SAMURAI TPC:
A Time Projection Chamber to Study the Nuclear Symmetry Energy at RIKEN-RIBF with Rare Isotope Beams

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For the SAMURAI-TPC Collaboration

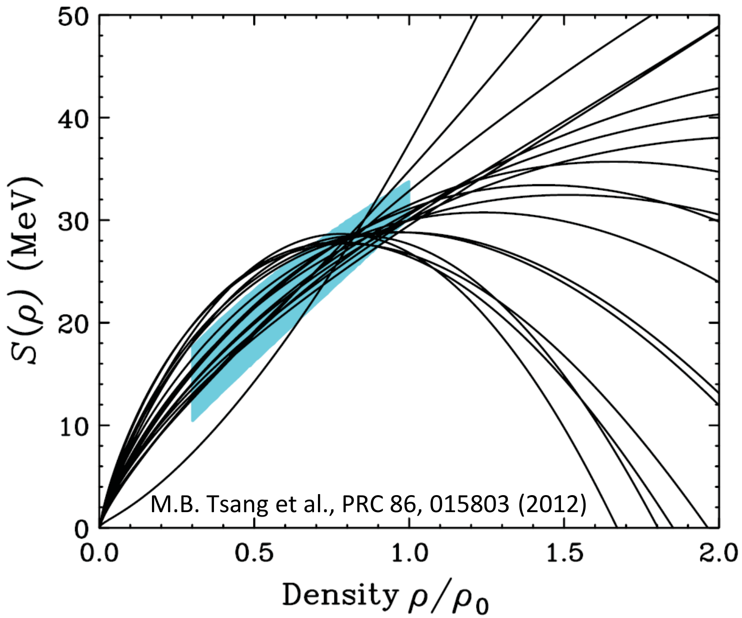
SAMURAI
Time Projection Chamber

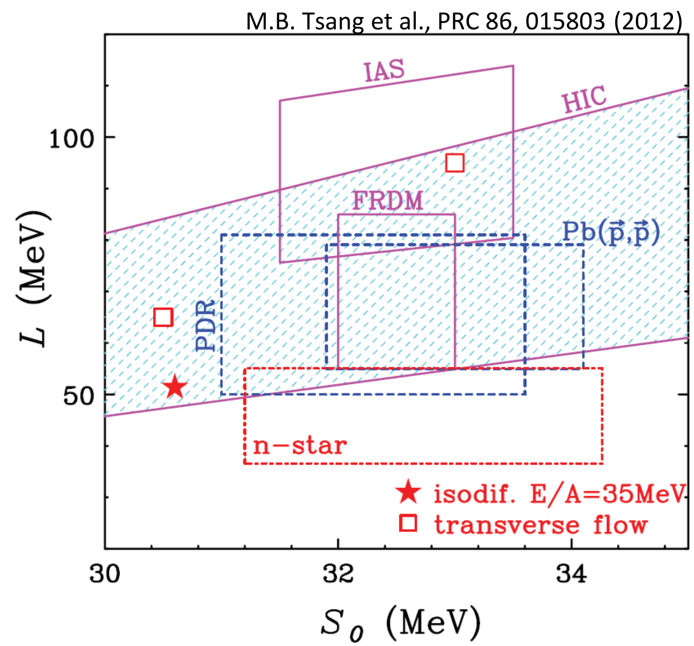
- Physics Motivation
  - Symmetry Energy, Observables & Measurement
- Conceptual Design & Fabrication
- Simulated TPC Performance
- Experimental Program at RIBF
- Summary

Primary Physics Goal:

Constrain the Nuclear Asymmetry Energy

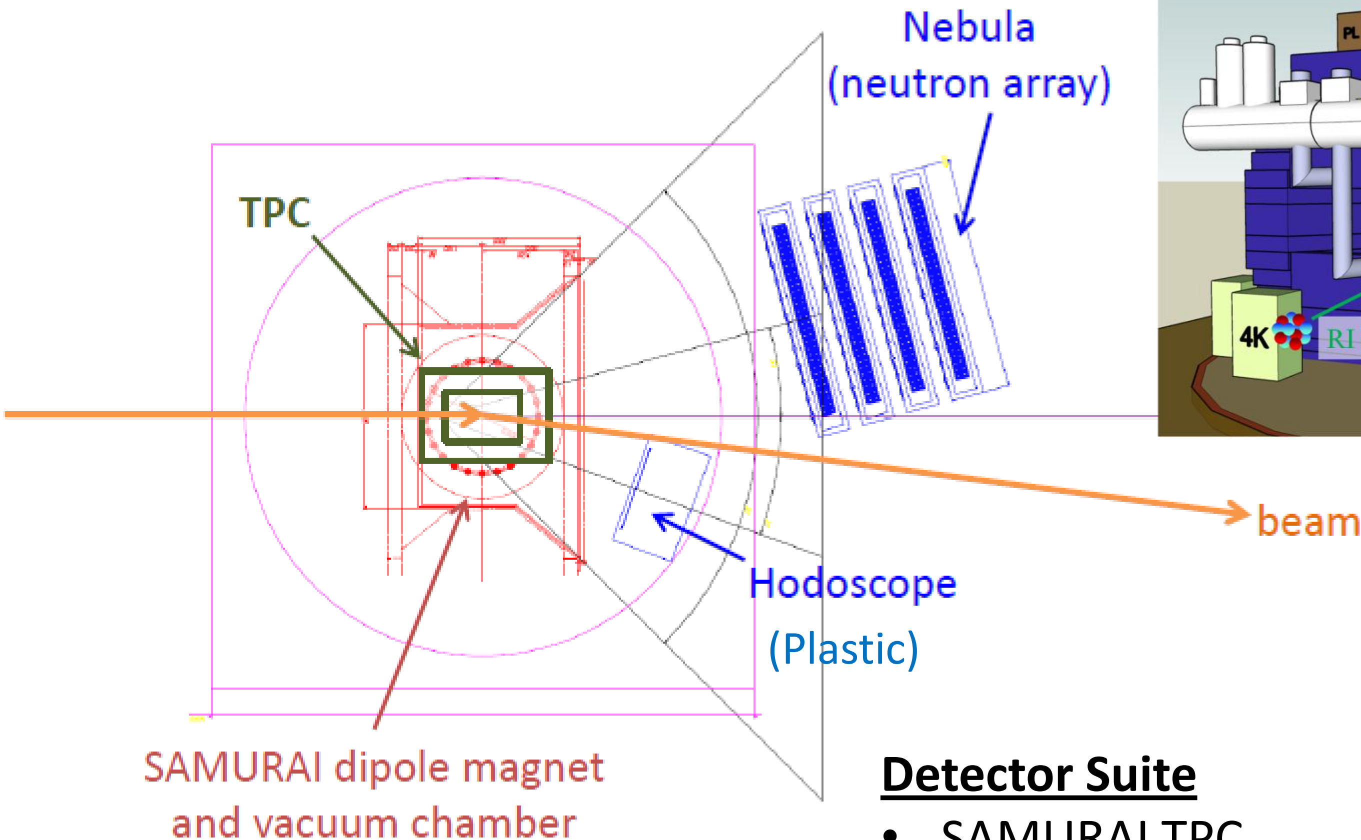
- Nuclear EOS: Impacts heavy-ion collisions, supernovae, neutron stars…
- Largest uncertainty: Density dependence of the asymmetry energy

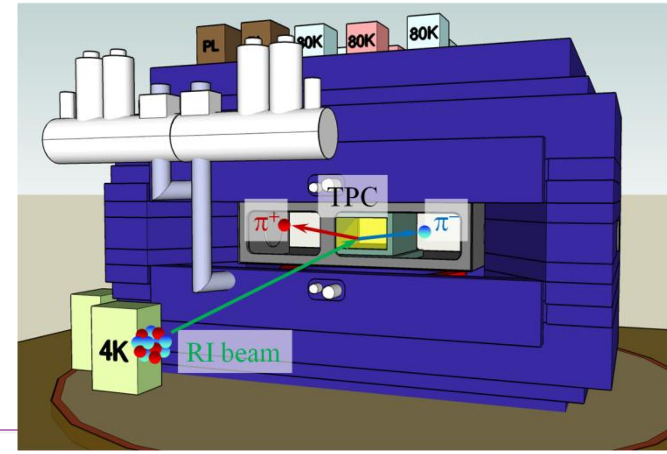




- Heavy-ion collisions, 200-300A MeV, rare isotope beams:
  - ^{105}Sn + ^{112}Sn, ^{132}Sn + ^{124}Sn, ^{36}Ca + ^{40}Ca, ^{52}Ca + ^{48}Ca, and others
- **Measure differential flow and yield ratios for (π^+ & π^-), (p & n), (^{3}H & ^{3}He)**
- In addition to constraining the symmetry energy, we are sensitive to nucleon effective masses and in-medium nucleon cross sections at $\rho \approx 2\rho_0$.

Experimental setup



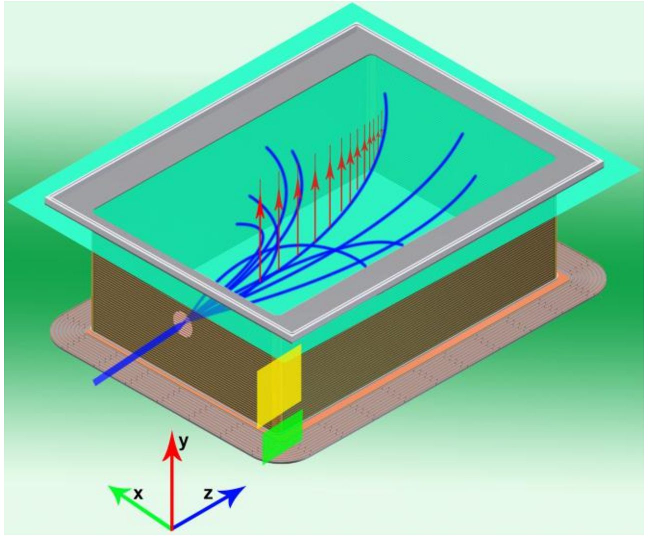


Detector Suite

- SAMURAI TPC
- NEBULA neutron detector array
- Hodoscope for heavy residues
- Space is available for ancillary detectors
  - TPC is thin-walled

How the TPC works

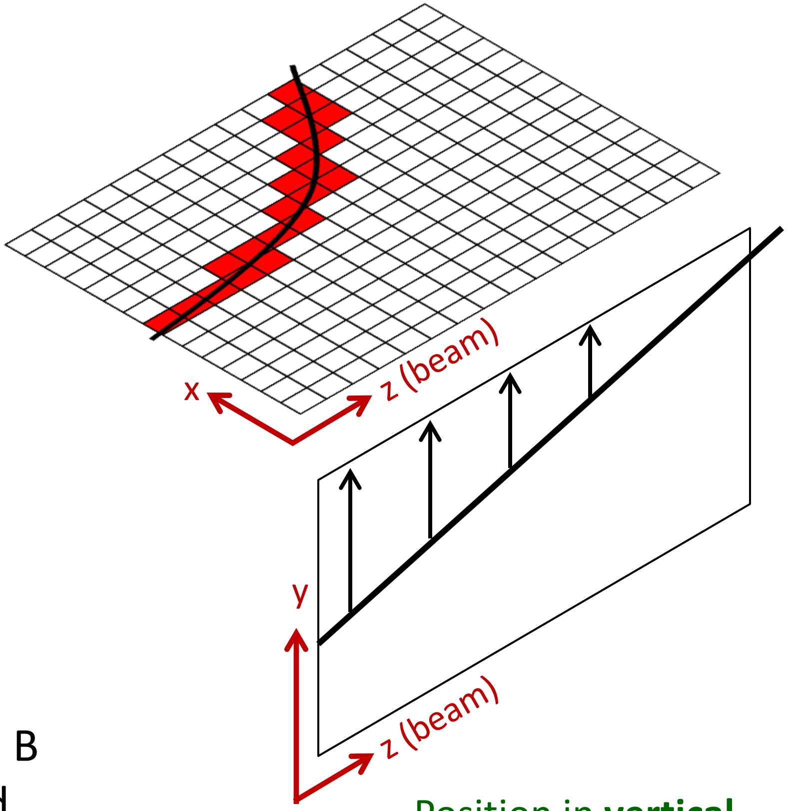
- Charged particles ionize gas inside
  - Ionized electrons drift toward pad plane
- Signal from electrons detected on pads
  - Positions and time of arrival → 3D path
- Infer momentum from curvature of particle tracks in magnetic field
- Particle type from energy loss and magnetic rigidity



E and B field direction

Figure courtesy of J. Estee

Path in **horizontal** plane from **pad positions**

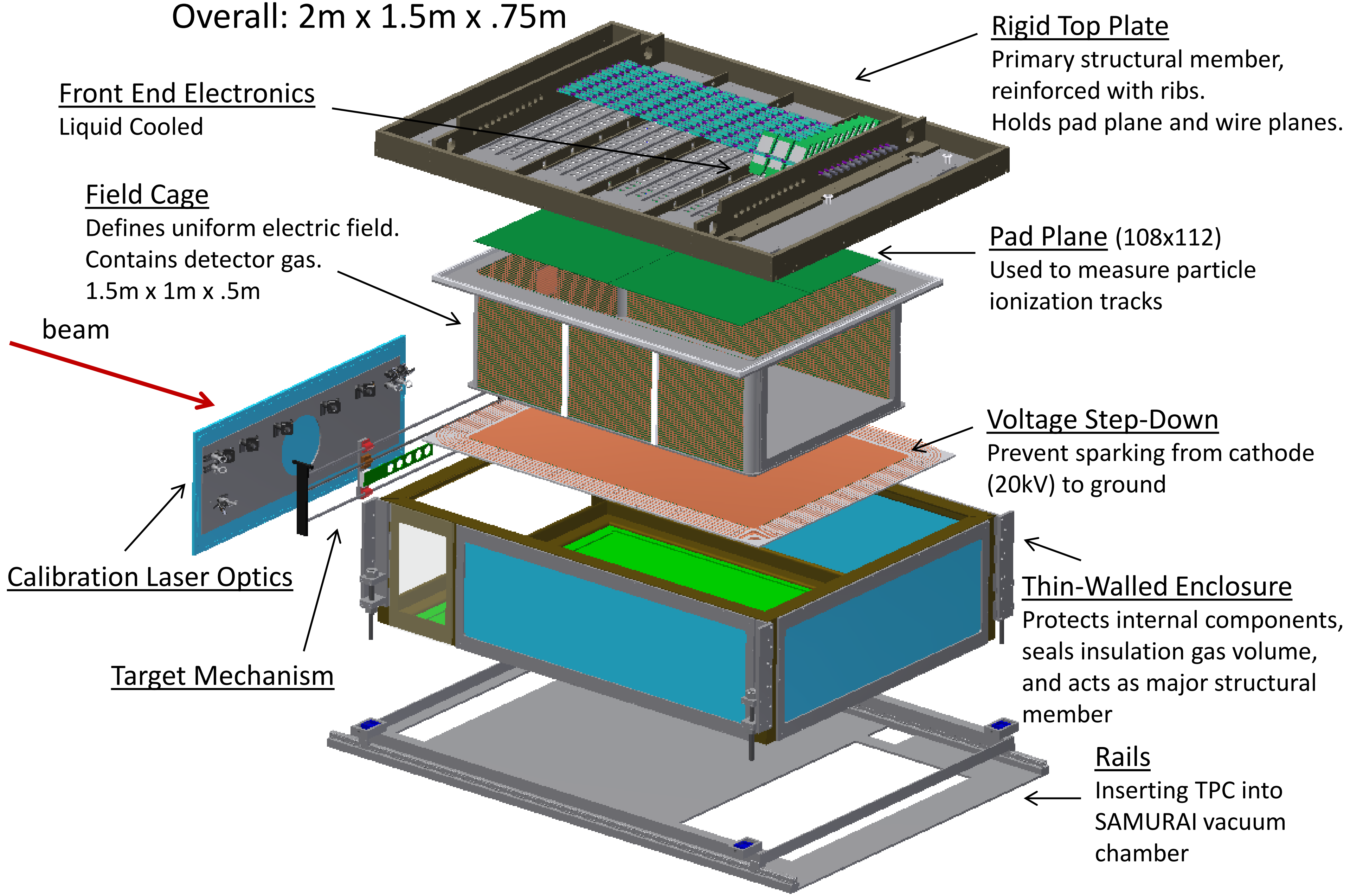


Position in **vertical** direction from **drift time**

Figure courtesy of J. Barney

SAMURAI TPC: Exploded View

Overall: 2m x 1.5m x .75m



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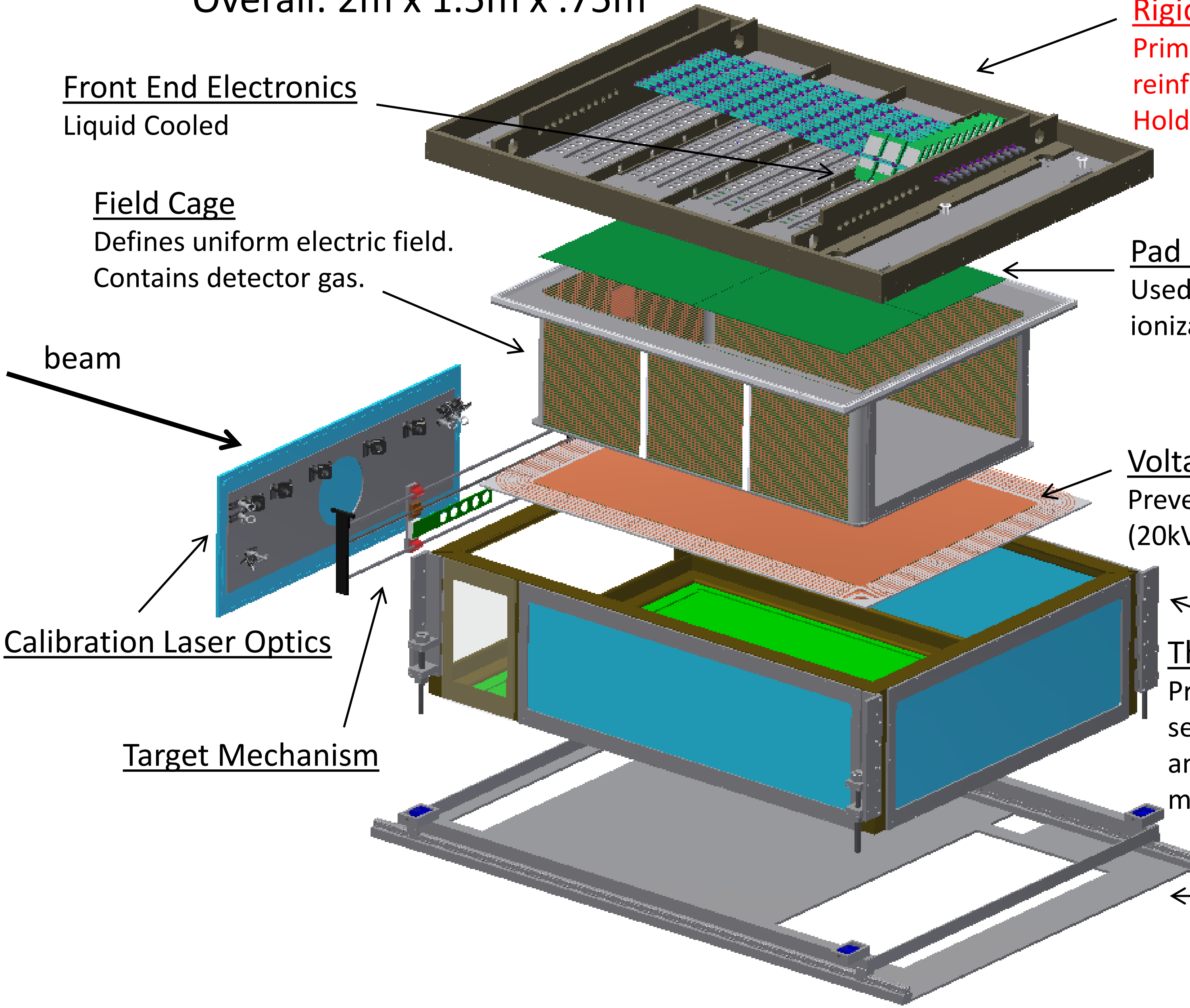


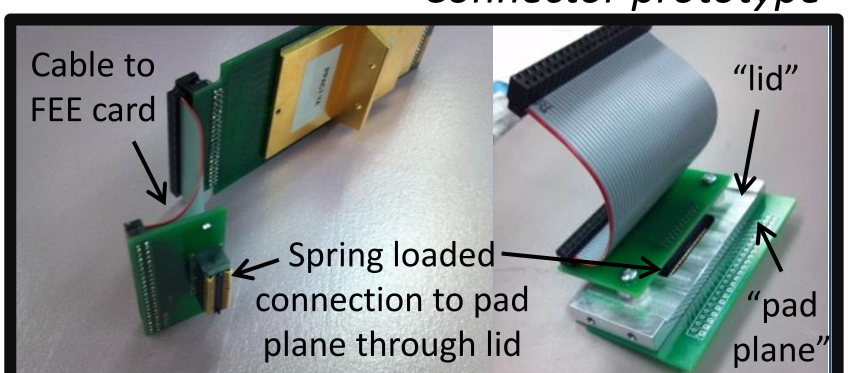
SAMURAI TPC Top plate fabrication

- **Top plate**: pad plane and wire planes mounted on bottom
- **Ribs:** cross-braces to prevent bowing/flexing

Holes for pad plane readout

Holes for electronic-card cooling lines

Connector prototype



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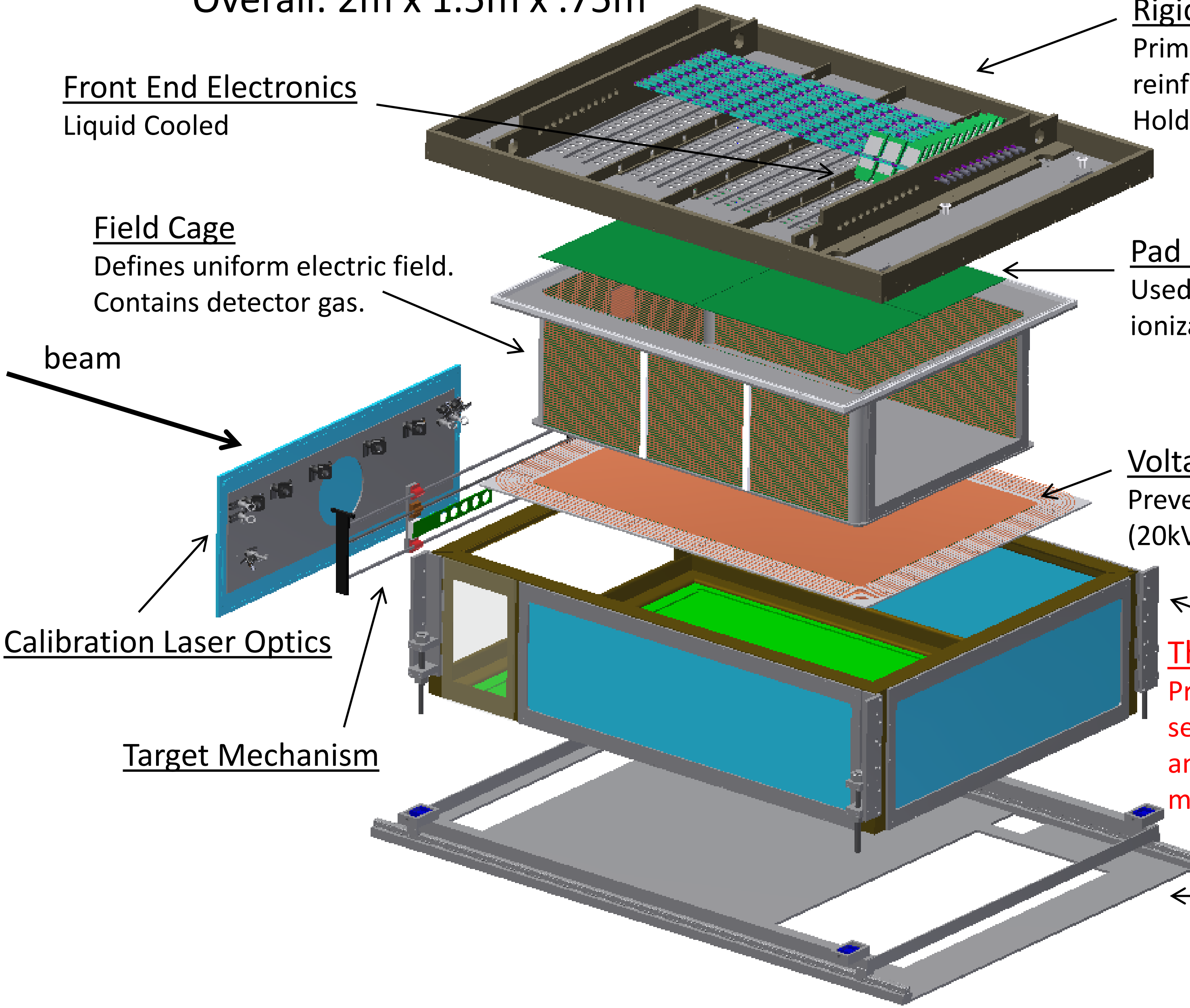
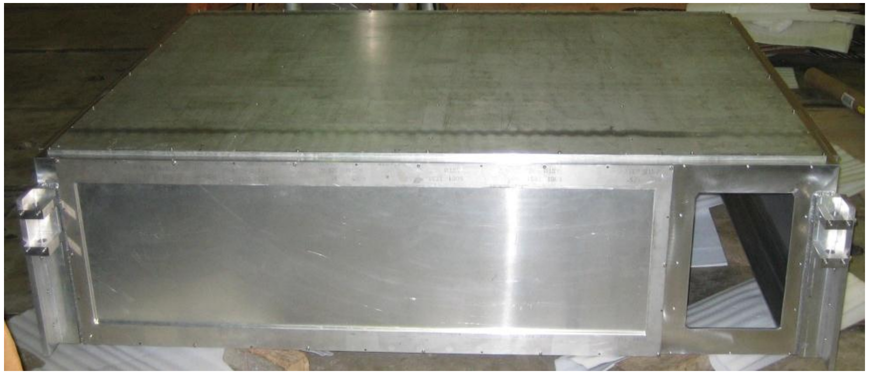
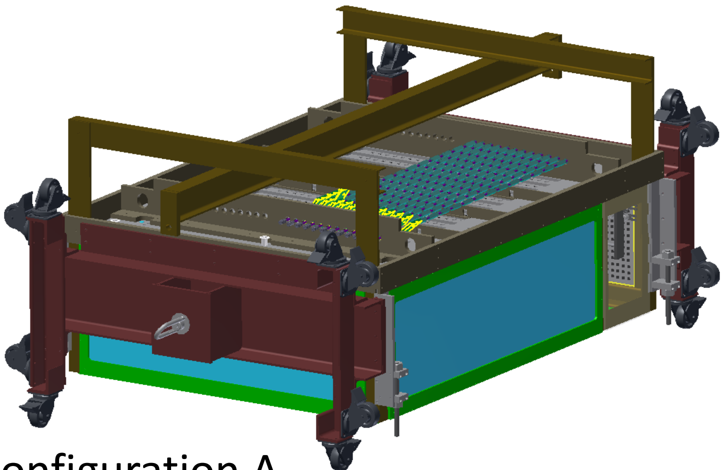


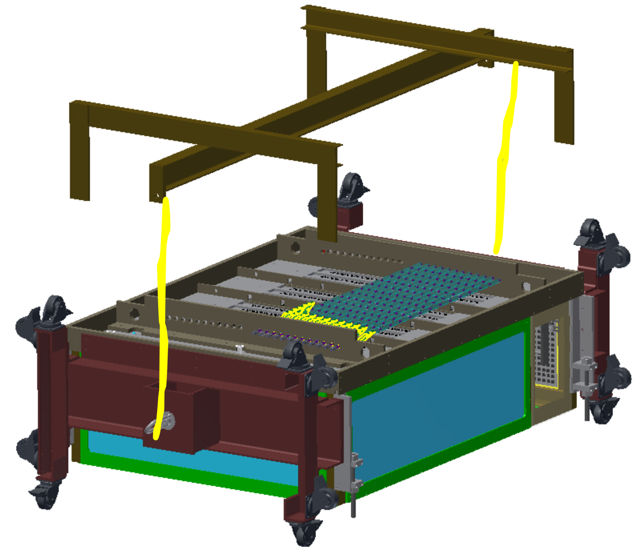
SAMURAI TPC Enclosure fabrication



- Aluminum, plus Lexan windows
- **Skeleton**: Angle bar, welded and polished for sealing.
- **Sides & Downstream Walls**: framed aluminum sheet, to minimize neutron scattering
- **Bottom Plate**: Solid, to support voltage step-down
- **Upstream Plate**: Solid, ready for beamline coupling hole to be machined

Manipulating the TPC (0.6 ton)





Configuration A

Hoist beams bolted to TPC

No relative motion

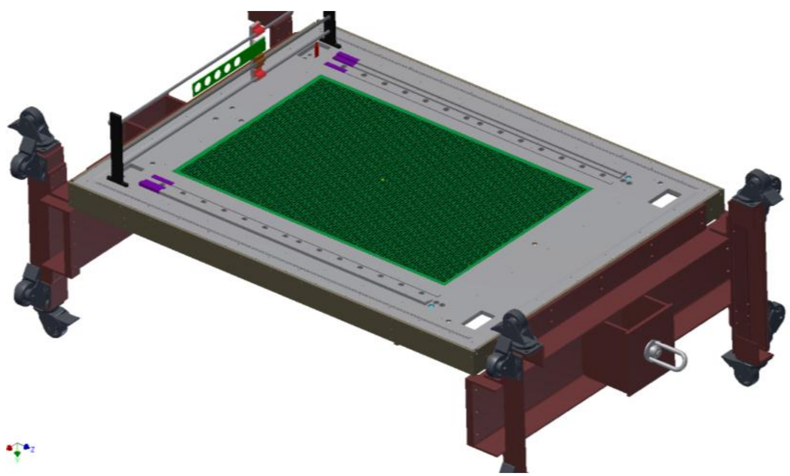
TPC moves as one - simple lifting/ lowering

Configuration B

TPC suspended from hoist beams with straps

TPC can be rotated 360

Allow to pass through standard doors



Configuration C

Motion chassis mounted upside-down

Acts as a table for wire winding, etc.

SAMURAI TPC Manipulation

Motion Chassis and Hoist Beams work as designed.
The TPC Enclosure can be lifted and rotated with relative ease.

SAMURAI TPC: Exploded View

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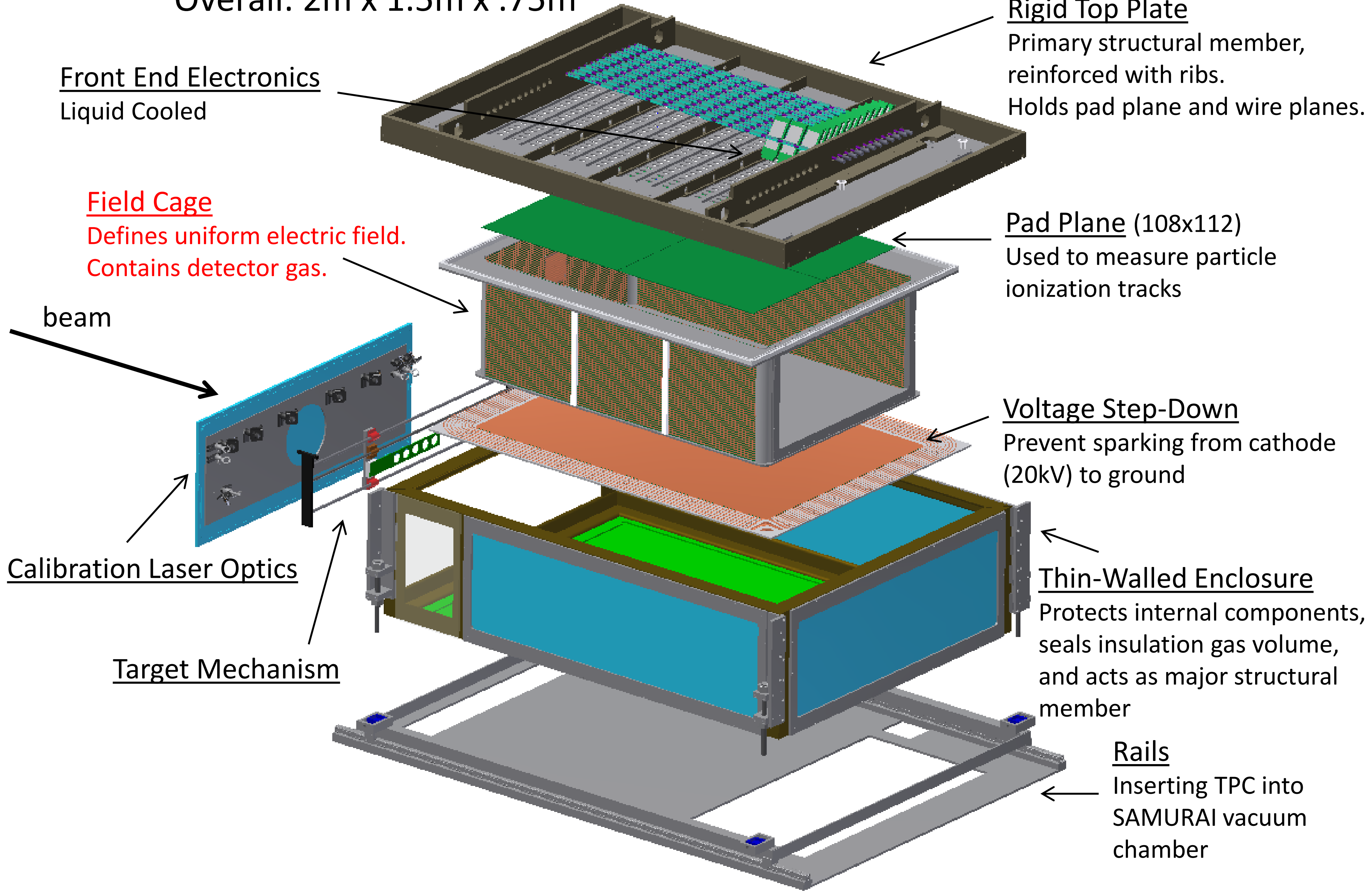
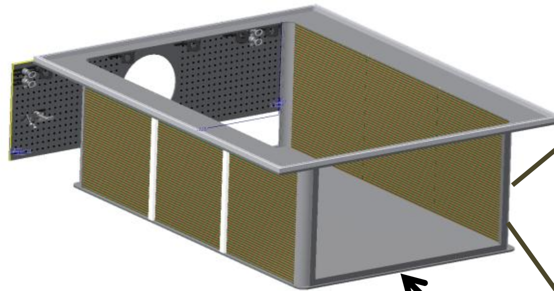
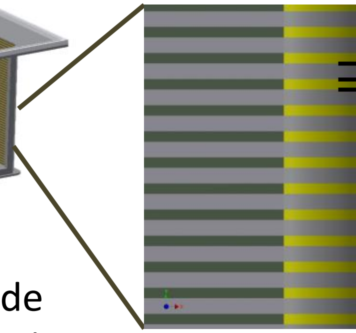


Field cage

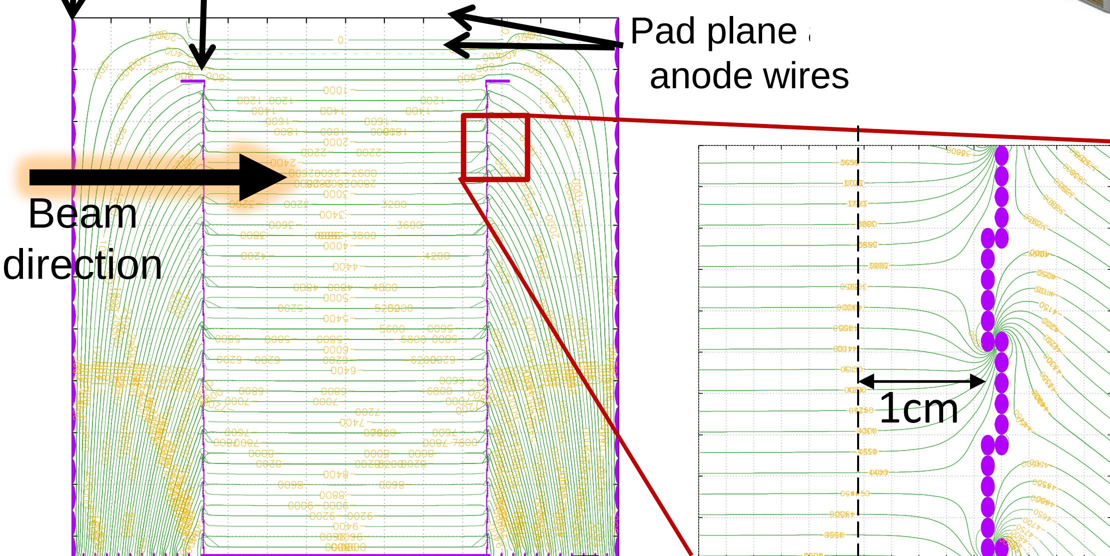
- Made of printed circuit board
- Thin walls for particles to exit
- Gas tight (separate gas volumes)





Cathode (9-20kV)

Enclosure FC wall

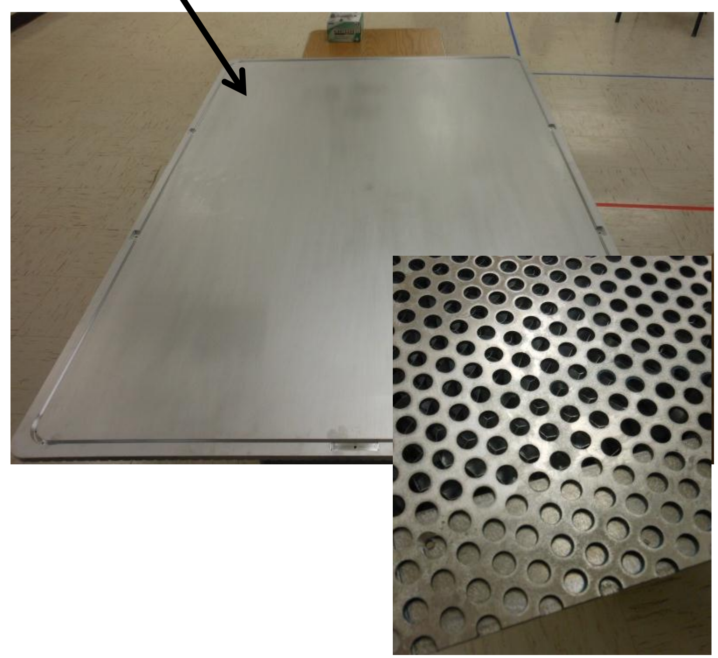


Calculations courtesy of F. Lu

Cathode (9-20kV)

Voltage step down

GARFIELD calculations (on scaled field cage) show uniform field lines 1cm from the walls



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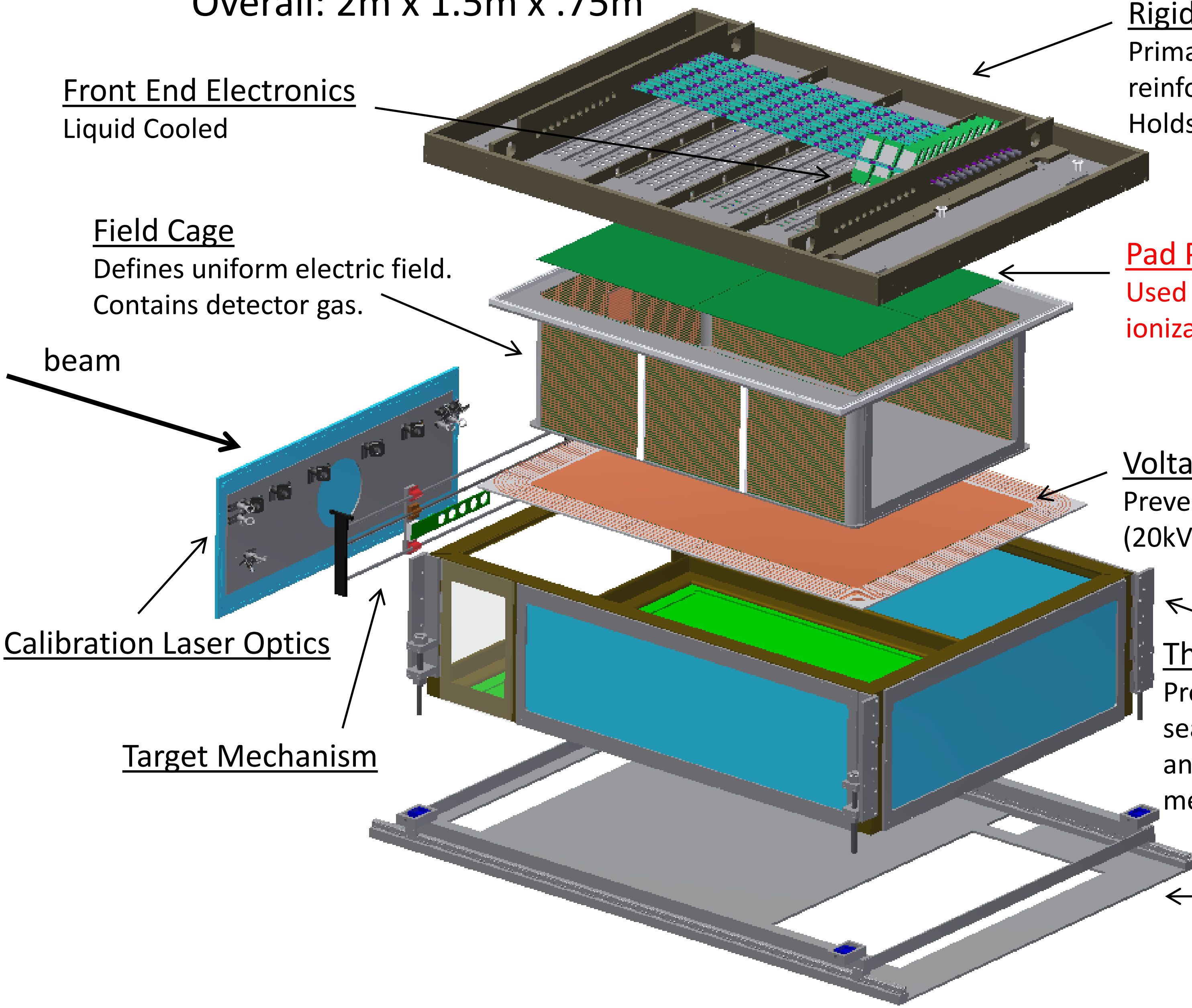


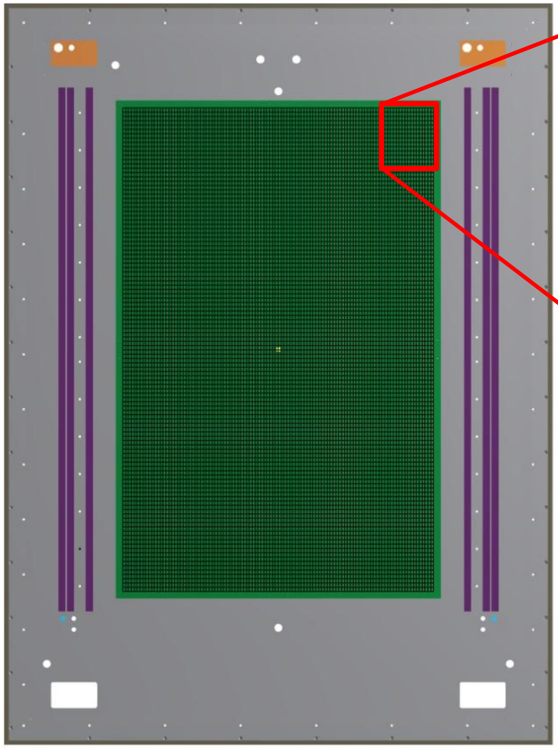
Pad plane

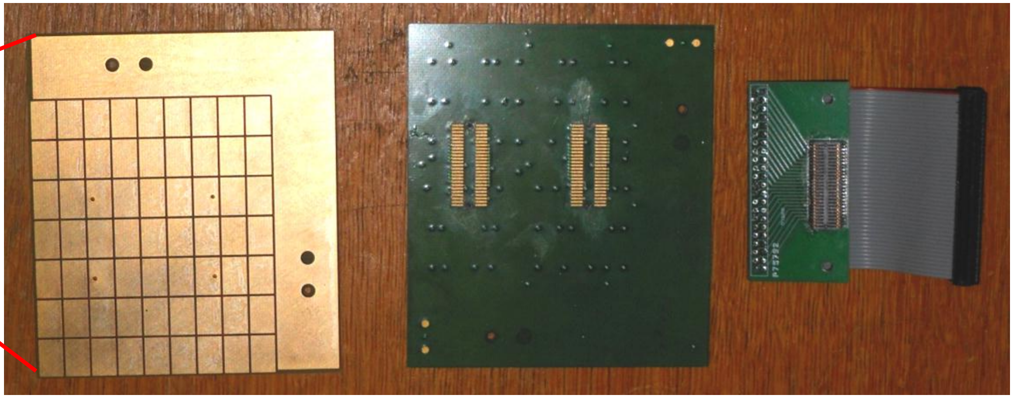
Full pad plane

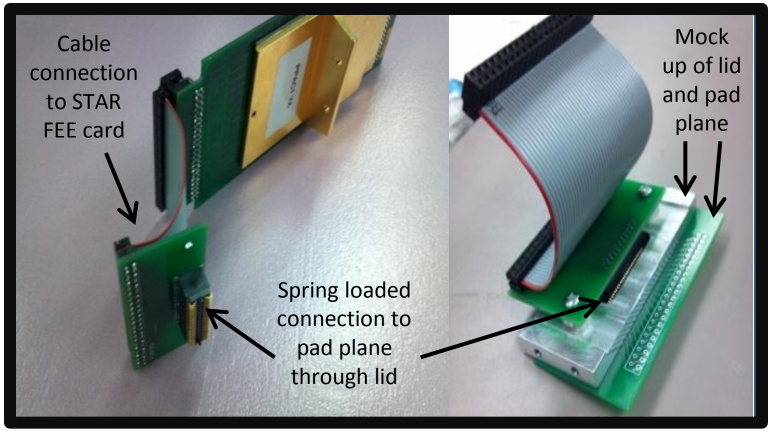
- Mounted on bottom of lid
- 112 x 108 = 12096 pads
- Each pad: 12mm x 8mm
- *Fabrication underway*

Pad plane unit cell (192 in full plane)

- Capacitance: 10pf pad-gnd, 5pf adjacent pads
- Cross talk:
  - ~0.2% between adjacent pads
  - <0.1% between non-adjacent pads



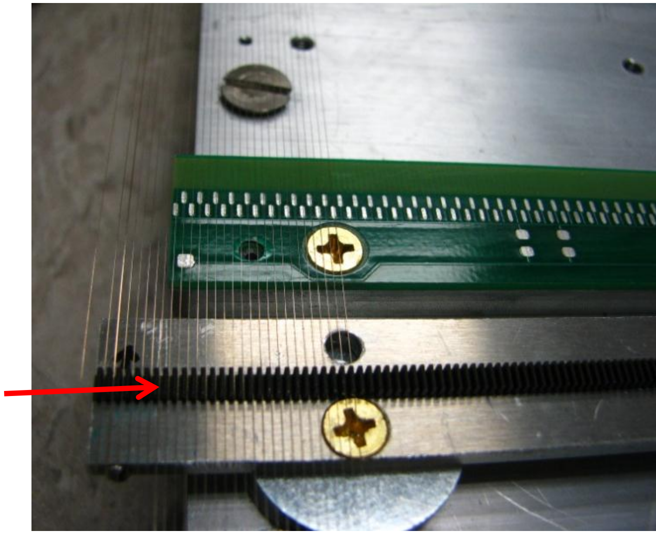




Wire planes – mounting (test setup)

- Wires are strung across frame
- Frame is positioned so that wires pass through teeth of comb and rest on circuit board (CB)
- Comb sets pitch, CB sets the height
- After gluing and soldering wires to CB, wires are cut and frame removed

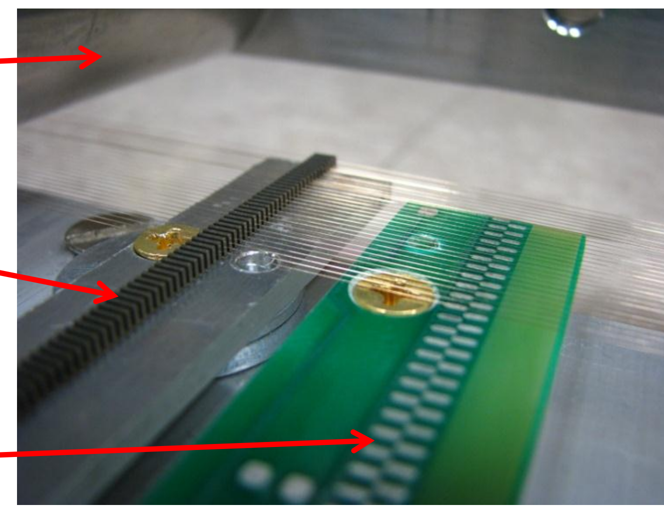
comb



frame

comb

circuit board with solder pads



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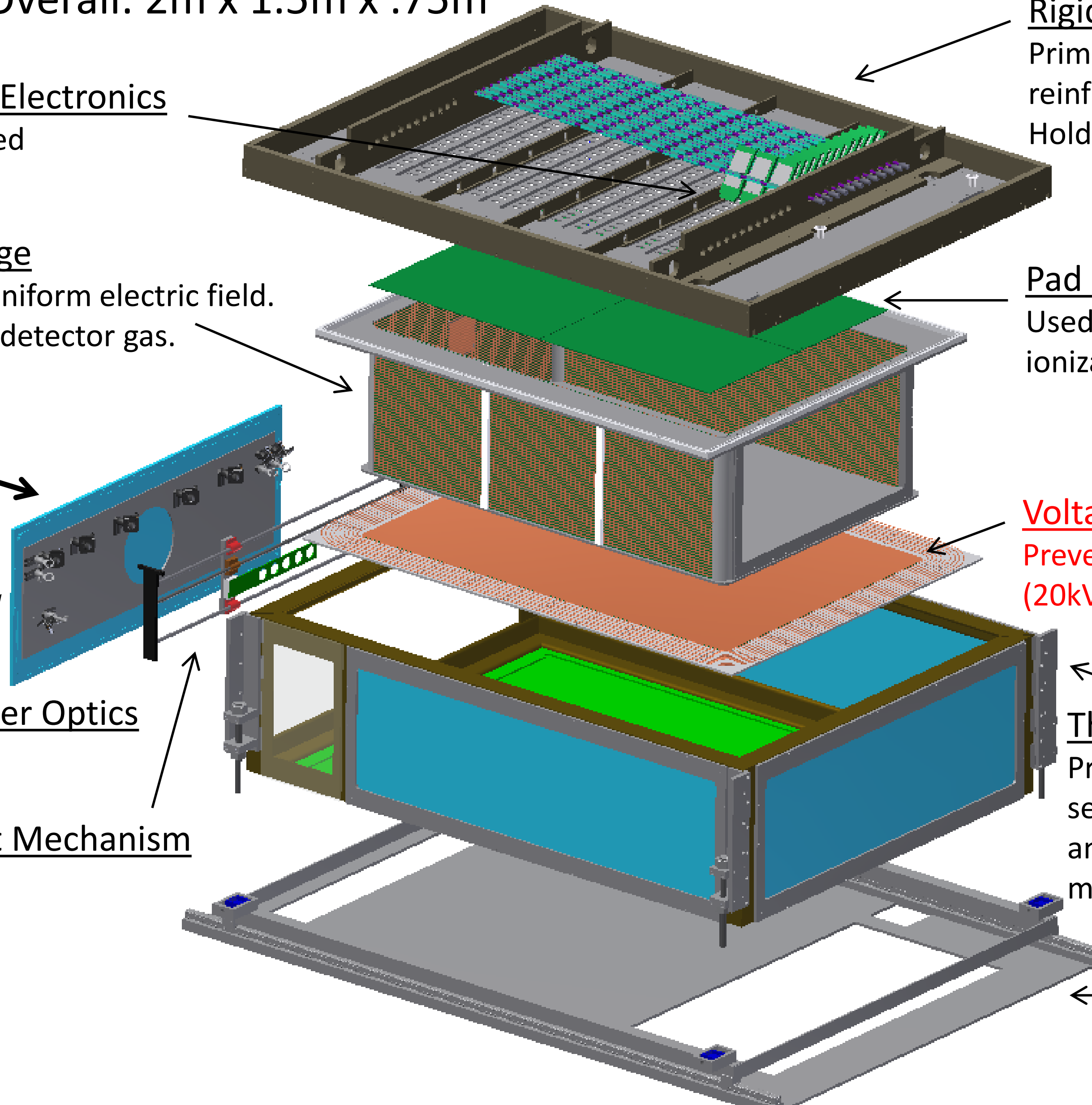


beam

Rigid Top Plate
Primary structural member, reinforced with ribs.
Holds pad plane and wire planes.

Front End Electronics
Liquid Cooled

Field Cage
Defines uniform electric field.
Contains detector gas.

Pad Plane (108x112)
Used to measure particle ionization tracks

Voltage Step-Down
Prevent sparking from cathode (20kV) to ground

Thin-Walled Enclosure
Protects internal components, seals insulation gas volume, and acts as major structural member

Calibration Laser Optics

Target Mechanism

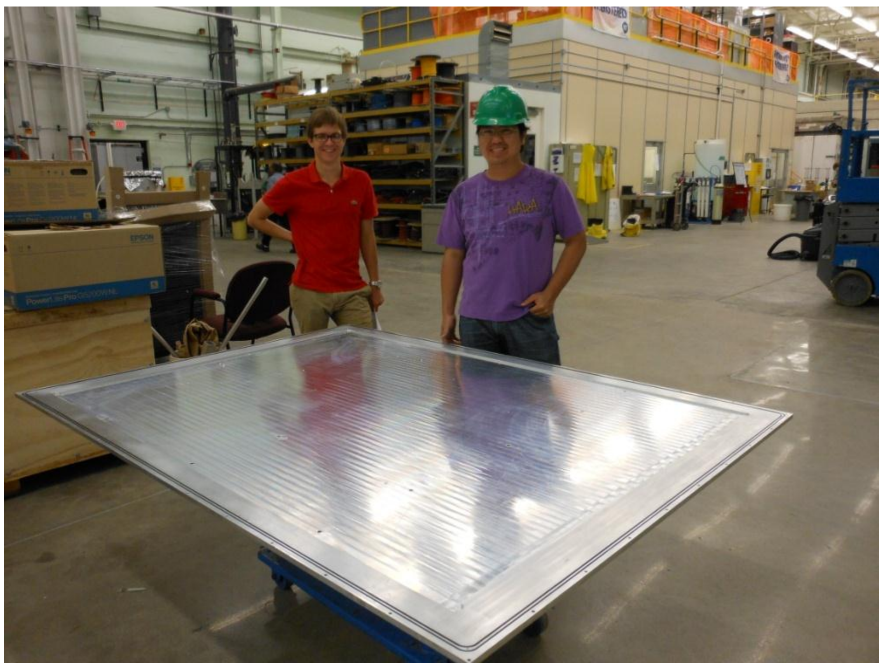
Rails
Inserting TPC into SAMURAI vacuum chamber

Voltage step down

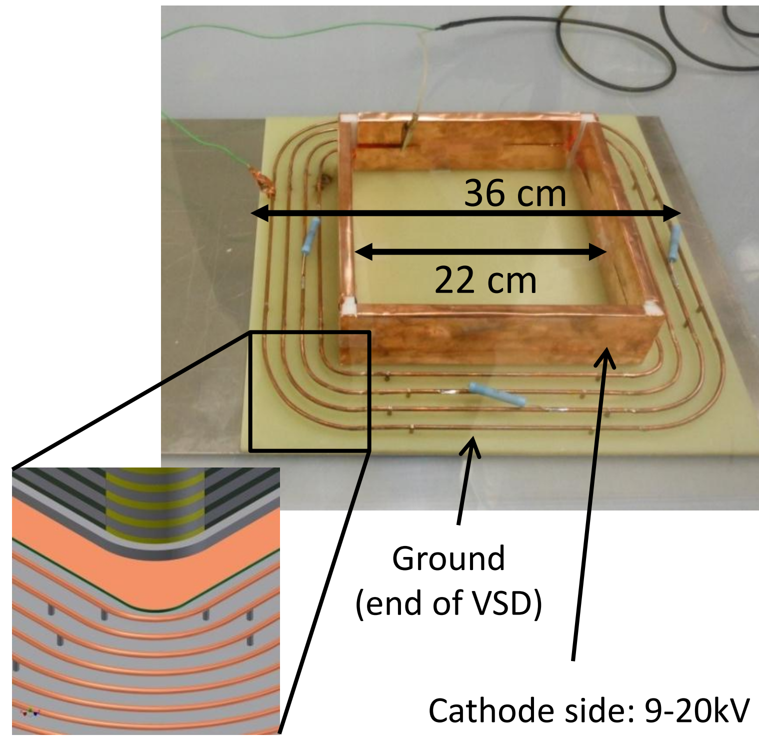
- Glued to recess in bottom plate
- Consists of 9 concentric copper rings with decreasing voltage from cathode to ground

VSD prototype: tested fabrication of rings, stability, and sparking

→ Full VSD fabrication underway



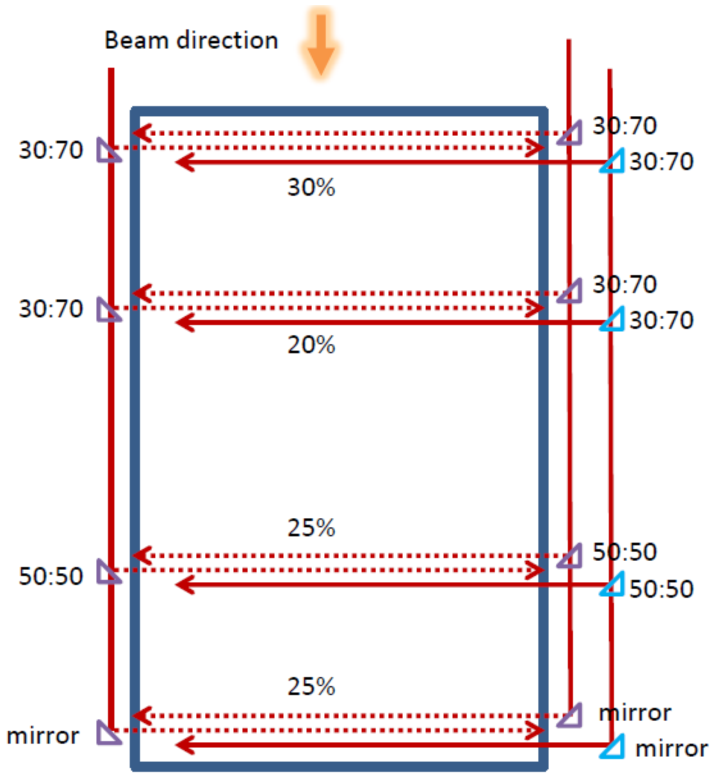
Bottom plate



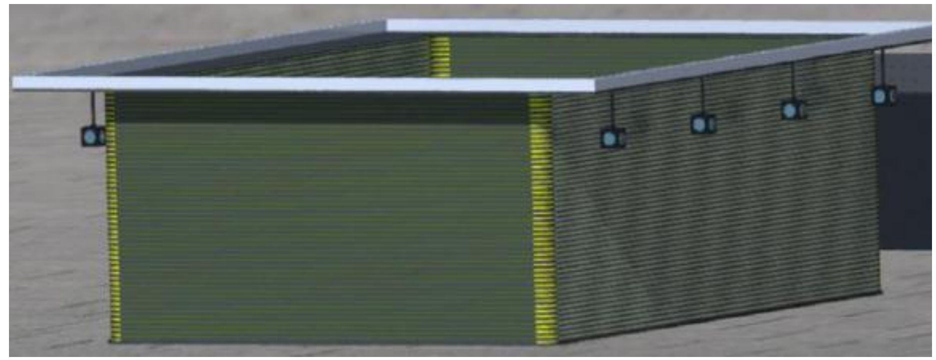
Ground (end of VSD)

Cathode side: 9-20kV (used 10kV for test of 4 rings out of 9)

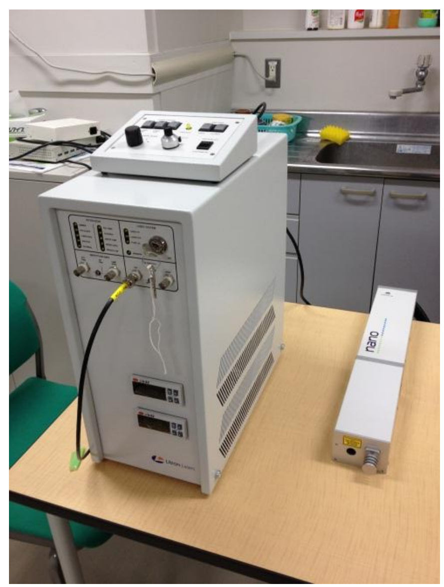
Laser Calibration System

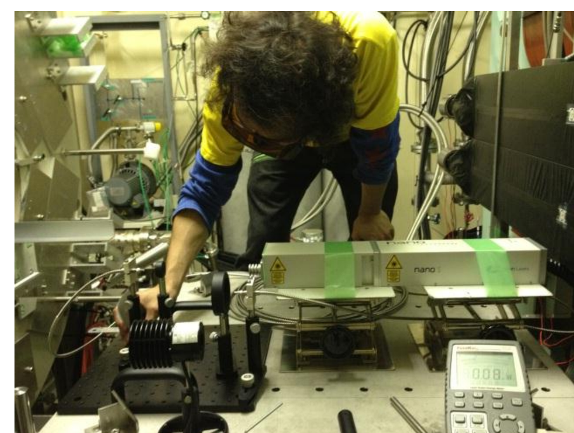


Top View



Litron Laser
266nm
15 mJ / pulse (10Hz)





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- Simulated TPC Performance
- Experimental Program at RIBF
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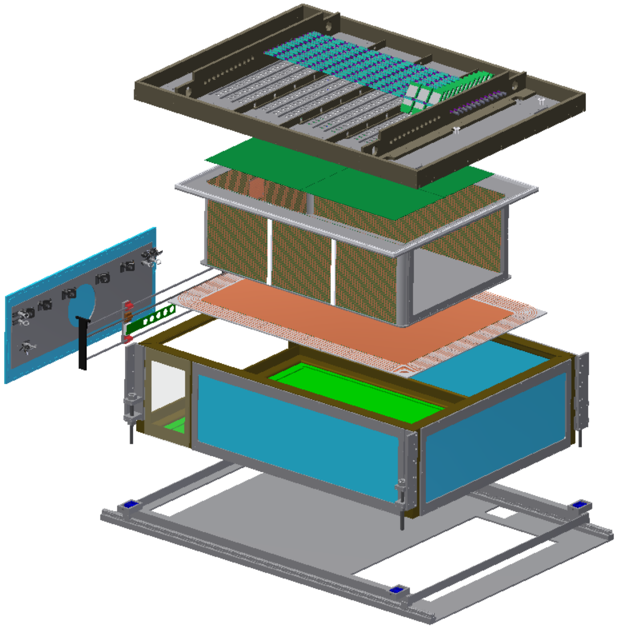


TPC electronics

Nuclear matter in neutron stars investigated by experiments and astronomical observations

- The study of neutron star matter is elected as ”Grant-in-Aid for Scientific Research on Innovative Areas” five year project.

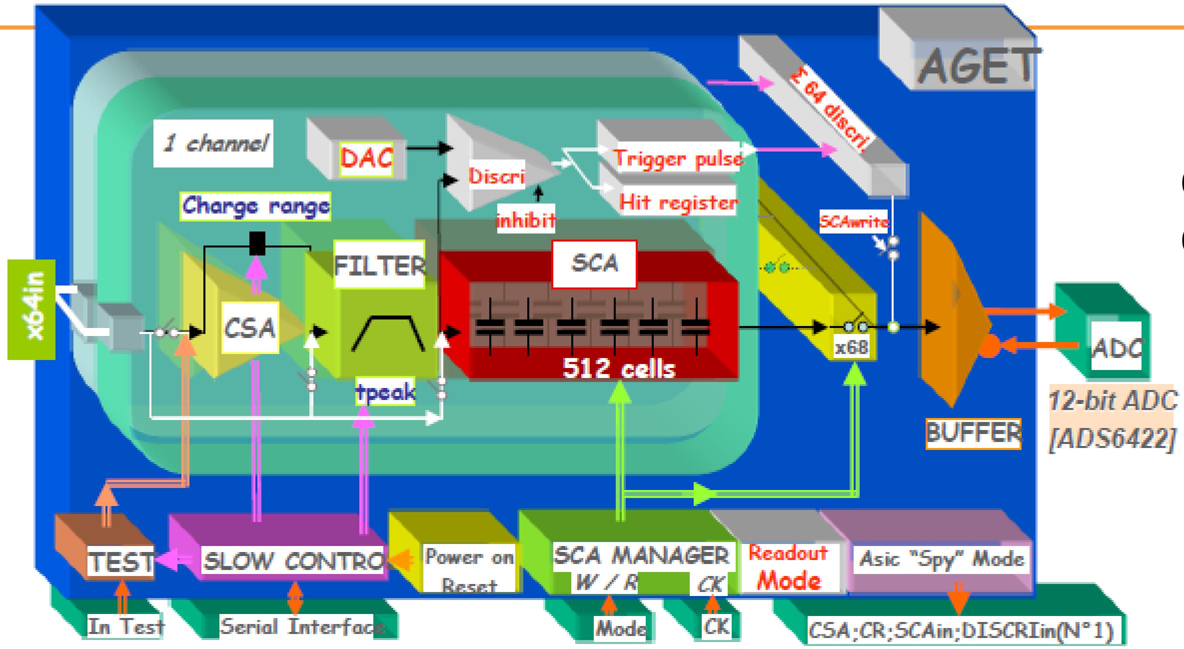
Astrophysical approach

Towards the science of QCD matter

SAMURAI-TPC

Strangeness nuclear physics

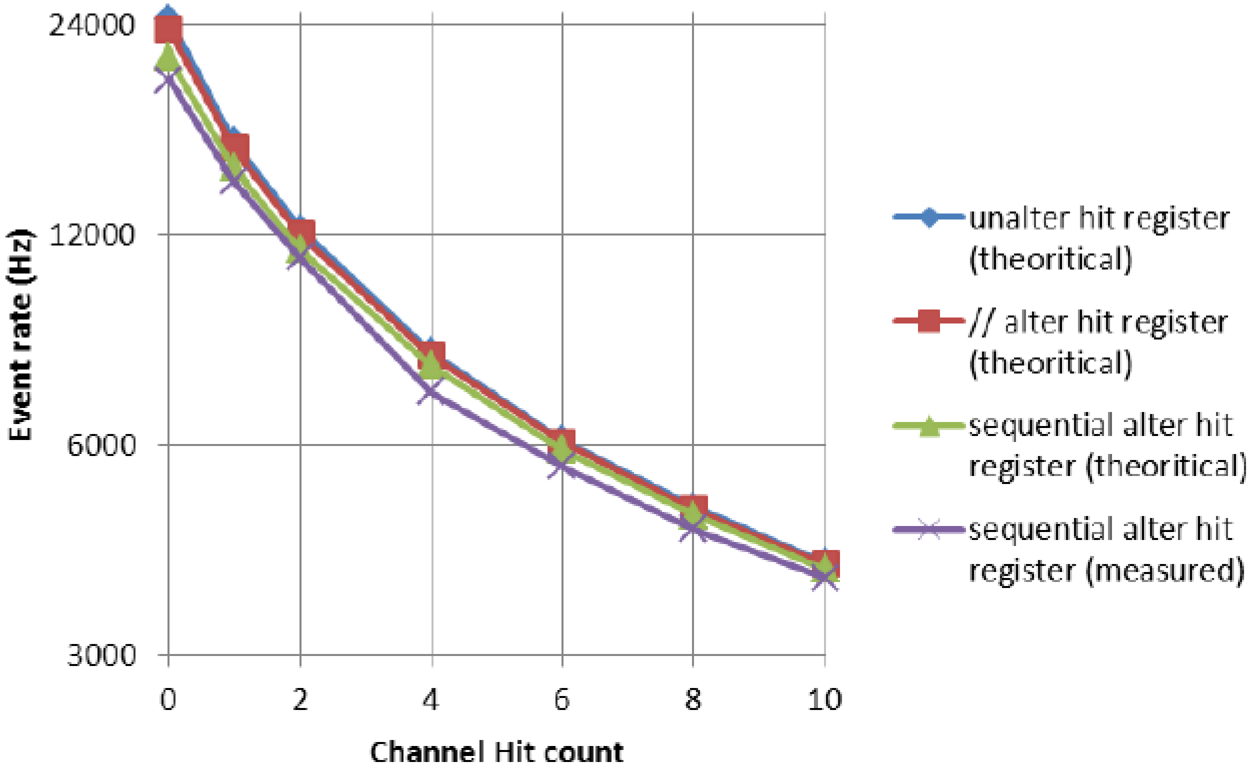
Novel TPC readout electronics: GET



New ASIC chip (AGET)
Preamp+Shaper+SCA(512 cells)
Conversion with 12-bit ADC
Channel by channel discriminator
DAQ rate of more than 1kHz

- R&D by GET (General Electronics for TPC) Collaboration for next generation of readout electronics.
  - Production will start soon.
- <u>Make it possible to readout 12bit ADC 512 samples from 12000 pads under 1kHz DAQ rate.</u>

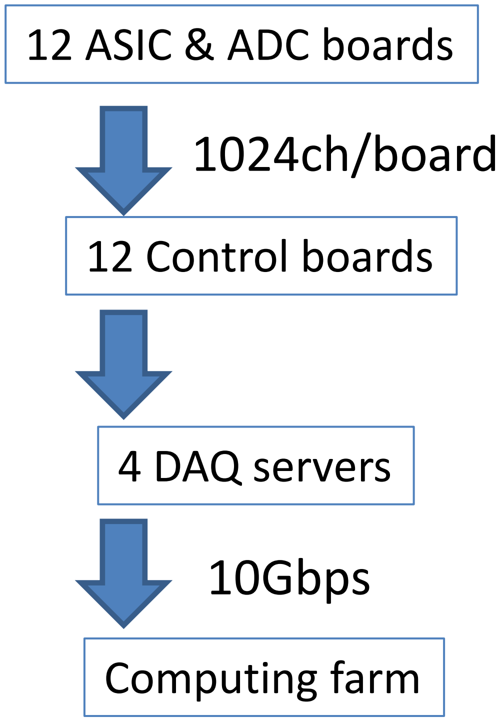
Selective digitization : improvement of DAQ rate limit



- Digitize only the channel with hit register.
  - Most of the TPC channel have pedestal data.
  - →loss of conversion time
- Rate at 512 time-bins and 8 hit channels: 4500 Hz

It needs modern computing infrastructure like high energy experiments

- On the assumption of 1kHz DAQ rate:
  - Data production rate is estimated to be 3.2GByte/sec without zero-suppression.
  - It would be ~320MByte/sec on the assumption of 10% data reduction after zero-suppression.
    - 188TByte/week
- TPC detector response time limits the DAQ trigger rate.
  - We design the TPC as the acceptable rate of 20kHz beam in total.
    - 50cm drift length, 5cm/μsec drift velocity, 10μsec drift time. → 10^5 at most.
  - 400Hz trigger rate for minimum bias trigger.
    - Assume 2% collision rate target.



Simulation study of basic TPC performance

- We intend to measure:

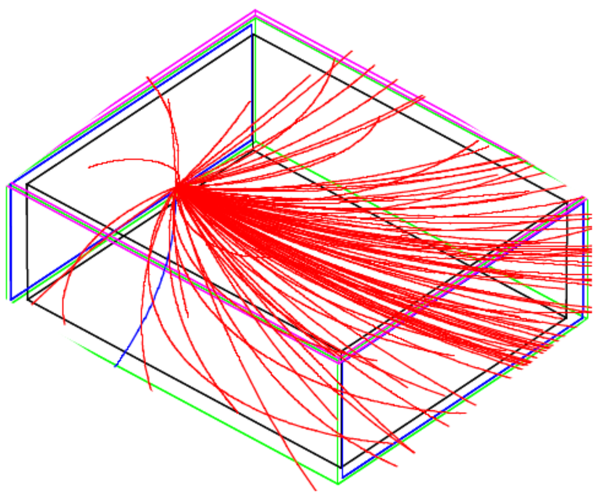
- π^+, π^-
- Neutron, Proton
- ^3H, ^3He
- Flow of each particles

Performances on

- Impact parameter measurement
- Reaction plane measurement
- Charged particle tracking

are important.

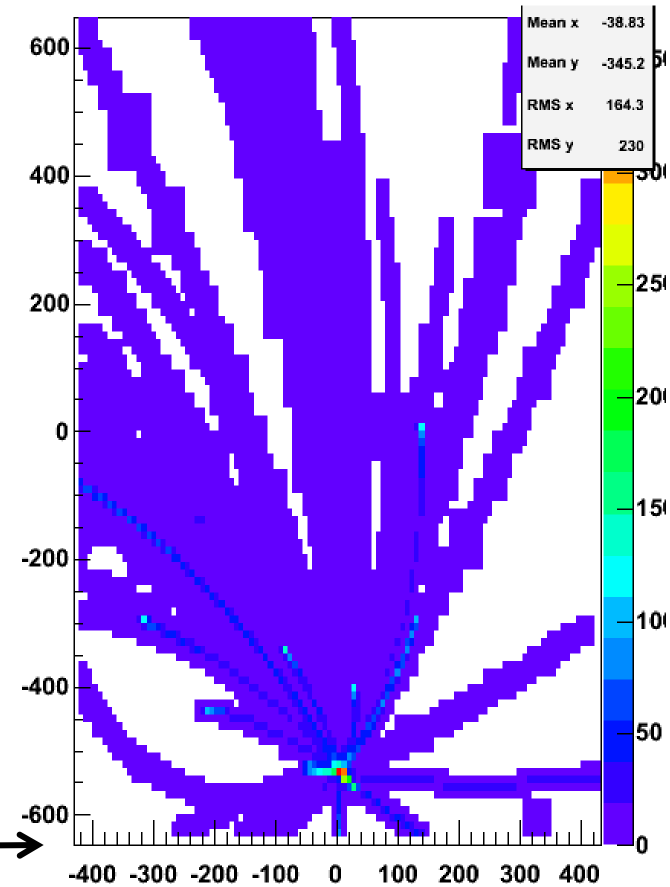
Event display of HIC

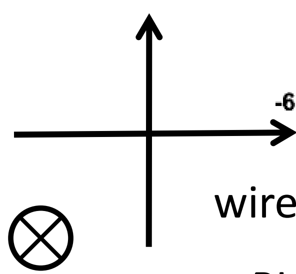


GEANT simulation

^{132}Sn+^{124}Sn collisions at E/A=300 MeV

- Deposited energy on each readout pads.
  - Tracks by light ions can be seen

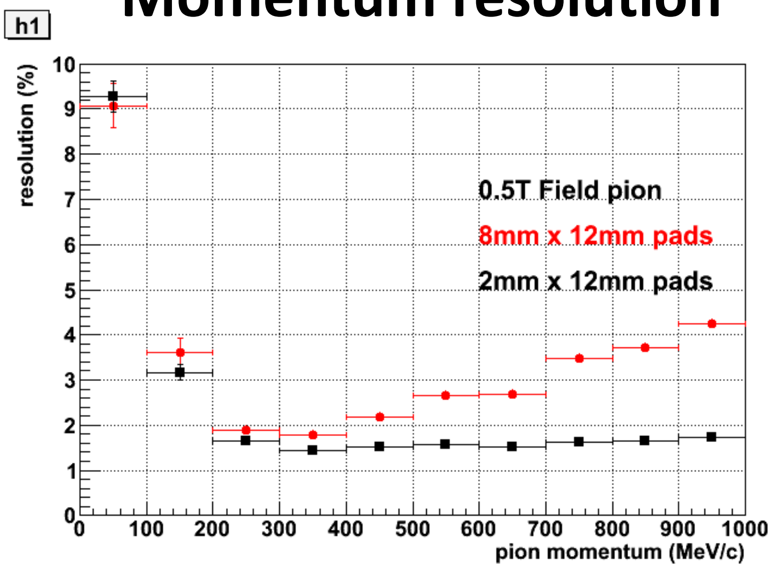




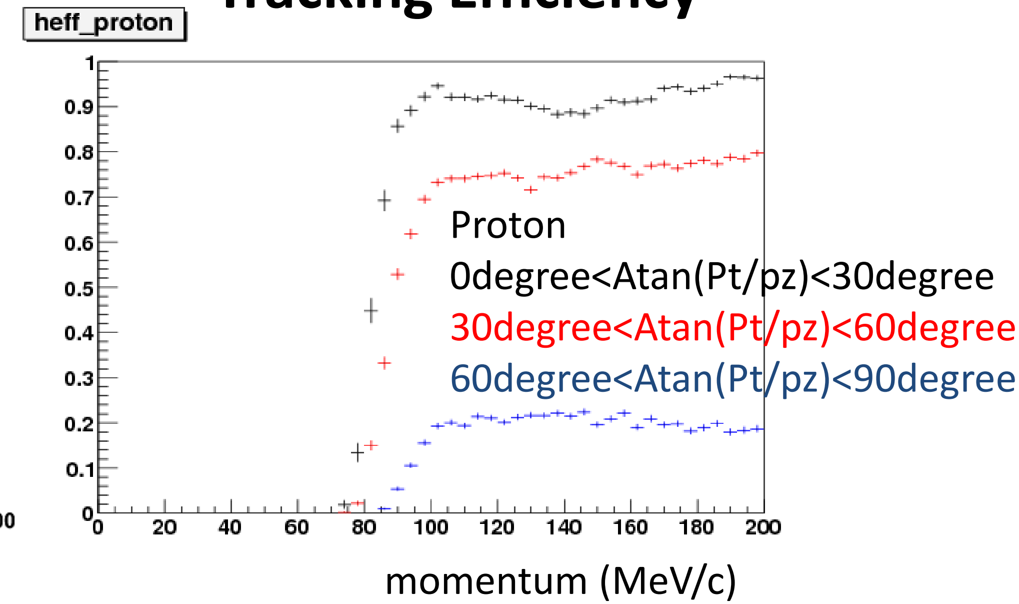
PHITS-2.15 124Sn+124Sn E=340MeV/u

Single track performance with simple algorithm: track finding with Kalman filter

Momentum resolution



Tracking Efficiency

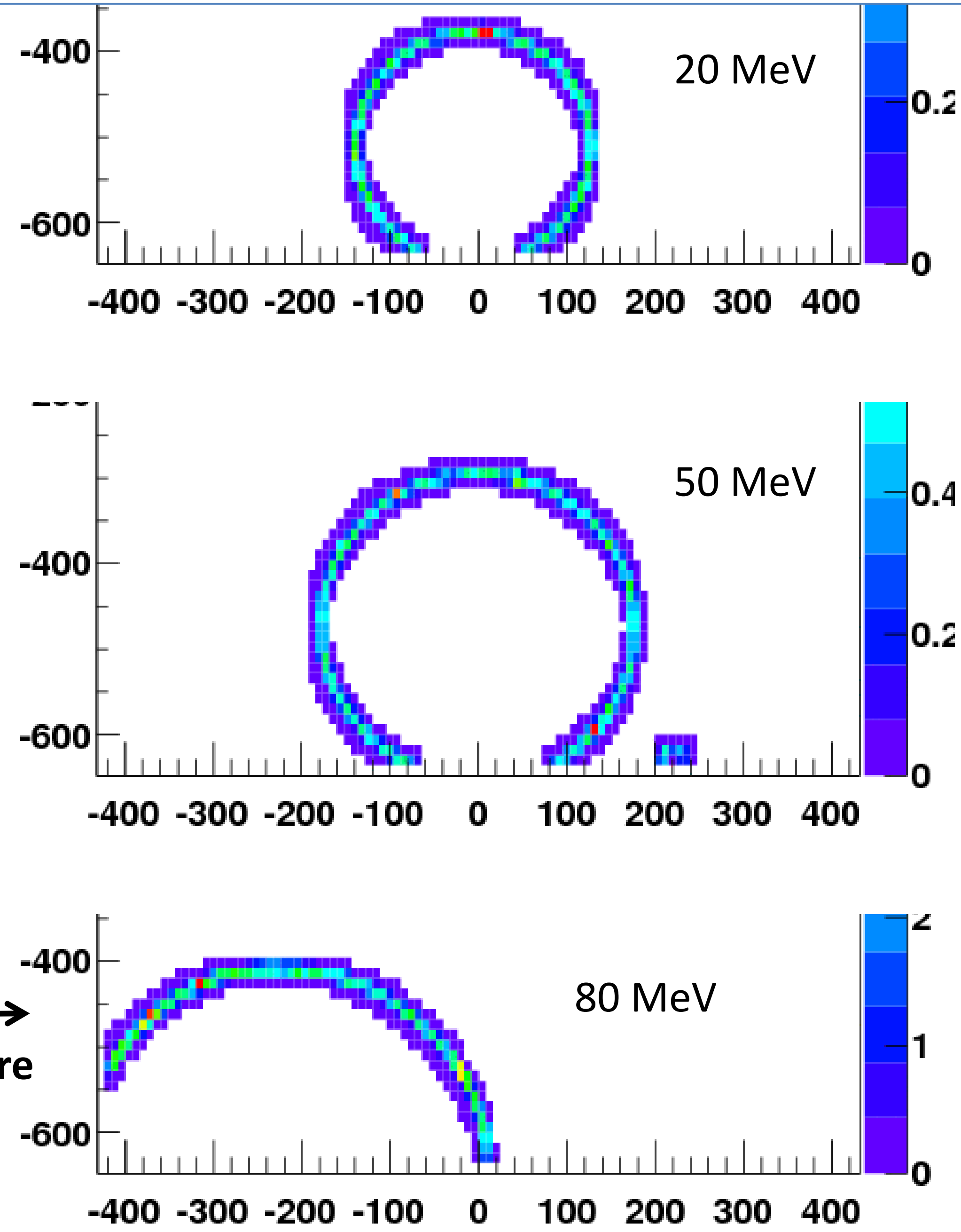


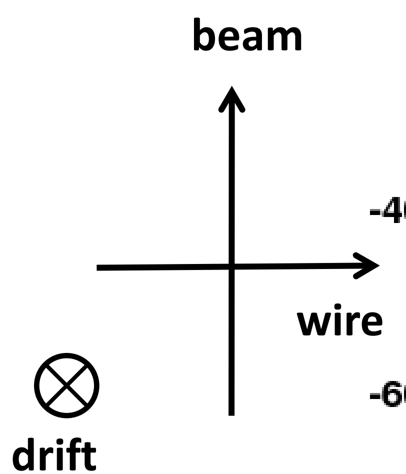
- Currently it is easy to measure:
  - pion p>80MeV/c
  - proton p>100MeV/c
  - Still room to improve for low-momentum particles.
- Momentum resolution: ~2%

Low-momentum pions

- Helical track is difficult to reconstruct with current algorithm.
- Different algorithm to connect two low-momentum tracks is invented.

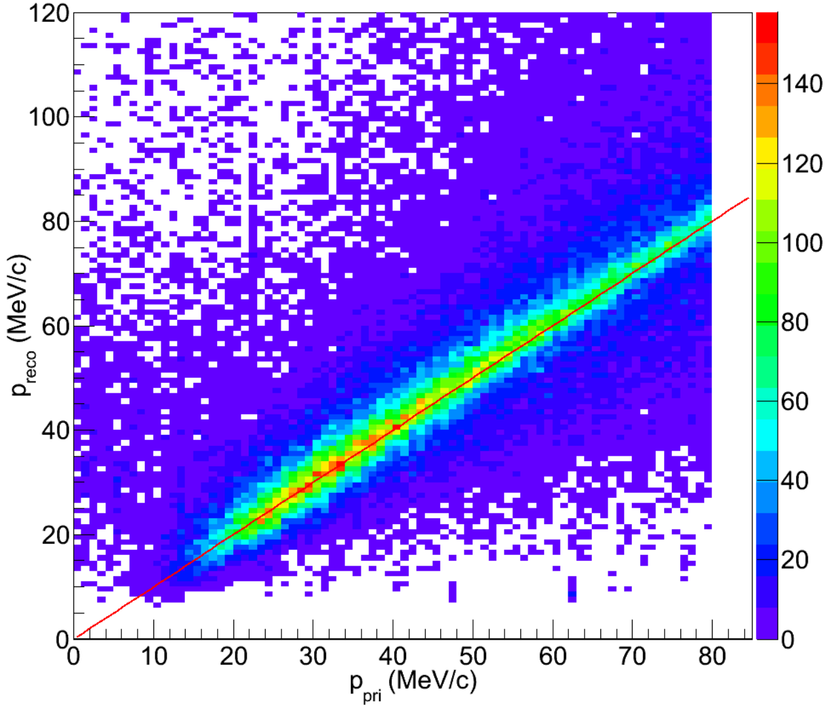
Deposited energy on each readout pads.





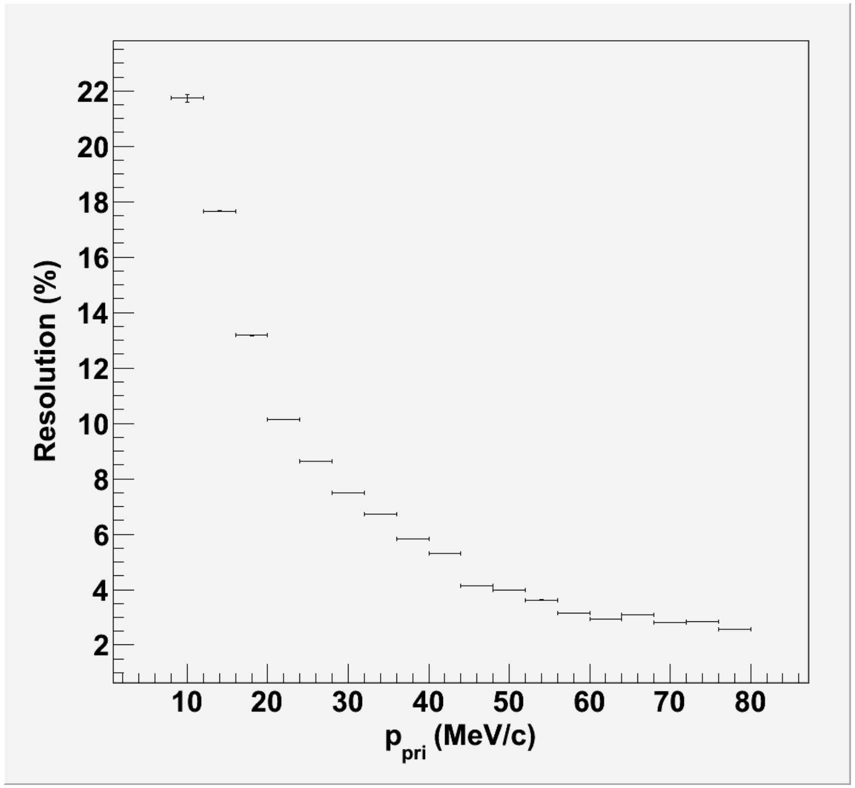
Performance on low-momentum pions

Reconstructed pion momentum vs. primary pion momentum



Possible to track the low-momentum pions of p>15MeV/c (~7MeV/c in c.m.).

Momentum resolution of low-momentum pions

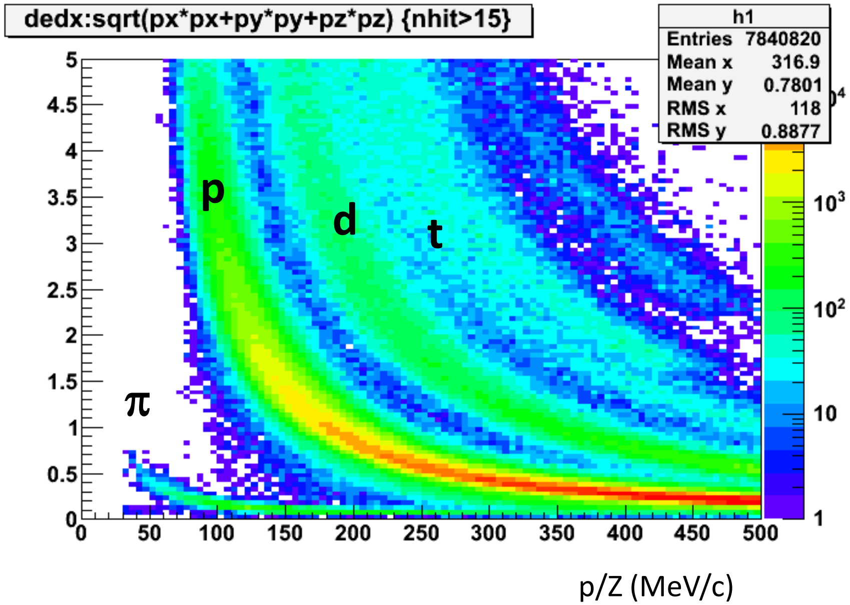


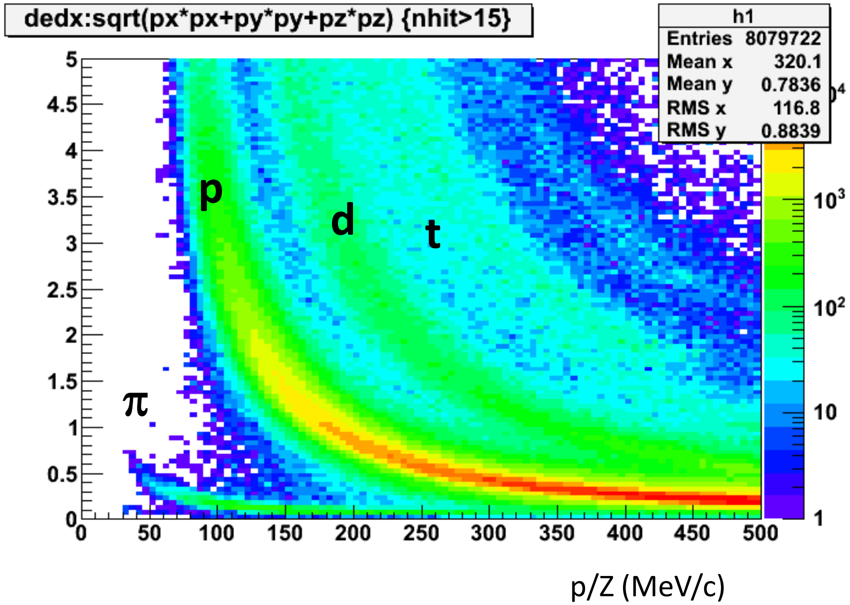
Genie Jhang

TPC PID performance

Single particle

$^{124}Sn+^{124}Sn$ 340 MeV/u min. bias



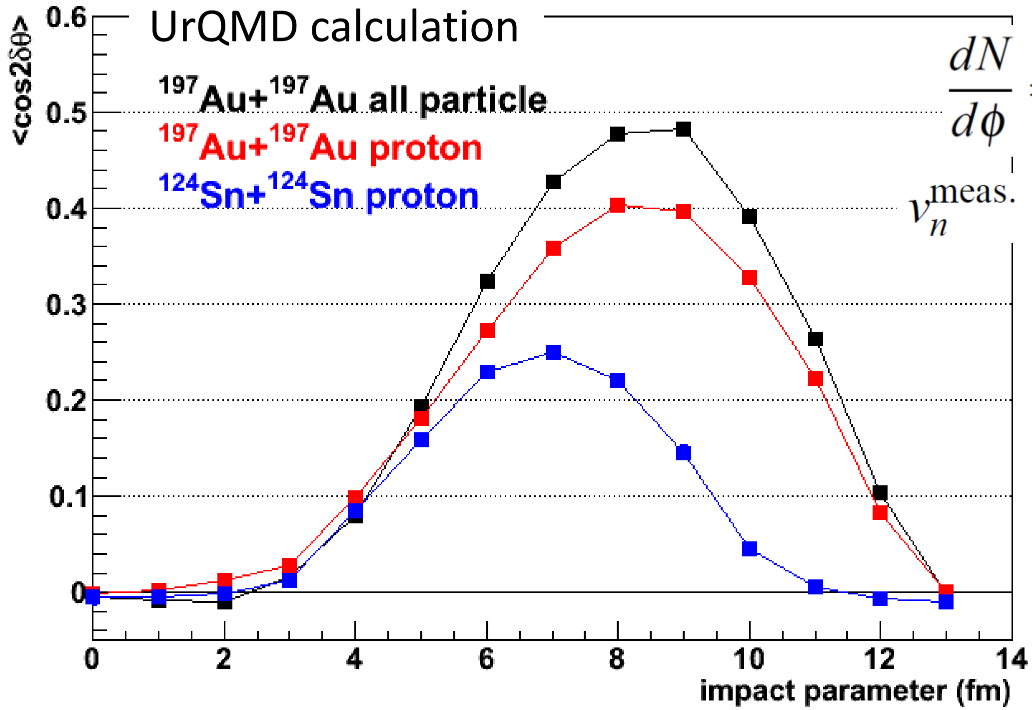


de/dx resolution

pion@140MeV/c	single:13.3%	<->	min. bias: 16%
proton@210MeV/c	single:12.7%	<->	min. bias: 14%

Contribution from low-momentum pion can be seen even in HIC.

Flow: Reaction plane resolution



$$\frac{dN}{d\phi} = N_0 \left\{ 1 + \sum_n 2 v_n \cos(n(\phi - \Psi_{R.P.})) \right\}$$

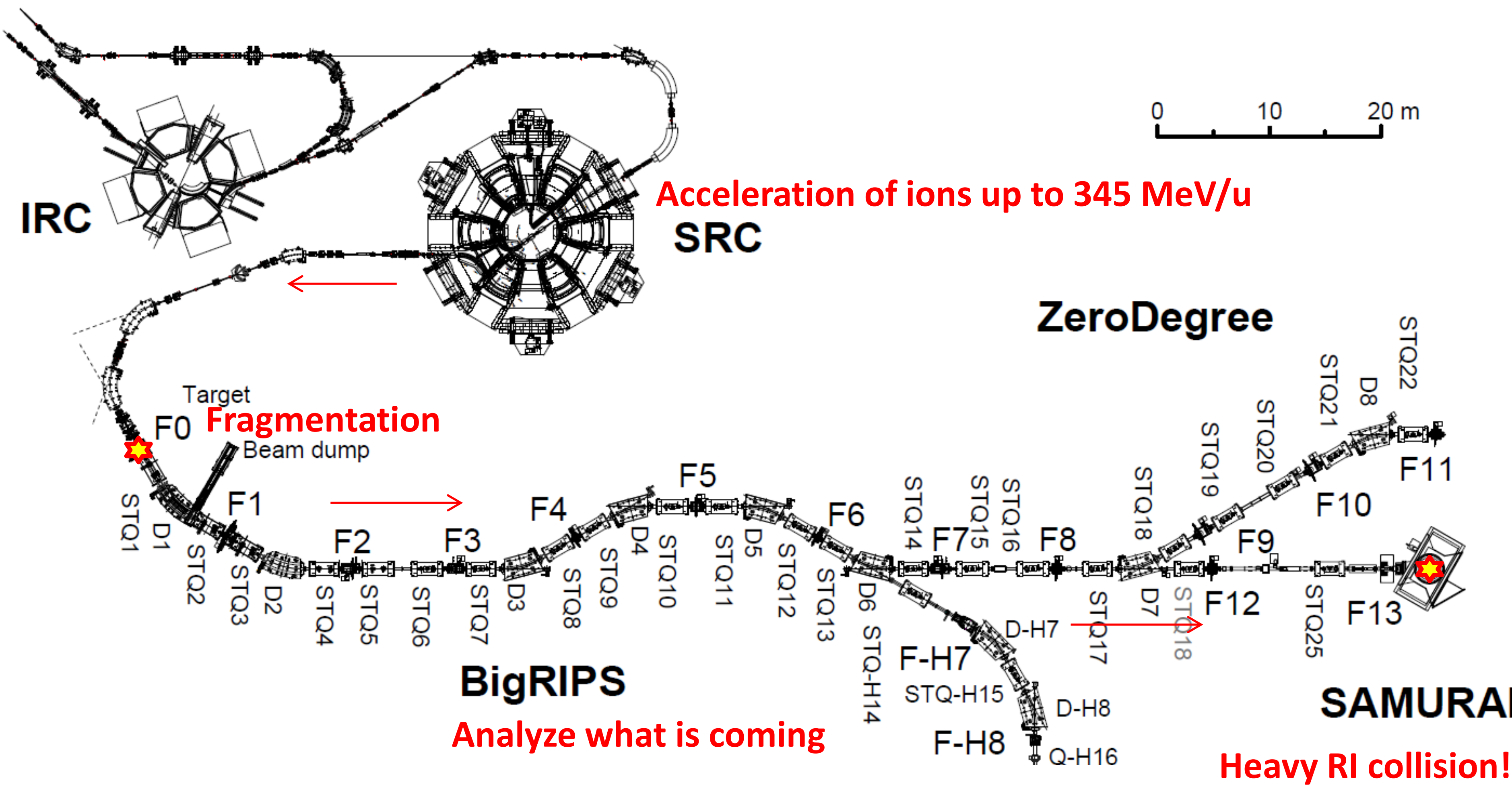
$$v_n^{\text{meas.}} = < \cos(n(\phi_i - \psi_{\text{meas.}})) >$$

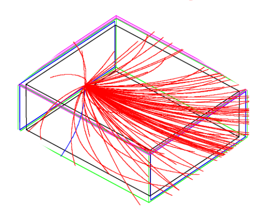
$$= v_n < \cos(n(\psi_{\text{meas.}} - \psi_{\text{true}})) >$$

Reaction plane resolution

- Large acceptance detector is preferable.
- High multiplicity collision is better in terms of good reaction plane resolution.
  - Higher Z RI is better.
- Measurement in Sn+Sn needs ~x2.5 larger statics than that in Au+Au.

Experiment at RIBF

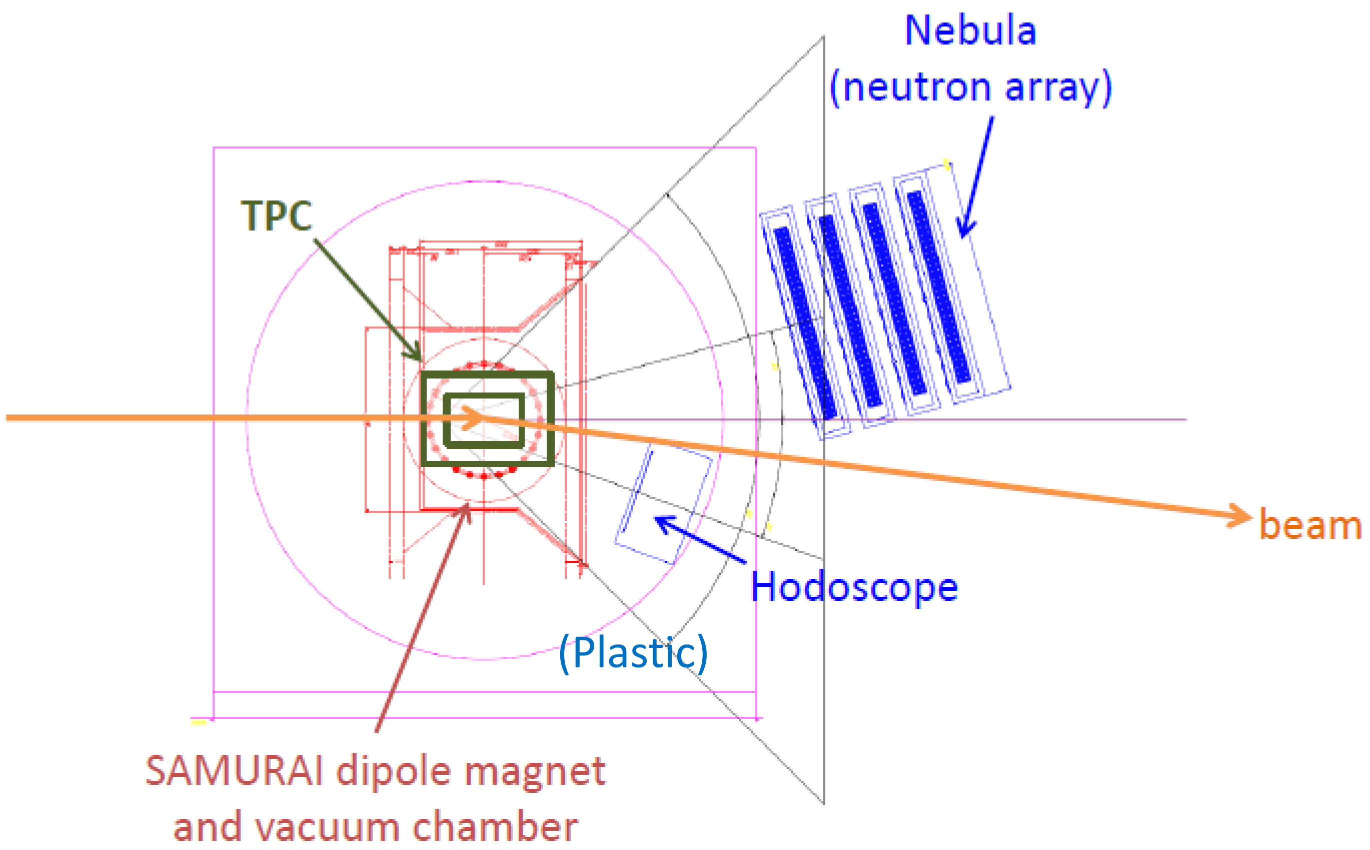


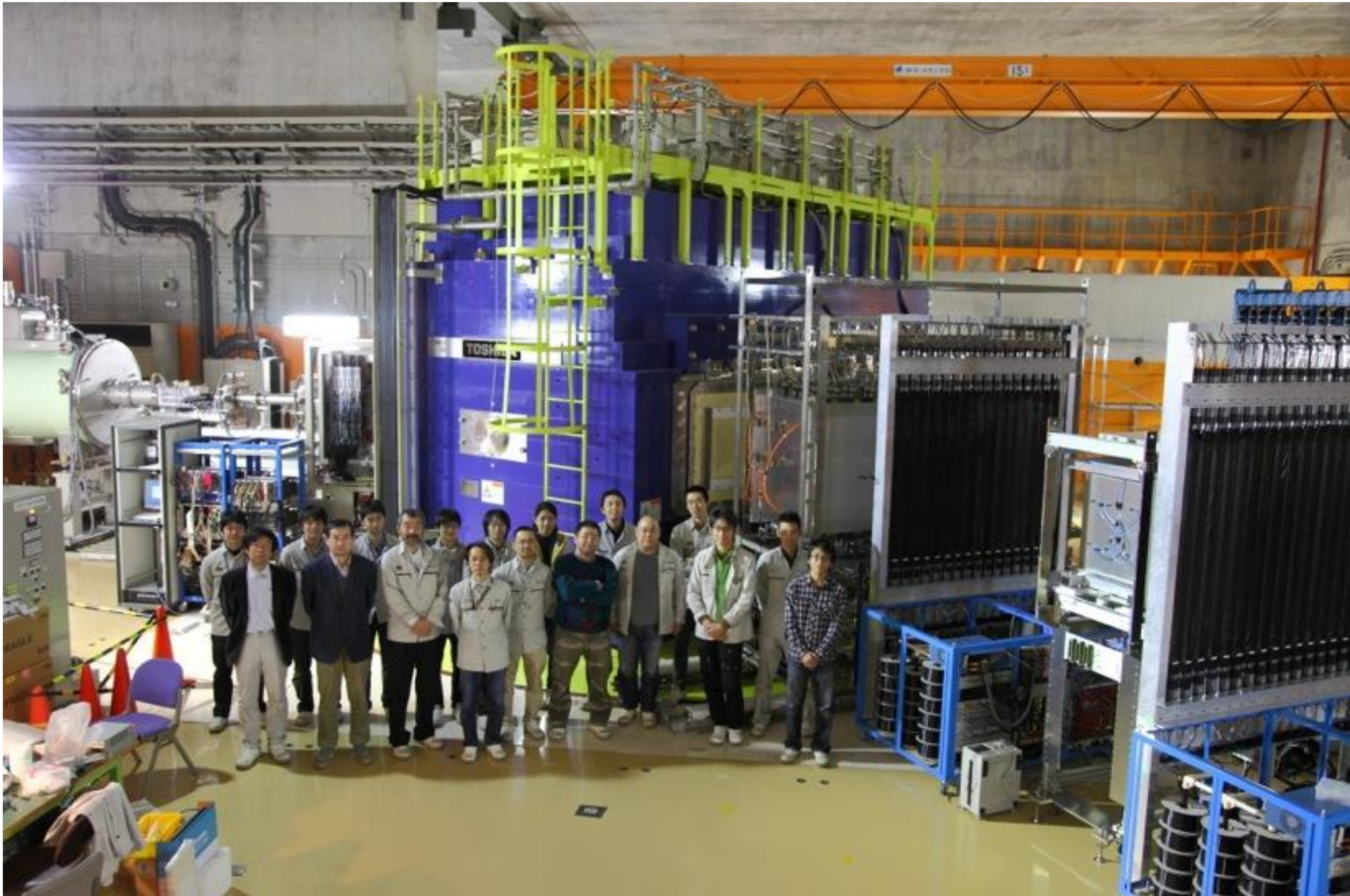


GEANT simulation

Experimental setup

- Plan first run in 2014.
- Auxiliary detectors for heavy-ions and neutrons, and trigger



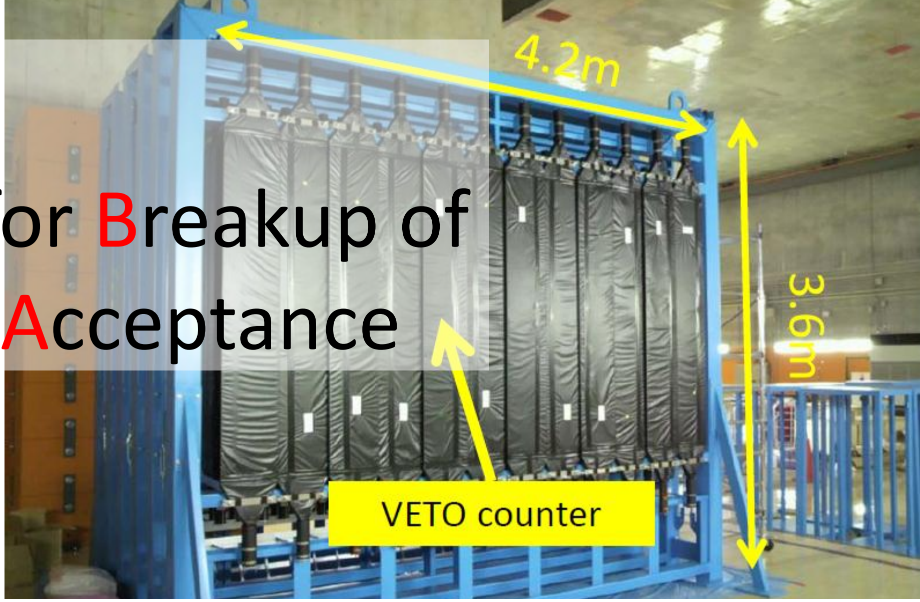


Commissioning Experiment March 2012

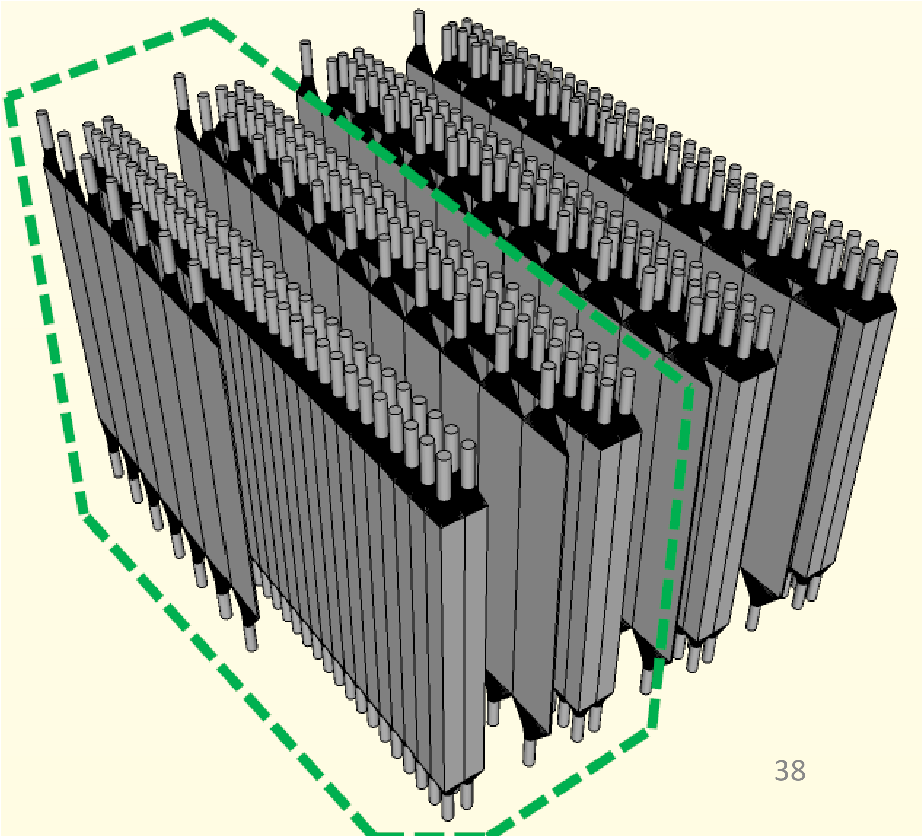

PL
80K
80K
80K
TPC
π^+
π^-
4K
RI beam

SAMURAI-NEBULA

Neutron-detection system for Breakup of Unstable-Nuclei with Large Acceptance

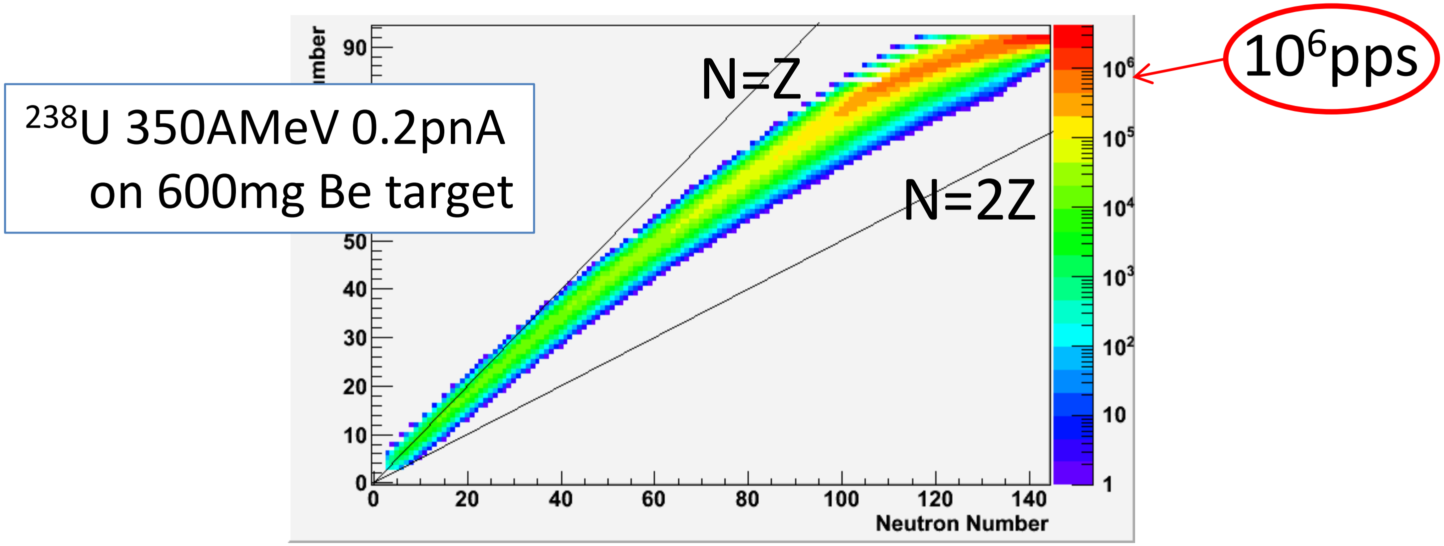


- Design
  - 240 Neutron counters
  - 48 VETO counters
  - arranged into 4 stacks
- Detection efficiency~40% for 1n (Currently)
- Large acceptance
  - 3.6m (H) x 1.8m (V) effective area



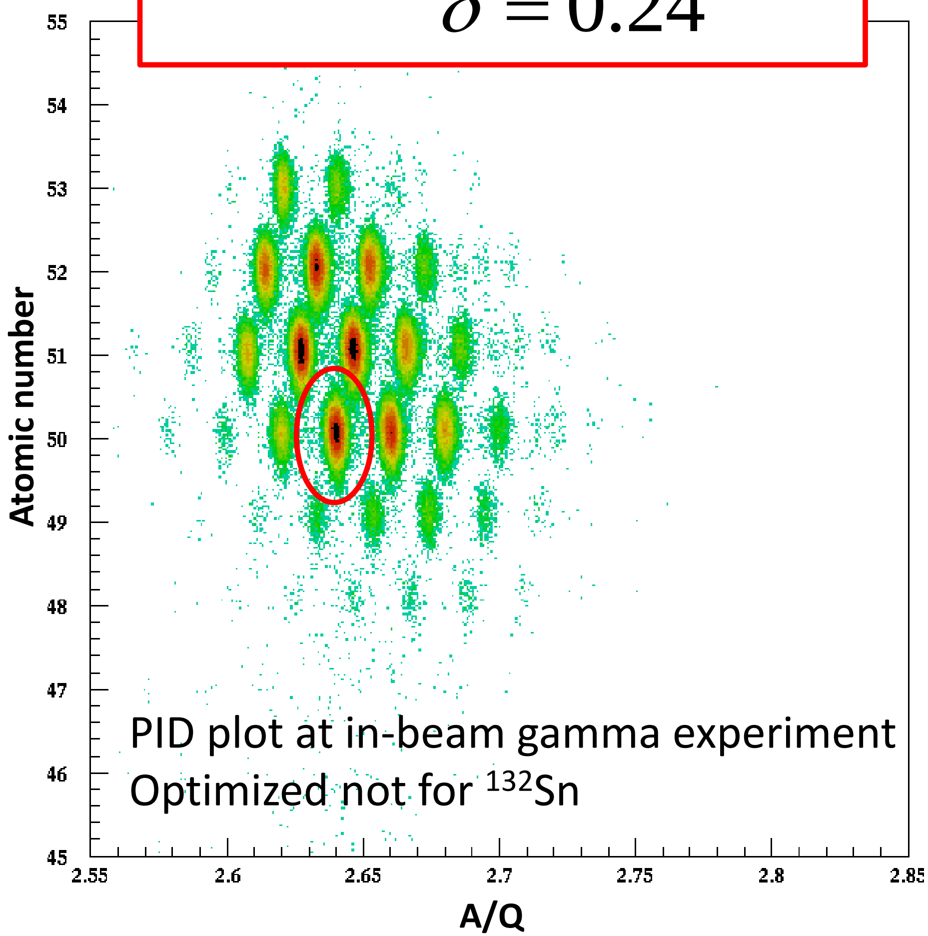
Available beam at RIBF

- ^{18}O, ^{48}Ca, ^{70}Zn, ^{124}Xe and ^{238}U primary beam.
- Fragmentation process for 2ndary RI beam production through Be or Pb primary target.
  - Mainly Uranium is used for making heavy neutron rich beams.
- It is possible to scan isotopes for wide range.
  - ^{108}Sn, ^{112}Sn, ^{124}Sn and ^{132}Sn.
  - Useful for the study of other nuclear effect.



^{132}Sn beam at RIBF

^{132}Sn: $N/Z = 1.64$, $\delta = 0.24$



PID plot at in-beam gamma experiment
Optimized not for ^{132}Sn

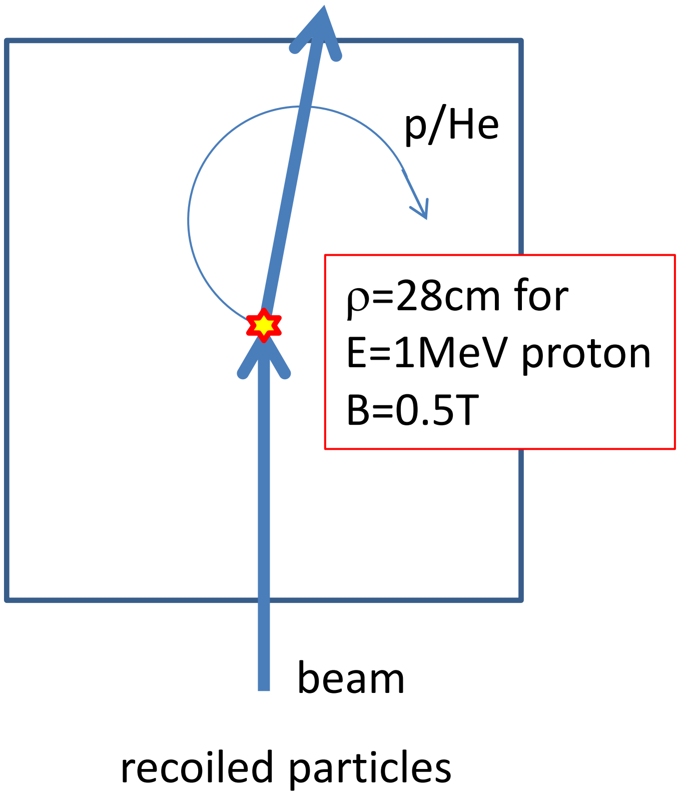
- From U primary beam: 345AMeV 5pnA
- 270 MeV/u, 1200cps, and purity of 12% ^{132}Sn beam was made at last in-beam gamma experiment.
- Rough LISE++ calculation shows ~3000cps, 30% purity, 300 MeV/u ^{132}Sn is possible to be made at RIBF.
- My question: other contaminations are useless??

Application of SAMURAI-TPC to other experiments.

- Only for HIC experiments?
  - Any suggestions are welcome.
- Forward angle inelastic scattering experiment?
  - Measurement of Giant monopole resonance.
- Inverse kinematics in the case of RI.

→Active target TPC.

  - Use TPC gas as target as well as TPC volume.
  - Low-pressure volume to gain range.
    - ^{4}He recoil energy at 0.5 degree (c.m.s.) is only 0.27MeV for ^{68}Ni at 100 MeV/u.
  - Internal trigger with GET electronics.



Summary

- TPC for use within the SAMURAI dipole magnet at RIKEN, Japan
  - Complete: Top Plate & Structural Ribs, Enclosure Frame and Sealing Plates, Motion Chassis and Hoisting Beams
  - Fabrication underway: Pad planes, field cage, voltage step down
  - Construction expected to finish in 2012; delivery to RIKEN 2013
- Dedicated electronics development in progress
- TPC Performance is simulated toward first experiment
  - Low energy thresholds are essential
- Experimental program at SAMURAI to begin in 2014

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