Muon to Electron Conversion in Muonic Atom

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Introduction

muon to electron conversion in a muonic atom

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

(charged lepton flavour violation = CLFV)

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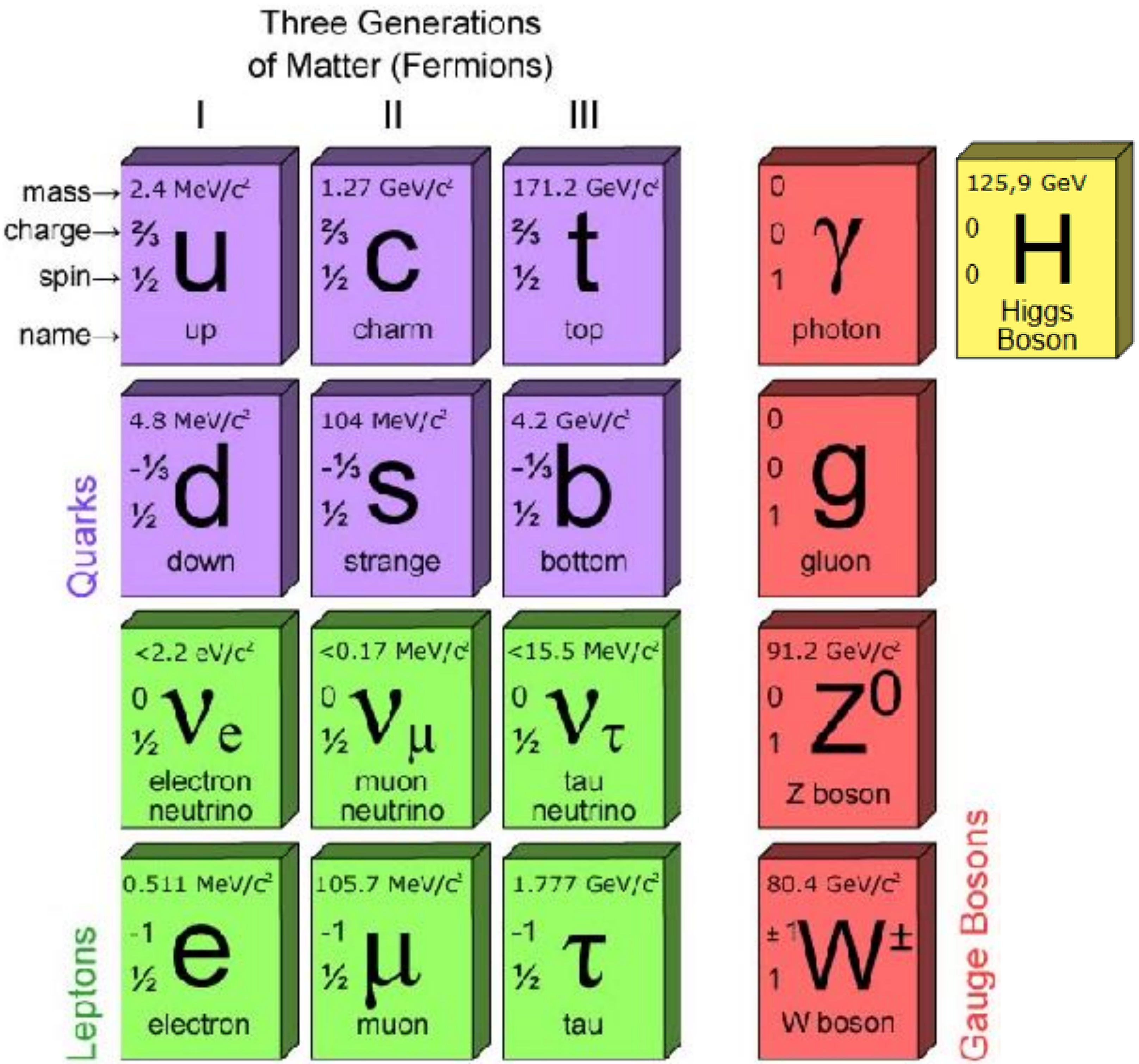
outline

- Physics Motivation of Charged Lepton Flavour Violation
- Muon to electron conversion
- COMET at J-PARC
- COMET Phase-I (under preparation)
- Summary

CLFV for BSM Search

Physics Motivation
- The Standard Model and Beyond



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ex.

mass and mixing,

strong CP,

dark matter,

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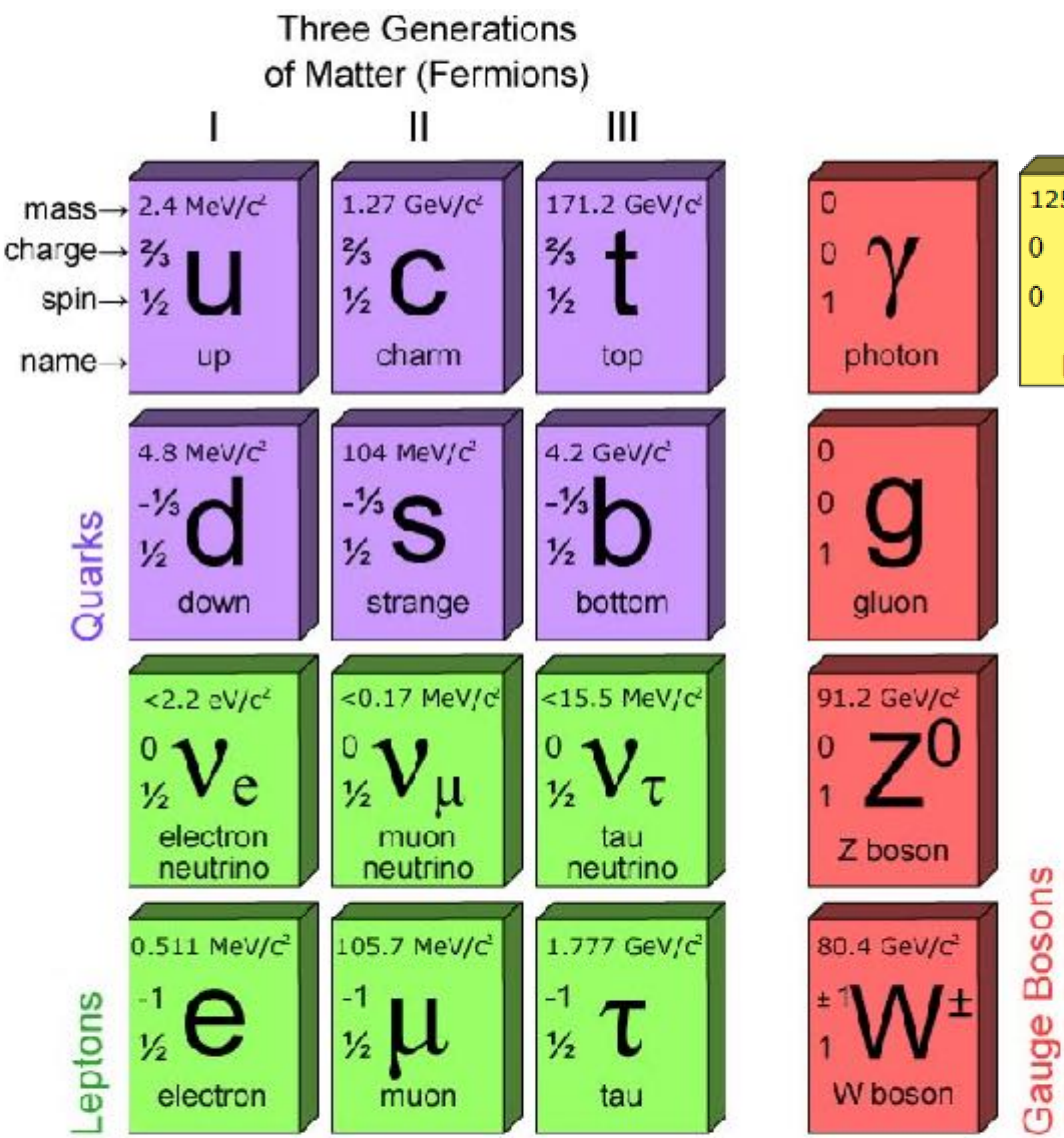

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New Physics is needed.

Sensitivity for BSM with CLFV

Effective Field Theory (EFT) Approach

$$\mathscr{L}_{eff} = \mathscr{L}_{\rm SM} + \sum_{d>6} \frac{C^{(d)}}{\Lambda^{d-4}} \mathscr{O}^{(d)}$$

Λ is the energy scale of new physics
$C^{(d)}$ is the coupling constant.

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	$\lvert C_a \rvert$ [$\Lambda = 1$ TeV]	Λ (TeV) [$\lvert C_a \rvert = 1$]	CLFV Process
$C^{\mu e}_{e\gamma}$	2.1×10^{-10}	6.8×10^{4}	$\mu \to e\gamma$
$C^{\mu\mu\mu e,e\mu\mu\mu}_{\ell e}$	1.8×10^{-4}	75	$\mu \to e\gamma$ [1-loop]
$C^{\mu\tau\tau e,e\tau\tau\mu}_{\ell e}$	1.0×10^{-5}	312	$\mu \to e\gamma$ [1-loop]
$C^{\mu e}_{e\gamma}$	4.0×10^{-9}	1.6×10^{4}	$\mu \to eee$
$C^{\mu eee}_{\ell\ell,ee}$	2.3×10^{-5}	207	$\mu \to eee$
$C^{\mu eee,ee\mu e}_{\ell e}$	3.3×10^{-5}	174	$\mu \to eee$
$C^{\mu e}_{e\gamma}$	5.2×10^{-9}	1.4×10^{4}	$\mu^- \mathrm{Au} \to e^- \mathrm{Au}$
$C^{e\mu}_{\ell q,\ell d,ed}$	1.8×10^{-6}	745	$\mu^- \mathrm{Au} \to e^- \mathrm{Au}$
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F. Feruglio, P. Paradisi and A. Pattori, Eur. Phys. J. C 75 (2015) no.12, 579
G. M. Pruna and A. Signer, JHEP 1410 (2014) 014

Sensitivity for BSM with CLFV

Osaka University

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from BR(μ→eγ)<4.2×10^{-13}

$$\frac{C^6}{\Lambda^2}\mathscr{O}^6 \rightarrow \frac{C^6}{\Lambda^2}\bar{e}_L \sigma^{\rho\nu} \mu_R \Phi F_{\rho\nu}$$

⬇

$$\Lambda \sim \mathscr{O}(10^4)\ \text{TeV}$$

$c.f.\ \Delta m_K, \varepsilon'$

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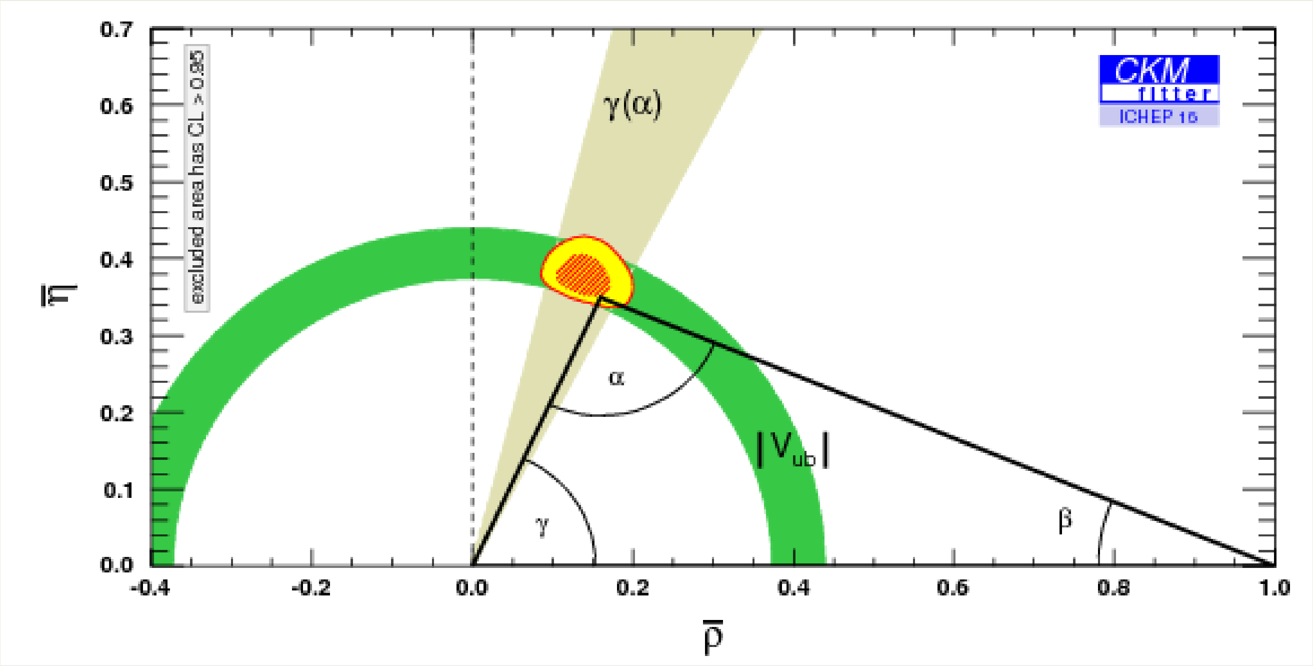
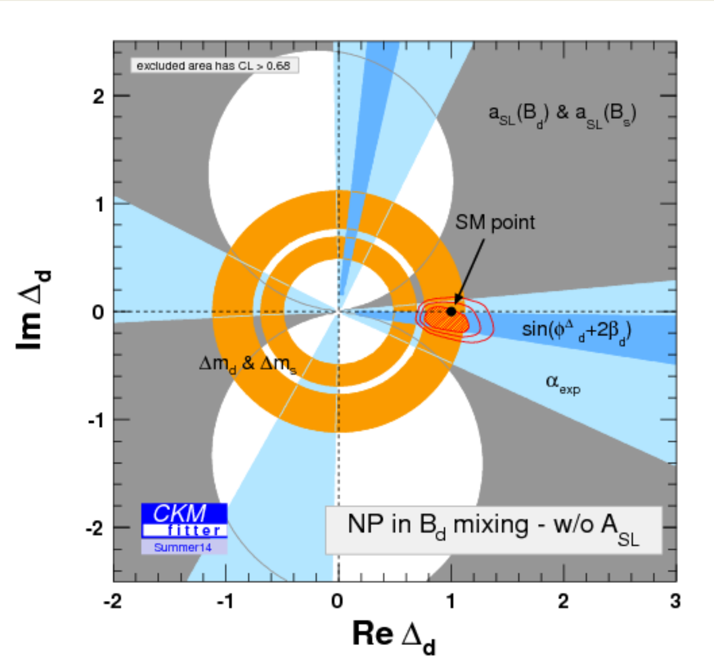
Probing NP with FCNC





ij	Λ [TeV] CPC	Λ [TeV] CPV	Observables
sd	9.8×10^2	1.6×10^4	$\Delta m_K; \epsilon_K$
bd	6.6×10^2	9.3×10^2	$\Delta m_B; S_{\psi K}$
bs	1.4×10^2	2.5×10^2	$\Delta m_{B_s}; S_{\psi\phi}$

Lower bounds on the NP scale in $\frac{1}{\Lambda^2}\ (\overline{q_{Li}}\gamma_\mu q_{Lj})(\overline{q_{Li}}\gamma^\mu q_{Lj})$

from presentation by Yossi Nir (Weizmann Institute) at EPPSU, Granada 2019

Future Sensitivity for BSM with CLFV

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Future planned experiments expecting improvements of >10,000 or more (will be described later) would probe ….

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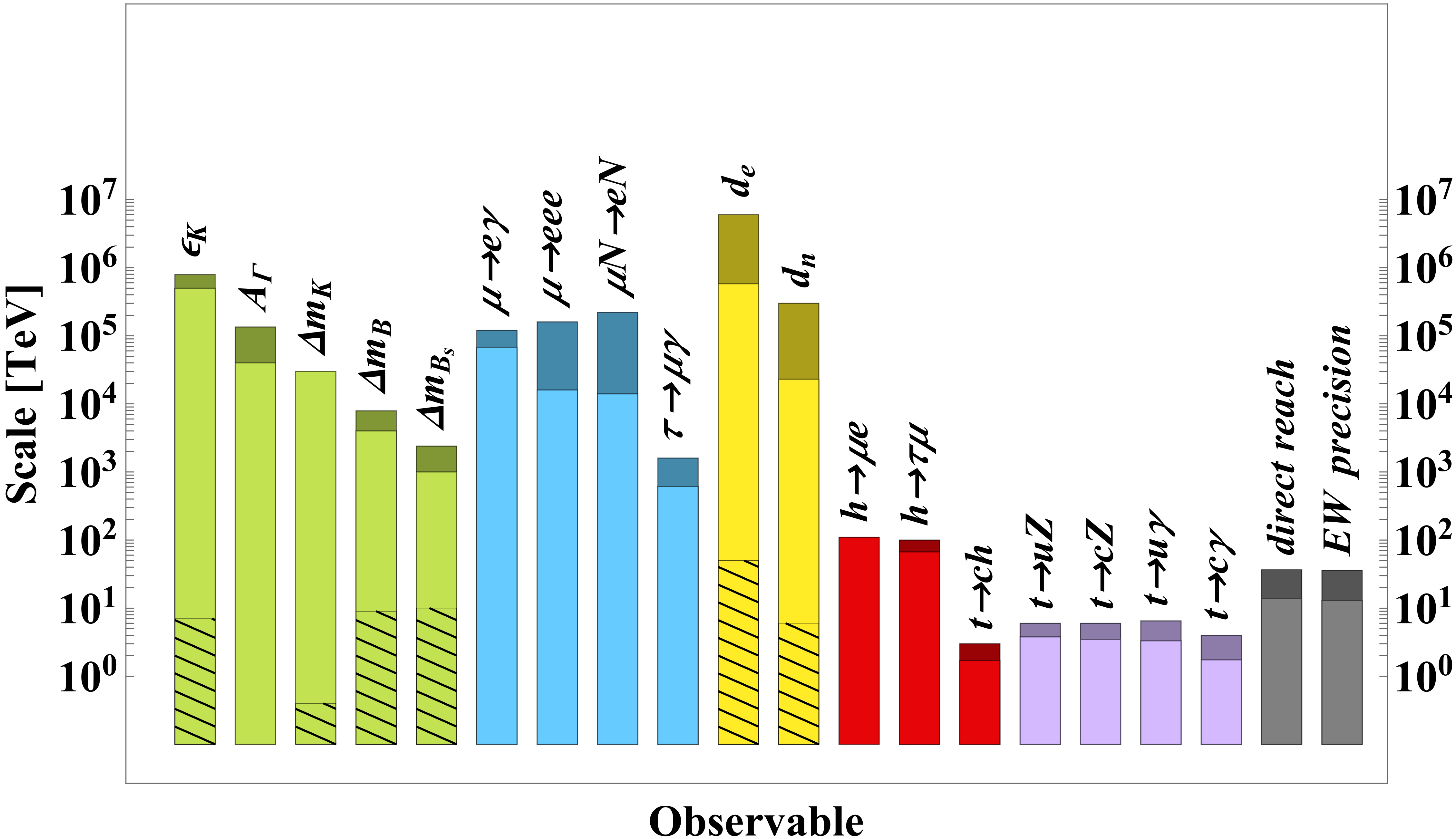
It is crucial in establishing where is the next fundamental scale above the electroweak symmetry breaking.

Sensitivity of New Physics



shown in EPPSU2019 Physics Briefing Book

http://cds.cern.ch/record/2691414/files/Briefing_Book_Final.pdf

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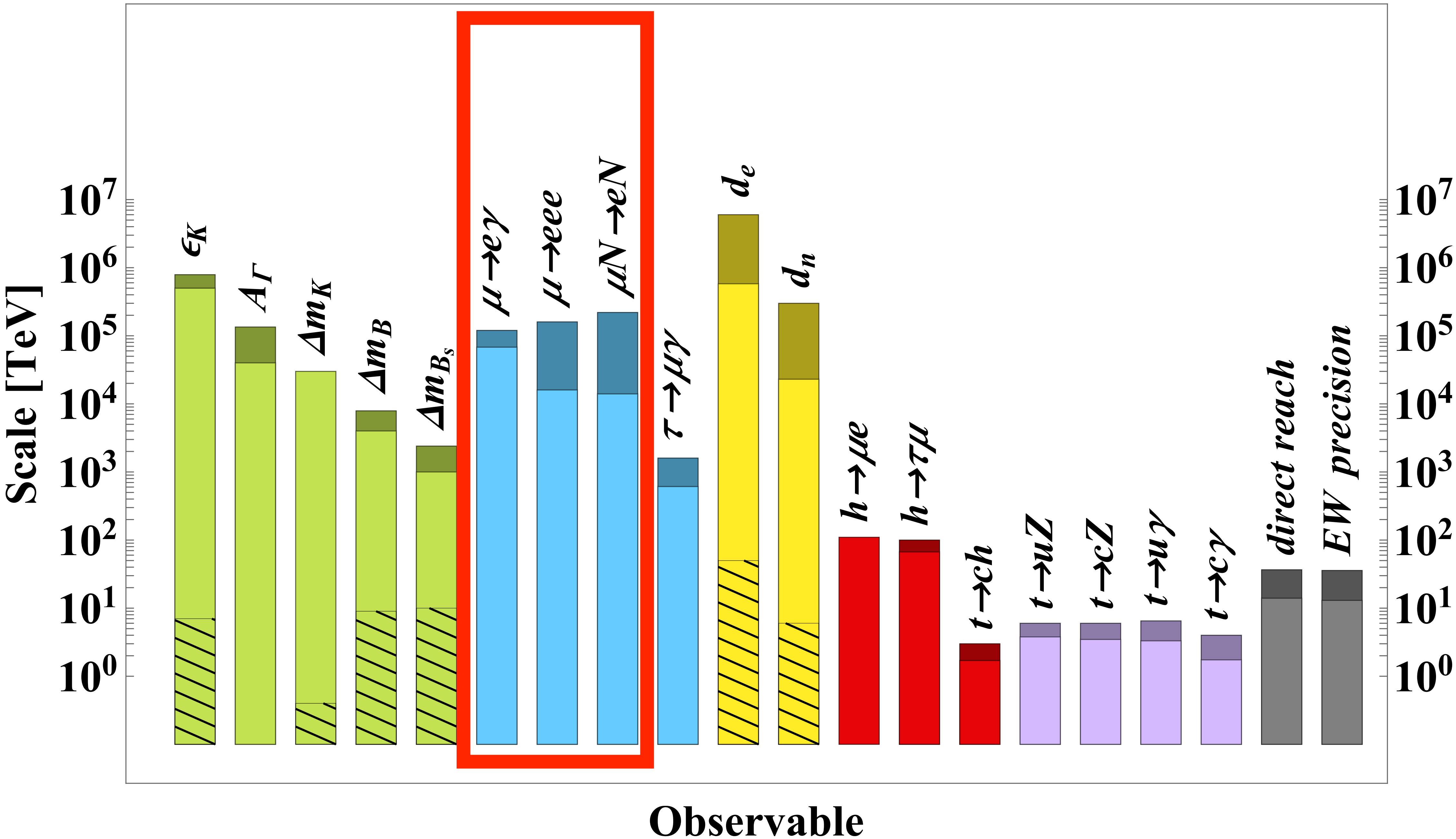

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CLFV in the SM

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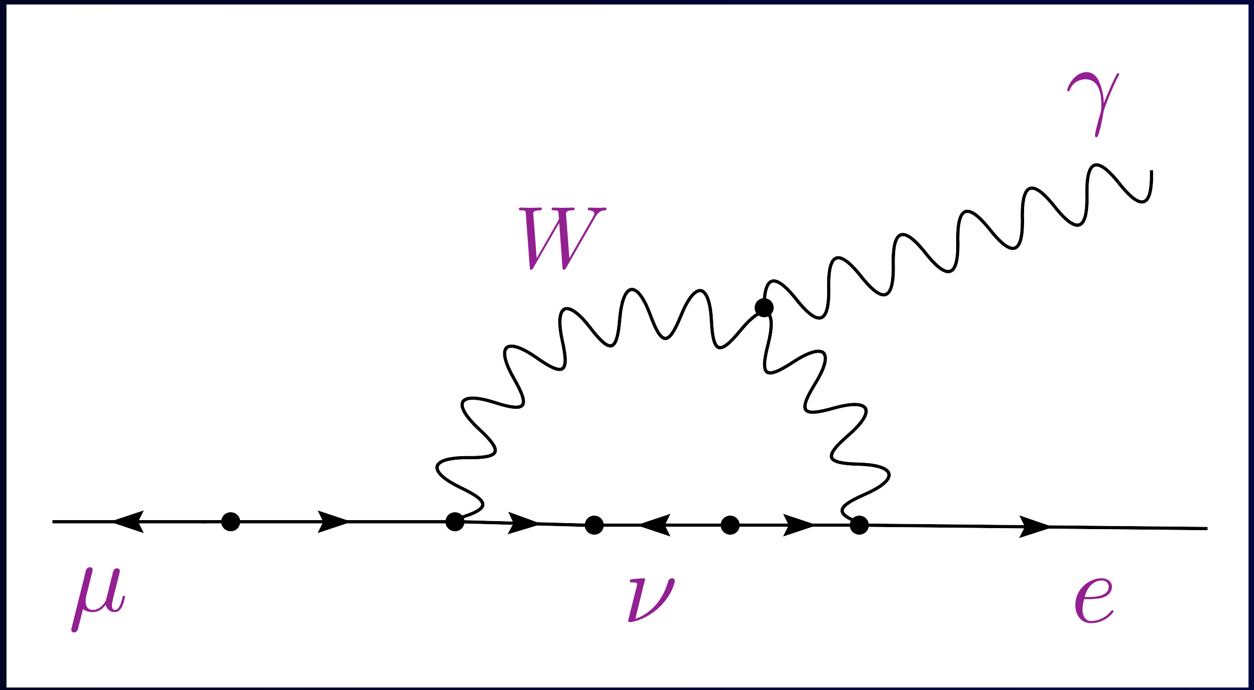

S.T. Petcov, Sov.J. Nucl. Phys. 25 (1977) 340

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

BR~O(10^{-54})

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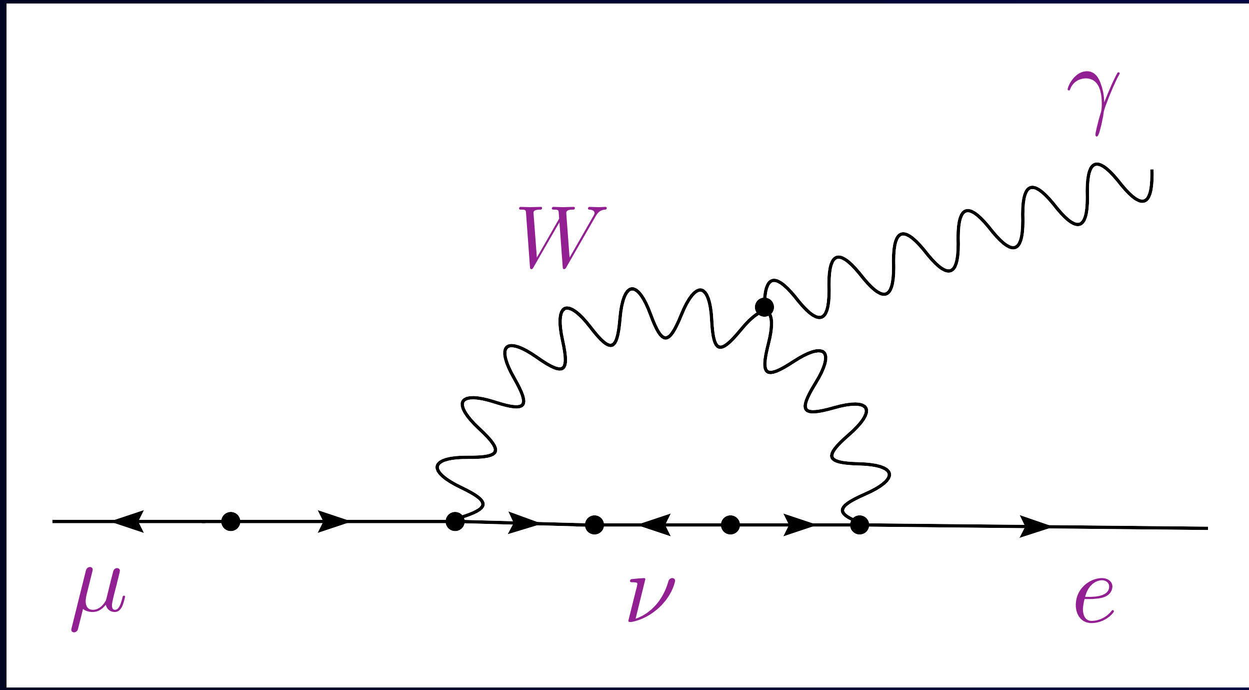

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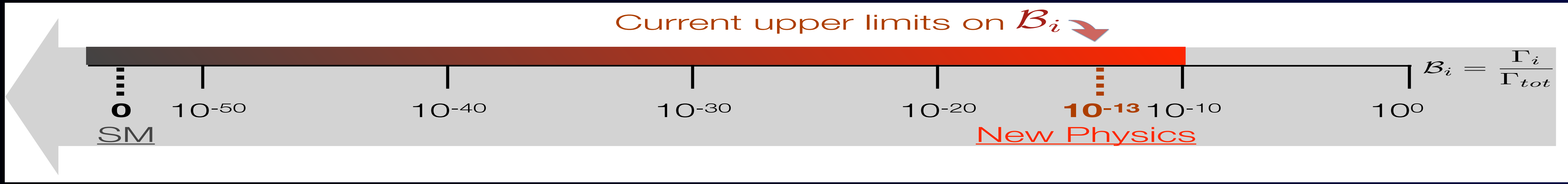

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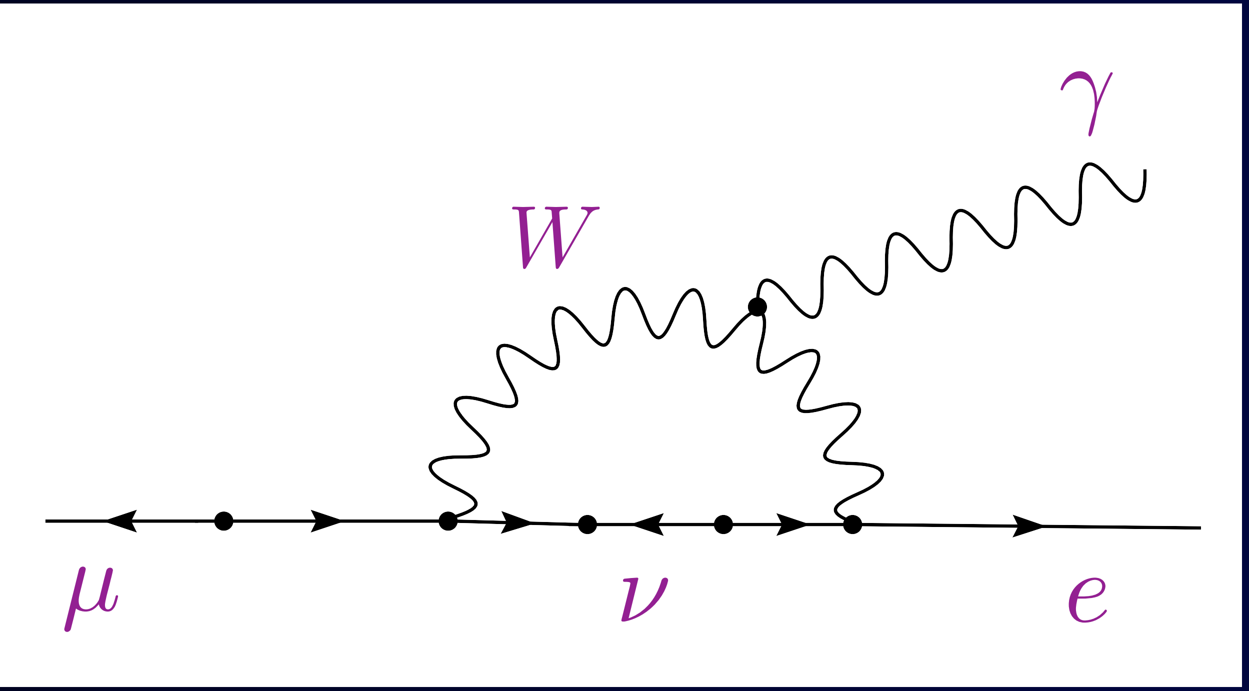

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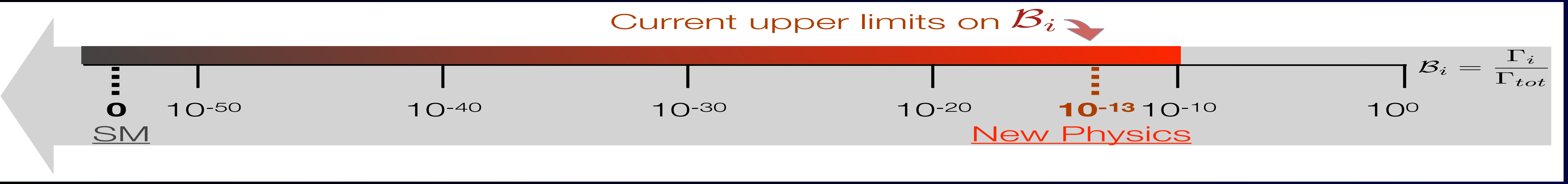

2

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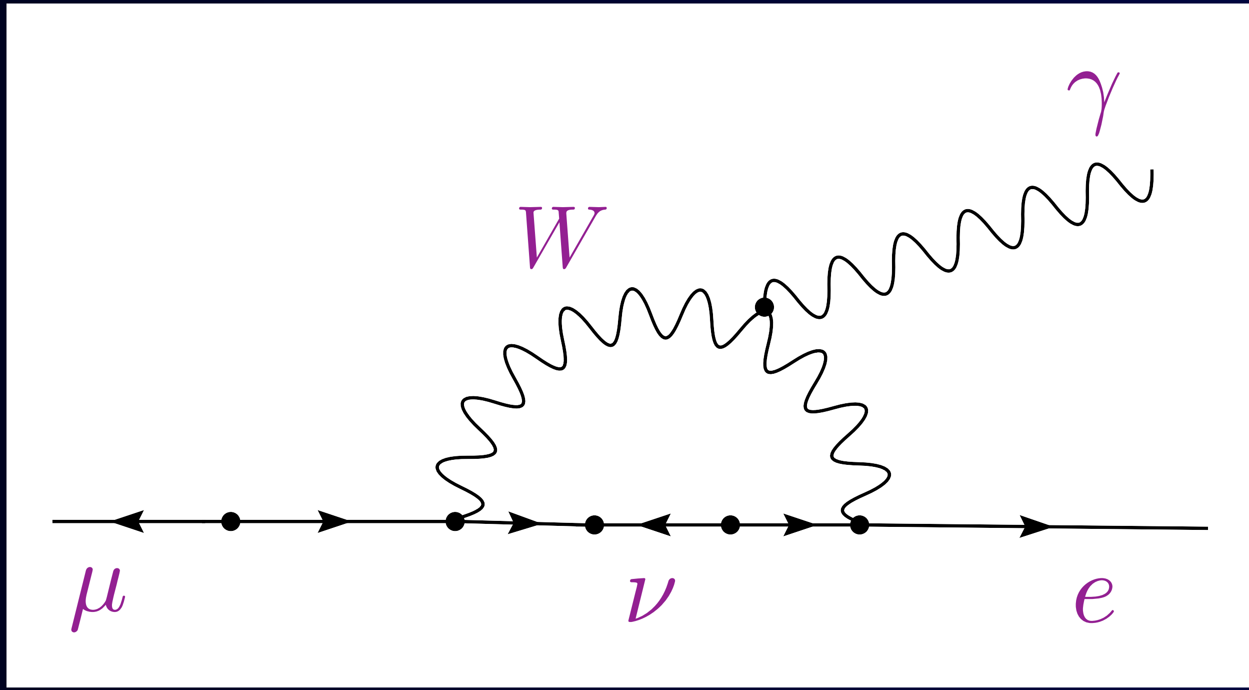

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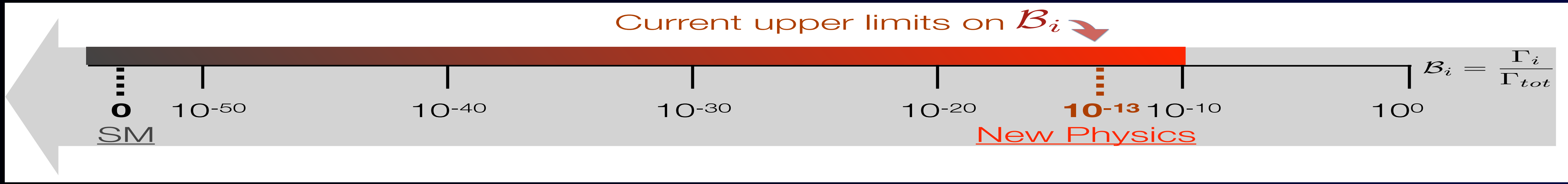

2

CLFV has a large window for BSM without SM backgrounds.

"Golden" μ→e CLFV Transition Processes

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

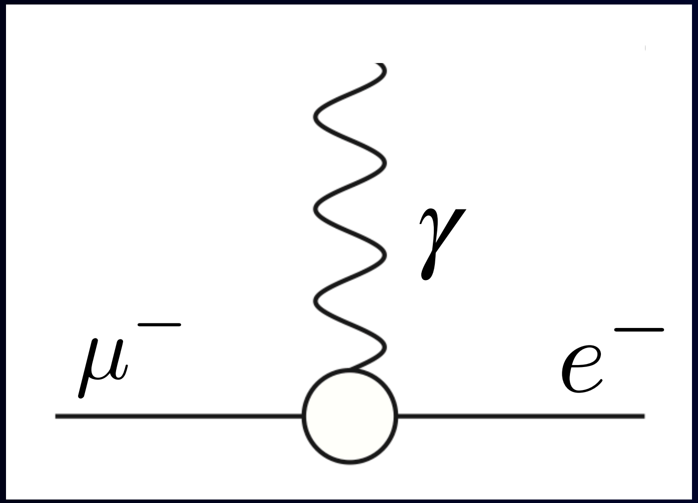
$$\mu^+ \to e^+e^+e^-$$

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

"Golden" μ→e CLFV Transition Processes

dipole interaction

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



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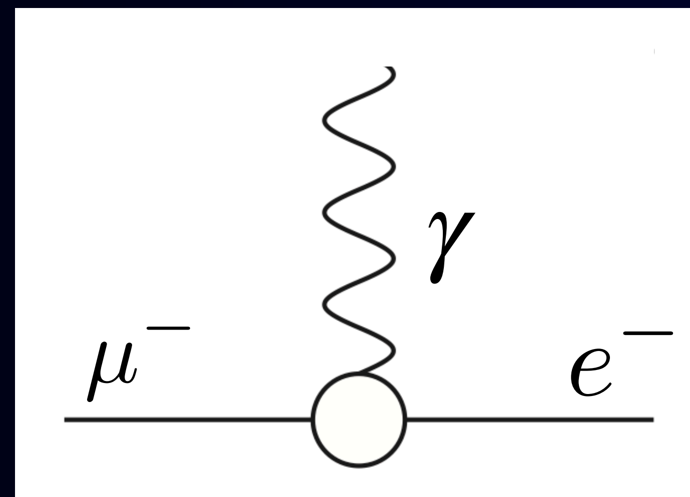

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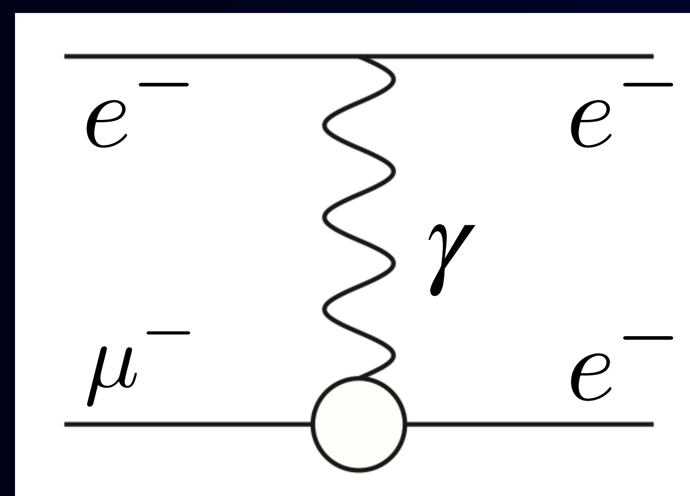
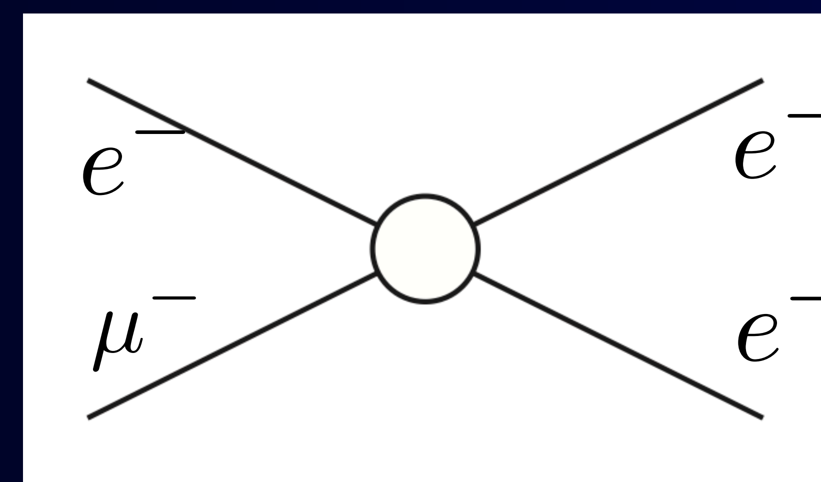


contact interaction



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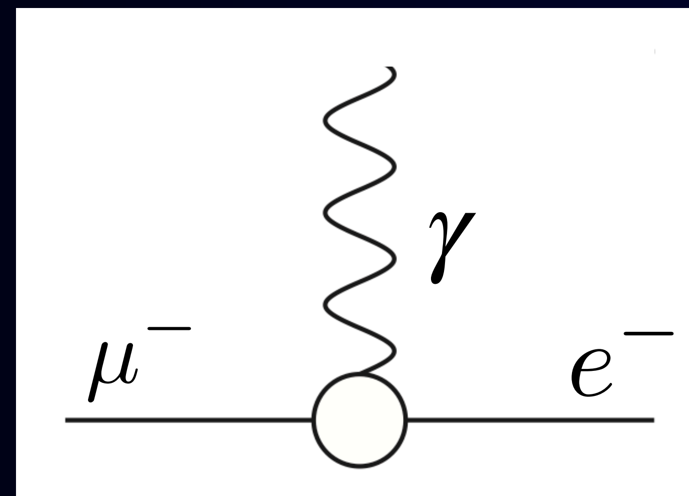

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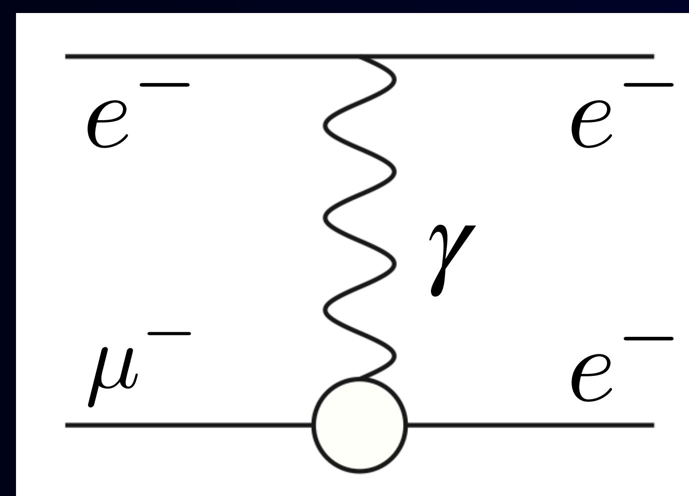

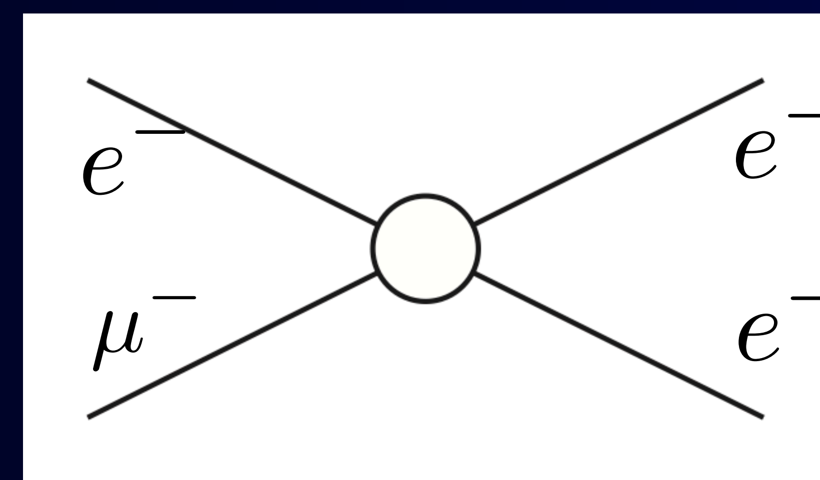

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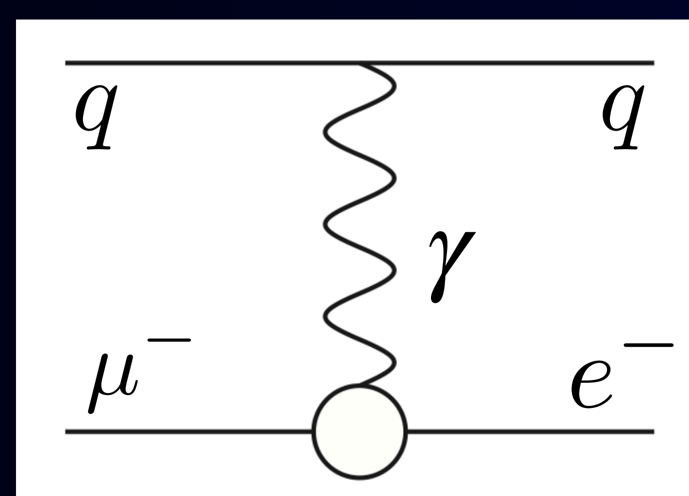
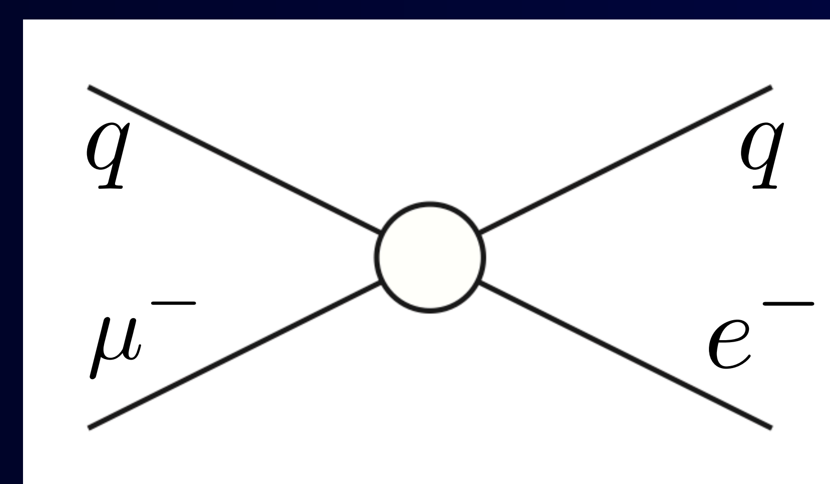
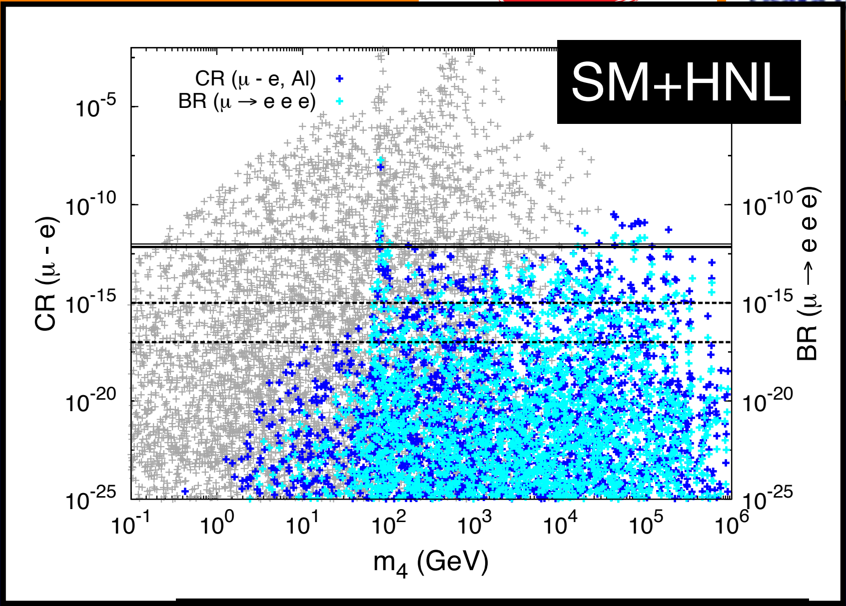


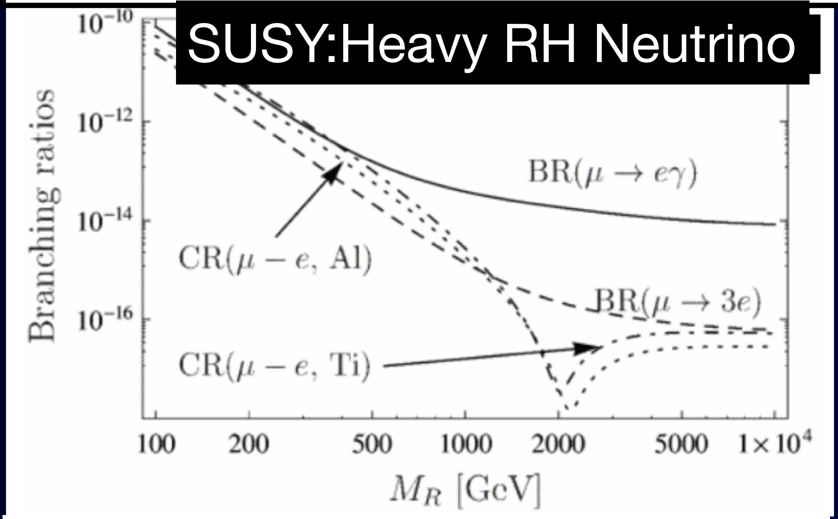


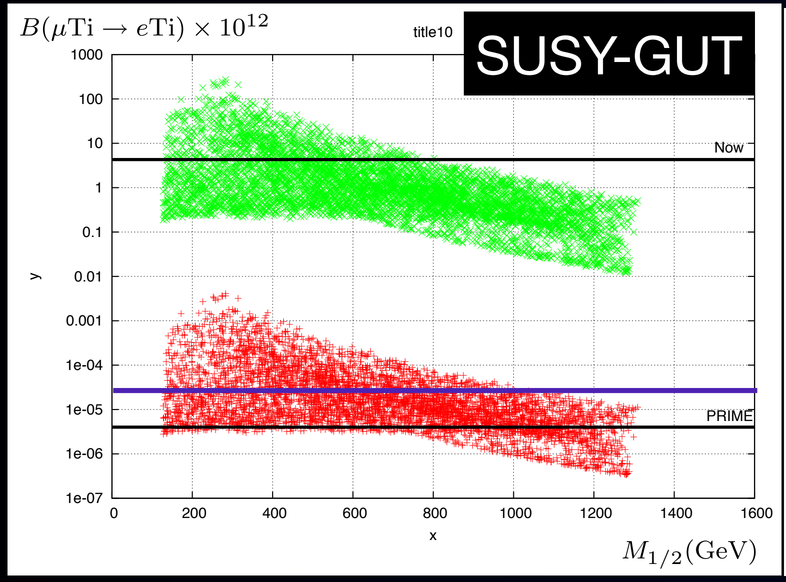
Model dependent CLFV

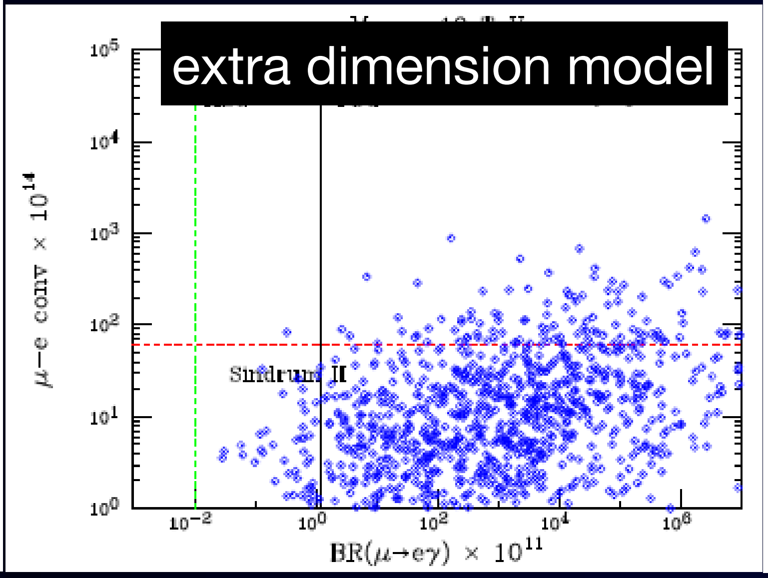
Model dependent CLFV

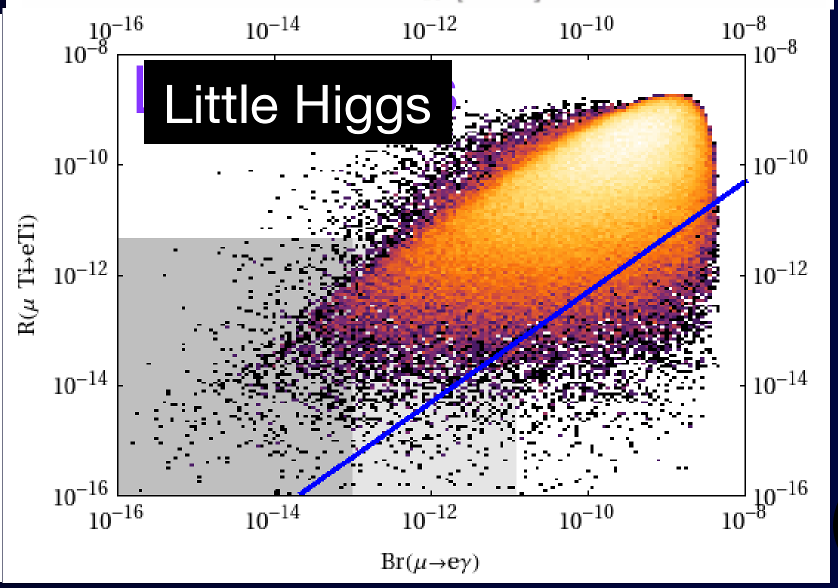
- SM + NHL (neutral heavy lepton)
- large extra dimensions
- extended Higgs sector
- additional vector boson (Z')
- leptoquark
- SUSY-GUT and SUSY seesaw
- R-parity violating SUSY
- low-energy seesaw
- etc. etc.

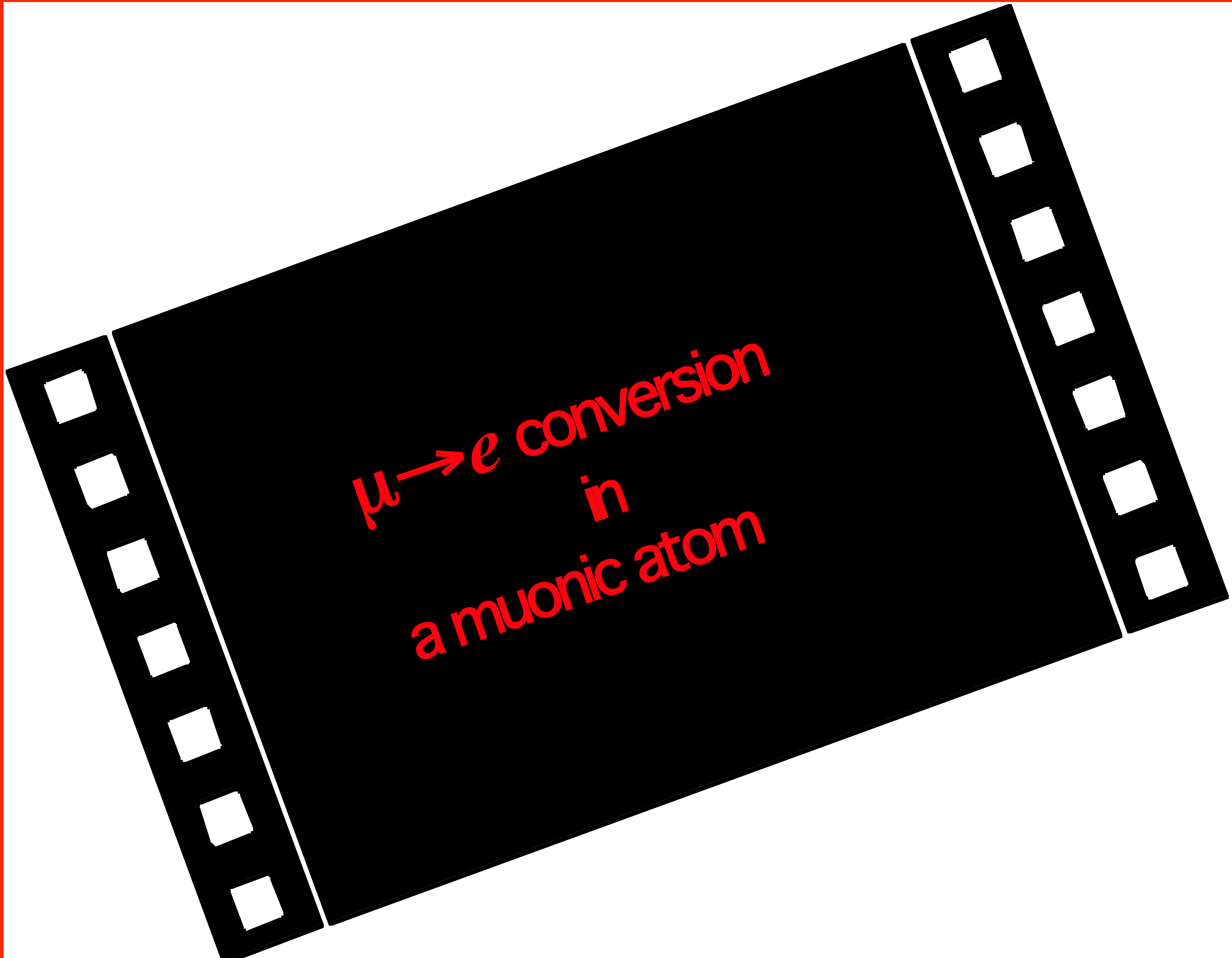











$\mu \to e$ conversion
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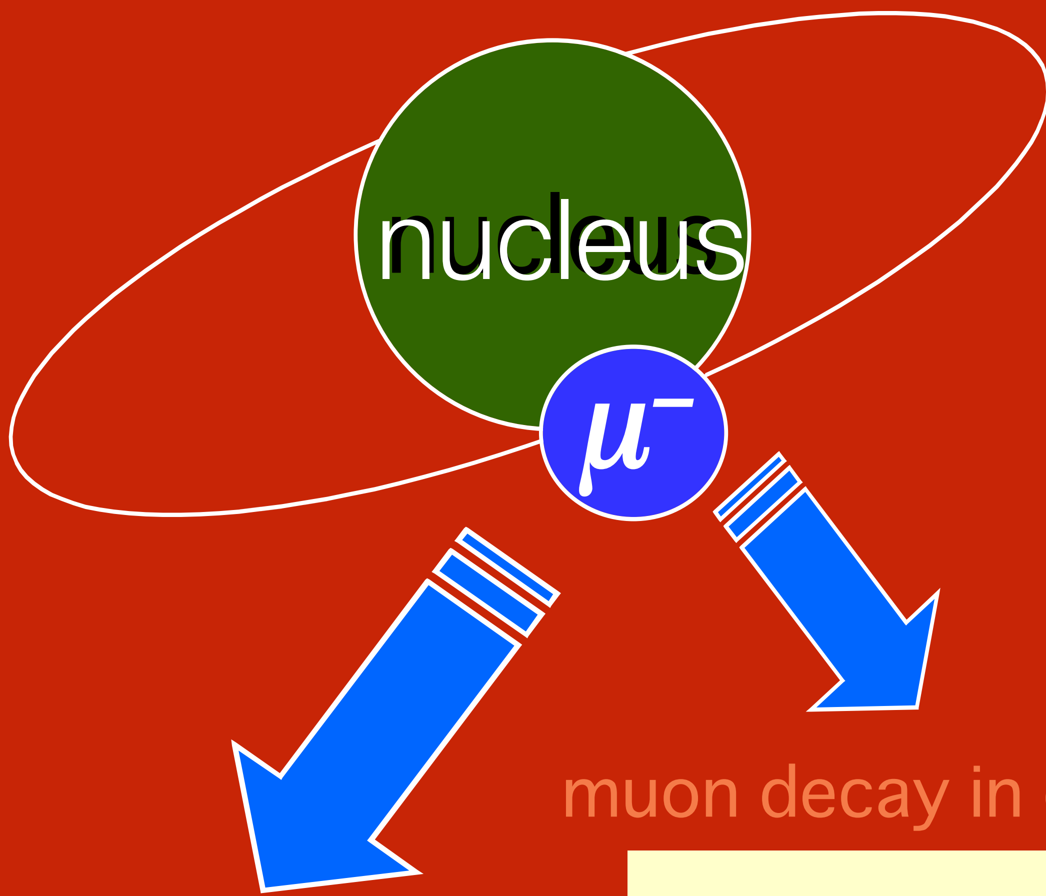
$\mu \rightarrow e$ Conversion in a muonic atom

$$\mathrm{CR}(\mu^- \mathrm{N} \to e^- \mathrm{N}) \equiv \frac{\Gamma(\mu^- \mathrm{N} \to e^- \mathrm{N})}{\Gamma(\mu^- \mathrm{N} \to \mathrm{all})}$$

μ→e Conversion in a muonic atom

1s state in a muonic atom



muon decay in orbit

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

nuclear muon capture

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

$$CR(\mu^- N \to e^- N) \equiv \frac{\Gamma(\mu^- N \to e^- N)}{\Gamma(\mu^- N \to \text{all})}$$

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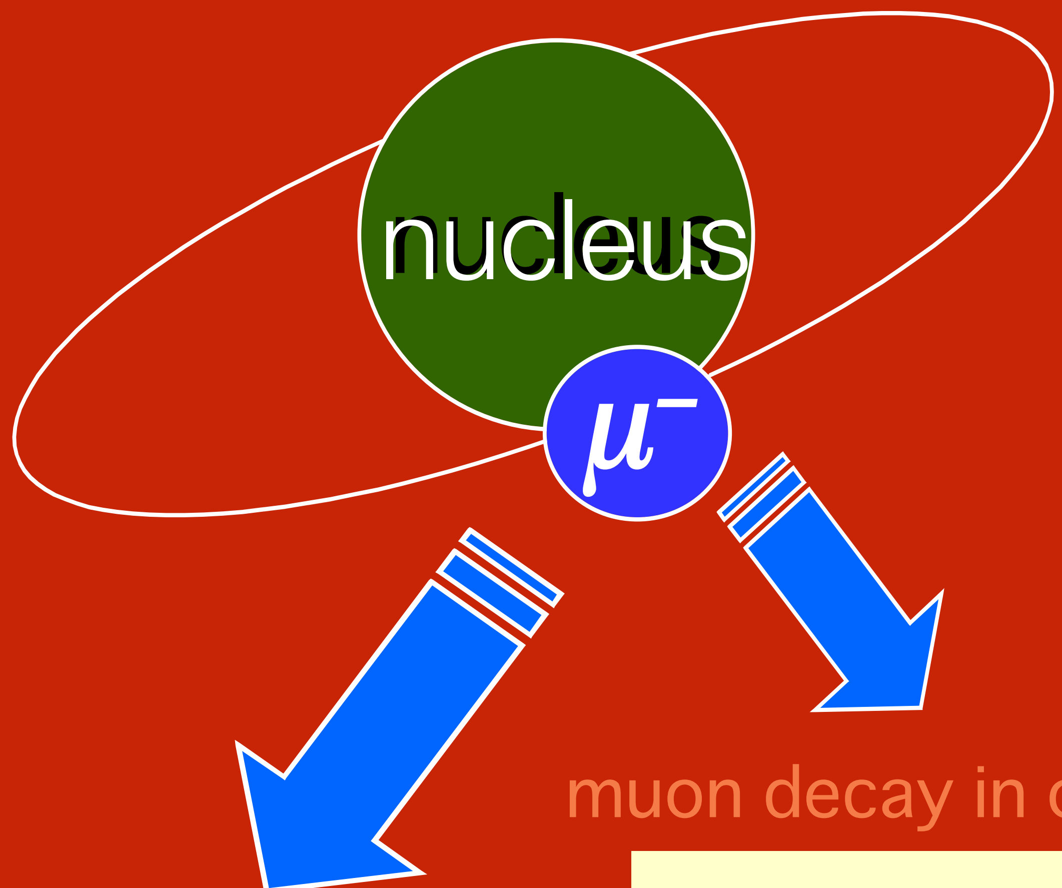

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$$\mu^- + (A,Z) \to e^- + (A,Z)$$

coherent process $\propto Z^5$

(for the case that the final nucleus is the ground state.)

Event Signature :
a single mono-energetic electron of 105 MeV

	Z	CR limit
sulphur	16	$<7 \times 10^{-11}$
titanium	22	$<4.3 \times 10^{-12}$
copper	39	$<1.6 \times 10^{-8}$
gold	79	$<7 \times 10^{-13}$
lead	82	$<4.6 \times 10^{-11}$

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

Experimental Comparison : μ→eγ and μ-e Conversion

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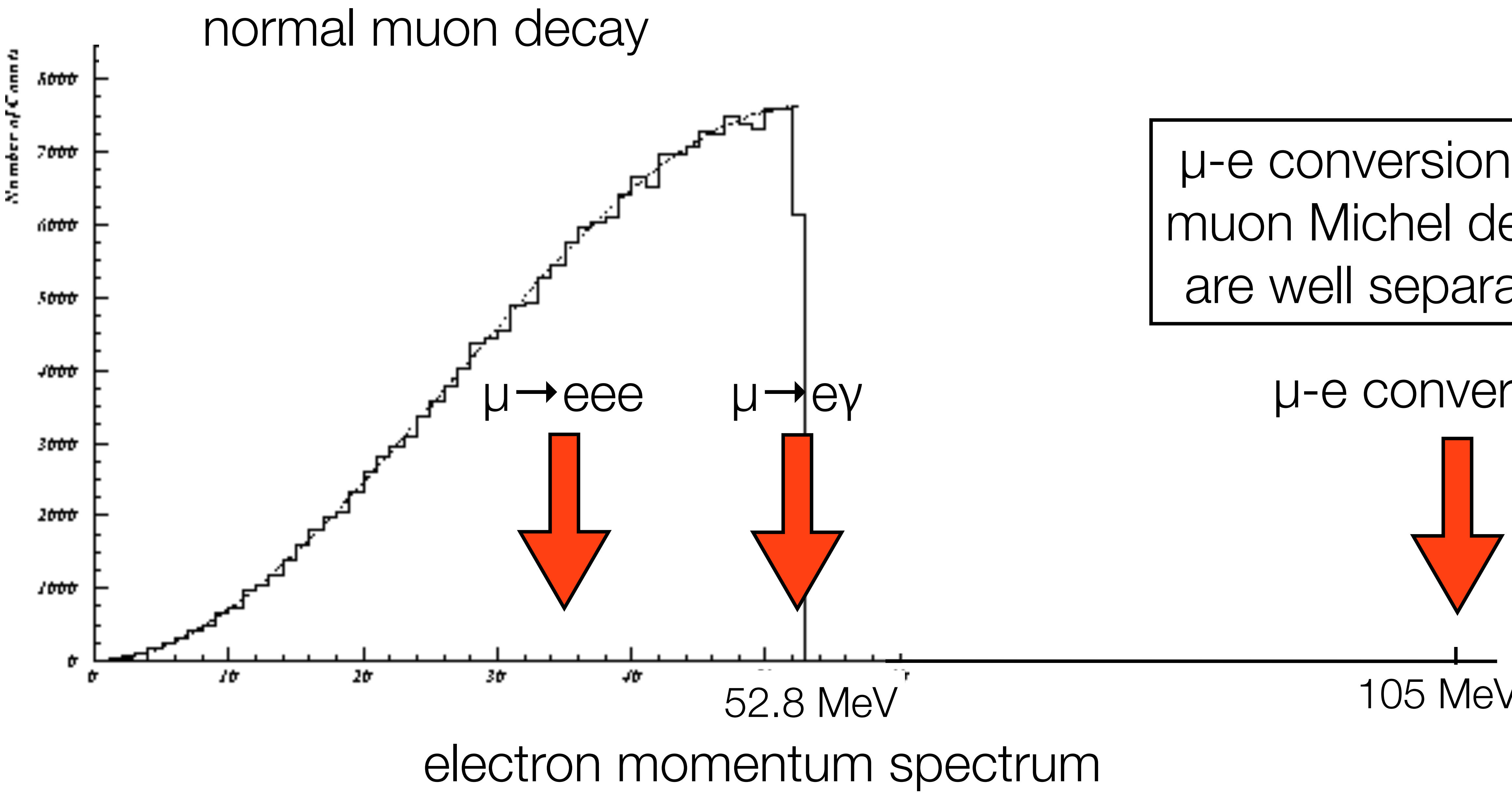


μ-e conversion and muon Michel decays are well separated.

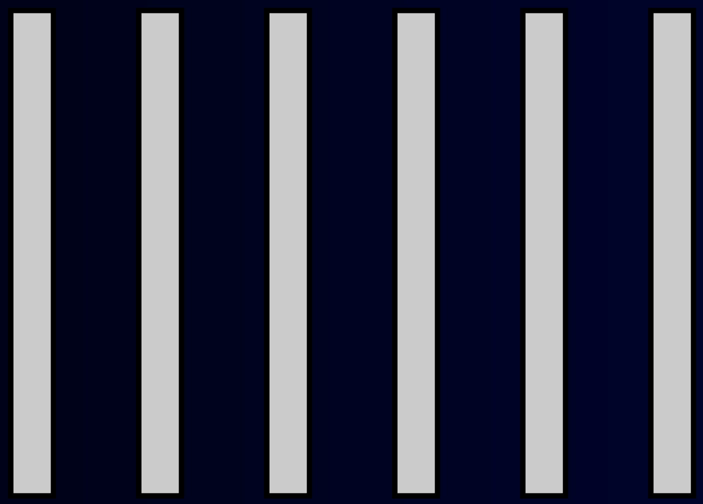
OMET

Osaka University

In order to make a new-generation experiment …

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

Principle of Measurement of μ-e Conversion


muon stopping target

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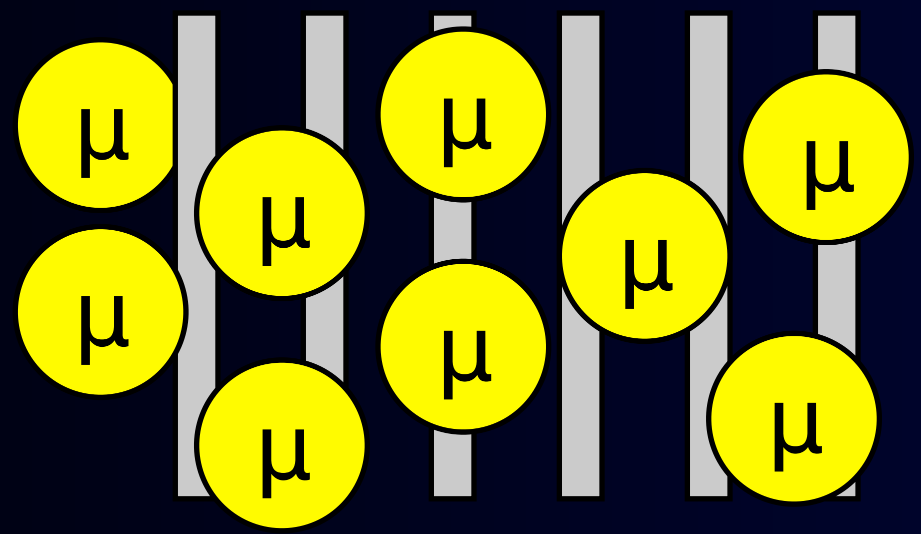

muon stopping target

A total number of muons is the key for success.

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

PSI can provide 10^{15} muons/year
and 1000 years are needed at PSI.

1 Improvements for Signal Sensitivity - Muon Production

① Improvements for Signal Sensitivity - Muon Production

To achieve a single sensitivity of <10^{-16}, we need

10^{11} muons/sec (with 10^{7} sec running)

whereas the current highest intensity is 10^{8}/sec at PSI.

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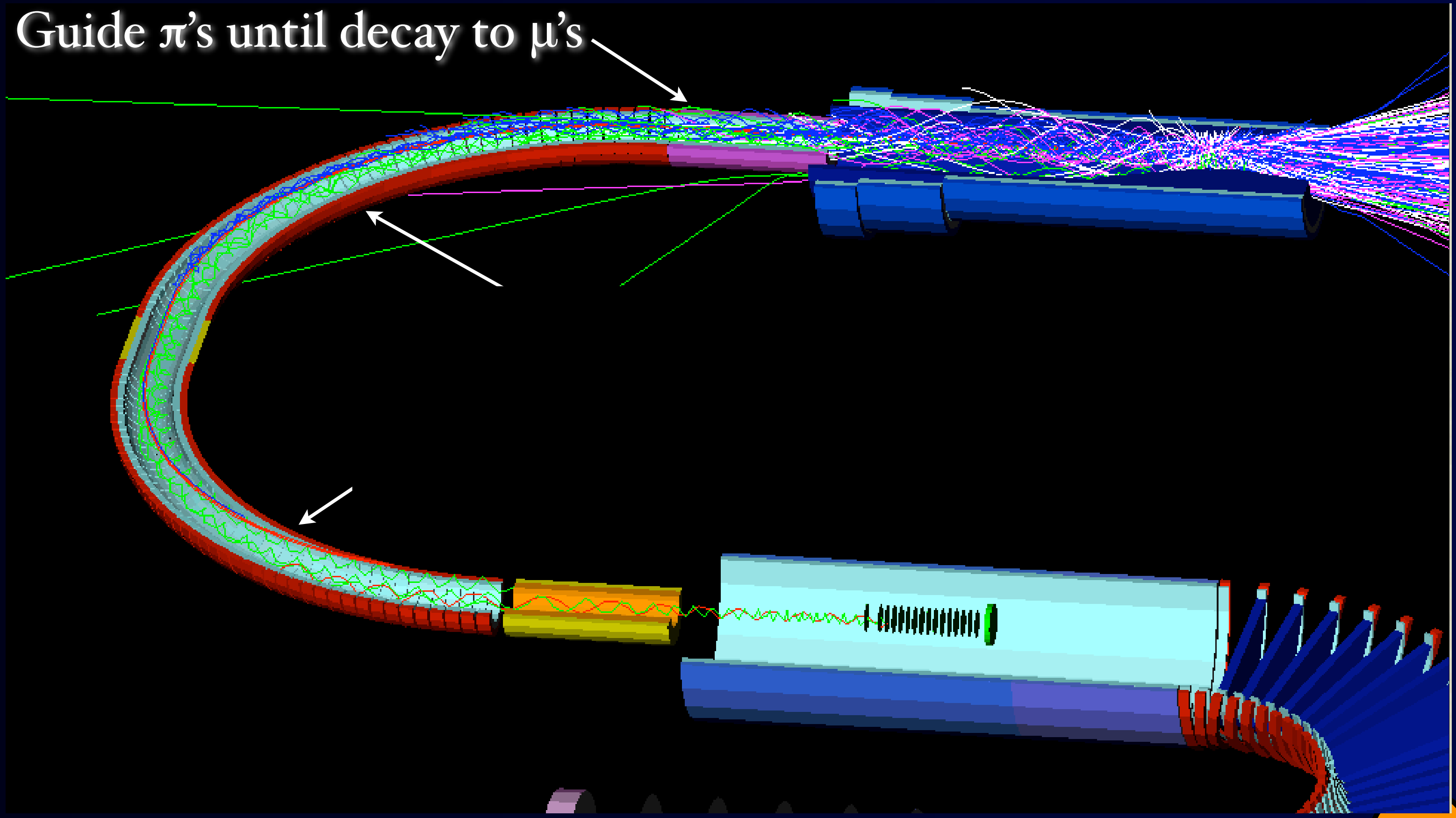
Pion Capture and Muon Transport by Superconducting Solenoid System

2×10^{11} muons for 56 kW beam power

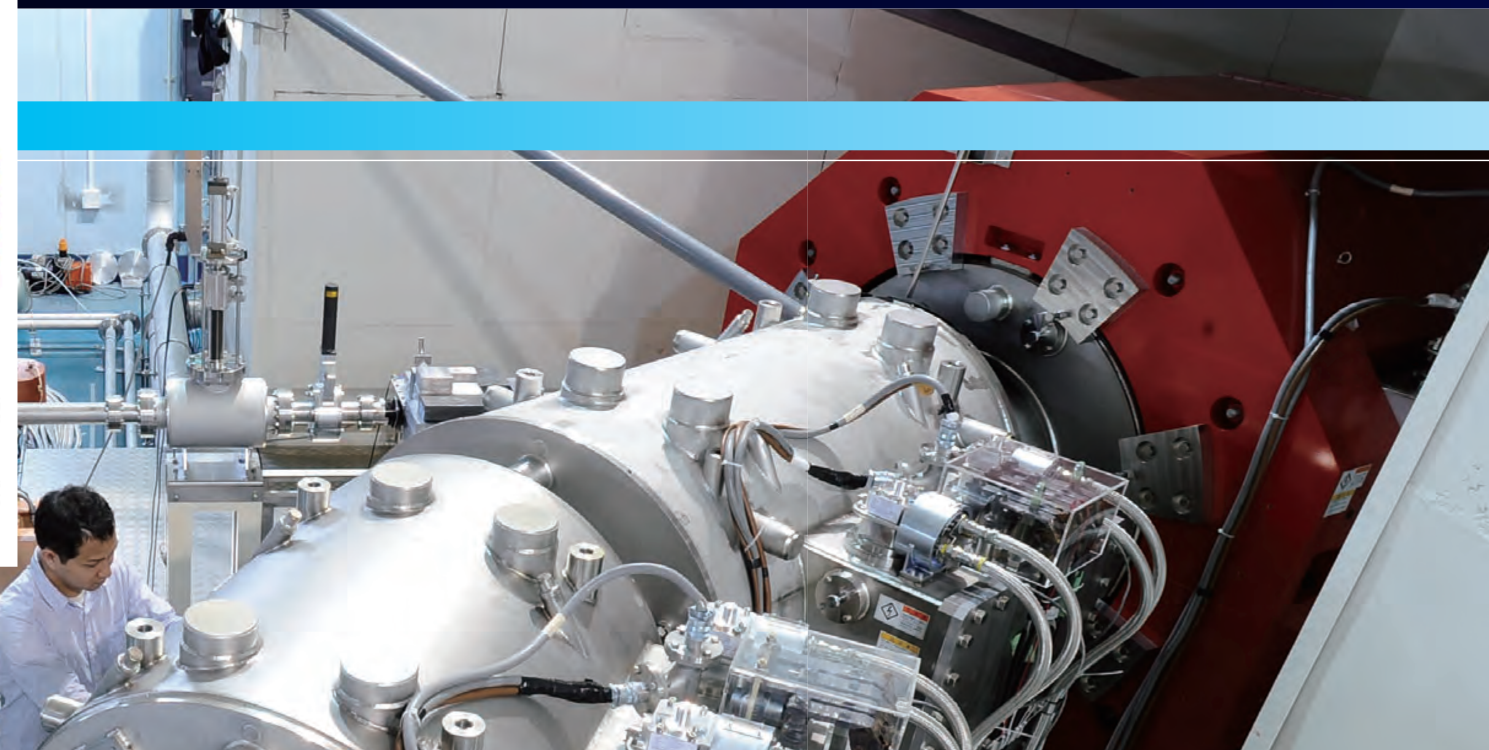


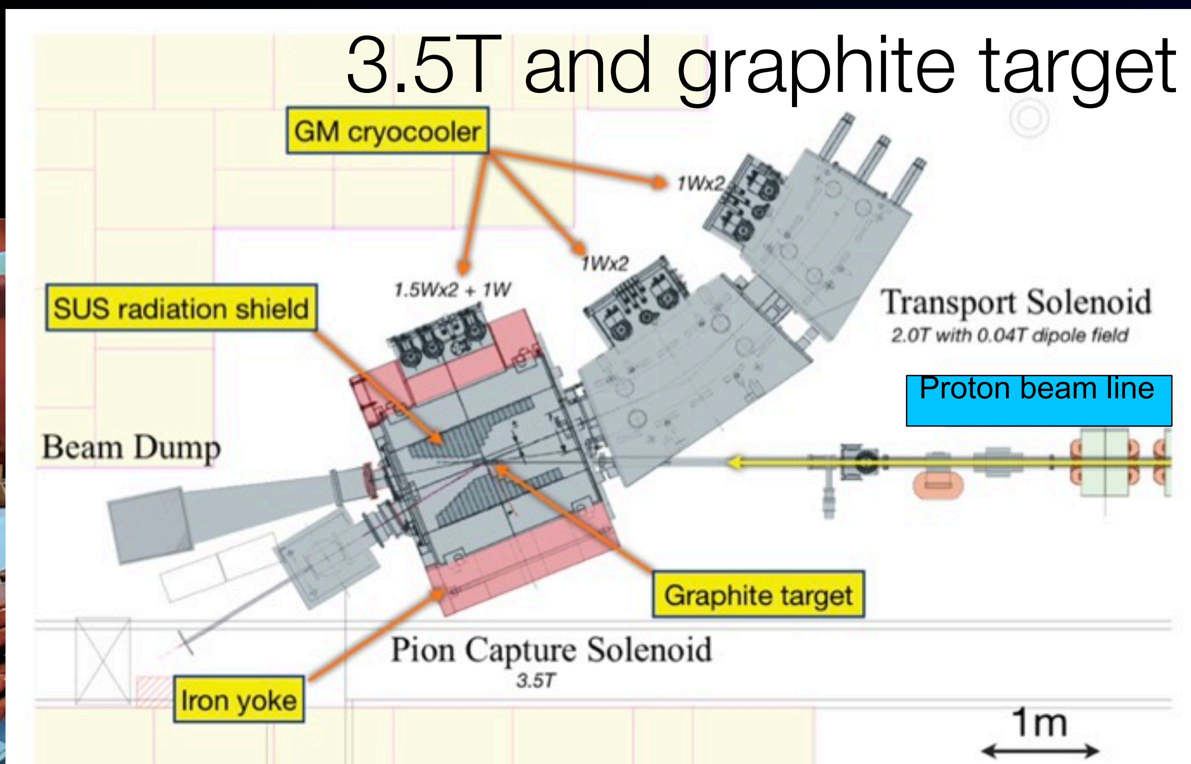
MuSIC at RCNP, Osaka University
- Highly Intense Muon Source -

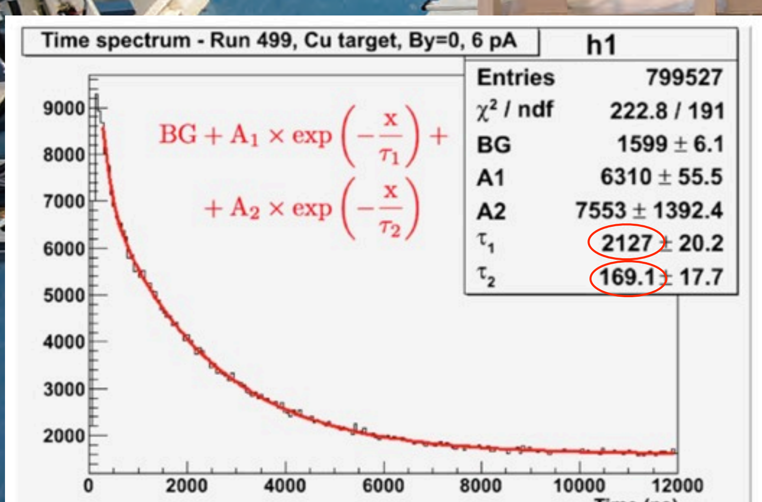
3.5T and graphite target

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

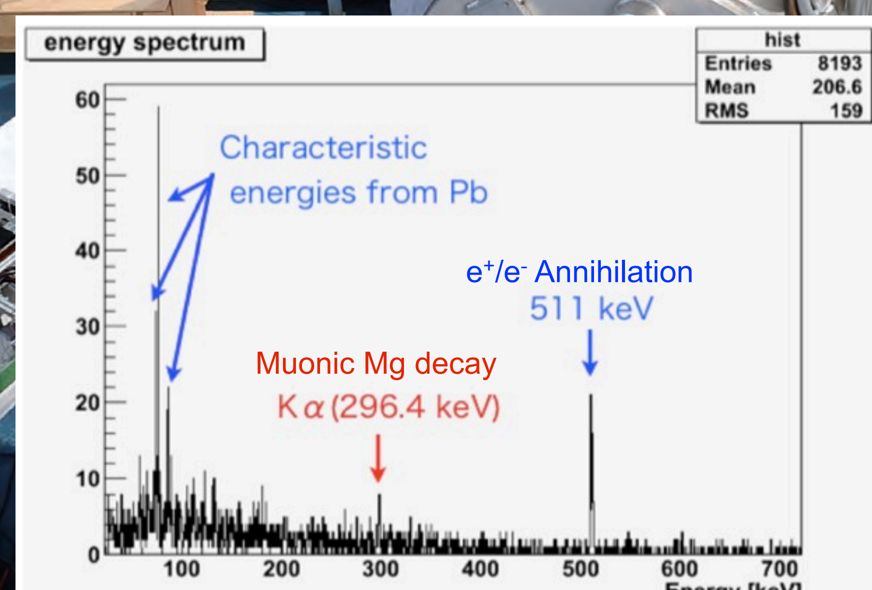
Muon Science Intense Channel (>2011)







	Free muon*	Cu**	Plastic scint.**
τ (ns)	2197.03 ± 0.04	163.5 ± 1	2026.3 ± 1.5



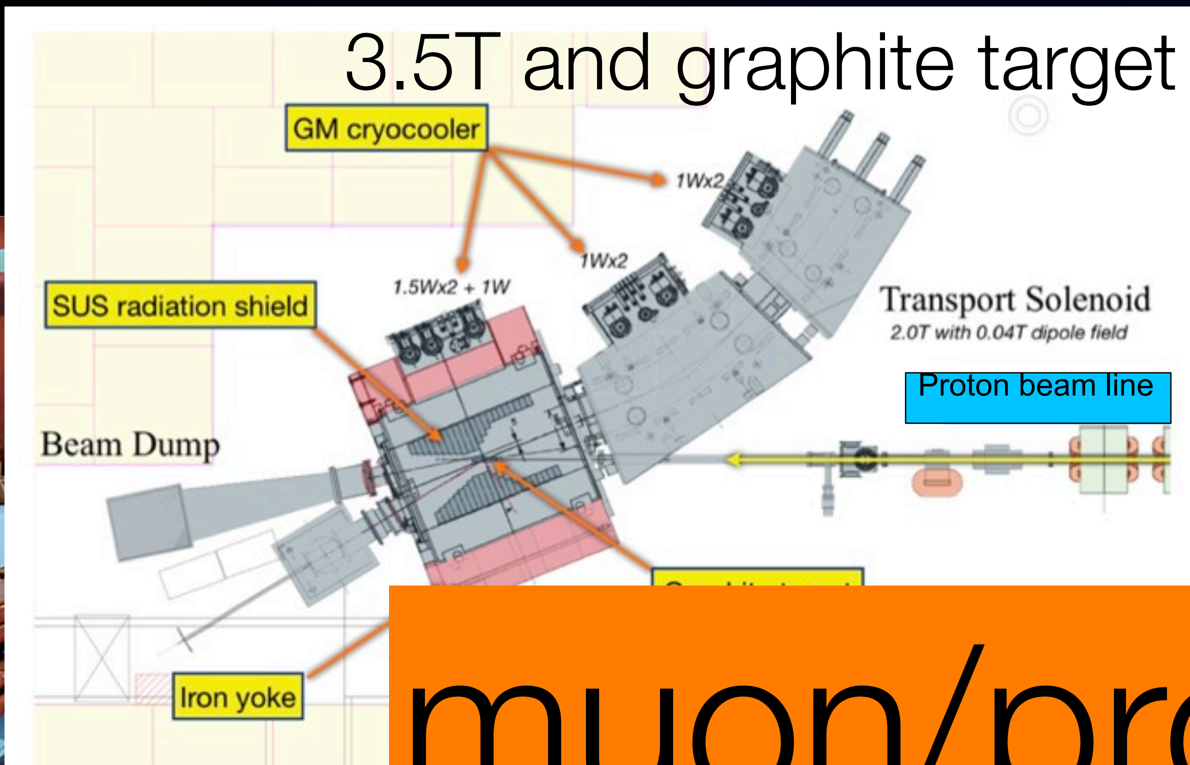
MuSIC muon yields

μ^+ : 3×10^8/s for 400W

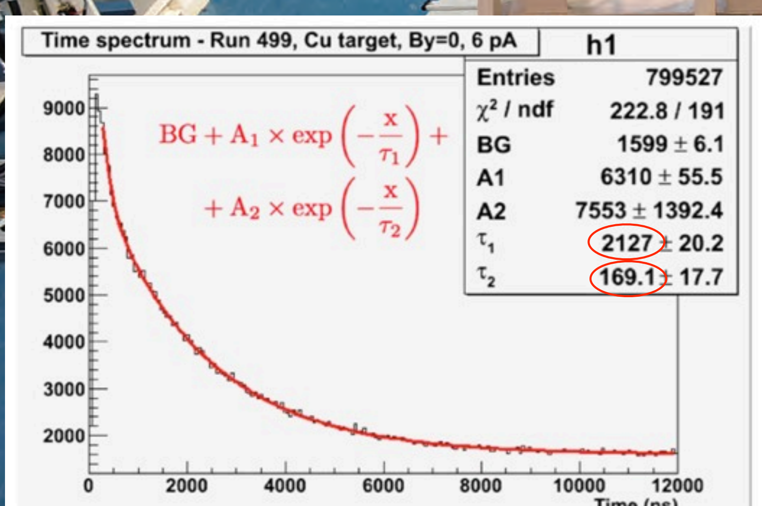
μ^- : 1×10^8/s for 400W

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

Muon Science Intense Channel (>2011)



muon/proton~x1000



	Free muon*	Cu**	Plastic scint.**
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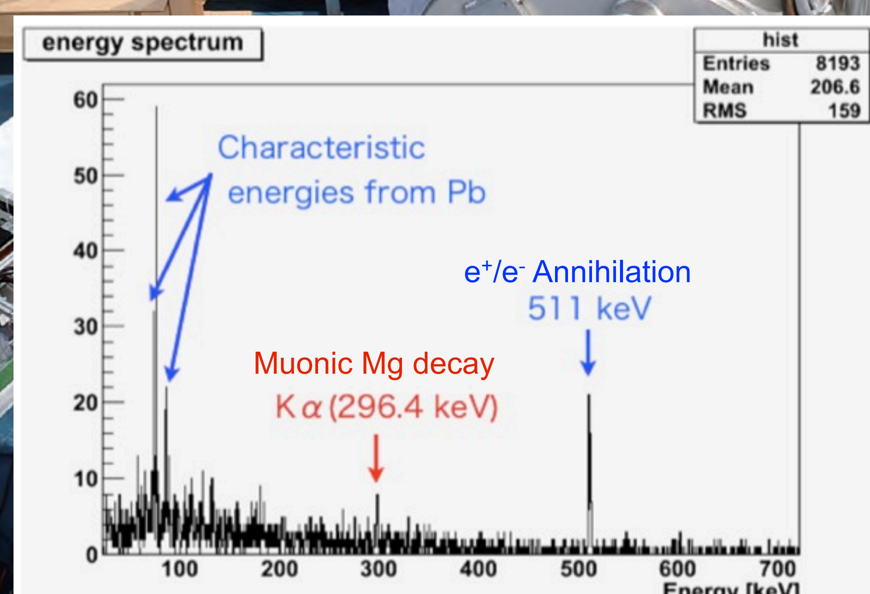


MuSIC muon yields

μ^+ : 3×10^8/s for 400W

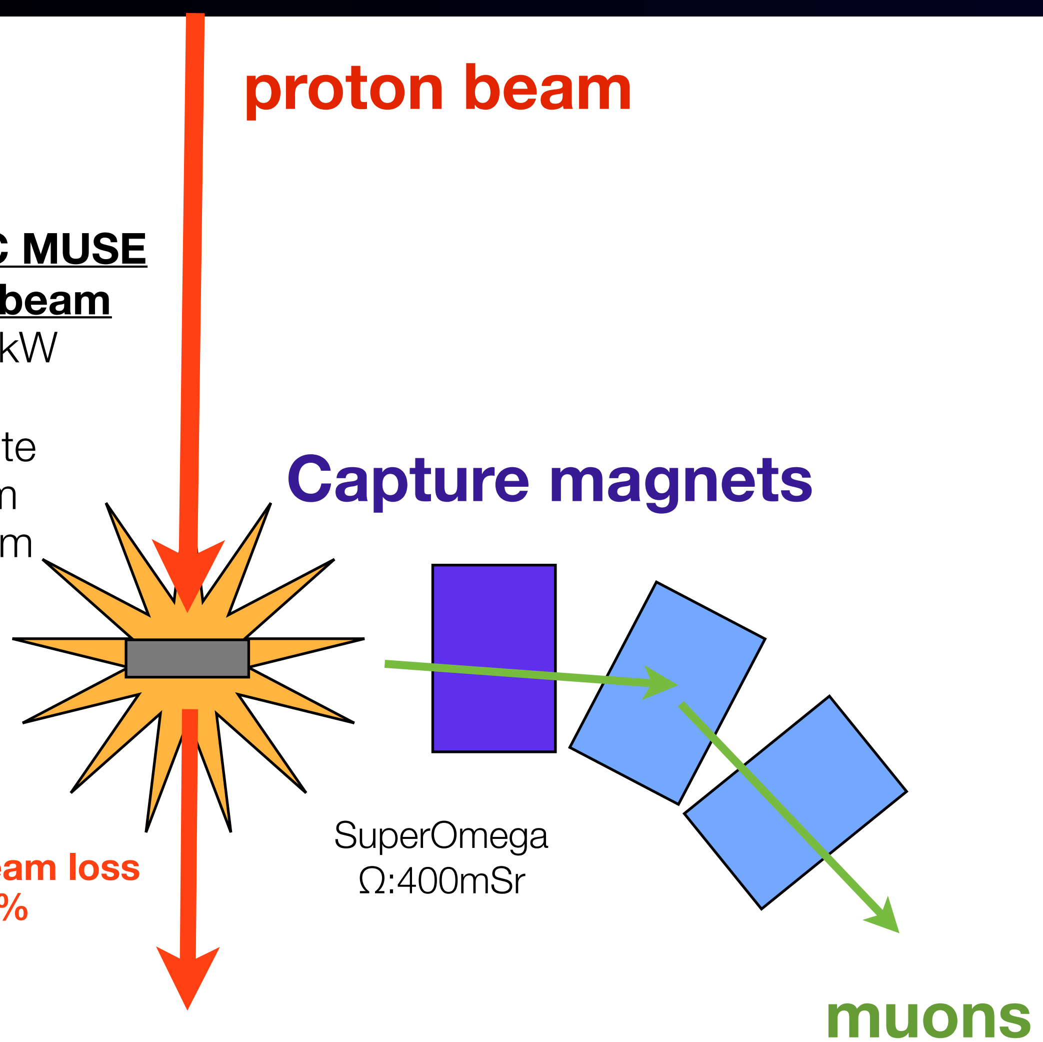
μ^- : 1×10^8/s for 400W

Production and Collection of Pions and Muons

Production and Collection of Pions and Muons

Conventional muon beam line

J-PARC MUSE
proton beam
-1000kW
target
graphite
t20mm
ϕ70mm

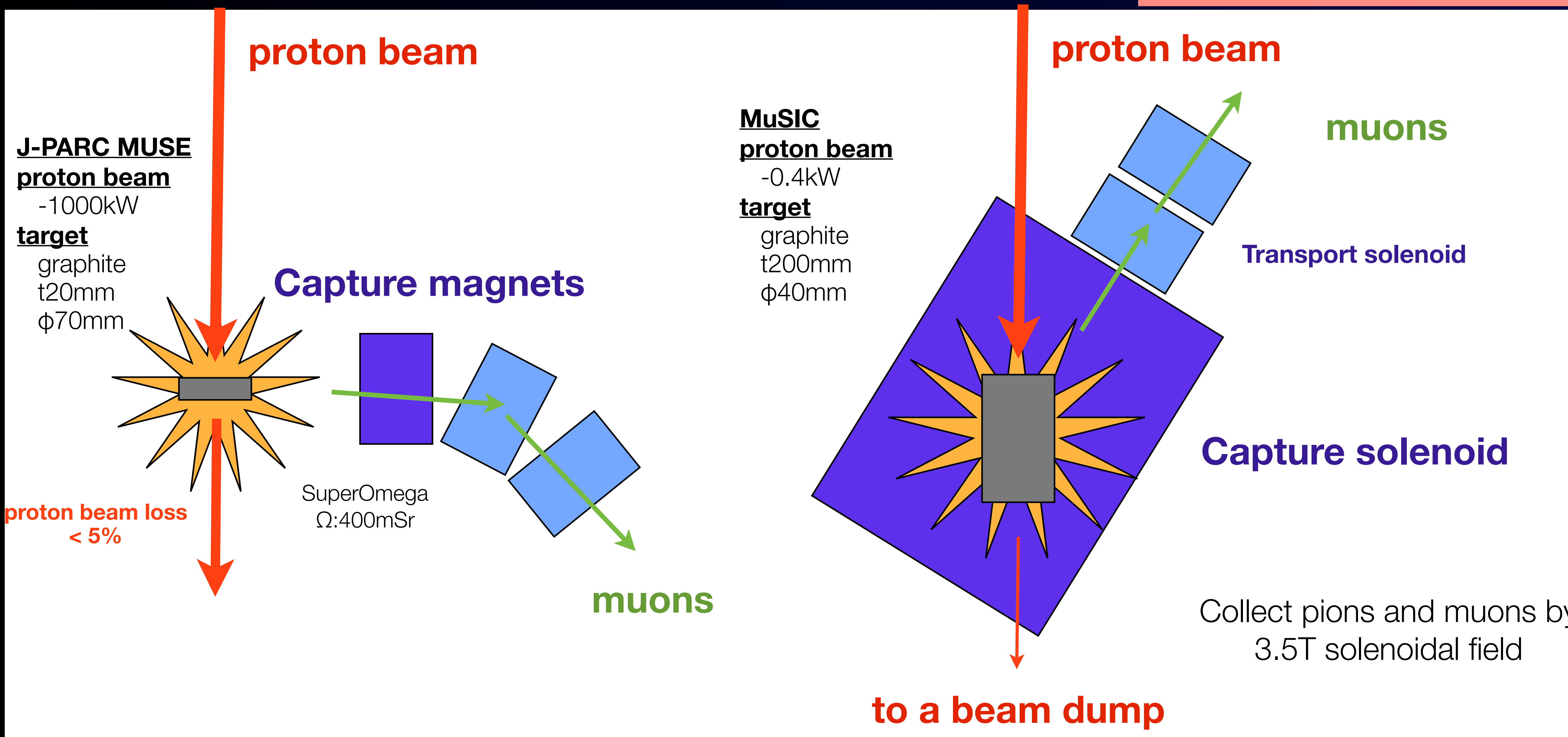


Production and Collection of Pions and Muons

Conventional muon beam line

More efficient

MuSIC,COMET,PRISM,
Neutrino factory,
Muon collider



Large solid angle & thick target

MuSIC Publication

Editors Suggestions

March, 2017, Editors Suggestions

PHYSICAL REVIEW ACCELERATORS AND BEAMS **20,** 030101 (2017)

Delivering the world's most intense muon beam

S. Cook,[1] R. D'Arcy,[1] A. Edmonds,[1] M. Fukuda,[2] K. Hatanaka,[2] Y. Hino,[3] Y. Kuno,[3] M. Lancaster,[1] Y. Mori,[4] T. Ogitsu,[5] H. Sakamoto,[3] A. Sato,[3] N. H. Tran,[3] N. M. Truong,[3] M. Wing,[1,*] A. Yamamoto,[5] and M. Yoshida[5]

[1]*Department of Physics and Astronomy, UCL, Gower Street, London WC1E 6BT, United Kingdom*
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[3]*Department of Physics, Graduate School of Science, Osaka University, Osaka 569-0043, Japan*
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(Received 25 October 2016; published 15 March 2017)

A new muon beam line, the muon science innovative channel, was set up at the Research Center for Nuclear Physics, Osaka University, in Osaka, Japan, using the 392 MeV proton beam impinging on a target. The production of an intense muon beam relies on the efficient capture of pions, which subsequently decay to muons, using a novel superconducting solenoid magnet system. After the pion-capture solenoid, the first 36° of the curved muon transport line was commissioned and the muon flux was measured. In order to detect muons, a target of either copper or magnesium was placed to stop muons at the end of the muon

2 Improvements for Background Rejection

2 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^{-10}

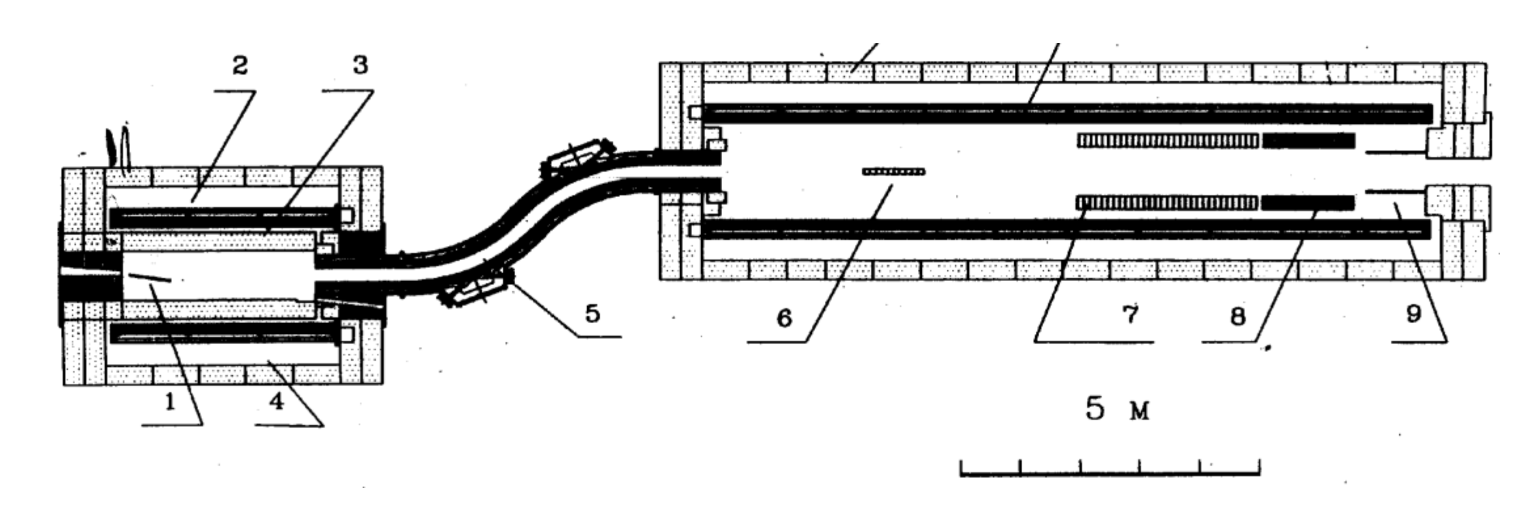
Muon DIO background	→	low-mass trackers in vacuum & thin target	improve electron energy resolution
Muon DIF background	→	curved solenoids for momentum selection	eliminate energetic muons (>75 MeV/c)

based on the MELC proposal at Moscow Meson Factory

From MELC to MECO

From MELC to MECO

MELC

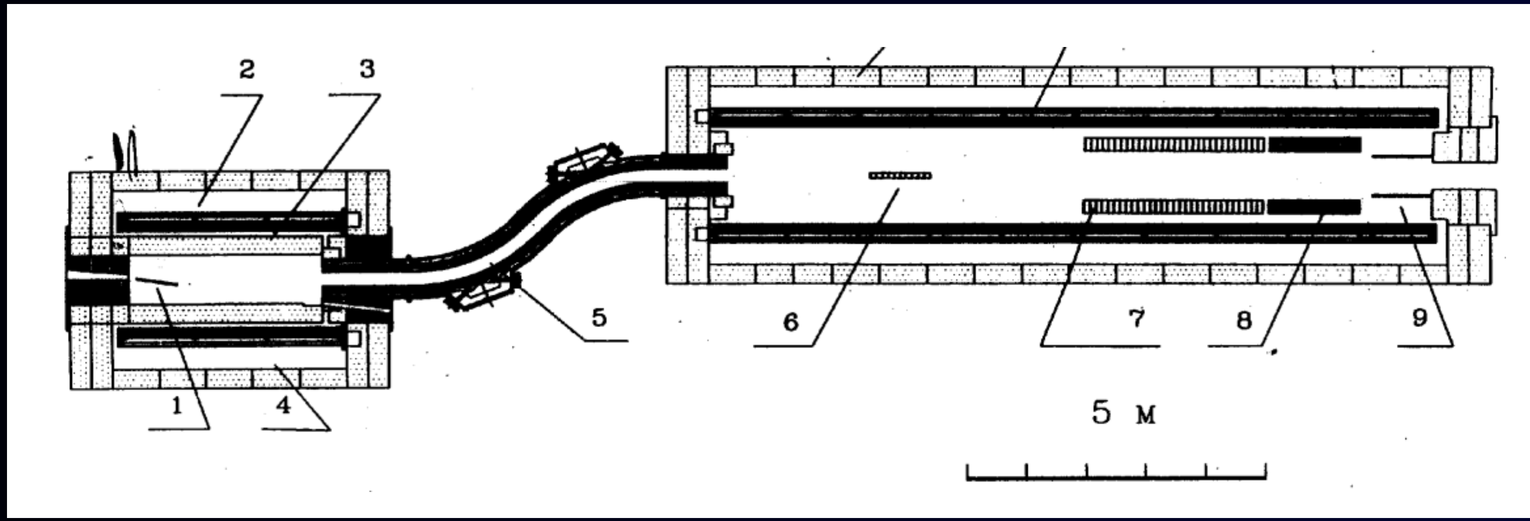


Proposal (1992) at Moscow Meson Factory

R. M. Dzhilkibaev and V. M. Lobashev, Sov. J. Nucl. Phys. 49, 384 (1989)

From MELC to MECO

MELC



Proposal (1992)
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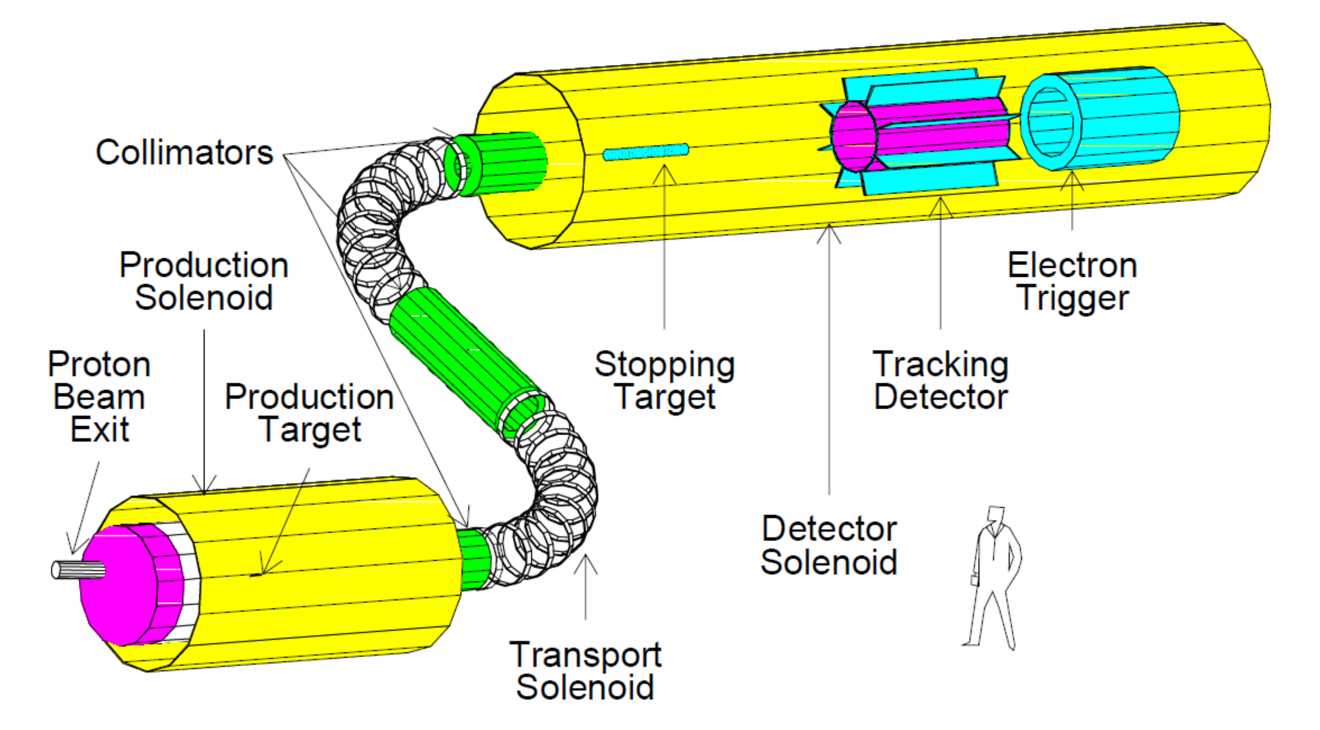
Meson Factory

R. M. Dzhilkibaev and V. M. Lobashev, Sov. J. Nucl. Phys. 49, 384 (1989)

MECO



BNL E940 (1997)
one of the RSVP (rare symmetry violating processes with KOPIO)

terminated in 2005

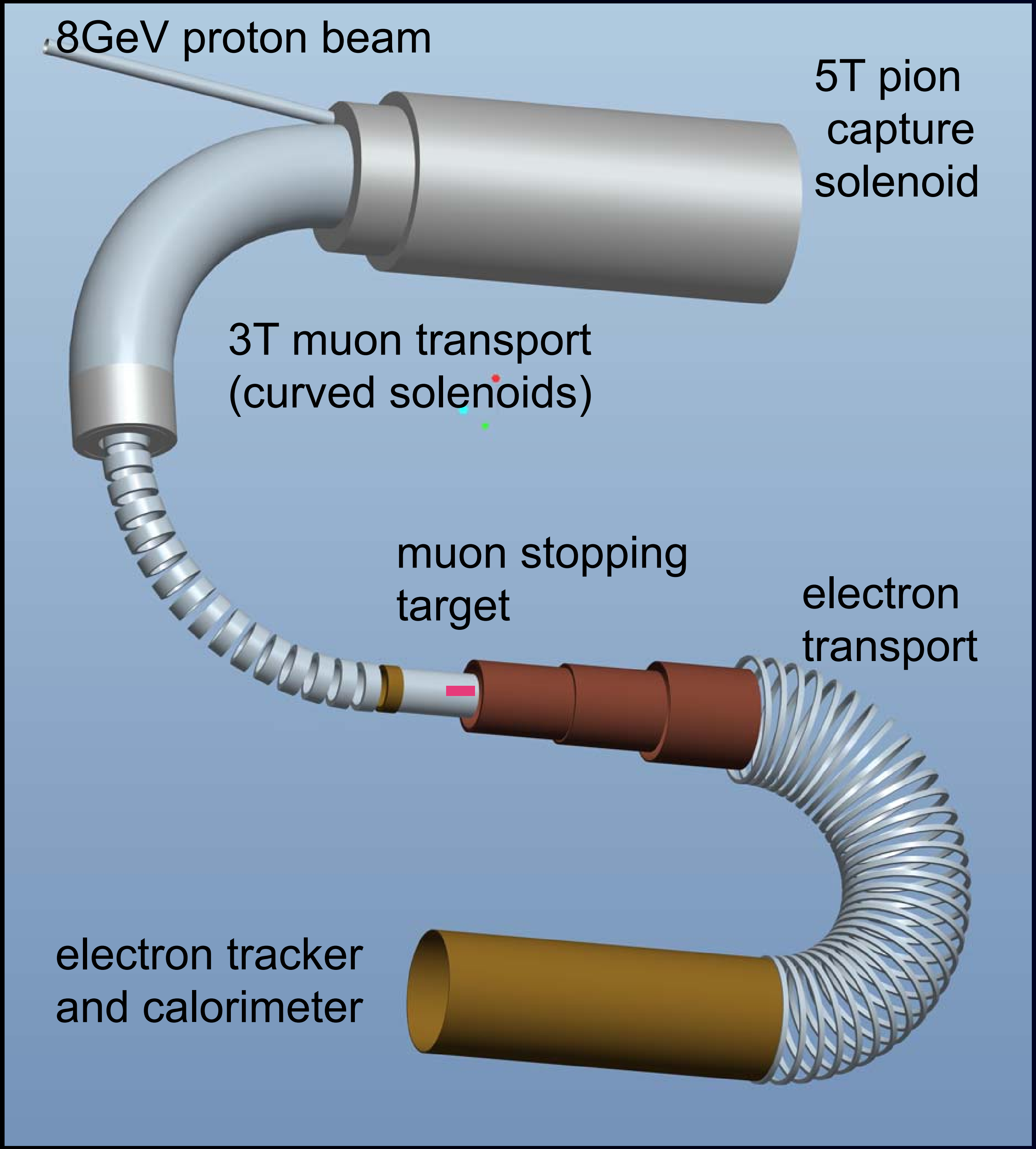
COMET@J-PARC

COMET = COherent Muon to Electron Transition

COMET at J-PARC: E21

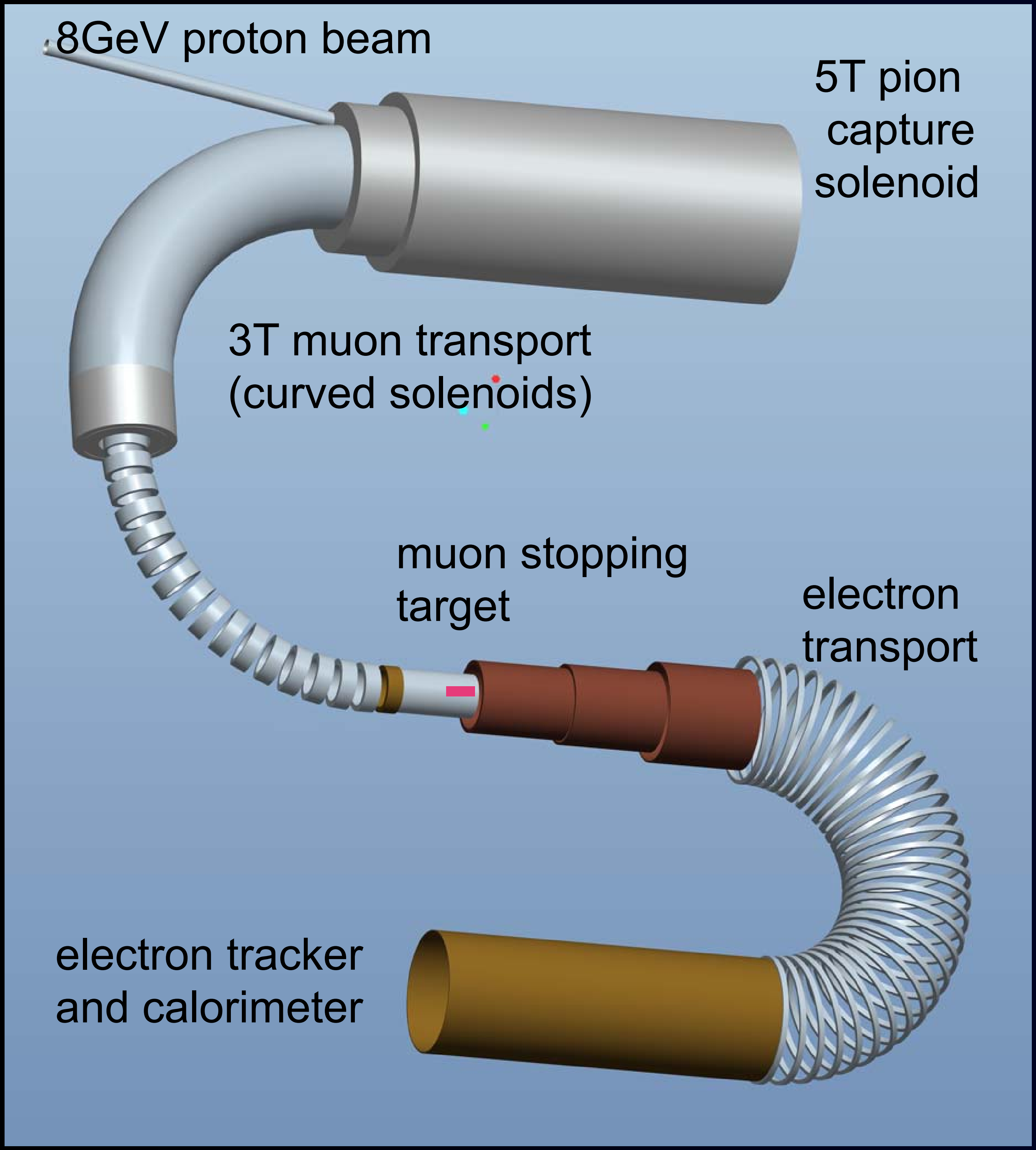
COMET = COherent Muon to Electron Transition

COMET at J-PARC: E21



COMET = COherent Muon to Electron Transition

COMET at J-PARC: E21



Single event sensitivity : 2.6×10^{-17}

Total background : 0.32 events

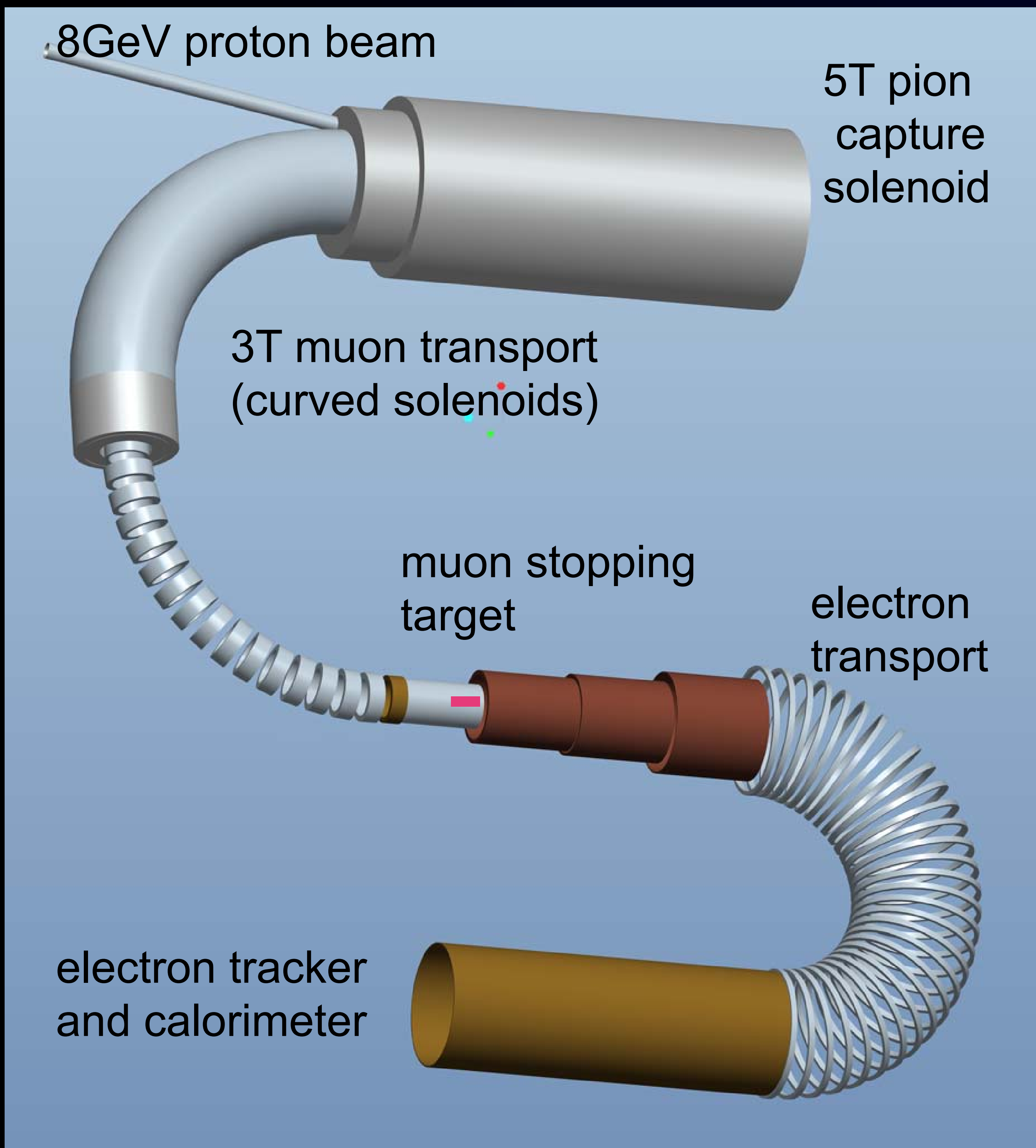
Expected limits : < 6×10^{-17}@90%CL

Running time: 1 years (2×10^{7}sec)

proton beam power = 56 kW

COMET = COherent Muon to Electron Transition

COMET at J-PARC: E21



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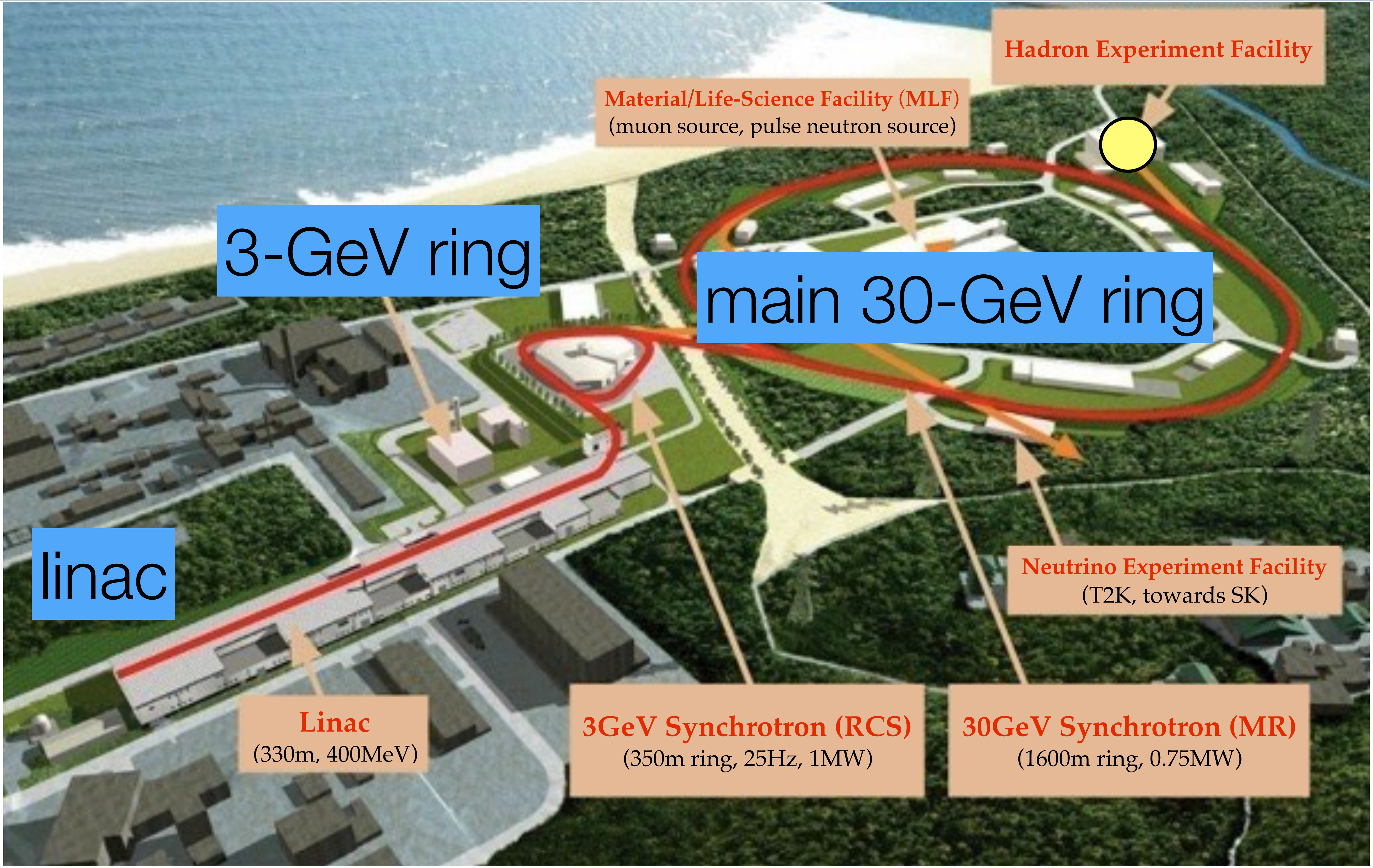
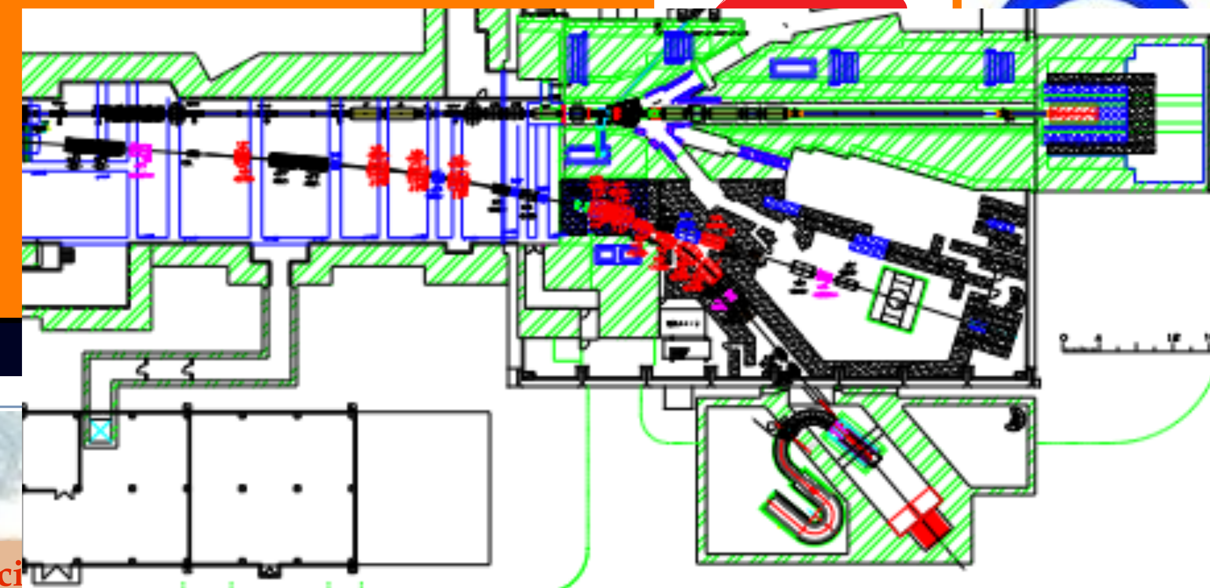
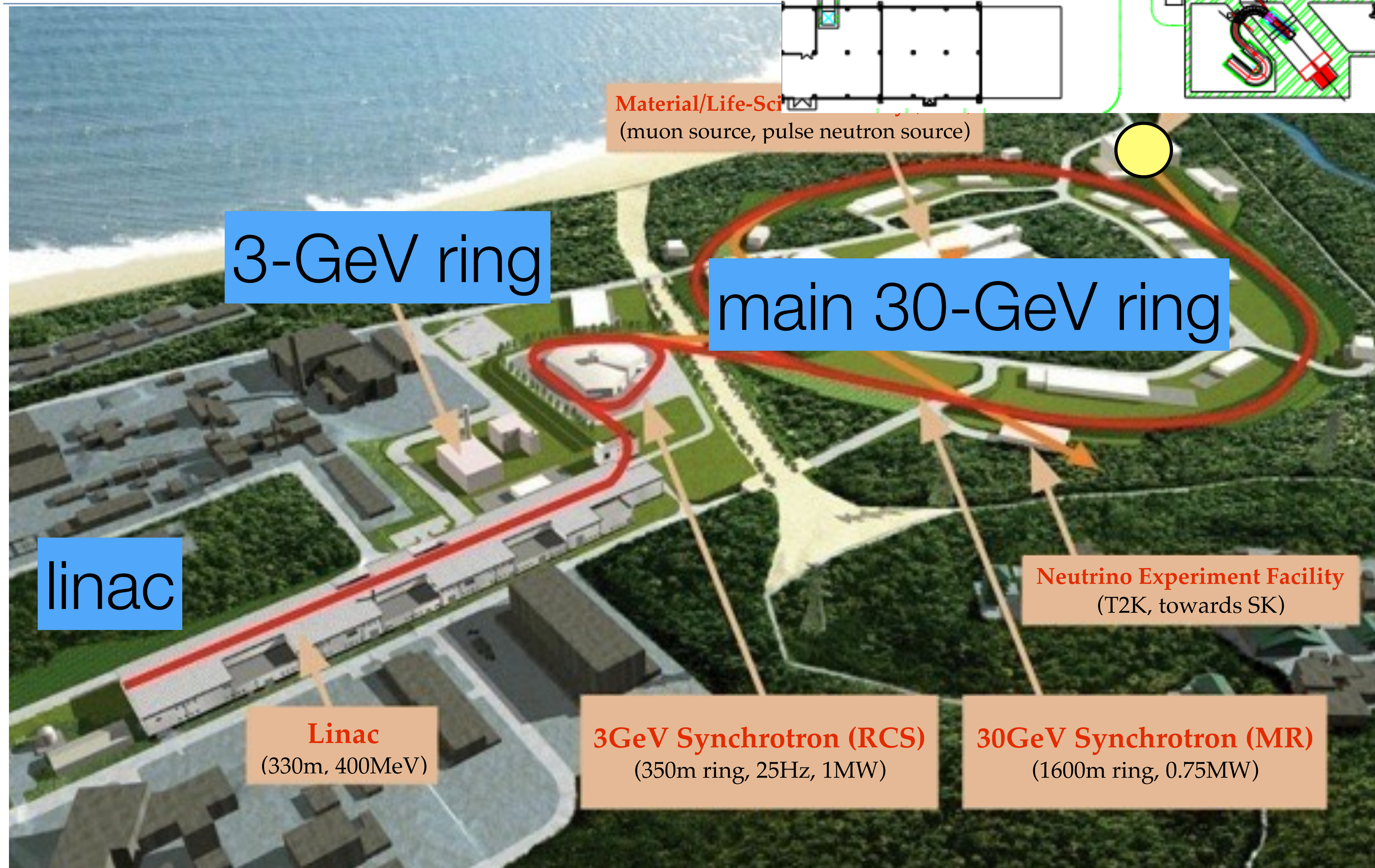
Proton Accelerator
J-PARC



Proton Accelerator
J-PARC





COMET Collaboration

PI: Y. Kuno

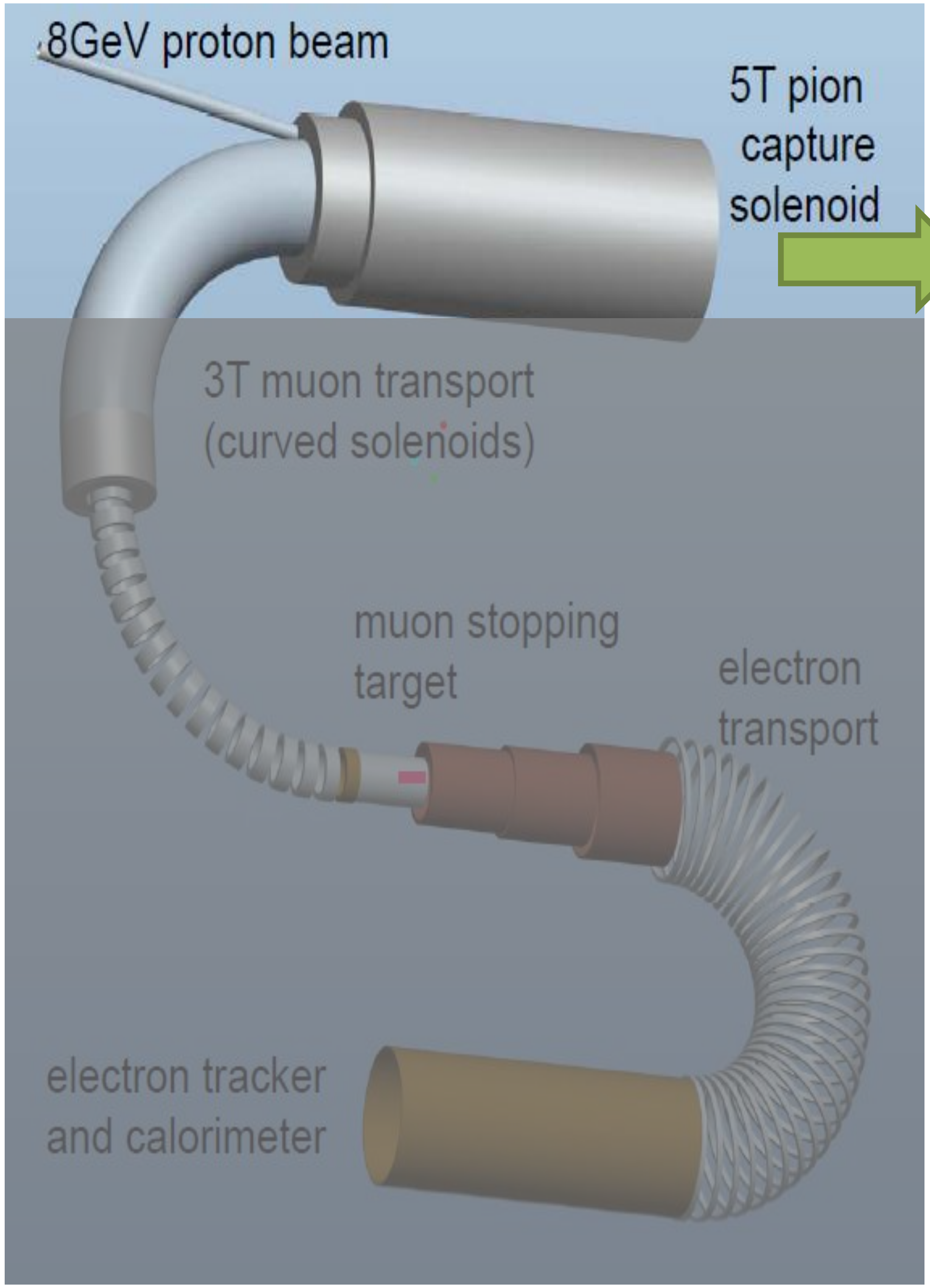
The COMET Collaboration

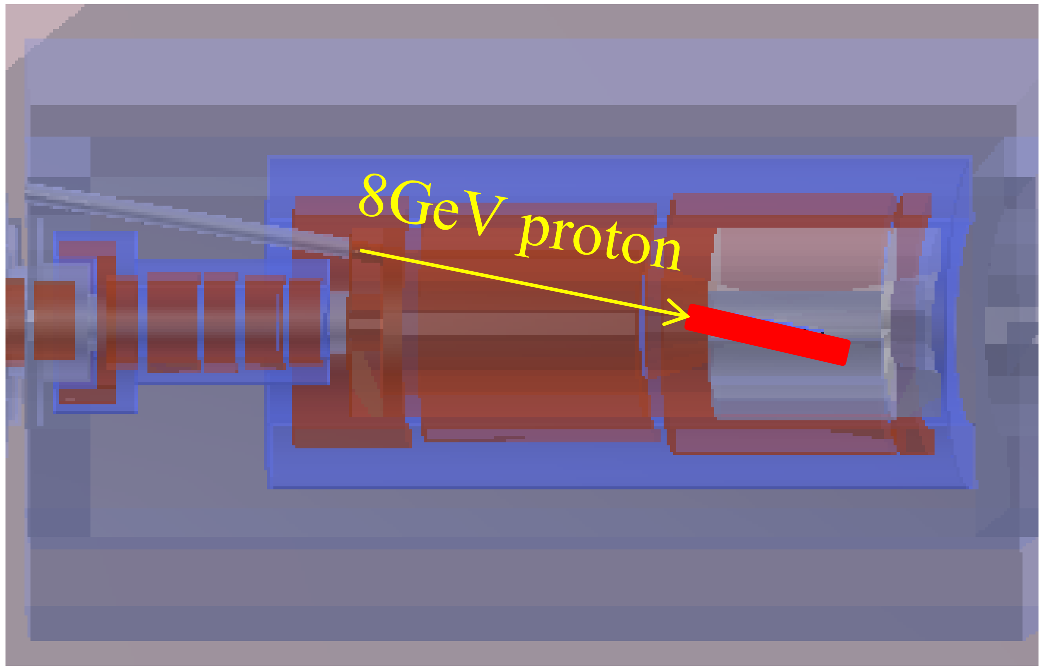
R. Abramishvili[11], G. Adamov[11], R. Akhmetshin[6,31], V. Anishchik[4], M. Aoki[32], Y. Arimoto[18], I. Bagaturia[11], Y. Ban[3], A. Bondar[6,31], Y. Calas[7], S. Canfer[33], Y. Cardenas[7], S. Chen[28], Y. E. Cheung[28], B. Chiladze[35], D. Clarke[33], M. Danilov[15,26], P. D. Dauncey[14], J. David[23], 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], … e[14,21], M. Lancast… an[29], D. Lomidze… Mao[3], O. Markin[15]… . Mo-hamed Kam… kai[22], T. Nakamot… chi[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]

about 200 collaborators

41 institutes, 17 countries

Pion Capture Section

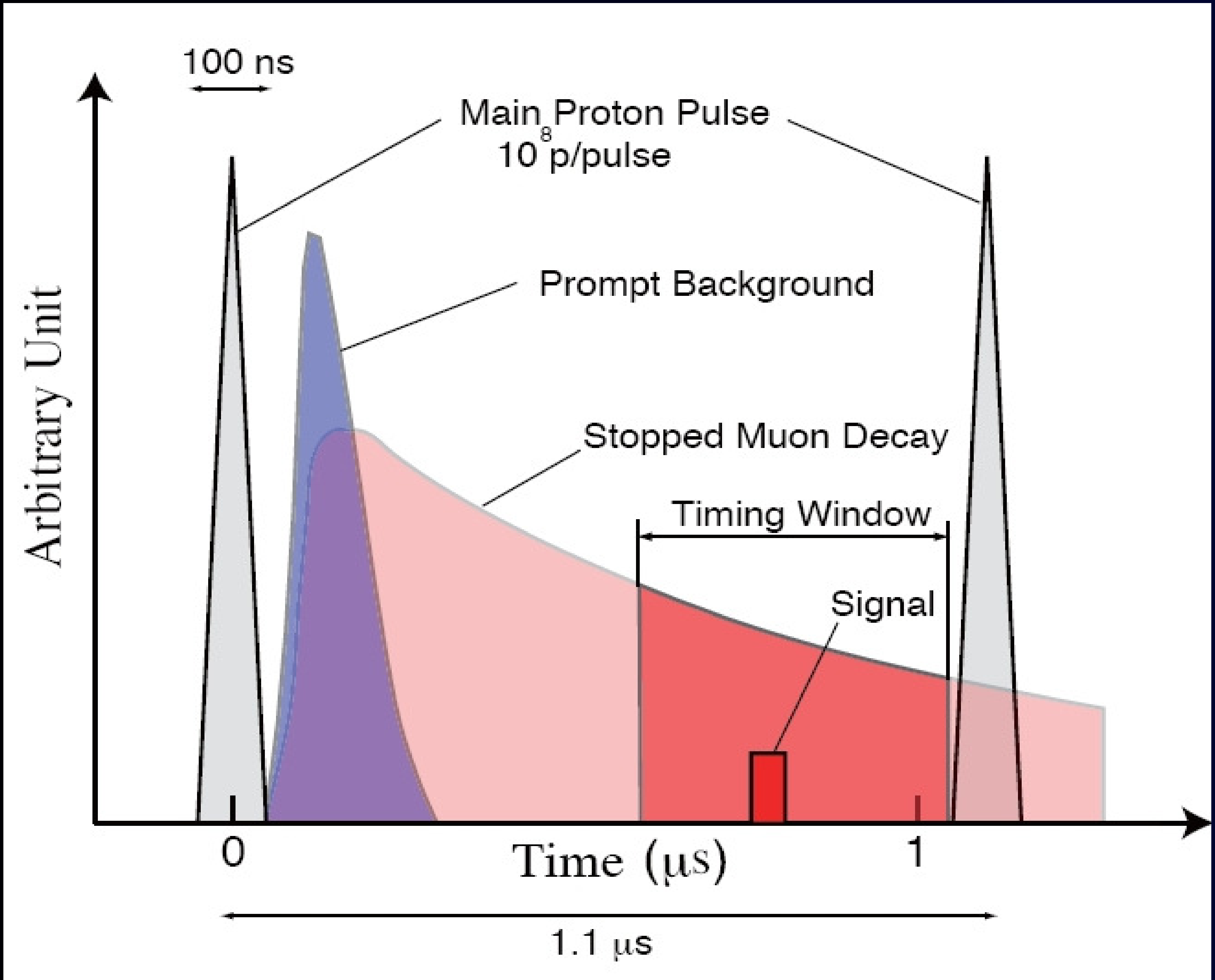




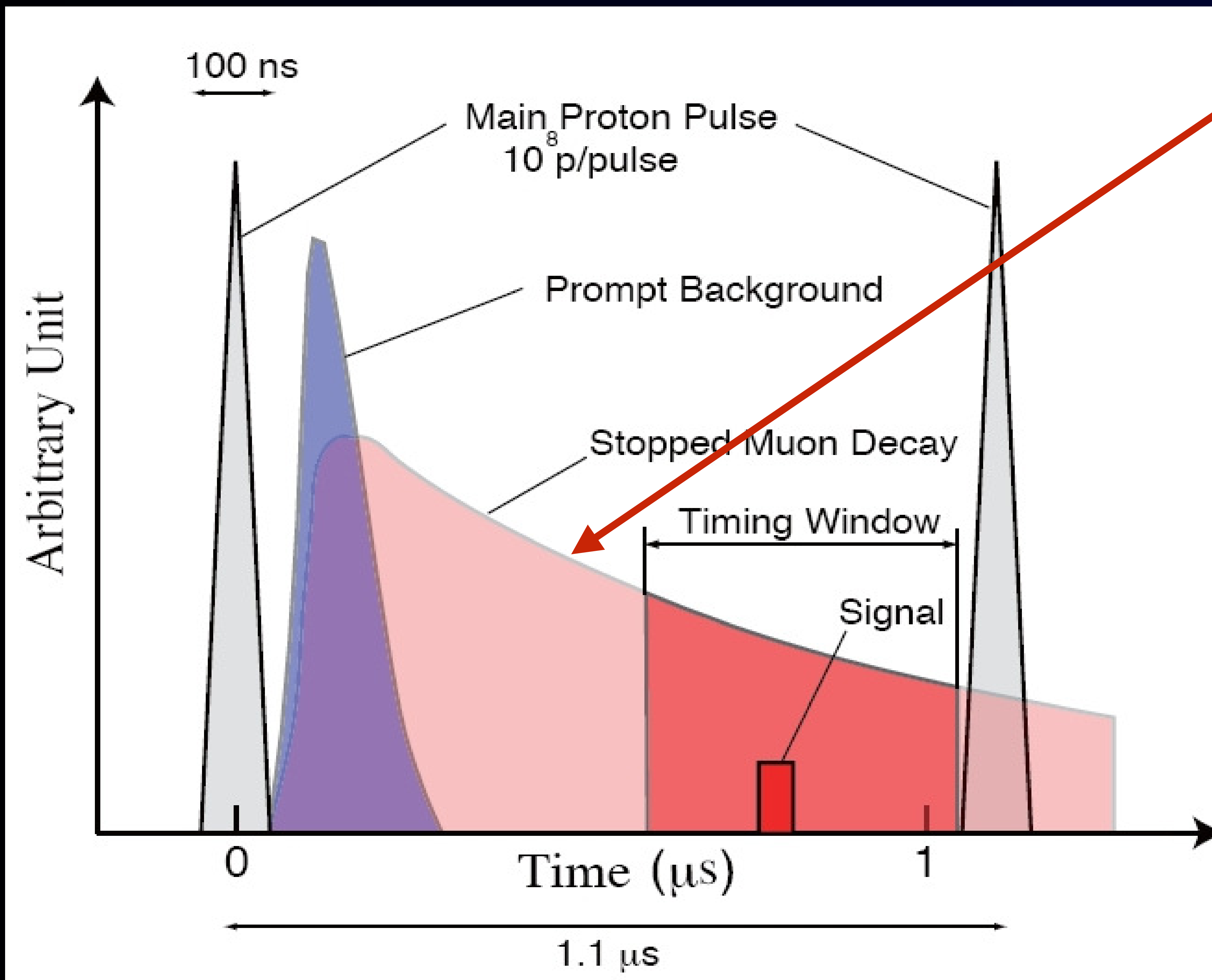
- 8 GeV 56 kW proton beam
- Thick target with 1~2 hadron interaction length
- Powerful capture magnet: 5 T
  - Large inner bore to fit in the shielding
  - Adiabatic decreasing field: focusing and mirroring
- Expected muon yield: 10^{11} muon/sec! (10^8 @ PSI)

Pulsed 8-GeV Proton Beam for COMET

Pulsed 8-GeV Proton Beam for COMET



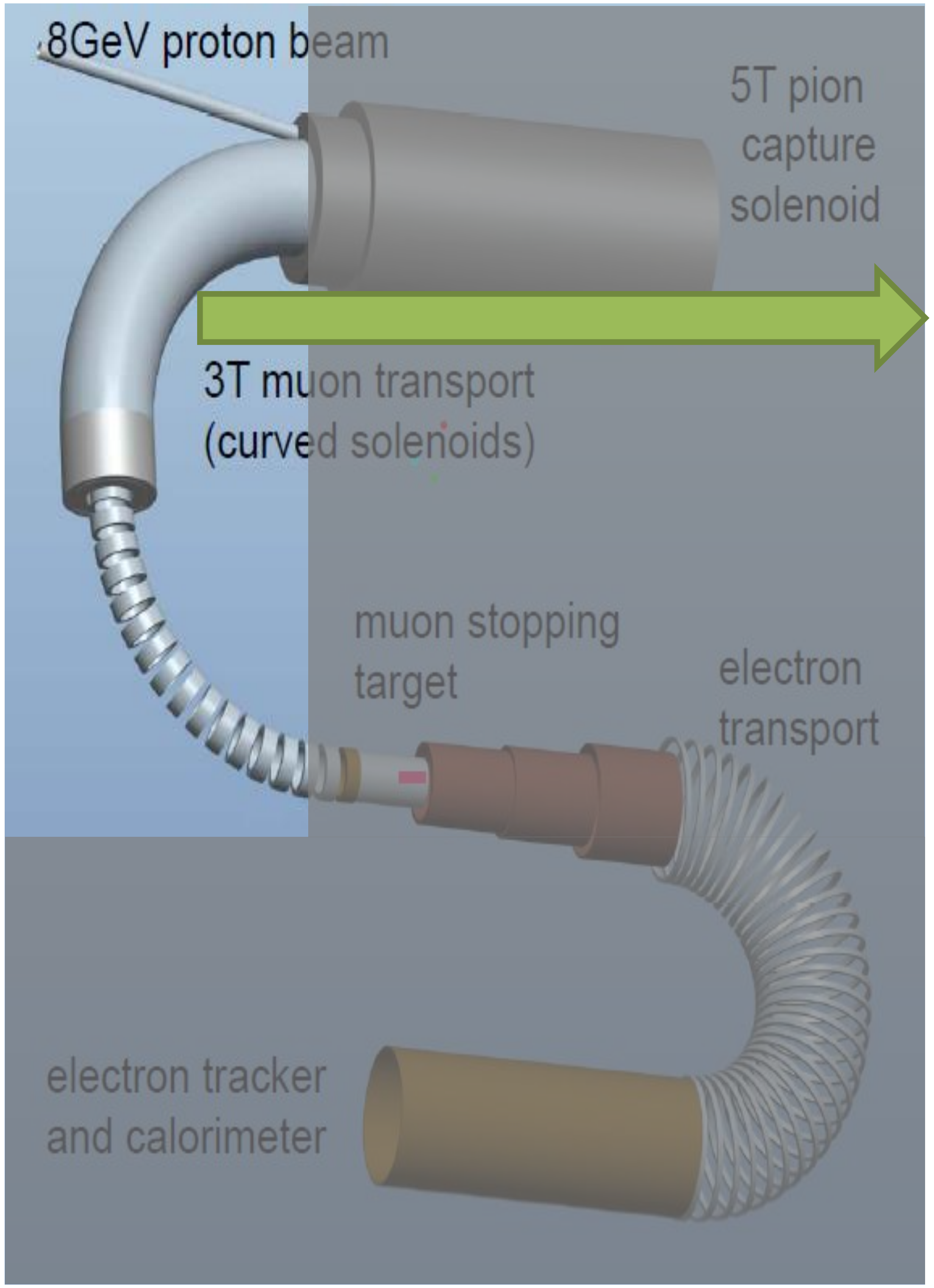
Pulsed 8-GeV Proton Beam for COMET



A lifetime of a muonic atom in aluminium ~ 864 ns

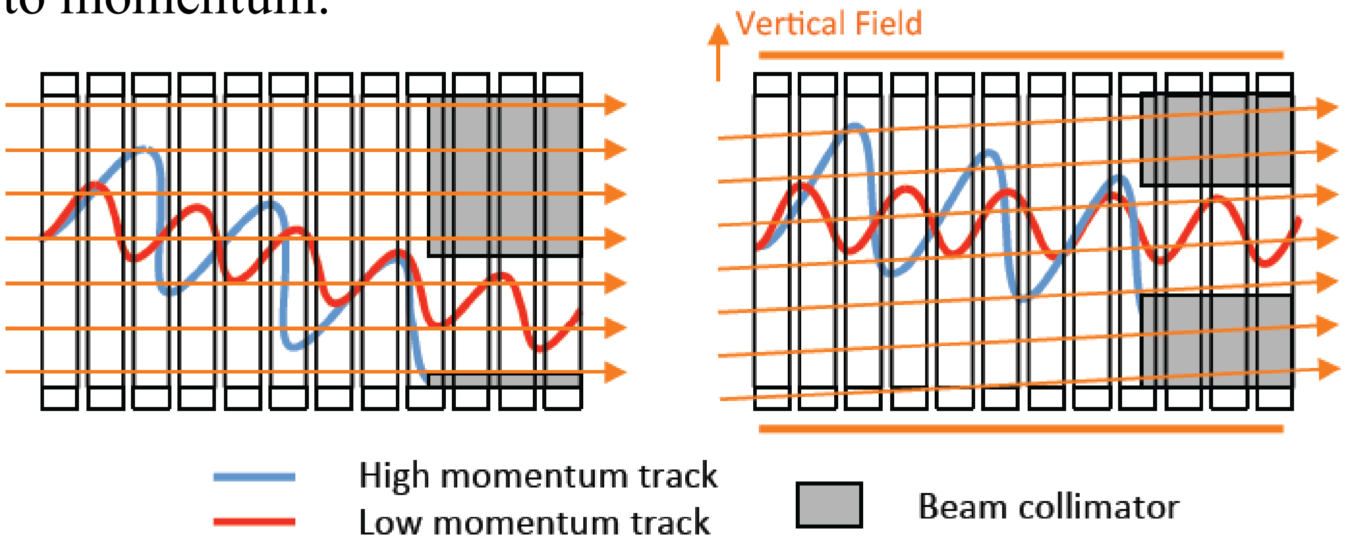
proton extinction factor (between pulses) ~ 10^{-10}

Muon Transport Section



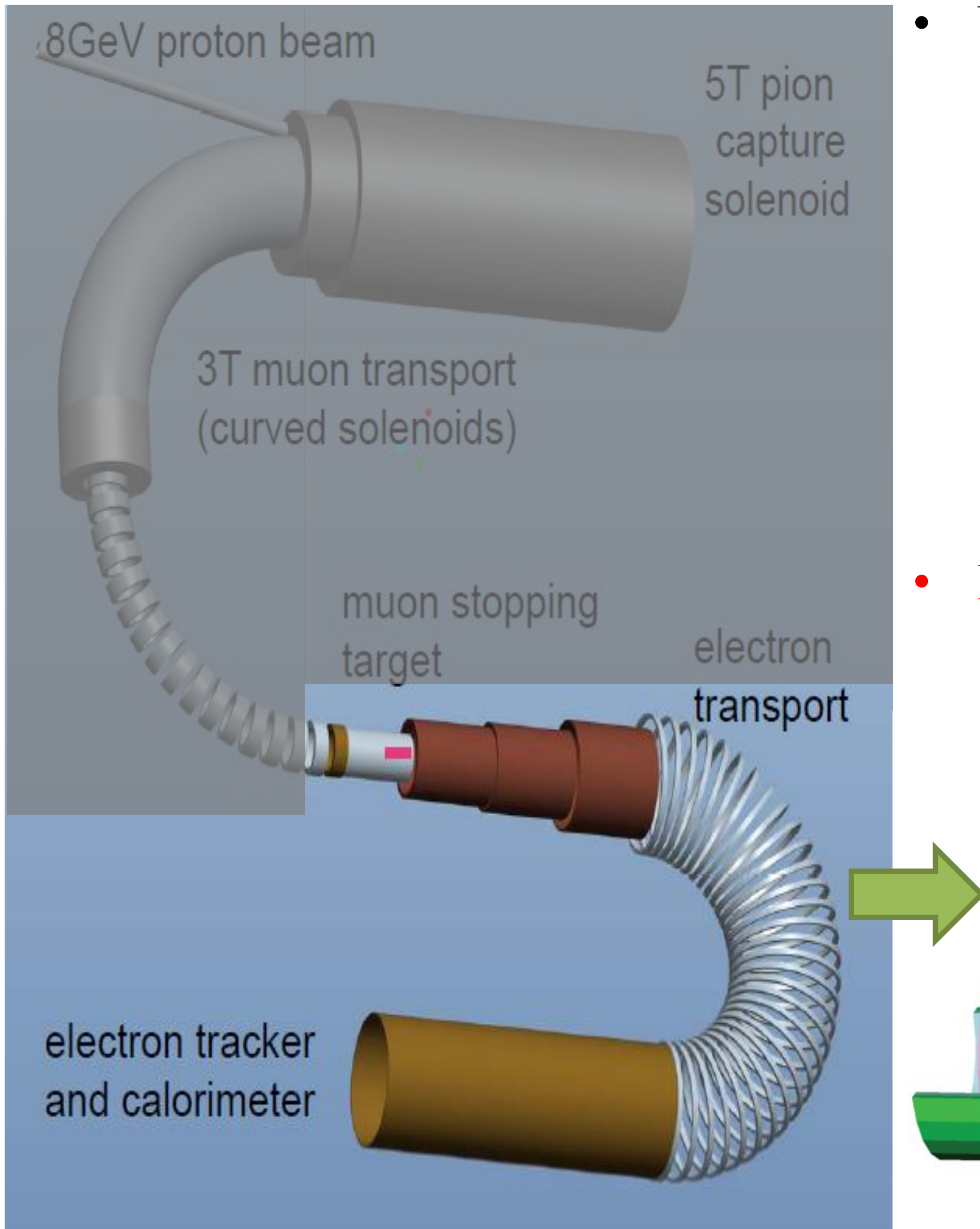
Drift vertically, proportional to momentum.

Vertical field as "correction"

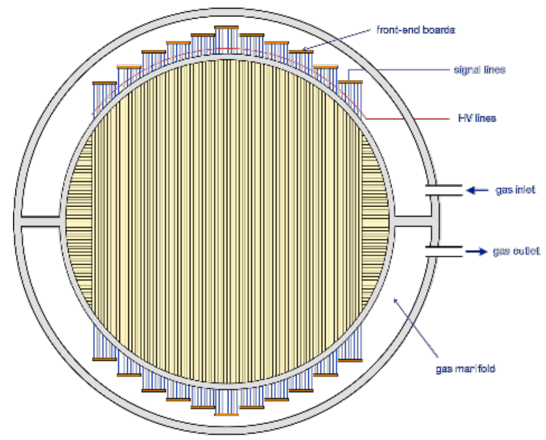


- Use C shape curved solenoid
  - Beam gradually disperses
    - Charge & momentum
  - Dipole field to pull back muon beam
    - Can be used to tune the beam
  - Collimator placed in the end
    - Utilize the dispersion in 180 degrees

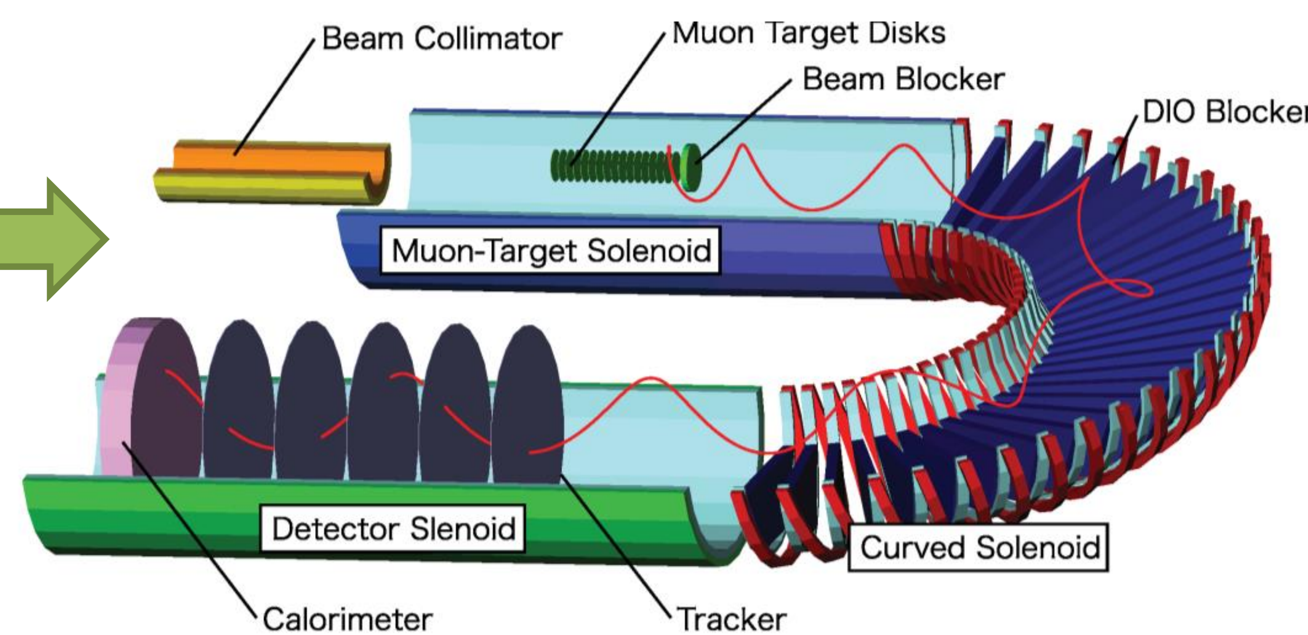
Muon Stopping Target and Detector Section



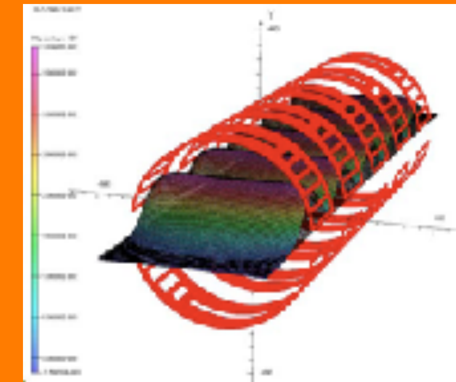
- Use straw tracker to measure the momentum
  - Really light: put in vacuum, 12 micro meter thin straw

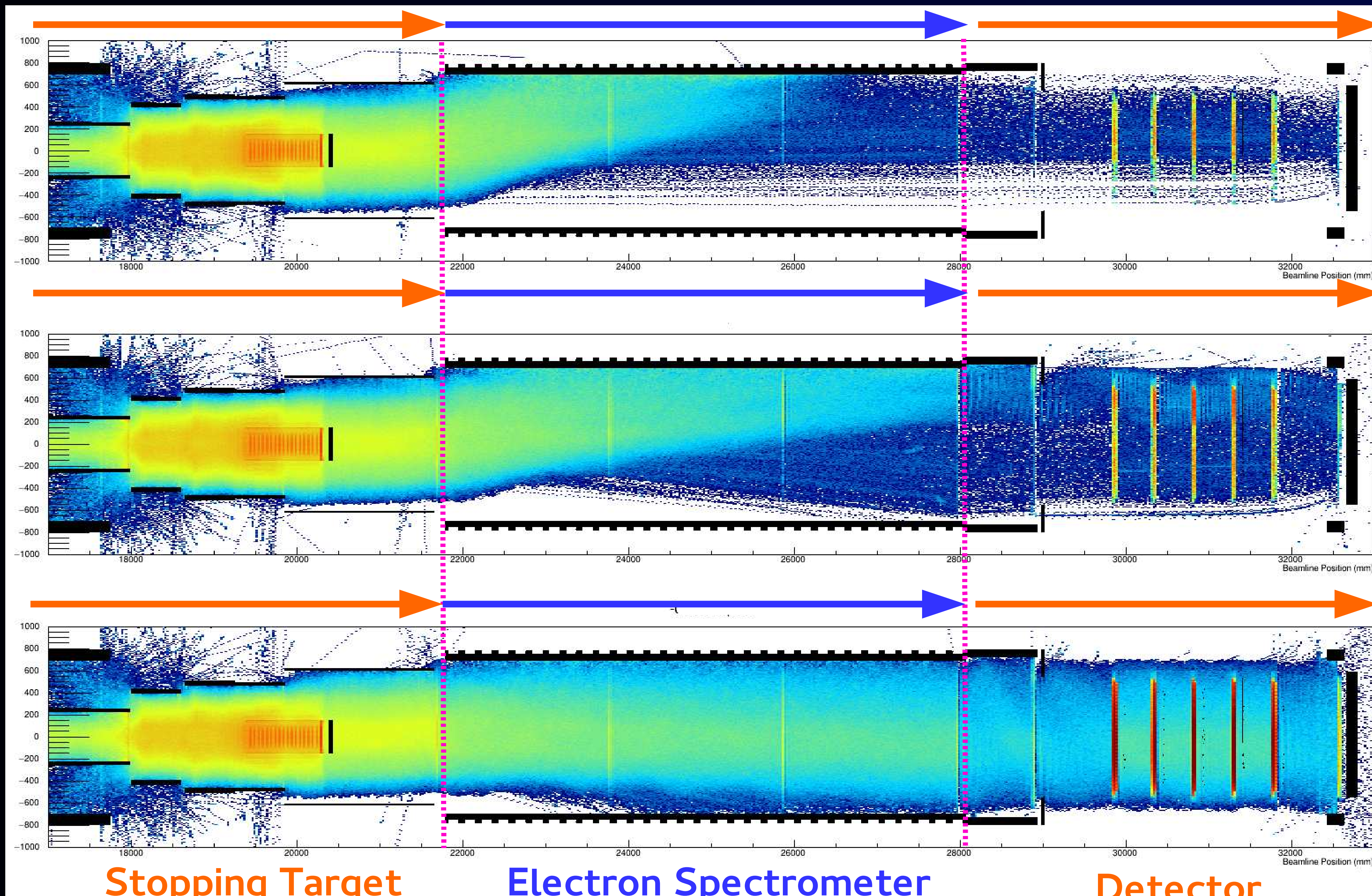


- Electromagnetic calorimeter
  - Providing trigger, TOF and PID



Curved Solenoid + Dipole Magnetic Field



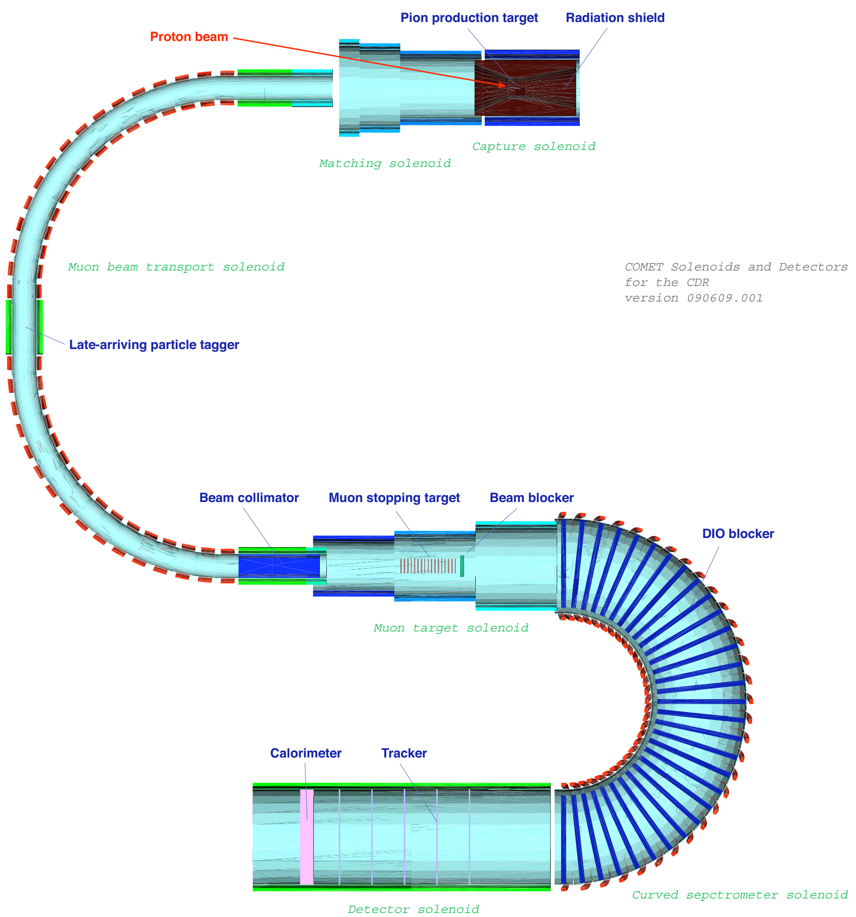


no dipole

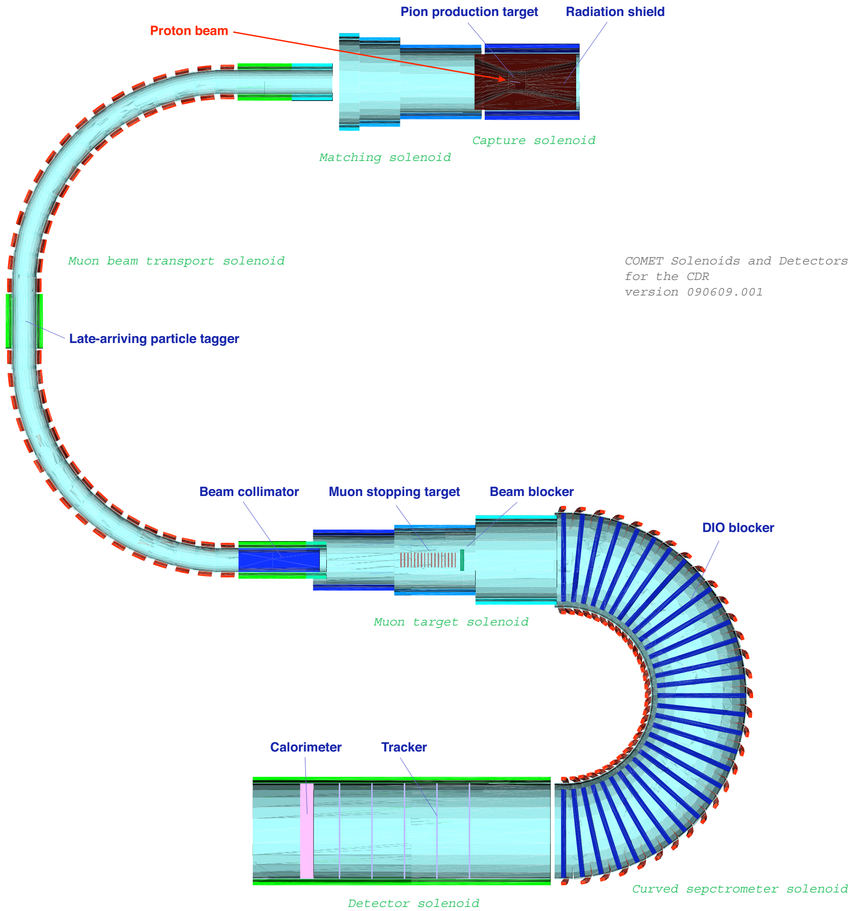
-0.08T dipole

-0.22T dipole

COMET Features
- difference from the original MECO

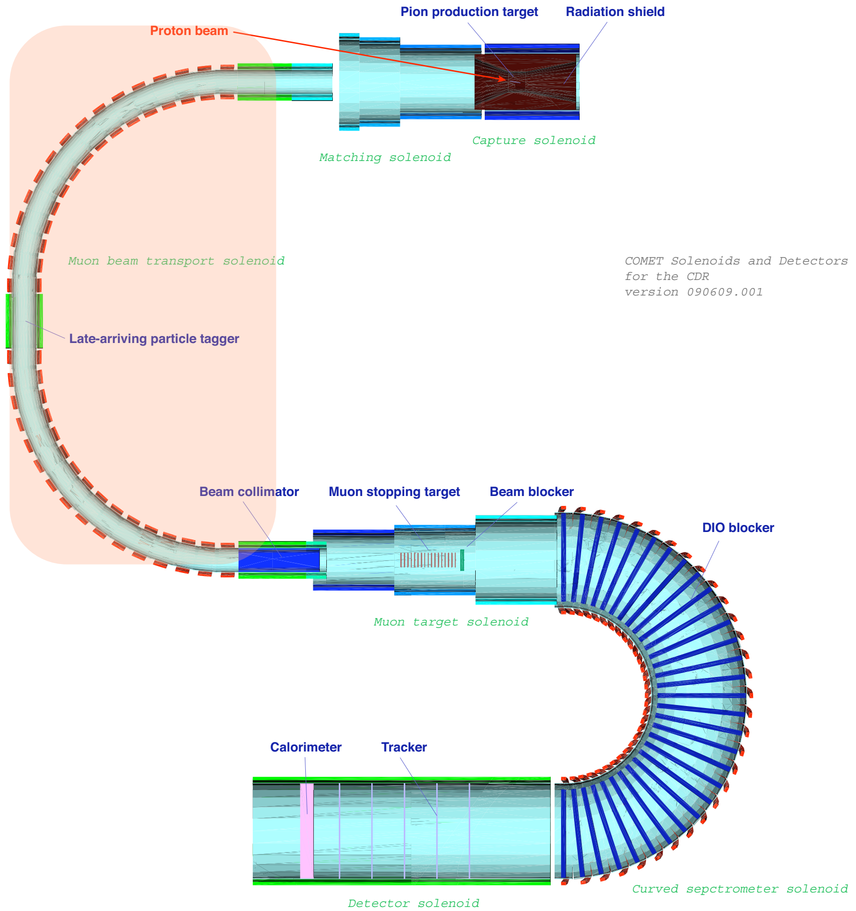


COMET Features
- difference from the original MECO



muon beam line	2x 90° bend (same direction)
electron spectrometer	180° bend curved solenoids

COMET Features
- difference from the original MECO



muon beam line	2x 90° bend (same direction)
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COMET Features
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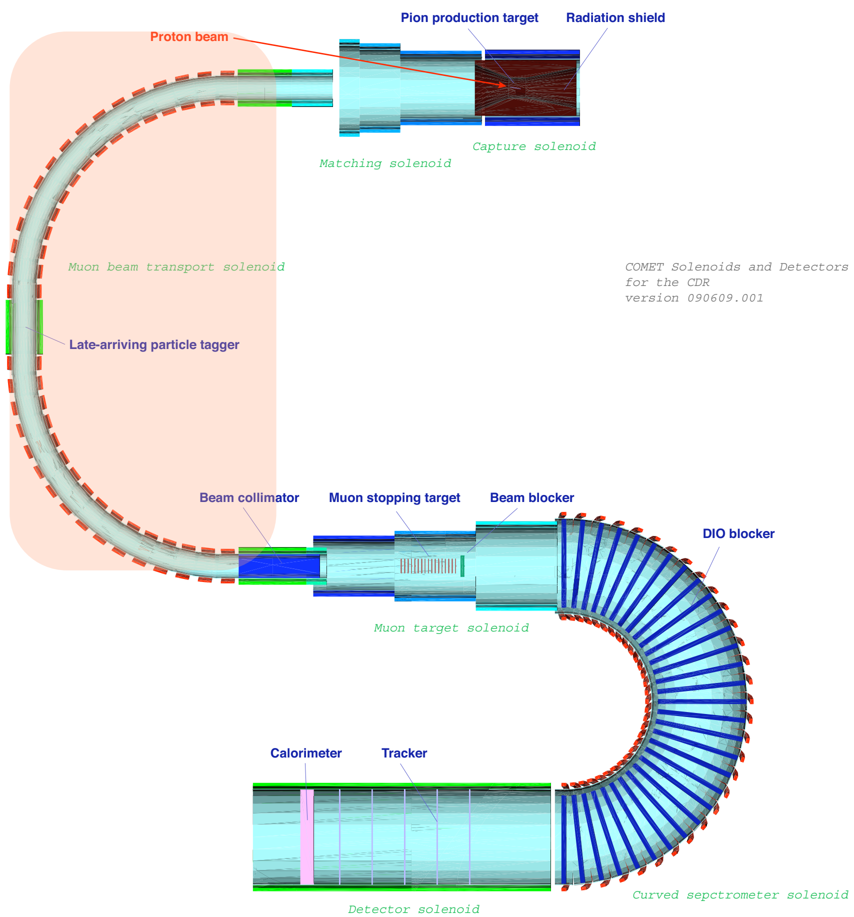


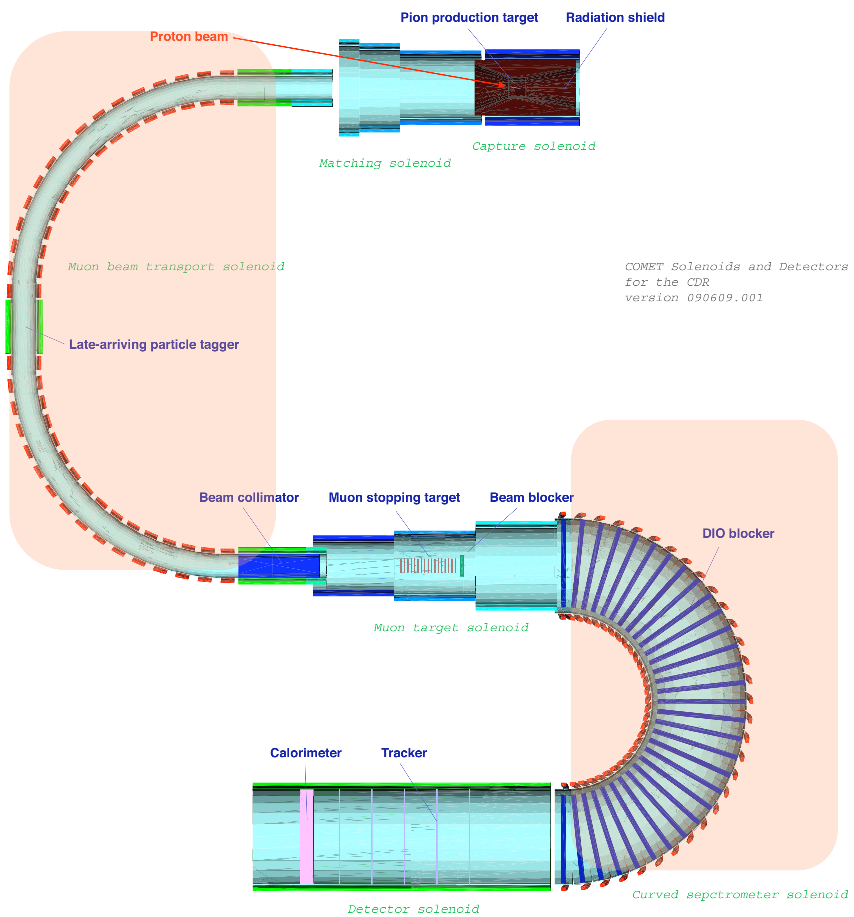
muon beam line	2x 90° bend (same direction)
electron spectrometer	180° bend curved solenoids

Selection of low momentum muons

- eliminate 105 MeV electrons from muon decays in flight

momentum selection capability is proportional to bending angle

COMET Features
- difference from the original MECO



muon beam line	2x 90° bend (same direction)
electron spectrometer	180° bend curved solenoids

Selection of low momentum muons

- eliminate 105 MeV electrons from muon decays in flight

momentum selection capability is proportional to bending angle

Selection of 105 MeV signal electrons

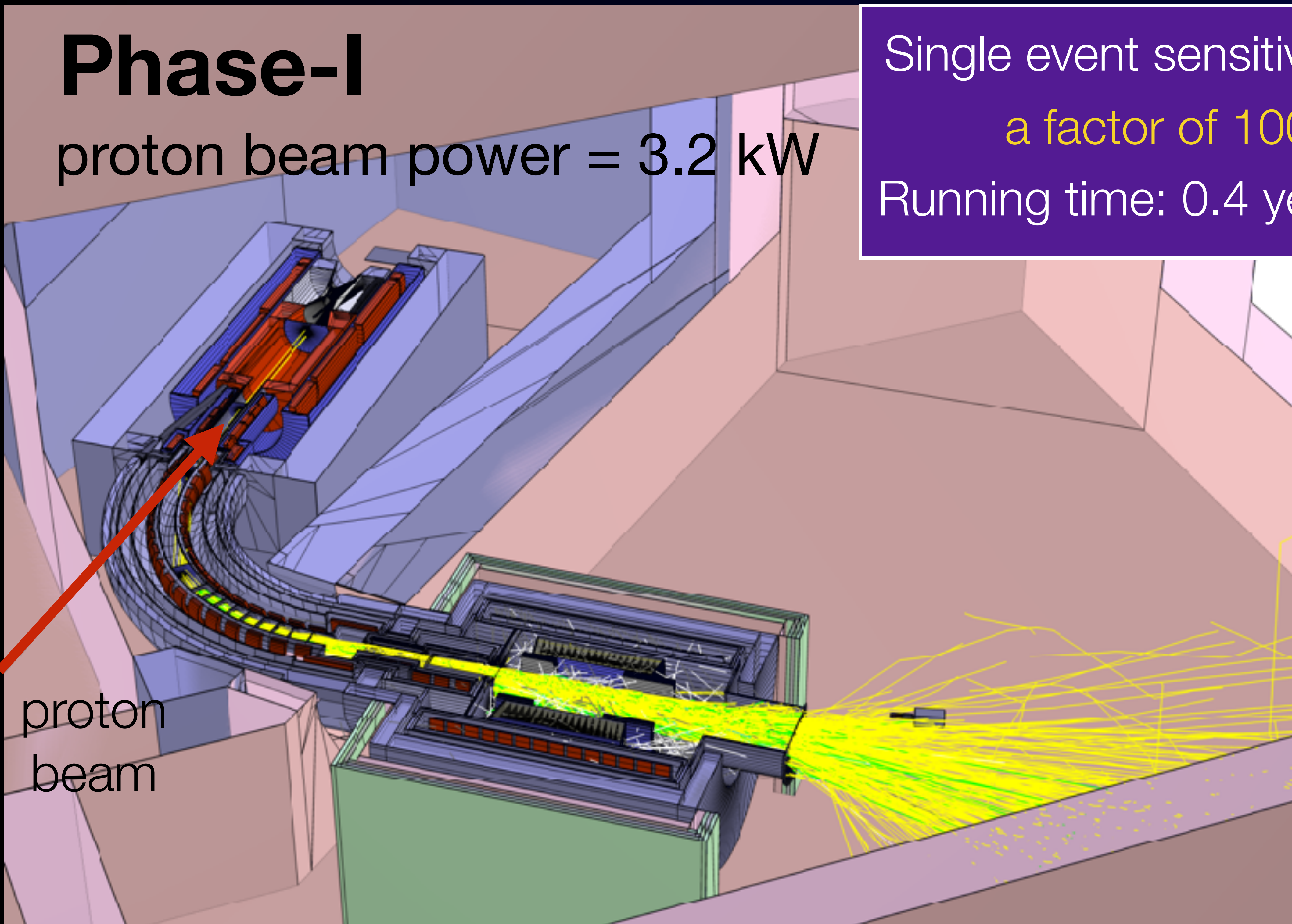
- eliminate neutrons and gamma-rays from muon target
- eliminate protons from muon target
- eliminate low energy electrons from muon decays from muon target

Staged Approach

COMET Phase-I

cylindrical
drift chamber

COMET Phase-I



Single event sensitivity : 2×10^{-15}

a factor of 100 improvement

Running time: 0.4 years (1.2×10^{7}s)

COMET Phase-II

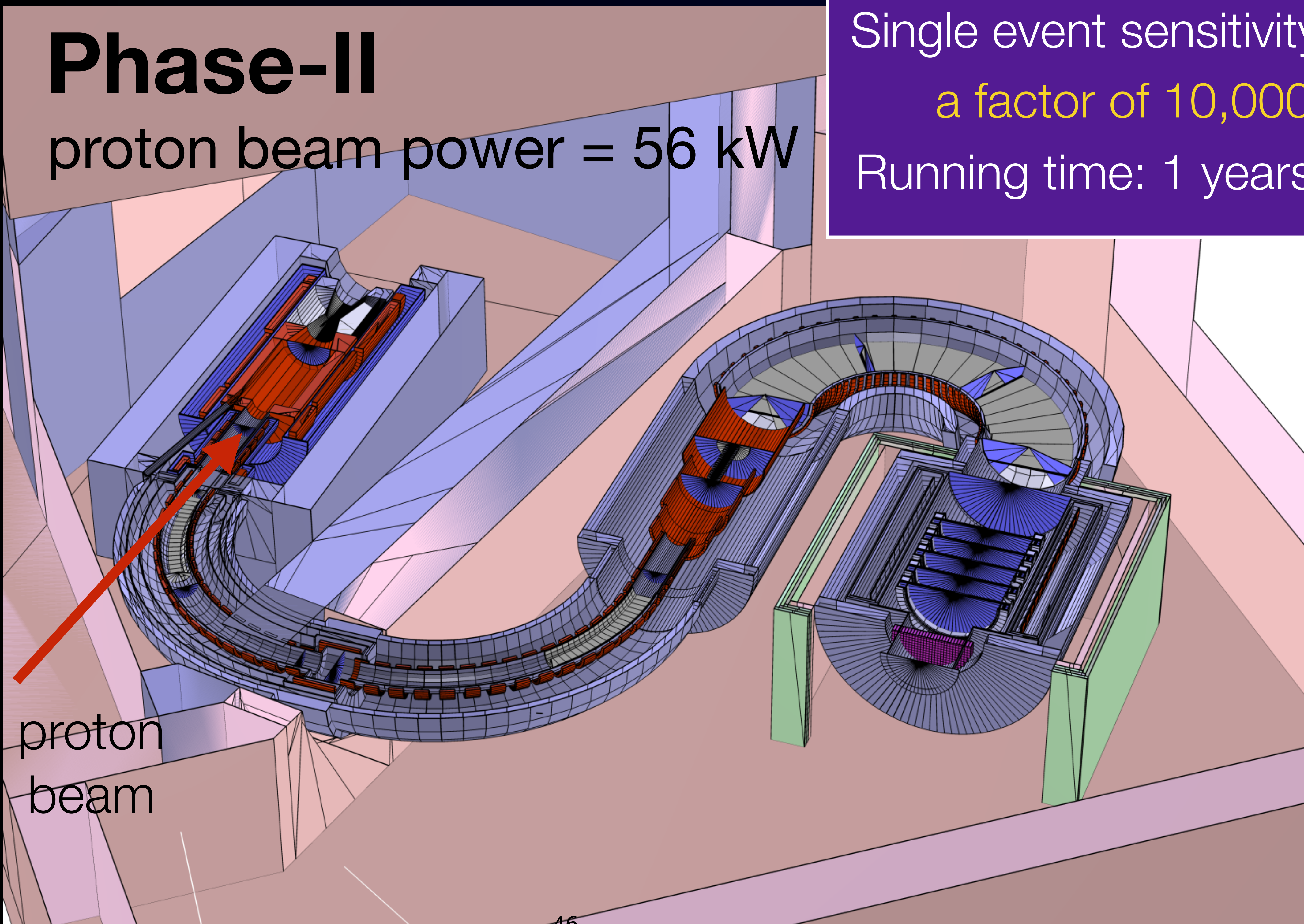
straw chamber
LYSO calorimeter

COMET Phase-II

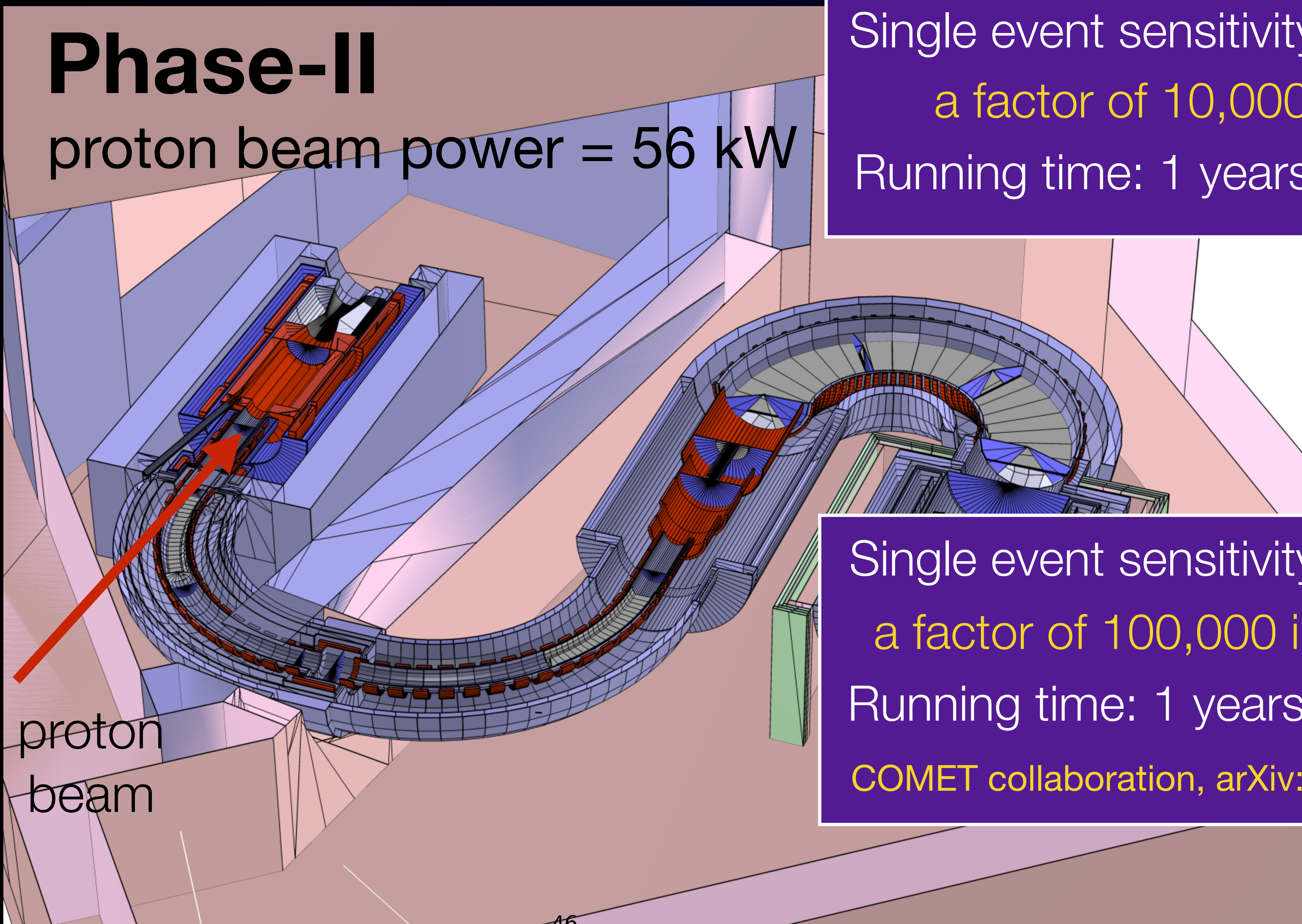
Single event sensitivity : 2.6×10^{-17}

a factor of 10,000 improvement

Running time: 1 years (2×10^{7} sec)



COMET Phase-II



Single event sensitivity : 2.6×10^{-17}

a factor of 10,000 improvement

Running time: 1 years (2×10^{7} sec)

Single event sensitivity : $O(10^{-18})$

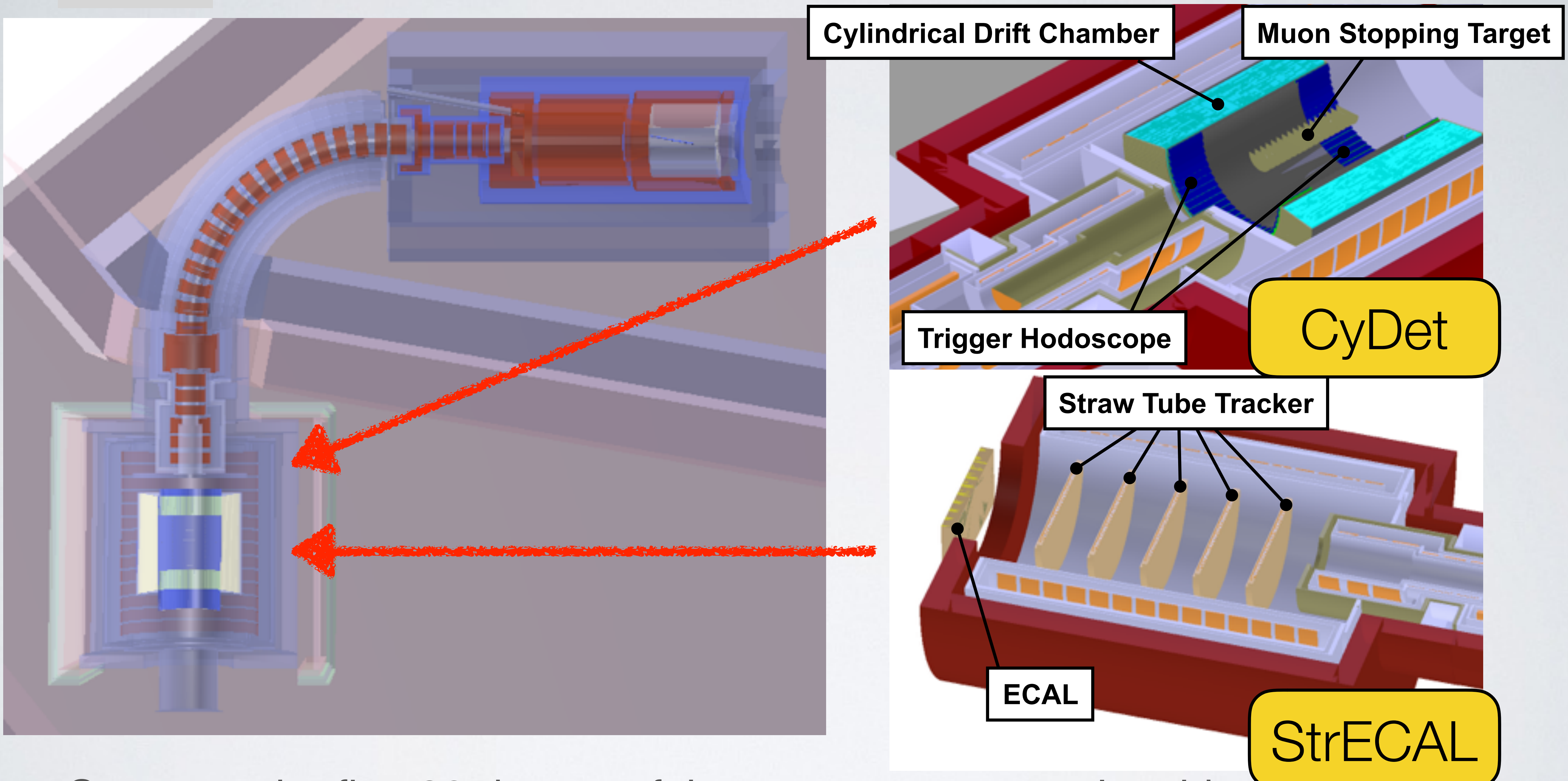
a factor of 100,000 improvement

Running time: 1 years (2×10^{7} sec)

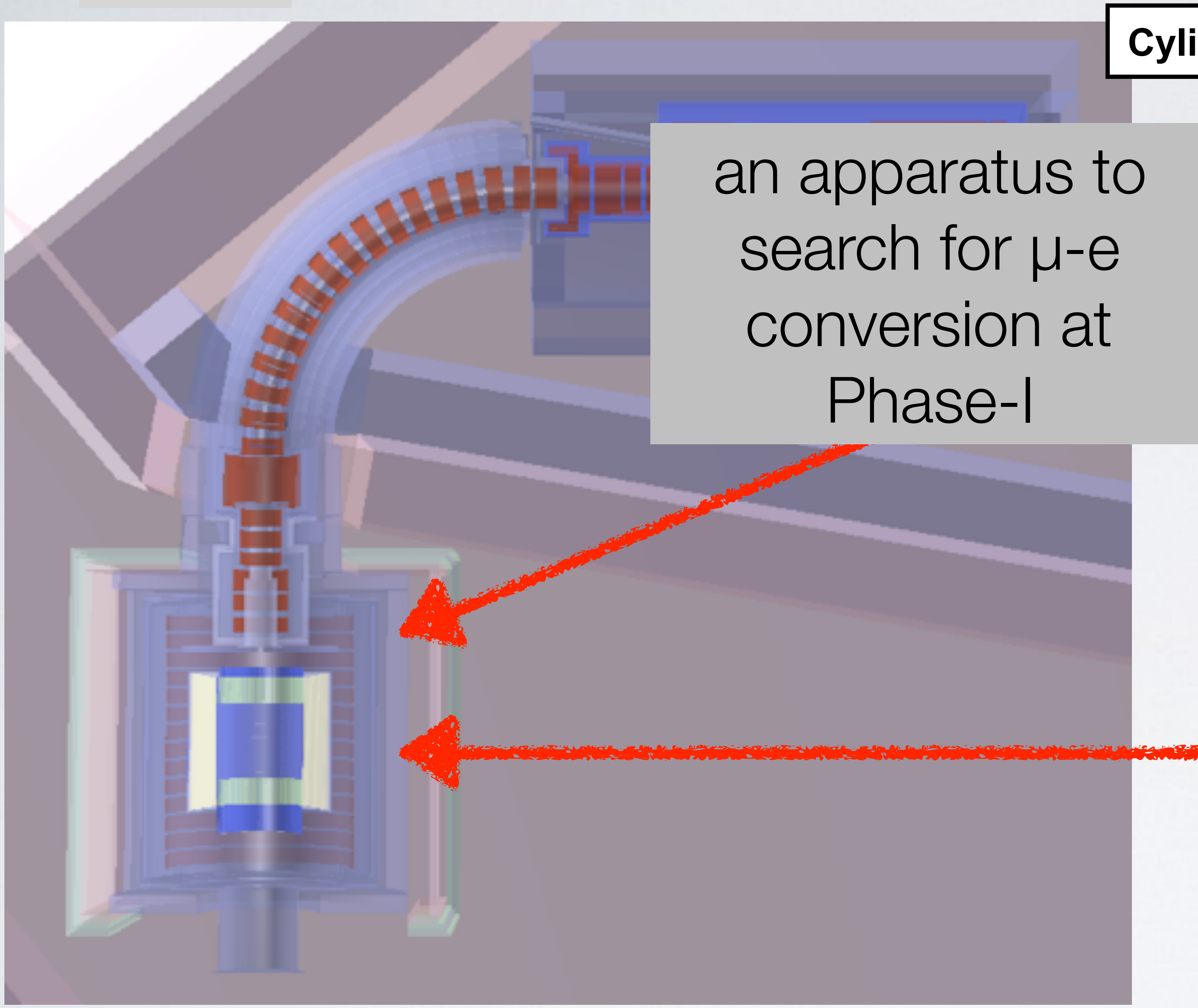
COMET collaboration, arXiv:1812.07824, 2018

COMET Phase-I Status

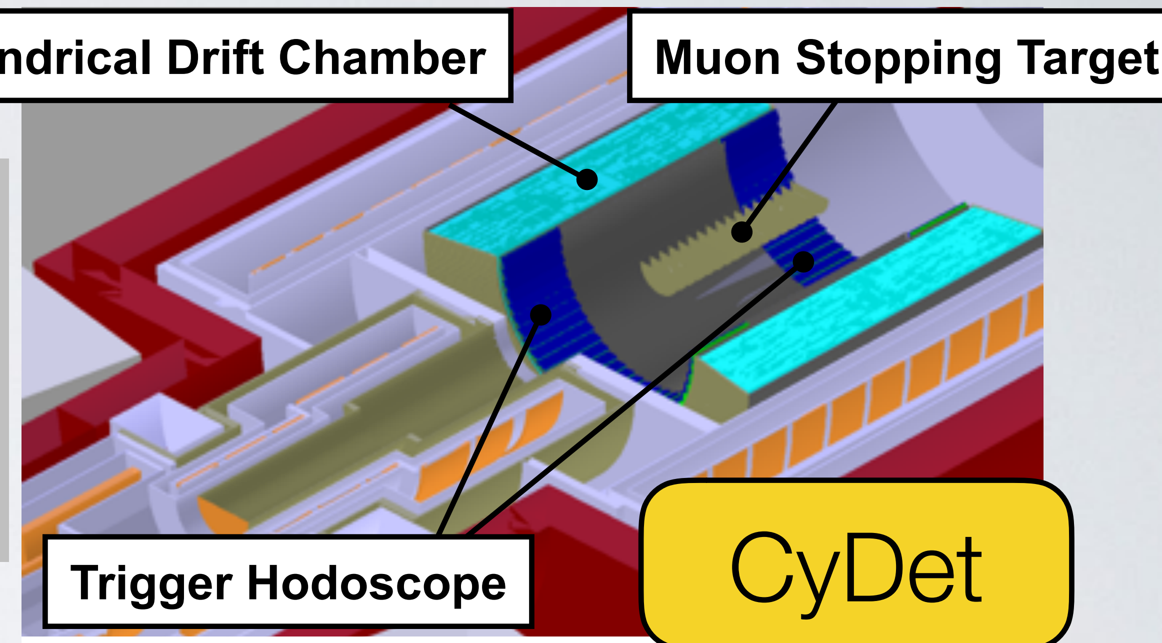
Two Detectors, CyDet and StrECAL , for COMET Phase-I

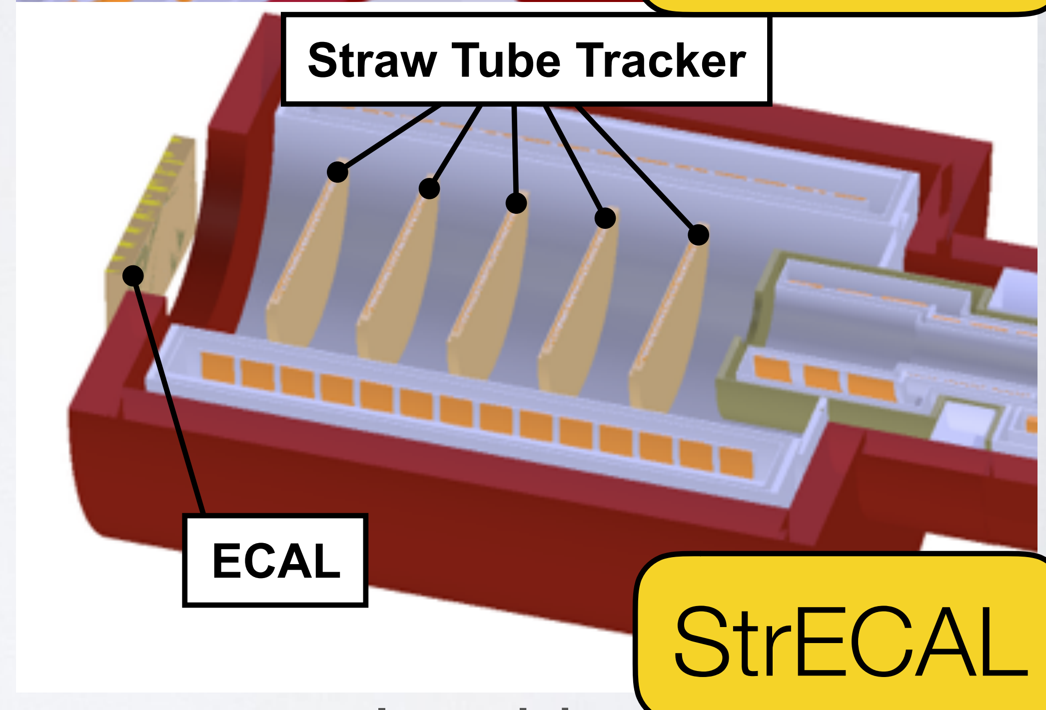


Two Detectors, CyDet and StrECAL , for COMET Phase-I

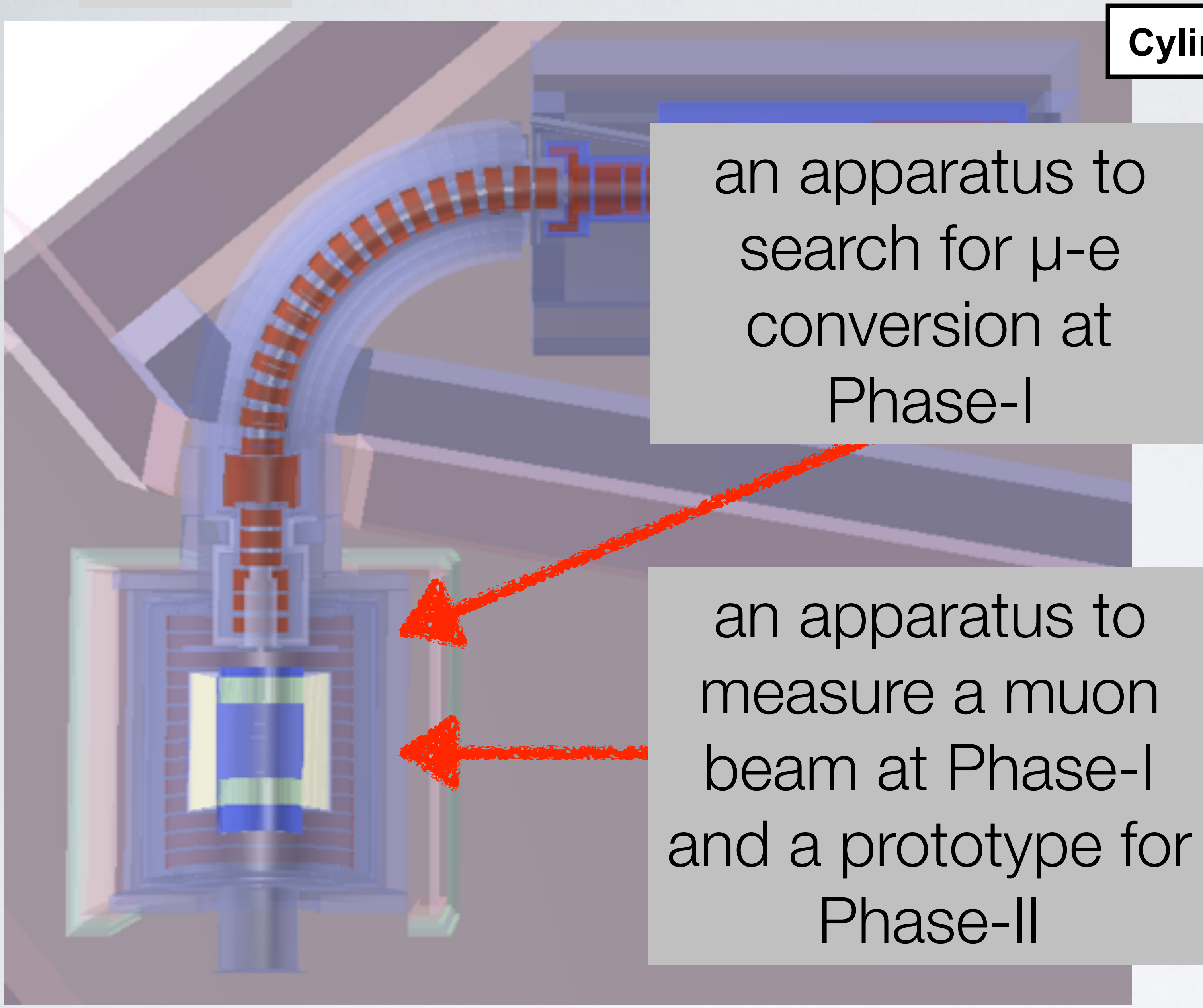


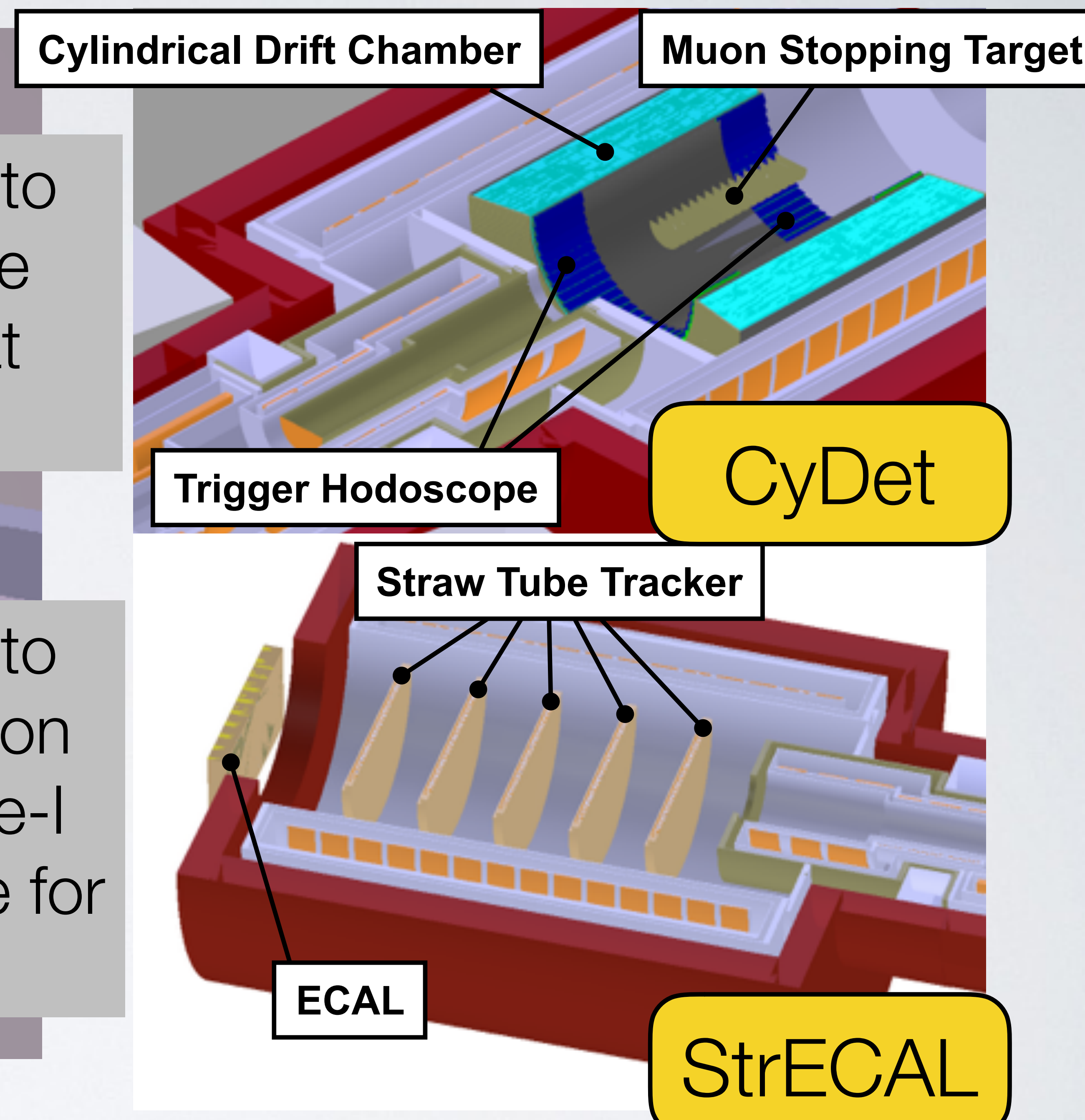
an apparatus to search for μ-e conversion at Phase-I



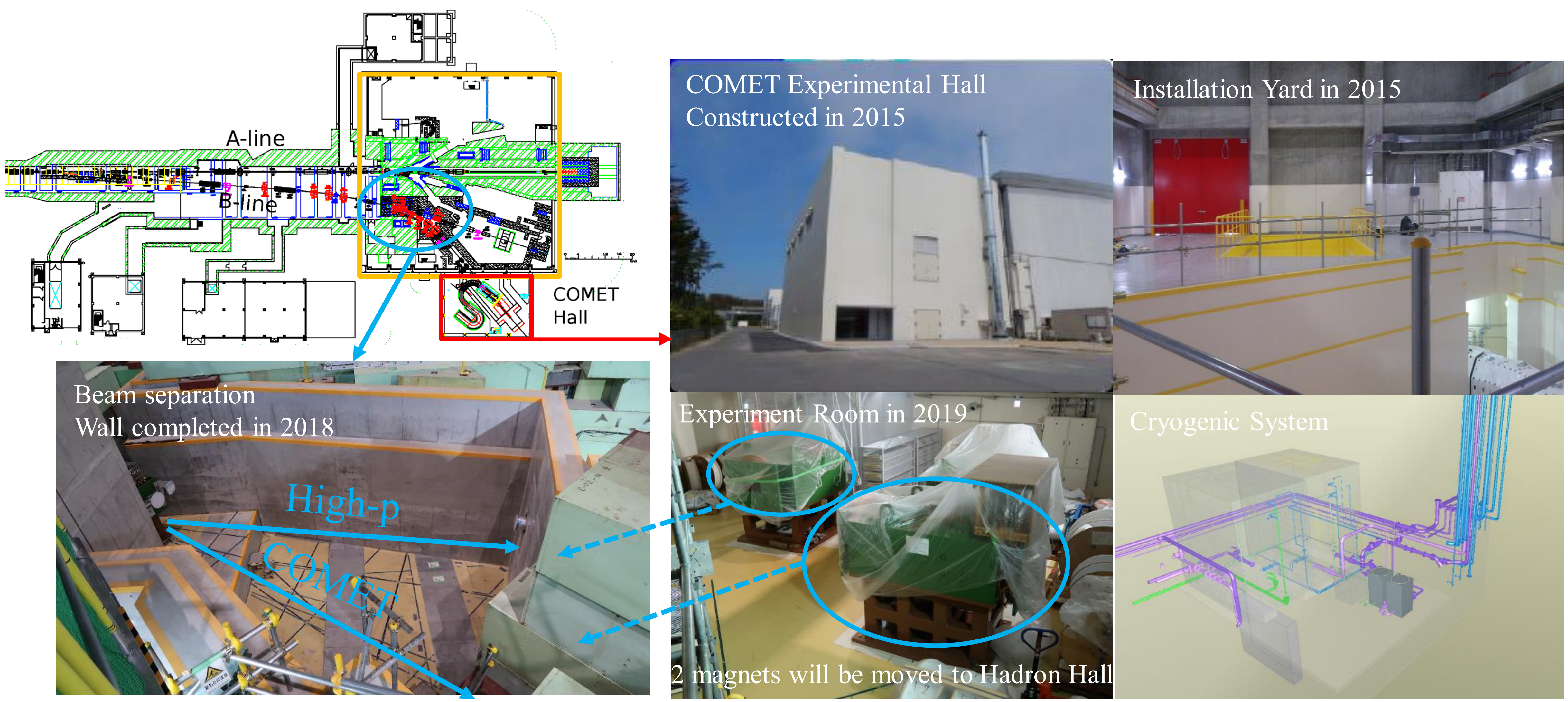


Two Detectors, CyDet and StrECAL , for COMET Phase-I



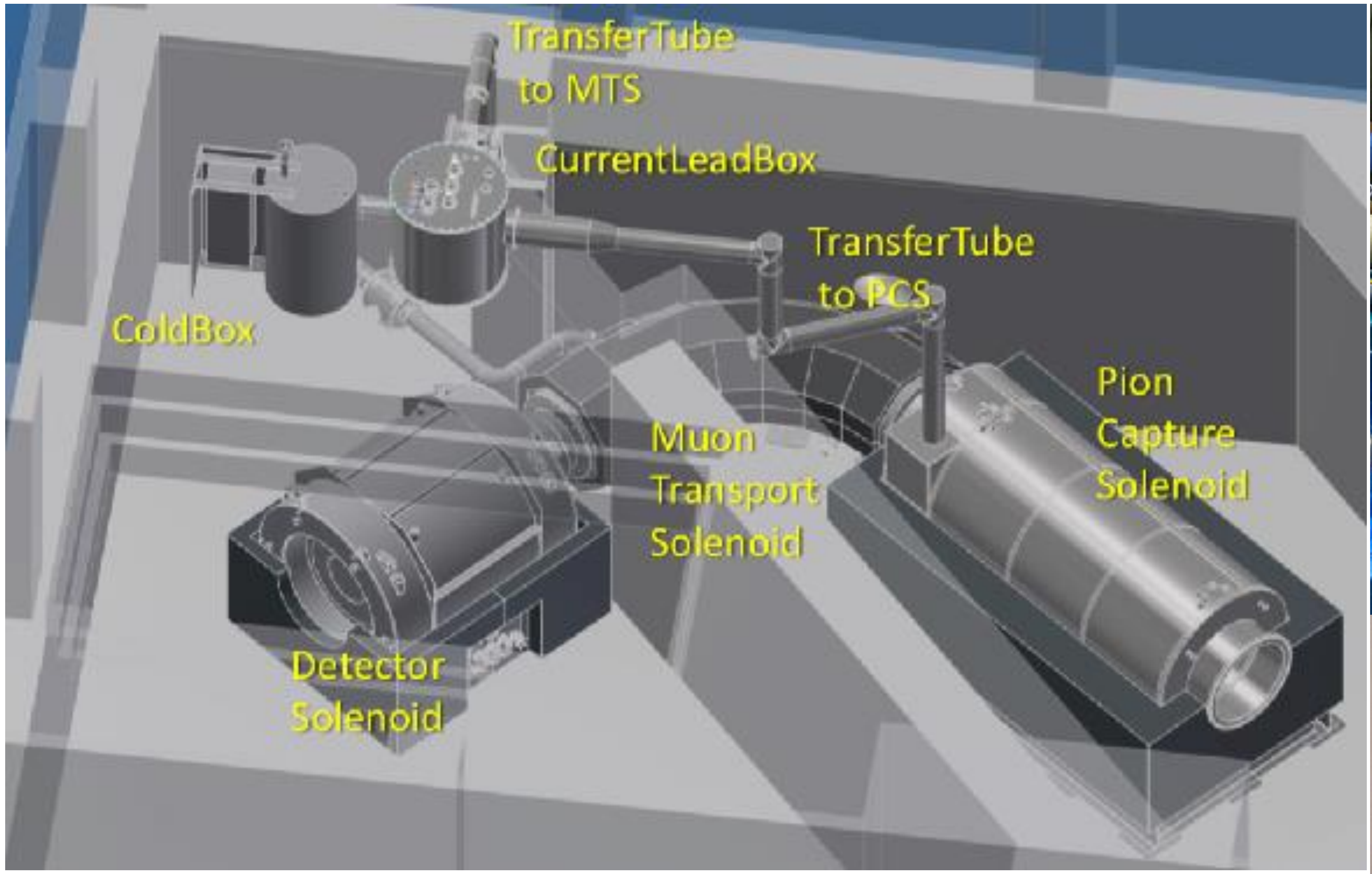


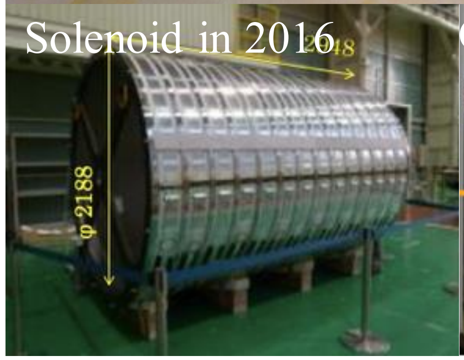
COMET Facility



- Experimental Hall building completed
- Cryogenic system under construction
- Proton beamline will be ready this year
  - Shield wall & power station completed. 2 more magnets to be located soon.

Construction of Superconducting Solenoids

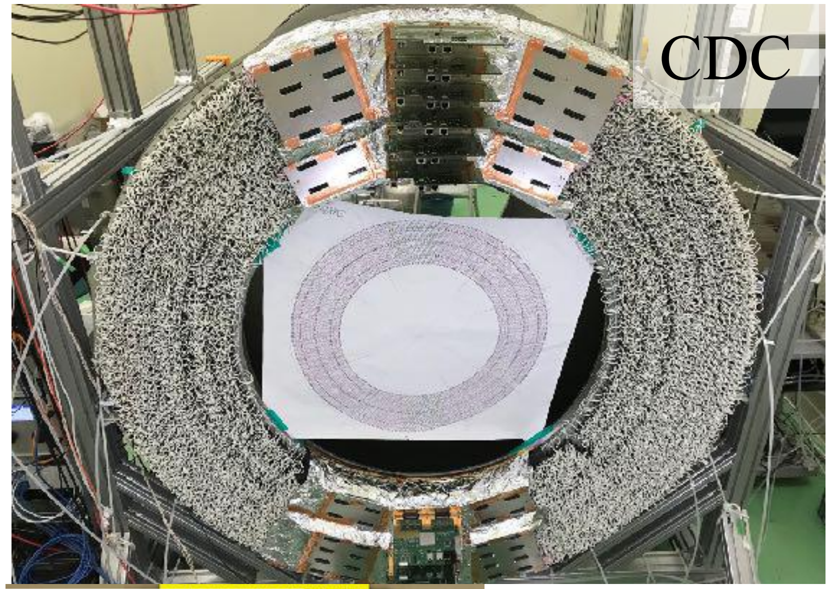


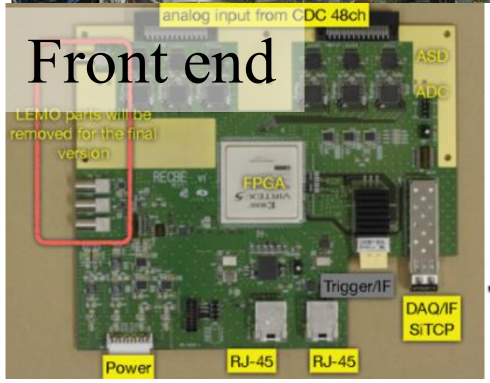


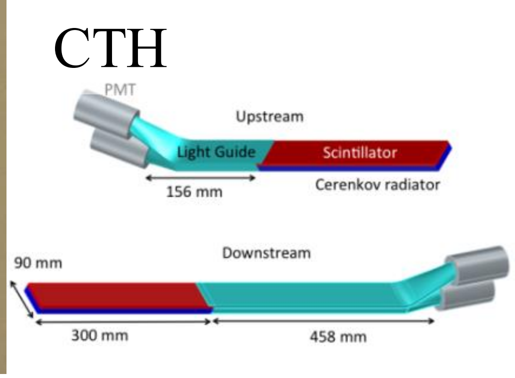
- Capture solenoid
  - Last coil under winding.
- Transport solenoid
  - Installed and ready for cryogenic test.
- Bridge & detector solenoid
  - DS coil and cryostat ready. BS coil delivered.
- Cryogenic system:
  - Refrigerator test completed.
  - Helium transfer tube in production.

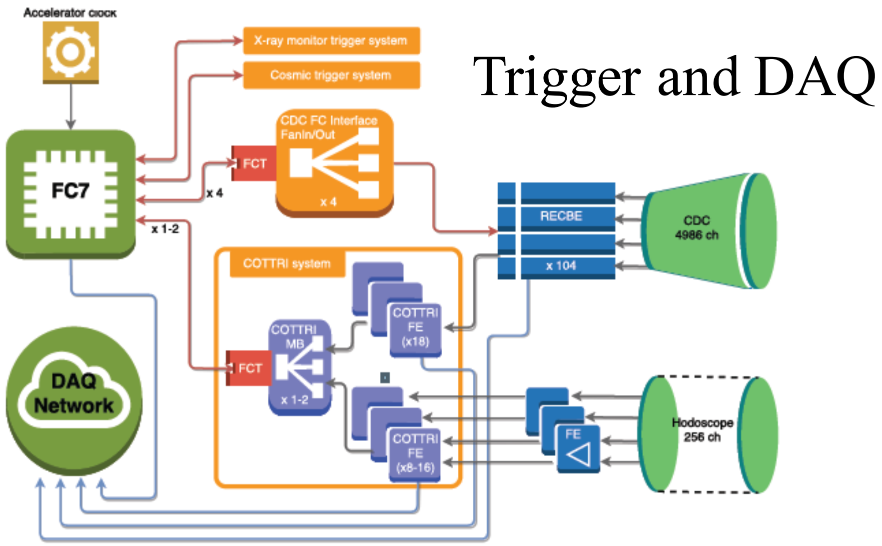
CyDet (Cylindrical Detector System)

- Cylindrical Drift chamber (CDC)
  - Prototype tests finished in 2015. 150 um spatial resolution and 99% hit efficiency were achieved.
  - Construction of the chamber was finished in 2016.
  - Cosmic ray test is under data taking phase.
- Front end electronics
  - Based on RECBE boards from BELLE-II
  - Finished the production and mass tests of 108 boards.
  - Radiation tests are published / to be published.
- Trigger system
  - Cylindrical trigger hodoscope (CTH) under mechanical design.
  - Trigger logic and trigger board design finished. Communication tests with FCT-FC7 trigger system is on going.

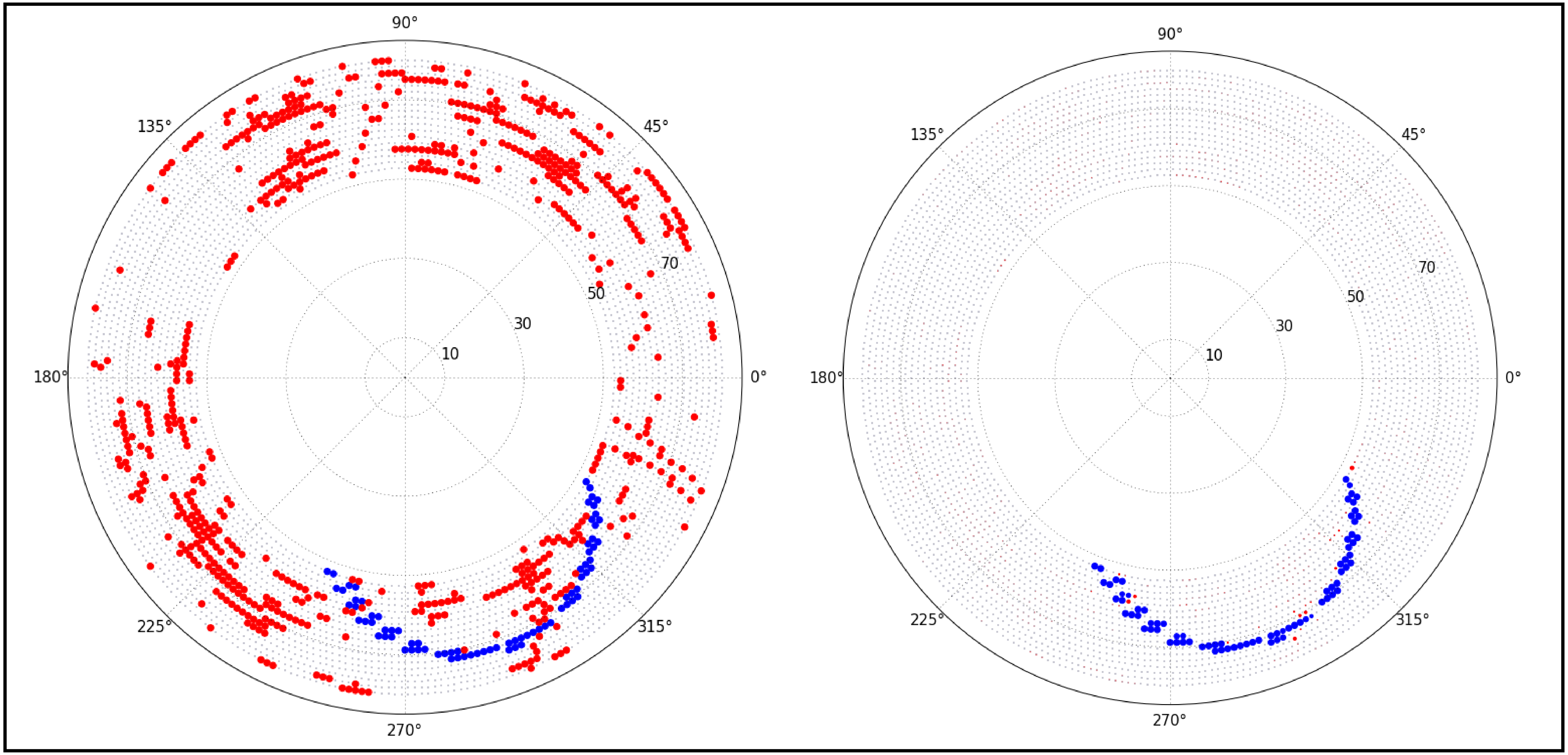








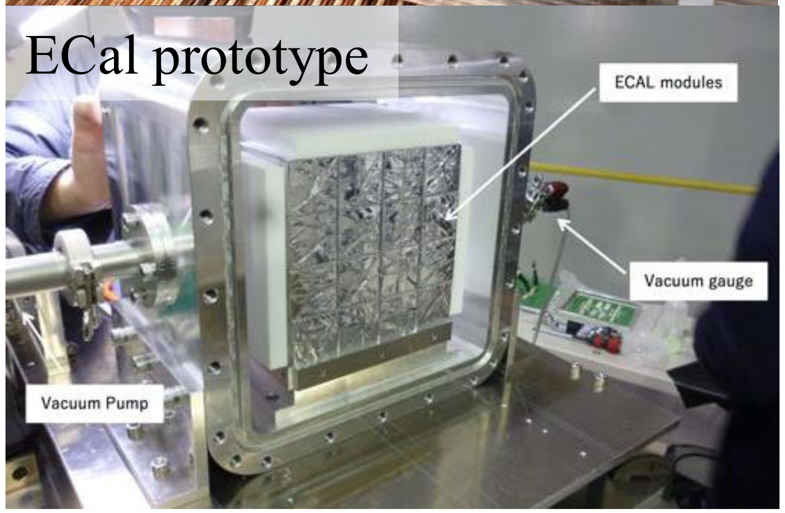
Track Finding in COMET Phase-I Machine Learning

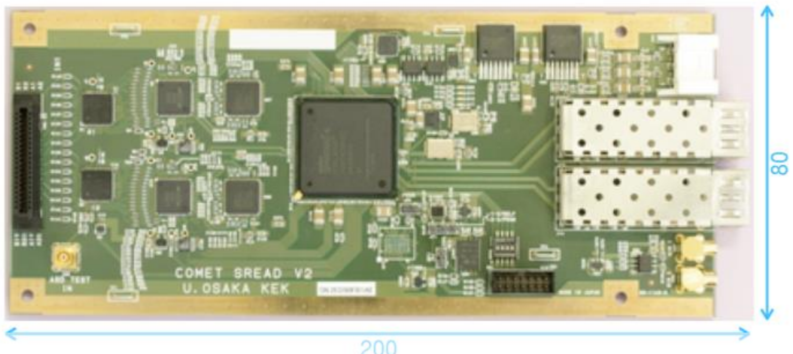


based on Boosted Decision Tree Method and Hough transformation

StrECAL (Straw Chamber+ECAL)

- Straw tube detector
  - Finished vacuum test with 20 um straw tubes.
  - Mass production for Phase-I finished.
  - Tested with 100 MeV electron beam. 150 um spatial resolution achieved.
- Electromagnetic calorimeter
  - Tested GSO and LYSO. Preliminary resolutions are 5.7% and 4.6% for each. LYSO chosen as final option.
- Front end electronics
  - Finished designing (ROESTI/EROS) based on DRS4 with GHz sampling rate.
  - Radiation tests results published.

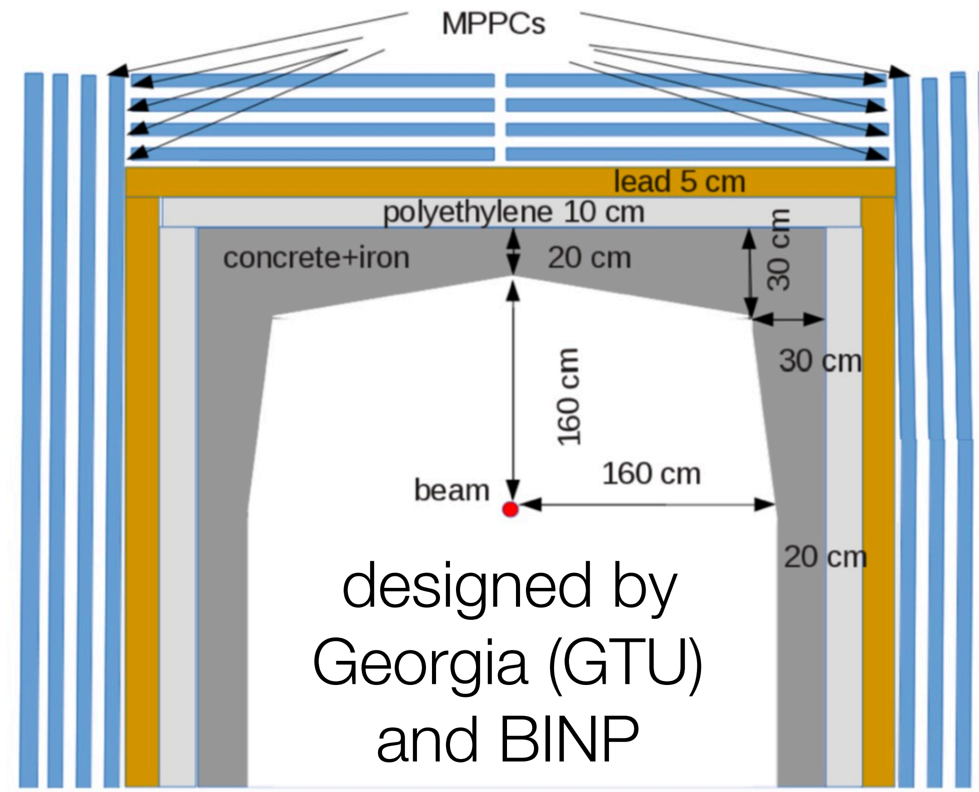


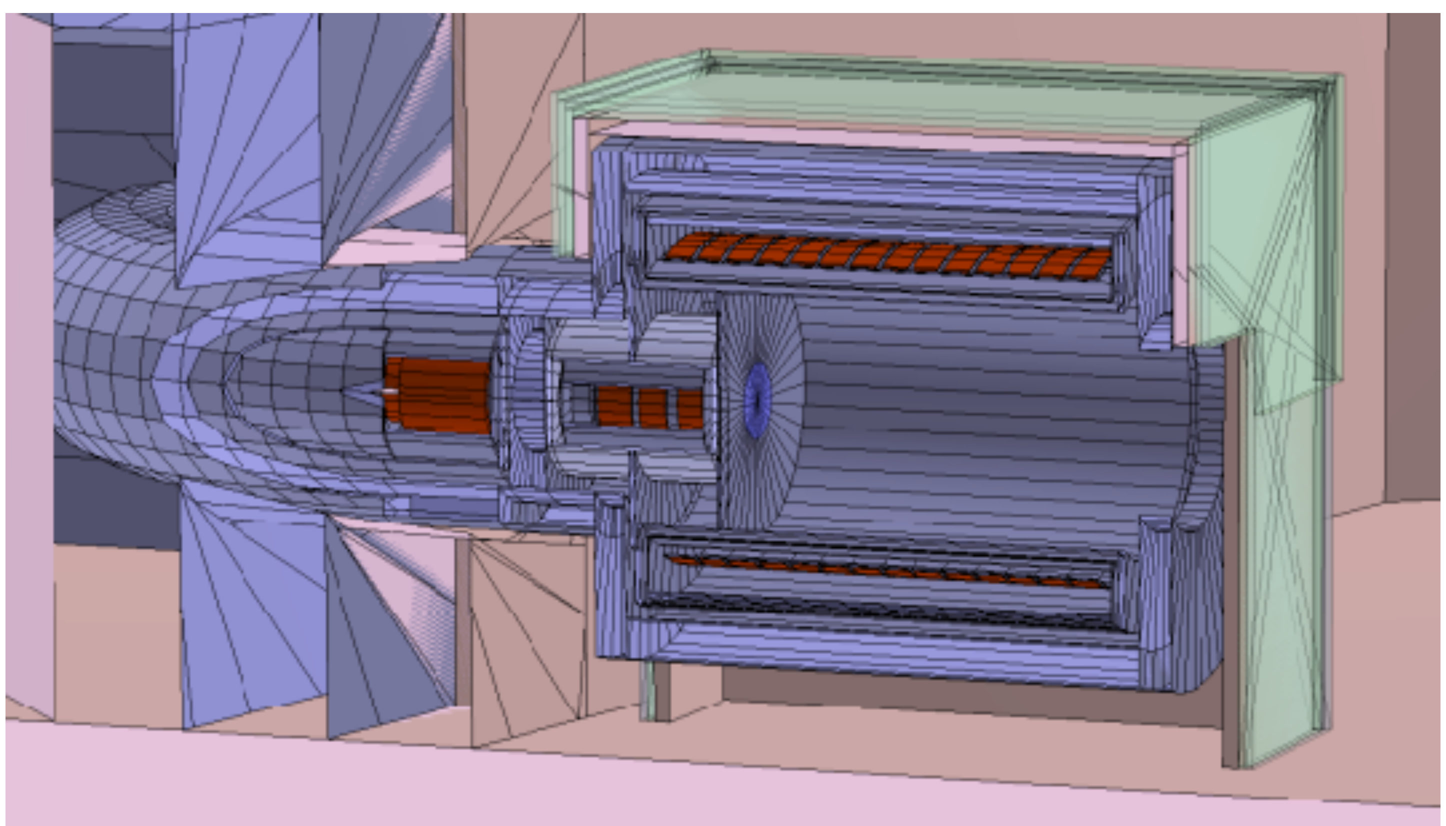


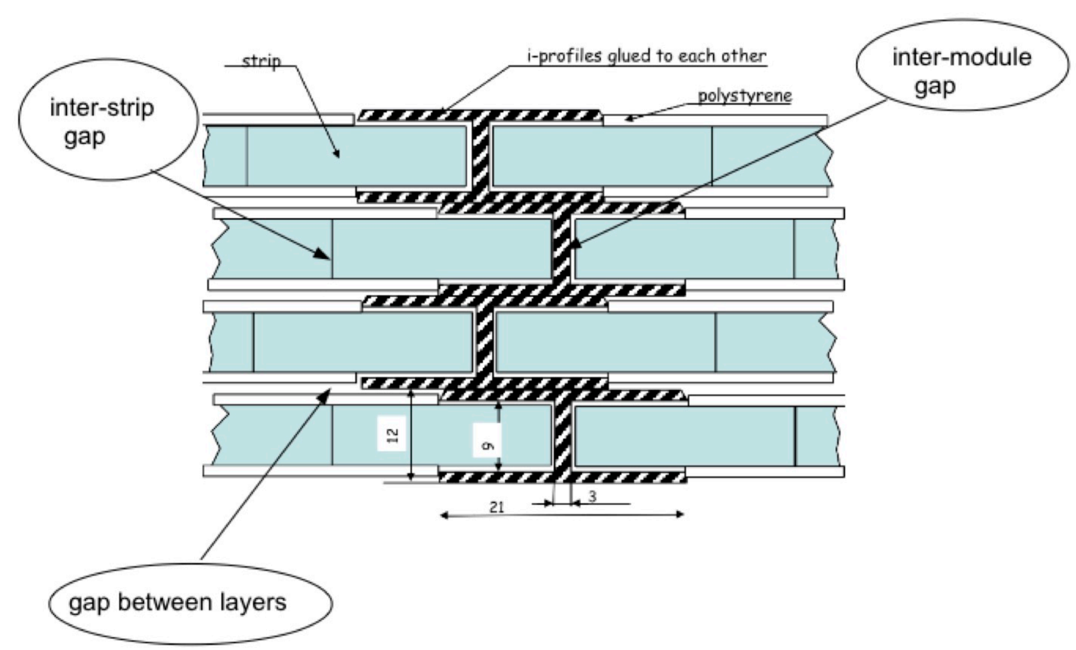
Front end electronics: ROESTI/EROS

Active Cosmic Ray Veto System

- Scintillator slabs with Sci-fibers embedded
  - SiPM readout, need radiation tolerance
  - 5 walls, each wall composed of panels
  - readout ASIC from LHCb from LPC
- Resistive Plate Chamber (RPC)
  - used in high neutron yield area.
  - LPC design, radiation tolerance







Other Physics Programs at COMET

μ^- to e^+ conversion in muonic atom

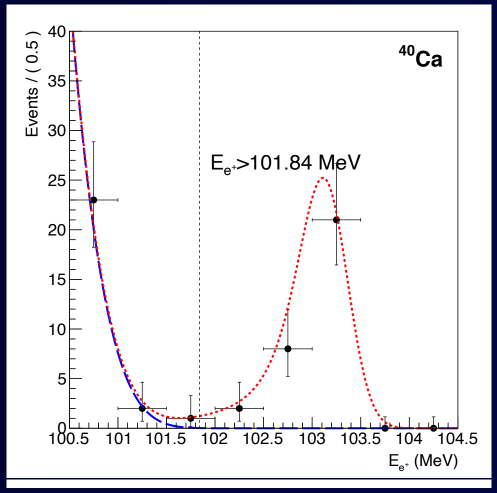
- Current limits :

$$\mu^- + \mathrm{Ti} \to e^+ + \mathrm{Ca(gs)} \leq 1.7 \times 10^{-12}$$

$$\mu^- + \mathrm{Ti} \to e^+ + \mathrm{Ca(ex)} \leq 3.6 \times 10^{-11}$$

J. Kaulard et al. (SINDRUM-II) Phys. Lett. B422 (1998) 334.

- Future prospects:
  - Mu2e or COMET can improve with proper targets,



μ^- to e^+ conversion in muonic atom

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

ground or excited final states.

Lepton number violation (LNV) and
Lepton flavour violation (LFV)

signal signature

$$E_{\mu e^+} = m_\mu - B_\mu - E_{rec} - (M(A,Z-2) - M(A,Z))$$

backgrounds

- radiative muon nuclear capture (RMC)
  $\mu^- + N(A,Z) \rightarrow N(A,Z-1) + \nu + \gamma$

$$E_{RMC} = m_\mu - B_\mu - E_{rec} - (M(A,Z-1) - M(A,Z))$$

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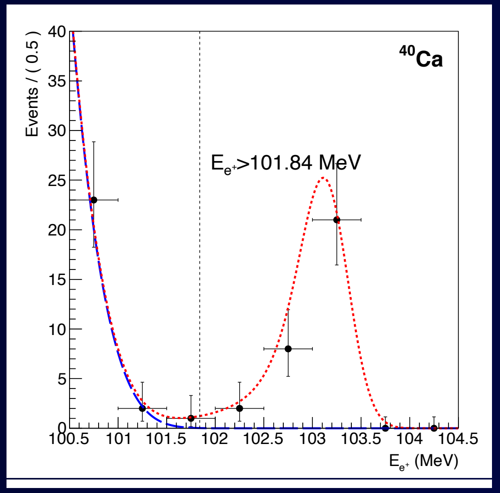


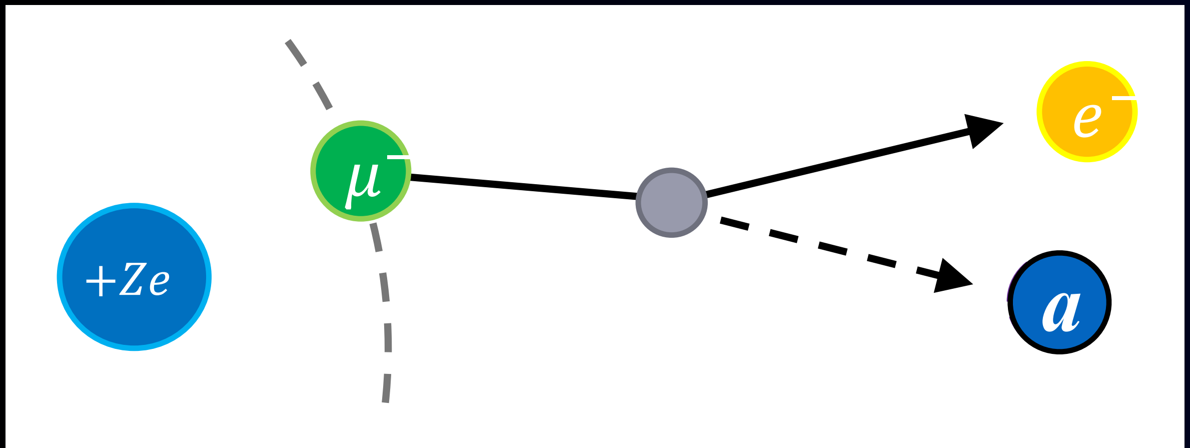
T. Geib, A. Merie, K. Zuber, Phys. Lett. B764 (2017) 157-162

B. Yeo, YK, M. Lee and K. Zuber, Phys. Rev. D96 (2017) 075027

Bound $\mu^- \to e^- a$ in a muonic atom

bound $\mu \to ea$

- Advantages
  - background less
  - spectrum shape
    - nucleus dependence
  - many μ-,s as parasite !!!
- Disadvantage
  - not monochromatic



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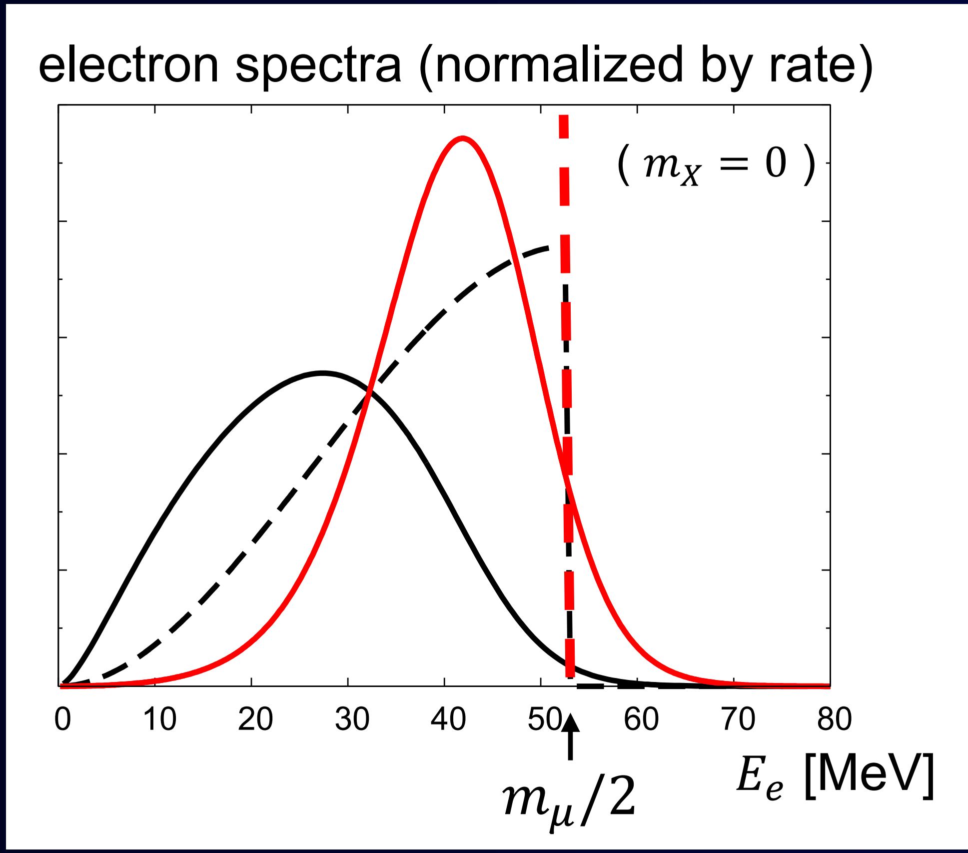
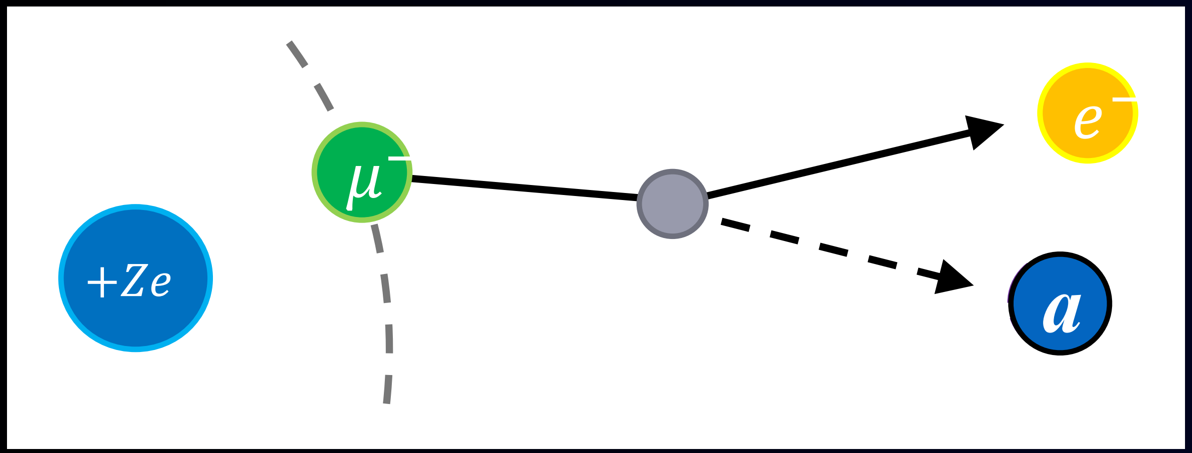
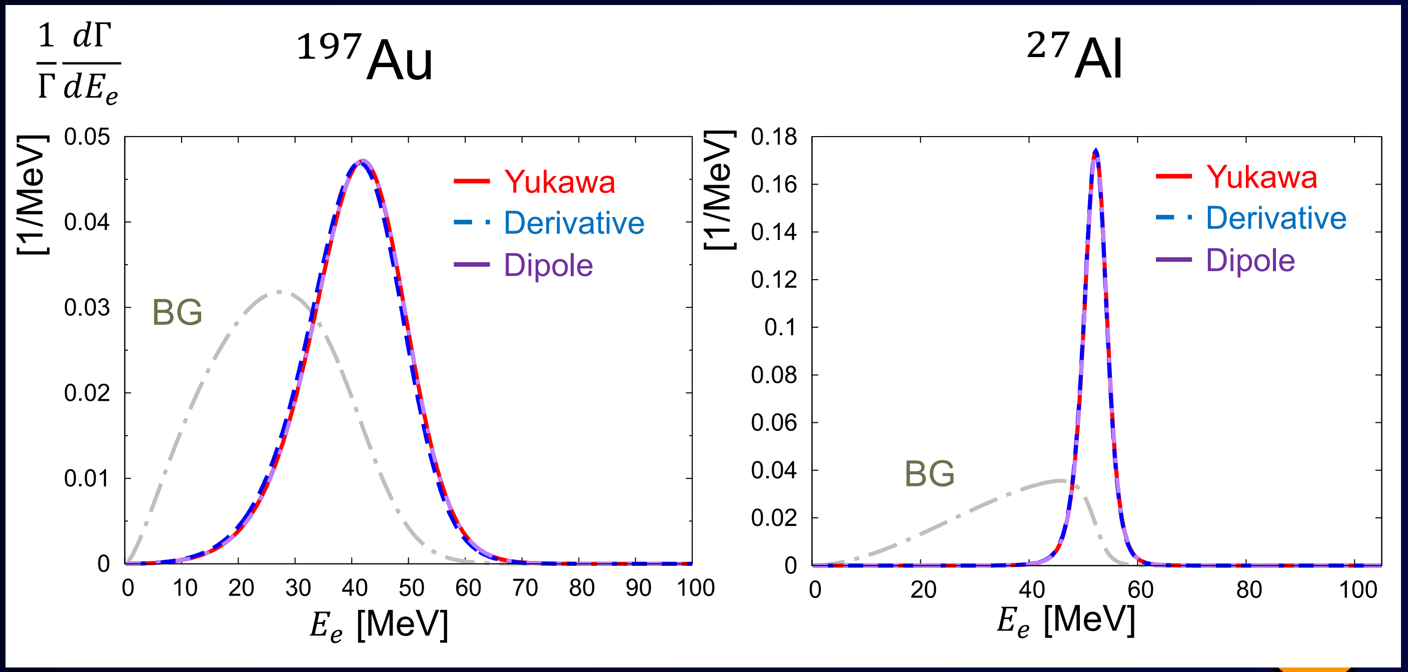


free decay in dashed
bound decay in solid





Y. Uesaka, at NuFACT2019

Future Schedule of Muon CLFV

Schedule of “golden” μ→e Transition processes in 2025 and beyond

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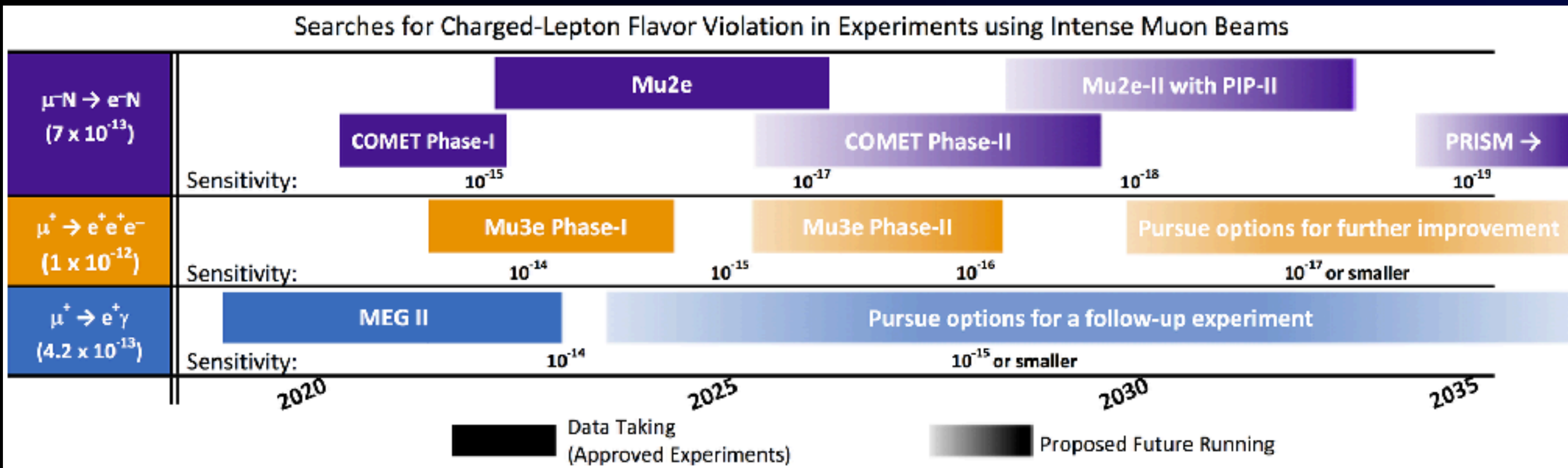
Timeline in a white paper submitted to EPPSU 2020



COMET, MEG, Mu3e, Mu2e, arXiv:1812.06540

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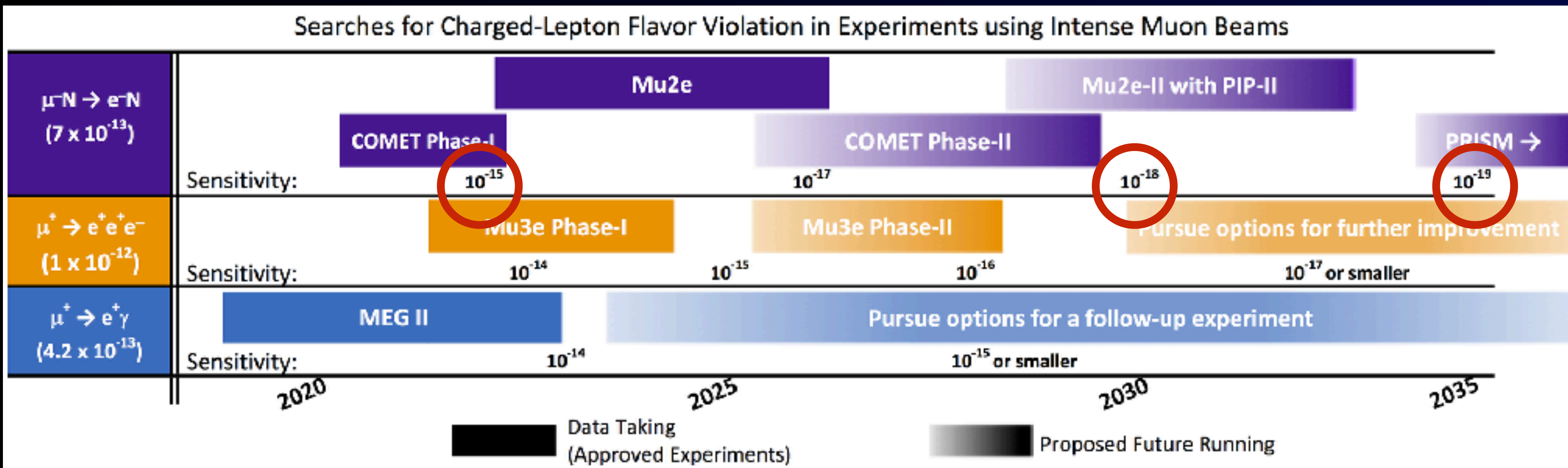

BR 10^{-15} 10^{-18} 10^{-19}

COMET, MEG, Mu3e, Mu2e, arXiv:1812.06540

Summary

Summary

- μ-e conversion in a muonic atom has a unique discovery potential for BSM.
- Current limits probe new physics at 10^4 TeV. Next generation experiments improve their sensitivities, probing 10^5 TeV.
- COMET Phase-I at J-PARC is aiming at a 100 times improvement over the current limit (i.e. S.E. sensitivity of 3×10^{-15}), whilst Phase-II aims at a factor of 10,000.
- The Phase-II sensitivity is considered to improve by another 10 times within the beam power and time originally assumed.
- COMET will start soon.