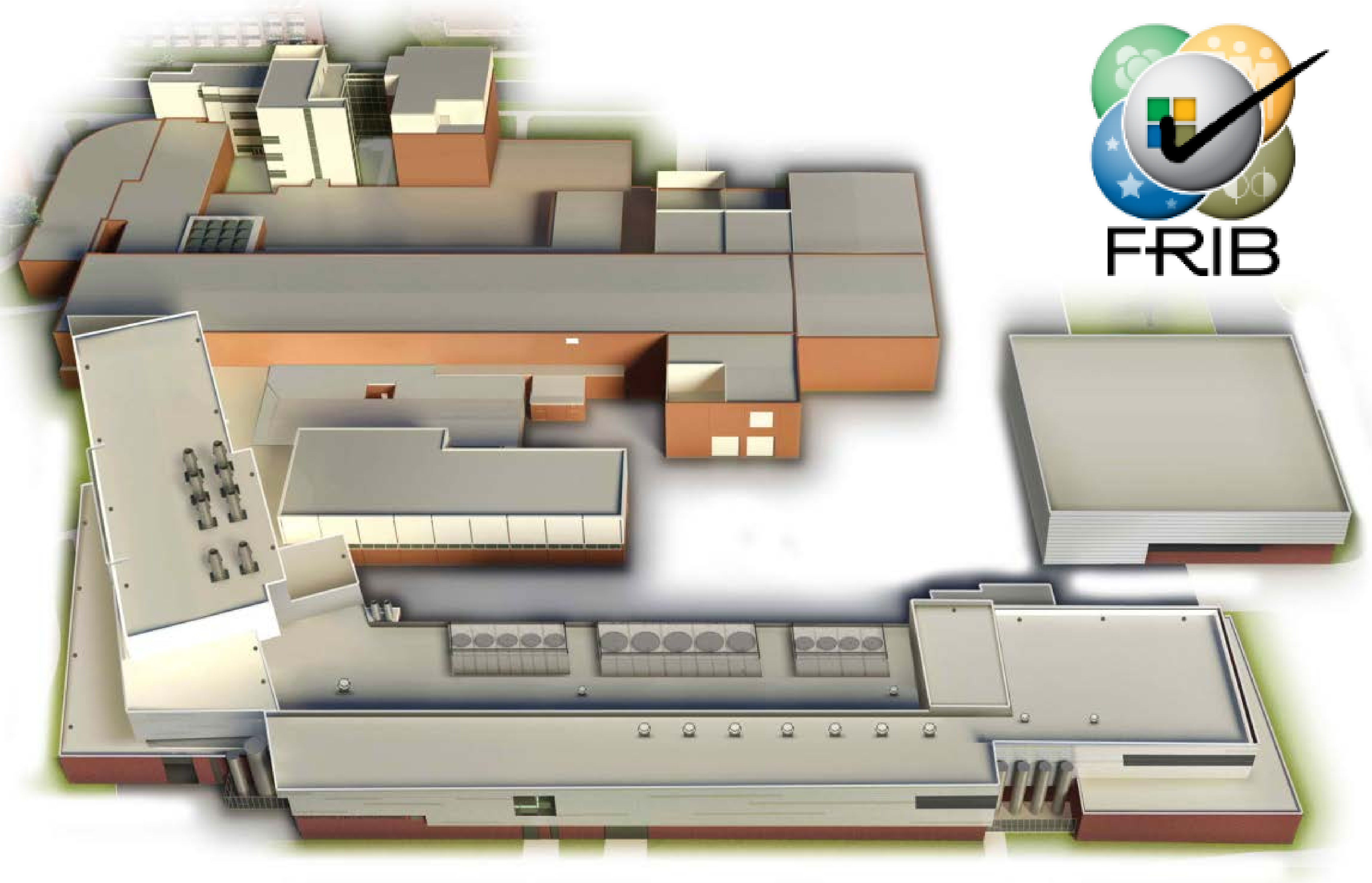
The National Superconducting Cyclotron Laboratory
Michigan State University

New Instrumentation for the Equation of State Study at present and future facilities

Betty Tsang

The National Superconducting Cyclotron Laboratory



FRIB

FRIB Construction Progress

March 17, 2014

above ground! April 1, 2015

Utility work on tunnel, April, 2015

Linac tunnel, May 2015

FRIB Construction Progress

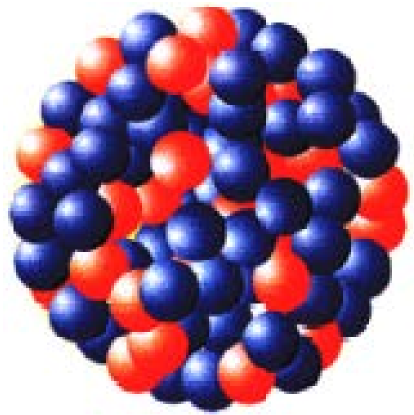
From Earth to Heavens:
Femto-scale nuclei to Astrophysical objects

Equation of State of nuclear matter

$$E/A(\rho,\delta) = E/A(\rho,0) + \delta^2 \cdot S(\rho)$$

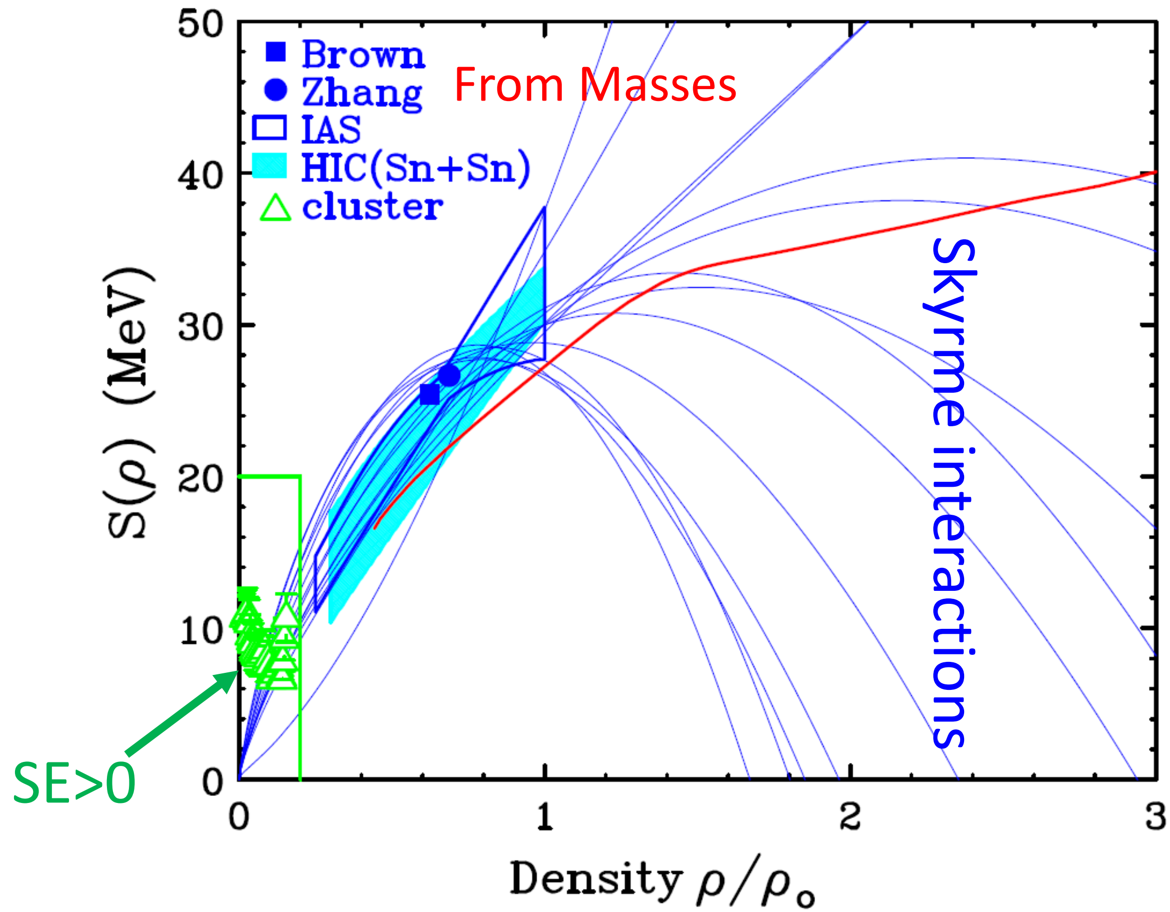
$$\delta = (\rho_n - \rho_p)/(\rho_n + \rho_p) = (N-Z)/A$$

Symmetry Energy of asymmetric matter



^{208}Pb

- To probe fundamental questions on the nature of nuclear matter especially the isospin asymmetric matter.
- To recreate and study astrophysical environments

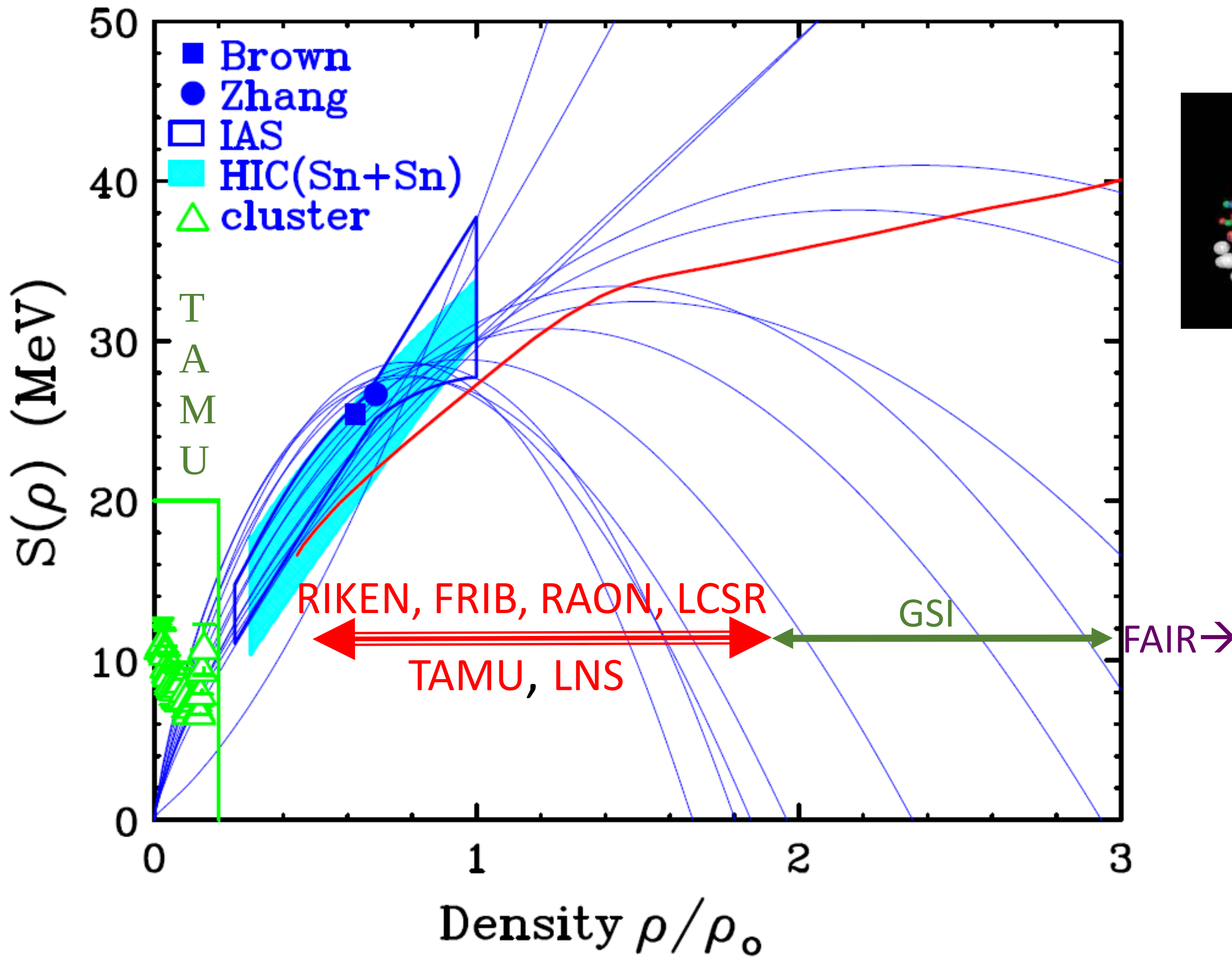


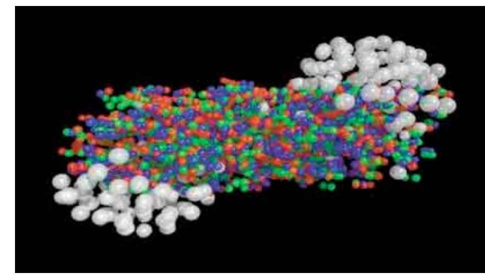
Recommendation to US Long Range Plan from EOS working group

- At $\rho \ll \rho_0$: Establish observables to study cluster effect and link to neutrinosphere physics.
- At $\rho \leq \rho_0$: Improve constraints from both structure and reaction experiments:
- At $\rho \approx 1.5 - 2\rho_0$: Determine symmetry energy and the momentum dependence of the isovector potential.

Symmetry Energy Project

nn collisions





International Efforts

TRIUMF

FRIB

NSCL

ANL

LBNL

TAMU

Notre Dame

GANIL

CERN ISOLDE

GSI

Dubna

Munich

Catania

RAON

IMP

RIBF RIKEN

NSC

VECC

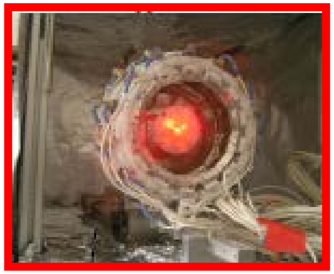
Sao Paulo

Productions of high intensity high energy Radioactive Isotope Beams for the EoS studies

ASY-EOS S394 experiment @ GSI Darmstadt (May 2011)

Au+Au, $^{96}Zr+^{96}Zr$, $^{96}Ru+^{96}Ru$ @ 400 AMev

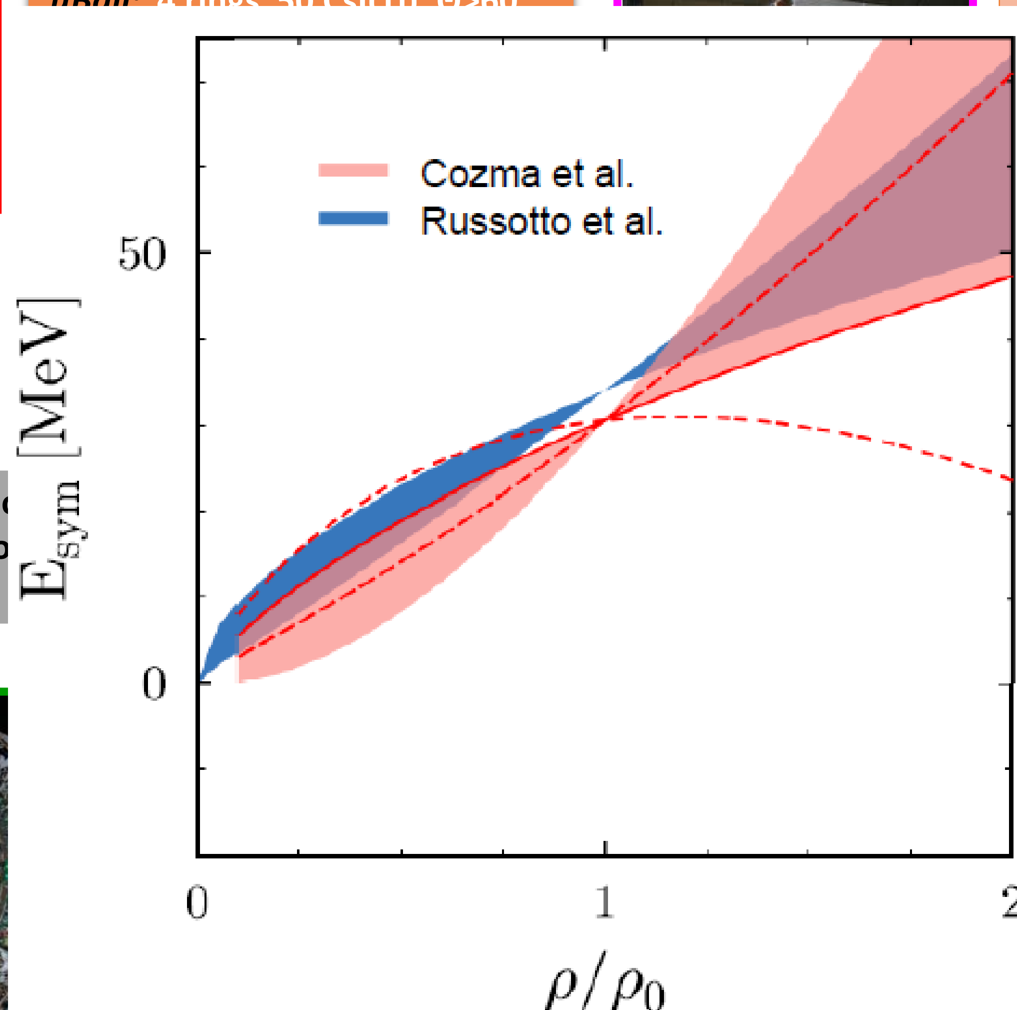
P. Russotto

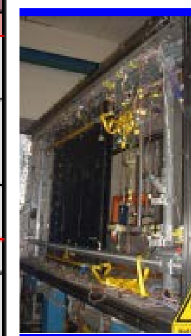


μBall: 4 rings, 50 CsI(Tl), Θ>60°

KraTTA: 35 (5x7) triple telescopes (Si-CsI-CsI) placed at 21°<Θ<60° with digital readout . Light particles and IMFs emitted at midrapidity

Shadow bar: evaluati
of background neutro
in LAND





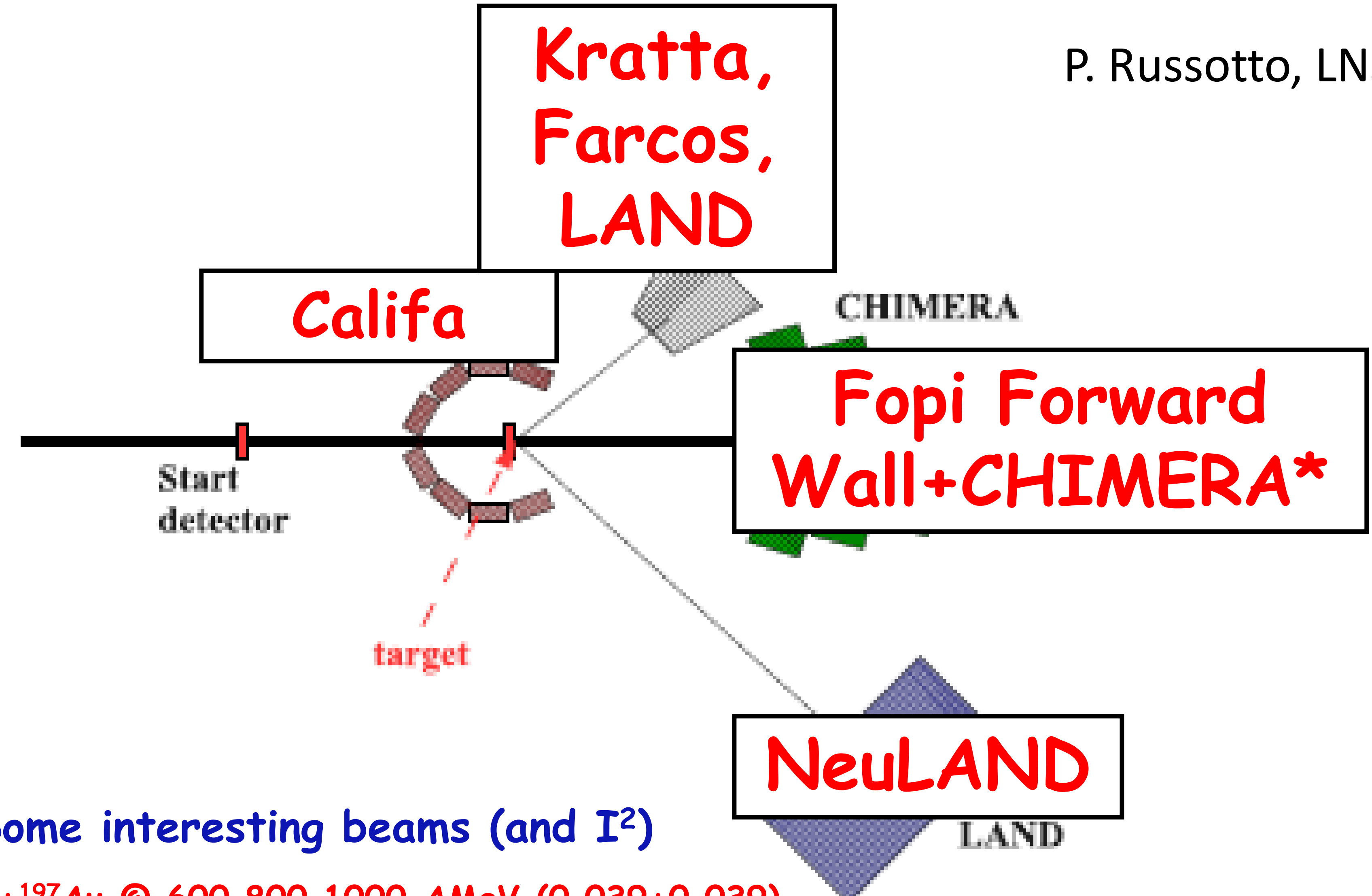
TOFWALL: 96 plastic bars; ToF, ΔE, X-Y position. Trigger, impact parameter and reaction plane determination

impact parameter and reaction plane determination

LAND: Large Area Neutron Detector . Plastic scintillators sandwiched with Fe 2x2x1 m^3 plus plastic veto wall. New Taquila front-end electronics. Neutrons and Hydrogen detection. Flow measurements

ASY-EOS future set-up?

P. Russotto, LNS



Some interesting beams (and I^2)

^{197}Au+^{197}Au @ 600,800,1000 AMeV (0.039+0.039)

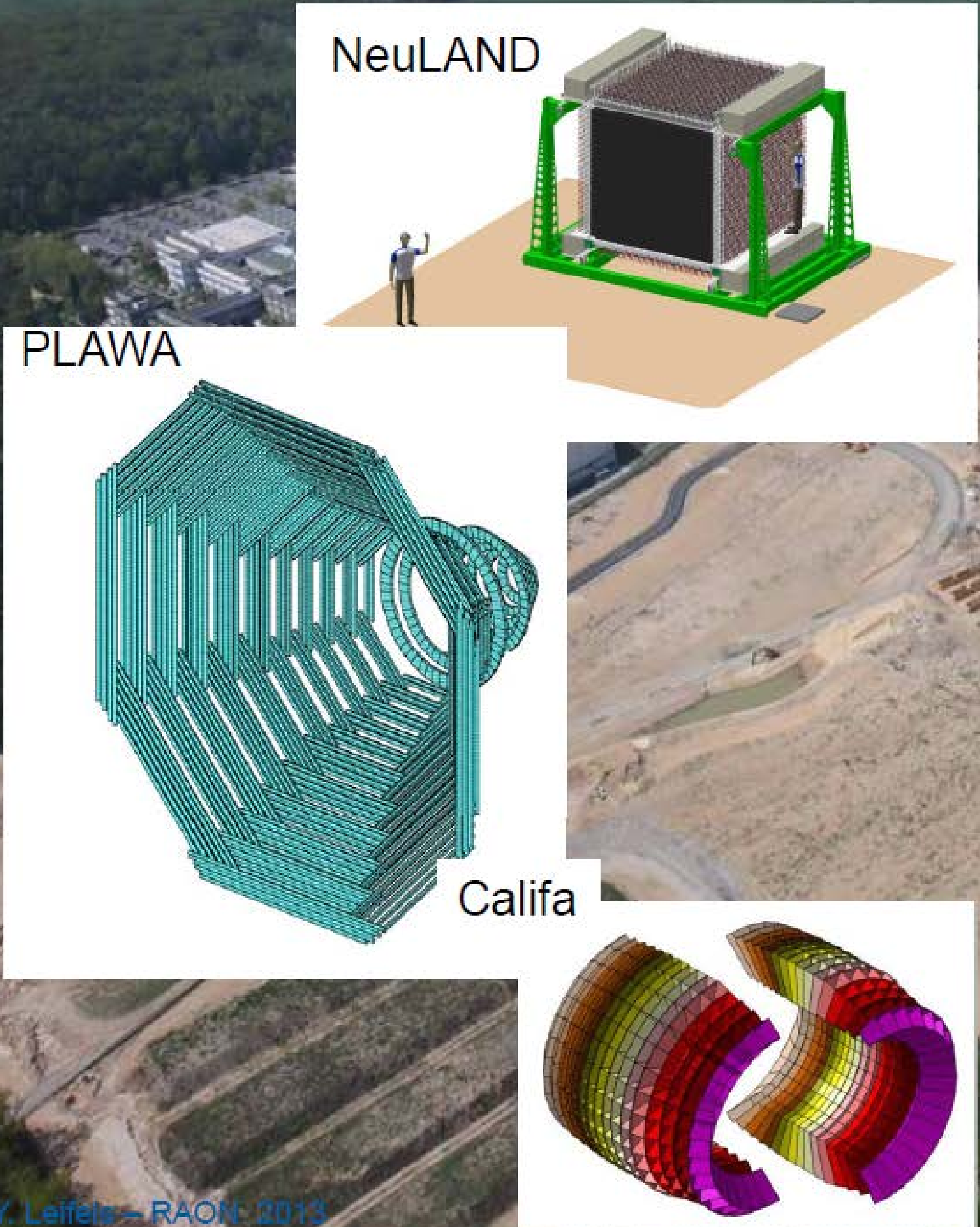
^{132}Sn+^{124}Sn @ 400, 800, 1000 AMeV (0.059+0.037)

^{106}Sn+^{112}Sn @ 400, 800, 1000 AMeV (0.003+0.011)

* Ring 1-2-3
(θ<7°)

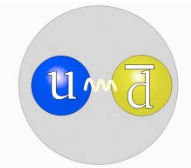
Prospects at GSI/FAIR

Yvonne Leifels



Symmetry energy at supra-normal densities

- Radioactive beams at the highest rigidities
- Study of momentum dependence of symmetry energy
- Extend studies to higher densities
- Pion ratio sensitive at 250-400A MeV -> complete systematics
- Kaon ratio requires dedicated detector (magnet + tracking + ToF)
  - Feasibility needs to be proven -> HADES stable beams
- n/p and t/3He ratio
  - neutron + charged particle detectors
  - detectors for reaction plane and impact parameter determination



Pion Observable

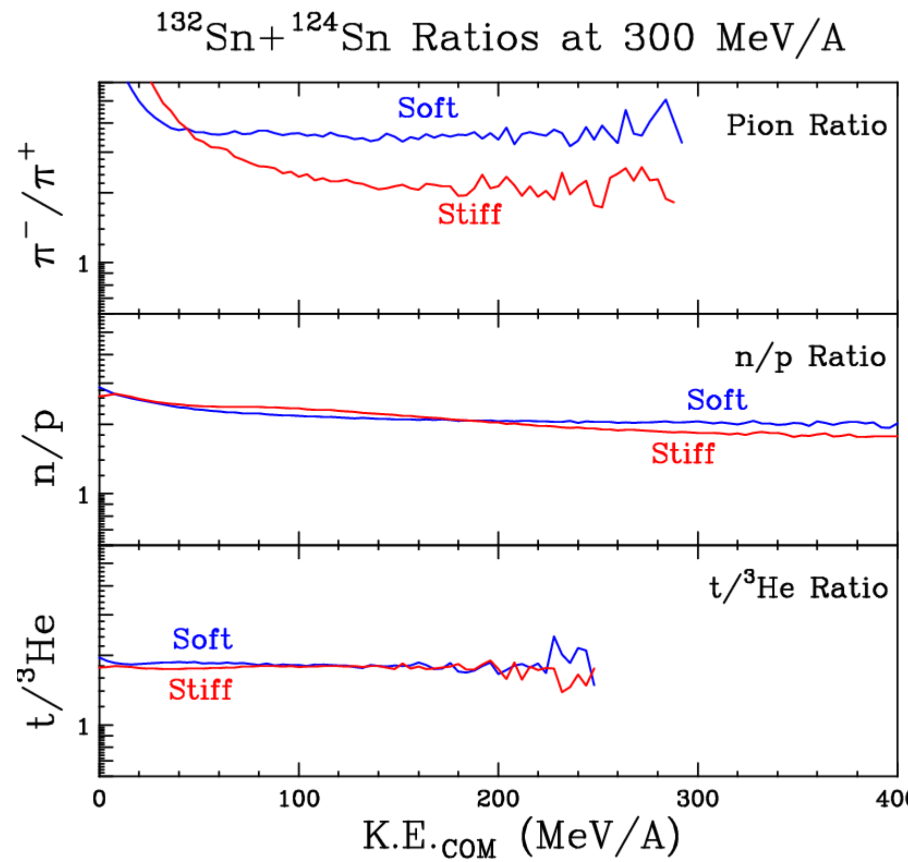
Resonance	Quarks	Δ Formation	Δ Decay
Δ^{++}	uuu	$p + p \rightarrow n + \Delta^{++}$	$\Delta^{++} \rightarrow \pi^{+} + p$
Δ^{+}	uud	$p + p \rightarrow p + \Delta^{+}$	$\Delta^{+} \rightarrow \pi^{+} + n$
Δ°	udd	$n + n \rightarrow n + \Delta^{\circ}$	$\Delta^{\circ} \rightarrow \pi^{-} + p$
Δ^{-}	ddd	$n + n \rightarrow p + \Delta^{-}$	$\Delta^{-} \rightarrow \pi^{-} + n$

Pros:

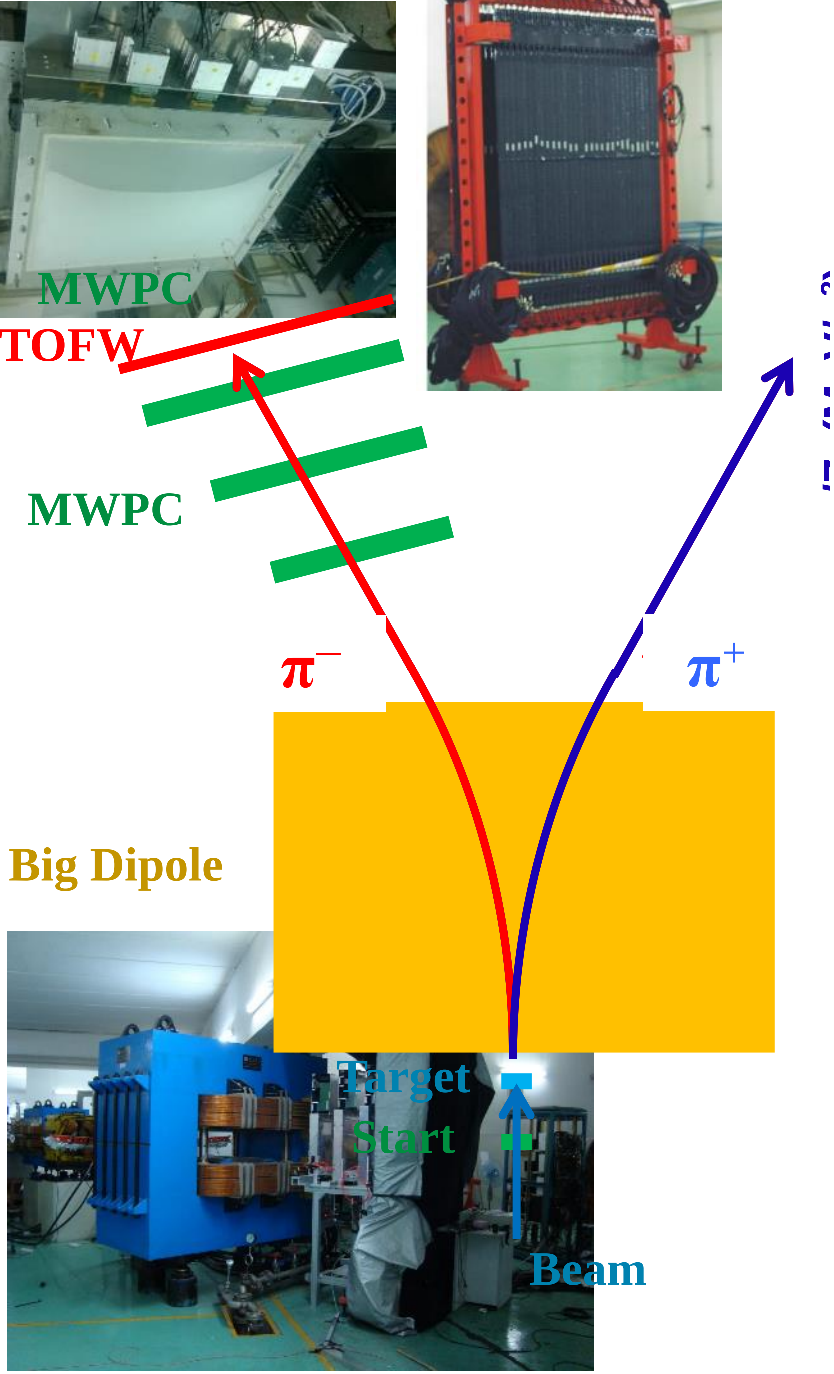
- Produced in direct n p collisions – sensitive to symmetry energy
- exit in early time

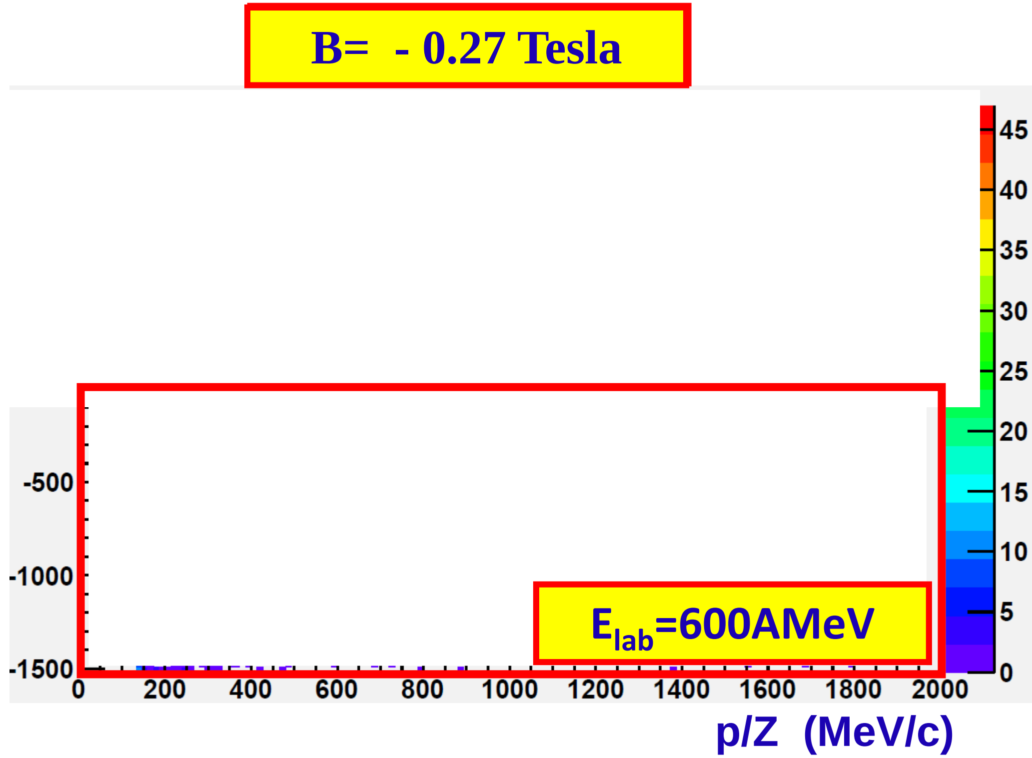
Cons:

- Cross-section is low and
- Easily reabsorbed in collision medium



Pion ratios are most sensitive

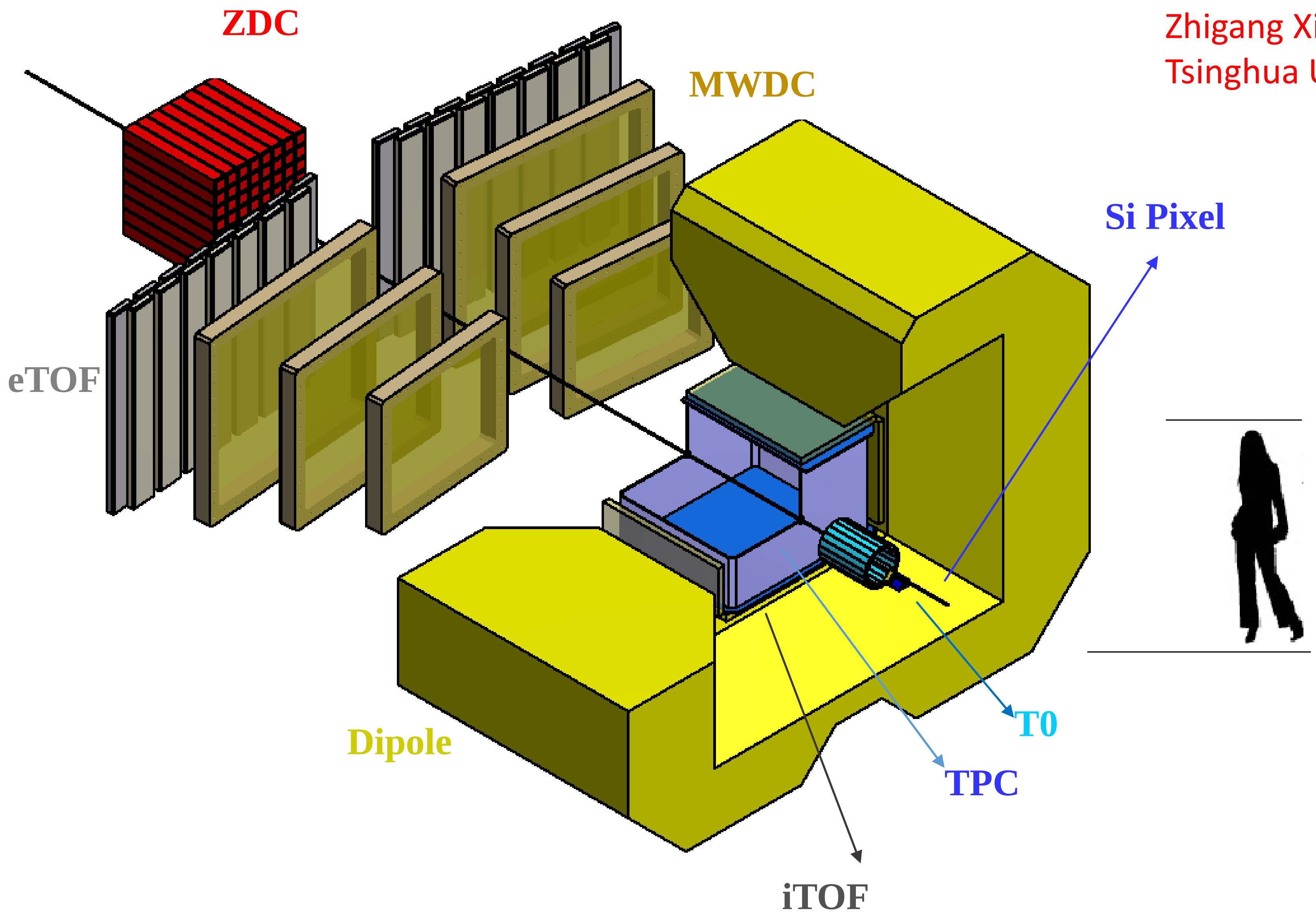

MWPC
TOFW
MWPC
π^-
π^+
Big Dipole
Target
Start
Beam


B= - 0.27 Tesla
-500
-1000
-1500
0
200
400
600
800
1000
1200
1400
1600
1800
2000
45
40
35
30
25
20
15
10
5
0
E_{lab}=600AMeV
p/Z (MeV/c)

Z. Sun, IMP

$E_{sym}(\rho)$ at supra-saturation studies at HIRFL-CSR

Zhigang Xiao,
Tsinghua University



New Detector

Radioactive Beam:

- low luminosity ➔ large coverage

High Resolution:

- resolve many different species of produced particles
- distinguish particles by mass and charge (π^+, π^-)
- track particles in an applied magnetic field

Versatile for a wide range of experimental programs

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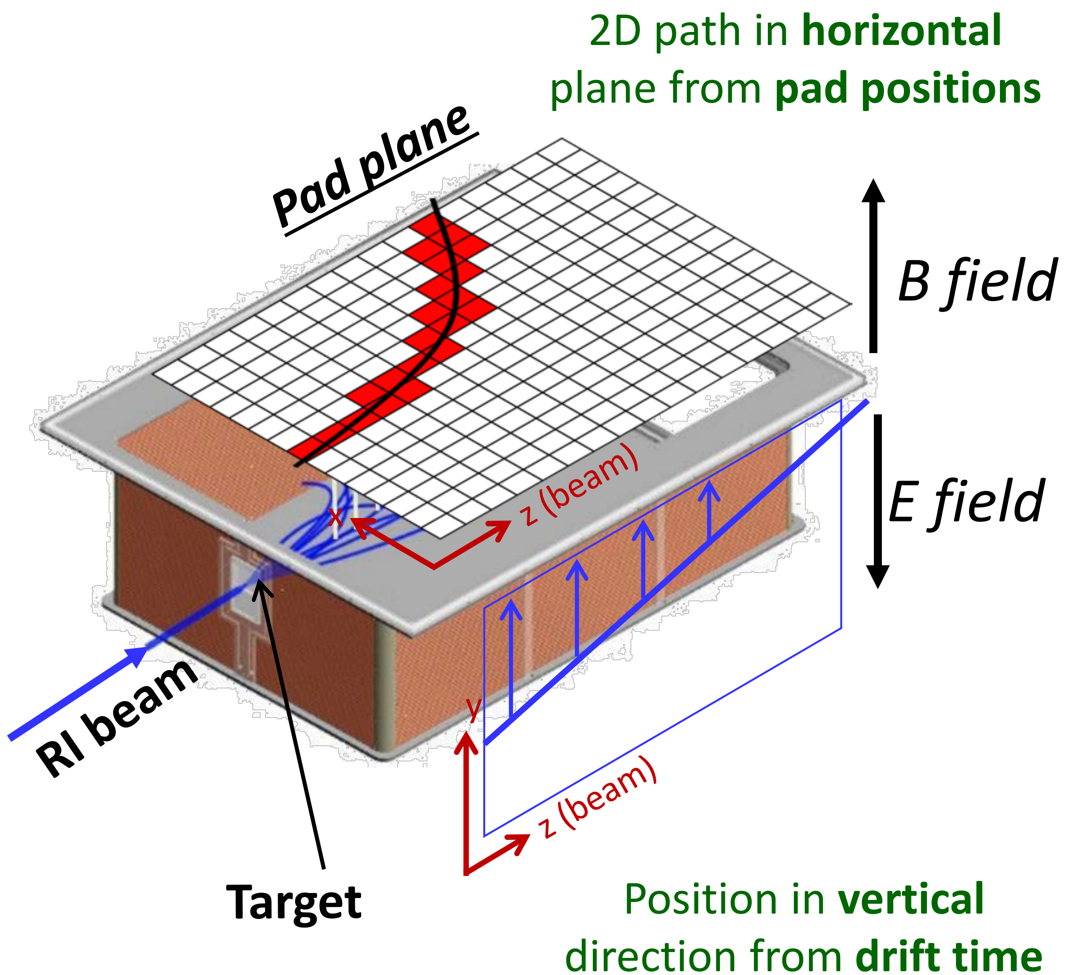
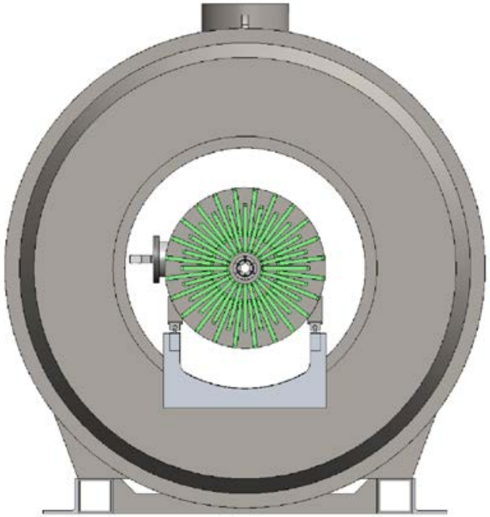
Time-Projection Chamber

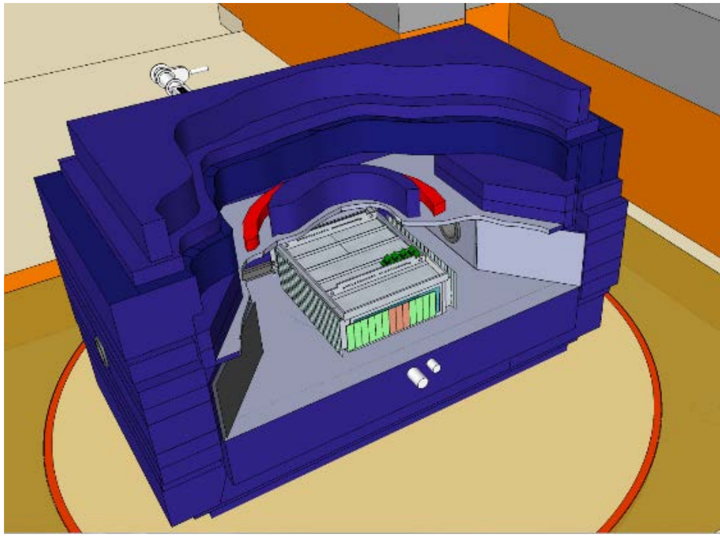
- Products from reaction ionize detector gas inside a field cage
- Electron signal is amplified by a wire plane
- The time at which the electrons hit the pads provides the third dimension



Field cage figure courtesy of J. Estee



Solenoid vs. Dipole



Solenoid

STAR, LHC, AT-TPC

- Beam trajectory can be centered in magnet independent of beam species & energy
- Optional field cage can be used to mask beam ionization
- Narrow downstream acceptance
- Limited momentum resolution at very forward angles.

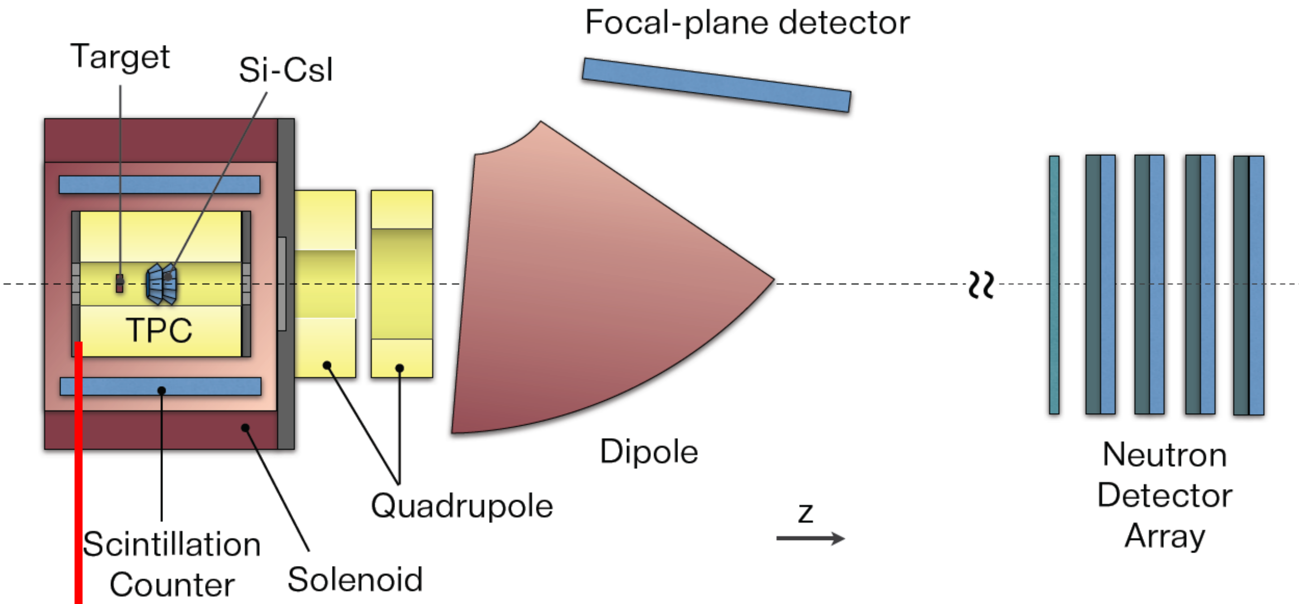
Dipole

EOS, T2K, SpiRIT

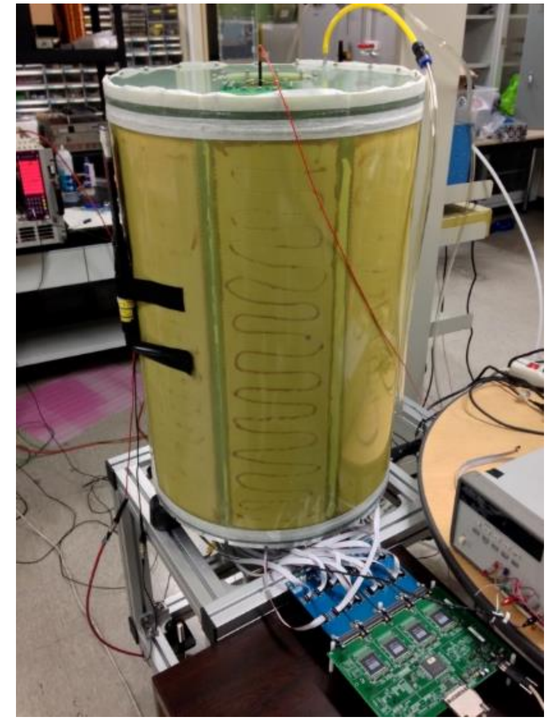
- Good momentum resolution in forward direction
- Wide downstream acceptance
Easier to incorporate axillary detectors
- Beam trajectory influenced by B field and depend on beam species & energy
- Difficult to mask beam ionization

LAMPS@RAON in Korea

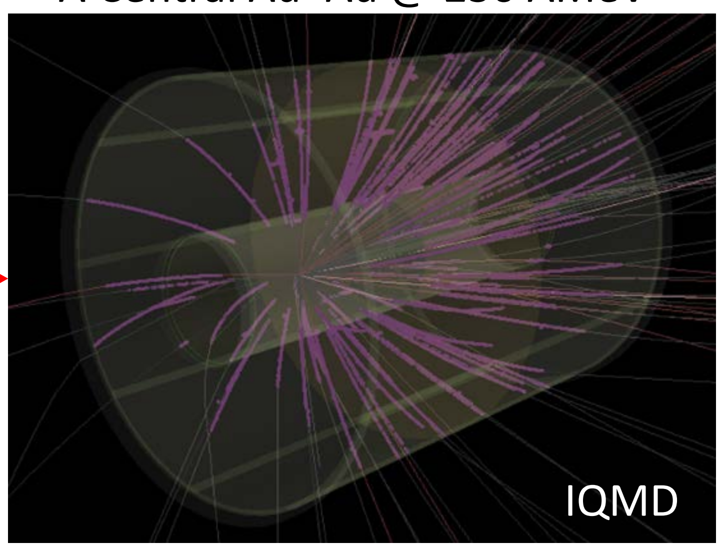
B. Hong

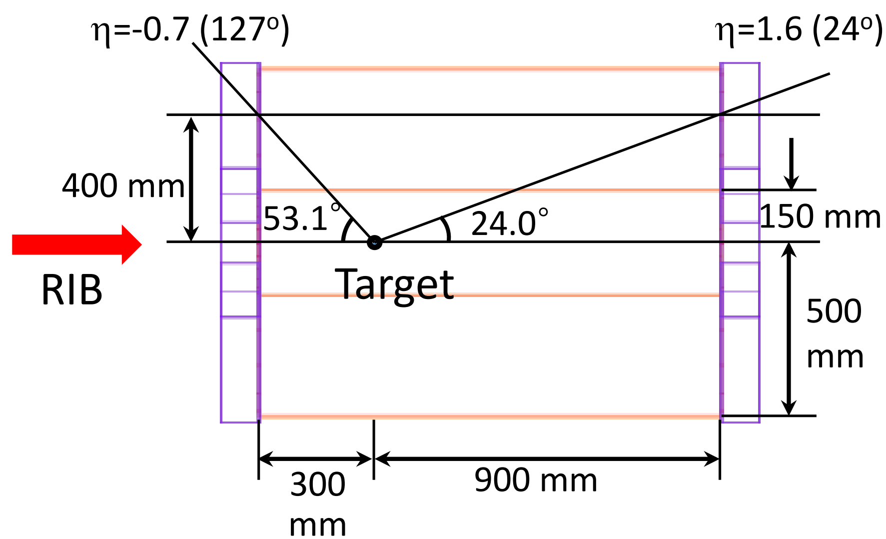


Prototype TPC assembled with prototype GET electronics



A Central Au+Au @ 250 AMeV





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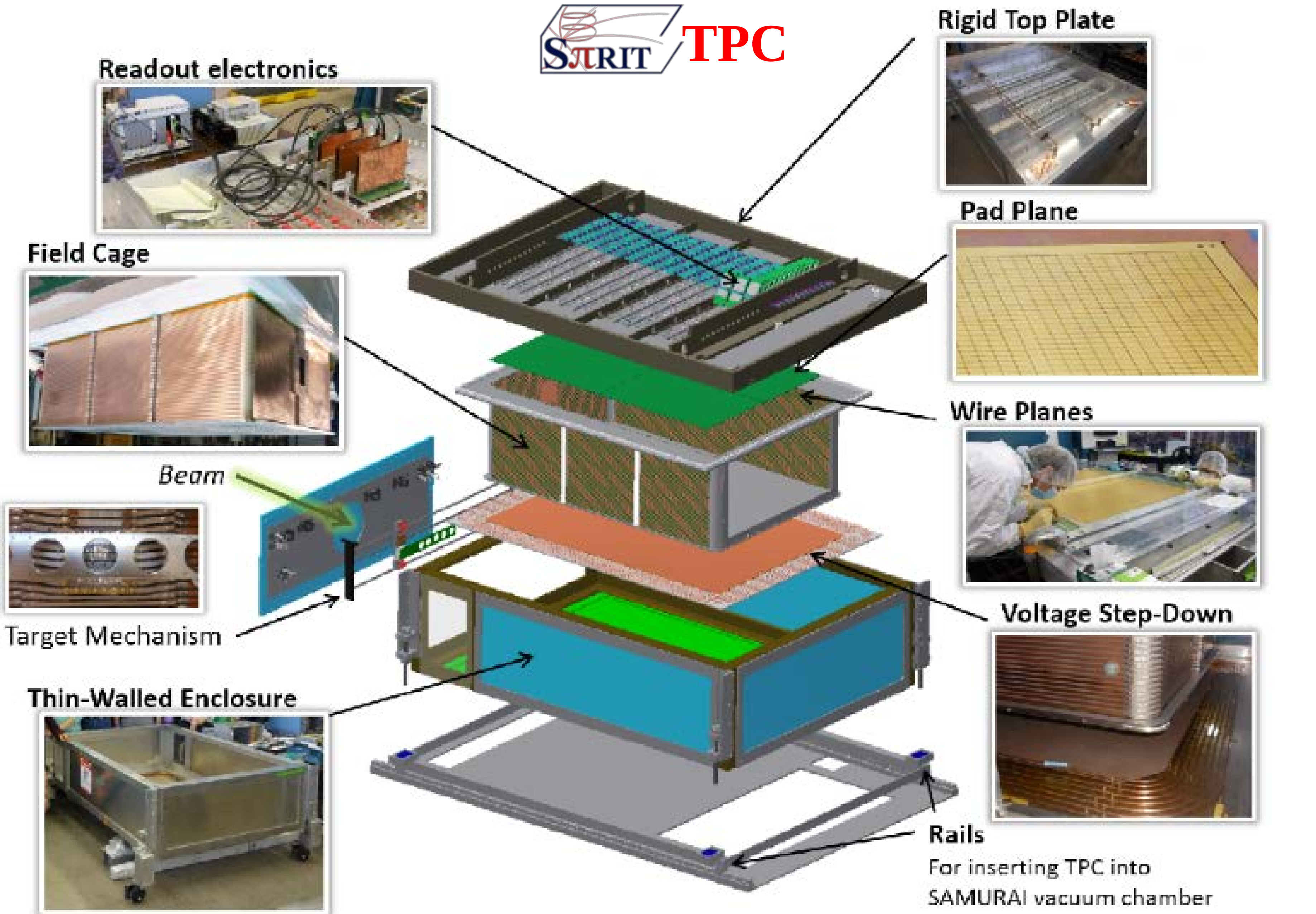
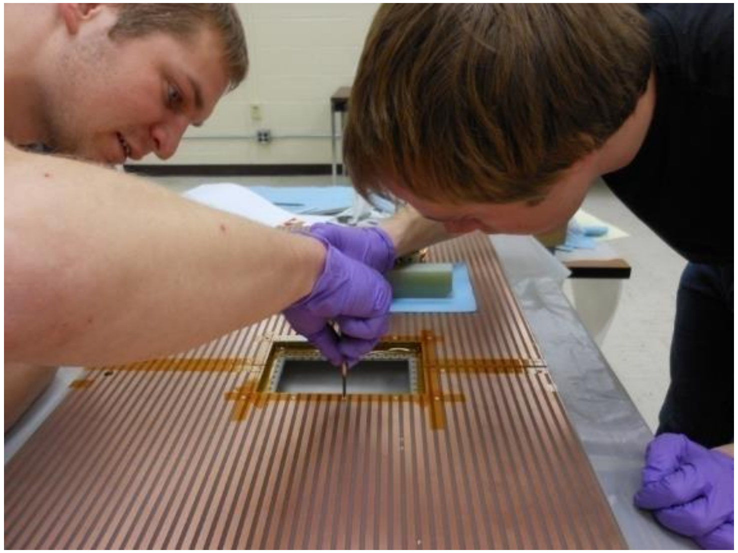
MINISTRY OF EDUCATION, CULTURE, SPORTS, SCIENCE AND TECHNOLOGY-JAPAN

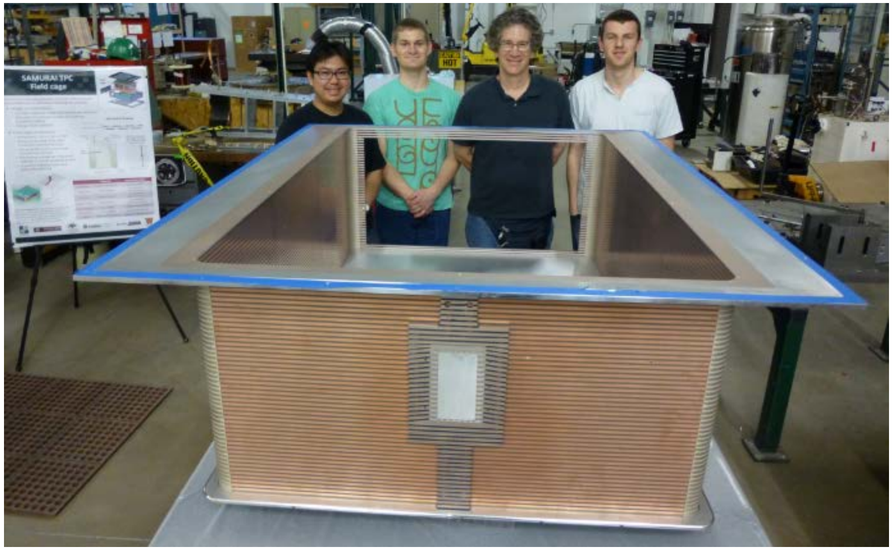


https://groups.nscl.msu.edu/hira/sepweb/pages/slideshow/tpc-exploded.html

Assembling Field Cage.

- 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.





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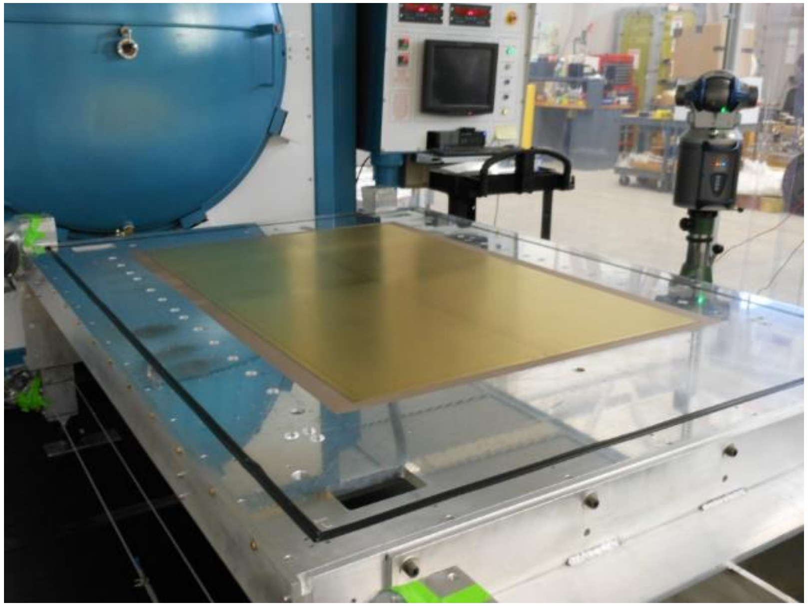
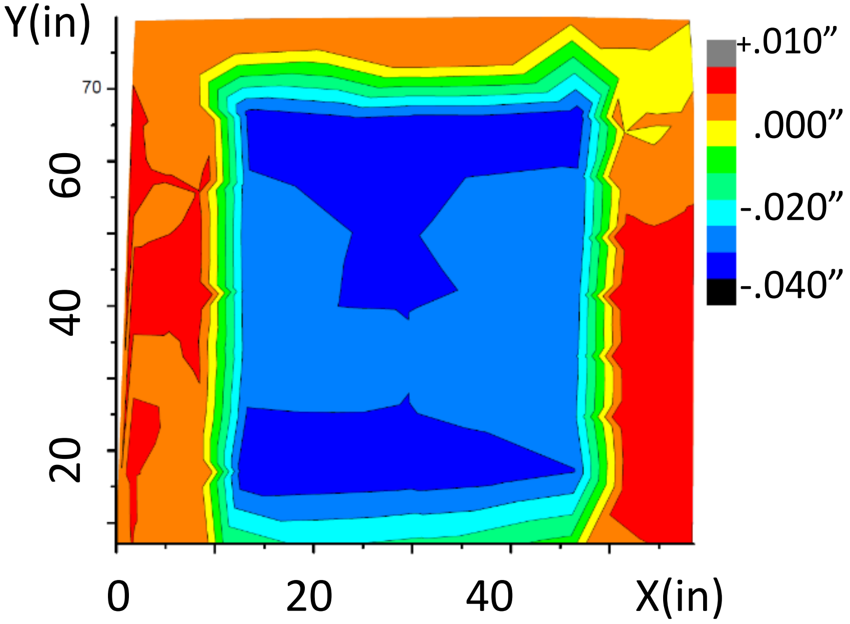
Leveling of top plate with laser

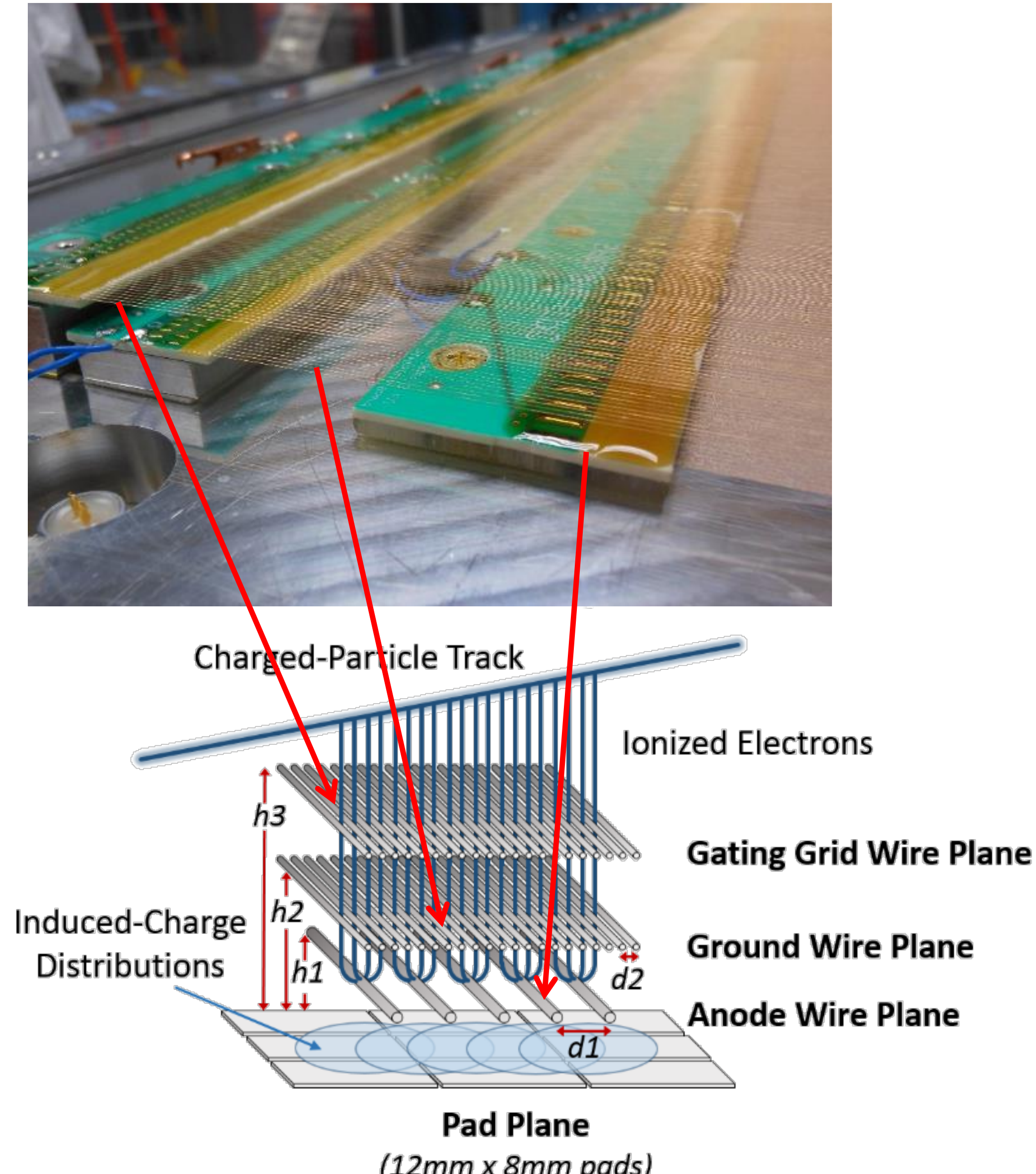




- 112 x 108 = 12096 pads
- Each pad: 12mm x 8mm
- Pad plane made with 4 PCB glued onto bottom of a rigid top plate
- The top plate is flat to within about 120 micron.
- As a result, pad-plane–anode wire heights should be constant to within 50 micron by adjusting anode and ground plane wires

Wire planes

- Anode and ground plane creates 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

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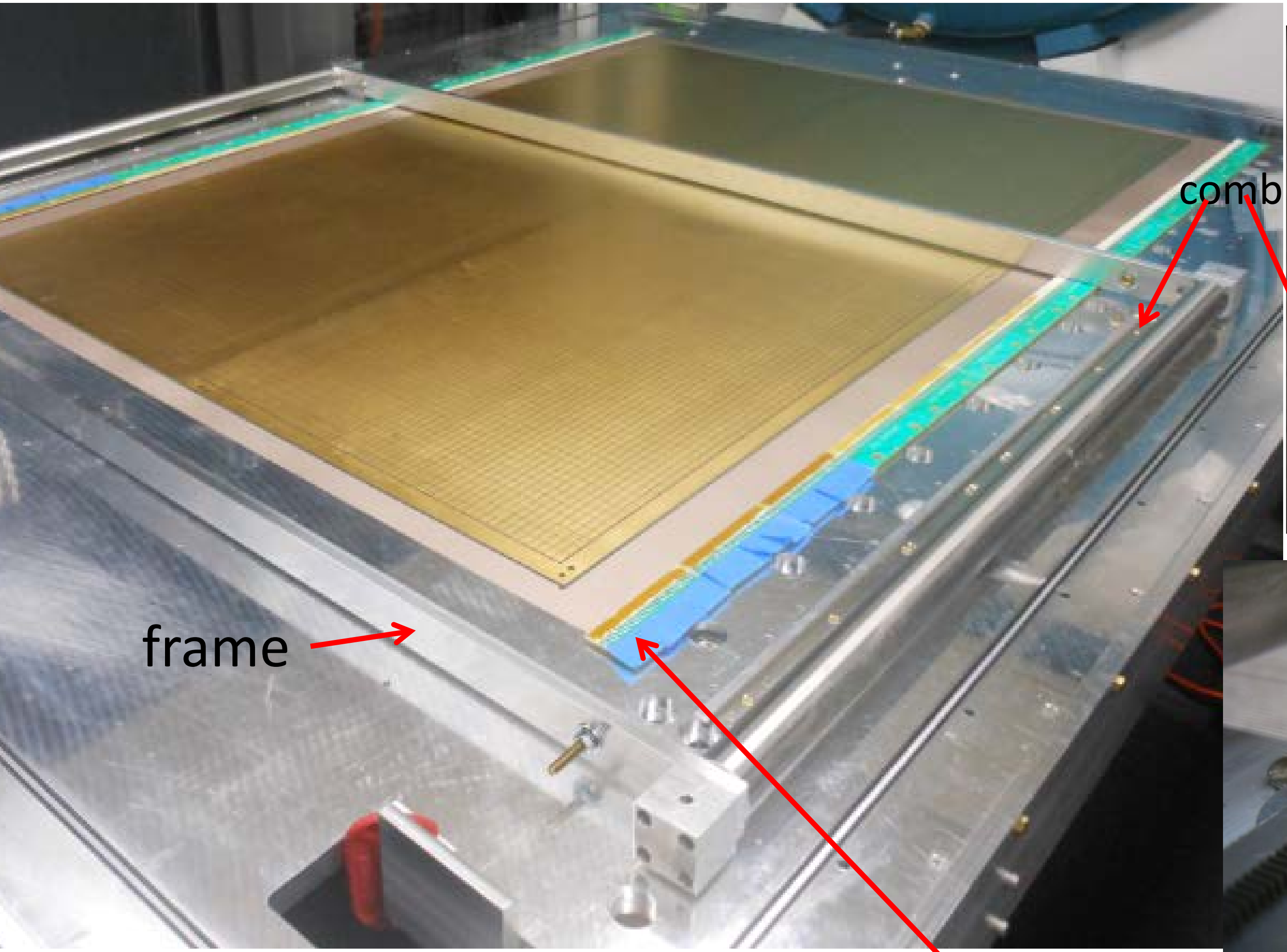
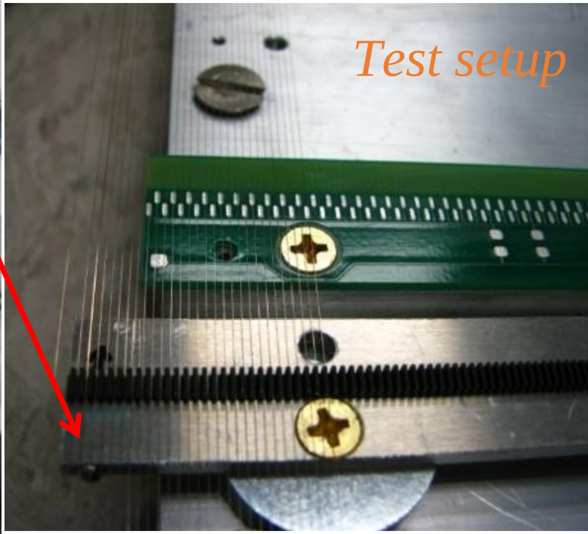
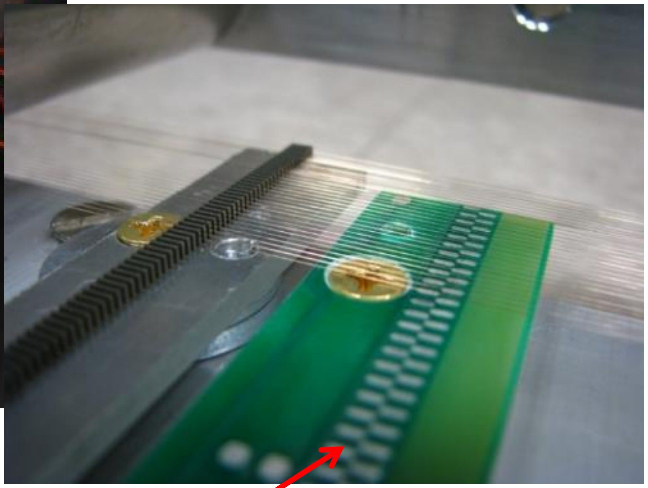
Wire planes – mounting

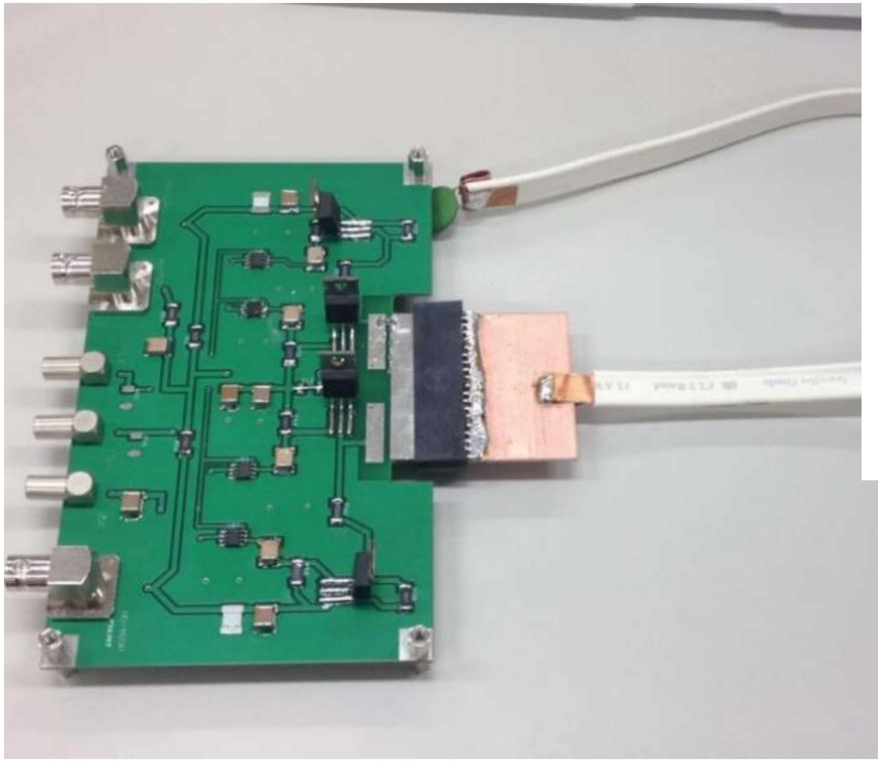


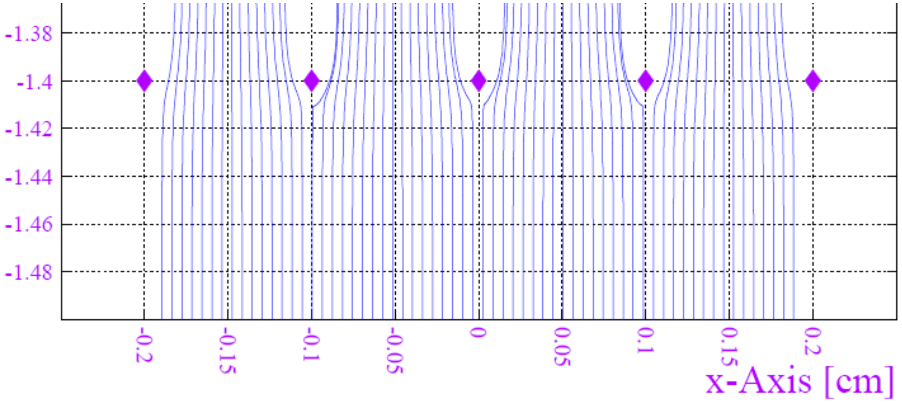




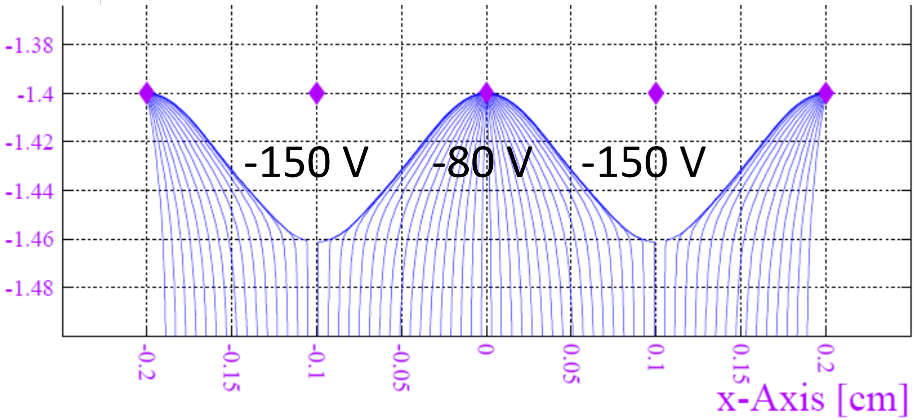
circuit board
with solder pads

Gating grid



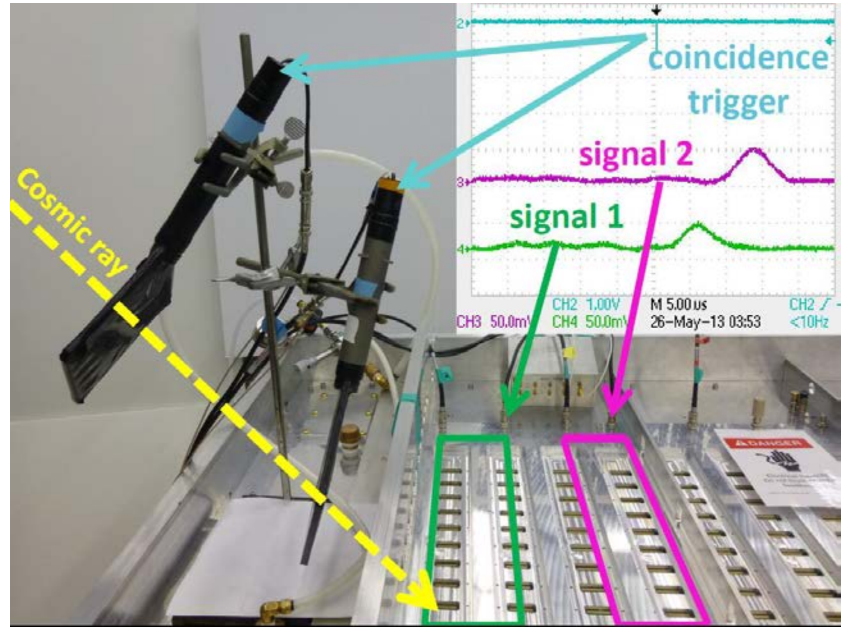


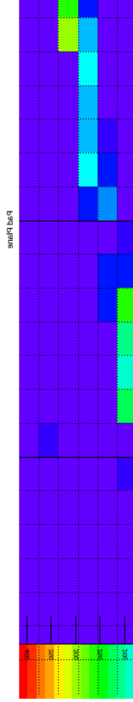
Garfield simulation of open gating grid - electrons pass through freely



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

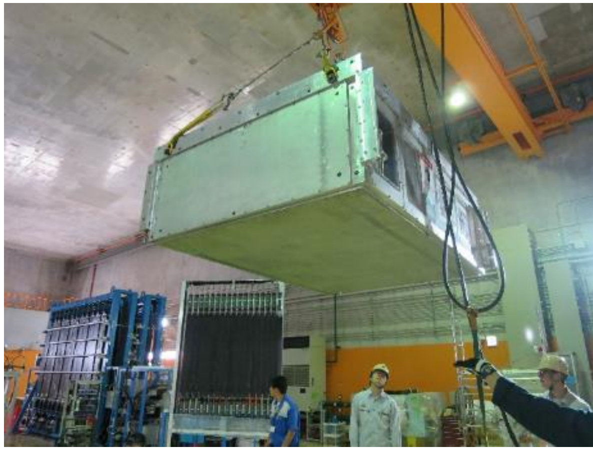

May, 2013

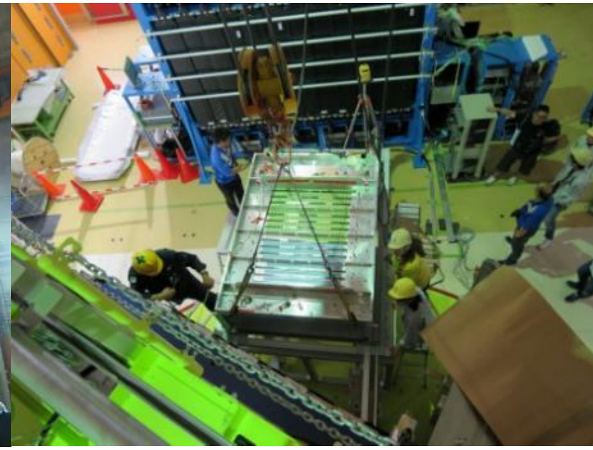

coincidence
trigger
signal 2
signal 1
Cosmic ray
CH3 50.0mV
CH2 1.00V
CH4 50.0mV
M 5.00us
26-May-13 03:53
CH2 /
<10Hz
DANGER




Feb, 2014

Installation of TPC into SAMURAI magnet





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

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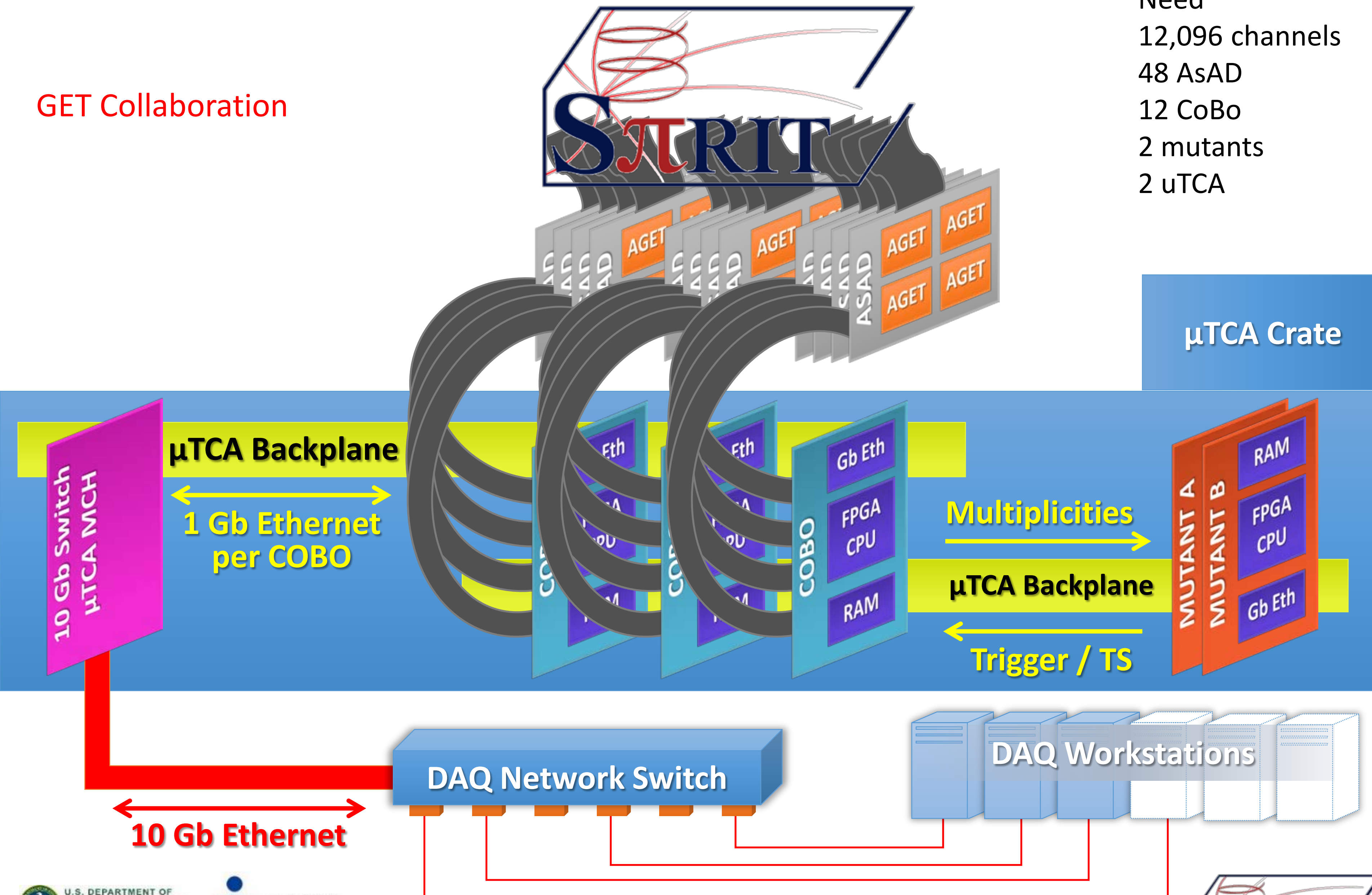
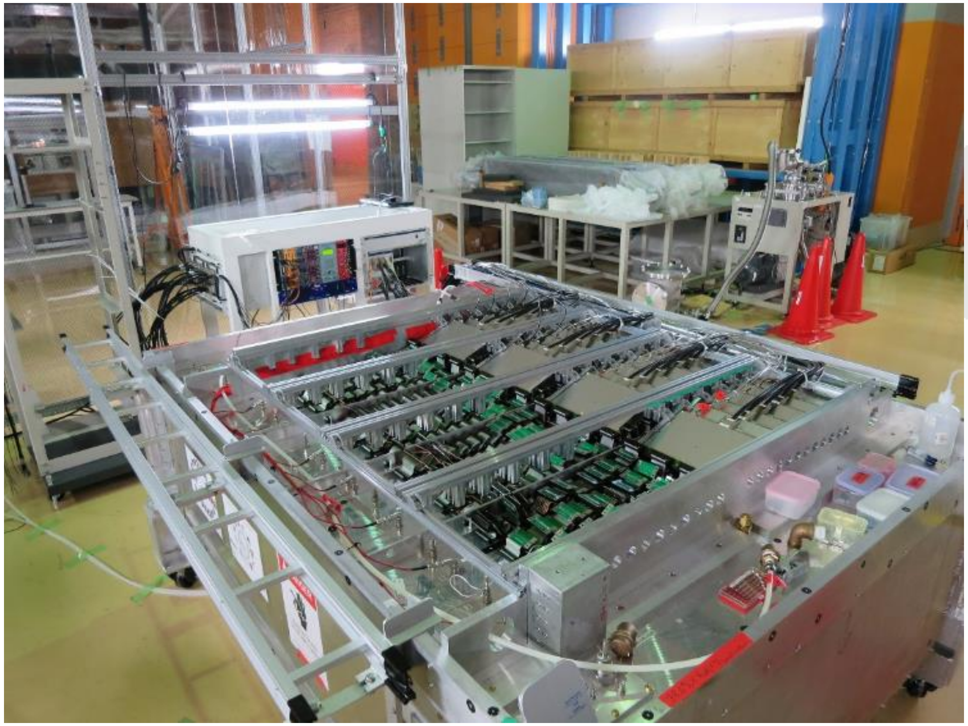
Electronic Architecture – GET

GET Collaboration

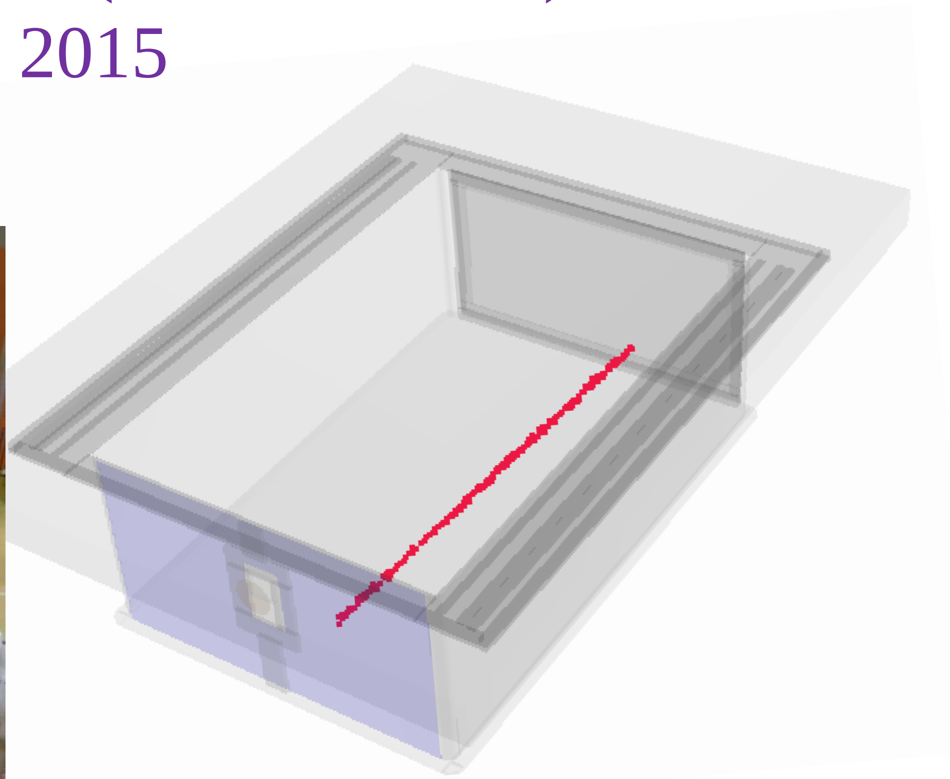
Need
12,096 channels
48 AsAD
12 CoBo
2 mutants
2 uTCA



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 (Genie Jhang & Jung Woo Lee)

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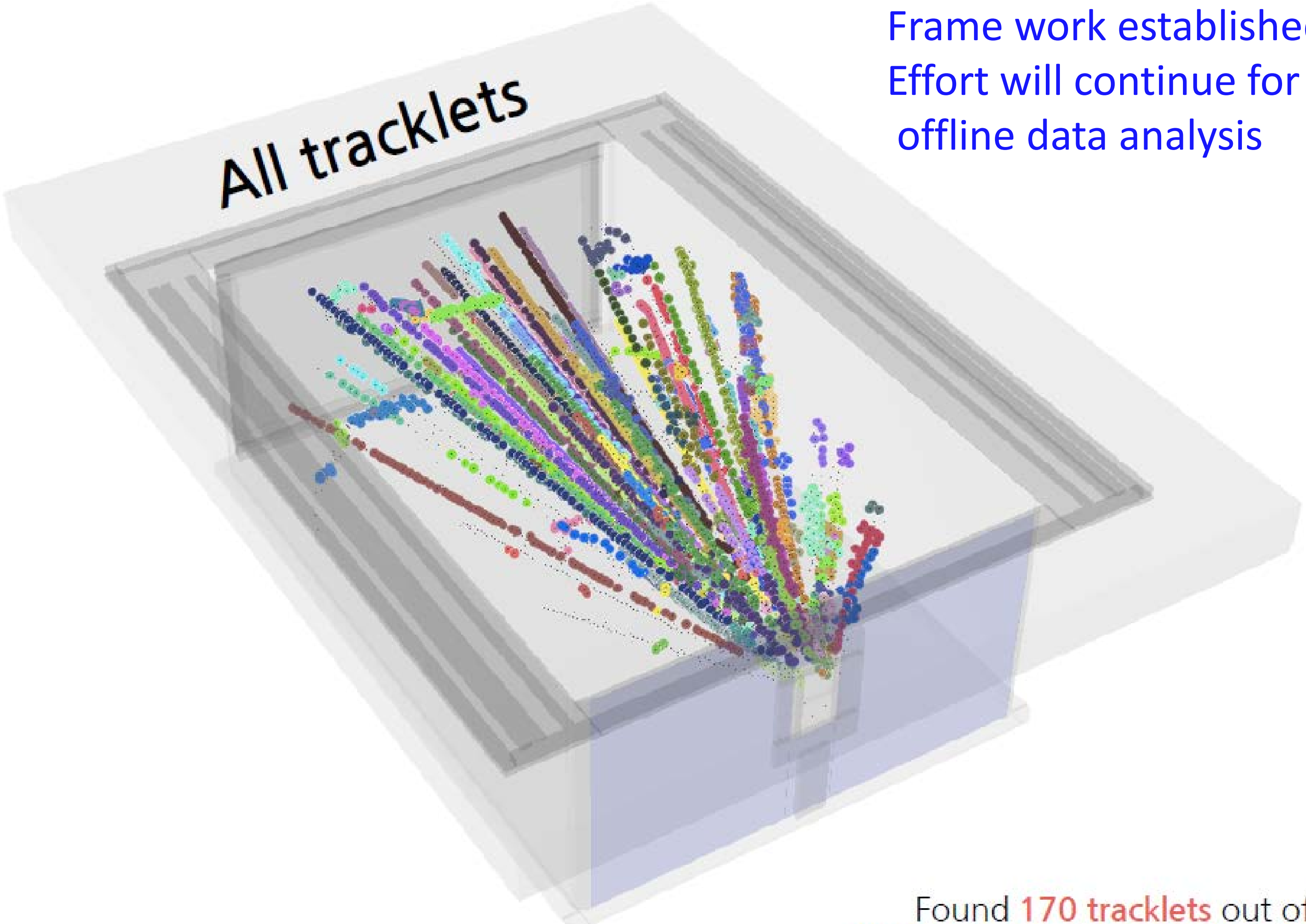
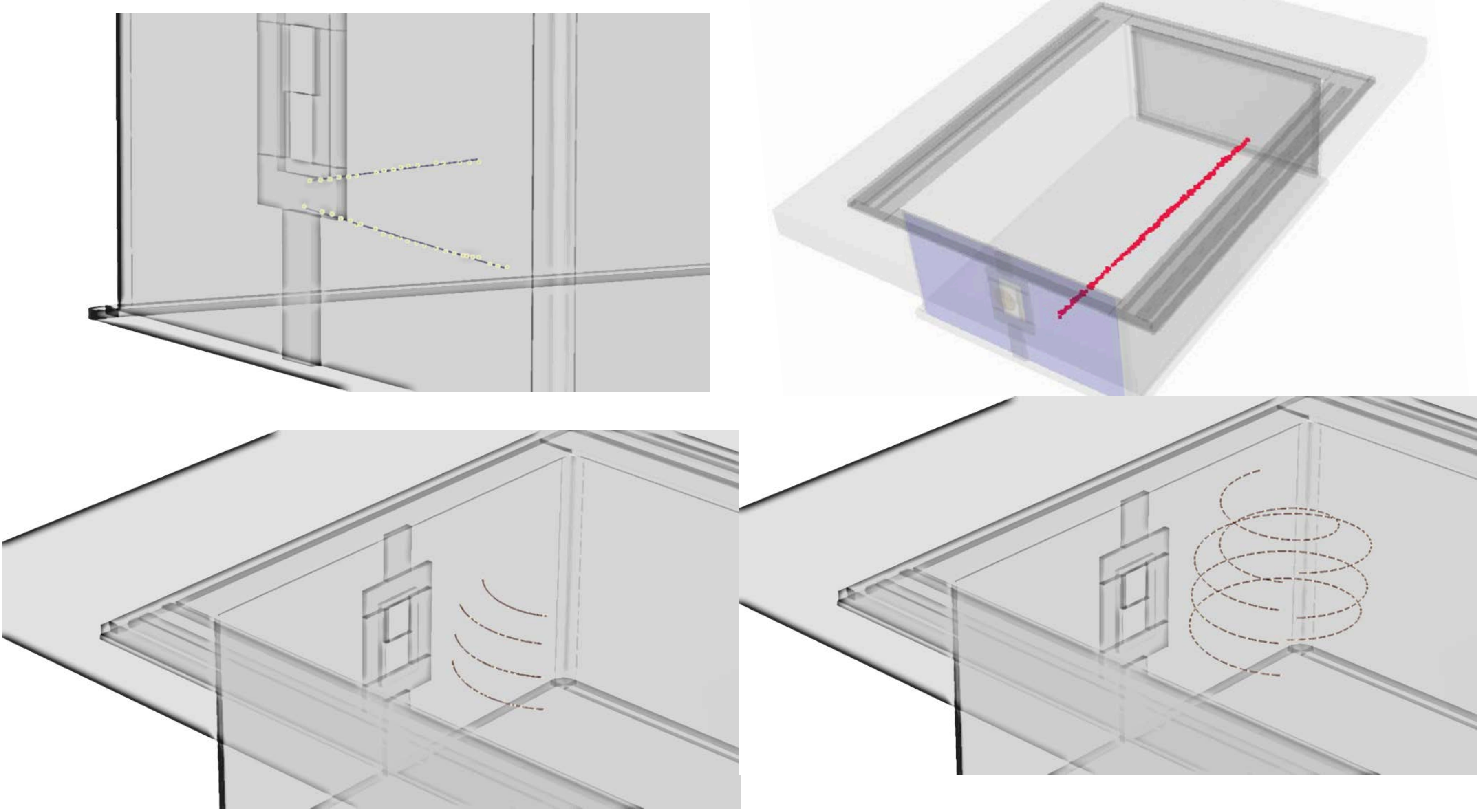
Software Development: Jhang et al

Frame work established
Effort will continue for on-line
offline data analysis

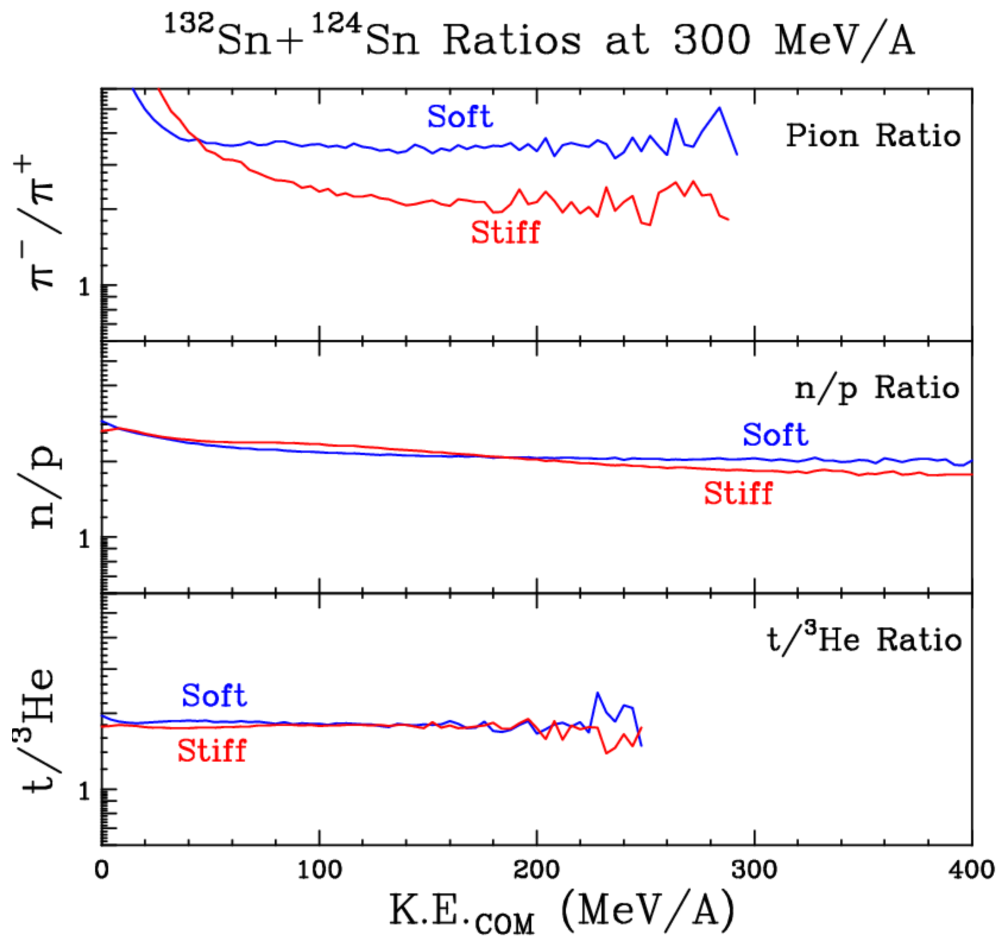


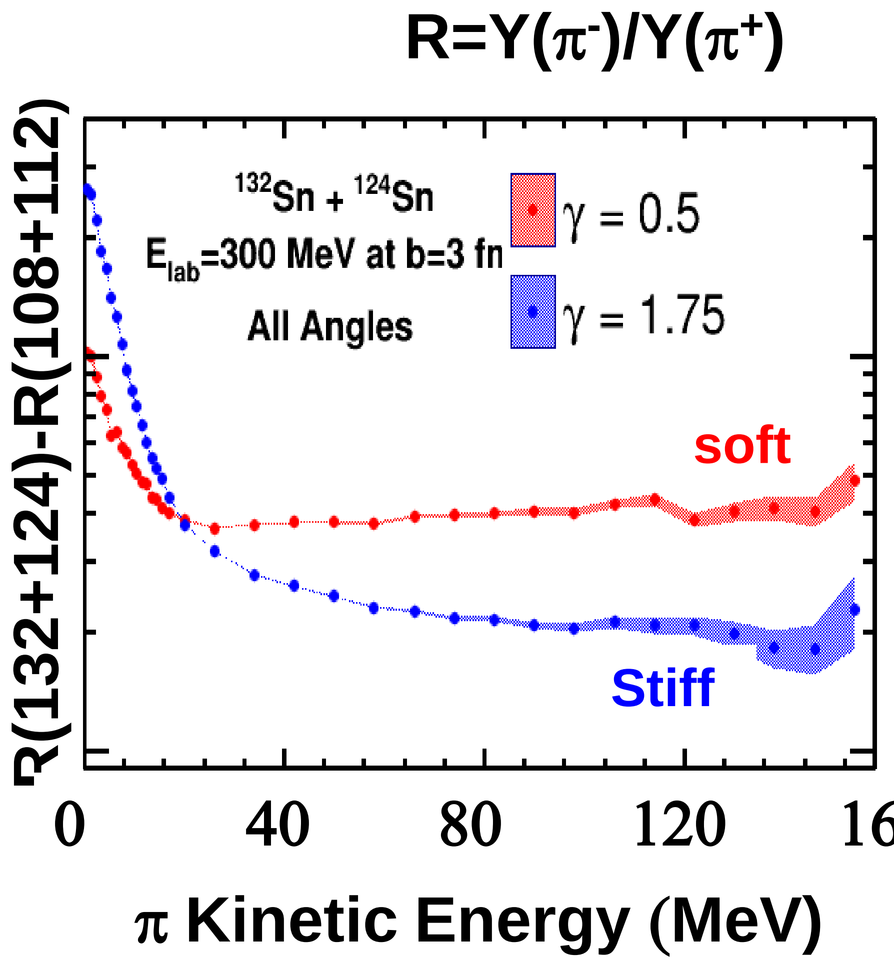
Found 170 tracklets out of
80 produced charged particles

Tracks from 90Sr, cosmic, and cosmic inside magnet



Genie Jhang & Jung Woo Lee





- Comparisons of neutron-rich to neutron-deficient reactions enhance the symmetry energy effect
- Sensitivity increases with $\Delta\delta$
- Propose 132Sn+124Sn; 108Sn+112Sn reactions

Heavy Ion Collisions at high density with RIB

Old data: Au+Au, E/A=150 to 1500 MeV

Proposed New Experiments at RIB facilities

pi-/pi+	300 MeV & 200 MeV				
Beam	tgt	N/Z(beam)	N/Z(tgt)	N/Z(CN)	N/Z diff
132Sn	124Sn	1.64	1.48	1.56	0.16
132Sn	112Sn	1.64	1.24	1.44	0.40
108Sn	124Sn	1.16	1.48	1.32	-0.32
108Sn	112Sn	1.16	1.24	1.20	-0.08
124Sn	124Sn	1.48	1.48	1.48	0.00
112Sn	112Sn	1.24	1.24	1.24	0.00
112Ru	112Sn	1.55	1.24	1.38	0.31
126Sn	112Sn	1.52	1.24	1.38	0.28

Beam	tgt	N/Z(beam)	N/Z(tgt)	N/Z(CN)	N/Z diff
132Sn	64Ni	1.64	1.29	1.51	0.35
108Sn	58Ni	1.16	1.07	1.13	0.09

Beam	tgt	N/Z(beam)	N/Z(tgt)	N/Z(CN)	N/Z diff
56Ni	58Ni	1.00	1.07	1.04	-0.07
68Ni	64Ni	1.43	1.29	1.36	0.14

First experiment
(132Sn+124Sn & 124+112Sn)
Planned in Spring 2016

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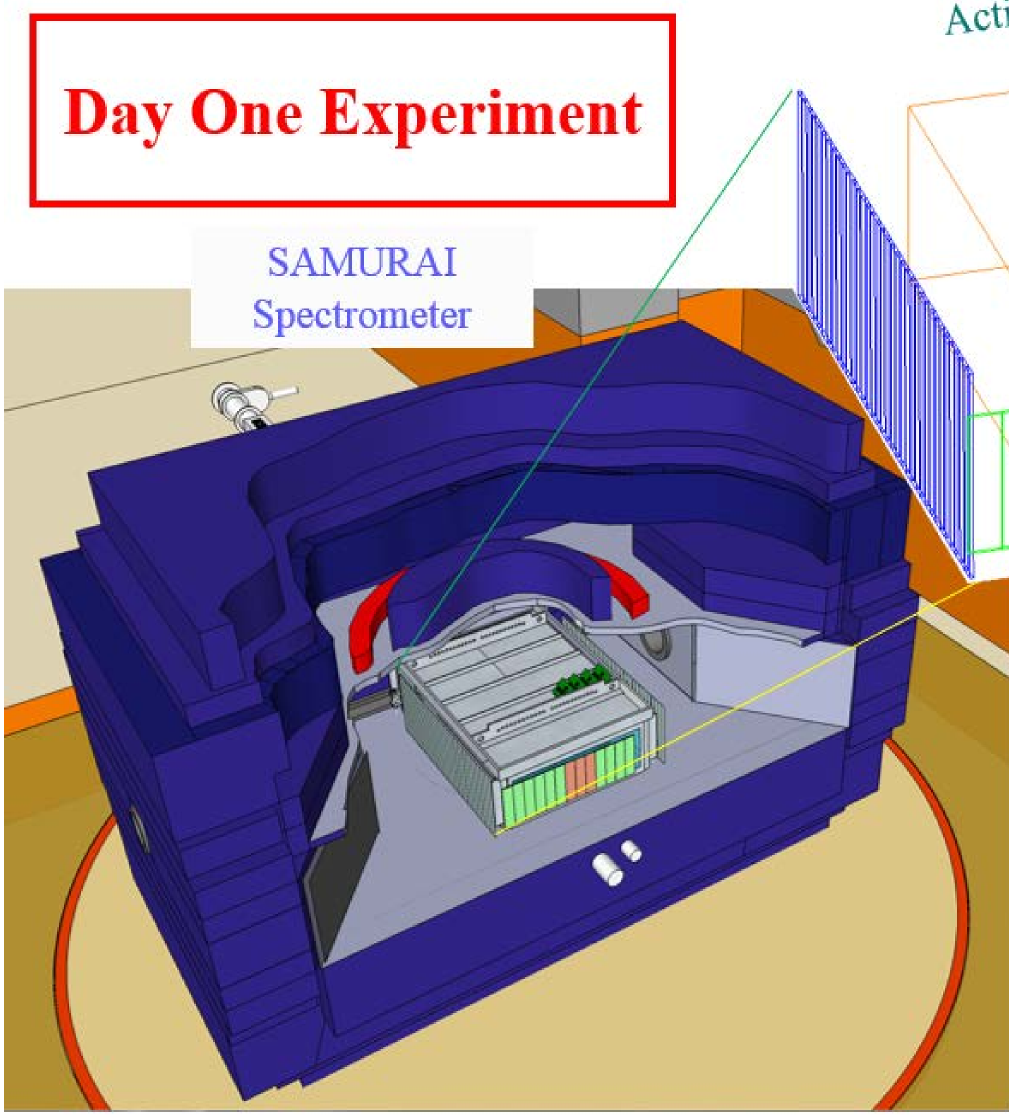
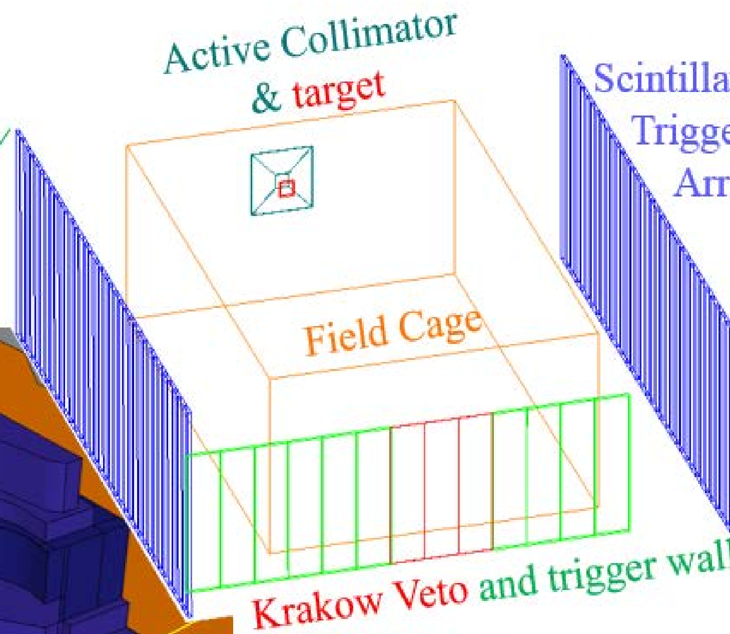
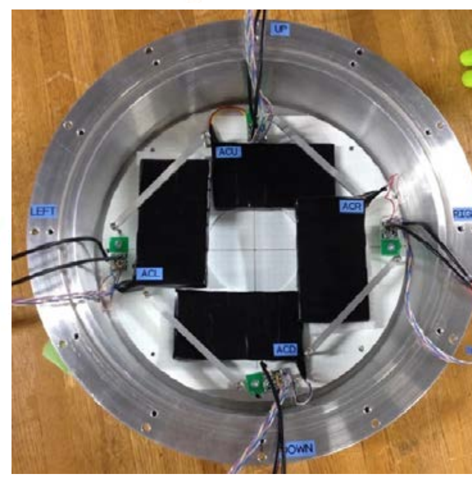
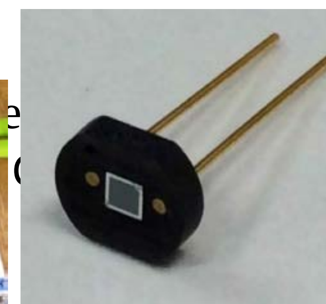
Day 1 experiment: Triggered by multiplicity and beam veto







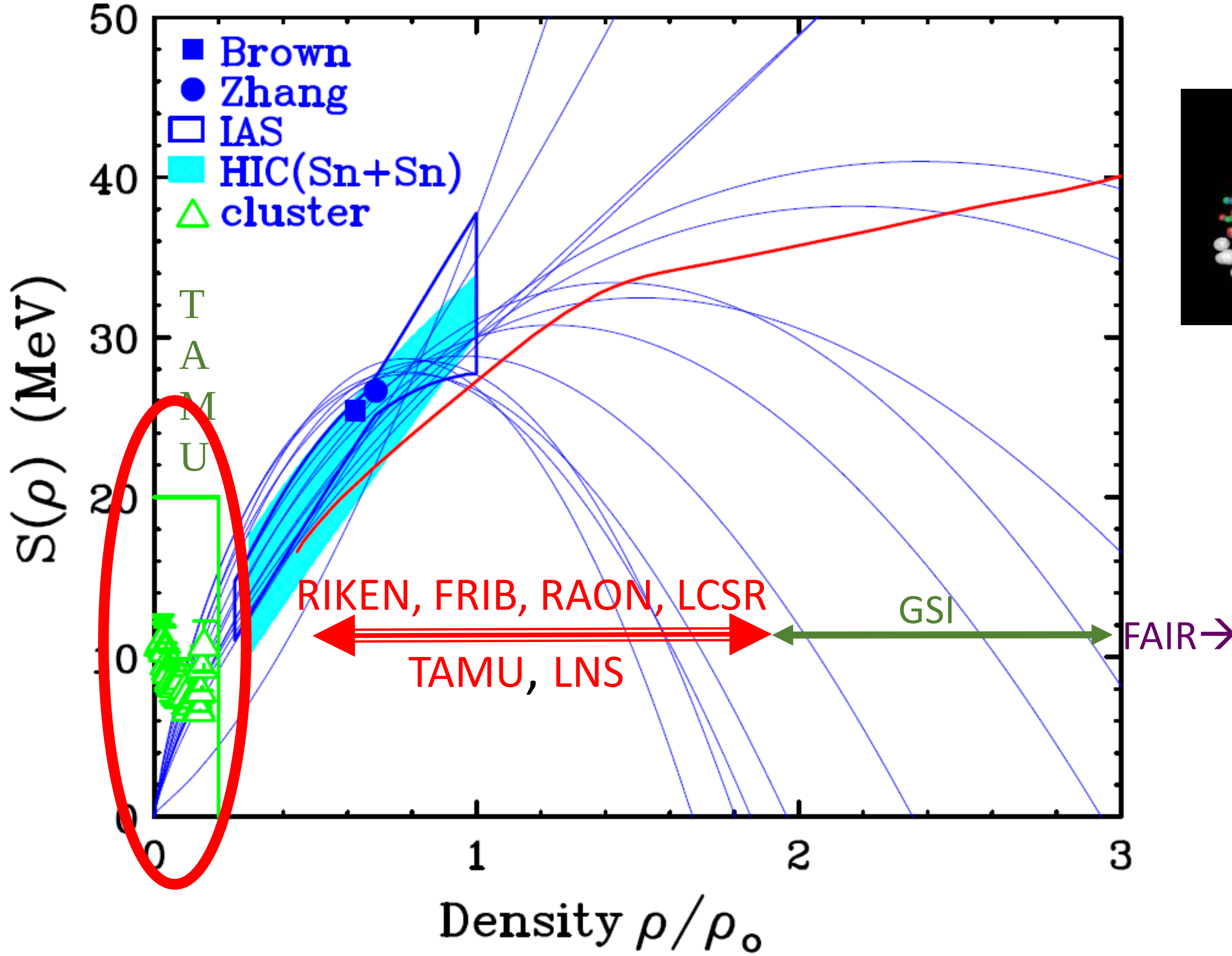


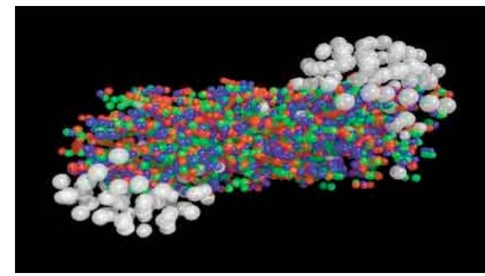
MPPC ranges from 1x1 to 3x3 mm^2

Workshop on Science with SπRIT

June 5-6, 2015, RIKEN

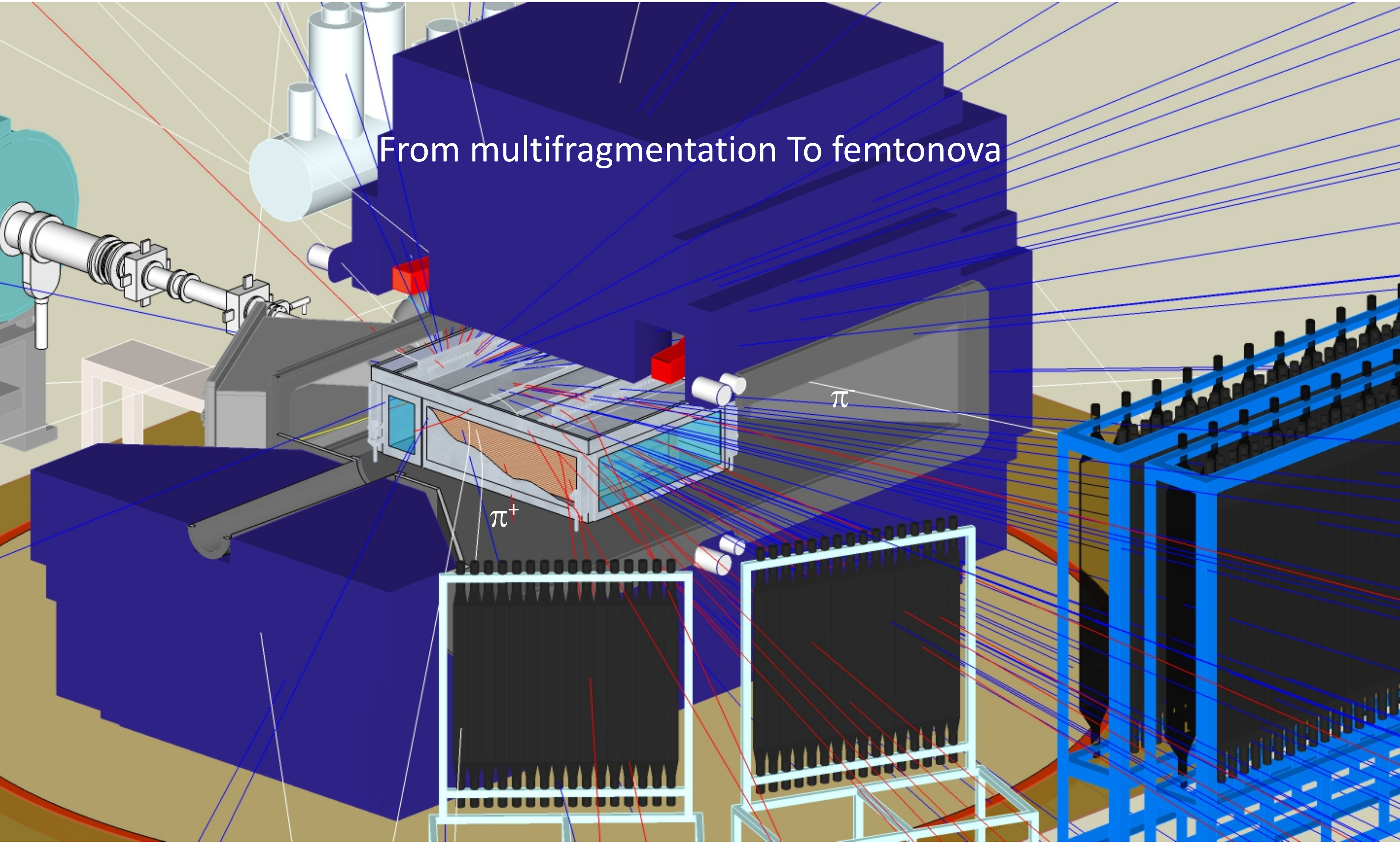
nn collisions





Workshop on Science with SπRIT

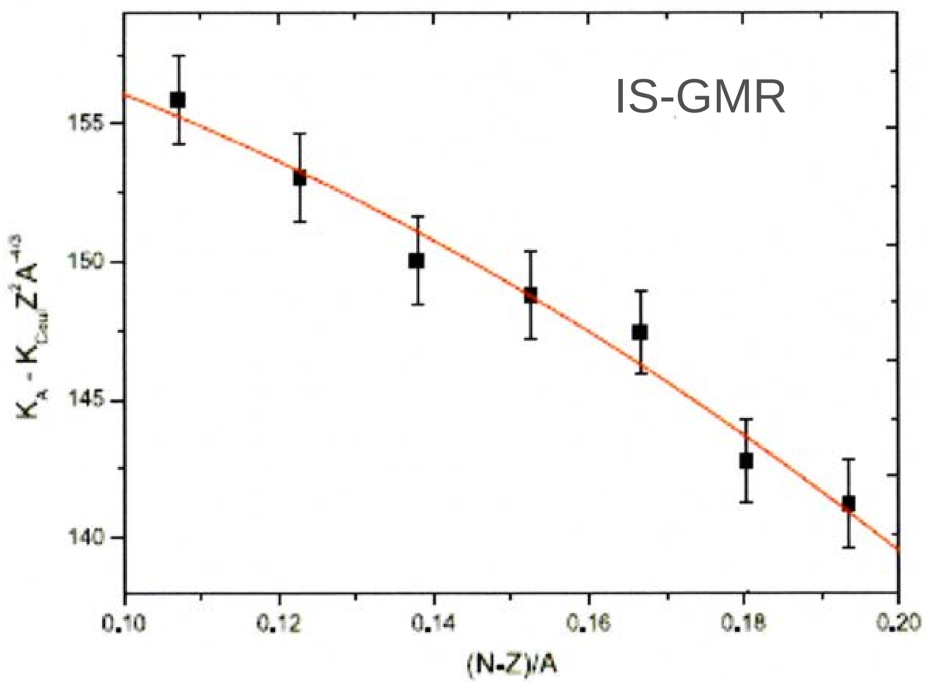
June 5-6, 2015, RIKEN



Lukasik & Isobe

Workshop on "Science with SpiRIT TPC", June 5-6, 2015

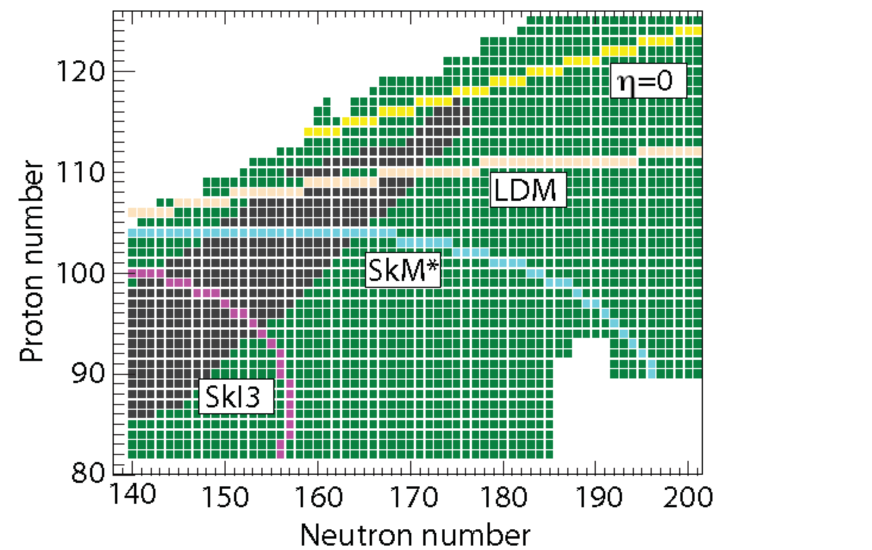
Li et al, PRL 99, 162503 (2007)

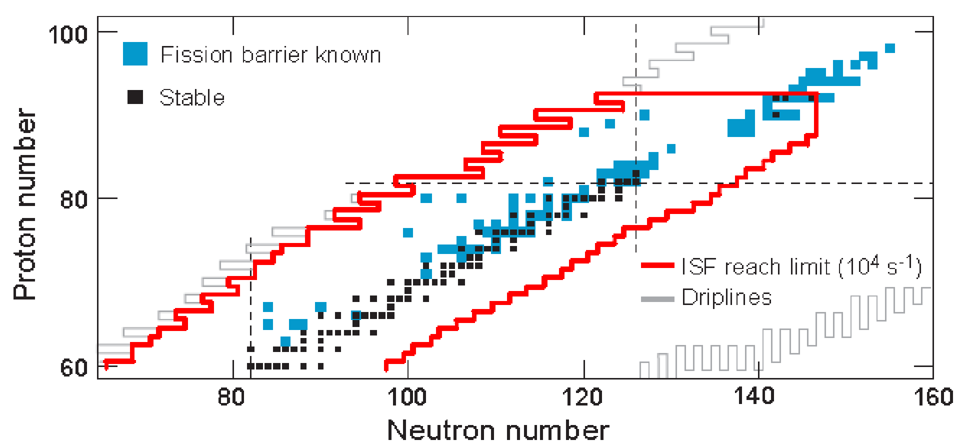


Measurements of the IS-GMR
in ^{54}Ni-^{70}Ni and ^{106}Sn-^{127}Sn nuclei

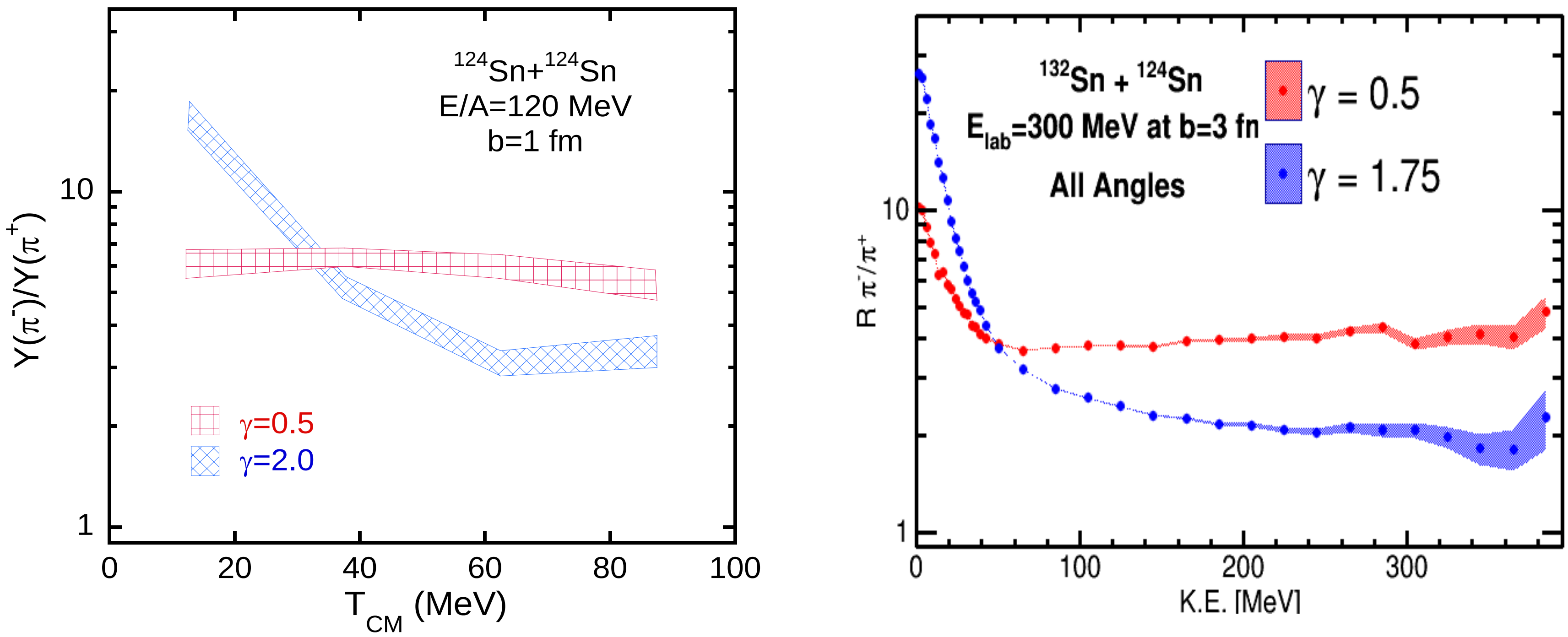
Fission barriers of exotic nuclei

N. Nikolov, et al, Phys. Rev. C, 83, 034305 (2011).

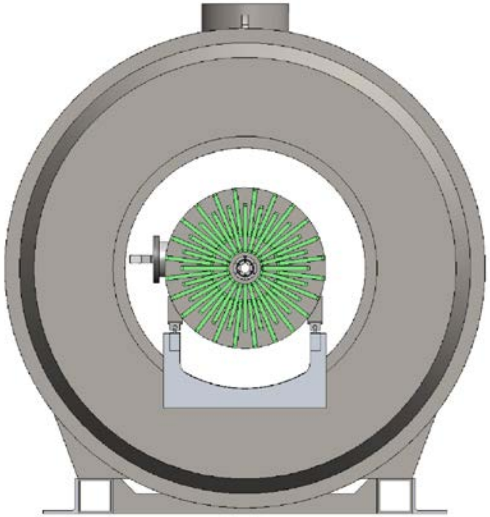




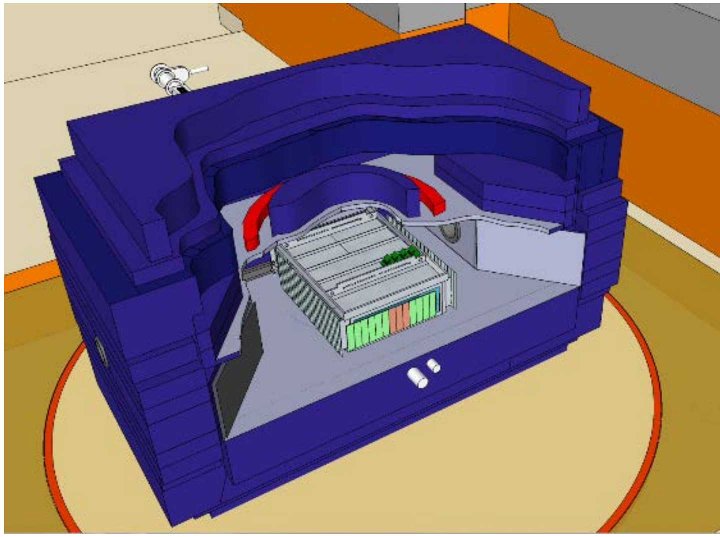
Probe symmetry energy $\rho>\rho_0$ with sub-threshold pions



- Pion ratio shows the strong dependence on the symmetry energy continues to lower incident energies.
- Measuring at several incident energies provides an important test of theoretical description of sub-threshold pion production.
- Requires moveable solenoid to allow placement of TPC on the high energy beam lines.



Magnetic Field Considerations



Solenoid

- active shield magnets eliminate the Fe shielding
- Decrease the size and weight of solenoid→ “portable” solenoid.
- price of solenoid comes down by refurbishing MRI magnets
- Advance in large area micro-Megas and GEM to replace wire planes
- Availability of GET electronics

Dipole

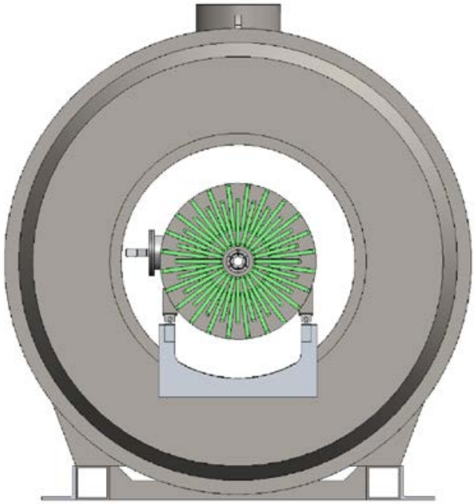
- dipole is expensive and heavy
- Not movable; Multi-users means difficulty with scheduling

HR-TPC: facilitating EoS and High resolution active target measurements with fast beams (Chajecki et al., WMU+MSU)

Adopts much of the design of the AT-TPC

- portable MRI magnet & MICROMEGAS gas amplification
- Beam enters through MICROMEGAS
- Cathode allows passage of charged particle ancillary detectors downstream.

Chajecki & Lynch



Summary & Outlook

Nature of Neutron Star and EoS of Asymmetric matter – Important topics in the nuclear physics community Long Range Plan.

- International programs: new instrumentation & collaborations
- Coordinate international effort to study EOS of neutron rich nuclear matter over a range of densities
- Exciting and Challenging times -- New Results from ASYS_EOS and SpiRIT Collaboration

- Instrumentation to measure neutrons, charged particles, and pions
- HRTPC at the HRS for FRIB (but can be used at NSCL now);
- Beam availability (FRIB, NSCL, TAMU, FSU, JLAB, RCNP, RIKEN, GANIL, GSI, Lanzhou, RAON, Mainz,...)
- Need theory support with immediate impact on experimental plans.
- Manpower: faculty, postdocs and students