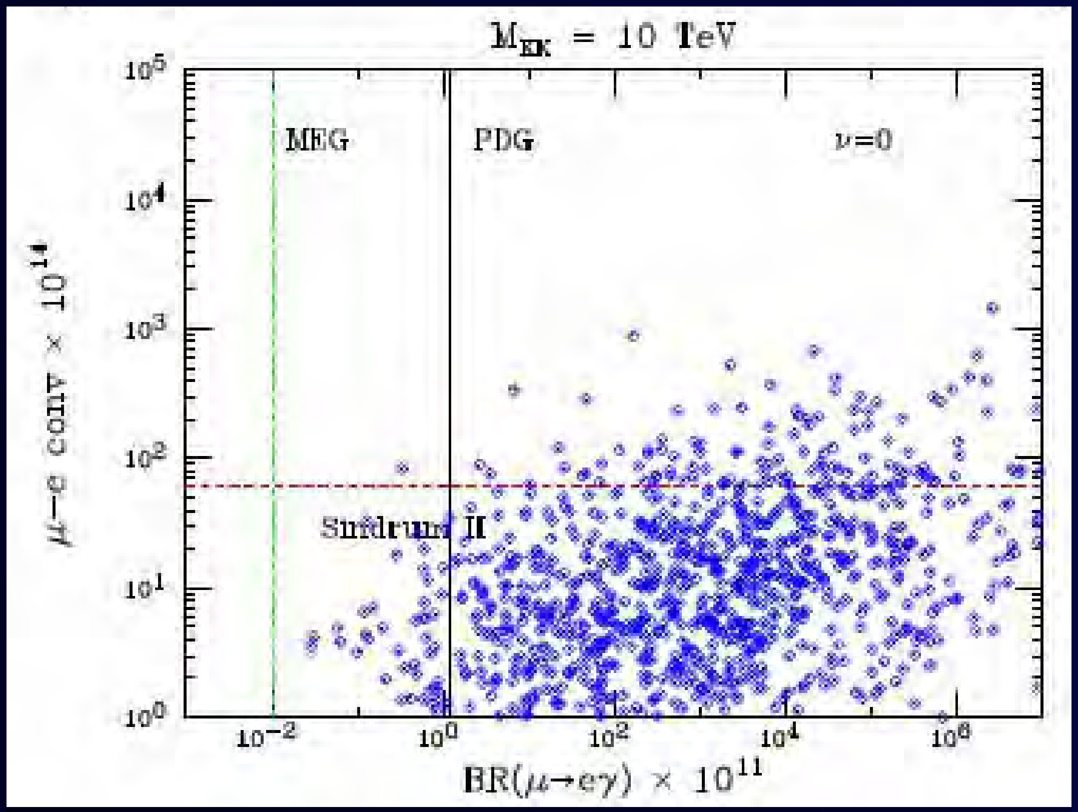
$$(m_L^2)_{21} \sim \frac{3m_0^2 + A_0^2}{8\pi^2} h_\tau^2 U_{31} U_{32} \ln \frac{M_{GUT}}{M_R}$$

SUSY neutrino seesaw model

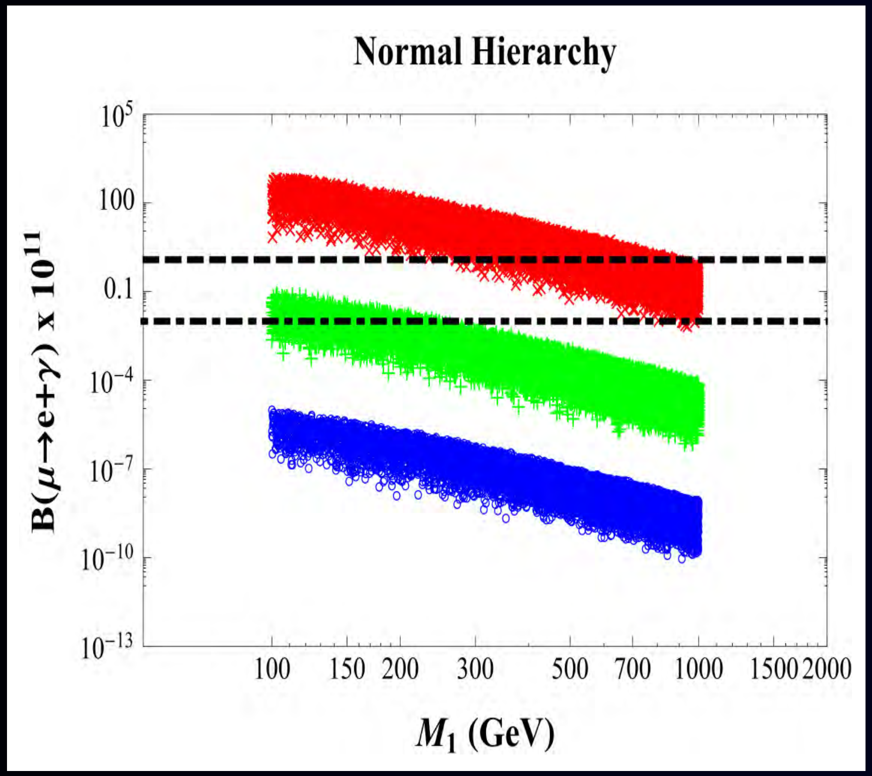
SUSY model



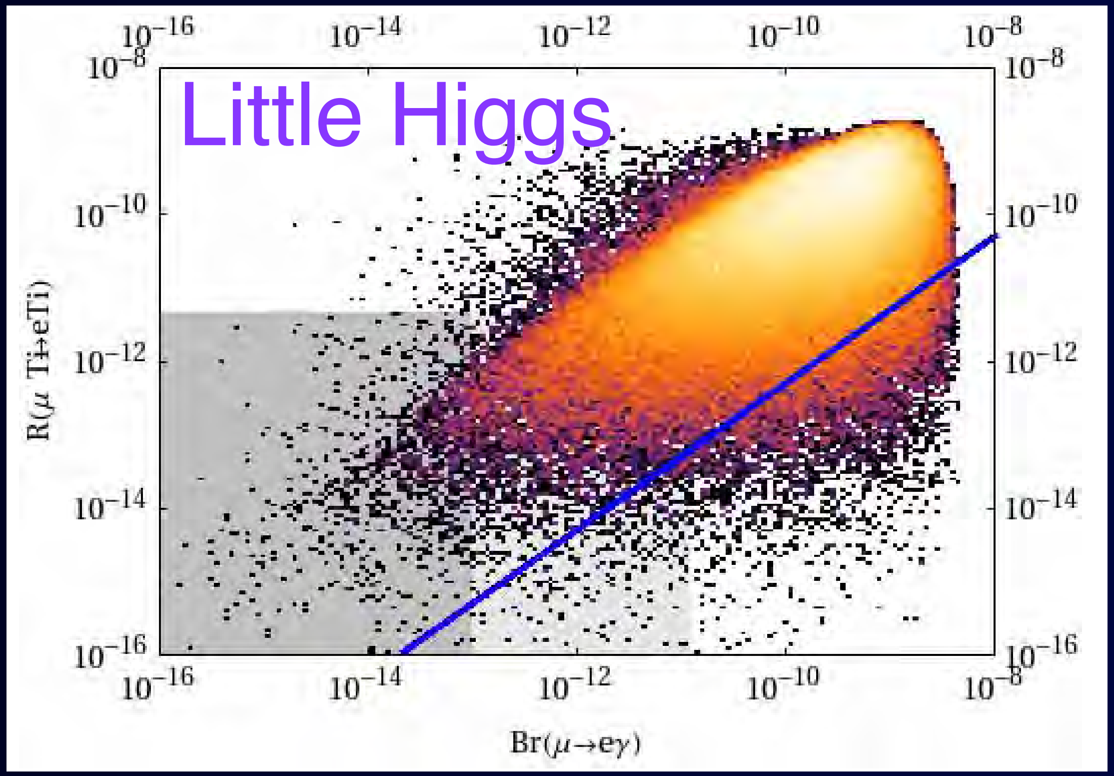
extra dimension model



low-energy seesaw model



little Higgs model



Why Muons ?

Why muons, not taus ?

of taus
~ $O(10^9)$/year

# of muons
~ $O(10^{15})$/year

# of muons
~ $O(10^{18})$/year

Muon CLFV

Experimental Limits at Present and in the Future

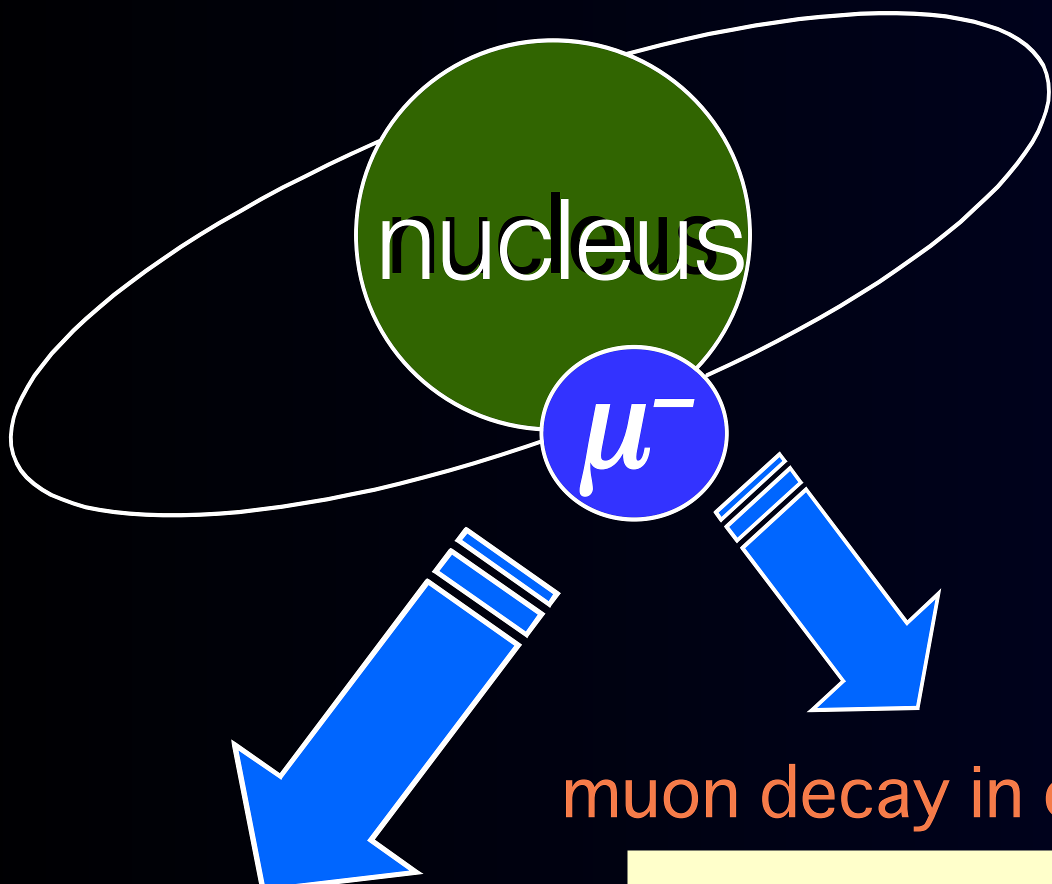
process	present limit	future	
$\mu \rightarrow e\gamma$	$<4.2 \times 10^{-13}$	$<10^{-14}$	MEG at PSI
$\mu \rightarrow eee$	$<1.0 \times 10^{-12}$	$<10^{-16}$	Mu3e at PSI
$\mu N \rightarrow eN$ (in Al)	none	$<10^{-16}$	Mu2e / COMET
$\mu N \rightarrow eN$ (in Ti)	$<4.3 \times 10^{-12}$	$<10^{-18}$	PRISM
$\tau \rightarrow e\gamma$	$<1.1 \times$ [illegible]	[illegible] $- 10^{-10}$	superKEKB
$\tau \rightarrow eee$	$<3.6 \times 10^{-8}$	$<10^{-9} - 10^{-10}$	superKEKB
$\tau \rightarrow \mu\gamma$	$<4.5 \times 10^{-8}$	$<10^{-9} - 10^{-10}$	superKEKB
$\tau \rightarrow \mu\mu\mu$	$<3.2 \times 10^{-8}$	$<10^{-9} - 10^{-10}$	superKEKB/LHCb

$X10^{-4}$

Why Muon to Electron Conversion ?

What is Muon to Electron Conversion?

1s state in a muonic atom



muon decay in orbit

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

nuclear muon capture

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

Neutrino-less muon nuclear capture

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

coherent process $\propto Z^5$

Event Signature :

a single mono-energetic electron of 105 MeV

Backgrounds:

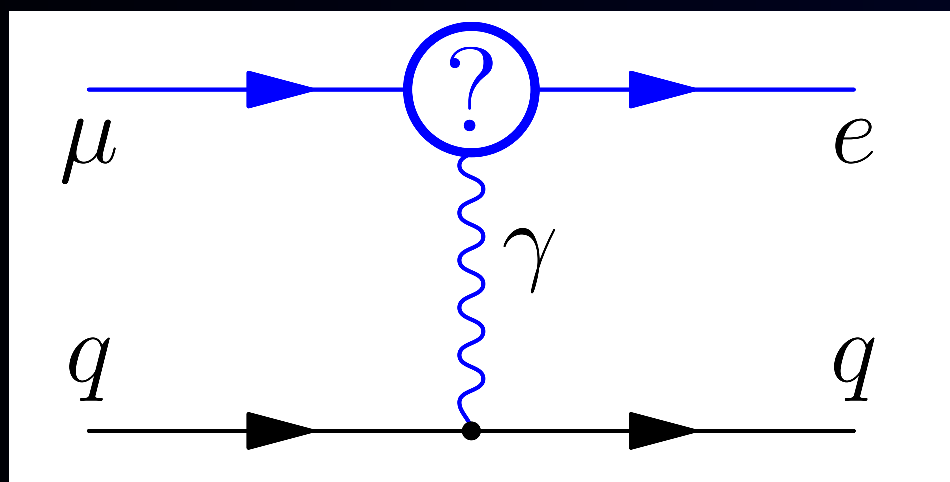
(1) physics backgrounds

(2) beam-related backgrounds

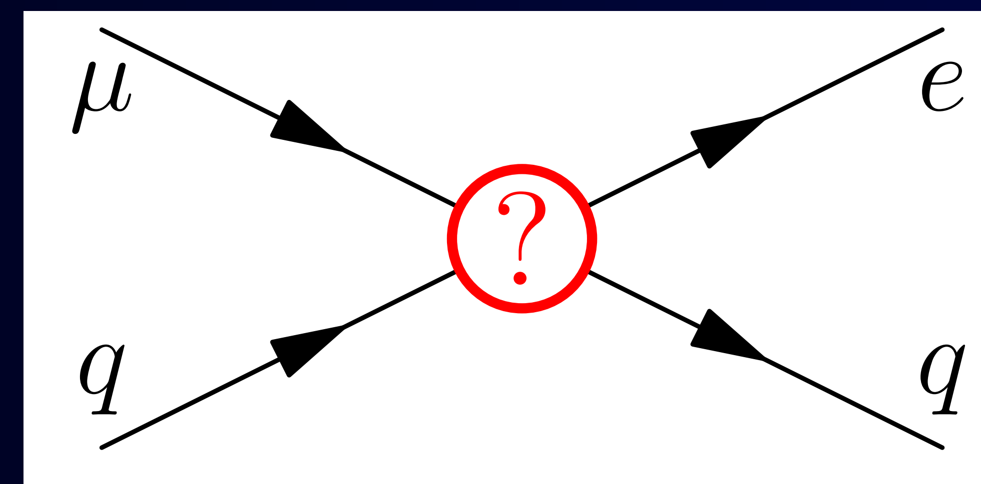
(3) cosmic rays, false tracking

Physics Sensitivity Comparison : μ→eγ vs. μ-e conversion

Photonic (dipole) interaction



Contact interaction



tree levels

$$L_{\mu N \to eN} = \frac{1}{1+\kappa}\frac{m_\mu}{\Lambda^2}\bar{\mu}_R \sigma^{\mu\nu} e_L F_{\mu\nu} + \frac{\kappa}{1+\kappa}\frac{1}{\Lambda^2}(\bar{\mu}_L \gamma^\mu e_L)(\bar{q}_L \gamma_\mu q_L)$$

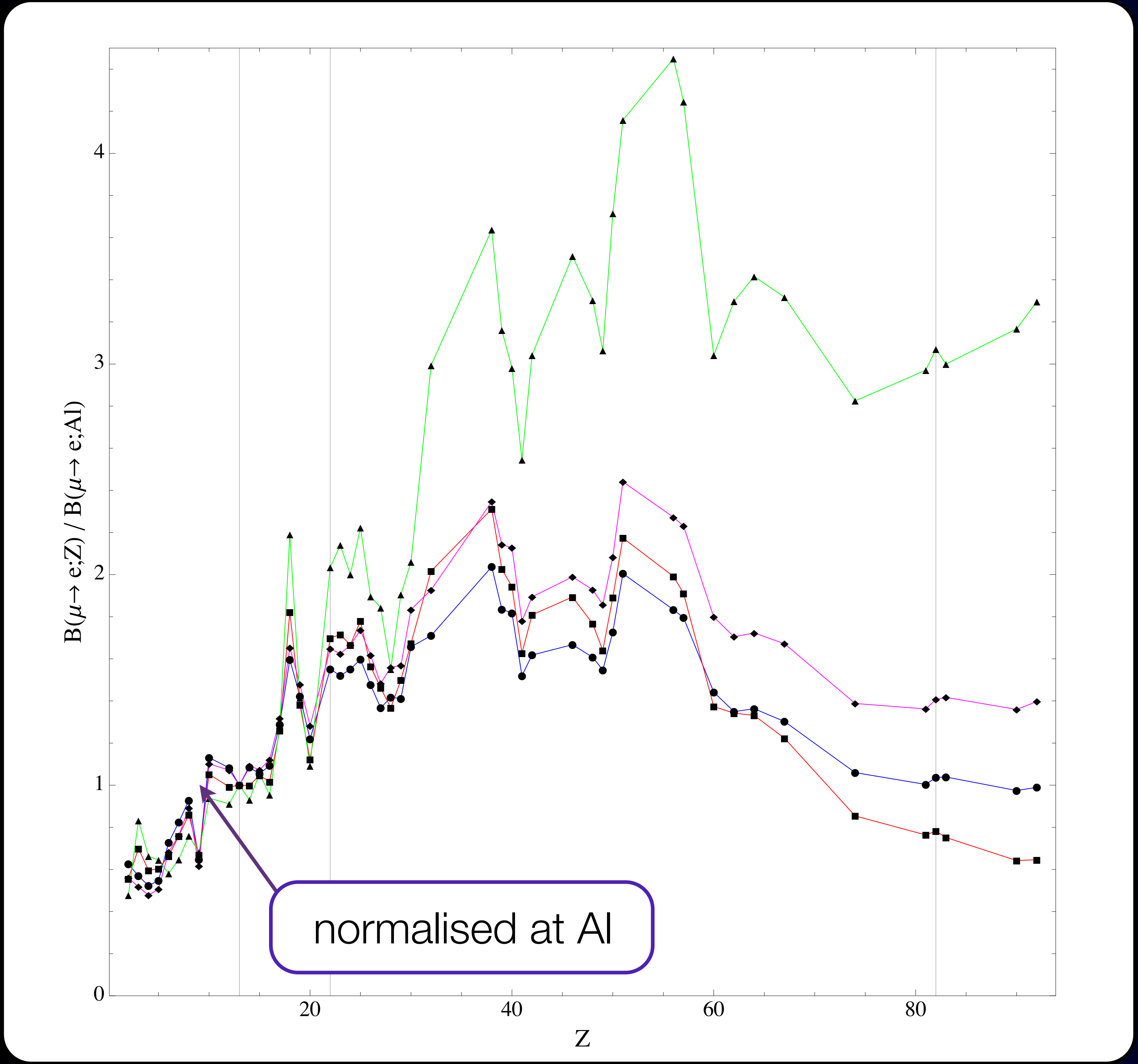
$$L_{\mu \to e\gamma} = \frac{m_\mu}{\Lambda^2}\bar{\mu}_R \sigma^{\mu\nu} e_L F_{\mu\nu}$$

μ-e conversion sensitive to many new physics

Experimental Comparison : μ→eγ and μ-e Conversion

	Beam	background	challenge	beam intensity
μ→eγ	continuous beam	accidentals	detector resolution	limited
μ→eee	continuos beam	accidentals	detector resolution	limited
μ-e conversion	pulsed beam	beam-related	beam background	no limitation

μ-e Conversion : Target dependence (discriminating effective interaction)



R. Kitano, M. Koike and Y. Okada, Phys. Rev. D66, 096002 (2002)

vector interaction (with z boson)

vector interaction (with photon)

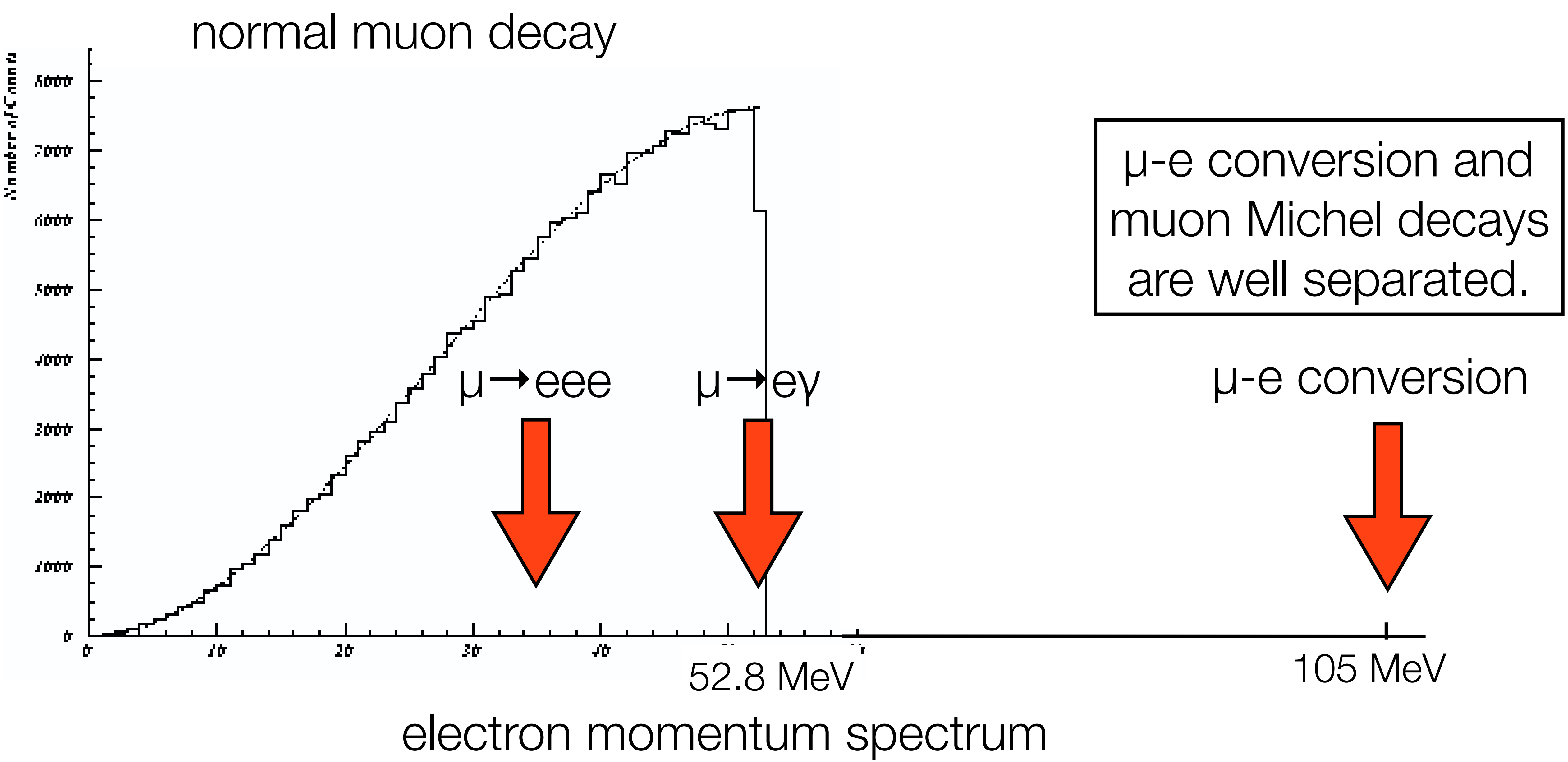
dipole interaction

scalar interaction

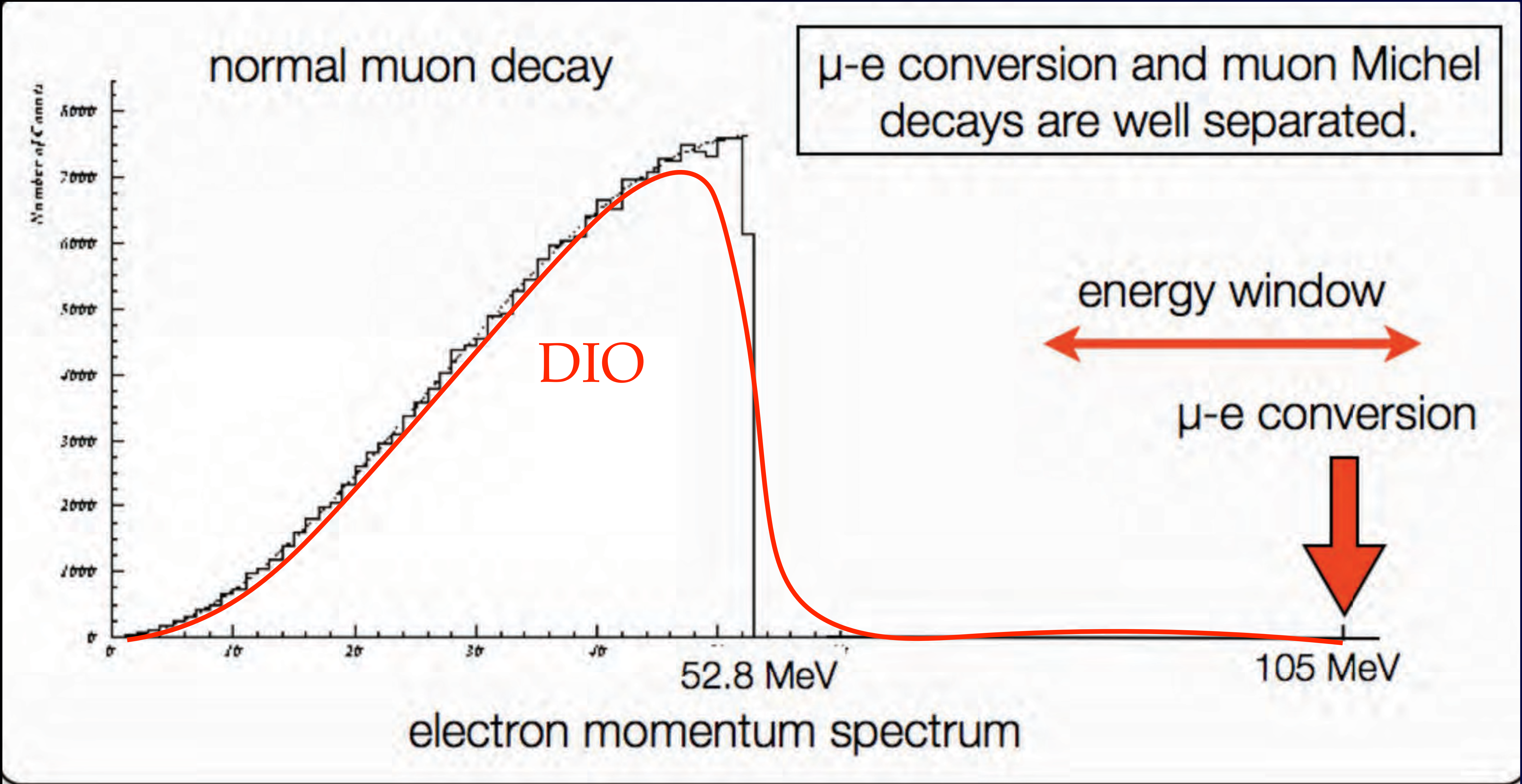
Backgrounds for μ-e conversion

intrinsic physics backgrounds	Muon decay in orbit (DIO) Radiative muon capture (RMC) neutrons from muon nuclear capture Protons from muon nuclear capture
beam-related backgrounds	Radiative pion capture (RPC) Beam electrons Muon decay in flights Neutron background Antiproton induced background
cosmic-ray and other backgrounds	Cosmic-ray induced background False tracking

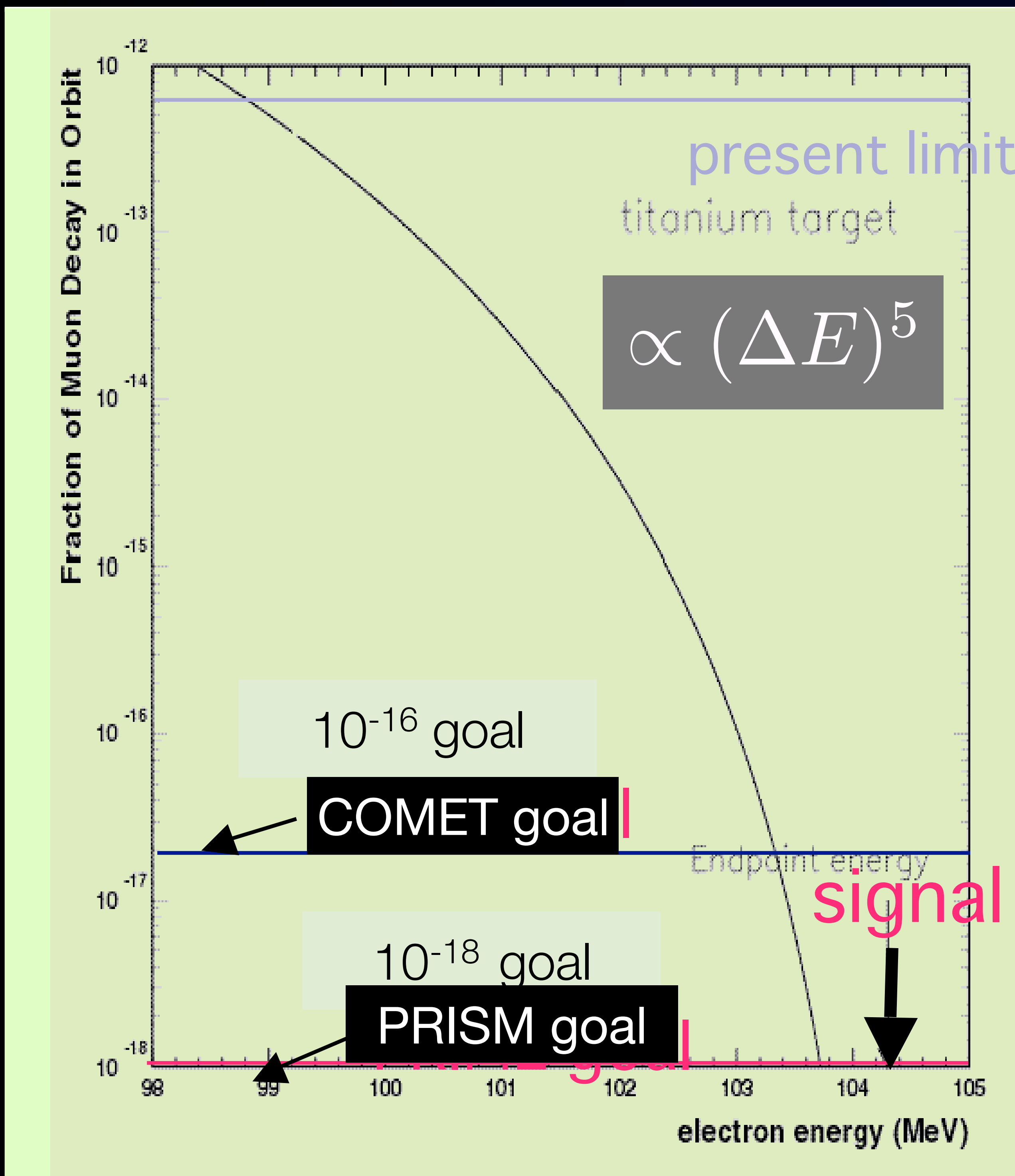
Signal of μ-e Conversion and Normal Muon Decays

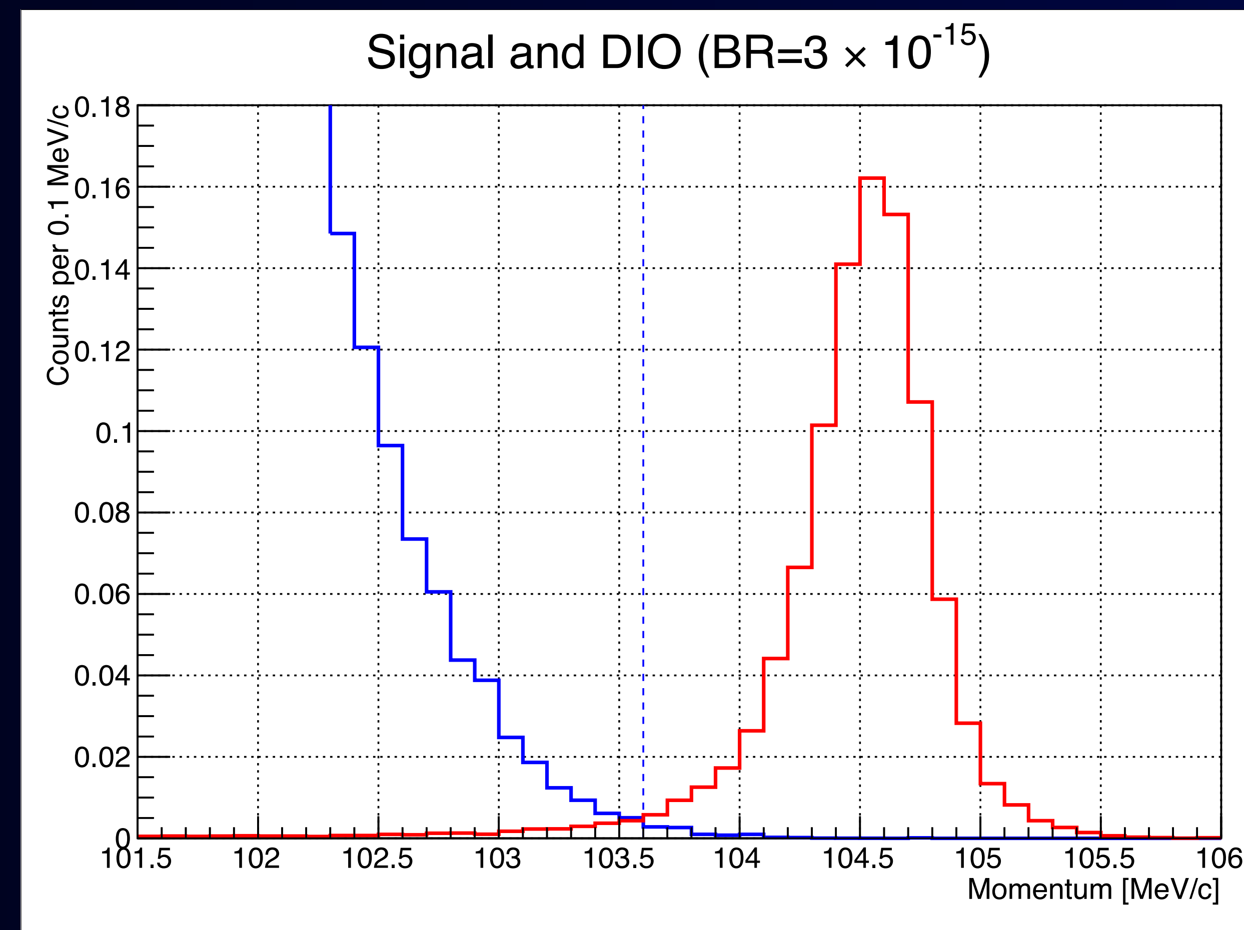


Muon Decay in Orbit



Intrinsic Physics Background: Muon Decay in Orbit (DIO)



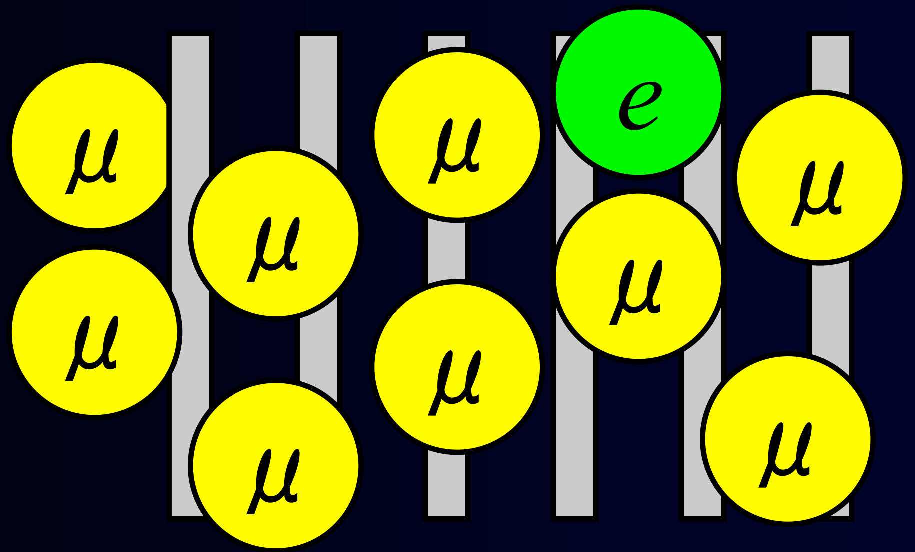


Good momentum resolution is needed.

In order to make a new-generation experiment to search for μ-e conversion …

$$B(\mu N \to eN) \leq 10^{-16}$$

Principle of Measurement of μ-e Conversion



muon stopping target

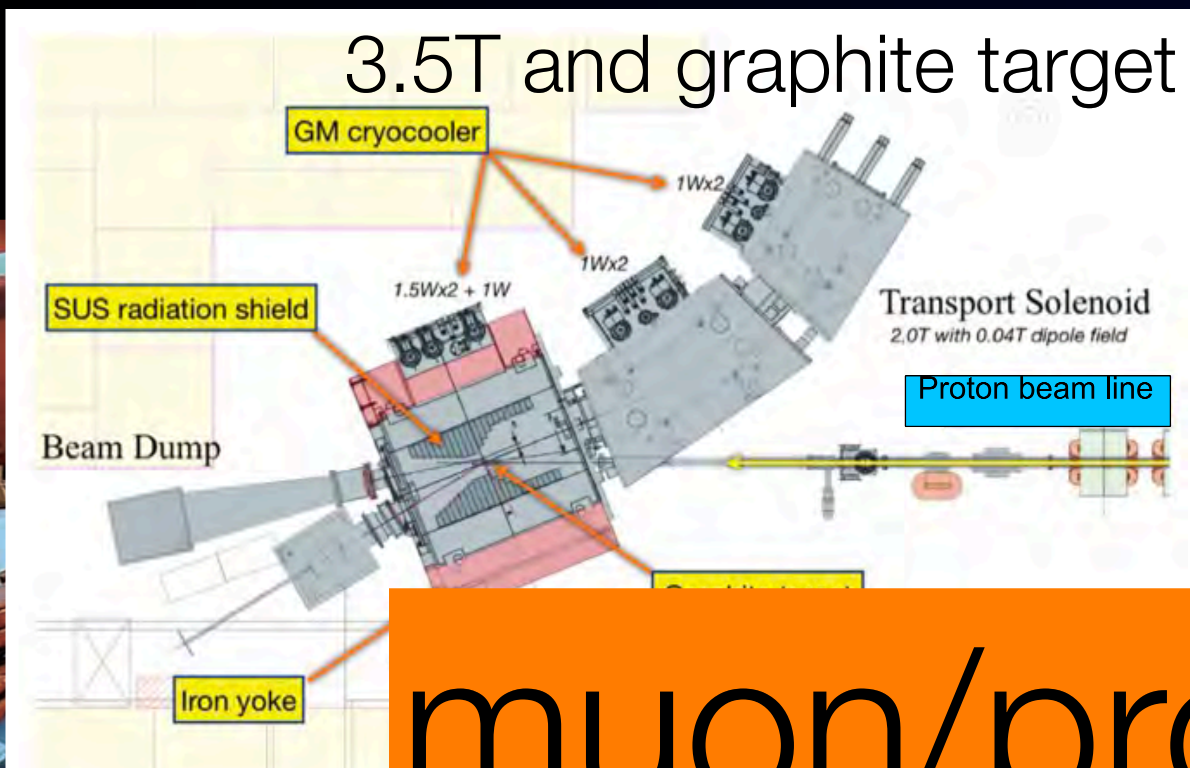
A total number of muons is the key for success.

COMET：10^{18} **muons** (past exp. 10^{14} muons)

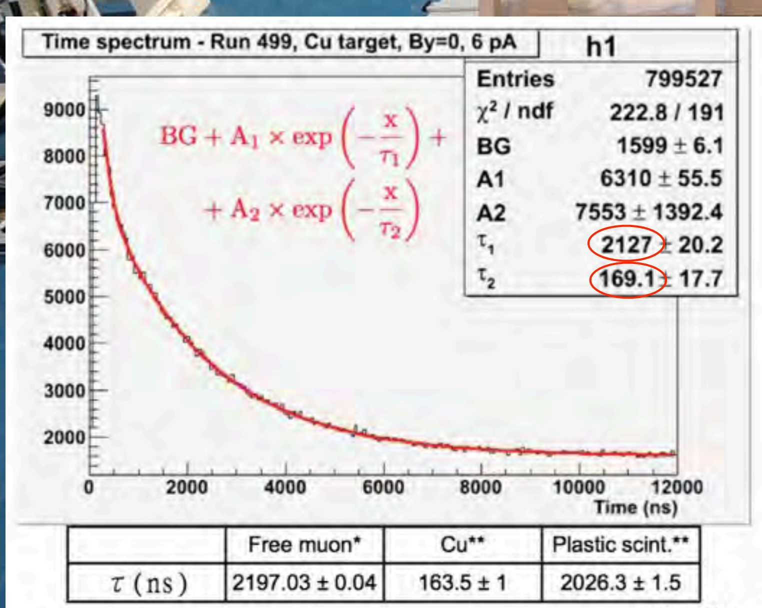
(note: 10^{10} sec=1000 years needed at PSI.)

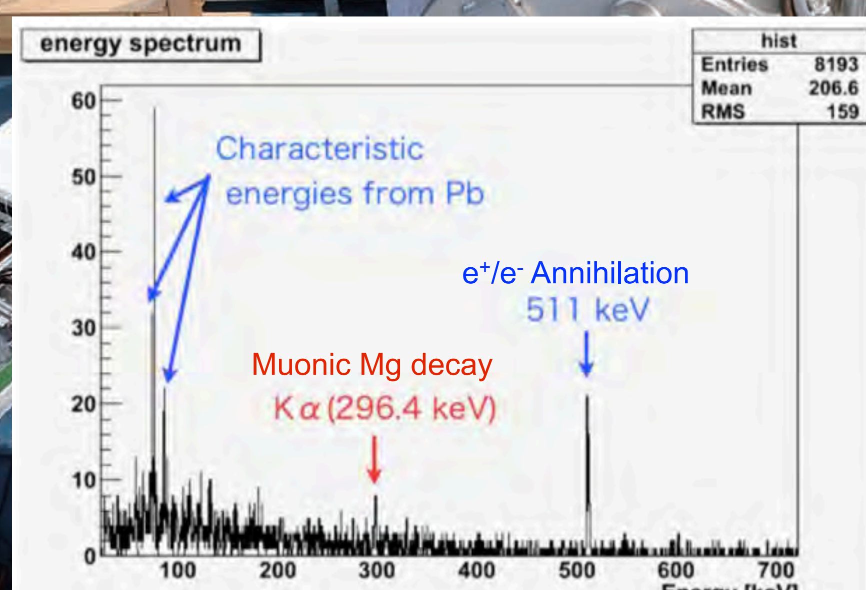
MuSIC at RCNP, Osaka University
- Highly Intense Muon Source -

Muon Science Intense Channel (>2011)



muon/proton~x1000





MuSIC muon yields

μ^+ : 3×10^8/s for 400W

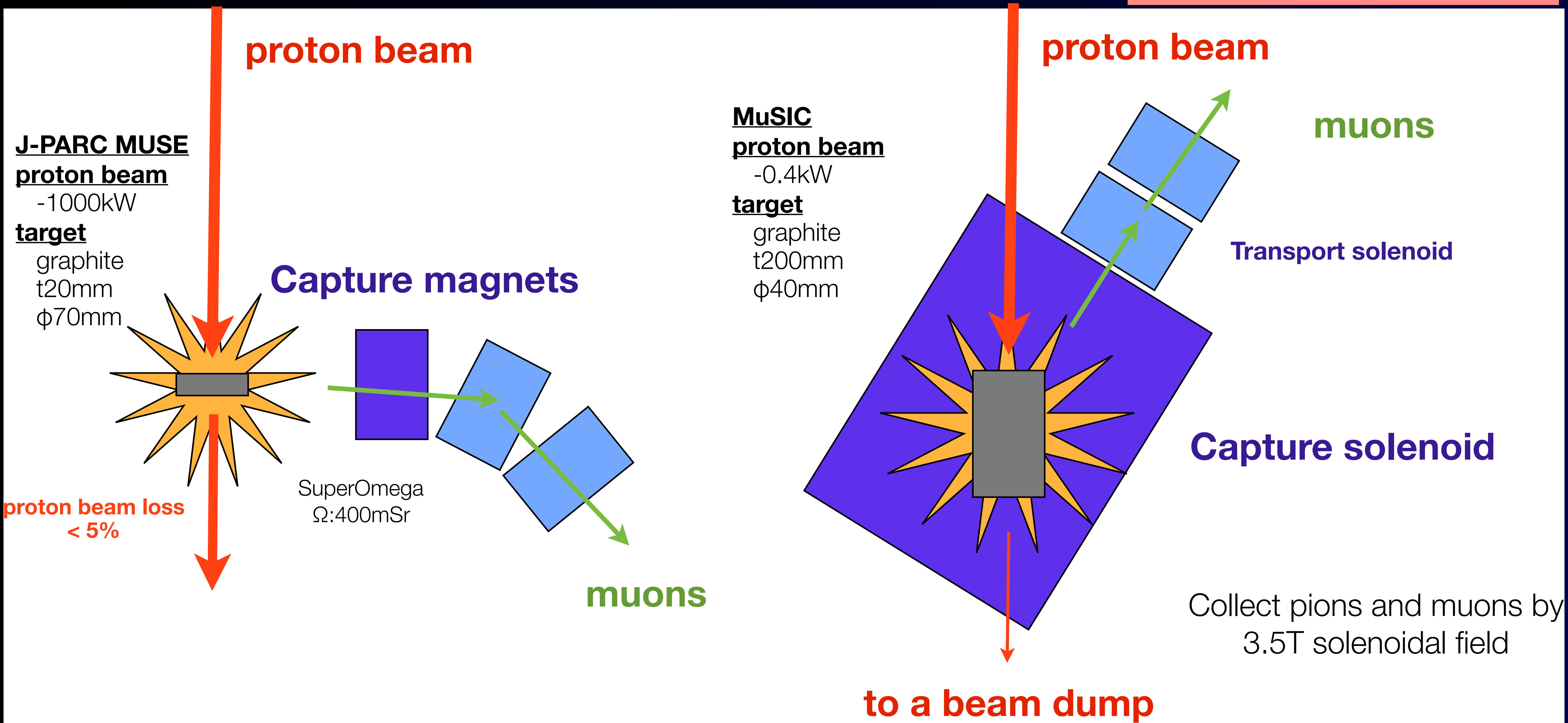
μ^- : 1×10^8/s for 400W

Production and Collection of Pions and Muons

Conventional muon beam line

More efficient

MuSIC,COMET,PRISM,
Neutrino factory,
Muon collider



Large solid angle & thick target

Improvements for Background Rejection

Beam-related backgrounds → Beam pulsing with separation of 1μsec

measured between beam pulses

proton extinction = #protons between pulses/#protons in a pulse < 10^{-9}

Muon DIO background → low-mass trackers in vacuum & thin target

improve electron energy resolution

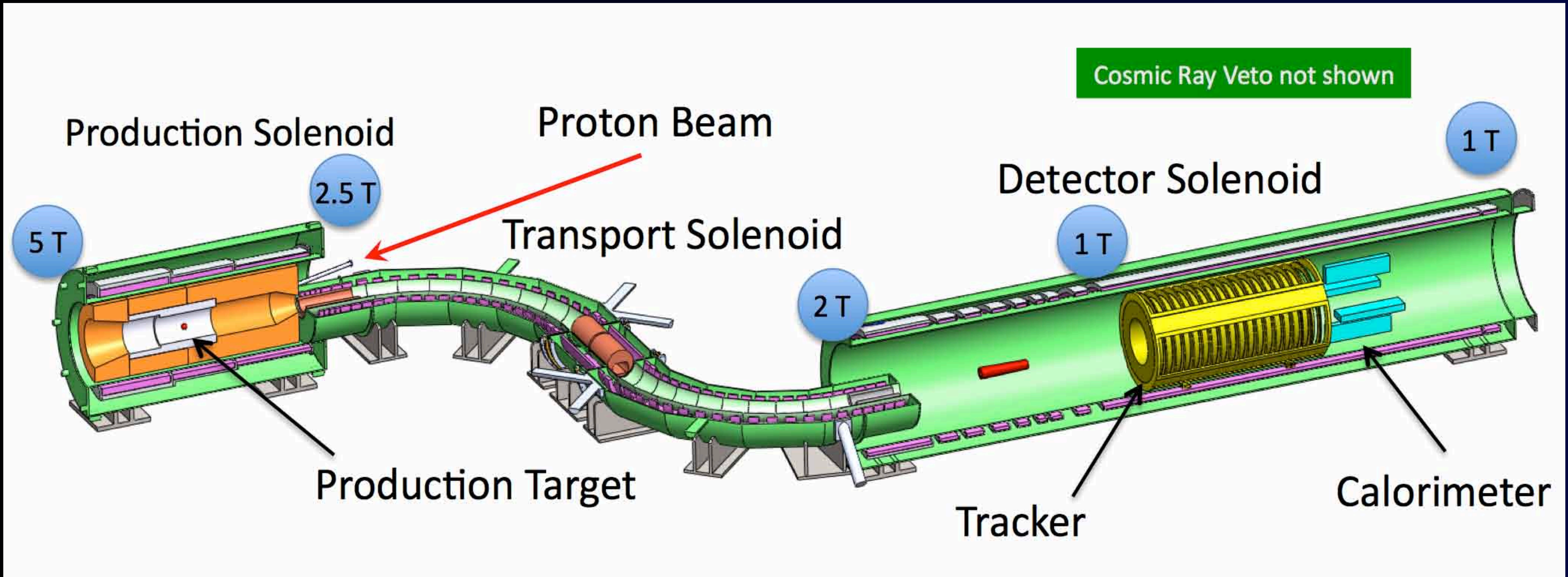
Muon DIF background → curved solenoids for momentum selection

eliminate energetic muons (>75 MeV/c)

based on the MELC proposal at Moscow Meson Factory

COMET at J-PARC

Mu2e at Fermilab



Single-event sensitivity : $(2.5\pm0.3)\times10^{-17}$

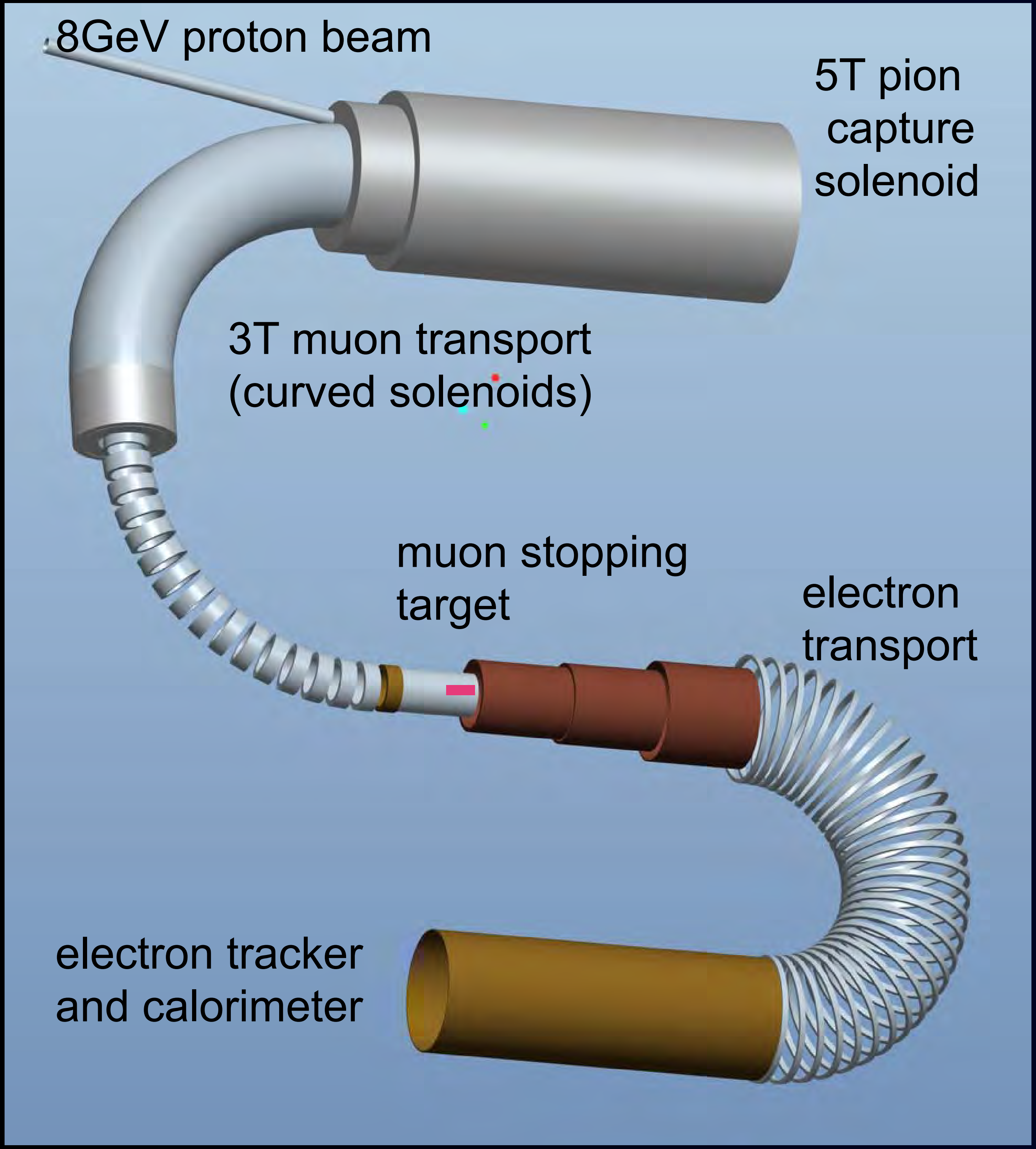
Total background : (0.36 ± 0.10) events

Expected limits : $< 6\times10^{-17}$ @90%C.L.

Running time: 3 years (2×10^{7} sec/year)

COMET=COherent Muon to Electron Transition

COMET at J-PARC: E21



Physics sensitivity : $(1.0\text{-}2.6)\times10^{-17}$

Total background : 0.32 events

Expected limits : $< 6\times10^{-17}$@90%CL

Running time: 1 years (2×10^{7}sec)

COMET Collaboration

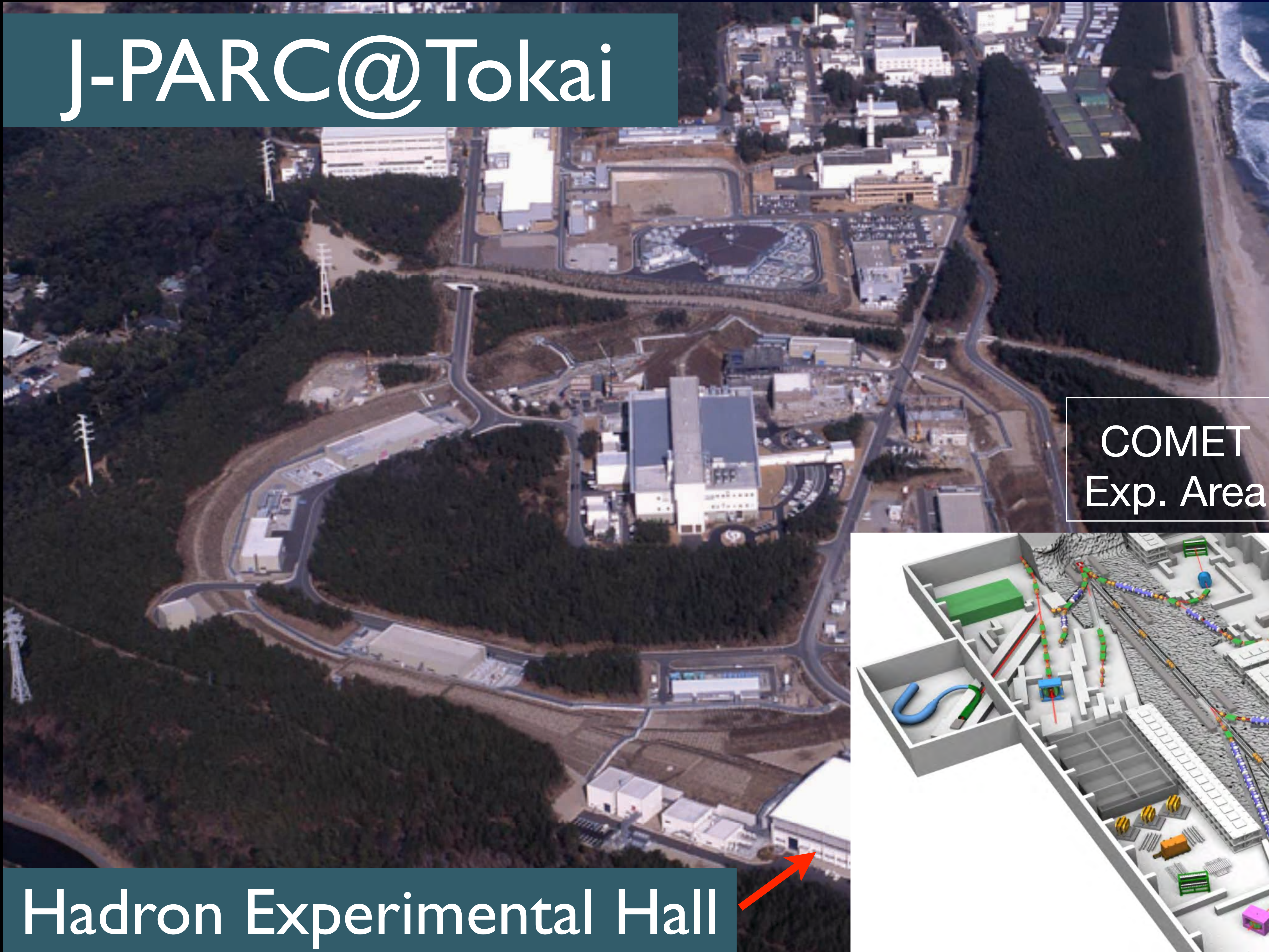
182 collaborators
37 institutes, 15 countries

PI: Y. Kuno

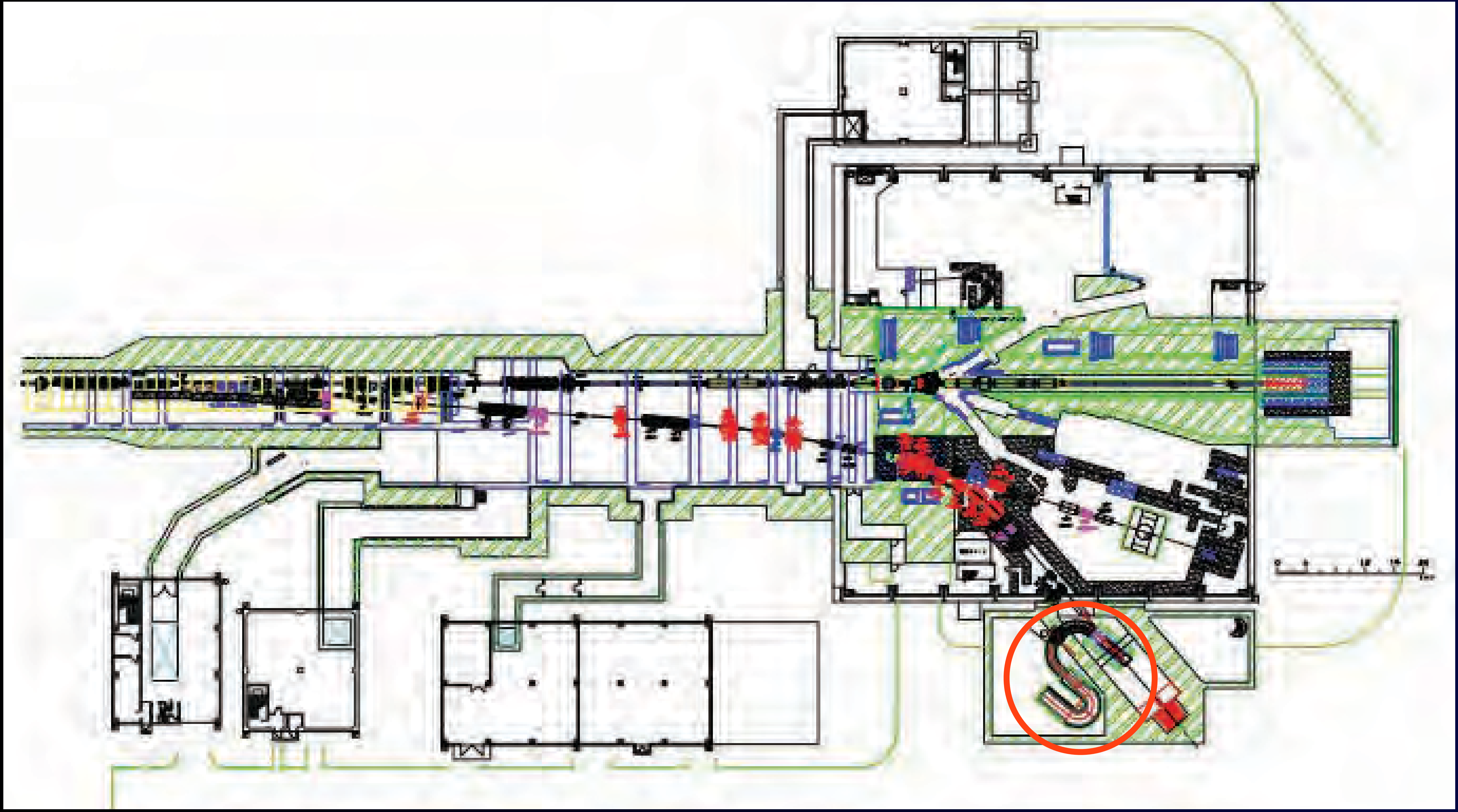
The COMET Collaboration

R. Abramishvili[11], G. Adamov[11], R. Akhmetshin[6,31], V. Anishchik[4], M. Aoki[32], Y. Arimoto[18], I. Bagaturia[11], Y. Ban[3], A. Bondar[6,31], Y. Calas[7], S. Canfer[33], Y. Cardenas[7], S. Chen[28], Y. E. Cheung[28], B. Chiladze[35], D. Clarke[33], M. Danilov[15,26], P. D. Dauncey[14], J. David[23], W. Da Silva[23], C. Densham[33], G. Devidze[35], P. Dornan[14], A. Drutskoy[15,26], V. Duginov[16], L. Epshteyn[6,30], P. Evtoukhovich[16], G. Fedotovich[6,31], M. Finger[8], M. Finger Jr[8], Y. Fujii[18], Y. Fukao[18], J-F. Genat[23], E. Gillies[14], D. Grigoriev[6,30,31], K. Gritsay[16], E. Hamada[18], R. Han[1], K. Hasegawa[18], I. H. Hasim[32], O. Hayashi[32], Z. A. Ibrahim[24], Y. Igarashi[18], F. Ignatov[6,31], M. Iio[18], M. Ikeno[18], K. Ishibashi[22], S. Ishimoto[18], T. Itahashi[32], S. Ito[32], T. Iwami[32], X. S. Jiang[2], P. Jonsson[14], V. Kalinnikov[16], F. Kapusta[23], H. Katayama[32], K. Kawagoe[22], N. Kazak[5], V. Kazanin[6,31], B. Khazin[6,31], A. Khvedelidze[16,11], T. K. Ki[18], M. Koike[39], G. A. Kozlov[16], B. Krikler[14], A. Kulikov[16], E. Kulish[16], Y. Kuno[32], Y. Kuriyama[21], Y. Kurochkin[5], A. Kurup[14], B. Lagrange[14,21], M. Lancaster[38], M. J. Lee[12], H. B. Li[2], W. G. Li[2], R. P. Litchfield[38], T. Loan[29], D. Lomidze[11], I. Lomidze[11], P. Loveridge[33], G. Macharashvili[35], Y. Makida[18], Y. Mao[3], O. Markin[15], Y. Matsumoto[32], T. Mibe[18], S. Mihara[18], F. Mohamad Idris[24], K. A. Mohamed Kamal Azmi[24], A. Moiseenko[16], Y. Mori[21], M. Moritsu[32], E. Motuk[38], Y. Nakai[22], T. Nakamoto[18], Y. Nakazawa[32], J. Nash[14], J. -Y. Nief[7], M. Nioradze[35], H. Nishiguchi[18], T. Numao[36], J. O'Dell[33], T. Ogitsu[18], K. Oishi[22], K. Okamoto[32], C. Omori[18], T. Ota[34], J. Pasternak[14], C. Plostinar[33], V. Ponariadov[45], A. Popov[6,31], V. Rusinov[15,26], A. Ryzhenenkov[6,31], B. Sabirov[16], N. Saito[18], H. Sakamoto[32], P. Sarin[13], K. Sasaki[18], A. Sato[32], J. Sato[34], Y. K. Semertzidis[12,17], D. Shemyakin[6,31], N. Shigyo[22], D. Shoukavy[5], M. Slunecka[8], A. Straessner[37], D. Stöckinger[37], M. Sugano[18], Y. Takubo[18], M. Tanaka[18], S. Tanaka[22], C. V. Tao[29], E. Tarkovsky[15,26], Y. Tevzadze[35], T. Thanh[29], N. D. Thong[32], J. Tojo[22], M. Tomasek[10], M. Tomizawa[18], N. H. Tran[32], H. Trang[29], I. Trekov[35], N. M. Truong[32], Z. Tsamalaidze[16,11], N. Tsverava[16,35], T. Uchida[18], Y. Uchida[14], K. Ueno[18], E. Velicheva[16], A. Volkov[16], V. Vrba[10], W. A. T. Wan Abdullah[24], M. Warren[38], M. Wing[38], T. S. Wong[32], C. Wu[2,28], H. Yamaguchi[22], A. Yamamoto[18], Y. Yang[22], W. Yao[2], Y. Yao[2], H. Yoshida[32], M. Yoshida[18], Y. Yoshii[18], T. Yoshioka[22], Y. Yuan[2], Y. Yudin[6,31], J. Zhang[2], Y. Zhang[2], K. Zuber[37]

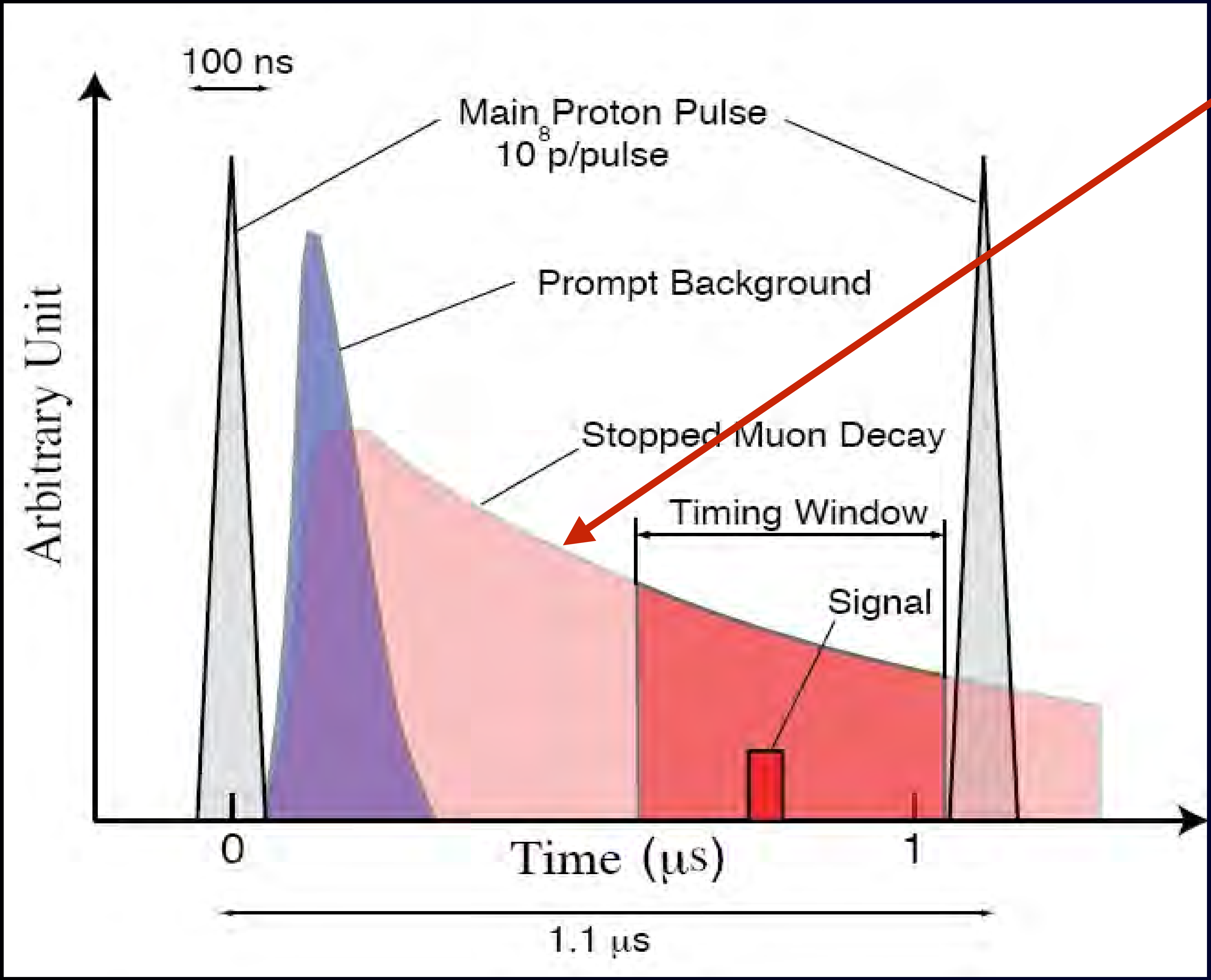
J-PARC@Tokai



COMET Proton Beamline



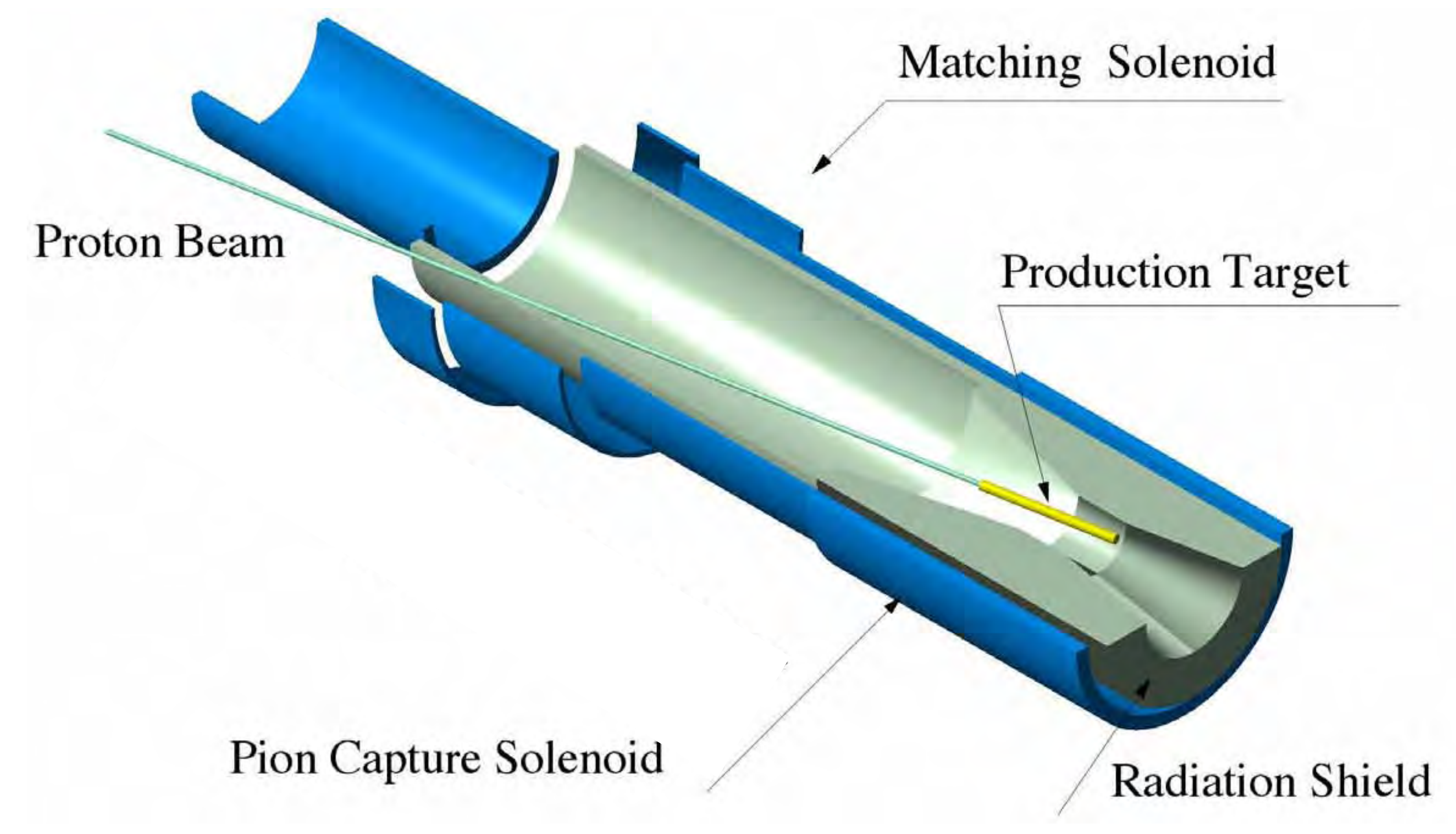
Time Structure of Measurement in COMET



A lifetime of a muonic atom in aluminium ~ 880 sec

Pion Capture in Solenoids

high muon yield



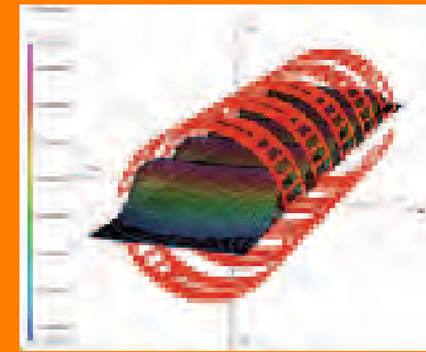
proton target in a solenoidal field (~5 T)

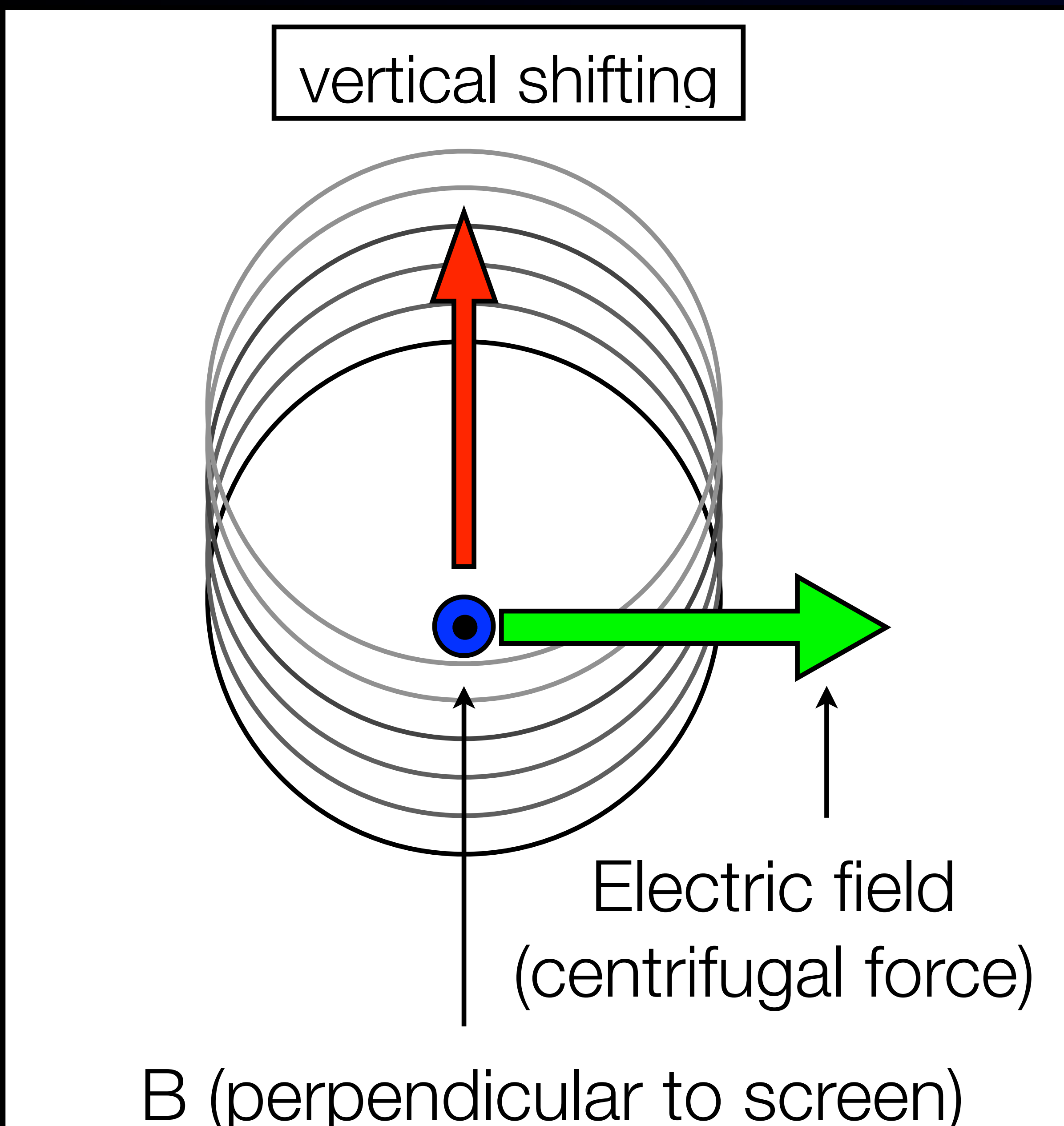
a long proton target (1.5~2 interaction length) of heavy material

O(10^{11}) stopped μ^-/sec for 50 kW protons

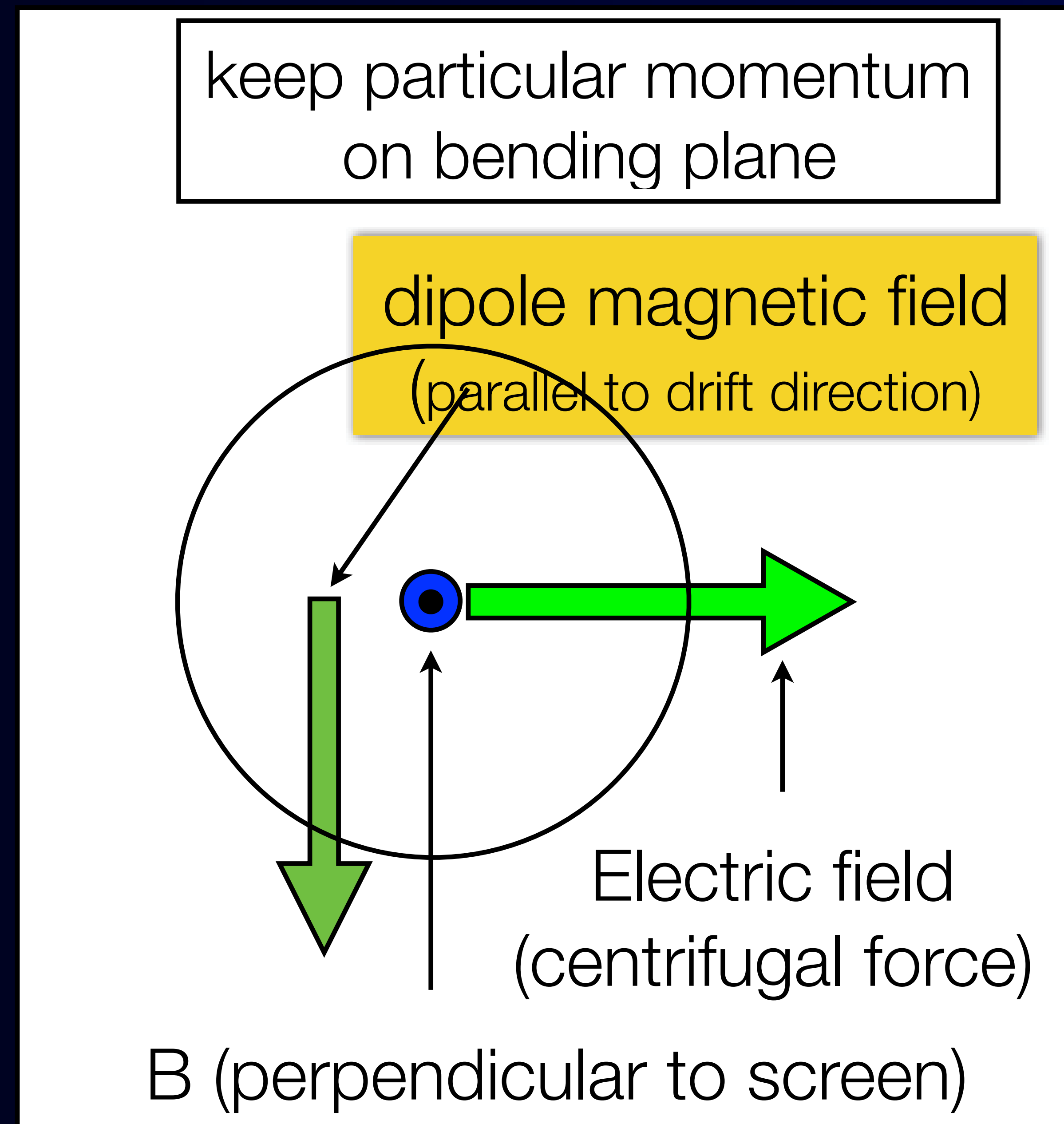
note: dependent on solenoid field and aperture, proton target material.

Particle Trajectories in Curved Solenoid



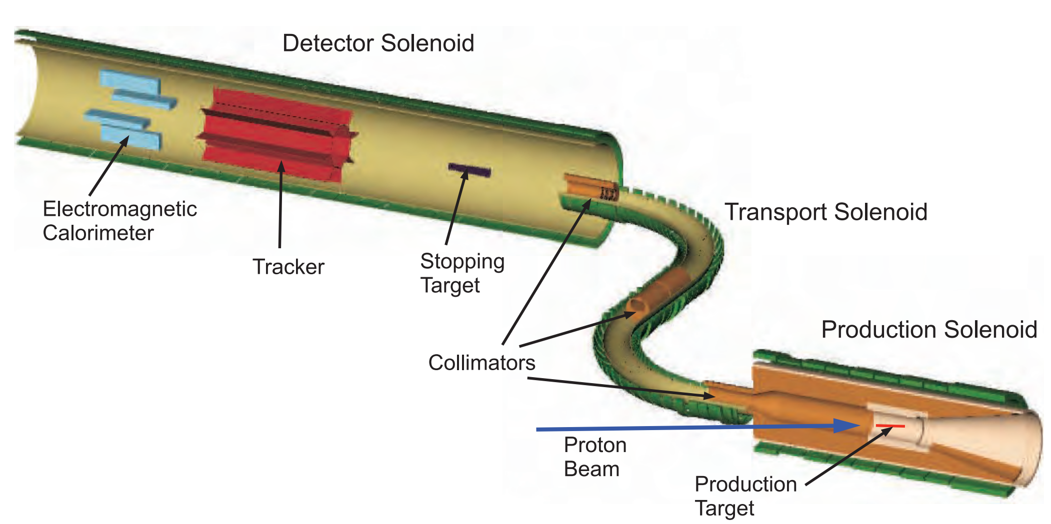


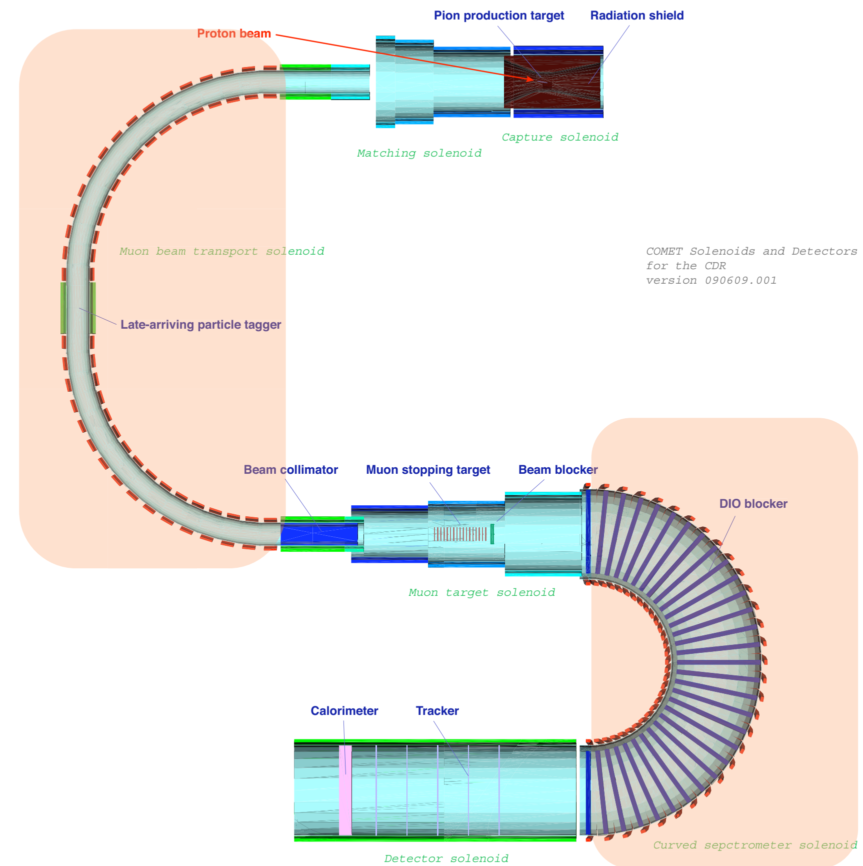
$$D = \frac{p}{qB}\theta_{bend}\frac{1}{2}(\cos\theta + \frac{1}{\cos\theta})$$



$$B_{comp} = \frac{p}{qr}\frac{1}{2}(\cos\theta + \frac{1}{\cos\theta})$$

Mu2e vs. COMET





	Mu2e	COMET
muon beam line	2x 90□bends (opposite direction)	2x 90□bend (same direction)
electron spectrometer	straight solenoid	curved solenoid

Select low momentum muons

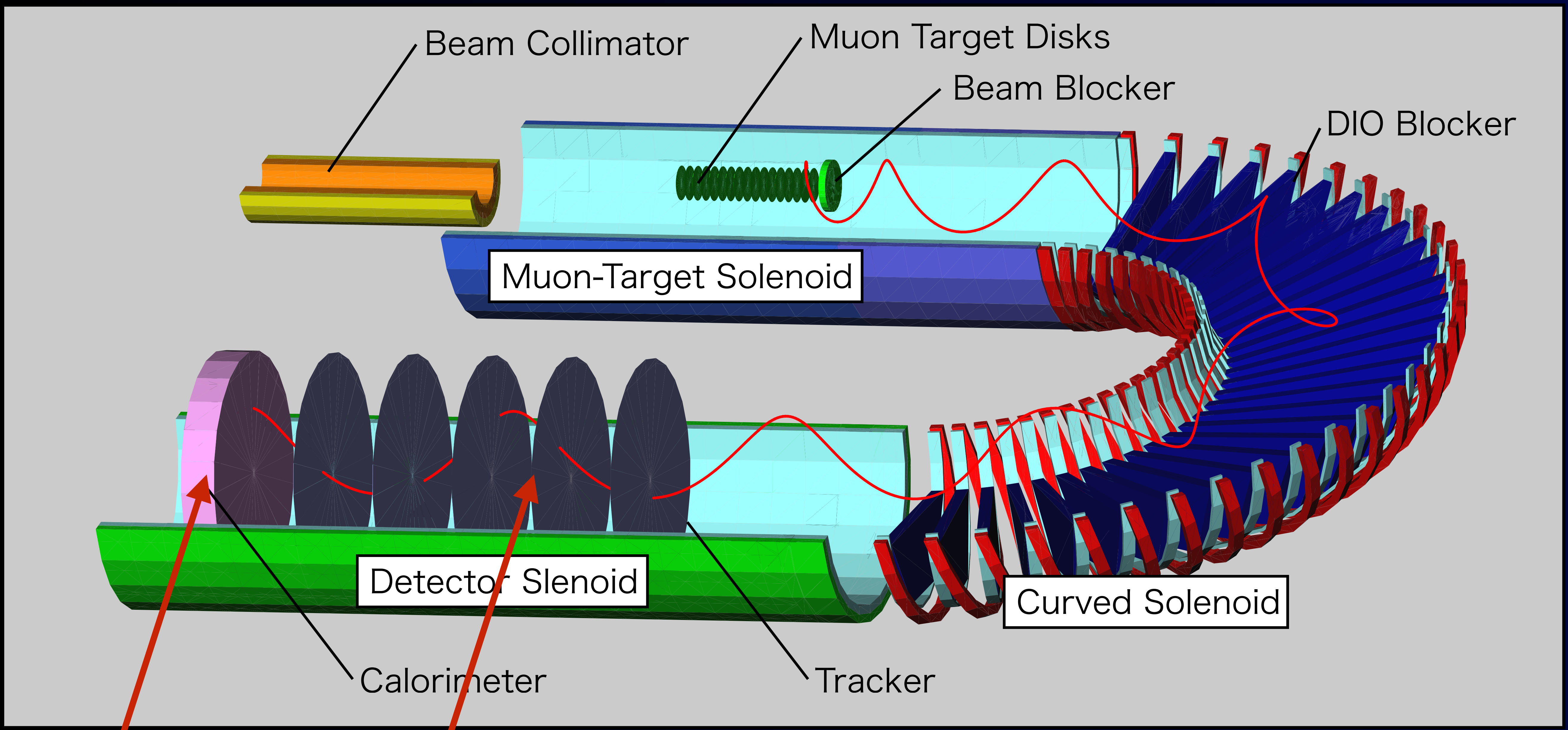
eliminate muon decay in flight

Selection of 100 MeV electrons

eliminate protons from nuclear muon capture.

eliminate low energy events to make the detector quiet.

COMET Detectors



ECAL

Straw Tracker

(# of straw stations is not determined)

in vacuum under 1T magnetic field

COMET Signal Sensitivity (/2x10^7 sec)

- Single event sensitivity

$$B(\mu^- + Al \to e^- + Al) \sim \frac{1}{N_\mu \cdot f_{cap} \cdot A_e},$$

- N_μ is a number of stopping muons in the muon stopping target. It is 2x10^{18} muons.
- f_{cap} is a fraction of muon capture, which is 0.6 for aluminium.
- A_e is the detector acceptance, which is 0.04〜0.08.

total protons muon transport efficiency muon stopping efficiency	8.5x10^{20} 0.008 0.3
# of stopped muons	2.0x10^{18}

$$B(\mu^- + Al \to e^- + Al) = 2.6 \times 10^{-17}$$

$$B(\mu^- + Al \to e^- + Al) < 6 \times 10^{-17} \quad (90\% C.L.)$$

Background Rates

Radiative Pion Capture	0.05
Beam Electrons	$< 0.1^{\ddagger}$
Muon Decay in Flight	< 0.0002
Pion Decay in Flight	< 0.0001
Neutron Induced	0.024
Delayed-Pion Radiative Capture	0.002
Anti-proton Induced	0.007
Muon Decay in Orbit	0.15
Radiative Muon Capture	< 0.001
μ^- Capt. w/ n Emission	< 0.001
μ^- Capt. w/ Charged Part. Emission	< 0.001
Cosmic Ray Muons	0.002
Electrons from Cosmic Ray Muons	0.002
Total	0.34

‡ Monte Carlo statistics limited.

beam-related prompt backgrounds

beam-related delayed backgrounds

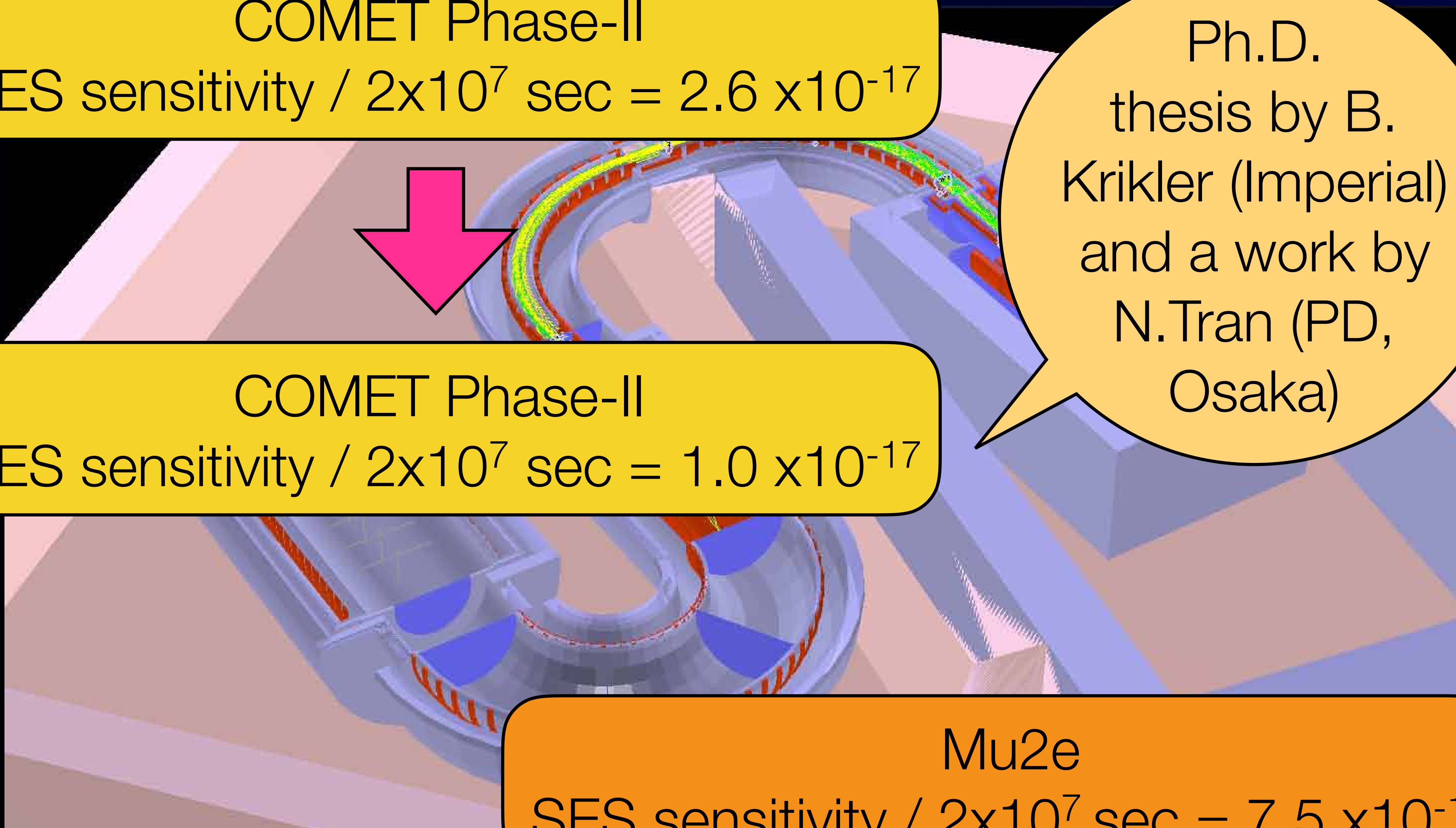
intrinsic physics backgrounds

cosmic-ray and other backgrounds

Expected background events are about 0.34.

New Optimization on COMET Physics Sensitivity

NOT OFFICIAL



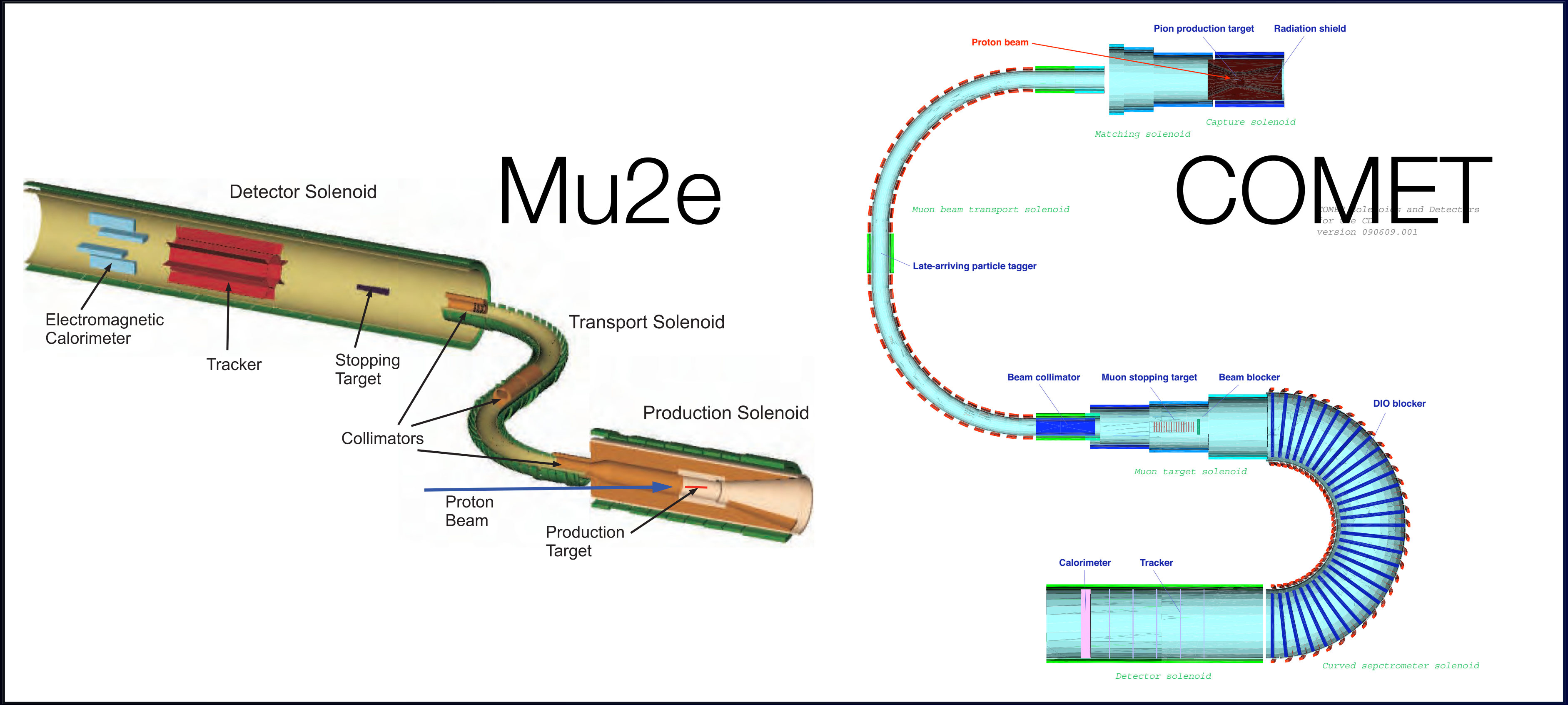
COMET Phase-II
SES sensitivity / 2×10^{7} sec = 2.6×10^{-17}

COMET Phase-II
SES sensitivity / 2×10^{7} sec = 1.0×10^{-17}

Ph.D. thesis by B. Krikler (Imperial) and a work by N.Tran (PD, Osaka)

Mu2e
SES sensitivity / 2×10^{7} sec = 7.5×10^{-17}

Why COMET, not Mu2e ?



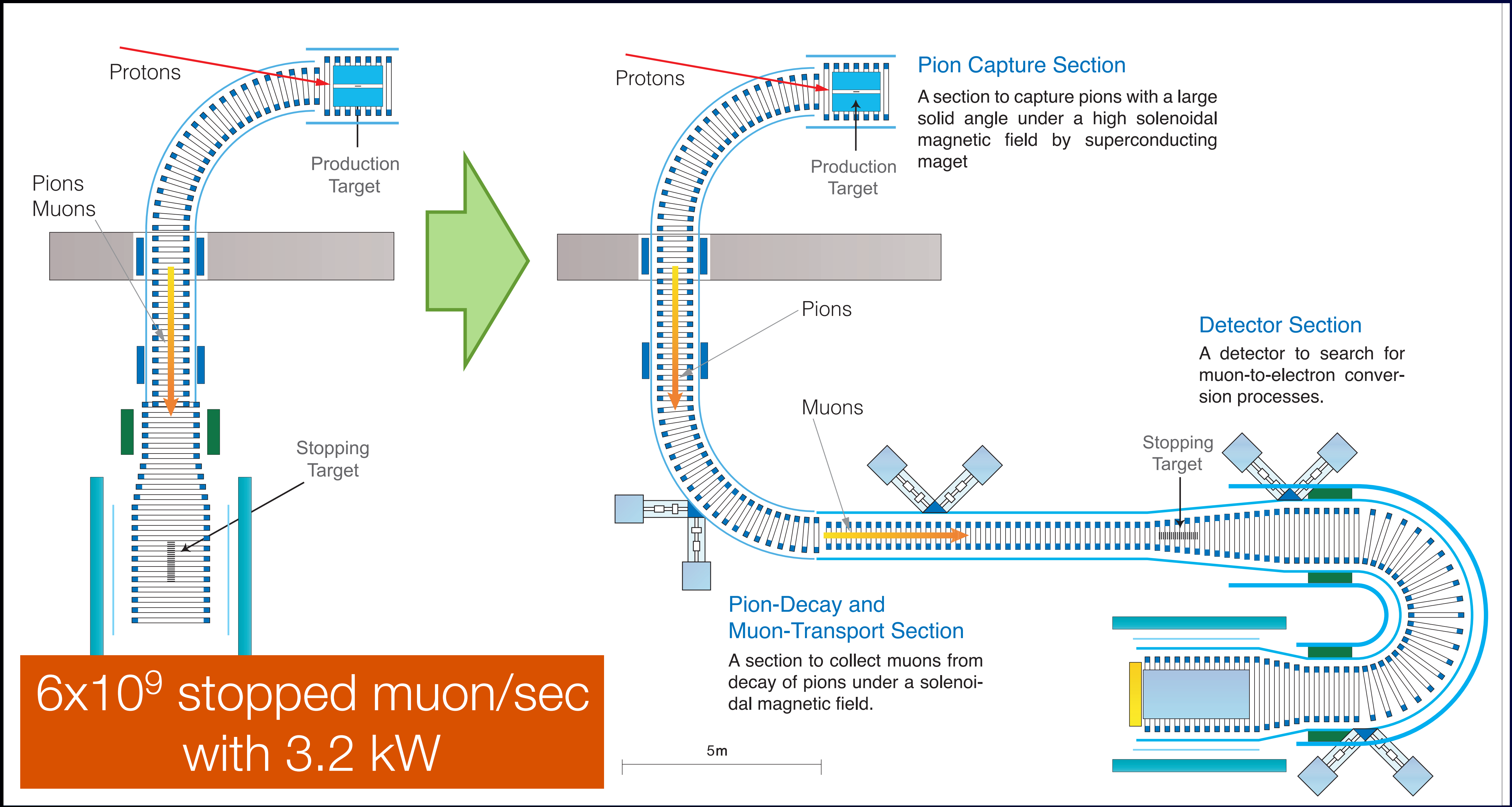
Mu2e	COMET
Sensitivity / 2×10^{7} sec = 7.5×10^{-17}	Sensitivity / 2×10^{7} sec = 1.0×10^{-17}
proton beam ~ 8kW	proton beam ~ 56kW

COMET Phase-I

COMET Staged Approach (2012~)

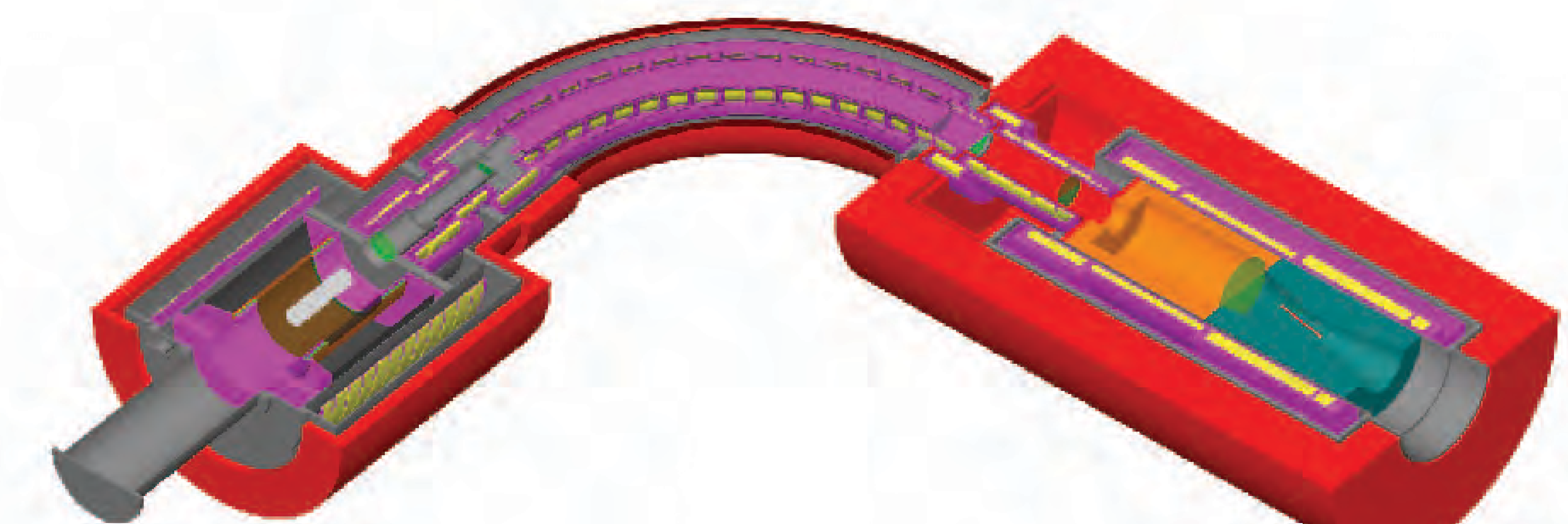
COMET Phase-I

COMET Phase-II



6×10^9 stopped muon/sec with 3.2 kW

COMET Phase-I



detector system   muon transport system   pion production system

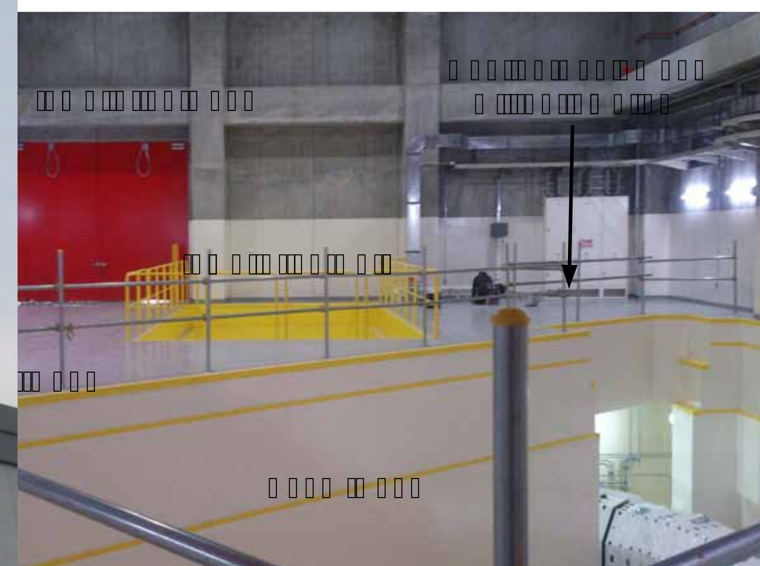
Single-event sensitivity : 3×10^{-15}

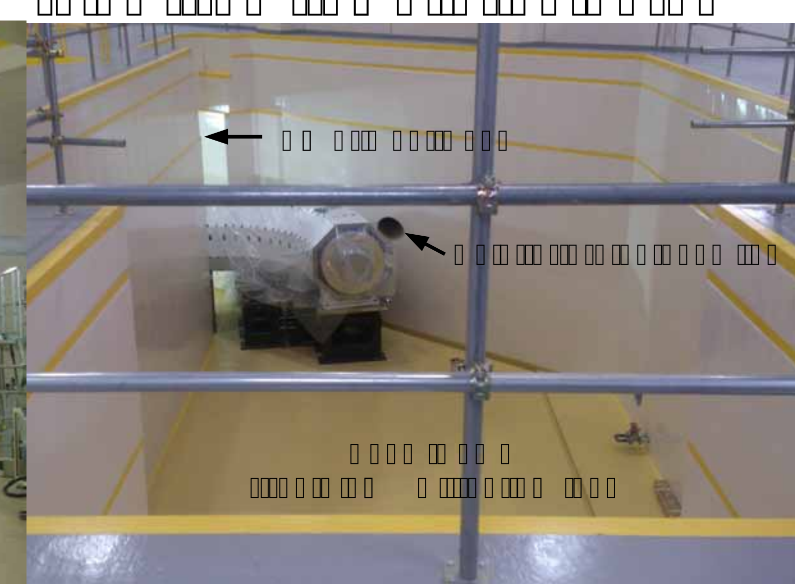
Total background : 0.2 events

Expected limits : < 6×10^{-15} @90%CL

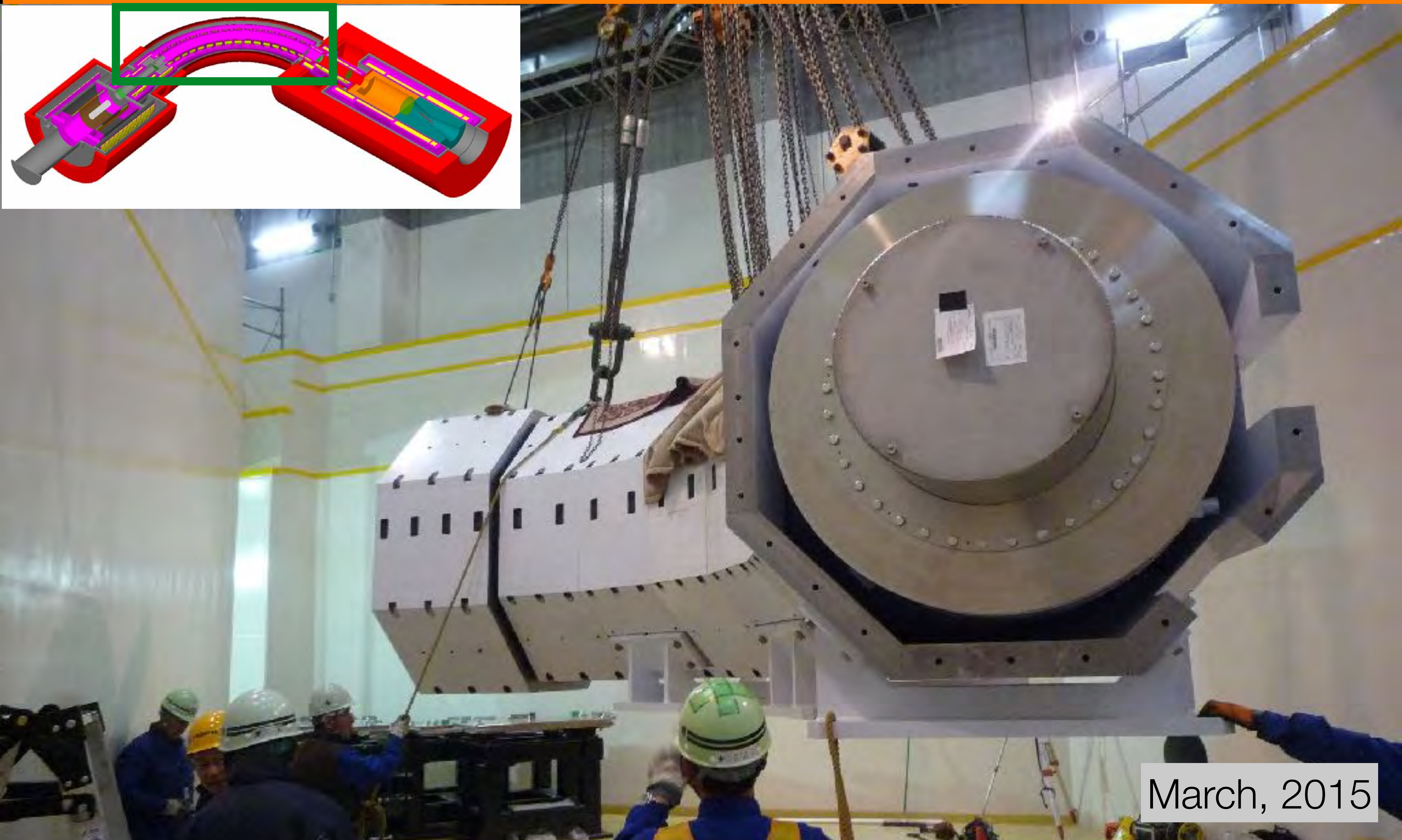
Running time: 150 days

COMET Building at J-PARC

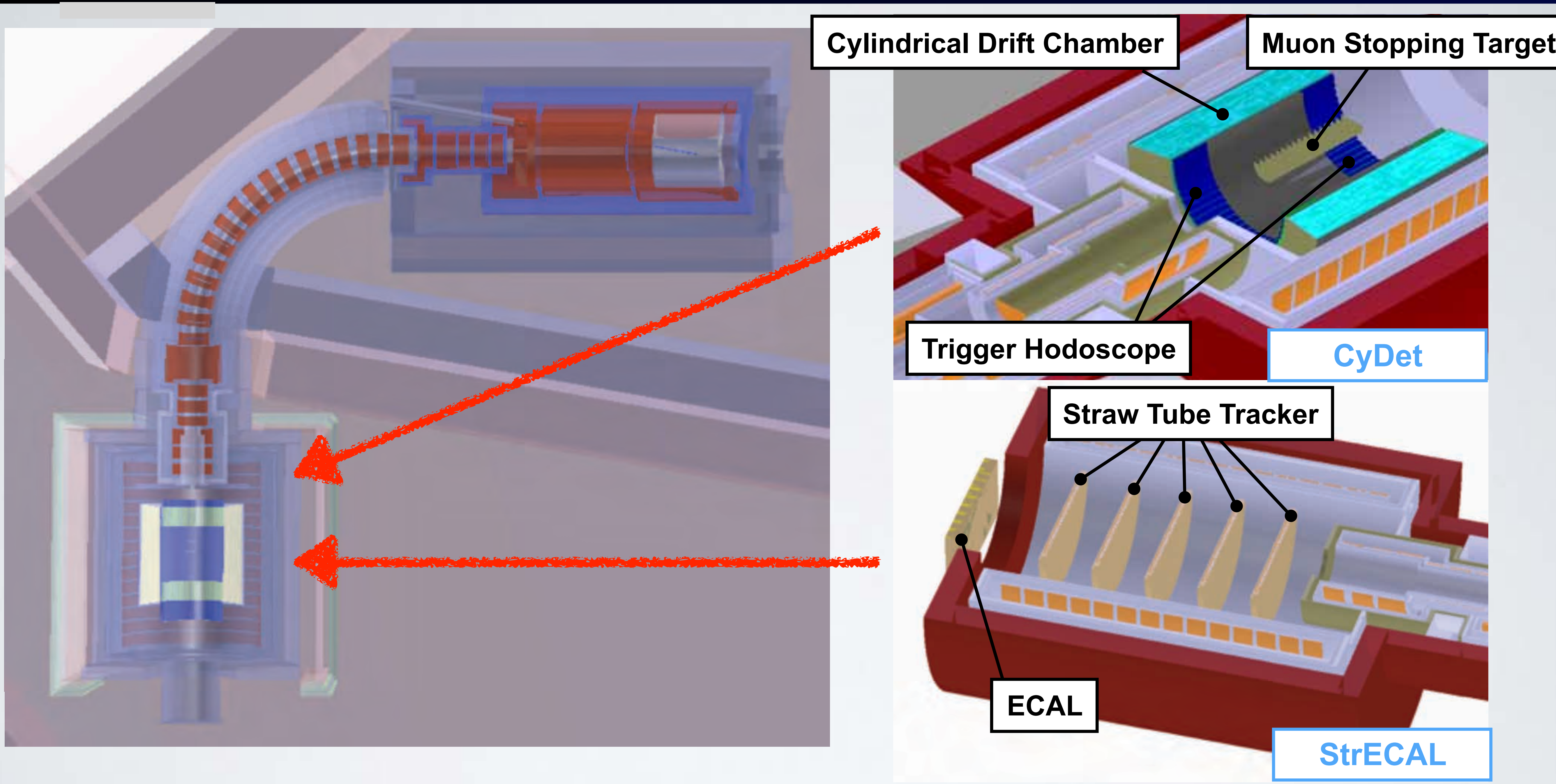




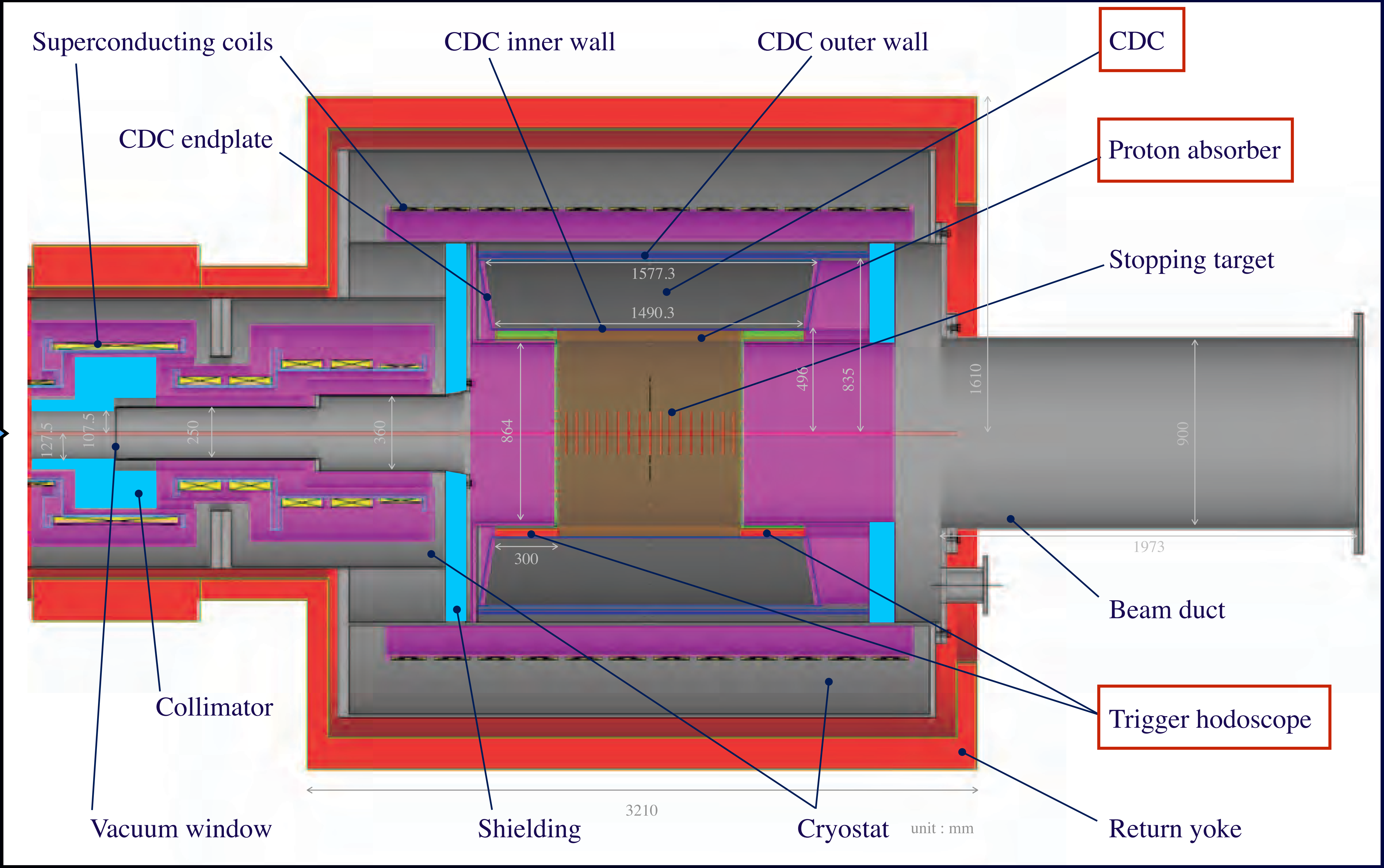
Curved Solenoids for Muon Transport Completed and Delivered!

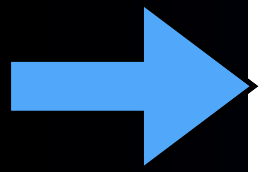


Two Detectors for COMET Phase-I



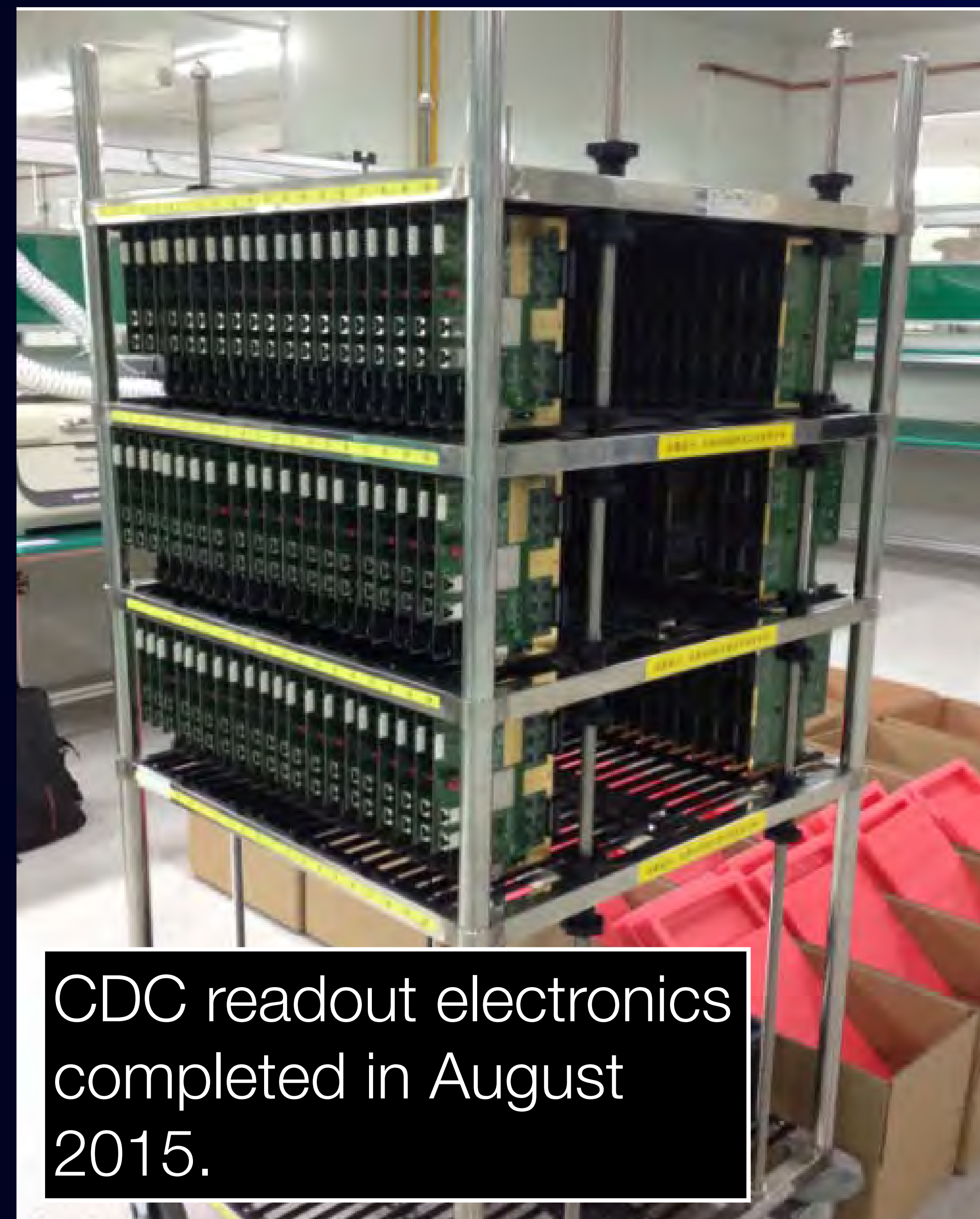
CyDet (Cylindrical Detector)





CDC Construction completed!

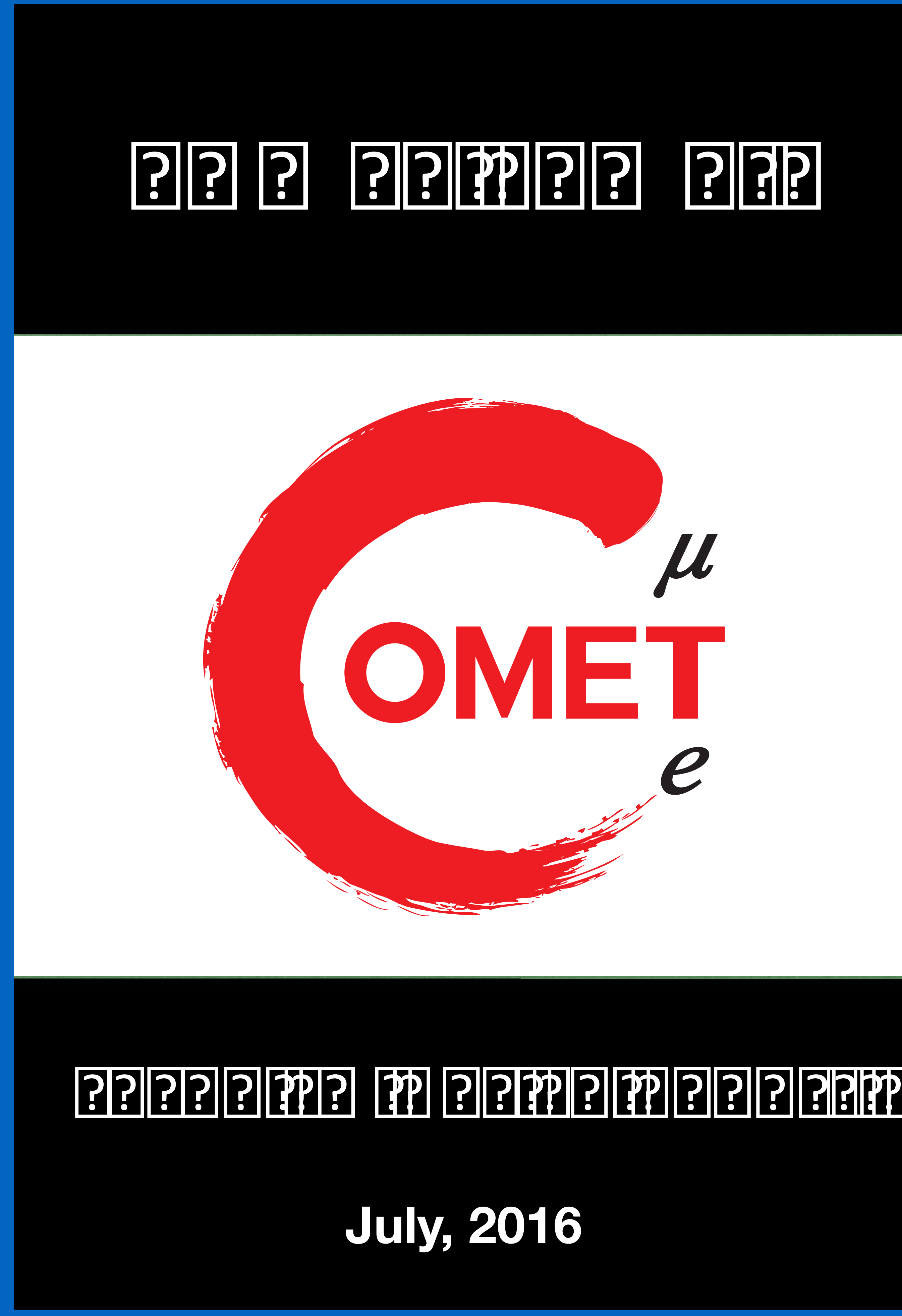
CDC wire stringing completed in December 2015.



CDC readout electronics completed in August 2015.

COMET Phase-I TDR

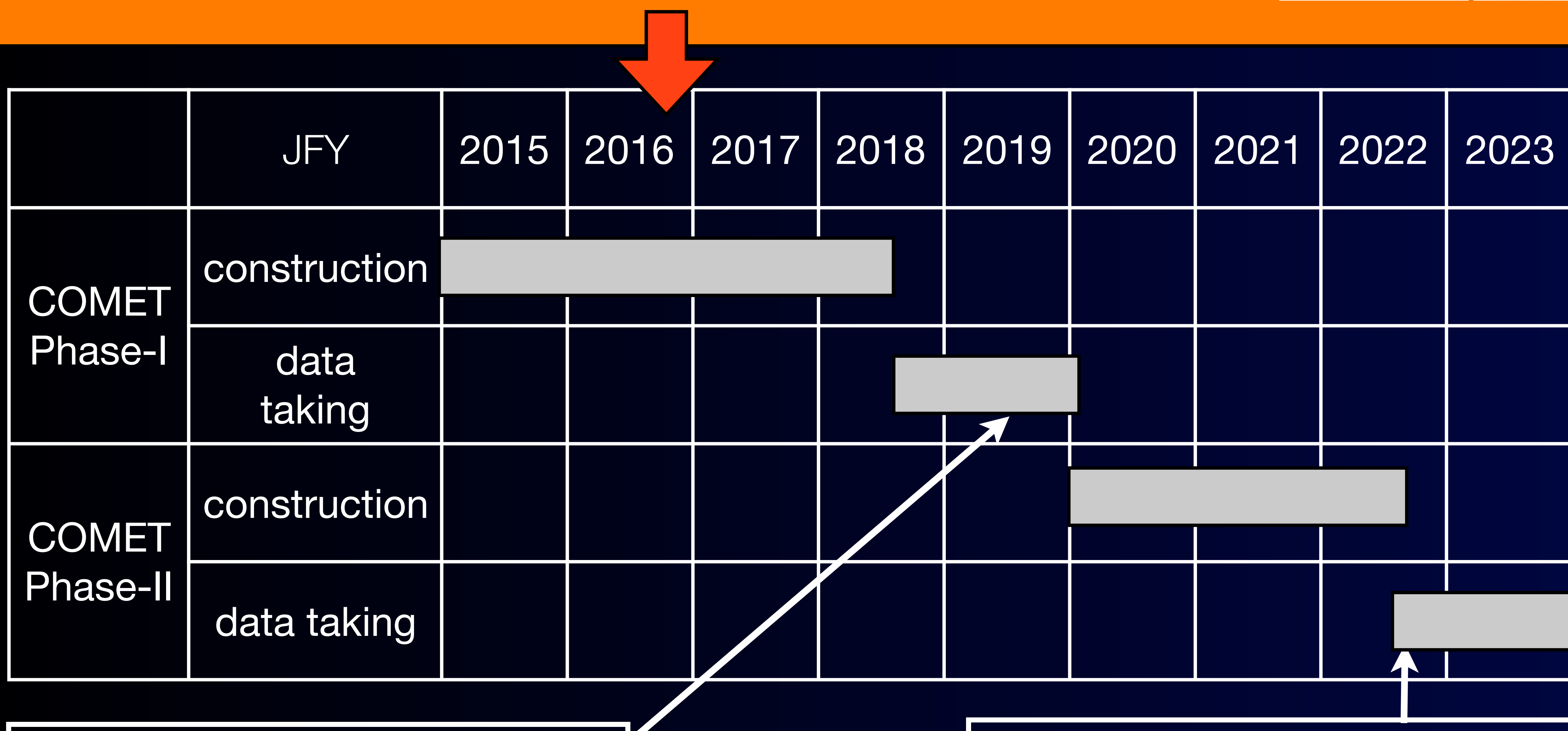
COMET Phase-I Technical Design Report (TDR) version July 2016) has been submitted in July 22nd.



Stage-2 Approved at J-PARC PAC in July 2016

stage 2 approved at J-PARC PAC

Schedule of COMET Phase-I and Phase-II



COMET Phase-I :
2018 ~
S.E.S. ~ 3×10^{-15}
(for 150 days
with 3.2 kW proton beam)

COMET Phase-II :
2022 ~
S.E.S. ~ $(1.0\text{-}2.6) \times 10^{-17}$
(for 2×10^{7} sec
with 56 kW proton beam)

Other CLFV at COMET

Physics Programs

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

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

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

Majoron emission in muon DIO

QED corrections in muon DIO

Other Physics at COMET Phase-I

$\mu^- + \mathrm{Ti} \rightarrow e^+ + \mathrm{Ca(gs)}$ 1.7×10^{-12}
$\mu^- + \mathrm{Ti} \rightarrow e^+ + \mathrm{Ca(ex)}$ 3.6×10^{-11}

$\mu^- + N(Z) \rightarrow e^+ + N^*(Z-2)$

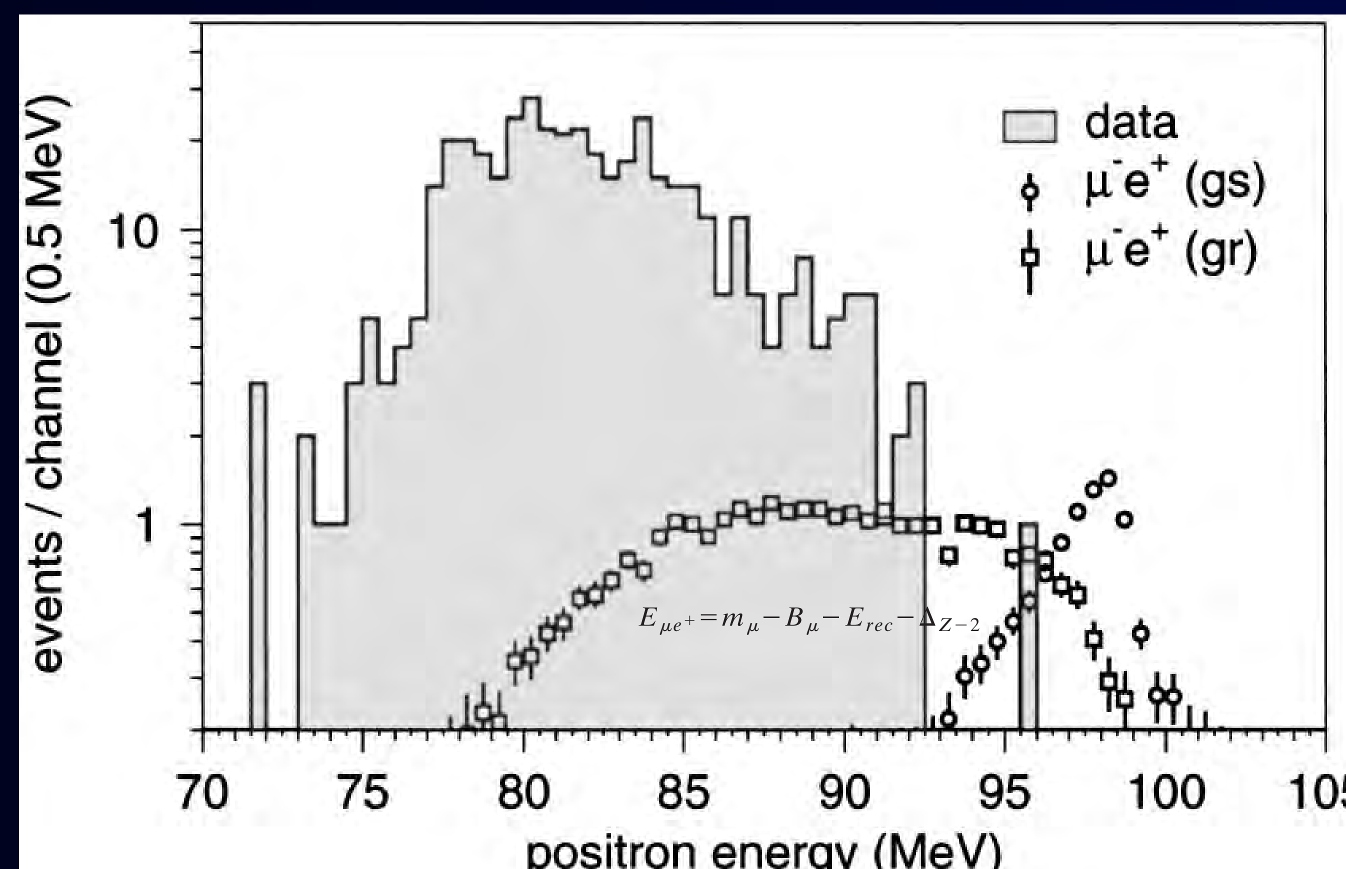
Lepton number violation (LNV)

signal signature

$$E_{\mu e^+} = m_\mu - B_\mu - E_{rec} - \Delta_{Z-2}$$

backgrounds

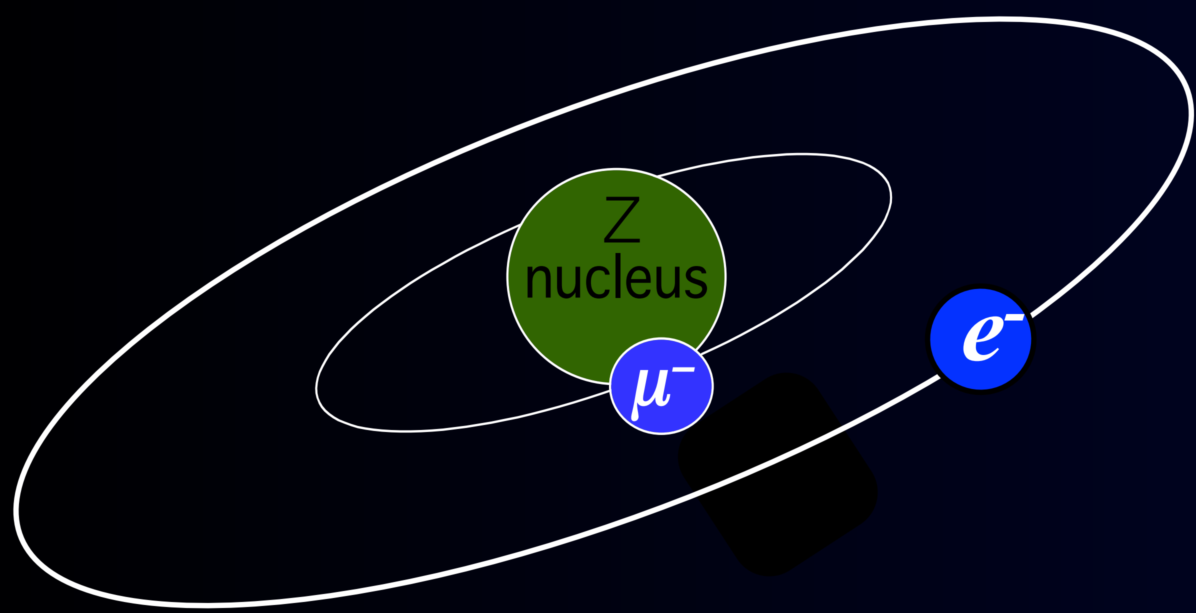
positrons from photon conversion after radiative muon/pion nuclear capture



$\mu^- + \mathrm{Ti} \rightarrow e^+ + \mathrm{Ca(gs)}$	1.7×10^{-12}
$\mu^- + \mathrm{Ti} \rightarrow e^+ + \mathrm{Ca(ex)}$	3.6×10^{-11}

Other CLFV Physics at COMET Phase-I

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



- $\mu^- e^- \rightarrow e^- e^-$ has two-body final state, although $\mu^+ \rightarrow e^+ e^+ e^-$ is a 3-body decay.
- A muonium CLFV decay such as $\mu^+ e^- \rightarrow e^+ e^+$ is a 2-body decay having a larger phase space, but the overwrap of μ^+ and e^- is small.

The overwrap between μ^- and e^- is proportional to Z^3. For Z=82 (Pb), the overwrap increases by a factor of 5×10^5 over the muonium. The rate is 10^{-17} to 10^{-18}.

PRL **105,** 121601 (2010) PHYSICAL REVIEW LETTERS week ending 17 SEPTEMBER 2010

New Process for Charged Lepton Flavor Violation Searches: $\mu^- e^- \rightarrow e^- e^-$ in a Muonic Atom

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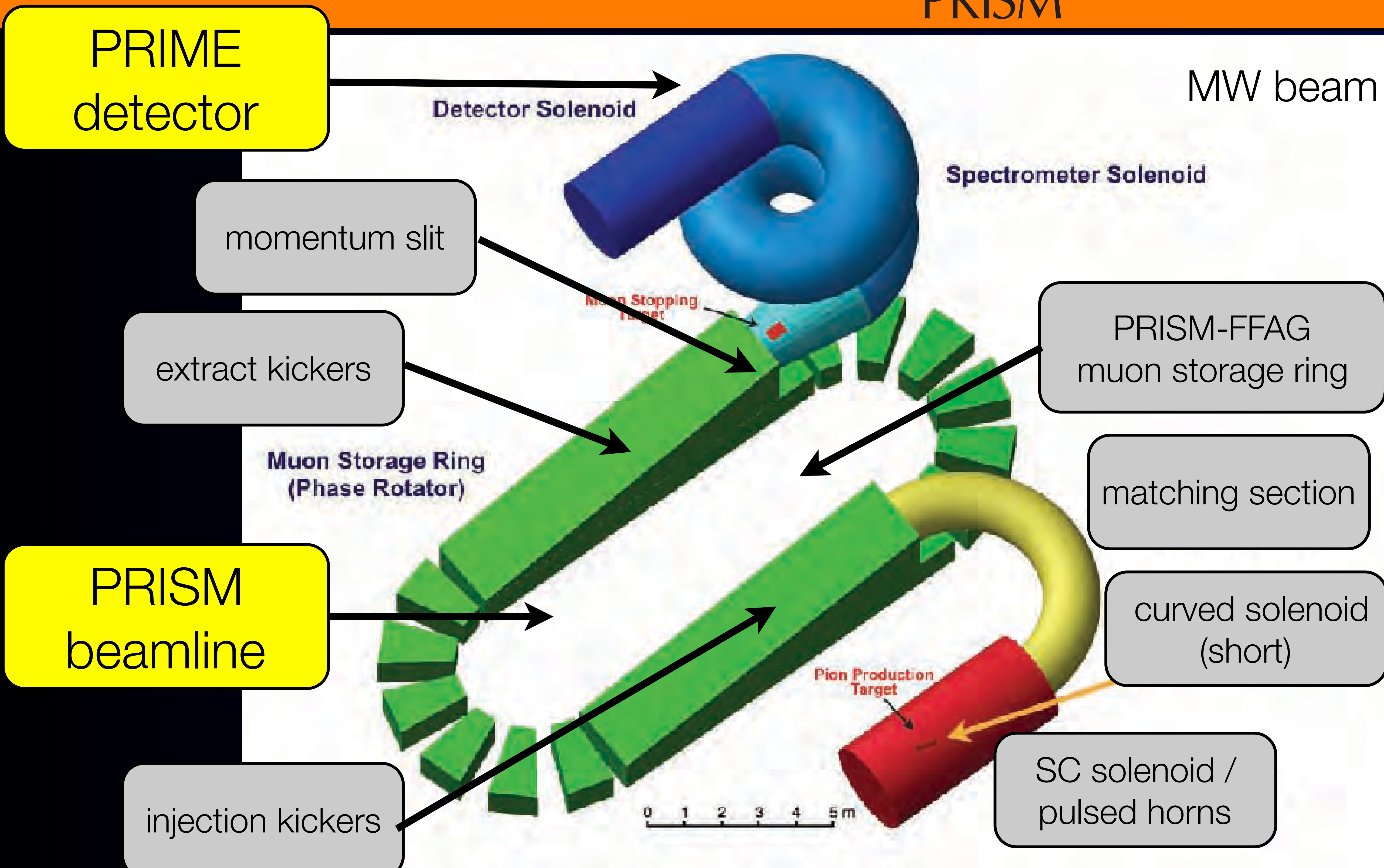
(Received 8 March 2010; published 15 September 2010)

… In the future

$$B(\mu N \to eN) \leq 10^{-18}$$

PRISM/PRIME : Future Search with S.E. sensitivity of 3×10^{-19}



Summary

- Flavor Physics at Intensity Frontier, in particular CLFV, would give the best opportunity to search for BSM.
- Muon to electron conversion could be one of the important CLFV processes.
- COMET Phase-I is aiming at S.E. sensitivity of 3×10^{-15}.
  - The construction of the beam line started at KEK in 2013.
  - The measurement will start in early 2018-2019.
- COMET (Phase-II) at J-PARC is aiming at S.E. sensitivity of $(1.0\text{-}2.6) \times 10^{-17}$. It will follow immediately after Phase-I.

my dog, IKU