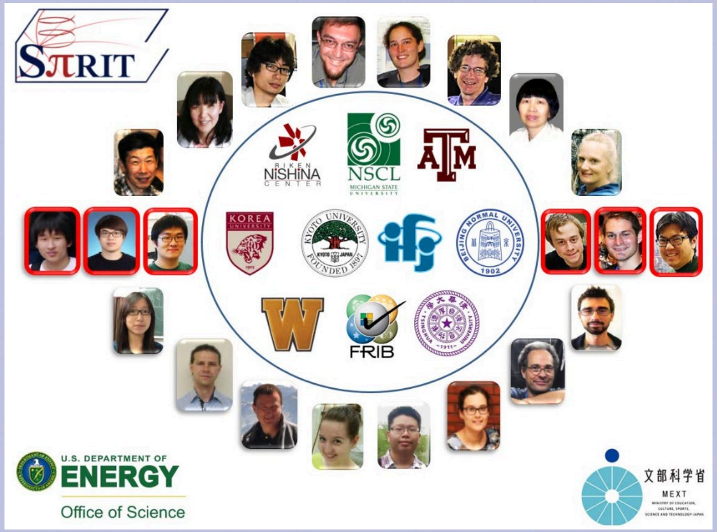
First Experiments with The SπRIT-TPC

Constraining EOS on symmetry energy using heavy ion collisions



Mizuki KURATA-NISHIMURA
RIKEN, Japan
For SπRIT-TPC collaboration

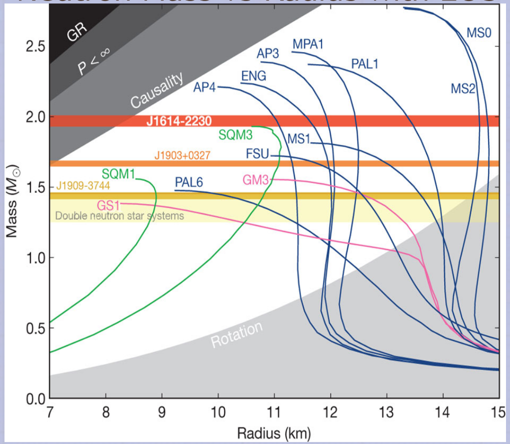
Contents

- Constrain EOS on symmetry energy at $\rho_0 < \rho < 2\,\rho_0$
  - Observables π-/π+ ratio, proton/neutron flow
- At SAMURAI RIBF-RIKEN using $^{132,108}Sn + ^{124,112}Sn$
  - Properties of SπRIT-TPC
  - Auxiliary detectors
- Fist Experimental results
- Summary and Perspectives

EOS of Nuclear Matter

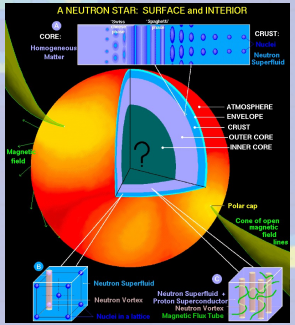
- Key subject not only for nuclear physics but also astronomy and QCD.

Neutron Mass vs Radius with EOS



Demorest *et al.*, *Nature* **467**, 1081-1083 (2010)
Antoniadiw et al., Science, 340, 1233232 (2013)

- Heavy neutron stars > 2 x M(sun)
  - PSR J1614-2230 (2010)
  - PSR J0348+0432 (2013)
- Supernove explosion?



http://www.astroscu.unam.mx/neutrones/NS-Picture/NStar/NStar_I.gif

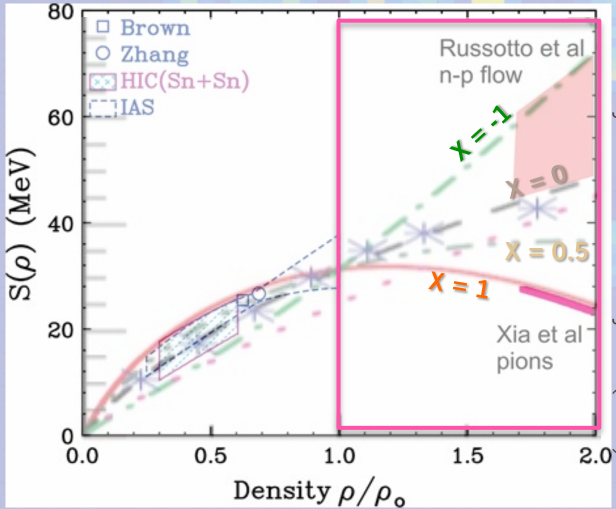
Constraining EOS on symmetry energy using RI beam experiment

S(ρ): Isospin asymmetry dependence at $\rho_0 < \rho < 2\rho_0$

$$E/A(\rho,\delta) = E/A(\rho,0) + \delta^2 \boxed{S(\rho)}$$:Symmetry energy term

Isospin asymmetry par.: $\delta = (\rho_n - \rho_p)/(\rho_n + \rho_p) = (N-Z)/A$

IBUU04 model
X = 1 softer EOS
X = -1 stiffer



Russotto et al., PLB, 697, 471 (2011)
Xiao et al., PRL 102, 062502 (2009).
Adapted fromHorowitz, et al.,
J. Phys. G: Nucl. Part. Phys. 41 (2014) 093001

Isospin asymmetry dependence of symmetry energy at RIBF-RIKEN using RI beam

Primary	Beam	Target	δ_{sys}	Goal
^{124}Xe	^{108}Sn	^{112}Sn	0.09	minimum δ
	^{112}Sn	^{124}Sn	0.15	Reference
^{238}U	^{132}Sn	^{124}Sn	0.22	maximum δ
	^{124}Sn	^{112}Sn	0.15	Reference

Feature : Systematic measurements at supra saturation density

π^-/π^+ Production Ratio

Bao-An Li, et al., PRC71,014608(2005)

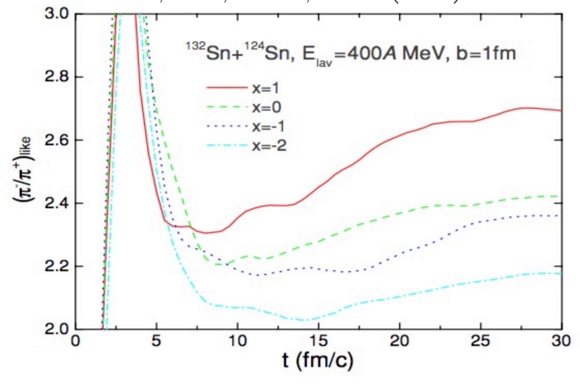
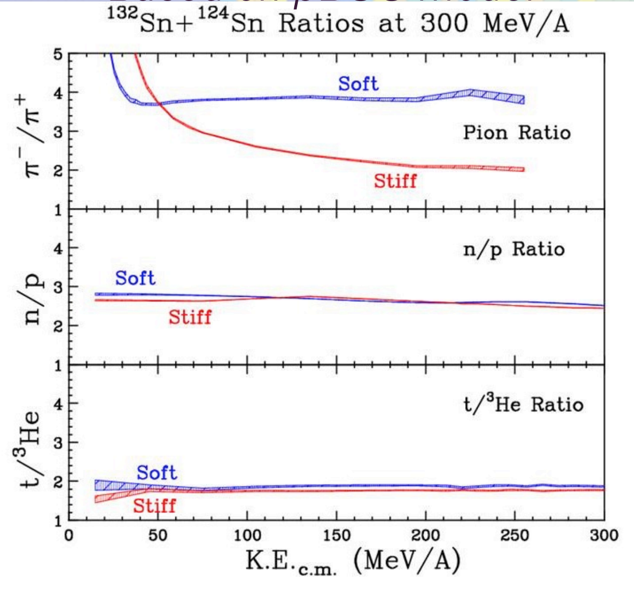


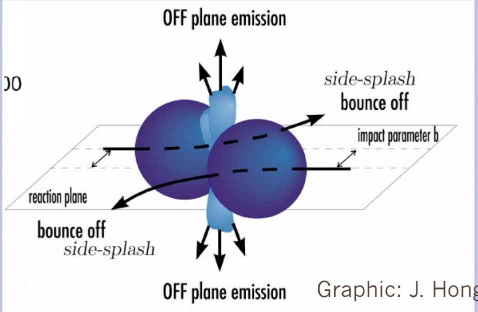
FIG. 6. (Color online) Evolution of the π^-/π^+ ratio in the reaction of ^{132}Sn + ^{124}Sn at a beam energy of 400 MeV/nucleon and an impact parameter of 1 fm.

Based on pBUU model



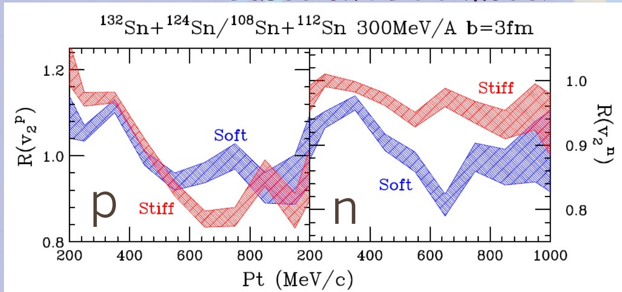
- In dense and isospin asymmetry medium, neutron is repulsive while Proton is attractive.
- π^-/π^+ ratio sensitive to the high-density behavior of symmetry energy.

Proton and neutron flow



Graphic: J. Hong thesis

Based on IBUU model



Differential flow

$$F_{n-p} = \frac{1}{N(y)} \sum_{i=1}^{N(y)} P_{x_i} \tau_i \qquad K_{sym} \equiv 9\rho_0^2 \left.\frac{\delta^2 S(\rho)}{\delta^2 \rho}\right|_{\rho=\rho_0}$$

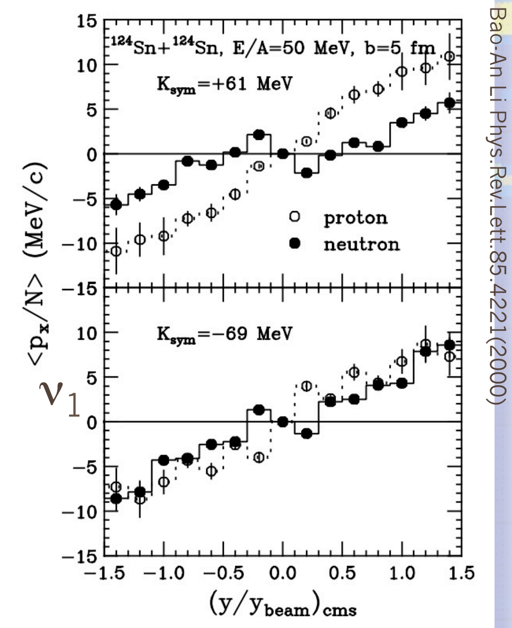


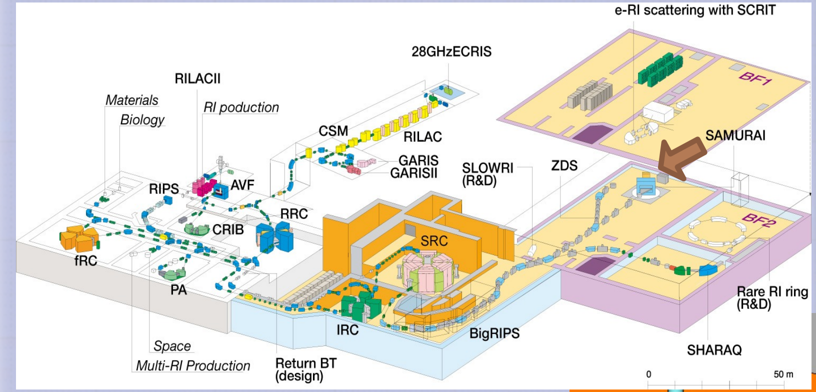
FIG. 2. The average transverse momentum per nucleon in the reaction plane for neutrons and protons as a function of reduced rapidity with the K_{sym} parameter of +61 MeV (upper window) and −69 MeV (lower window), respectively.

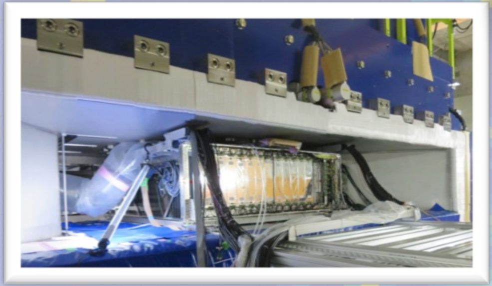
Bao-An Li Phys.Rev.Lett.85.4221(2000)

$$\frac{dN}{d\phi} \sim [1 + 2\nu_1 cos(\phi) + 2\nu_2 cos(2\phi) + ...]$$

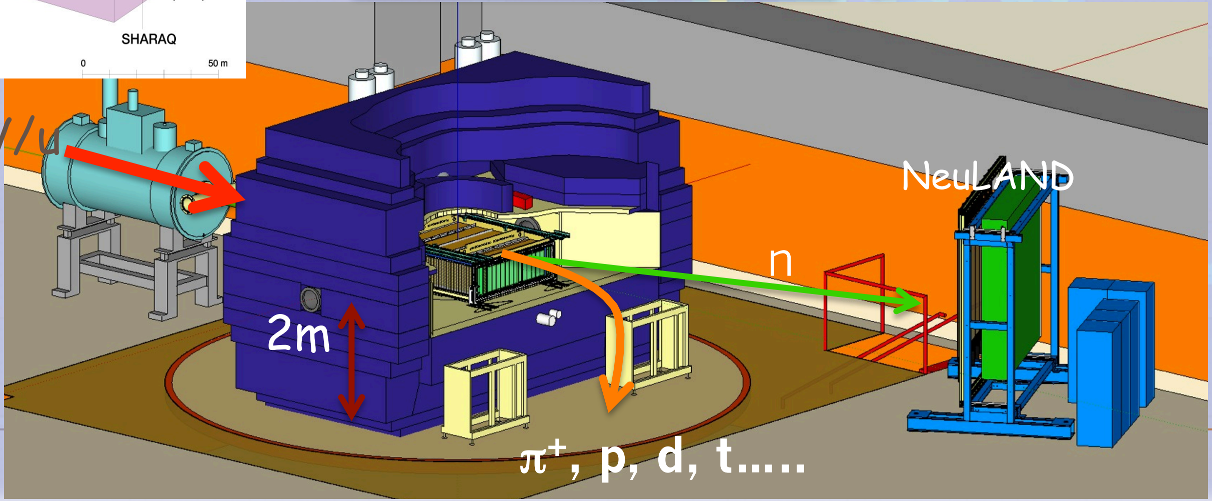
- BUU model predicts proton and neutron flow is sensitive to EOS
- Observe azimuthal asymmetry emission with respect to a reaction plane
  - ν_1 : Directed flow
  - ν_2 : Elliptic flow

First experiment at SAMURAI in RIBF-RIKEN



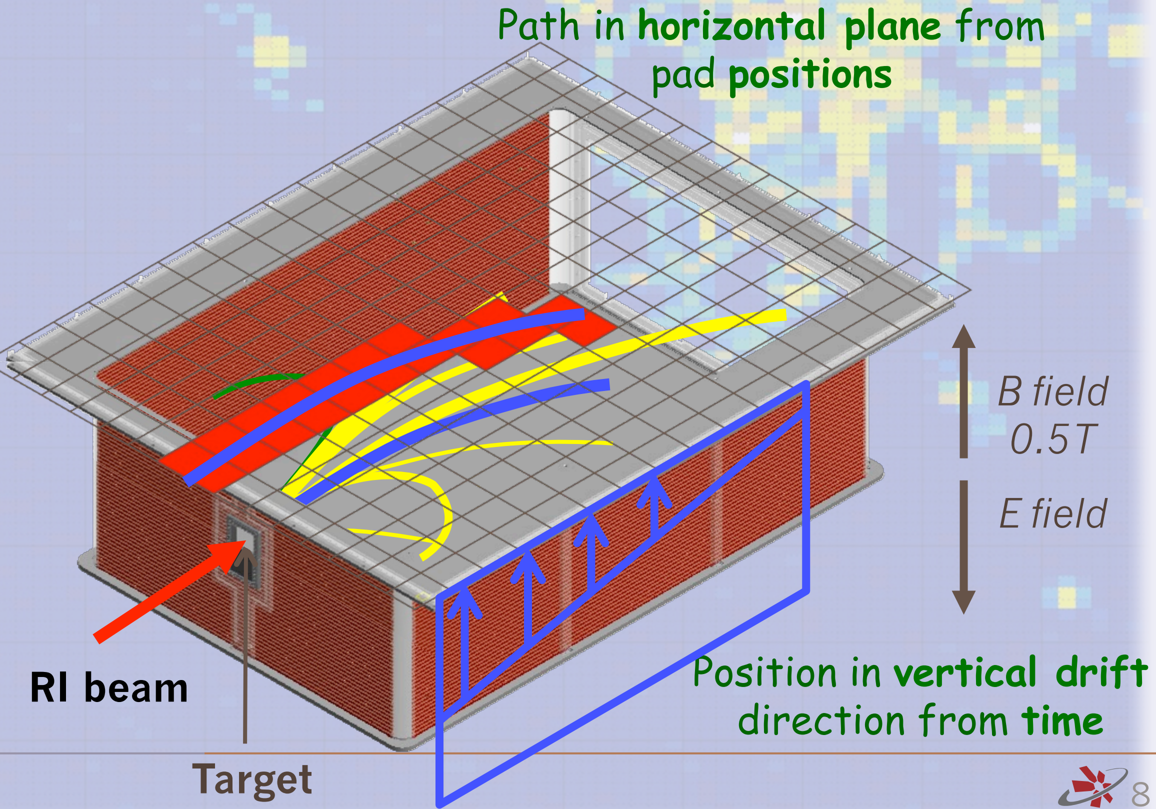


^{132,108}Sn ~300MeV/u



TPC: Time Projection Chamber "Snap shot"

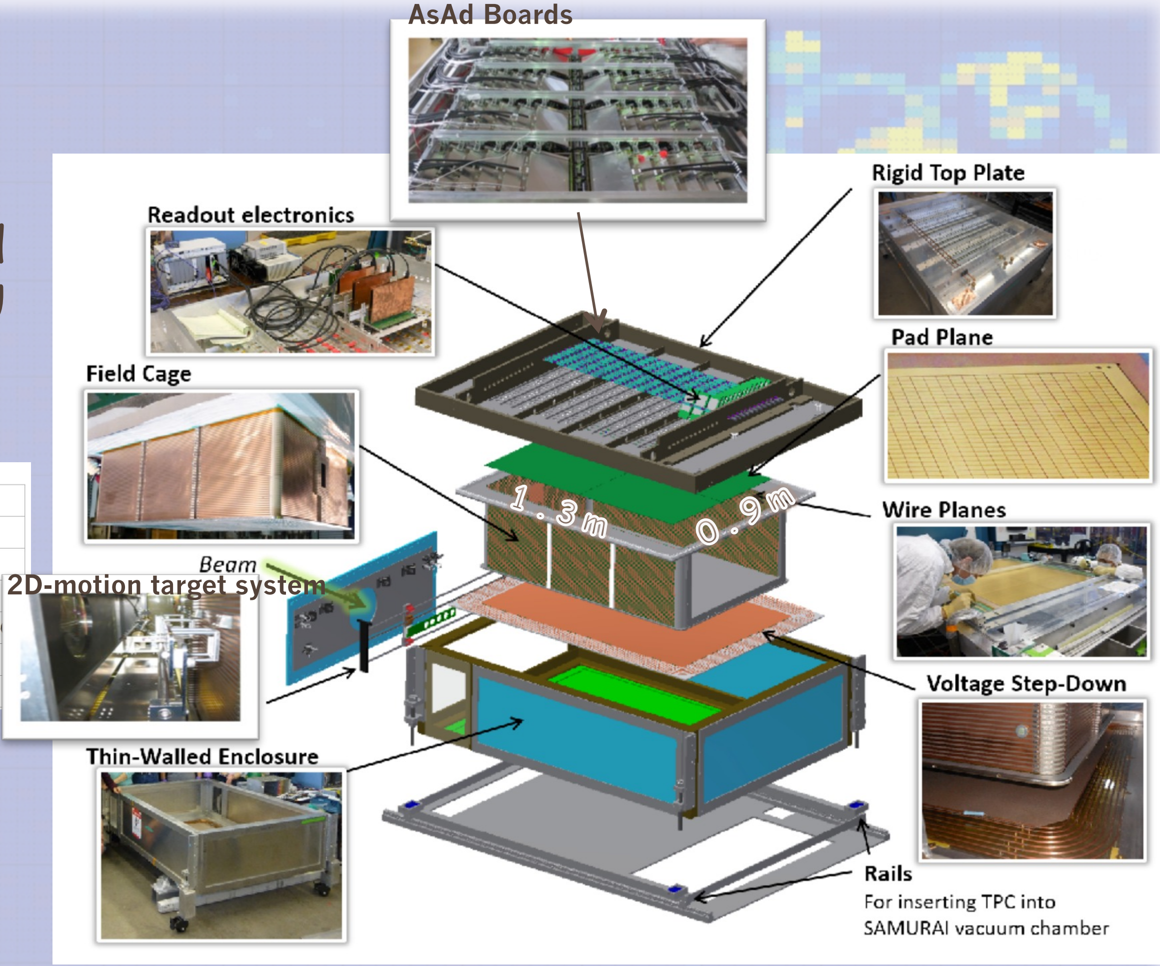
- Time projection chamber is ideally suited for identifying particles in magnetic field
- Products from reaction ionize gas inside a detection volume, called the field cage
- In field cage, electric field and magnetic field are applied perpendicular to beam direction.
- 2-D path traced out on pad plane
- The time at which the electrons hit the pads provides vertical dimension

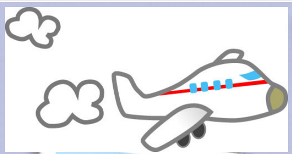


SpiRIT-TPC

- SπRIT-TPC is designed and constructed at NSCL/MSU to be used in SAMURAI magnet chamber.

SπRIT TPC Parameters			
Pad Plane Area	1.3 m x 0.9 m	**Gas Gain**	2000
Number of Pads	12096 (112x108)	**E-field**	135 V/cm
Pad size	12 mm x 8 mm	**Drift velocity**	5.5 cm/μs
Drift Distance	50 cm	**dE/dx range**	Z=1-8, π, p, d, t, He, Li-
Pressure	1 atmosphere	**Two-track res.**	2.5 cm
Gas composition	90% Ar + 10% CH_4	**Multiplicity limit**	200





SπRIT-TPC Read-out Electronics

Assembling AsAds

Air cooling

AsAd Temperature Monitor (2016/05/03 17:31:39)

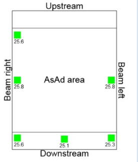
Beam left

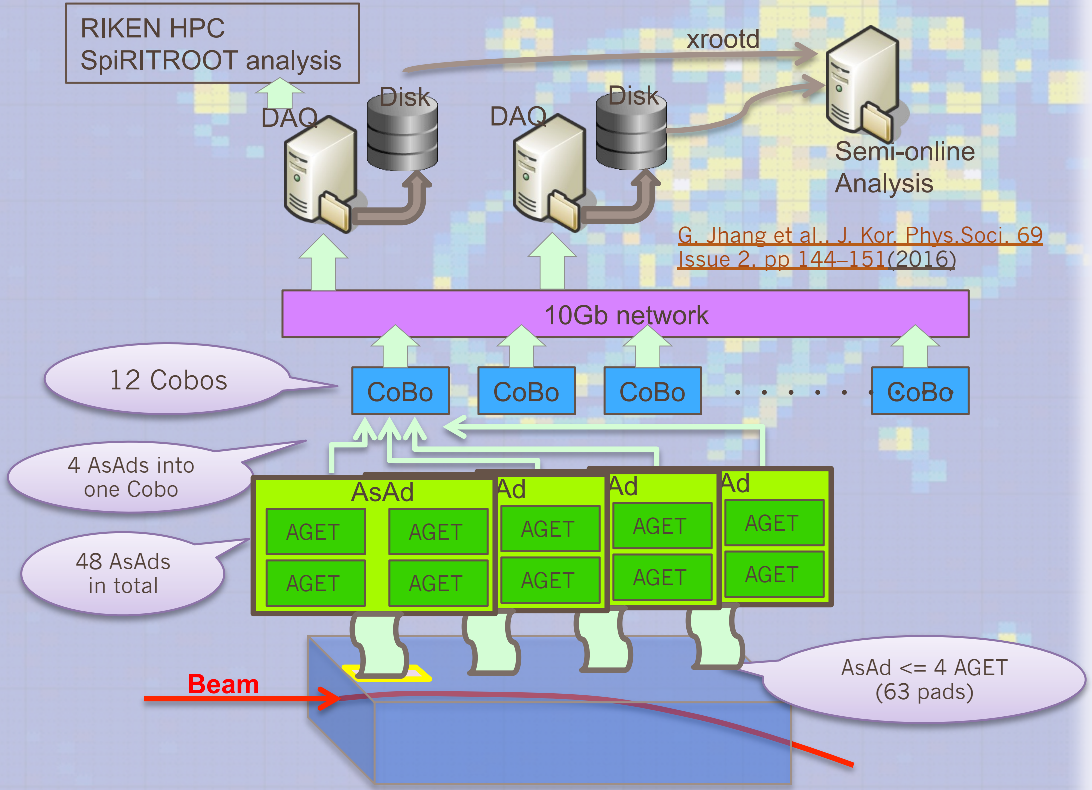
Int: 29	Ext: 31	Int: 29	Ext: 29	Int: 29	Ext: 29	Int: 34	Ext: 33
Int: 29	Ext: 29	Int: 30	Ext: 31	Int: 31	Ext: 31	Int: 28	Ext: 28
Int: 28	Ext: 30	Int: 32	Ext: 33	Int: 32	Ext: 33	Int: 29	Ext: 31
Int: 28	Ext: 29	Int: 30	Ext: 32	Int: 31	Ext: 32	Int: 27	Ext: 31
Int: 30	Ext: 31	Int: 29	Ext: 31	Int: 29	Ext: 31	Int: 27	Ext: 30
Int: 31	Ext: 31	Int: 27	Ext: 28	Int: 27	Ext: 31	Int: 27	Ext: 31
Int: 31	Ext: 34	Int: 30	Ext: 32	Int: 31	Ext: 31	Int: 27	Ext: 28
Int: 29	Ext: 31	Int: 28	Ext: 29	Int: 31	Ext: 31	Int: 27	Ext: 27
Int: 29	Ext: 31	Int: 29	Ext: 29	Int: 29	Ext: 31	Int: 27	Ext: 29
Int: 29	Ext: 30	Int: 27	Ext: 29	Int: 30	Ext: 31	Int: 27	Ext: 29
Int: 29	Ext: 31	Int: 29	Ext: 31	Int: 31	Ext: 31	Int: 26	Ext: 28
Int: 29	Ext: 29	Int: 34	Ext: 34	Int: 33	Ext: 33	Int: 30	Ext: 30

Upstream / Downstream

Beam right

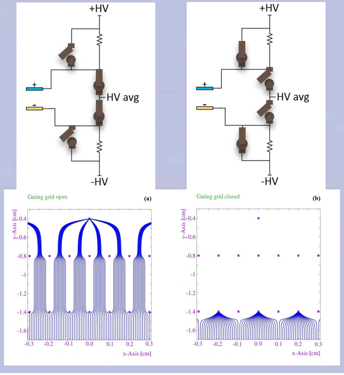
Top plate temperature (2016/05/03 17:31:01)

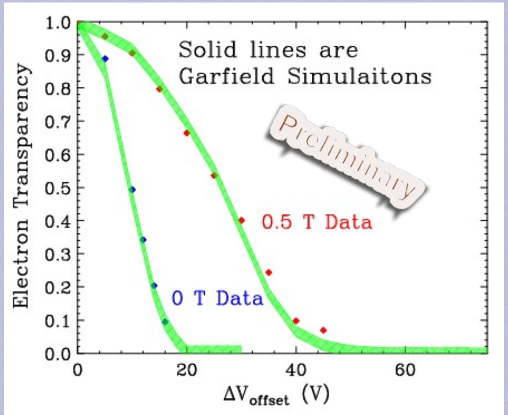




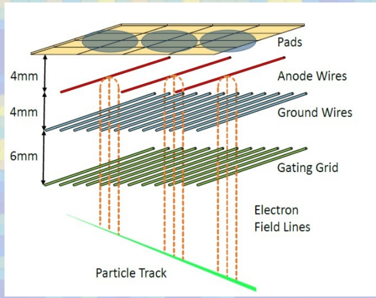
G. Jhang et al., J. Kor. Phys.Soci. 69 Issue 2, pp 144–151(2016)

Performance of Gating Grid





- Gating grid wires block
  - unwanted events
  - Ions from avalanche



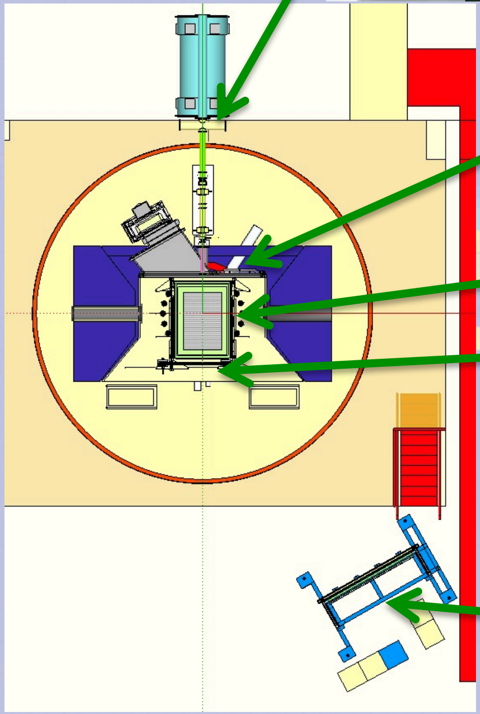
- Electron transparency as a function of the different voltage between adjacent wires (ΔV) agreed with Garfield simulations.
- *This result has been submitted to NIMA!*

Auxiliary detectors

Detector	Location	In trigger	Purpose
SBT: Start Counters	After STQ mag.	Hitting	Count number of beam and determine start timing
Active Collimator	In front of the target	No hit	Eject beam passing through out of the target.
KATANA-Veto	After the exit window	Pulse Height <= -30mV	Eject more than Z=20 beam passing through
Kyoto Array	Left and Right side	Multiplicity >= 4	Trigger central collision events
BDC: Beam Drift Chamber	In beam line after S.C.	not included	Reconstruct a beam track
NeuLAND	8.5m, 30deg	not included	Detect neutron and charged light particles

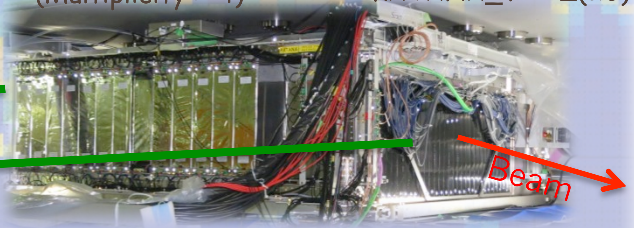
SBT:Start Counter (hitting)

Active Collimator (no hit)



Kyoto Array
(Multiplicity >=4)

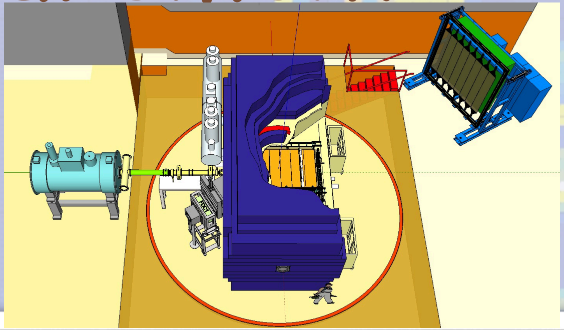
KATANA_V <= Z(20)

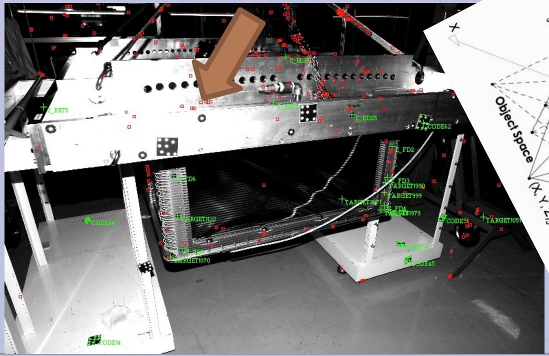


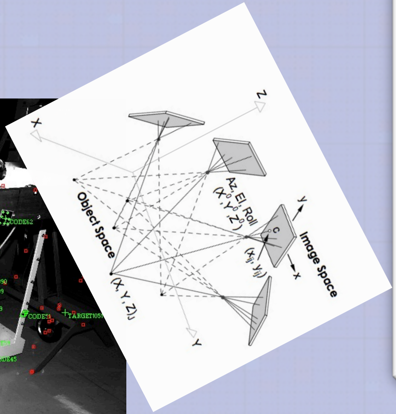
NeuLAND

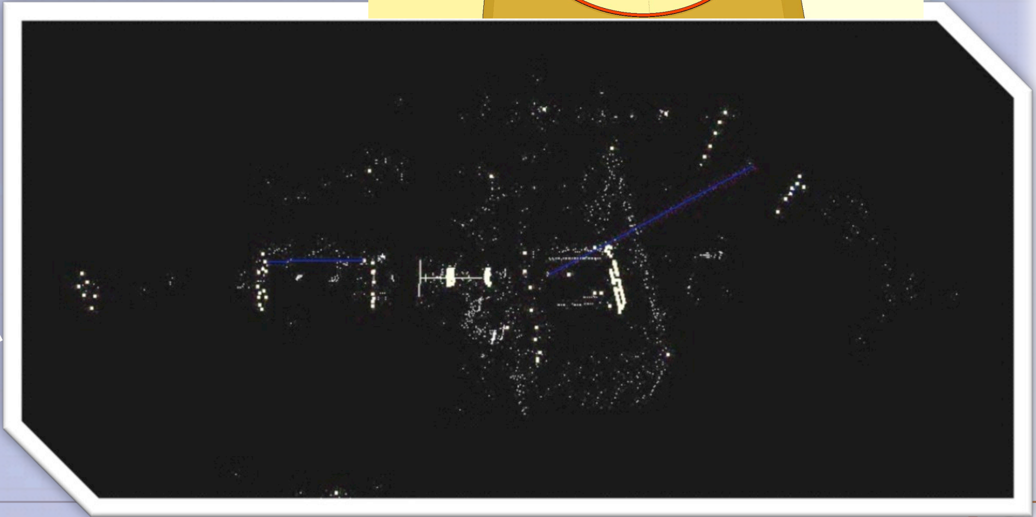
Photogrammetry Measurement

1. Put reflecting point stickers on the measuring surface
2. Take pictures from a several angles.
3. Analyze picture data.
4. The absolute position of point is reconstructed.
5. Absolute position determined with ~0.2mm.
6. This results will be submitted soon!

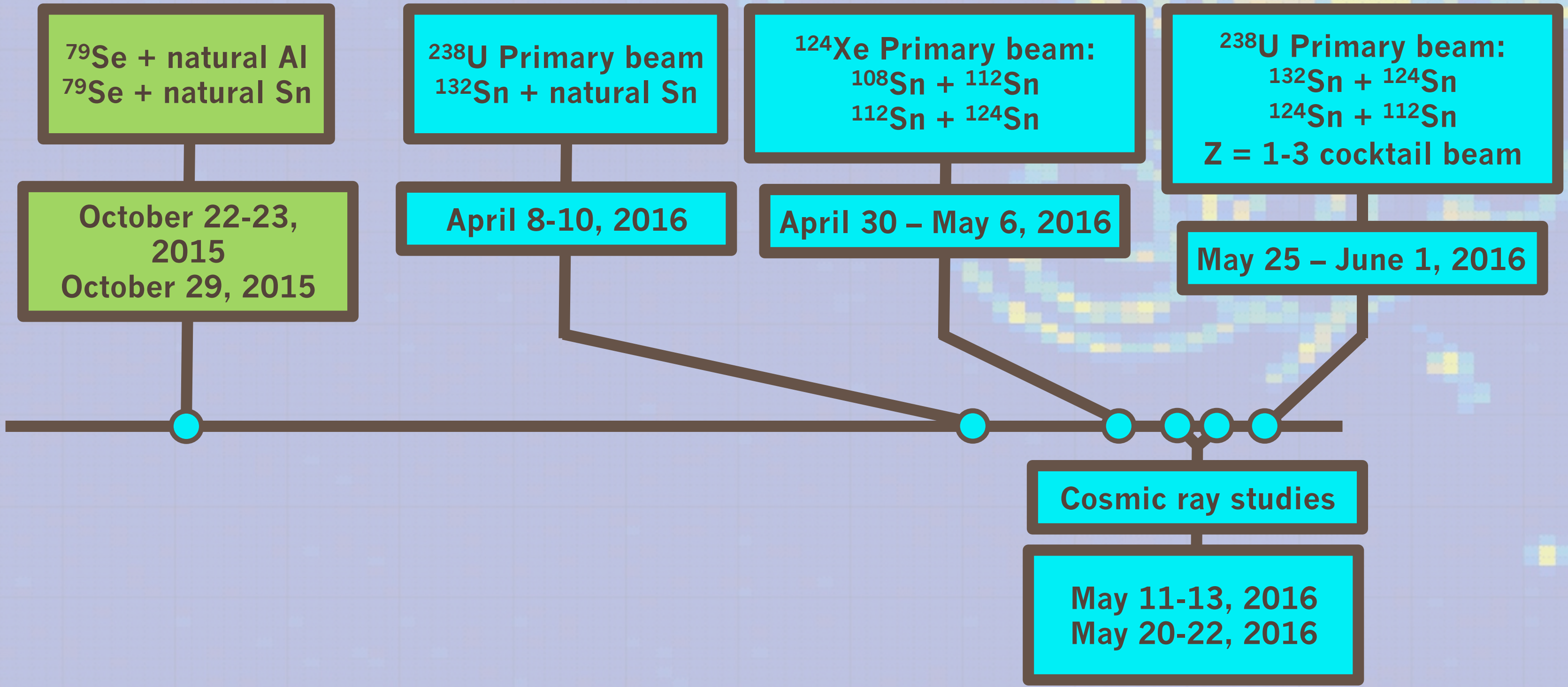






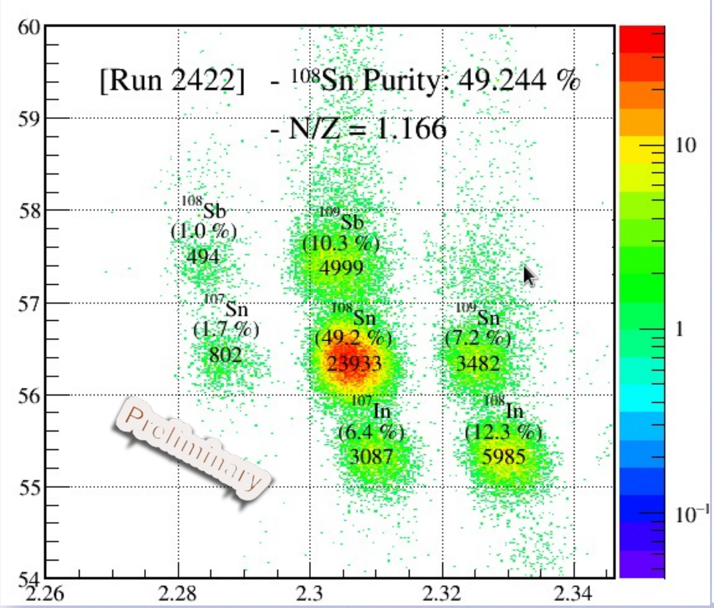


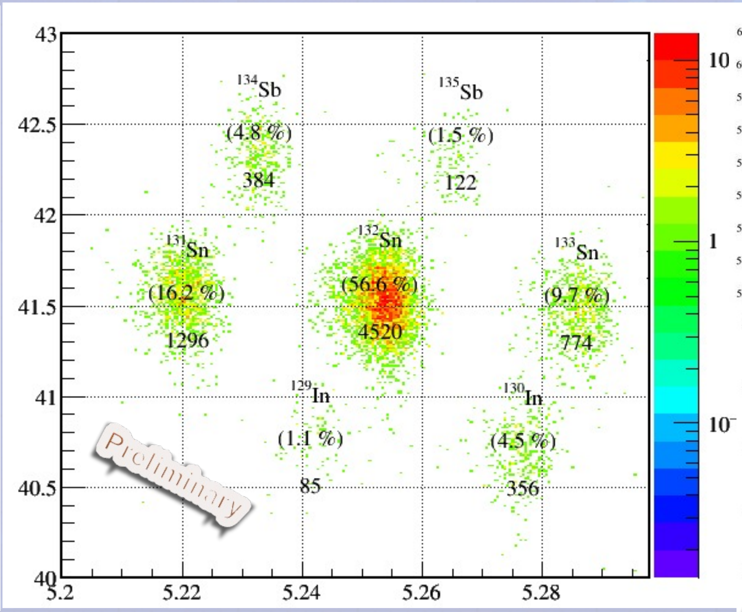
TPC measurement timeline

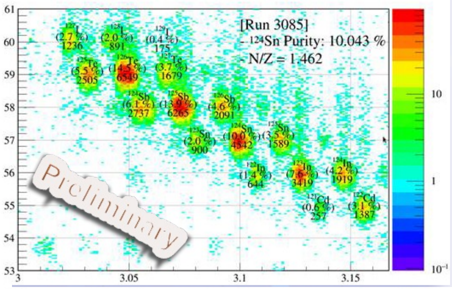


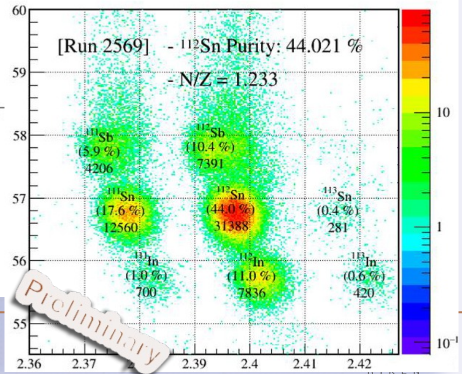
Sn Beam ID

Primary	Beam	Target	E/A	δ_{sys}	Goal	Date
^{124}Xe	^{108}Sn	^{112}Sn	269	0.09	minimum δ	4/30-5/4
	^{112}Sn	^{124}Sn	270	0.15	Reference	5/4-5/6
^{238}U	^{132}Sn	^{124}Sn	269	0.22	maximum δ	5/25-5/29
	^{124}Sn	^{112}Sn	270	0.15	Reference	5/30-6/1

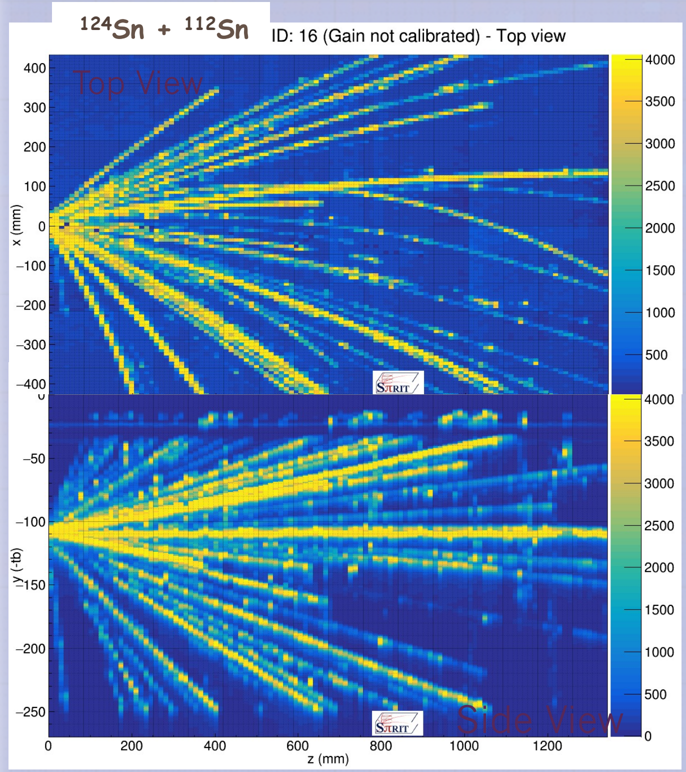


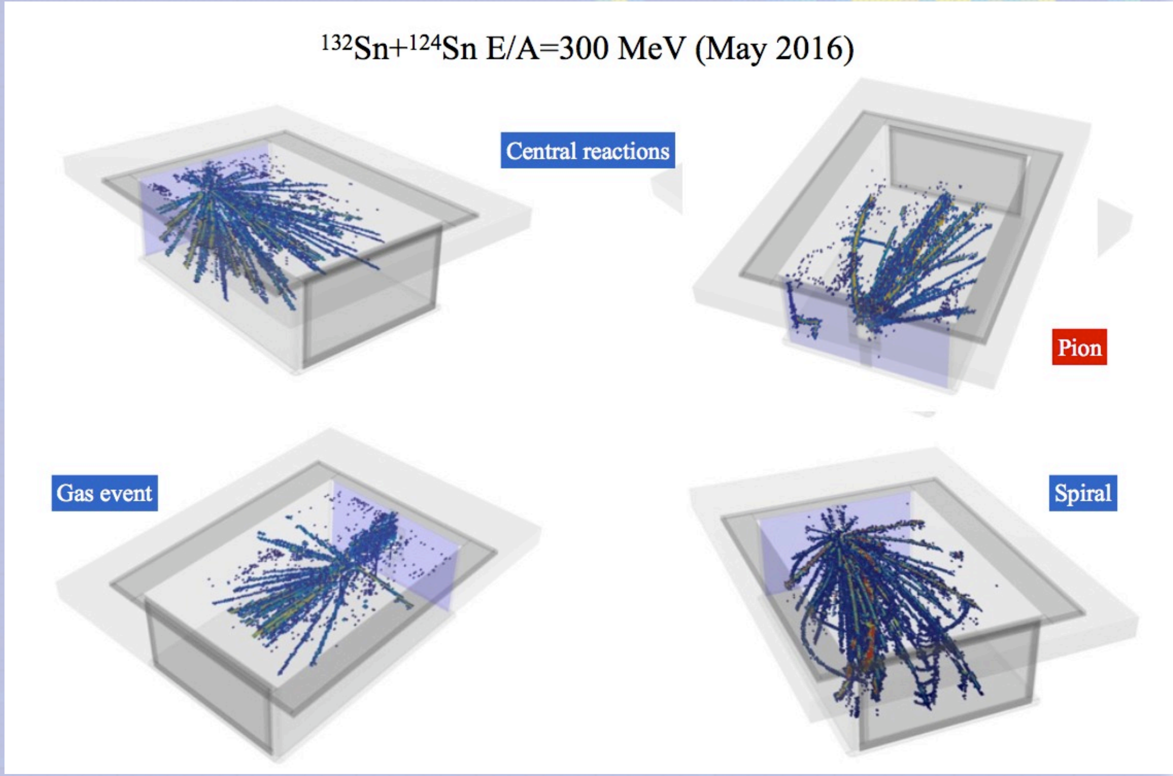






2D & 3D Event Display

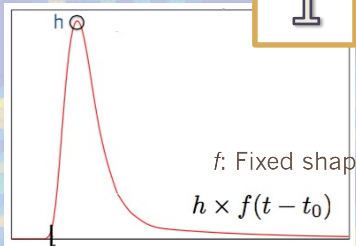




Track Reconstruction

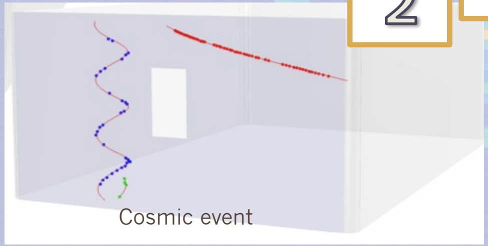
1. Pulse Shape Analysis
2. Helix tracking: 3D momentum
   1. Track separation
   2. Riemann fit: 2D
   3. Helix fit: 3D
   4. Clustering
   5. Initialize GENFIT parameters
3. GENFIT: precise fitting
   (Parameterization, extrapolation)
4. RAVE(Reconstruction vertices)

1

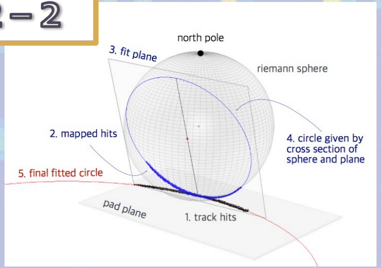


t_0: time at 5% of h

2



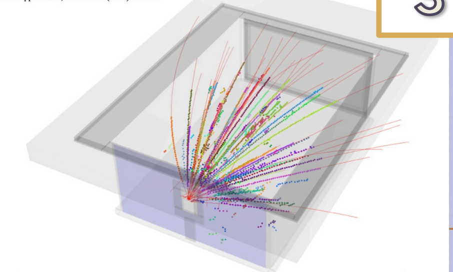
2−2



3

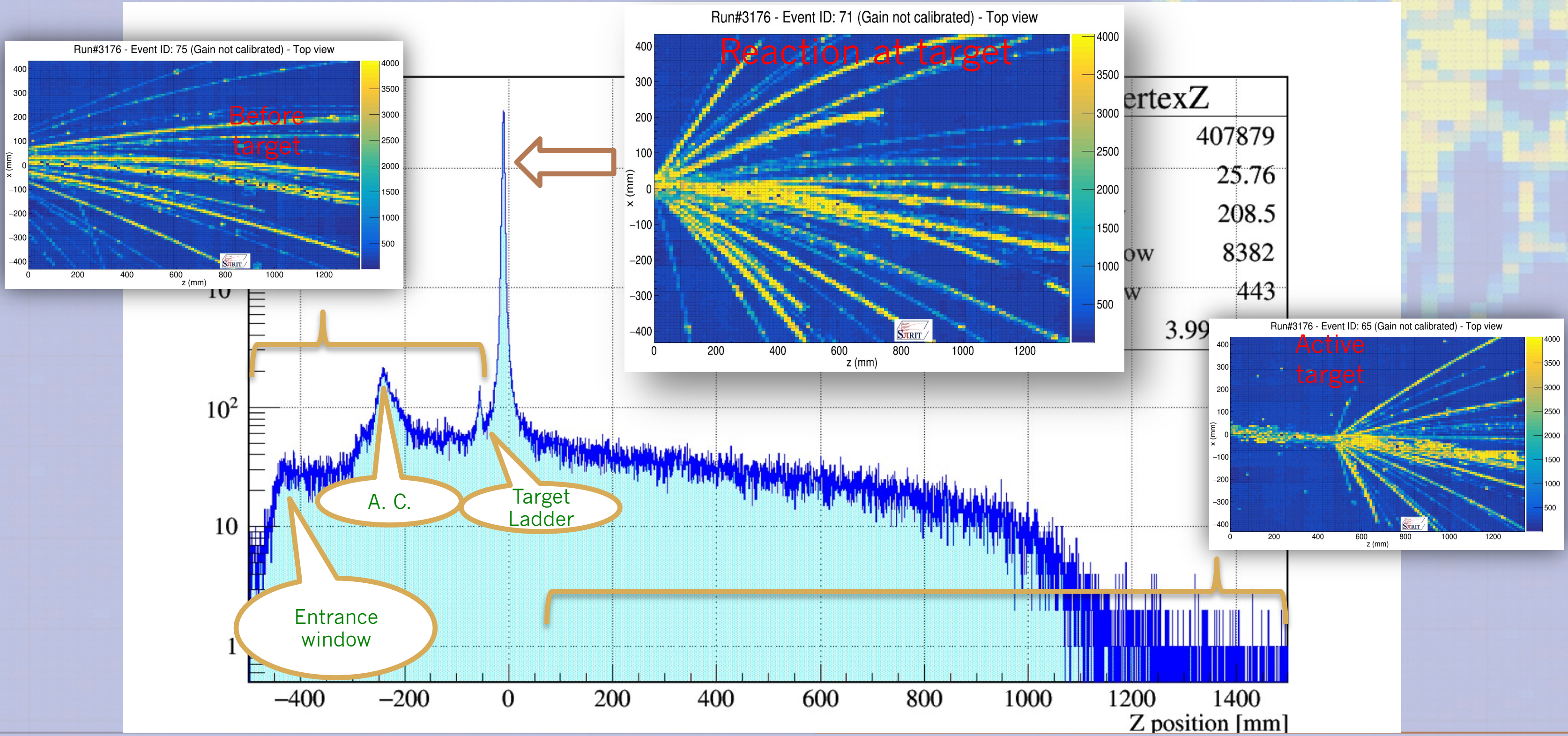
$^{132}Sn+^{124}Sn$ E/A=300 MeV (May 2016)

C. Höppner et al, NIM A 620 (2012) 518-525



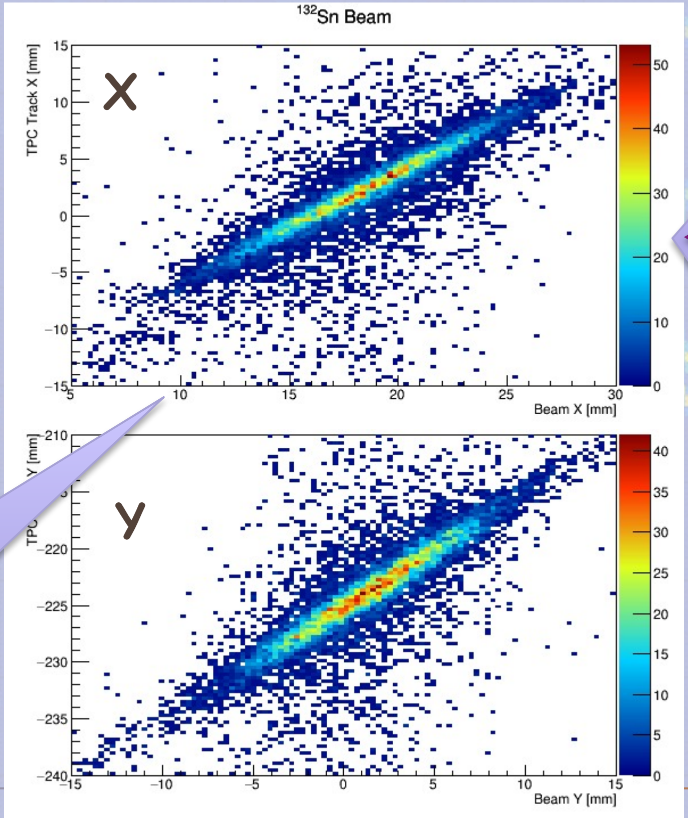
RIKEN SπRIT RIKEN NISHINA CENTER

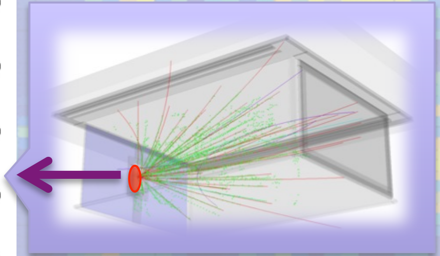
Vertex Reconstruction



Background can be eliminated

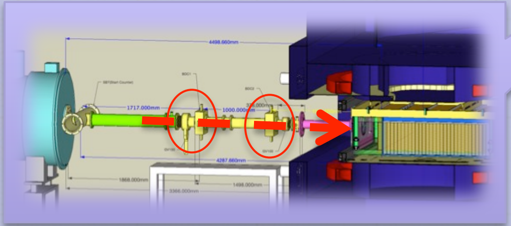
Correlation between Extrapolated track from TPC and Beam at the target.





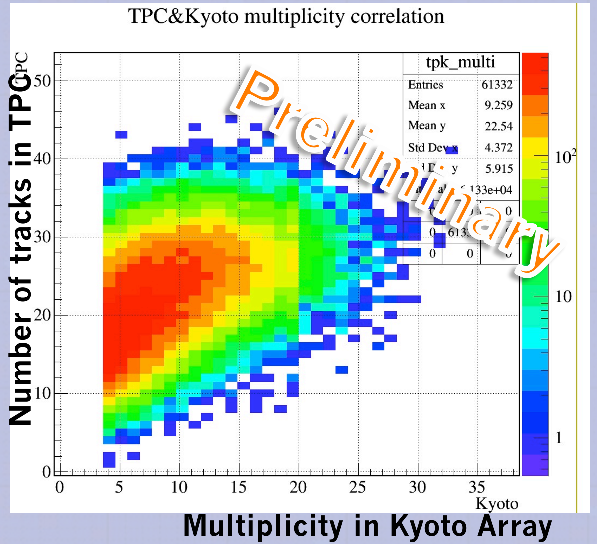
Each track extrapolated onto the target

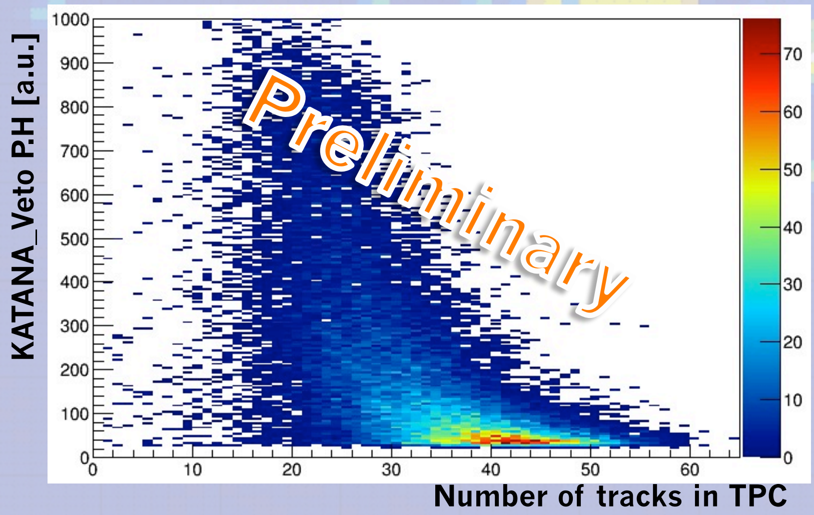
Two drift chambers provide us beam position at the target



Nice correlation verifies vertex reconstruction algorithm.

Correlation with auxiliary detectors



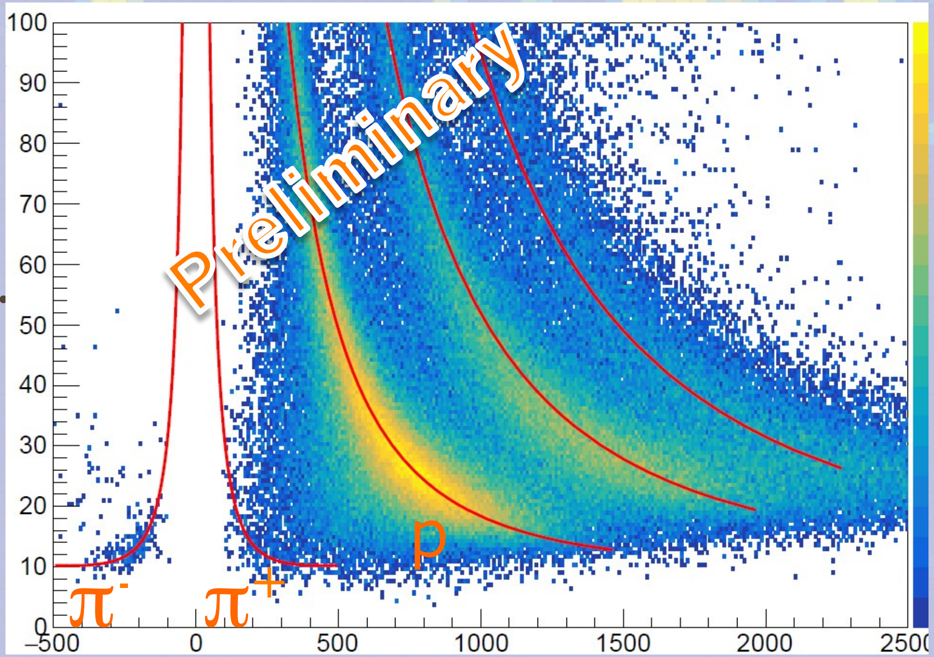


Nice correlations show confirmation of successful event triggering systems

Preliminary PID

- Gains are not calibrated.
- π^-/π^+ can be identified.
- Better resolution is obtained in latest studies.

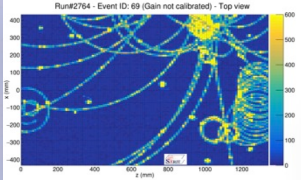
PID by TPC (^{132}Sn + ^{124}Sn @E/A=280MeV)

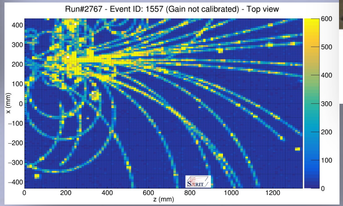


Summary

- The first SπRIT-TPC experiments performed at SAMURAI RIKEN-RIBF successfully in Spring 2016.
- Track reconstruction software is under development.
- Correlations with auxiliary detectors show confirmation of successful event triggering systems.
- Good progress to obtain π^-/π^+ spectral ratios to eventual place constraints on the symmetry energy at high density.
- Perspectives
  - Several technical papers on TPC are being prepared.
  - New physics results are coming!

Thank you for your attention





Other Participants: H. Baba, Chica, Ichihara, Kondo, T. Nakamura, H. Otsu, Saito, Togano

NeuLAND Collaboration: Leyla Atar, Tom Aumann, Igor Gasparic, A. Horvat, H. Scheit

On Site Experimenters

J. Barney (MSU)
G. Cerizza (MSU)
J. Estee (MSU)
B. Hong (Korea U)
T. Isobe (RIKEN)*
G. Jhang (Korea U)
M. Kaneko (Kyoto U)
M. Kurata-Nishimura (RIKEN)
P. Lasko (IFN, Krakow)
H. Lee (RISP)
J. Lee (Korea U)
J. Lukasik (IFN, Krakow)
W. Lynch (MSU)*
A. McIntosh (TAMU)
P. Morfouace (MSU)
T. Murakami (Kyoto U)*
S. Nishimura (RIKEN)
P. Pawlowski (IFN, Krakow)
C. Santamaria (MSU)
R. Shane (MSU)
D. Suzuki (RIKEN)
B. Tsang (MSU)*
Y. Zhang (Tsinghua U)

*spokespersons