Nuclear physics with Time Projection Chambers: SπRIT & AT-TPC

NSCL

January 12th, 2018

Clémentine Santamaria

SπRIT Time Projection Chamber: Probing the EoS with Pions

NUCLEAR EQUATION OF STATE

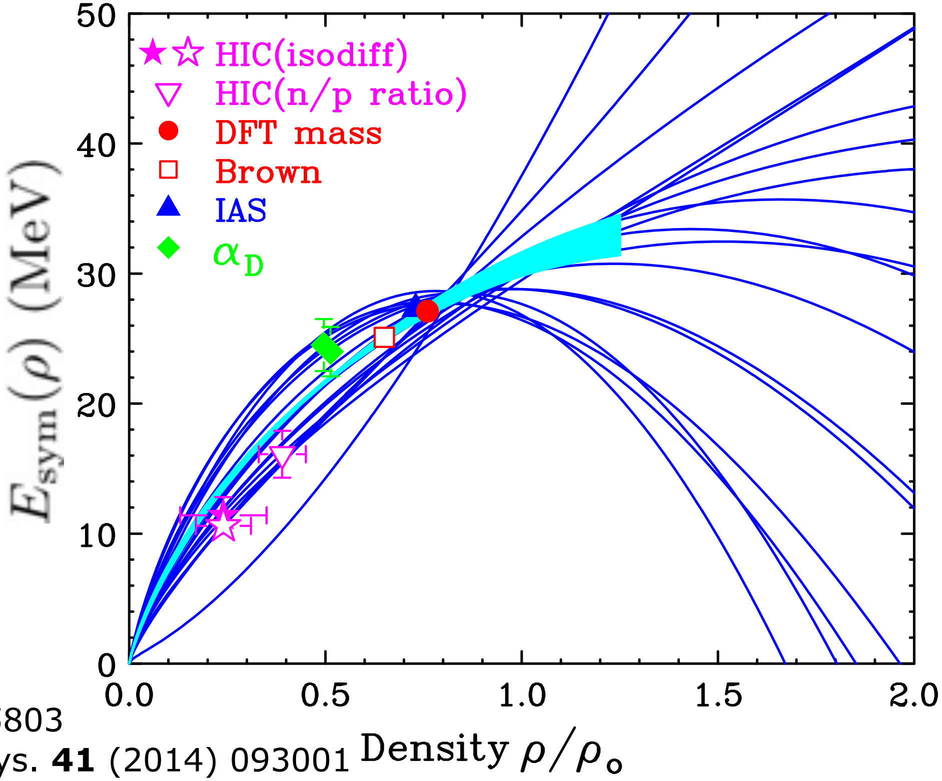
An equation that describes the relations among the pressure, energy, temperature, density and isospin asymmetry of nuclear systems.

$$E(\rho,\delta) = E(\rho,\delta=0) + E_{\mathrm{sym}}(\rho)\delta^2 + O(\delta^4), \quad \delta = \frac{\rho_{\mathrm{n}} - \rho_{\mathrm{p}}}{\rho}$$

Symmetry energy

- Affects the relationship between neutron star radius and mass.
- Very few laboratory constraints
- Experimental constraints emerging at sub-saturation density.

Private communication with M. B. Tsang



M. B. Tsang *et al.*, Phys. Rev. C **86** (2012) 015803
C. J. Horowitz *et al.*, J. Phys. G: Nucl. Part. Phys. **41** (2014) 093001

SπRIT: CONSTRAINING THE SYMMETRY ENERGY

- Measurements of the density dependence of the nuclear symmetry energy at supra-saturation densities ($\rho \sim 2\rho_0$).
- Systematic study by changing beams and targets with different Sn isotopes

Primary Beam	Secondary Beam	Secondary Target	δ_{sys}	Goal
^{238}U	^{132}Sn	^{124}Sn	0,22	maximum δ_{sys}
^{238}U	^{124}Sn	^{112}Sn	0,15	intermediate δ_{sys}
^{124}Xe	^{112}Sn	^{124}Sn	0,15	intermediate δ_{sys}
^{124}Xe	^{108}Sn	^{112}Sn	0,09	minimum δ_{sys}
^{238}U	Cocktail Beam Z~1-3	Al Brick	-	dE/dx calibration

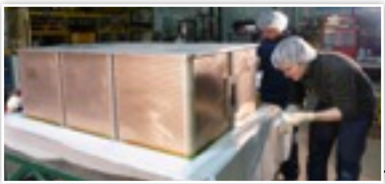
⇒ Need to reconstruct the momentum distributions of pions and light particles with $Z \leq 3$ emitted in central collisions of neutron-rich nuclei.

SπRIT TPC STRUCTURE

R. Shane, NIM A **784**, 513-517 (2015)

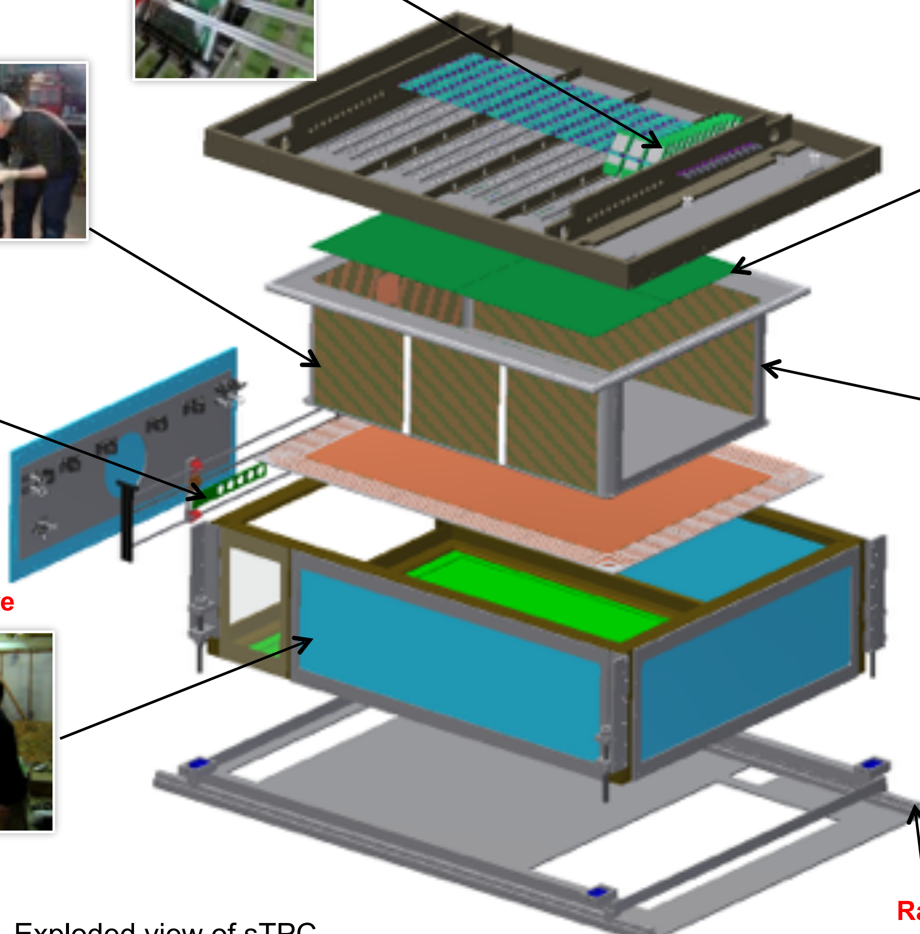
Front End Electronics

Field Cage



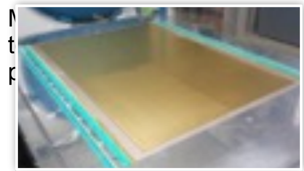
Target mechanism

Thin-Walled Enclosure

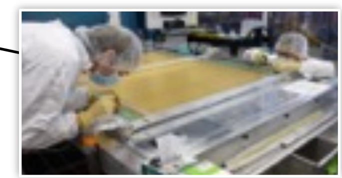


Exploded view of sTPC

Pad Plane



Wire Planes



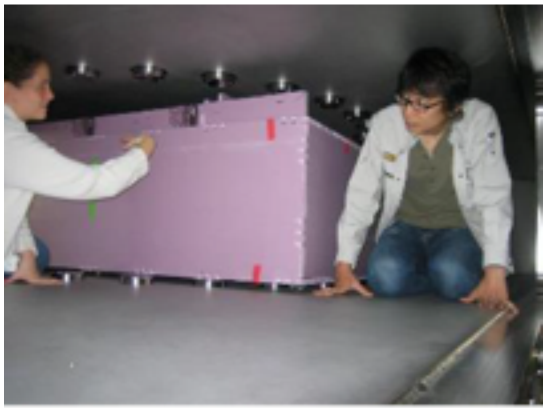
Rails for smooth, safe insertion of TPC into magnet

Rails

Slide adapted from R. Shane

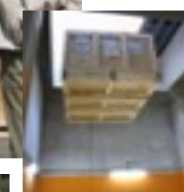
SπRIT MILESTONES

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



May 2013 (MSU)

Feb 2014: Shipped to RIKEN



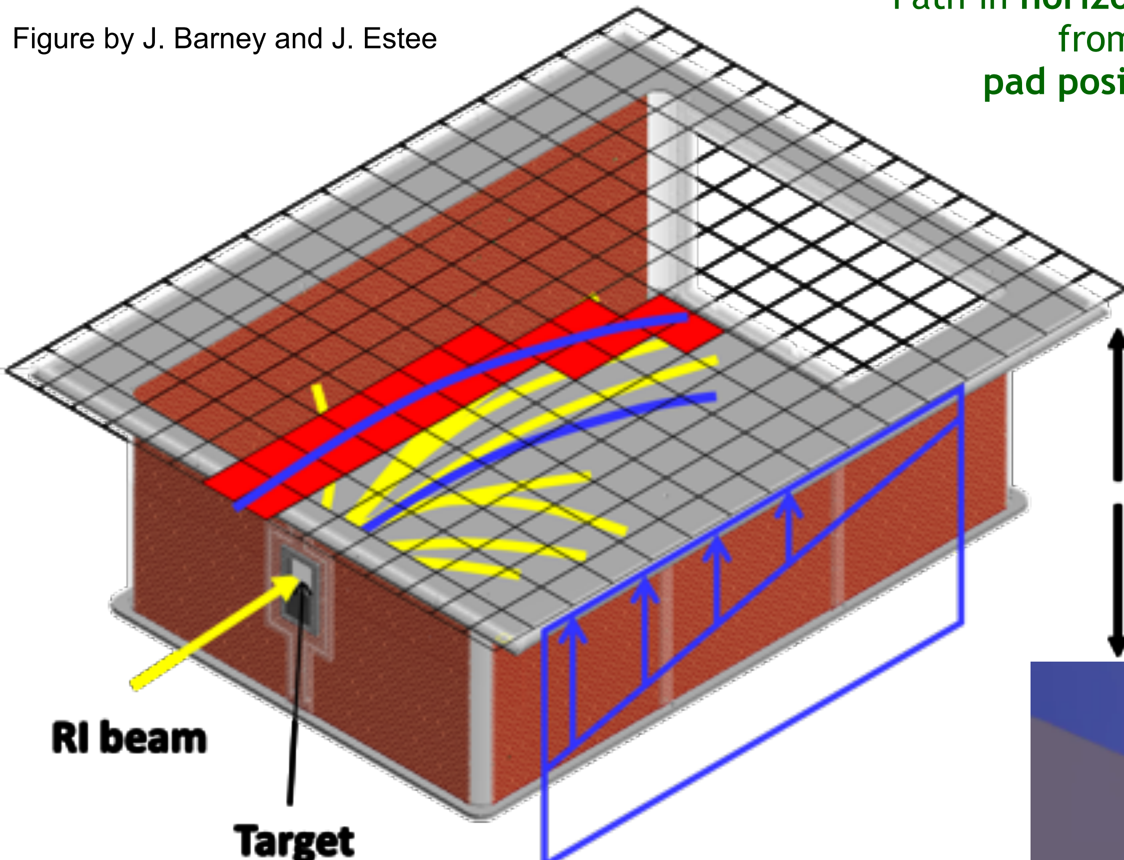
August 2015
GET electronics installed (MEXT)

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

SπRIT DETECTION MECHANISM

Figure by J. Barney and J. Estee

Path in **horizontal** plane
from
pad positions

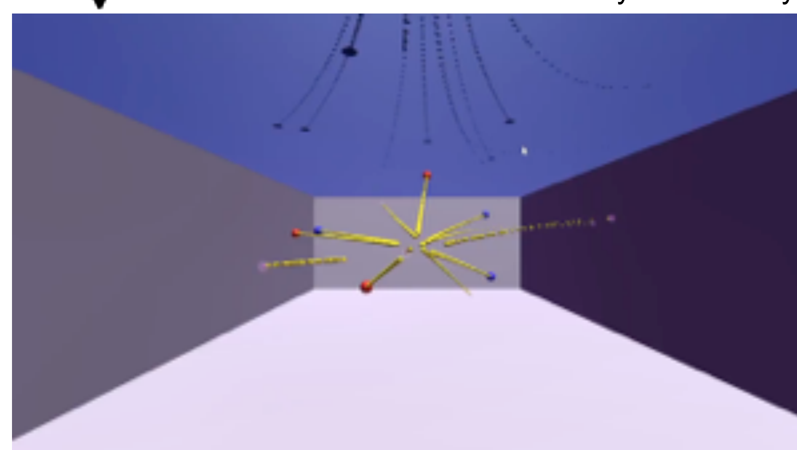


B field

E field

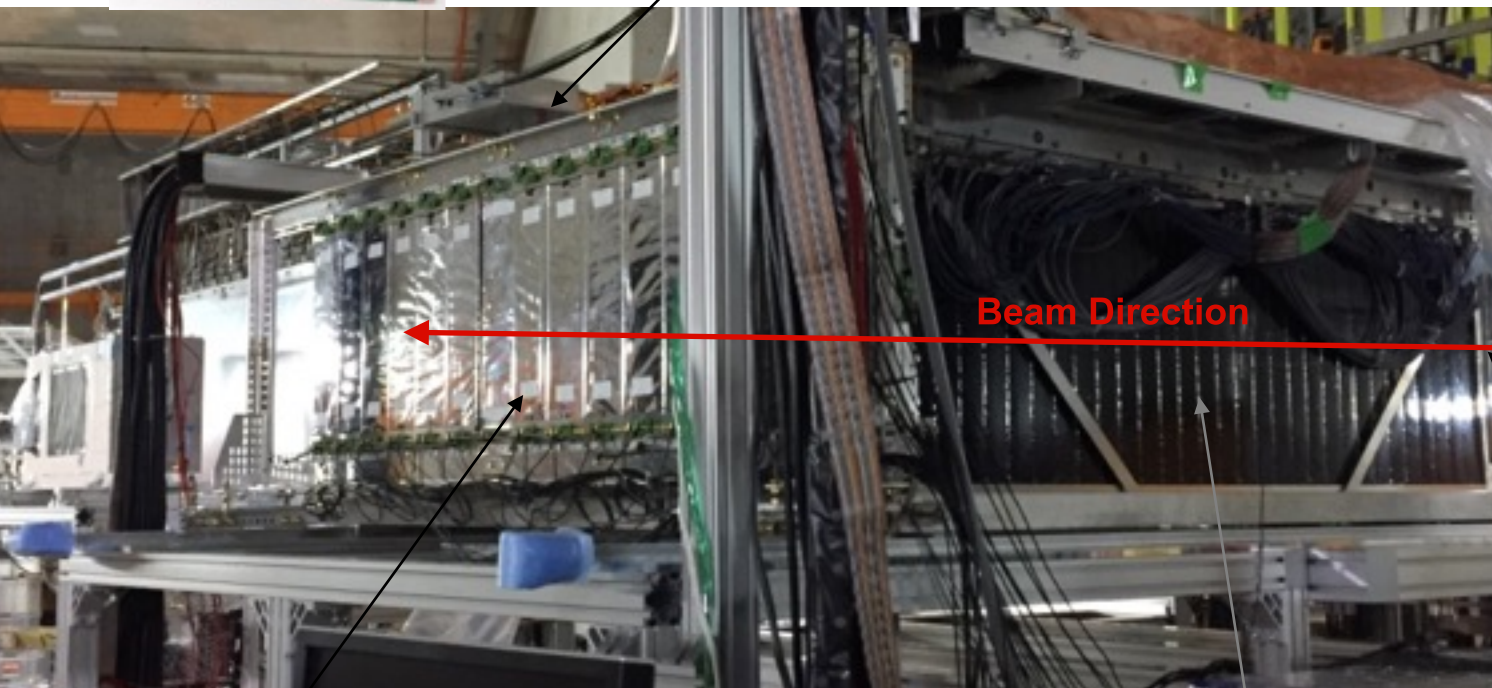
Position in **vertical**
drift direction from
time

Movie courtesy of J. Crosby



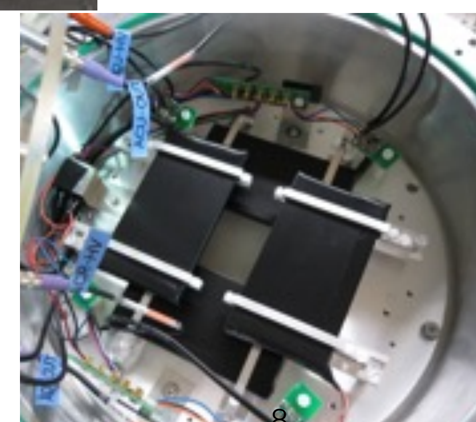
SπRIT SETUP

Gating Grid Driver (GGD)
NSCL



At RIBF facility
Japan

Active Collimator
(Upstream)
Tsinghua University

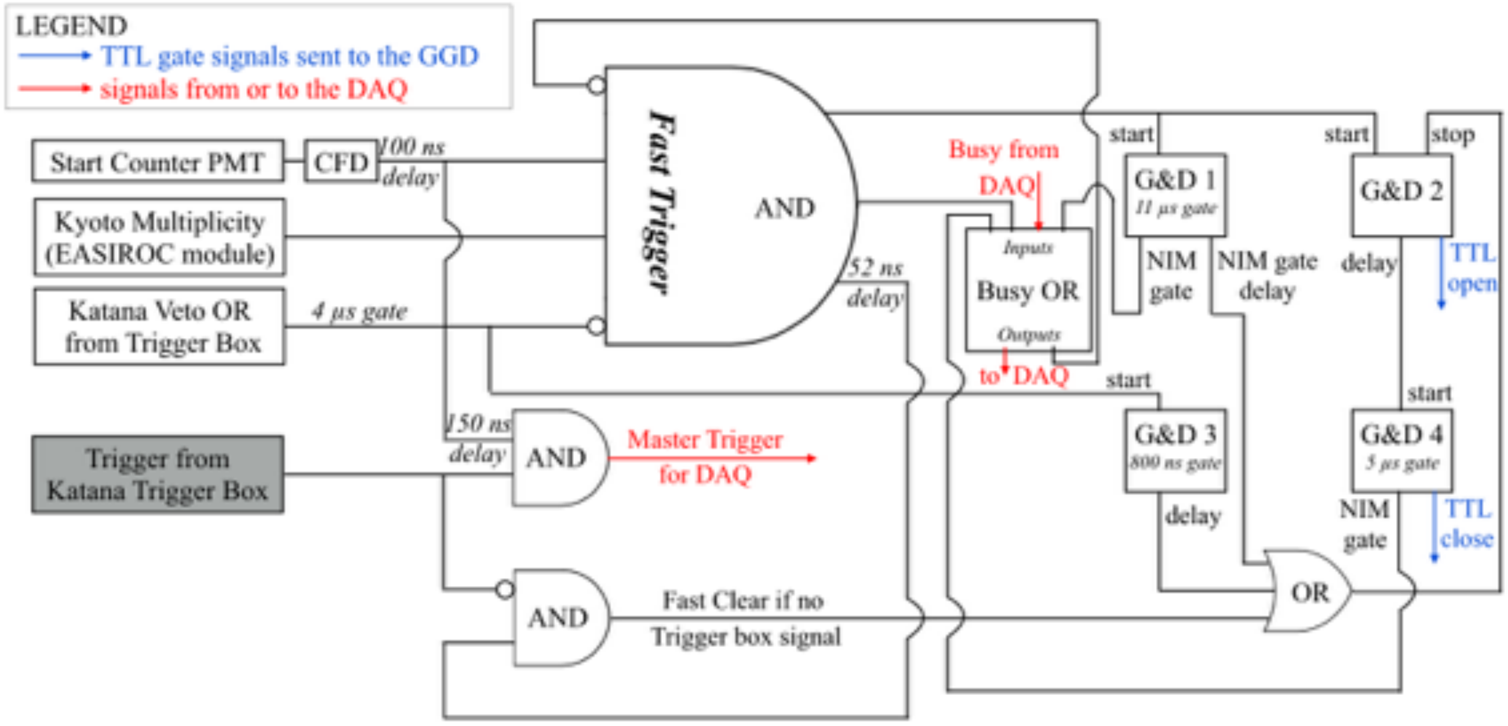


KATANA
(12 + 3 scintillators)
IFJ Poland

Kyoto array
(30x2 scintillators)
Kyoto University

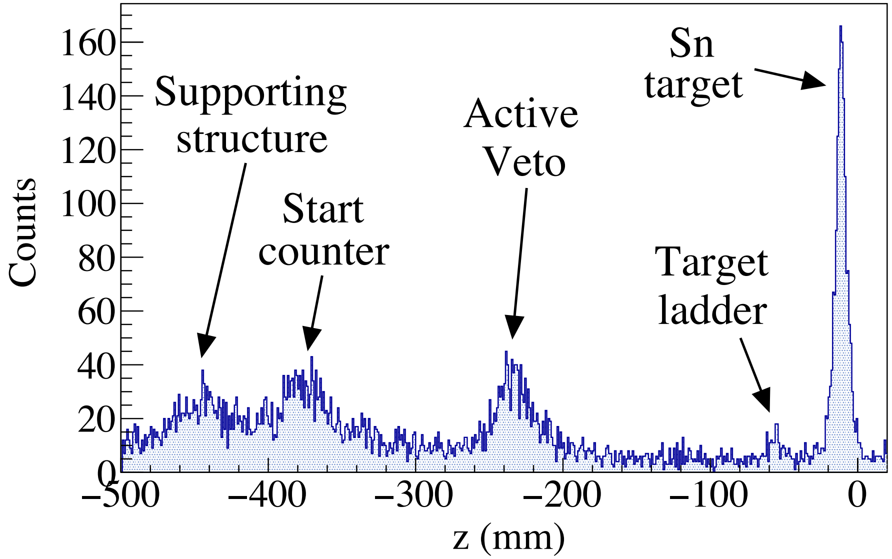
Trigger Box
IFJ Poland

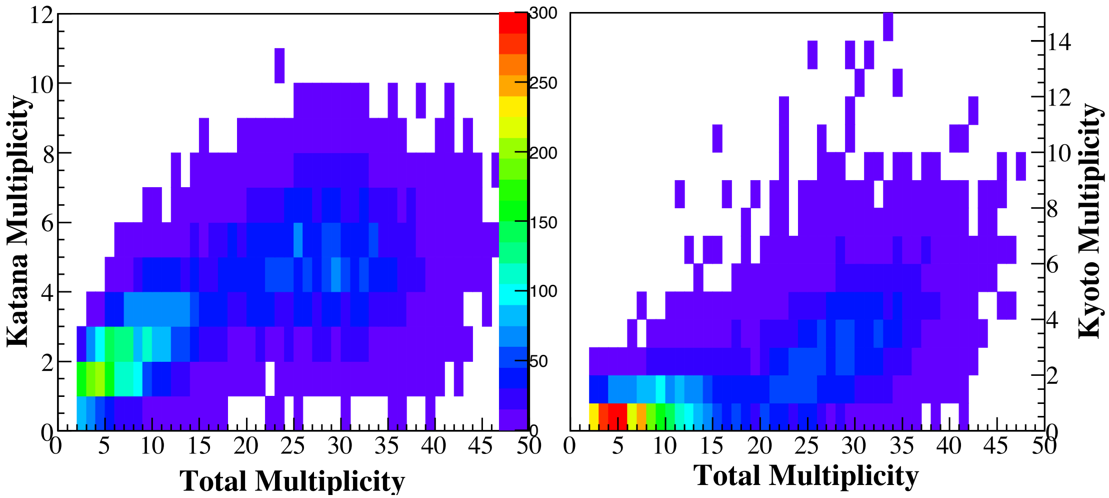
SπRIT EXPERIMENT: TRIGGER LOGIC

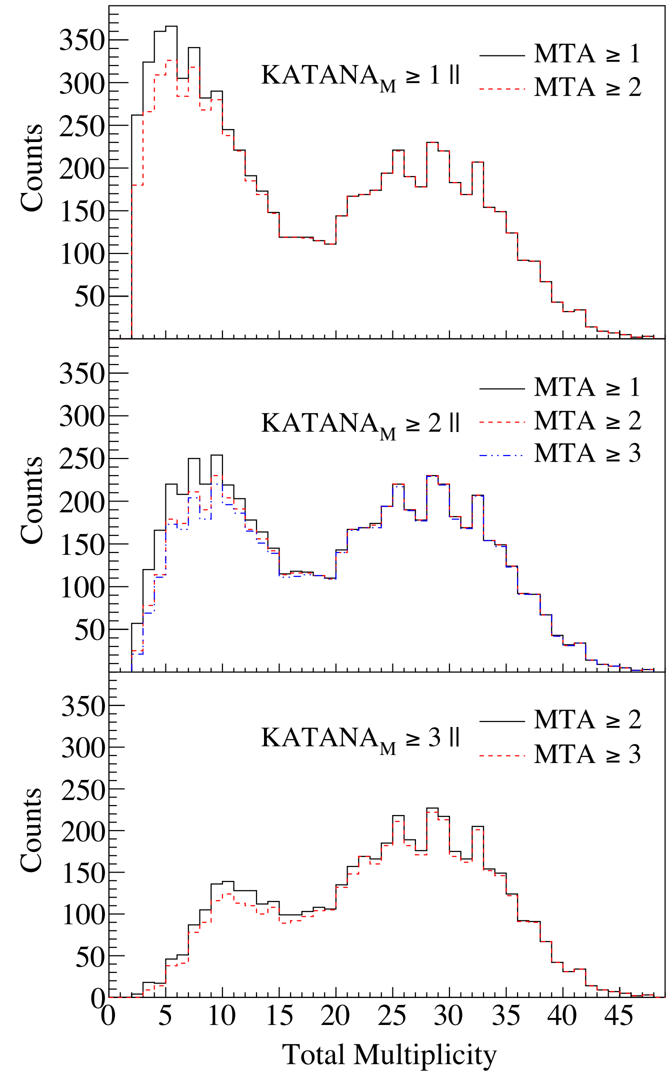


SπRIT COMMISSIONING (OCT. 2015)

G.Jhang *et al.*, J. of the Korean Phys. Soc. **69**, 144 (2016)

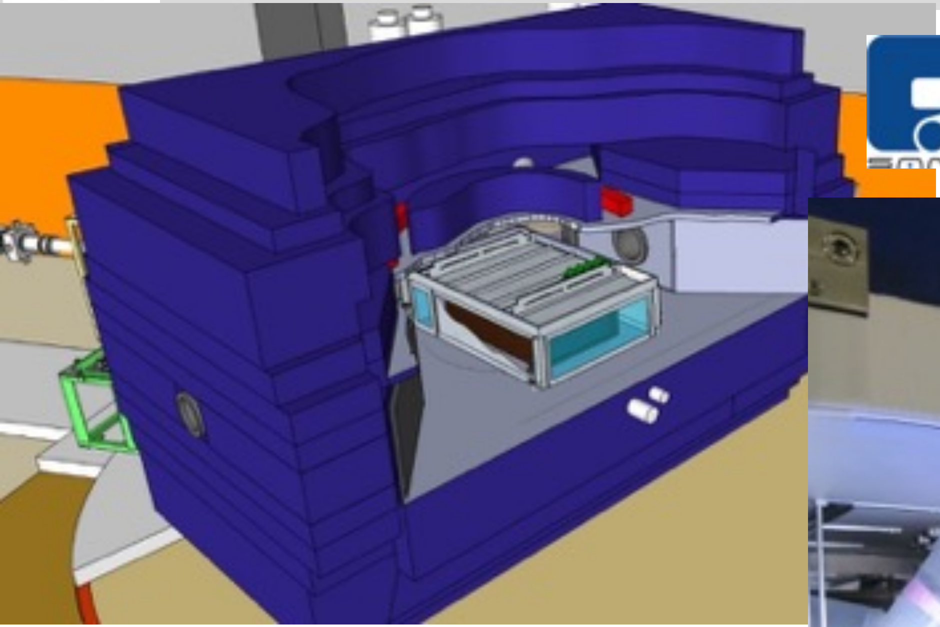


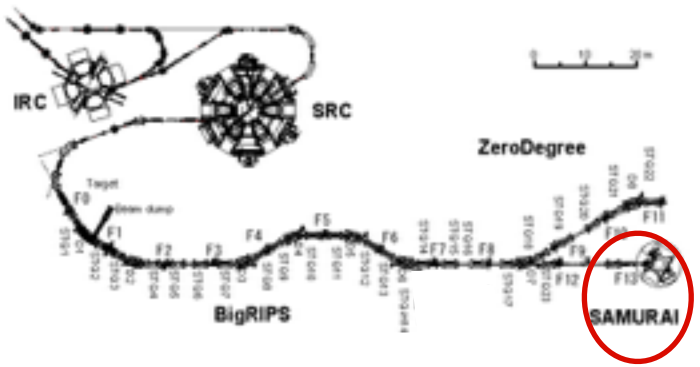


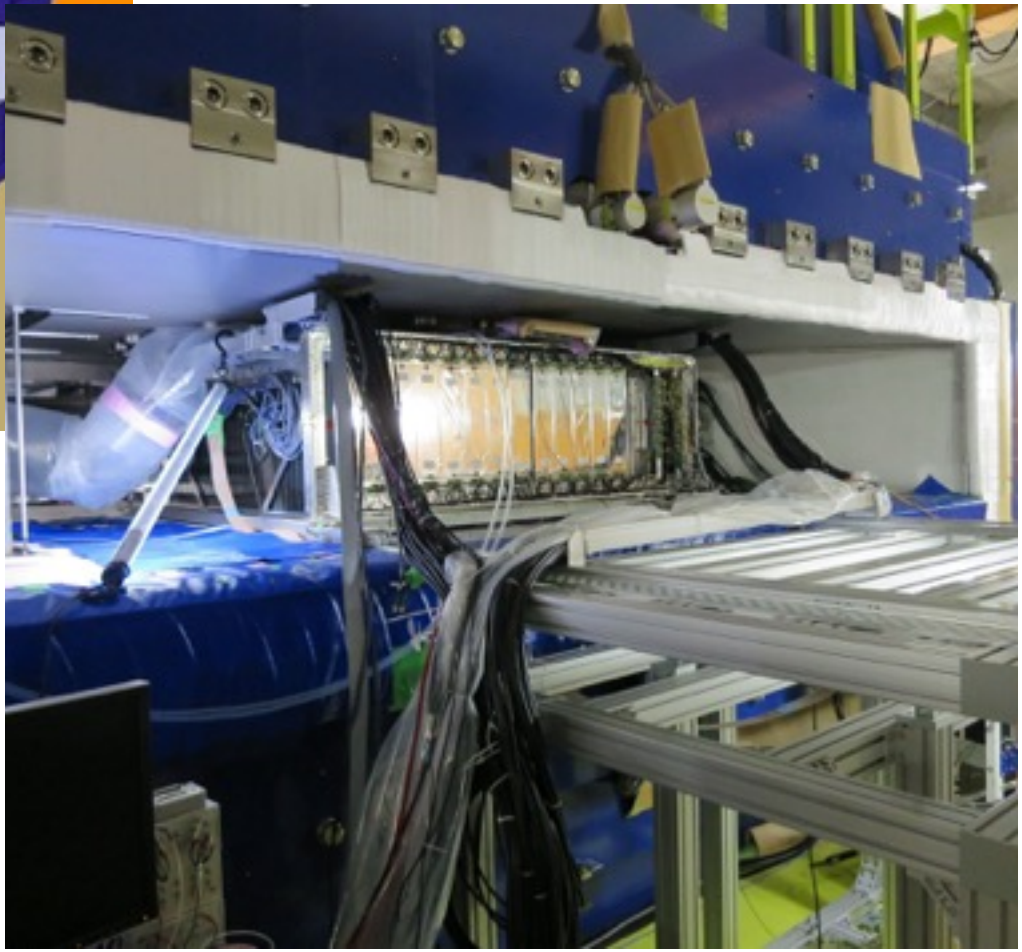


SπRIT EXPERIMENT (SPRING 2016)

At RIBF facility
Japan



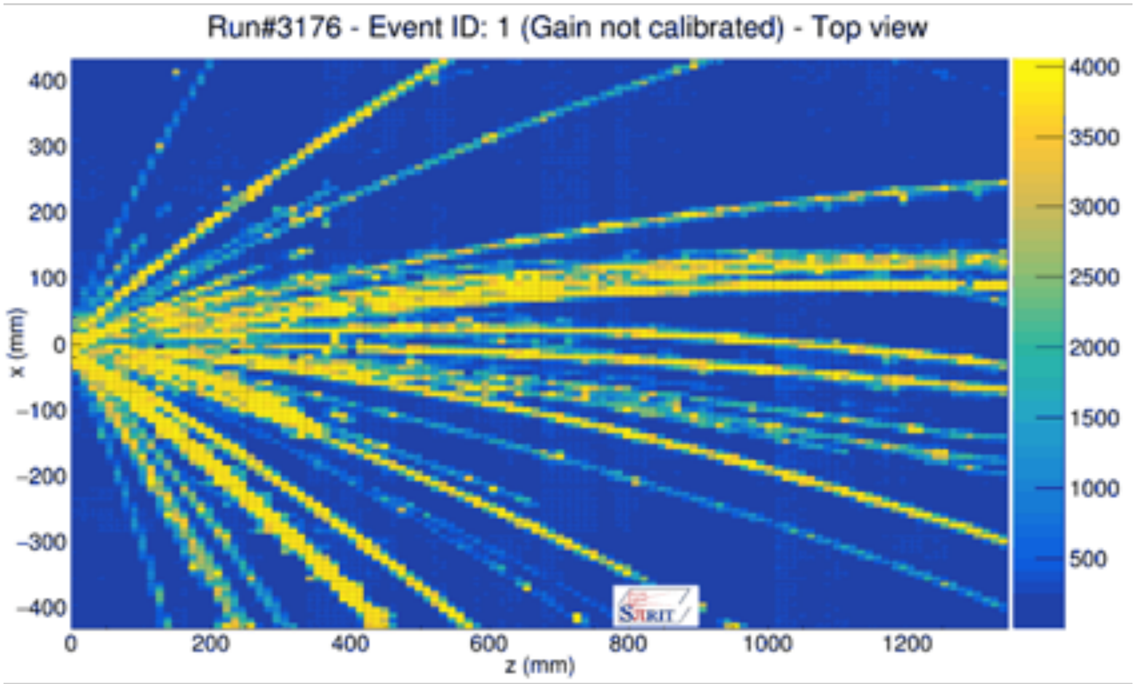




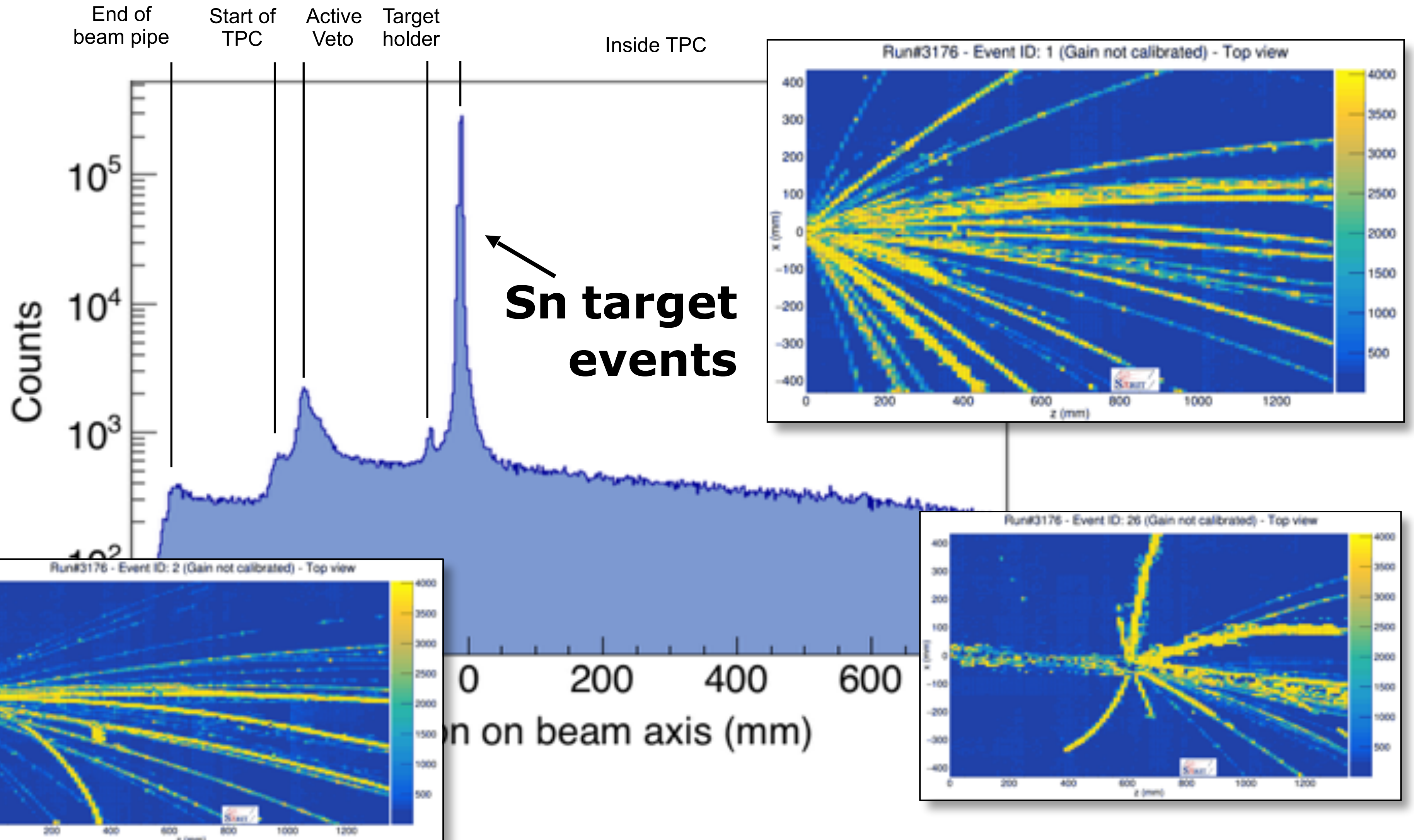
SπRIT TPC: 2D EVENTS

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

- The experiment was finished on 6/1/2016.
- Monitoring plots were generated right after the start of data acquisition is started using our analysis software, SpiRITROOT.
- Positively charged particles bends towards –x direction and vice versa.

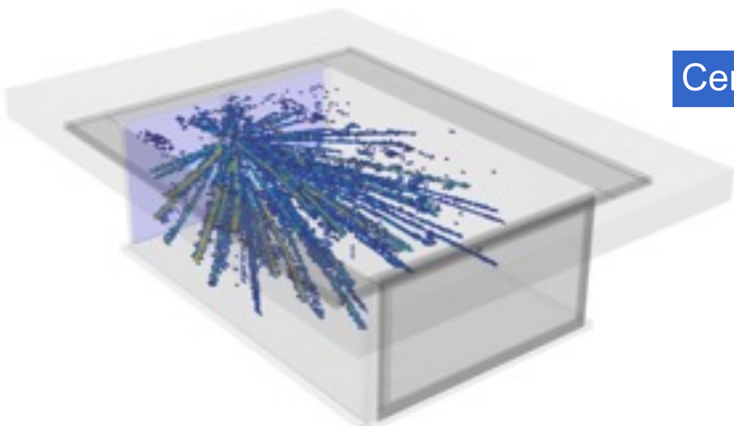


VERTEX RECONSTRUCTION

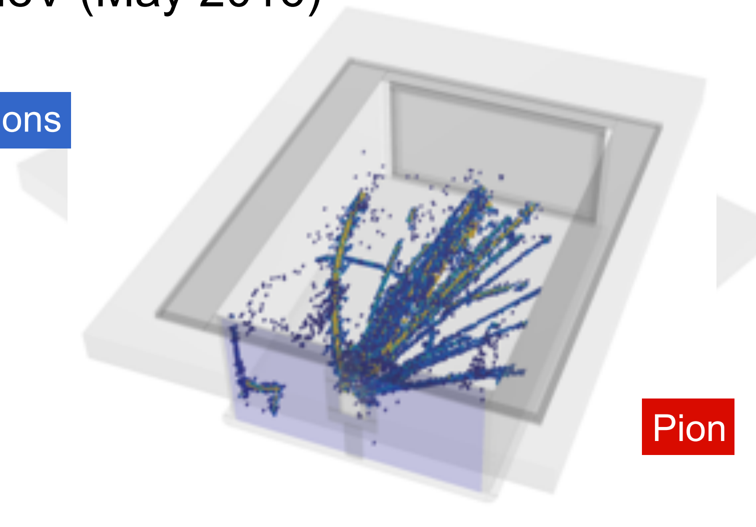


SπRIT TPC: 3D EVENTS

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

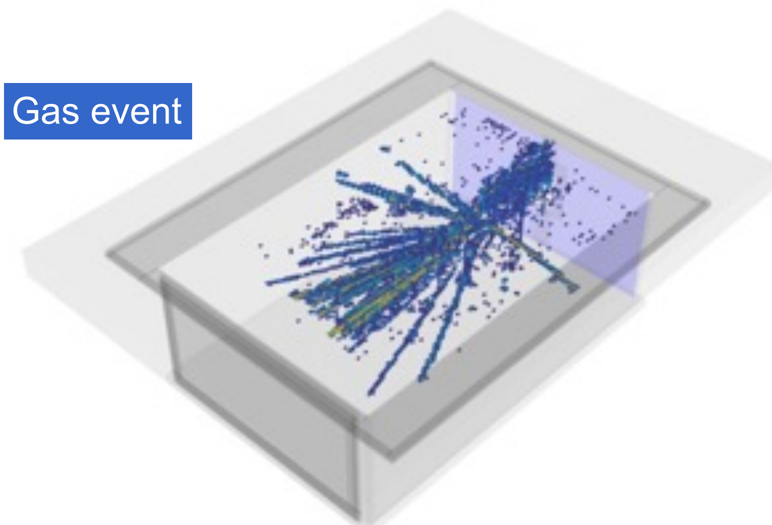


Central reactions

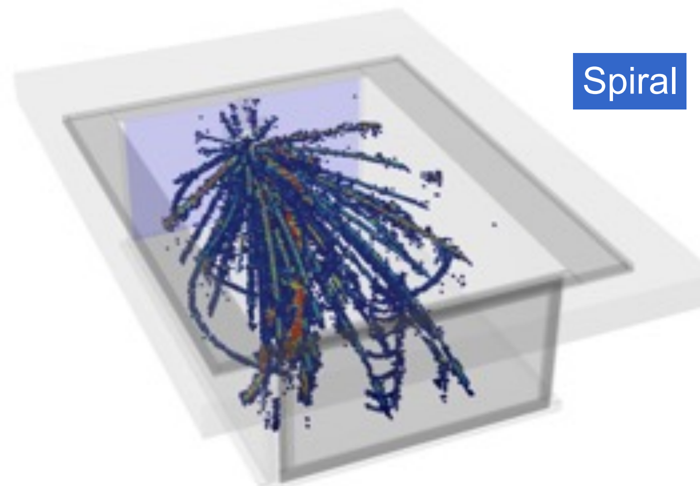


Pion

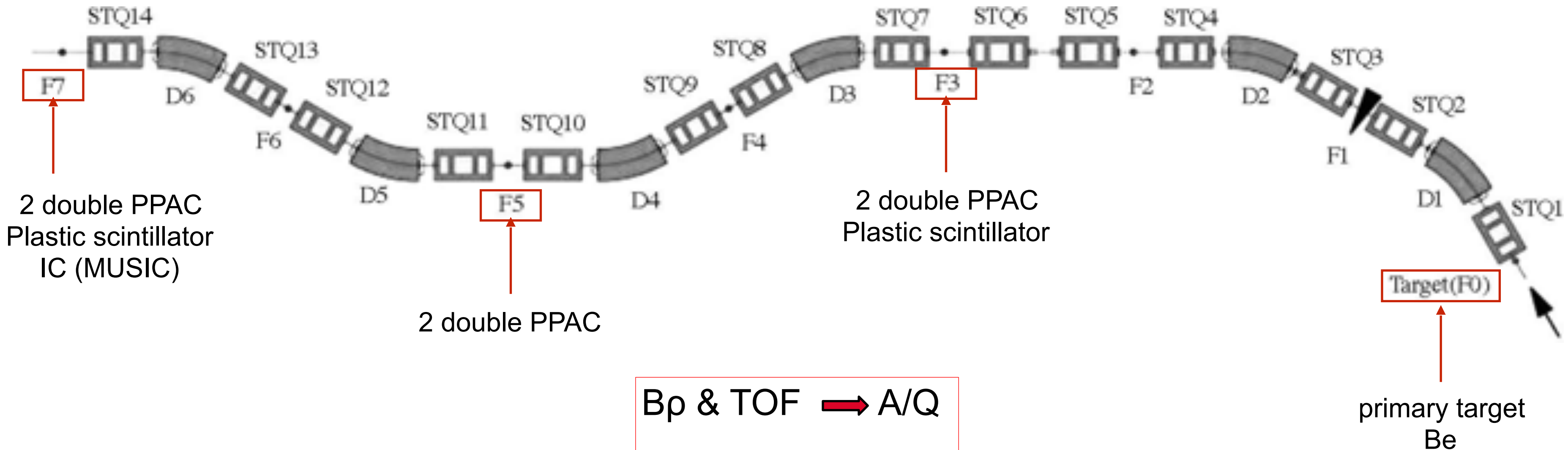
Gas event



Spiral



Identification event-by-event with the Bρ – ΔE – TOF method:
Bρ: position in dispersive plane (PPAC)
ΔE: energy loss in ionization chamber (MUSIC)
TOF: Time Of Flight in the line with plastic scintillators

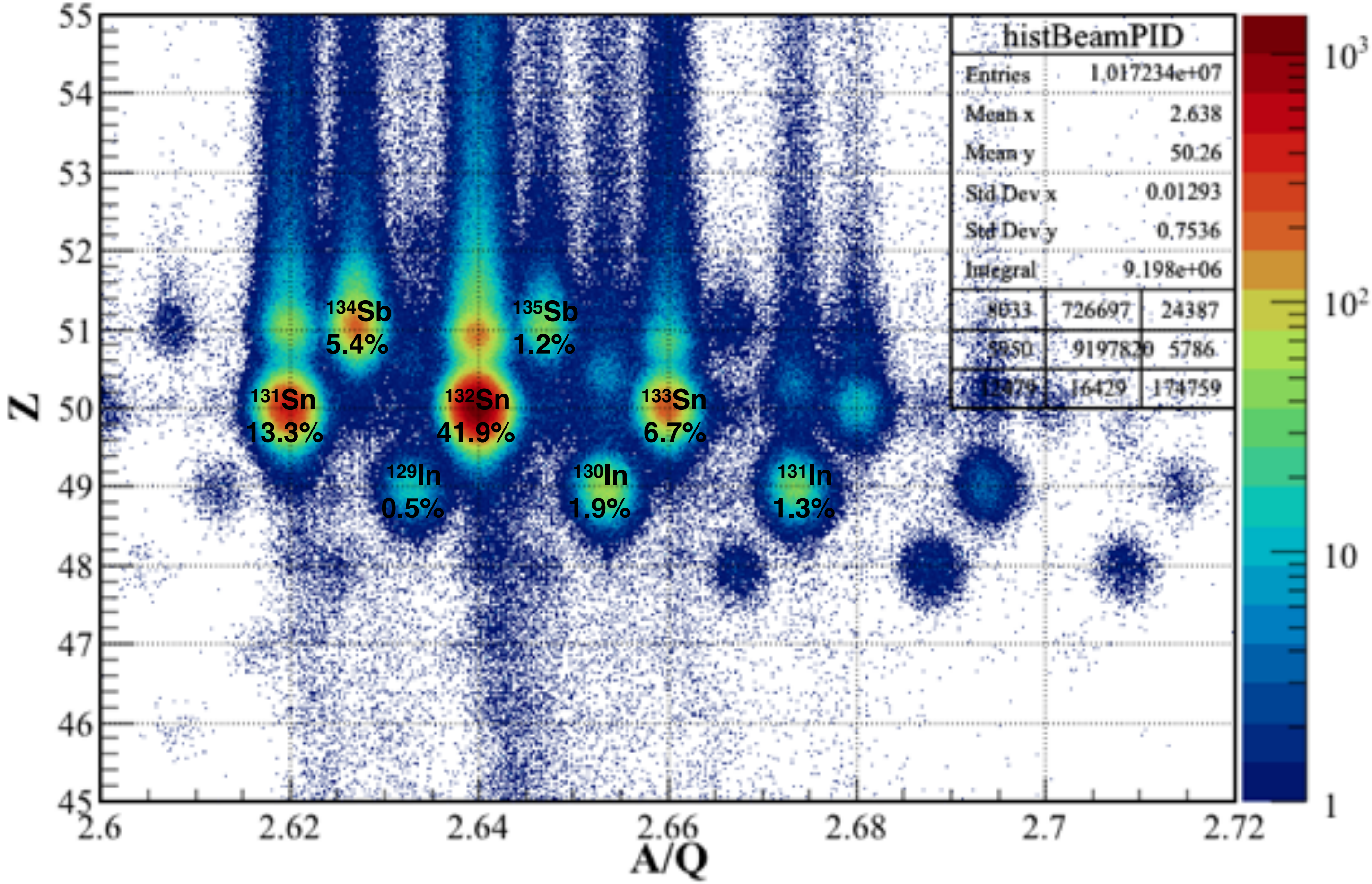


Bρ & TOF → A/Q

ΔE & TOF → Z

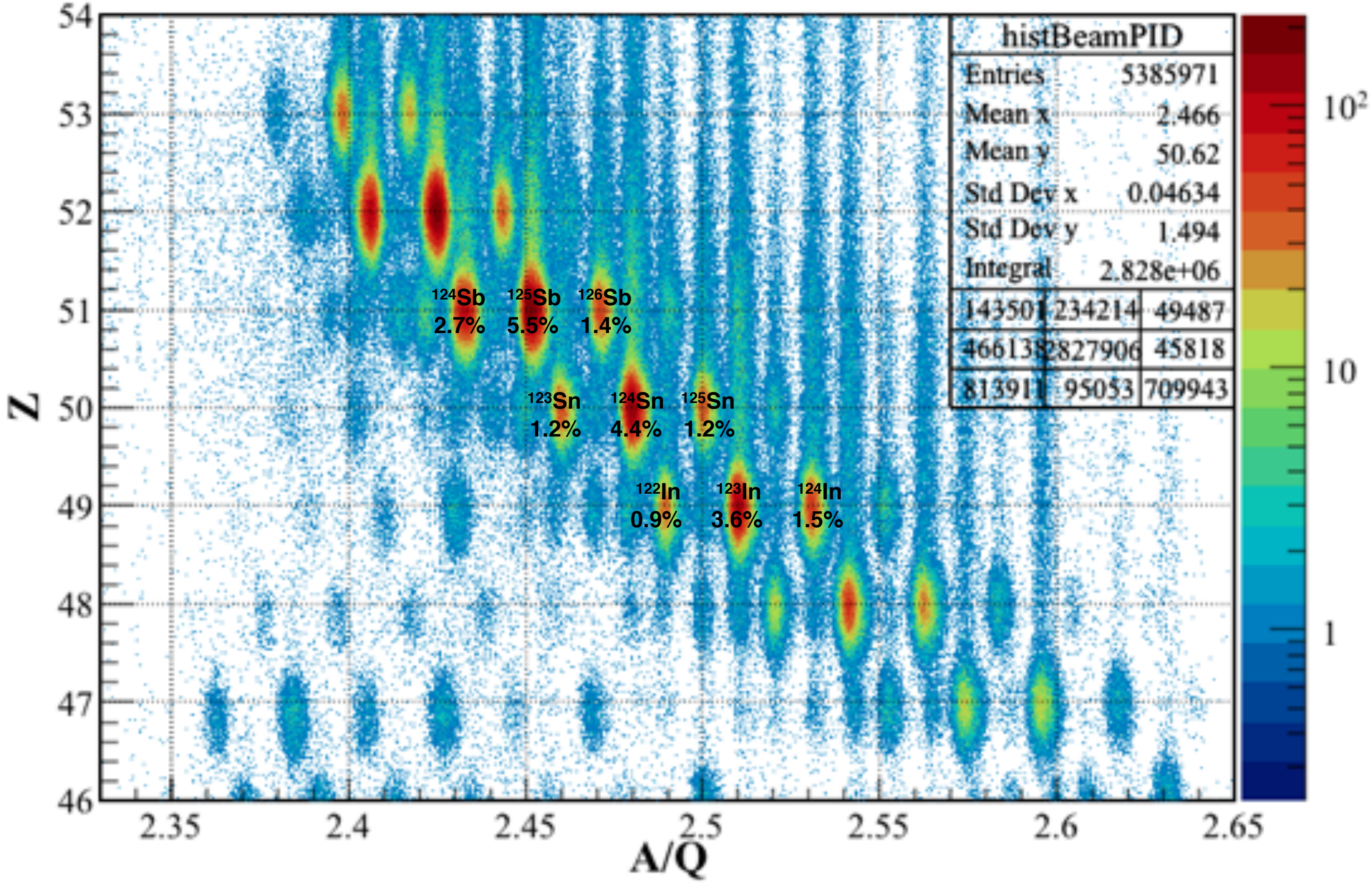
N. Fukuda *et al.*, NIM B **317** (2013) 323

BIGRIPS PID: ^{132}Sn

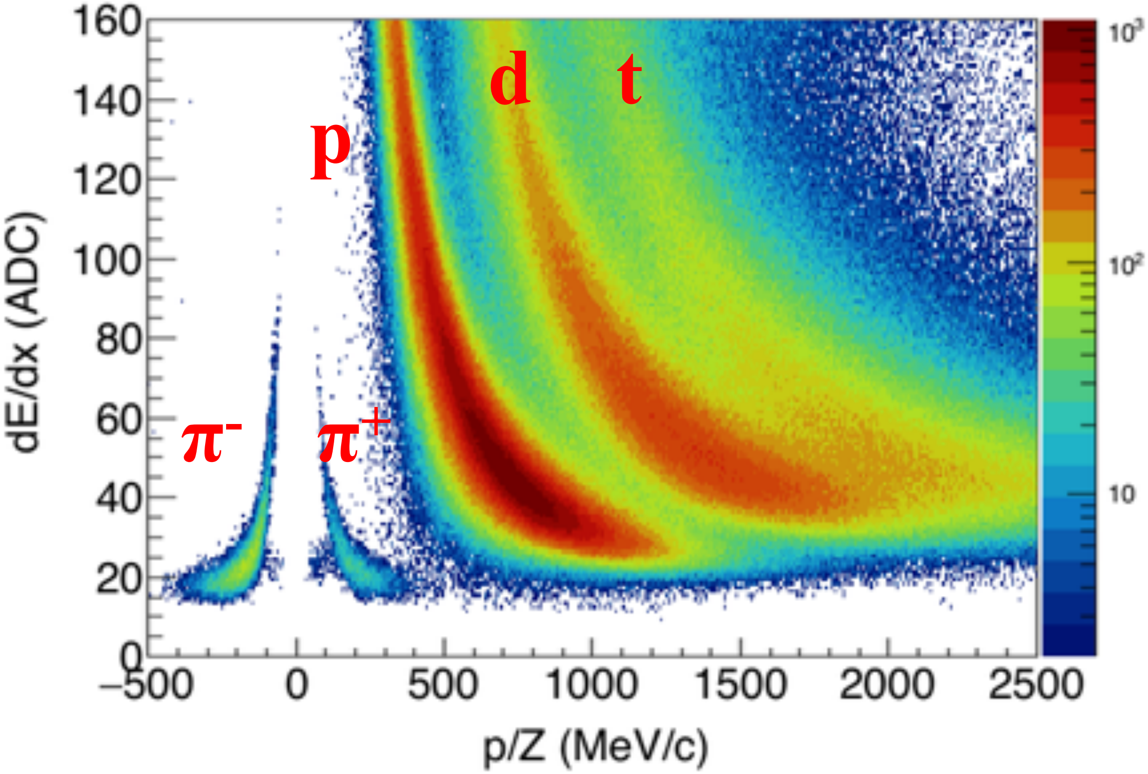


Clémentine Santamaria

BIGRIPS PID: ^{124}Sn



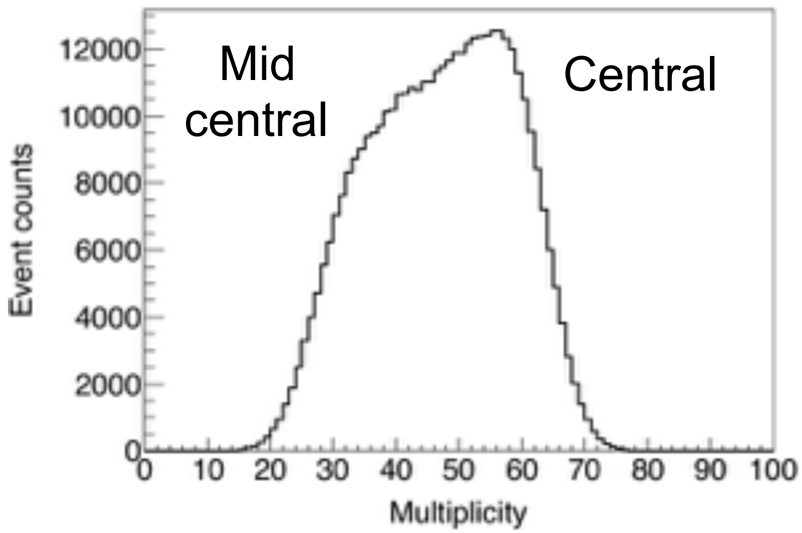
SπRIT RESULTS: ^{132}Sn



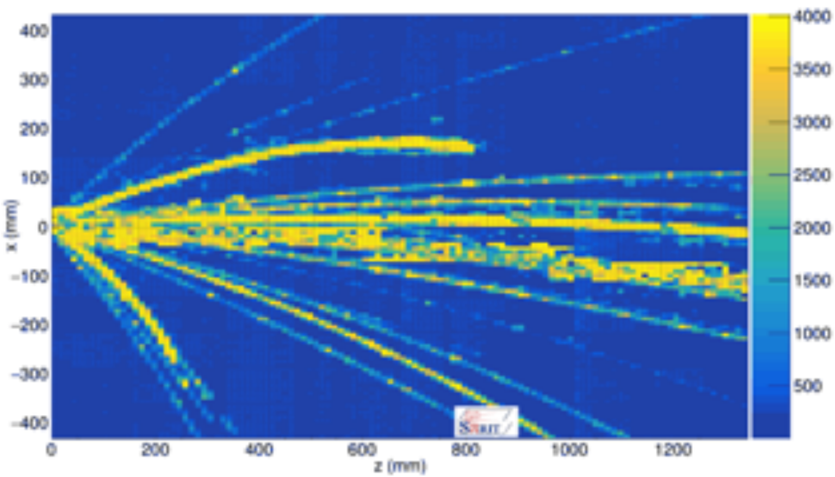
- Software team is focused on extracting pions and protons for now.
- We observed pions, protons, deuterons and tritons.
- π^- are generated more than π^+.
- E_{beam}/A=270 MeV

System	(N-Z)/A	#events
^{132}Sn+^{124}Sn	0.22	O(10^8)
^{108}Sn+^{112}Sn	0.09	
^{112}Sn+^{124}Sn	0.15	
^{124}Sn+^{112}Sn	0.15	

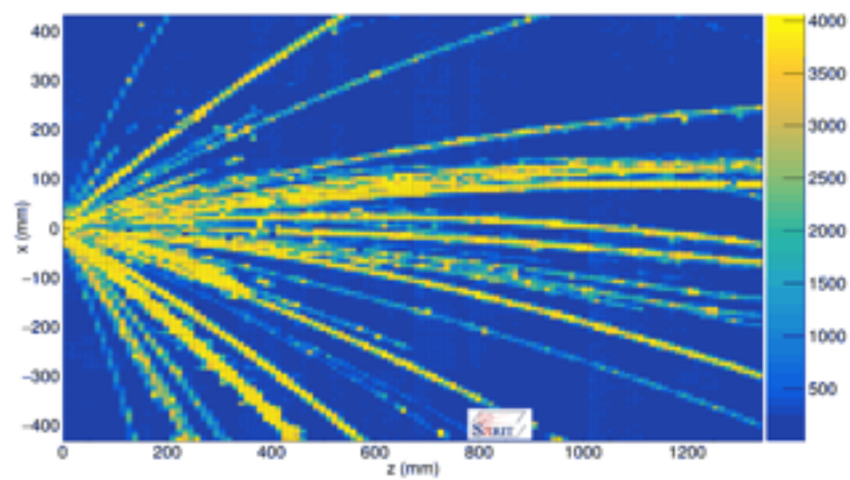
MULTIPLICITY DISTRIBUTION



Multiplicity distribution of the collisions with ^{132}Sn target shows more events in high multiplicity as we expected.

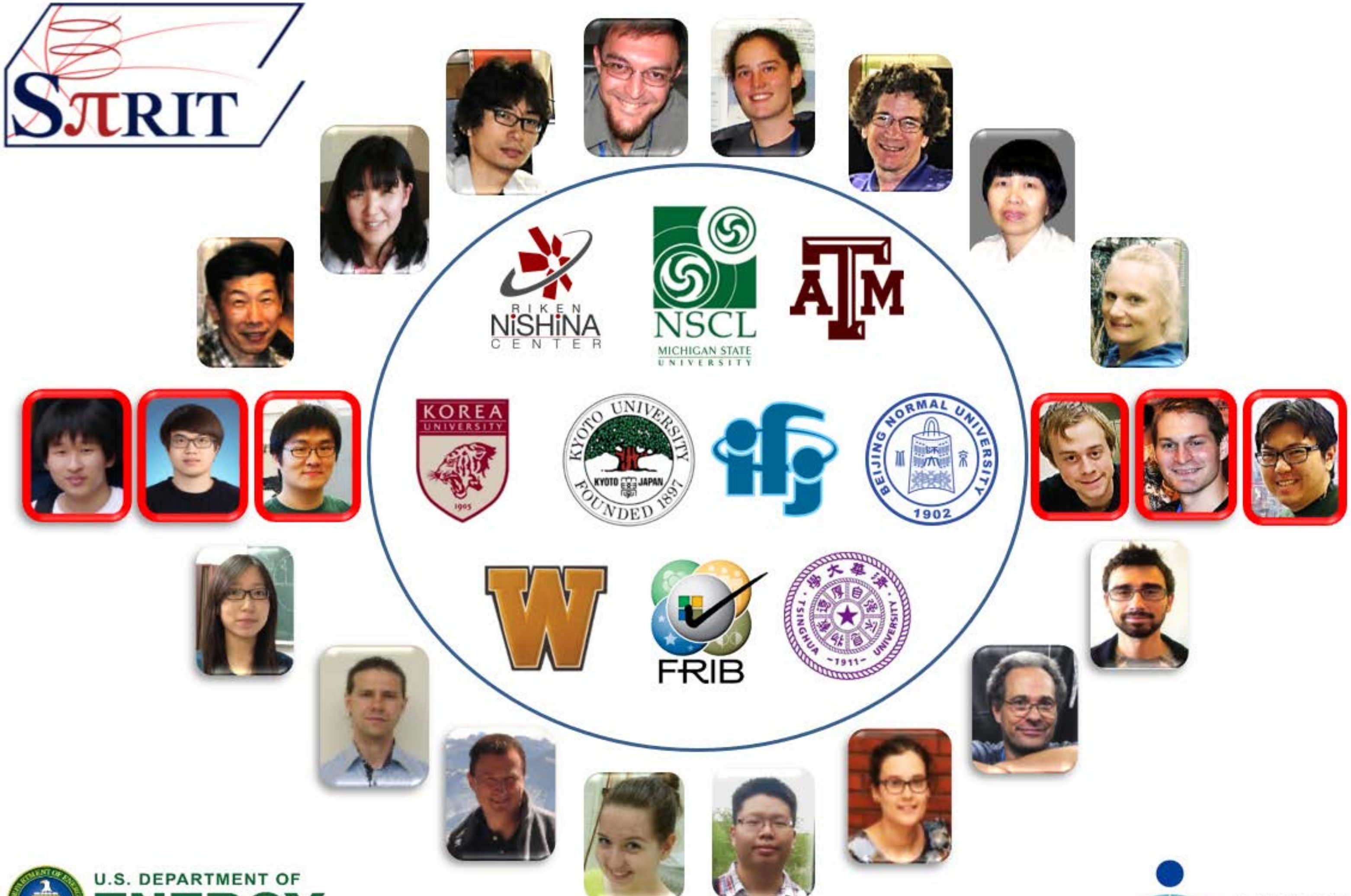


Mid-central event



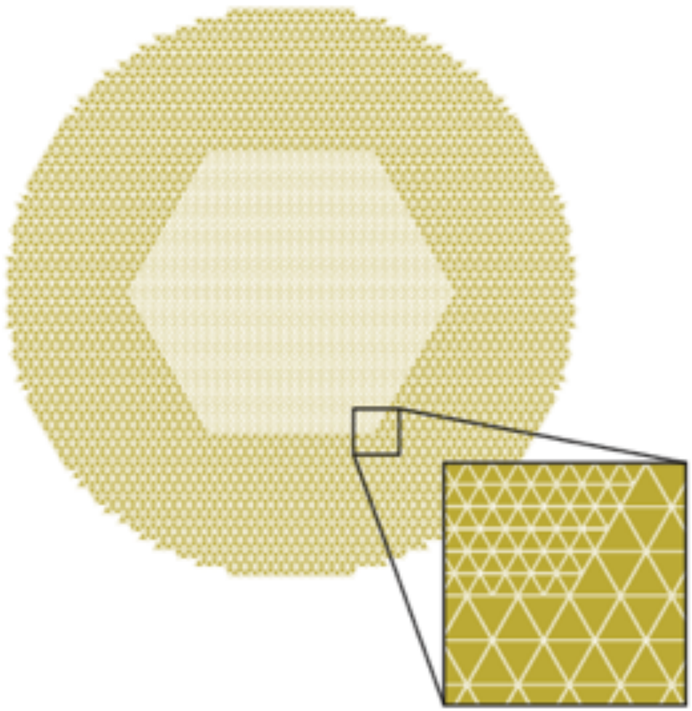
Central event

SπRIT COLLABORATION



AT-TPC: A versatile active target for nuclear structure

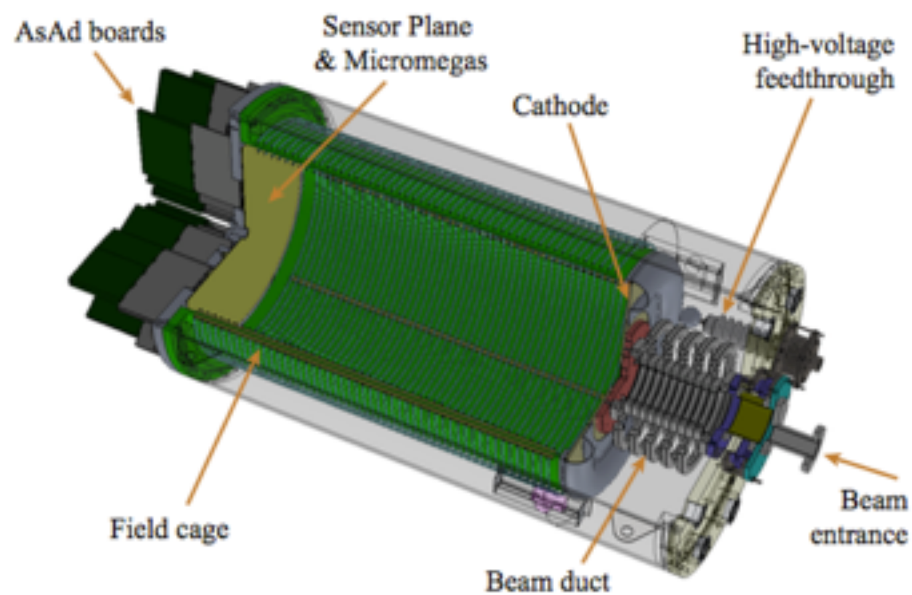
AT-TPC DETECTOR



- Active Target of 1 m length, 55 cm diameter

➡ Thick target, good resolution, 4π detection

- MicroMegas detection pad plane
- 10,240 pads, equilateral triangles
- GET electronics with internal trigger
- Coupling with magnetic field

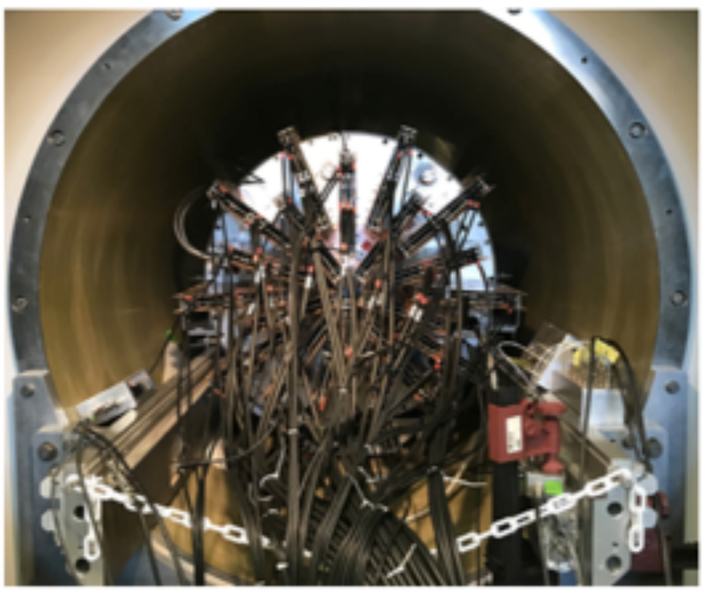


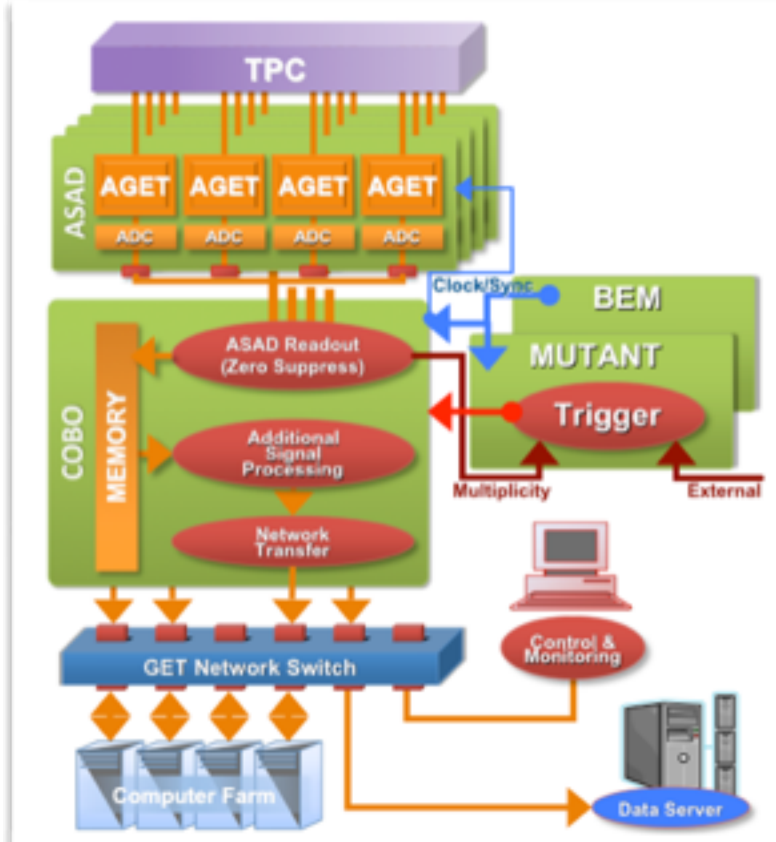
Resolution capabilities

- Scattering angle = 1° for (α, α')
- Energy resolution of 30-40 keV/u in c.m. despite phasing issues

GET ELECTRONICS

★Trigger needs to filter out unreacted beam events
- GET electronics provides discriminators on each pad
- Running multiplicities of each AsAd routed to MuTanT through CoBos
- Trigger configuration can be programmed





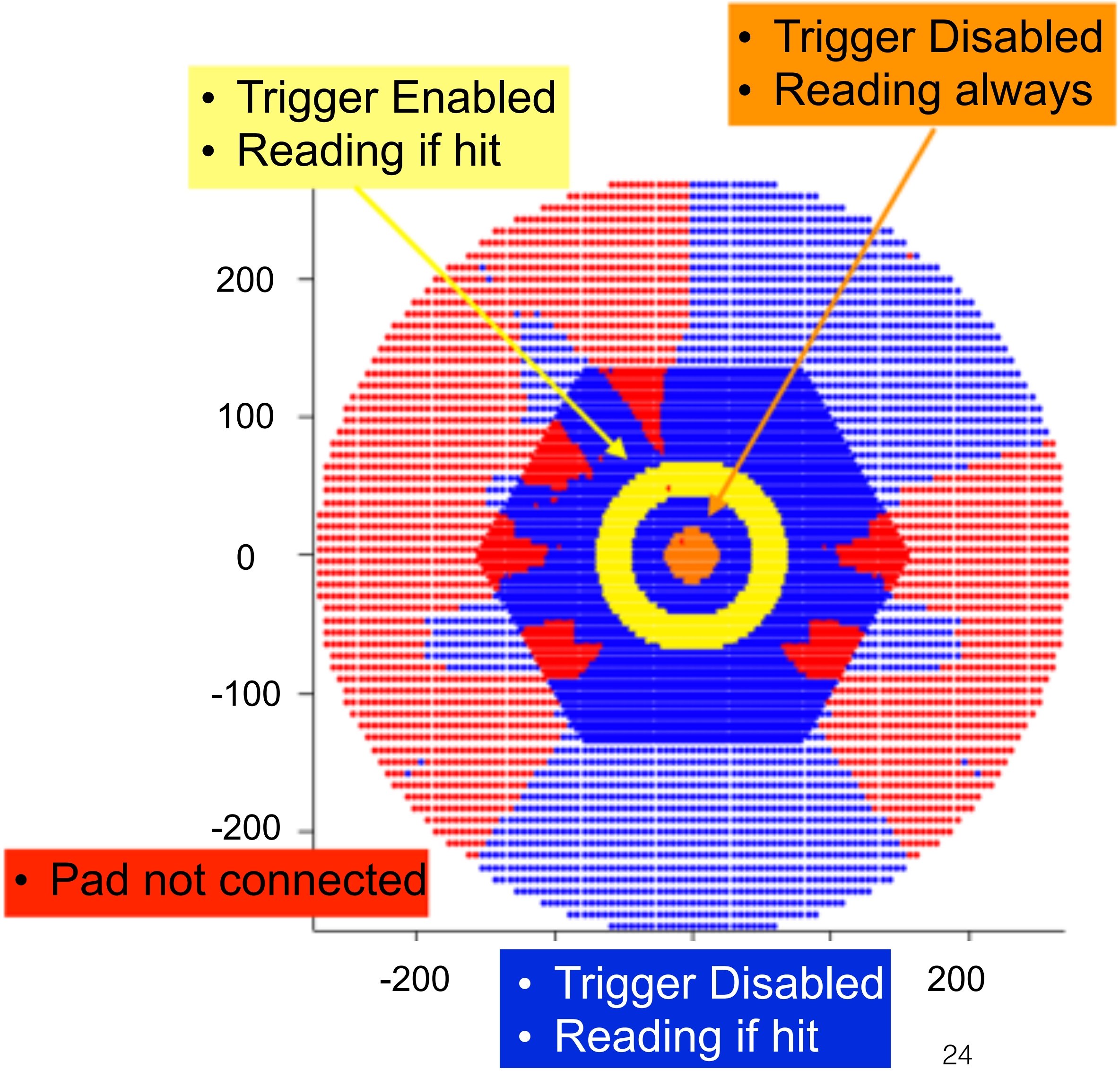
★AGET front-end chips provide various gains and shaping times

★GET: CEA-Saclay, CENBG- Bordeaux, GANIL-Caen, NSCL

★Define pad regions with different trigger attributes

★Example shows configuration for elastic scattering

★More complex pattern triggering can be programmed



AT-TPC EXPERIMENTS

NSCL

Stable beam commissioning of the AT-TPC (D. Bazin): α + α scattering
Commissioning of the AT-TPC with radioactive beam (D. Bazin): ^{46}Ar experiment
Capture cross sections and fusion barrier measurements with the AT-TPC (S. Beceiro-Novo)
Fusion with neutron-rich rare isotope beams (S. Beceiro-Novo)
Measurement of the fission barriers for heavy exotic nuclei (Z. Chajecki)
Direct measurement of a key reaction for the rp-process with the AT-TPC (Y. Ayyad)
Spectroscopy of chlorine isotopes at the proton-drip line (R. Kanungo)
Death of first stars. Measurement of ANC of 12N(p,g)13O relevant for the rap process (J. Pereira)

Notre Dame (pAT-TPC)

^{10}Be+α (D. Suzuki) + higher energy (3-body analysis)
D. Suzuki *et al.*, Phys. Rev. C **87**, 054301 (2013)
A. Fritsch *et al.*, Phys. Rev. C **93**, 014321 (2016)
^{10}Be + ^{40}Ar fusion barrier (J. Kolata)
F.D. Bechetti *et al.*, NIM B **376**, 397 (2016)
^{12}C Hoyle state decay
^{10}C + α , mirror of ^{10}Be

TRIUMF (pAT-TPC)

Investigation of nuclear forces, nucleon correlation and resonances in ^{8}He (R. Kanungo) ^{8}He+α
Search for cluster structures in ^{16}C through resonant alpha scattering (Y. Ayyad, W. Mittig) ^{12}Be+α

LBNL (pAT-TPC) => Campaign in Spring 2018 ?

RCNP (AT-TPC)

^{17}C (d,p) (B. Fernandez Dominguez)

AT-TPC ANALYSIS FRAMEWORK

★ Two analysis frameworks developed in parallel:
- ATTPCROOT (C++, ROOT, and FairROOT)
- pyTPC (Python)

★ Provides tools for analysis & simulation in the same framework:
- Merger of raw data taken by GET electronics (hdf5 or ROOT files)
- Pulse Shape Analysis of signals on pads + calibration (time, charge)
- Transforms (Hough, RANSAC…) to distinguish tracks & get starting points for the fitting procedure
- Fitter (MC fitting) to get final parameters for the tracks

★ Development of cross-platform libraries INDEPENDENT of framework

★ Maintenance of those libraries by the AT-TPC group, with the availability to use the 2 frameworks (no maintenance for them)

FairSoft

- ★ All the necessary packages collected to run FairRoot
- ★ Designed to be installed on both Linux and OS X
- ★ Included packages:
- ★ gtest, gsl, boost, Pythia6, Pythia8, HepMC, GEANT3, GEANT4, XRootD, Pluto, ROOT, VGM, VMC, Millepede, ZeroMQ, Protocol Buffers, nanomsg
- ★ RAVE, CLHEP, and GENFIT2 packages added for SπRITROOT

FairRoot

- ★ A framework containing base classes for running simulation, reconstruction and analysis

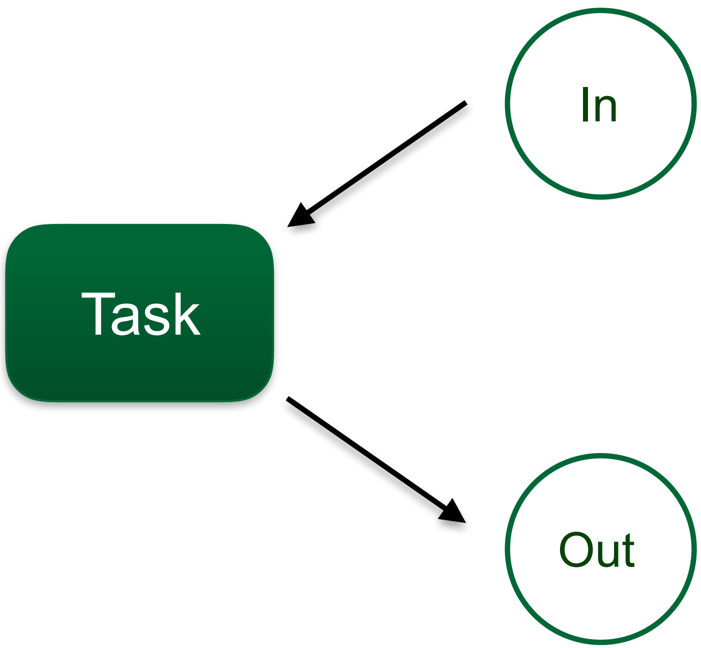
ATTPCROOT

- ★ Based on the SπRIT analysis framework SpiRITROOT
- ★ A framework containing specific modules for AT-TPC experiment on top of FairRoot
- ★ Composed of task-based modules, TGeo geometry and steering macro
- ★ Written by following the structure of FOPIROOT

. M. Ball et al., Technical Design Study for the PANDA Time Projection Chamber, http://arxiv.org/abs/1207.0013

ATTPCROOT: A TASK BASED MODULE

★ Easy to turn on and off
★ Analysis separated in steps
★ Easy to debug and maintain

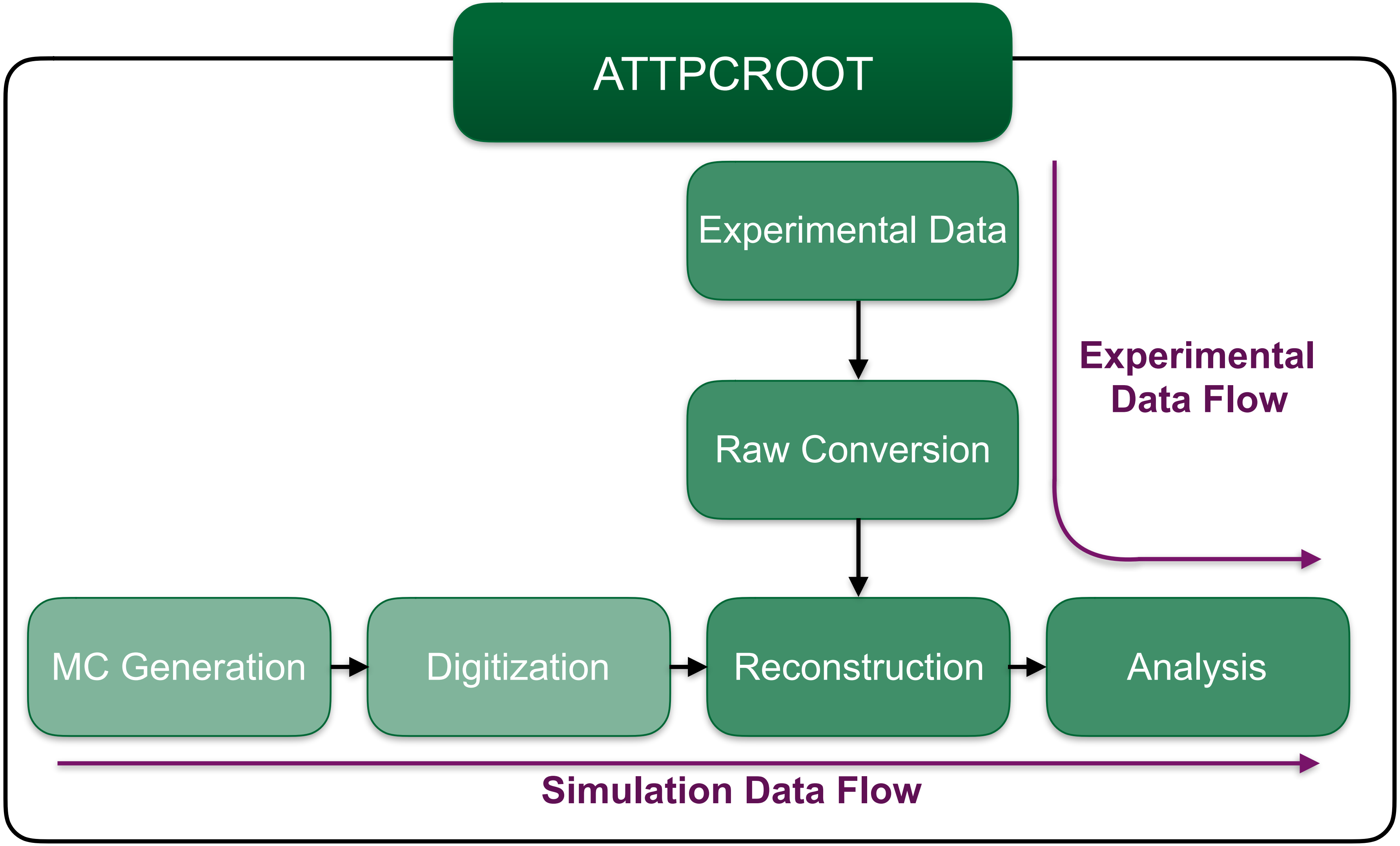


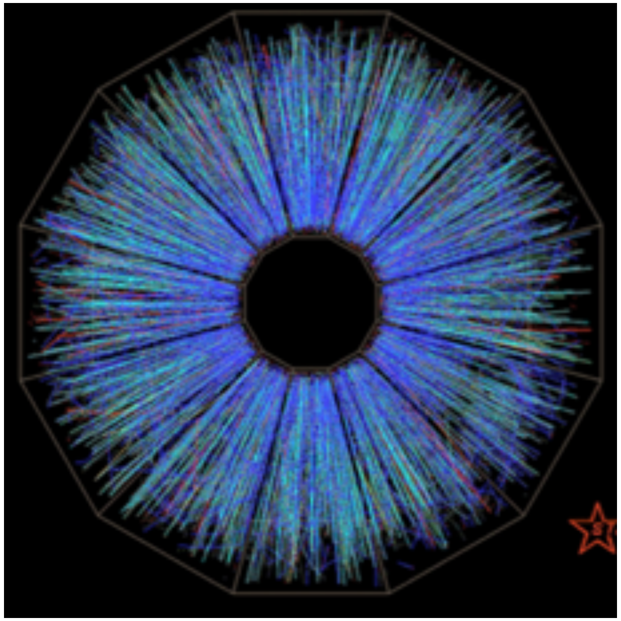
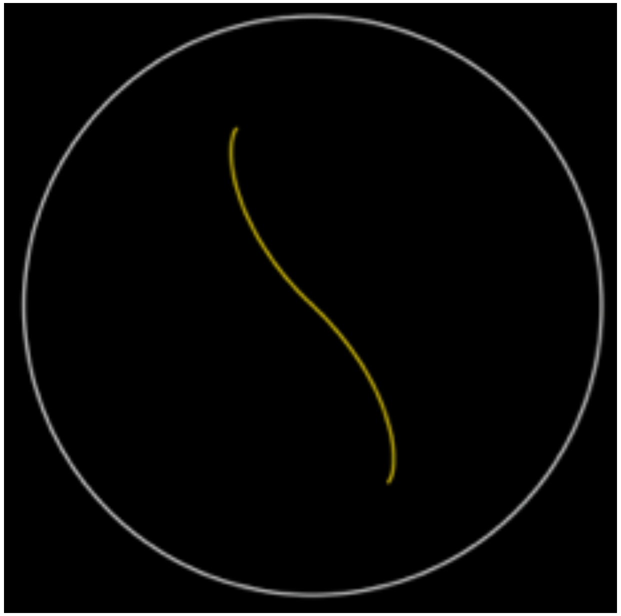
- ASCII
- GRAW
- ROOT
- An object on memory (TClonesArray*)

- ROOT
- An object on memory (TClonesArray*)

*TClonesArray is a container class provided in ROOT which can be stored in ROOT file.

SCHEMATICS OF ATTPCROOT



High Energy Physics	AT-TPC
	

- Many tracks
- Tracks leave volume
- Constant curvature

- Few tracks
- Tracks stop in volume
- Changing curvature
- Tracking protons to fission products
- With & without B field

TRACKING RECONSTRUCTION

Initial fit of tracks

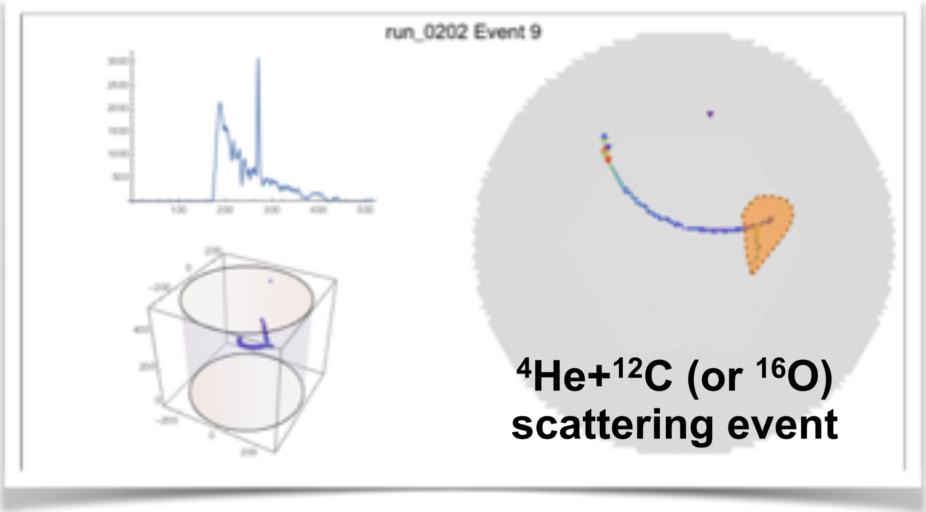
- Hough transform for lines (without B field) and for circles (with B field)
- RANSAC= RANdom SAmple Consensus algorithm for line detection
- Hierarchical clustering
- 3D Hough Transform (from Dalitz)
- Neural network envisioned

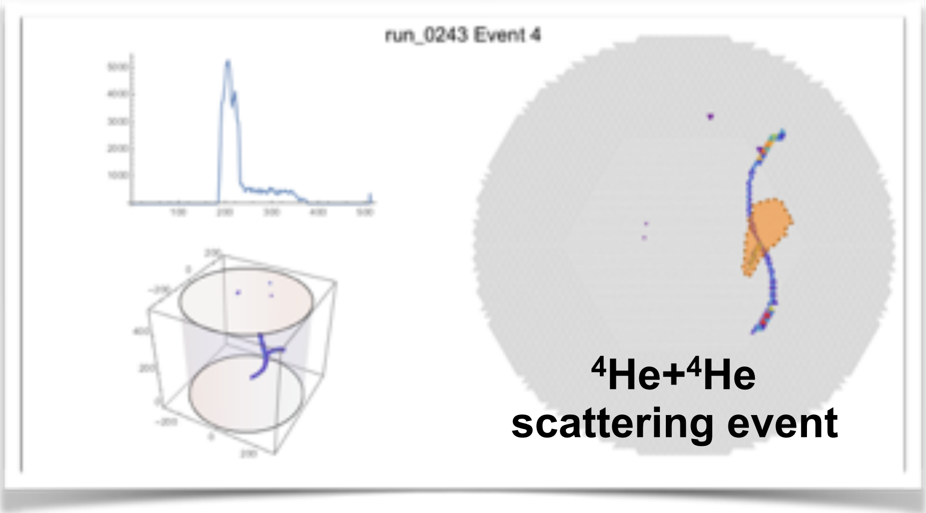
Final fit of the tracks

- Monte Carlo iterative procedure to correctly fit the tracks
- Starting point of the parameters from the initial fit

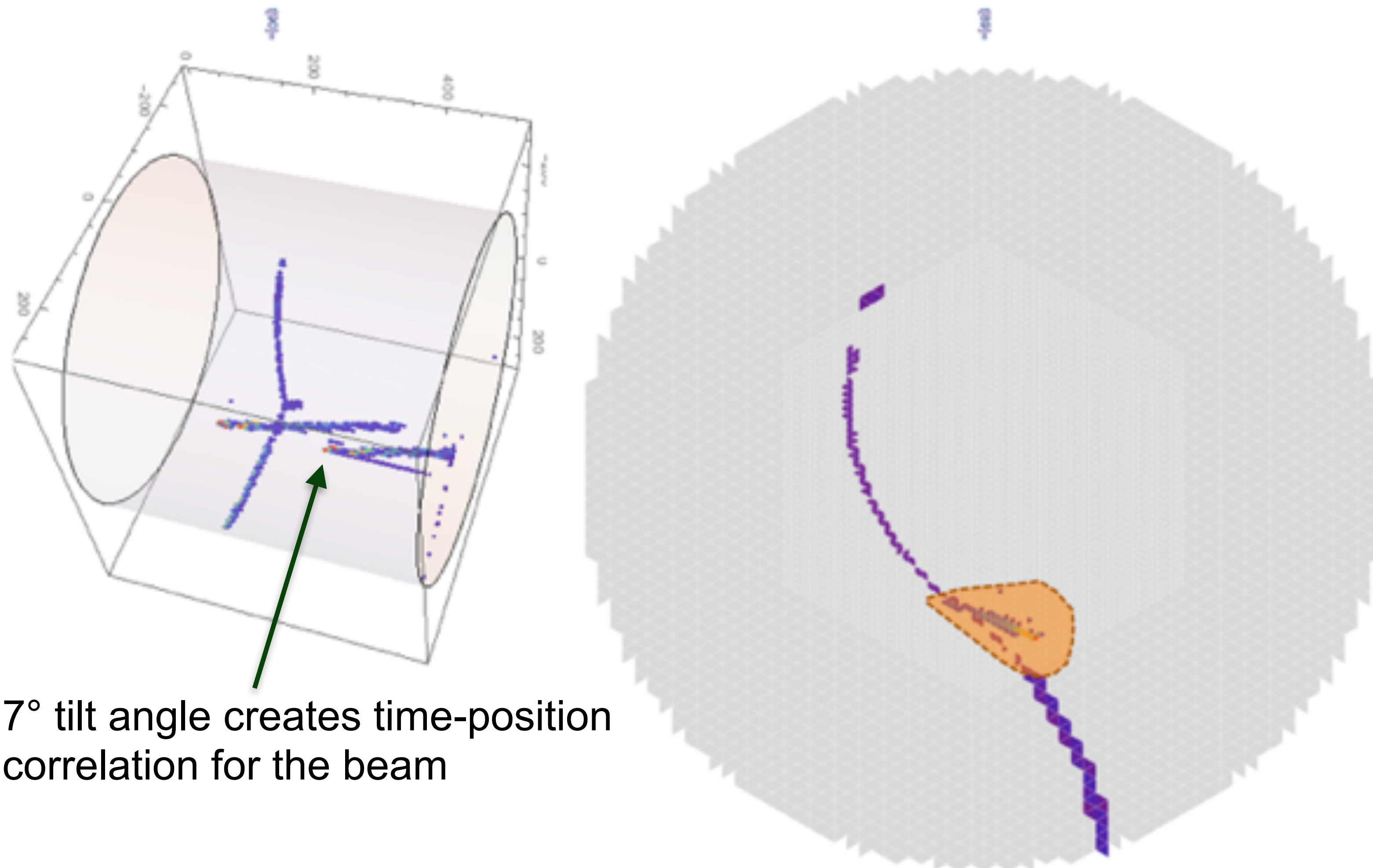
EVENT EXAMPLES

- ★ Commissioning in December 2014
  - Beam: 4He at 3 MeV/u
  - Target: He(90%) + CO2(10%) @ 100 torr
  - Magnetic field: 1 Tesla
- ★ Event displays
  - Right: hit pattern on pad plane, orange region is trigger exclusion zone
  - Top Left: integrated time projection
  - Bottom Left: 3D reconstruction of the event





PILE UP REJECTION

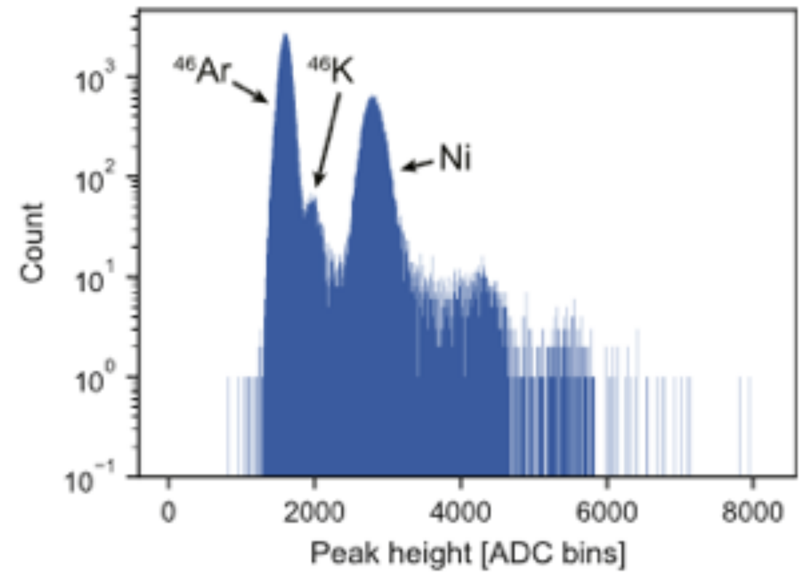


7° tilt angle creates time-position correlation for the beam

Track reconstruction more complex as B and E field not aligned

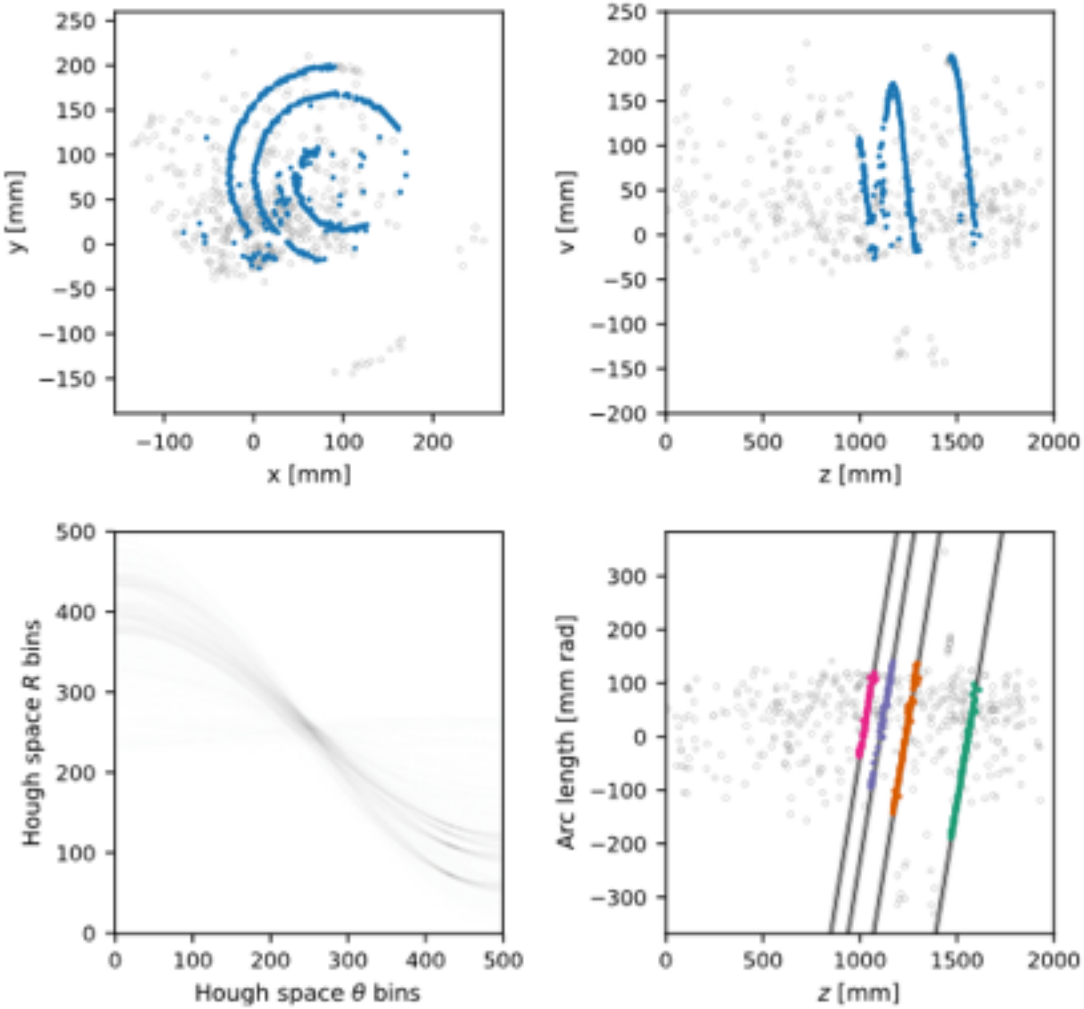
^{46}Ar EXPERIMENT @ NSCL

- ★ Resonant proton scattering in inverse kinematics: ^{46}Ar (p,p')
- ★ Validation of reaction for TPCs
- ★ Commissioning of the AT-TPC with radioactive beam



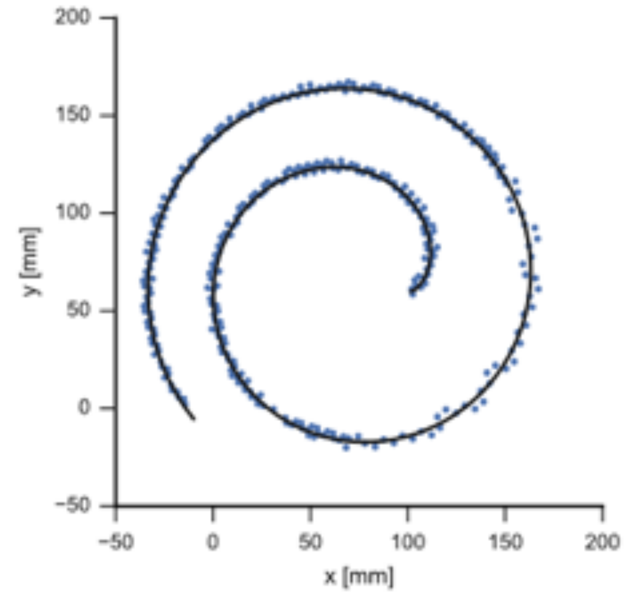
★ Figure: Ion chamber spectrum

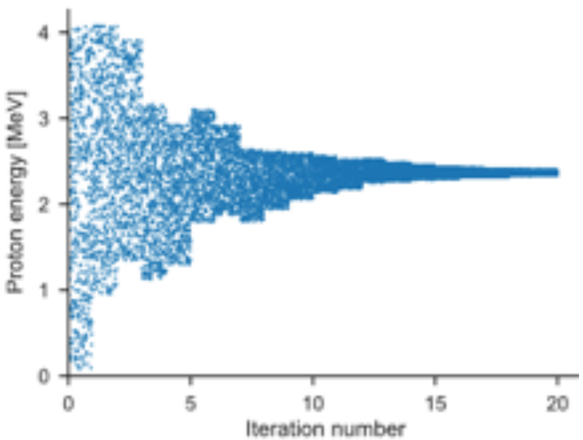
TRACKING: HOUGH TRANSFORM (^{46}Ar)

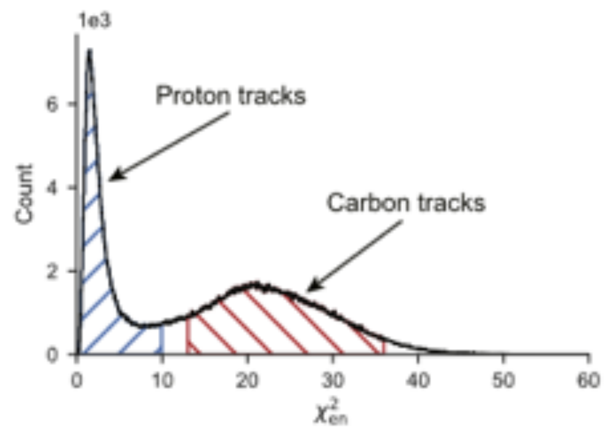


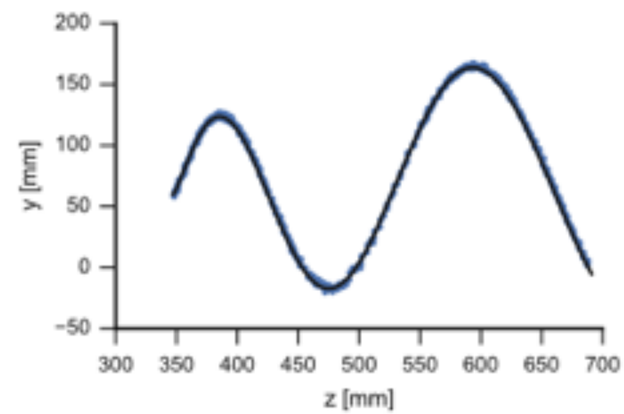
TRACKING: MONTE CARLO FIT (^{46}Ar)

- ★ Right: Sample event from ^{46}Ar run, result of the MC fit with line, proton energy reconstructed at 2.081 MeV with a scattering angle of 63.5° (lab frame)
- ★ Bottom Left: Monte Carlo fitted energy for proton track with respect to iteration
- ★ Bottom Center: χ^2 energy fit, we can distinguish proton from carbon scattering









J. Bradt, NIM A **875**, 65-79 (2017)

FUSION-FISSION CROSS SECTION

PHYSICAL REVIEW C 75, 054603 (2007)

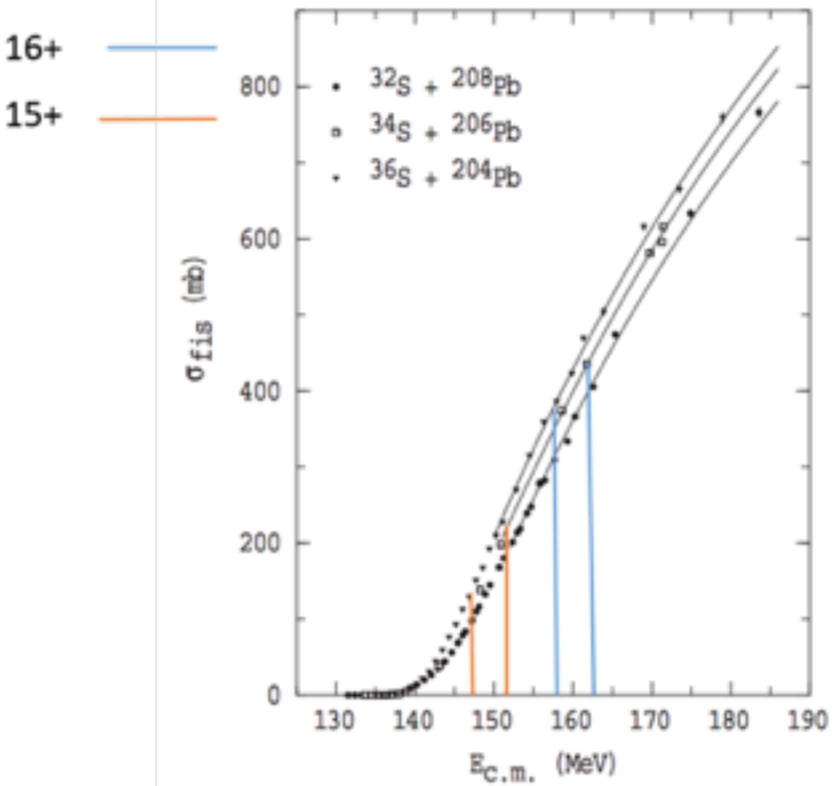
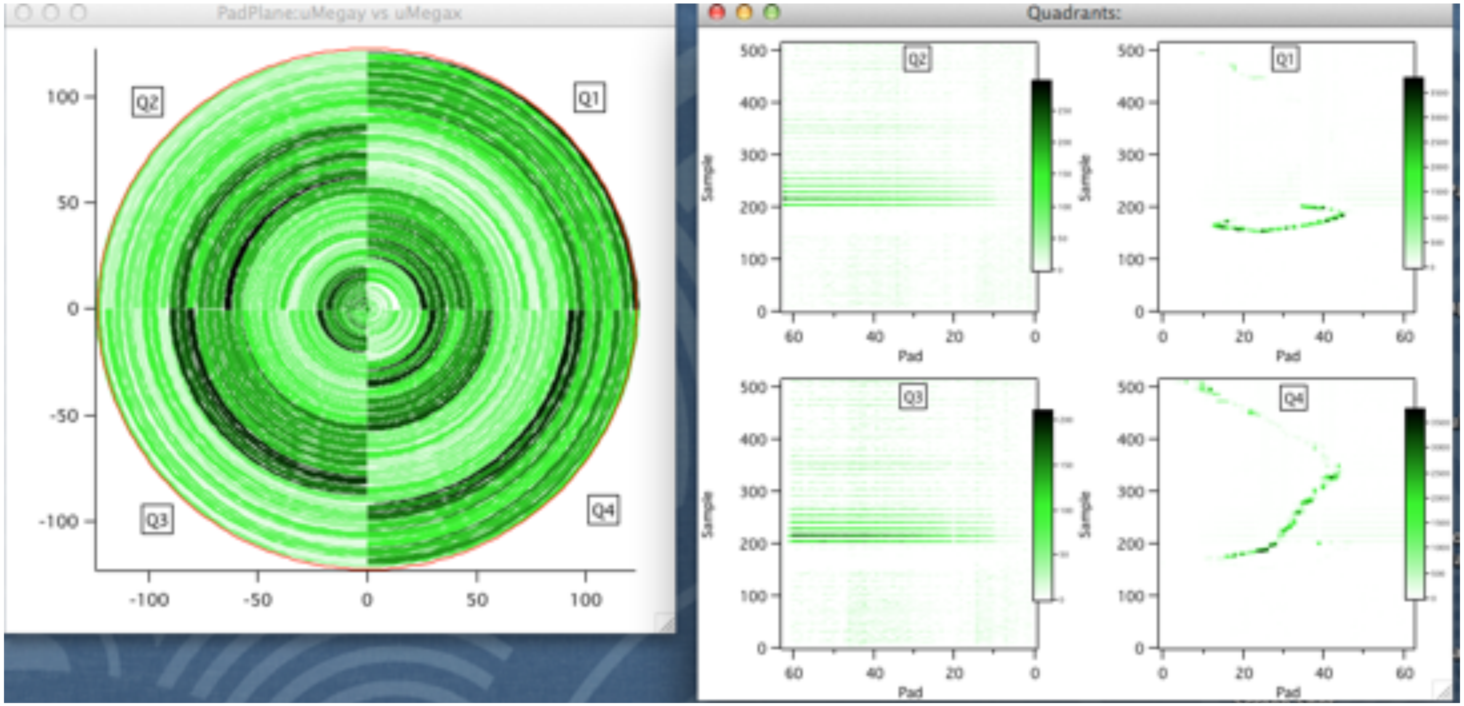


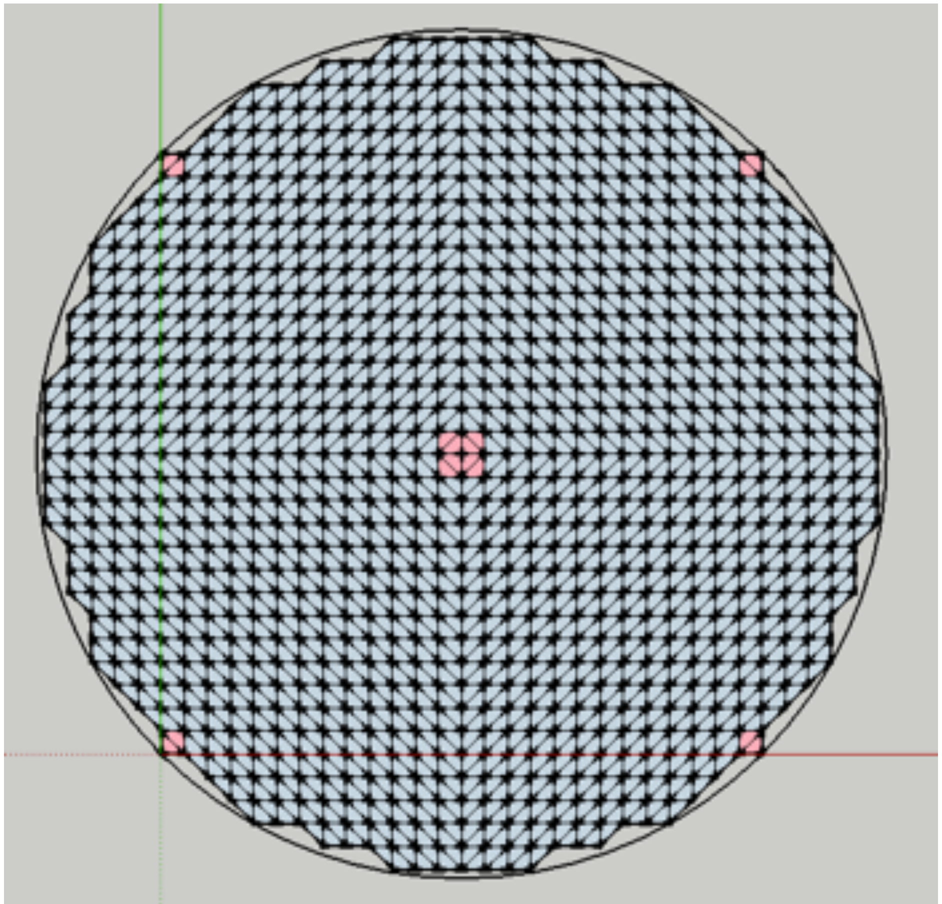
FIG. 2. Fission excitation functions for the three reactions measured in this work. The curves show the best-fitting barrier passing model fusion calculations for each reaction over the energy regions fitted.

- ★ Pb target at the beginning of the TPC
- ★ Focus of fusion-fission reactions with beams
- ★ Only see one fission product
- ★ Energy at fission barrier = max for ReA3 line
- ★Stable beam test with ^{32}S
- ★ Experiment with ~~^{38}S~~ => ^{46}K
- ★ Fission products ID ?
- ★ Statistical challenge

AT-TPC: LATEST DEVELOPMENTS

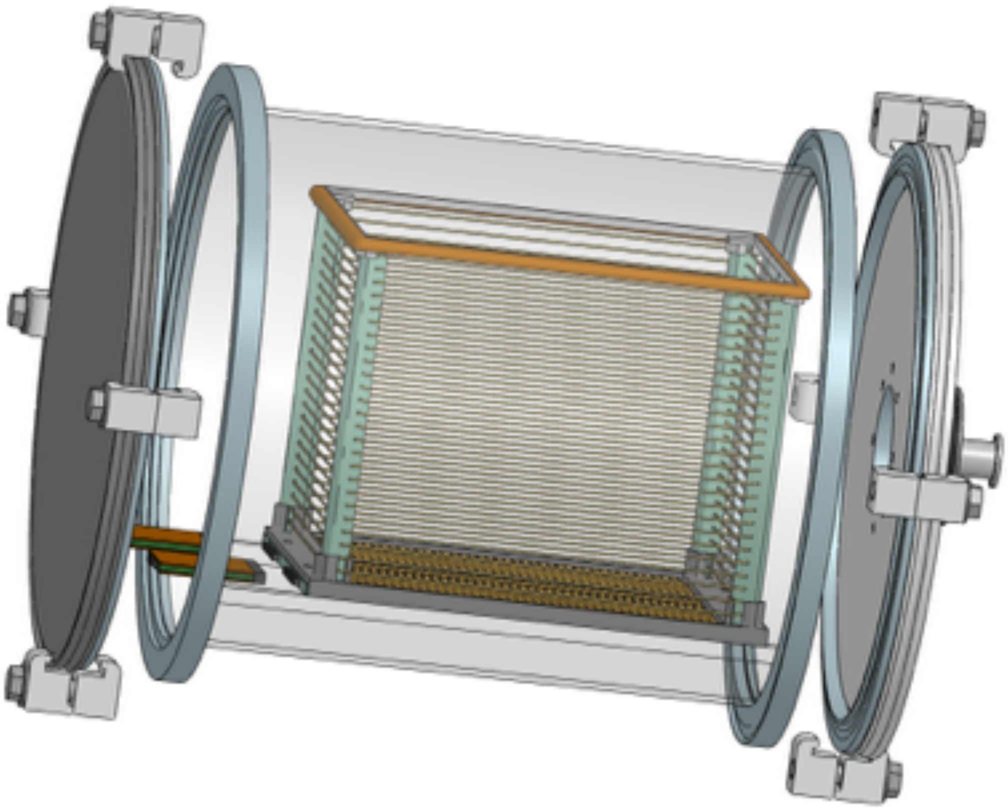


★ Single electron detection (delayed decay such as 2p disintegration)
★ Dual gain on pads to measure light particles and heavier nuclei
★ MicroMegas Th-GEM detector for higher gains
★ H_2 gas, CD_4 gas in future TPC experiments



- ★ new pad plane
- ★ ~2000 pads
- ★ triangular pads
- ★ better granularity
- ★ smaller radius than AT-TPC
- ➡ coupling to other detectors

AT-TPC: FUTURE DEVELOPMENT



★ smaller TPC (200 mm diameter)
★ smaller drift time
➡ Higher count rates

★ Exit window possible in the design for higher beam energies

★ Different pad plane orientation for beam tracking
★ Coupling with gamma detection & neutron detection
★ example: (d,n) reactions

SUMMARY

SπRIT

★ SπRIT commissioning in October 2015: full test of DAQ & trigger conditions

★ SπRIT experiment in April-May 2016: ^{132}Sn+^{124}Sn & ^{108}Sn+^{112}Sn

★ Analysis

- Software development in parallel of analysis with dedicated group
- Analysis for ^{132}Sn + ^{124}Sn at NSCL, other by Japanese collaborators
- TPC efficiency needed

AT-TPC

★ ATTPCROOT in development using SpiRITROOT as basis
★ Comissioning experiment in 2015 (^{46}Ar)
★ Future exciting campaigns at LBNL, NSCL, RCNP
★ Upgrade of the pAT-TPC
★ New TPC design for the future