OEDO Beamline: New Energy-degrading Ion Optics of RI Beams

Shin'ichiro Michimasa

Center for Nuclear Study, Univ. of Tokyo

Contents

- **Introduction**
  - Physics motivation of OEDO beamline
- **OEDO beamline: Upgrade of SHARAQ beamline**
  - Schematic/Ion-optical design
  - Simulative estimation

Motivation

- We want to study Low-energy Nuclear reactions with (very exotic) RI isotopes.
  RIBF is the top performance among RI-Beam facilities…
  But RIBF energy is too high for adopting low-energy reactions,

➡ Naturally we started to think
how to produce effectively low-energy beam from high-E beam.

- OEDO scheme as one of solutions
  ImPACT program supports development of the E-degrading technique.
  (OEDO = Optimized Energy Degrading Optics for RI beam)

Physics at OEDO

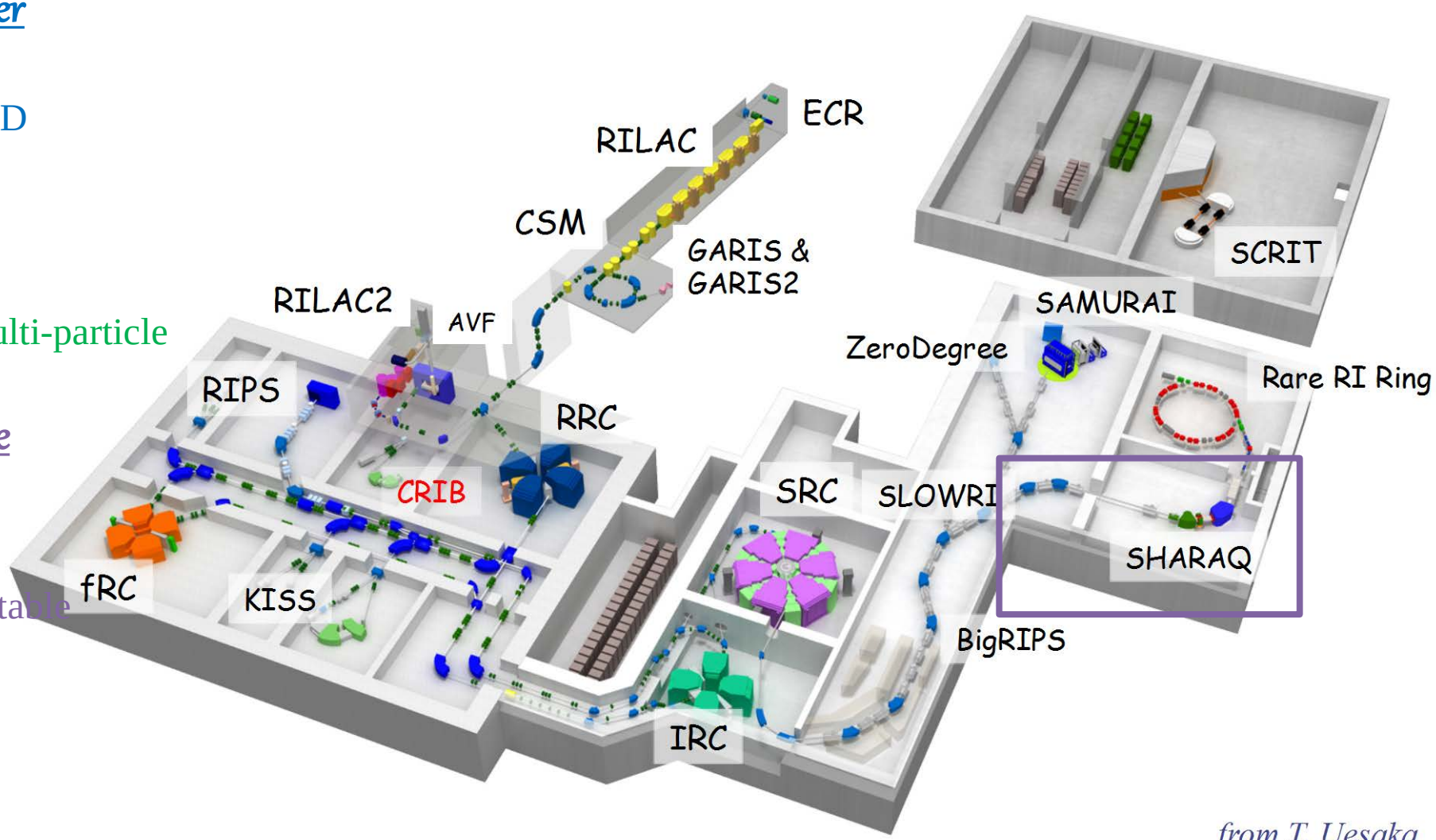
OEDO provides a research field using 5-50 MeV/u in-flight RI beams

- **Coulomb excitations for low-lying states of medium/heavy nuclei**
  - Reducing atomic backgrounds
  - Gamma spectroscopy with SHARAQ (PID/missing mass)
- **Transfer reactions**
  - (d,p), (d,n), (α,t), (α,τ), …
  - Cluster transfers
  - Combination with Gamma/Active target/SHARAQ
- **Resonance elastic/inelastic scattering**
  - Thick target method (well established at Low-energy Facilities)
- **Fusion/Deep inelastic scattering of Exotic nuclei**
  - Ultra-high spin / Hyper-deformation
    - Medium-heavy / Light nuclei
  - Phase diagram in E-J plane

Construction Site for OEDO

RIBF was equipped with 3 spectrometers for RI beams:

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



from T. Uesaka

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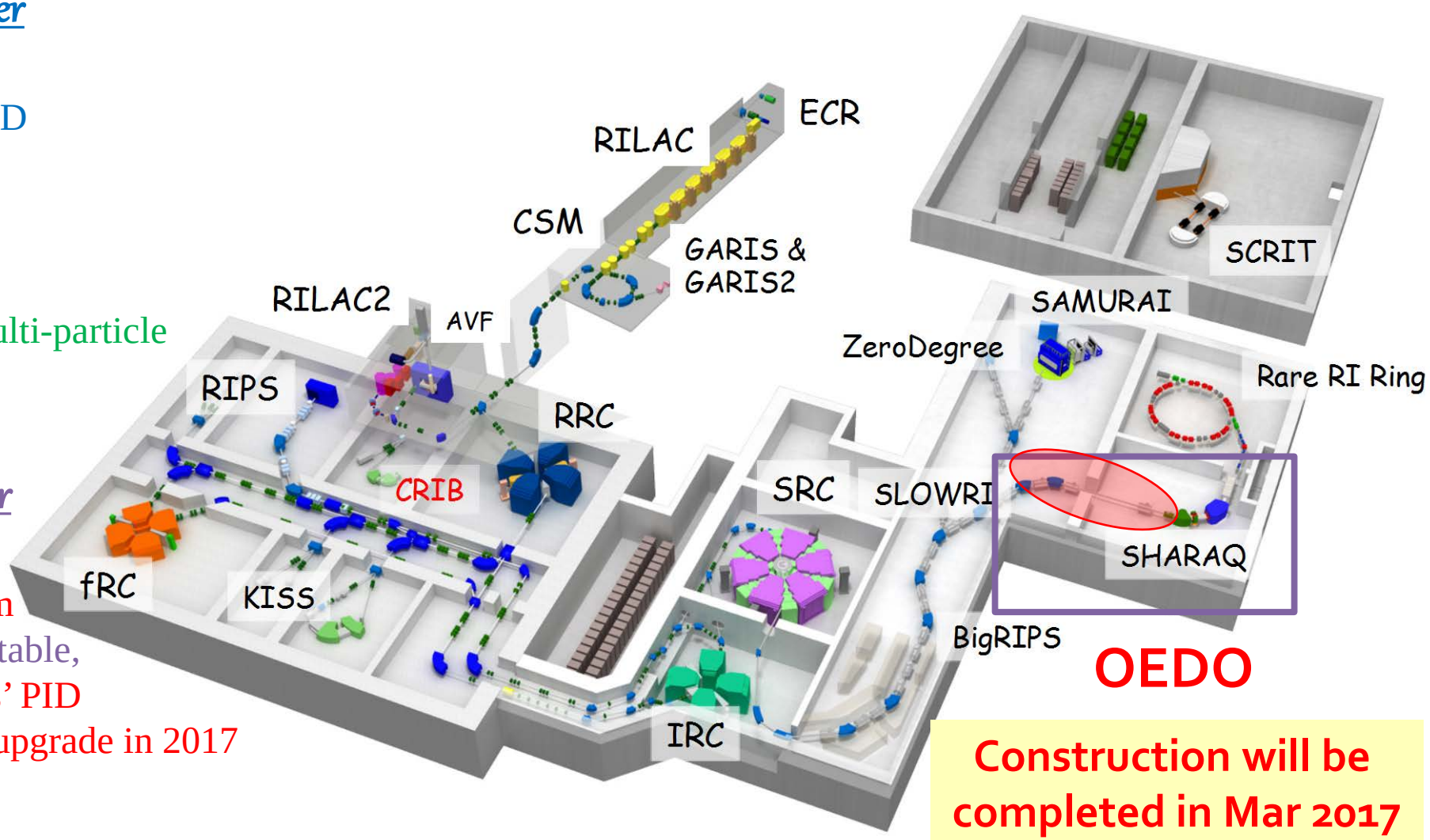
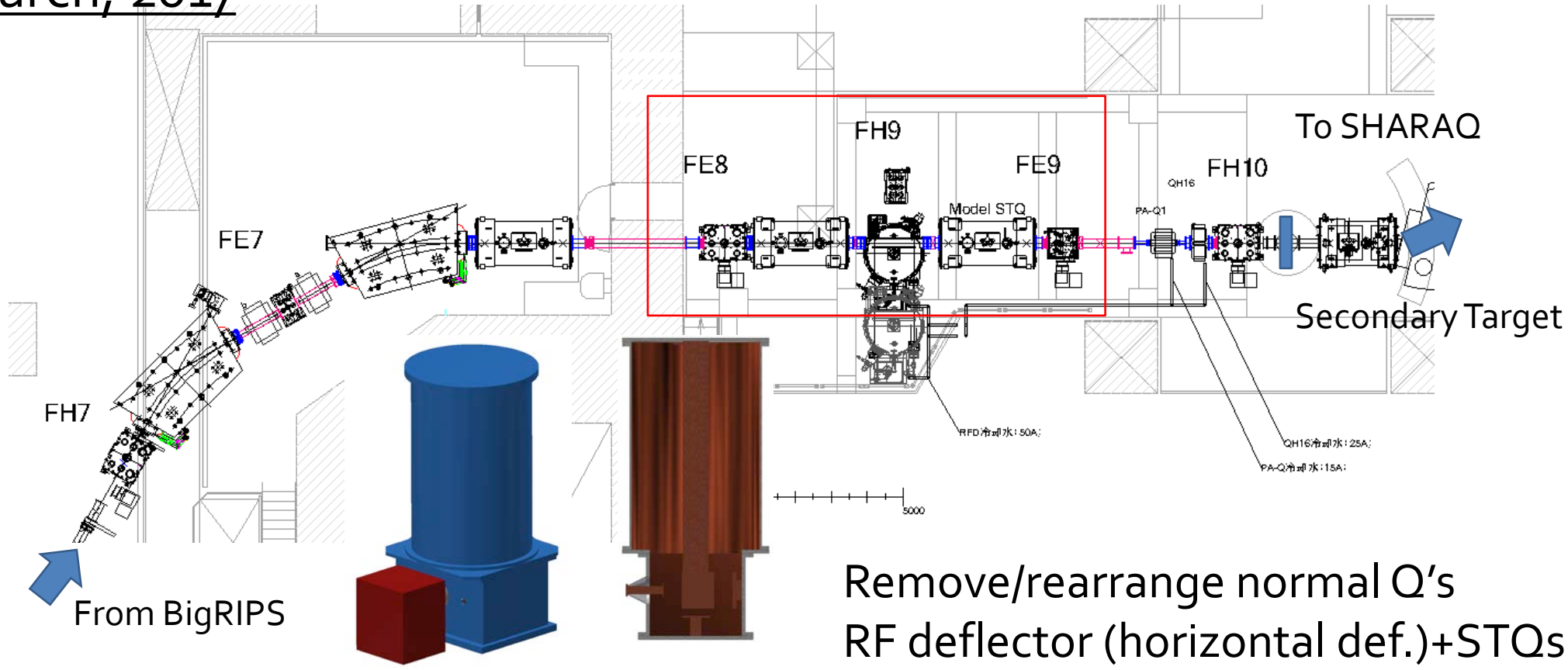
  (RIKEN)
  - multi-purpose for PID
  - completed in 2007
- SAMURAI spectrometer
  (Tohoku Univ.)
  - large acceptance, multi-particle
  - completed in 2011
- OEDO beamline
  + SHARAQ spectrometer
  (Univ. of Tokyo)
  - Low-energy RI beam
  - high resolution, rotatable, outgoing heavy-ions' PID
  - completed in 2009, upgrade in 2017



Construction will be completed in Mar 2017

OEDO beamline
- Upgrade of High-resolution beamline -

in March, 2017

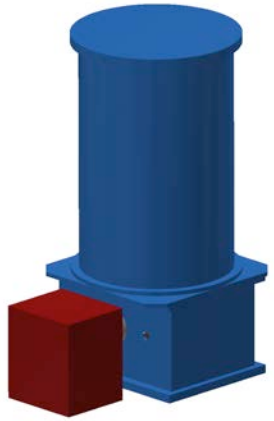


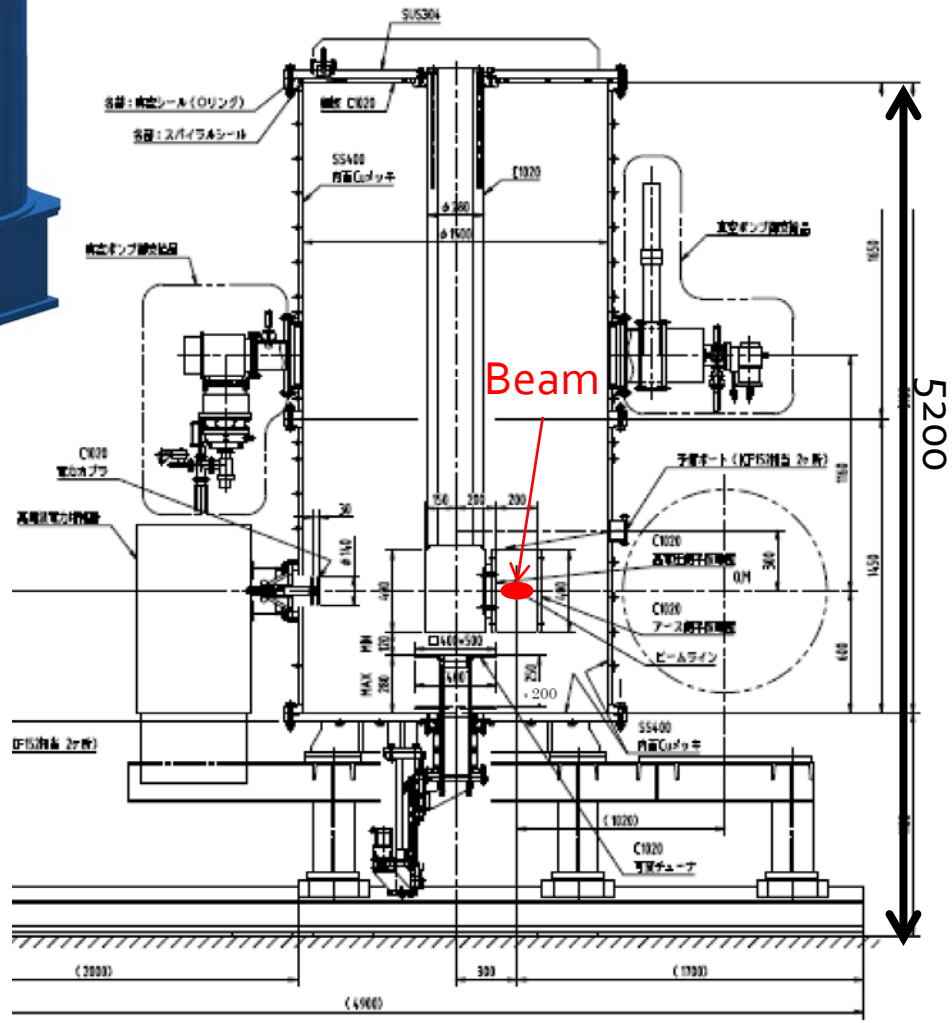
Remove/rearrange normal Q's
RF deflector (horizontal def.)+STQs
Reaction pruducts → SHARAQ (QQD)

Specification of OEDO RF deflector

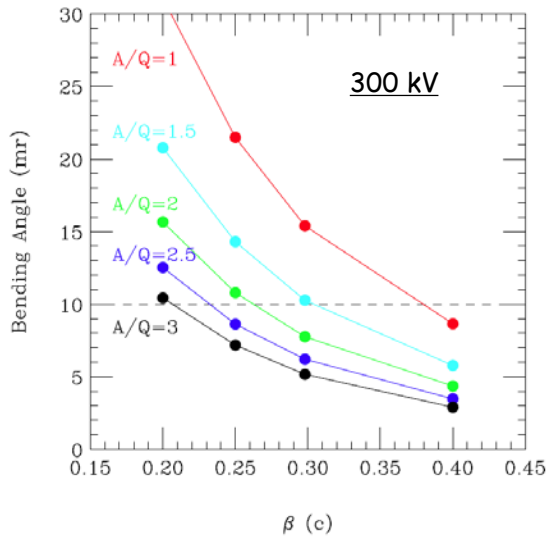
Design values:

RF frequency	18.0-18.5 MHz (matching to SRC frequency)
Max Voltage	> 300kV
Electrode Gap	200 mm
Electric field	horizontally 1.5 kV/mm (max)
Electrode Length	1200 mm
Electrode Width	400 mm
Beam duct	JIS V250
Vacuum	< 5 × 10^{-6} Pa
Height	5.2 m
Weight	8 ton

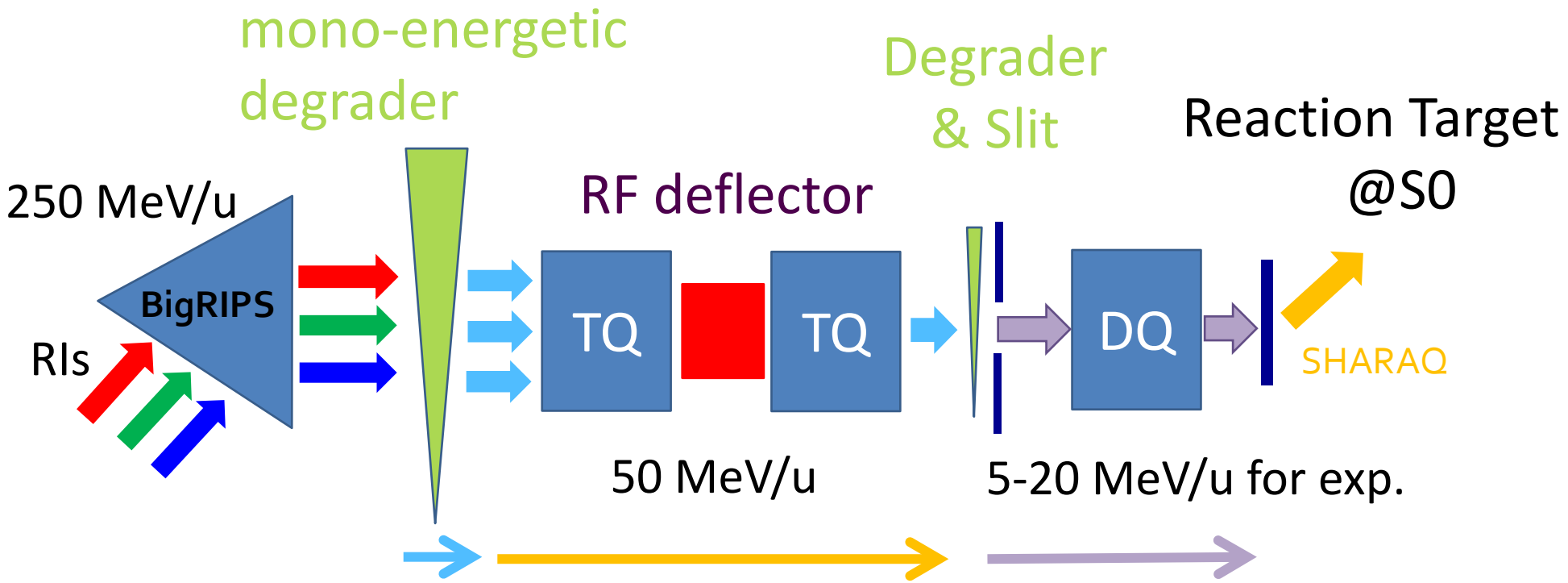




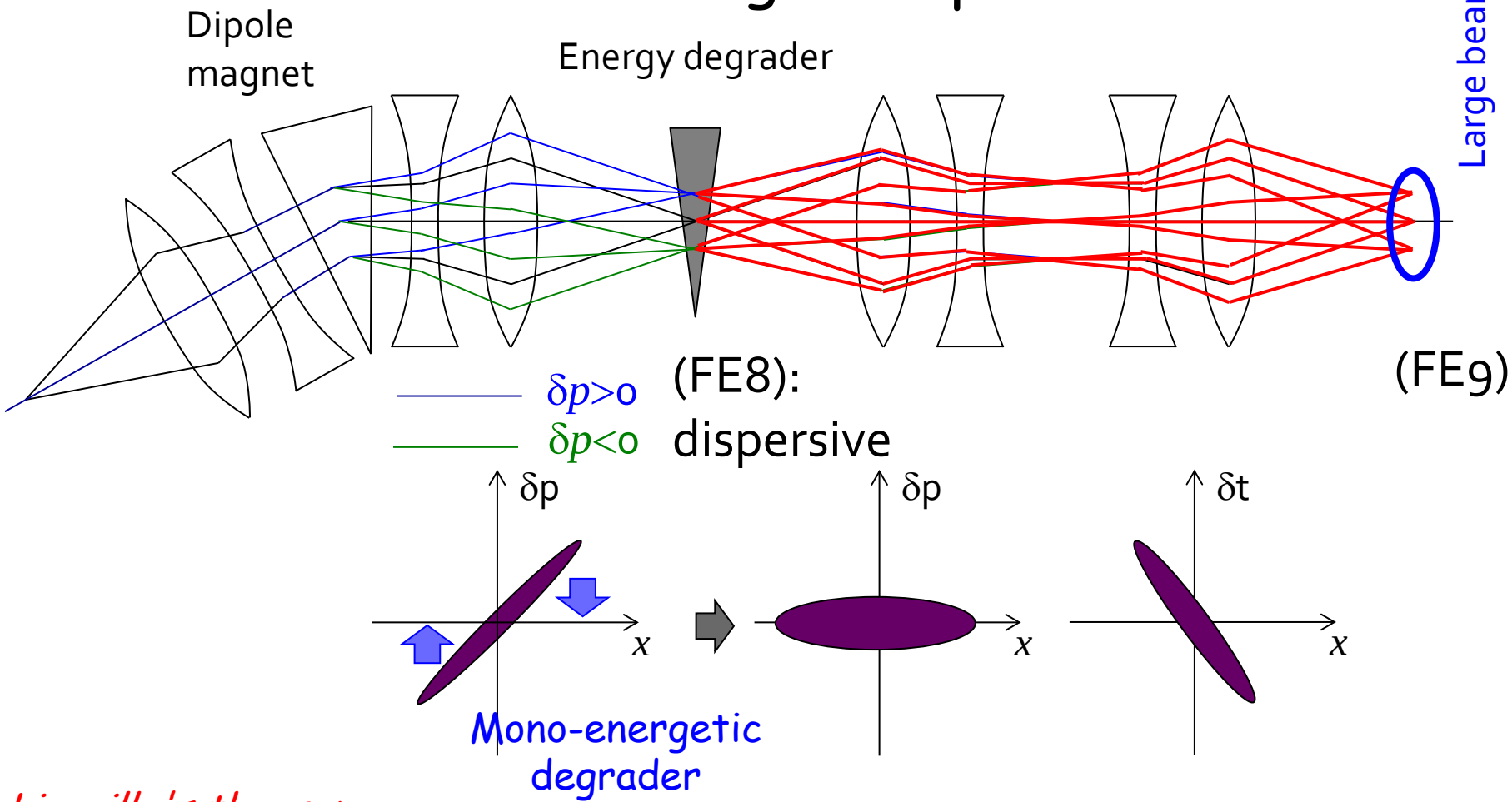
Maximum angle of Beam
(cor. ±3% mom.)



Scheme of OEDO Beamline



Basic Method of Energy Degrading
- Mono-energetic optics -



Liouville's theorem

Energy spread can be decreased, but beam size becomes large.
Larger dispersion is better energy resolution, but larger beam size.

p → small; δp → large, δ=δp/p → very large

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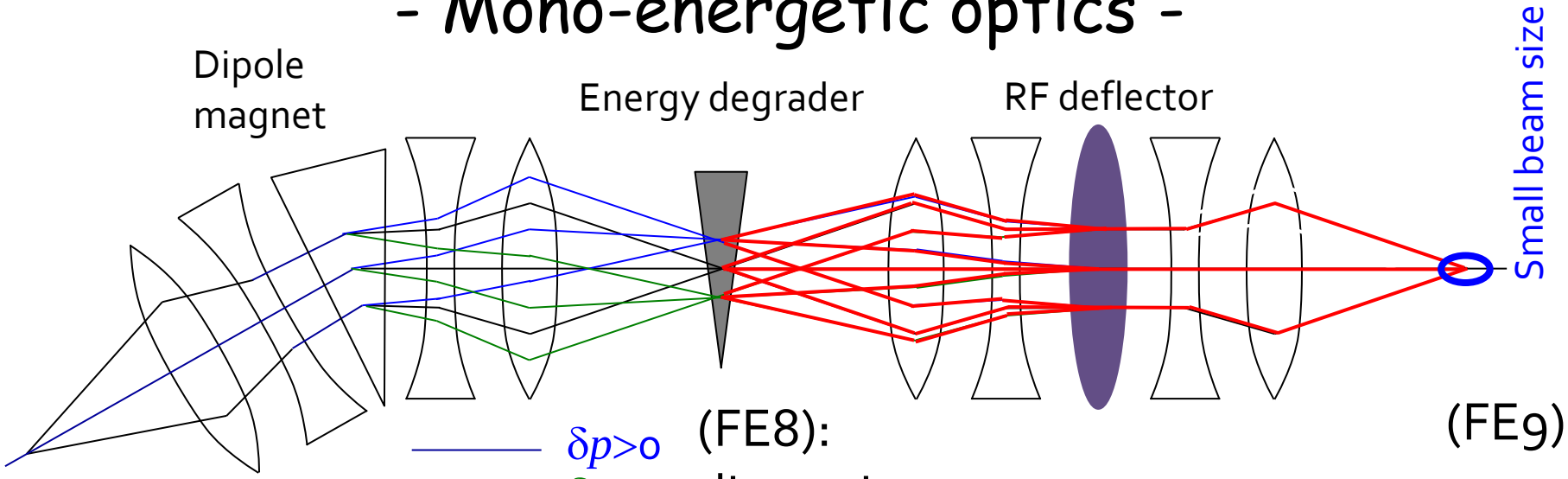

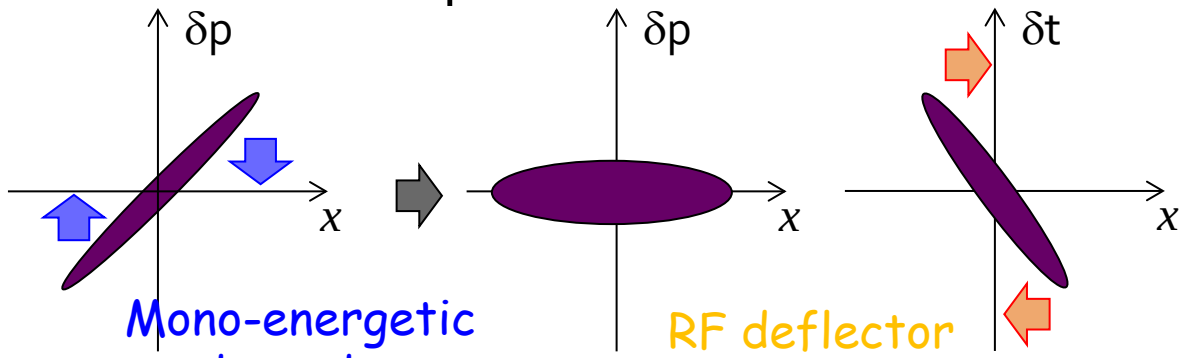

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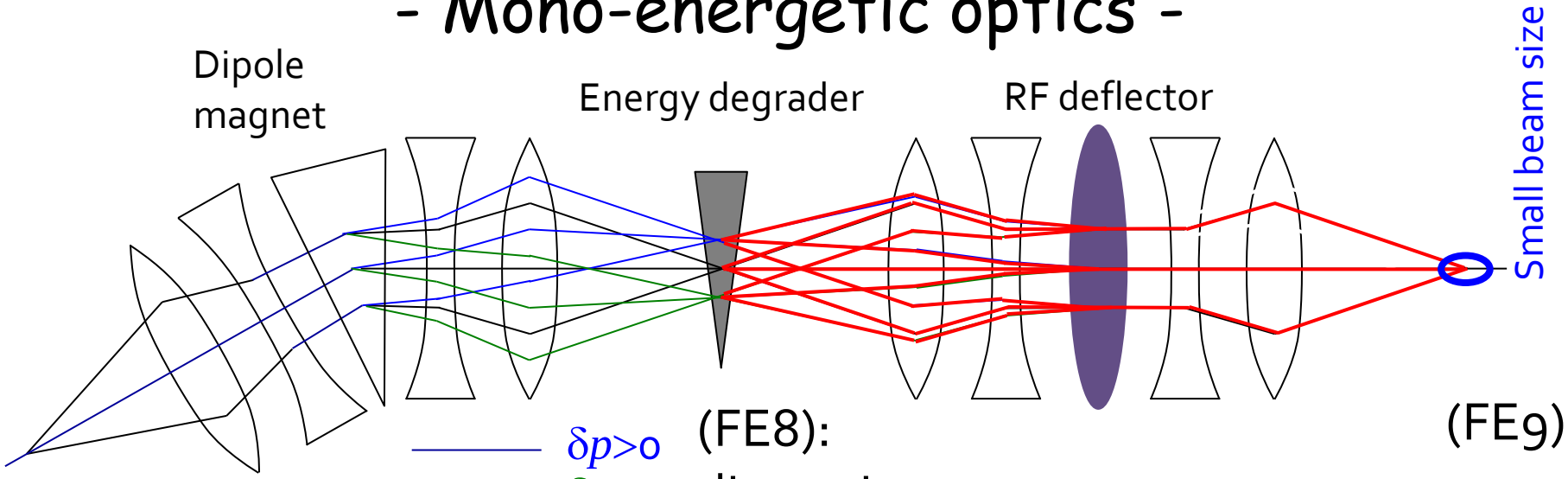

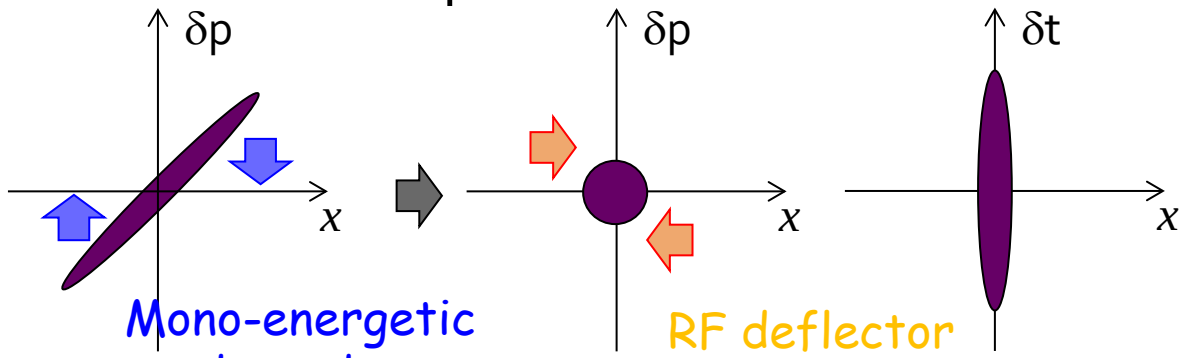

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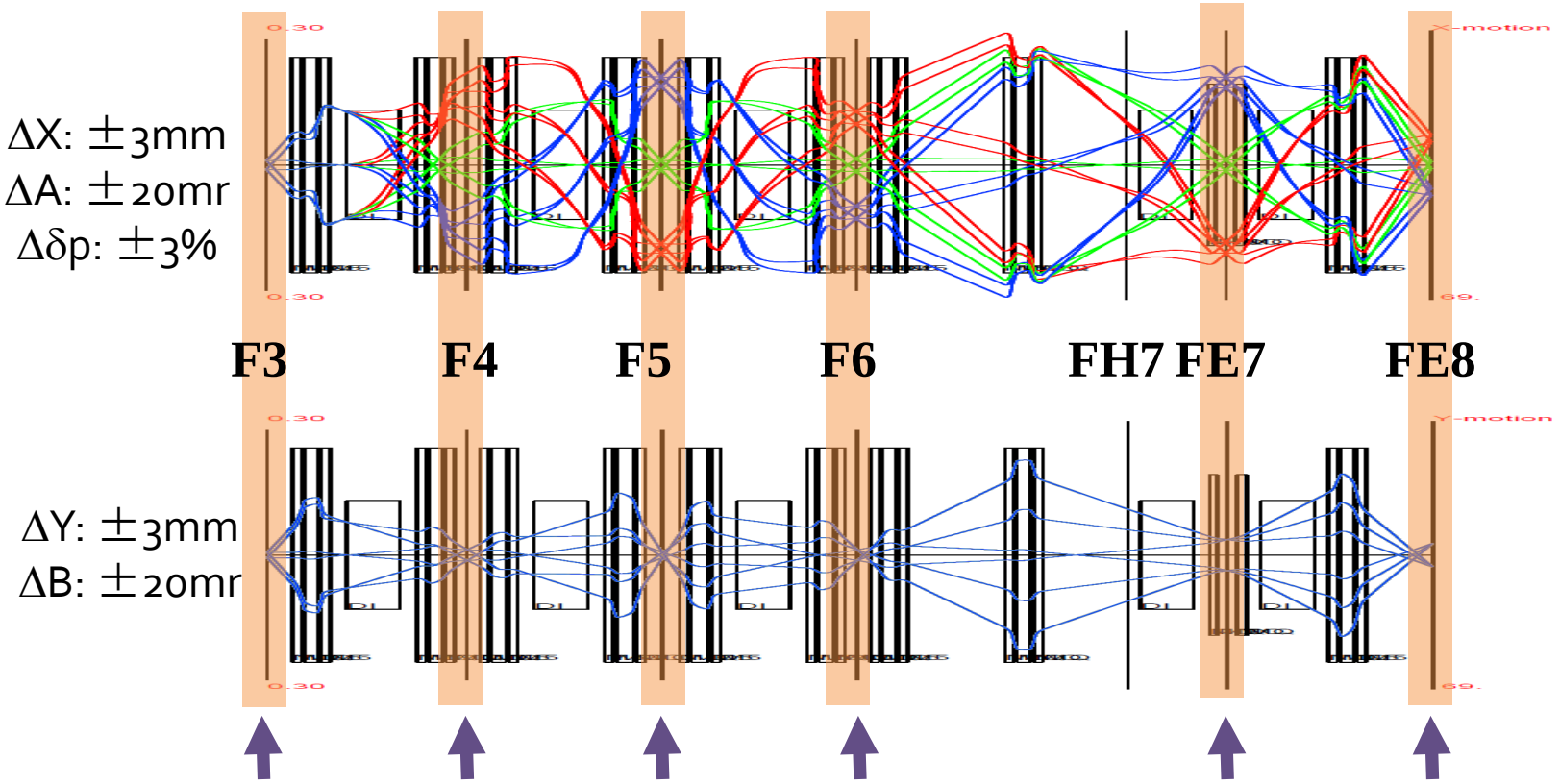
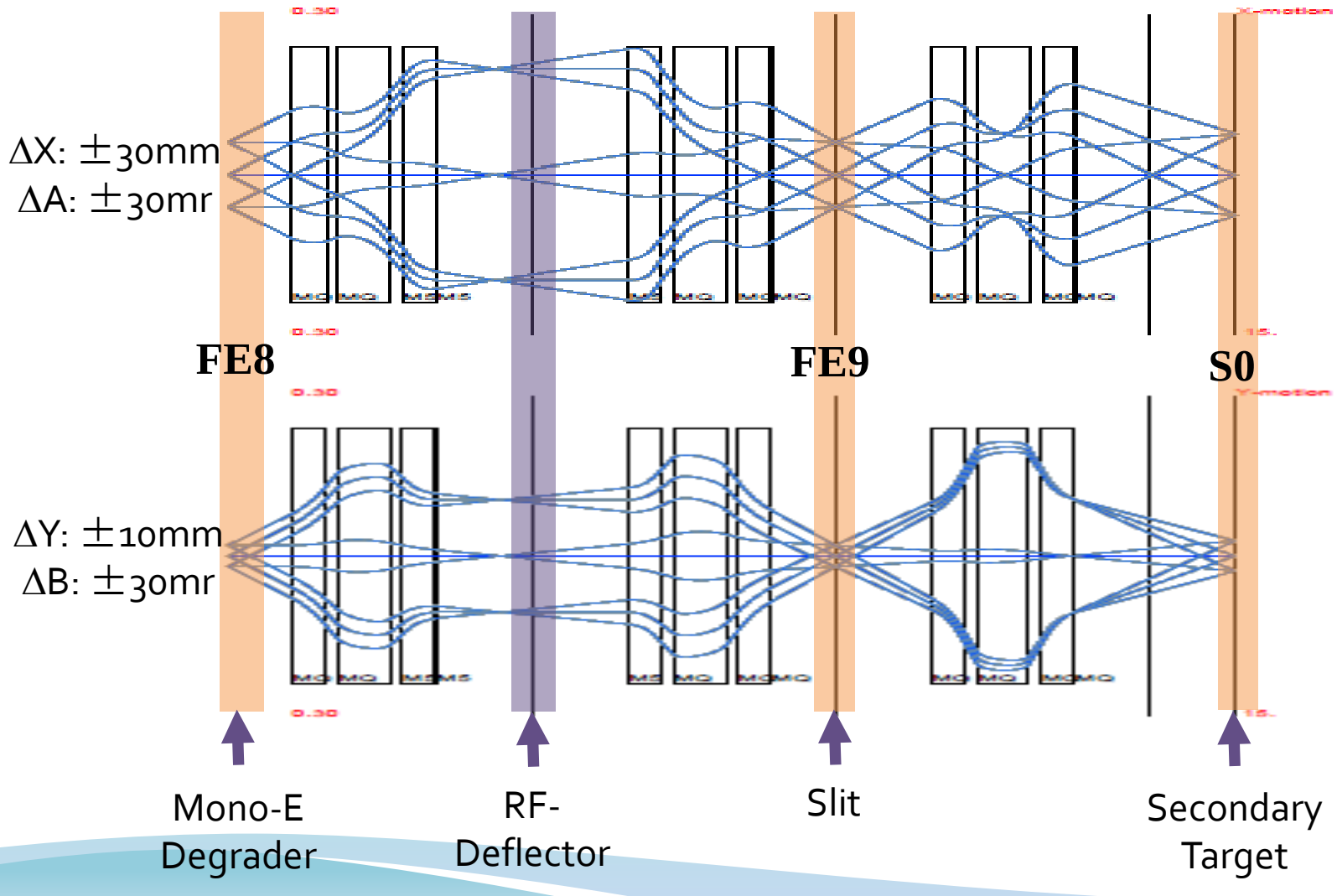
Optics of Beamline (1)
F3 - FE8



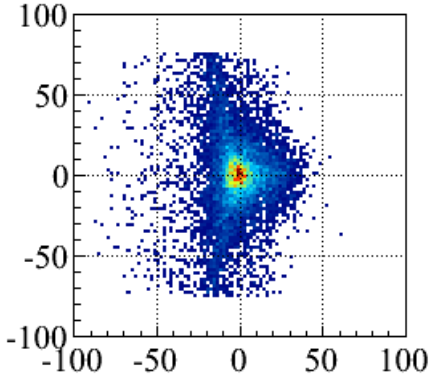
F3	F4	F5	F6	FE7	FE8
X: Achr.	X: ------	X: Disp. (3.3 m)	X: Disp. (1.7m)	X: Disp. (2.9m)	X: Disp. (1m)
Y: Achr.	Y: Achr.	Y: Achr.	Y: Achr.	Y: Achr.	Y: Achr.

Optics of Beamline (2)
FE8 – S0

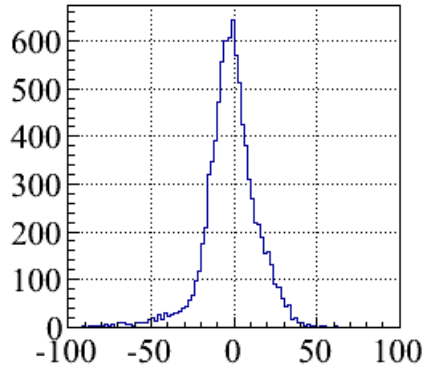


Beam image and charge state @2ndary target

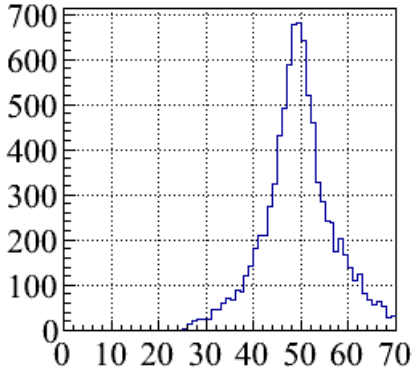
^{132}Sn degraded to 50 AMeV



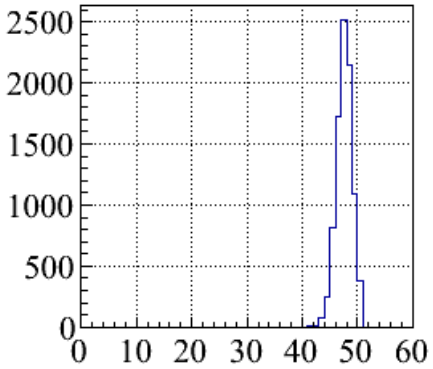
So X – Y [mm]



So X [mm]

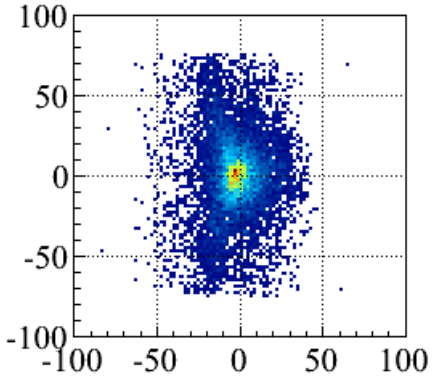


Energy [AMeV]

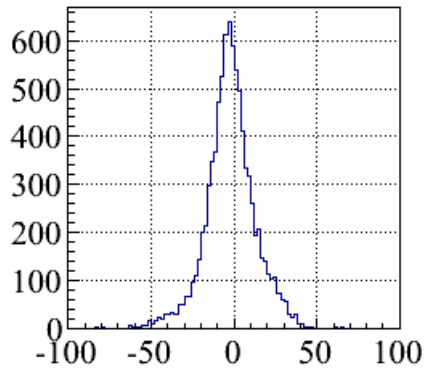


Charge State [e]

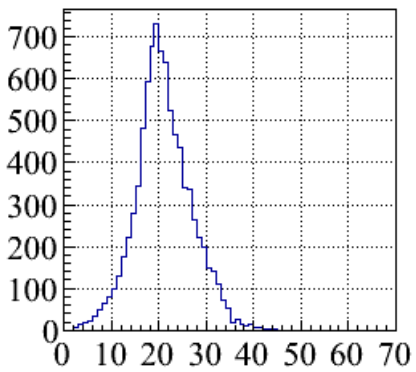
^{132}Sn degraded to 20 AMeV



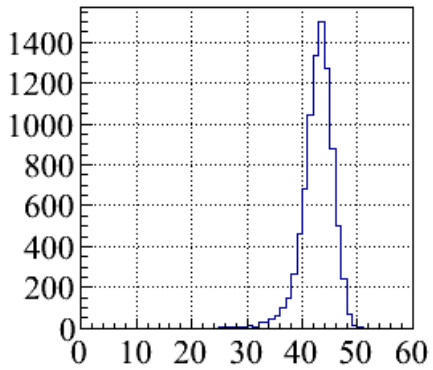
So X – Y [mm]



So X [mm]



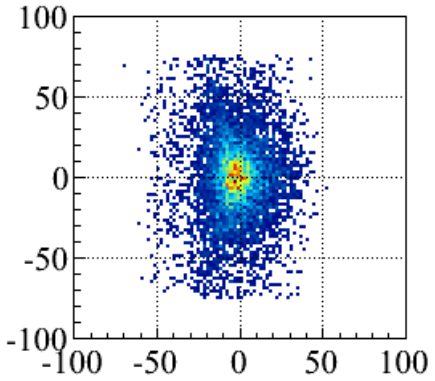
Energy [AMeV]



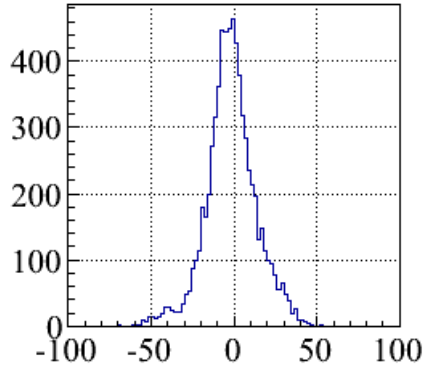
Charge State [e]

Beam image and charge state @2ndary target

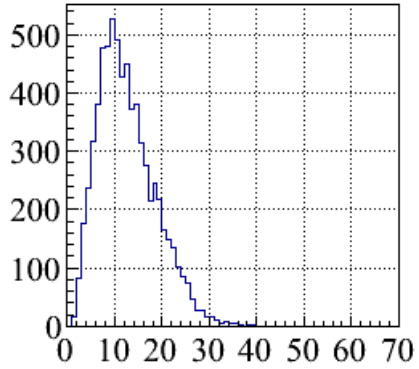
^{132}Sn degraded to 10 AMeV



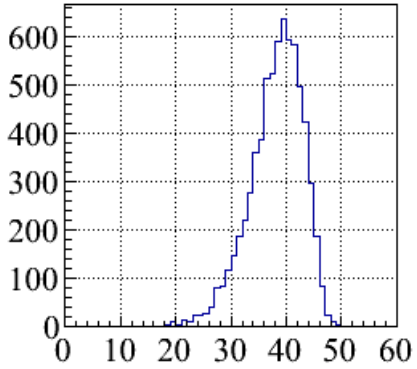
So X – Y [mm]



So X [mm]

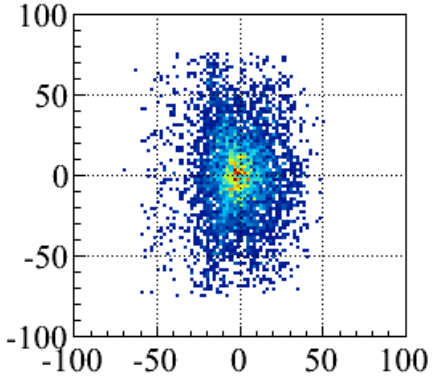


Energy [AMeV]

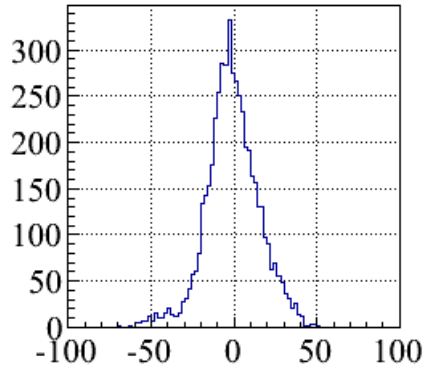


Charge State [e]

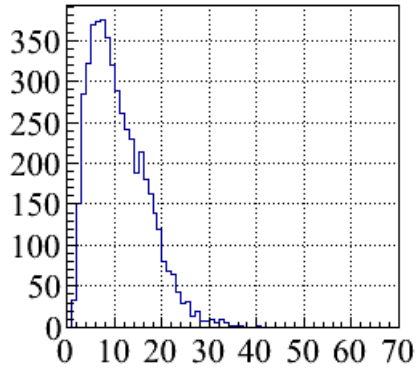
^{132}Sn degraded to 5 AMeV



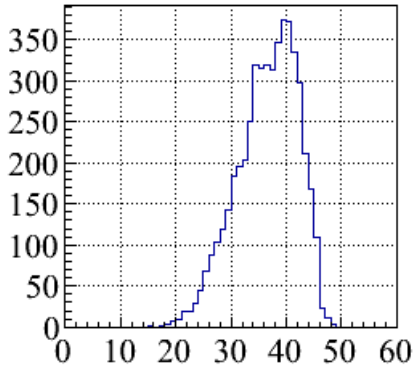
So X – Y [mm]



So X [mm]

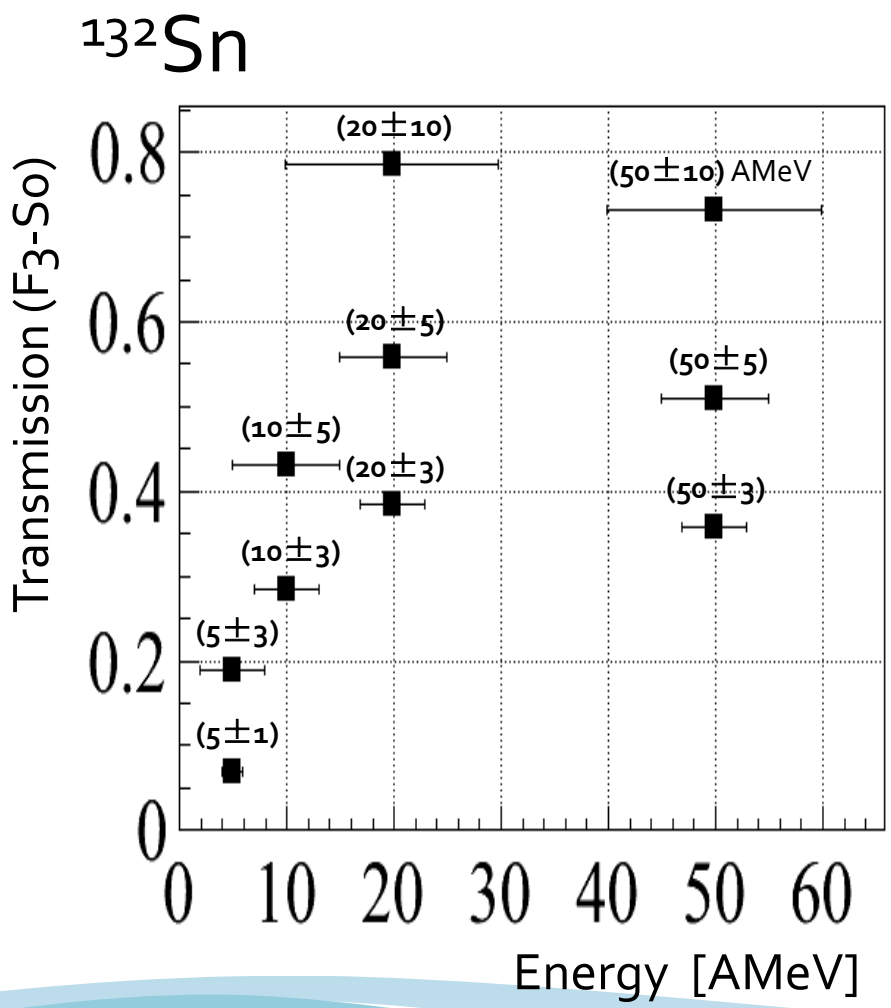


Energy [AMeV]



Charge State [e]

Transmission and intensity



Transmission (F_3 - So)
×
Intensity @ F_3
‖
Intensity @ OEDO (So)

Typical example of ^{132}Sn

based on actual intensity in experiment by using 345 AMeV 30pnA U primary beam (Apr. 2015)

Intensity @ F_3 (Apr. 2015)	2.5×10^6 [pps]
50 ± 5 AMeV @ So	1.3×10^6
20 ± 3 AMeV @ So	9.5×10^5
10 ± 3 AMeV @ So	7.5×10^5
5 ± 1 AMeV @ So	1.7×10^5

cf. 1.4×10^4 pps ^{132}Sn in CARIBU proposal

Development plan of OEDO beamline

End of FY2016 (Mar.,2017)

Construction is completed

First half of FY2017

Beam Commissioning

Second half of FY2018

First Experiment (for ImPACT program)

Later, OEDO will be open for physics experiments.

Summary

- **Present status of OEDO system**
  - Main part of OEDO system consists of RF deflector, STQs and energy degrader.
  - OEDO will enlarge scientific opportunities at RIBF for studies with low-energy reaction.
  - Ion-optics design was fixed and magnet arrangement is going on.
  - Simulative consideration is continued for high-quality Low-E RI beams. (e.g. estimate/reduction of higher-order aberrations)
  - Major part of the beam line is funded from ImPACT.
  - Construction will be finished by end of FY2016 (March, 2017).

Collaborators

S.Michimasa, S.Shimoura, M.Matsushita, N.Imai, K.Yako, H.Yamaguchi, S.Ota, H.Sakurai[1], T.Sumikama[1], K.Yoshida[1], K.Yamada[1], Y. Yanagisawa[1], K. Kusaka[1], M. Otake[1],E. Ideguchi[2]

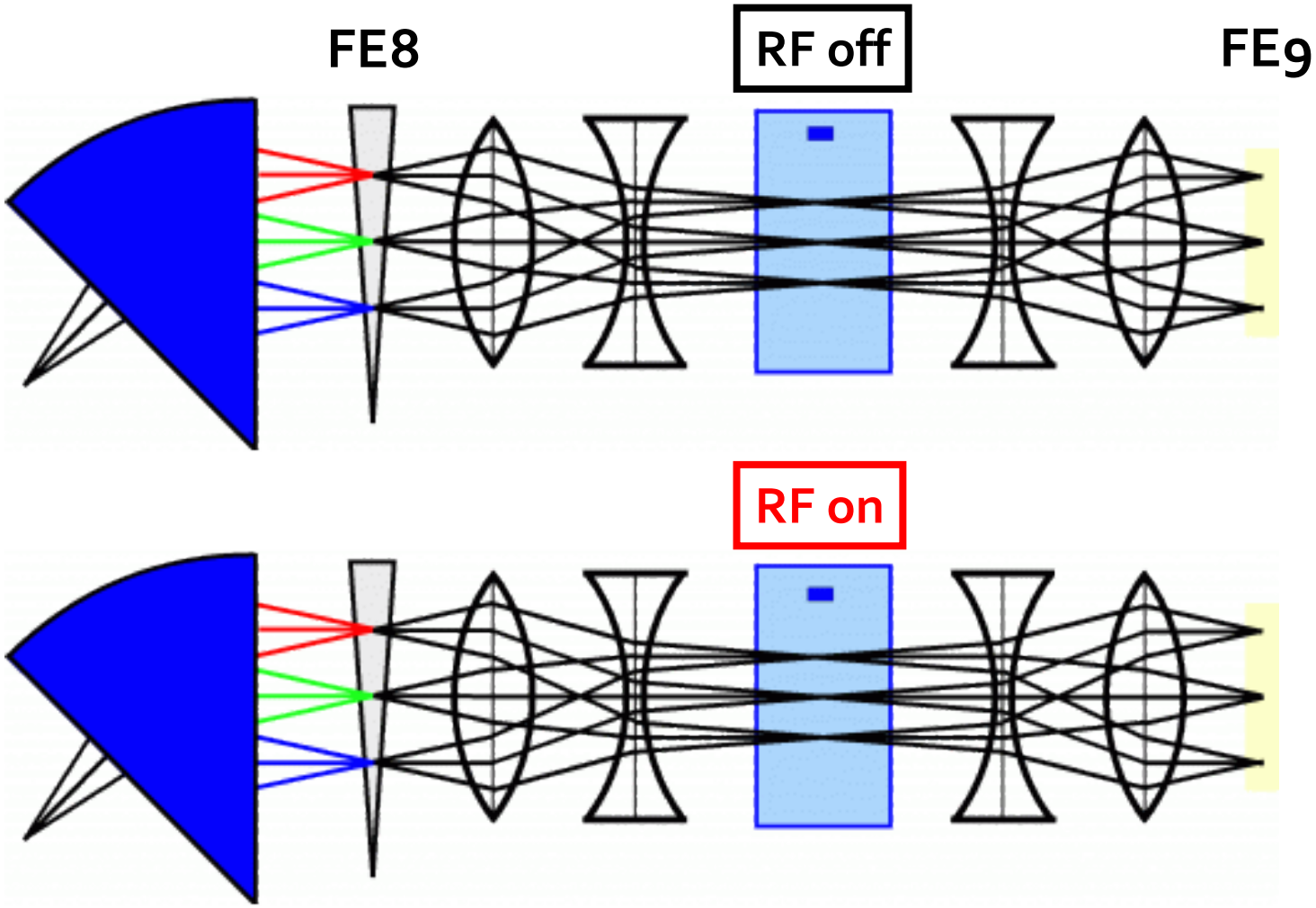
Center for Nuclear Study, University of Tokyo.

[1]RIKEN Nishina Center

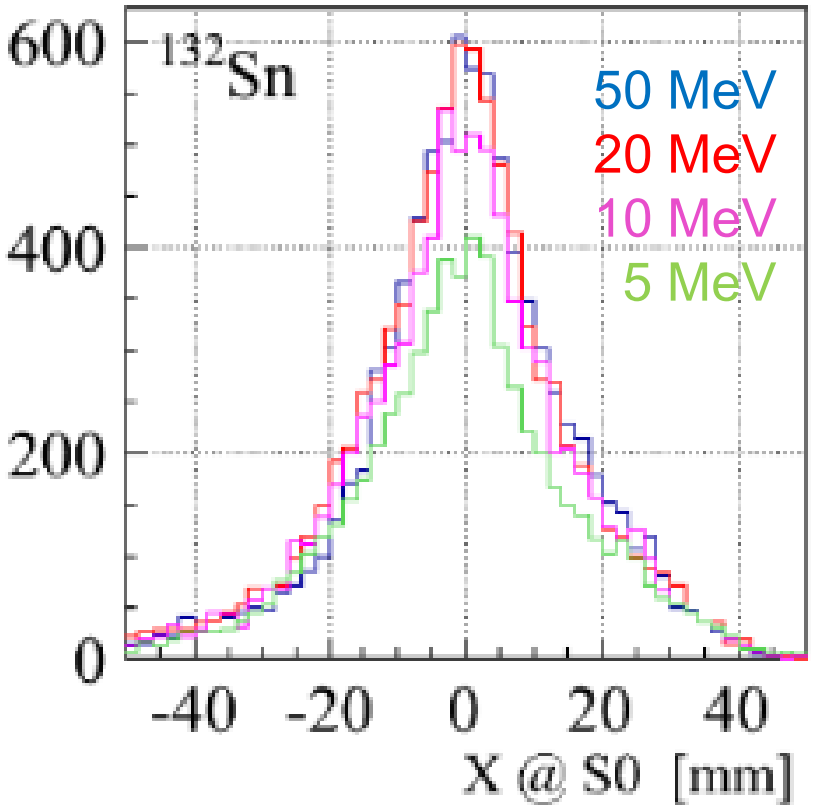
[2]RCNP, Osaka University

Backup

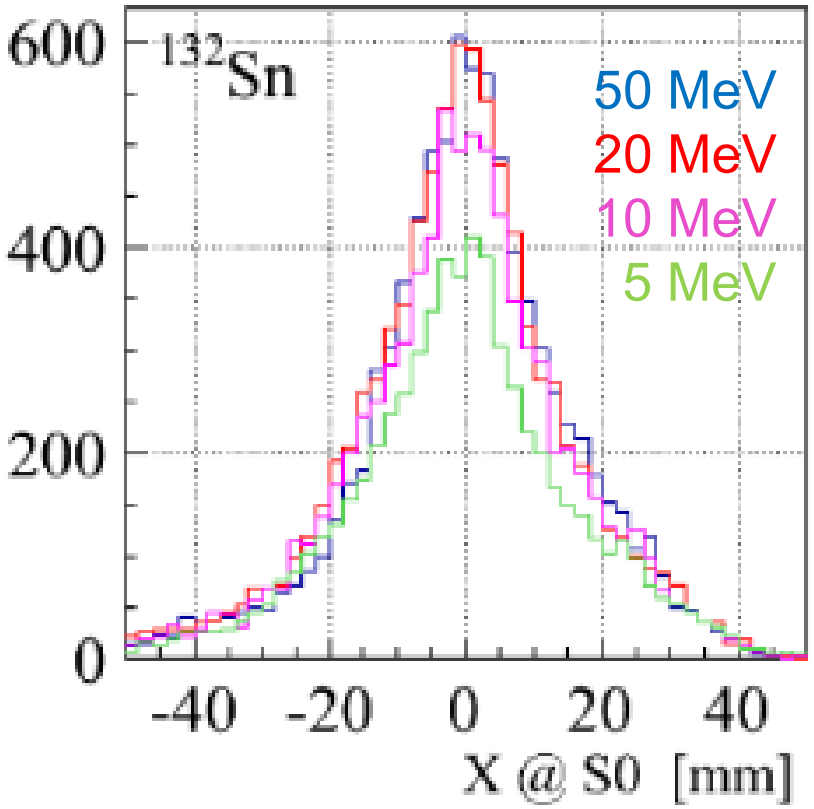
Optics of Beamline (FE8 – S0)

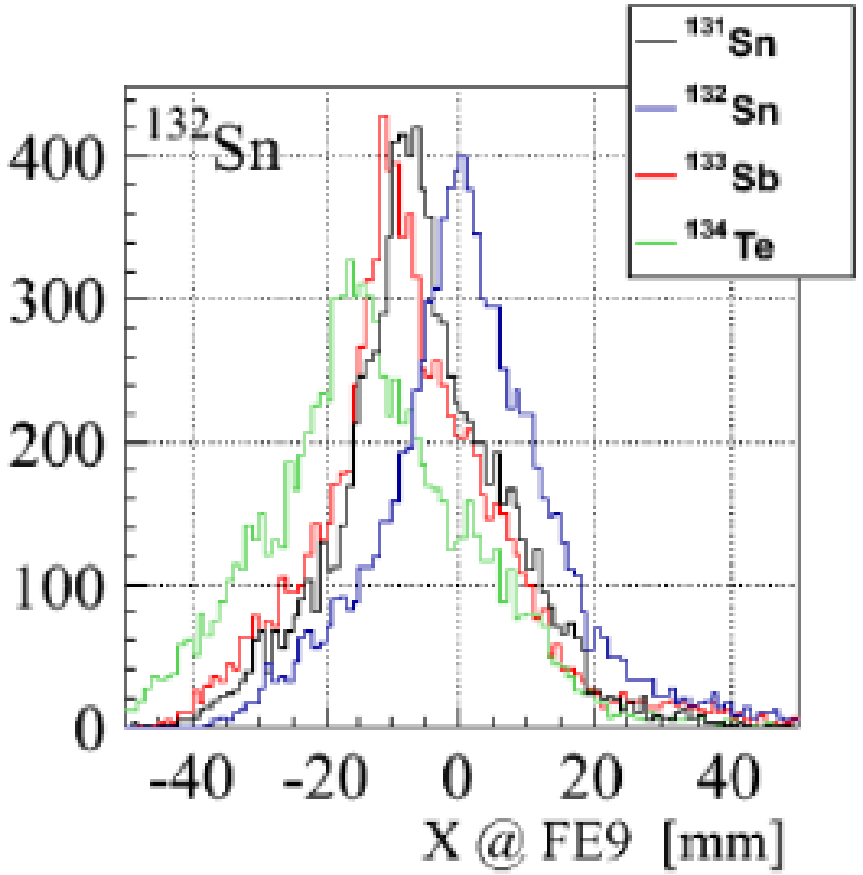


Compare beam image @ 2ndary target

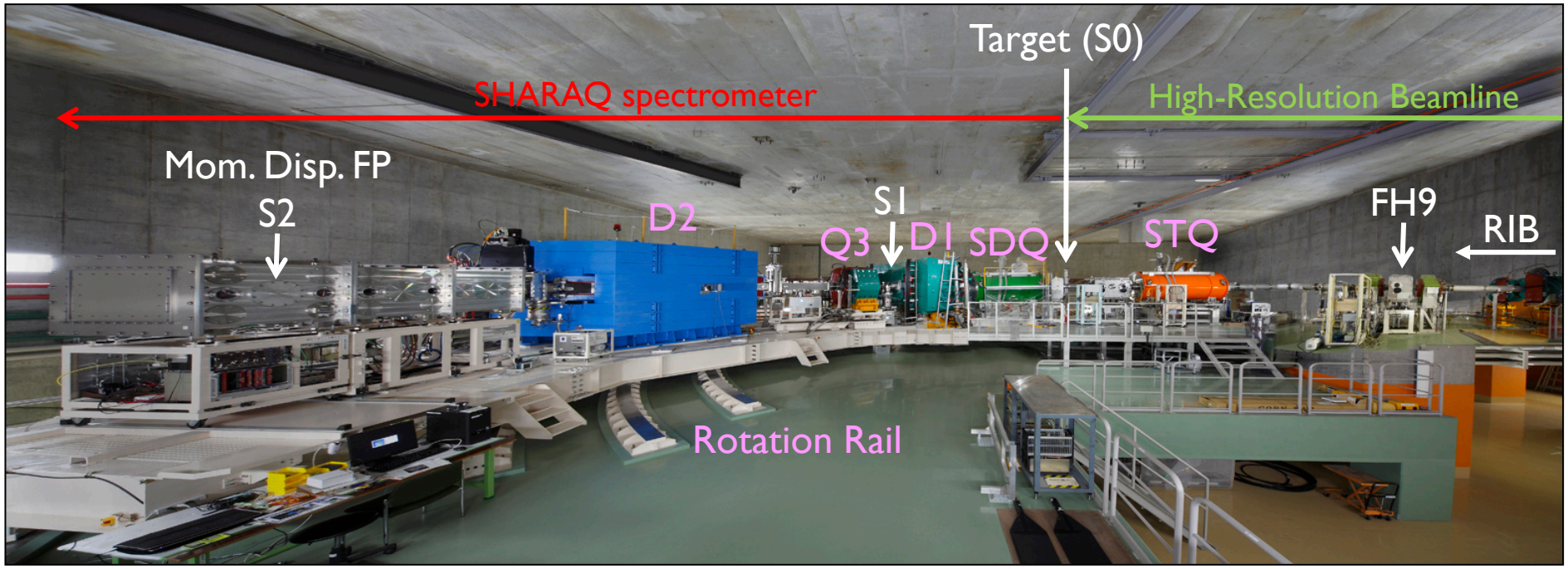


Beam purification by using OEDO





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

Basic Performance

Maximum rigidity	**6.8 Tm**
Dispersion (D)	**5.86m**
Horizontal magnification (M_x)	**0.40**
D/M_x	**14.7m**
Momentum resolution	**1/14700**
Vertical magnification (M_y)	**0.0**
Angular resolution	**< 1mrad**
Vertical acceptance	**± 3 deg**
Dispersion matching	**p & θ_x**

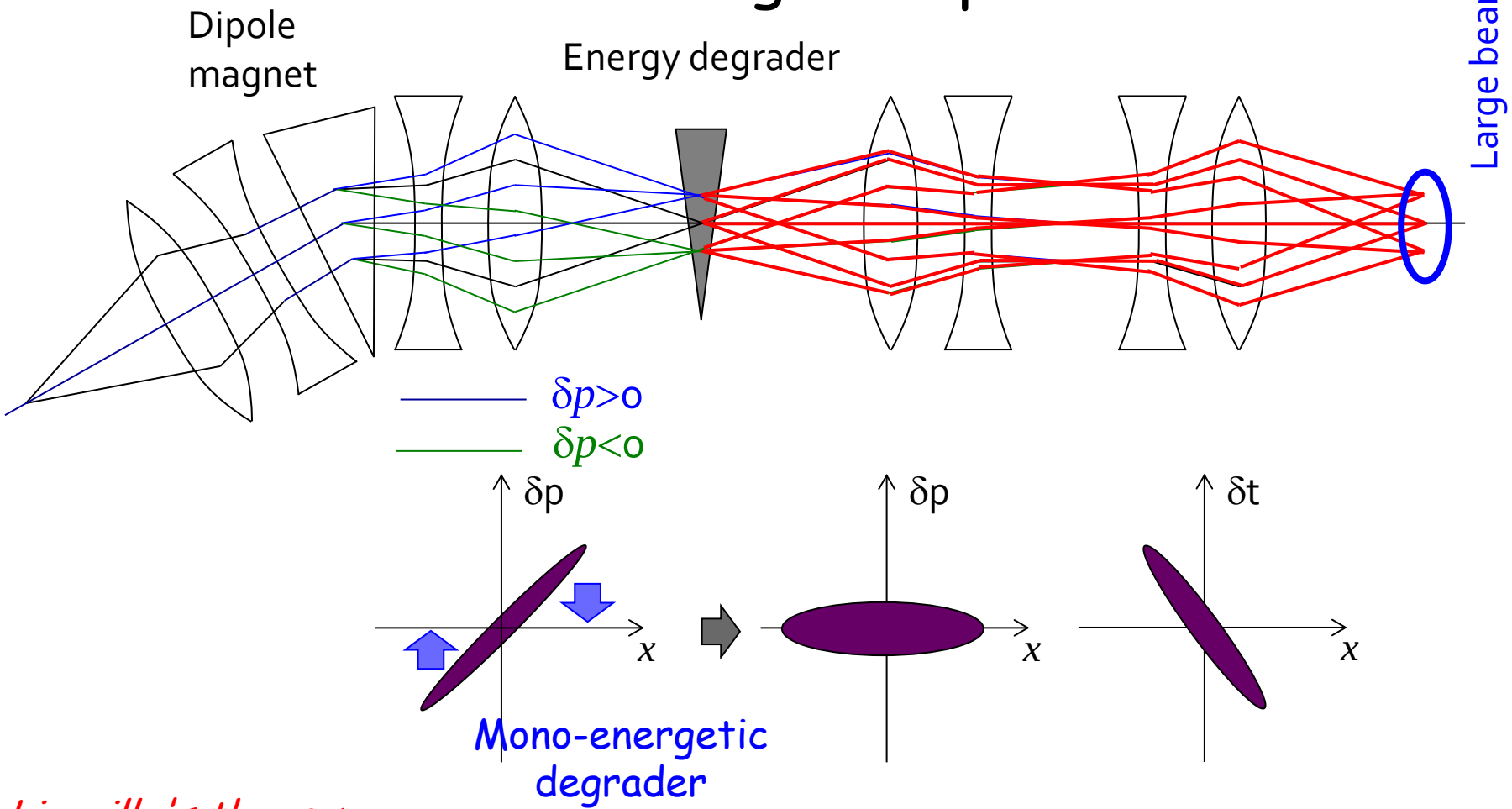
For spot size of 60mm(H)×10mm(V)
(*in dispersion matching operation*)

Horizontal acceptance	± 1 deg
Solid angle	2.7 mrad

For spot size of 10mm(H)×10mm(V)
(*in achromatic focus operation*)

Solid angle	4.8 mrad

Basic Method of Energy Degrading
- Mono-energetic optics -



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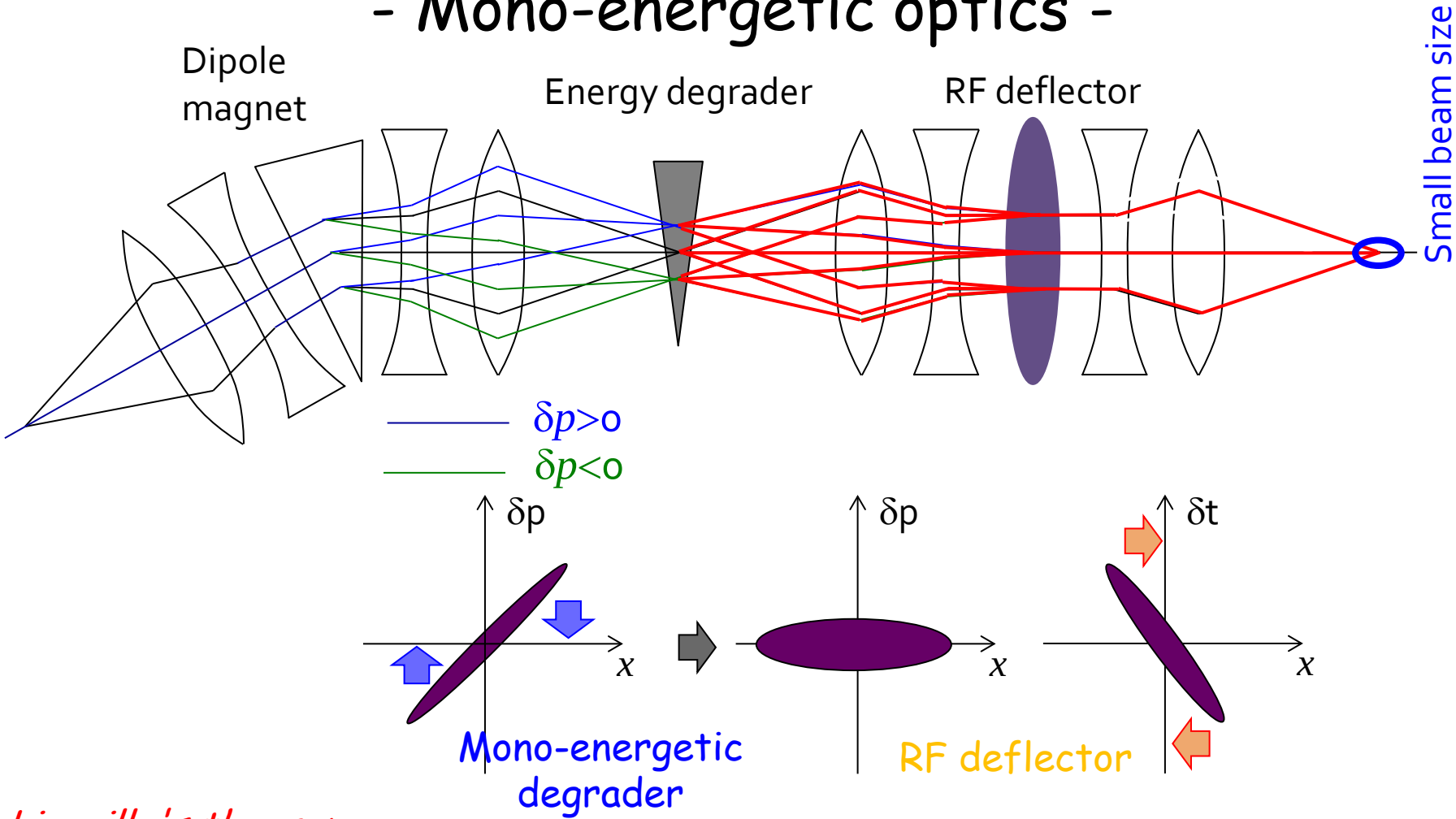

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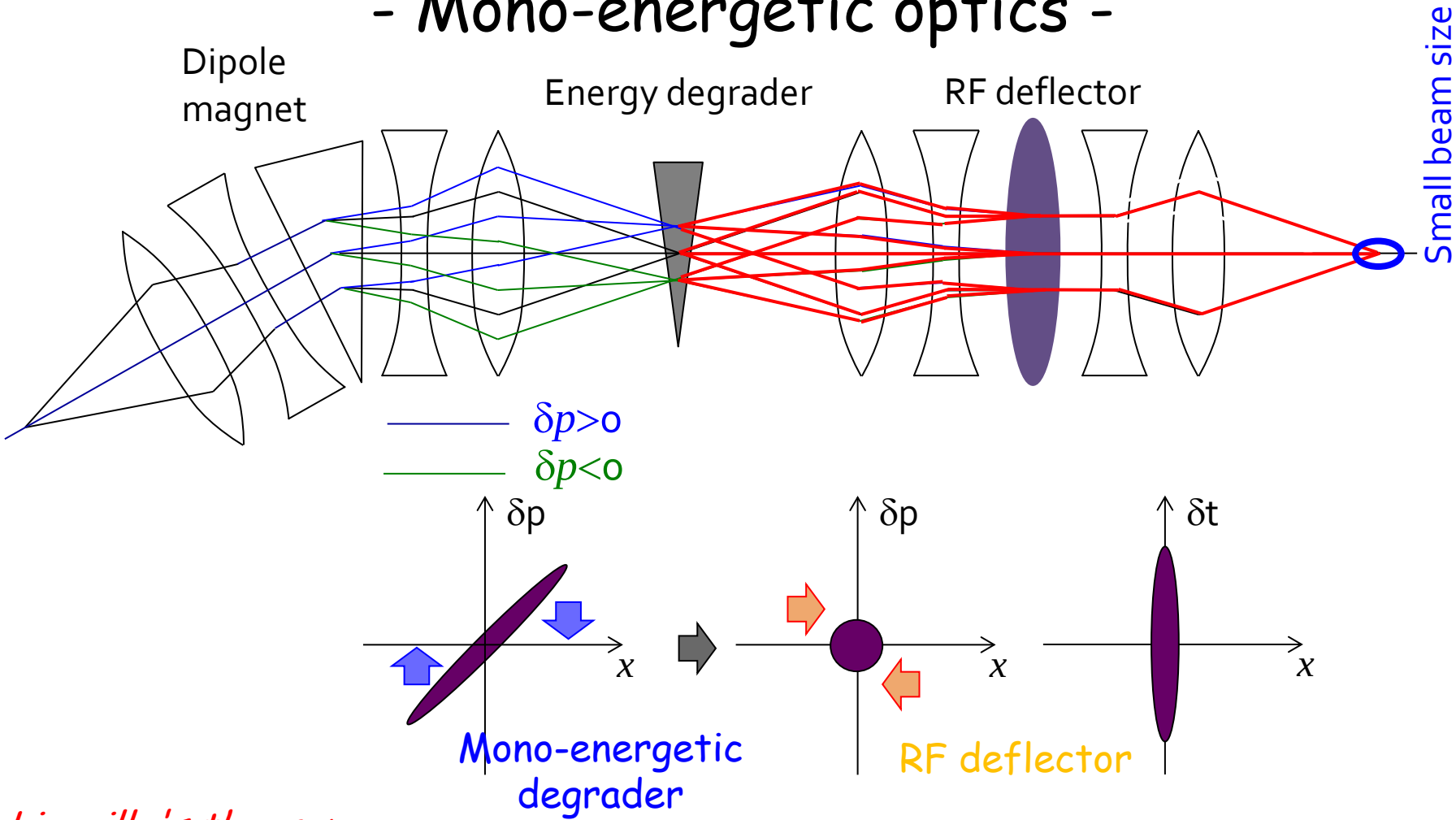

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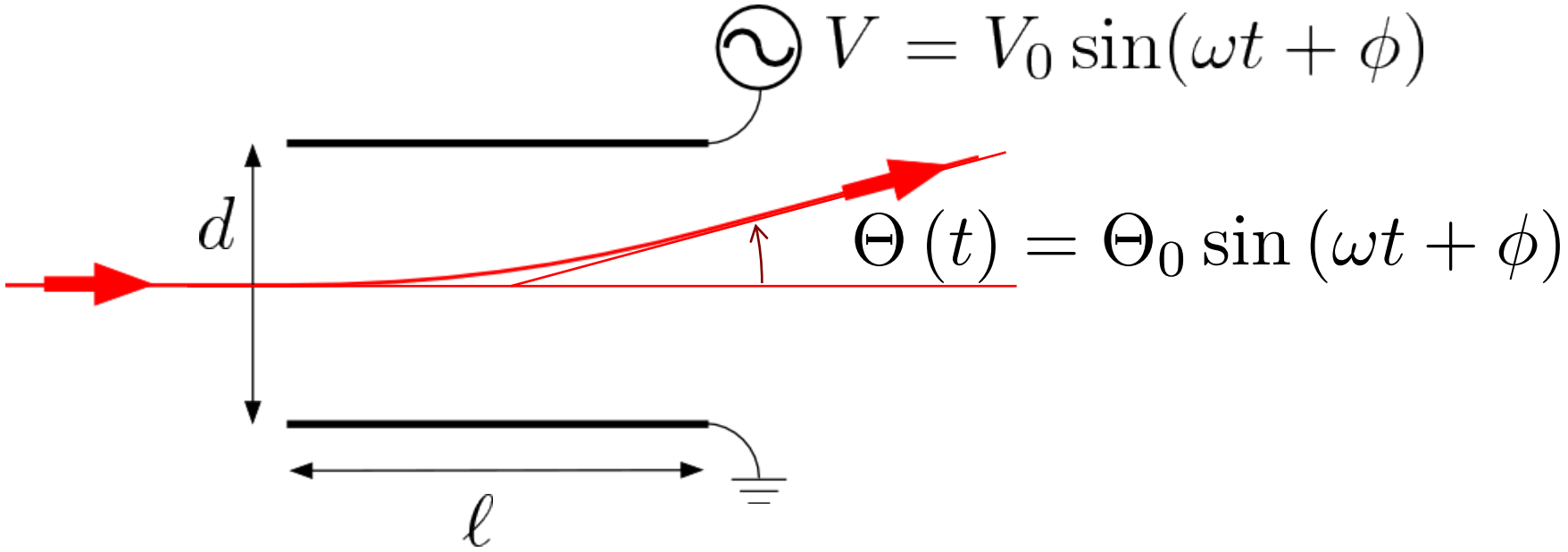
RF deflector



$d = 240$ mm

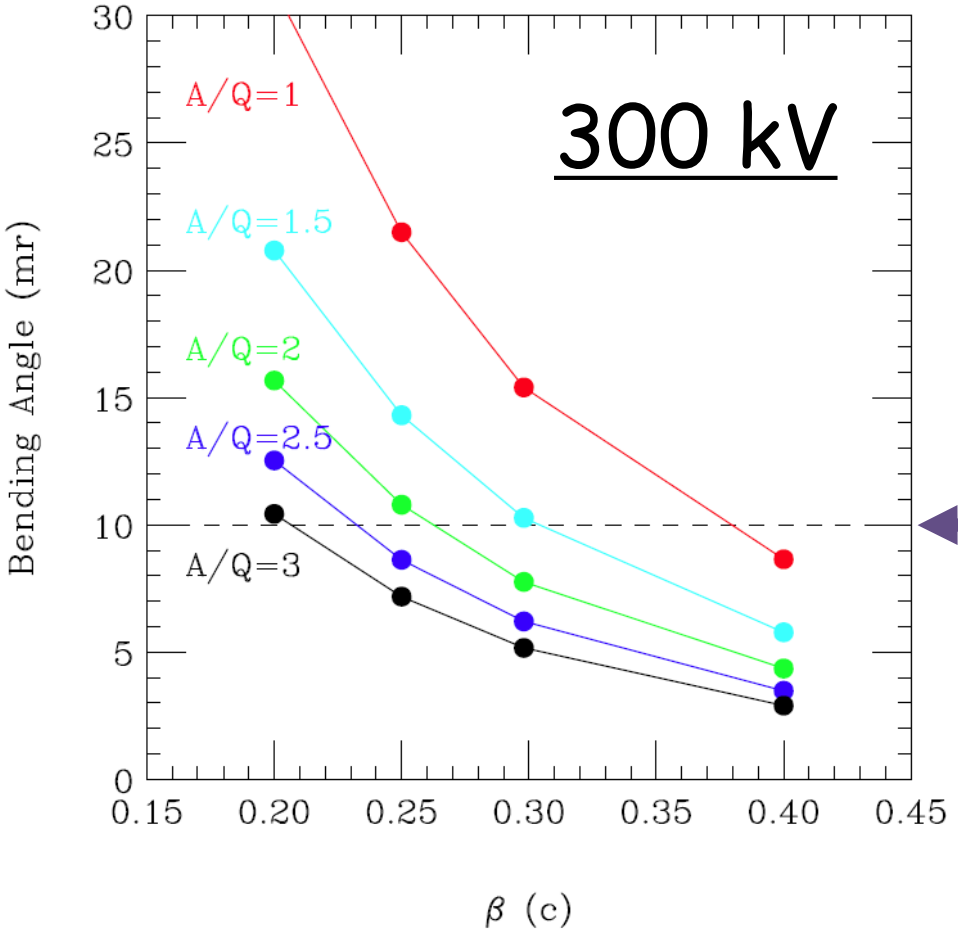
$\ell = 1200$ mm

$V_0 = 300$ kV

Synchronize to Cyclotron Frequency

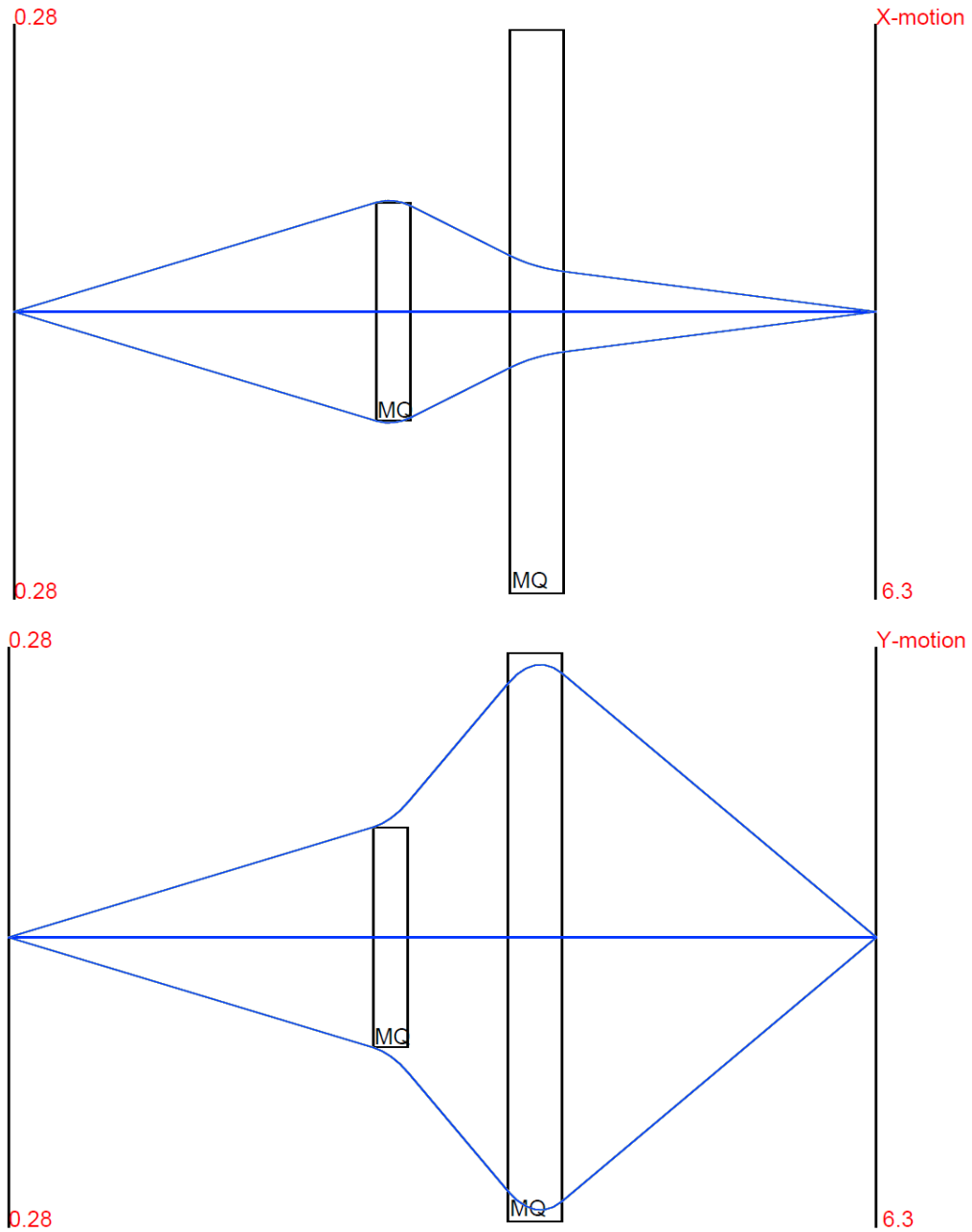
$f = \omega/2\pi = 17.6 - 18.5$ MHz

Bending power of RF def.



Maximum angle of Beam
(cor. ±3% mom.)

FE9 – S0：イオン光学　（１次）

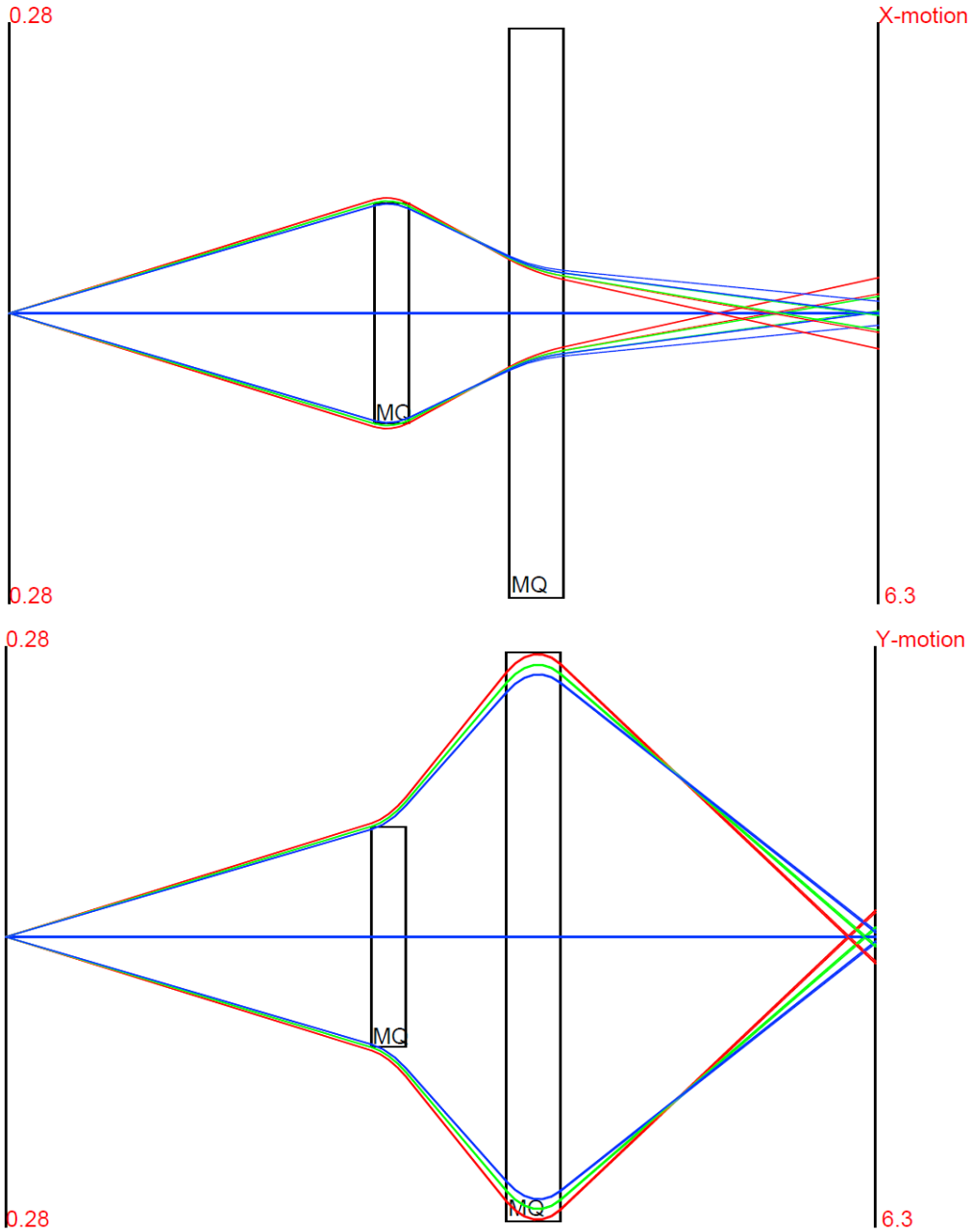


ΔA = ±20mrad

ΔB = ± 20mrad

ΔP/P = ± 3%

FE9 – S0：イオン光学　（3次）



ΔA = ±20mrad

ΔB = ± 20mrad

ΔP/P = ± 3%