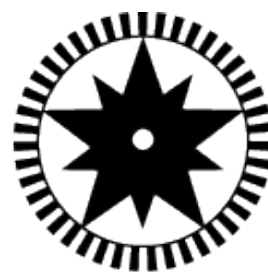




MONASH University

COMET Detectors to search for a muon to electron conversion



IO_{th}
Anniversary

Yuki FUJII

for the COMET collaboration

Monash University

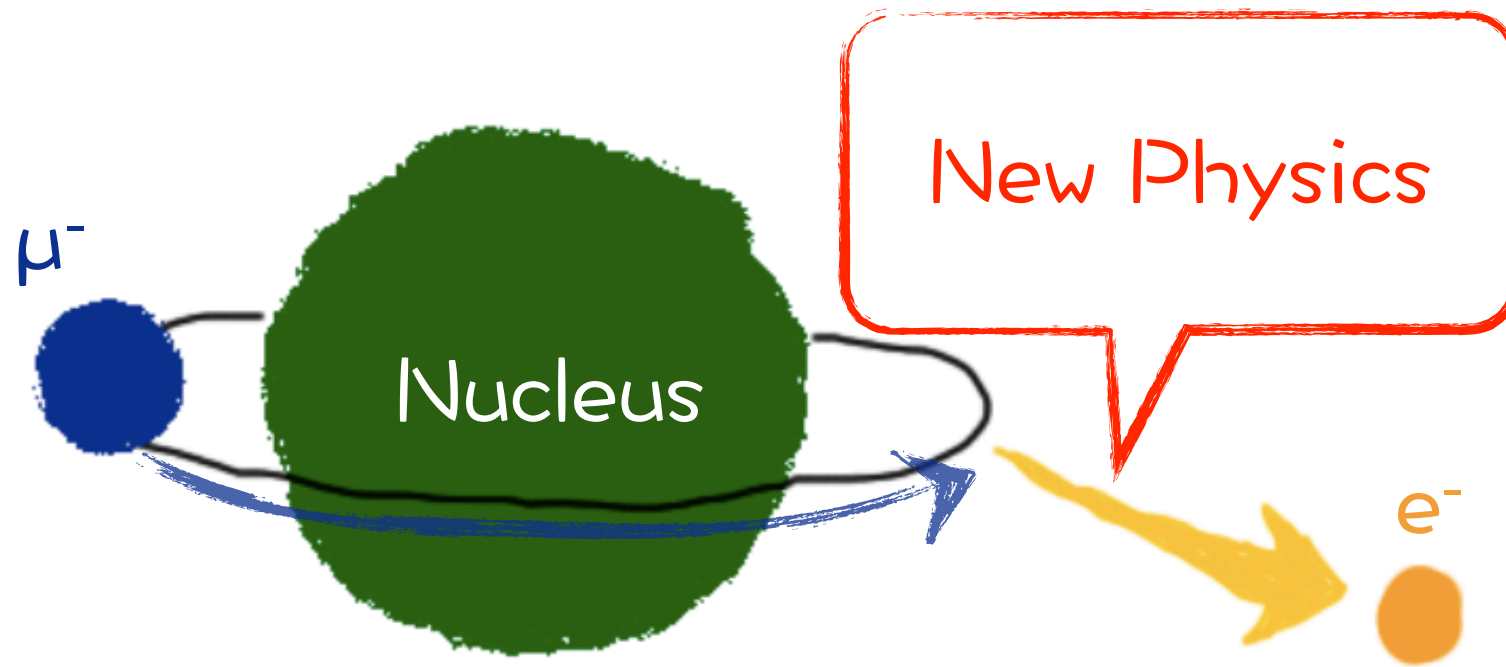
25 September 2019

Tsukuba, JAPAN

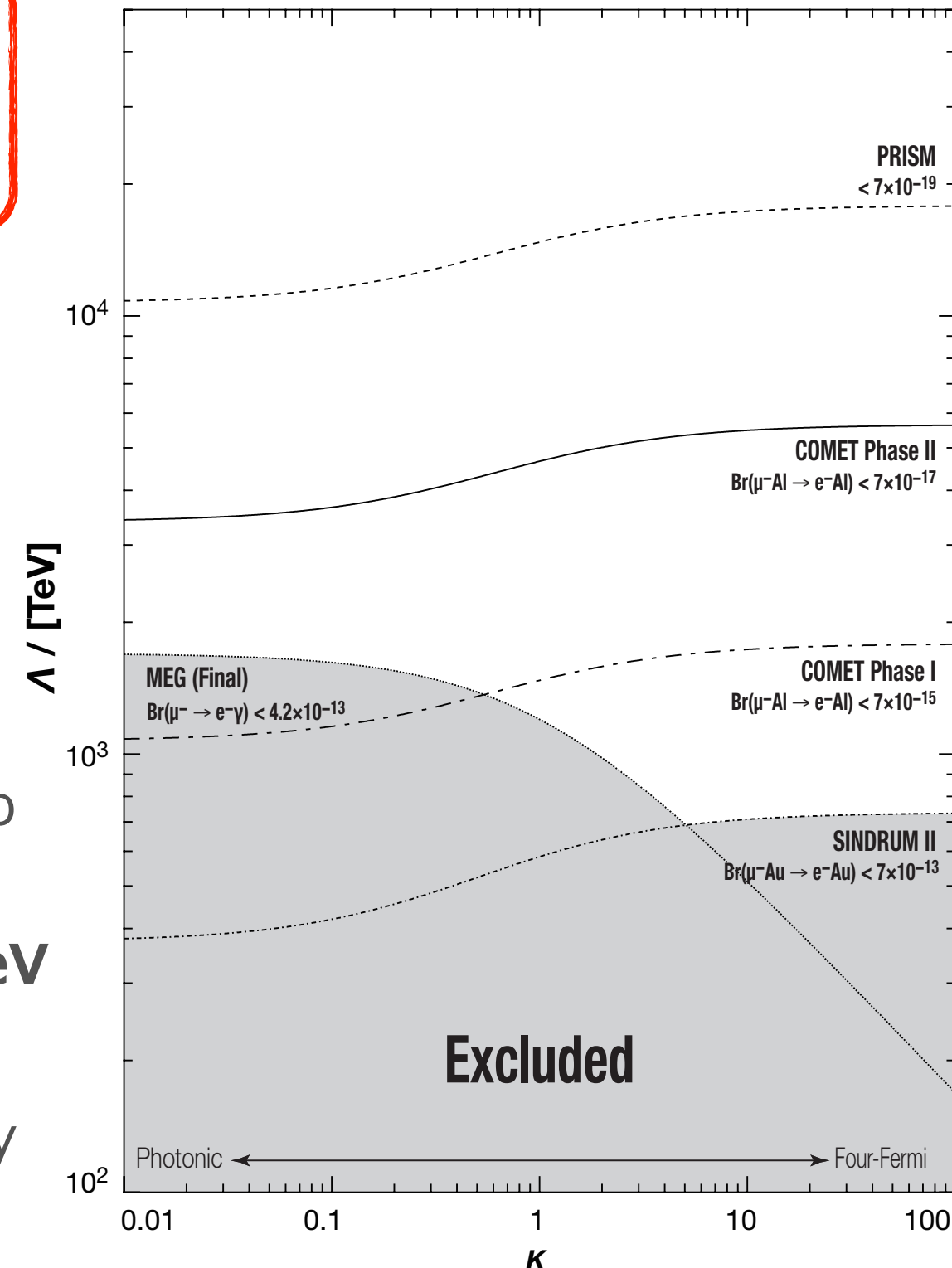


J-PARC Symposium 2019

The μ -e Conversion

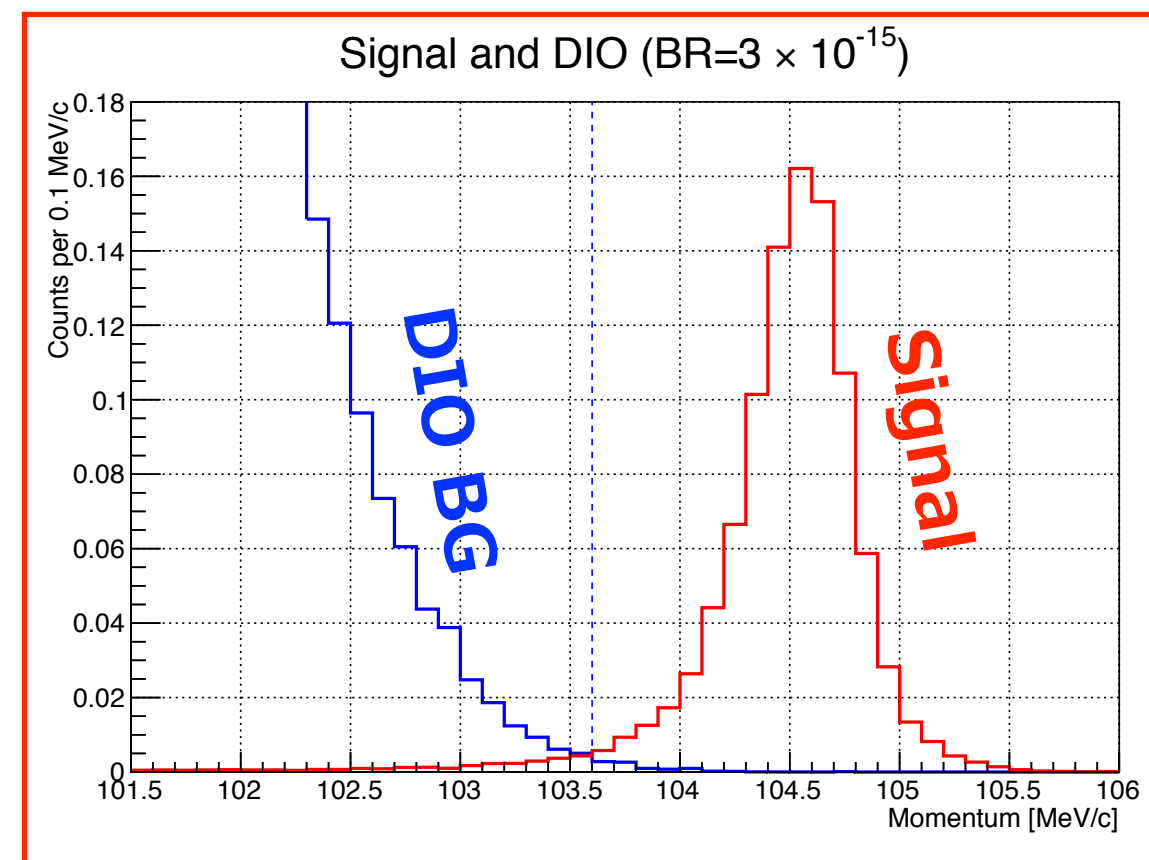
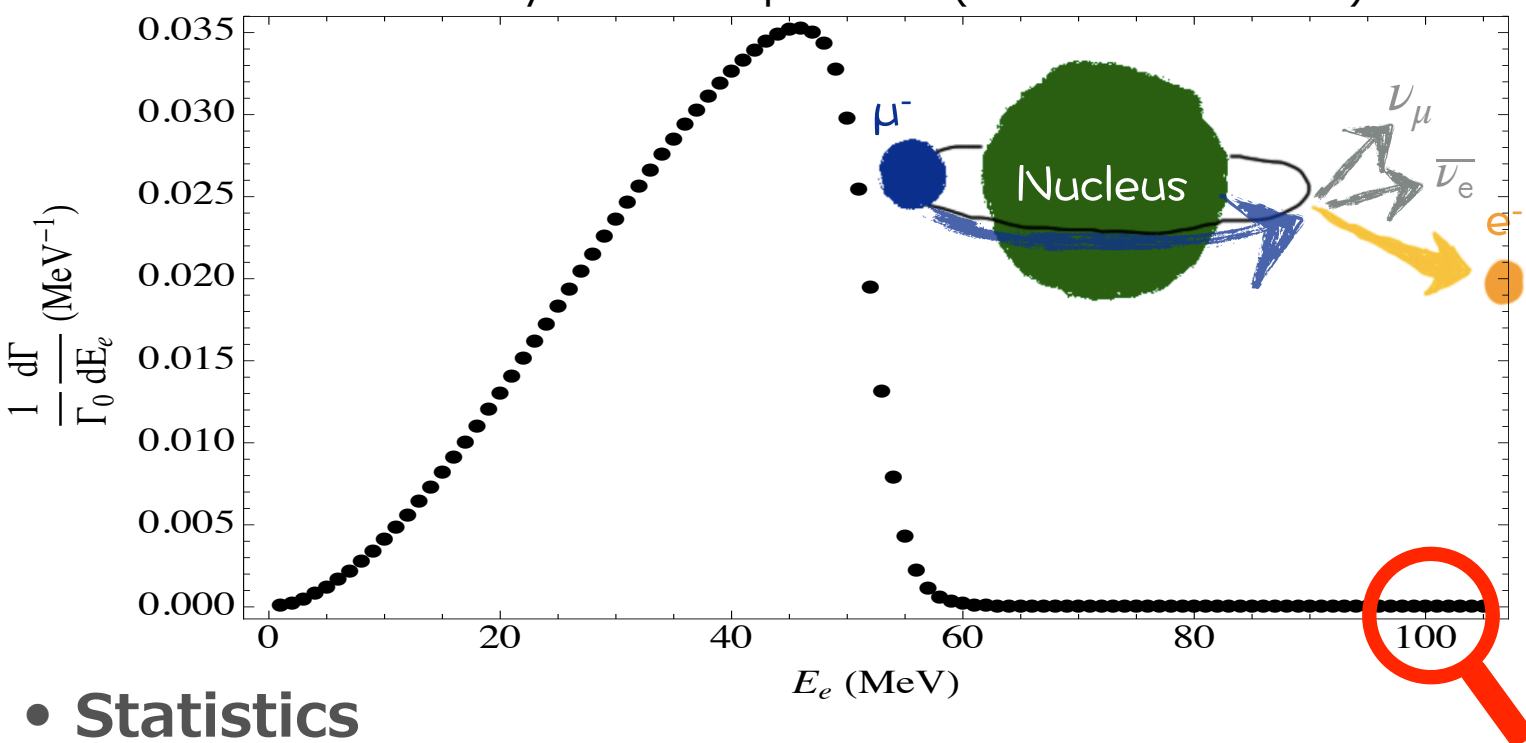


- A charged lepton flavour violation (CLFV)
 - Strongly suppressed in the SM, $<10^{-50}$
 - $\Leftrightarrow$ NP predict the larger conversion rate up to 10^{-14} "clear sign of new physics"
- Simple kinematics; $E_{\mu e} = M_{\mu} - E_B - E_{\text{recoil}} \sim 105 \text{ MeV}$
- Current limit; 7×10^{-13} by SINDRUM-II (2006)
- COMET aims **$\times 100(10,000)$** better sensitivity in Phase-I (Phase-II)



Requirements

Muon Decay In Orbit Spectrum (A. Czarnecki *et.al.*)



Statistics

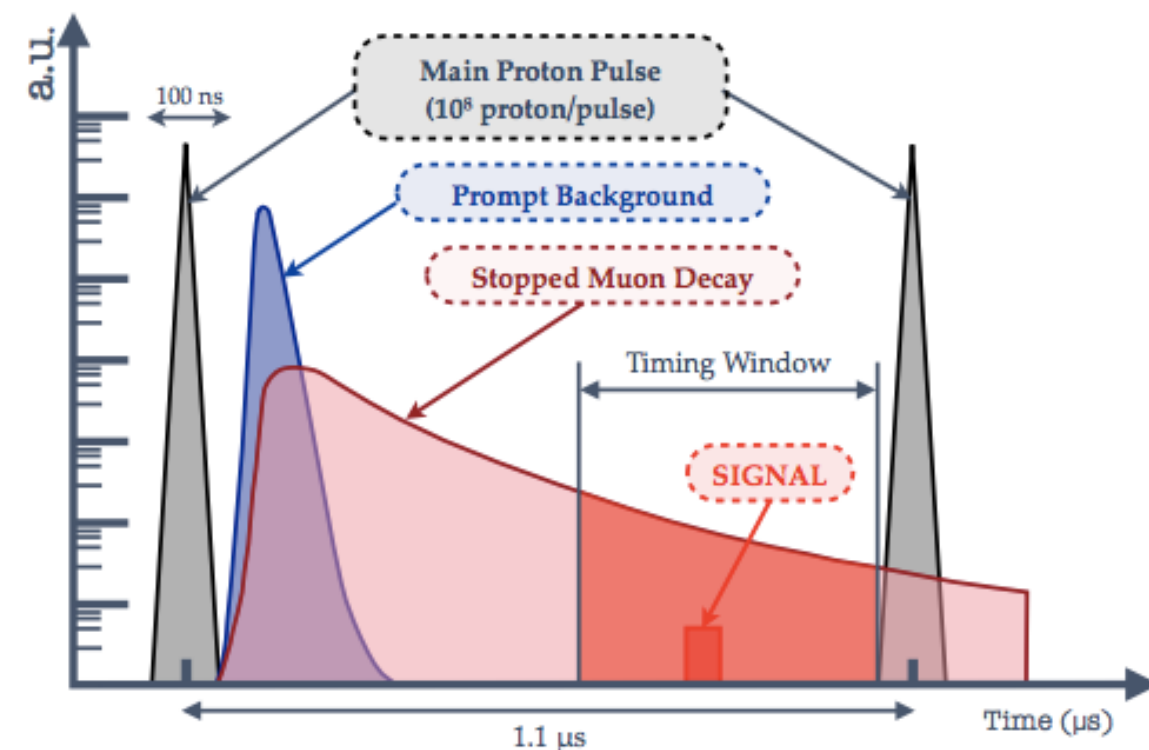
- > 10^{17} of stopping muons $\rightarrow$ Powerful beam @ J-PARC

Background reduction

- Decay In Orbit (DIO) $\rightarrow$ Momentum resolution **better than 200keV/c in σ**
- Beam related BG $\rightarrow$ High purity pulsed beam
- Cosmic-ray BG $\rightarrow$ Veto detector

High rate environment

- Fast response and signal discrimination**

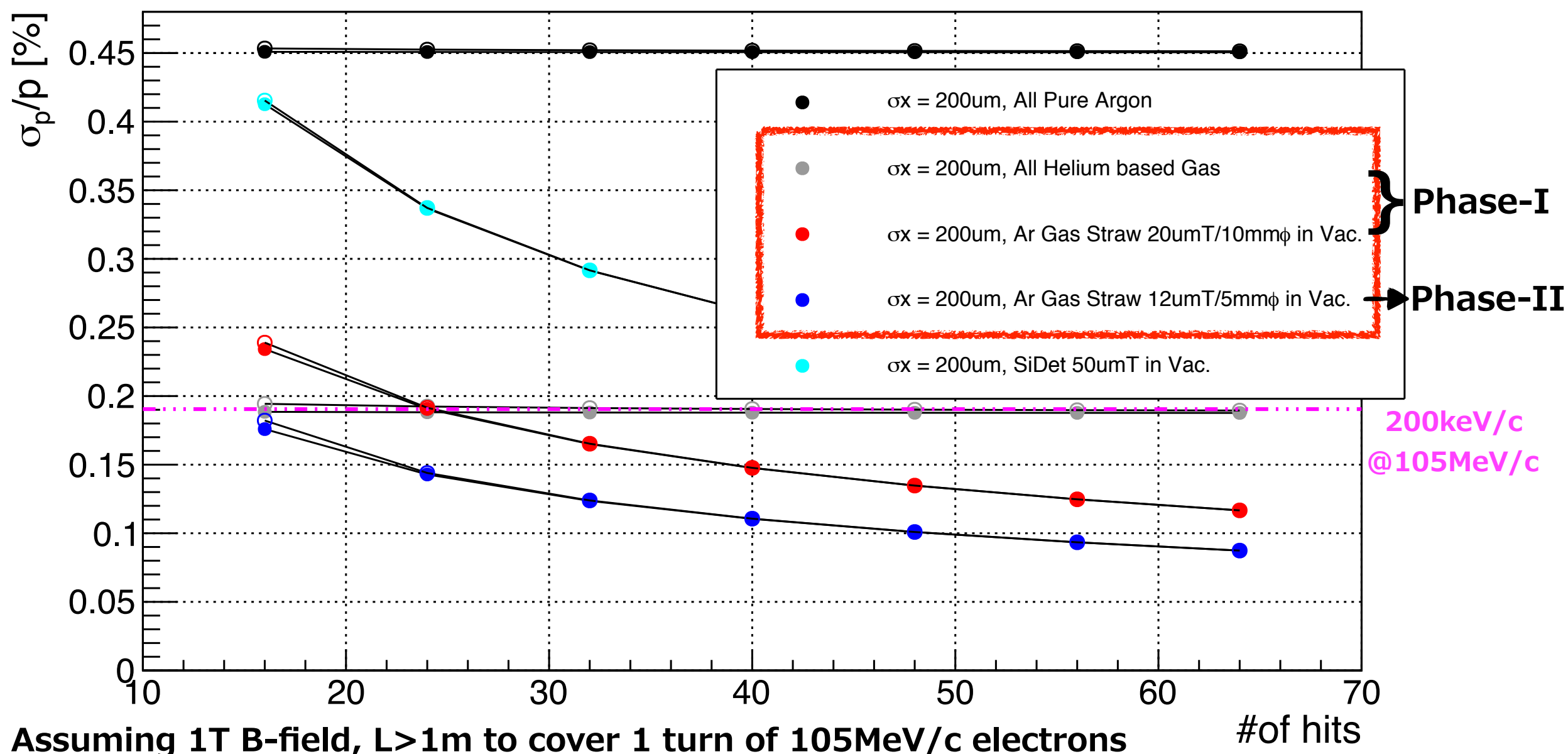


Choice of Detectors

$$\left(\frac{\sigma_p}{p}\right)^2 \approx \left(\sqrt{\frac{720}{N+4}} \frac{\sigma_x p \sin \theta}{0.3BL^2}\right)_{\text{Meas}}^2 + \left(\frac{0.2}{B\sqrt{LX_0 \sin \theta}}\right)_{\text{MS}}^2$$

dominant

Momentum resolution @105MeV/c w/ Proportional L model





The COMET Experiment



MONASH University

8GeV, 54kW Proton Beam

Production Target + Pion Capture Solenoid $\sim 5\text{T}$

Proton Beam

$\pi^- \rightarrow \mu^-$

Muon Stopping Target

Electron Spectrometer $\sim 1\text{T}$

Muon Transport Solenoid $\sim 3\text{T}$

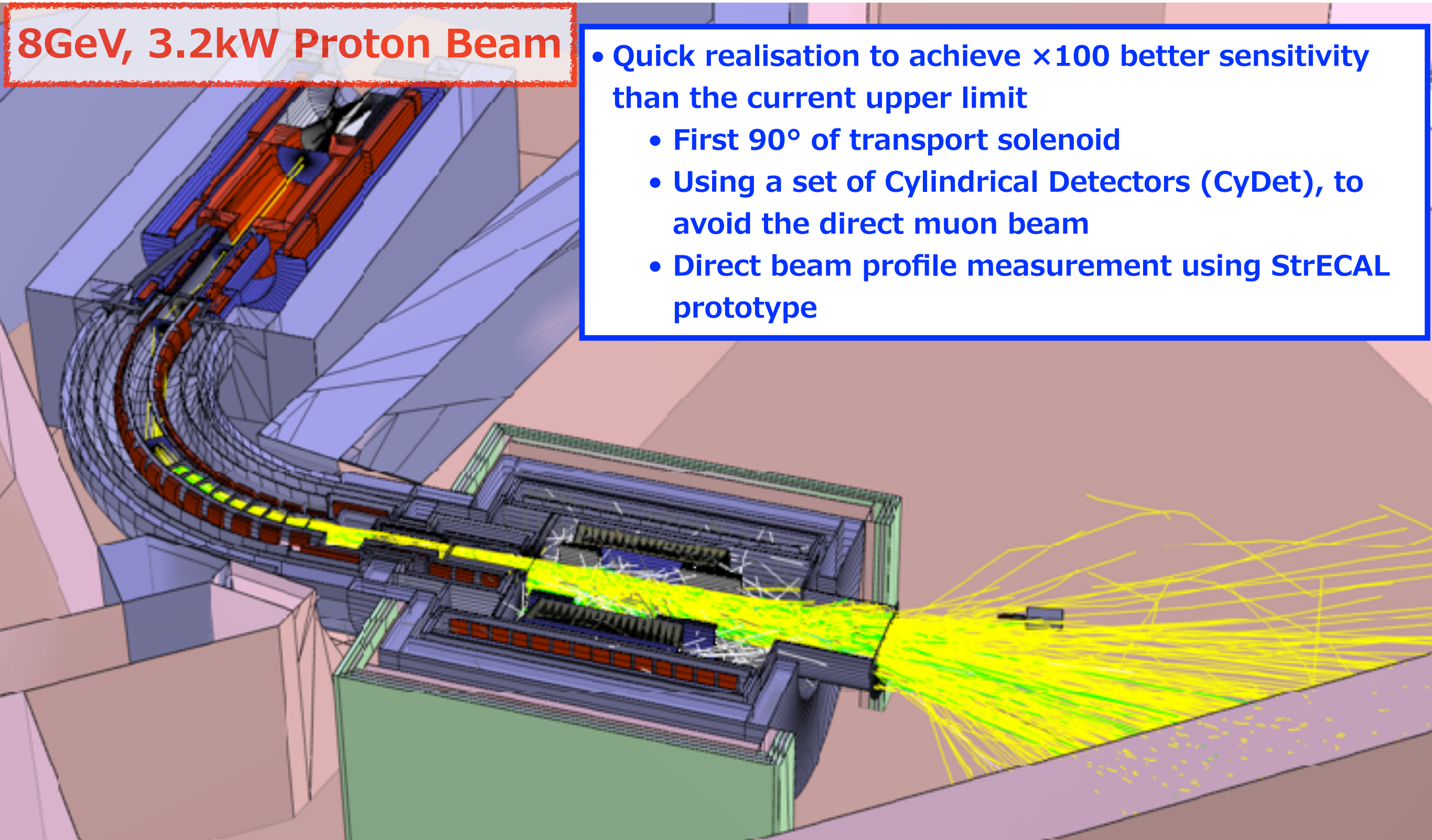
e^-

- C-shape transport solenoid to suppress beam BG
- Curved Electron spectrometer to suppress DIO+beam BG
 - Straw+ECAL (StrECAL) Detectors all in Vacuum (almost full 2π coverage)

Detector Solenoid $\sim 1\text{T}$

8GeV, 3.2kW Proton Beam

- Quick realisation to achieve $\times 100$ better sensitivity than the current upper limit
 - First 90° of transport solenoid
 - Using a set of Cylindrical Detectors (CyDet), to avoid the direct muon beam
 - Direct beam profile measurement using StrECAL prototype



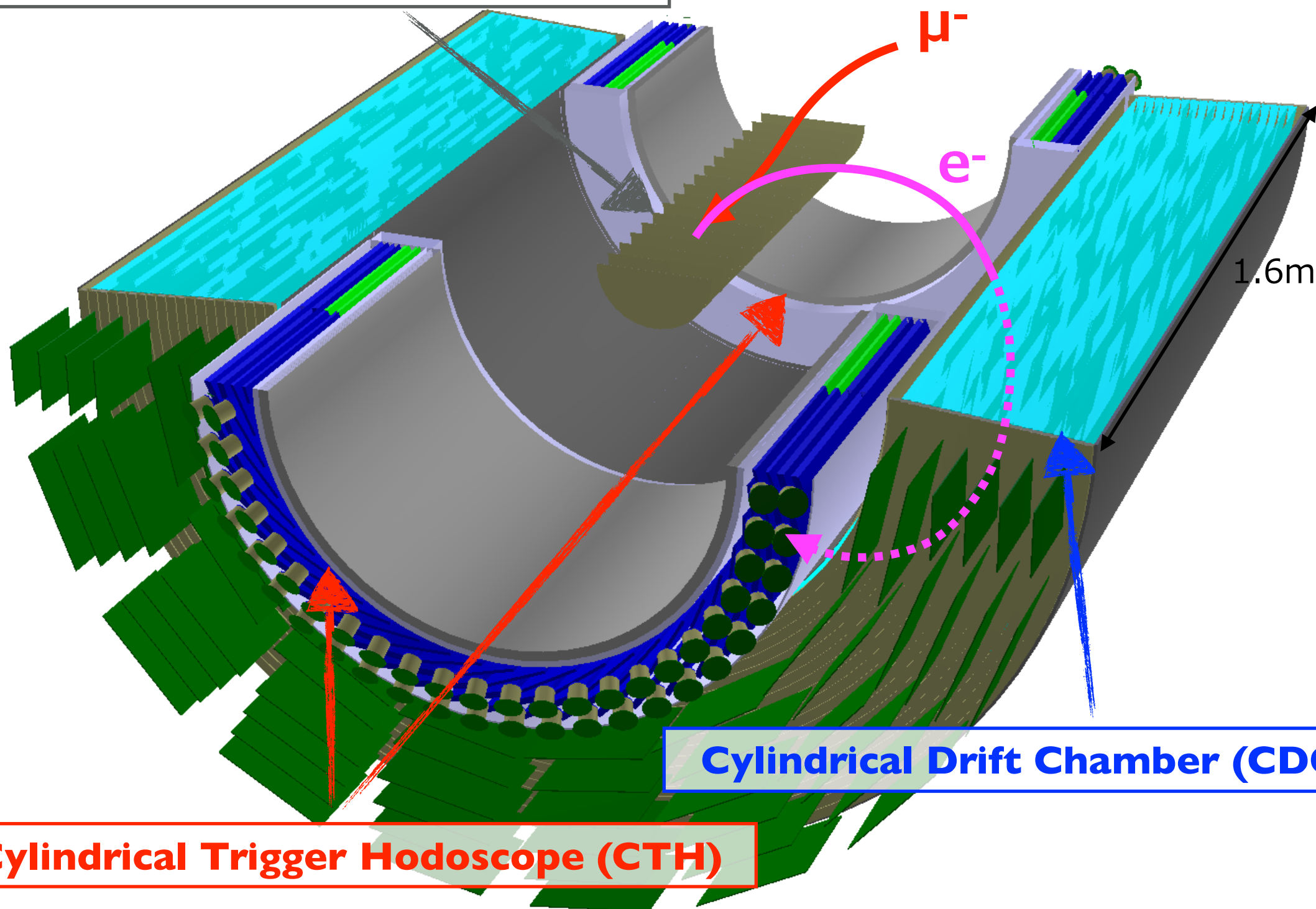
A large, thick, pink brushstroke that forms a partial circle, framing the central text. The stroke has a textured, hand-painted appearance with visible bristles and varying opacity.

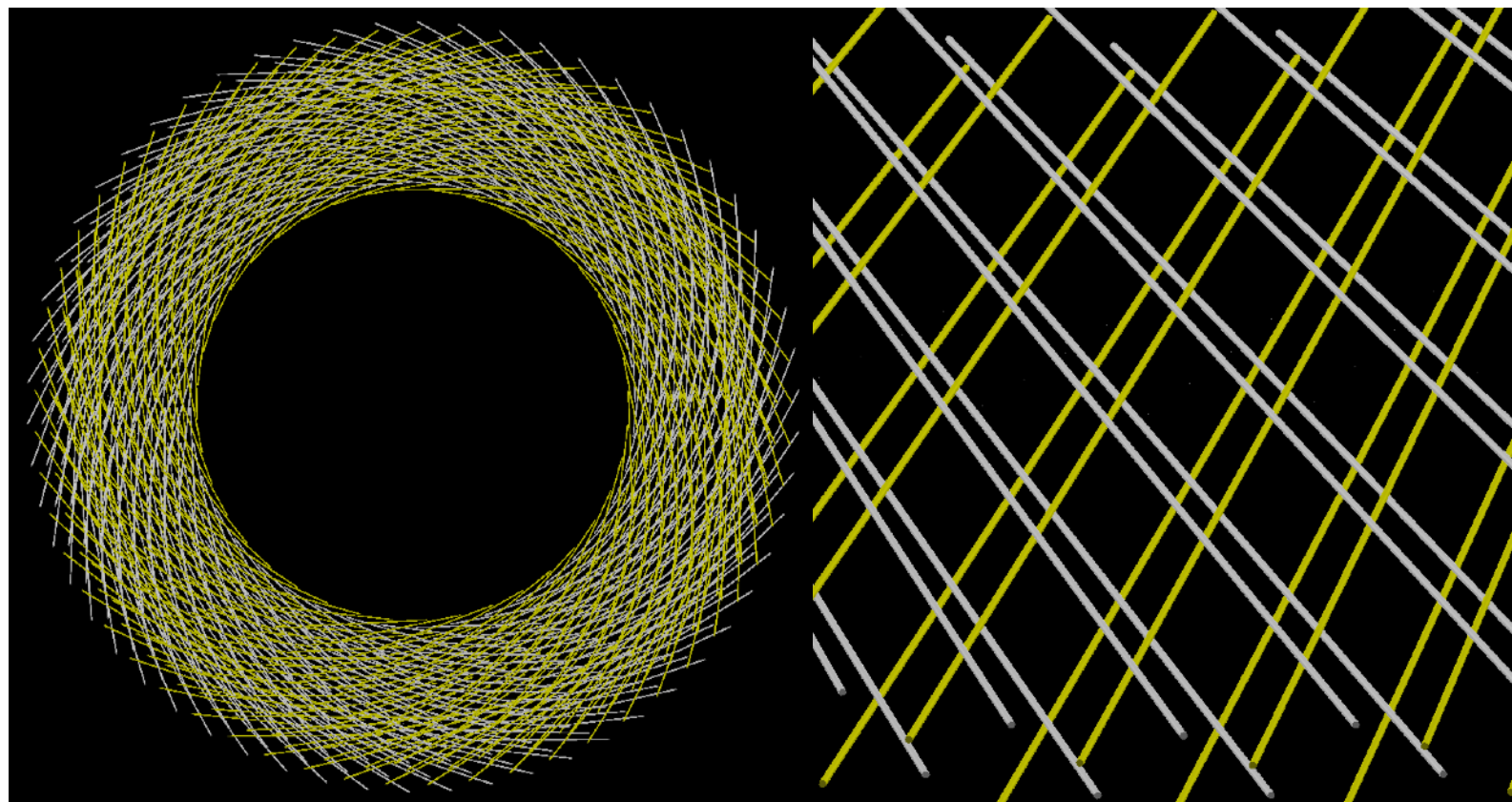
Detectors

μ

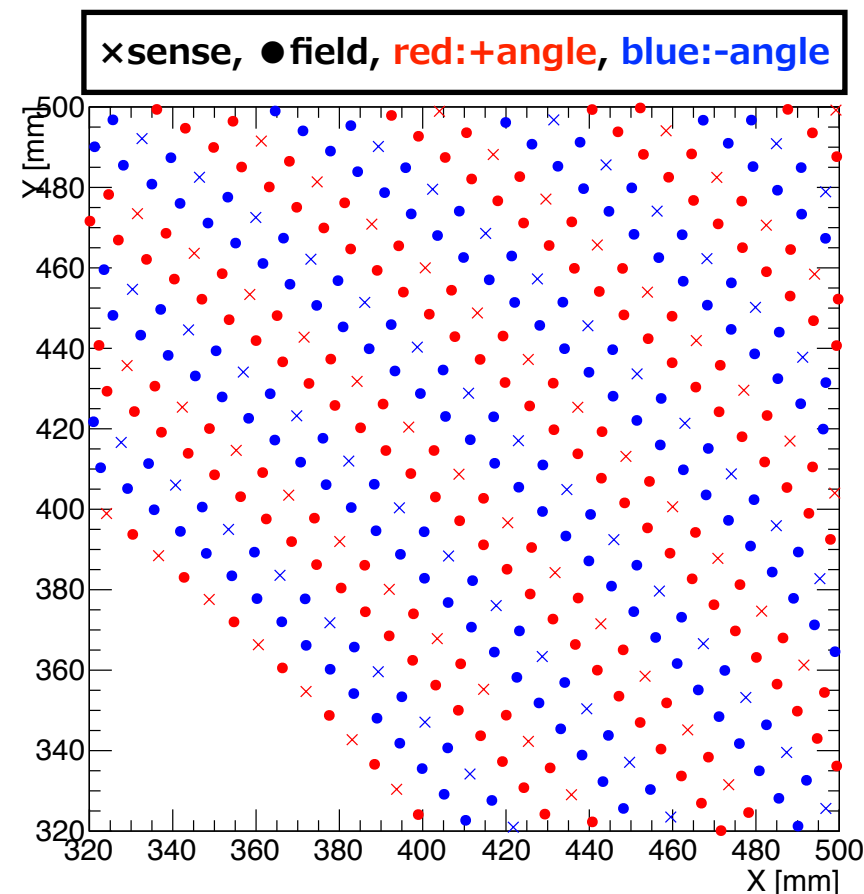
e

17 Stopping target disks, 0.2mT AI



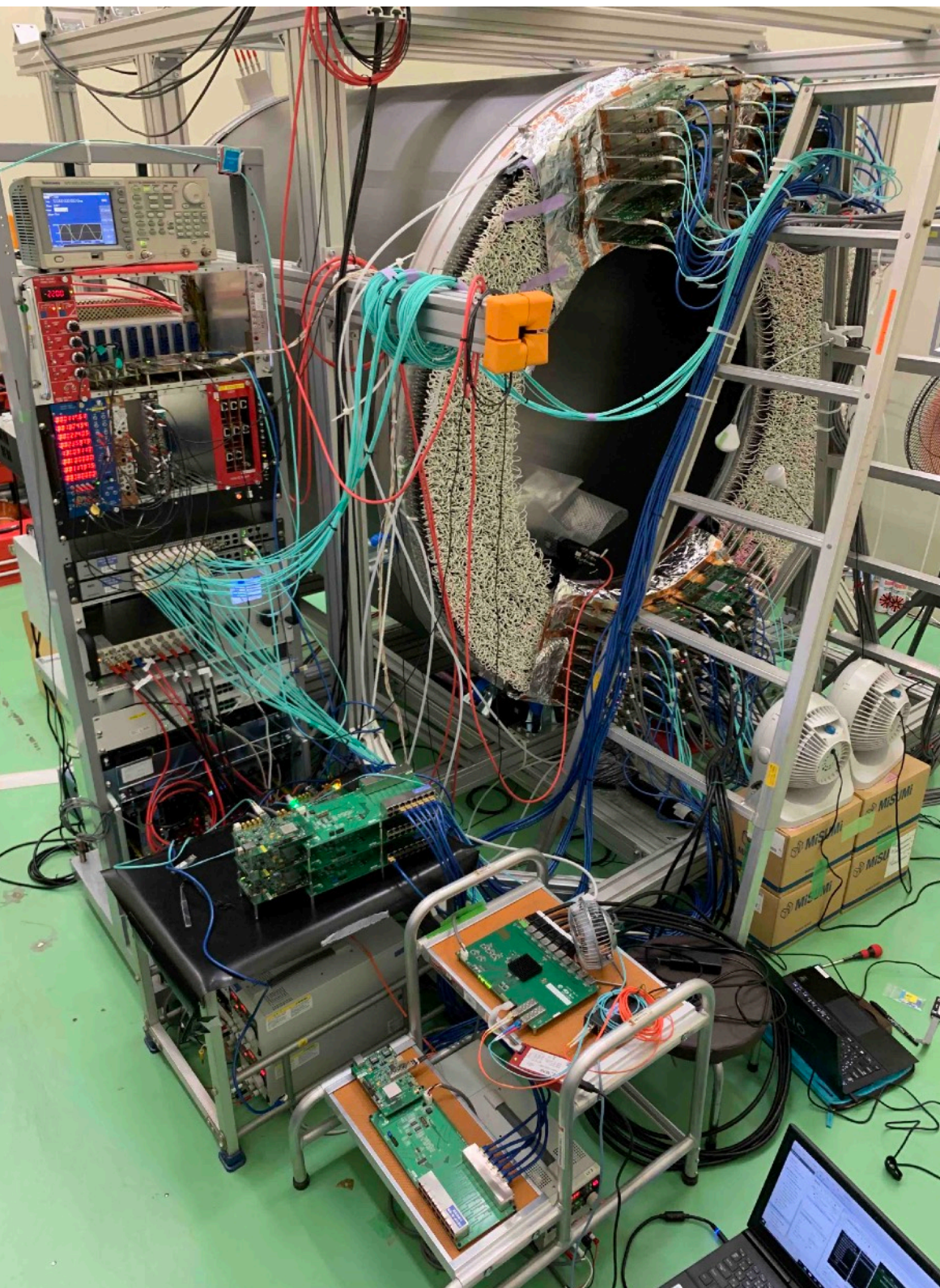


※Not in the correct scale & wire configurations



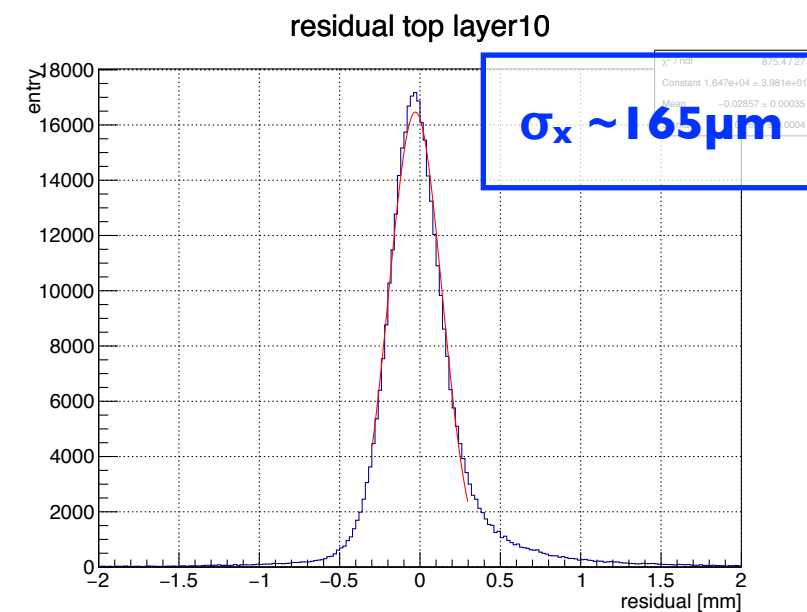
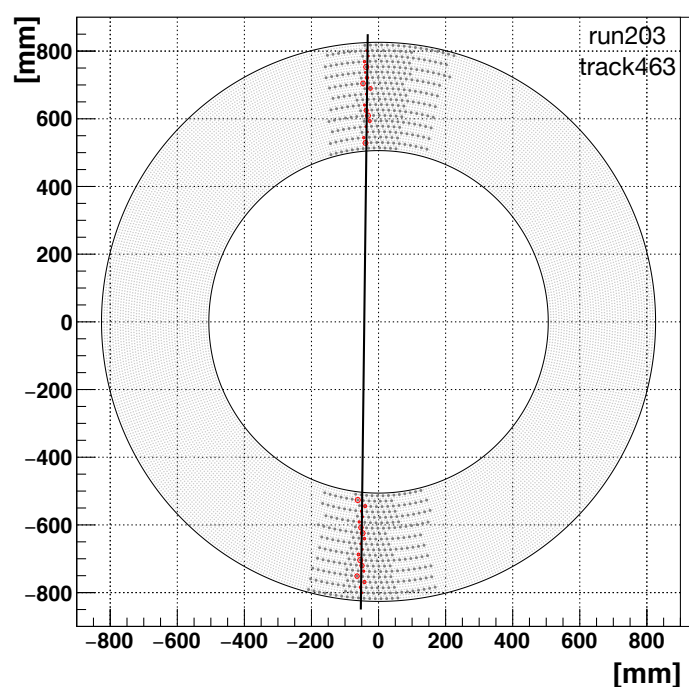
- Main tracking detector for the Phase-I physics measurement
- He:iC₄H₁₀=90:10 based on the MC&prototype studies
- All stereo wires to measure the 3D momentum
- 18 layers (+2 guard layers), ~5k sensitive wires
 - Sense: Au plated W, 25μmφ, Field: Al 126μmφ
- A 0.5mmT CFRP inner wall to reduce the proton BG



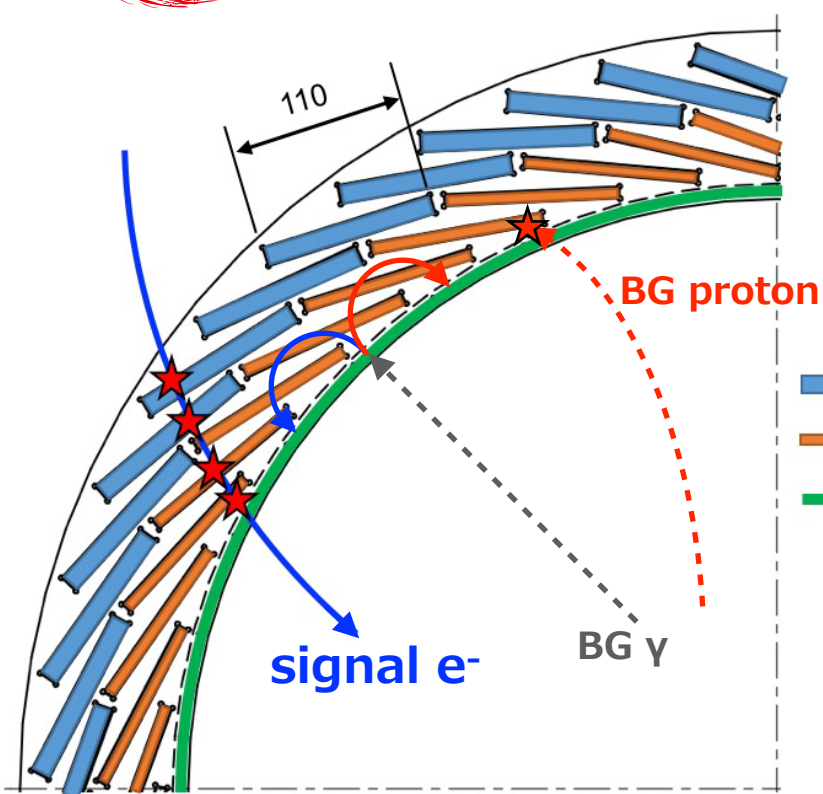


An example of cosmic-ray event

(a) Event Display

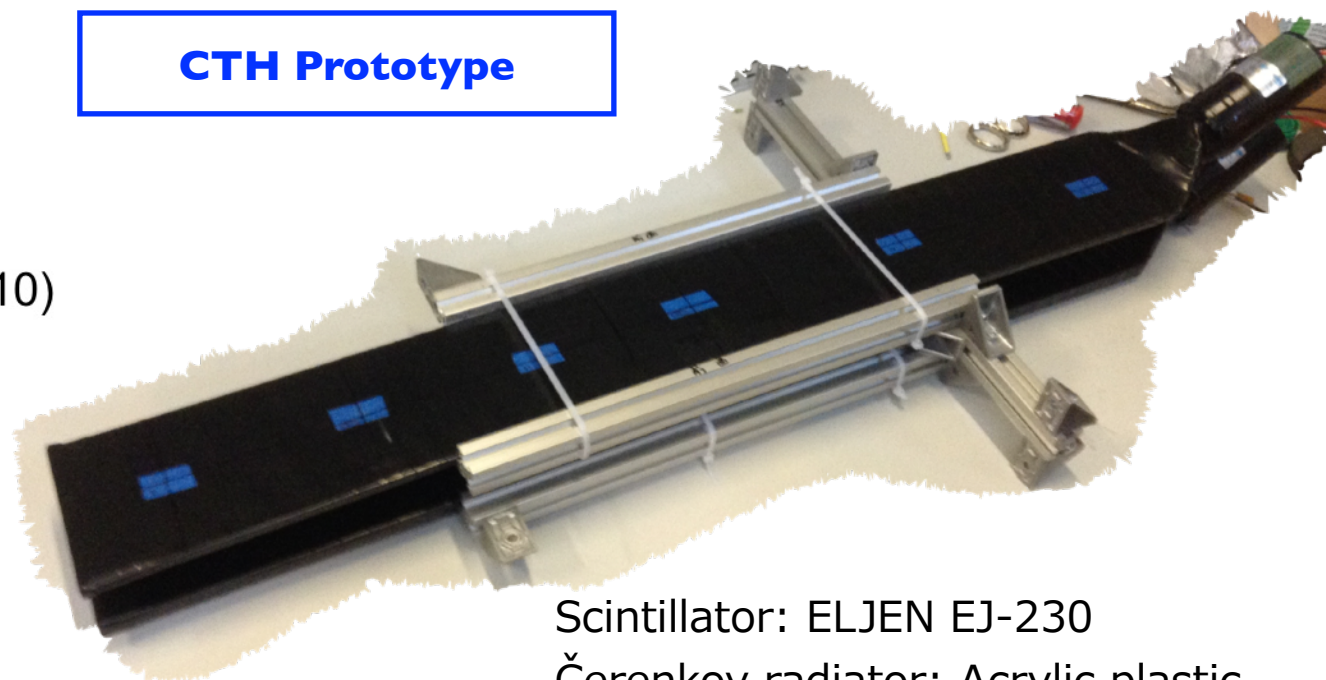


- Detector has been constructed and being tested using cosmic-rays @KEK Tsukuba
- Detector shows excellent stability after the construction >2-y ago
- Spatial resolution of **165 μm** has been confirmed
- Almost ready to transport to J-PARC



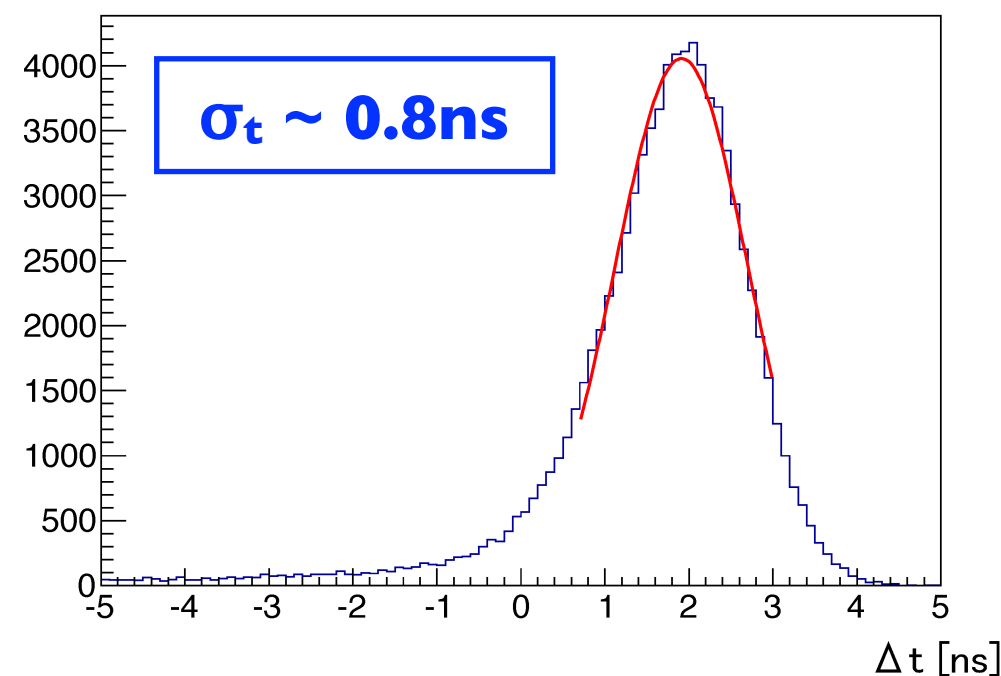
- Cherenkov radiator (t10)
- Plastic scintillator (t5)
- Lead shielding (t16)

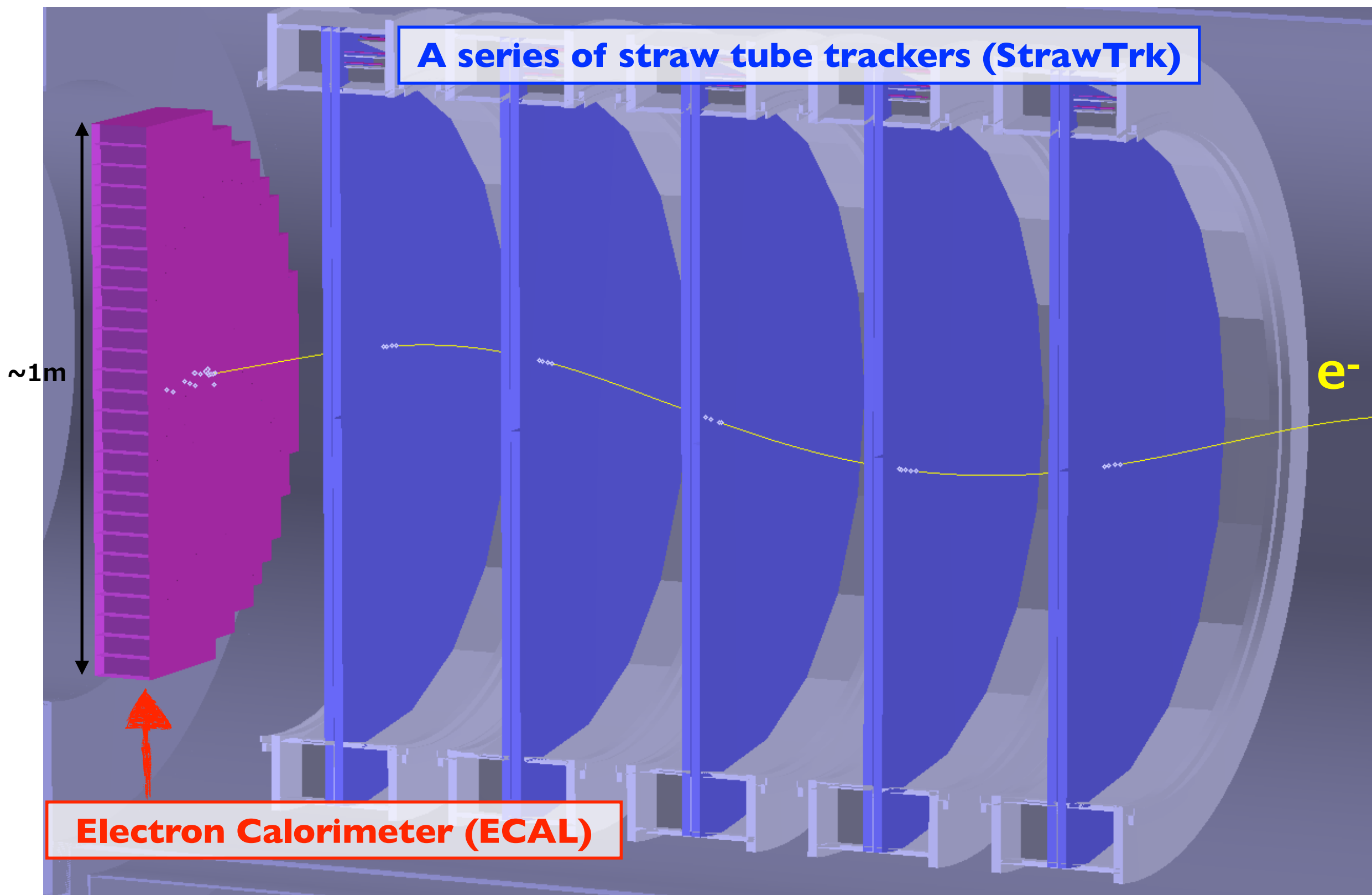
CTH Prototype



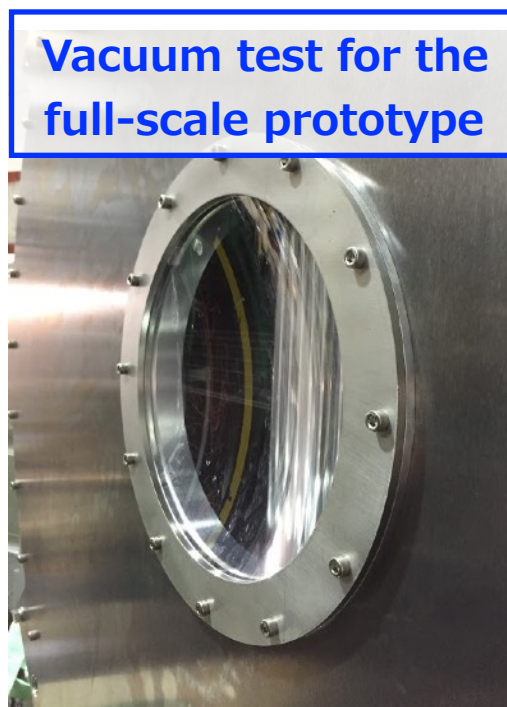
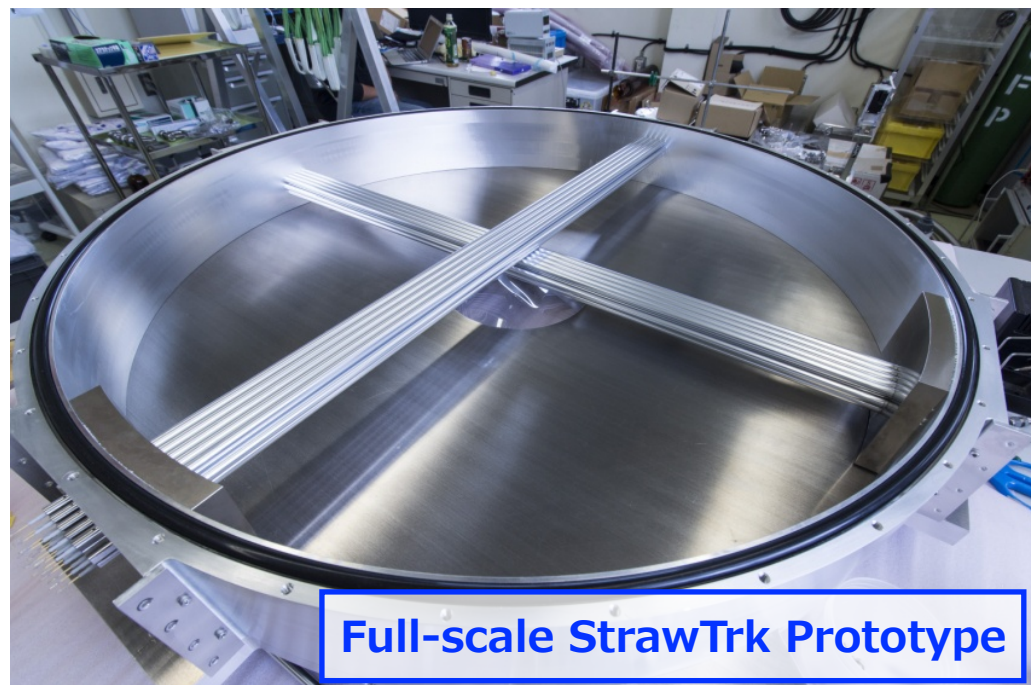
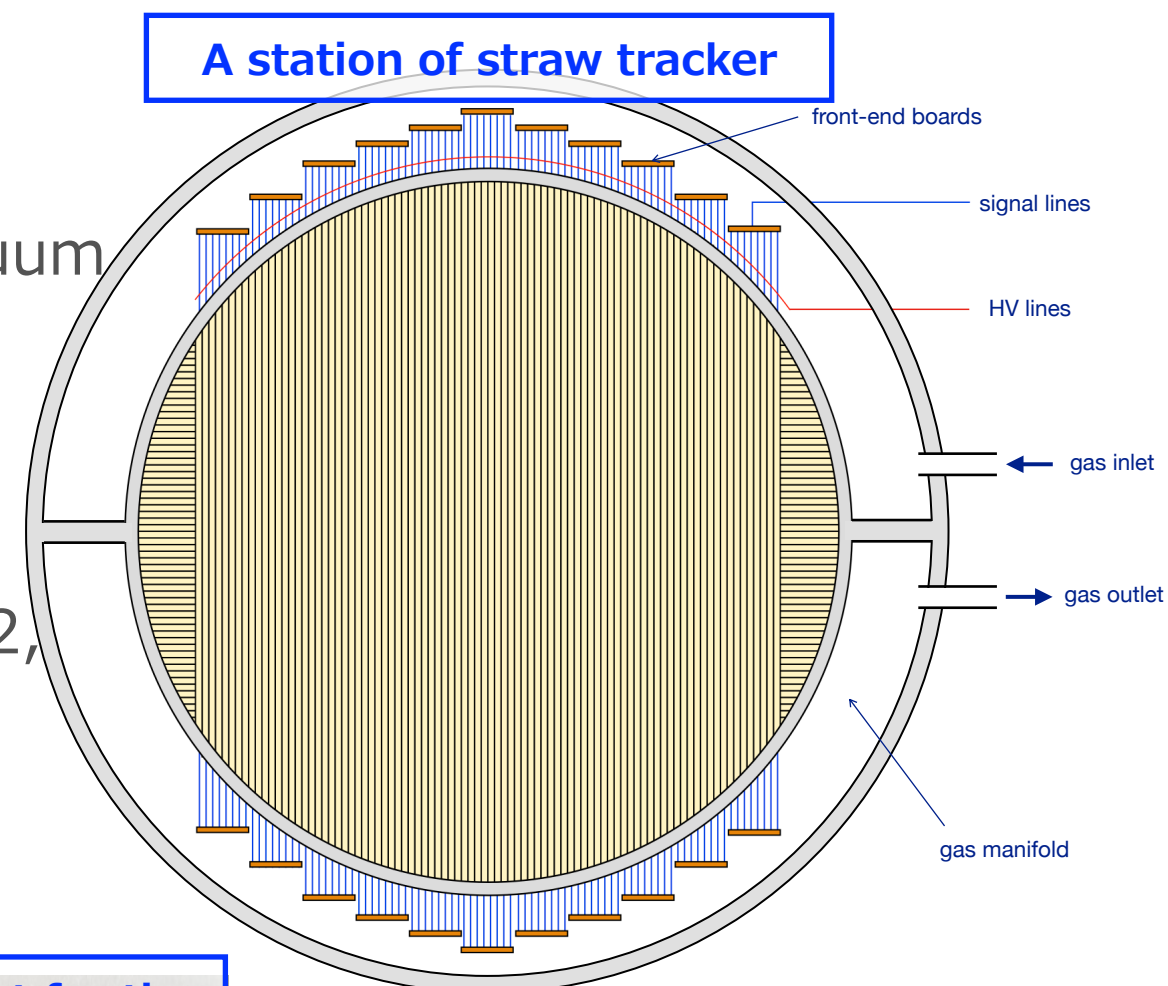
Scintillator: ELJEN EJ-230
 Čerenkov radiator: Acrylic plastic
 PMT: Hamamatsu H8403-70

- Determine the primary trigger and precise T0 value within the 1ns precision
- 64 or 48 plastic scintillators/acrylic Čerenkov radiators cylindrically aligned both upstream/downstream
- A Čerenkov layer reject all low- β particles (<0.65)
- Use the magnetic field tolerable fine-mesh PMTs
- 4-fold coincidence strongly suppresses the accidental pileups
- Final detector design is almost fixed

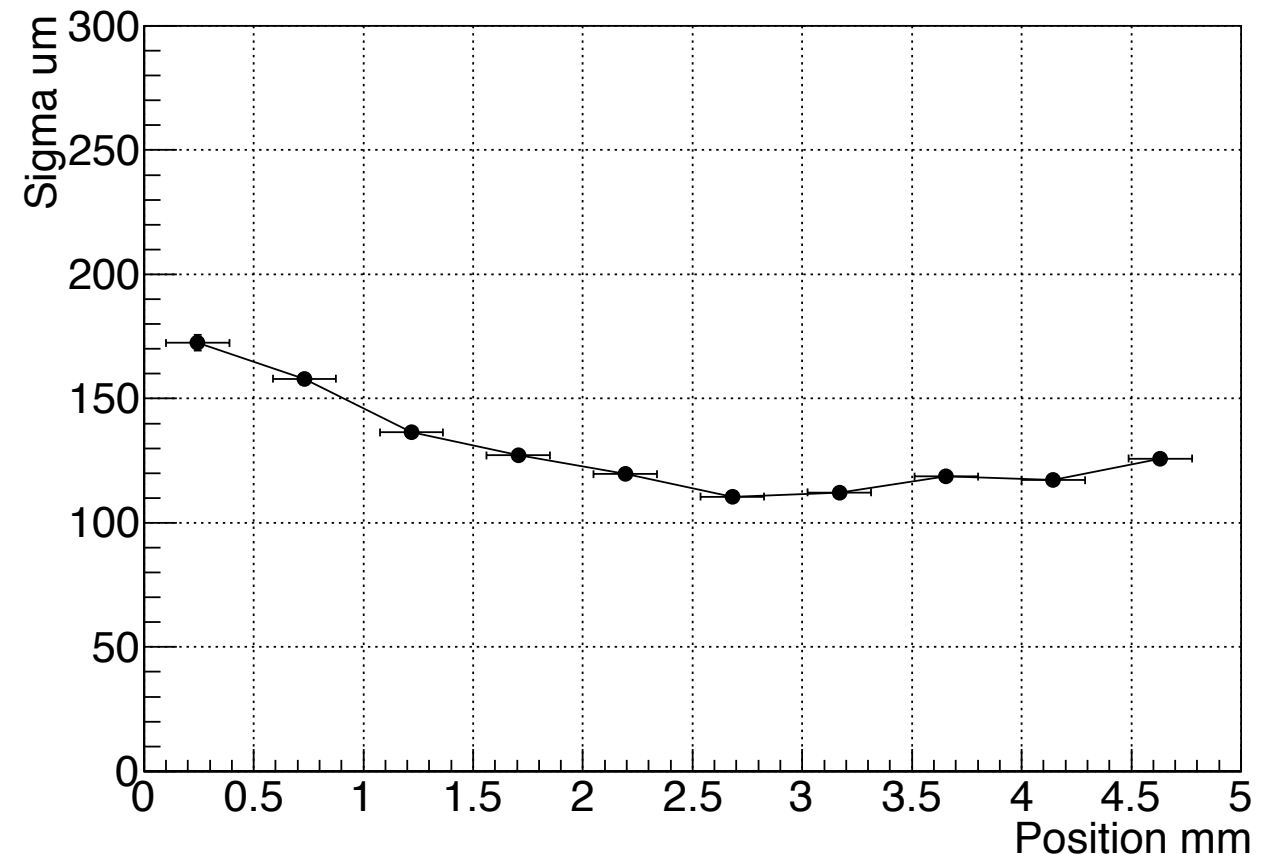
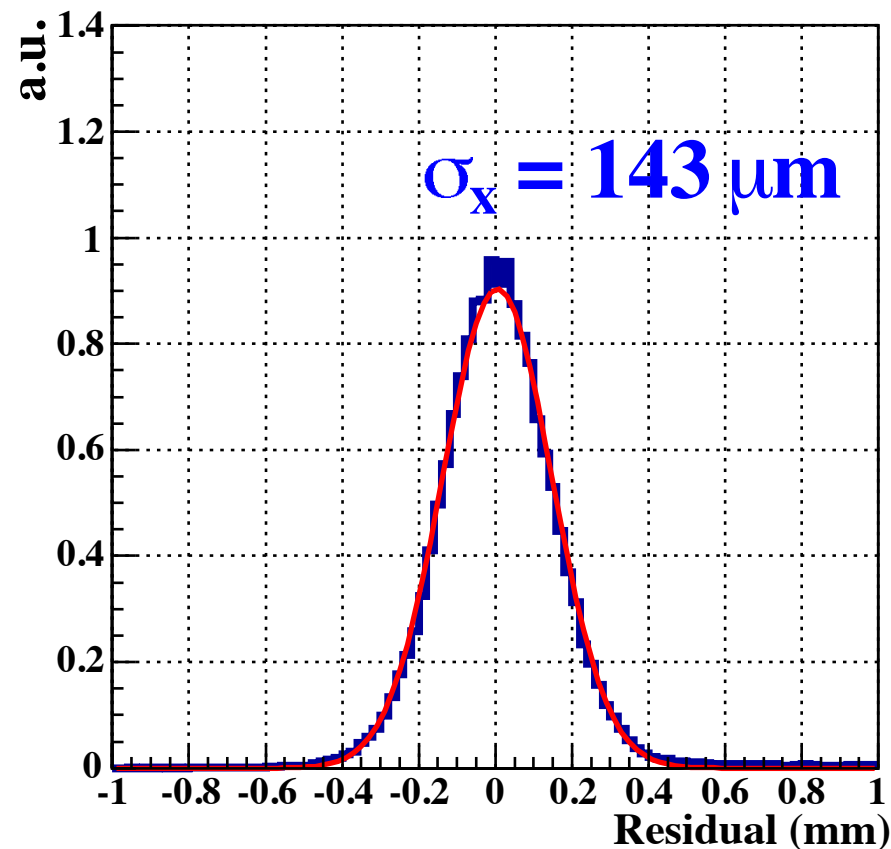




- Main tracker for Phase-I beam measurement & Phase-II physics run
- Ultra thin straw-tube chambers operational in Vacuum
 - $20\mu\text{T}/10\text{mm}\phi$ for Phase-I
 - $12\mu\text{T}/5\text{mm}\phi$ for Phase-II
 - $\text{Ar}:\text{C}_2\text{H}_5=50:50$
 - Each “station” consists of $240(\sim 500)$ straws $\times 2$, $5(>6)$ stations for Phase-I (Phase-II)
- Large prototype was constructed to evaluate the detector performance and to finalise the design



Sigma vs Position for Ar/C₂H₆=50/50, 2000V



- Vacuum tightness has been proven down to 0.1Pa
- Spatial resolution better than **150μm** has been confirmed with the StrawTrk Phase-I full-scale prototype
- Detector design has been fixed based on these studies
 - Construction of Phase-I StrawTrk will start soon

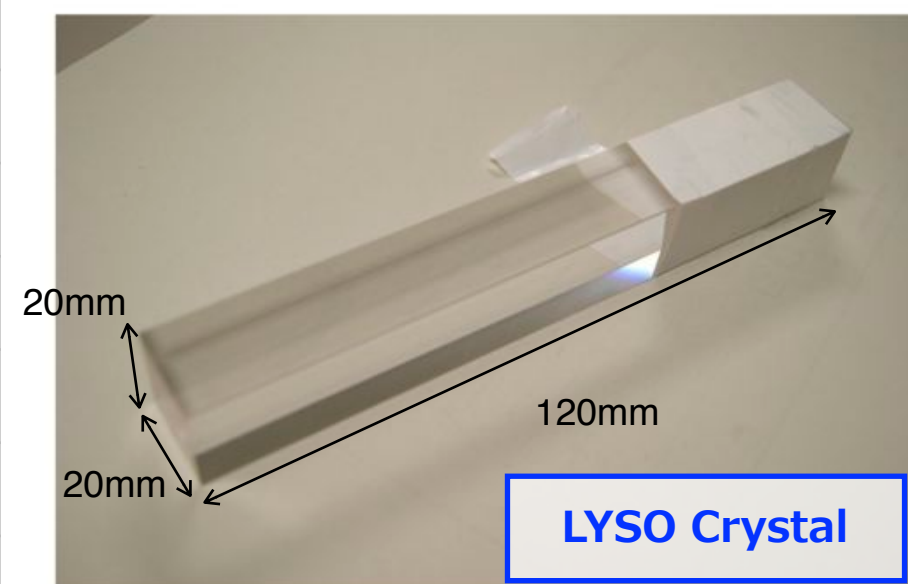
12 μ m/4.8mm ϕ straw tubes



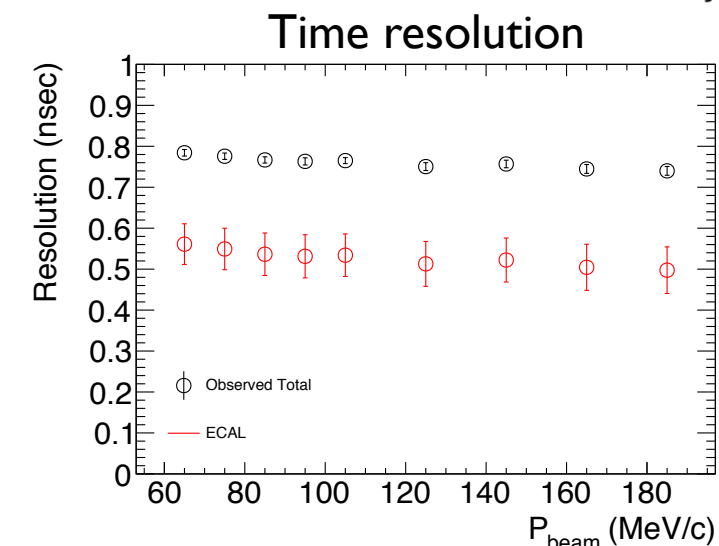
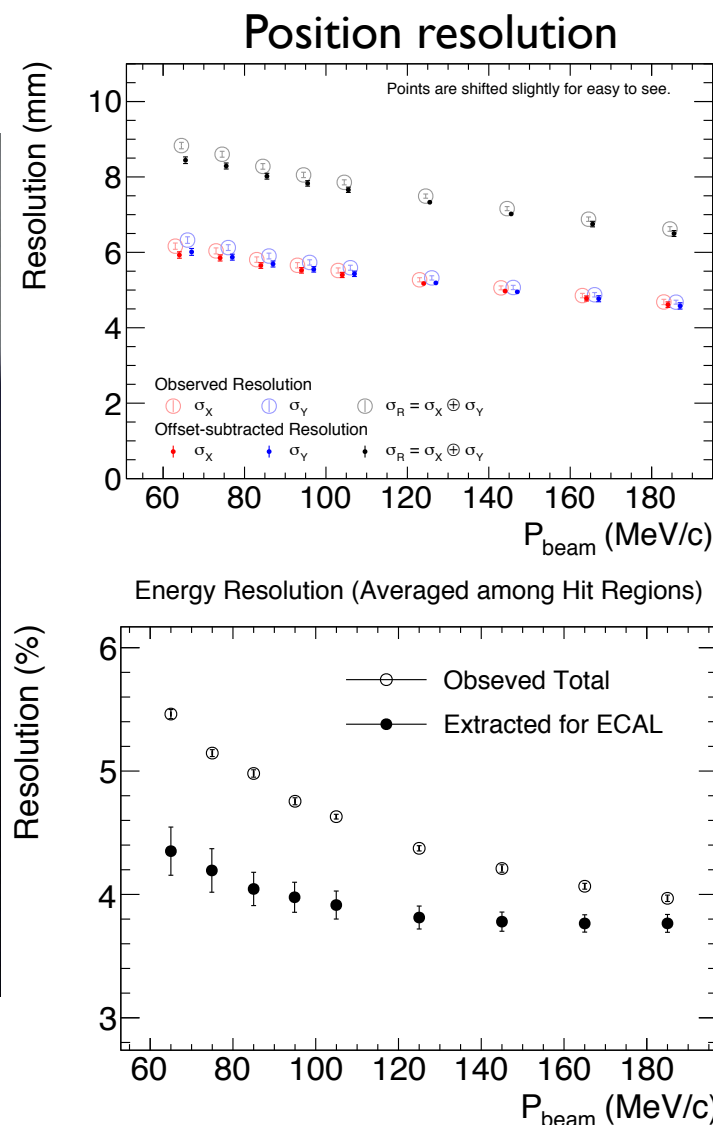
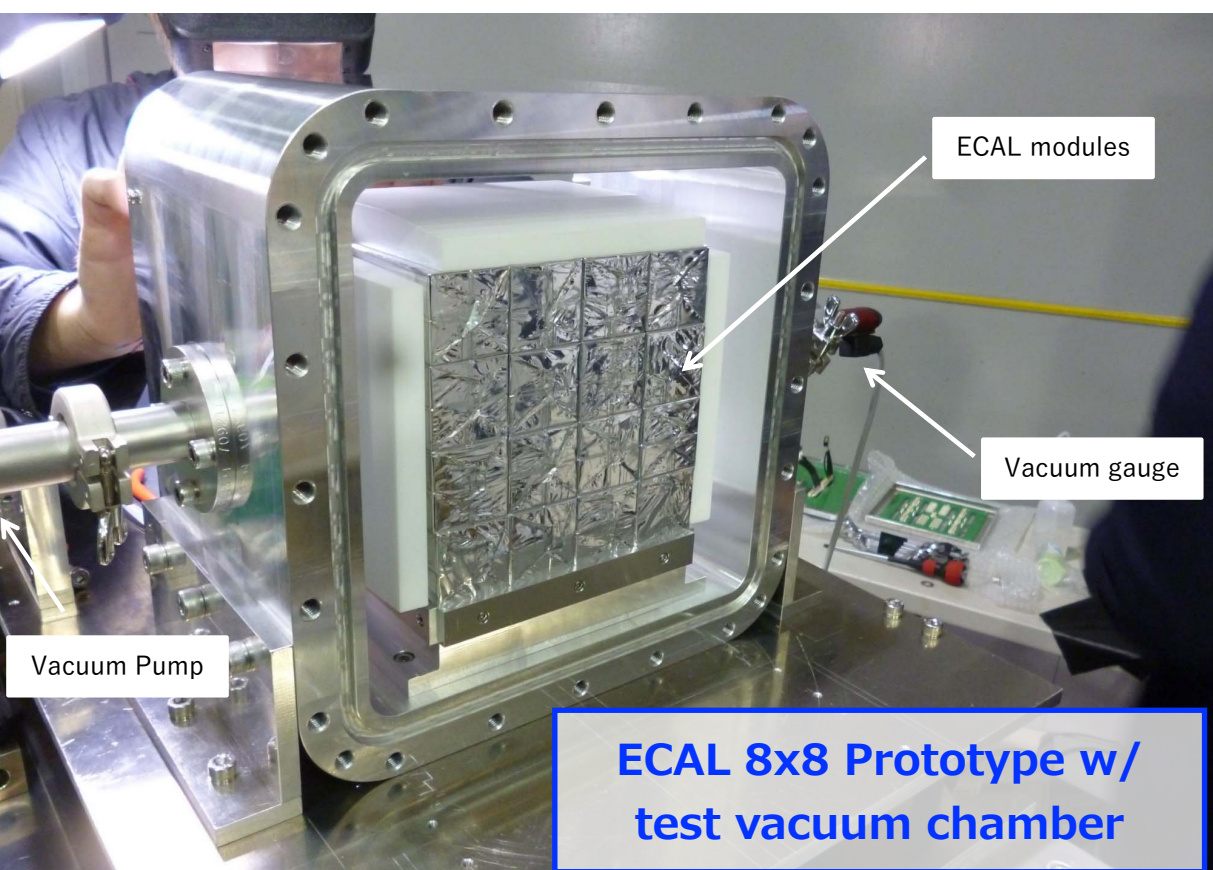
- Phase-II straw tube is under development in parallel
- Succeeded to manufacture **12 μ m** thick/ 5mm ϕ straw tubes
- Achieve the vacuum tightness against 4 bar pressure
- Further studies are ongoing

- Measure the energy and timing of particles
- Provide the trigger signal
- Located inside the 1T magnetic field & <10Pa vacuum
- 500-1,000 (~2,000) LYSO crystals for Phase-I(Phase-II)
 - Fast time response + high light yield
- Cost-effective/B-field tolerant APDs (Hamamatsu S8664-1010 10×10mm²) to read-out the scintillation light

	GSO(Ce)	LYSO	PWO	CsI(pure)
Density (g/cm ³)	6.71	7.40	8.3	4.51
Rad. length (cm)	1.38	1.14	0.89	1.89
Moliere radius (cm)	2.23	2.07	2.00	3.57
Decay constant (ns)	600 ^s ,56 ^f	40	30 ^s ,10 ^f	35 ^s ,6 ^f
Wave length (nm)	430	420	425 ^s ,420 ^f	420 ^s ,310 ^f
LY (NaI(Tl)=100)	3 ^s ,30 ^f	83	0.08 ^s ,0.29 ^f	3.6 ^s ,1.1 ^f



ECAL (2/2)



- Succeed to operate the ECAL prototype inside the vacuum
- In the beam test using mono-energetic electron beam, the prototype showed an excellent performance that satisfies our requirements
 - σ_E/E **4%**, $\sigma_{x/y}$ **<6mm**, σ_t **0.5ns** @105MeV e-
 - Scalable to the actual detector 📖 final design for Phase-I has been almost fixed

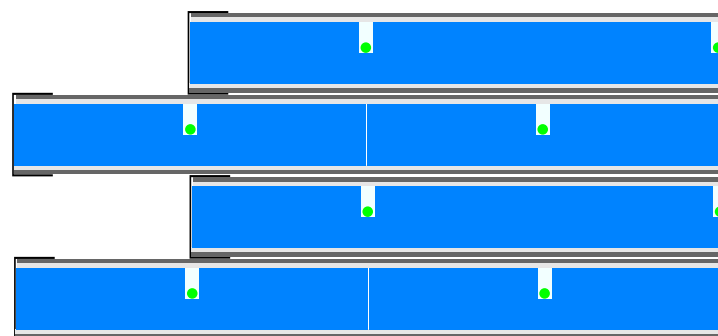
Germanium Detetor (GeDet)

- Measure the muonic X-ray to determine the precise normalisation factor
- A prototype detector has been developed

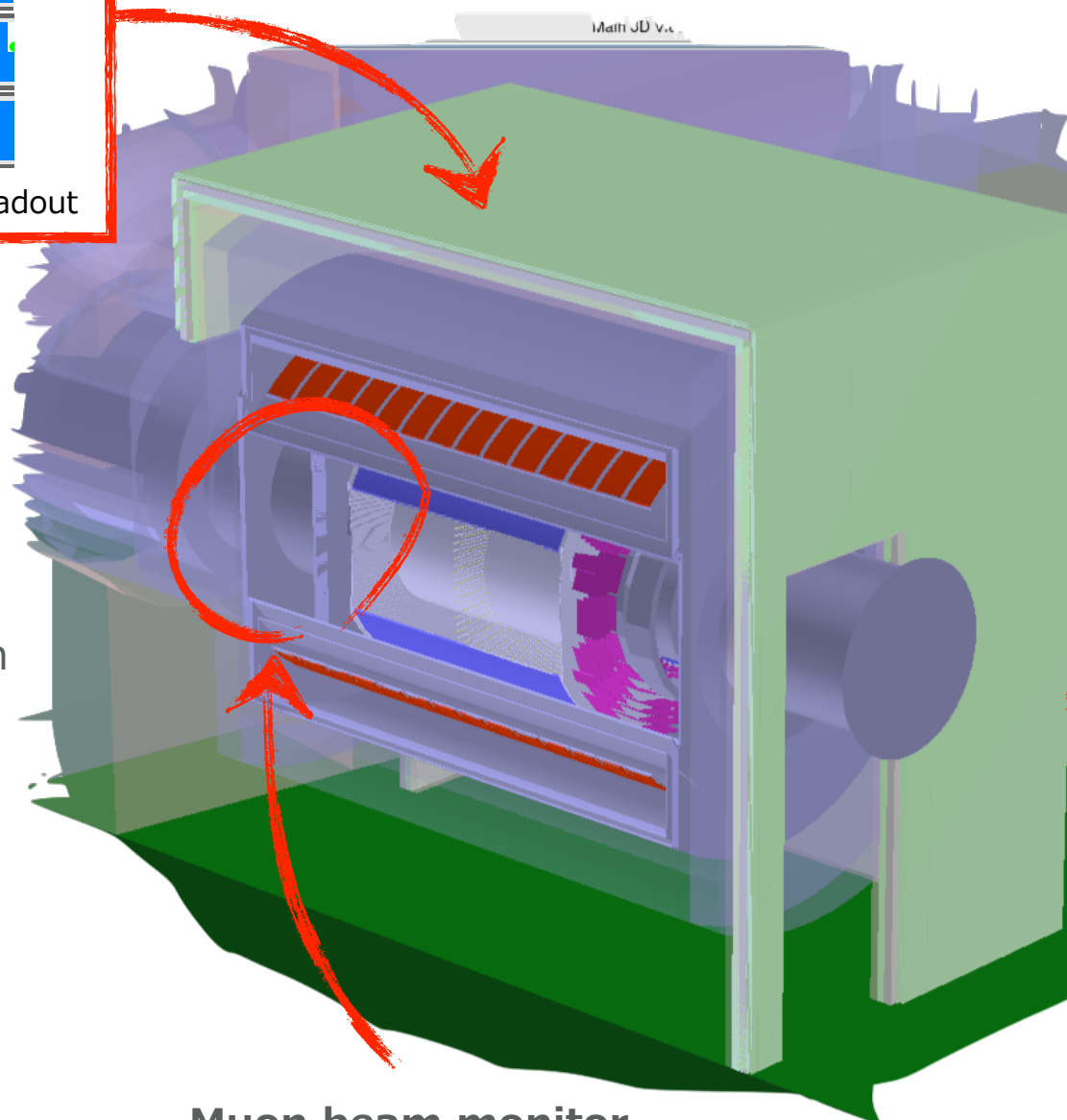


Cosmic-ray Veto (CRV)

- Inefficiency less than 0.4%
- Radiation tolerance @ 10^{11} n/cm²

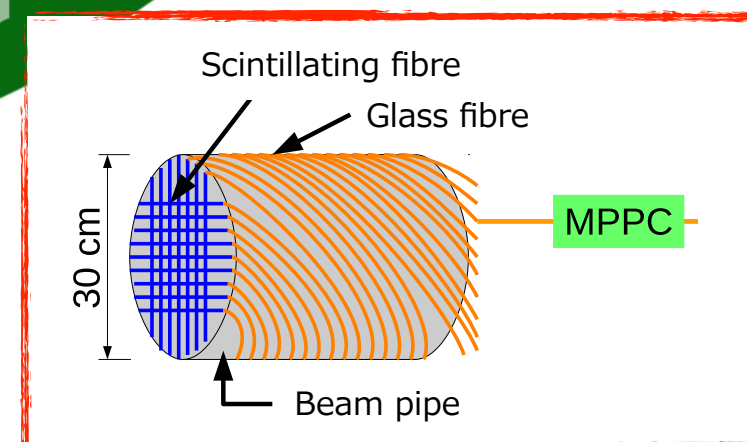


Plastic Scintillator+WLS fibre ×4 layers, SiPM readout



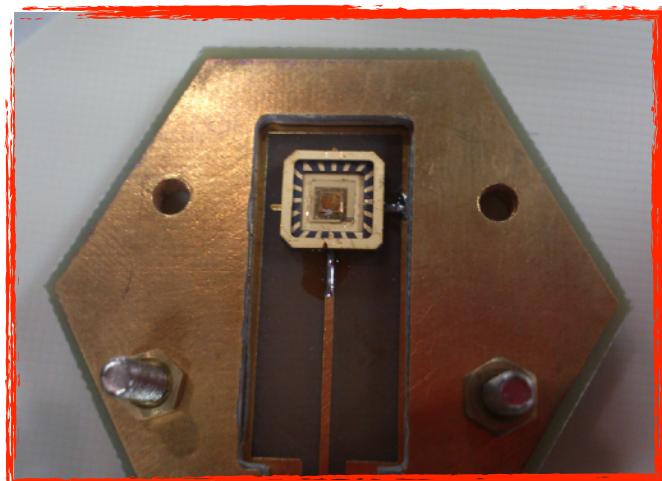
Muon beam monitor

- Can provide the timing and beam profile at the end of the curved solenoid
- Still under the discussions/R&D



Extinction Monitor

- Diamond detector has shown excellent performance to distinguish the single leakage proton in-between high-intense proton bunches
- GaN detector also being considered alternatively





List of Related Talks



MONASH University

- M. Moritsu, 26-Sep, PN-FM, **“The COMET experiment: search for muon-to-electron conversion”**
- H. Yoshida, Poster PN-01, **“Study of gas-gain saturation and cross-talk effect by low-energy protons with a test chamber for the COMET-CDC”**
- K. Ueno, Poster PN-02, **“Status on the StrECal system for COMET Phase-I”**
- Y. Nakatsugawa, Poster PN-03, **“Development of a Cylindrical Drift Chamber for the COMET Phase-I Experiment”**
- Y. Fukao, Poster PN-04, **“Irradiation Test of Scintillating and Clear Optical Fibers”**
- Y. Igarashi, Poster PN-05, **“A cost-effective network configuration of data taking for COMET phase-I”**
- R. Murayama, Poster PN-13, **“Radiation tolerance of LYSO crystal for the COMET experiment”**
- J. SATO, 25-Sep, PN review, **“Theoretical overview of Lepton Flavor Violation”**
- E. PASSEMAR, 26-Sep, PN-FM, **“Theory of Charged Lepton Flavour Violation”**



Summary



MONASH University

- COMET aims to search for the μ -e conversion with unprecedented sensitivity of $10^{-15}/10^{-17}$ to inspect the plausible NP scenarios
- The performance of each detector is essential to achieve our aiming sensitivity
 - A construction of helium based CDC has been completed and good spacial resolution of **165 μ m** was confirmed
 - The CTH prototype shows enough timing resolution, the design has been almost fixed
 - The development of the 20 μ mT vacuum tight straw-tube has been completed with an excellent spatial resolution of **150 μ m**, blue light to start the assembly for Phase-I
 - Further thin **12 μ mT** straw tubes are also being developed for Phase-II
 - The ECAL prototype based on LYSO crystals shows an excellent performance, the final design for Phase-I is almost done
 - R&Ds and constructions are ongoing for other supportive detectors as well
- More details can be found in our Technical Design Report; [arXiv:1812.09018](https://arxiv.org/abs/1812.09018)

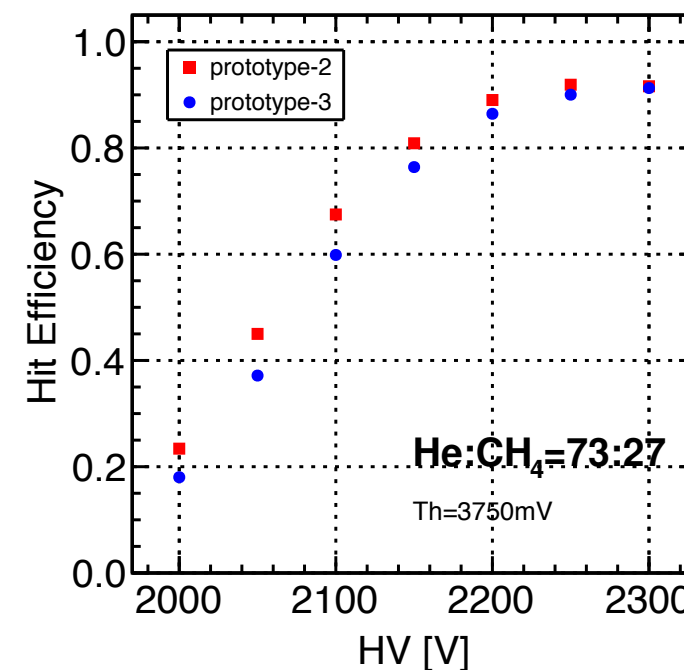
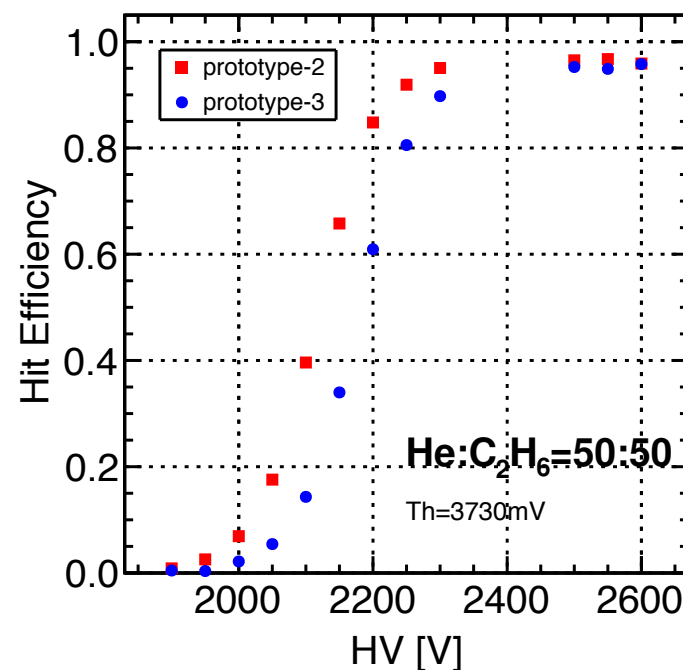
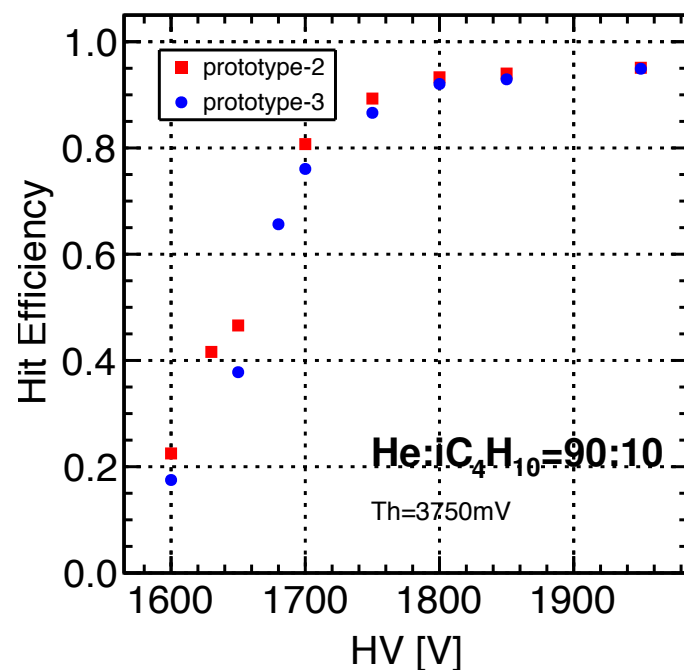
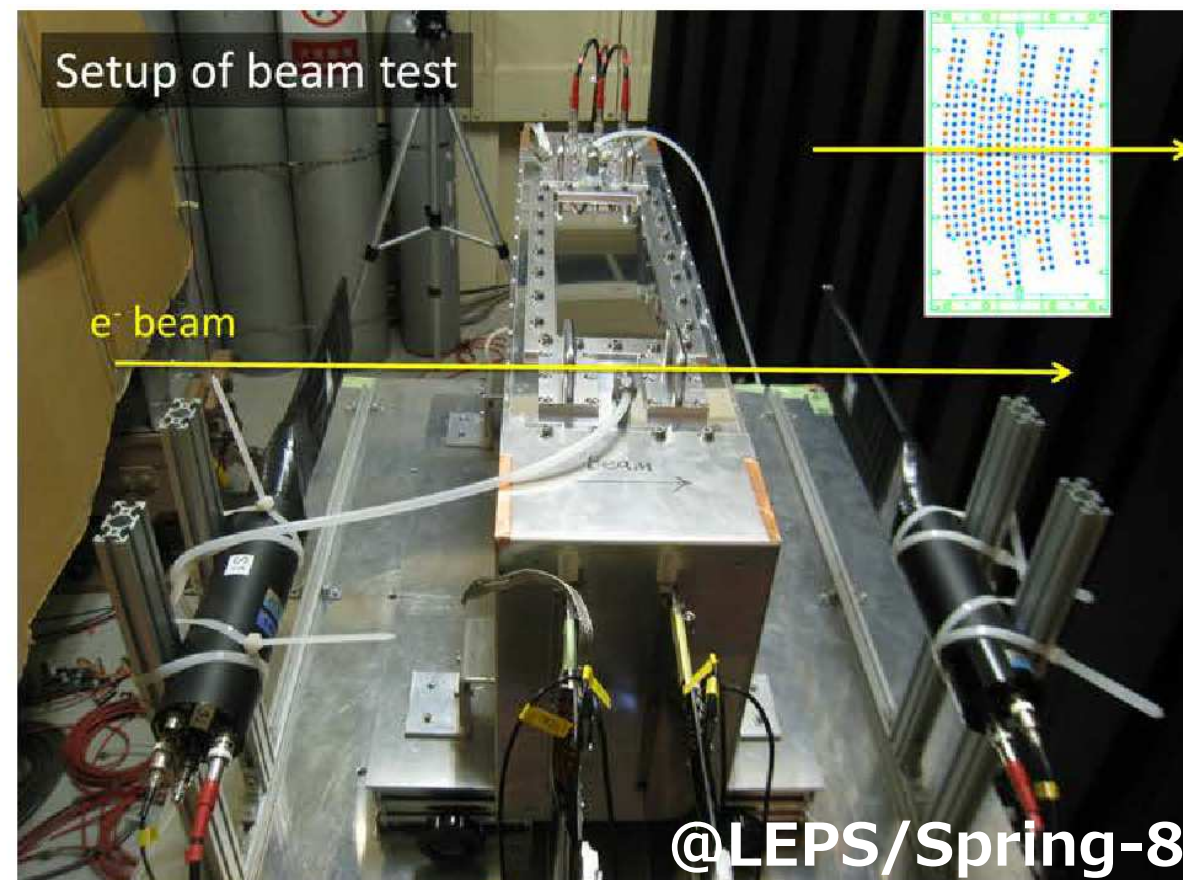
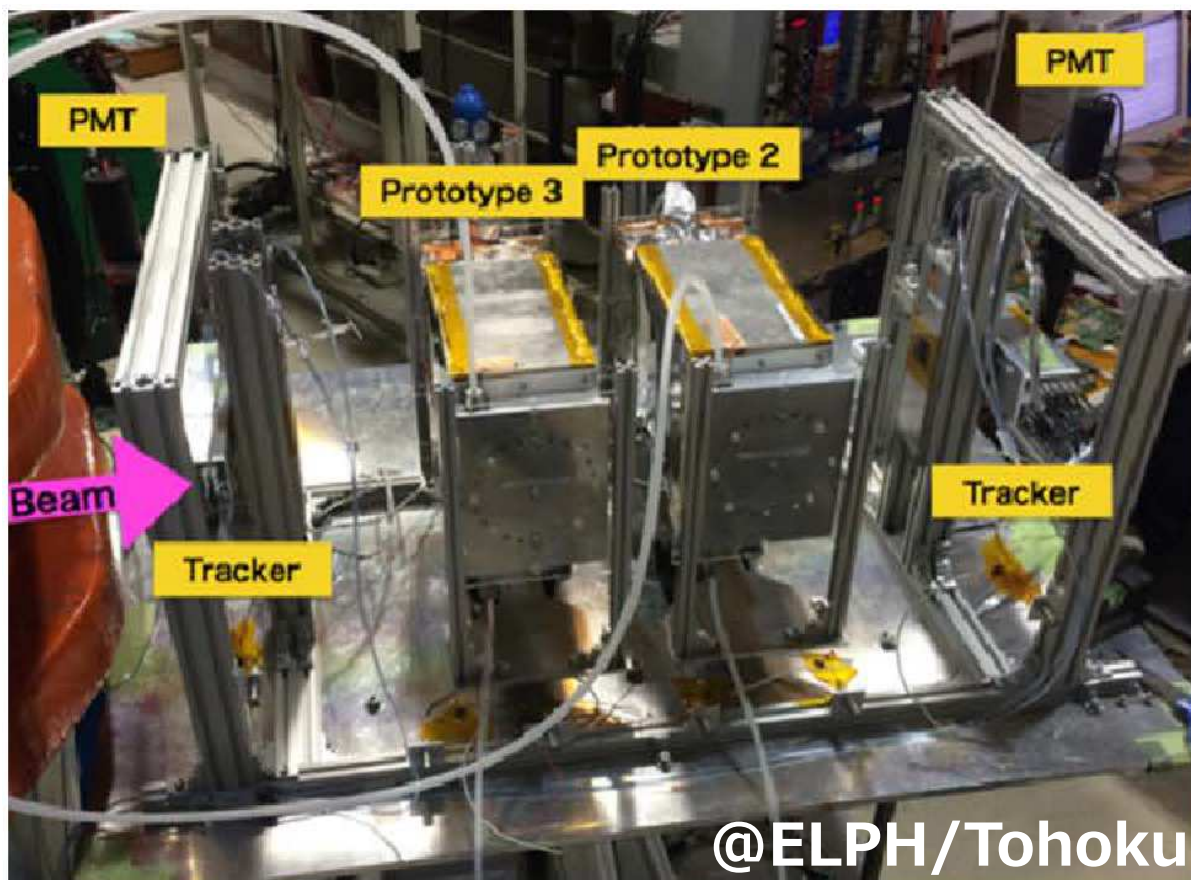


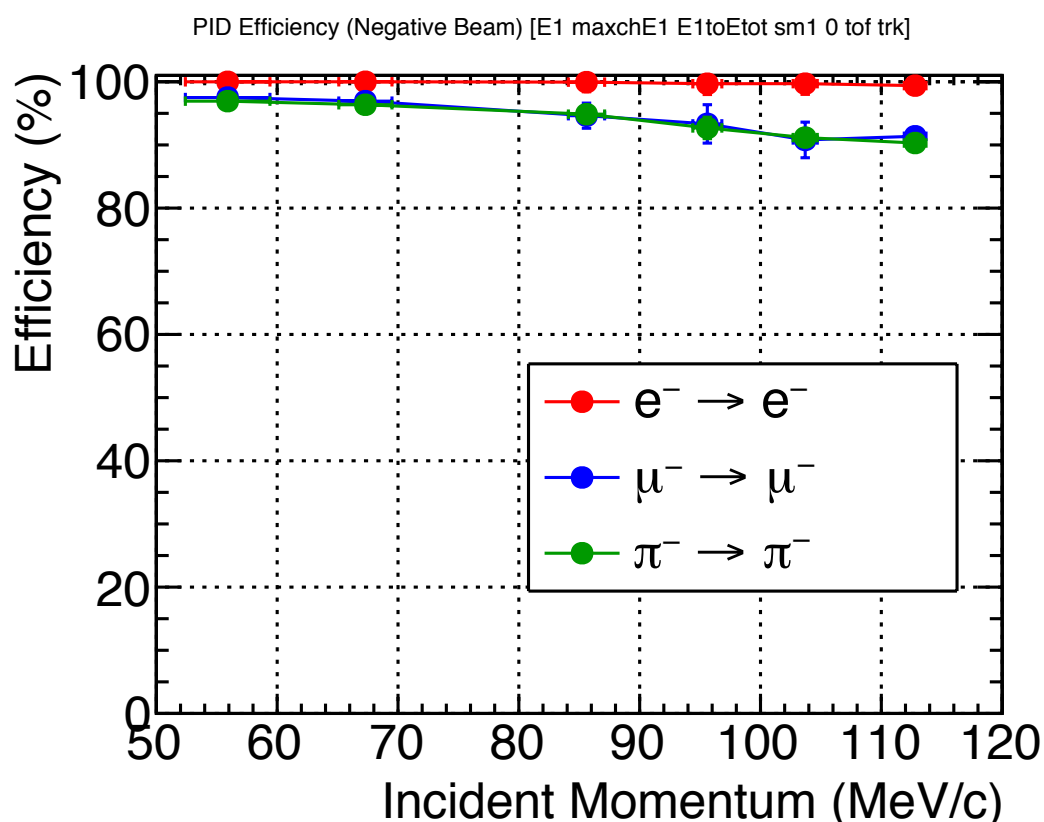
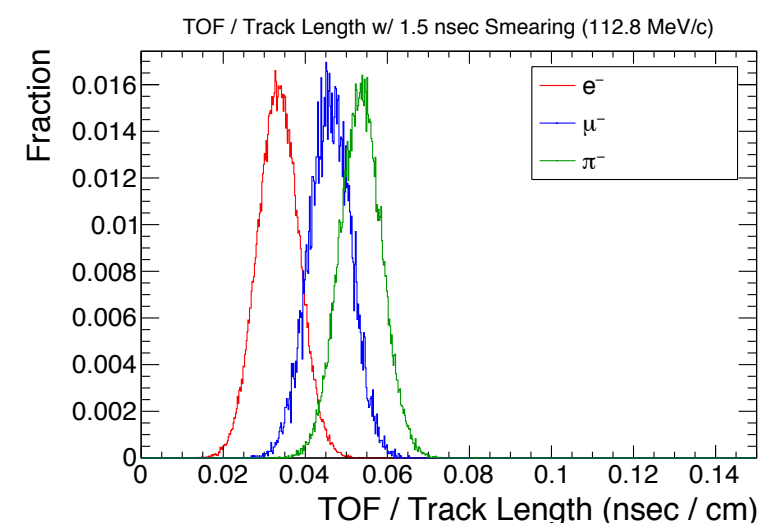
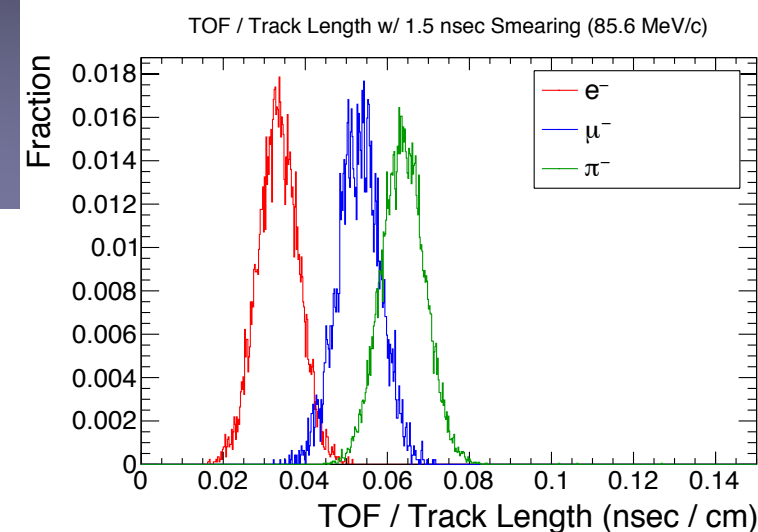
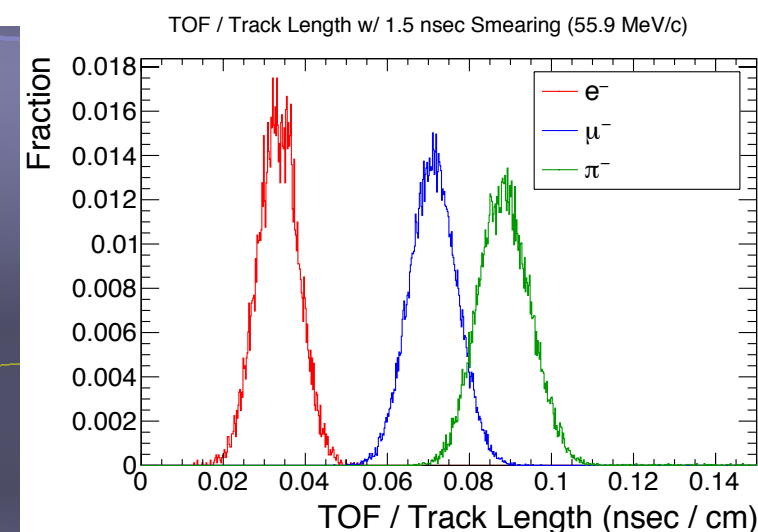
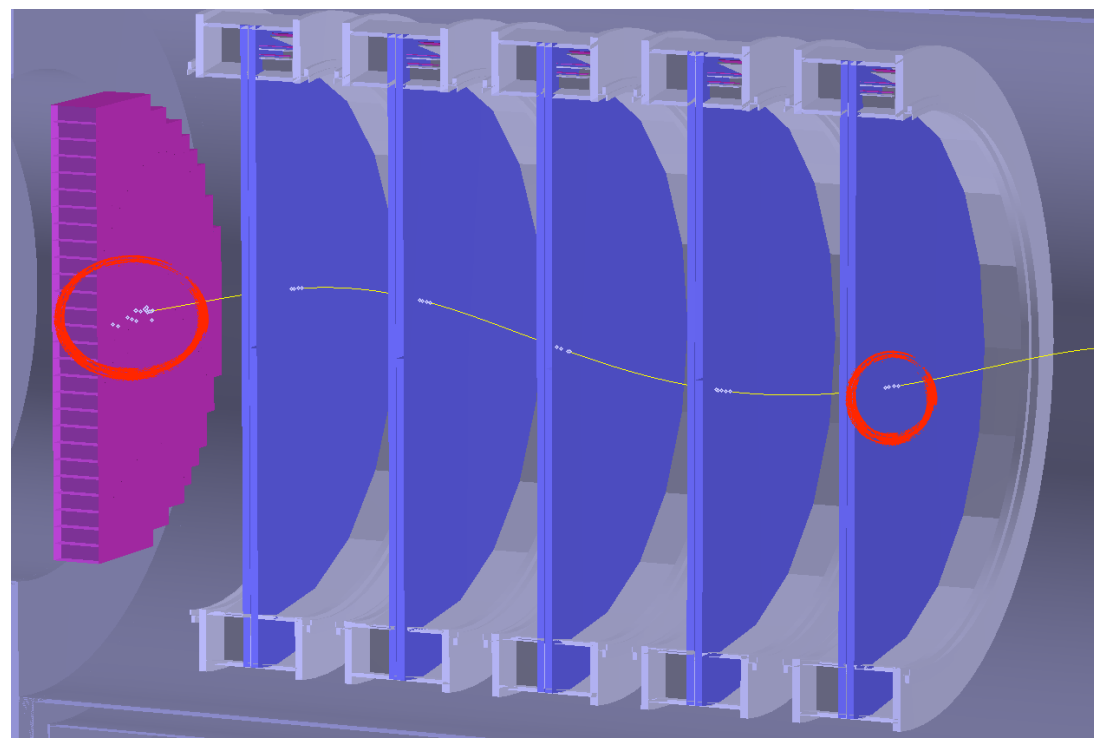
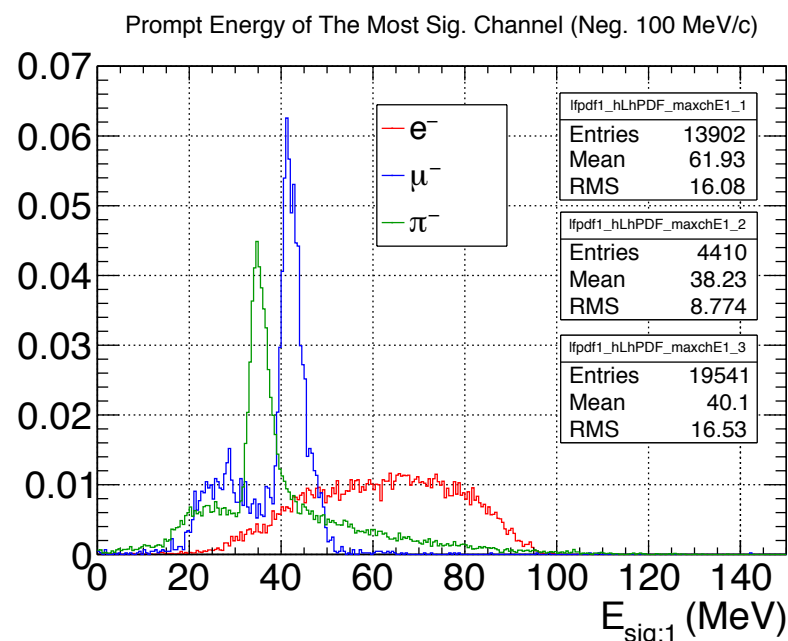
Backup

μ

OMET

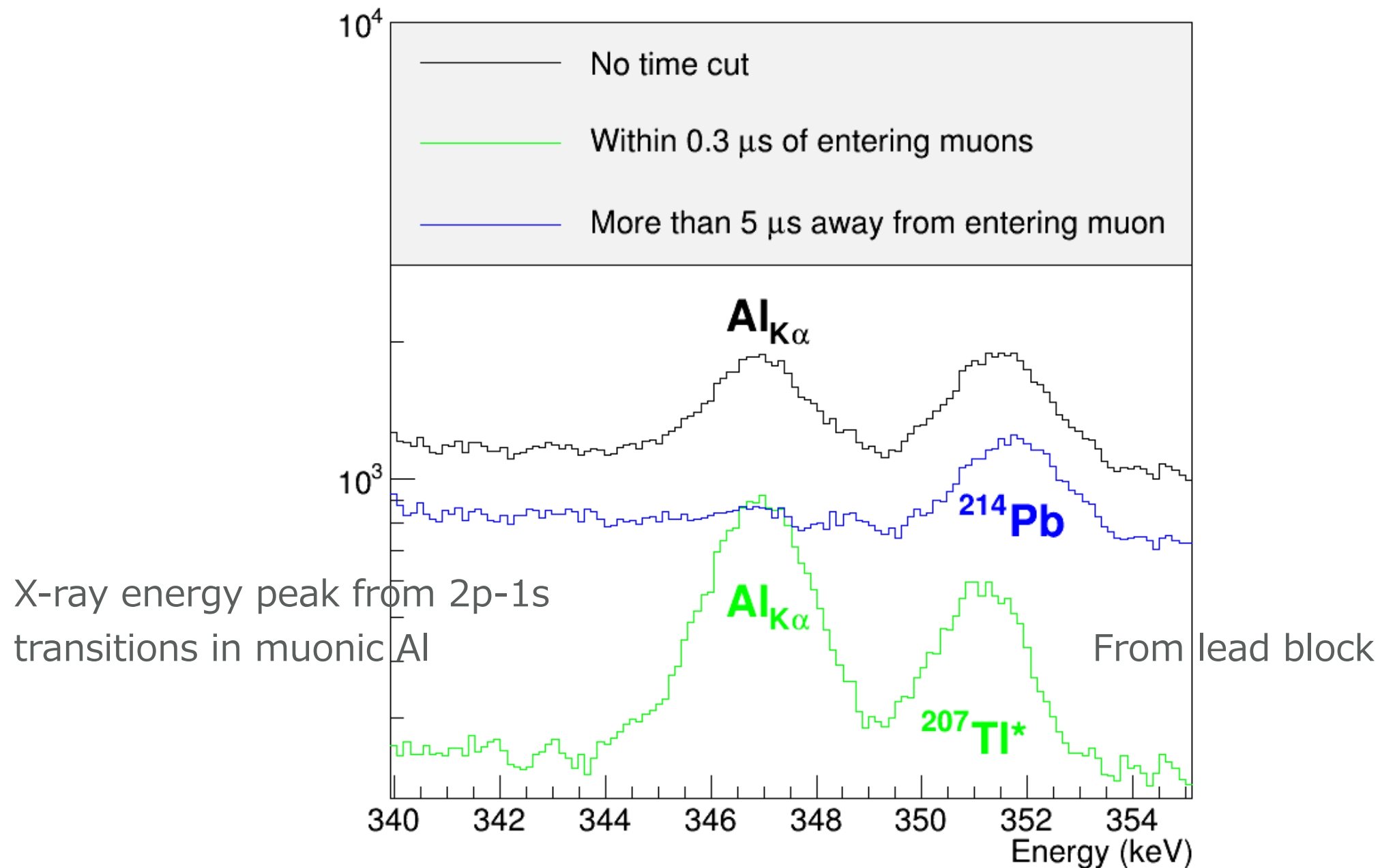
e





More than **90%** $\pi^-/\mu^-/e^-$ PID efficiencies are achieved by combining E1/p and TOF/L information using both StrawTrk + ECAL (evaluated by using the MC data based on the measured detector response)

K- α X-ray from μ Al



- Measured by AlCap