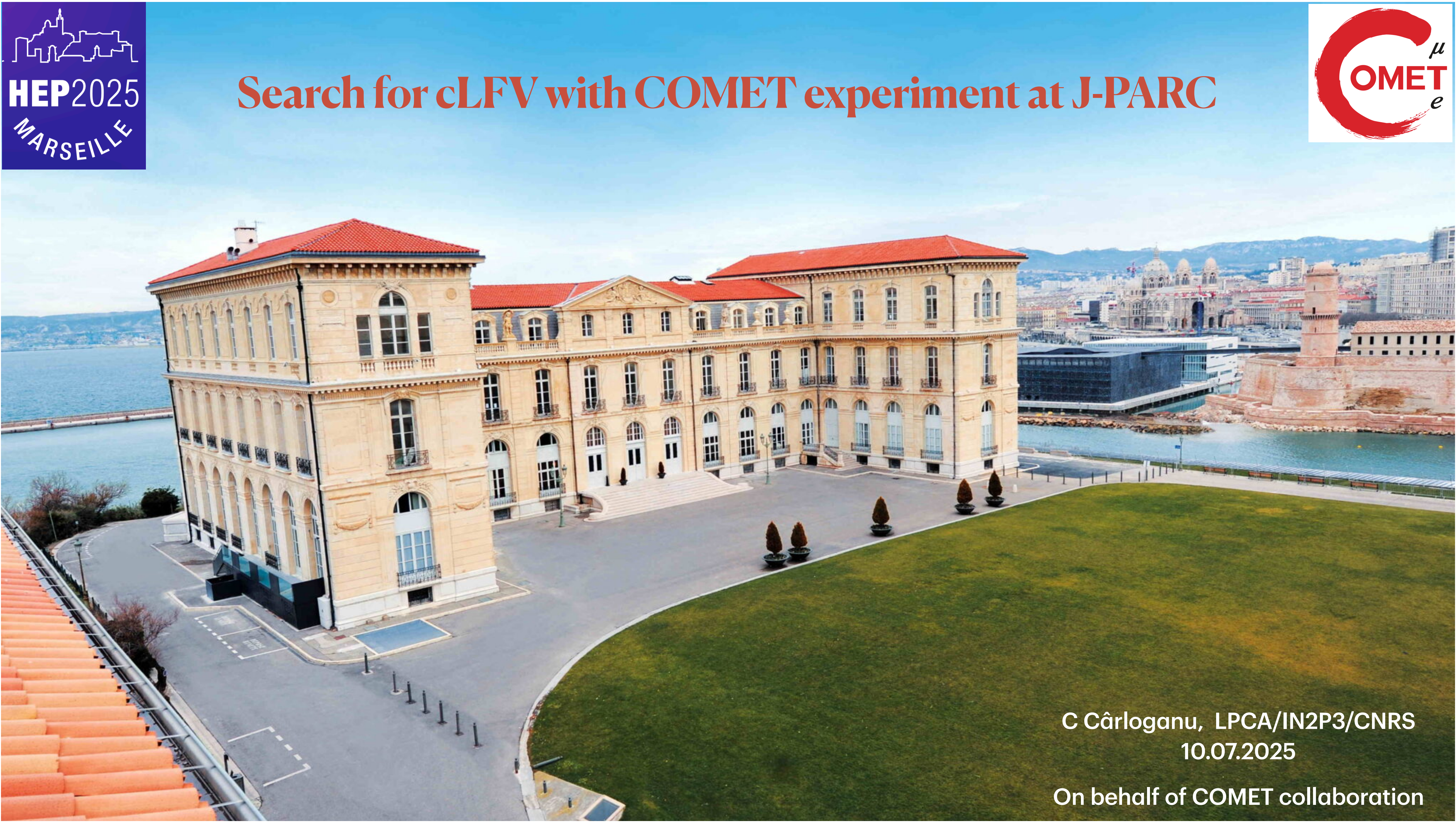
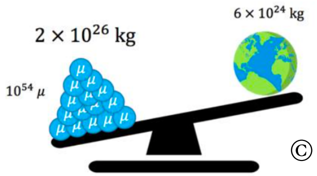
Search for cLFV with COMET experiment at J-PARC



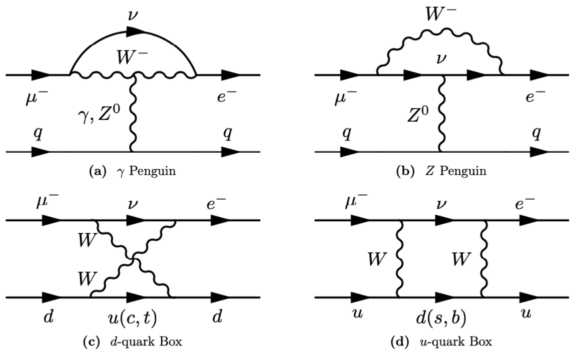
C Cârloganu, LPCA/IN2P3/CNRS
10.07.2025
On behalf of COMET collaboration

cLFV observed ⇒ New Physics in the lepton sector beyond minimally extended SM

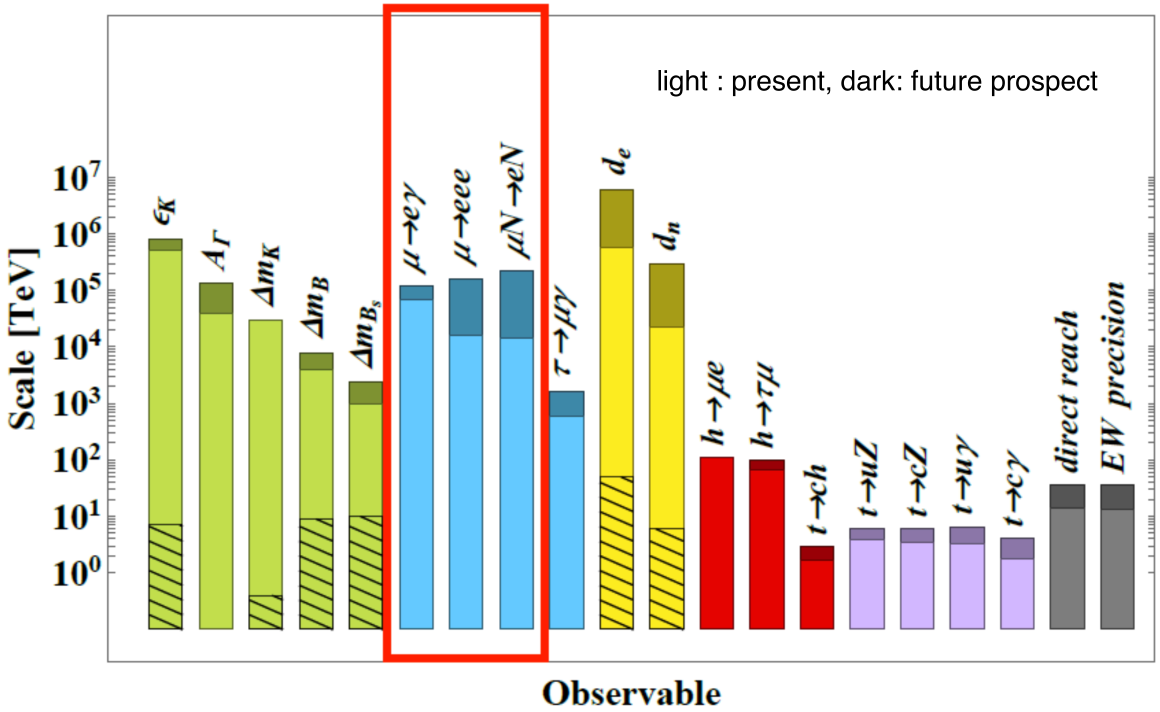
$$\mathrm{BR}(\mu \to e\gamma) \propto \left| \sum U^*_{\mu i} U_{ei} \frac{m^2_{\nu_i}}{M^2_W} \right|^2 \sim 10^{-54}$$



© MJ Lee



muon observables among the most sensitive to high scale new physics



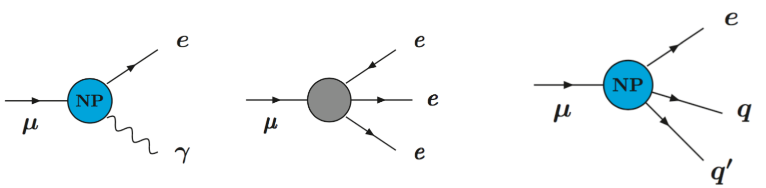
European Particle Physics Strategy Update (2019)

$\mu \to e\gamma$ / $\mu \to eee$ / $\mu N \to eN$ Complementarity

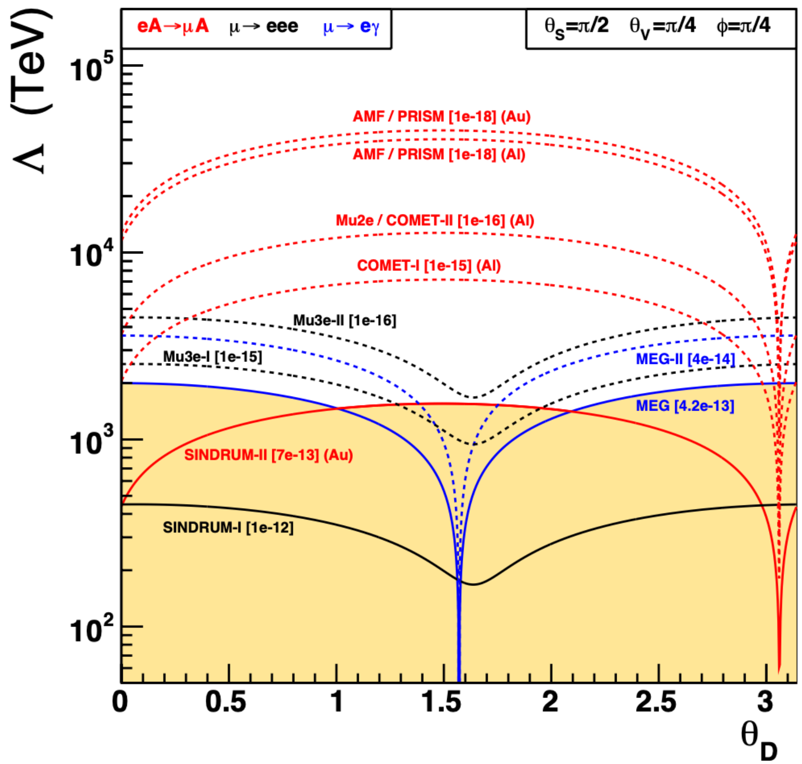
$$\delta\mathcal{L} = \frac{1}{\Lambda^2_{LFV}}\left[m_\mu C_D(\bar{e}\sigma^{\alpha\beta}P_R\mu)F_{\alpha\beta} + C_S(\bar{e}P_R\mu)(\bar{e}P_Re) + C_{VR}(\bar{e}\gamma^\alpha P_L\mu)(\bar{e}\gamma_\alpha P_Re) + C_{VL}(\bar{e}\gamma^\alpha P_L\mu)(\bar{e}\gamma_\alpha P_Le) + C_{Alight}\mathcal{O}_{Alight} + C_{Aheavy\perp}\mathcal{O}_{Aheavy\perp}\right]$$

S. Davidson, B.Echenard, Eur. Phys. J. C **82** (2022) no.9, 836

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



	Collaboration	year	BR 90% C.L.
$\mu \to e\gamma$	**PSI/MEG+MEG2**	**2025**	**1.5×10^{-13}**
$\mu \to eee$	**PSI/SINDRUM**	**1988**	**1×10^{-12}**
$\mu N \to eN$ (A,Z)	**PSI/SINDRUM**	**2006**	**7×10^{-12}**
	JParc/COMET Phase I / Phase II	2028 / 20XX	*3×10^{-15} / 10^{-17}*



$$Rate \sim \frac{[]^2}{\Lambda^4}$$

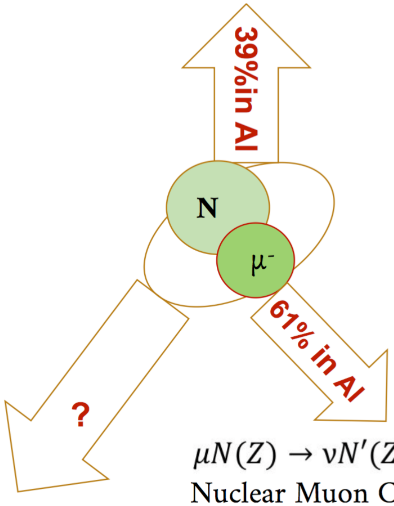
Need to improve the SES by **10000** to reach **10** times higher in energy scale!

Improve by a factor 10^4 the present limit $R_{\mu e} < 1.5\ 10^{-13}$

This requires:
- **10^{18} stopped muons**
- high background suppression

Decay In Orbit

$\mu N \rightarrow e\nu\bar{\nu}N$

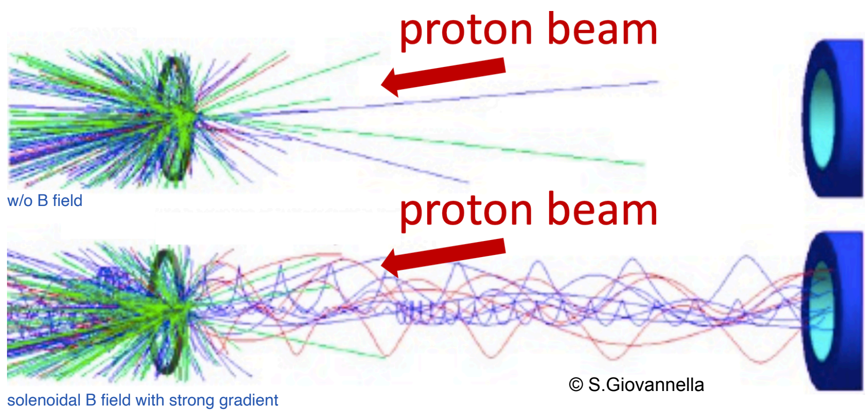


$\mu N(Z) \rightarrow \nu N'(Z-1)$

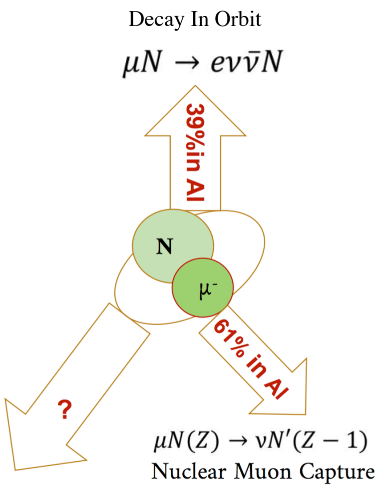
Nuclear Muon Capture

© Lobashev and Djilkibaev

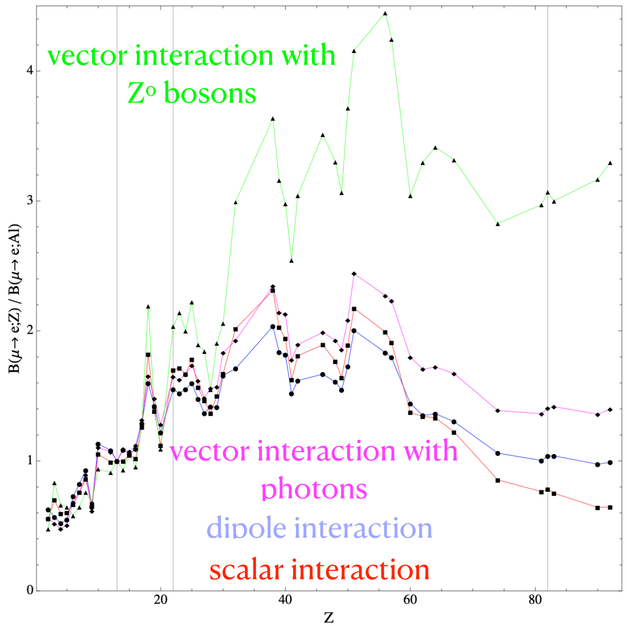
MELC experiment [Sov.J.Nucl.Phys. 49, 384 (1989)]



COMET Measurement Strategy

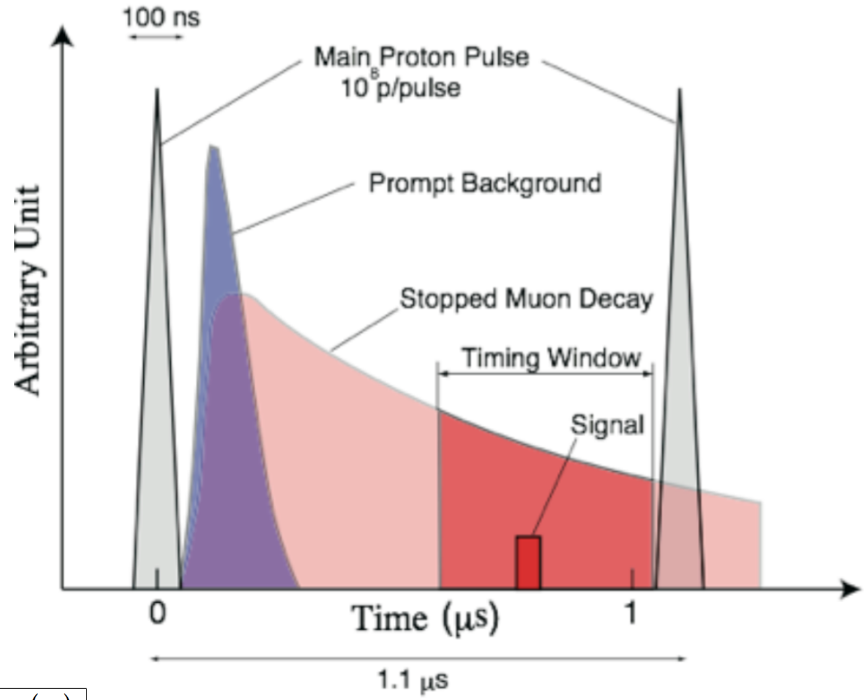


V Cirigliano, R Kitano, Y Okada, P Tuzon, Phys.Rev., D80, 013002 (2009)



Material target	Atomic number (Z)	Muonium lifetime (ns)
Aluminum	13	864
Titanium	22	330
Lead	82	74

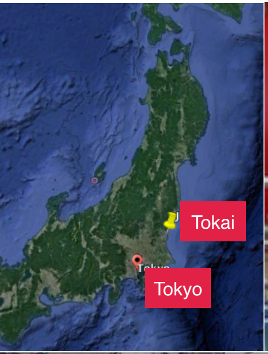
Pulsed beam



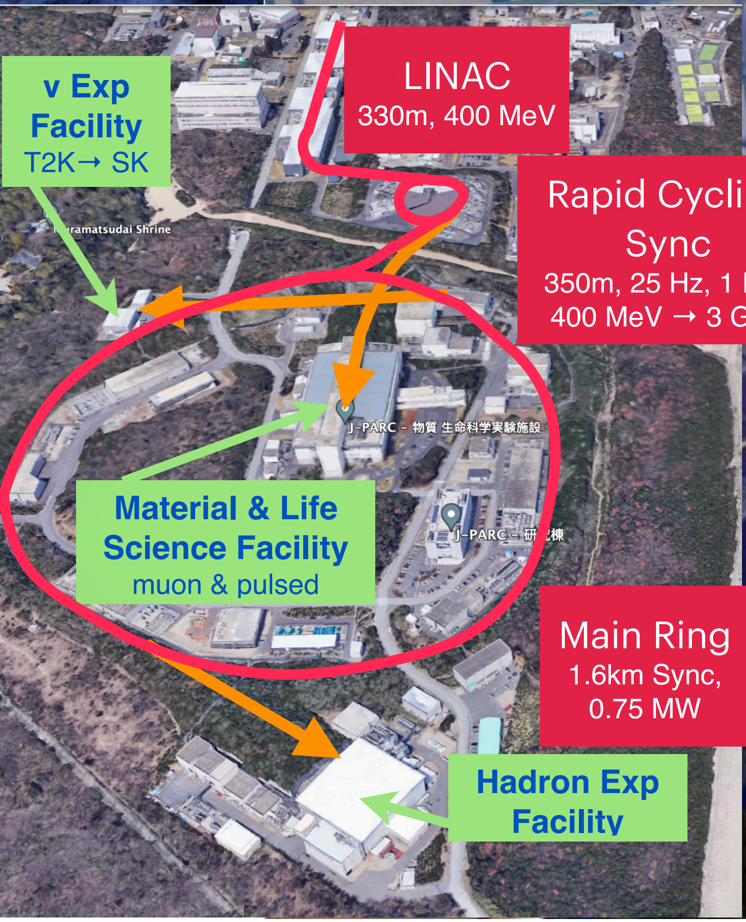
Delayed DAQ gate (700ns-1,17μs)

Narrow proton pulses

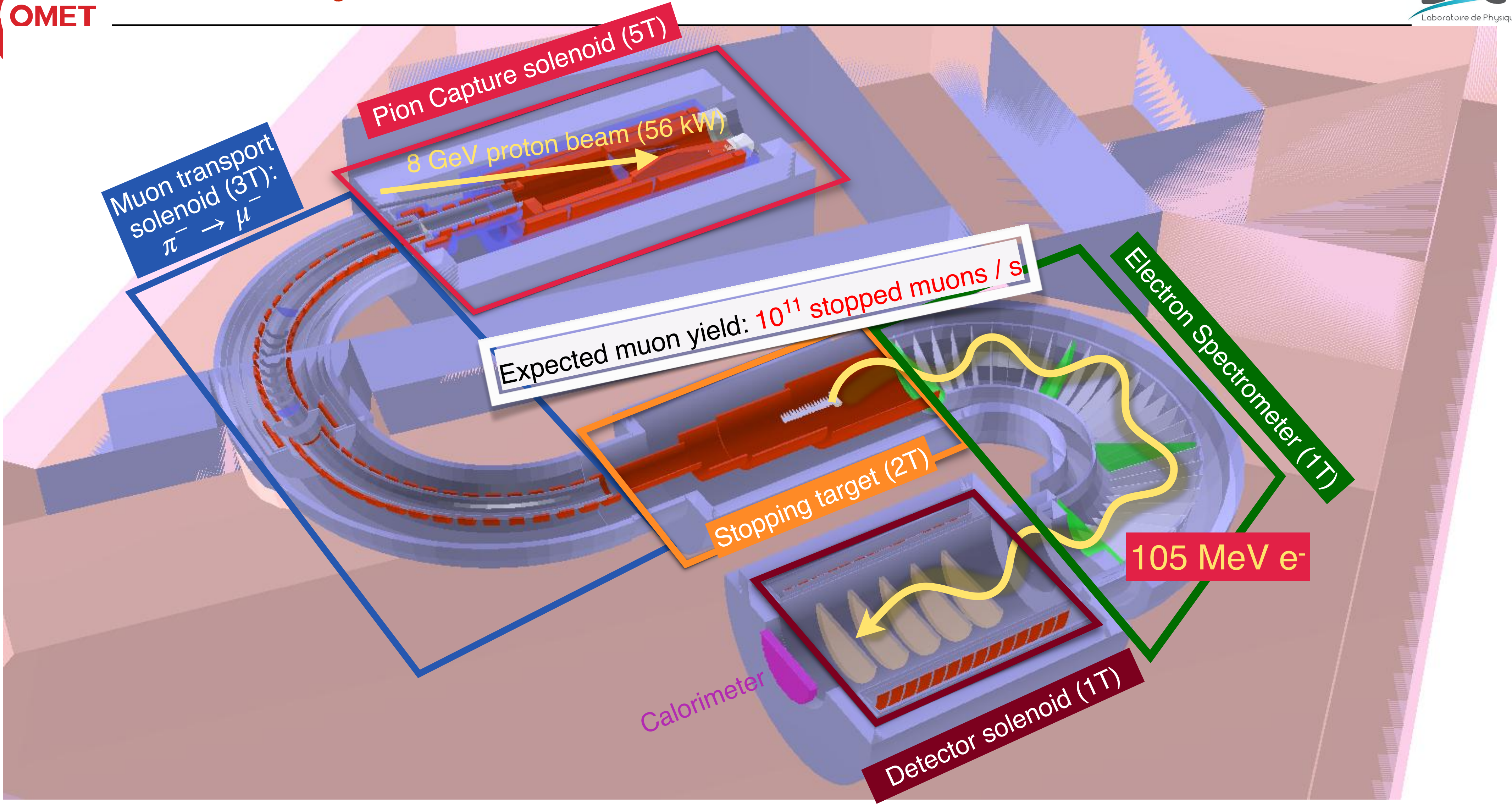
O(10^{10}) out-of-time proton suppression



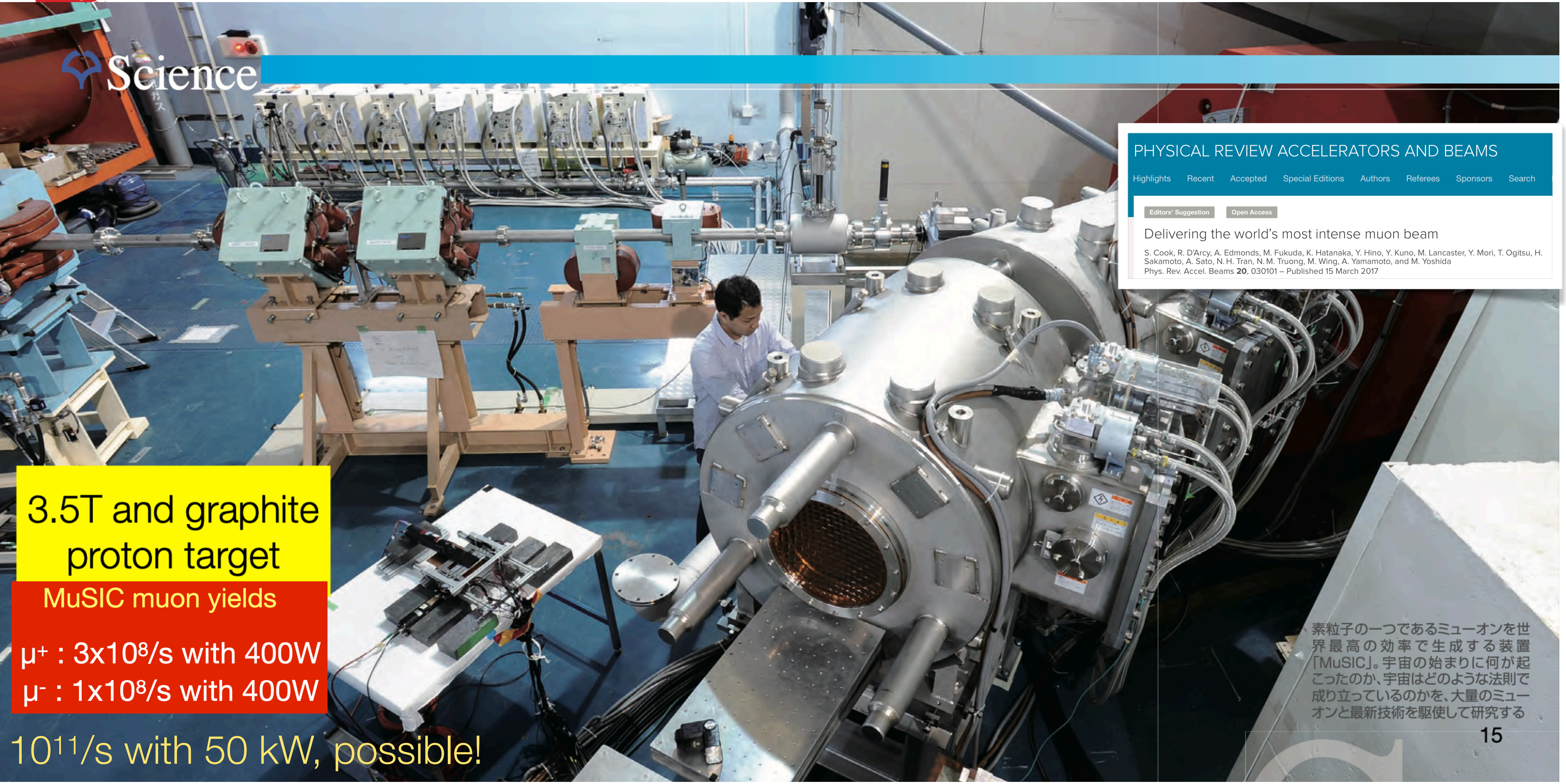
μ
OMET
e



大強度陽子加速器施設
J-PARC
Japan Proton Accelerator Research Complex


Pion Capture solenoid (5T)
8 GeV proton beam (56 kW)
Muon transport solenoid (3T): $\pi^- \to \mu^-$
Expected muon yield: 10^{11} stopped muons / s
Electron Spectrometer (1T)
Stopping target (2T)
105 MeV e-
Calorimeter
Detector solenoid (1T)

Proof of Principle : MuSIC @ RCNP, OSAKA University



3.5T and graphite proton target

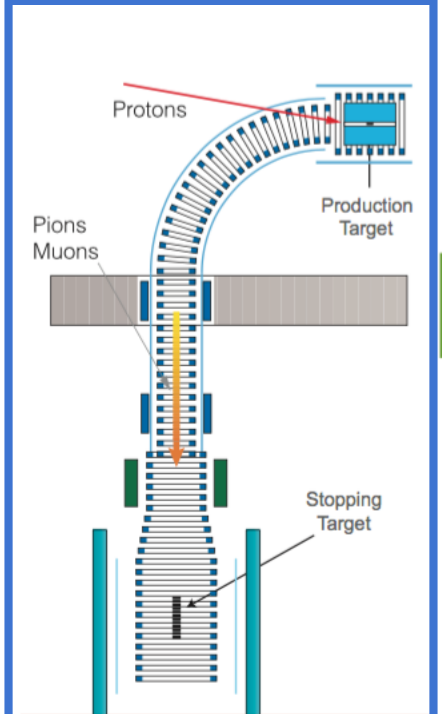
MuSIC muon yields

μ^+ : 3x10^8/s with 400W

μ^- : 1x10^8/s with 400W

10^{11}/s with 50 kW, possible!

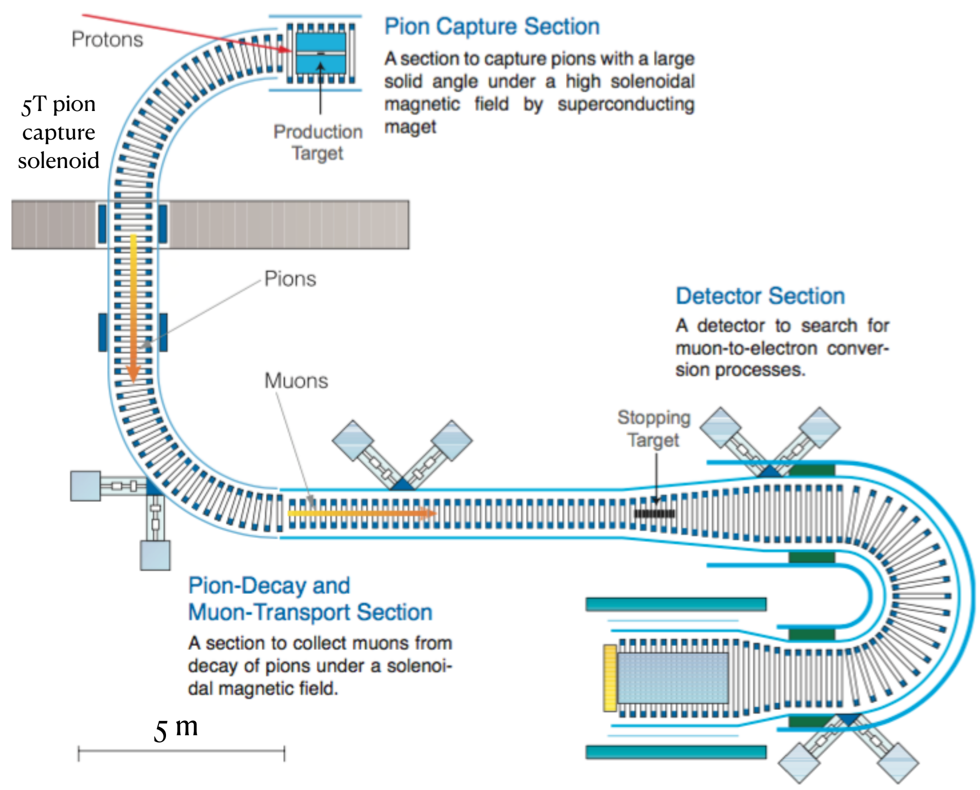
Phase I



8 GeV proton beam (3.2 kW)
Graphite proton target
1.2 10^9 stopped muons/s

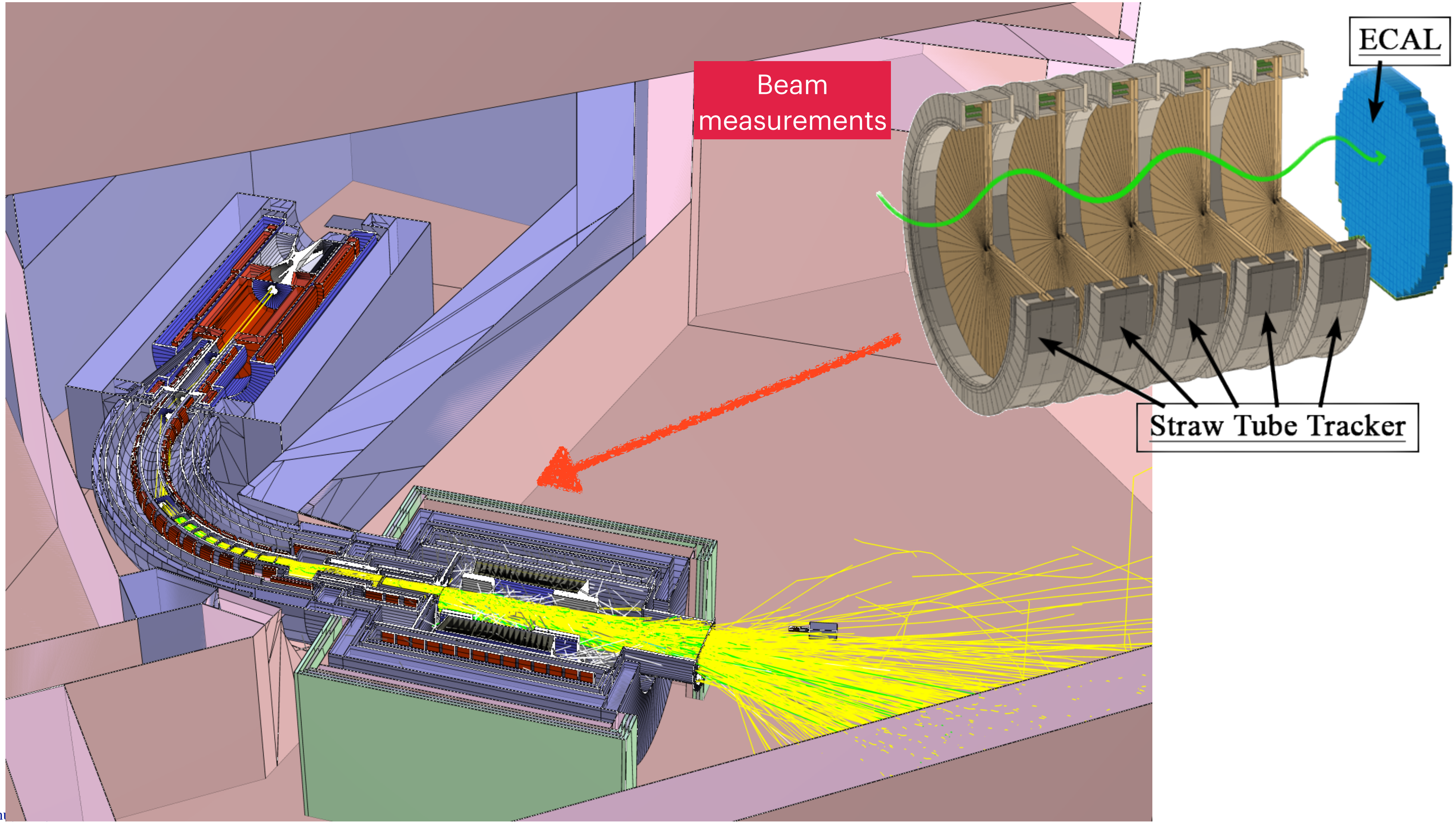
Expected limit : 7 10^{-15} @ 90% CL
Total background: 0.01 events
Running time: 0.4 yrs (1.2 10^7 s)

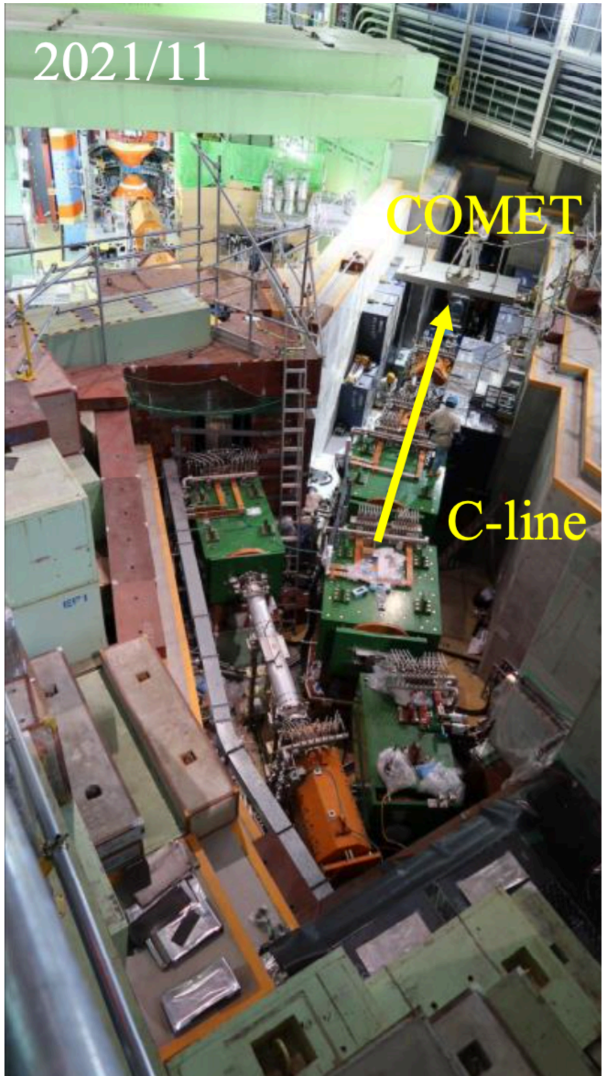
Phase II

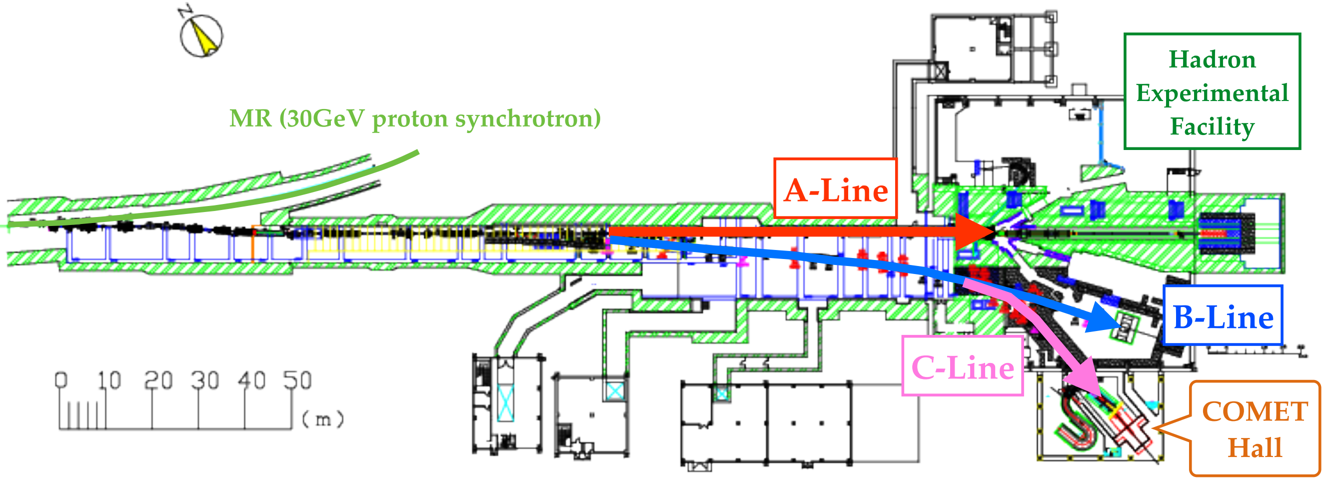


8 GeV proton beam (56 kW)
Tungsten proton target
1.2 10^{11} stopped muons/s

Expected limit : 7 10^{-17} @ 90% CL
Total background: 0.32 events
Running time: 1 yr (2 10^7 s)

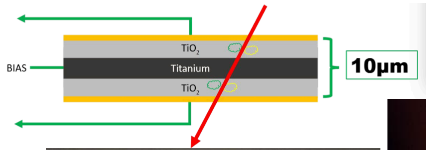

Beam
measurements
ECAL
Straw Tube Tracker

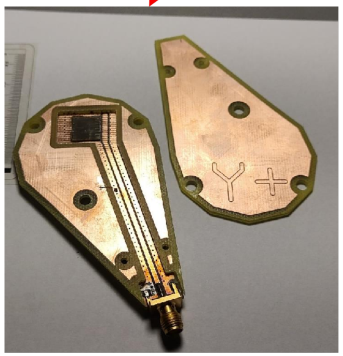


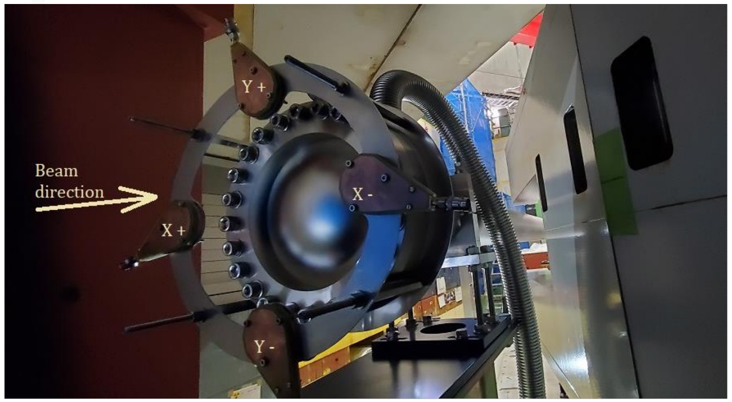


Proton Beam Monitors

- Polycrystalline TiO_2 developed in India. Very thin (10 μm) and much cheaper (handmade) than diamonds.. Tested in Phase-alpha
- diamond
- SiC

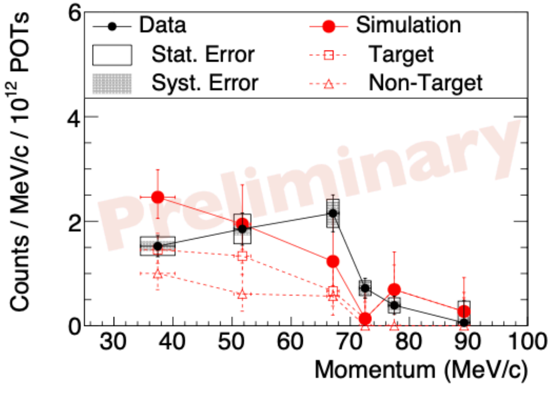


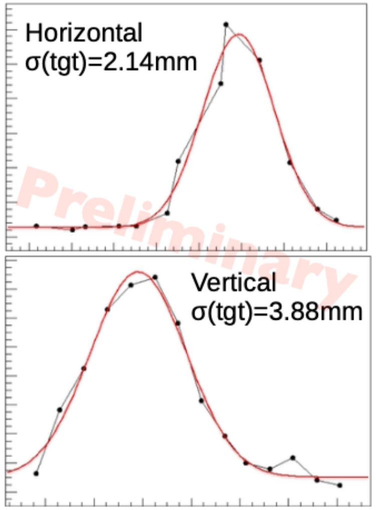




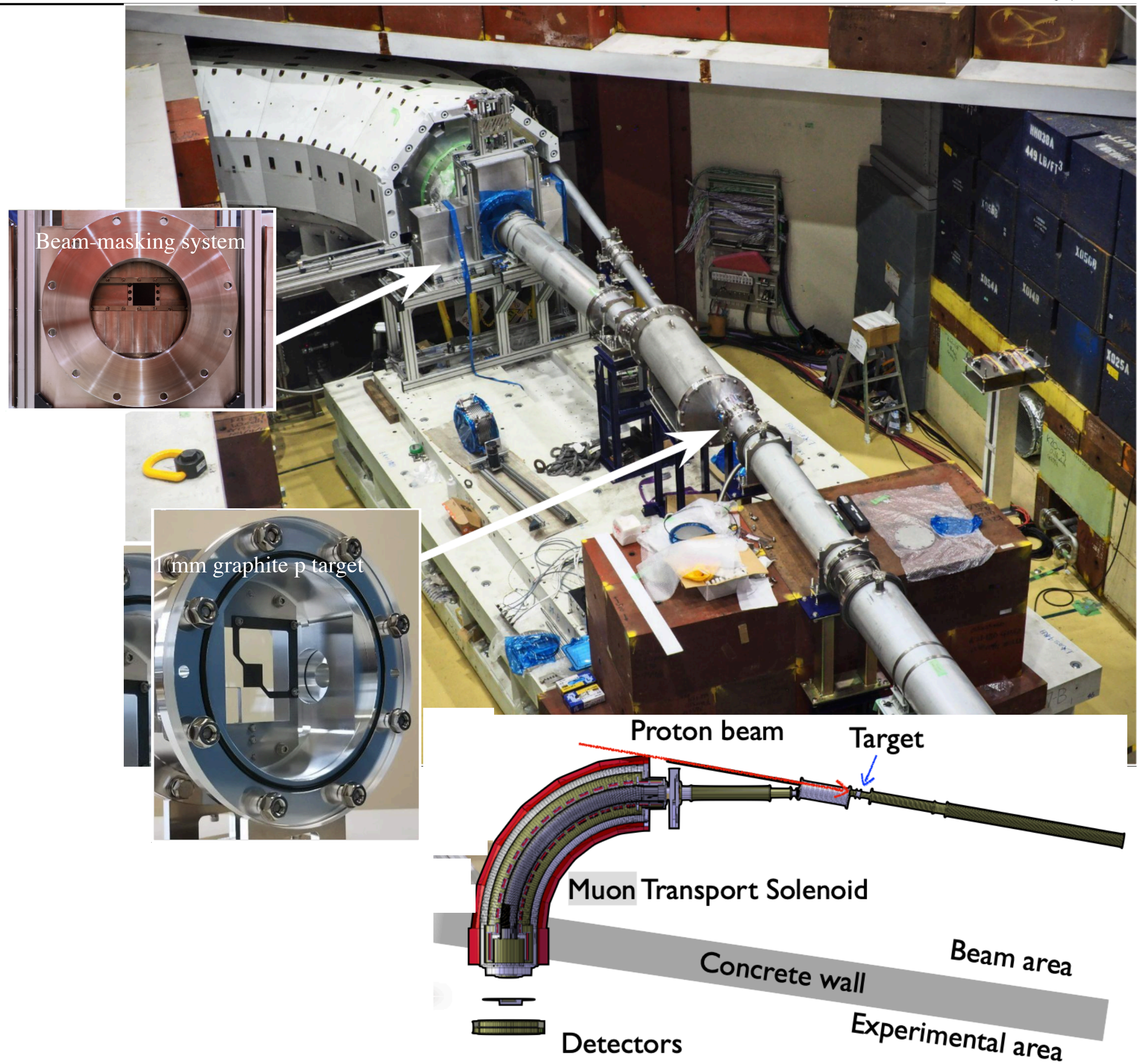
Phase-α : first proton beam in COMET Hall (Feb-March 2022)

- Slowly-extracted pulsed 8 GeV proton beam at 260 W (~1/10 of Phase-I
- Thin graphite pion-production target
- Proton beam diagnostic detectors (time, intensity & xy distribution)
- Secondary particle detectors -> muon range distribution



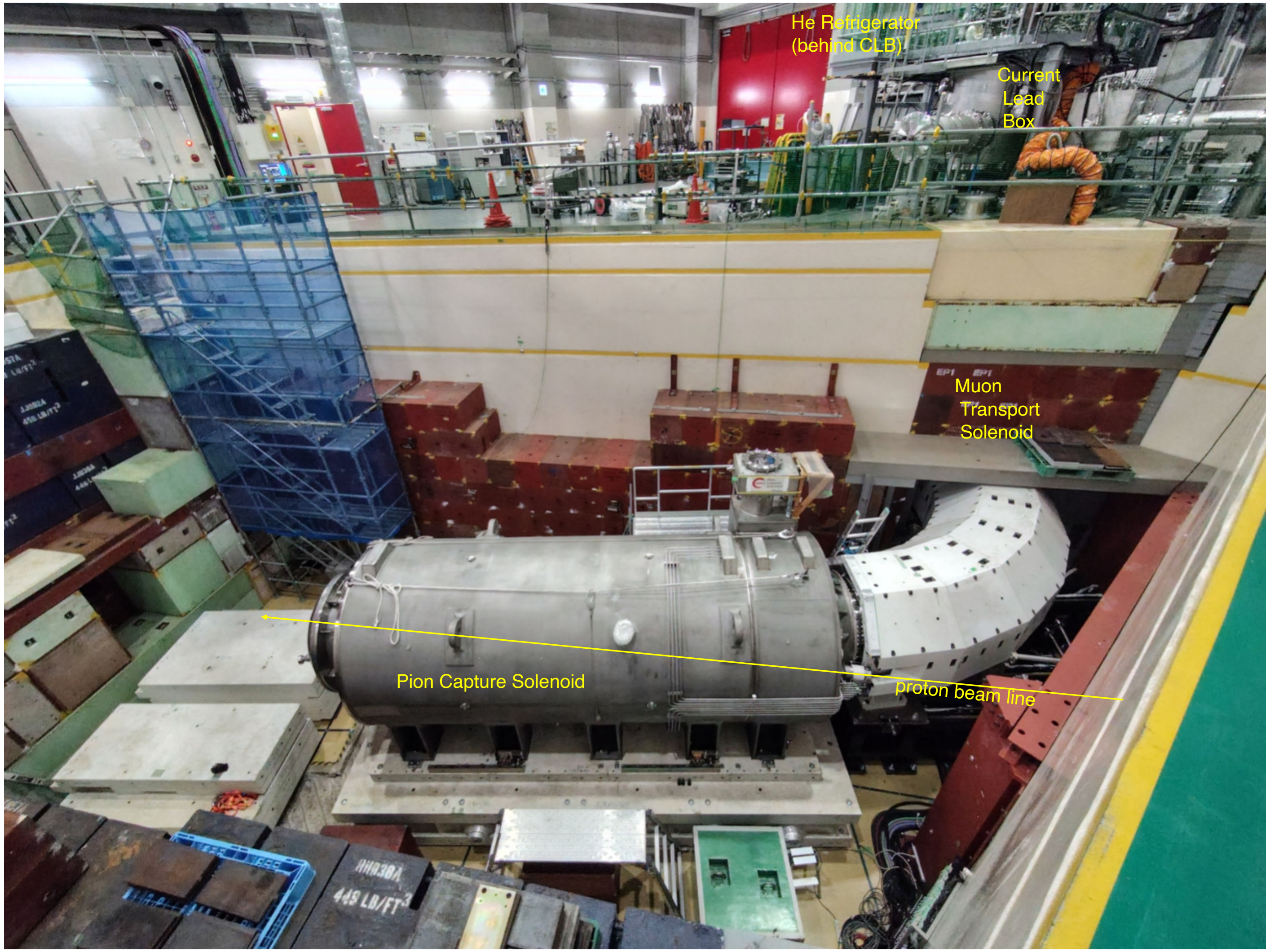


Measured beam size



The PCS was installed in its final position in Dec. 2024

Acceptance tests finished.
- No leak
- Coil resistance is OK.



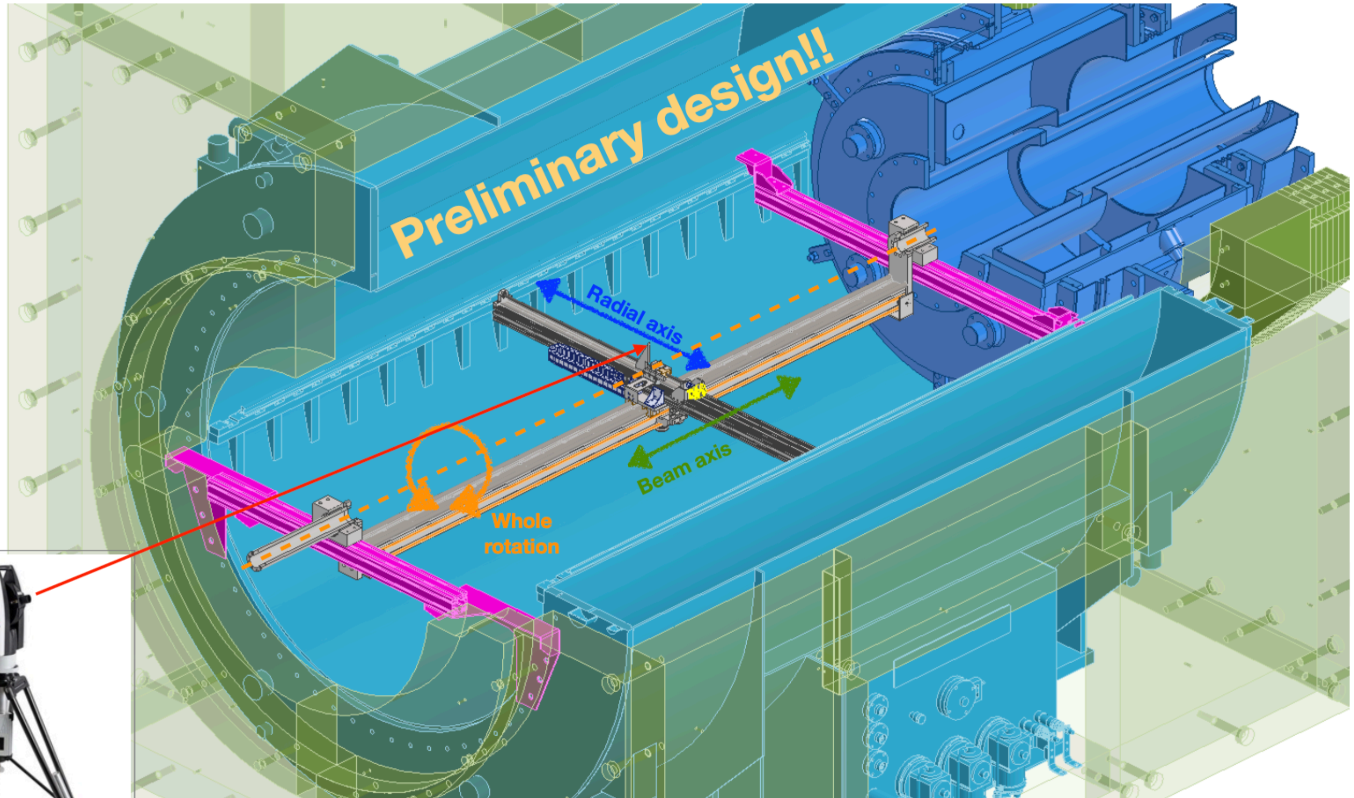
They will come to the hall in this summer.

DS magnet is at North Counter Hall in Tsukuba, to be moved to J-PARC this year followed by the field measurement

BS magnet is at NU1 in J-PARC, stand-alone commissioning has been completed

- **Beam axis**
- **Radial axis**
- **Whole rotation**

- Target accuracy 0.1%
- Measurement area
  - L 1700 mm
  - R 800 mm



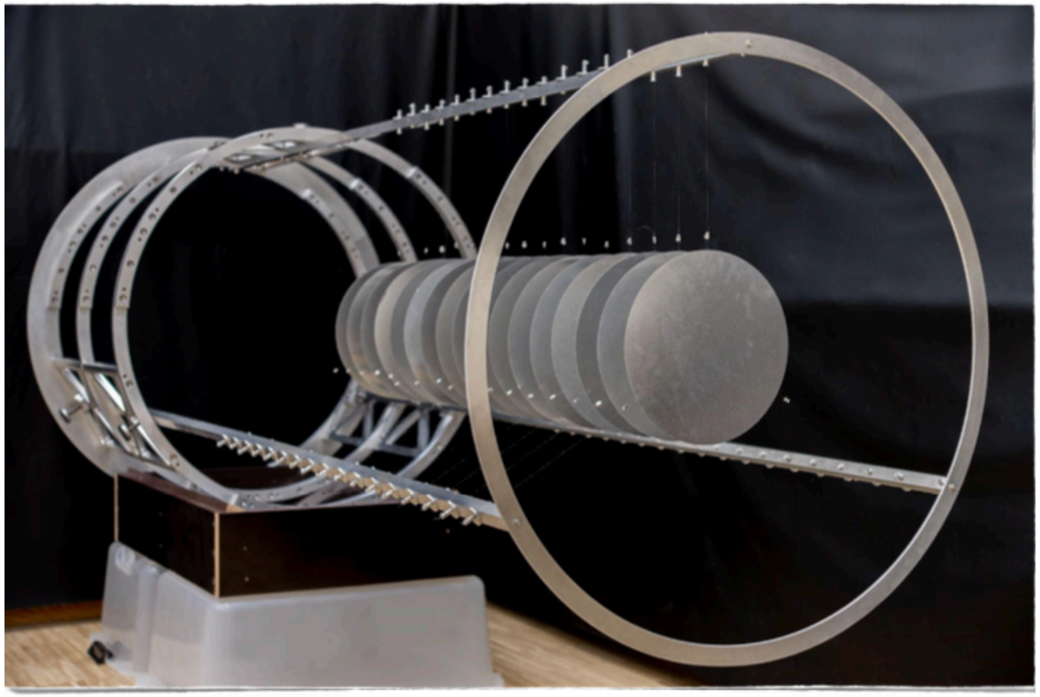

Laser Tracker ATS600

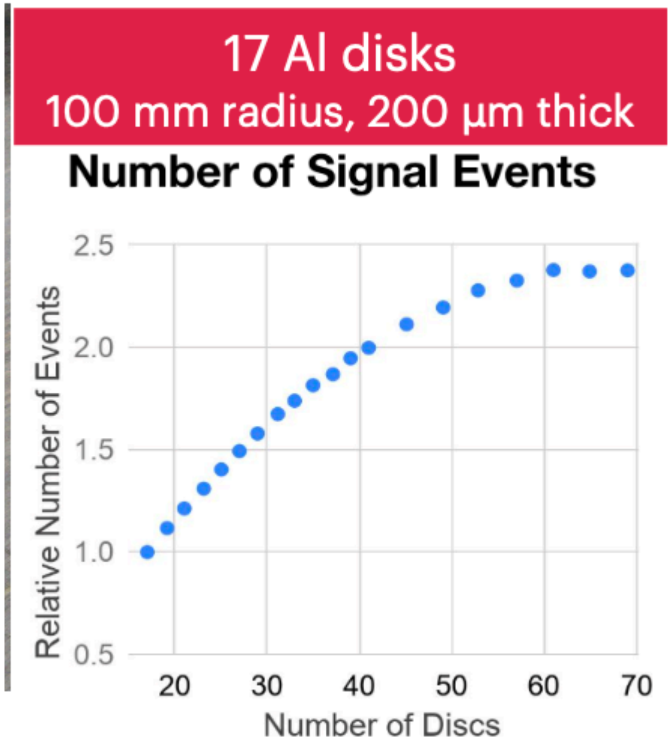

SHINSEI co. / USR 60-E3NT


Retroreflector

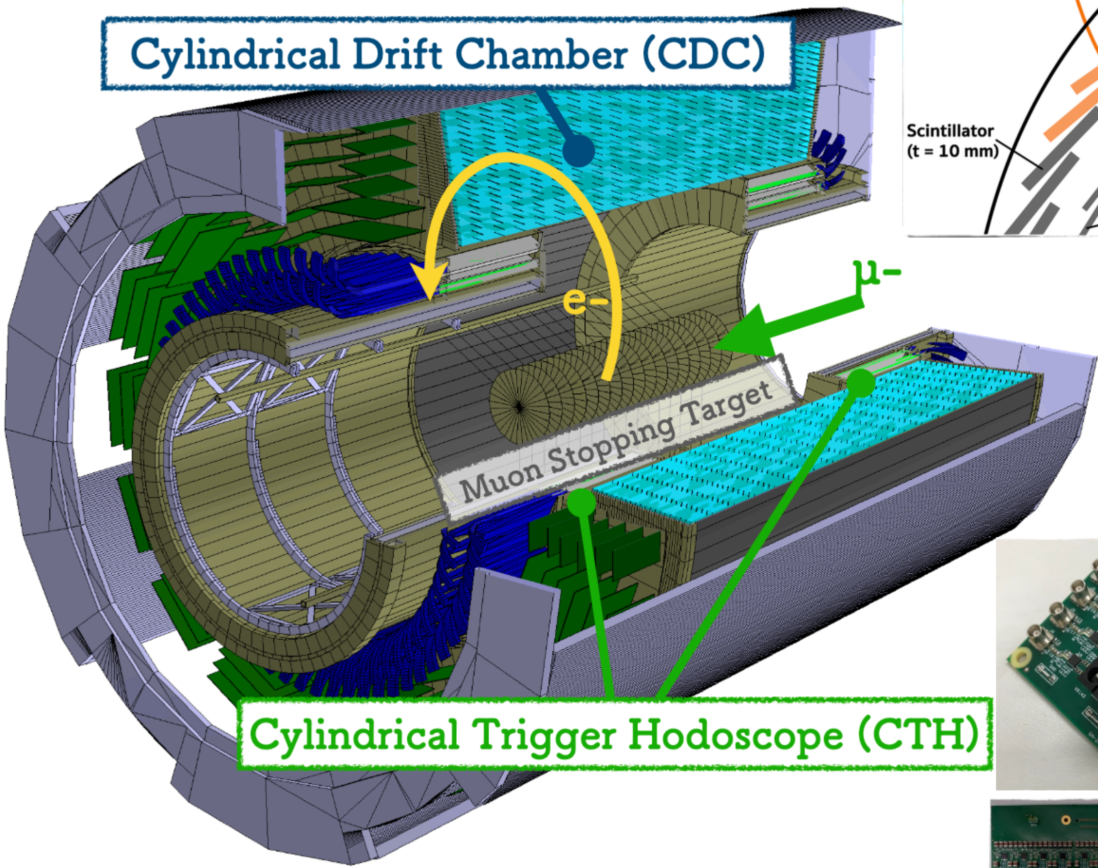
COMET Phase-I :: Aluminium Muon Target

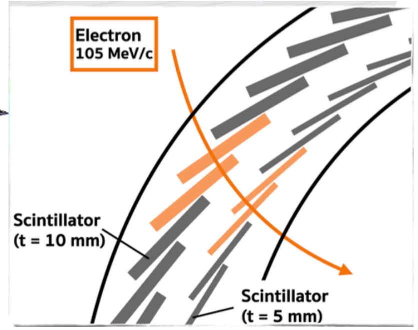
- 17 aluminium discs
- 10 cm radius, 200 µm thickness, and 50 mm spacing.
- Stability and performance tests of various aluminium alloys concluded.

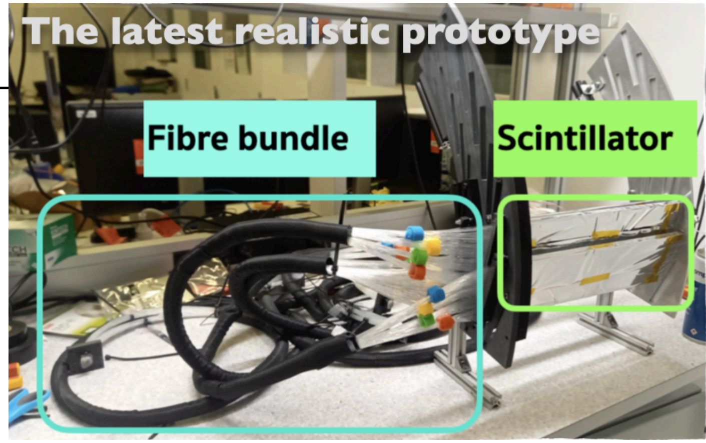


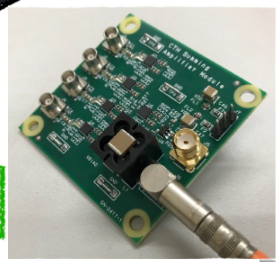


COMET Phase-I :: Cylindrical Drift Chamber and CTH









- Trigger : 4-fold coincidences
- *T0* measurement for tracking

- 2 wheels of 2×64 plastic scintillators
- 5 mm (inner) 10 mm (outer) thick
- > 40 p.e. for a detection efficiency > 99%
- MPPCs + plastic fibre bundle readout.
- Inner lead shield to block gamma rays from inside.

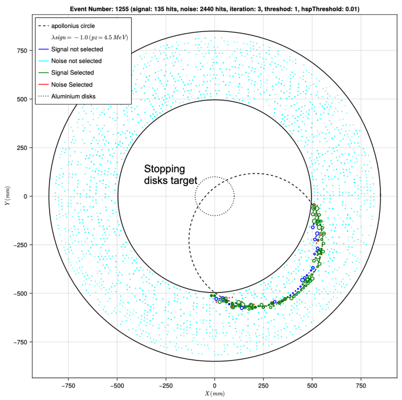
- MPPCs operated < −36°C (radiation damage).

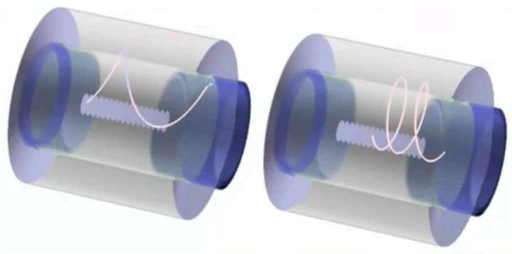
- Front-end electronics being produced
- Mass production will start soon

- Y. Fujii, et al., Nucl. Instrum. Methods Phys. Res. A, 1067 (2024)

COMET Phase-I :: Cylindrical Drift Chamber

da Silva et al, https://arxiv.org/abs/2401.04576

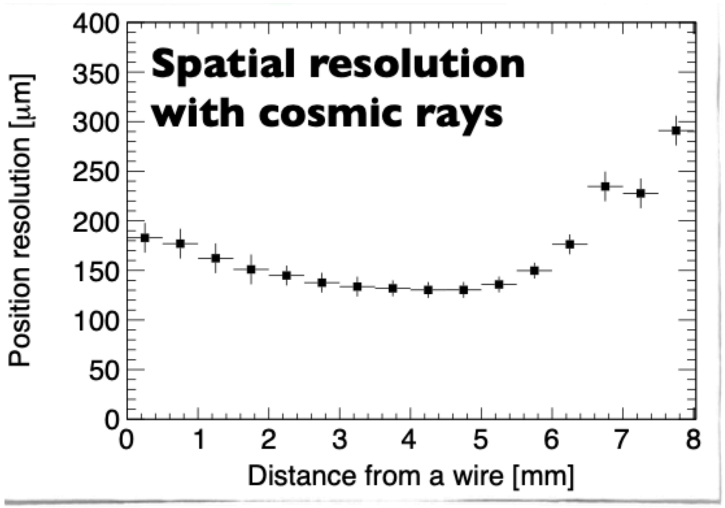


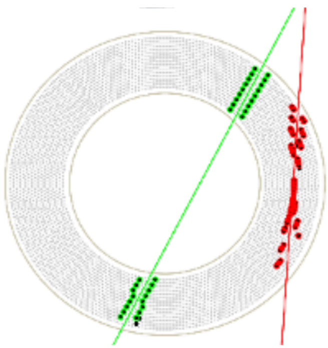


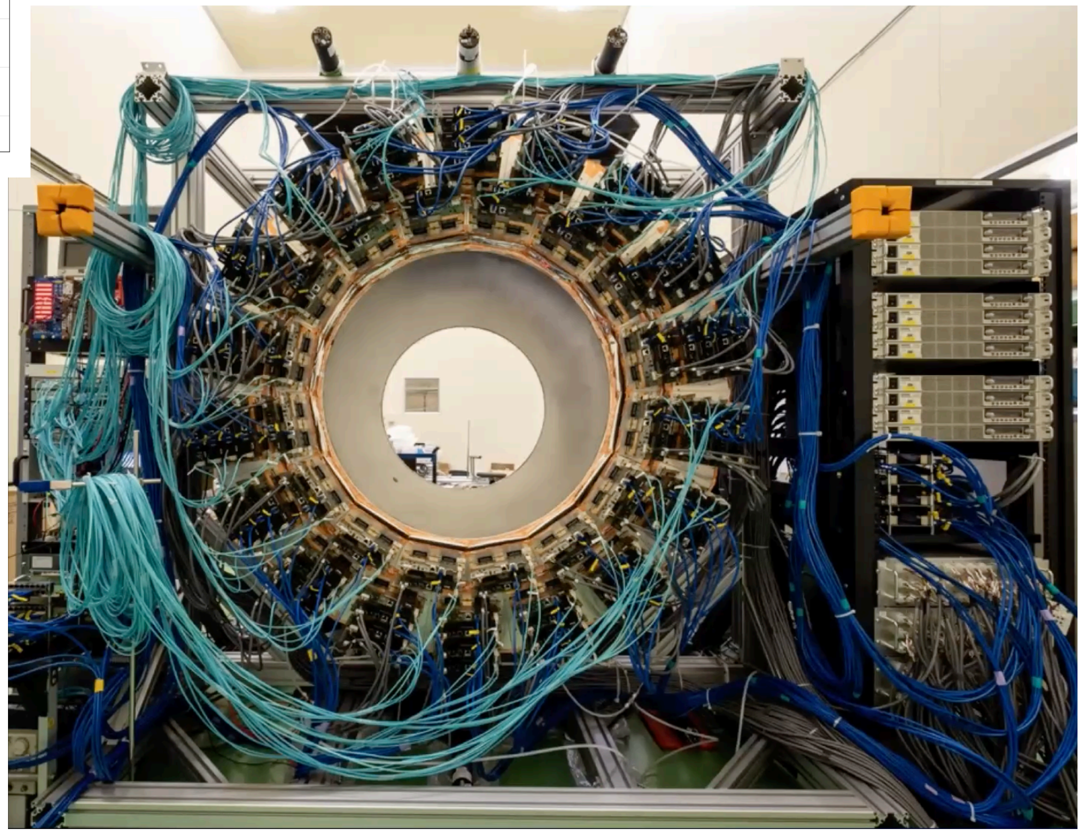
A. Sato, et al., Nucl. Instrum. Methods Phys. Res. A, 1069 (2024), 169926

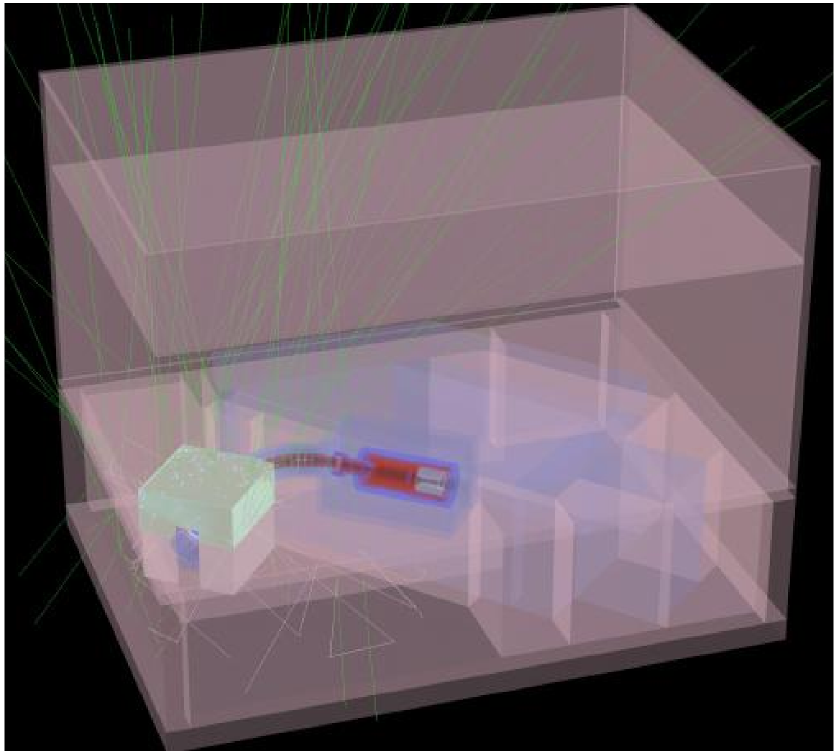
- 20 concentric sense layers (~5000 gold plated sense wires)
- mechanical design based on Belle II CDC
- all stereo layers ± 70 mrad (alternate)
- Helium based gas (He:iC4H10=90:10) to minimise multiple scattering
- large inner bore (~500 mm) to avoid beam flash and DIO

Momentum resolution: better than 200 keV/c @ 105 MeV/c







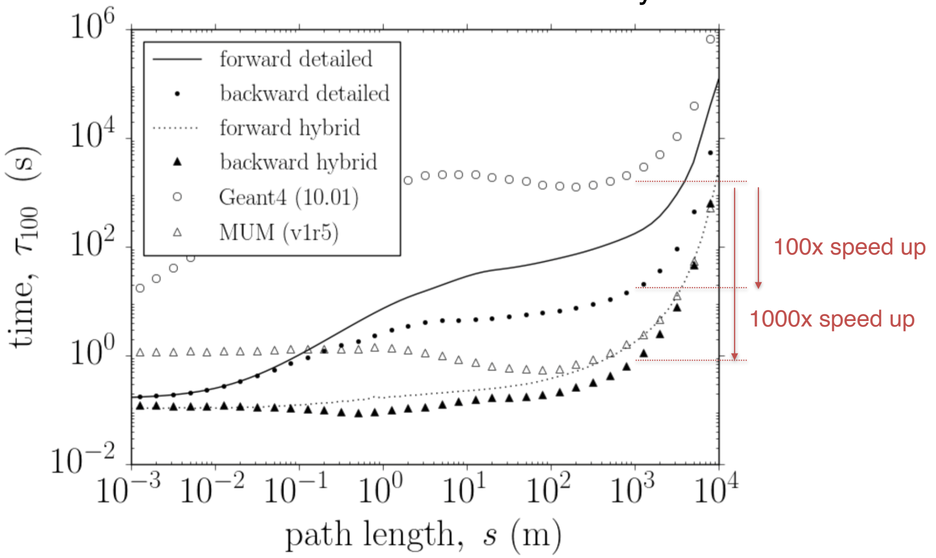


Rare muons and muon-induced electrons w/o CRV signals, undergoing high angle scattering before penetrating in the detection volume

Very expensive to simulate with high accuracy with direct MC (G4),much better with a backward MC

V. Niess *et al*, CPC 2018, 229, pg 54

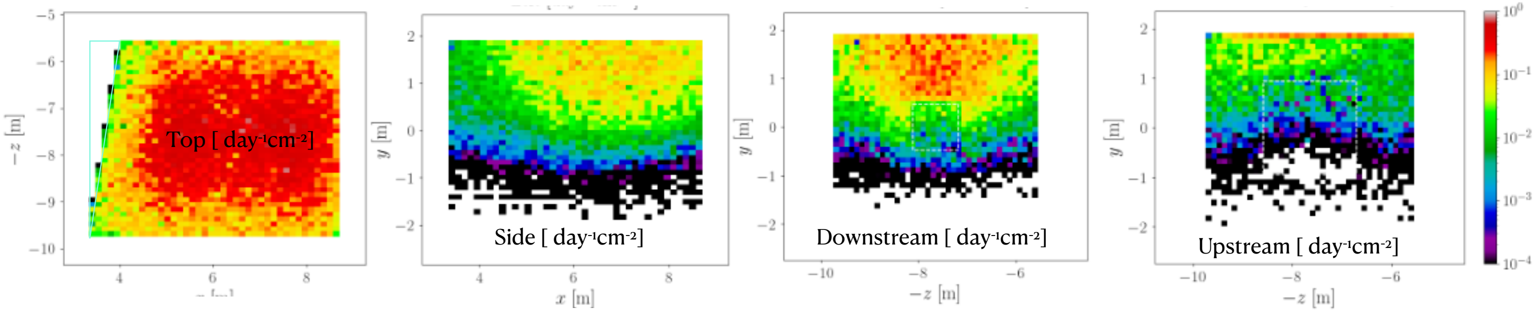
CPU time needed to simulate the transmitted flux with 1% accuracy

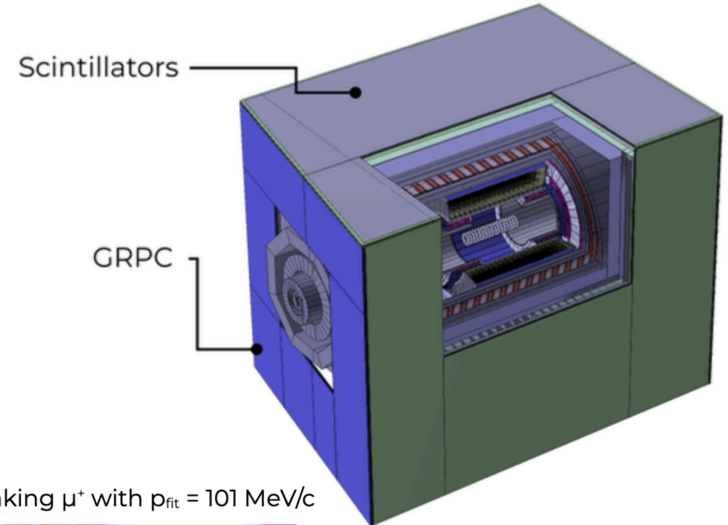


Non analog simulation using Importance Sampling and Backward Monte Carlo

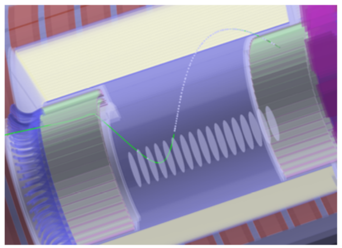
Mitigating the Atmospheric Background

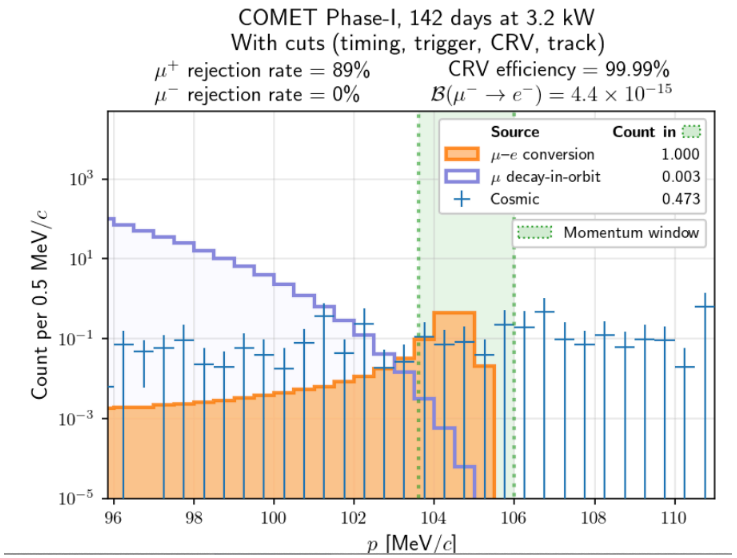
Maps of the triggering atmospheric muons

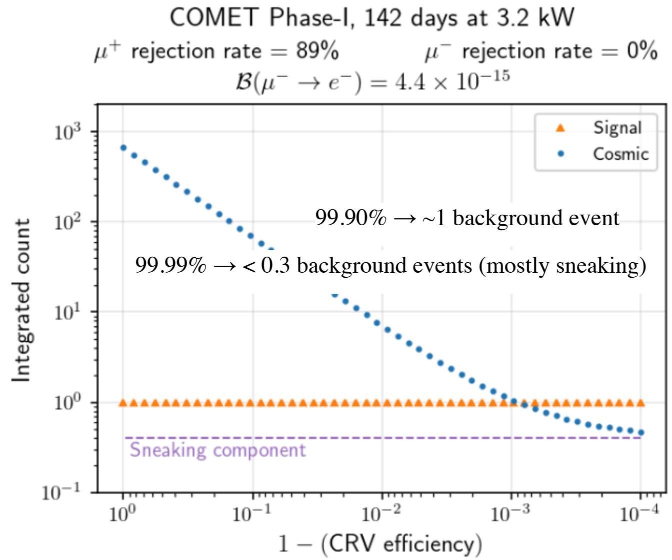


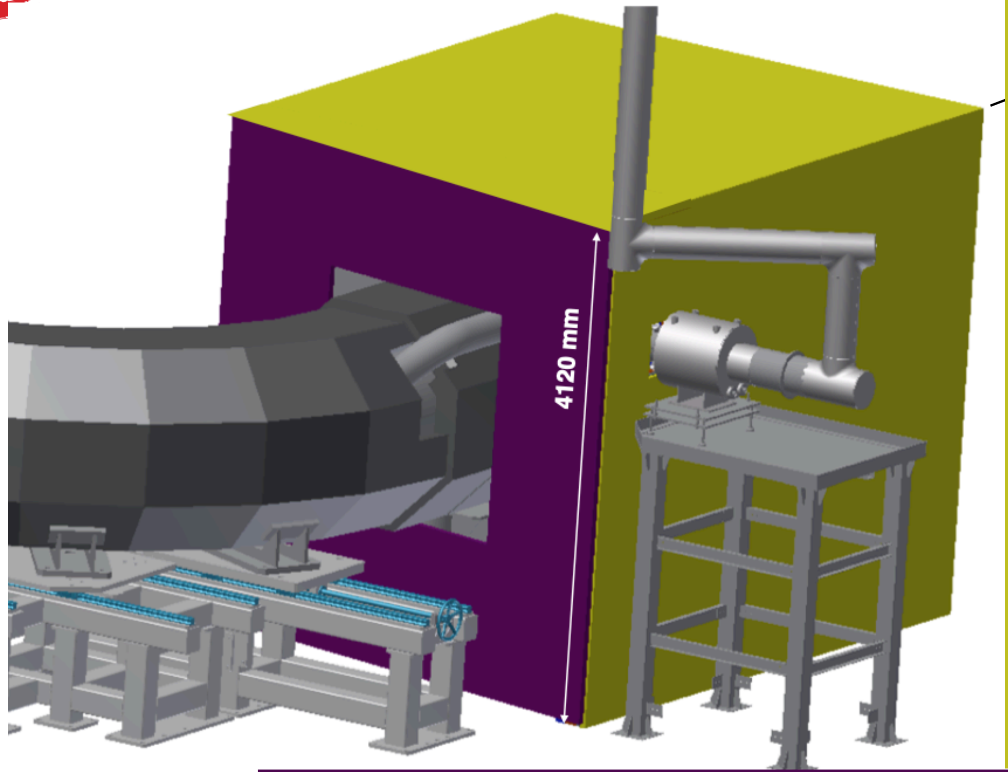


Sneaking μ^+ with p_{fit} = 101 MeV/c

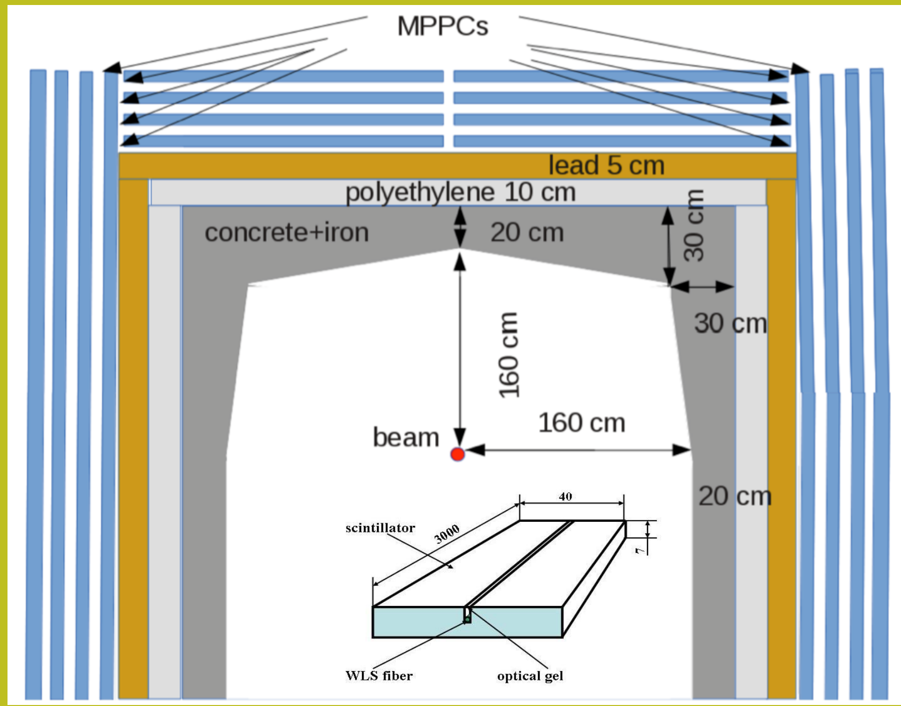








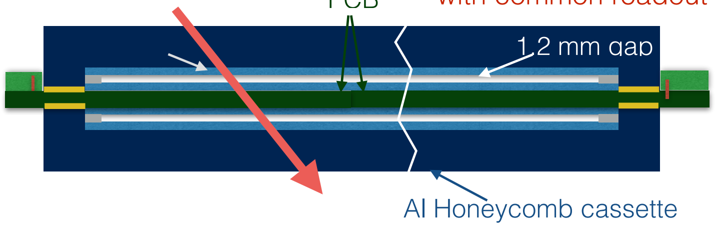
Scintillators CRV



iRPC CRV (© CMS)

A tracker module: 5 detector modules (baseline)

a module (1900x600 mm2):
two single-gap RPCs
with common readout



Conclusion

- COMET at J-PARC will search for neutrinoless muon to electron conversion with an expected SES of 3×10^{-15} (Phase-I) and $O(10^{-17})$ (Phase-II).
- A direct measurement of the beam profile and backgrounds to be performed in Phase-I.
- The facility & beam line construction expected to be completed ~ next year.
- Very busy finishing building the detectors right now …
- We will start with low-intensity (~10% power) commissioning runs in 2027.