The SπRIT and pion detectors in RIKEN for the experimental study of symmetry energy with heavy ion collisions

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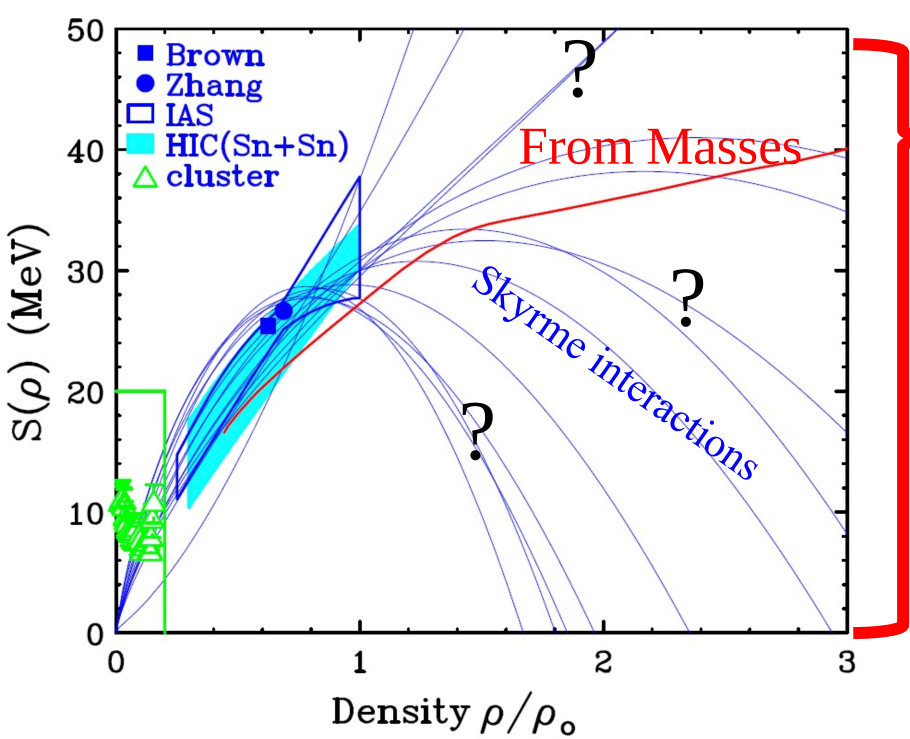
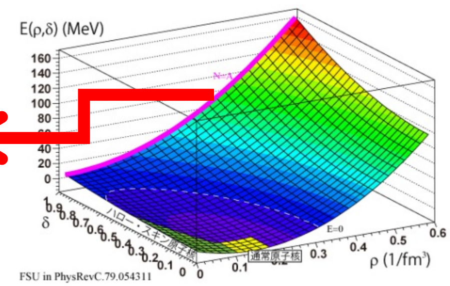
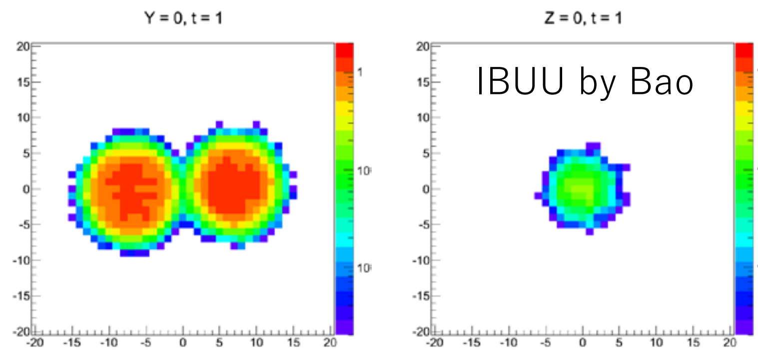
RIKEN Nishina Center

IWM-EC 2018

Heavy Ion Collision to study density dependent symmetry energy







- Large uncertainty on nuclear symmetry energy at $\rho \gg \rho_0$ compared with that for $\rho \leqq \rho_0$ region.
- Heavy ion collision is currently unique way to produce high dense matter in the laboratory.
- It is challenging to extract the information related to EoS because of complicated nuclear collision dynamics.

One of the high density probes for E_{sym}: pion production

- Larger values for ρ_n/ρ_p at high density: softer Esym causes stronger emission of negative pions.
- In delta resonance model, $Y(\pi^-)/Y(\pi^+) \approx (\rho_n/\rho_p)^2$
- In equilibrium, $\mu(\pi^+)-\mu(\pi^-)=2(\mu_p-\mu_n)$

π^- production (main reaction)

$$nn \rightarrow p\Delta^-$$
$$\Delta^- \rightarrow n\pi^-$$

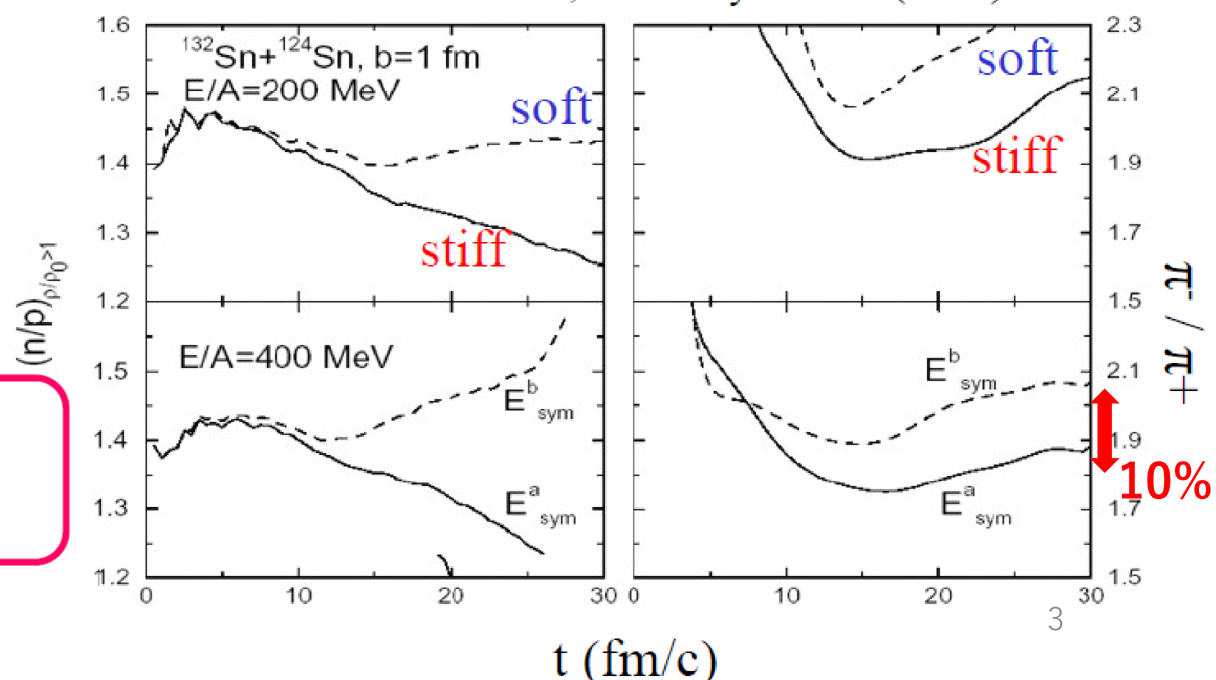
π^+ production (main)

$$pp \rightarrow n\Delta^{++}$$
$$\Delta^{++} \rightarrow p\pi^+$$

Simple expectation :

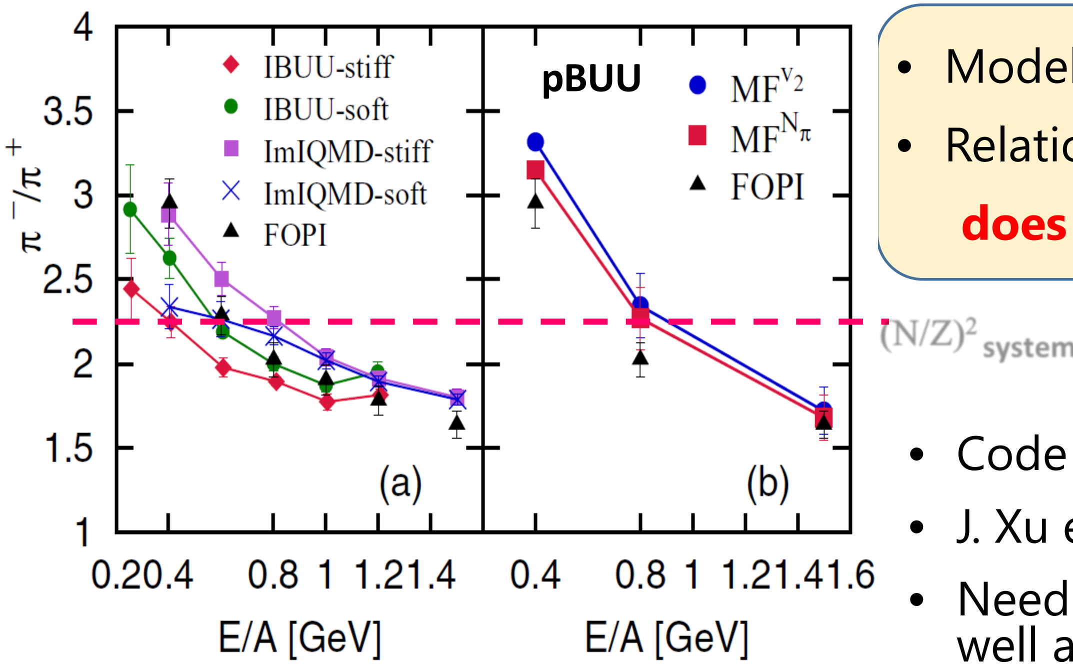
$$\left(\frac{\pi^-}{\pi^+}\right) \simeq \frac{5N^2+NZ}{5Z^2+NZ} \simeq \left(\frac{N}{Z}\right)^2$$

Li et al., Nucl.Phys. A734 (2004) 593.



Pion Calculation and Symmetry energy

- Pion Calculations by some models
  - B. A. Li, PRL 88 (2002) 192701 **: IBUU**
  - Z. Xiao, B. A. Li, L. W. Chen, G.-C. Yong, and M. Zhang, PRL102 (2009) 062502 **: IBUU04**
  - Z. Q. Feng and G. M. Jin, PLB 683 (2010) 140 **: ImQMD**
  - J. Hong and P. Danielewicz , PRC90 (2014) 024605 **: pBUU**
  - N. Ikeno, A. Ono et al., PRC93 (2016) 044612 : **AMD+JAM**
  - Wen-Mei Guo, Gao-Chan Yong and Wei Zuo, PRC90 (2014) 044605 ... etc.
- Pion ratio in central Au+Au collisions: Theory vs. Exp. Data



J. Hong and P. Danielewicz , PRC90 (2014) 024605

- Model predictions **do not agree**.
- Relation $\pi^-/\pi^+ \cong N^2/Z^2$ **does not hold**.

- Code Comparison Project is on going.
- J. Xu et al., PRC93 (2016) 044609.
- Need to understand the dynamics as well as pion production.

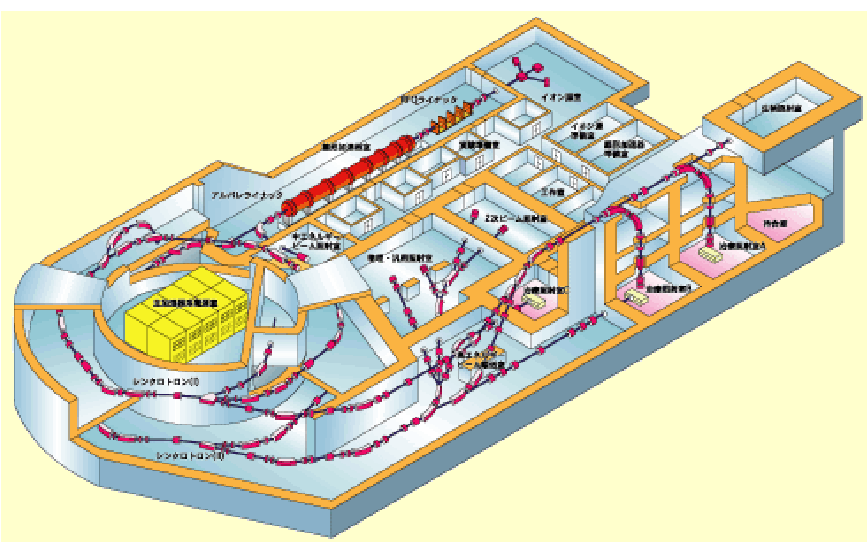
Series of HIC experiments under GeV energy beam in Japan

- Most of previous experimental studies use mass symmetric collisions so far.
- It is useful also to study with mass-asymmetric collision to distinguish different moving source like NN, participant-participant and nucleus-nucleus.

- HIC experiment with RI-beam
  - →SPiRIT project at RIKEN
- Pion experiments using stable beam
  - → Pilot experiment of SPiRIT at HIMAC
  - RI-beam → require large acceptance
  - Stable beam → small acceptance detector still works.

HIC experiment at HIMAC

- HIMAC: Heavy Ion Medical Accelerator in Chiba
- Synchrotron type accelerator for medical usage
- C, Si, Xe projectile can be utilized
- Up to sub-GeV/A beam energy



- Collaborators
  - M. Sako1;2,
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  - Y. Ichikawa1,
  - K. Ieki3,
  - S. Imajo1,
  - T. Isobe2,
  - M. Matsushita3,
  - J. Murata3,
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  - H. Sakurai2,
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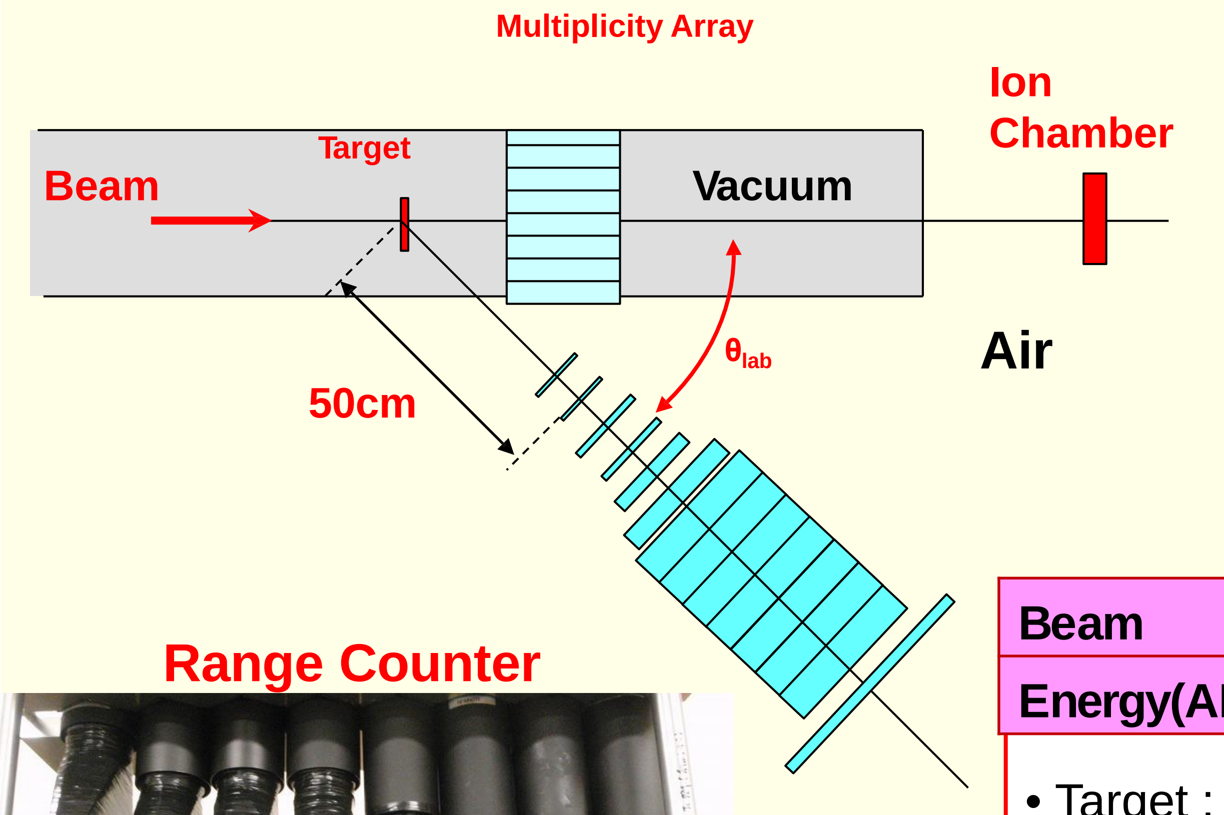
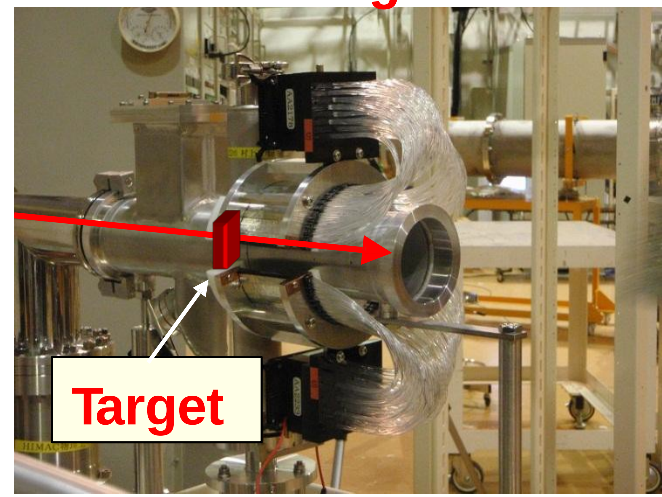
  - E. Takada4

1 Kyoto Univ.
2 RIKEN
3 Rikkyo Univ.
4 NIRS

Pion range counter for detecting pions



Multiplicity Array
27-58 deg.

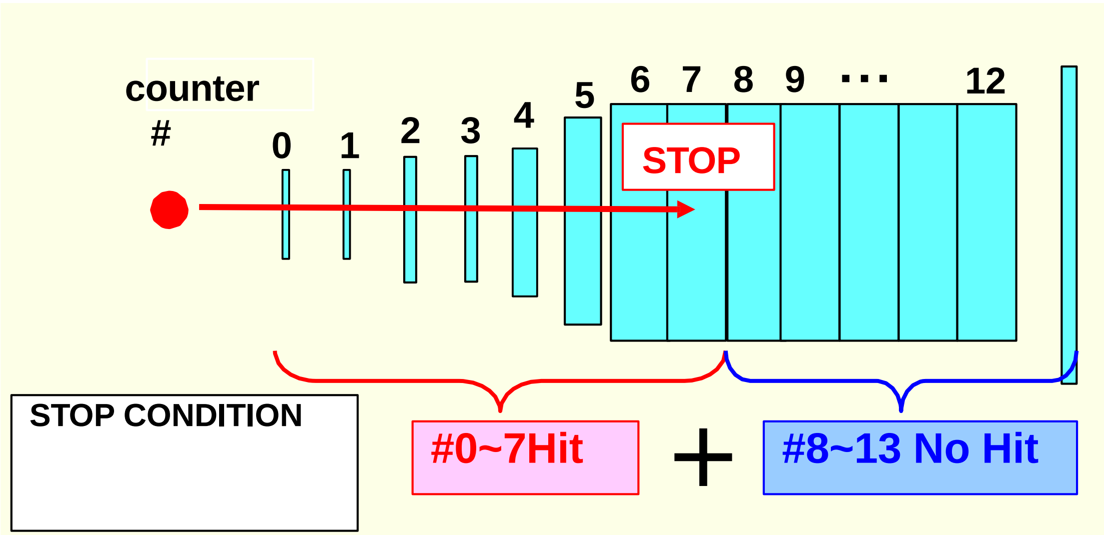


Range Counter

Beam	^{28}Si	^{132}Xe
Energy(AMeV)	400, 600, 800	400

- Target : In ~ 390 mg/cm^2
- Typical Intensity : ~ 10^7 ppp
- Range Counter : 14 layers (+2) of Sci.
- measured angle (θlab)
  : 30, 45, 60, 75, 90, 120 degree
- solid angle : 10 msr

Pion Detection Principle

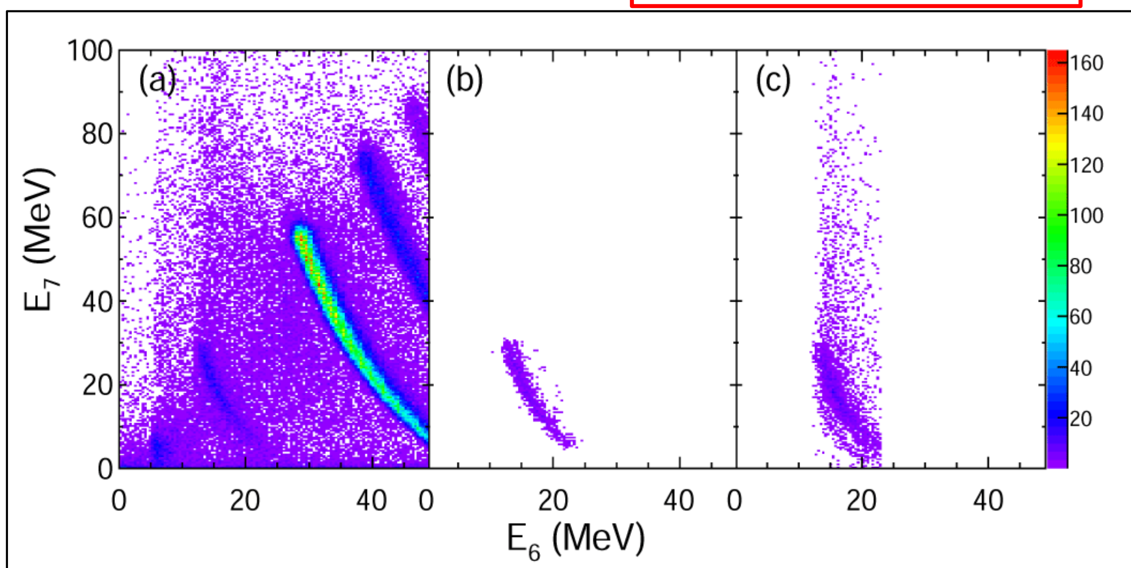


·π^+ decay to μ^+

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

·μ^+ : Energy ~ 4 MeV
: Range ~ 1 ㎜

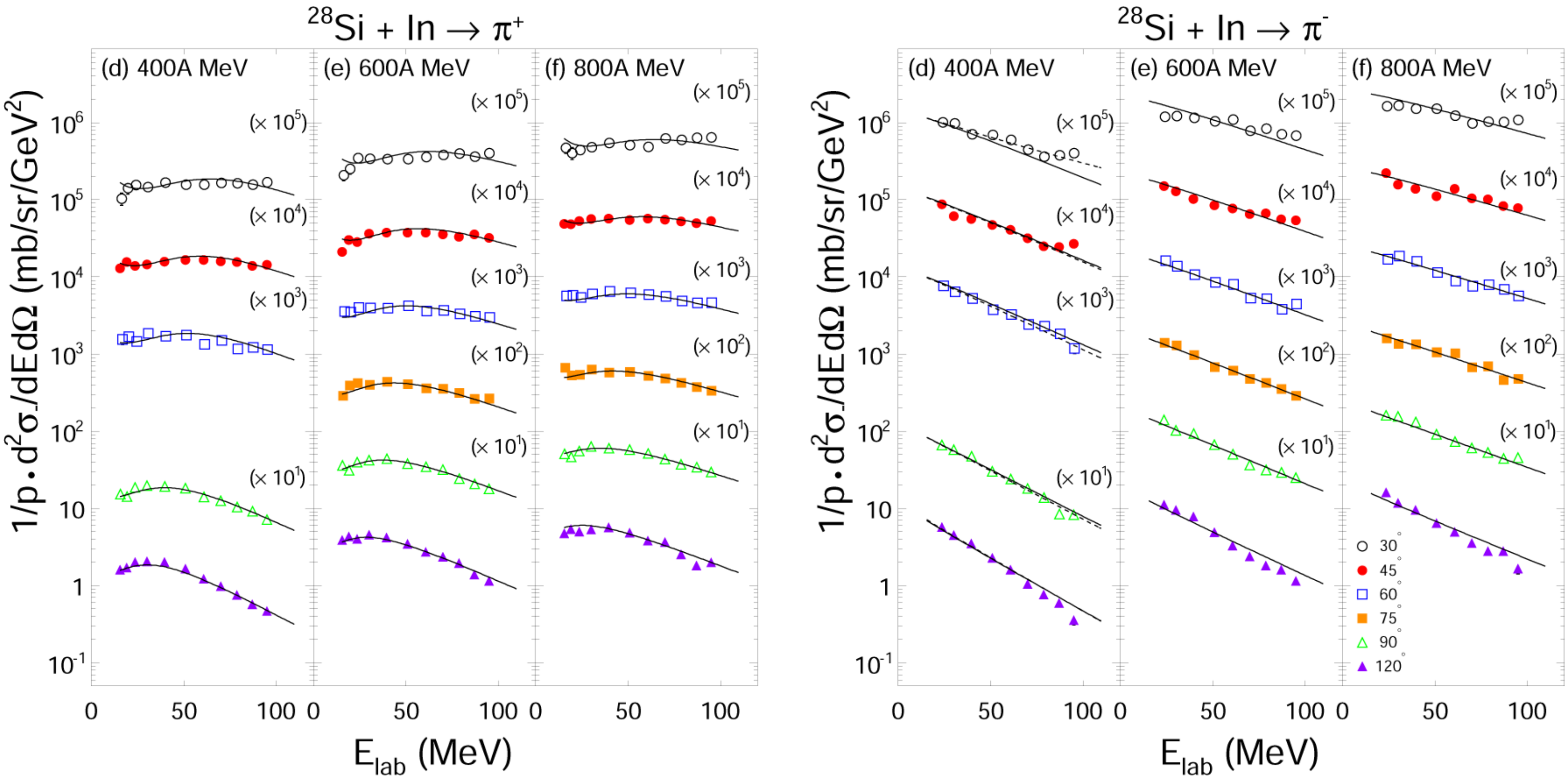
Double pulse in one layer



~400MeV/u beam energy
→ Pion's are rare

* less than 1/100 of protons

Result of pion production
→It well overlaps with moving source frame.



$$f_{-}(E_{mov}) = N_{-}exp(-E_{mov}/E_0),$$

$$f_{+}(E_{mov}) = N_{+}P(E_{mov})exp(-E_{mov}/E_0),$$

$$E_{mov} = \gamma_{mov}(E_{lab} - \beta_{mov}p_{lab}cos\theta_{lab}),$$

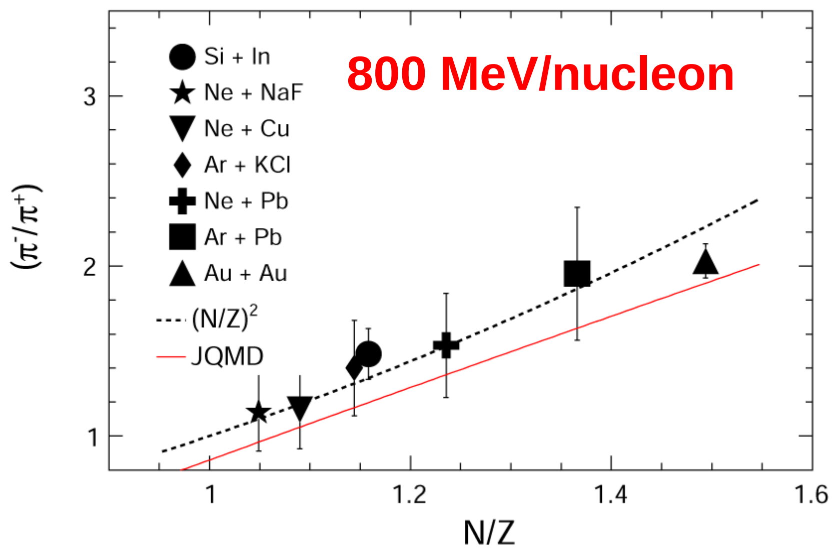
$$P(E_{mov}) = \Delta B_c/E_{mov}ln\{1 + exp[(E_{mov} - B_c)/\Delta B_c]\}.$$

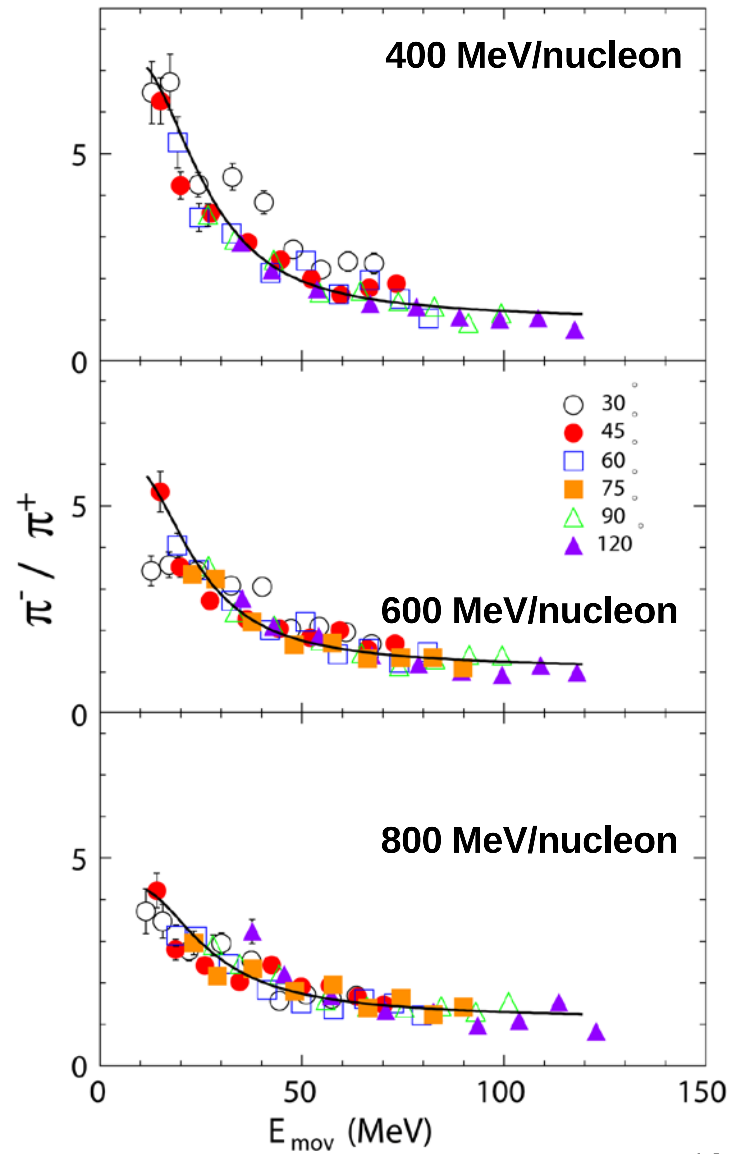
$$1 + a_2cos^2\theta_{mov} \quad p_{mov}cos\theta_{mov} = \gamma_{mov}(p_{lab}cos\theta_{lab} - \beta_{mov}E_{lab})$$

Differential π-/π+ ratio

weak angular dependence
clear energy dependence

π -/π+ supports $(N/Z)^2$





Heavy RI Collision experiment @RIKEN-RIBF → SPiRIT project

- Experimental project to give a constrain on the density dependent symmetry energy main for higher dense region.
- Systematic measurement in same *Z* but different *N* system realized with heavy RI beam.
  - Scaling with δ.
  - $\rho \sim 2\rho_0$ nuclear matter at RIBF energy (E/A=270MeV).

Primary	Beam	Target	E_{beam}/A	$(N-Z/A)_{sys}$
^{238}U	^{132}Sn	^{124}Sn	270	0.22
	^{124}Sn	^{112}Sn	270	0.15
^{124}Xe	^{108}Sn	^{112}Sn	270	0.09
	^{112}Sn	^{124}Sn	270	0.15

- Successfully finished.
  - 2016 Apr. – Jun.

Collaboration for New Exp. at RIBF: SPiRIT

SAMURAI Pion Reconstruction and Ion Tracker

International Collaboration aiming to study density dependent symmetry energy through **<u>Heavy RI Collision</u>** experiments.

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

U.S. DEPARTMENT OF
ENERGY
Office of Science

SPiRIT Collaboration (2009~)

SAMURAI Pion Reconstruction and Ion-Tracker

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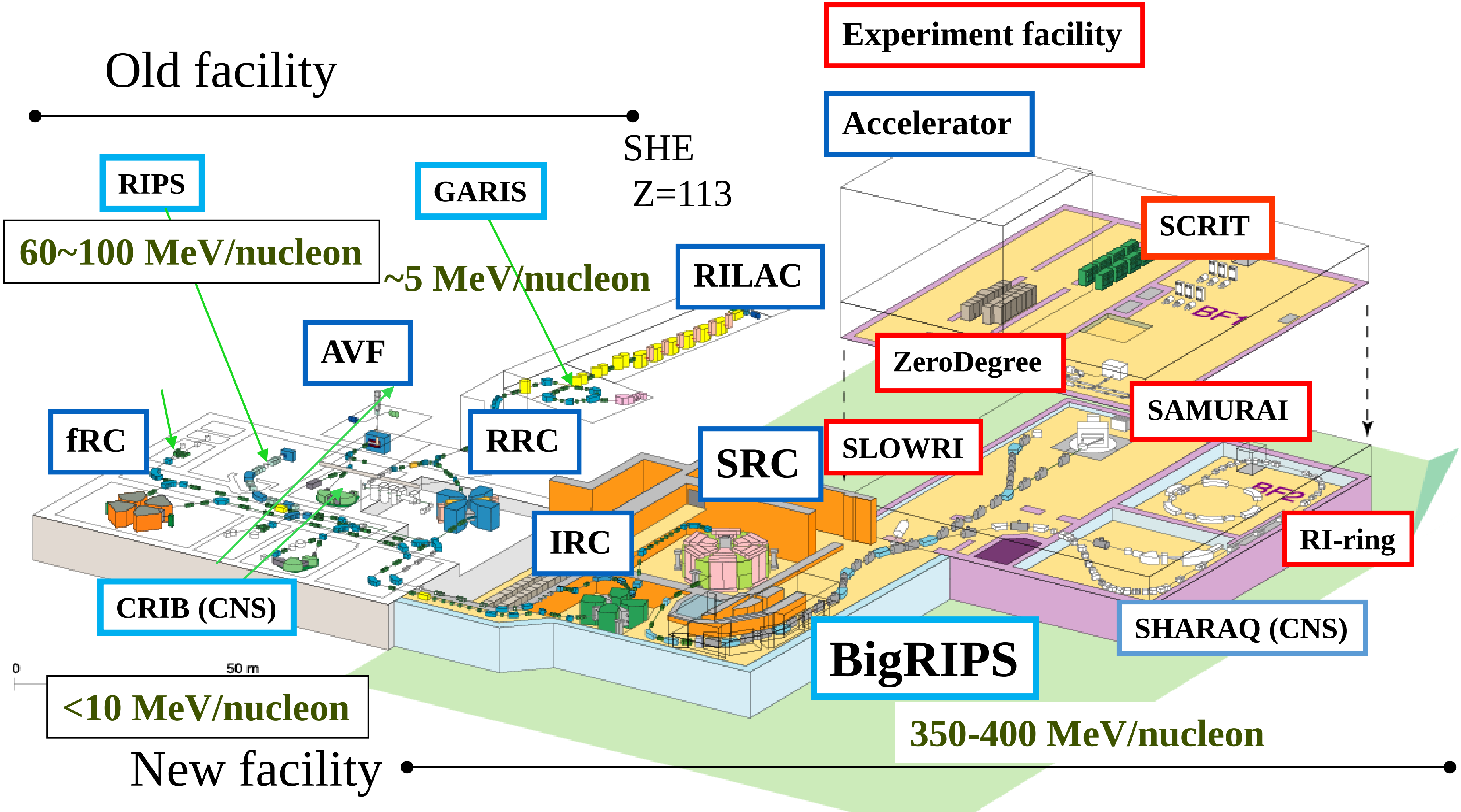
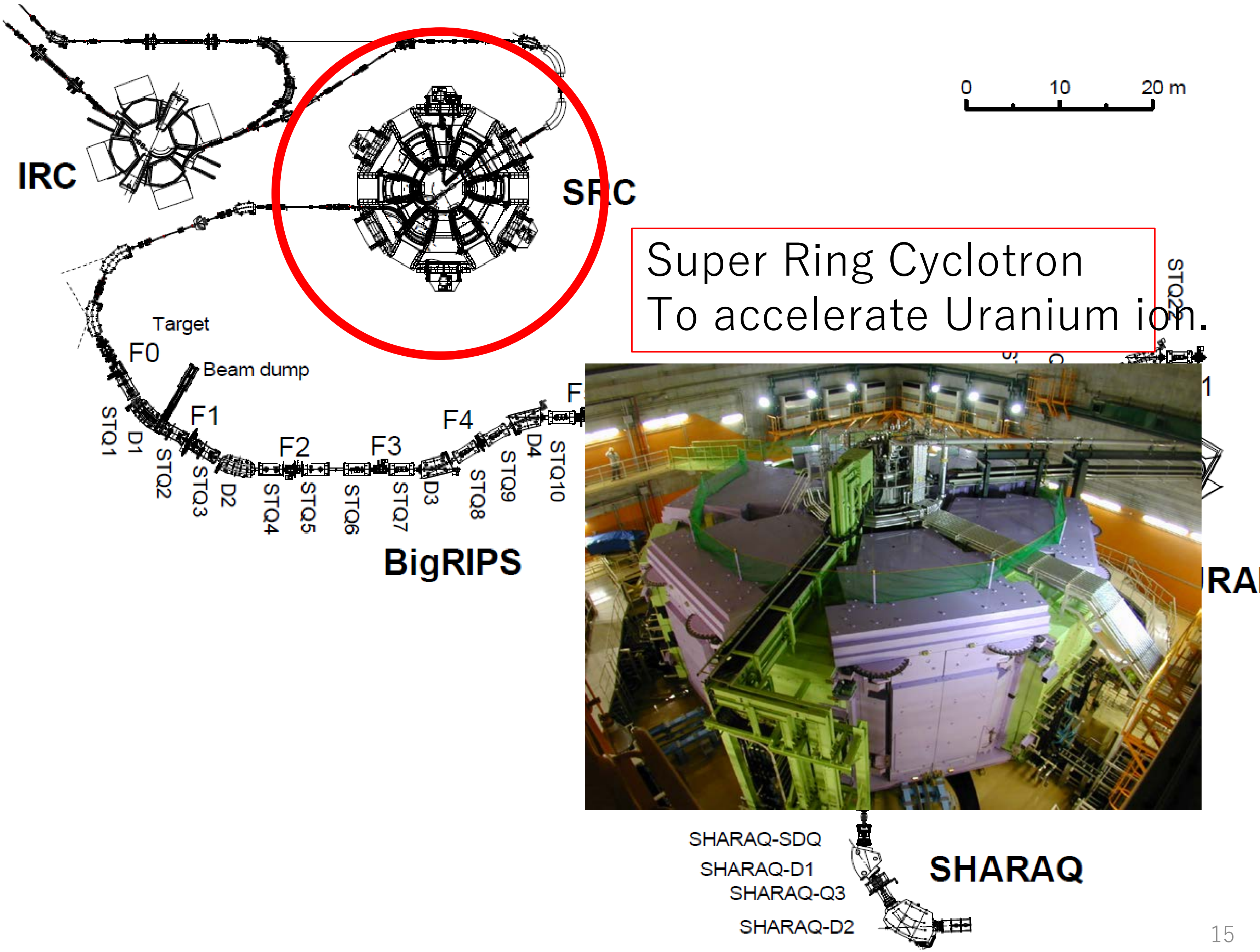
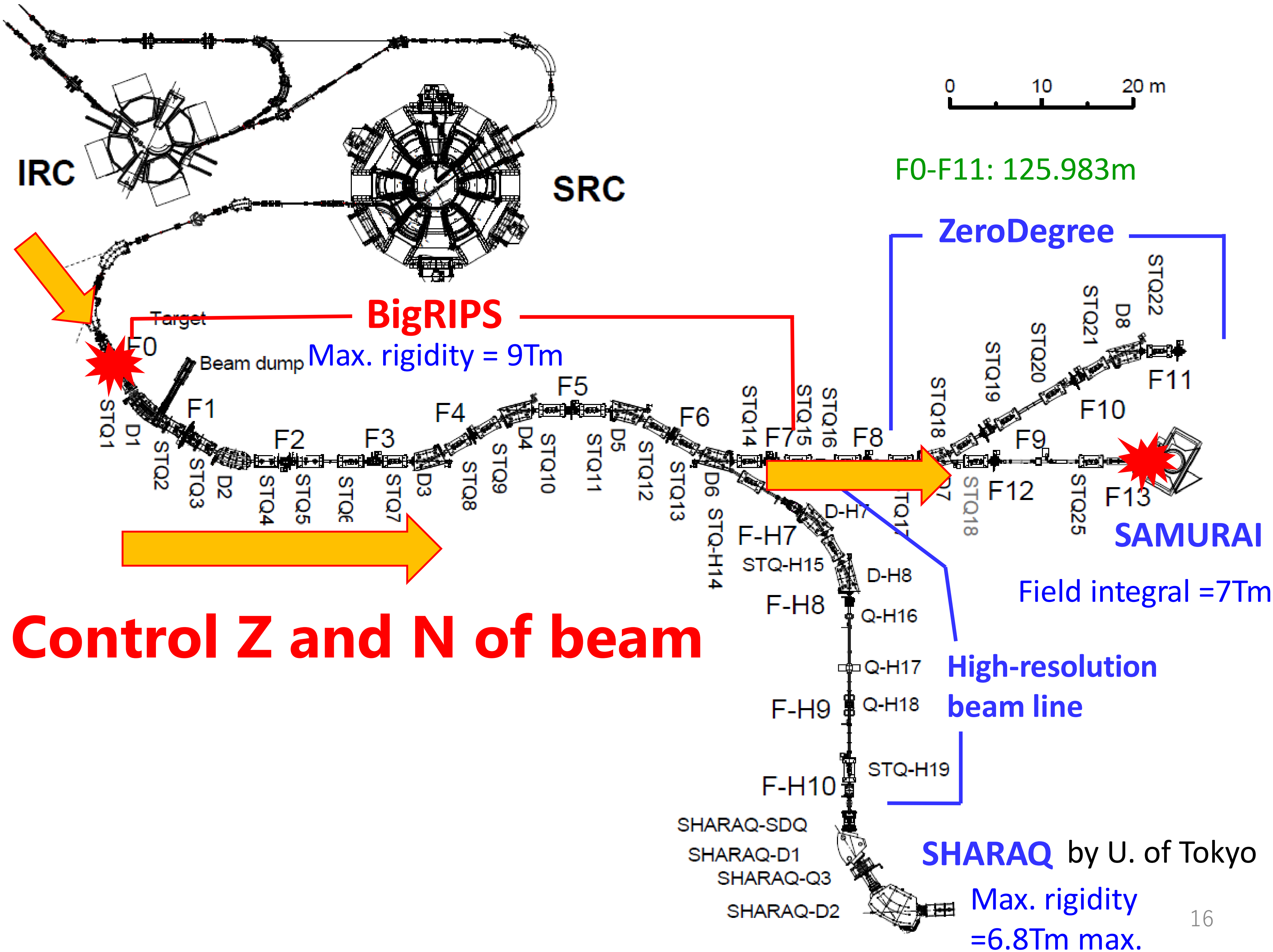
RIKEN RI Beam Factory (RIBF)



Intense (80 kW max.) H.I. beams (up to U) of 345*A*MeV at SRC
Fast RI beams by projectile fragmentation and U-fission at BigRIPS
Operation since 2007



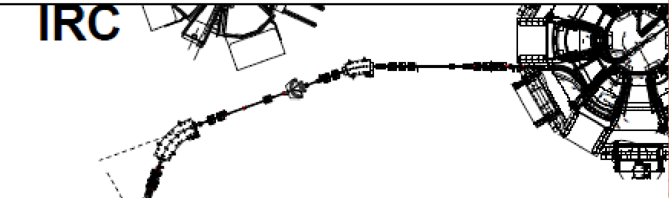
Super Ring Cyclotron
To accelerate Uranium ion.



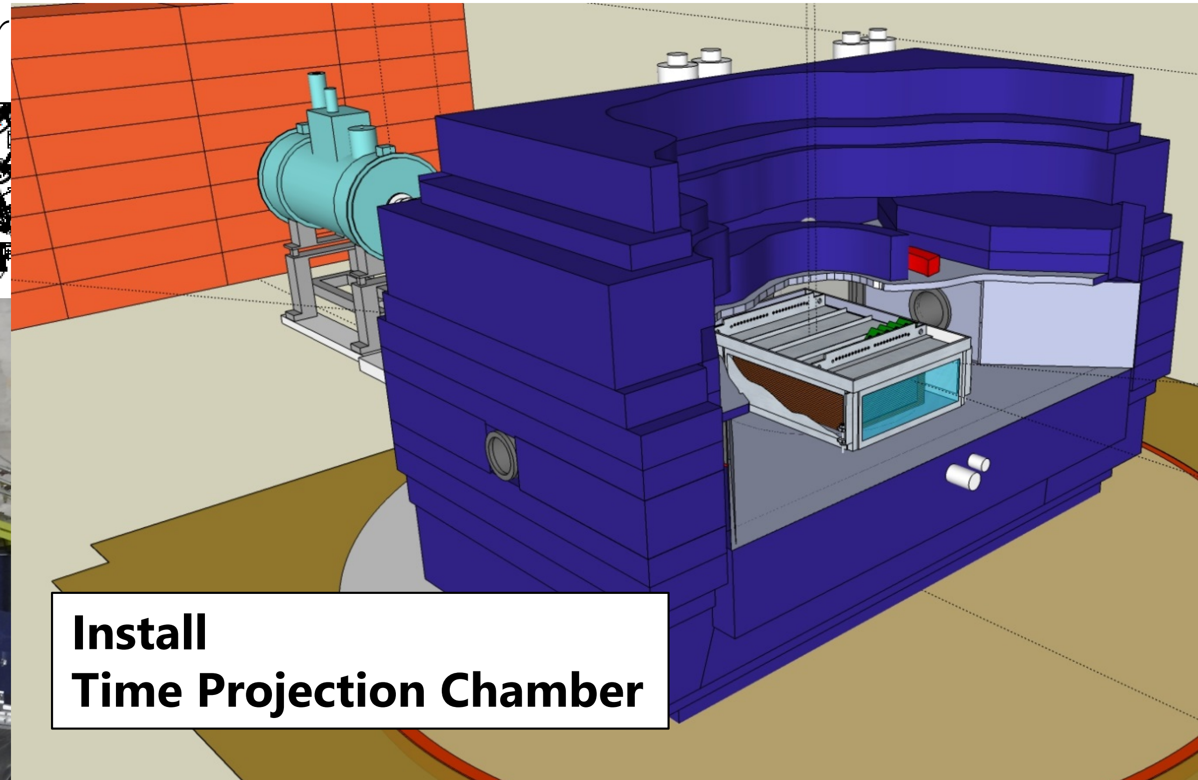
IRC
SRC
0
10
20 m
F0-F11: 125.983m
ZeroDegree
BigRIPS
Target
F0
Beam dump
Max. rigidity = 9Tm
F1
F2
F3
F4
F5
F6
F7
F8
F9
F10
F11
F12
F13
STQ1
D1
STQ2
STQ3
D2
STQ4
STQ5
STQ6
STQ7
D3
STQ8
STQ9
D4
STQ10
STQ11
D5
STQ12
STQ13
D6
STQ14
STQ15
STQ16
STQ18
STQ19
STQ20
STQ21
D8
STQ22
STQ25
D-H7
F-H7
STQ-H14
STQ-H15
D-H8
F-H8
Q-H16
Q-H17
F-H9
Q-H18
STQ-H19
F-H10
SAMURAI
Field integral =7Tm
High-resolution
beam line
Control Z and N of beam
SHARAQ-SDQ
SHARAQ-D1
SHARAQ-Q3
SHARAQ-D2
SHARAQ by U. of Tokyo
Max. rigidity
=6.8Tm max.

SAMURAI Spectrometer

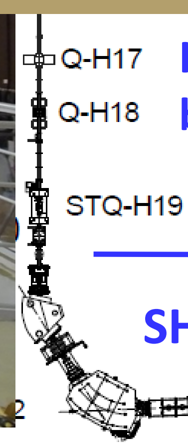
Superconducting Analyzer



B<3T
R: 1m
Gap: 80cm



Install
Time Projection Chamber



High-resolution beam line

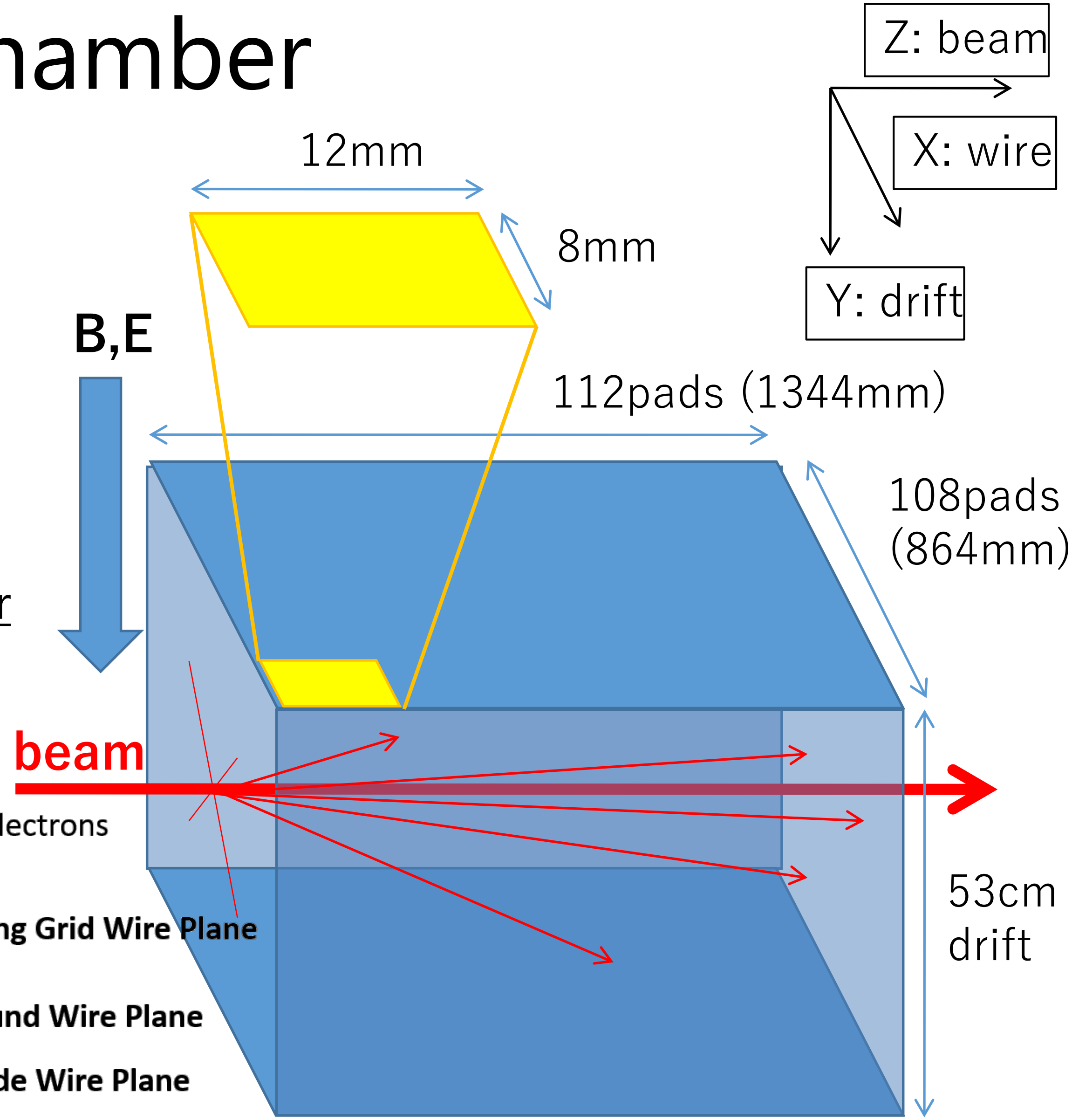
SHARAQ by U. of Tokyo

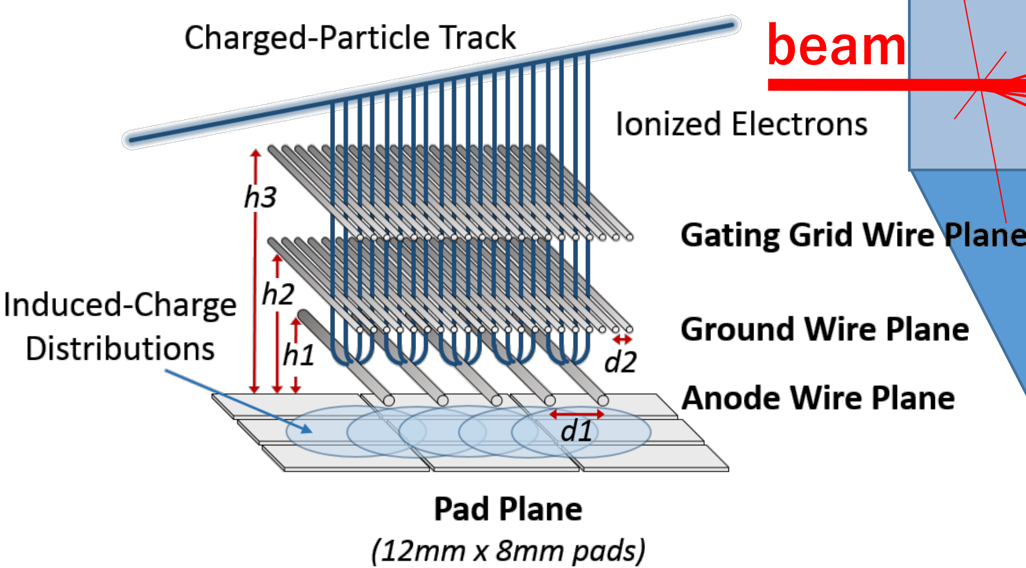
Max. rigidity
=6.8Tm max.

New Device: SPiRIT-Time Projection Chamber

- Based on Bevalac EOS TPC.
- Wire amplification with P10 gas (1atm).
- Target at the entrance of chamber.
- ~12000 readout pads.
- Multiplicity: 10~100.

- <u>Beam passes through chamber as well.</u>





Readout Electronics for TPC: GET

NIMA 887 (2018) 81

- GET: novel readout system for TPC
  - Integrated system from Frontend to DAQ.
  - Developed by France-USA Collaboration.
- Configurable even after the installation
  - gain can be selected pad by pad: 120fC~10pC
  - Shaping T, Sampling rate
- Ch. by ch. hit registering →Selective digitization

Interface to TPC

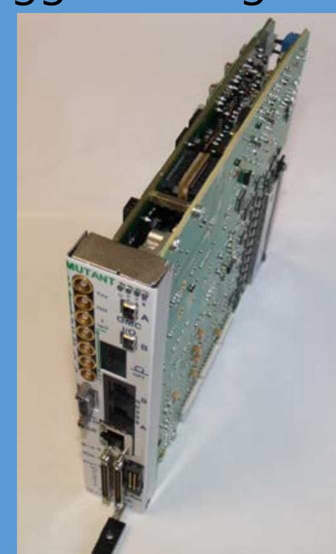
ASIC+Frontend

AsAd

Backend

CoBo

Trigger management

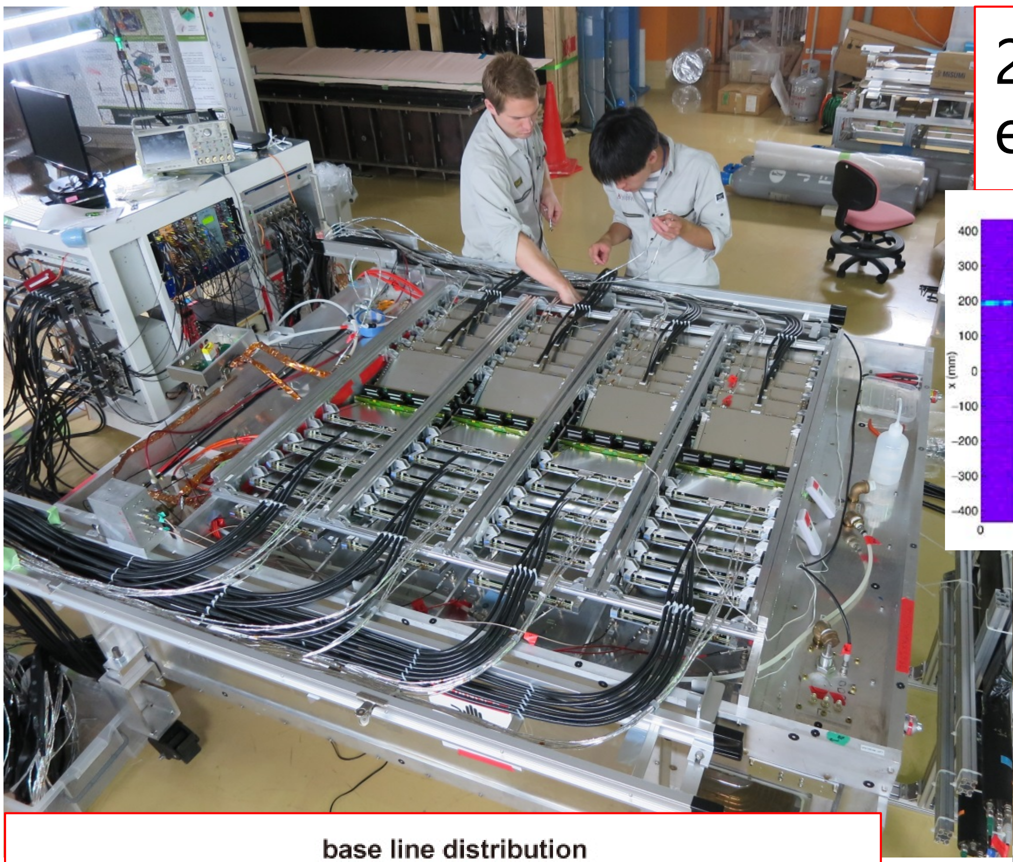


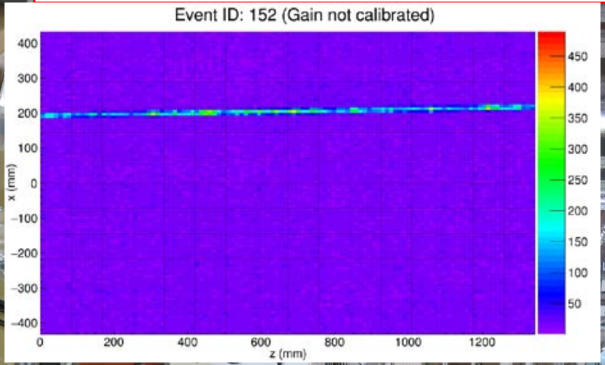
Mutant

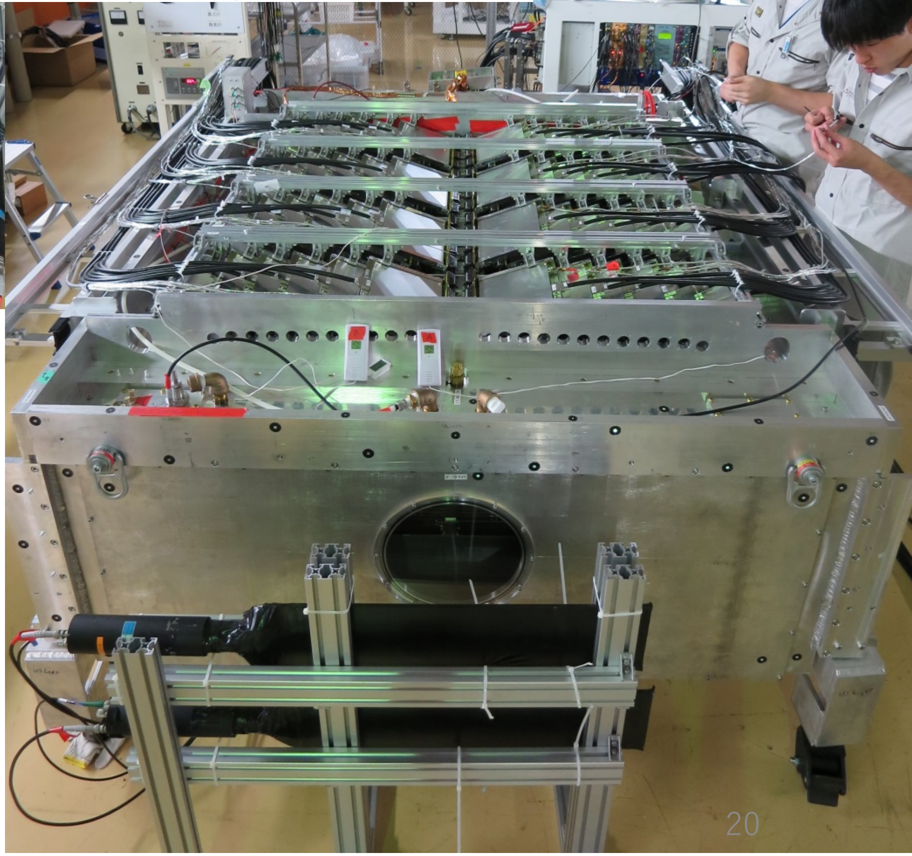
GET

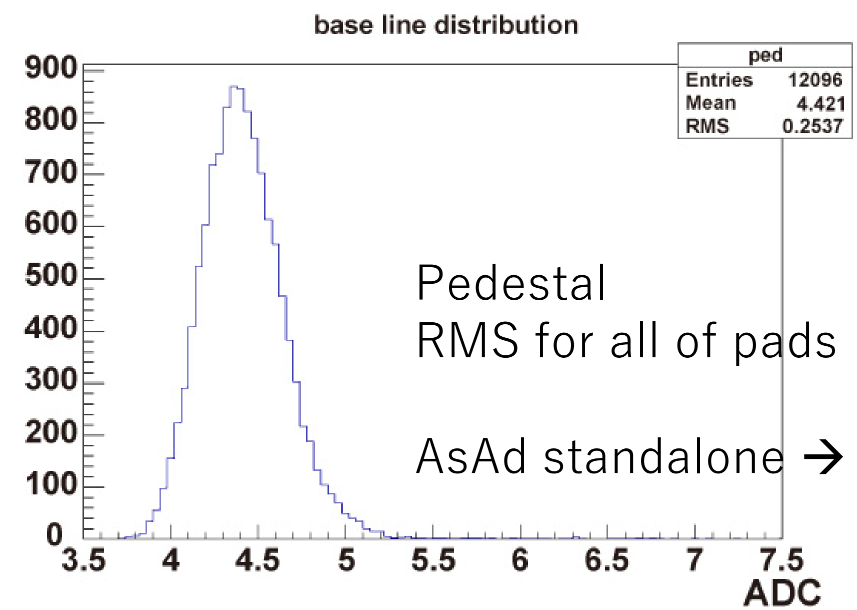
DAQ

2015 Aug.: Installation of electronics finished



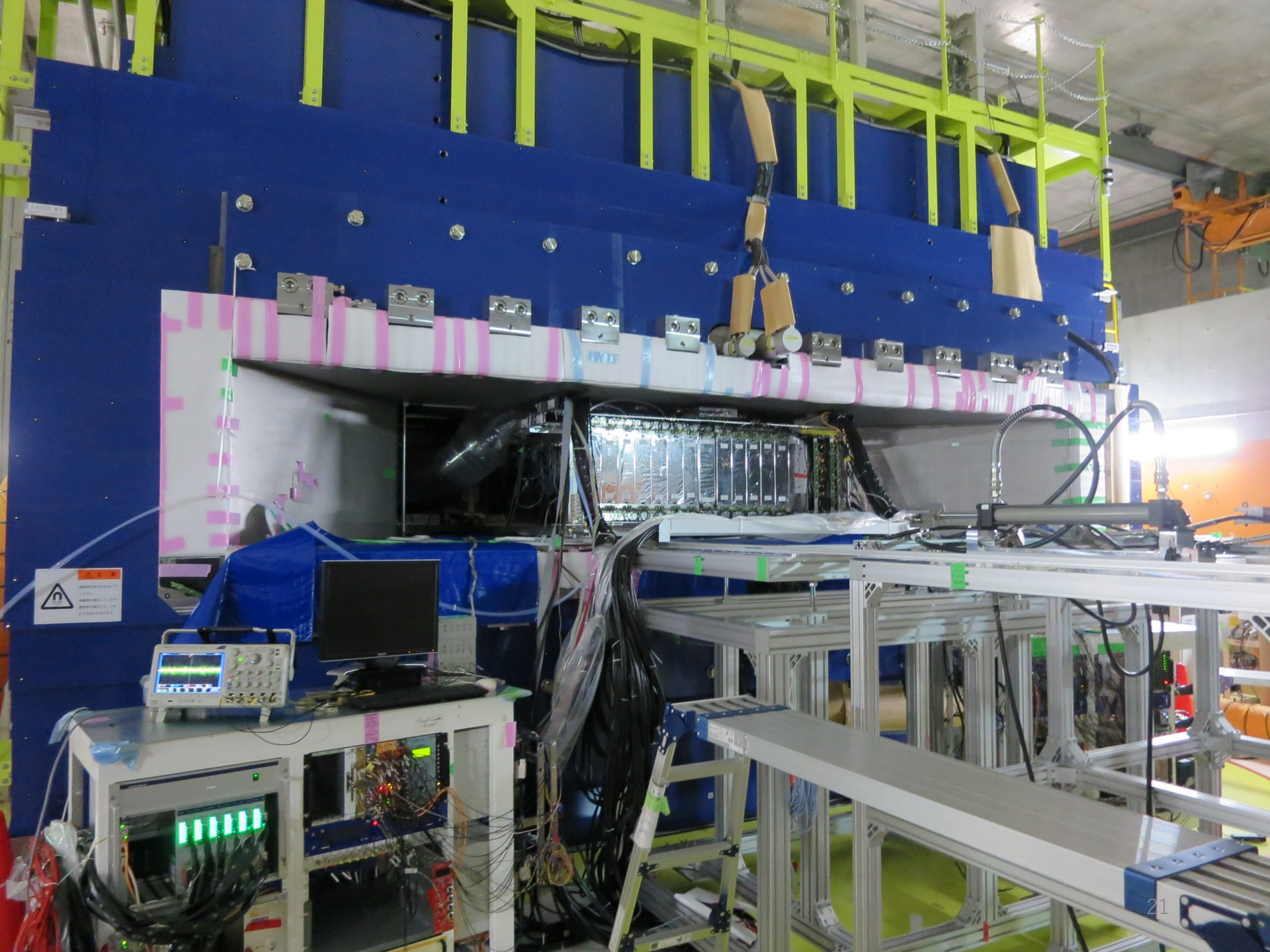




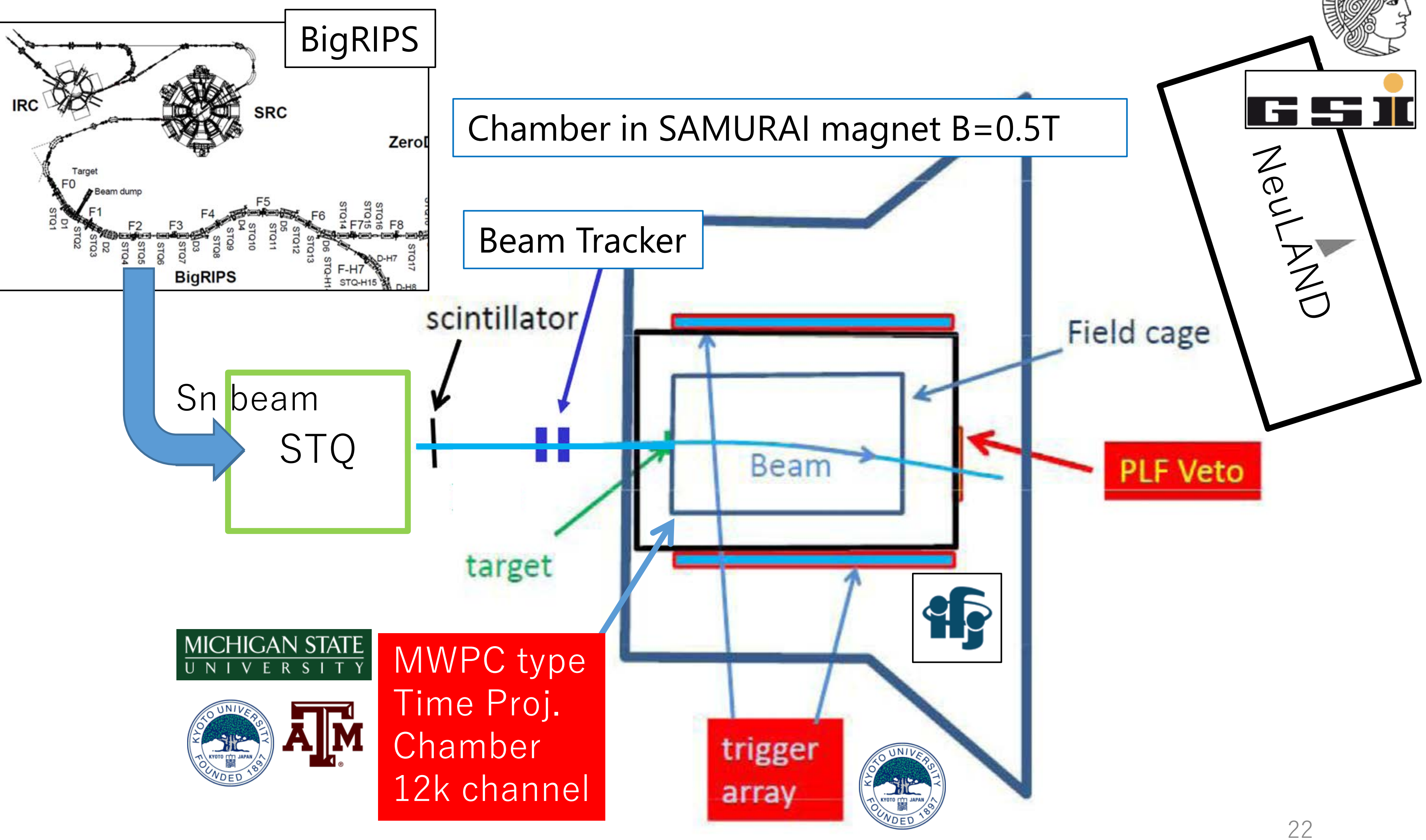


Pedestal
RMS for all of pads

AsAd standalone → ~2.5



SPiRIT experimental setup: beam line+TPC+trigger+NeuLAND



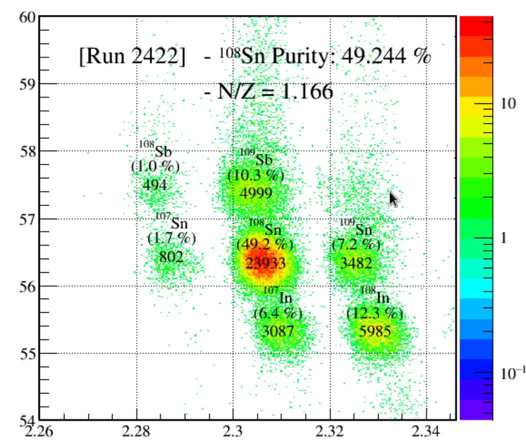
Functionality of each devices

- **<u>Main devices for produced particle measurement:</u>**
- TPC
  - Measure charged particles produced in collision
  - R. Shane et al., NIM A 784 (2015) 513
  - G. Jhang et al., Jour. of Korean Phys. Soc. 69-2 (2016) 144
  - S. Tangwancharoen et al., NIM A 853 (2017) 44
- NeuLAND
  - Measure neutrons produced in collision

- **<u>Event characterization:</u>**
- Beam line detector (BigRIPS)
  - Identify projectile colliding with Sn target.
- Trigger array
  - Trigger “central” collision events.
  - NIM A 856 (2017) 92

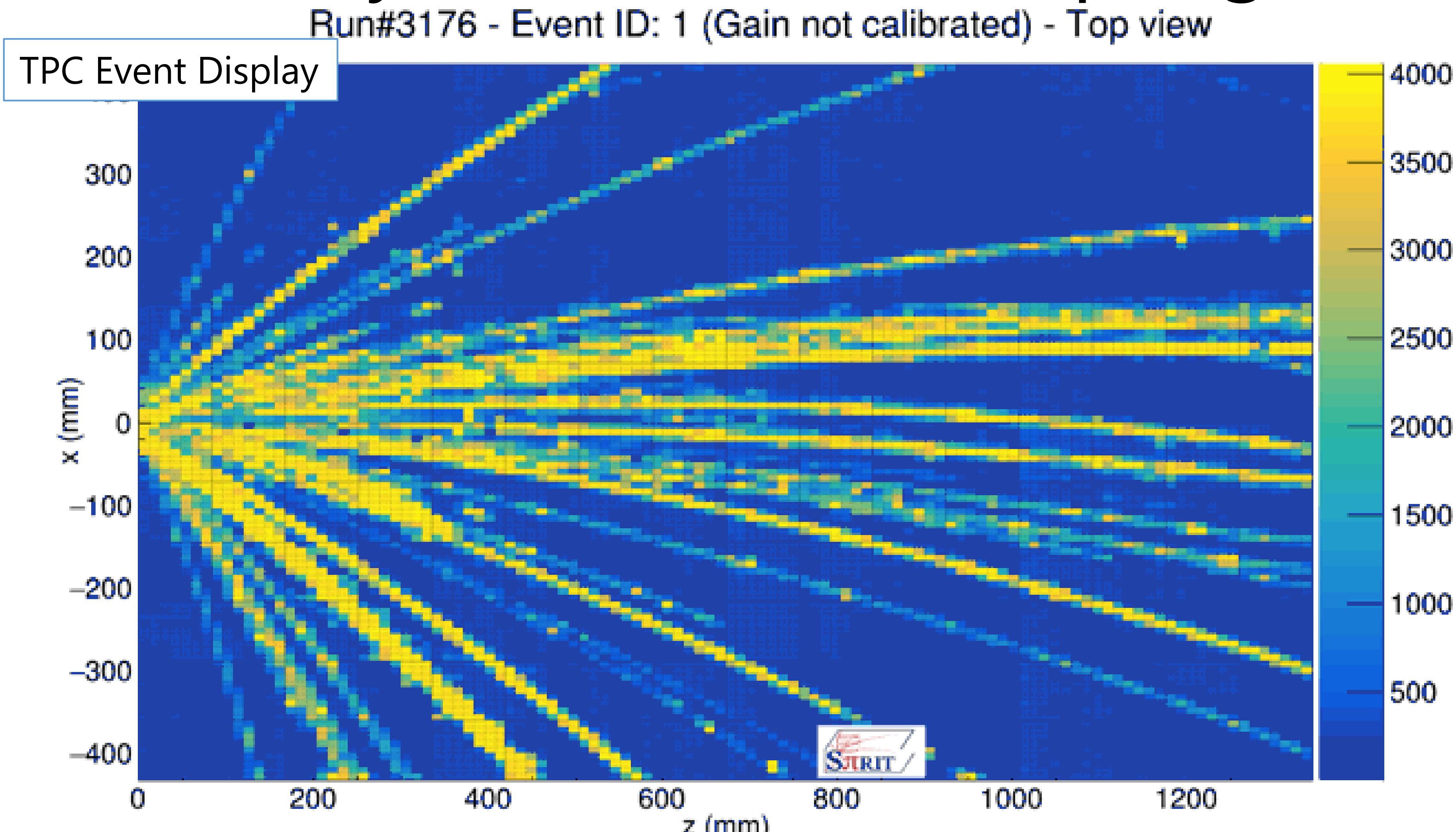
Beam PID

Z(A.U.)



A/Q(A.U.)

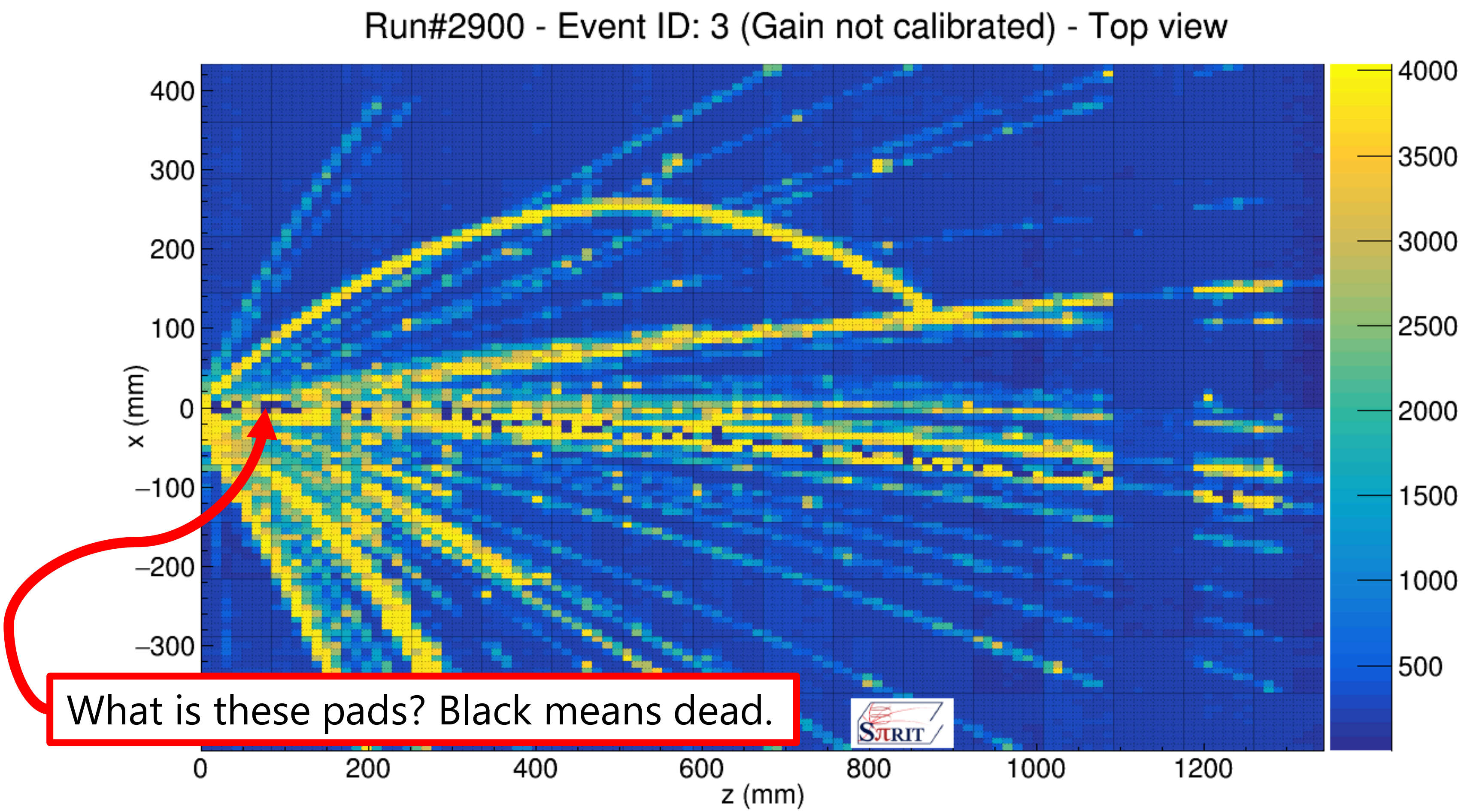
First Physics Run at 2016 spring



- Successfully finished. 2016 Apr. – Jun.
  - Beam rate: 10kHz, trig. rate: 70Hz
  - ~30M Events: 60Hz, 7MB/eve →420MB/sec
  - 250TB/2week (no selective digitization, no zero-suppression)

1 pixel: 1 pad

Dead channels along beam trajectory

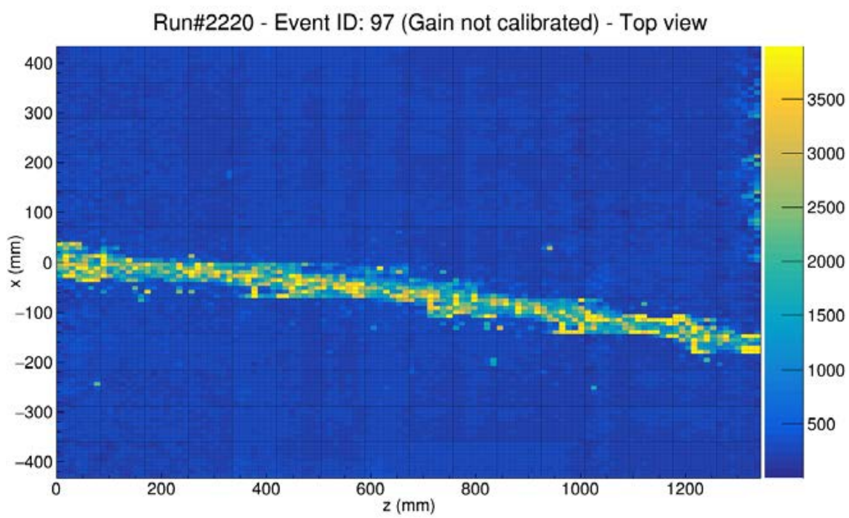


- Seen along beam trajectory → due to δ-ray?
  → but δ-ray is supposed to be suppressed with B-field.
- Could not be seen in the case of cosmic
- Varies event by event

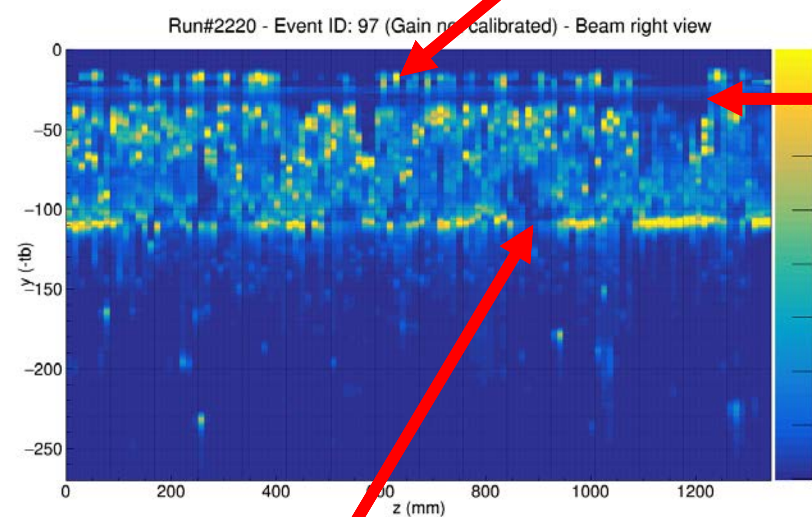
How signal from heavy ion would be seen with high gain for the measurement of protons

δ-rays passing GG wires
GG can not block these δ-rays

Top view



Side view



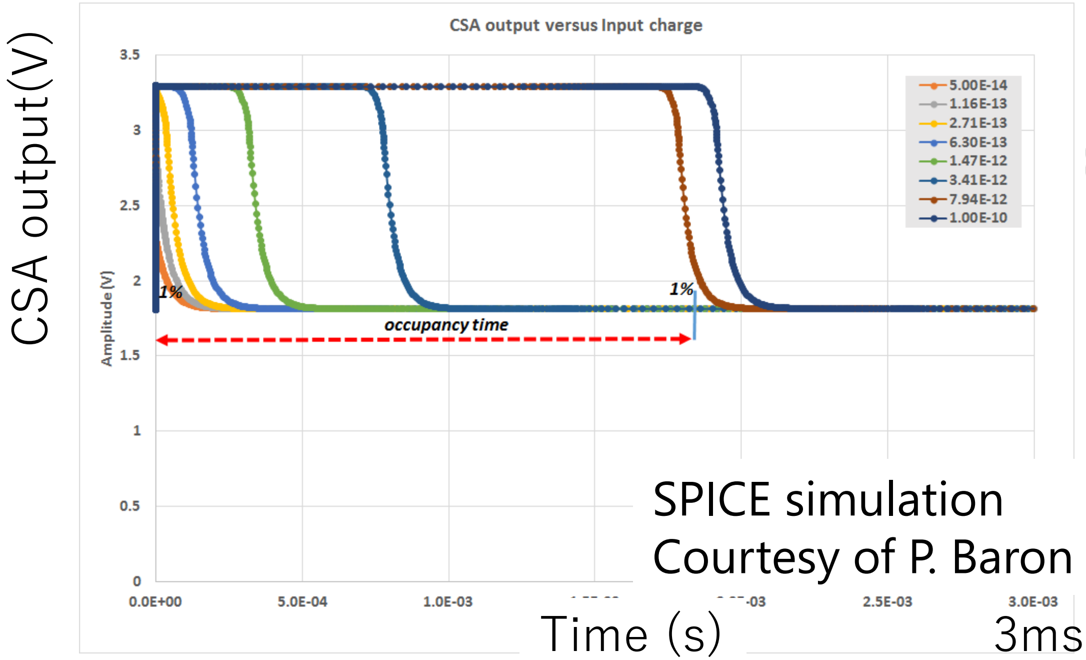
GG

Drift direction

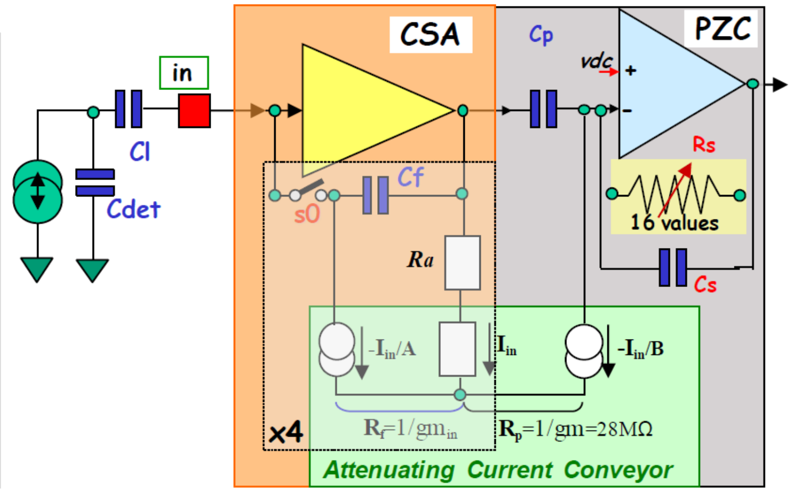
Spread over neighboring pads through C between the pads.

Beam signal is not seem.

Preamp becomes dead for a certain time due to huge signal



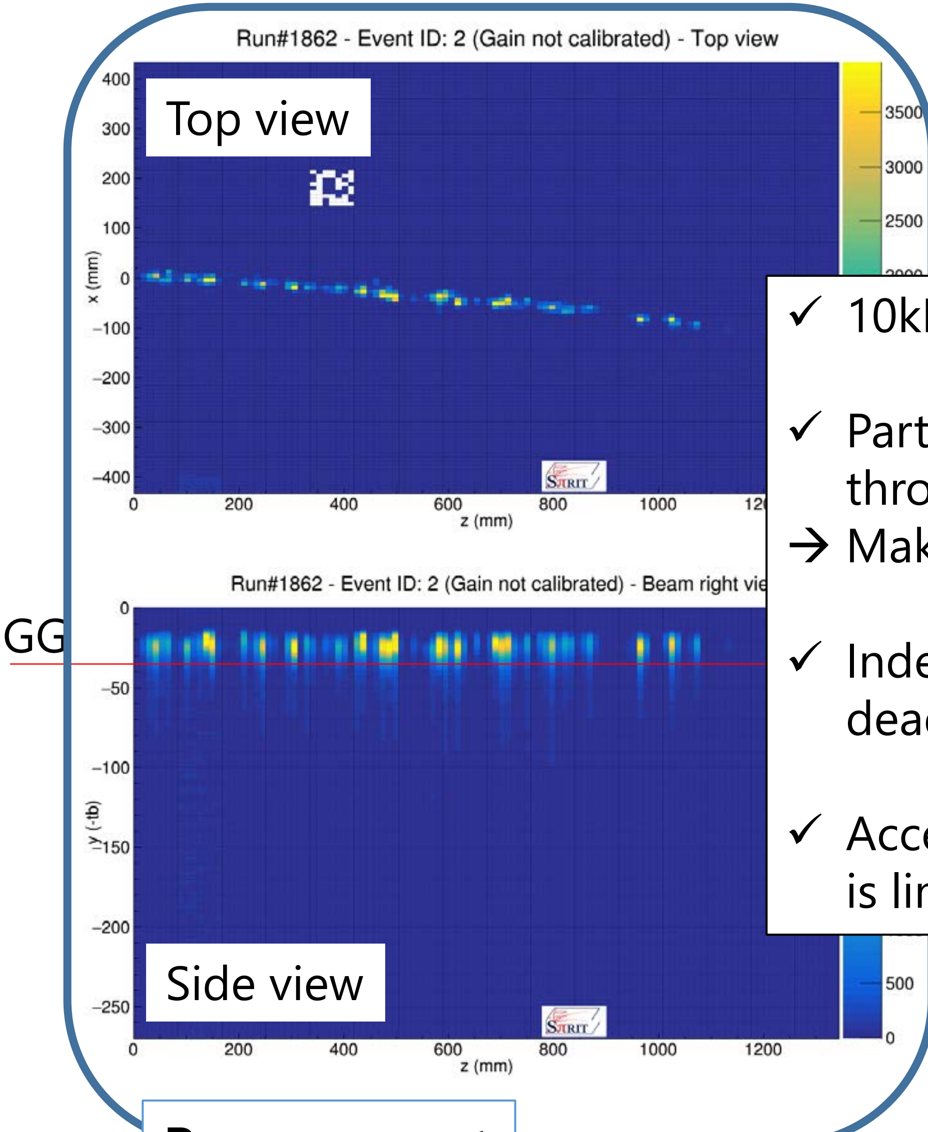
SPICE simulation
Courtesy of P. Baron

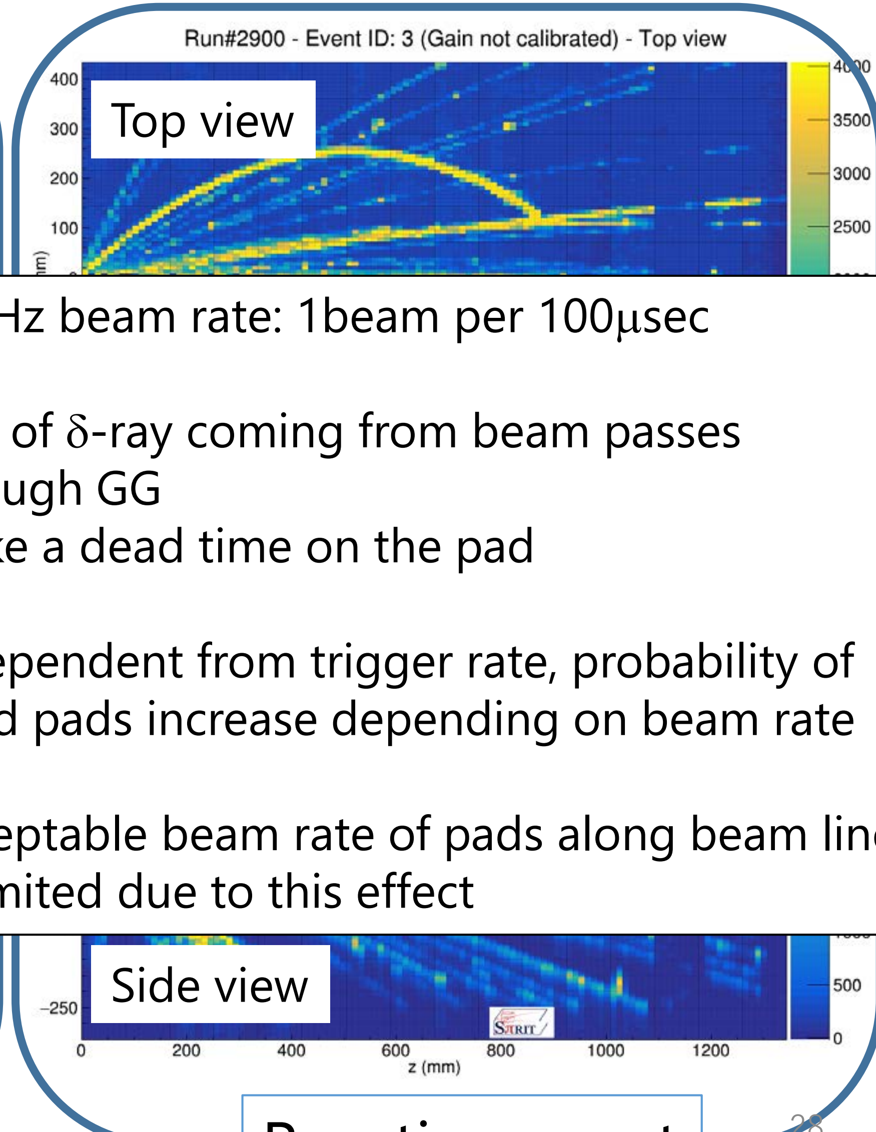


- Output of CSA is kept to be saturated in the case of huge signal
- As long as output is saturated, no signal comes out from following shaper →behaves as dead
- Dead for 2 msec in the case of 10pC charge input
- 10pC corresponds to the charge from Z~35 nuclei

Z	Q (fC)	deadtime (μ-sec)
2.886751	50	0
4.472136	120	0
6.324555	240	65
6.879922	284	100
8.944272	480	255
Sn Beam	28398	22024.52
87.5595	46000	35800

δ-ray which cannot be blocked with GG



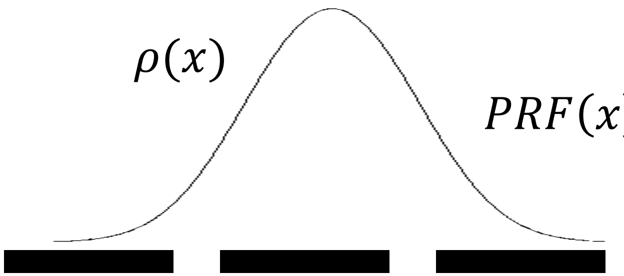


- ✓ 10kHz beam rate: 1beam per 100μsec
- ✓ Part of δ-ray coming from beam passes through GG
  → Make a dead time on the pad
- ✓ Independent from trigger rate, probability of dead pads increase depending on beam rate
- ✓ Acceptable beam rate of pads along beam line is limited due to this effect

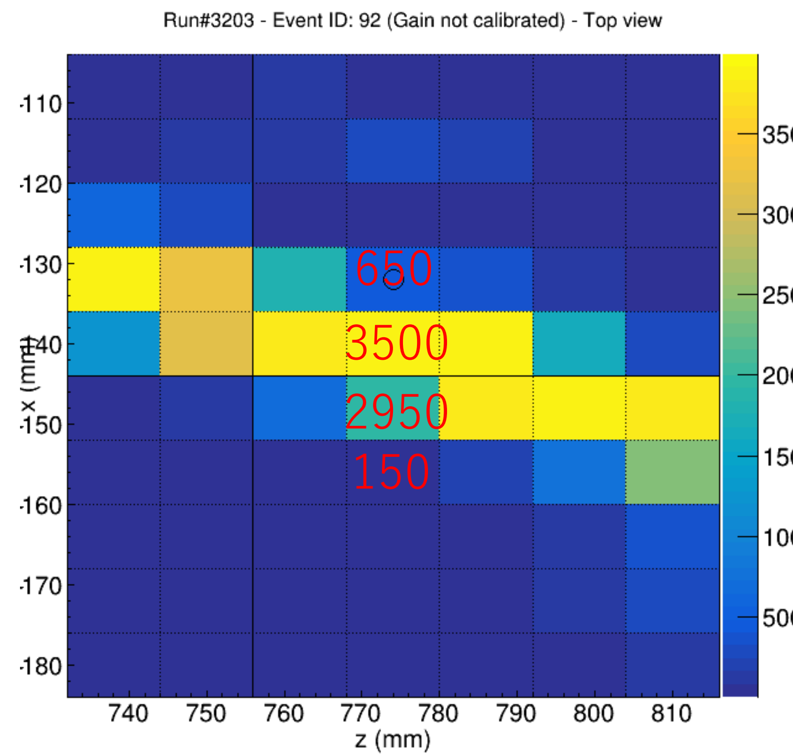
Increasing dynamic range: pad desaturation

Goal: extend the dynamic range of the TPC

Problem: saturated pads lose charge info



$$PRF(x) = \int_{x-\frac{w}{2}}^{x+\frac{w}{2}} \rho(x')dx'$$



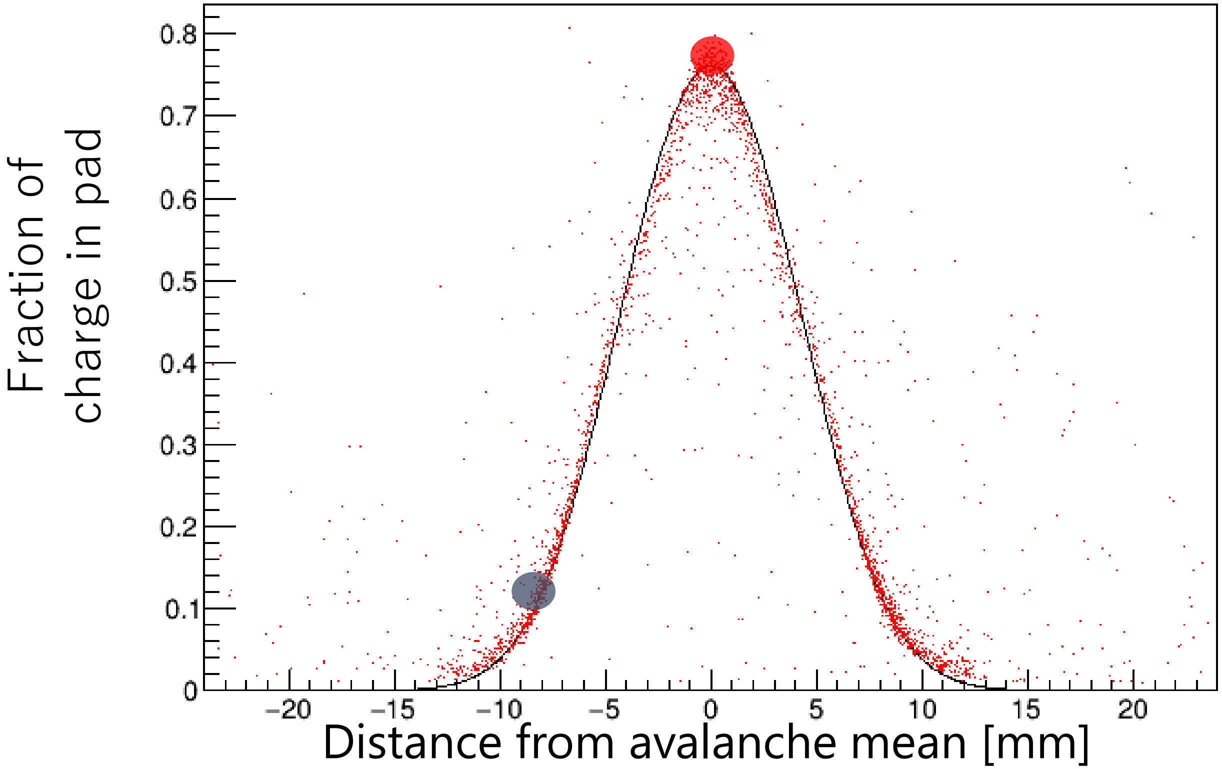
Idea: usage of pad response function (PRF)

Integral of the charge distribution over one pad.

How to use:

1) Find the charge center of gravity
2) Calculate the distance of the center of each pad from the c.o.g.
3) Calculate the fraction of charge of the pad over the total charge
4) From the tails of the distribution we can estimate the charge of the saturated pad

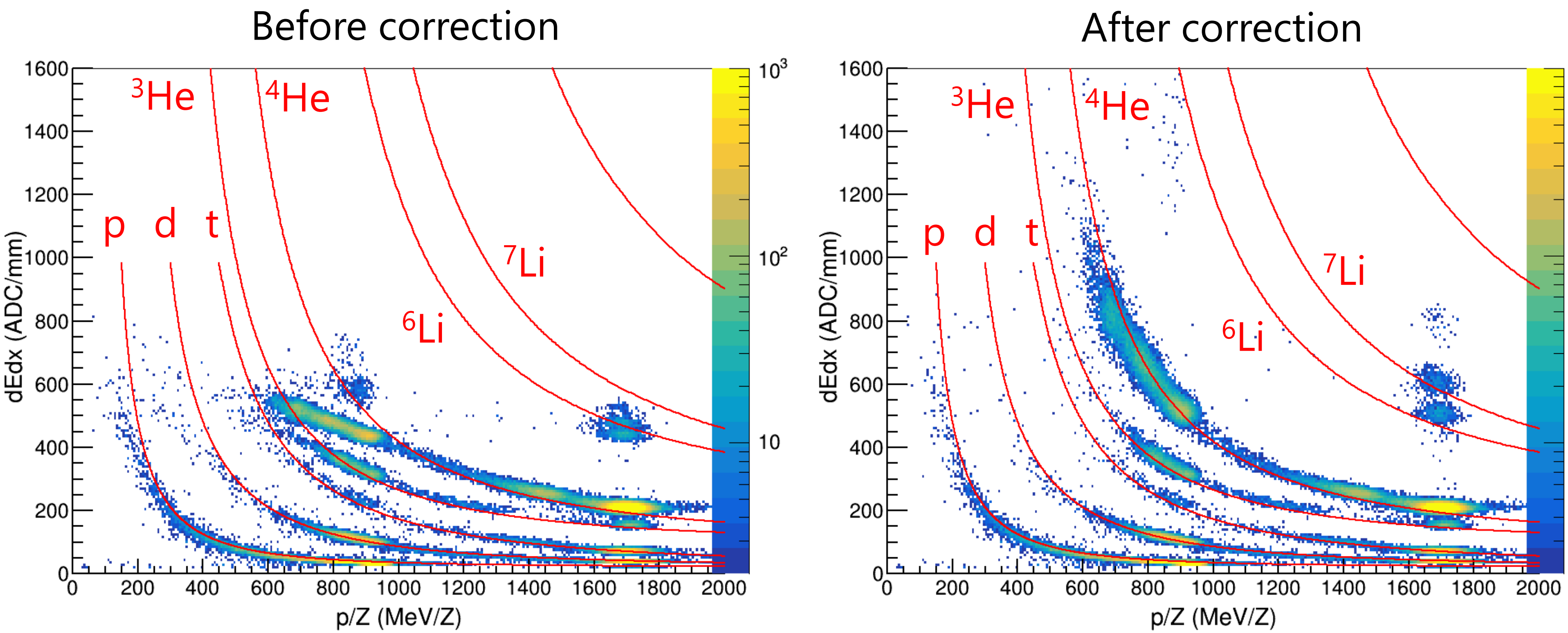
Increasing dynamic range: pad desaturation



- Avalanche is directly over pad (i.e. 0mm).
  - The fractional charge seen on that pad would be 75% of the total charge.
- Center of pad is 8mm from the avalanche
  - The fractional charge would be about 10% of the total charge

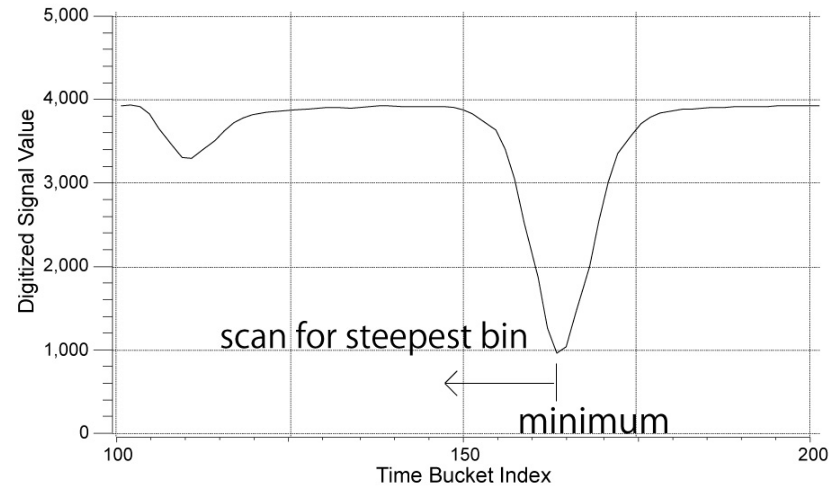
Increasing dynamic range: pad desaturation

- Test performed on the E=100-300MeV Z=1-3 cocktail beam
- Preliminary overlap of energy loss calculation (Bichsel curves) with data

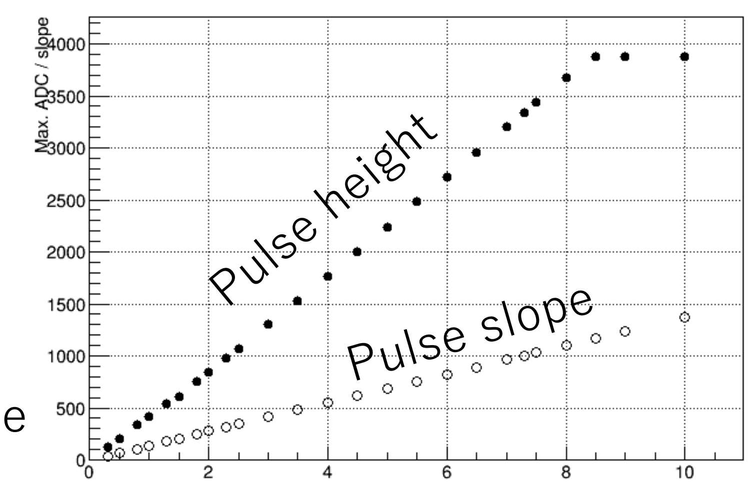


2nd way: using signal slope value as deposited charge information

- Scan for steepest bin of a signal.
- Slope of signal shows linearity for higher pulser voltage.
- According to SPICE simulation, linearity can be kept up to 240fC input.
  - i.e. ~2 times wider



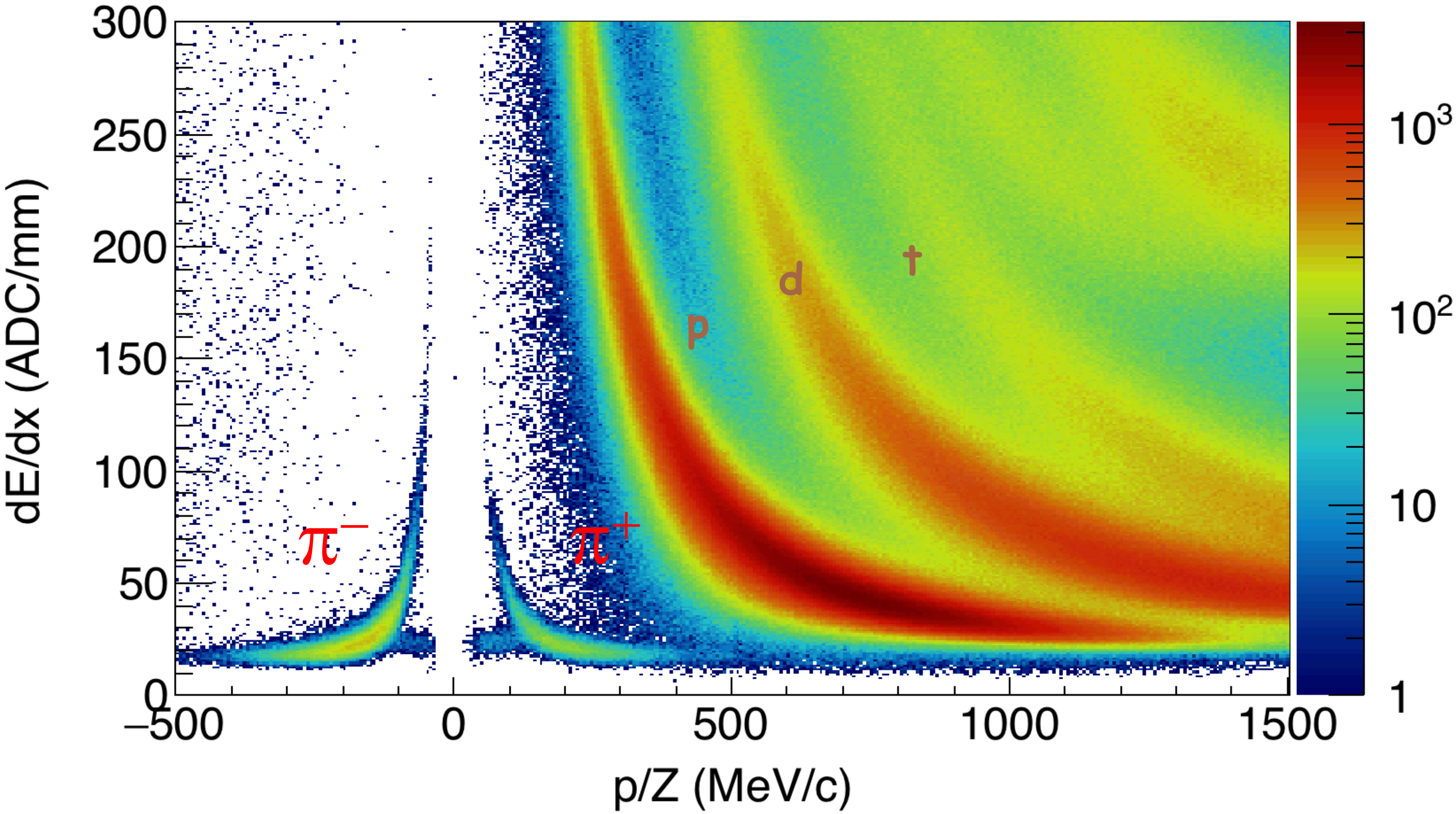
120fC D.R.
117 ns Shaping time



Pulser voltage on TPC ground wire

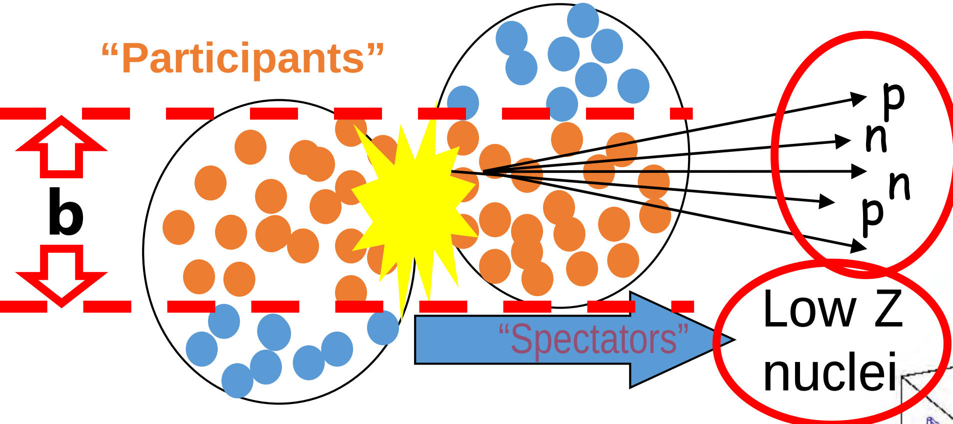
- Work in progress for combining two methods.

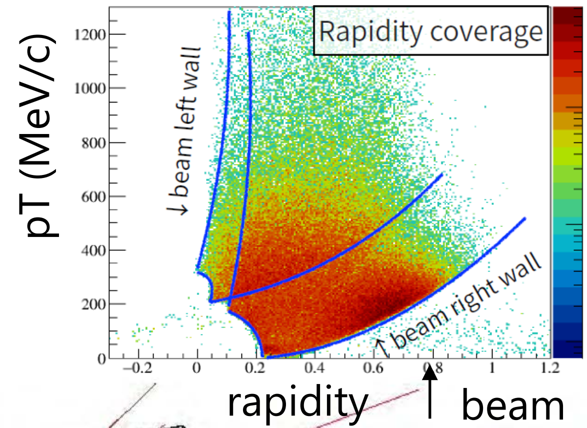
^{132}Sn+^{124}Sn Particle ID spectra

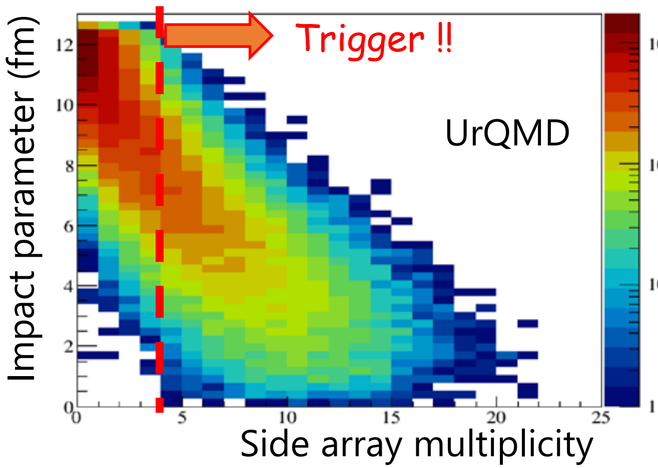


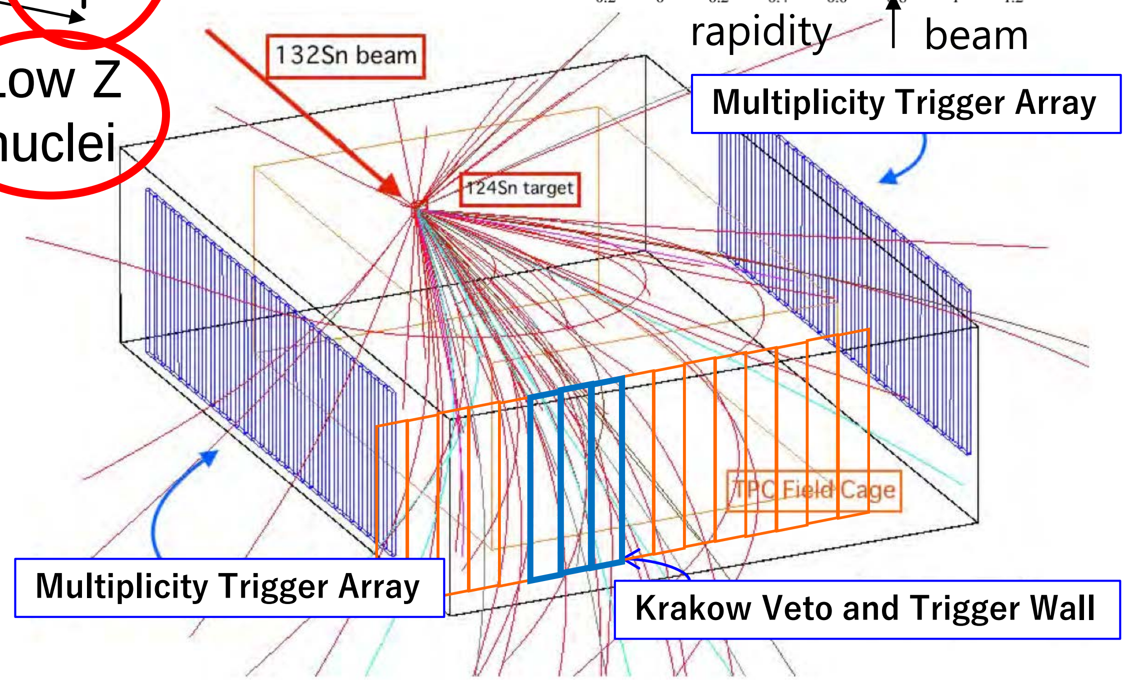
While we took a long time to establish the sophisticated tracking software…, we finally to move on to the physics analysis!!

Trigger system for high dense matter
#hits(side)>4 && Z<20





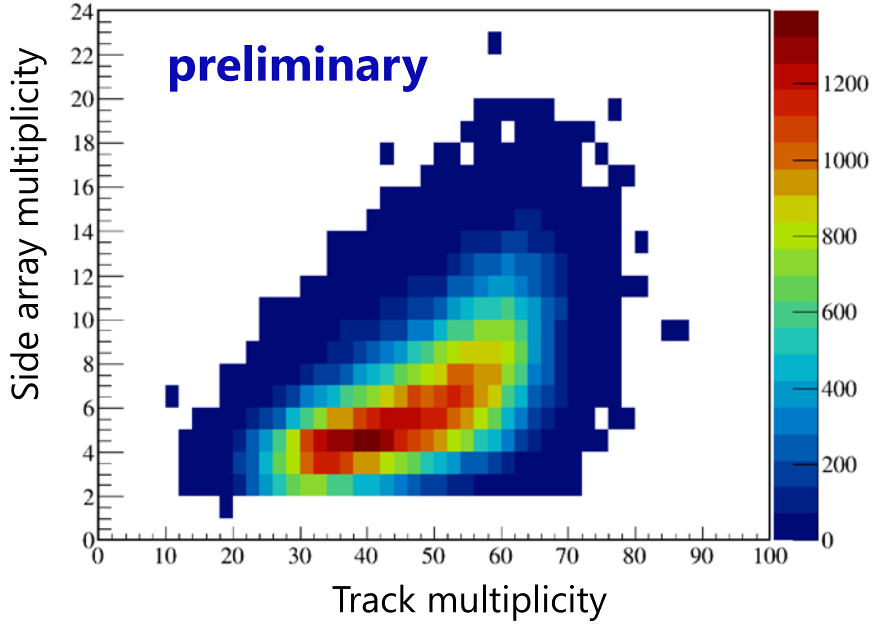


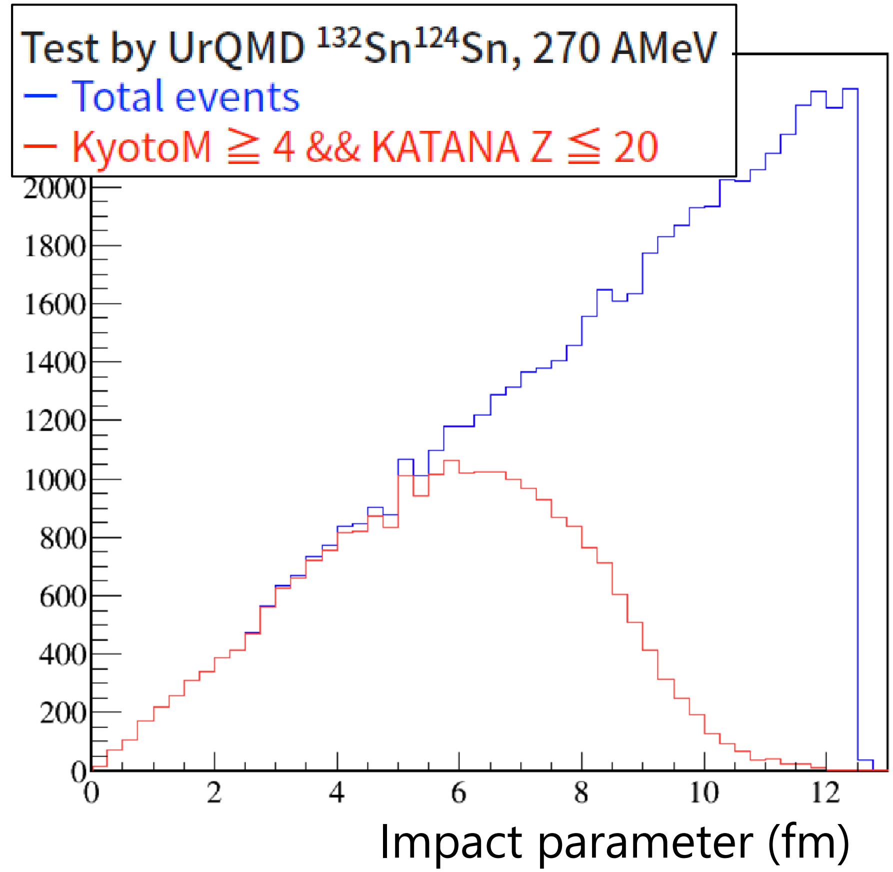


- Suppress background events and take "central" collision events
  - The fraction of events that we are interested in is only O(0.1)%
- Sophisticated trigger system to take central collision data: side array + Forward VETO.

The impact parameter triggered by SpiRIT

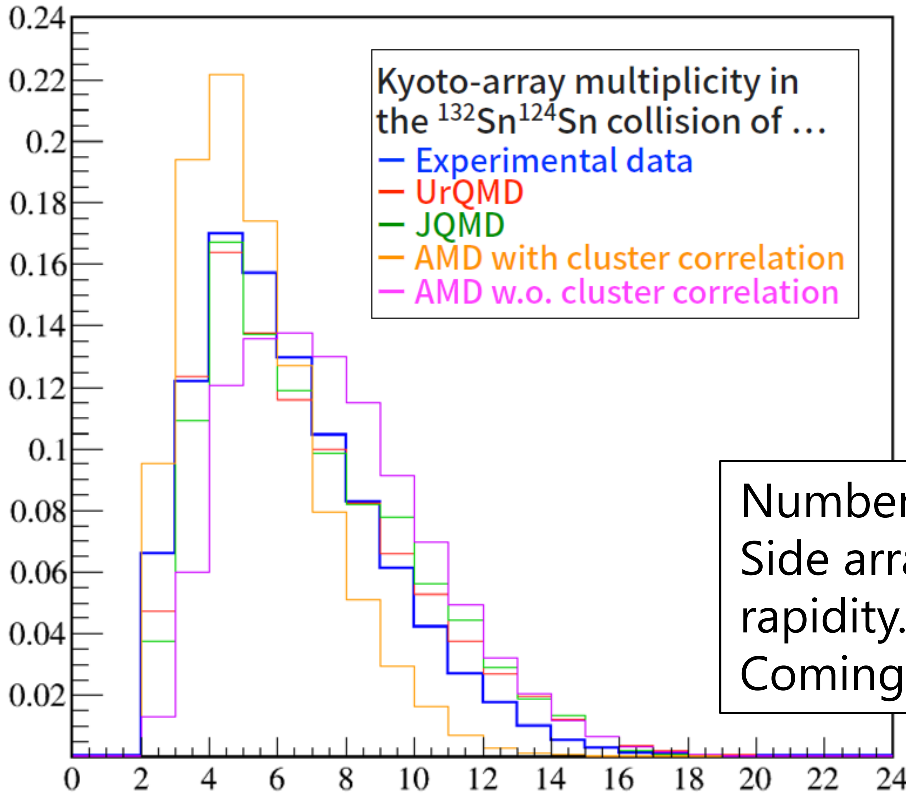
Clear correlation between number of hits on side array and TPC is seen!

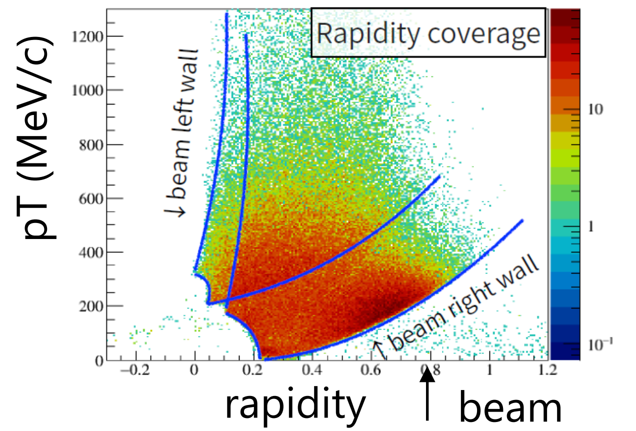




- Trigger efficiency and impact parameter are evaluated with transportation code.
  - Finite resolution of impact parameter(b): Mean of b: 6fm, width of b: 4fm.
- Possible to centrality selection with number of track information.
- Need to evaluate the transportation code itself.

Comparison with several transportation codes





Number of Hit on side array
Side array located at mid-rapidity. → Looking particles Coming to mid-rapidity.

- Number of hit on side array is compared with simulation filtered with trigger acceptance.
- Side array located at mid-rapidity. → Looking particles coming to mid-rapidity.
- AMD w/ cluster shows less multiplicity → Too much cluster in AMD?

Summary

- Experimental projects to study the density dependent symmetry energy is ongoing in Japan.
- Doubly differential cross sections of p+ an p- for the Si+In reactions at 400, 600 and 800 AMeV were measured with Pion range counter.
- First experiment of heavy RI collision, SPiRIT project, was performed at RIKEN-RIBF.
- SPiRIT-TPC + GET
  - →We try to understand the detector/electronics response for the simultaneous measurement of light and heavier particles.
- SPiRIT Trigger system for central collision
- Experimental data will come soon. Maybe pion at first. Can we understand what will come?