The COherent Muon to Electron Transition (COMET) experiment

Project extension for the period 2022-2024

Experiment COMET at the J-PARC

<u>JINR COMET team</u>

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The JINR COMET team leader: Z. Tsamalaidze

On the 52nd PAC meeting for Particle Physics, 03.02.2020, COMET, MU2E and MEG II projects were considered

Recommendation: The PAC proposes that efforts and resources be focused on one single experiment, thus providing better conditions for the JINR team to achieve stronger impact, visibility and leadership in that experiment. The PAC also realizes the complexity associated with such a decision and thus recommends approval of the project with the three experiments for only one year. This should allow enough time for the proponents, in coordination with the DLNP Director and JINR management, to consider the PAC's proposal and to decide on their long-term involvement in this interesting physics project.

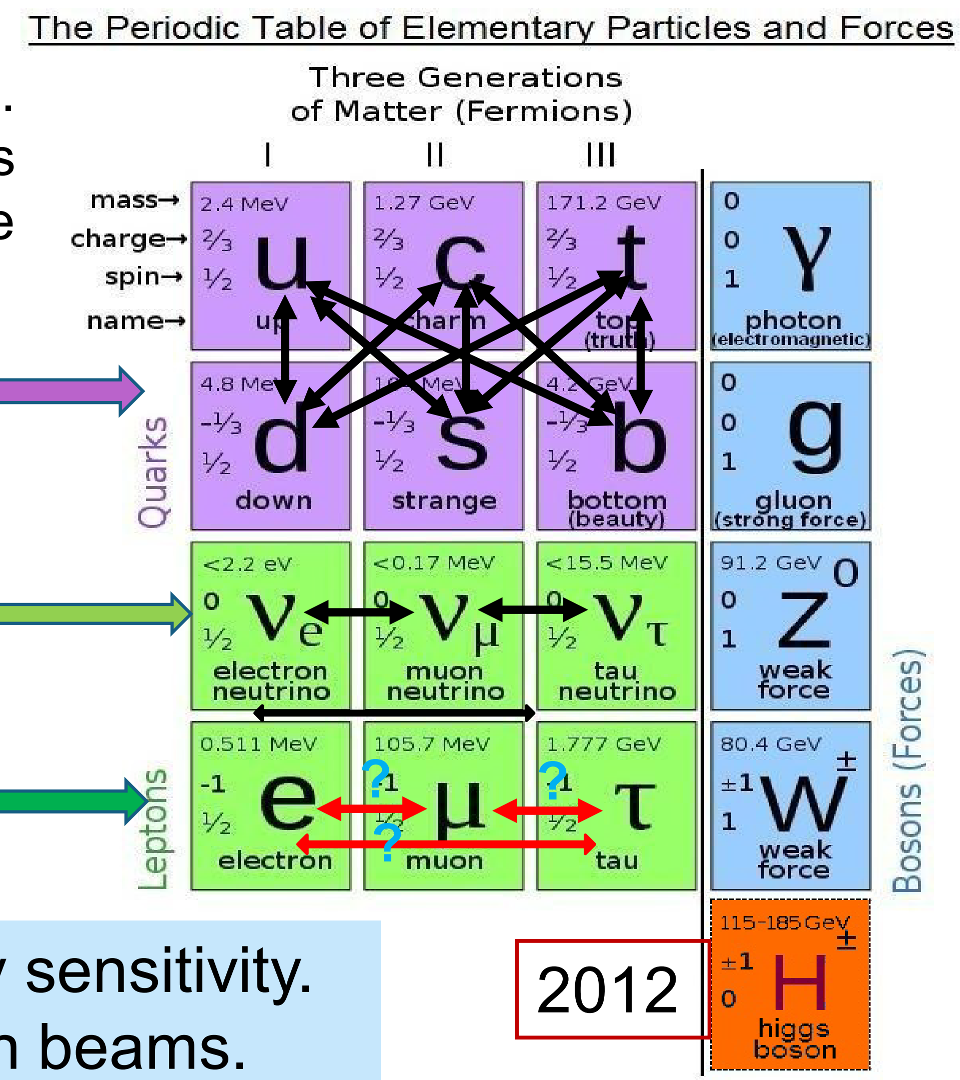
Charged Lepton Flavor Violation (CLFV)

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})**



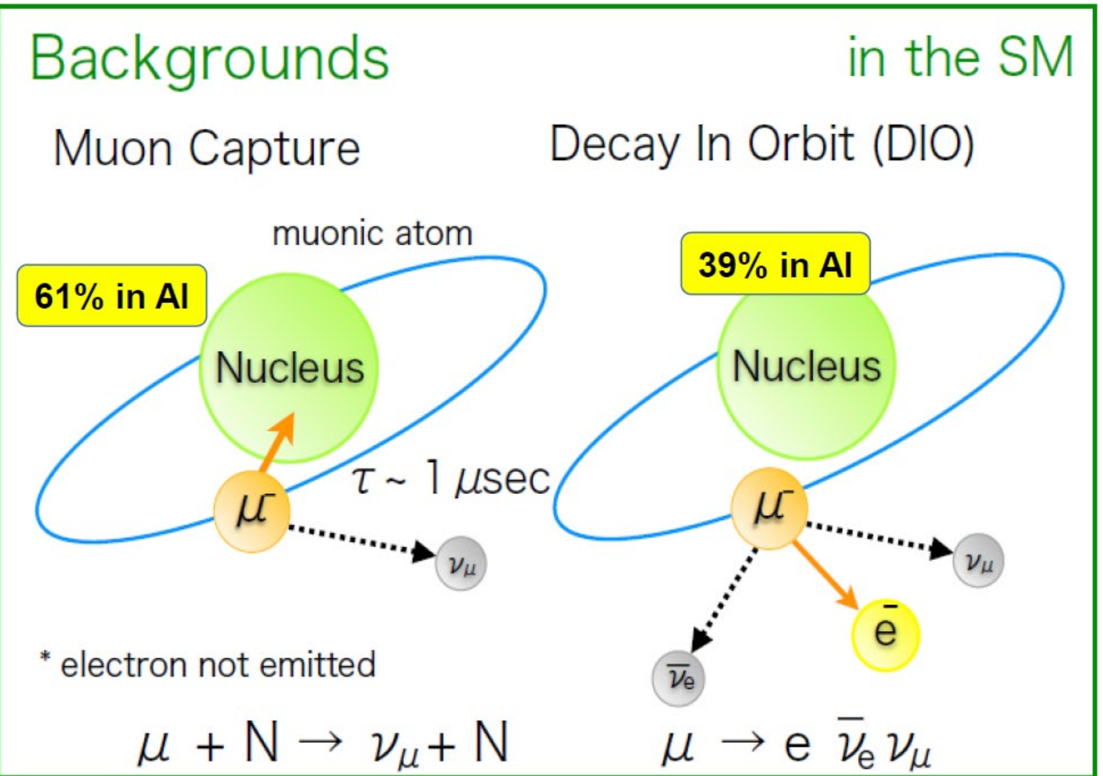
CLFV processes offer probes for **new physics** with discovery sensitivity.
The most sensitive probes of **CLFV** utilize high-intensity muon beams.

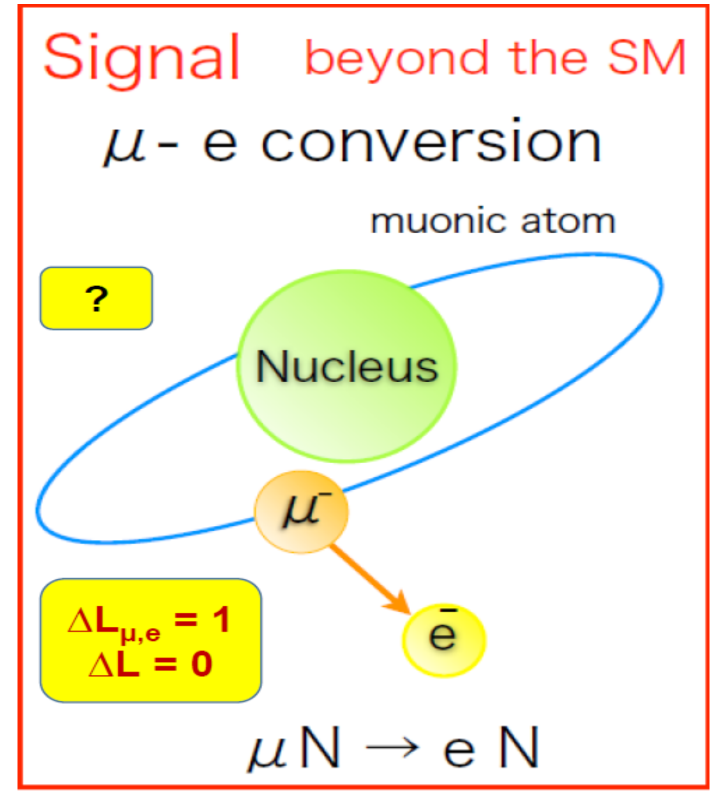
In 2001, the BNL found that muons seem to wobble slightly faster than the SM predicts. In 2021, Fermilab's Muon g-2 experiment has seen the same anomaly. The combined results from Fermilab and Brookhaven show a difference with theory at a significance of 4.2 sigma. The chance that the results are a statistical fluctuation is about 1 in 40,000, a sign that **extra particles and forces could be affecting the muon's behavior**. The results aren't yet a "discovery", until the results achieve a statistical certainty of five sigma, reaching could take a couple of years, 2023
The new Fermilab's results provide the biggest clue in decades that physical particles or properties exist BSM—but any theory tries to explain Muon g-2's results, should also take into account the absence of new particle detected on the LHC.
The Fermilab's results comes after CERN's LHCb experiment **announced new findings hinting at a violation of the SM—found independent evidence of misbehaving muons in B mesons decays**. LHCb has found evidence that these muon decays occur less often than predicted (by SM), with odds of a fluke in the experiment at roughly one in a thousand.

Muon g-2 and LHCb needs more data before claiming a new discovery. But even now, the combination of the two results has physicists think about the strange behavior of muons.

Muon-to-Electron conversion mechanism

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





New Physics Process

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

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

Experimental Signal:

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

The COMET collaboration

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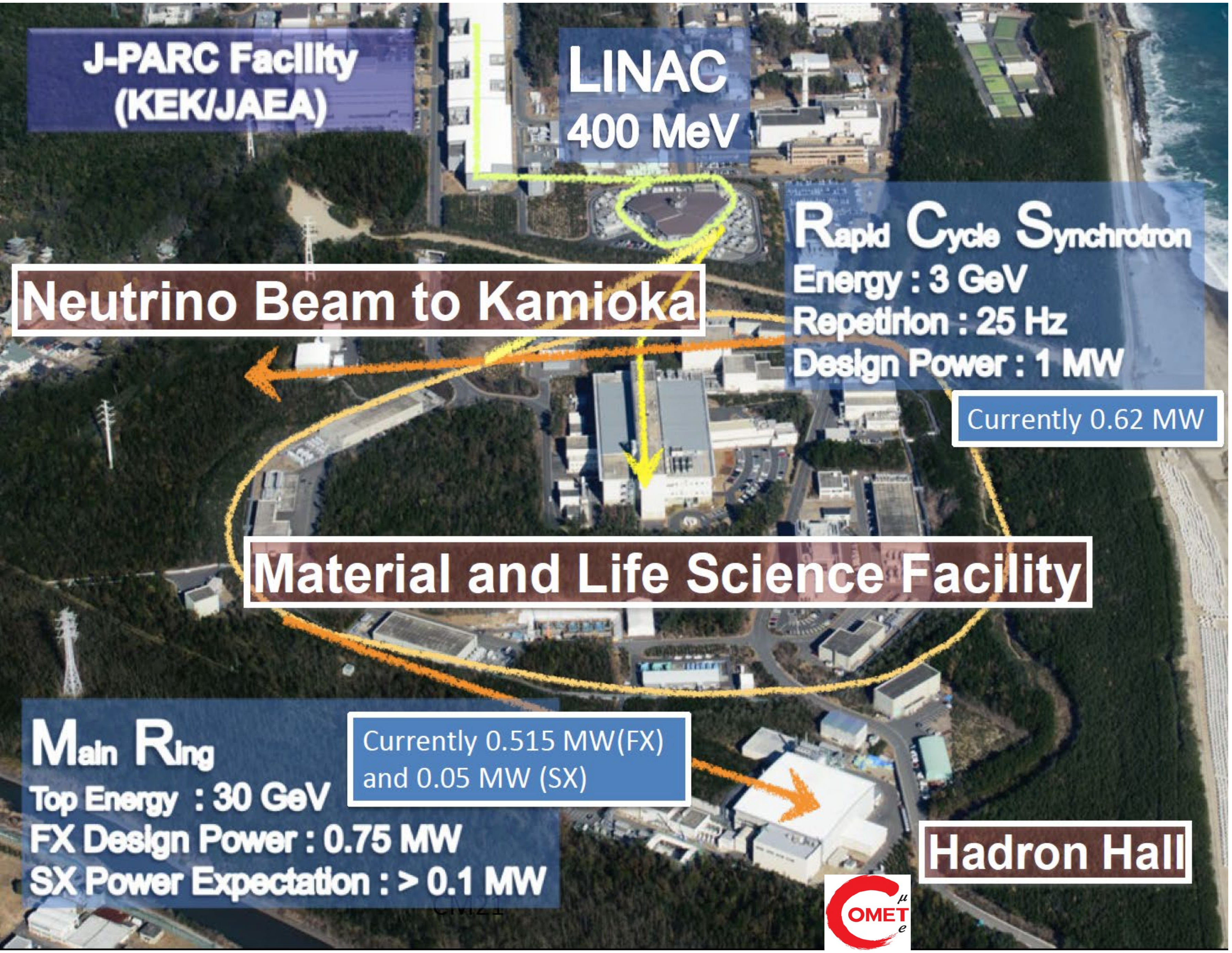
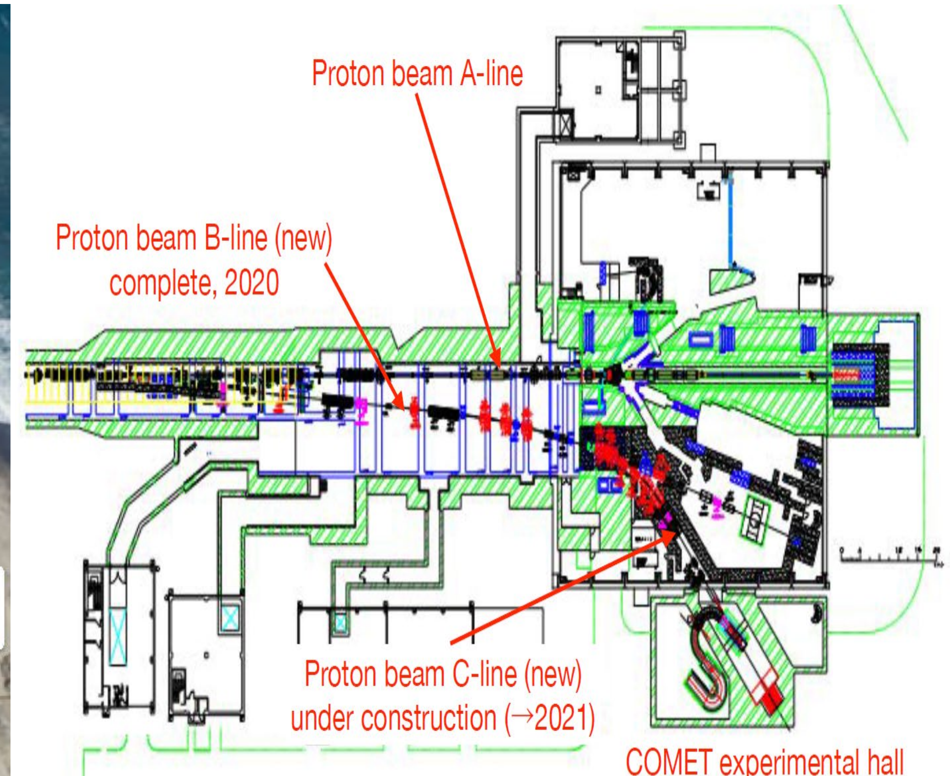
Still growing!

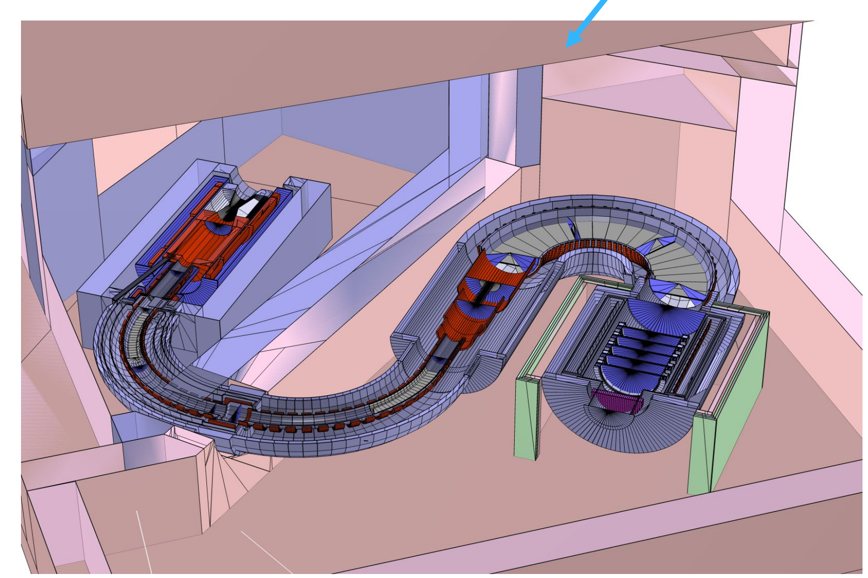
43 institutes, 17 countries

Including six JINR member states countries
Belarus, Czech Republic, Georgia, Kazakhstan, Russia, Vietnam

COMET at J-PARC

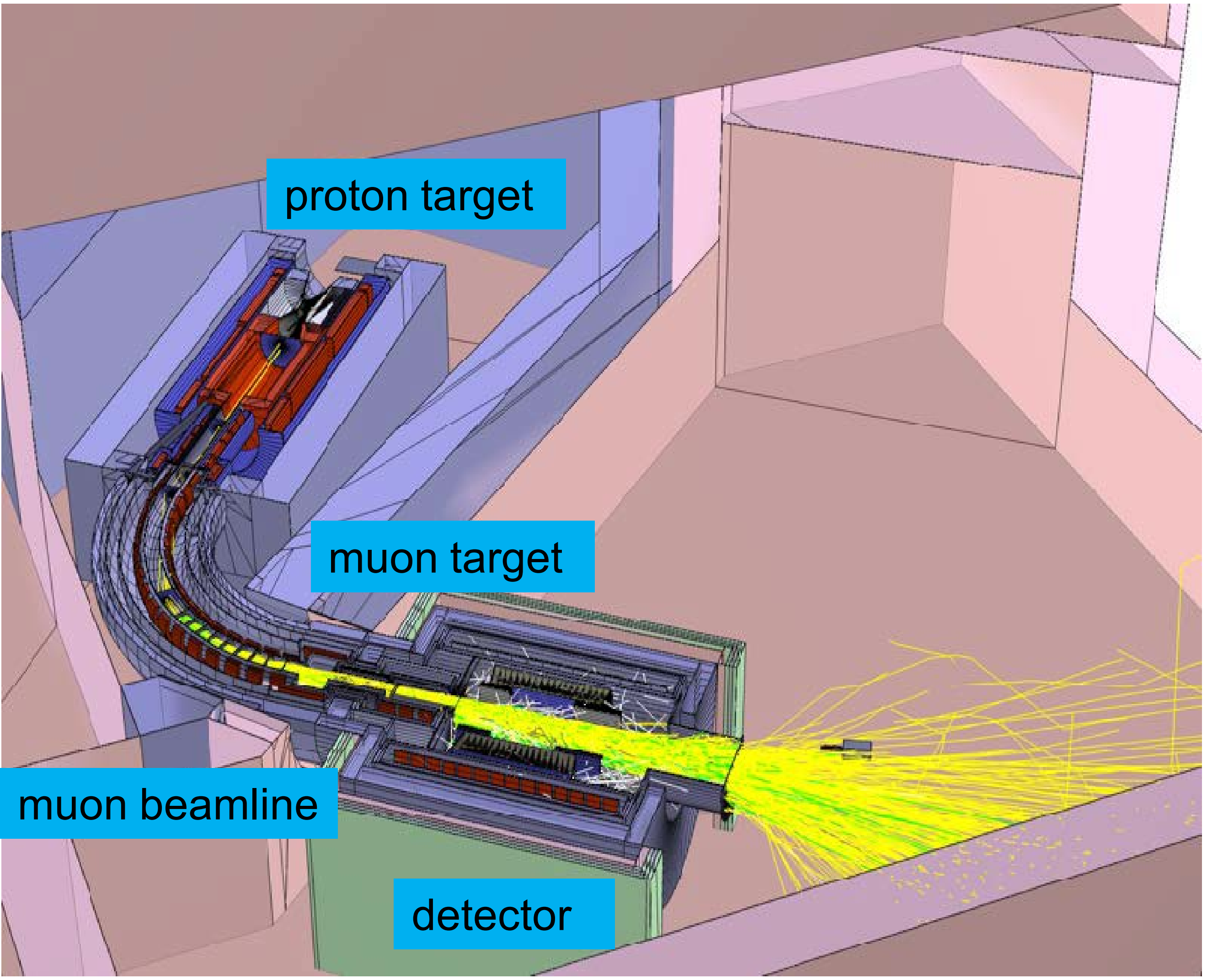






Two-phase realization

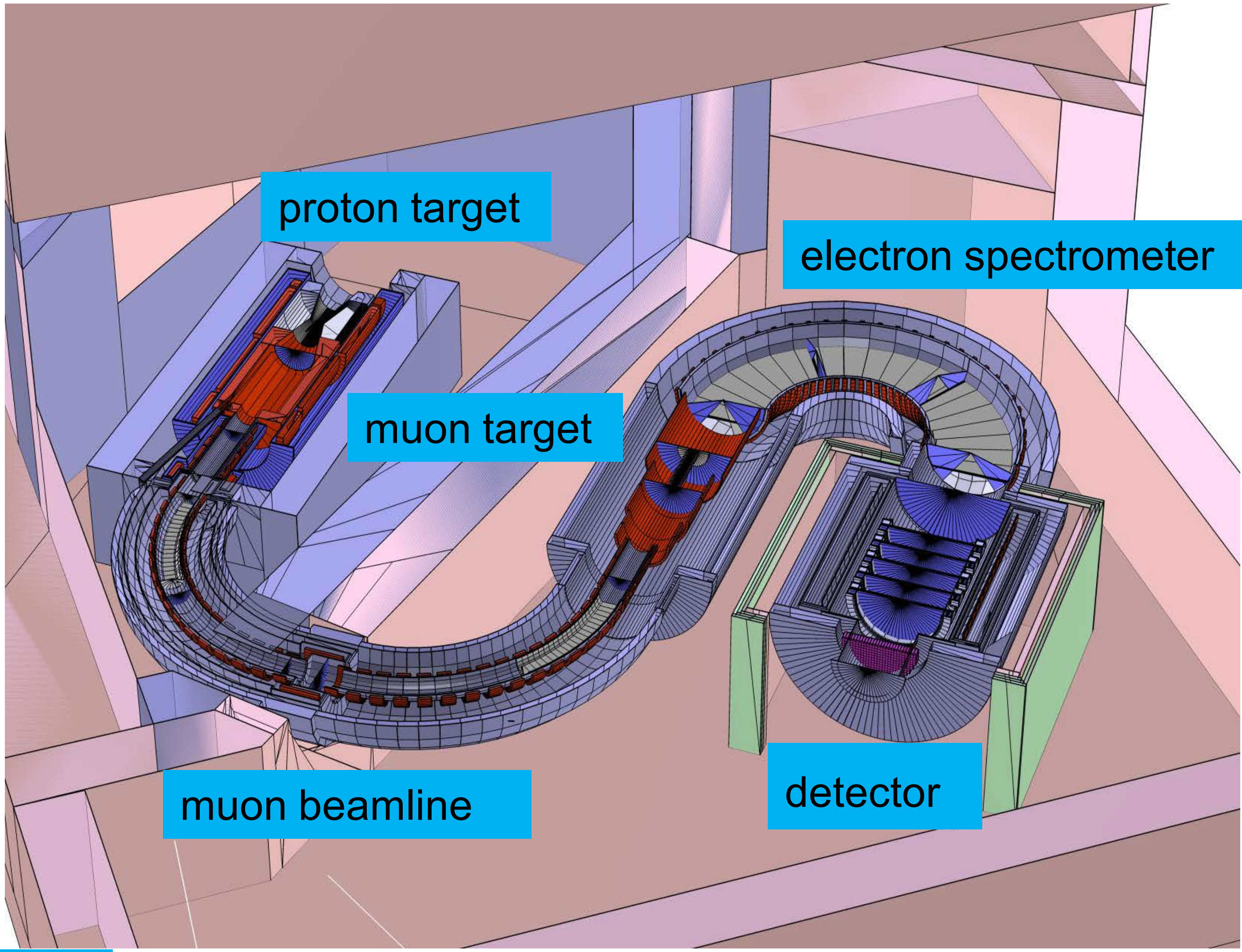
COMET Phase-I, 2023



- Proton beam, 8 GeV, 3.2kW
- Graphite proton-target, length – 600 mm, radius 20 mm
- 17 aluminium disks, radius -100 mm, thickness - 200 μm, spacing 50 mm
- 1.2 x 10^9 stopped muons/sec

Single Event sensitivity: 3.1 x 10^{-15}
Expected limits: <7 x 10^{-15} @90%CL
Total background: 0.032 events
Running time: 0.4 years (1.2 x 10^7 sec)

COMET Phase-II, 2026-2027



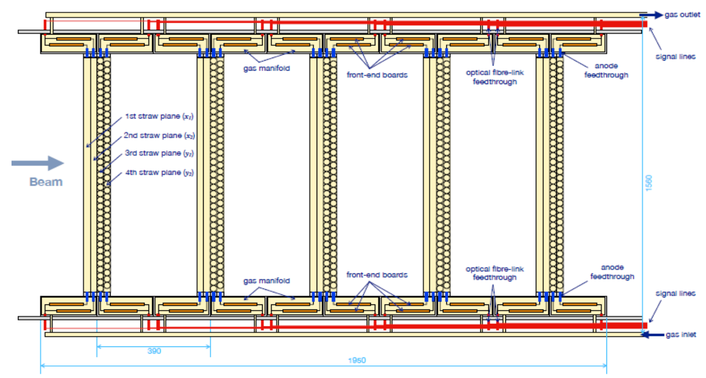
Proton beam, 8 GeV, 56kW
Tungsten proton-target
2 x 10^{11} stopped muons/sec

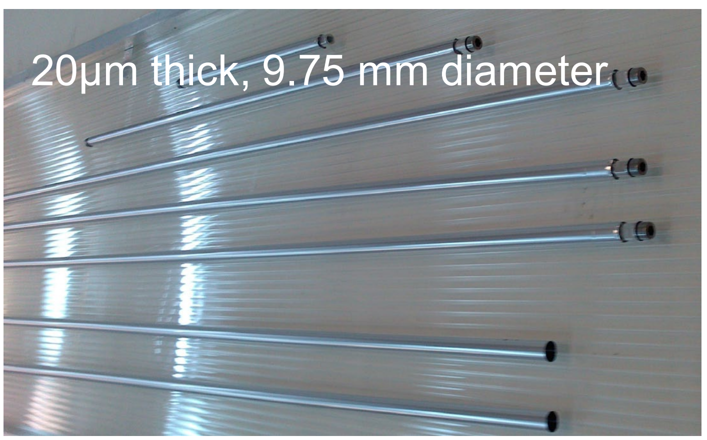
Single Event sensitivity: 2.7 x 10^{-17}
Expected limits: <7 x 10^{-17} @90%CL
Total background: 0.34 events
Running time: 1 years (2 x 10^7 sec)

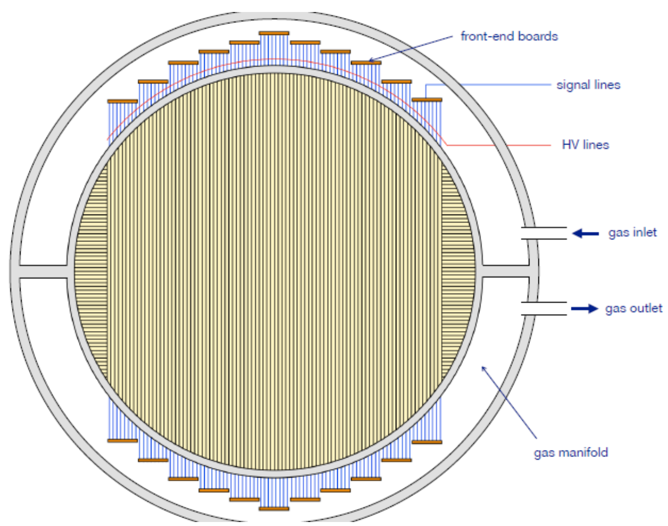
COMET Detector System and Requirements

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



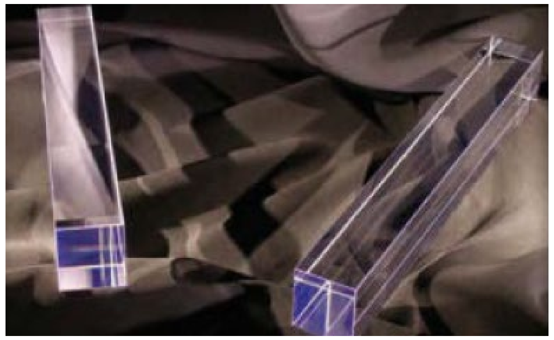


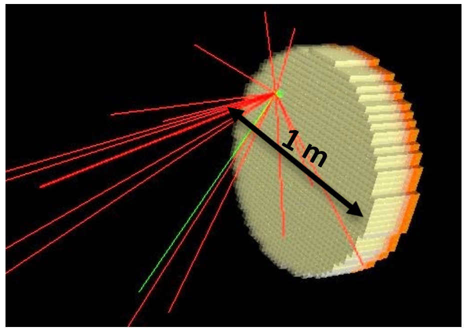


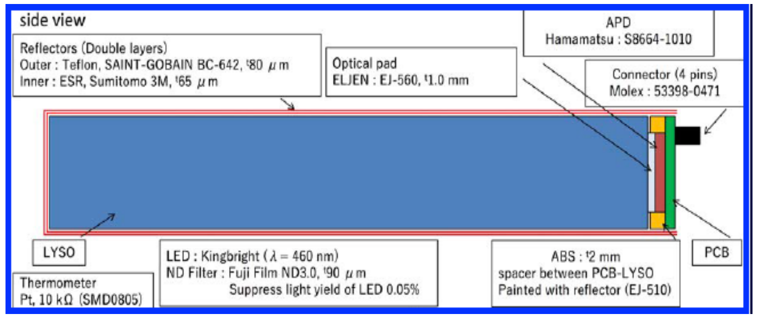
Electromagnetic calorimeter

ECAL (crystal type LYSO, $Lu_{1.8}Y_{2}SiO_{5}Ce$)
- Combination of around 600 (for Phase II 2272) LYSO crystals for Phase-I
- Total size: diameter ~ 1m
- Crystal size 20x20x120 mm^3 (11 radiation length)
- Photon detector: APD

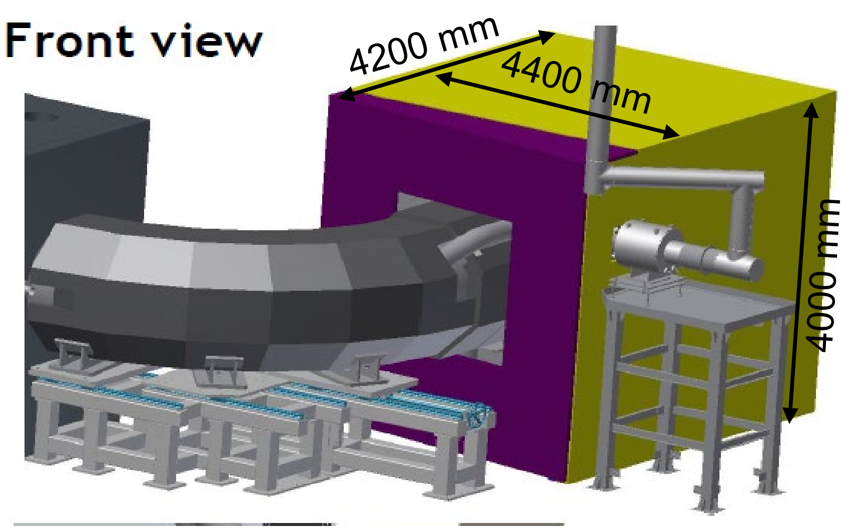
Requirements:
- < 5% ER at 105 MeV
- <10 mm space resolution
- < 100 ns time resolution
- Work in vacuum and magnetic field of 1 Tesla







Cosmic Ray Veto (CRV)

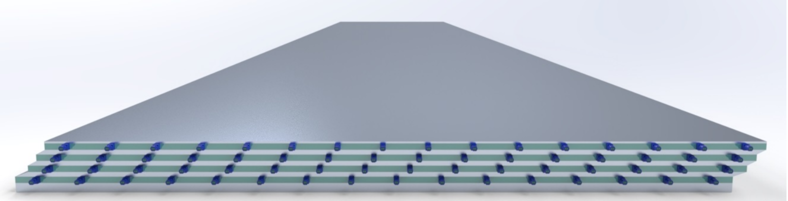


Also used passive CRV, concrete and lead.

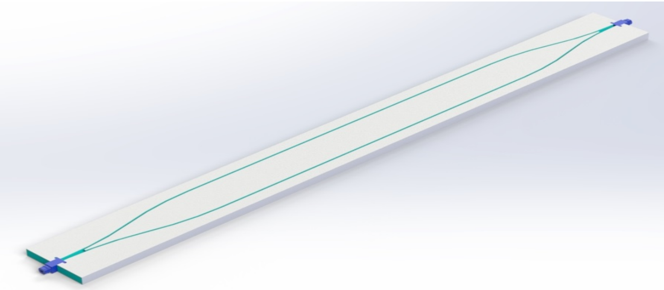
Requirement: Efficiency ≥ 99.99%.

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 cm^3, 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).



CRV module's front view

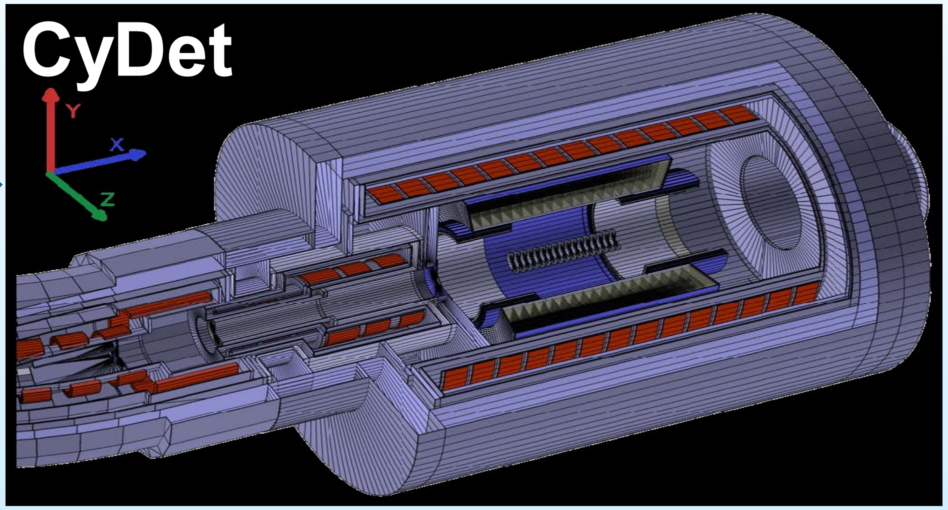


Design of the strips with 2 WLS fiber

Phase-I

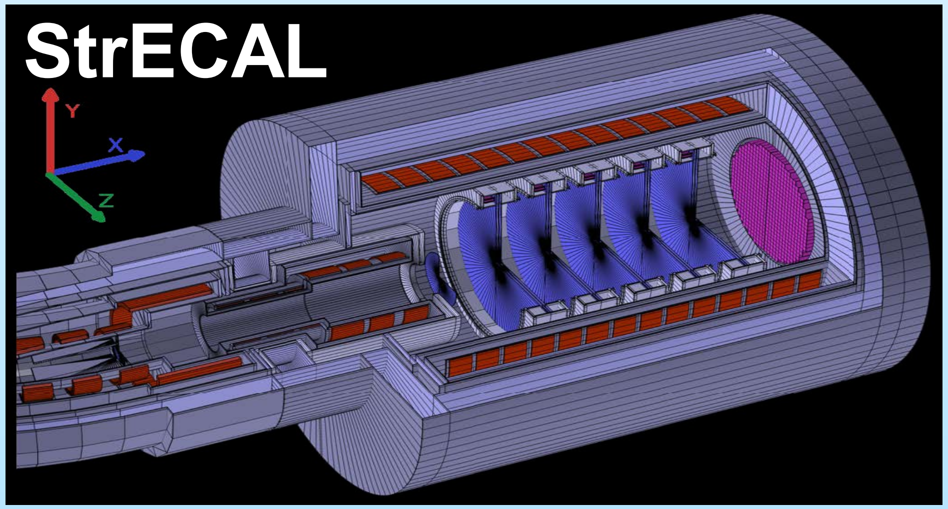
1 Search for μ-e conversion

- A search for μ-e Conversion at the intermediate sensitivity with would be 100-times better than the present limit (SINDRUM-II) $3x10^{-15}$. 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 Phase-I serves several roles that are highly complementary to the Phase-II experiment. It provides a working experience of many of the components to be used in Phase-II and enables a direct measurement of backgrounds. Significantly it will also produce competitive physics results for the μ−e conversion process.

COMET Phase-I Requirements and Detectors

How to reach unprecedentedly high sensitivity ($7.0 \times 10^{-13} \rightarrow 10^{-15,-17}$)

COMET Requirements:

1. Reduce Beam Associated Background

Pulsed proton beam with high proton extinction and used the long μ lifetime

2. Highly intense muon source, 10^{11} muons/sec (with 10^{7} sec running). The current highest intensity is $10^{8/sec}$

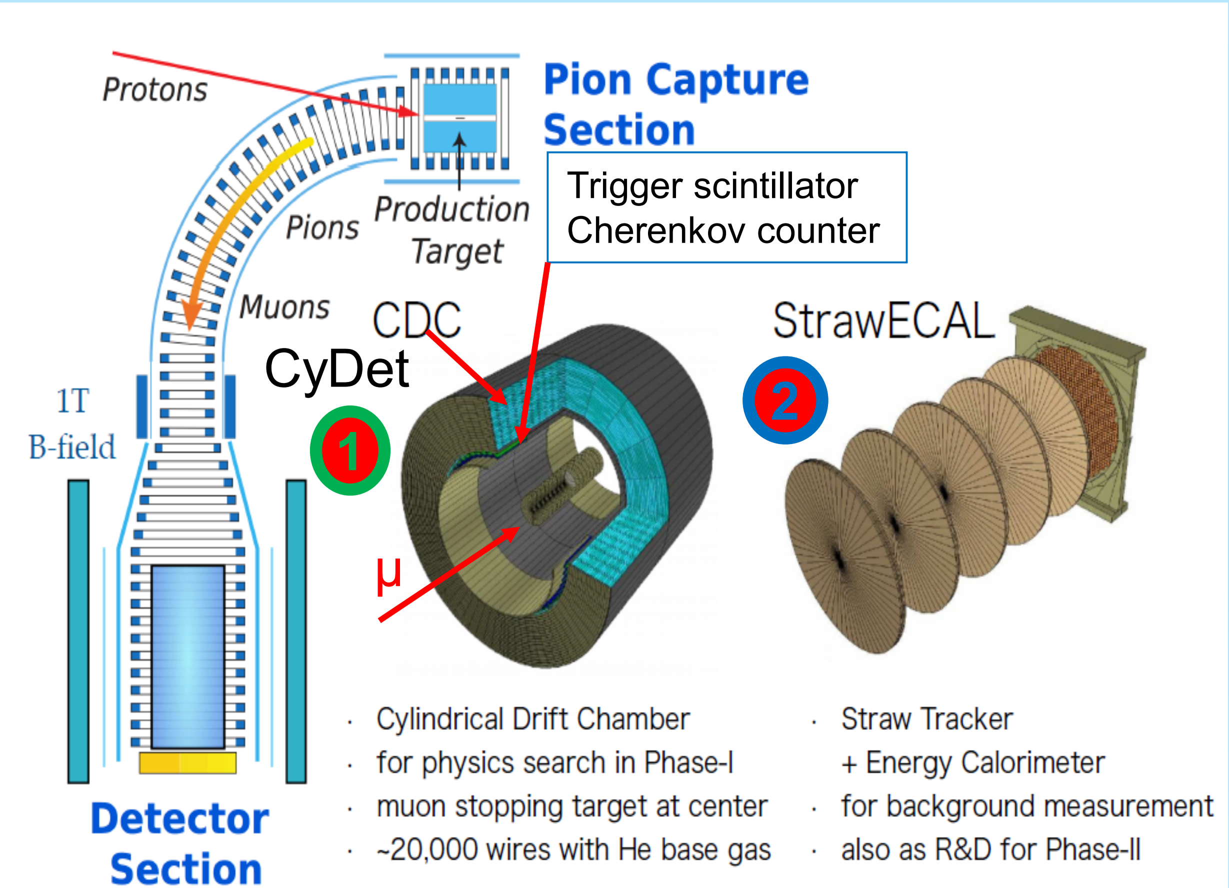
High Intensity Pion Production (μ from π decay)

Use magnetic solenoids to capture, transport, charge and momentum selection, detect μ

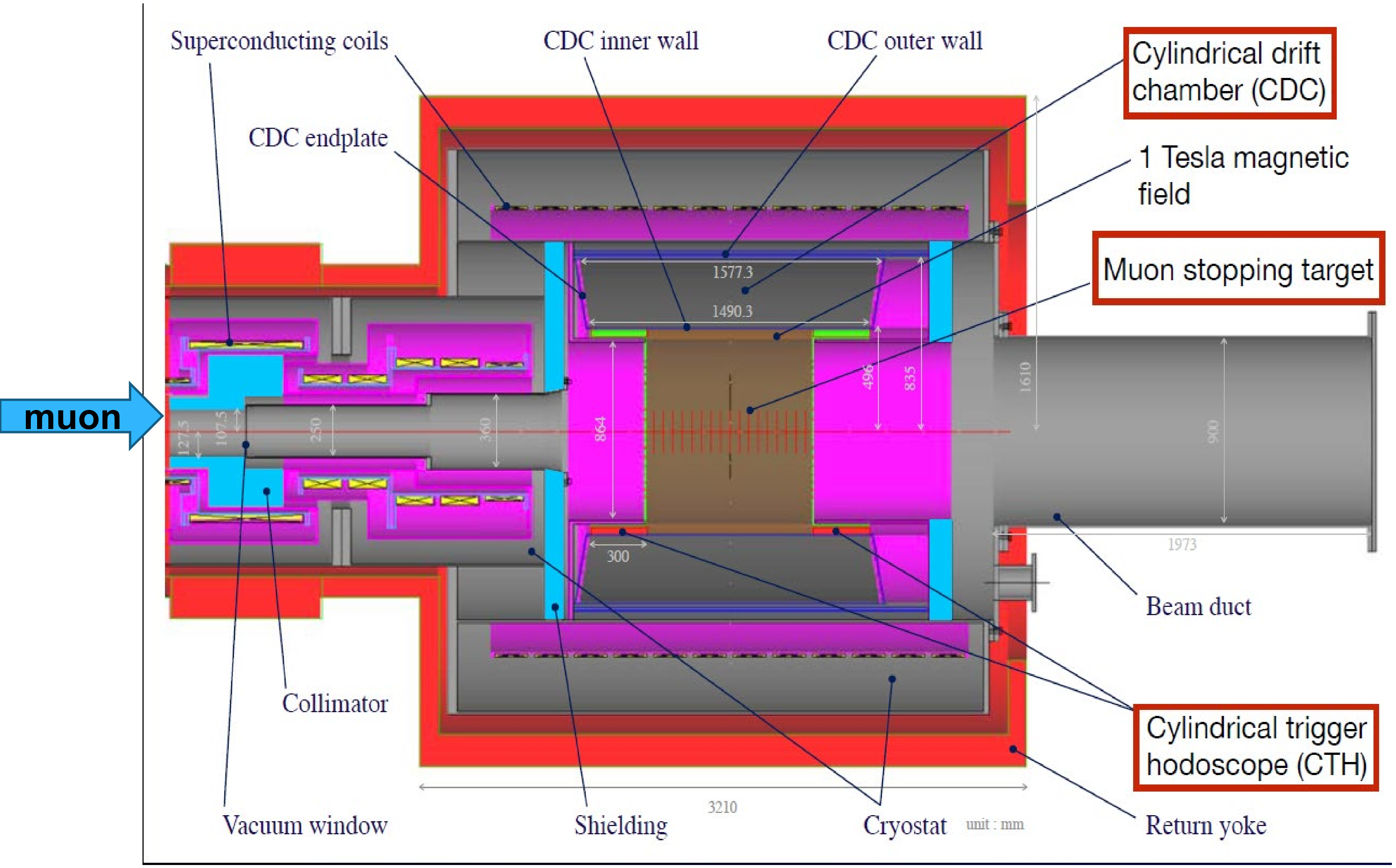
3. Curved solenoids for charge and momentum selection, Electron Energy Resolution and Timing

Excellent calorimeter and tracking detectors,

employ new electronic technology to handle higher rates.



CyDet (Cylindrical Detector)



- 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

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

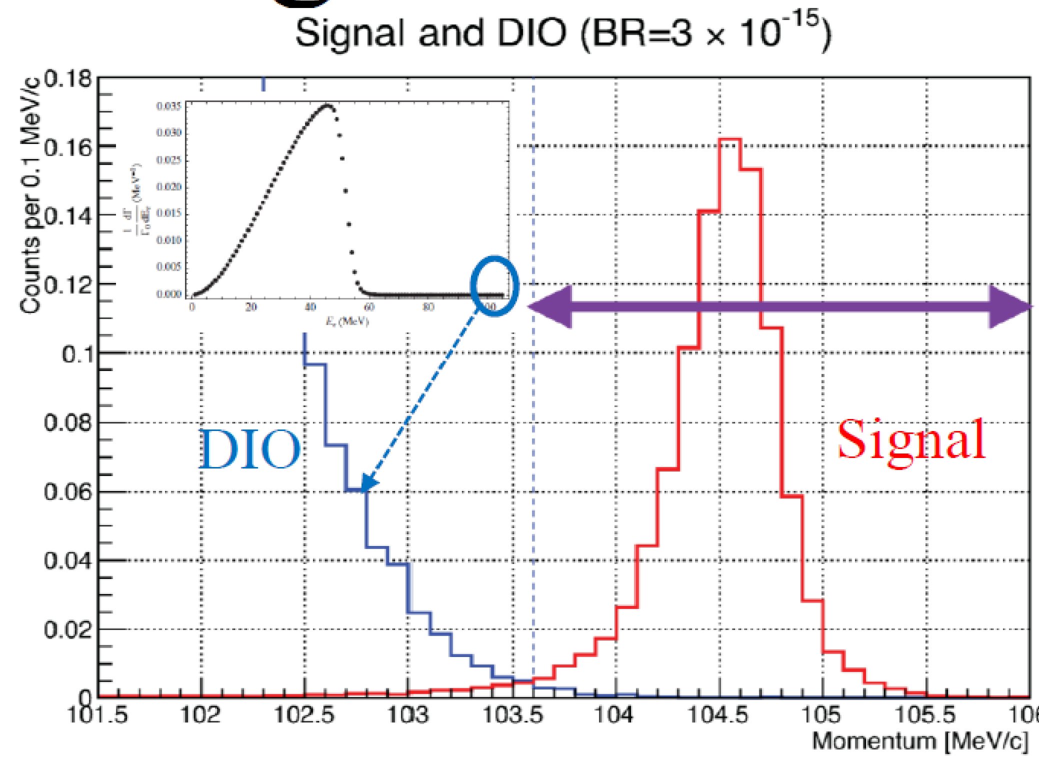
To control the background

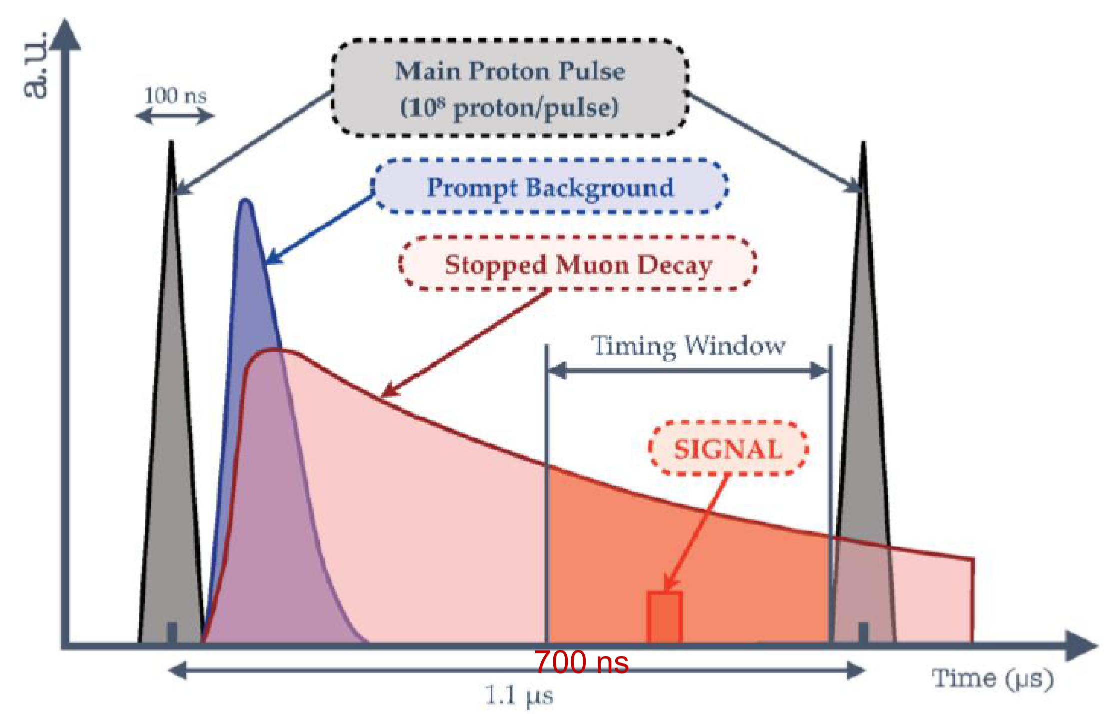
- Intrinsic physics background
  - Mostly from muon decay in orbit (DIO)
    - Calculated by Czarnecki with radiative correction. Branching ratio drops with order-5 function near end point.
    - Momentum resolution required to be better than 200 keV/c
- Beam related background
  - Energetic particles 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 x 10^{-15} in COMET Phase – I with a proton extinction factor 3 x 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

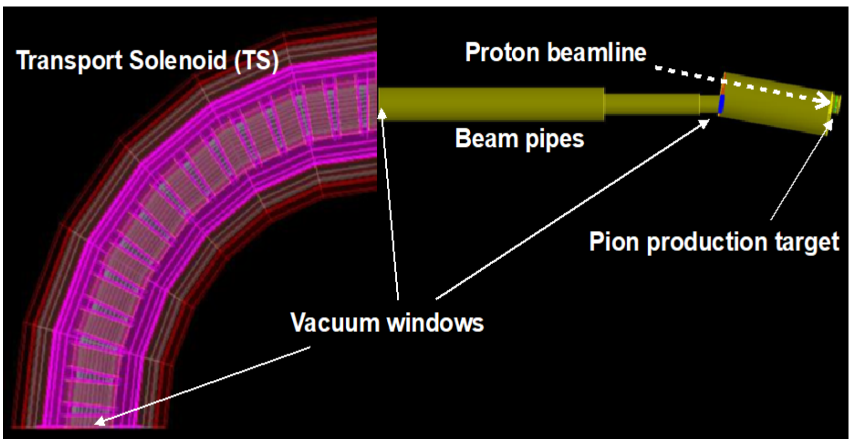
3×10^{-15} (as SES) achievable in ~ 150 days, or $< 7 \times 10^{-15}$ (as 90% C. L/ upper limit)

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)

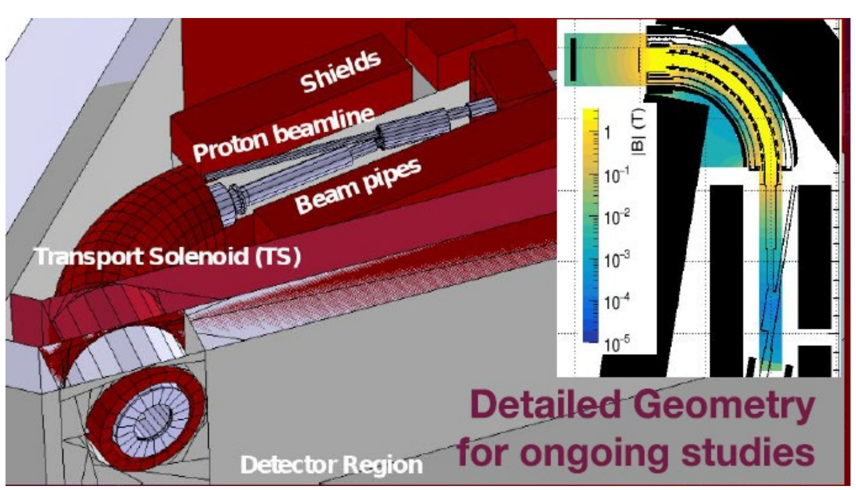
1. Secondary beam yield measurement with simplified geometry & magnetic field at both TS ends

- 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



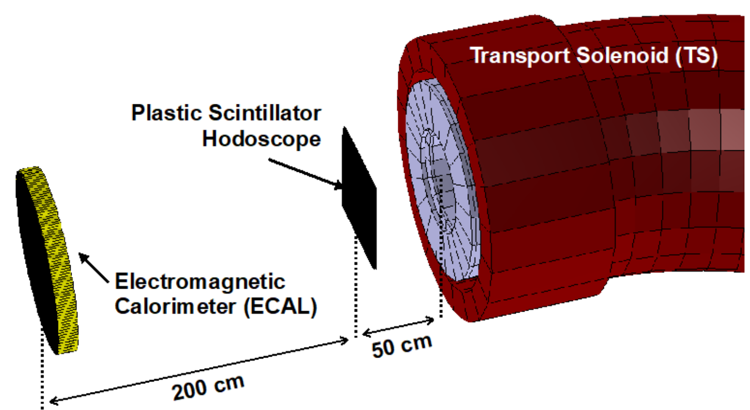
Particle	TS entrance	TS exit
e^-	8.3×10^{-8}	4.6×10^{-8}
e^+	3.2×10^{-8}	3.3×10^{-8}
μ^-	2.0×10^{-8}	6.9×10^{-9}
μ^+	2.8×10^{-8}	1.1×10^{-8}
π^-	5.2×10^{-8}	1.7×10^{-9}
π^+	7.3×10^{-8}	2.8×10^{-9}
p	1.6×10^{-7}	4.0×10^{-10}

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



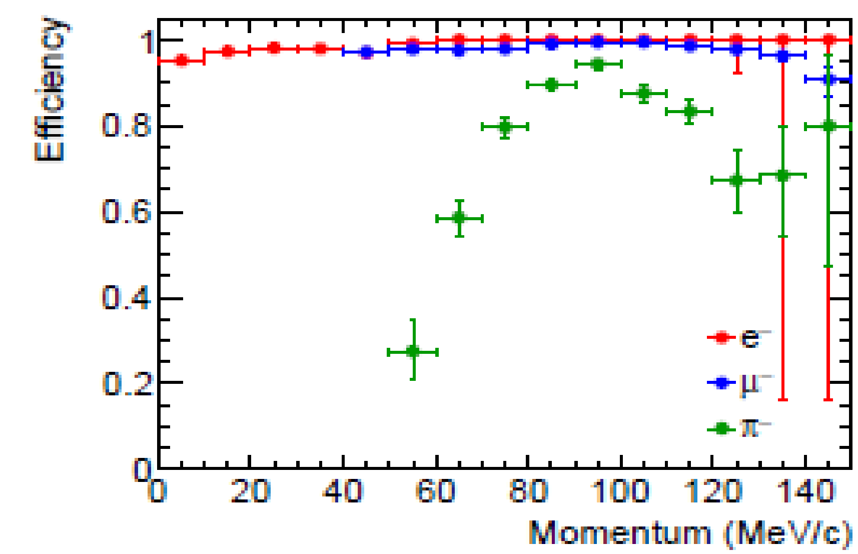
Baseline Detector Layout

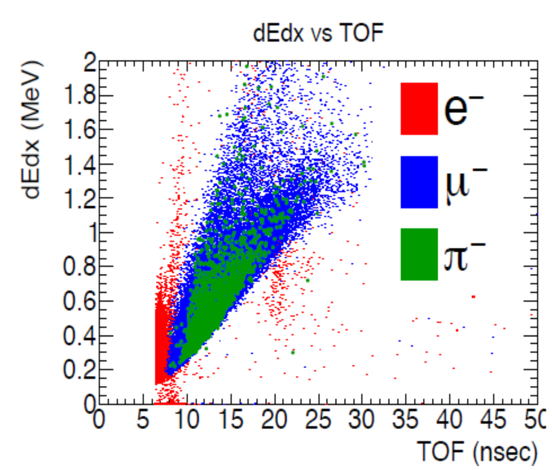
Next steps and Prospects

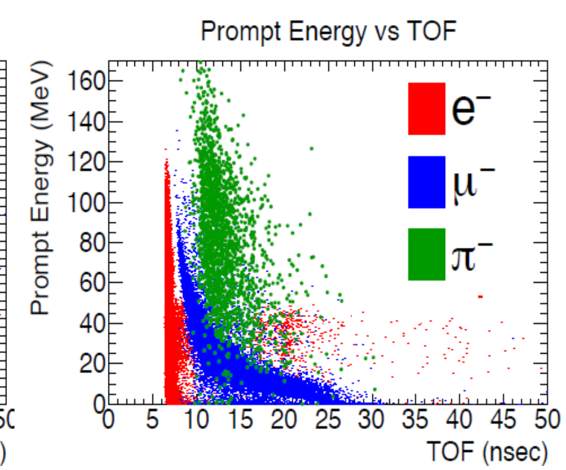
- Large-scale MC production
- Exploration of different detector configurations
- Optimization of geometries, measurement schemes
- Antiproton measurements
- "Beam blocker" studies for Phase-I beam measurement programme.

	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.







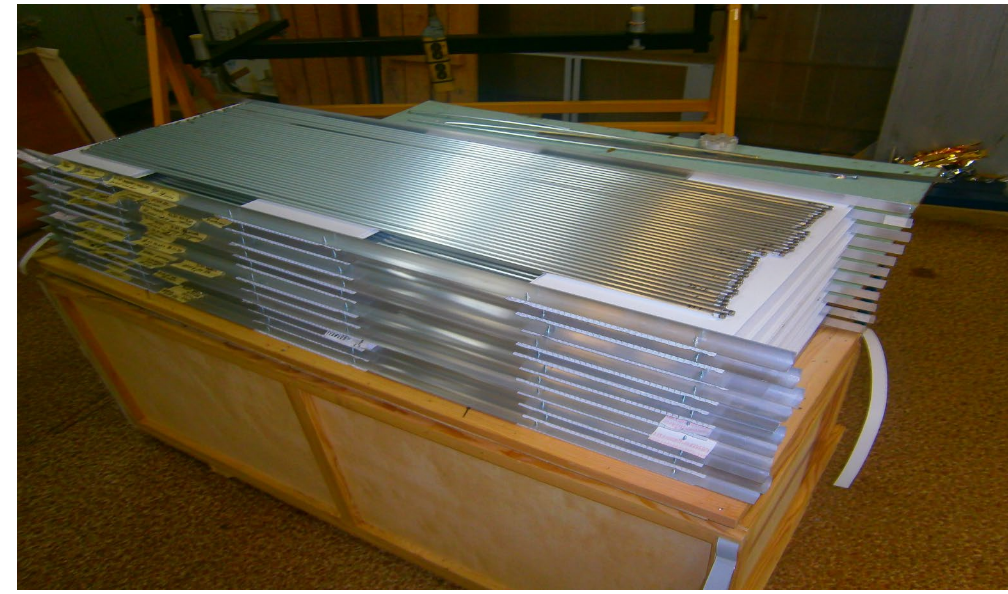
JINR activities and responsibilities

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

Straw tubes production and the study of the properties for Phase-I

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

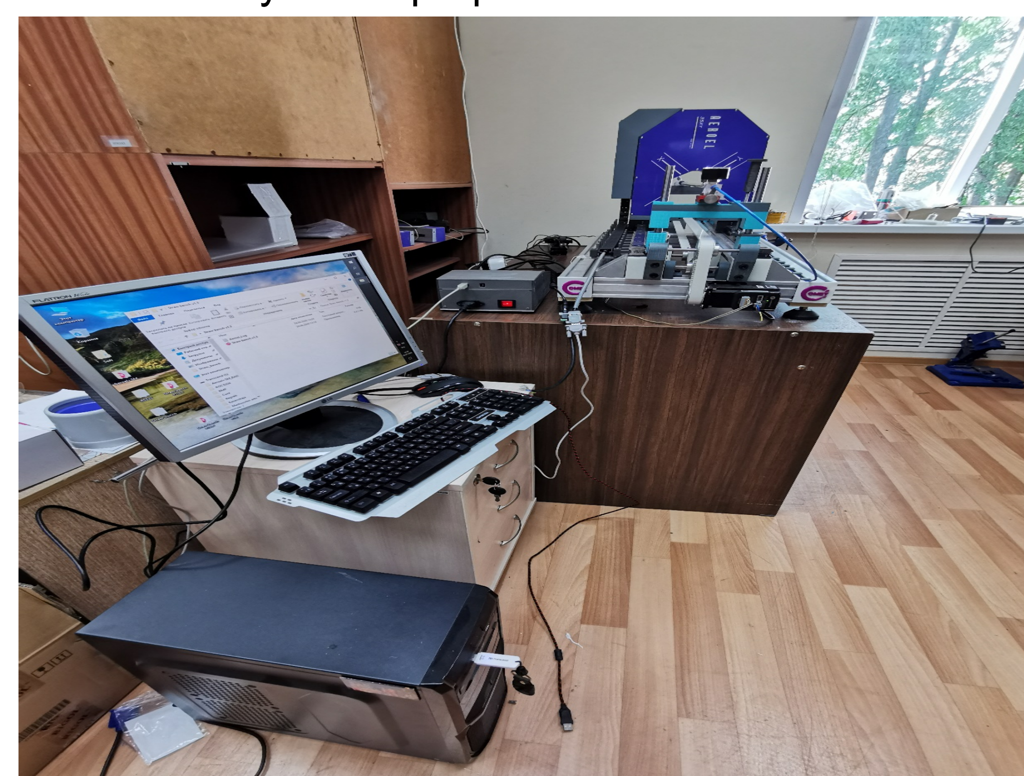
- 2700 tubes of 20 μ wall thickness, Ø 9.8 mm 120 and 160 cm length have been produced
- These tubes passed all the tests and have been sent to Japan



The 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°C**
- The tubes aging
  - **Results: The service life of straw detector is 9 years.**

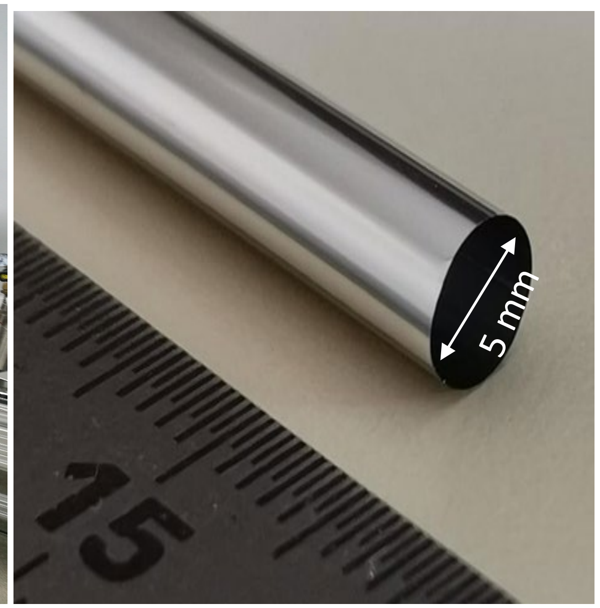
The study of the properties of straws

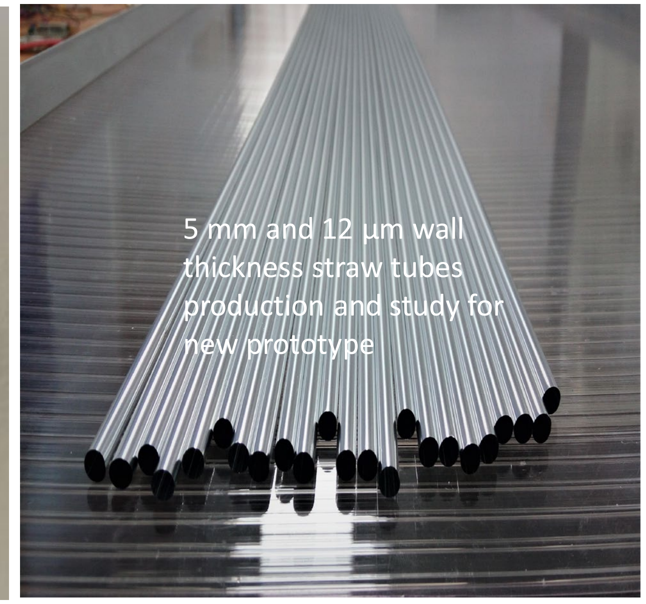


For Phase-II we need even thinner and less diameter tubes:
5 mm diameter and 12 μm wall thickness.
For this purpose we prepared a new straw production line in our laboratory.

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

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



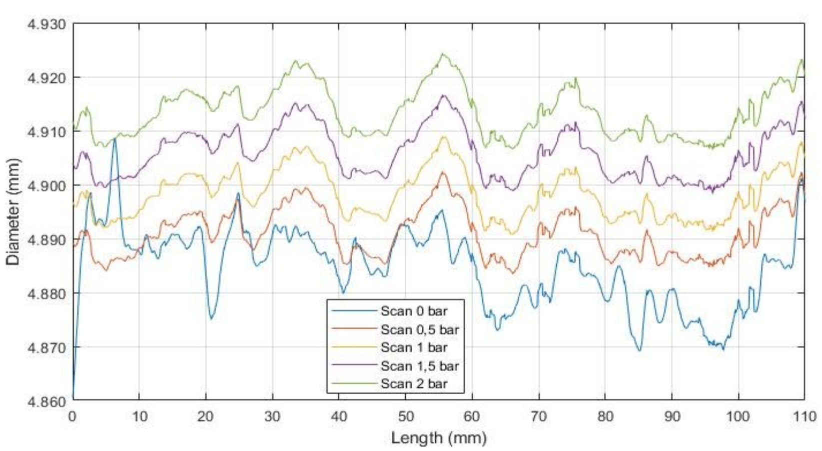


Produced straw parameters for prototype

- 100 pieces
- 70 cm in Length
- 5 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

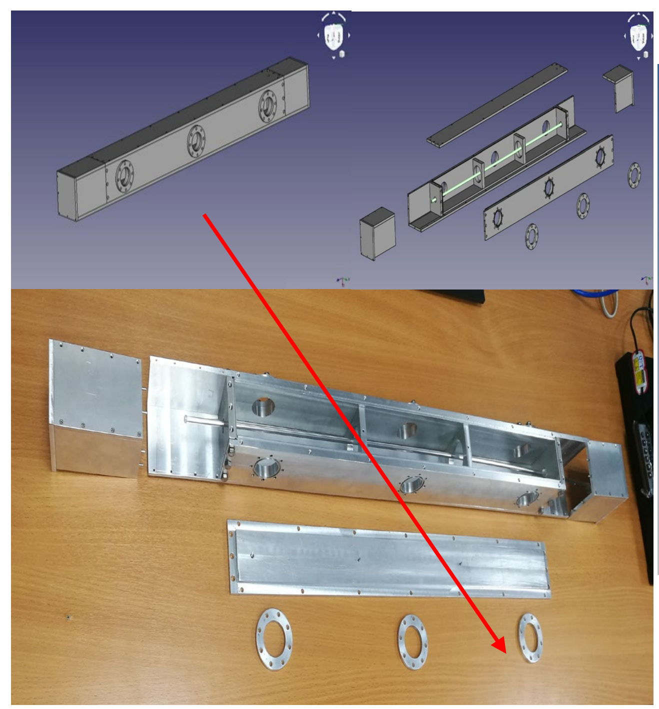
Cabability of the new straw tubes production facility

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



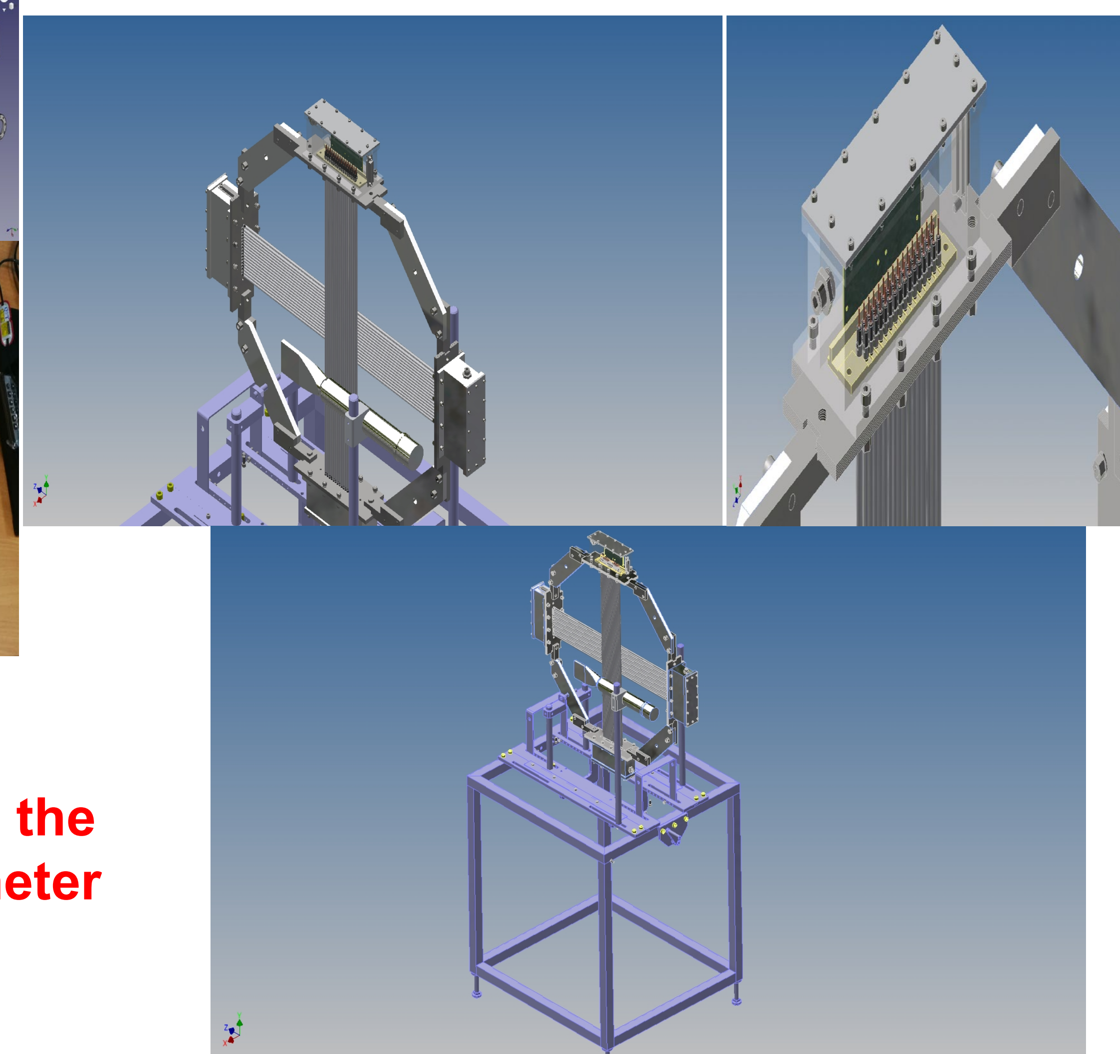
- Diameter scan along straw tube length with different inner pressures
- Diameter deviation along the tubes is less than 20 μm,
- Shape stays consistent under different pressures

Single channel prototype



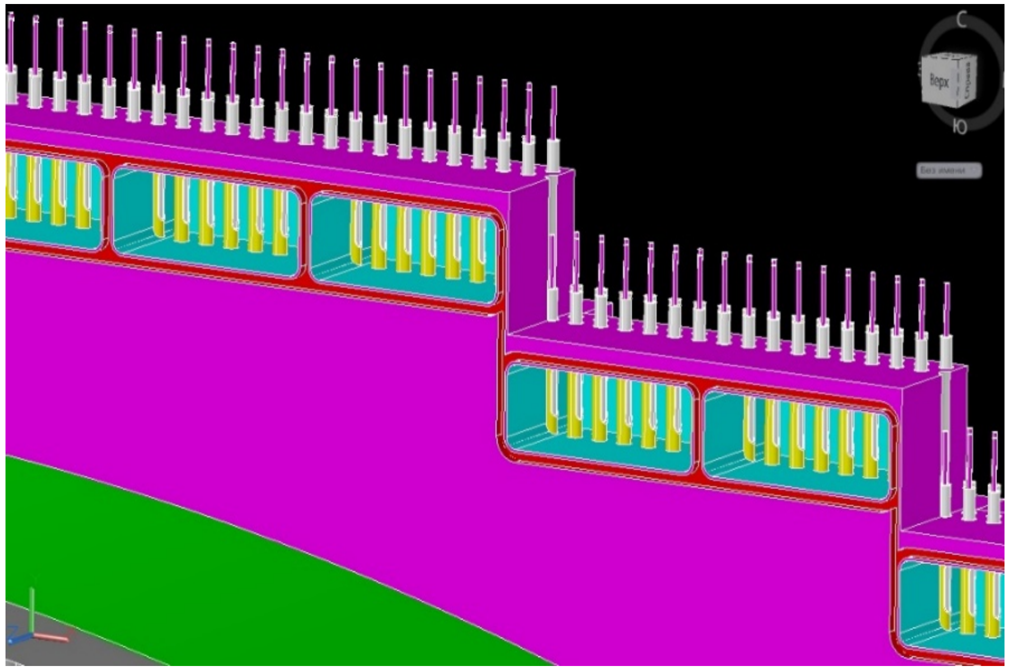
Great success in R&D, in the production of 5 mm diameter and 12 μm thick tubes

64 channel prototype

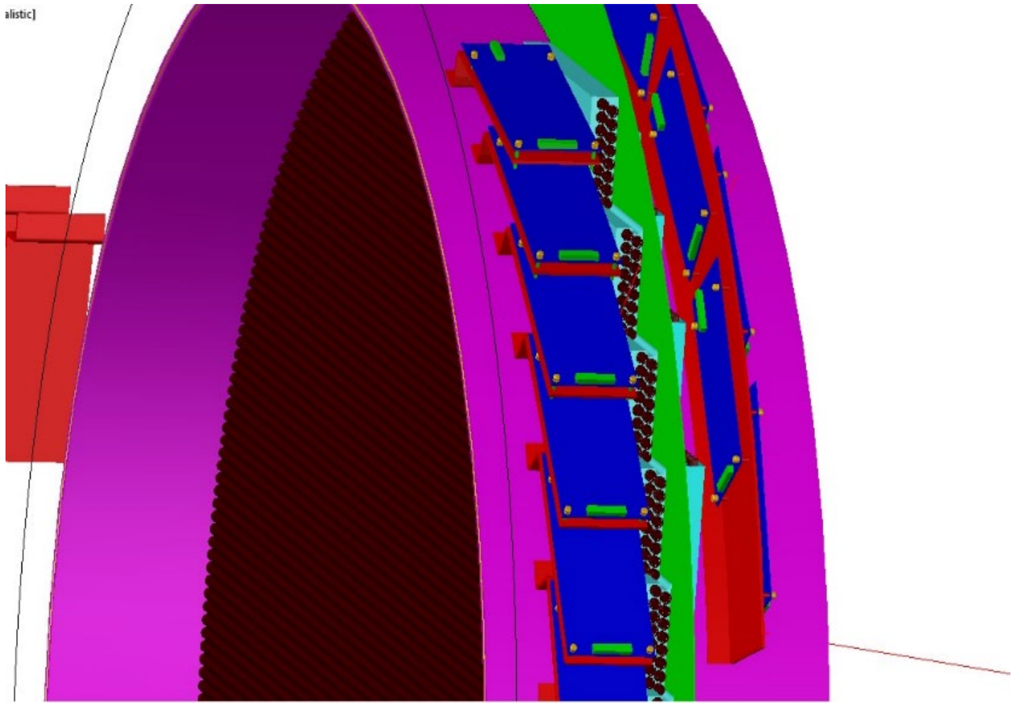


Straw module design

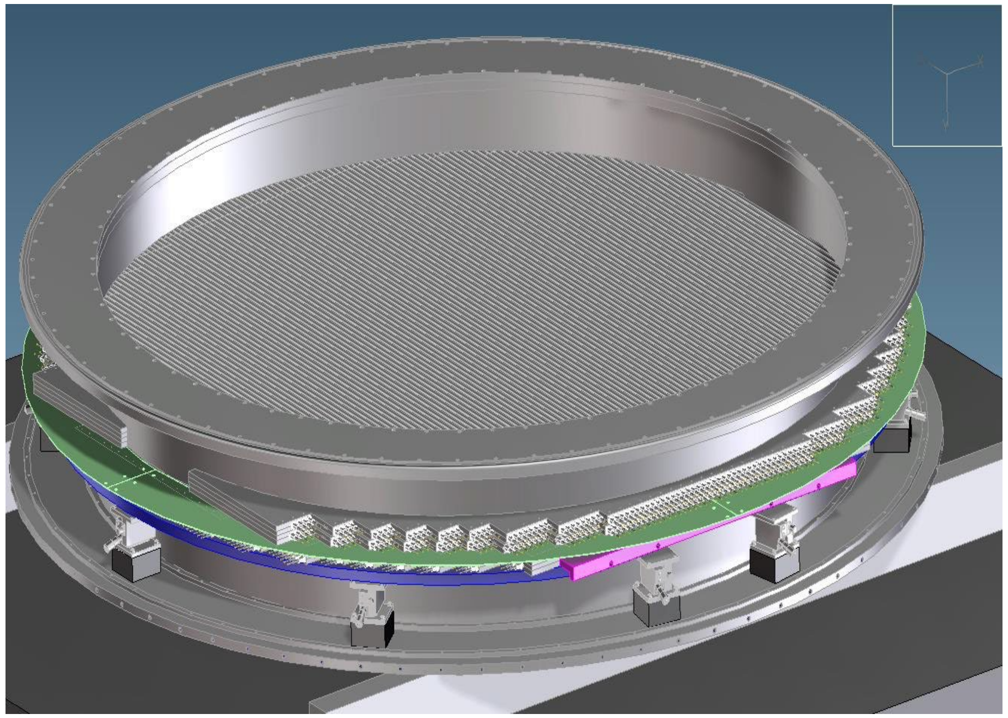
Taking into account the success of JINR, DLNP COMET group in R&D and production of thin-wall tubes with 5 mm diameters , 12 μm wall thickness , and development of straw station design, **the COMET CB supported the idea of JINR group to use an additional station with new tubes at Phase-1**



Design of support structure



Schematic view of the ROESTI boards



Design of a complete module

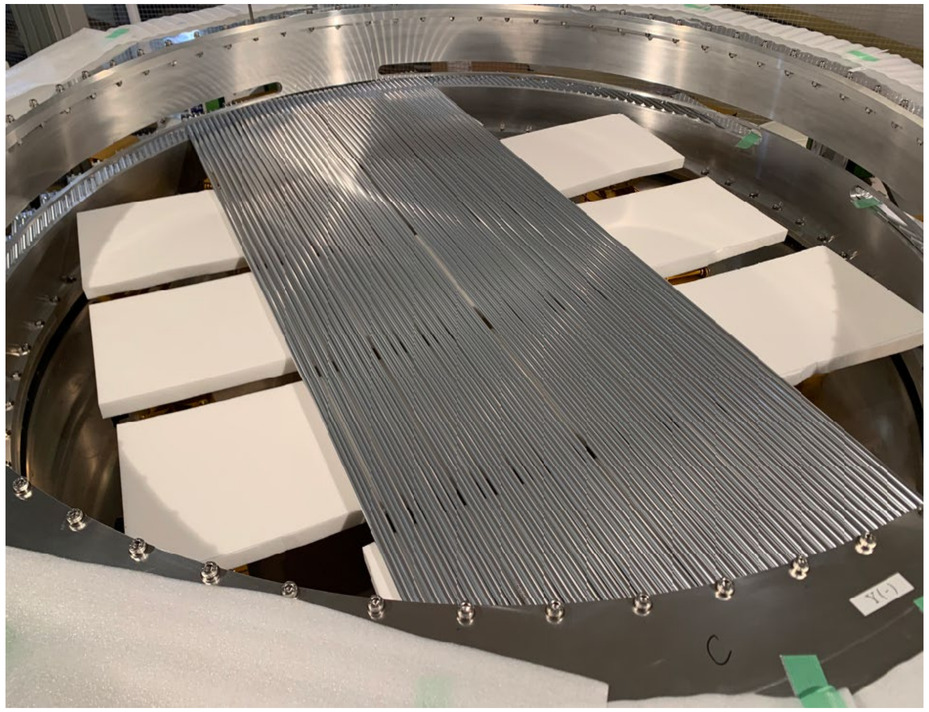
Module contains about 1000 straws with the diameter of 5mm (500 in horizontal direction + 500 in vertical direction) which in its turn means 60 ROESTI boards for both direction have to be allocated along the circular surface which are cooled down by cooling gas

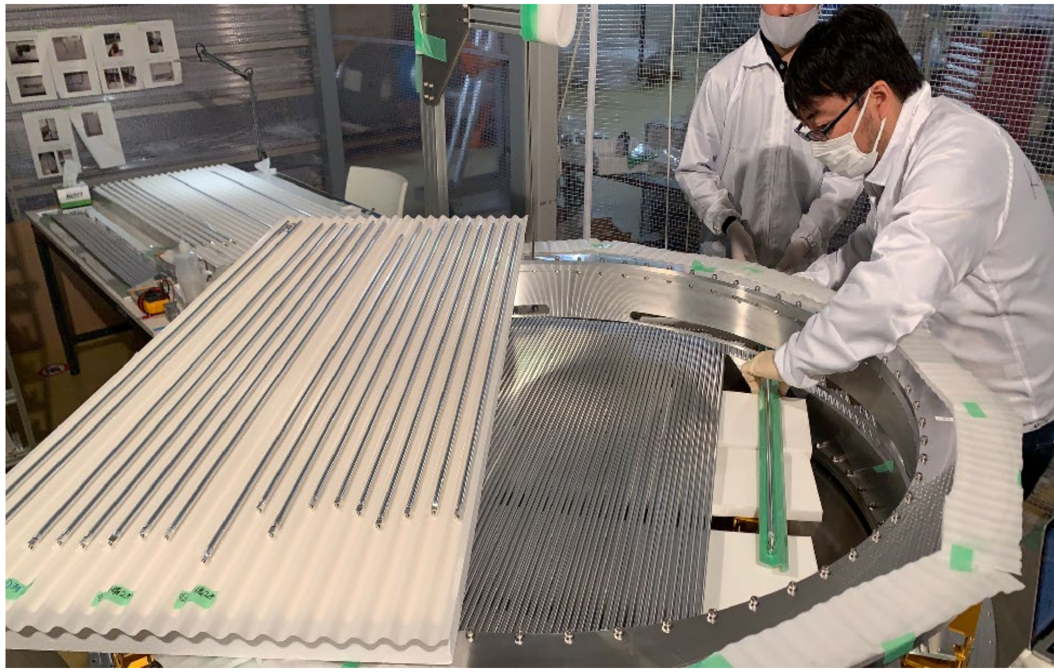
- Next to final design of the straw module for the 5mm diameter straws is developed
- Complete construction documentation for production is in progress
- Also full documentation on the ROESTI board, we will try to produce in RUSSIA, 60pcs.
- If we are lucky to produce the module in time, it can be used for Phase-I measurements

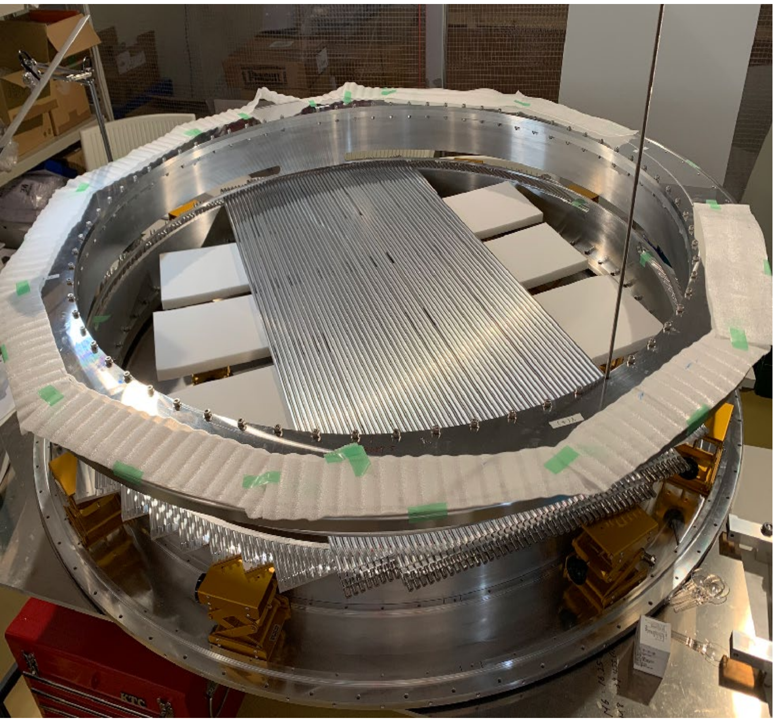
Straw Tracker Status — COMET Phase-I

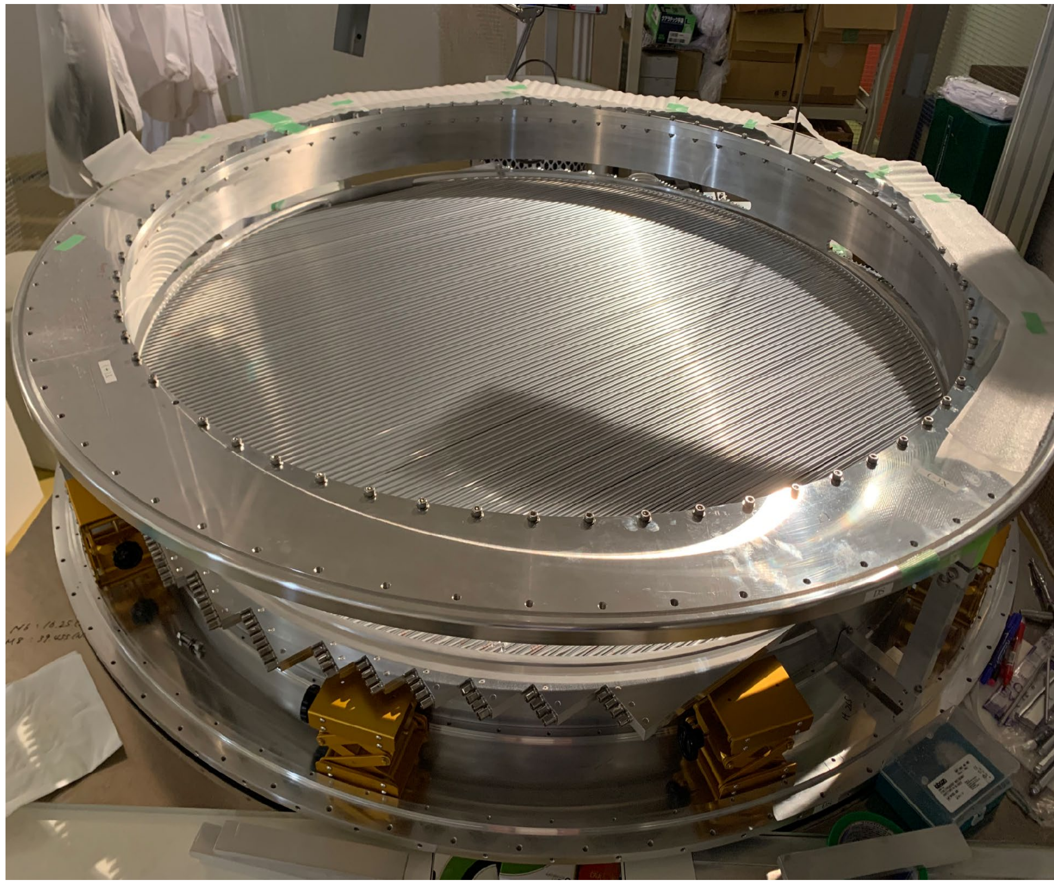
Straw-Tracker Assembly

Assembly for 1st Station is ongoing



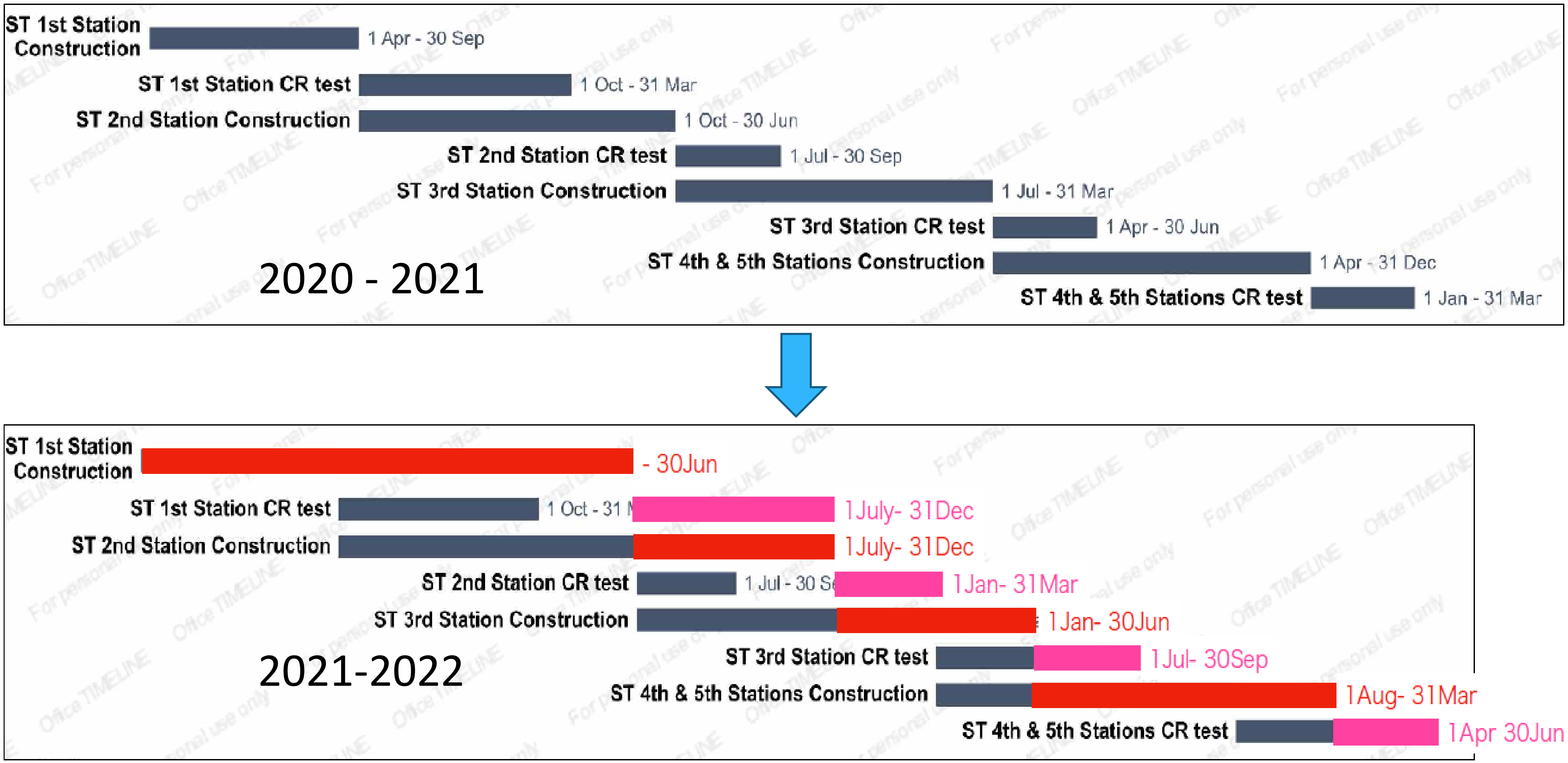






1st layer, completed !!!

Assembly Schedule update



- Unclear schedule, depends on the "man power" and "budget".
  - Current manpower @ KEK (2 physicists, 2 technicians, 1 students),
  - For the next FY 2nd-5th station, **JINR people is supposed to join, and the collaboration is very much looking forward to this (depends on COVID situation…**)

Electromagnetic calorimeter

Three candidates vendors

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

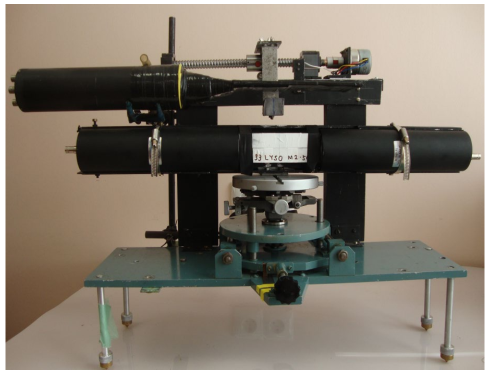
Saint-Gobain has introduced an engineered version of LYSO which, compared to standard LYSO, offers up to:

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

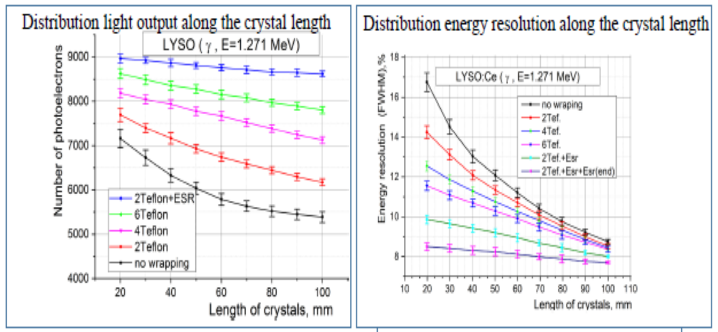
Properties	Standard LYSO	Engineered LYSO
Density [g/cm³]	7.1	
Hygroscopic	no	
Attenuation length for 511keV (cm)	1.2	
Energy resolution [%] @ 662 keV*	**8.5**	**8**
Wavelength of emission max [nm]	420	
Refractive index @ emission max.	1.81	
Decay time [ns]	**45**	**36**
Light yield [photons/MeV]*	**27600**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

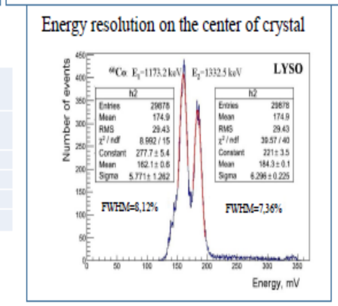


Optimal wrapping of LYSO:Ce crystal



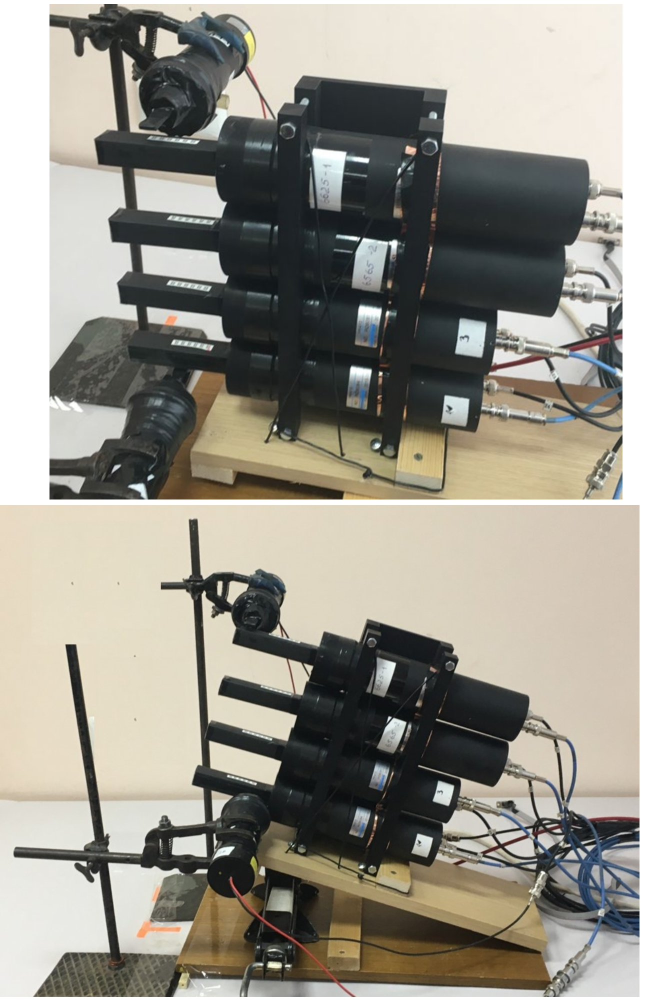
	Wrapping		Energy resolution (L= 60 mm), [%]
1	Without wrapping	60	11.37
2	2Teflon	74	11.44
3	4Teflon	79	10.59
4	6Teflon	83	9.5
5	2Teflon+ESR	~98,5	8.1

Energy resolution on the center of crystal



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.

Measurement of the electromagnetic calorimeter prototype parameters on cosmic muons



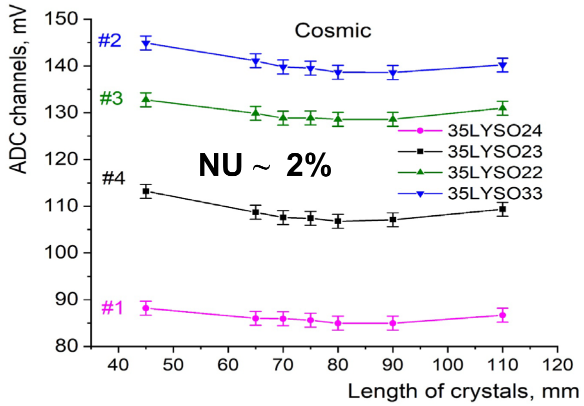
Measuring setup: measurements under the angels

Crystals: LYSO - 4
Wrapper
Two layers of TEFLON
-Thickness = 65 µm
- Absorbance 28 %/cm

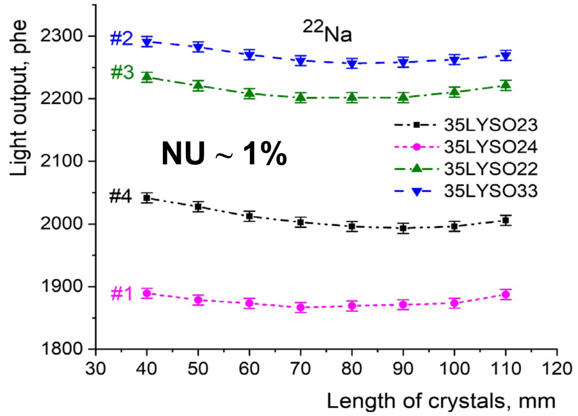
One layer of ESR film
Thickness = 65 µm
Refl.Coeff. = 0,99/0,1

One layer of paper
Thickness = 200 µm

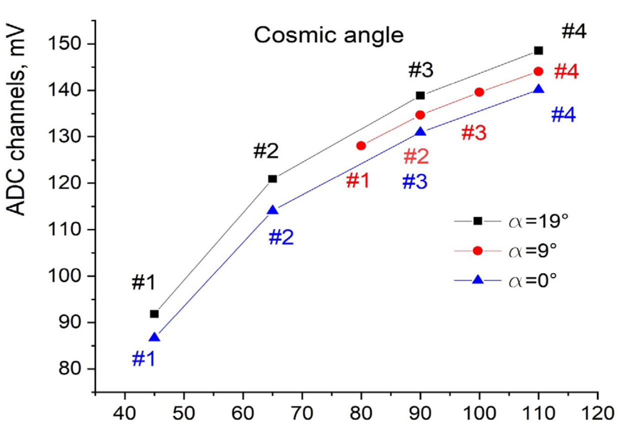
Photomultipliers: 6
For Crystals (4) and and coincidence (2)



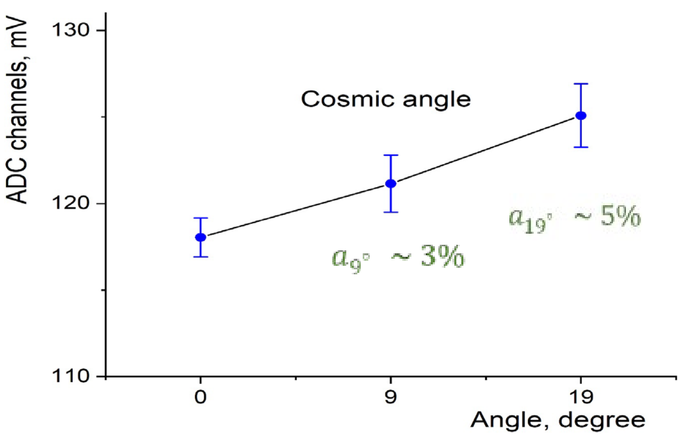
Non-uniformity of the prototype response along the crystals measured using cosmic muons



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



Prototype response non-uniformity, using cosmic muons for angles of 19 and 9 degrees relative to the end plane of crystals



Deviations of the non-uniformity response of crystals from their average values for angles of 9 and 19 degrees (non-uniformity of the response depending on the angle)

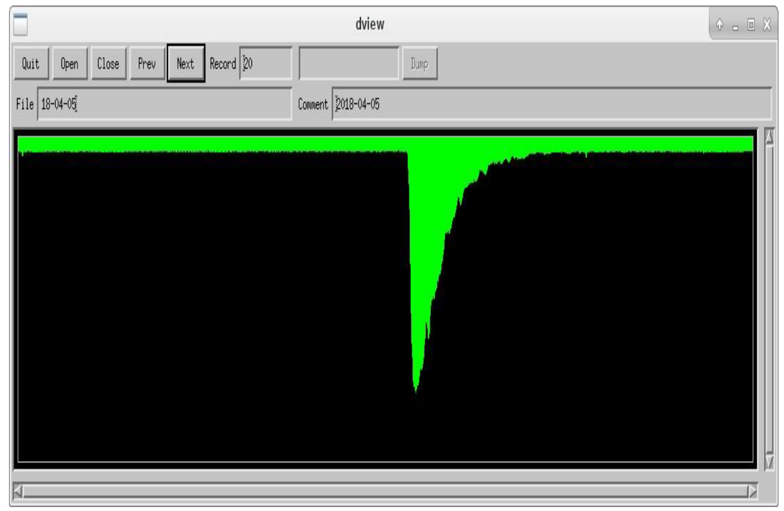
- Simulation of processes in crystals, ongoing
- Comparison of the crystal types, finished
- Simulation of optimal structure of the calorimeter, ongoing
- Simulation of the calorimeter geometry in framework ICEDUST, ongoing
- Experimental study of the main parameters (uniformity, light output) LYSO crystals 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

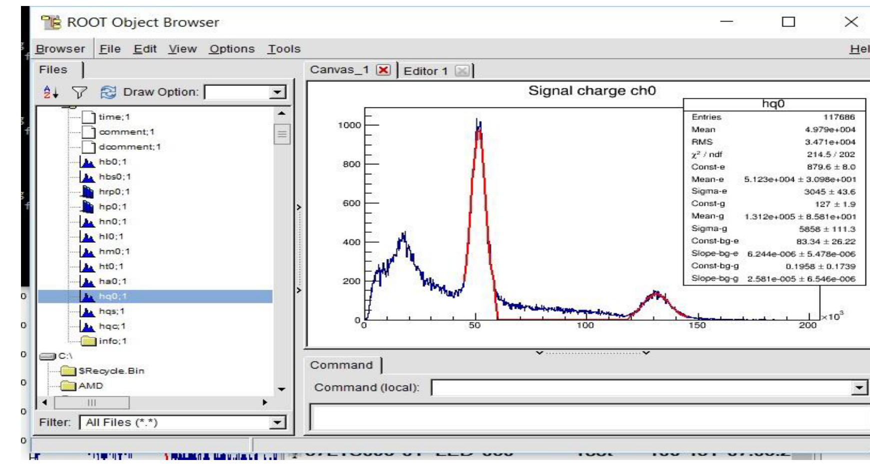
The LYSO crystal certification

A stand was created for certification of the crystals for the COMET calorimeter Passport for every crystal

The light output and the losses of the light along the crystal length for each crystal are measured.

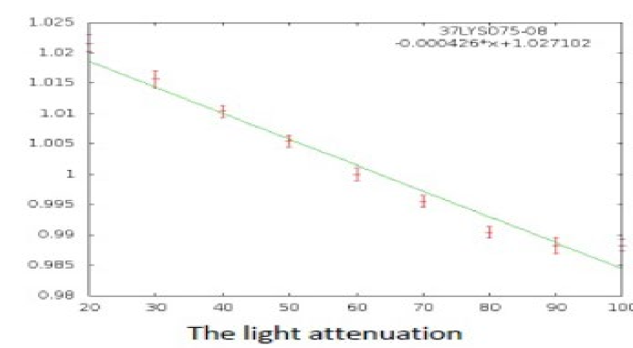
The measuring setup

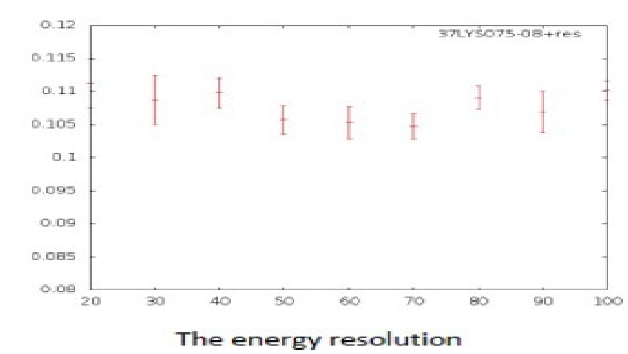




The spectrum of Na-22

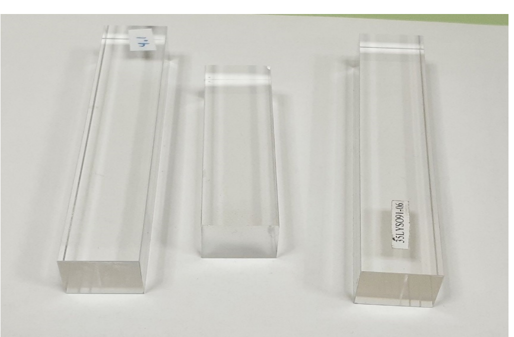
Passport for every crystal





Light attenuation ~ 0.426 ± 0.08 %/cm, 0.6 %/cm with good linearity.

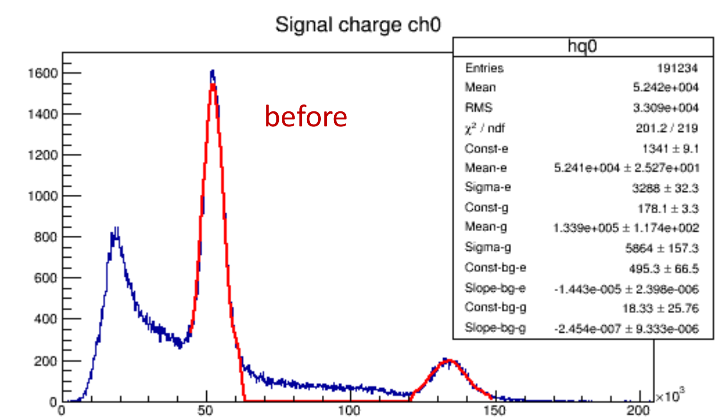
3 crystals
$6 \cdot 10^{11}$ n/cm^2
(~50 Gy/cm^2)

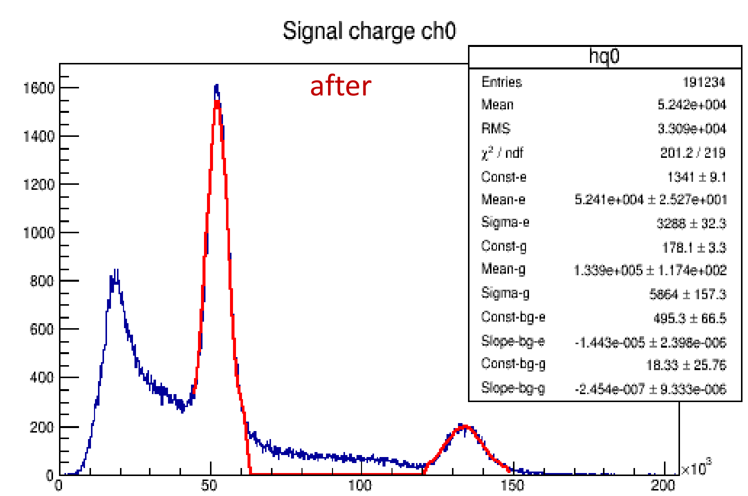


The middle crystal was cut because it had a defect in the form of the bubbles.

Radiation test

- Light output increased by about 1.1-1.2 times, but after 3 months returned to almost the initial value.
- Own radioactivity increased from 12 kHz to 30 kHz, but after 3 months fell to 15 kHz.





More than 200 crystals have already been certified

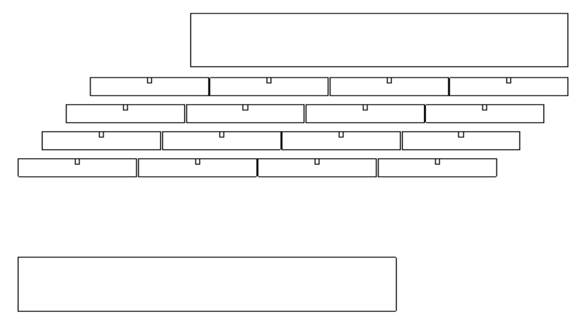
Cosmic Ray Veto (CRV) system

JINR participates in R&D, in design and in development of the CRV subsystem. This activity includes two parts:

- to finalize design of the CRV with providing scintillation strips production, testing, CRV modules creation schedule and
- to design/create/test the electronics embedded to the scintillators.

* In 2020, we did some R&D searches with such design (including the simulation and experimental results for 4x4 module) and was found that the design of CRV was based on 4-layers array of plastic scintillator strips 7x40 mm^2 (produced in "UNIPLAST", Vladimir, Russia) in cross section and with one 1.2-mm in diameter WLS fiber glued in the groove along the strip will not be able to provide necessary 99.99% efficiency for muon registration.
* At the next stage we will use 56 3-m-long strips with different geometry and thickness.
* Also, we simulated using Geant 4 the muon registration probability of the CRV module with different pattern of shifts layers to each other and created the map of its distributions of transversal distance and of muon entrances angles with average light yield of 21 ph.e.

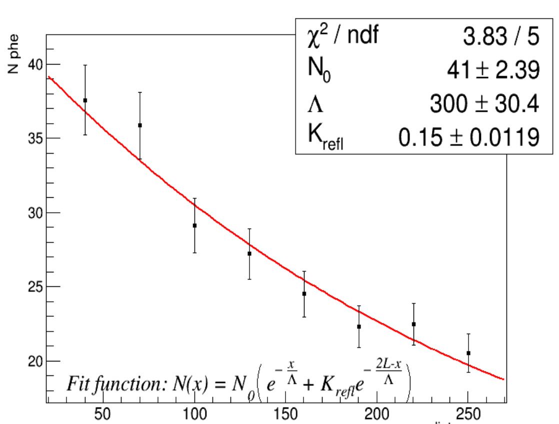
Assembly of the CRV prototype module for cosmic tests.



4x4 CRV module geometry for simulation with muons

Shift pattern	Overall efficiency
20-20-20 mm	0.99902
10-10-10 mm	0.99976
8-8-8 mm	0.99988
-----------	------------
8-10-6 mm	0.99983
8-10-8 mm	0.99985
8-10-10 mm	0.99981
8-10-12 mm	0.99976
8-10-14 mm	0.99968
8-10-16 mm	0.99963
8-10-18 mm	0.99958

Simulation of the muon registration probability for modules with different pattern (21ph.e)



Attenuation Length: Average Light Yield & strip length fitted with modified exponential function

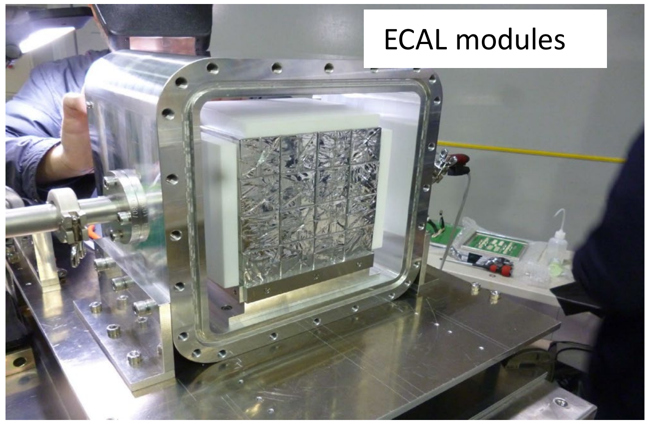
- Average light yield at 250 cm distance is 21 ph.e.
- **The overall module efficiency with real cosmic muons and "5 ph.e." threshold is 99.69%**
- **Simulation**, for the overall module efficiency "5 ph.e." threshold with this geometry, gave us (an angle distribution of muon intensities is included):
  99.74% for average light yield of 20 ph.e.
  99.93% for average light yield of 25 ph.e.

Our research showed that it is quite difficult to achieve 99.99% overall efficiency for CRV module based on 300x40x7 mm strips with 1 1.2-mm WLS fiber. Work on R&D +simulation to achieve the required efficiency (0.9999) of the experiment continues.

StrECAL system integration tests at ELPH in Tohoku

Energy range: 65 -145 MeV

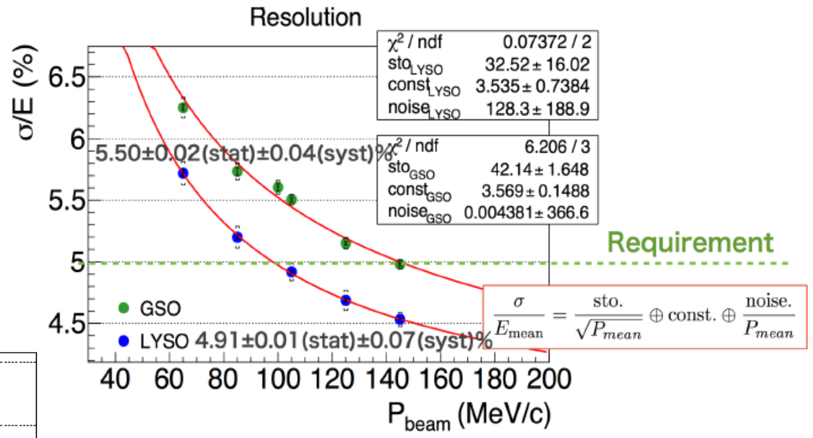
Straw prototype

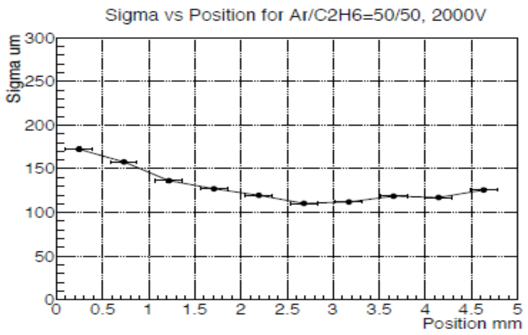


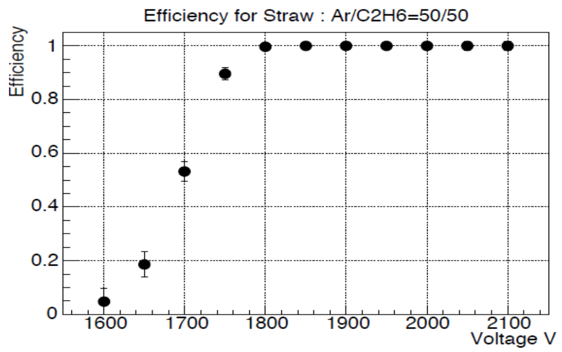
ECAL prototype 64 (8x8) JINR cryst.

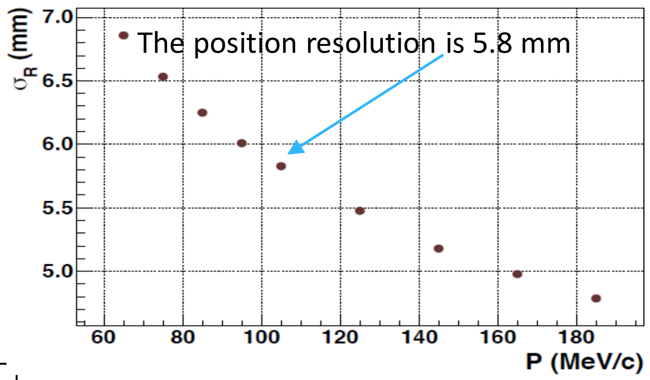
The energy resolution at 105 MeV for

- GSO - 5.5 ± 0.02 (stat) ±0.04 (syst) %
- LYSO – 4.91 ± 0.01 (stat) ± 0.07 (syst) %









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

Current Status

Straw tube Tracker

- the straw tubes were already mass-produced and checked.
- the 1st station of the straw tracker system is ongoing

ECAL

- in the process to purchase ~500-600 LYSO crystal for Phase-I
- the design work for the real detector is completed, and in the near future the assembly of calorimeter will start

Schedule of works on the project in 2022-2024

- Participation in the preparation, engineering and physics run, the data acquisition and analysis of Phase-α, 2022-2023
- Finalization assembling, testing, calibration, installation, cosmic test and maintenance of the straw detector for Phase-I, 2022-2023
- 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, 2022 -2023
- Creating a straw prototype (64 channels) with new tubes (12 μm, 5 mm) and measurement on the beam, 2022 - 2023
- Production of straw tubes (about 1000 pcs) for full-scale prototype, 2022
- Production of a full-scale straw station for Phase-I, with new tubes (12 μm, 5 mm), and measurements on the beam, 2022-2024
- Preparation for mass-production and testing of straw tubes for Phase-II, 2024
- Test (certification) of the LYSO crystals, to be used in the calorimeter, 2022-2023
- 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, 2022-2023
- Participation in the calorimeter designing, assembling, installation, cosmic test and maintenance, 2022-2023
- Participation in the assemble and maintenance of the CRV for Phase-I, 2022-2023
- Participation in assembling, testing, installation and maintenance of whole detector system for Phase-I, 2022-2023
- Complex detector system (tracker, calorimeter, etc.) simulation, 2022-2024
- Participation in the engineering and physics run, 2023-2024
- Participation in the data acquisition and analysis, 2023-2024
- Participation in the beam tests of the detector components for Phase II, 2023-2024

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 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 CRV team leader.

10. Estimation of human resources

COMET JINR group members (bold – new members)

#	Name	FTE	Position	Work (apart common duties like shifts)
1	**G. Adamov**	0.7	Junior researcher PhD student	Hardware and Software tools development, data quality control, analysis
2	**A.M.Artikov**	0.5	Senior scientist	Hardware development and support of CRV
3	D. Aznabayev	0.3	Junior researcher	Theoretical issues, physics analysis
4	D. Baygarashev	0.4	Junior researcher	Data quality control, calibration, physics analysis
5	**A. Boikov**	0.3	Junior researcher PhD student	CRV electronics, R&D COMET
6	**D. Chokheli**	1.0	Senior scientist	CRV construction, Leader of COMET-CRV detector system
7	V.N. Duginov	0.8	Deputy head of department	Calorimeter development, analysis
8	T.L. Enik	0.3	Senior scientist	Hardware development and support
9	I.L. Evtoukhovitch	0.9	Senior engineer	Hardware development and support
10	D. Goderidze	0.5	Junior researcher PhD student	Software/analysis
11	P.G. Evtoukhovitch	1.0	Senior scientist	Coordinator of Straw Tracker detector system
12	A. Issadykov	0.3	Senior scientist	Theoretical issues, physics analysis
13	V.A. Kalinnikov	1.0	Leading scientist	Calorimeter development, MC, analysis
14	E.S. Kaneva	1.0	Engineer	Hardware/software
15	X. Khubashvili	0.9	Engineer	Hardware development and support
16	A. Khvedelidze	0.4	Leading scientist	Theoretical issues, models development
17	**A. Kobey**	0.5	Master student	Calorimeter development, MC, analysis
18	G.A. Kozlov	0.3	Leading scientist	Theoretical issues, models development
19	A.S. Moiseenko	1.0	Scientist	Hardware development and support
20	A.V. Pavlov	1.0	Junior researcher PhD student	MC, Data quality control, physics analysis
21	B.M. Sabirov	1.0	Scientist	Hardware development and support
22	A.G. Samartsev	0.4	Senior engineer	Hardware development, detector design
23	**A.V. Simonenko**	1.0	Senior scientist	CRV creation and maintenance
24	**V.V. Tereschenko**	0.3	Head of group	CRV electronics, R&D COMET
25	**S.V. Tereschenko**	0.5	Engineer	CRV electronics, R&D COMET
26	Z. Tsamalaidze	0.8	Head of sector	Leader of COMET-JINR group, IB represent.
27	N. Tsverava	1.0	Junior researcher PhD student	Hardware development, calibration, analysis
28	**I.I. Vasilyev**	0.3	Junior researcher	Calorimeter R&D and tests
29	E.P. Velicheva	1.0	Senior scientist	Calorimeter development, MC, analysis
30	A.D. Volkov	1.0	Scientist	Hardware development
31	**I. Zimin**	0.5	Junior scientist PhD student	Software, simulation, analysis
	Total FTE	**20.9**		

The average age of the JINR COMET team is ~ 44 years, including 1 master and 9 junior researchers.

Detector Schedule

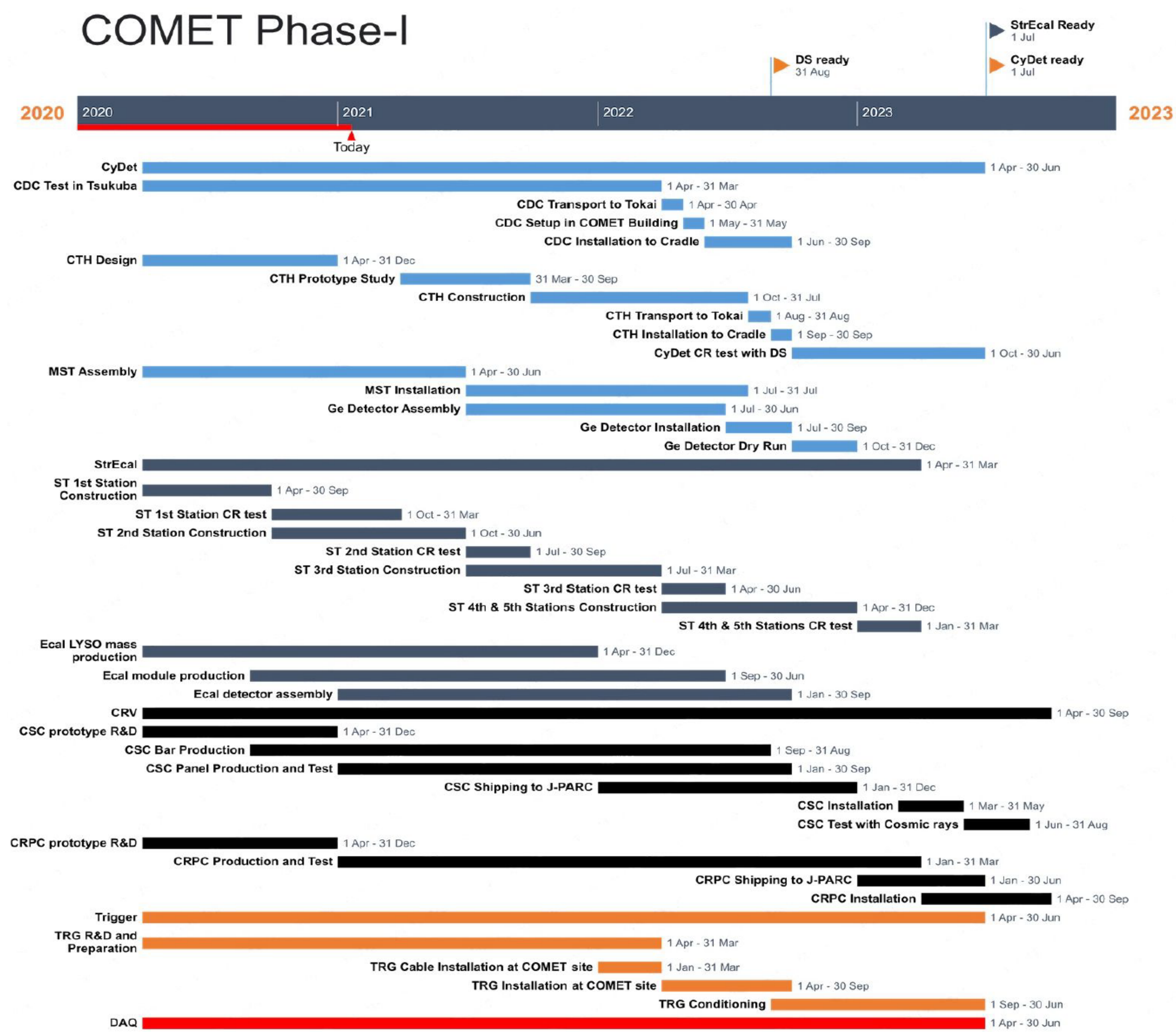
CyDet will be ready at COMET site by 30 September 2022

- On-site long-term CR test

StrECAL will be ready at COMET site by 31 March 2023

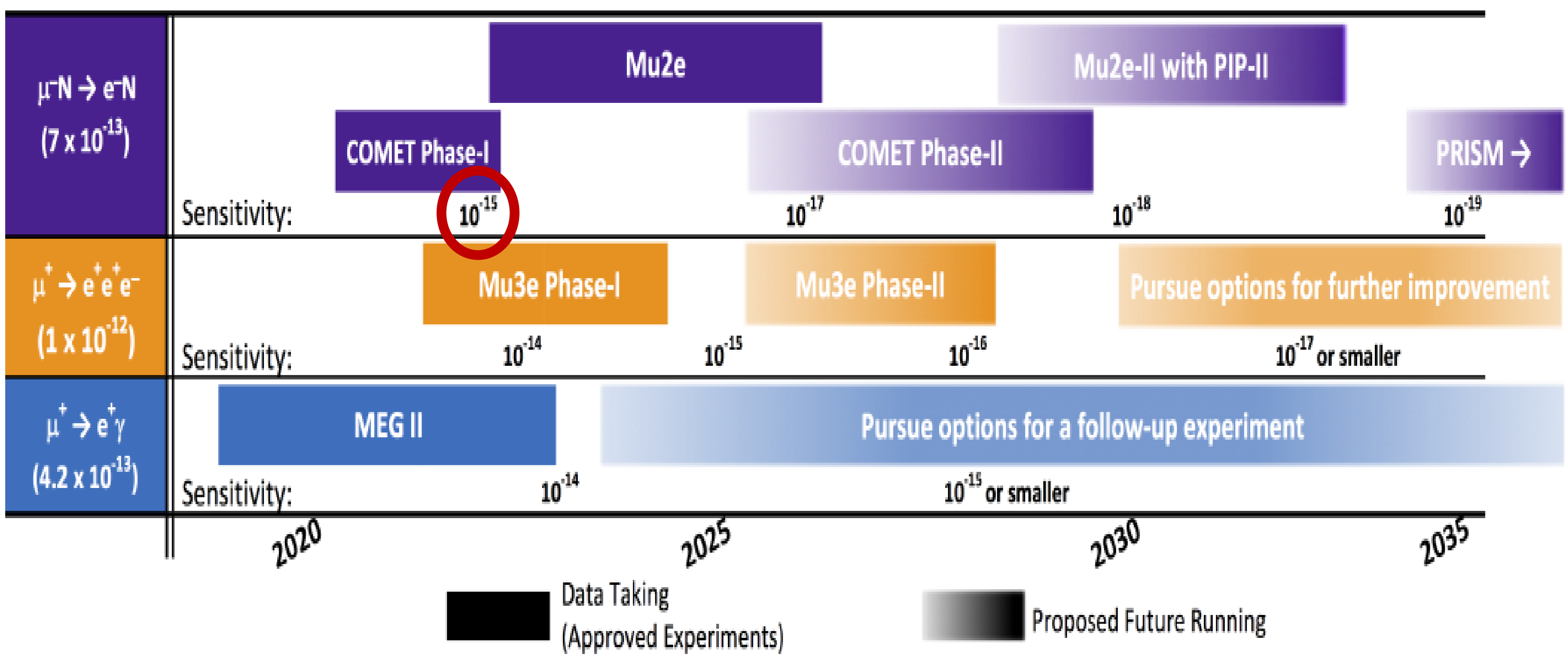
- ECAL and part of the Straw-Tracker will be ready earlier

The **Cosmic Ray Veto** comes in at the very end after all other installation is complete



CLFV Schedule in the near future

Searches of Charged-Lepton Flavor Violation in Experiments using Intense Muon Beams



Summary

- 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, 1.0×10^{-17}
  - staging approach called **Phase-I** (under construction) / Phase-II
  - Before Phase-I we need **Phase-α** – a low beam intensity run in 2022
- **Phase-α Goal**
  - The beam and secondary beam yield estimation, measurement w/ PID
- **COMET Phase-I** is now under construction
  - aiming improvement the sensitivity x 100 better than the past

Phase-I Goal:
(in 150 days operation)

$$B(\mu^- + Al \rightarrow e^- + Al) = 3.0 \times 10^{-15} \ \text{(S.E.S)}$$
$$B(\mu^- + Al \rightarrow e^- + Al) < 7 \times 10^{-15} \ (90\% C.L.)$$

Up to 10^{-15} → sensitive to “new physics”

  - The creation of CDC detector for physics search is already finished
  - The other system is under construction
  - **We plan to be ready in 2023.**
- 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 **2026-2027**
- JINR plays a **leading role** in the preparation and implementation of this fundamentally important experiment.

15. Estimation of costs and resources

Form No. 26

Schedule proposal and resources required for the implementation of the **Project COMET**

<table>
<tr><td colspan="3" rowspan="2">Expenditures, resources, financing sources</td><td rowspan="2">Costs (k$) Resource requirements</td><td colspan="3">Proposals of the Laboratory on the distribution of finances and resources</td></tr>
<tr><td>2022</td><td>2023</td><td>2024</td></tr>
<tr><td colspan="2" rowspan="3">Expenditures</td><td>Computers (Simulation, data analysis)</td><td>30</td><td>10</td><td>10</td><td>10</td></tr>
<tr><td>Laboratory electronic devices</td><td>110</td><td>30</td><td>30</td><td>50</td></tr>
<tr><td>Materials and Equipment for:
- The R&D and construction of CRV modules (scintillation strips, SiPM, fibers and other components),
- The straw tubes R&D, straw tubes production and prototype creation (equipment for straw tube stand, optical sensors, pressure sensors, printing plastic for the 3D, other components).
- The R&D and construction of ECAL.</td><td>190</td><td>70</td><td>70</td><td>50</td></tr>
<tr><td>Required resources</td><td>Standard hour</td><td>Resources of:
- Laboratory design bureau;
- JINR Experimental Workshop;
- Laboratory experimental facilities division;
- electron accelerator; reactor</td><td>600 h
900 h

1050h</td><td>200 h
300 h

350 h</td><td>200 h
300 h

350 h</td><td>200 h
300 h

350 h</td></tr>
<tr><td rowspan="4">Financing sources</td><td>Budgetary Resources</td><td>Budget expenditures including foreign-currency resources.</td><td>690</td><td>230</td><td>230</td><td>230</td></tr>
<tr><td rowspan="3">External resources</td><td>- Grant of the Plenipotentiary of Georgia</td><td>30</td><td>10</td><td>10</td><td>10</td></tr>
<tr><td>- Program of the JINR-Belarus Cooperation</td><td>15</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>- Grant of the Plenipotentiary of Kazakhstan</td><td>15</td><td>5</td><td>5</td><td>5</td></tr>
</table>

Form No. 29

Estimated expenditures for the **Project COMET**

	Expenditure items	Full cost	2022	2023	2024
	Direct expenses for the Project				
1	Accelerator, reactor	*1050 h*	*350h*	*350h*	*350h*
2	Computers	-	-	-	-
3	Computer connection	-	-	-	-
4	Design bureau	*600 h*	*200 h*	*200 h*	*200 h*
5	Experimental Workshop	*900 h*	*300 h*	*300 h*	*300 h*
6	Materials (k$)	190	70	70	50
7	Equipment (k$)	140	40	40	60
8	Construction/repair of premises	-	-	-	-
9	Research operation fee (k$)	60	20	20	20
10	Travel allowance (k$)	300	100	100	100
	Total direct expenses (k$)	690	230	230	230

Thank you for attention!

BACKUP

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

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

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

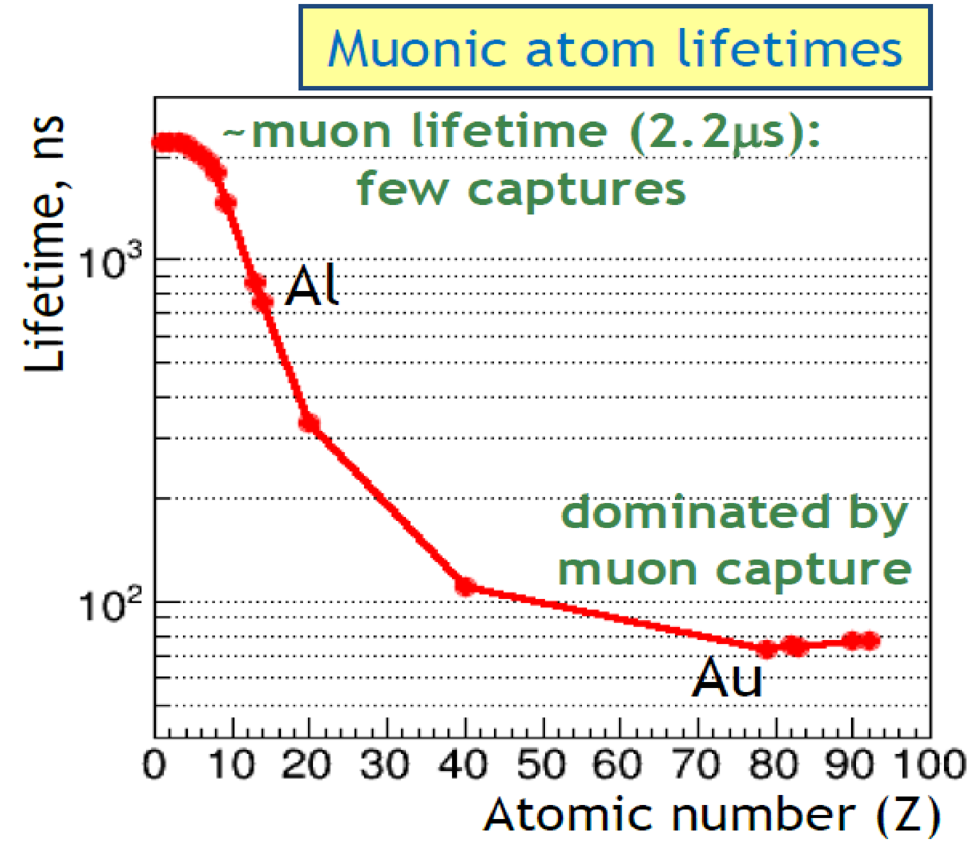
$$\mu^- + e^- \rightarrow e^- + e^- \ \text{conversion}$$

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

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

Models	Simulator	$N(\pi^- + \mu^-)/p$ at 3 m
CEM	MARS	0.061 ± 0.001
CEM/LAQGSM	MARS	0.138 ± 0.001
LAQGSM	MARS	0.144 ± 0.001
LAQGSM	GEANT	0.1322 ± 0.0007
QGSP_BERT	GEANT	0.0511 ± 0.0002
QGSP_BIC	GEANT	0.1278 ± 0.0005
FTFP_BERT	GEANT	0.0440 ± 0.0002

Comparison of the π^- and μ^- yields three meters backwards from the proton target for different hadron production codes.



Yield (per proton):	After muon-transport section	Stopped in muon target
Muons	5.0×10^{-3}	4.7×10^{-4}
Pions	3.5×10^{-4}	3.0×10^{-6}

For Phase-I, total number of protons on target 3.2×10^{19}

Plans for the Mu2e and Mu2e-II experiments. Jim Miller, 30.03.2021

- RUN 1. Mu2e planning beam (8 GeV, 8kW,) run 2025, for two years, expected 8×10^{-16}
  To complete before 2027 LBNF/PIP-II 2 years shutdown 3×10^{-15} (COMET, Phase-I), 2023
- RUN 2. Mu2e-II (800 MeV, 100 kW,) planning after 2029-2030, for three year run, expected 8×10^{-17}
  2.7×10^{-17} (COMET), 2026-27

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 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)	7.0×10^{-15}	2.6×10^{-17}
U.L. (upper limit, 90%CL)	$< 7.0 \times 10^{-15}$	$< 6.0 \times 10^{-17}$
Measurement start	2023	2026-2027

Detector single rate: tracker and calorimeter

	Timing	Tracker (kHz)	Calorimeter (kHz)	Energy (MeV)
DIO electrons	Delayed	10	10	50–60
Back-scattering electrons	Delayed	15	200	< 40
Beam flash muons	Prompt	$< 150^{\ddagger}$	$< 150^{\ddagger}$	15–35
Muon decay in calorimeter	Delayed	—	$< 150^{\ddagger}$	< 55
DIO from outside of target	Delayed	< 300	< 300	< 50
Proton from muon capture	Delayed	—	—	—
Neutron from muon capture	Delayed	—	10	~ 1
Photons from DIO e^- scattering	Delayed	150	9000	$\langle E \rangle = 1$