Improvement of a dc-to-pulse conversion efficiency of FRAC

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Highlights

- We developed a **2-step bunching method** by cooperation of

  ERIS※1 (Electron-beam-driven RI separator for SCRIT)

  and

  FRAC※2 (Fringing-RF-field-activated dc-to-pulse converter)

- The DC beam was converted to a pulse beam with up to **~90% efficiency.**

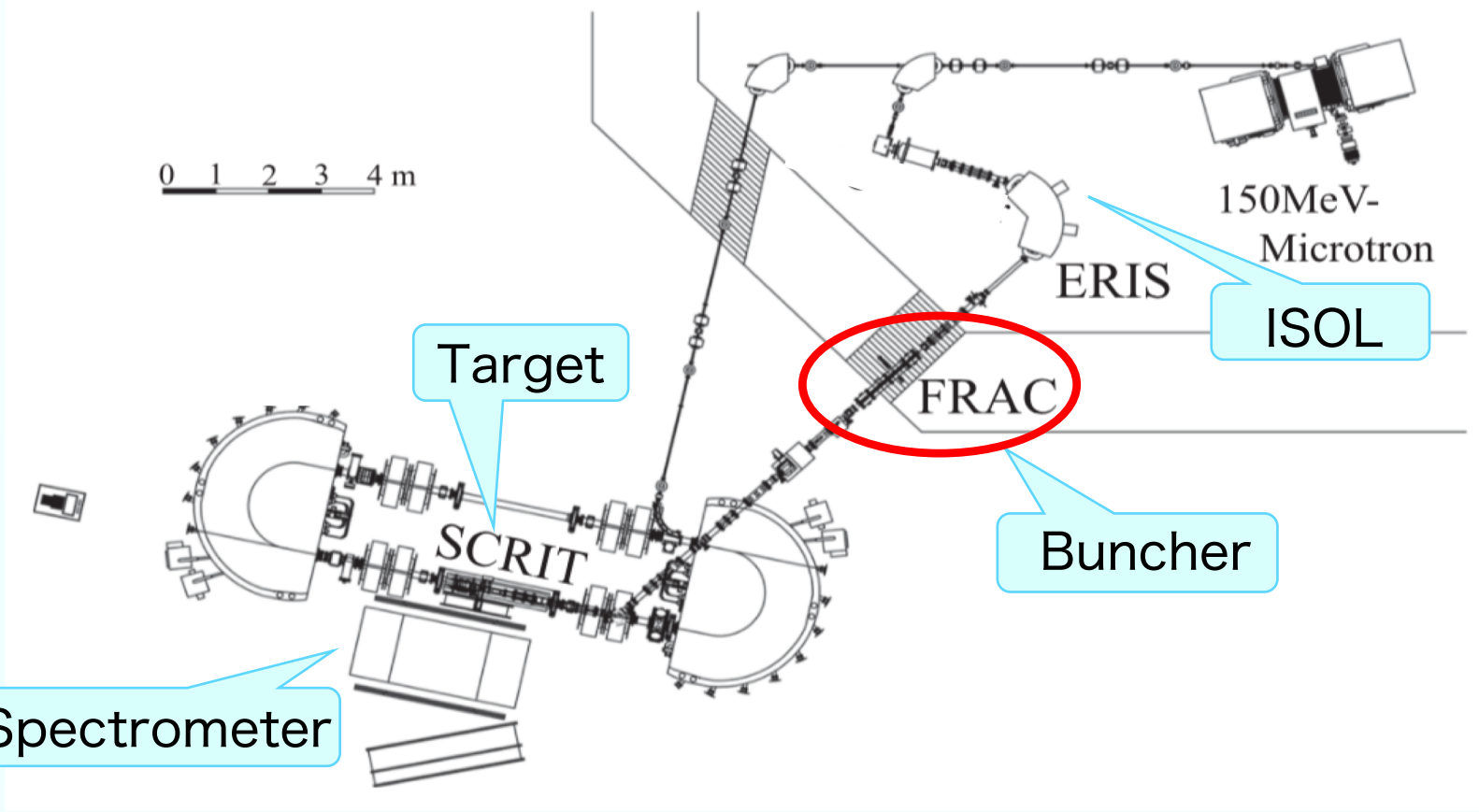
※1 Nucl. Instrum. Meth. B317, 357 (2013).

※2 Rev. Sci. Instrum. 89, 095107 (2018).

SCRIT facility @ RIKEN

SCRIT (Self Confining Radioactive isotope Ion Target)

The world's first **electron scattering of unstable nuclei**



Nucl. Instrum. Methods B317(2013)668

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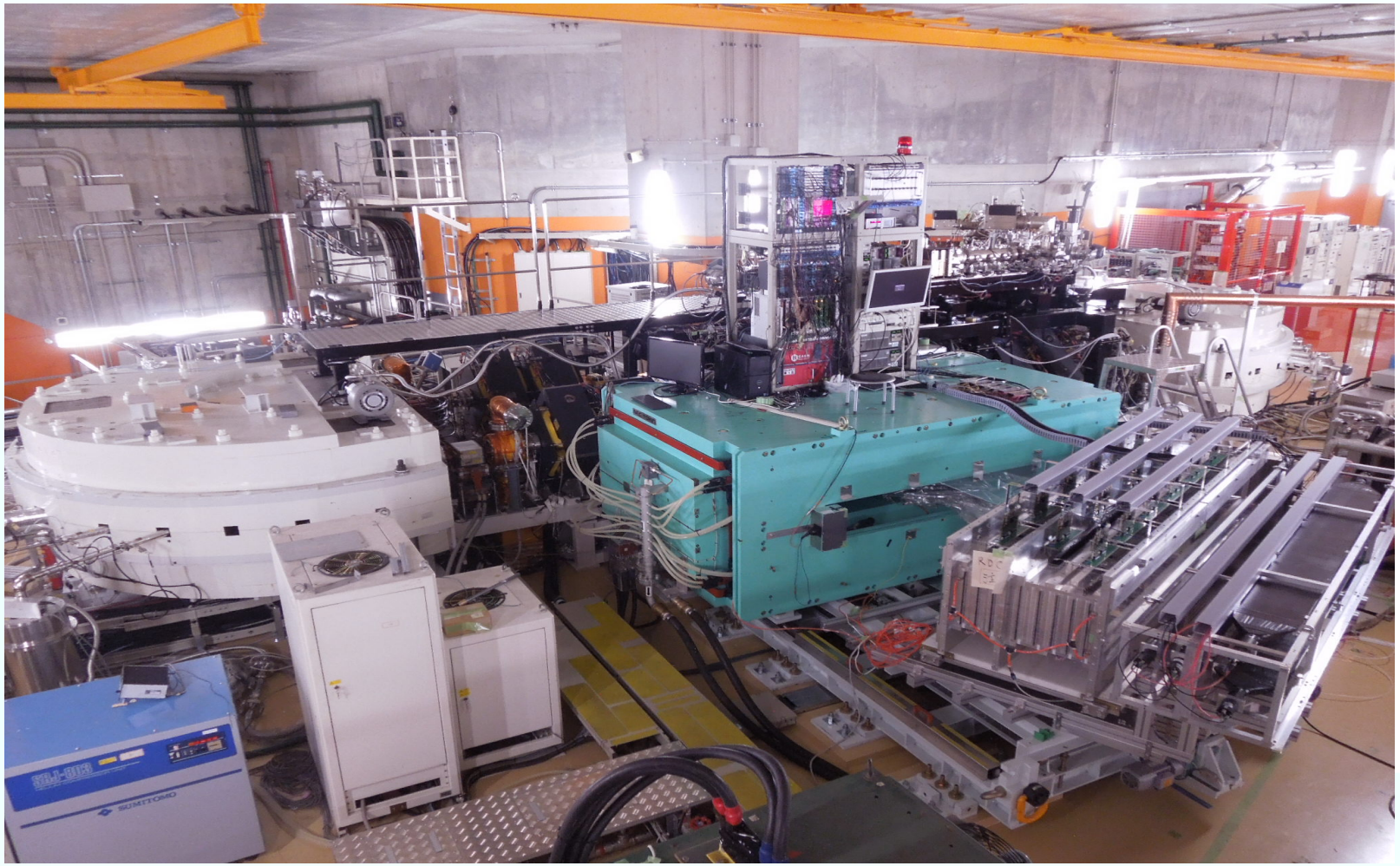
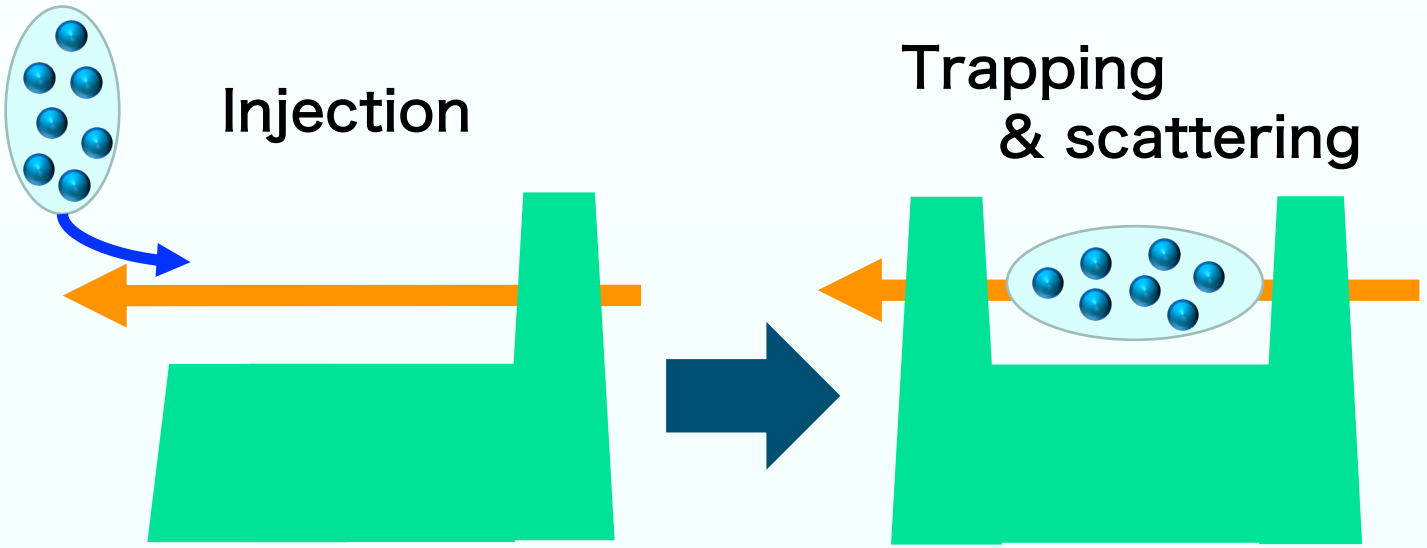


Operation of SCRIT



Potential is opened <u>for 500μs</u>

● : Ion ← : e^- beam ▬ : SCRIT potential

<u>~10^8 ions</u> need to be injected to SCRIT <u>in 500μs</u>

Goal and condition

- The dc-to-pulse conversion efficiency : 100%.

Because

- SCRIT requires : ~10^8 ions
- The production rate : 10^5 ~10^7 ions/s

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■ The dc-to-pulse conversion efficiency : 100%.

Because

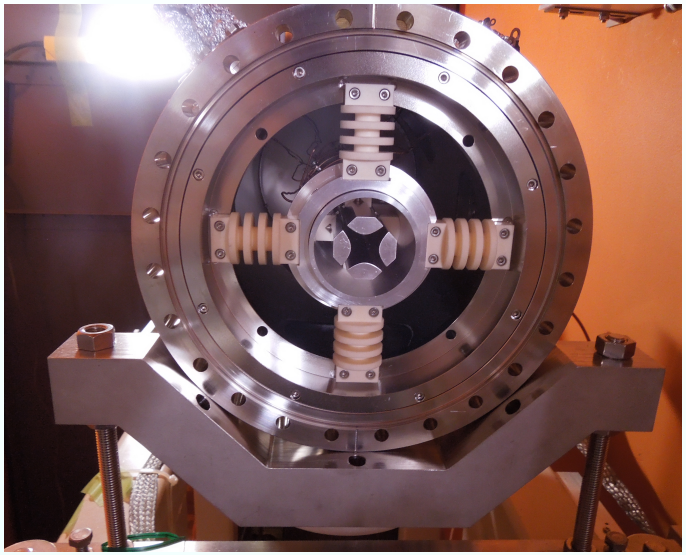
- SCRIT requires : ~10^8 ions
- The production rate : 10^5 ~10^7 ions/s

■ The degree of vacuum of FRAC : ~10^{-3} Pa.

Because

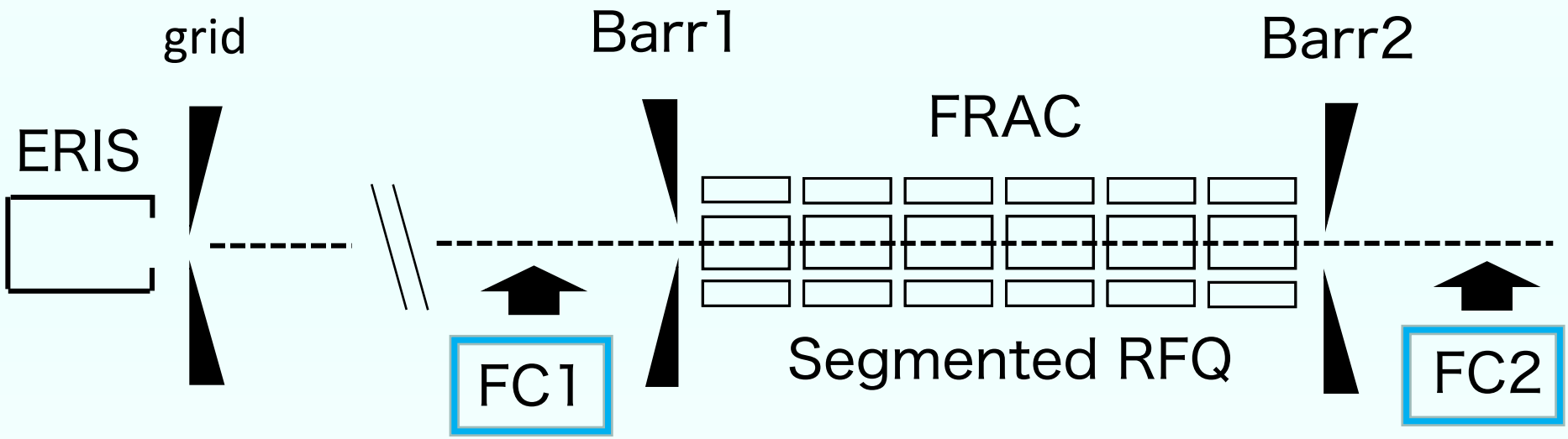
- SCRIT is operated under high vacuum of ~10^{-8} Pa.
- Ion capacity needs to be ~10^8 ions.
- Ions in FRAC need to be extracted with in 500us.

Setup



end view of FRAC

- Length : 0.9m
- Bore radius : 8 mm
- RF amplitude : 500 V
- RF frequency : 1.5 MHz
- Buffer gas : Xe, ~10^{-3} Pa



2-step bunching method

Ion cooling by buffer gas of ~10^{-3} Pa

↓

Long cooling time

↓

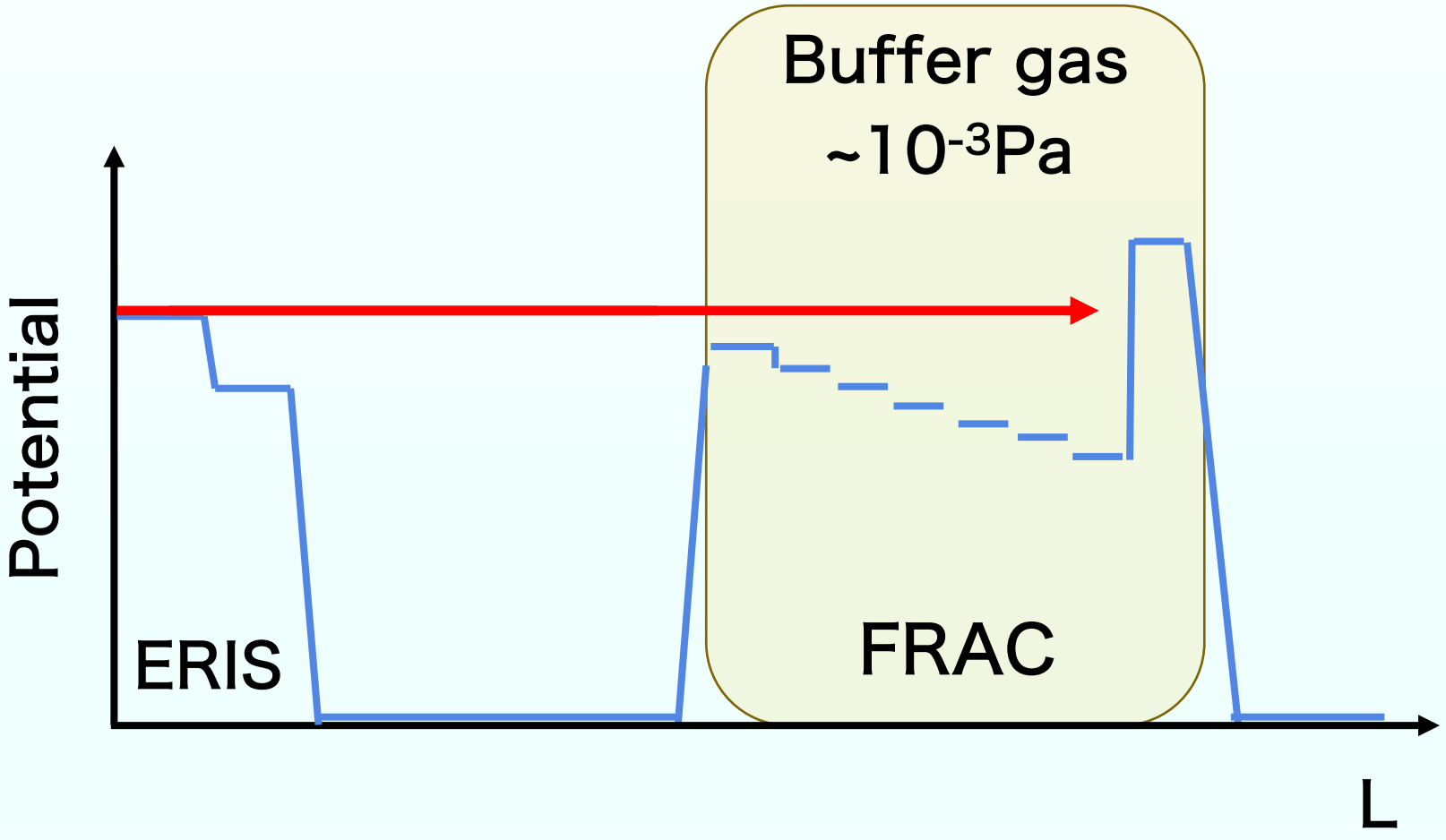
DC beam can not be stacked

↓

2-step bunching method

2-step bunching method

If the DC beam is injected…



2-step bunching method

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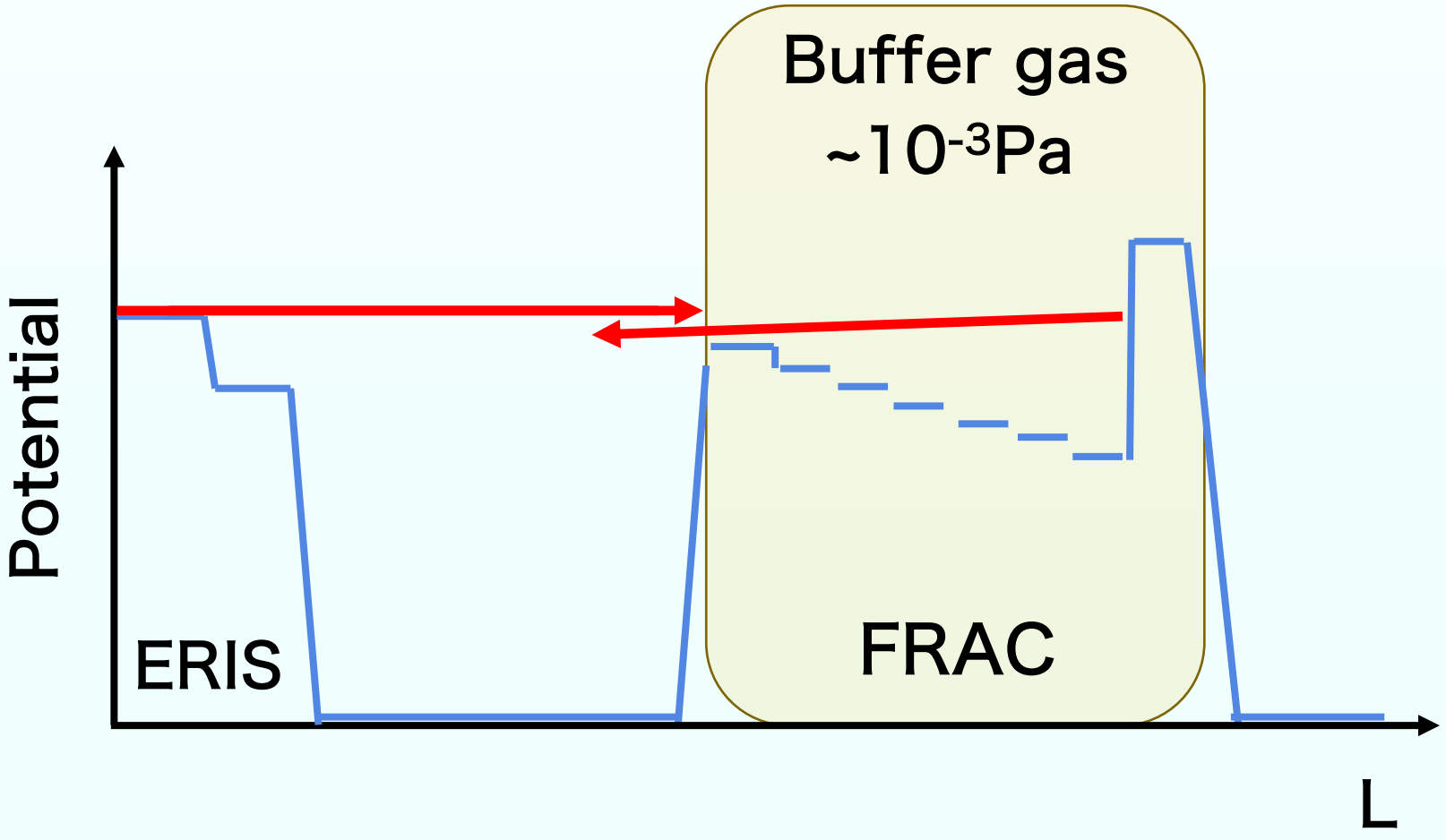

2-step bunching method

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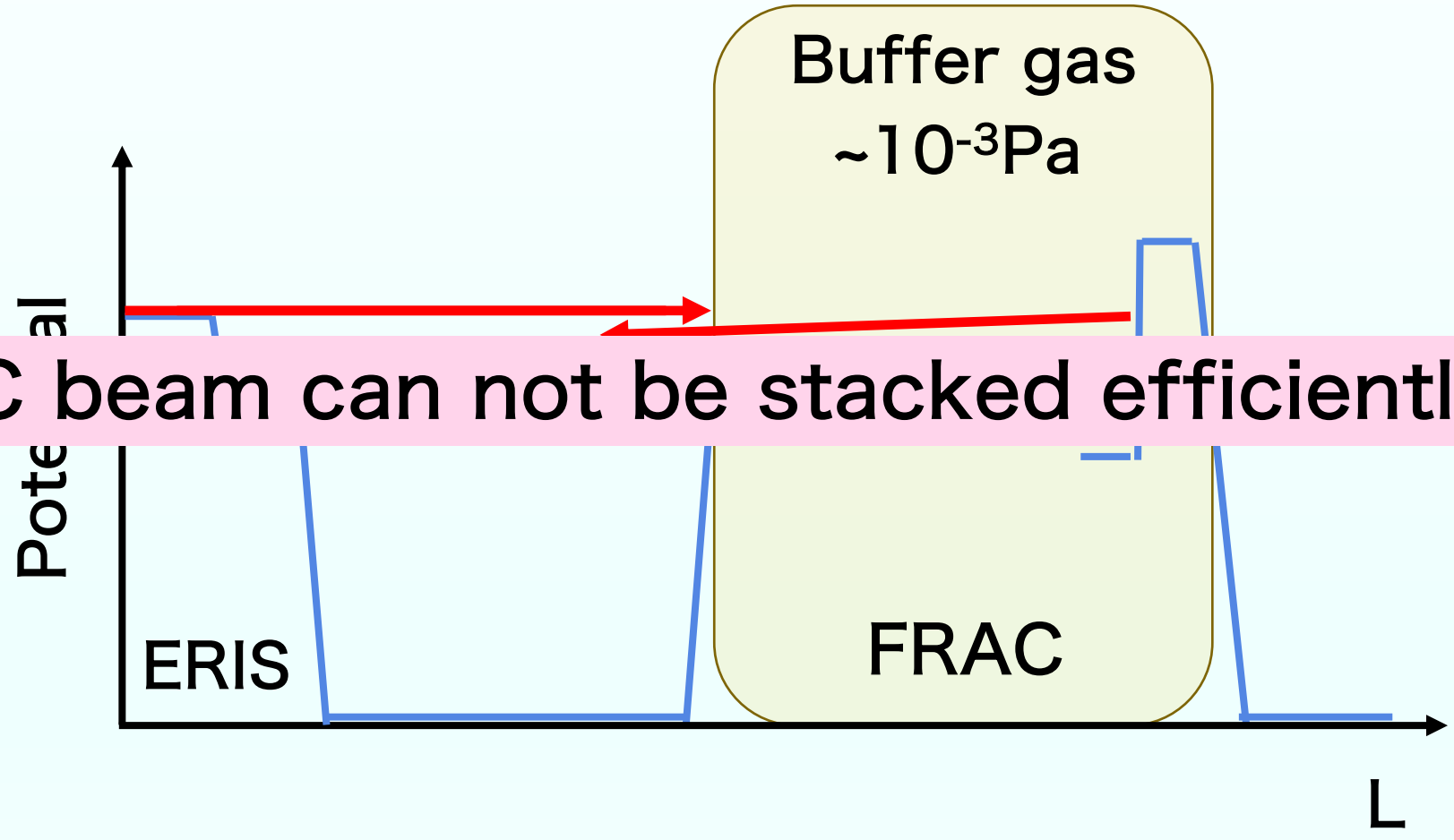
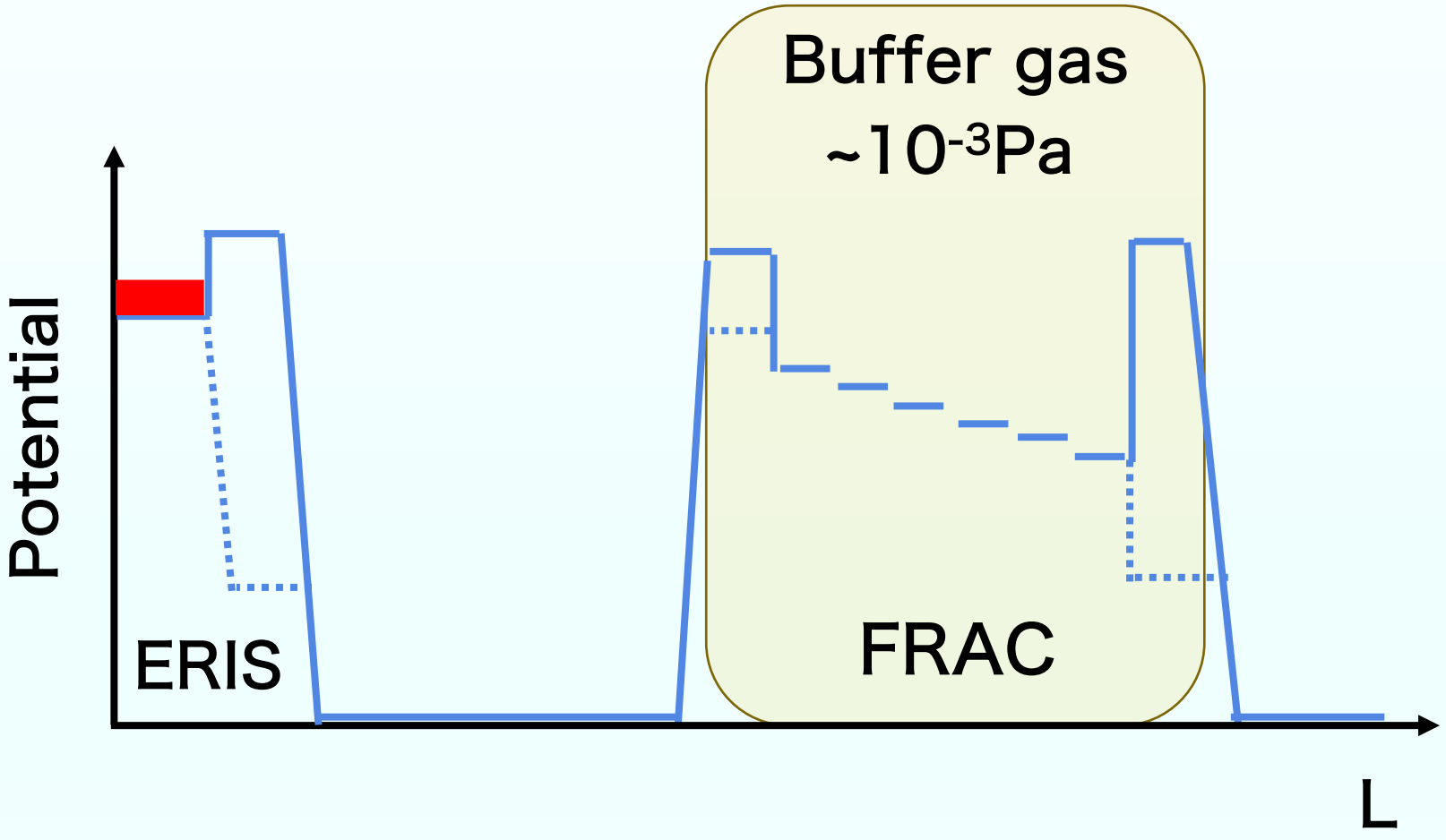


DC beam can not be stacked efficiently

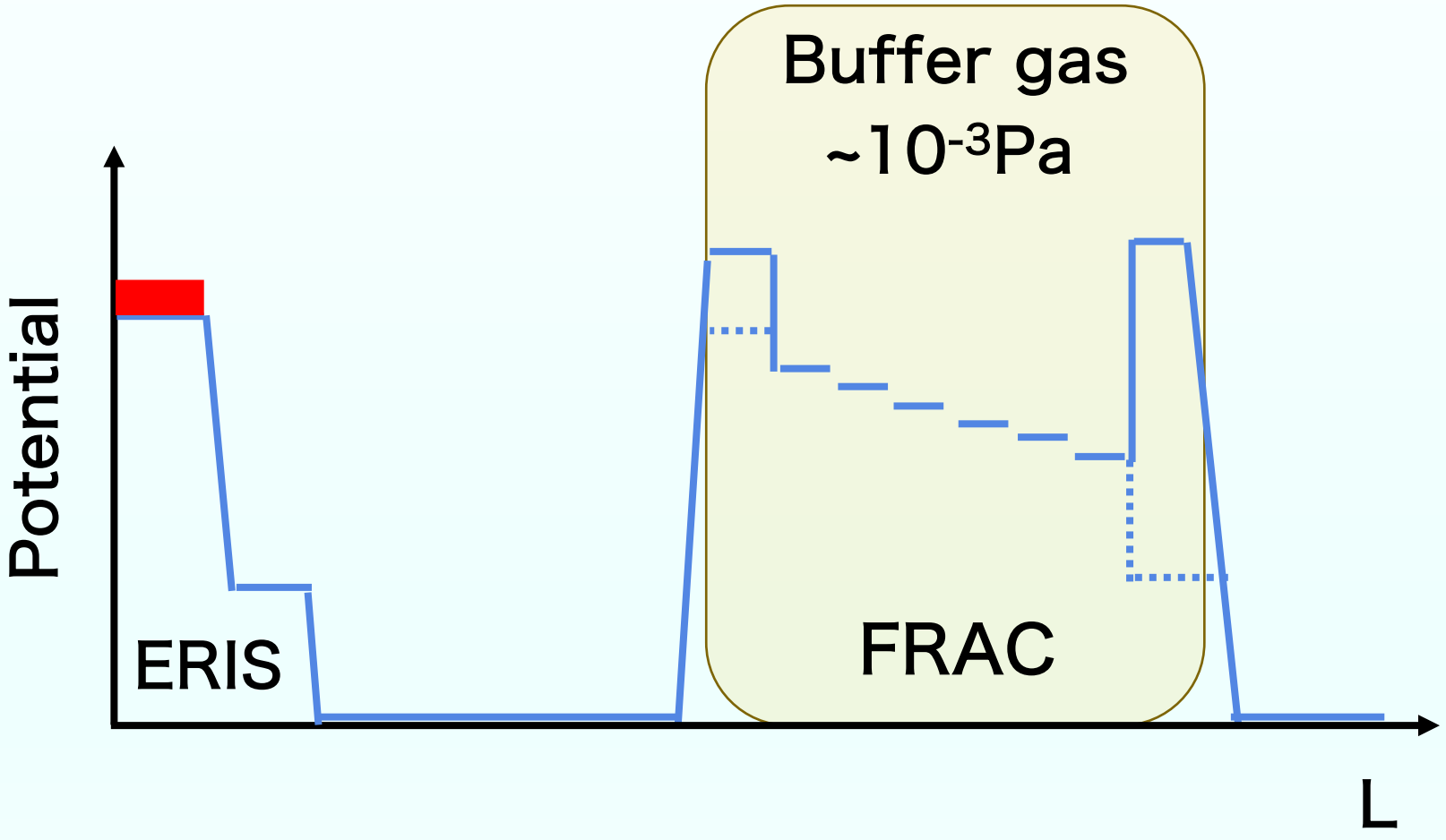
2-step bunching method

1. The ions are stacked by ERIS



2-step bunching method

2. The ions are extracted as a pre-pulse beam



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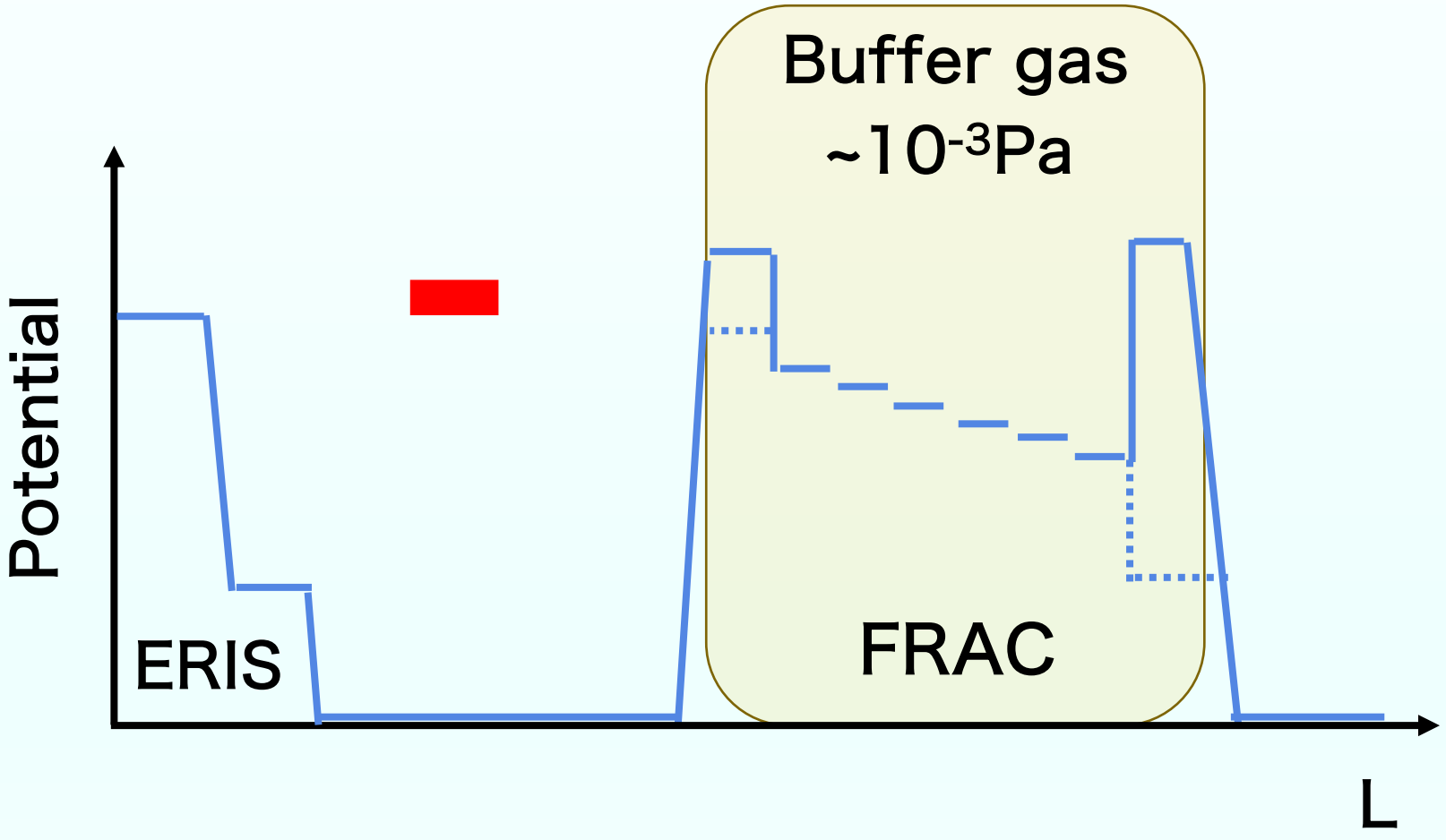
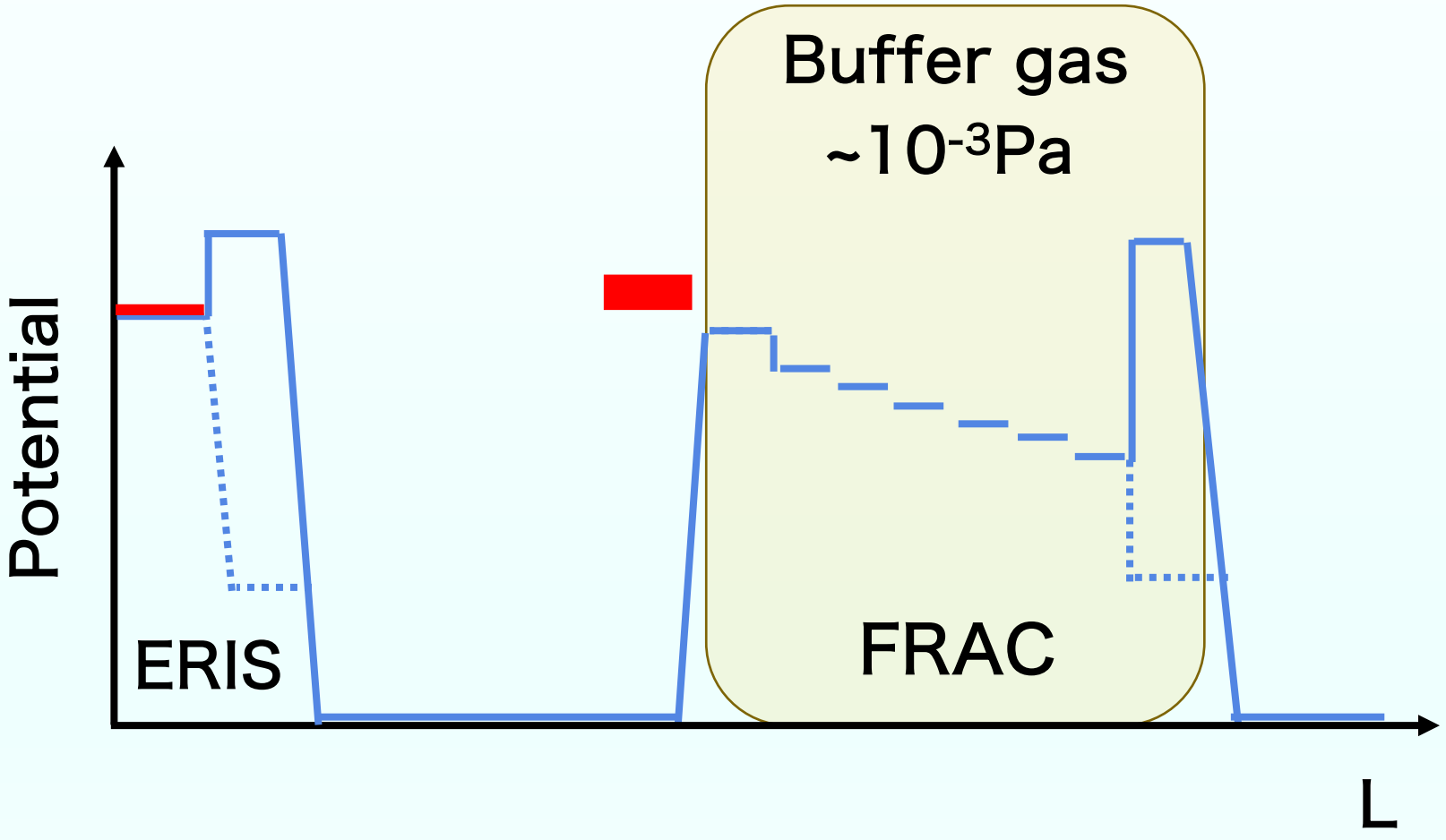


2-step bunching method

3. The injection barrier of FRAC is opened



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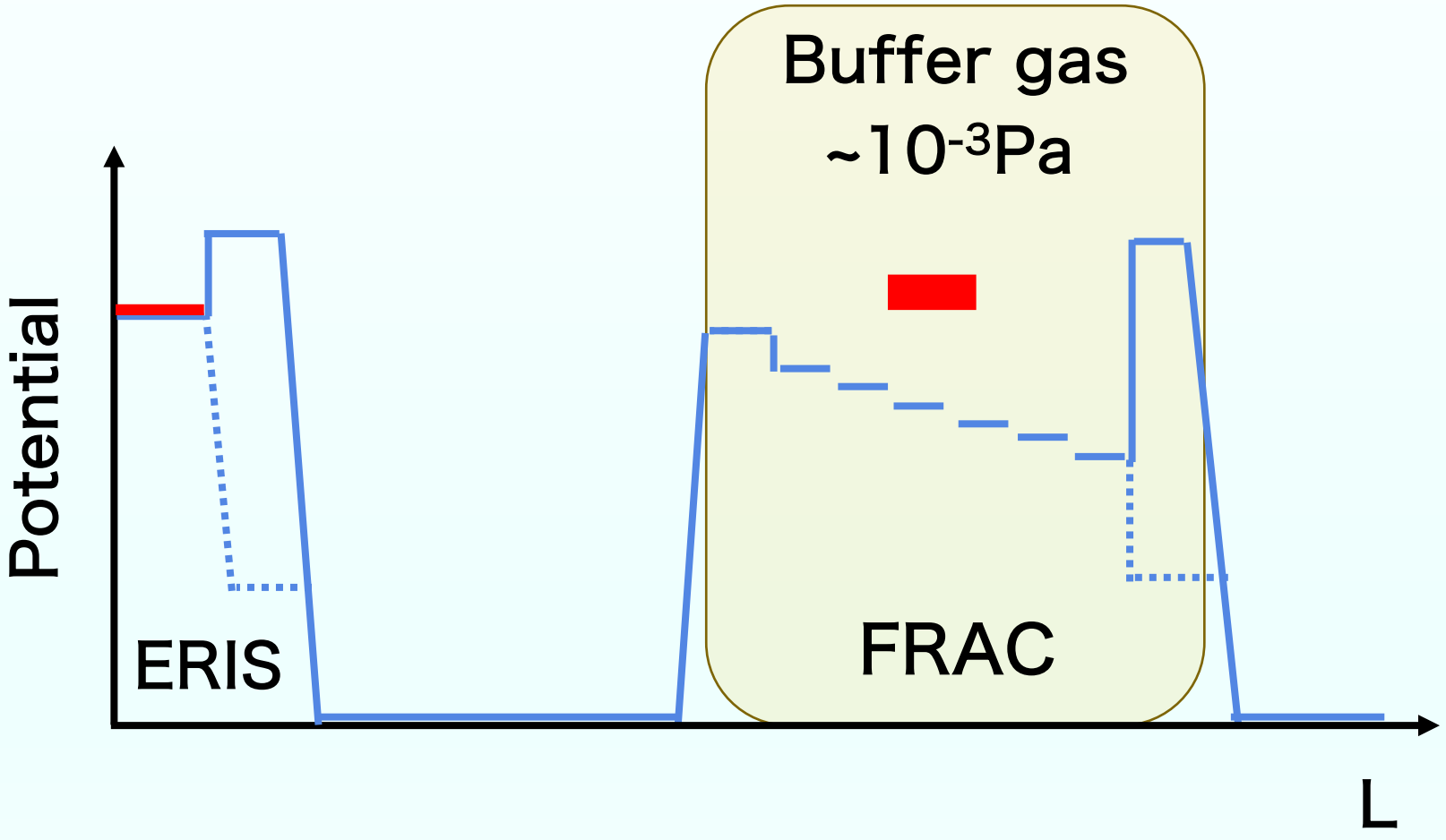
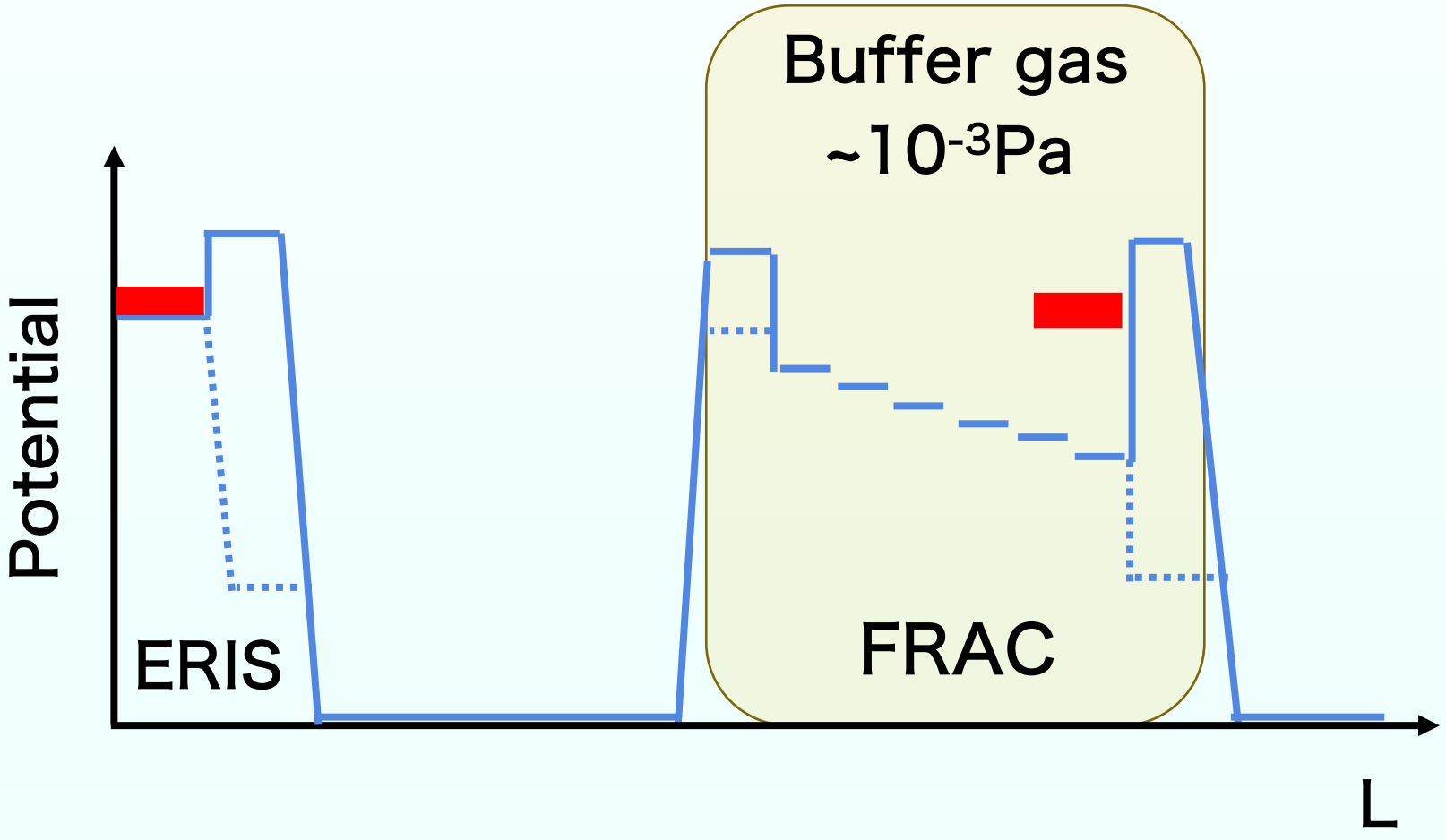


2-step bunching method

3. The ions are trapped and cooled in FRAC



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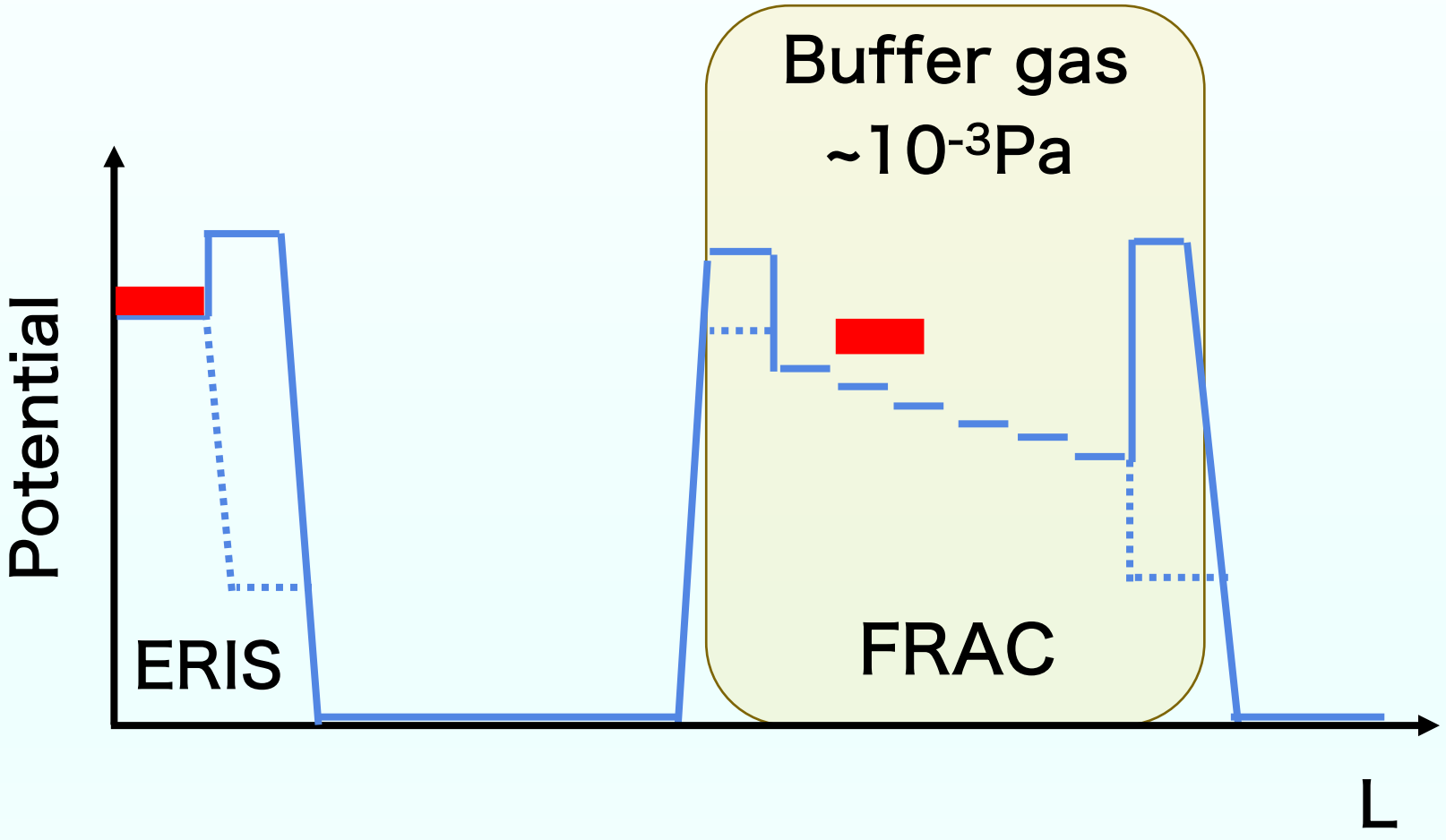

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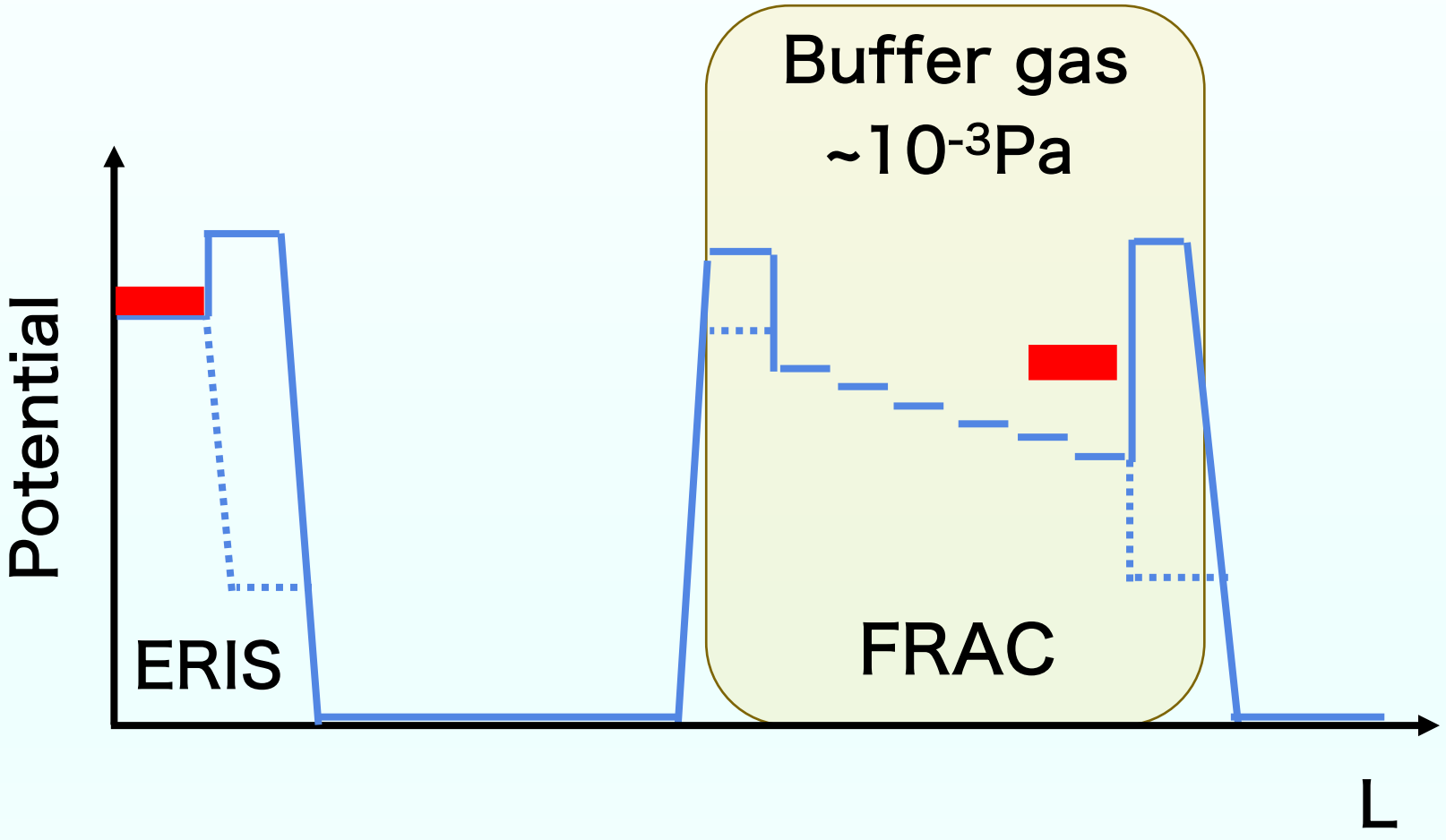

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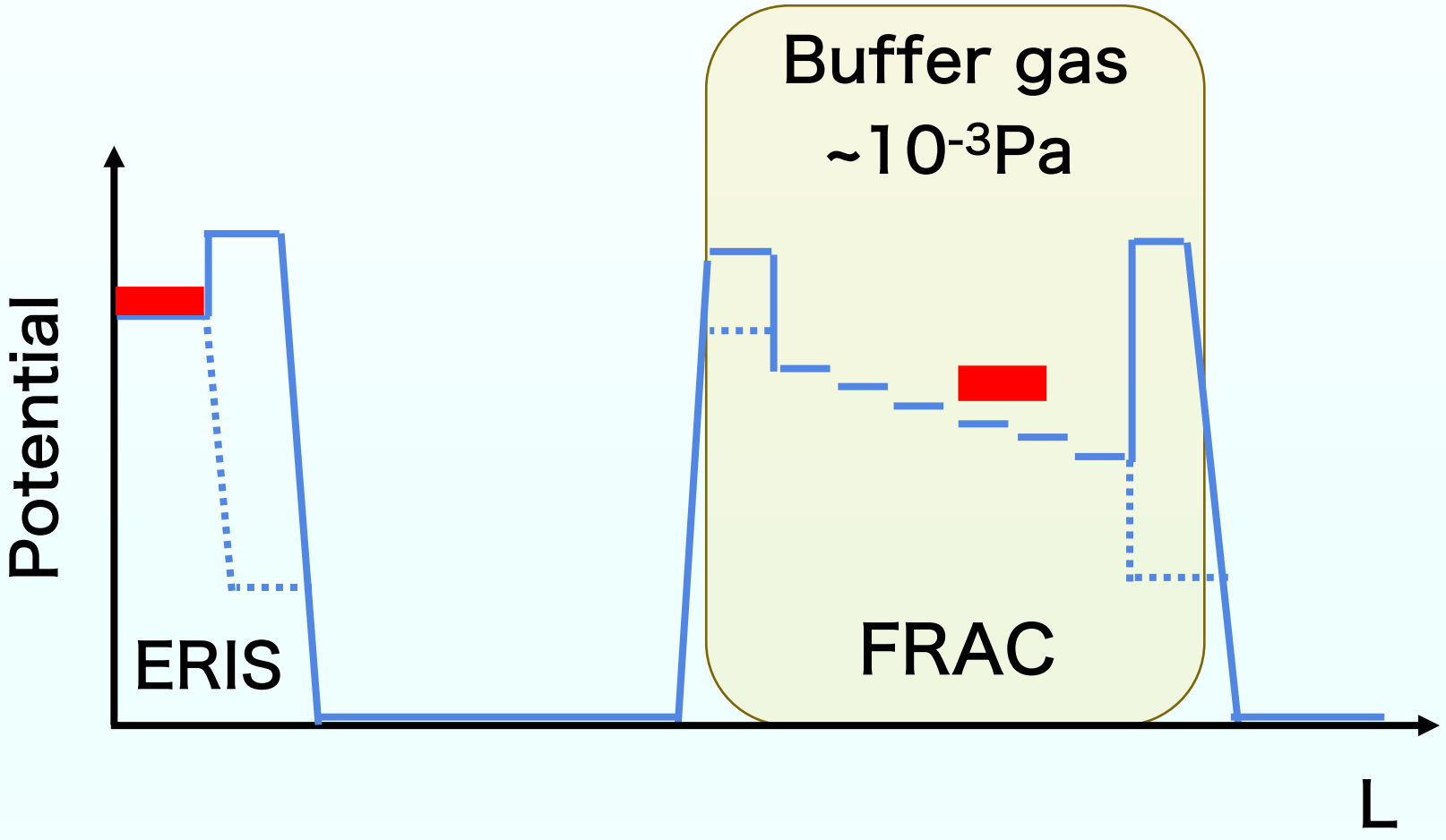
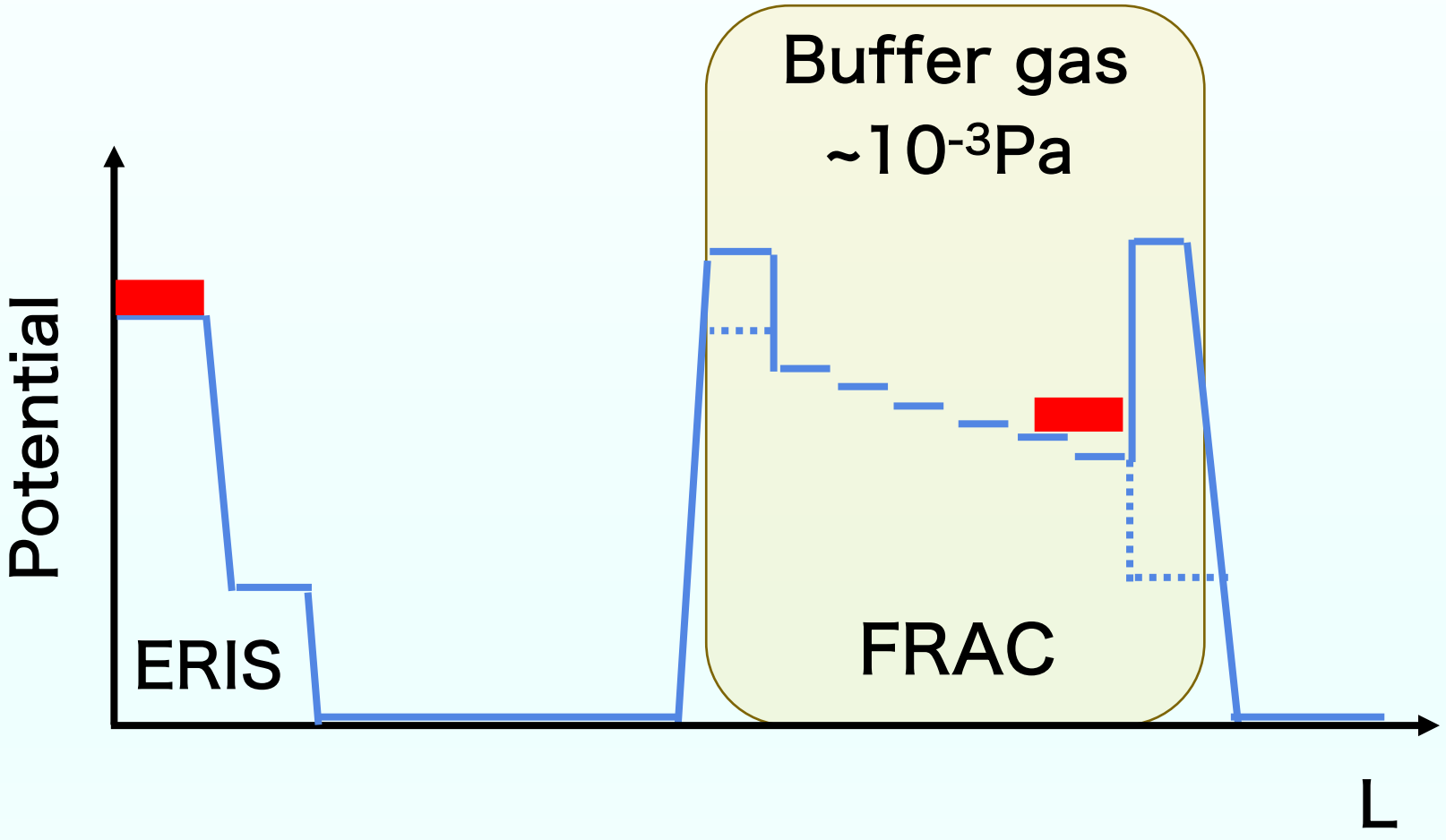


2-step bunching method

4. Next pre-pulse is extracted from ERIS



2-step bunching method

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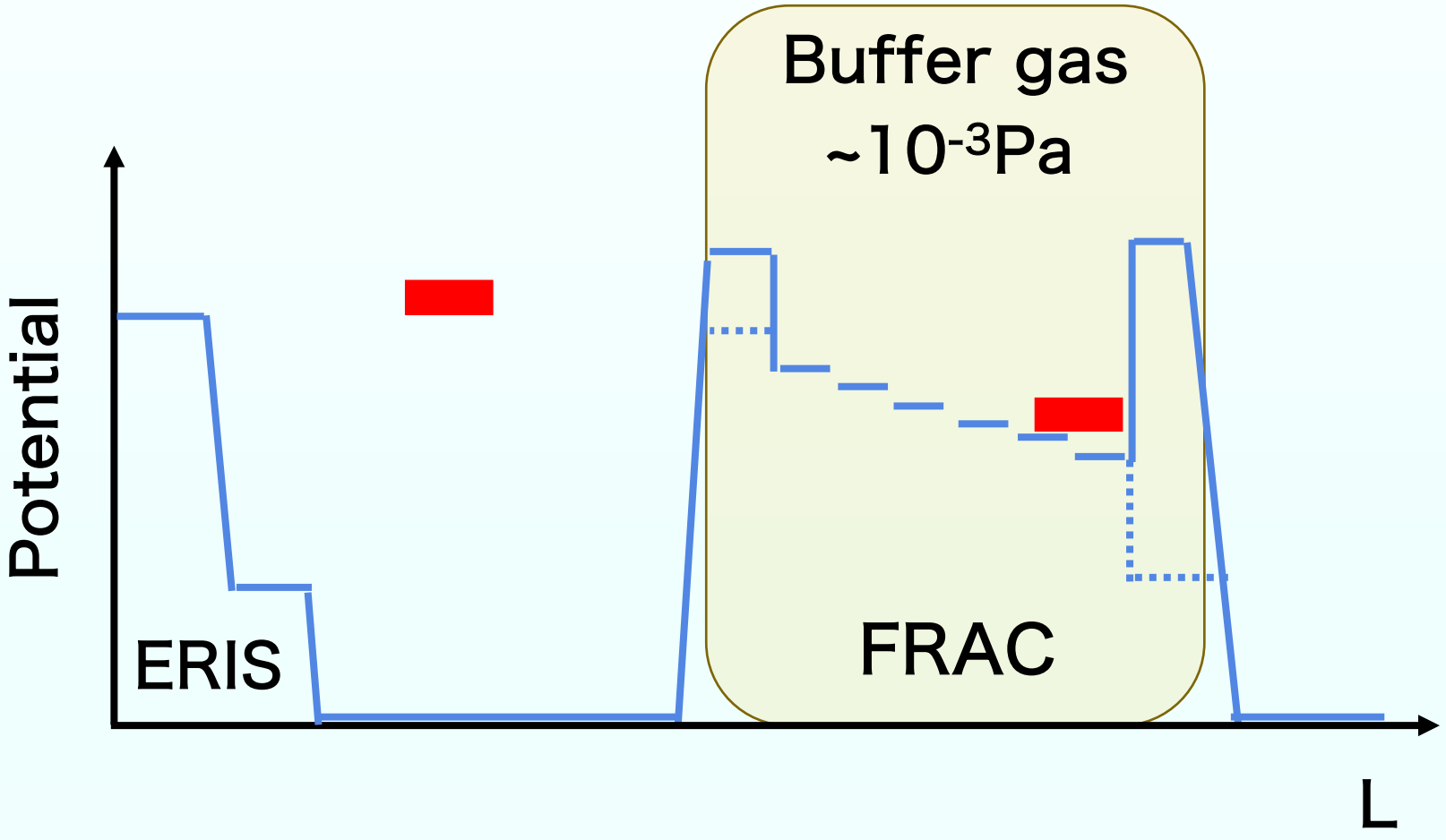
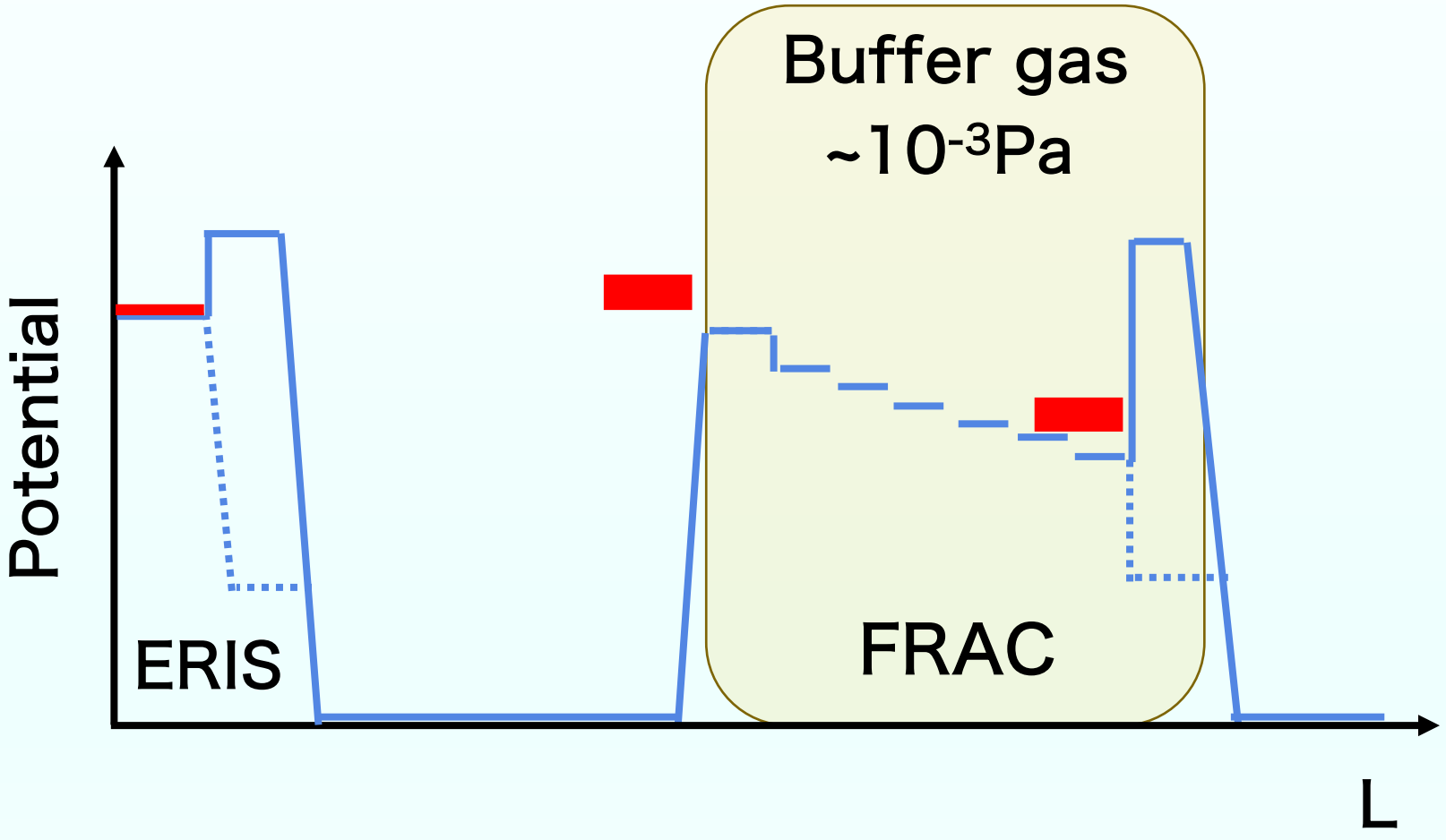


2-step bunching method

5. Next pre-pulse is injected to FRAC



2-step bunching method

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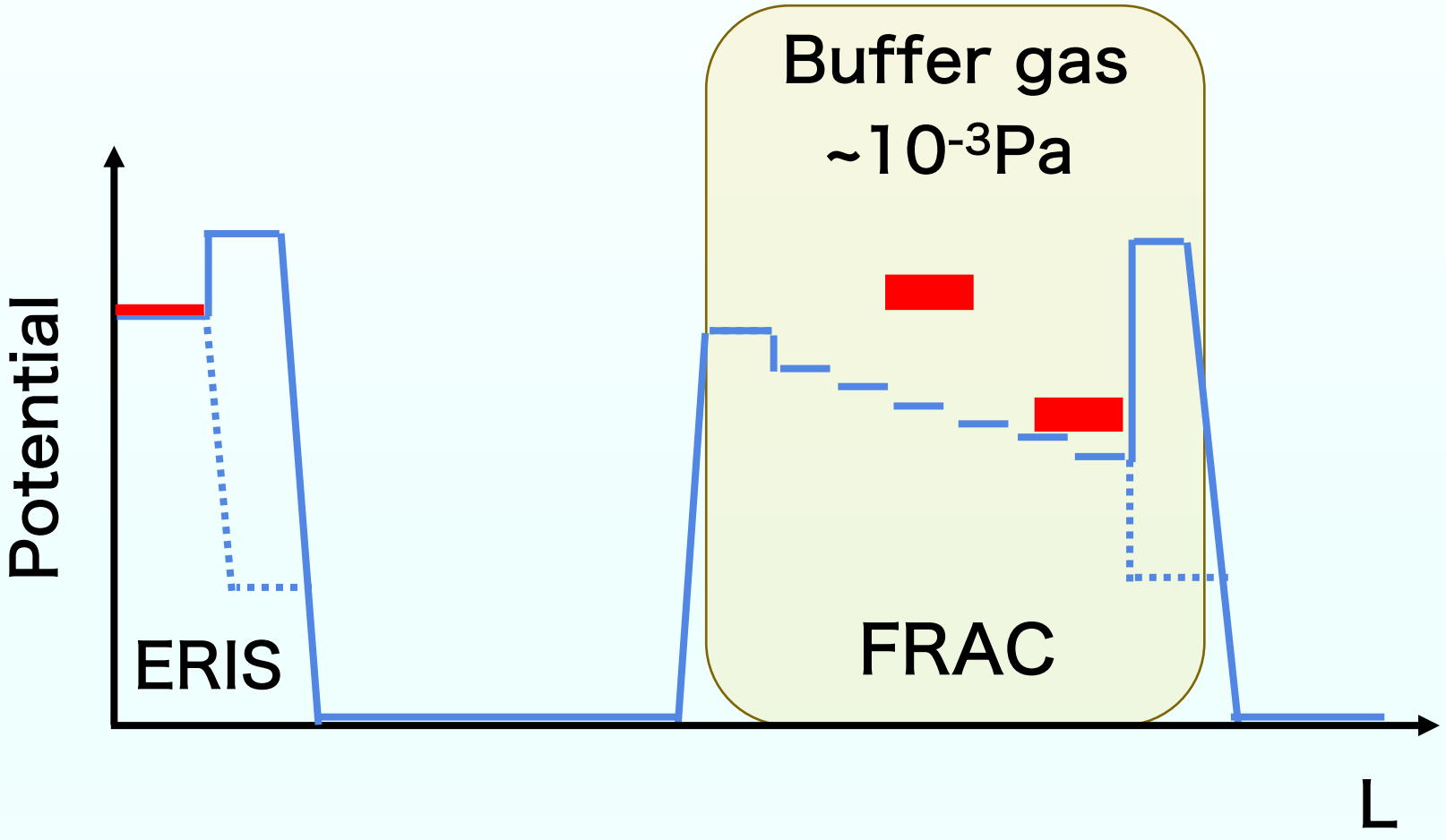
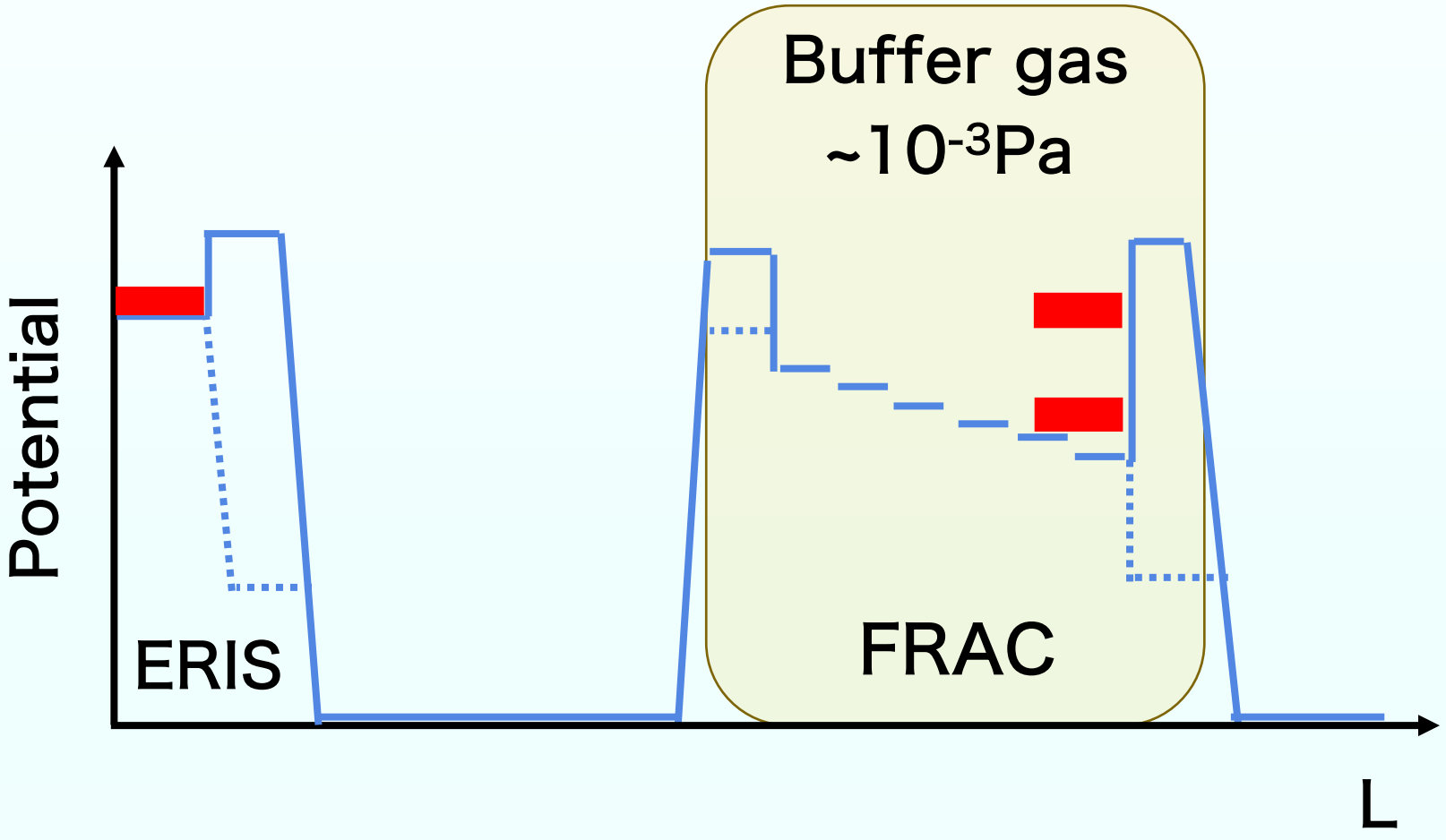


2-step bunching method

6. The ions are trapped and cooled in FRAC



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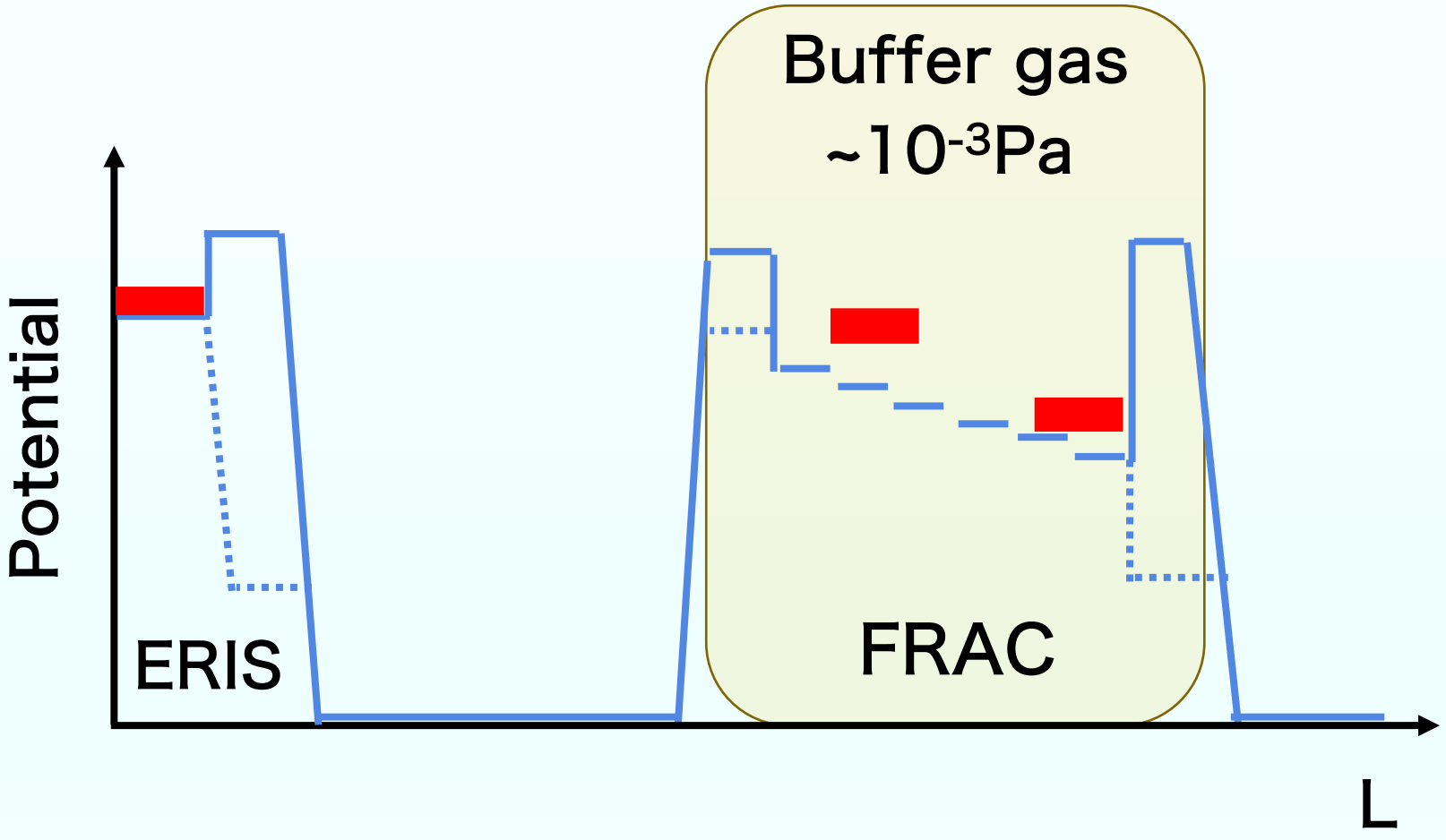

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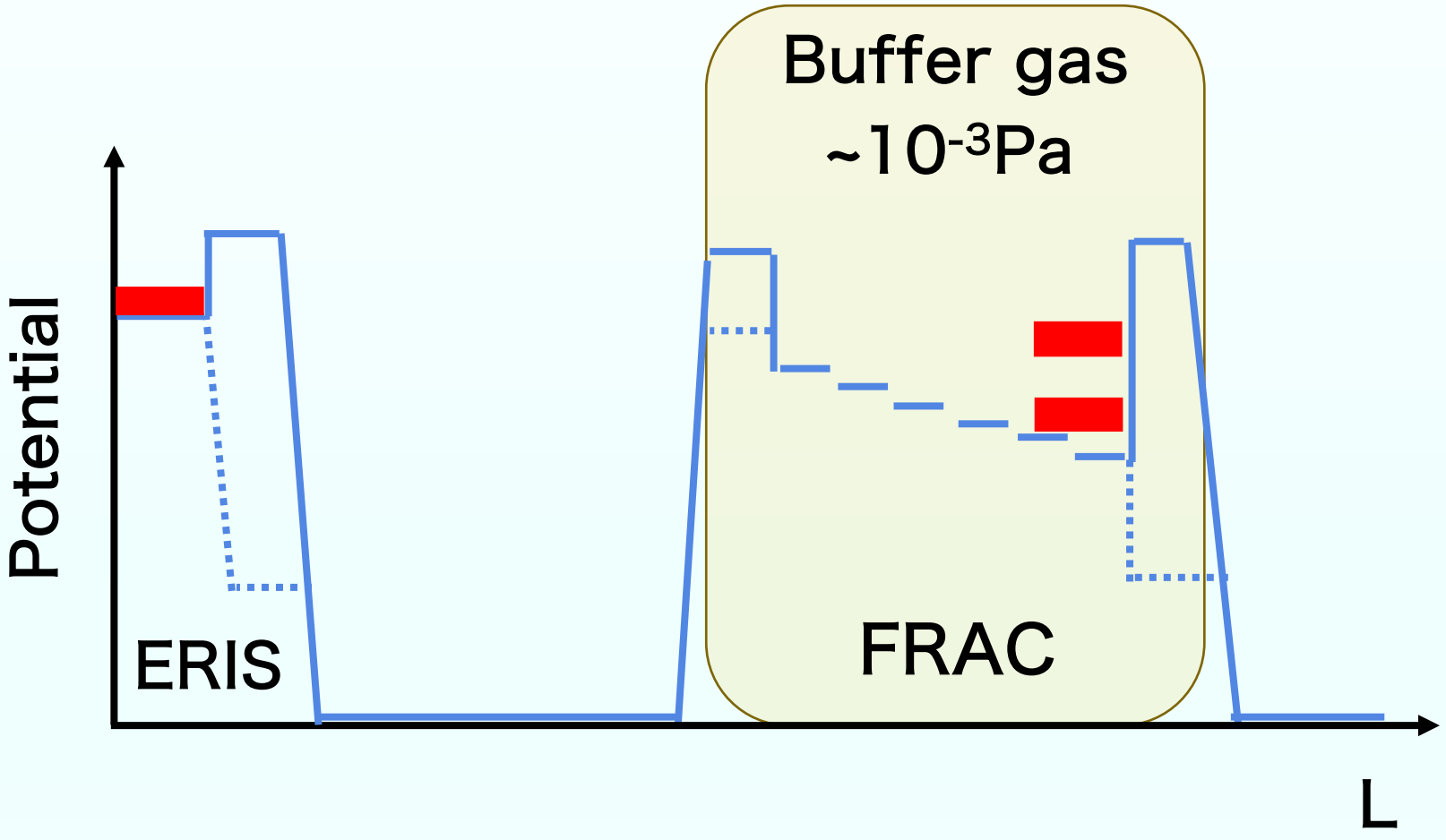

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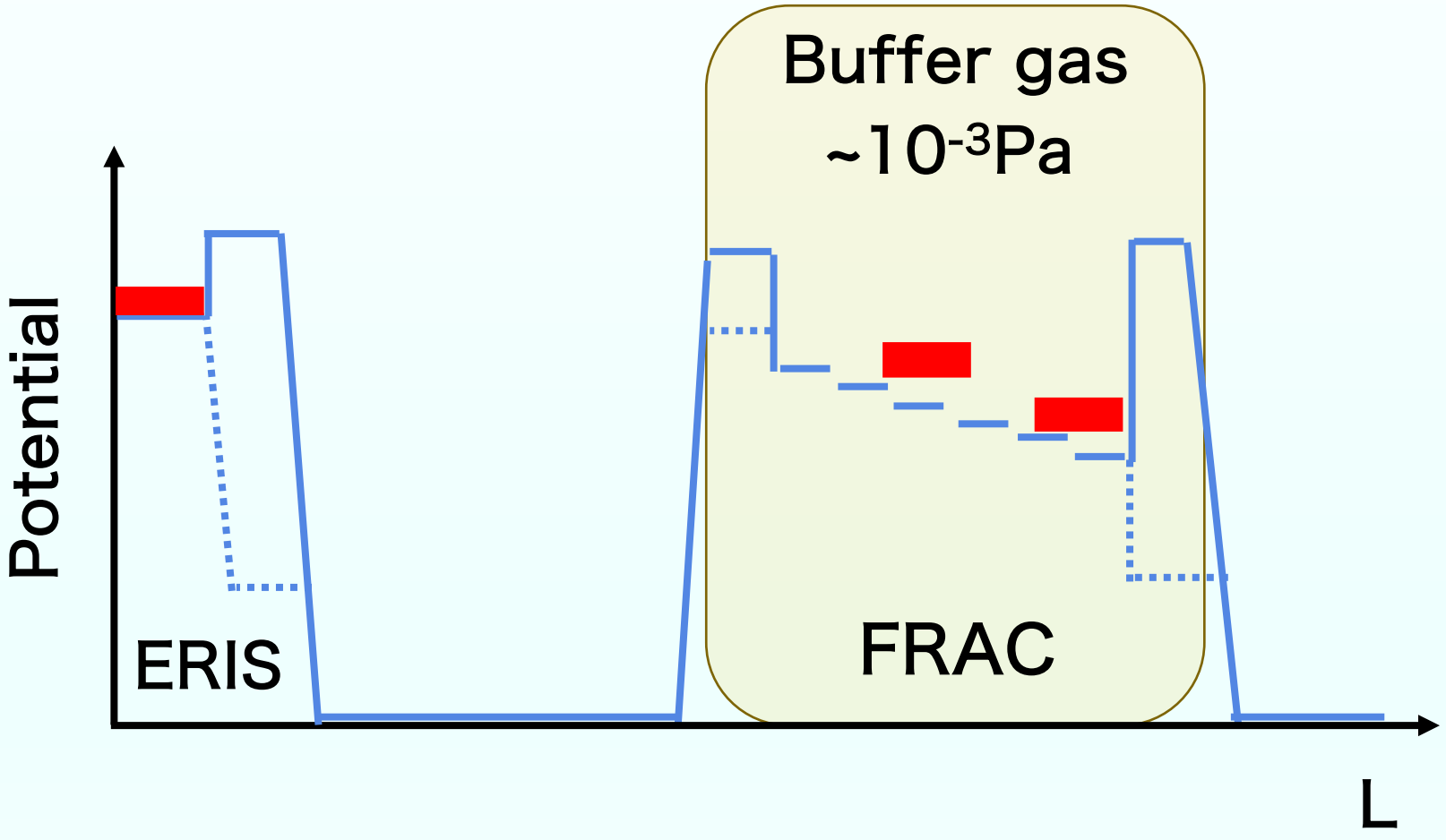

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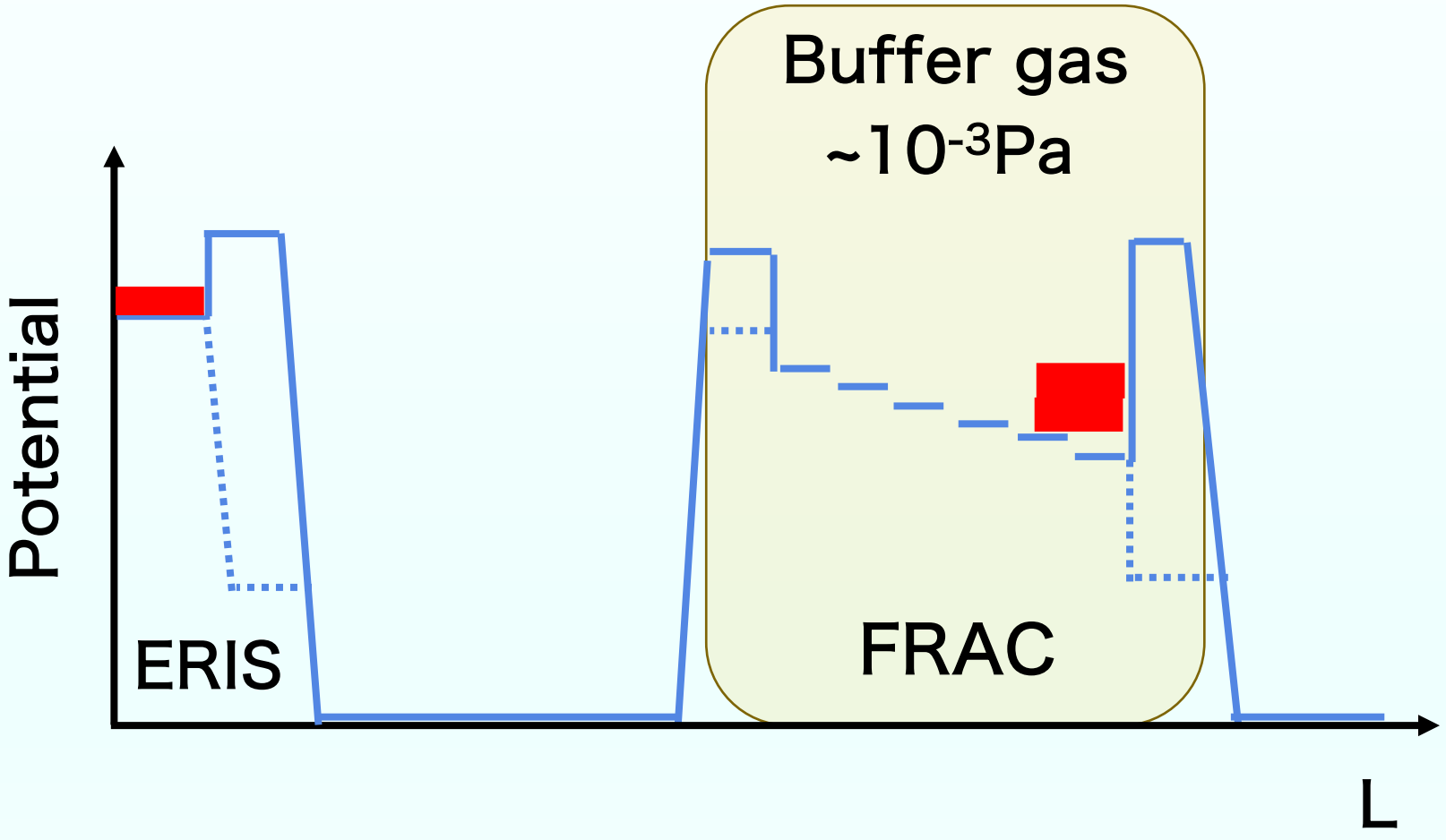
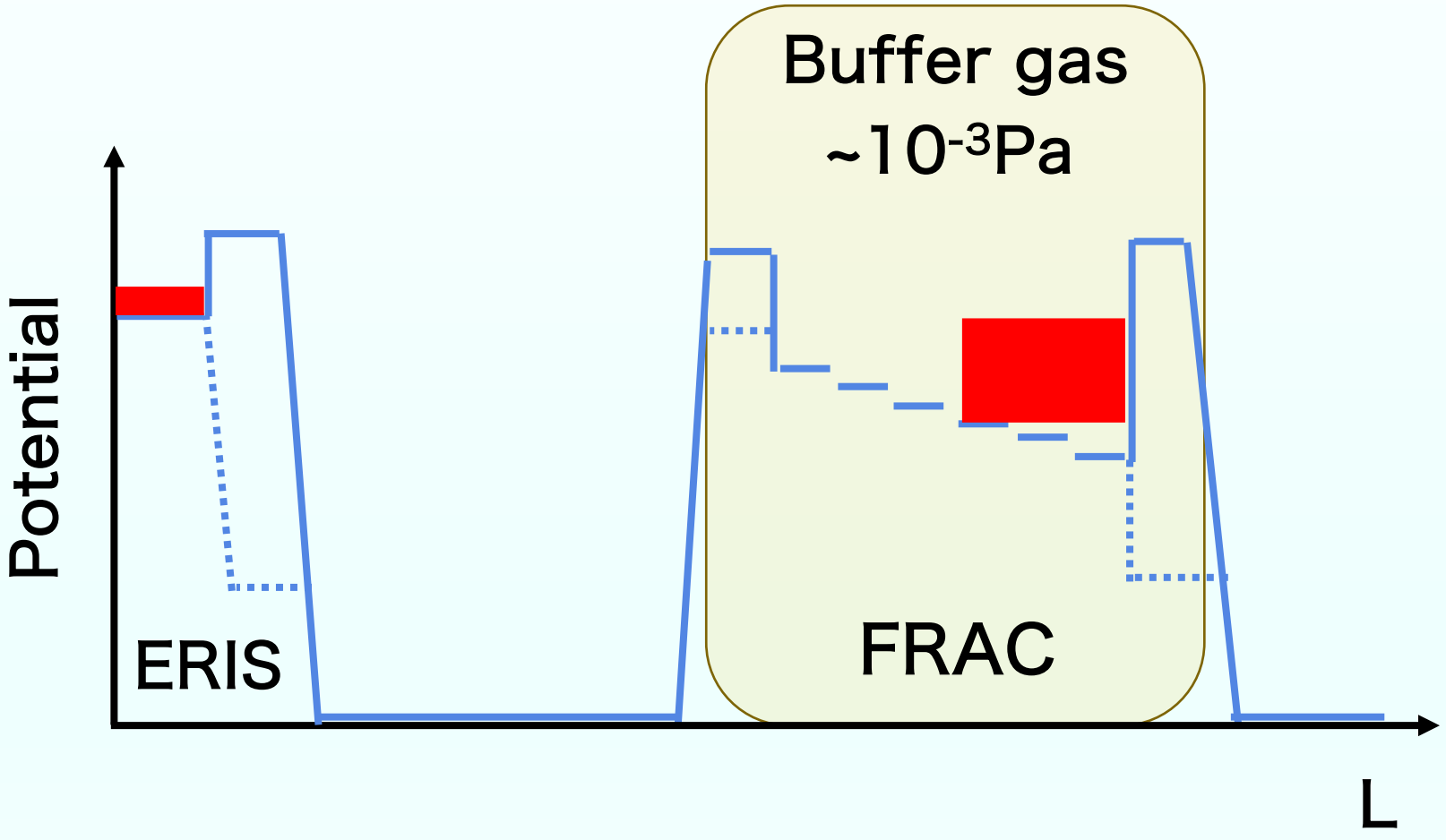


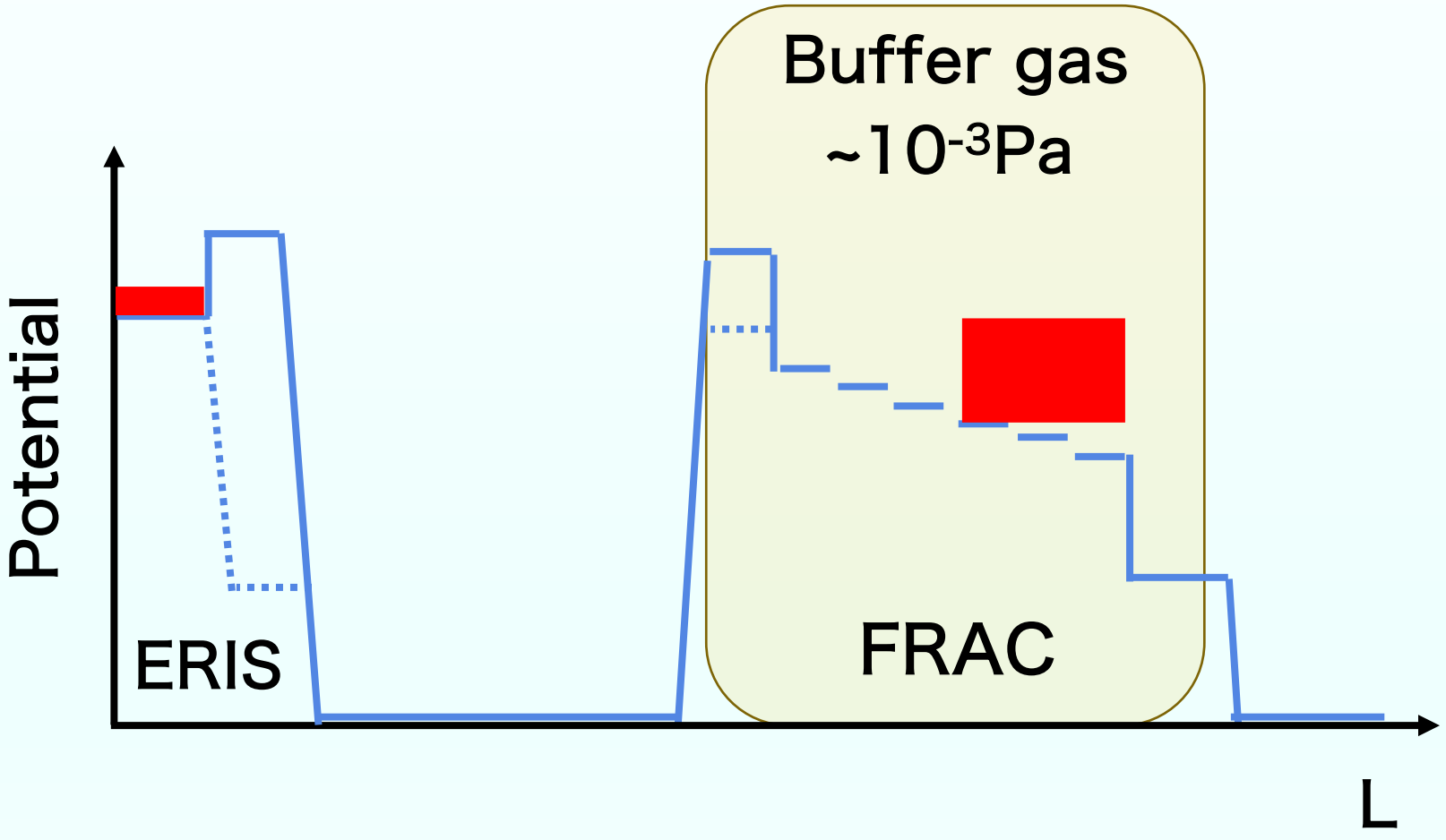
2-step bunching method

7. The pre-pulses are stacked in FRAC



2-step bunching method

8. The ions stacked in FRAC is extracted



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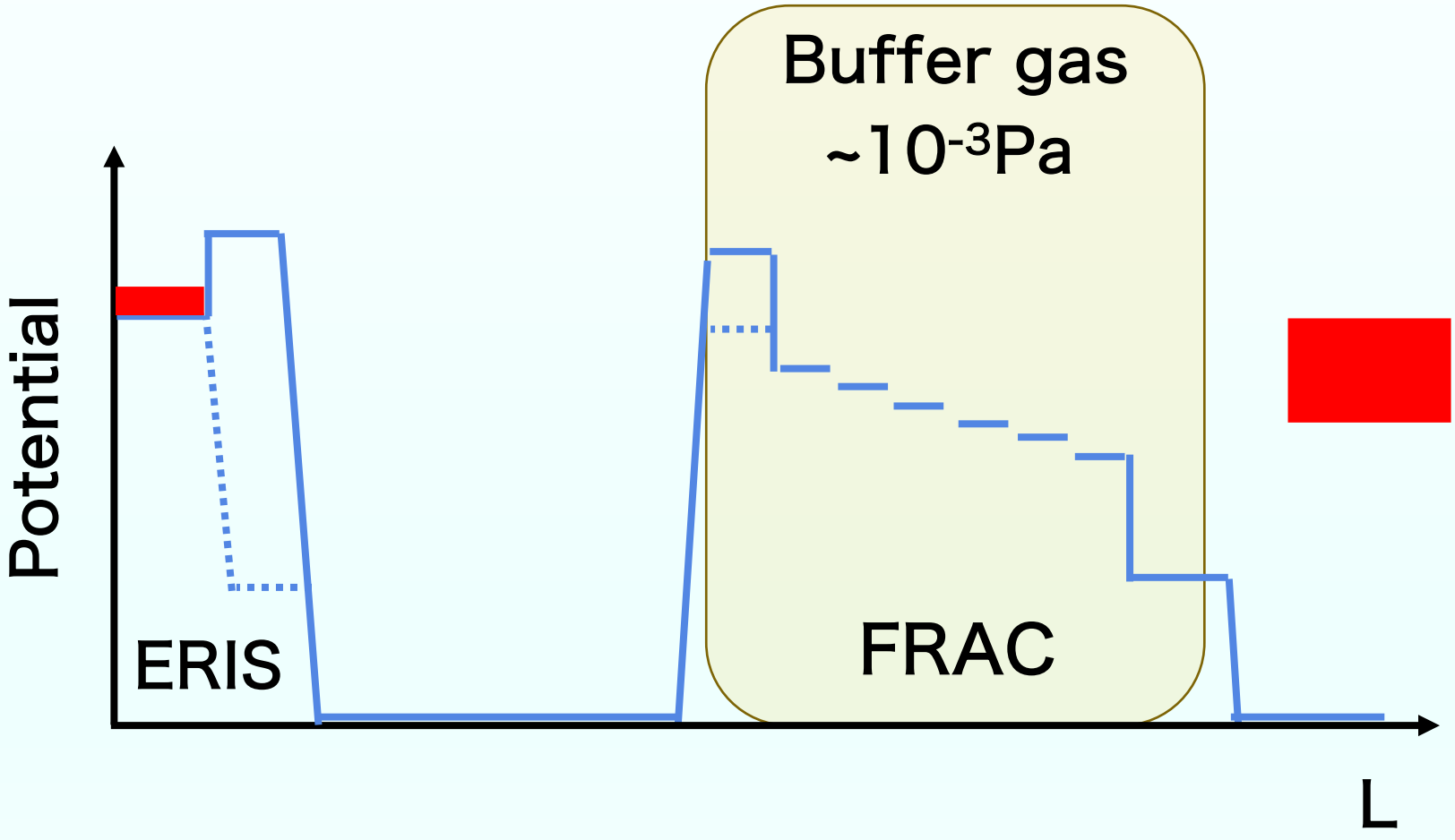
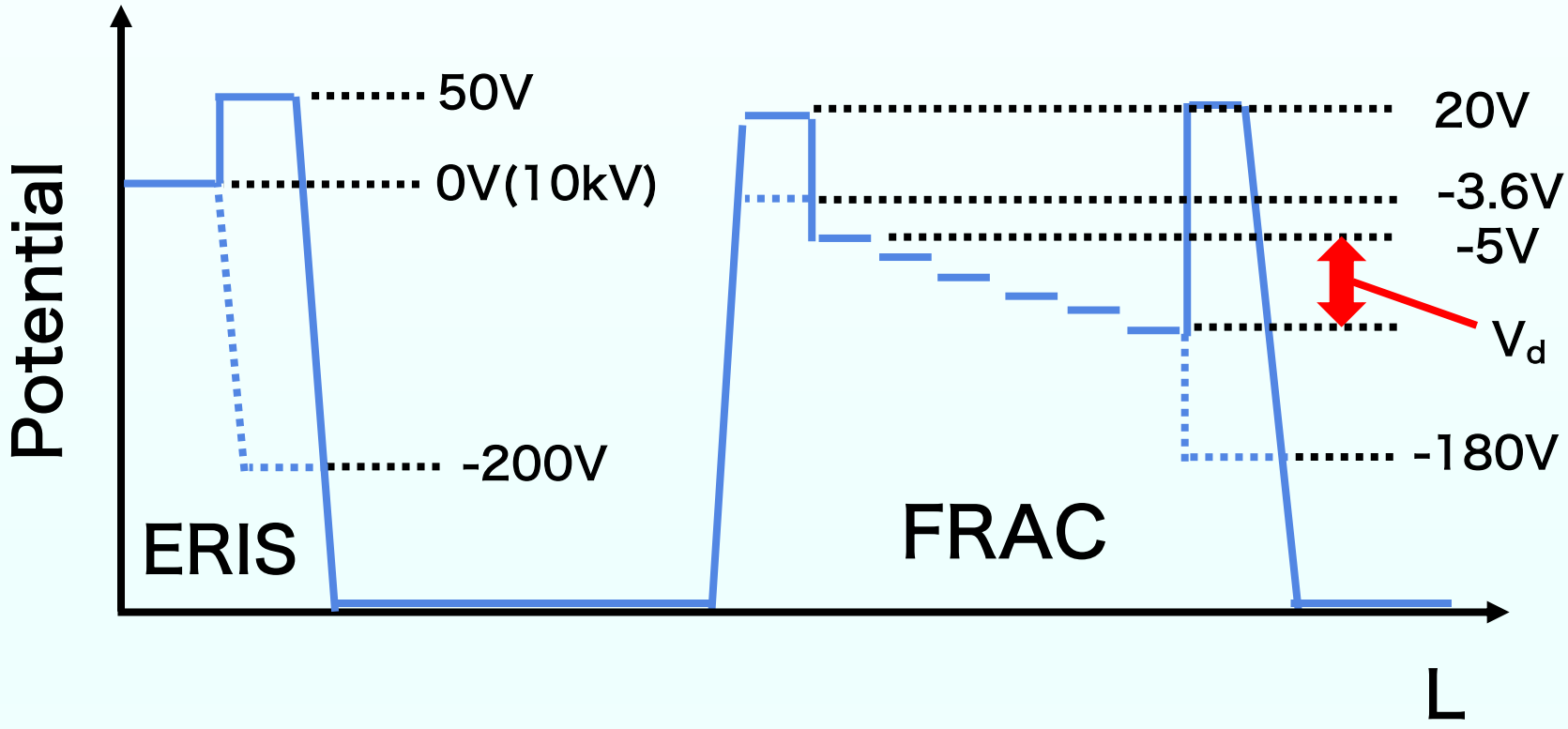


2-step bunching method

The potential value relative to the beam energy



2-step bunching method

ERIS : converts the DC beam to pre-pulse beam

FRAC : cools and stacks the pre-pulse beam

1. How long can ERIS hold the ions efficiently?
2. How long FRAC takes to cool the ions sufficiently?

Pre-pulsing frequency	ERIS efficiency	FRAC efficiency
High	↑	↓
Low	↓	↑

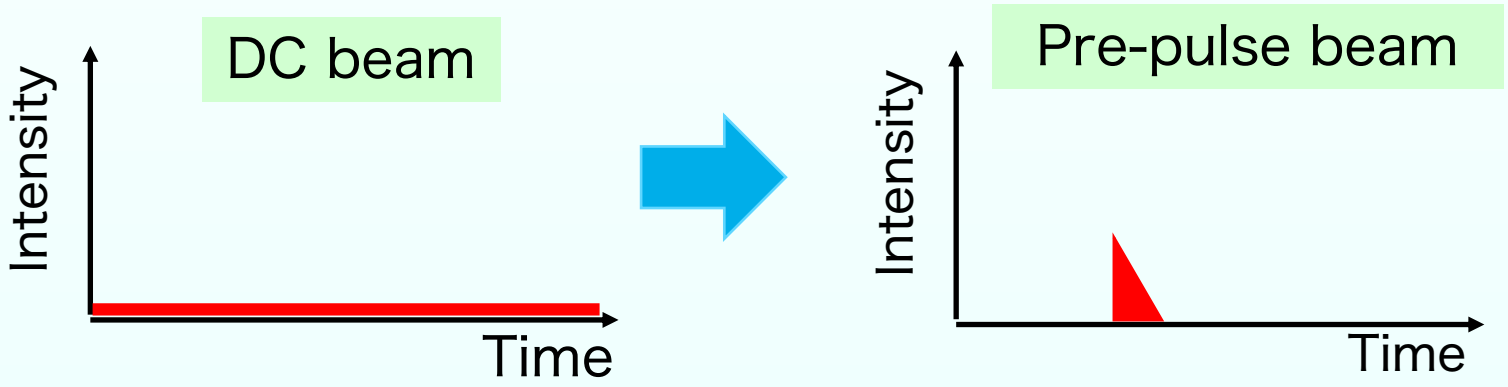
Pre-pulsing frequency is very important.

Determination the pre-pulsing frequency

1. The pre-pulsing frequency dependence of ERIS efficiency

Ion beam : $^{140}Cs^{+}$

$$\text{ERIS efficiency} = \frac{\text{ions in the pre-pulse}}{\text{ions in DC}}$$



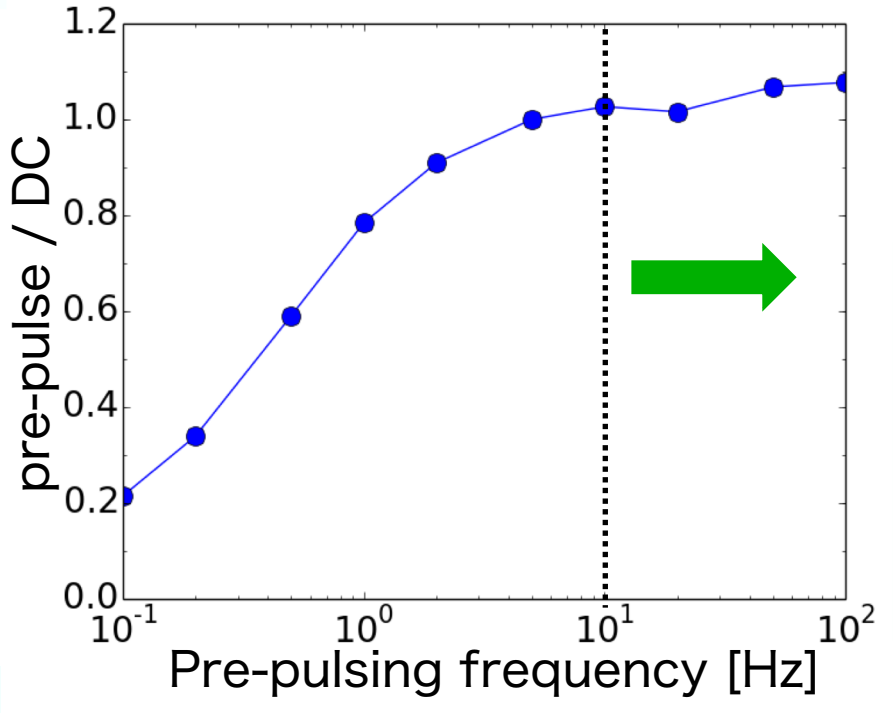
2. The energy of the ions in FRAC

Ion beam : ^{133}Cs

The energy of the ions in FRAC is estimated by pulse width of extracted pulse.

Determination the pre-pulsing frequency

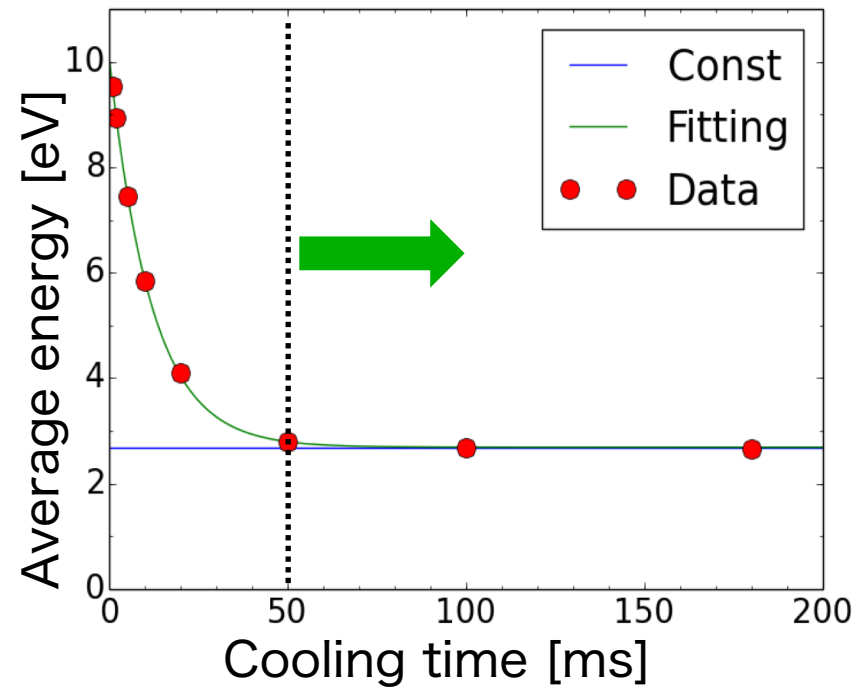
ERIS efficiency



Pre-pulsing frequency ≥ 10Hz

ERIS efficiency : 100%

The energy of the ions in FRAC



Cooling time ≥ 50ms

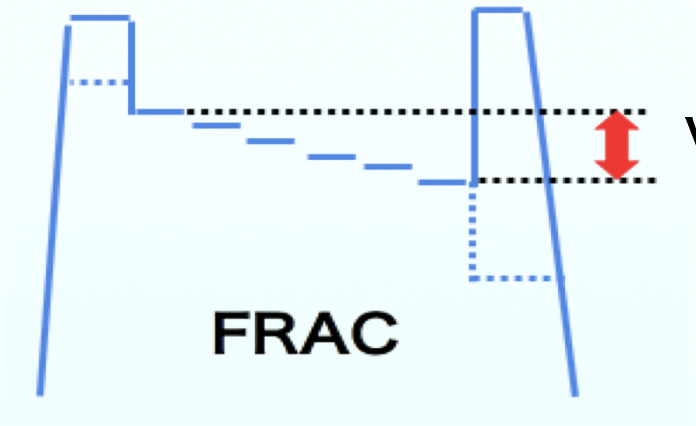
The ions are cooled sufficiently.

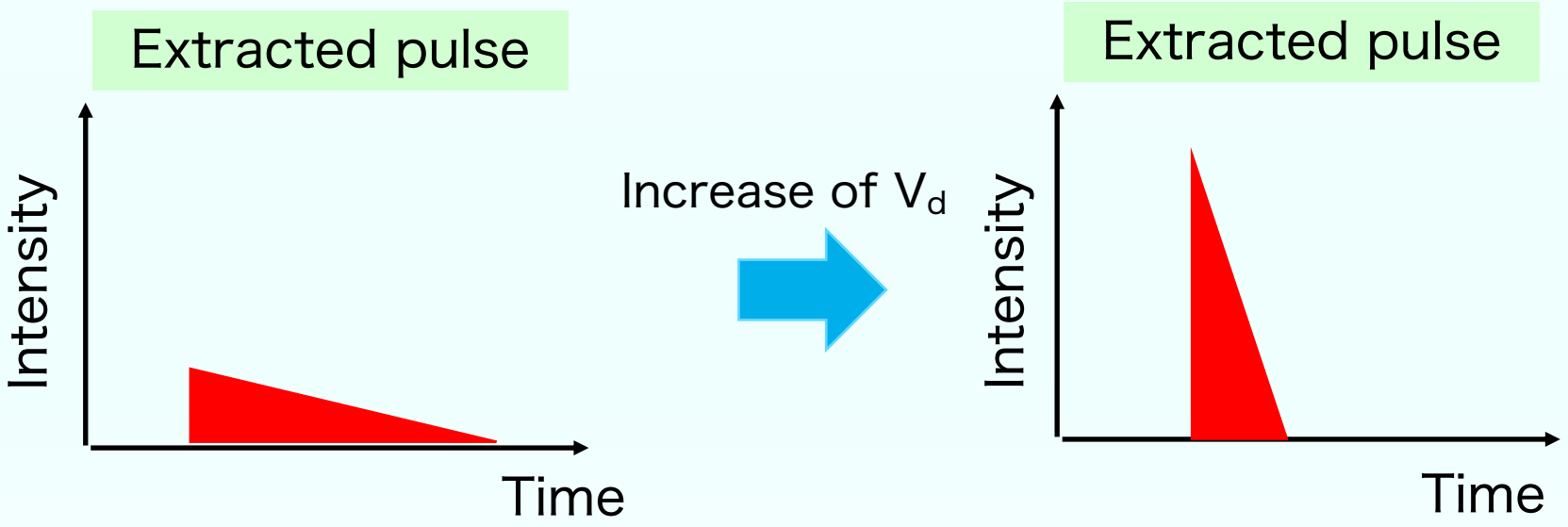
The pre-pulsing frequency was determined 10Hz

V_d dependence of pulse width

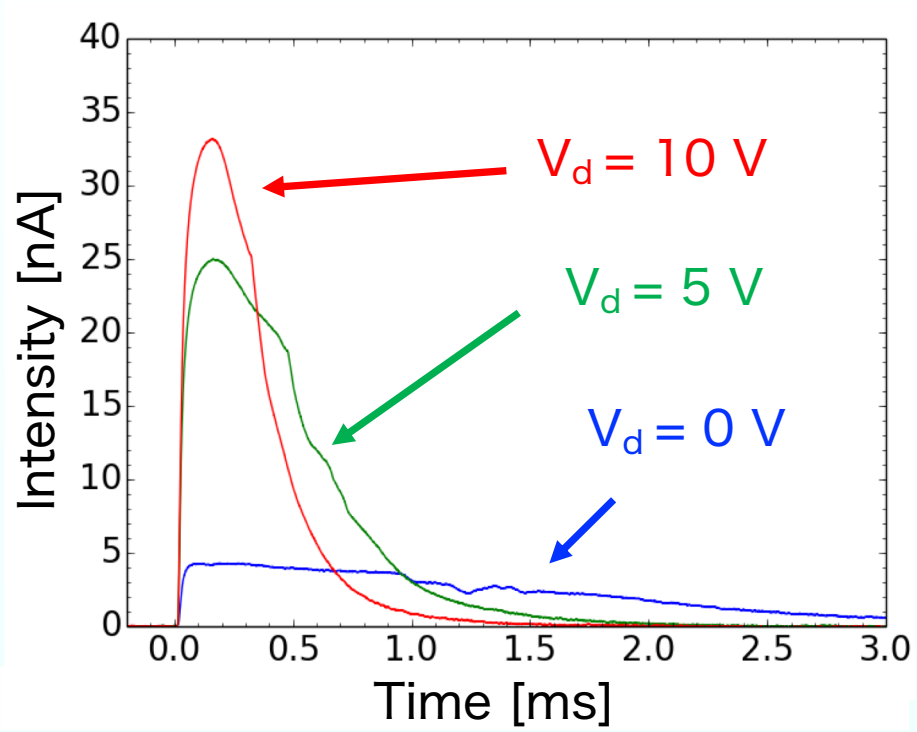
- Measurement to determine appropriate V_d

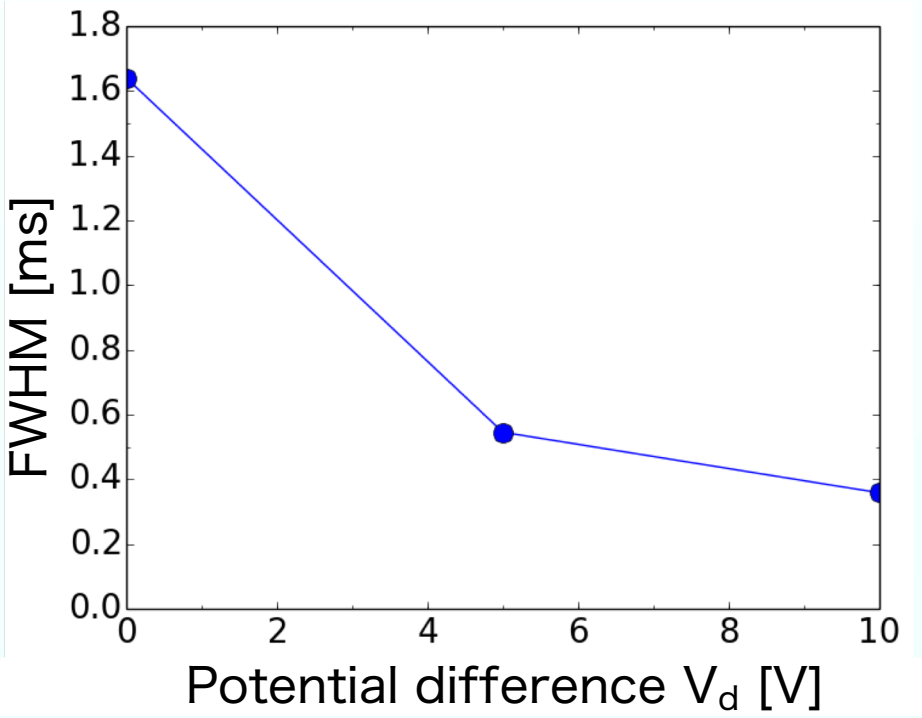
Ion beam : $^{133}Cs^+$





V_d dependence of pulse width





The pulse width was close to the target value when the potential difference V_d =10V

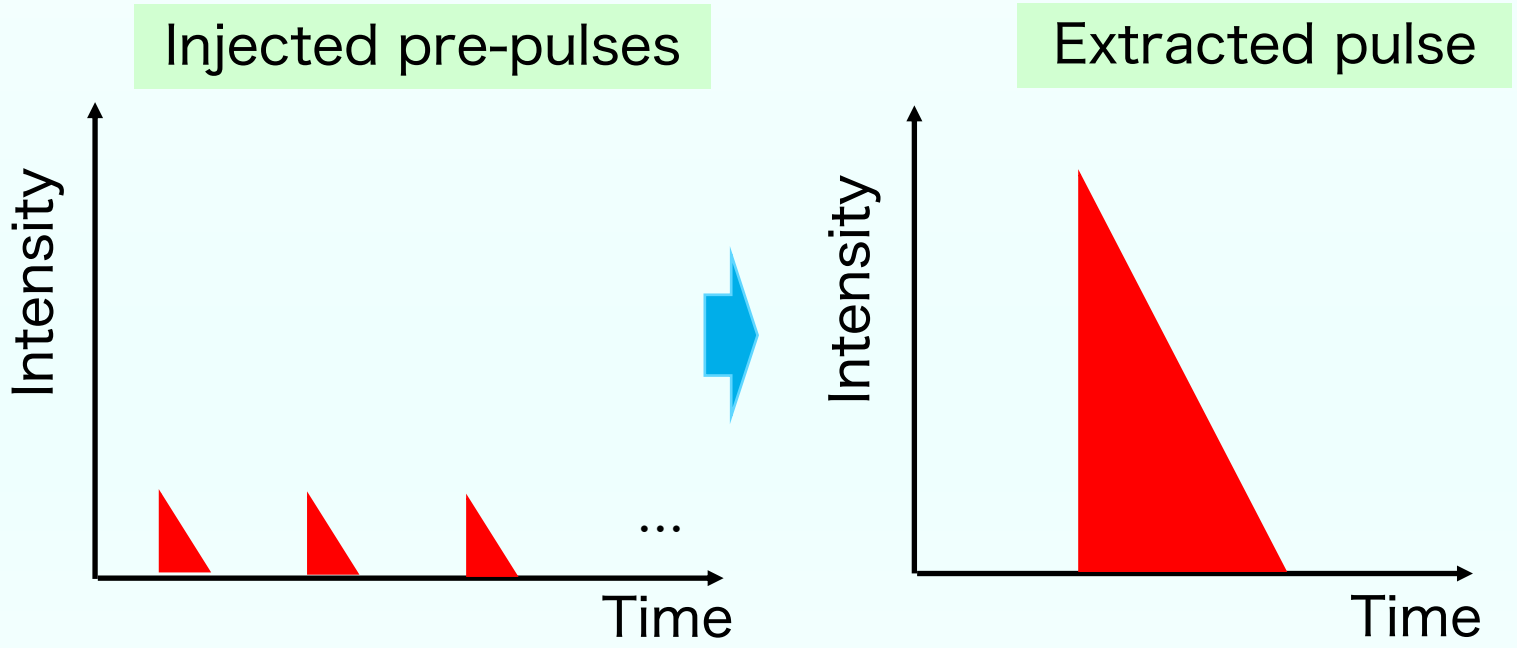
FRAC efficiency

The pre-pulsing frequency : 10Hz

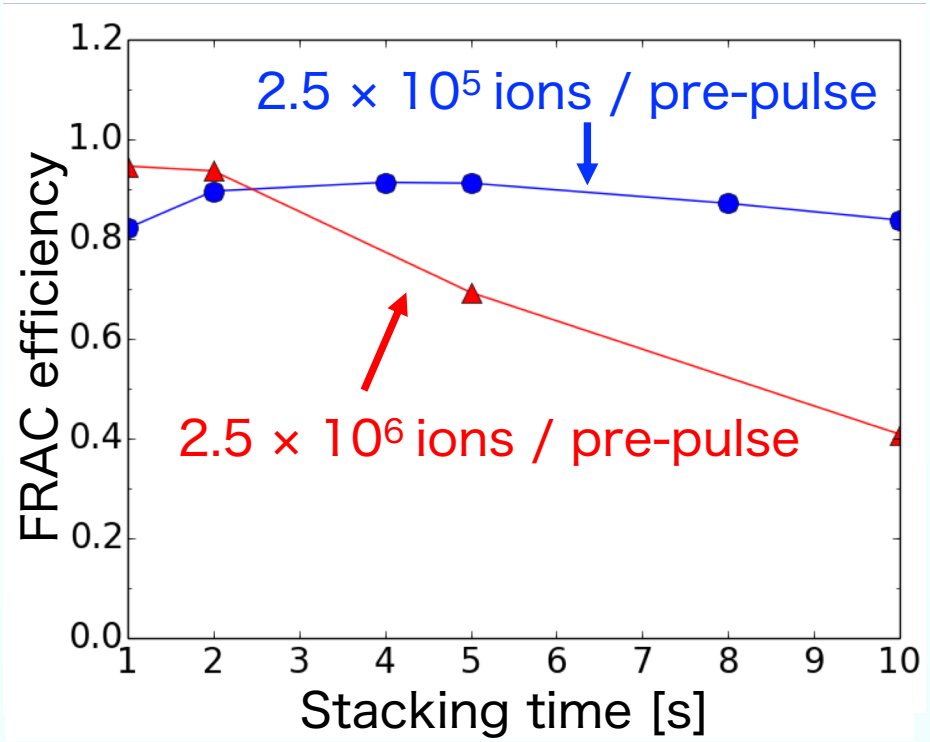
The potential difference V_d : 10V

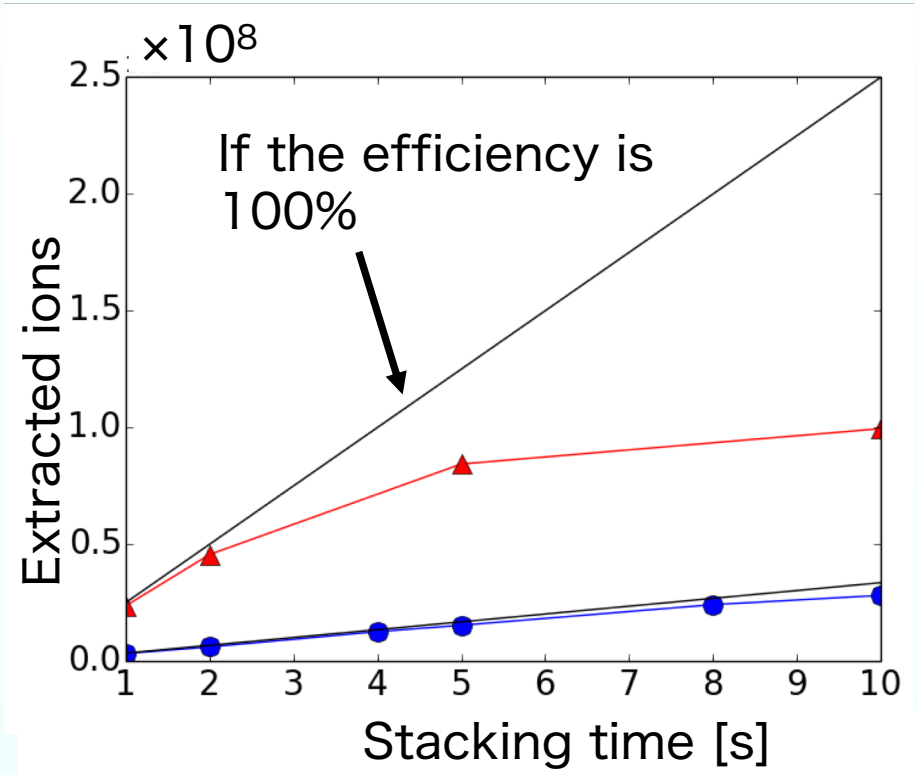
Ion beam : $^{133}Cs^+$

$$\text{FRAC efficiency} = \frac{\text{extracted ions}}{\text{Injected ions}}$$



FRAC efficiency





Injected ions	FRAC efficiency
< 4×10^7	~90%
1×10^8	~70%
2.5×10^8	~40%

Summary

- The DC beam is converted to a pulse beam with up to **~90% efficiency** by the 2-step bunching method.
- 10^8 ions can be extracted as a pulse beam with slightly lower efficiency above 4×10^7 ions.

■ Next step

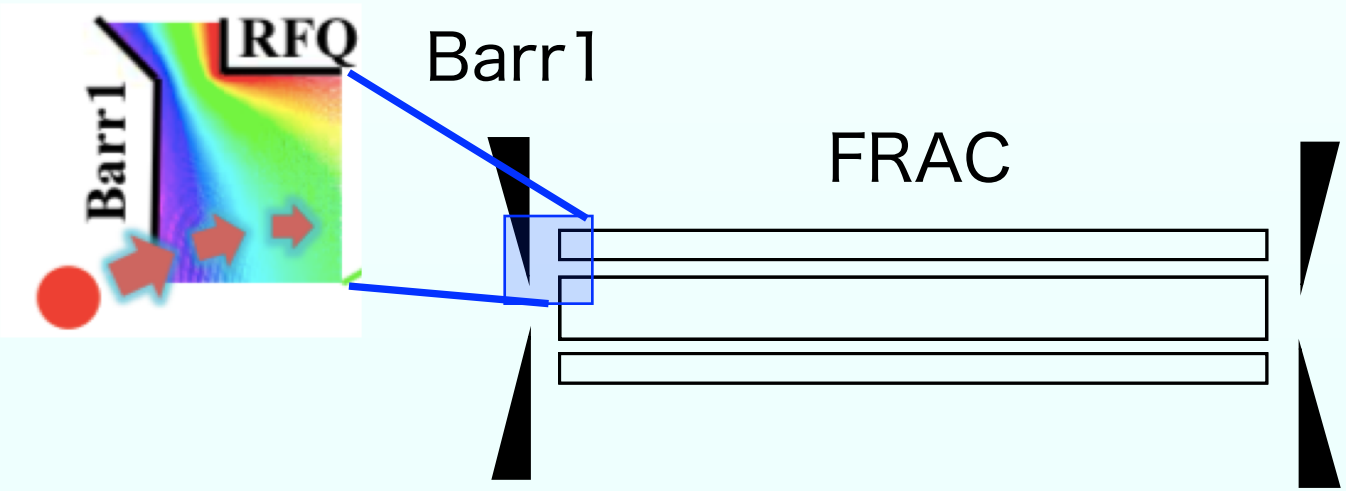
- We want to convert the DC beam more efficiently when the injected ions is more than 4×10^7.
- Modification for that is planned.

Back up

Previous performance of FRAC

FRAC(Fringing-RF-field-activated dc-to-pulse converter)

- FRAC was operated under high vacuum of ~10^{-6} Pa
- The ions were decelerated by fringing RF field



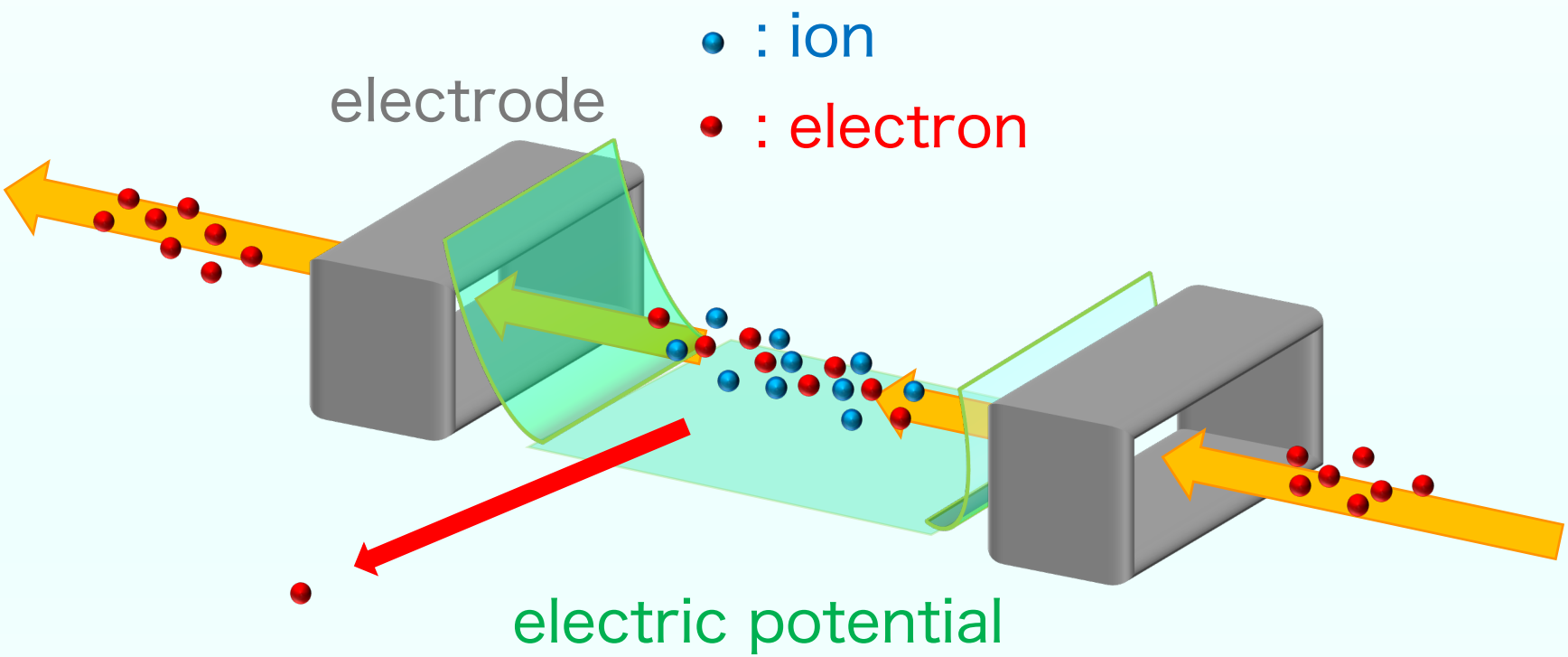
The conversion efficiency was achieved up to ~5%.

RI ion trapping by SCRIT

Transverse trap : Focus force made by electron beam

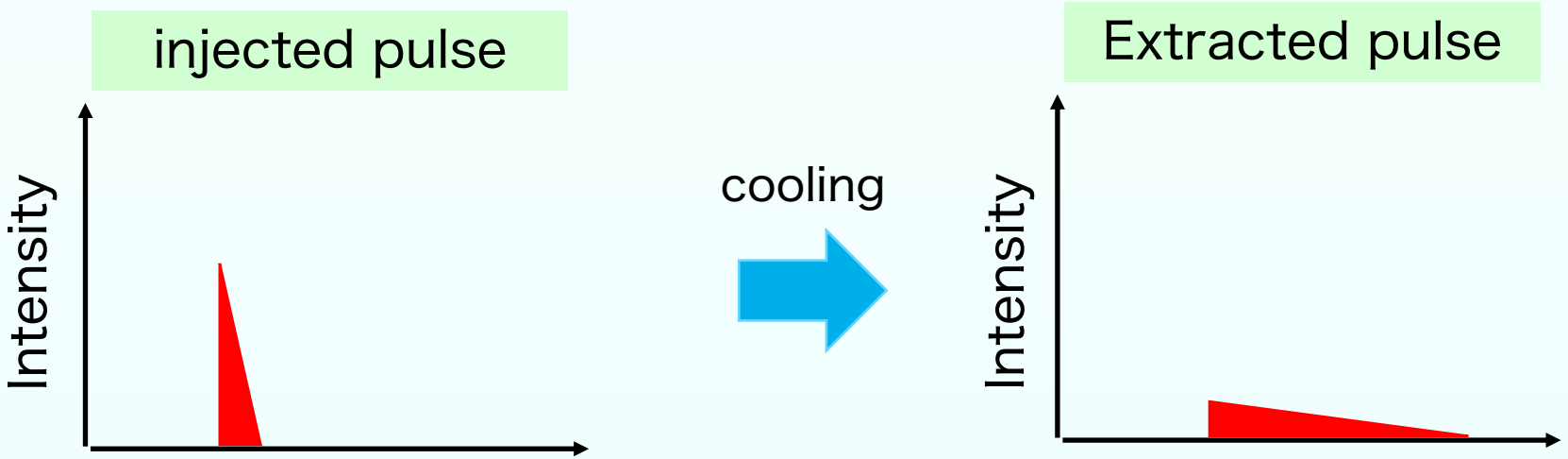
+

Longitudinal trap : electric potential made by barrier electrode



Method to estimate the energy

The potential difference V_d : 0V



$$\text{The width} = \frac{\text{The length of FRAC}}{\text{The velocity of ions}}$$

The energy is estimated