SHARAQ spectrometer

for high-resolution studies of RI-induced reactions

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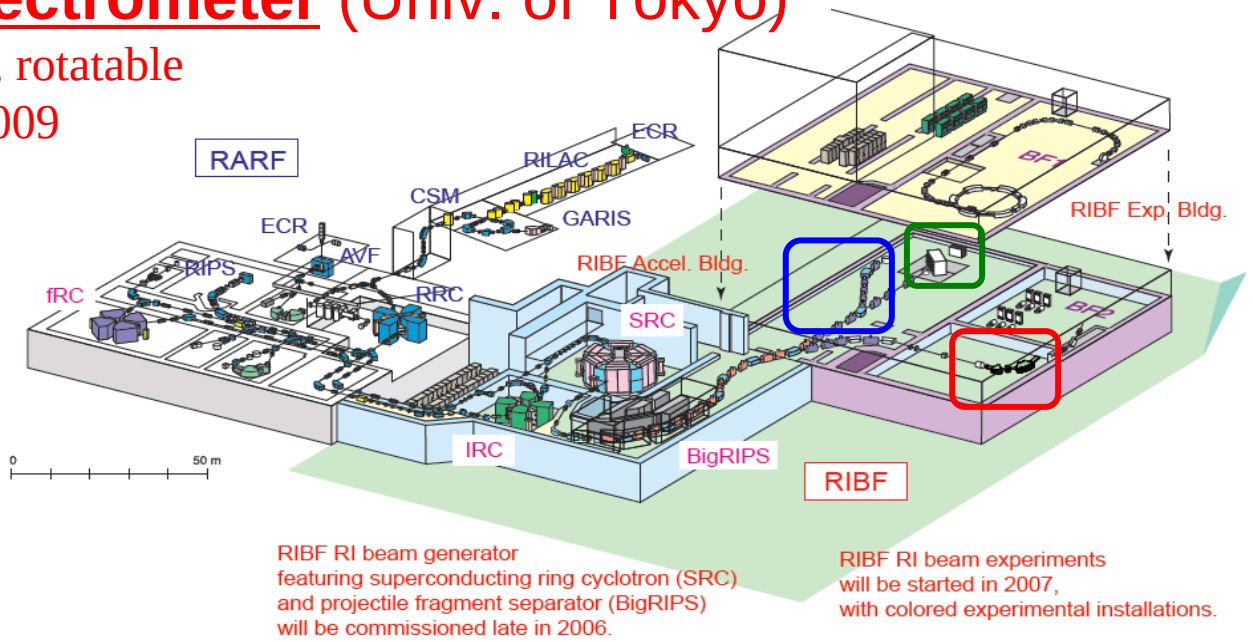
Contents

- Introduction of “SHARAQ”
  - High resolution beam line and SHARAQ spectrometer
  - Performed experiments and development
- Detectors for optics tuning
- Ion optics of SHARAQ
- Summary

Introduction of SHARAQ

RIBF was equipped with 3 spectrometers:

- **ZeroDegree spectrometer** (RIKEN)
  - multi-purpose for PID
  - completed in 2007
- **SAMURAI spectrometer** (Tohoku Univ.)
  - large acceptance, multi-particle
  - completed in 2011
- **SHARAQ spectrometer** (Univ. of Tokyo)
  - high resolution, rotatable
  - completed in 2009



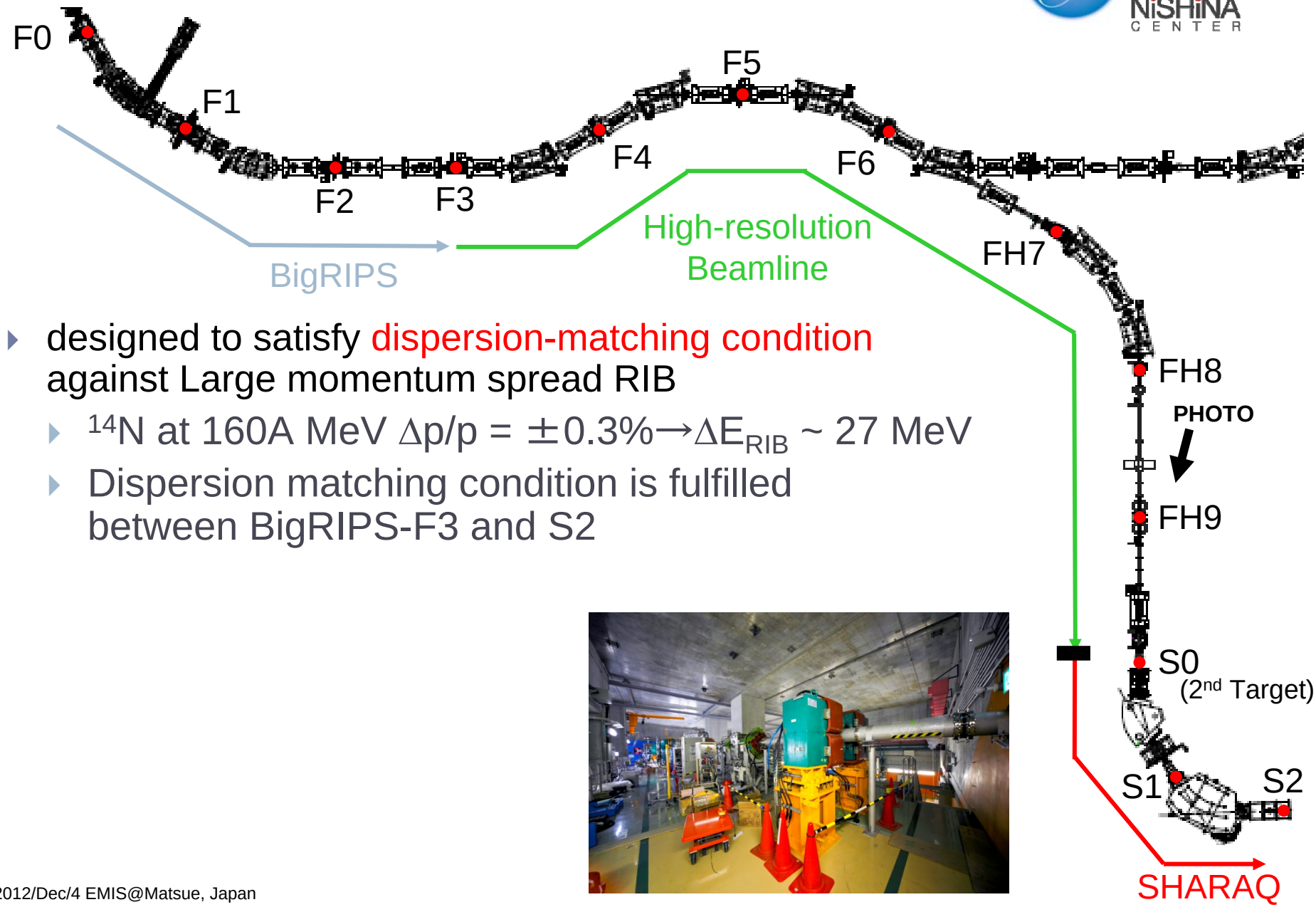
What is SHARAQ

- **SHARAQ**

  = **S**pectroscopy with **H**igh-resolution **A**nalyzer
  and **R**adio**A**ctive **Q**uamtum beams

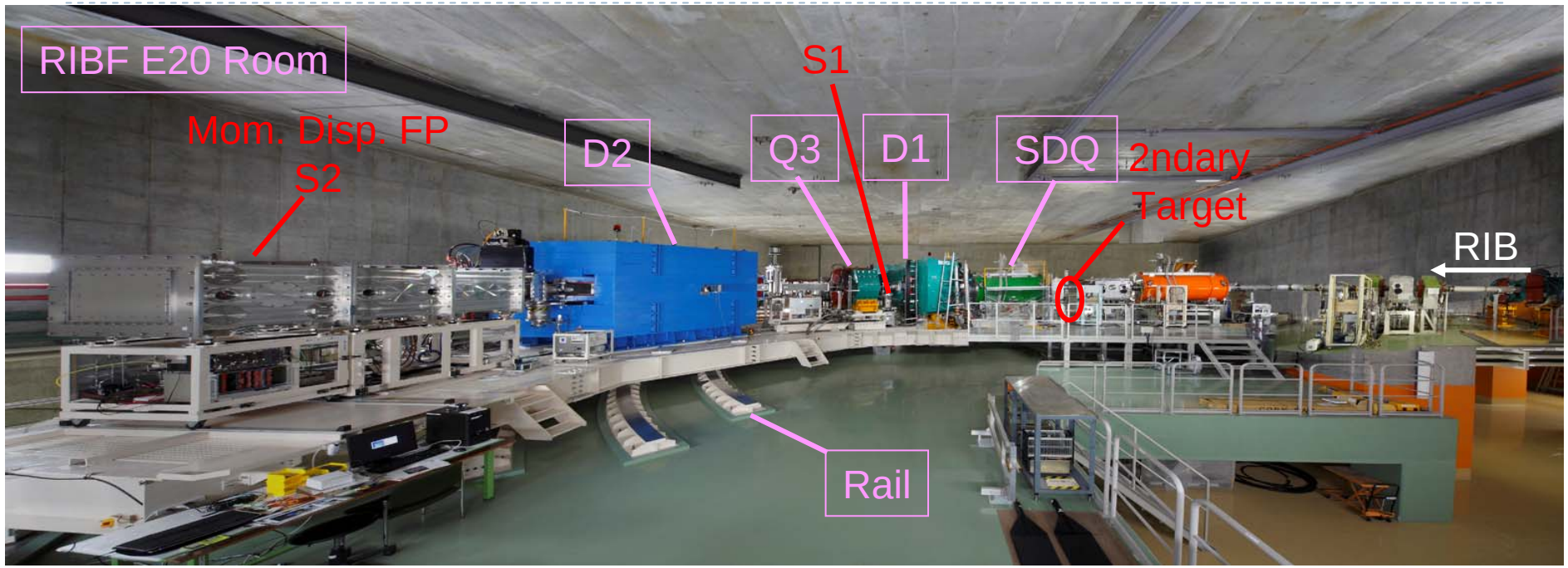
- BigRIPS × High-resolution beamline × SHARAQ spectrometer
  - BigRIPS
    provides High intense RI beam
  - High-Resolution beamline
    realizes dispersion-matching transport
    against large momentum spread of RI Beam
  - SHARAQ spectrometer
    analyzes momentum of reaction products with high resolution

High-resolution Beamline



- designed to satisfy dispersion-matching condition against Large momentum spread RIB
  - ^{14}N at 160A MeV $\Delta p/p = \pm 0.3\% \rightarrow \Delta E_{RIB} \sim 27$ MeV
  - Dispersion matching condition is fulfilled between BigRIPS-F3 and S2

SHARAQ spectrometer



- **QQDQD configuration**
  - good angular resolution and momentum resolution
- **Dipole Magnets**
  - Minimization of higher-order aberration by pole-edge curving
    - Easier tuning to dispersion matching conditions and data analysis
- **Superconducting doublet Q**
  - Higher resolution & Larger acceptance

Experiments at SHARAQ

- SHARAQ spectrometer was launched in Mar. 2009.
- Performed 6 physics experiments.
  - Charge exchange type reactions induced by RI beams.
  - Momentum analysis for outgoing particles in inverse kinematics.
- Development for upcoming experiments
  - Development of CVD diamond detector for very high-rate and good timing resolution. (See Poster.)

Experiments at SHARAQ

- Charge exchange type reactions induced by RI beams
  - Charge exchange study by (t,^{3}He) reaction at 300 MeV/u.
    - Search for IVSM resonance in ^{90}Zr, and ^{208}Pb
    - Miki et al. , PRL 108, 262503 (2012).
  - Ch.ex. reaction (^{12}N,^{12}C) with large positive Q value.
    - Noji et al., doctor thesis, to be published.
    - Combined DALI2 array for excitation γ-rays. (Poster by Takeuchi)
  - Ch.ex. reaction (^{10}C(0^{+}),^{10}B(0^{+})) with non-spin-flip process.
    - Sasamoto et al., doctor thesis, to be published.
    - Combined DALI2 array for excitation γ-rays.
  - Double-charge exchange reaction (^{8}He,^{8}Be).
    - Shimoura, Kisamori, Miya et al., in data analysis.
    - Search for 4n system by ^{4}He(^{8}He,2^{4}He)4n measurement with Q~0.
    - Development of 2α detection capability of the focal-plane detector.

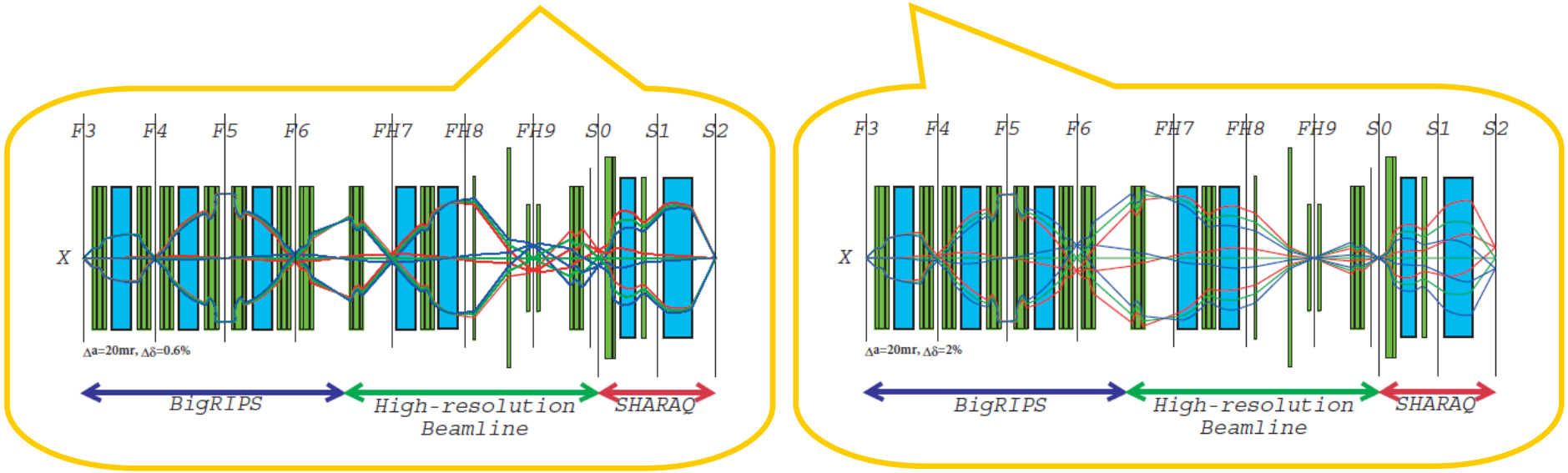
Experiments at SHARAQ

- Momentum analysis for outgoing particles
  - (p,n) reaction from ^{12}Be with inverse kinematics.
    - Yako et al. in data analysis
    - Combined with WINDS array for low-energy neutron detection.
      → Talk by Yako.
  - Polarized (p,2p) reaction from ^{14,22,24}O.
    - Uesaka, Kawase et al., in data analysis
    - Combined with Polarized proton target
      → Talk by Sakaguchi.

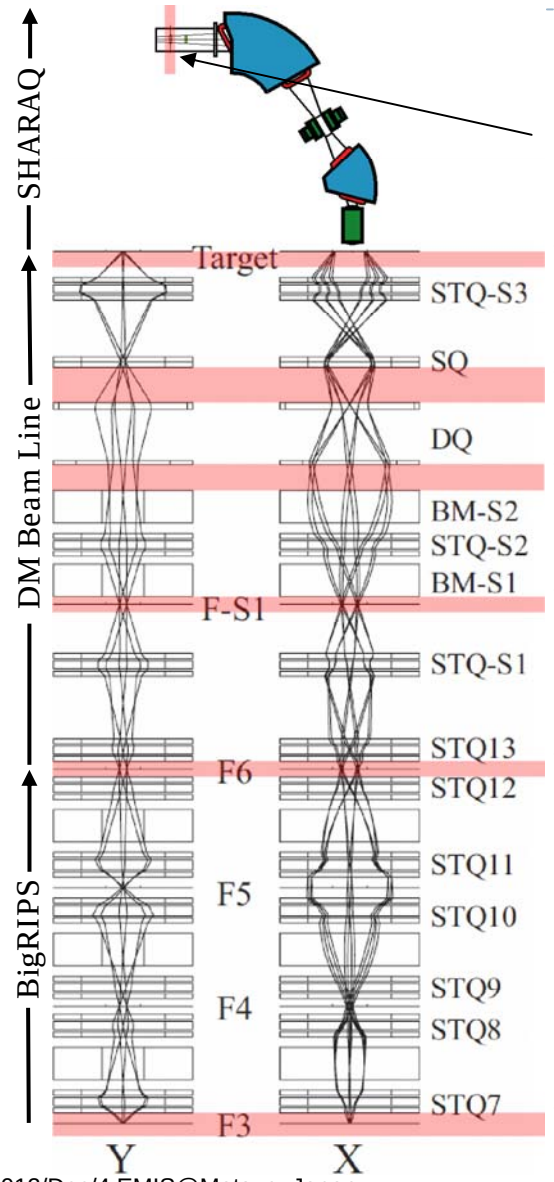
SHARAQ performed unique experiments
based on the SHARAQ high-resolution performance,
and by combinations
with high-performance detectors and/or an exotic target.

Beam Transport Mode of HRBL & SHARAQ

Mode	**Dispersion Matching**	**High-resolution Achromatic**	Large-Acceptance Achromatic
Acceptance			
$\Delta p/p$ (%)	±0.3	±1	**±2**
$\Delta\theta_x$ (mrad)	±10	±10	±20
$\Delta\theta_y$ (mrad)	±30	±30	±20
Maximum Dispersion	S0	F6	F5
Typical Spot size at S0 target (mm)	100 × 10	**10 × 10**	20–30 × 10
Reso. of BL ($\Delta p/p$)	**1/15000**	**1/7500**	1/1500
S2	**Lateral & Angular DM**	Mom. Disp.	Mom. Disp.



Detectors for Ion Optics Tuning



	Beam Tuning	Exp.
S2	✓	✓ $\vec{p}_{out}$/PID
FH10	✓	✓ $\vec{p}_{beam}$
FH9	✓	
FH8	✓	
FH7	✓	
F6	✓	
F3	✓	✓ p_{F3} /Spot Size monitoring

Beam Tuning

- Confirmation of beam transport
- (x,y,a,b) at focus points

Experiment

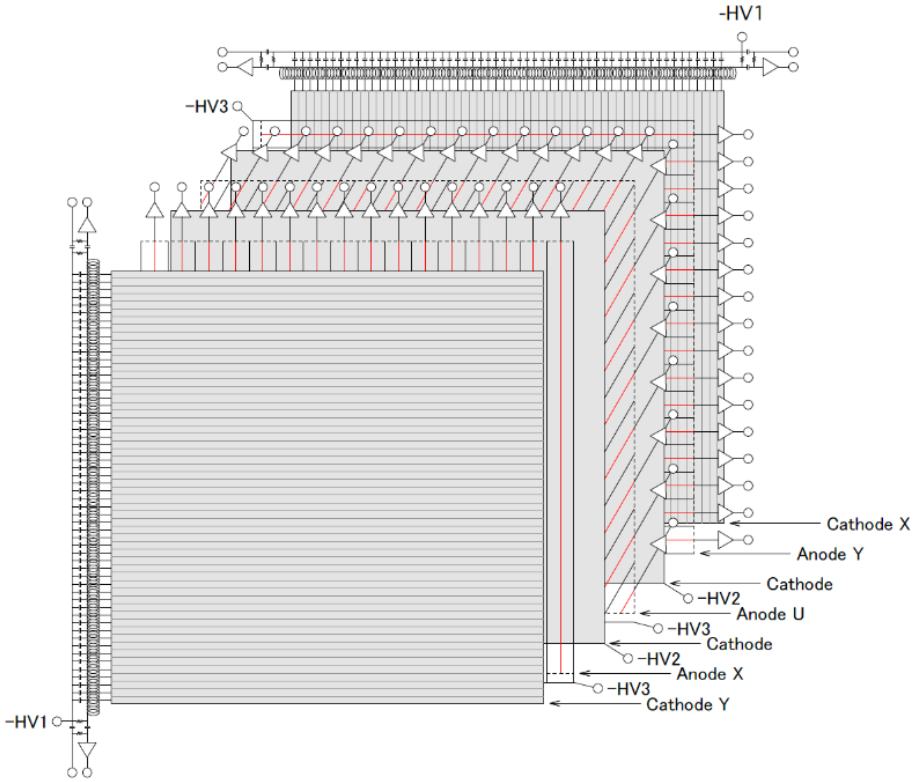
- $\vec{p}_{F3}$: essential for DM correction
- $\vec{p}_{out}$: Reaction Q value
- $\vec{p}_{out}$-$\vec{p}_{beam}$: Scattering Angle

Low-pressure MWDC for Beamline

H.Miya et al.

- Low-pressure MWPC
  - Thin thickness: $t/L_R < 10^{-4}$
  - Isobuthane (iso-C_4H_{10}) gas at p=10,30,50 kPa
  - Configuration: xx'yy'xx'yy' (@F3) and xuy (@F6,FH7,FH9,FH10)

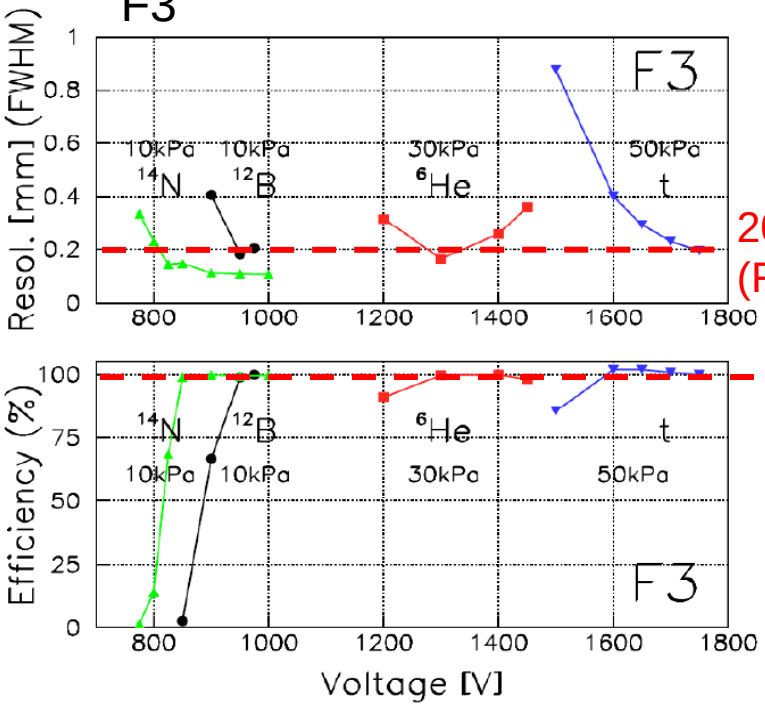
Number of planes	8 (X1X1'Y1Y1'X2X2'Y2Y2')
Number of cells	16 cells/plane
Cell size	5 mm^w × 4.8 mm^t
Sensitive Area	80 mm × 80 mm
Anode wire Potential wire Cathode foil	Au-W 12.5 μm Cu-W 75 μm Al-PET 2 μm
Operation Gas	pure isobutane



Performance of Beamline Detectors

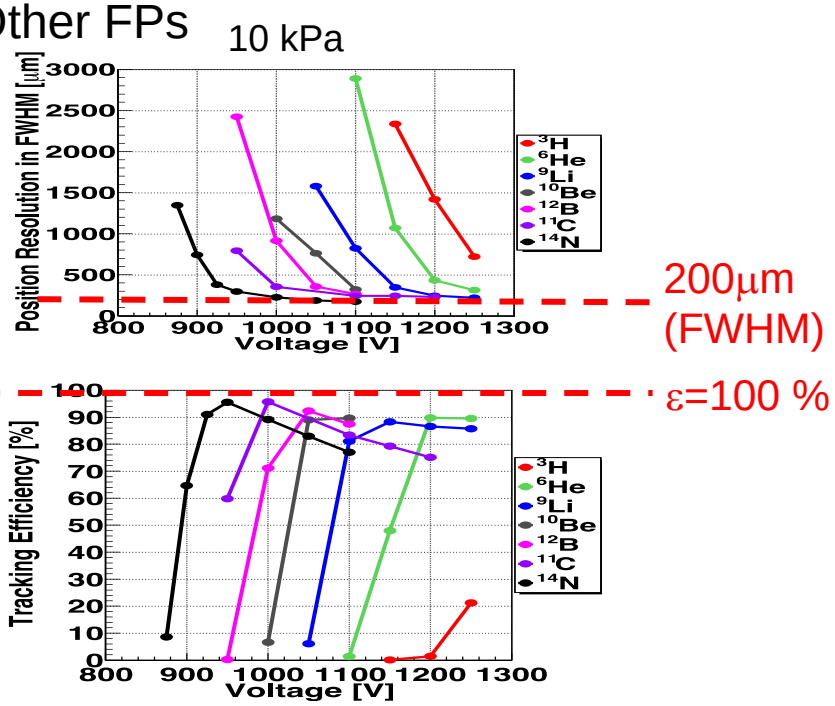
H.Miya et al.

F3



200μm (FWHM)

Other FPs



200μm (FWHM)

ε=100 %

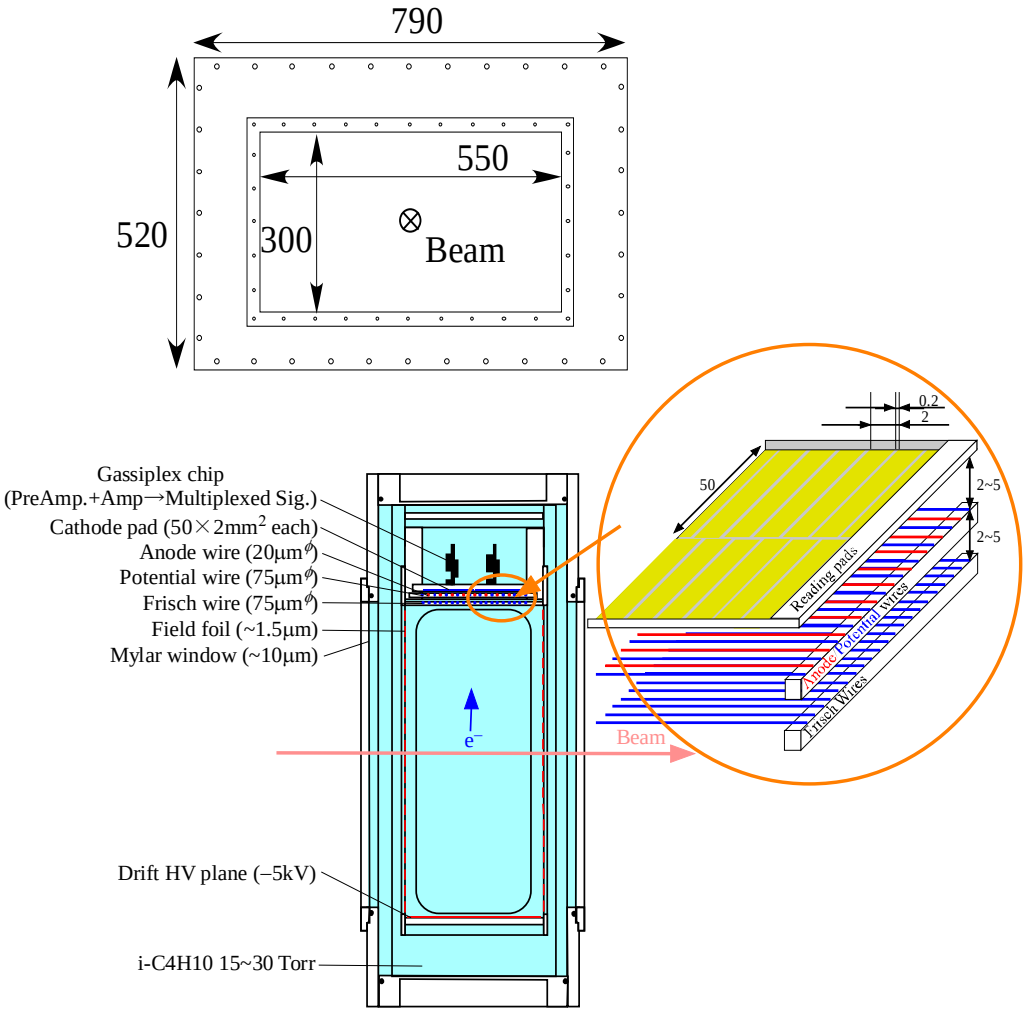
→ Development for its high-rate counting property.
Successfully operated under 2 MHz beam.

Details are in Poster by Miya

Focal-plane Detector of SHARAQ Spectrometer

S.Michimasa, H.Tokieda, S.Noji et al.

Schematic view of CRDC



Designed specification

Thickness: < 1 mrad of multiple scattering
Gas: isobutane < 5 kPa
Read-out information
- T,Q from Sensing wires
- Q from 512 Cathode pads

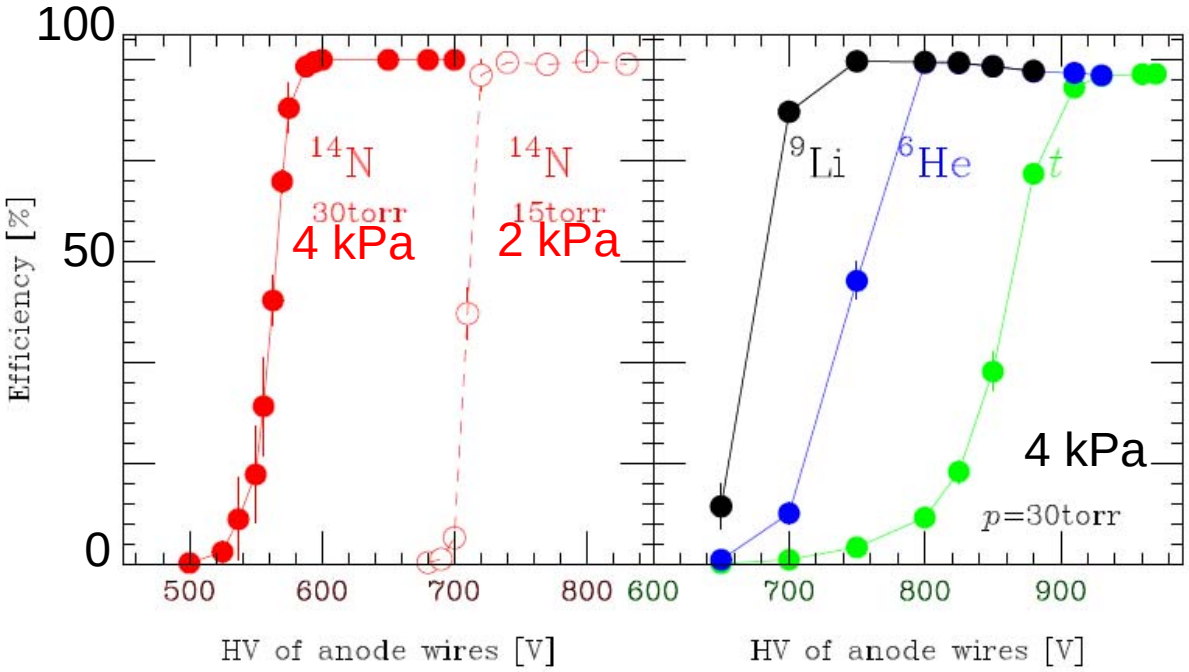
Ch. Number: total 4 ch.
- 2 ch Anode
- 2 ch Cathode (256-ch multiplexed)

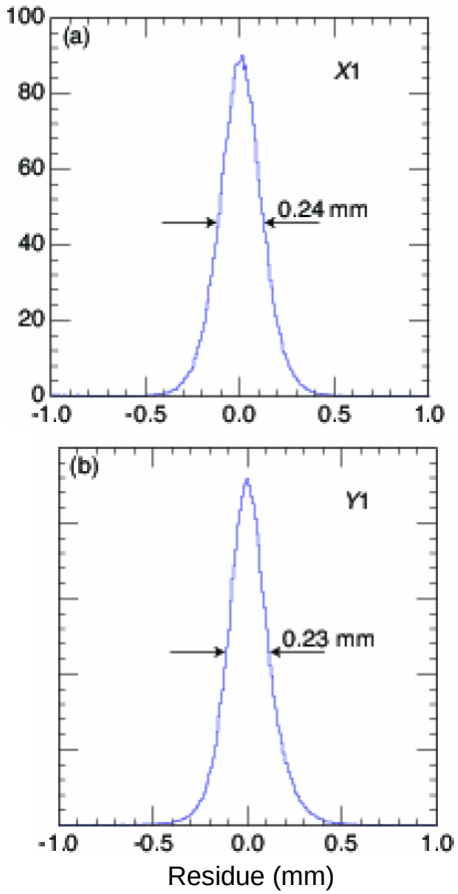
Position-measurement:
- x: induced charge distribution
- y: drift time

Resolution:
- x: 300μm(FWHM)
- y: 300μm(FWHM)

Counting Rate:
- up to 10^3 Hz

Performances of CRDC





Evaluation of Position resolution for ^{12}N particles.

Horizontal (x; Pad)	~ 0.24 mm (FWHM)
Vertical (y; Drift)	~ 0.23 mm (FWHM)

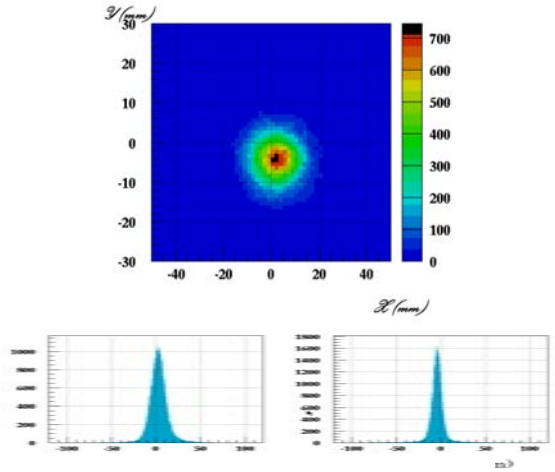
Tracking detectors work well even for light ions of Z=1-7

Ion Optics in SHARAQ

- Achromatic transport to SHARAQ
- Dispersion matching transport
  in the High-reso. beamline and SHARAQ spectrometer

Achromatic transport in HRB & SHARAQ

Beam spot at the 2nd target



		1st order estimate
Horizontal	**7.9mm(σ)**	4.8 mm(σ)
Vertical	**5.2mm(σ)**	4.1 mm(σ)

Matrix elements

$(x_{S0}\|a_{F3})$	= -0.06	-0.02
$(y_{S0}\|b_{F3})$	= -0.14	+0.00
$(x_{S0}\|\delta)$	= -0.38	+0.18

SHARAQ spectrometer

1st order matrix elements were checked by correlation between S0 and S2

Measured

S2 \ S0	x	a	y	b	δ
x	−0.48	+0.01			−58.40
a	−1.13	−2.31			3.36
y			−0.09	−1.37	
b			0.76	0.20	
δ					1.

R.P = 12200

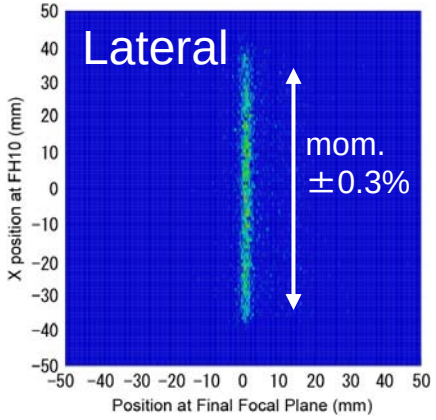
Calc.

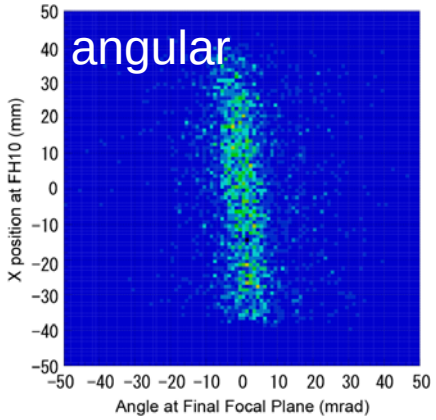
	x	a	y	b	δ
x	−0.58	+0.00			−60.80
a	−1.51	−1.73			6.42
y			−0.00	−1.34	
b			0.71	0.16	
δ					1.

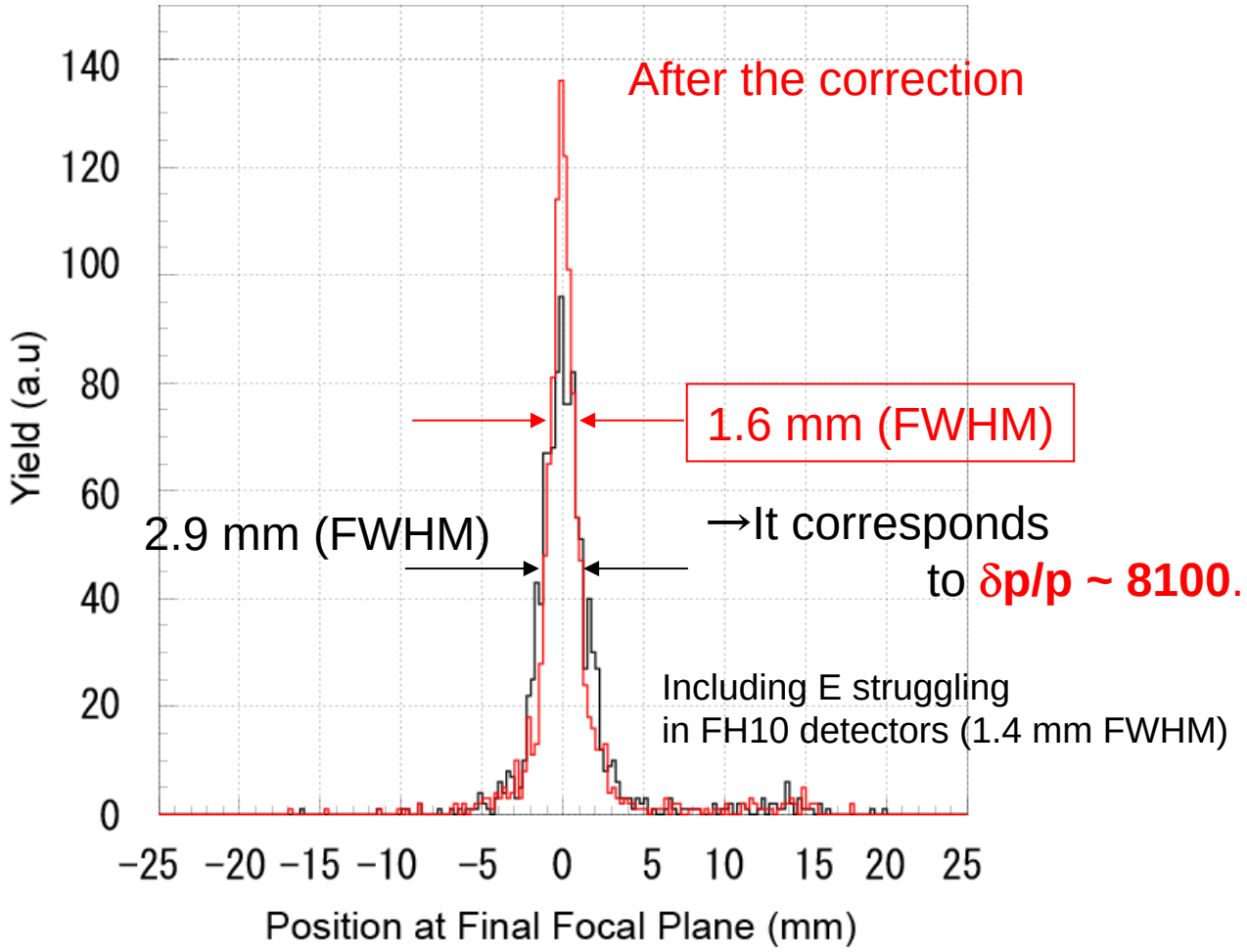
R.P = 10500

Dispersion matching transport

- Dispersion Matching condition





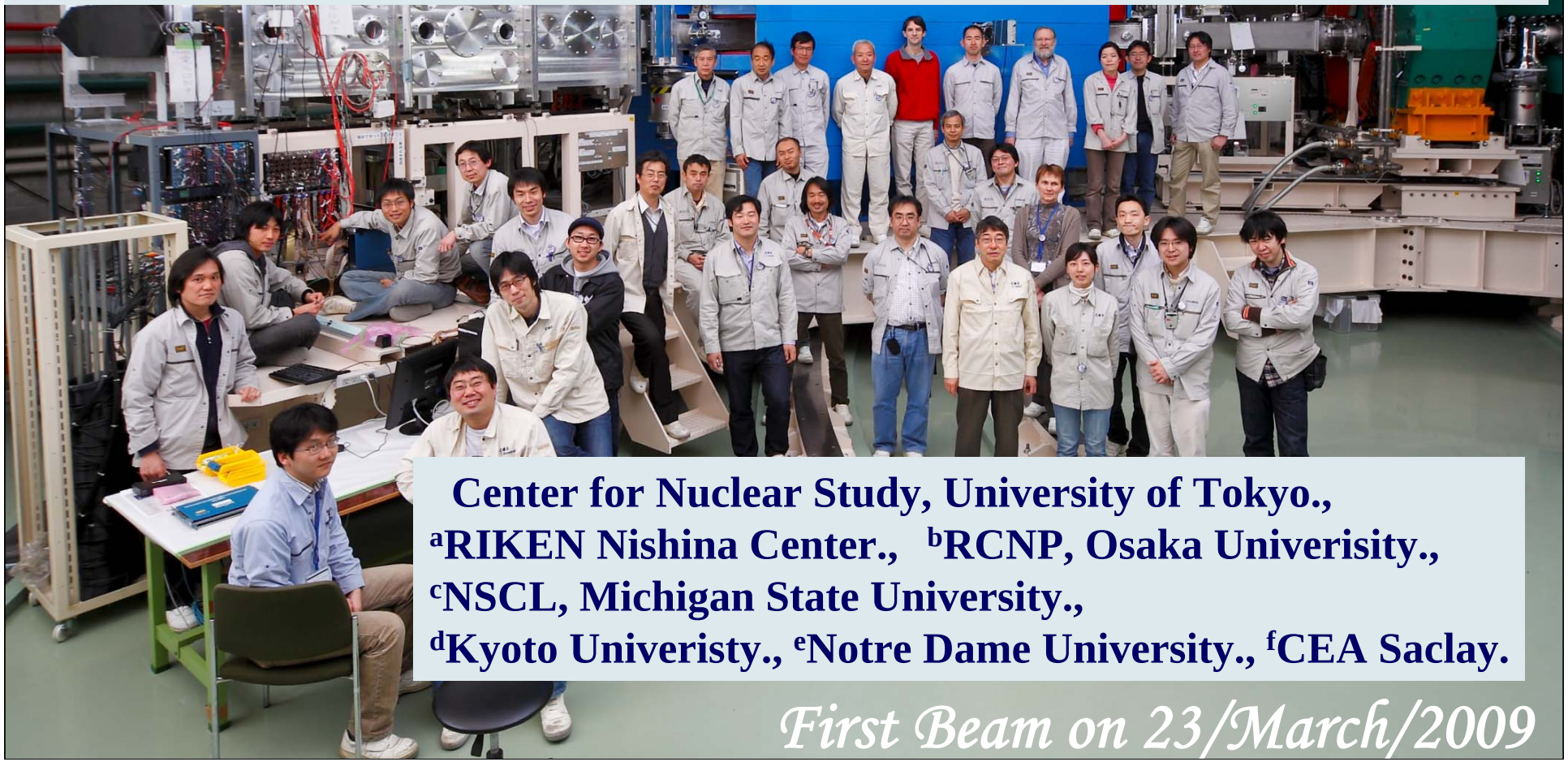


Summary

- SHARAQ spectrometer and High-resolution beamline were launched in March 2009.
- We successfully achieved dispersion matching beam transport and achromatic beam transport from BigRIPS to SHARAQ.
- DM transport achieved mom. resolution of 8100 (FWHM) for 0.6% momentum-spread RI beam by correction of first-order matrices.
- Six physics experiments was successfully completed.
- SHARAQ demonstrates new types of reaction probes by involving RI beams, and has a large capability by combinations with high-performance detectors and/or unique 2ndary targets.

Collaborators

S.Michimasa, T.Uesaka[a], S.Ota, S.Shimoura, Y.Sasamoto, K.Miki[b], S.Noji[c], H.Miya, H.Tokieda, S.Kawase, K.Kisamori, M.Takaki, M.Dozono[a], T.Kawabata[d], Y.Kikuchi, Y.Kubota, H.Kurei, C.S.Lee, H.Matsubara[a], K.Yako, T.Nishi N.Yamazaki, A.Yoshino, H.Sakaia, T.Kubo[a], Y.Yanagisawa[a], H.Baba[a], G.P.Berg[e], P.Roussel-Chomaz[f], D.Bazin[c], for the SHARAQ collaboration.



Center for Nuclear Study, University of Tokyo.,
[a]RIKEN Nishina Center., [b]RCNP, Osaka Univerisity.,
[c]NSCL, Michigan State University.,
[d]Kyoto Univeristy., [e]Notre Dame University., [f]CEA Saclay.

First Beam on 23/March/2009