International Workshop on
"New Aspects of the Hadron and Astro/Nuclear Physics"
National University of Uzbekistan, Tashkent, November 5-10, 2018

Status of LAMPS at RAON for Nuclear Symmetry Energy

Korea University

CENuM Center for Extreme Nuclear Matter

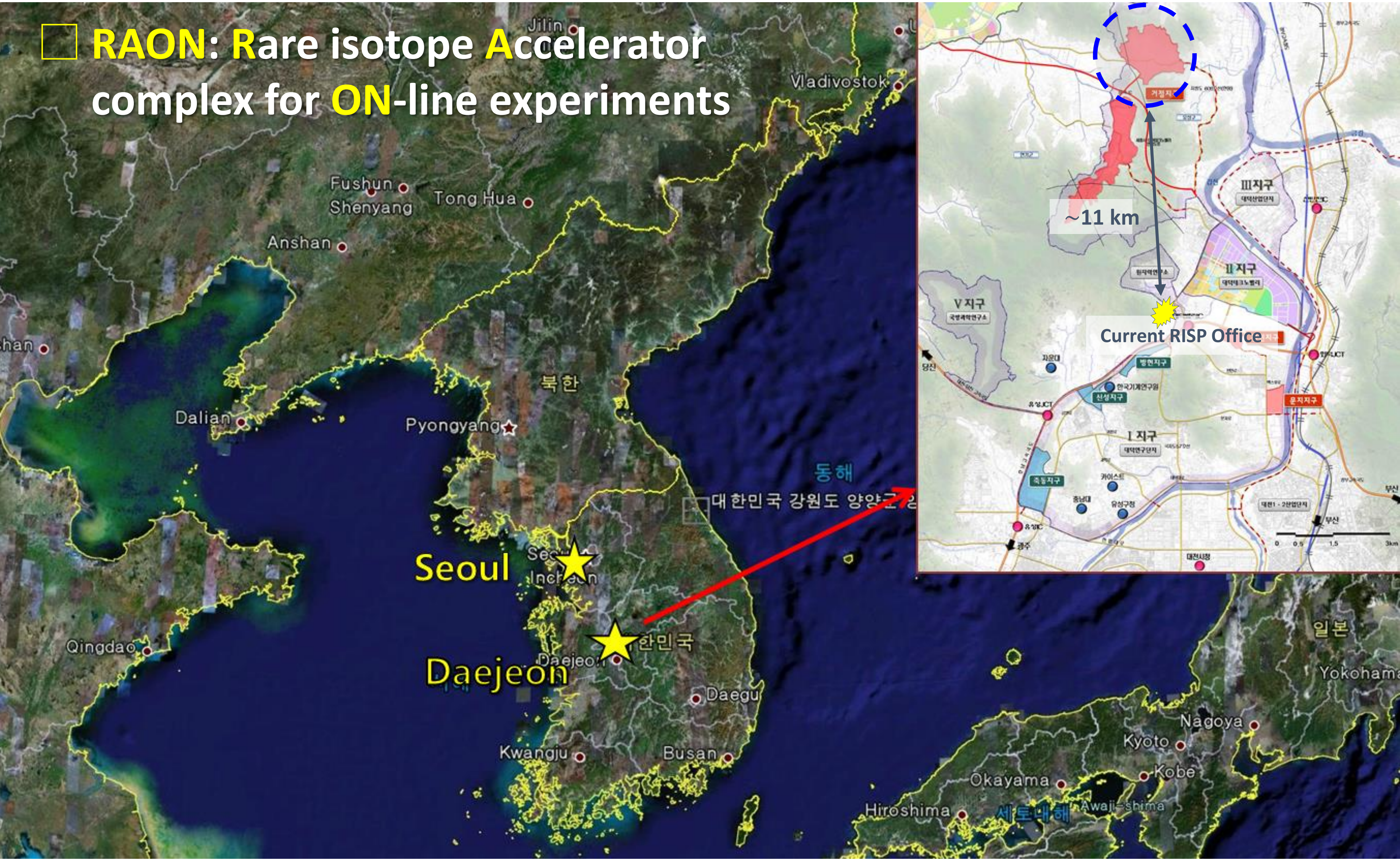
Byungsik Hong
(Korea University)

RAON

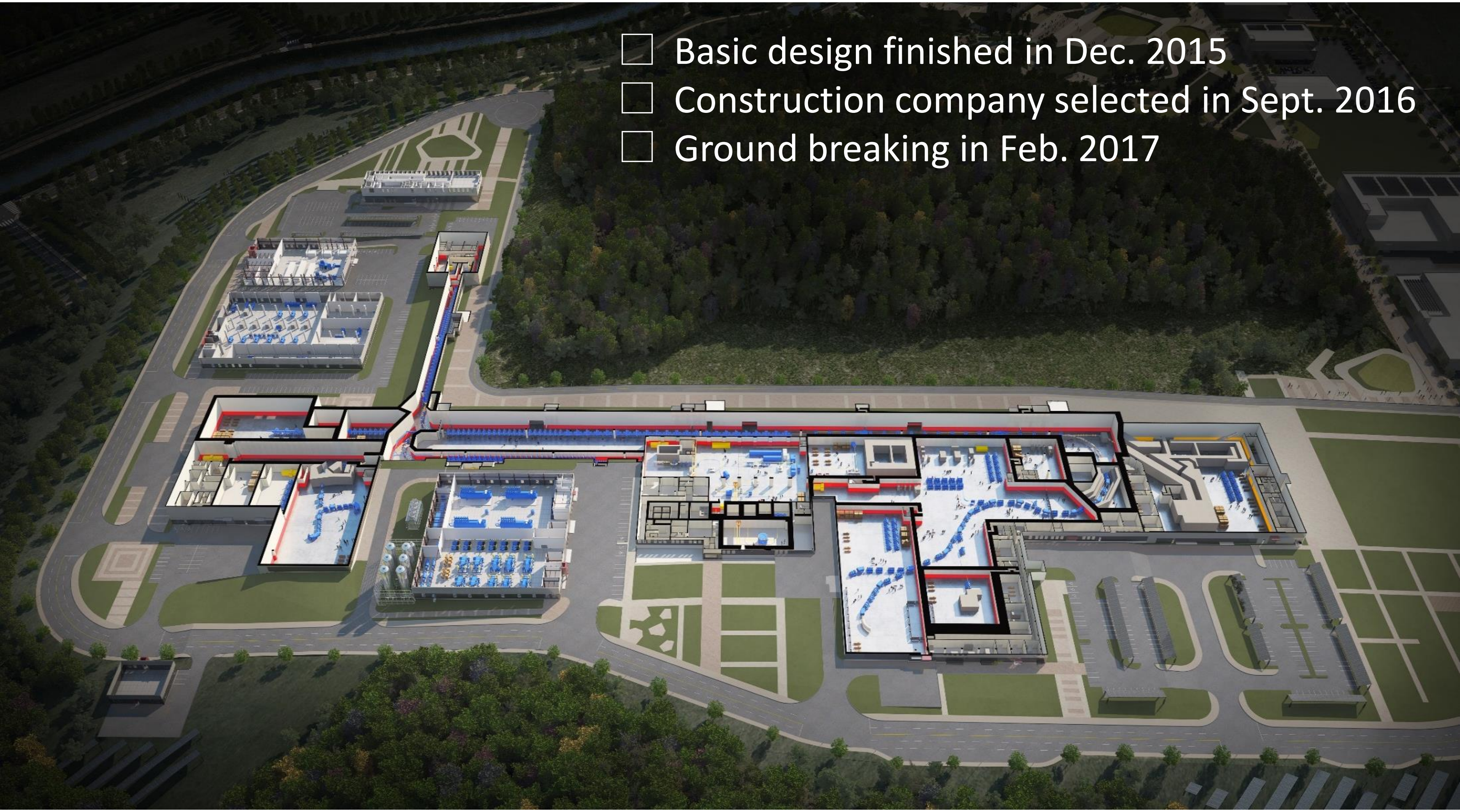
RISP Rare Isotope Science Project

Location of New RIB Complex RAON

- **RAON**: **R**are isotope **A**ccelerator complex for **ON**-line experiments



Site Plan



- Basic design finished in Dec. 2015
- Construction company selected in Sept. 2016
- Ground breaking in Feb. 2017

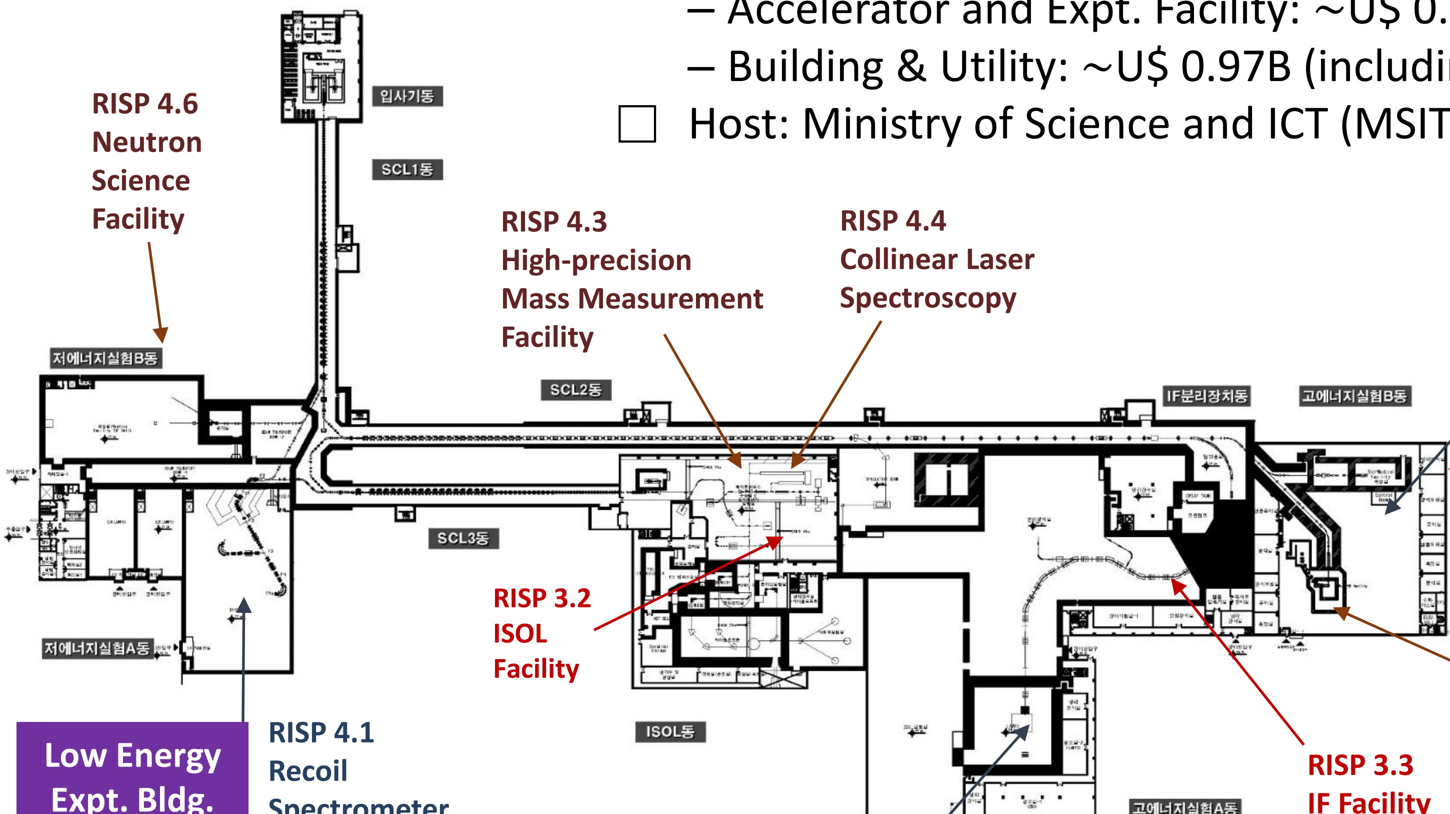
Status in Early 2017

Status in April 2018

Status in April 2018

Layout of RAON

- Project period: Dec. 2011 ~ Dec. 2021
- Scope: Accelerator Facility, Buildings & Utilities
- Budget: Total ~U$ 1.43B
  - Accelerator and Expt. Facility: ~U$ 0.46B
  - Building & Utility: ~U$ 0.97B (including the land cost)
- Host: Ministry of Science and ICT (MSIT)



RISP 4.6 Neutron Science Facility

RISP 4.3 High-precision Mass Measurement Facility

RISP 4.4 Collinear Laser Spectroscopy

High Energy Expt. Bldg. (B)

RISP 4.7 Bio-medical Research Facility

RISP 3.2 ISOL Facility

RISP 4.5 μ-SR

RISP 3.3 IF Facility

Low Energy Expt. Bldg.

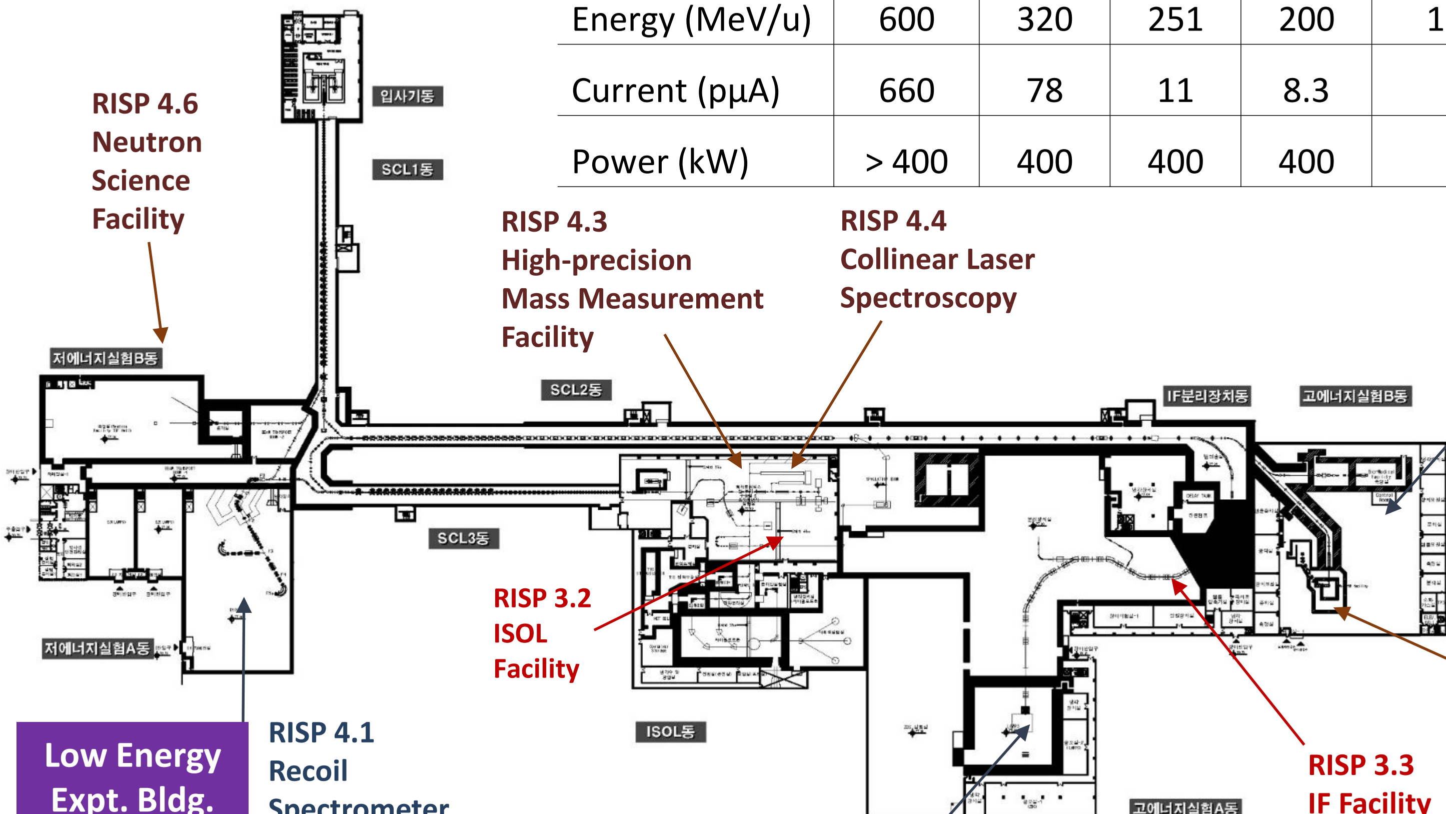
RISP 4.1 Recoil Spectrometer (KOBRA)

High Energy Expt. Bldg. (A)

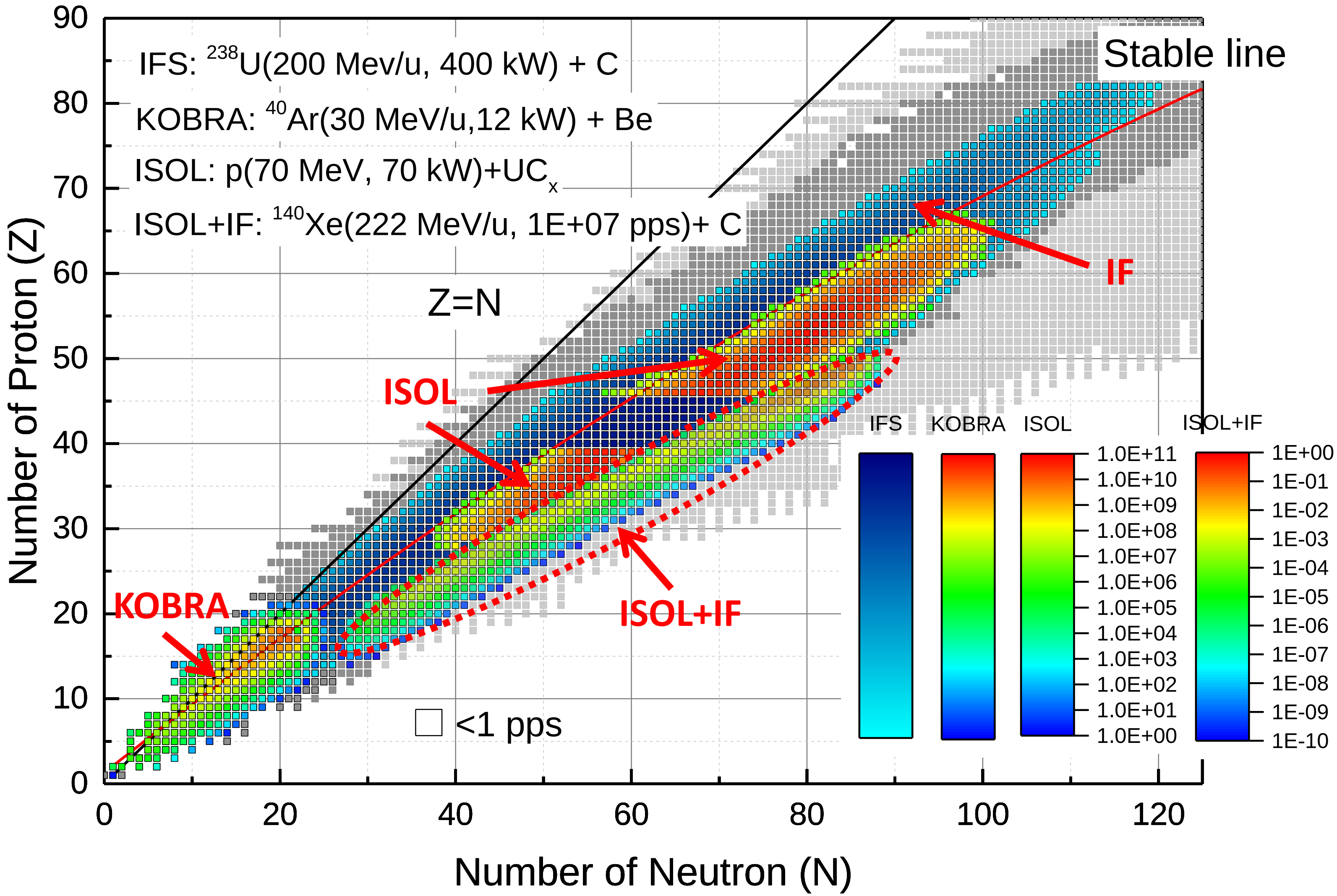
RISP 4.2 Large Acceptance Multipurpose Spectrometer (LAMPS)

Layout of RAON

	Driver Linac				Post Acc.	Cyclotron
Particle	H^{+}	O^{+8}	Xe^{+54}	U^{+79}	RI beam	proton
Energy (MeV/u)	600	320	251	200	18.5	70
Current (pμA)	660	78	11	8.3	-	1000
Power (kW)	> 400	400	400	400	-	70



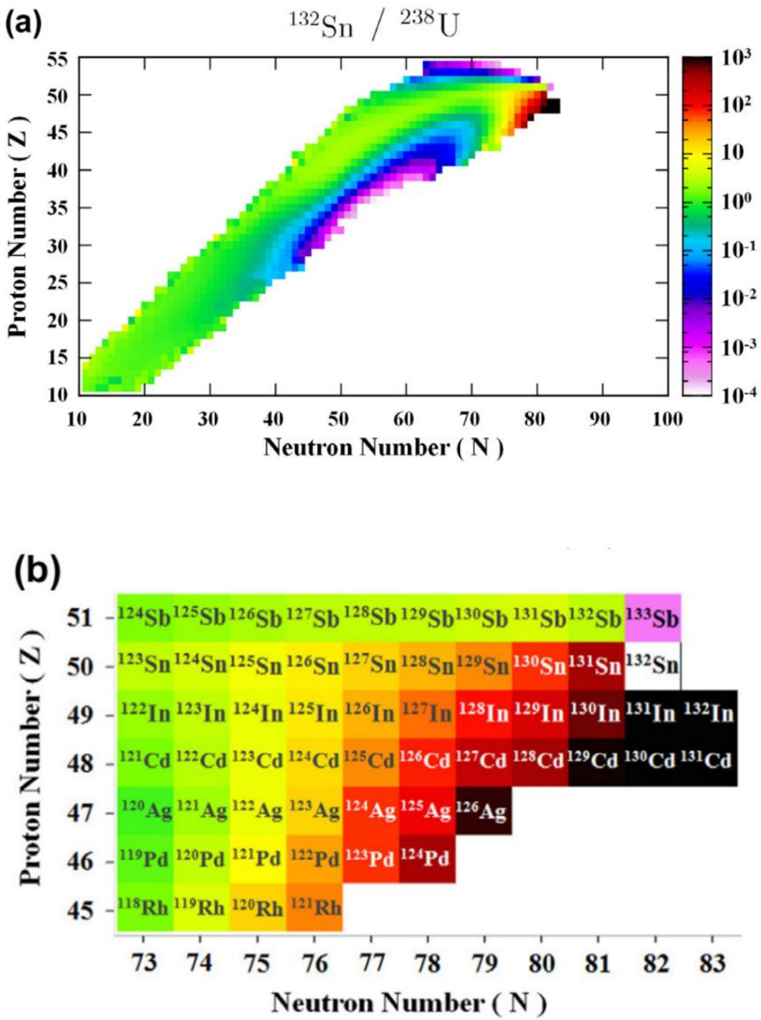
Expected RIBs at RAON



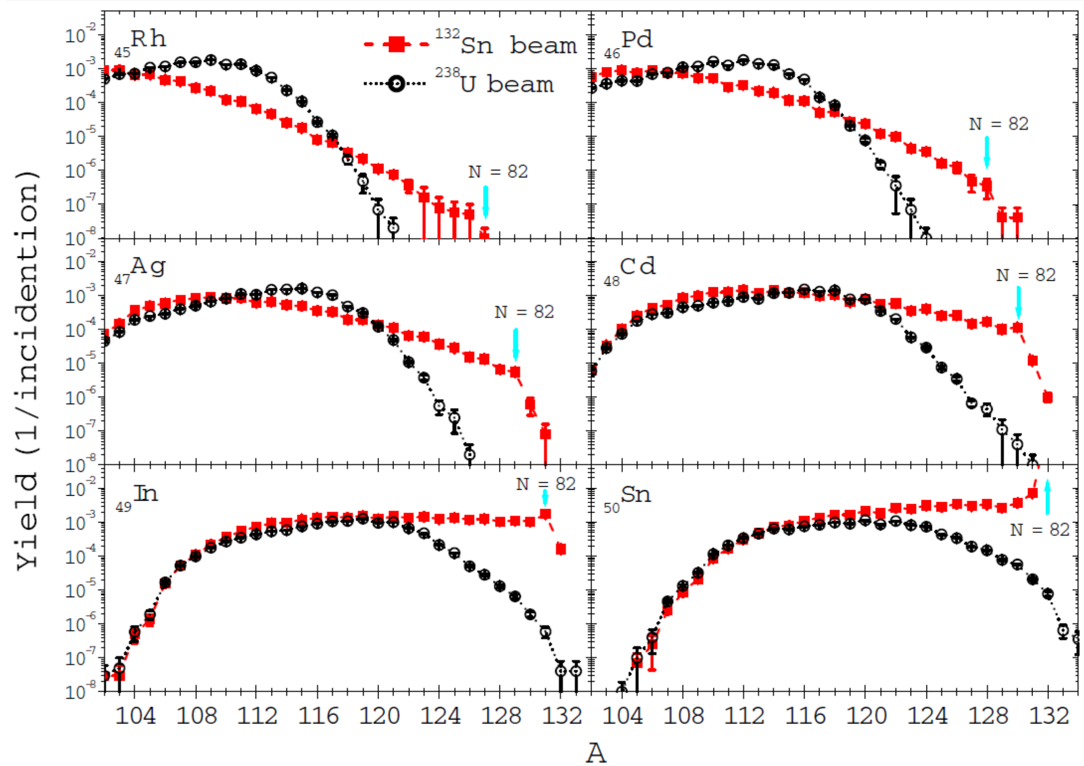
RAON aims to provide an access to unexplored regions of nuclear chart.

Expected RIBs at RAON

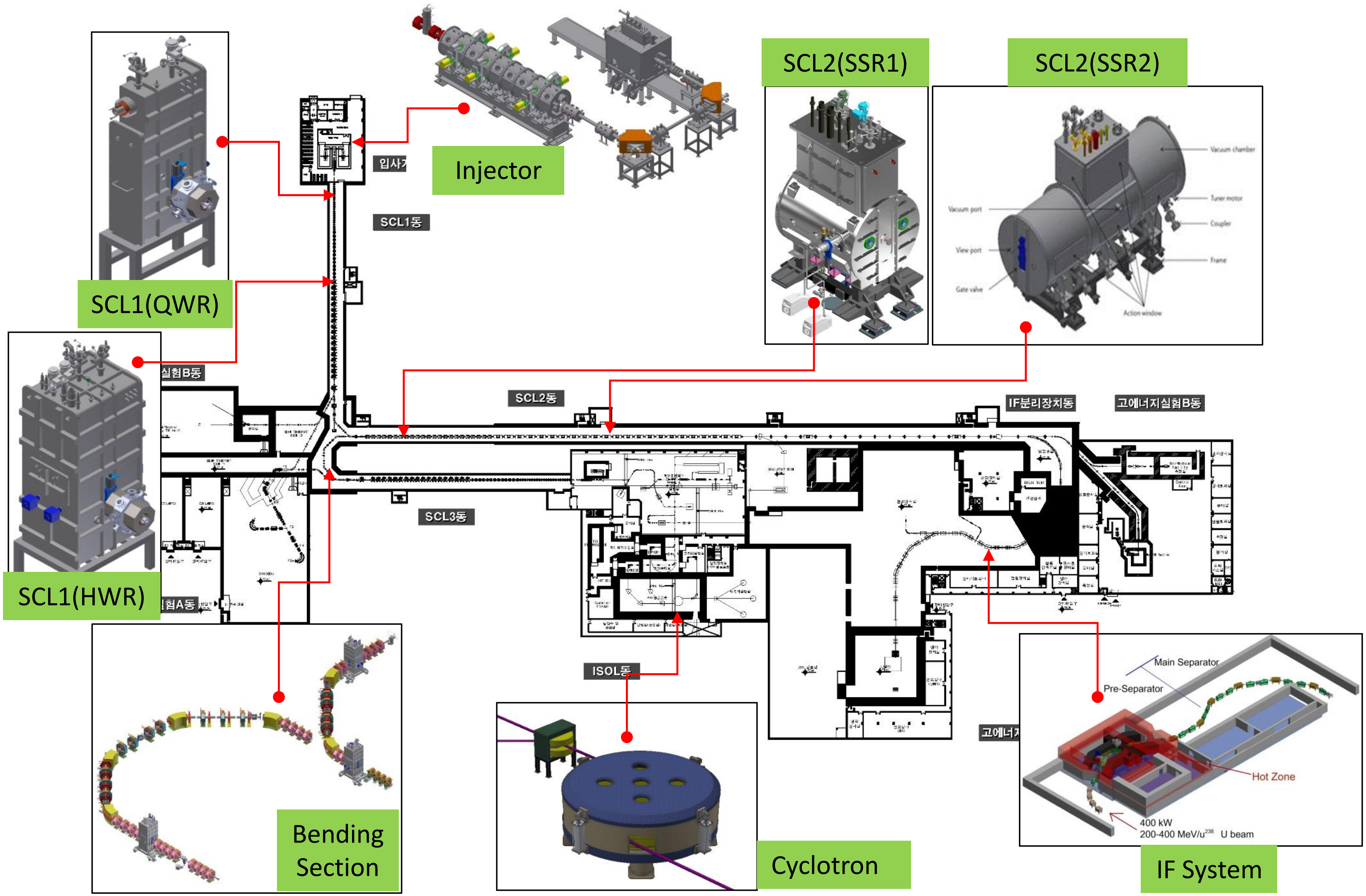
J. W. Shin et al., NIMB349, 221 (2015)



- ☐ Yield ratio: ^{132}Sn+^{9}Be/^{238}U+^{9}Be
- ☐ ISOL+IF is beneficial, for example, for the n-rich isotopes for $45 \le Z \le 50$

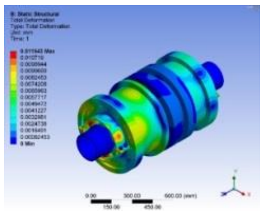


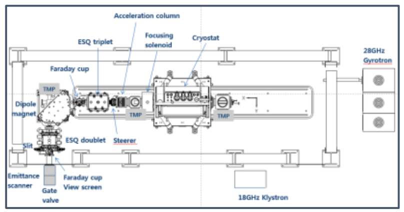
Accelerator Systems



ECR Ion Sources

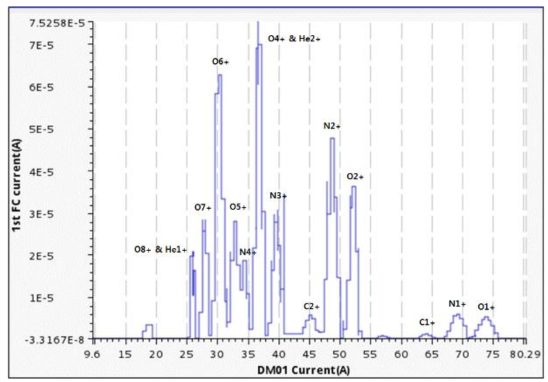
28 GHz	Design & Fabrication	Installation & **Test (Munji Campus)**	Transfer to main site	Commissioning	Operation
	2011~2014	**~2019.06**	~2019.12	2020	2021

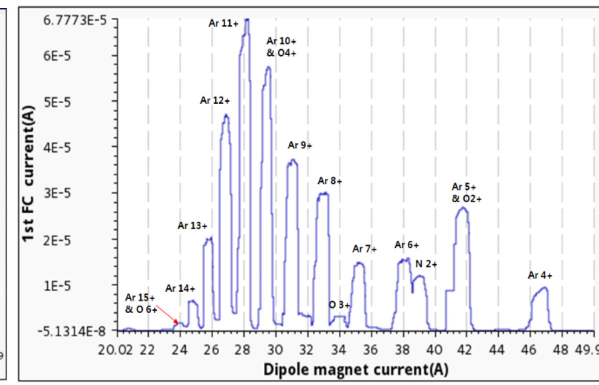




28GHz ECR test results

- ☐ Successful extraction
  - O^{7+} of 30euA, Ar^{11+} of ~70euA
- ☐ After cryo-cooler maintenance, cooling capacity margin improved





14.5 GHz	**Purchasing process**	Manufacturing	Installation & Commissioning	Operation
	2018	~2019	~2020.5	2020.6~

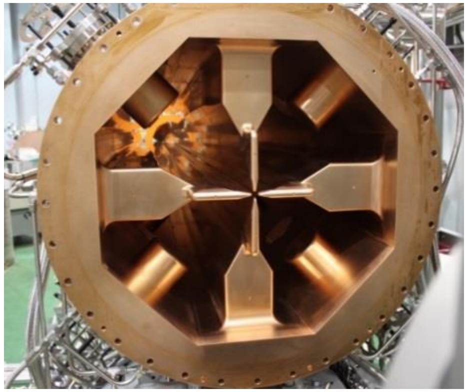
- ☐ A secondary ion source
- ☐ 14.5 GHz ECRIS and 28 GHz ECRIS will supply a stable isotope beam to SCL3 alternately.
- ☐ 14.5 GHz ECRIS will be a main ion source when 28 GHz ECRIS moves to SCL1

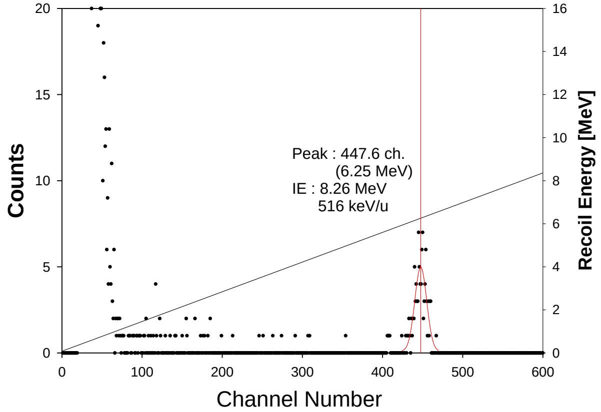
Injector

Conceptual design	Prototype	**Test & Upgrade**	Installation	Commissioning	Operation
2011~2012	~2015	**~2018**	2019	2020	2021

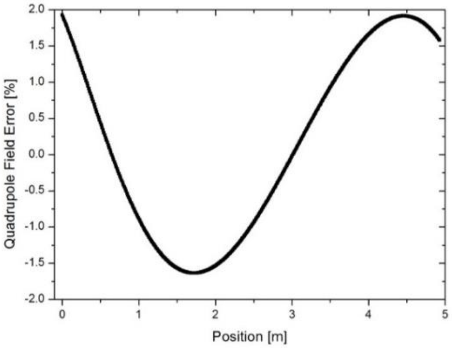
Installation & Test of injector @ SCL demo

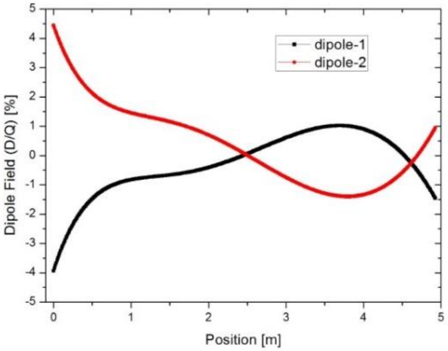
- ☐ Completion of manufacturing and tuning of RFQ (Quad. Field < ±2%, Dipole Field < ±5%)
- ☐ Installation of injector and test for beam acceleration performance of RFQ (> 500 keV/u)

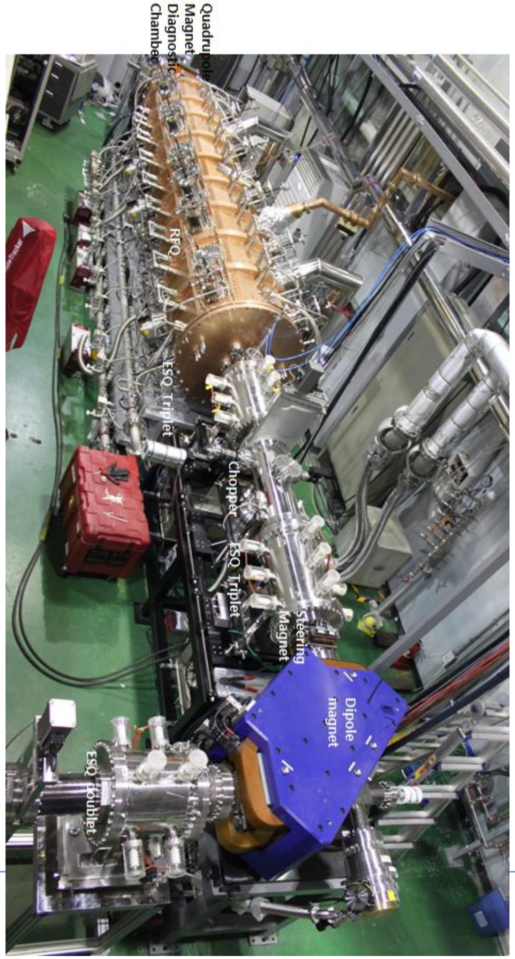




RFQ tuning result







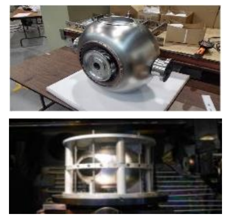
RFQ at SCL DEMO

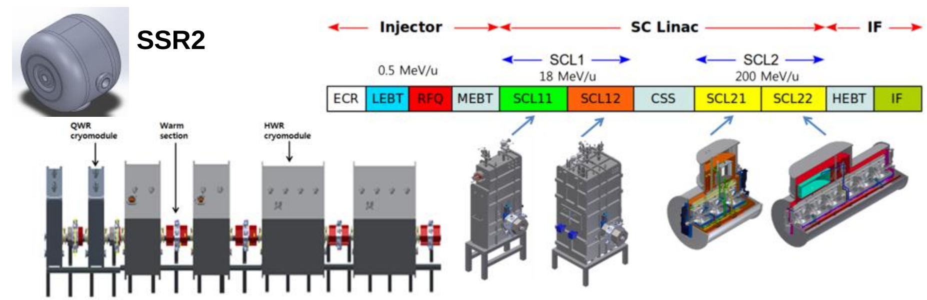
Superconducting Linear Accelerators

SCL3 (QWR/HWR)	Conceptual design 2011~2012	Prototype ~2016	**Test and Manufacturing** **~2018**	Installation 2019	Commissioning 2020	Operation 2021
SCL2 (SSR1/SSR2)	Conceptual design 2011~2012	**Prototype** **~2018**	Test and Manufacturing ~2019	Installation & Commissioning ~2021		Operation 2022

QWR

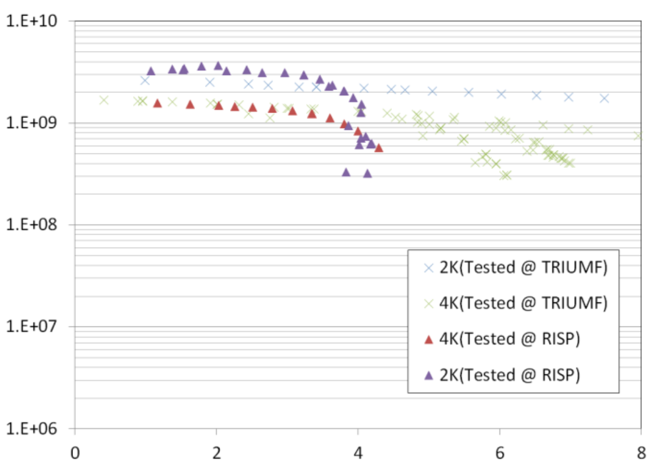
HWR





Superconducting cavity test

- ☐ SRF test facility @ KAIST Munji Campus
- ☐ Manufacturing and Performance test for QWR x 4, HWR x 6, SSR1 x 1 is under way ('18)



Result of HWR cavity performance test

Cavity test pit, Cryostat, Control room

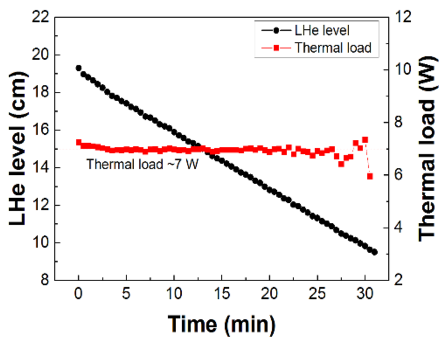
Superconducting Linear Accelerators

Cryomodule test

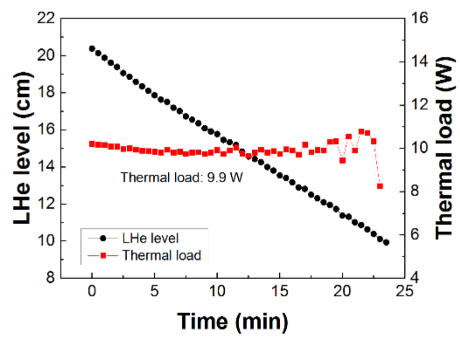
- ☐ Cryomodule test facility set up
- ☐ Completion of performance tests for QWR module and HWR module A (two cavities)

QWR module

Static thermal load @ 6MV/m



Total thermal load @ 6MV/m



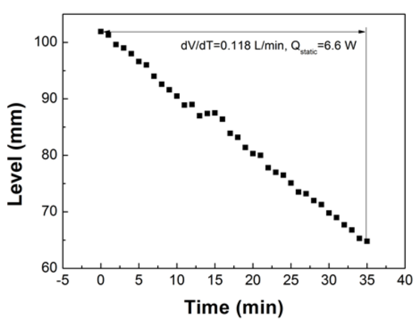
Total thermal load at various Eacc

E_{acc}(MV/m)	6.1	6.4	7
Q (W)	9.9	13	23.7

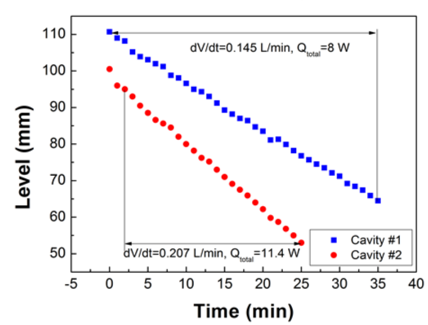
Target total thermal load @ 6 MV/m : 25 W

HWR module A

Static thermal load @ 6.6MV/m



Total thermal load @ 6.6MV/m



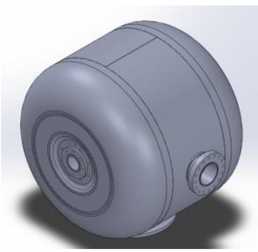
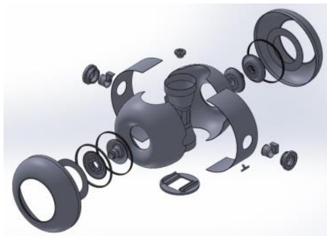
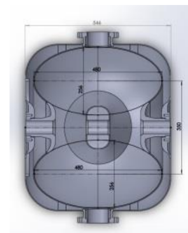
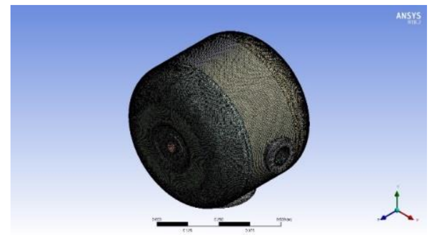
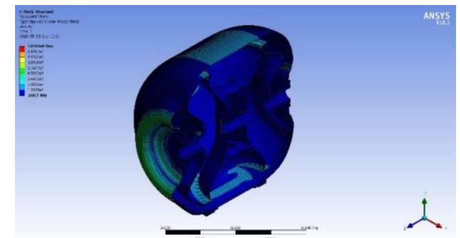
Q (Static)	Q (Dynamic)	Q (Total)
6.6 W	1.4 W (cavity#1)	**12.8 W**
	4.8 W (cavity#2)	

Target total thermal load @ 2.92 MV : 14.1 W

Development of SSR2 (b=0.51)

	Design	Prototype & Test	Manufacturing	Installation & Commissioning	Operation
SSR2	2018	~2019.7	~2021.6	~2021.12	2022

- ☐ Prototype of SSR2 cavity designed by the RISP accelerator team is in procurement process.

- ☐ Two-track strategy to minimize the risk in the development

Track 1

Prototype (3 ea) - Domestic vendor → Module test (1 ea) - RISP SRF test facility → Module test (3 ea) - RISP SRF test facility → Preproduction

Track 2

Prototype(3 ea) - Consortium (oversea + domestic) → Module test (1 ea) - Vendor test facility → Module test (3 ea) - Vendor test facility → Preproduction

Module test (1 ea) ⇢ Procurement (Mass production) → Preproduction → Qualification test → Mass production

※ Global Committee for Performance Verification

Cyclotron & ISOL

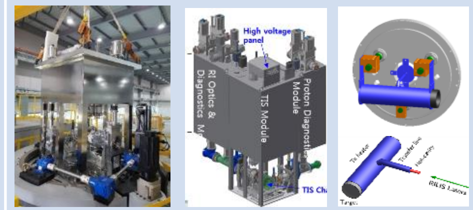
Cyclotron — Contract with "Best Cyclotron" (Canada) in April 8, 2017

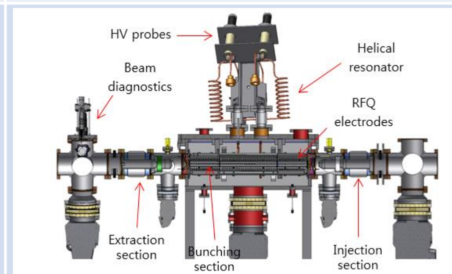
Procurement	Manufacturing & delivery	Install. & commi.	beam to ISOL
2016~2017.4	**2017.4~2019.3**	2019.4~2020.3	2020~

ISOL

Conceptual design	Prototype	Manufacturing	Installation	Commissioning	Operation
2011~2012	~2017	**~2019.3**	~2020.7	2021.6	2021

System	Specification	Current Status
Target ion source	• UCx fission target (10 kW) • SIS, RILIS, FEBIAD	• Manufacturing (partly)
Beamline, Remote handling, Hot cell system (incl. A/q separator)	• $R_{A/q}$: ~200 (for EBIS) • E+B Combination	• Purchasing process
RFQ cooler & buncher	• Cooling time : < 100 ms • Transmission ε > 50% (Sn) • Output emittance: < 3 • Capacity: <10^8 ions/bunch	• Under design
EBIS charge breeder	• E/A : 10 keV/u • A/q : 10 keV/u • ε = 15% ($^{133}Cs^{27+}$) • Breeding time: 50~100 ms • Capacity: <10^8/bunch	• Start integration of – e-gun/collector – SC solenoid – Drift tube • Breeding test ('18.12~)





IF System

Conceptual design	Prototype & Test	Manufacturing	Installation	Commissioning	Operation
2011~2012	~2018	~2020.11	~2021.7	2021.12	2022~

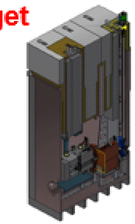
Max. beam power : 400 kW
^{238}U beam energy : 200 - 400 MeV/u

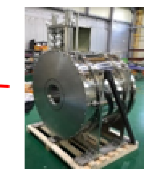
Target/dump: Staged 80 kW → 400 kW

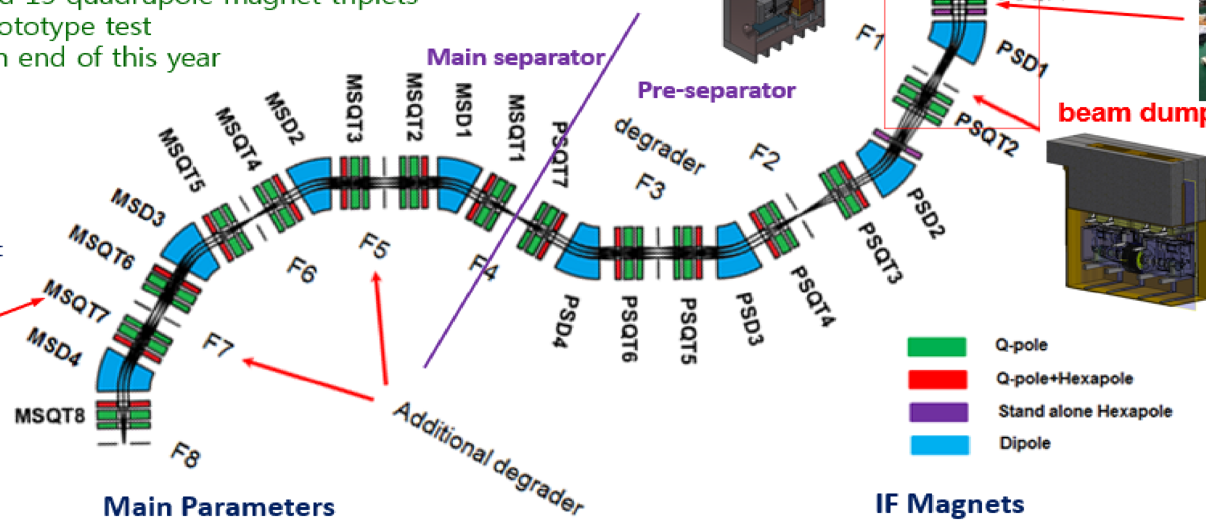
- **Target**: multi rotating graphite disks, benchmarking of FRIB design
- **beam dump**: two water-filled rotating disk
- finalizing manufacturing design, start manufacture from 2019

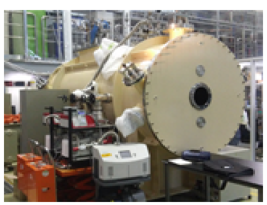
Magnet

- 8 dipole magnets and 15 quadrupole magnet triplets
- HTS, LTS: finish of prototype test
- Production start from end of this year









Prototype LTS quad. triplet

Main Parameters

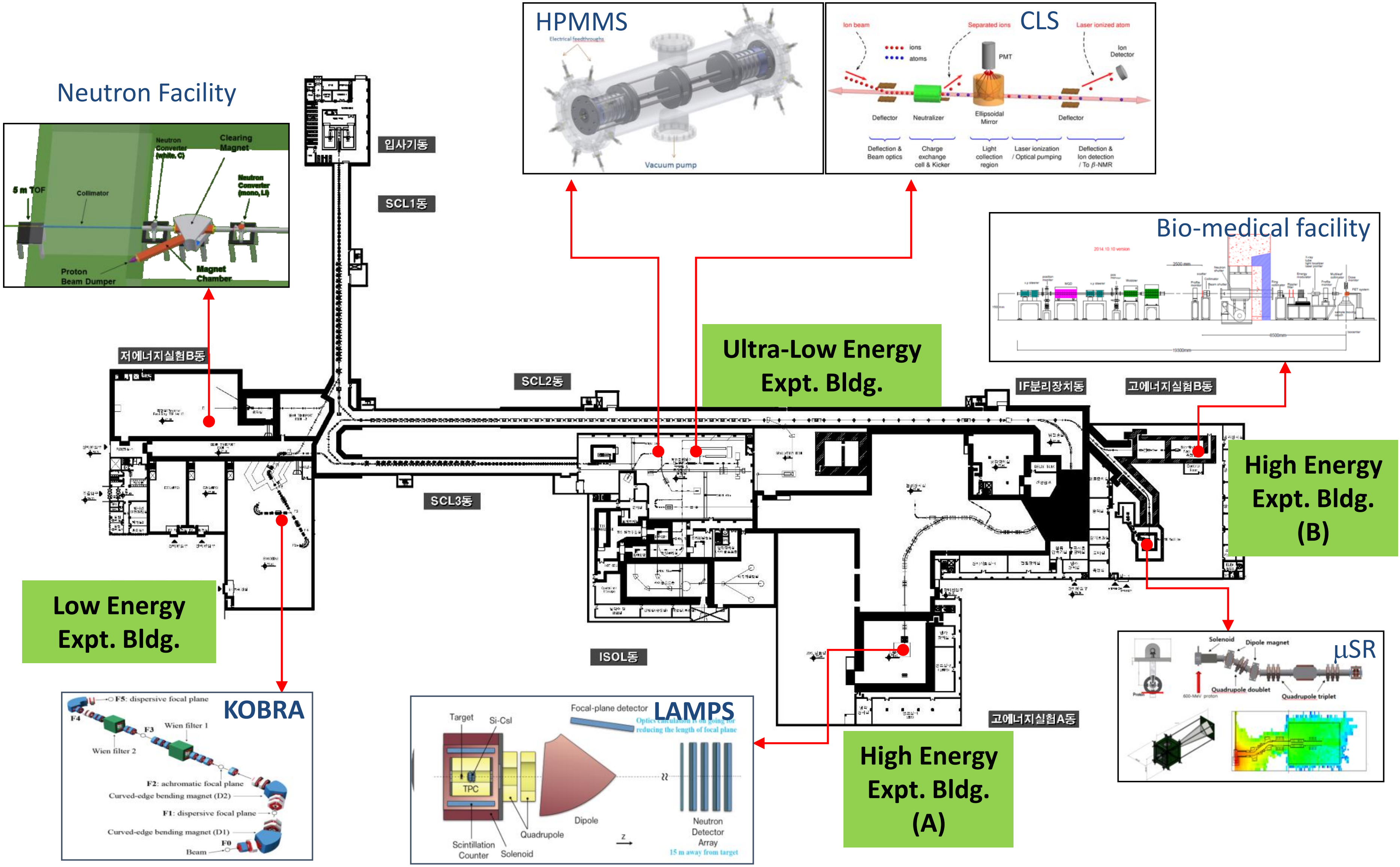
Max. Bρ	~ 9.6 T.m
Δp/p	<±3%
Angular acceptance	±40 mrad (H) ±50 mrad (V)

IF Magnets

HTS Dipole (x1)	LTS Dipole (x7)
HTS Quad. (x6)	LTS Quad. Triplet (x13)
HTS Hexapole(x1) NC Hexapole (x1)	LTS Hexapole (x13)

- HTS (LTS): High (Low) Temperature Superconducting
- NC: Normal Conducting

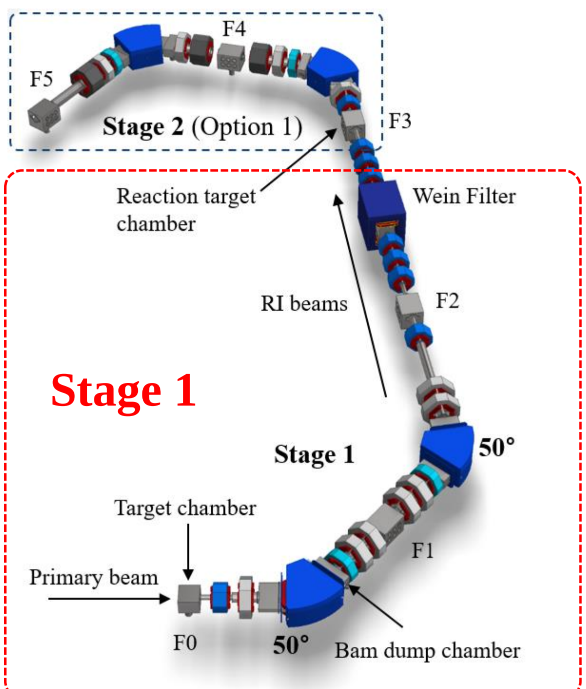
Experimental Systems



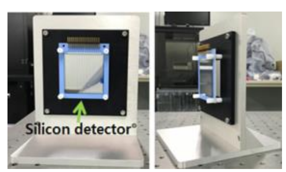
KOBRA
(KOrea Broad acceptance Recoil spectrometer and Apparatus)

Conceptual design	Prototype & Test	**Manufacturing**	Installation & Commissioning	Operation
2011~2012	~2017.9	**~2019.4**	~2020.12	2021.1~

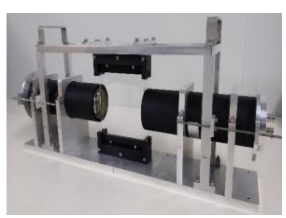
- ☐ The first part of stage1 (stage1 part1) was contracted with foreign & domestic companies in April 2018. (Presently, parts are being produced.)
- ☐ The design of second part of stage1 (stage1 part2) was finally done among the various options in June, 2018 after consultation with potential domestic users.
- ☐ The stage1 will be installed in the Low Energy Expt. room (E1) by the end of June 2020.
- ☐ The commissioning of Stage1 will start in the beginning of 2021 with stable ion beams.



PPAC
- Two 10x10 cm^2, two 20x20 cm^2, and one 40x20 cm^2 active area PPACs were built.
- Four 10x10 cm^2 and one 40x20 cm^2 PPACs will be built in addition.



SSD
- Two 16 Channel detectors with 5x5 cm^2 active area and 50 μm thickness
- Energy resolution~0.7% and S/N~272 for 5.5 MeV α in vacuum

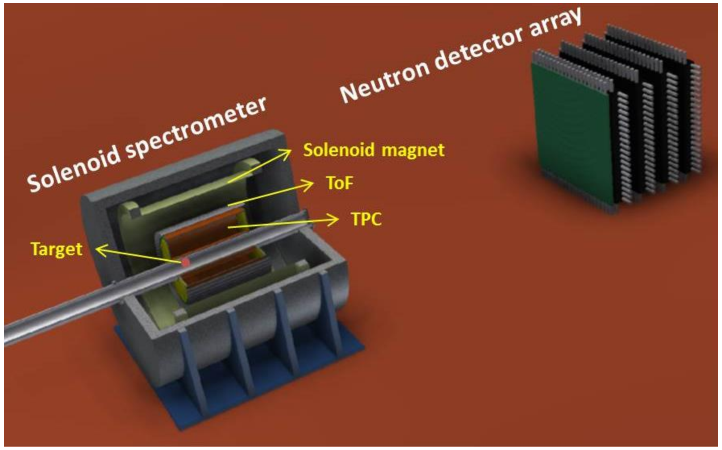


Plastic scintillator detector
- Two detectors read out both ends with 10x10 cm^2 active area and 100 μm thickness
- Time resolution < 42 ps for 5.5 MeV α in vacuum

LAMPS

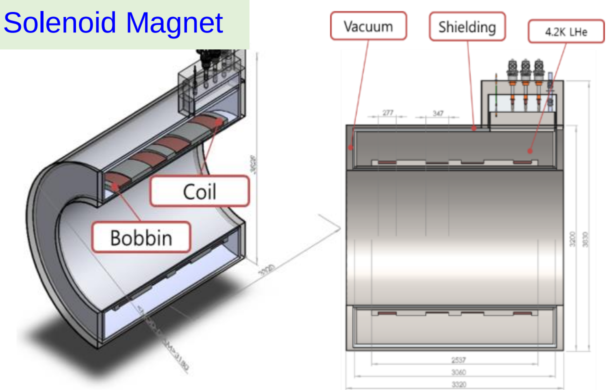
(Large Acceptance Multi-Purpose Spectrometer)

Conceptual design	**Prototype & Test**	Manufacturing	Installation	Commissioning	Operation
2011~2012	**~2018.12**	~2020.12	~2021.7	2021.12	2022~



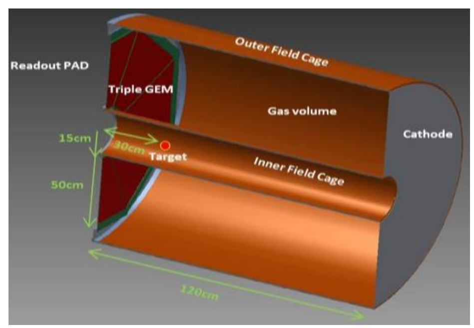
- Beam energy: 250 MeV/u for ^{132}Sn
- Solenoid Spectrometer
  - Maximum 1 T solenoid magnet
  - TPC (~3π sr coverage for tracking)
  - Barrel scintillation counter (trigger & ToF)
- Forward neutron wall (neutron energy spectrum)

Solenoid Magnet



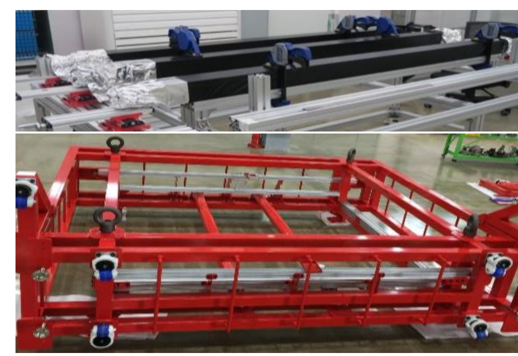
Superconducting magnet
Coil radius: 0.8 m
Specifications
- Nominal operation B-field: 0.5 T
- Maximum B-field: 1 T, ΔB/B < ±1% in the TPC region

Time Projection Chamber (TPC)



Test completed with prototype TPC
Fulfill the requirement
Specifications
- GET electronics read out from one side
- Gas mixture: P-20

Forward Neutron Detector Array

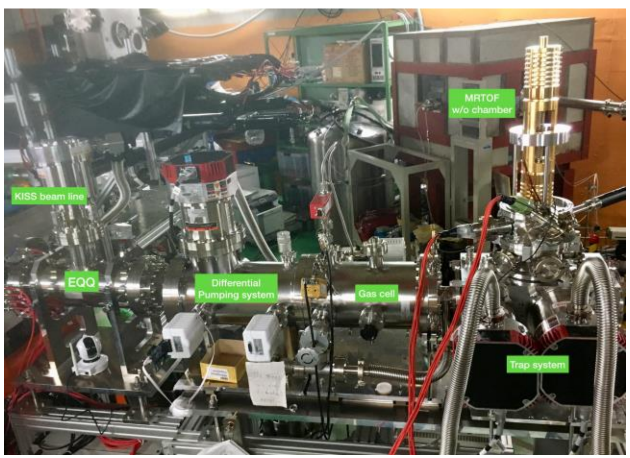


Completed extensive R&D
Detector construction is in progress
Construction will be completed by the end of 2018

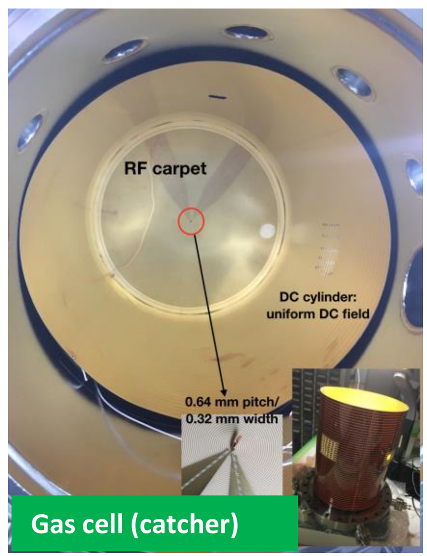
HPMMS: MR-TOF
(High Precision Mass Measurement System)

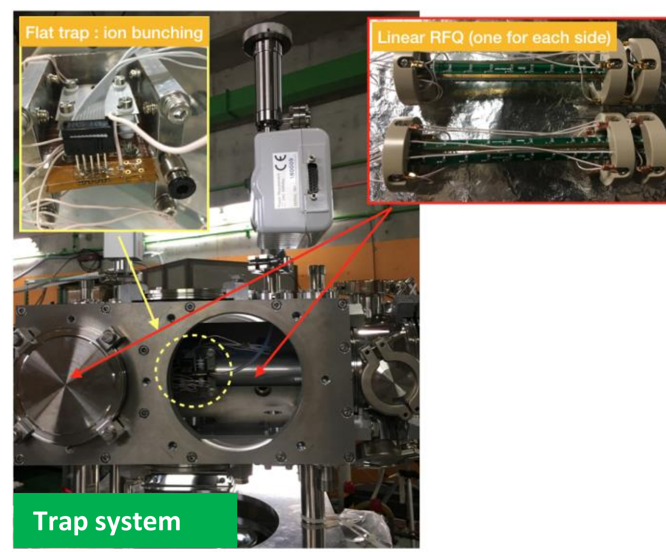
Conceptual design	**Manufacturing & Test**	Installation	Commissioning	Operation
2011~2012	**~2020.1**	~2020.10	~2021.12	2022~

- ☐ R&D performed by the WNSC MRTOF group (Leader: Prof. Wada).
- ☐ Additional beamline to the MRTOF-MS system was constructed in 2017.
- ☐ Differential pumping system, gas cell (or catcher), trap system, and MRTOF analyzer were assembled, waiting for the offline ion-source test.
- ☐ Test of the differential pumping system with the gas cell filled with 1 mbar helium gas was performed at 3.4×10^{-4} Pa upstream side (acceptable).
- ☐ Optimizing the beam transmission through the ϕ=2 mm gas cell hole was performed: 72% efficiency achieved (It will be improved by additional beam steerer.)

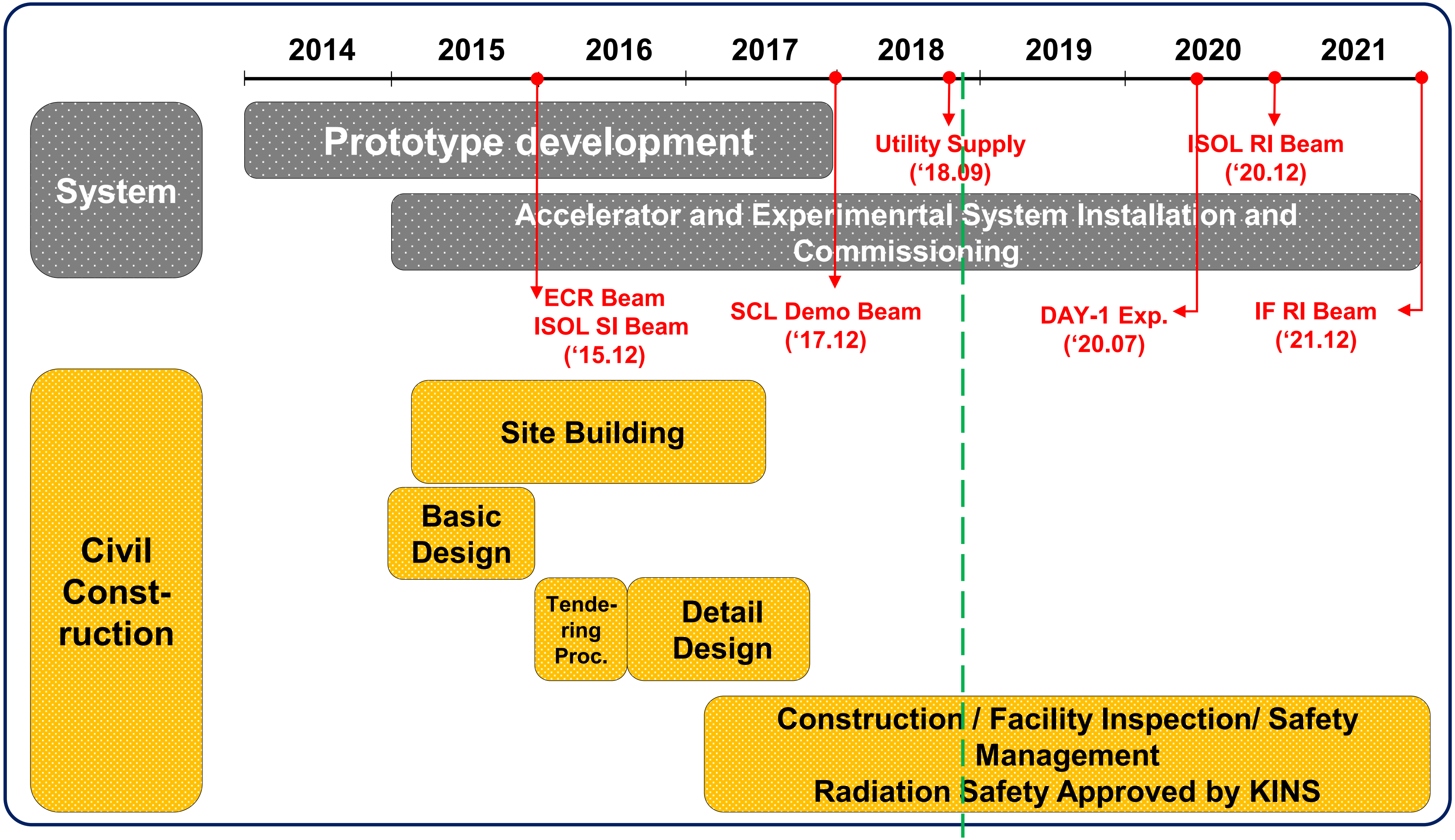


A picture of MRTOF-MS system and other parts at RISP-KEK/WNSC



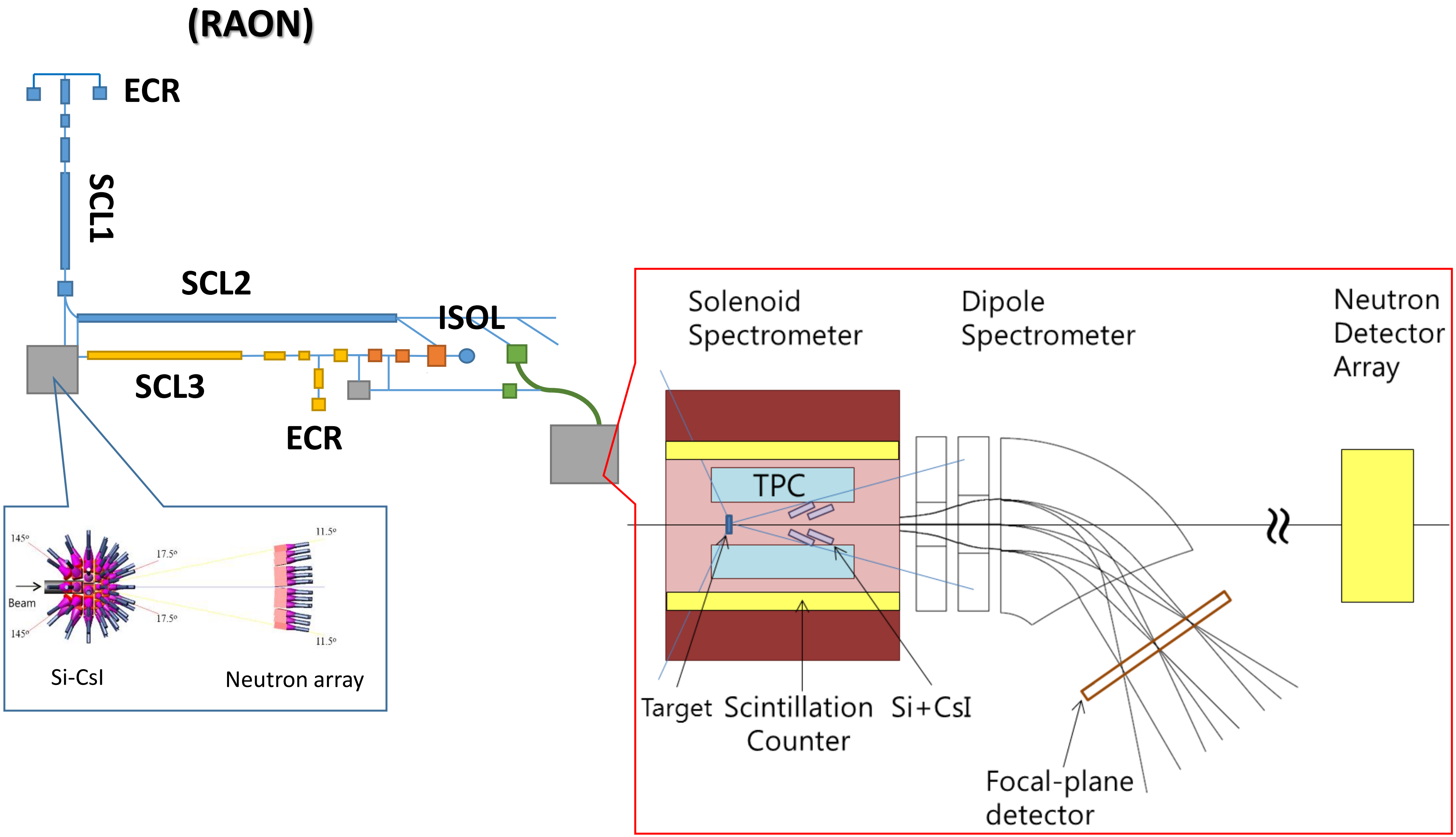


Milestones

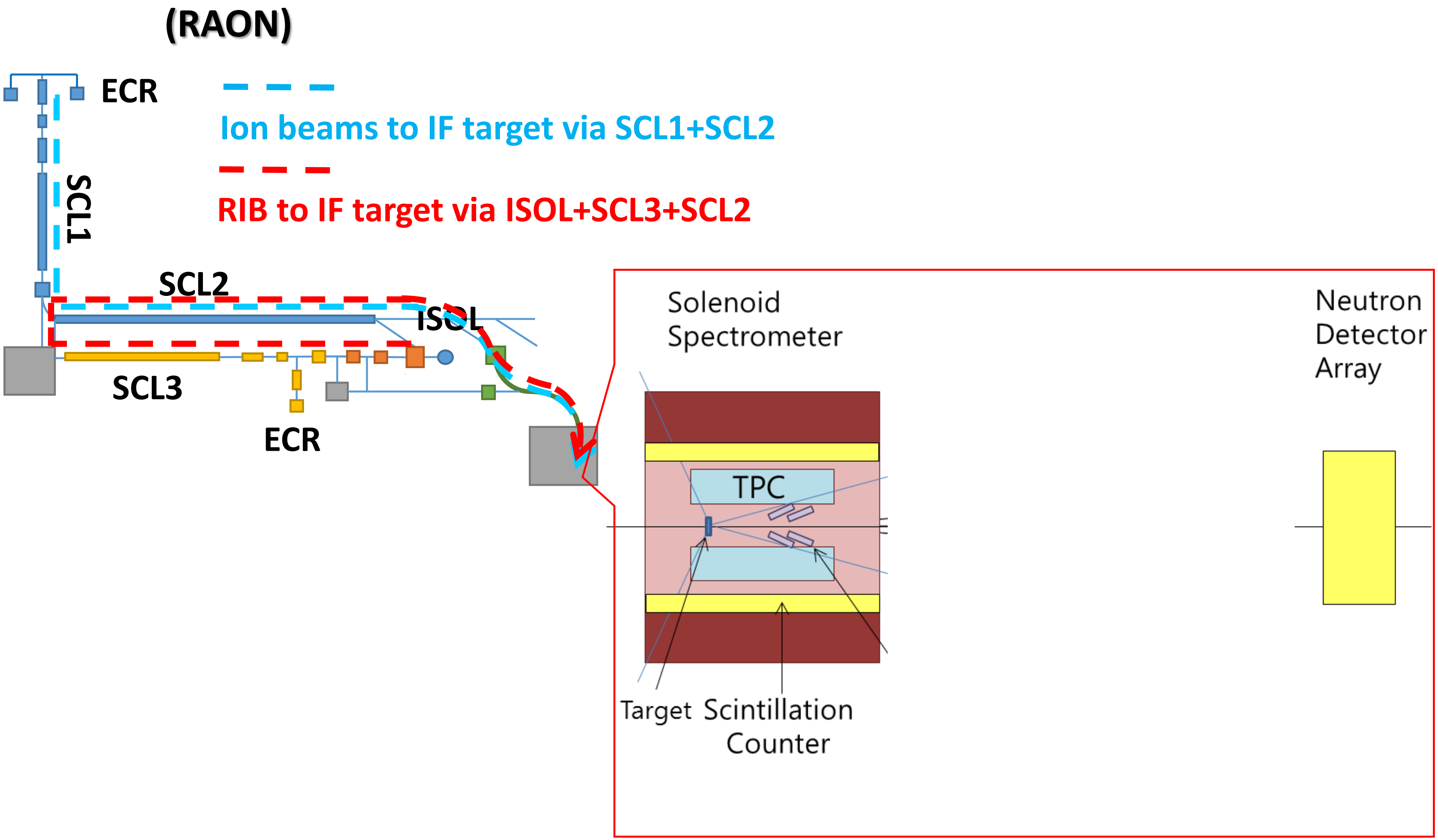

2014
2015
2016
2017
2018
2019
2020
2021
System
Prototype development
Utility Supply ('18.09)
ISOL RI Beam ('20.12)
Accelerator and Experimenrtal System Installation and Commissioning
ECR Beam
ISOL SI Beam ('15.12)
SCL Demo Beam ('17.12)
DAY-1 Exp. ('20.07)
IF RI Beam ('21.12)
Civil Const-ruction
Site Building
Basic Design
Tende-ring Proc.
Detail Design
Construction / Facility Inspection/ Safety Management
Radiation Safety Approved by KINS

LAMPS: Large-Acceptnce MultiPurpose Spectrometer

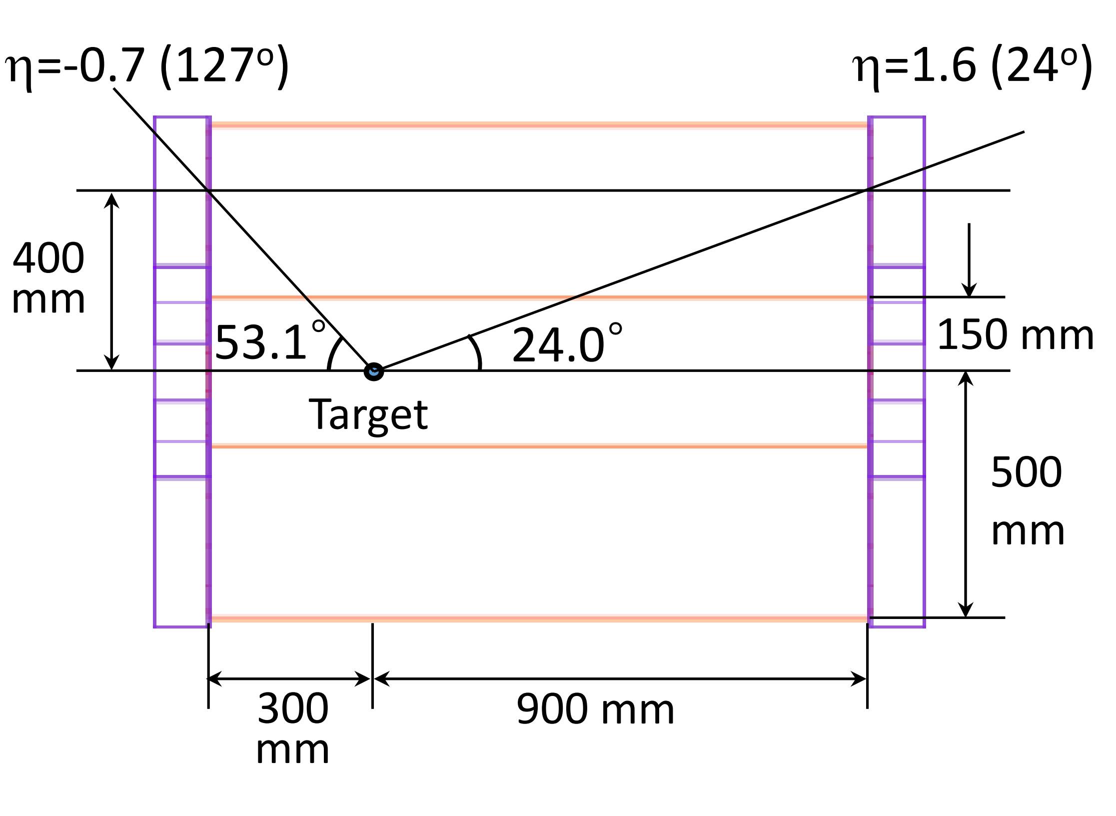
Overview of LAMPS

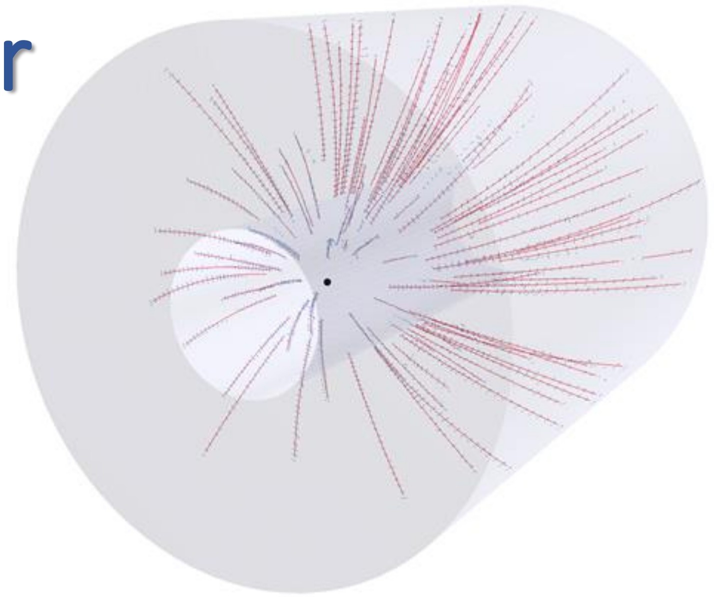


Overview of LAMPS

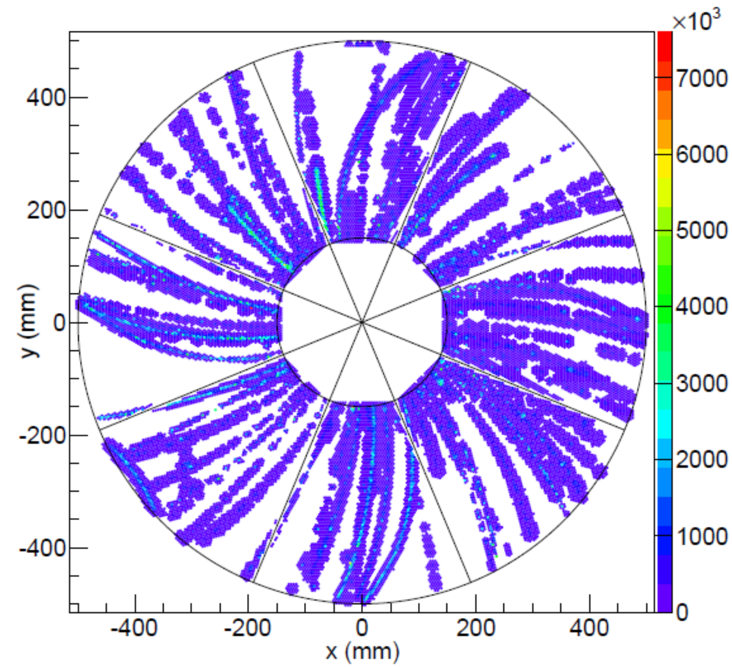


Time Projection Chamber

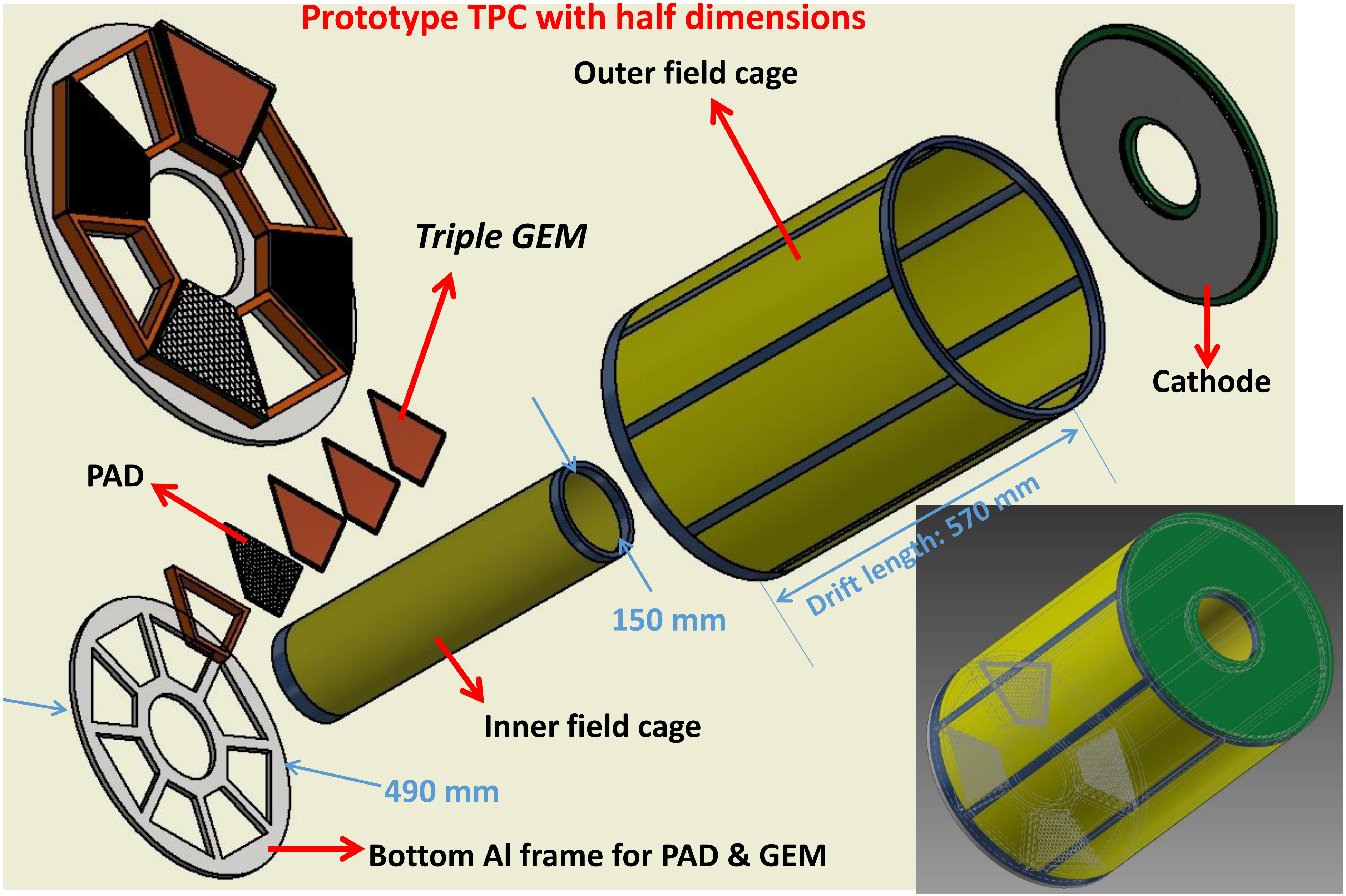




Simulation of one central Au+Au event at 250 AMeV (IQMD)

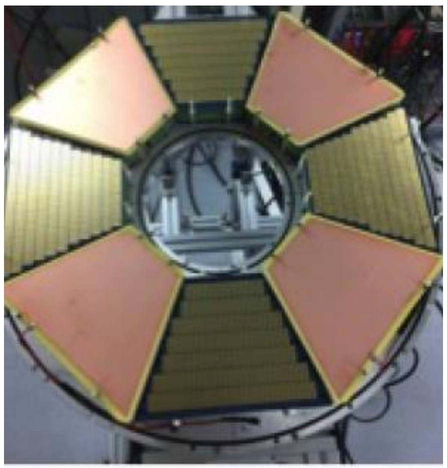


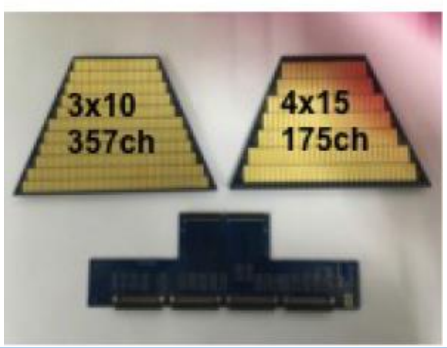
Prototype TPC: Design



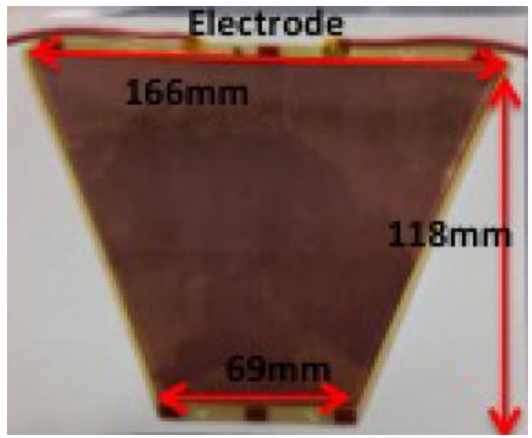
Prototype TPC: Components

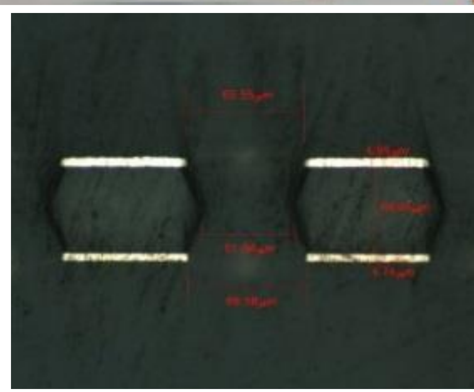
[Readout Pads]
Tested pads with the two different dimensions
3×10 mm^2: 357 Ch./Oct.
4×15 mm^2: 175 Ch./Oct.
Multi-layer PCB board





[GEM Foil]
Trapezoidal shape
Thickness: 75 μm
Area: 166×118 mm^2
Triple layers for each plane

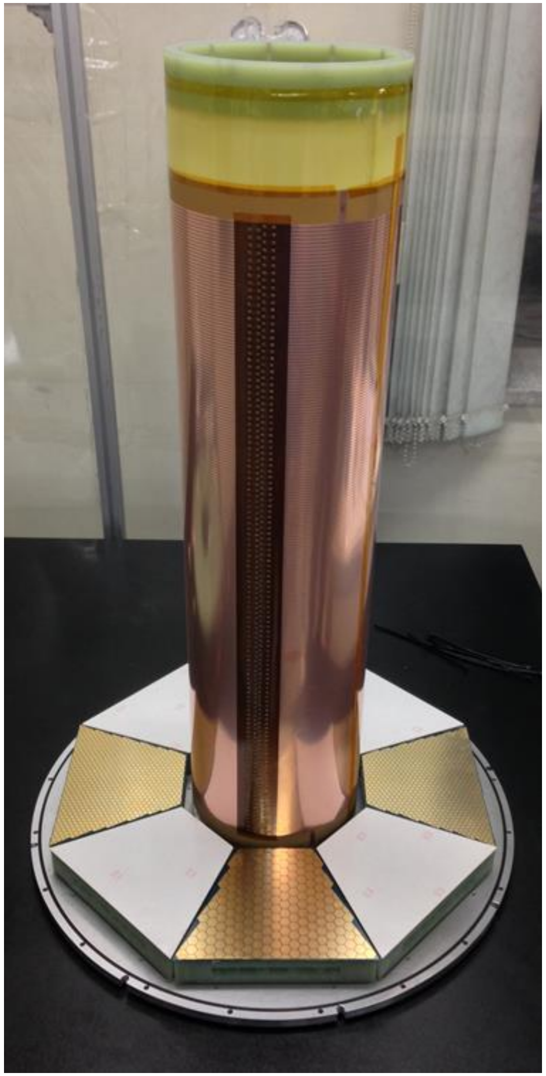




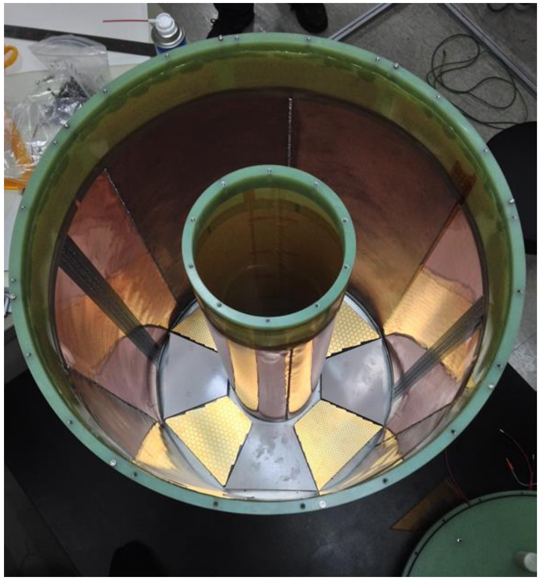
[Field Cage]
35 μm thick and 2 mm wide Cu strips
500 μm gap between adjacent strips
Mirror strips on the back
1 MΩ resistors with 0.1% var.
TPC body: G10 + Aramid honeycomb

Prototype TPC: Assembly

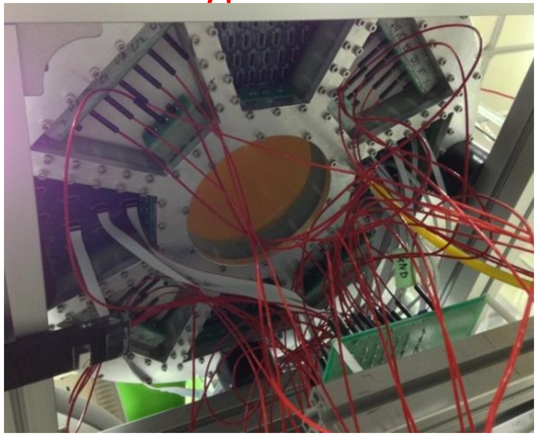
Inner Field Cage installed



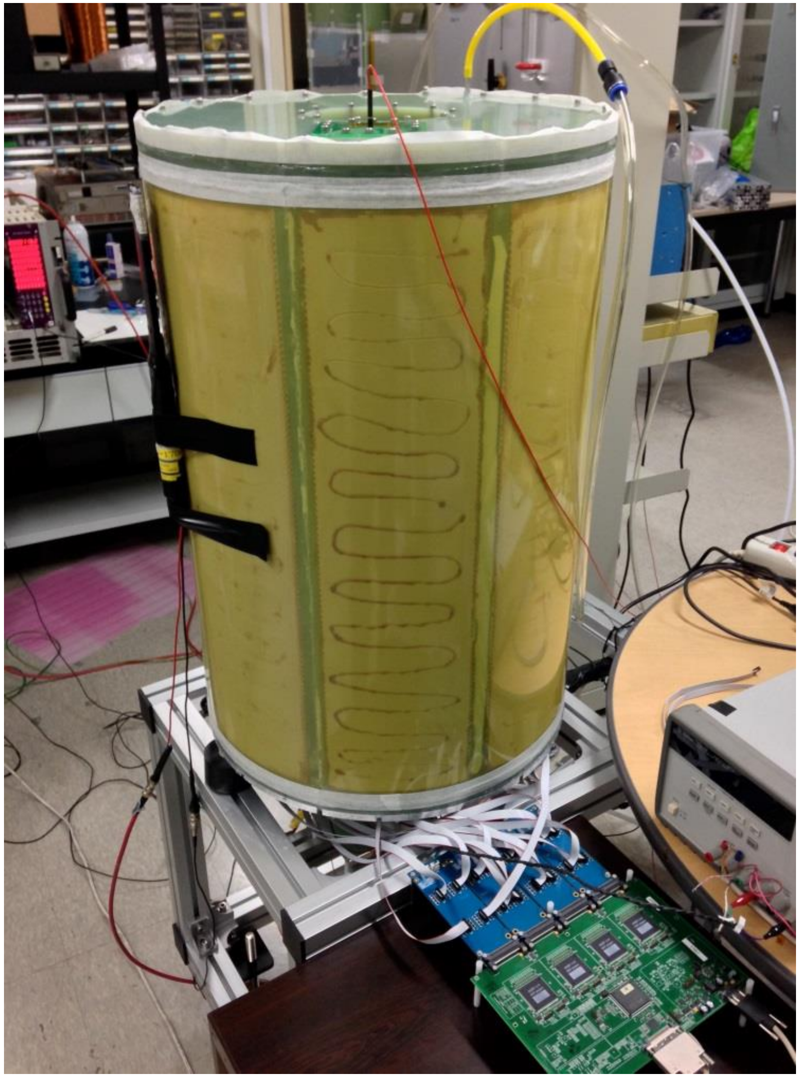
Outer Field Cage installed



Prototype TPC: back



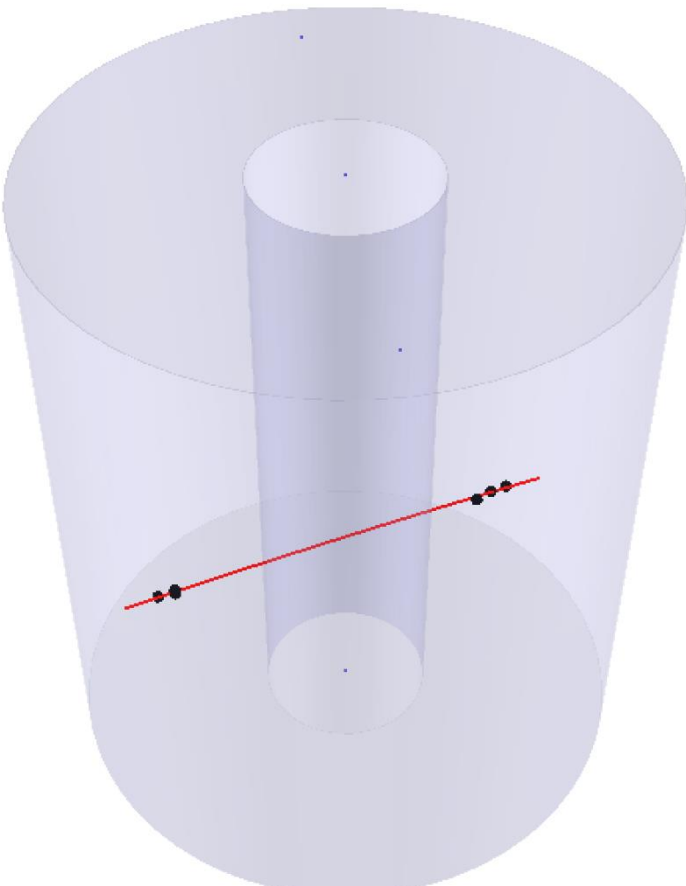
Prototype TPC assembled

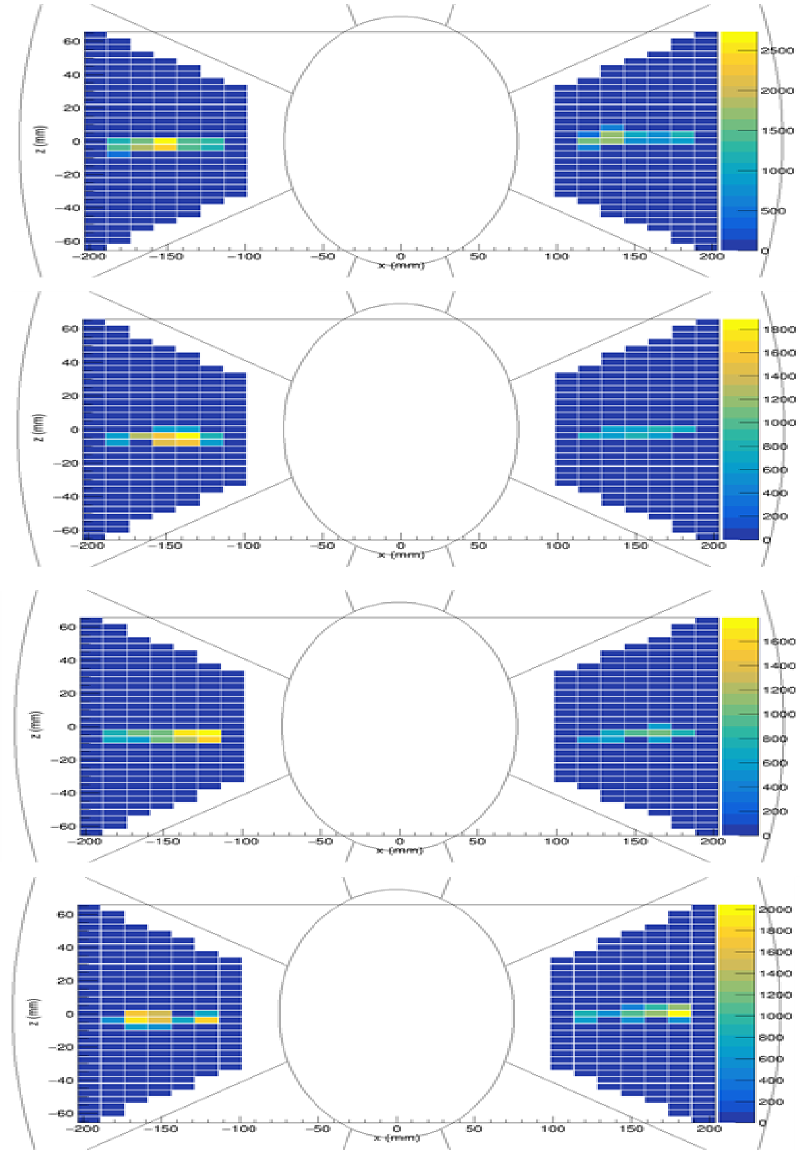


Prototype TPC: Test at ELPH

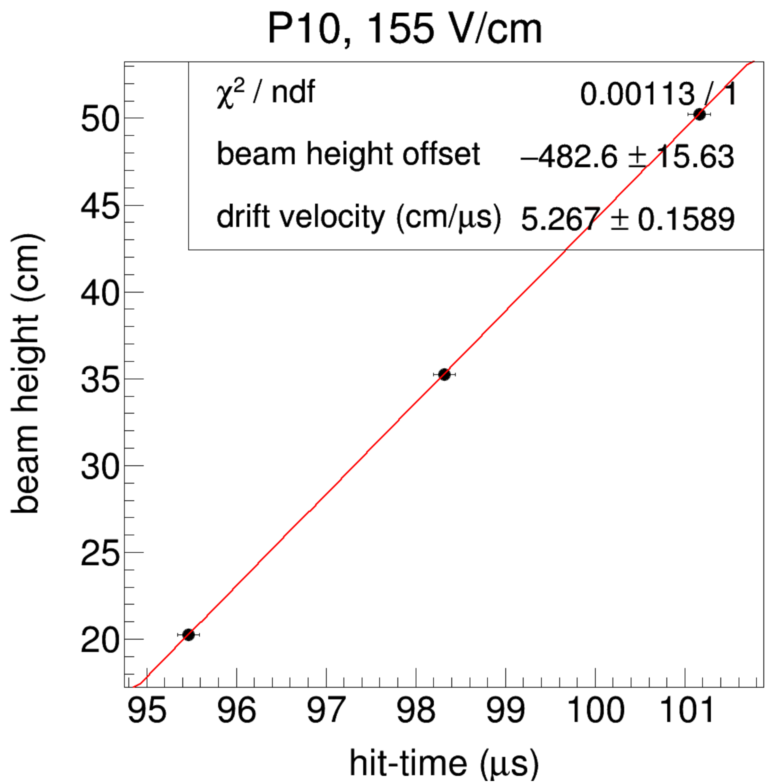
- ELPH: Research Center for Electron Photon Science at Tohoku University, Japan
- Dates: November 2016
- Beams: e^+ beams at 500 MeV
- Gas: Ar(90%)+CH_4(10%) (P10)
  Ar(90%)+CO_2(10%) ($ArCO_2$)
- Purpose: To study the detailed characteristics, such as v_{drift}, diffusion and σ_x, of LAMPS TPC

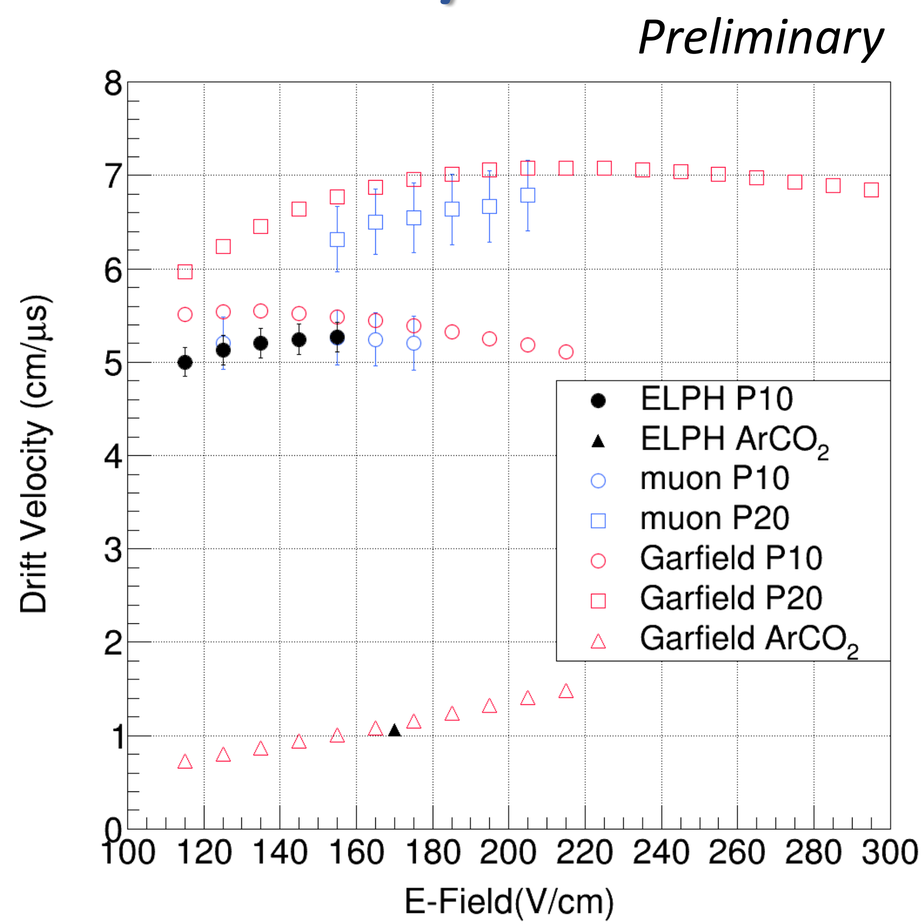
Prototype TPC: Event Displays





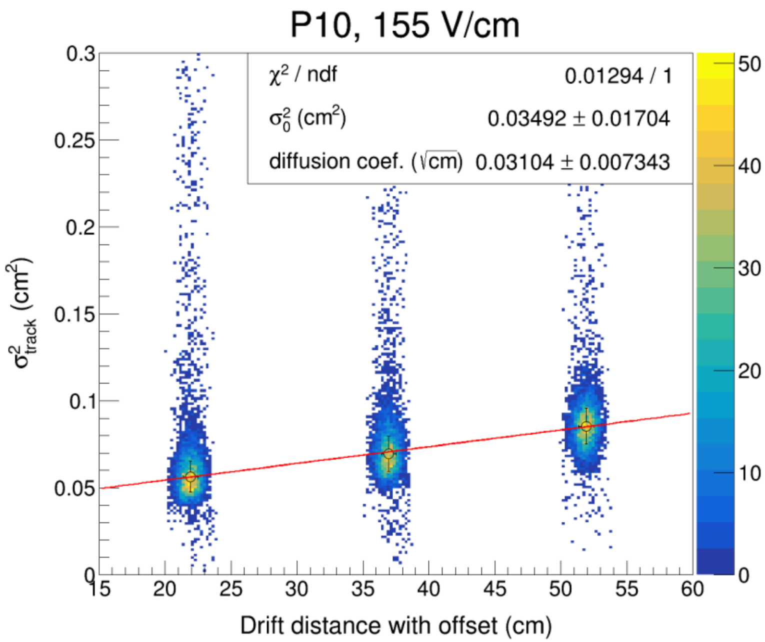
Prototype TPC: Drift Velocity

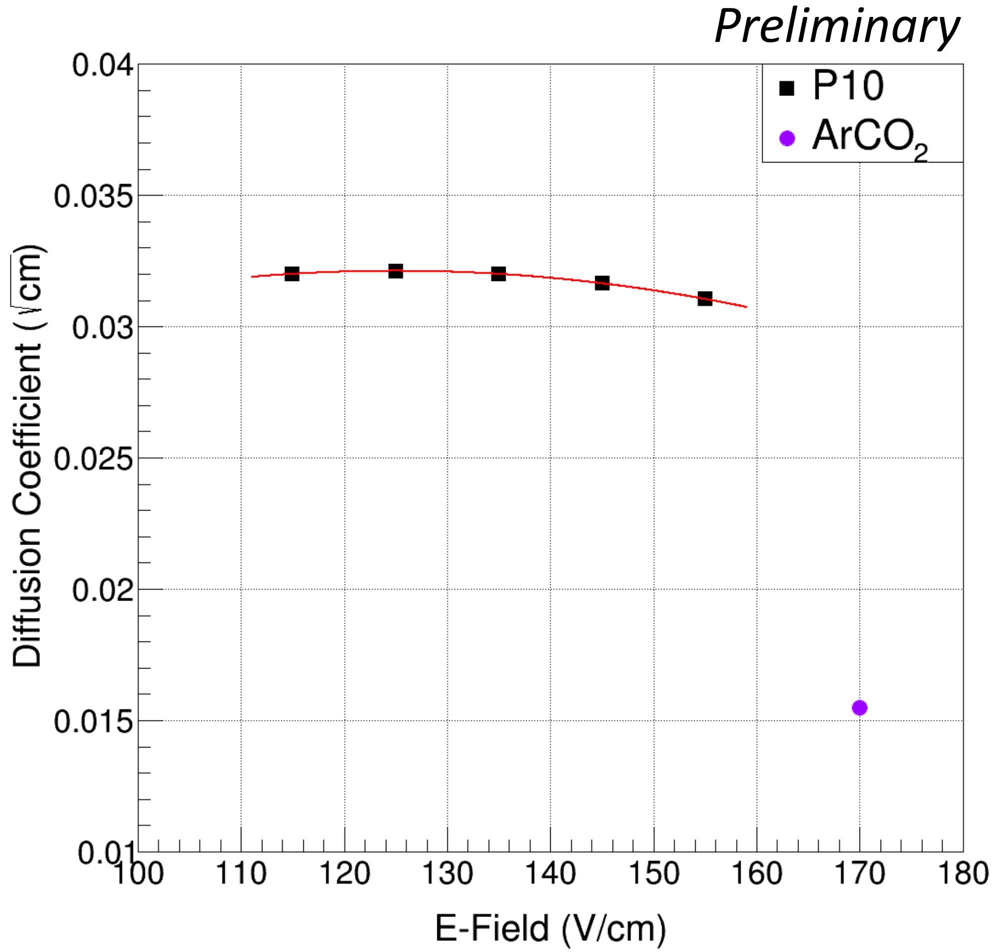




- ☐ $v_{drift} \lesssim 5.3\ \text{cm}/\mu s$ for P10:
  Maximum distance: $512\ \text{timing bins} \times 0.04\ \ \mu s/\text{bin} \times 5\ \text{cm}/\mu s \cong 100\ \text{cm}$
- ☐ Tested P20 with cosmic muons: $v_{drift} > 6\ \text{cm}/\mu s$ that will be suitable for LAMPS TPC if read out from only one endcap side.

Prototype TPC: Diffusion





$$\sigma_{track}^2 = D^2 z + \sigma_0^2$$

where

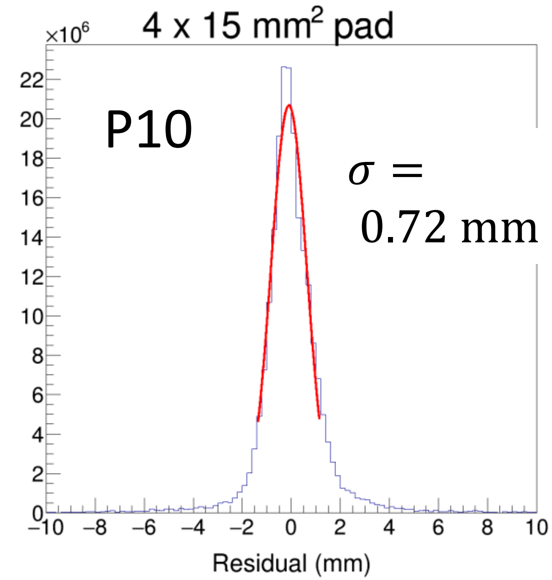
z: drift length

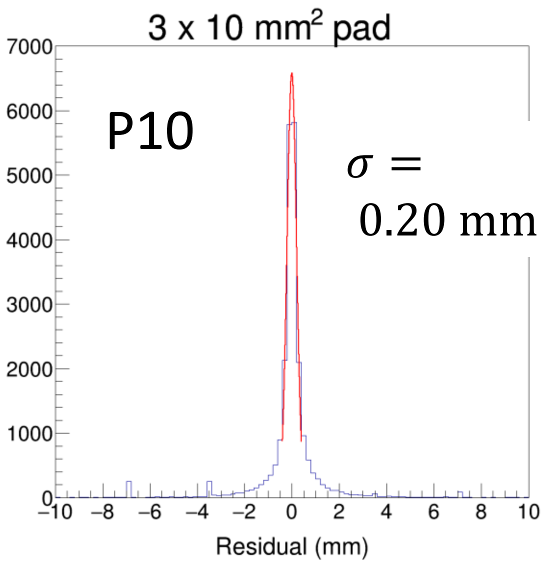
σ_{track}: width of hit distributions w.r.t. the fitted track

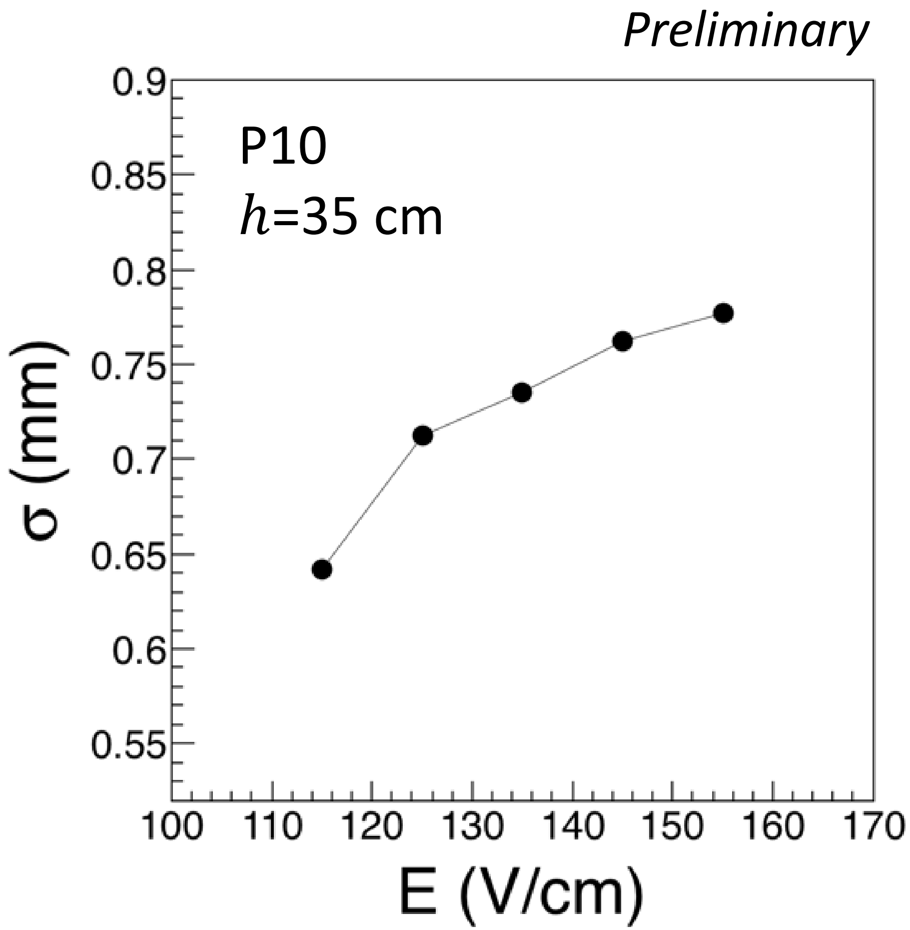
D: diffusion coefficient

σ_0: coefficient depending on the amplification system

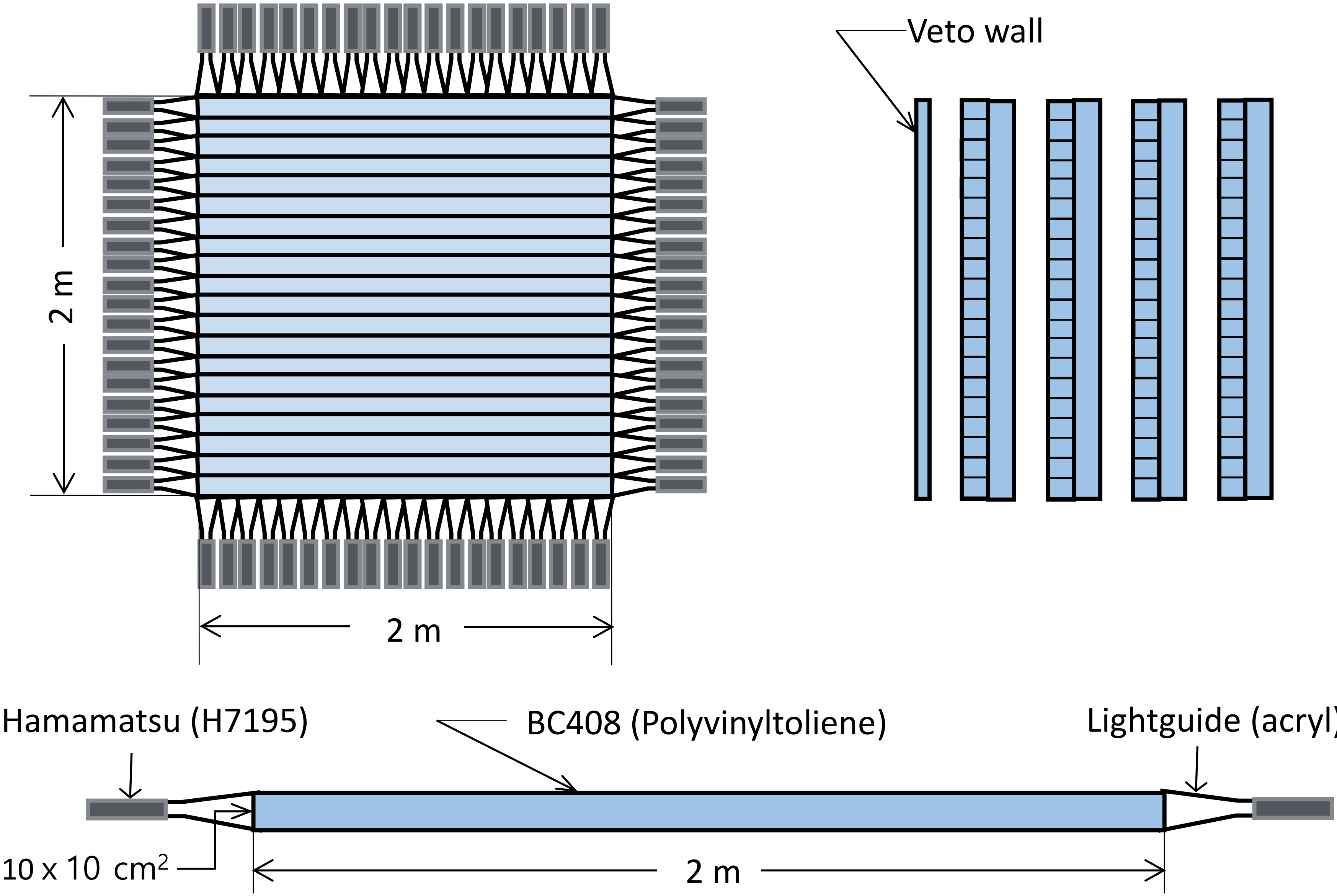
Prototype TPC: Position Resolution







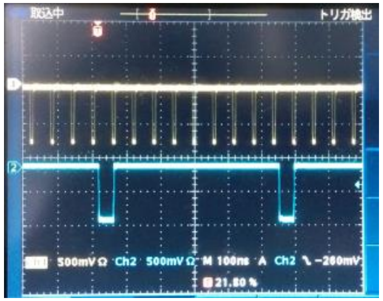
Neutron Detector Array

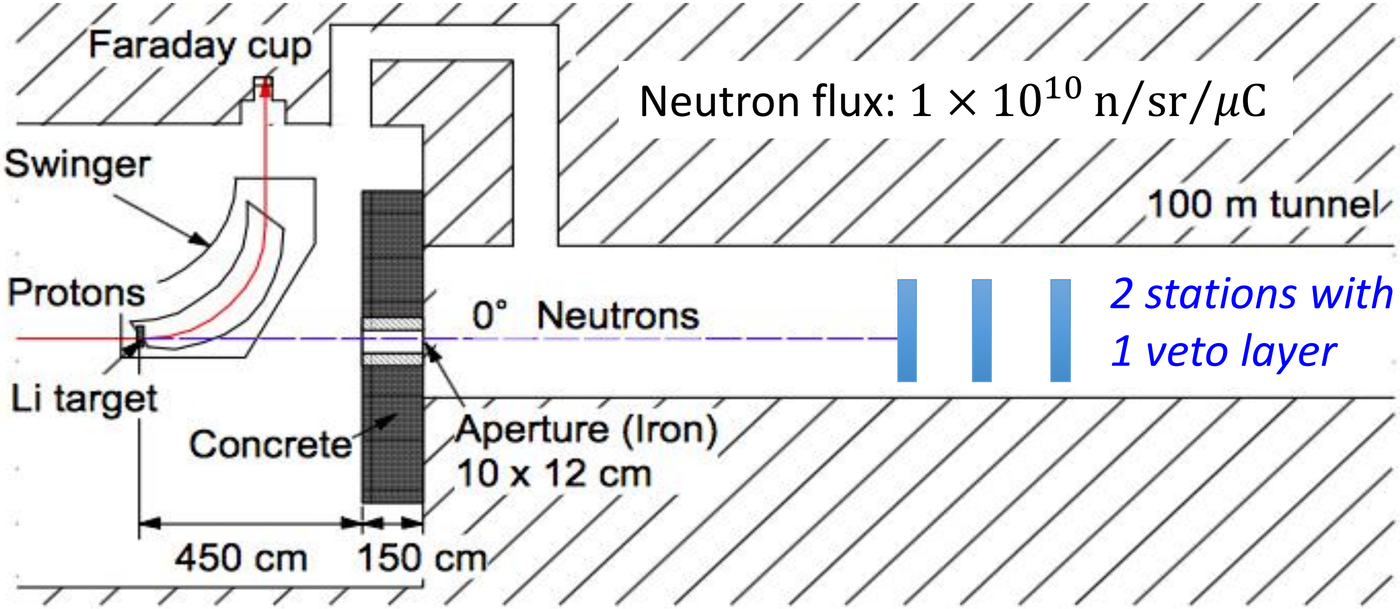


Beam Test at RCNP

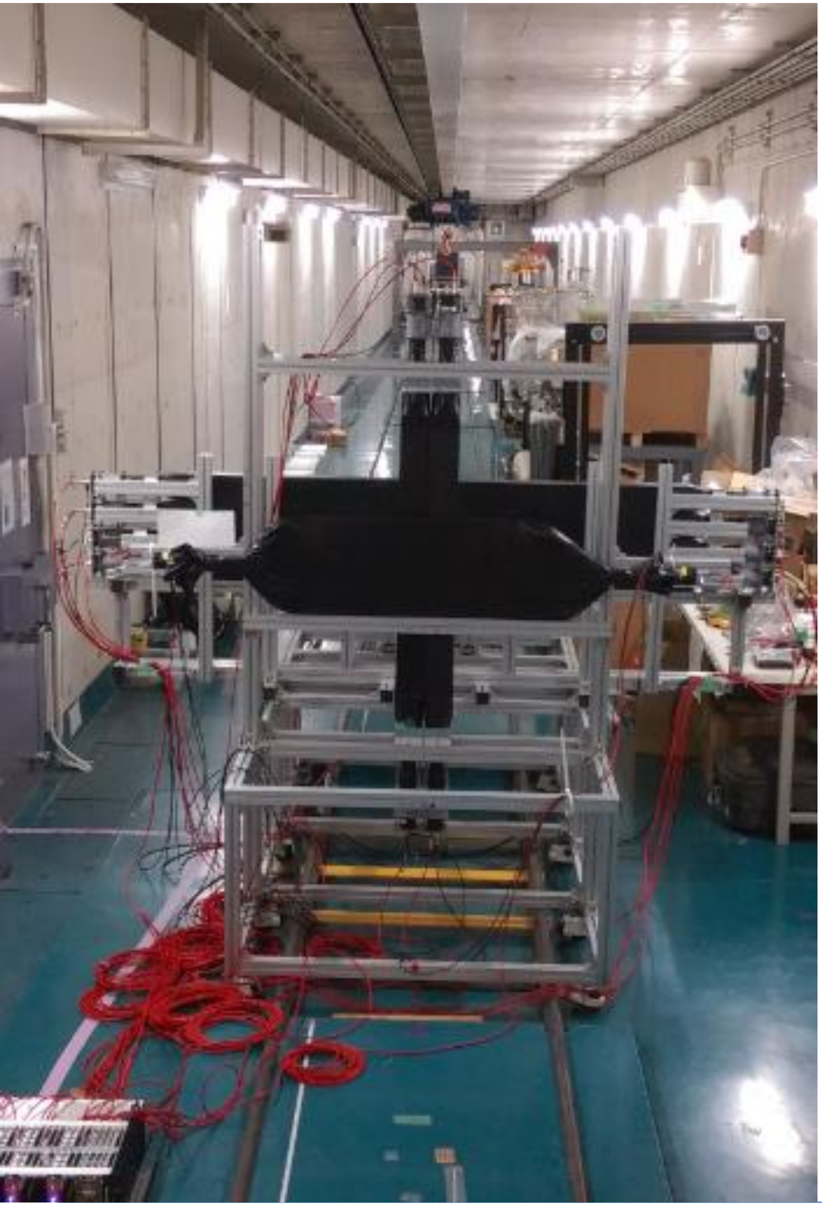
- E479 approved in B-PAC in March 2016
- Date: May 2016
- Beam specifications
  - Protons on Li production target (p+^{7}Li → n + ^{7}Be)
  - Neutron energies: 65 and 392 MeV in N0 beamline
  - 10 nA flux × 1/9 chopping
  - Background neutron above 3MeV is less than 1% [NIMA629, 43 (2011)]

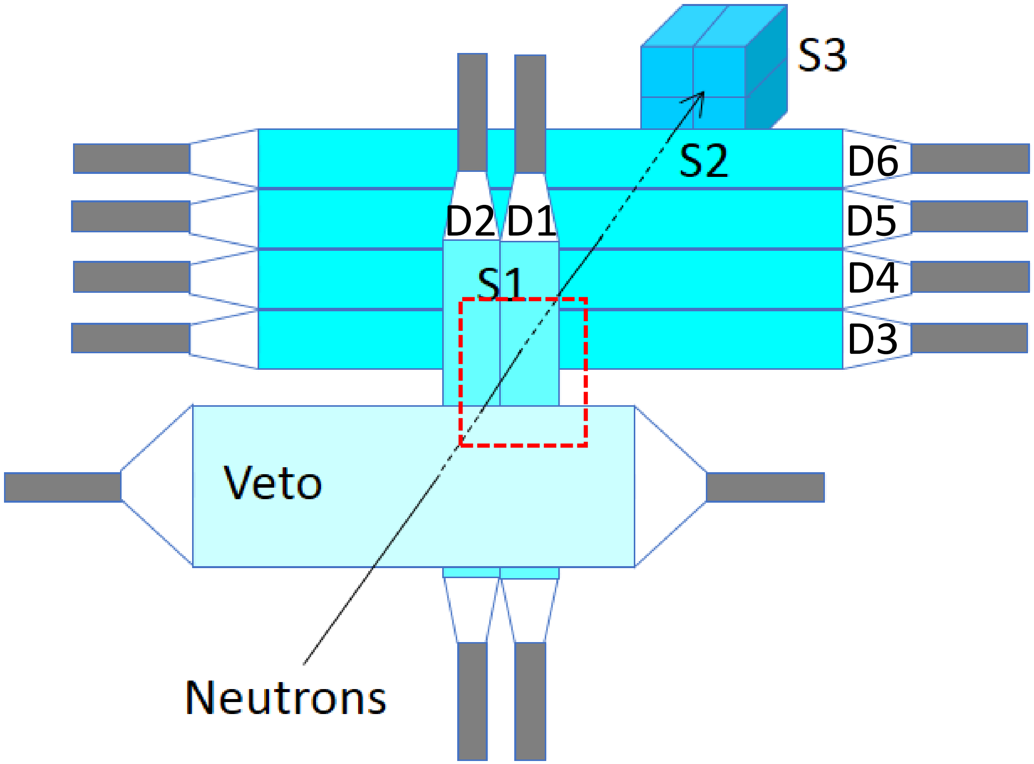
Chopping signals





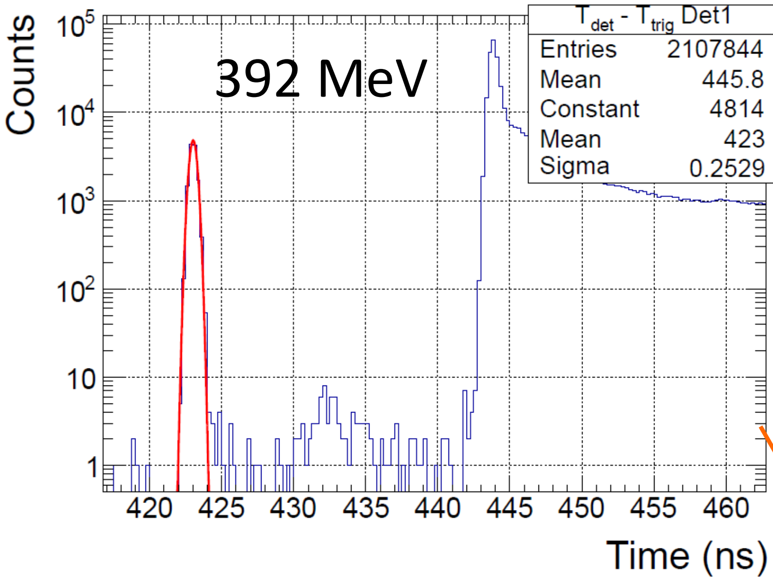
RCNP-E479

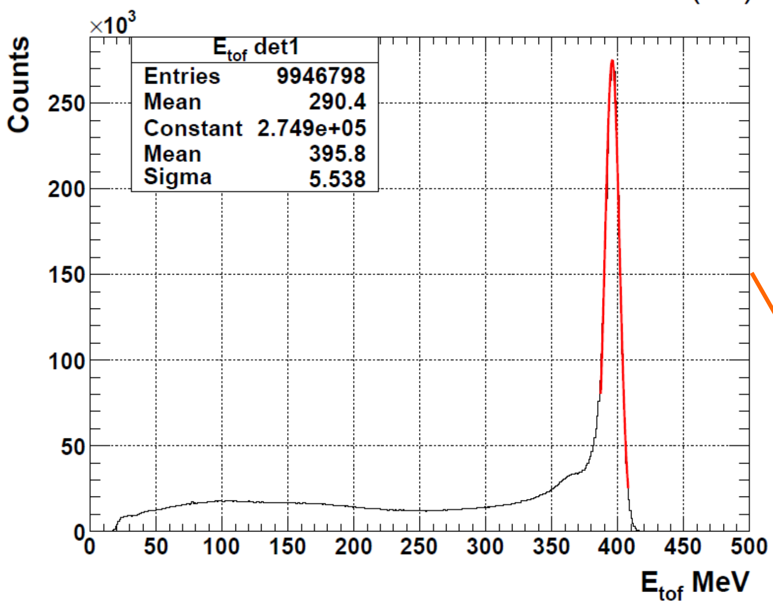




- Distance from target to the detector: 15 m
- Gap between stations: 60 cm
- Dim. of each S1 detector: $10 \times 10 \times 100$ cm^3
- Dim. of each S2 detector: $10 \times 10 \times 200$ cm^3
- Beam size at S1: 25×30 cm^2

Energy Resolution for Neutrons

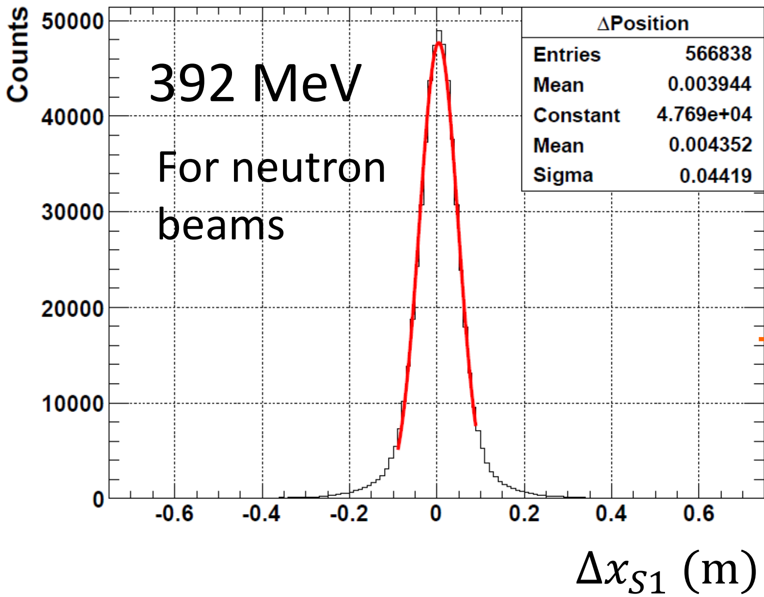


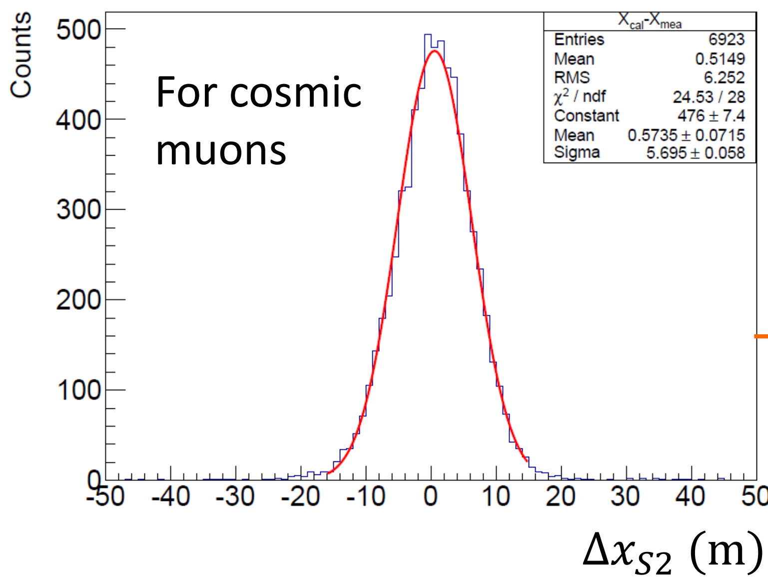


Preliminary

- Time resolution:
  $\Delta t = \sqrt{(\Delta\tau)^2 + (\Delta x/v)^2} = 0.66\text{ ns}$
  where
  $\Delta\tau$ = FWHM of γ peak = 0.60 ns
  Δx = effective thickness of the detector
  = (Total thinness of Li target, veto, and neutron detector)/2 = 6.0 cm
  v = neutron velocity = 21.3 cm/ns
- Neutron energy resolution:
  $\frac{\Delta E}{E} = \gamma(\gamma+1)\frac{\Delta t}{t} = 3.2\%$
  where
  Lorentz $\gamma = 1 + E/mc^2 = 1.42$
  $t = 70.4\text{ ns}$
- Energy resolution (FWHM/E)= 3.3 %

Position Resolution





Preliminary

- Hit position difference between $D1$ and $D2$ for neutrons:

$$\Delta x_{S1} \equiv x_{D1} - x_{D2}$$

for 10 MeV threshold and $\delta t < 3$ ns

- Relative position resolution for neutrons for one bar:

$$\sigma_n = \frac{\sigma(\Delta x_{S1})}{\sqrt{2}} = 3.1 \text{ cm}$$

- Position difference between the projected hit position and the hit position for $D3$ for cosmic muons:

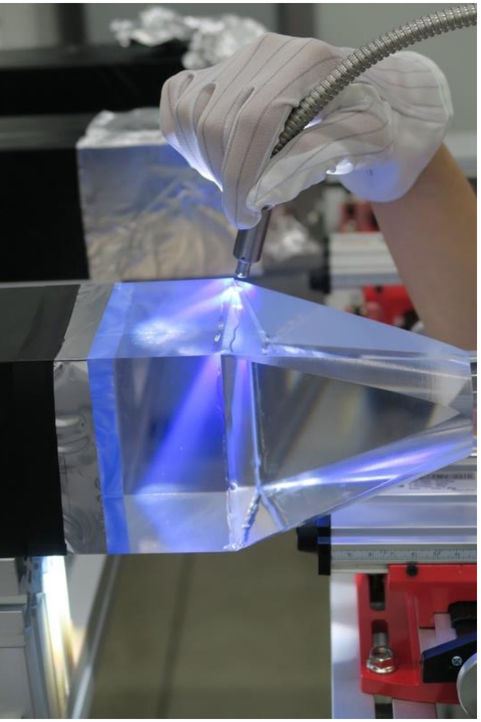
$$\Delta x_{S2} \equiv x_{D3,proj} - x_{D3,hit}$$

- Relative position resolution for cosmic muons for one bar:

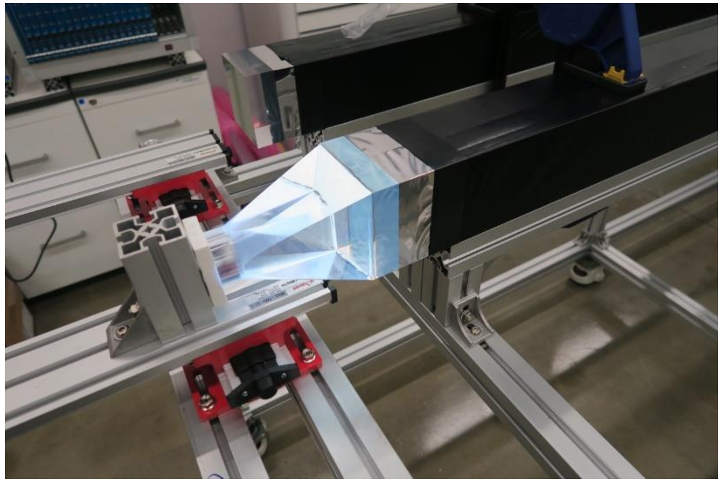
$$\sigma_\mu = \frac{\sigma(\Delta x_{S2})}{1.87} = 3.1 \text{ cm}$$

Assembly

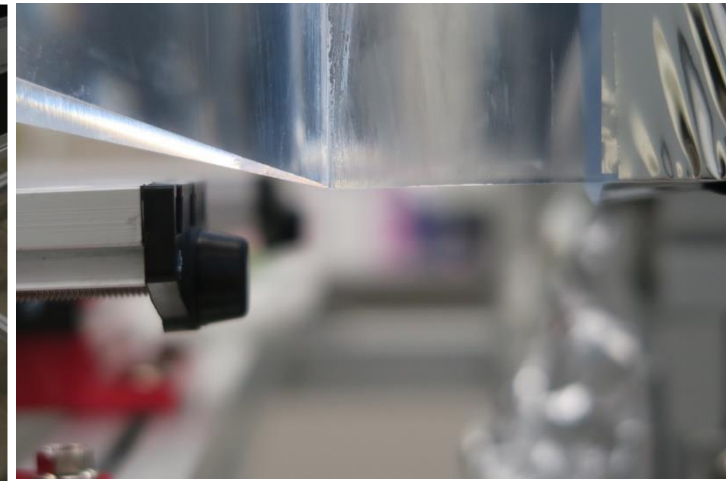
Curing UV glue



Fixing light guide with vice



Closeup view of the interface between scintillator & lightguide



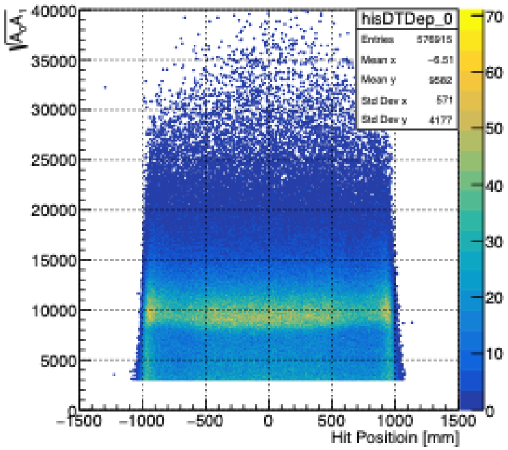
Assembly

↙ Clamps for installing PMTs

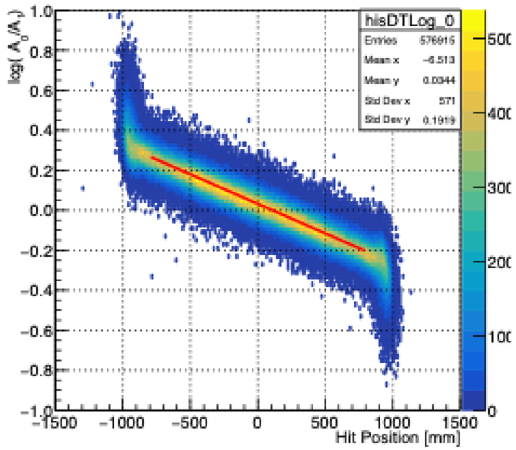
↓ Frames in the assembly site at the Sejong Campus of Korea Univ. close to RAON complex

Basic Performance

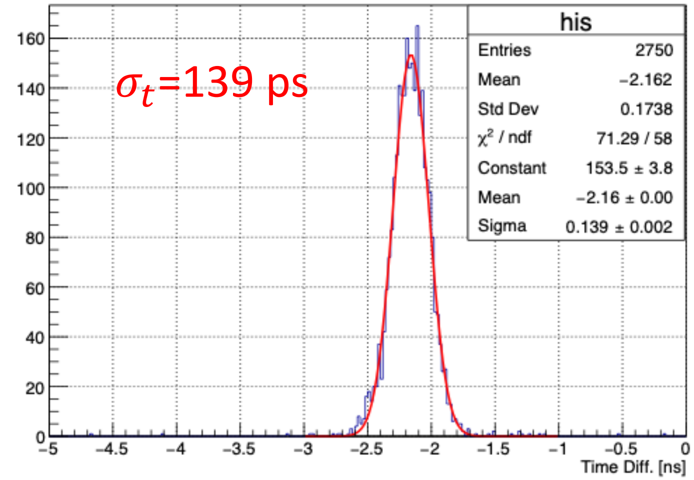
Cosmic-ray hit dist.



Attenuation

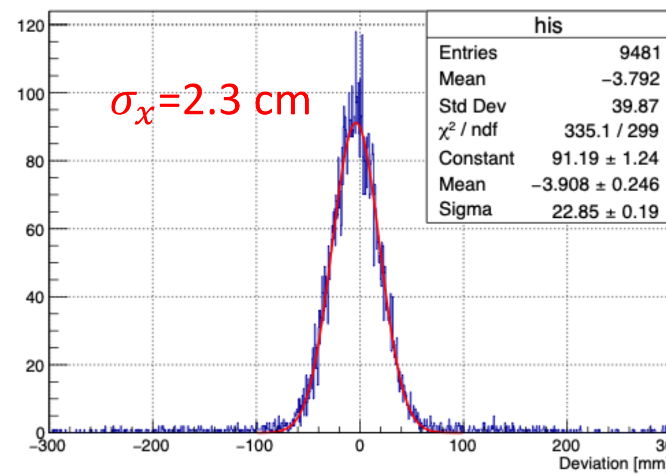


Timing resolution



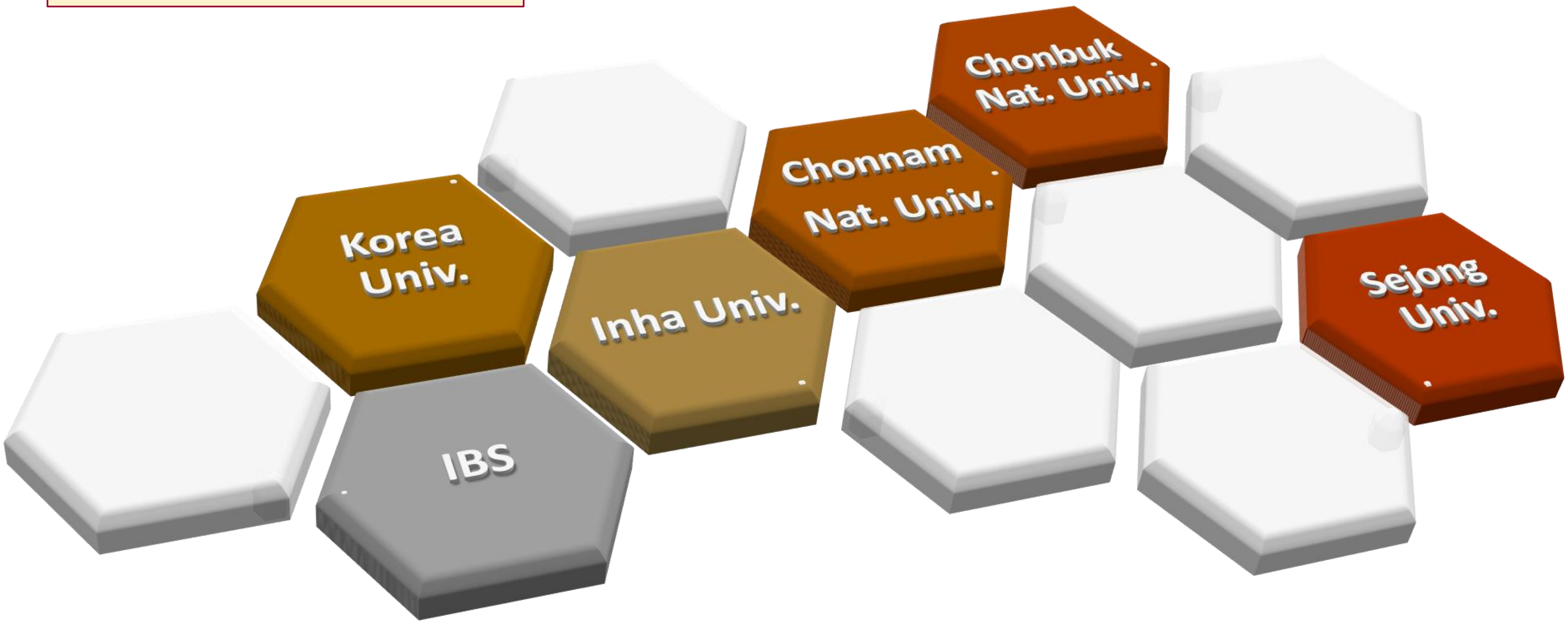
Parameters	Performance
MIP peak position variance	~10% (based on 9-10k events)
Attenuation length	339±2 cm (50% for 2m)
Speed of light in detector	156±2 mm/ns

Position resolution



LAMPS Collaboration

So far 5 domestic Universities and IBS



- We invite more collaborators, especially, from foreign countries.
- Contact me (bhong@korea.ac.kr) if you're interested in the project.

Rare Isotope Science Project

Summary

CENuM

- The Rare Isotope Science Project (RISP) at IBS is the first large-scale nuclear physics project in Korea.
- The civil engineering, accelerator development, and detector construction for RAON have been aggressively progressed.
- LAMPS is a dedicated spectrometer for nuclear symmetry energy at RAON.
- Various components for LAMPS, including TPC, neutron detector array, magnet, are making a very good progress.
- Expect to finish the detector construction in about 2-3 years for early nuclear physics experiment.