Symmetry energy at supra nuclear density from heavy-ion reactions

SπRIT scientific program

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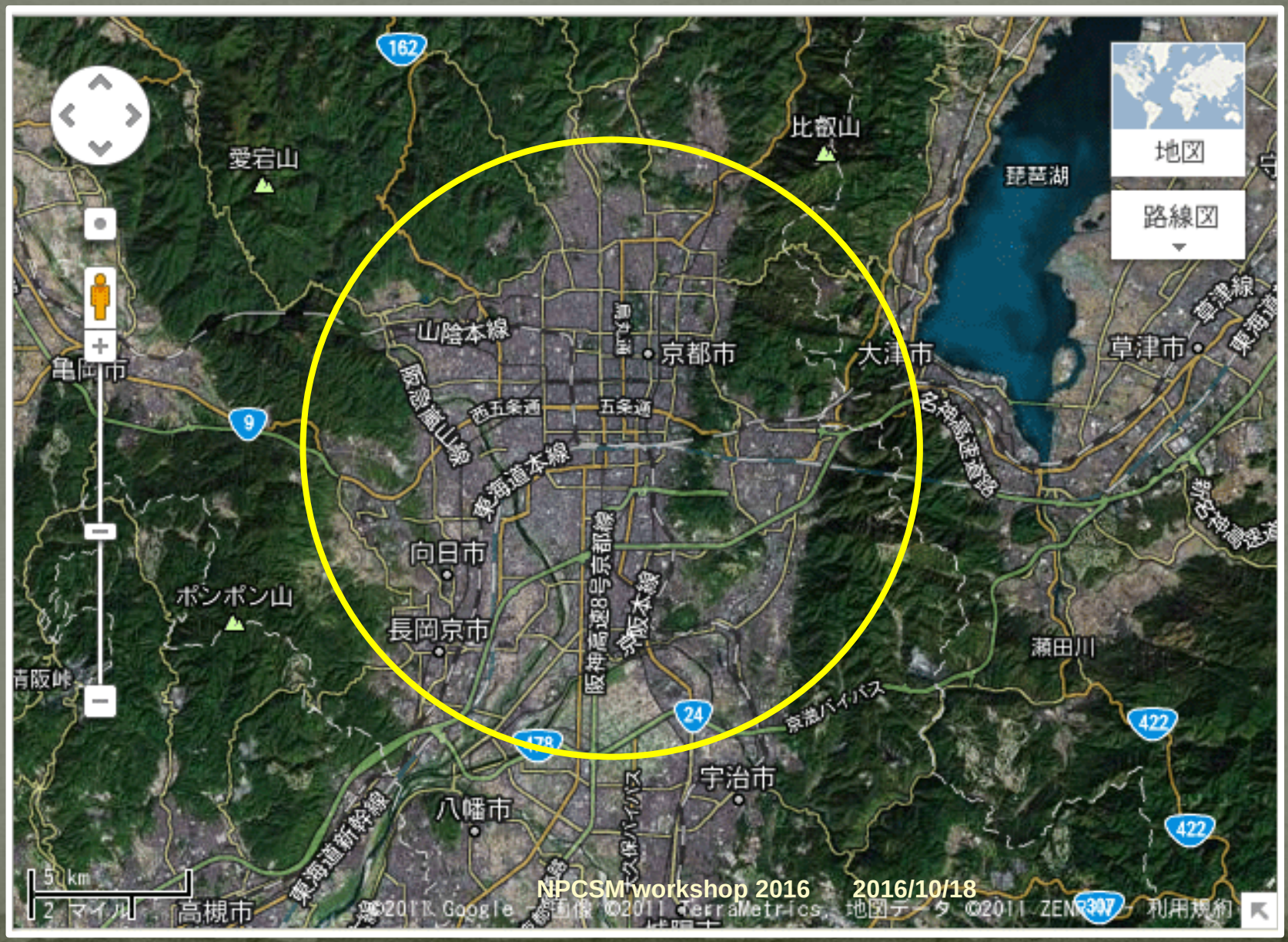
For the SπRIT Collaboration

SπRIT Collaboration

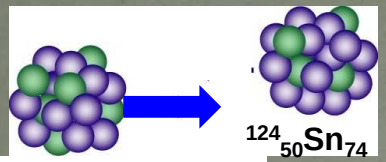
SAMURAI Pion Reconstruction and Ion-Tracker

U.S. DEPARTMENT OF ENERGY
Office of Science

NeutronStar and Kyoto

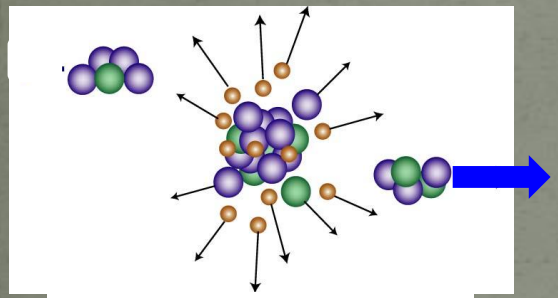


Heavy ion collisions



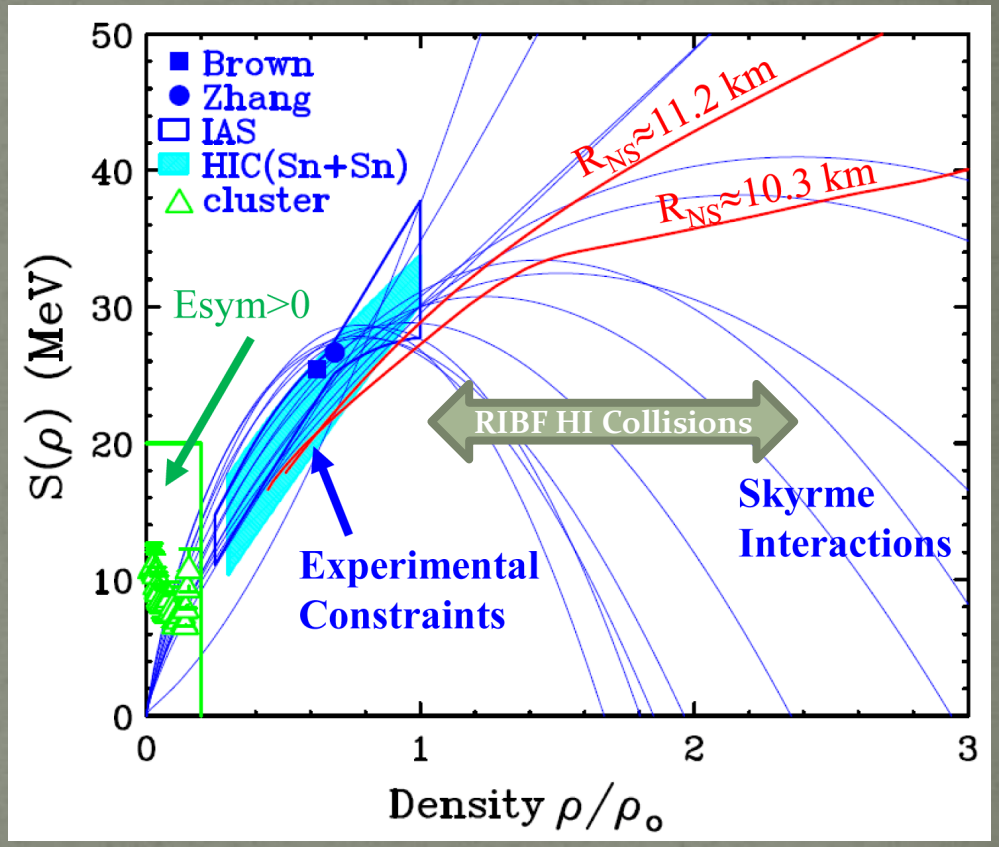
$^{132}_{50}Sn_{82}$ (n-rich)
@200~300 MeV

$\rho/\rho_0 \sim (\gamma+1)$ 2.3 @ 300 MeV/nucleon



High-density
(participant region)

Light particle production



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

Naïve Approach

The pressure from symmetry energy

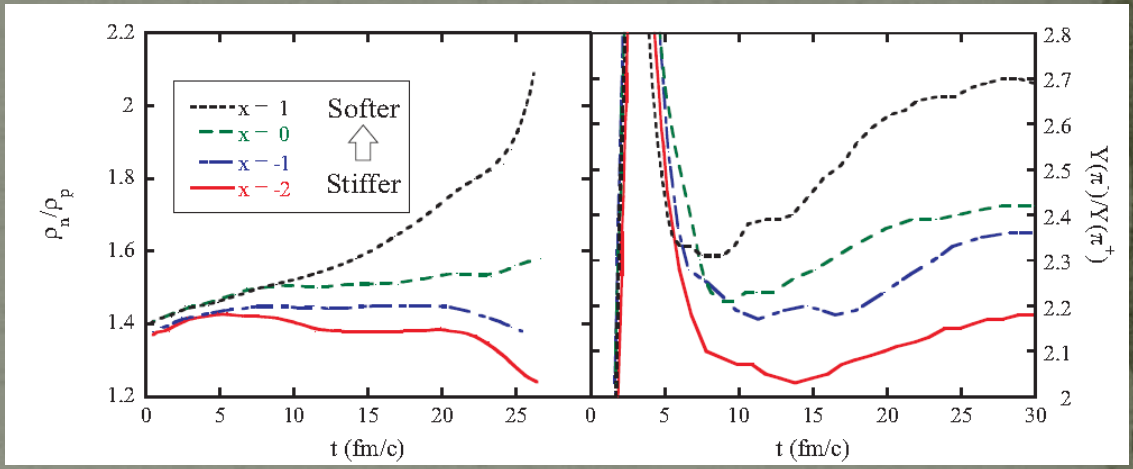
expels neutrons from

attracts protons to

high density region of neutron-rich system.

Prediction of transport theory

Suppress Y(n)/Y(p), $Y(\pi^-)/Y(\pi^+)$, etc.

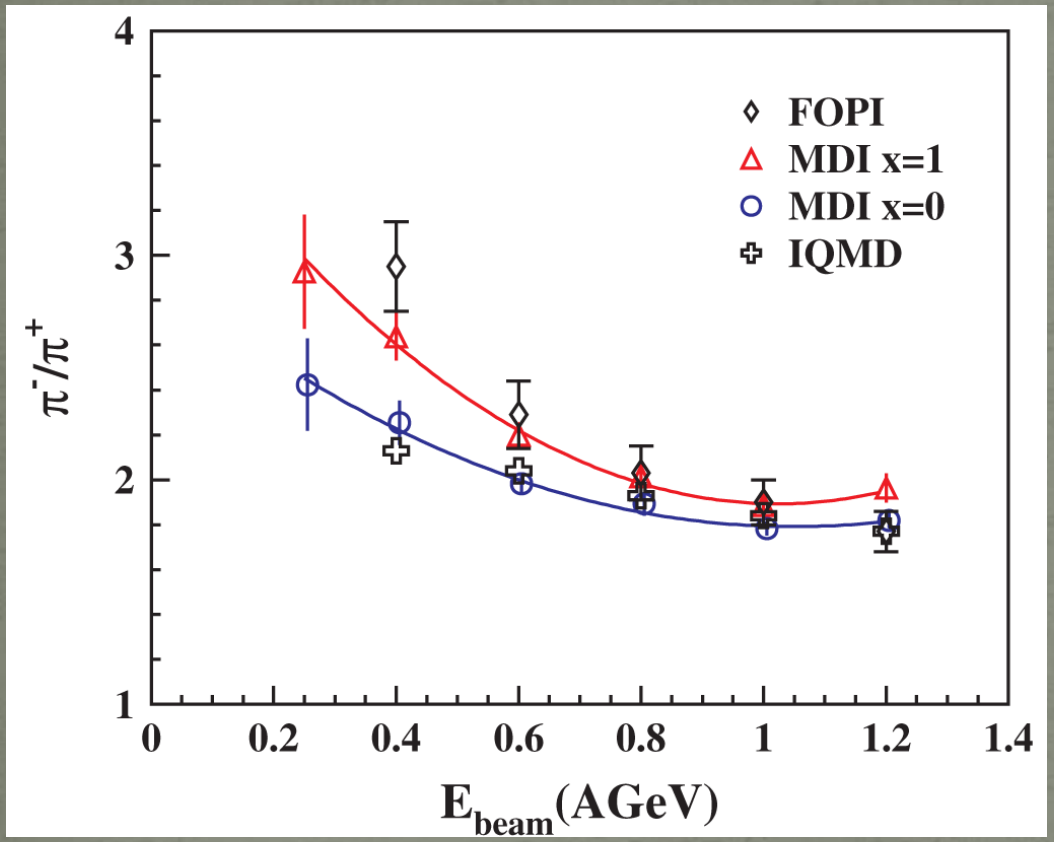


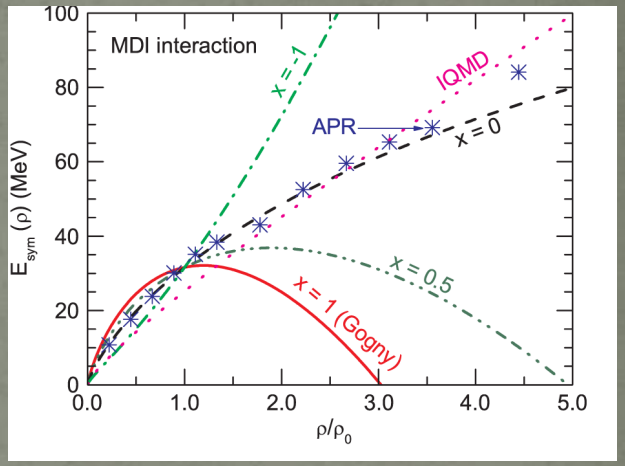
Bao-An Li et al., Phys. Rev. C 71, 014608 (2005)

One of good probes

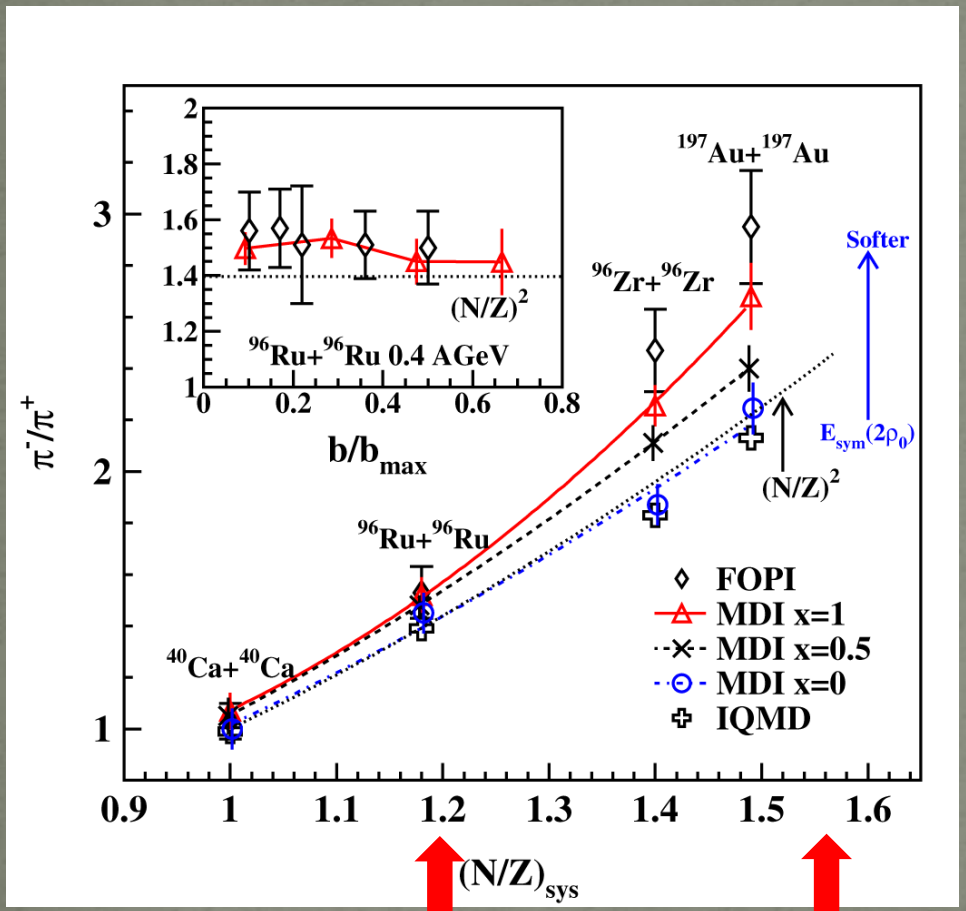
π^-–π^+ production ratio from HI collisions in wide range of δ

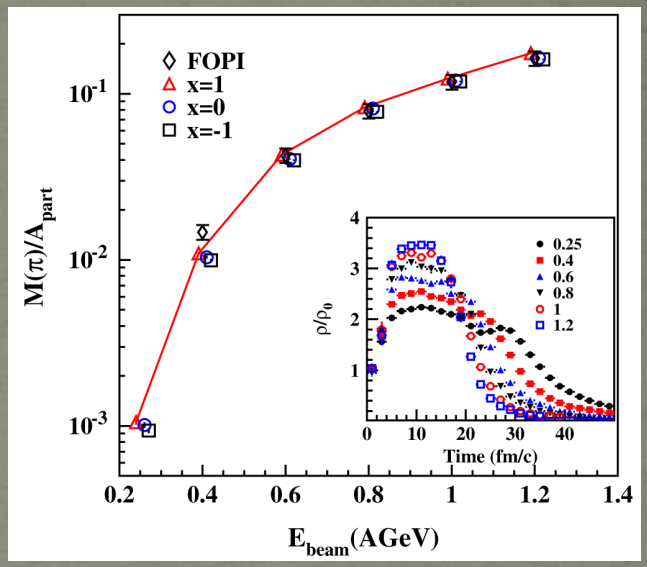
What Z.Xiao et al. found PRL 102 062502 (2009)

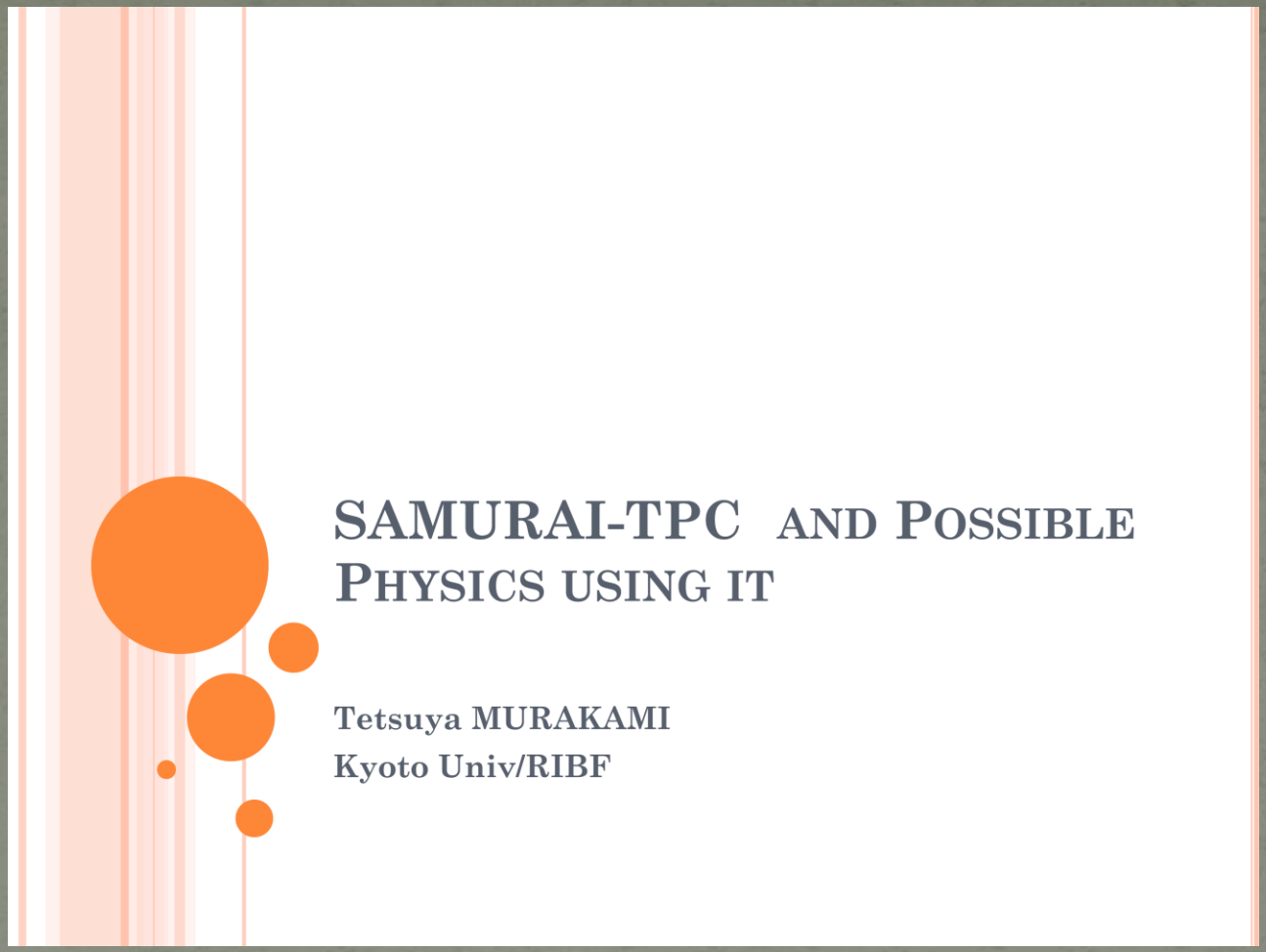




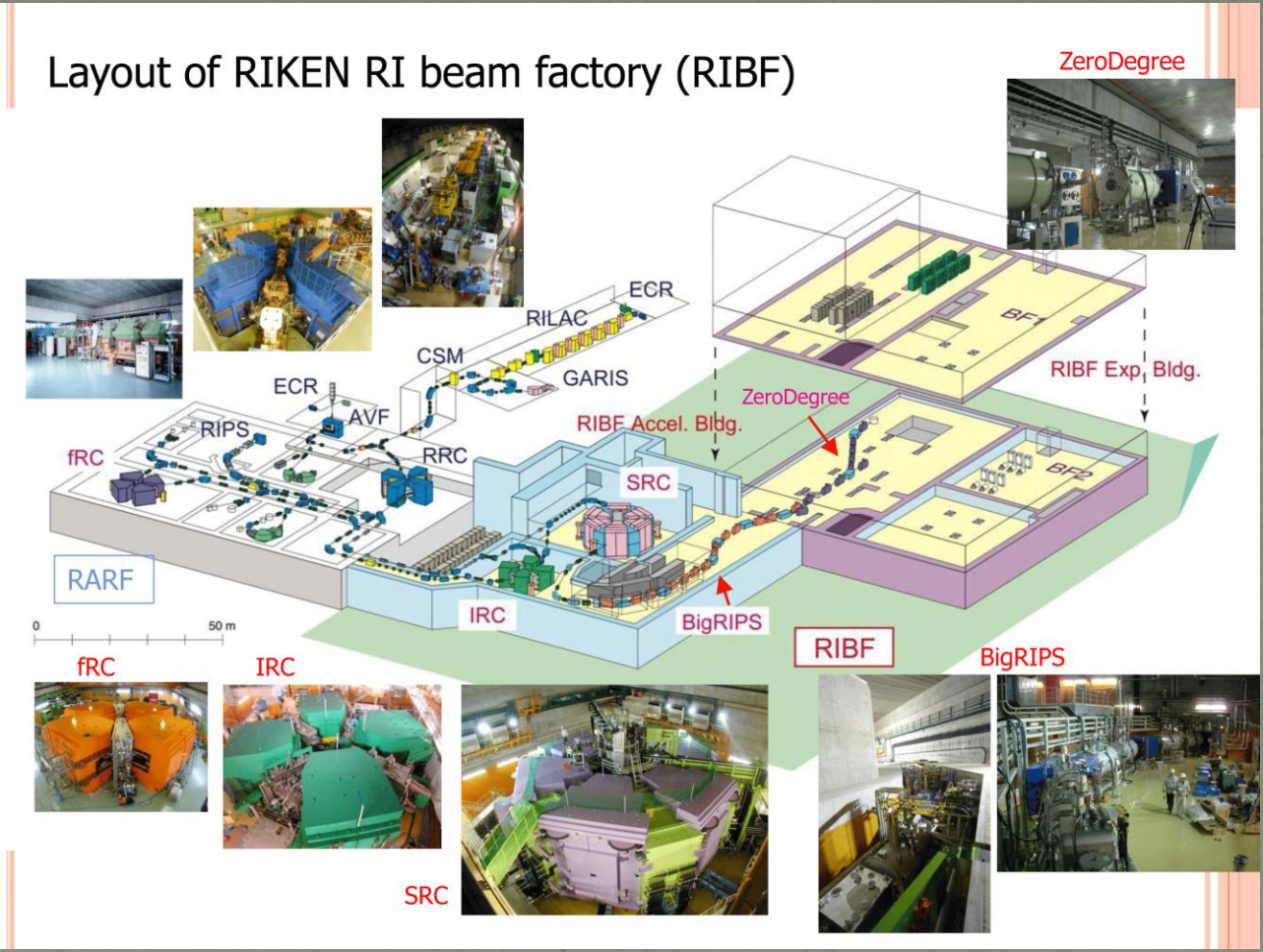
Also


π^-/π^+
b/b$_{max}$
^{96}Ru+^{96}Ru 0.4 AGeV
(N/Z)^2
^{197}Au+^{197}Au
^{96}Zr+^{96}Zr
^{96}Ru+^{96}Ru
^{40}Ca+^{40}Ca
Softer
$E_{sym}(2\rho_0)$
(N/Z)^2
FOPI
MDI x=1
MDI x=0.5
MDI x=0
IQMD
(N/Z)$_{sys}$
^{108}Sn+^{112}Sn
^{132}Sn+^{124}Sn


FOPI
x=1
x=0
x=-1
M(π)/A$_{part}$
E$_{beam}$(AGeV)
ρ/ρ$_0$
Time (fm/c)
0.25
0.4
0.6
0.8
1
1.2

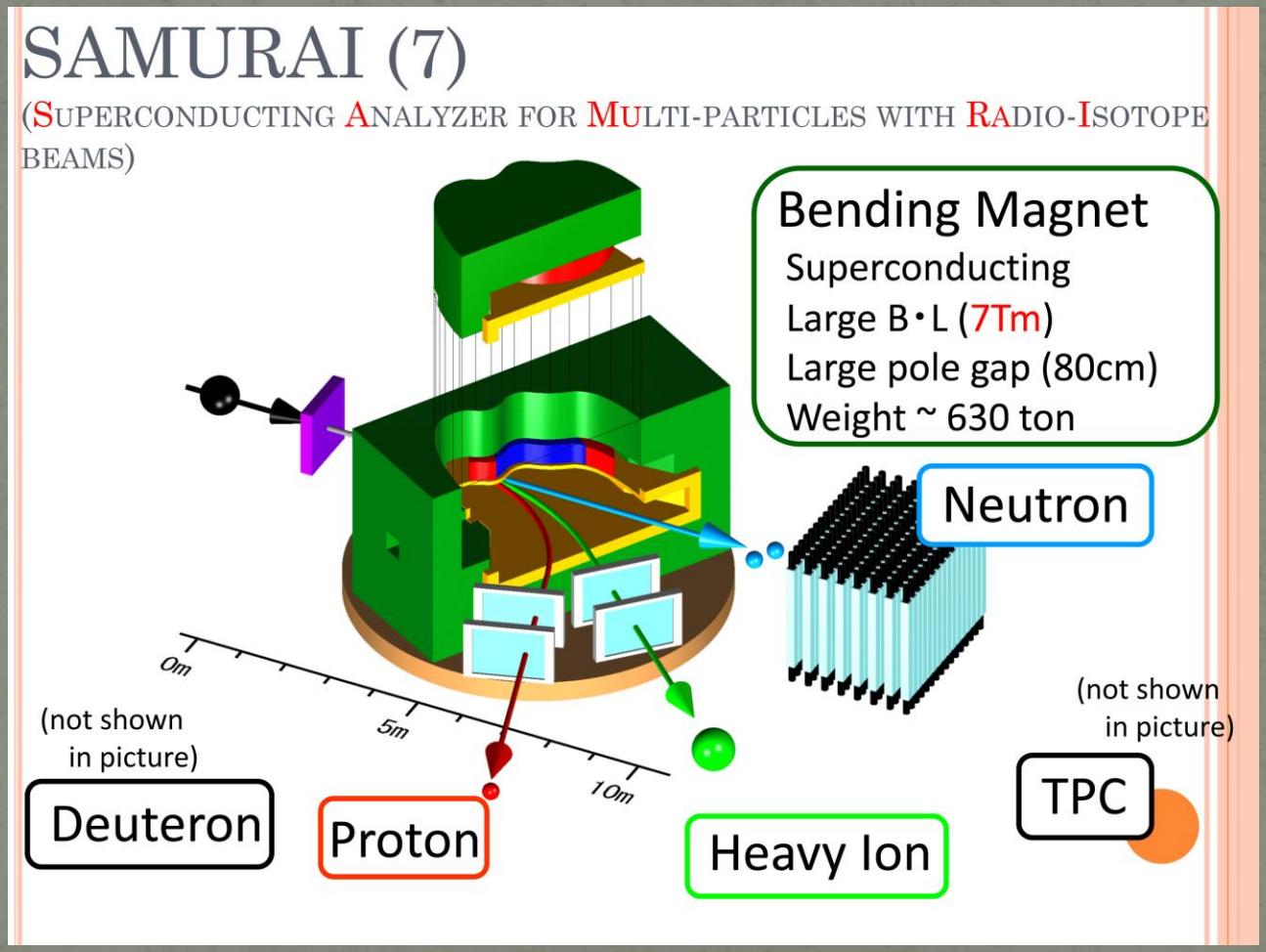


@GET Meeting at GANIL in 2009



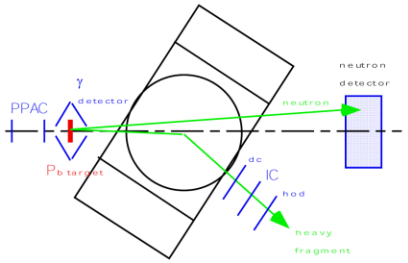
RIBF before 2007

Fixed design of Large Magnet ~2004-5

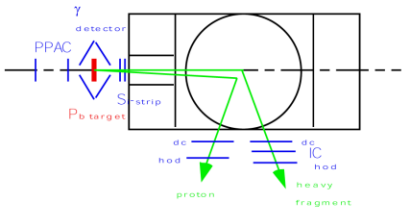


WHAT KIND OF EXPERIMENT ?

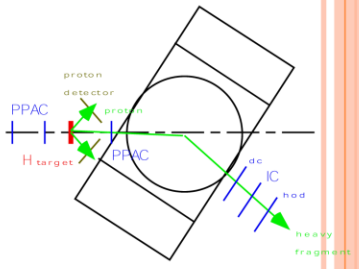
(γ,n) reaction: neutron-rich side



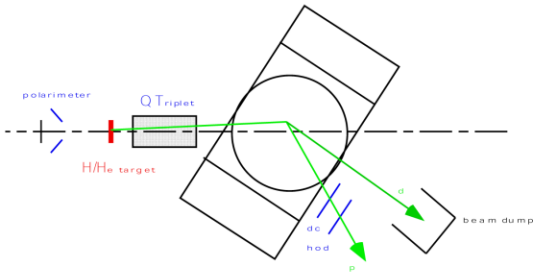
(γ,p) reaction: proton-rich side



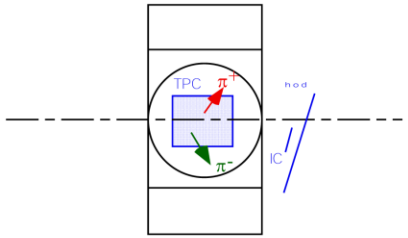
(p,p'), (p,2p) etc.



Pol. d-induced reaction



EOS measurement



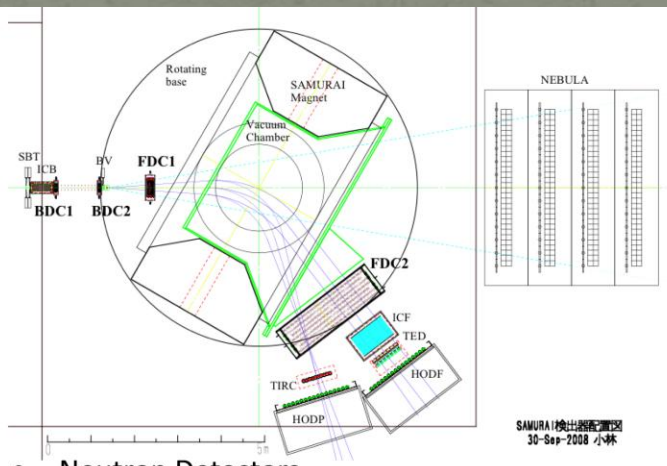
Status ~2009

Current Status

- Budget approved 1.5BJPY in FY2008 – 2011
- All the contracts have been made in FY 2008
  -- all the specifications are fixed
- Contracts done for
  - Superconducting dipole magnet
  - Almost full set of HI detector
  - Almost half volume of the neutron detector
  - Proton detectors
  - Triplet quadrupole magnet for beam transmission
  - Peripherals (vacuum pumps, circuit modules,…)
- START EXPERIMENTS IN SUMMER 2011

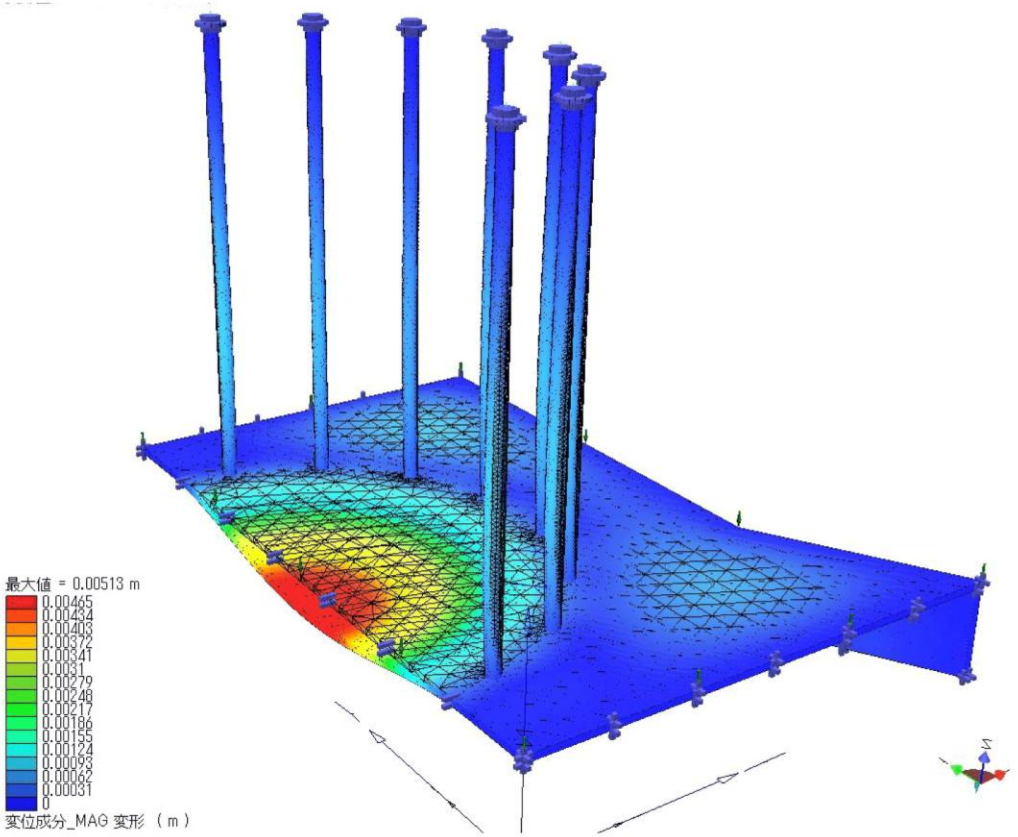
DETECTORS

- Heavy Ion Detectors
  - Beam chamber
    - Chamber/case/feedthru
    - Electronics
    - Gas handling
  - Upstream chamber
    - Chamber/case
    - Electronics
    - Gas handling
  - Downstream
    - Chamber/case/feedthru
    - Electronics
    - Gas handling
  - Charge measurement
    - Ion chamber
    - Electronics
  - Velocity measurement
    - Plastic hodoscope
    - Cherenkov
  - Total E (pure CsI)
    - Detector
    - Electronics



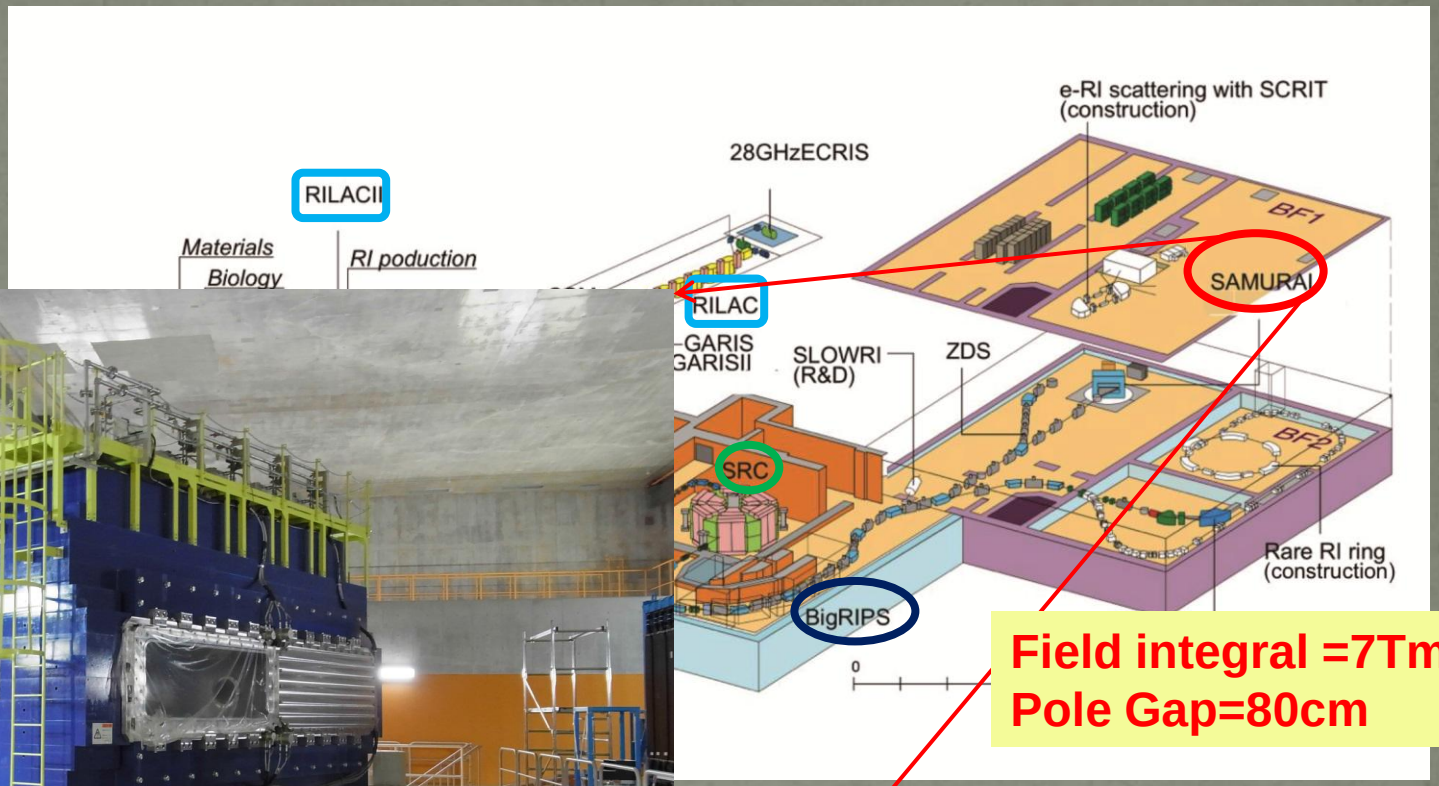
- Neutron Detectors
  - Scintillator, PMT, Electronics
- Proton Detectors
  - Microstrip Silicon
  - Readout circuit
  - Proton Drift chamber
  - Hodoscope + elec.
- Polarized Deuteron Experiments
  - MWDC – Hodoscope
  - Z=1 detector – Beam dump
  - Polarimeter
- TPC

POSSIBLE STRUCTURE OF VACUUM CHAMBER



RIBF: Radio-Isotope Beam Factory

Accelerator complex of two linacs and five cyclotrons



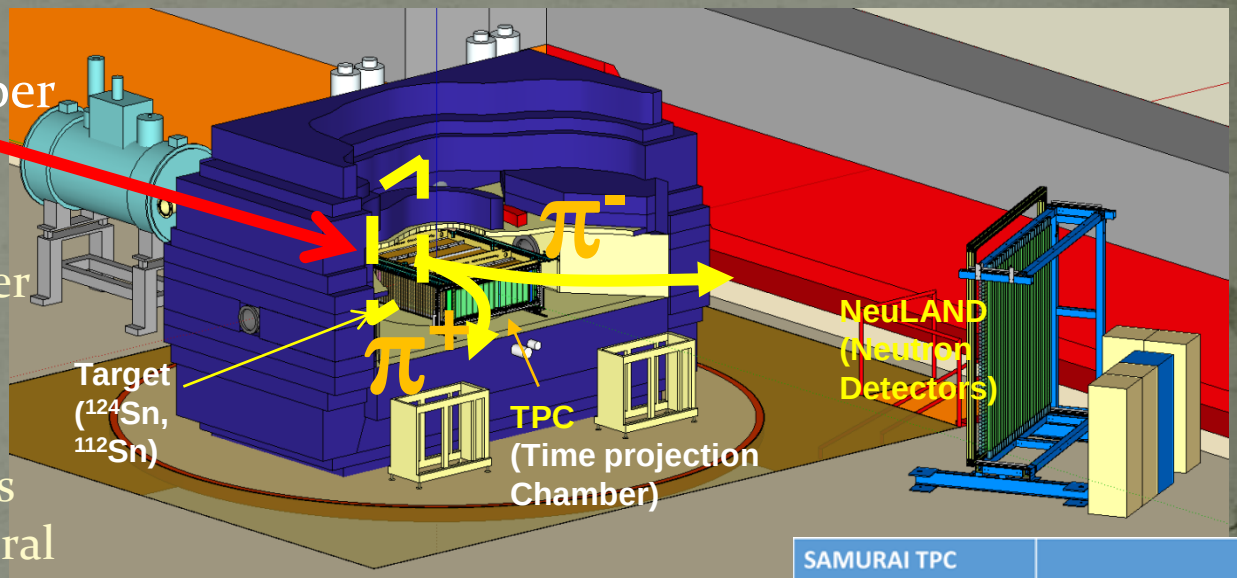
Field integral =7Tm
Pole Gap=80cm

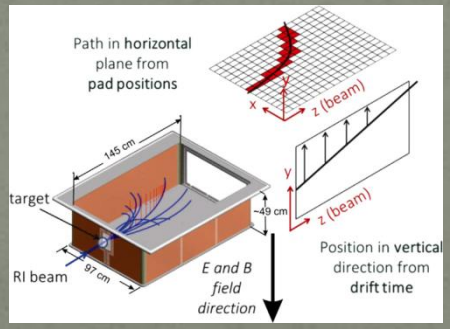
eV/u (Light Ions up to 440MeV/u)
Separator (80mradx100mrad,

Final experimental setup

Equipment

- TPC
  - –Time Projection Chamber
    - 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.
- NeuLAND:
  - provides neutron information





R. Shane et al.
Nucl. Instr. Meth. A 784 (2015) 513-517

SAMURAI TPC Parameters	Values
Pad plane area	1.34m x 086 m
Number of pads	12096 (108 x 112)
Pad size	12 mm x 8 mm
Drift distance	53 cm
Pressure	1 atmosphere
dE/dx range	Z=1-3 (STAR El.), 1-8 (GET El.)
Two track resolution	2.5 cm
Multiplicity limit	200 (may impact absolute pion eff. in large systems.)

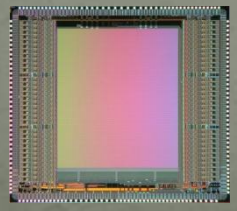
Readout system of SPiRIT-TPC

~65 MJPY(including DAQ)

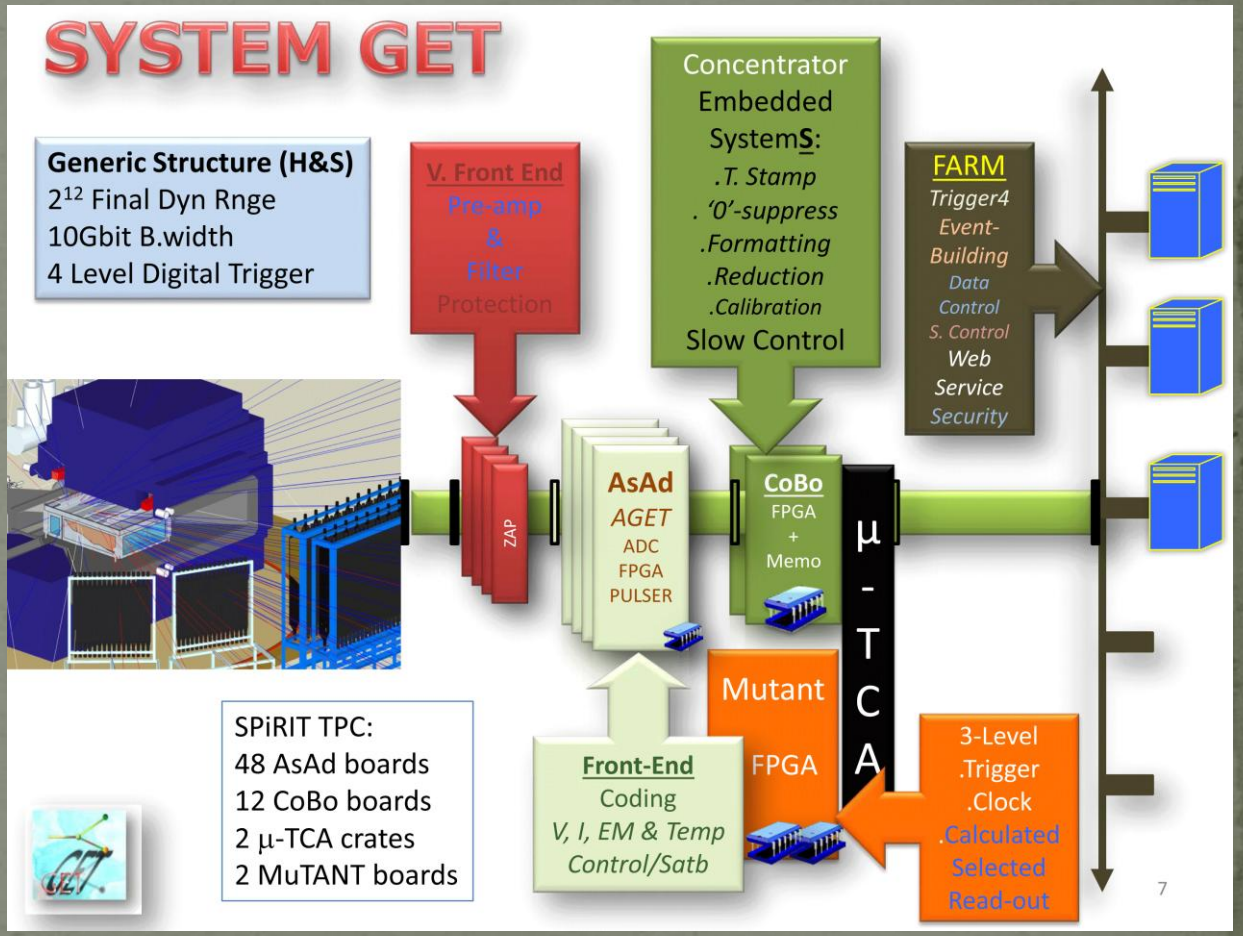
E. Pollacco, et al., Procedia 37 (2012) 1799-1804

Requirements:
high DAQ rate (~1kHz)
Good ADC resolution (>10bit).
Z=1 particle measurement in the chamber where Z>50 beam passing through.

Apply newly developed GET system:
General Electronics for TPC



AMS CMOS 0,35 µm



Passage to the Experiment

Oct 2010: DOE Funded ($1.2 M)
July 2011: Conceptual design

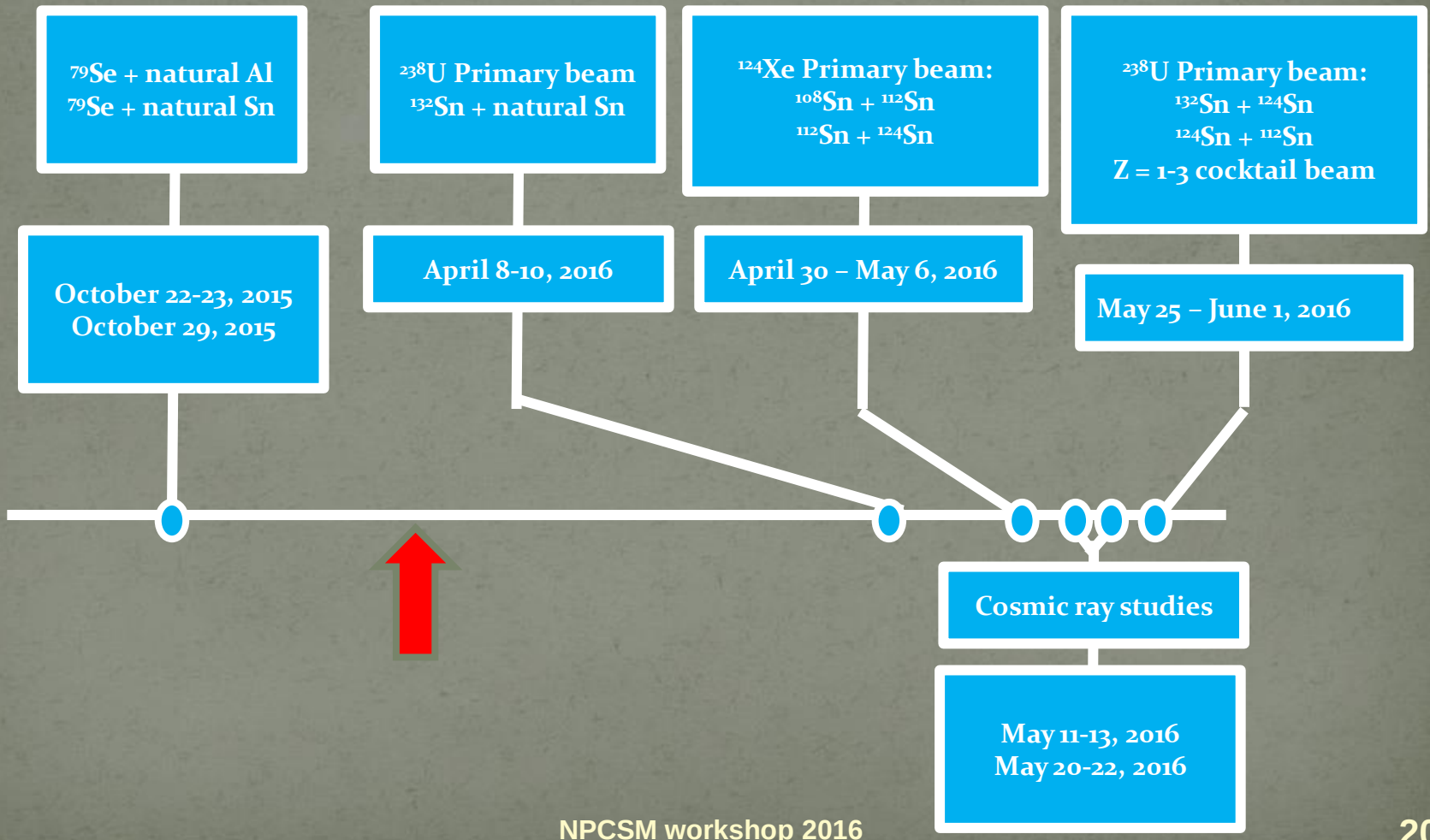
May, 2013 (MSU)

Feb, 2014
Shipped to RIKEN

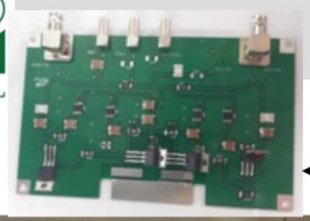
August, 2015
GET electronics installed
(MEXT)

Oct, 2015: Beam test
April 2016: Commission
May 2016: 108Sn+112Sn
May 2016: 132Sn+124Sn

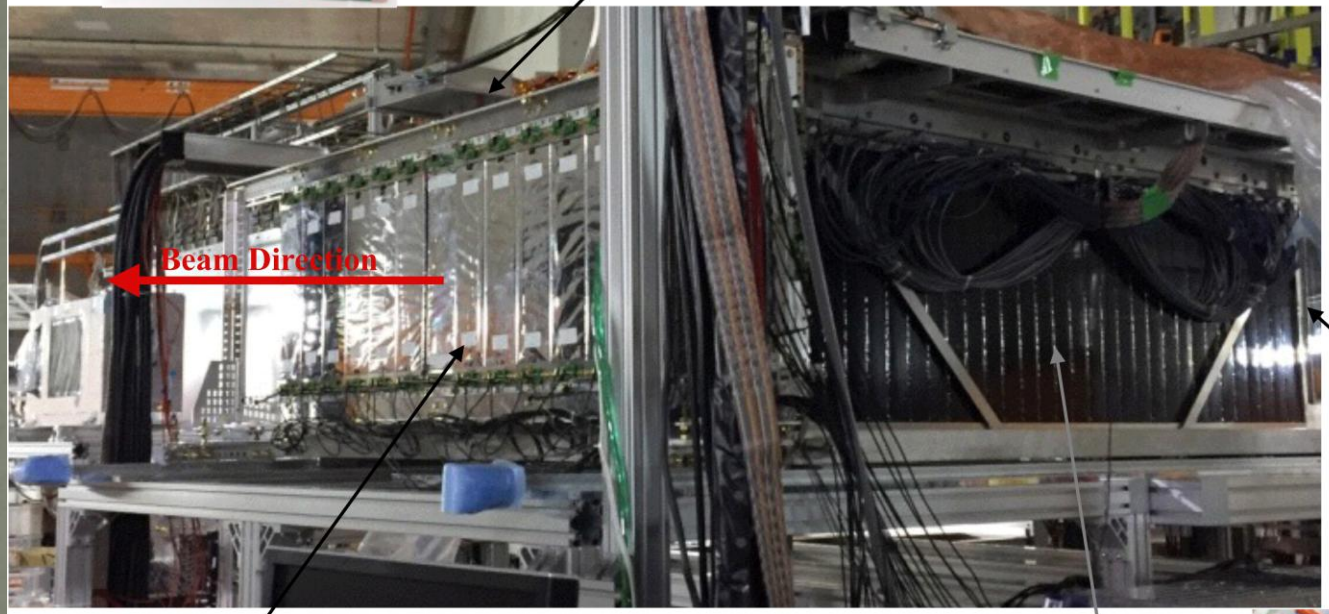
TPC measurement timeline



Trigger system

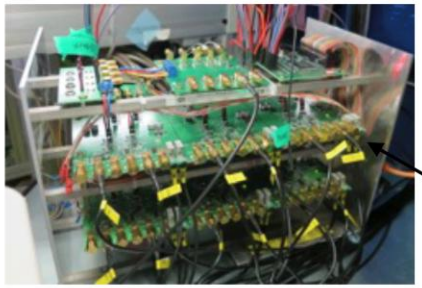


Gating Grid Driver (GGD)
NSCL



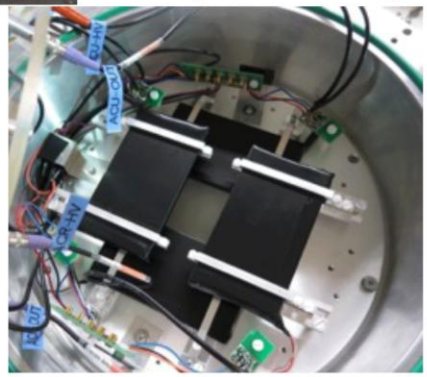
Active Collimator
(Upstream)
Tsinghua University

KATANA
(12 + 3 scintillators)
IFJ Poland



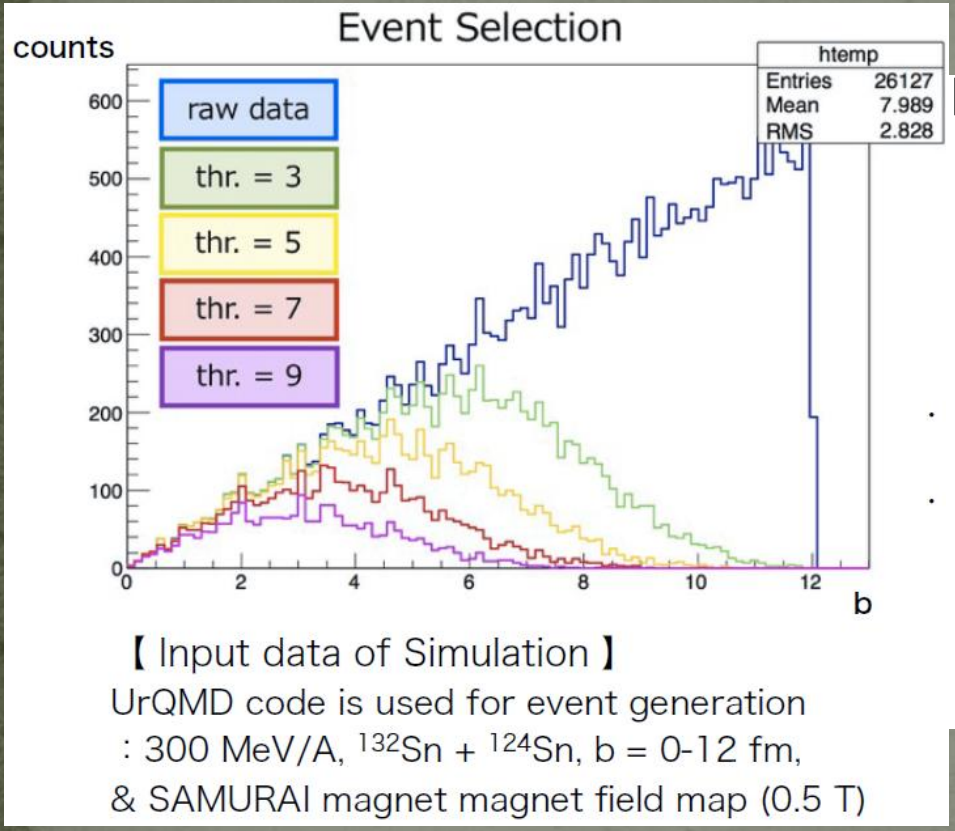
Trigger Box
IFJ Poland

Kyoto array
(30x2 scintillators)
Kyoto University



Clementine Santamaria, NSCL

Centrality selection

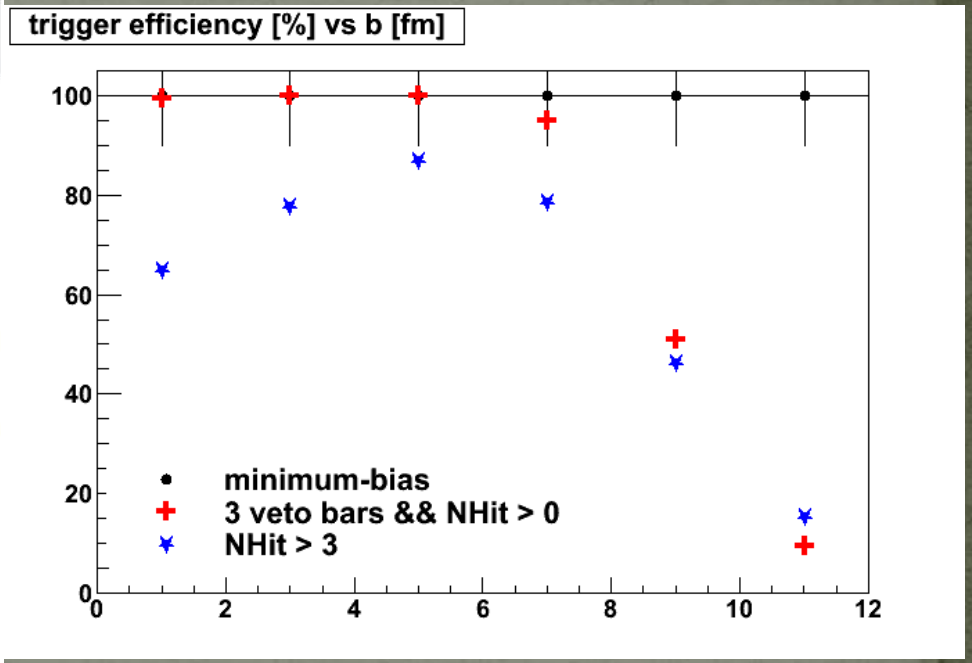


【 Input data of Simulation 】

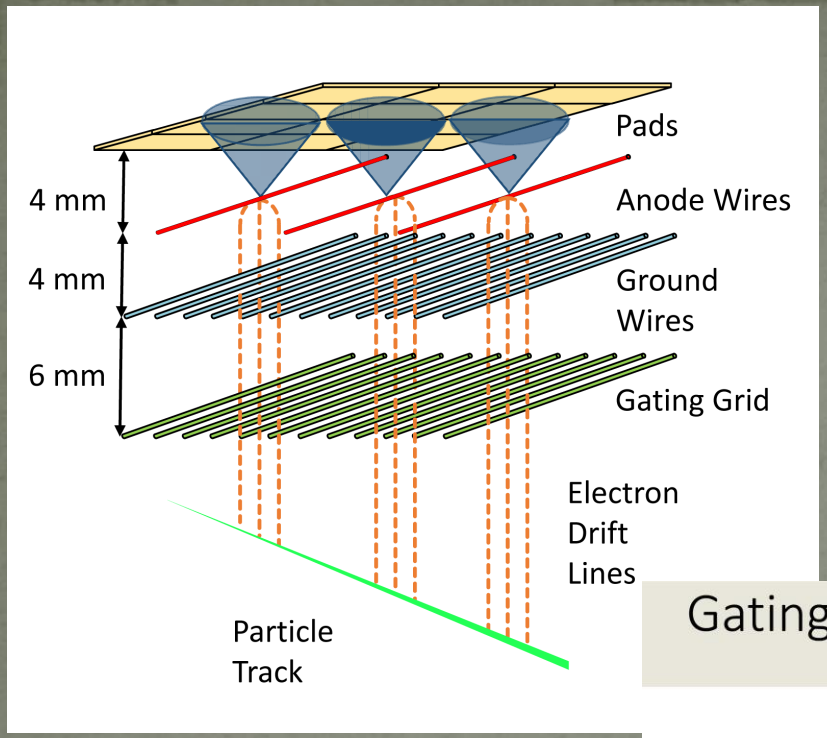
UrQMD code is used for event generation

: 300 MeV/A, ^{132}Sn + ^{124}Sn, b = 0-12 fm,

& SAMURAI magnet magnet field map (0.5 T)

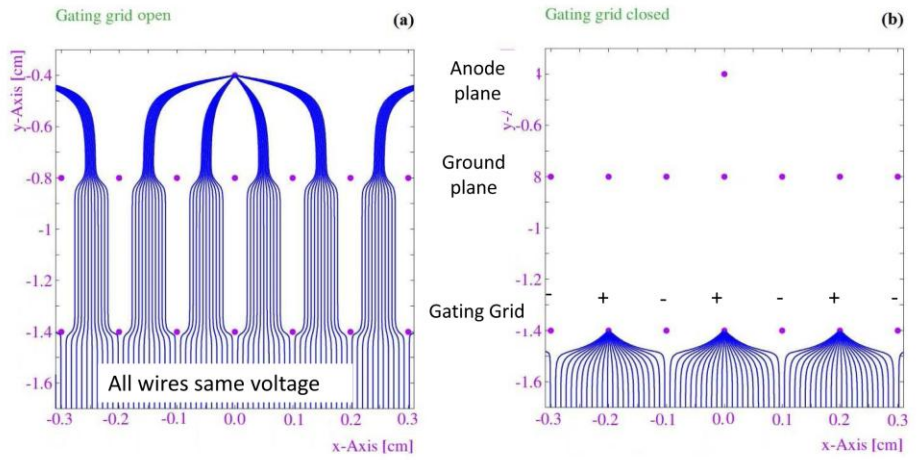


Impact parameter

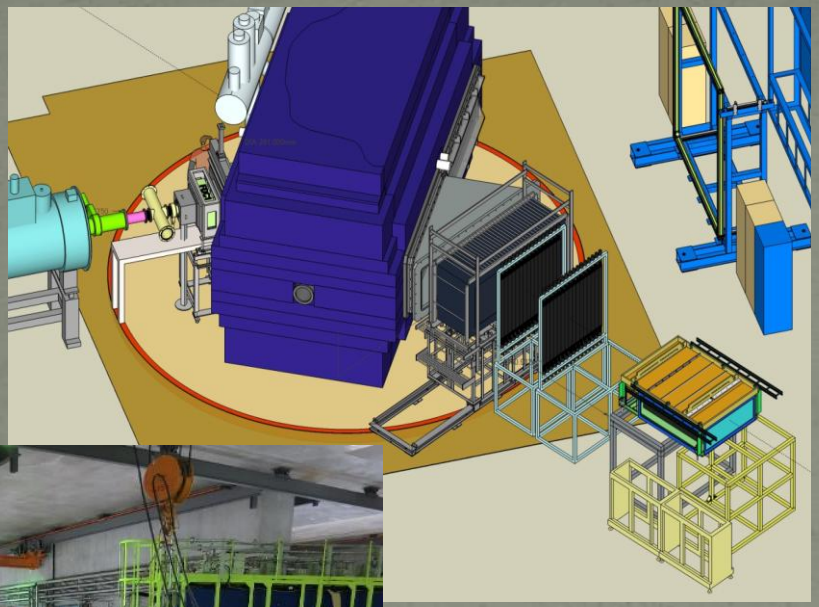


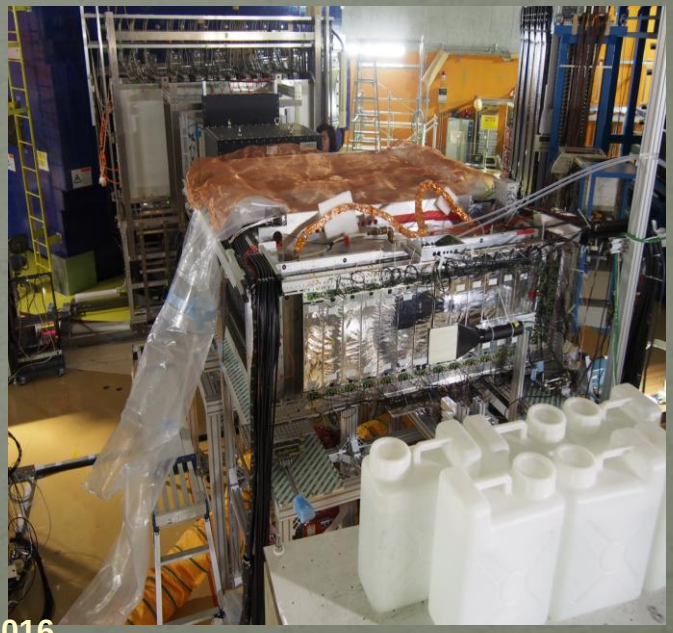
Gating grid Open and Closed

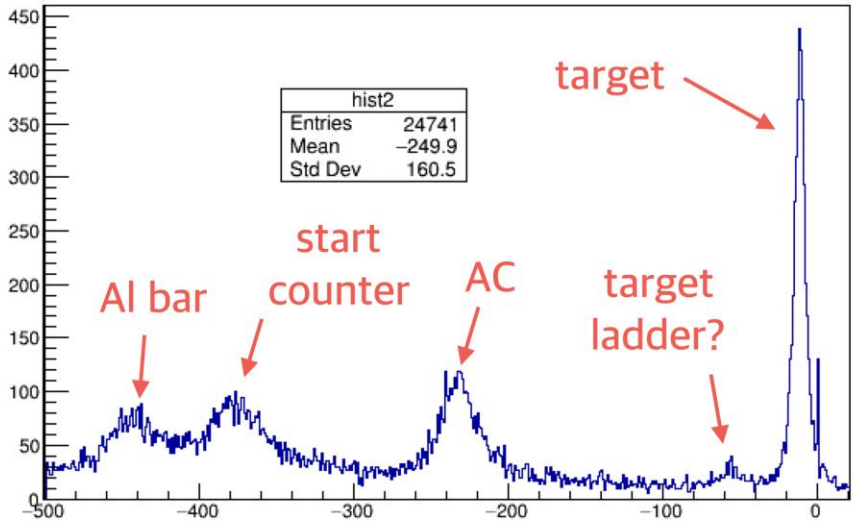
Yao Feng

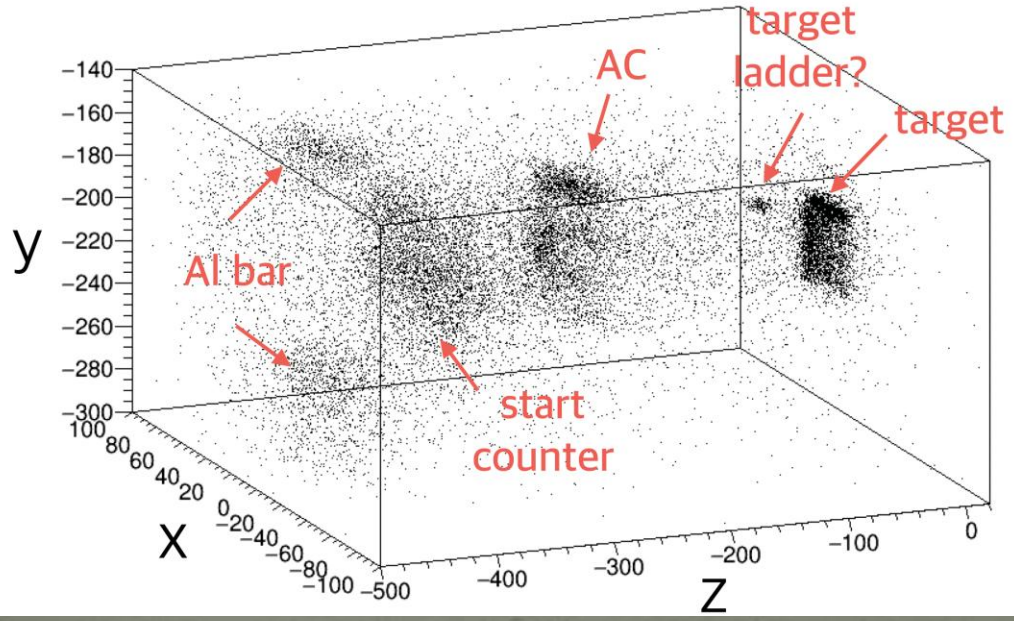


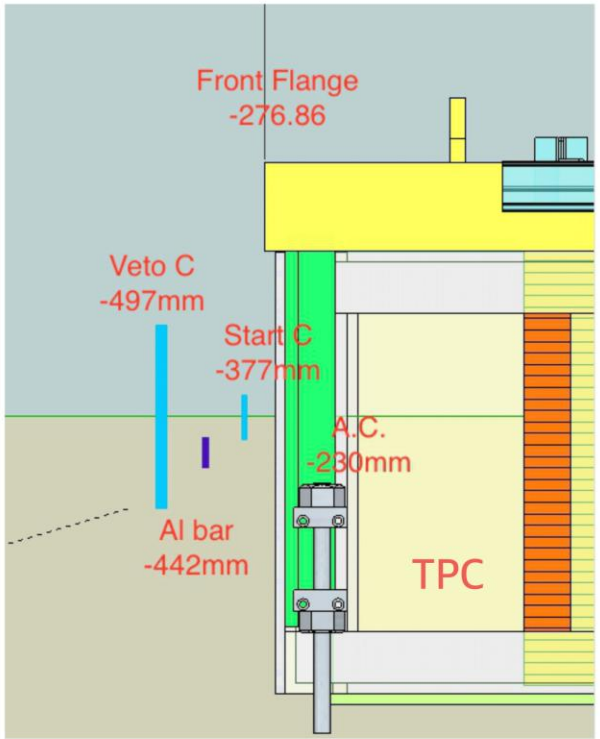
Commission Run in October 2015



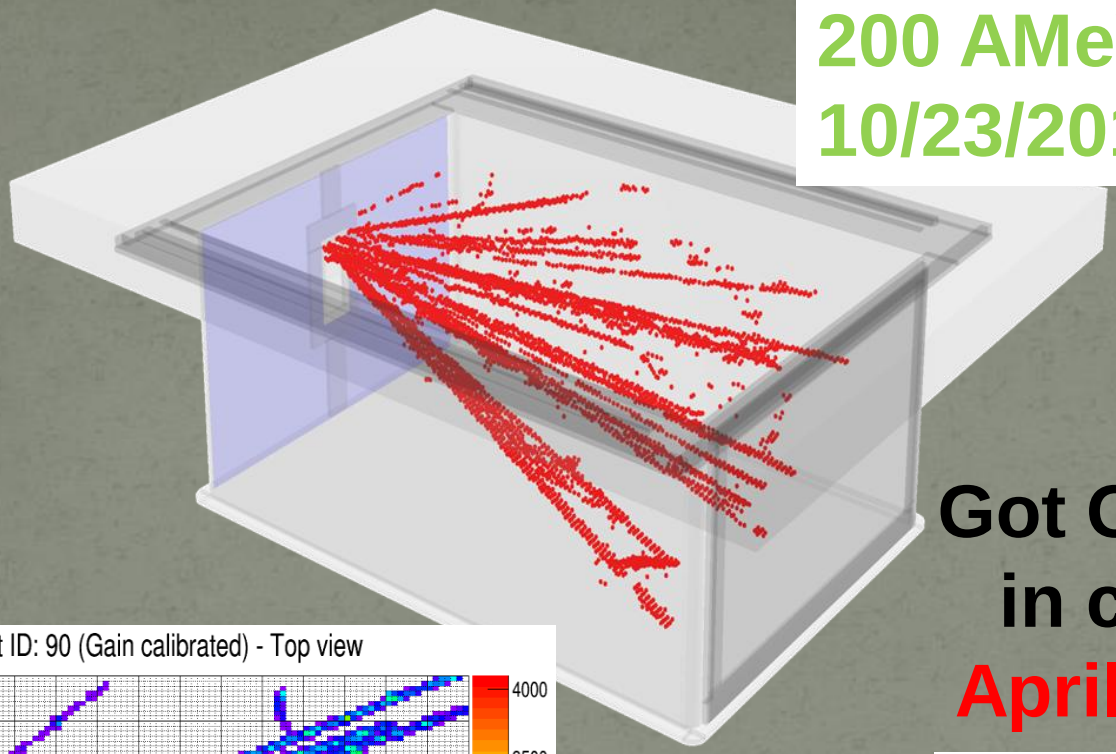



hist2
Entries 24741
Mean −249.9
Std Dev 160.5
target
start counter
Al bar
AC
target ladder?


target ladder?
AC
target
Al bar
start counter
y
x
z

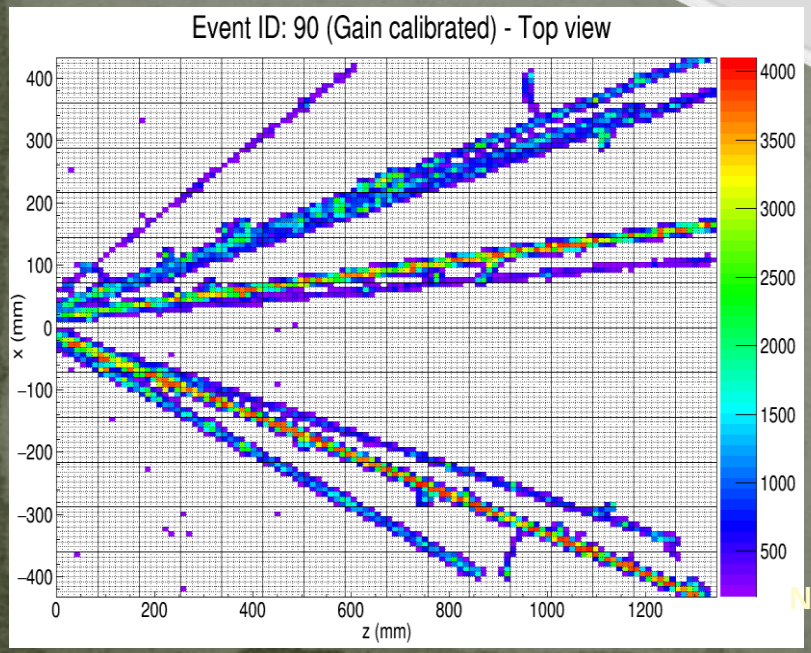

Front Flange
-276.86
Veto C
-497mm
Start C
-377mm
A.C.
-230mm
Al bar
-442mm
TPC

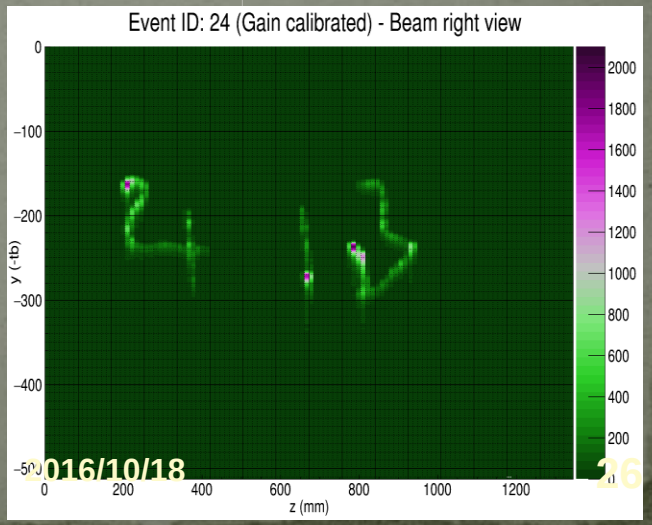
Reactions from 200 AMeV ^{79}Se+Al 10/23/2015, RIKEN

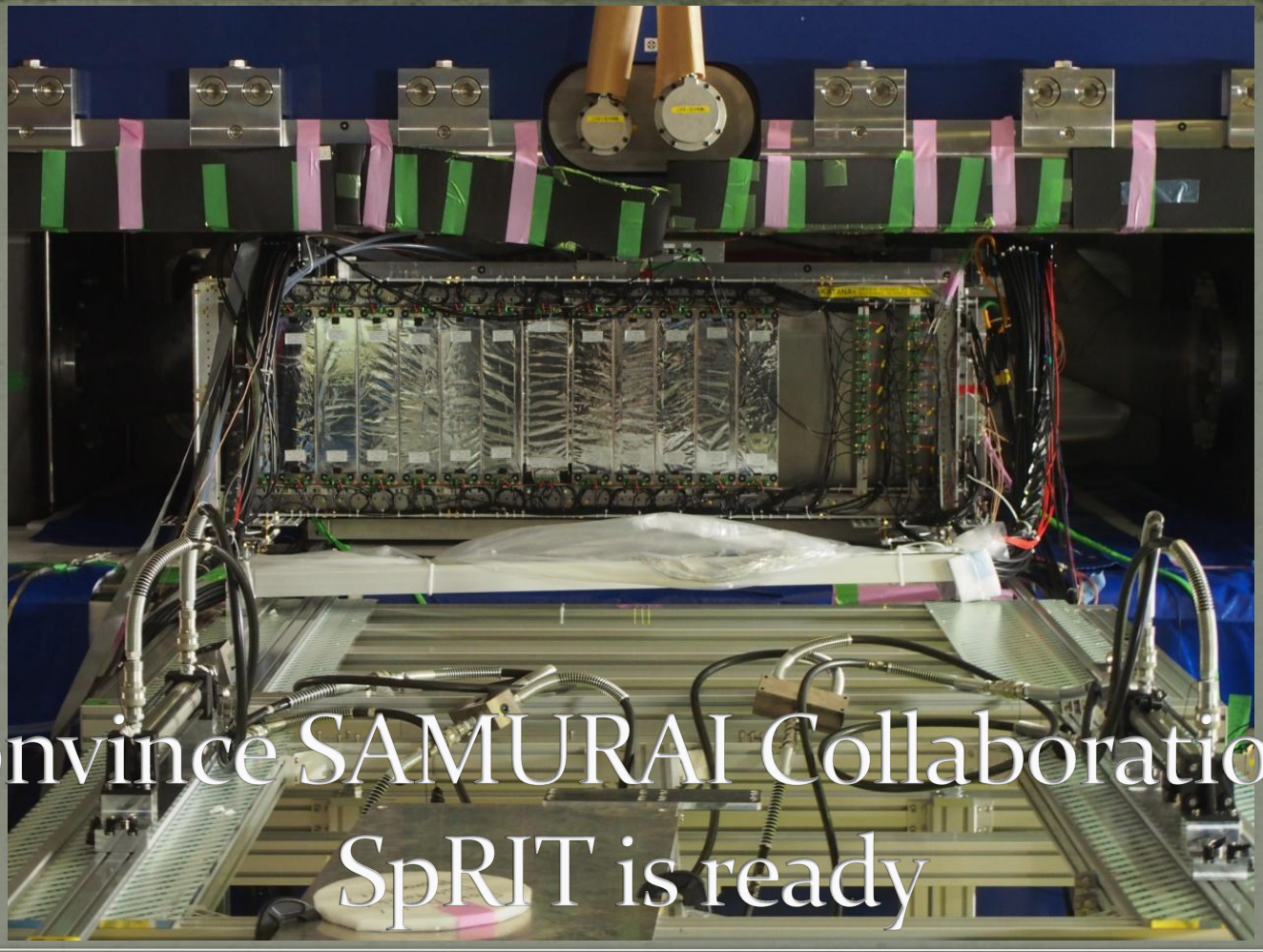


Got OMEN in cosmic event

April 13, 2016







Convince SAMURAI Collaboration : SpRIT is ready

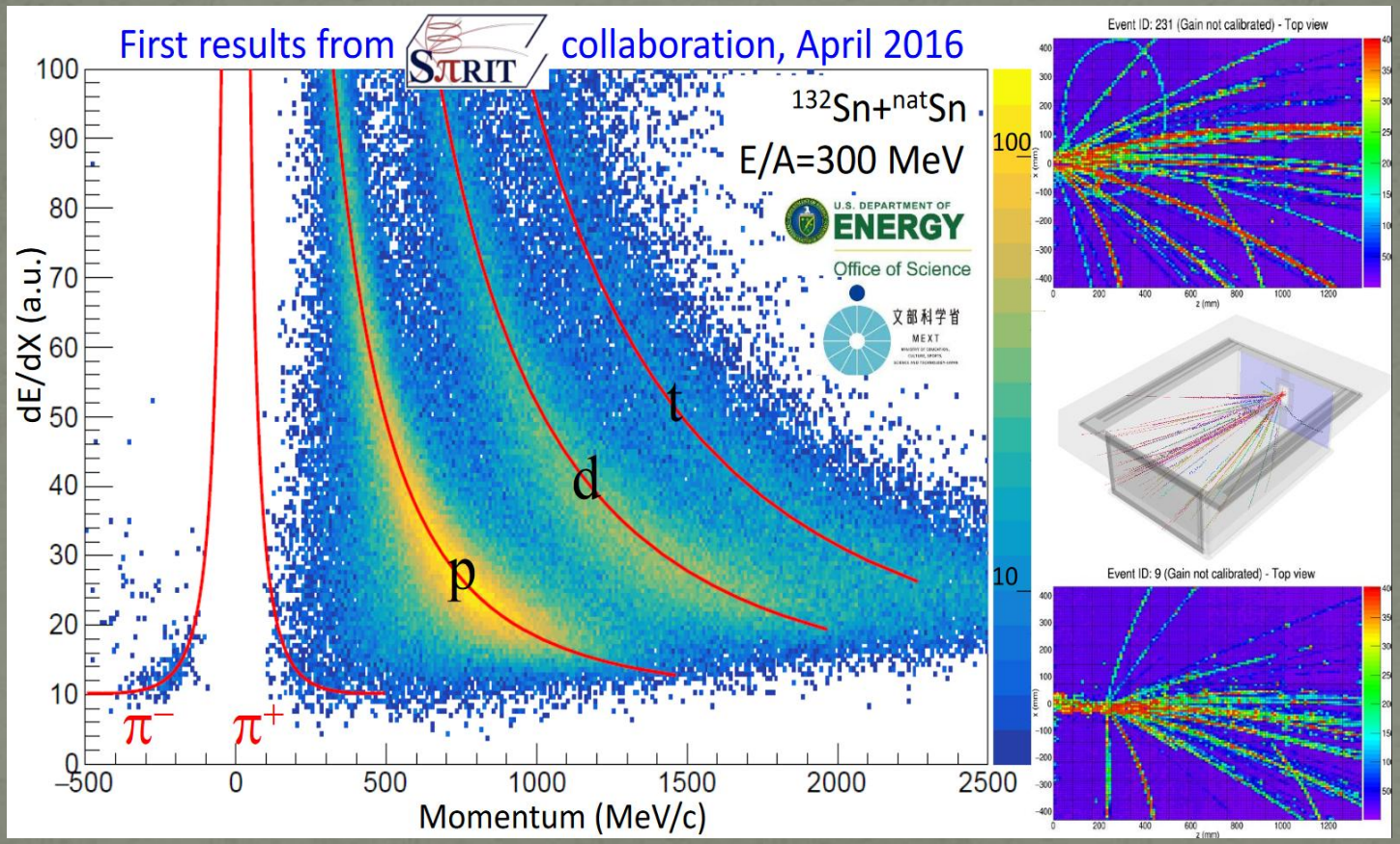
Final Roadmap of SπRIT project

- Nov. 2015 – Mar, 2016: Data analysis, calibration and improvement and development of online/offline software.
- Jan – Mar, 2016: Insert and test TPC as well as all auxiliary detectors inside SAMURAI magnet. Move NeuLAND to 30 deg. Set up experiment SAMURAI22 and 15.
- Apr., 2016: Commission of TPC inside SAMURAI magnet

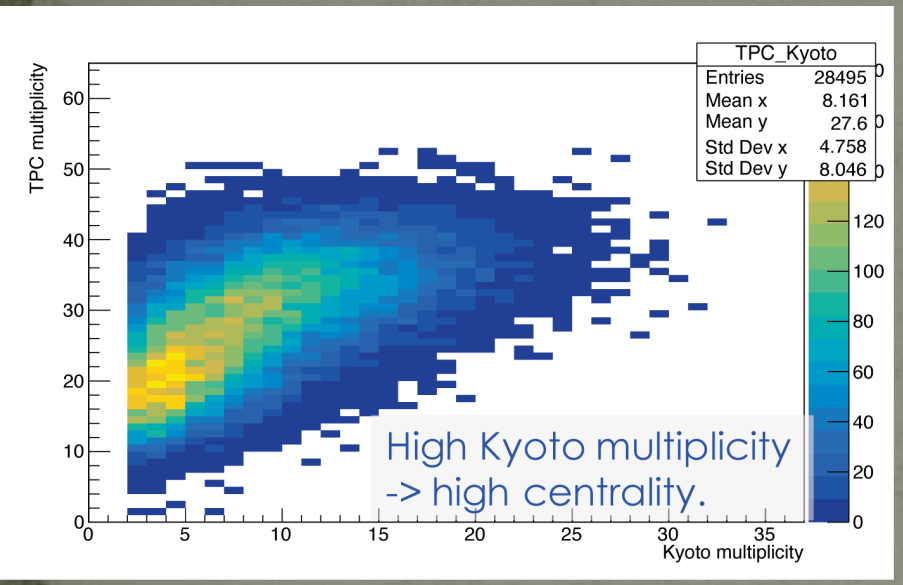
Primary	Beam	Target	E_{beam}/A	δ_{sys}	Goal	Date
^{124}Xe	^{108}Sn	^{112}Sn	300	0.09	Probe minimum δ	4/30-5/4
	^{112}Sn	^{124}Sn	300	0.15	Probe intermed. δ	5/4-5/6
^{238}U	^{132}Sn	^{124}Sn	300	0.22	Probe maximum δ	5/25-5/29
	^{124}Sn	^{112}Sn	300	0.15	Probe intermed. δ	5/30-6/1

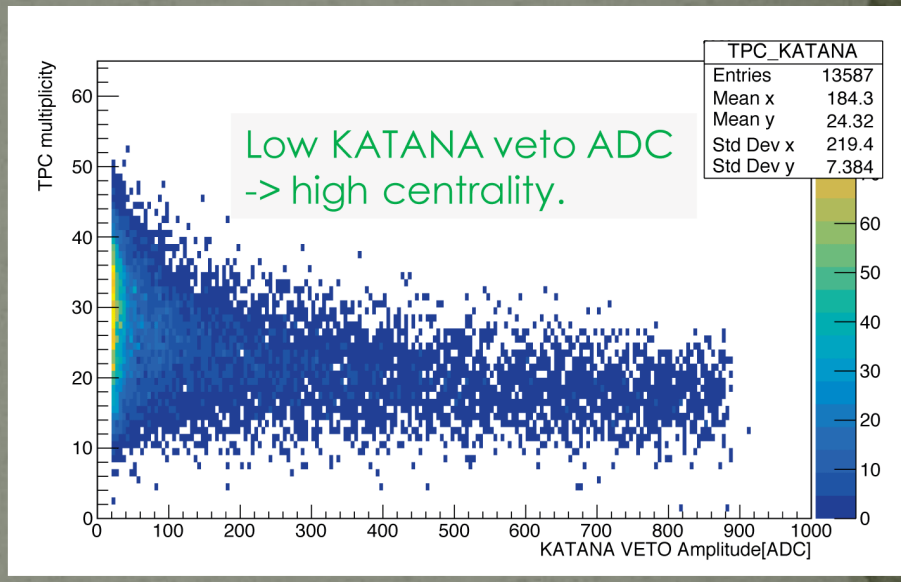
Original plan

Commissioning in magnetic field April 2016



Verify performance of trigger detectors





Select Kyoto Multiplicity ≥ 4
KATANA veto cuts peripheral events

Ready for Production Run

Obtain right beam energies

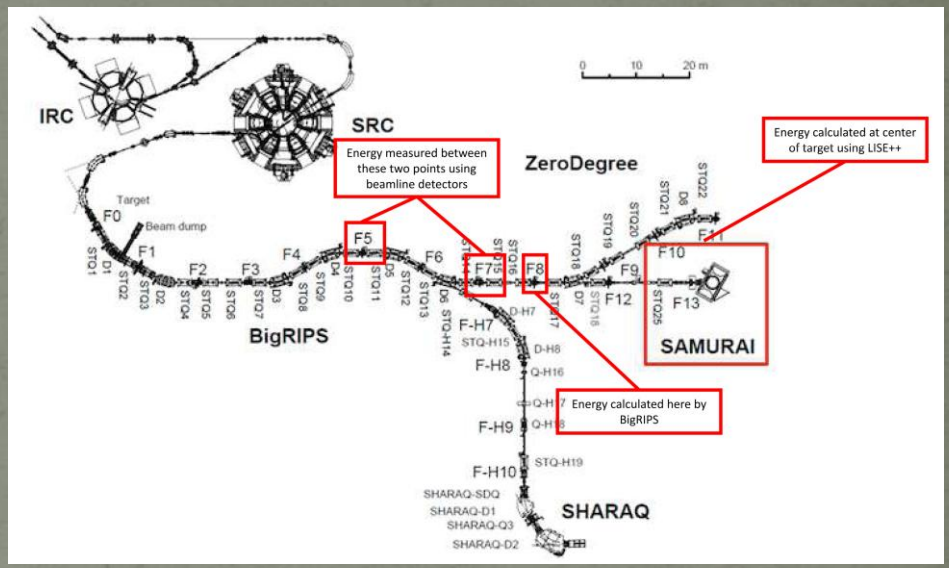
Adjusting thicknesses of production target and degraders

$^{108}Sn+^{112}Sn$:
@F7: 298.68 AMeV
@ Tgt center: 269 AMeV

$^{112}Sn+^{124}Sn$:
@F7: 298.42 AMeV
@ Tgt center: 270 AMeV

$^{132}Sn+^{124}Sn$:
@F7: 293.11 AMeV
@ Tgt center: 269 AMeV

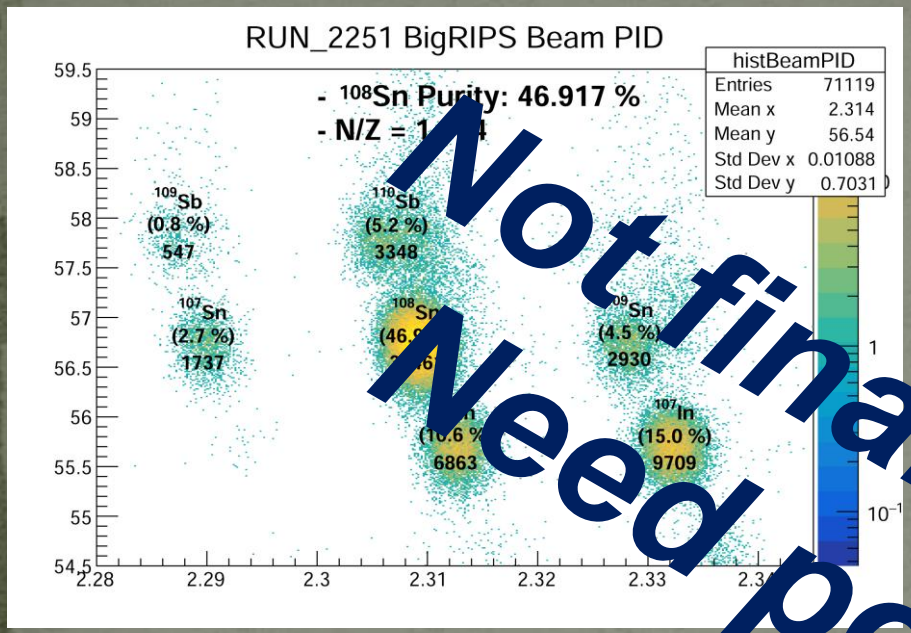
$^{124}Sn+^{112}Sn$:
@F7: 295.89 AMeV
@ Tgt center: 270 AMeV

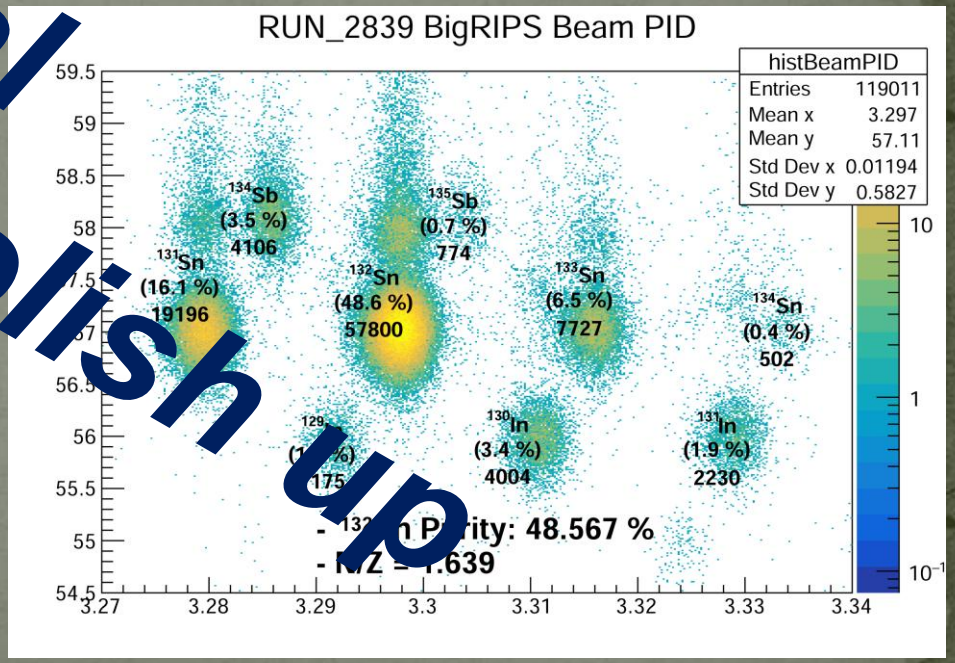


Data summary: 253TByte

- TPC:
  - Run 750-1023 : 2015 Oct commissioning → 9.7TByte
  - Run 1735-2047 : 2016 Apr commissioning → 15TByte
  - Run 2261-2509 : Sn-108+Sn-112 → 70TByte
    - Num of Matched events: 8.3M
  - Run 2542-2653 : Sn-112+Sn-124 → 42TByte
    - Num of Matched events: 5.0M
  - Run 2836-3039 : Sn-132+Sn-124 → 73TByte
    - Num of Matched events: 9.5M
  - Run 3044-3184 : Sn-124+Sn-112 → 38TByte
    - Num of Matched events: 5.3M
  - Run 3185-3196 : Cocktail 300MeV/u → 1.7TByte
  - Run 3197-3211 : Cocktail 100MeV/u → 3.0TByte
- RIDF: 0.1TByte
- KATANA: 0.7TByte

Managed to get about 50% purity for most of beams (except for ^{124}Sn)

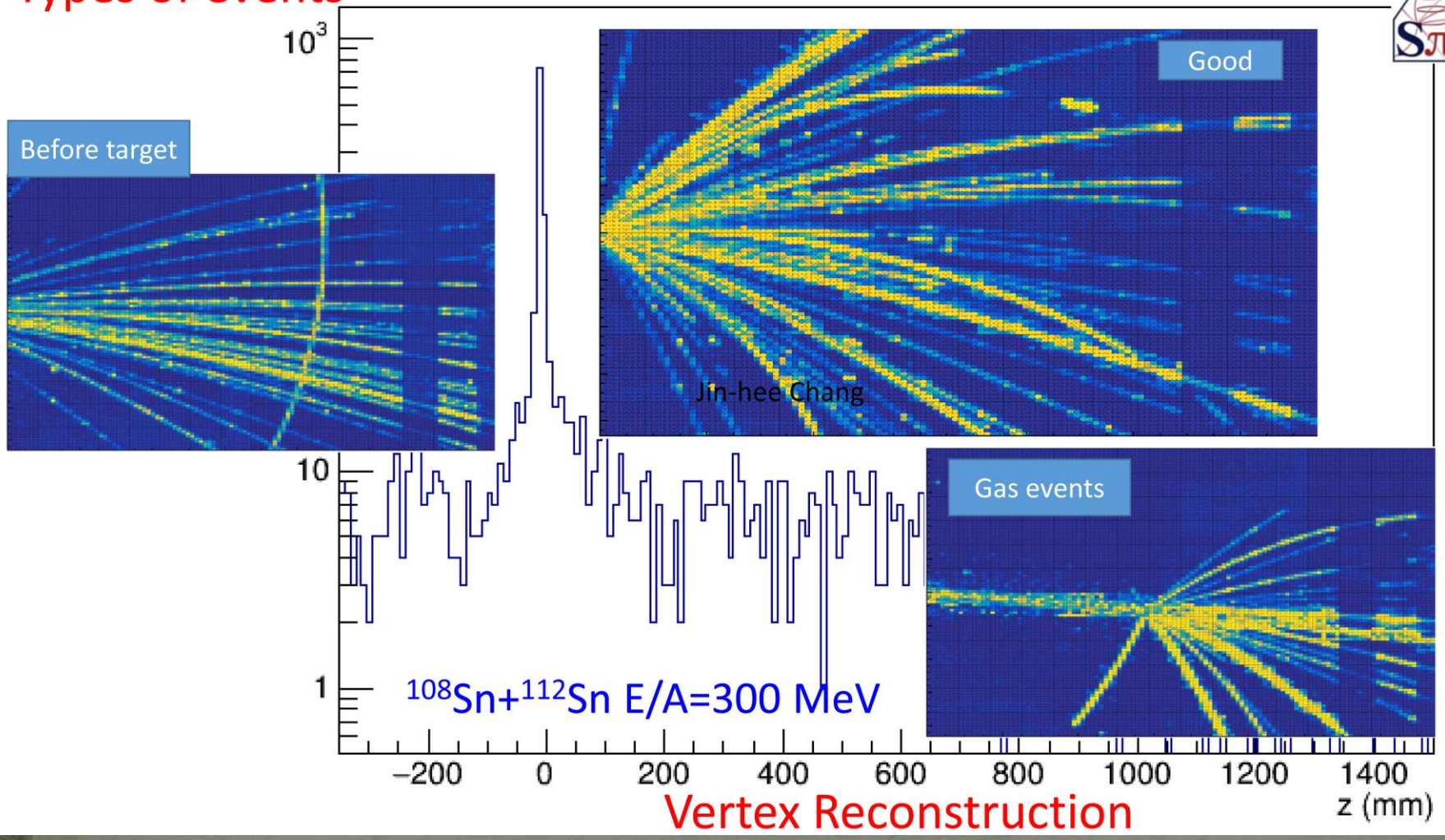




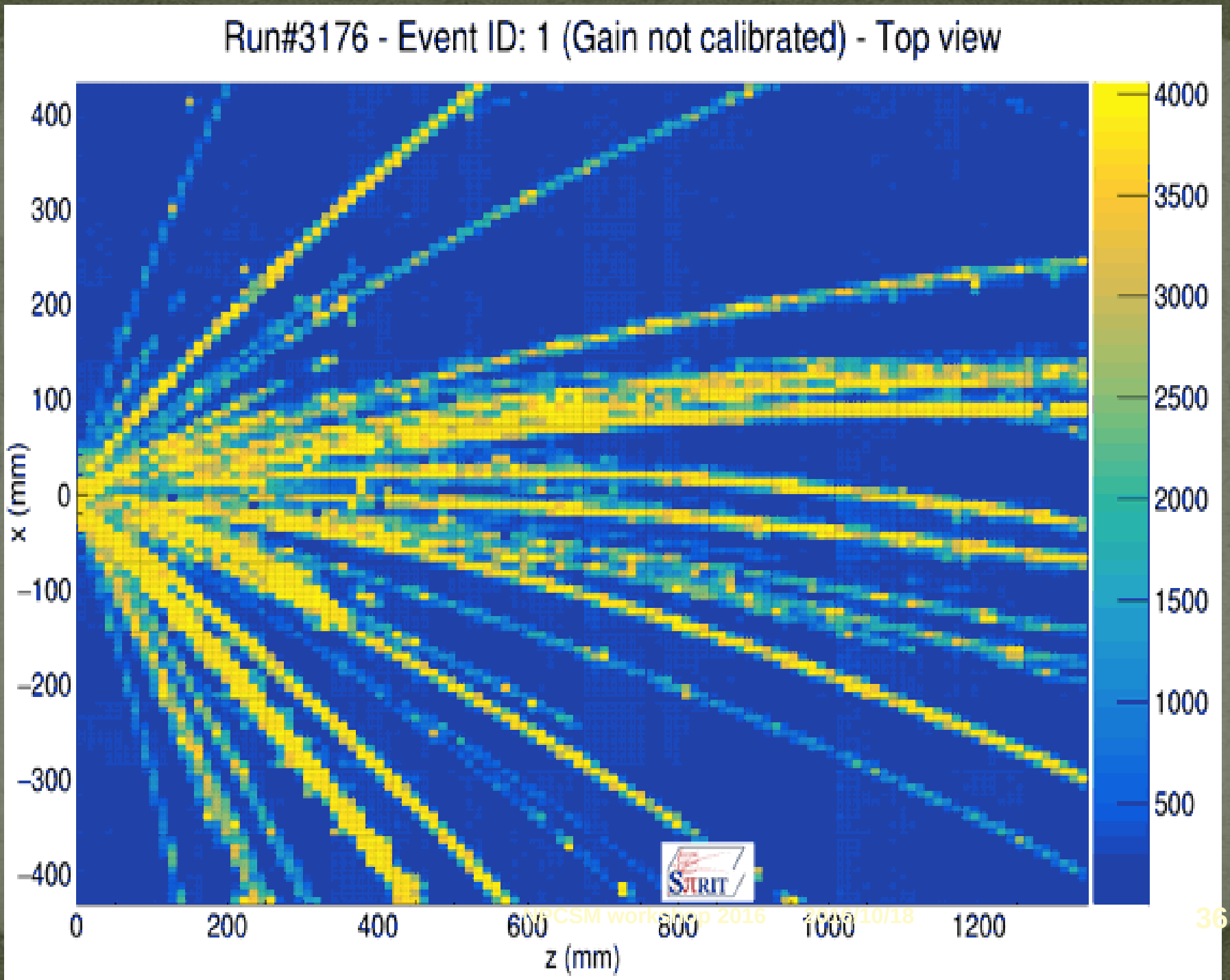
Not final
Need polish up

Scales are not yet correct.

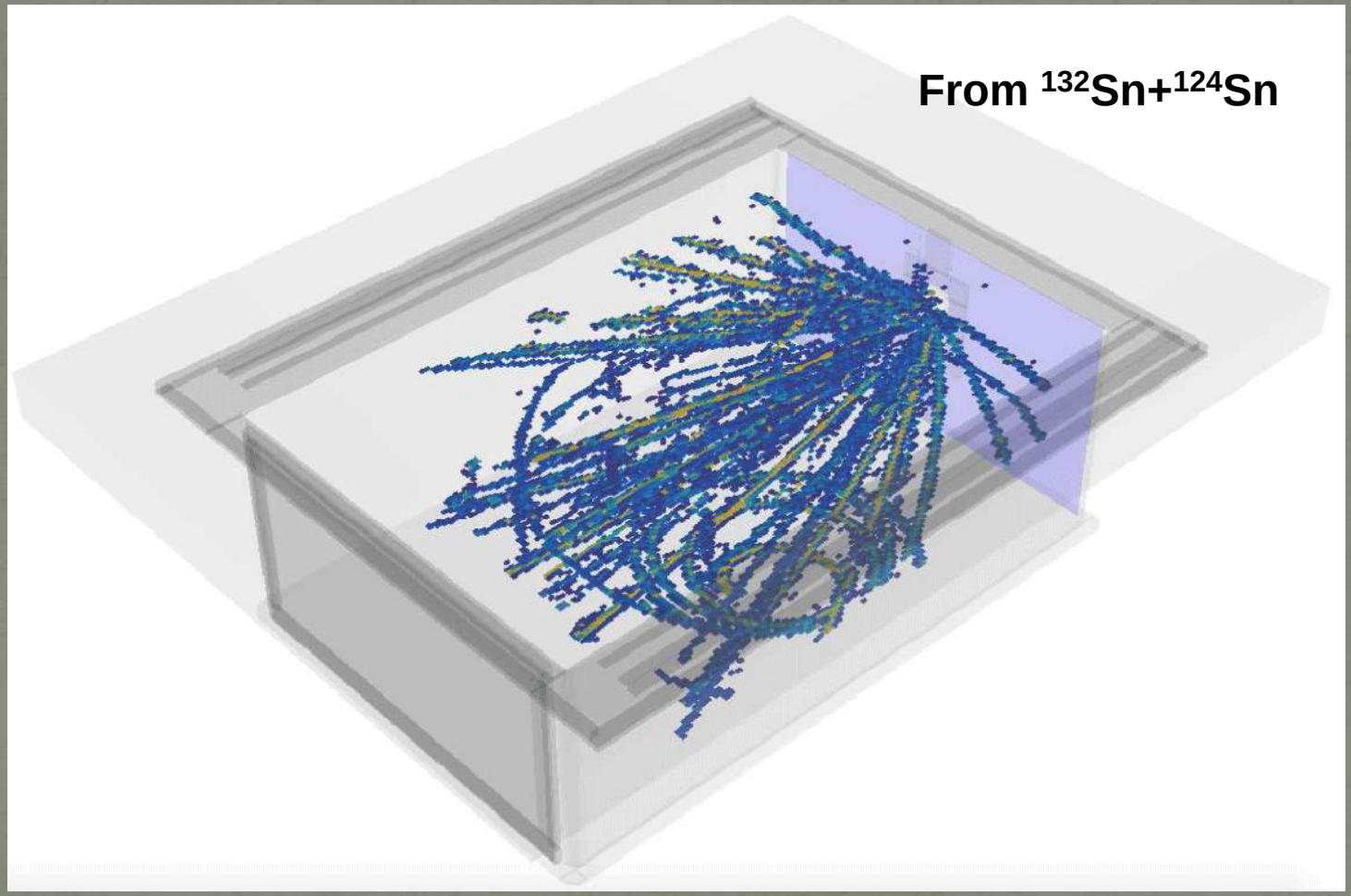
Types of events



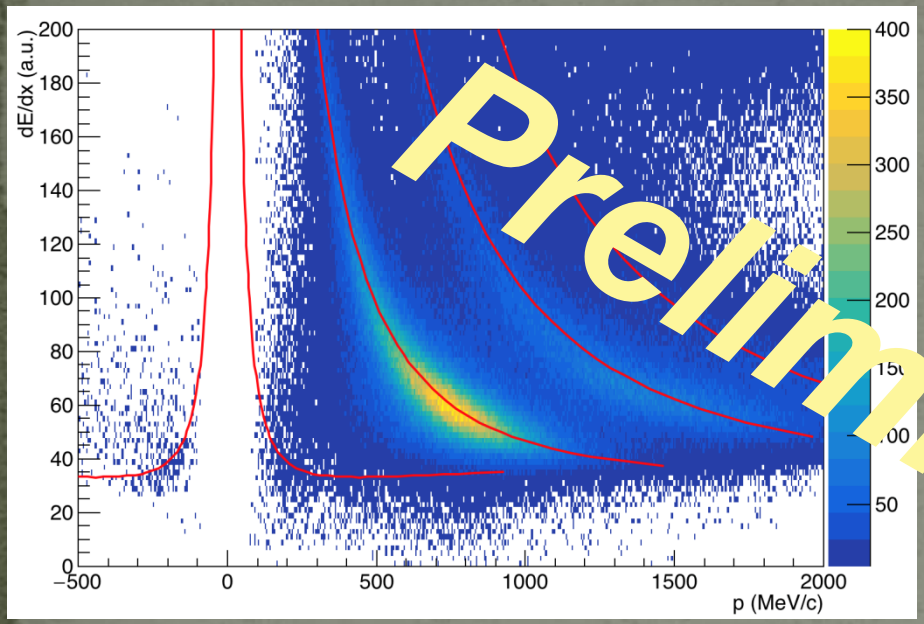
Vertex Reconstruction


Run#3176 - Event ID: 1 (Gain not calibrated) - Top view
x (mm)
z (mm)
400
300
200
100
0
−100
−200
−300
−400
0
200
400
600
800
1000
1200
4000
3500
3000
2500
2000
1500
1000
500
SπRIT

Impressive Example of events

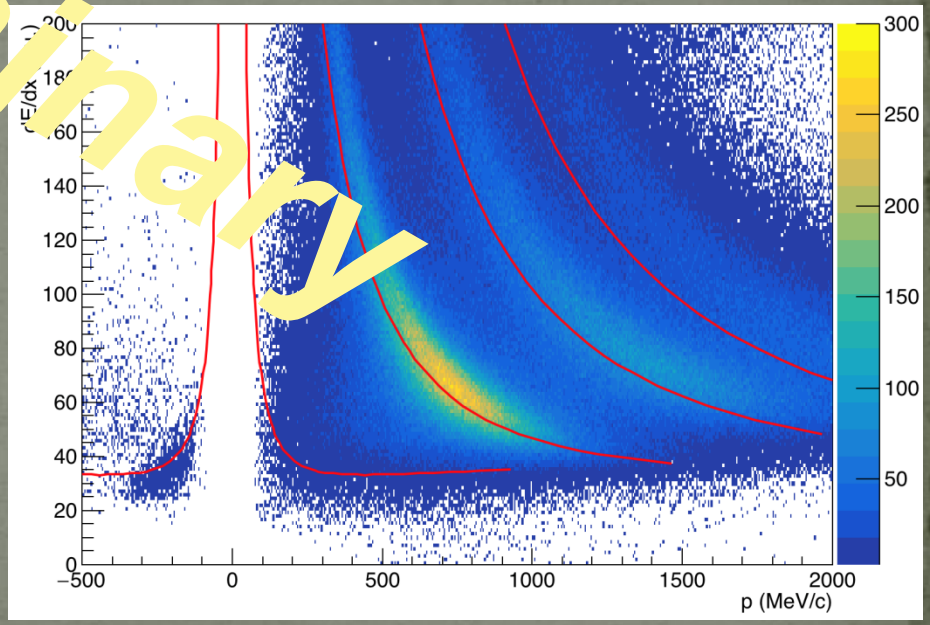


Sneak view of 150k events!!!



$^{108}Sn+^{112}Sn$

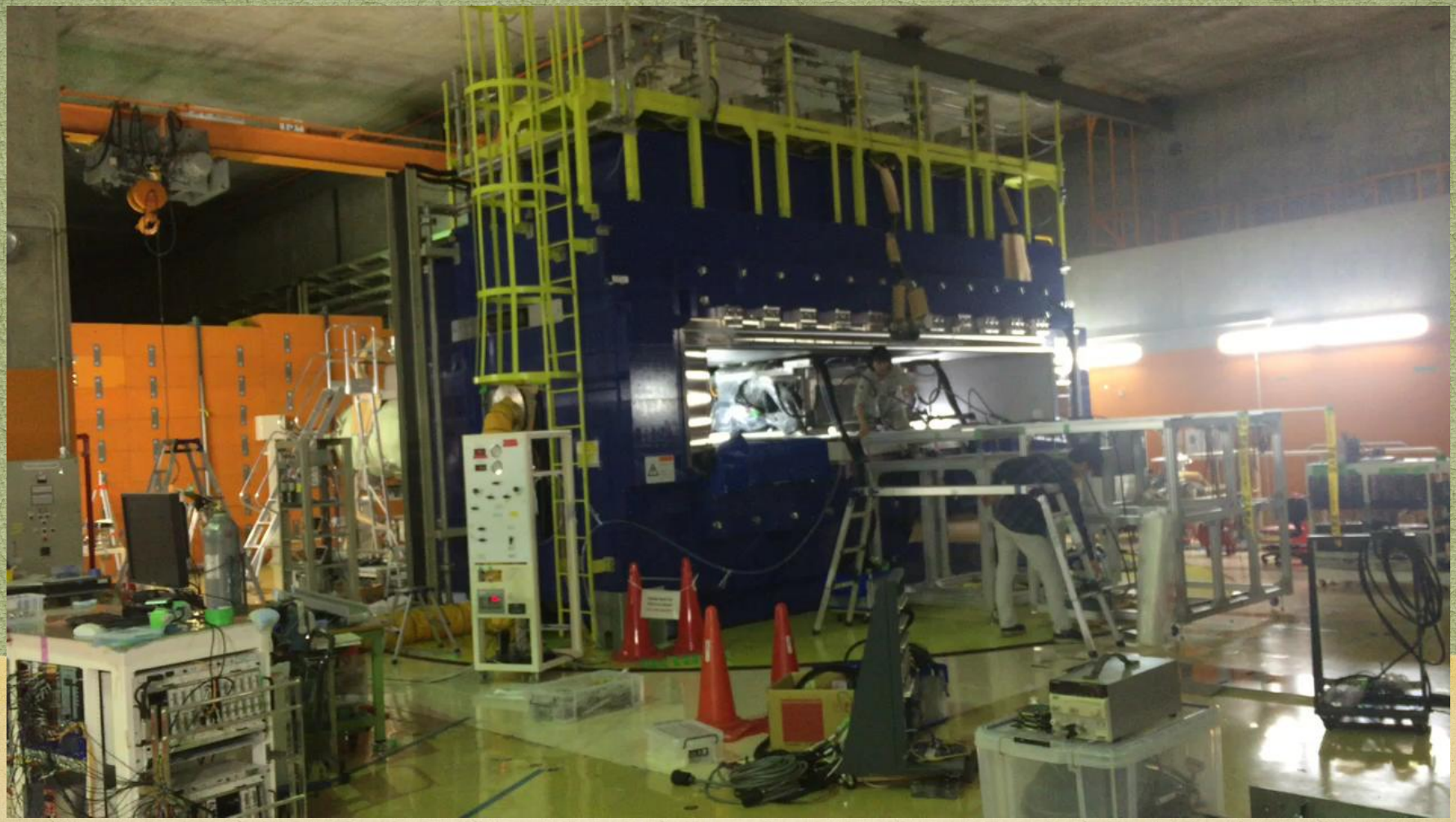
$^{132}Sn+^{124}Sn$



Summary

- We have just finished the first series of SπRIT experiments in May.
- First sight of data seems very promising.

  Need various checks of analysis.
- A few technical reports have been prepared as PhD thesis.
- We hope to release the first results in a year.



Removing TPC from SAMURAI

5 sec./frame. No cut !

It was ~2.5 hour.