SAMURAI @ RIBF

Hideaki Otsu (RIKEN Nishina Center)

FRIB HRS Workshop
on July 11, 2014
at Michigan State University

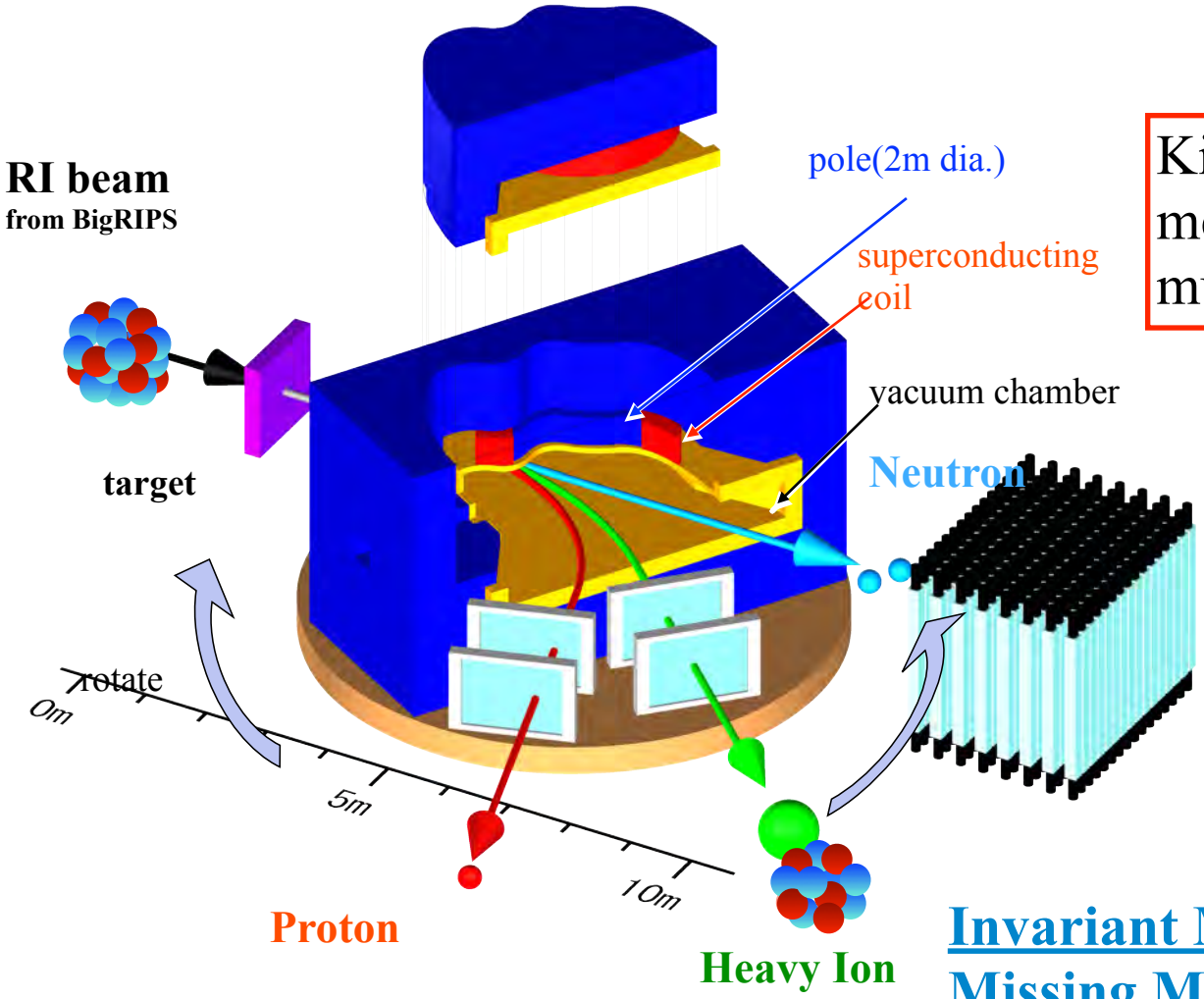
"SAMURAI @ RIBF"
Today's contents

1. Overview
2. History
3. Properties/Constituents
4. Experimental programs
5. Summary

SAMURAI
~ New Spectrometer in RIBF ~

Construction ~ 2011
Commissioning : 2012/03
First experiments : 2012/05

Superconducting **A**nalyzer for **MU**lti-particle from **RA**dio **I**sotope Beam with 7Tm of bending power

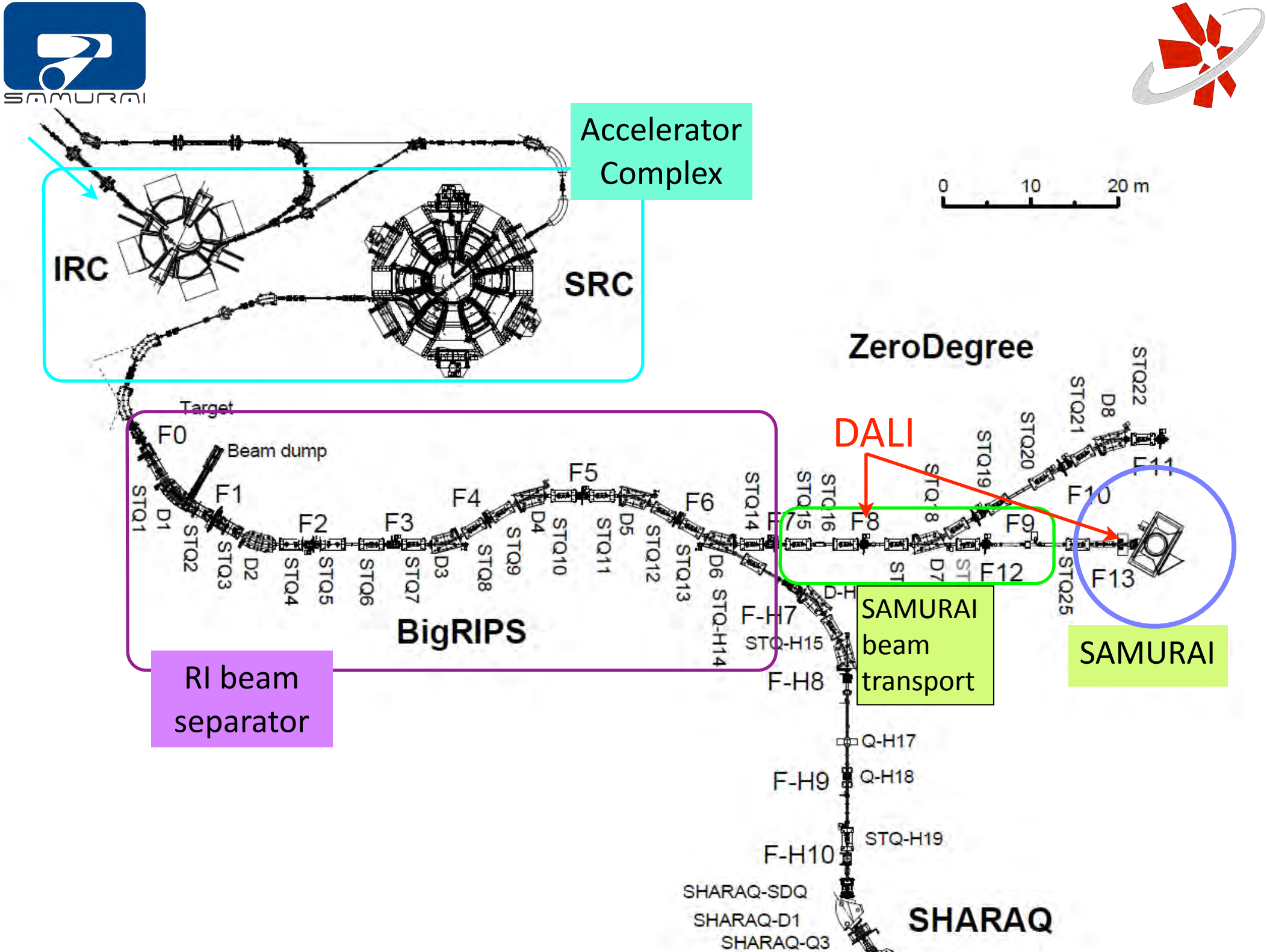


Kinematically complete measurements by detecting multiple particles in coincidence

- Superconducting Magnet
  3T with 2m dia. pole
  (designed resolution 1/700)
  80cm gap (vertical)
- Heavy Ion Detectors
- Proton Detectors
- Neutron Detectors
- Large Vacuum Chamber
- Rotational Stage

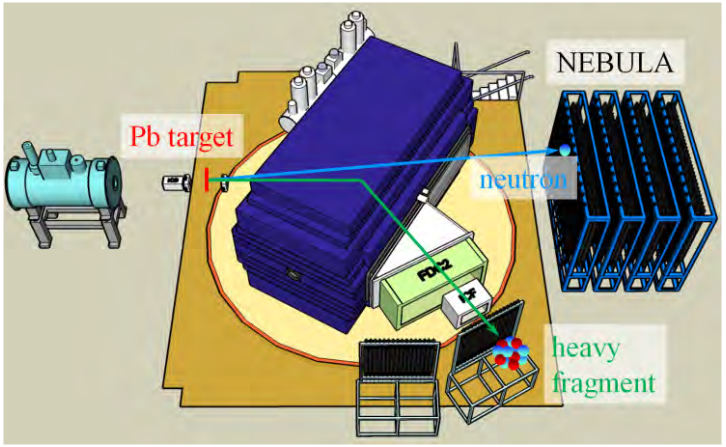
Invariant Mass Measurement
Missing Mass Measurement

Slide: K. Yoneda

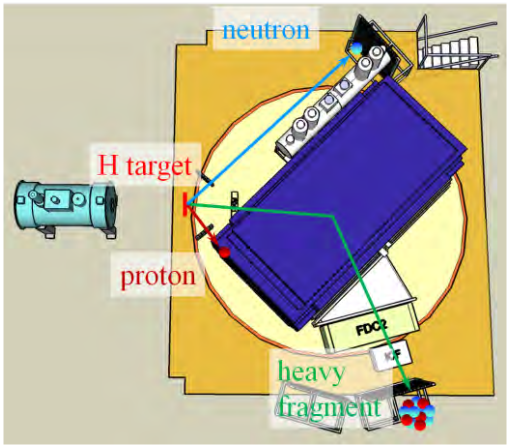

Accelerator Complex
IRC
SRC
0
10
20 m
ZeroDegree
DALI
Target
Beam dump
F0
F1
F2
F3
F4
F5
F6
F7
F8
F9
F10
F11
F12
F13
STQ1
D1
STQ2
STQ3
D2
STQ4
STQ5
STQ6
STQ7
D3
STQ8
STQ9
D4
STQ10
STQ11
D5
STQ12
STQ13
D6
STQ-H14
STQ14
STQ15
STQ16
STQ19
STQ20
STQ21
D8
STQ22
STQ25
BigRIPS
RI beam separator
SAMURAI beam transport
SAMURAI
F-H7
STQ-H15
F-H8
Q-H17
F-H9
Q-H18
STQ-H19
F-H10
SHARAQ-SDQ
SHARAQ-D1
SHARAQ-Q3
SHARAQ

Various Physics scoped on SAMURAI

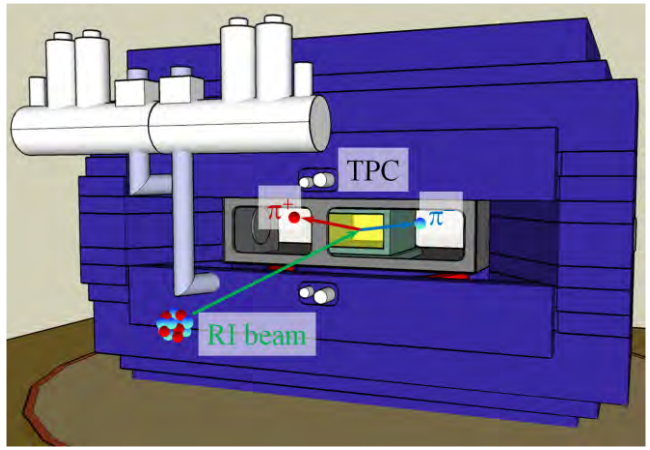
x*n*+HI (neutron-rich side)
(γ, *n*), unbound nuclei…



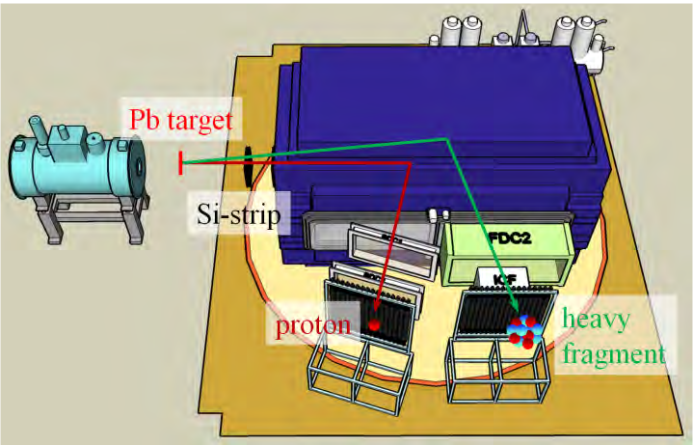
***p*,*n*(target frame)+HI**
(*p*,*p*'), (*p*,2*p*), (*p*,*pn*), …



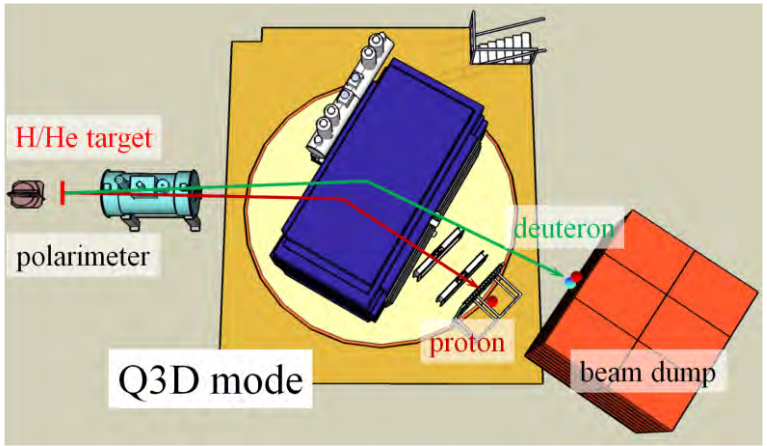
EOS measurement



***p*+HI (proton-rich side)**
(γ, *p*) reaction,…

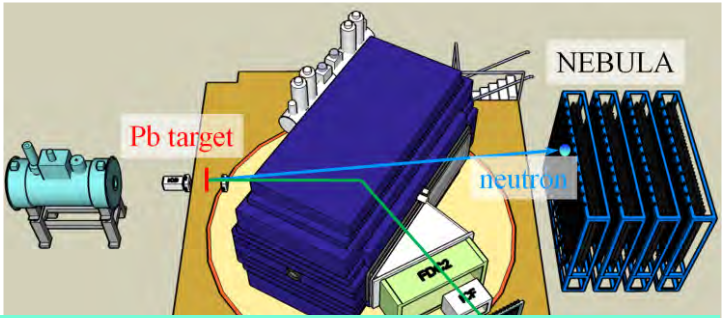


pol. *d*-induced reaction



Approved programs and SAMURAI configuration

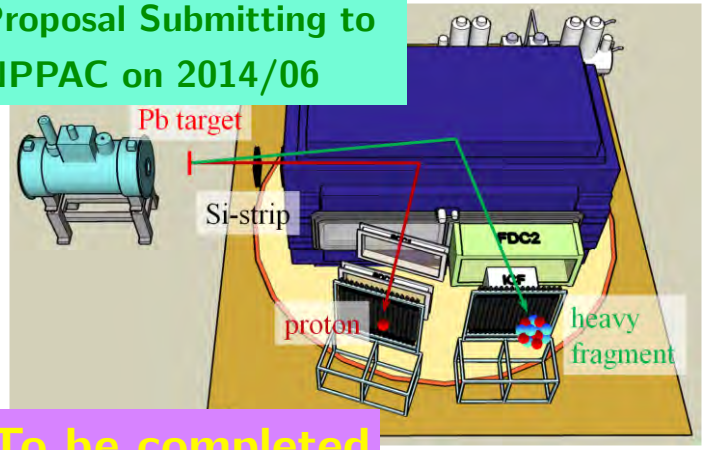
xn+HI (neutron-rich side)
(γ, n), unbound nuclei…



Commissioning RUN:
Day-one/two
SAMURAI21(S grade): ^{28}O
SAMURAI20: ^{26}O life
SAMURAI09: Pigmy Dipole

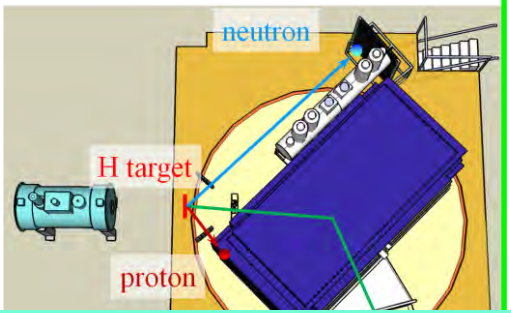
(γ, p) reaction,…

Proposal Submitting to NPPAC on 2014/06

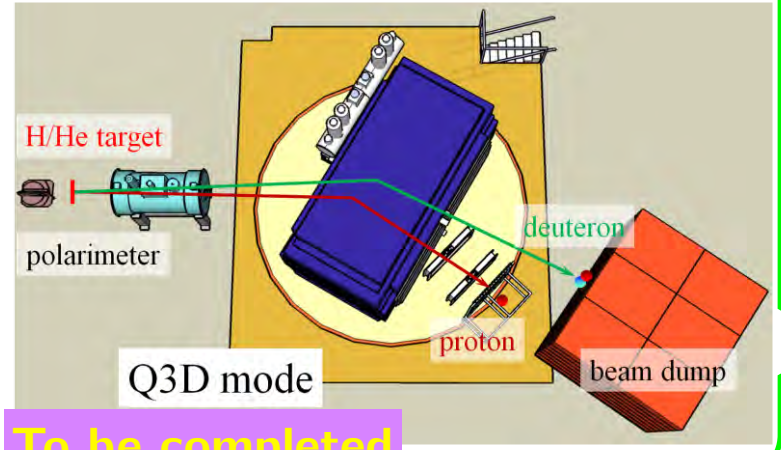


To be completed

***p*,*n*(target frame)+HI**
(*p*,*p*'), (*p*,2*p*), (*p*,*pn*), …

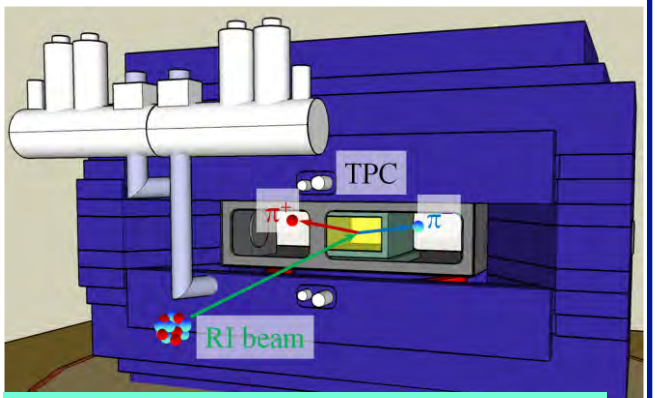


SAMURAI17,11: (p,n) inverse
SAMURAI14: Fission
SAMURAI12: Cluster on Be
SAMURAI13: Polarization
SAMURAI18(w/ MINOS): 2n correlation



To be completed

EOS measurement



SAMURAI15,22: EOS by π-/π+ measurement on HIC

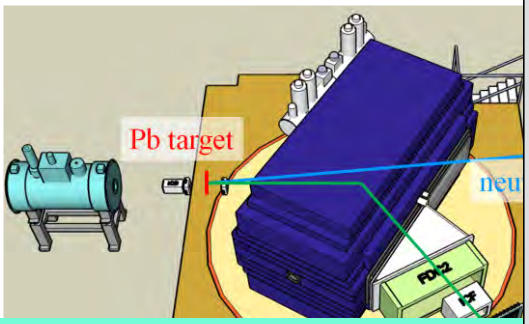
On-Going
On-Preparation
～2014–2015

To be advanced
A>100 region

Budgetary
Strategy Stage

Approved programs and SAMURAI setup modes

xn+HI (neutron-rich sid
(γ, n), unbound nuclei…



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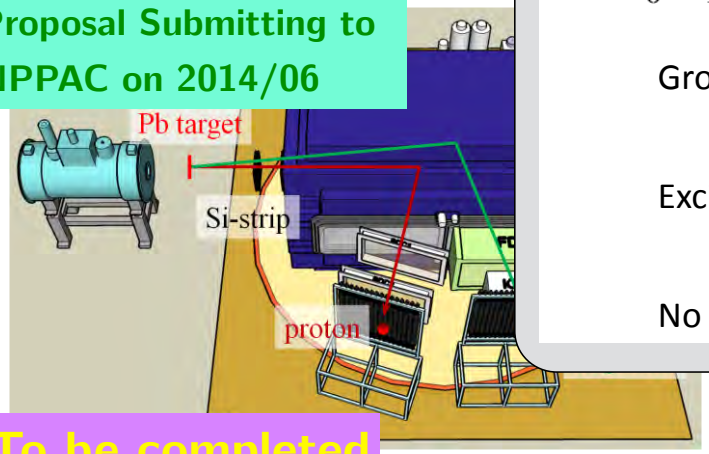
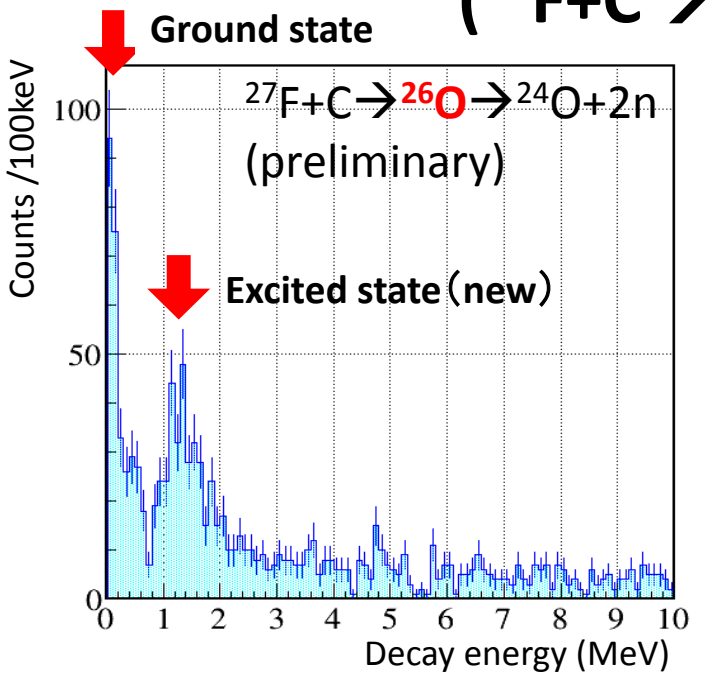


To be completed

Slide by
Y. Kondo(Tokyo Tech)

Decay energy spectrum (^{27}F+C→^{26}O→^{24}O+2n)

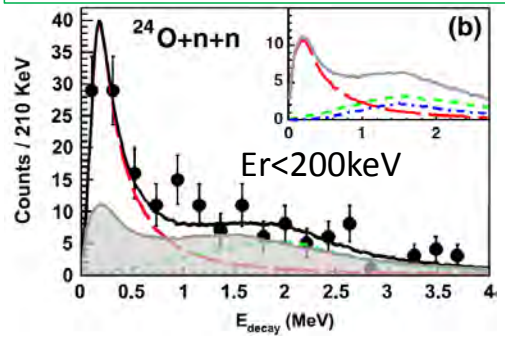


Ground state
- 5 times higher statistics
- →better determination of energy

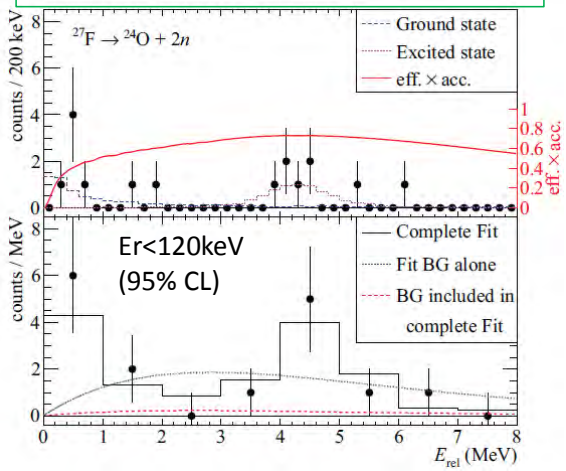
Excited state at ~1.3MeV
- First observation
- Most probably 2$^+$

No peak at ~4.2MeV

E. Lunderberg et al.PRL108, 142503 (2012)



C. Caesar et al.PRC88, 034313 (2013)

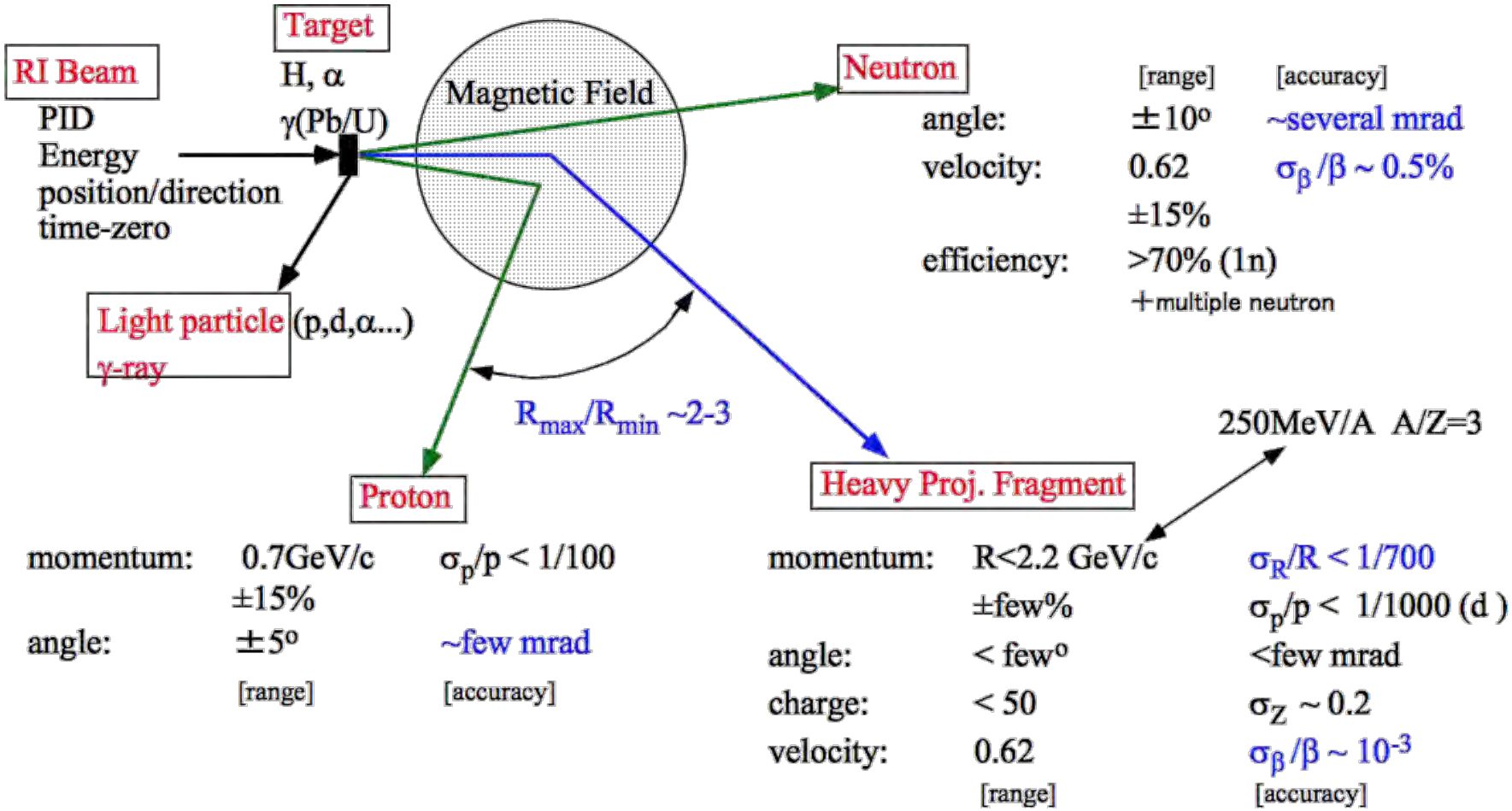


To be completed

SAMURAI
History

Designing phase

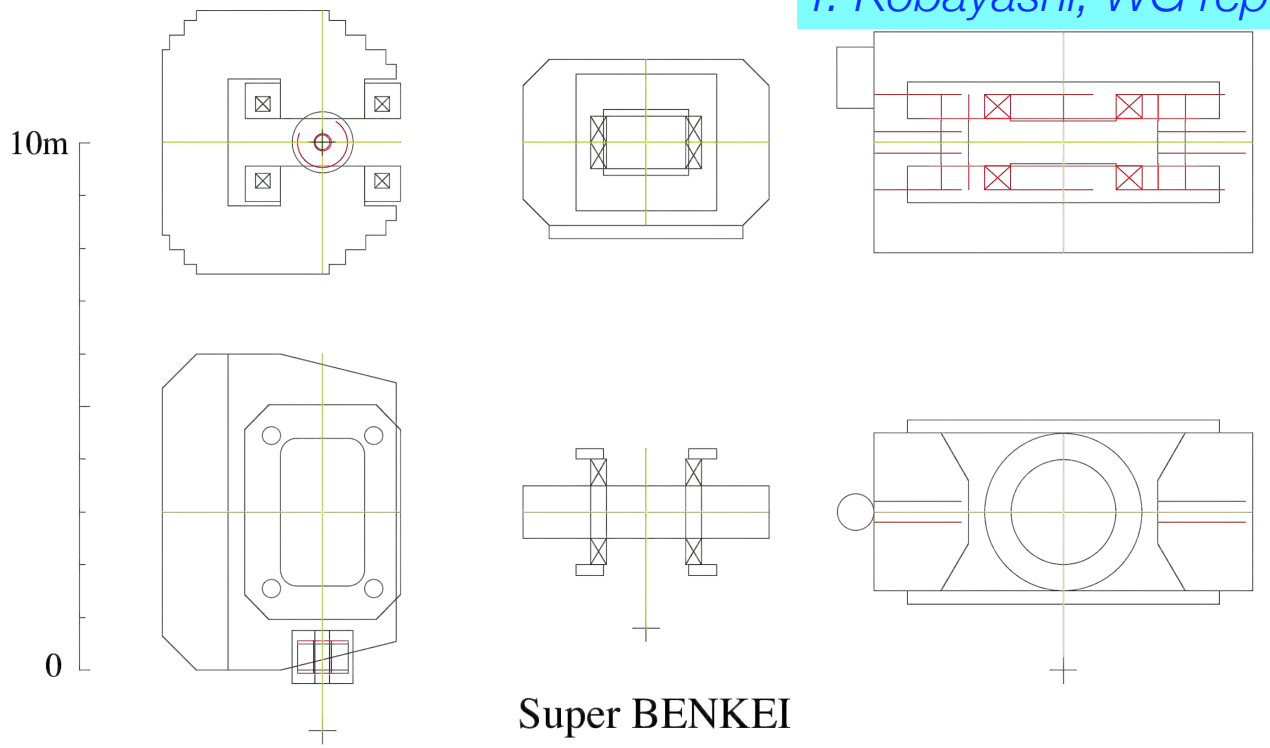
- Broadband type spectrometer was originally designed as key device in RIBF project from the beginning (~ 1997).



T. Kobayashi, TAC report, Fig. 1-3, 2004

Magnetic spectrometer so far considered (till 2004)

T. Kobayashi, WG report, 2004



Super BENKEI

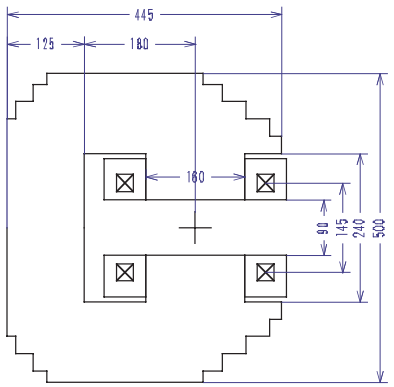
Type	Q + C-magnet	H-type window frame	H-type round pole
B_{max}[T], BL[Tm]	3 T, 7 Tm	1.5 T, 2.3 Tm	3 T, 7 Tm
pole&gap[m], weight[t]	1.6x2.8x1.0 m, 620 t	1.5x1.0x1.0 m, 140 t	2.0m diam.x0.8 m, 650 t
AT & Stored Energy	4.4 MAT, 36 MJ	1.4 MAT, 36 MJ	3.6 MAT, 28 MJ
cost	1500 MY	100 MY(transfer+mod.)	<1000 MY
angle for 2.2GeV/c	55°	18°	53°
angular focussing	yes	no	no
drawbacks	force, cost, fringing field	low field	no angular focus, focal plane

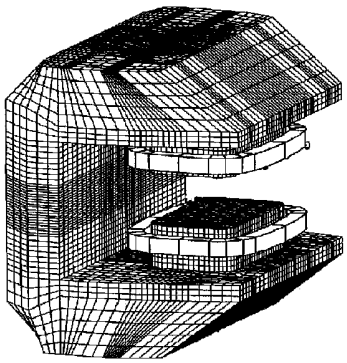
QD type

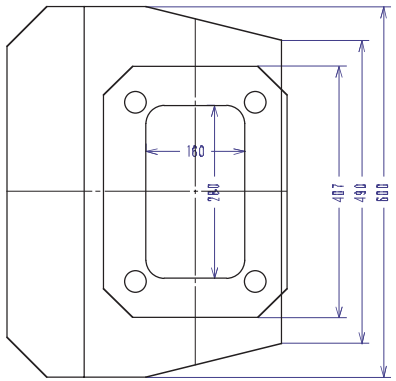
Magnetic spectrometer so far considered (till 2004)

T. Kobayashi, WG report, 2004

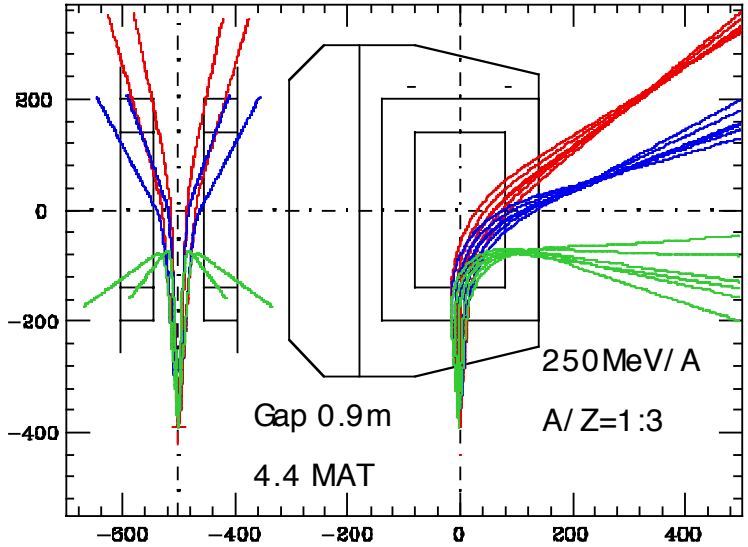
pole: 1.6(W)x 2.8 (D)x1.0m(G) → 0.3m with Q
field: 3.0 T @4.4MAT
weight: 620 t (585 t + 35t)
stored energy: 36 MJ
max field on coil: 4.0 T



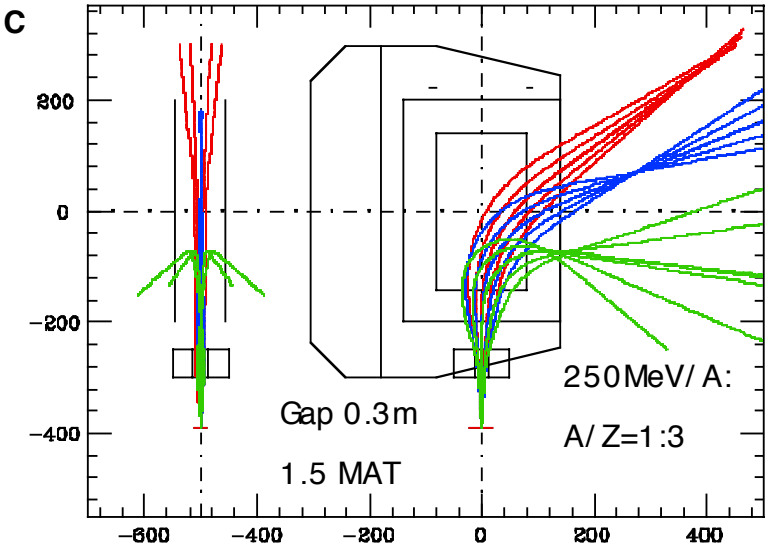




(1) C



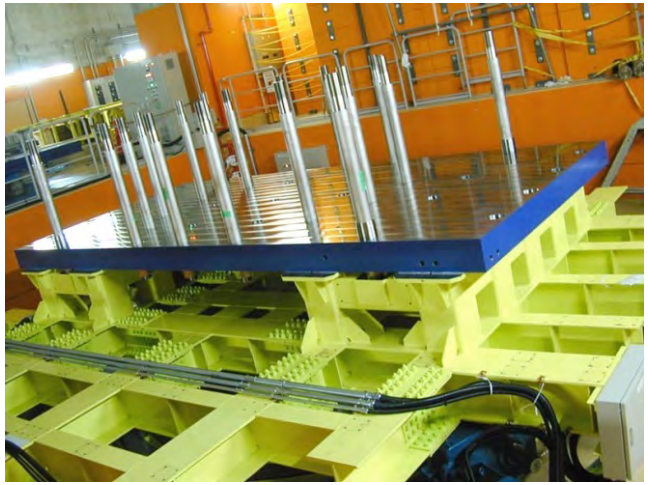
(2) Q+C



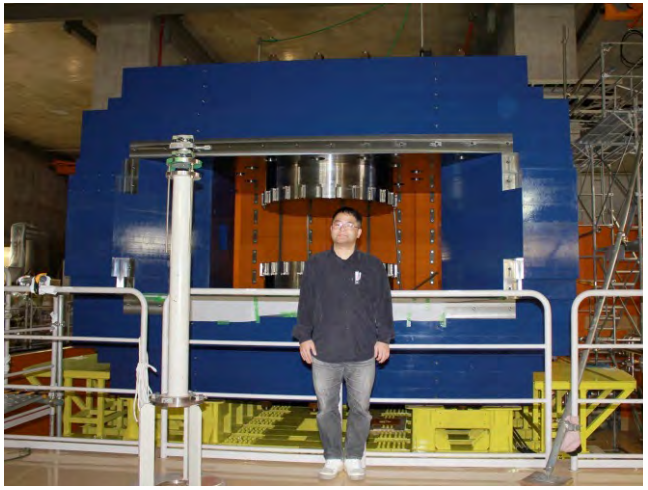
Disadvantage:
Inhomogeneous Power support of SC coil,
Power support for yoke
Coil link for SC coil, ...

Magnet construction (2009-2011)

Rails for rotatable base

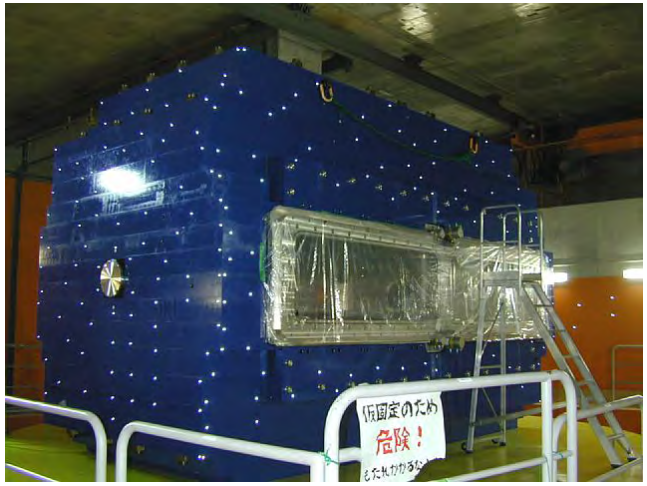


Rotatable base with the first layer



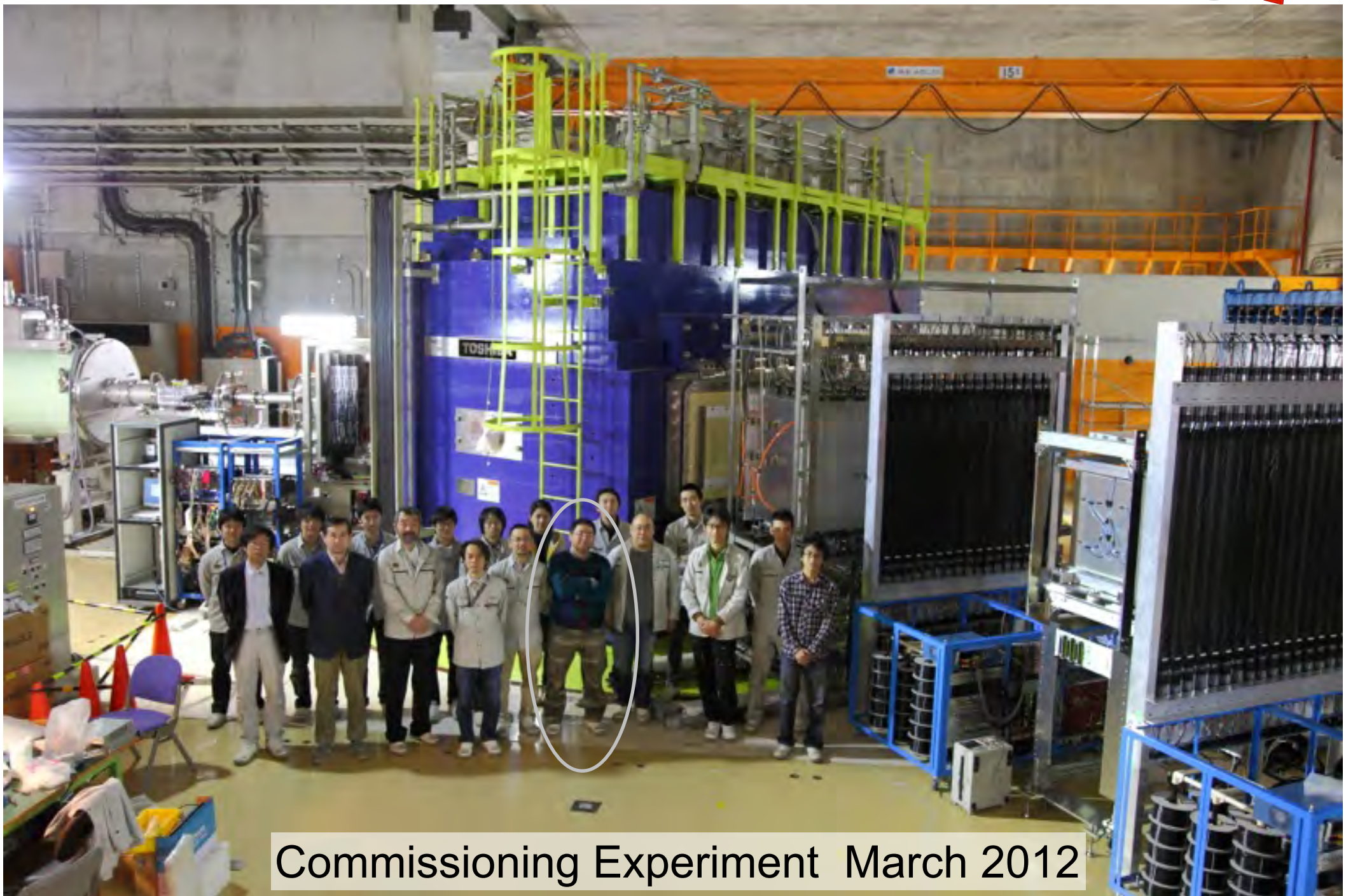
Magnet yoke with poles

Coils with cryostats, LHe vessels



Vacuum chamber

COMPLETED 2011/03



Commissioning Experiment March 2012

Spectrometer on RIBF

- SAMURAI : large/huge acceptance broadband type
  - Planned on RIBF design (~1997 ?)
  - Construction completed : 2011
  - First beam : 2012
  - dδ/δ~1/1500 (achieved value), 1/1000 (designed value)
  - Rmax/Rmin : 2~3
  - Vertical acceptance : 170mrad (± 5°) designed → 140mrad
  - Horizontal acceptance (for n) : 340 mrad (± 10°)

- ZeroDegree : extension of beam line from BigRIPS
  - Planned on RIBF design (~1997 ?)
  - Construction completed : 2007
  - First beam : 2008
  - dδ/δ=1/1240 (Large acceptance mode : 6%, H/V 90/60 mrad)
  - dδ/δ=1/4000 (Dispersive spectrometer mode : 4%, H/V 40/60 mrad)

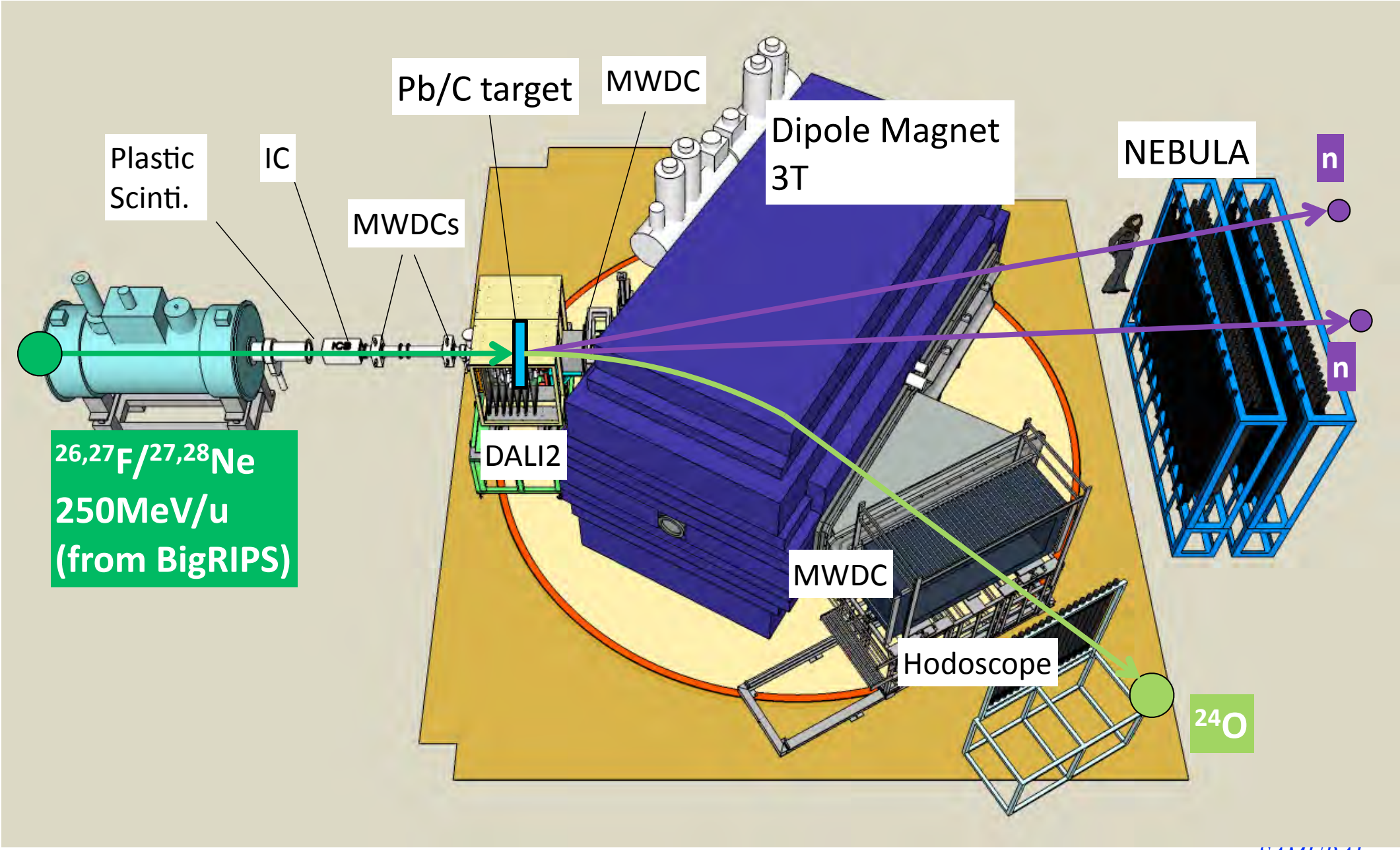
Spectrometer on RIBF

- ZeroDegree : extension of beam line from BigRIPS
  - Planned on RIBF design (~1997 ?)
  - Construction completed : 2007
  - First beam : 2008
  - $d\delta/\delta=1/1240$ (Large acceptance mode : 6%, H/V 90/60 mrad)
  - $d\delta/\delta=1/4000$ (Dispersive spectrometer mode : 4%, H/V 40/60 mrad)

- SHARAQ : high resolution spectrometer for RI beam by CNS
  - Kick off on 2004(?)
  - TAC : 2005
  - Construction completed : 2009 (2 years earlier than SAMURAI)
  - First beam : 2010 (2 years earlier than SAMURAI)
  - $d\delta/\delta=1/15000$

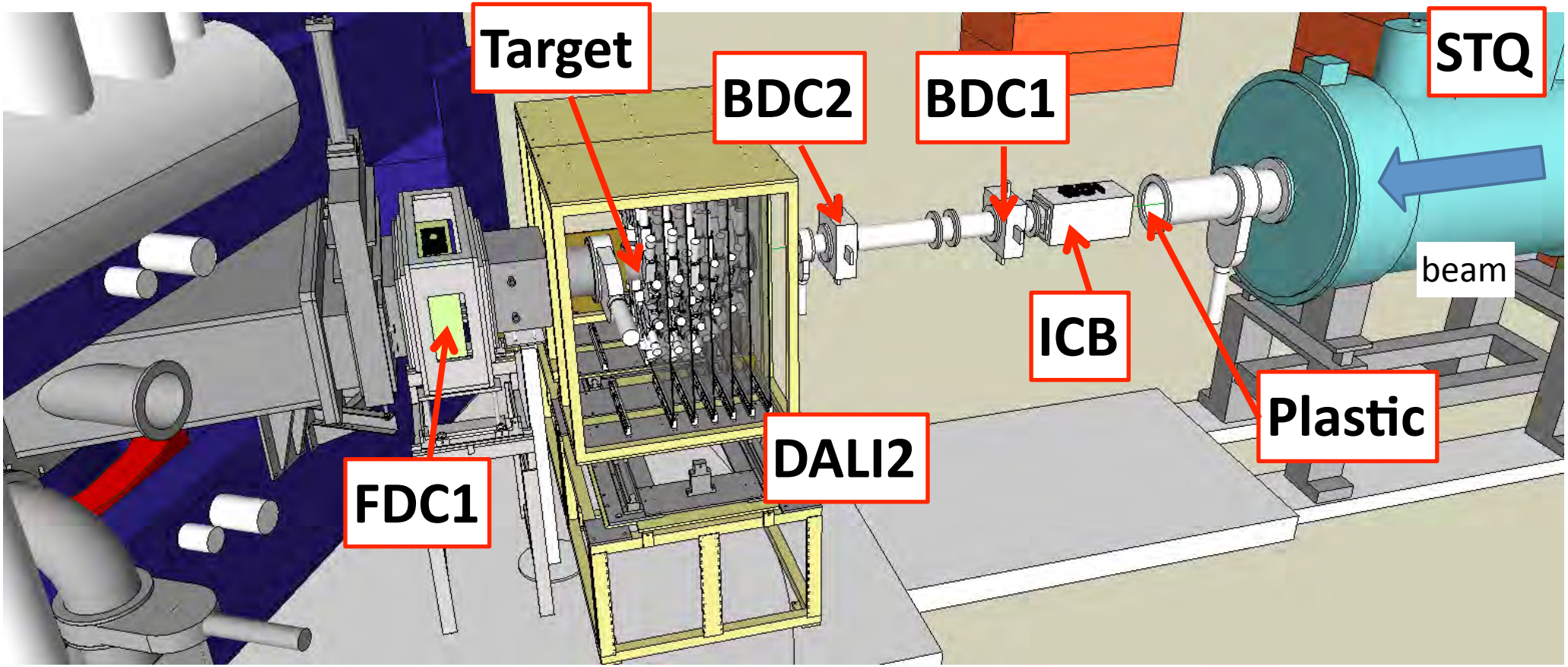
SAMURAI
Properties/Constituents

Typical n-HI measurement
Experimental setup



SAMURAI beam line detectors

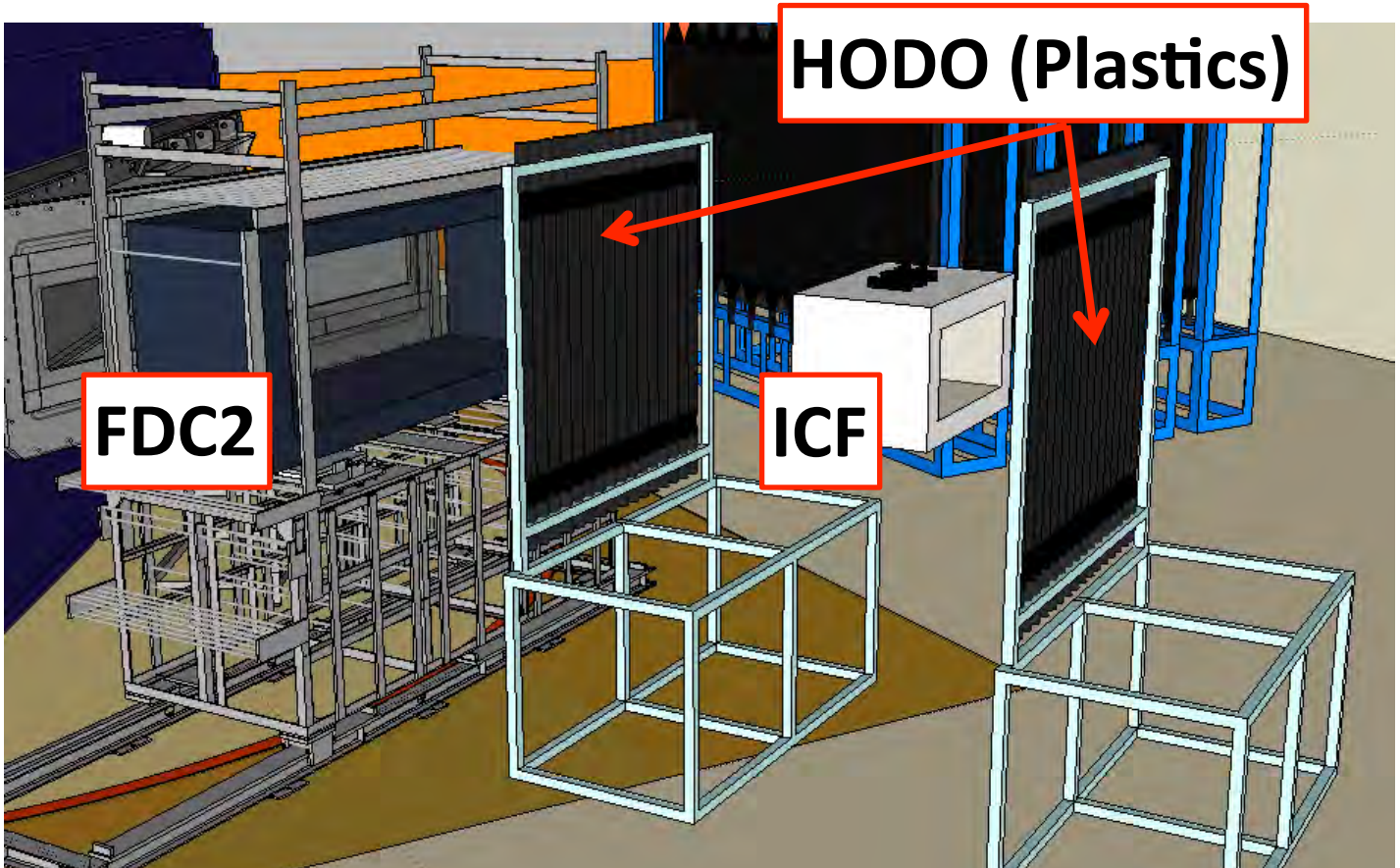
- Detectors for incoming beams: beam position (BDC), PID(Plastic and ICB), γ(DALI2) and tracking detector(FDC1) for electro-magnetic spectroscopy at SAMURAI.



SAMURAI Focal plane detectors

- Detectors for fragments: FDC2 for tracking, HODO for ΔE and TOF, ICF for ΔE.
- Proton drift chamber (PDC), CsI total energy detector (TED), and total internal reflection Cherenkov (TIRC) will come in the future.

fragments



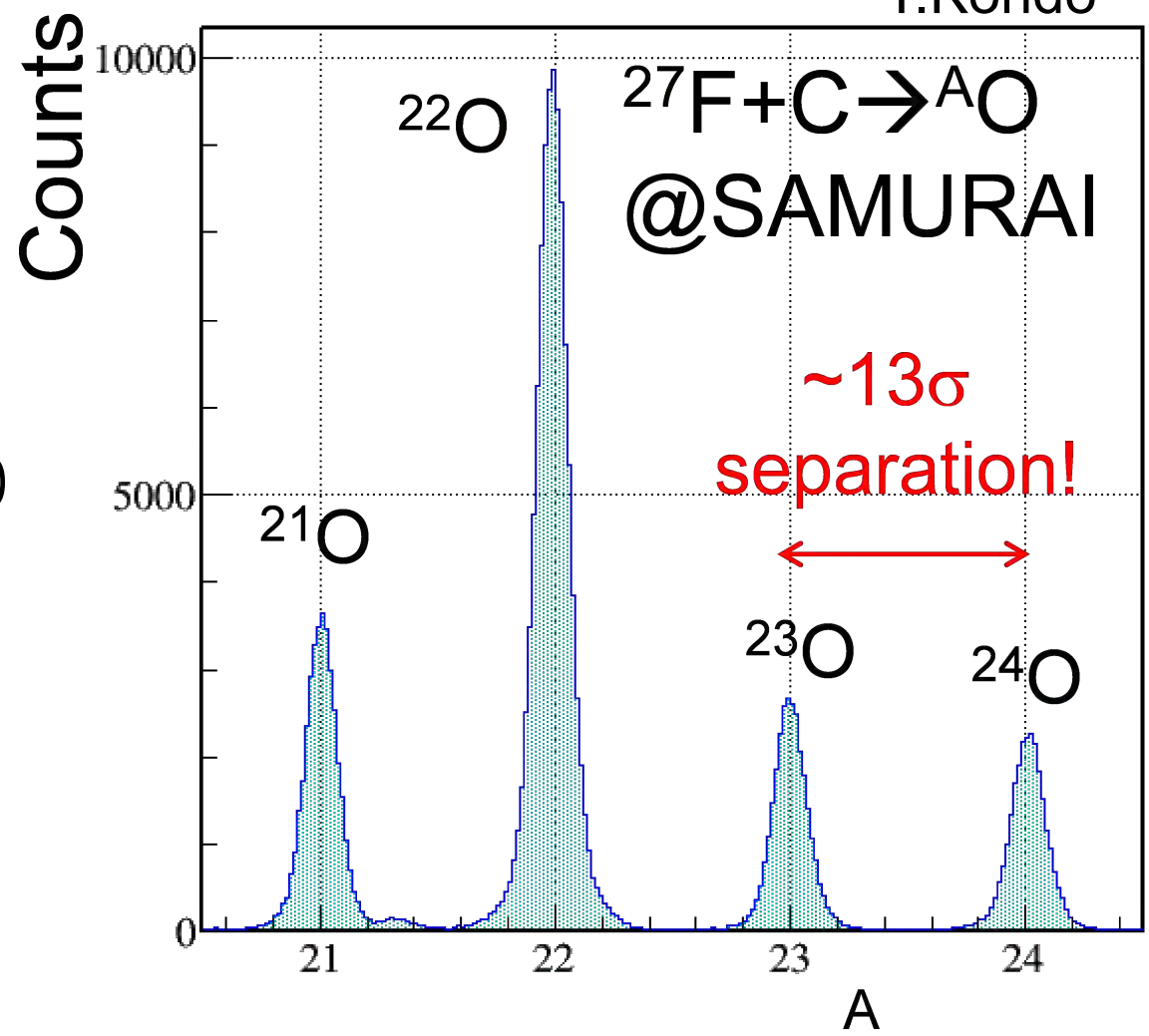
Offline analysis : much better than those of on-line phase.

Courtesy of Y.Kondo

- On-line : 7σ separation

↓

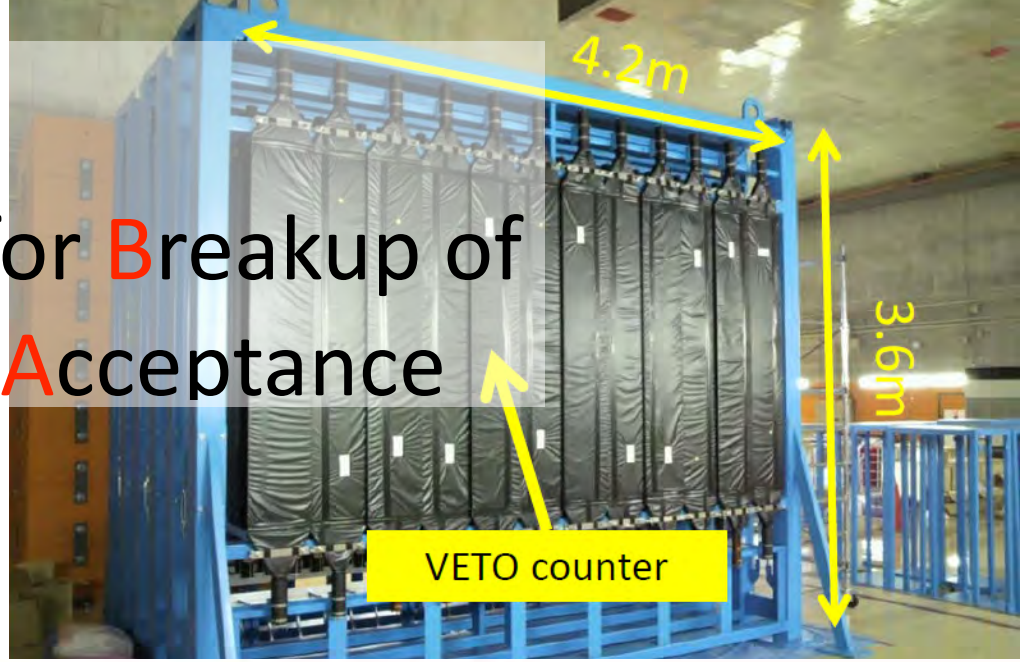
- 13 σ separation @ A~25
  →3σ separation @ A~100 (expected)



Clear Particle identification!
→ High resolving power of SAMURAI

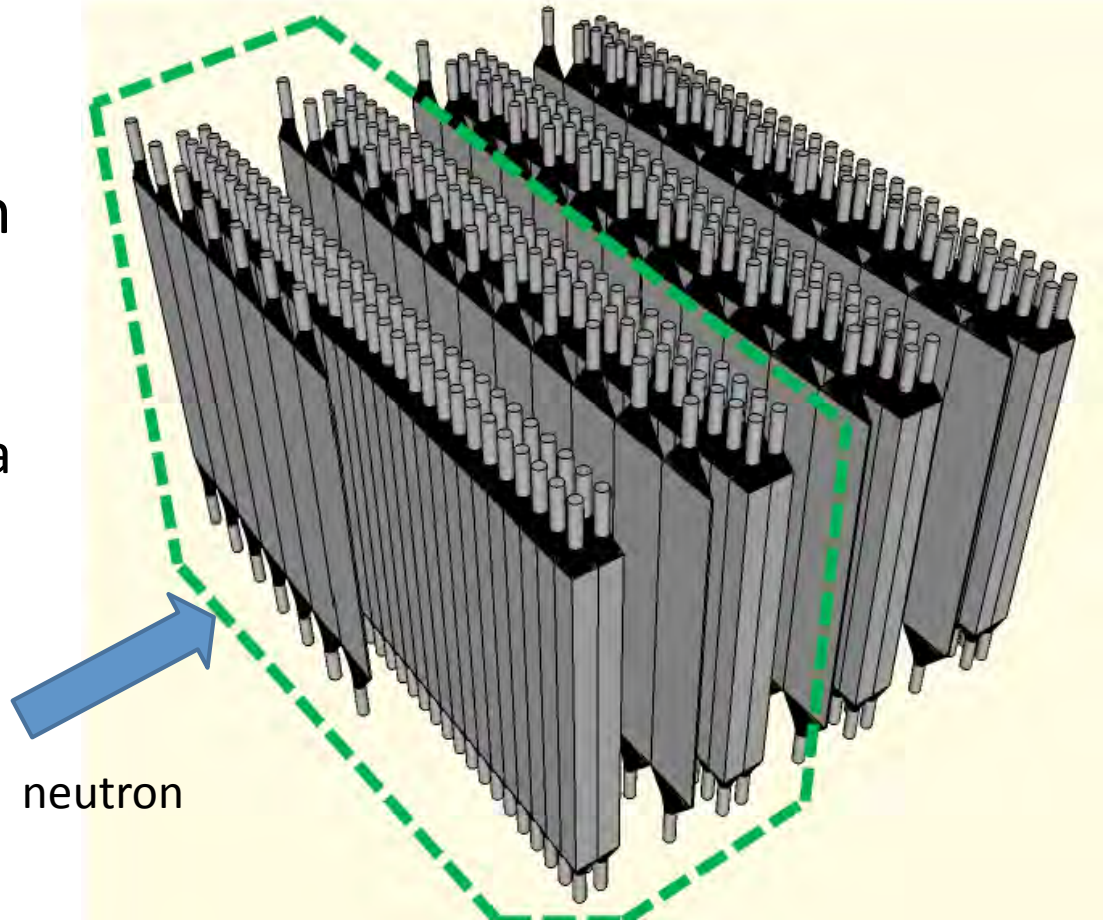
SAMURAI-NEBULA

Neutron-detection system for Breakup of Unstable-Nuclei with Large Acceptance



- Design
  - 240 Neutron counters
  - 48 VETO counters
  - arranged into 4 stacks
- Detection efficiency~40% for 1n (Currently)
- Large acceptance
  - 3.6m (H) x 1.8m (V) effective area

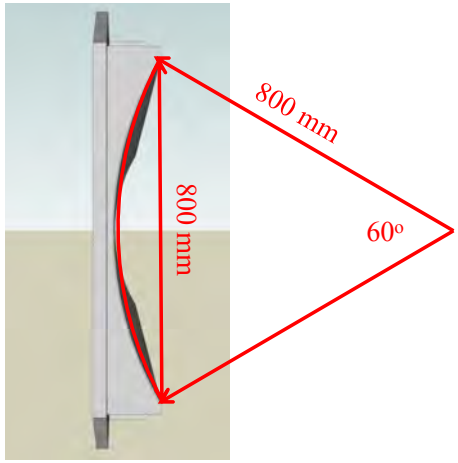
Half(120 modules) is funded and completed.

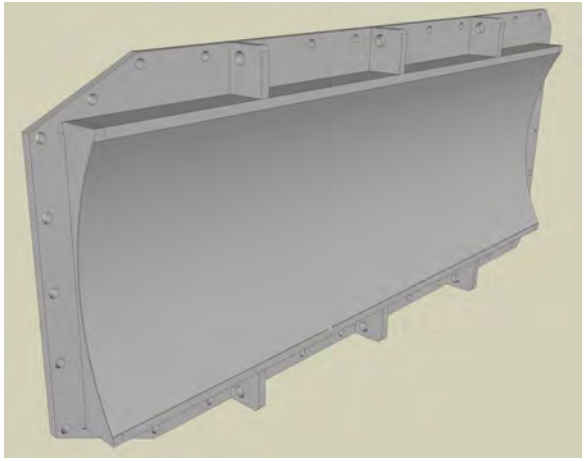


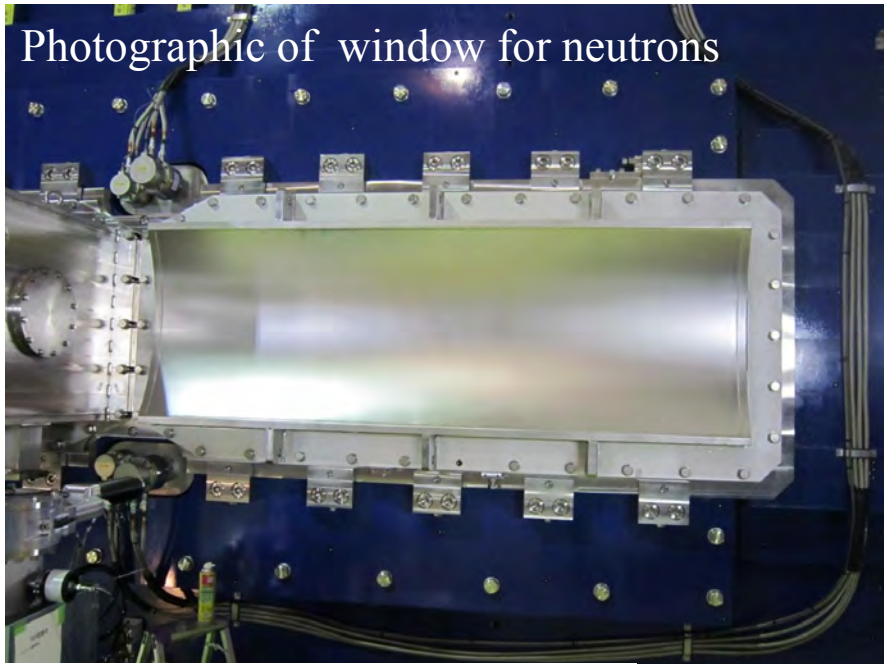
SAMURAI Vacuum Window

- Neutron window : SUS 3mm^t : 2430 × 800 mm^2
  - for neutrons ~ 250 MeV to pass through
  - De-dimension configuration applied
    Estimated by ANSYS calculation → Deformation is reasonably small

CONCEPT: De-dimension
2D geometrical degree of freedom
→ approximately restricted to 1D deformation







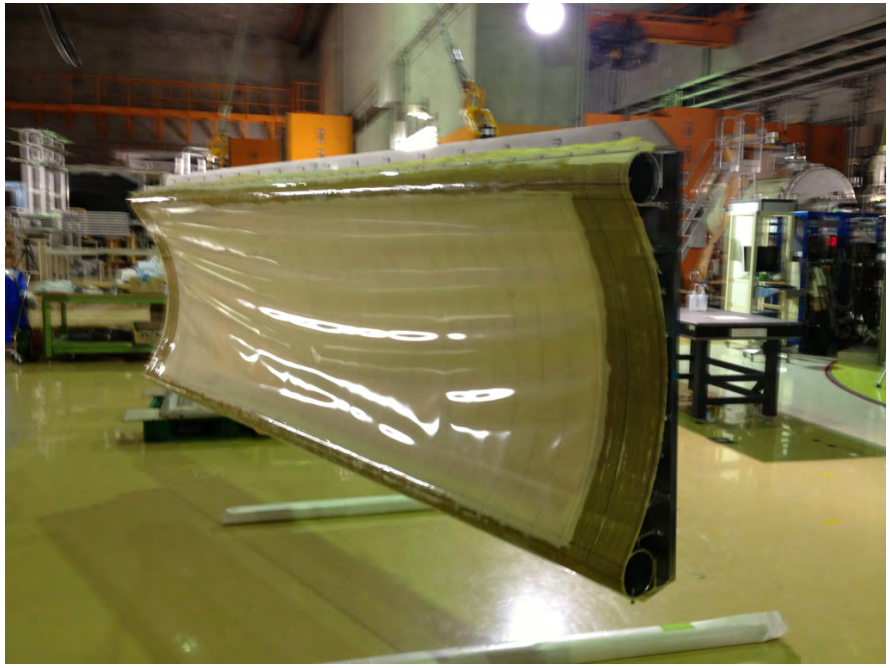
Calculation results:
Deflection : 0.22 mm
Stress(Max.) : 29 MPa

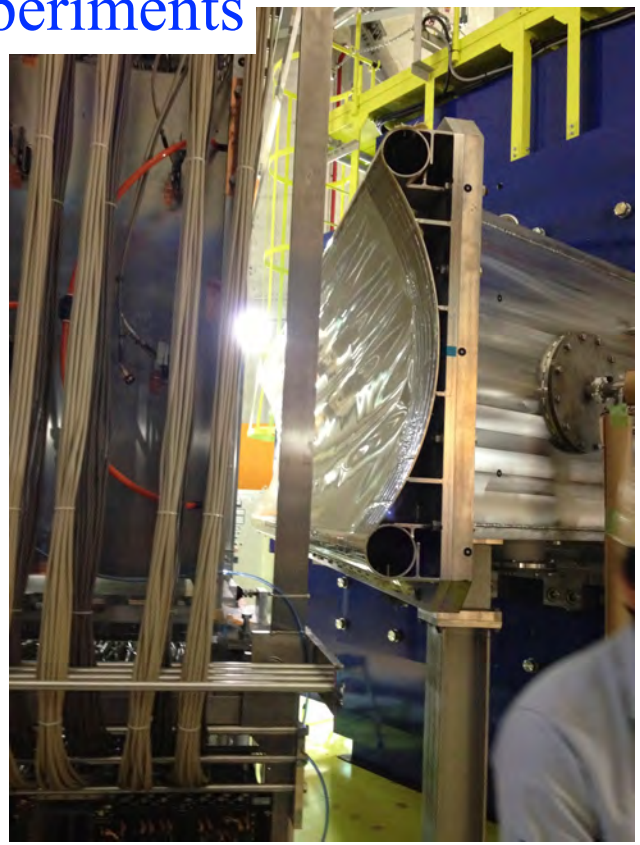
Y. Shimizu, EMIS2012 proceedings

SAMURAI Vacuum Window

- Charged particle window : 2940 × 800 mm^2
  for HI ~ 250 MeV to pass through
- 400mm → 800mm
  by De-dimension concept successfully introduced on n-window

Put to the practical usage on 2013/01 for Day-2 experiments





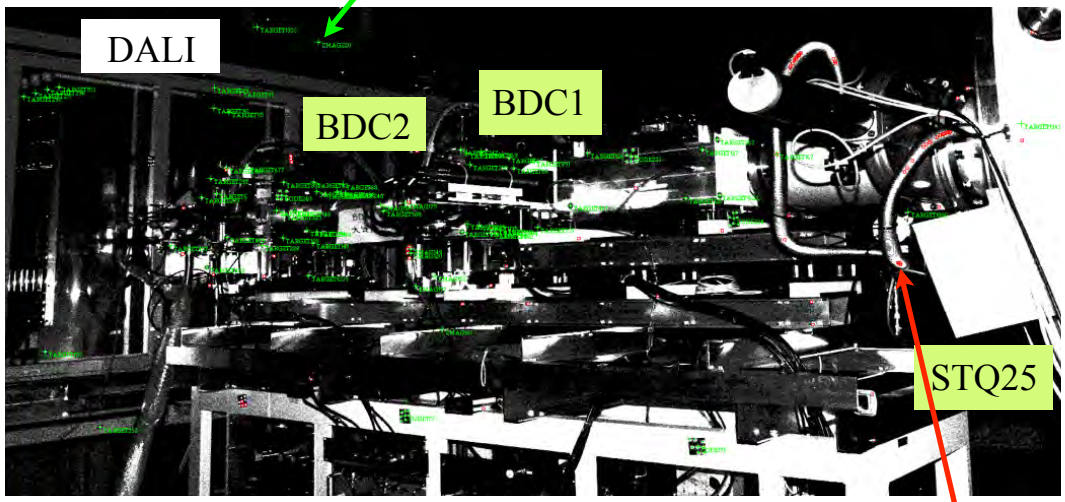
Membrane configuration : (same)
Mylar 75 μm / Kevlar(K49) 0.28 mm^t

Position determination of devices upstream and downstream of the magnet

- Photo Grammetry System (PGS)
  - as RIKEN Common usage device , FY2010

1. Paste target markers on devices
2. Take pictures surrounding from the devices

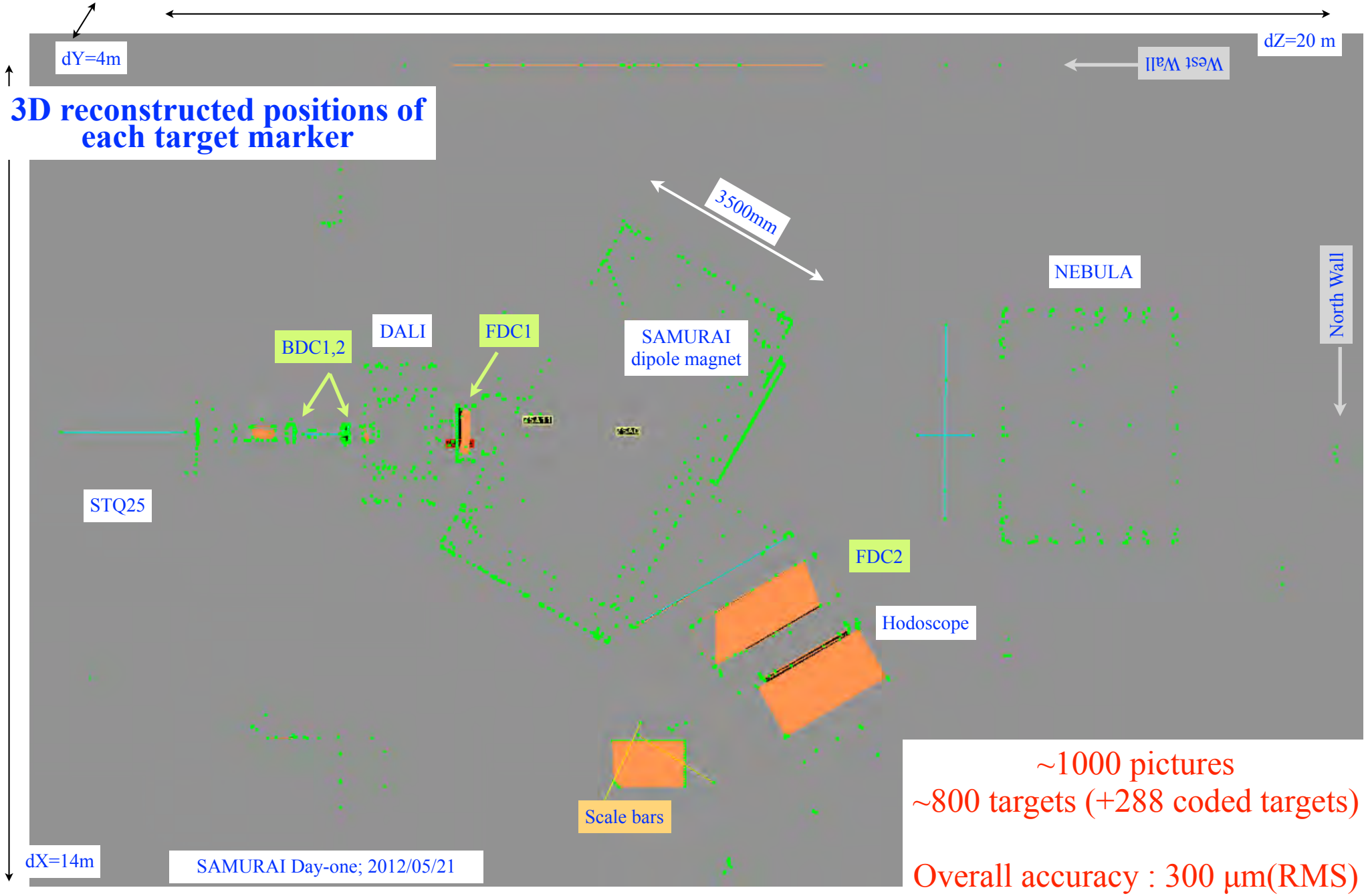
Every target is identified as a green marker.



Spurious reflections are noted as red markers

Reconstruct to 3D position by dedicated software (VStars)

Establishment of position measurement by PGS unbiased by human experiences or eyes



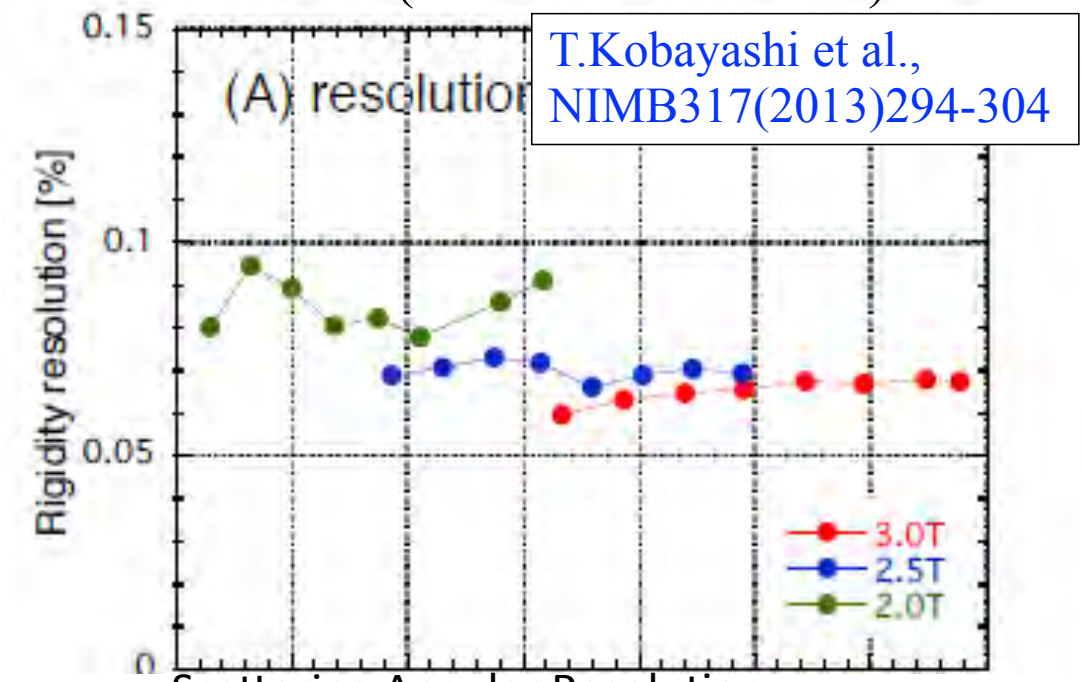
~1000 pictures
~800 targets (+288 coded targets)

Overall accuracy : 300 μm(RMS) *r*

Results of precise position determination

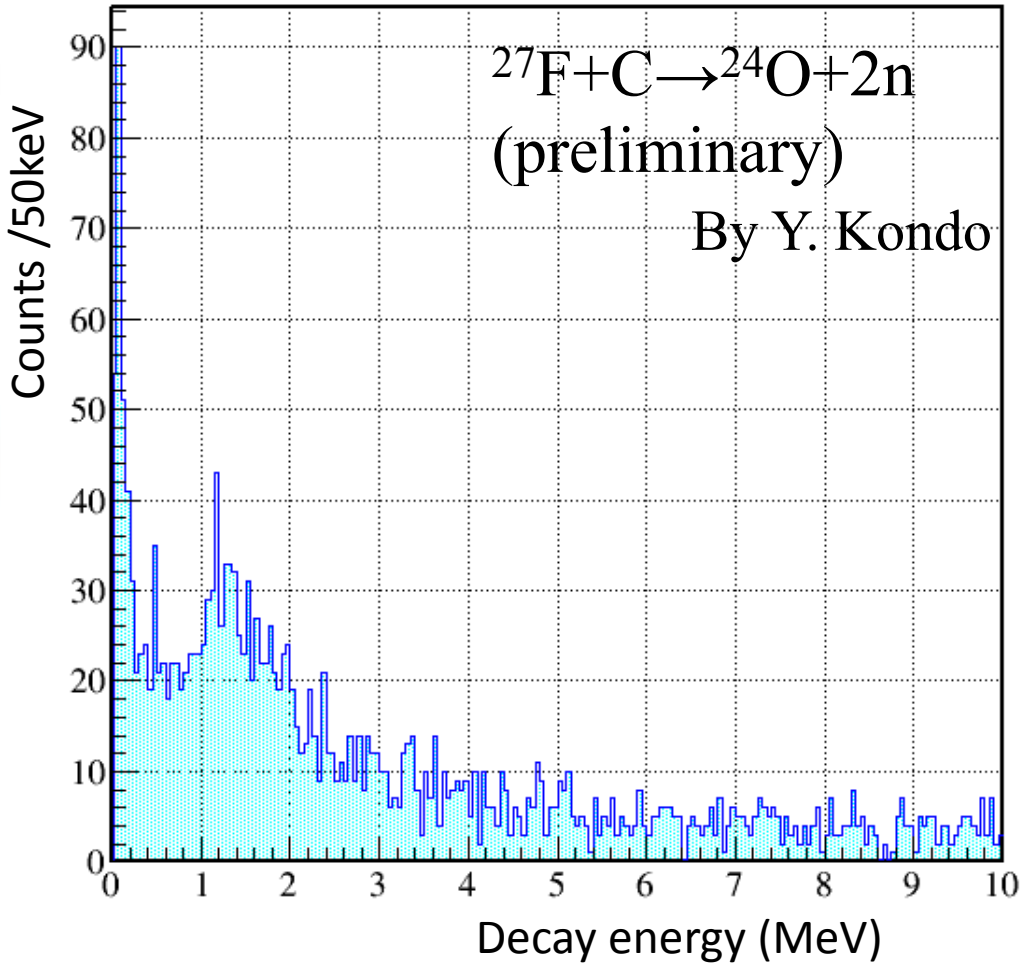
Each detector position (and angle) are determined within 150μm(RMS)
→ Successfully reduce the large contribution of systematic error on momentum analysis

Absolute momentum analysis
from BDC1,2 − FDC1,2 tracking
+ B field(TOSCA calculation)



Scattering Angular Resolution
→**0.9mrad (rms)**
Bρ Resolution
→1/700 (one-path analysis)
→**1/1500 (sophisticated)** Here
→**5σ mass resolution for A=100**

Decay energy spectrum: ^{26}O
w/o artificial offsets/treatments



Utilized to other RIBF beam line

SAMURAI experimental programs

Approved experimental program and Related devices

1) "Ready" programs

- SAMURAI17 M. Sasano/R.G.T. Zegar Done on 2014/03-04 WINDS
  Study of Gamow-Teller and spin-dipole transitions from ^{132}Sn via the (*p,n*) reaction at 270 MeV/u
- SAMURAI11 M. Sasano
  Study of Gamow-Teller transitions from ^{48}Cr (and ^{64}Ge) via the (*p,n*) reaction at 190 MeV
- SAMURAI14 D. Muecher(W. Henning) Done partly on 2014/03-04 Only test part is ready
  Fission Barrier Studies of Neutron-Rich Nuclei via the (*p,2p*) Reaction
- SAMURAI12 D. Beaumel Si tele.
  Cluster structure of Beryllium isotopes and study of multi-neutron systems
- SAMURAI13 S. Sakaguchi pol-p Target
  Vector analyzing power measurement for *p*-^{6}He elastic scattering at 200 MeV/A

Approved experiments (2013/12) to be performed in near future

2) Programs waiting for "User Devices"

- SAMURAI15/SAMURAI22 W. G. Lynch/T. Murakami/T. Isobe/B. Tsang
  Study of density dependence of the symmetry energy with the measurements of charged pion ratio in heavy RI collisions

SAMURAI TPC

Decay Tagging

- SAMURAI20 C. Caesar(T. Aumann)
  Measurement of the neutron-decay lifetime of the ^{26}O ground state at the SAMURAI setup at RIBF
- SAMURAI21 Y. Kondo
  Spectroscopy of unbound oxygen isotopes II : ^{28}O → 4*n* Detection
- SAMURAI09R1 T. Kobayashi/Y. Togano
  Electric dipole response of neutron-rich Ca isotopes
- SAMURAI18R1 A. Corsi/Y. Kubota
  Two-Neutron Momentum Correlation in Borromean Nuclei

neu-LAND / MINOS

γ-CATANA

MINOS / recoil p,n detector

3) Programs waiting for "SAMURAI Development"

A~200 Detection @ FP

- SAMURAI14 D. Muecher(W. Henning)
  Fission Barrier Studies of Neutron-Rich Nuclei via the (*p,2p*) Reaction

MINOS : Operated at RIBF on 2014 Spring

Submitted program on coming NP-PAC(2014/06)

4) Very new programs

- SAMURAI23 T. Isobe/T. Murakami/W. G. Lynch/B. Tsang
  Study of density dependence of the symmetry energy with the measurements of proton to neutron ratio in heavy RI collisions

  SAMURAI TPC

  Deferred
  because 2weeks MT has been already approved

- SAMURAI24 V. Panin(RNC)
  Investigation of proton-unbound states in neutron-deficient isotopes ^{66}Se and ^{58}Zn

  SAMURAI 90Deg.

  γ-CATANA

- SAMURAI26 N. Iwasa(Tohoku)
  Study of resonance states in ^{34}Ca using neutron removal reactions of ^{35,36}Ca
- SAMURAI25 Z. Elekes(ATOMKI)
  Study of nuclear reactions relevant for type I X-ray bursts

  Approved as B grade,
  Plenned to be upgrade

- SAMURAI27 N. Kobayashi (UT)
  Spectroscopy of Odd-A Nuclei in the Island of Inversion ; ^{31}Ne, ^{37}Mg

- SAMURAI19R1 S. Paschalls (TU Darmstadt)
  Investigation of the 4n system at SAMURAI
  by measuring p,pα quasi-free scattering at large momentum transfer in complete kinematics

SAMURAI TPC status

Assembly completed May 2013

Slide from Sπrit group

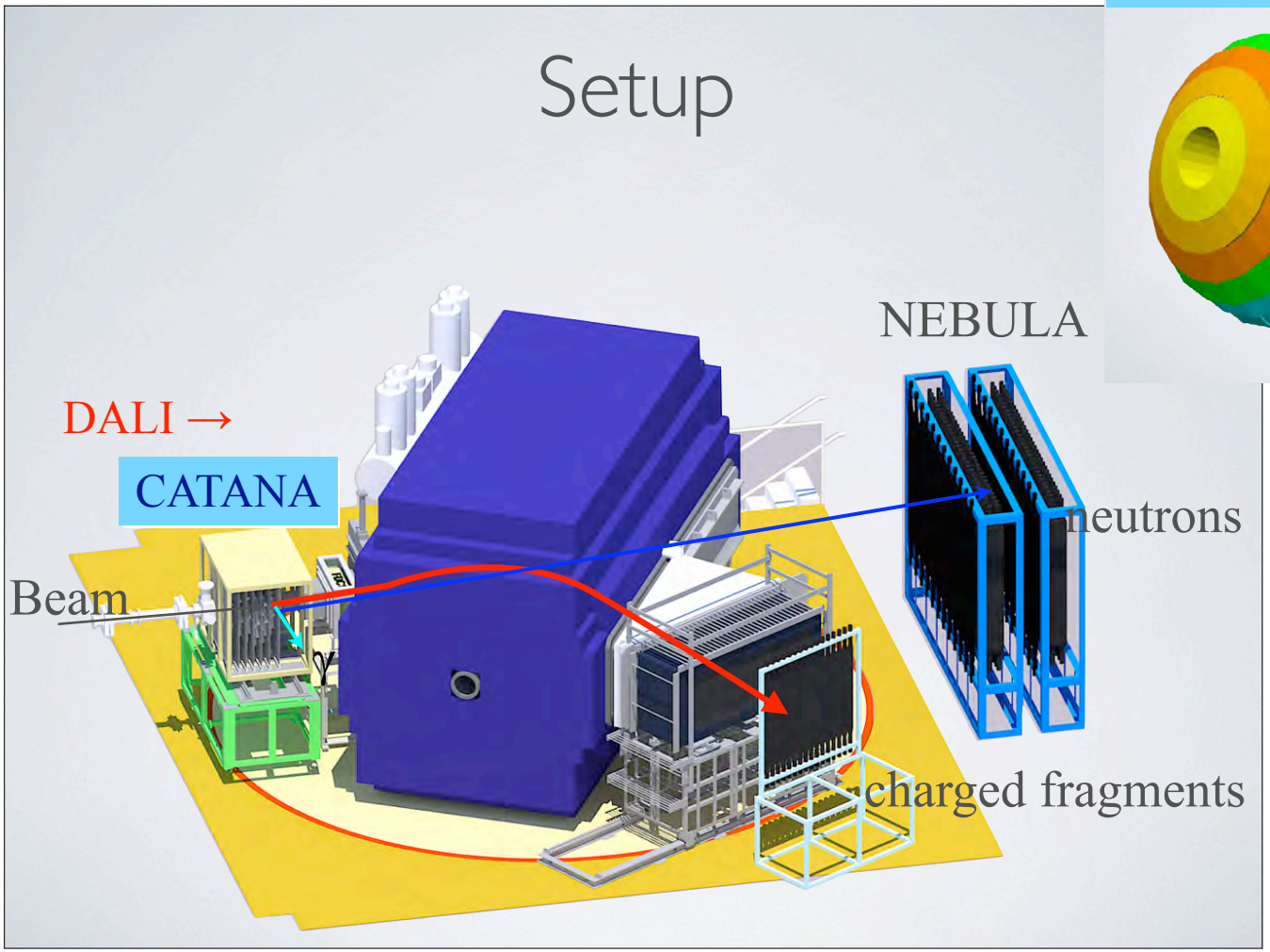
Pad plane readout tested with pulsers.
Testing with cosmic rays and sources are on going.
Experiments will use GET (Generic Electronics for TPC's) readout electronics.
Testing with gating grid driver is on going.
TPC will be shipped to RIKEN at February 2014.

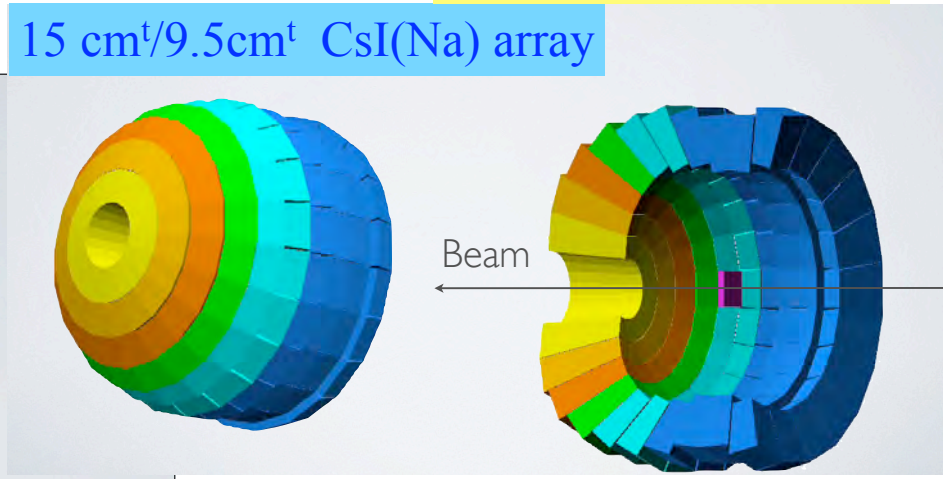
CATANA

CAlorimetric deTector for rAdiation from exotic Nuclear beAms

- Study for E1 responses on medium heavy (n-rich) nuclei
  → high multiplicity γ detection from residual nuclei

Slide from Y. Togano





ε_γ(1MeV) : 25%(DALI)
→ 65 %(CATANA)

Ready on 2015

SAMURAI

Summary

- SAMURAI Overview
- History

- Properties/Constituents
  - $d\delta/\delta \sim 1/1500$ (achieved value),
  - $dA/A \sim 1/300$ (achieved value, governed by lack of TOF resolution)
    - to be improved up to design value of 1/500 (5σ on $A \sim 100$)

- Experimental programs
  - Experiments with each SAMURAI configuration proposed
  - Several programs are waiting for MT assignment
  - Various user devices will be introduced coupled with SAMURAI (??? because of simplicity of SAMURAI ???)

One more thing…

- SAMURAI ⇄ SHARAQ
  - SAMURAI : Neutron detection but limited resolution
  - SHARAQ : high resolution but no chance on neutron

- + no chance to extend Zero degree type spectrometer downstream of SAMURAI because of limitation of building

- So, I think high resolution property coupled with neutron detection is very unique,
  even if it is designed on R3B-Grad magnetic spectrometer.

- QD for HI-p configuration for recovering vertical divergence.