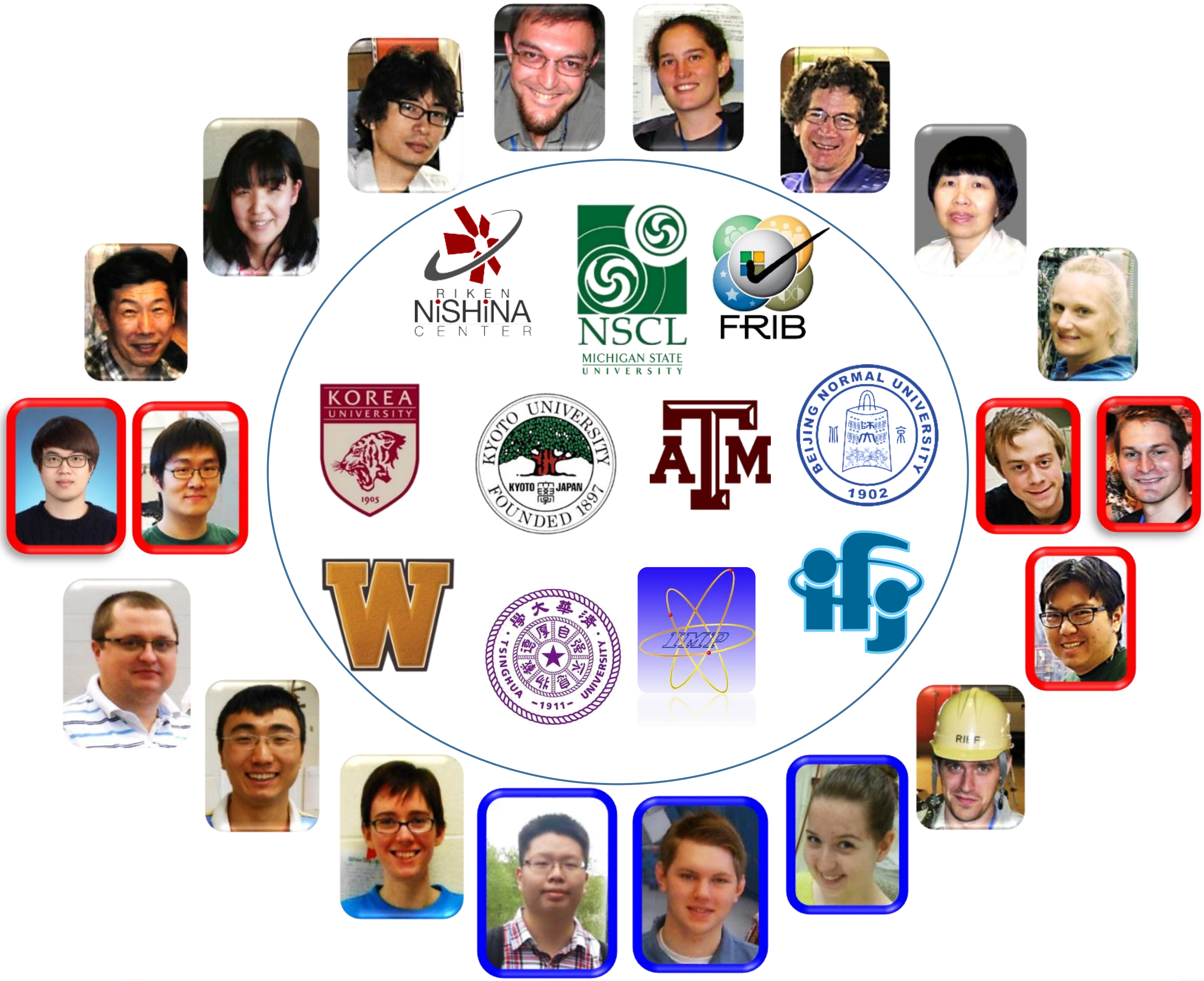
SπRIT TPC: Device to constrain the symmetry energy at supra-saturation densities

Jonathan Barney for SπRIT TPC Collaboration
4/17/2015

Outline

- Motivation: Probing the EoS at supra-saturation densities $\rho \approx 2\rho_0$
- Design and Construction of SpRIT TPC
- Experimental Programs.

R. Shane, et al., Nuclear Instruments & Methods in Physics Research A (2015), http://dx.doi.org/10.1016/j. nima.2015.01.026i



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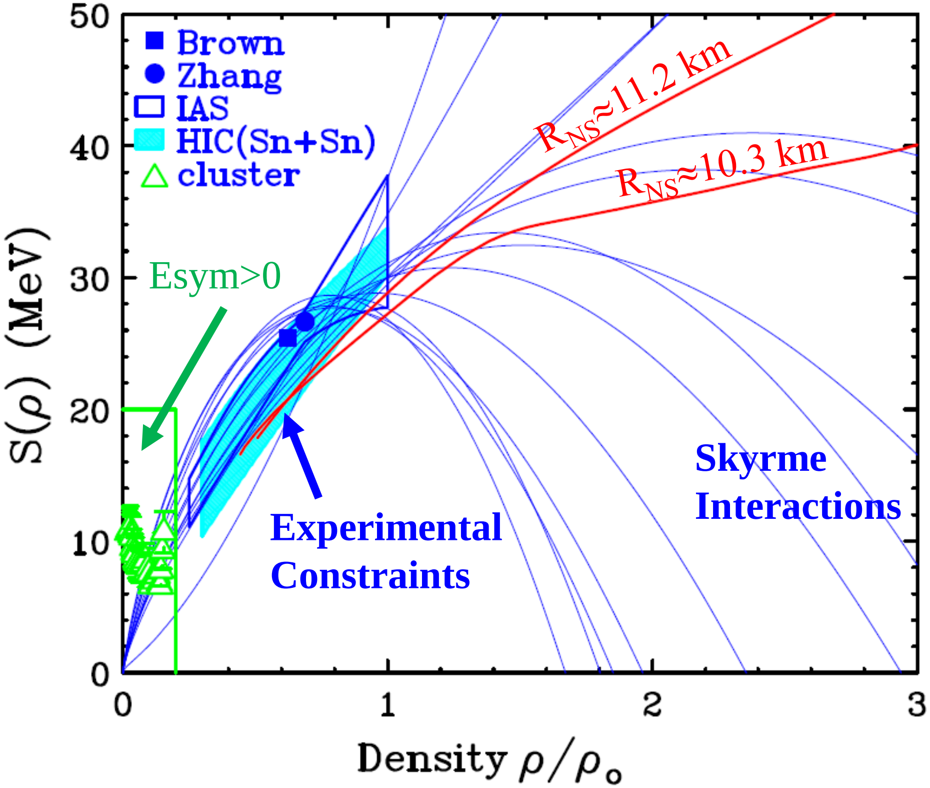
From Earth (Finite Nuclei) to Heavens (Neutron Star) Density Dependence of Symmetry Energy



•Status and LRP objectives:

- At $\rho \ll \rho_0$: Initial measurements to benchmark
  - Clustering effects in low-density EoS.
  - Relevant to Core-Collapse SN neutrino-sphere.
- At $\rho \leq \rho_0$: Consistent constraints from both structure and reaction experiments:
  - Need precision measurements of skins (PREXII and CREX), polarizability, Giant Resonances, isospin transport, (n/p, t/^{3}He) from heavy ion reactions and sub-barrier fusion cross-sections.
  - New measurements of fission barriers of exotic nuclei - surface symmetry energy.
- At $\rho \approx 1.5 - 2.5\ \rho_0$: Large uncertainties from theory, and NS mass vs. radius relationship.
  - Need laboratory experiments to constrain density and momentum dependence of symmetry energy at $\rho > \rho_0$.

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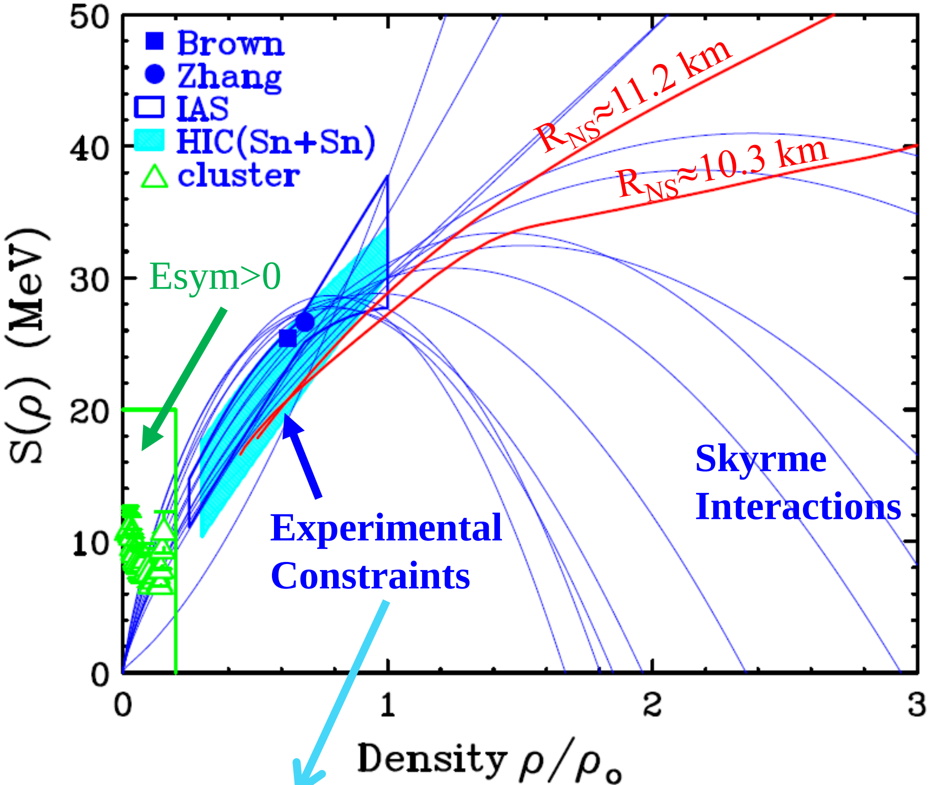
The Equation of State of Asymmetric Matter

•$E/A(\rho, \delta) = E/A(\rho,0) + \delta^2 \cdot S(\rho)$ $\delta = (\rho_n - \rho_p)/(\rho_n + \rho_p) = (N-Z)/A \approx 1$



The symmetry energy influences many properties of neutron stars but is highly uncertain especially at high density.

•Future Directions: Constrain the symmetry energy at supra-saturation densities with comparisons of (π^-, π^+), (n, p) (t, ^{3}He) production and flows. Such observables are selectively sensitive to the symmetry energy.

•At $\rho<\rho_0$, consistent constraints obtained from different observables:

•Heavy Ion Collisions , Giant Dipole Resonances, Isobaric Analog States, Nuclear masses, Pygmy Dipole Resonances, Pb skin thickness measurements, and neutron star radii.

M.B. Tsang et al., Phys. Rev. C 86, 015803 (2012) http://link.aps.org/doi/10.1103/PhysRevC.86.015803

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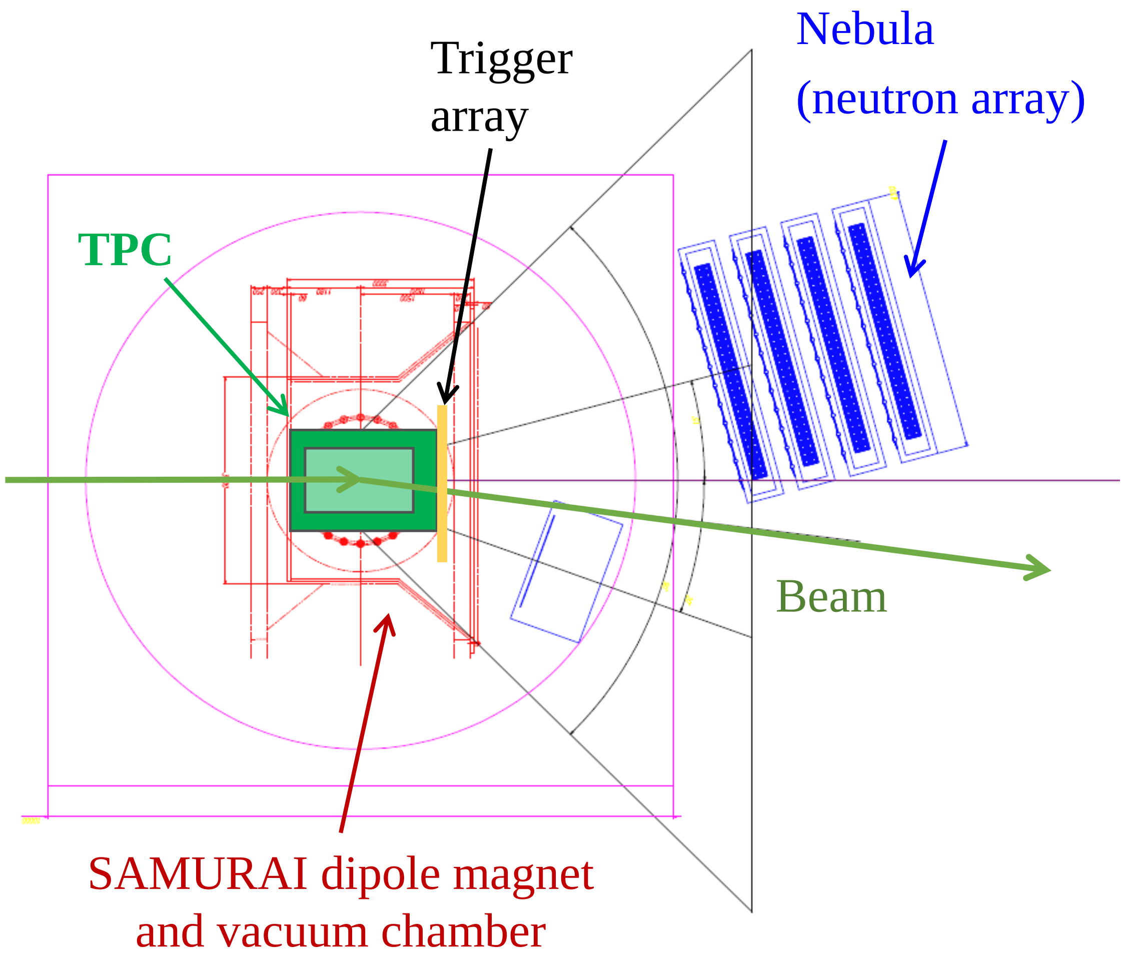
TPC and SAMURAI

- Time-projection chamber (TPC) will sit within SAMURAI dipole magnet.

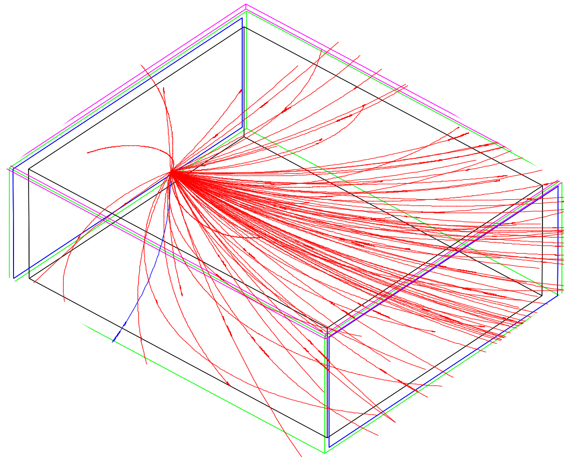
Mass	
B_{typ}, B_{max}	0.5T, 3T
R, pole face	1 m
Gap	80 cm
Usable gap	75 cm

- Open allows detection with auxiliary detectors for heavy-ions, light charged particles, neutrons, and an external trigger



Drawing courtesy of T. Isobe

Desired TPC properties



GEANT simulation

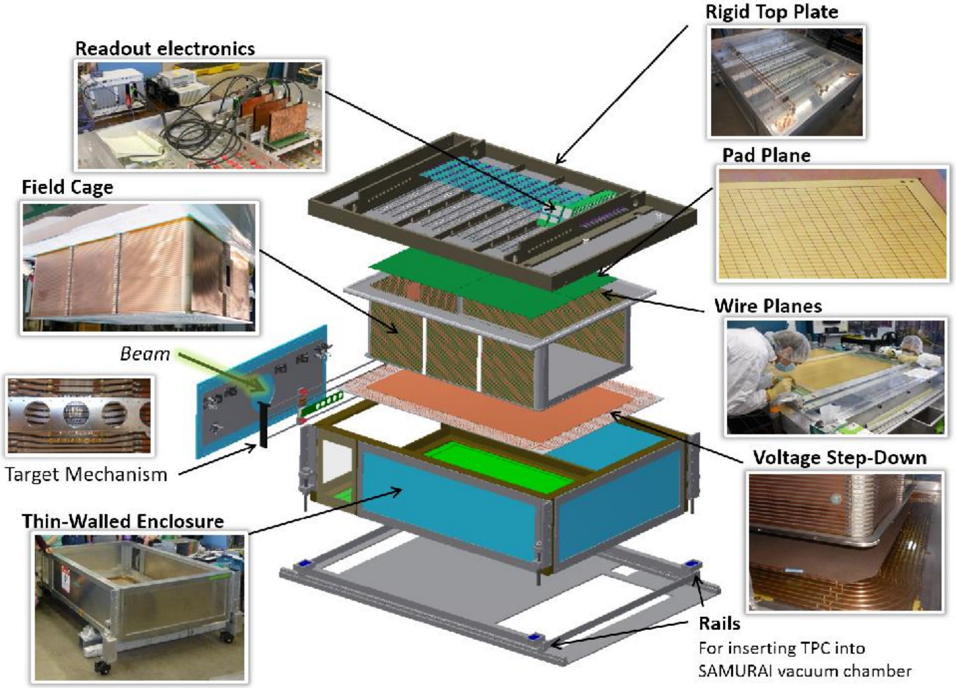
^{132}Sn+^{124}Sn collisions at E/A=300 MeV

- Good efficiency for pion track reconstruction is essential.
- Initial design is based upon EOS TPC, whose properties are well documented.
- SAMURAI has same pole diameter (2 m) as HISS, but a smaller gap of 80 cm (really 75 cm) vs. the 1m gap of HISS)

SAMURAI TPC Parameters	Values
Pad plane area	1.34m x 086 m
Number of pads	12096 (108 x 112)
Pad size	12 mm x 8 mm
Drift distance	53 cm
Pressure	1 atmosphere
dE/dx range	Z=1-3 (STAR El.), 1-8 (GET El.)
Two track resolution	2.5 cm
Multiplicity limit	200 (may impact absolute pion eff. in large systems.)

TPC Design and construction:

- Construction of TPC finished May 2013. Shipped to RIKEN January 2014. Tested with 6048 channels February 2015
- Construction Topics
  - Chamber enclosure
  - Field cage
  - Entrance and exit windows
  - Voltage step down
  - Pad plane
  - Wire planes
- Development Topics:
  - Electronics systems
  - Electronics cooling
  - Insertion



https://groups.nscl.msu.edu/hira/sepweb/pages/slideshow/tpc-exploded.html

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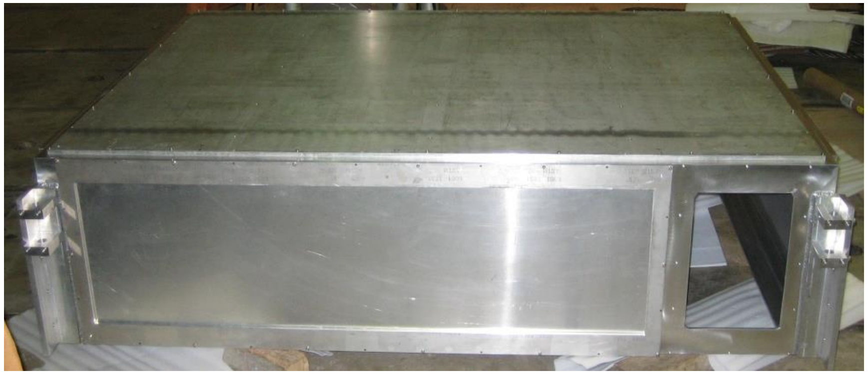
SAMURAI TPC Enclosure fabrication

A. McIntosh, Texas A&M



- Contains gas, and keeps pad plane and field cage protected
- 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. Beam line-coupling hole machined

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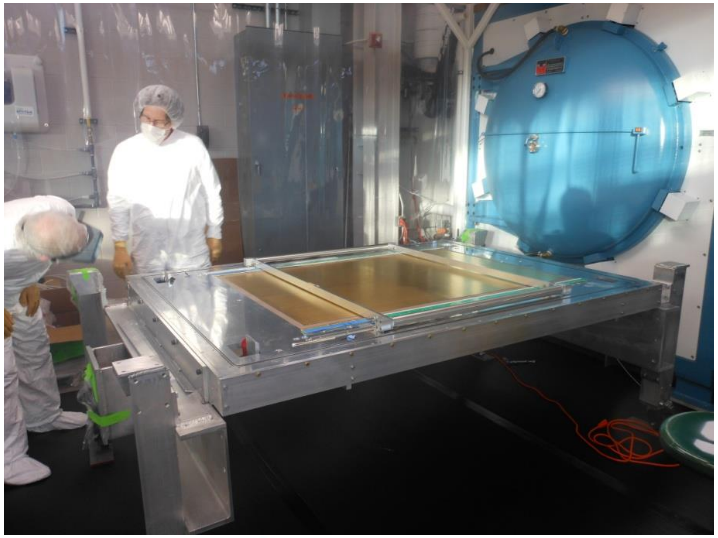
Manipulation of SAMURAI TPC (~ 0.6 ton)



- Motion Chassis and Hoist Beams work as designed.
- The TPC Enclosure can be lifted and rotated with relative ease.
- The Motion Chassis can also be mounted on the top plate and facilitates transportation of the TPC and work on the top plate.

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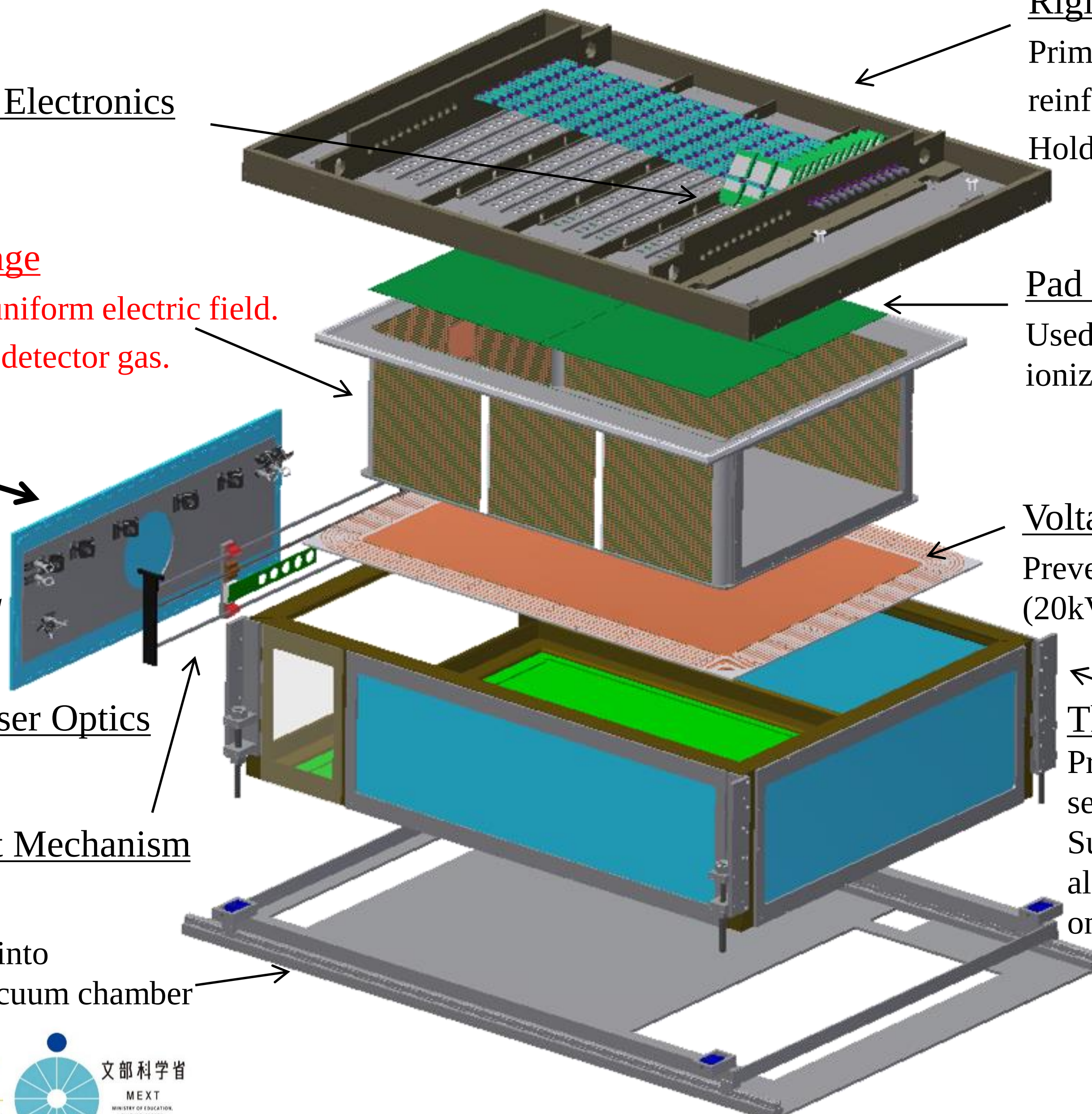
SAMURAI TPC: Exploded View



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

Front End Electronics
Air Cooled

Field Cage
Defines uniform electric field.
Contains detector gas.

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

beam

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

Calibration Laser Optics

Thin-Walled Enclosure
Protects internal components, seals insulation gas volume, Supports pad pan while allowing particles to continue on to ancillary detectors.

Target Mechanism

Rails
Inserting TPC into SAMURAI vacuum chamber

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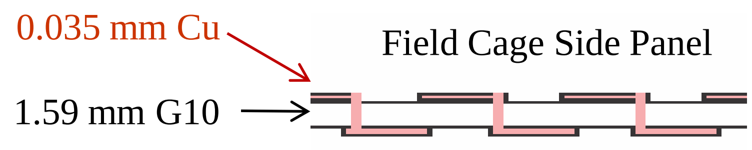
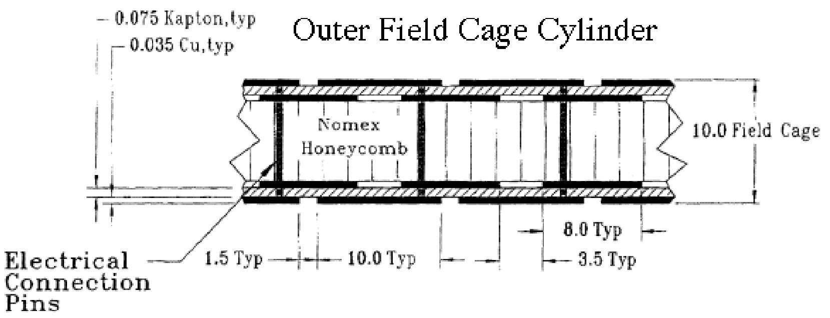
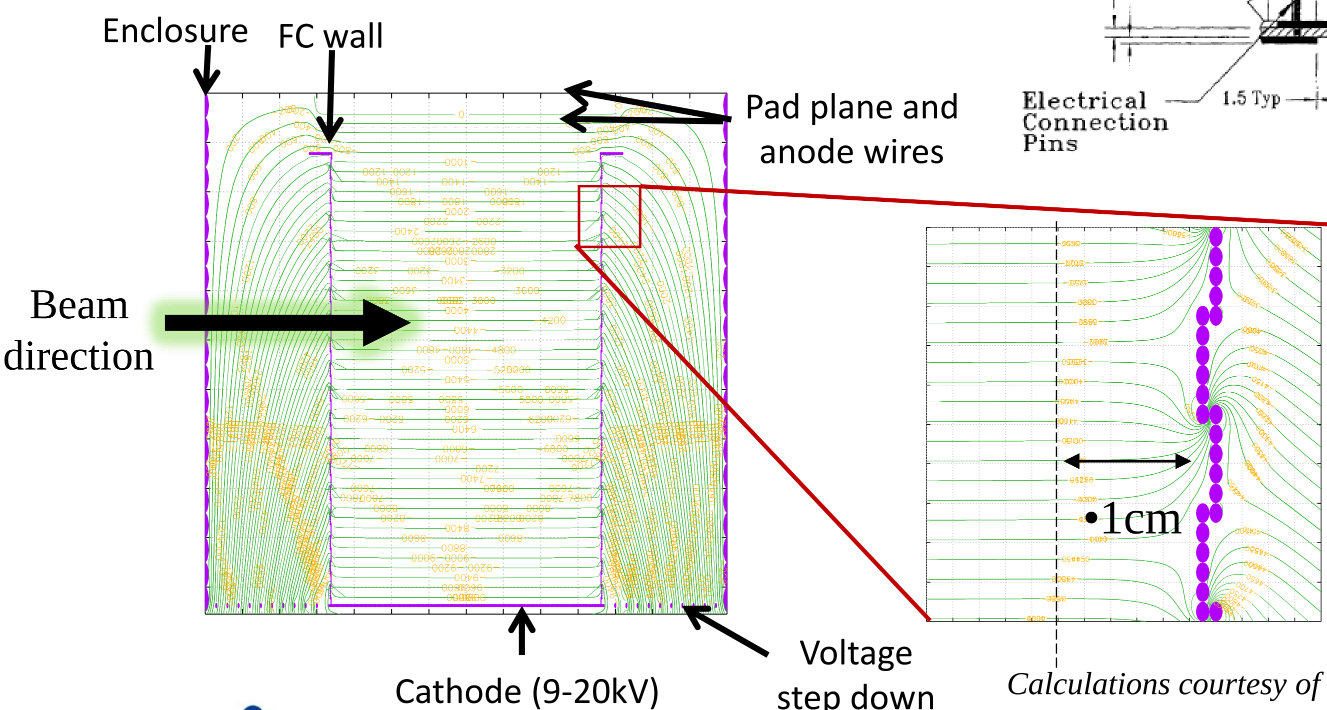
Field cage – the Heart of the TPC

- Produces uniform electric field for electron drift to amplification region
- Made of two layer PCB's
- Thin walls for particles to exit
- Gas tight (separate gas volumes)



STAR Design





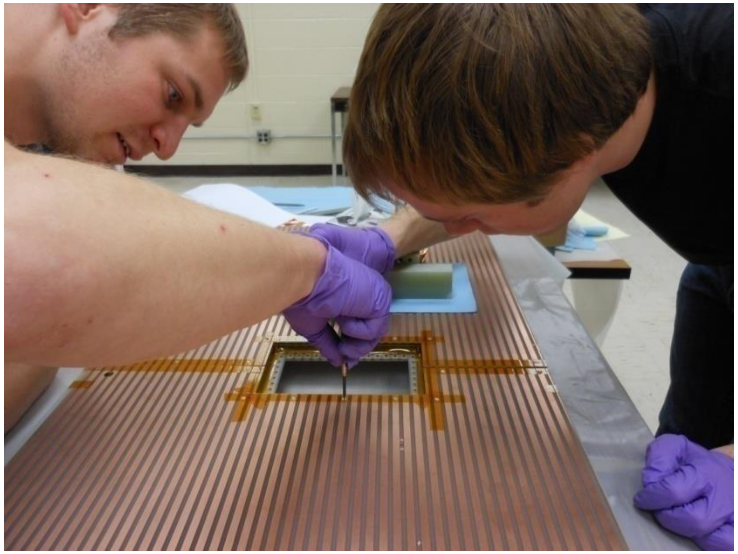
GARFIELD calculations (on scaled field cage) show uniform field lines 1cm from the walls

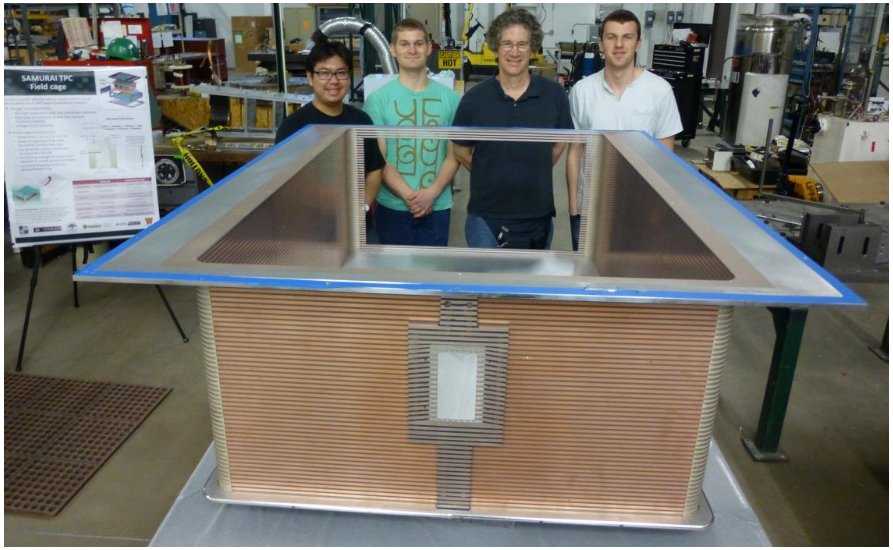
Calculations courtesy of F. Lu

Assembling Field Cage.

Components

- Side panels are PCB's fabricated with Halogen-free G-10.
- Corners are fabricated from Halogen-Free G-10.
- Front and rear window frames and side struts are polycarbonate.
- Front window will be 12 μm PPTA and back window will be 125 um Kapton, with evaporated Aluminum electrodes.
- Electrode surfaces on polycarbonate and on G-10 corners are conductive epoxy.
- Cathode is aluminum honeycomb. Cathode electrode surface is Aquadag E.
- Field cage is insulated from top plate by polycarbonate ring.

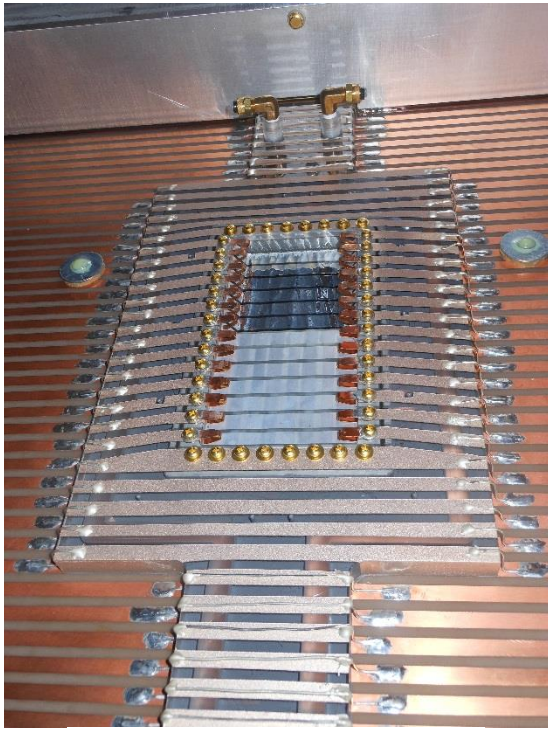




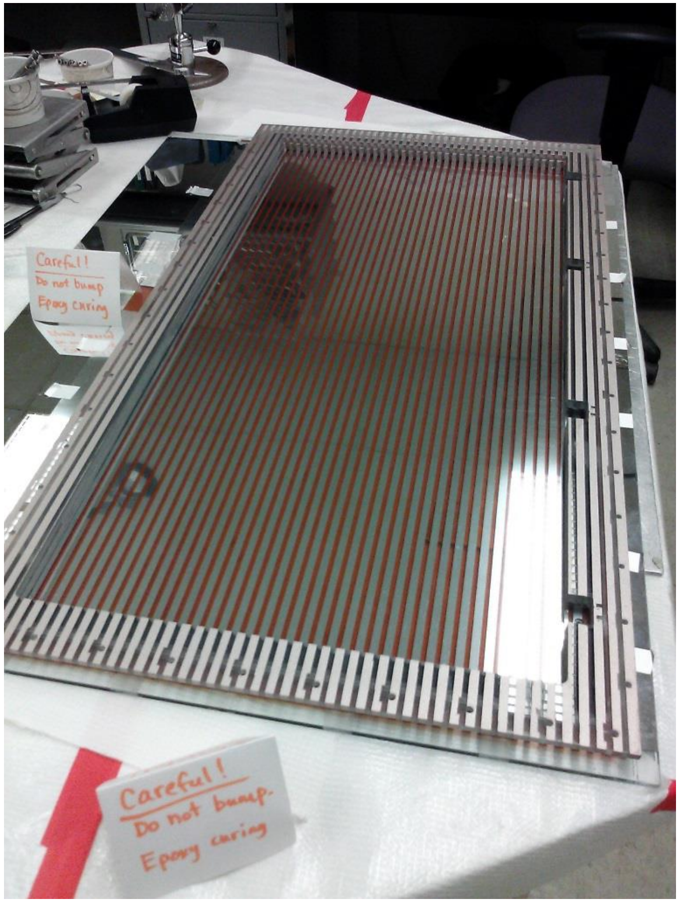
Windows on Field Cage

- Aluminum entrance and exit window electrodes evaporated on PPTA and Kapton foils, respectively.
- Thin windows allow beam to enter and light fragments to pass through

- Evaporation performed at the NSCL detector lab



Entrance window



85 cm x 50 cm exit window.

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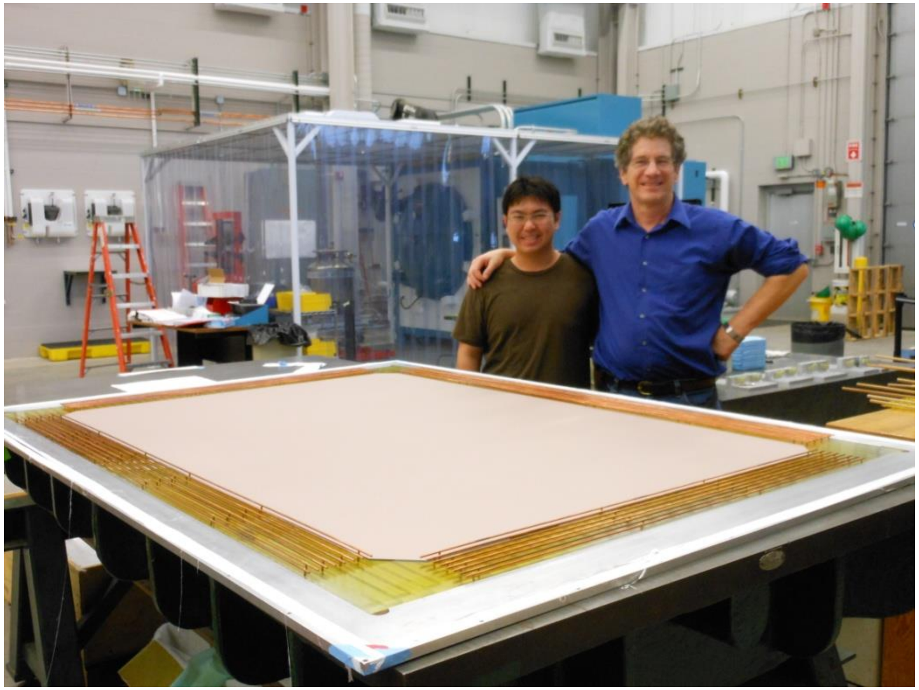
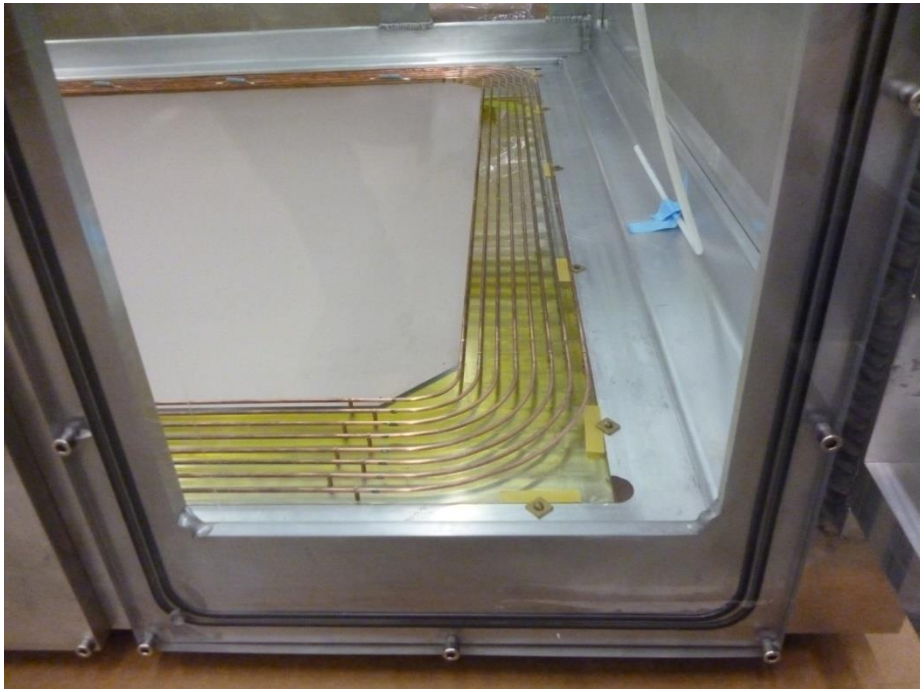
Voltage step down





- Eight concentric copper rings step the voltage down from cathode HV (~10kV) to ground without sparking. Tested to 20 kV.
- Situated about 6 mm below the cathode
- Polycarbonate (6 mm) epoxied to bottom plate of enclosure.
- Copper-silver epoxy electrode surface below cathode is biased to the cathode voltage.

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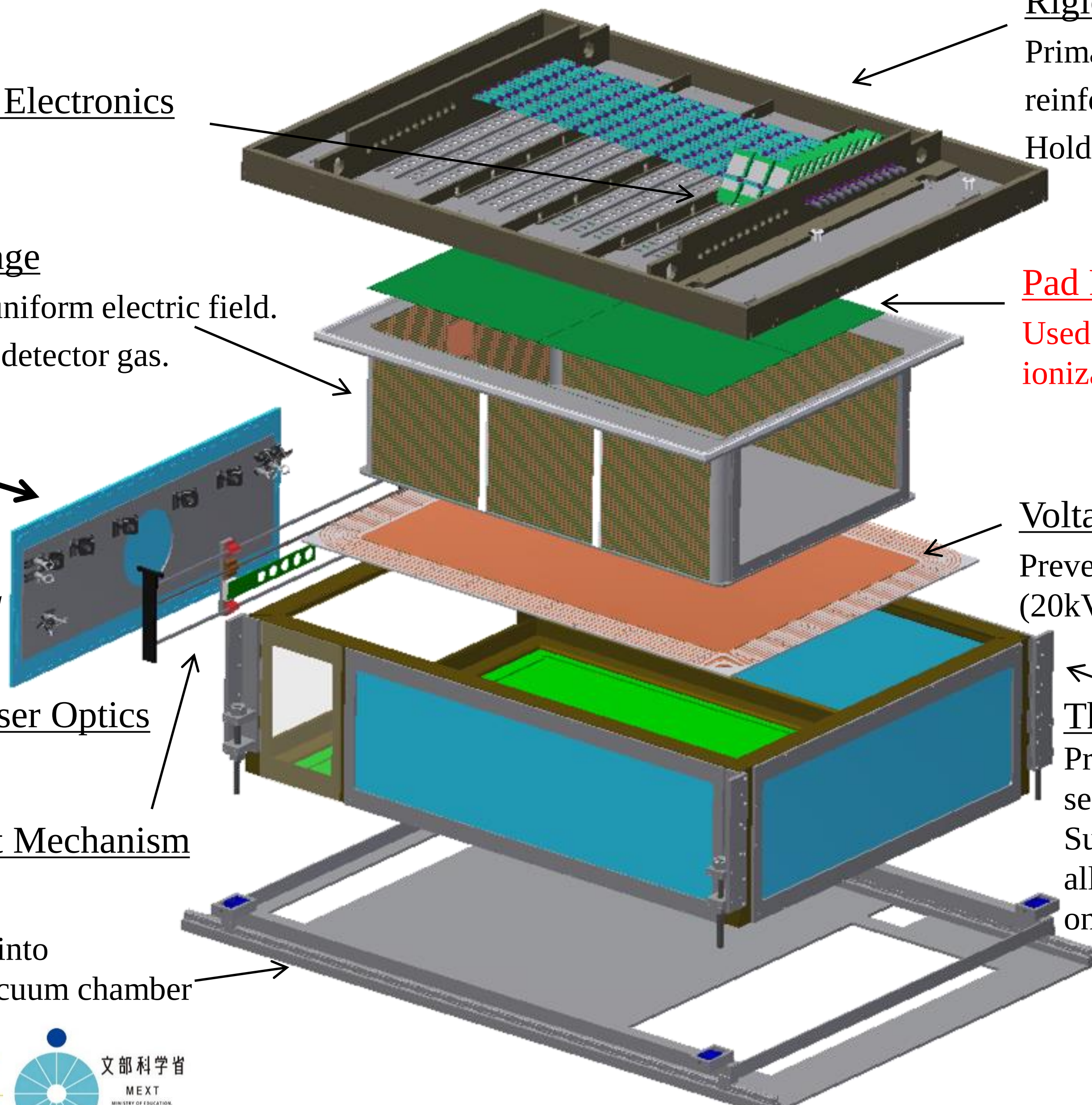
SAMURAI TPC: Exploded View



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

Front End Electronics
Air Cooled

Field Cage
Defines uniform electric field.
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Pad Plane (108x112)
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beam

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

Calibration Laser Optics

Thin-Walled Enclosure
Protects internal components, seals insulation gas volume, Supports pad pan while allowing particles to continue on to ancillary detectors.

Target Mechanism

Rails
Inserting TPC into SAMURAI vacuum chamber

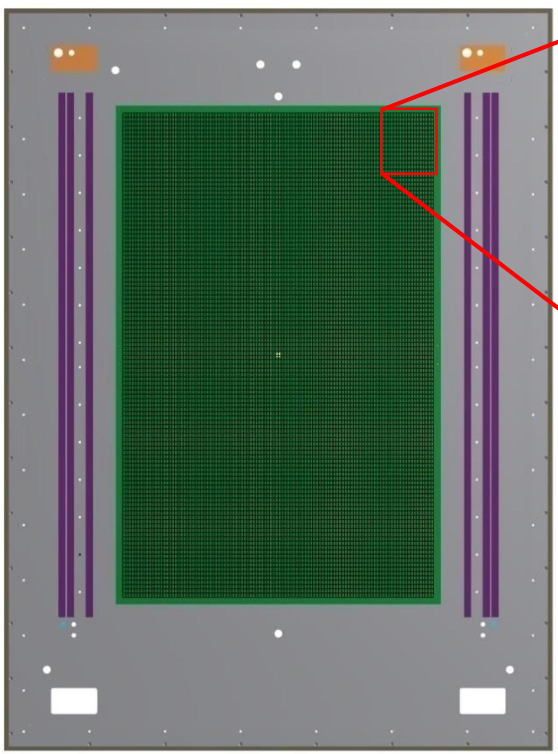
Pad plane

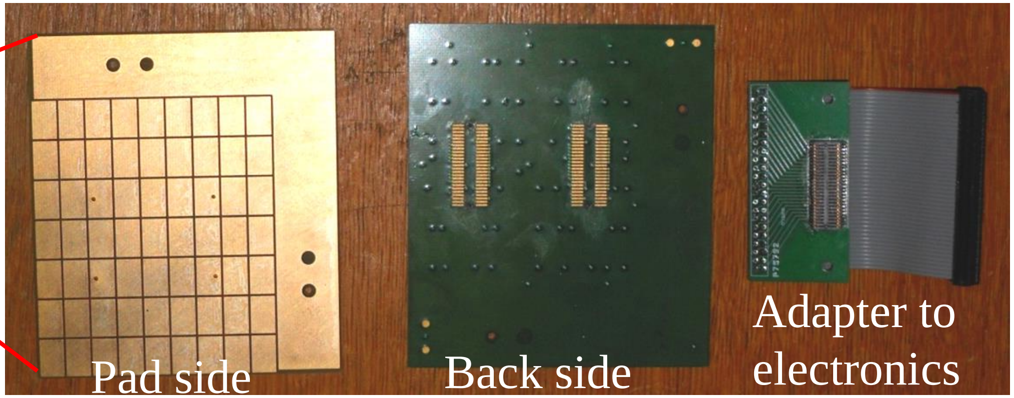
Full pad plane

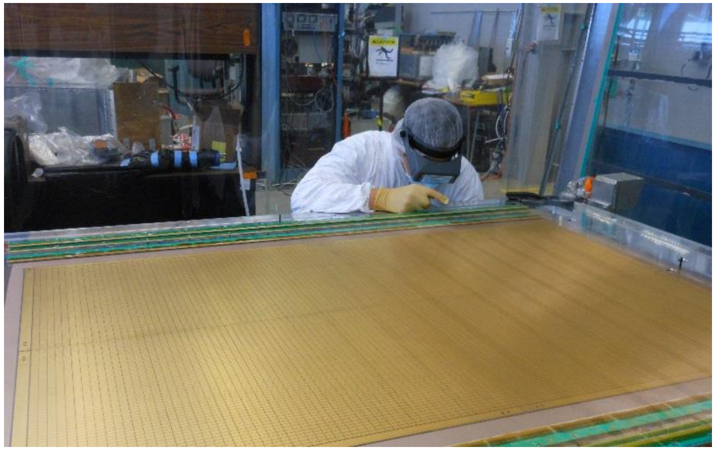
- Provides 2-D readout of tracks
- Mounted on bottom of top plate
- 112 x 108 = 12096 pads
- Each pad: 12mm x 8mm

• Small scale prototype: 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







Full pad plane mounted on top plate

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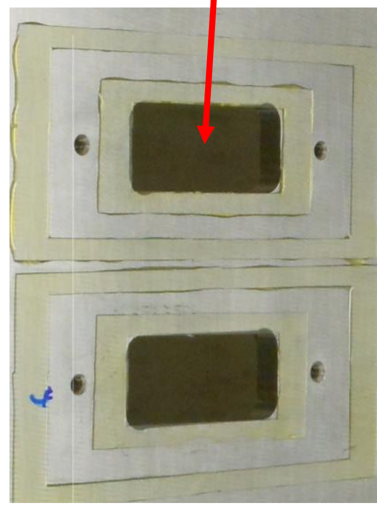
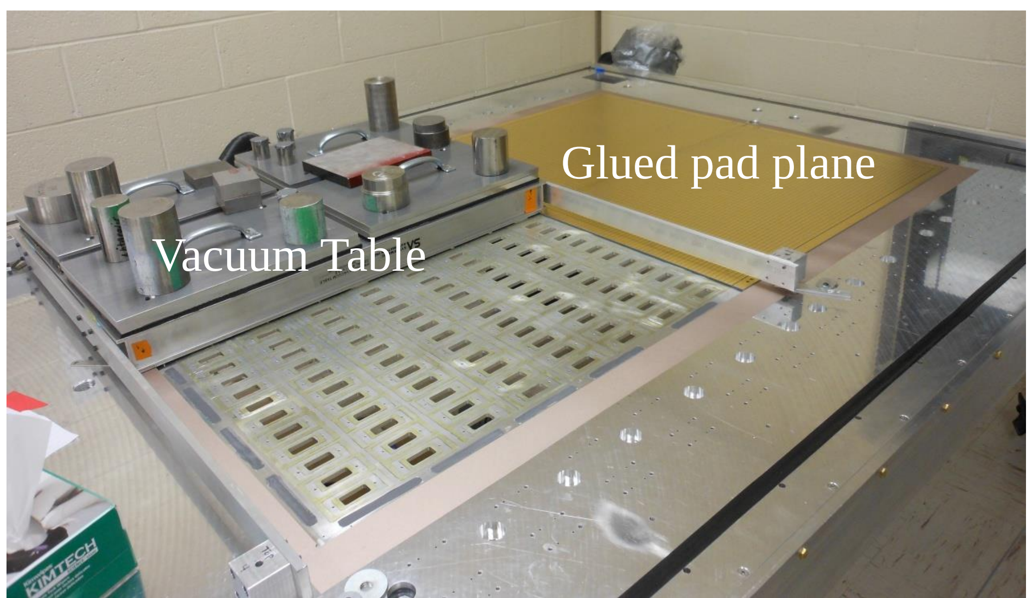
Gluing and Assembly of pad planes

- Pad plane glue applied in a grid layout to facilitate leak repair
- Pad planes held flat relative to one another by use of a vacuum table during gluing
- Leak-tested on sealed TPC
- Small leaks were found and fixed successfully

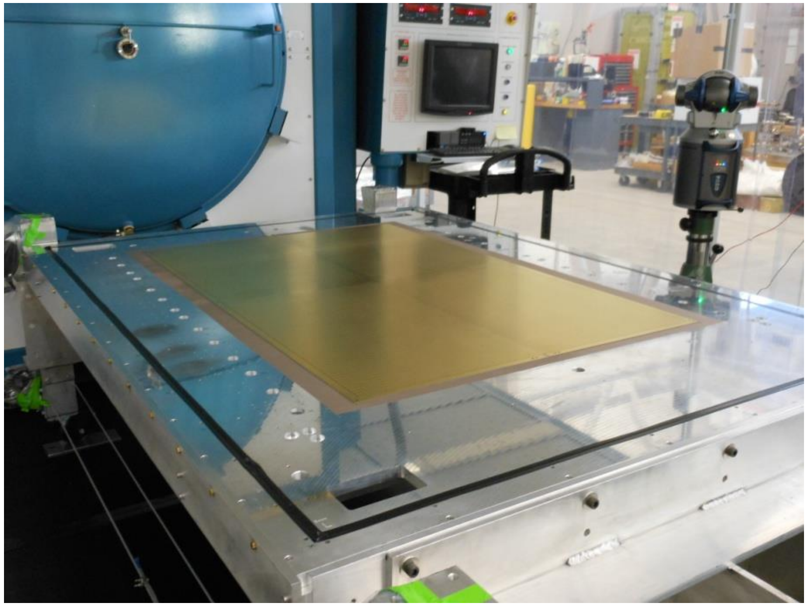
Hole for connection to electronics

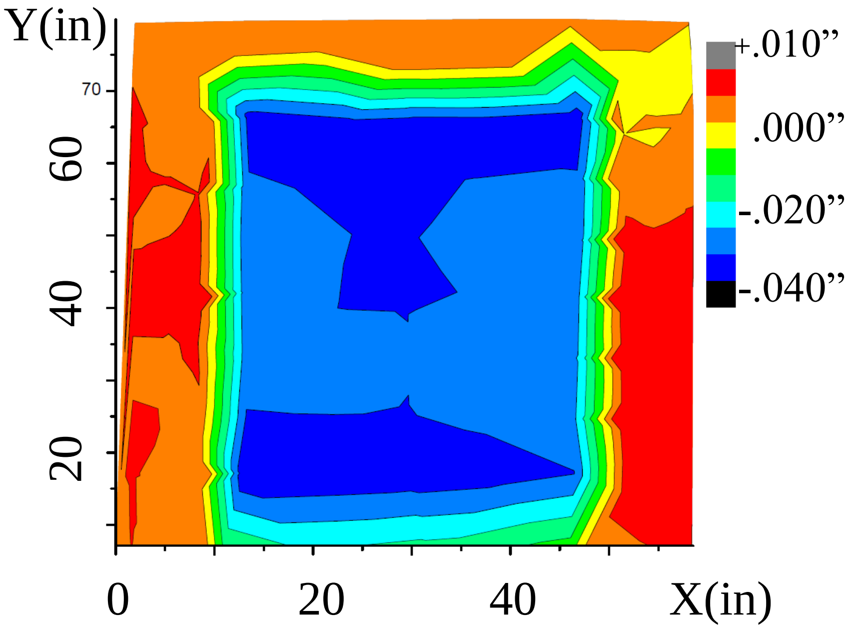


Cell layout allows repair

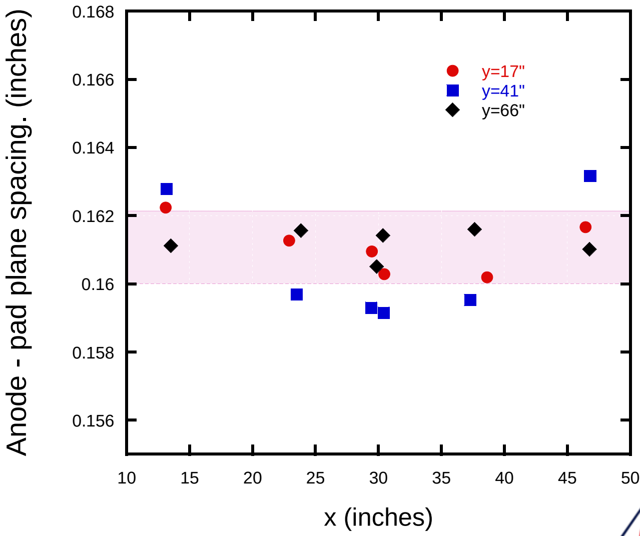


Leveling of top plate with laser





- The top plate is flat to within about 5 mils.
- The pad plane is slightly higher at the center than elsewhere. This is likely the result of the weight applied while gluing.
- Based on these measurements, we adjusted the bars for anode and ground plane to make the anode – pad plane spacing to be approximately 4.05 mm.
- As a result, pad-plane–anode wire heights should be constant to within 2 mils.



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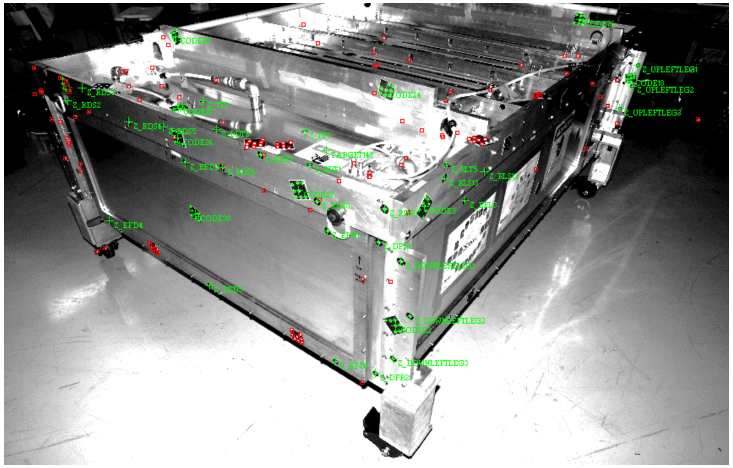
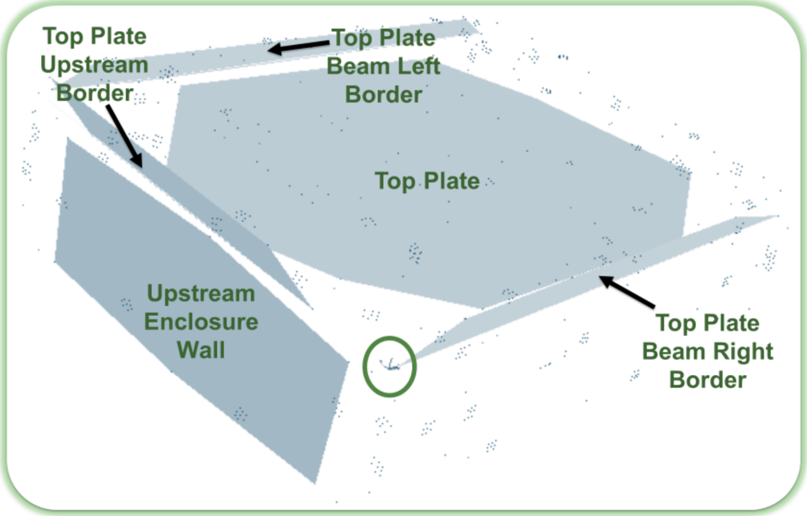
Photogrammetry Checks

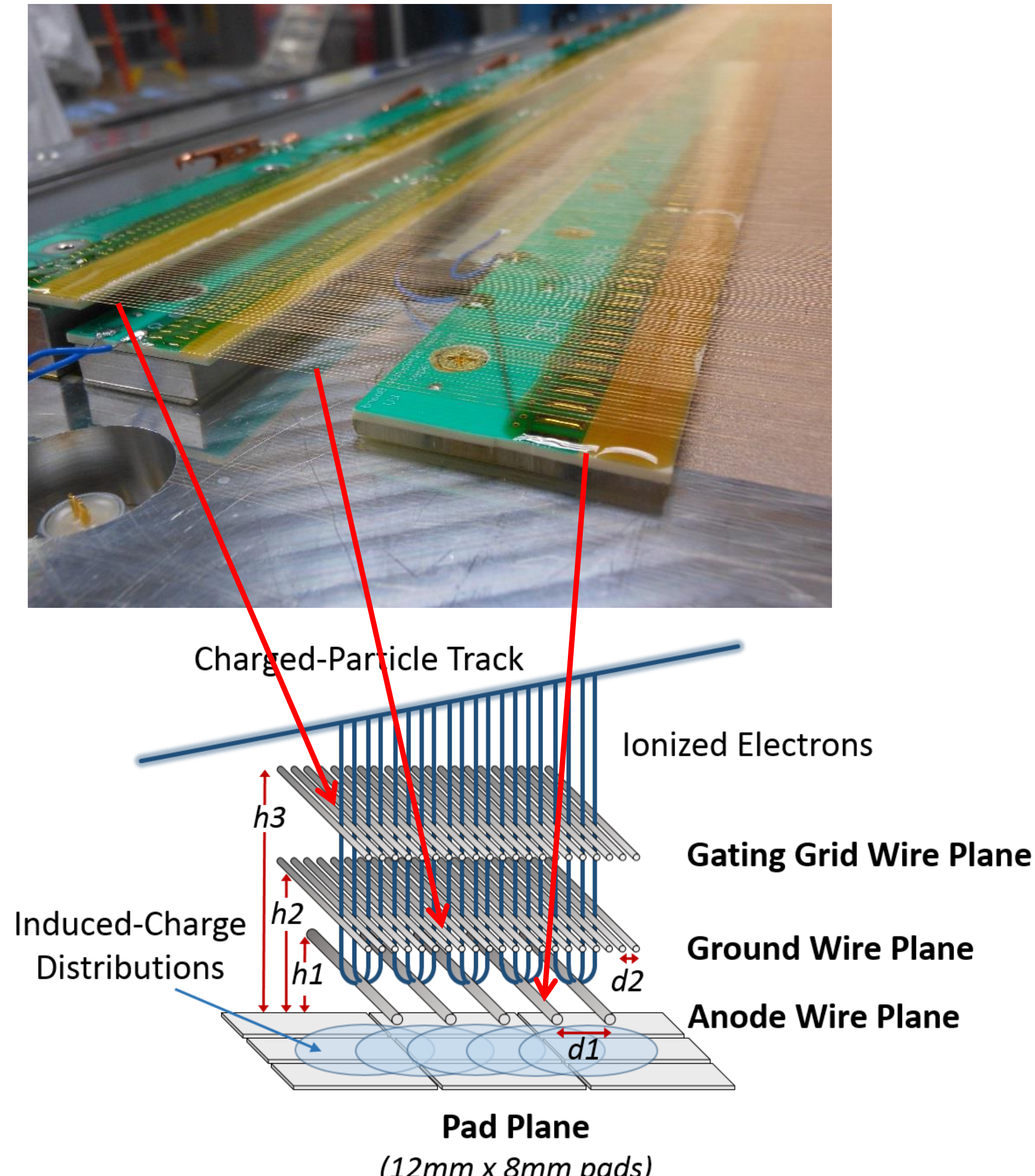


- The assembled TPC was checked using photogrammetry measurements
- The flatness of the top plate is consistent with the laser level checks
- Photogrammetry will be used to determine the position in the magnet chamber



Wire planes

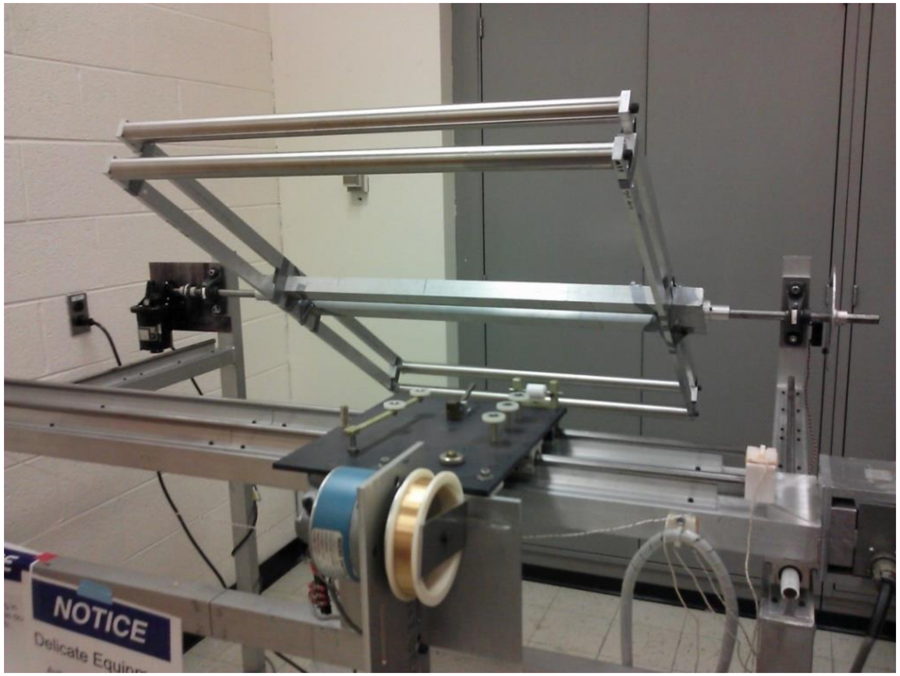
- Anode and ground plane create avalanche region for electrons
- Anode plane induces image charge on the pad plane
- Gating grid closes off amplification region when not triggered

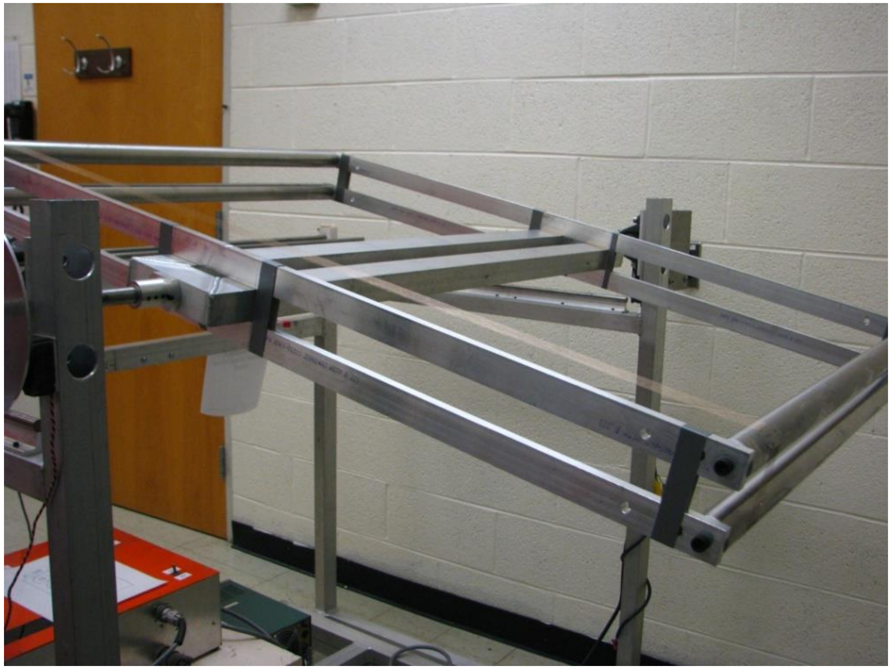


Plane	height (mm)	pitch (mm)	diameter(µm)
Anode	4.05	4	20
Ground	8.1	1	75
Gating grid	14	1	75

Wire planes – winding

- Wire winding and wire plane assembly are performed in separate class 10K clean areas.
- Frame size allows winding of a complete wire plane in one pass.
- Each frame holds ½ of a wire plane.





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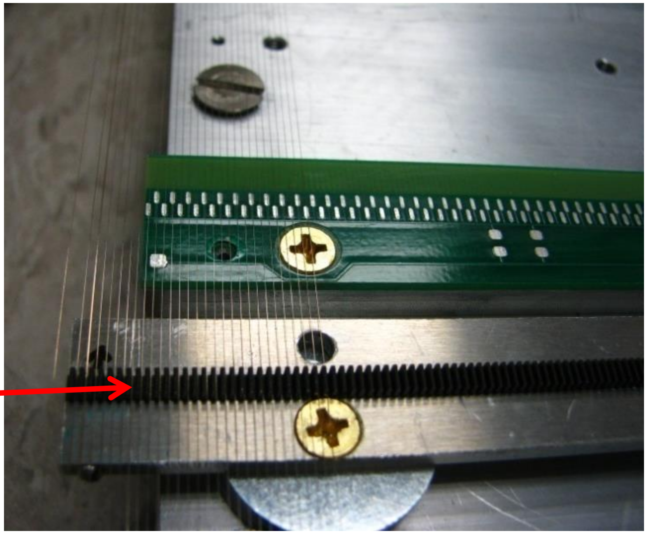
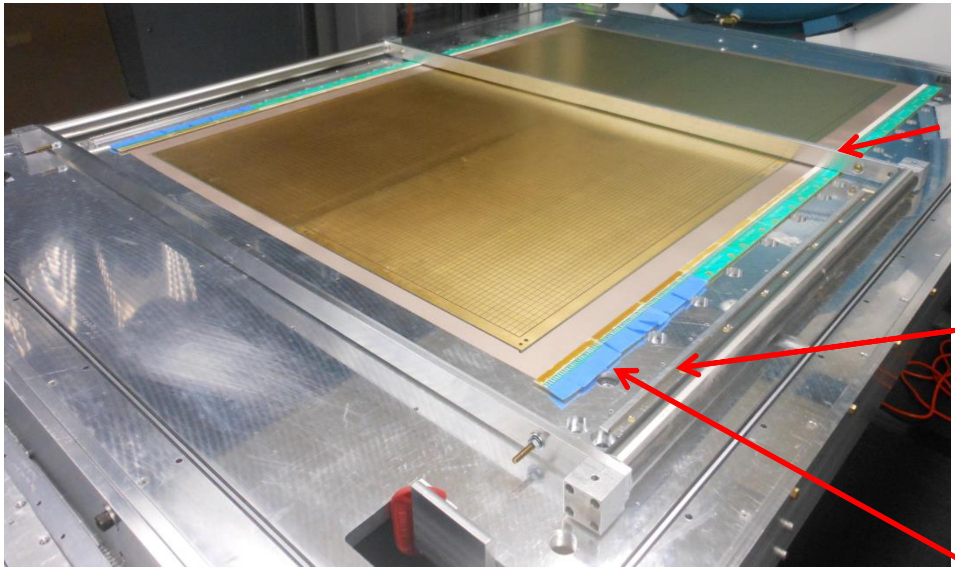
Wire planes – mounting

Test setup

- Wires were wound on frame in detector lab and transported in box to assembly area.
- 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.

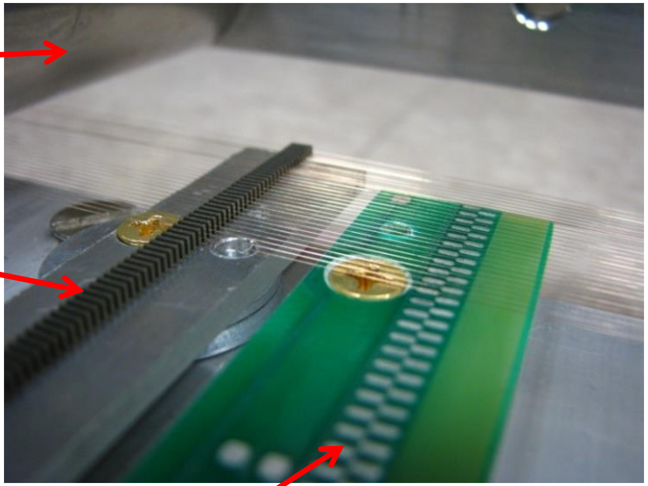


comb



frame

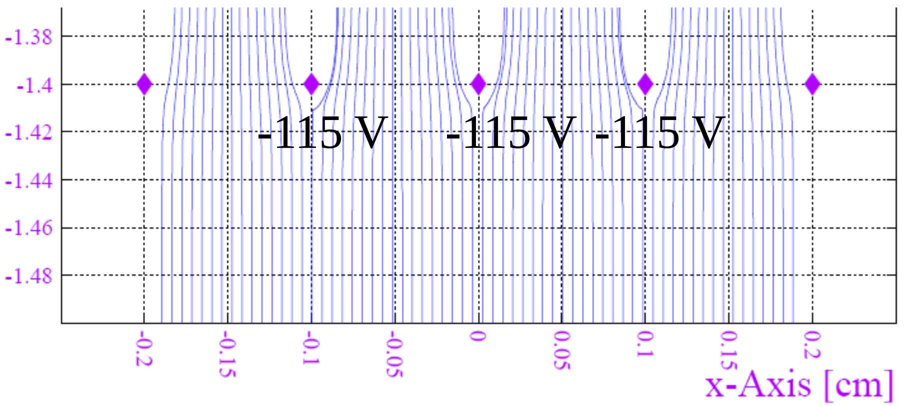
comb



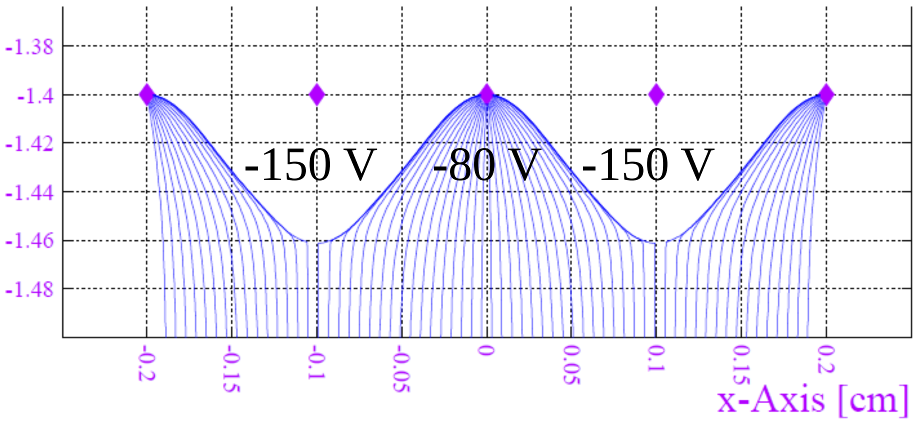
circuit board
with solder pads

Gating grid

- Gating grid closes amplification region when not needed
- Beam height is 18.7 cm from gating grid.
- "Lost" drift length = $\Delta t_{grid} \cdot v_{drift}$ should be minimized by shortening Δt_{grid}
- Δt_{grid} is governed by three factors:
  - The capacitance of the grid (~15 nF).
  - The impedance of the driver and transmission line.
  - The matching of the currents drain the positive and negative wires on the grid as it discharges. (Charging can take longer.)



Garfield simulation of open gating grid - electrons pass through freely



Garfield simulation of closed gating grid – electrons trapped by the wires

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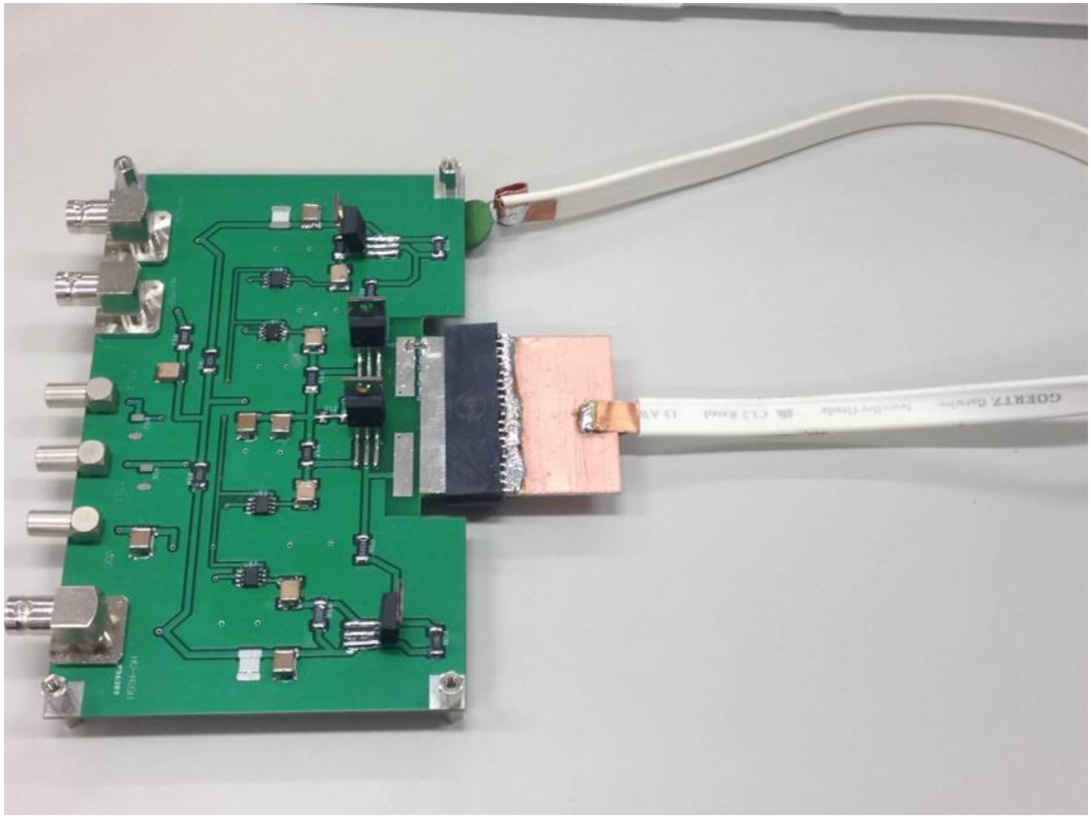
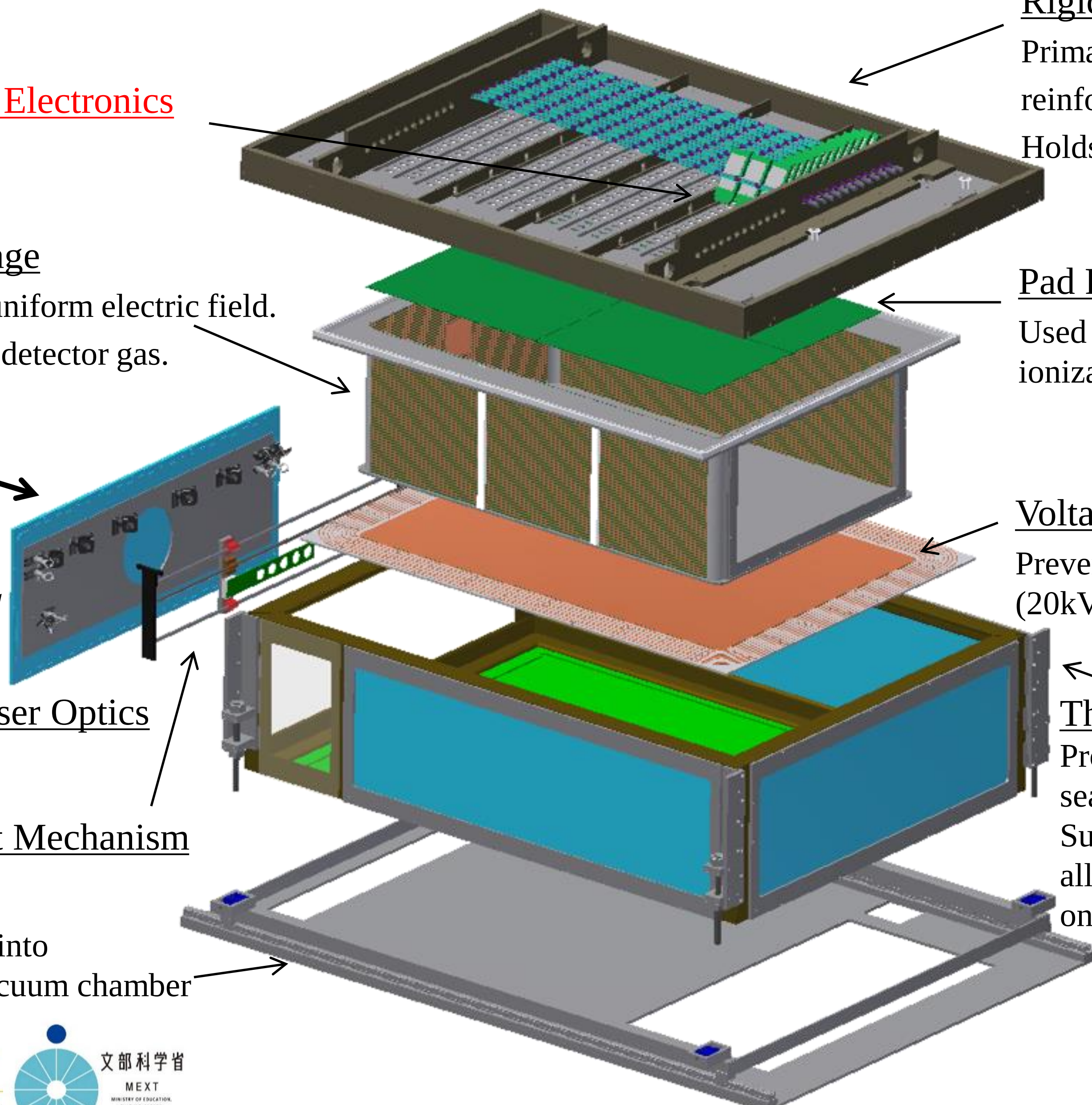
Gating Grid Driver

- Switches gating grid from closed to open in as little time possible
- Impedance matching is critical to reduce noise
- Circuit board has an on-board 50 Ω transmission line that could be decreased to 2Ω.
- This is supplemented with two commercial 4 Ω transmission lines that go along both ends of the gating grid.



SAMURAI TPC: Exploded View



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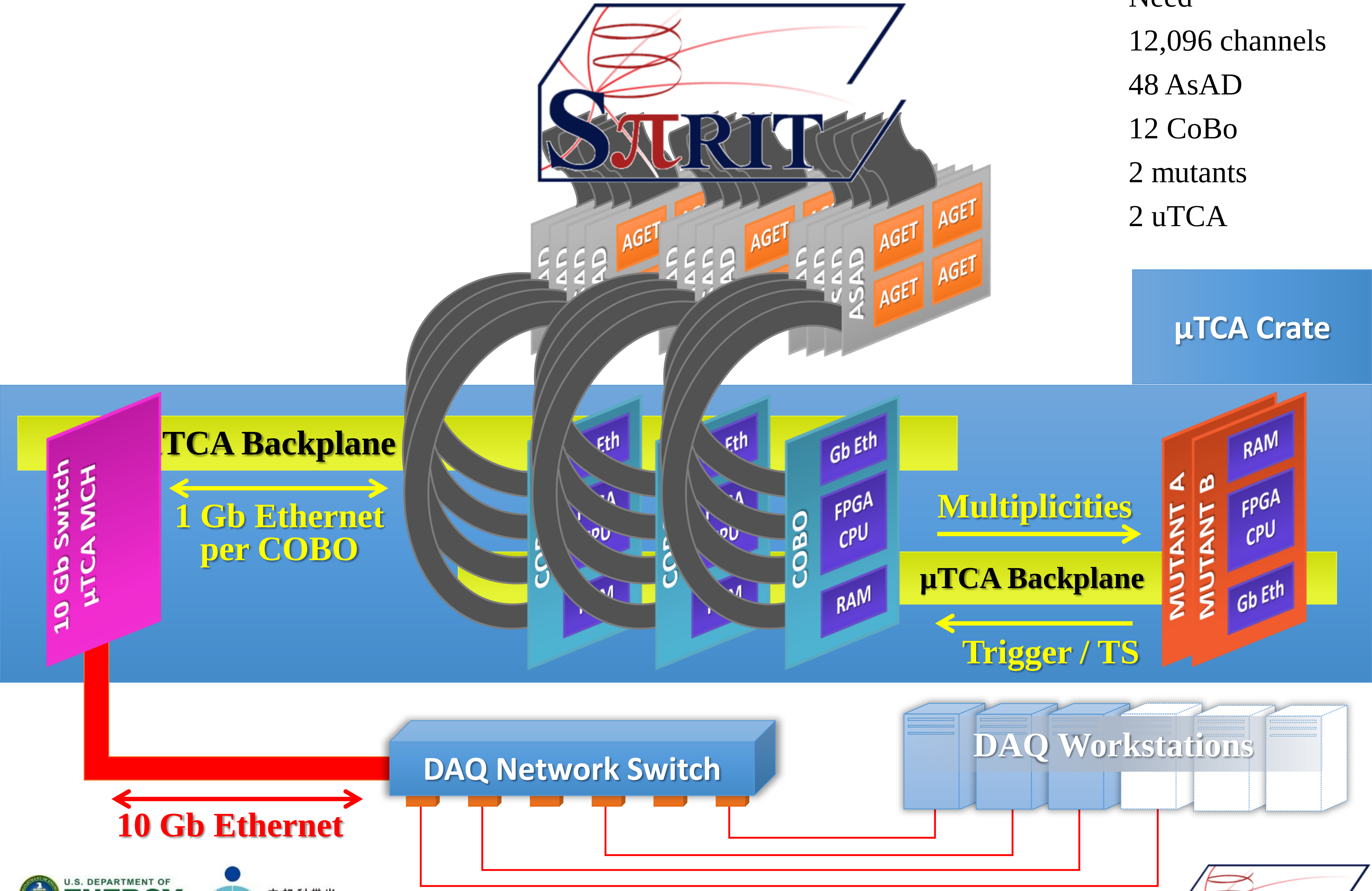
Hardware Architecture – GET

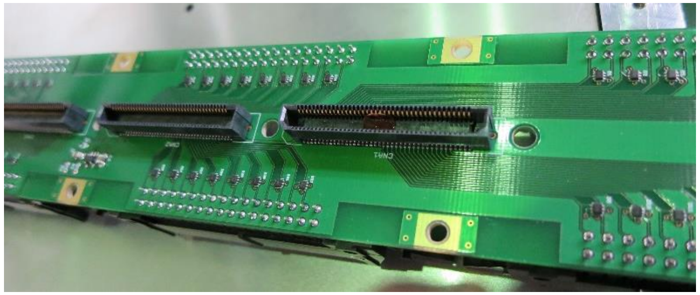
Need
12,096 channels
48 AsAD
12 CoBo
2 mutants
2 uTCA



GET Front End Electronics

- •Generic Electronics for TPC
- •Newly developed by GET collaboration
- •Used by other TPC projects

AsAd board mounted on TPC



ZAP board for interface between TPC and GET electronics

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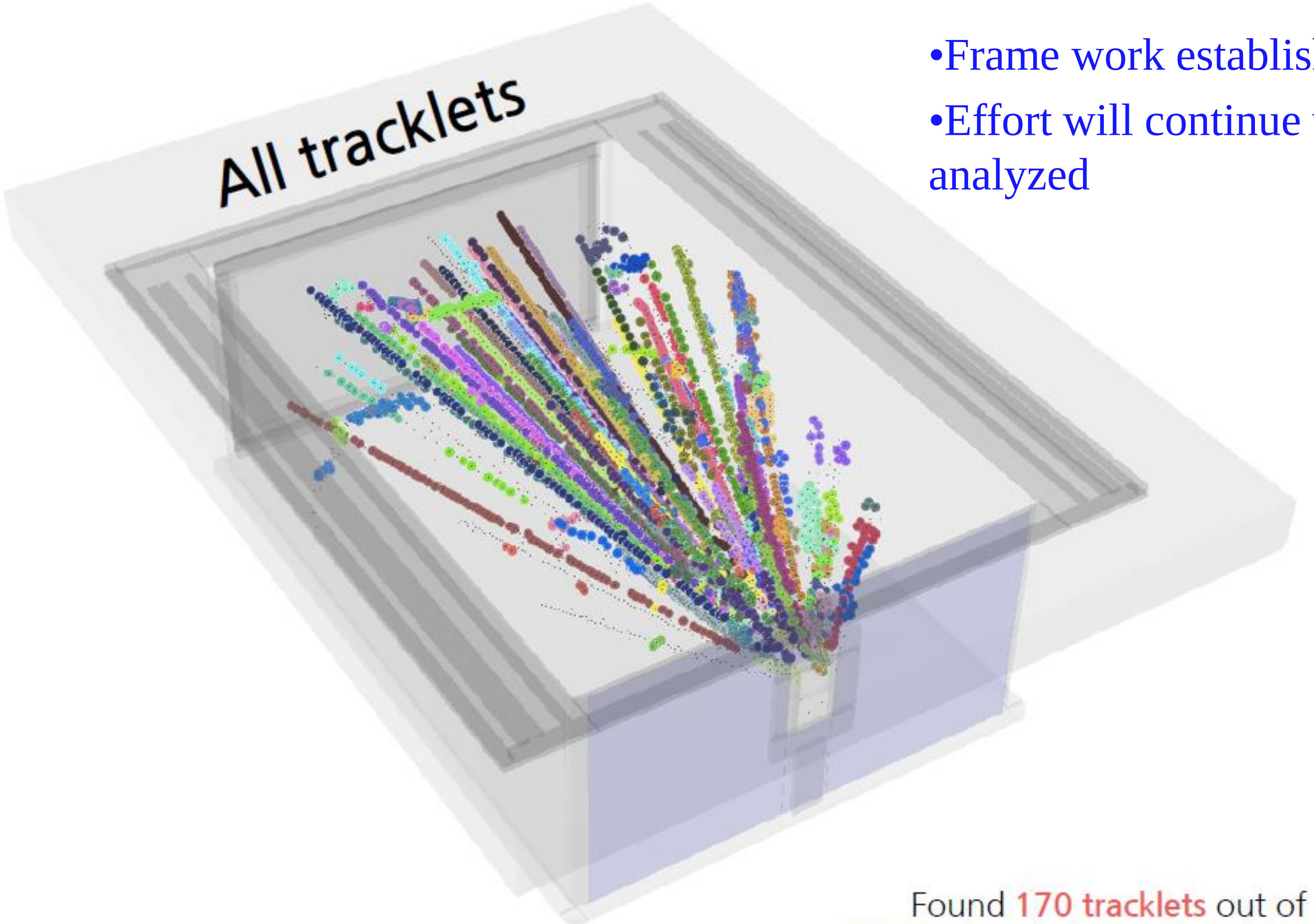
•Software Development: Jhang et al



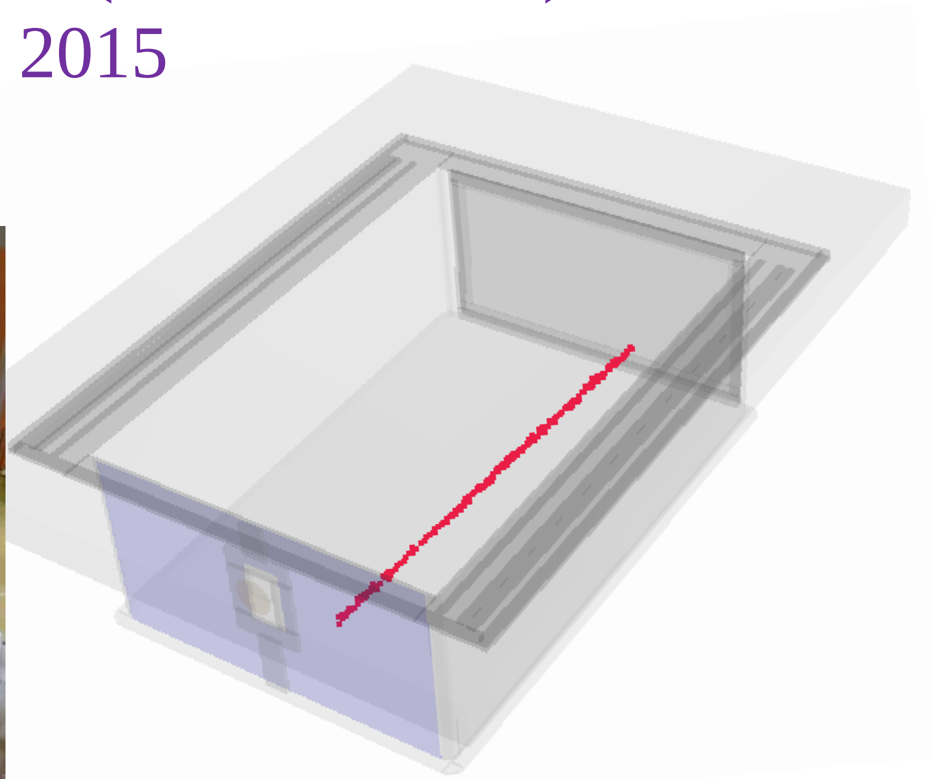
•Frame work established

•Effort will continue until data analyzed

Found 170 tracklets out of
80 produced charged particles

Cosmic tracks with GET (6048 channels)
February 2015

TPC with GET electronics installed
on half of pad plane



Reconstructed path from cosmic ray
in TPC

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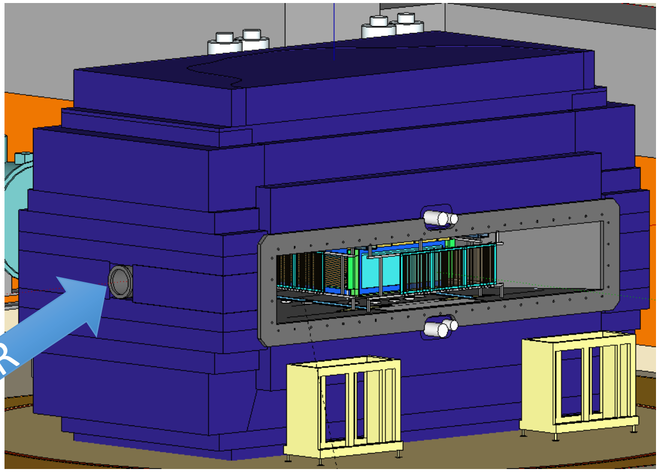
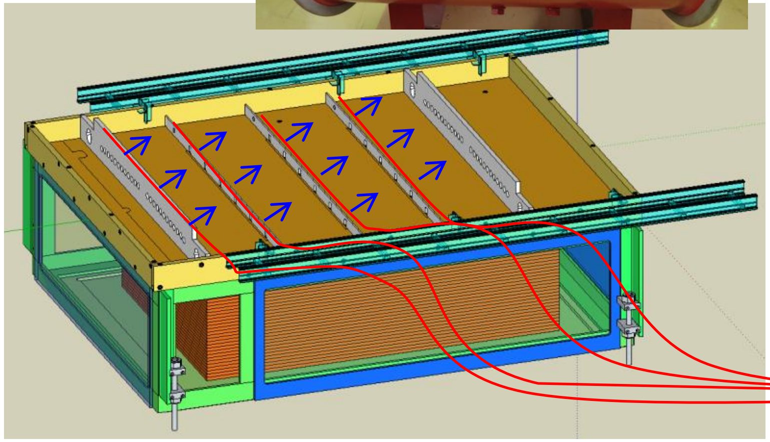
Cooling Design

- Air flow around the surface of AsAd to cool electronics
- Necessary to dissipate heat from small space
- Test results: w/o cooling, ~44 deg; w/cooling ~37 deg





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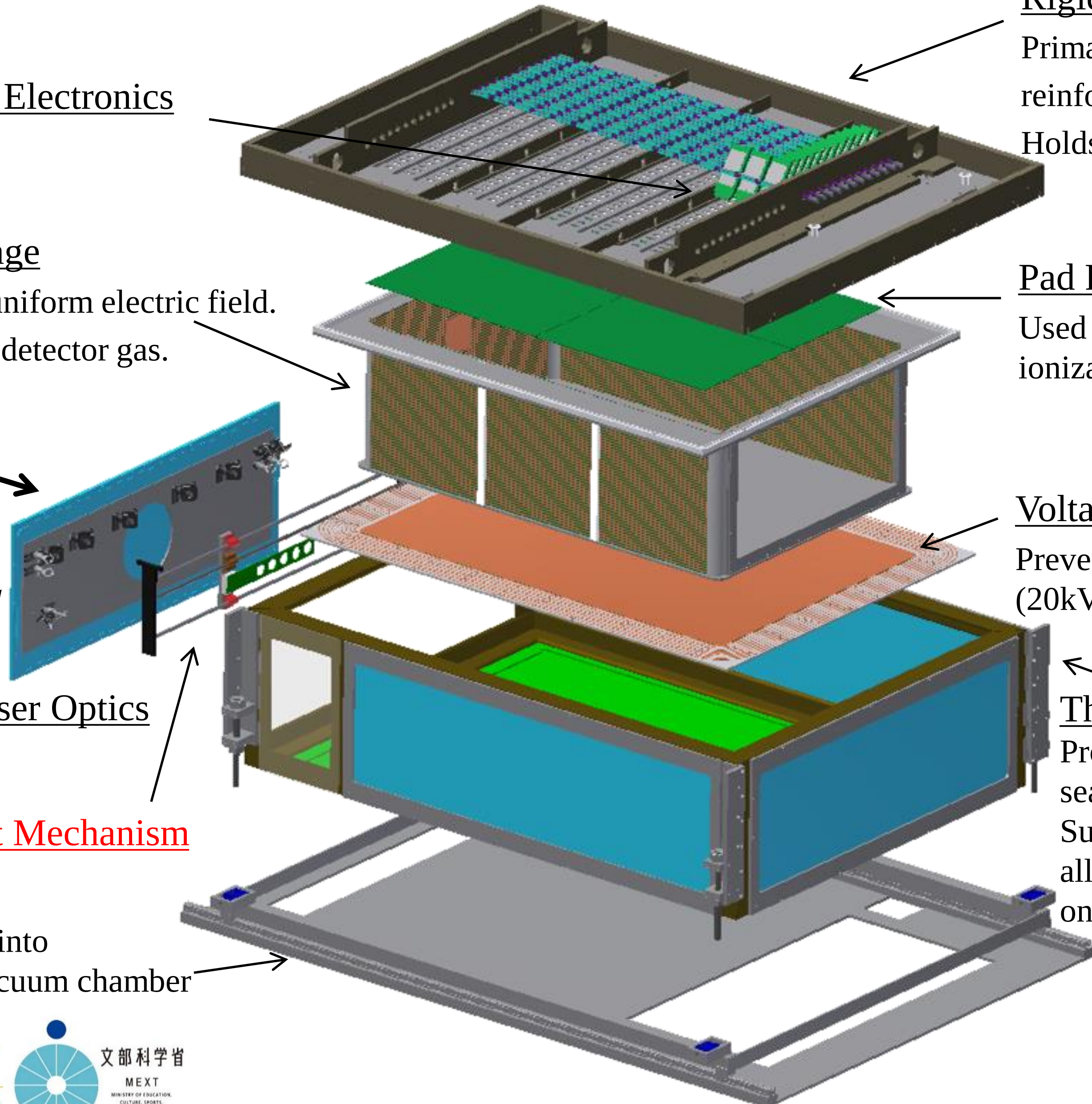
SAMURAI TPC: Exploded View



Rigid Top Plate

Primary structural member, reinforced with ribs.

Holds pad plane and wire planes.

Front End Electronics

Air Cooled

Field Cage

Defines uniform electric field.

Contains detector gas.

Pad Plane (108x112)

Used to measure particle ionization tracks

beam

Voltage Step-Down

Prevent sparking from cathode (20kV) to ground

Calibration Laser Optics

Thin-Walled Enclosure

Protects internal components, seals insulation gas volume, Supports pad pan while allowing particles to continue on to ancillary detectors.

Target Mechanism

Rails

Inserting TPC into SAMURAI vacuum chamber

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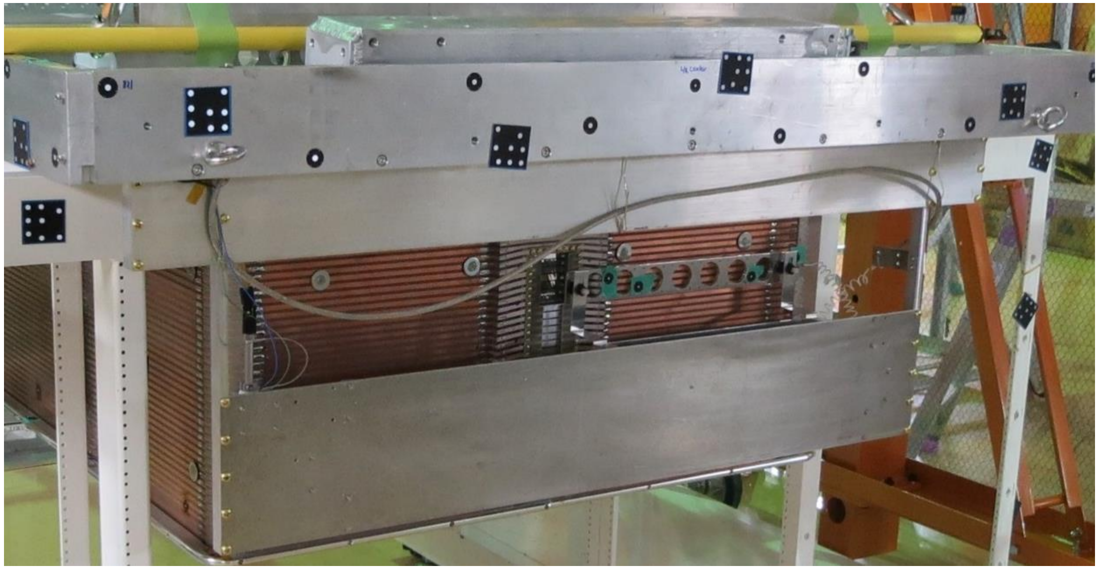
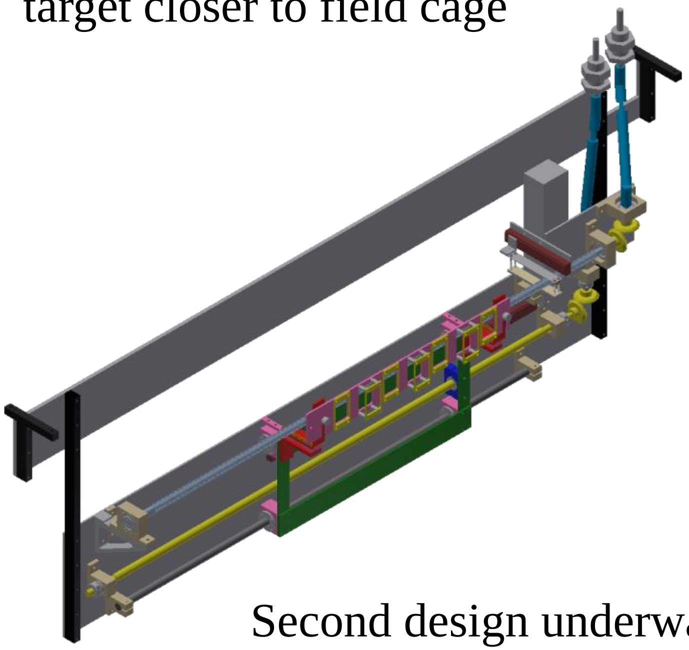
Target Ladder

- Contains multiple targets for experimental run
- First design installed on TPC
- Motion is controlled from outside the magnet chamber
- Second design underway to bring target closer to field cage

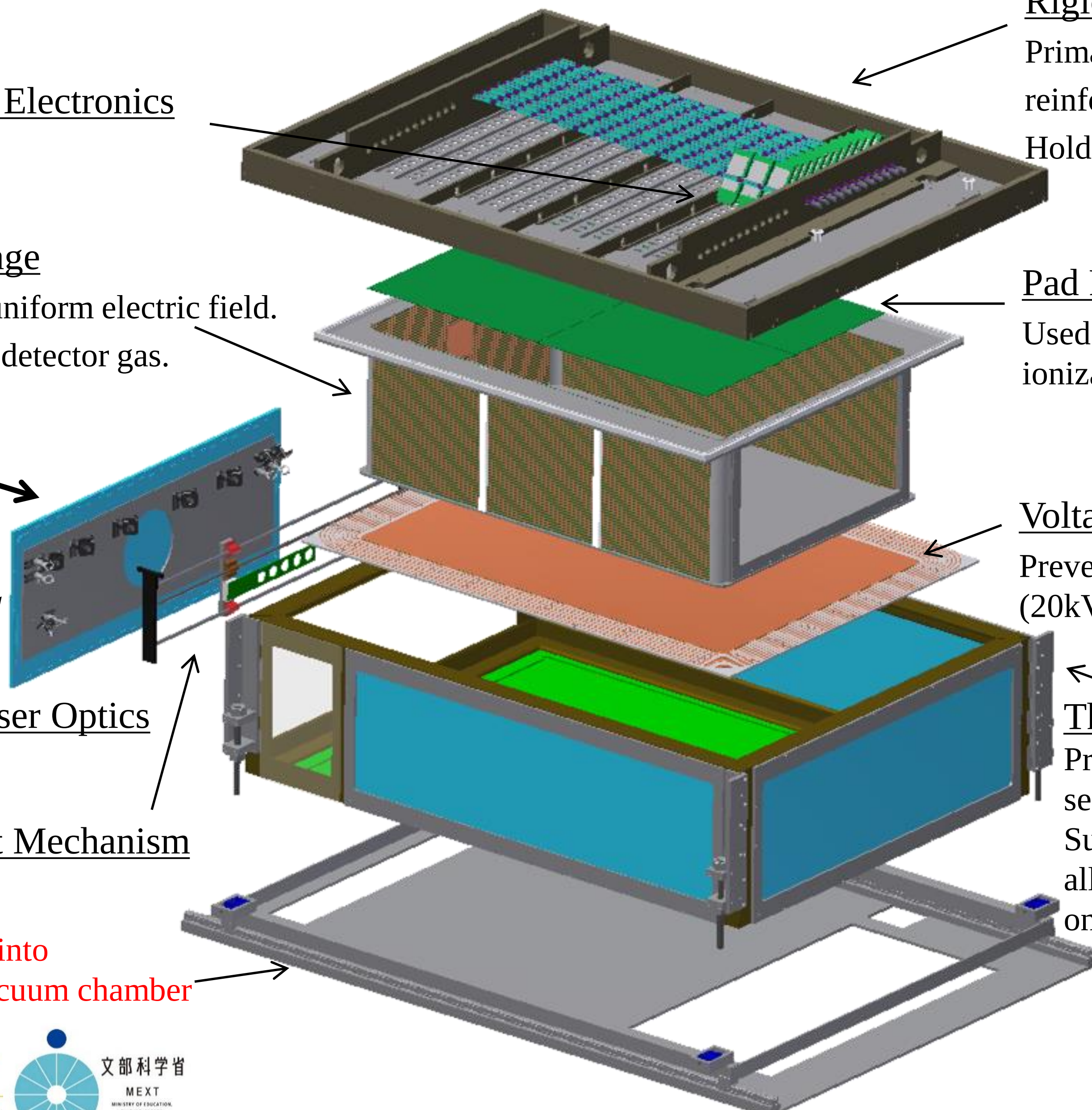


Target ladder installed on TPC



Second design underway

SAMURAI TPC: Exploded View



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

Front End Electronics
Air Cooled

Field Cage
Defines uniform electric field.
Contains detector gas.

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

beam

Voltage Step-Down
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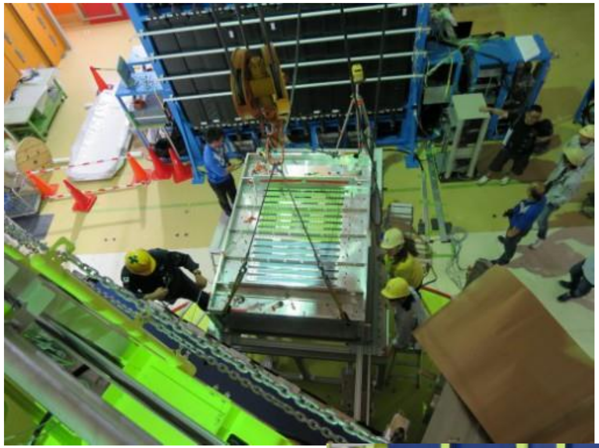
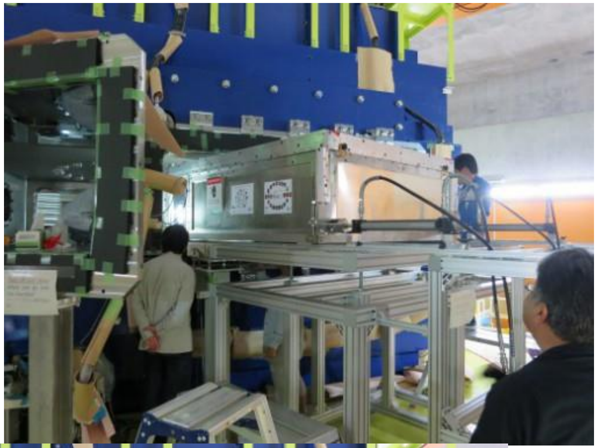
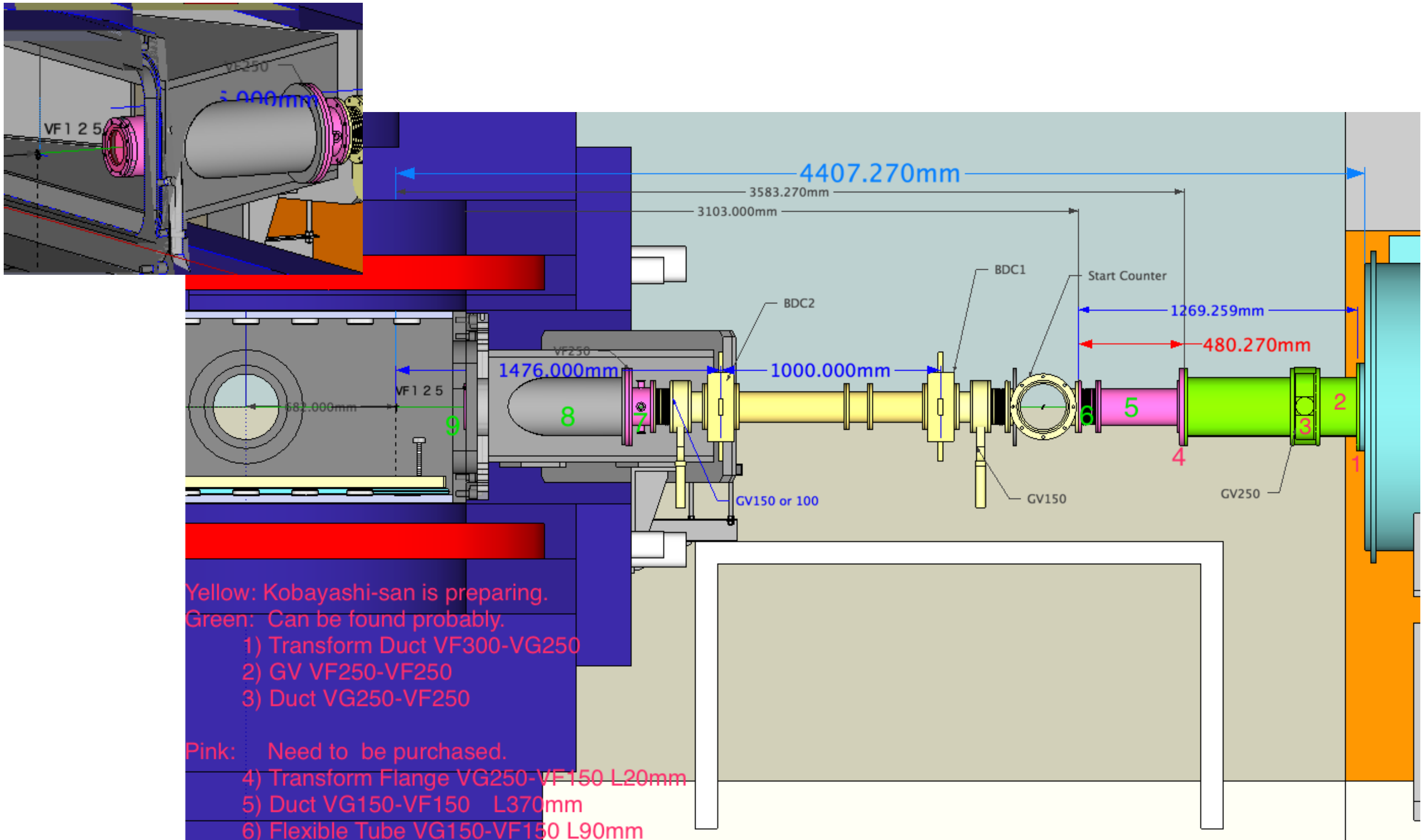
Installation of TPC into magnet





- Rails allow TPC to be inserted and removed from magnet chamber
- Successful insertion first tested Summer 2014

Beam Line configuration design



Yellow: Kobayashi-san is preparing.
Green: Can be found probably.

1) Transform Duct VF300-VG250
2) GV VF250-VF250
3) Duct VG250-VF250

Pink: Need to be purchased.

4) Transform Flange VG250-VF150 L20mm
5) Duct VG150-VF150 L370mm
6) Flexible Tube VG150-VF150 L90mm
7) Transform Duct VG250-VG150 w NW25x4 L110mm
8) Inner Extension Duct
9) Window Flange VF125 w foil

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Upcoming Experimental Plans with *SπRIT*

Determination of the density and momentum dependence of EOS (m*)

at supra-saturation density

Symmetric and asymmetric reactions

^{132}Sn+^{124}Sn; ^{124}Sn+^{112}Sn

^{108}Sn+^{112}Sn; ^{112}Sn+^{124}Sn

E/A=300 MeV at RIKEN

Observables:

π^+/π^-, n/p, t/^{3}He ratios,

13.5 days approved by NP-PAC in 2013.