The COherent Muon to Electron Transition (COMET) experiment

COMET experiment on the J-PARC

status and prospects

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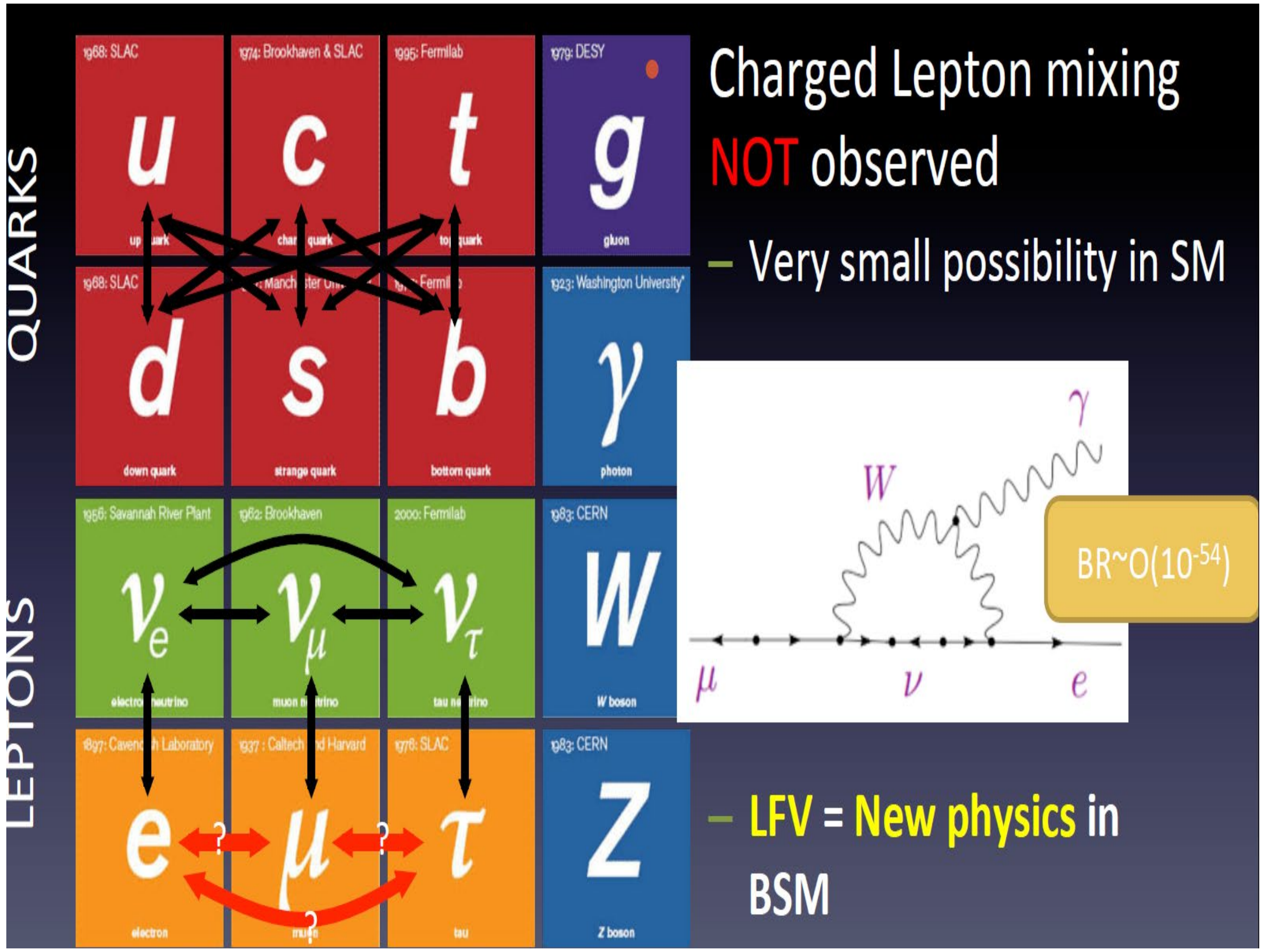
OUTLINE

- Physics motivation, Mu-e conversion
- COMET at J-PARC
- JINR contribution and plans
- Summary

Charged Lepton Flavor Violation (CLFV)

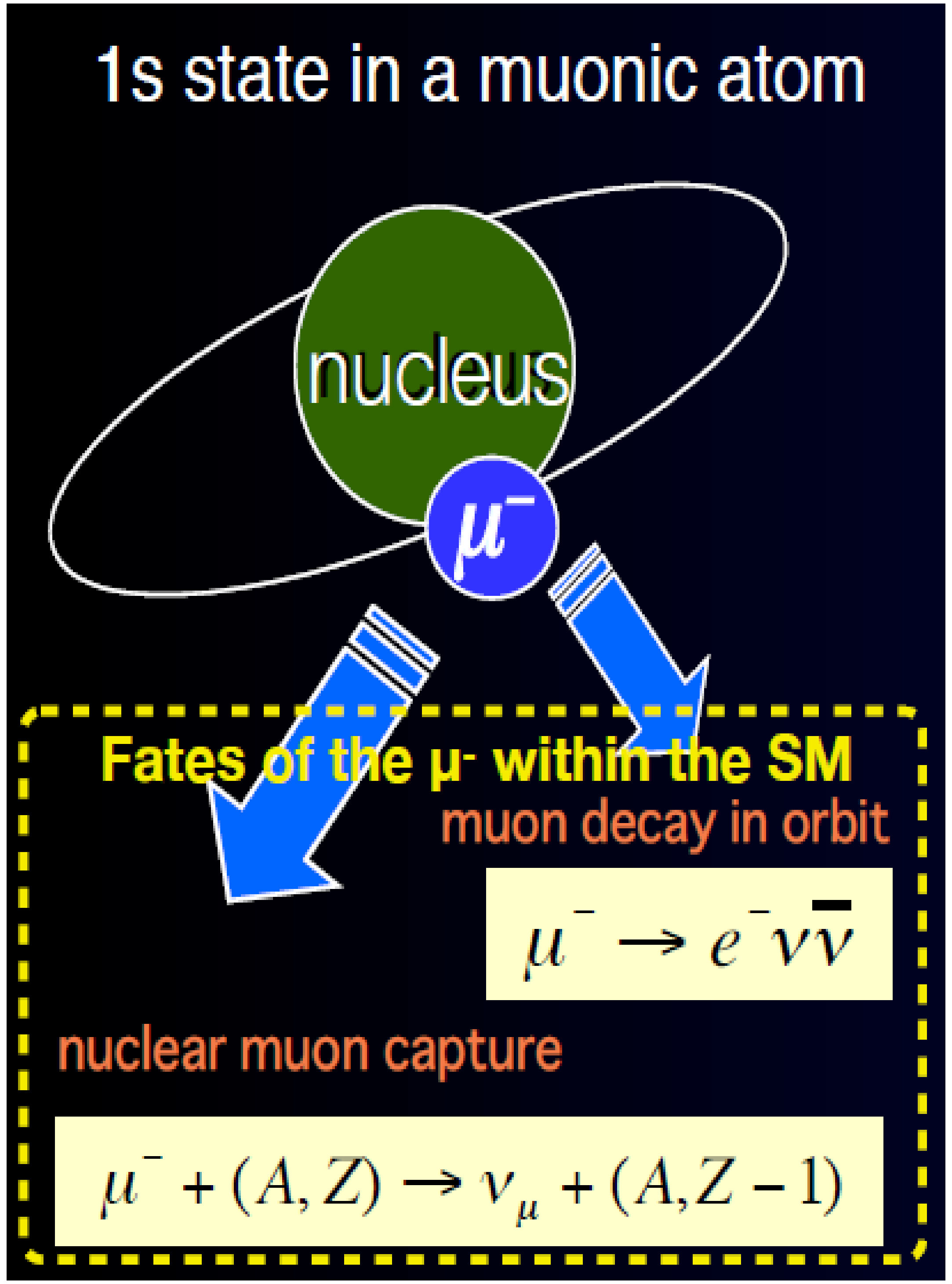
The Standard Model (SM) is very good, however there are still such mysteries like

- baryon/antibaryon asymmetry
- dark matter
- dark energy
- particle mass prediction
- no theory of gravitation
- neutrino oscillations
- ……………………………



What is a Muon to Electron Conversion?

The most sensitive probes of CLFV utilize high-intensity muon beams.



Beyond the SM

μ-e conversion

$$\mu^- + (A,Z) \to e^- + (A,Z)$$

Forbidden by the SM, because
the lepton flavor is changed to μ-flavor to e-flavor.

Event signature :

a single mono-energetic electron of 105MeV (for Al)

in the SM + ν masses

μ-e conversion can be occur via ν-mixing, but expected rate is well below the experimentally accessible range. Rate ~O(10^{-54})

Discovery of the μ-e conversion is a clear evidence of new physics beyond the SM.

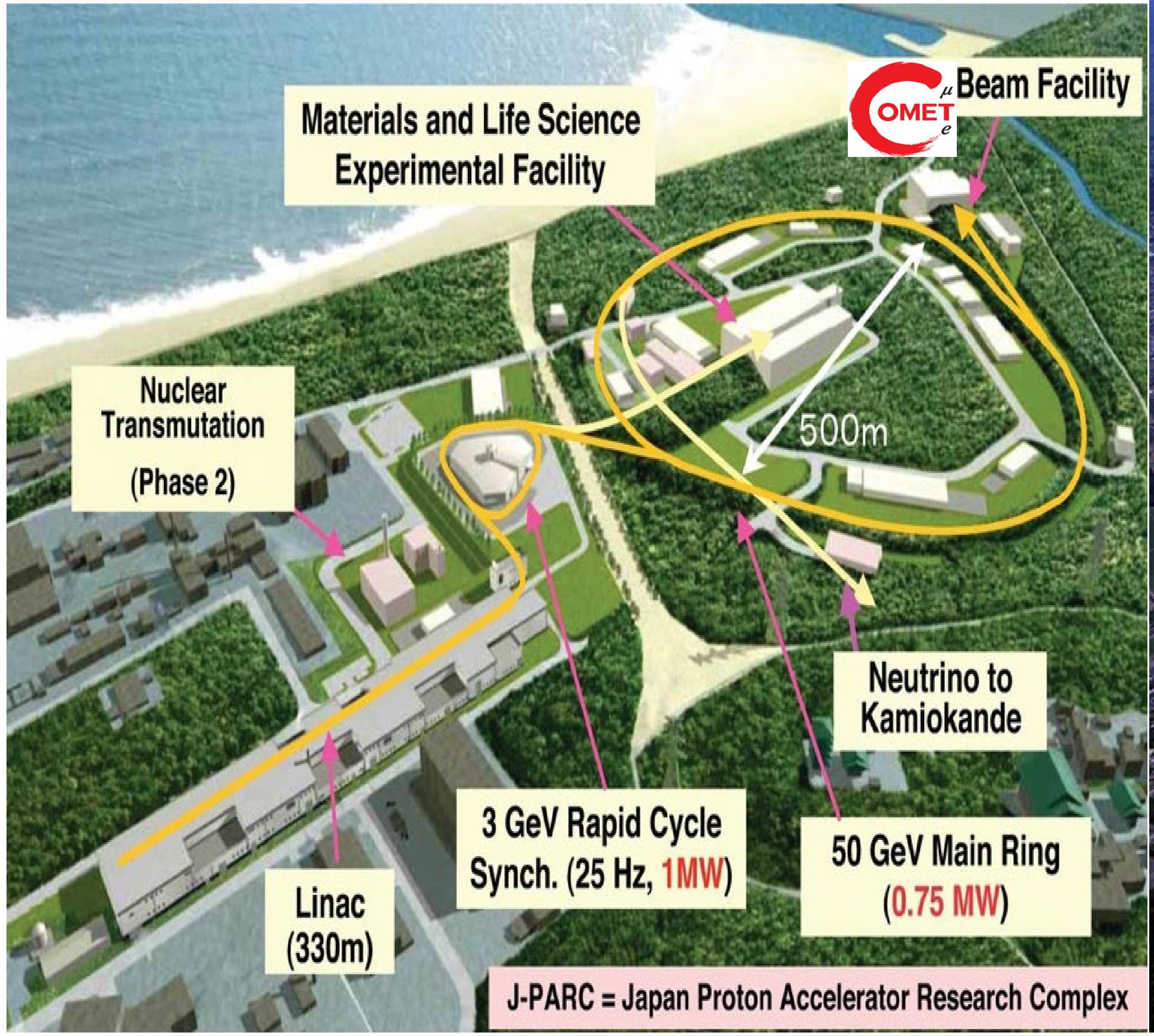
in the SM + new physics

A wide variety of proposed extensions to the SM predict observable μ-e conversion rate.

The COherent Muon to Electron Transition (COMET) experiment

We are in the project since 2008

COMET at J-PARC, Tokai)



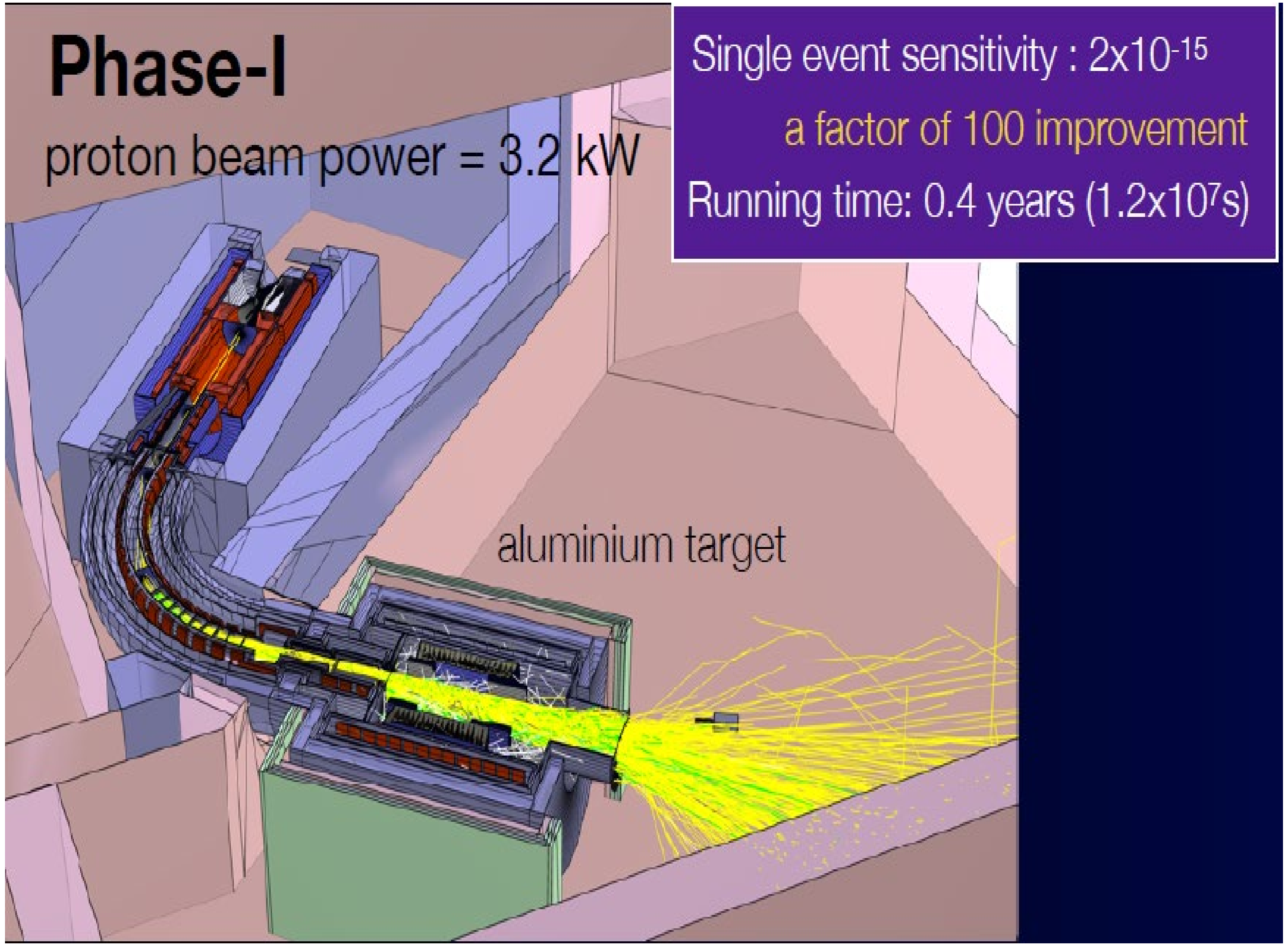
43 institutes, 17 countries

Still growing!

Joint Project between KEK and JAEA

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

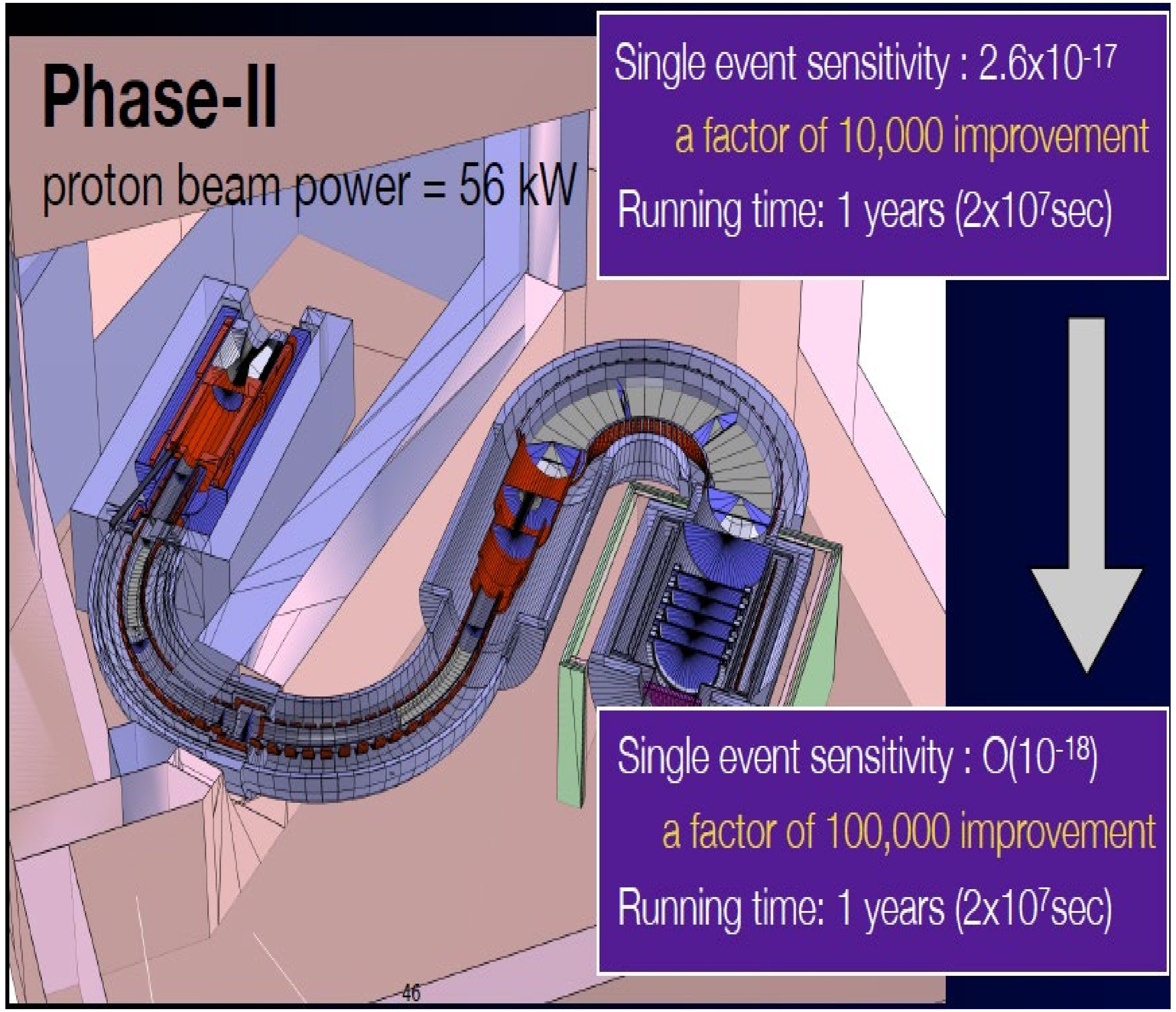
Two-phase realization



COMET Phase-I, 2025 - 2026

POT 3×10^{19}

Stopped muons on target $1{,}5 \times 10^{16}$

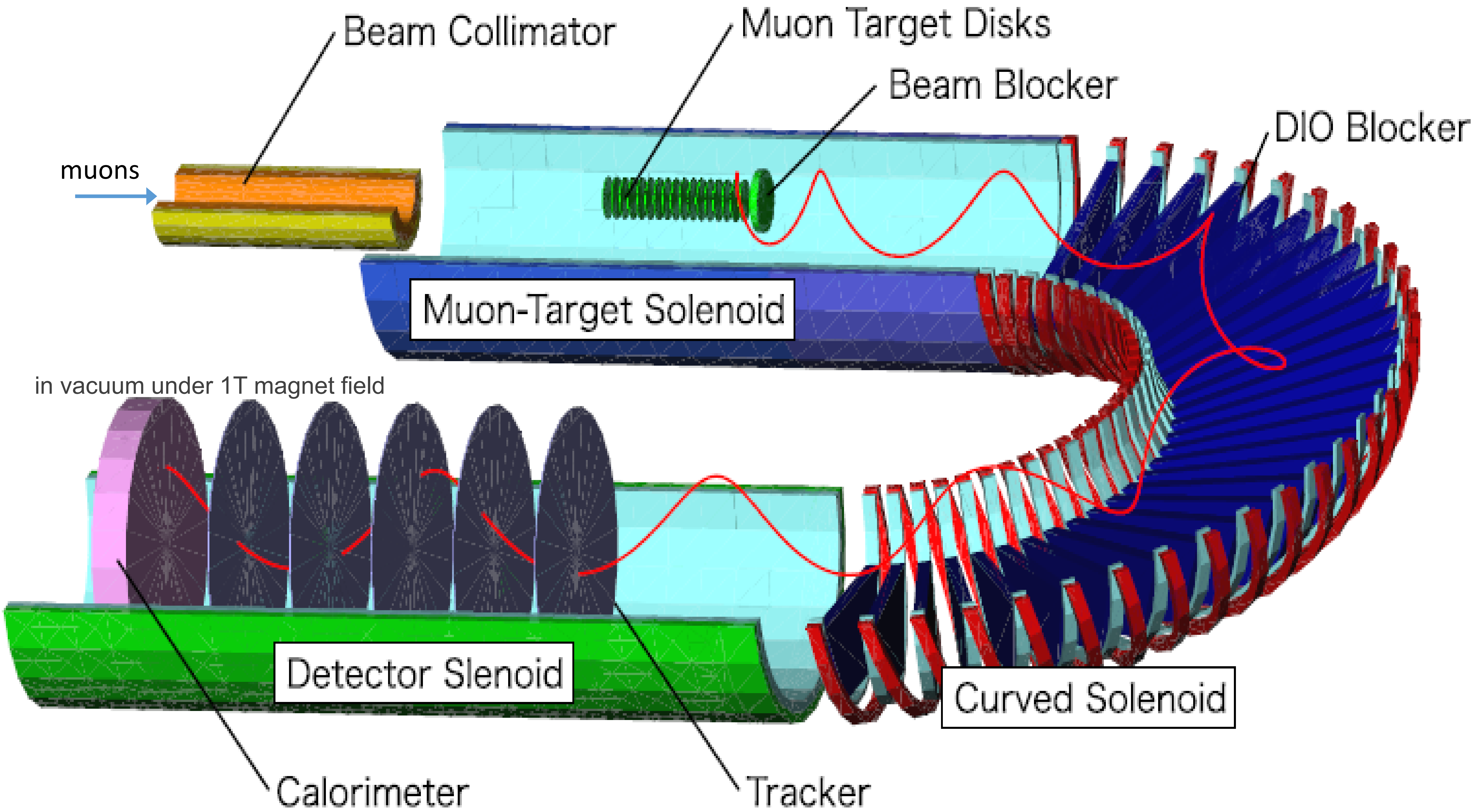


COMET Phase-II, 2029-2030

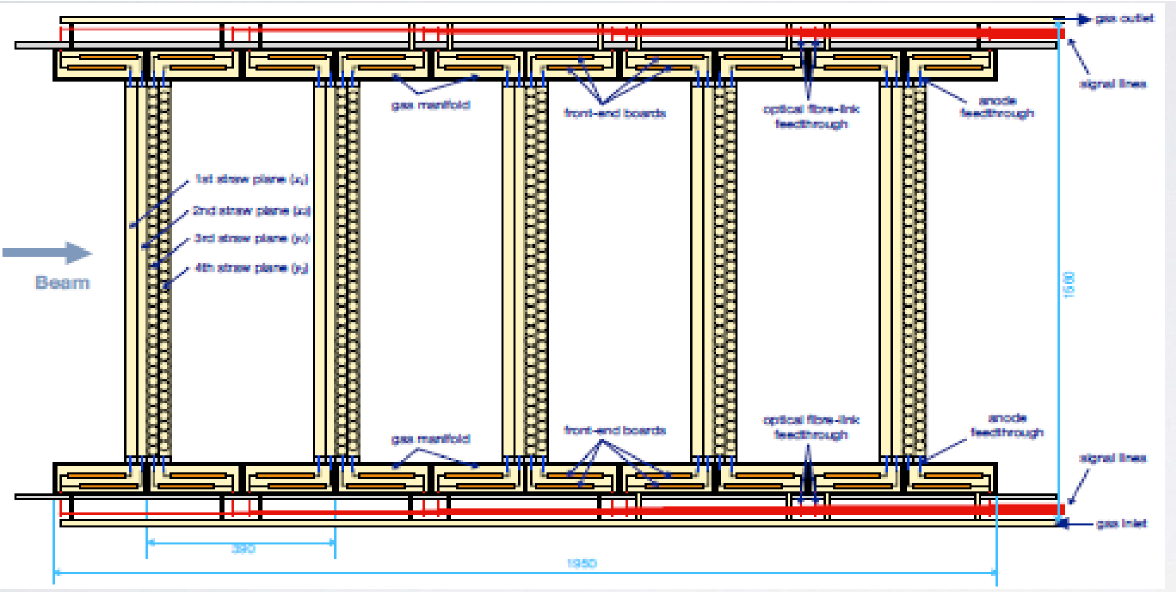
POT - 3×10^{21}

Stopped muons on target $1{,}5 \times 10^{18}$

COMET Detector



Straw Tracker: 5 station (Phase – I)~ 2500 straw tubes, 9.75 mm diameter, 20 μm thickness, Ar:CO_2 = 50:50

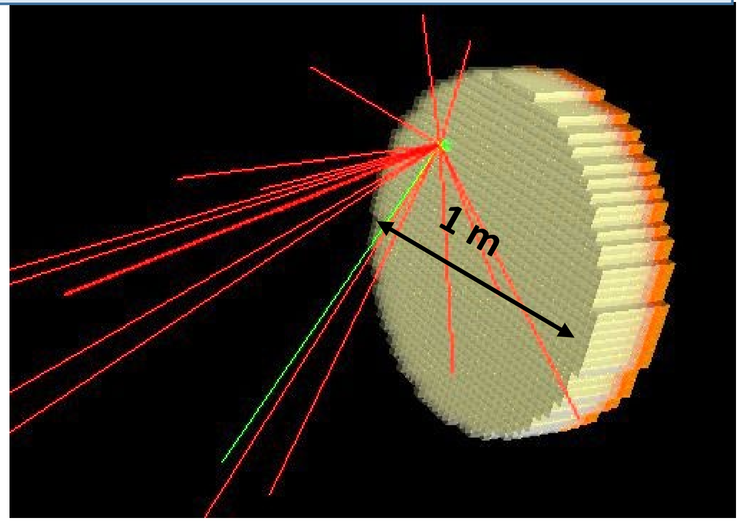


Requirements:
- Work in vacuum, magn. field 1 Tesla
- Momentum resolution ≤ 200 keV/c
- Space resolution ≤ 200 μm

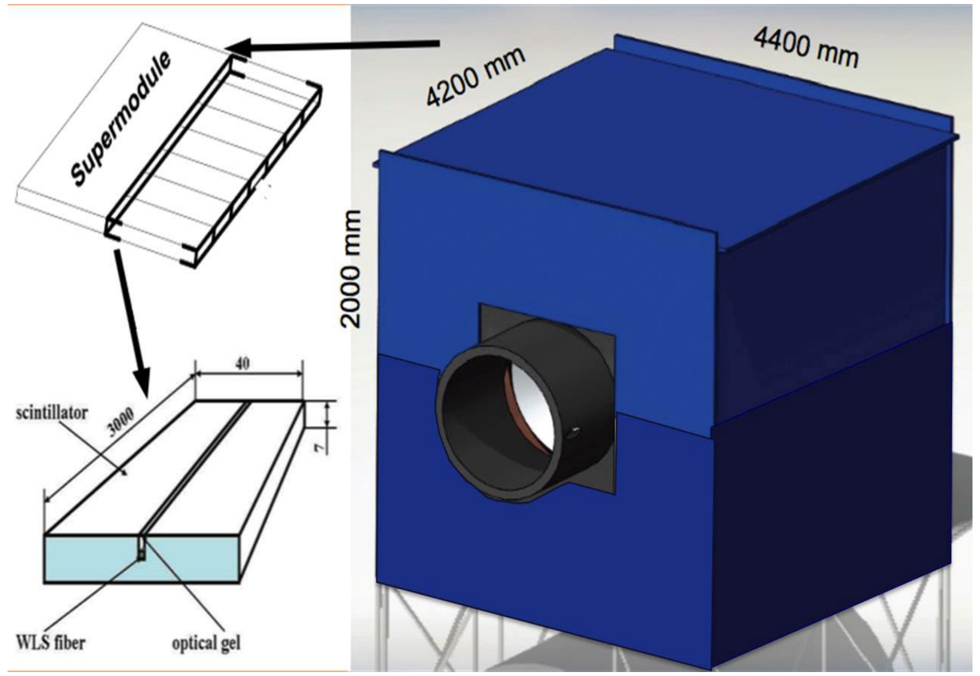
Electromagnetic calorimeter

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 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)

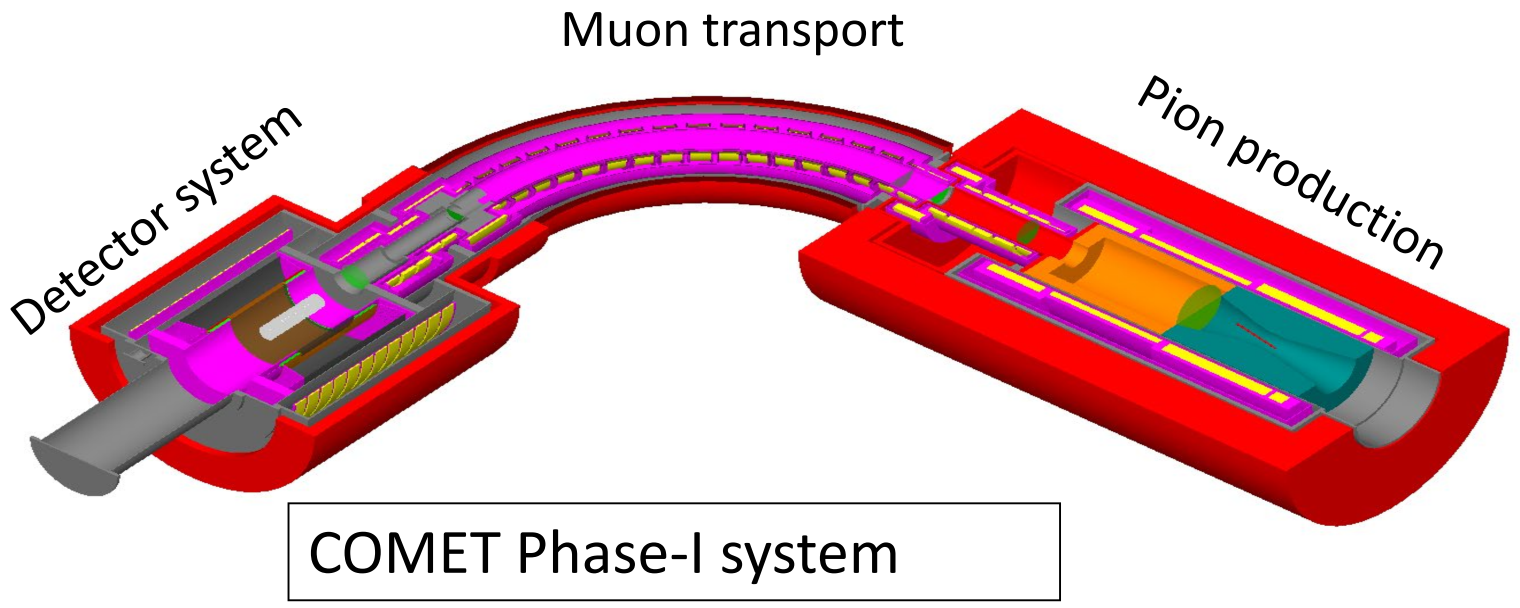


Requirement: Efficiency ≥ 99.99%.

CRV will be consist of two major parts: scintillator based (SCRV) and Glass Resistive Plate Chambers (GRPC). 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 will be placed in hottest area at front of the COMET (active shield).
- 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

Also used passive shields, 2 meter of concrete and 0.5 m thick steel.

COMET phase-I detectors



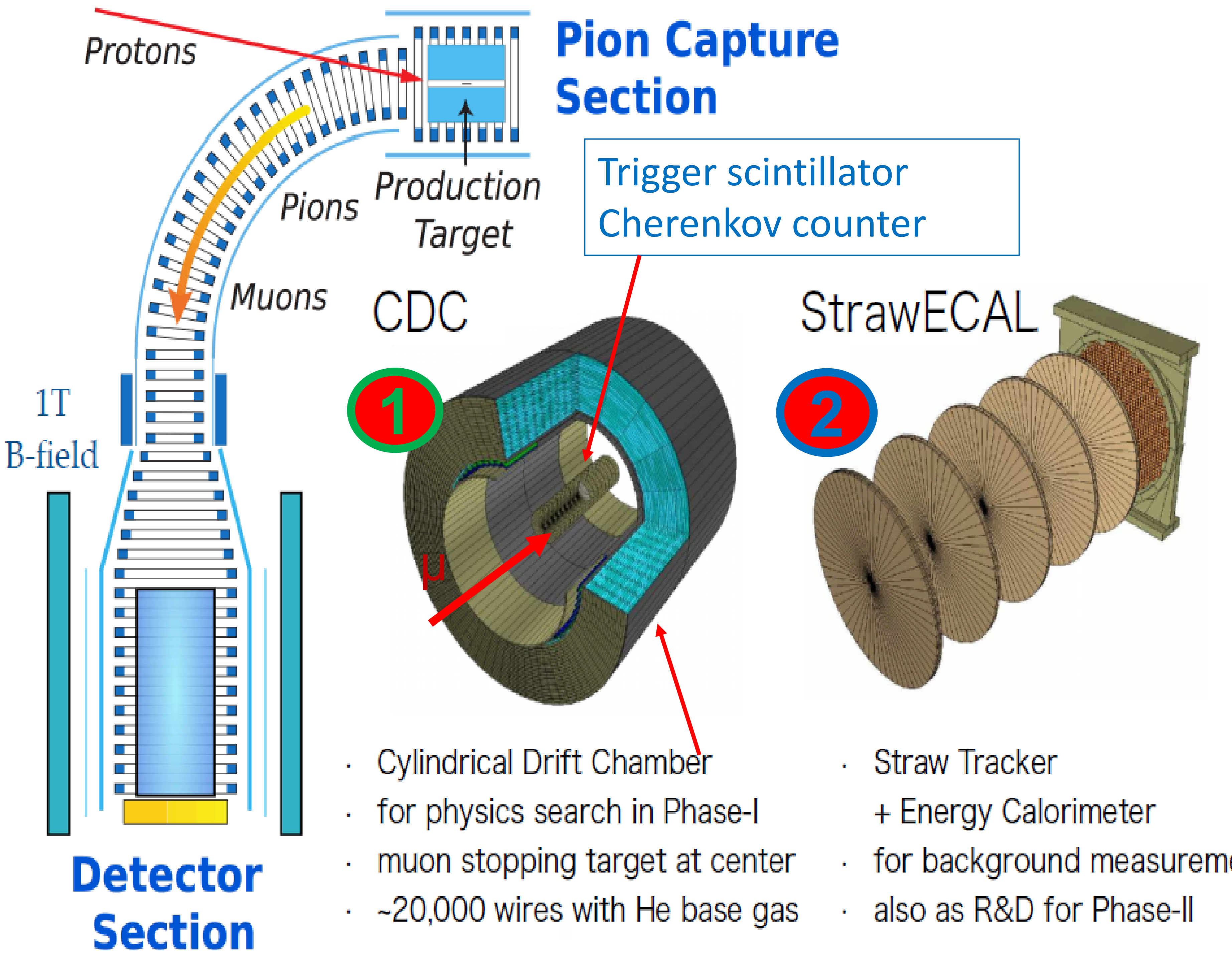
1 Search for μ-e conversion

- A search for μ-e Conversion at the intermediate sensitivity with would be 100-times better than the present limit (SINDRUM-II) 3×10^{-15}

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

COMET Phase-I Detectors

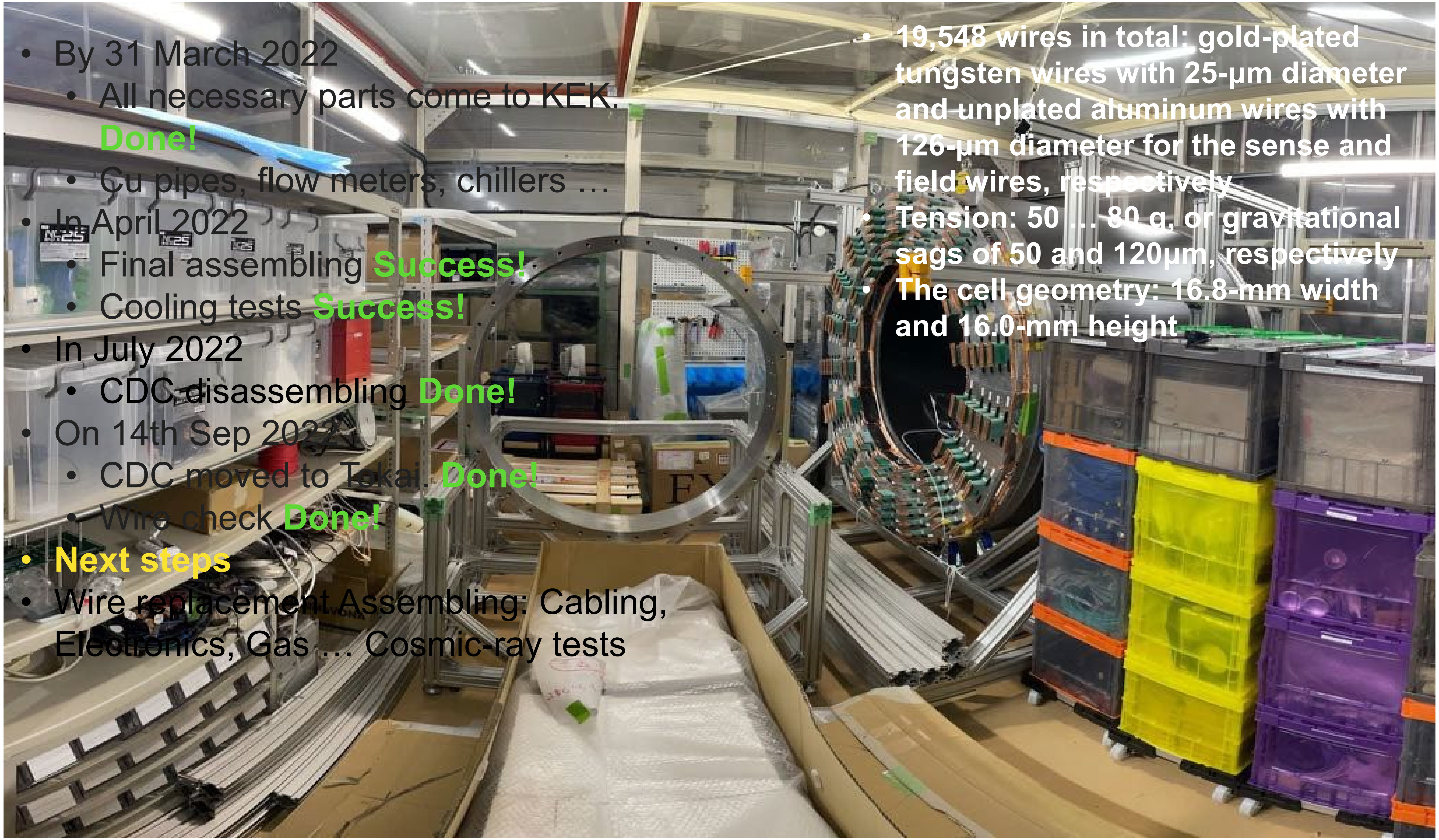


- Cylindrical Drift Chamber
- for physics search in Phase-I
- muon stopping target at center
- ~20,000 wires with He base gas

- Straw Tracker
- + Energy Calorimeter
- for background measurement
- also as R&D for Phase-II

- Gas mixture Helium Based gas (Isobutane, Ethane or Methane)
- The spatial resolution resolution < 200μm
- The momentum resolution must be better than 200keV/c for 105 MeV

Cylindrical Drift Chamber (CDC) already at 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

- **19,548 wires in total: gold-plated tungsten wires with 25-μm diameter and unplated aluminum wires with 126-μm diameter for the sense and field wires, respectively**
- **Tension: 50 … 80 g, or gravitational sags of 50 and 120μm, respectively**
- **The cell geometry: 16.8-mm width and 16.0-mm height**

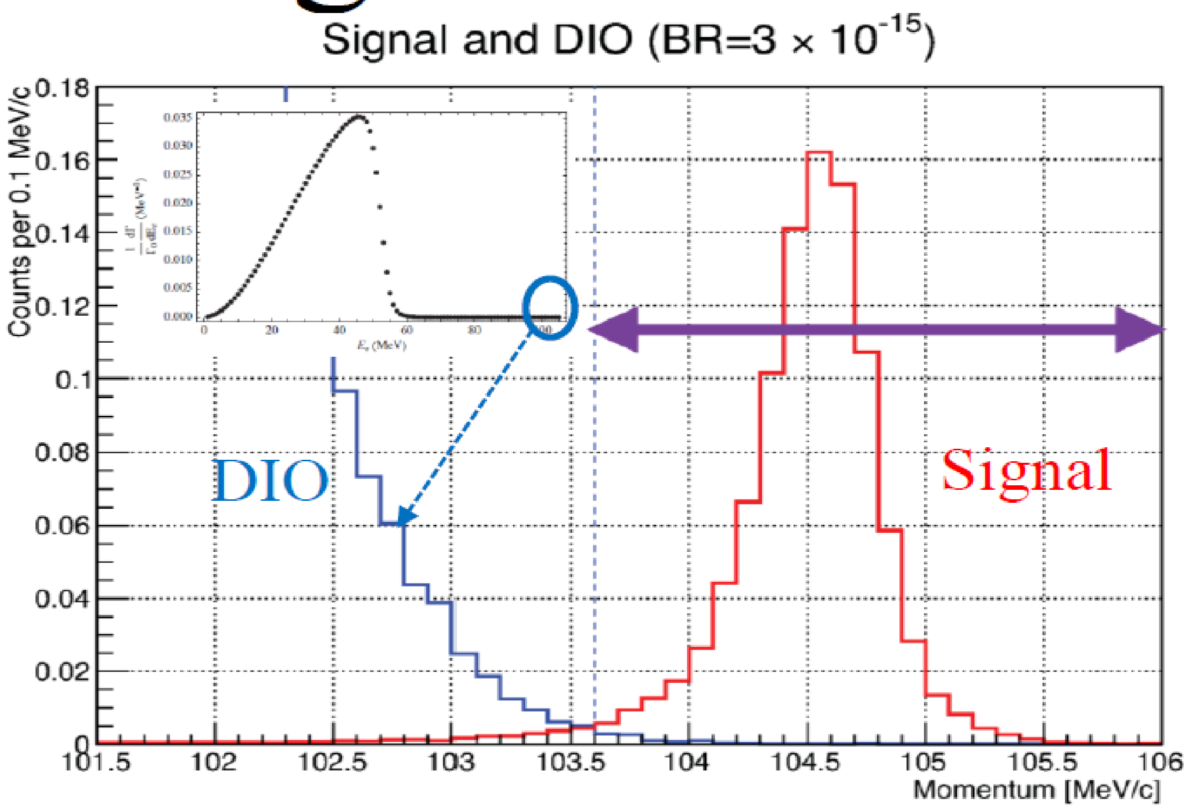
To control the background

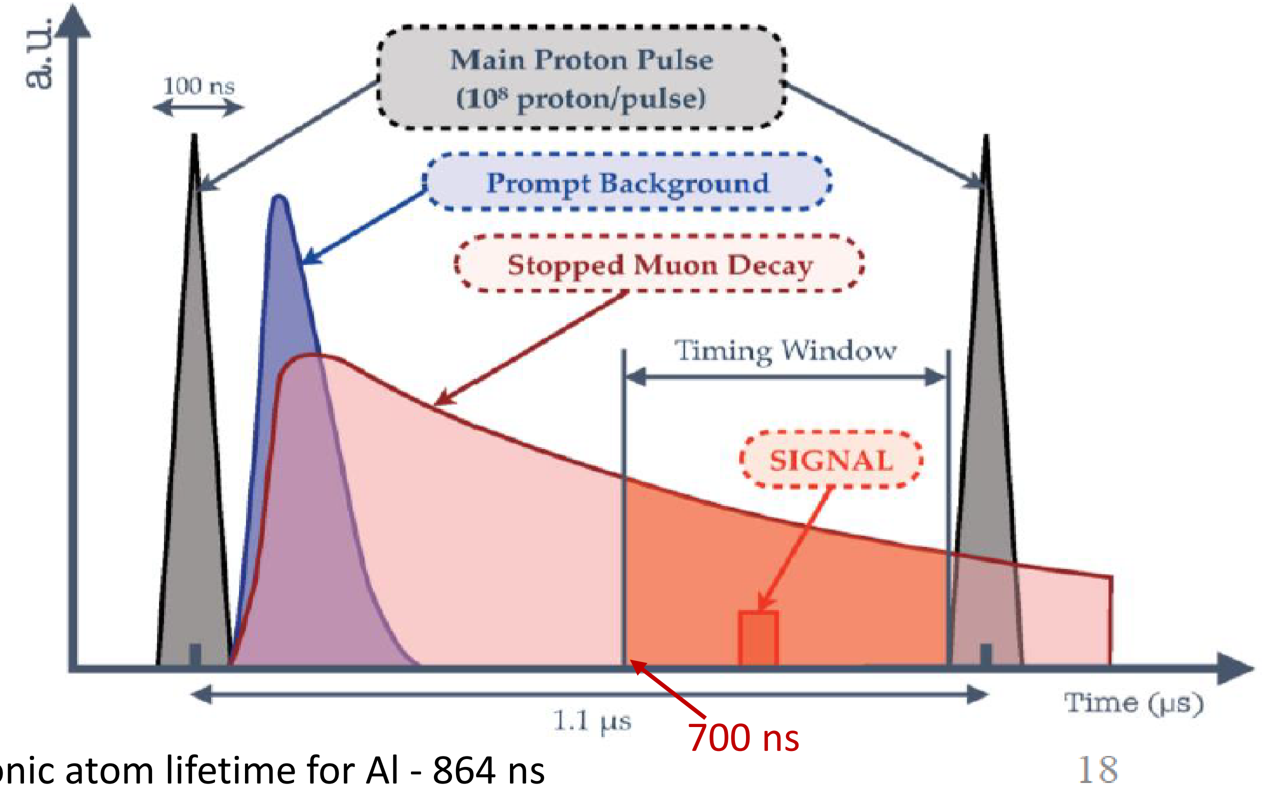
- Intrinsic physics background
  - Mostly from muon decay in orbit (DIO)
    - Calculated by Czarnecki with radiative correction. Branching ratio drops with order-5 function near end point.
    - Momentum resolution required to be better than 200 keV/c
- Beam related background
  - Energetic particles 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.

Inefficiency < 10^{-4}





Muonic atom lifetime for Al - 864 ns

The total 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 **0.032 events (DIO ~ 0.001, RPC ~0.003, Cosmic < 0.01)**

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 ns $< t_e <$ 1170 ns**
Total (Signal Acceptance for the μ-e conversion)	**0.041**	

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

Number of muons stopped inside targets
N_μ = 1.5 x 10^{16}

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

Fraction of muons to be captured by Al target = 0.61

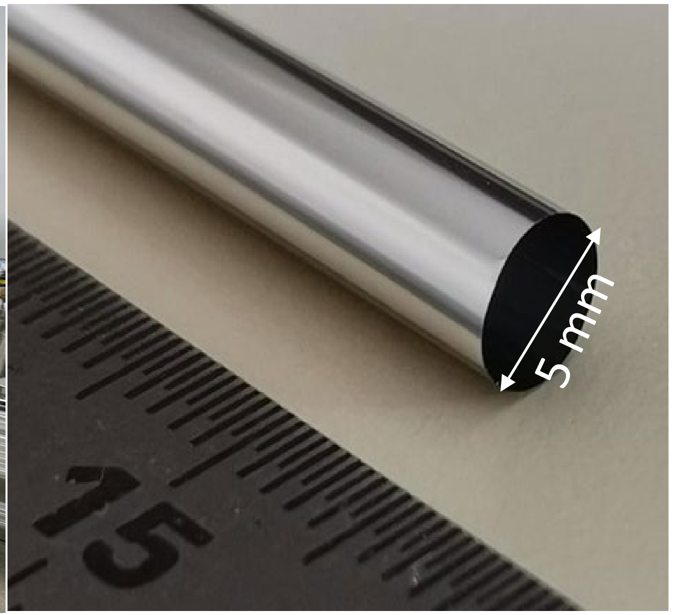
3 x 10^{-15} (as SES) achievable in ~ 150 days, or < 7 x 10^{-15} (as 90% C. L/ upper limit)

JINR group’s contributions and responsibilities

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

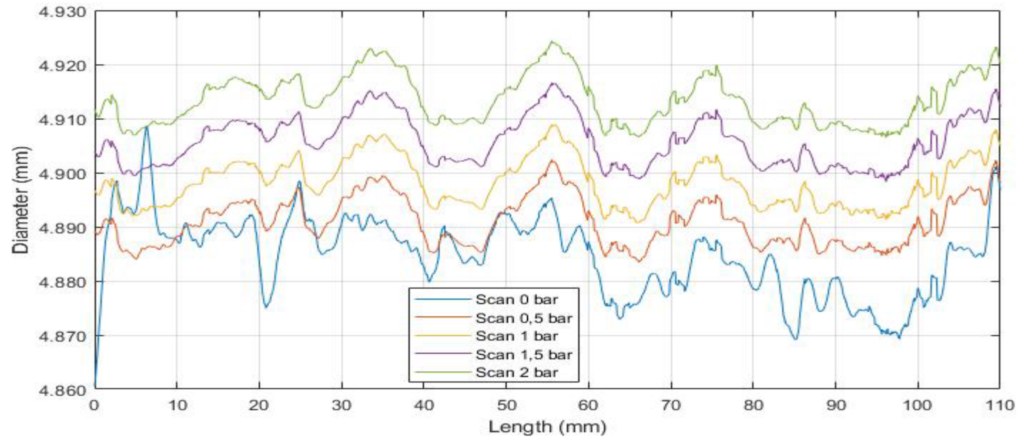
The manufacturing area for straw-tube R&D at DLNP

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



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

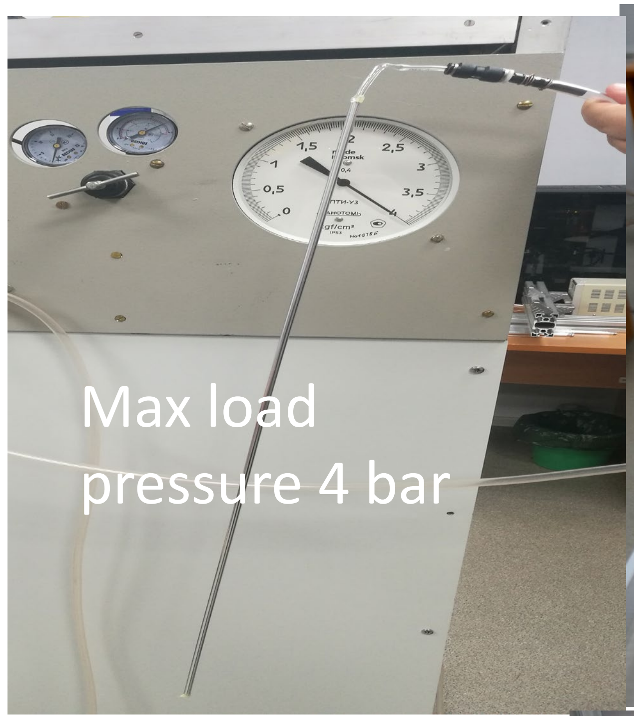


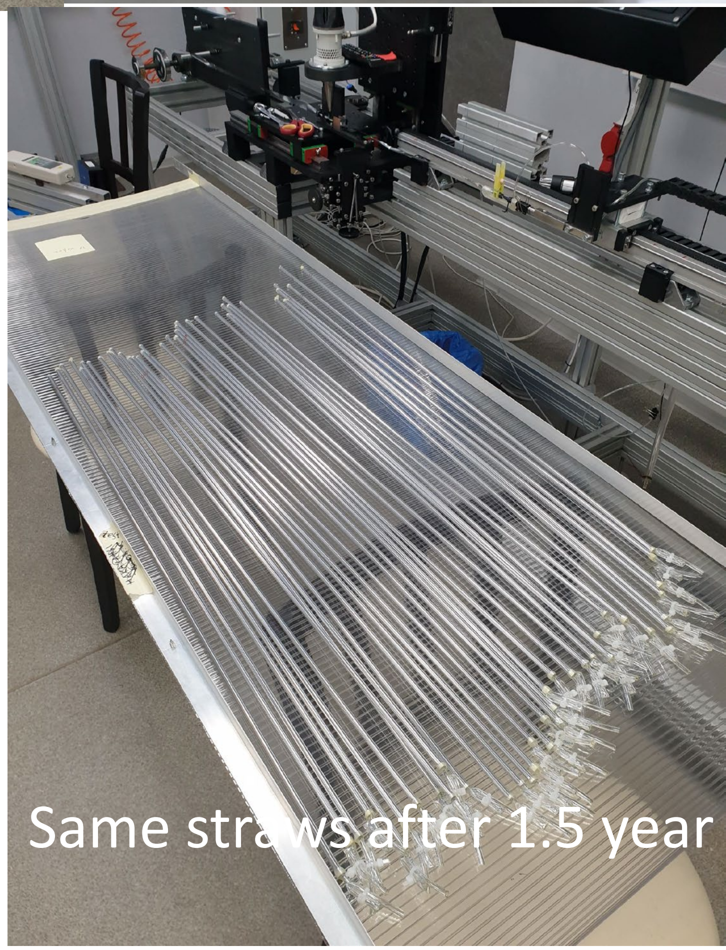
- Diameter scan along straw tube length with different inner pressures
- Diameter deviation along the tubes is less than 20 µm,
- Shape stays consistent under different pressures

Prototype straw parameters

- ❑ 3-4 years ago, the first R&D for 12 µm straw tubes started
- ❑ In a scope of new straw tube mass production for JINR straw tracker prototype
  - 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

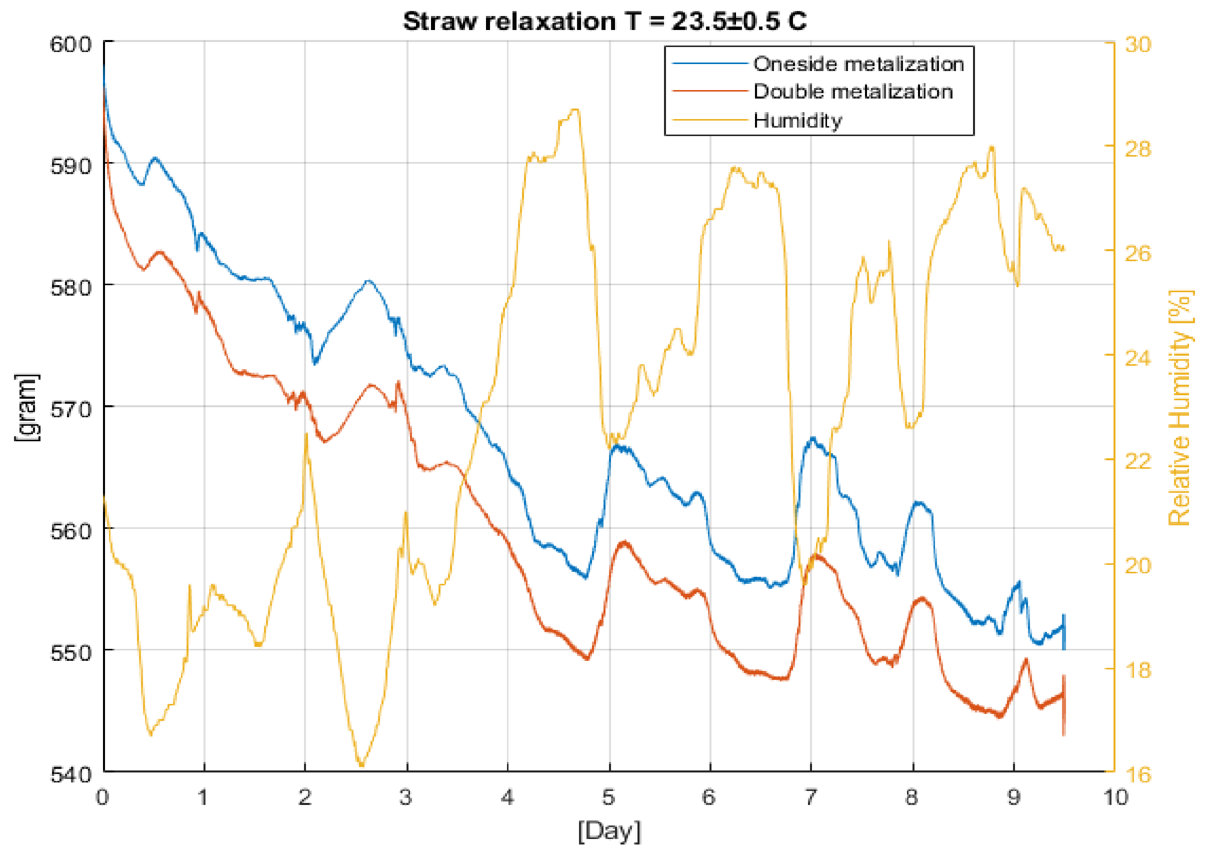
Straw tube tension versus humidity

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.

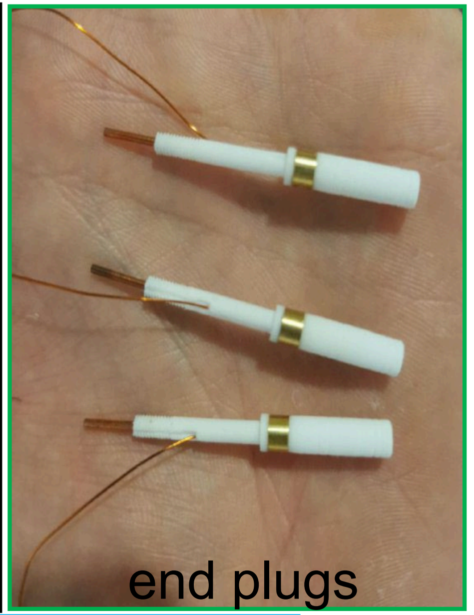


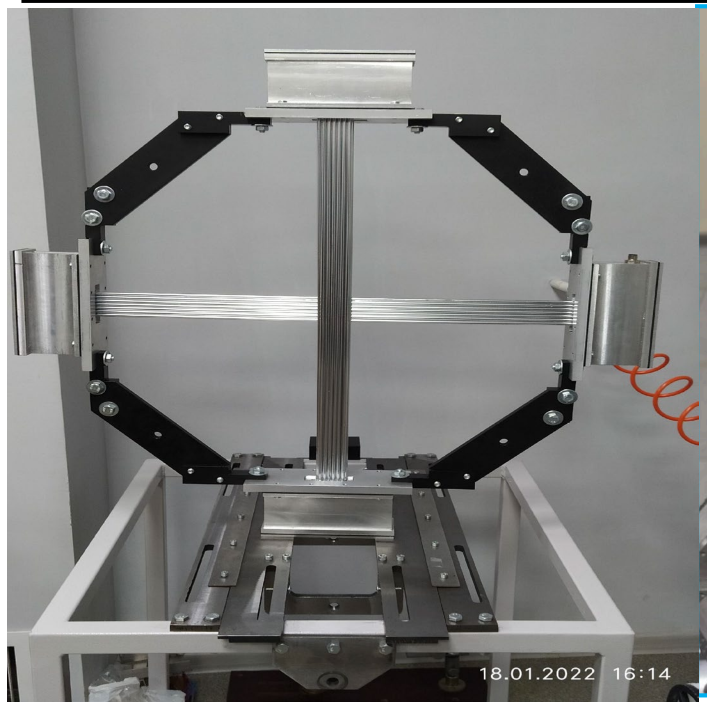
Frame build in progress

- ✓ 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

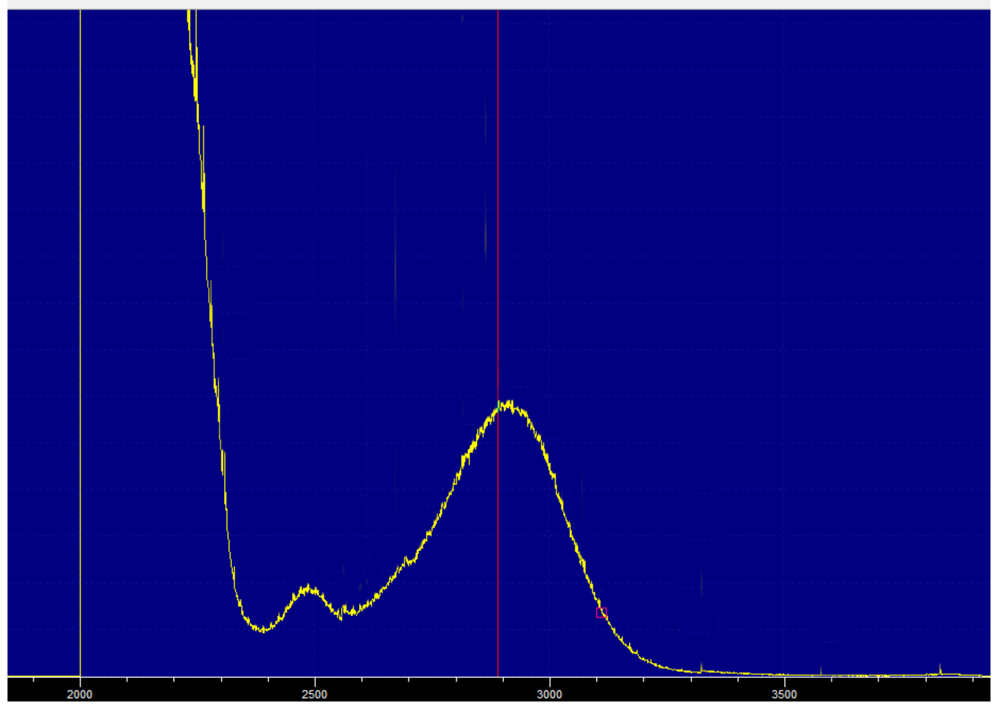

components

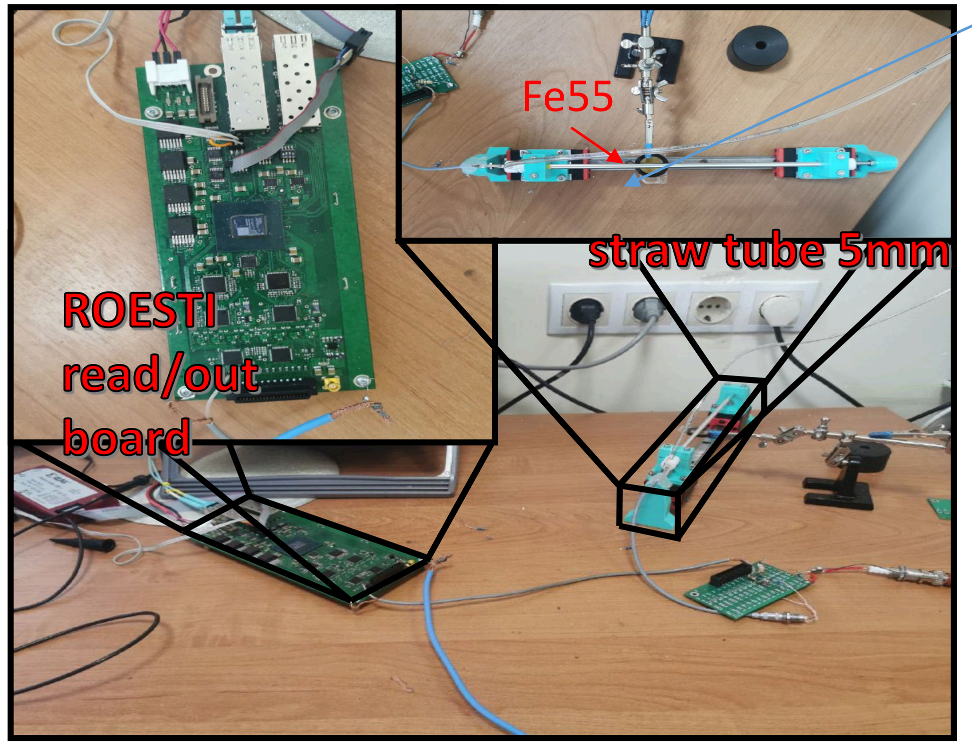

end plugs



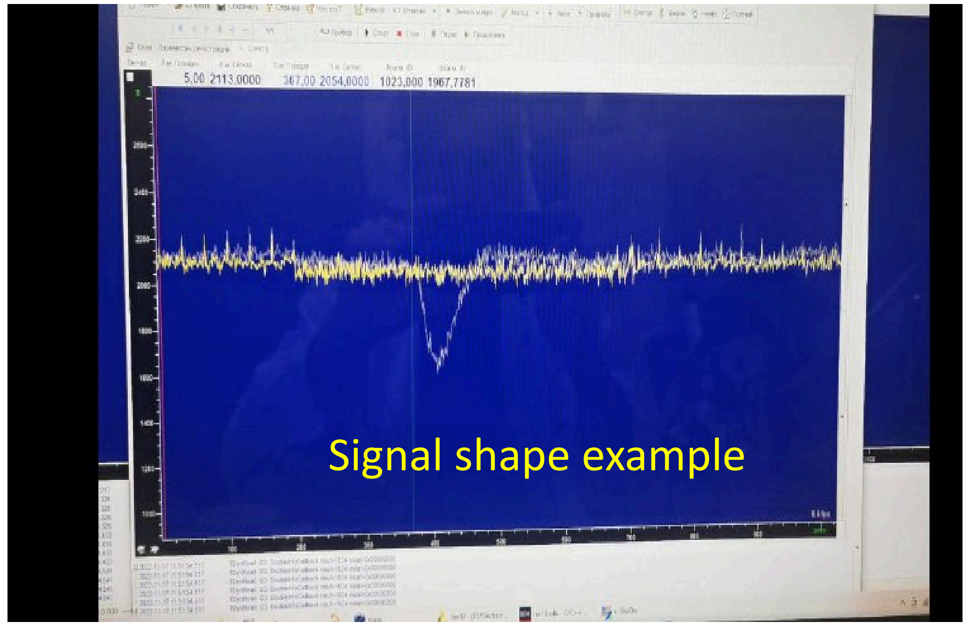
Test setup for ROESTI (read-out) COMET board

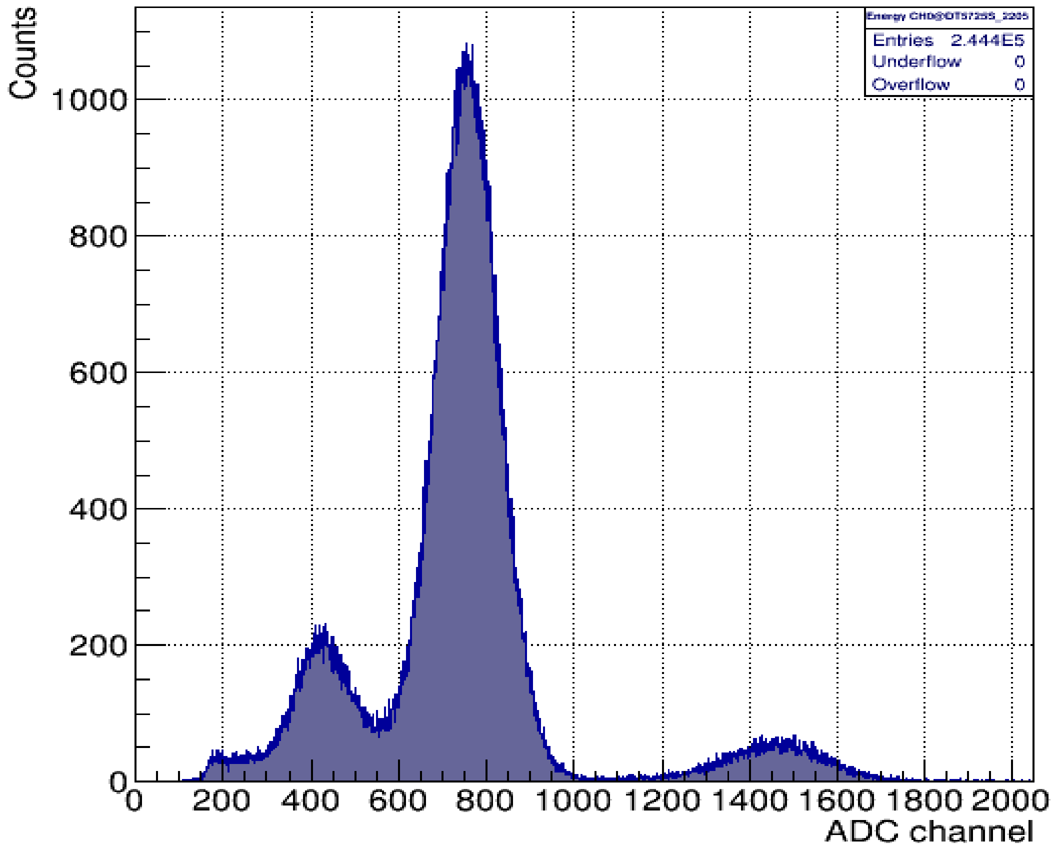
Gas Mixture – Ar-70% CO2 – 30% , Straw tube 5mm, Anode wire – 50 μkm, HV – 1800 V





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



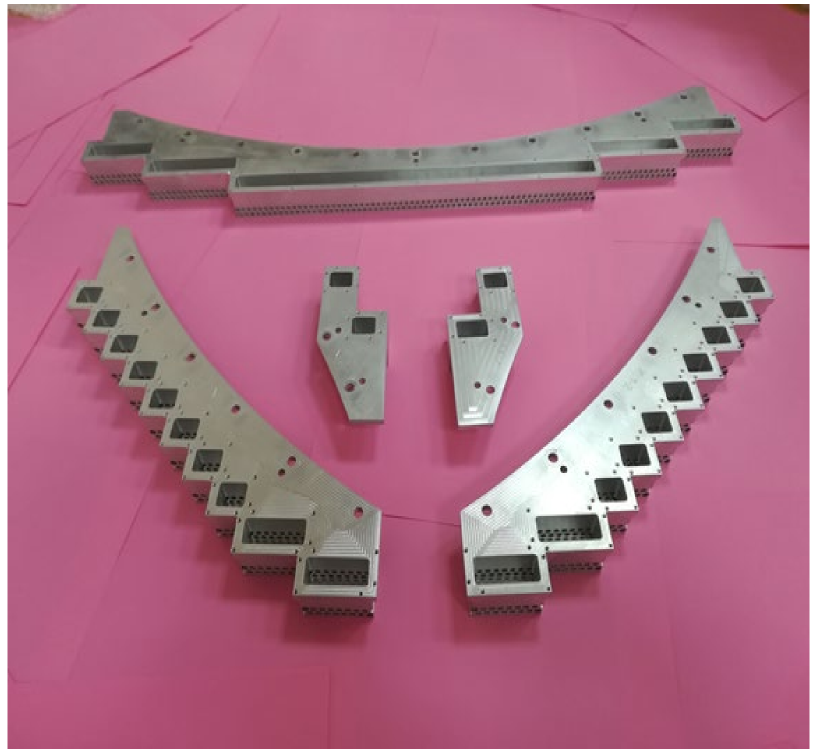


In progress
- Assembly of the channel on a wire of 20 and 15 microns

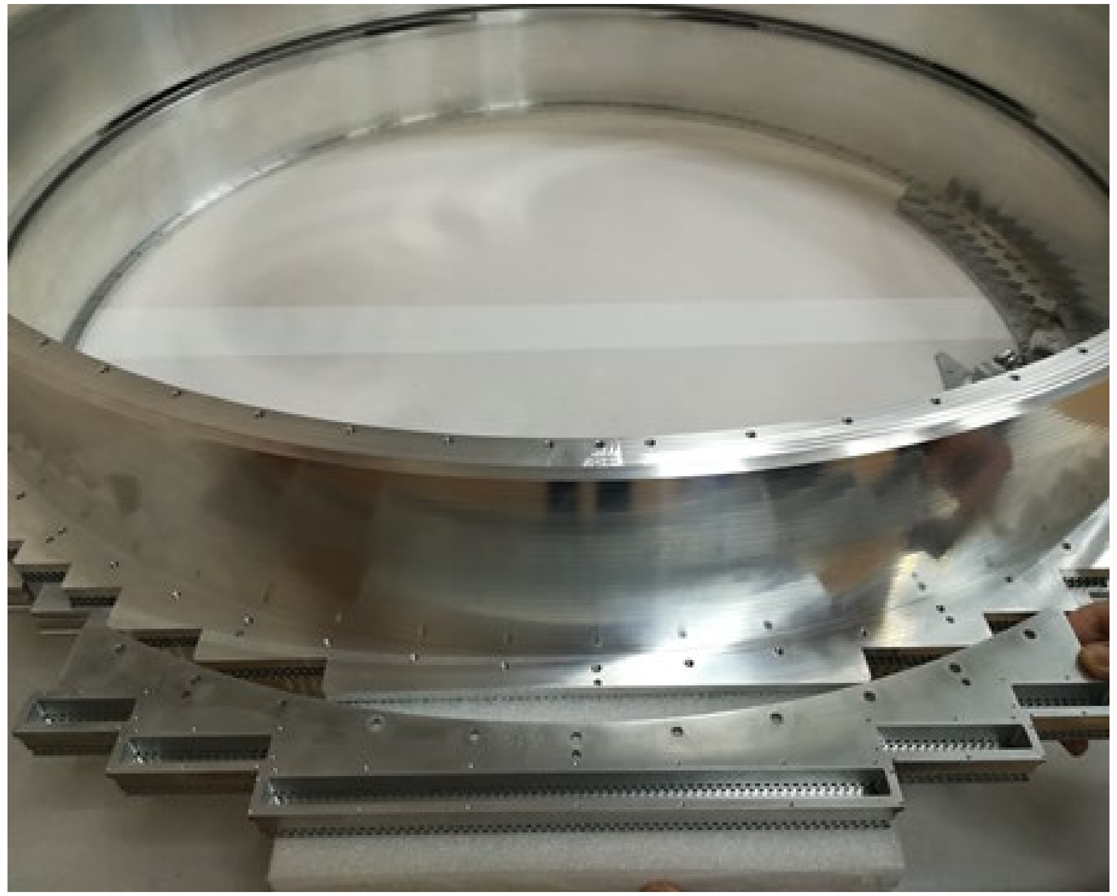
Straw 5mm; Monitor ^{55}Fe + ^{57}Co; Expos.100sec; . HV-1680V; Gas 60:40(Ar:Co^{2}); Anod 20mkm

JINR straw module

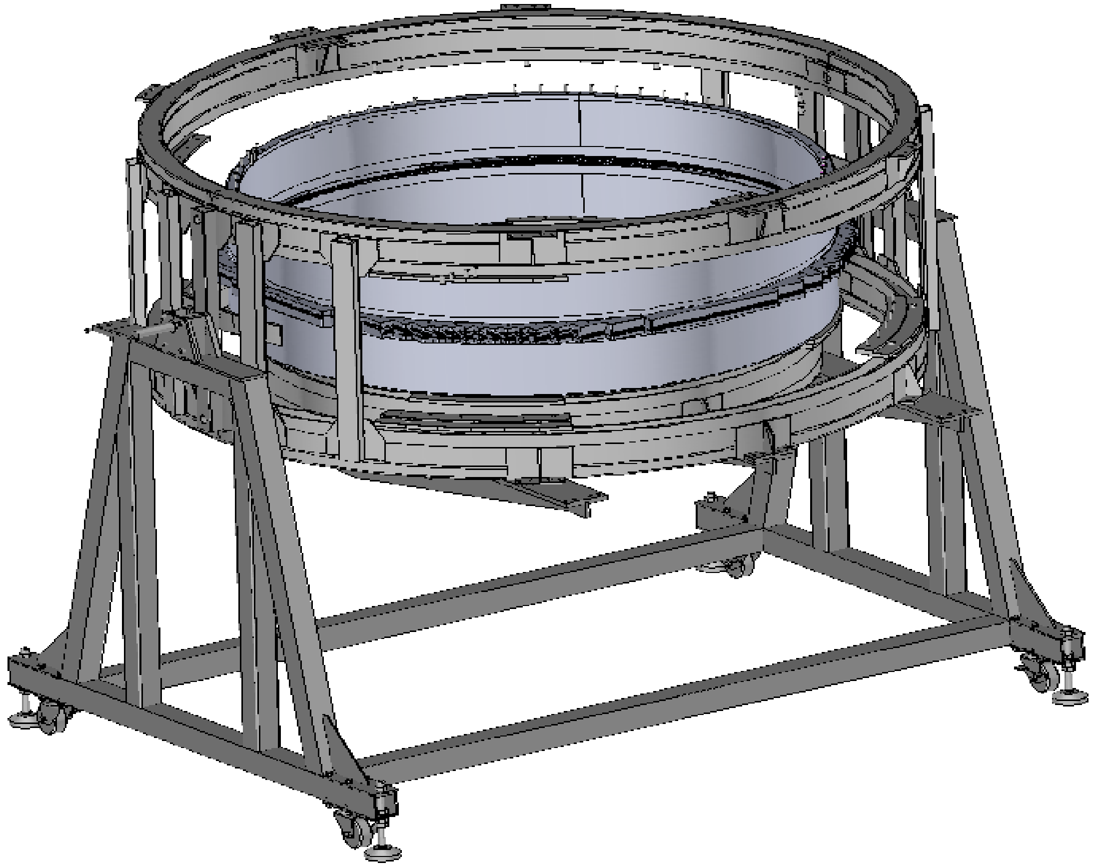
Support frame of the straw module



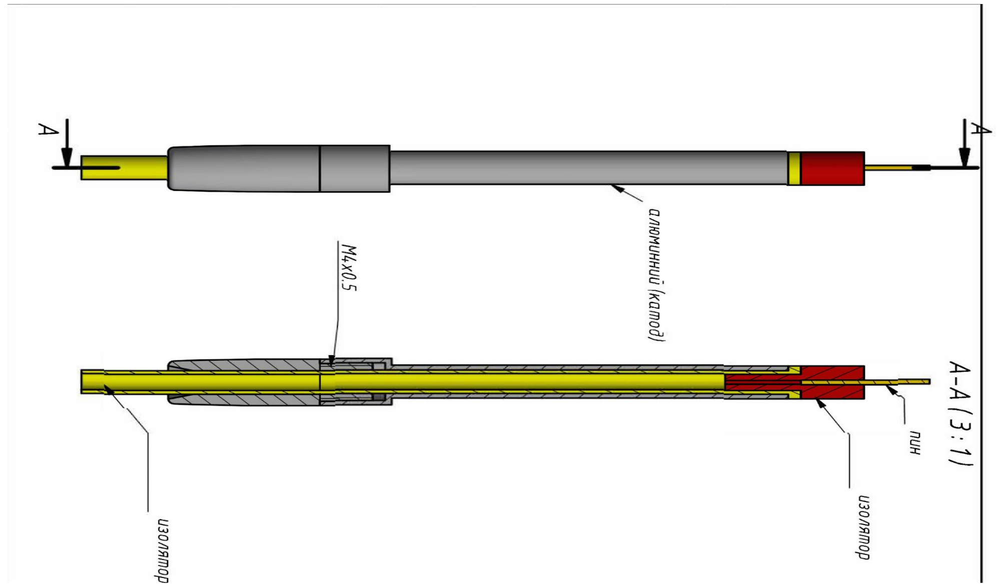
Built-up construction of the manifold



Central part of the gas manifold is attached to the frame.

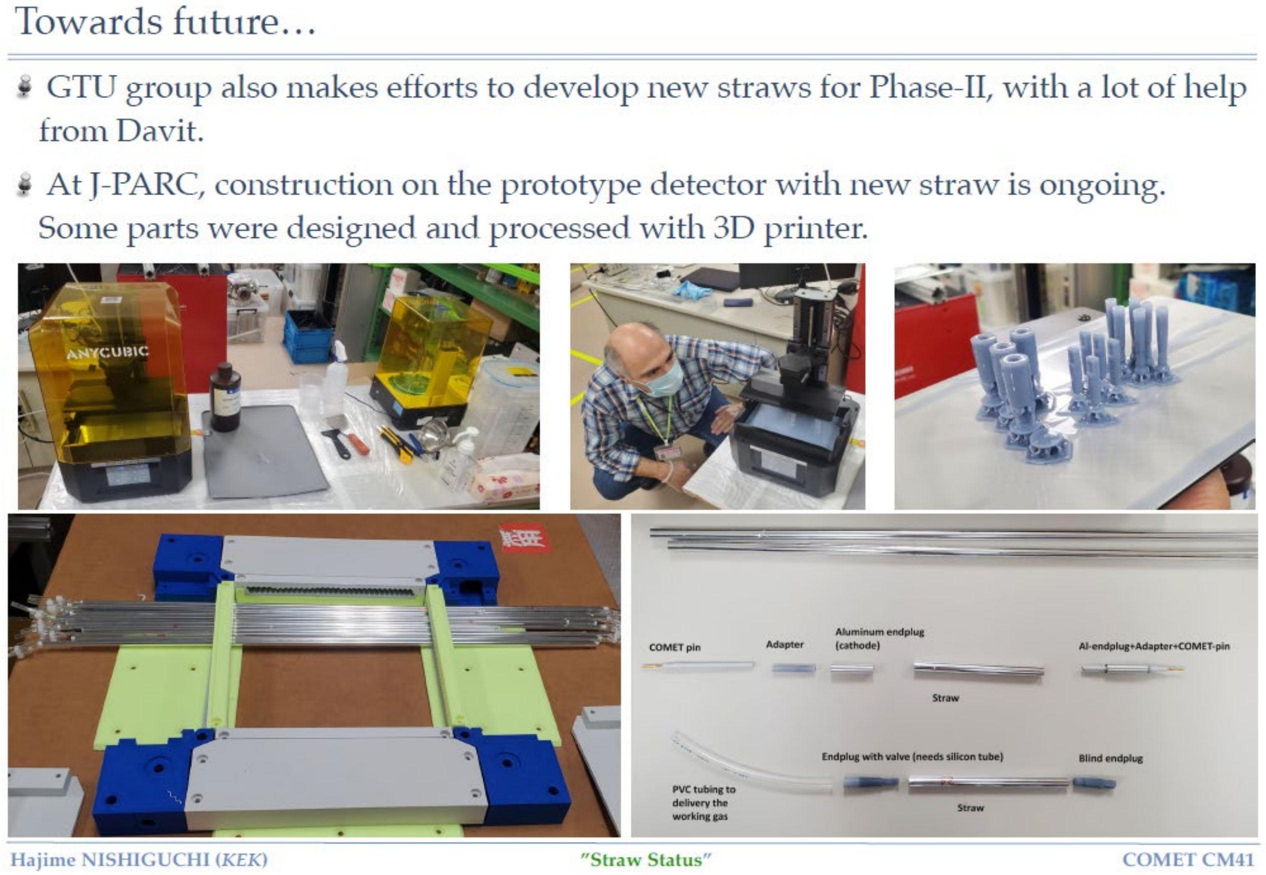


View of the jig for assembling the module



View of the end-plug

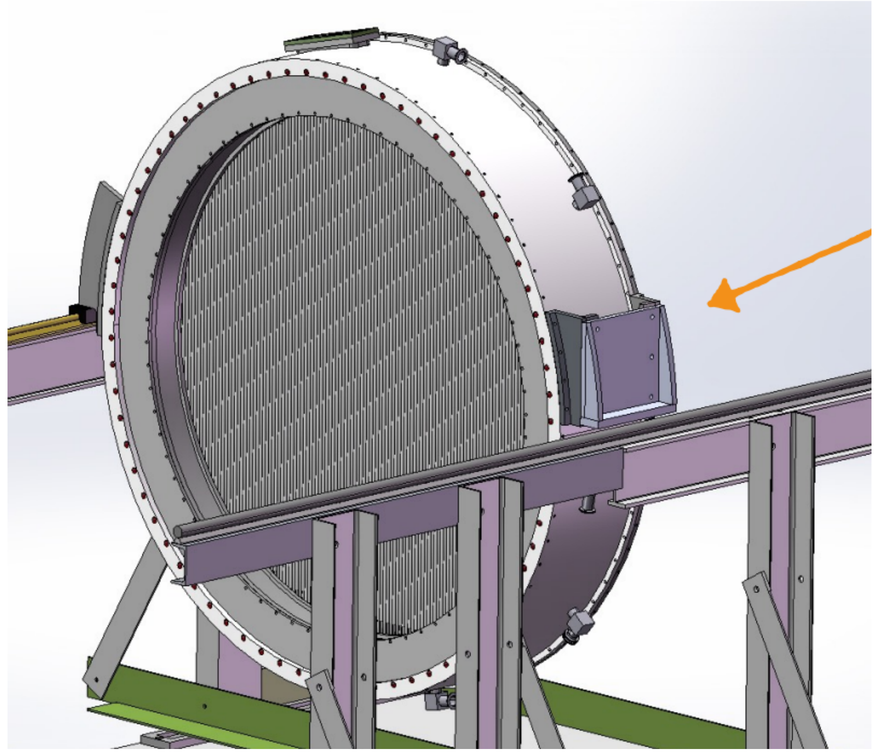
Straw Tracker Status — COMET Phase-I



1st layer, completed !!!

- 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

Modification is ongoing to be also used for Phase-α



Assembly for Straw Station #2 and #3

Electromagnetic calorimeter

R&D of the COMET calorimeter

R&D of LYSO crystals for COMET calorimeter:

1) simulation of the LYSO electromagnetic calorimeter for COMET experiment
2) optical parameters (relative light output, decay time, energy resolution) of LYSO:Ce crystals, LYSO:Ce,Ca from Saint-Gobain (France) and LYSO:Ce from JT Technology (China) were measured;
3) non-uniformity of the of light yield distribution along the length for these crystals, which is the main reason for the deterioration energy resolution for the case of curvilinear electron tracks, as is the case in the COMET calorimeter located in a uniform magnetic field;
4) a method for optimal wrapping of crystals has been developed, which makes it possible to improve the uniformity of light collection from crystals;

R&D of the COMET calorimeter:

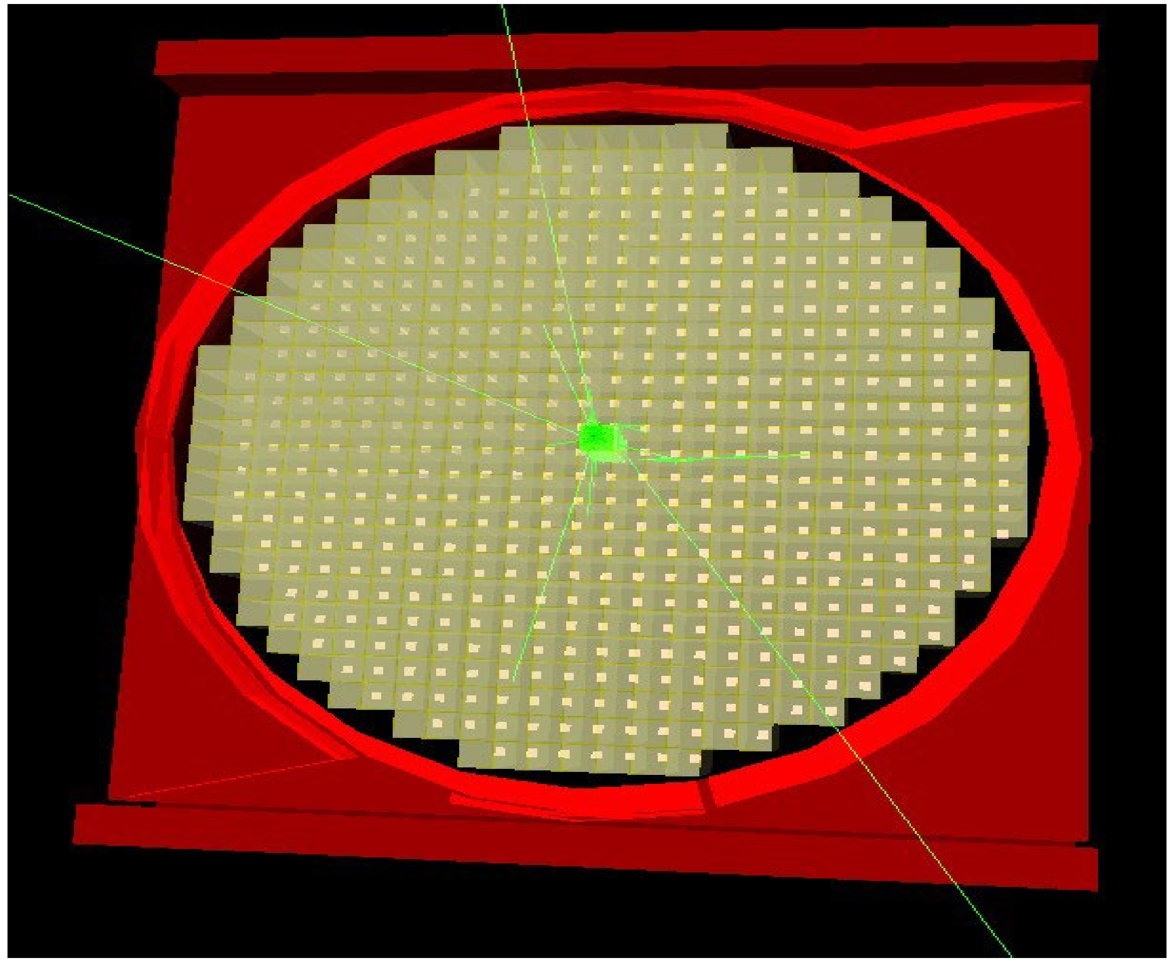
1) measurement results of the detector response along the crystal length was obtained using cosmic muons:
2) measurement results of the detector response for angles of 0, 9 and 19 degrees was obtained using cosmic muons:

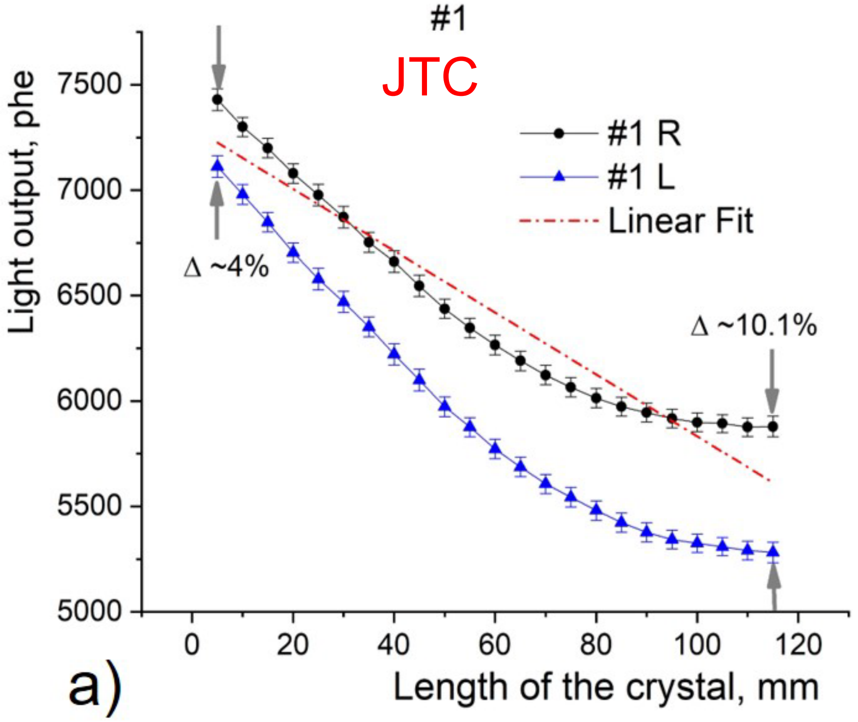
R&D of LYSO crystals, LYSO crystal parameters investigation

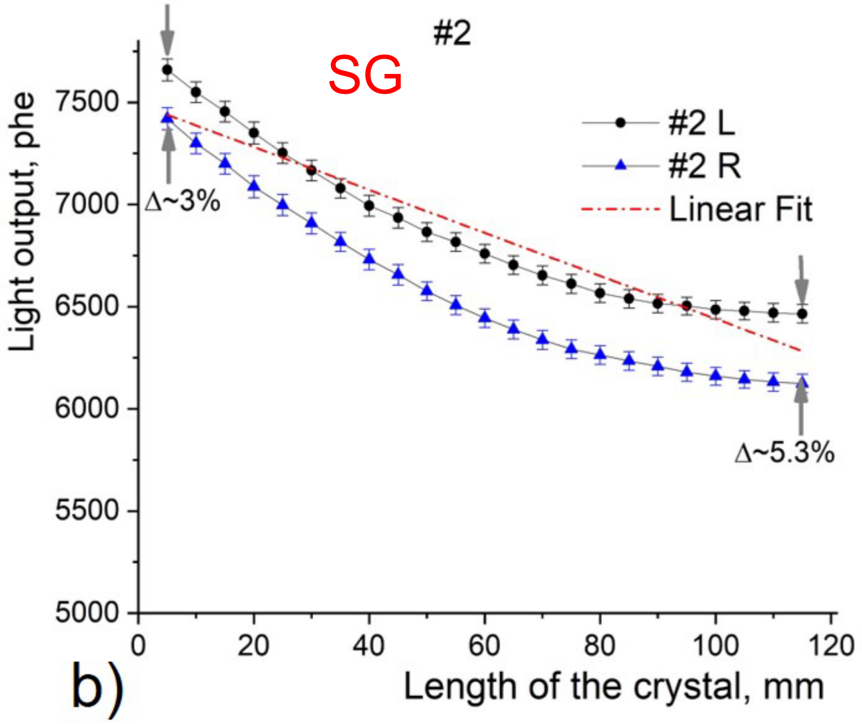
Three candidates vendors
- **Saint-Gobain (SG), Baseline**
- OXIDE (OX), Japan
- Suzhou JT Crystal Technology (JTC)

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	

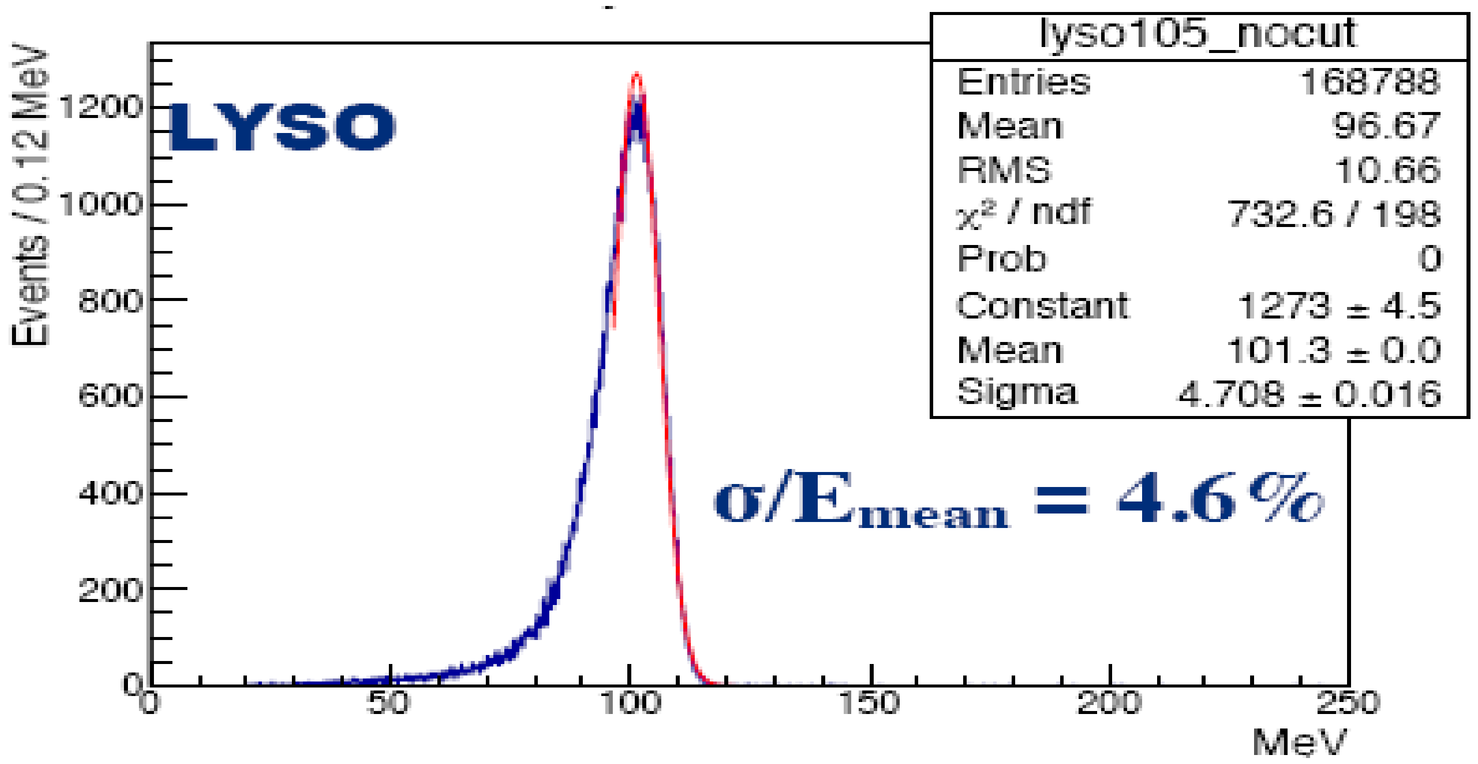




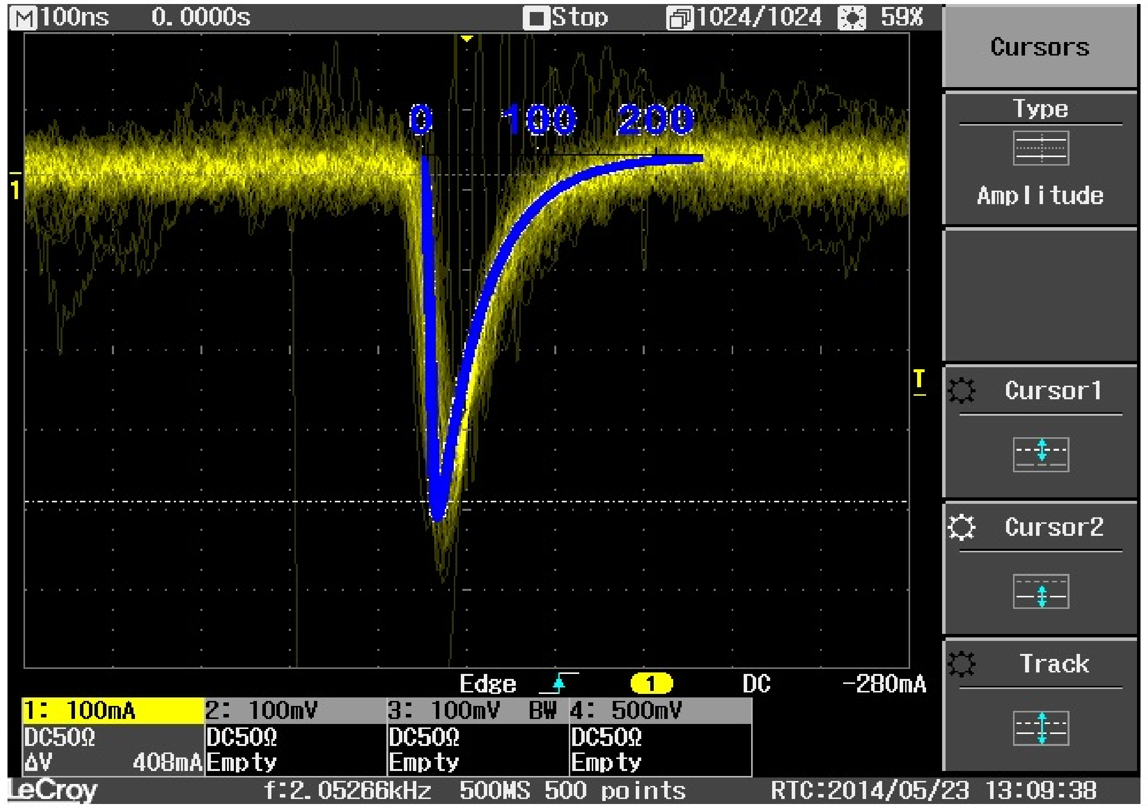


Light yield distribution along the LYSO:Ce crystals length for two positions of the photodetector (left and right) relative to the length of the crystal: a) JT Technology crystal; b) Saint-Gobain crystal

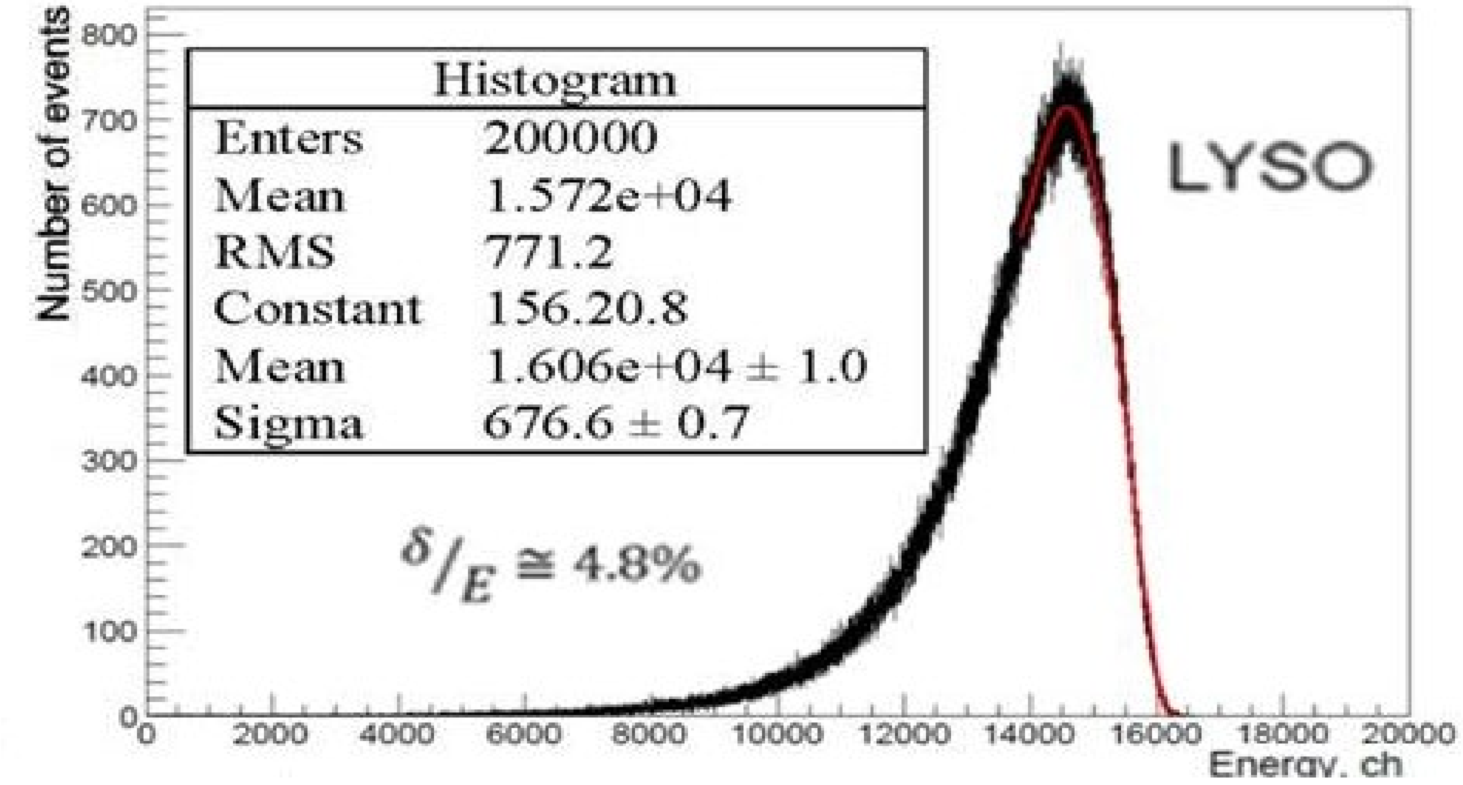
G4 simulation of the LYSO calorimeter: energy resolution



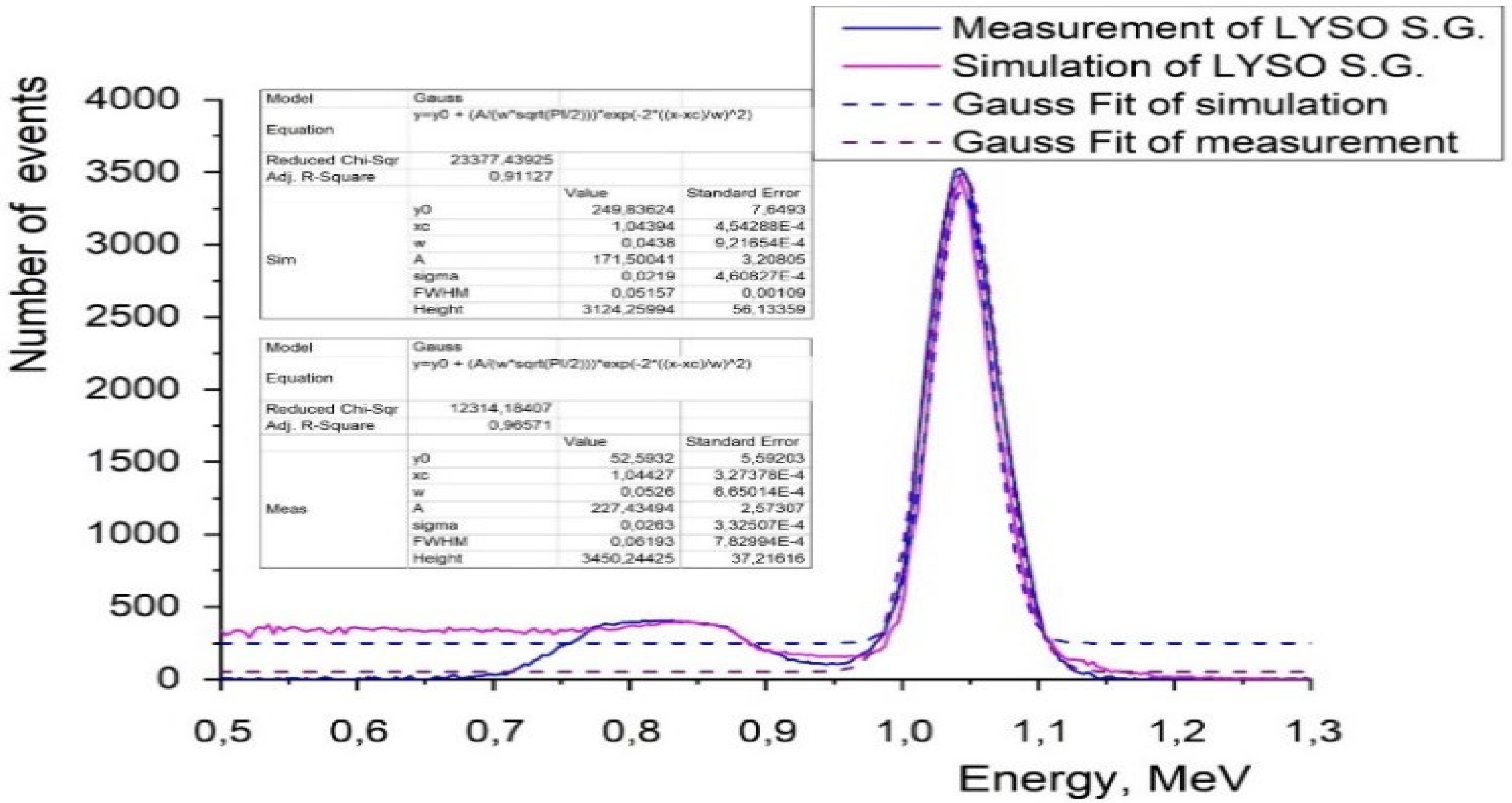
Energy resolution of calorimeter prototypes
at the 105- MeV electron beam (measurement, Tohoku)



Comparison between simulated and measured LYSO spectrum arrived

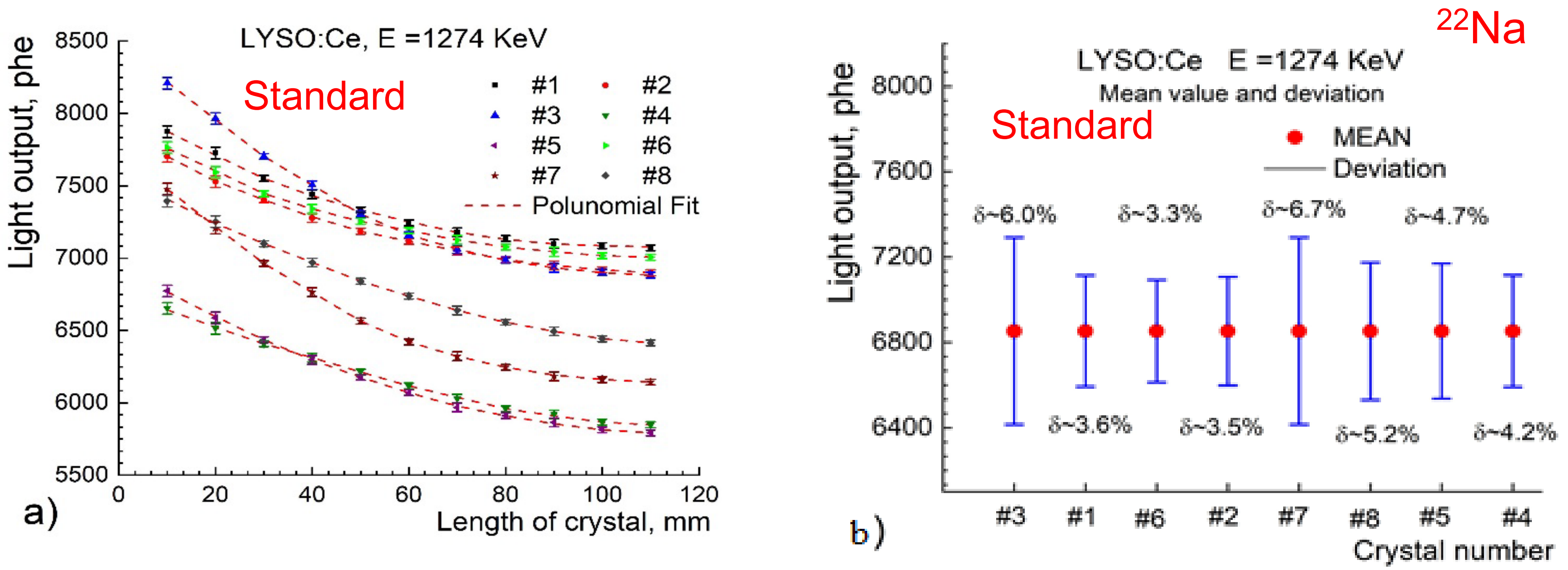


Energy resolution of the calorimeter on LYSO crystals
at the 105 –MeV electron beam (simulation using optical model)



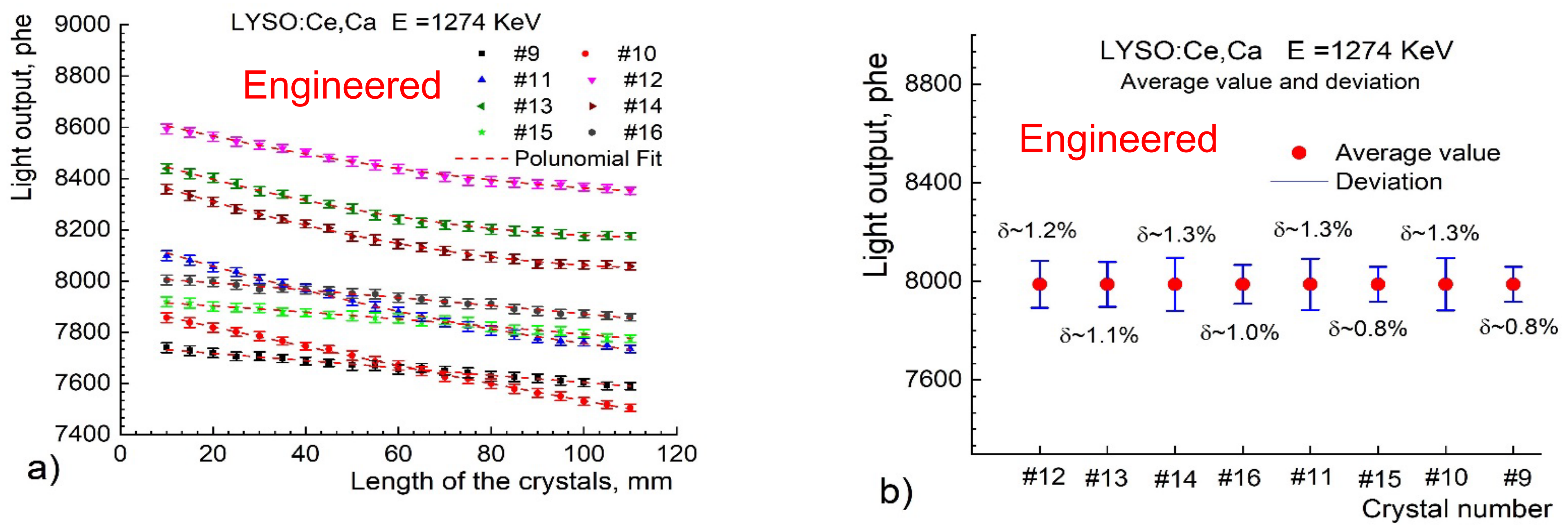
Comparison between simulated and measured energy spectra of LYSO crystal

Studying of the light yield distribution along the crystal length



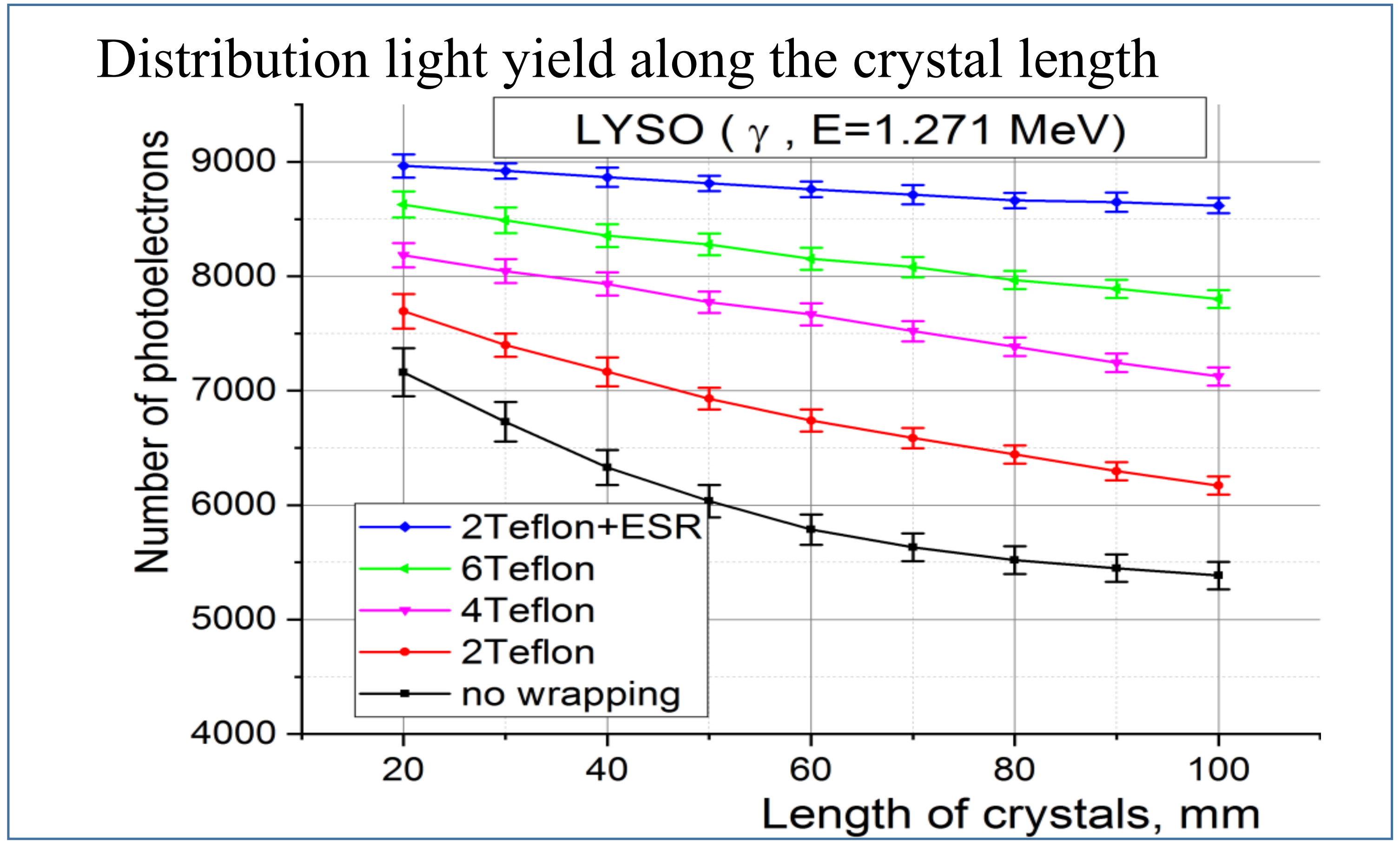
Crystal	Energy resolution,%		Light yield scatter, %	Mean value of scintillator response non-uniformity, %
	511, keV	1274, keV		
LYSO:Ce	9	8,5	17	4,6
LYSO:Ce,Ca	6,4	6	10	1,1

a) Light yield non-uniformity along the LYSO:Ce crystals length
b) (scintillator responses); b) scintillator responses non-uniformity

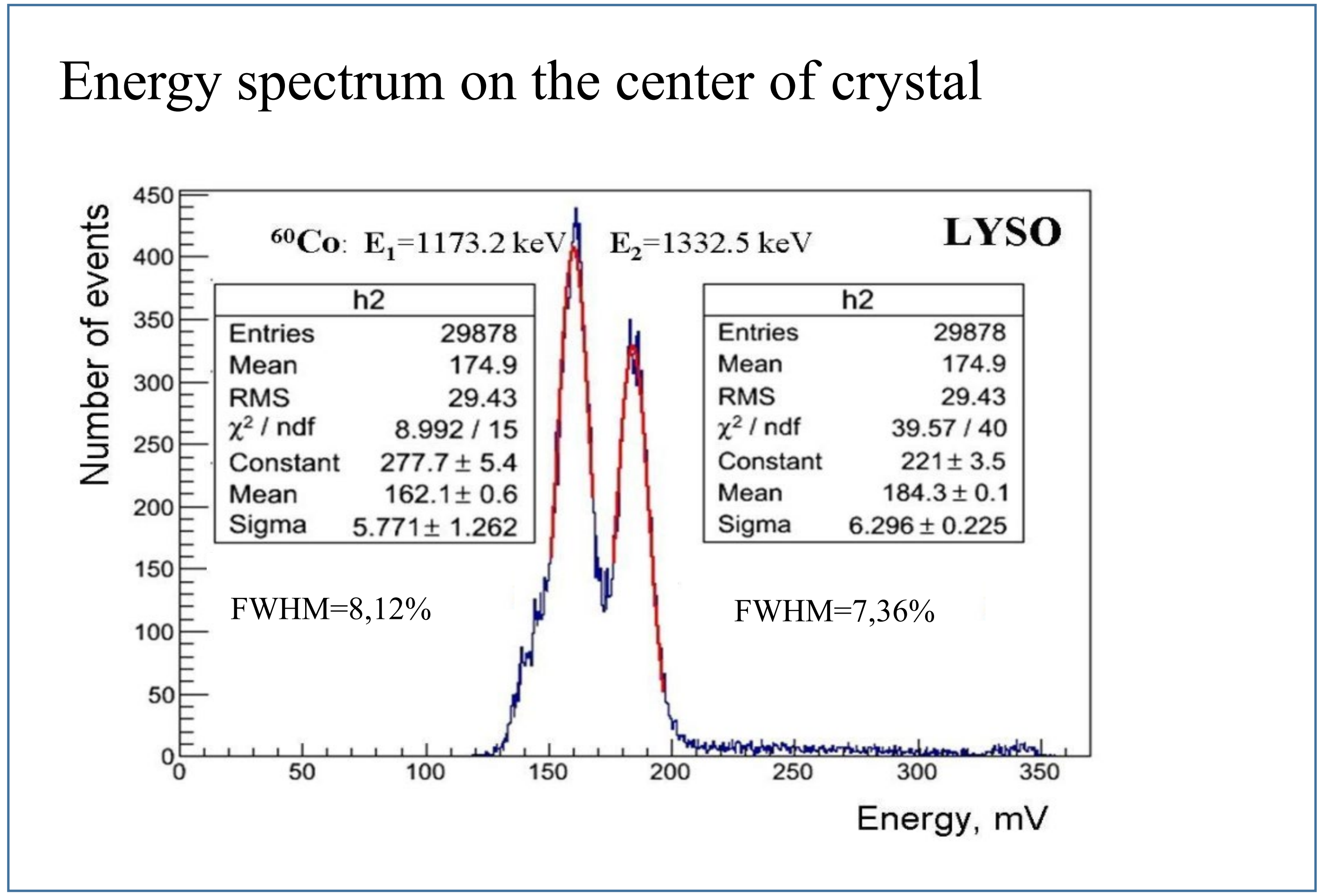


a) Light yield non-uniformity along the LYSO:Ce,Ca crystals length of (scintillator responses); b) scintillator responses non-uniformity

Development of the optimal wrapping of crystals



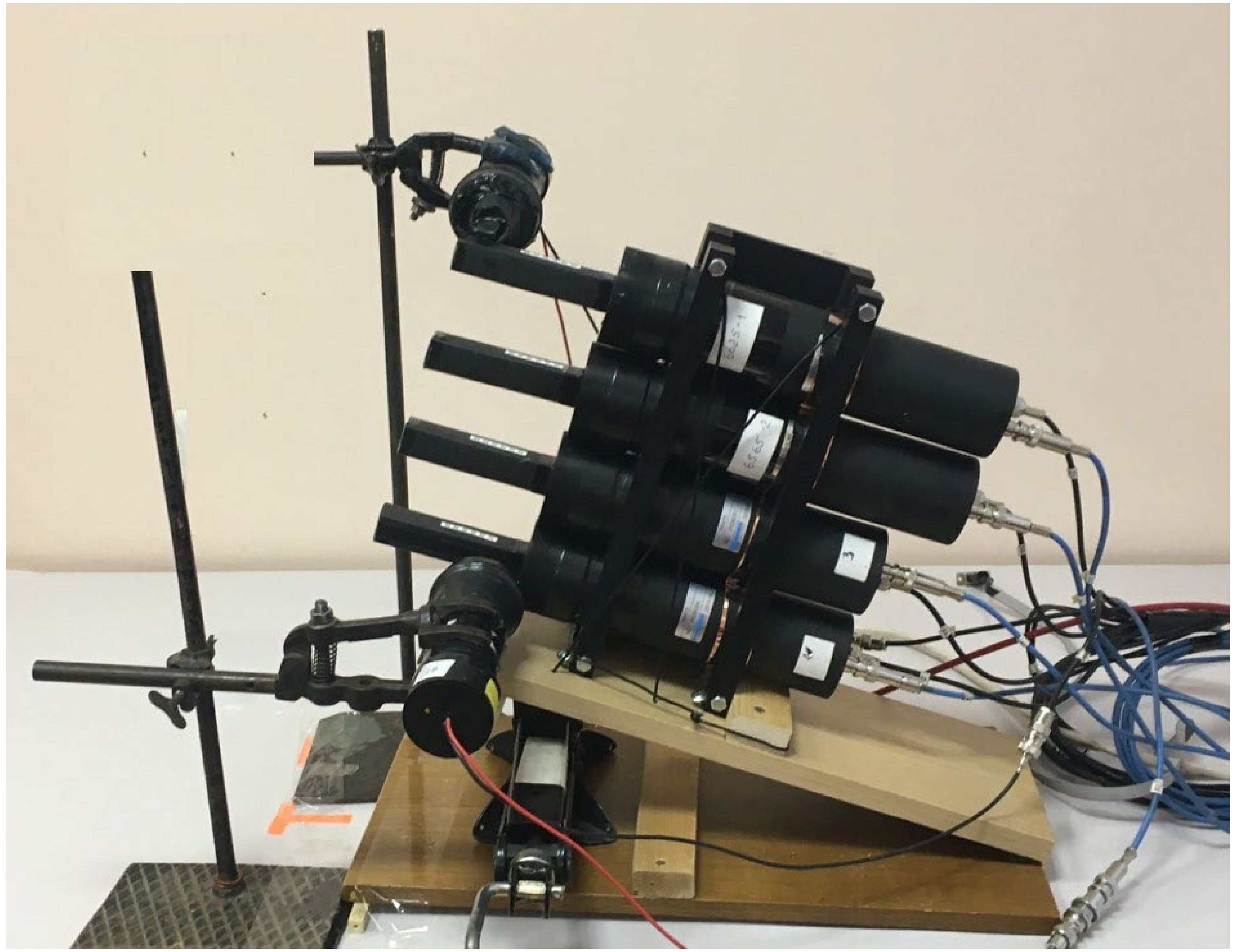
Light yield non-uniformity along the crystal length for various types of reflective materials



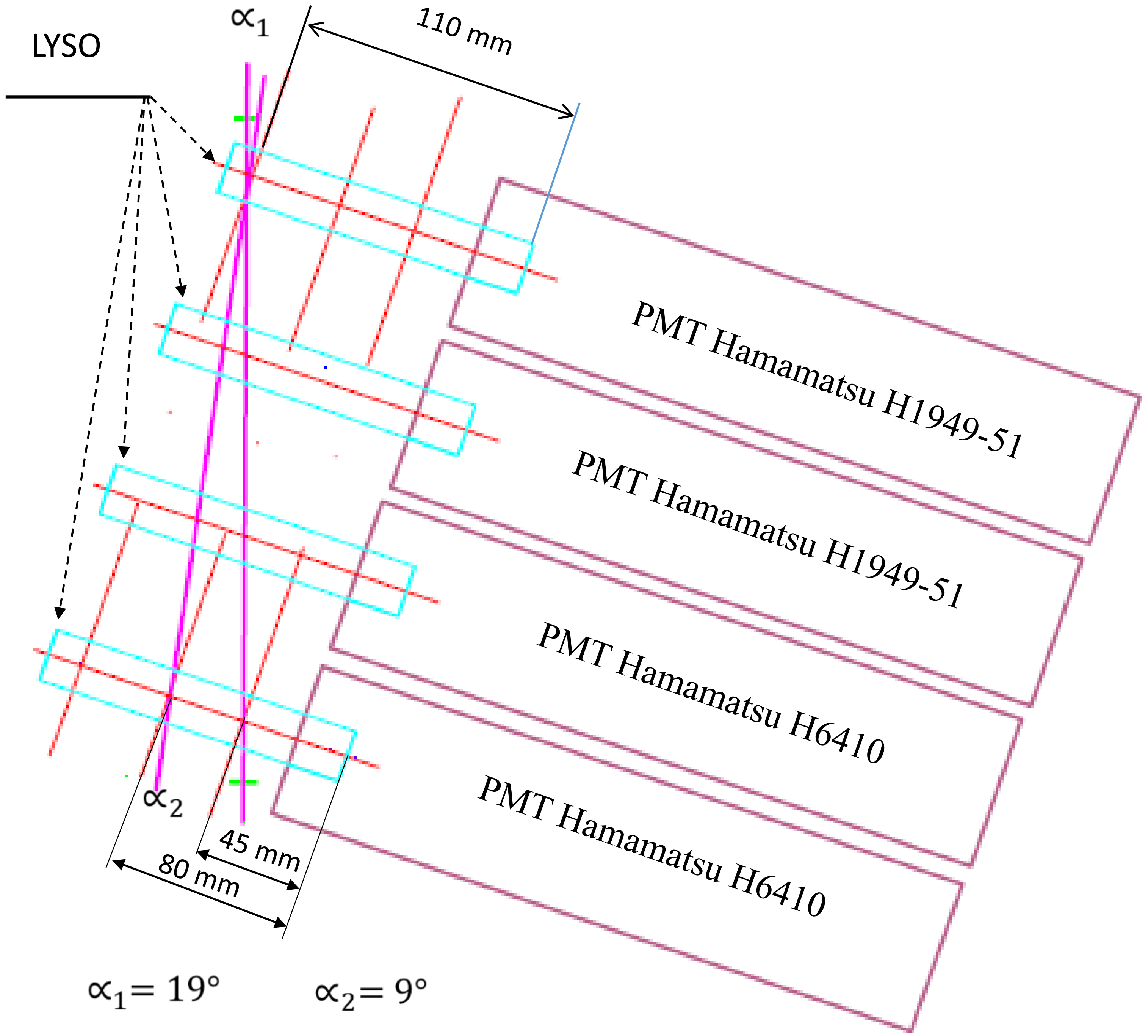
Energy spectrum of a crystal with optimal wrapping

	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

Measurement of parameters and estimate of the energy resolution of the calorimeter prototype using cosmic muons



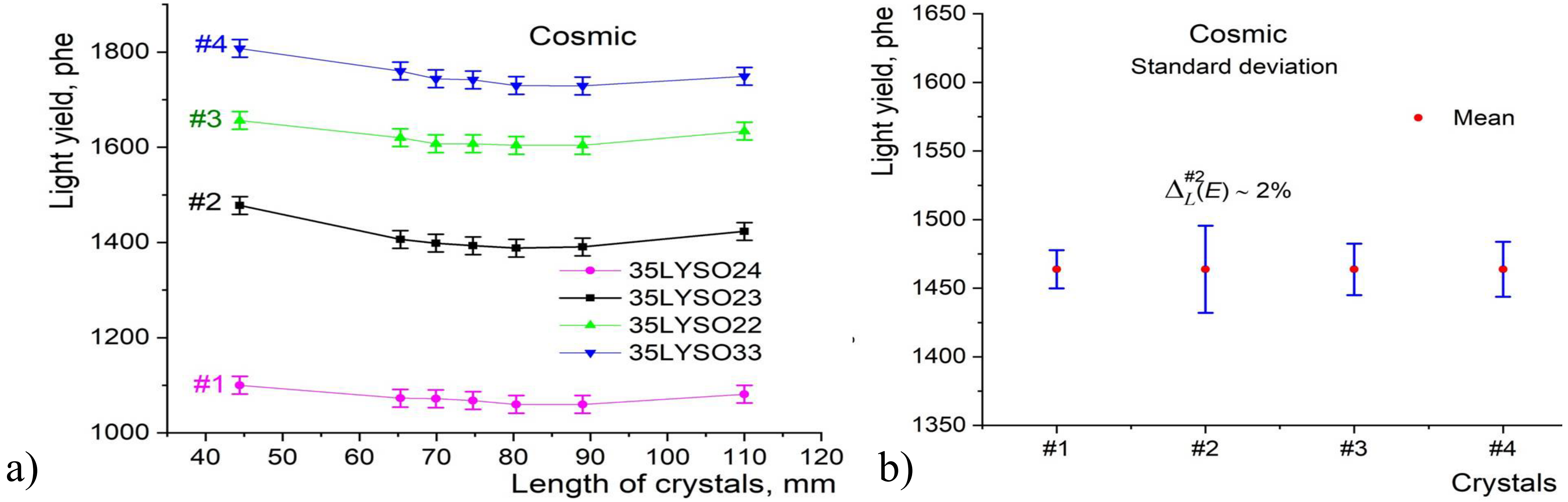
a)



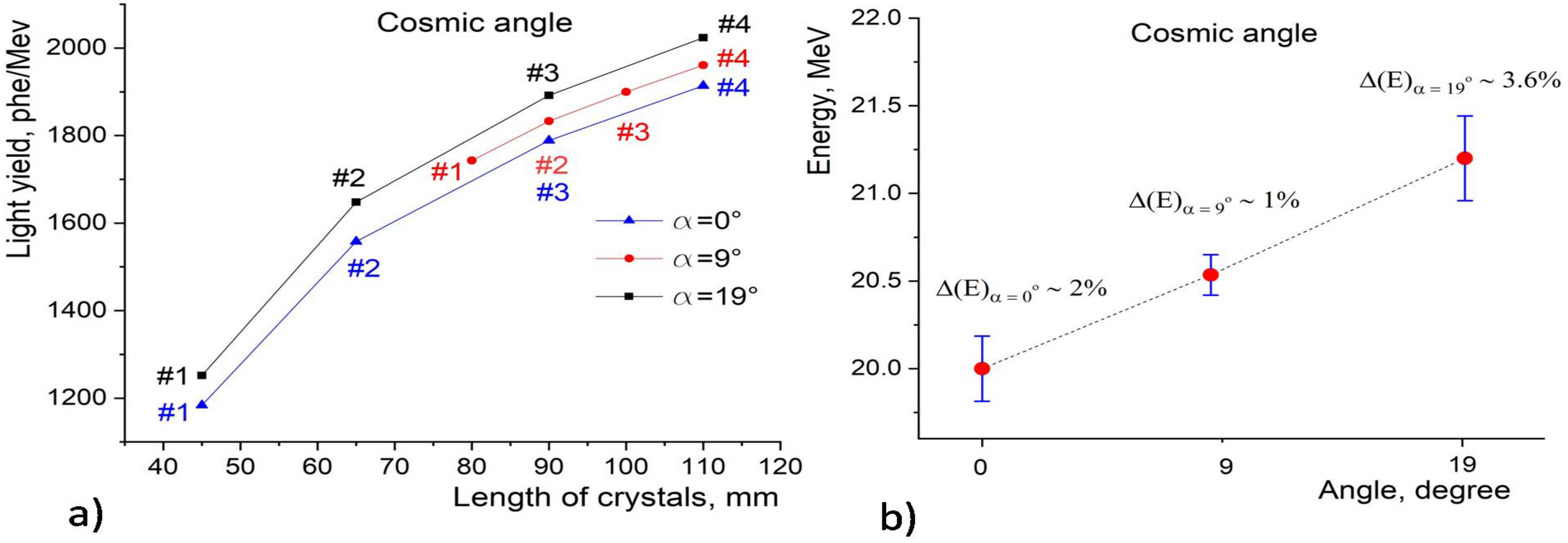
b)

a) Measuring setup

b) Measurement scheme



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



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

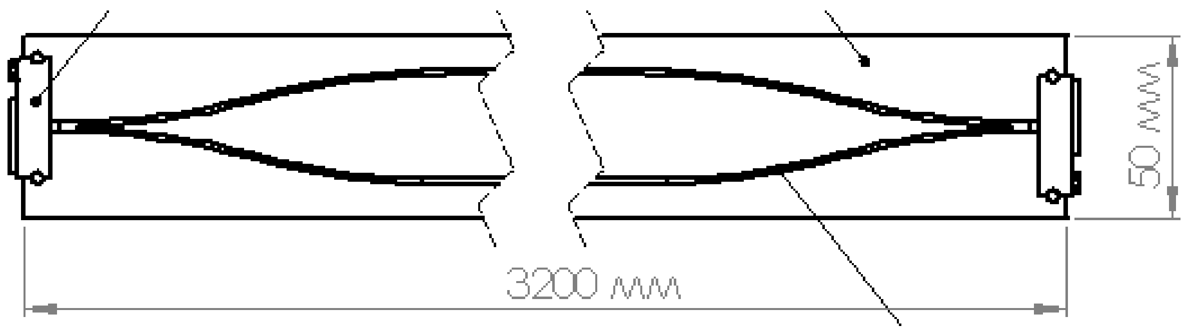
Cosmic-Ray Veto (CRV)

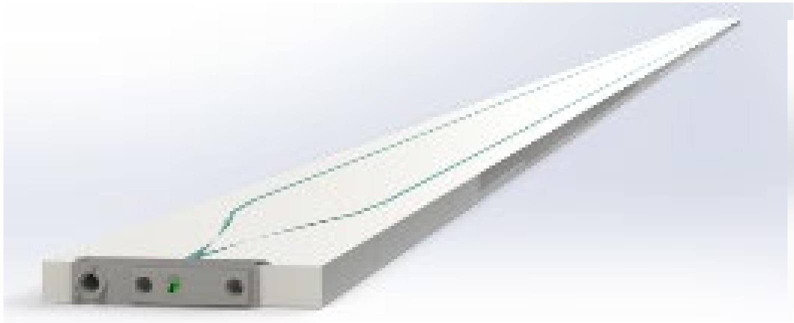
COMET CRV major goals

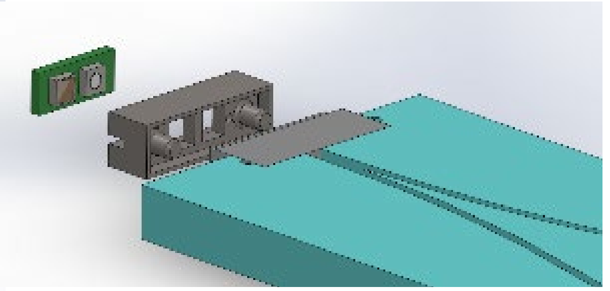
- Muons from cosmic rays mimic the 105 MeV conversion electrons and, as a major source of background, would reduce the experiment overall precision. So, to suppress the cosmic muons, the Cosmic-Ray Veto (CRV) system becomes as an essential part of the COMET experiment. It will cover around of the COMET 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.
- **We proposed the final designs of the strip and CRV module were discussed during the COMET Collaboration Meeting 34 and 35 and it was approved for SCRV-LS-0**.
- **First 3.2-meter long CRV module already created and sent to J-PARC**

Scintillation strips as a base element of the COMET SCRV modules

Design of the strip







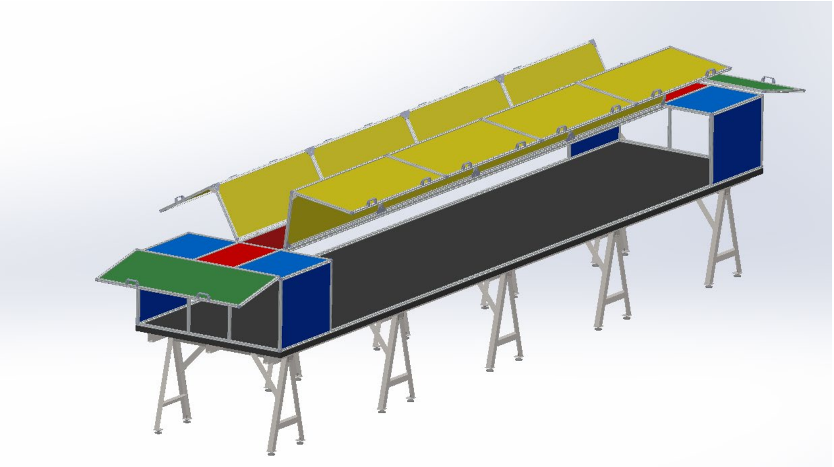
Sketch of the strip with SiPM board and housing. The real look of the SiPM PCB inserted to the housing

Real strip

Hamamatsu MPPC/SiPM S14160-3050HS in housing

- Whitin of this search (including the aging (deterioration of the light yield by time) effect prediction based of our previous research) 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 thus ensuring maximum efficiency of the strip to detect the cosmic muons

Strips test stand



The test stand sketch

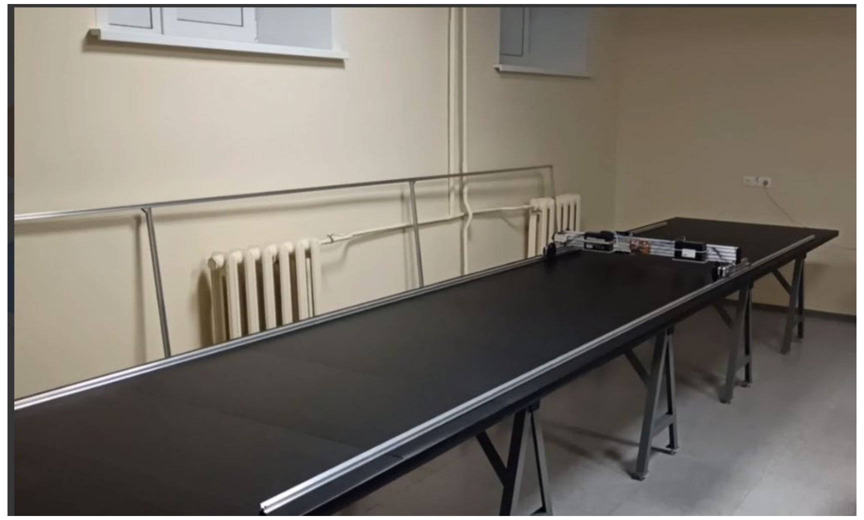
Test stand full assembly

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.

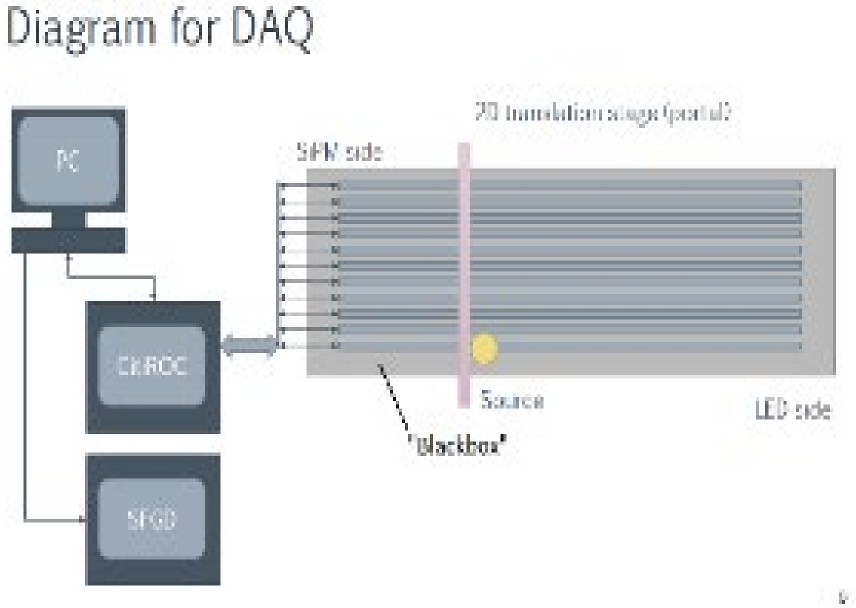
- To test the strips, we created the lightproof 6-m-long test stand with 2D translation stages (so-called 2D-portal). The collimated by 1 mm diameter radioactive by $^{90}Sr/^{90}Y$ β-source with 0.06 mCi beta-source was used to exam the strips along the distances. Light from SiPMs were collected using 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

Layer	left 1	2	3	4	5	Top mount point view 6	7	8	9	10	11	12	13	14	15	right 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

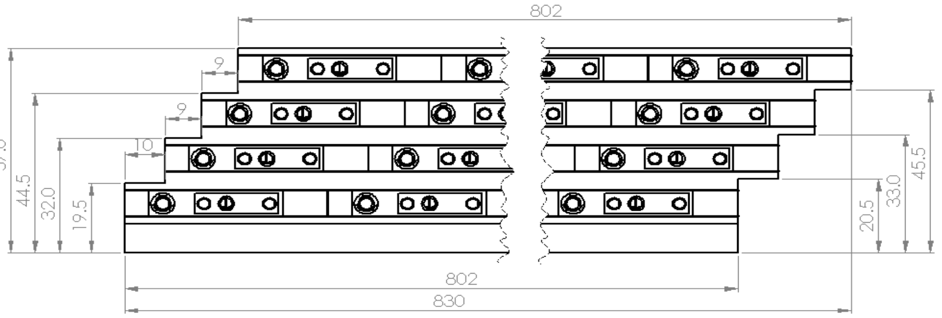


2D portal in the table



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

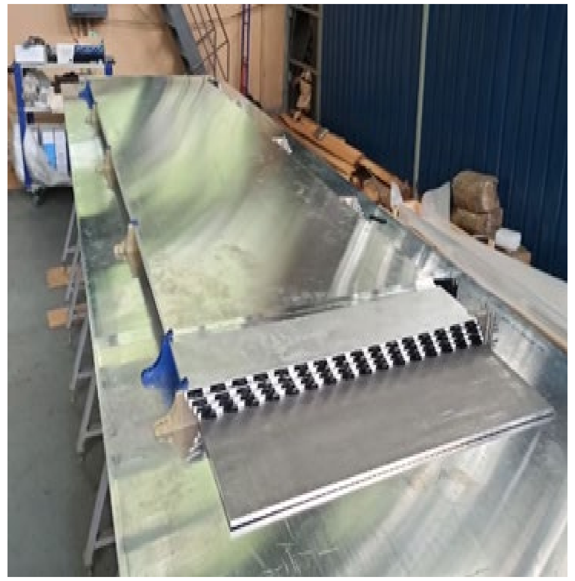
First CRV module assembly and preliminary test on cosmic



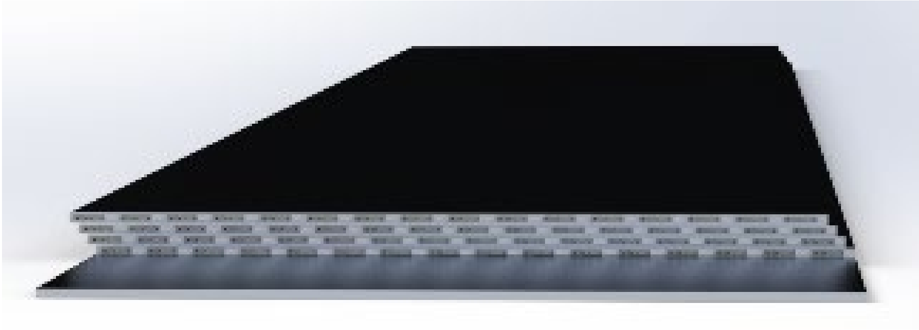
SCRV design

- 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

Compressed by 1 bar CRV module

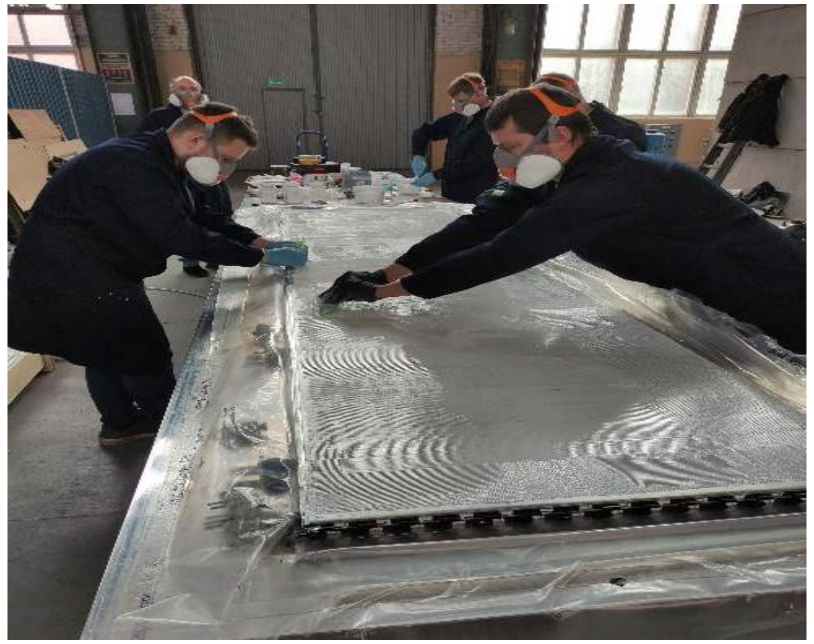


CRV module

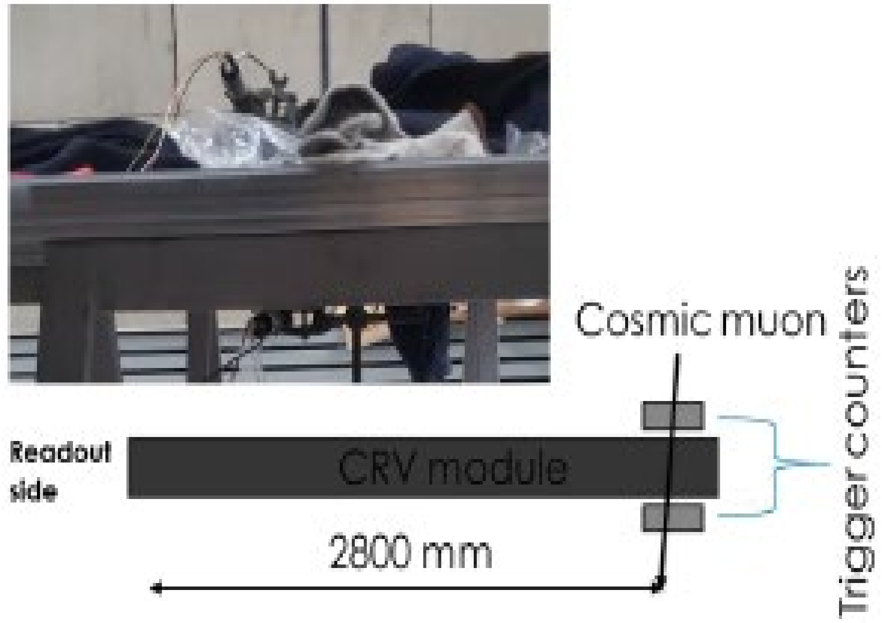


sketch of the first module

CRV module ready to send



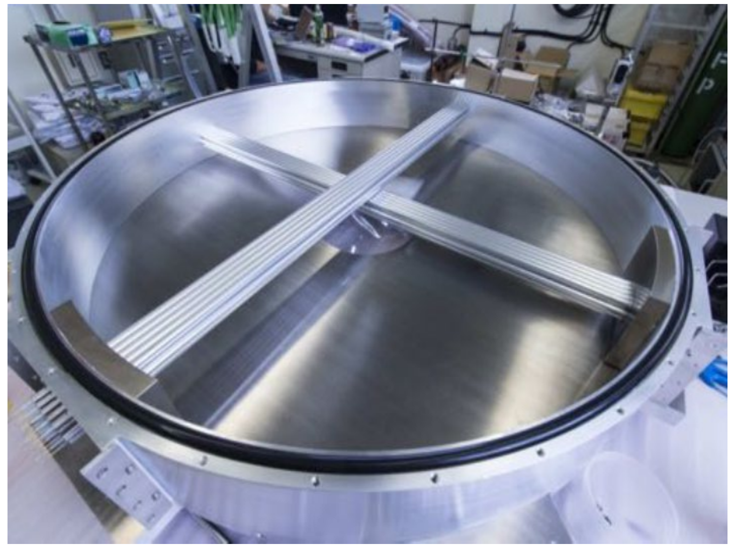
Assembly of CRV module



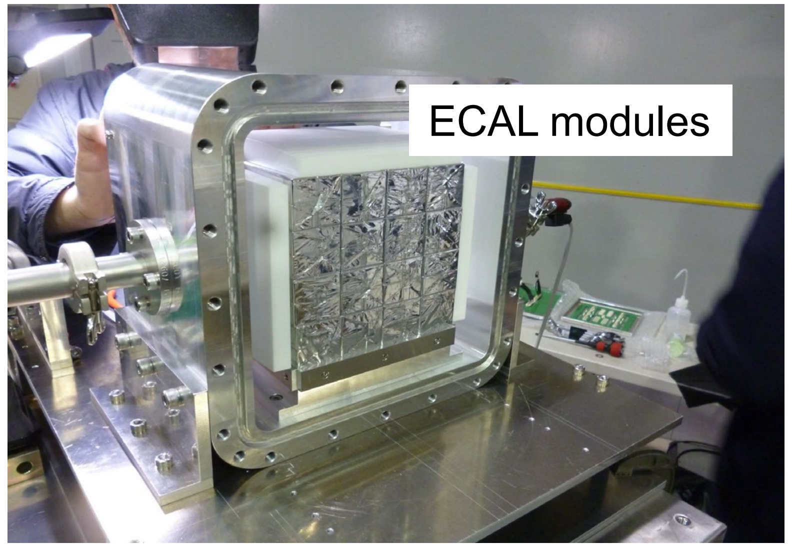
First test of CRV module with Meteor 32 provided at JINR

StrECAL system integration tests at ELPH in Tohoku Univ.

Energy range: 65 -145 MeV



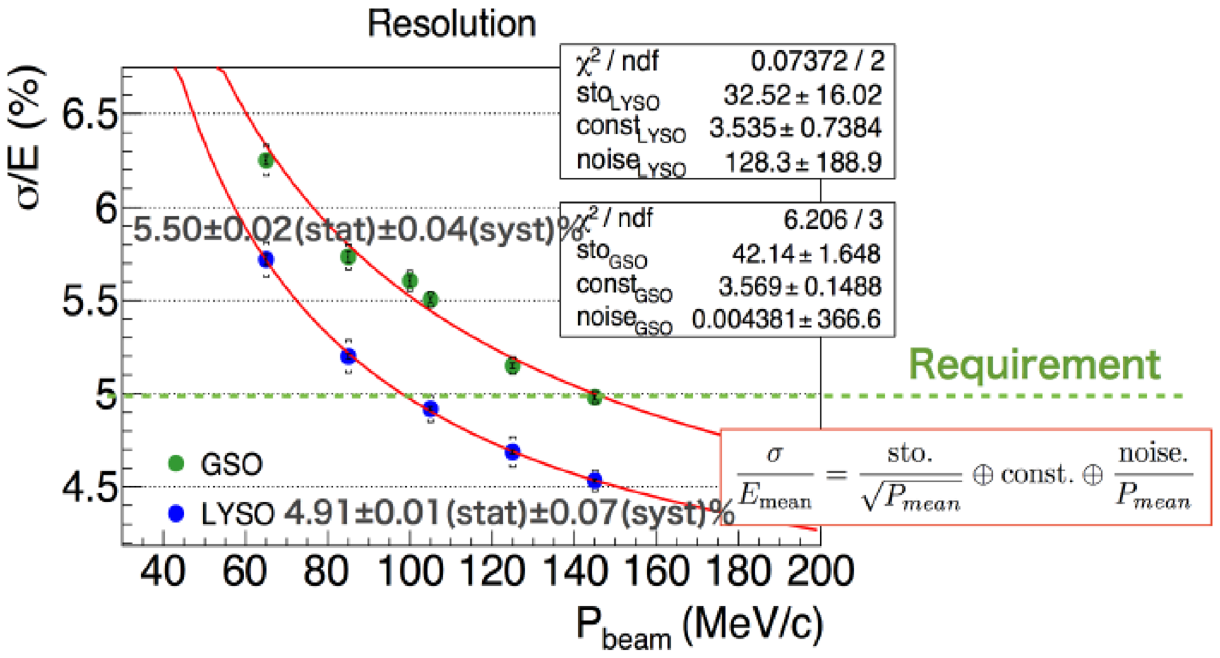
Straw prototype

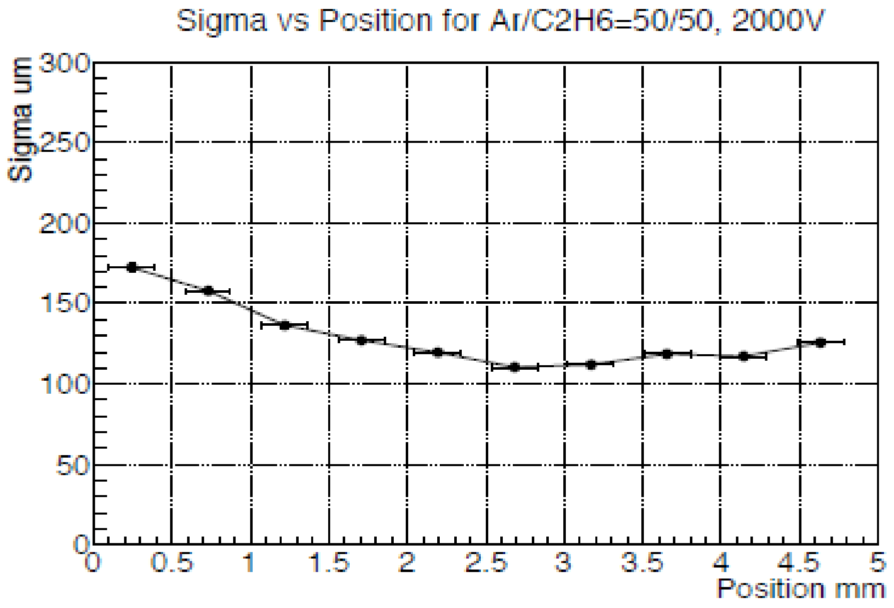


ECAL prototype 64 (8x8) JINR cryst.

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) %

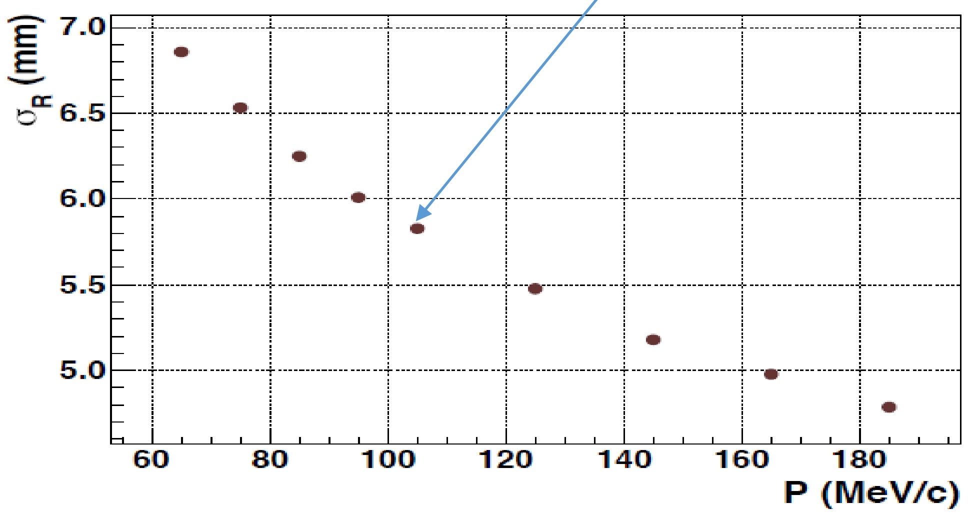




The results of straw efficiency and spatial resolution HV 2000)

- ε > 96%
- σ ~ 119 μm

The position resolution is 5.8 mm



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

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 LYSO crystals are to meet the required for ECAL, ER and PR of better than 5 % and, <10 mm accordingly at 105 MeV in all the area

Schedule of works on the project in 2025-2029

•Participation in the preparation, engineering and physics run, the data acquisition and analysis of Phase-I, 2025-2027
•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, 2025
•Finalization assembling, testing, calibration, installation, cosmic test and maintenance of the straw detector (3,4,5) for Phase-I, 2025-2026
•Production of straw tubes (about 1000 pcs) for full-scale prototype, 2026-2027
•Production of a full-scale straw station in JINR, with new tubes (12 μm, 5 mm), and measurements on the beam, 2027-2028
•Preparation and mass-production and testing of straw tubes (around 1000(for Phase-II, 2028-2029
•Production of a full-scale straw station at JINR with new straw tubes (12 μm, 5 mm), and test on the beam, 2027-2029
•Preparation for mass production and testing of straw tubes for Phase-II, 2028-2029
•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**,** 2025-2026
•Participation in the full calorimeter designing, assembling, installation, cosmic test and maintenance**,** 2025-2029
•Participation in the assemble and maintenance of the CRV for Phase-I and Phase-II, 2025-2029
•Participation in the beam tests of the detector components for Phase I and Phase-II, 2025-2029
•Participation in assembling, testing, installation and maintenance of whole detector system for Phase-I and Phase-II, 2025-2029
•Complex detector system (tracker, calorimeter, etc.) simulation, 2025-2028
•Participation in the engineering and physics run for Phase I, 2025-2027
•Participation in the data acquisition and analysis for Phase-I, 2025-2028

The responsibility of the JINR in the COMET

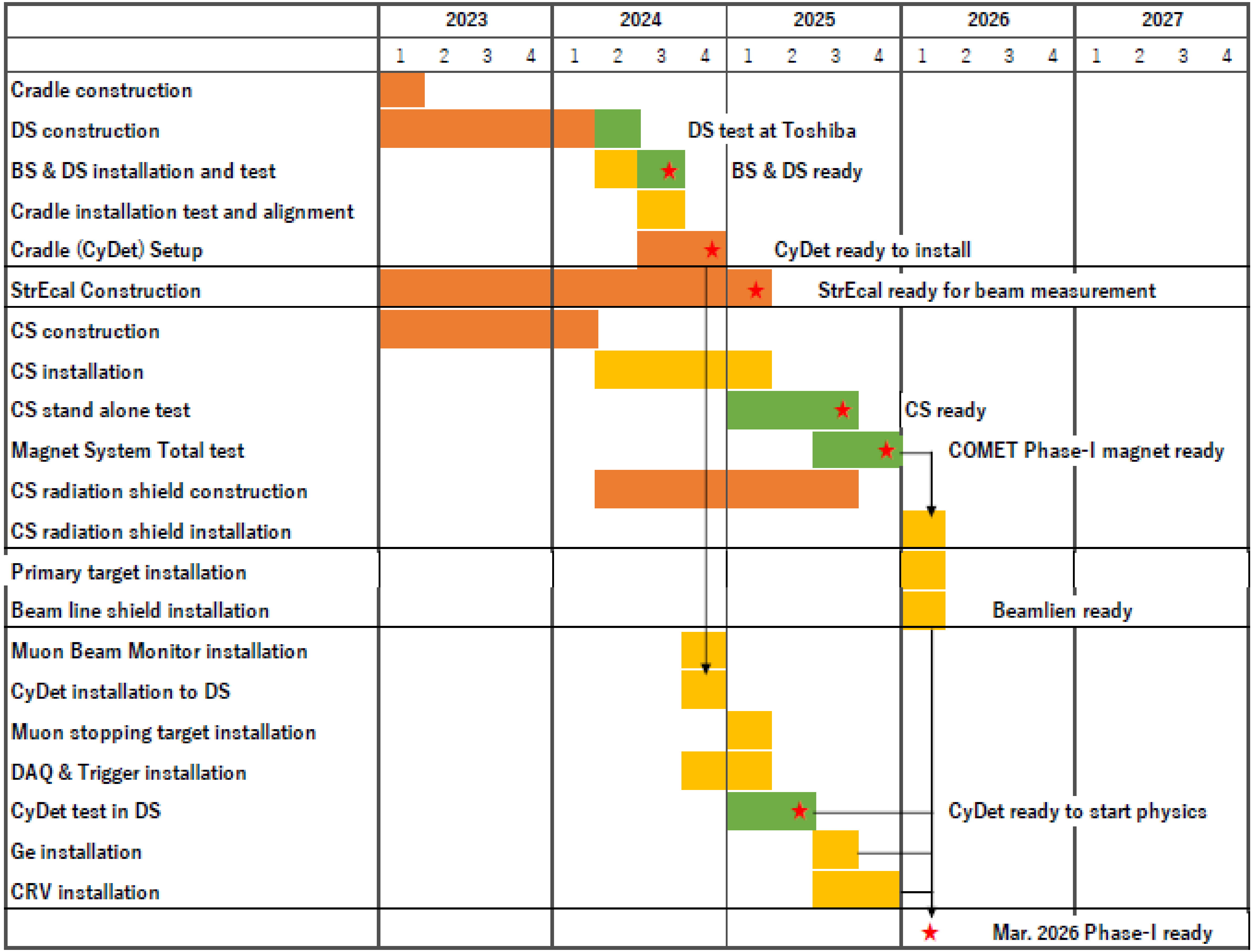
- The JINR group is a single one in the COMET collaboration, which is capable to produce thin-wall straw tubes. Therefore, we are fully responsible for manufacturing of all straw tubes. Different procedures of the tube tests on pressure, gas leakage and elongation have been also updated in accordance 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.

COMET Phase-I Facility Construction Schedule

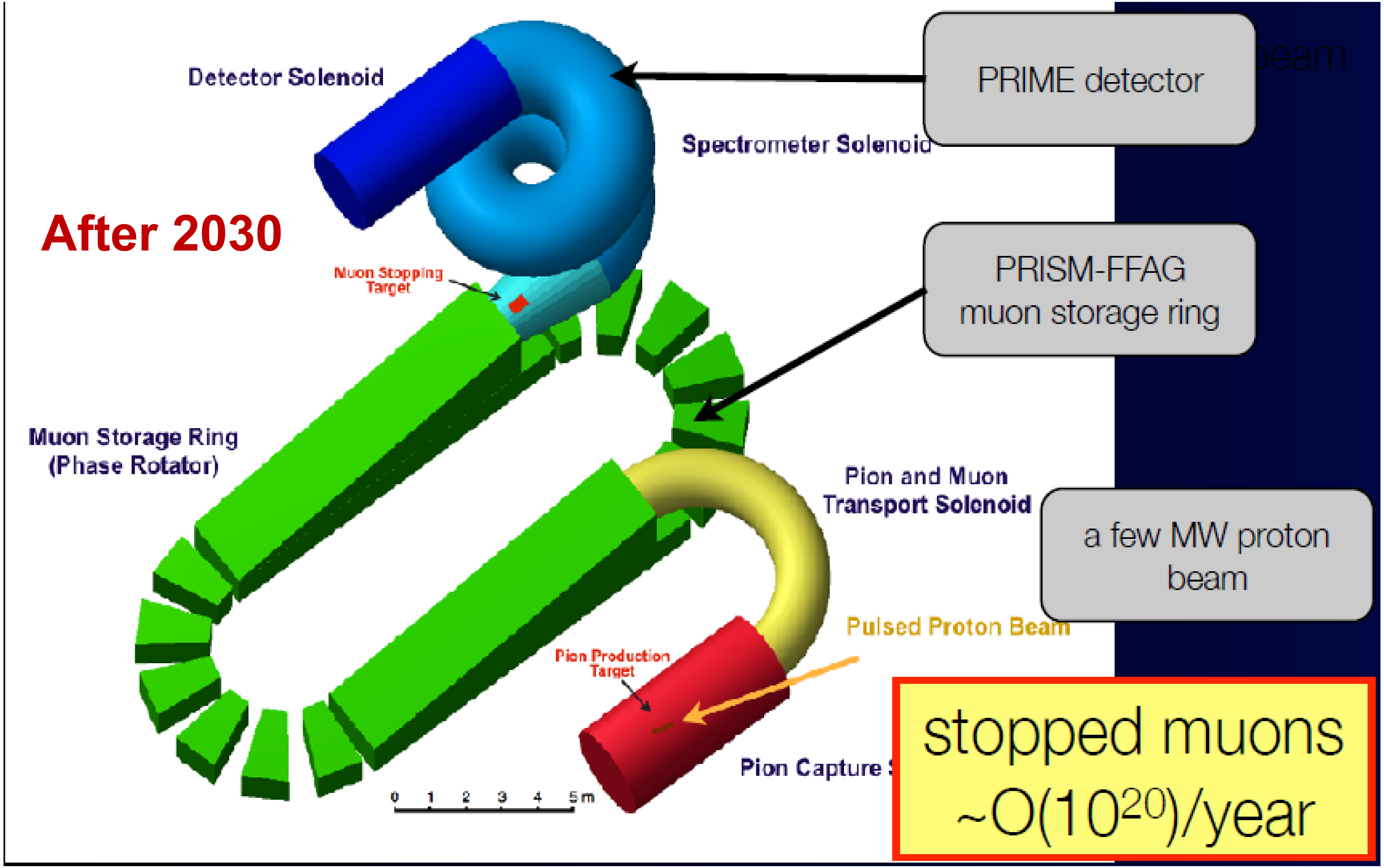
Detector Schedule

- **CyDet will be ready by the end of June, 2025**
- **StrECal should be ready by the end of January, 2025**
- **CRV should be ready by the end of September, 2025**

COMET Phase-I is ready at March, 2026.



PRISM (=Phase Rotated Intense Slow Muon source), PRISM/PRIME



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 x 10^{-17}
  - staging approach called Phase-I (under construction) / Phase-II
- **COMET Phase-I** is now under construction

Phase-I Goal:
(in 150 days operation)

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

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 the beginning of 2026.
- 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 2028-2030
- JINR plays a **leading role** in preparation of this experiment of fundamental importance.

Thank you for attention!

BACKUP

Mu2e Run 1 Timeline

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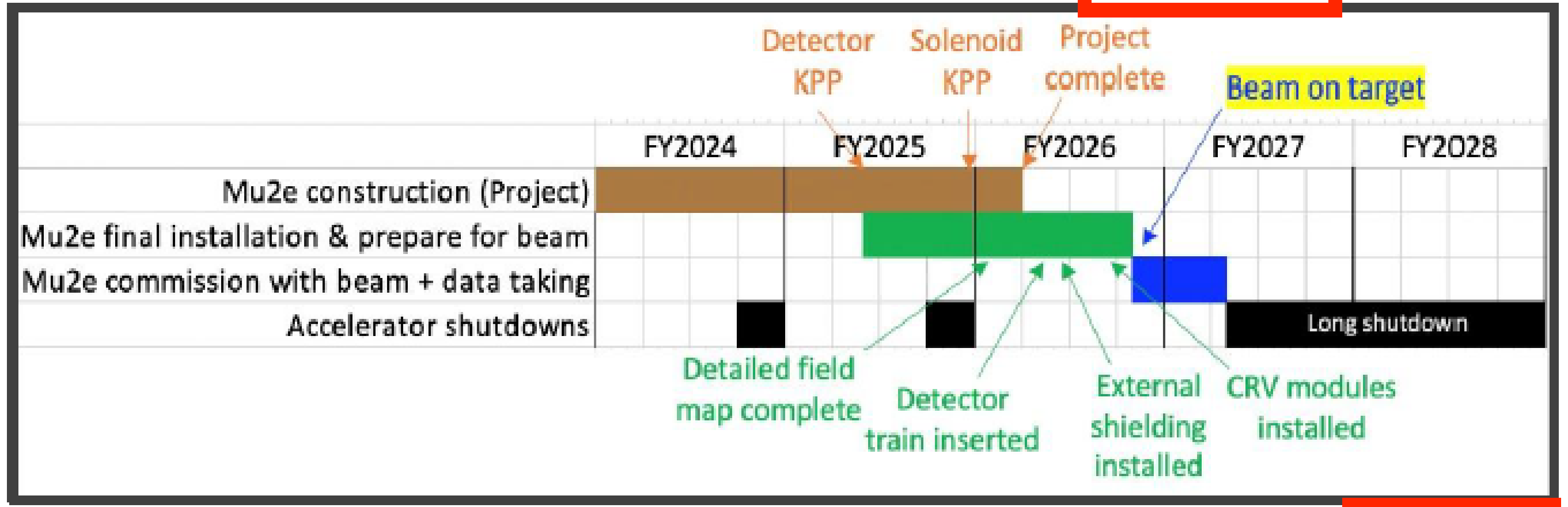
Mu2e Timeline

- Mu2e Project is fully funded and 85% complete
- High priority and high level of support from Fermilab
- Aiming for Project early completion date Dec 2025
- Begin Run 1 data taking mid- CY2026 - for about 6 months of data collection



- Resume data collection after shutdown and collect data for 4 years
- Request P5 endorsement of physics and for operations and collaboration support

Run 1
August 2026 -
April 2027

Run 2:
FY2029-FY2032

Phase-α (2023)

- **A low beam intensity run, 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

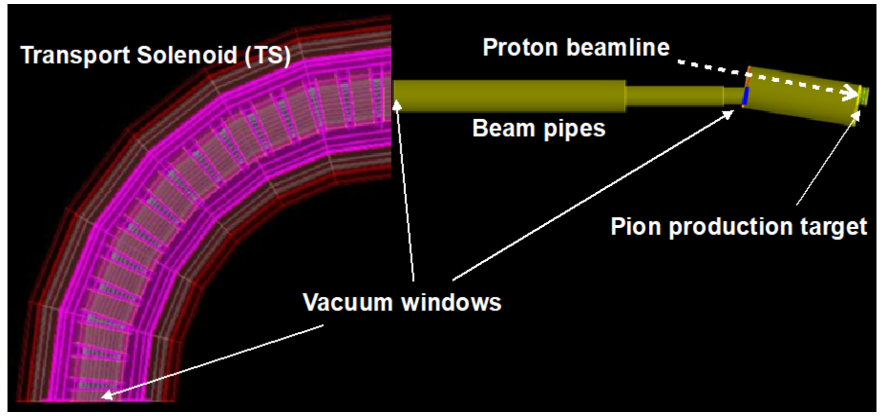
Particle Yields per POT at both TS ends

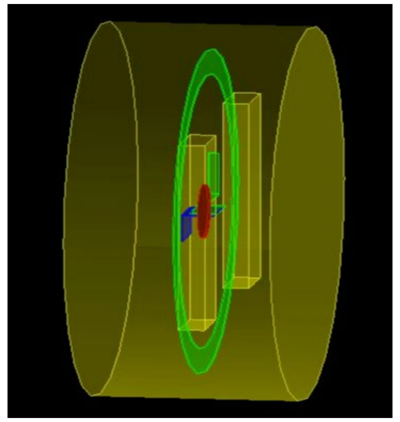
Particle	TS entrance	TS exit
e^-	8.3×10^{-8}	4.6×10^{-8}
e^+	3.2×10^{-8}	3.3×10^{-8}
μ^-	2.0×10^{-8}	6.9×10^{-9}
μ^+	2.8×10^{-8}	1.1×10^{-8}
π^-	5.2×10^{-8}	1.7×10^{-9}
π^+	7.3×10^{-8}	2.8×10^{-9}
p	1.6×10^{-7}	4.0×10^{-10}

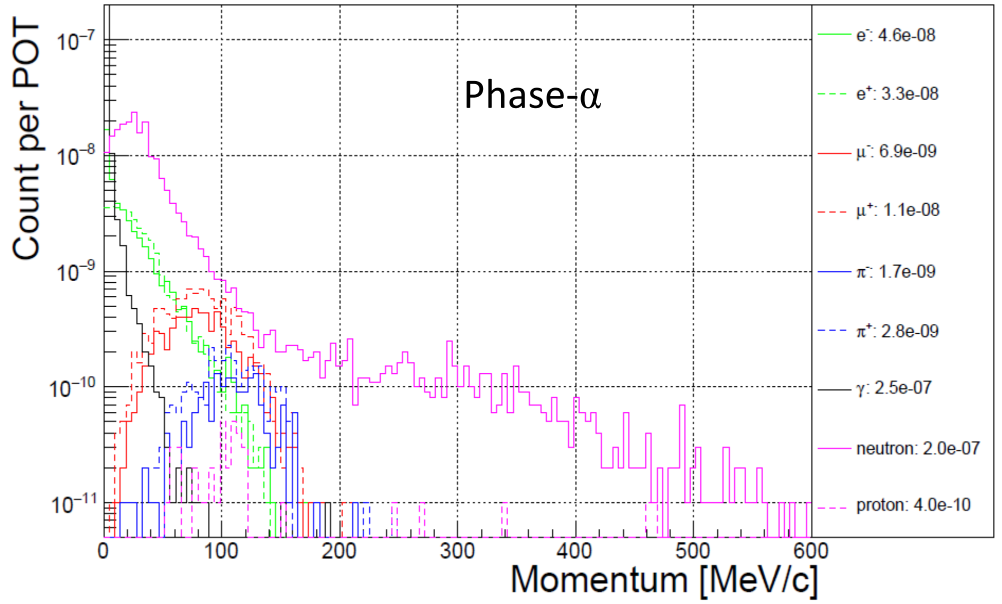
Proton Beam Parameters

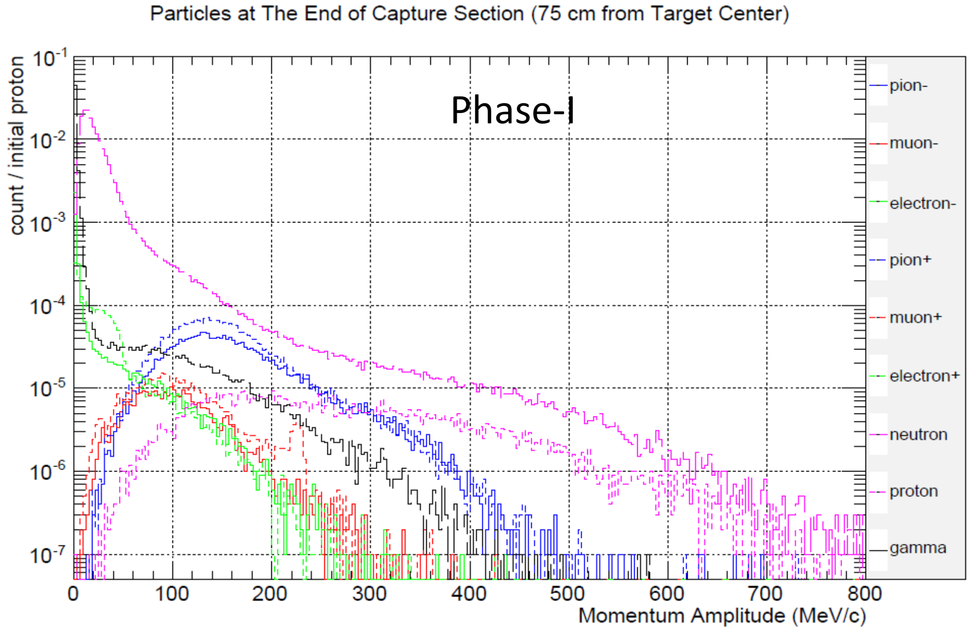
	Phase-α	Phase-1
Energy (GeV)	8	
Beam Power (kW)	0.26	3.2
Spill Cycle (sec)	9.2	2.48
Extraction Period (sec)	0.5	
# of Bunches / sec	7.6e+5	
# of Protons / Bunch	4.9e+6	1.6e+7
# of Protons / Spill	1.9e+12	6.2e+12

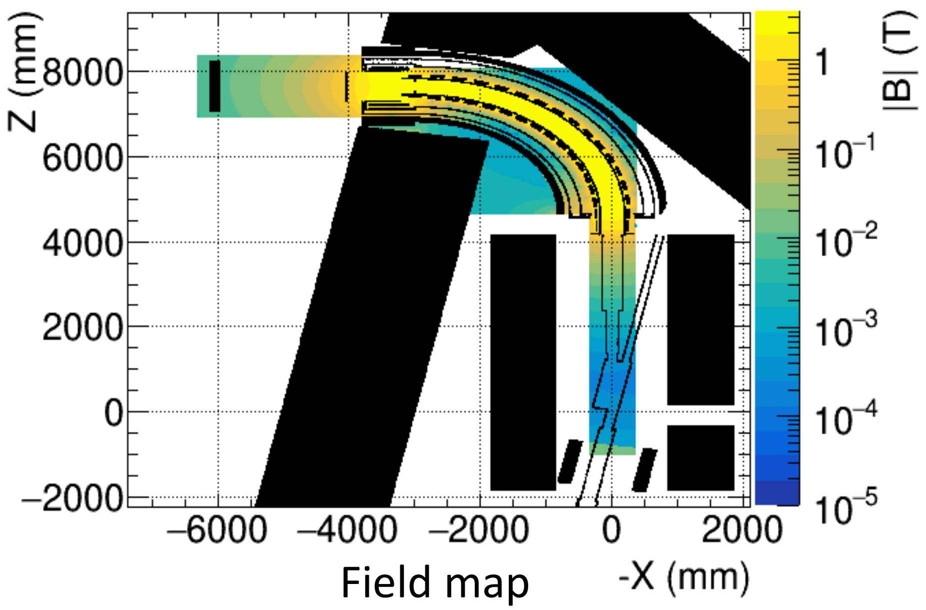
The proton beam characteristics such as the bunch length, extinction, time structure of 1.17 -1.75 μsec bunch-to-bunch are identical to COMET Phase-I.



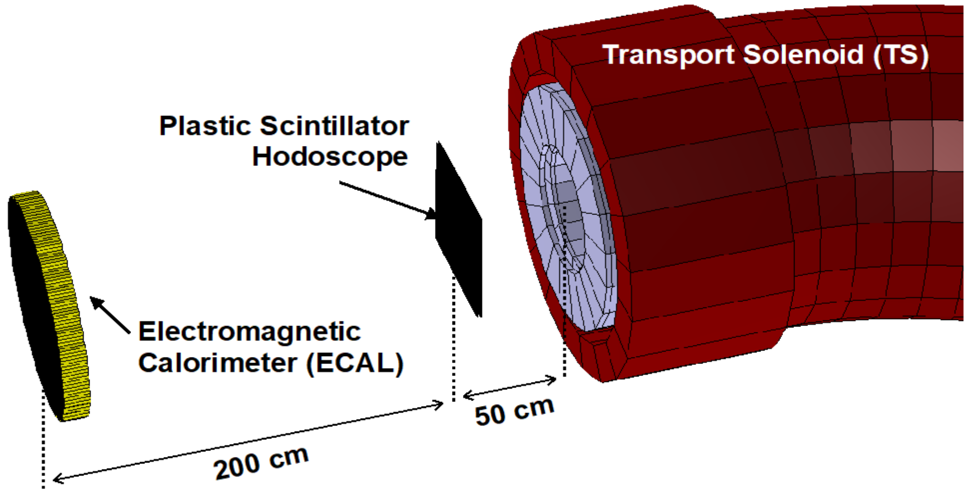








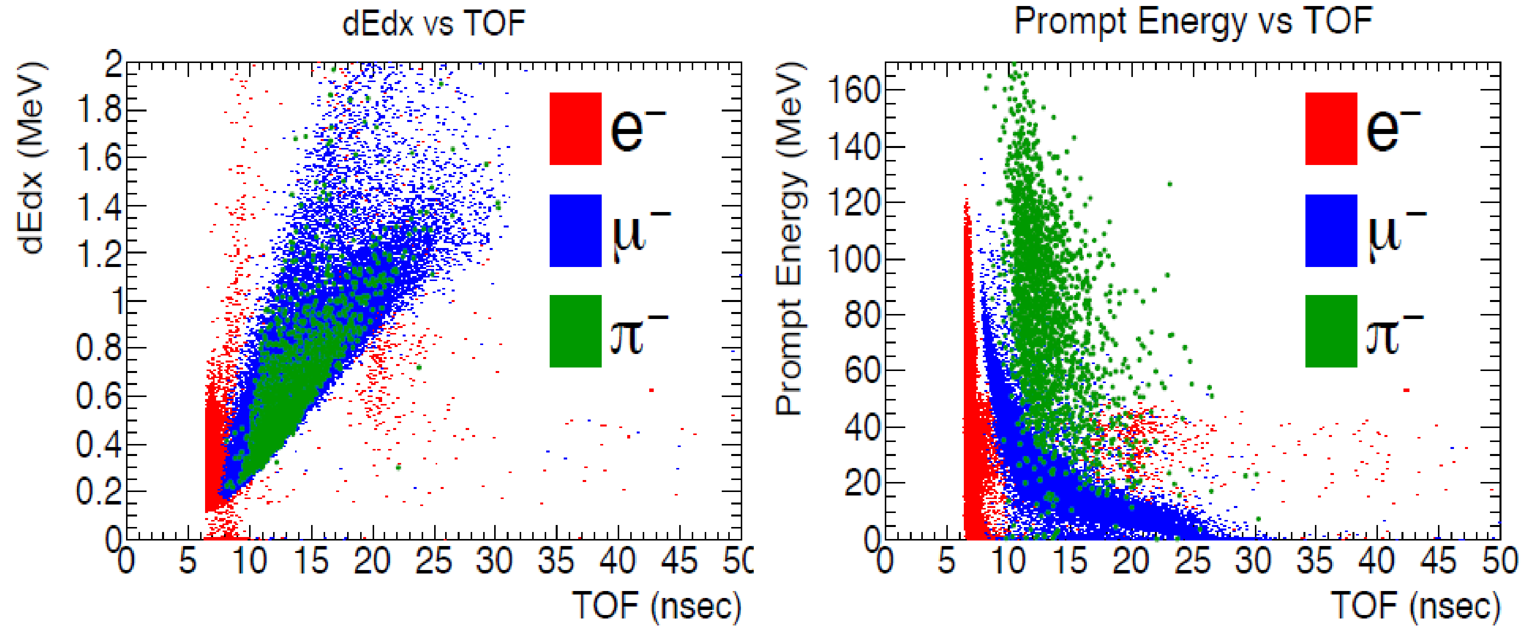
Phase-α (2023)

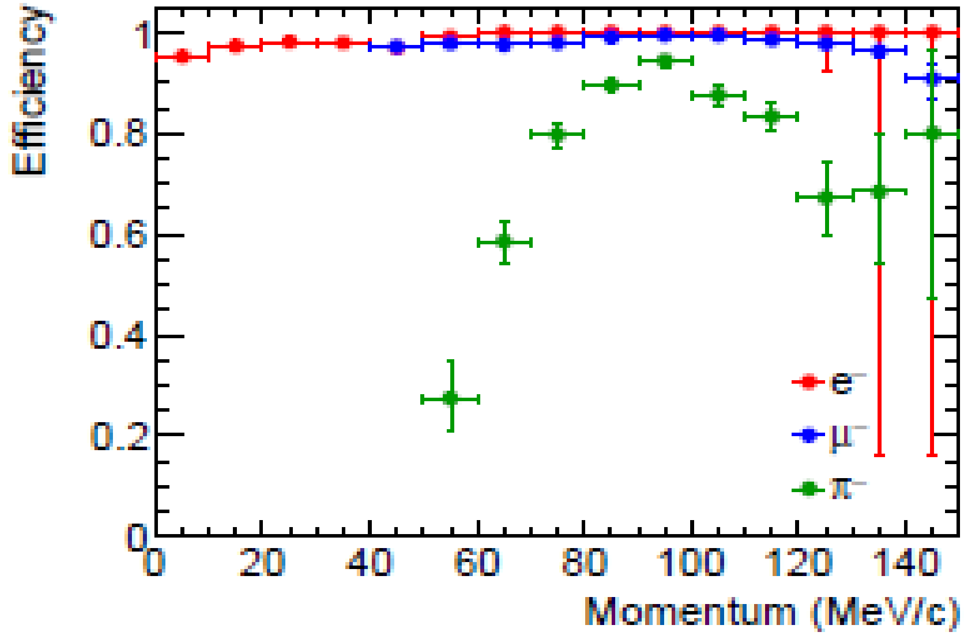


Baseline Detector Layout

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% for.
  - μ^-: Good > 90% but drops at high momentum.
  - π^-: Still low over the range, need improvement

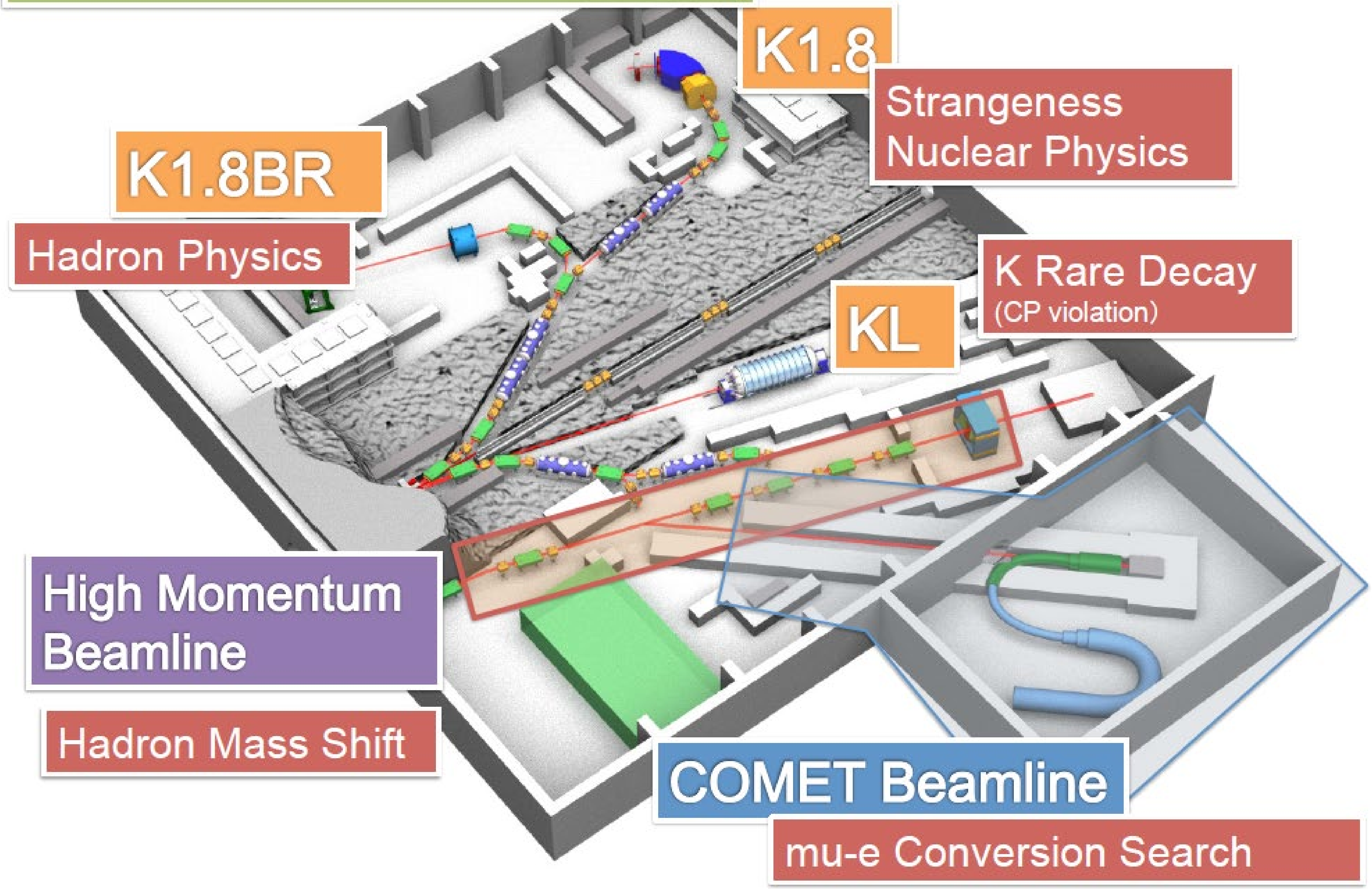




Next steps and Prospects

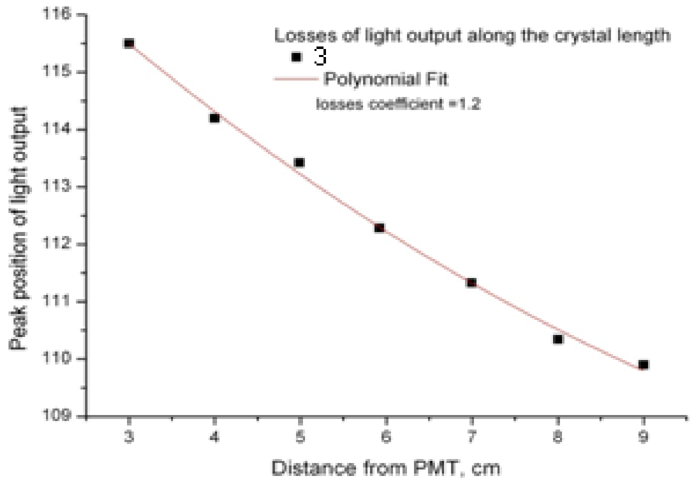
- Large-scale MC production
- Exploration of different detector configurations
- Optimization of geometries, measurement schemes
- Antiproton measurements
- "Beam blocker" studies for Phase-I beam measurement programme.

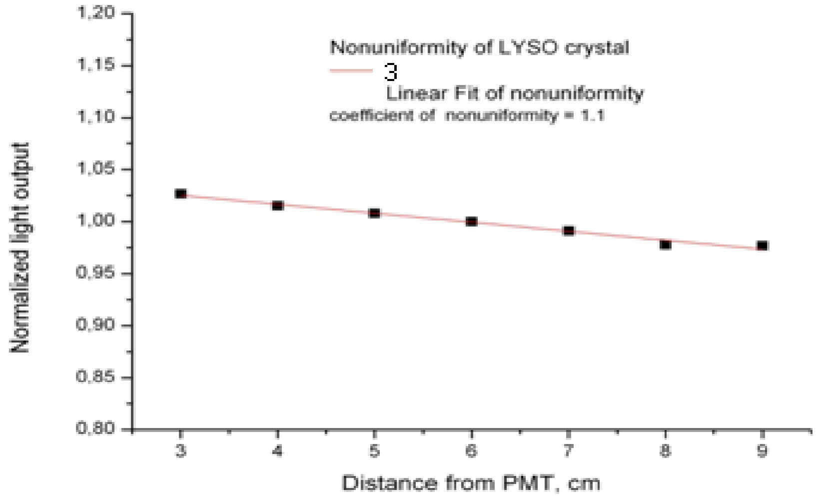
Hadron Hall in 2016

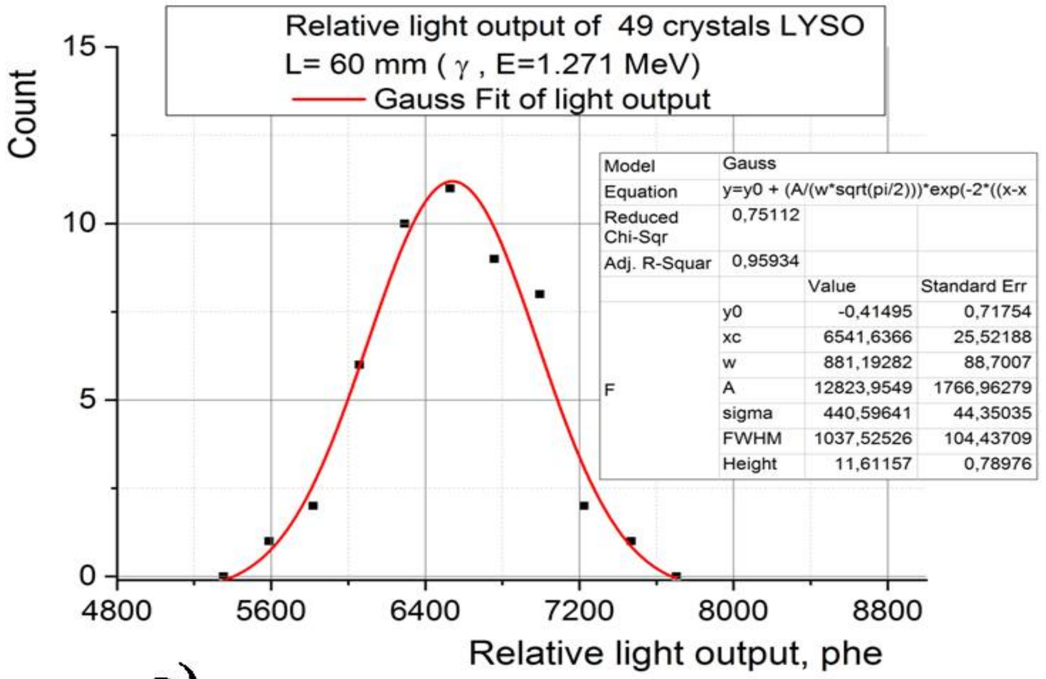


Calibration of the 50 samples of LYSO crystals for calorimeter prototype

Parameter	Mean value
Coefficient nonuniformity, % cm^{-1}	1.25 ± 0.15
Energy resolution, %	8.85 ± 0.06
Relative light output, phe	9926.75 ±1000







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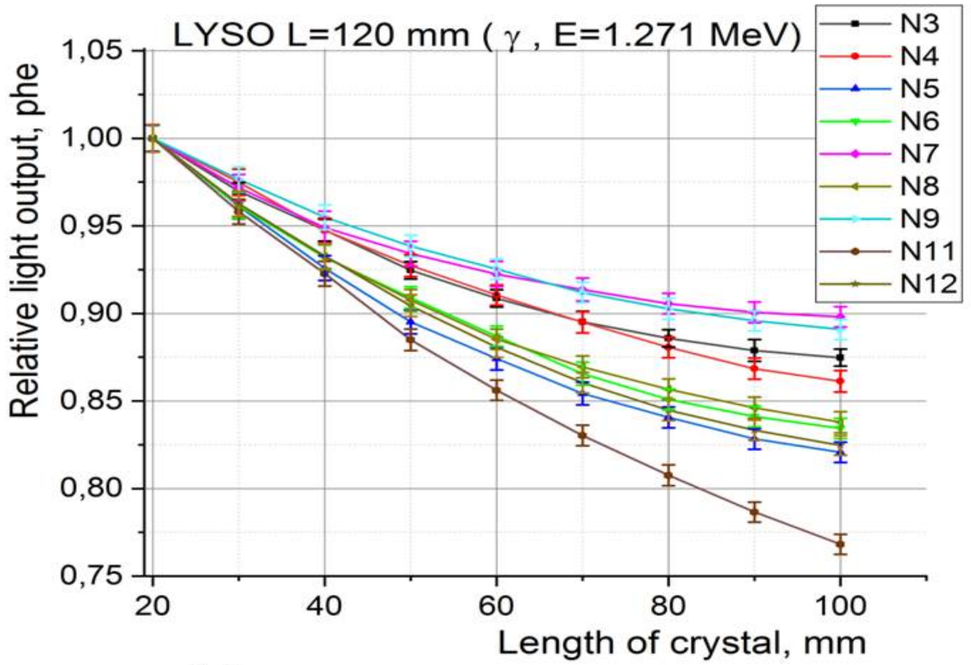

b)

Fig. (a) Light yield measured at the center (L = 60 mm) for 49 LYSO:Ce crystals by the gamma spectroscopy; (b) Normalized distribution of the light yield along the length (light yield was measured by the gamma spectroscopy)

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	$\langle E \rangle = 1$