The COherent Muon to Electron Transition (COMET) experiment

Experiment COMET at the J-PARC

Status report and prospects

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JINR COMET team

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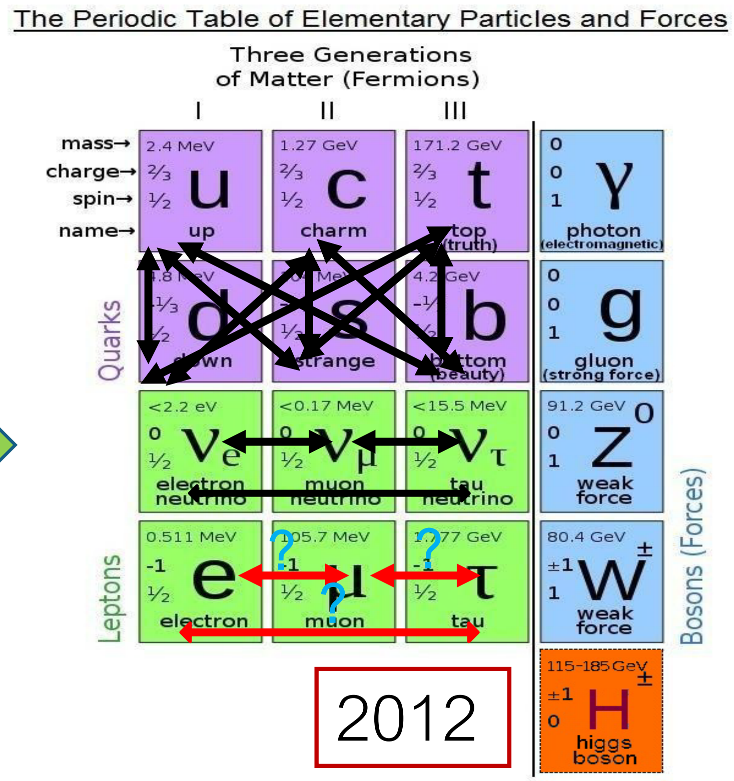
Charged Lepton Flavor Violation (CLFV)

The Standard Model (**SM**) can explain most of the experimental results. However, there are still many questions to answer. All these motivates physicists to go Beyond the Standard Model (**BSM**) to explain these the phenomenon.



We've quark mixing, Flavor Violation

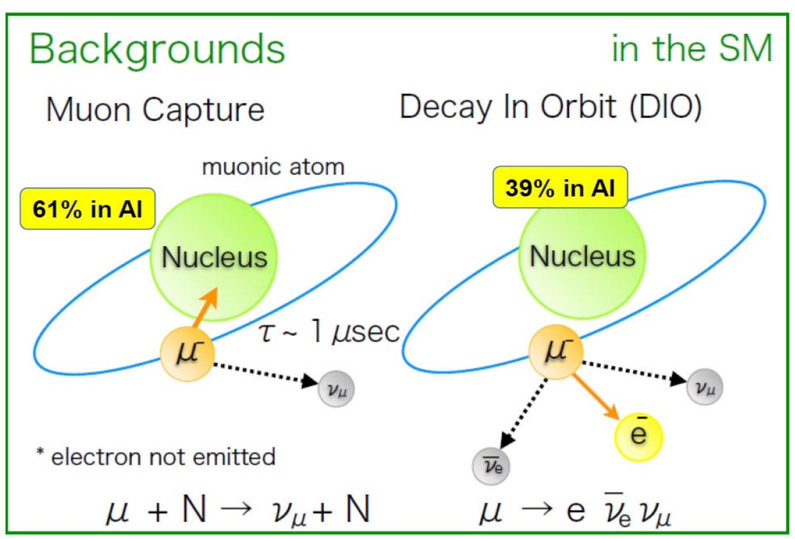
We've neutrino mixing, Lepton Flavor Violation (LFV)
LFV = New physics in BSM

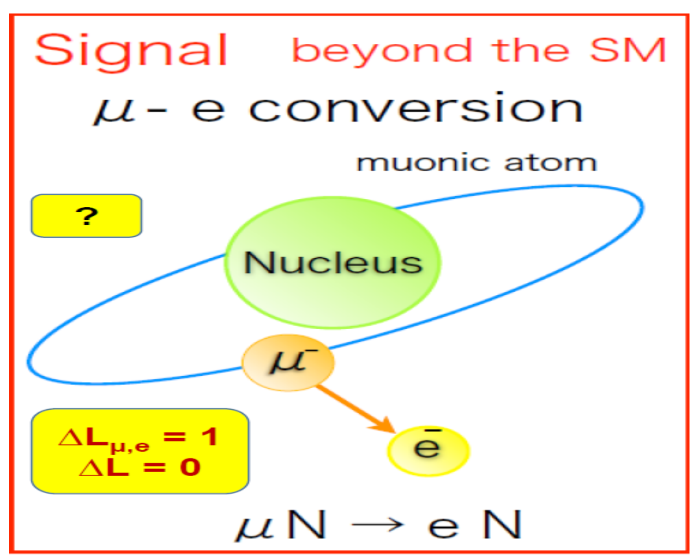
Charged Lepton mixing NOT observed. Why not charged leptons? Charged Lepton Flavor Violation (CLFV). Very small possibility in SM, BR ~**O (10^{-54})**

CLFV processes offer probes for new physics with discovery sensitivity. The most sensitive probes of CLFV utilize high-intensity muon beams.

Muon-to-Electron conversion mechanism

Stopped μ^- in matter (Al), generate "muonic atom" (lifetime in Al ~ 864ns)





New Physics Process

Neutrino-less nuclear capture of a muon
(= μ-e conversion)
$\mu^- + (A,Z) \rightarrow e^- + (A, Z)$
Muonic atom single mono - energetic electron.
$E_e = m_\mu - E_{recoil} - E_{binding} = 104.97\text{MeV (Al)}$
coherent recoil of nucleus
The fraction of coherent transition for Al ≈ 90-92 %

$$R_{\mu e} = \frac{\Gamma(\mu^- + N(A,Z) \rightarrow e^- + N(A,Z))}{\Gamma(\mu^- + N(A,Z) \rightarrow \text{all muon captures})}$$

Experimental Signal:
Measured emitted mono-energetic (~105 MeV) electron from muonic atom

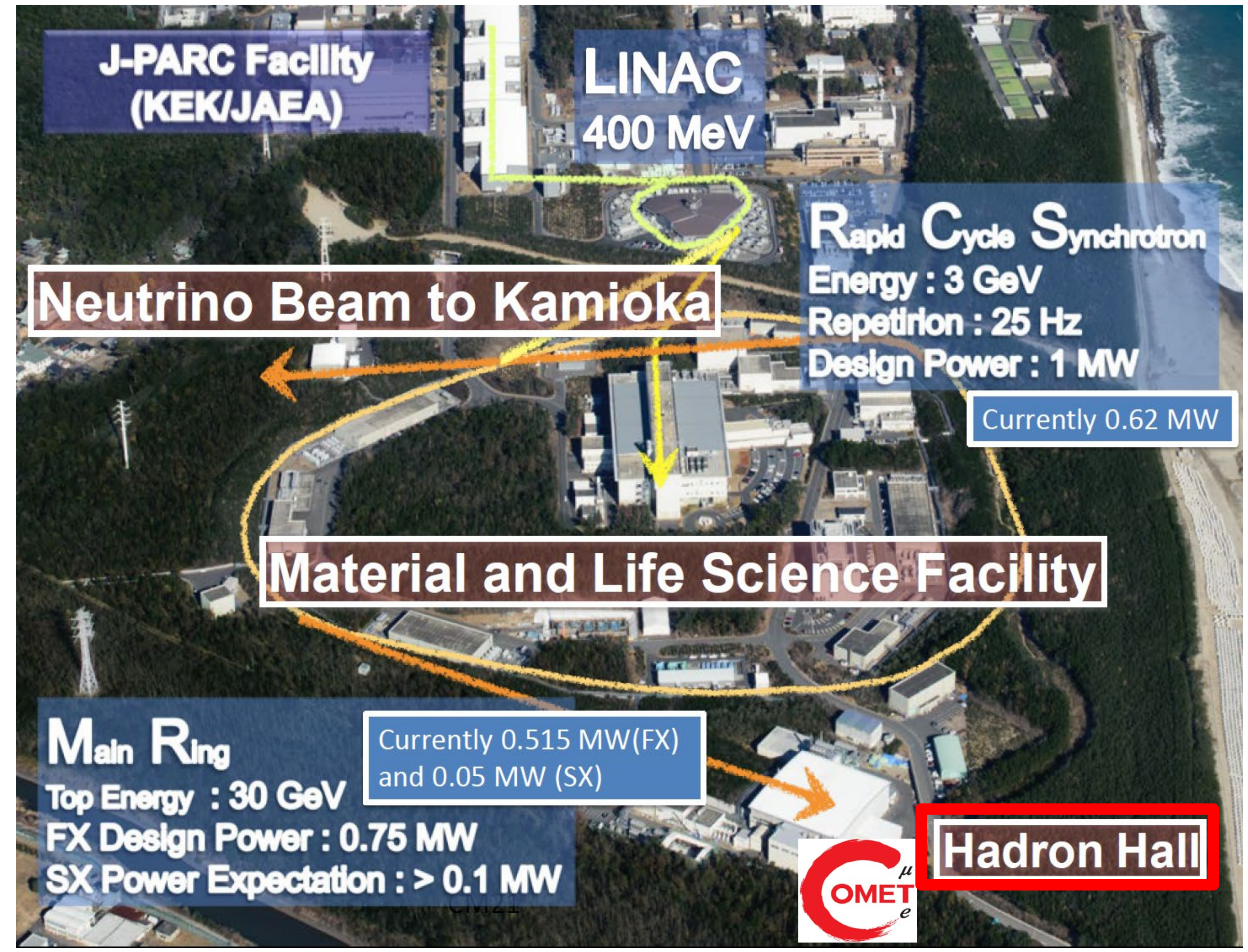
The COMET collaboration

Still growing!

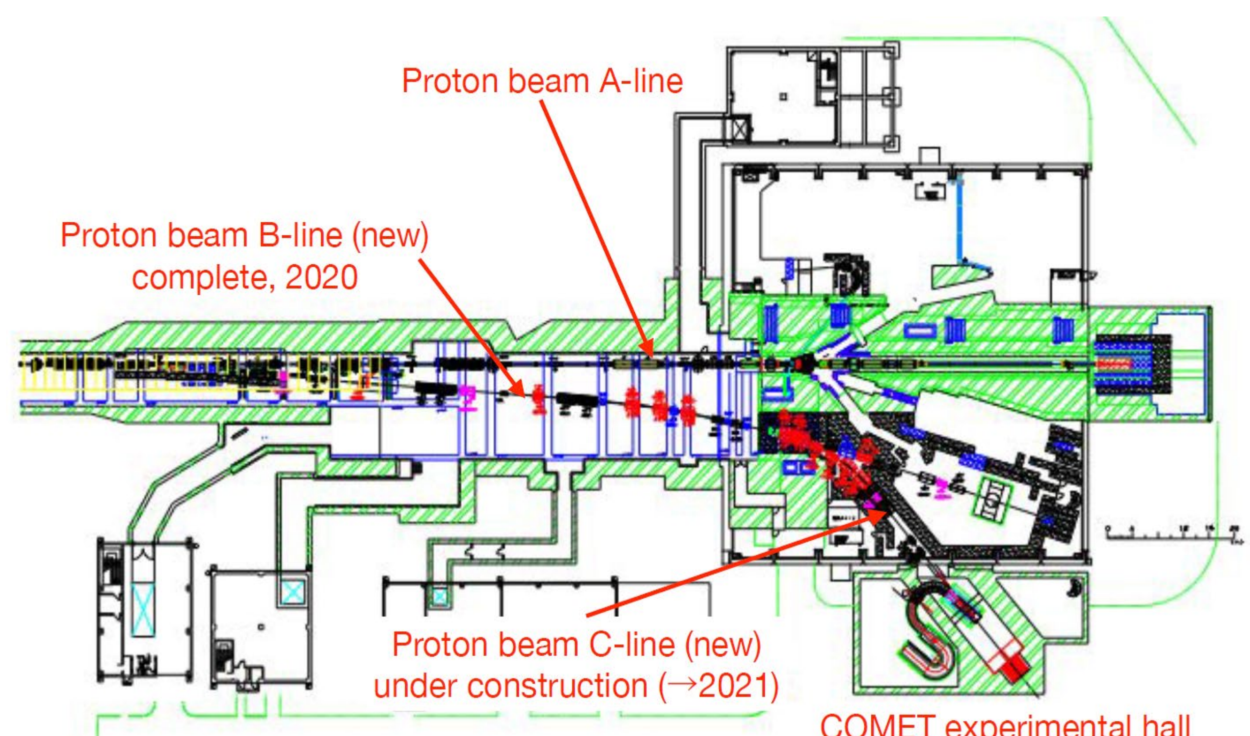
43 institutes, 17 countries

Including five JINR member states countries
Belarus, Georgia, Kazakhstan, Russia, Vietnam

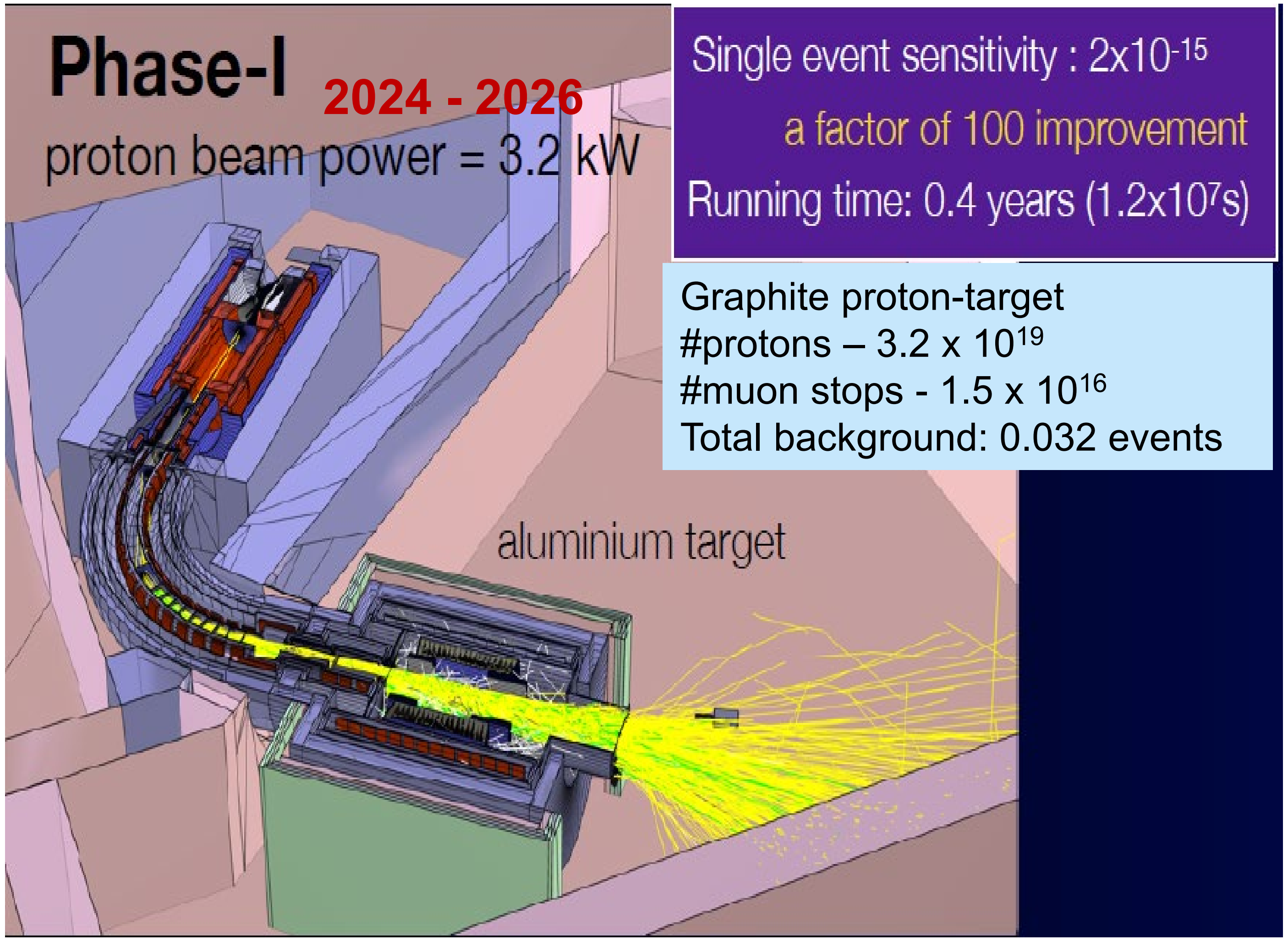
COMET at J-PARC

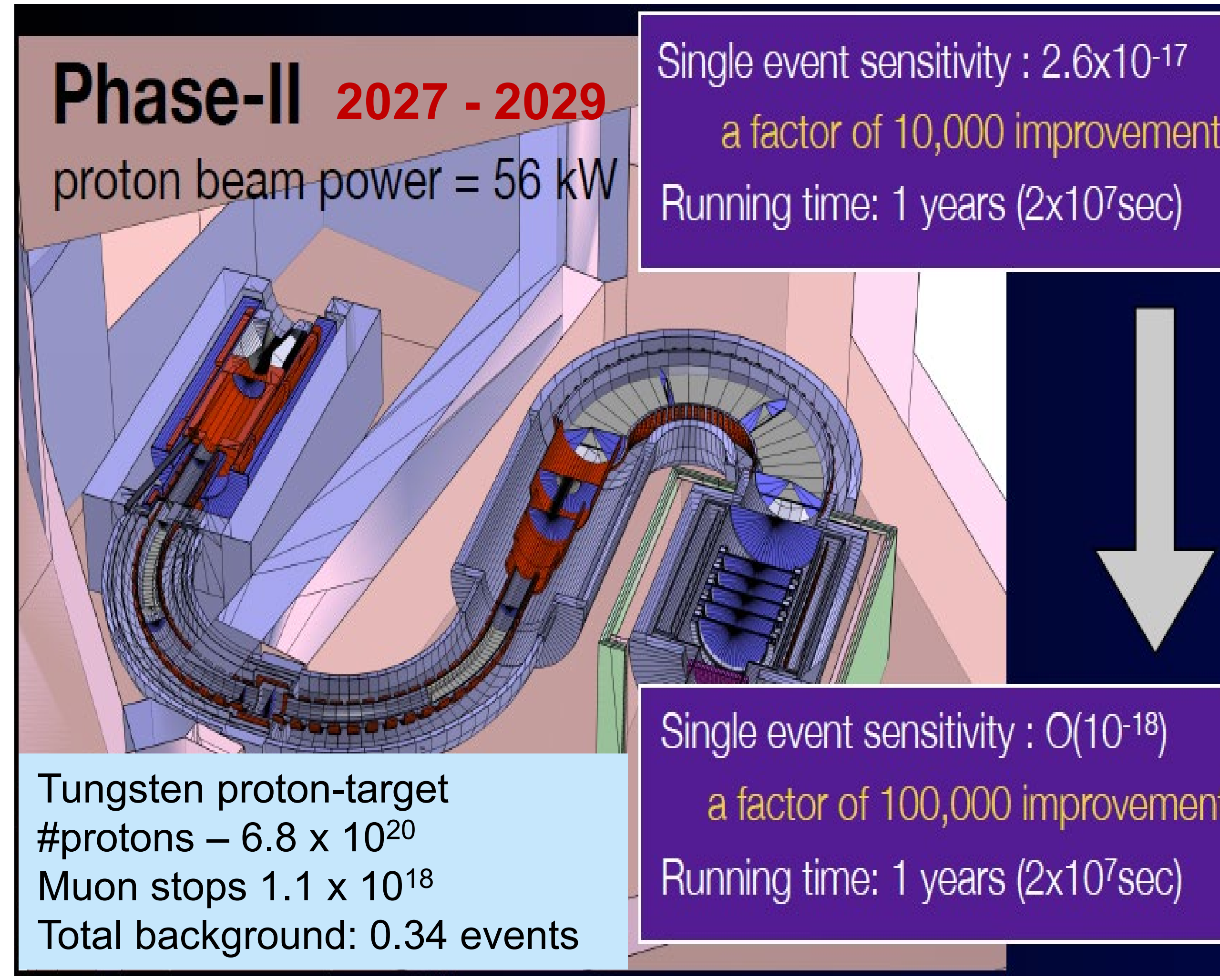


Joint Project between KEK and JAEA



Two-phase realization





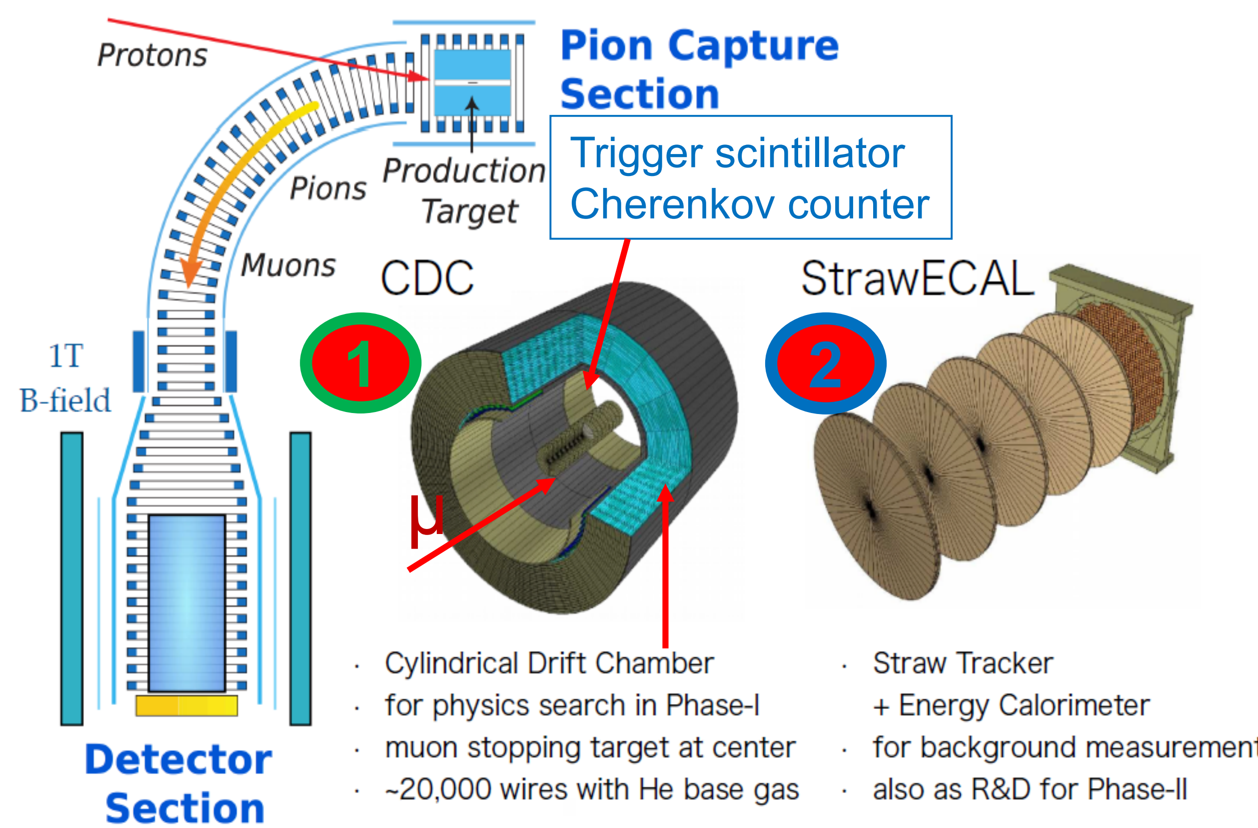
Phase-I Goal

1 Search for μ-e conversion

- A search for μ-e Conversion at the intermediate sensitivity with would be 100-times better than the present limit (SINDRUM-II) **2×10^{-15}** . For this measurement used Cylindrical Detector System (**CyDet**)

2 Background Study for the full COMET Phase-II

- Direct measurement of potential background sources for the full COMET experiment by using the actual COMET beam line. For this measurement used Straw Chamber + ECAL (**StrECAL**)

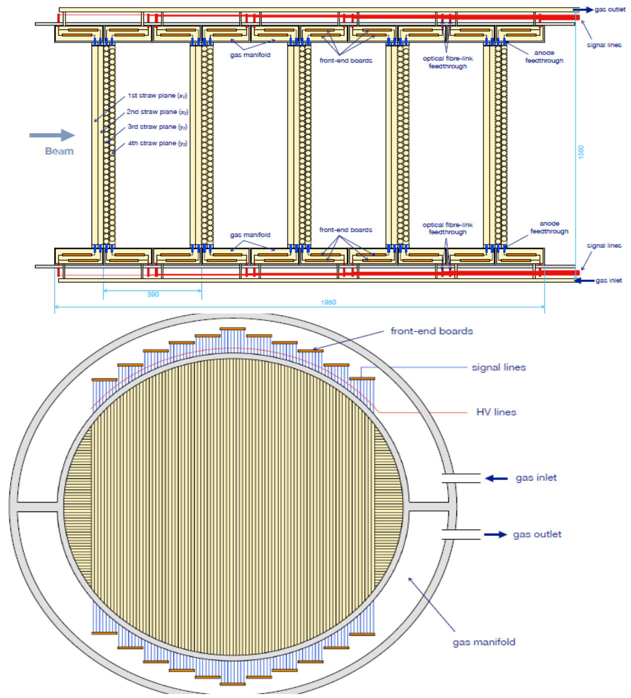


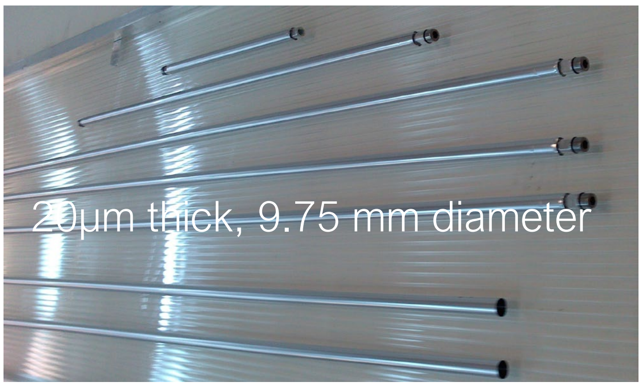
COMET Detector System and Requirements

Straw Tracker: 5 station (Phase – I) ~ 2500 straw tubes, 9.75 mm diameter, 20 μm thickness, Ar:C_2H_6 = 50:50

Requirements:

- Momentum resolution ≤ 200 keV/c
- Space resolution ≤ 200 μm
- Work in vacuum, magnetic field 1 Tesla





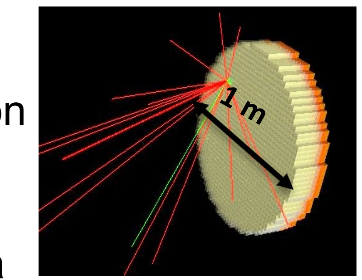
Electromagnetic calorimeter

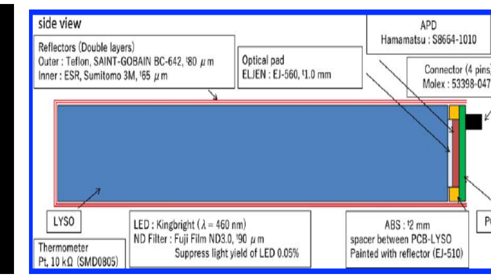
ECAL (crystal type LYSO, $Lu_{1.8}Y_{.2}SiO_5Ce$)

- Combination of around 600 (for Phase II 2272) LYSO crystals for Phase-I
- Total size: diameter ~ 1m
- Crystal size 20x20x120 mm³ (11 radiation length)
- Photon detector: APD

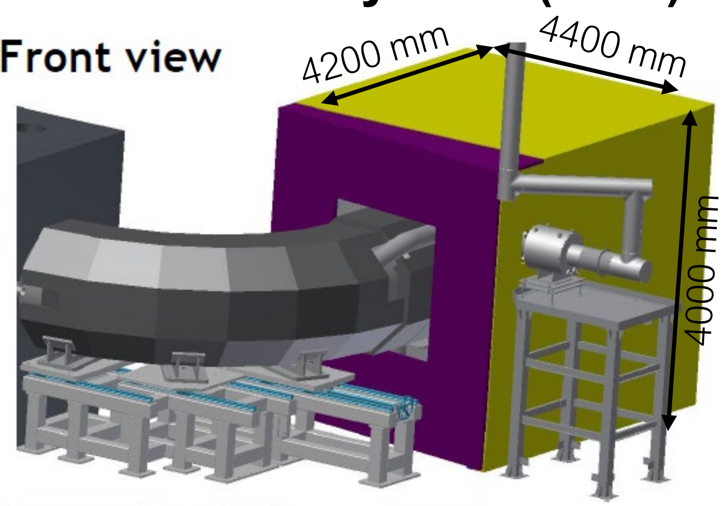
Requirements:

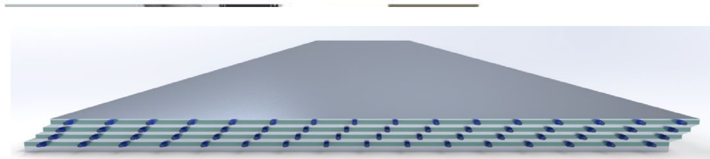
- < 5% ER at 105 MeV
- <10 mm space resolution
- < 100 ns time resolution
- Work in vacuum and magnetic field of 1 Tesla



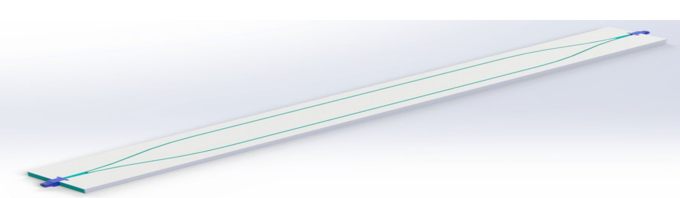


Cosmic Ray Veto (CRV)





CRV module's front view



Design of the strips with 2 WLS fiber

Requirement: Efficiency ≥ 99.99%.

CRV will be consist of two major parts:

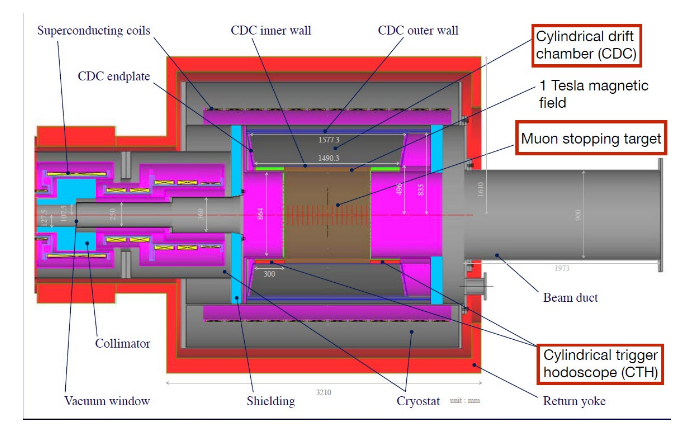
- scintillator based (SCRV)
  - CRV consists of 8 supermodules
  - The modules are formed from four layers, 15 strips
  - Strip sizes: 0.7 x 4 x 220 cm³, 1.2 mm diameter WLS
- Glass Resistive Plate Chambers (GRPC).

The SCRV subsystem placed on top and back sides of the COMET and based on extruded plastic scintillation strip with WLS fiber glued to the strip groove. The GRPC will be placed in hottest area at front of the COMET (active shield).

Also used passive CRV, concrete and steel.

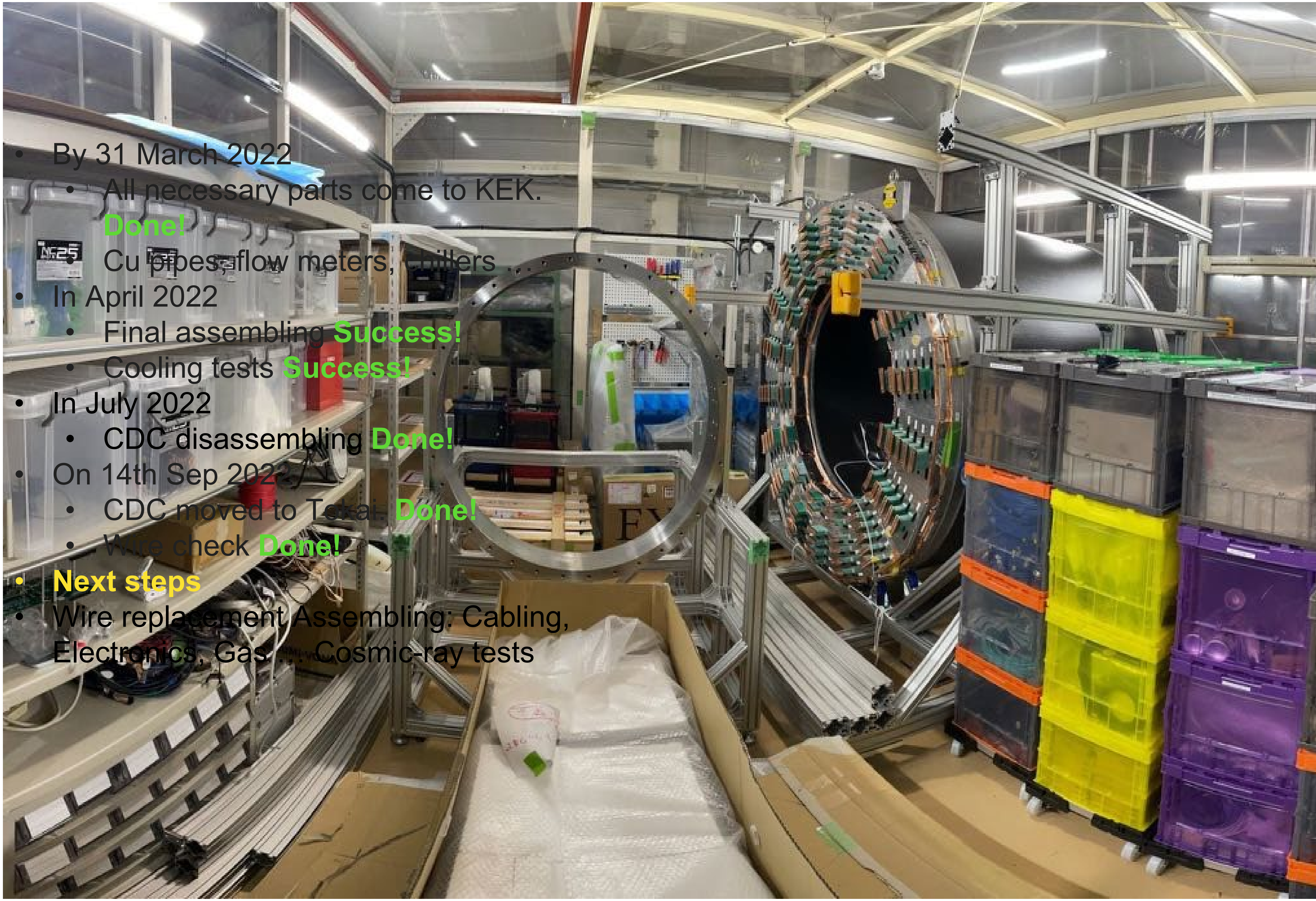
CyDet (Cylindrical Detector)

- Cylindrical drift chamber (CDC) surrounds the muon stopping target under 1T magnetic field
- Cylindrical Trigger Hodoscope (CTH) at the both ends



- 19 layers structure
- 5000 sense wires
- 15000 field wires
- He base gas
  (He : iC_4H_{10} = 10:90)
- Study of chamber is done
- Basic performance study of chamber was done, it's OK
- Spatial resolution < 200μm obtained
- Momentum resolution < 200 keV/c obtained
- Wire aging test is done
- Commissioning with cosmic-ray was done in KEK

CDC moved to J-PARC



- By 31 March 2022
  - All necessary parts come to KEK. **Done!**
  - Cu pipes, flow meters, chillers …
- In April 2022
  - Final assembling **Success!**
  - Cooling tests **Success!**
- In July 2022
  - CDC disassembling **Done!**
- On 14th Sep 2022
  - CDC moved to Tokai. **Done!**
  - Wire check **Done!**
- **Next steps**
- Wire replacement Assembling: Cabling, Electronics, Gas …, Cosmic-ray tests

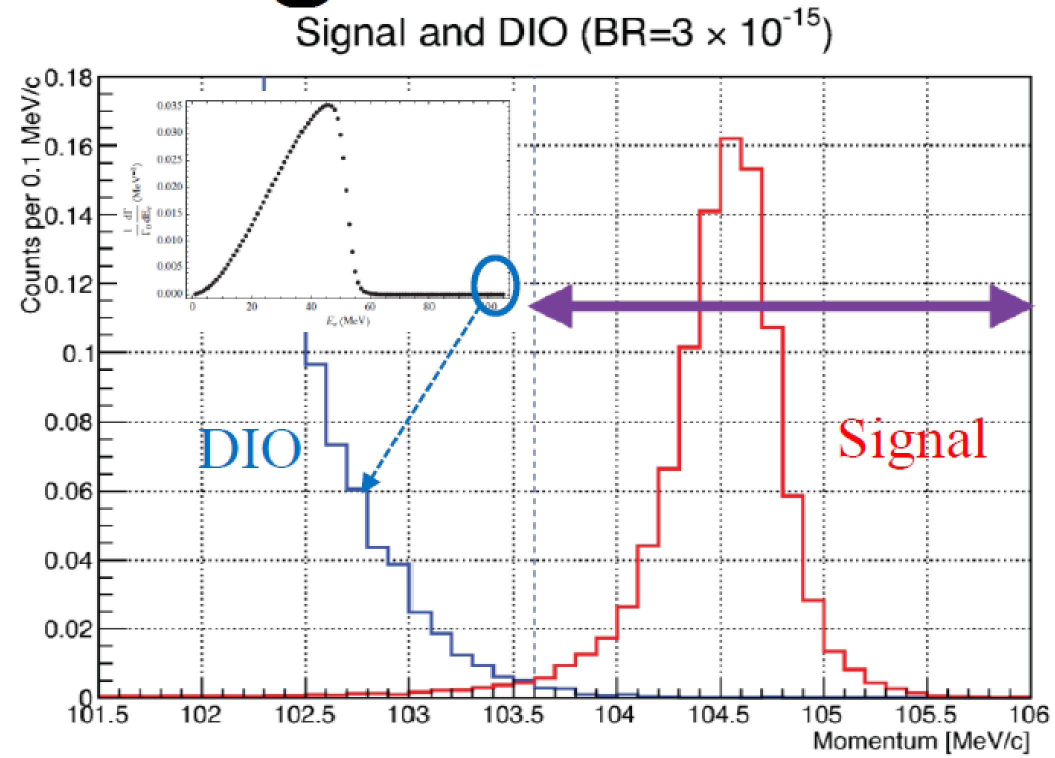
To control the background

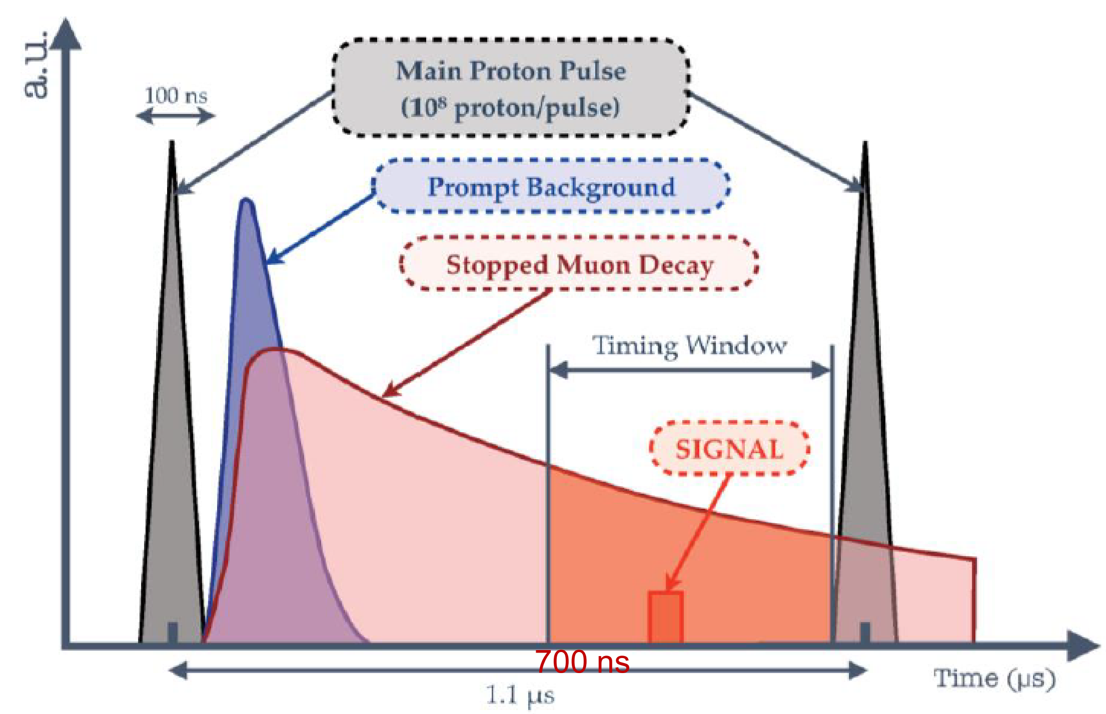
- Intrinsic physics background
  - Mostly from muon decay in orbit (DIO)
    - Calculated by Czarnecki with radiative correction. Branching ratio drops with order-5 function near end point.
    - Momentum resolution required to be better than 200 keV/c
- Beam related background
  - Energetic particles in beam with E>100MeV
    - Mostly prompt. Can be suppressed by a delayed measurement window (~700 ns)
    - Some due to leaked proton. Proton extinction factor required to be $< 10^{-10}$。

actually achieved ~ 10^{-11} !

- Cosmic ray background
  - Cosmic ray: cover the system with cosmic ray veto detectors.

Required Inefficiency < 10^{-4}





Muonic atom lifetime for Al - 864 ns is good

The estimated background events for a single-event sensitivity of 3×10^{-15} in COMET Phase – I with a proton extinction factor 3×10^{-11} is, DIO: 0.01, RPC: 0.01, anti-protons: 0.01, cosmic rays: < 0.01, Total: **0.032 events**

COMET Phase-I Sensitivity

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 (ε_{mom}) (a signal acceptance)	0.93	$103.6 < p_e < 106.0$ MeV/c
Timing window (ε_{time})	0.3	$700 < t_e < 1170$ ns
Total (Signal Acceptance for the μ-e conversion)	**0.041**	

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

Number of muons stopped inside targets
$N_\mu = 1.5 \times 10^{16}$

Fraction of muons to be captured by Al target = 0.61

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

3 x 10^{-15} (as SES) achievable in ~ 150 days

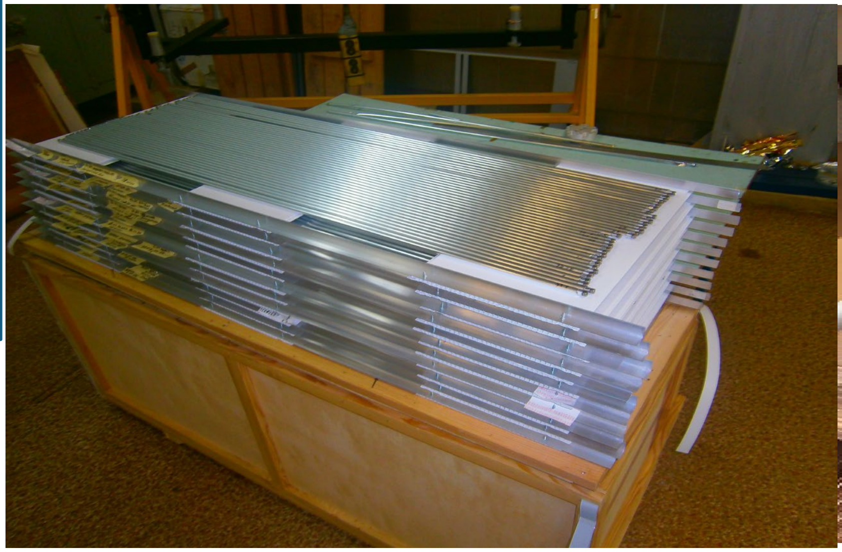
JINR activities and responsibilities

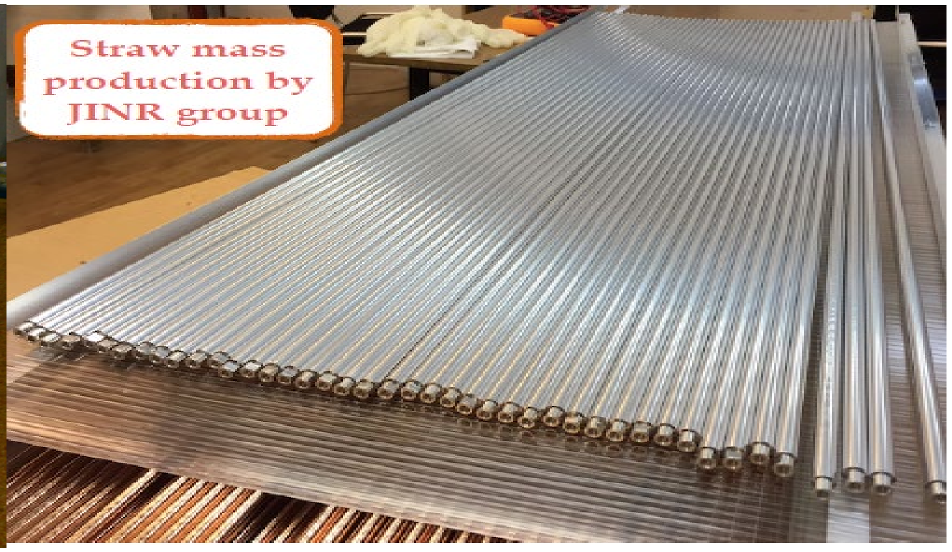
1. Straw tracker
2. Electromagnetic calorimeter (ECAL)
3. Cosmic Ray Veto (CRV)
4. Software studies (simulations) for straw tracker, ECAL and CRV

Straw tubes muss-production for Phase-I

The complete set tubes for Phase-I has been produced and tested:

- 2700 tubes of 20 μ wall thickness, Ø 9.8 mm 120 and 160 cm length have been produced
- These tubes passed all the tests and have been sent to Japan





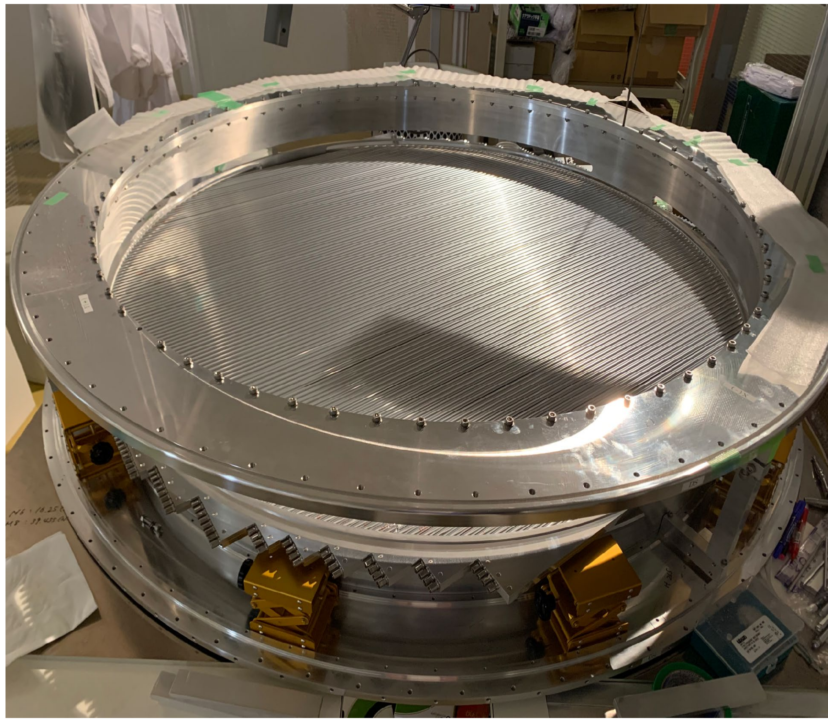
The study of the properties of straws

The following mechanical properties of the 9.8 mm straws have been measured:

- the range of elastic deformation of the straw
  - **Results: The limit value of the straw tension is obtained 1.85kg (in COMET up to 1 kg)**
- the influence of temperature and the dependence of the elastic properties of the straw on its thickness
  - **Results: The maximum tension of the straw is provided at temperature from 10 to 20^{o}C**
- The tubes aging
  - **Results: The service life of straw detector is 9 years.**

- First straw tracker module for Phase-α is on final stage of assembling
- 480 straw tubes already glued into the frame and wired
- Electronic boards “Roesty” are ready for installing
- After that is planed system gas leakage and vacuum tests
- Within working visit all straw tubes were checked for quality, gas leakages and mechanical damages
- **After 7 year All straws are in perfect condition and ready to be used for next modules**
- Future activities include conclusion R&D of new 12 μm straw tubes and preparation for new mass production

Straw Tracker Status — COMET Phase-I



Straw-Tracker Assembly 1st layer, completed !!!

The manufacturing area for straw-tube R&D at DLNP

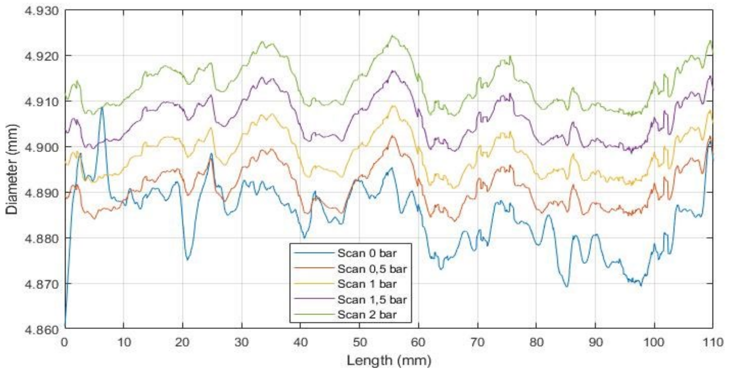
For Phase-II we need even thinner and less diameter tubes: 5 mm diameter and 12 μm wall thickness.

For this purpose we prepared a new straw production line in our laboratory.

Completed real working machine for full dimension 12 μm thickness and 5 mm diameter straw tube production with controllable parameters

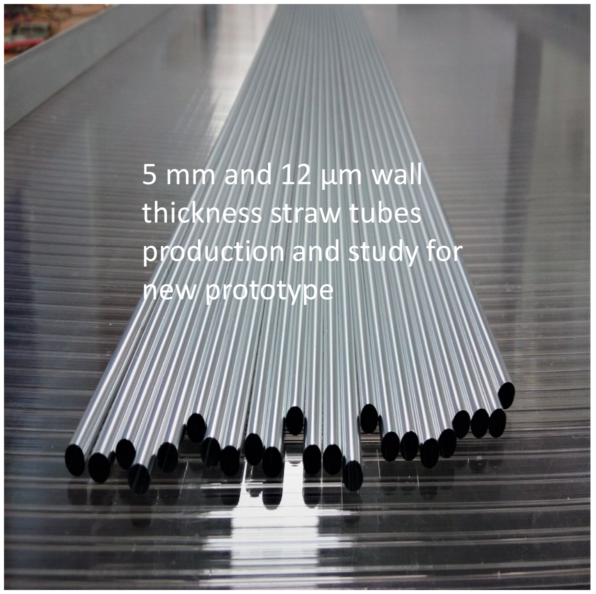
Cabability of the new straw tubes production facility

1) New welding machine design and 5-th class clean room with temperature and humidity control
2) 5 mm diameter and 12 μm wall thickness straw tube production
3) Examination of straw quality control of tubes
4) Study straw tube properties
5) Precise measurements and monitoring of straw diameter with optical methods, accuracy of 0.1 μm



- Diameter scan along straw tube length with different inner pressures
- Diameter deviation along the tubes is less than 20 μm,
- Shape stays consistent under different pressures

64 channel prototype



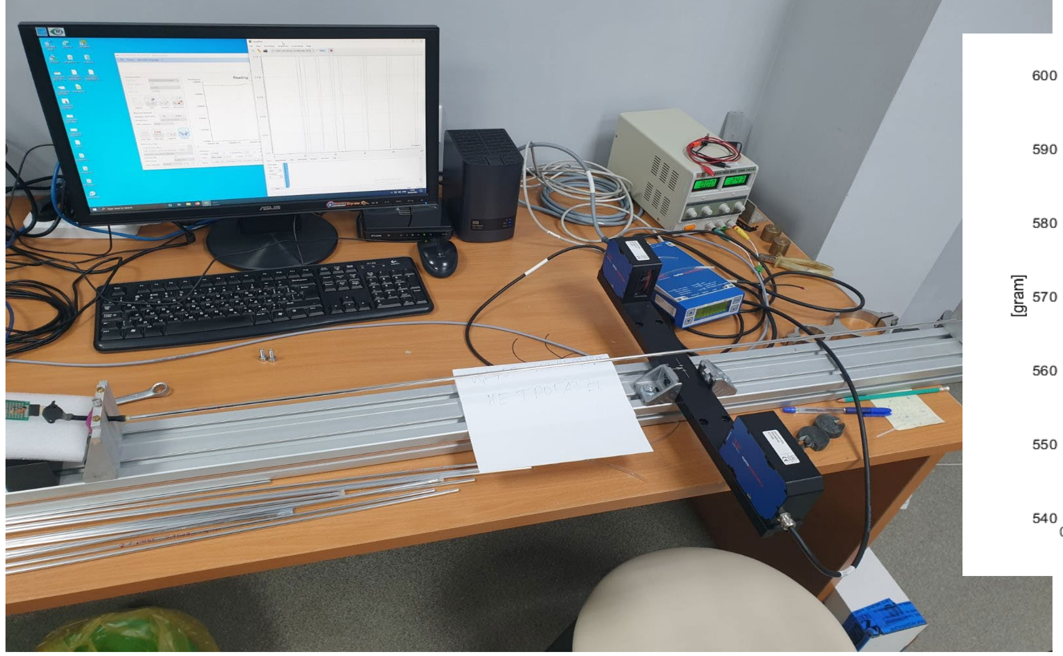
Produced straw parameters

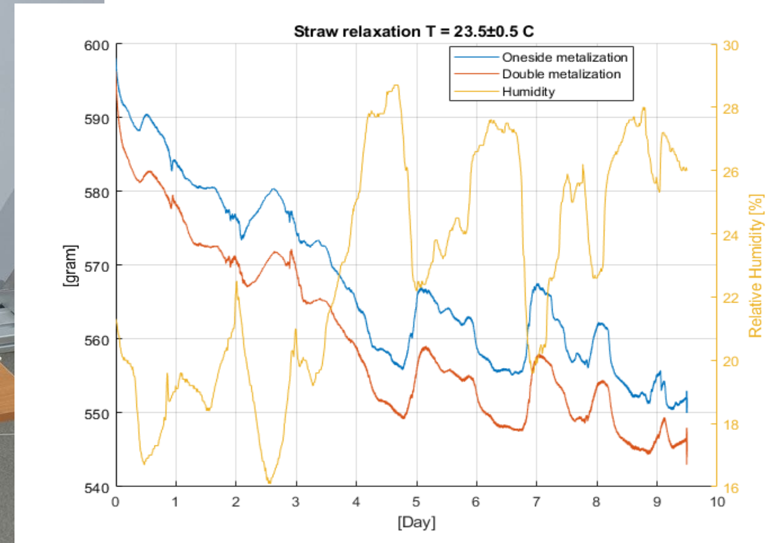
- 140 pieces
- 70 cm in Length
- 4.98±0.12 mm Diameter
- 12 μm Mylar tape thickness
- Aluminum layer 70 nm
- Prototype working pressure 1 bar
- Long term testing pressure 2 bar
- Max safe pressure 3 bar
- Max load pressure 4 bar

- Long term tests still ongoing
- Straws stably staying pressurized
- No any mechanical damages
- After while Only 5% of straws dropped pressure

Great success in R&D, in the production of 5 mm diameter and 12 μm thick tubes

Taking into account the success of JINR, DLNP COMET group in R&D and production of thin-wall tubes with 5 mm diameters , 12 μm wall thickness , and development of straw station design, **the COMET CB supported the idea of JINR group to use an additional station with new tubes at Phase-1**





Main goal of this study is to see how humidity affects tension force and how well outside metallization can shield straw tube from it.
On picture one shown

- Temperature (23.7 C)
- Humidity (Yellow)
- Mylar with one side metallization(Blue)
- Mylar with Double metallization(RED)

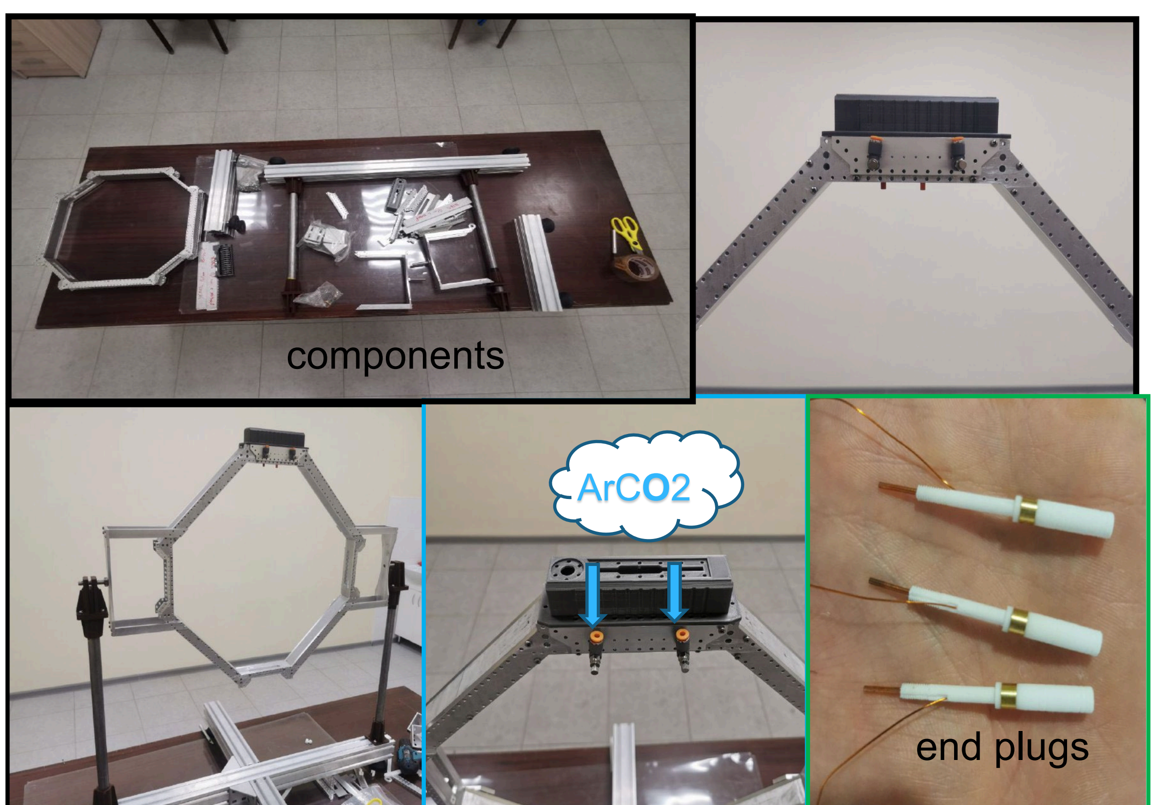
As graphs are showing, tension of both straws strongly depend on environment humidity. This study still ongoing.

Frame build in progress

✓ The assembly of the main frame is completed
  - ✓ End plugs
  - ✓ Gas supply

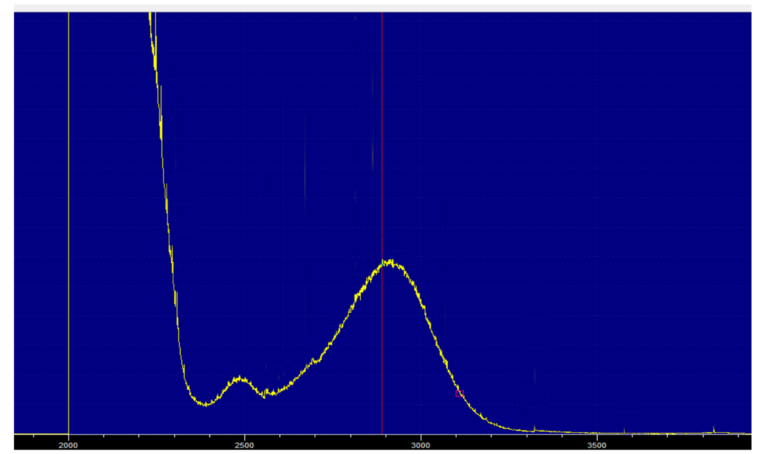
In progress

- Mixing gas system assembly
- ROESTI fixing system
- Production of flexible boards for signal transmission from straw tubes to ROESTI

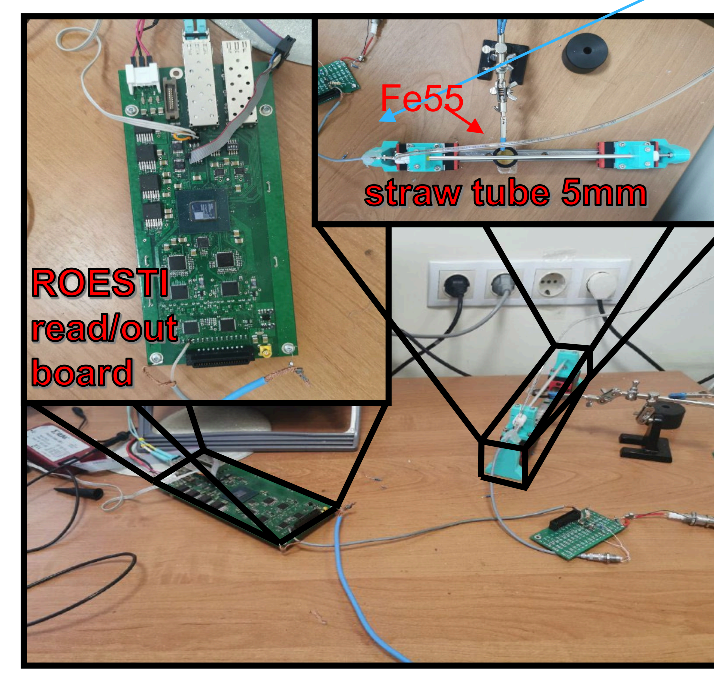


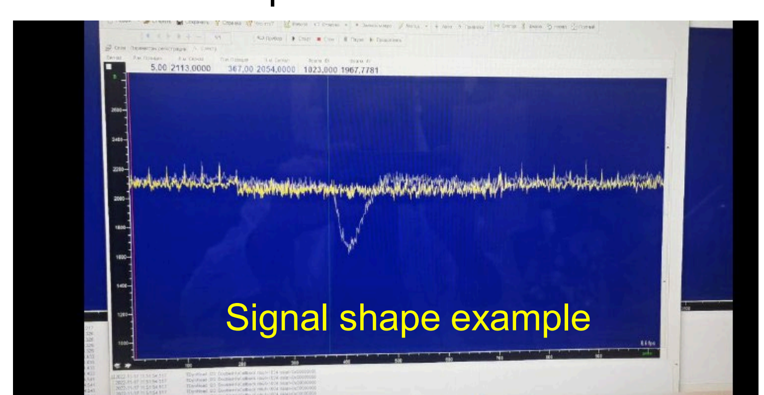
Test setup for ROESTI (read-out) COMET board

Gas Mixture – Ar-70% CO2 – 30% , Straw tube 5mm, Anode wire – 50 µkm, HV – 1800 V



✓ The spectrum of the signal from the electronics boards for the comet experiment was obtained





In progress

- Assembly of the channel on a wire of 20 and 15 microns

Electromagnetic calorimeter

Three candidates vendors

- **Saint-Gobain (SG), Baseline**
- OXIDE (OX), Japan
- Suzhou JT Crystal Technology (JTC)

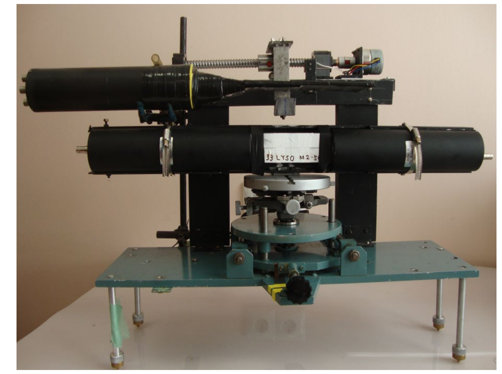
Saint-Gobain has introduced an engineered version of LYSO which, compared to standard LYSO, offers up to:

- **6% improvement in energy resolution**
- **20% higher light yield**
- **20% faster decay time**

Properties	Standard LYSO	Engineered LYSO
Density [g/cm³]	7.1	
Hygroscopic	no	
Attenuation length for 511keV (cm)	1.2	
Energy resolution [%] @ 662 keV*	**8.5**	**8**
Wavelength of emission max [nm]	420	
Refractive index @ emission max.	1.81	
Decay time [ns]	**45**	**36**
Light yield [photons/MeV]*	**27600**	**33200**
Average temperature coefficient from 25 to 50° C (%/°C)	-0.28	

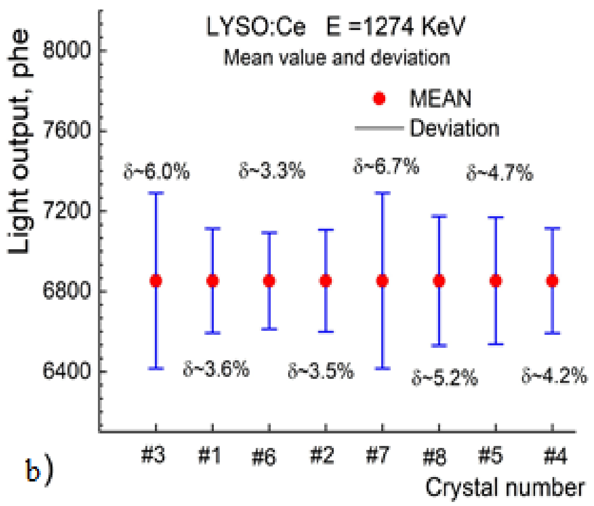
R&D of LYSO crystals

The test bench has been prepared in DLNP



The LYSO crystal certification
More than 200 crystals have already been certified

The samples of the two companies SG and JTC have comparable scintillation parameters: high light output, short flash time and suitable energy resolution.
The uniformity is better in Saint-Gobain crystals.
Despite the fact that the optical properties of SG crystals are slightly better than those of JTC, under certain conditions, both crystals can be used in the COMET calorimeter of the experiment.



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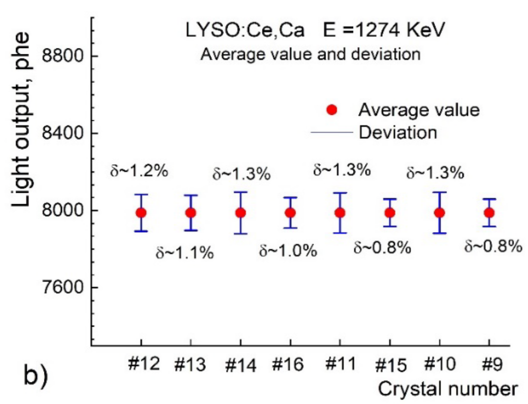

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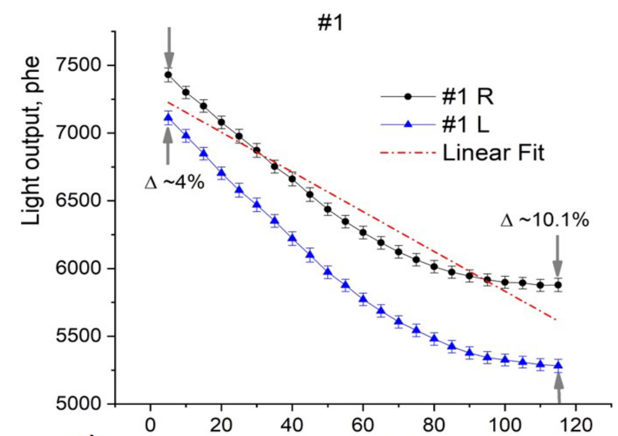
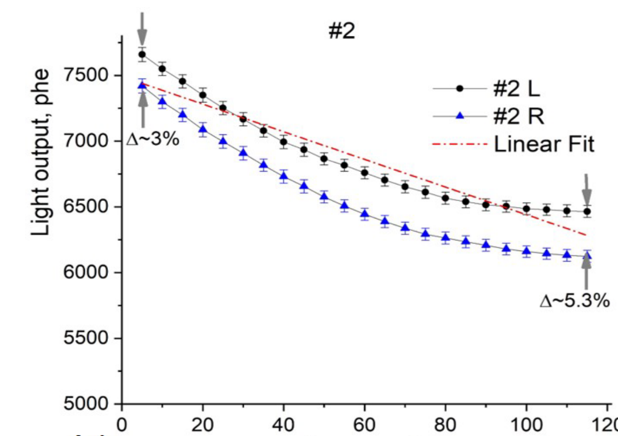


a)



b)

Measurement of the electromagnetic calorimeter prototype parameters on cosmic muons

Measuring setup: measurements under the angels

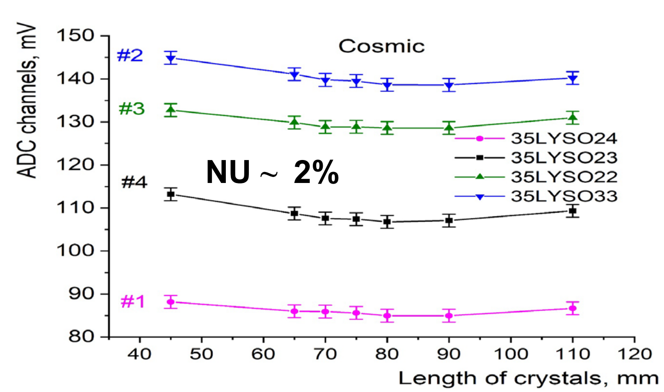
Crystals: LYSO - 4

Wrapper

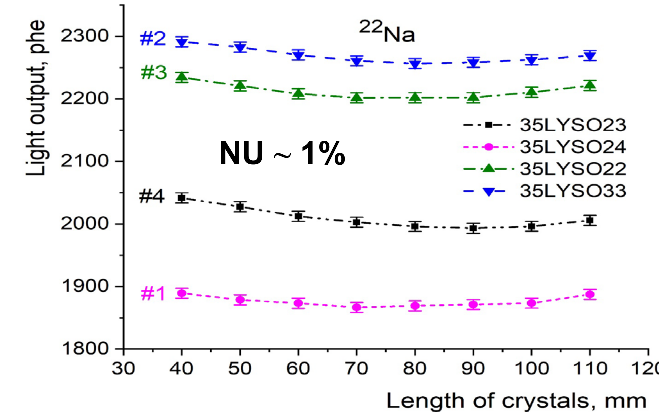
Two layers of TEFLON
-Thickness = 65 μm
- Absorbance 28 %/cm

One layer of ESR film
Thickness = 65 μm
Refl.Coeff. = 0,99/0,1

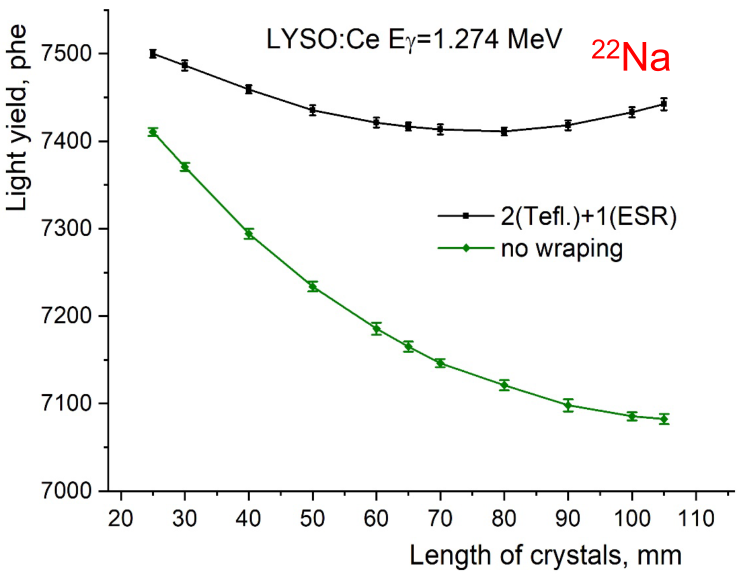
One layer of paper
Thickness = 200 μm



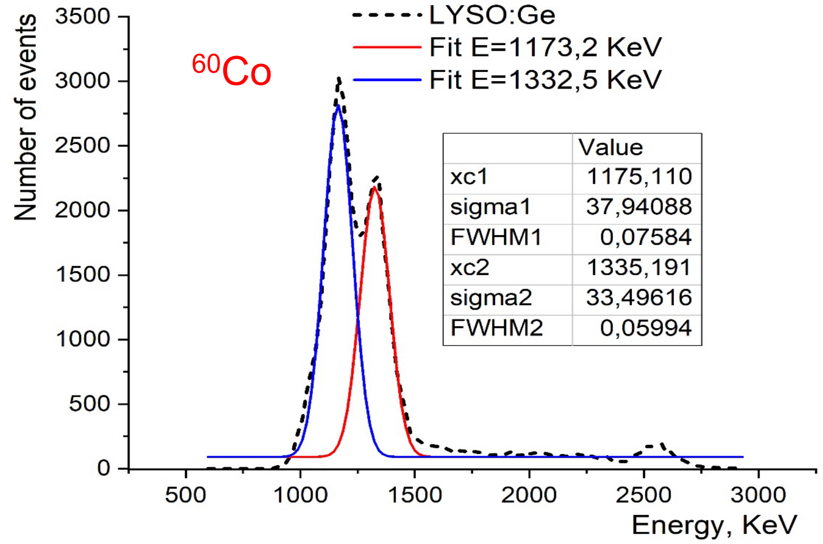
Non-uniformity of the prototype response along the crystals measured using cosmic muons



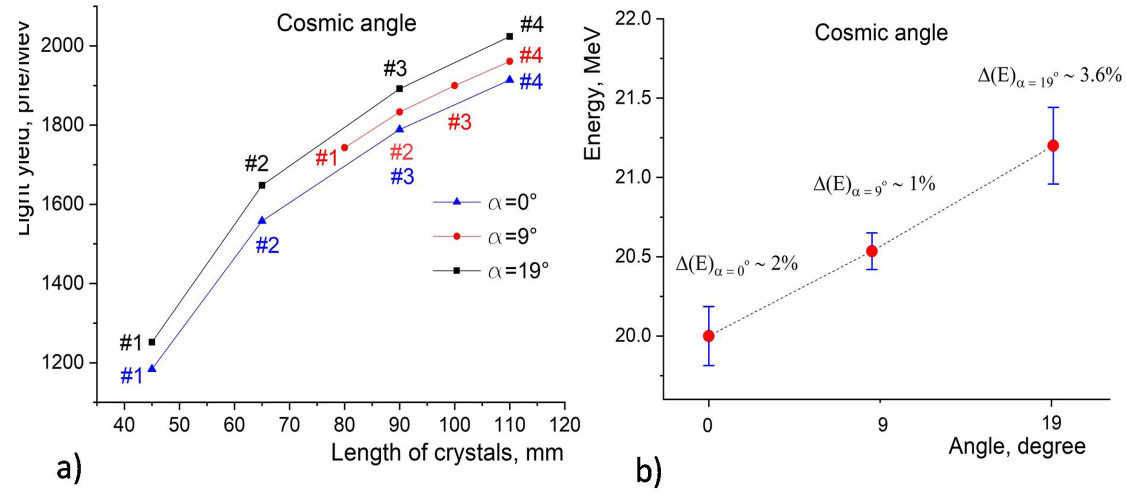
Non-uniformity of the LY along the crystals length, measured at an energy of 511 keV



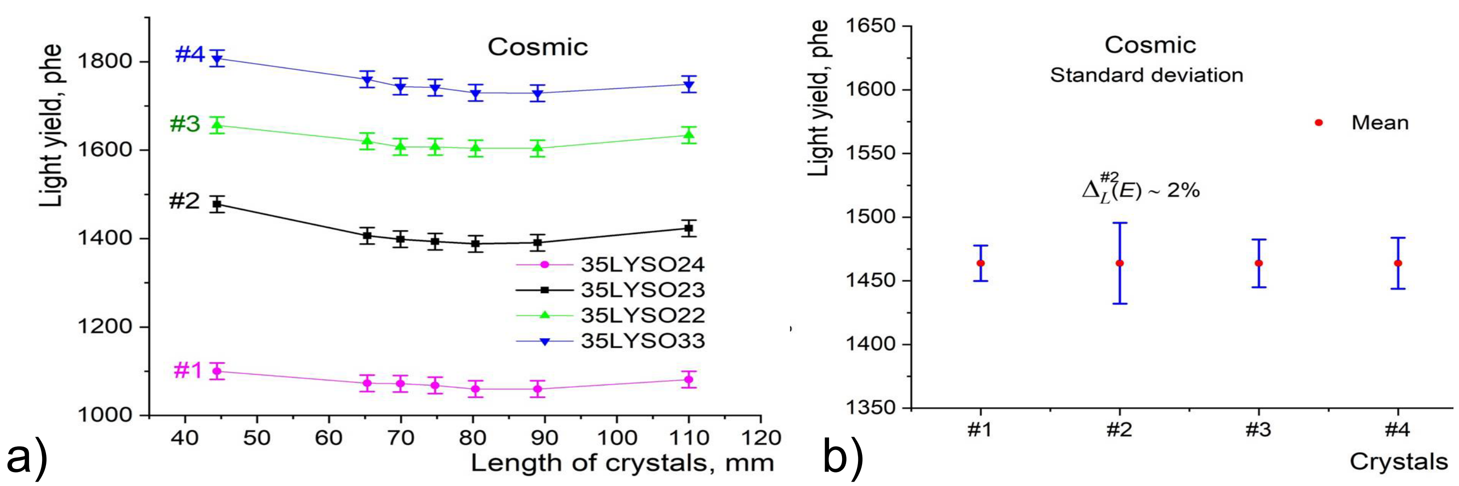
Light yield non-uniformity along the crystal length for various types of reflective materials



Energy spectrum of a crystal with optimal wrapping



a) Scintillator responses of the calorimeter prototype for angles of 0, 9 and 19 degrees ; b) Detector response non-uniformity for angles 0, 9 and 19 degree



a) Light yield distribution along the crystal length (scintillators responses) measured with cosmic muons; b) Mean value of response and response non-uniformity for each scintillator

Plan for further work is continuation of work on the development of a calorimeter calibration technique:
1) measurement of the calorimeter prototype parameters at electron beam ;
2) calculation of the energy resolution of the calorimeter prototype..

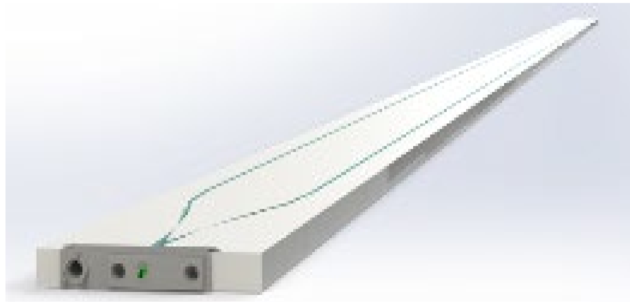
- Simulation of processes in crystals, ongoing
- Comparison of the crystal types, finished
- Simulation of optimal structure of the calorimeter, ongoing
- Simulation of the calorimeter geometry in framework ICEDUST, ongoing
- Experimental study of the main parameters (uniformity, light output) LYSO crystals on a precision JINR stand, ongoing
- Calibration of 64 crystals of LYSO at the JINR stand for Beam Test (Tohoku), finished
- Participation in a calorimeter design, ongoing
- Quality control (certification) of all crystals in JINR (full responsibility), ongoing
- Calorimeter assembling, testing, calibration and installation at setup, in the near future

Cosmic-Ray Veto (CRV)

- Muons from cosmic rays mimic the 105 MeV conversion electrons and, as a major source of background, would reduce the experiment overall precision. So, to suppress the cosmic muons, the Cosmic-Ray Veto (CRV) system becomes as an essential part of the COMET experiment. It will cover around of the COMET other systems and will acting as an active shielding and efficiency to record the muon is required on 99.99% level.
- CRV will consist of two major parts: scintillator based (SCRV) and GRPC based (GRPC-CRV) subsystems. The SCRV subsystem placed on top, sides and back of the COMET and based on extruded plastic scintillation strip with WLS fiber glued to the strip groove. The GRPC-CRV will be placed in hottest area at front of the COMET and will be consists of array of GRPC.
- The JINR group is the leader in R&D, in design and in development of the SCRV subsystem. This activity includes two parts: to finalize design of the SCRV with providing scintillation strips production, testing, CRV modules creation schedule and to design/create/test the electronics embedded to the scintillators.
- Within of this search (including the aging) we investigated the different configurations for strips: with one or two Wave-Length Shifting (WLS) optical fiber in parallel grooves, with different WLS fibers diameters, combination of it.

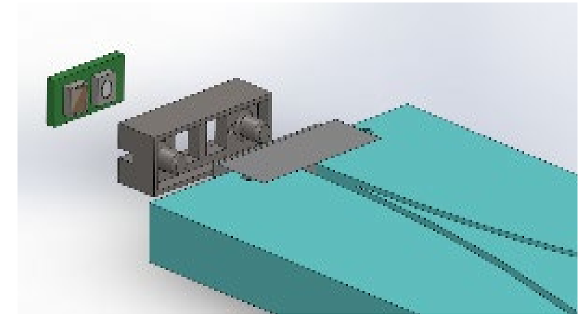
- The investigation included a search of the best values for the shift layer to each other (so called pattern) by simulation with GEANT-4 and it tested on 4x4 module.
- We found the reasonable compromise between the strip's geometry, number of WLS fibers, its diameter and SiPM type should be attached
- design of SCRV based on 4-layers array of plastic scintillator strips of 7x50 mm^2 in cross section and with two 1.2-mm (for sides) and 1.4-mm (for top) in diameter WLS fiber glued in the groove along the strip
- With this geometry it will be possible to achieve required up to 99.99% efficiency for cosmic muon registration.
- The light collection will be done with Hamamatsu MPPC/SiPM S14160-3050HS since it have up to 50% of quantum efficiency on required green light area.

Scintillation strips as a base element of the COMET SCRV modules



Design of the strip

real strip

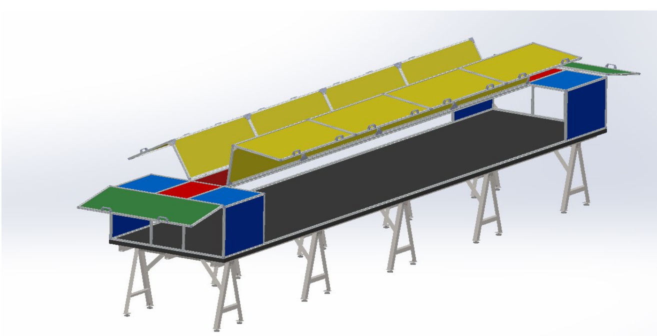


Sketch of the strip with SiPM board and housing.
The real look of the SiPM PCB inserted to the housing

Strips test stand

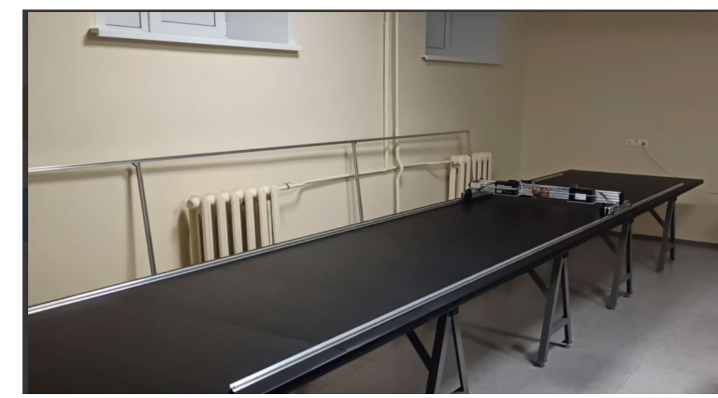
To create of this, first CRV module, we needed to provide a proper procedure of the mass production of the strips, including the quality check on each step of the production. At first, we need to choose the optical glue to fix the WLS fiber in grooves. Next, we need to check the WLS fiber state before its gluing into grooves. Then, we need to check the strips in geometry and light output prior of the CRV module creation.

- To test the strips, we created the lightproof 6-m-long test stand with 2D translation stages (so-called 2D-portal). The collimated by 1 mm diameter radioactive by $^{90}Sr/^{90}Y$ β-source with 0.06 mCi beta-source was used to exam the strips along the distances. Light from SiPMs were collected using Front-End based on CitiROC.
- 100 strips were produced, and quality test was provided. 64 best of them were selected to create the first CRV module.

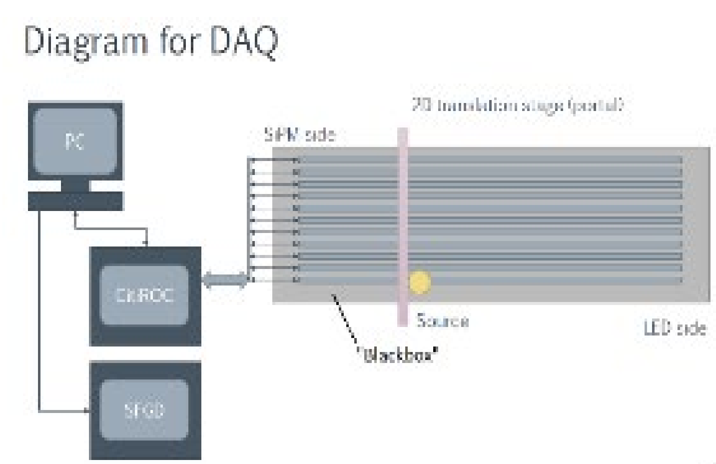


The test stand sketch

Test stand full assembly



2D portal in the table

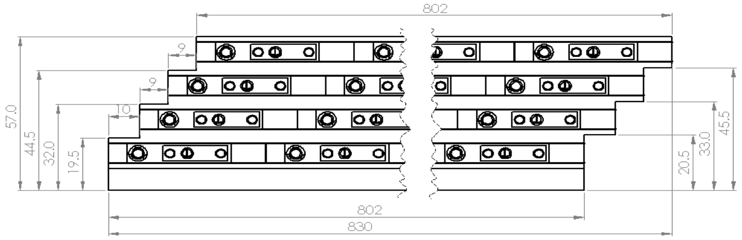


DAQ layout for strips quality test using collimated beta-source.

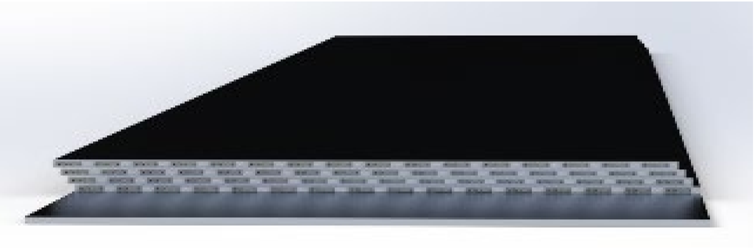
Layer	left					Top mount point view										right
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Top, L4	78	31	56	68	40	52	8	36	46	6	27	29	9	12	38	48
Middle, L3	97	33	50	47	58	35	37	53	2	39	43	11	23	4	21	70
Middle, L2	63	61	64	57	25	18	42	7	28	1	96	3	13	14	99	45
Bottom, L1	55	54	80	67	59	26	5	10	17	49	30	32	15	24	98	22

64 for strips order for first CRV module

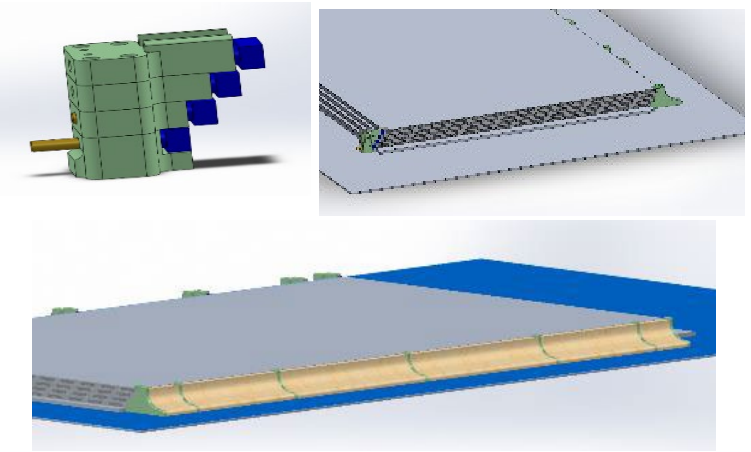
CRV module assembly



SCRV design

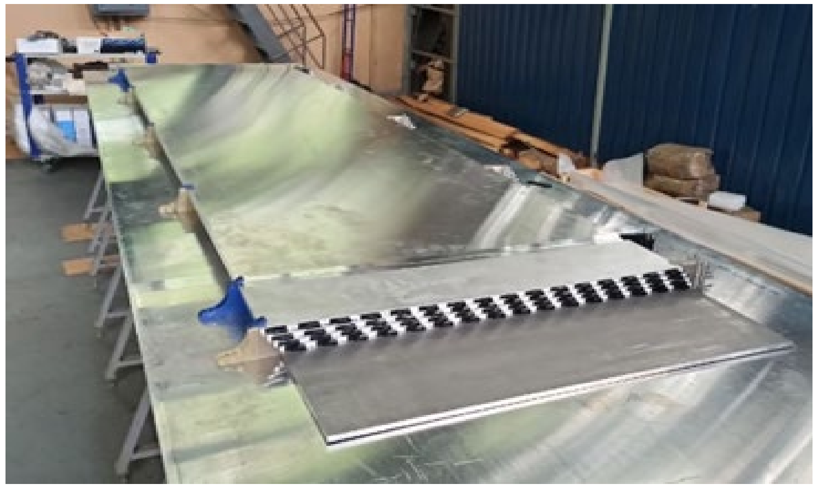


sketch of the first module



geometry fixing tools sketch
The wooden addons were used between of holding tools to prevent failure of the cover while vacuuming

- The mix of the optical epoxy with TiO2 in proportion of 1:1 was found as best solution to glue the CRV module and be prevented of light loss due to gluing and to establish the necessary bonding strength for CRV module.
- We used the vacuum to provide equivalent to 25-ton force over the total CRV surface to properly fix the CRV module geometry while epoxy cures



CRV module

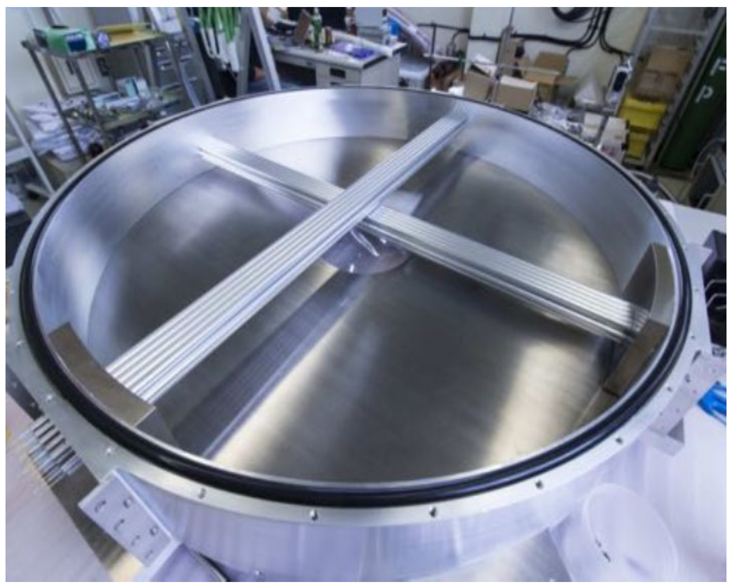
Assembly of CRV module

Compressed CRV module

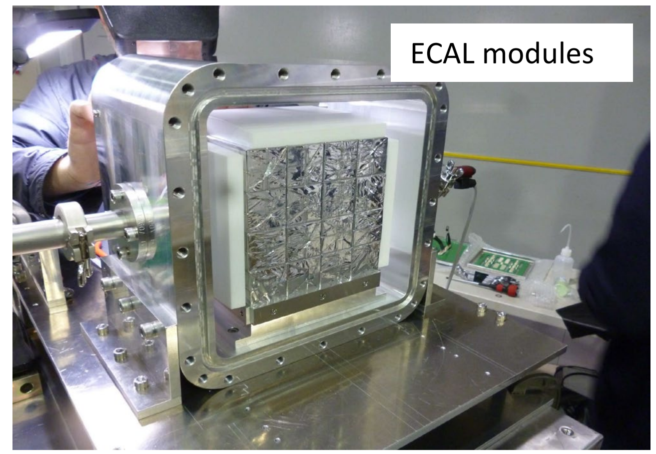
➢We proposed the final designs of the strip and CRV module were discussed during the COMET Collaboration Meetings it was approved for SCRV-LS-0.

StrECAL system integration tests at ELPH in Tohoku

Energy range: 65 -145 MeV

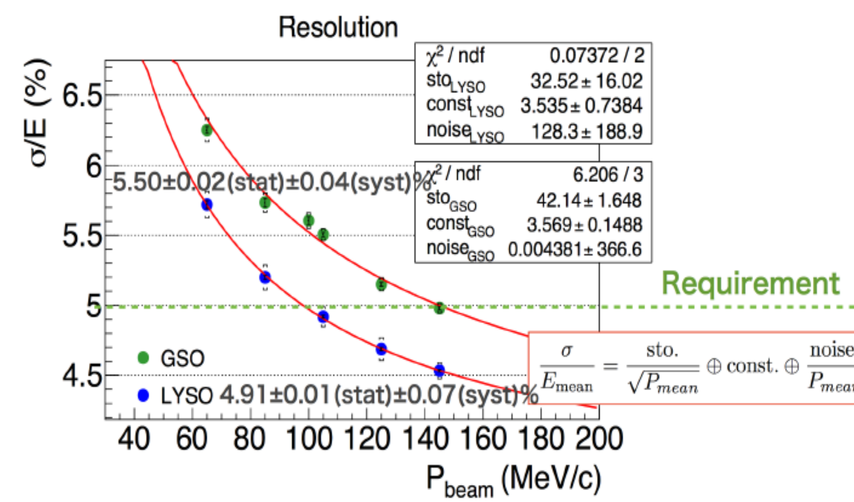


Straw prototype

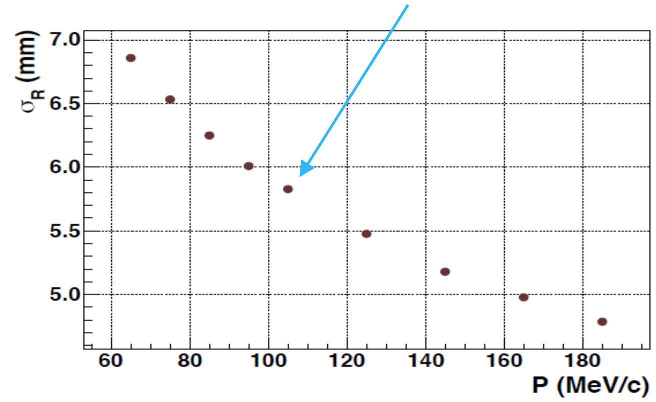


ECAL prototype 64 (8x8) JINR cryst.

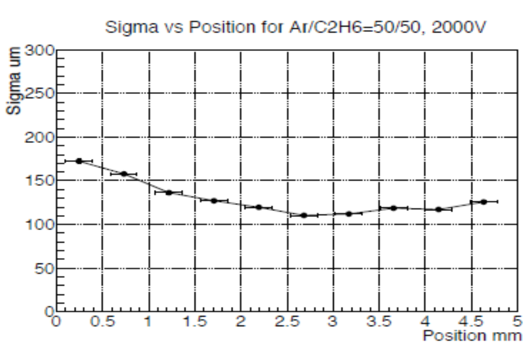
The energy resolution at 105 MeV for
- GSO - 5.5 ± 0.02 (stat) ±0.04 (syst) %
- LYSO – 4.91 ± 0.01 (stat) ± 0.07 (syst) %

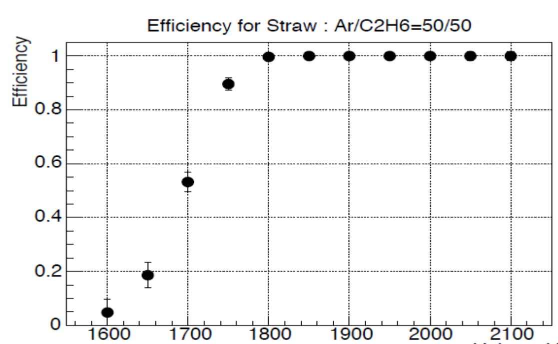


The position resolution is 5.8 mm



At 105 MeV/c, the energy resolution varying from 3.8% to 4.8%, depends on where the electron hits (center, border, corner) on the ECAL





The position resolution varying from 5.3 mm to 8.5 mm, depends on where electron hits (center, border, corner)

The results of ECAL prototype test
- **Energy Resolution 4.8% @105MeV**
- **Position resolution < 10 mm @105 MeV**
- **Timing resolution < 1.0 nsec**

The results of straw efficiency and spatial resolution HV 1800- 2000) for Argon/Ethan
- **ε > 96%**
- **σ ~ 119 μm**
- **Momentum resolution ~ 180-200 keV/c**

The results of StrECAL system integration beam tests meet all the requirements of the experiment

Schedule of works on the project in 2024-2026

- Participation in the preparation, engineering and physics run, the data acquisition and analysis of Phase-I, **2024-2026**
- R&D program for production of the straw tubes of 12 μm wall thickness and 5 mm diameter. Measuring of all mechanical properties and development of standards for quality control of manufactured of the 5 mm brand-new straw tubes, **2024 -2025**
- Finalization assembling, testing, calibration, installation, cosmic test and maintenance of the straw detector for Phase-I, **2024**
- Production of straw tubes (about 1000 pcs) for full-scale prototype, **2024-2025**
- Production of a full-scale straw station in JINR, with new tubes (12 μm, 5 mm), and measurements on the beam, **2024-2025**
- Preparation and mass-production and testing of straw tubes for Phase-II, **2025-2026**
- Development and optimization of a crystal calibration method for a COMET calorimeter, given the features of the experiment: the presence of a magnetic field and high resolution calorimeter**, 2024-2026**
- Participation in the full calorimeter designing, assembling, installation, cosmic test and maintenance**, 2024-2026**
- Participation in the assembly and maintenance of the CRV for Phase-II, **2024-2026**
- Participation in the beam tests of the detector components for Phase II, **2025-2026**
- Participation in assembling, testing, installation and maintenance of whole detector system for Phase-II, **2025-2026**
- Complex detector system (tracker, calorimeter, etc.) simulation, **2024-2026**
- Participation in the engineering and physics run for Phase I**, 2024-2025**
- Participation in the data acquisition and analysis, **2025-2026**

The responsibility of the JINR in the COMET

- The JINR group is a single one in the COMET collaboration, which is capable to produce thin-wall straw tubes. Therefore, we are fully responsible for manufacturing of all straw tubes. Different procedures of the tube tests on pressure, gas leakage and elongation have been also updated in accordance with the COMET requirements and new test standards have been established.
- JINR takes full responsibility for the next step to this direction, carrying out of R&D works of straw tubes for the COMET Phase-II, with the tubes of 5 mm diameter and 12μ wall thickness. For this purpose, we are preparing a new straw line in DLNP.
- JINR physicists together with the KEK colleagues take full responsibility in assembling, tests and installation of the full-scale straw tracker for Phase-I. Appreciating the crucial contribution of the JINR to the creation of the straw tracker, a member of JINR-COMET team was elected as one of the coordinator for the COMET-straw tracker system.
- JINR takes full responsibility in production of a full-scale straw station for Phase-I, with new type of straw tubes.
- JINR takes full responsibility for development and optimization of a crystal calibration method for the calorimeter to be used in COMET Phase I and Phase-II.
- Physicists from JINR take full responsibility for the certification of crystals, and are the leaders in the R&D work.
- JINR together with KEK and Kyushu University takes full responsibility for assembling, testing, installation and operation of the calorimeter.
- JINR physicists have implemented a full-scale R&D program to create a cosmic veto system. The program was completed successfully, and the results were reported at the collaboration meetings. Based on these results, all the parameters and methods for creating the CRV are determined. Also, the main responsibility in the assembly, testing and installation of the CRV for Phase-I will be on scientists from JINR. Based on these, a member of JINR-COMET group was elected as the COMET-CRV team leader.

Conclusion

- The COMET is a search experiment for μ-e conversion at J-PARC
  - aiming improvement the sensitivity x 10,000 better than the past limit, 1.0 x 10^{-17}
  - staging approach called **Phase-I** (under construction) / Phase-II
  - Before Phase-I we have **Phase-α** – a low beam intensity run in 2023
- **Phase-α Goal**
  - The beam and secondary beam yield estimation, measurement w/ PID
- **COMET Phase-I** is under construction

  Phase-I Goal: 2.0 x 10^{-15} Up to 10^{-15} → sensitive to "new physics"

  (in 150 days operation)
  - CyDet is ready at COMET site
  - StrECAL will be ready at COMET site by 31 March 2024
  - CRV will be ready by autumn 2024
  - **We plan to be ready by the end of 2024.**
- In parallel preparation and carrying out Phase-I, will go work on creation of a full muon bunch, R&D for COMET Phase-II is underway. After completion of Phase-I, will immediately begin installation and assembly for Phase-II. Expecting to start in **2027-2029**
- JINR plays a **leading role** in the preparation and implementation of this fundamentally important experiment.

Thank you for attention!

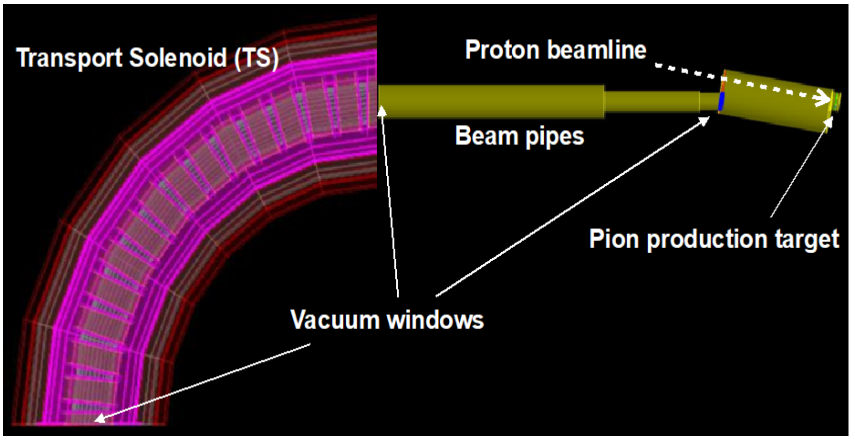
BACKUP

Phase-α (2022)

A low beam intensity run, 15-20 days in November 2022, **without Pion Capture Solenoid (PCS).**
A thin (1 x 20 x 20 mm^3) graphite plate as a pion production target. **Simulation Study (GEANT4)**

1. Secondary beam yield measurement with simplified geometry & magnetic field at both TS ends

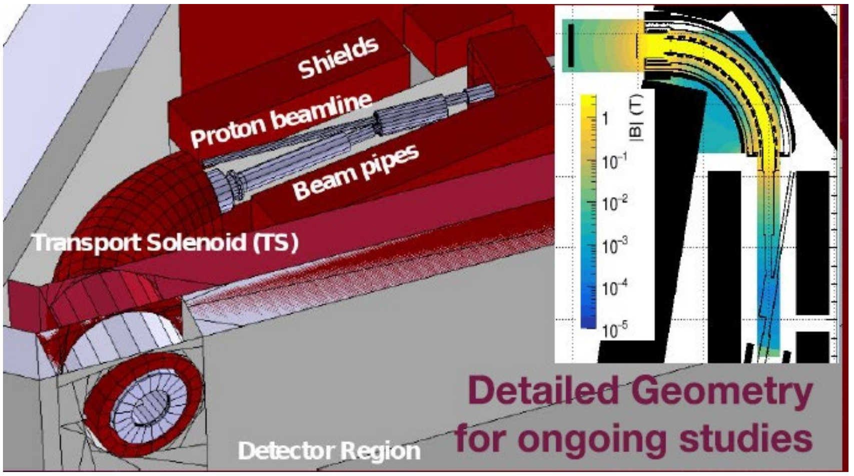
- Detectors
  - Proton-beam diagnostic detectors around the target area
  - Secondary-beam measuring detectors in the exp. area.
- 10^{11} proton-on-target (POT) events.
- **10^5 – 10^6 magnitude smaller yields than Phase-I**



Particle	TS entrance	TS exit
e^-	8.3×10^{-8}	4.6×10^{-8}
e^+	3.2×10^{-8}	3.3×10^{-8}
μ^-	2.0×10^{-8}	6.9×10^{-9}
μ^+	2.8×10^{-8}	1.1×10^{-8}
π^-	5.2×10^{-8}	1.7×10^{-9}
π^+	7.3×10^{-8}	2.8×10^{-9}
p	1.6×10^{-7}	4.0×10^{-10}

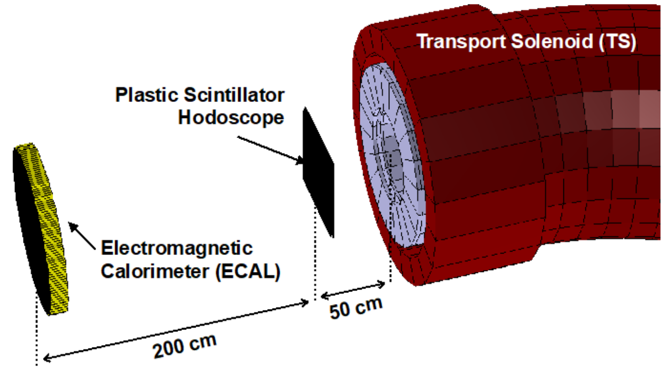
Phase-I
Particles at TS exit
10^{-2} – 10^{-5}

Particle Yields per POT at both TS ends



2. Measurement w/ PID

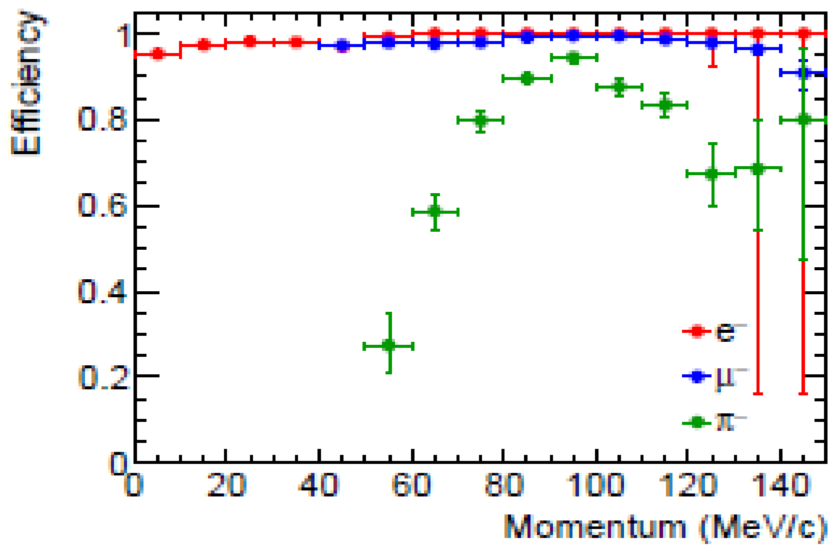
- Detectors
  - Combination of fibre plastic scintillator hodoscope and COMET ECAL
- Particle Identification (PID) method and performance
  - Multi-variate analysis (MVA) with three observable parameters
    - dE/dx in the hodoscope
    - ECAL prompt energy deposit (< 10 ns after hit)
    - Time-of-flight (TOF) between both detectors
- **The results: PID efficiency for e^-, μ^-, and π^-.**
  - **e^- : Good ~ 100%.**
  - **μ^-: Good > 90% but drops at high momentum.**
  - **π^-: Still low over the range, need improvement**

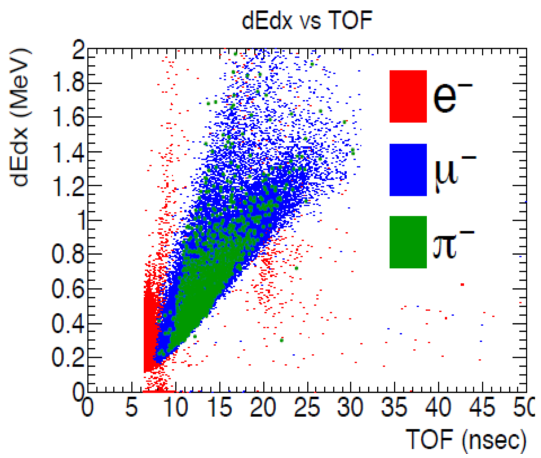


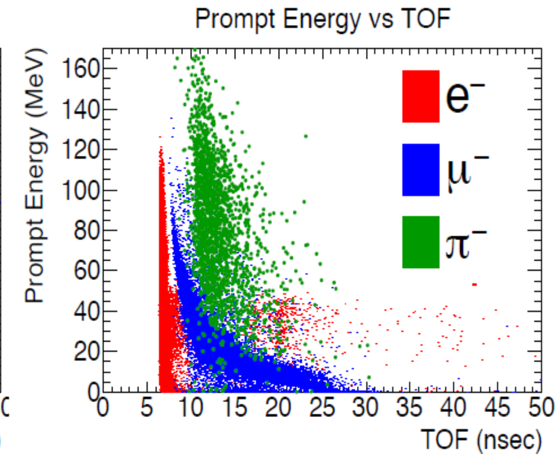
Baseline Detector Layout

	Phase-α	Phase-1
Energy (GeV)	8	
Beam Power (kW)	0.26	3.2
Spill Cycle (sec)	9.2	2.48
Extraction Period (sec)	0.5	
# of Bunches / sec	7.6e+5	
# of Protons / Bunch	4.9e+6	1.6e+7
# of Protons / Spill	1.9e+12	6.2e+12

The proton beam characteristics such as the bunch length, extinction, time structure of 1.17 -1.75 μsec bunch-to-bunch are identical to COMET Phase-I.







Next steps and Prospects

- Large-scale MC production
- Exploration of different detector configurations
- Optimization of geometries, measurement schemes
- **Antiproton measurements**
- "Beam blocker" studies for Phase-I beam measurement programme.

Comparison of Phase-I and Phase-II parameters

Parameters	**Phase-I**	**Phase-II**
Beam power	3.2 kW (8 GeV)	56 kW (8 GeV)
Running time	150 - 200 days	1 year
Target materials	graphite	tungsten
#protons	3.2×10^{19}	6.8×10^{20}
#muon stops (N_μ)	1.5×10^{16}	1.1×10^{18}
Muon rate/s	5.8×10^{9}	1.0×10^{11}
#muon stops/proton	0.00052	0.00052
The detector acceptance ($A_{\mu\text{-}e}$)	0.06	0.04
S.E.S (single event sensitivity)	2.0×10^{-15}	2.6×10^{-17}
Measurement start	2024-2026	2027-2029

Physics programs

Other searches In contrast to COMET Phase-II, the CyDet detector surrounds the muon stopping target directly in Phase-I, and can observe both positive and negative particles from the muon stopping target. This allows for a search for the lepton-number-violating process

$$\mu^- N \rightarrow e^+ N', \quad (\mu^- - e^+ \quad \text{conversion}), \quad \Delta L = 2$$

concurrently with the $\mu^- N \rightarrow e^- N$ search.The anticipated experimental sensitivity for $\mu^- - e^+$ conversion could be similar to $\mu^- N \rightarrow e^- N$ conversion, although a detailed estimation has not yet been performed.

In addition, the Cylindrical Drift Chamber will have a relatively large geometrical coverage, and thereby a coincidence measurement with a large solid angle is achievable. This allows a search for

$$\mu^- + e^- \rightarrow e^- + e^- \quad \text{conversion}$$

in a muonic atom, which is an as-yet unmeasured process.

Bound $\mu^- + e^- \rightarrow e^- + \alpha$ decay