Search for Muon to Electron Conversion at J-PARC: The COMET Experiment

Dmitry Grigoriev

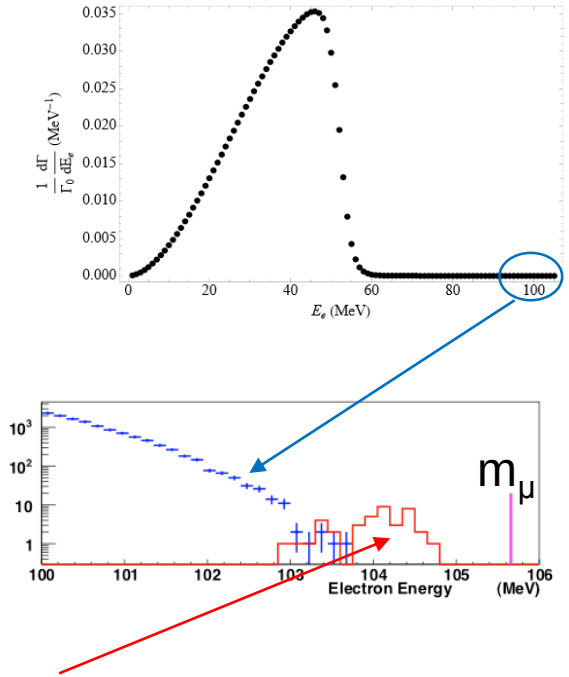
On behalf of the COMET collaboration

The COherent Muon to Electron Transition: (COMET) Experiment – the world wide collaboration

The O(200) participants from 39 institutes of 16 countries.

Muon to electron conversion experiments

- The cLFV is strongly forbidden in SM (Br<<10^{-54}) so any signal is a clear indication of new physics.
- The COMET is very important: another technique and others physics contributions than muon decays experiments MEG and Mu3e (for example a contact interaction with quarks)
- The idea – use the pulse beam and look for the delayed electron from muon capture on nucleus
- Signal electron is monoenergetic $E_e=(m_\mu-m_e-E_{binding})=104.97$ MeV (Al target)
- The physics background: decay on orbit - an extremely high momentum resolution required

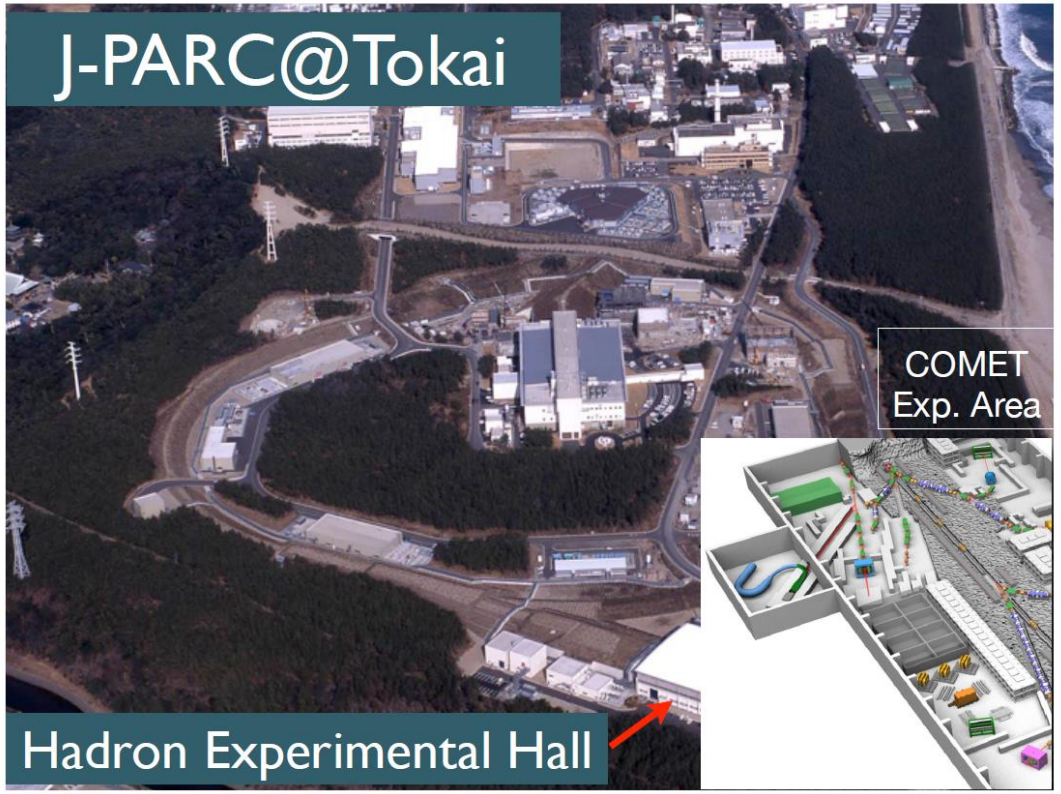


$E_e=(m_\mu-m_e-E_{binding})-E_{loss\_in\_target}$

(MC COMET Phase-1 for Br 3×10^{-15})

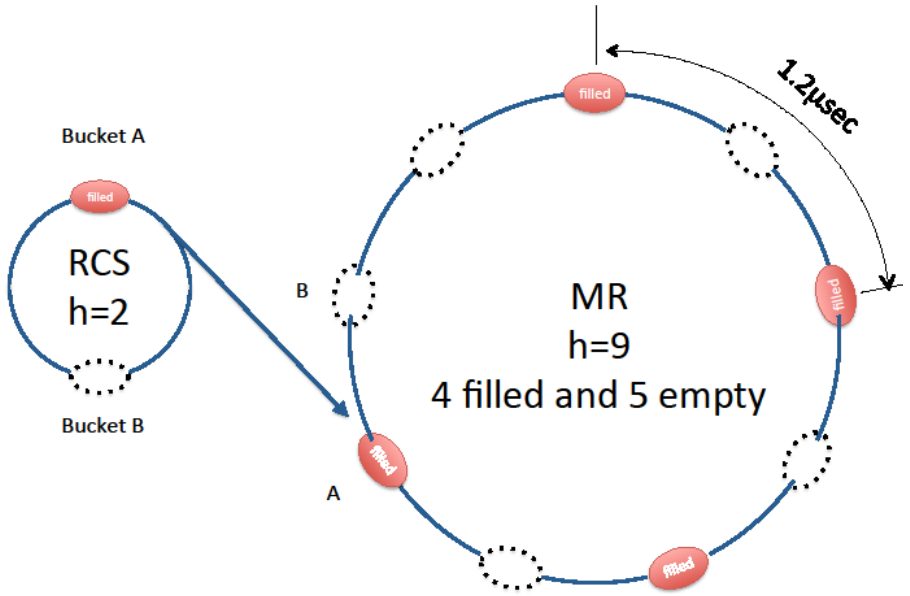
The COMET experiment – beam challenging

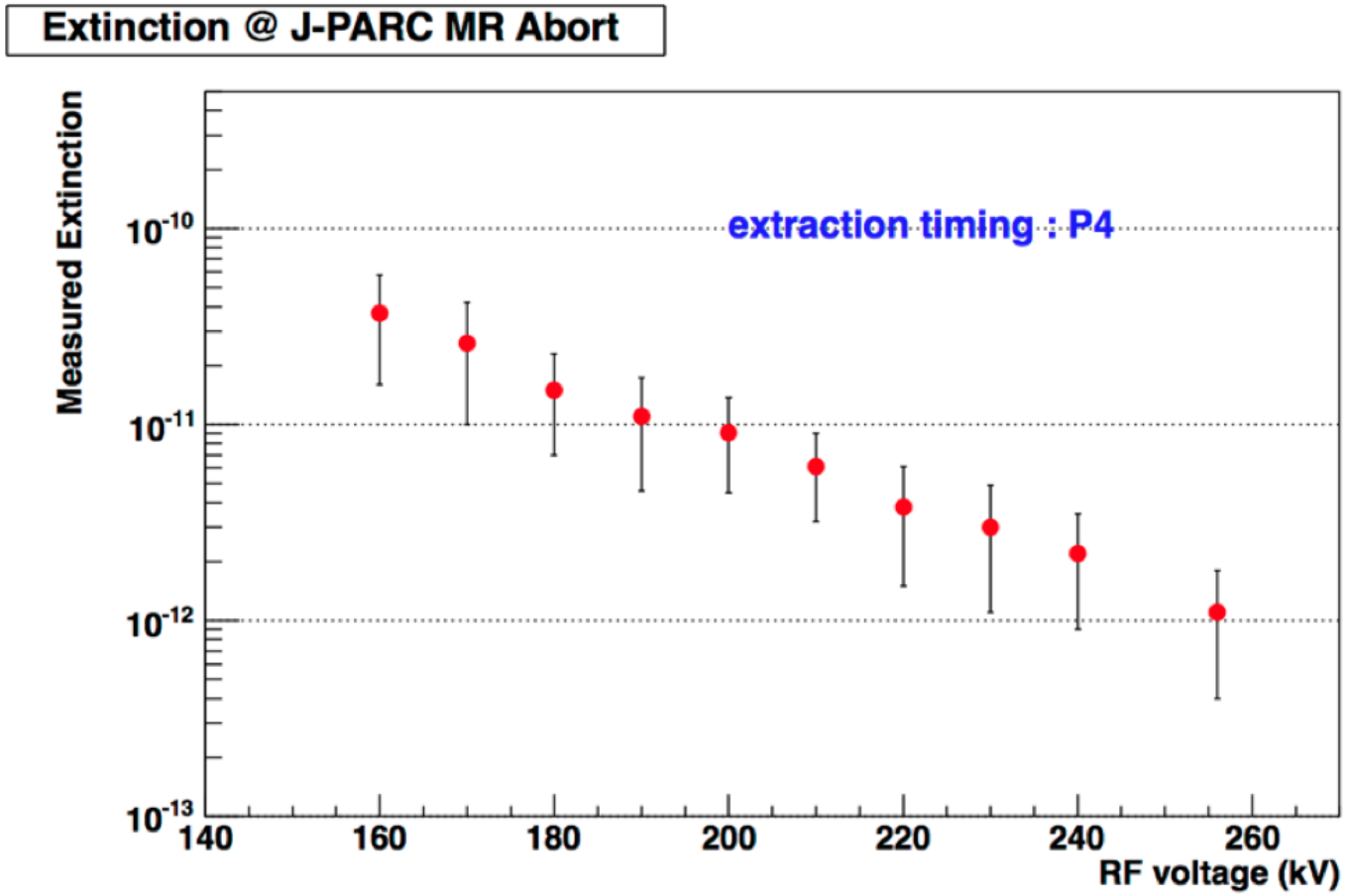
- The source of the muons: the high power pulse proton beam with 8 GeV energy from J-PARC main ring at slow extraction.
- The key issues:
  - Extinction
  - Dedicated beam line
  - Beam related background
  - Beam diagnostic



The extinction

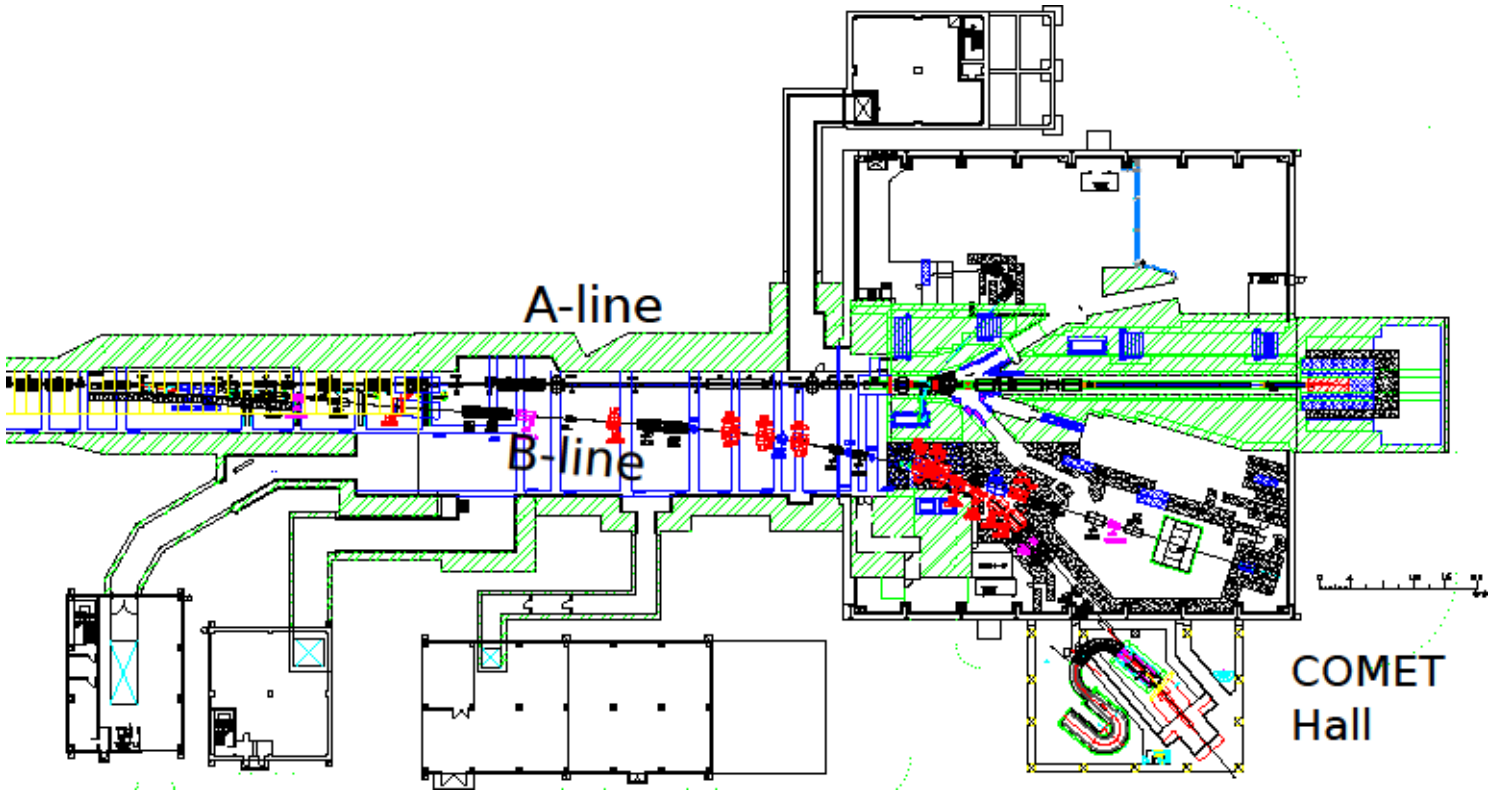
Strategy

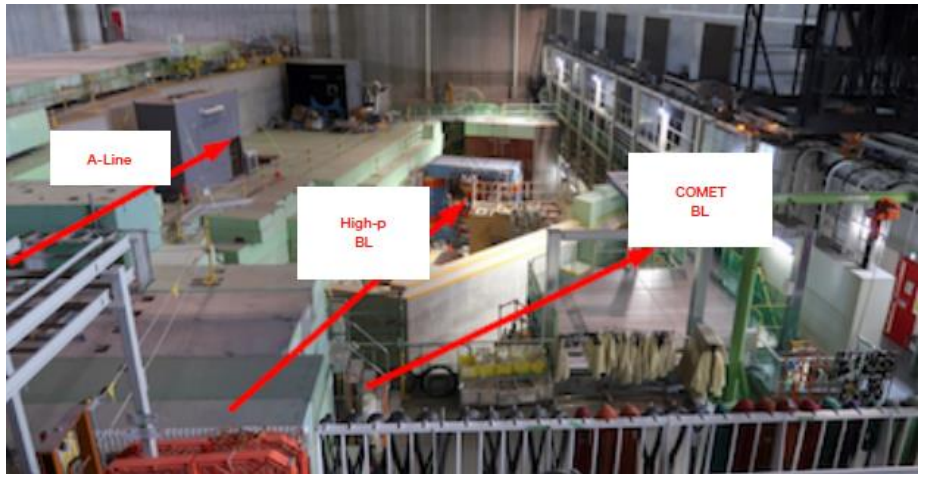




The new measurements with slow extraction are made. The data is under analysis.
The preliminary result meets the requirements of the experiment.

The dedicated proton beam line

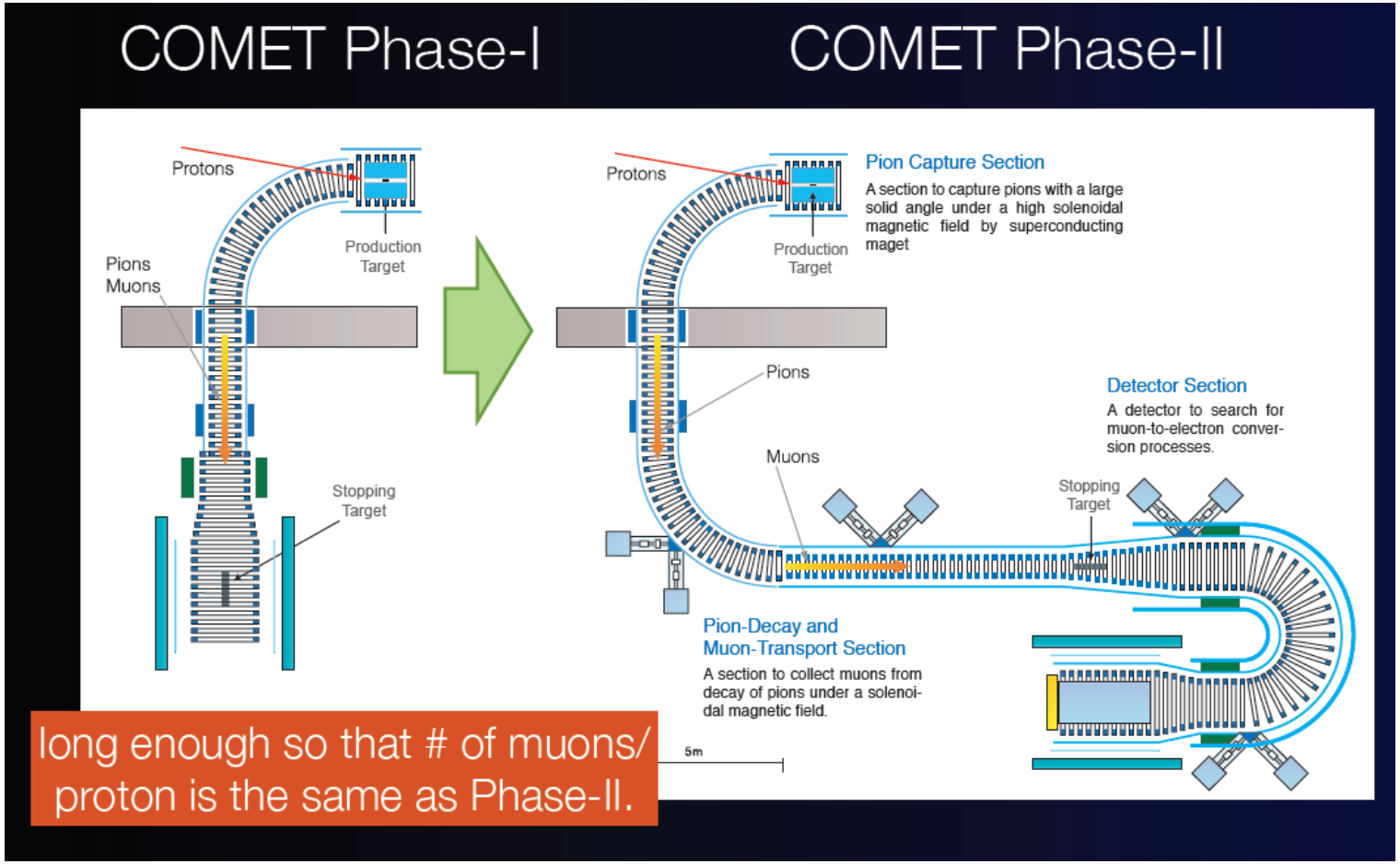




The beamline summary

- The acceptable level of the extinction is achieved with 4 of 9 bunch solution and high HV operation.
- The dedicated beamline is designed and under construction now.
- According to MC the beam related background is less then DIO but must be checked experimentally (see Phase-1 goals).
- The proton beam diagnostic is under development and testing. Plan A is a diamond detector.
- The muon beam diagnostics as under discussion.

The two phases approach

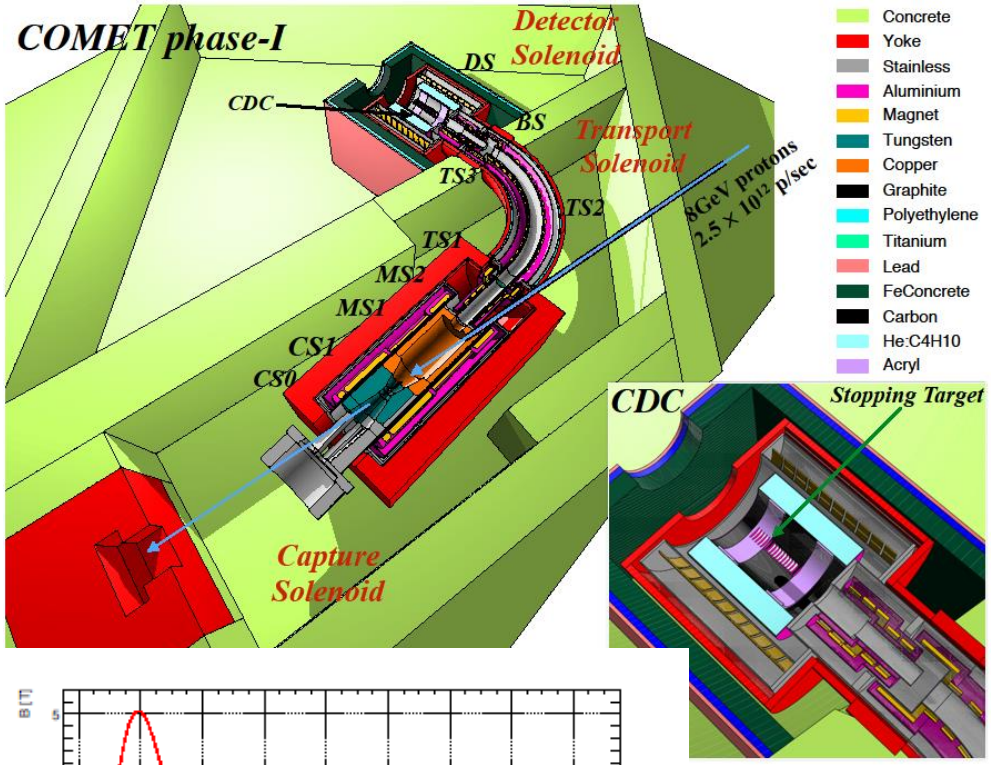


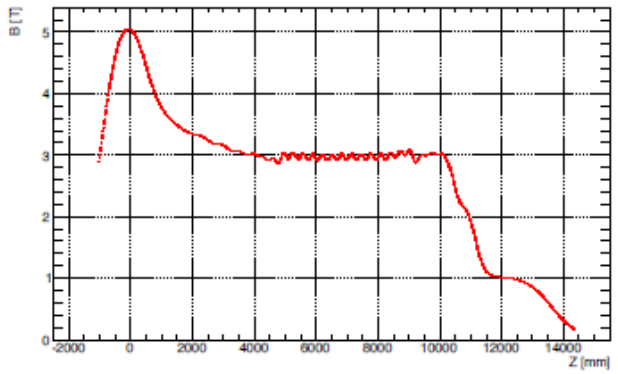
The two phases approach

Parameter	Phase 1	Phase 2
Bending	90 degrees (beam) + 0 degrees (detector)	180 degrees (beam) + 180 degrees (detector)
SES	$3x10^{-15}$	$3x10^{-17}$
Beam power	3.2 kW	56 kW
POT	$3x10^{19}$	$3x10^{21}$
Stopped muons on target	$1{,}5x10^{16}$	$1{,}5x10^{18}$
Running time	O(100 days)	O(1 year)

The phase 1 will be discussed below

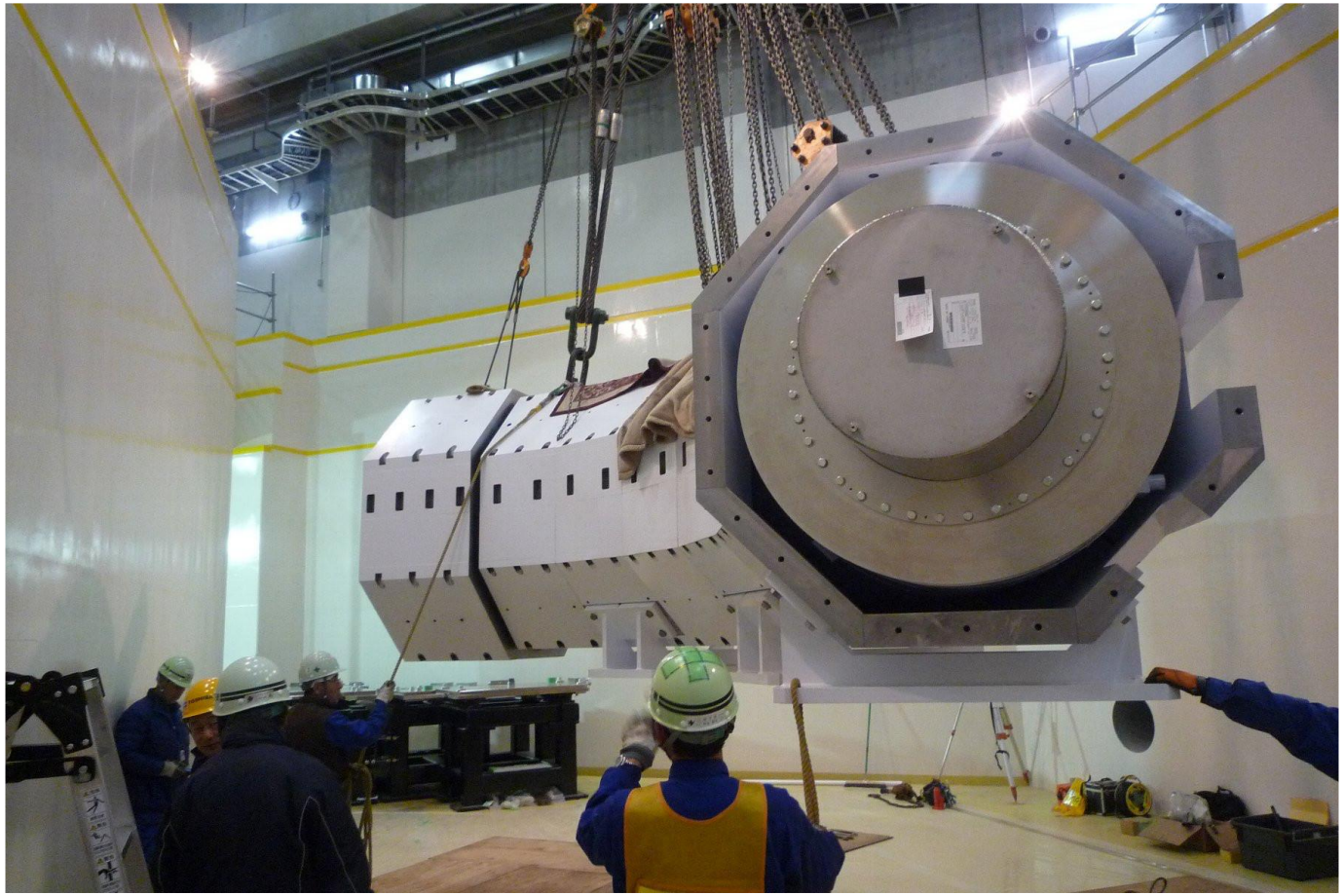
The target, pions and muons production and transport





- Key points:
- Target – graphite 70 cm long
- Pion capture solenoid – 5 T D=1324 mm
- Transport solenoid – 3 T D=O(500 mm)
- Detector solenoid – 1 T D=2156 mm
- Solenoid matching – adiabatic with implementation of the special bridge solenoid

Installation of the transport solenoid



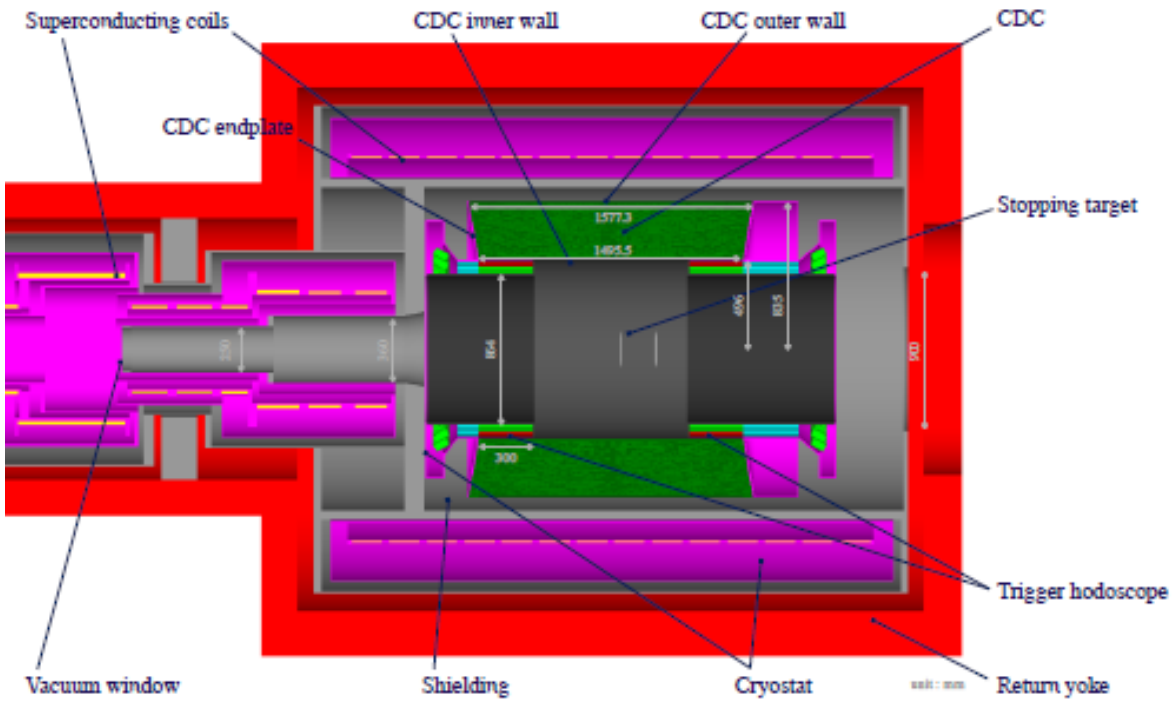
2 detectors for phase-1

- Cylindrical detector (CyDet)
- Base on custom cylindrical drift chamber and sophisticated trigger counters hodoscopes
- The goal – to perform physics measurements

- Planar detector (StrEcal)
- Base on straw tubes and electromagnetic calorimeter as planned for the Phase 2.
- The goal – large prototype test and background measurements

The both detectors will uses the same solenoid and operates one at time

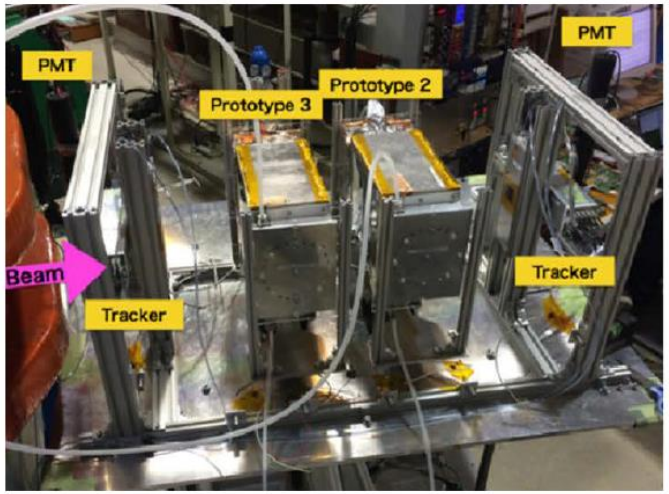
Cydet: layout

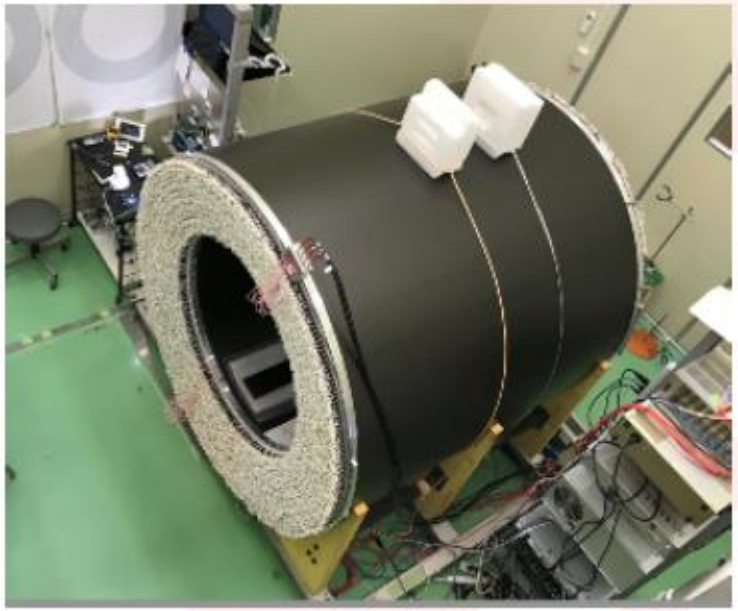


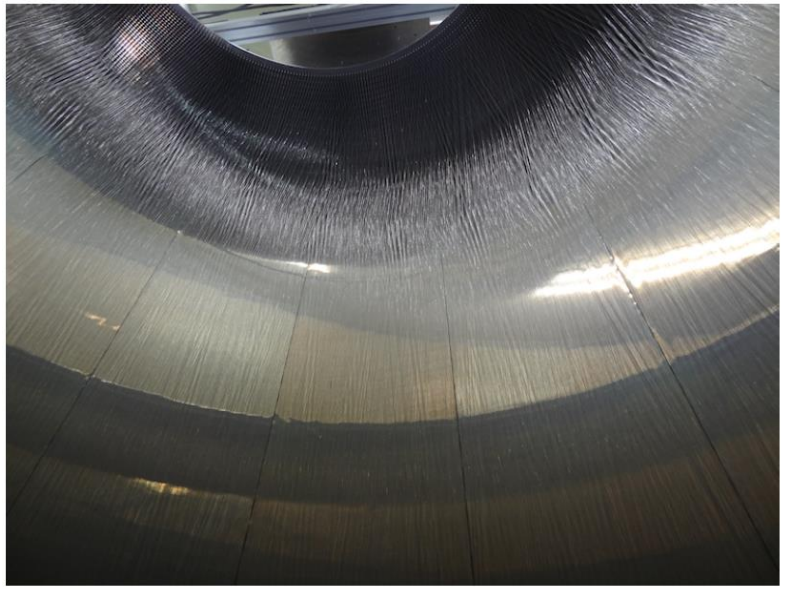
Muon stopping target: 17 aluminum disks of 0,2 mm thickness and 100 mm radius with 50 mm spacing

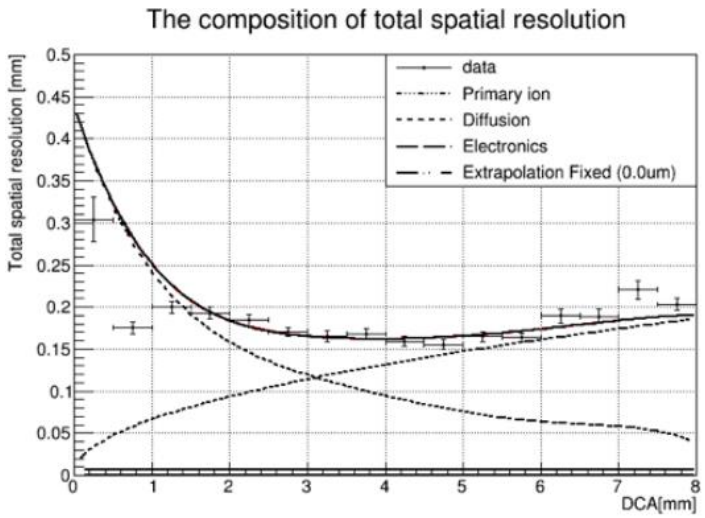
The main drift chamber parameters

- Material of walls – carbon fiber reinforced plastic (CFRP)
- Inner wall radius, length and thickness – 496, 1495 and 0,5 mm
- Outer wall radius, length and thickness – 840, 1577 and 5 mm
- Sell structure – almost square containing 20 alternative stereo layers with angles of 64-75 mrad (2 are guards ones)
- Sense wires – 4986 Au plated W with diameter 25 μm (50 g tension)
- Field wires – 14562 Al with diameter 126 μm (80 g tension)
- Gas mixture – He:i-C_4H_{10} (90:10%)
- Momentum resolution – better 200 keV/c at 105 MeV/c
  - See Manabu MORITSU (IPNS, KEK) talk at detector session this morning and Beomki Yeo (KAIST, IBS/CAPP), poster number S-6



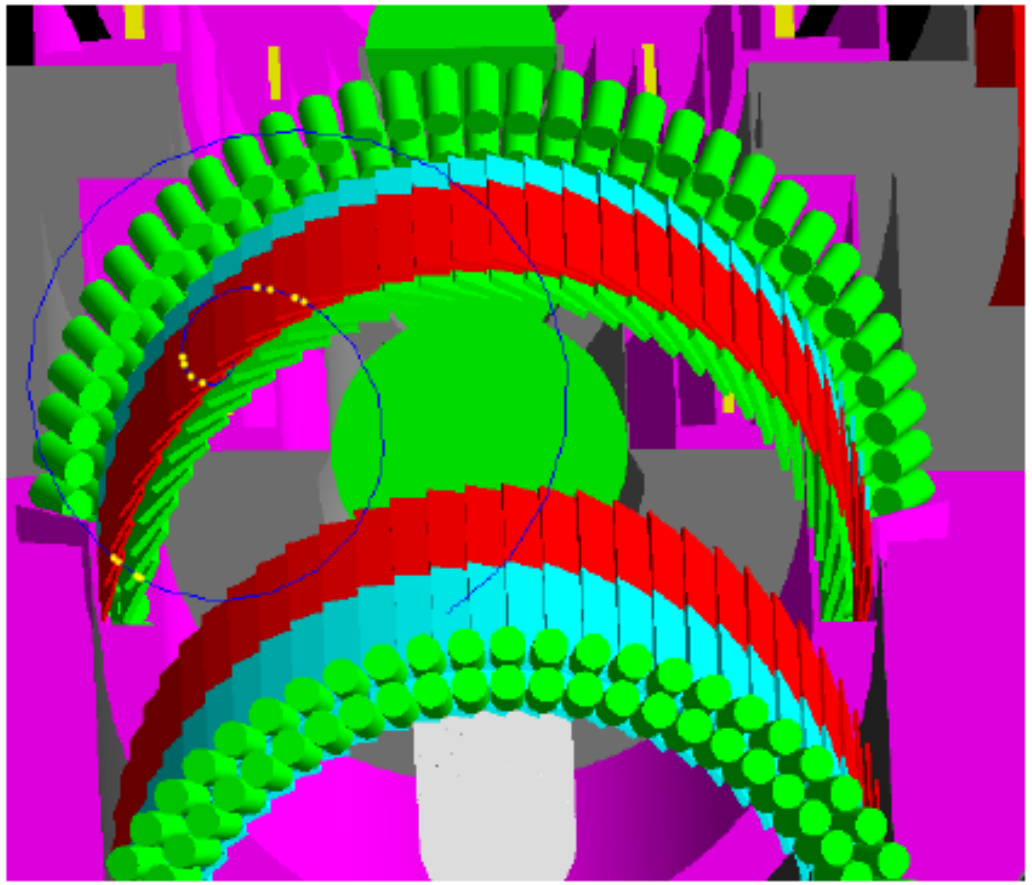






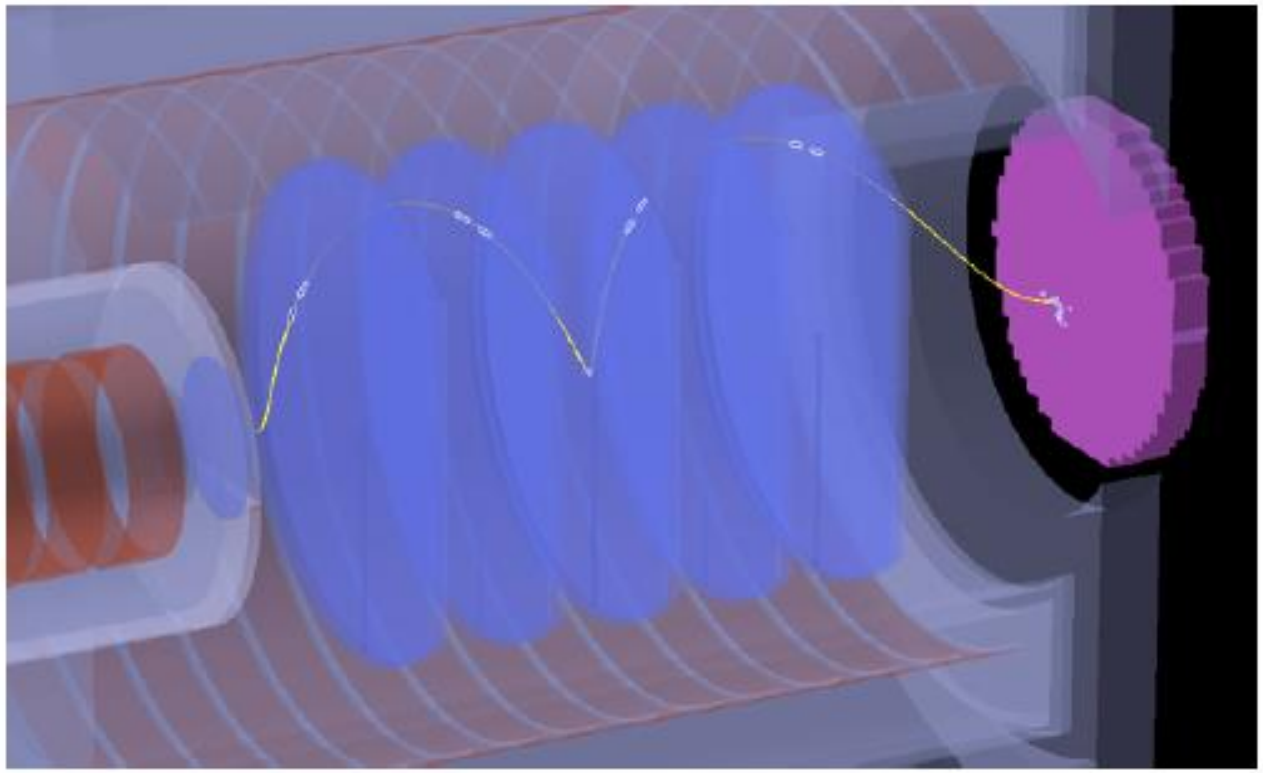
The intensive tests with prototypes are done.
The construction and wiring are finished
The aging test is done
Partially equipped with electronics and tests with cosmic rays are going.

Trigger hodoscopes



- Red – Ultra fast scintillator EJ-230 300x90x5 mm
- Blue – Cherenkov counter base on UV-transparent acrylic plastic 300x90x10 mm
- Both scintillator and Cherenkov hodoscopes consists of 2 layers, with shift on half of counter width
- Readout independently by fine mesh PMT H8409-70 (operates in 1T)
- The design and tests are almost finished

StrEcal detector



The proposed layout of the detector for Phase-2
The blue – planes of the straw tubes
The pink – wall of the ecal crystals

StrEcal detector

- Straw tubes:

  Diameter – 9,75 mm, Outer wall – 20 microns thick Al-coated mylar (for Phase 1)

  a smaller diameter and thinner wall are under study for Phase 2

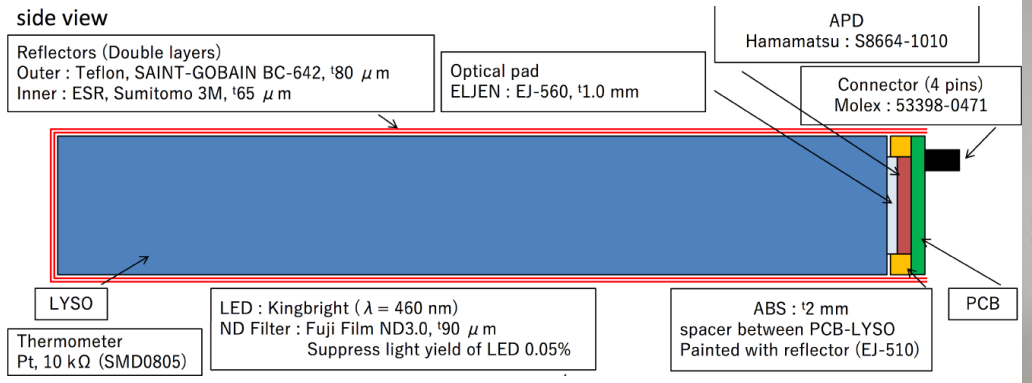
  Anode wire – gold plated tungsten 25 microns diameter

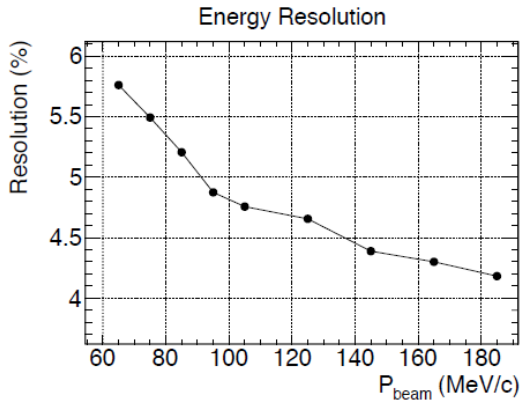
  Length – from 692 to 1300 mm

  Gas mixture – Ar-methane 50:50

StrEcal detector

- Electromagnetic calorimeter
  - Scintillator – 20x20x120 mm LYSO crystals
  - Light readout – Hamamatsu APD S8864-1010 with 10x10 mm sensitive area
  - Electronics – custom design low noise fast amplifiers
  - Location – crystals and APD are inside vacuum volume to minimize multiple scattering and noise while electronics is outside vacuum to easier cooling
  - Measured energy resolution – better 5% for the 105 MeV electrons

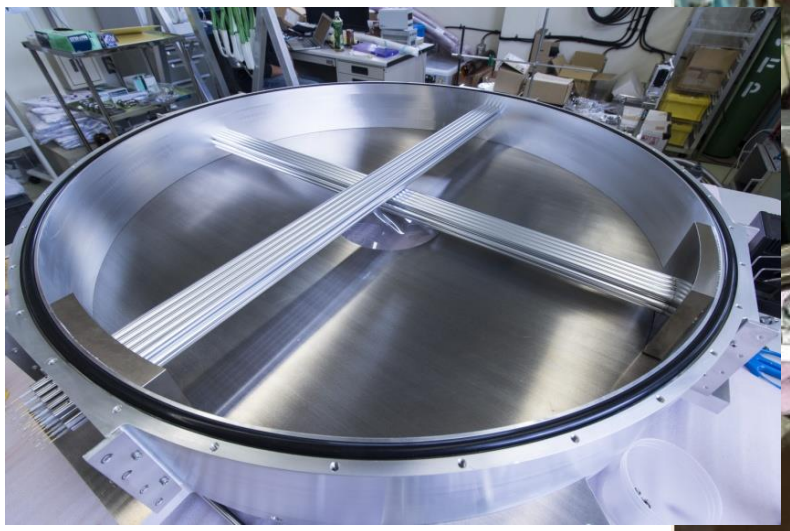


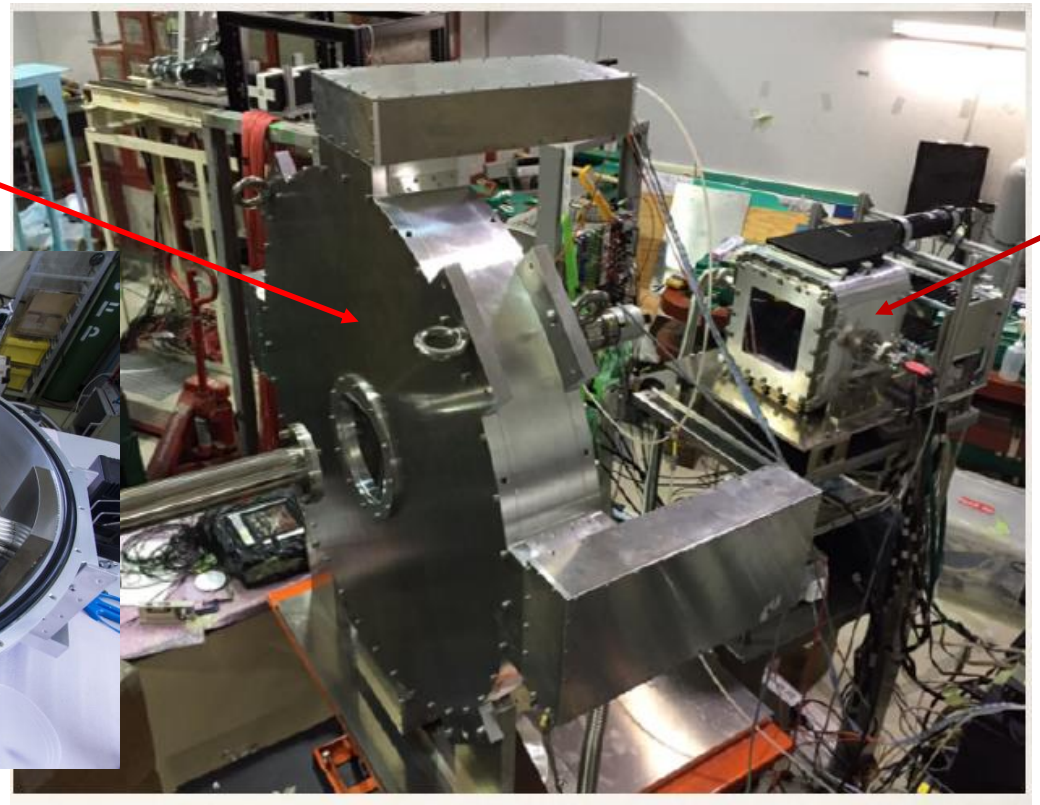


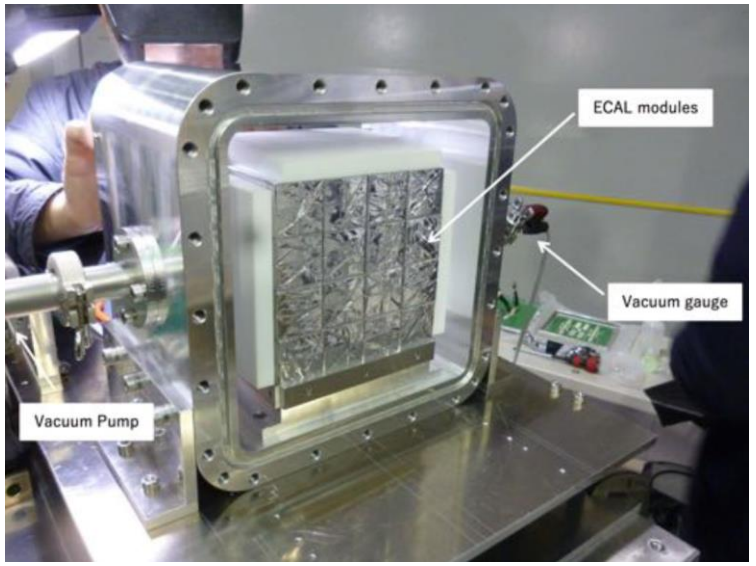
StrEcal detector

Straw tubes prototype

Ecal prototype

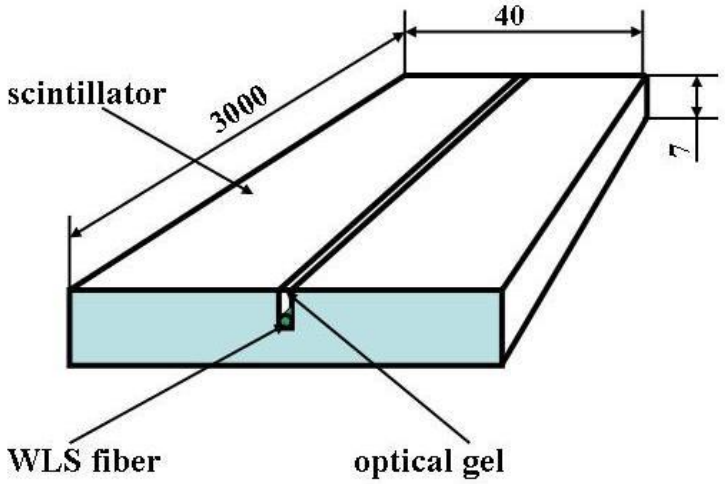


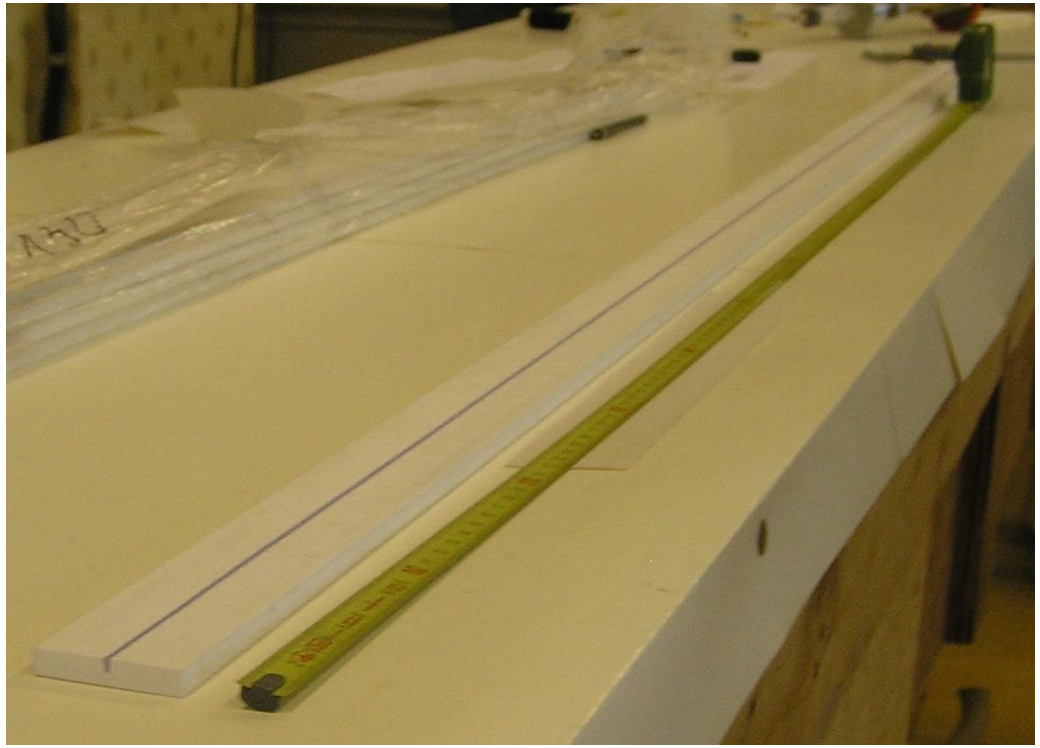


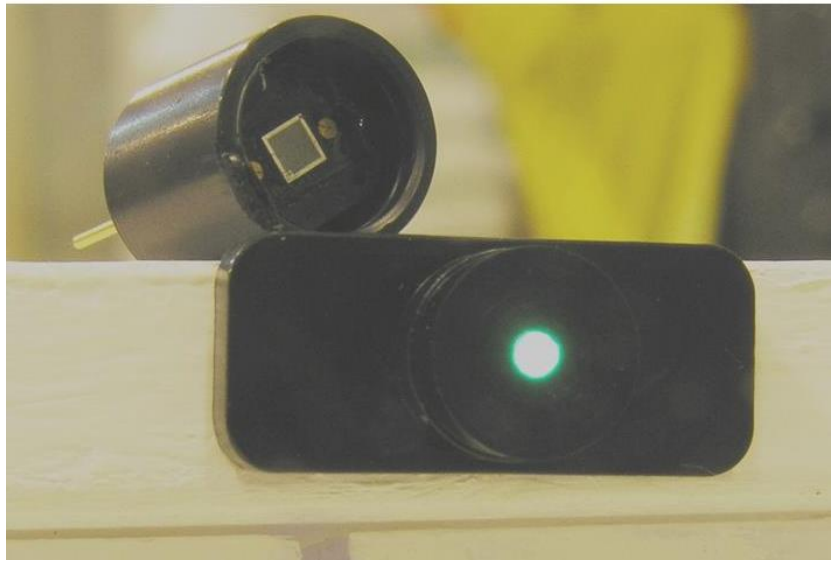


- The consisting of Straw tubes and Ecal module prototype is successfully tested with electron beam and fulfill the requirements

Cosmic ray veto







- Goal – unefficiency $<10^{-4}$
- Base on BELLE-2 design:
  - Plastic scintillator readout with WLS+SiPM
- The design in progress
  (depends on overall final design
  of the magnets, detector and infrastructure)

The Experiment status

- The preparation of the beam and detector systems is in a good shape
- Trigger and DAQ: the design in on finish line
  - See M.J.Lee (IBS/CAPP), poster number D-93
- Radiation tests:
  - the all components were irradiated by neutrons and gammas
  - the selection of enough radiation hard components is almost done
  - the final tests are in preparation
- **The commissioning will start at the end of 2019**

Single Event Sensitivity (SES)

Event selection	Value	
Online event selection efficiency	0.9	
DAQ efficiency	0.9	
Track finding efficiency	0.99	
Geometrical acceptance + Track quality cuts	0.18	
Momentum window ($\varepsilon_{\mathrm{mom}}$)	0.93	$103.6 < p_e < 106.0$ MeV/c
Timing window ($\varepsilon_{\mathrm{time}}$)	0.3	$700 < t_e < 1170$ ns
Total	0.041	

$$B(\mu^- + \mathrm{Al} \to e^- + \mathrm{Al}) = \frac{1}{N_\mu \cdot f_{\mathrm{cap}} \cdot f_{\mathrm{gnd}} \cdot A_{\mu\text{-}e}},$$

Number of muons stopped inside targets

Fraction of μ-e conversion to the ground state = 0.9

Fraction of muons to be captured by Al target = 0.61

3×10^{-15} S.E.S. achievable in ~150 days of DAQ time corresponds to $N_\mu=1.5\times10^{16}$

Background estimation

Type	Background	Estimated events
Physics	Muon decay in orbit	0.01
	Radiative muon capture	0.0019
	Neutron emission after muon capture	< 0.001
	Charged particle emission after muon capture	< 0.001
Prompt Beam	* Beam electrons	
	* Muon decay in flight	
	* Pion decay in flight	
	* Other beam particles	
	All (*) Combined	≤ 0.0038
	Radiative pion capture	0.0028
	Neutrons	$\sim 10^{-9}$
Delayed Beam	Beam electrons	~ 0
	Muon decay in flight	~ 0
	Pion decay in flight	~ 0
	Radiative pion capture	~ 0
	Anti-proton induced backgrounds	0.0012
Others	Cosmic rays†	< 0.01
Total		0.032

† This estimate is currently limited by computing resources.

Thanks for your attention!