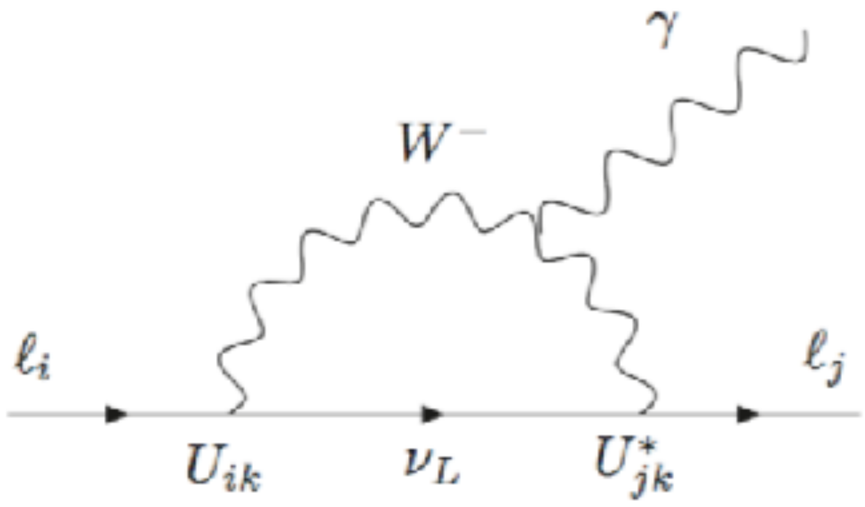
Société Française
de Physique

Search for new Physics with Muons at J-PARC

COMET

C Cârloganu, LPC/IN2P3/CNRS

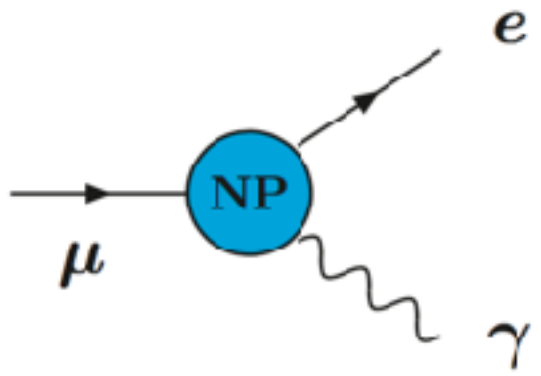
cLFV in muon channels



SM with $m_\nu > 0$

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

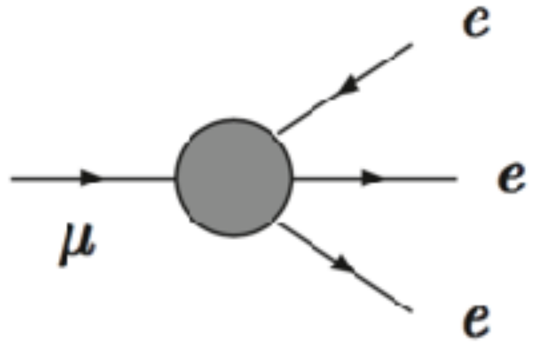
$\mu \to e\,\gamma$



Coincident
back-to-back e^+ - γ
$E_e = E_\gamma = m_\mu/2$ (~ 52.8 MeV)

BR($\mu \to e\gamma$) 90% C.L.		
PSI/MEG	**2016**	**4.2×10^{-13}**
PSI MEG II		4×10^{-14}

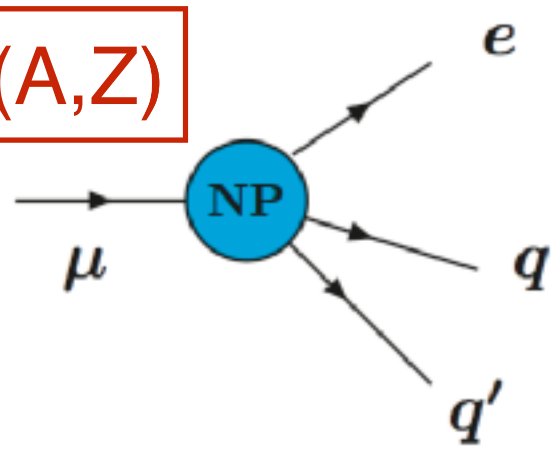
$\mu^+ \to e^+e^-e^+$



Σ E =m; $\Sigma \vec{P} = 0$
vertex; coincidence

BR($\mu \to$ eee) 90% C.L.		
PSI/SINDRUM	**1988**	**1.0×10^{-12}**
JINR	1991	3.6×10^{-11}
PSI/PSI/Mu3e		10^{-15} -

μ^-+ (A,Z) $\to$ e^-+ (A,Z)



E(Al, Pb, Ti) ≈100 MeV
single electron;
well defined energy
well defined time

$CR(\mu \to e, N), bound$		
4.3×10^{-12}	Ti	1993
4.6×10^{-11}	Pb	1996
7×10^{-13}	Au	2006

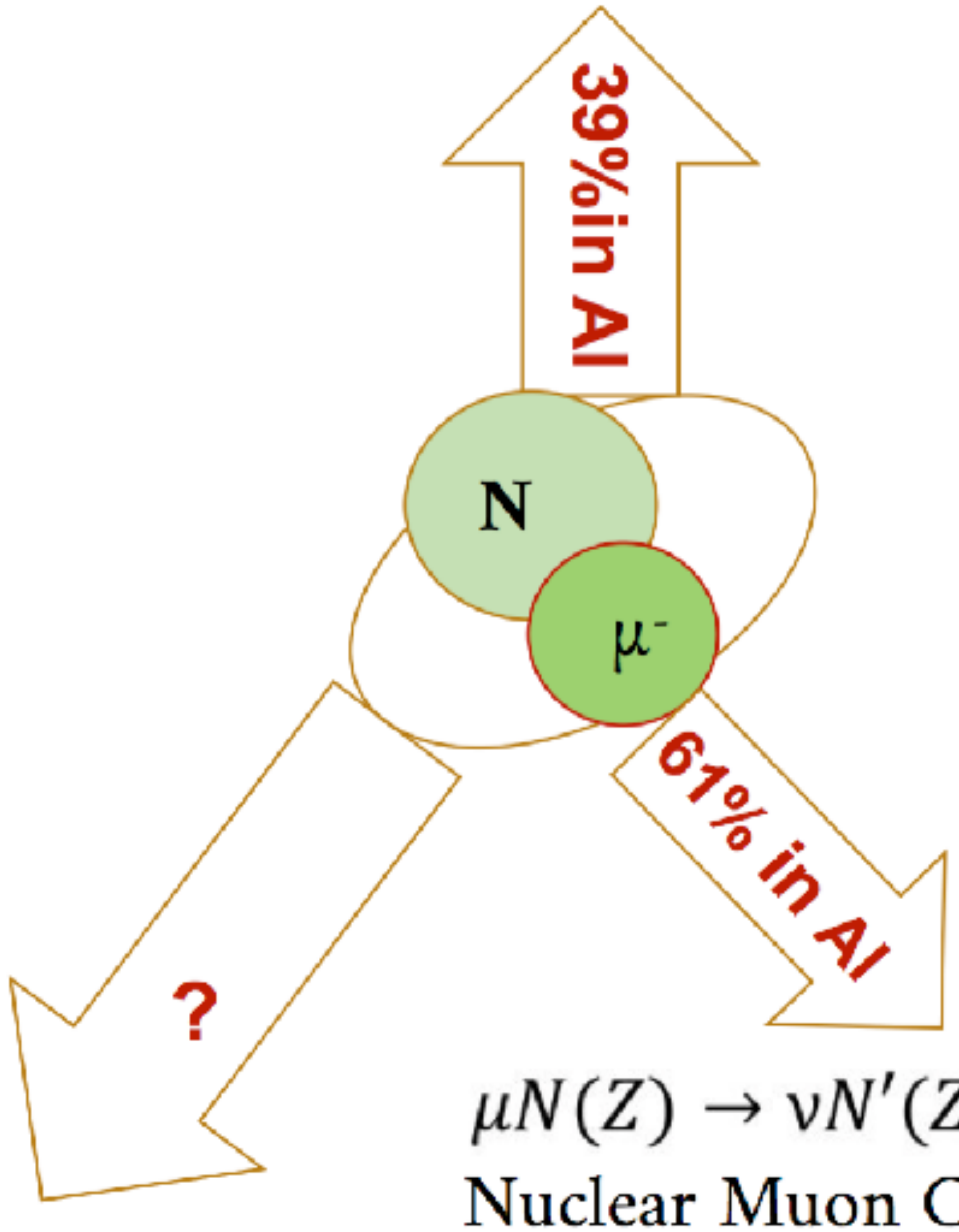
Muonic atoms

μ^- stopped in a target → 1s bound state

+

muonic X-Rays

Decay In Orbit $\mu N \rightarrow e \nu \bar{\nu} N$



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

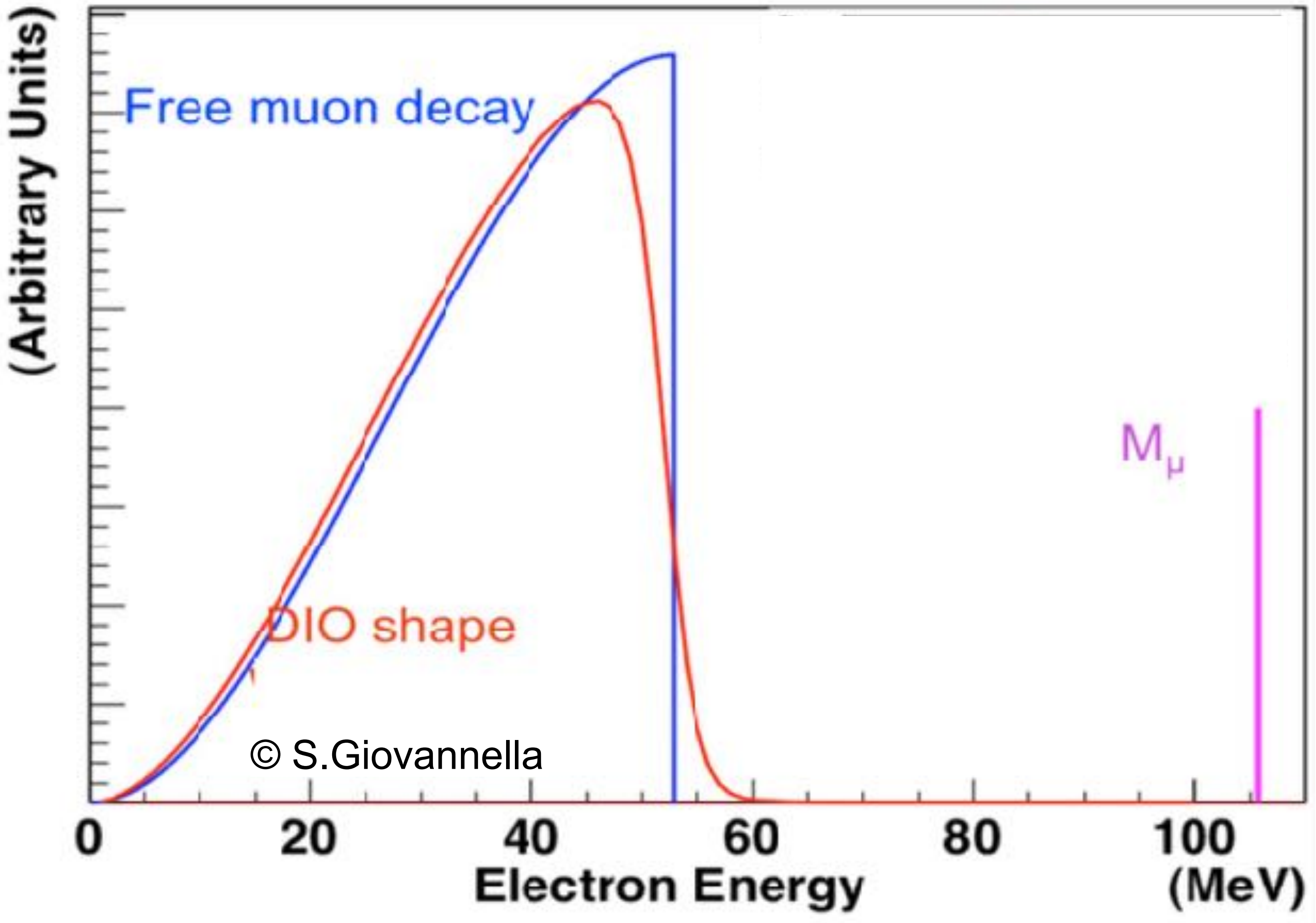
Nuclear Muon Capture

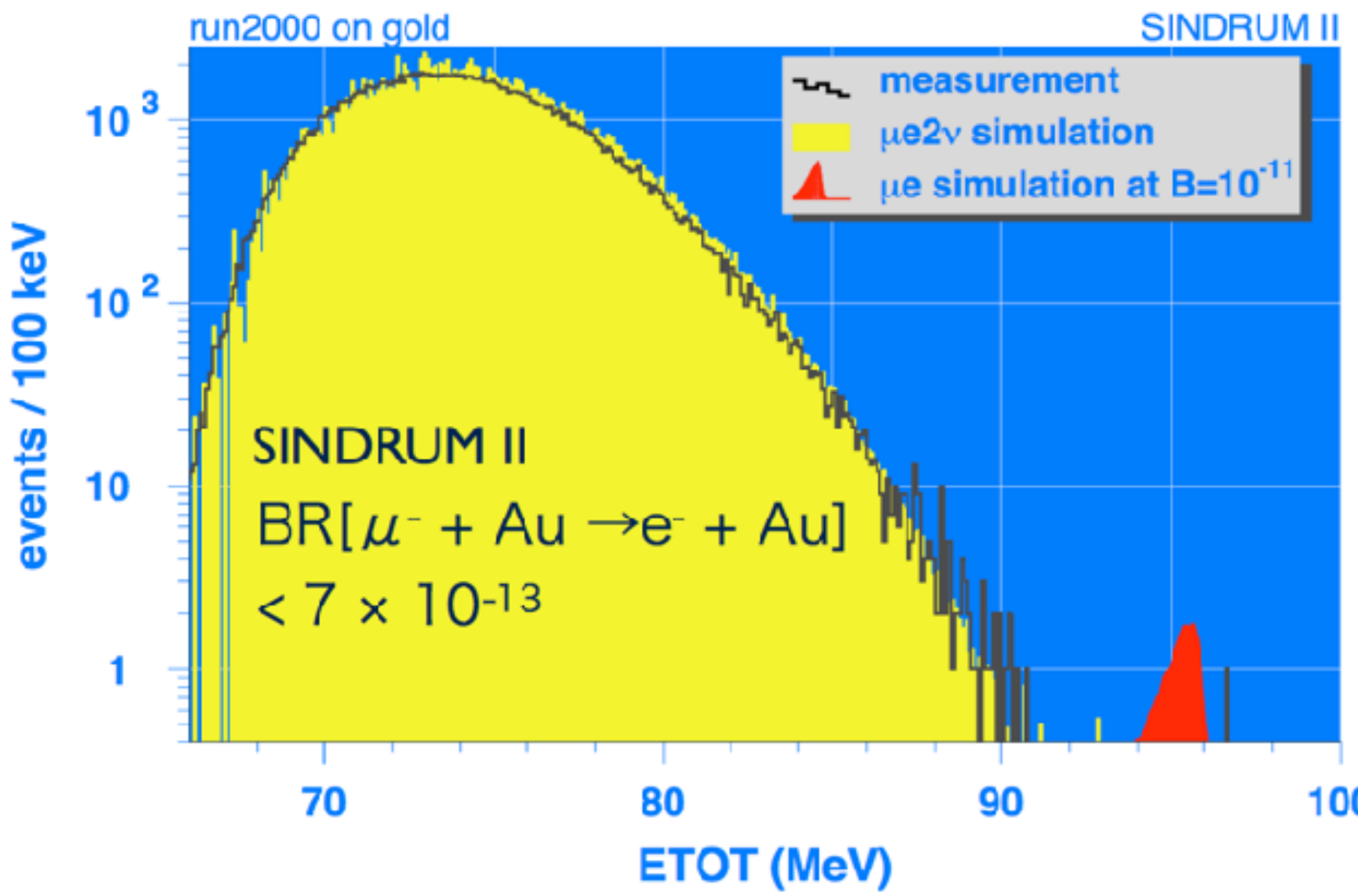
⇩

low energy neutrons, protons, γ's

⇩

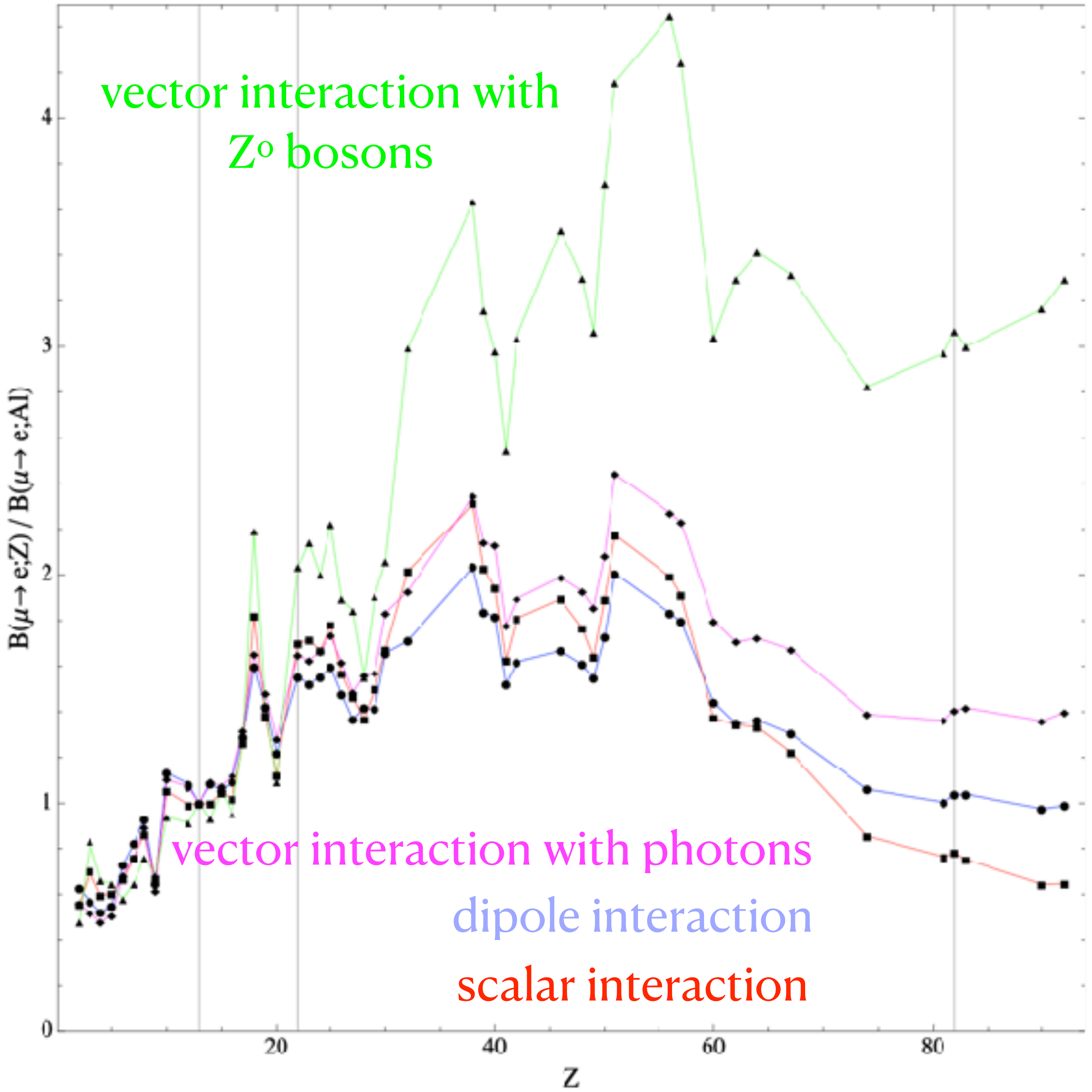
noise in the detector



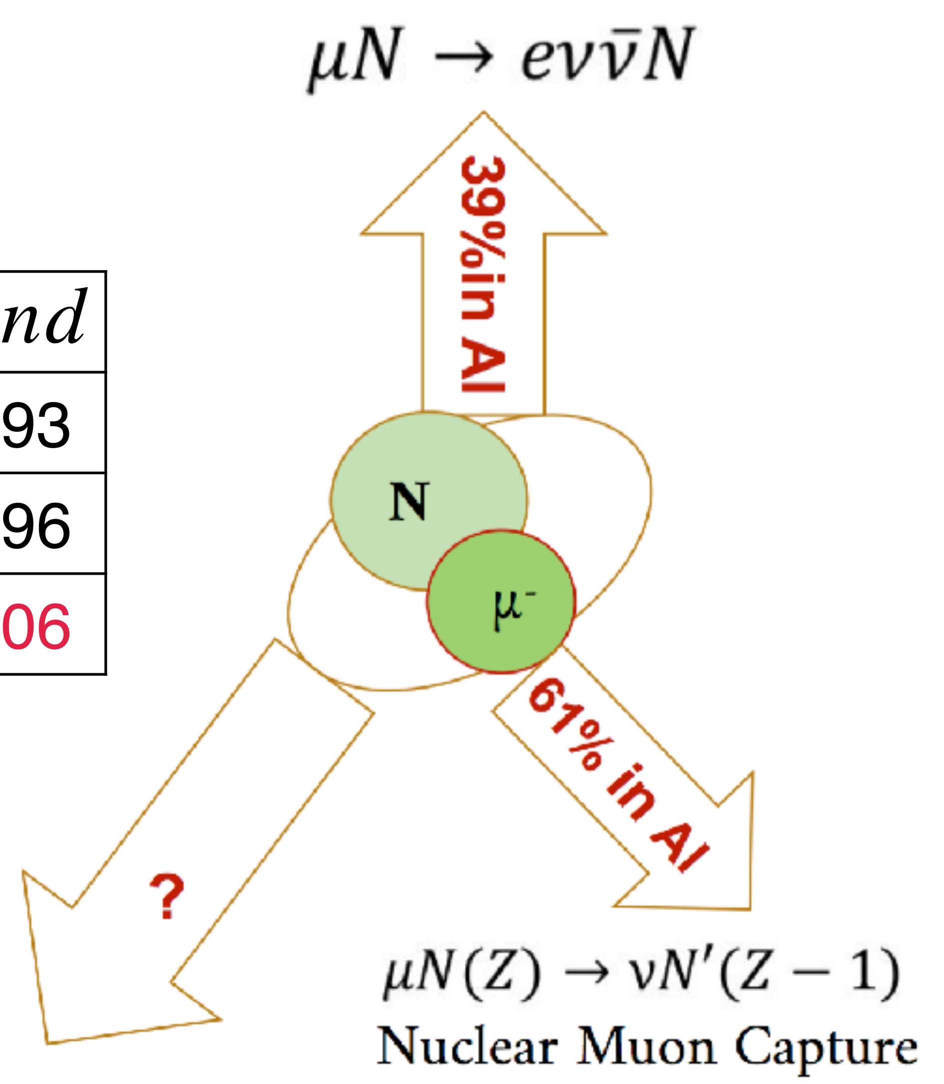


Required momentum resolution : better than 200 keV/c

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



Decay In Orbit

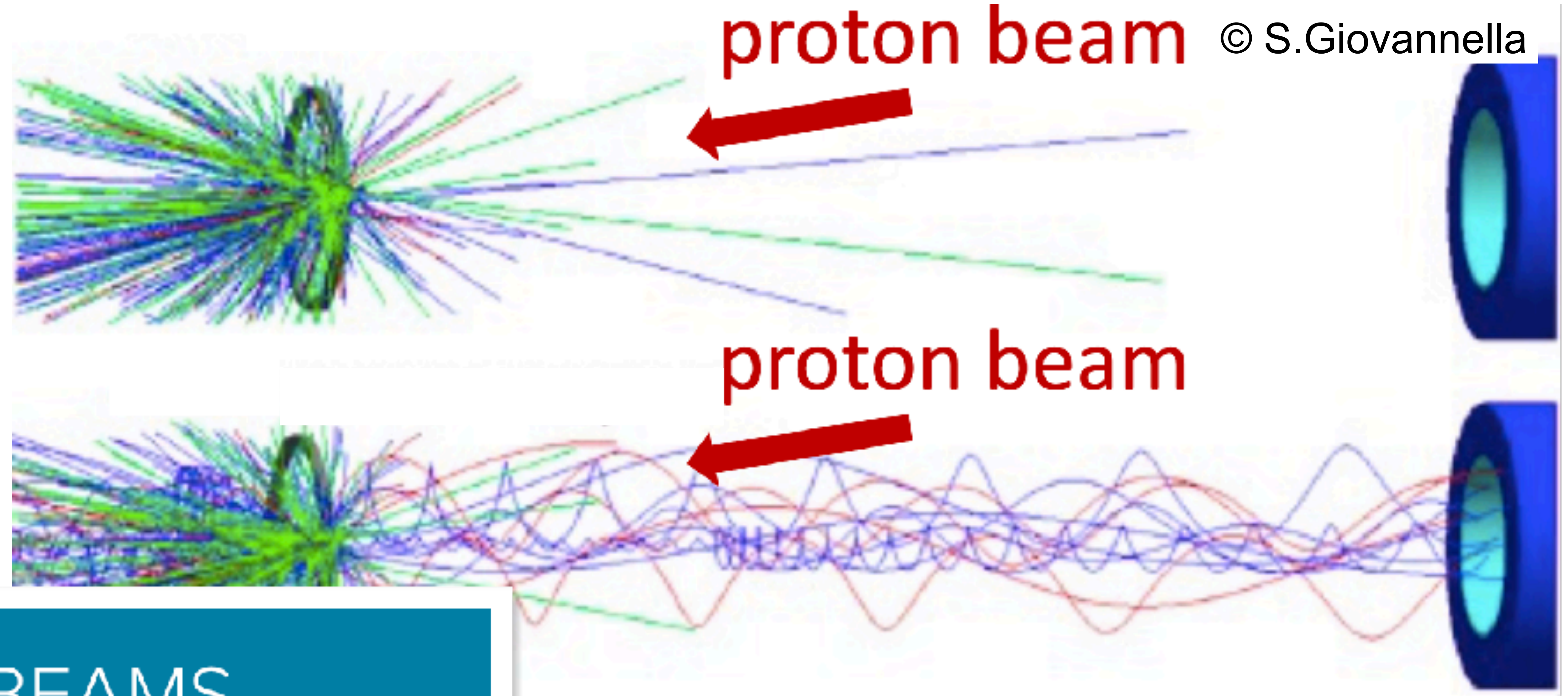


$CR(\mu \to e, N), bound$		
4.3 x 10^{-12}	Ti	1993
4.6 x 10^{-11}	Pb	1996
7 x 10^{-13}	Au	2006

© Lobashev and Djilkibaev, MELC experiment [Sov.J.Nucl.Phys. 49, 384 (1989)]

Soft pions confined with solenoidal B field

Strong gradient to increase the yield through magnetic reflection



PHYSICAL REVIEW ACCELERATORS AND BEAMS

Highlights Recent Accepted Special Editions Authors Referees Sponsors Search

Editors' Suggestion Open Access

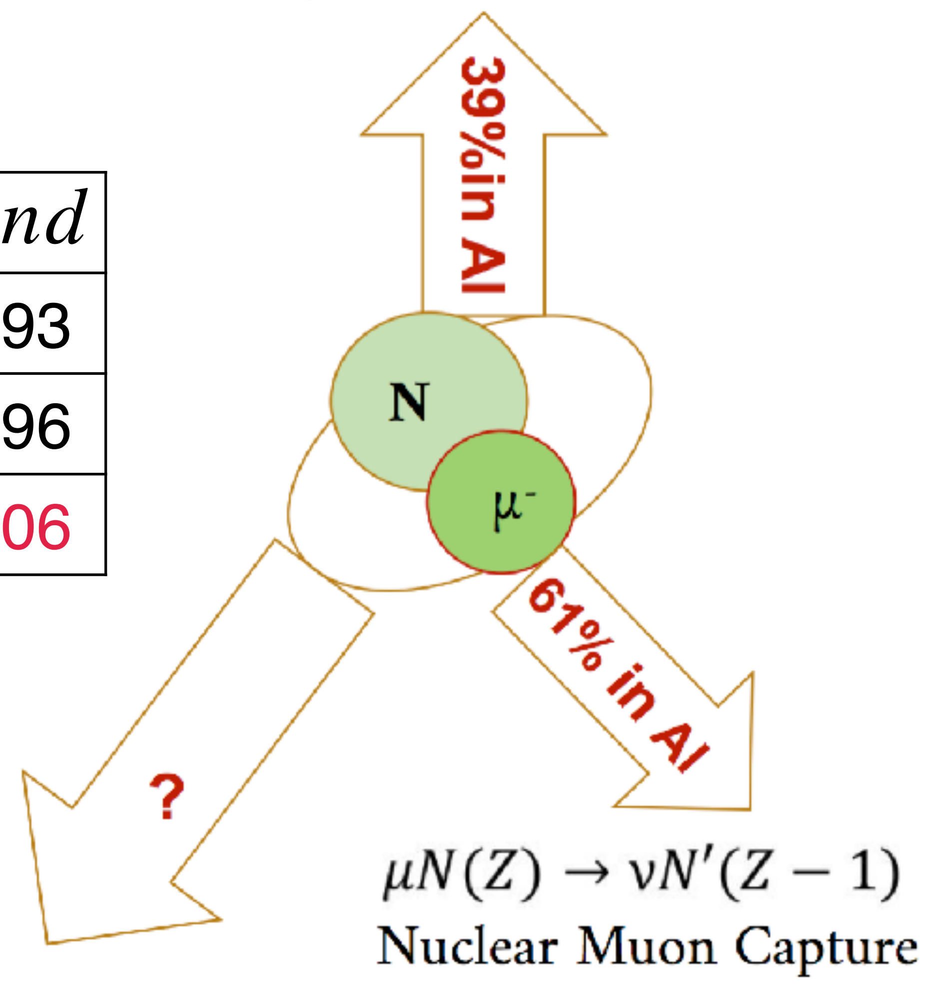
Delivering the world's most intense muon beam

S. Cook, R. D'Arcy, A. Edmonds, M. Fukuda, K. Hatanaka, Y. Hino, Y. Kuno, M. Lancaster, Y. Mori, T. Ogitsu, H. Sakamoto, A. Sato, N. H. Tran, N. M. Truong, M. Wing, A. Yamamoto, and M. Yoshida

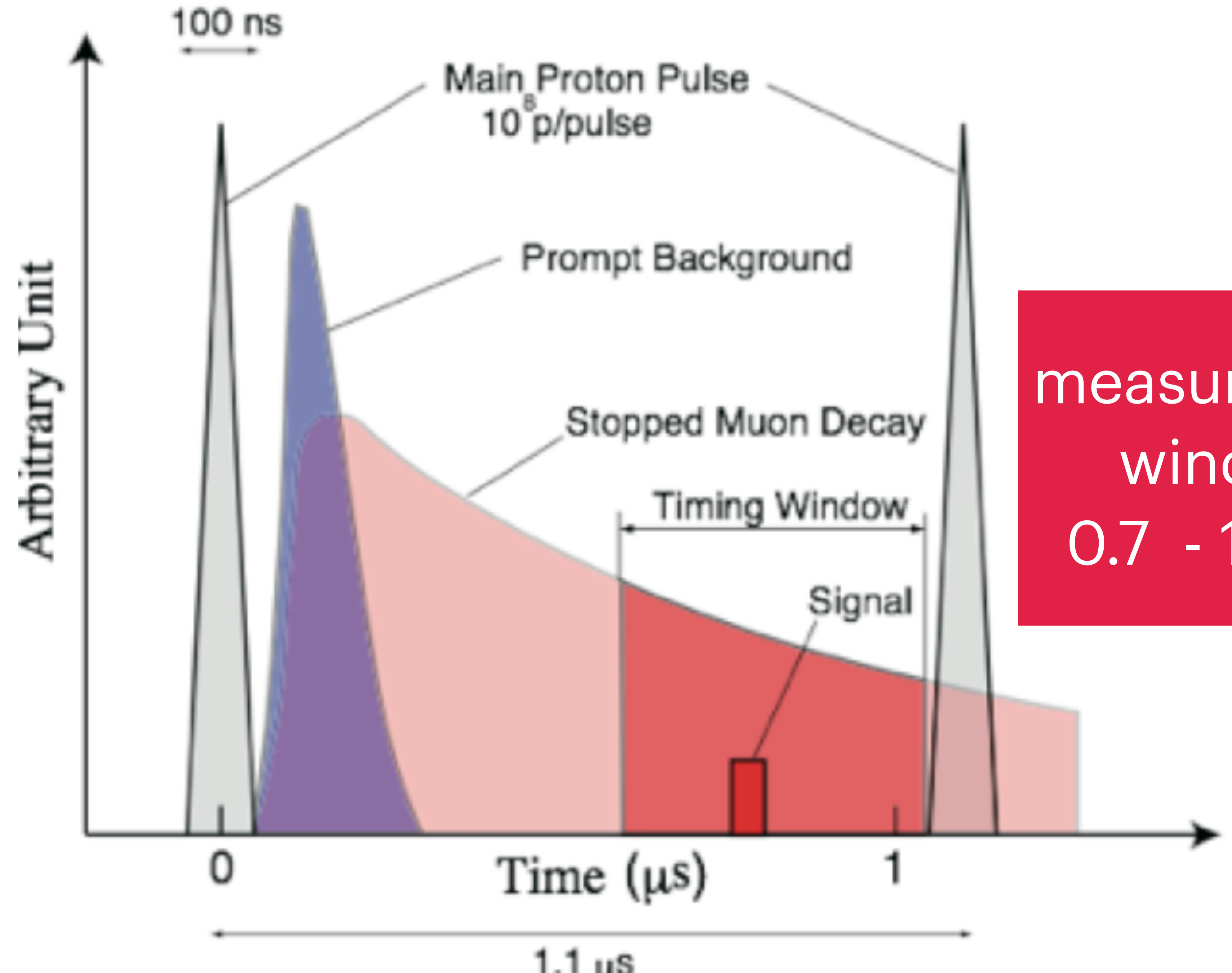
Phys. Rev. Accel. Beams **20**, 030101 – Published 15 March 2017

Decay In Orbit

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



$CR(\mu \to e, N)$, bound		
4.3 x 10^{-12}	Ti	1993
4.6 x 10^{-11}	Pb	1996
7 x 10^{-13}	Au	2006

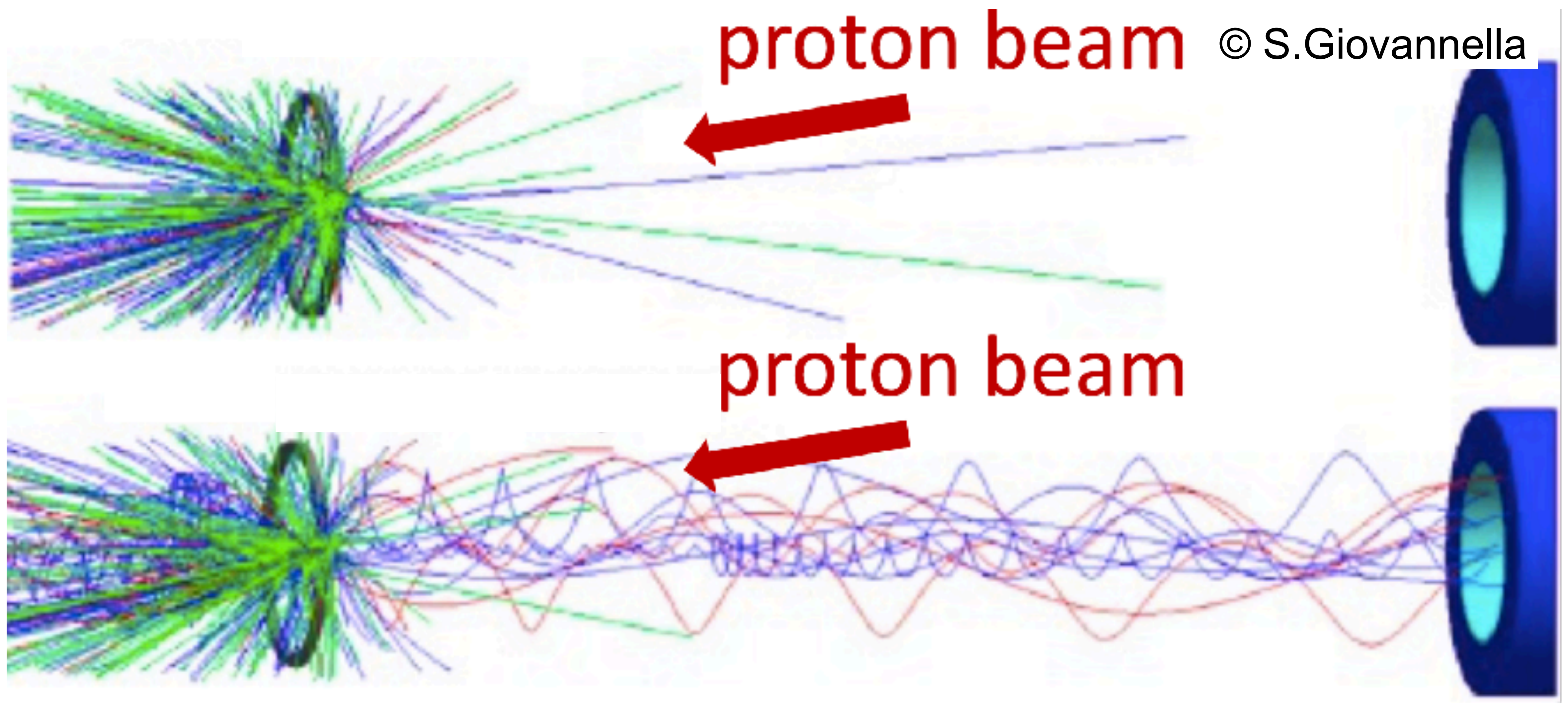


measurement window
0.7 - 1.17 μs

© Lobashev and Djilkibaev, MELC experiment [Sov.J.Nucl.Phys. 49, 384 (1989)]

Soft pions confined with solenoidal B field

Strong gradient to increase the yield through magnetic reflection



Delayed DAQ gate to suppress prompt backgrounds

Narrow proton pulses

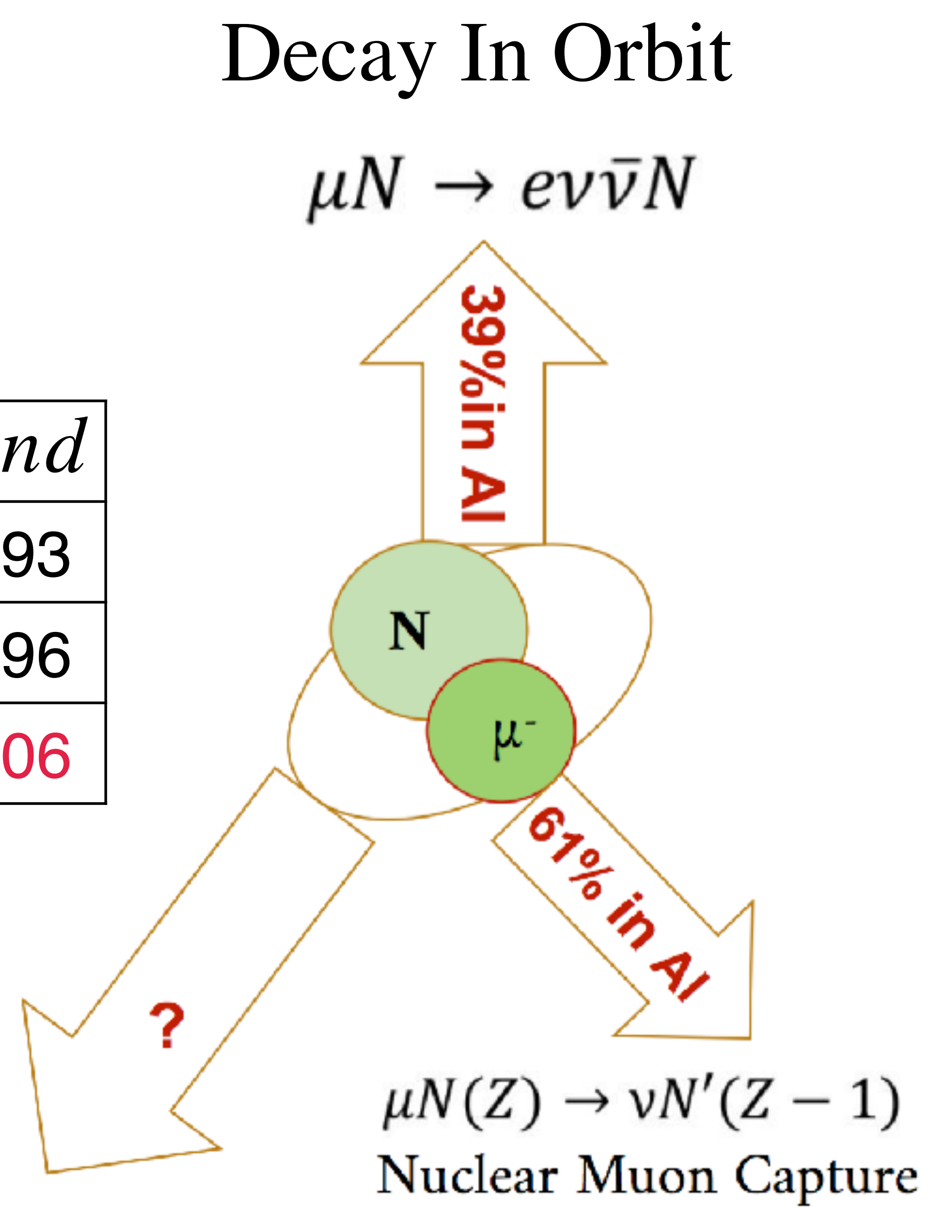
$O(10^{10})$ out-of-time protons suppression

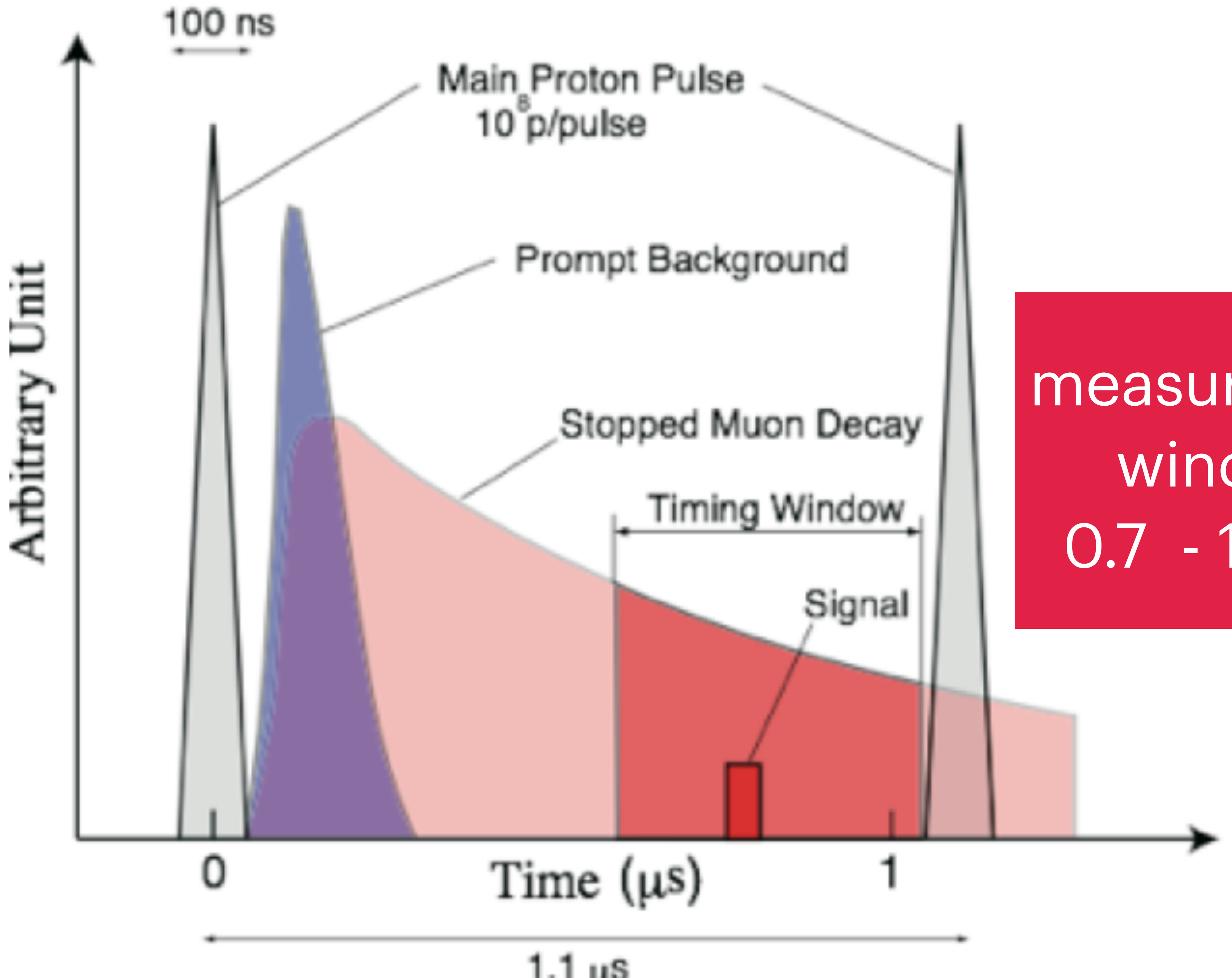
Material target	Atomic number (Z)	Muonium lifetime (ns)
Aluminum	13	864
Titanium	22	330
Lead	82	74

$\mu - e$ conversion in muonic atoms :: experimental concept

© Lobashev and Djilkibaev, MELC experiment [Sov.J.Nucl.Phys. 49, 384 (1989)]

$CR(\mu \to e, N), bound$		
4.3 x 10^{-12}	Ti	1993
4.6 x 10^{-11}	Pb	1996
7 x 10^{-13}	Au	2006

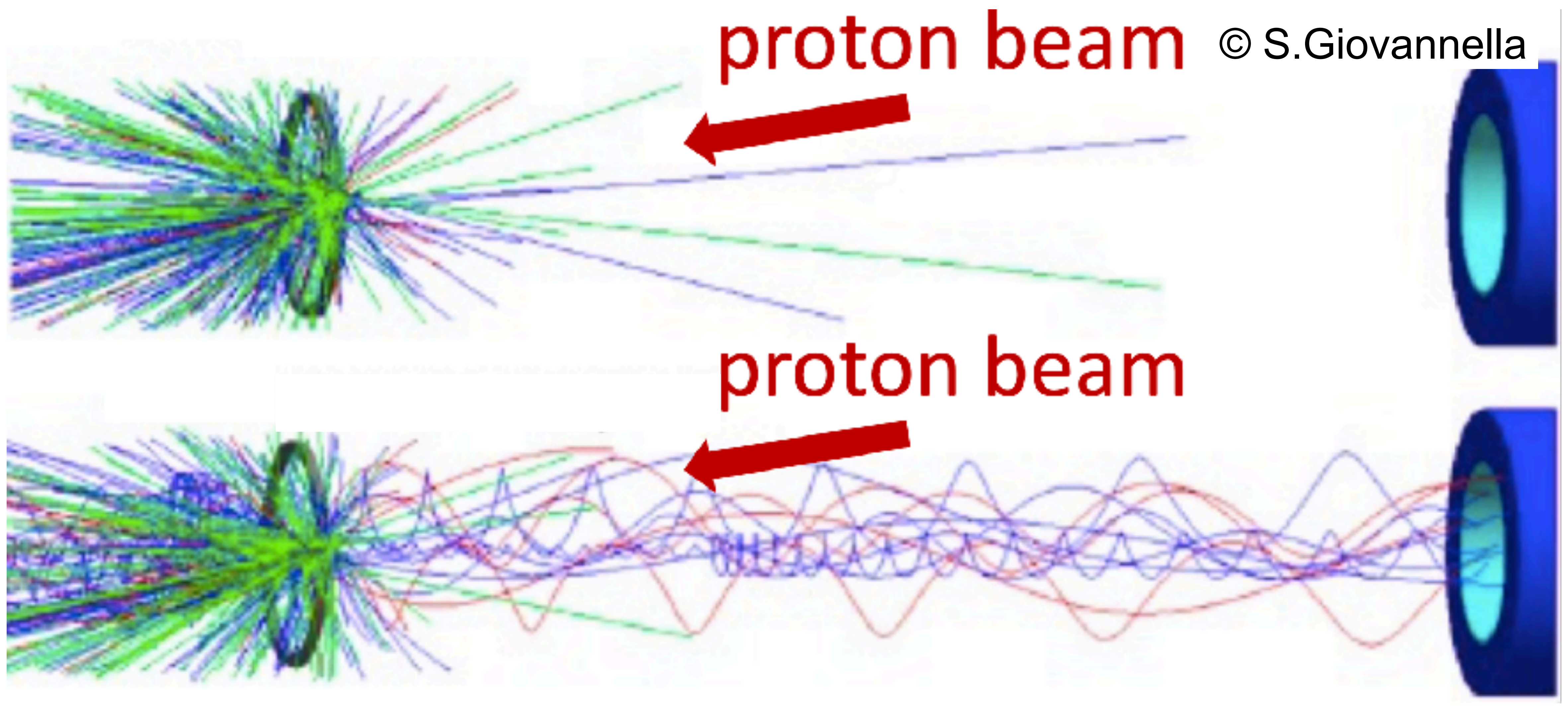




measurement window
0.7 - 1.17 μs

Soft pions confined with solenoidal B field

Strong gradient to increase the yield through magnetic reflection



Delayed DAQ gate to suppress prompt backgrounds

Narrow proton pulses

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

Atmospheric muons can fake signal events

⇒ proportional to the running time

⇒ higher beam intensity is preferrable

$\mu - e$ conversion in muonic atoms :: experimental strategy

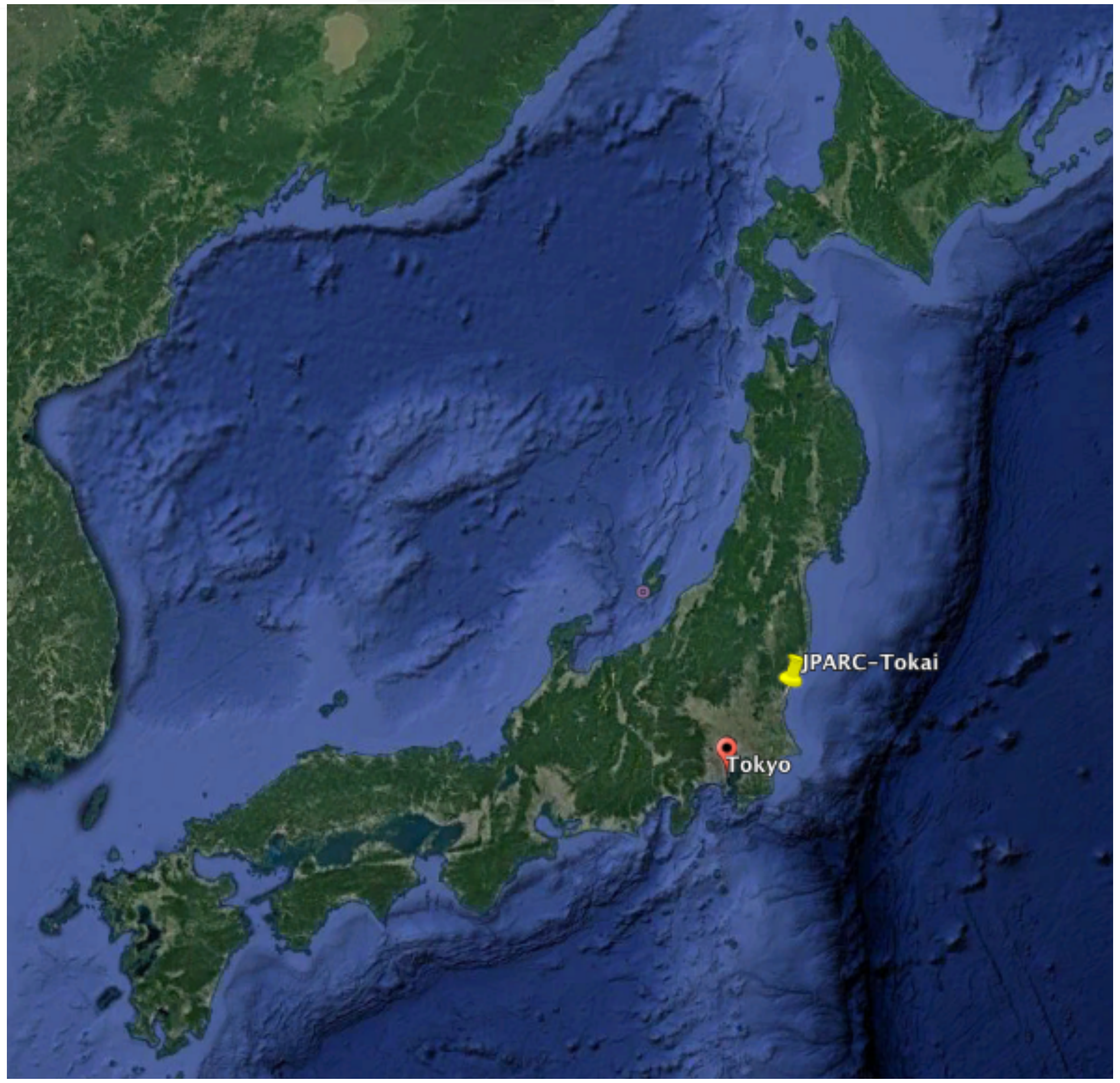
Improve by a factor 10^4 the present limit $R_{\mu e} < 7\ 10^{-13}$

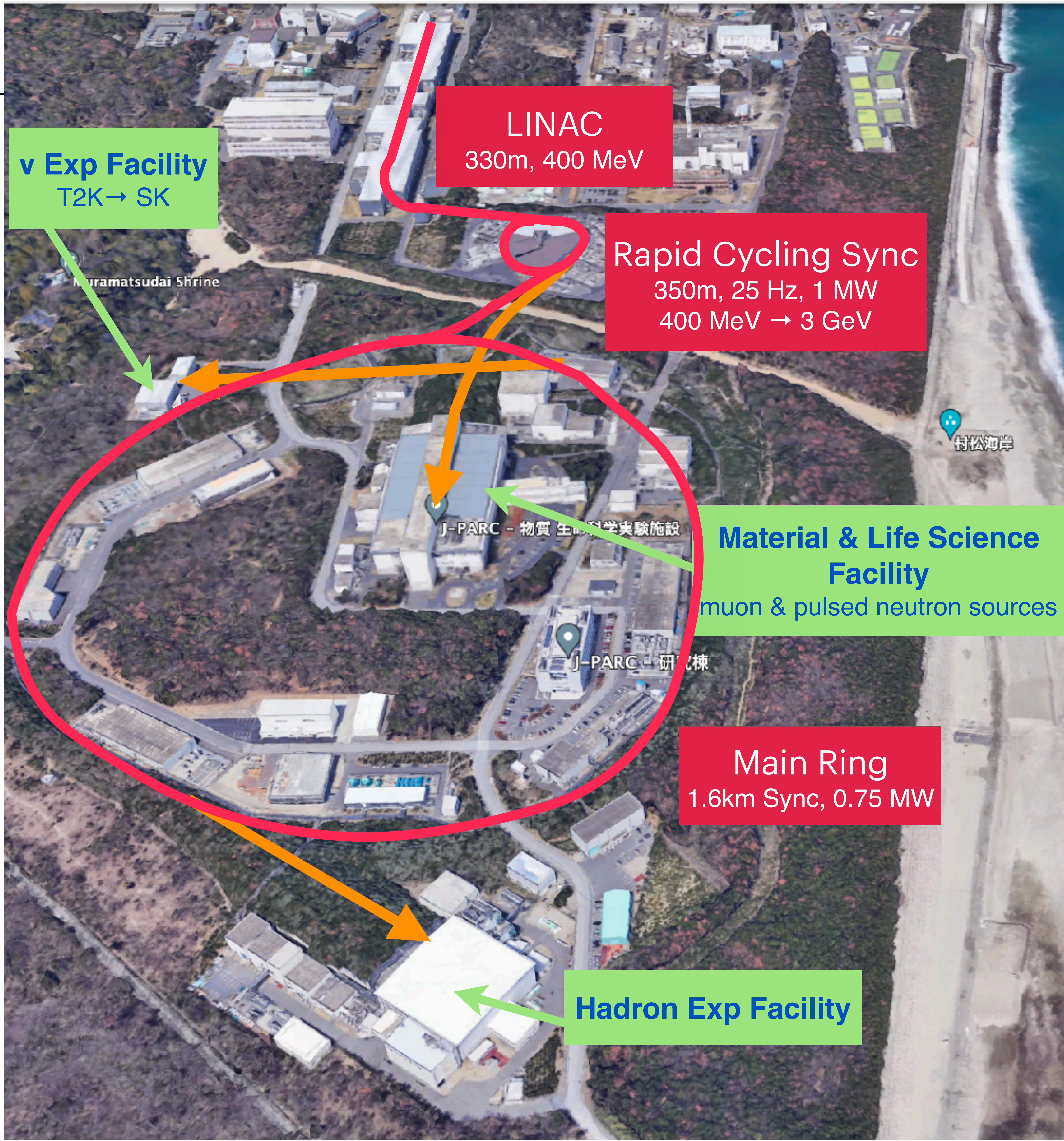
$$R_{\mu e} = \frac{\Gamma\left(\mu^- + N(A,Z) \rightarrow e^- + N(A,Z)\right)}{\Gamma\left(\mu^- + N(A,Z) \rightarrow \nu_\mu + N(A,Z-1)\right)}$$

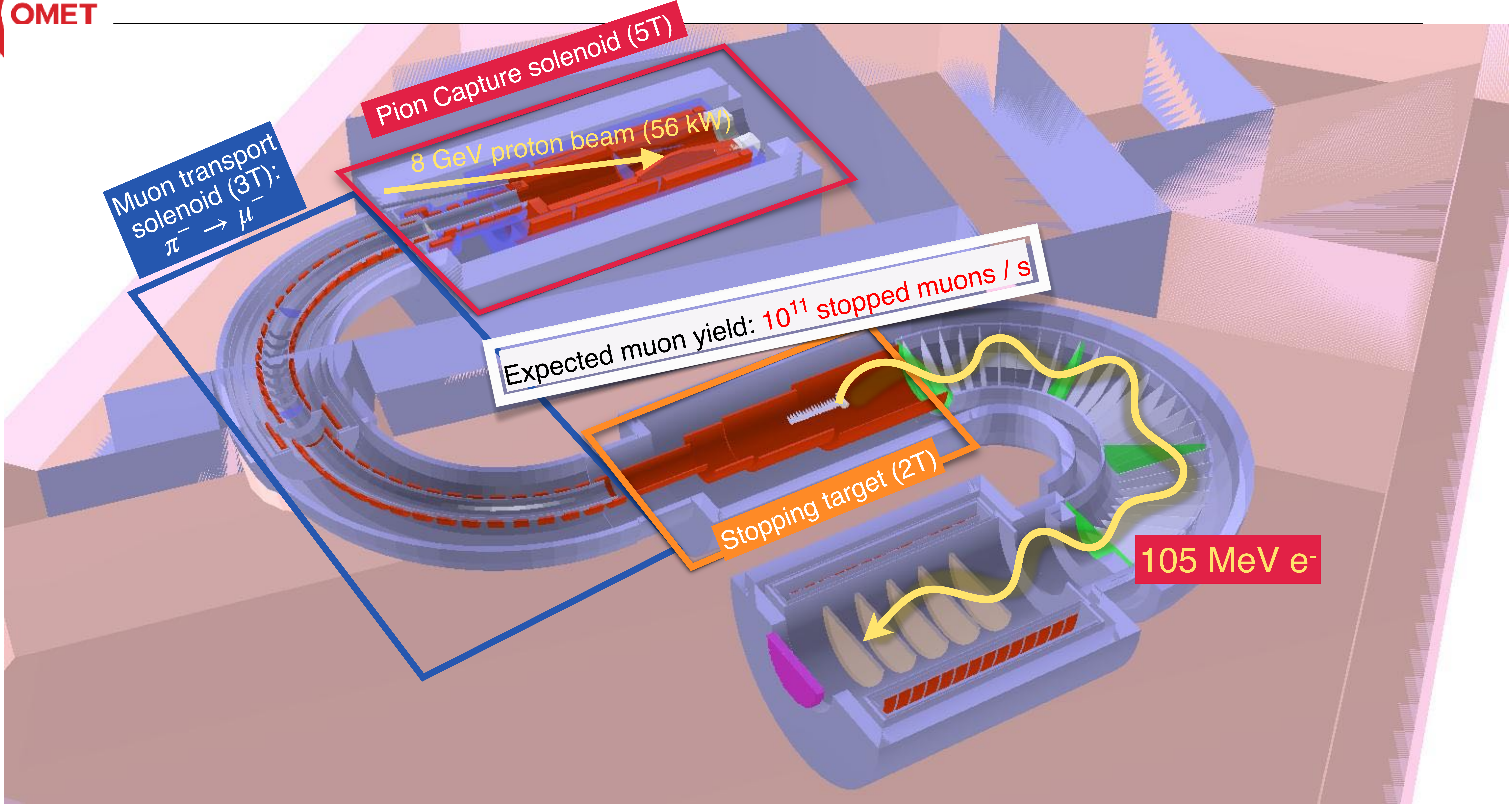
This requires:
- **10^{18} stopped muons**
- high background suppression (**$N_{bckg} \ll 0.5$**)

COMET @JParc Facility (KEK/JAEA)

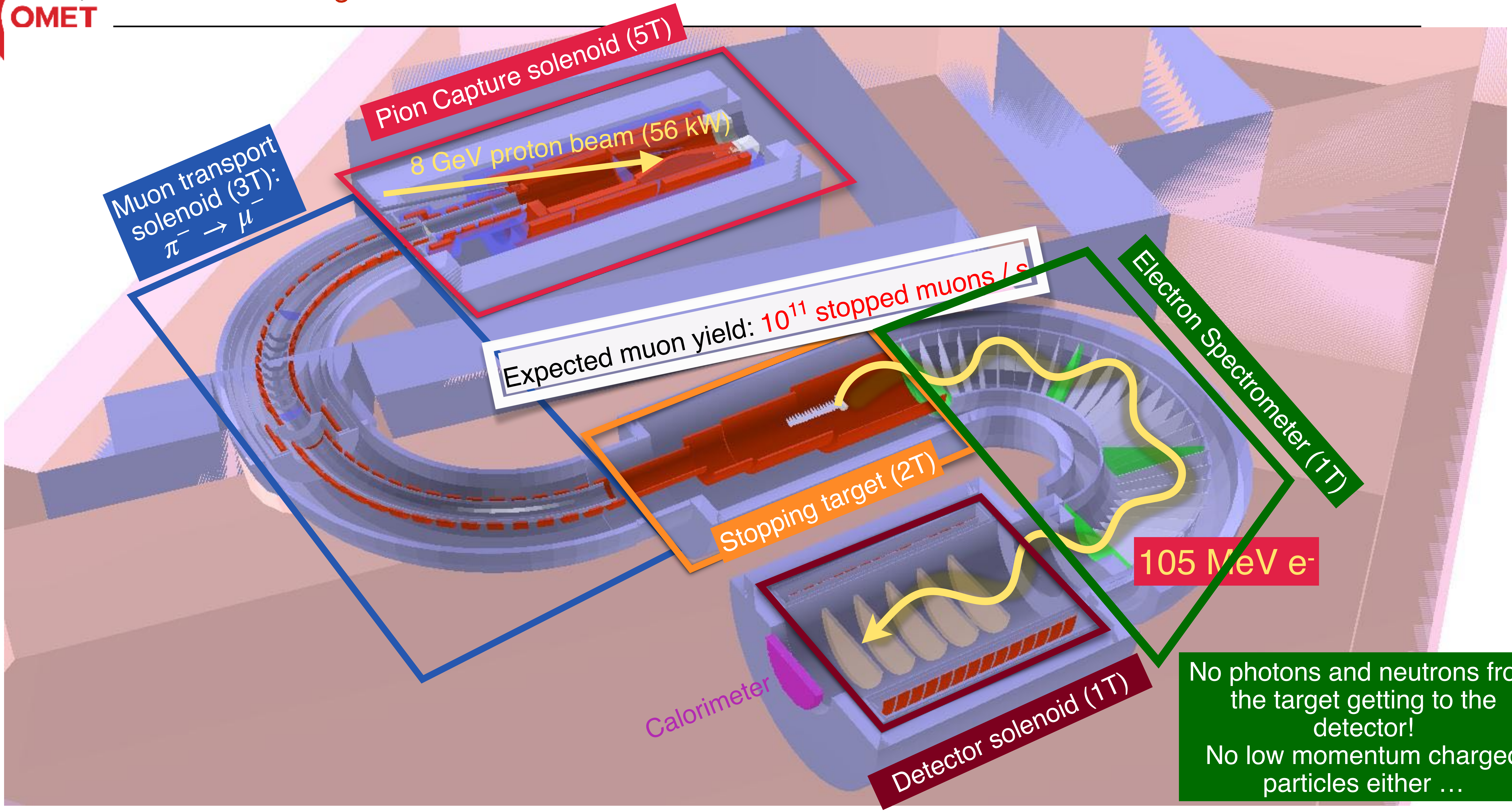
43 institutes,18 countries





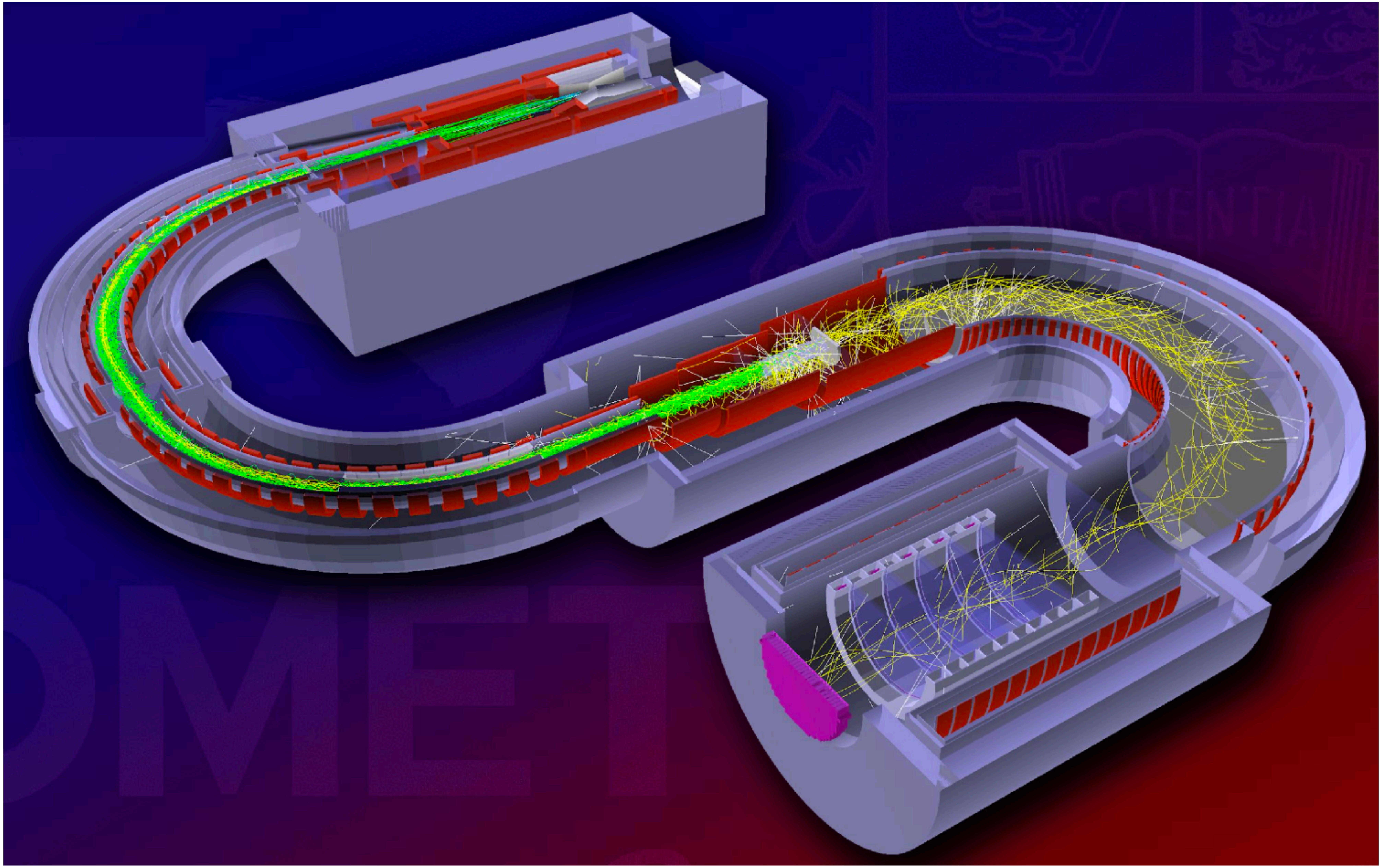

Pion Capture solenoid (5T)
8 GeV proton beam (56 kW)
Muon transport solenoid (3T): $\pi^- \to \mu^-$
Expected muon yield: 10^{11} stopped muons / s
Stopping target (2T)
105 MeV e-

COMET design

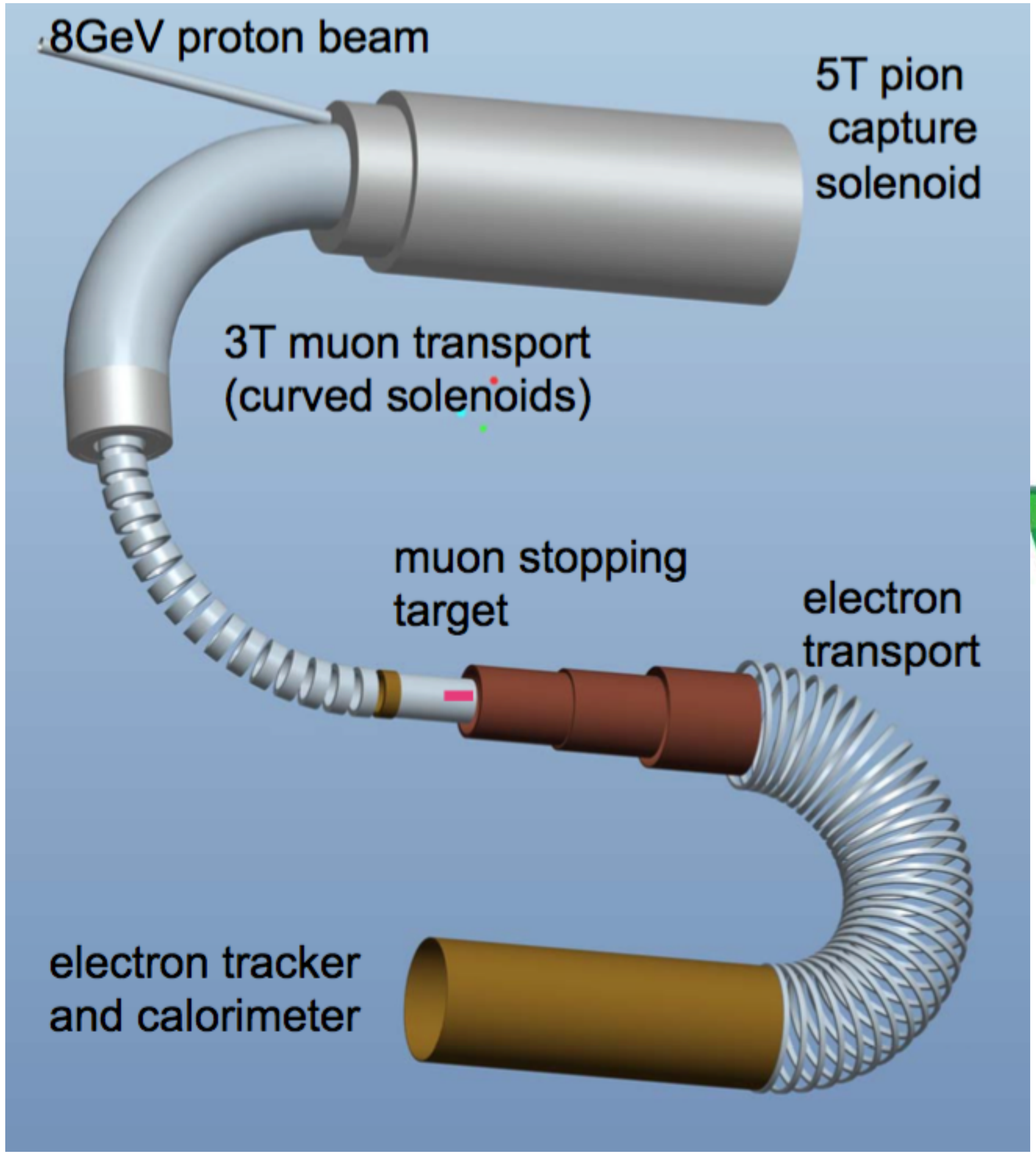


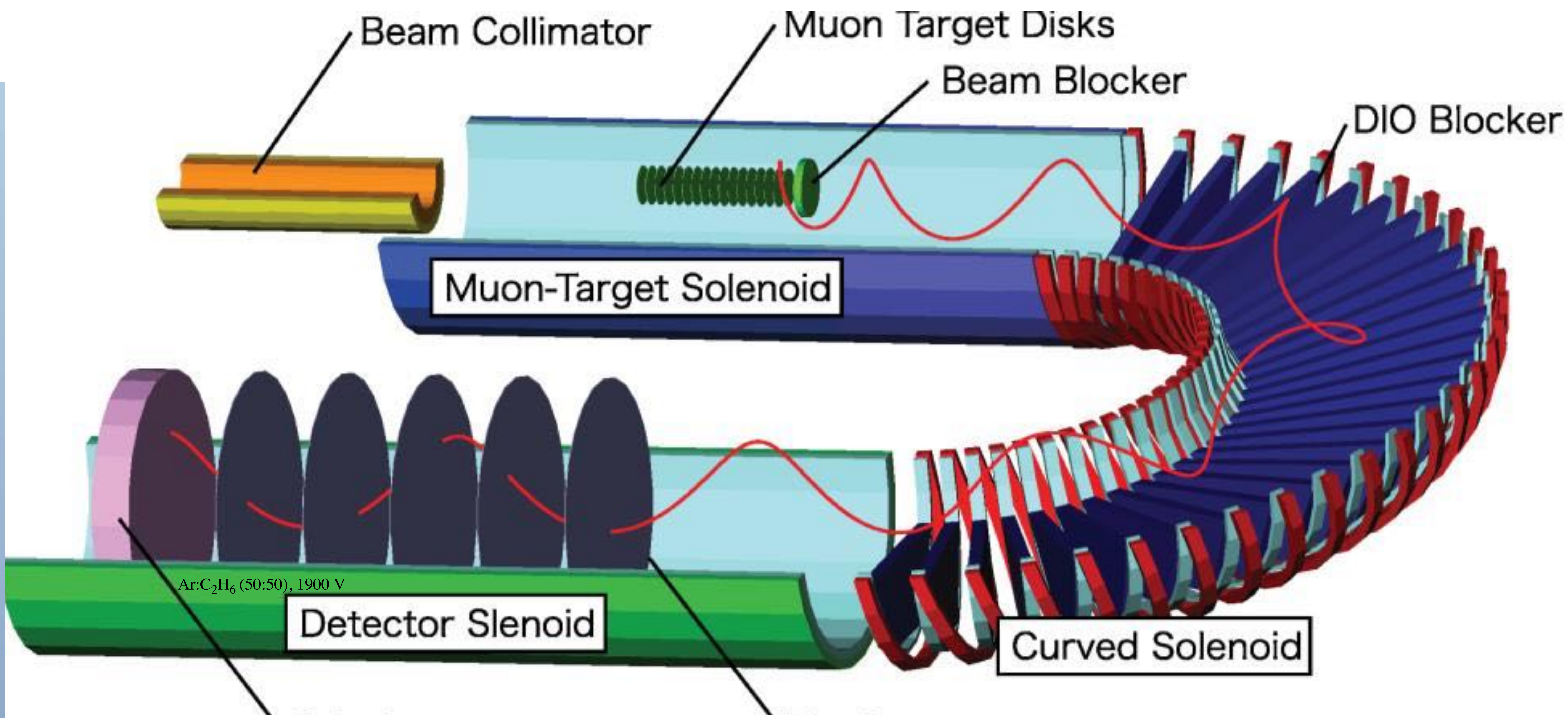
No photons and neutrons from the target getting to the detector!
No low momentum charged particles either …

A simulated COMET event



COMET design :: detection section





Electromagnetic calorimeter

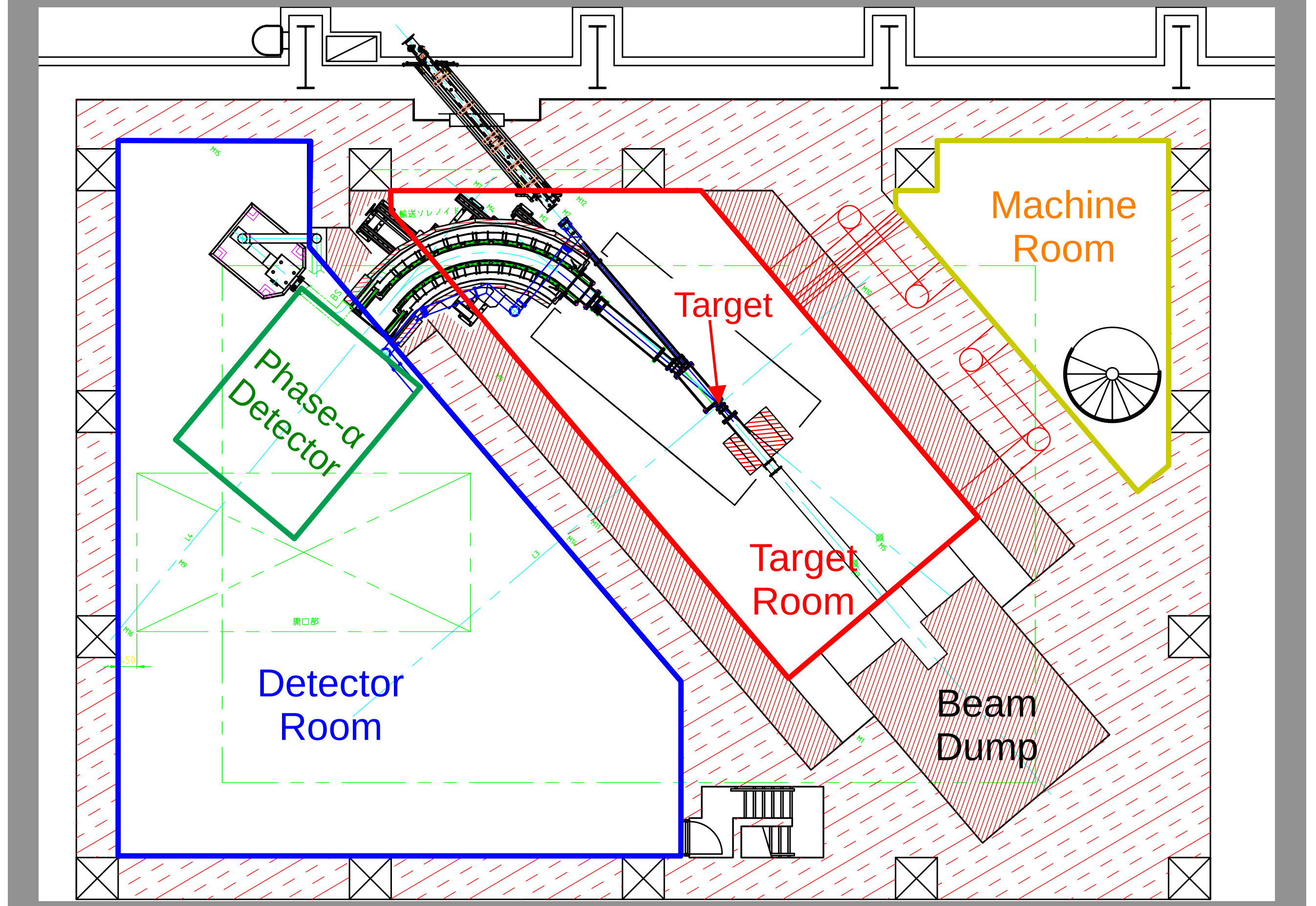
- trigger & timing: response time faster than 100 ns
- electron energy : $\Delta E/E < 5\%$ (@105 MeV)
- cluster position: σ_x<1 cm
- 50 cm of radius
- made of 1920 LYSO crystals 2×2×12 cm³ (10.5 X_0)
- read out by APDs (operates @ 1 T)

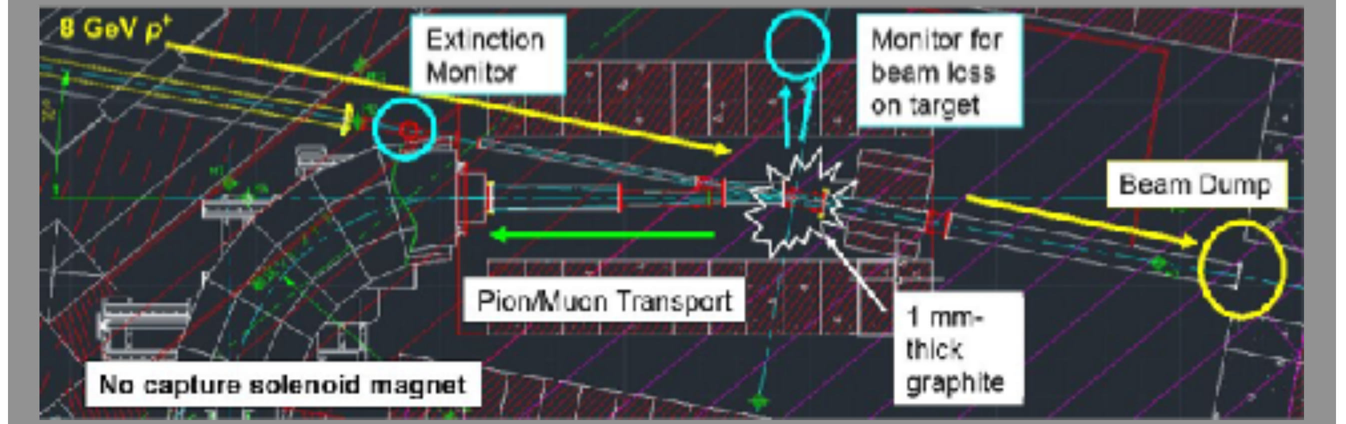
Straw tubes tracker

- operates in vacuum @ 1T
- Δp = 150~200 keV/c (@105 MeV/c)
- 12 µm thick, 5 mm diameter for Phase-II
- at least five stations

COMET , a 2(,5) -stage experiment

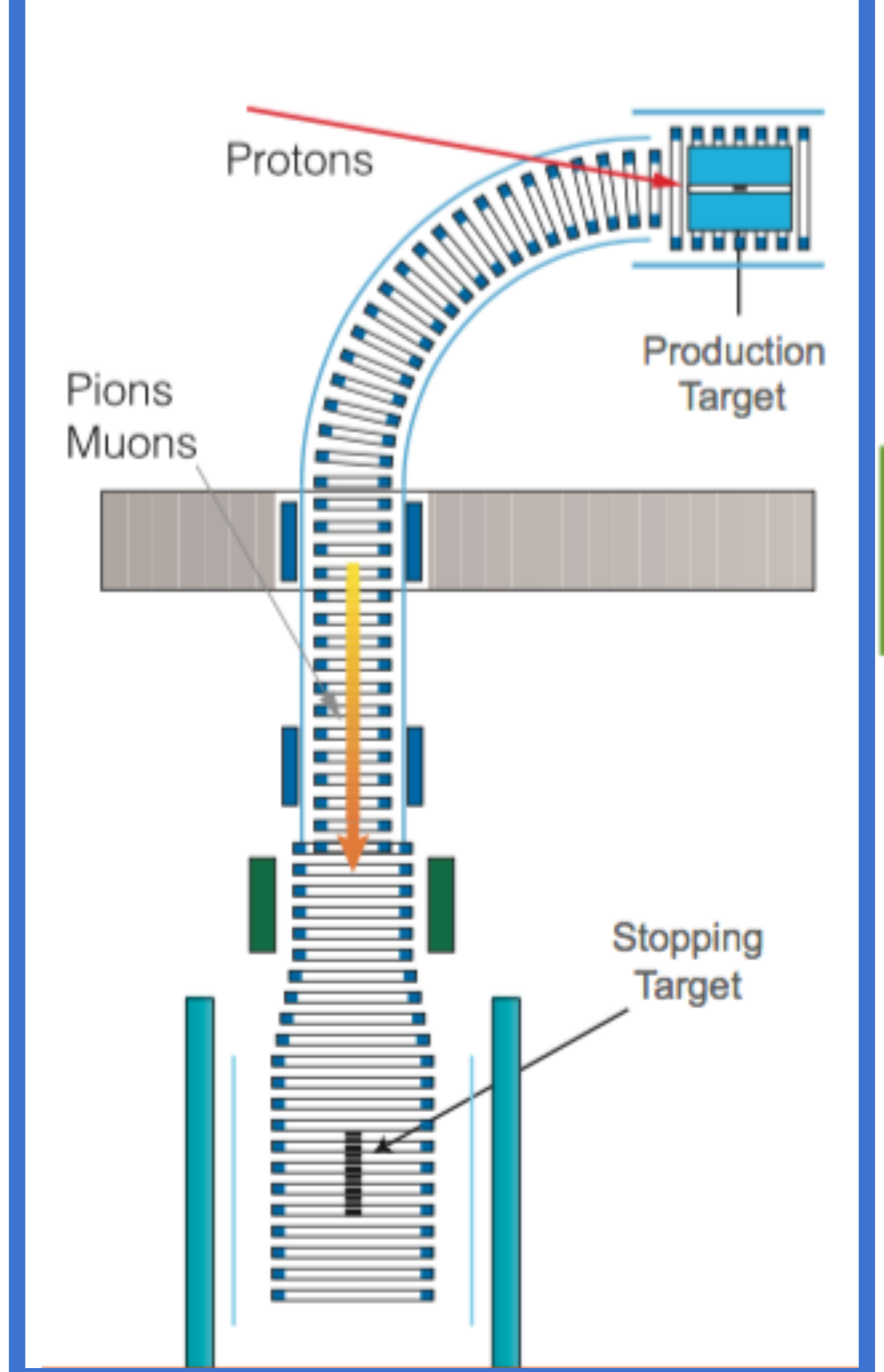
Phase α 2022





- Low intensity run (260 W) without Pion Capture Solenoid
- Thin graphite p-target
- Proton beam diagnostic detectors
- Secondary particle detectors

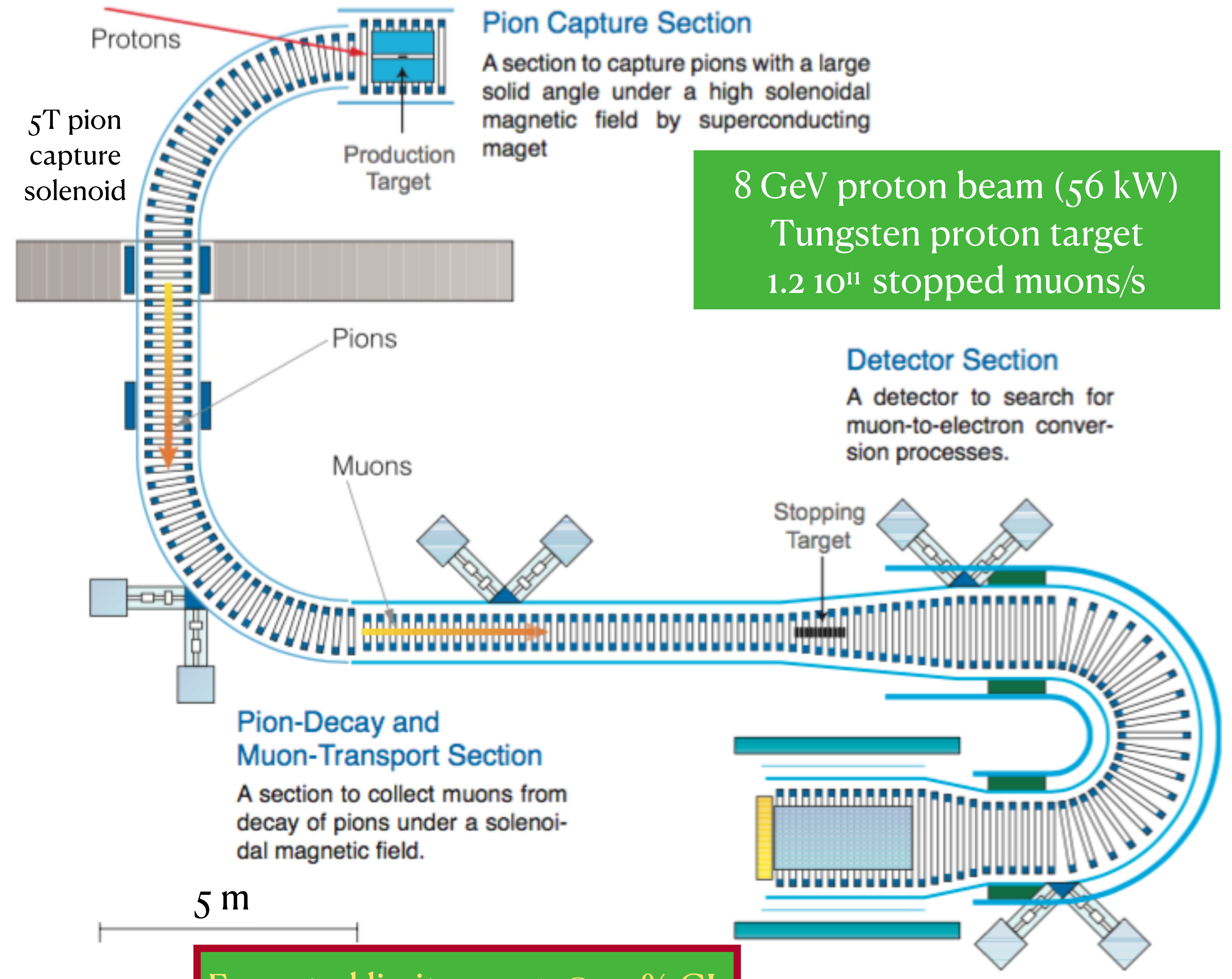
Phase I



8 GeV proton beam (3.2 kW)
Graphite proton target
1.2 10⁹ stopped muons/s

Expected limit : 7 10 $^{-15}$ @ 90% CL
Total background: 0.01 events
Running time: 0.4 yrs (1.2 10⁷ s)

Phase II



8 GeV proton beam (56 kW)
Tungsten proton target
1.2 10¹¹ stopped muons/s

Expected limit : 7 10 $^{-17}$ @ 90% CL
Total background: 0.32 events
Running time: 1 yr (2 10⁷ s)

Pulsed beam to reduce the electron and pion beam background

Tiny leakage of protons in between consecutive pulses can cause a background through Beam Pion Capture process:

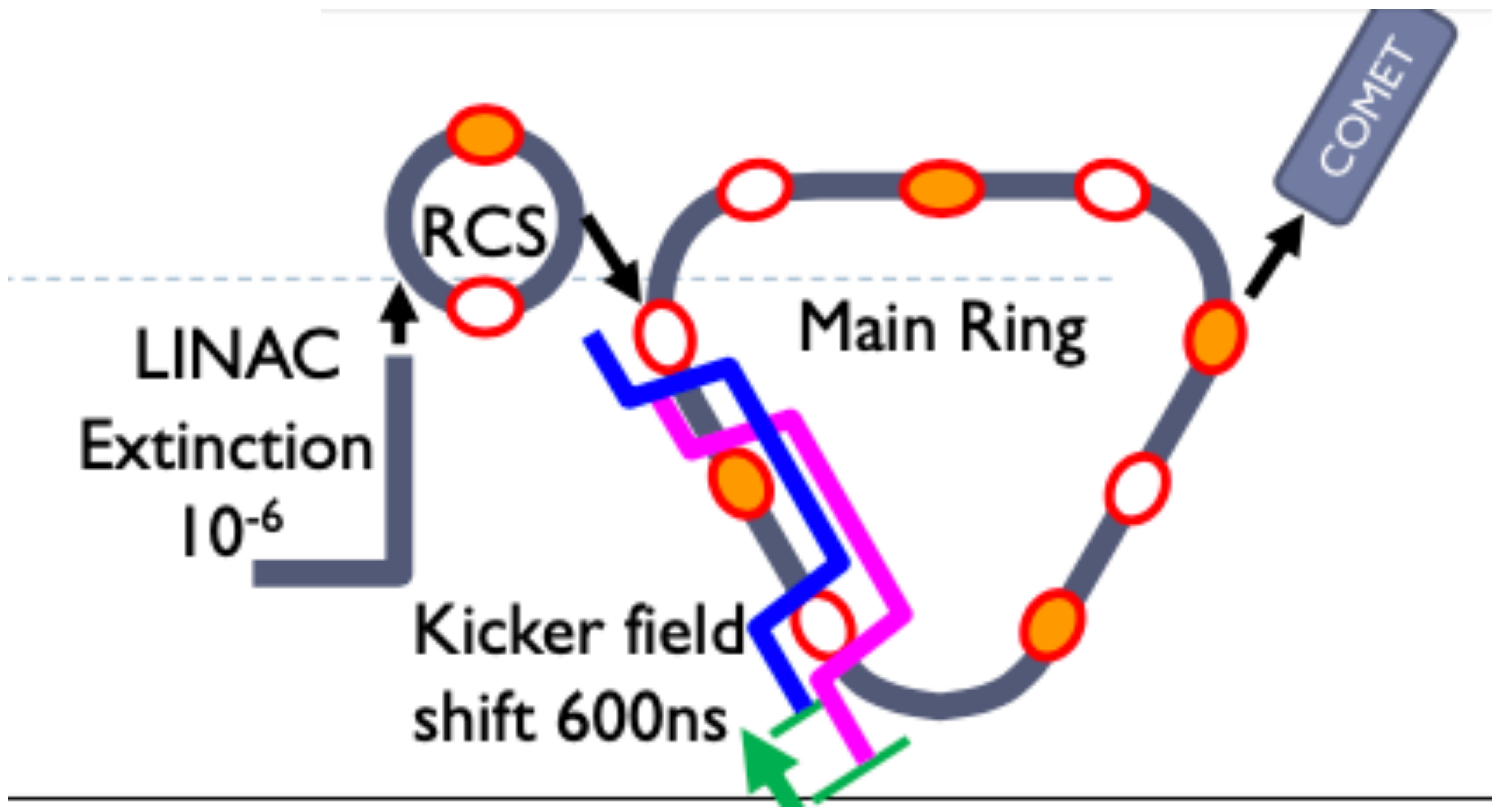
$\pi^- + (A,Z) \rightarrow (A,Z-1)^* \rightarrow \gamma + (A,Z-1)$

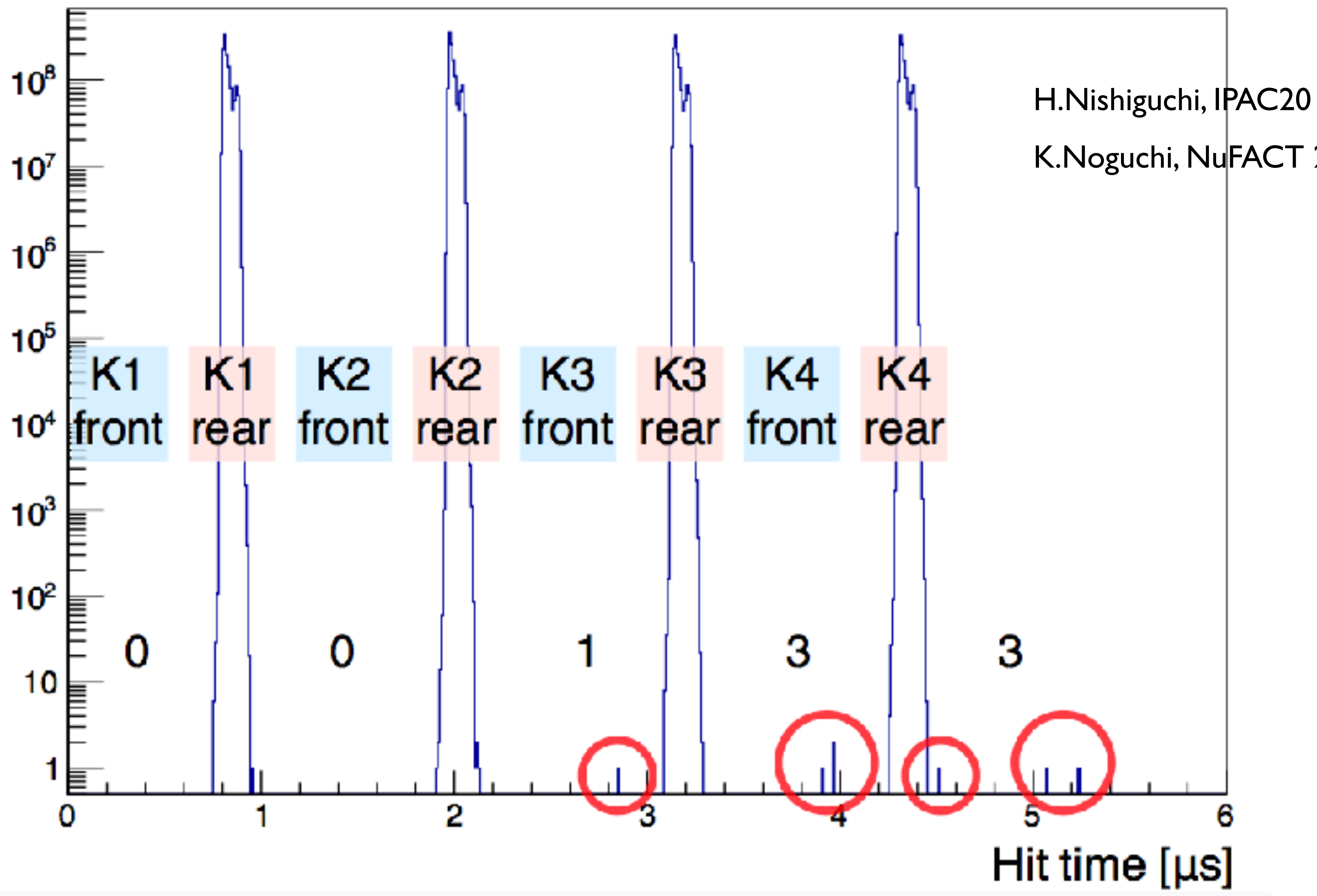
$\gamma \rightarrow e^+ e^-$

Requirement:

extinction better than 10^{-10} to reach design sensitivity $O(10^{-17})$

Measurement in Hadron hall $9.3\text{x}10^{-11}$ Extinction achieved (Preliminary)



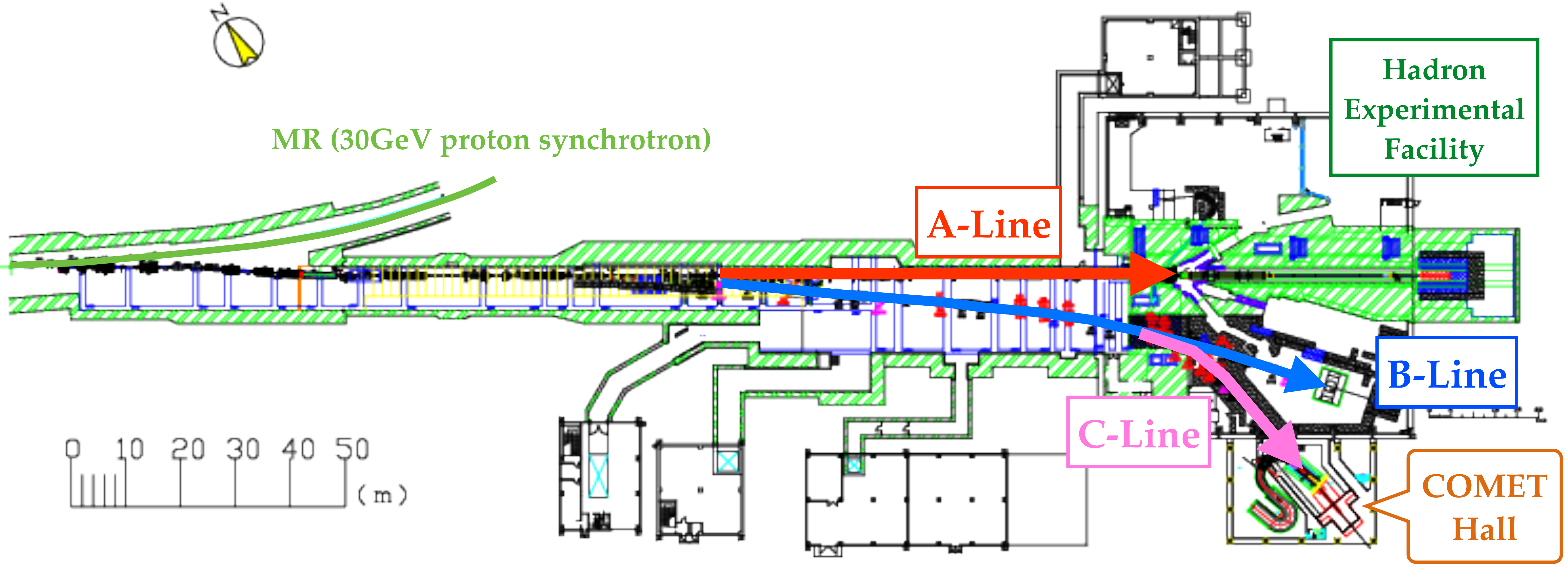


H.Nishiguchi, IPAC2019

K.Noguchi, NuFACT 2021

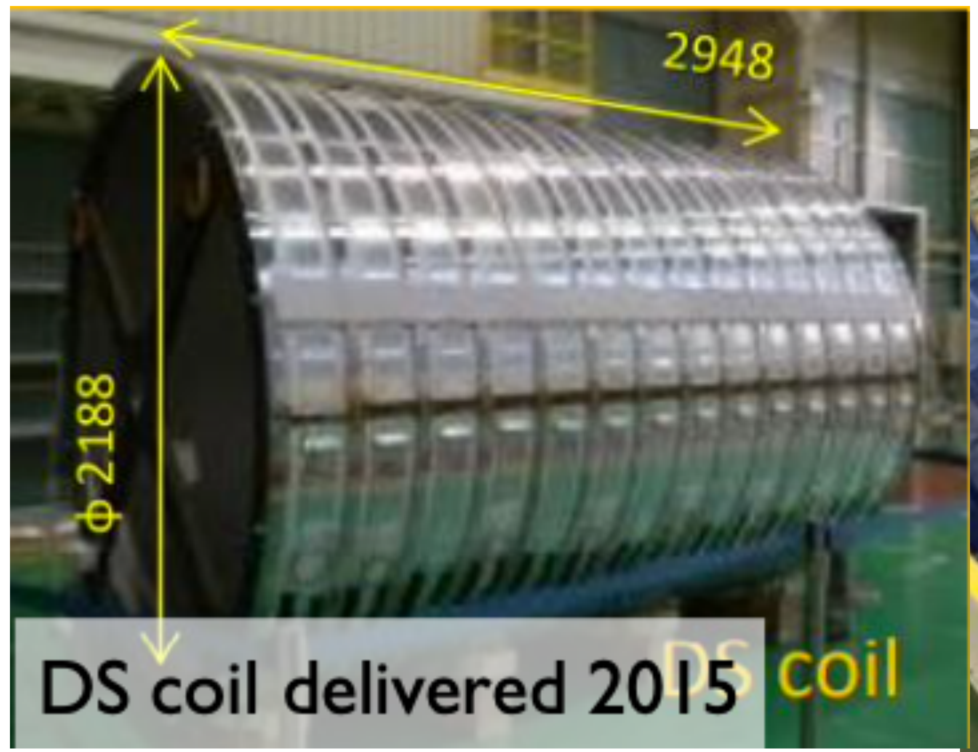
COMET Status :: Facility Construction

Upstream of the proton C-line completed in 2021

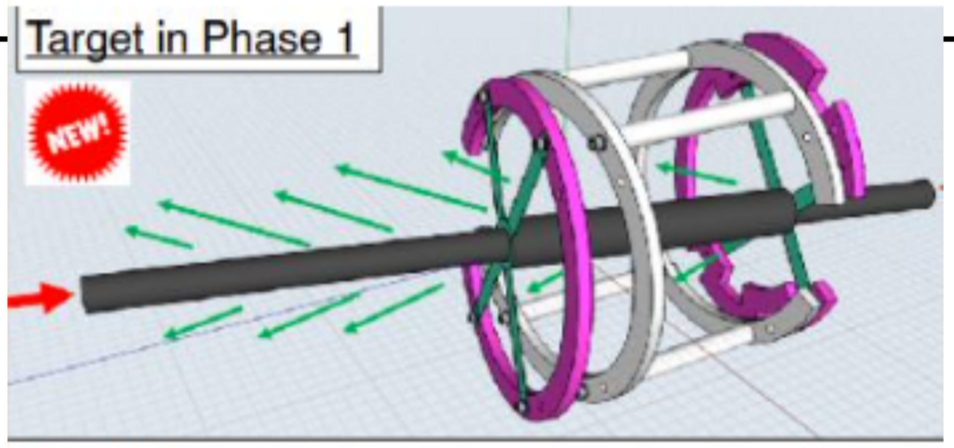


Shutdown of J-PARC MR until middle of 2022 for PS upgrade for MW beam

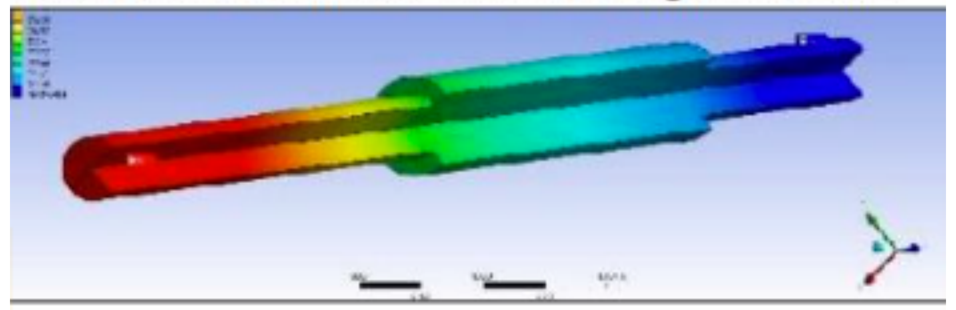
COMET beamline construction to be completed during shutdown



Phase-I Graphite target design done

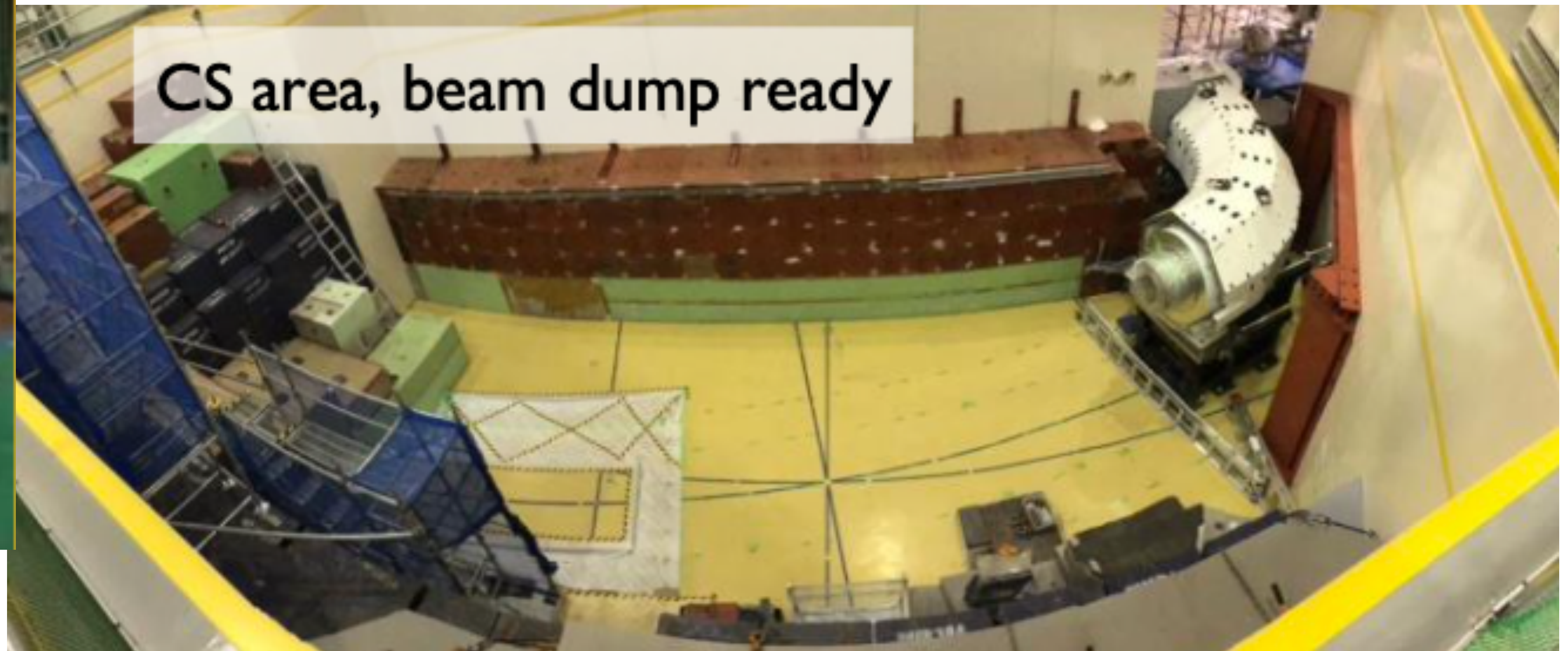


Graphite
Diameter: 26 mm and 40 mm, Length: 700 mm

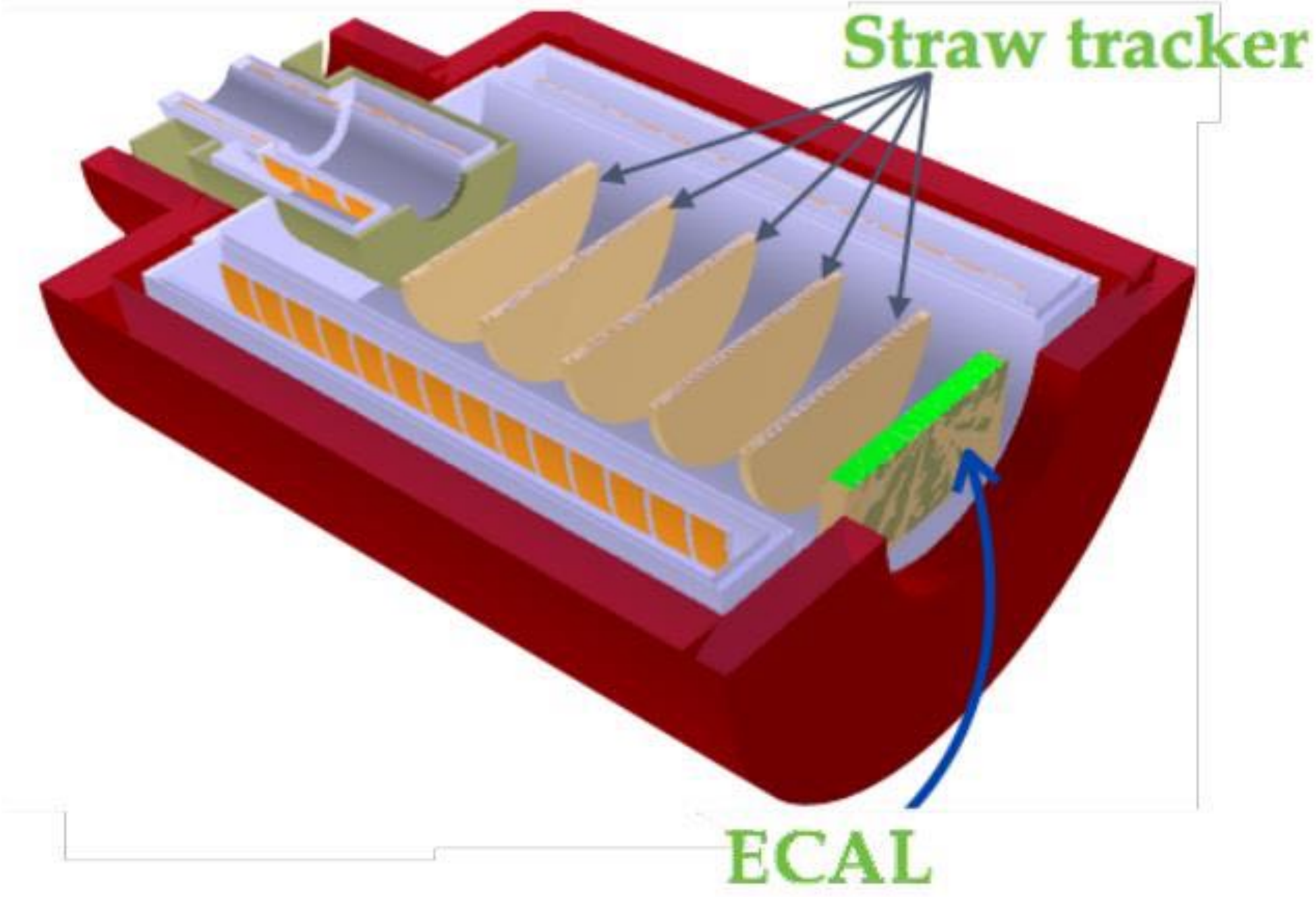


FEM simulation is completed. Max. temp. 245 degC.

Pion capture solenoids (CS and TS cold mass) to be delivered in summer 2023. Cryostats under construction.



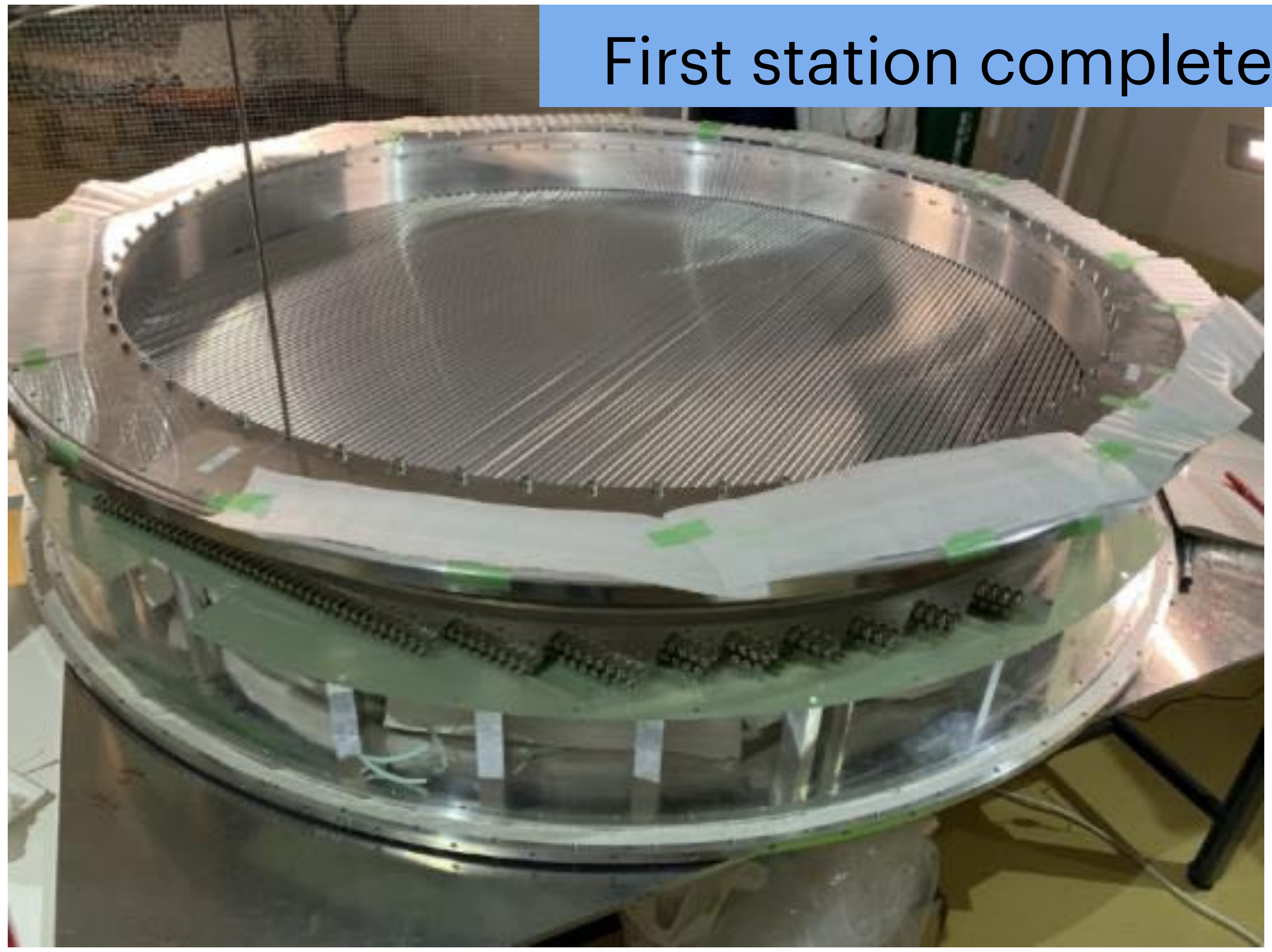
COMET Status :: StrawECAL (Staw tracker + ECAL)

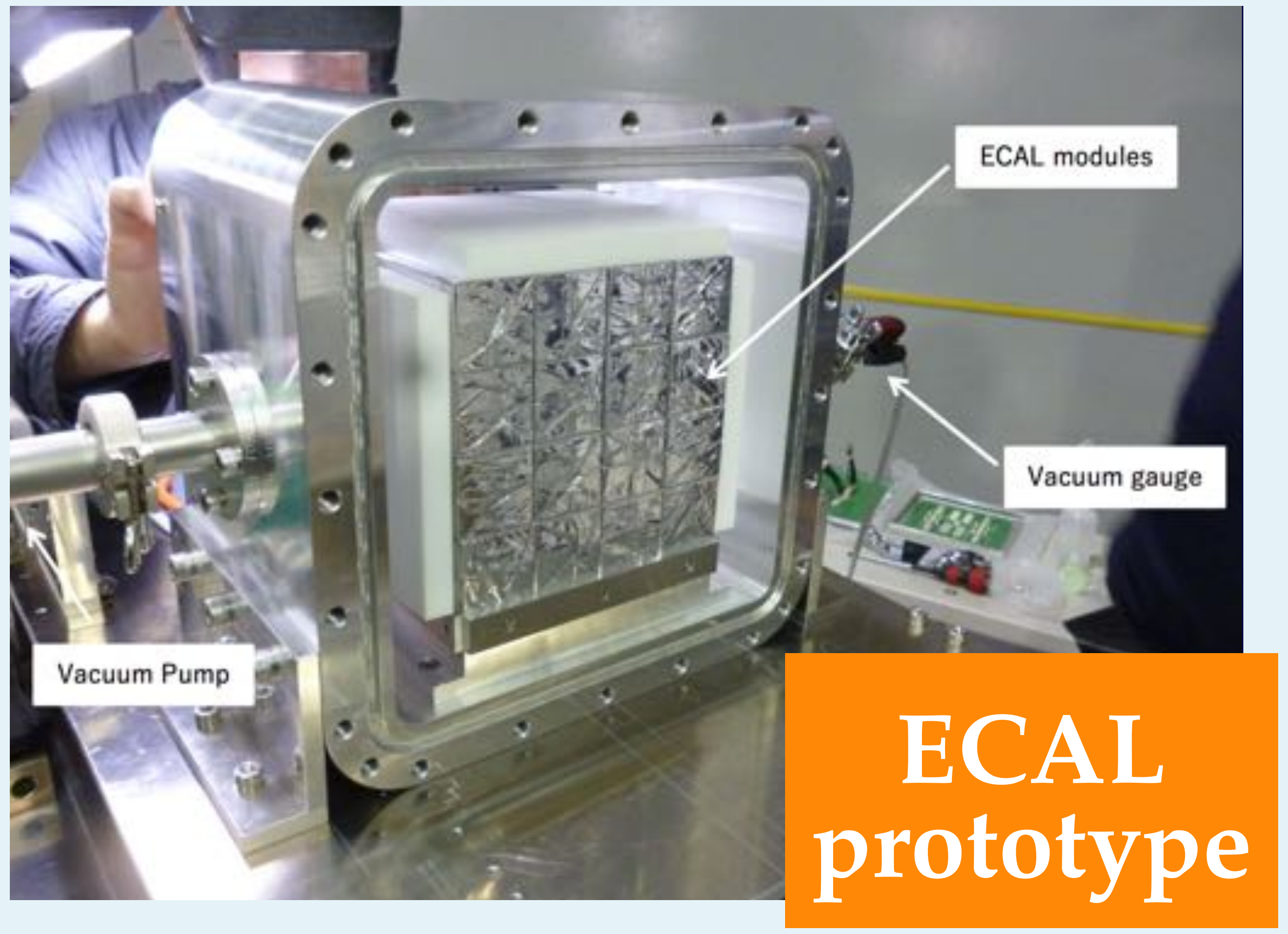


5 stations of straw detectors+ ~2000 LYSO-cells calorimeter

Hajime Nishiguchi
NuFact2021

First station completed !



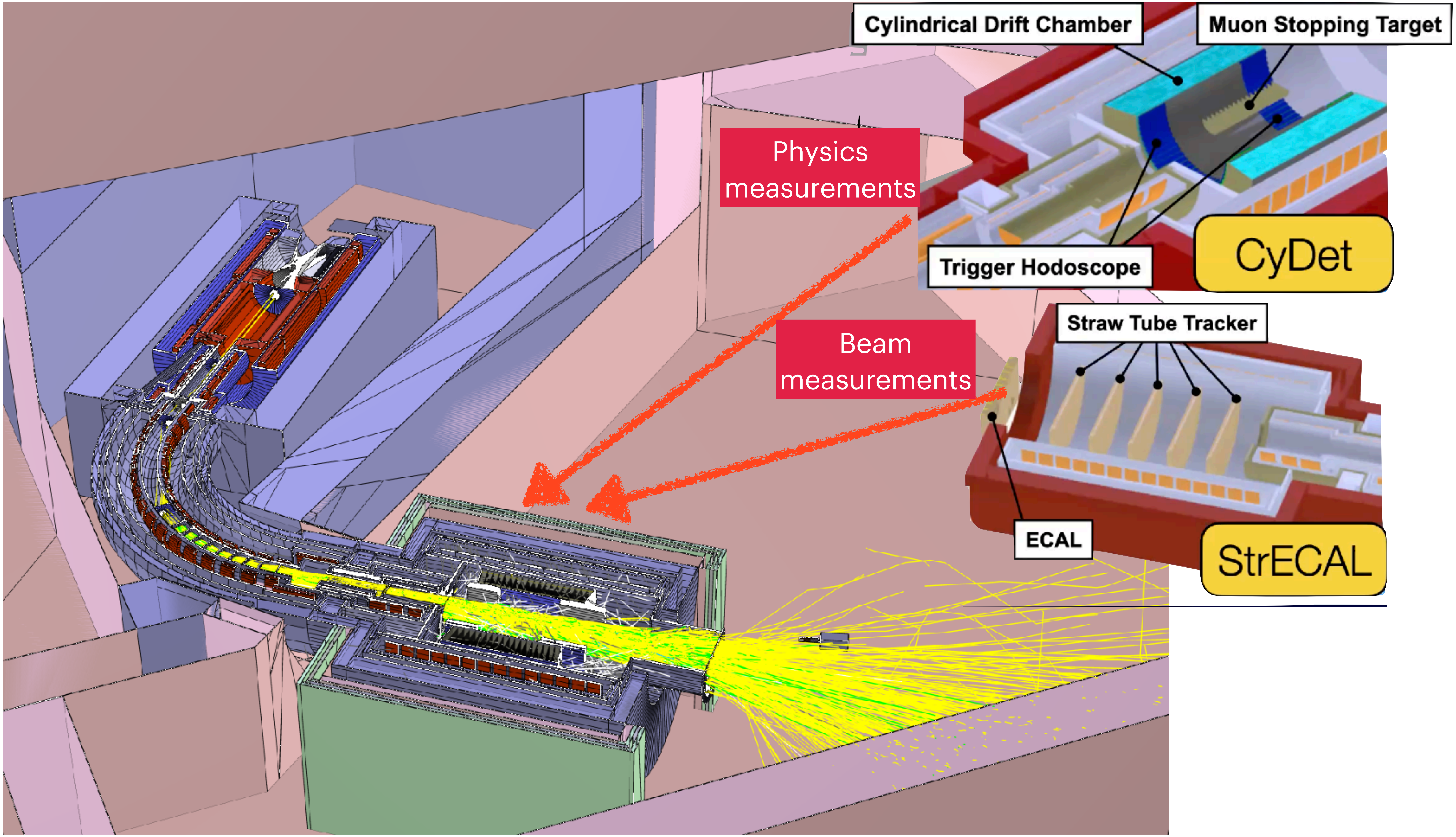


ECAL prototype

- ECAL prototype successfully completed.
- Detector assembly will start soon.

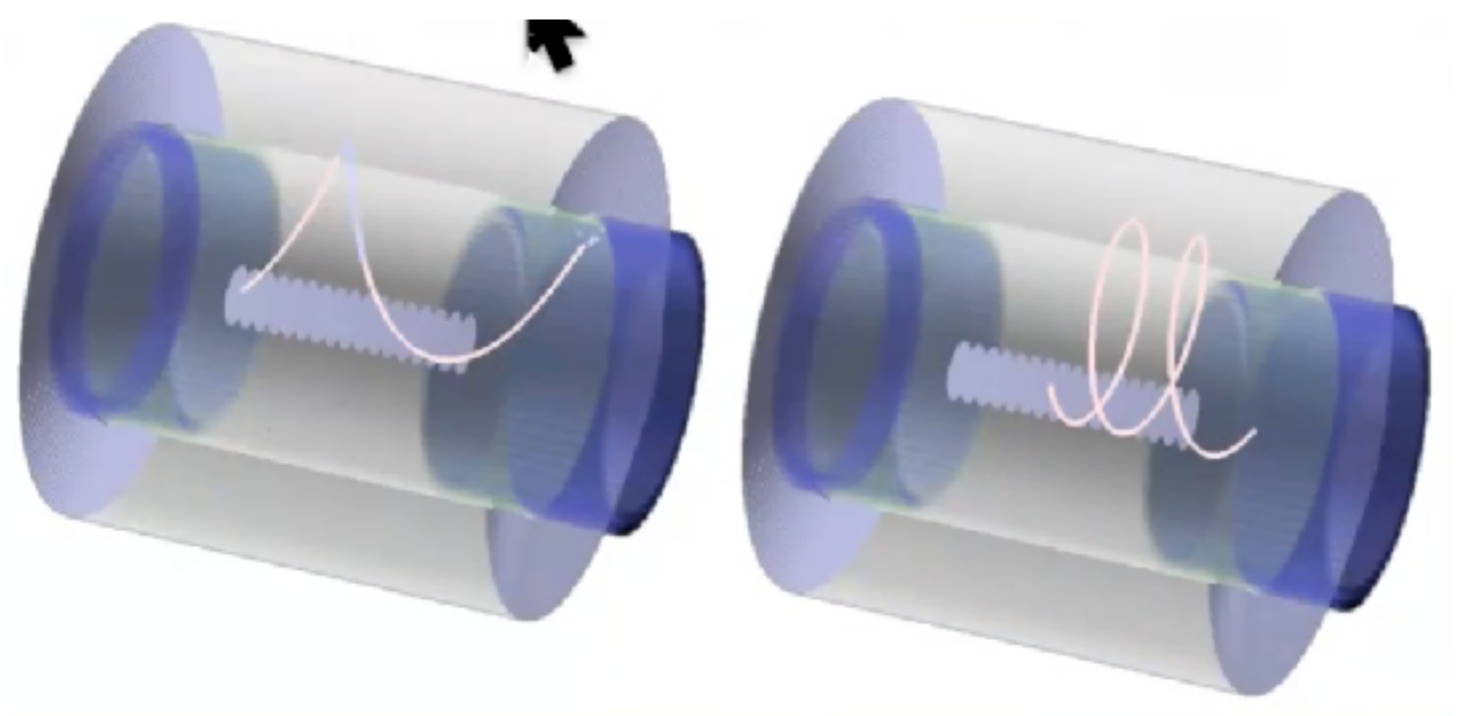
Beam test with prototype achieved 150um spatial resolution, <200keV/c momentum resolution feasible

COMET Phase I



COMET Phase-I :: Cylindrical Drift Chamber

- 20 concentric sense layers
- 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

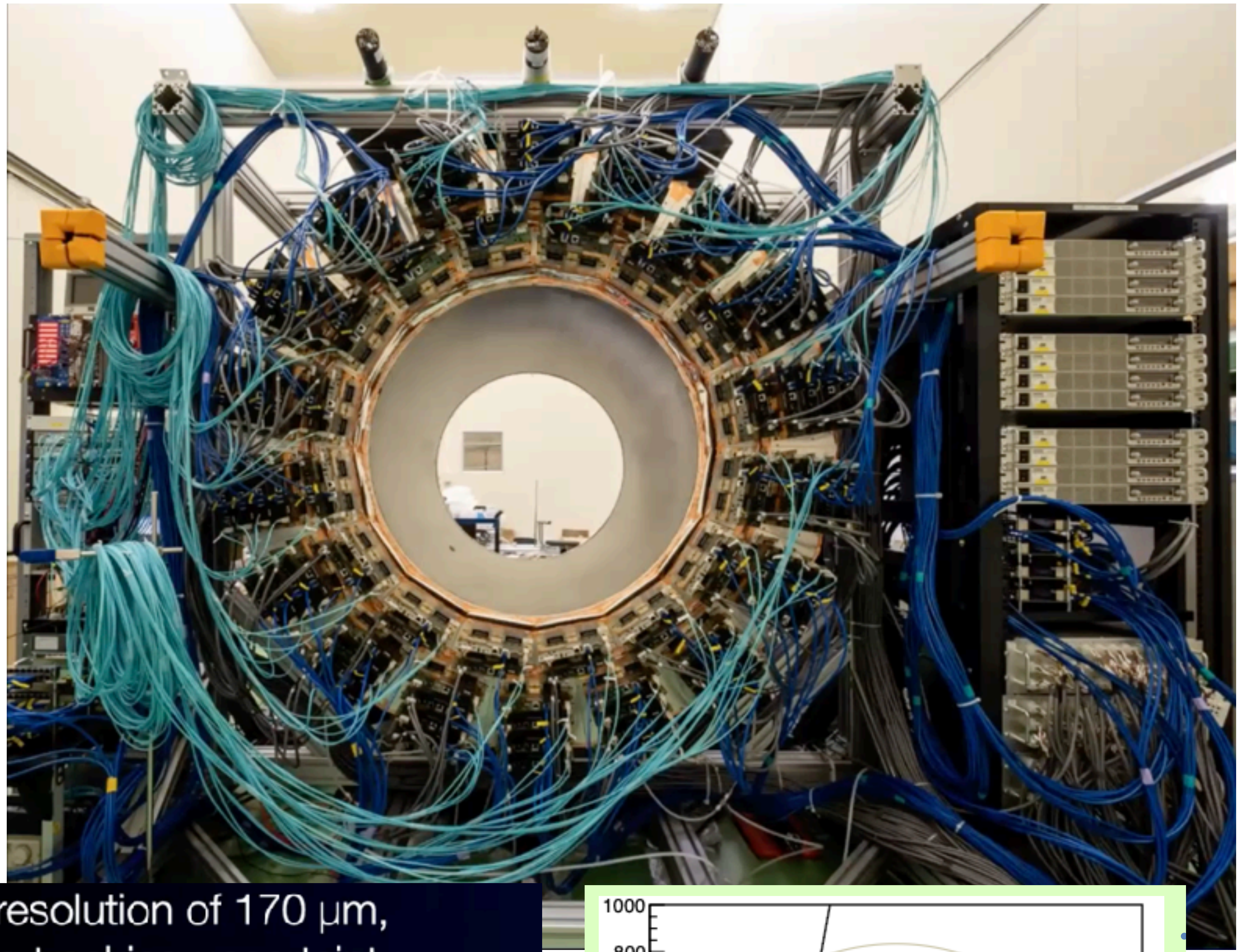


- CDC fully read out since 2019
- Currently at KEK being commissioned with cosmic rays

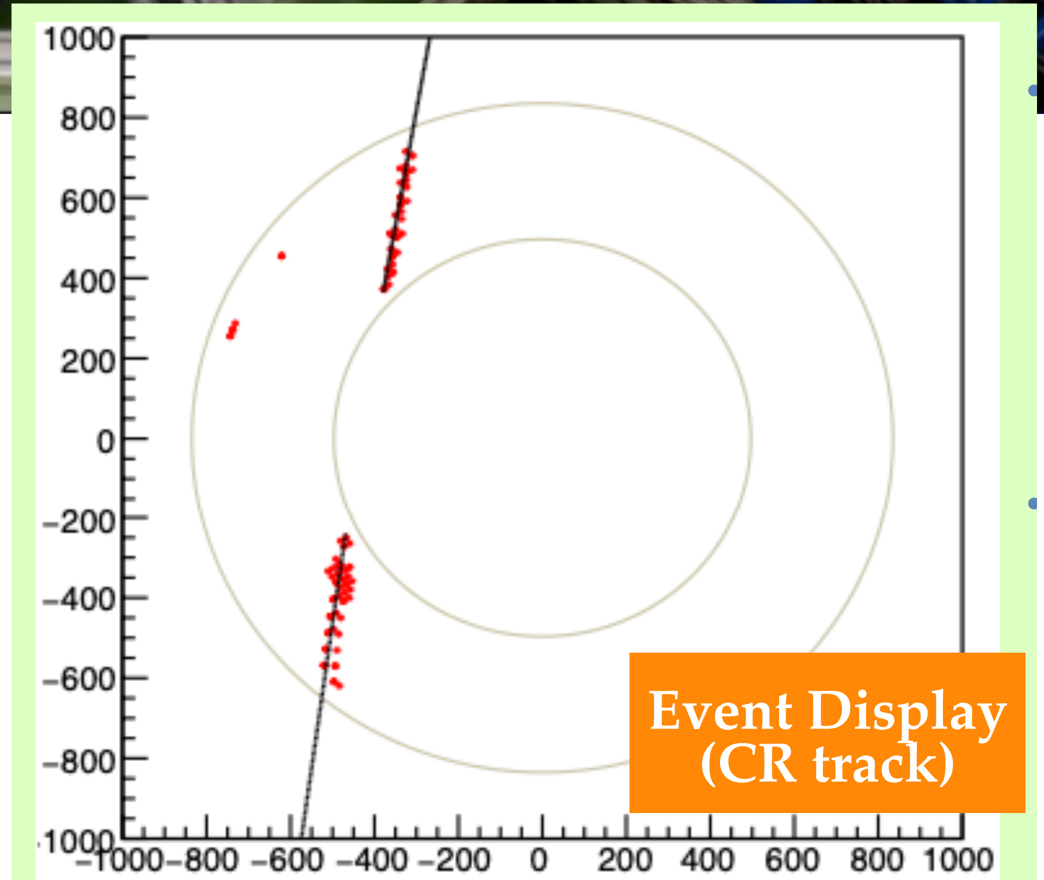
- signal tracks (~100 MeV/c) contained inside the CDC for better signal resolution
- triggered events : 60% single turn tracks & 40% multiple turn tracks

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

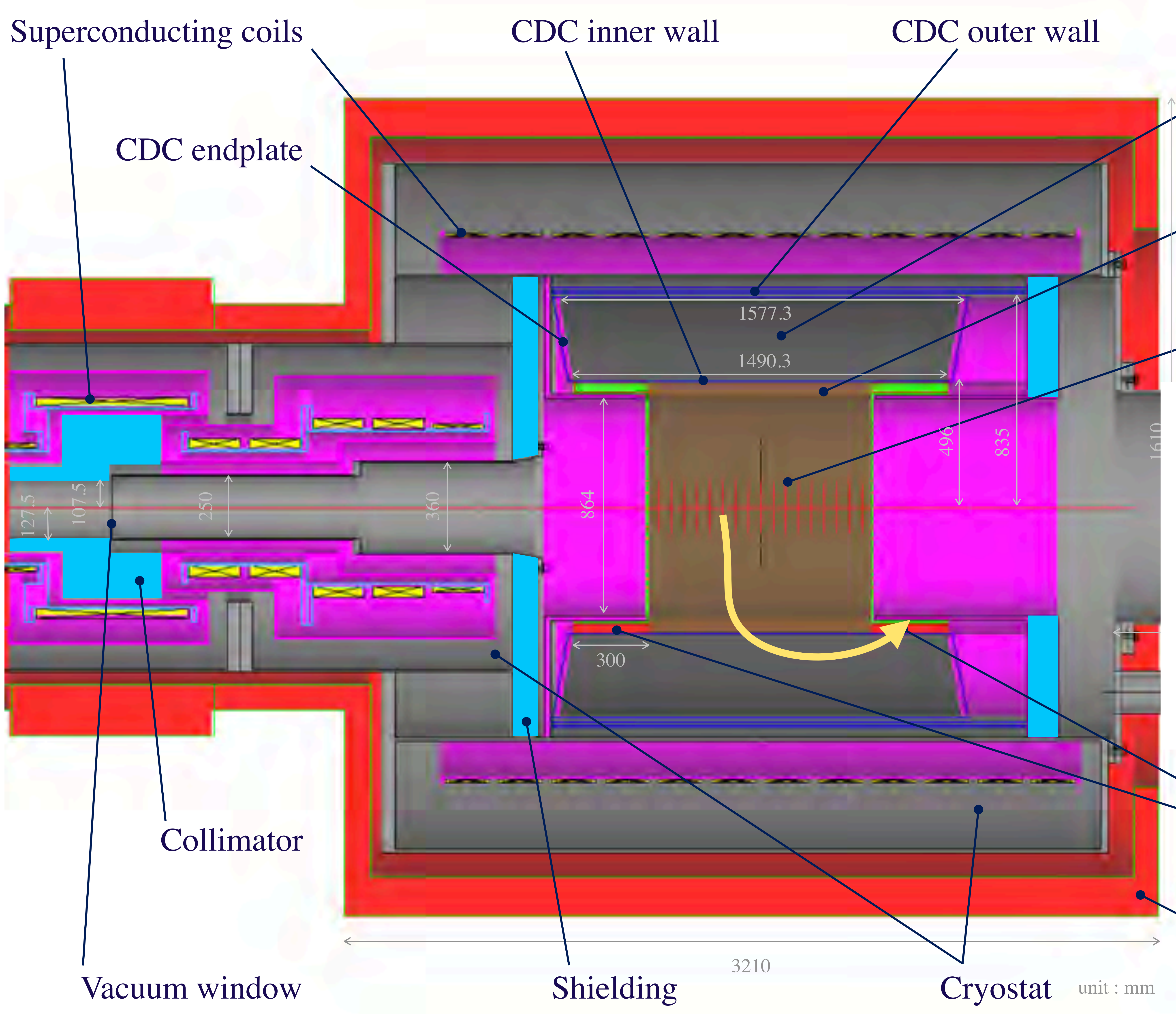
Test of a small prototype of the COMET cylindrical drift chamber
Nucl. Inst. Meth A 1015 (2021) 165756.

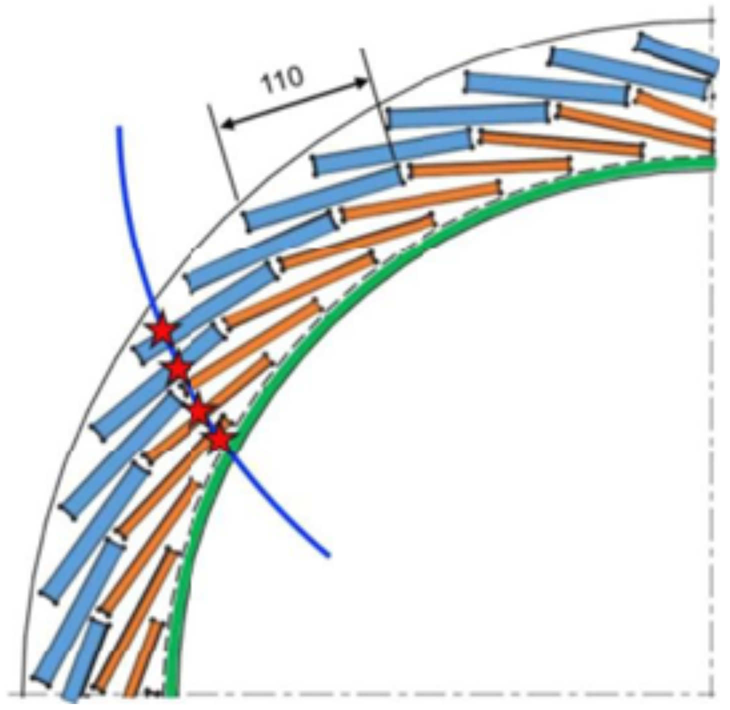


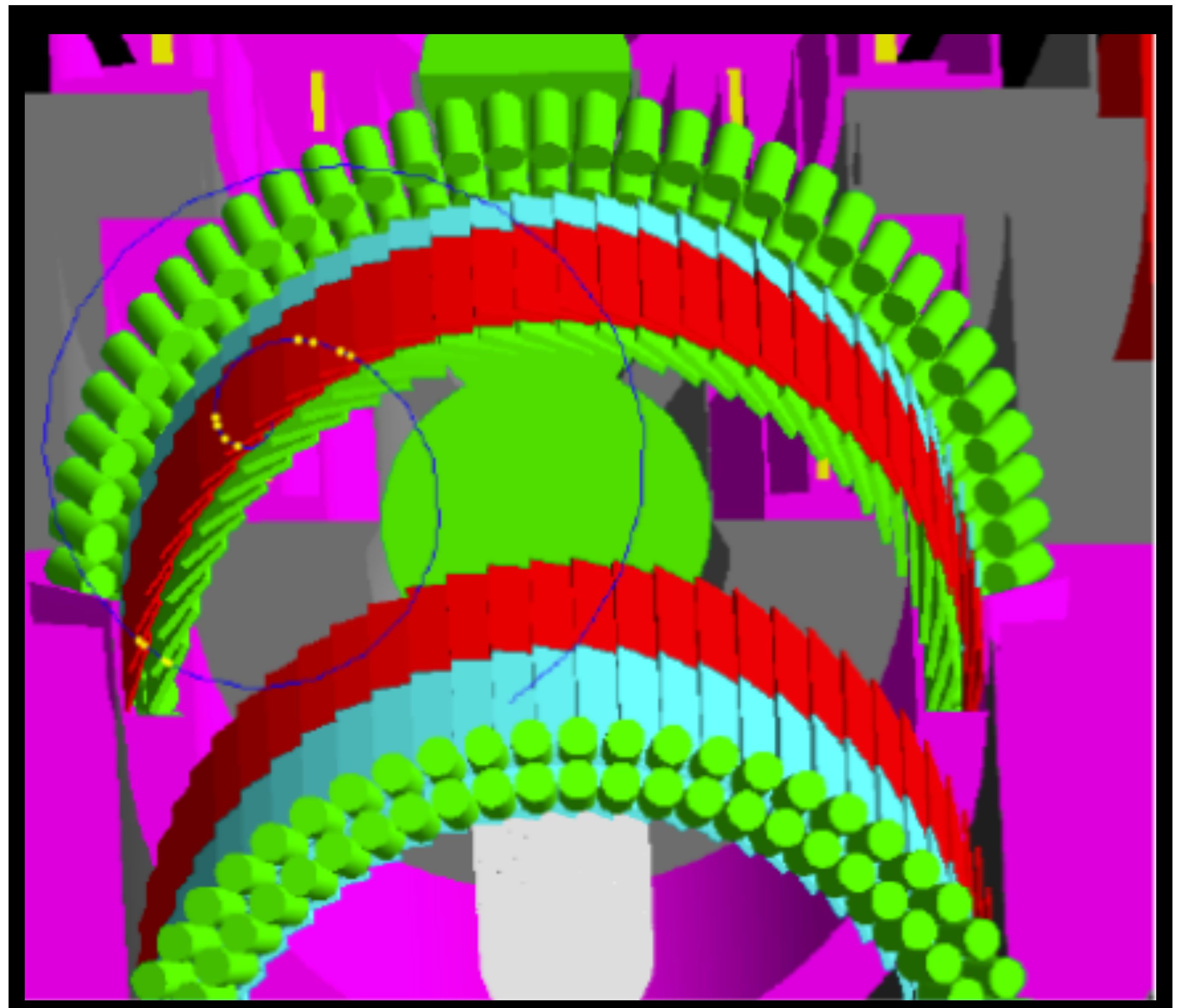
- Spatial resolution of 170 μm, including tracking uncertainty, achieved.
- Hit efficiency of 98% achieved
- Significant noise reduction achieved
- Detail study of detector response
  - space-charge effects
  - crosstalks
- Water cooling testing of the CDC readout underway



COMET Phase-I :: Electron Detectors (CyDet)





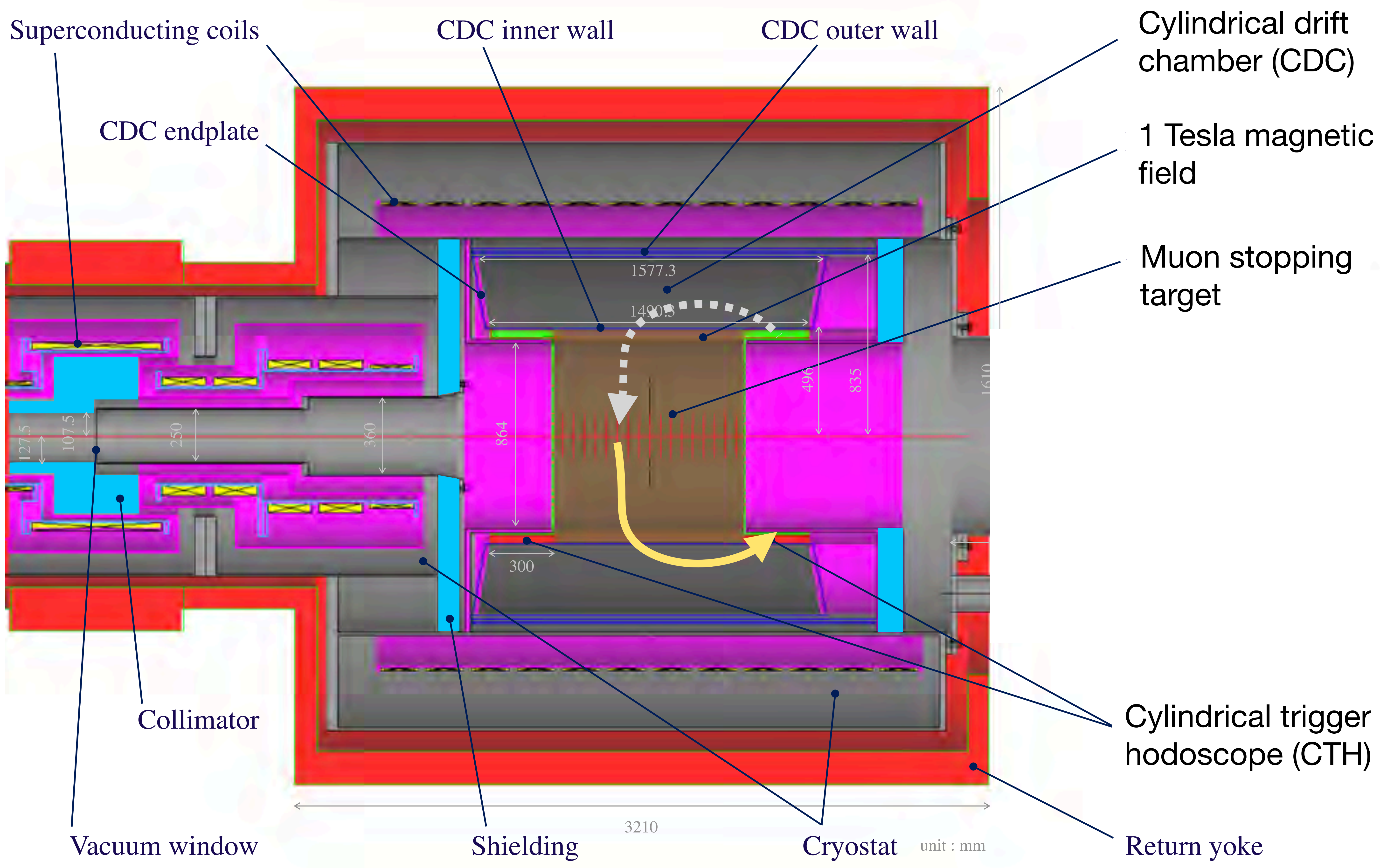


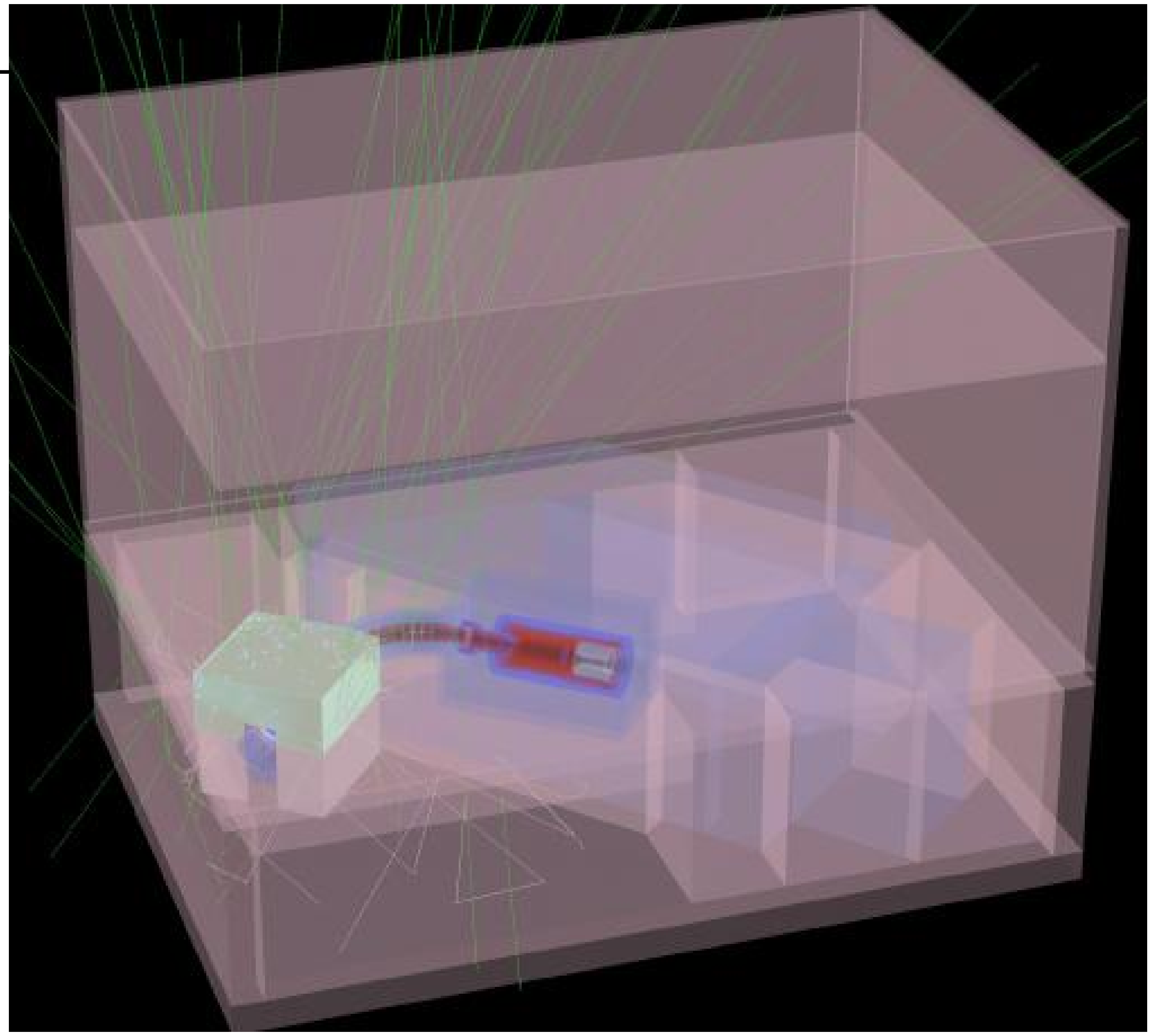
2-rings of ultra fast scintillators (64 segments, 33/36 x 1 x 1 cm3) read by optical fibres and SiPMs

2-rings of Cherenkov counters (acrylic plastic, 300x90x10 mm3) to be added in a second step

Four-hold coincidence provides trigger and PID

COMET Phase-I :: Atmospheric background

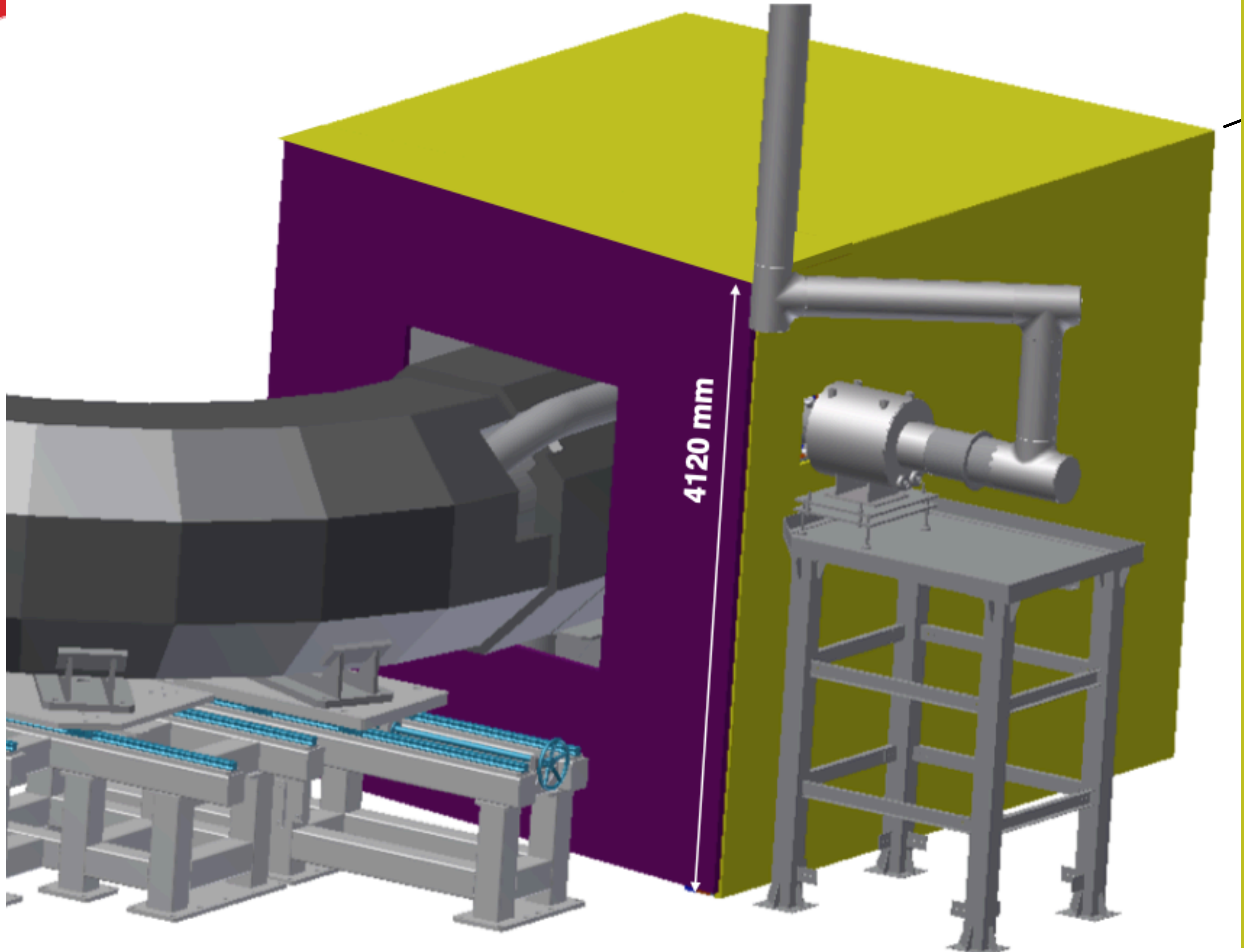




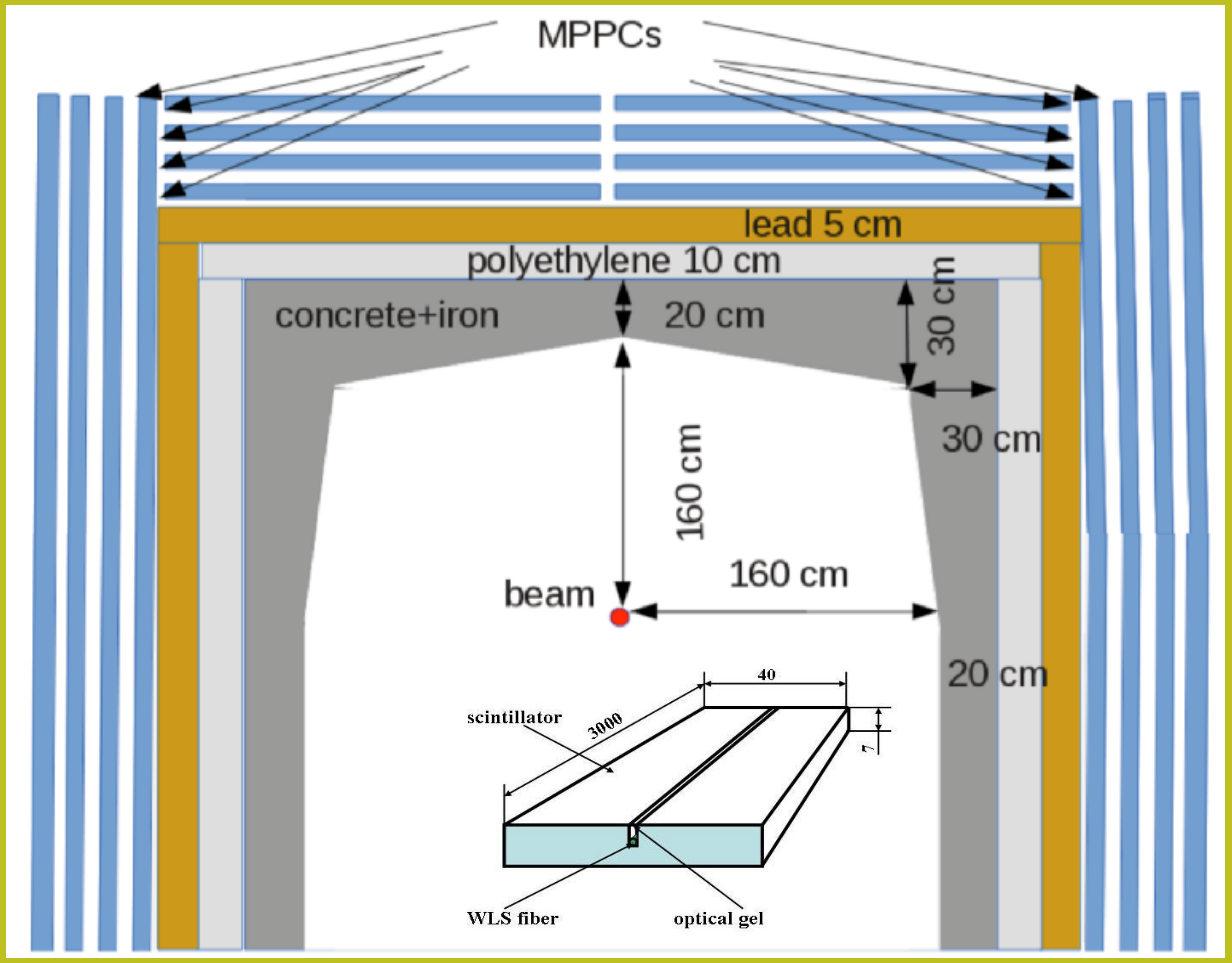
Atmospheric muons = main background

Cover as hermetically as possible the detectors (C
with very high efficiency veto counters (CRV)

requirement : < 0.01 evts for COMET Phase 1
(The short data acquisition foreseen helps!)



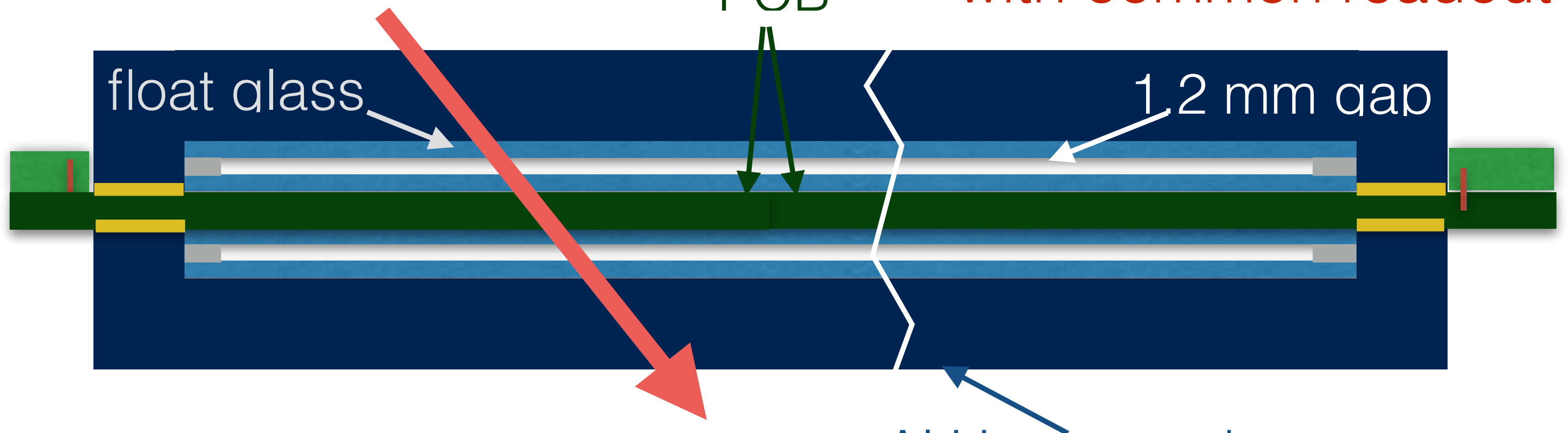
Scintillators CRV



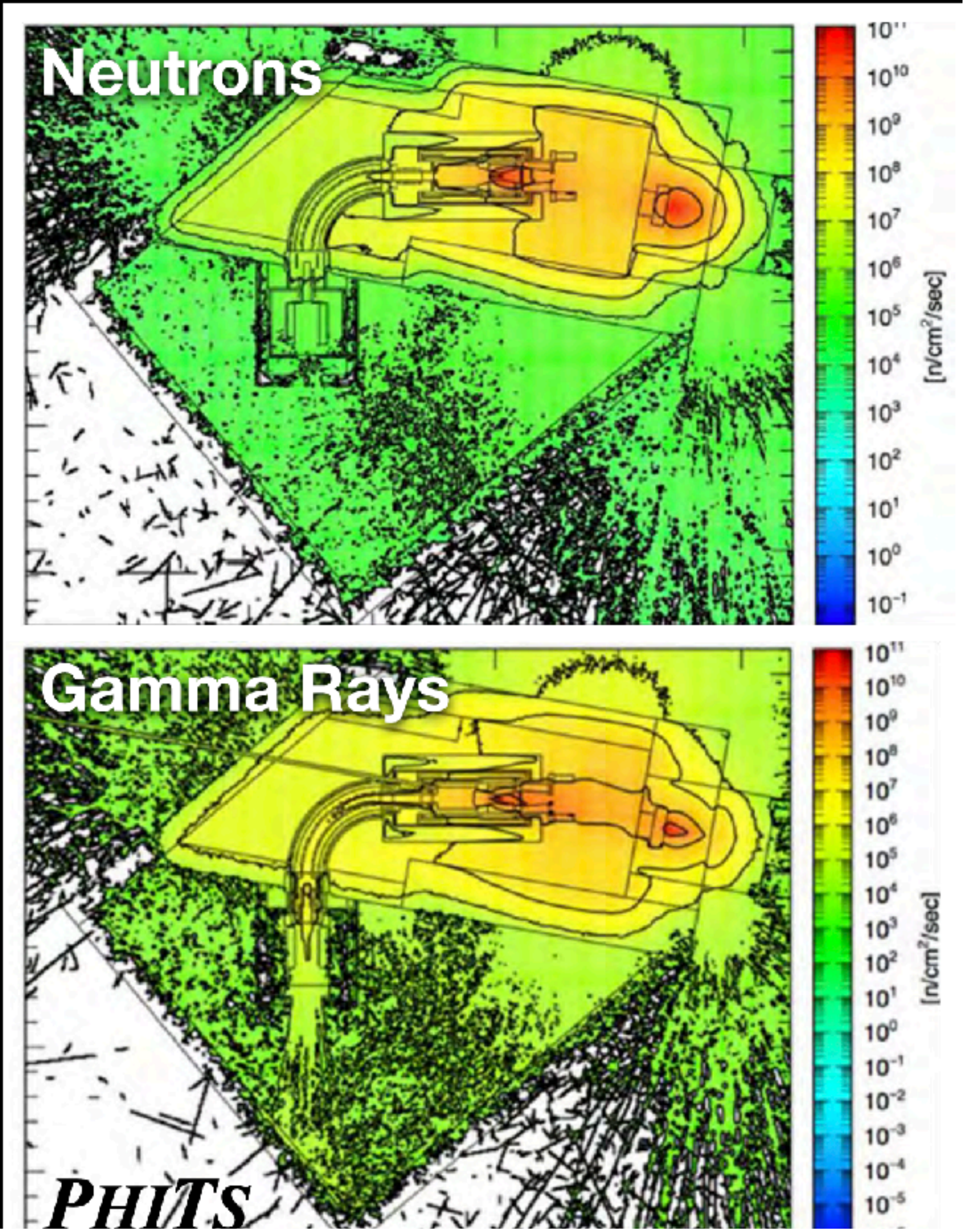
GRPC CRV

A tracker module: 7 detector modules (baseline)

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



- Radiation levels for COMET Phase-I, studied by PHITS, MARS and Geant
- In the detector regions for 150 days, including margin of safety:
  - Neutrons: 10^{12} n/cm^2
  - Gamma rays: 2 kGy
- Radiation issues
  - Electronics components
    - Regulators, optical transceiver etc.
  - FPGA
    - SEU, MBE etc.
- Irradiation tests carried out



COMET Phase I Timeline

- **Facility - expected to be completed in 2023:**
  - COMET Proton beam for the COMET : in 2022
  - Commissioning of proton and muon beams (COMET Phase α) : by end 2022
  - Pion capture system : in 2023

- **Detectors - expected for 2023:**
  - CyDet will be moved to J-PARC in 2022
  - StrCAL : by summer 2023
  - CTH : by end 2022
  - CRV : 2023.

- Start of the COMET Phase-I engineering run foreseen for end 2023 followed immediately by physics data taking.

- COMET Phase-II expected to follow shortly COMET Phase-I.

Conclusion

- COMET at J-PARC will search for neutrinoless muon to electron conversion with an expected S.E.S of 2.6×10^{-17} (4 orders of magnitude below the current limit) after 1 year of data taking using a 56 kW, 8 GeV proton beam.
- The experiment will proceed in two phases, with Phase-I (currently in preparation) expected to reach a S.E.S of 3×10^{-15} within 150 days of data taking using a less intense 8 GeV proton beam (3.2 kW).
- COMET Phase-I preparation (proton beam, experimental area and detectors construction) proceeds rapidly and on schedule despite the pandemics .
- COMET physics data expected in 2024.