ACCELERATION OF POLARIZED DEUTERON BEAMS WITH RIBF CYCLOTRONS

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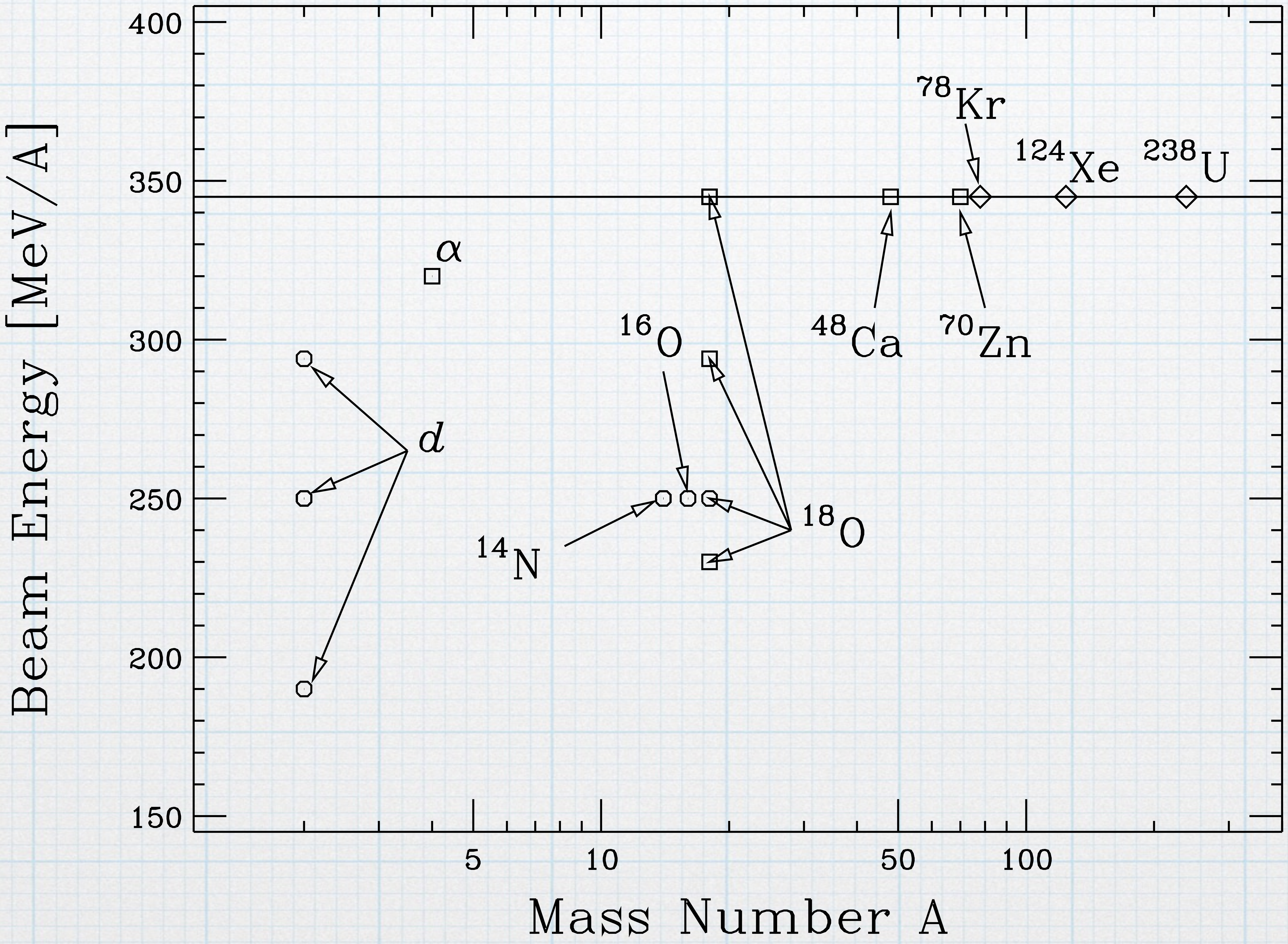
DELIVERED BEAMS AT RIBF



pol-d:300 MeV/u, 250 MeV/u, 190 MeV/u

OVERVIEW

1. INTRODUCTION

2. POLARIZED ION SOURCE AND CYCLOTRONS

3. BEAM TUNING *-SINGLE-TURN OPERATION-*

SUMMARY

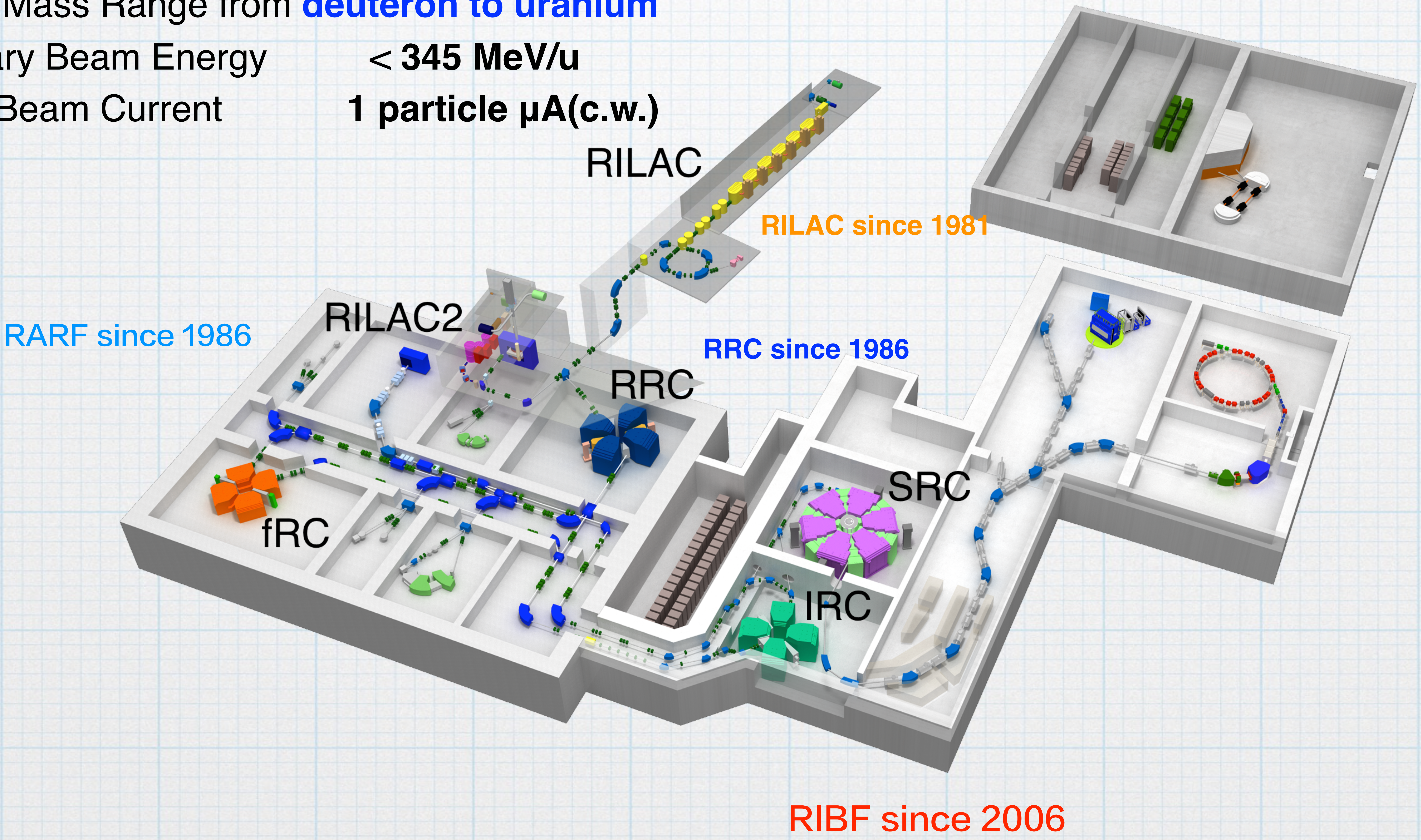
RIKEN RI-BEAM FACTORY

Mission : Expand the availability of **heavier RIB**

Beams: Wide Mass Range from **deuteron to uranium**

Primary Beam Energy < **345 MeV/u**

High Beam Current **1 particle μA(c.w.)**



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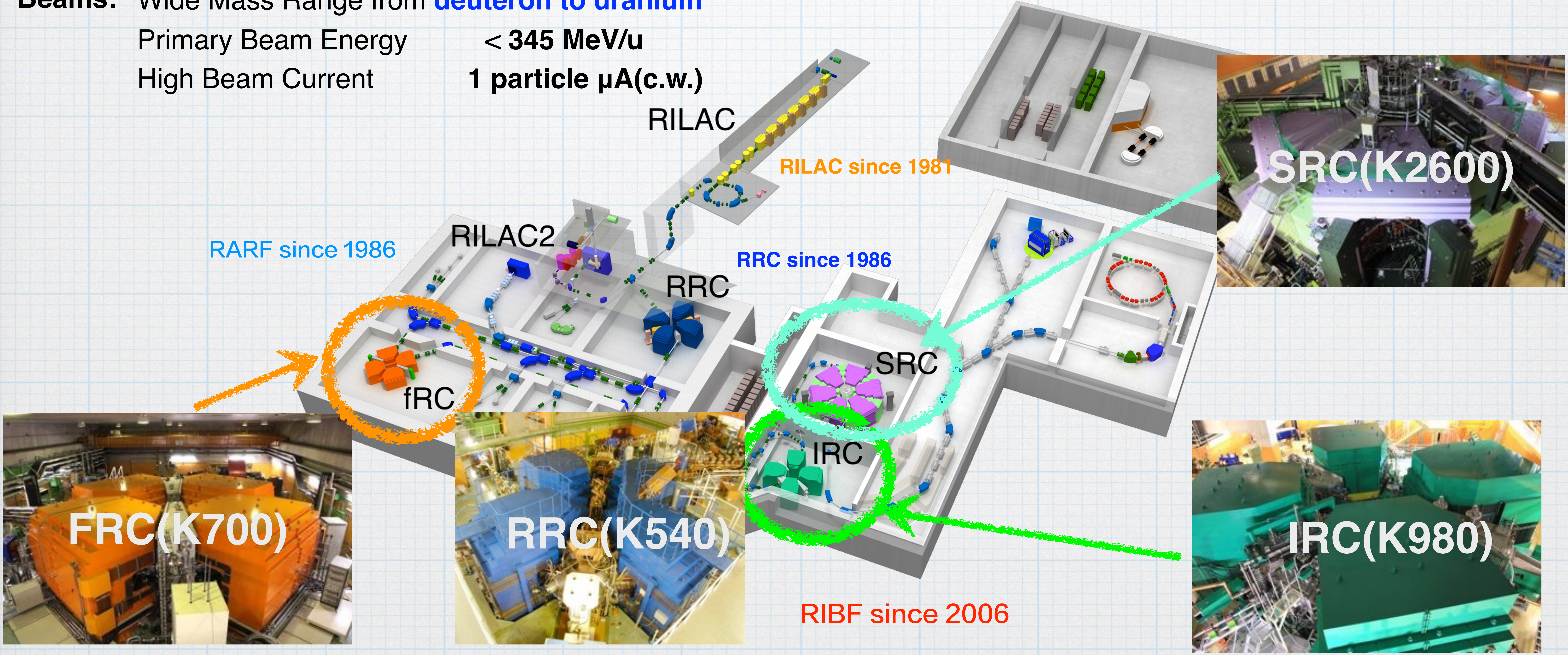

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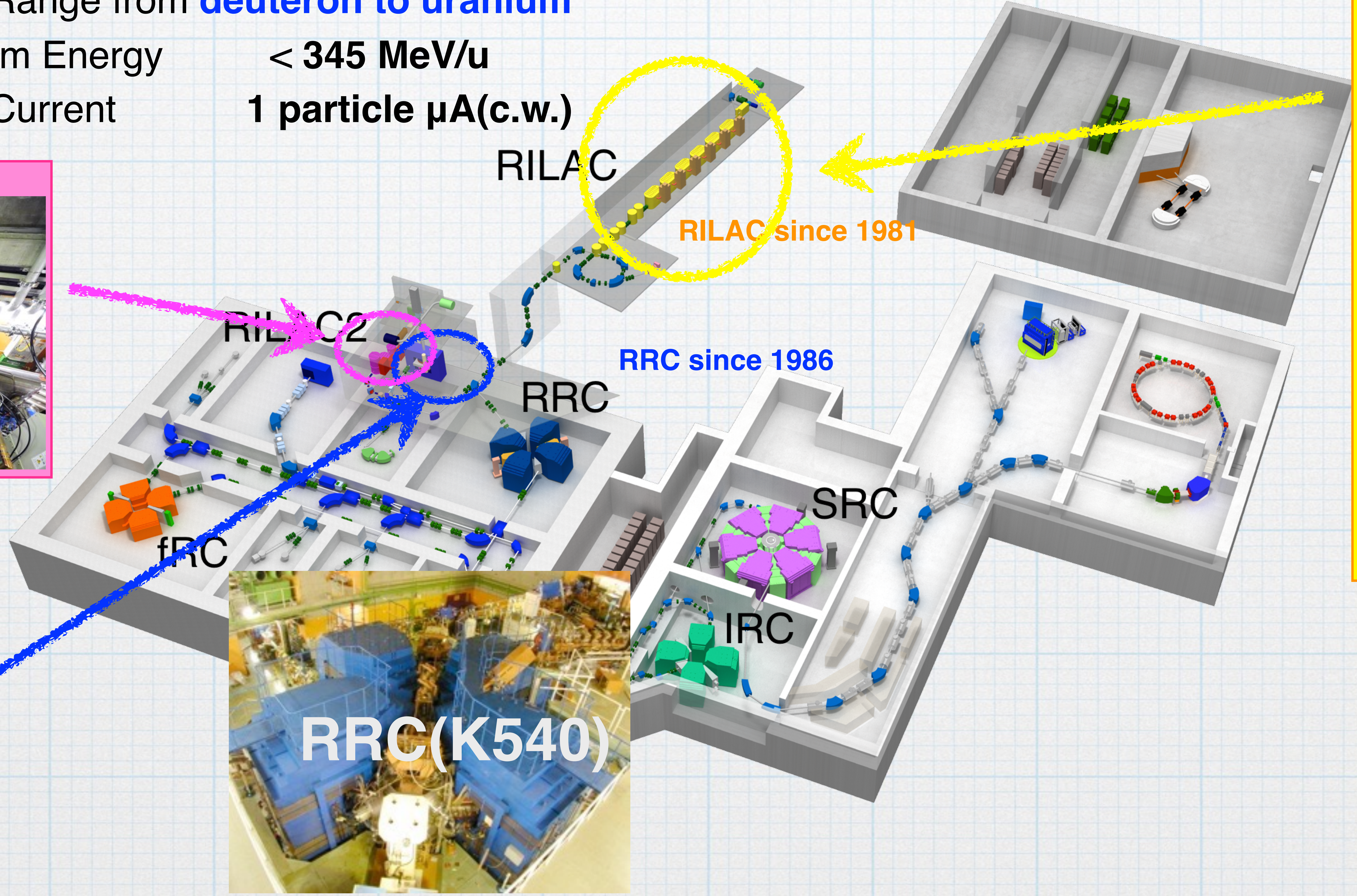


RIKEN RI-BEAM FACTORY

Mission : Expand the availability of **heavier RIB**

Beams: ^{18}O 230, 250,294,345 MeV/u

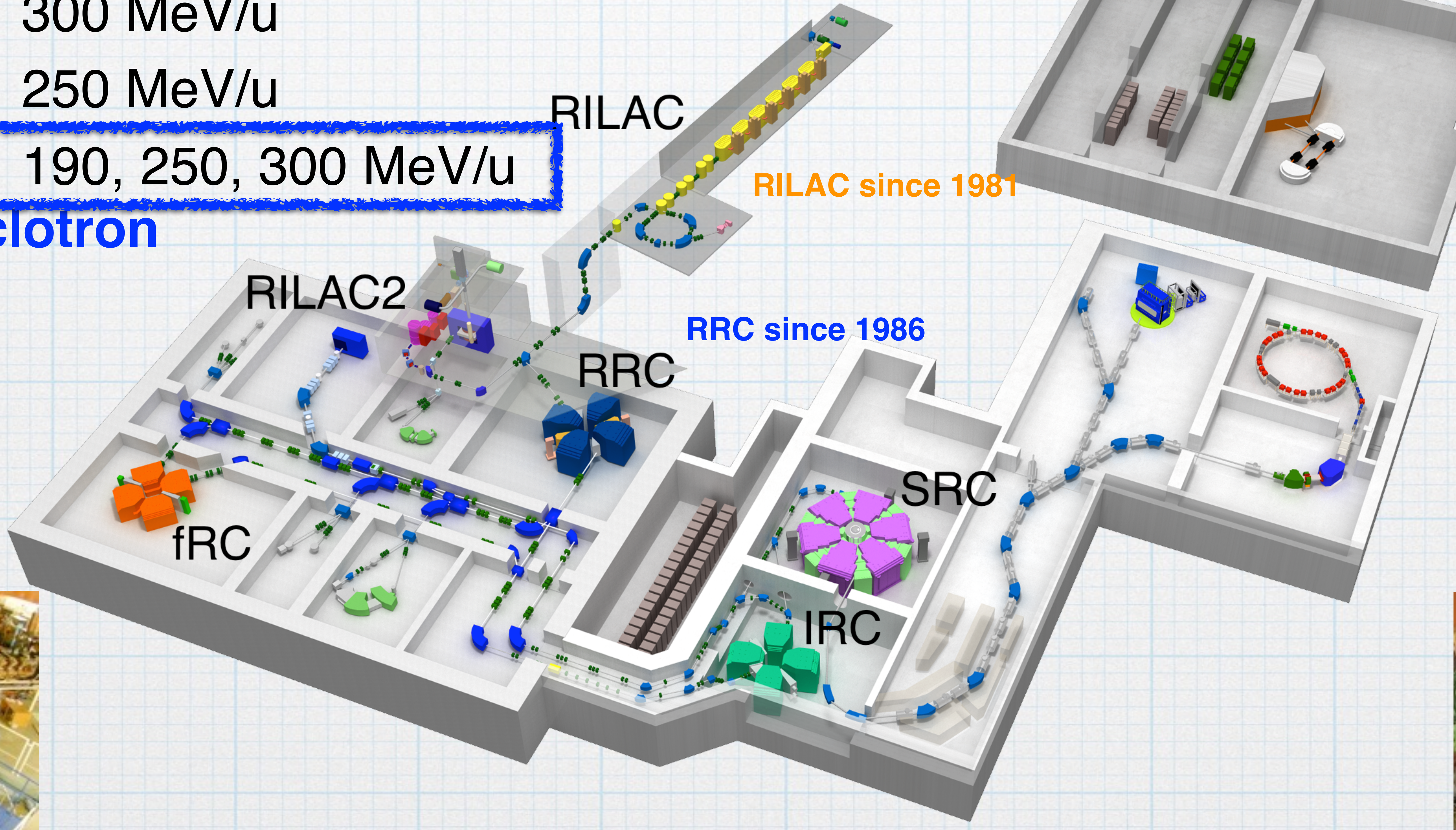
^{16}O 300 MeV/u

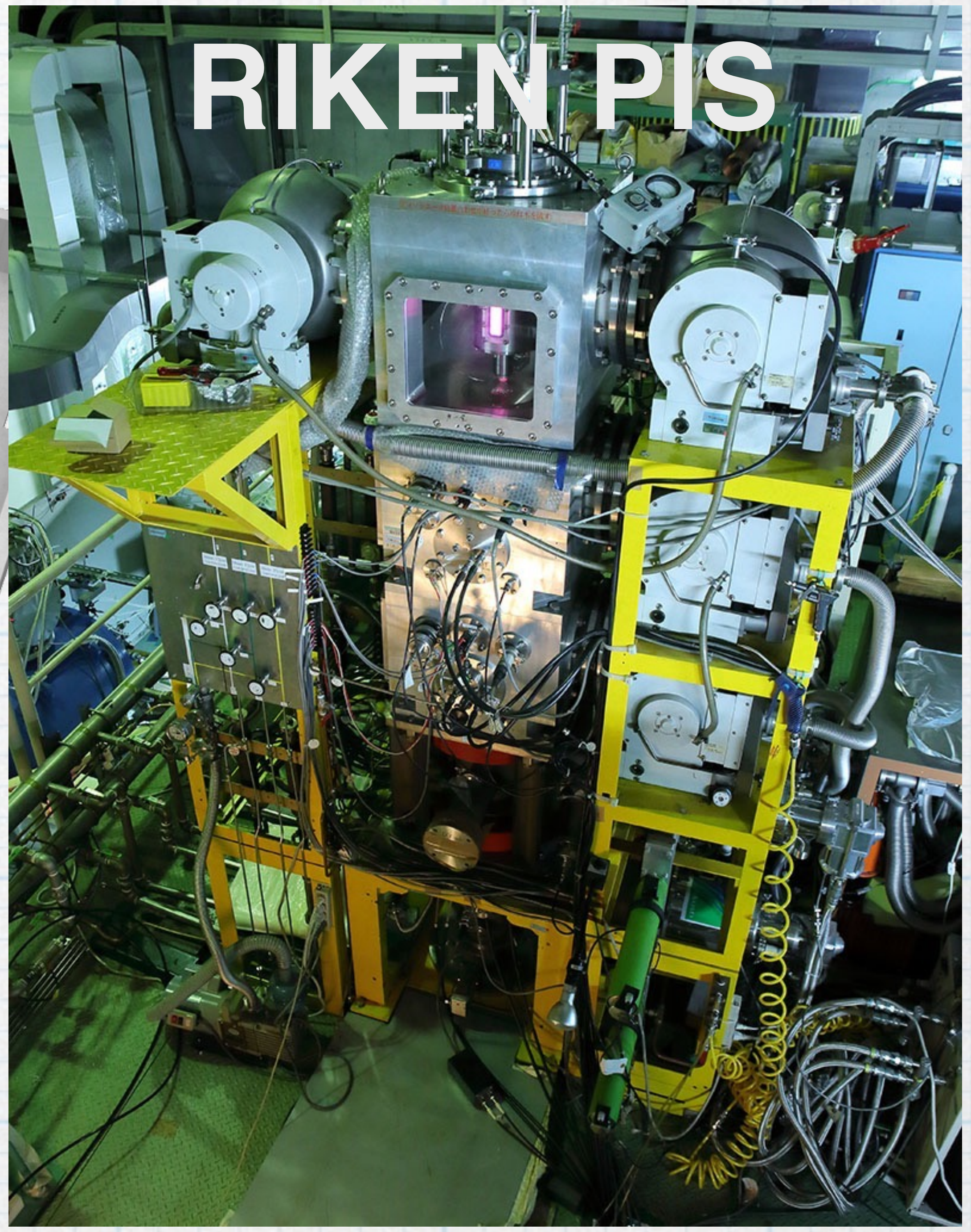
^{14}N, ^{12}C 250 MeV/u

$\boxed{d \quad 190,\ 250,\ 300\ \text{MeV/u}}$

Injector: AVF Cyclotron

AVF (K70) d, α, C, N, O, C, Ar





Physics experiments requiring high precision with polarized deuteron beams have been performed.

Deuteron-Proton Scattering at RIKEN RIBF (Sekiguchi et al.)

Good probe to study the dynamical aspects of 3NFs.

- Direct Comparison between Theory and Experiment
- Extract information of 3NFs

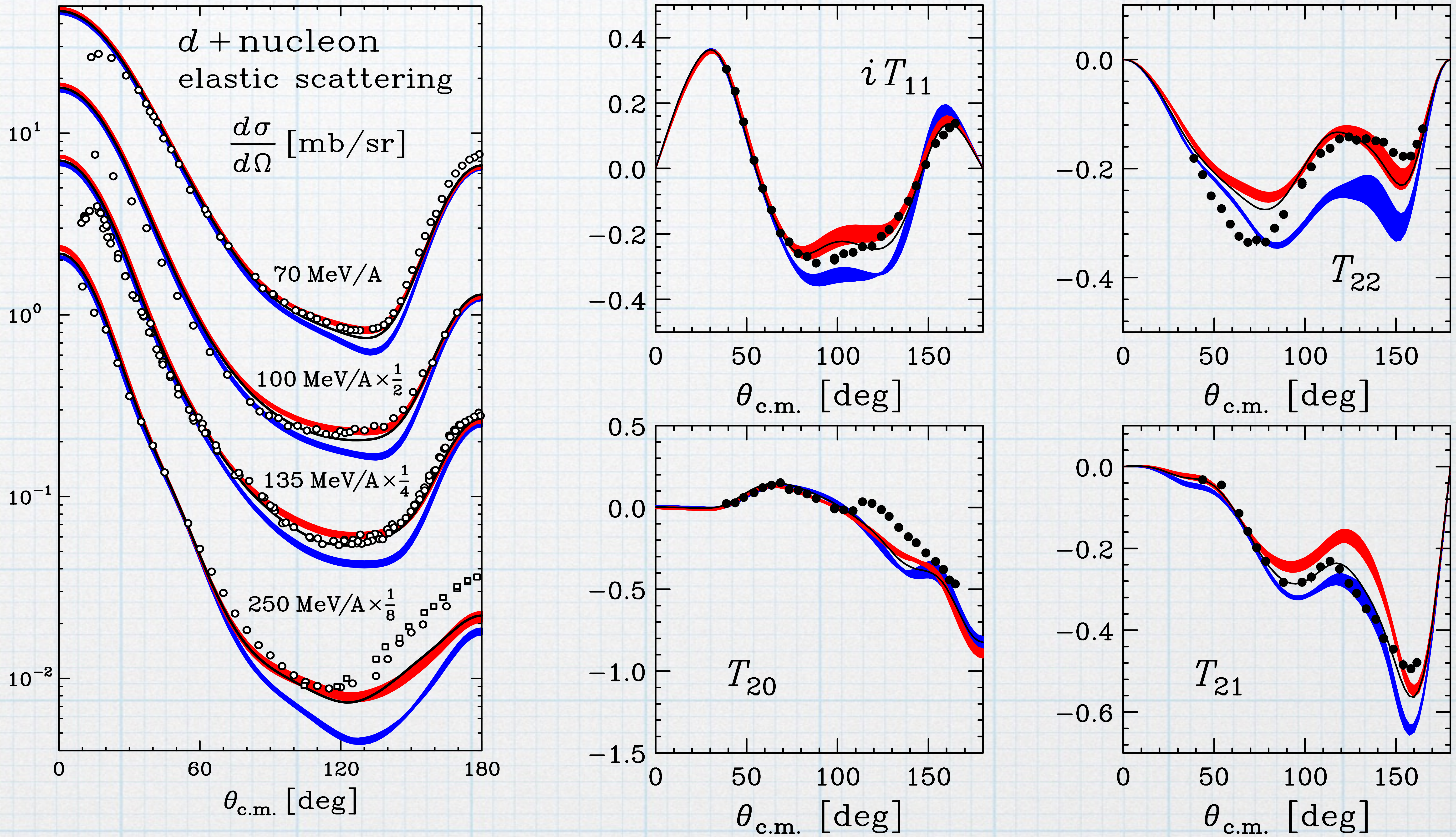
✓ Momentum & Spin dependence
✓ Iso-spin dependence : only T=1/2

Cross Section and Spin Observables

$$\frac{d\sigma}{d\Omega}, iT_{11}, T_{20}, T_{22}, T_{21}$$

NN (CDBonn, AV18, Nijm I,II)
TM'(99) 3NF + NN(CD Bonn, AV18, Nijm I,II)
Urbana IX 3NF+AV18

dp @ 190 MeV/nucleon



Spin observables of *dp* elastic scattering have measured at RIBF with deuteron energies of 190, 250, 300 MeV/u

Deuteron-Proton Scattering at RIKEN RIBF (Sekiguchi et al.)

a good probe to study the dynamical aspects of 3NFs.

To obtain the spin observables deuteron spin on the target is required to be directed to vertical, horizontal, longitudinal directions and some azimuthal angles in horizontal plane.

✓ Iso-spin dependence : only T=1/2

Cross Section and Spin Observables

$$\frac{d\sigma}{d\Omega}, iT_{11}, T_{20}, T_{22}, T_{21}$$

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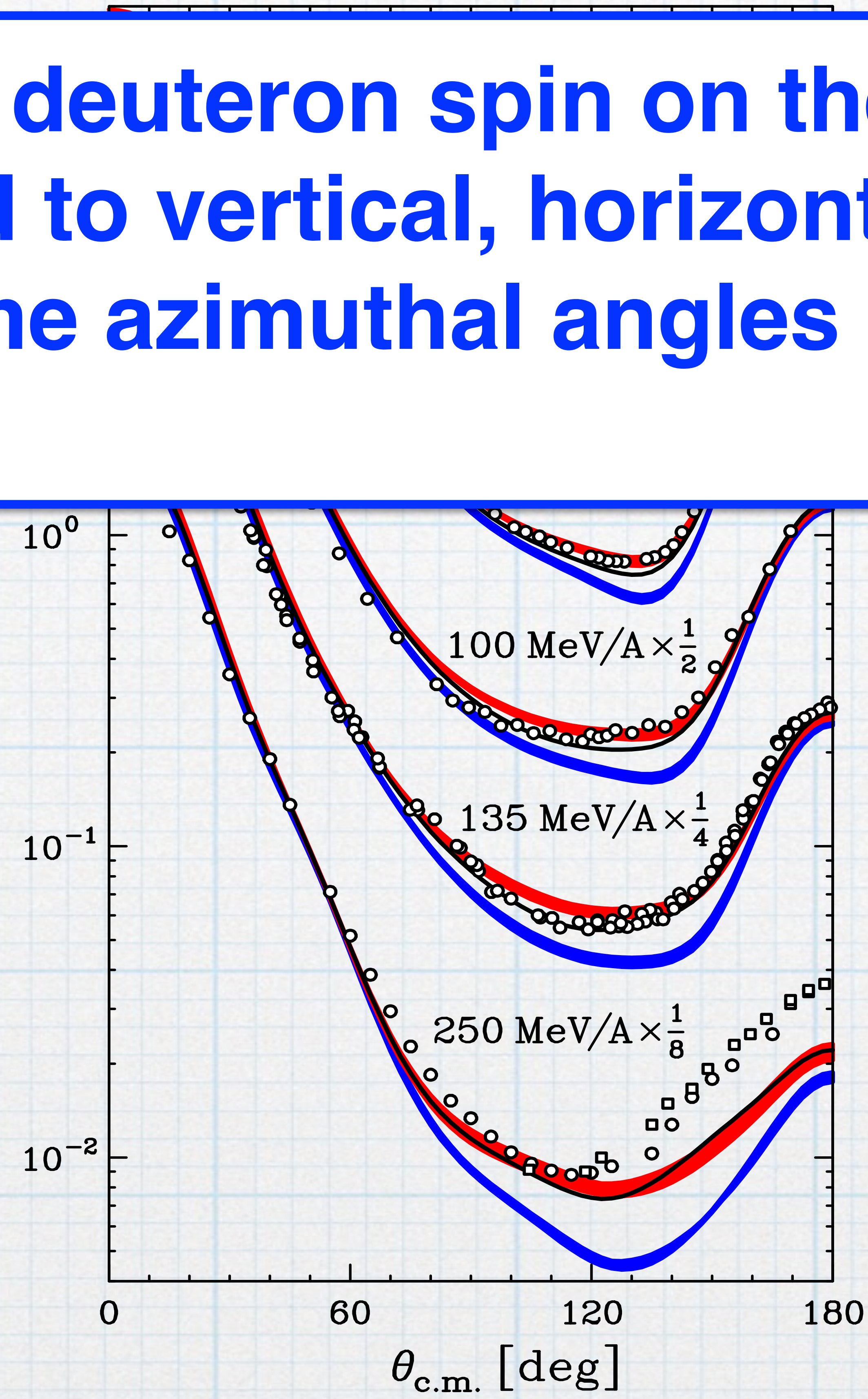
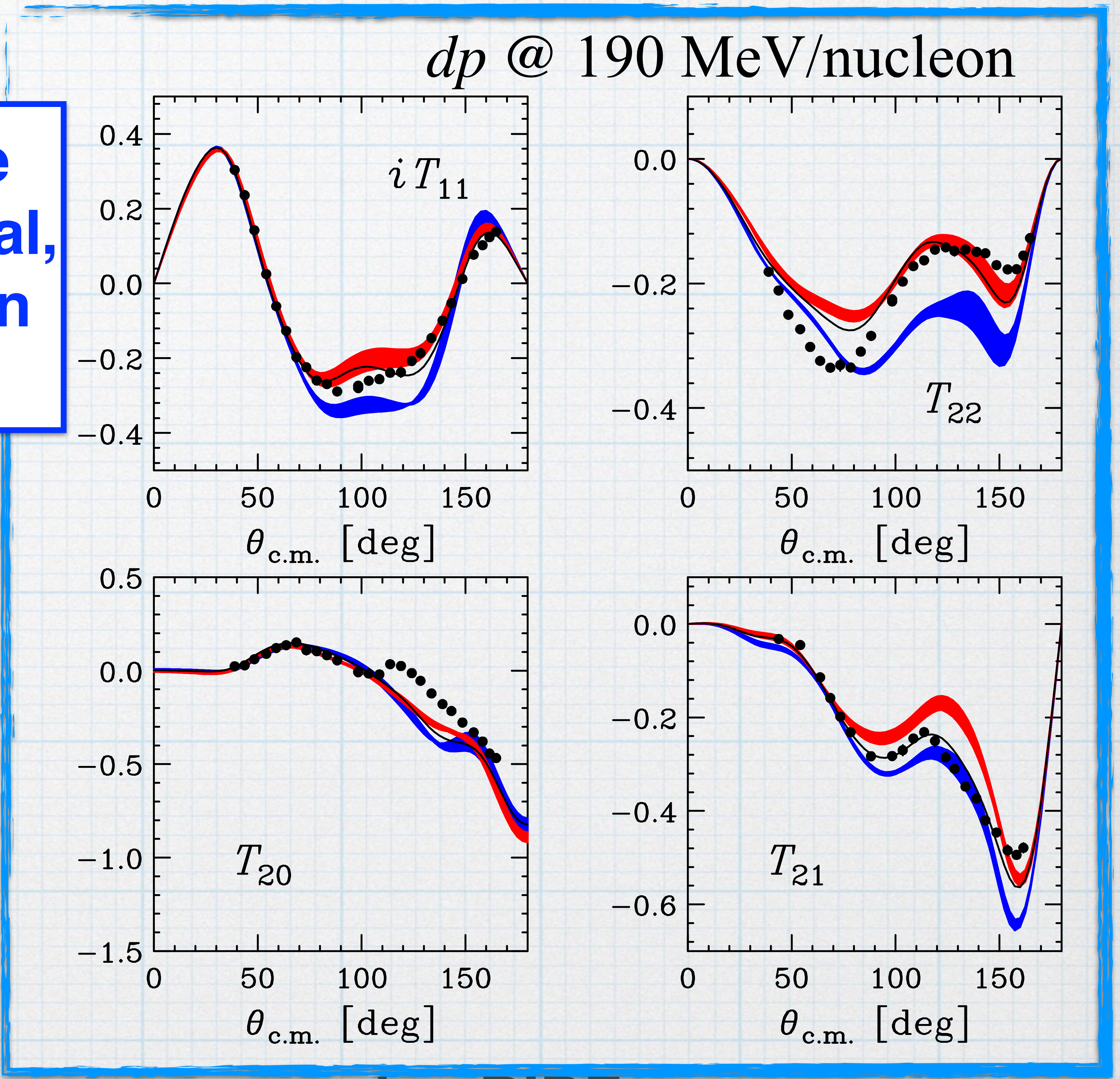




Spin observables of *dp* elastic scattering have measured at RIBF with deuteron energies of 190, 250, 300 MeV/u

ACCELERATOR SETUP

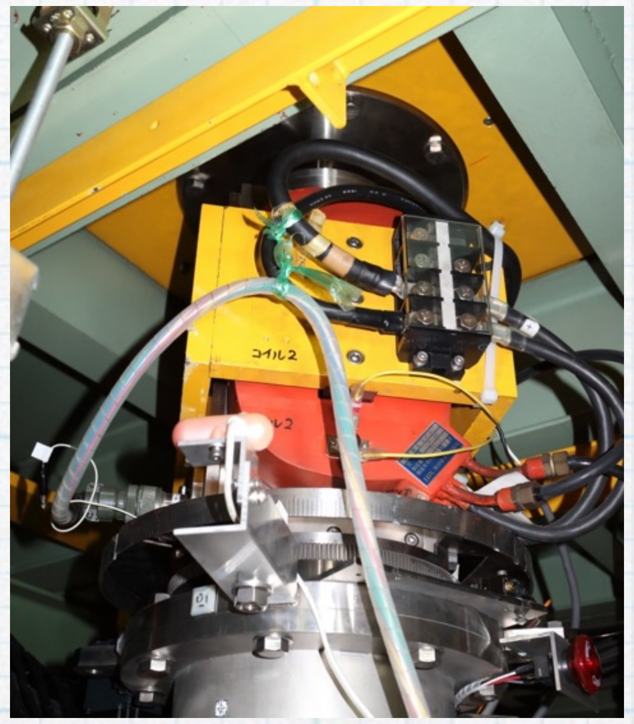
Polarized Deuteron Source

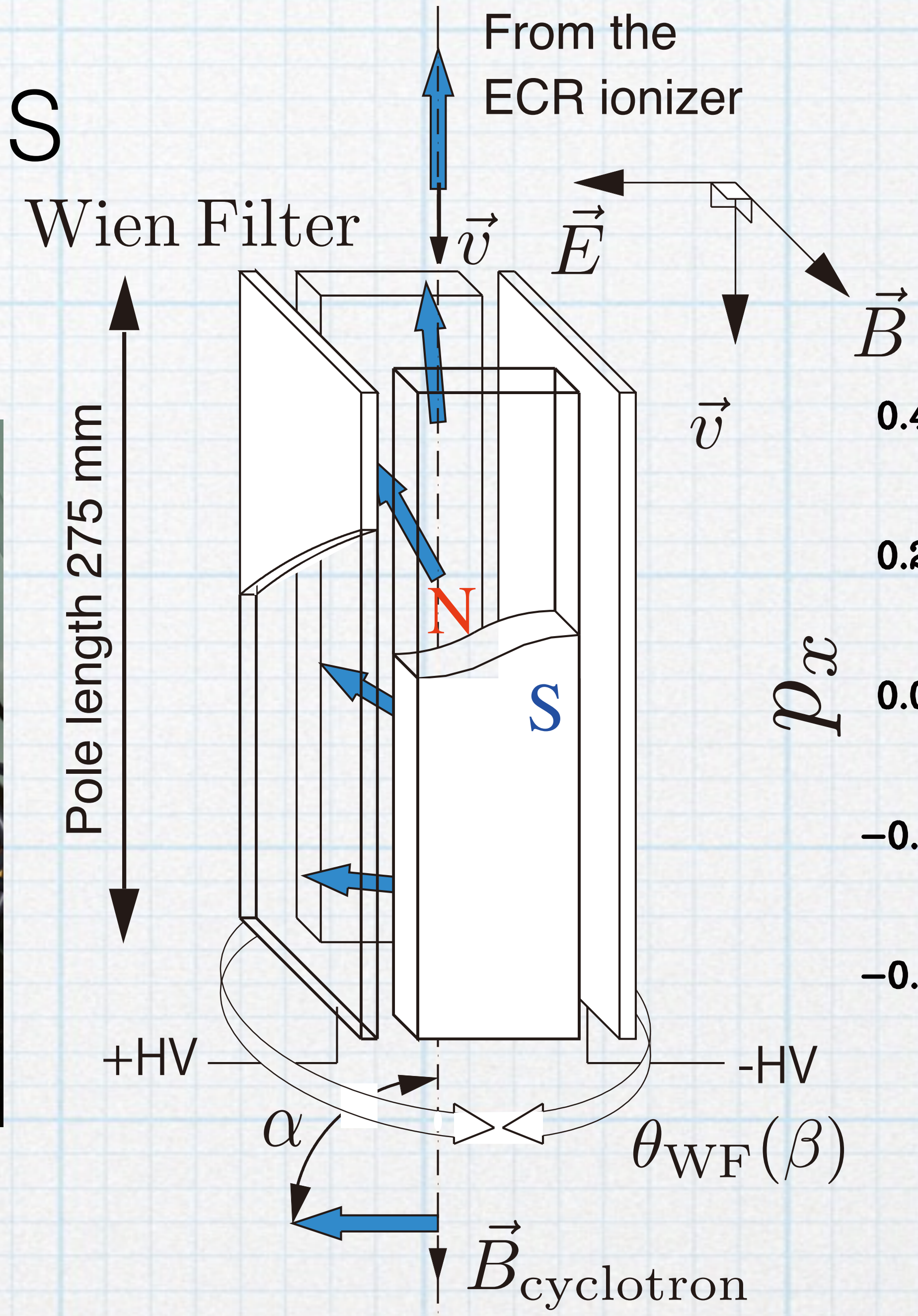
- Vector and tensor polarized deuteron beams provided by RIKEN PIS
- Spin rotation by a Wien filter prior to acceleration

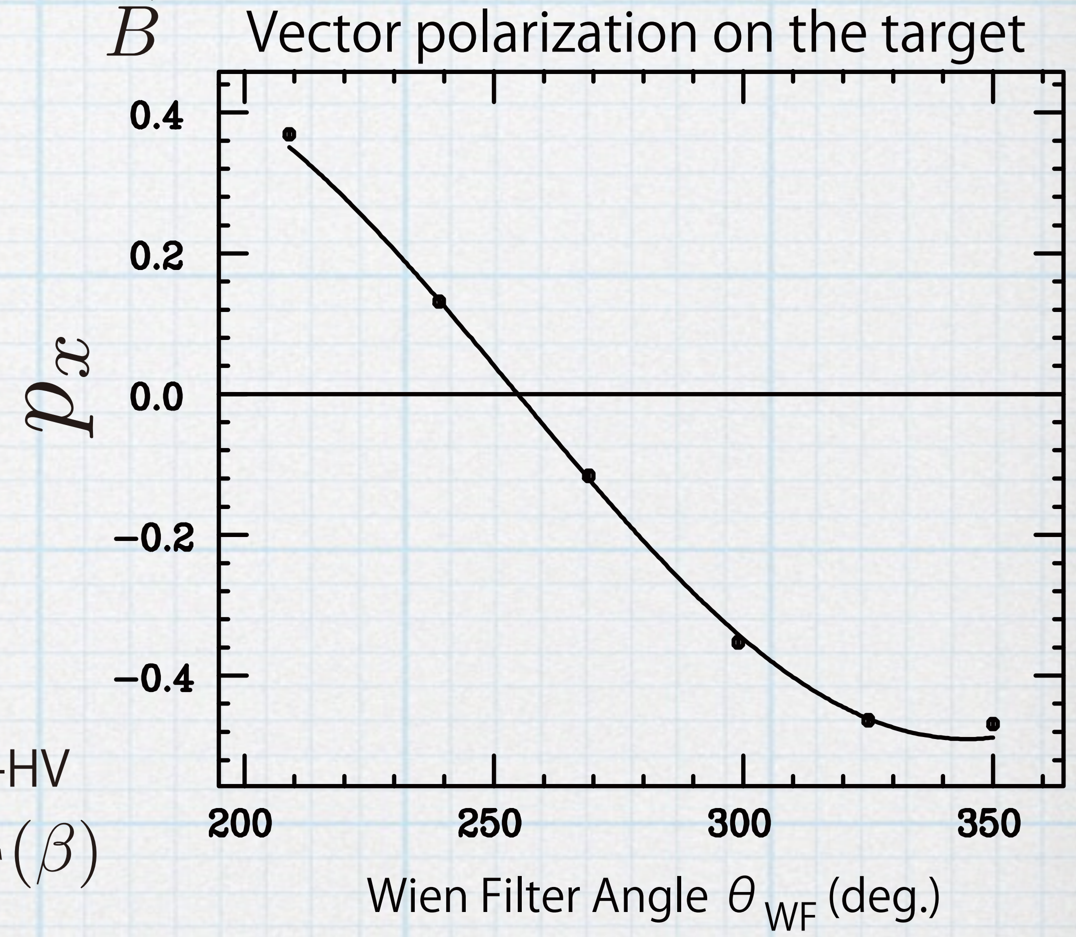
  →**The size of the magnet for spin rotation is very compact.**

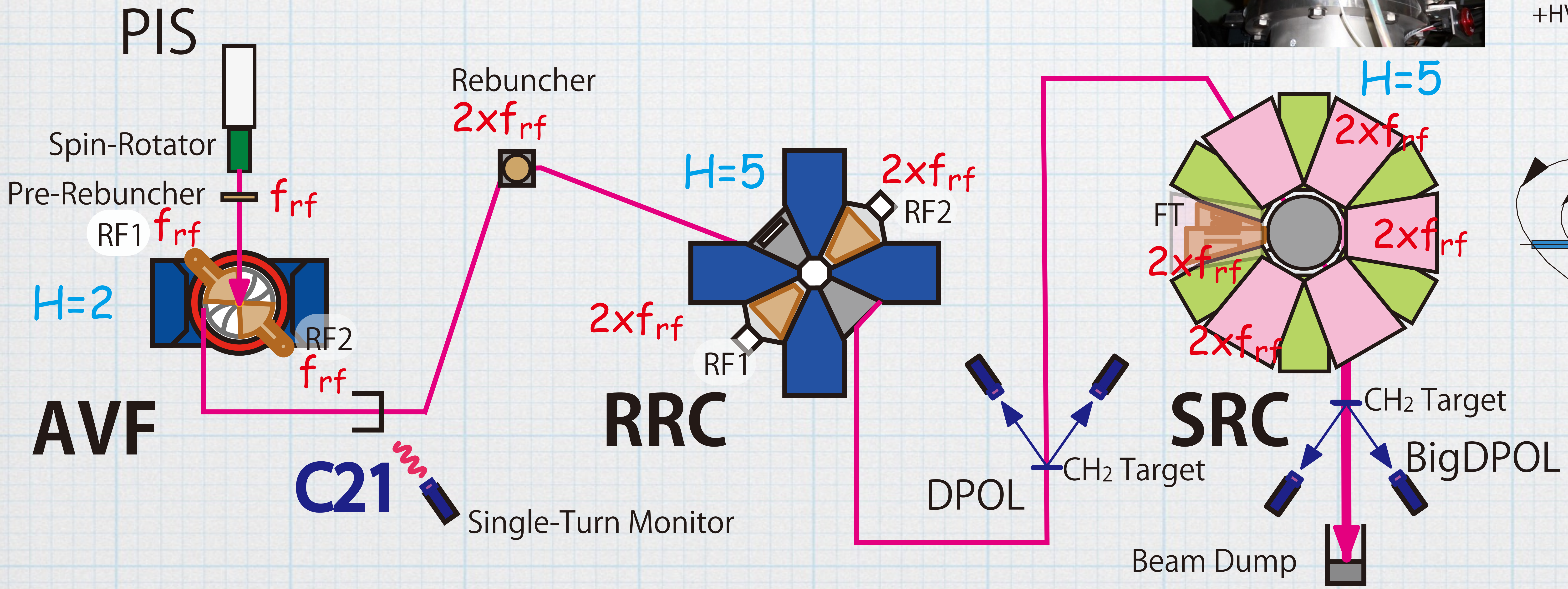
Accelerators and a spin-rotator

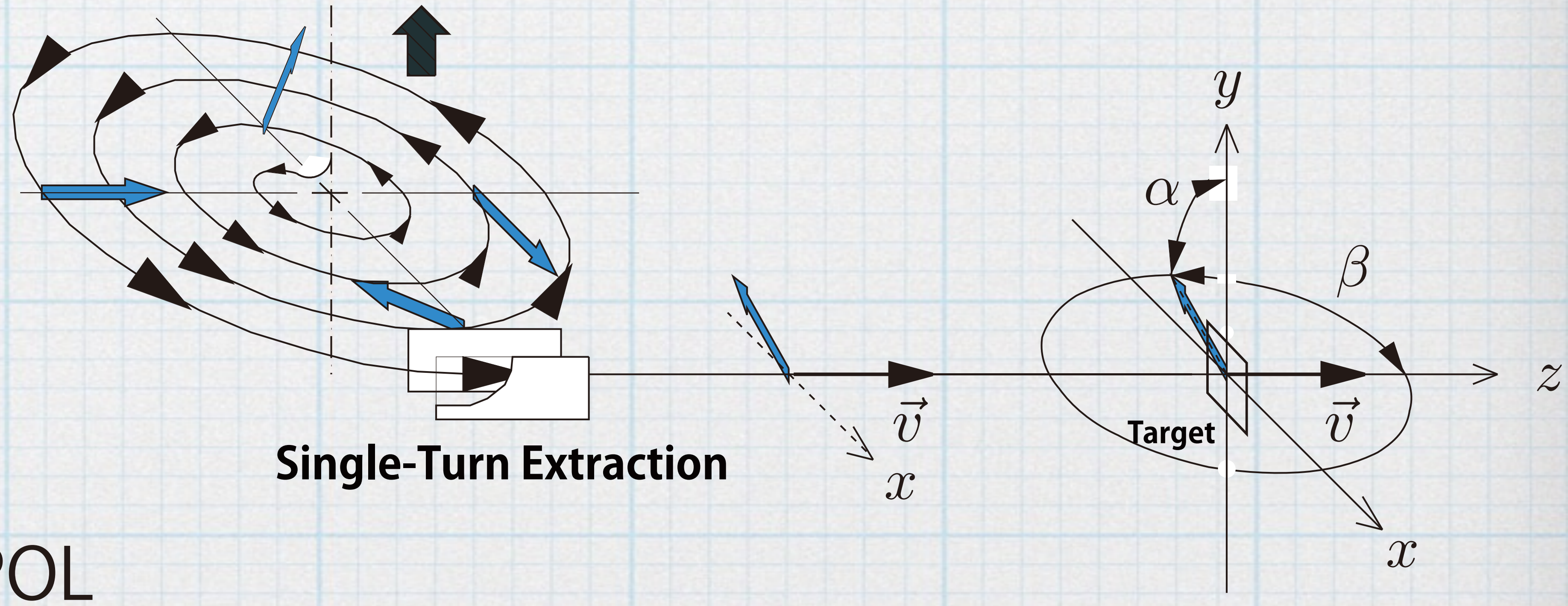
- Cyclotron cascade of **AVF**, **RRC** and **SRC**











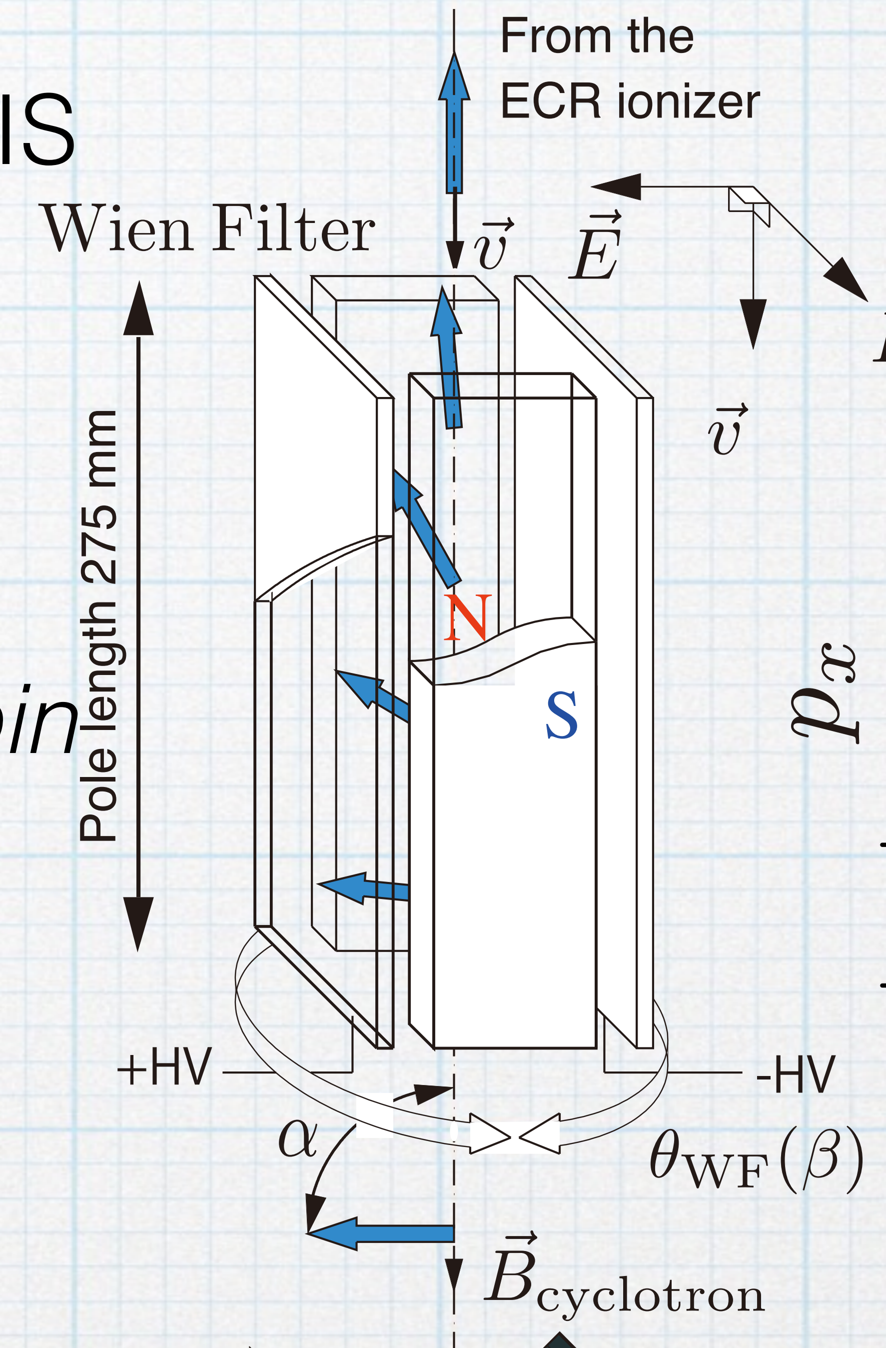
Setup of accelerators and monitors

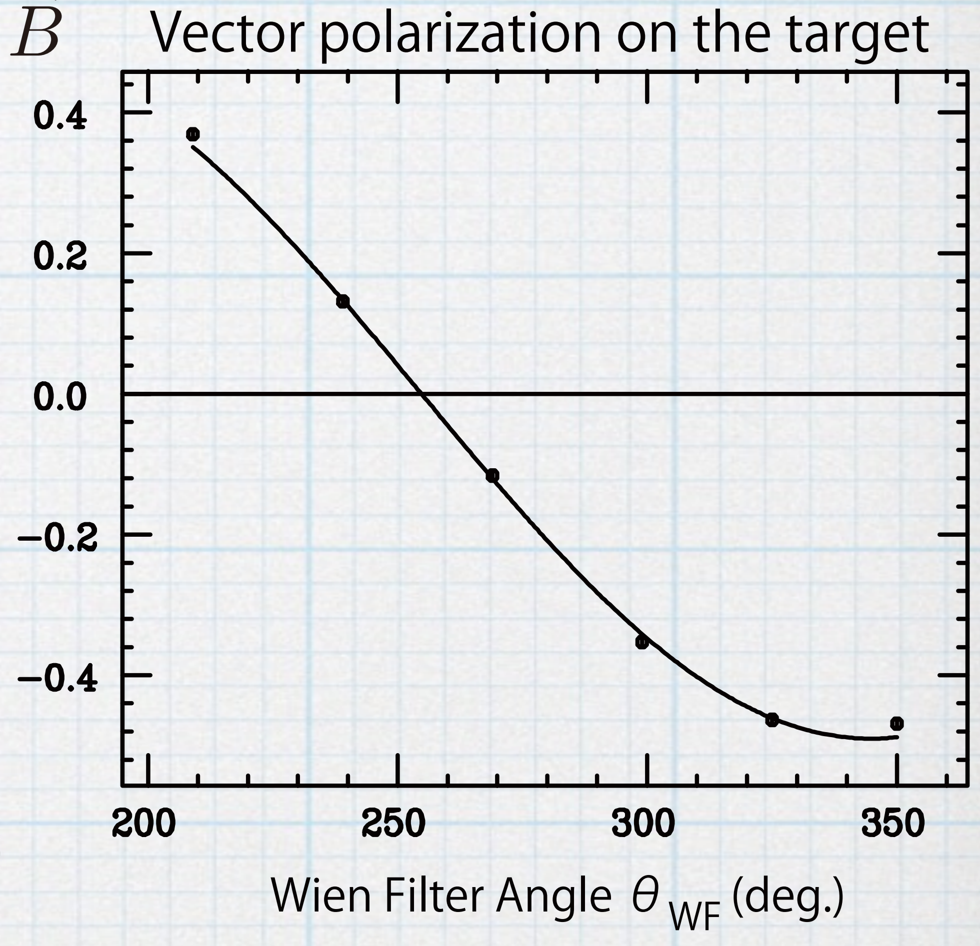
Polarized Deuteron Source

- Vector and tensor polarized deuteron beams provided by RIKEN PIS
- Spin rotation by a Wien filter prior to acceleration
  →**The size of the magnet for spin rotation is very compact.**

Accelerators and a spin-rotator

- Cyclotron cascade of **AVF**, **RRC** and **SRC**
- *The cyclotron magnetic field causes precession of the deuteron spin resulting in a deviation between its spin orientation and the beam propagation direction.*





Strict single-turn extraction for each cyclotron is required. Requested turn purity is >99%.

RIKEN POLARIZED ION SOURCE

The RIKEN atomic-beam-type polarized ion source (PIS) is a copy of one developed at TUNL*, modified at IUCF.**

*T.B.Clegg,AIPConf.Proc.187(1989)p1227. **V .P. Derenchuk et al., AIP Conf. Proc. 343(1995)p72.

1. Dissociation

D2 gas is dissociated, cooled by cold nozzle and formed into atomic beam.

2.Selection of electron spin

Electron spin of deuterium atoms is selected by

3. RF Transition

RF transition apparatus flips the deuteron spins using Stern-Gerlach separation magnets.

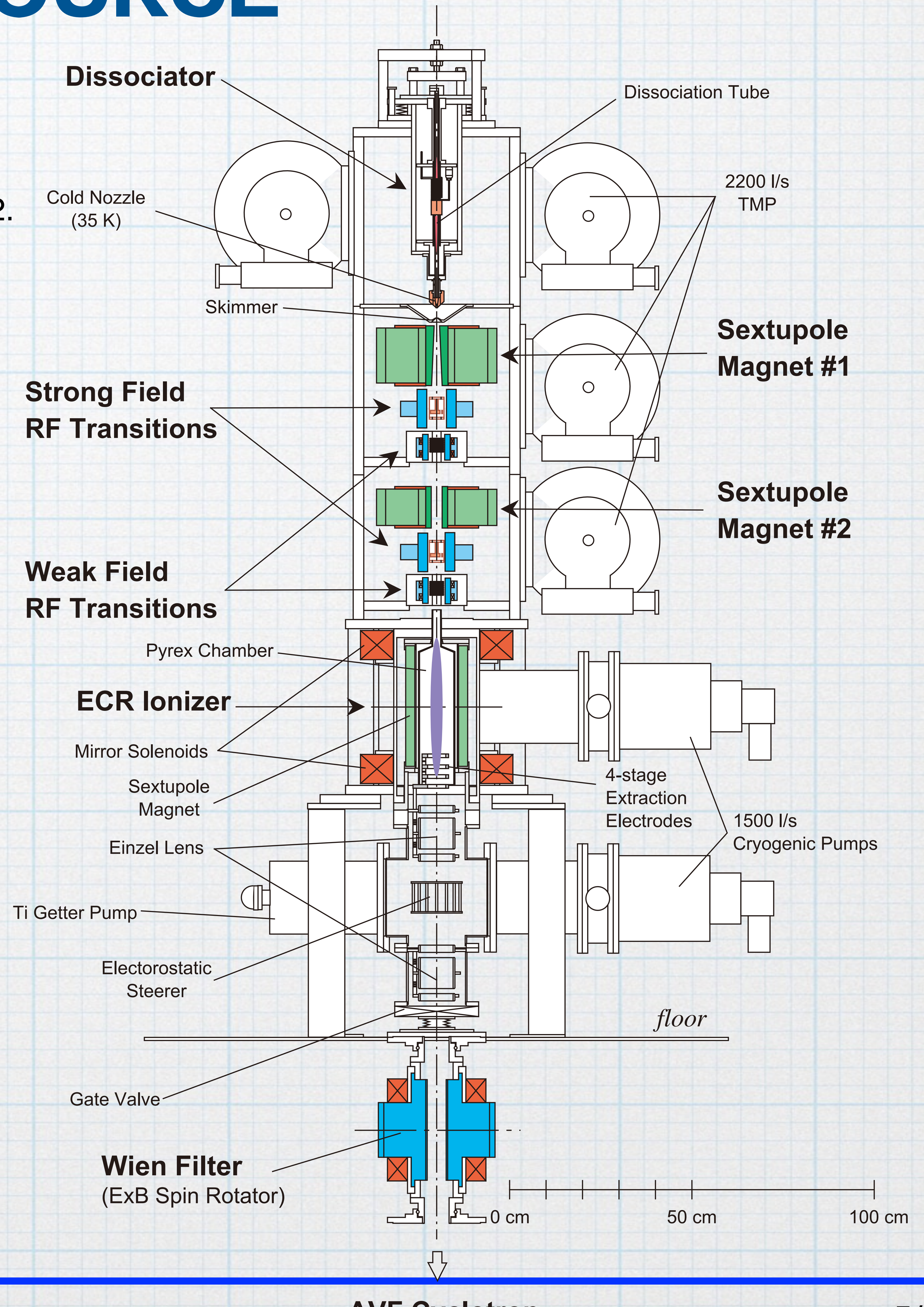
4. Ionization

Spin-selected deuterium atoms are ionized by the 2.45 GHz ECR ionizer.

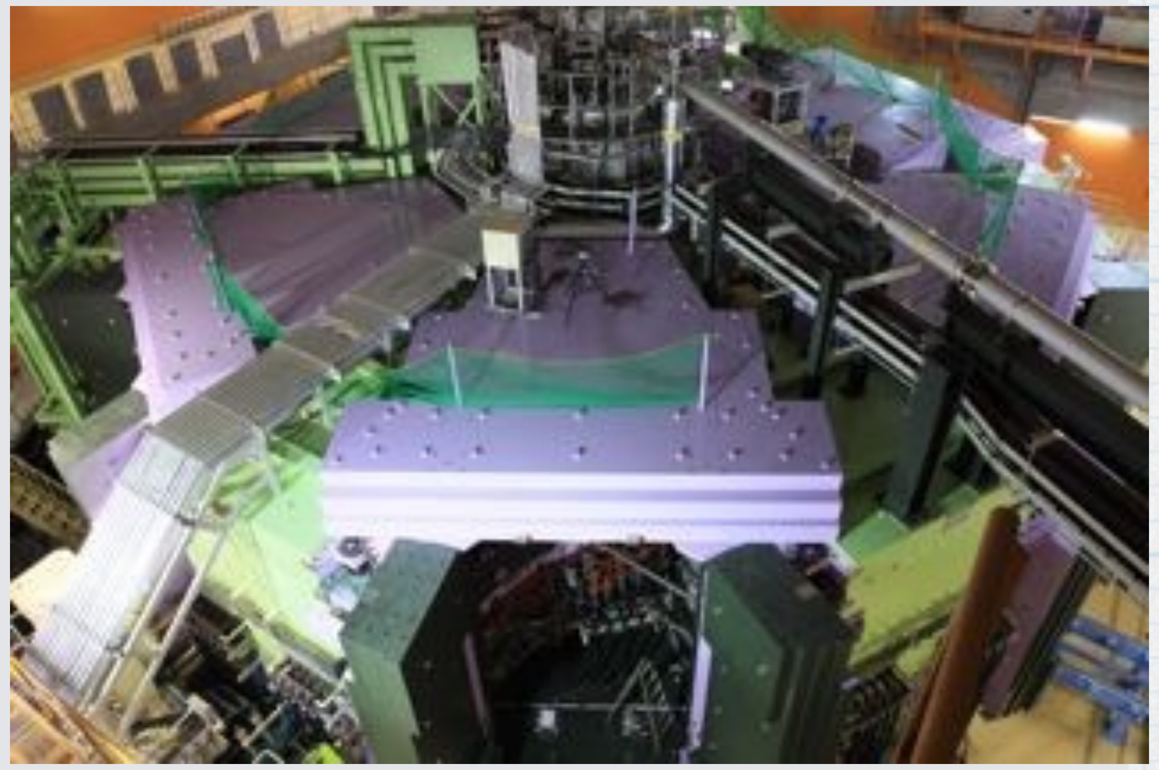
Beam intensity 30 μA (< 100 μA), Polarization 80%

5. Spin-rotation

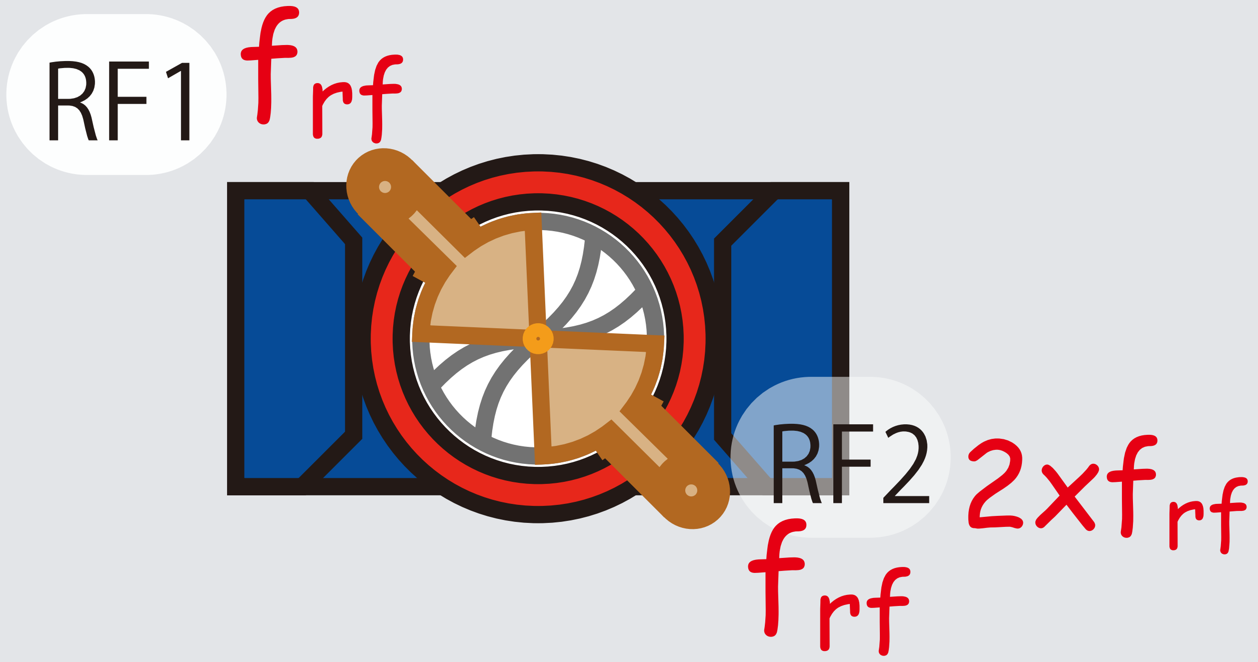
The orientation of the deuteron spin can be tilted and rotated to any direction by **Wien filter.**

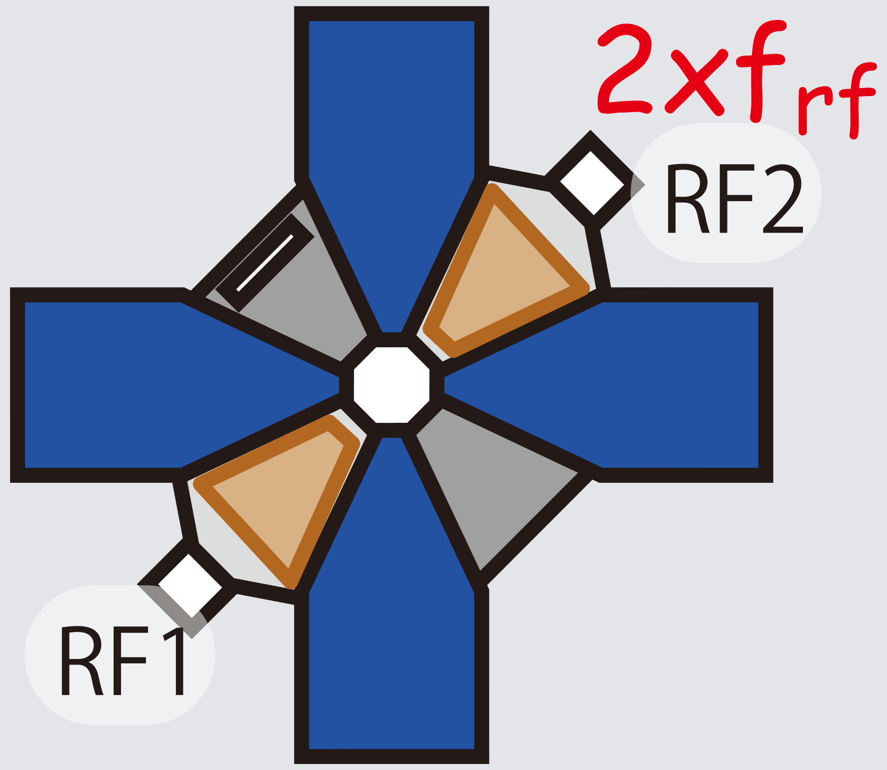


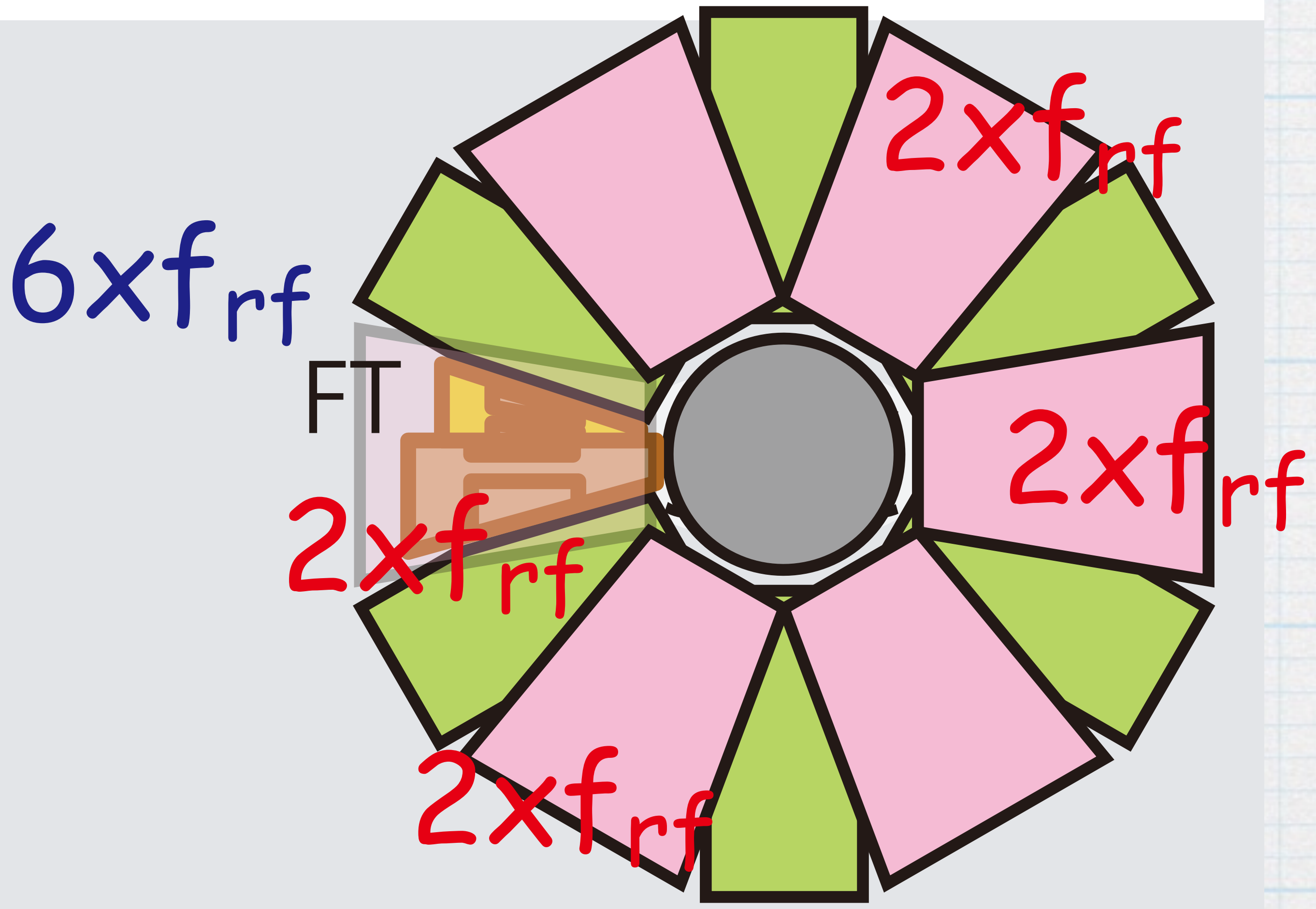
SPECIFICATION OF MAGNETS OF CYCLOTRONS

	AVF	**RRC**	**SRC**
			
K-number(MeV)	70	540	2600
Number of Sectors	4(spiral)	4	6
Sector Angle	50 deg.	50 deg.	25 deg.
Maximum Magnetic Field	1.7 T	1.55 T	3.8 T
Rinj/Rext	Inflector/0.712	0.89/**3.56**	**3.56**/5.36

SPECIFICATION OF RF SYSTEM OF CYCLOTRONS







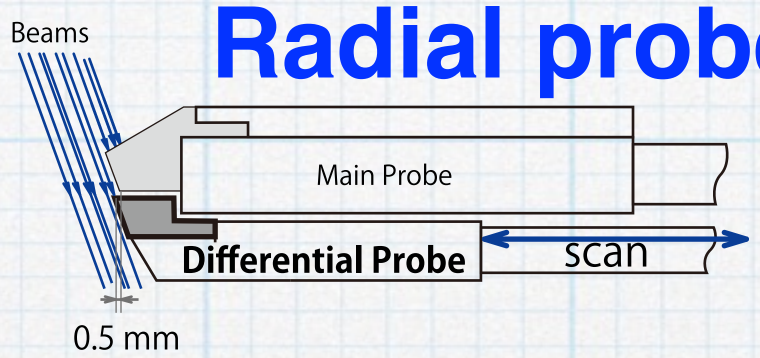
	AVF	RRC	SRC
RF Resonators	2 (Double gap)	2 (Double gap)	4+**FT** (Single gap)
Dee Angle	85	23.5	-
Frequency	12-24 MHz	18-40 MHz	18-38.2 MHz
Harmonic Number	**2**	**5**	**5**
Operation Frequency	**f_{rf}**	**$2xf_{rf}$**	**$2xf_{rf}$**

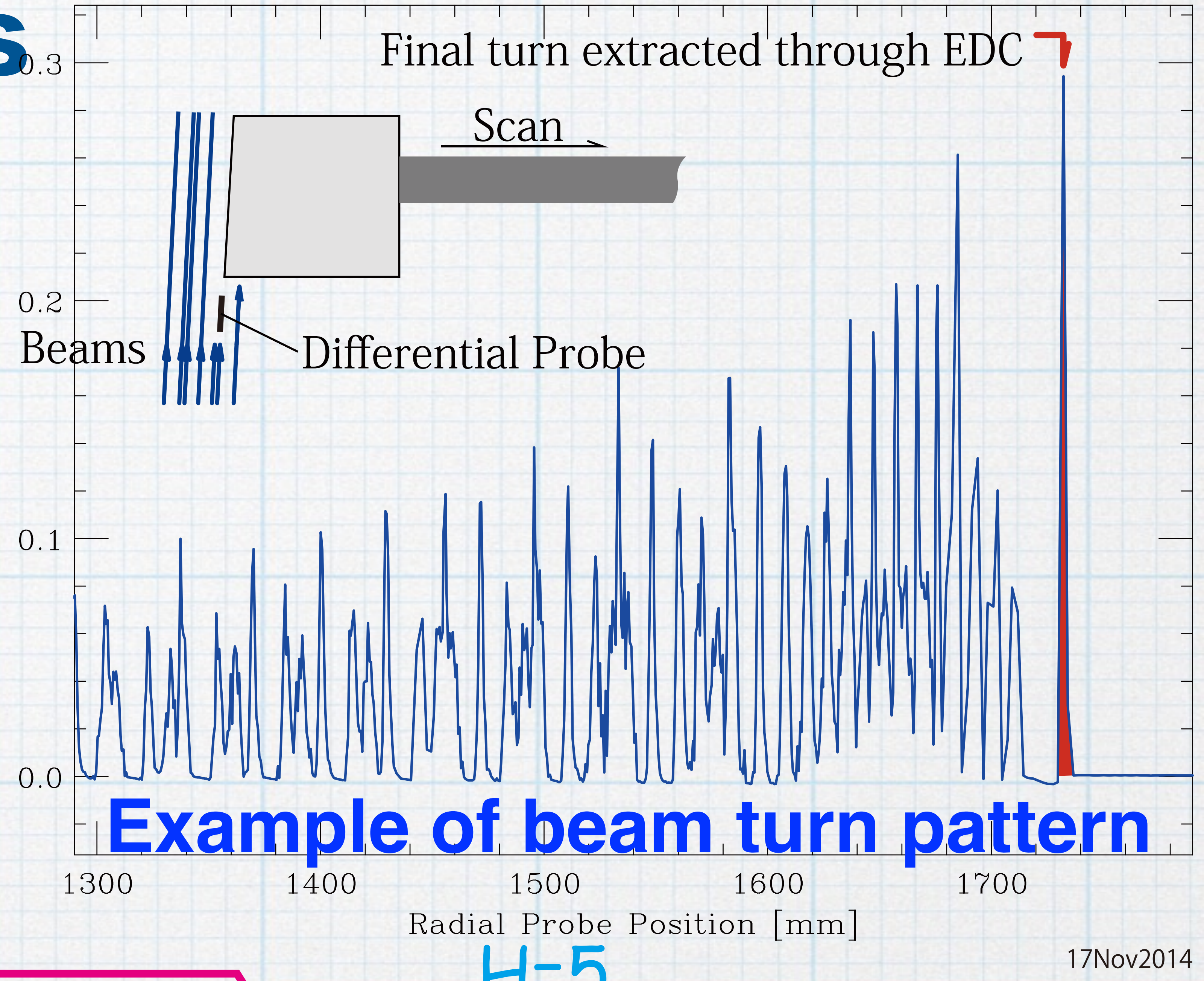
Tuning of Cyclotrons

AVF⇄RRC⇄SRC

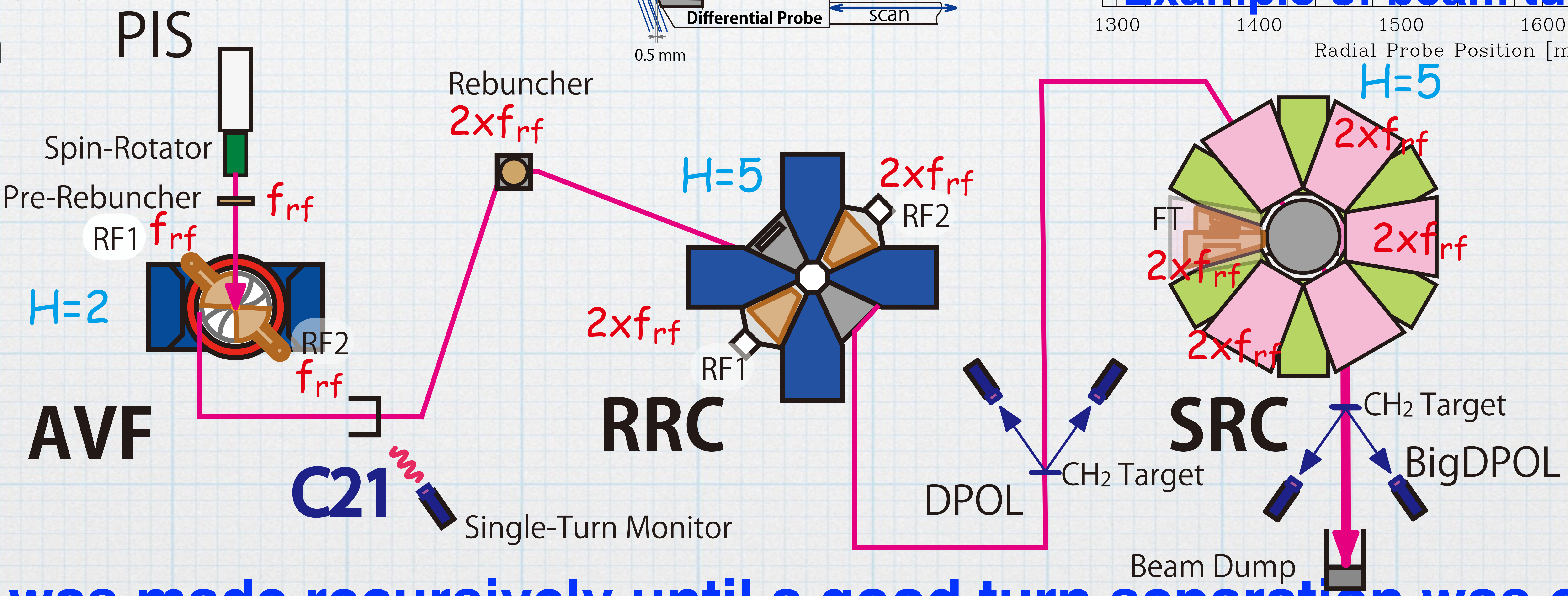
1. **Injection** (Main radial probe)
2. Tuning of **isochronous field** (Phase probe)
   Tuning of RF voltage and phase
   (Differentia radial probe)
3. Centering acceleration
4. **Betatron oscillation** control
5. Extraction

Radial probe



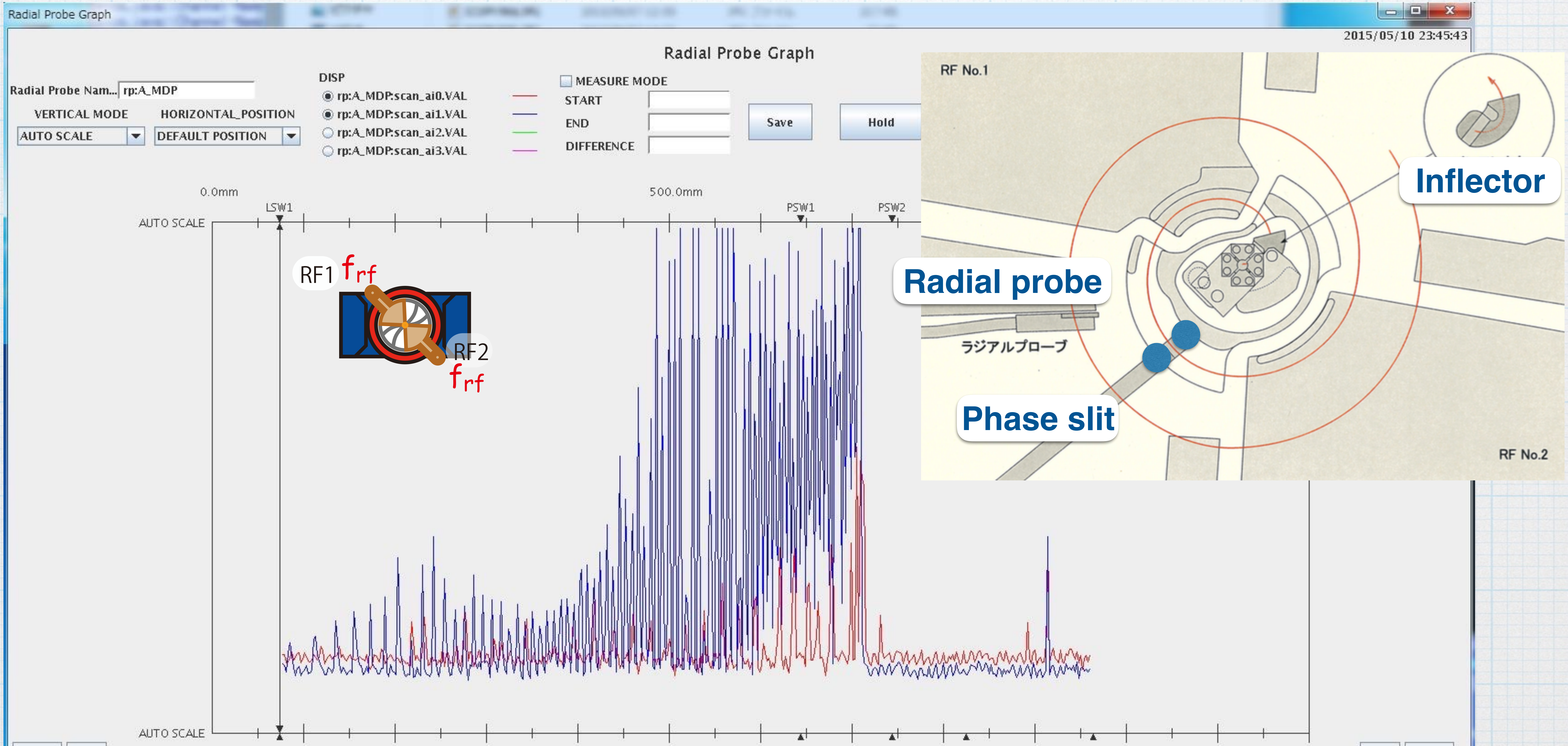


Example of beam turn pattern



Elaborate tuning was made recursively until a good turn separation was obtained.

Tuning (AVF)



Phase slit cuts the longitudinal emittance at the injection.

Tuning (RRC)

It is unclear the turn separation at the extraction region is enough or not.

Tuning (SRC)

Deflected beam

4 acceleration cavity

4 acceleration cavity**+FT**

Effect of the flattop acceleration was beautifully demonstrated.

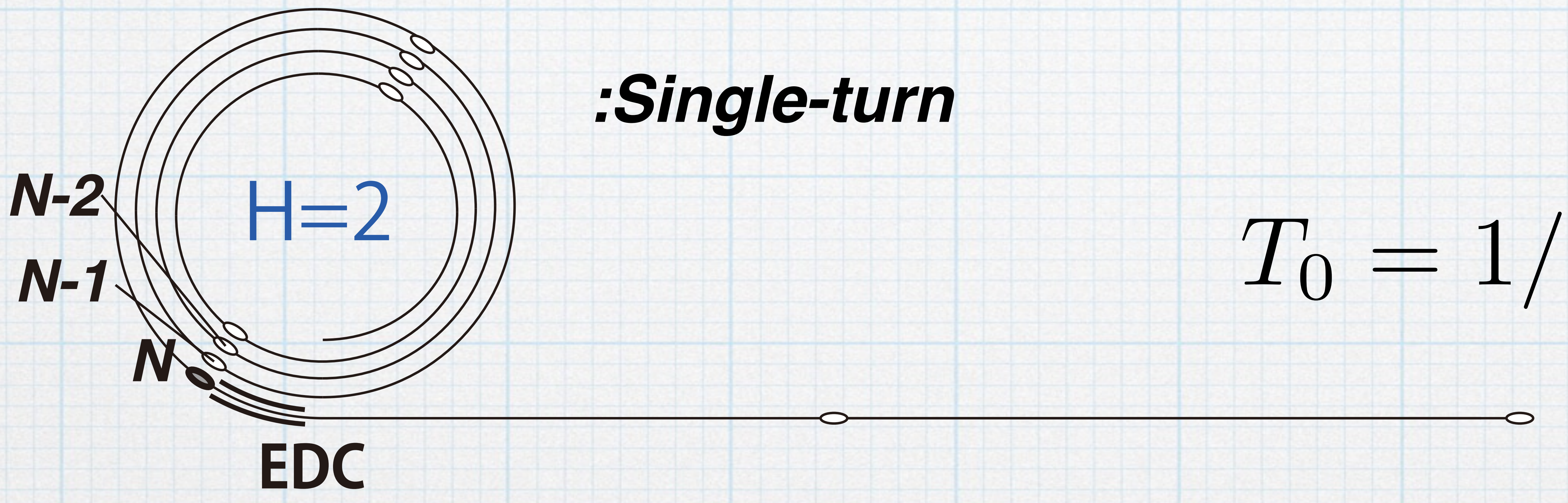
Tuning (SRC)

How to verify the turn purity?

Single-Turn (AVF)

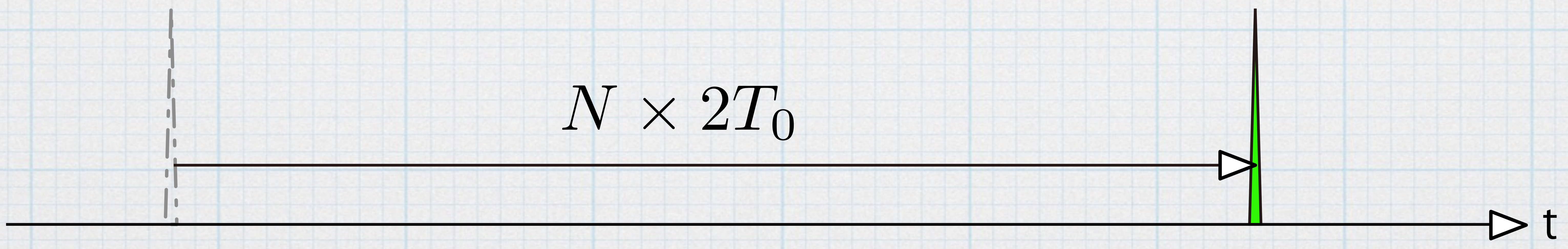
Single-Turn Extraction:

Beam bunches are extracted passing through EDC with a certain **turn number *N*** of orbital motion.



$$T_0 = 1/f_{\mathrm{beam}}$$

a) Extracted beam bunch after N turns



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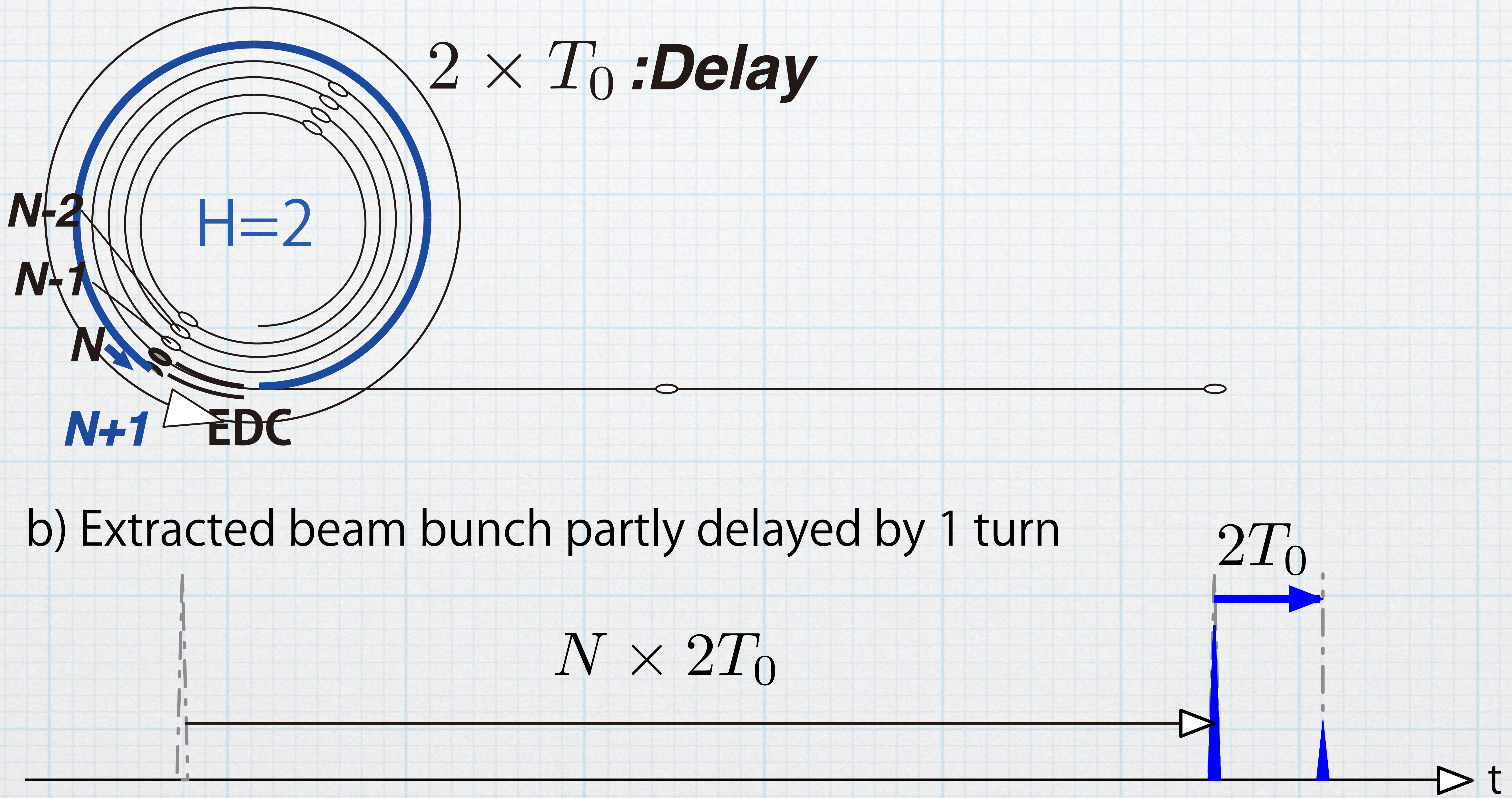

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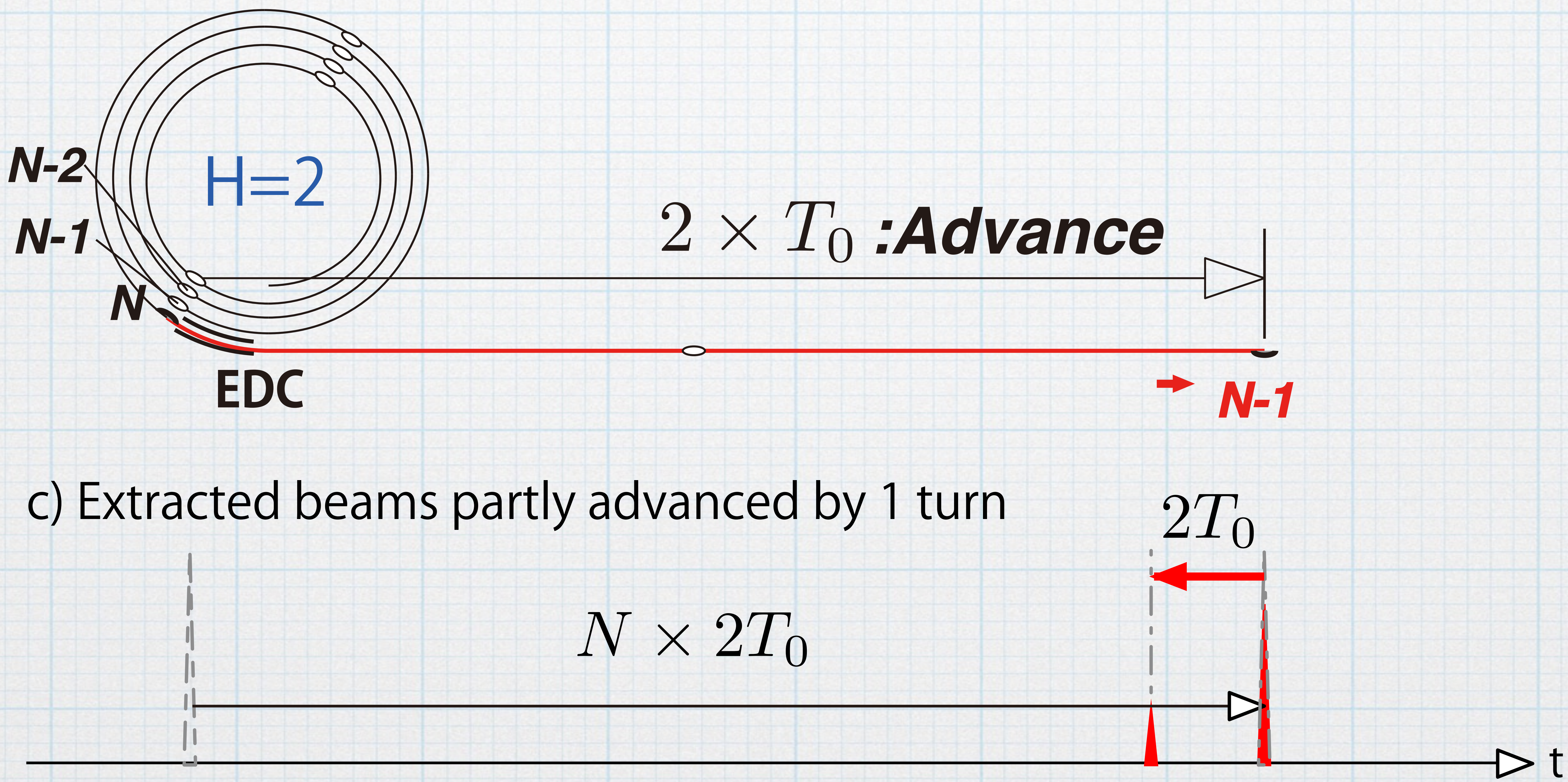
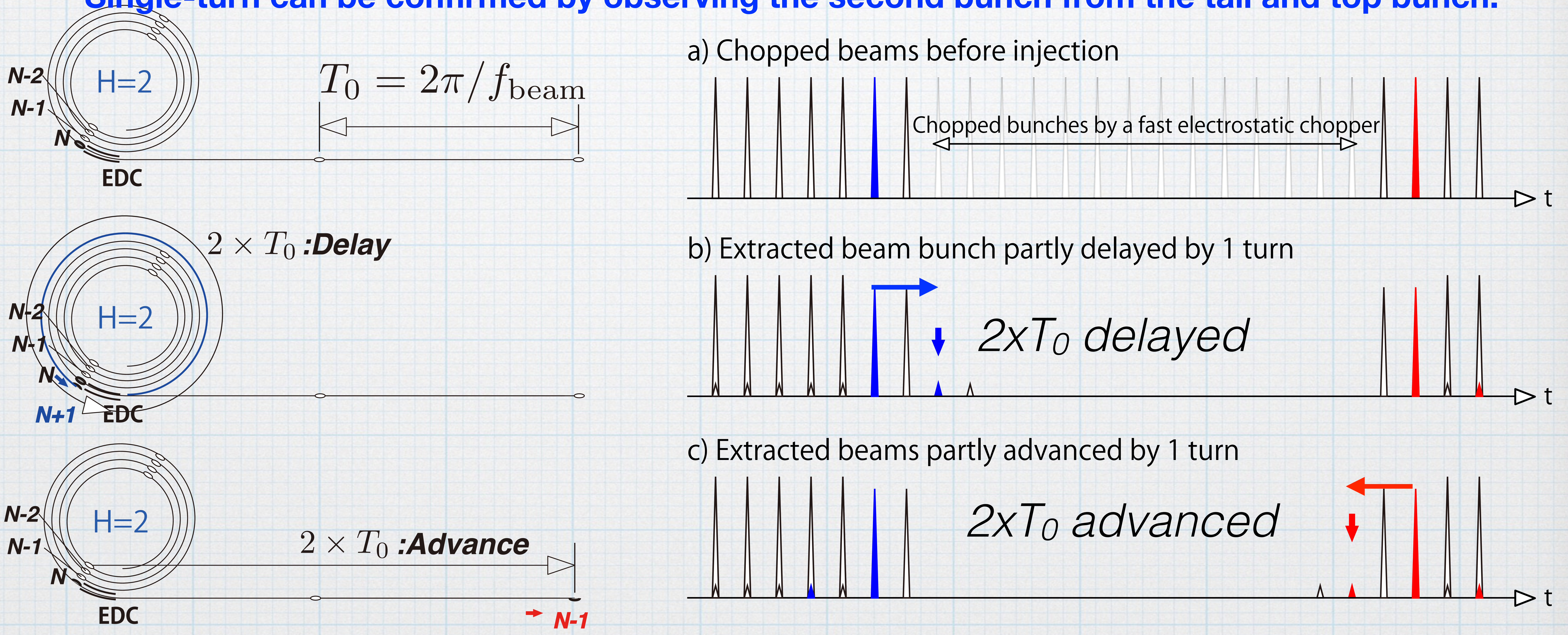


Single-Turn (AVF)

Single-Turn Extraction:

Beam bunches are extracted passing through EDC with a certain **turn number *N*** of orbital motion.
Tuning is made by observing chopped bunch time structure of the extracted beams.

Single-turn can be confirmed by observing the second bunch from the tail and top bunch.



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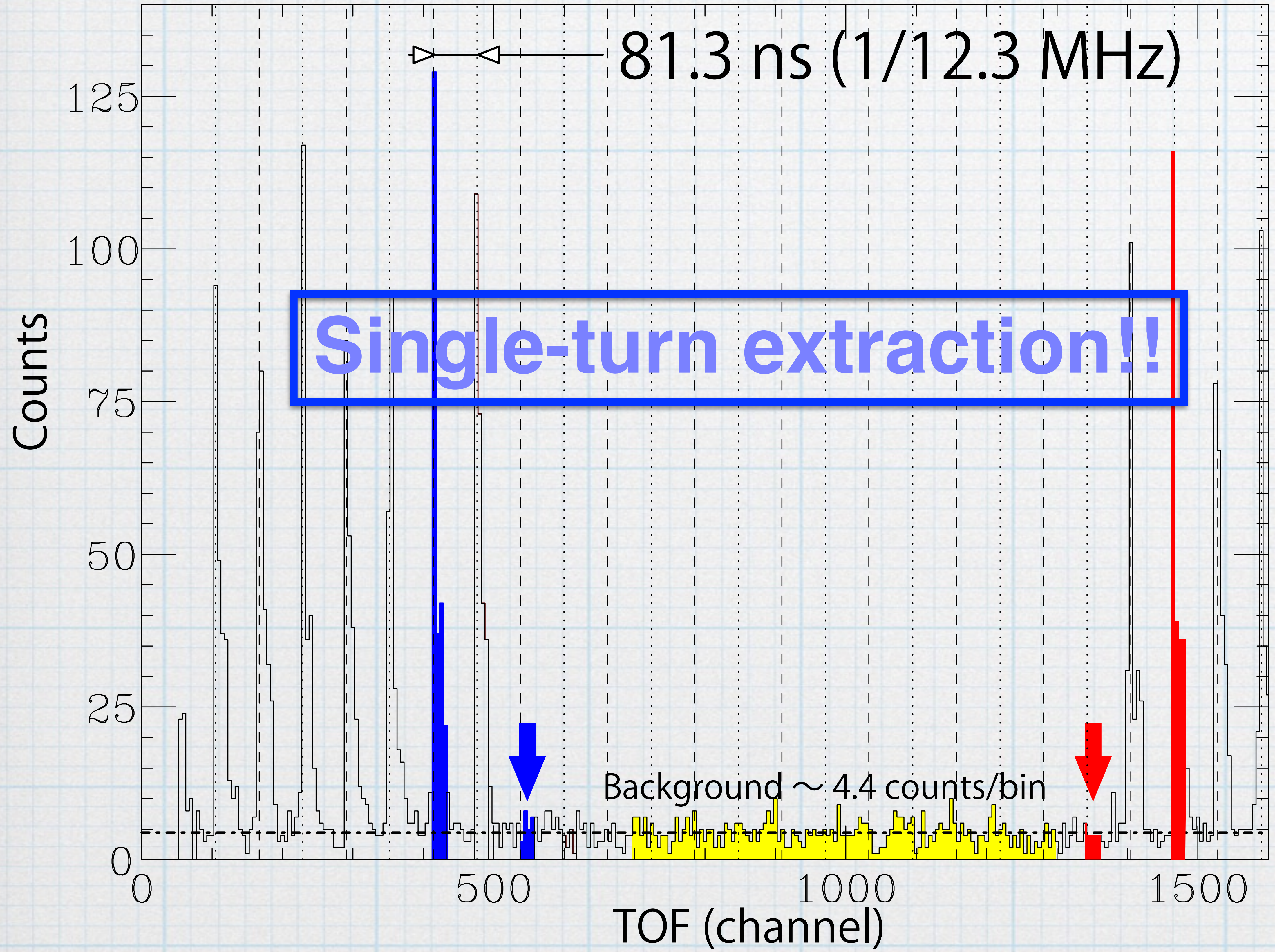
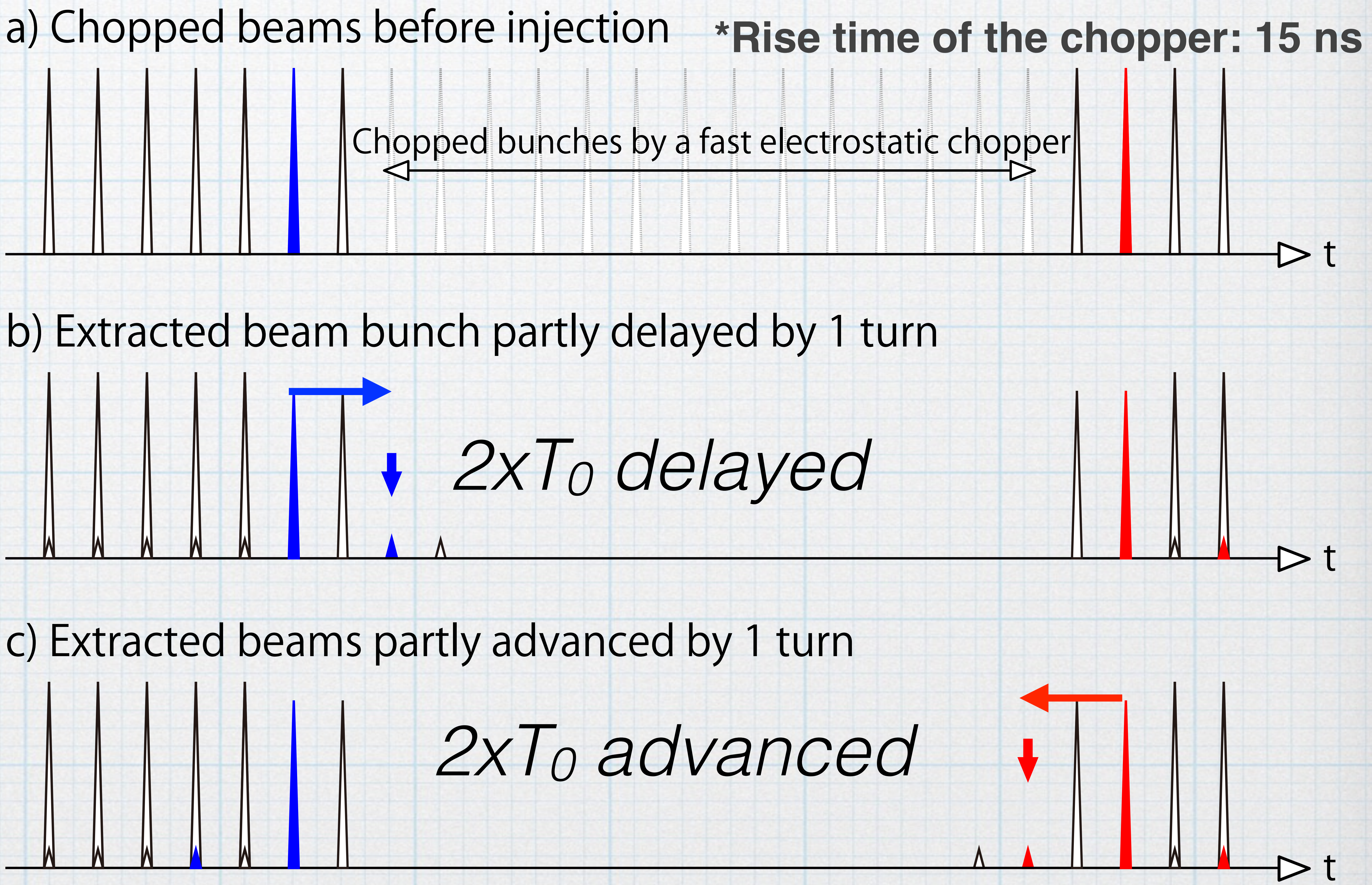
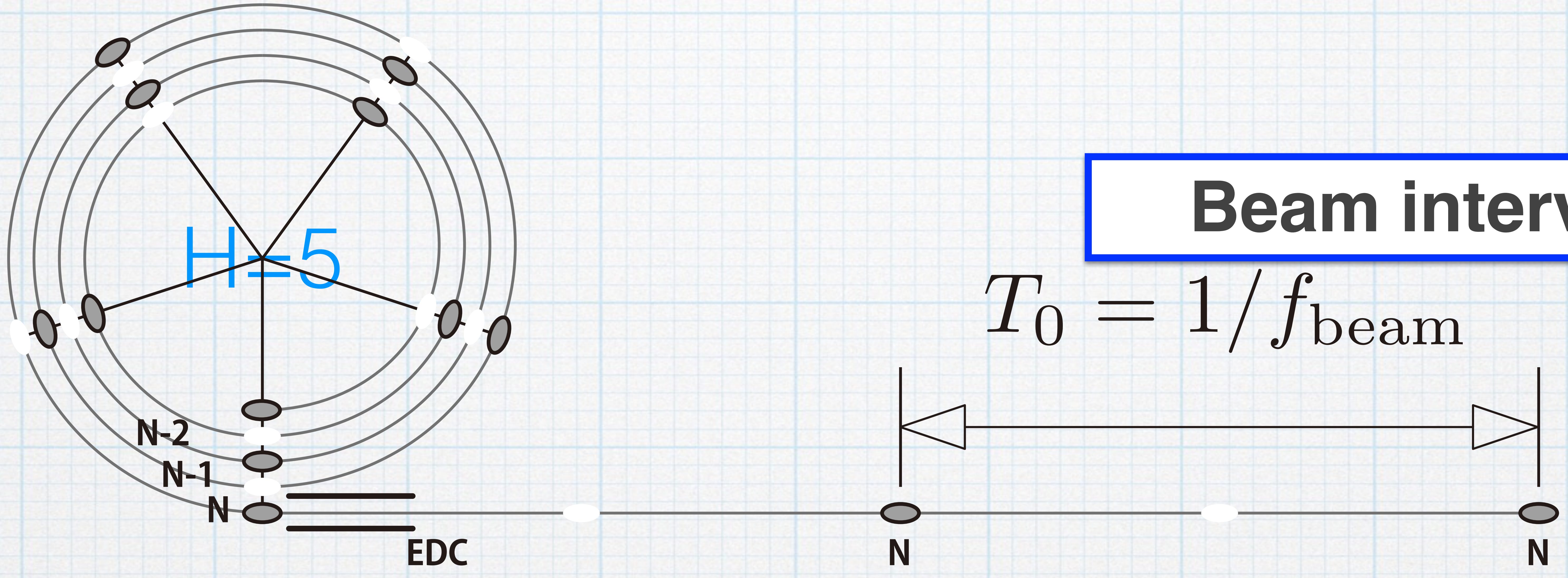




Single-Turn (RRC, SRC)

RRC

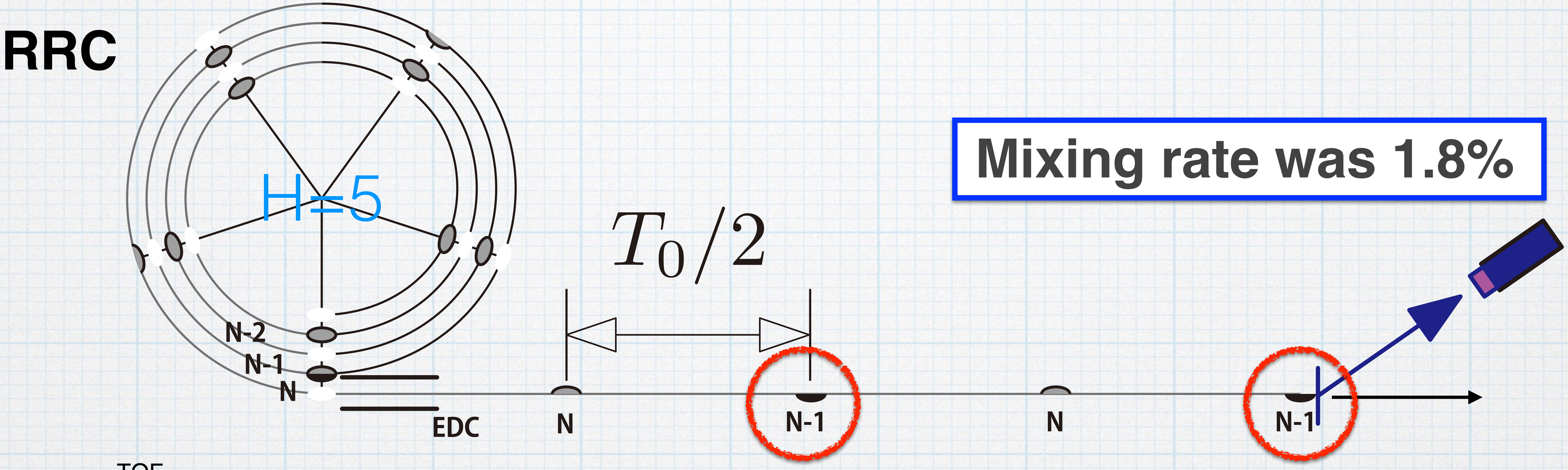


Beam interval:T_0

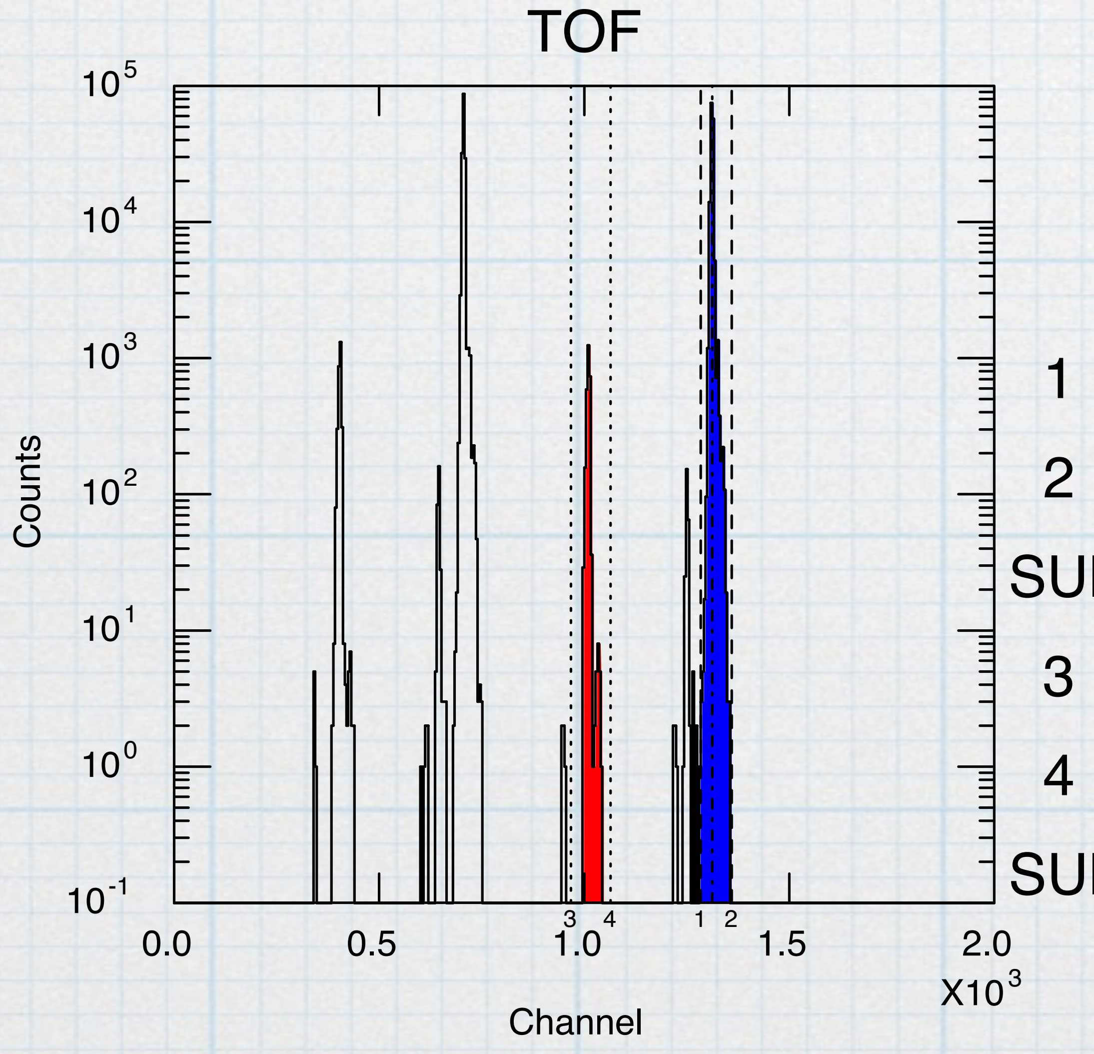
$$T_0 = 1/f_{\mathrm{beam}}$$

There is no bunch at adjacent turn.

Single-Turn (RRC)



Mixing rate was 1.8%

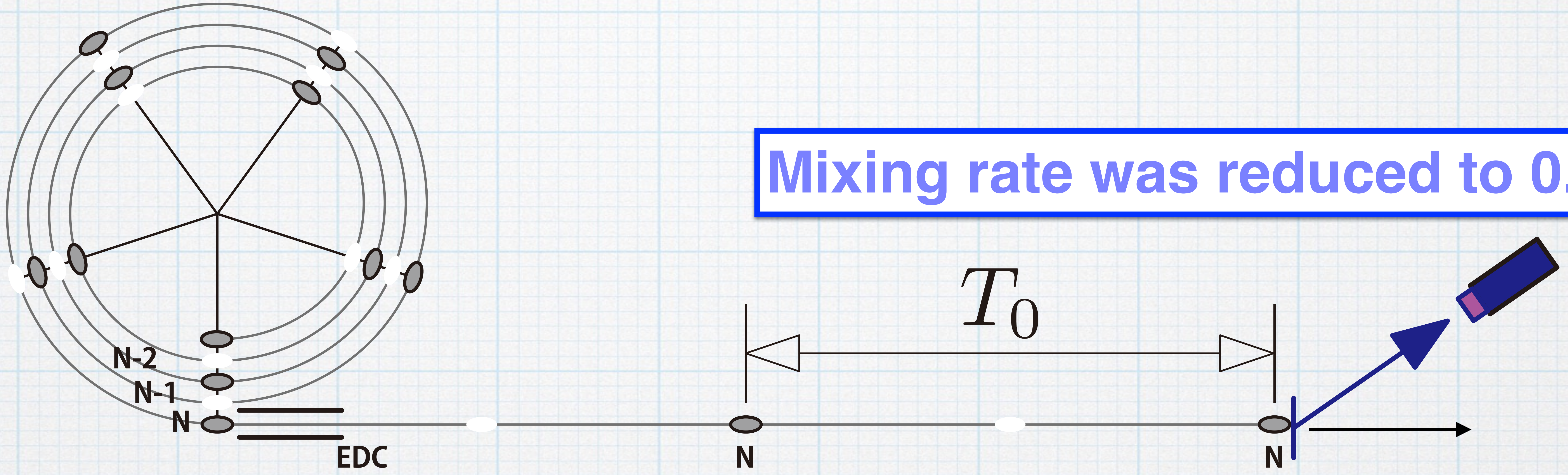


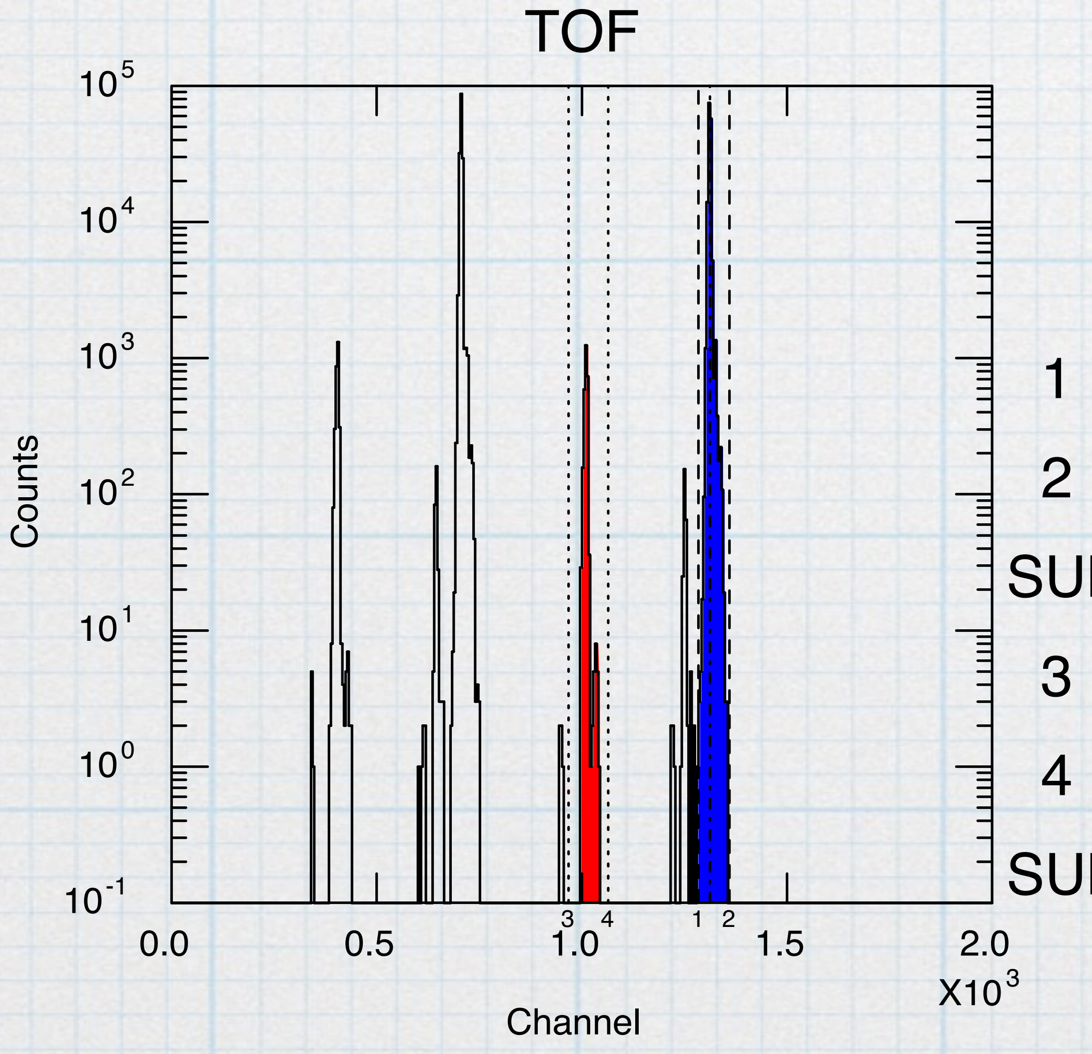
	CURSOR	VALUE
1	1284	3
2	1360	0
SUM	156090	(395.08)
3	968	0
4	1064	0
SUM	2812	(53.028)

Mixing rate 1.8%

Single-Turn (SRC)

Mixing rate was reduced to 0.4%





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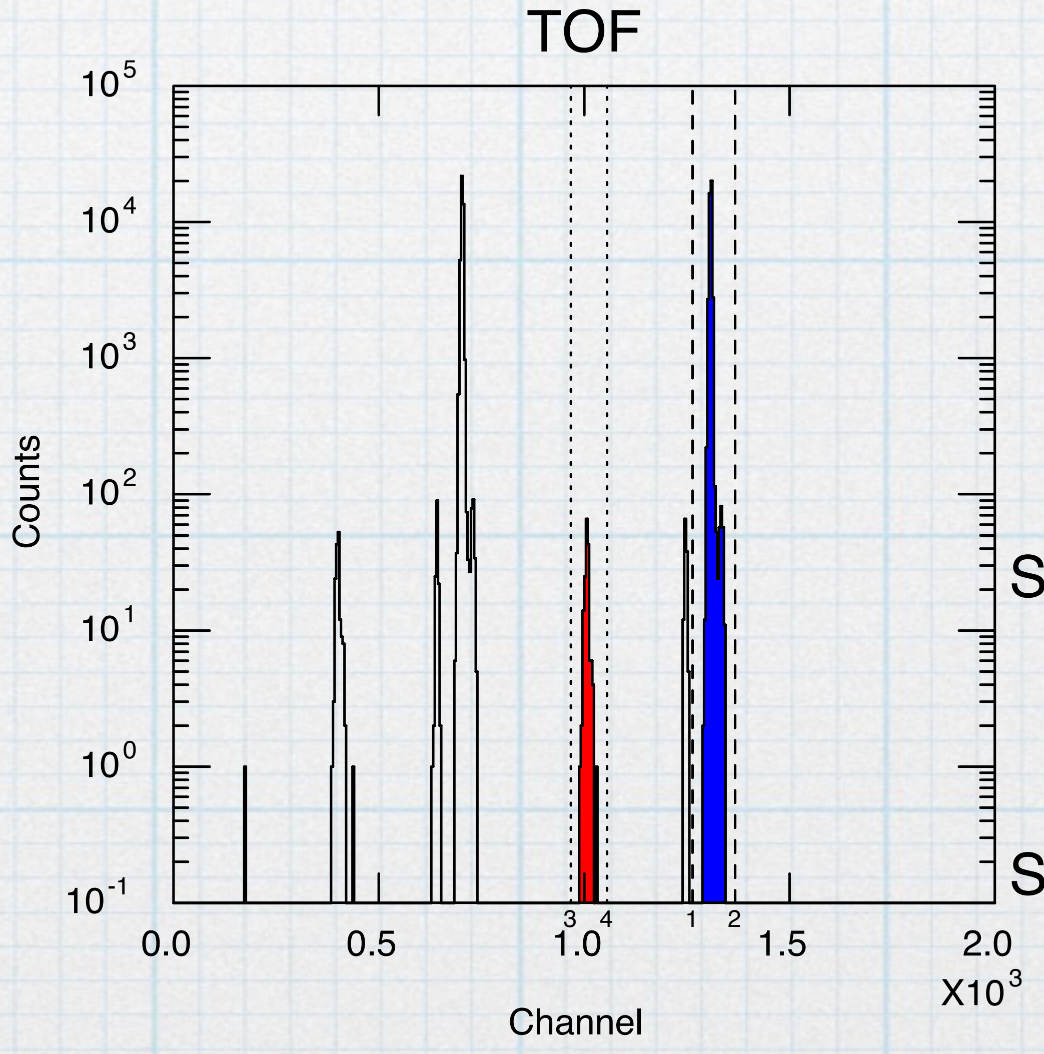
Tuning

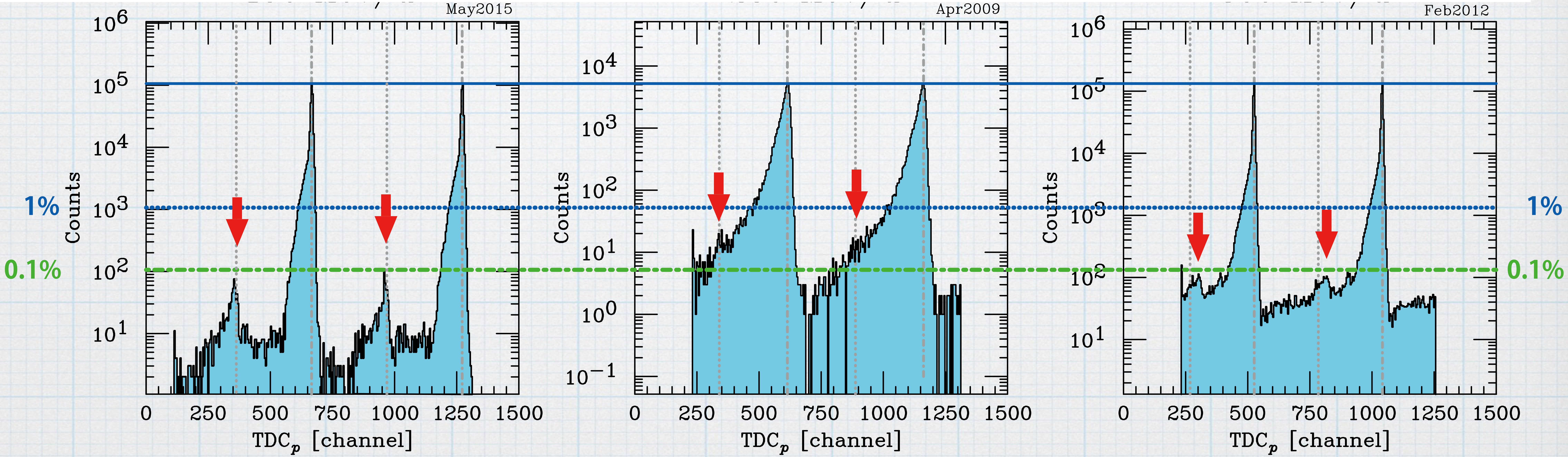


	CURSOR	VALUE
1	1264	0
2	1368	0
SUM	42606	(206.41)
3	968	0
4	1056	0
SUM	168	(12.961)

Mixing rate 0.4%

Single-Turn (SRC)

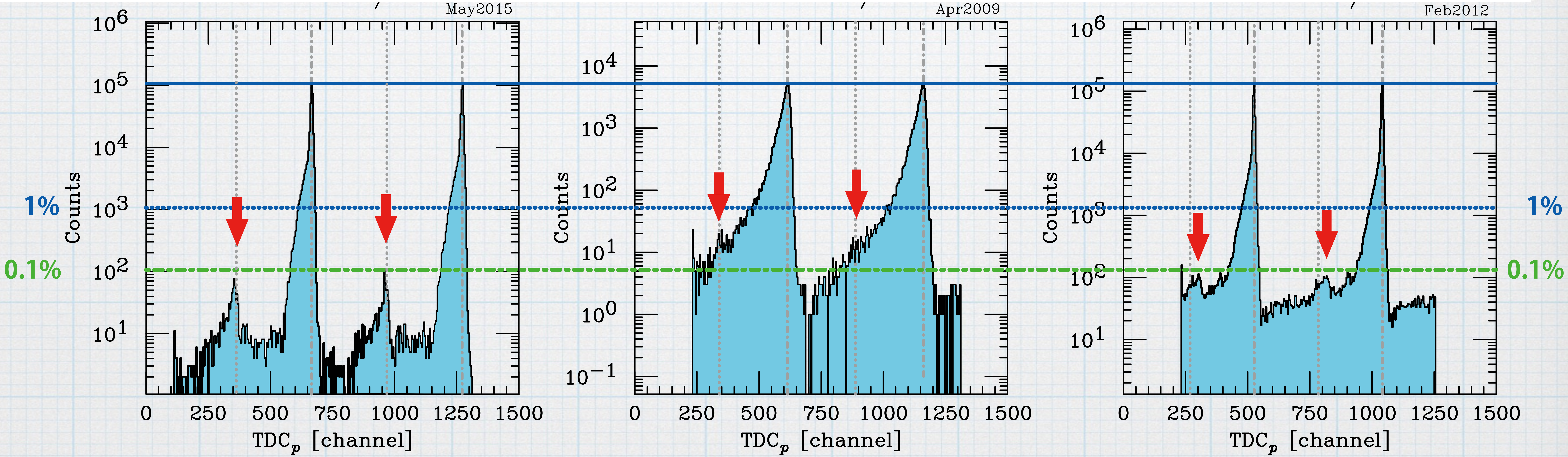
E_d (MeV/u)	190	250	300
f_{beam} (MHz)	12.3	13.7	14.5
V_{acc} (kV/turn)	1403	1482	**1461**
ΔR_{ext} (mm)	7.6	5.5	4.3
Mixed rate	<0.1%	<0.5%	<0.1%



Purity of Single-Turn (SRC)

Obtained turn purity was >> 99%.(➡satisfy the requirement!)
Single-turn operation was ***stable*** so that extracted turn was successfully maintained during the experiments for a couple of days.

Mixed rate	<0.1%	<0.5%	<0.1%



SUMMARY

- Versatility of primary beams is one of the advantages of RIBF.
- **Polarized deuteron beams** with energies of **190, 250, 300 MeV/u** have been provided to physics experiments requiring high precision.
- Since <u>spin rotation was made prior to the acceleration</u> by cyclotrons:

    Spin control is realized by very compact system. (Pro)

    Single -turn extraction operation is crucial for all the cyclotrons of AVF, RRC, SRC. (Con)
- **Single-turn monitor system** measured their purity of extracted turns instantly.
- Single-turn operation was feasible for these series of experiments <u>even with an energy of 190 MeV/u which was below the lower limit of the designed magnetic field of the SRC.</u>
- **The purity of the single-turn was satisfactory (>>99%) and the accelerators were stable enough to perform the experiments.**

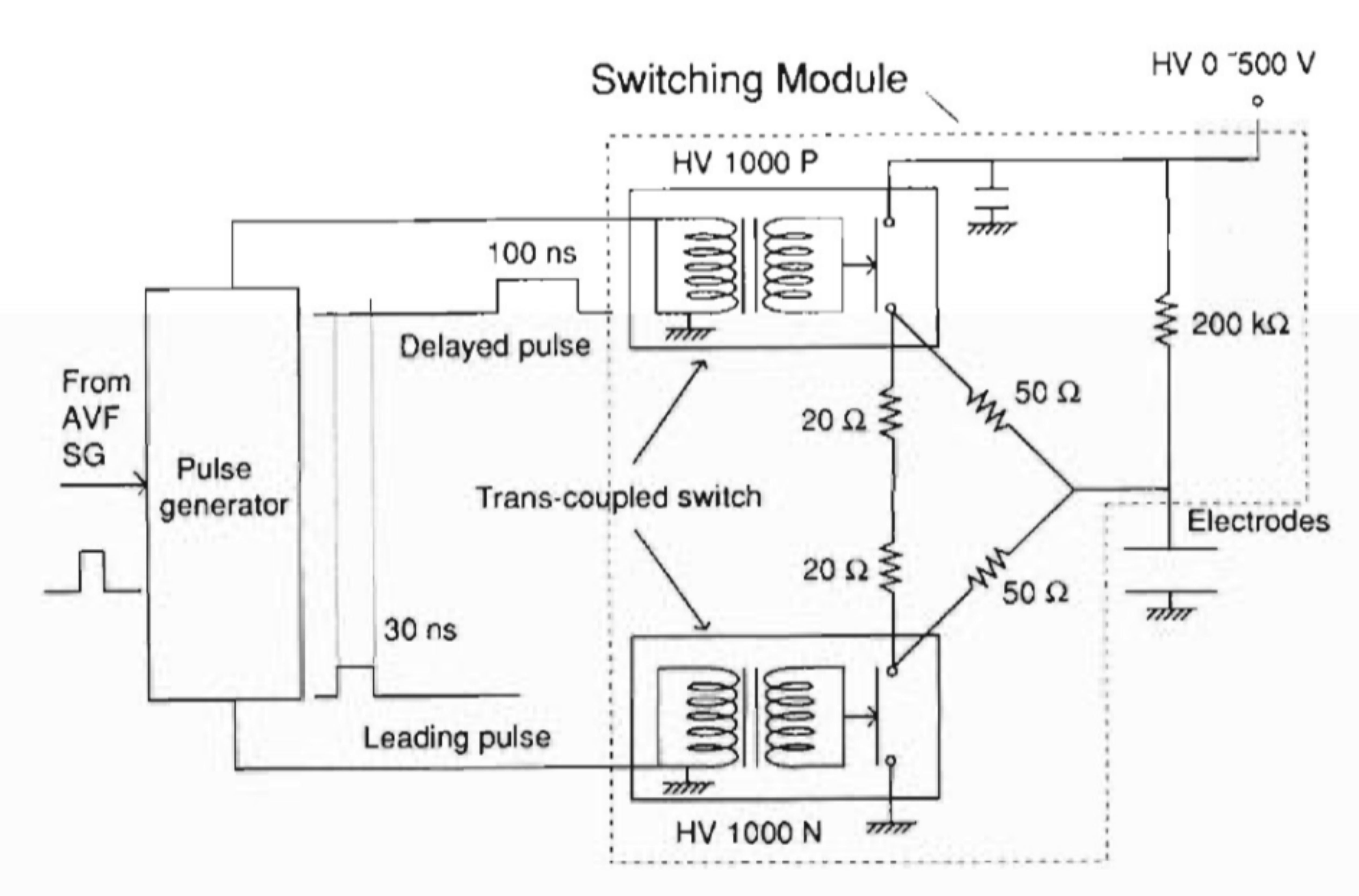
THANK YOU FOR YOUR ATTENTION

BACKUPS

ELECTROSTATIC BEAM CHOPPER DRIBEN BY FAST SWICH

Two trans-coupled type.

Voltage:0-500 V (DC)
Repetition rate <1 MHz
Rise time 15 ns
Duration time 100-250 ns.



N. Inabe et al., RIKEN Accel. Prog. Rep. 28(1995)p160.

Single-Turn Monitor (SRC)