The COherent Muon to Electron Transition (COMET) experiment

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JINR COMET team

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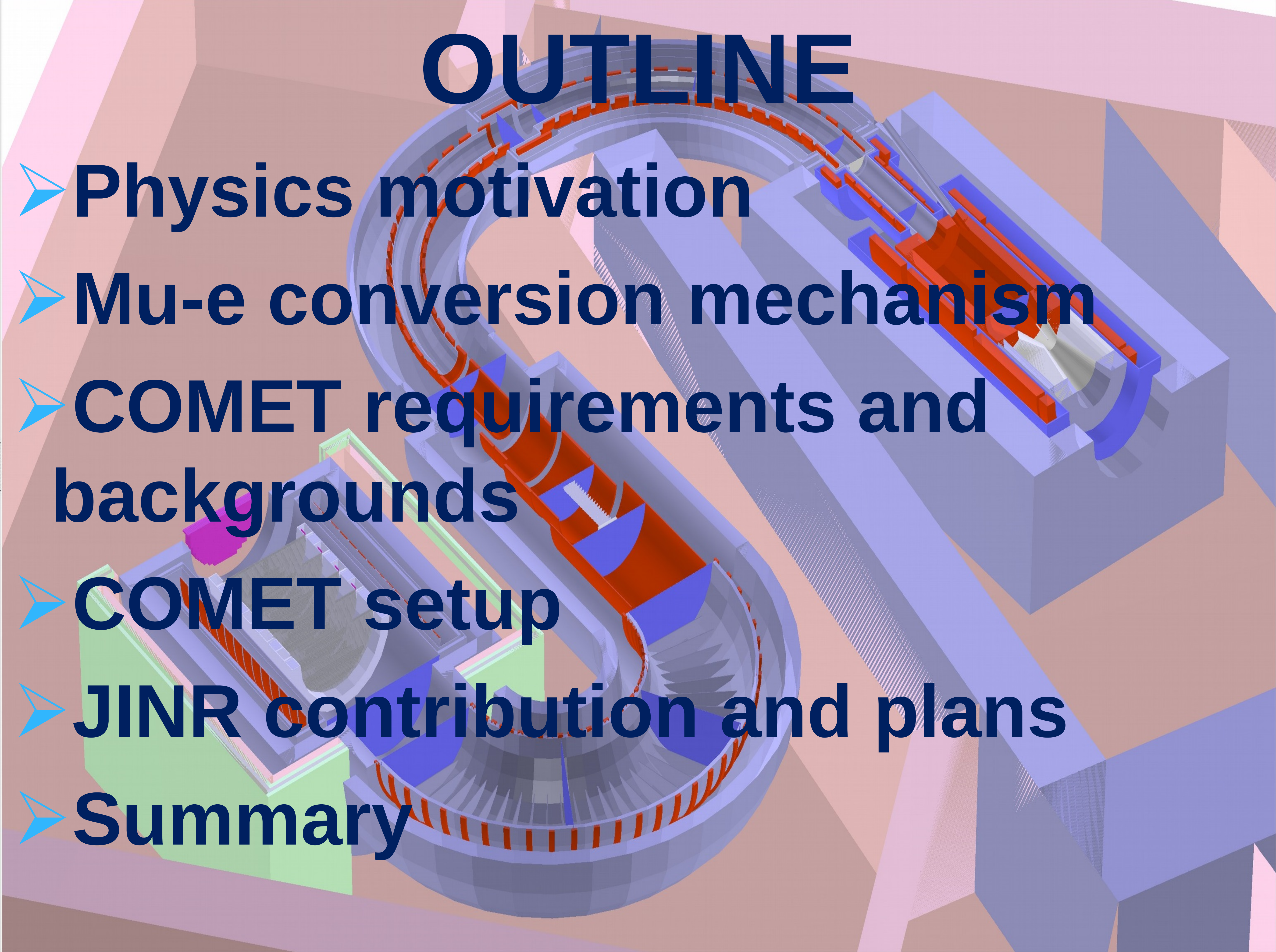


OUTLINE

- Physics motivation
- Mu-e conversion mechanism
- COMET requirements and backgrounds
- COMET setup
- JINR contribution and plans
- Summary

Standard Model (SM)

The SM can explain most of the experimental results. However, there are still many questions to answer →

Where doesn't work SM:

baryon/antibaryon asymmetry
nature of dark matter, and energy
particle mass prediction
no theory of gravitation
neutrino oscillations
and etc.

All these motivates physicists to go Beyond the Standard Model (BSM).

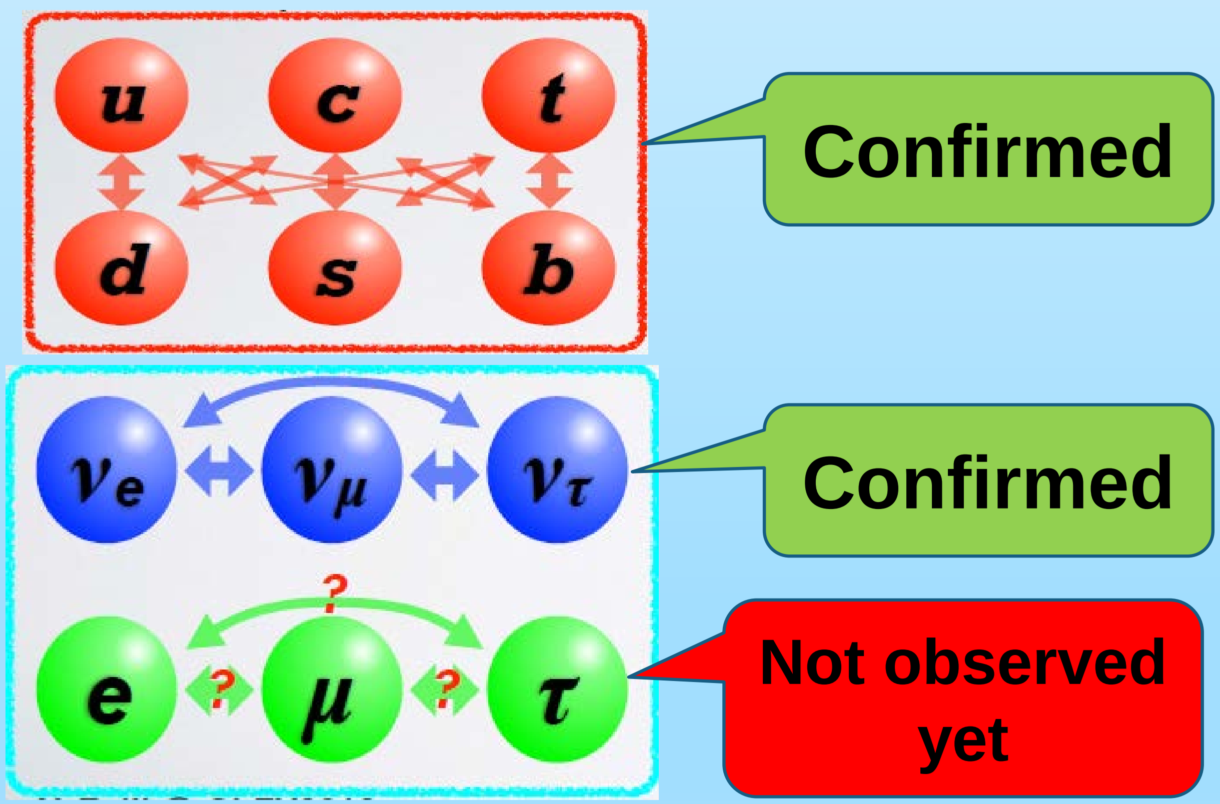
Many of these models predict Charged Lepton Flavor Violation (CLFV)

What is CLFV?

A transition between μ, e, τ, where lepton family number is violeted

CLFV in the SM

- CLFV is forbidden, but, quark family number is violated via CKM matrix
- In the SM + ν masses
  - it's violated in neutral leptons: neutrino oscillations (PMNS matrix), but expected CLFV processes rate is too small ($\sim 10^{-54}$). Not observed so far
- In the SM + new physics
  - A wide variety of proposed extensions to the SM predict rate ~ 10^{-15} (model dependent)



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

In COMET is planned to reach sensitivity of $2.6 \cdot 10^{-15,-17}$

Search of CLFV provides a sensitive test for BSM

What is a μ-e Conversion?

Muon decay in orbit **39% in Al**

$\mu^- \longrightarrow e^- \nu_\mu \bar{\nu}_e$

New Physics Process

Neutrino-less nuclear capture of a muon

(= μ-e conversion)

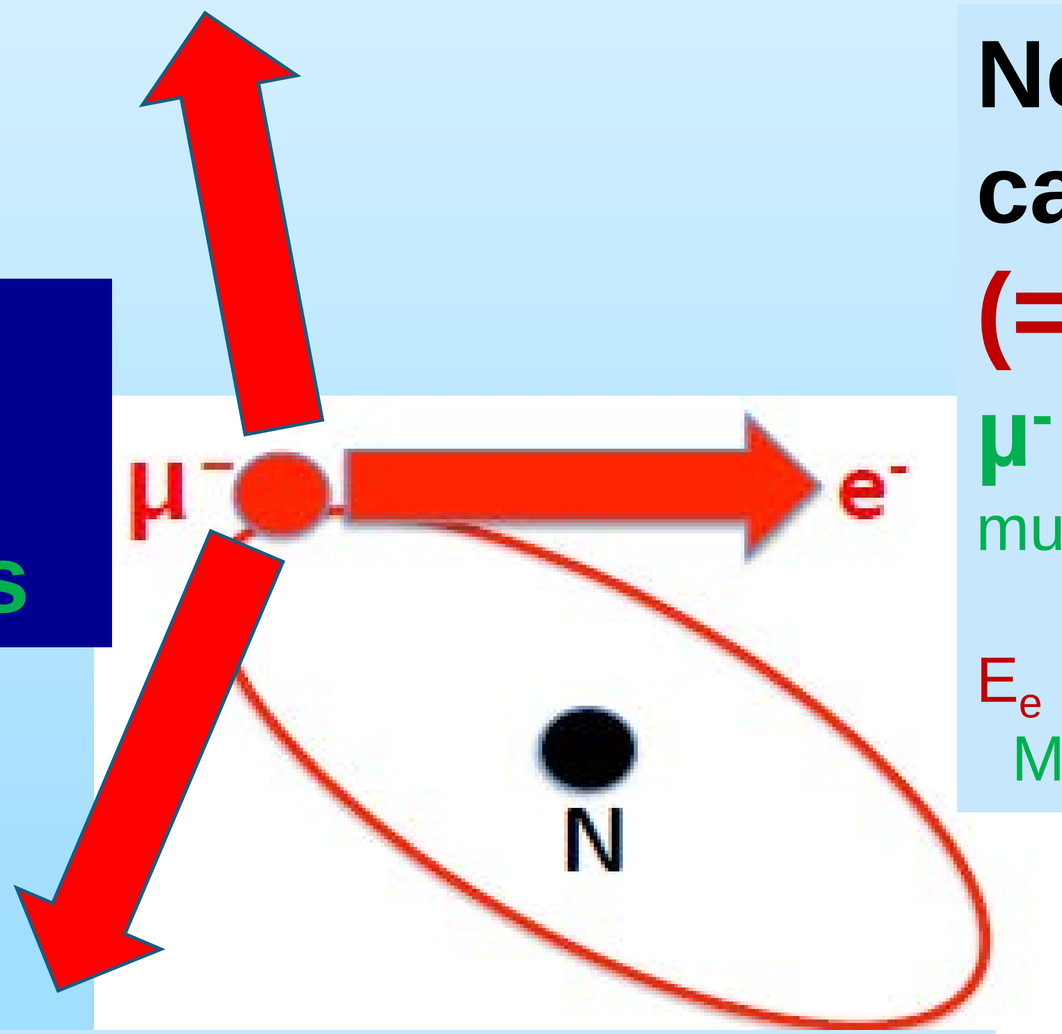
$\mu^- + (A,Z) \rightarrow e^- + (A, Z)$

muonic atom — single mono-energetic electron.

$E_e = m_\mu - E_{recoil} - E_{binding} \approx 105\text{MeV (Al)}$

Muon lifetime in Al ~ 864ns

Standard Model Processes



$$B(\mu^- N \rightarrow e^- N) = \frac{\Gamma(\mu^- N \rightarrow e^- N)}{\Gamma(\mu^- N \rightarrow \nu N')}$$

Nuclear muon capture **61% in Al**

$\mu^- + (A,Z) \longrightarrow \nu_\mu + (A,Z-1)$

	L_e	L_μ	L_τ
ν_e, e^-	+1	0	0
ν_μ, μ^-	0	+1	0
ν_τ, τ^-	0	0	+1

$\Delta L_{\mu,e} = 1$
$\Delta L = 0$

Lepton flavors change in this process

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

NEED NEW IDEAS !!!

1. Reduce Beam Associated Background

Pulsed proton beam and used the long μ lifetime

2. Highly intense muon source

High Intensity Pion Production (μ from π decay)

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

3. Electron Energy Resolution and Timing

Excellent calorimeter and tracking detectors,

employ new electronic technology to handle higher rates.

Many of these ideas were elaborated in MELC, (V.M Lobashev, INR, Moscow, 1992)

(1) R.M. Djilkibaev and V.M. Lobashev, Sov. J. Nucl. Phys. 49(2), (1989) 384

(2) V.S. Abdjev, et al, “MELC Experiment to search for the μ-A →e- A Process”, INR Preprint 786/92 (1992).

MECO, BNL

COMET, J-PARC

Mu2e Fermilab

The COMET collaboration

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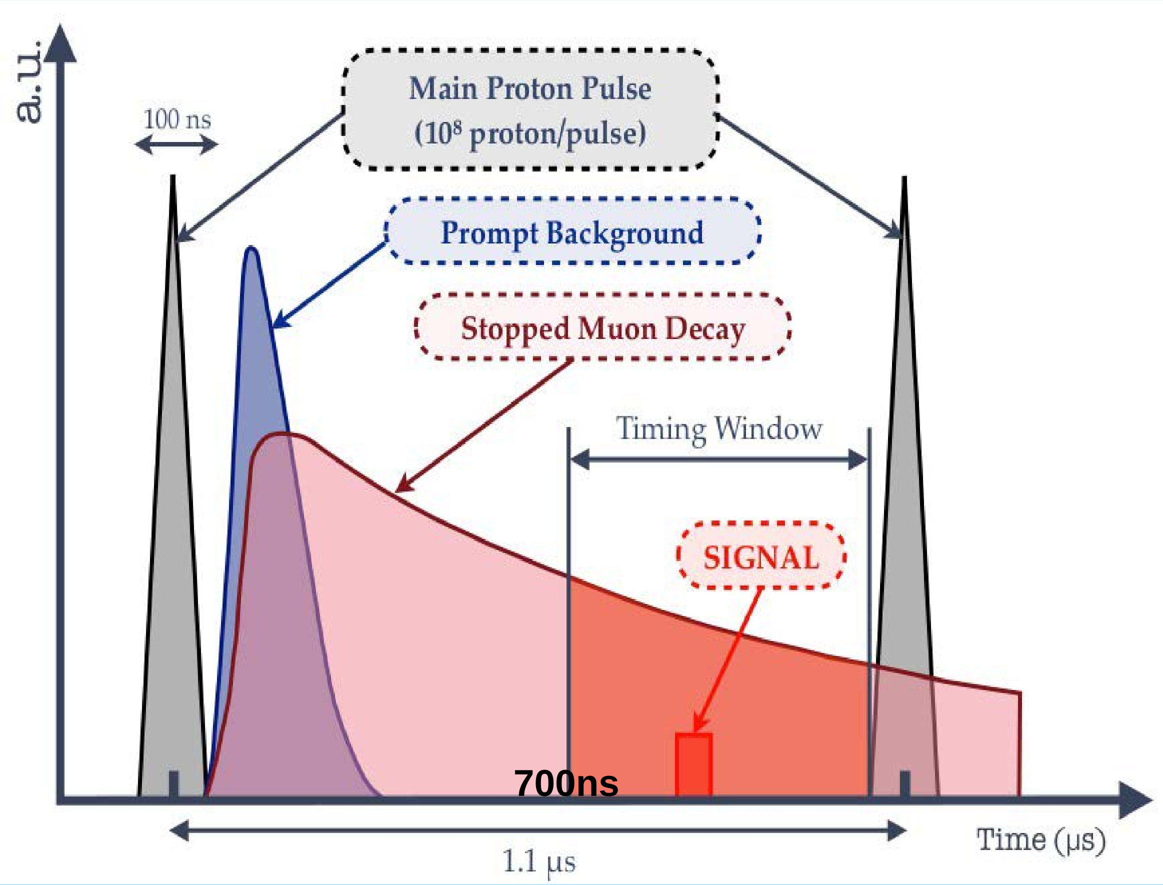
182 collaborators
32 institutes, 14 countries

Including four JINR member states

Belarus, Czech Republic, Georgia, Russia

COMET requirements and backgrounds



Pulse structure allows us to measure in a timing window and reduce beam-related backgrounds, and mainly determined by muonic lifetime For Al lifetime is 864ns

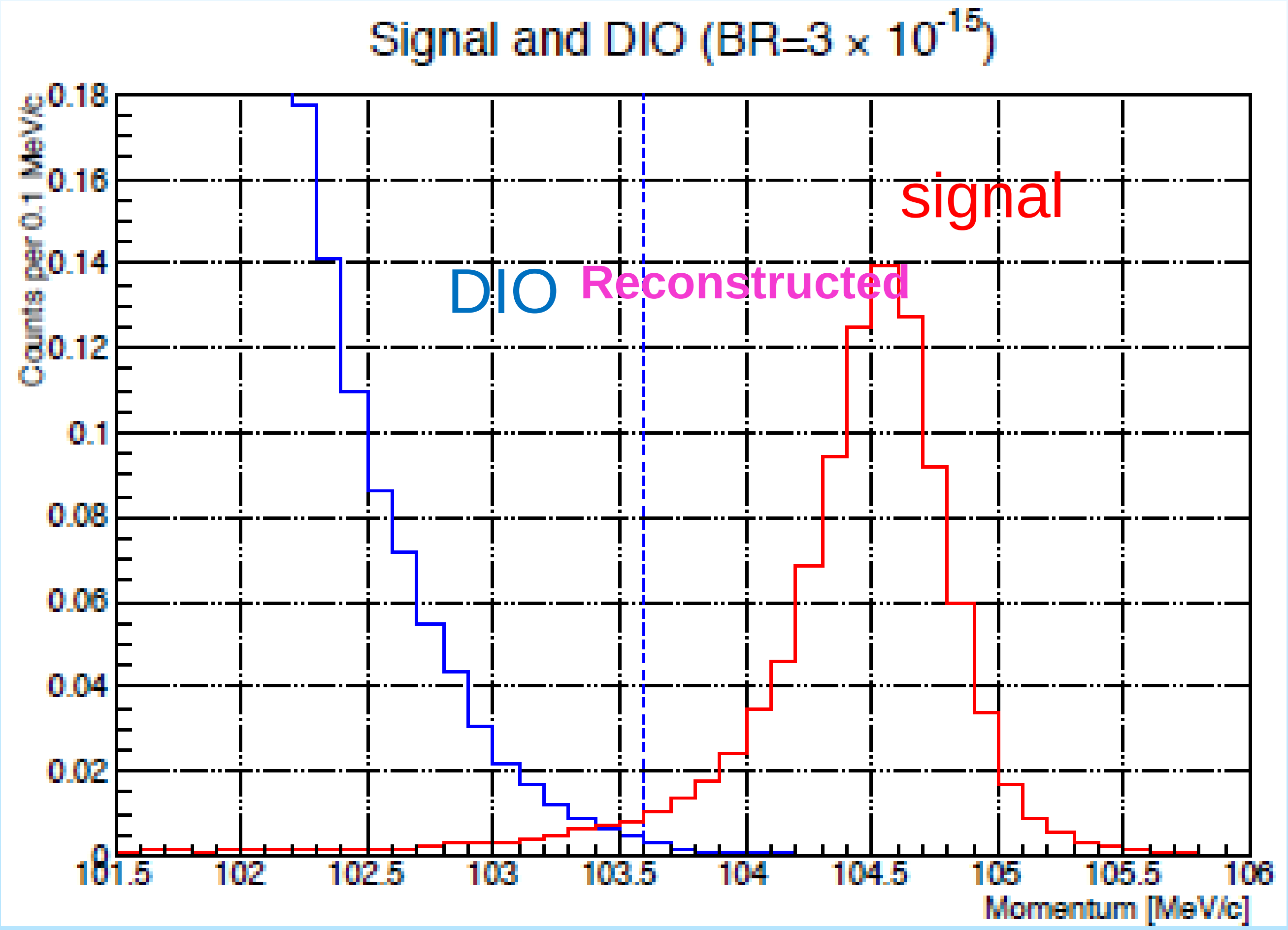
$$\text{Extinction} = \frac{N(\text{Protons between pulse})}{N(\text{Protons in pulse})}$$

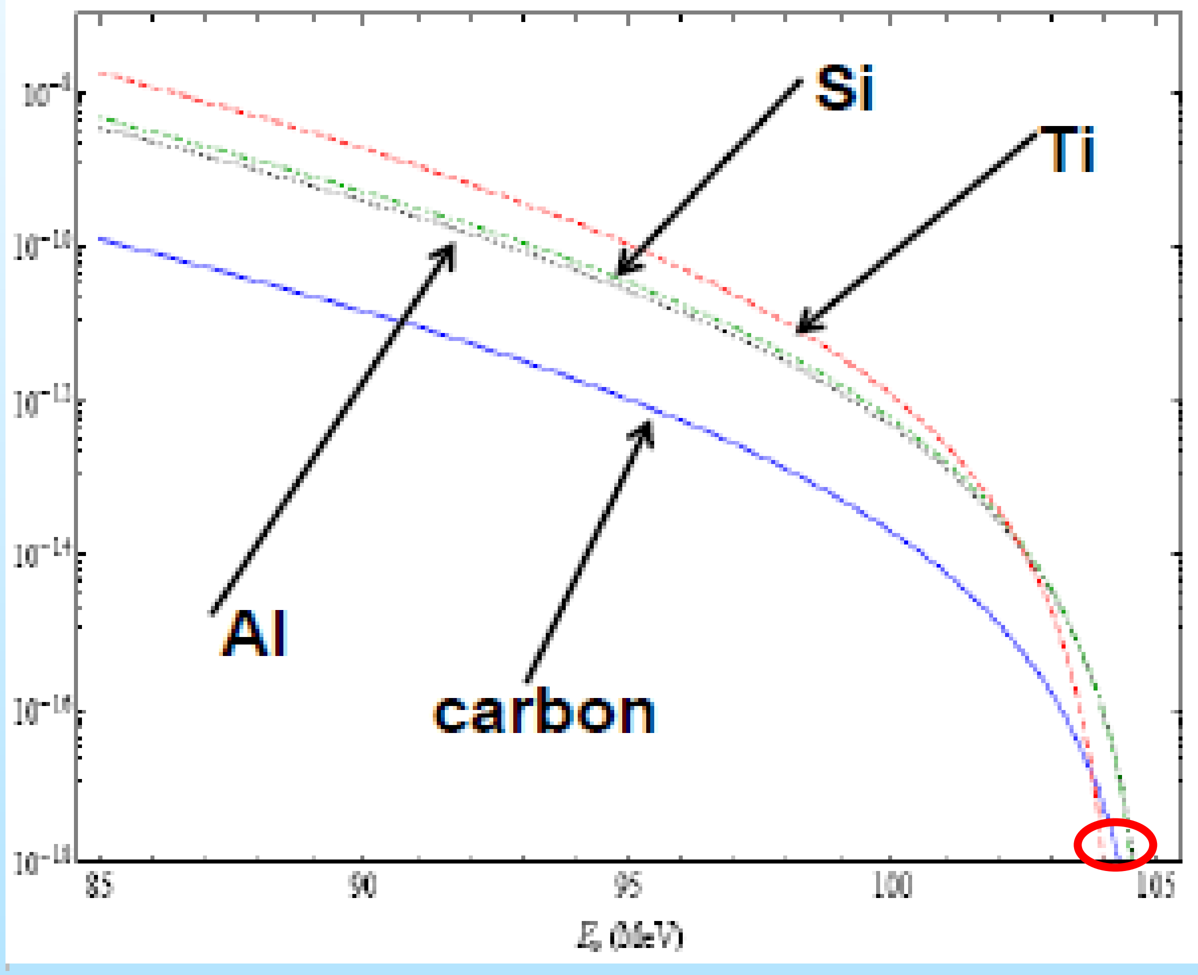
In COMET the extinction factor must be less 10^{-9} ,

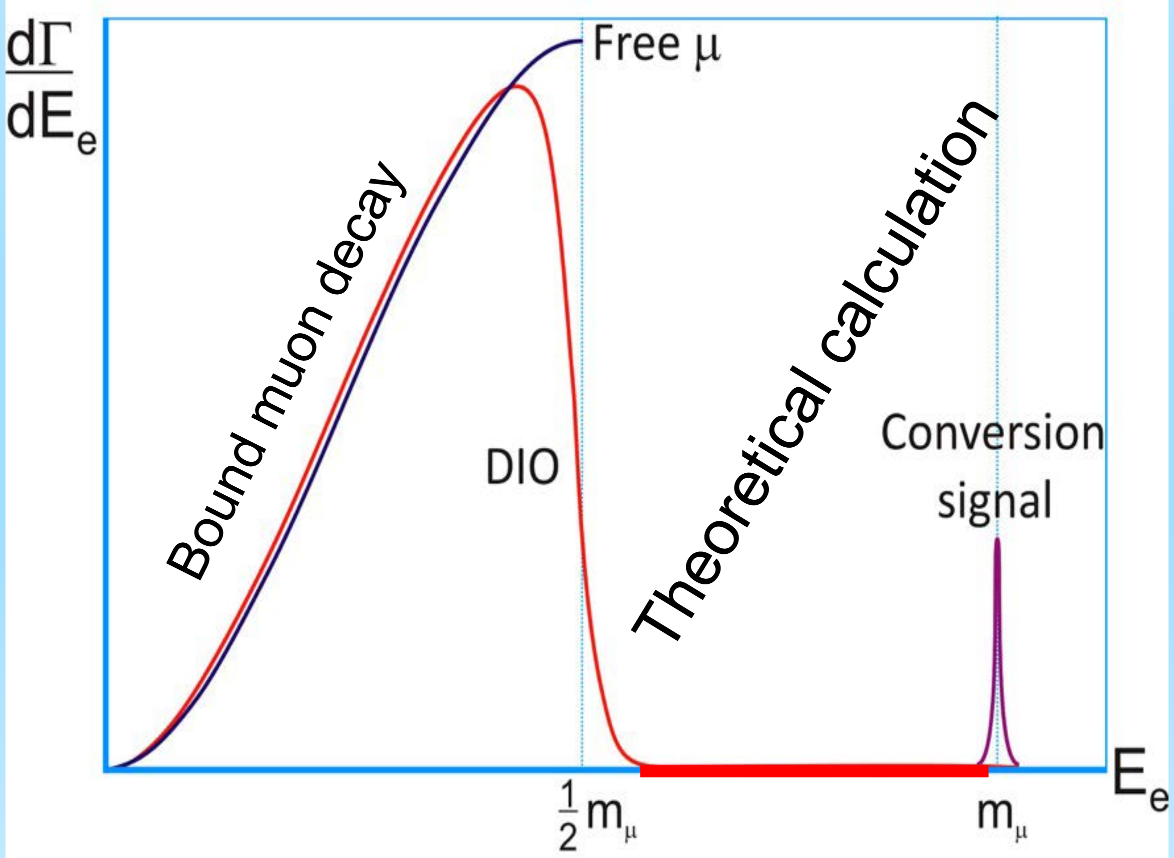
actually achieved ~ 10^{-11} !

- **Proton Beam, high statistics**
  - Energy: 8 GeV
  - Power: 3.2 kW/56kW (Phase-I/Phase-II)
  - Pulsed beam
  - > 10^{17} of stopping muons are required
    - High intensity proton beam at J-PARC
    - π/μ collection using capture solenoid
- **BackGrounds and suppression**
  - **Intrinsic Physics BG:** Muon DIO (Decay In Orbit), Radiative muon capture, Neutrons or charged particles emission after muon capture
    - **Excellent energy and momentum resolution**
  - **Beam-related prompt/delayed BG:** Radiative pion capture, Muon decay in flight, Antiproton, Proton leakage, etc.
    - **Pulse beam + delayed time window**
    - **Good extinction factor (less than 10^{-9})**
    - **Curved solenoid**
  - **Cosmic ray induced BG:** Cosmic ray
    - **Add detector for cosmic ray veto counters. Assumed 10^{-4} veto inefficiency**

DIO Spectrum





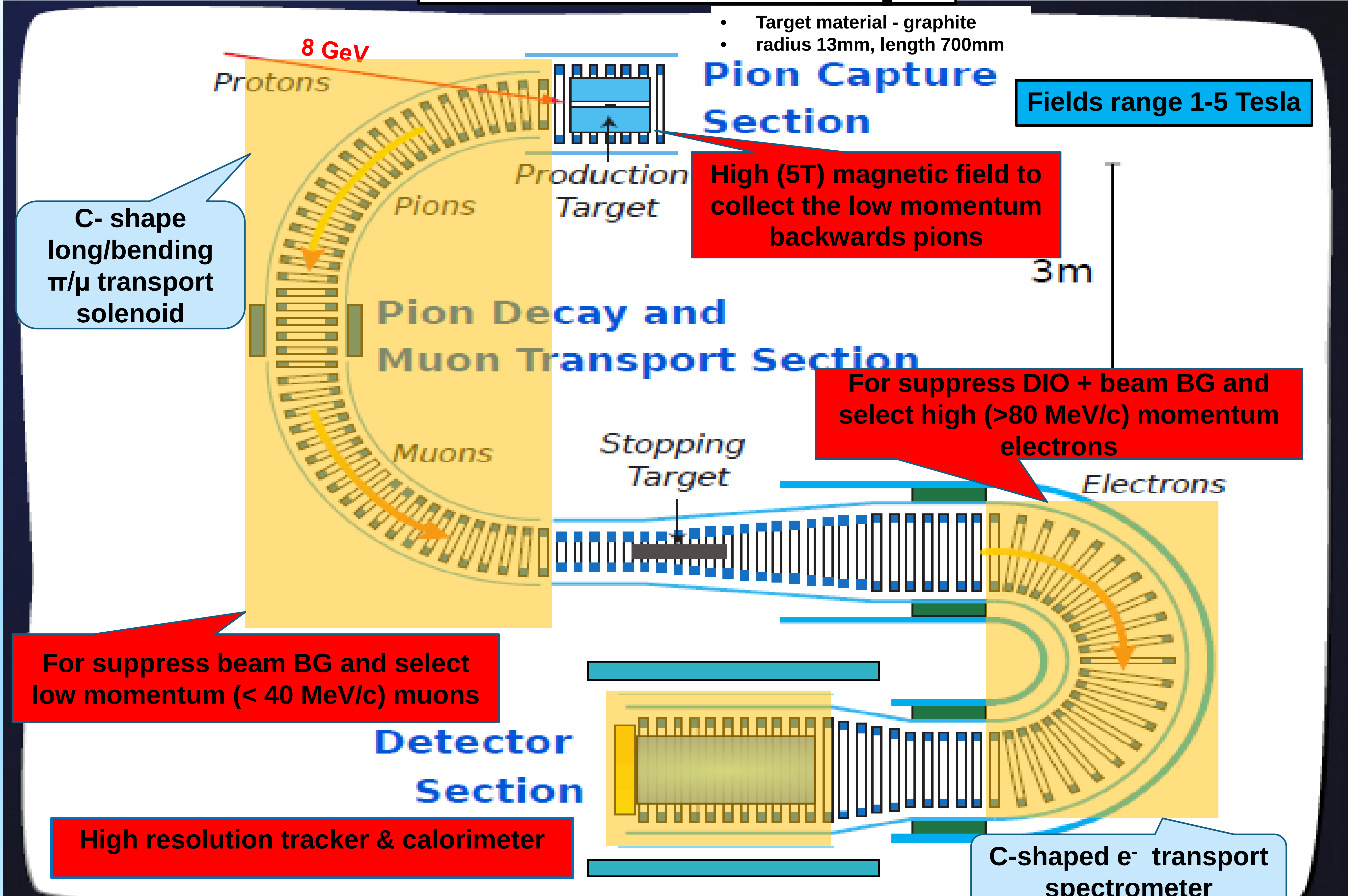


Electrons spectrums from DIO, theoretical calculation

Precise measurement of the electron momentum and energy is required

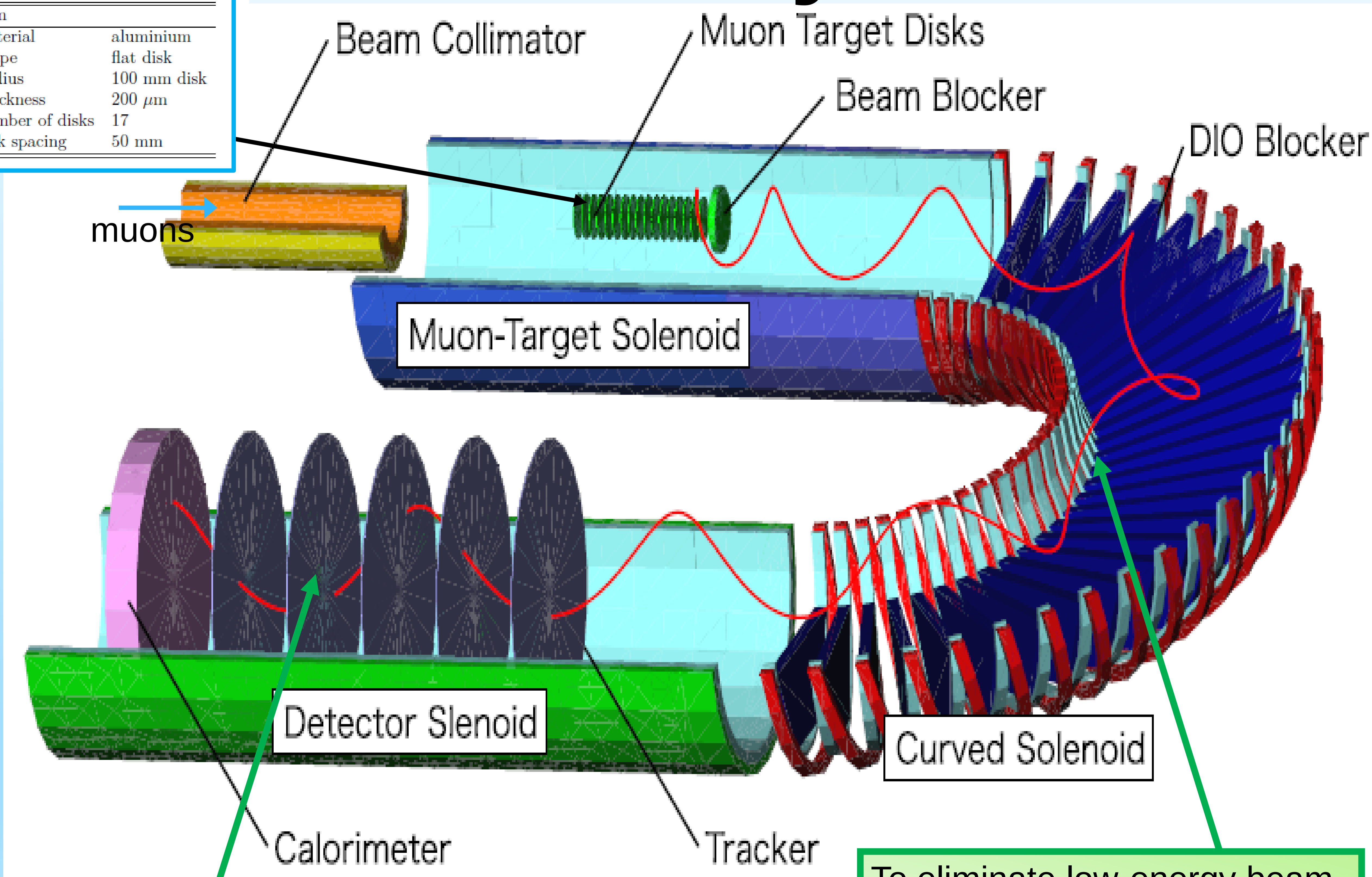
COMET setup

- Target material - graphite
- radius 13mm, length 700mm



Detector system

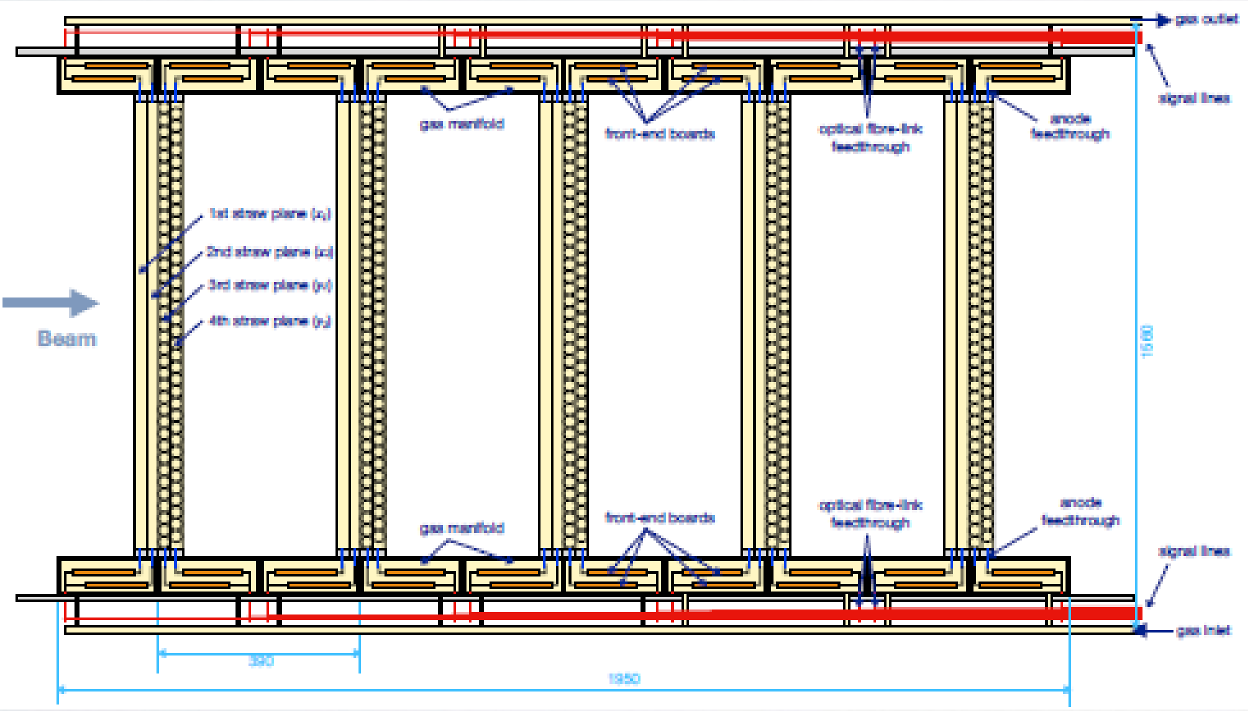
Item	
Material	aluminium
Shape	flat disk
Radius	100 mm disk
Thickness	200 μm
Number of disks	17
Disk spacing	50 mm



To detect and identify
105 MeV electrons

To eliminate low-energy beam
Particles and to transport only
100 MeV electrons

Straw Tracker, 5 station ~ 5000 (10000) tubes



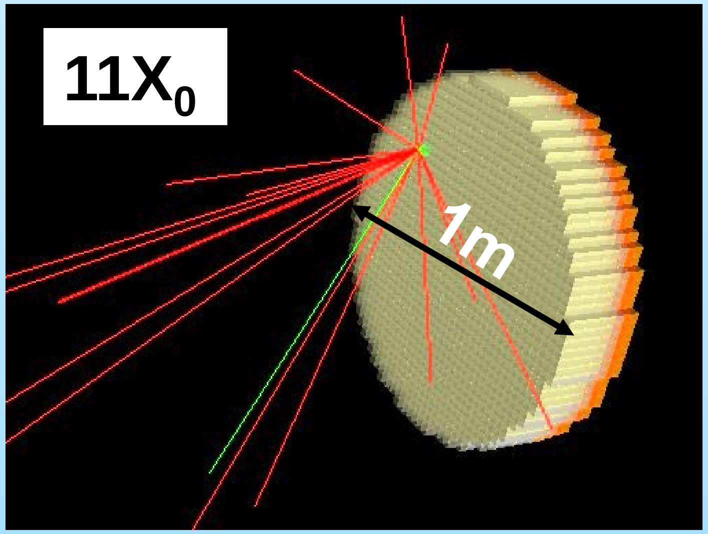
Requirements:

- Work in vacuum, magn. field 1 Tesla
- Momentum resolution ≤ 150 keV/c
- Space resolution ≤ 150 µm

Electromagnetic calorimeter

Crystal detector (The crystal type LYSO)

- Initial crystal candidates were LYSO and GSO. **LYSO** has been selected after the beam test of the GSO and LYSO prototypes with the 105 MeV electron beam at Tohoku in March 2014
- Total size: diameter ~ 1m
- Crystal size 20x20x120 mm^3, in total ~2272 crystals.
- Photon detector: APD

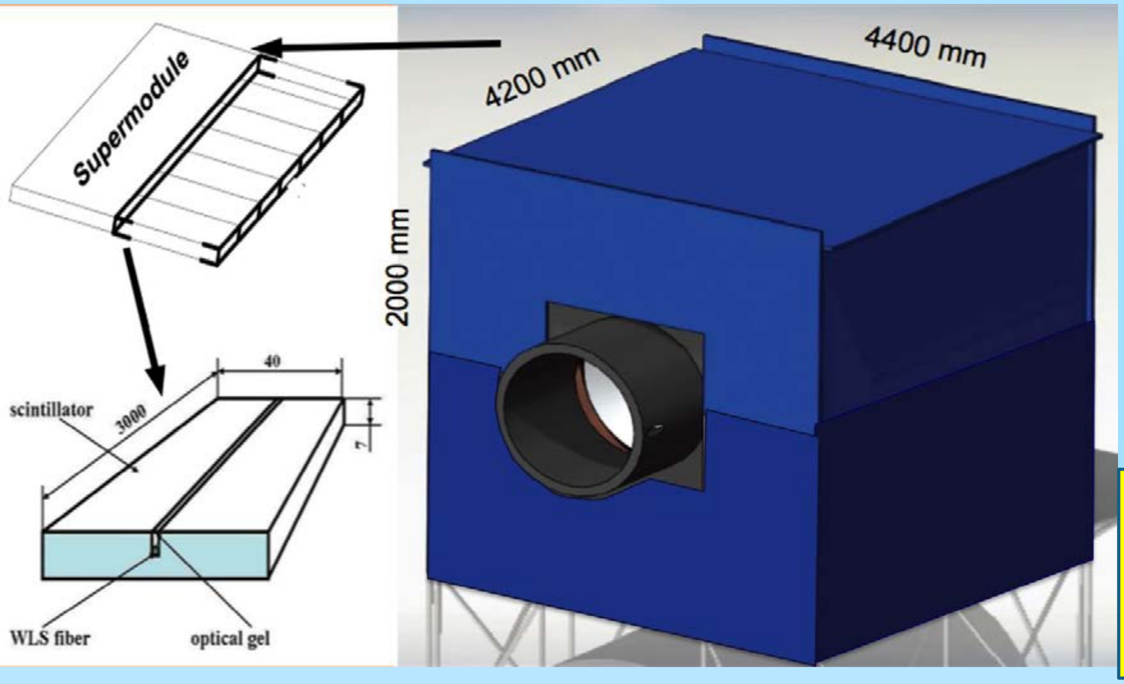


Requirements:

- < 5% ER at 105 MeV
- 1 cm space resolution
- Work in vacuum and magnetic field of 1 Tesla

Cosmic Ray Veto (CRV)

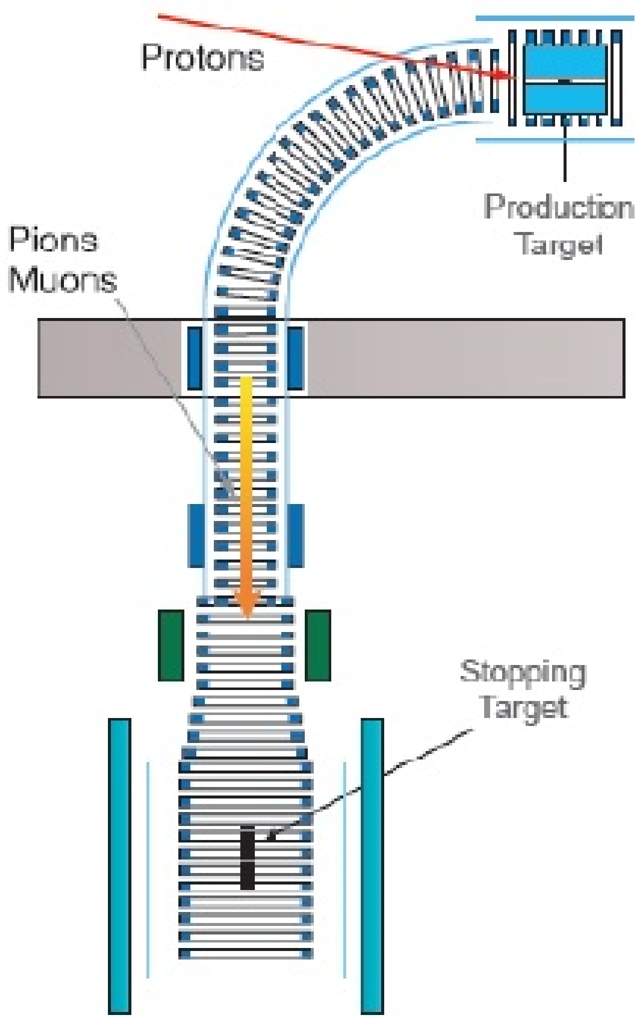
The whole detector will be shielded from cosmic rays by 4 layers of plastic scintillators (active shield)



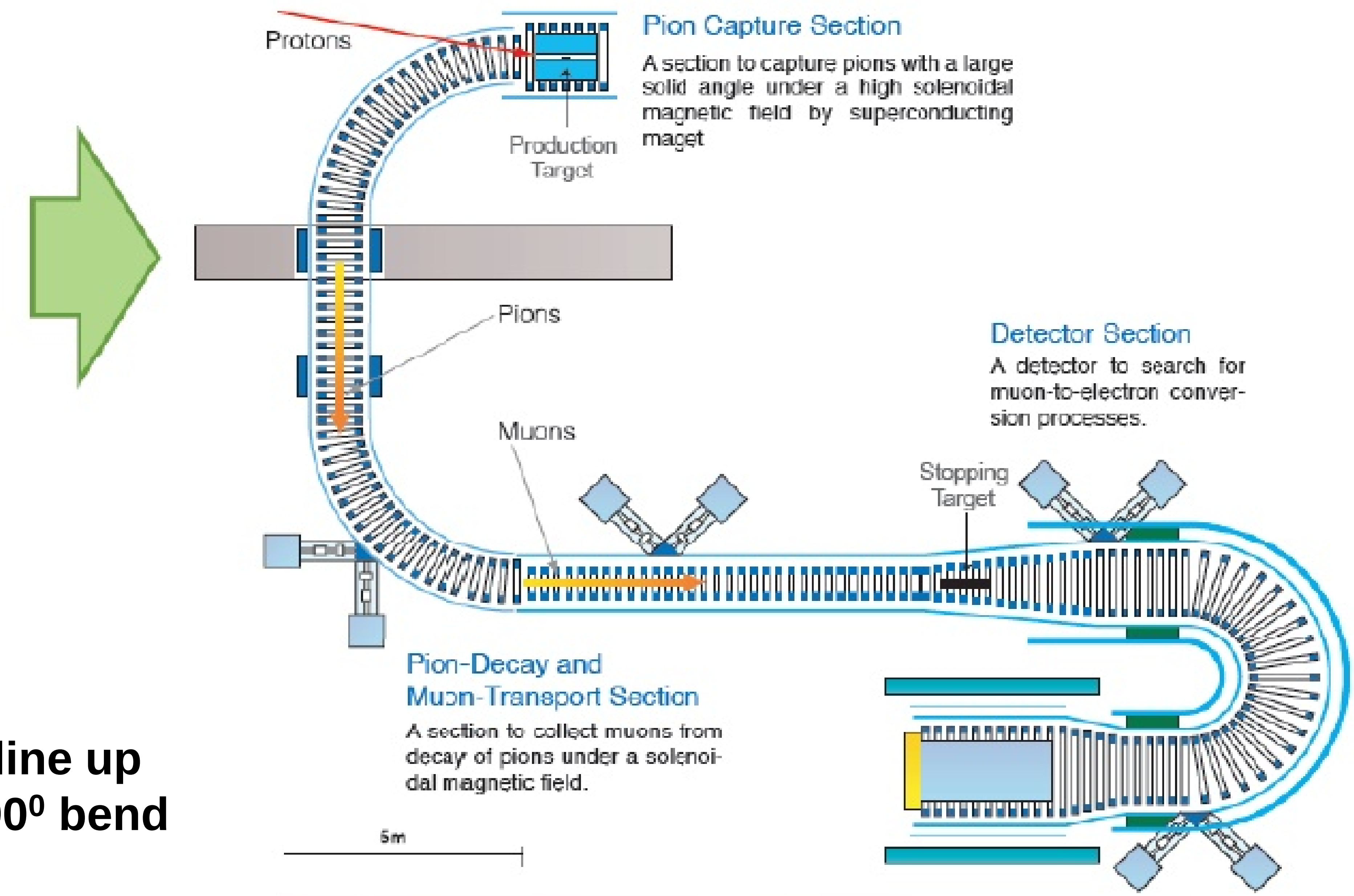
Requirement:
Efficiency ≥ 99.99%.

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

Two-phase realization



Construct Muon beamline up to the end of the first 90^0 bend



COMET Phase-I

COMET Phase-II

Goal of COMET phase-I

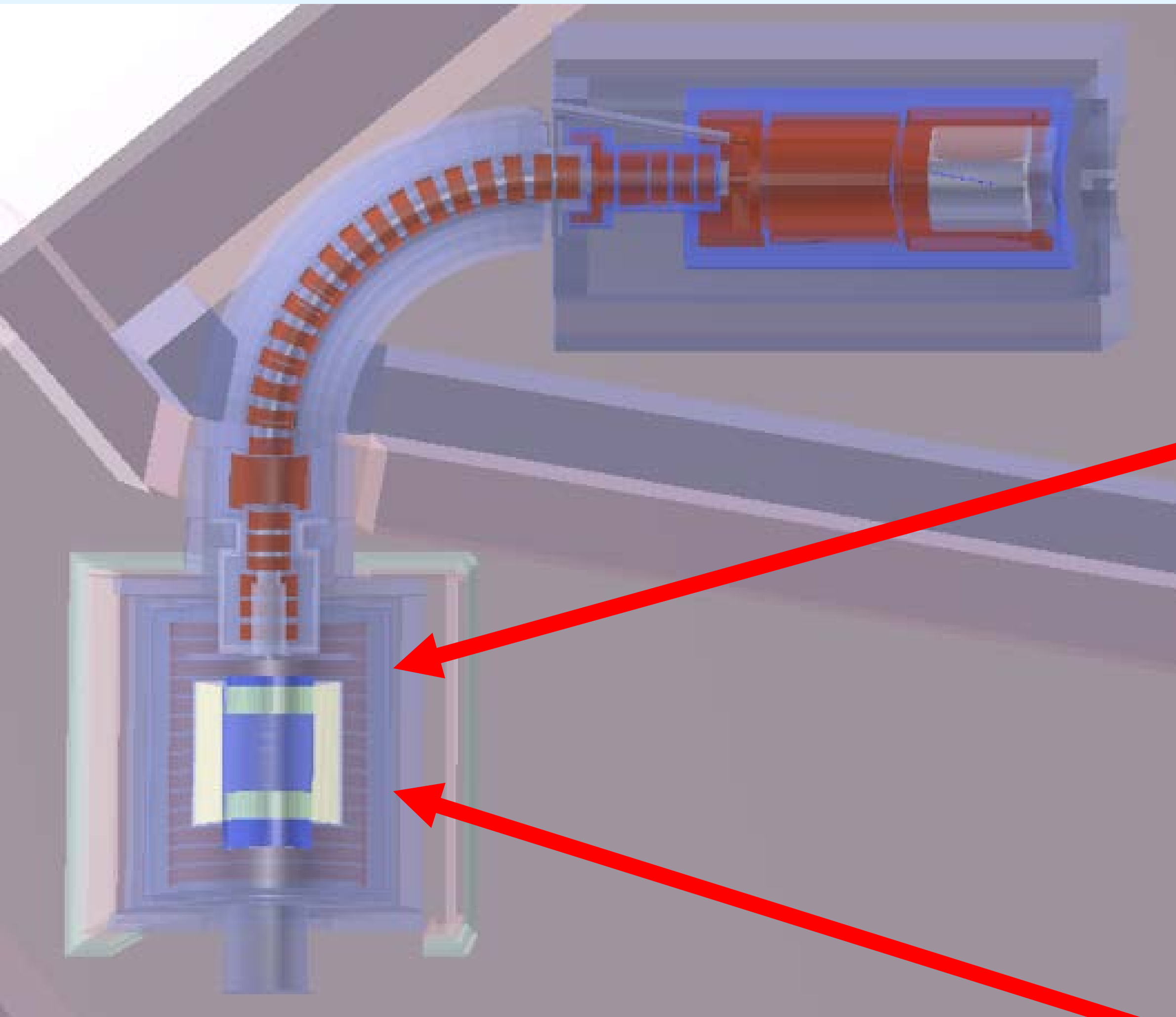
1 Search for μ-e conversion

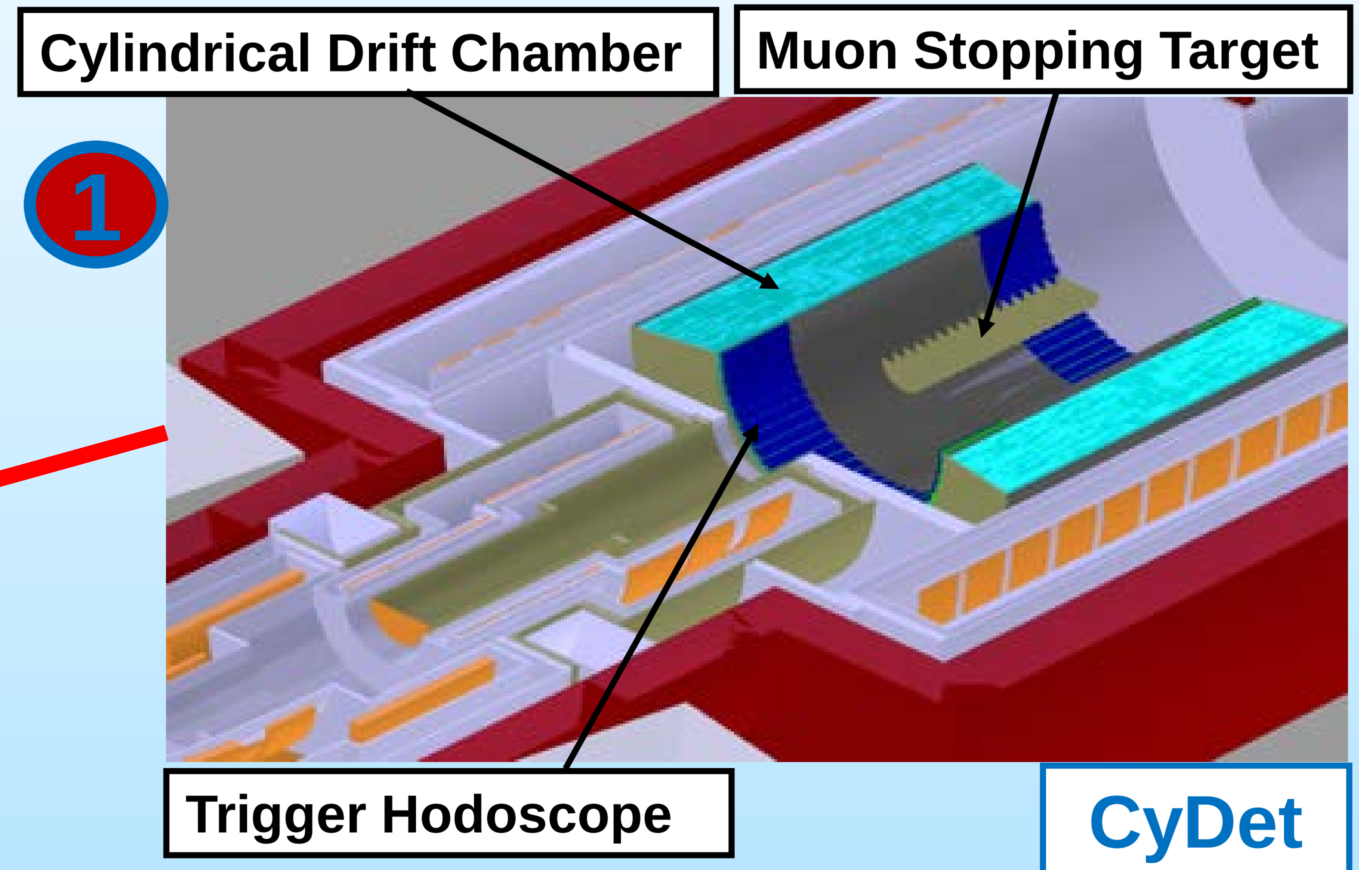
- A search for μ-e Conversion at the intermediate sensitivity witch would be 100-times better than the present limit (SINDRUM-II)

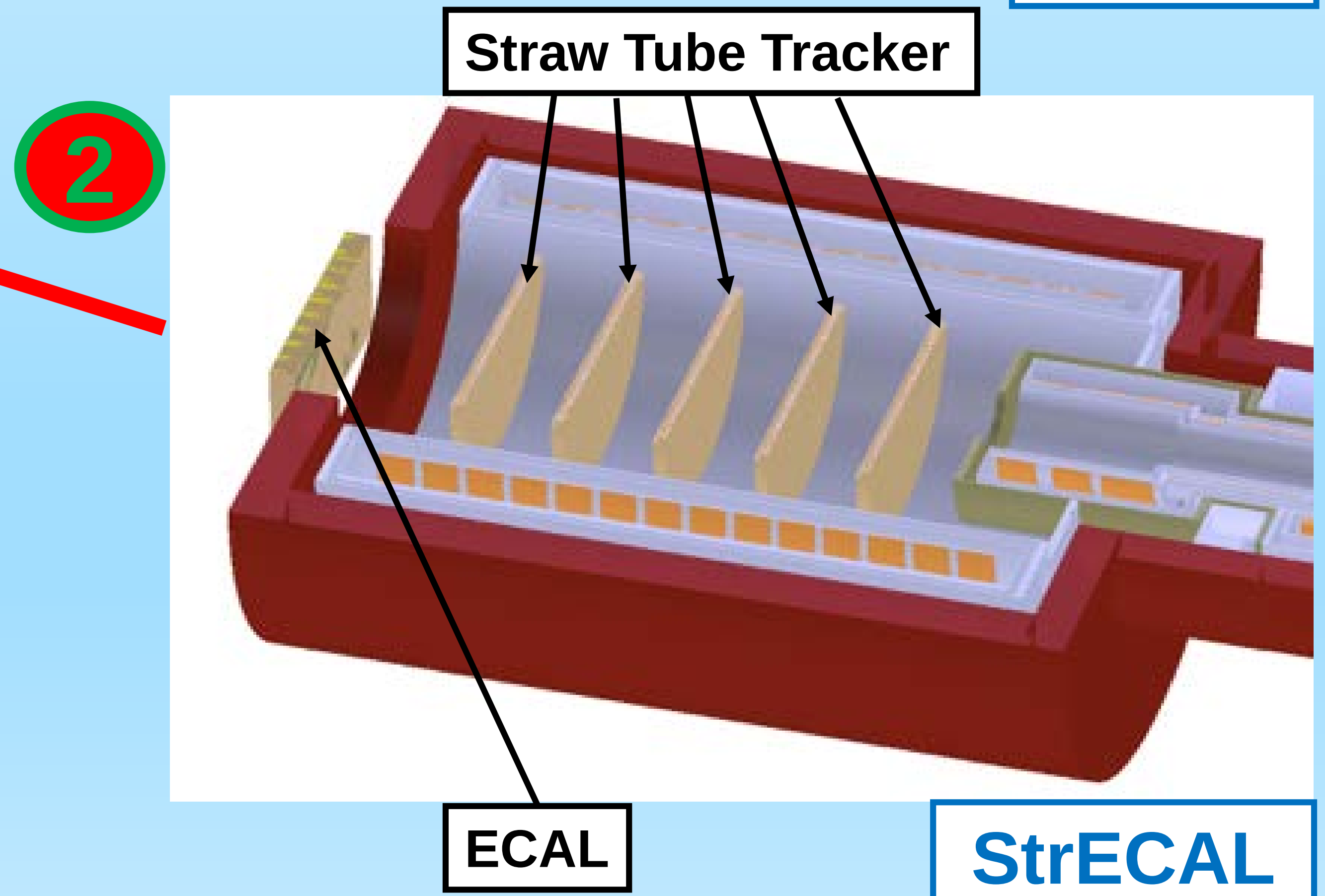
2 Background Study for the full COMET Phase-II

- Direct measurement of potential background sources for the full COMET experiment by using the actual COMET beam line

COMET Phase-I







	Phase-I	Phase-II
#of crystals	~500	~ 2272
#straw tubes	~2500	~ 5000 (10000)
Straw tube Diameter	9.8 mm	5 mm
Straw tube Thickness	20µm	12µm

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
Timing window (ε_{time})	0.3
Total (Signal Acceptance for the μ-e conversion)	**0.041**

$103.6 < p_e < 106.0$ MeV/c

$700 < t_e < 1170$ ns

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

Number of muons stopped inside targets

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

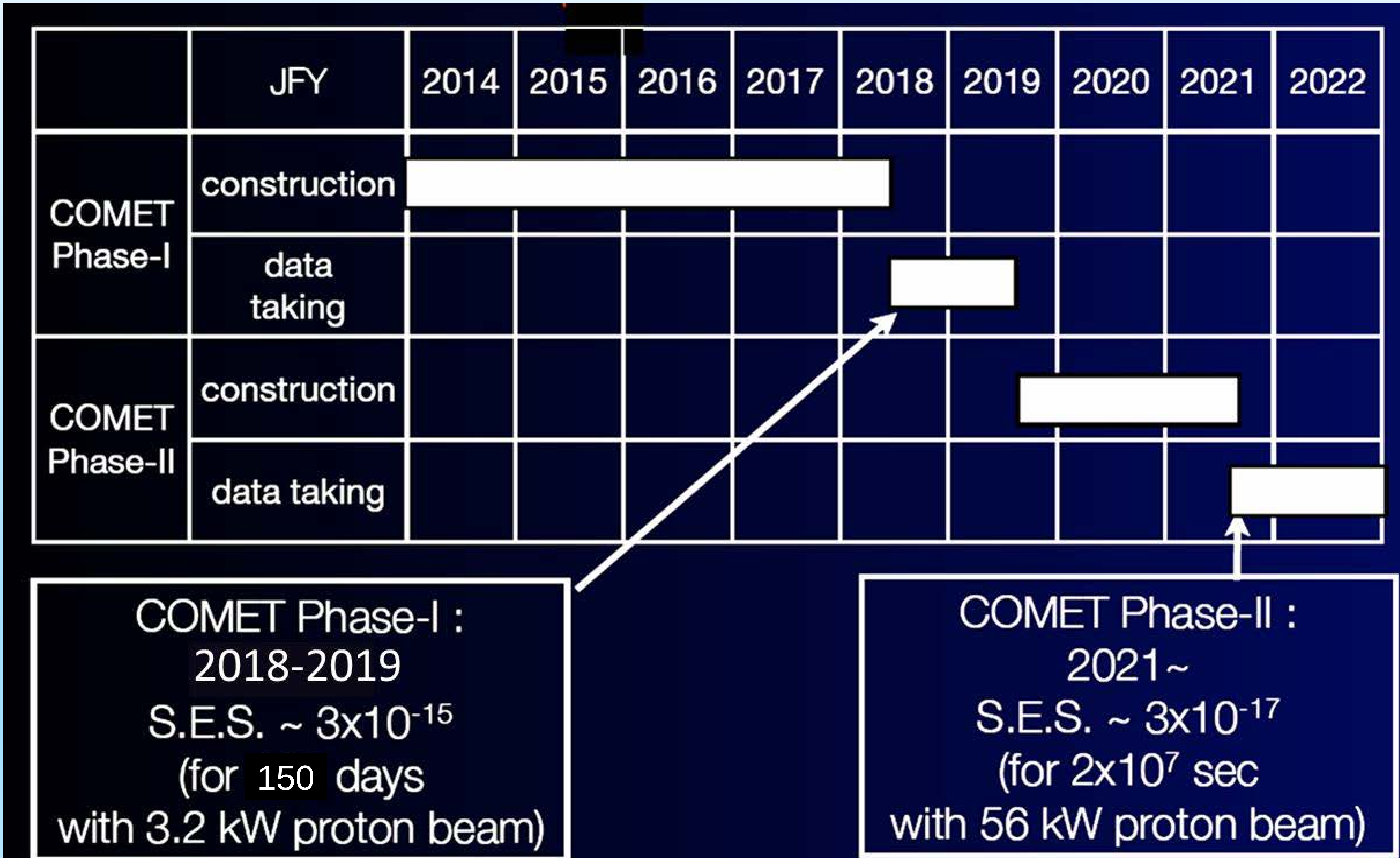
Comparison of Phase-I and Phase-II parameters

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	2.37×10^{19}	8.5×10^{20}
#muon stops (N_μ)	1.3×10^{16}	2.0×10^{18}
Muon rate/s	5.8×10^{9}	1.0×10^{11}
#muon stops/proton	0.00052	0.00052
#BG events	0.027	0.34
The detector acceptance ($A_{\mu\text{-}e}$)	0.06	0.04
S.E.S (single event sensitivity)	**3.1×10^{-15}**	**2.6×10^{-17}**
U.L. (upper limit, 90%CL)	**$< 7.2 \times 10^{-15}$**	**$< 6.0 \times 10^{-17}$**
Measurement start	**2018-2019**	**2021**

ICEDUST Study on COMET Phase-II

COMET Phase-II
SES sensitivity / 2×10^{7} sec = 1.0×10^{-17}

Schedule of COMET Phase-I and Phase-II



JINR group's contributions in 2014-2016 and responsibilities

We are in the project since 2008

JINR has been participated in development and production of two detector systems:

1. Straw tracker
2. ECAL
3. Software studies (simulations)

We are coauthors of CDR (2009) and TDR (Phase-I, 2016)

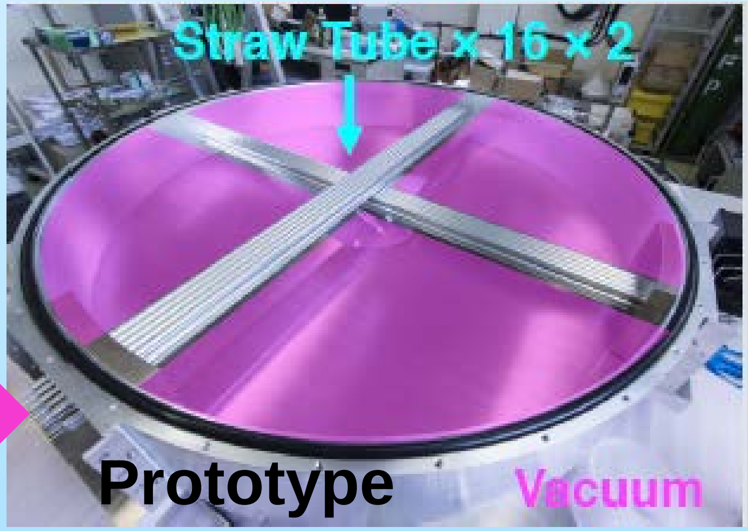
Straw tracker

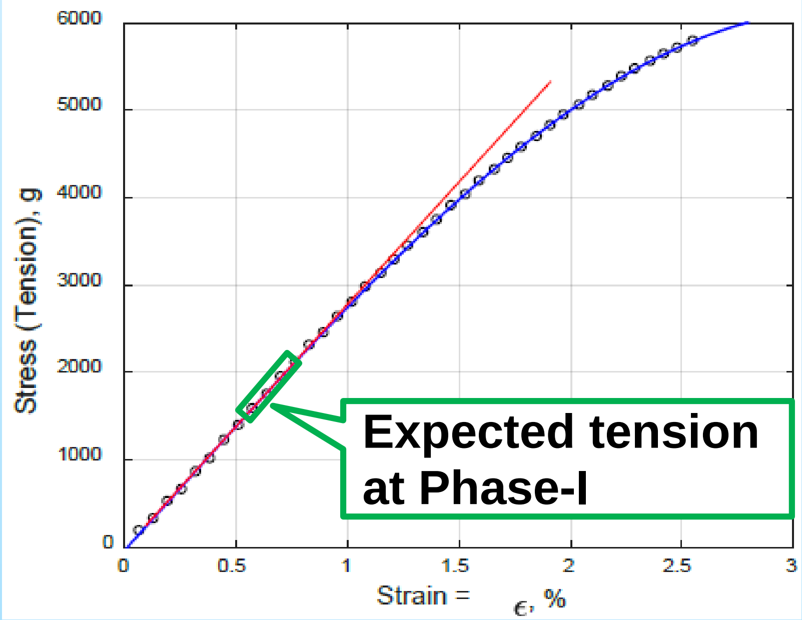
- Simulations: efficiency, resolution etc.
- R&D on straw tube modifications
  (full responsibility)
- All the methods of quality control for NA62 36 µm tubes was adapted for COMET- 20 µm (aluminized Mylar)
- All devices were re-calibrated: welding machine, breaking force machine, gas leaking test machine
- Production of straw tubes, quality checks in accordance to the COMET requirements
  (full responsibility)
- Participated in assembling, calibration and beam testing of the prototype

Straw tube thickness and diameter:
COMET Phase-I - 20µm, 9.8mm

The complete set tubes for Phase-I has been produced and tested in 2015:

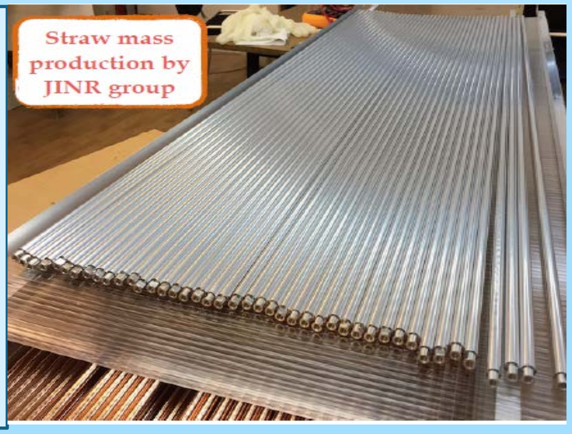
- 2700 tubes of 20 µm wall thickness, Ø 9.8 mm 120 and 160 cm length have been produced
- These tubes passed all the tests and have been sent to Japan





Stress–Strain dependence of straw

For Phase-II we need even thinner and less diameter tubes:
5 mm diameter and 12 µm wall thickness.
For this purpose the R&D works are planning in our laboratory.

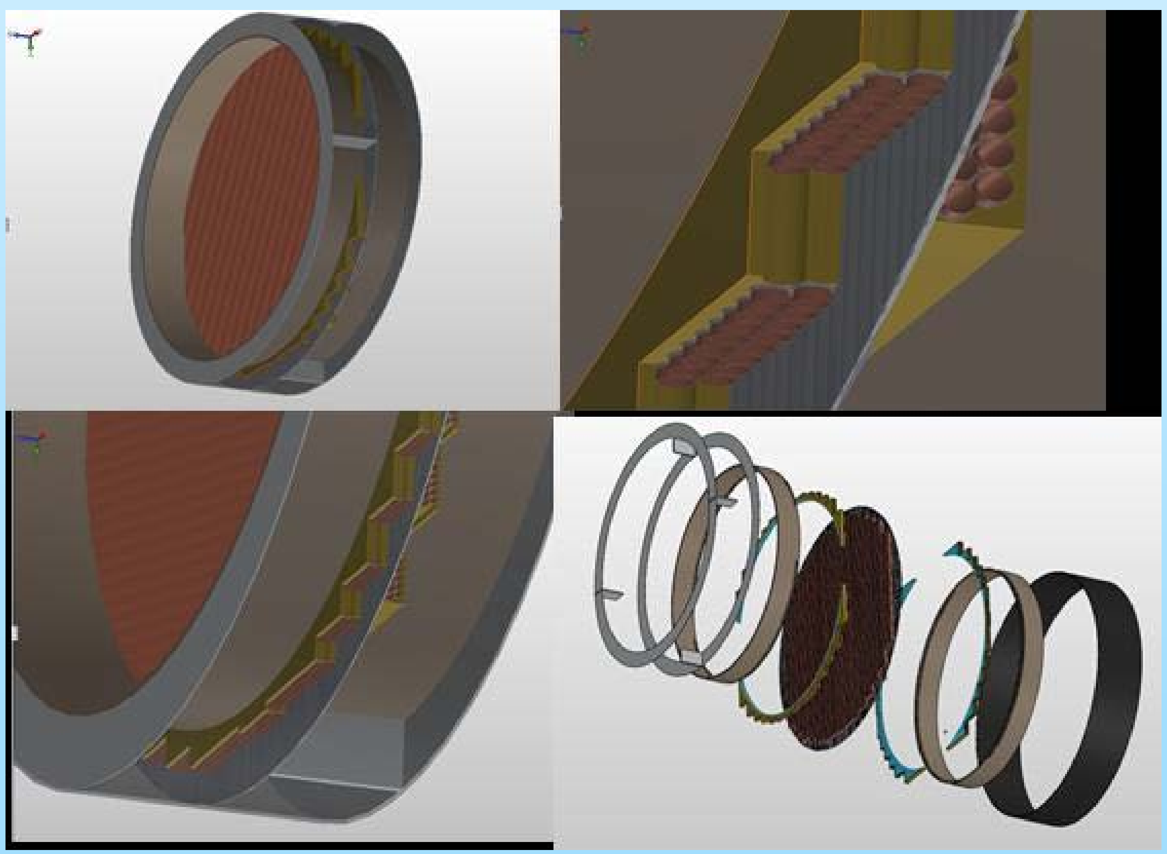


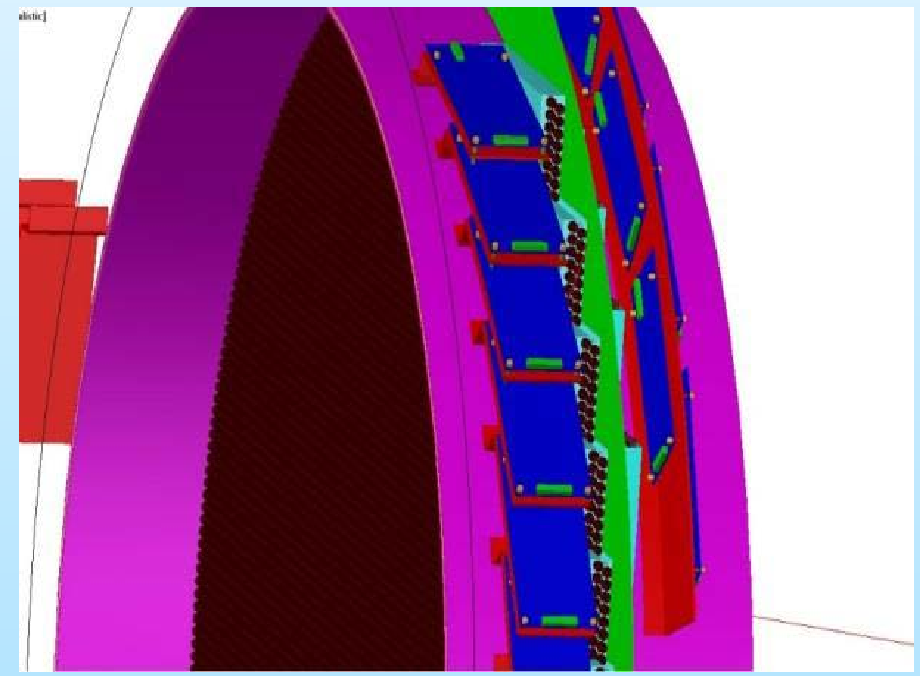
In 2014-2016 the R&D for Phase-I have been done by the members of our group, using the straw production facility of the Veksler and Baldin Laboratory of High Energy Physics of JINR.

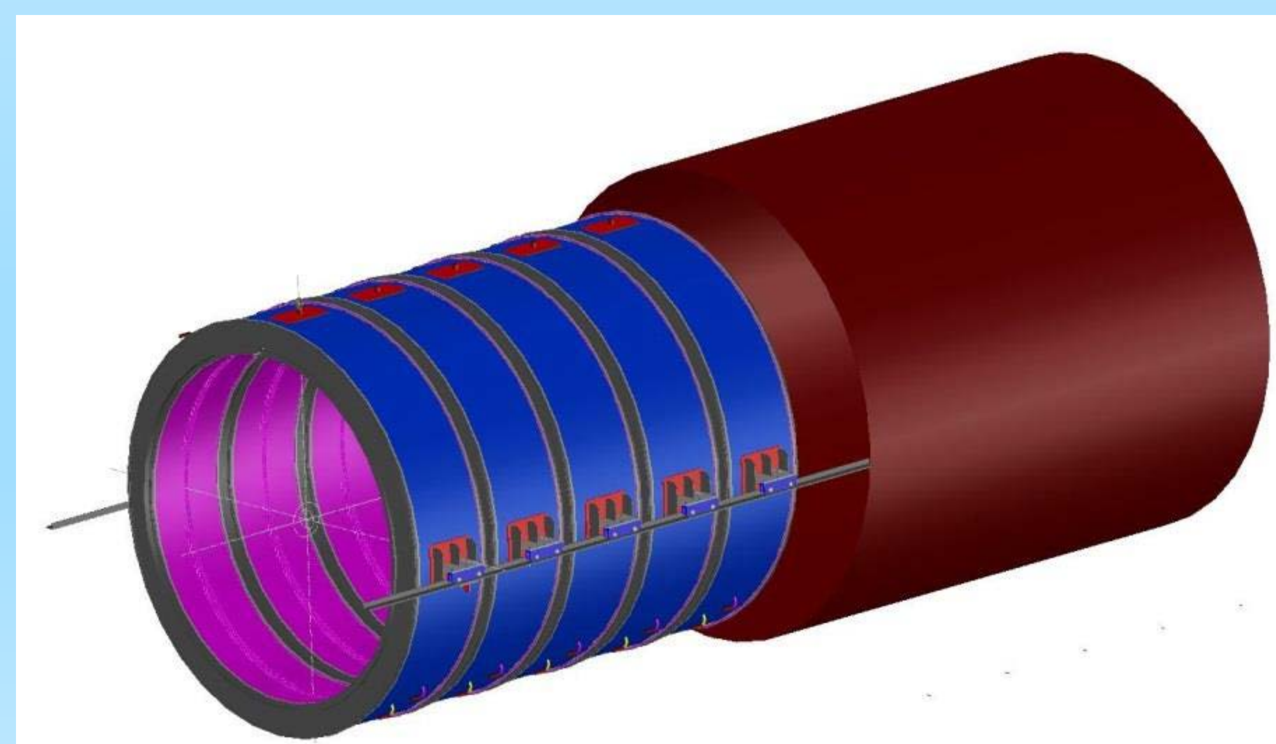
Our big gratitude to VBLHEP!

Straw design and development

Development of versions of mechanical structure of the straw-detector, location of electronics and assembly of the detector in the solenoid

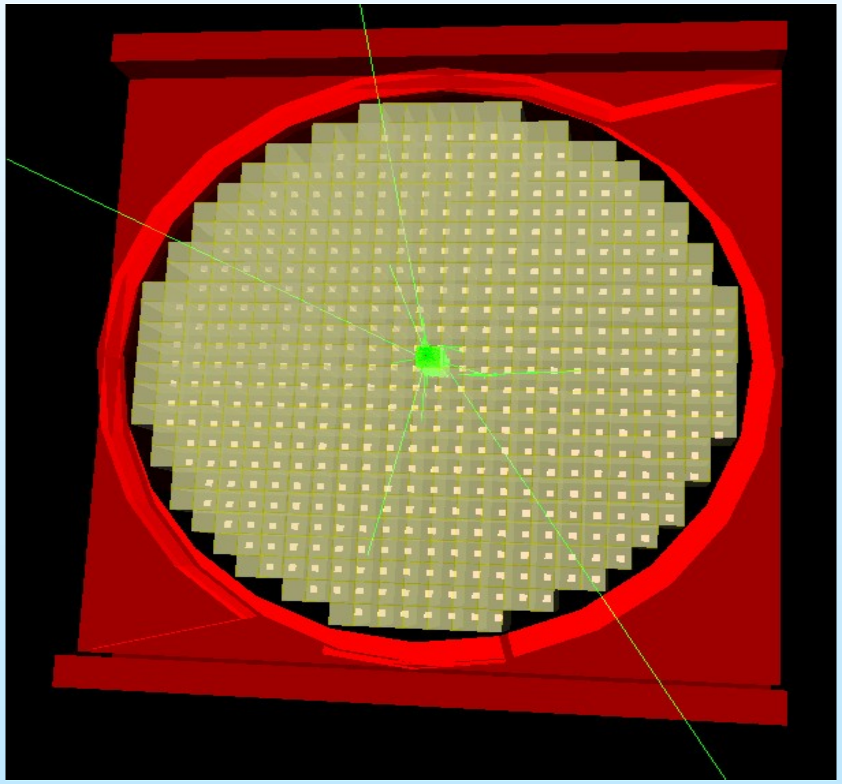






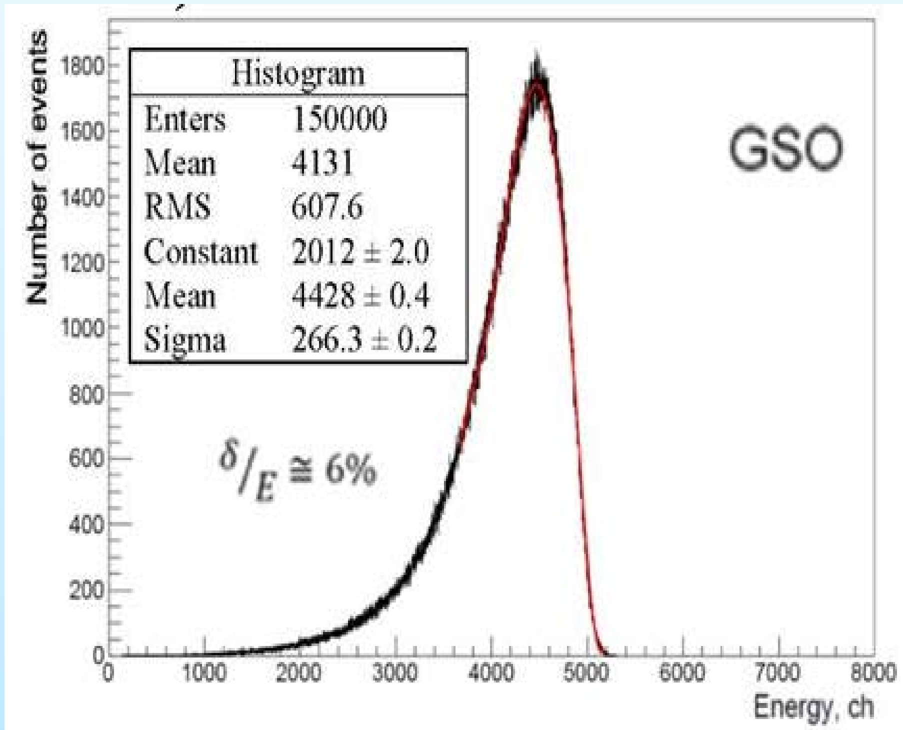
Calorimeter

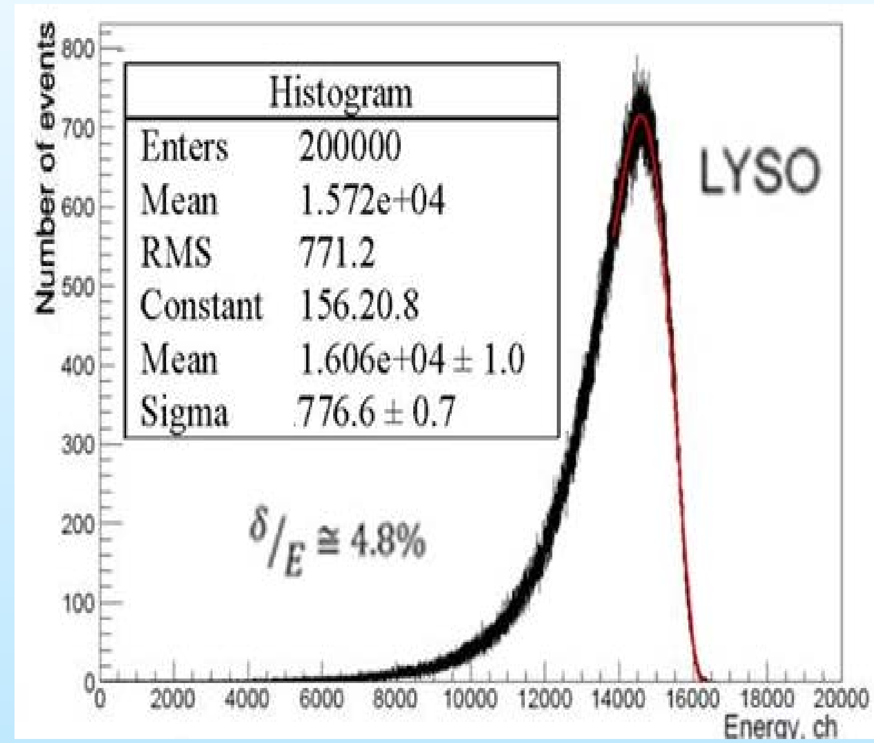
- Simulation of processes in crystals
- Comparison of the crystal types
- Simulation of optimal structure of the calorimeter
- Simulation of the calorimeter geometry in framework ICEDUST
- Experimental study of the main parameters (uniformity, light output) LYSO crystals on a precision JINR stand
- Calibration of 64 crystals of LYSO at the JINR stand for Beam Test (Tohoku, March, 2014)
- Participation in a calorimeter design
- Quality control of all crystals will be tested in JINR (full responsibility)
- Calorimeter assembling, testing, calibration and installation at setup. (In the future)



The test bench has been prepared in DLNP

Studies of the crystal properties, light collection, wrapping materials etc. have been done both by simulations and experimentally





GEANT4

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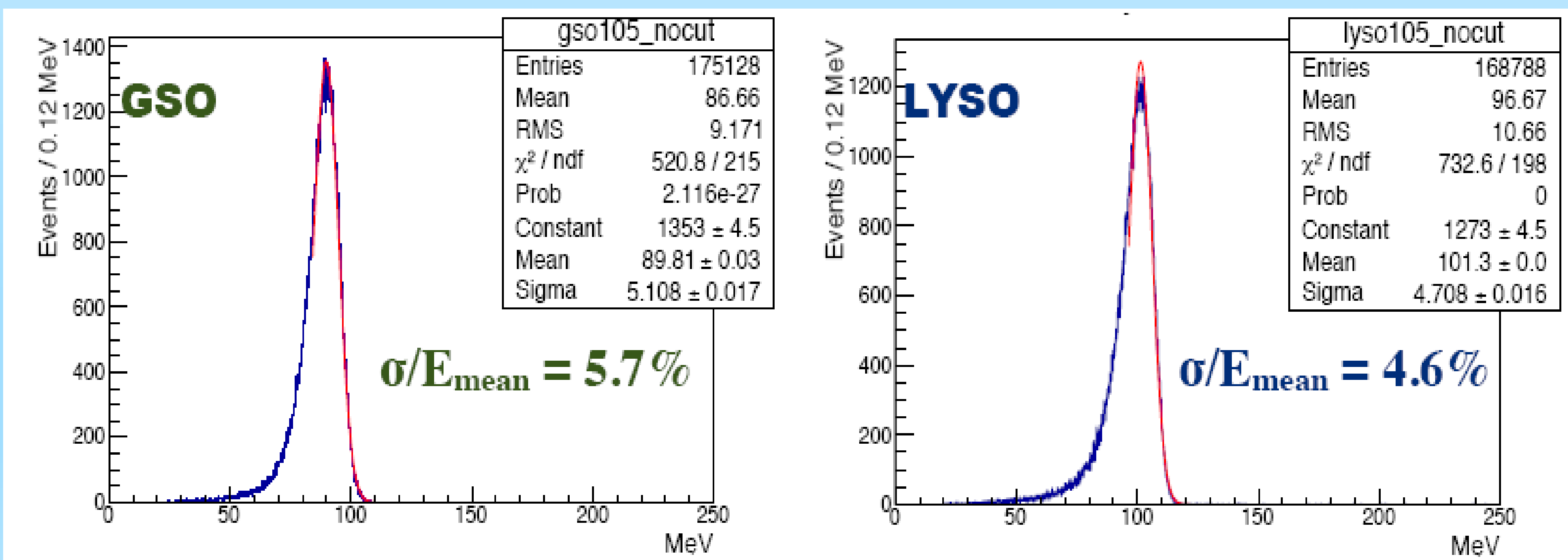
LITRANI

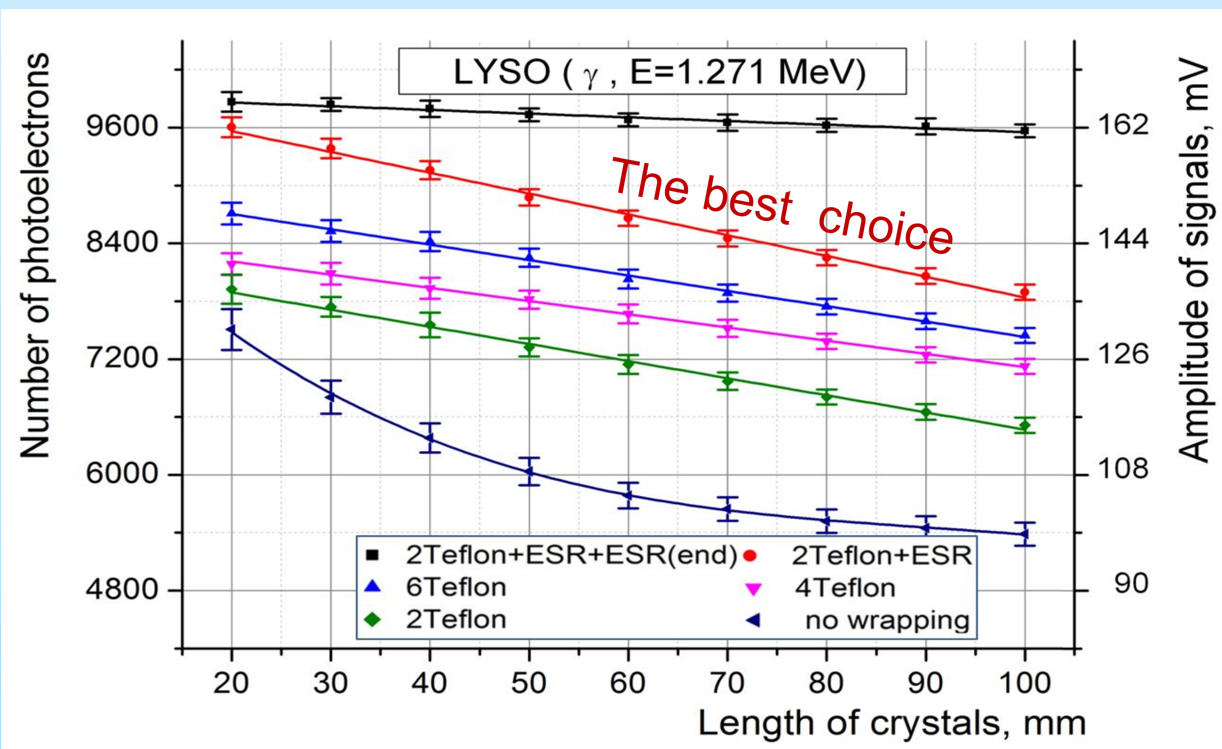
Energy resolution of the calorimeter on GSO and LYSO crystals at the 105–MeV electron beam (simulation)



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

A detailed experimental study of LYSO crystals, at JINR using radiation sources

Light yield non-uniformity along the crystal length with various types of wrapping materials

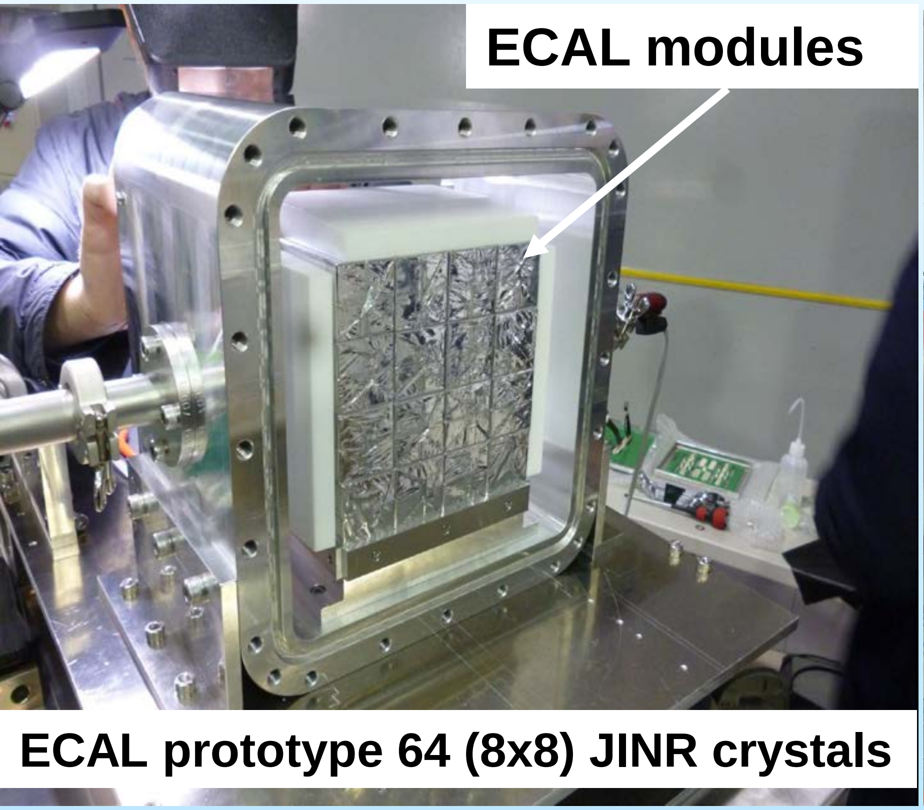


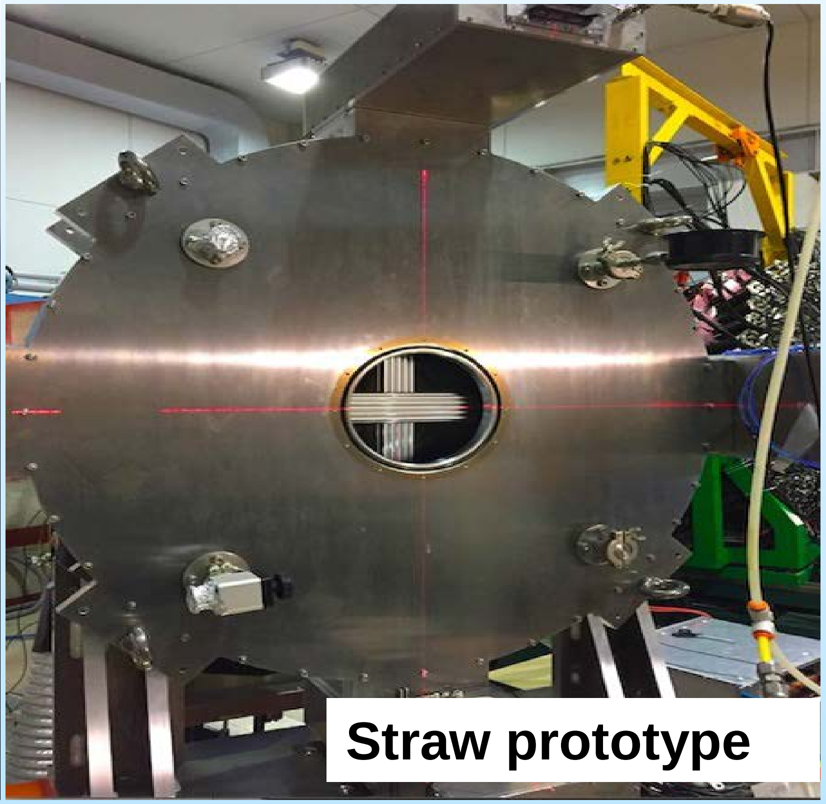
Light yield (LY) non-uniformity, relative yield and energy resolution for various methods of crystal wrapping

Wrapping	LY non-uniformity, % cm^{-1}	Relative LY (L=60nm), %	Energy resolution, (L=60 nm),%
Without wrapping	0.78 ± 0.01	60	11.4
2Teflon	0.4 ± 0.06	74	11.4
4Teflon	0.36 ± 0.05	79	10.6
6Teflon	0.27 ± 0.004	83	9.5
2Teflon+ESR	0.23 ± 0.004	90	8.6
2Teflon+ESR +ESR(end)	0.064 ± 0.003	100	8.6

Materials:
- Teflon (AF1601, 60 μm)
- ESR film (VM2000, 69 μm)

Straw-Ecal prototypes combine beam test (2014, 2015 and March 2016) at Tohoku University, Japan (1.3 GeV electron cyclotron)



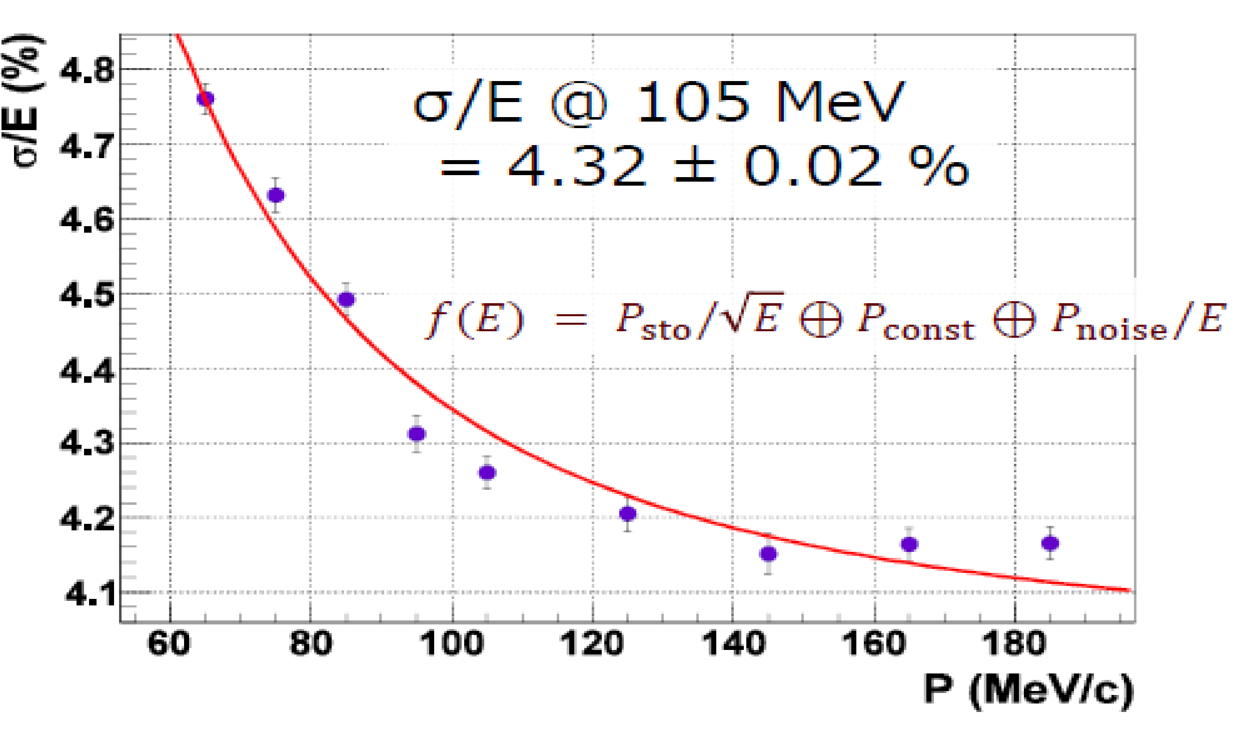


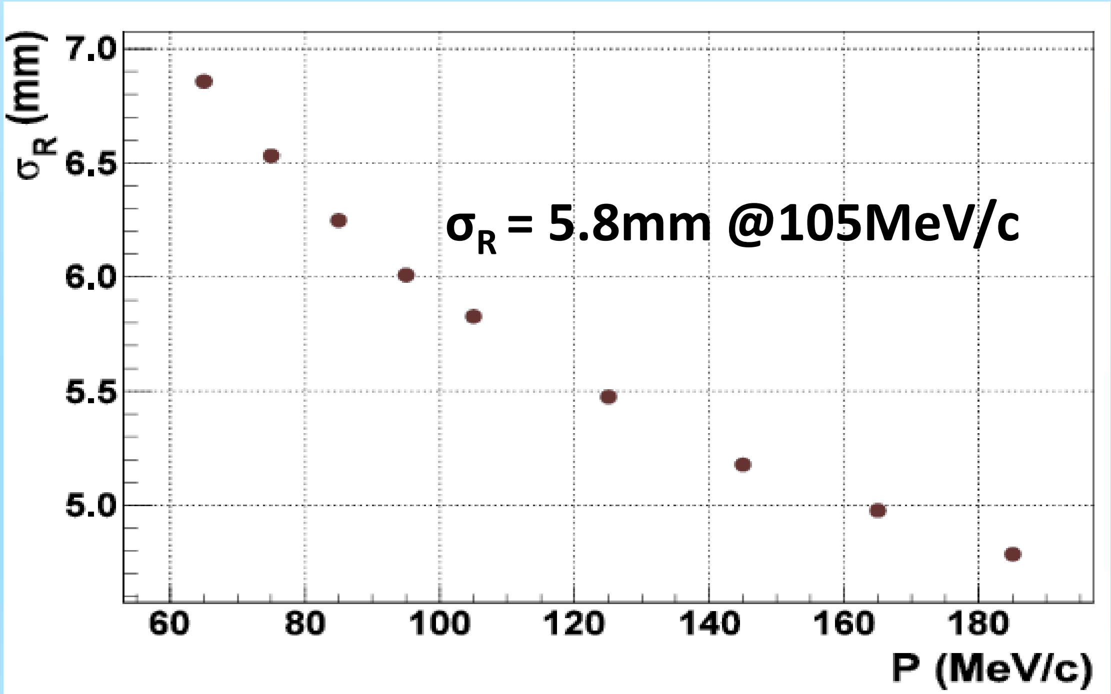
Many tests carried out using full-scale prototype

- Establish the construction procedure
- Evaluate out-gas rate of straw tubes
- No, leak, no significant out-gas
- **Operation in vacuum performed in success**

The results of straw efficiency and spatial resolution

- **ε > 96%**
- **σ =143μm**





The results of the measurement, March 2016

StrEcal test-beam at Tohoku, 3rd-13th March 2017, Should be FINAL!!

Simulation and data analysis

- **A large amount of work on simulation of processes in crystals and straw detector has been done. This work continues.**

- **By simulation of the main ring of J-PARC the optimal configuration have been found giving the best *extinction factor for* operating modes. The work is finished.**

- **The analysis of data from prototypes of a calorimeter and a straw from the an electron beam in Tohoku, is carried out. The work is under way.**

- **It is planned to creation of COMET computer farm in LIT-JINR, for full-scale participation in the simulation of physical processes, optimization of all detector system, and in the physical analysis of data. The work will start in 2017.**

Schedule of works on the project in 2017-2019

1.	Participation in assembling and tests of the straw detector for Phase-I	**2017-2018**
2.	R&D for production of the straw tubes of 12 μ wall thickness and 5 mm diameter for Phase-II:	**2017-2018**
3.	Test of the crystals in JINR to be used in the calorimeter:	**2017-2019**
4.	Participation in the calorimeter designing, assembling and tests:	**2017-2019**
5.	Participation in the beam tests of the detector components:	**2017-2019**
6.	Creation of the COMET computer farm in LIT-JINR	**2017**
7.	Complex detector system (tracker, calorimeter, etc.) simulation to define the acceptance, expected uncertainties, sources of systematics, reconstruction algorithm development, etc.	**2017-2019**
8.	Participation in assembling, installation and testing of the whole detector	**2017-2019**
9.	Participation in the engineering and physical run:	**2018-2019**
10.	Participation in the data acquisition and analysis:	**2019**

Summary

- The COMET is a search experiment for $\mu^- N \rightarrow e^- N$ at J-PARC with an excellent sensitivity of O (-17) which is four orders of magnitudes better than the present limit.
- The COMET experiment employs the staged approach
  1. In Phase-I, beam measurement and $\mu^- N \rightarrow e^- N$ search with an intermediate sensitivity at level O (-15).
     - Construction for COMET Phase-I is fully supported by KEK/J-PARC as a first priority project.
     - The realization of Phase-I experiment is finally approved; the "J-PARC Stage-II" approval.
     - In 2018 we will be ready for the COMET experiment Phase-I.
  2. Phase-II = Full COMET sensitivity.
- In parallel to preparation and carrying out Phase-I experiment, the work on creation of a full muon bunch, and R&D on detectors for a Phase-II will be performed. After completion of Phase-I the installation and assembly for Phase-II will be start.
- JINR already made very big contribution to COMET experiment and we hope it will continue to play a visible role in the feature of this experiment of fundamental importance.

COMET

is

A big challenge and great discovery potential experiment !

A flagship experiment for J-PARC and worldwide physics in the decade.

Thank you for attention!

BACKUP

Estimation of costs and resources

Proposal for resources necessary for realization of the project "Search for coherent neutrino-less μ -e conversion at J-PARC (COMET) ", 2017-2019

Form №26

Units and systems of The setup, resources, Sources of financing			Cost of units (k$). Required resources	Laboratory proposal for schedule of financing and re-sources		
				1 year	2 year	3 year
Main	Computers Electronic devices Materials		15 96 210	5 50 110	5 27 60	5 19 40
Resources	Hours	Design bureau DLNP Workshop	800 hours 1200 hours	300 500	300 500	200 200
rce of financing	Budget	Budget expenses (without salary)	477	217	144	116
	n-budget	Grant of the Plenipotentiary of Georgia	30	10	10	10
		Program of the JINR-Belarus Cooperation.	15	5	5	5

Estimate of expenses for the project "Search for coherent neutrino-less μ -e conversion at J-PARC (COMET) ", 2017-2019

Form №29

NN	Purpose of expenses from DLNP	Full cost	1st year	2nd year	3rd year
	Direct expenses				
1.	Accelerator	-	-	-	-
2.	Computing	-	-	-	-
3.	Design bureau	800 hours	300	300	200
4.	Workshop LNP	1200 hours	500	500	200
5.	Materials	210k$	110	60	40
6.	Equipment	111k$	55	32	24
7.	Contracts for R&D	-	-	-	-
8.	Business trips:				
	a) To the non-rouble zone countries	150k$	50	50	50
	b) To the cities of rouble zone countries	6	2	2	2
	c) By protocols	-	-	-	-

CLFV processes with muons

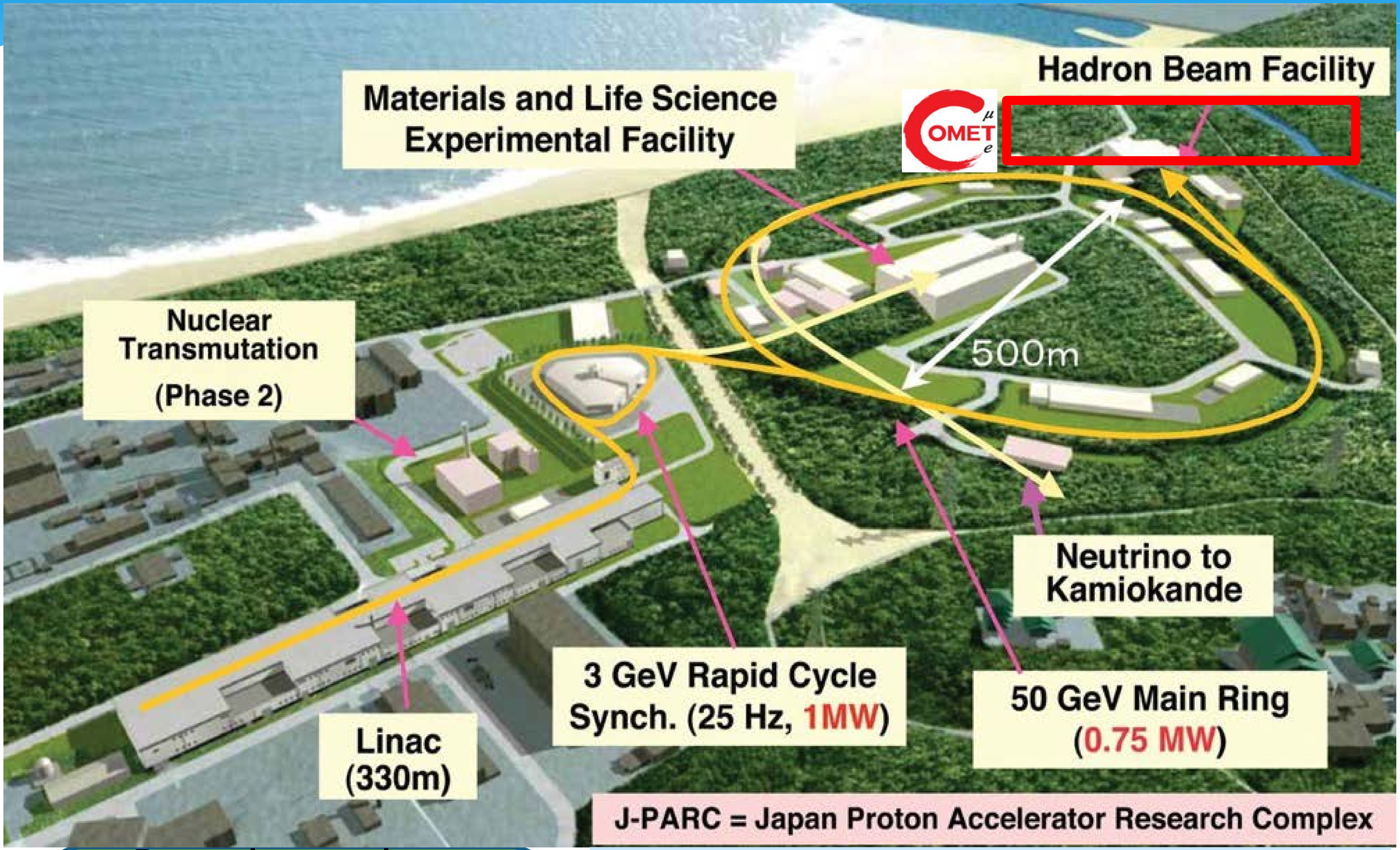
Process	Present limit	BSM model level	Future Exp.
μ N → e N	< 7.0x 10^{-13} (in Au) SINDRUM-II, 2006)	$10^{-15\text{-}16}$ *Phys. Rev.*, D87(9):096020, 2013	10^{-17} COMET/J-PARC 10^{-17} Mu2e/FNAL
μ →e γ	< 4.2x10^{-13},latest result (MEG, April, 2016)	10^{-14}	10^{-13} , 10^{-14} , PSI
μ → 3e	<1.0x10^{-12} (SINDRUM, 1988)	10^{-16} , 10^{-17}	10^{-14} , 10^{-15} , PSI

Process	Major backgrounds	Beam	Sensitivity Issues
μ N → e N	Beam-associated	Pulsed beam	Beam qualities
μ →e γ	Accidental	DC beam	Detector resolution (limited)
μ → 3e	Accidental	DC beam	Detector resolution (limited)

From an experimental point of view μ-e conversion is a very attractive process.

- The *e*− energy of about 105 MeV is far from the end-point energy of the Michel spectrum (52.8MeV).
- The event signature is a mono-energetic electron, no coincidence measurement is required.
- This process has the potential to improve sensitivity by using a high muon rate without suffering from accidental background events, which is a serious problem for searches using *μ* →eγ and *μ* →3e decays.

COMET at J-PARC



Proton beam and power current (maximal in design)

COMET	J-PARC
8GeV	30 (50) GeV
56kW	450 (750) kW

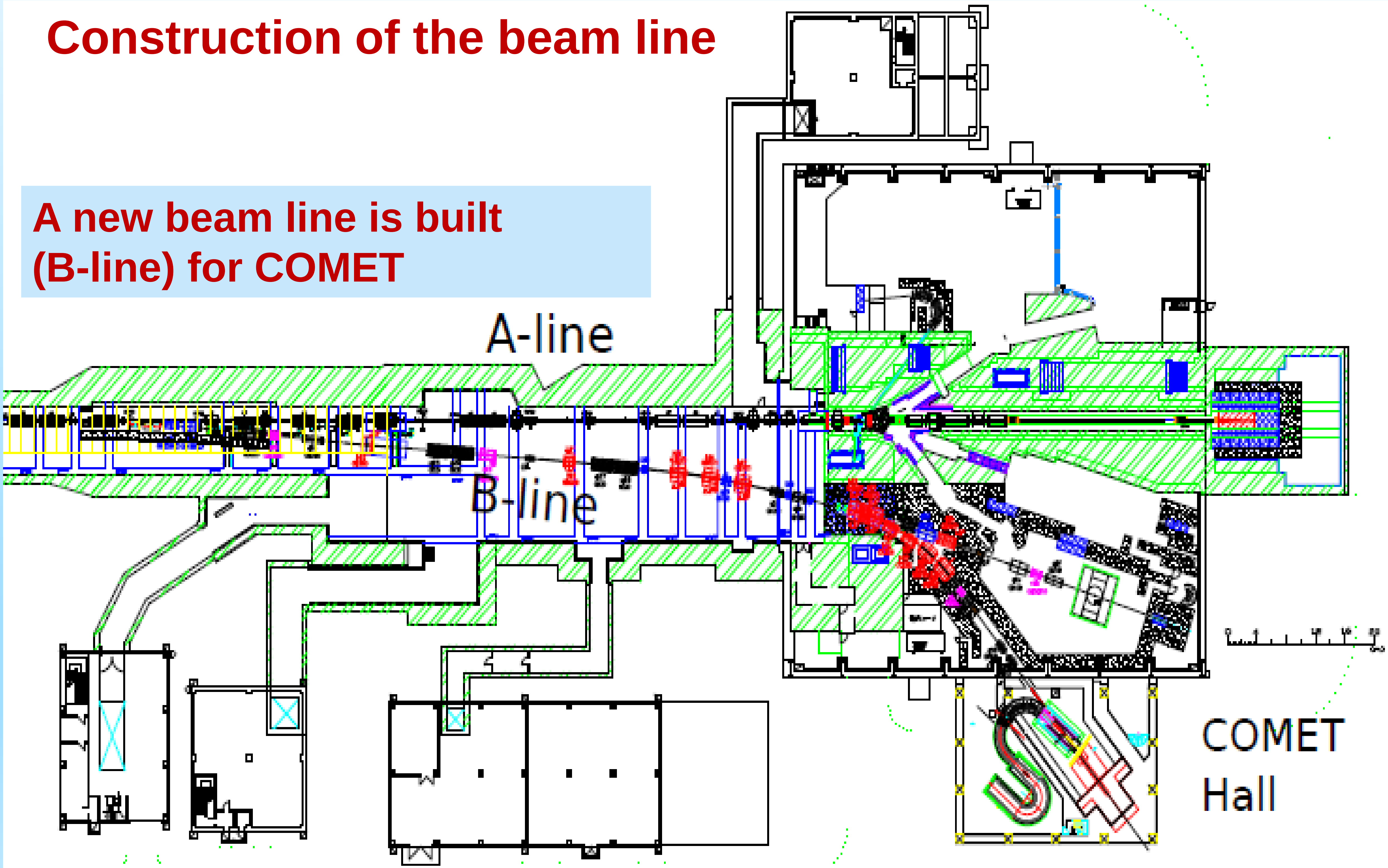
Joint Project between KEK and JAEA

J-PARC beam will be used not at full power and energy

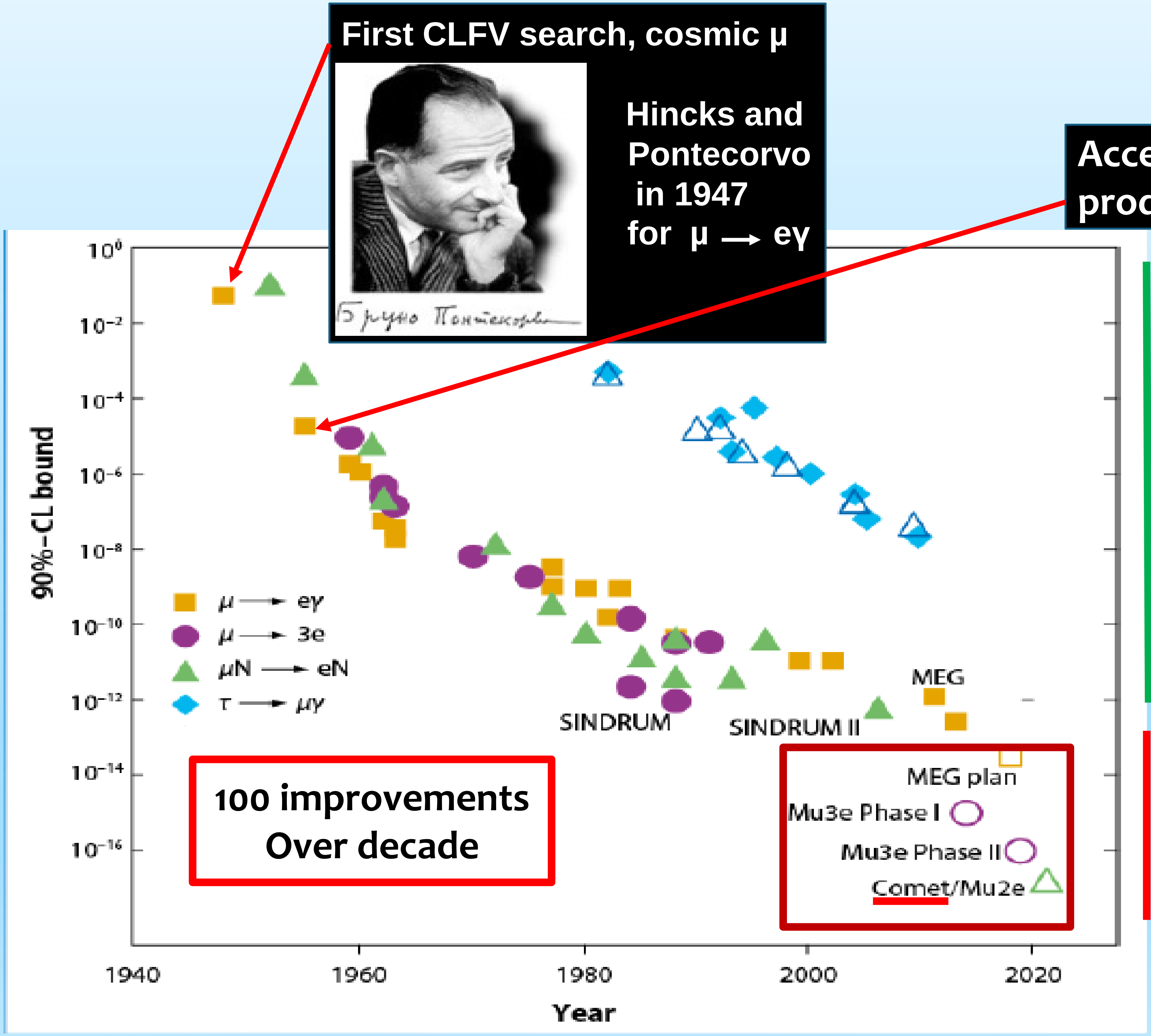
The experimental facilities

Construction of the beam line

A new beam line is built (B-line) for COMET



History of search for CLFV



70 years of searches

New generation of CLFV experiments

The high-p/COMET beam-line construction in FY2016
Main part of pion/muon transport solenoid is already installed

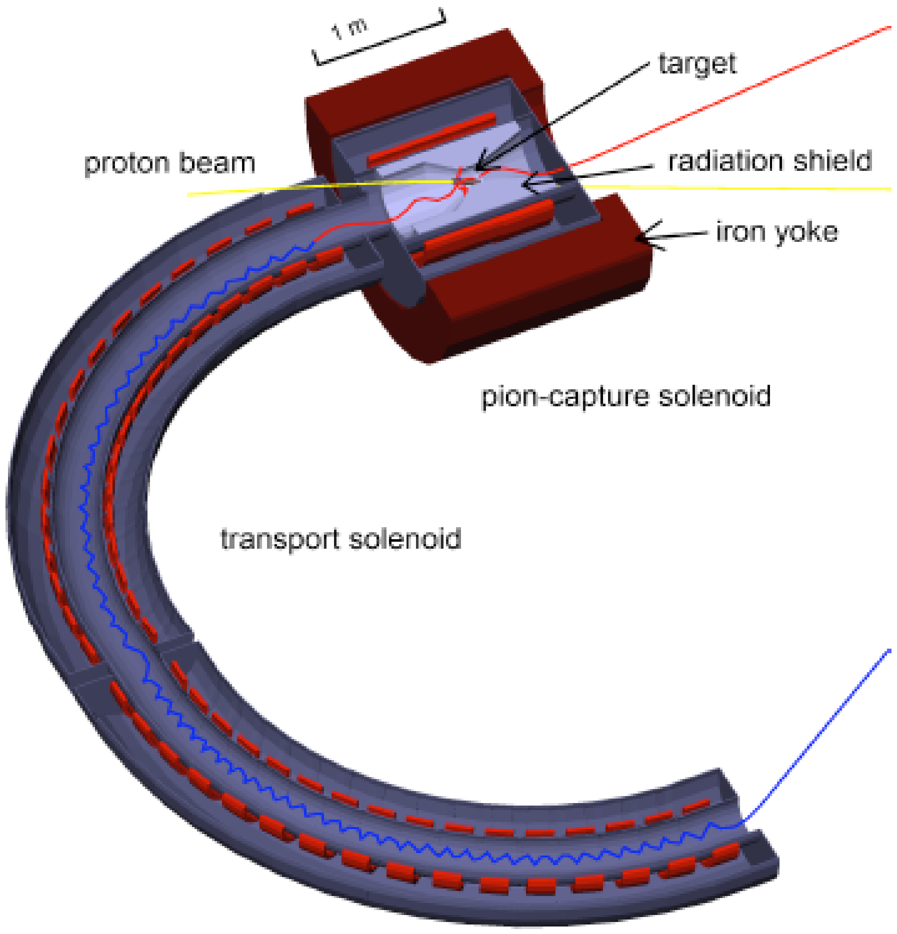
The works are on schedule

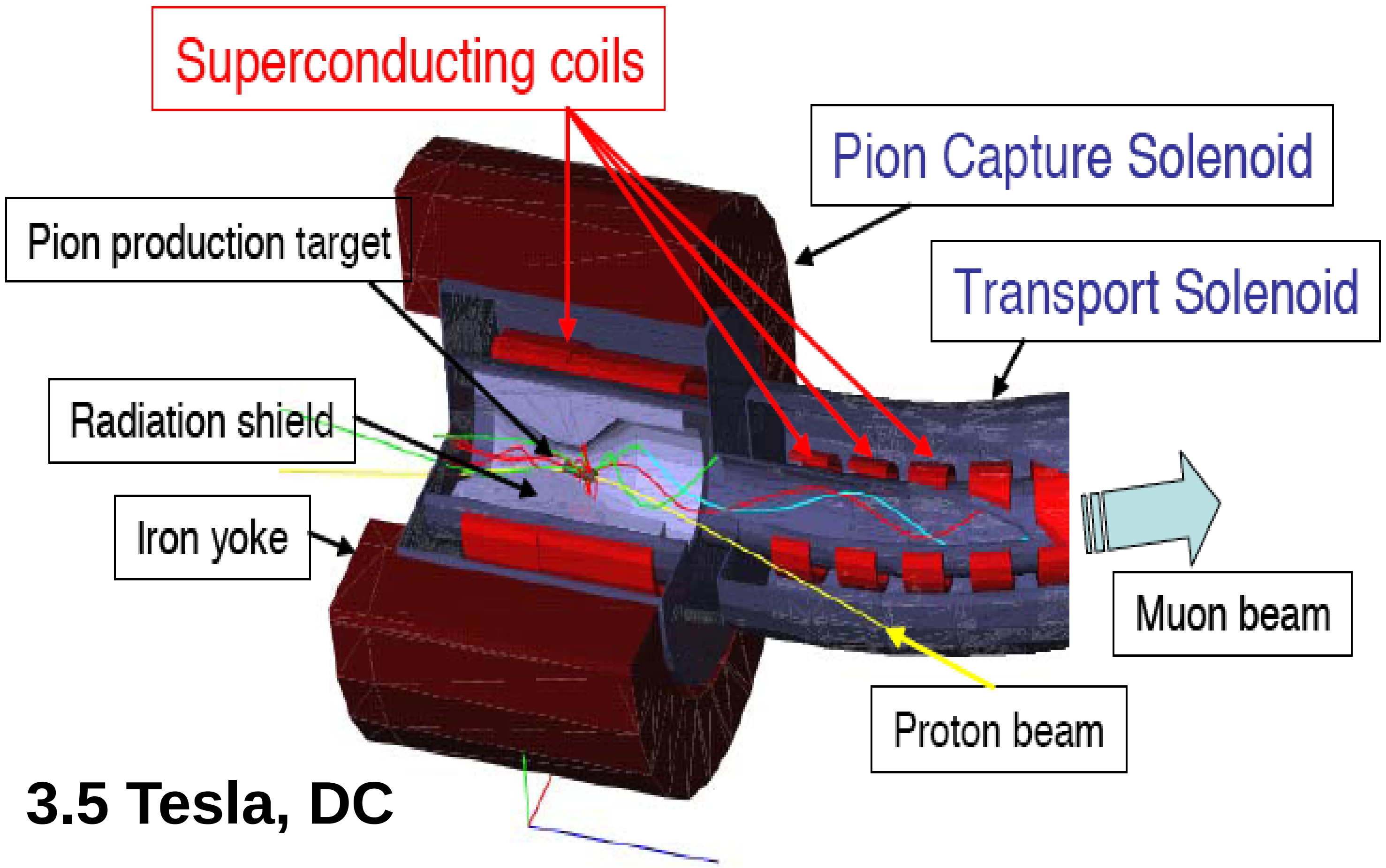
Construction of shielding wall of COMET beam line is finished

Transport Solenoid has been produced by TOSHIBA.

Demonstration of the Pion Capture System for COMET

It is very important that this is experimental confirmation



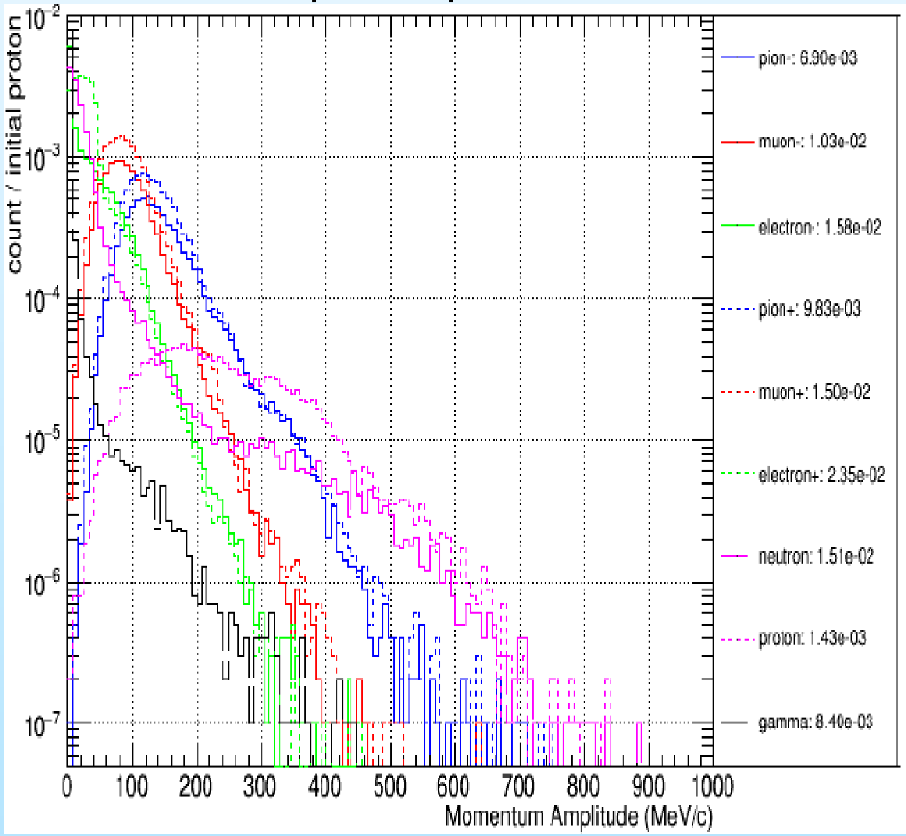


3.5 Tesla, DC

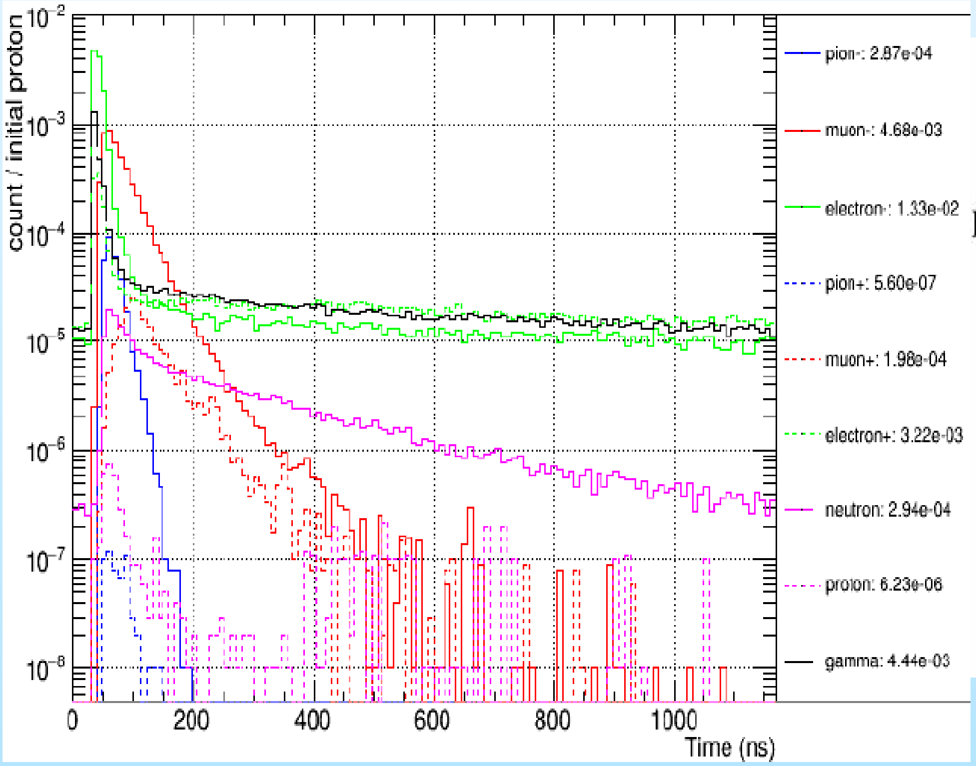
A muon beam intensity of 10^8 muons/sec with a proton beam of 400MeV energy with 1μA beam current from the RCNP proton ring cyclotron.
This beam intensity is almost the same as in PSI.
10^{-4} muons/proton/GEV for MUSIC, RCNP
10^{-7} muons/proton/GEV for PSI
The muon production efficiency per proton is about 1000

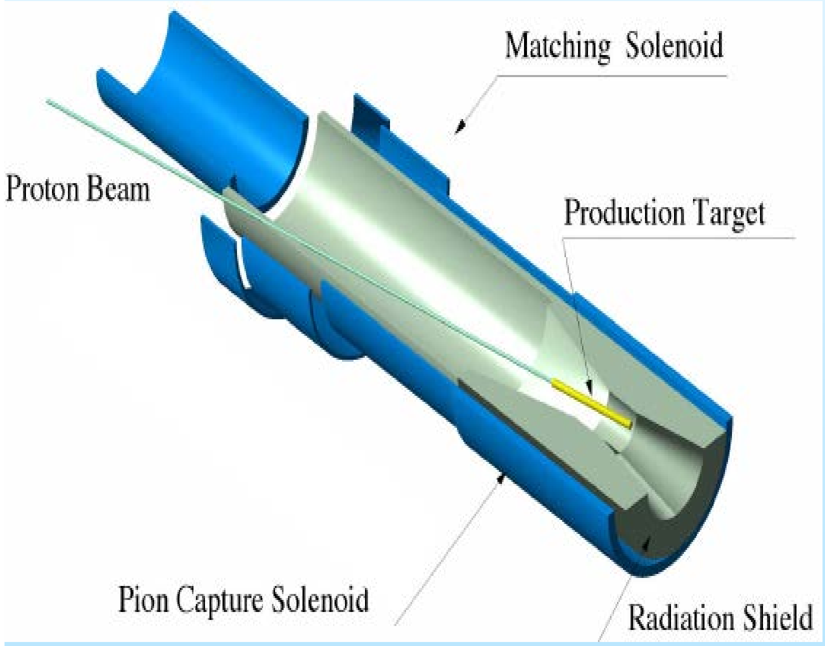
Pion production

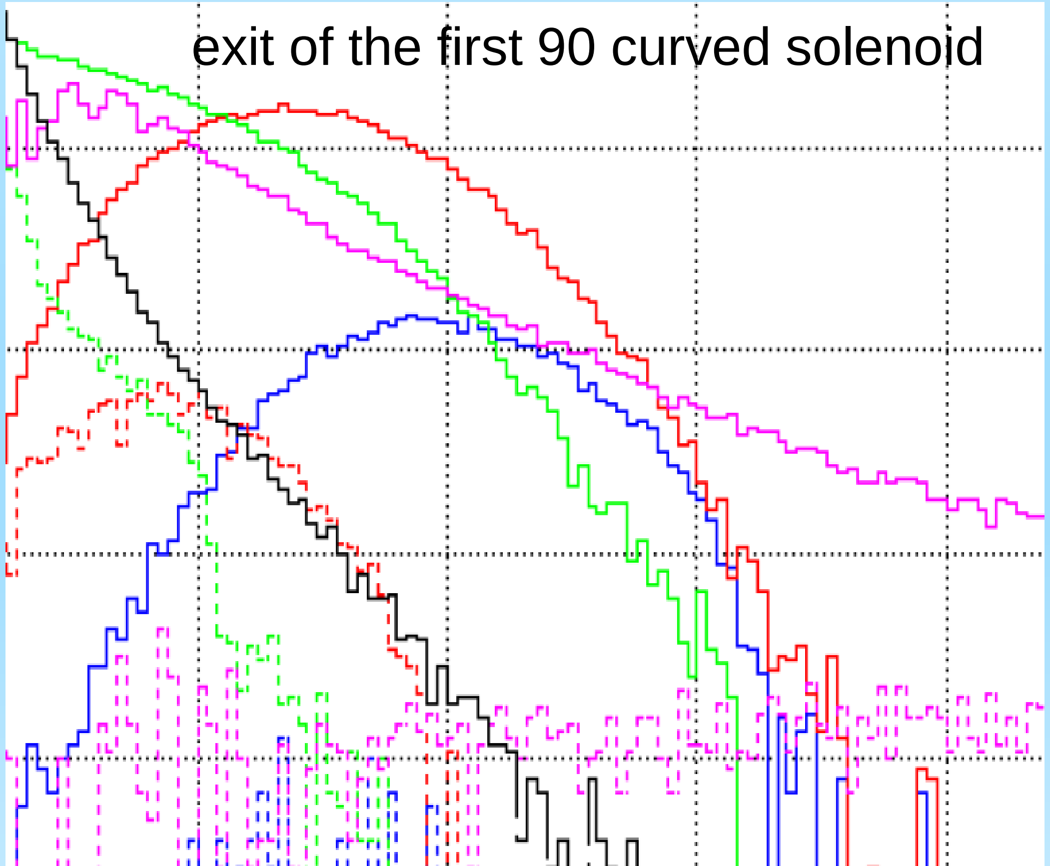
Momentum distribution of beam particles at the end of the pion capture solenoid section.

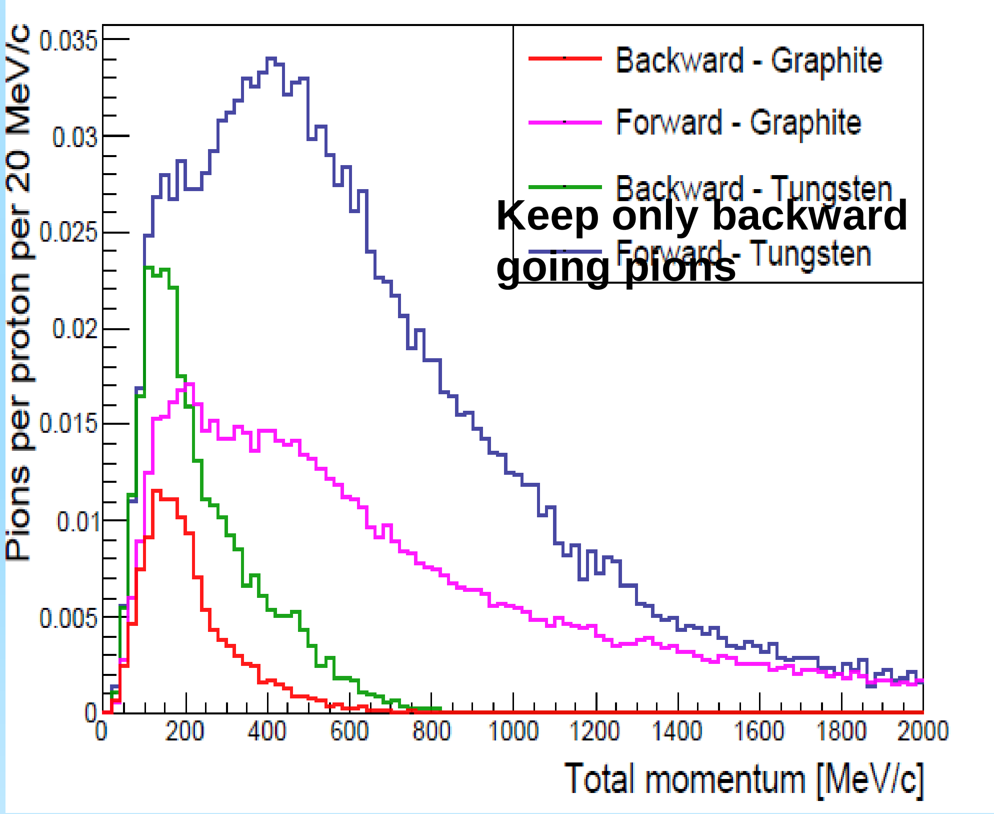


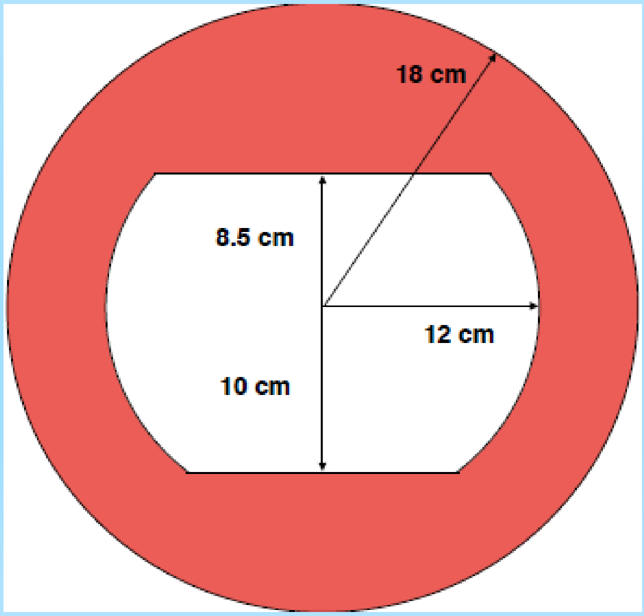
Arrival time distributions of beam particles at the exit of the first 90 curved solenoid







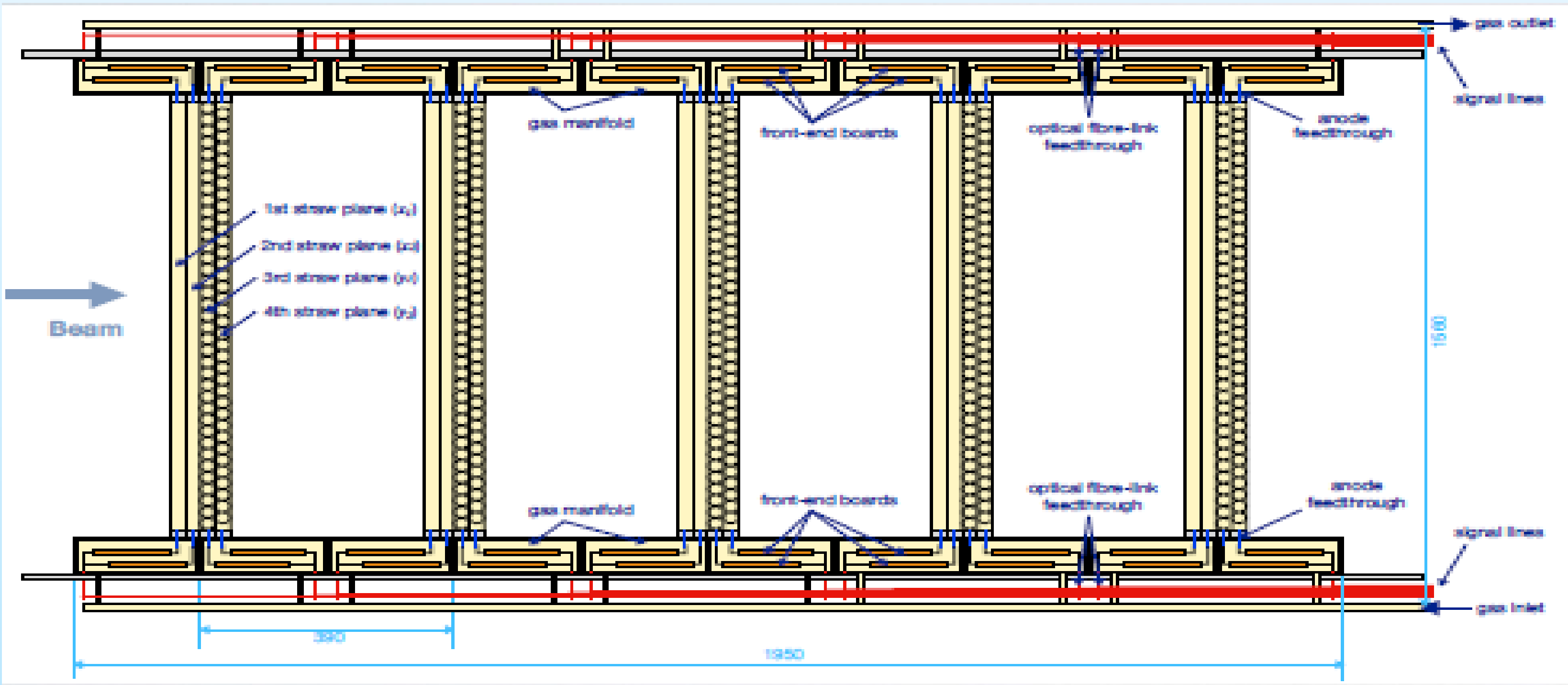


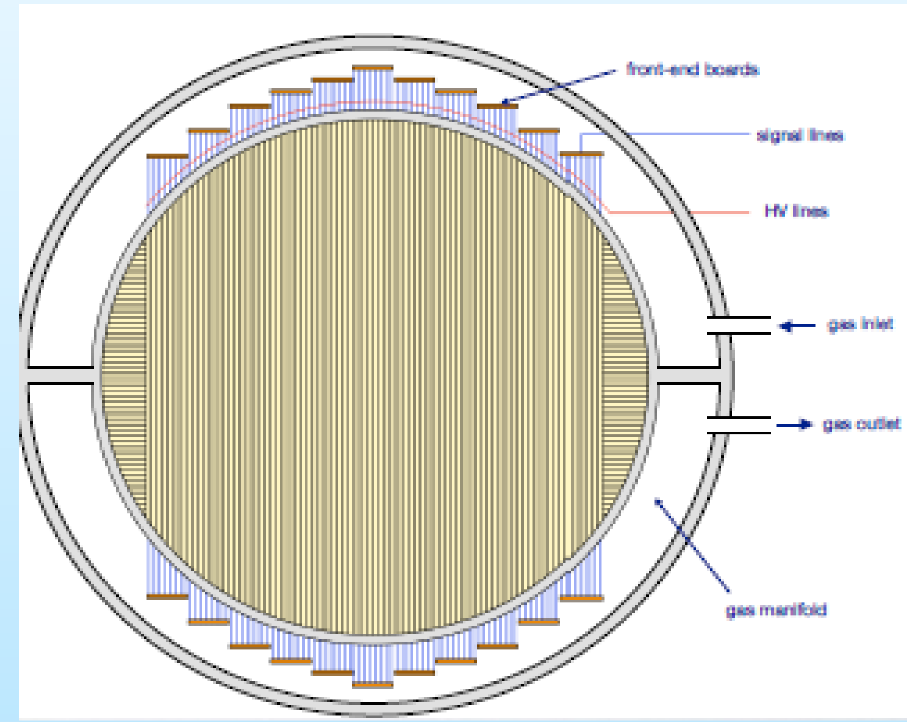


A muon beam collimator, stainless steel. Eight.

Straw tracker

Tracker to measure electron momentum and trajectory





Straw Tube **Tracker** consists of ~2500 straw tube

- Main tracker for Phase-I beam measurement /Phase-II physics measurement
- 20/12µm thick, 9.8/5 mm diameter straw for Phase-I/Phase-II
- Gas mixture candidates: Ar:C_2H_6 (Ethan)=50:50, Ar:CO_2 =70:30
- Complete the mass production of Phase-I straw tube

Requirements:

- work in vacuum and under a magnetic field of 1 Tesla
- Momentum resolution ≤ 150 keV/c
- Space resolution ≤ 150 µm

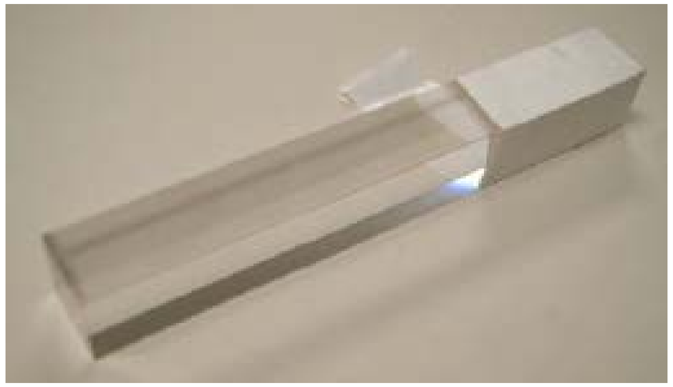
The five stations can be changed to more (around 10) stations. It's under studies

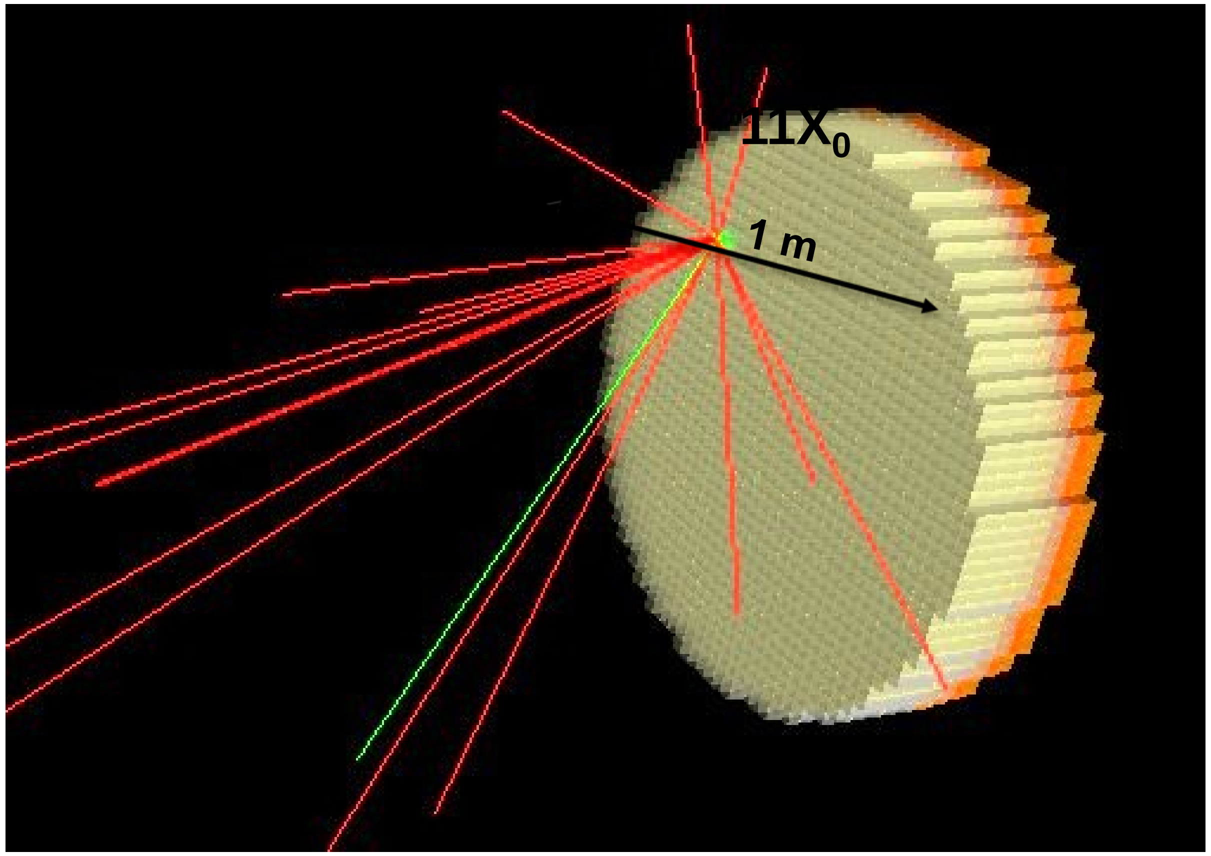
Electromagnetic calorimeter

- To measure electron energy
- To provide a timing signal for trigger
- To give additional hit position

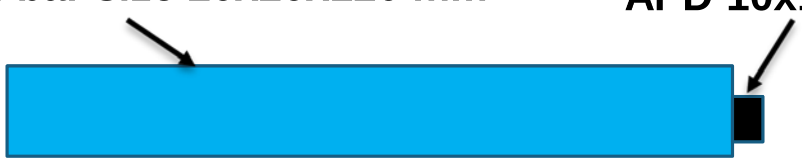
Requirements:
- < 5% energy resolution at 105 MeV
- 1 cm space resolution
- Work in vacuum and magnetic field of 1 Tesla

	NaI(Tl)	GSO	LYSO
Density, g/cm^3	3.67	6.71	7.1
Att. length, cm	2.6	1.38	1.12
Decay const., ns	230	30-60	41
Max emission, nm	415	430	420
Relative LY	100	20	70-80





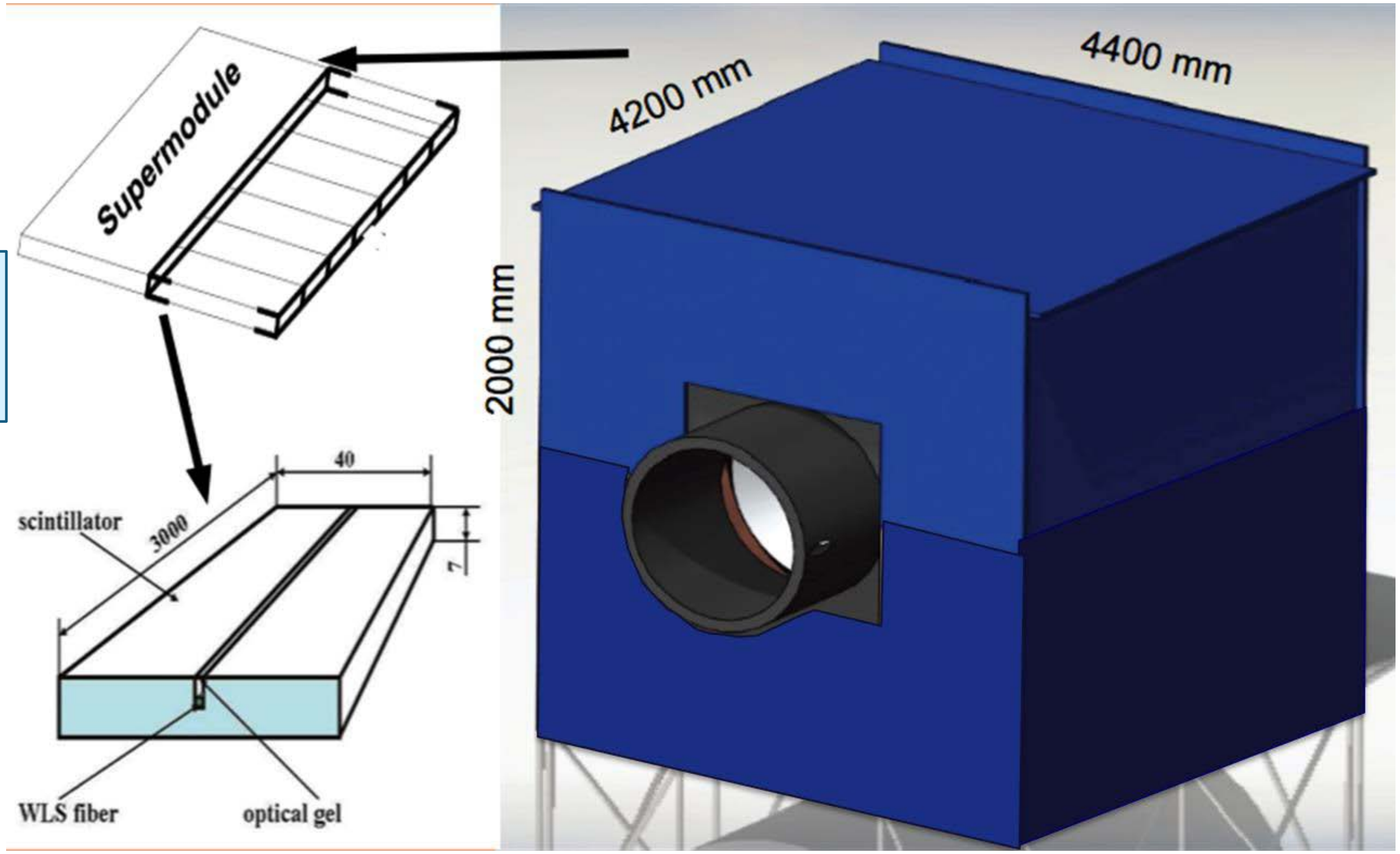
Crystal detector
- Initial crystal candidates were LYSO and GSO, **after the beam test LYSO has been selected**
- Total size: diameter ~ 1m
- Crystal size 20x20x120 mm^3, in total ~2272 crystals.
- Photon detector: APD



Cosmic Ray Veto (CRV)

The whole detector will be shielded from cosmic rays by 4 layers of plastic scintillators (active shield)

Requirement:
Efficiency ≥ 99.99%.



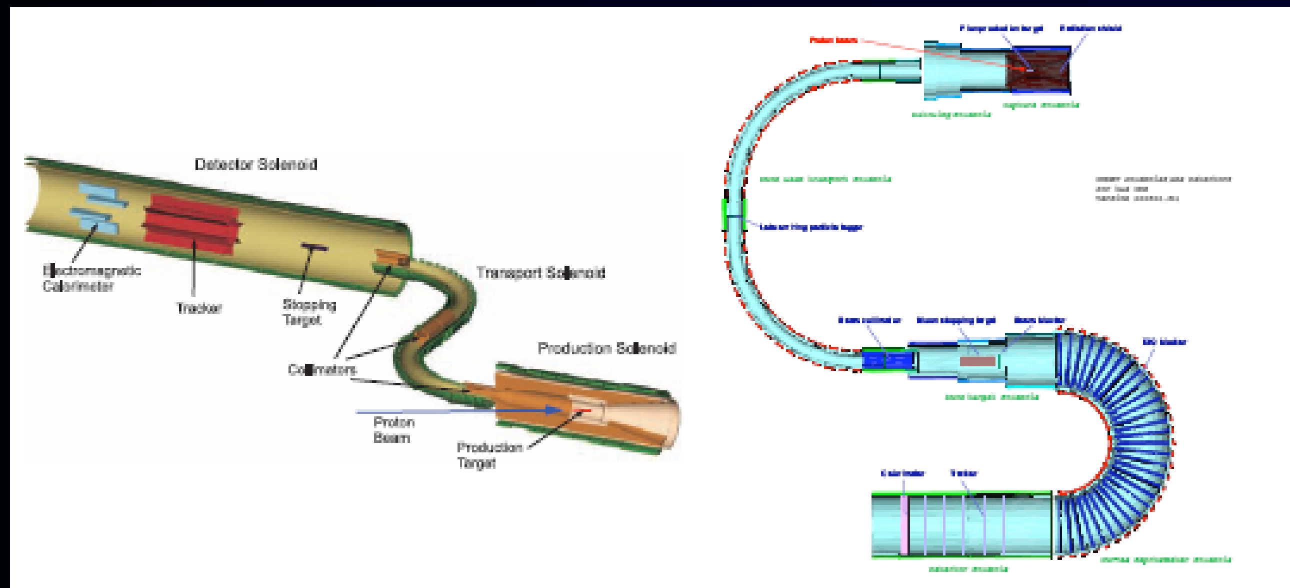
- CRV consists of 8 supermodules
- The modules are formed from 15 strips

Strip sizes: 0.7 x 4 x 220 cm^3 , 1.2 mm diameter WLS is equipped in a center of groove, 2700 strips in total

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

Mu2e vs. COMET

2021 or 2022



2018-2019 Phase-I

	Mu2e	COMET
muon beamline	S-shape	C-shape
electron spectrometer	Straight solenoid	Curved solenoid

→ better selection of low momentum muons
- eliminate muon decay in flight

↓ better selection of 100 MeV electrons
- eliminate protons from nuclear muon capture.
- eliminate low energy junk events to make the detector quiet.

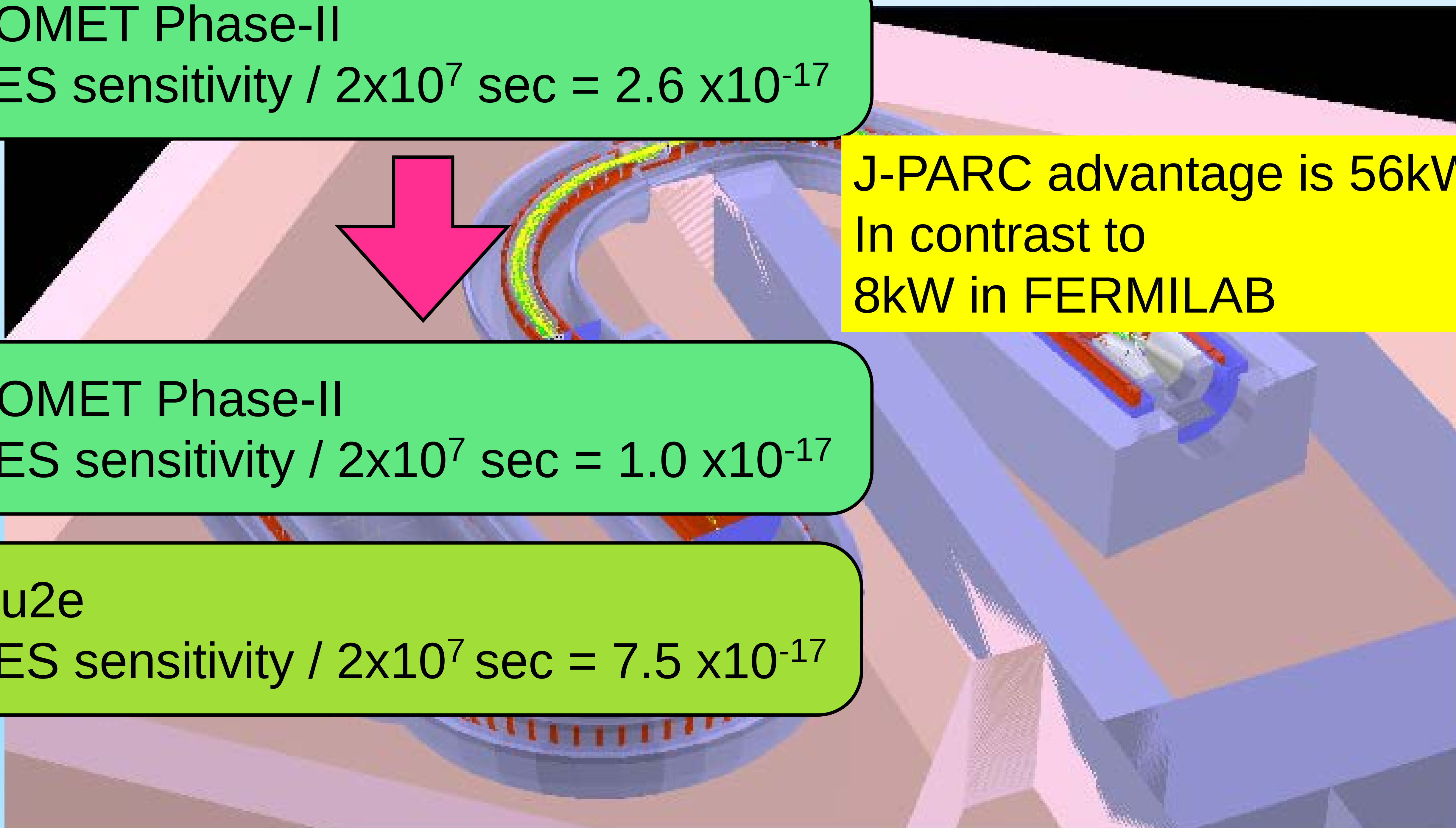
ICEDUST Study on COMET Phase-II

COMET Phase-II
SES sensitivity / 2×10^{7} sec = 2.6×10^{-17}

COMET Phase-II
SES sensitivity / 2×10^{7} sec = 1.0×10^{-17}

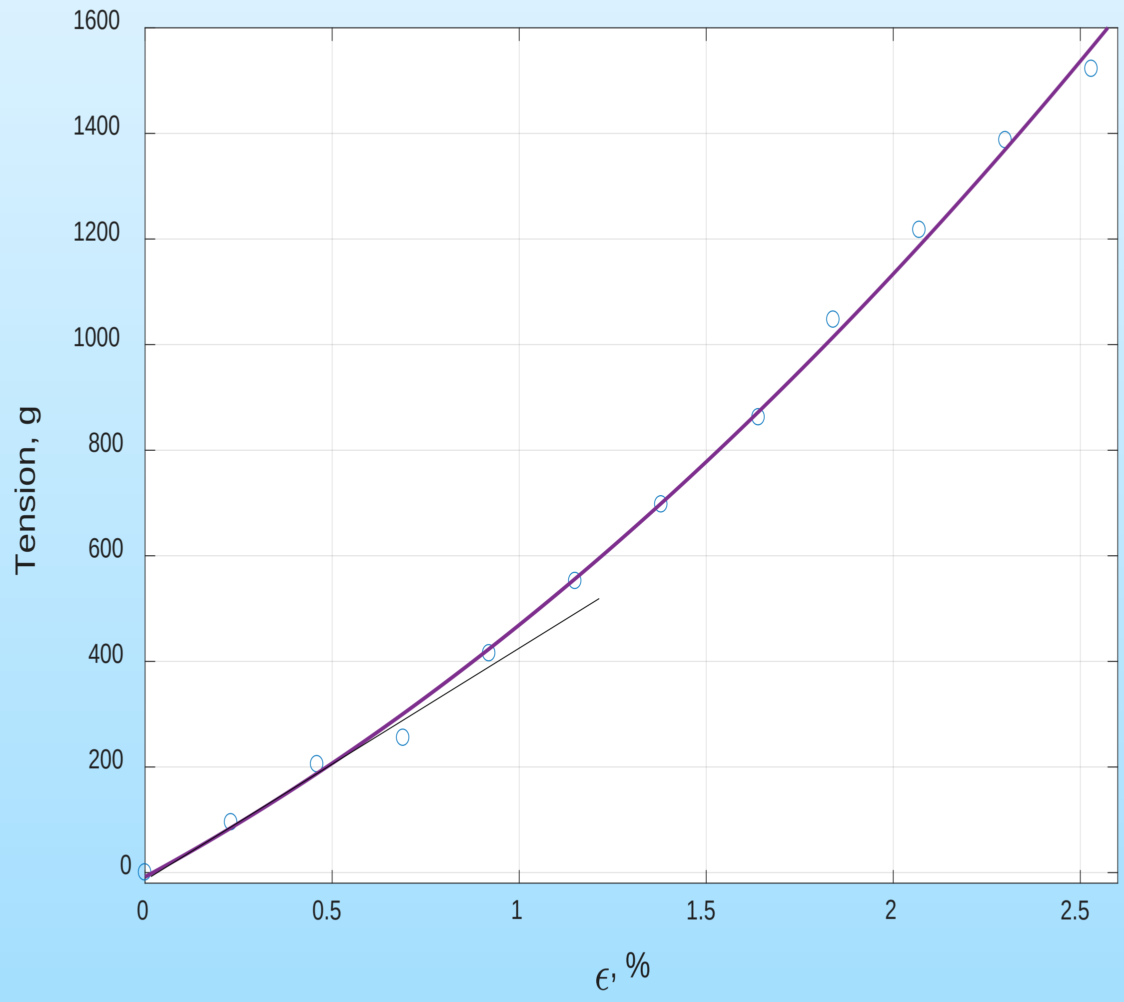
Mu2e
SES sensitivity / 2×10^{7} sec = 7.5×10^{-17}

J-PARC advantage is 56kW
In contrast to
8kW in FERMILAB

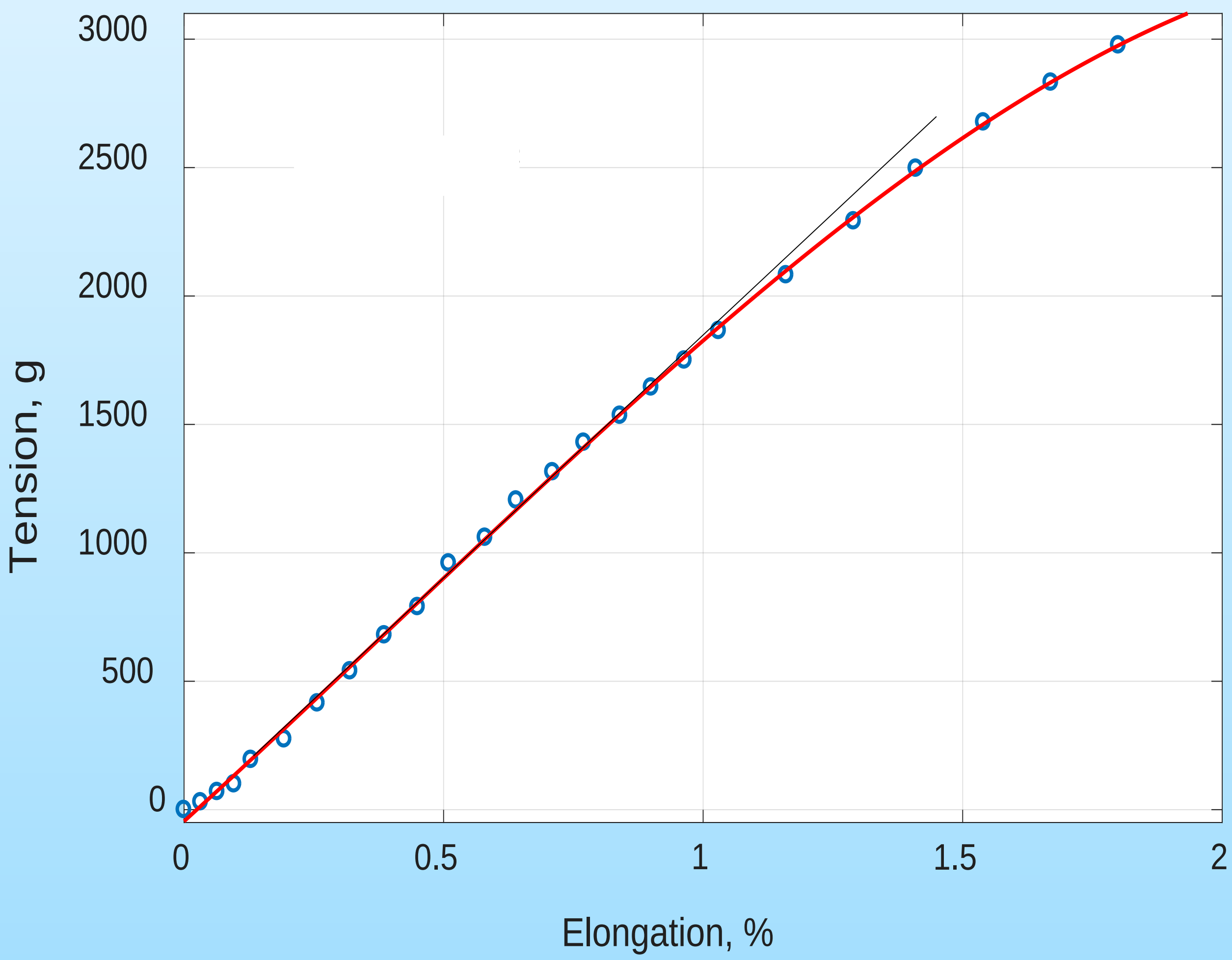


Test Results of FermiLab and COMET Straws

FermiLab straw: h = 15 μm, D = 5 mm



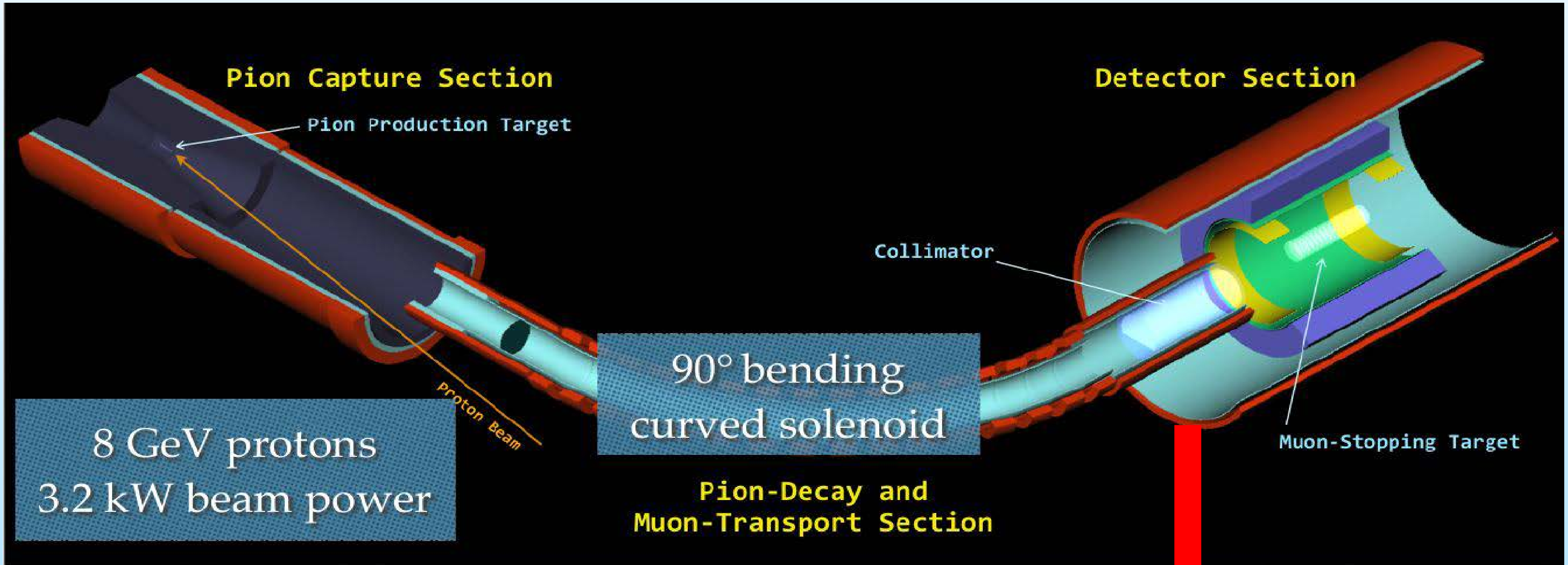
COMET straw: h = 12 μm, D = 9.8 mm



Малое значение модуля упругости. Квадратичная зависимость деформации от натяжения указывает на влияние клея на механические свойства строу.

Большое значение модуля упругости. Стандартное поведение деформации от натяжения.
Лучшие механические свойства COMET строу обеспечат более длительный ресурс работы детектора в эксперименте.

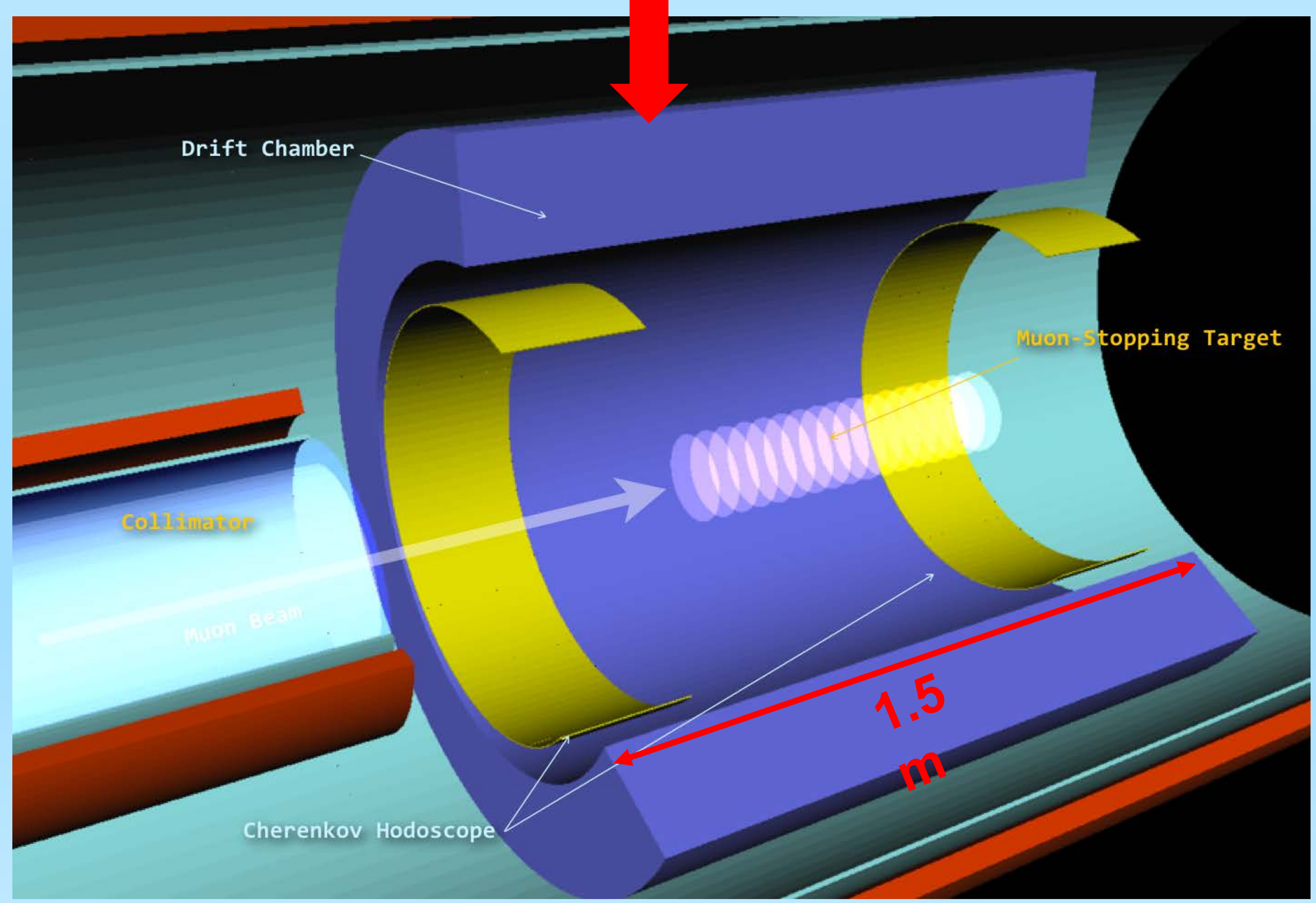
μ-e conversion search at Phase-I



Cylindrical Detector System (CyDet)

- Cylindrical Drift Chamber (CDC)
- Cylindrical Trigger Hodoscope (CTH)

Inner wall	Length	1500 mm
	Radius	500 mm
Outer wall	Length	1740.9 mm
	Radius	831 mm
Number of sense layers		20
Sense wire	Material	Au plated W
	Diameter	30μm
	Number of wires	4986
	Tension	50 g
	Radius of the innermost wire at the EP	530 mm
	Radius of the outermost wire at the EP	802 mm
Field wire	Material	Al
	Diameter	80μm
	Number of wires	14562
	Tension	50 g
Gas	He:Ethane (C2H6) = 50:50 or	90%He-10%isoC_4H_{10}



Backgrounds

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

† This estimate is currently limited by computing resources.

Due to incident protons arriving between the main proton bunches

Due to particles delayed inside capture/transport solenoids

- Normalized to a 3×10^{-15} of S.E.S., assuming extinction factor=3×10^{-11}
- To be measured directly in Phase-I beam measurement

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	$\langle E \rangle = 1$

Source of backgrounds

8 x 10^{20} protons, beam extinction 10^{-9}, at 10^{-17}

Intrinsic physics backgrounds:

(come from muon stopped in target)

Muon decay in orbit - 0.05 events

Radiative muon capture, μ^- Al $\rightarrow \upsilon_\mu$ + Mg + γ , $\gamma \rightarrow e^+ e^-$. Max. E_{ph} =102.5 MeV, <0.001 even.

Neutrons or charged particles emission after muon capture, 0.02 events

Beam-related prompt/delayed backgrounds:

(caused by beam particles of muons and other contaminated particles)

Radiative pion capture, π^- (A,Z) $\rightarrow$ (A,Z-1)* $\rightarrow \gamma$ + (A,Z-1), $\gamma \rightarrow e^+ e^-$, 0.12 events

Muon decay in flight, 0.02 events

Pion decay in flight, 0.001 events

Beam electrons, 0.08 events

Neutron and antiproton induced background, 0.024 and 0.007 events respectively

Cosmic ray induced background

Assumed 10^{-4} veto inefficiency

0.10 events

Total 0.4 events

Signal Sensitivity (preliminary) - $2x10^7$ sec

- Single event sensitivity

$$B(\mu^- + Al \rightarrow e^- + Al) \sim \frac{1}{N_\mu \cdot f_{cap} \cdot A_e},$$

  - N_μ is a number of stopping muons in the muon stopping target. It is $2x10^{18}$ muons.
  - f_{cap} is a fraction of muon capture, which is 0.6 for aluminum.
  - A_e is the detector acceptance, which is 0.04.

total protons	$8.5x10^{20}$
muon transport efficiency	0.008
muon stopping efficiency	0.3
# of stopped muons	$2.0x10^{18}$

3.8 signal events with 0.4 background events in $2x10^7$ s running if B (μe) = 10^{-16}

$$B(\mu^- + Al \rightarrow e^- + Al) = 2.6 \times 10^{-17}$$

$$B(\mu^- + Al \rightarrow e^- + Al) < 6 \times 10^{-17} \quad (90\% C.L.)$$