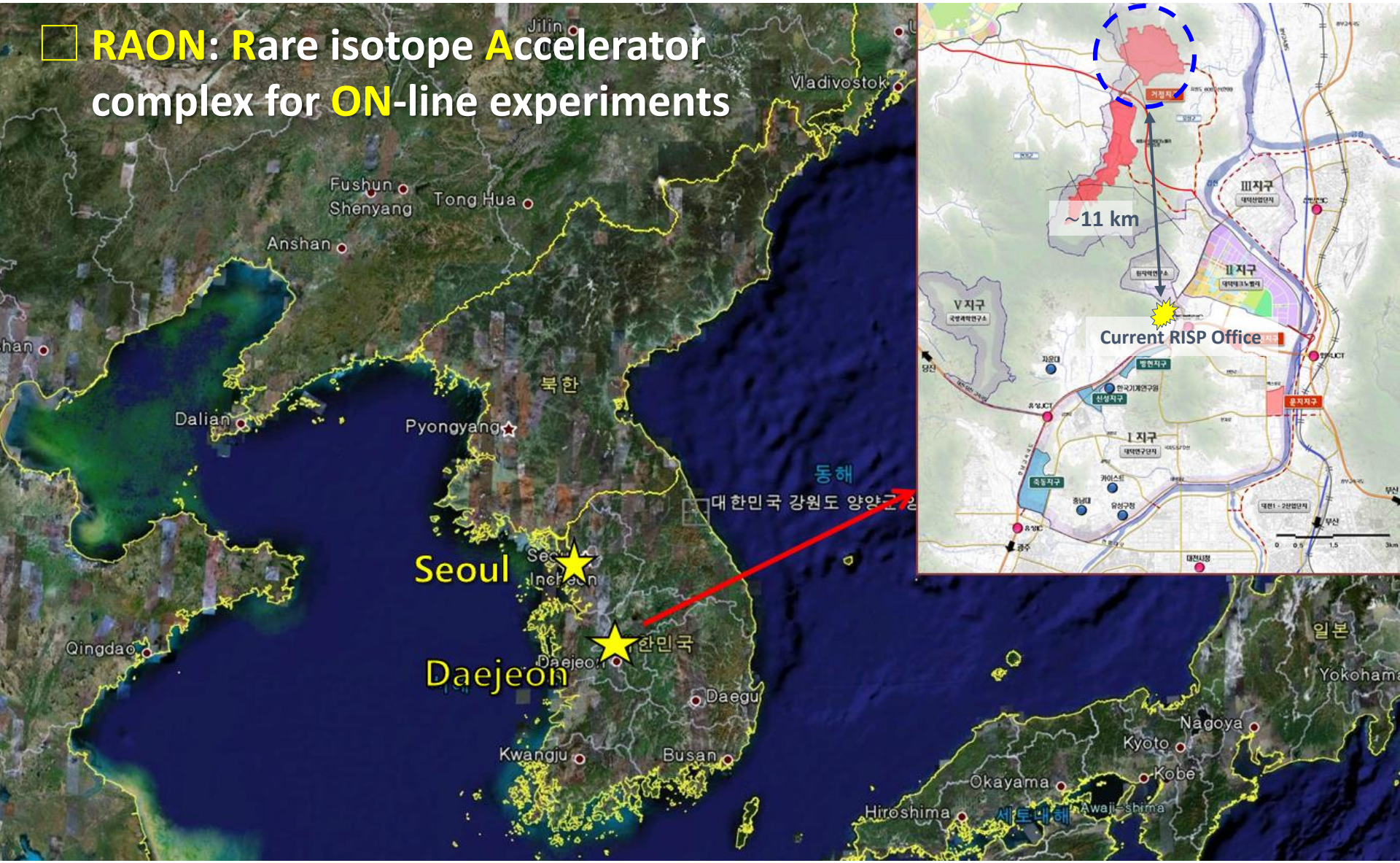
12th APCTP-BLTP JINR Joint Workshop
"Modern problems in nuclear and elementary particle physics"
Centum Premier Hotel, Busan, Korea, August 20-24, 2018

Status of LAMPS at RAON

Byungsik Hong
(Korea University)

Location of RAON RIB Complex



Site Plan

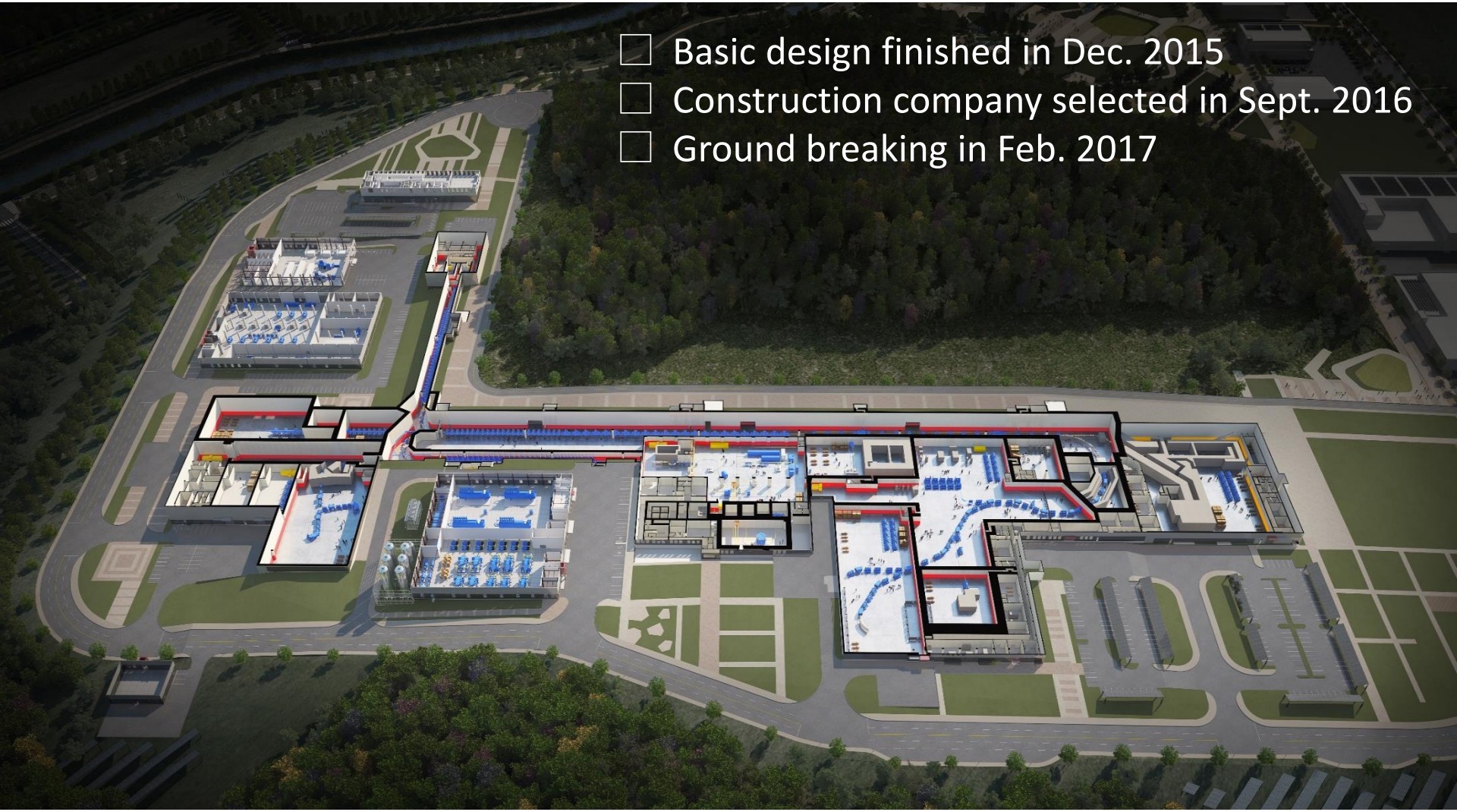
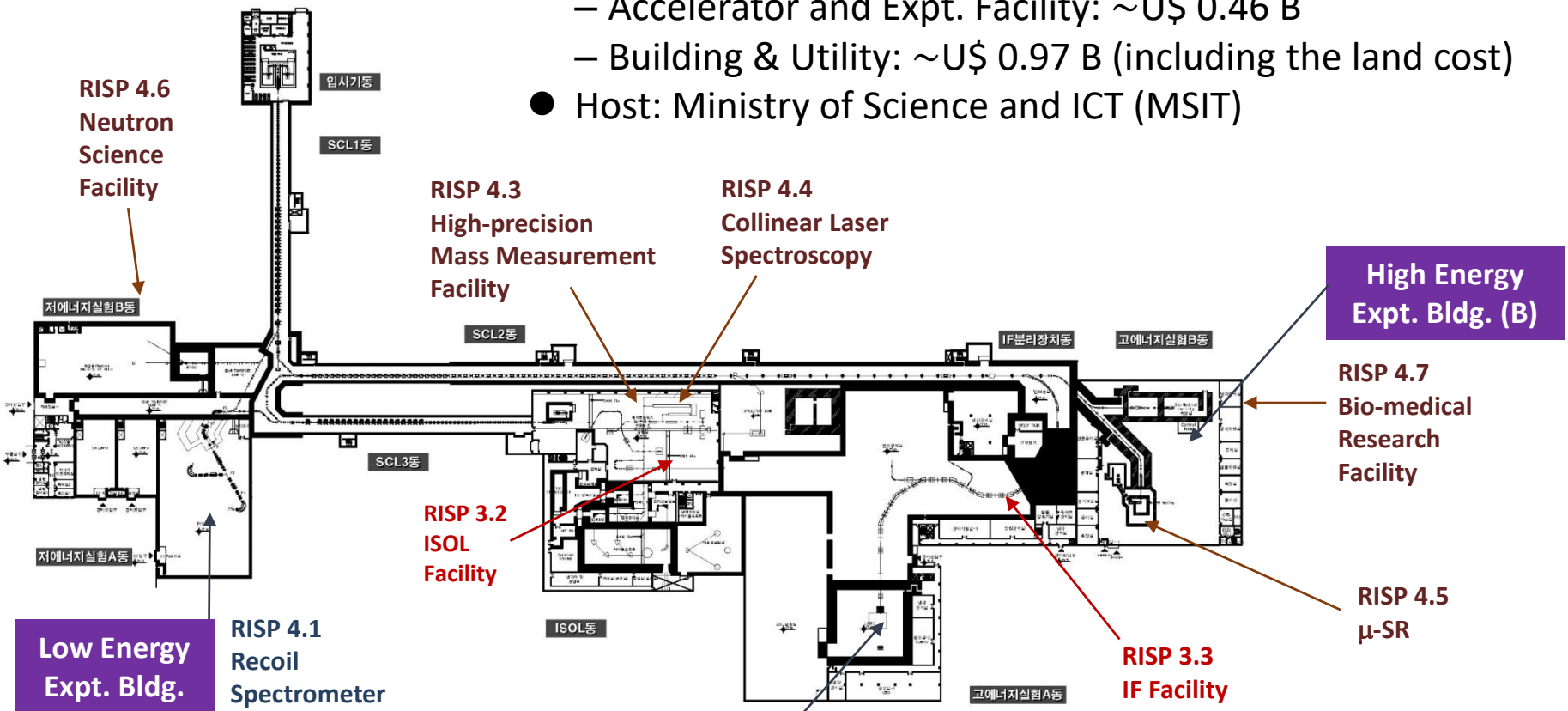

Basic design finished in Dec. 2015
Construction company selected in Sept. 2016
Ground breaking in Feb. 2017

Photo taken in April 2018

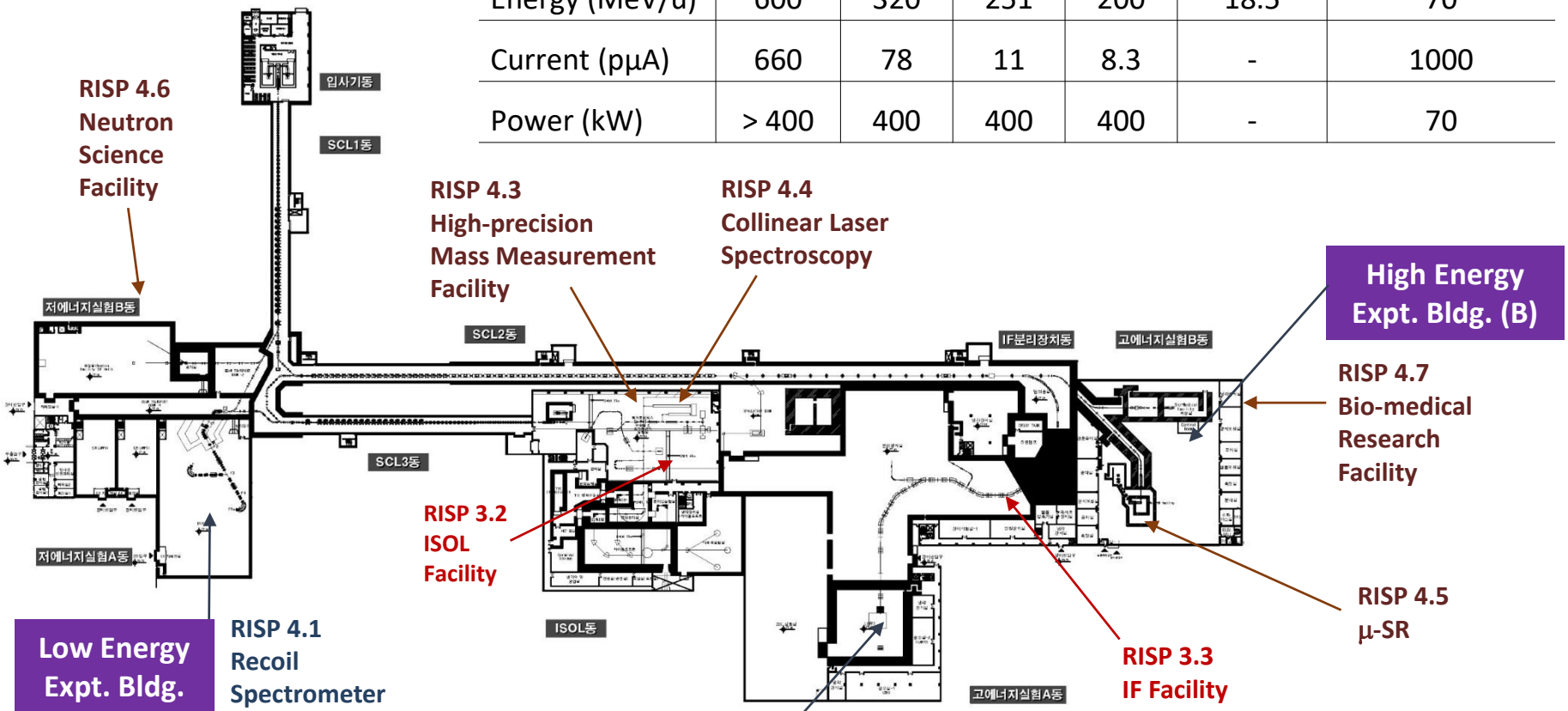
Layout of RAON

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

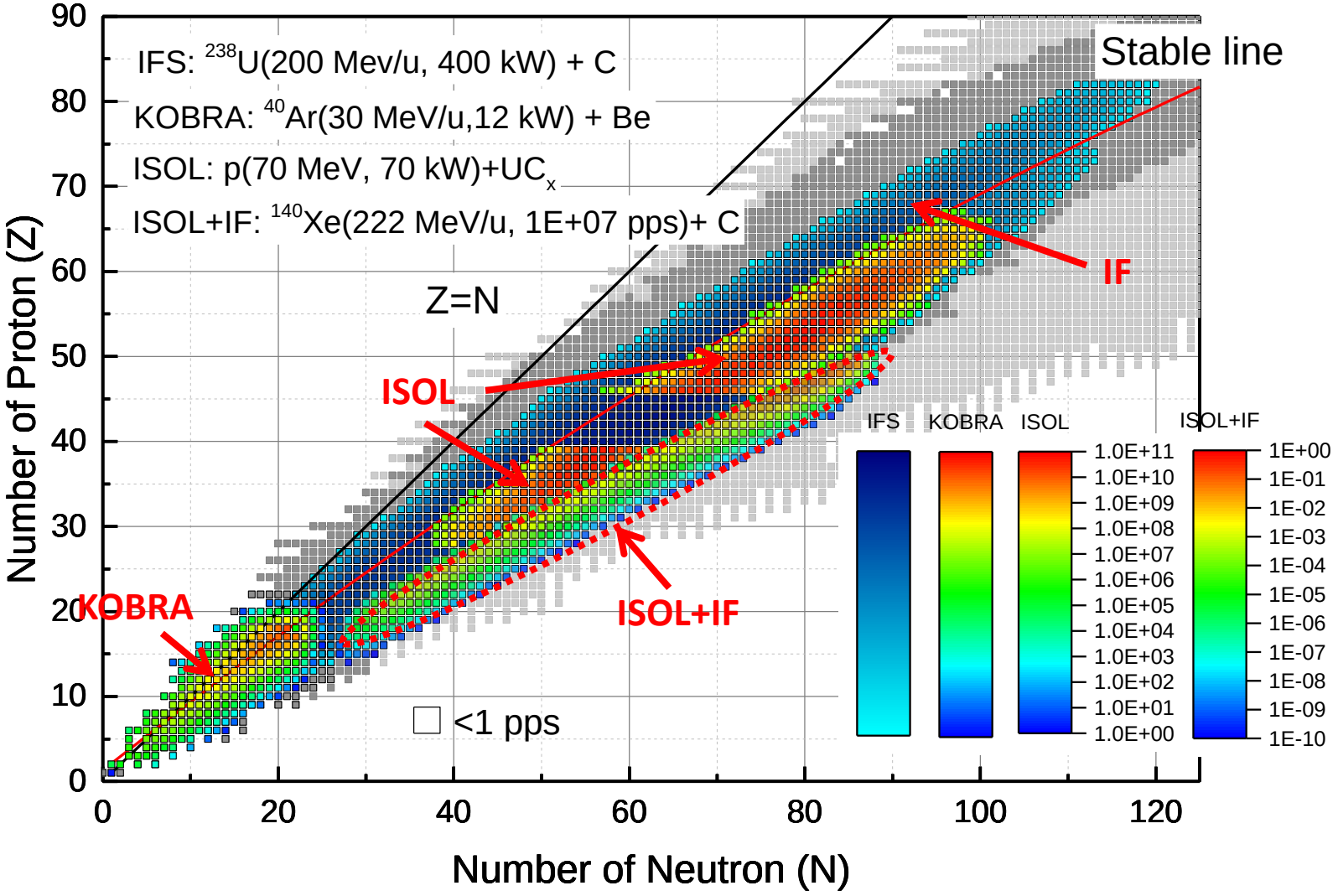


Layout of RAON

	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

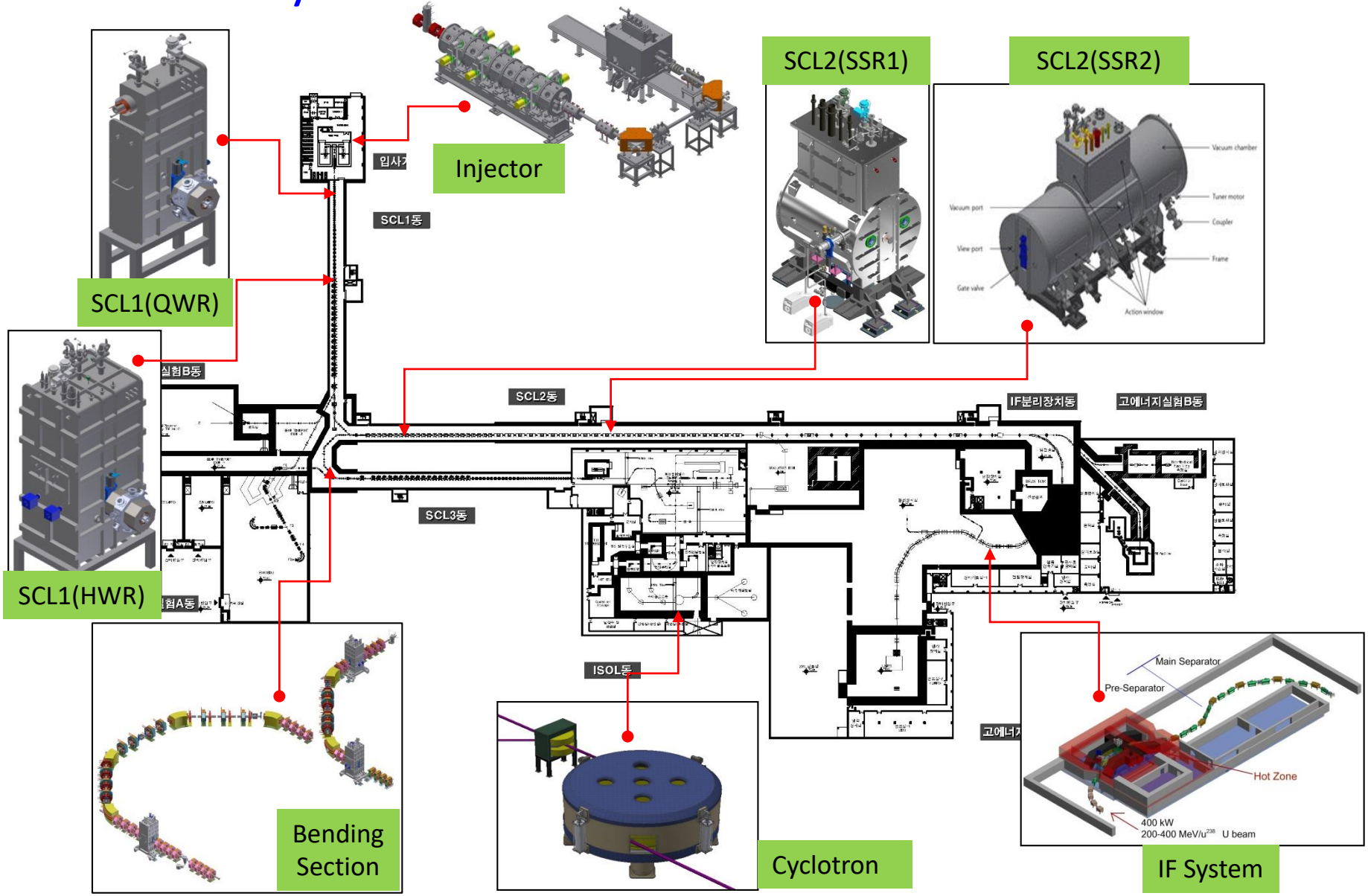


Expected RIBs at RAON

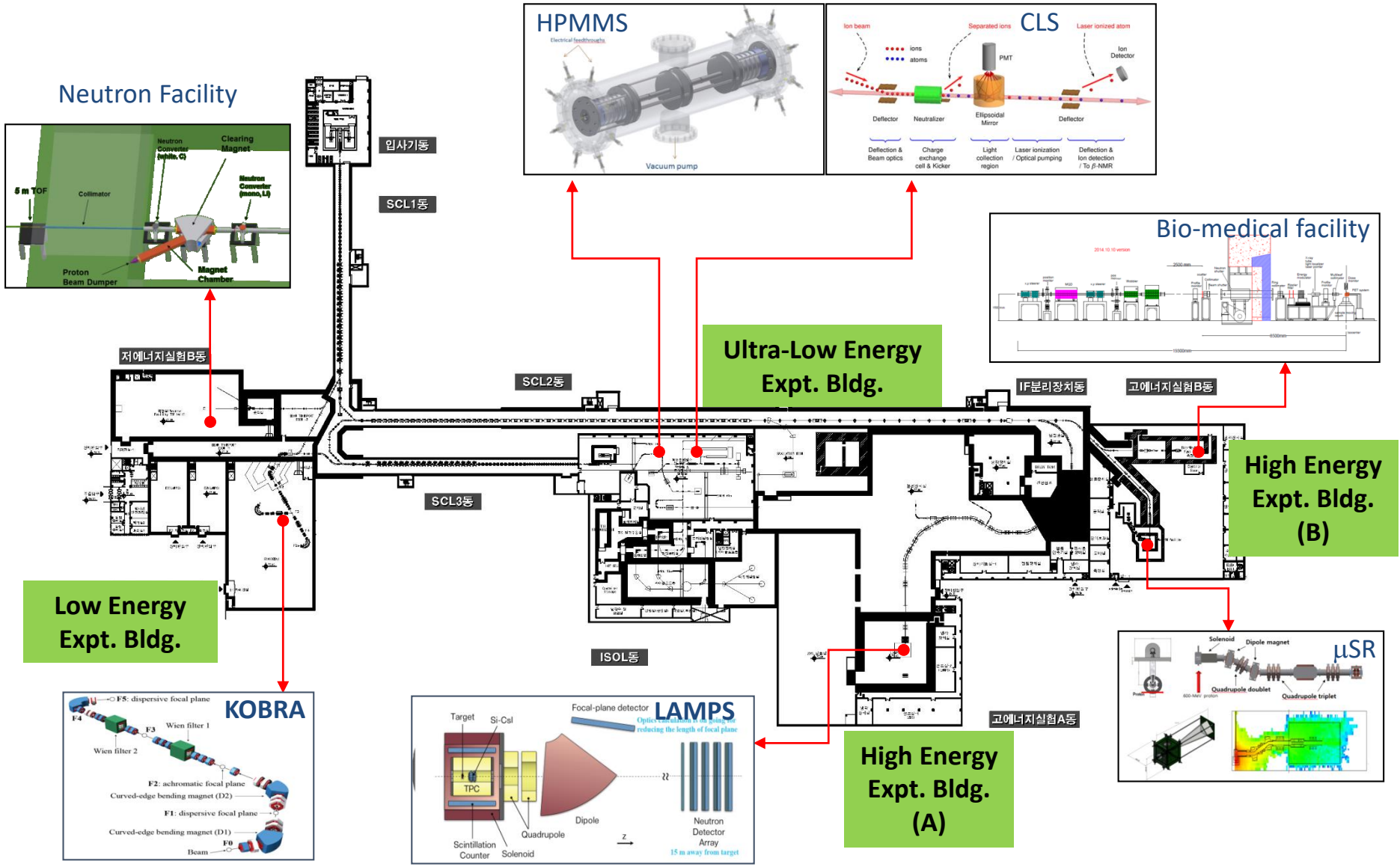


RAON aims to provide an access to unexplored regions of nuclear chart.

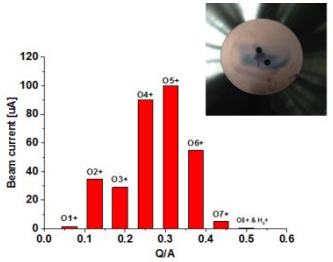
Accelerator Systems



Experimental Systems



Major Achievements

<table>
<tr><th>Items</th><th colspan="3">Major achievements</th></tr>
<tr><td rowspan="3">TDR/ Test facilities</td><td colspan="3">• Technical Design Report (TDR, 2013.06)
- Updated baseline design summary (BDS), Established system requirement (SR)
• Superconducting RF test facility (2016.06) → QWR cryomodule test complete! (2017.05)</td></tr>
<tr><td>  </td><td>  </td><td>  </td></tr>
<tr><td>Demonstration of SC Linac</td><td>Cryogenic Plant</td><td>Cavity Performance Test</td></tr>
<tr><td rowspan="3">Components for Accelerating system</td><td colspan="3">• Technical Designs for SRF cavities, ECR Ion source, LEBT, RFQ, etc. (2012.06~2013.06)
• Prototyping of RFQ (2013.10~)
• Prototyping of RF power systems (2013.10~)
• Prototyping of SRF cavities & modules(QWR, HWR) (2013.09~)
• 1st Oxygen Ion beam Injection with ECR IS (2015.03)
• 1st Oxygen beam acceleration with RFQ (0.5MeV/u, 2016.12)</td></tr>
<tr><td>  </td><td>  </td><td>  </td></tr>
<tr><td>Performance test of prototype QWR SRF cavity</td><td>Performance test of prototype QWR module</td><td>Heavy Ion Beam Injection with 28GHz superconducting ECR ion source</td></tr>
</table>

Major Achievements

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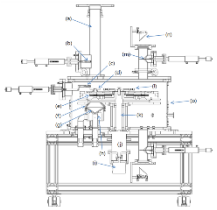
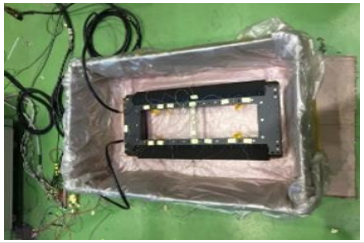
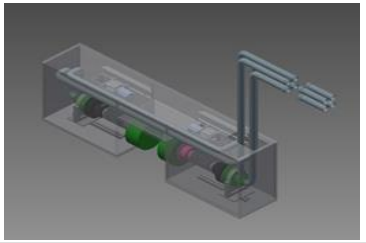
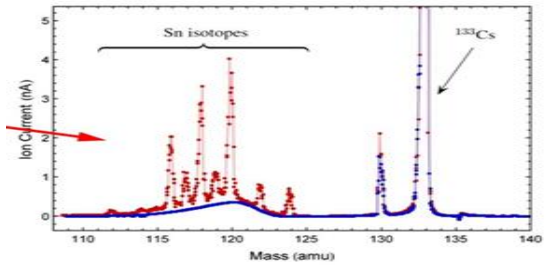
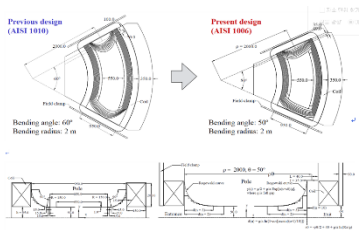
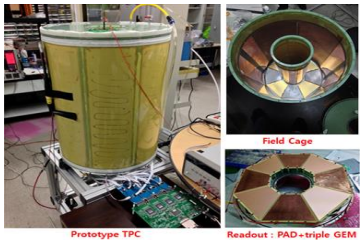
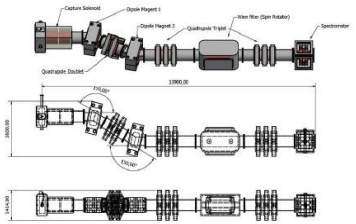
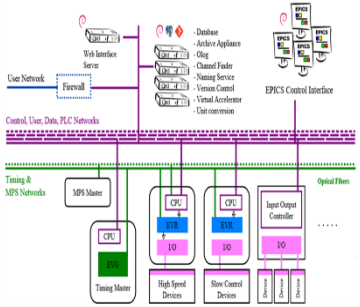
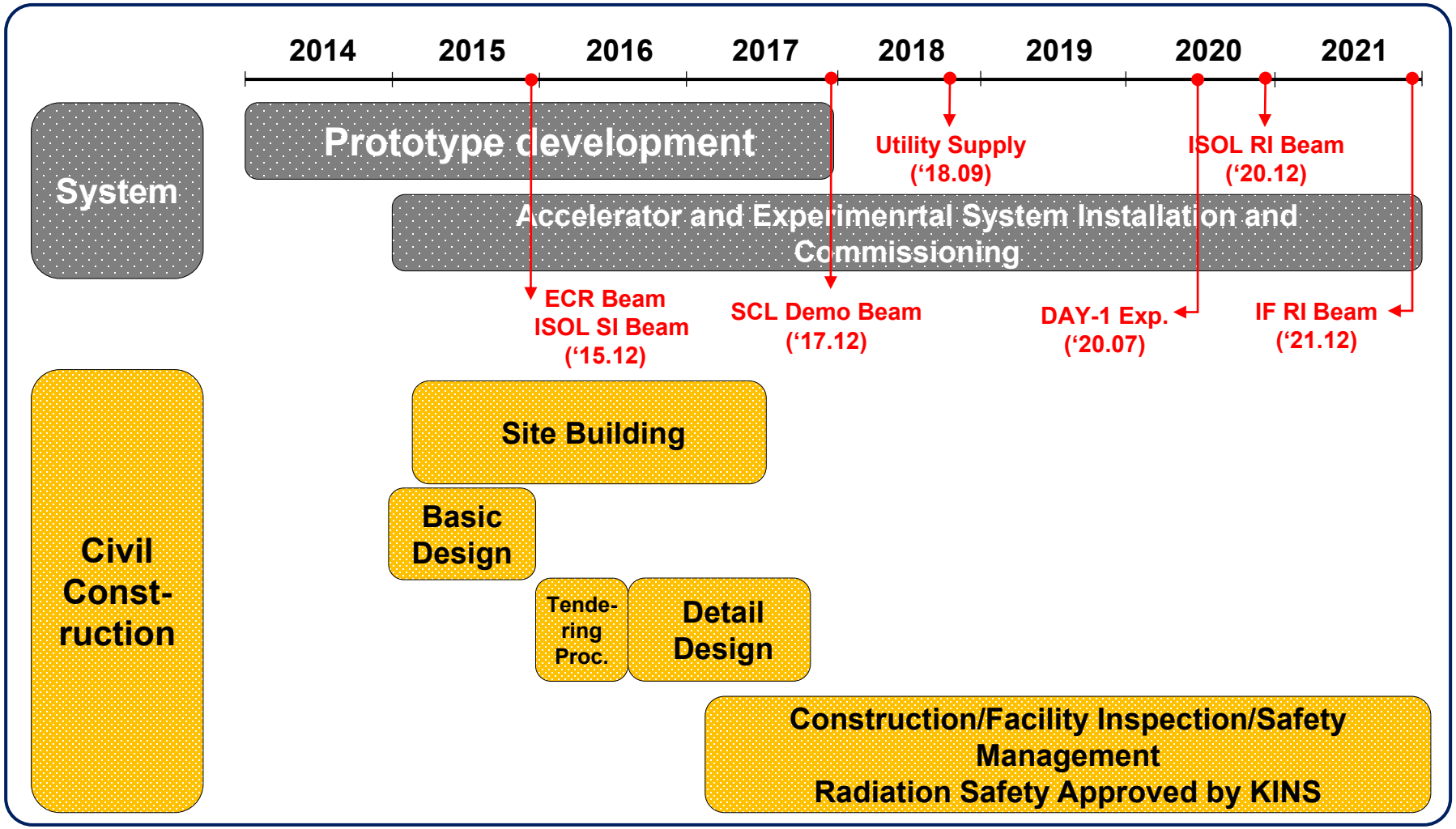
<tr><th>Items</th><th colspan="3">Major achievements</th></tr>
<tr><td rowspan="3">IF System</td><td colspan="3">• Optimization of optical design for in-flight fragments separator system (2012.06 ~ 2014.02)
• Performance test of single-slice graphite target using electron beam (2012.10 ~ 2013.10)
• Design, manufacture and test of LTS quadrupole magnet (2012.06 ~ 2014.04)
• Manufacture and test of HTS coil (2013.10 ~ 2014.04)
• Successful low temperature test for LTS quadrupole prototype magnet (2016.01)</td></tr>
<tr><td>  </td><td>  </td><td>  </td></tr>
<tr><td>Engineering design for IF target system</td><td>Performance test for LTS quadrupole prototype magnet</td><td>Engineering design for IF beam dump system</td></tr>
<tr><td rowspan="3">ISOL System</td><td colspan="3">• Construction of ISOL offline test facility (2012.06 ~ 2013.05)
• Optimization of ISOL beamline optical design (2013.06 ~ 2015.04)
• Manufacture of Surface ion source and FEBIAD-type ion source (2015.04)
• High purity Sn beam extraction using RILIS for the first time in Korea (2015.12)</td></tr>
<tr><td colspan="2">  </td><td> 
</td></tr>
<tr><td colspan="2">Installation of ISOL test facility</td><td>Extraction and separation of Sn and Cs ion beams</td></tr>
</table>

Major Achievements

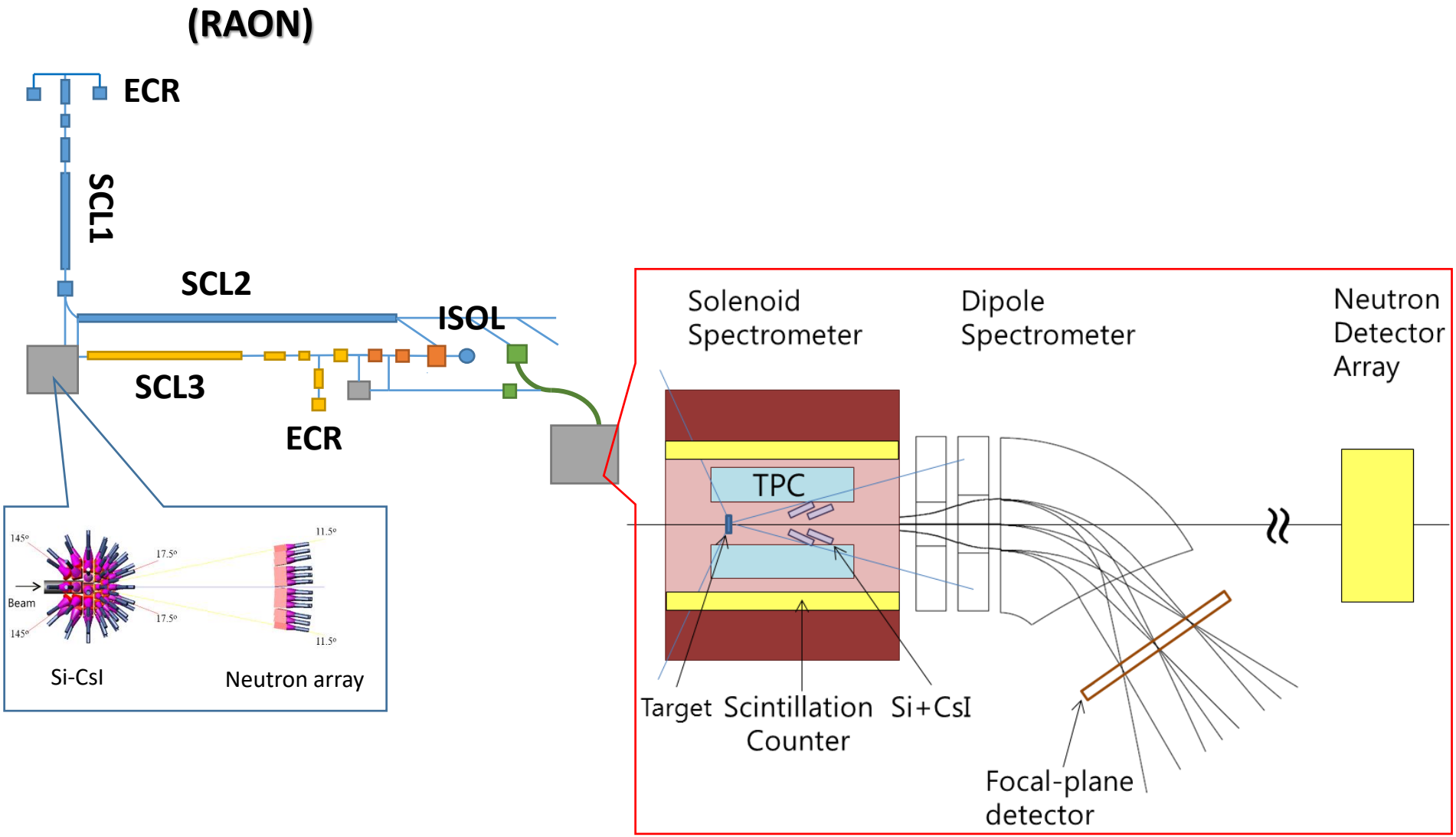
<table>
<tr><th>Items</th><th colspan="3">Major achievements</th></tr>
<tr><td rowspan="3">Experimental system</td><td colspan="3">• Manufacture of TPC, neutron detector prototypes for nuclear physics (2013.10 ~ 2014.12)
• Manufacture and performance test of PPAC prototype detector for beam tracking (2013.10 ~ 2015.03)
• Installation of laser cooled Calcium ion system (2015.04)
• Manufacturing DAQ module prototype for μSR (2013.10 ~ 2015.04)
• Performance test of neutron detector for LAMPS (2015.10)</td></tr>
<tr><td>  </td><td>  </td><td>  </td></tr>
<tr><td>Engineering design of KOBRA system</td><td>Manufacture and performance test of TPC for LAMPS</td><td>Engineering design of application Expt. systems (μSR, NDPS, BIS)</td></tr>
<tr><td rowspan="3">Cryo-, control, RF systems</td><td colspan="3">• Start the purchasing process of SCL3 (18.5 MeV/u) cryoplant (4.2 kW) (2017.03)
• Building the control infrastructure with EPICS (2013.01 ~ 2015.04)
• Solid state power amp (SSPA) testing for superconducting & normal conducting cavities (2013.01 ~ 2016.07)</td></tr>
<tr><td>  </td><td>  </td><td>  </td></tr>
<tr><td>Cryogenic System
(Warm pumping system for 2K)</td><td>Control system testbed</td><td>Prototype RF system</td></tr>
</table>

Major Milestones

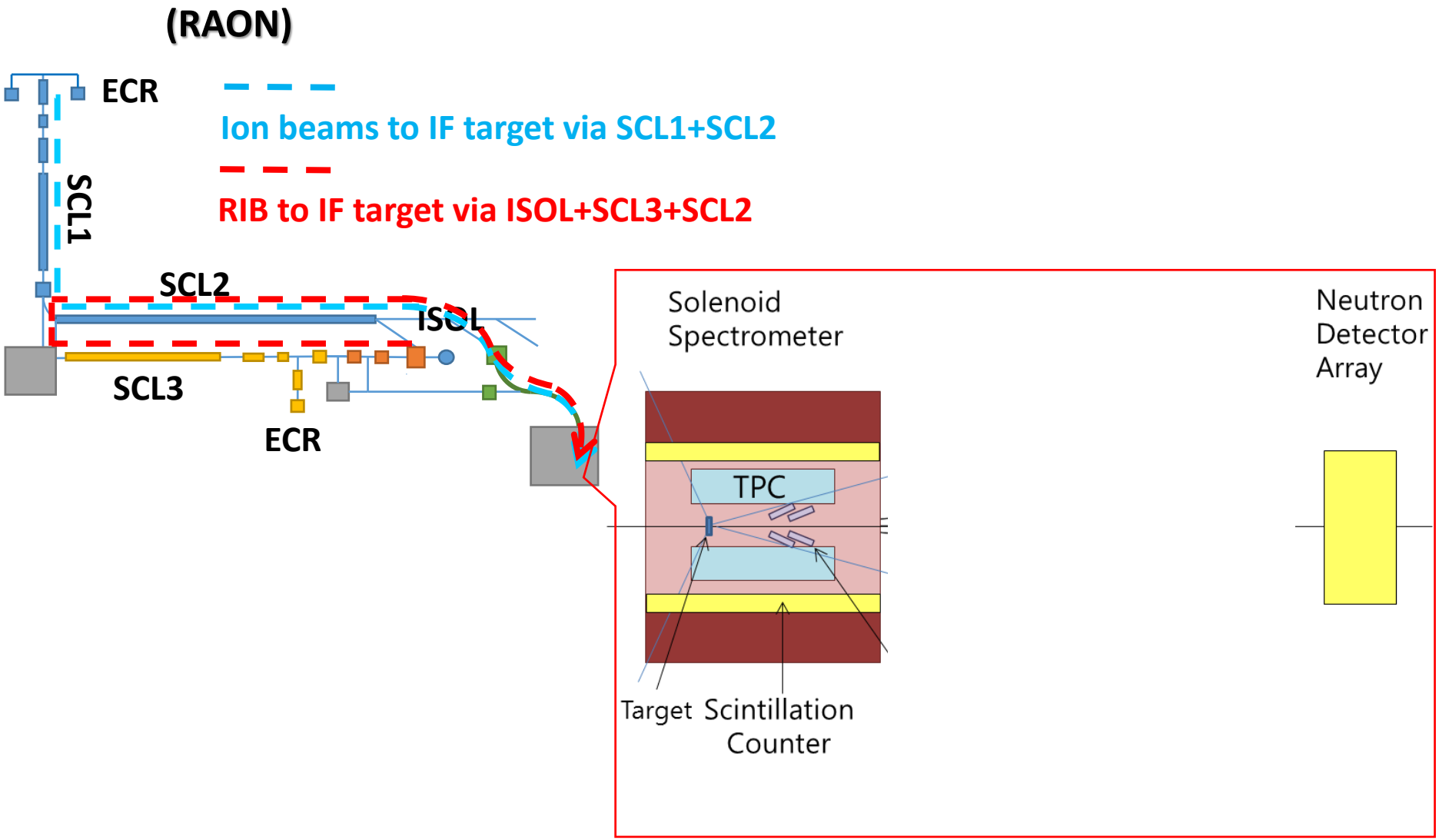


LAMPS: Large Acceptance Multi-Purpose Spectrometer

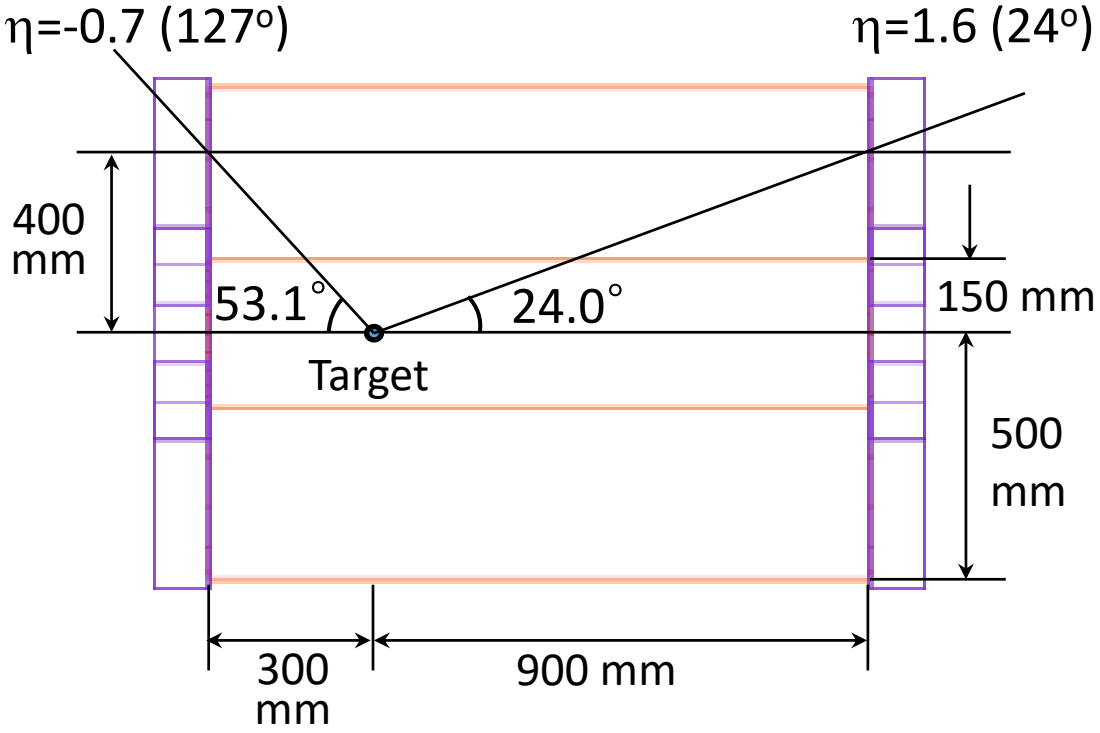
Overview of LAMPS

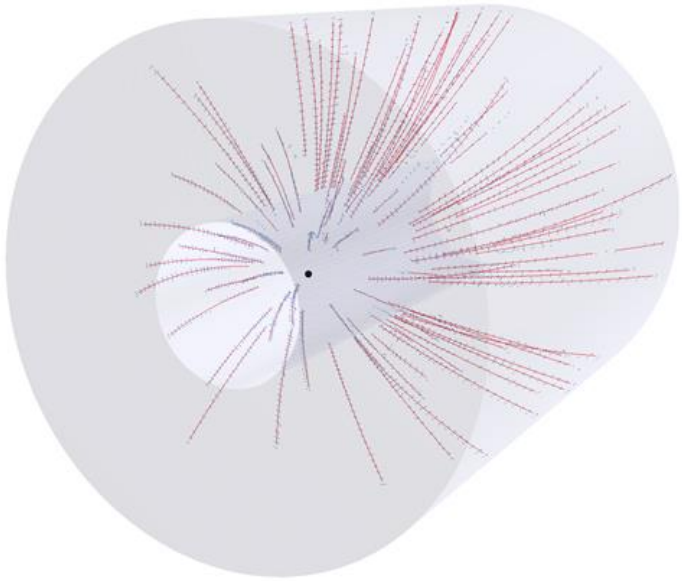


Overview of LAMPS

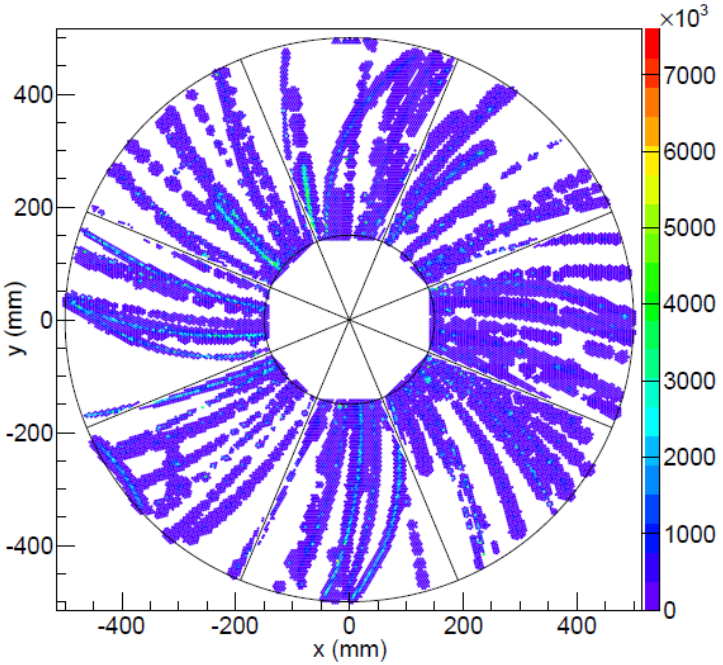


Time Projection Chamber

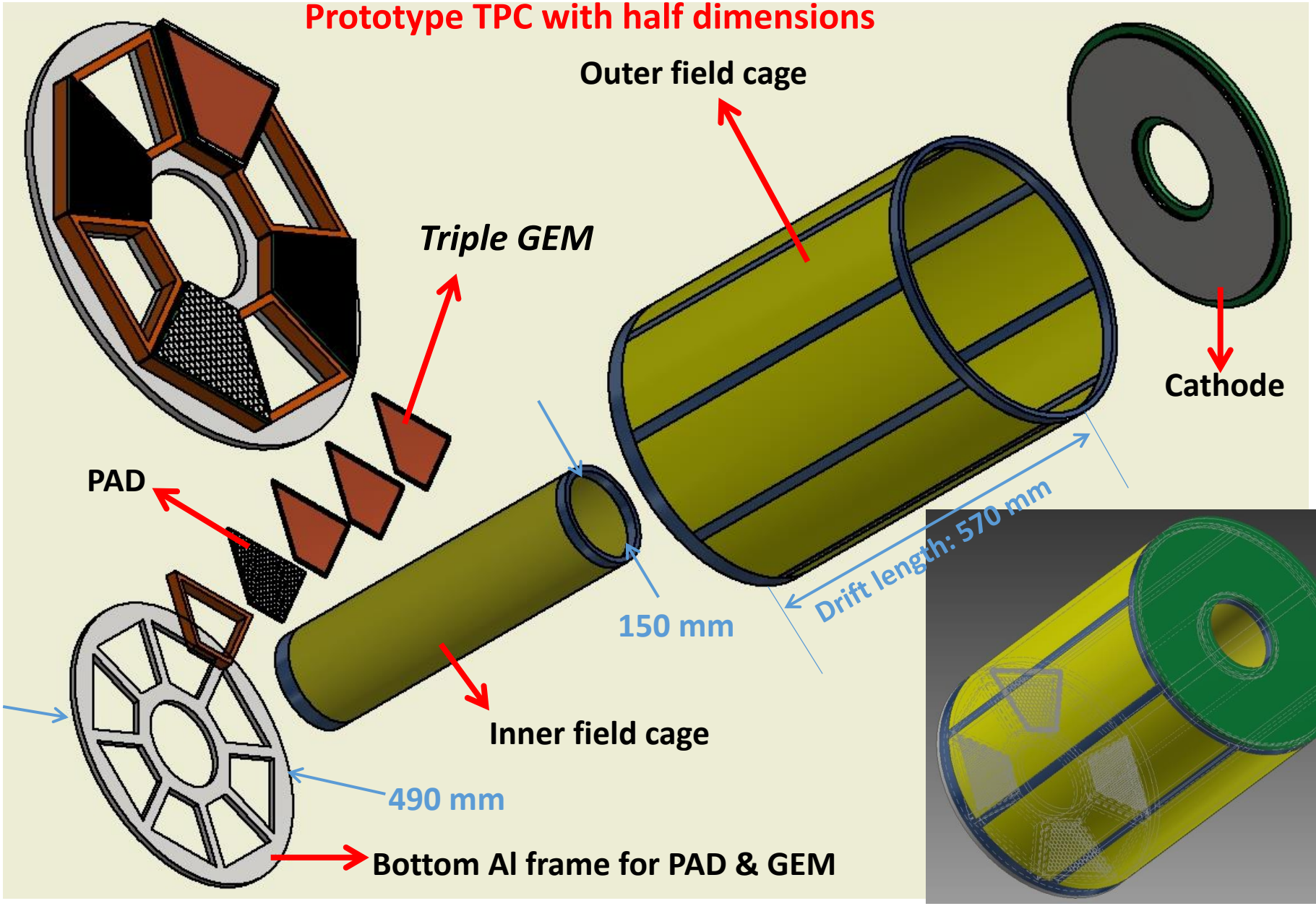




Simulation of one central Au+Au event at 250 AMeV (IQMD)

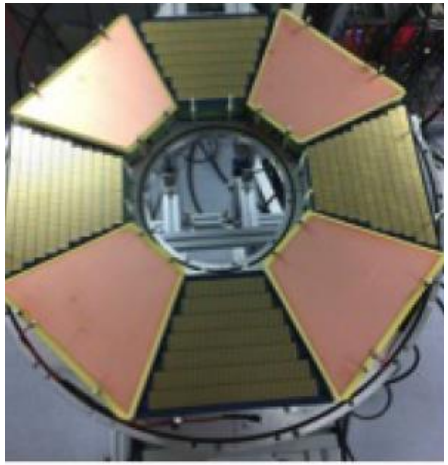


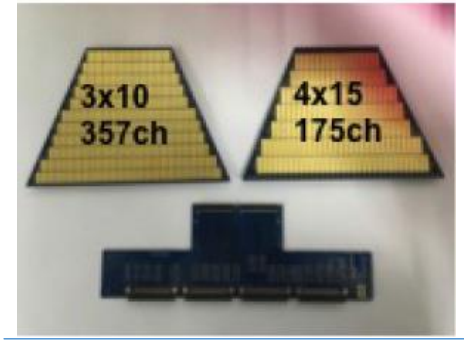
Prototype TPC: Design



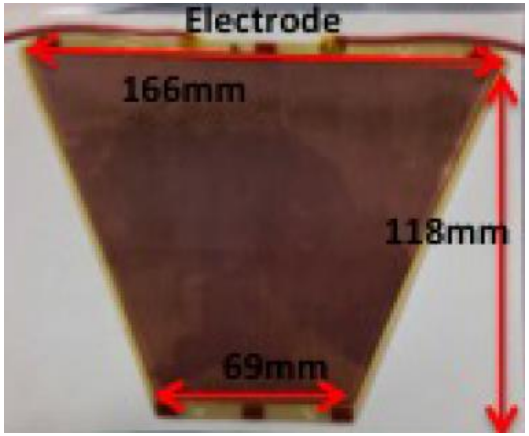
Prototype TPC: Components

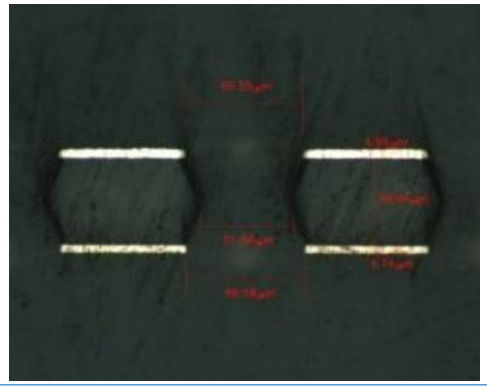
[Readout Pads]
Tested pads with the two different dimensions
$3 \times 10\ \mathrm{mm}^2$: 357 Ch./Oct.
$4 \times 15\ \mathrm{mm}^2$: 175 Ch./Oct.
Multi-layer PCB board



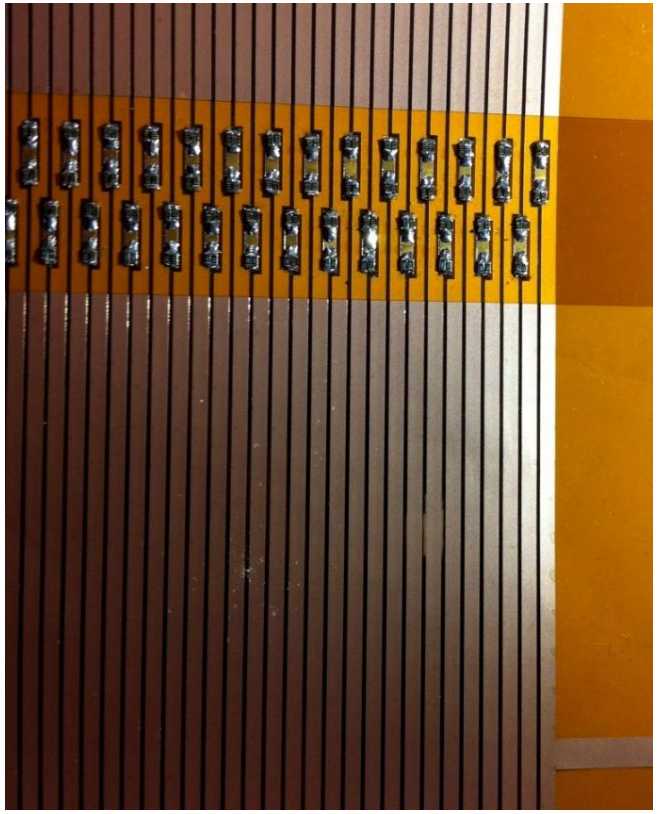


[GEM Foil]
Trapezoidal shape
Thickness: 75 μm
Area: $166 \times 118\ \mathrm{mm}^2$
Triple layers for each plane



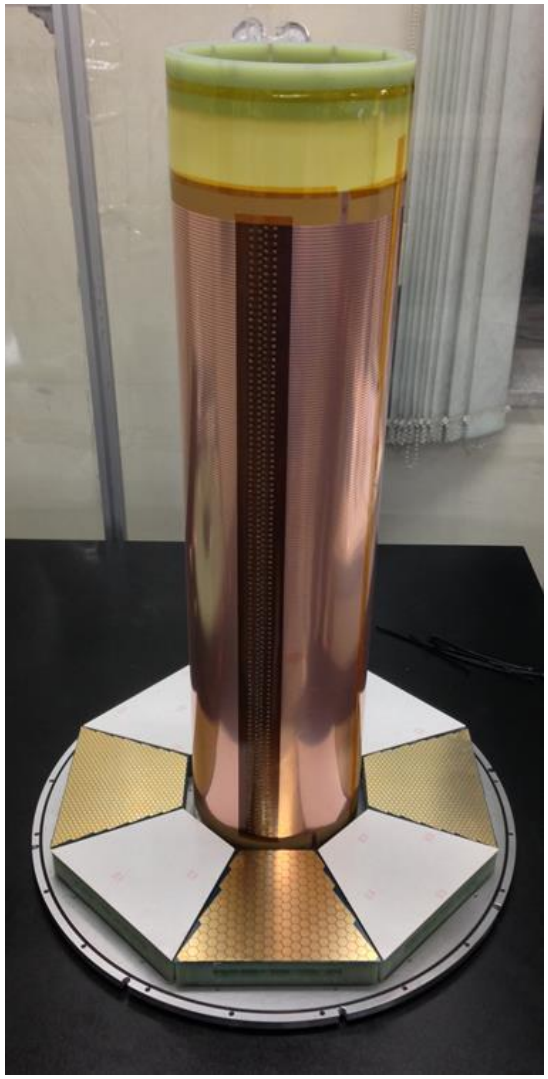


[Field Cage]
35 μm thick and 2 mm wide Cu strips
500 μm gap between adjacent strips
Mirror strips on the back
1 MΩ resistors with 0.1% var.
TPC body: G10 + Aramid honeycomb

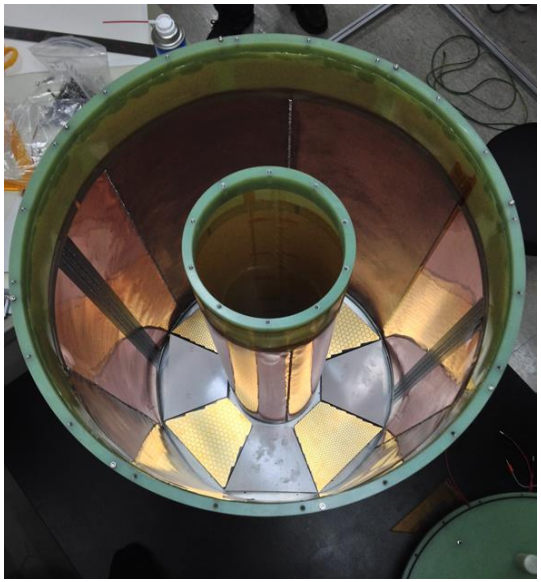


Prototype TPC: Assembly

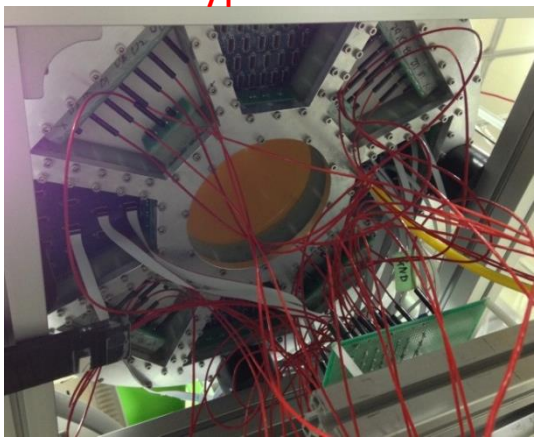
Inner Field Cage installed



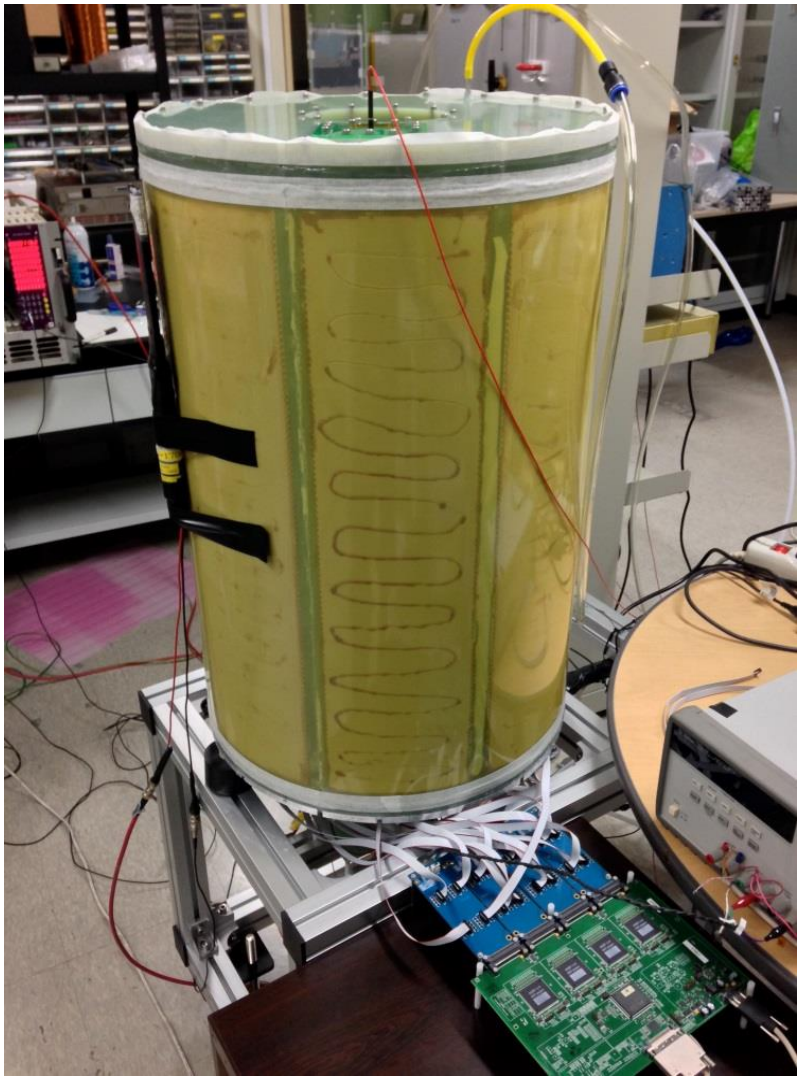
Outer Field Cage installed



Prototype TPC: back



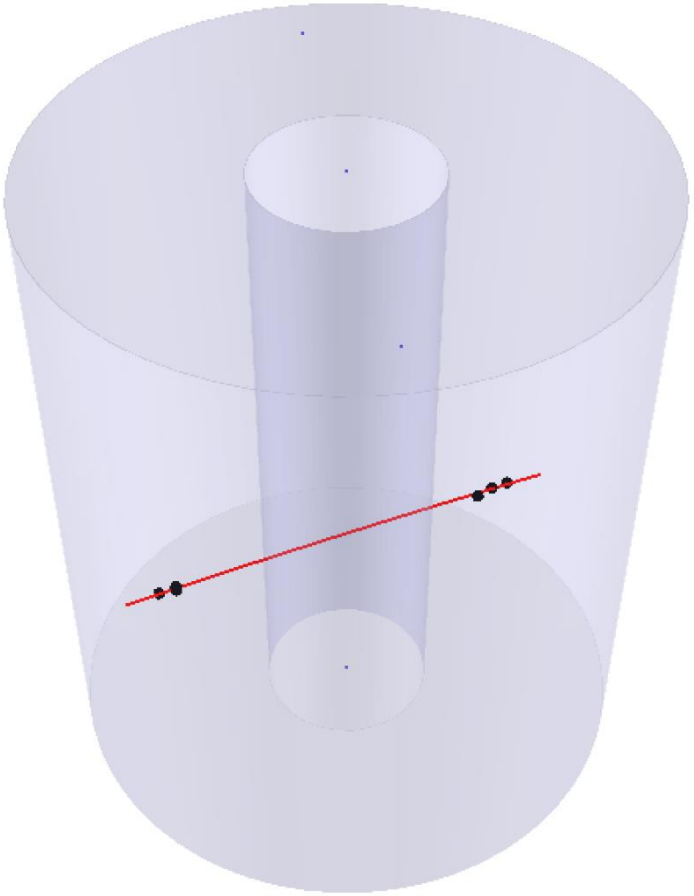
Prototype TPC assembled

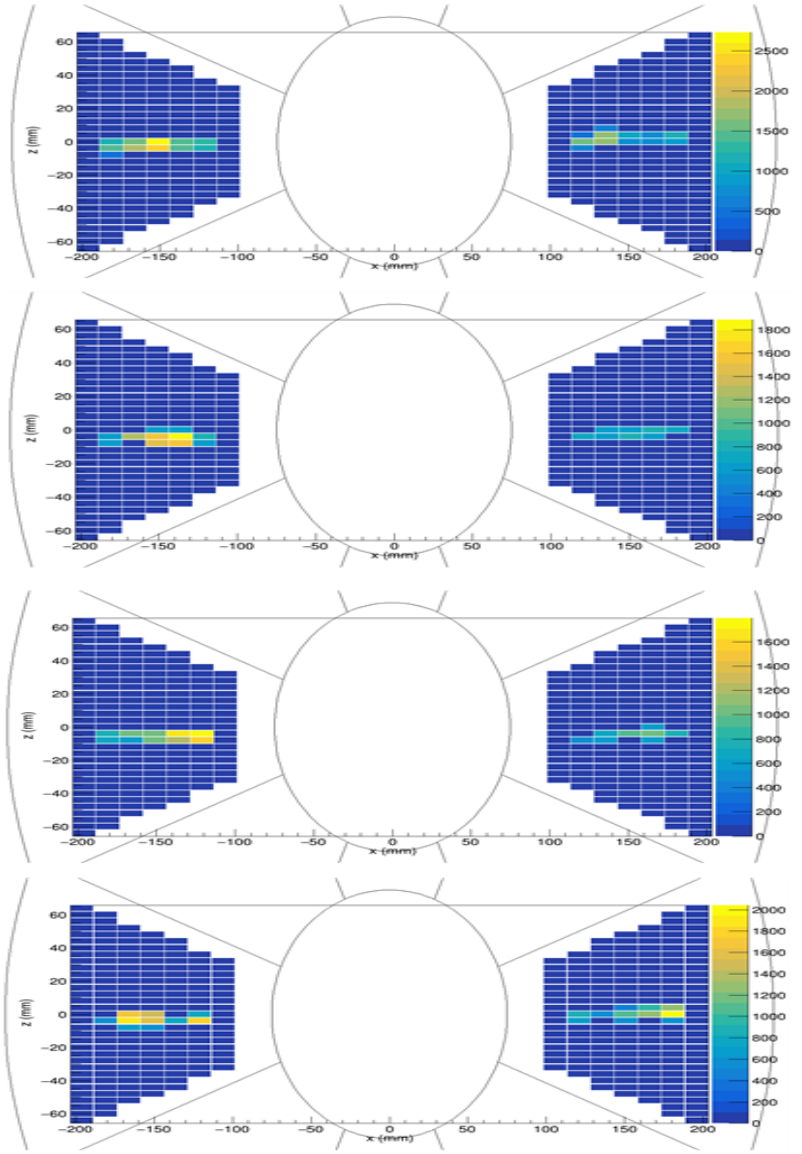


Prototype TPC: Test at ELPH

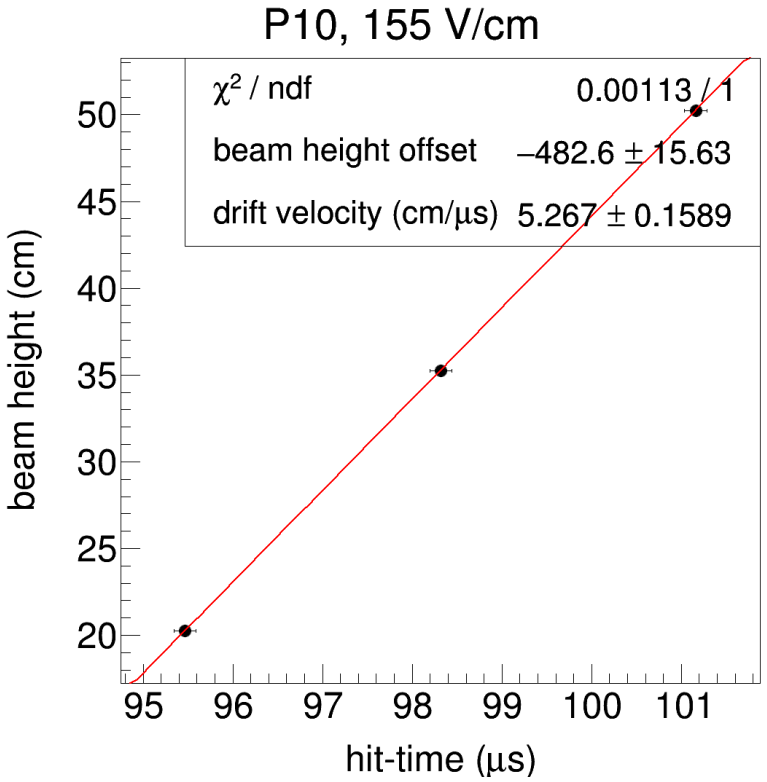
- ELPH: Research Center for Electron Photon Science at Tohoku University, Japan
- Dates: November 2016
- Beams: e^+ beams at 500 MeV
- Gas: Ar(90%)+CH_4(10%) (P10)
  Ar(90%)+CO_2(10%) ($ArCO_2$)
- Purpose: To study the detailed characteristics, such as v_{drift}, diffusion and σ_x, of LAMPS TPC

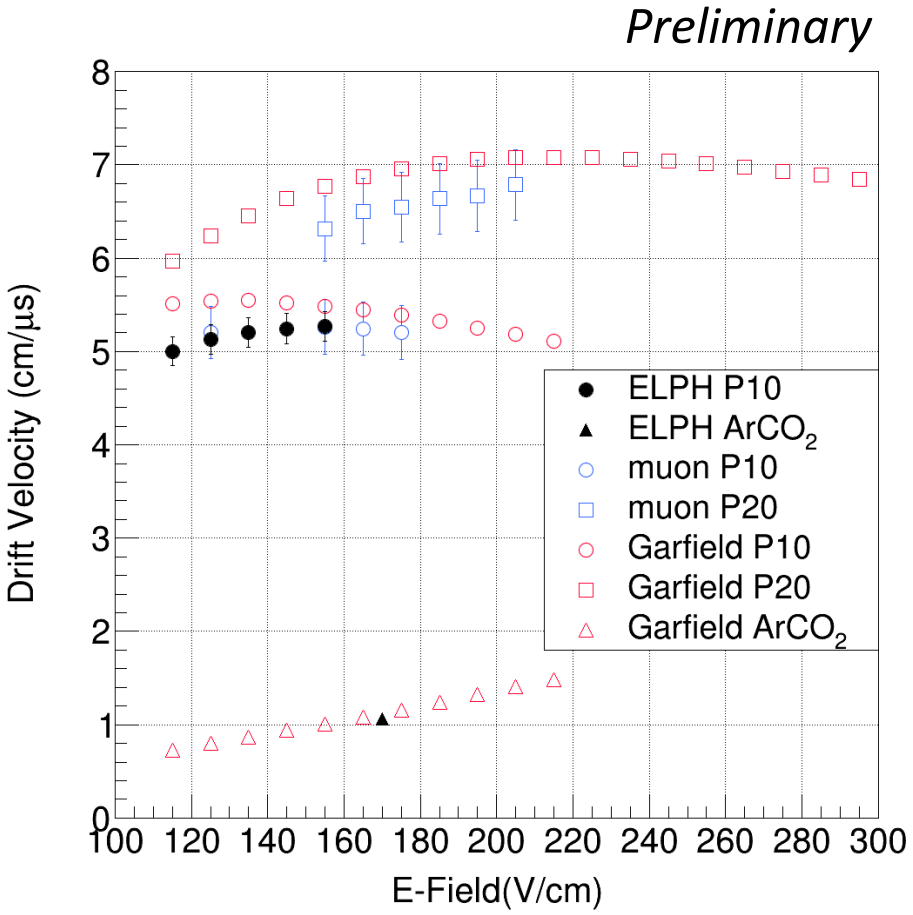
Prototype TPC: Event Displays





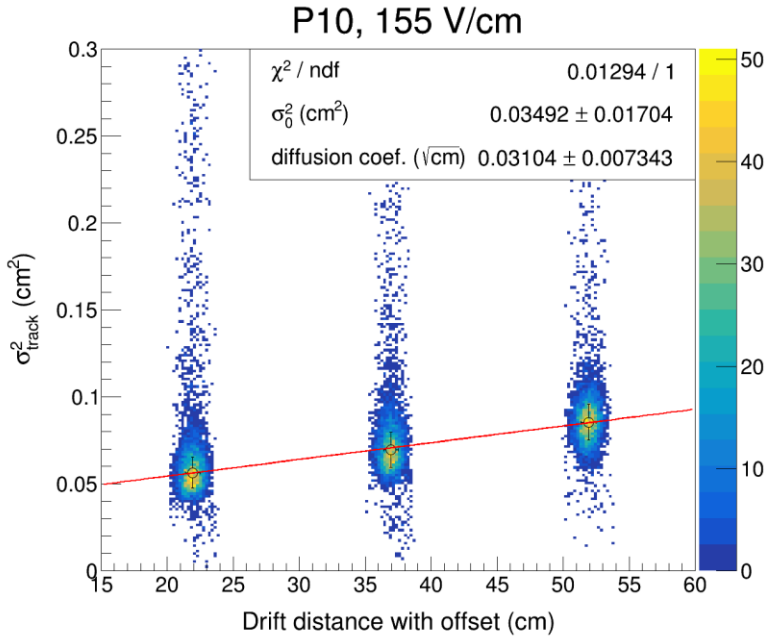
Prototype TPC: Drift Velocity



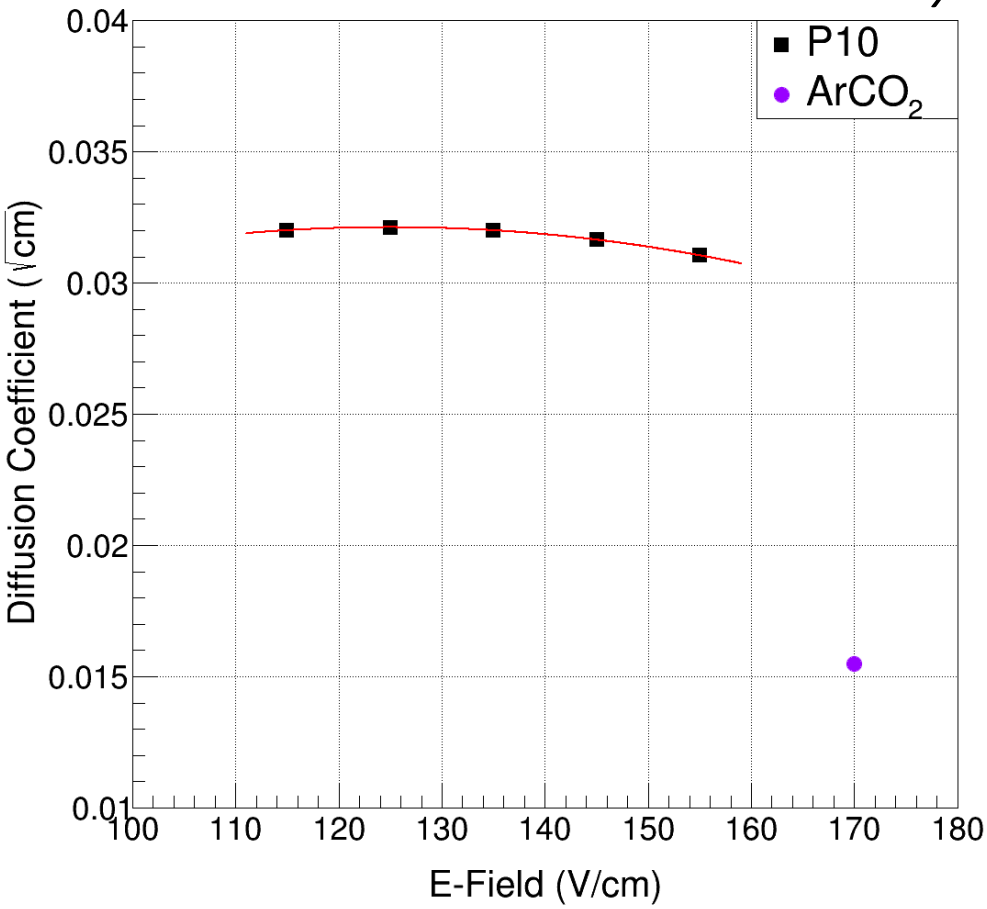


- $v_{drift} \lesssim 5.3\ \mathrm{cm}/\mu s$ for P10:
  Maximum distance: $512\ \text{timing bins} \times 0.04\ \mu s/\text{bin} \times 5\ \mathrm{cm}/\mu s \cong 100\ \mathrm{cm}$
- Tested P20 with cosmic muons: $v_{drift} > 6\ \mathrm{cm}/\mu s$ that will be suitable for LAMPS TPC if read out from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

Prototype TPC: Diffusion



Preliminary



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

where

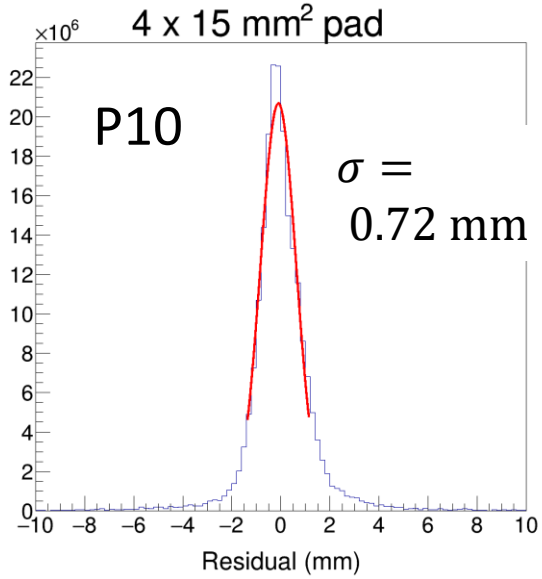
z: drift length

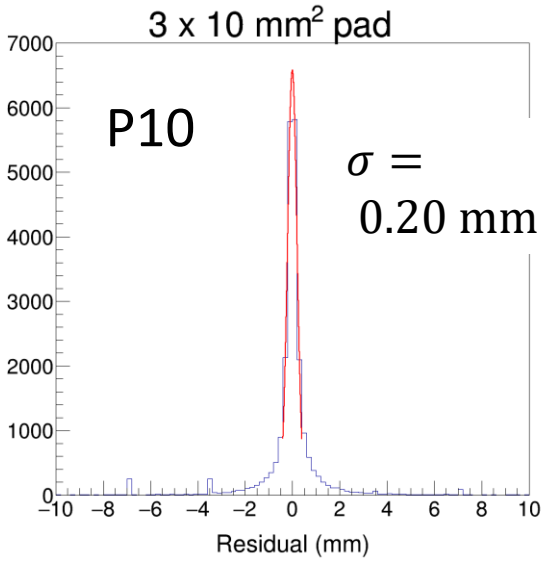
σ_{track}: width of hit distributions w.r.t. the fitted track

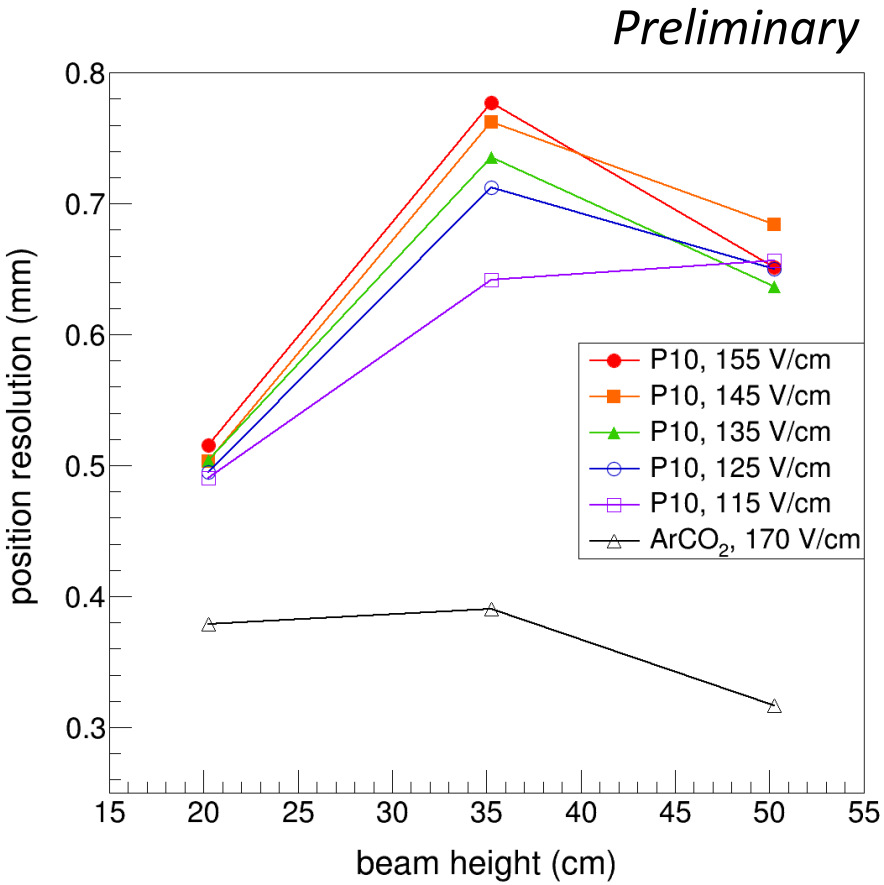
D: diffusion coefficient

σ_0: coefficient depending on the amplification system

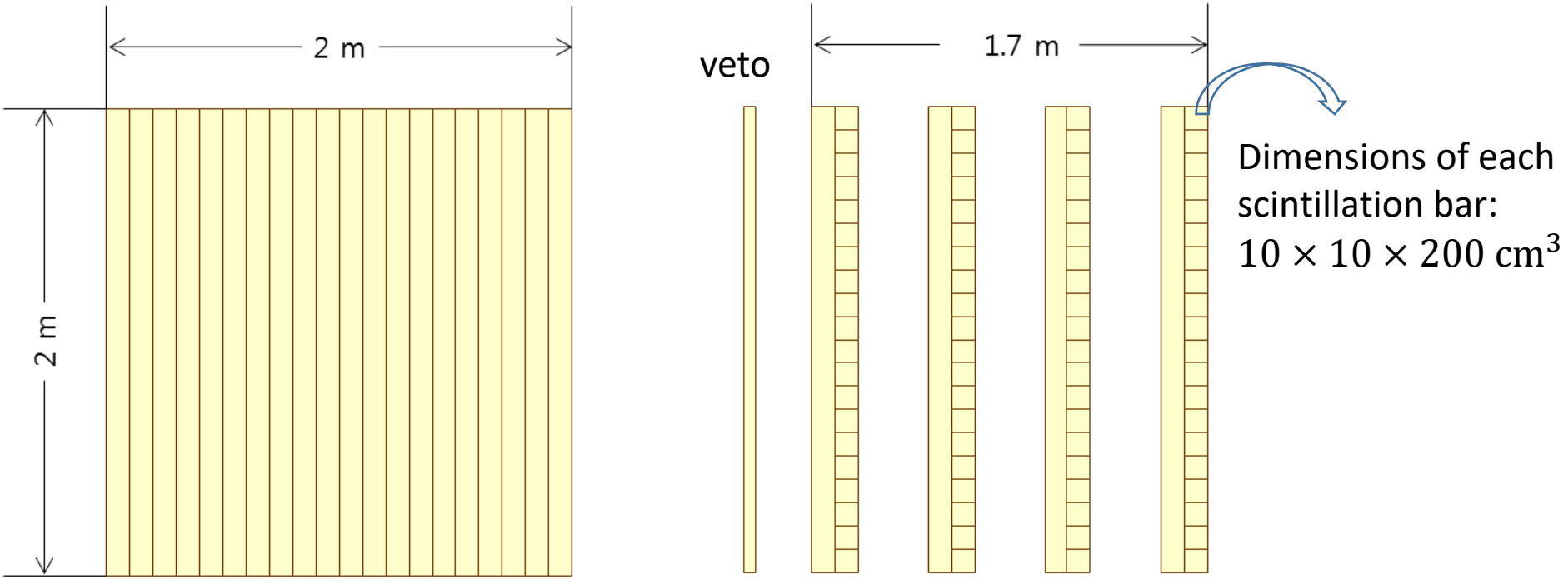
Prototype TPC: Position Resolution







Neutron Detector Array (NDA)

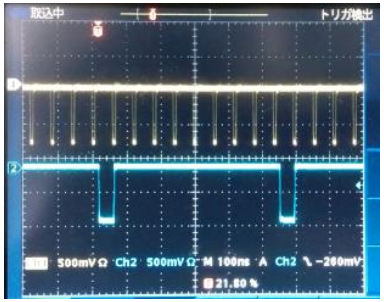


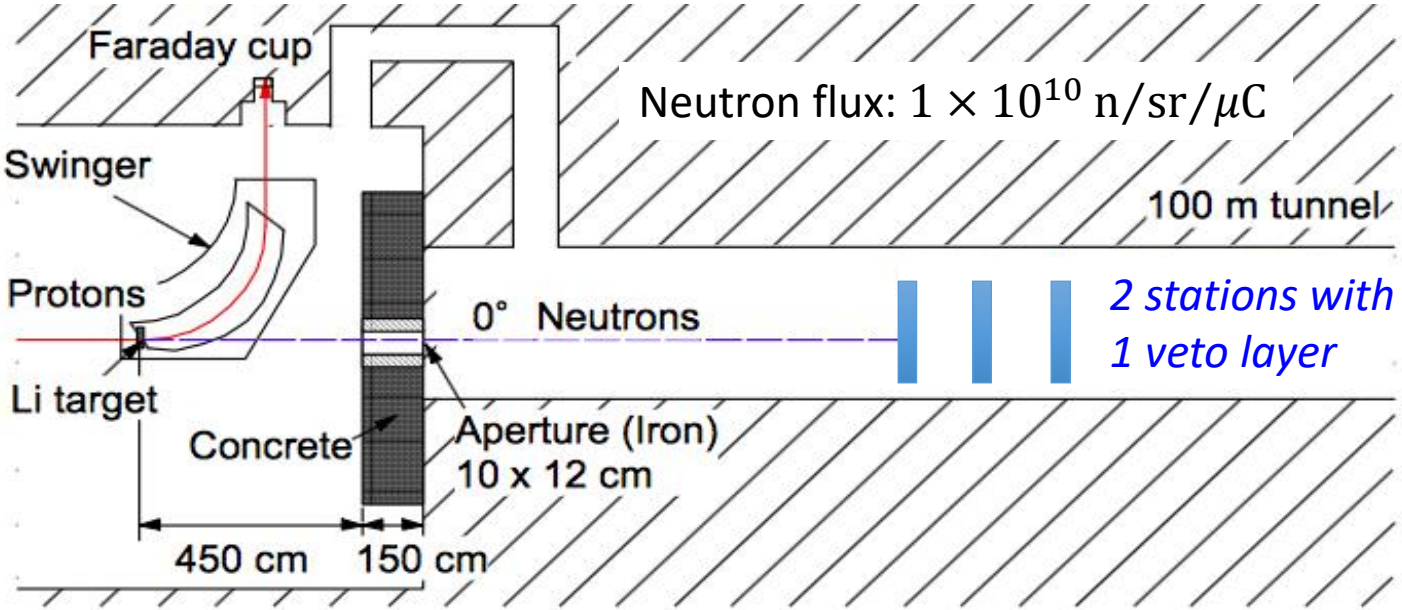
- Constructed the real-size prototype detectors and tested their performances using
  - Radiation sources: ^{60}Co and ^{252}Cf
  - *Neutron beams at RCNP, Japan (this talk)*

NDA: Beam Test at RCNP

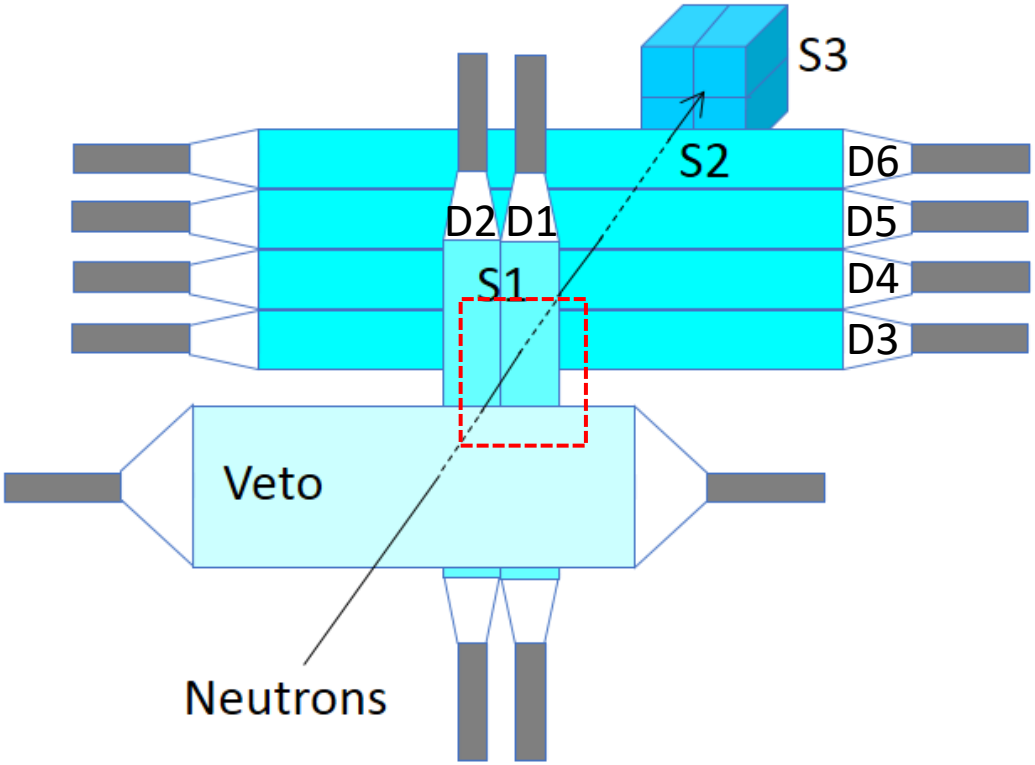
- E479 approved in B-PAC in March 2016
- Date: May 2016
- Beam specifications
  - Protons on Li production target (p+^{7}Li → n + ^{7}Be)
  - Neutron energies: 65 and 392 MeV in N0 beamline
  - 10 nA flux × 1/9 chopping
  - Background neutron above 3MeV is less than 1% [NIMA629, 43 (2011)]

Chopping signals



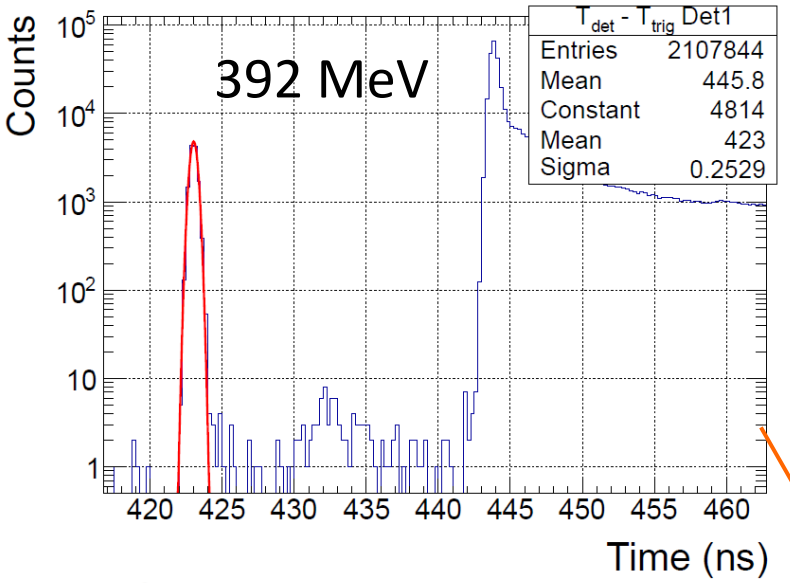


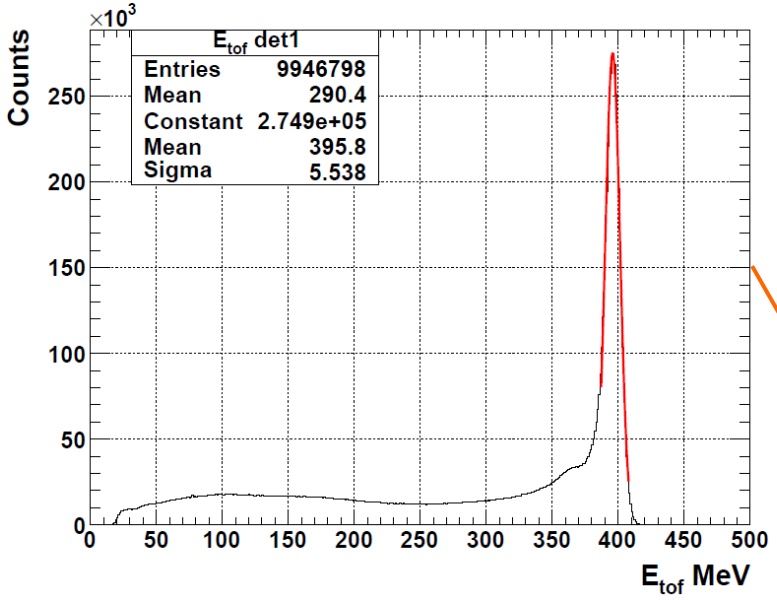
NDA: RCNP-E479



- 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

NDA: Energy Resolution for Neutrons

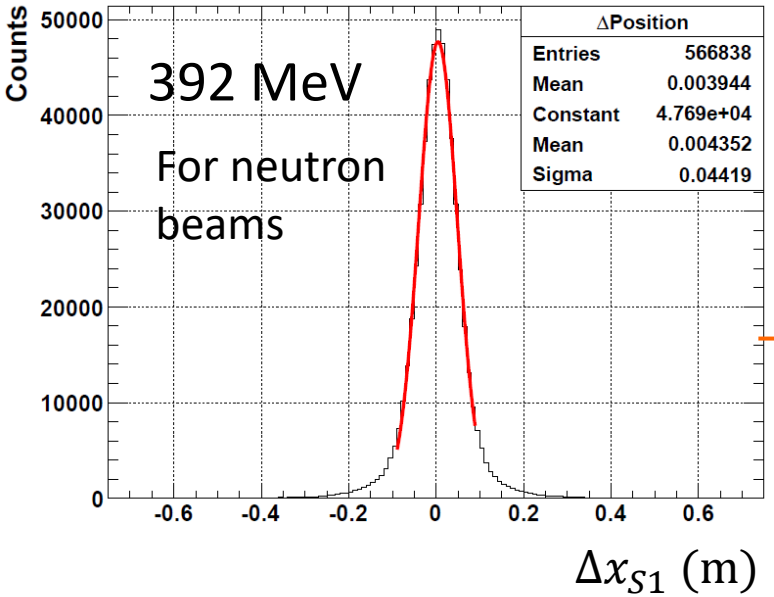


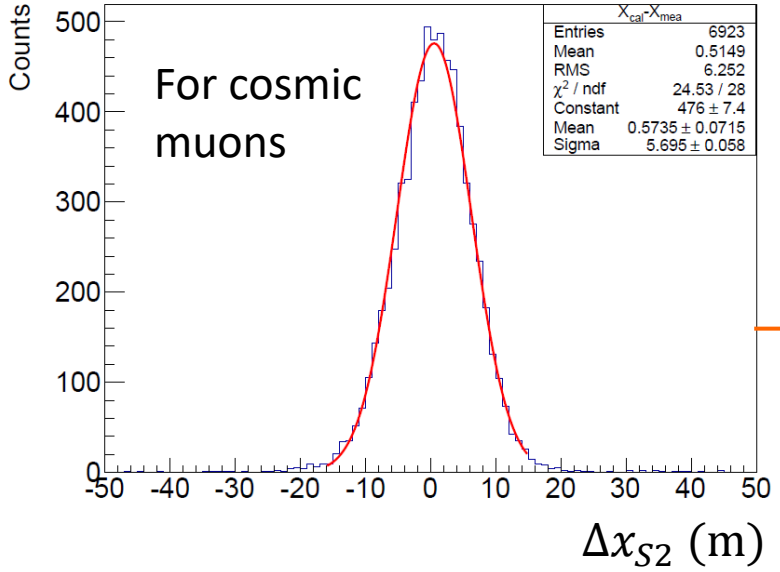


Preliminary

- Time resolution:
  $\Delta t = \sqrt{(\Delta\tau)^2 + (\Delta x/v)^2} = 0.66$ 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 $\gamma = 1 + E/mc^2 = 1.42$
  $t = 70.4$ ns
- Energy resolution (FWHM/E)= 3.3 %

NDA: Position Resolution for Neutrons & Cosmics





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:

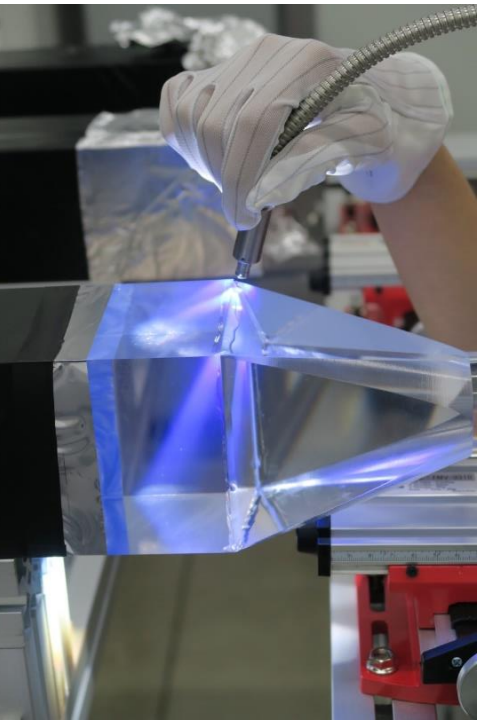
$$\Delta x_{S2} \equiv x_{D3,proj} - x_{D3,hit}$$

- Relative position resolution for cosmic muons for one bar:

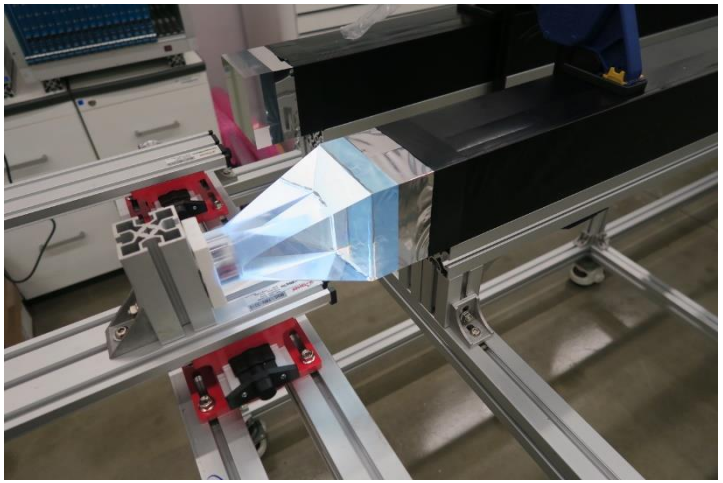
$$\sigma_\mu = \frac{\sigma(\Delta x_{S2})}{1.87} = 3.1 \text{ cm}$$

NDA: Assembly

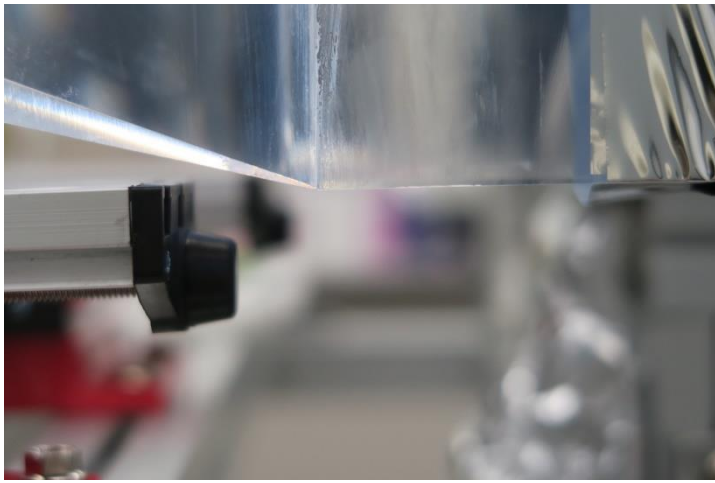
Curing UV glue

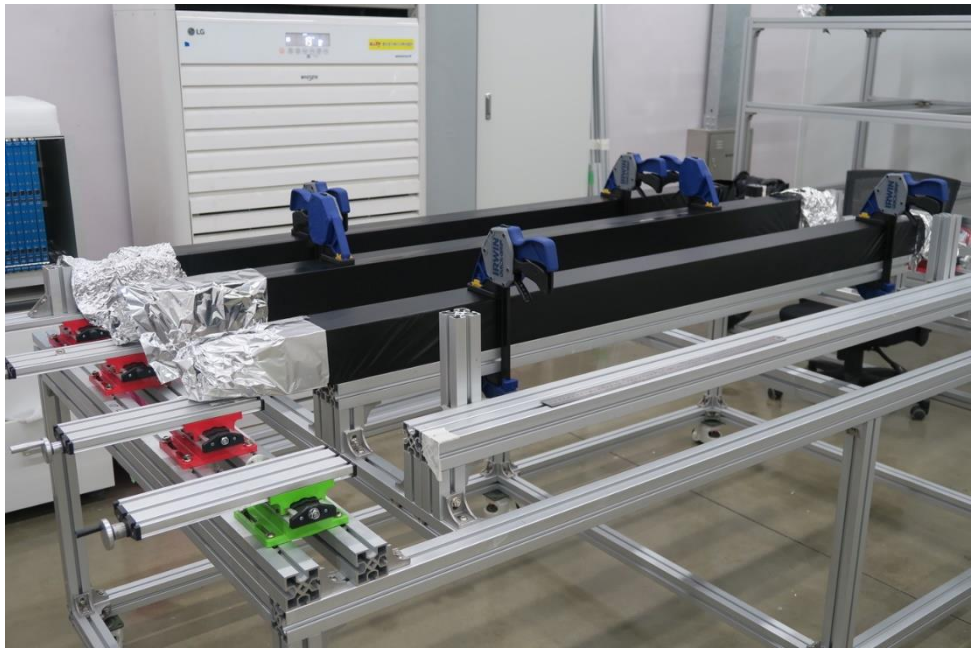


Fixing light guide with vice



Closeup view of the interface between scintillator & lightguide





Assembly facility at Sejong Campus of Korea University which is close to the RAON site

Summary

- Rare Isotope Science Project (RISP) at IBS, Korea is moving forward.
- The construction and civil engineering for RAON has begun.

- LAMPS is a dedicated spectrometer for nuclear symmetry energy at RAON.
- Performance tests of the prototype TPC and the neutron-detector-array modules with accelerator beams were done.
- Assembly of neutron-detector-array modules recently started. Plan to finish the construction this year.