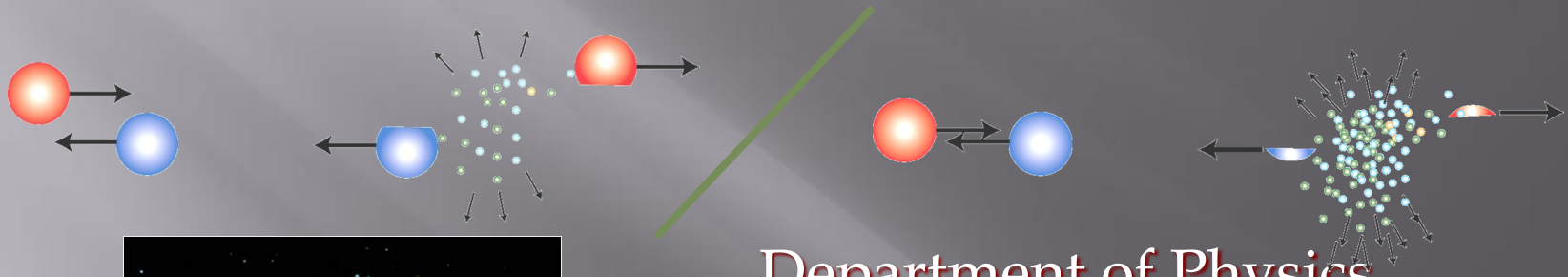
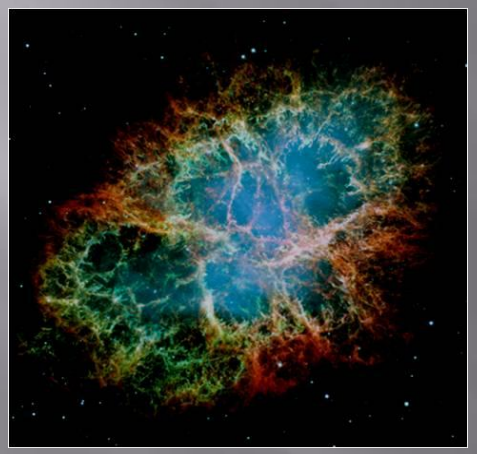
B01: EQUATION OF STATES OF THE NEUTRON-RICH NUCLEAR MATTER AT SUPRA-DENSITY





Department of Physics
Kyoto University
Tetsuya MURAKAMI

For the B01 collaboration, a part of project "Nuclear Matter in Neutron Stars investigated by Experiments and Astronomical Observations" (Grant-In-Aid for Scientific Research on Innovative Areas)

SPiRIT Collaboration

S amurai Pi on- R econstruction and I on-tracker T PC

MSU: W. Lynch, M.B. Tsang, S. Tangwancharoen, Z. Chajecki, J. Estee, R. Shane, Jon Barney

TAMU: A. Mchintosh, S. Yennello

RIKEN : T. Isobe, H. Baba, H. Otsu, K-I Yoneda, H. Sato, Y. Nakai, S. Nishimura, A-K. Perrevoort, J. Lee, H. Sakurai, A. Taketani, He Wang, N. Fukuda, H. Takeda, D. Kameda, H. Suzuki, N. Inabe, T. Kubo

Kyoto Univ.: T. Murakami, N. Nakatsuka

Rikkyo Univ.: K. Ieki, T. Usukura, T. Yoshida

Liverpool/ Darsbury: M. Chartier, W. Powell, J. Sampson, R.Lemmon

Korea Univ.: B. Hong, G. Jhang

WMU: M. Famiano

INFN: G. Verde

SIAP CAS: Fei Lu, W.G. Ma

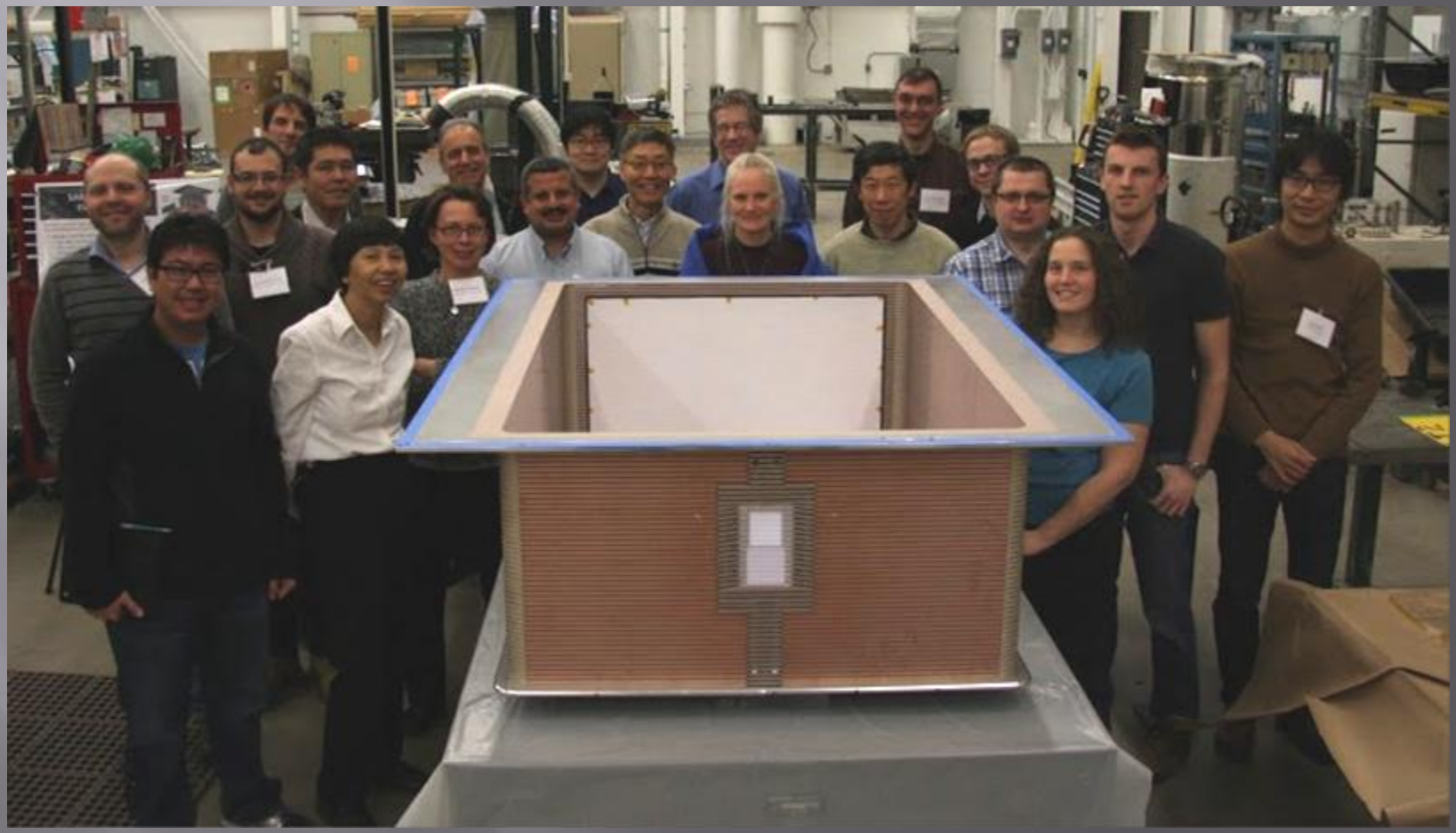
CEA: E. Pollacco

INP: J. Lukasik

ORNL: A. Galindo-Uribarri

Tohoku Univ.: T. Kobayashi

TITech: T. Nakamura, Y. Kondo



Equation of State

$$E(\rho,\delta) = E(\rho,0) + E_{sym}(\rho)\delta^2 + o(\delta^4)$$

$$\delta = (\rho_n - \rho_p)/\rho$$

$$E(\rho,0) = E(\rho_0,0) + \frac{K_0}{2}\varepsilon^2 + o(\varepsilon^3)$$

$$E_{sym}(\rho) = E_{sym}(\rho_0) + L\varepsilon + \frac{K_{sym}}{2}\varepsilon^2 + o(\varepsilon^3)$$

$$\varepsilon = (\rho - \rho_0)/3\rho_0$$

$$K_0 = 9\rho_0^2 \left.\frac{\partial^2 E(\rho,0)}{\partial\rho^2}\right|_{\rho=\rho_0}$$

$$S_0 = E_{sym}(\rho_0)$$

$$L = 3\rho_0 \left.\frac{\partial E_{sym}(\rho)}{\partial\rho}\right|_{\rho=\rho_0} = (3/\rho_0)P_0$$

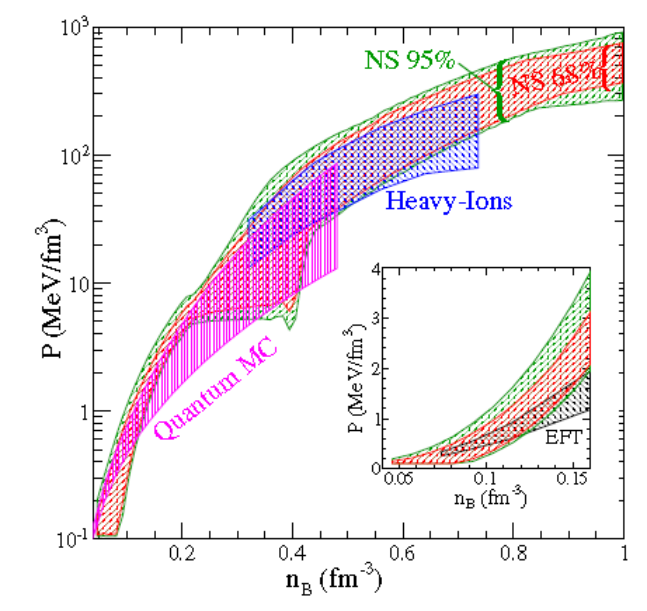
$$K_{sym} = 9\rho_0^2 \left.\frac{\partial^2 E_{sym}(\rho)}{\partial\rho^2}\right|_{\rho=\rho_0}$$

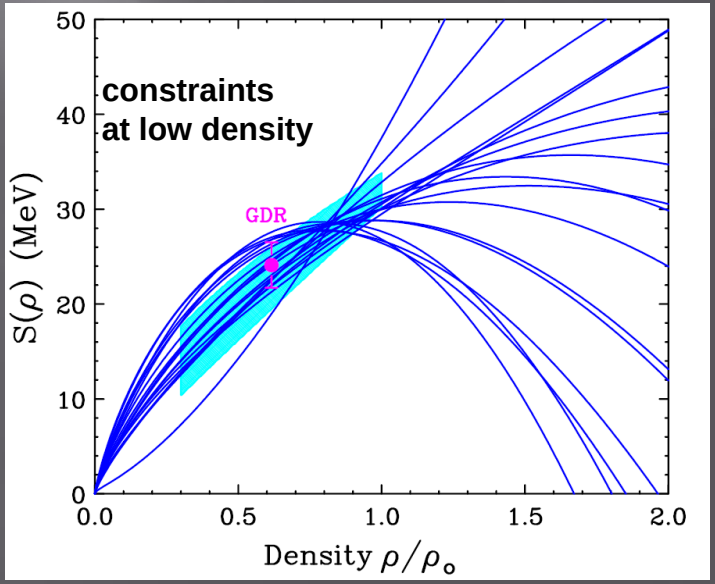
$$K_\tau \approx K_{sym} - 6L$$

Motivation

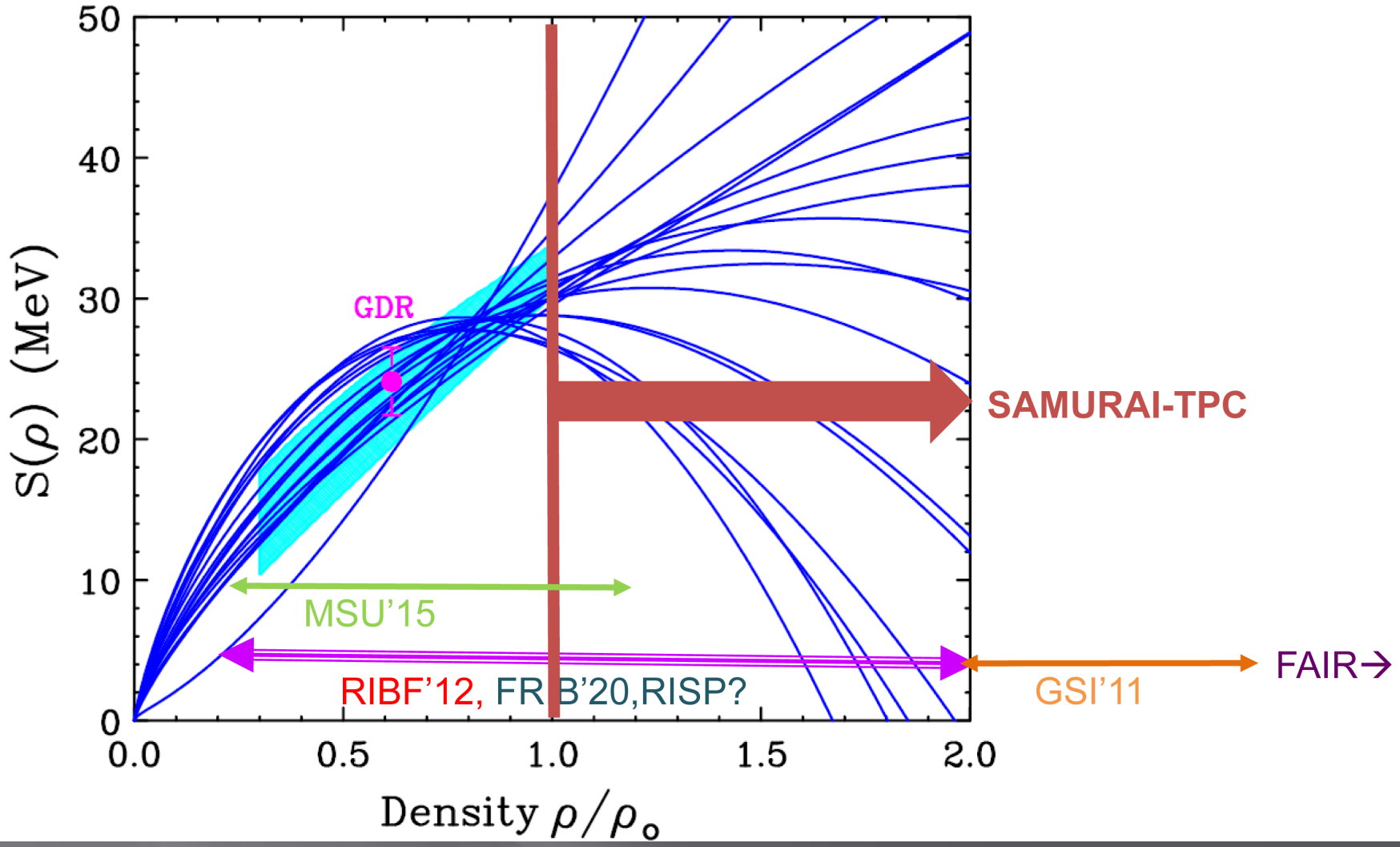
- Constraints from nuclear structure, nuclear reactions and neutron stars (left panel).
- Neutron star constraints at high density obtained from X-ray burst light curves.
- QMC constraints extrapolate nuclear structure information to high density. Width is compatible with uncertainty expected for a successful PREX experiment.
- Heavy ion collision constraints combine those from collective flow with guesses about symmetry energy. >> Still uncertain!!
- Uncertainties in the symmetry energy at high density weaken N.P constraints. (right panel).

Goal is to decrease the factor of 2 uncertainty in symmetry pressure at $\rho \approx 2\rho_0$.





Symmetry Energy Project: International collaboration to determine the symmetry energy over a range of densities



Prediction of Bao-An

NPA 708 (2002) 365

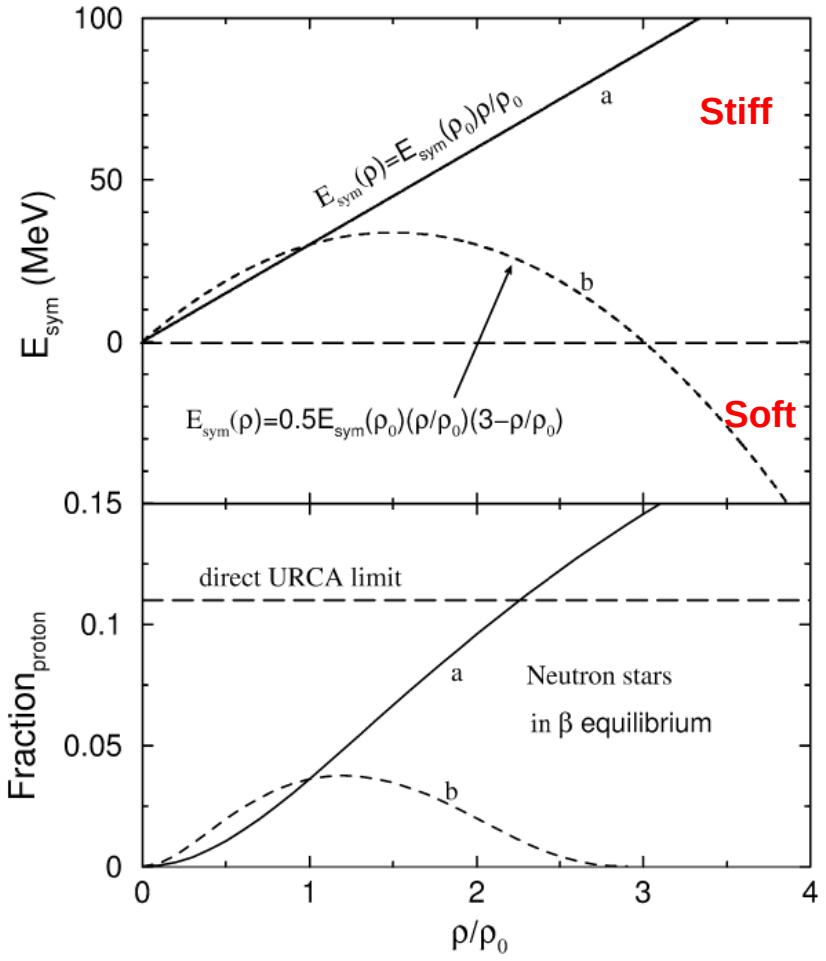
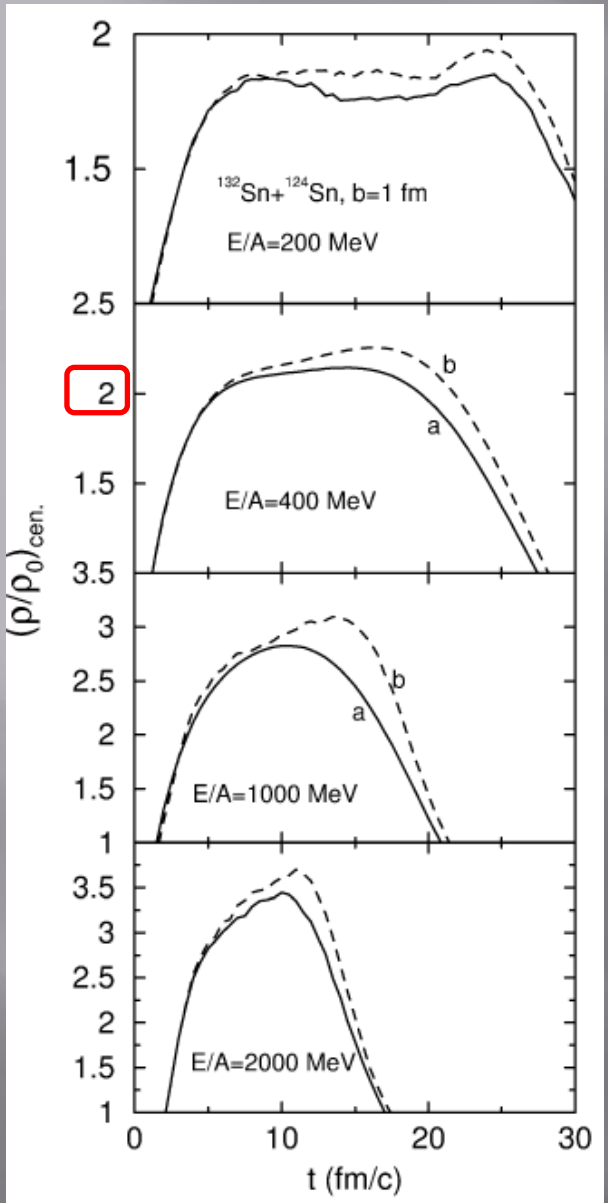
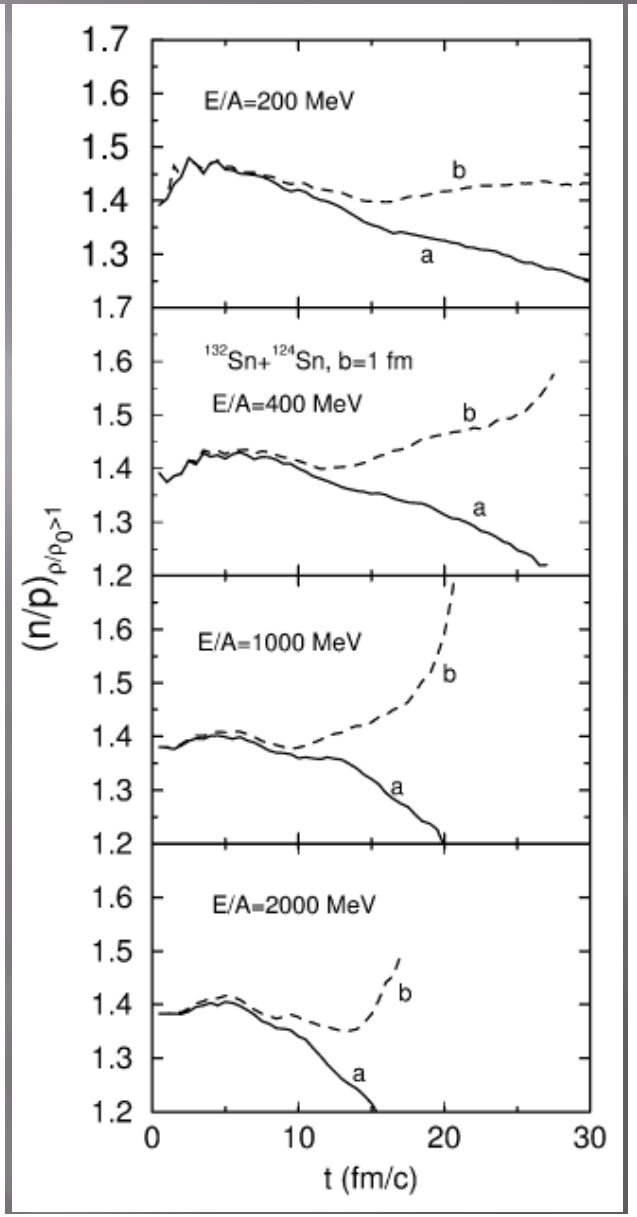
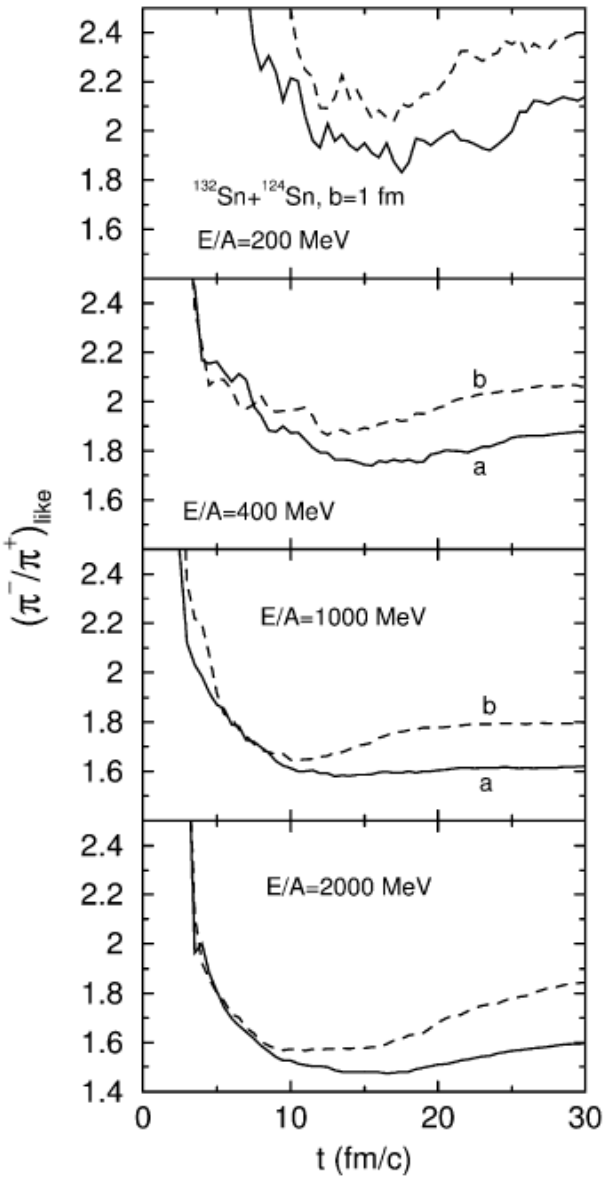


Fig. 1. Upper window: two representatives of the nuclear symmetry energy as a function of density. Lower window: the corresponding proton fractions in neutron stars at β equilibrium.



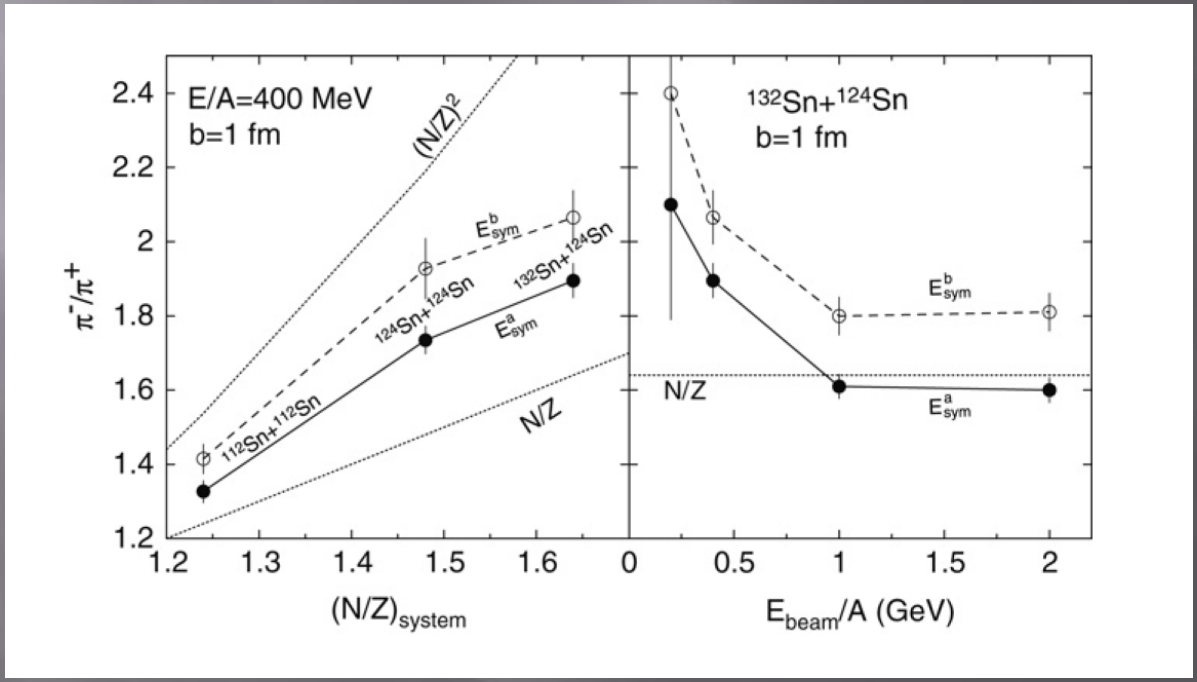




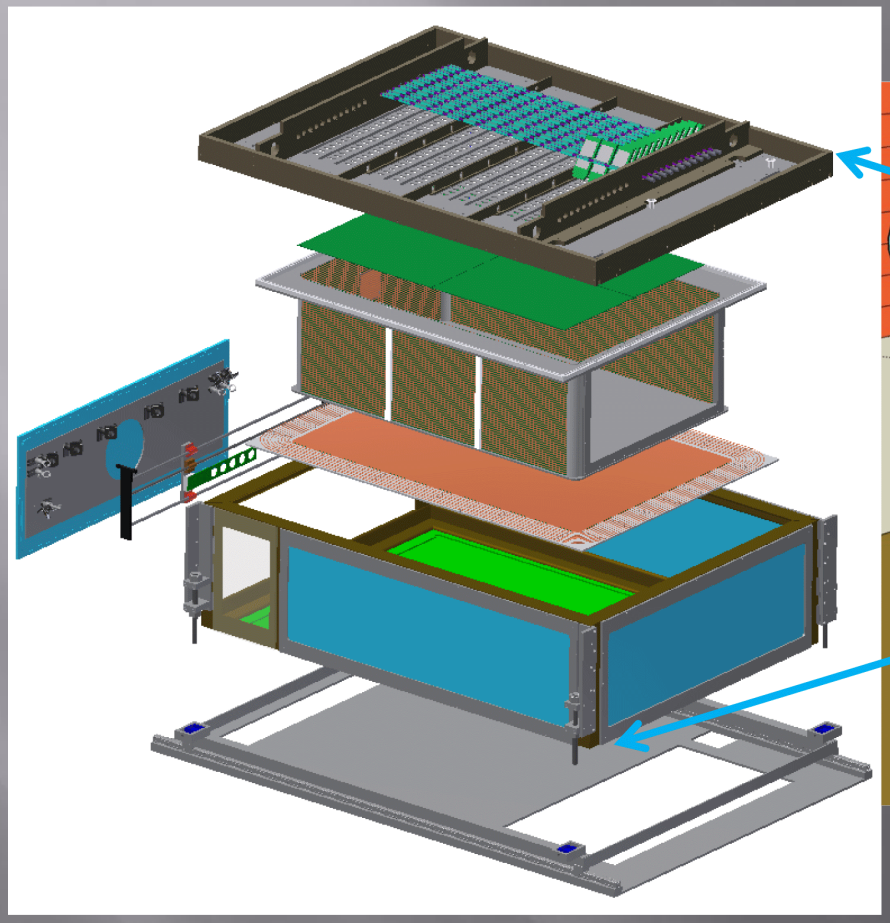
$$\pi^- / \pi^+ \equiv (5N^2 + NZ)/(5Z^2 + NZ)$$

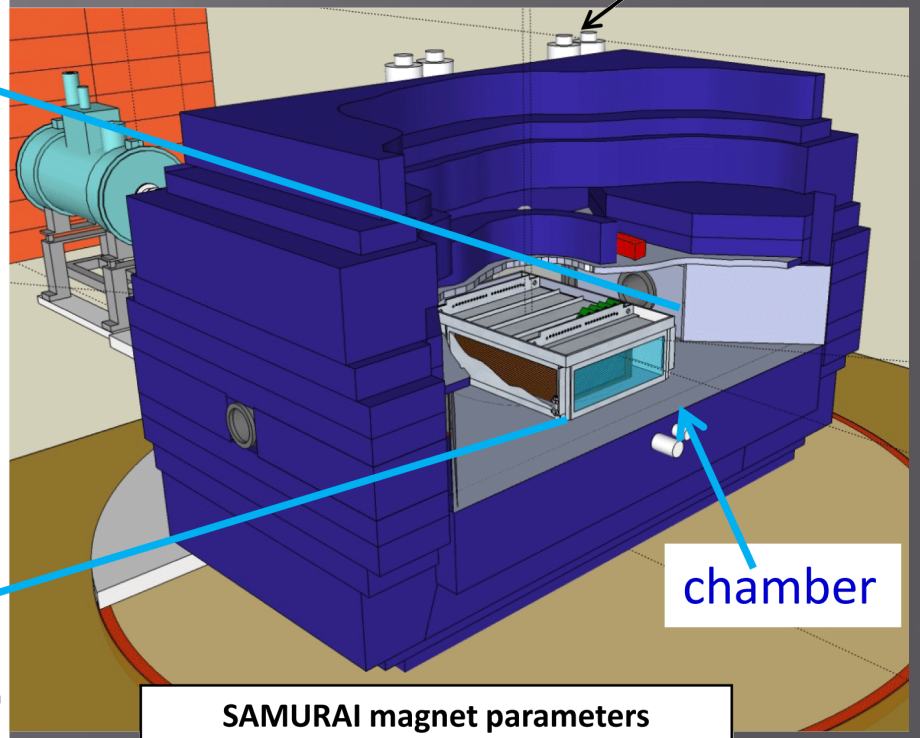
Possible Probe

- $\pi^+ - \pi^-$ ratio
- Proton-neutron ratio
- Light ion ratio (t-^{3}He)
- Particle flow of pions, protons, neutrons and light ions



Construction of SPiRIT



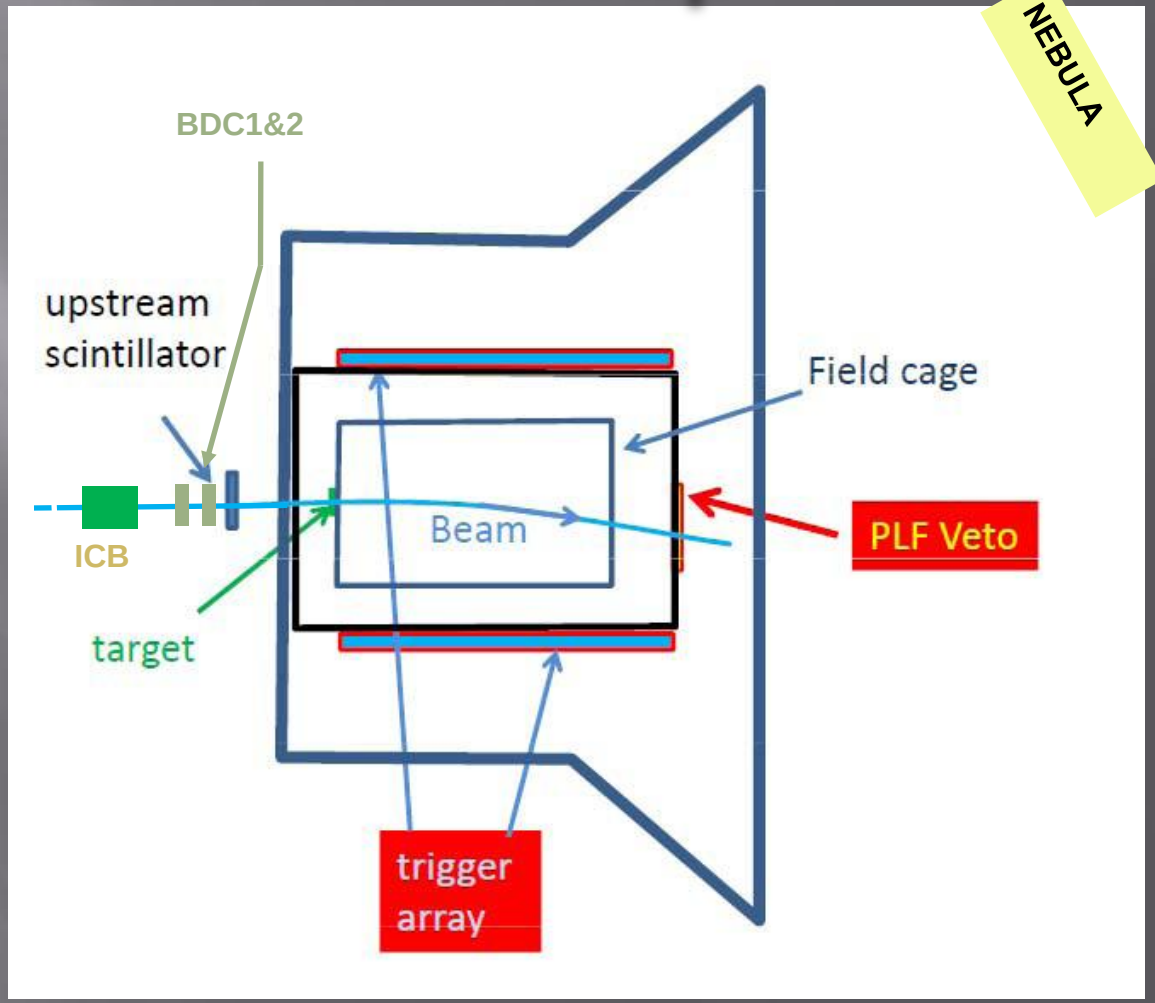


SAMURAI magnet parameters	
B_{typ}, B_{max}	0.5T, 3T
R, pole face	1 m
Gap	80 cm
Usable gap	75 cm

Supported by USA DoE funding ($1.2M), and Japanese Grant-in-Aid for Scientific Research on innovative areas ($1.3M).

Experimental Setup

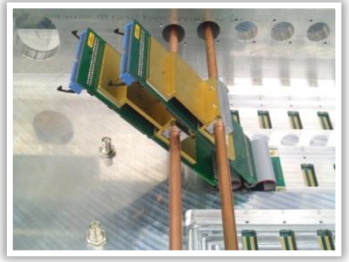
- Equipment
  - TPC - measures:
    - π^+ , π^- , p, d, t, ^{3}He, ^{4}He, IMF's
    - The SAMURAI chamber is at air
  - Trigger scint. array:
    - selects central collisions and suppresses peripheral collisions.
  - NEBULA:
    - provides neutron information



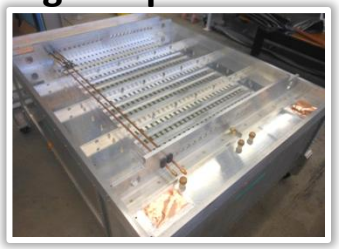
Magnet is at 0 degrees.

SPiRIT: Exploded View

Front End Electronics

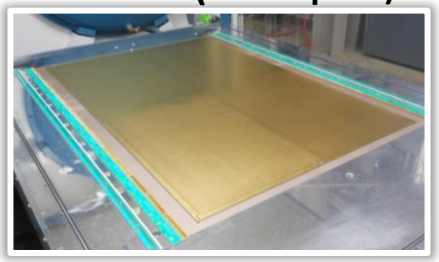


Rigid Top Plate

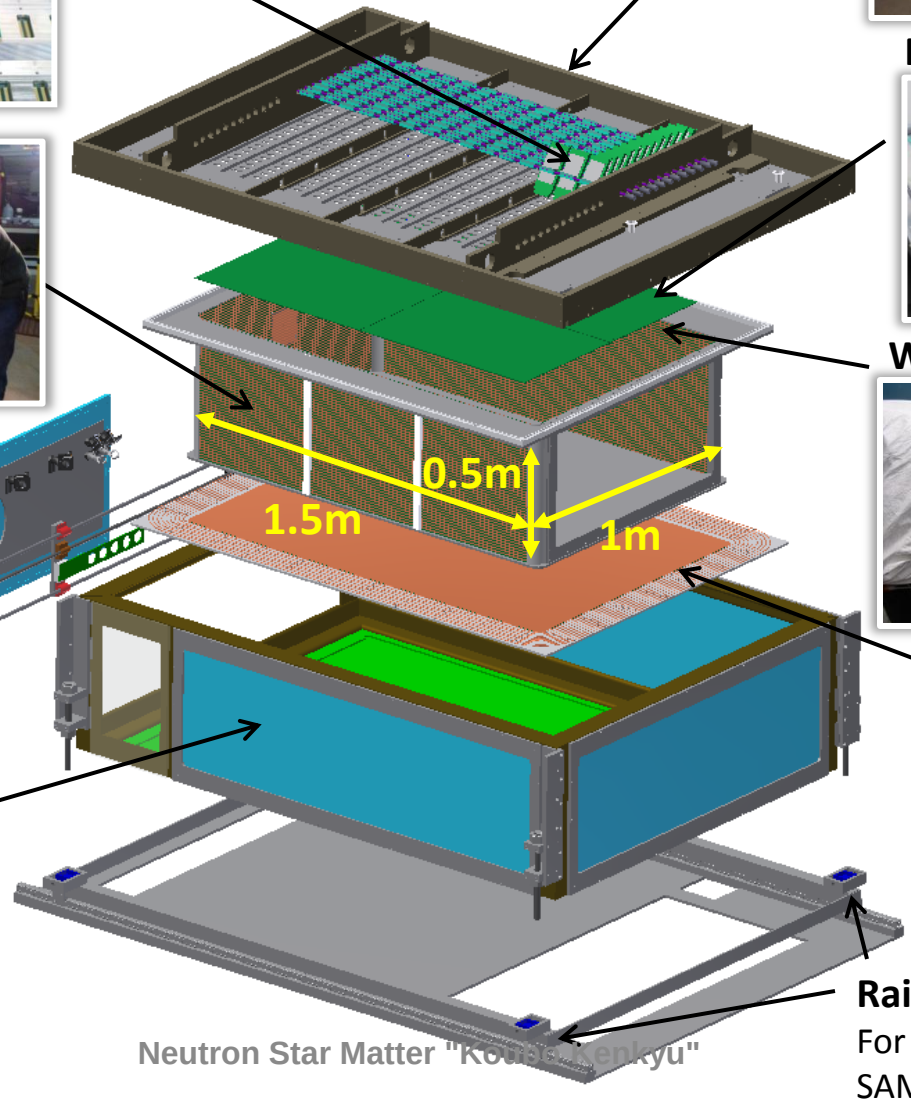


Field Cage

Pad Plane (12096 pads)



Wire Planes (e- mult)

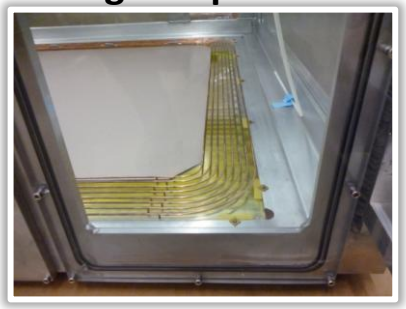


Beam

Calibration
Laser Optics

Target Mechanism

Voltage Step-Down



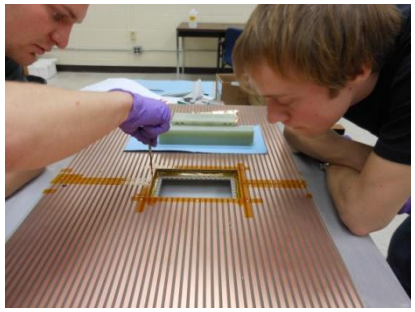
Thin-Walled Enclosure

Rails

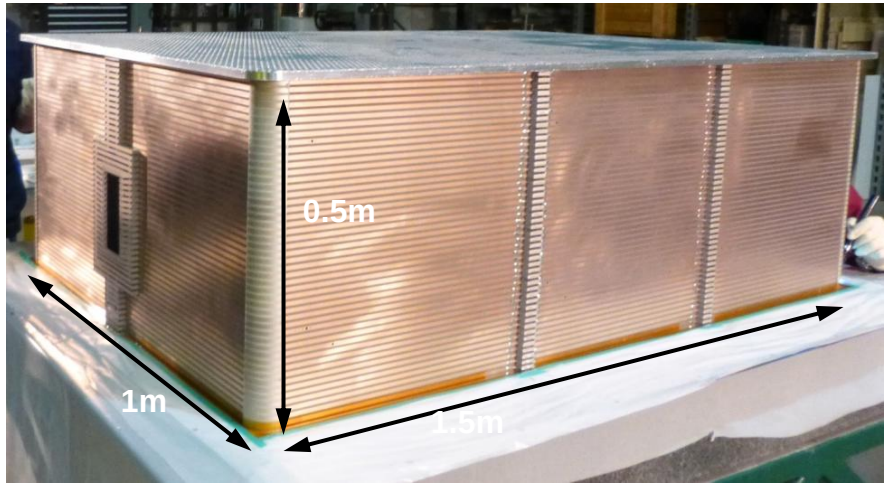
For inserting TPC into
SAMURAI vacuum chamber

S-TPC: *Field cage*

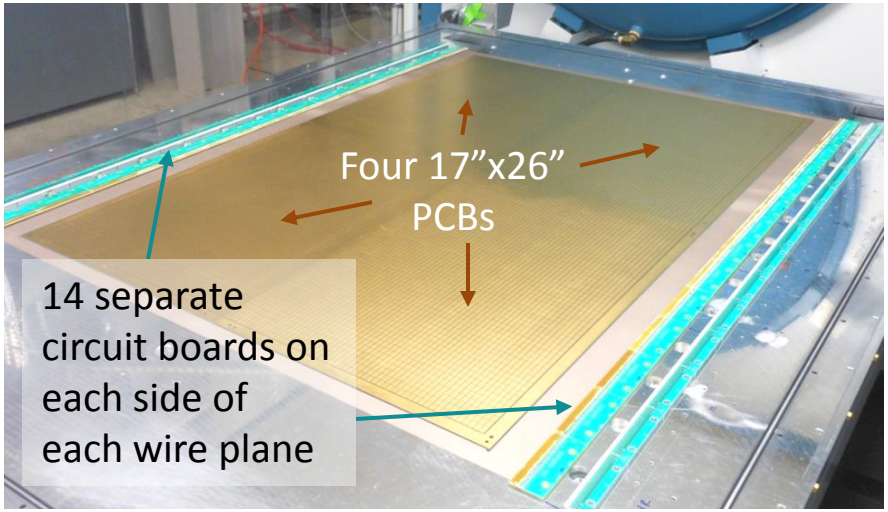
- Thin walls for particles to exit, but maintain structural stability
  - 8 circuit boards with copper strips
- Removable beam windows
  - 25um mylar entry window
  - 125um kapton exit window
- Cathode (bottom)
  - Aluminum honeycomb: light, strong
  - Graphite coating: incr. work function
- Gas tight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



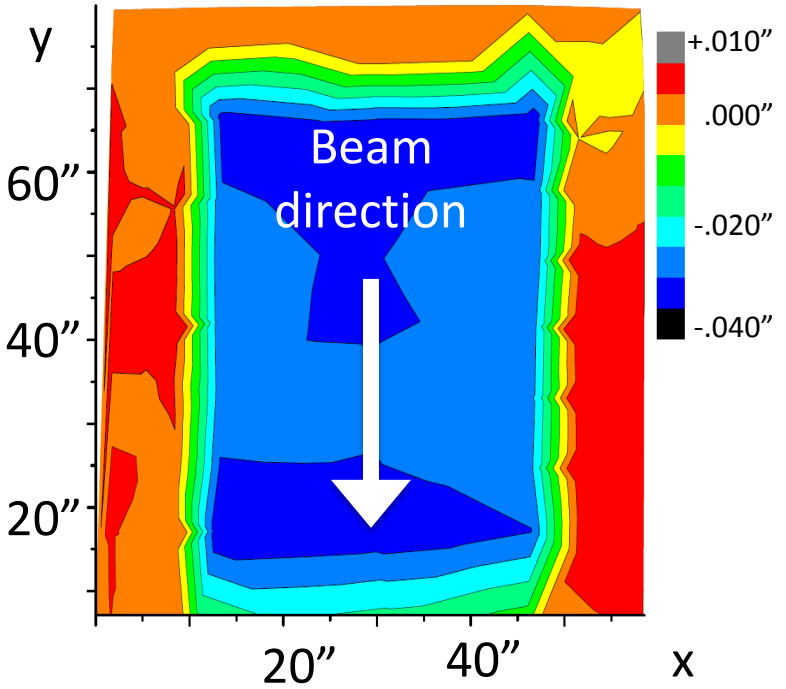
Gluing field cage together



Pad and wire planes



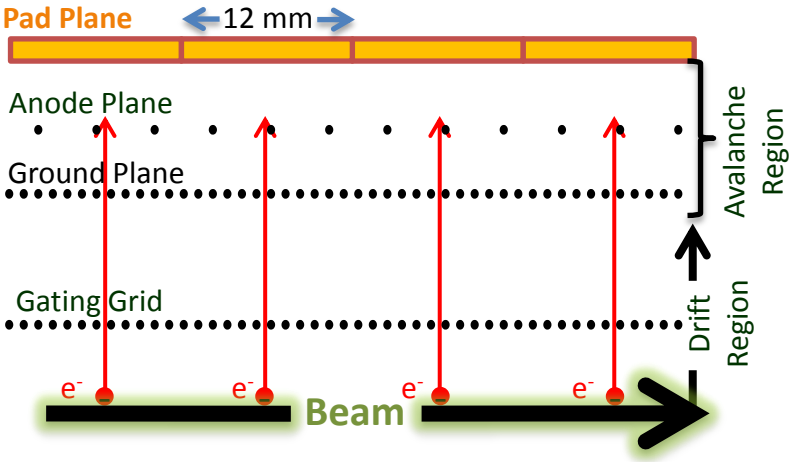
Pad plane laser measurements



- Pad plane is ***flat to within 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



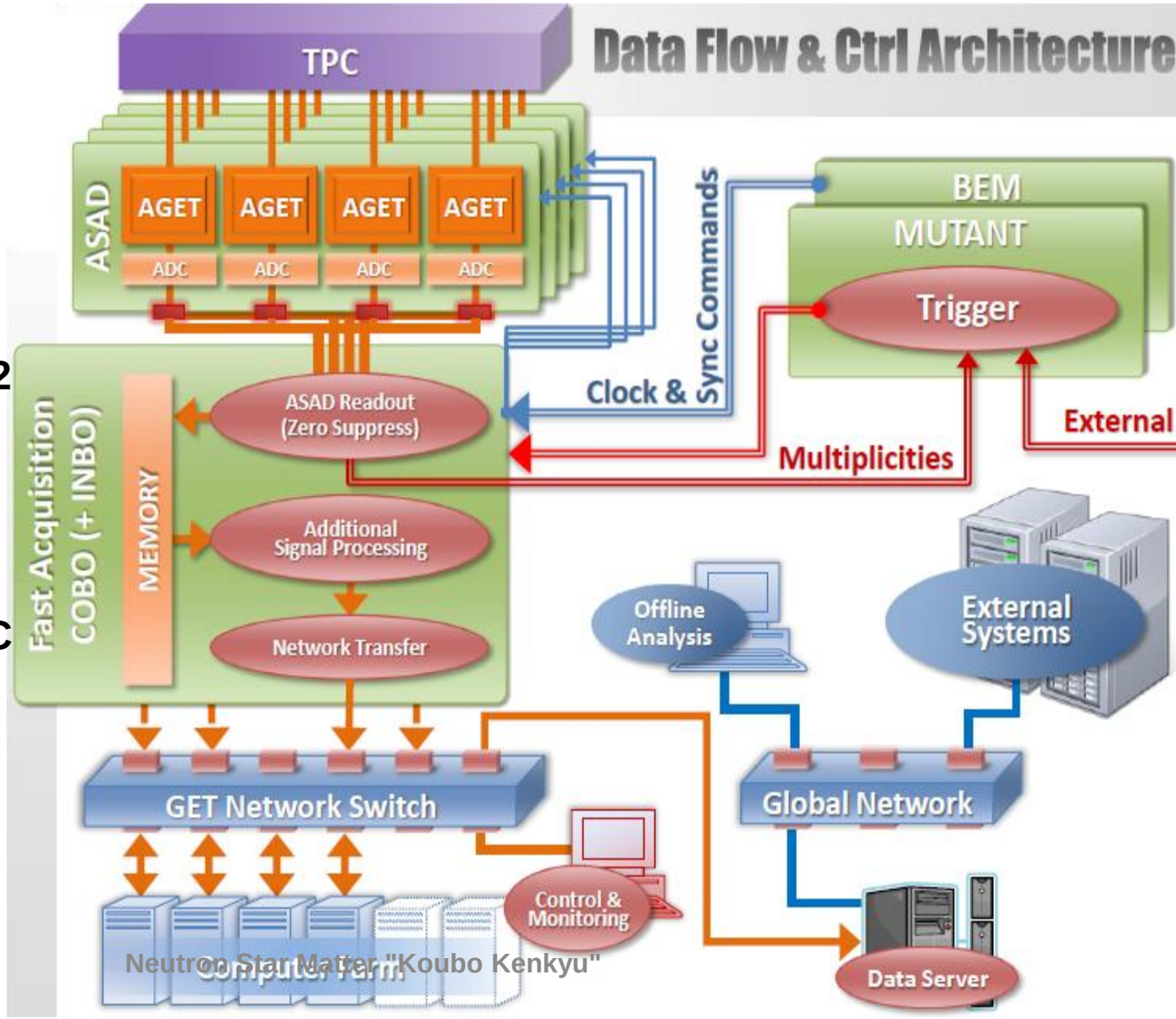
Assembly completed May 2013

Pad plane readout tested with pulsers.
Testing with cosmic rays and sources are on going.
Experiments will use GET (Generic Electronics for TPC's) readout electronics.
Testing with gating grid driver is on going.
TPC will be shipped to RIKEN at February 2014.

TPC electronics (read-out; GET)

Basic feature:
State of Arts technology
Capable to handle
1KHz – 10Gb/s
Wide dynamic range
10.5 bits
Capacitive Array 1-512
Sampling 1-100MHz

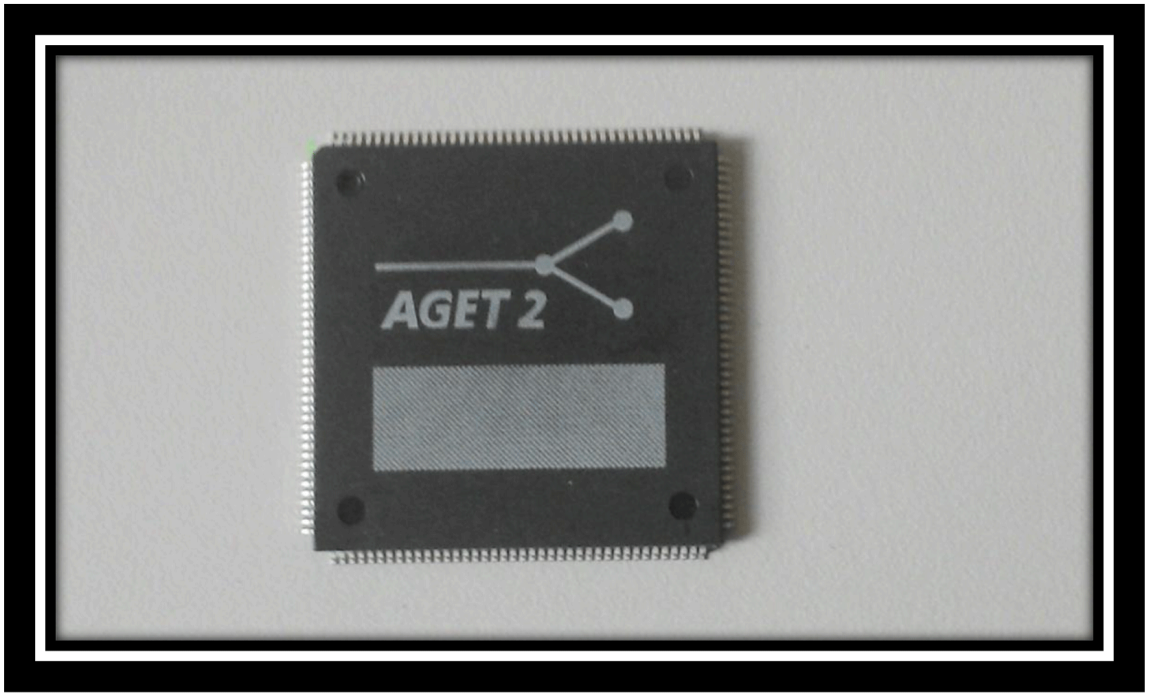
Ideal for SAMURAI-TPC Read-out



July 5: 700 AGET ASICS received at IRFU

- **First Test performs on one ASIC with:**
- **Oscilloscope**
- **Actual production test bench**

These results are obtained with the ASIC on the socket which is not optimal for the characterization of the circuit..



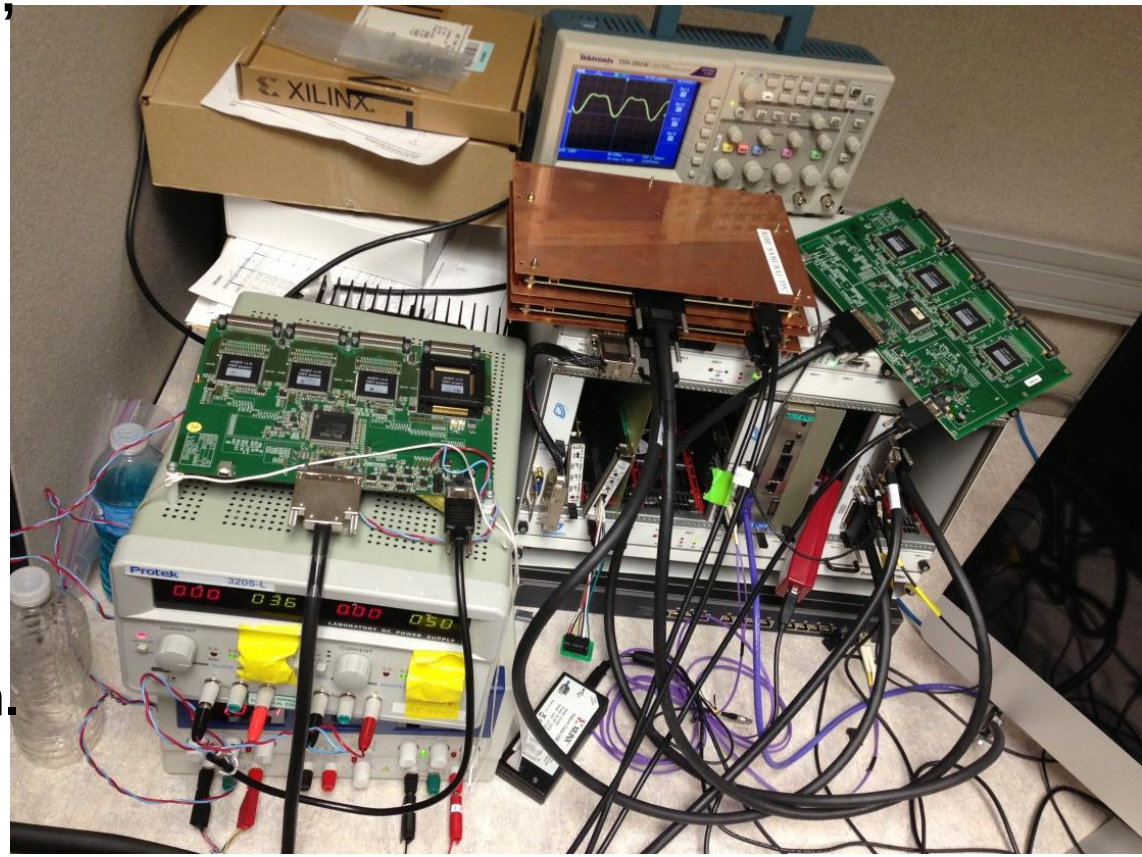
Status of electronics

Pduction of AGET (ASIC-chip), AsAd board and CoBo is on going.

Reduced system with Xilinx evaluation board (ML507, Vertex5) has been finished with RHIC-BRAHMS TPC.

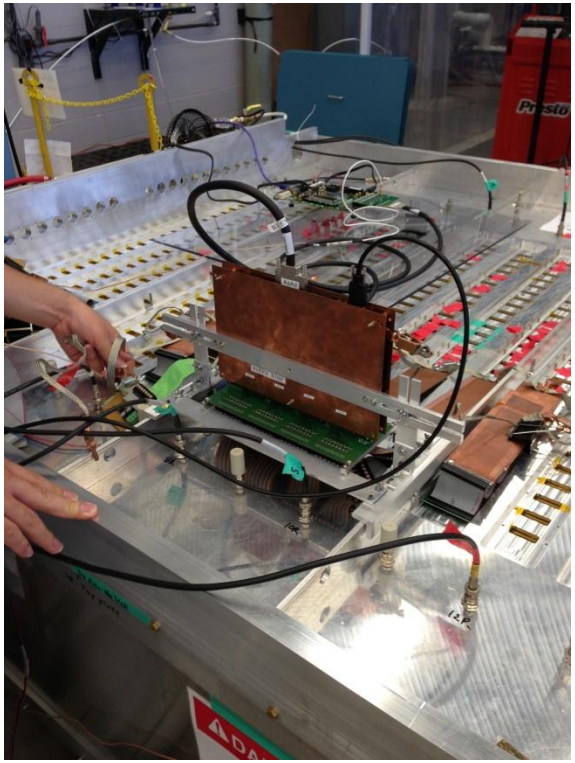
Testi of μ-TCA CoBo with 4 AsAd board has just started at the beginning of this month. (Optimization of firmware)

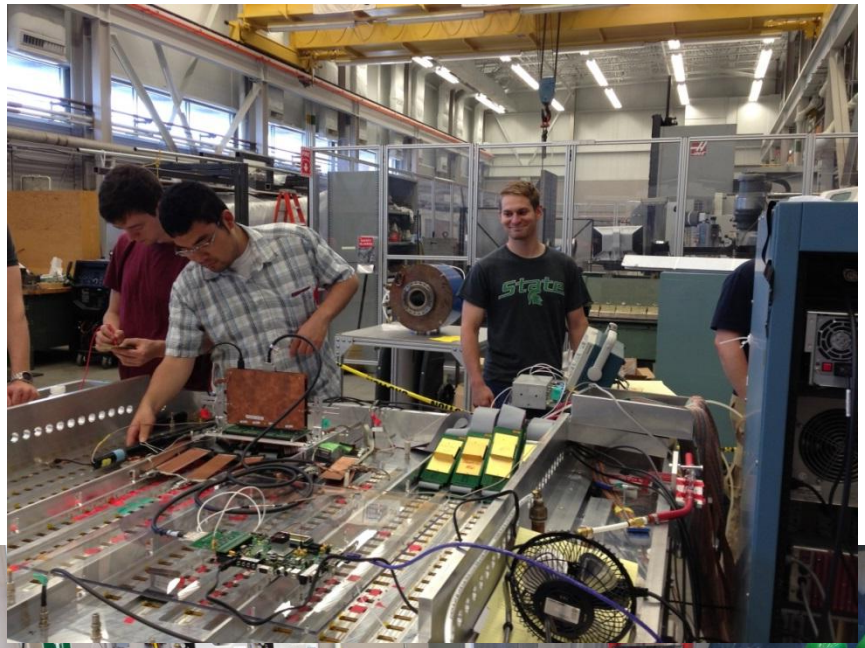
Testing TPC with GET electronics is on going.

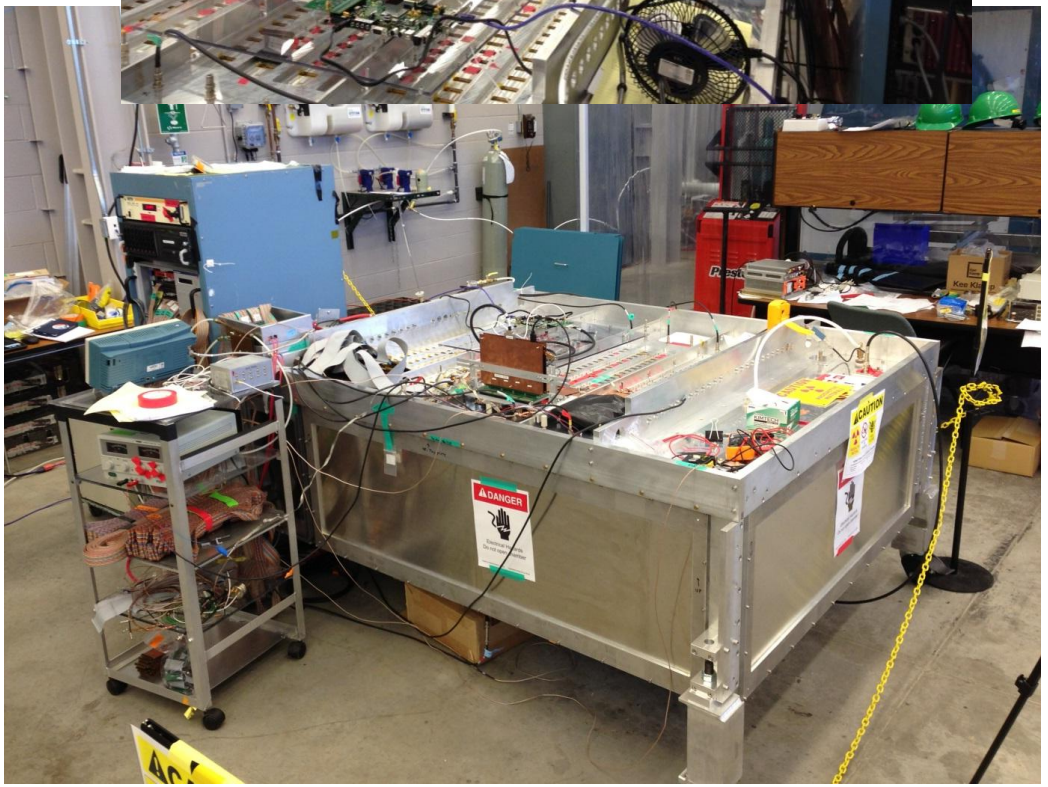


4AsAd + CoBo testi as in Sep. 1st

GET on SPiRiT







NP1306-SAMURAI15

Approved – Grade A

6.5 days (including 1 day for the BigRIPS tuning)

…. **Due to the limitation of beam time,** the NPPAC recommends that this first experiment should be performed with 6.5 days of beam time only for the ^{132}Sn+^{124}Sn and ^{124}Sn+^{112}Sn collisions at 300 MeV/u with the primary ^{238}U beam.