



The SHARAQ spectrometer

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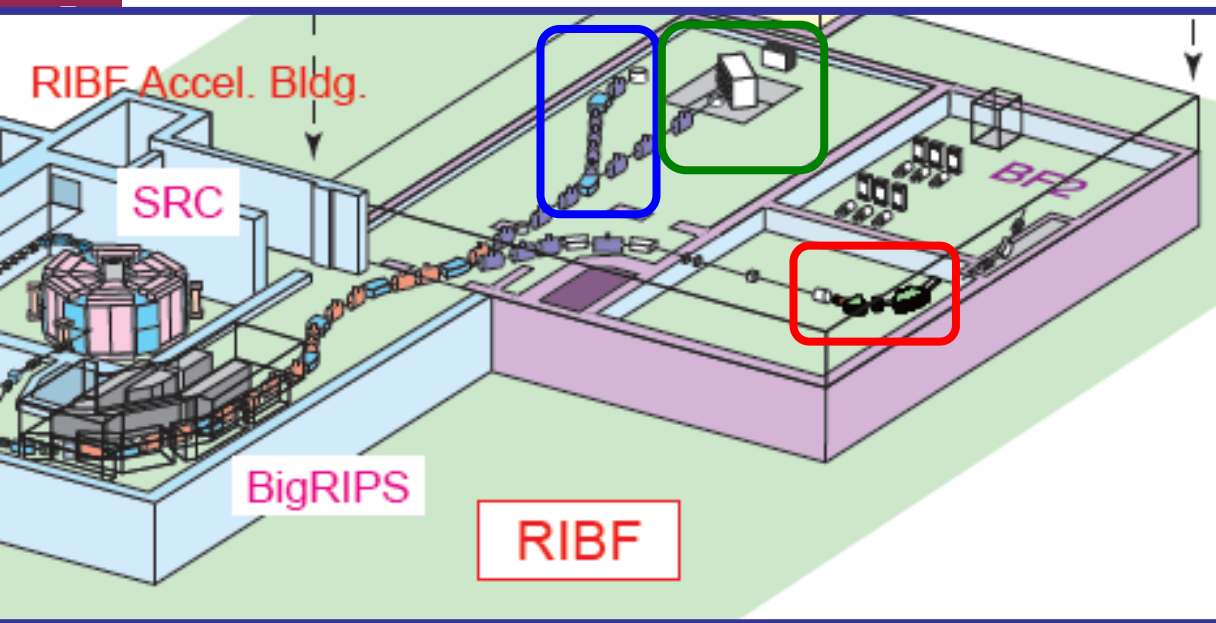
G.P.Berg
(Notre Dame)



SHARAQ Spectrometer

SHARAQ is a high resolution magnetic spectrometer under construction at the RIBF.

University of Tokyo - RIKEN collaboration



- Spectrometers at RIBF**
- ZeroDegree spectrometer**
multi-purpose
completed in 2007
 - SAMURAI spectrometer**
large acceptance
multi-particle detection
completed in 2012
 - SHARAQ spectrometer**
high resolution
finite angle meas.
completed in 2009

Current status of RIBF → Ohnishi

Scientific Opportunities with SHARAQ

- Nuclear structure in the vicinity of drip lines**
 correlation in (extremely) neutron/proton rich systems
 ex. tetra-neutron/superheavy hydrogen
 change of in-medium interaction depending on N/Z ratio
 ex. (\vec{p}, pN) reactions \rightarrow spin-orbit splitting
- High resolution analysis of reaction products by SHARAQ
 should greatly enhance experimental opportunities,
 especially when combined with γ and/or recoil/decay
 particle detectors.
- New spin-isospin excitation modes in nuclei**
 by use of RI-beam induced reactions as probes to nuclei
 ex. isovector spin-monopole resonances (IVSMR)
 double Gamow-Teller resonances (DGTR)
 ex. ($^{12}\text{N}, ^{12}\text{C}$) reaction
- Reaction mechanism of weakly-bound nuclei**
 elastic/inelastic scattering of halo/skin nuclei

Required Resolutions

Energy resolution

$\Delta E \approx 500 \text{ keV}$ for $A=12$ $E/A=300 \text{ MeV}$ particle

$$0.5 \text{ MeV} / (300 \times 12) \text{ MeV} = 1.3 \times 10^{-4}$$

→ corresponds to momentum resolution of $p/\Delta p \sim 15000$

Angular resolution □□ momentum transfer resolution

crucial in experiments with heavy ion beams,

where momentum of beam particle is huge

ex. ^{12}N , $300 \text{ MeV}/A$ $9 \text{ GeV}/c$

CRITERION: $\Delta q < 0.1 \text{ fm}^{-1}$

$$\Delta q \approx p(\text{beam}) \times \Delta\theta$$

$$\rightarrow \Delta\theta < 2 \text{ mrad}$$

$$\Delta\theta = 1 \text{ mrad}$$

Maximum rigidity

6.8 Tm

Momentum resolution

$dp/p = 1/14700$

Angular resolution

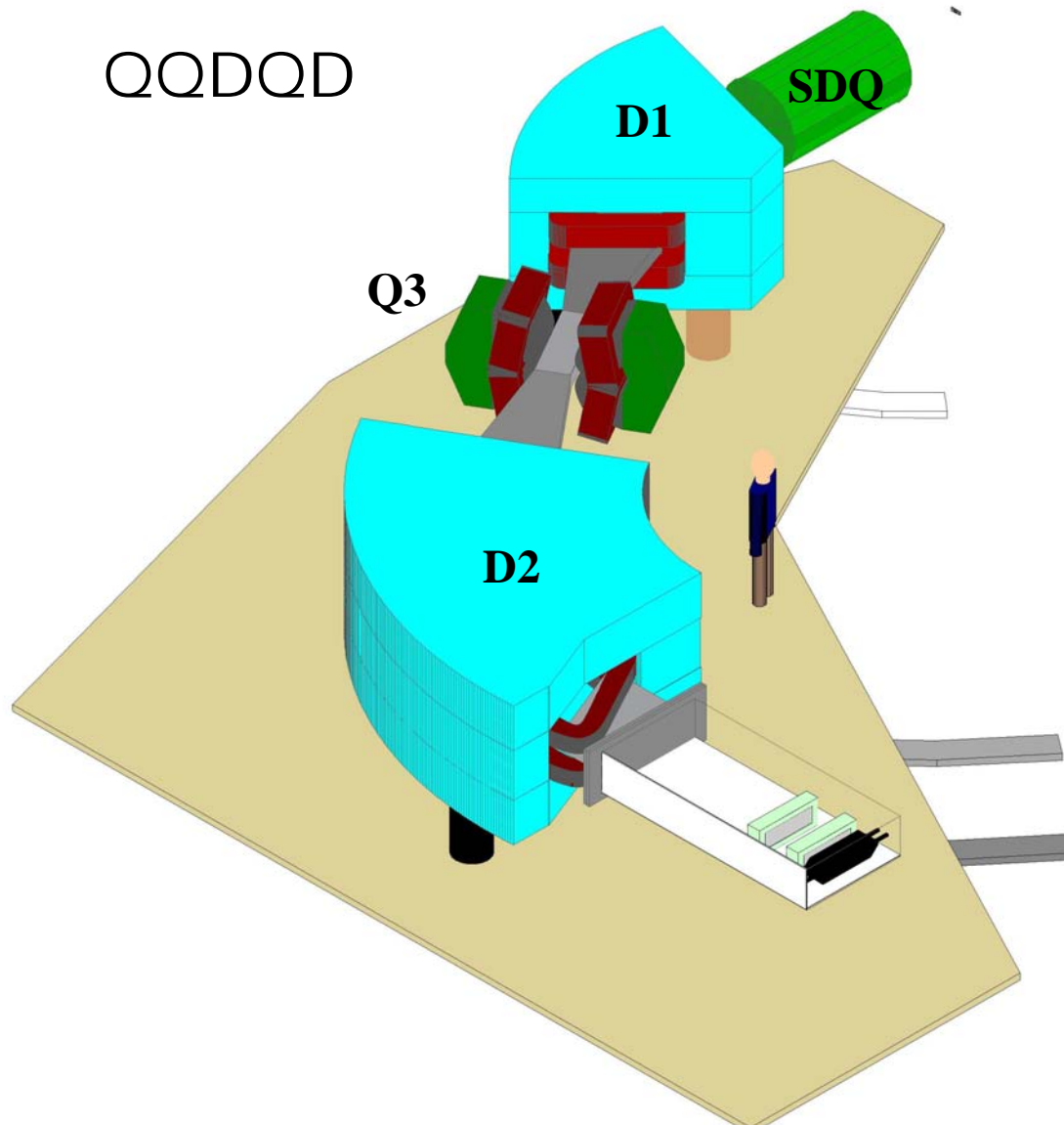
~ 1 mrad

Momentum acceptance

$\pm 1\%$

Angular acceptance

~ 5 msr



Specifications

dispersion (D)	5.86 m
horizontal magnification (M_x)	0.40
D/M_x	14.7 m
momentum resolution (image size 1mm)	1/14700
vertical magnification (M_y)	0.0
angular resolution	< 1 mrad
vertical acceptance	± 3deg

for spot size 60mm \times 10mm (in dispersion matching operation)

horizontal acceptance	± 1deg
solid angle	2.7msr

for spot size of 10mm \times 10mm

solid angle	4.8 msr
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1st order matrix & Req. for FP detectors

$$\begin{pmatrix}
 \boxed{-0.3974} & -0.0000 & 0.0000 & 0.0000 & 0.0000 & -5.8582 \\
 -0.7727 & \boxed{-2.5164} & 0.0000 & 0.0000 & 0.0000 & 0.6608 \\
 0.0000 & 0.0000 & \boxed{-0.0000} & \boxed{-2.3039} & 0.0000 & 0.0000 \\
 0.0000 & 0.0000 & 0.4340 & -0.1971 & 0.0000 & 0.0000 \\
 -0.2948 & -0.9073 & 0.0000 & 0.0000 & 1.0000 & -0.0279 \\
 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 1.0000
 \end{pmatrix}$$

Small horizontal magnification of 0.4

→ Δx of FP detectors should be < 0.4 mm

(image size of 1 mm is assumed)

Angular magnification in horizontal plane of 2.5

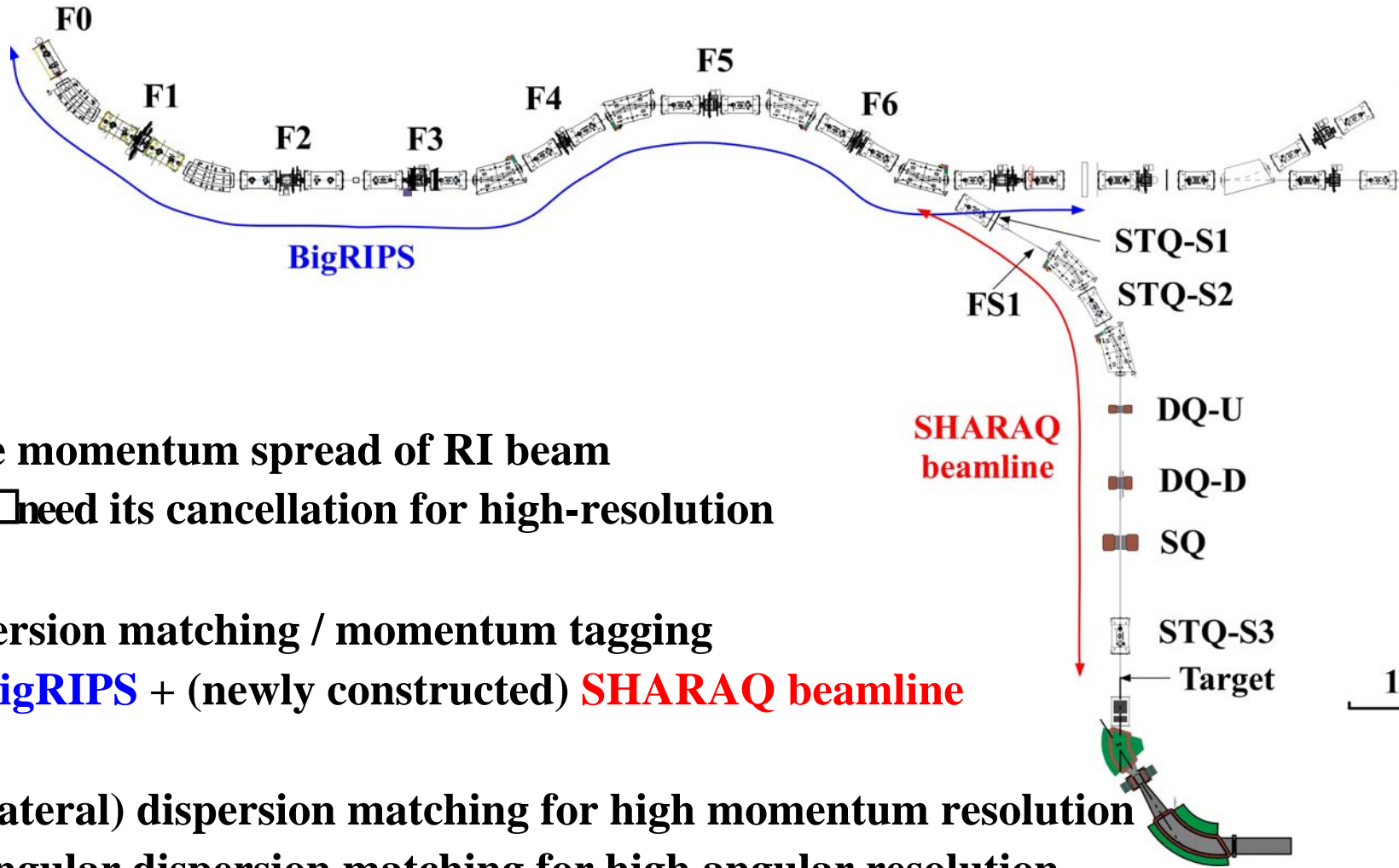
Existing technology is O.K for the FP detector.

CRDC is being made under UT-GANIL collaboration

→ Michimasa's talk

Requirement for Δy is more or less relaxed, $\sim 1-2$ mm.

High-resolution beamline for SHARAQ



large momentum spread of RI beam

→ need its cancellation for high-resolution

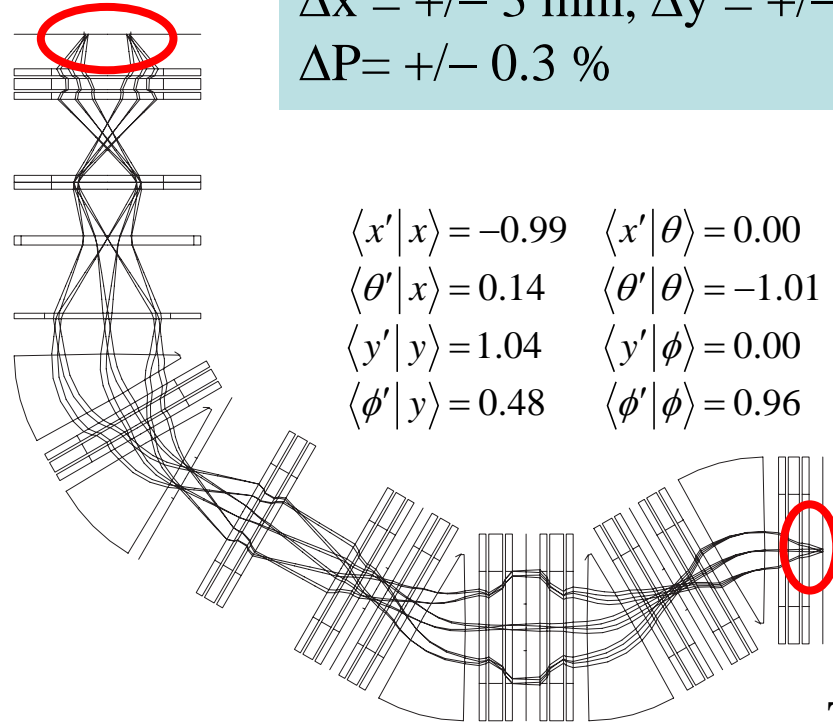
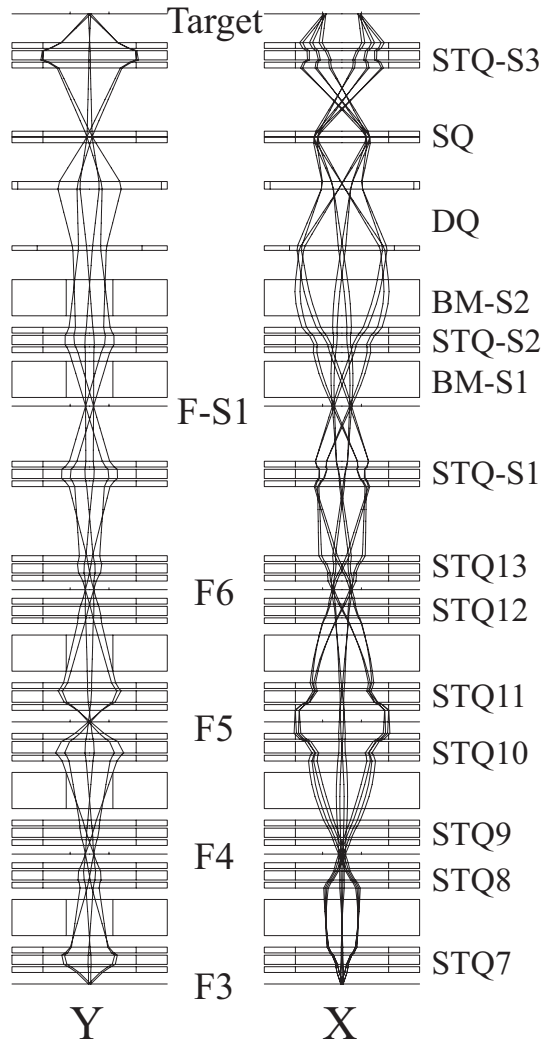
dispersion matching / momentum tagging

BigRIPS + (newly constructed) **SHARAQ beamline**

(lateral) dispersion matching for high momentum resolution

angular dispersion matching for high angular resolution

Dispersion matched transport



$$\Delta\theta_x = \pm 10 \text{ mr}, \Delta\theta_y = \pm 30 \text{ mr},$$

$$\Delta x = \pm 3 \text{ mm}, \Delta y = \pm 3 \text{ mm},$$

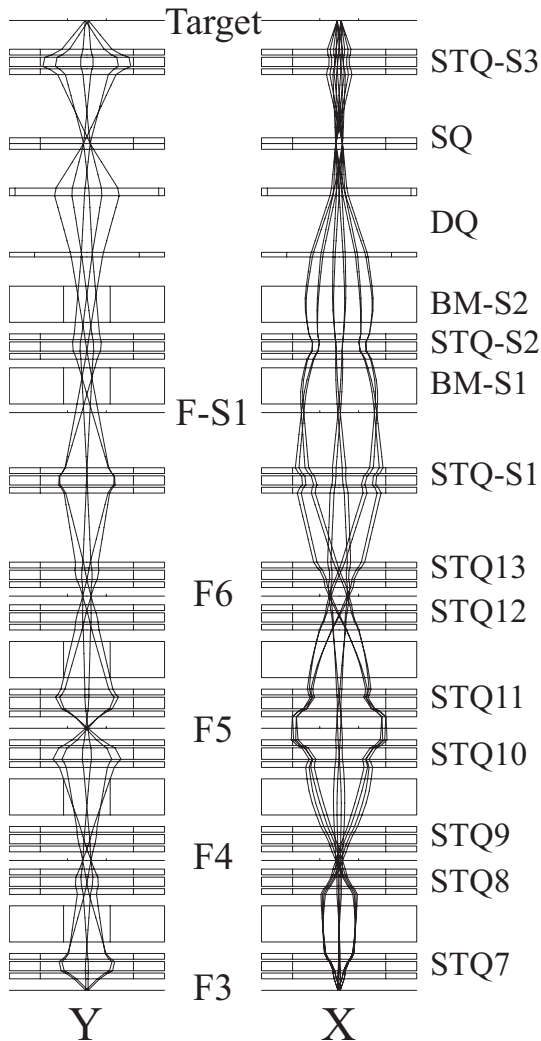
$$\Delta P = \pm 0.3 \%$$

$\langle x' x \rangle = -0.99$	$\langle x' \theta \rangle = 0.00$	$\langle x' \delta \rangle = -14.76$
$\langle \theta' x \rangle = 0.14$	$\langle \theta' \theta \rangle = -1.01$	$\langle \theta' \delta \rangle = 4.79$
$\langle y' y \rangle = 1.04$	$\langle y' \phi \rangle = 0.00$	
$\langle \phi' y \rangle = 0.48$	$\langle \phi' \phi \rangle = 0.96$	

T. Kawabata

In the dispersion matched mode, trajectories at F3 and before the target are measured.

Achromatic Transport

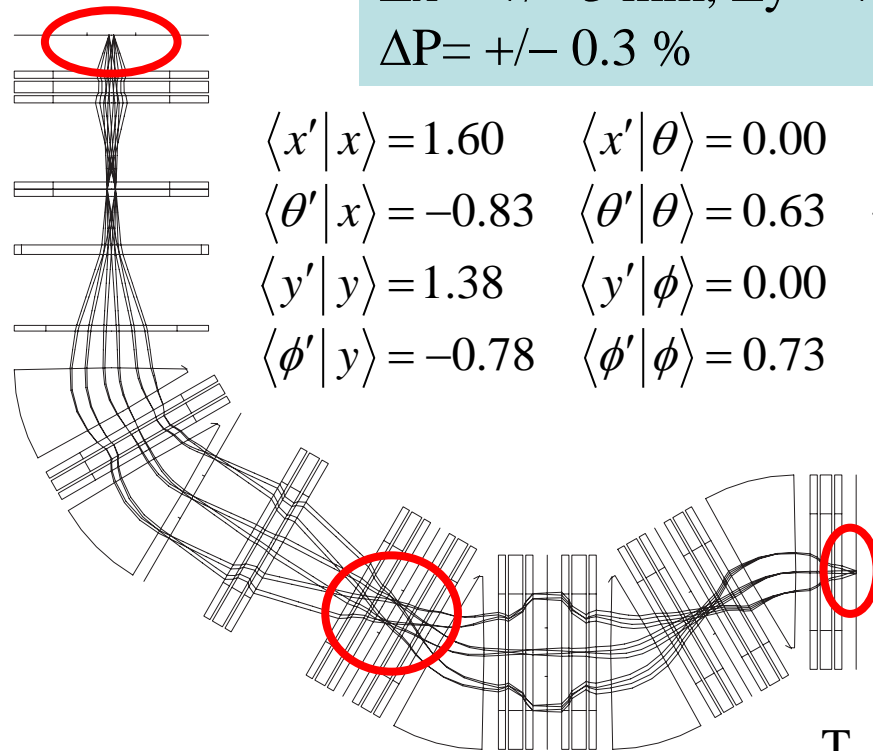


$$\Delta\theta_x = \pm 20 \text{ mr}, \Delta\theta_y = \pm 30 \text{ mr},$$

$$\Delta x = \pm 3 \text{ mm}, \Delta y = \pm 3 \text{ mm},$$

$$\Delta P = \pm 0.3 \%$$

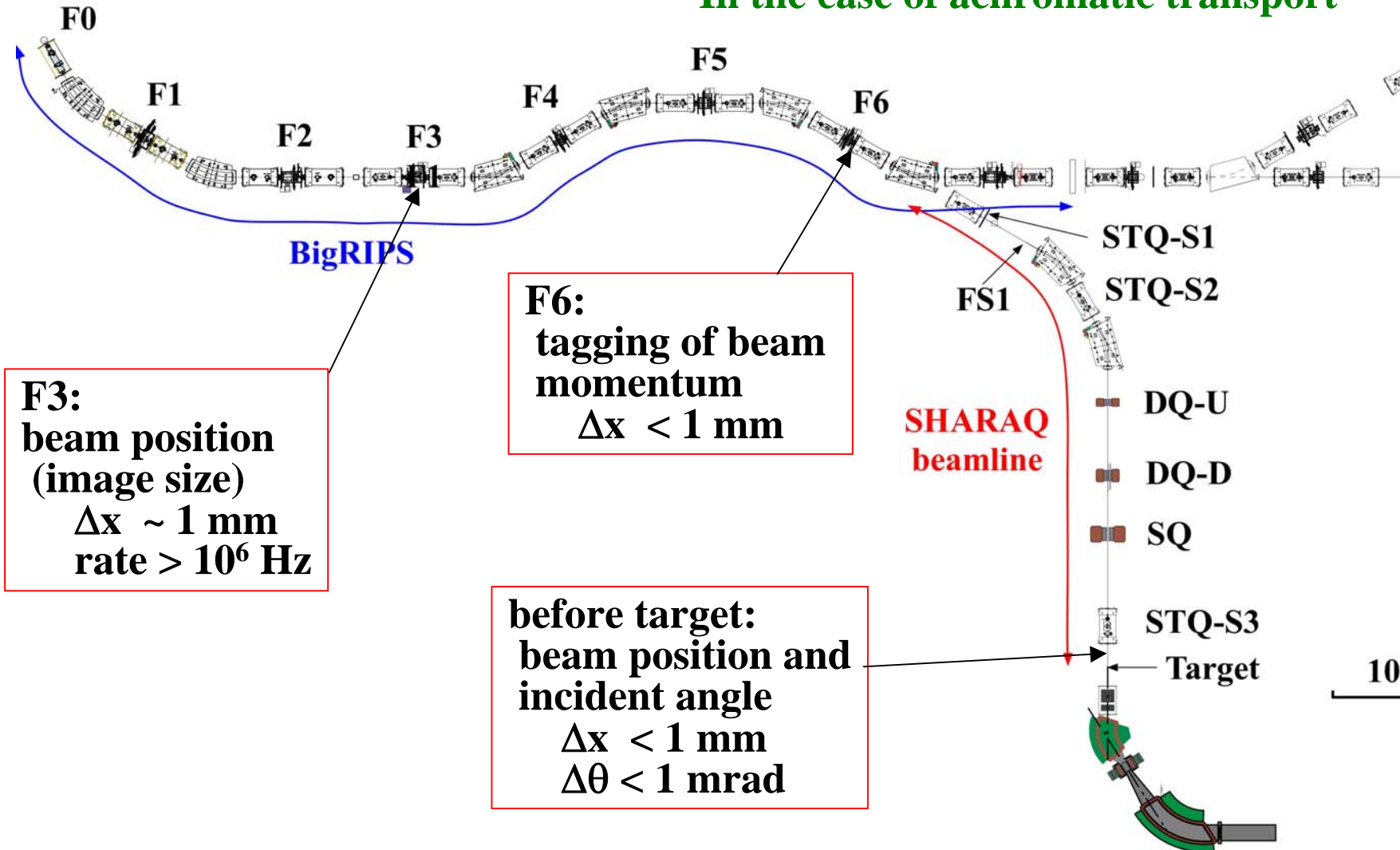
$$\begin{aligned} \langle x' | x \rangle &= 1.60 & \langle x' | \theta \rangle &= 0.00 & \langle x' | \delta \rangle &= -0.00 \\ \langle \theta' | x \rangle &= -0.83 & \langle \theta' | \theta \rangle &= 0.63 & \langle \theta' | \delta \rangle &= -0.47 \\ \langle y' | y \rangle &= 1.38 & \langle y' | \phi \rangle &= 0.00 & & \\ \langle \phi' | y \rangle &= -0.78 & \langle \phi' | \phi \rangle &= 0.73 & & \end{aligned}$$



In the achromatic mode, trajectories at F6 are needed to be measured for momentum tagging.

Measurements of beam trajectory

In the case of achromatic transport



Requirements for beam-line detectors

- **should determine the beam trajectory with**
 - $\Delta x \sim 0.5 \text{ mm}$
 - $\Delta\theta < 1 \text{ mrad}$
- **should not spoil the energy/angular resolutions**
 - $\Delta E < 0.5 \text{ MeV}$
 - $\Delta\theta < 1 \text{ mrad}$
 - $Z < 10$: multiple scattering limits the detector thickness.**
 - $x/X_0 \sim 10^{-4}$
- **should work at $> 10^6$ particle/sec**

Low-pressure MWDC can be the solution.

→ **Michimasa (and Ozeki)**

works at a higher beam rate?

Target for high-resolution measurements

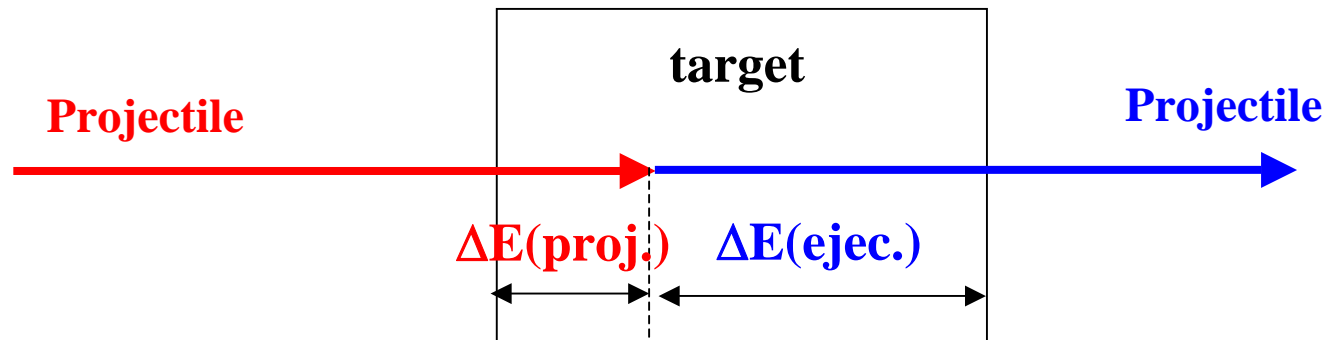
In many cases, target thickness is most critical.

ex. charge exchange reaction:

energy loss difference between projectile and ejectile.

For a better use of SHARAQ,

we need a “next generation TARGET system” such as an active target, or a multi-layered target with a sensitivity to reaction point.

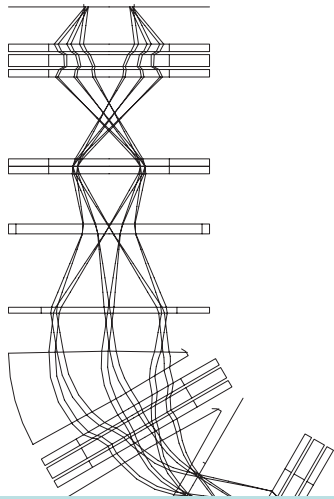


- **The high-resolution SHARAQ spectrometer is being constructed at RI beam factory by University of Tokyo, in collaboration with RIKEN.**
- **Demands for FP and beam-line detectors are presented.**
 - $\Delta x < 0.5 \text{ mm}$
 - $\Delta\theta < 1 \text{ mrad}$
 - **Michimasa's talk**
- **“Next generation detector/target system” will enhance the applicability of the spectrometer.**

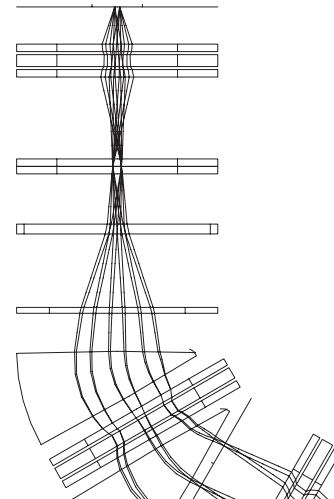
- **Missing mass spectroscopy with RI beams**
 - spin-isospin excitation via RI-beam induced reaction
 - probe highly excited states of stable nuclei
 - with extremely small momentum transfer
 - ex. IVSMR, DGTR, tetra neutron spectroscopy
 - elastic scattering experiments

- **High resolution analysis of reaction products**
 - in inelastic, breakup, knockout reactions
 - combined with γ -ray and/or decay-particles measurements

- **and more**
 - model case: S800 @NSCL, MSU

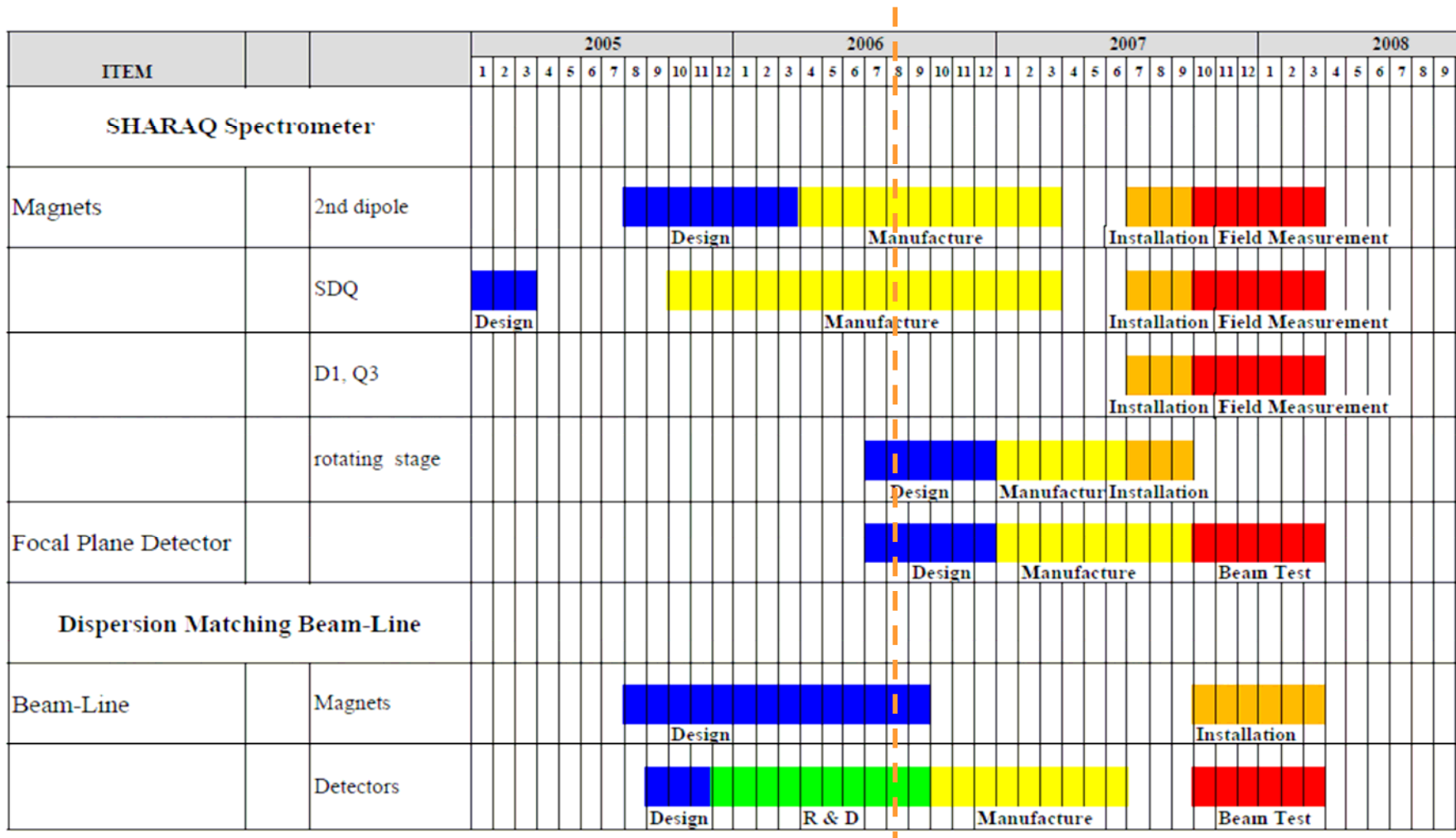


$\Delta\theta_x = \pm 10 \text{ mr}$, $\Delta\theta_y = \pm 30 \text{ mr}$,
 $\Delta x = \pm 3 \text{ mm}$, $\Delta y = \pm 3 \text{ mm}$,
 $\Delta P = \pm 0.3 \%$



$\Delta\theta_x = \pm 20 \text{ mr}$, $\Delta\theta_y = \pm 30 \text{ mr}$,
 $\Delta x = \pm 3 \text{ mm}$, $\Delta y = \pm 3 \text{ mm}$,
 $\Delta P = \pm 0.3 \%$

Current Status & Schedule



The high-resolution SHARAQ spectrometer is under construction and will be completed in 2008.

design of magnetic elements:	fixed
design of beamline:	fixed
development of detectors:	in progress

**Still there are much room to introduce your devices, ex.
for γ -ray and/or decay-particle detection.**

We are pleased to start collaboration for the BEST use of the spectrometer.

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