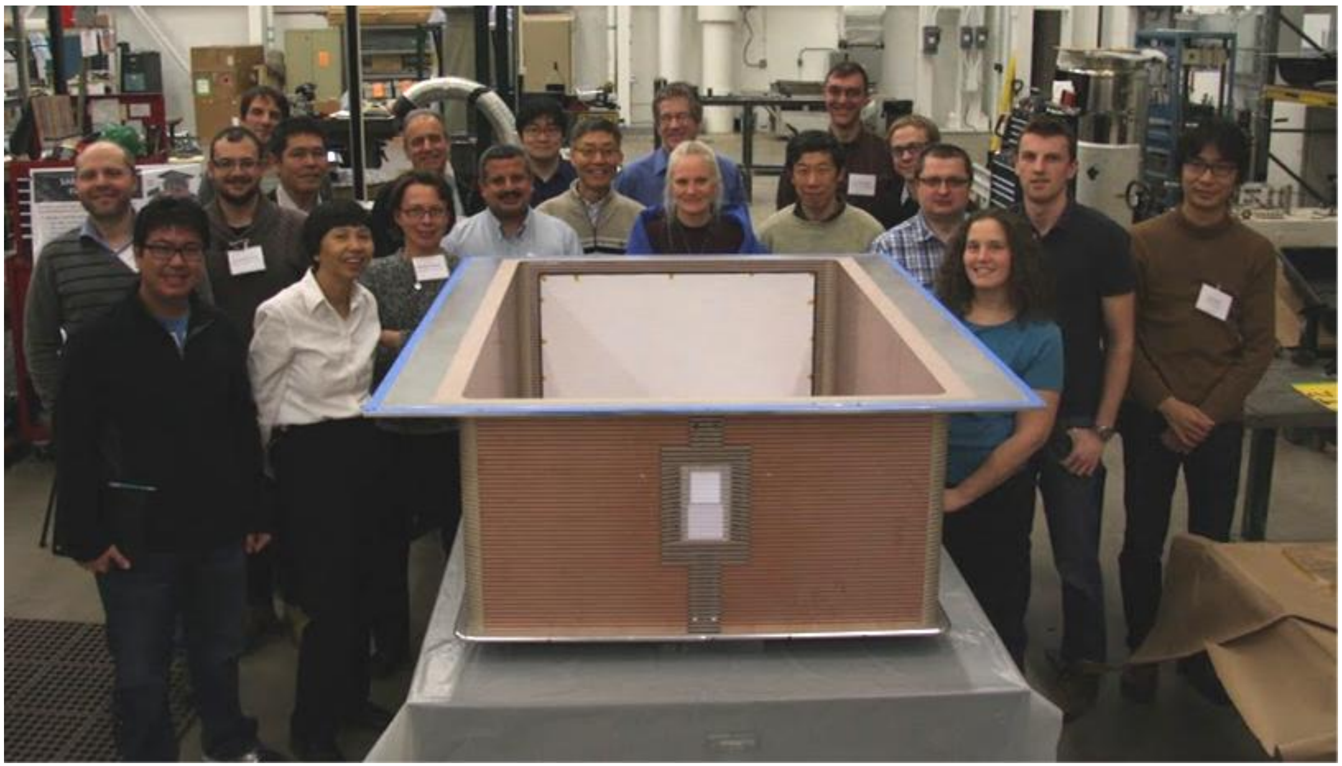
Construction of time-projection chambers to probe the symmetry energy at high density



R. Shane, for the SAMURAI-TPC collaboration

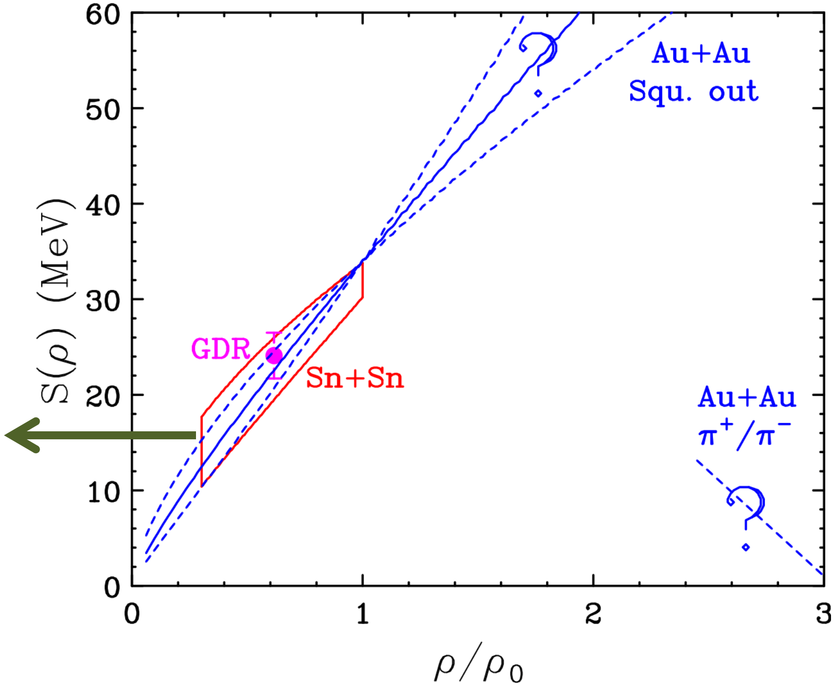
Constraints on the Nuclear Symmetry Energy

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

At $\rho < \rho_0$, consistent constraints on symmetry energy obtained from different experiments:

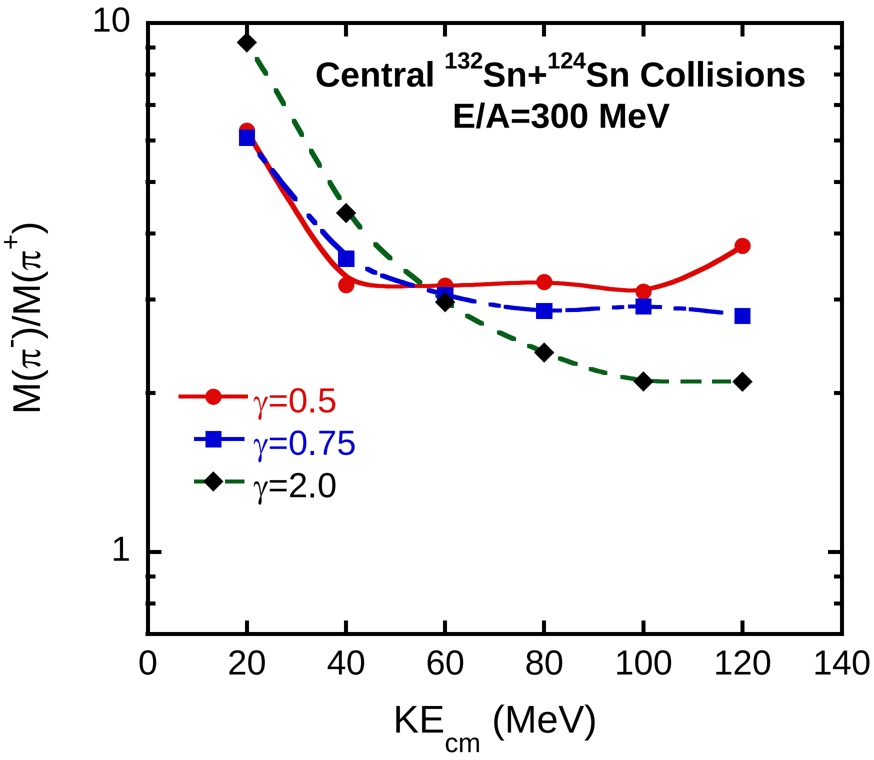
Heavy-ion collisions, giant dipole resonances, isobaric-analog states, pygmy dipole resonances, Pb skin-thickness measurements, neutron-star radius

M.B. Tsang et al., Phys. Rev. C 86, 015803 (2012)



…from flow/yields in heavy-ion collisions

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



- Conduct heavy-ion collisions at 200-300A MeV with rare isotope beams (isospin multiplets):

  ^{108}Sn + ^{112}Sn, ^{132}Sn + ^{124}Sn, ^{36}Ca + ^{40}Ca, ^{52}Ca + ^{48}Ca

- Measure differential flow and yield ratios for (π^+ & π^-), (p & n), (^{3}H & ^{3}He)

- In addition to constraining the symmetry energy at $\rho \approx 2\rho_0$, we are sensitive to nucleon effective masses and in-medium nucleon cross sections.

- Use TPCs to perform these types of experiments

Time-projection chamber operation

TPC is a particle tracker sitting in a magnet

- Charged collision fragments ionize detector gas
- Electrons drift in E-field toward charge-sensing pads
  - **Positions** and **time** of arrival → 3D path
- Momentum from curvature of path in B-field
- Particle type from energy loss and magnetic rigidity

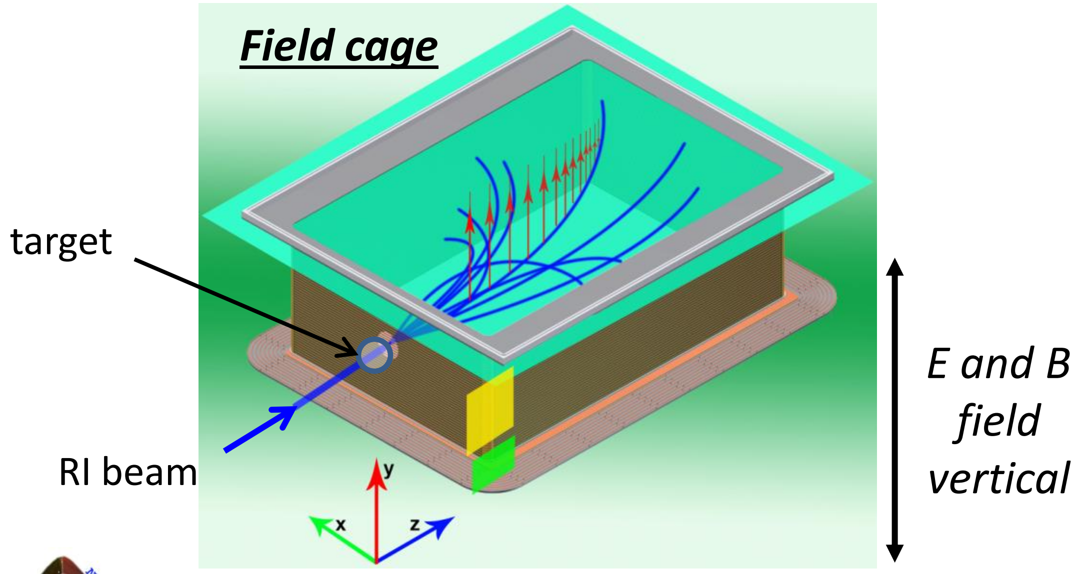


Figure courtesy of J. Estee

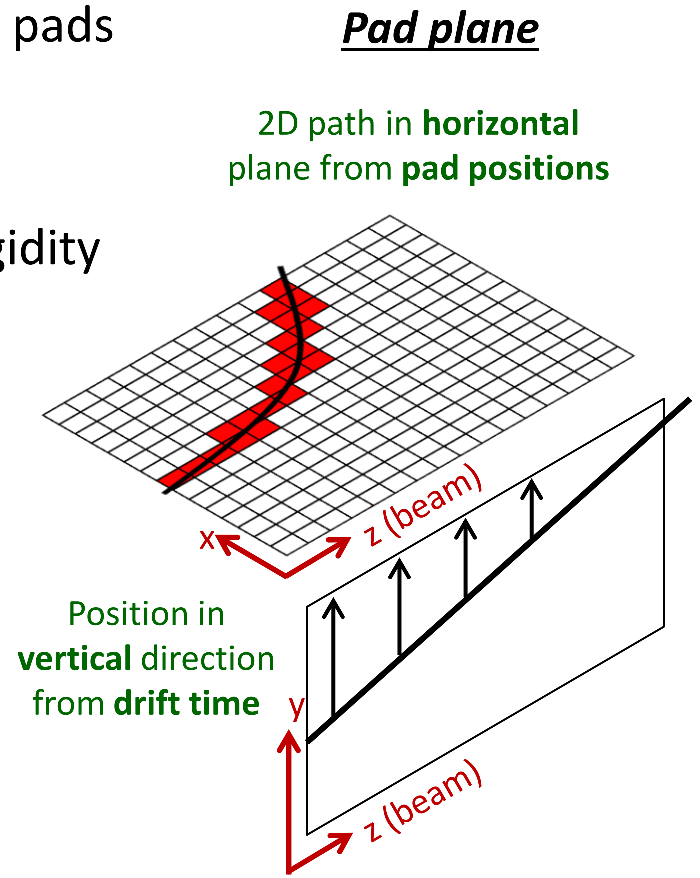
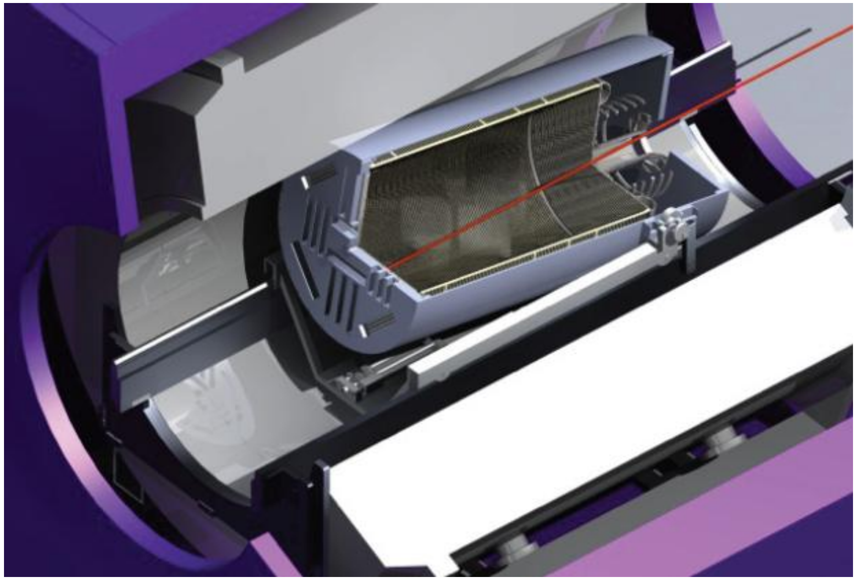


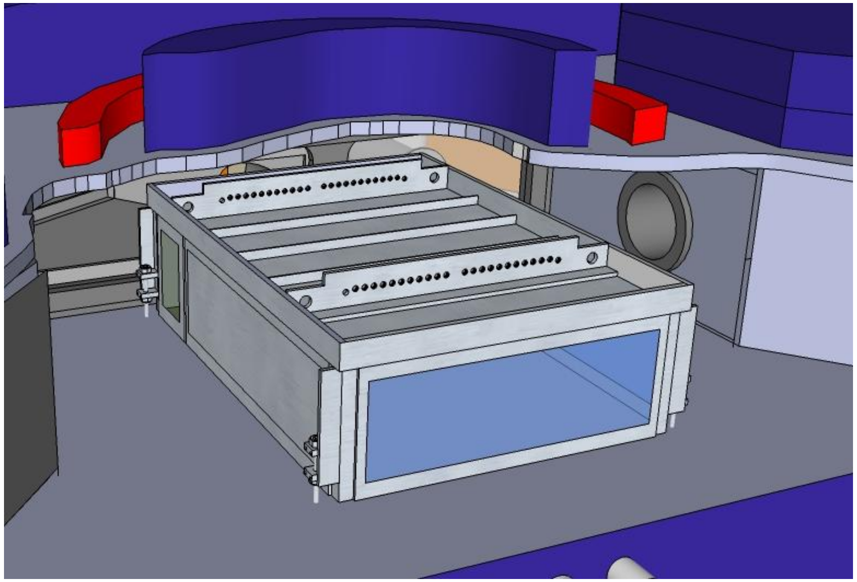
Figure courtesy of J. Barney

TPCs for symmetry-energy studies

Active-Target Time-Projection Chamber

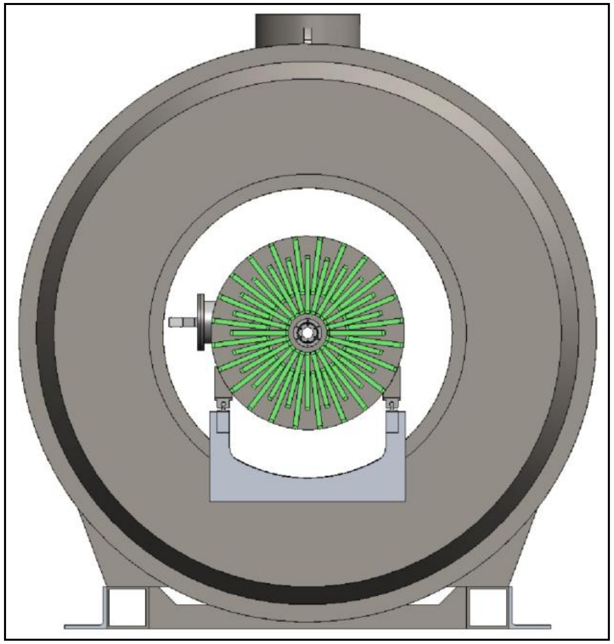


SAMURAI TPC



	AT-TPC	SAMURAI TPC
Magnet	Solenoid	H-Dipole
Geometry	Cylindrical	Rectangular
Multiplication	MICROMEGAS	Wires

AT-TPC: *ReA3*

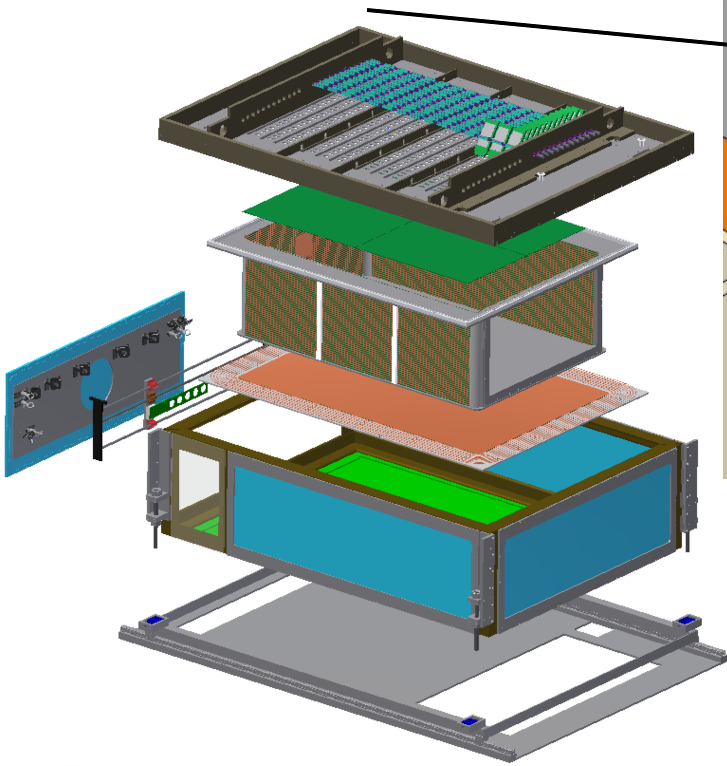


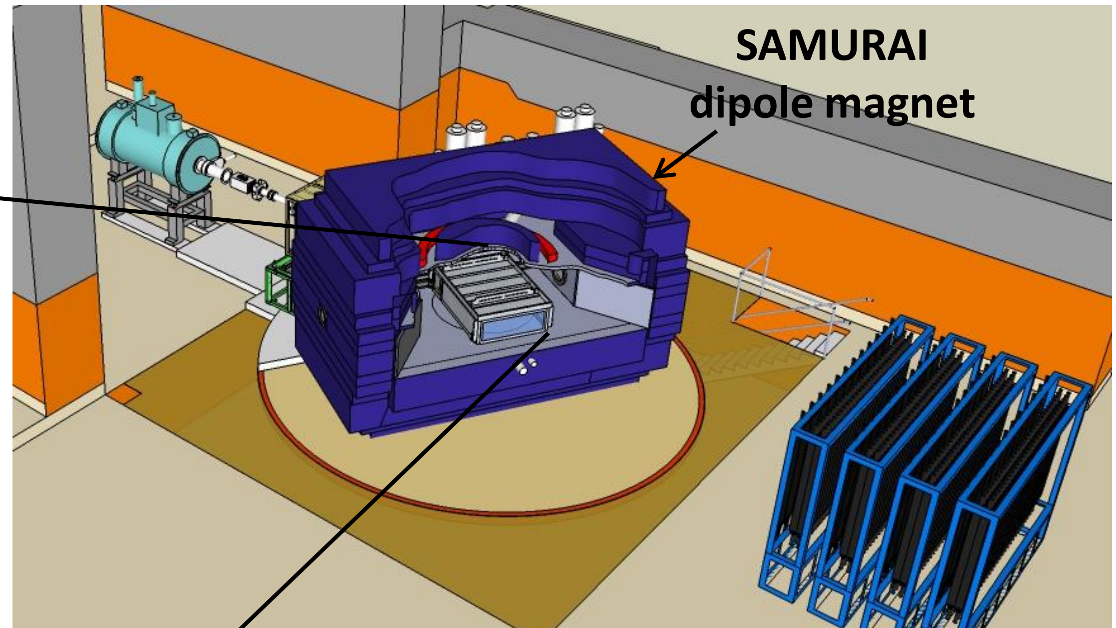
- ReA3: reaccelerated rare-isotopes, energies up to 3 A MeV
- Superconducting solenoid magnet, 2 Tesla field

Slide adapted from T. Ahn

S-TPC: *SAMURAI Spectrometer*

- SAMURAI: high-resolution spectrometer at RIKEN, Japan

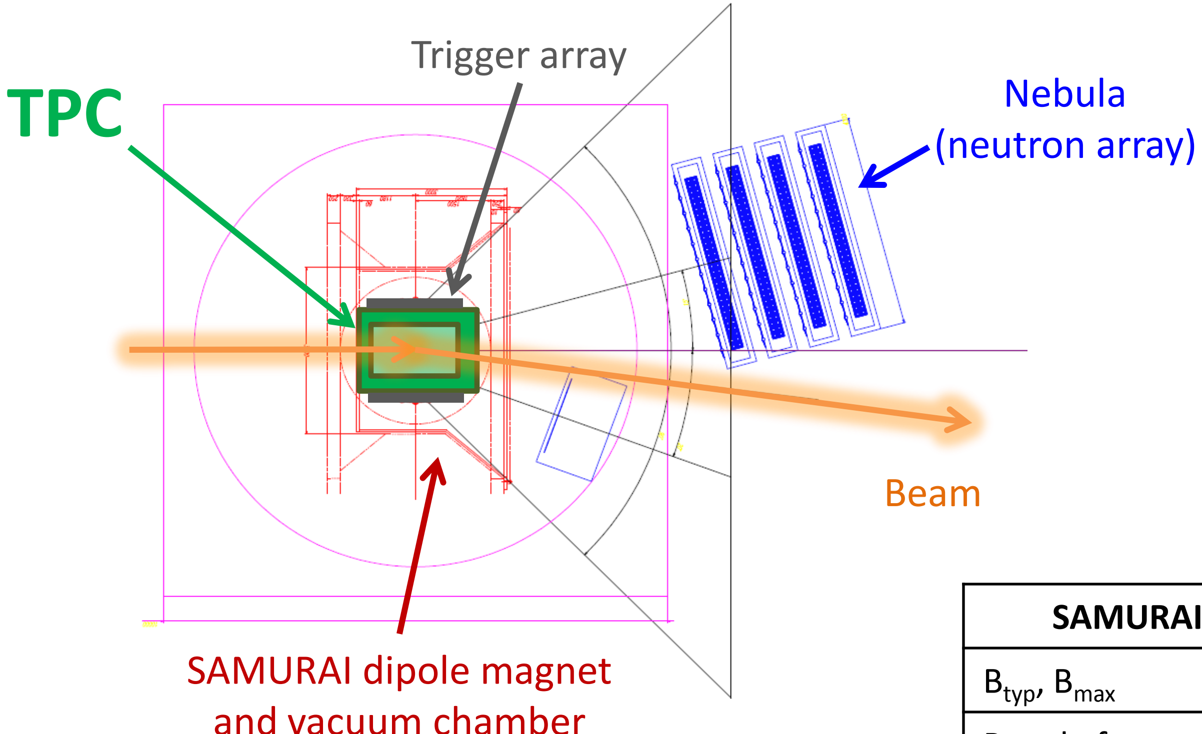




SAMURAI magnet parameters	
B_{typ}, B_{max}	0.5T, 3T
R, pole face	1 m
Gap	80 cm
Usable gap	75 cm

S-TPC: *SAMURAI Spectrometer*

- SAMURAI: high-resolution spectrometer at RIKEN, Japan
- Auxiliary detectors for heavy-ions, neutrons, and trigger



Drawing courtesy of T. Isobe

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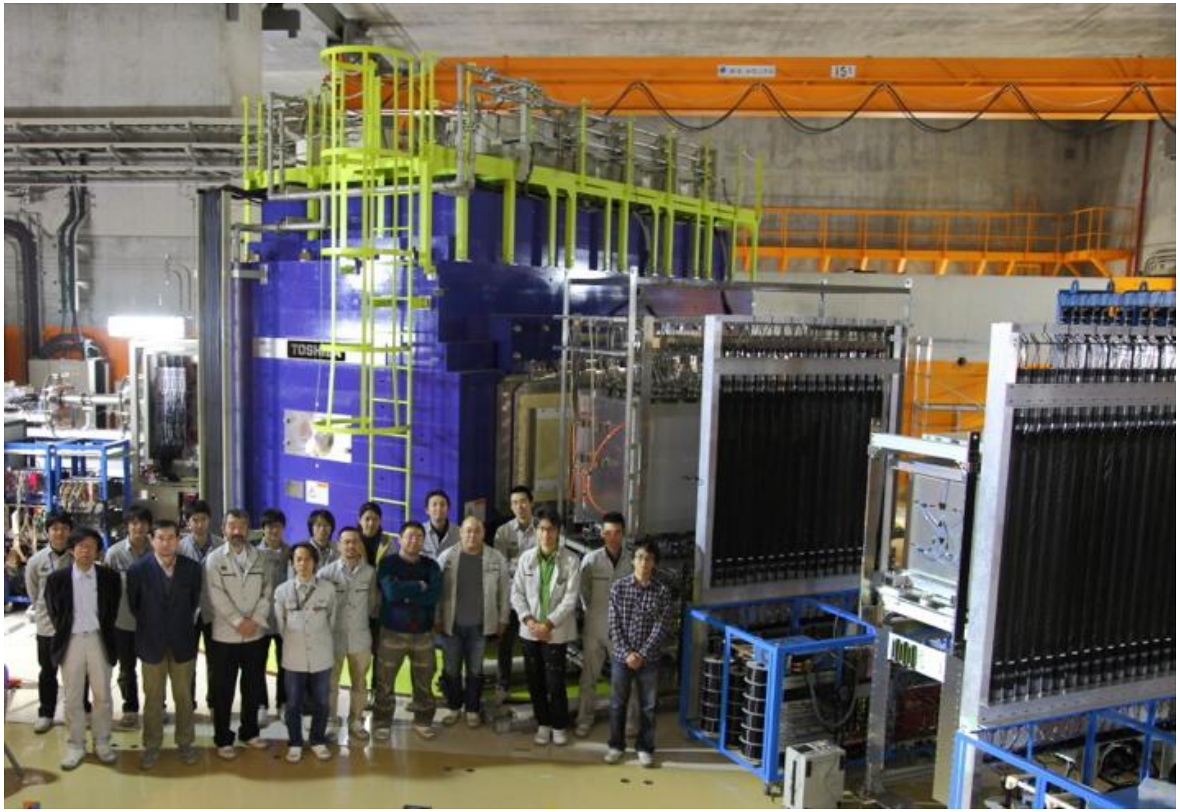
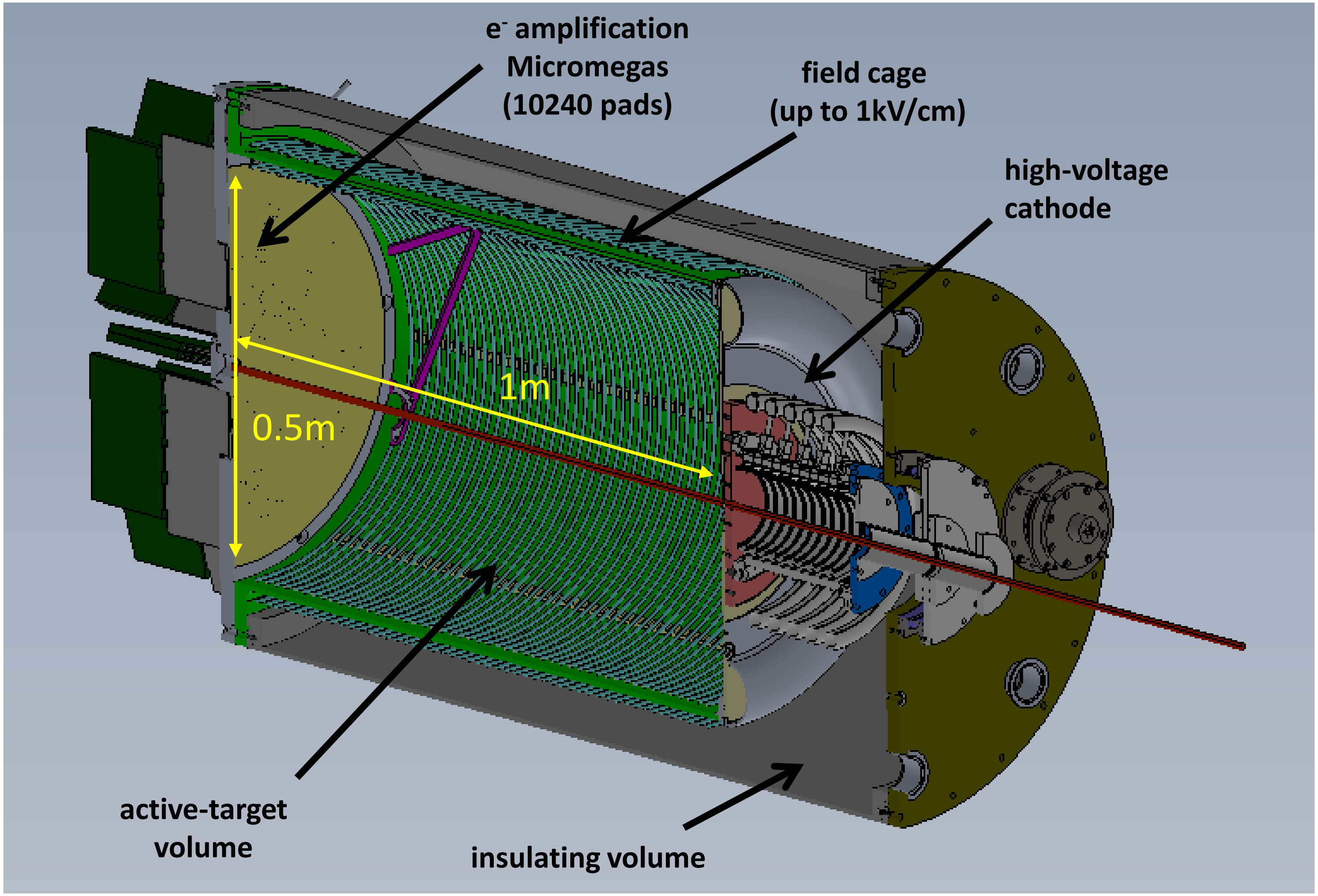


Photo courtesy of T. Isobe

Astrophysics Nuclear Structure S E P HI Reactions

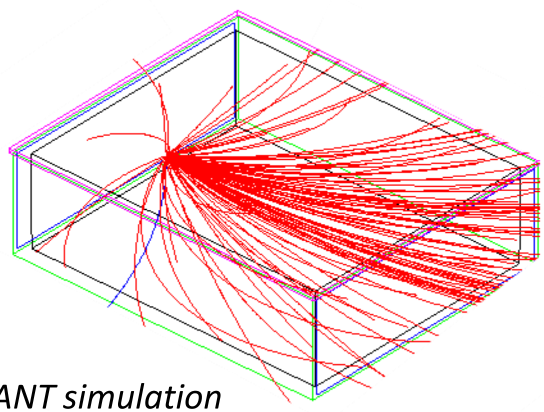
AT-TPC: *Design*



Slide adapted from T. Ahn

S-TPC: *Design*

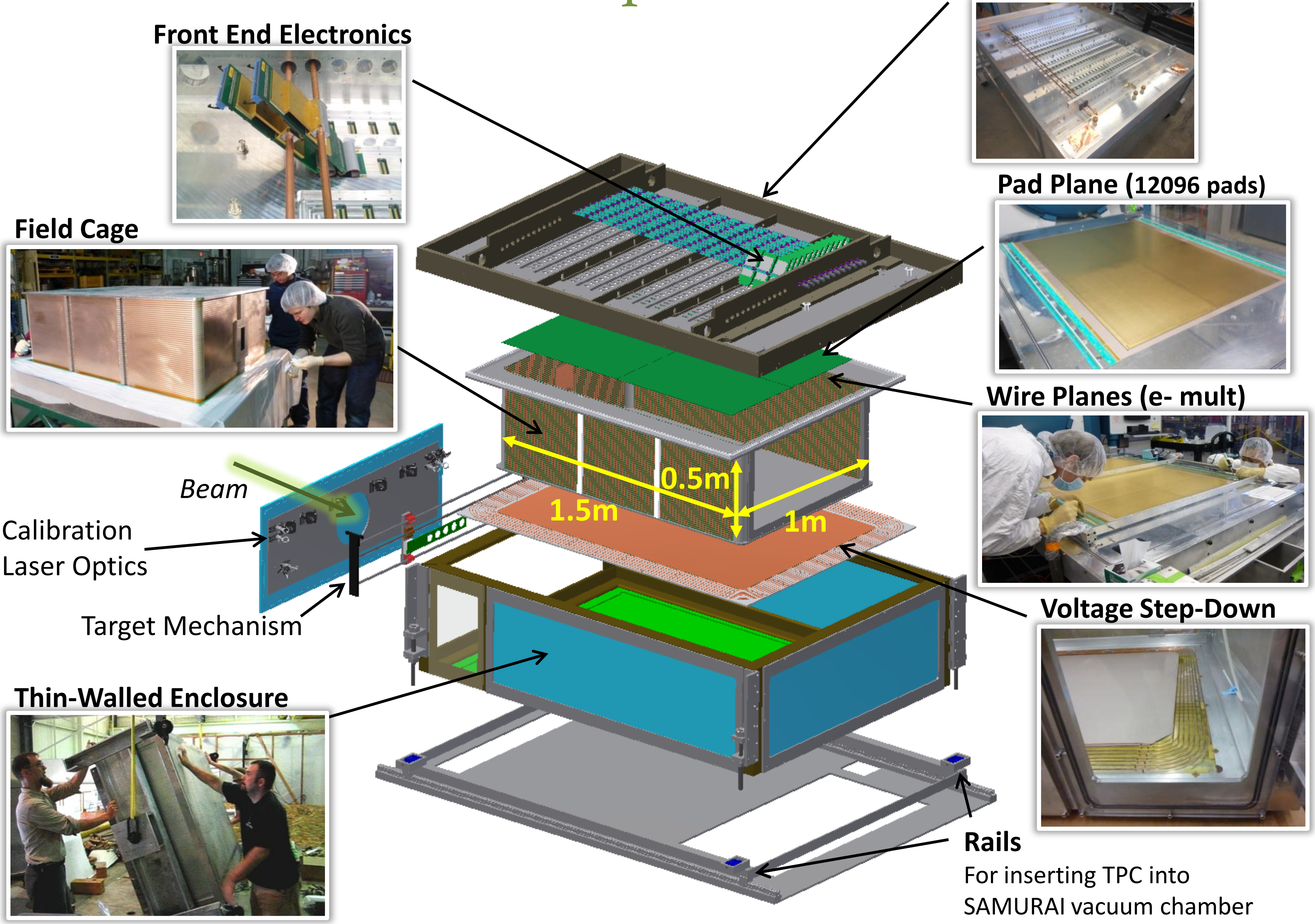
- Considerations
  - Good track-reconstruction efficiency for pions
  - Physical space constraints (limit drift length, vertical spatial res.)
  - Tolerances (affect momentum resolution)
- Design influenced heavily by EOS and STAR TPCs



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

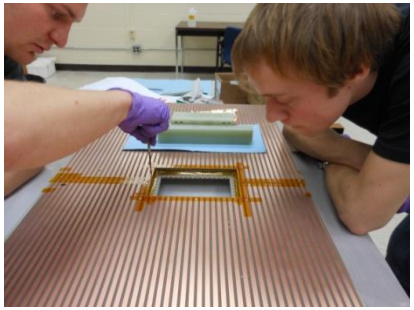
Pad plane area	1.34m x 0.86 m
Number of pads	12096 (108 x 112)
Pad size	12 mm x 8 mm
Drift distance	53 cm
Pressure	1 atm
dE/dx range	Z=1-8 (GET electr.)
Two track resolution	2.5 cm
Multiplicity limit	200 (may impact pion eff. in large systems)

SAMURAI TPC: Exploded View

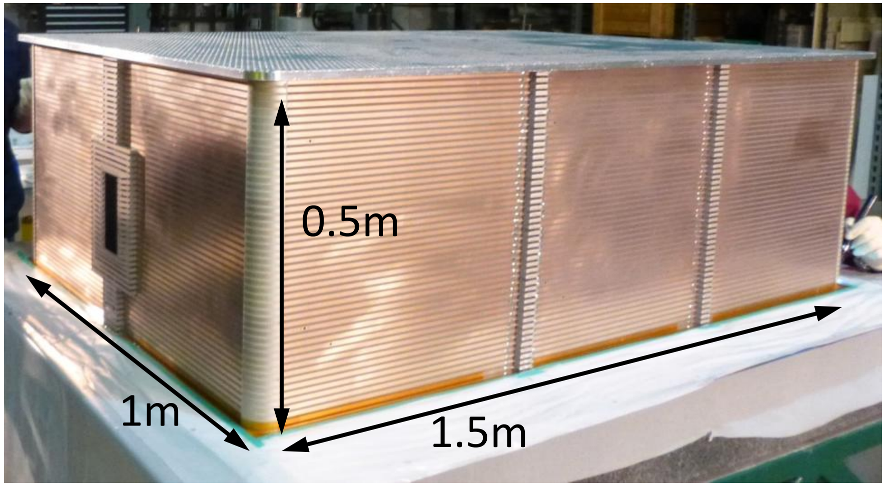


S-TPC: *Field cage*

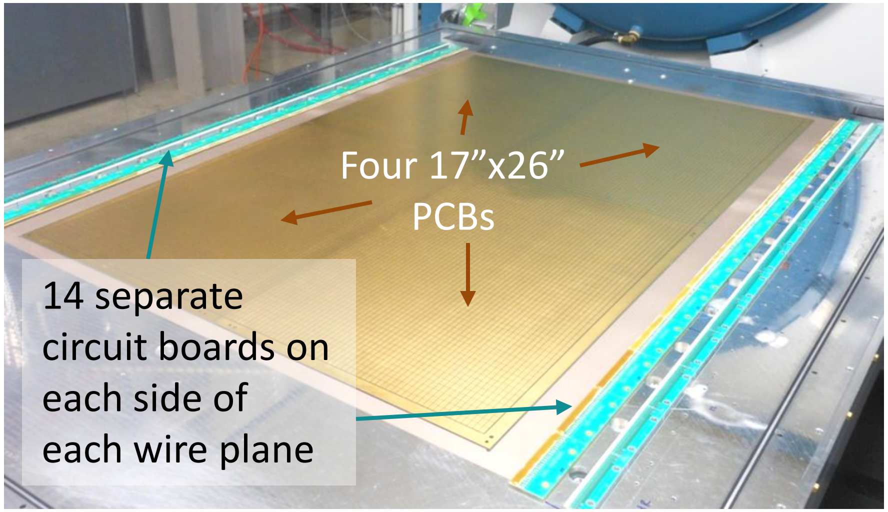
- Thin walls for particles to exit, but maintain structural stability
  - 8 circuit boards with copper strips
- Removable beam windows
  - 25um mylar entry window
  - 125um kapton exit window
- Cathode (bottom)
  - Aluminum honeycomb: light, strong
  - Graphite coating: incr. work function
- Gas tight (all seams glued)
  - Allows separate gas volumes:
    - P10 detector gas in FC
    - P10 or dry N_2 insulation gas
  - Useful in active-target mode

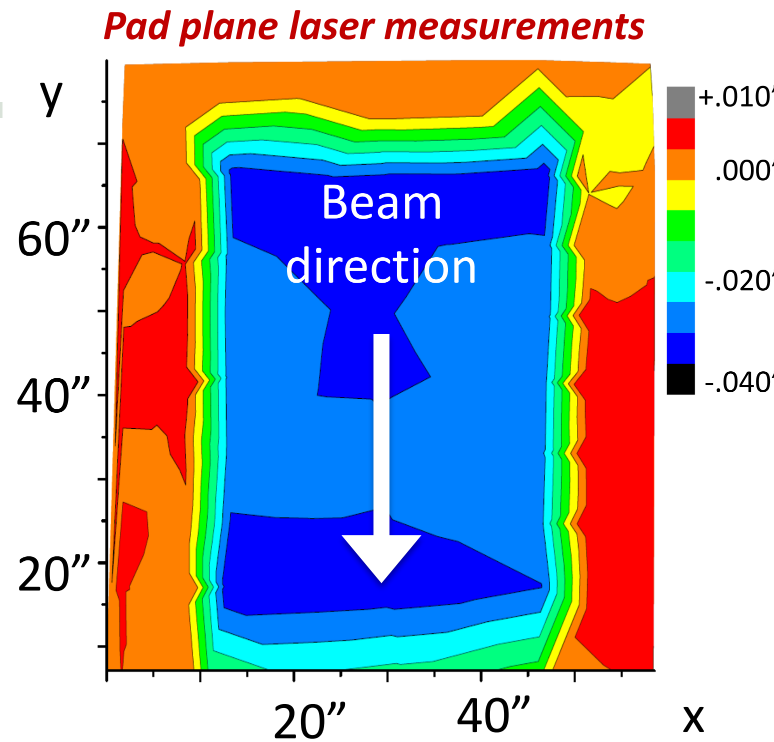


Gluing field cage together



S-TPC: *Pad and wire planes*

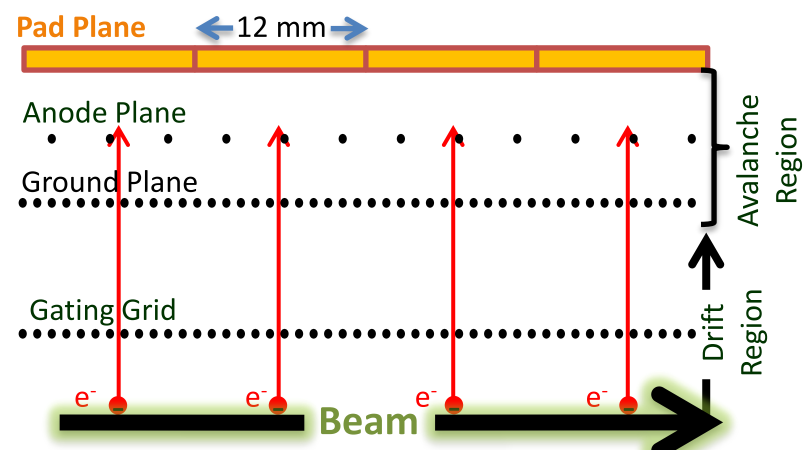




- Pad plane is ***flat to within 0.005" (125 um)***
- Ready for testing (mount gating grid later)

Plane	Material	Diam (µm)	Pitch (mm)	Height (mm)	Tens. (N)	Volt. (V)	# of wires
Anode	Au-W	20	4	4	0.5	~1400	364
Ground	Cu-Be	75	1	8	1.2	0	1456
Gating	Cu-Be	75	1	14	1.2	100±30	1456

Based on STAR-TPC operating parameters



S-TPC: *Assembly completed May 2013*

AT-TPC and S-TPC: *Readout electronics*

- S-TPC: 1k-ch. testing system using STAR FEE
  - Hardware assembled and tested
  - Will fully test completed detector this summer
- Both: Generic Electronics system for TPCs
  - Wide dynamic range: effectively 10.5 bits
  - Self triggering (useful for active targets)
  - AsAd is 256 chan (four 64 ch. ASICs)
  - Capable of handling 1KHz – 10Gb/s
  - GET is collaborative effort of Saclay, Bordeaux, GANIL and NSCL
  - Status/completion:
    - AGET 1st batch prod.: May 2013
    - ASAD 1st batch prod.: July 2013
    - COBO 2nd prototype: April 2013,
      - 1st batch production – July 2013
  - AT-TPC will be first detector to use

STAR FEE on S-TPC

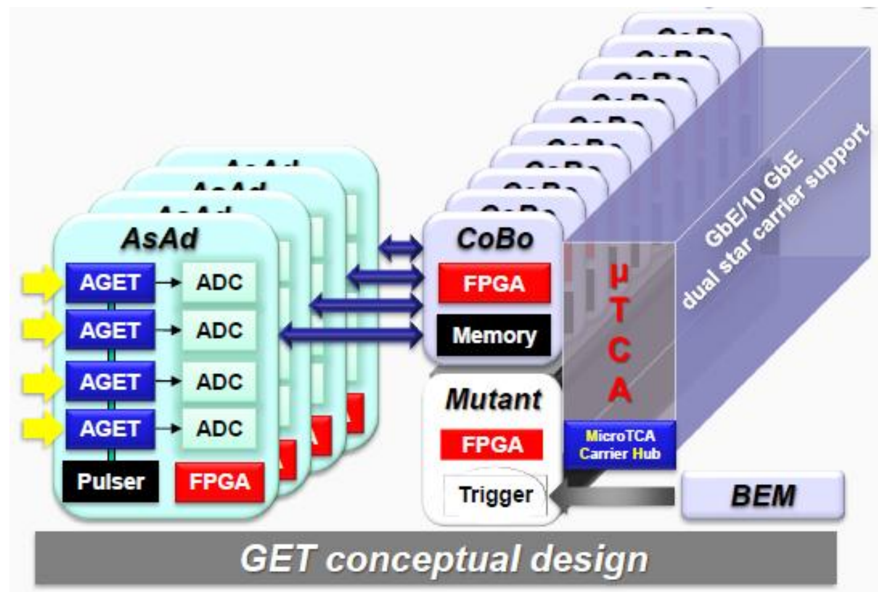
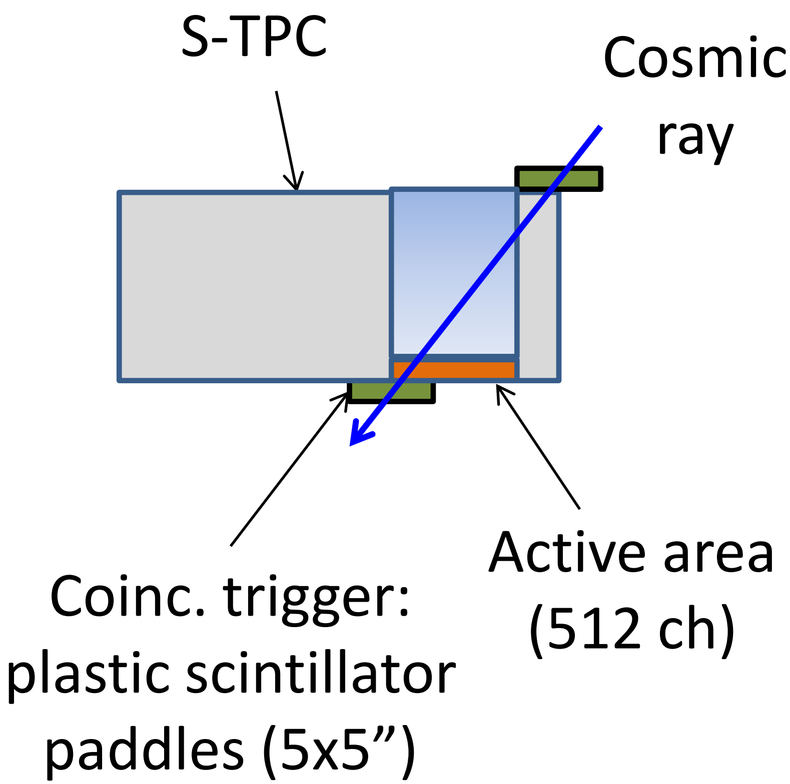


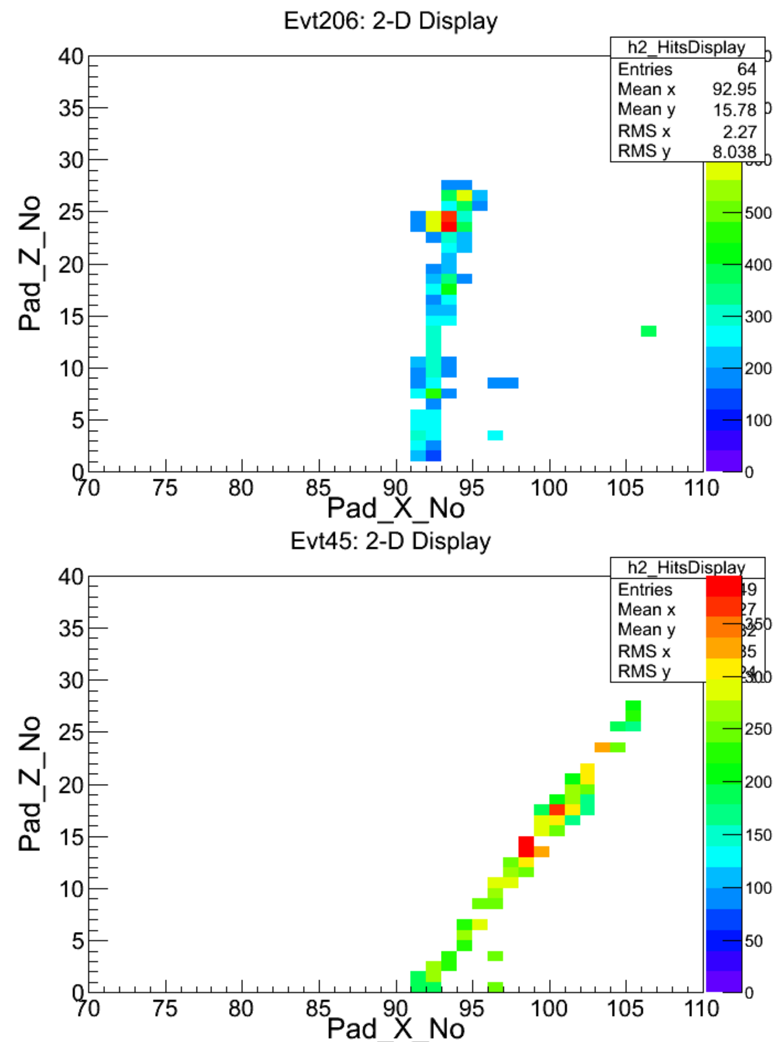
Figure courtesy of GET collaboration

S-TPC: *Preliminary testing with STAR FEE cards*



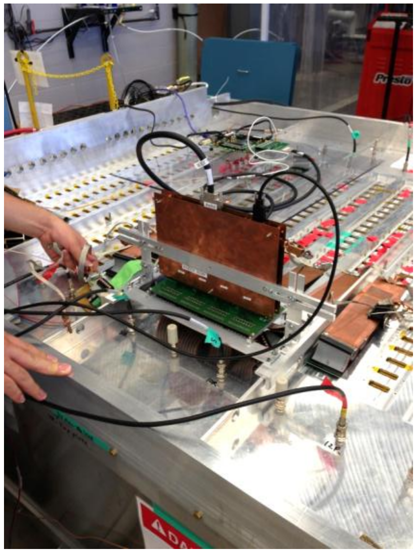
1-2 counts/min

<u>Pads that “see” cosmic ray</u>



Plots courtesy of R. Wang

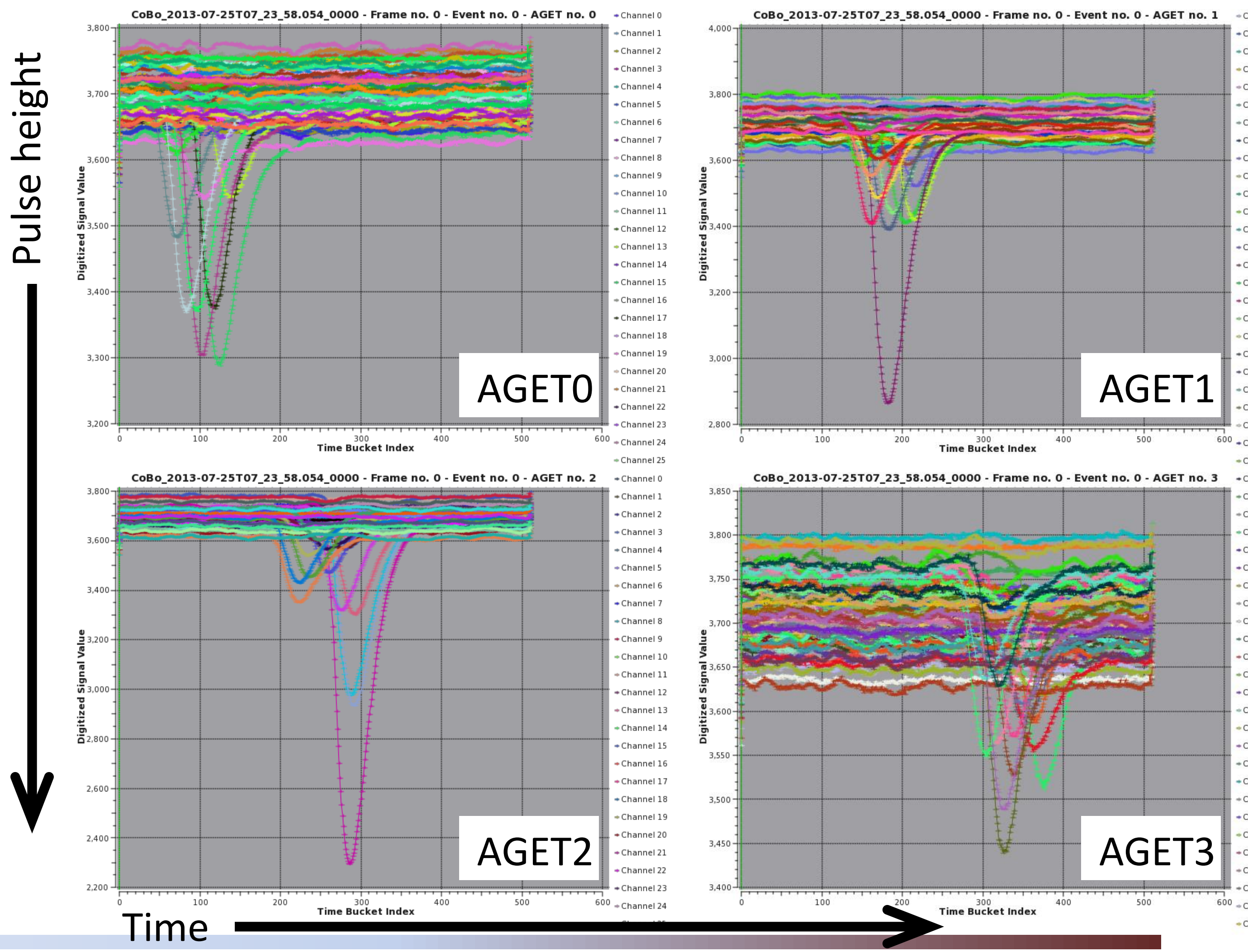
S-TPC: *Preliminary testing with GET system*



Cosmic Event 0:
July 24th, 2013
@NSCL

>500 cosmic events so far

Plot shows induced signal on each pad



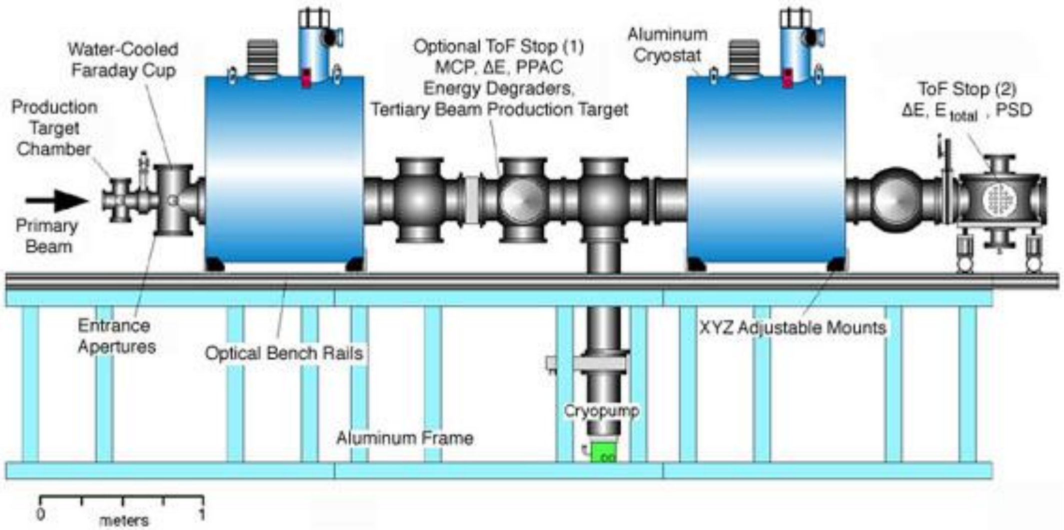
Plots courtesy of T. Isobe

AT-TPC: *Proposed research program*

Measurement	Physics	Beam Examples	Beam Energy (A MeV)	Min Beam (pps)	Scientific Leader
Transfer & Resonant Reactions	Nuclear Structure	$^{32}Mg(d,p)^{33}Mg$ $^{26}Ne(p,p)^{26}Ne$ $^{66,..,70}Ni(p,p)$	3	100	Kanungo
Astrophysical Reactions	Nucleosynthesis	$^{25}Al(^{3}He,d)^{26}Si$	3	100	Famiano, Montes
Fusion and Breakup	Nuclear Structure	$^{8}B+^{40}Ar$	3	1000	Kolata
Transfer	Pairing	$^{56}Ni+^{3}He$	5-19	1000	Macchiavelli
Fission Barriers	Nuclear Structure	^{199}Tl, ^{192}Pt	20 - 60	10,000	Phair
Giant Resonances	Nuclear EOS, Nuclear Astro.	^{54}Ni-^{70}Ni, ^{106}Sn-^{127}Sn	50 - 200	50,000	Garg
Heavy Ion Reactions	Nuclear EOS	^{106}Sn - ^{126}Sn, ^{37}Ca - ^{49}Ca	50 - 200	50,000	Lynch

Slide adapted from T. Ahn

PAT-TPC: *Measurements at Notre Dame*



Twinsol, superconducting solenoid magnets

- Half-scale prototype AT-TPC
- d(^{7}Li,^{3}He)^{6}He, 15 MeV
- ^{13}C(^{11}B, ^{14}N)^{10}Be, 40 MeV
- Clustering/n correlation, molecular structure, fusion

Slide adapted from T. Ahn

S-TPC: *Proposed research program*

Probe	Devices	E_{lab}/A (MeV)	Part./s	Main Foci	Possible Reactions	FY
$\pi^+\pi^-$,p, n,t,^{3}He	TPC Nebula	200-300 350	10^4-10^5	E_{sym} m_n^*, m_p^*	^{132}Sn+^{124}Sn, ^{108}Sn+^{112}Sn, ^{52}Ca+^{48}Ca, ^{36}Ca+^{40}Ca ^{124}Sn+^{124}Sn, ^{112}Sn+^{112}Sn	2014
$\pi^+\pi^-$ p, n,t,^{3}He	TPC Nebula	200-300	10^4-10^5	σ_{nn},σ_{pp} σ_{np}	^{100}Zr+^{40}Ca, ^{100}Ag+^{40}Ca, ^{107}Sn+^{40}Ca, ^{127}Sn+^{40}Ca	2015 - 2017

Slide adapted from T. Murakami

Summary and outlook

- TPCs are useful tools to probe nuclear symmetry energy
  - Measure yield ratios and flows from HIC to improve constraints near $\rho \approx 2\rho_0$
- AT-TPC
  - Successful experiments with prototype at Notre Dame
  - Full-scale detector construction underway, for use with ReA3
- SAMURAI TPC
  - Construction finished in spring, testing ongoing
  - Successfully tested GET readout and obtained cosmic-ray data
  - Begin with Sn+Sn collisions in 2014 at RIKEN

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SAMURAI-TPC Collaboration members

United States: J. Barney, Z. Chajecki, P. Danielewicz, J. Estee, M. Famiano, U. Garg, W. Lynch, A. McIntosh, R. Shane, M. B. Tsang, S. Tangwancharoen, G. Westfall, S. Yennello, M. Youngs

Japan: K. Ieki, T. Isobe, T. Murakami, J. Murata, Y. Nakai, N. Nakatsuka, S. Nishimura, A. Ono, H. Sakurai, A. Taketani

China: F. Lu, R. Wang, Z. Xiao, Y. Zhang

United Kingdom: M. Chartier, R. Lemmon, W. Powell

France: E. Pollacco

Italy: G. Verde

Korea: B. Hong, G. Jhang

Poland: J. Lukasik

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TAMU staff: R. Olsen