Status of the development of the setup for the fission barrier determination via the (p,2p) reaction in inverse kinematics

Masaki Sasano

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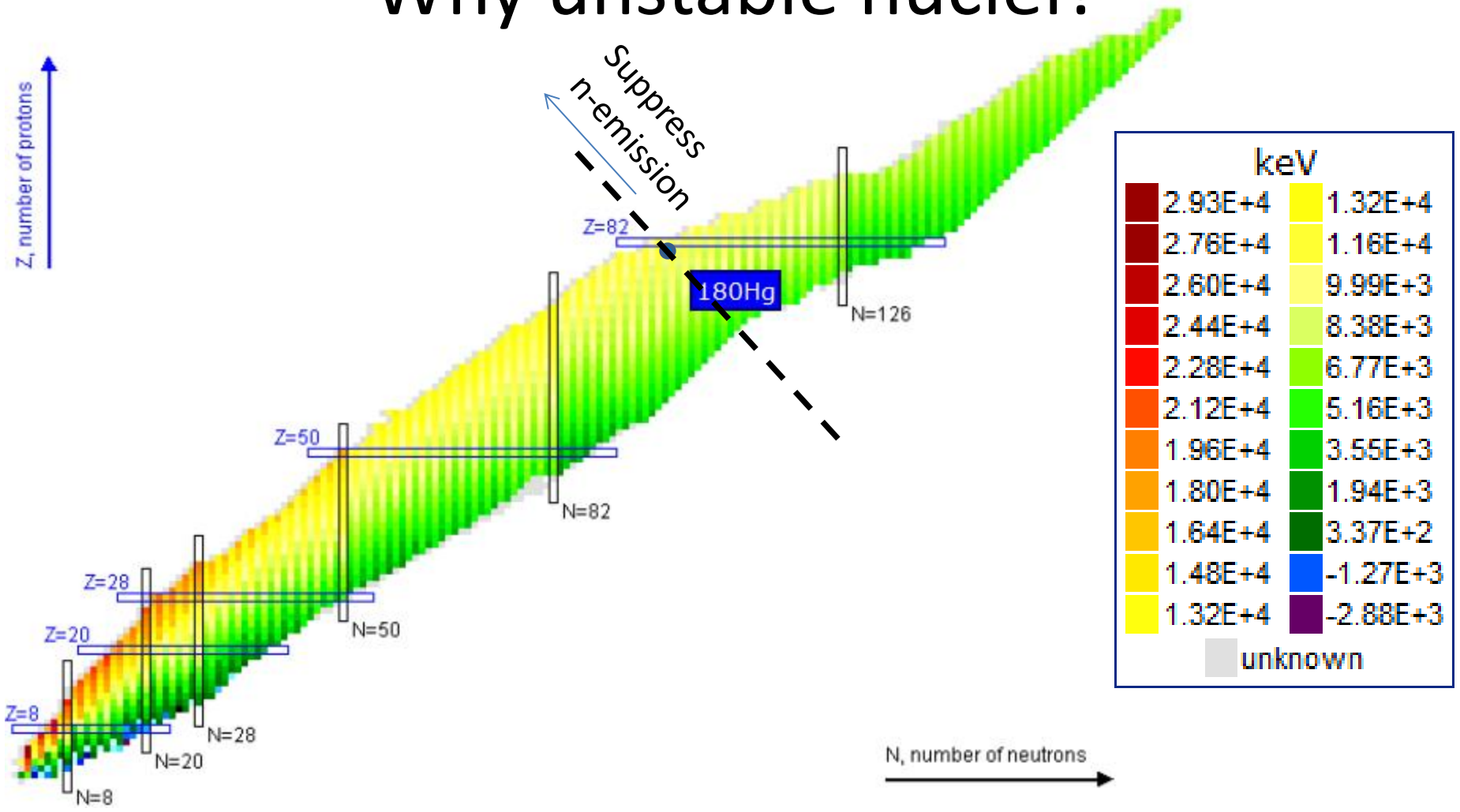
Why unstable nuclei?

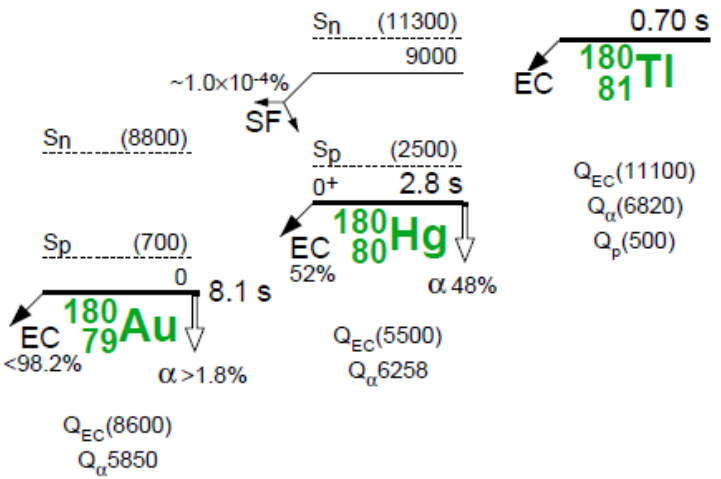


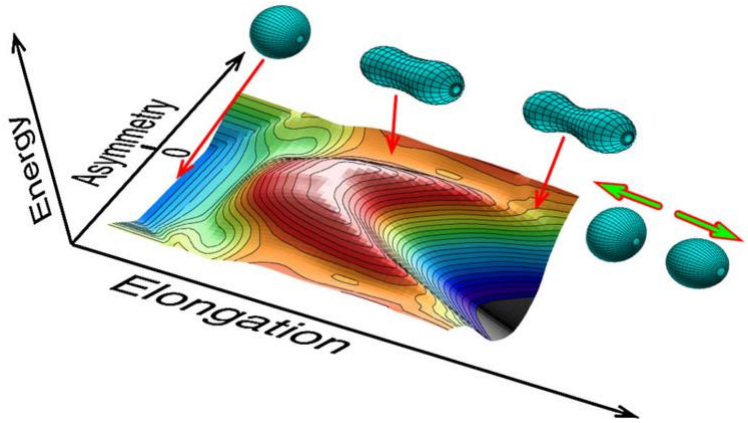
- Systematic studies

→ **Barrier shape** with change of isospin
Competition between fission and other processes
(larger Z → larger fissility, lower neutron emission)

An example: ^{180}Hg

Beta-delayed fission from ^{180}Tl
(A. Alexeyev et al., PRL105,252502 (2010))





^{180}Tl
→ EC/beta+ decays to ^{180}Hg
(Z=80, N=100)
→ Populates states around fission barrier
→ Asymmetric mass pattern
(not symmetric ^{90}Zr+^{90}Zr)

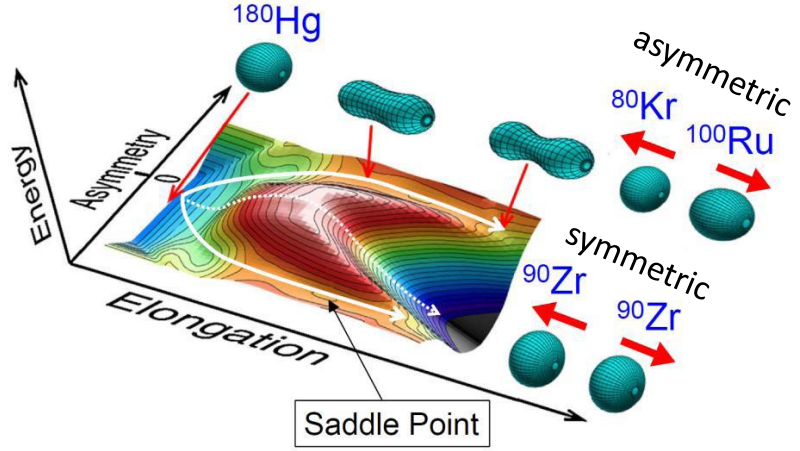
Limitations of EC studies…

- **No information on**
  - **total spin (J)**
  - **parity (π)**
  - **excitation energy (Ex)**
- **Ex < Q(beta) ~ 10 MeV**

Determination of potential energy surface

Keyword : potential energy surface

Theoretically predicted potential energy surface

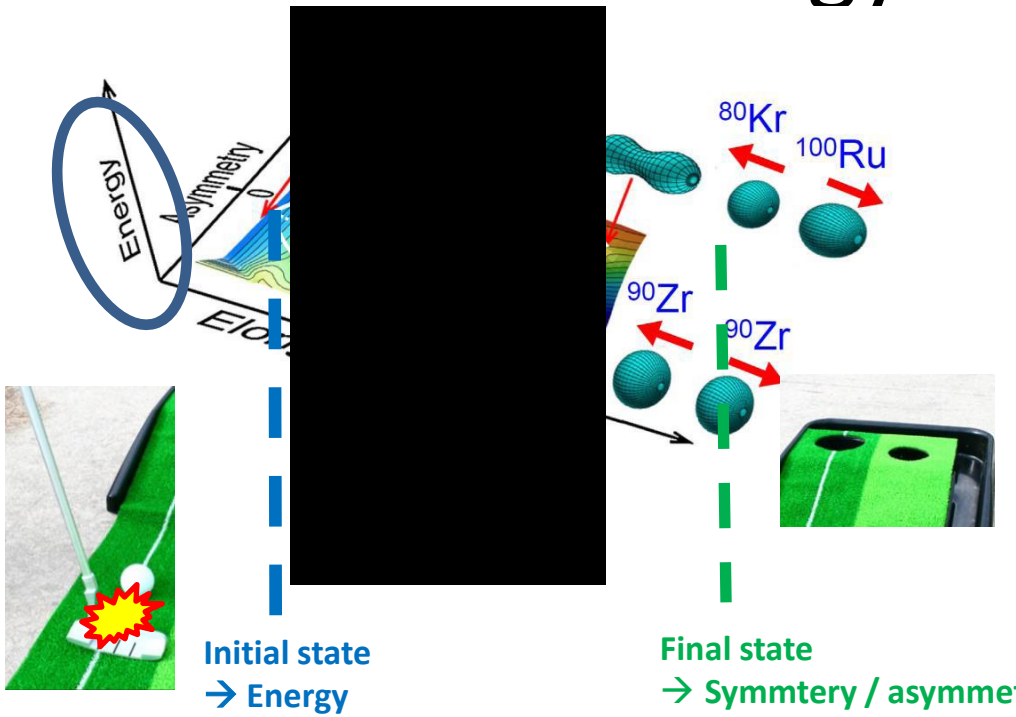


Governs

Please imagine putting golf

Asymmetric / symmetric pattern of elements made by fission

How do you know the potential energy?

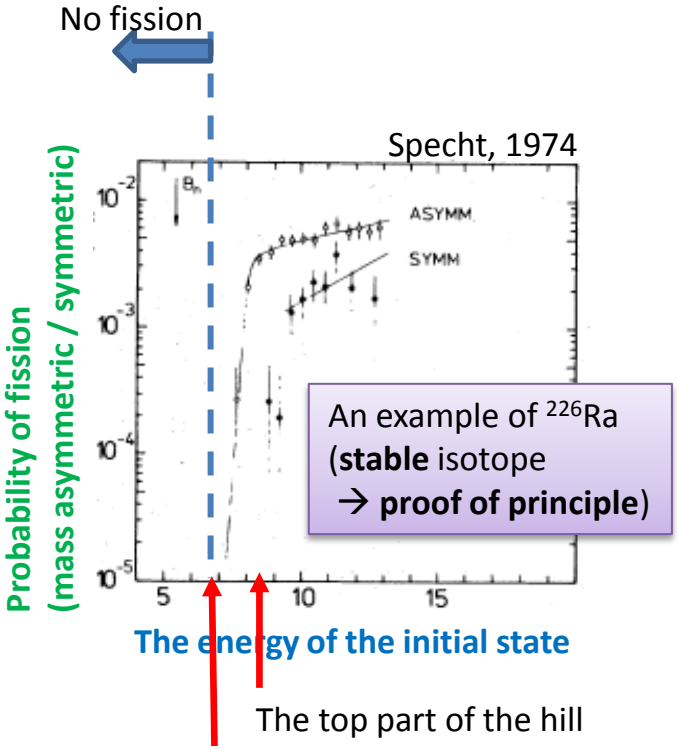


Initial state
→ Energy

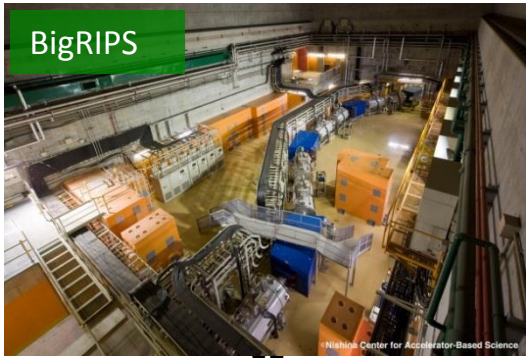
Final state
→ Symmtery / asymmetry

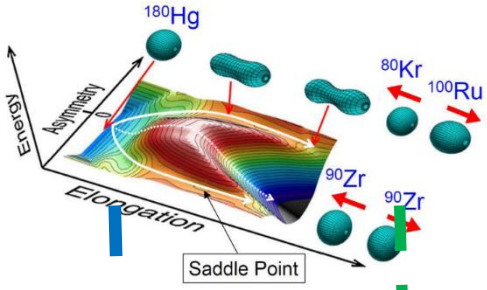
New approach : missing mass w/ RI beam
Tech. breakthrough : seg. neutron detector

SAMURAI spectrometer
seg. ion chamber

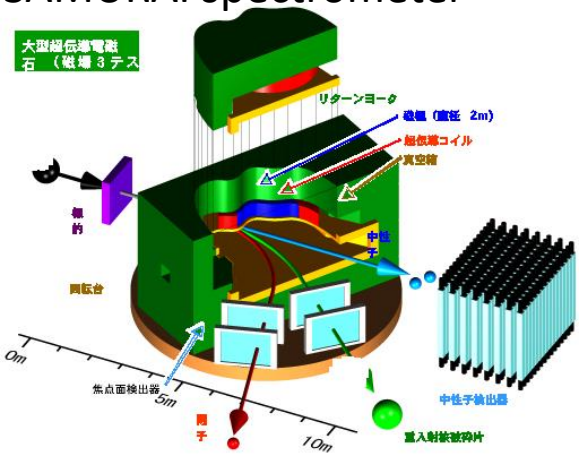


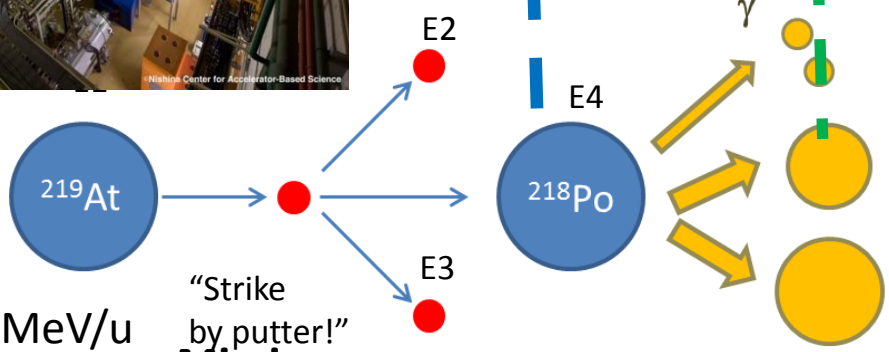
New approach @ RIKEN





SAMURAI spectrometer





200 ~ 350 MeV/u

"Strike by putter!"

Missing mass

E4 = E1 – E2- E3

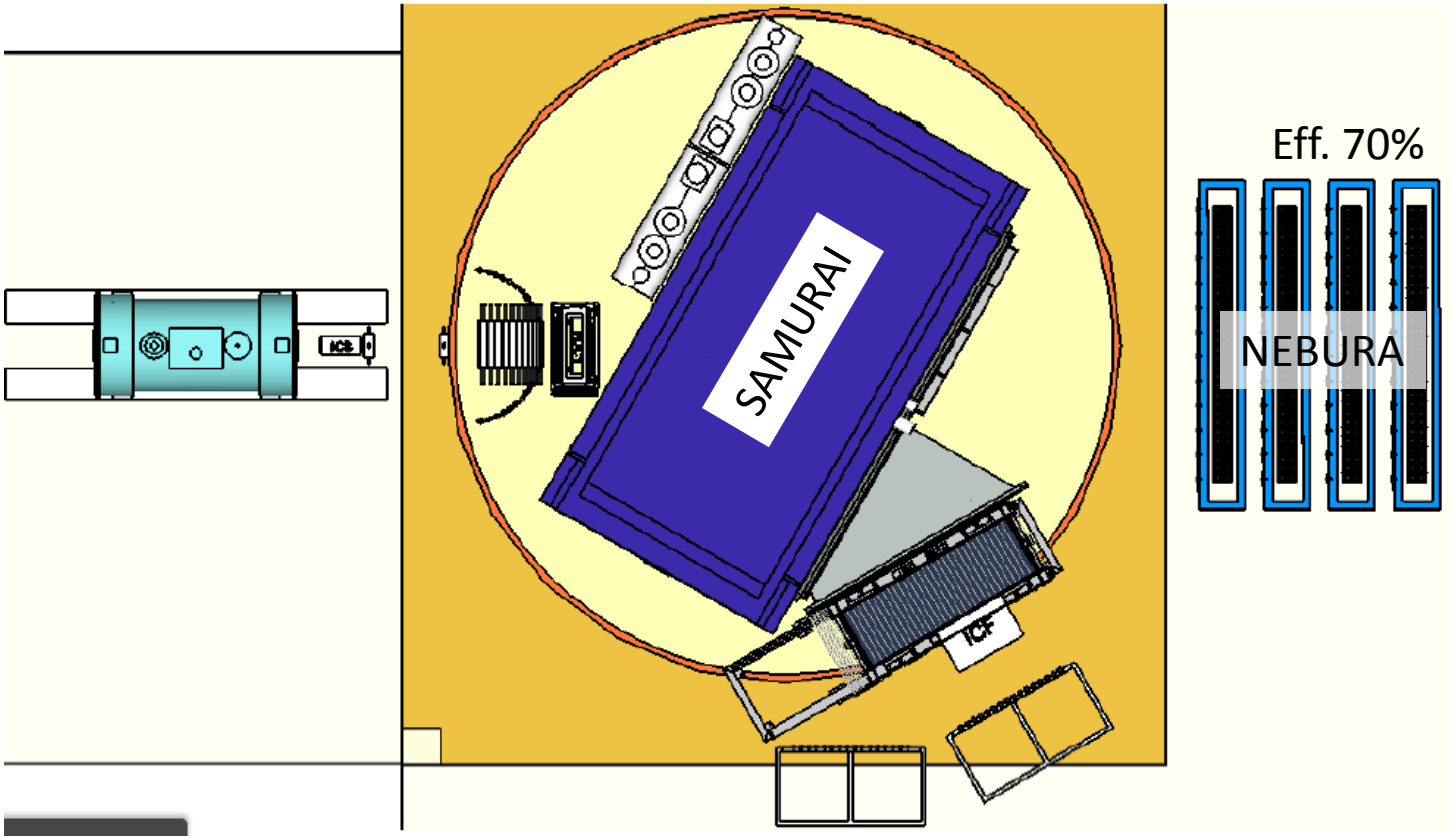
Simple and easy!

Fission fragments

Measure
atomic numbers and masses

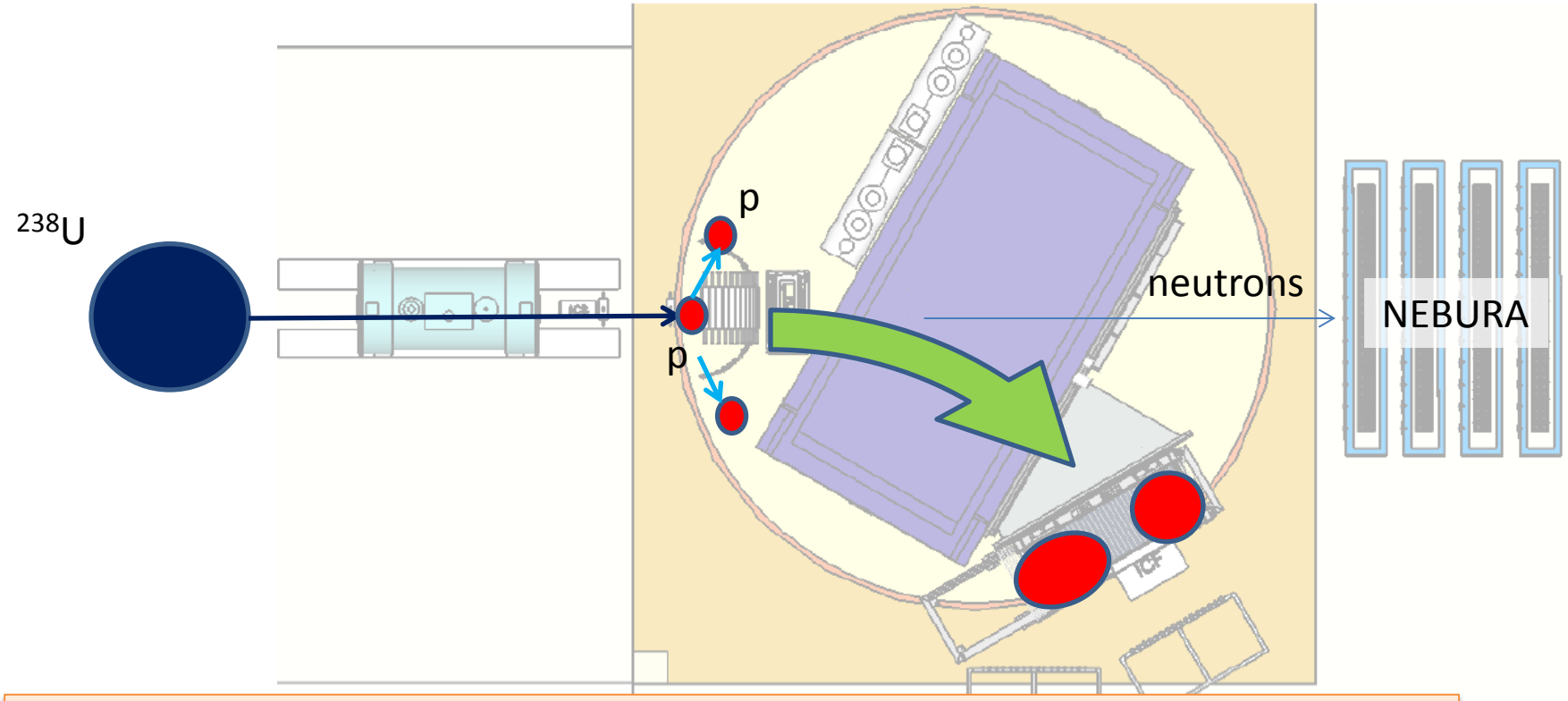
RIKEN RIBF x missing mass x SAMURAI spectrometer
→ All the fragments with excitation energy information
with an uncertainty of ~1 MeV over a wide energy range (up to ~ 50 MeV or so…)
→ **PERFECT!!!**

A test experiment (performed in spring, 2014)



A/Q
IC → ΔE
MWDC → Trajectory radius
Plastic hodoscope → TOF

A top view of setup

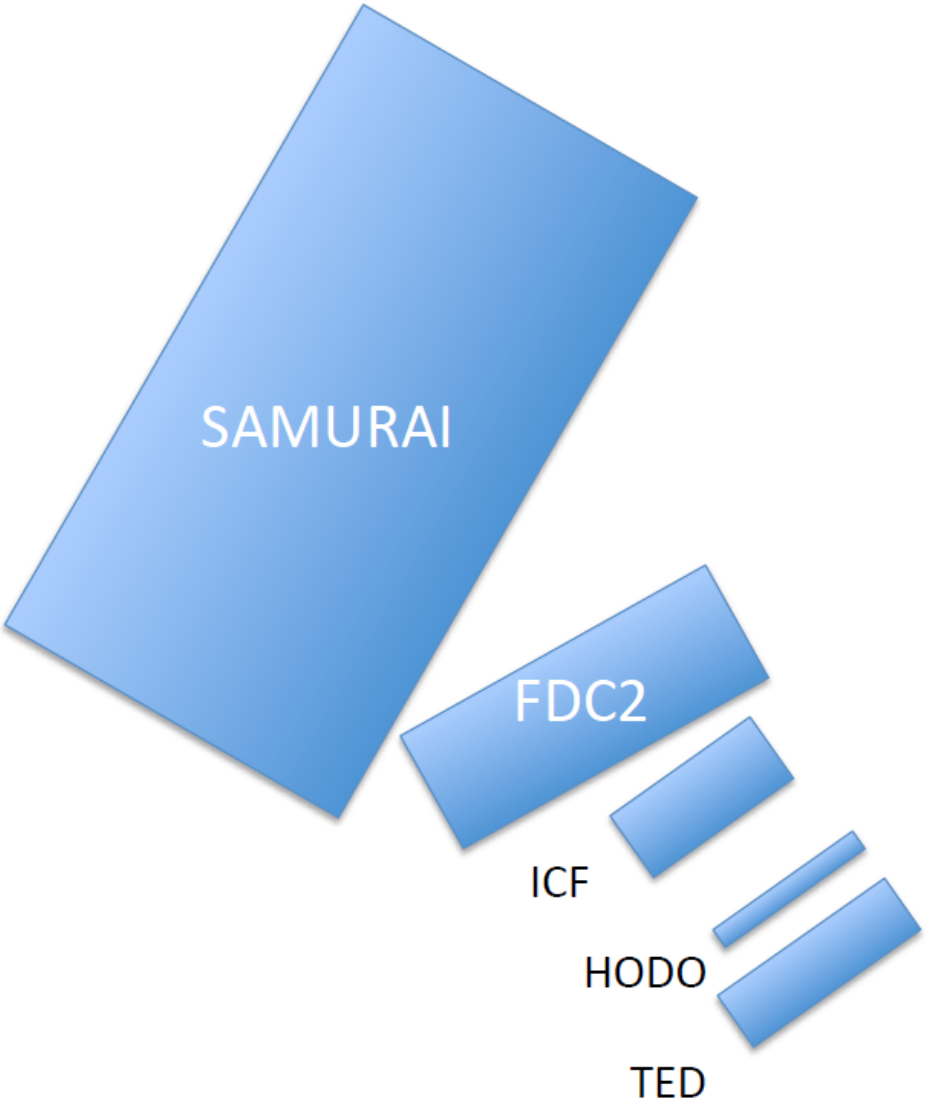


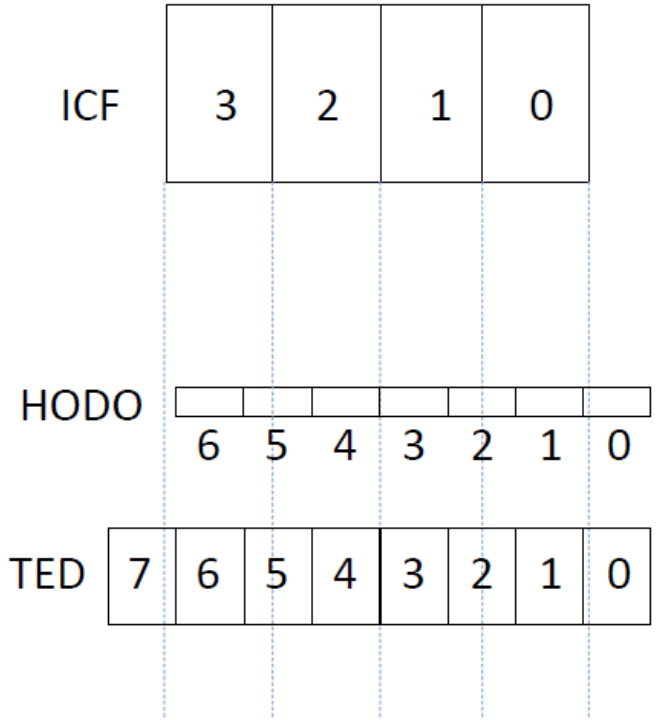
Ex resolution : this time, we didn't measure
Fission fragments :
Kinetic energies (from Brho analysis) and emission angles (4-momentum vectors)
Charge res. ~0.2
Mass res. ~0.3

Preliminary analysis results...

The analysis of this part is being done by **M. Sako** (Postdoc, RIKEN, Nishina Center)

Experimental Setup After SAMURAI



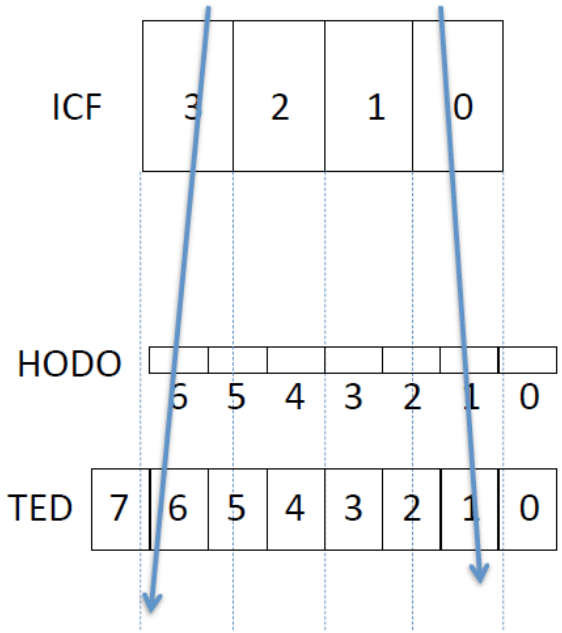


ICF : 75cm(4 divide) * 48cm(12 layers)
HODO : 10cm(width)*5mm(thickness)*7
TED(CsI) :10*10*10cm^3 * 8*4

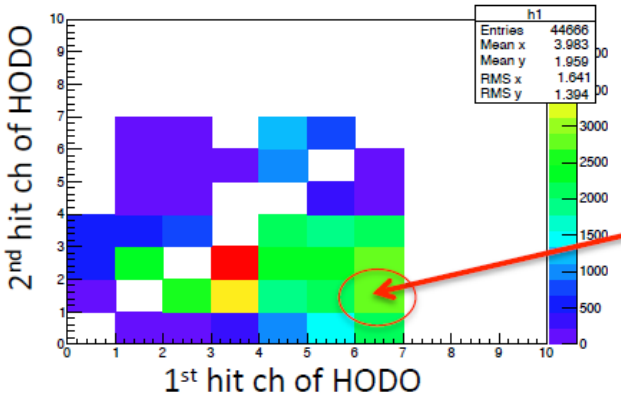
Analysis data : run#443
magnet setting : 2.54 T
U beam hit mainly hodo ch=3

preparation for fission analysis

- select the event which has 2 separate hit @ HODOSCOPE
- -> check hit pattern of
  upstream and
  downstream counter
- ->2 tracking analysis with drift chamber



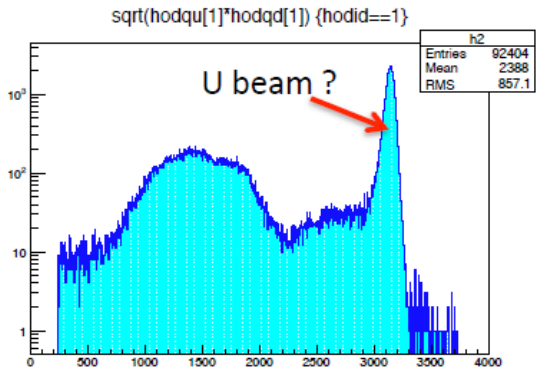
multiplicity = 2 @ HODO



event selection : multiplicity = 2 @ HODO
1st hit ch =6 and 2nd hit ch =1

QDC raw value of HODO ch = 1

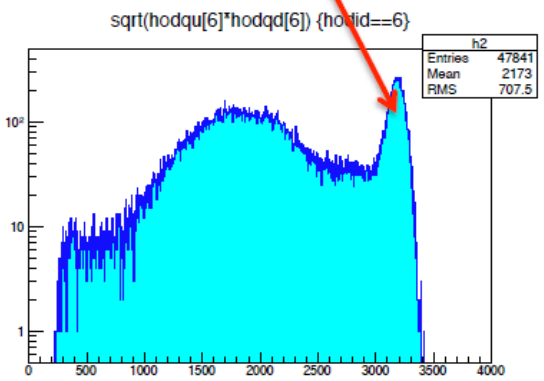
event selection :
hit ch = 1
multiplicity≧1



U beam ?

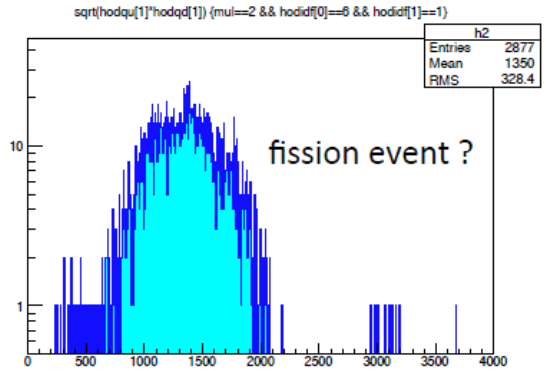
QDC raw value of HODO ch = 6

event selection :
hit ch = 6
multiplicity≧1



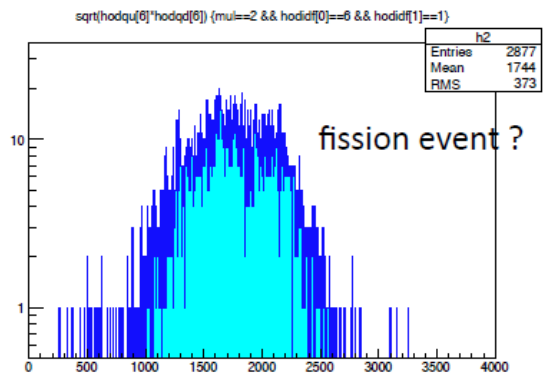
QDC raw value of HODO ch = 1

event selection :
multiplicity=2
1st =6 , 2nd =1

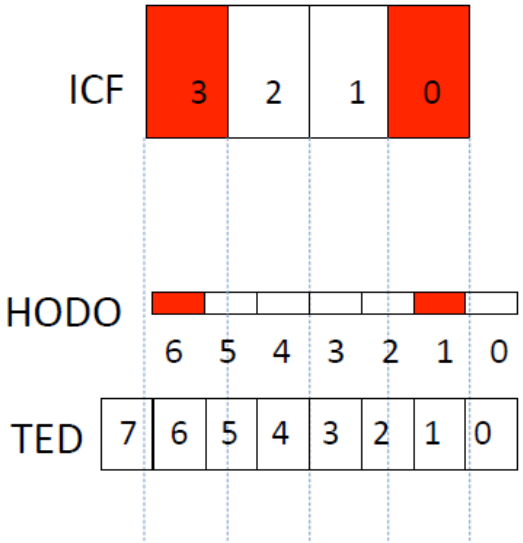


QDC raw value of HODO ch = 6

event selection :
multiplicity=2
1st =6 , 2nd =1



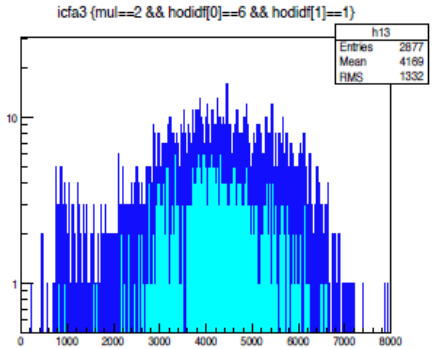
ICF hit pattern



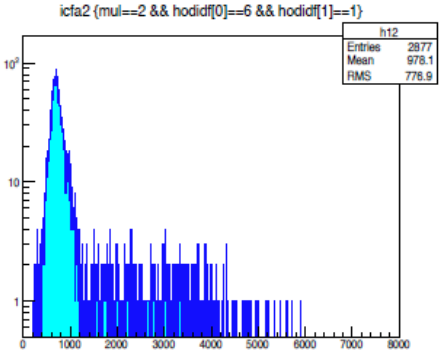
event selection : multiplicity = 2 @ HODO
1st hit ch =6 and 2nd hit ch =1

QDC value of ICF is average of 12 layers
(ICF is consist of 12 anode layers)

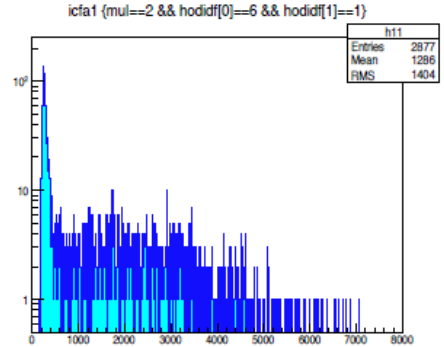
The hit ch of ICF is corresponding to the HODO



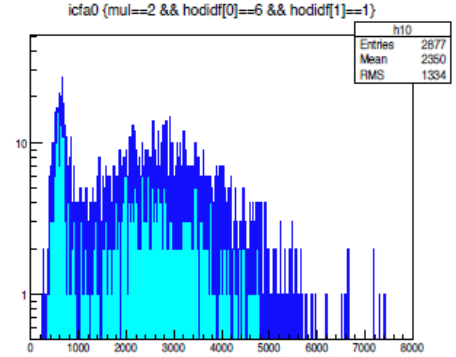
ICF ch=3



ICF ch=2



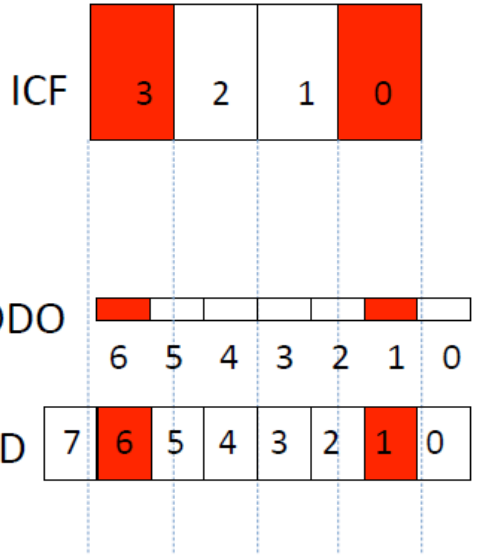
ICF ch=1

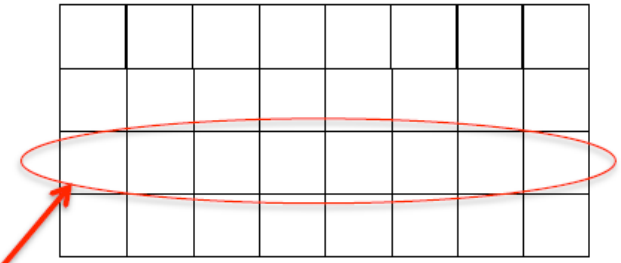


ICF ch=0

TED hit pattern

event selection : multiplicity = 2 @ HODO
1st hit ch =6 and 2nd hit ch =1

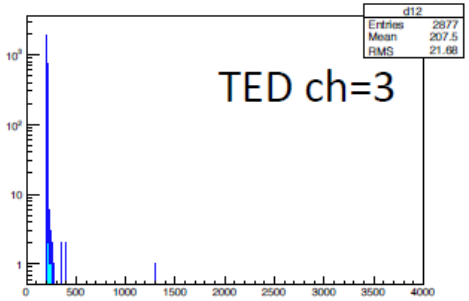


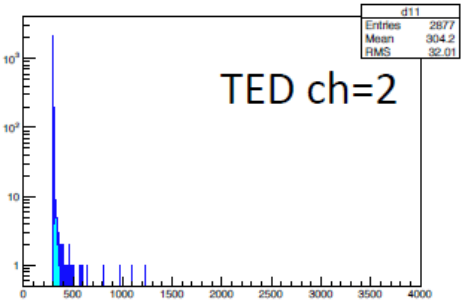


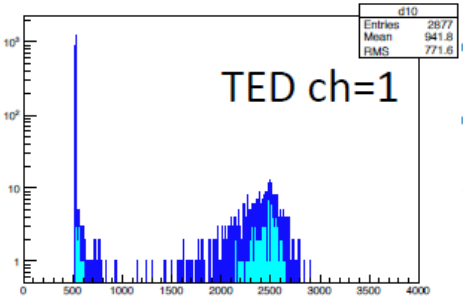
TED is consist of
8(horizontal)×4(vertical)

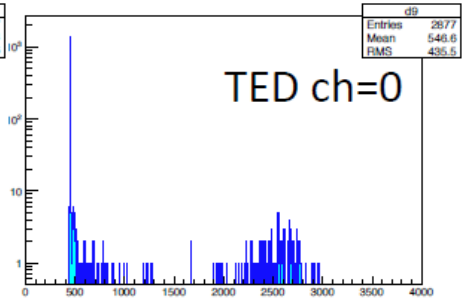
The center of beam height
was set to the second layer from the bottom

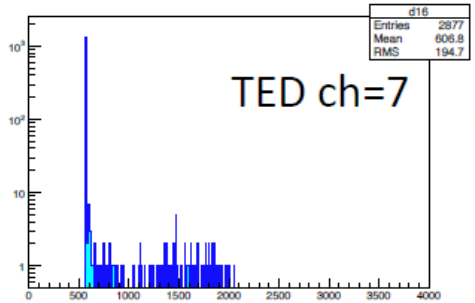
These histograms are the QDC value of the second layer from the bottom

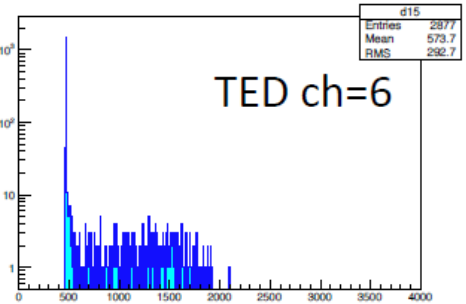


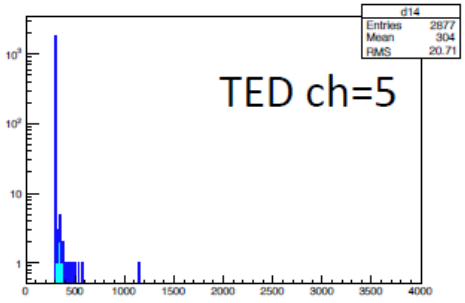


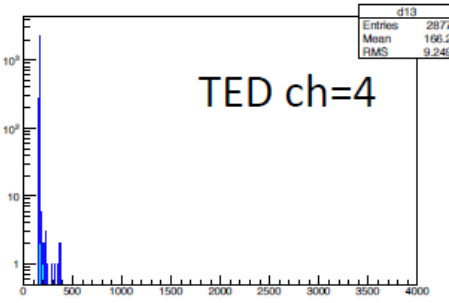




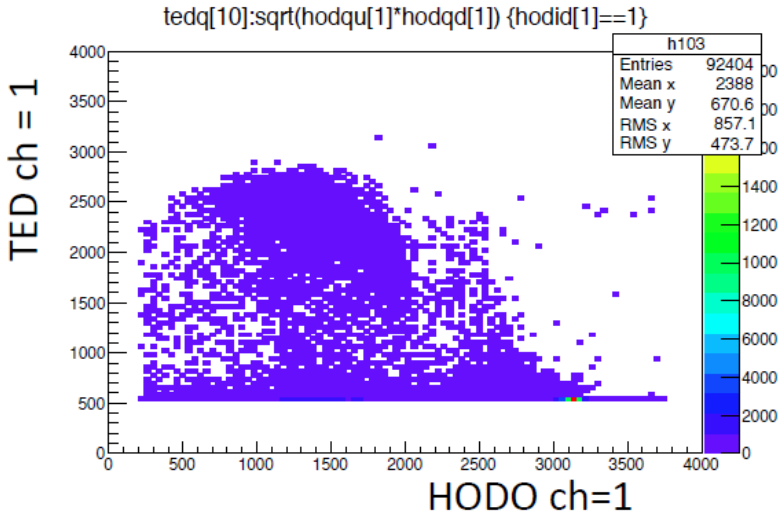


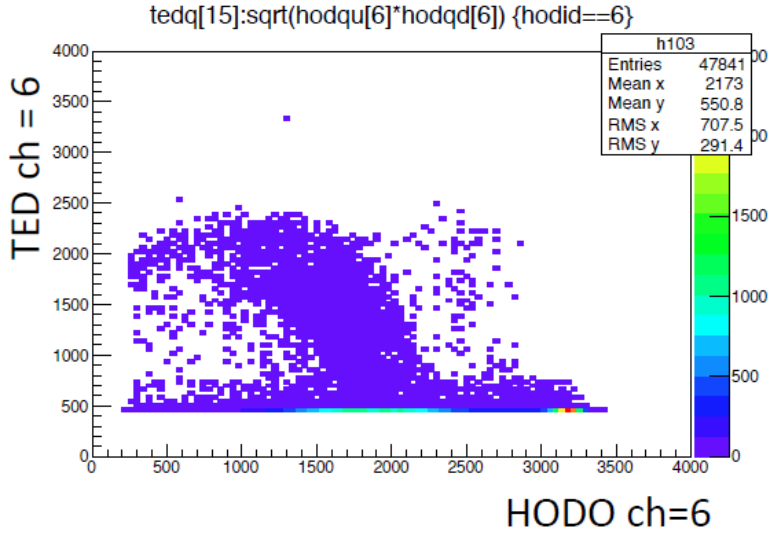


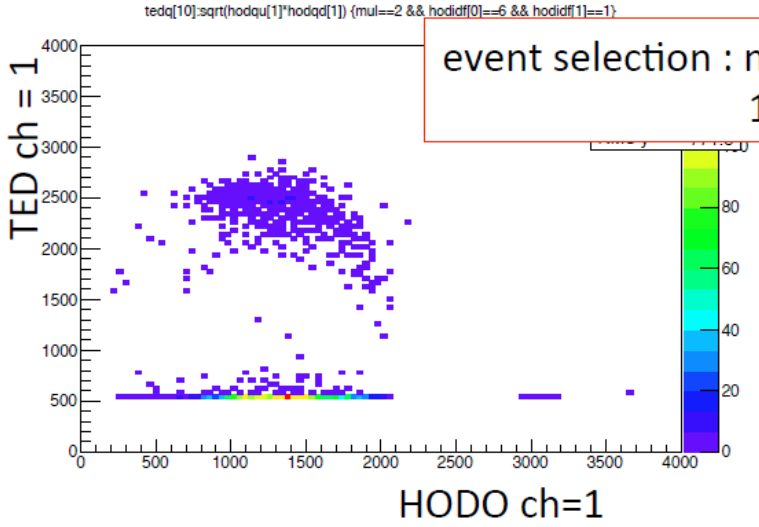




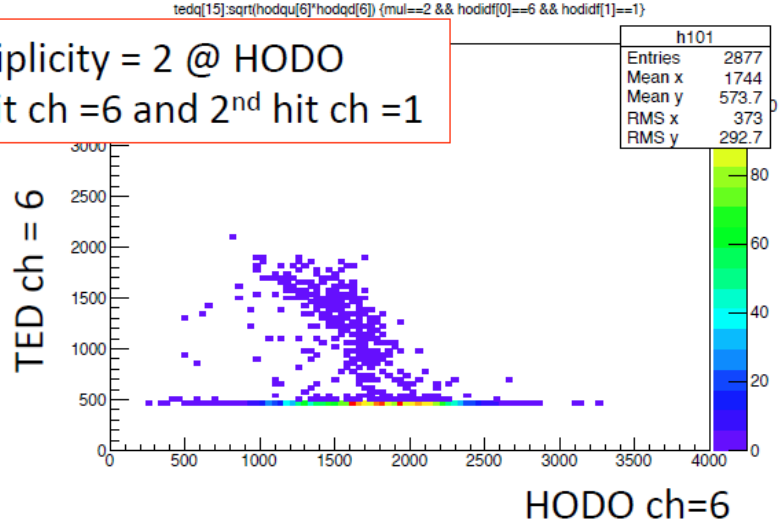
Delta E vs E



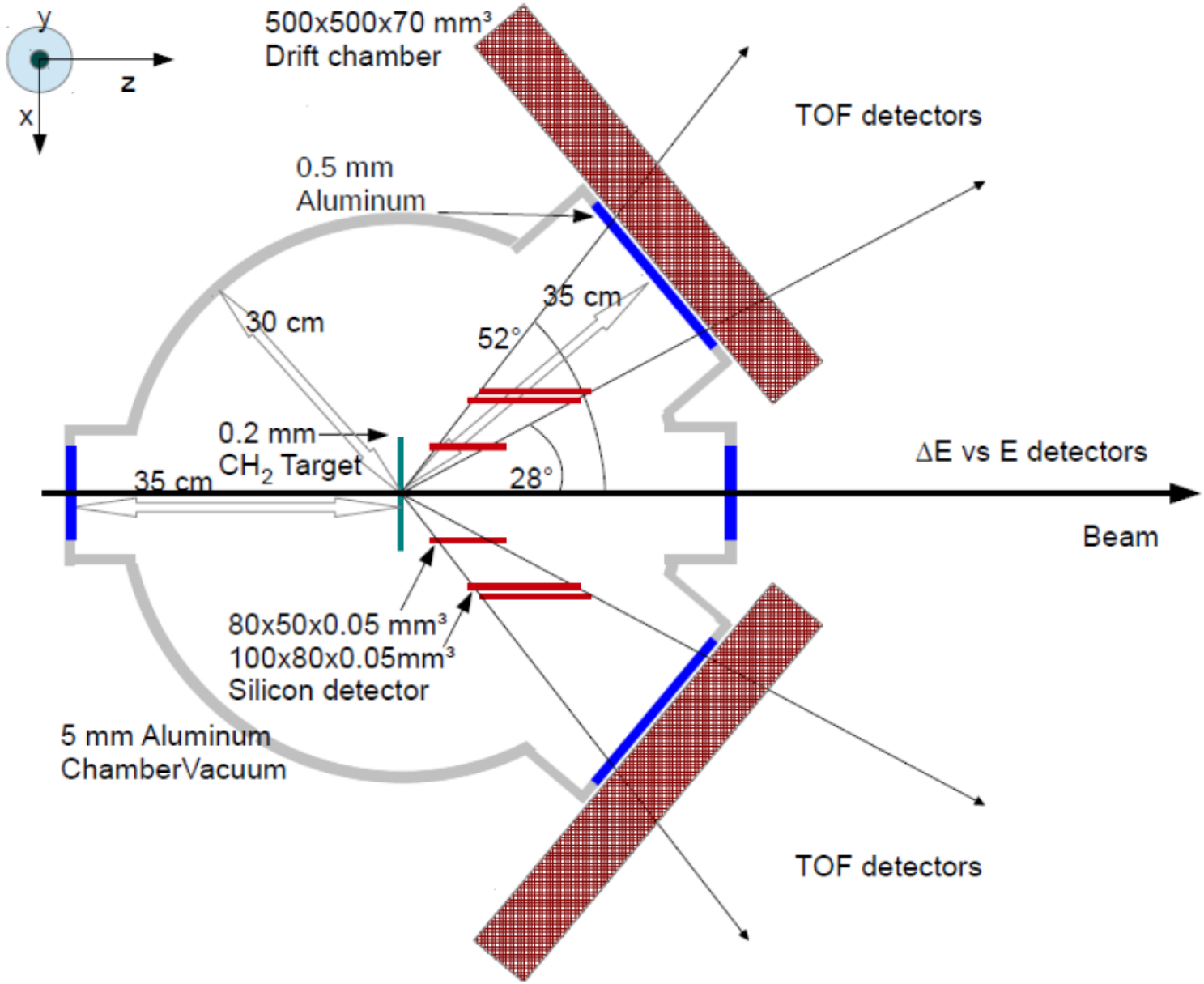




event selection : multiplicity = 2 @ HODO
1st hit ch =6 and 2nd hit ch =1



Development of (p,2p) setup



(p,2p) setup

- We need following resolution for the proton energy E_p:

$$\frac{\Delta E_p}{E_p} \leqslant 2\% \quad \text{(in sigma)} \qquad (1)$$

- This energy resolution is equivalent to a minimum time of flight (TOF) resolution of

$$\frac{\Delta TOF}{TOF} \leqslant 1.5\% \quad \text{(in sigma)} \qquad (2)$$

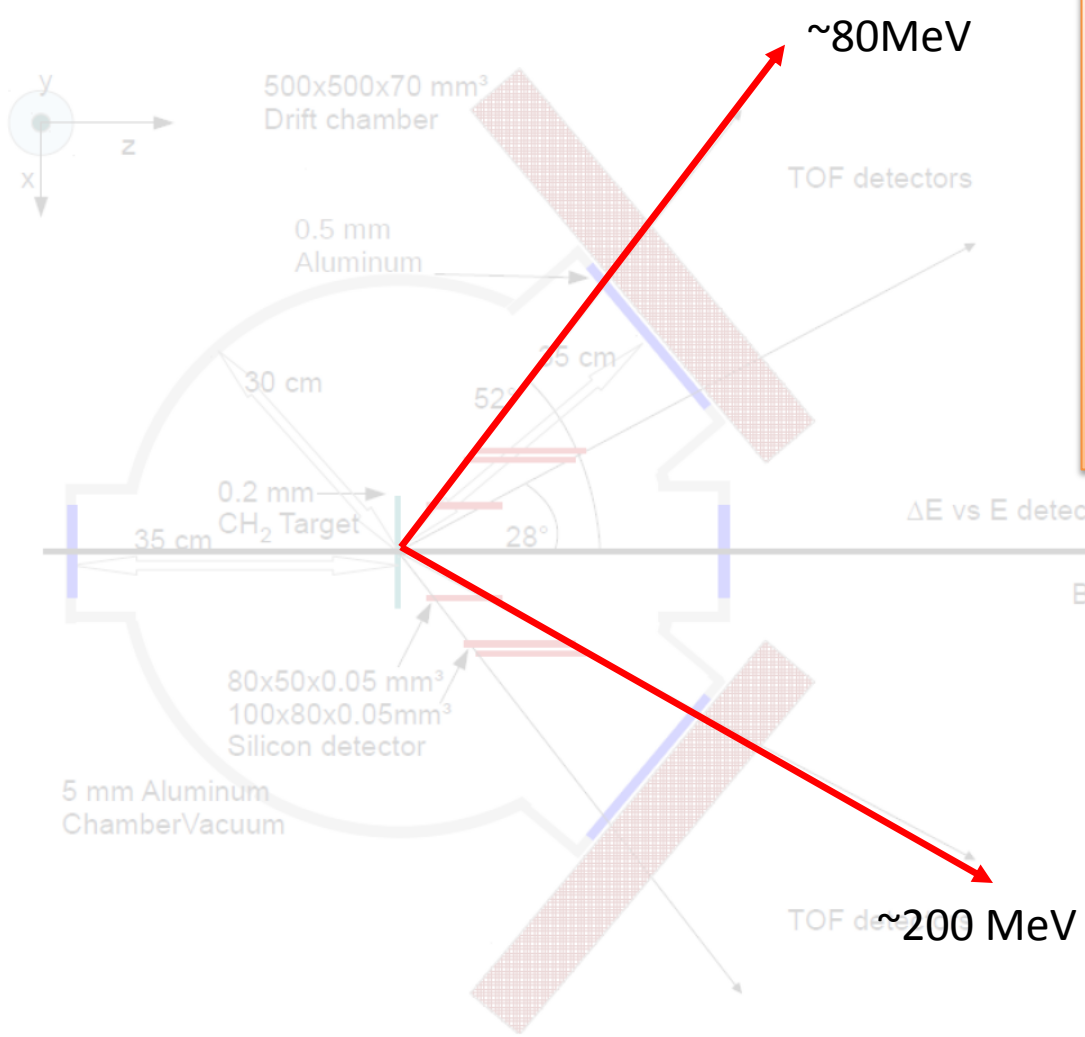
- The determination of the fission barrier height requires also the measurement of the opening angle θ_{op} between the two emitted protons. The second condition of the setup is to provide an angular resolution of

$$\Delta\theta_{op} \leqslant 3 \quad \text{mrad} \quad \text{(in sigma)}. \qquad (3)$$

➡ Fission barrier uncertainty ~< 1 MeV in sigma

Missing mass energy resolution ~ 300 keV/mr x Opening resolution in milli radian

Thin silicon detectors



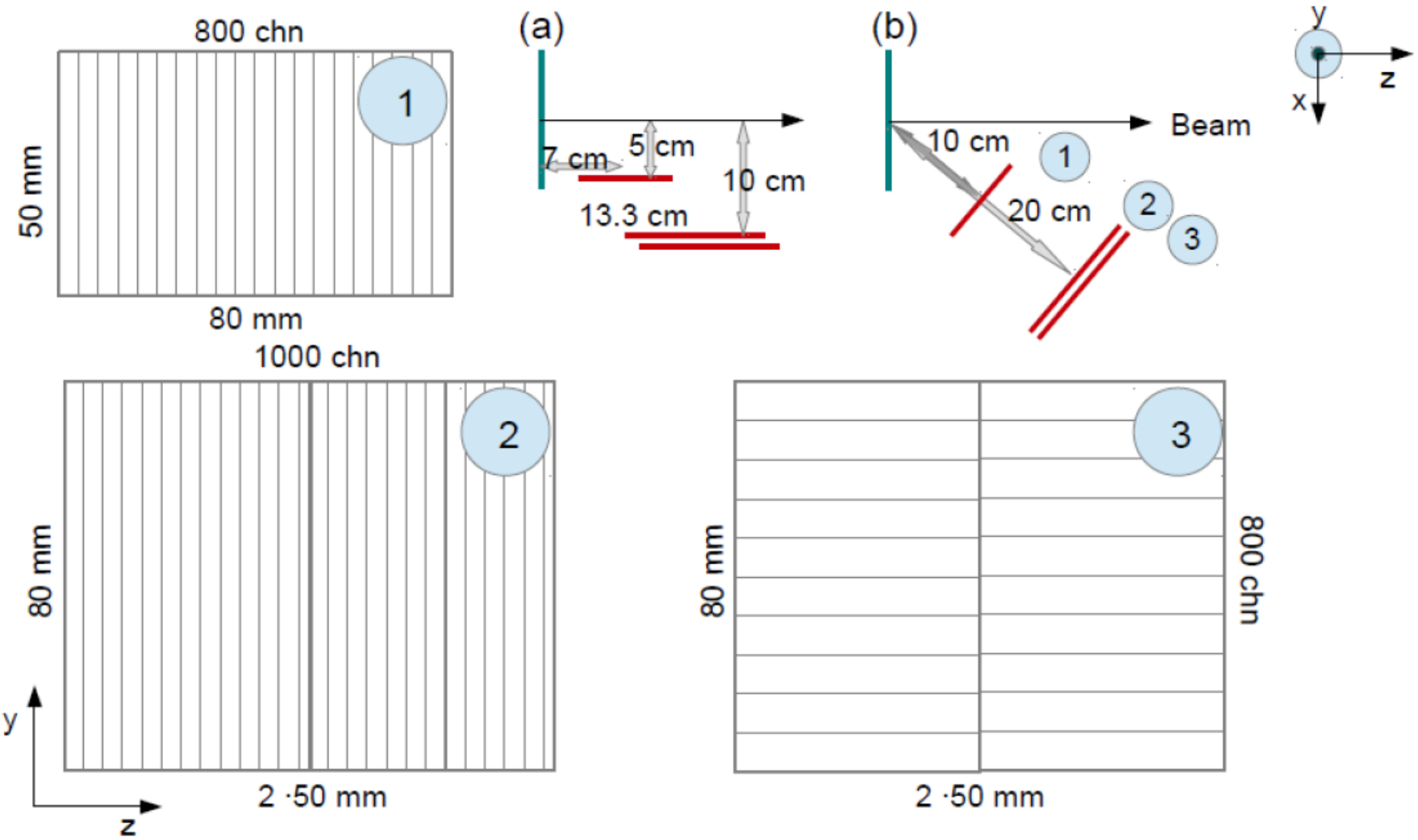
Protons with lower energies
→ Larger angular straggling
→ 80 MeV => 1 mr @ 10 mg/cm^2

Reaction vertex
→ 100 microns in vertex position
→ 1 mr uncertainty at 10 cm
→ Trackers very closet to the taget

Thin silicon detectors
with 100 micron pitch

50 microns ~ 1.5 mr for 80 MeV

Design of Silicon detector



A technical challenge

- Thin silicon (~ **50** microns)

→small signals

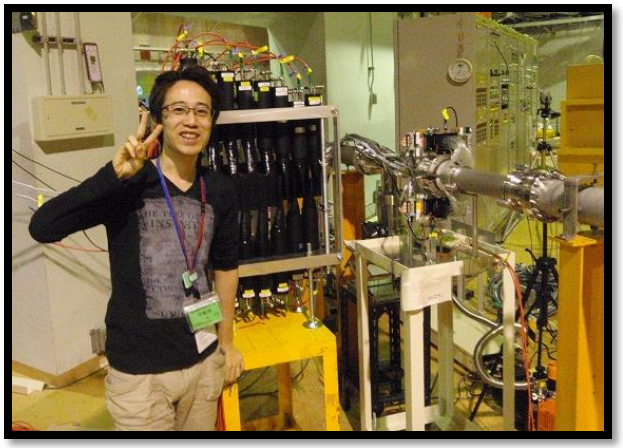
(100 keV energy loss for 200 MeV protons)

→ S/N is the key

→ A solution :

AC type Silicon detectors coupled with APV25

Being prepared by
Sebastian Reichert &



Summary

- Measurement of the fission fragment with the missing energy info.

→ Energy surface of the fission process

- At RIKEN, complete information will be obtained;

  Ex: 0~a few tens MeV

  with a resolution of 1MeV in sigma

  Fission fragments : (A,Z, Kinetic energy)

  Neutrons : multiplicity and their energies

- A test experiment of SAMURAI

→Fission fragment identification works

- Thin silicon detectors are the key factor and being developed for the fission barrier height determination