Reaction studies of Exotic Nuclei with Rare-RI Ring

Tomohiro Uesaka
uesaka@riken.jp
RIKEN Nishina Center

Reaction studies of Unstable Nuclei

(Static) ground state properties

Mass $\mathcal{H}|0\rangle = E|0\rangle$

Moments $\langle 0|\mathcal{O}|0\rangle$

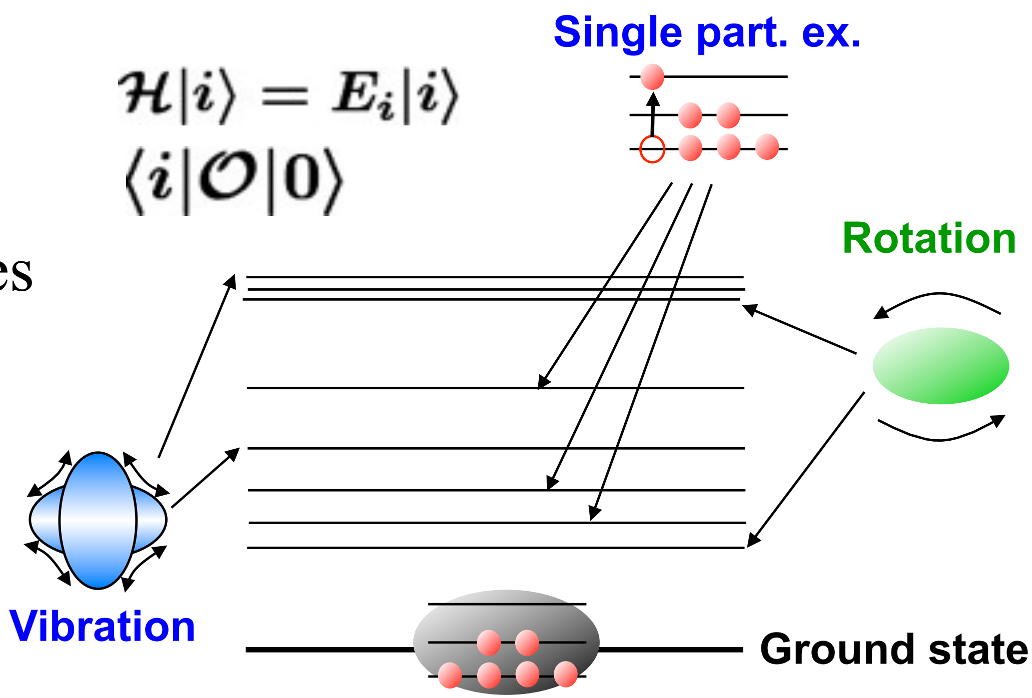
Spin-parity

Reaction observables

Excitation energy $\mathcal{H}|i\rangle = E_i|i\rangle$

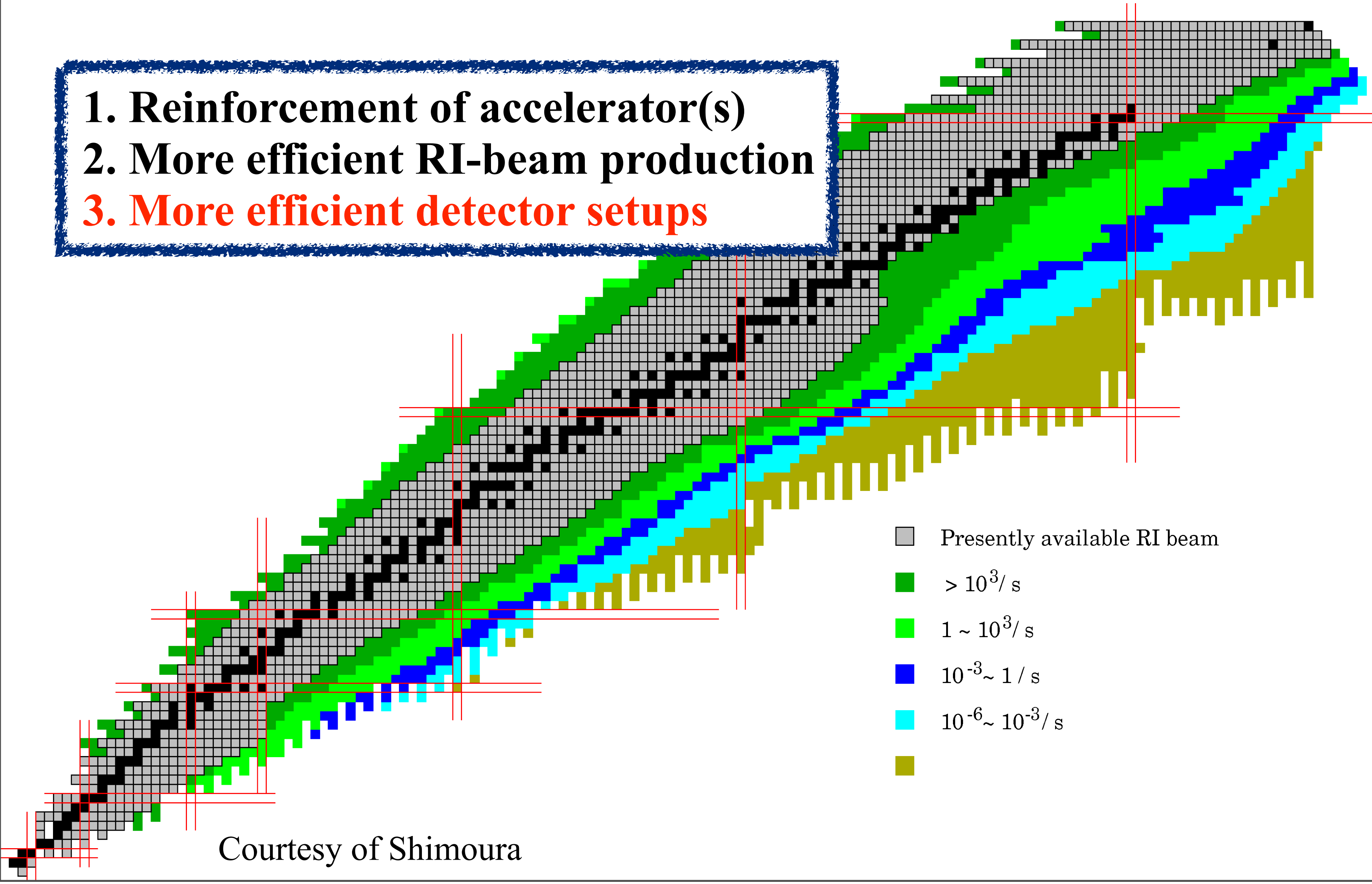
Transition probabilities $\langle i|\mathcal{O}|0\rangle$

Single particle properties



Reaction studies of very rare isotopes

1. **Reinforcement of accelerator(s)**
2. **More efficient RI-beam production**
3. **More efficient detector setups**



Courtesy of Shimoura

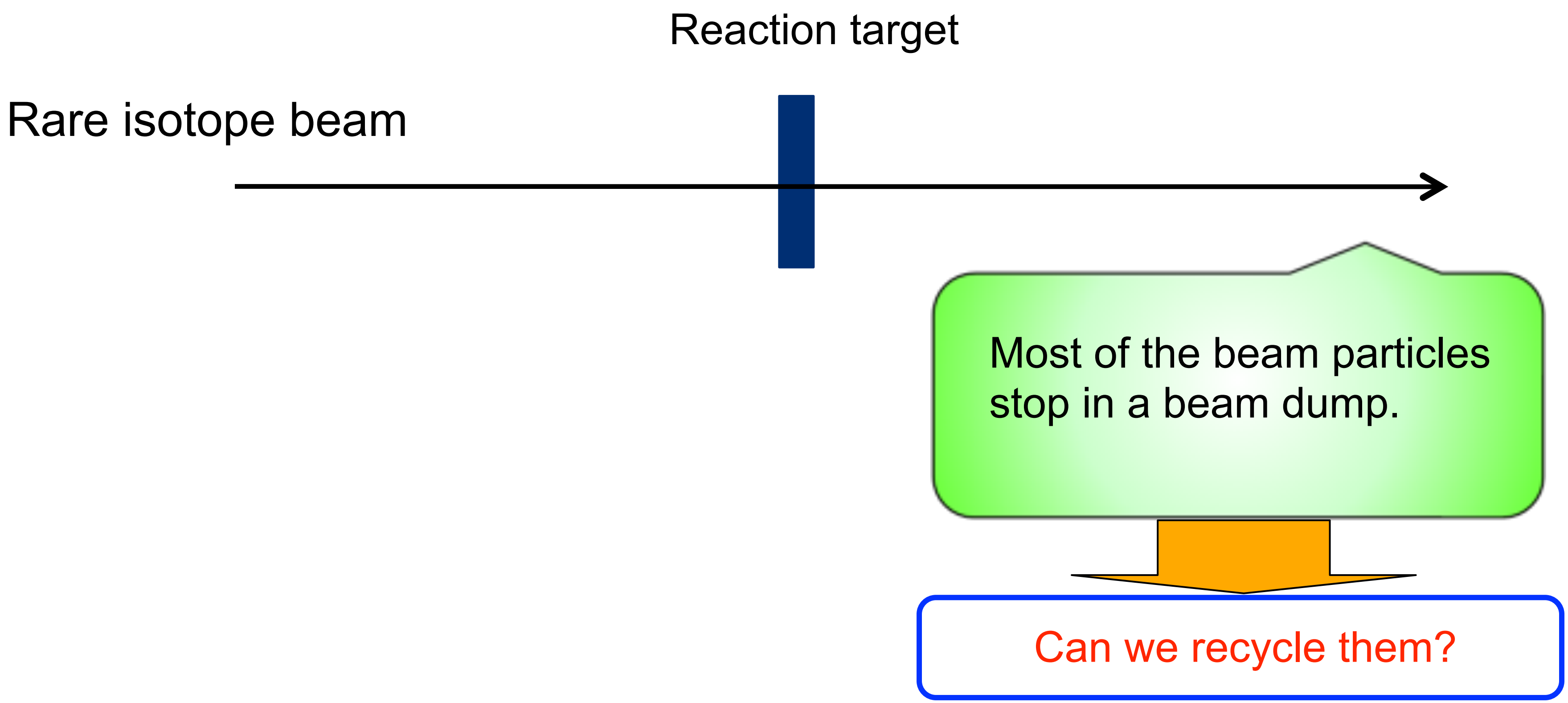
Typical target thickness in RI-beam exp.

1 mg/cm^2 — 1 g/cm^2

^{68}Ni, 200 MeV/u in a 1 g/cm^2 carbon target
$\Delta E = 3.5$ GeV ($\Delta E/E_{init} = 26\%$)

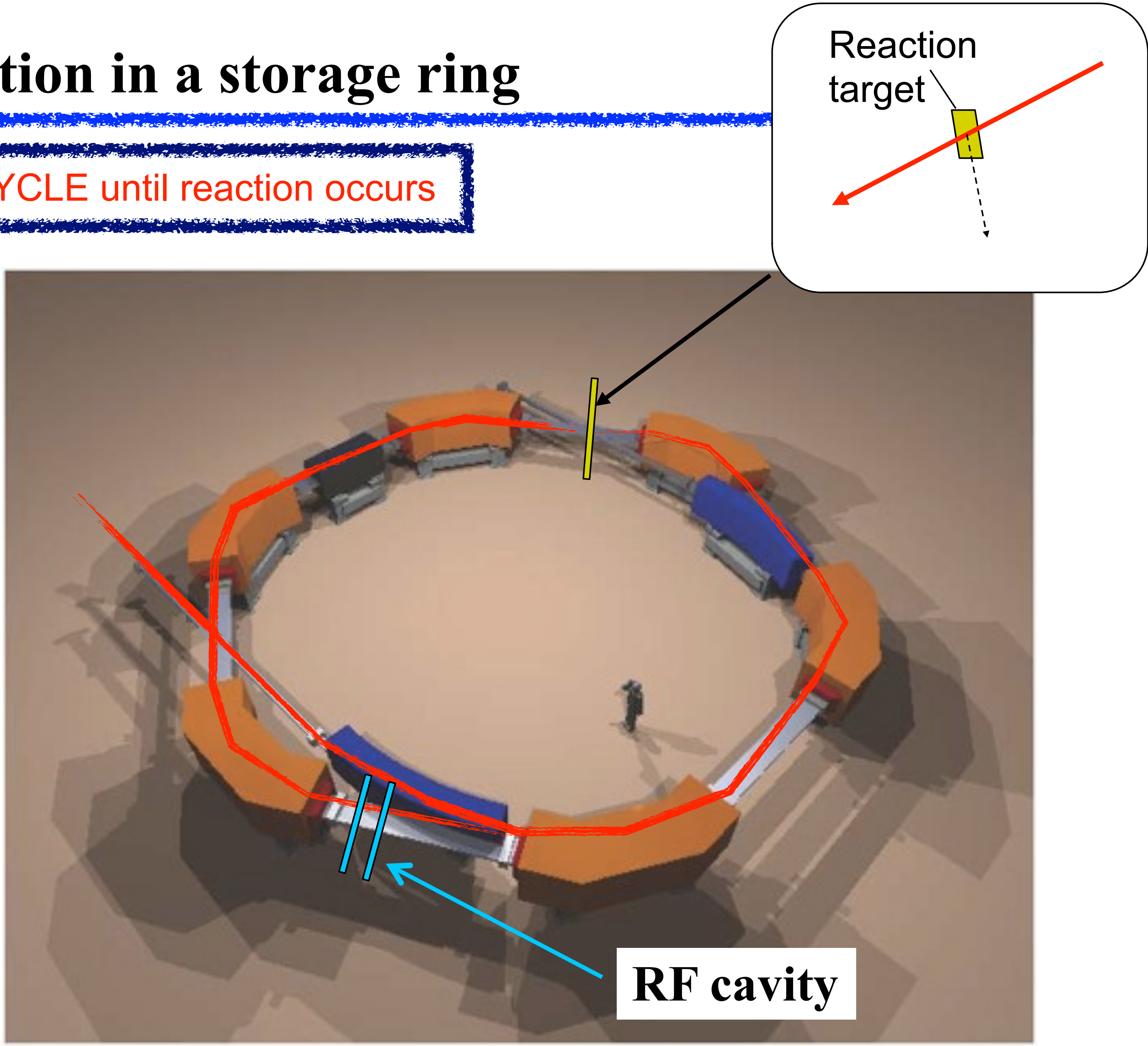
Range of 1-MeV proton in a CH_2 target
~ 3 mg/cm^2

Road to experiments with VERY rare isotopes



Reaction in a storage ring

RECYCLE until reaction occurs



Mismatch between CYCLOTRONs & RING

A DC beam

→ Injection efficiency is low. $< 10^{-3}$

→ Storage ring can be efficient only for a ~1-Hz beam. . .

Gas jet targets with a thickness of 10^{14-15} /cm^2 are too thin.

Is it possible to perform spectroscopic studies with a 1-Hz beam?

→ What is the MAXIMUM target thickness?

What is MAXIMUM target thickness?

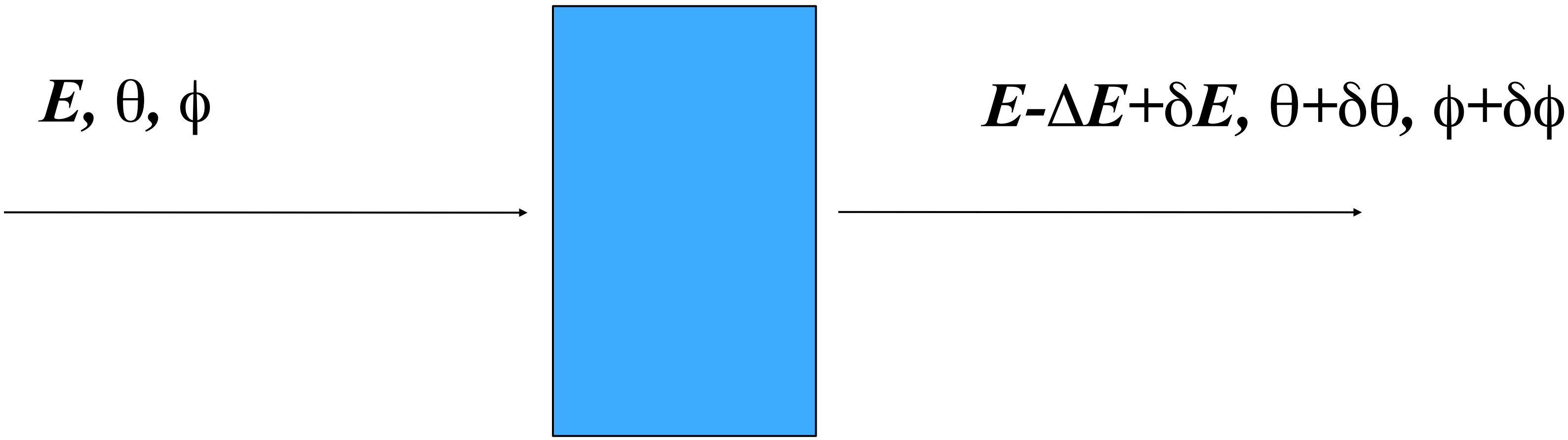
Reaction cross section: ∼1 b = 10^{-24} cm^2

On average, the beam particle survives after traveling a 10^{24} /cm^2-target.

H: 1.5 g/cm^2 ~ 20 cm (liquid)
C: 18 g/cm^2 ~ 9 cm
Pb: 300 g/cm^2 ~ 30 cm
≫ stopping range

Usual TARGETs (<1 g/cm^2) are
THICK in the sense of energy loss/recoil energy, but
THIN in the sense of its 'LIFETIME'

1-mg/cm² in the ring



Δ*E*: constant

200-MeV/u ^{68}Ni in carbon of 1 mg/cm²

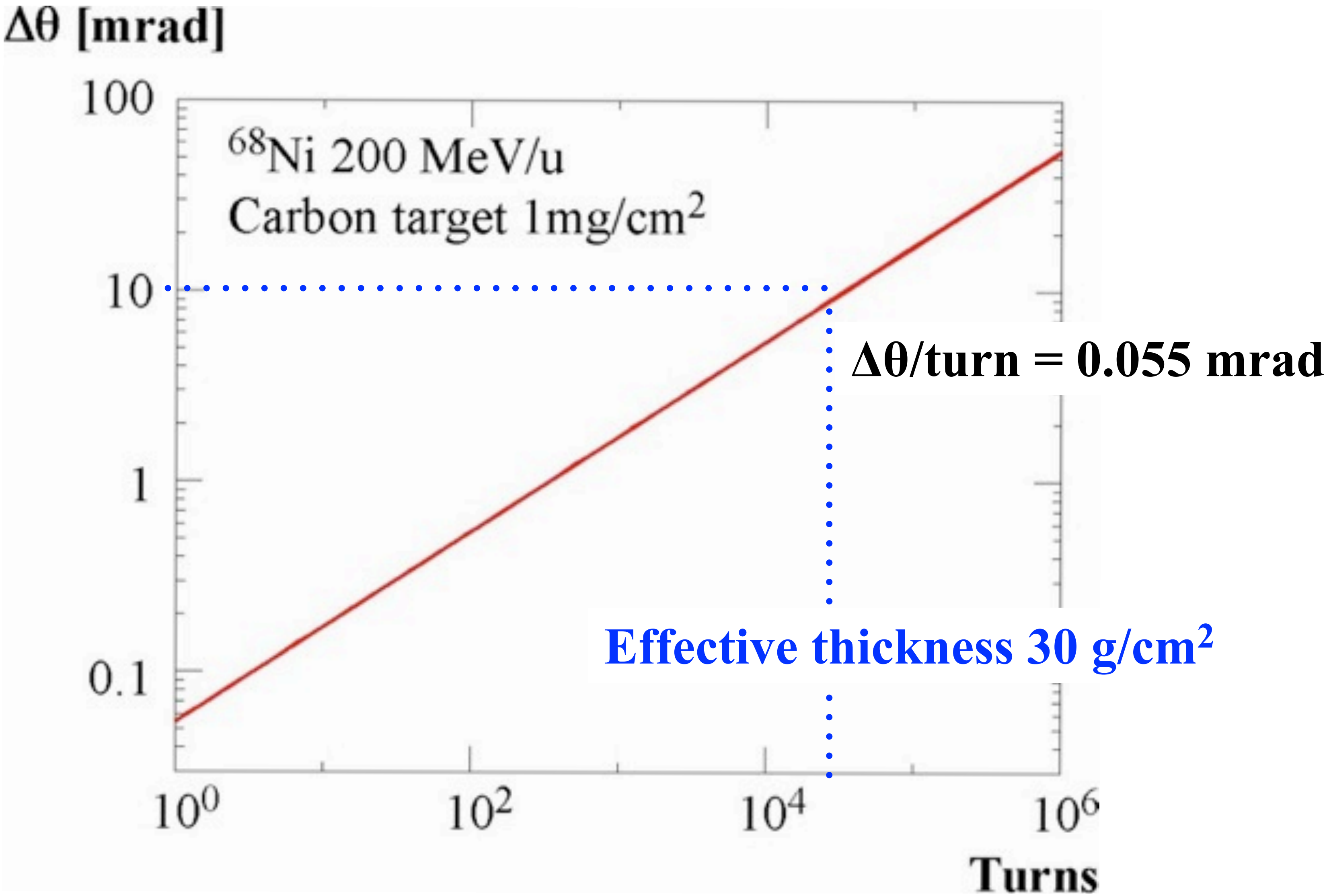
→ Δ*E*~ 3 MeV ⇔ *Z* × 100 kV

if we recycle the beam 10^6 times

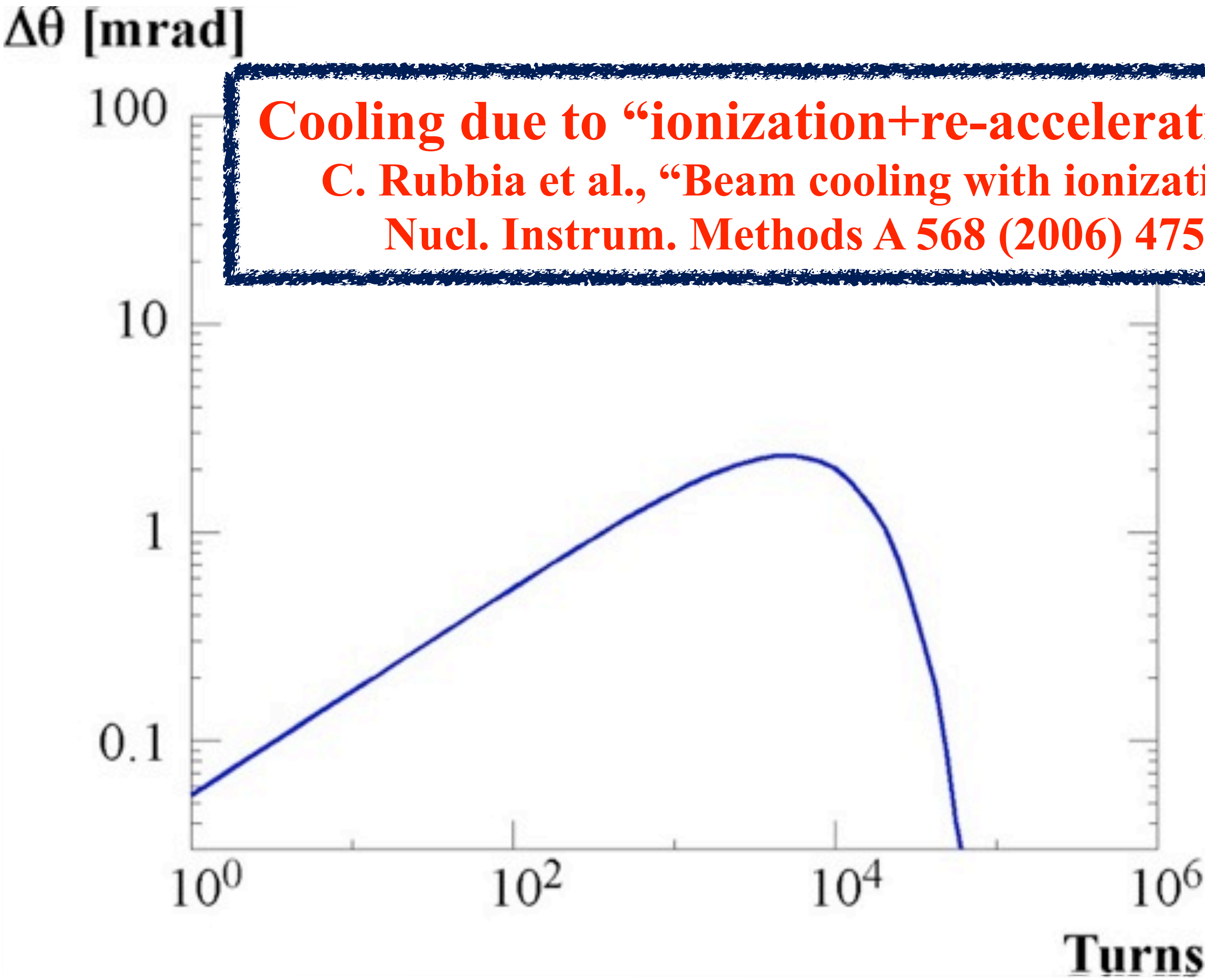
→ effective target thickness 1000 g/cm²

δE, δθ, δφ : statistical

Emittance growth w/o cooling/correction



Emittance growth with ΔE_{target} and re-acceleration



Cooling due to "ionization+re-acceleration"

C. Rubbia et al., "Beam cooling with ionization losses"

Nucl. Instrum. Methods A 568 (2006) 475.

Ionization (+re-acceleration) cooling

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Beam cooling with ionization losses

C. Rubbia[a,b,*], A. Ferrari[b], Y. Kadi[b], V. Vlachoudis[b]

[a] INFN, Sezione di Pavia, Italy
[b] CERN AB Department, Geneva, Switzerland

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Classic Ionization Cooling [A.A. Kolomensky, Atomnaya Energiya 19 (1965) 534; Yu.M. Ado, V.I. Balbekov, Atomnaya Energiya 31(1) (1971) 40–44; A.N. Skrinsky, V.V. Parkhomchuk, Sov. J. Nucl. Phys. 12 (1981) 3; E.A. Perevendentsev, A.N. Skrinsky, in: Proceedings of th... y Acceleration ... d to cool the direct beam until it has been compres... is limits its app... ing muon beams. Instead, in this new method, applicable to strongly interacting collisions, the circulating beam is not extracted. Ionization cooling provides "in situ" storage of the beam until it is converted by a nuclear interaction with the target.

Strongly interacting collisions

No extraction

(stored) until it is converted by a nuclear reaction with the target

Ionization cooling

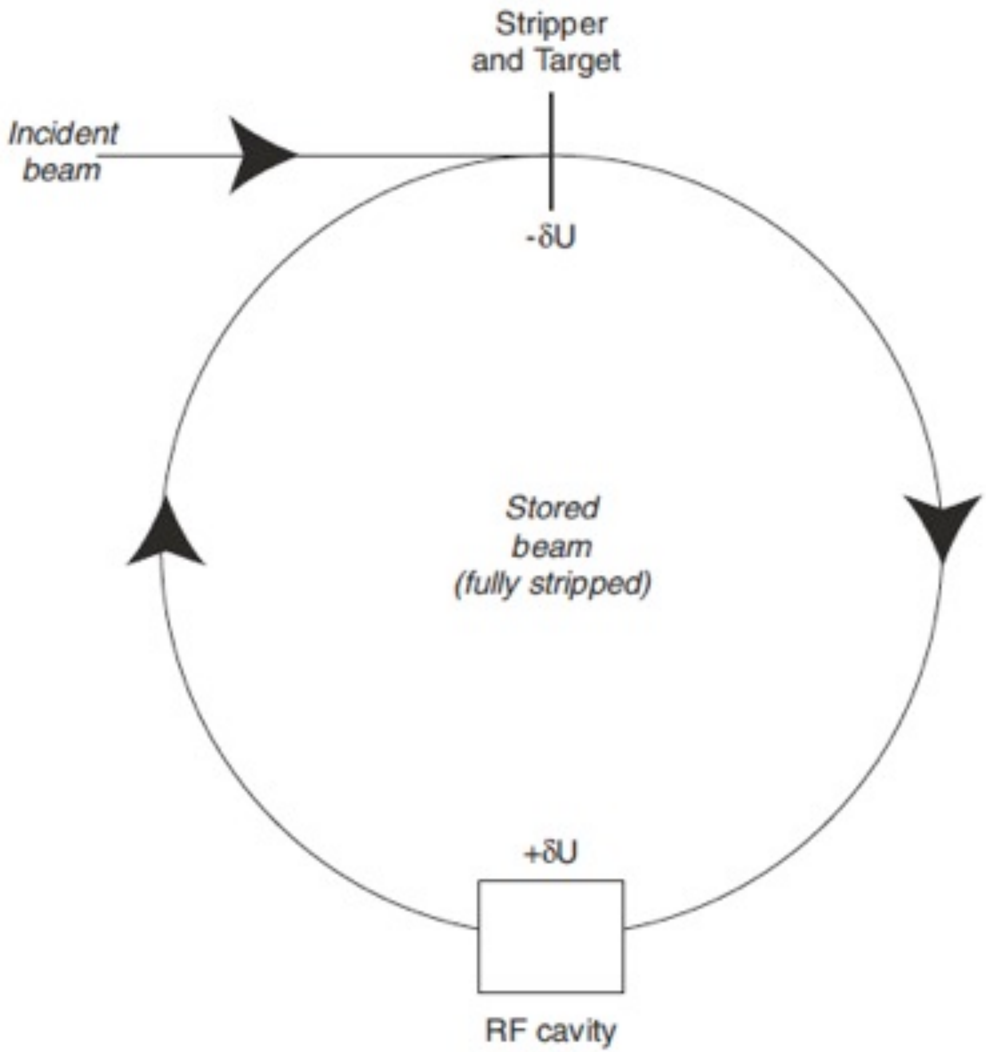
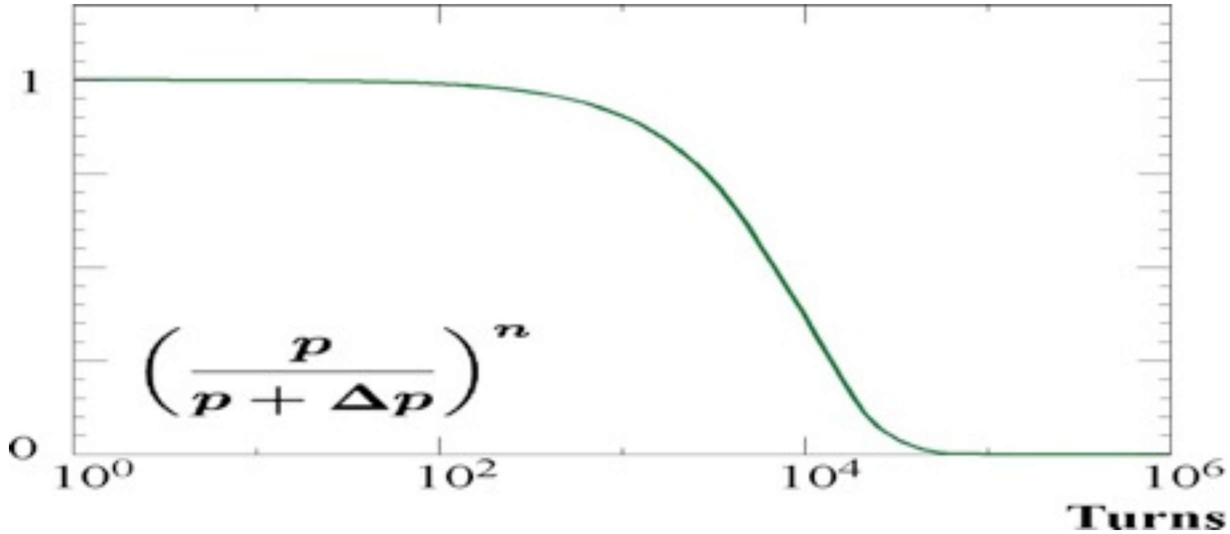


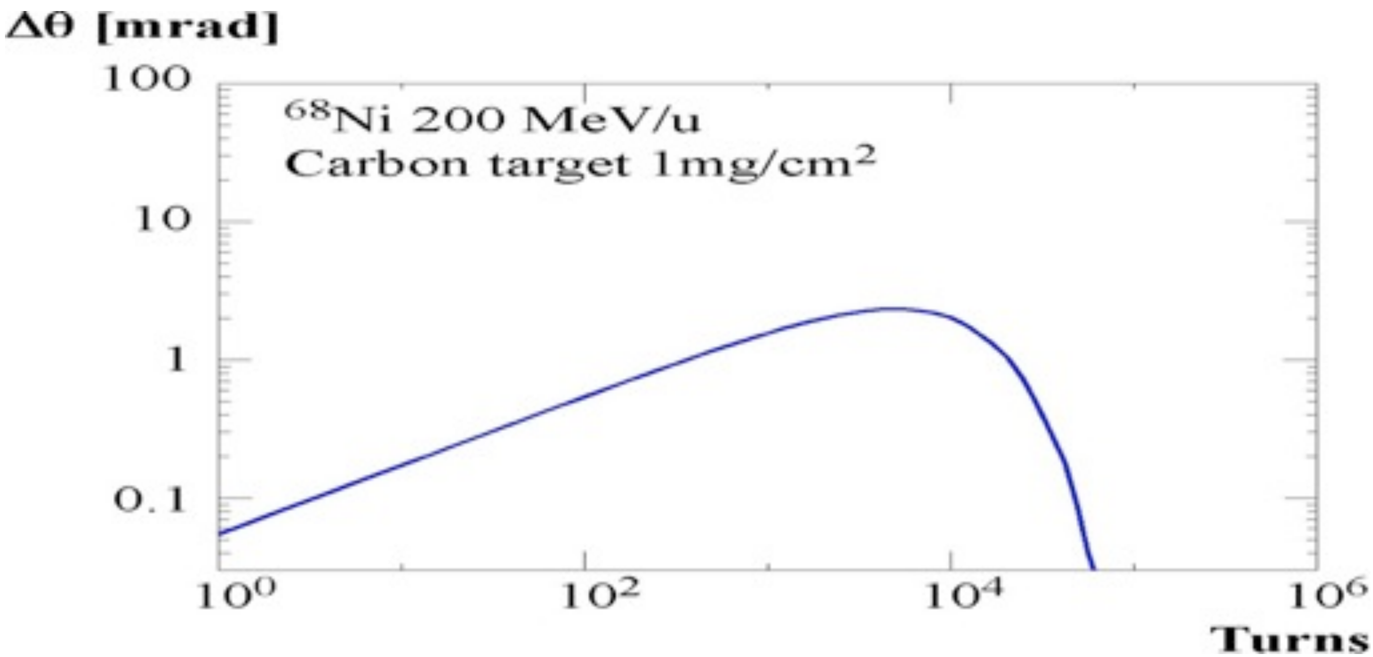
Fig. 1. Principal diagram of ionization cooling.

$$\left(\frac{p}{p+\Delta p}\right)^n$$

^{68}Ni 200 MeV/u
in 1 mg/cm^2 carbon
$\Delta p/p \sim 10^{-4}$

Emittance growth with ΔE_{target} and re-acceleration





Effective Luminosity

Intensity	$1\ s^{-1}$
Target thickness	$10^{24}\ cm^{-2}$
LUMINOSITY	$10^{24}\ s^{-1}cm^{-2}$

Issues to be considered:

- Losses due to charge exchange reactions etc.
- Longitudinal cooling
  - wedge-shaped target or
  - phase of re-acceleration RF

Towards reaction study with Rare-RI Ring

INSTEAD OF SUMMARY

1. Realistic simulation: COSY MC simulation is under preparation
   by C.S. Lee (Ph.D student)

2. Proof of Principle experiment: @ESR or @CSR
   I appreciate your helps!

3. Modification of Rare-RI Ring
   Quadrupole magnets
   Internal target station
   Detectors
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   ・
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