

Overview of SHARAQ

Under the Program

“Isospin-spin responses in CHarge-exchange exOthermic Reactions”

and

CNS, University of Tokyo



H. Sakai (on behalf of the ICHOR collaboration)

What is SHARAQ?

- ◆ SHARAQ is a **high resolution** magnetic spectrometer for unstable (secondary) beam experiments.

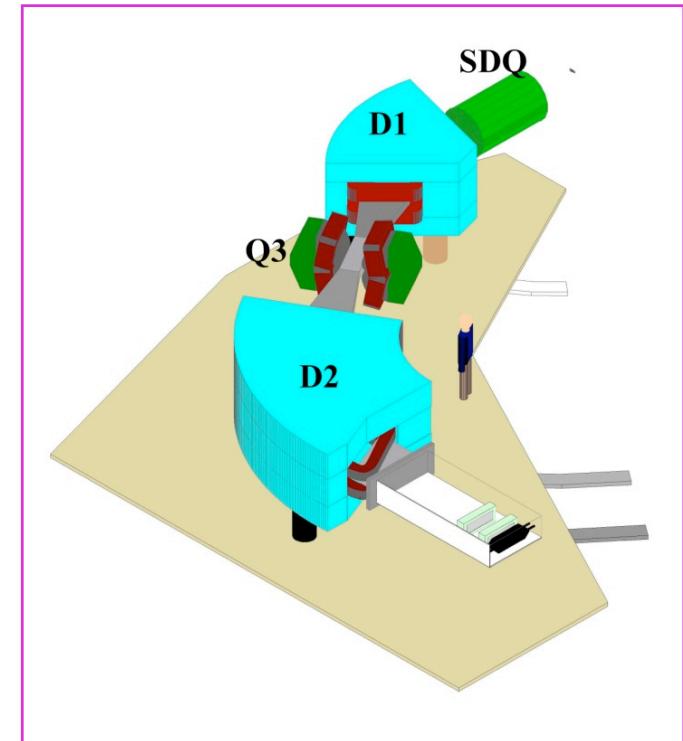
- Grant-in-Aid of MEXT at 2005.
(ICHOR program: H.S. spokesperson)
initiative of University of Tokyo (UT)

- ◆ UT - RIKEN collaboration (joint venture).

- SHARAQ spectrometer: UT
 - Department of Physics
 - CNS
 - Beam line + infrastructure : RIKEN

- ◆ Collaborations

- SHARAQ: G. Berg(Notre Dame), A. Zeller(NSCL),
Focal plane det.: P. Chomaz(GANIL) + ... ; MOU(UT-GANIL)
 - ICHOR: R. Zegers(NSCL)



Documentary film of SHARAQ construction

Experimental room E20 @RIBF

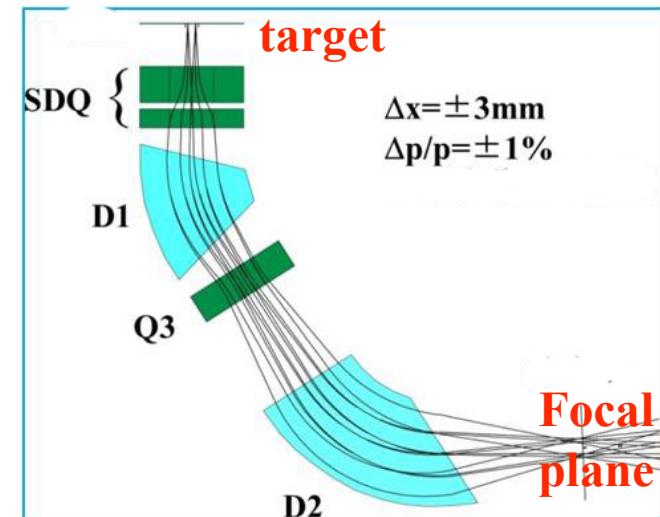
14 July 2008 – 19 October 2008



Conclusion: on schedule!

SHARAQ Characteristic

- QQDQD type
- Maximum rigidity 6.8 Tm
- $\Delta p/p = 14700$
- Dispersion matching ($x|\delta$), ($\theta|\delta$)
- Angular resolution < 1 mrad
- Solid angle 2.7 msr / 4.8 msr
- Rotatable (-2 to 15 degree)
- Weight 500 tons



Energy resolution

$\Delta E \sim 500\text{keV}$ 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 \Leftrightarrow momentum transfer resolution

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

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

$$\Delta q \sim p(\text{beam}) \times \Delta\theta \quad \rightarrow \quad \Delta\theta < 2 \text{ mrad}$$

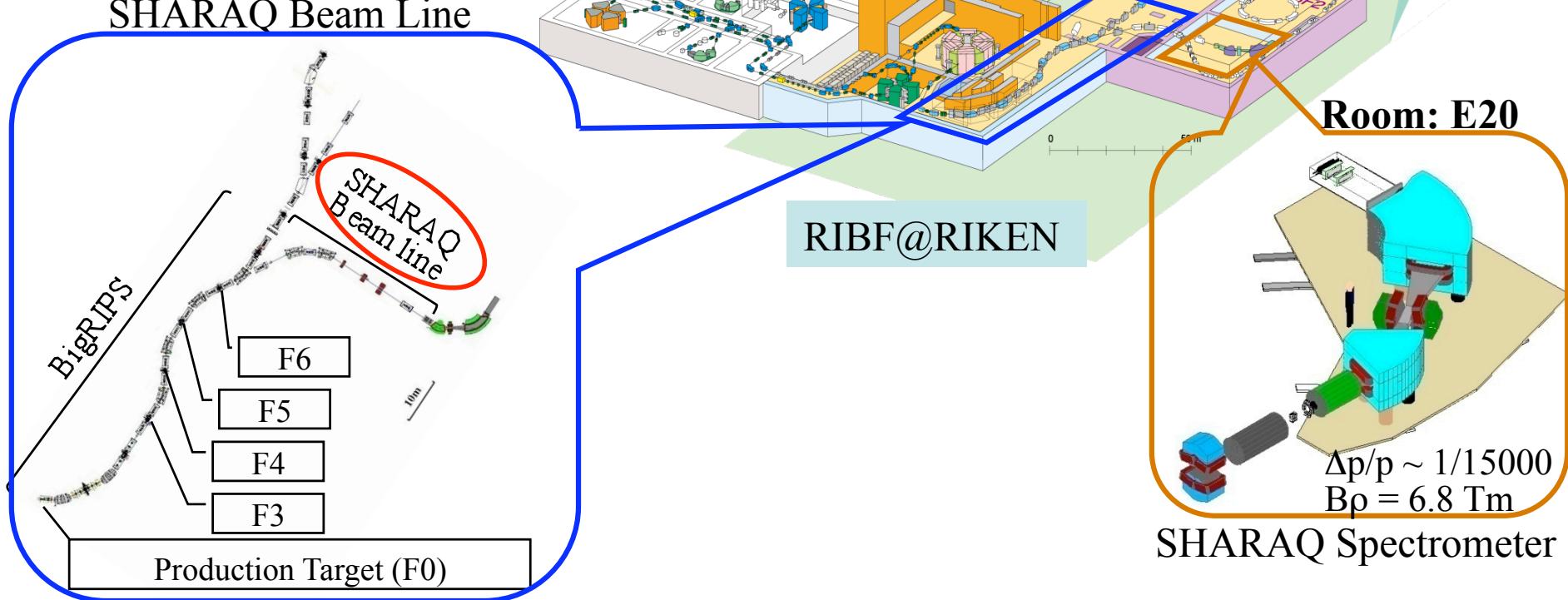
$$\Delta\theta = 1 \text{ mrad}$$

High-resolution beam line for SHARAQ

Large momentum spread of RI beam

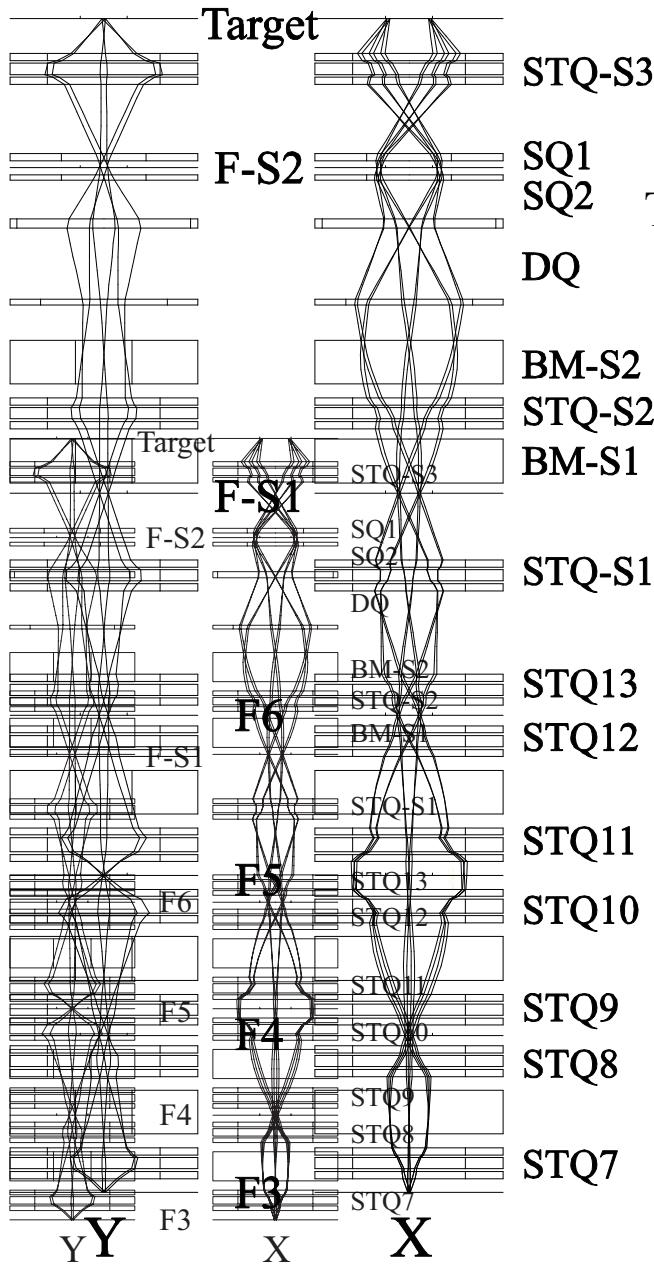
200 MeV/A ^{12}Be beam with $\Delta p/p = \pm 0.3\% \rightarrow \Delta E \sim 30 \text{ MeV}$

Need a high resolution beam line
with the dispersion matching technique.



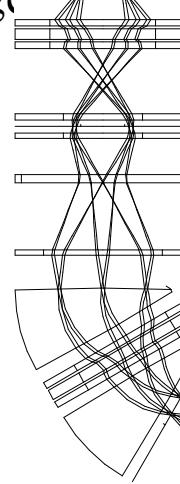
lateral dispersion matching for high momentum resolution.
angular dispersion matching for high angular resolution.

High- Ion Optical Calculation (1st order)



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

Target



$$\langle x_{\text{FC}} \rangle = 2.0960.00 |N\rangle$$

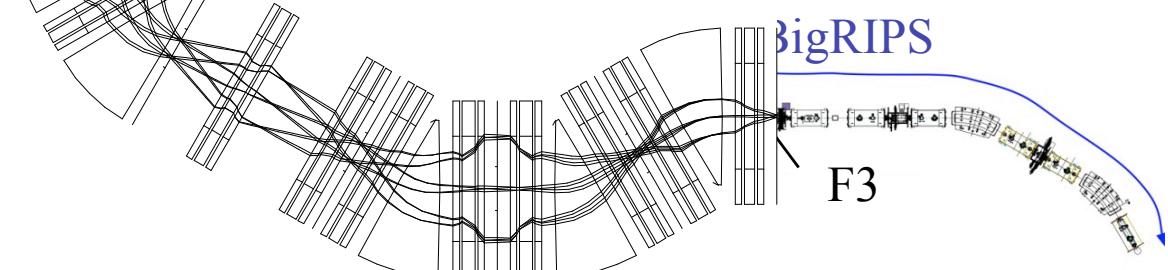
$$\langle N_{\text{FC}} \rangle = -0.2091.0 \langle | \rangle$$

$$\langle y_{\text{FC}} \rangle = -1.220.00 |A\rangle$$

$$\langle A_{\text{FC}} \rangle = -0.610.82 |A\rangle$$

$$\langle x_{\text{FC}} \rangle = 2.14.76$$

$$4 \langle N_{\text{FC}} \rangle = 4.79$$

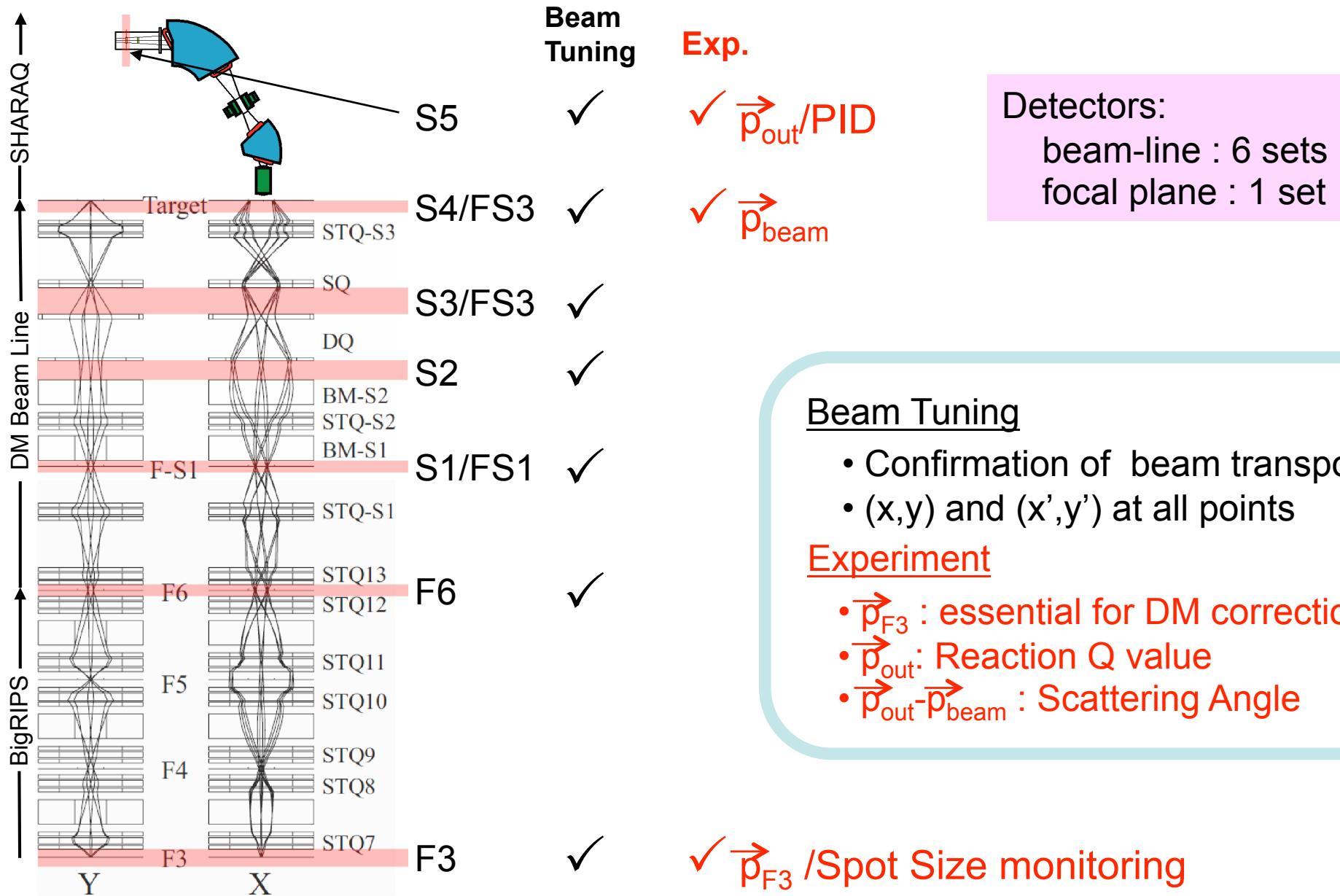


Matching conditions are satisfied.

Symmetric design is introduced.

STQ10-11, STQ8-12, STQ13-S1 are symmetric.
 19 DOFs for 34 Quadrupoles.

Beam-line/SHARAQ focal-plane detectors



Beam Tuning

- Confirmation of beam transport
- (x,y) and (x',y') at all points

Experiment

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

Schedule (target date)

Commissioning: Starts March 2009!

To do lists

SHARAQ

- ▶ magnetic field measurements
- ▶ establish optics [ANL/NSCL?]
- ▶ target chamber
- ▶ focal plane detectors (CRDC+...) [GANIL]
- ▶ data acquisition system
- ▶ vac. system
- ▶ etc.

Beam line

- ▶ dipole(2), STQ(3) and Q(3) magnets to be equipped.
- ▶ focal plane detectors (6 sets) for beam diagnosis.
- ▶ infrastructure
- ▶ control system
- ▶ DAQ
- ▶ etc.

UT and RIKEN(Nishina Center) Collaboration

◆ Strong collaboration is essential !

- MOU for SHARAQ spectrometer(2006)
- Meetings
 - UT-Nishina Center: once/month
 - Construction group: 1-2/month

◆ Commissioning (to be discussed)

- development of light-ion unstable beams
 ^{12}B , ^{12}N , t , ^8He etc.
- Dispersion matching including initial measurements [$(^{12}\text{B}$, ^{12}C), (t , ^3He) etc.], test of exothermic reaction.

◆ Operation after commissioning (to be discussed)

- MOU
- Similar to CRIB, (operation+maintenance by CNS)
 - Collaboration base

MOU between UT and RIBF

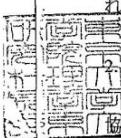
資料5

「高分解能 RI ビーム分析装置 SHARAQ 共同研究」に関する覚書

国立大学法人東京大学理学系研究科（以下「甲」という）と独立行政法人理化学研究所仁科加速器研究センター（以下「乙」という）は、「高分解能 RI ビーム分析装置 SHARAQ 共同研究」（以下「SHARAQ 共同研究」という）を実施するために、次とおり覚書を締結する。

1. (目的)

「SHARAQ 共同研究」は、甲および乙の間で既に締結している「東京大学大学院理学系研究科附属原子核科学研究センターと理化学研究所との「重イオン物理」に関する研究協力協定」（以下「研究協力協定」という。）に基づき、乙の RI ビームファクトリー（RIBF）施設内において、甲が建設する SHARAQ スペクトロメータと乙が建設する分散整合ビームラインを接続して高分解能 RI ビーム分析装置を形成し、これを用いて RI ビームによる原子核物理研究の新たな展開をはかることを目的とする。



2. (実施)

共同研究の実施にあたっては、甲および乙は以下のとおり建設を分掌することとし、協議をもって円滑に運営を行う。

2-1 甲の分掌事項

- (a) SHARAQ スペクトロメータの建設
- (b) 分散整合ビームラインの設計

2-2 乙の分掌事項

- (a) SHARAQ スペクトロメータの設置場所の提供
- (b) 計測室・実験準備室の提供
- (c) 分散整合ビームラインの建設
- (d) 共同研究に必要な電力・冷却水の提供
- (e) 高分解能 RI ビーム分析装置の試運転および調整のためのビームタイムの提供

3. (特記事項)

甲および乙は、平成 20 年度に、高分解能 RI ビーム分析装置を用いた原子核物理研究を遂行できるよう、SHARAQ スペクトロメータおよび分散整合ビームラインの建設に必要な措置を遅滞なく行うものとする。建設完了後の個別の研究プログラムの策

定およびビームタイムの割当に関しては別途協議する。

4. (期間)

平成 18 年 12 月 1 日～平成 22 年 3 月 31 日

甲および乙両者の協議に基づき、更新できるものとする。

5. (その他の事項)

この覚書に定めていない事項については、既に締結している研究協力協定の事項に従うものとする。

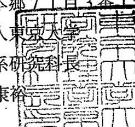
6. (協議)

前項にかかわらず、あらたに事項を定めようとするとき又はこの覚書の解釈に疑義が生じたときは、甲乙協議する。

以上、この覚書を証するため、本覚書 2 通を作成し、甲乙各 1 通を保管するものとする。

平成 18 年 12 月 1 日

甲 東京都文京区本郷 7 丁目 3 番 1 号
国立大学法人東京大学
大学院理学系研究科長
岩澤 康裕



乙 埼玉県和光市広沢 2 番 1 号
独立行政法人理化学研究所
仁科加速器研究センター長
矢野 安重



Backup slides

Why Exothermic HICE reaction ?

■ utilize mass excess of unstable nucleus.

■ GT-type transition ($L=0$) : $q=0$ important.

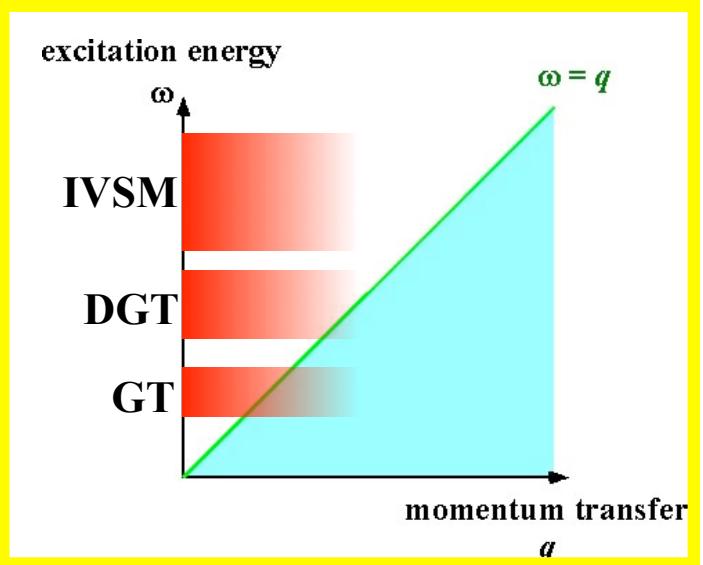
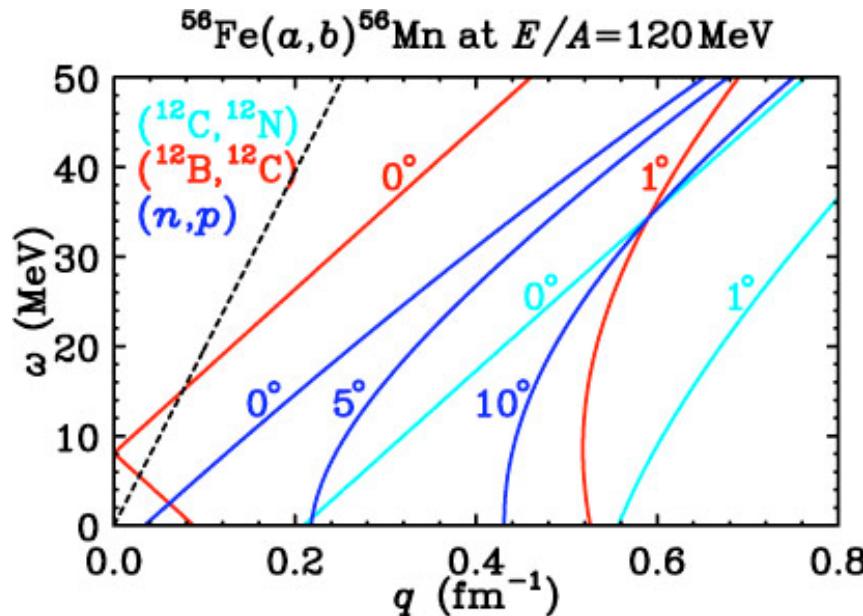
$q=0$ can be achieved!

■ spin-isospin selection: $\Delta S=1$, $\Delta T=1$

(cf. $\Delta S=\pm 1$, $\Delta T=1$ for $(p,n)/(n,p)$)

- $(^{12}\text{B}, ^{12}\text{C})/(^{12}\text{N}, ^{12}\text{C})$ reaction

(cf. $(^{12}\text{C}, ^{12}\text{B})/(^{12}\text{C}, ^{12}\text{N})$ reaction)



reaction	Q -value		$q(\text{fm}^{-1})$		
	Δ_{em} (MeV)	Q_{gg} (MeV)	$\omega = 10 \text{ MeV}$	$\omega = 20 \text{ MeV}$	$\omega = 30 \text{ MeV}$
(p, n)	-1.29	-6.89	0.189	0.308	0.433
(n, p)	+1.29	-1.50	0.129	0.264	0.368
$(^{12}\text{N}, ^{12}\text{C})$	+16.83	+11.23	0.007	0.109	0.216
$(^{12}\text{B}, ^{12}\text{C})$	+13.88	+11.08	0.005	0.108	0.215
$(^{12}\text{C}, ^{12}\text{B})$	-13.88	-19.48	0.302	0.410	0.518
$(^{12}\text{C}, ^{12}\text{N})$	-16.83	-19.52	0.301	0.409	0.517

Isovector Spin Monopole Resonance

■ Breathing (compression) mode

$$\text{IVSM} \quad \hat{\mathbf{0}}_{1\mu}^{\pm} = \sum \sigma \tau_{\pm} \mathbf{r}^2, \quad 2\hbar\omega$$

■ (p,n) @ 795 MeV

D.L. Prout et al., PRC **63** (2000) 014603.

- $A \geq 90$
- $T_p \geq 500$ MeV

■ $(^3\text{He},t)$ @ 900 MeV

A. Brockstedt et al., NPA **530** (1991) 571.

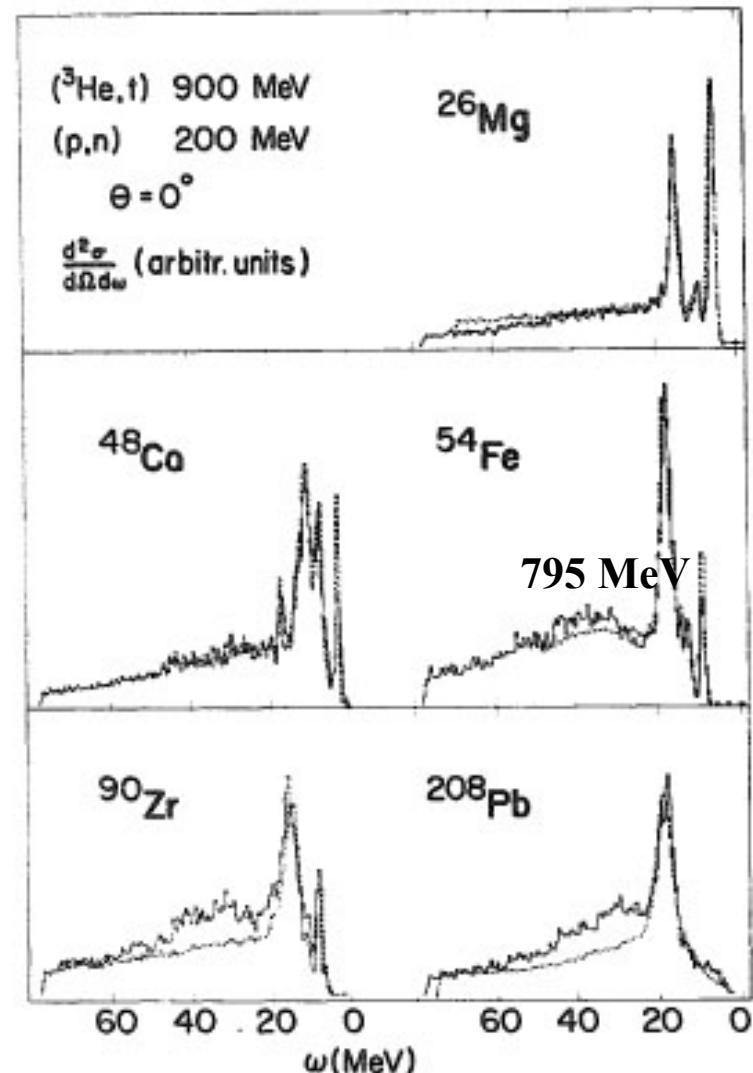
- $A \geq 54$
- $T_h \geq 300$ MeV/A

■ $(^3\text{He},t)$ @ 450 MeV p-decay

R.G.T.Zegers et al. PRL 90 (2003) 202501

- $A = 208$
- $T_h = 150$ MeV/A

◆ only β^- direction !



IVSMR with exothermic HICE reation

● IVSMR

□ β^- & β^+ directions

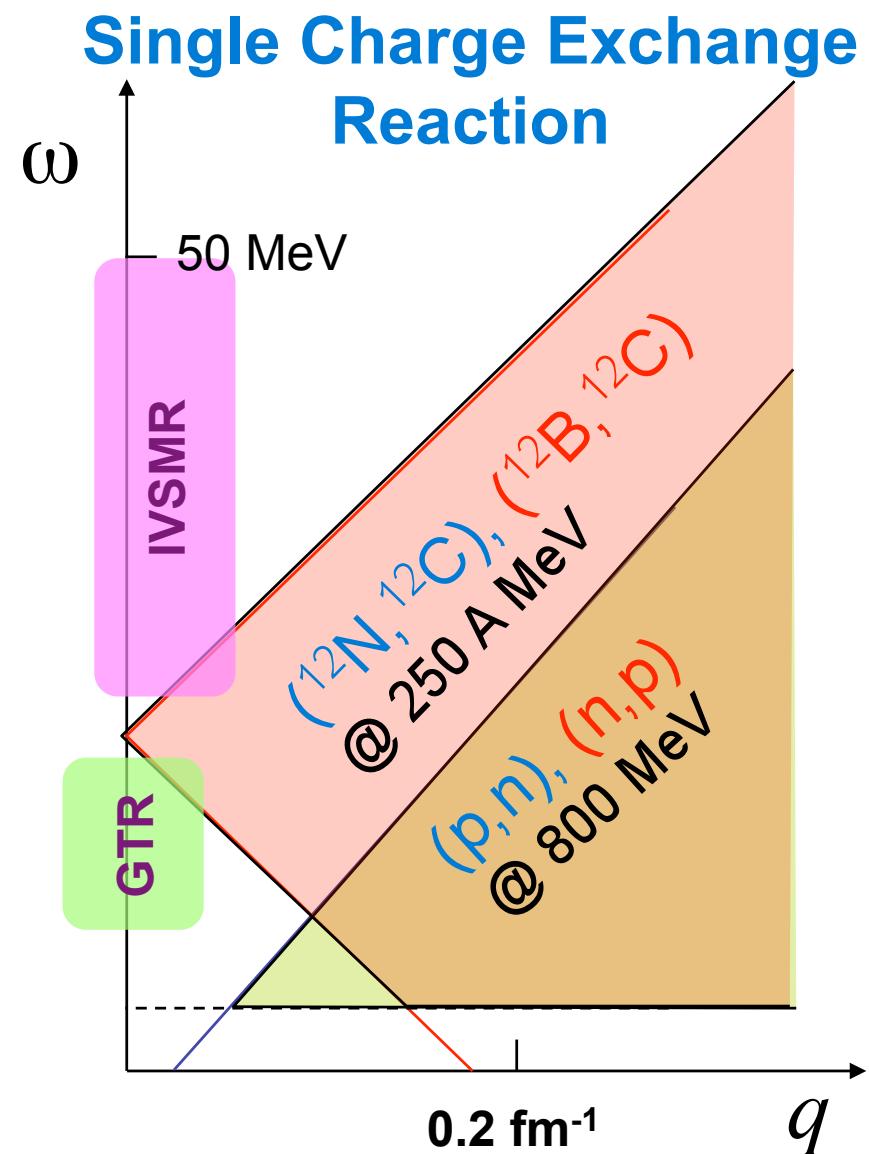
- $(^{12}\text{N} (1^+), ^{12}\text{C}), (^{12}\text{B} (1^+), ^{12}\text{C})$
- $Q=+17 \text{ MeV}/+13 \text{ MeV}$
- Compression mode with $\sigma\tau$
 - $O \sim r^2\sigma\tau$
- Ex, width
 - Spin compressibility of nuclear matter

● GT strengths @ higher Ex

SM sum rule

very sensitive to surface

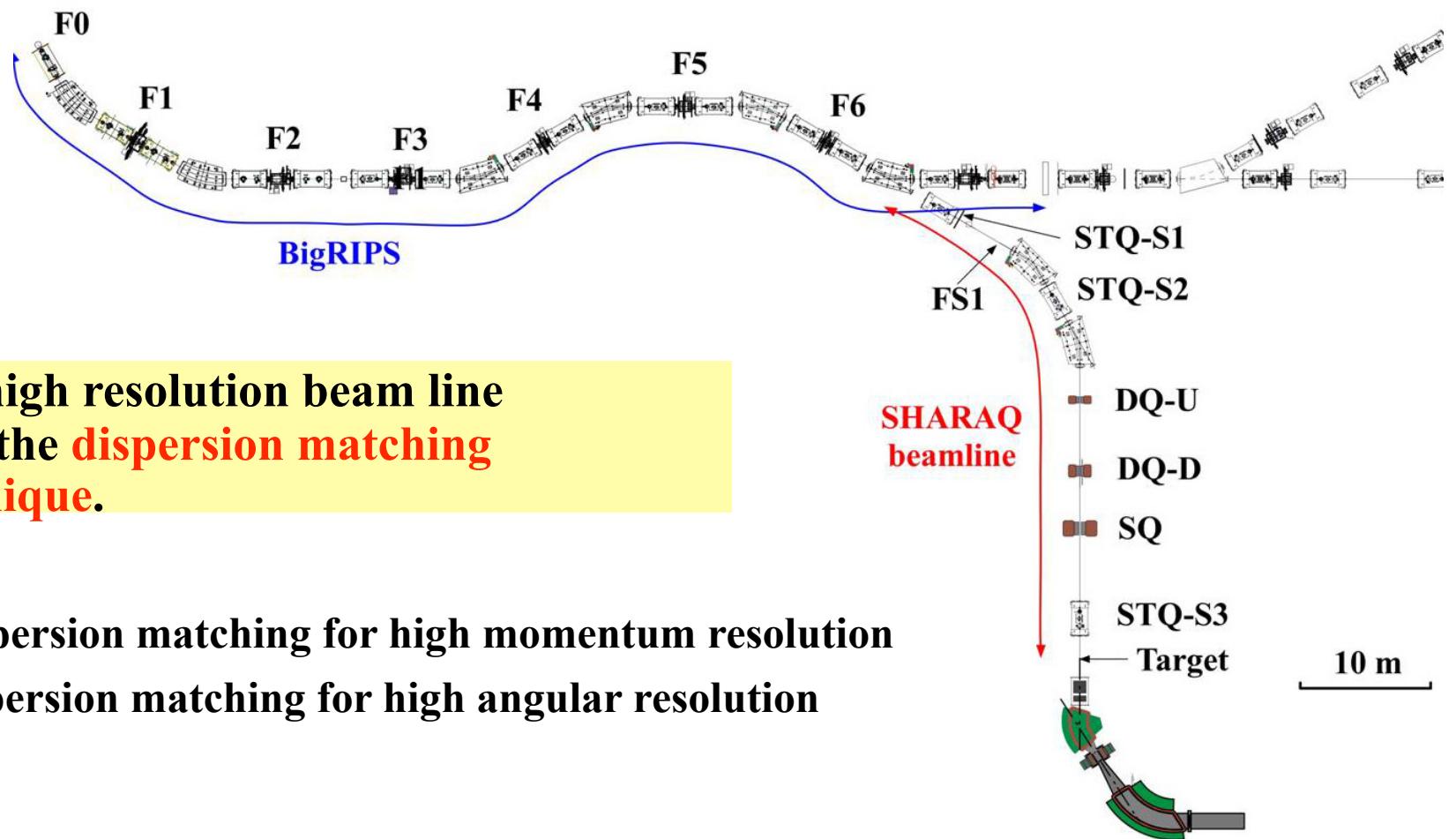
$$\delta_{np} = \sqrt[4]{\langle r^4 \rangle_n} - \sqrt[4]{\langle r^4 \rangle_p}$$



High-resolution beam line for SHARAQ

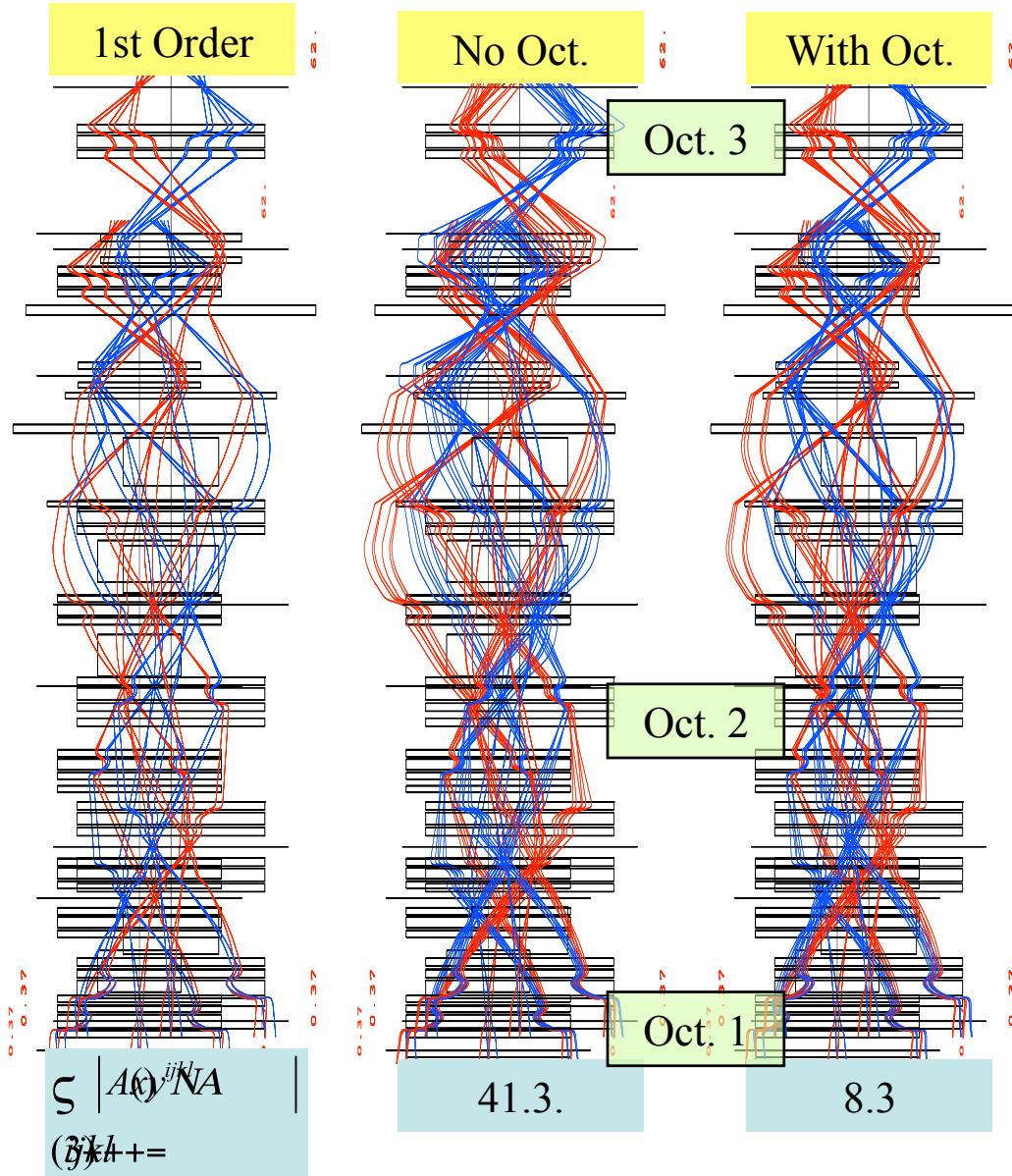
Large momentum spread of RI beam

200 MeV/A ^{12}Be beam with $\Delta p/p = \pm 0.3\% \rightarrow \Delta E \sim 30 \text{ MeV}$

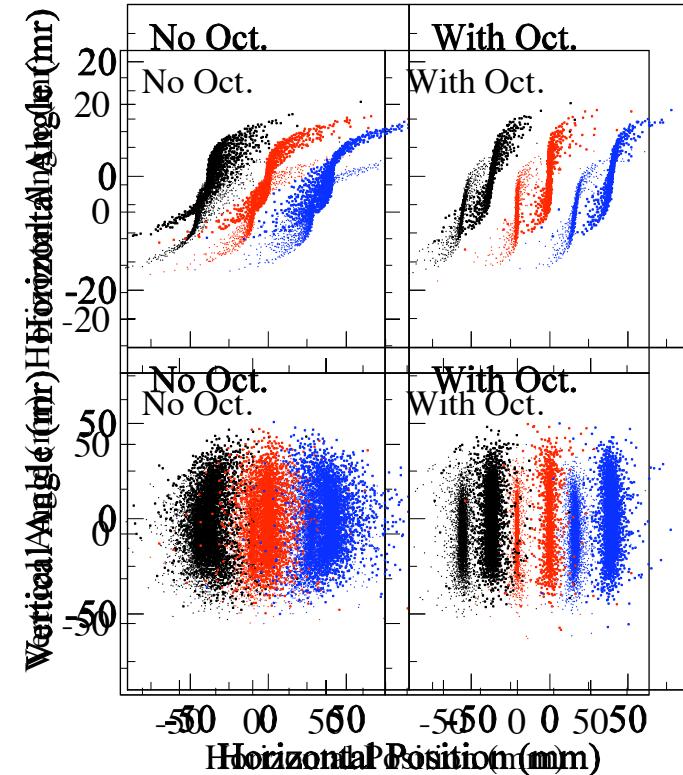


Higher Order Aberration

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



$$\delta = +0.3\%, 0\%, -0.3\%$$

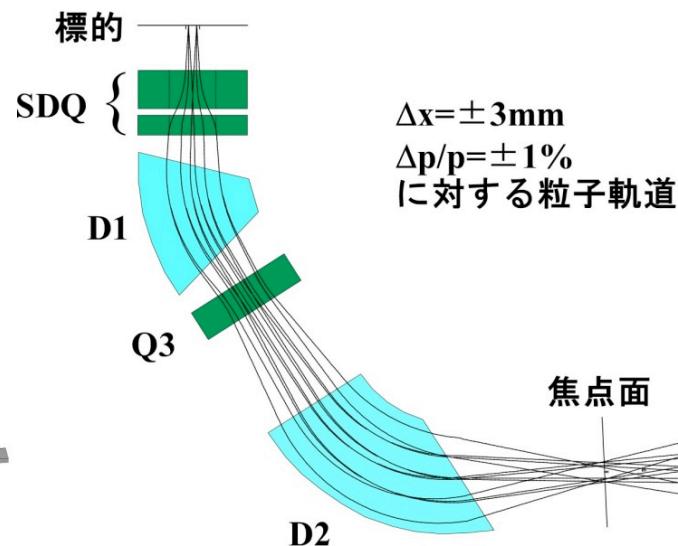
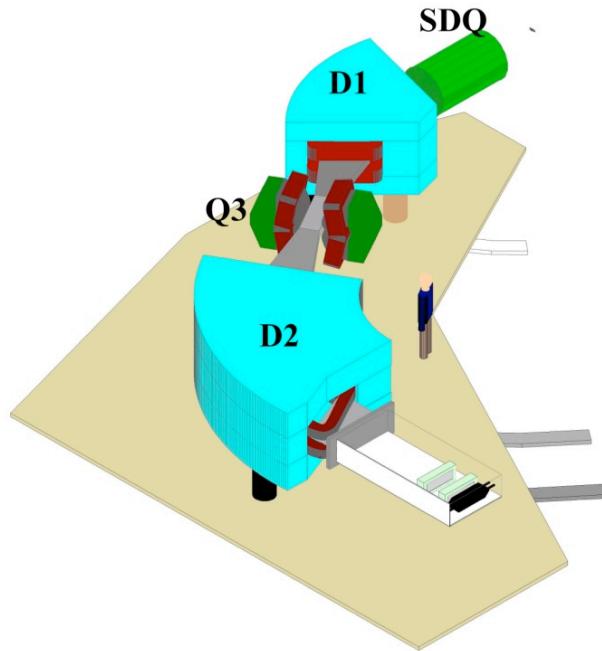


Three oct. mags. significantly improve the aberration.



	SHARAQ			S800	Grand Raiden
Configuration	QQDQD			QQDD	QSQDMD
Modes	Standard	High resolution	Large acceptance		
Maximum Rigidigy [Tm]	6.8	6.8	6.8	4	5.41
Dispersion (D) [m]	5.86	5.86	5.86	9.5	15.4
Horizontal Magnification (M_x)	0.40	0.3	0.52	0.74	-0.41
D/M_x [m]	14.7	19.8	12.0	12.8	37
Momentum resolution (object size : 1mm)	14700	19800	12000	20000	37076
Vertical Magnification (M_y)	0	0	0	0	6.0
Horizontal angular resolution (mrad)	~1	~1	~1	2	2
Vertical angular resolution (mrad)	~1	~1	~1	2	3–5
Momentum acceptance	+/-1%	+/-1%	+/-1%	+/-3%	+/- 2.5
Horizontal angular acceptance (mrad)	+/-17	+/-17	+/-34		+/- 20
Vertical angular acceptance (mrad)	+/-60	+/-60	+/-60		+/- 40
Flight Path length (m)	20	19.4		13.1	
Dispersion Matching	x & θ	x & θ		x	x & θ

SHARAQスペクトロメータ



磁気剛性範囲	1.8–6.8 Tm
運動量分解能(p/dp)	14700
立体角	2.7 msr
角度アクセプタンス	$\pm 17\text{ mrad}$ (横) $\pm 51\text{ mrad}$ (縦)
角度分解能	1 mrad
回転範囲	–2度から+15度
総重量	500トン



特別推進研究中間ヒヤリング

Requirements of Tracking Detectors

for dispersion matching

- Little disturbing of the beam
 - Low Multiple Scattering: ~ 1 mrad (σ)
 - Low Energy Straggling: $< 1/1650$ (Energy Resolution of BigRIPS)
- Precise measurement of the beam trajectory
 - High Position Resolution: ~ 300 μm (FWHM)
 - [$30 \text{ cm} * 1 \text{ mrad} \sim 300 \mu\text{m}$]

for using RI Beam

- Overcoming of Low intensity
 - High Detection Efficiency $\rightarrow 100\%$ for light particles

in Beam-line detectors, especially

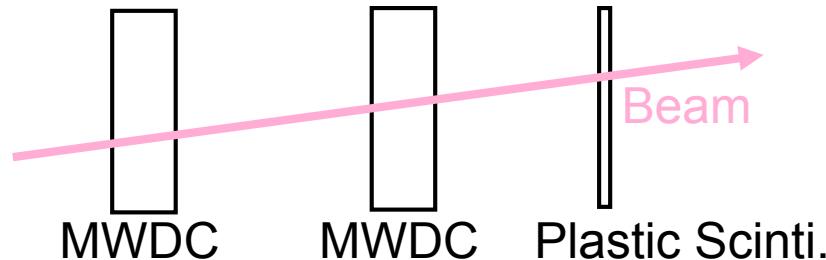
- Operate under High Counting Rates $\rightarrow \sim 1 \text{ MHz}$

We have selected

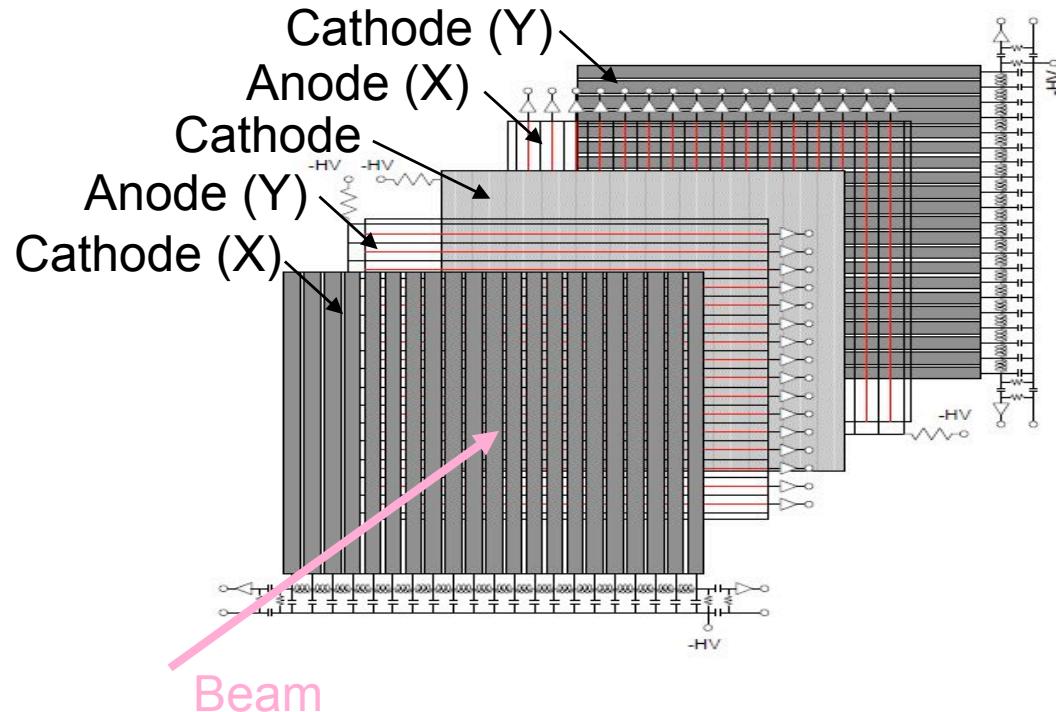
Drift Chambers Operated with Low Pressure

Design of Beam-line Detector

Detector setup at each focus of BL



MWDC with low gas pressure
(100*100 proto-type)



Specifications:

Thickness

- Gas Window: $12\mu\text{m}$
- Cathode: $2.2\mu\text{m}$
- Anode wire: $20\mu\text{m}^\phi$
- Potential wire: $75\mu\text{m}^\phi$
- Gas: isobutane $75\sim150$ Torr
- Total: $t/L_R \sim 10^{-4}$

Effective area :

- 100×100 (for achromatic focus)
- 216×144 (for dispersive focus)

Readout (100×100/200×140)

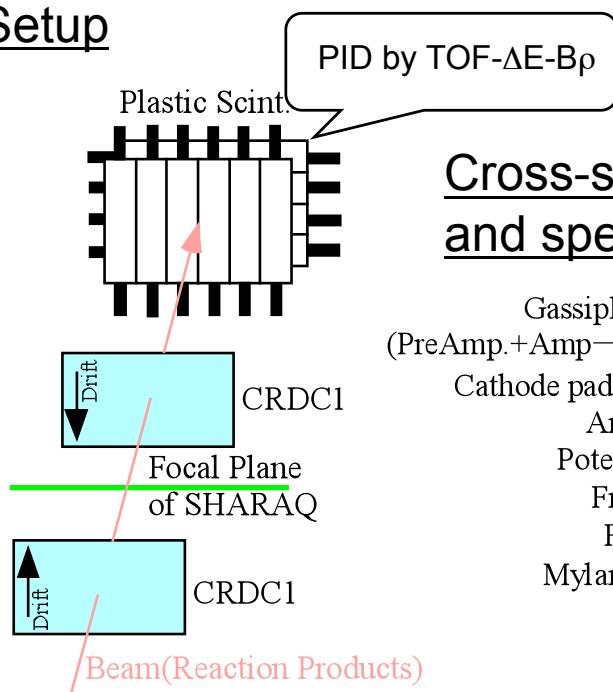
- Anode: 32 ch / 88 ch
- Cathode: Delay Line 4 ch (X, Y)

Position Info.

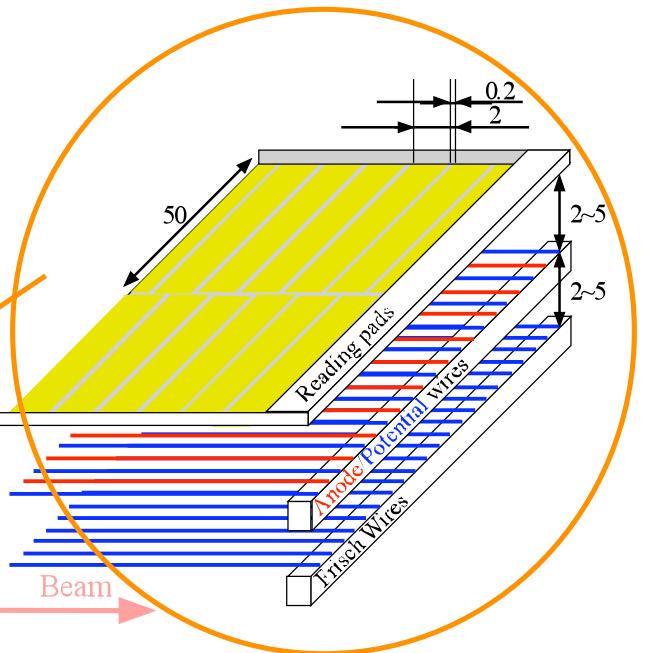
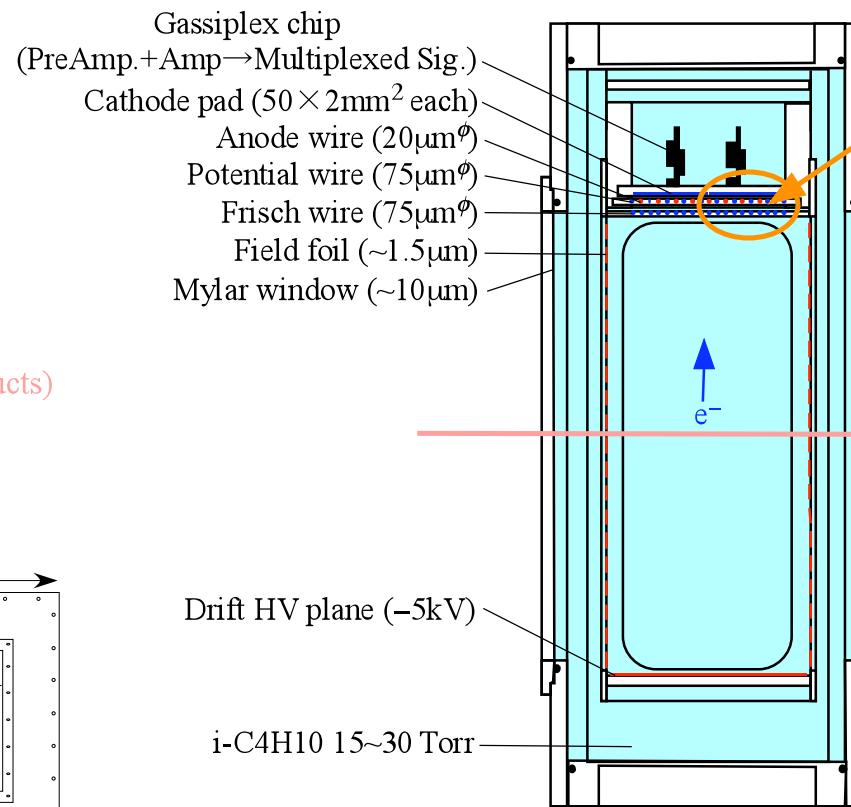
- Anode: Wire ID + Drift time
- Cathode: Delay-line

Design of Focal-Plane Detector

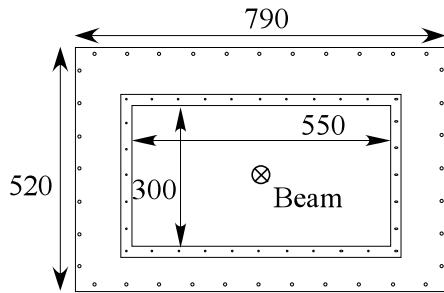
Setup



Cross-section view and specification of CRDC

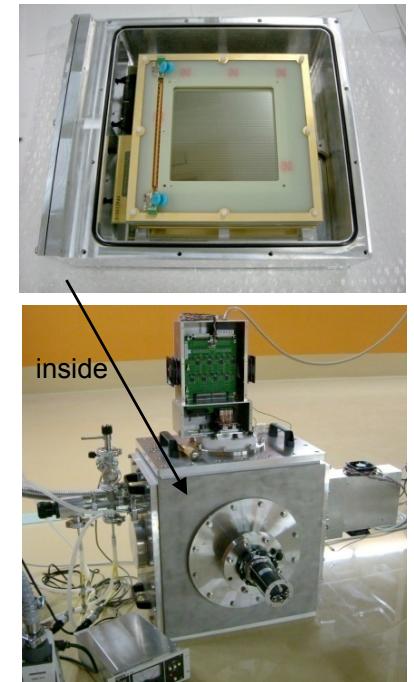
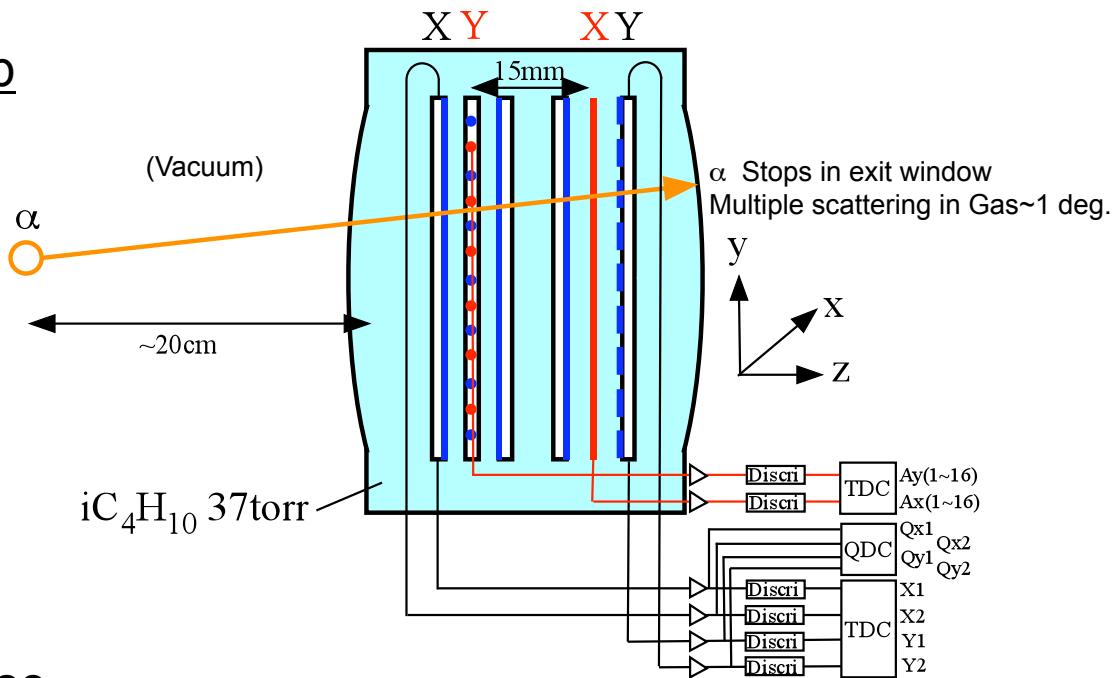


Size of CRDC



MWDC Test using Alpha source

Setup



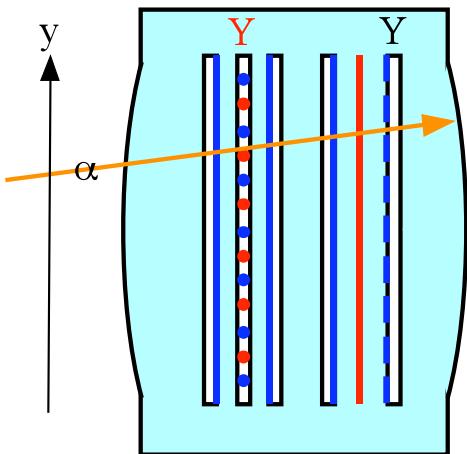
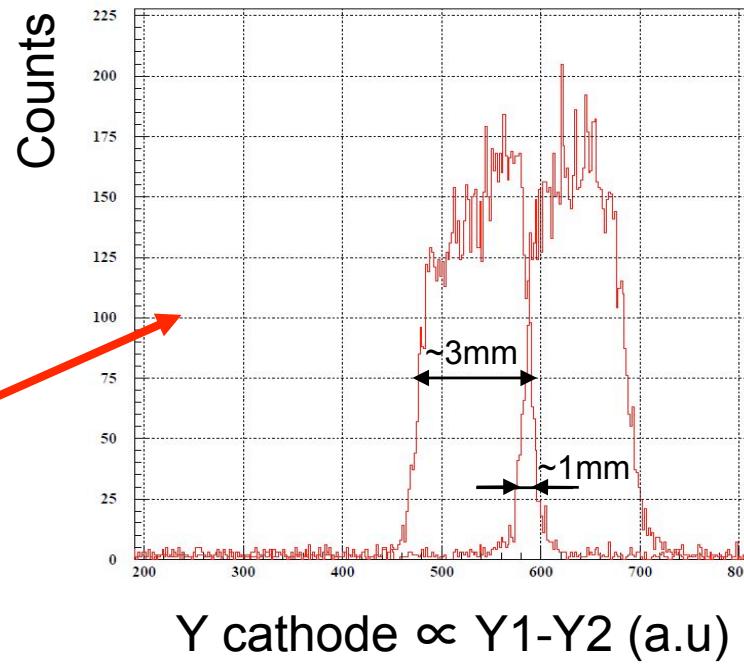
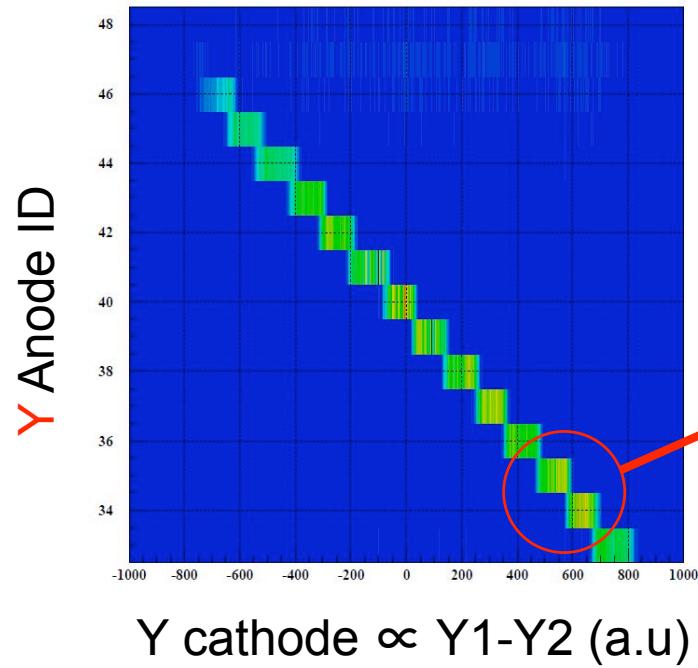
Purpose

- First operation of MWDC (proto type)
- Debug/Development of pulse-processing electronics and Data acquisition

Estimate:

- Position Resolution of Delay-line readout (Cathode)
- Avalanche gain as functions of Gas Pressure and HV

Position Resolution of Cathode



Though not taking into account ...

- α incident angle
- multiple scattering
- and so on...

→ Position deduced from Cathode is consistent.
Resolution may be less than \sim 1 mm