

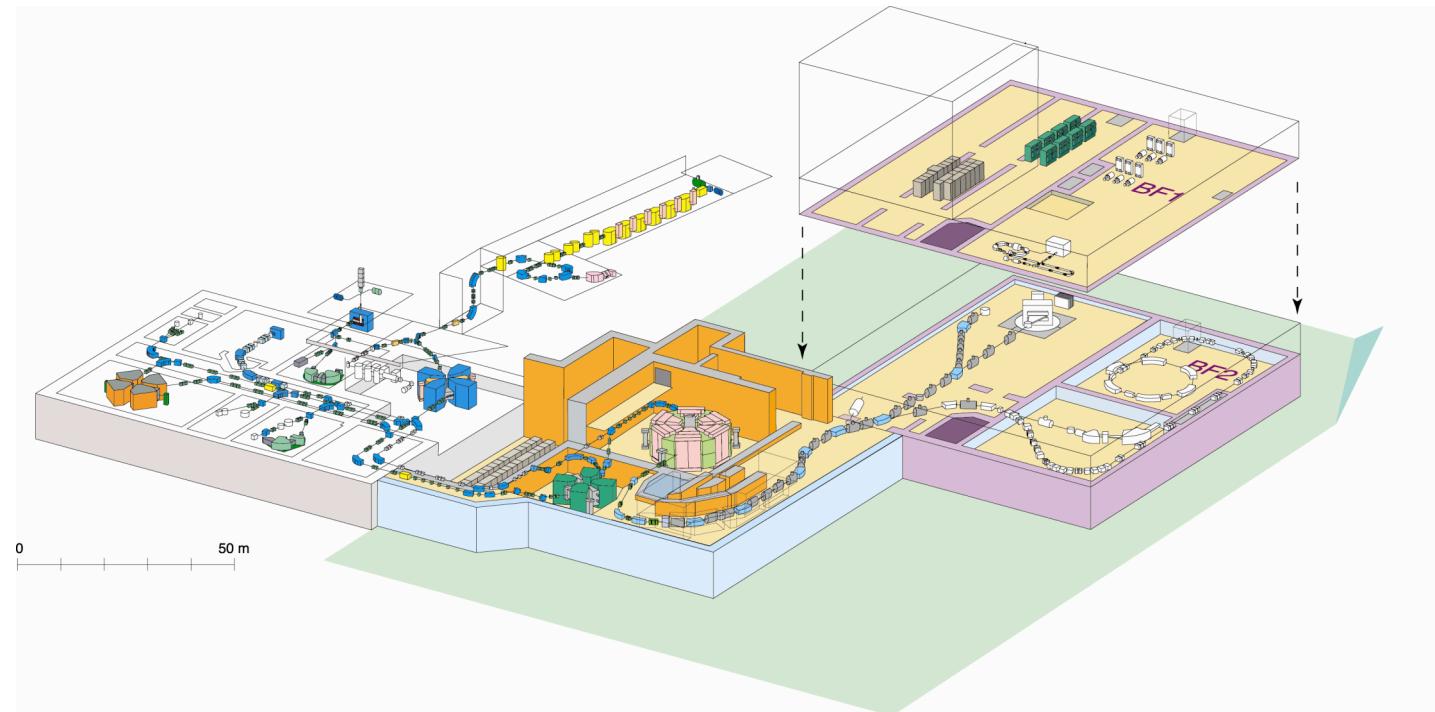
RI* Beam Factory and Scientific Opportunity

-- Reactions for nuclear structure studies with fast exotic beams

Tohru Motobayashi

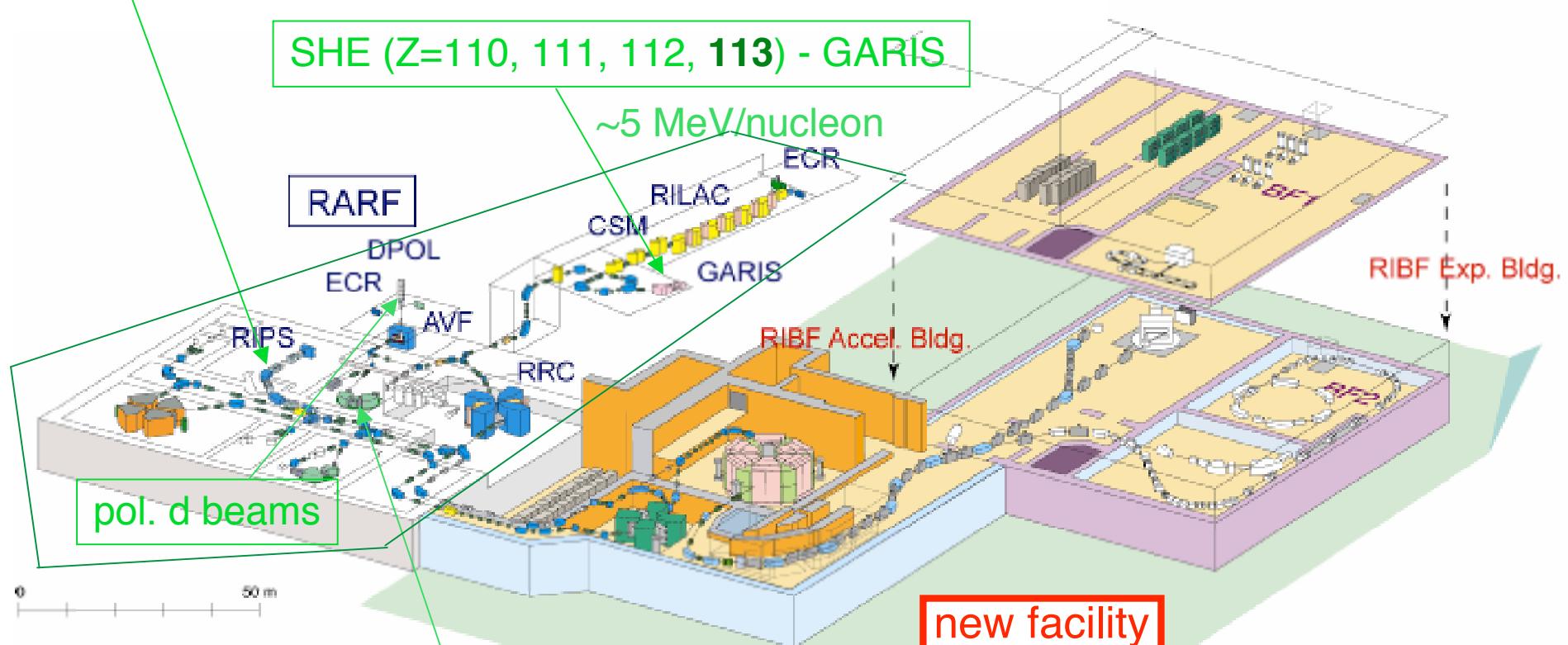
(RIKEN Nishina Center for Accelerator-Based Science)

* radioactive isotope



**Fast RI beams
- RIPS**

**RIBF: Accelerator Complex in
RIKEN Nishina Center for Accelerator-Based Research**



0 135 MeV/nucleon
for light nuclei

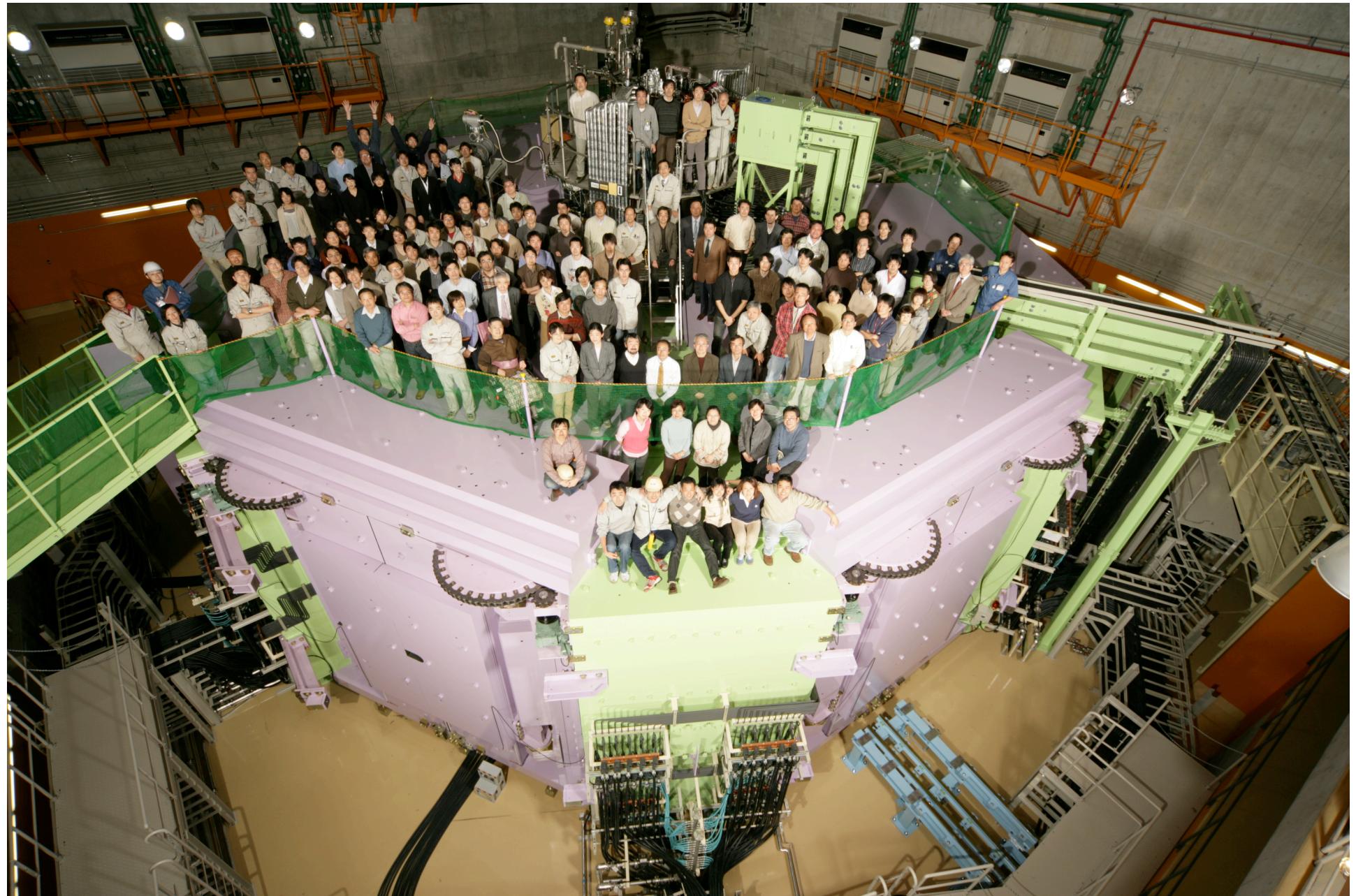
RI beams (<5 AMeV) - CRIB

CNS, U. Tokyo

350 MeV/nucleon
up to U
1st beam in Dec. 2006

2 to be built

1 built up to Big RIPS



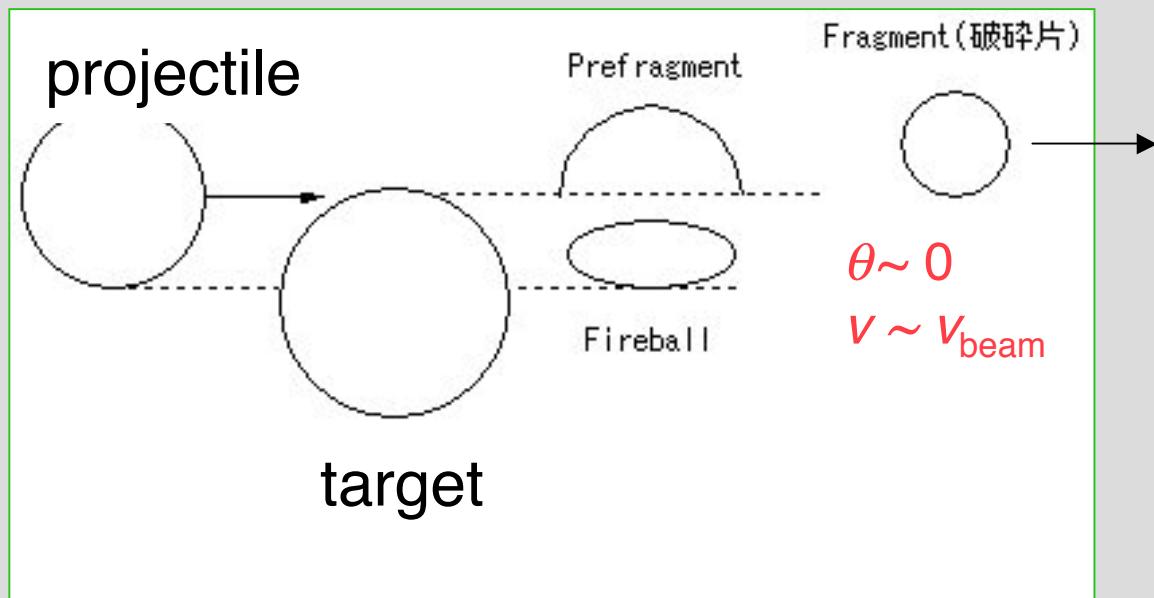
SRC the world largest superconducting cyclotron (8,300 t)

First beam !!

Dec. 28 (2006) 16:00



projectile fragmentation



wide range of (unstable) nuclei
regardless of chemical properties

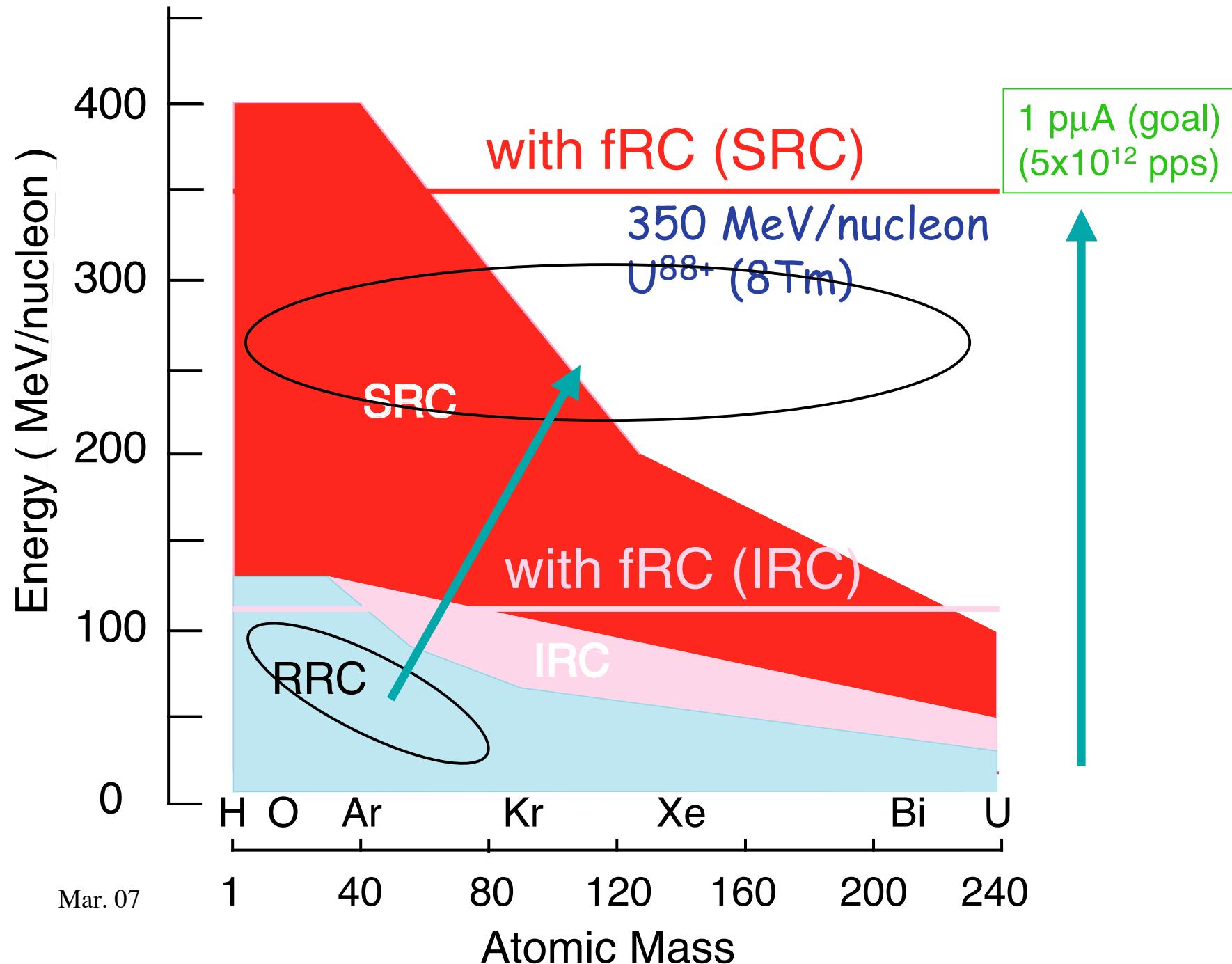
$E > 50$ MeV/nucleon (“fast”)



ISOL
+ reacceleration

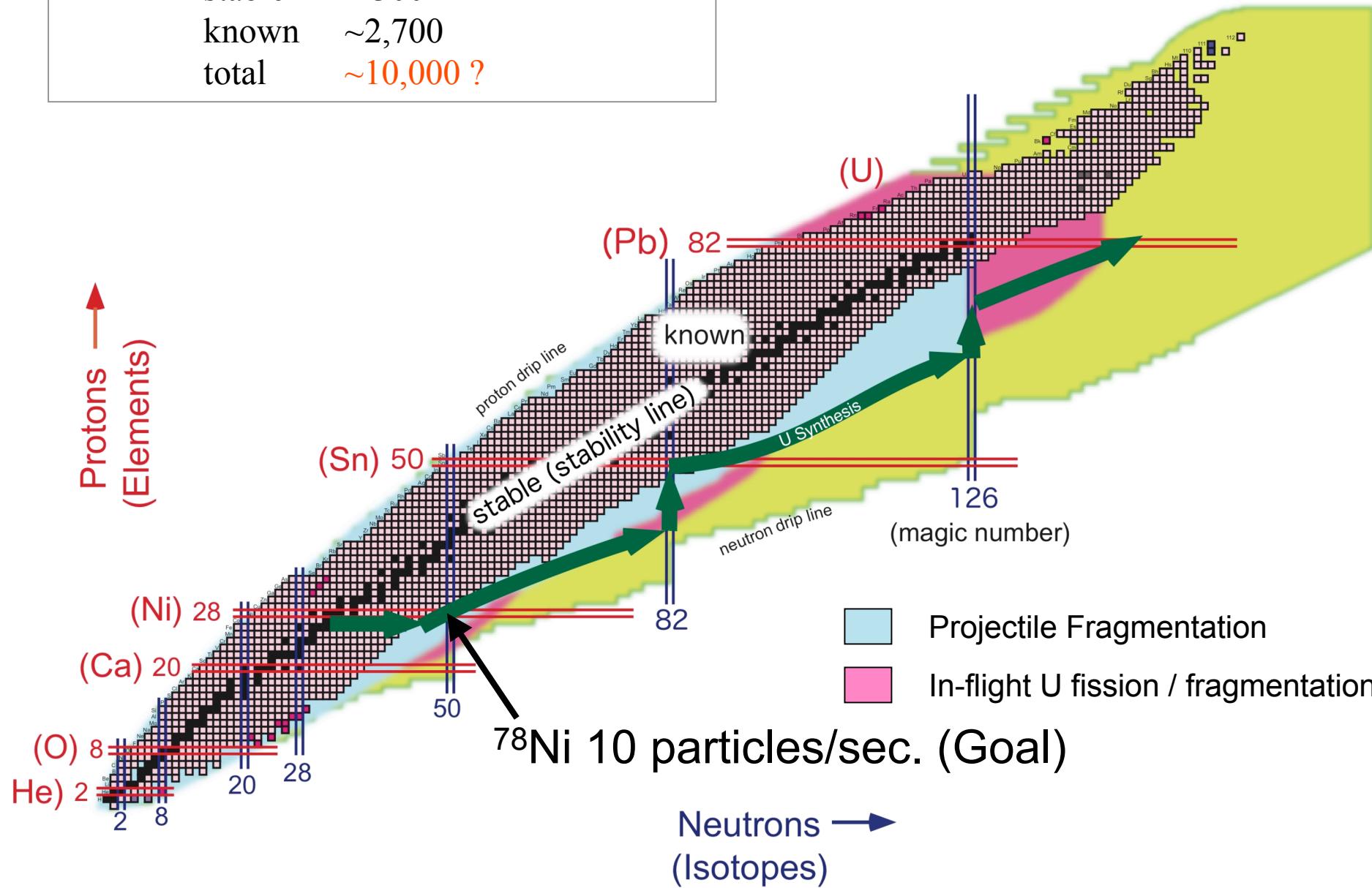
In-flight fission

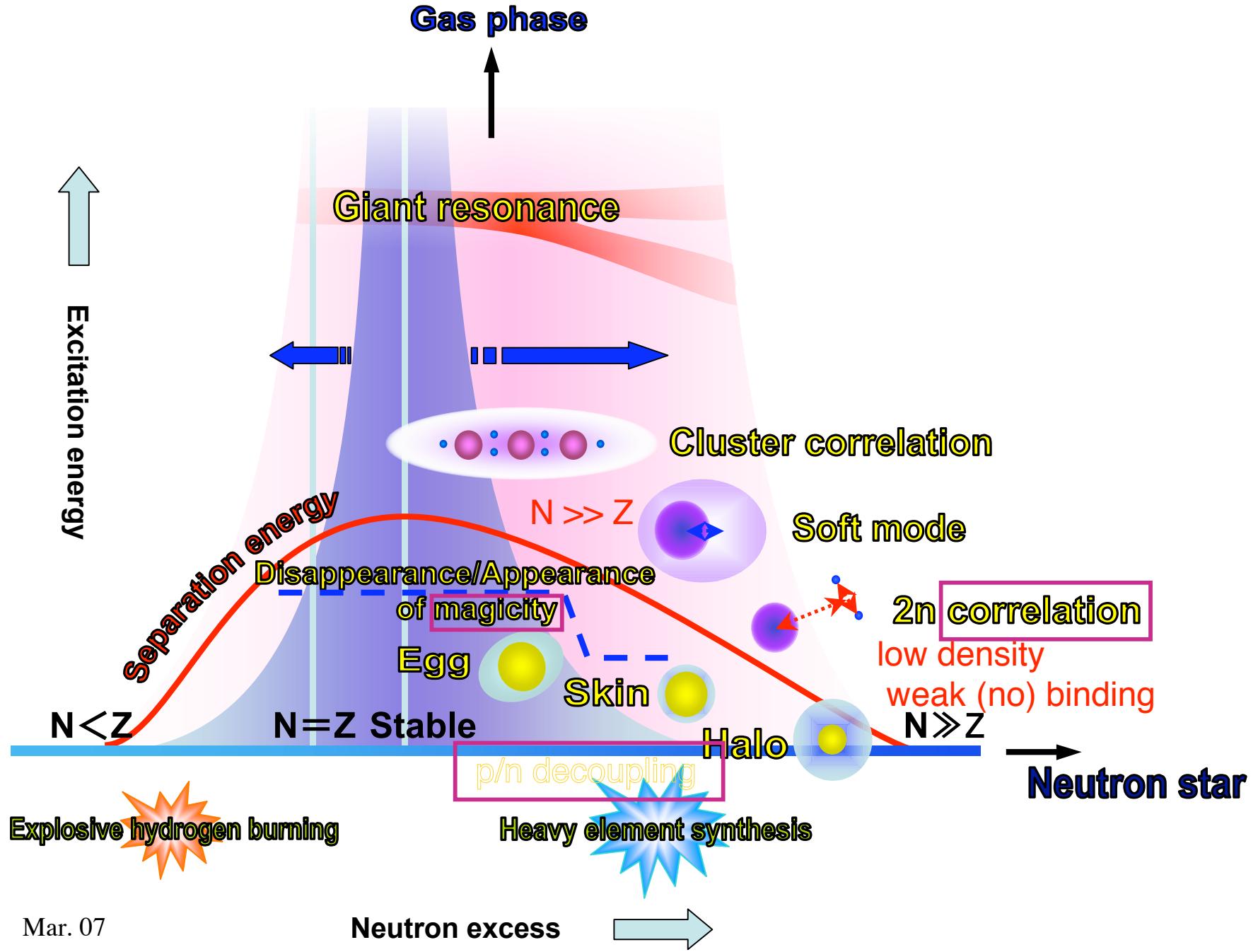
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Atomic nuclei (isotopes)

stable	~ 300
known	$\sim 2,700$
total	$\sim 10,000 ?$





RI beams at RIKEN so far

Ring Cyclotron (1987) + RIPS (~1990) <= LBL, GANIL (LISE)
fast “RI-beam” or “RNB” by fragmentation (< 100 AMeV)
the most intense beams for some light nuclei

- stop μ - and Q -moments for neutron-rich nuclei
- fast new lifetime measurements (^{16}C , ...)
- fast Coulomb dissociation
 - for structure of light drip-line nuclei ($^{11}\text{Li}, ^{11}\text{Be}$, ...)
 - for astrophysics ($^{14}\text{O}, ^8\text{B}$.)
- fast fast Coulomb excitation, inelastic scattering (^{32}Mg , ..)
- fast γ spectroscopy w. secondary fragmentation (^{34}Mg , ..)
- fast charge exchange, “knockout” or nucleon removal, ...
- deg. lower energy reactions w. degraded beams (fusion, astro.)
- fast new isotopes (^{31}F , ...), nuclear radii, ..

reactions with small mass transfers

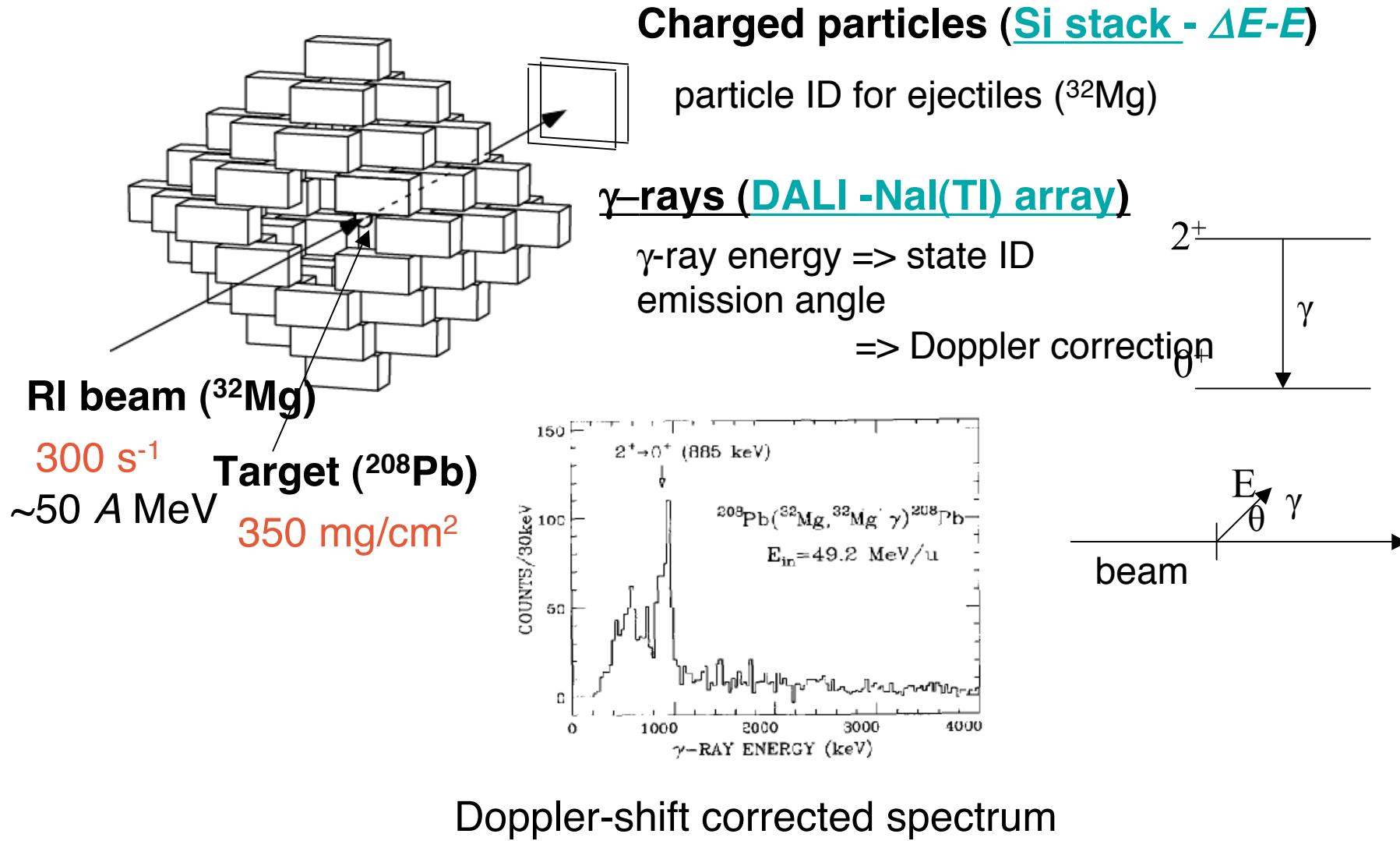
$$v/c \sim 0.3 \Rightarrow 0.6$$

Fate of magic numbers

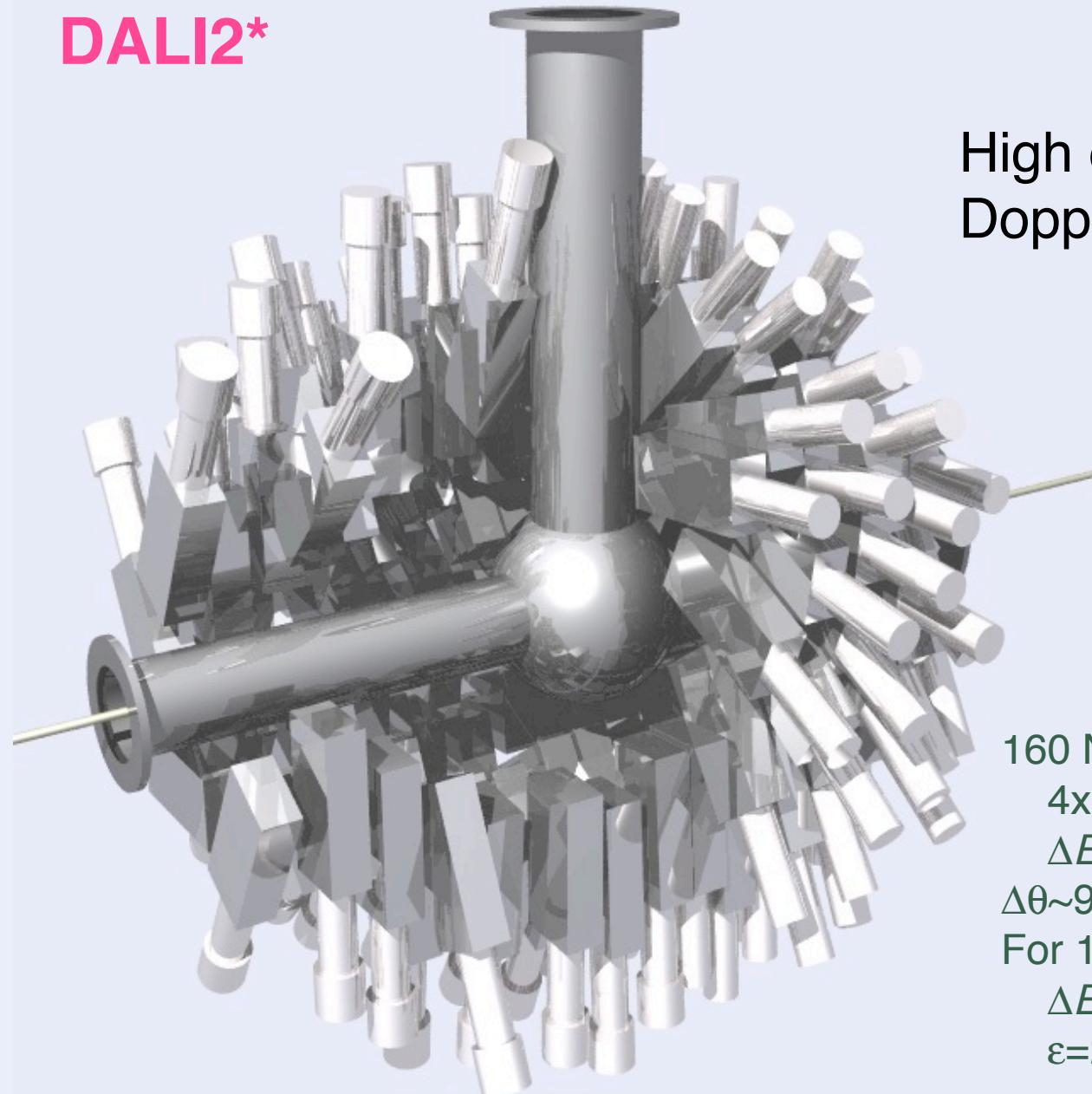
$N=(8,)$ 20

Coulomb excitation
(p,p')
2ndary fragmentation

Intermediate-energy Coulomb excitation



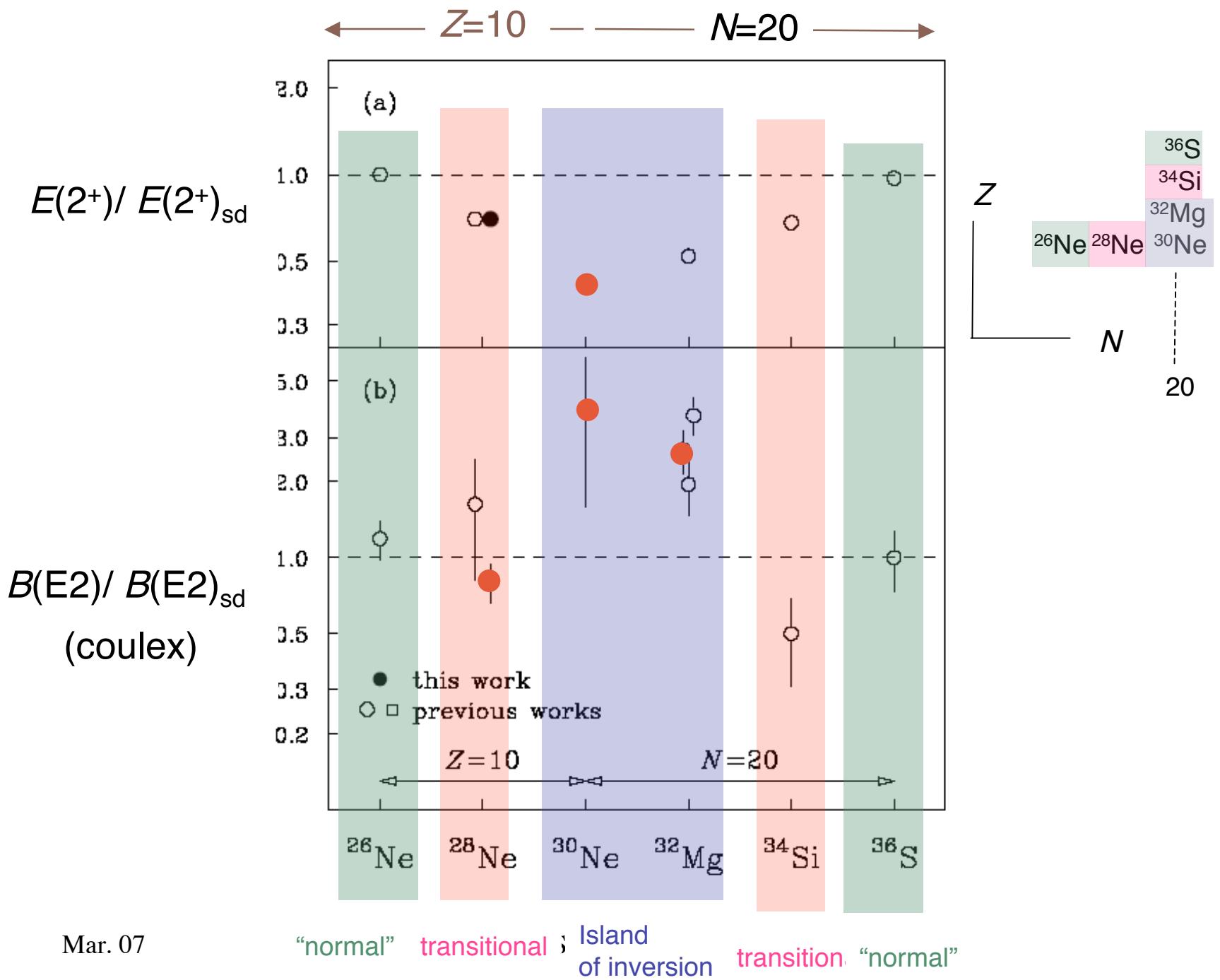
DALI2*



High efficiency
Doppler-shift correction

160 NaI(Tl) crystals
 $4 \times 8 \times 16 \text{ cm}^3$
 $\Delta E \sim 9\% \text{ (FWHM)} @ 662 \text{ keV}$
 $\Delta\theta \sim 9 \text{ deg.}$
For 1 MeV γ ($\beta = 0.3$, $\Delta\beta/\beta = 10\%$)
 $\Delta E = 8.7\%$
 $\varepsilon = 20\%$

* Detector Array for Low Intensity radiation



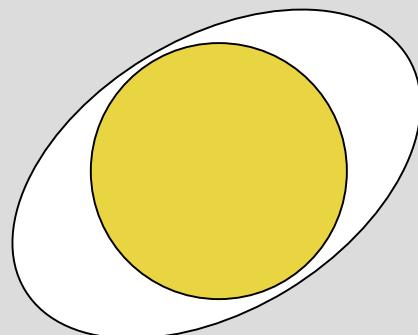
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^{16}C

- decoupling of p/n motion
sensing p/n motion

Coulomb-nuclear interference
Lifetime
(p, p')
(Q moment of neighbors)

$^{16}\text{C} + ^{208}\text{Pb}$ Inelastic scattering



"egg-like" structure ?

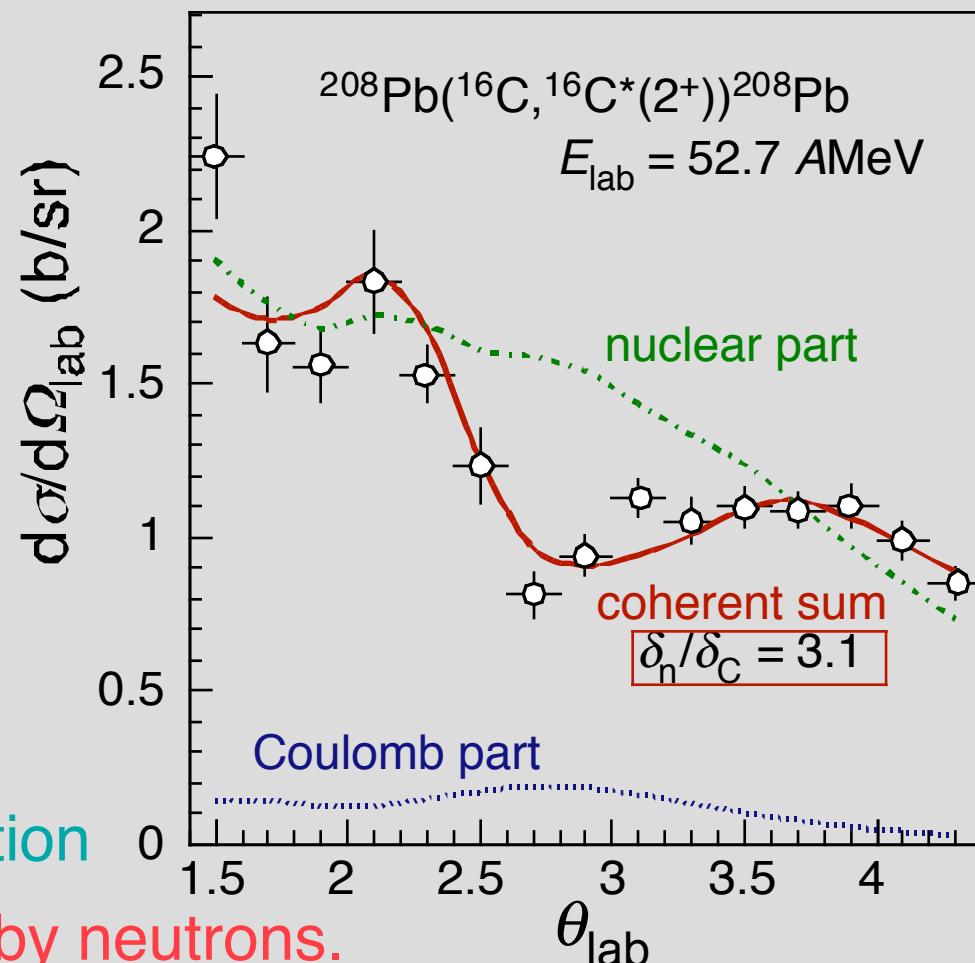
↑ ↘
strong
p-n interaction

2+ excitation: almost only by neutrons.

\Leftrightarrow lifetime, (p, p')

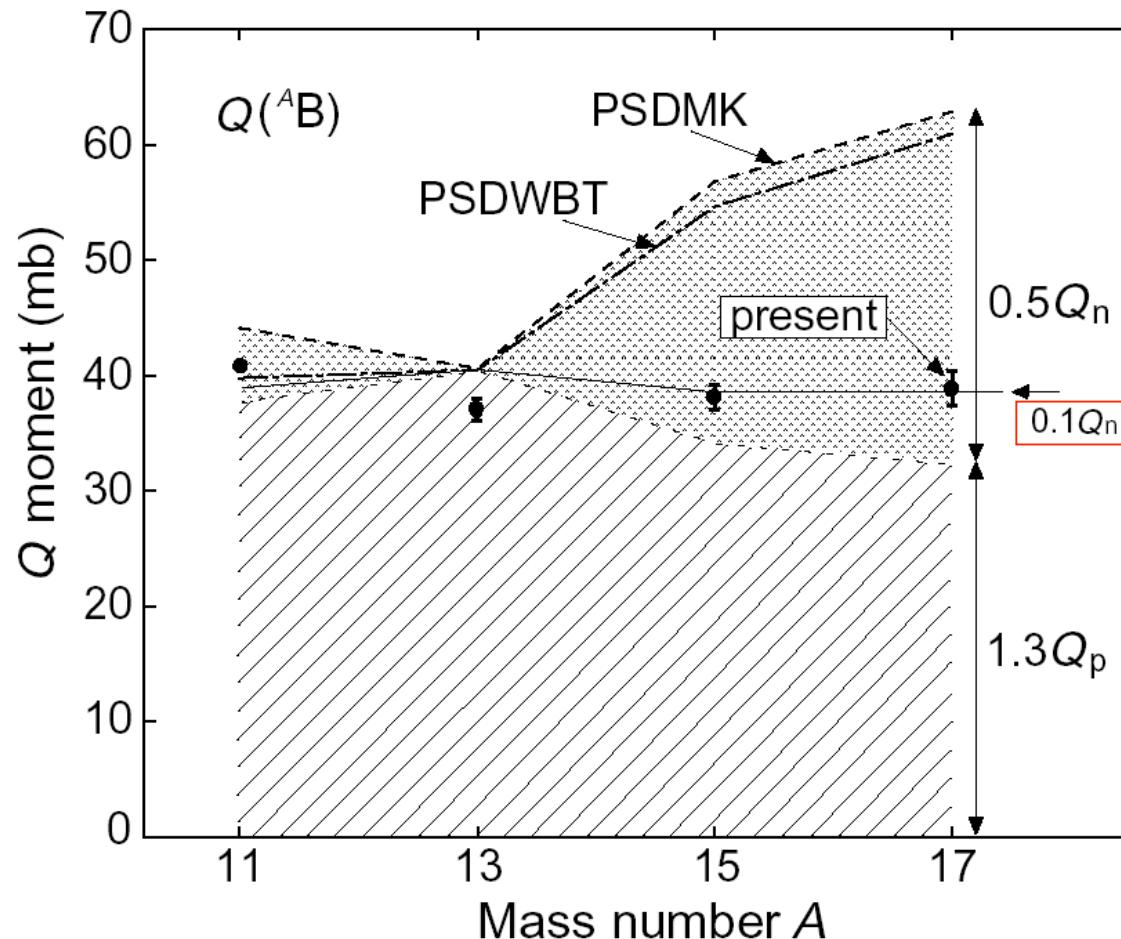
Coulomb-nuclear Interference in angular distribution

Elekes *et al.*, Phys. Lett. B586 (2004) 34
Japan-Hungary (ATOMKI) collaboration

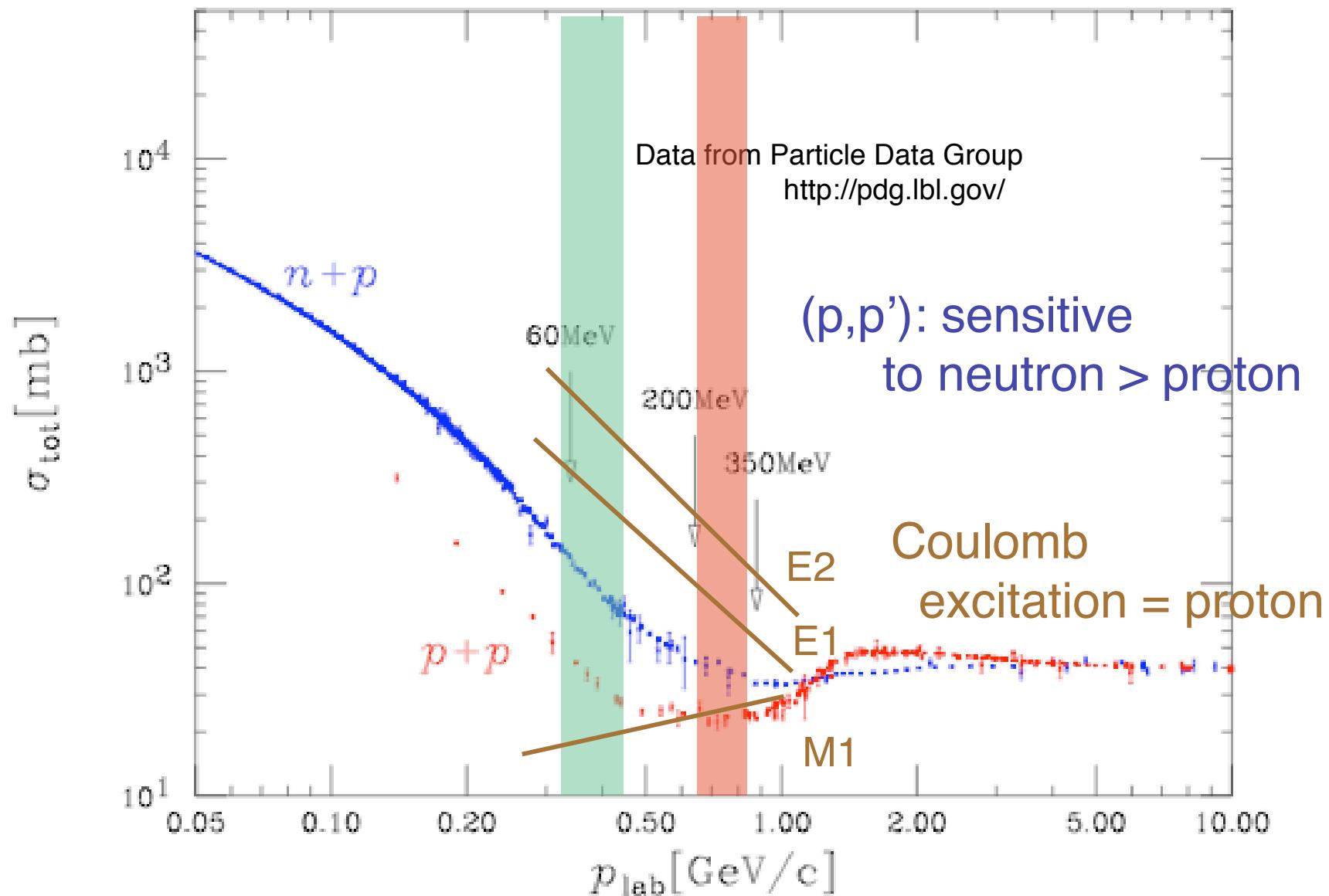


Electric quadrupole moments

for neutron-rich B isotopes

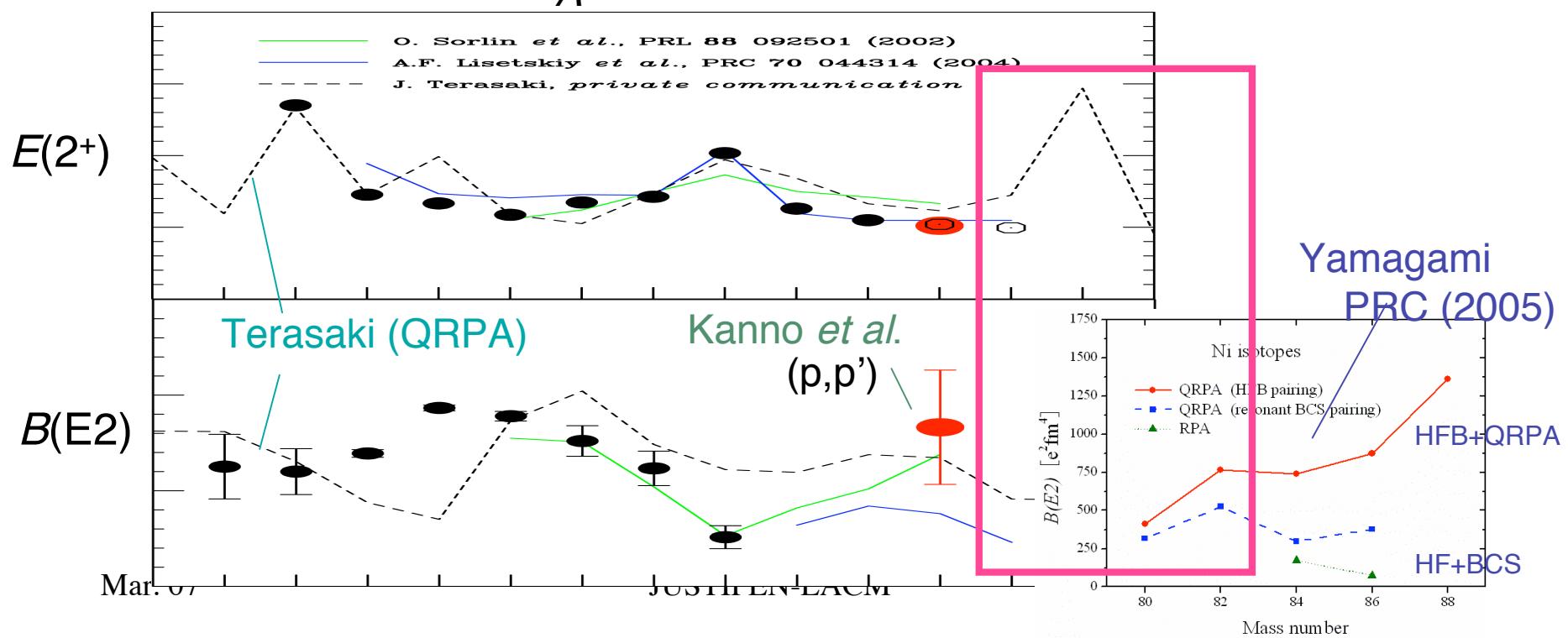
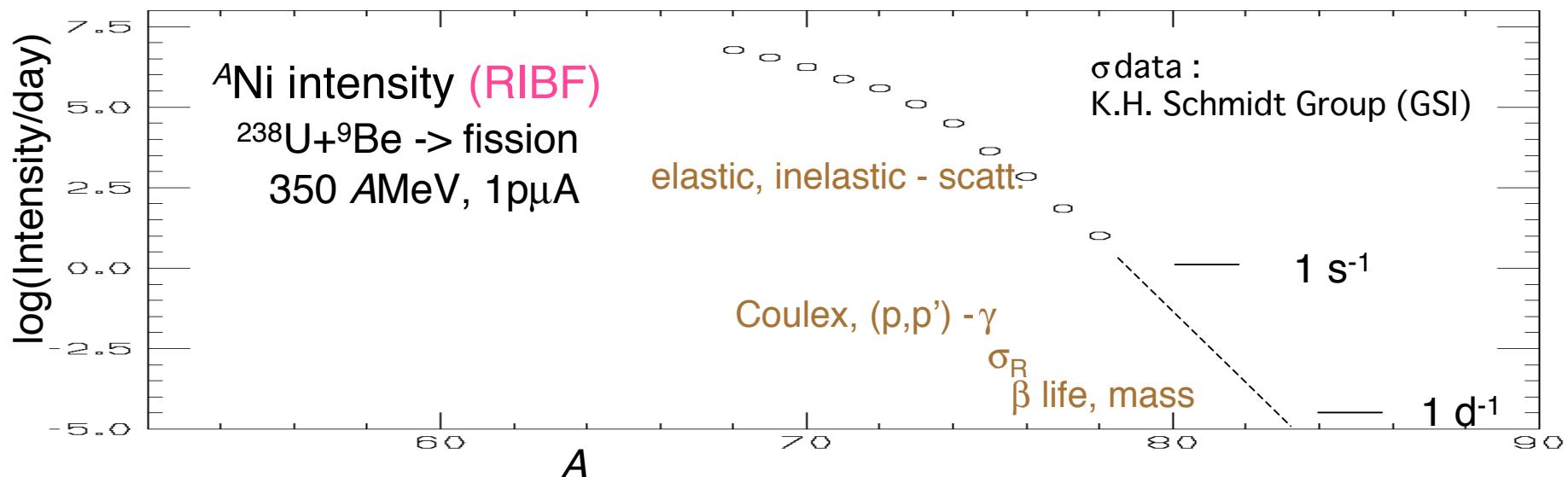


NN cross section



How far can we go with RIBF ?

Ni isotopes



RIBF

fast RI beams very far from stability

as is (200-300 MeV/nucleon): Zero Deg., SHARQ, SAMURAI
nuclear reactions with no mass transfer <= matching
elastic, inelastic, charge exchange, knockout,
projectile fragmentation, multi fragmentation,
(reaction cross section, isotope search)

trap by an isochronous ring (**Rare RI Ring**)

stopped

in solid: β decay, μ , Q by β -NMR, isomers, ...(**IRC beam**)

in gas: mass (trap), (charge) radius,, electron scatt.

SLOWRI, (SCRIT)

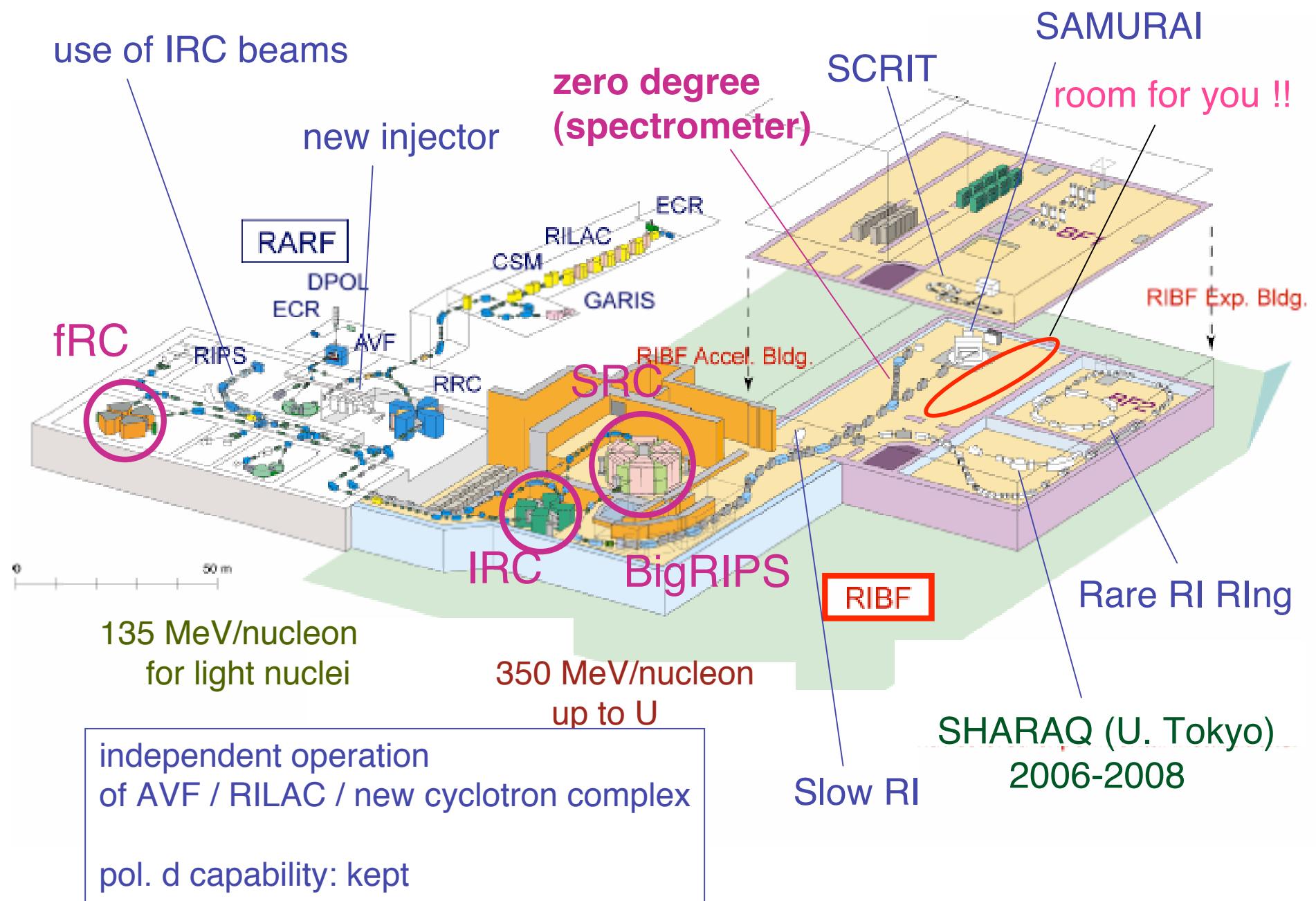
degraded (< 50 MeV/nucleon)

reactions with mass transfer

fusion (spectroscopy), transfers, ...

some topics: possible by BigRIPS alone (+ small setups)

RIBF in future (2007 - 2010 ?)

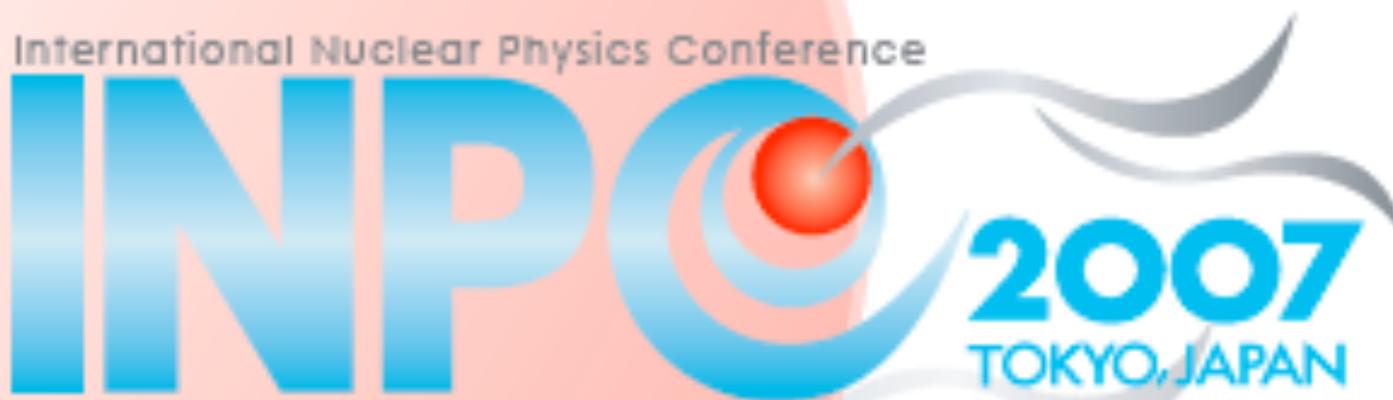


RI beams @ RIKEN --> RIBF

fast ($b \sim 0.3 \rightarrow 0.6$) RI beam -- fragmentation, fission in flight reactions w. gamma or particle decay measurements applications w. degraded / stopped RI beams

farther from the stability valley

- large p/n asymmetry
- low density / weakly (un) bound states
- shell evolution
- change of “correlations”



23rd International Nuclear Physics Conference (INPC07)

Tokyo, June 3-8, 2007 <http://www.inpc2007.jp>

(early registration: May 13, 2007)

<satellite meetings>

Direct Reactions with Exotic Beams (DREB)

RIKEN, May 30- June 2 <http://rarfaxp.riken.jp/DREB2007/>

Nuclear Physics at J-PARC (pre-symposium)

J-PARC, before INPC07

Nucl. Structure: New Pictures in the extended Isospin Space

Kyoto, June 11-14 <http://wwwnucl.ph.tsukuba.ac.jp/NS07/>

International Baryon Conference (BARYONS07)

Seoul, Korea, June 11-15

THE END
FIN
おしまい

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JUSTIPEN-LACM

Nucleus with protons and neutrons

Behaviors <= different n- and p- numbers

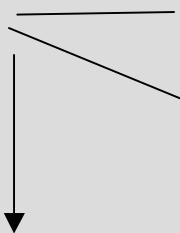
v.s. E_x , I , T , ρ ,



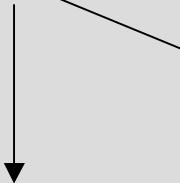
A challenge:

extension in the n-p plane

RI beams



isotope production
secondary reaction



new nuclear dynamics

nuclear response in high isospins

explosive nuclear burning

exotic nuclear structure

shell closure

behaviors of p & n - correlated / decoupled

astrophysics

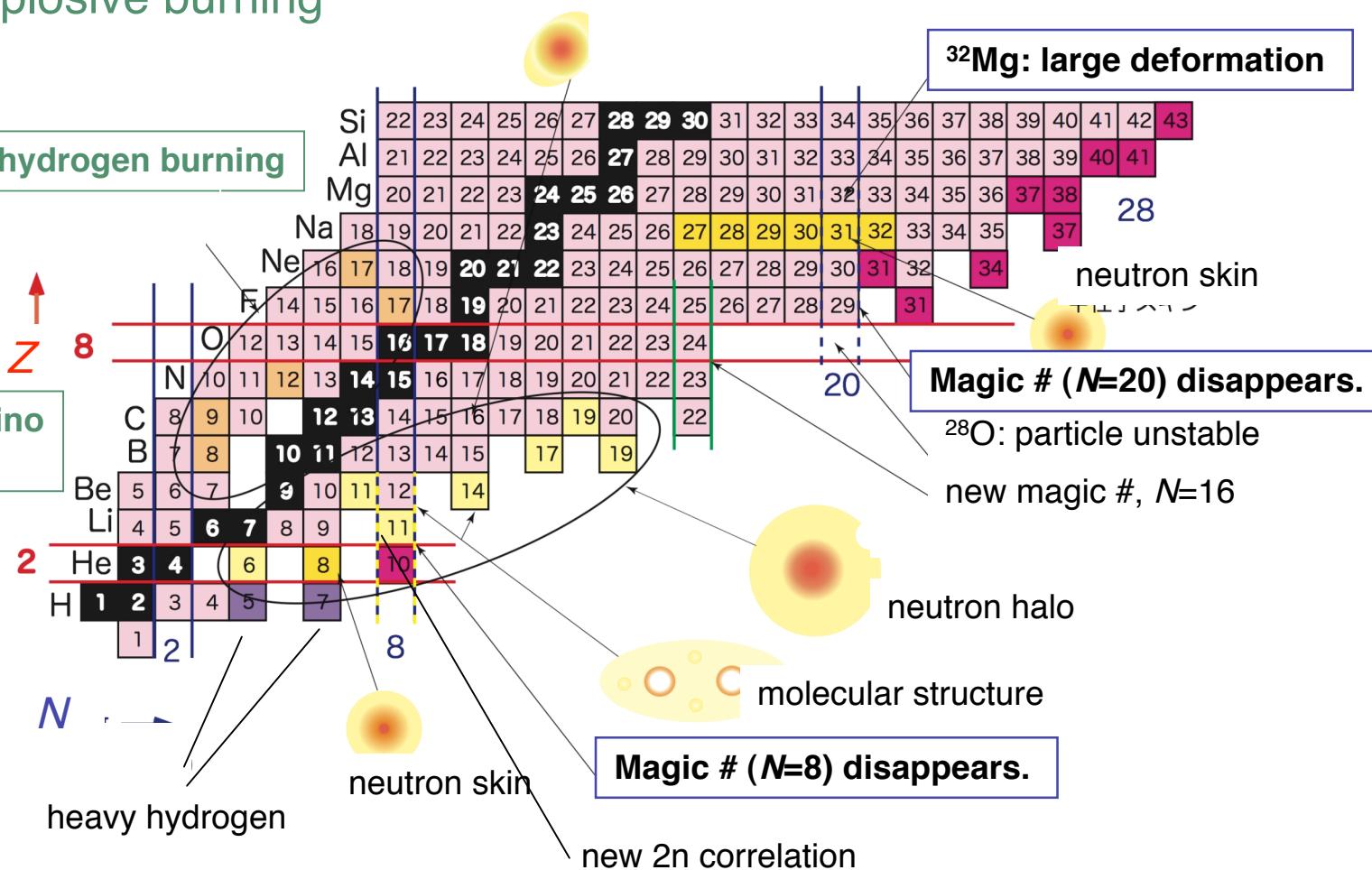
solar fusion

explosive burning

^{16}C : “egg” structure ? decoupled n-motion

explosive hydrogen burning

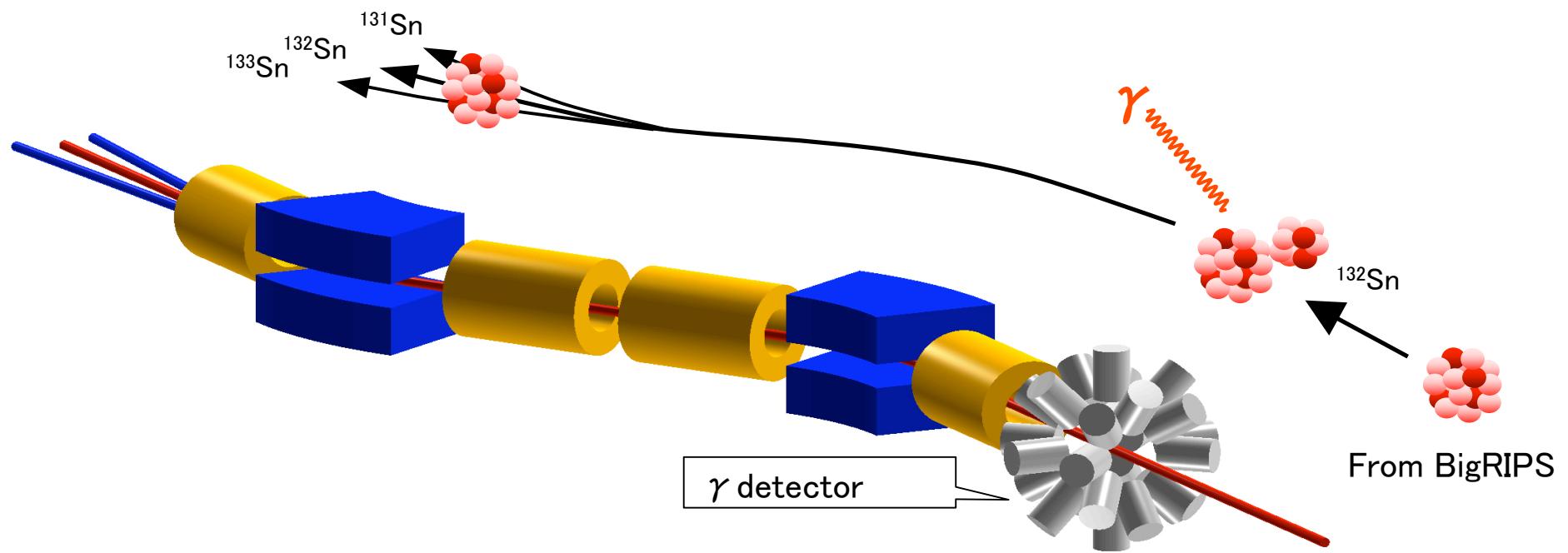
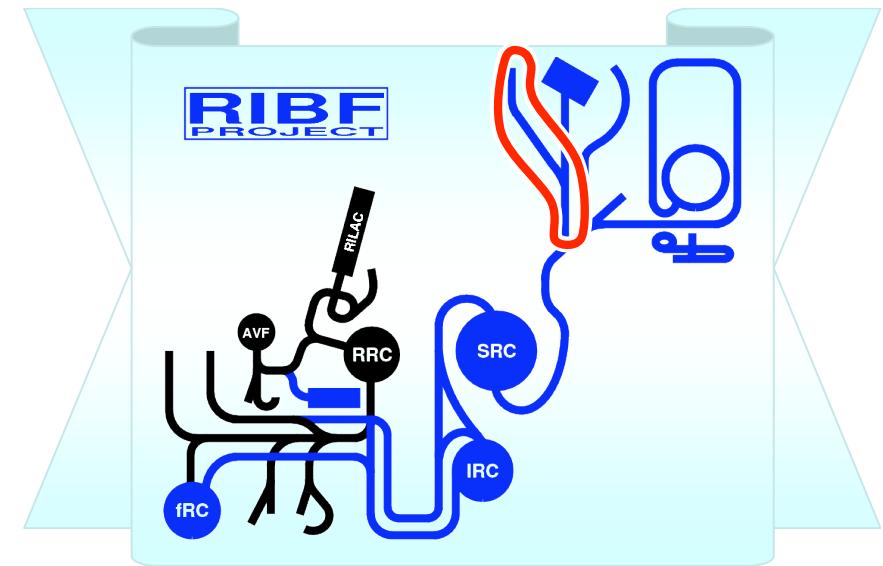
solar neutrino production



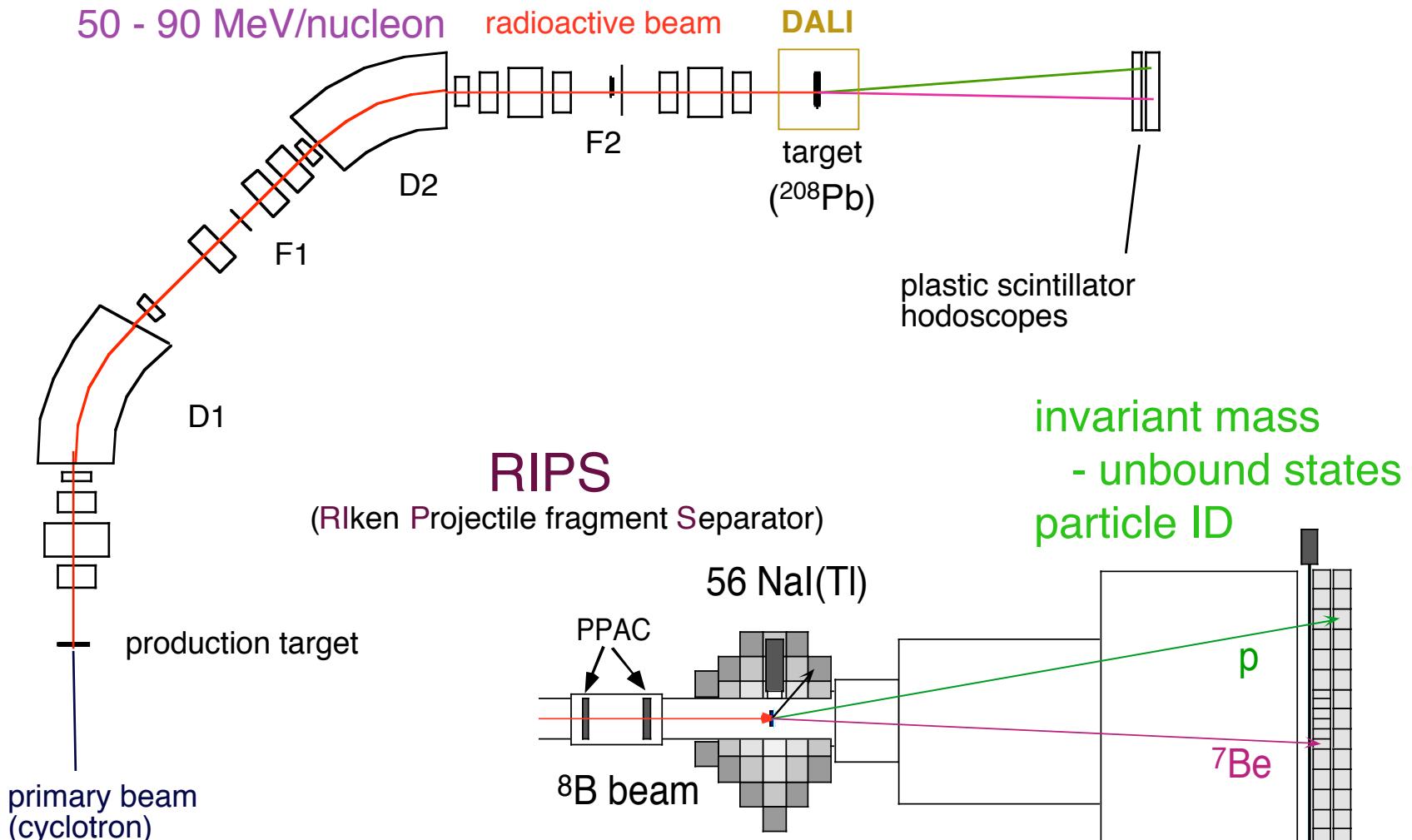
Zero-degree spectrometer

particle ID / momentum analysis

e.g. inbeam γ spectroscopy

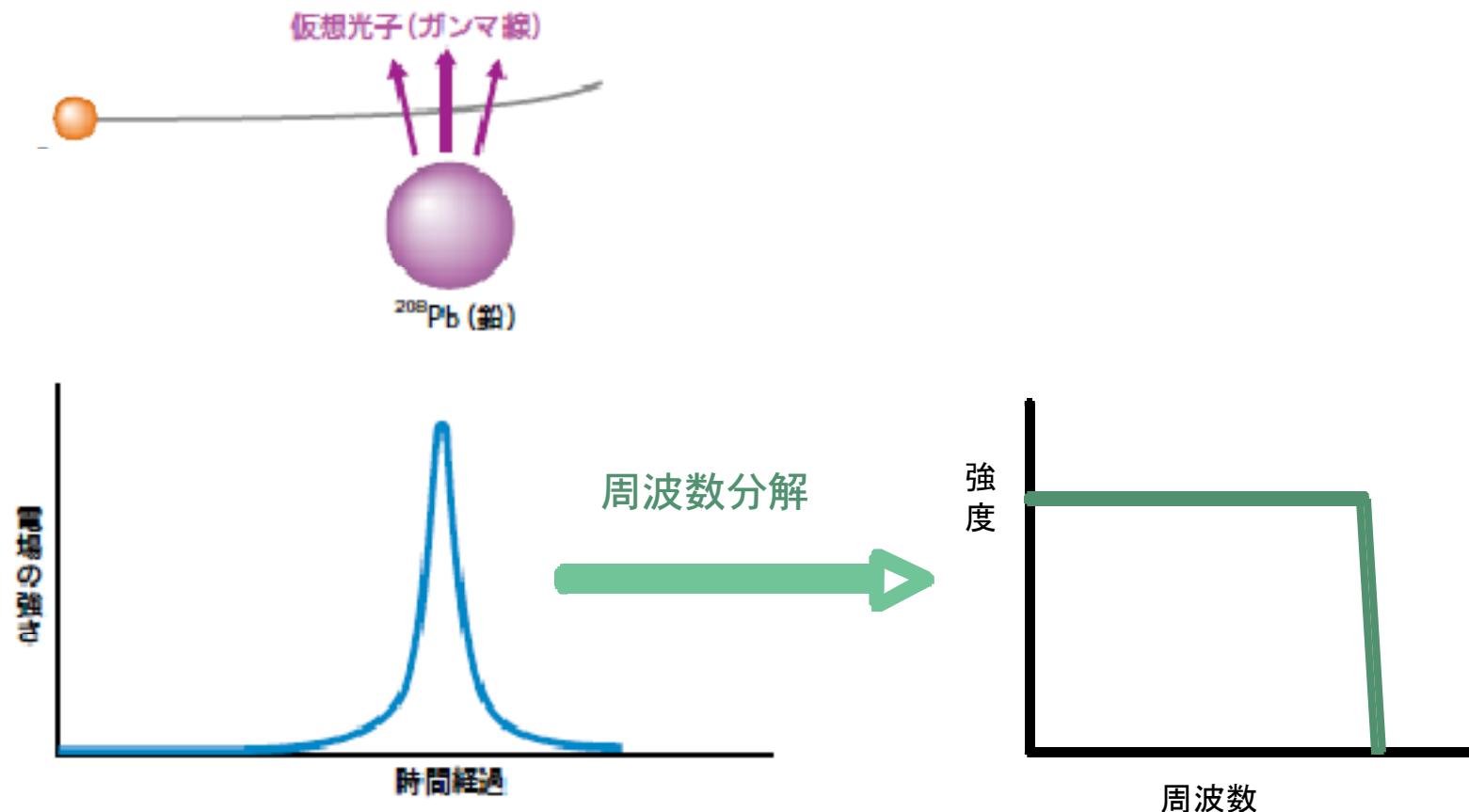


spectroscopy of unstable nuclei / nucl. astrophysics



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原子核の衝突で高いエネルギーの光子を作る クーロン励起法



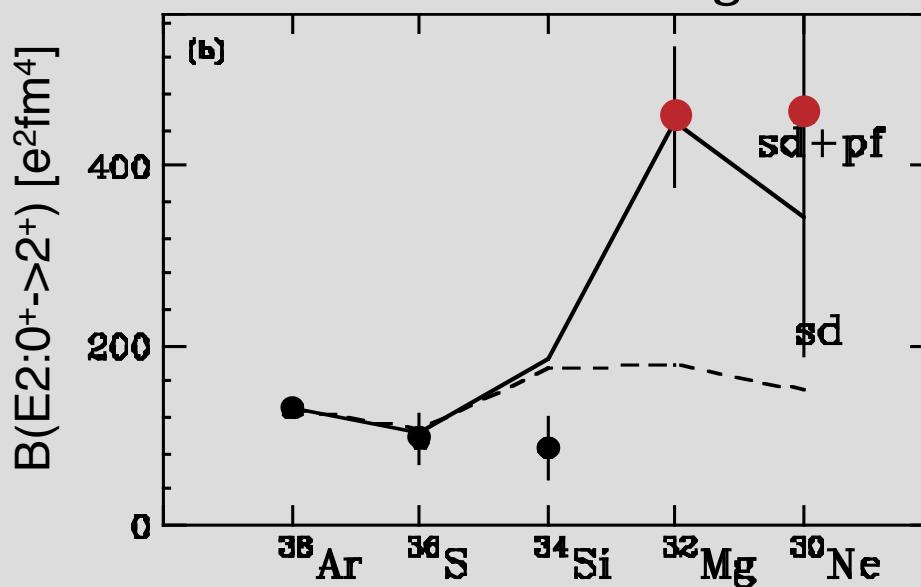
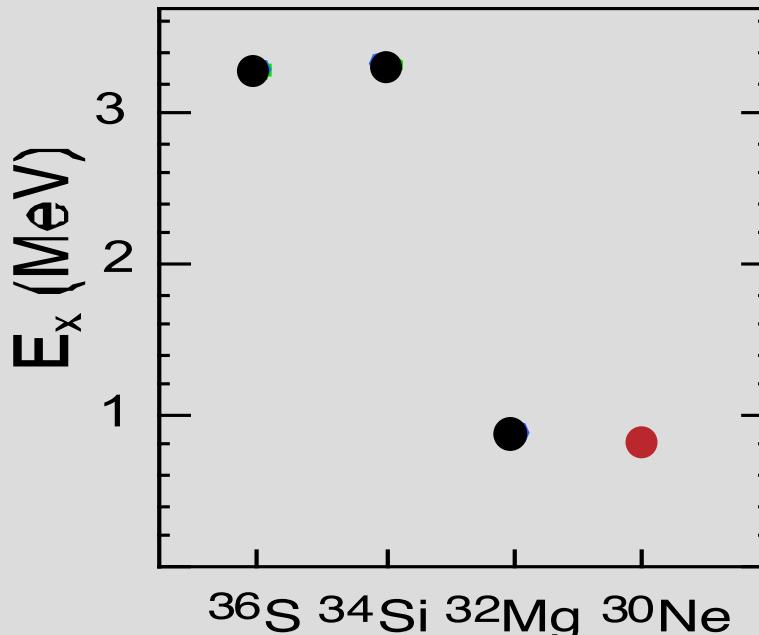
**2⁺ location / $B(E2)$
of $N = 20$ nuclei**



**Disappearance
sd-pf shell gap($N=20$)
in ^{32}Mg and ^{30}Ne**

**In-beam γ spectroscopy
with Coulex / (p,p')**

Motobayashi *et al.*, PLB 346 (95) 9
Yanagisawa *et al.*, PLB 566 (03) 84

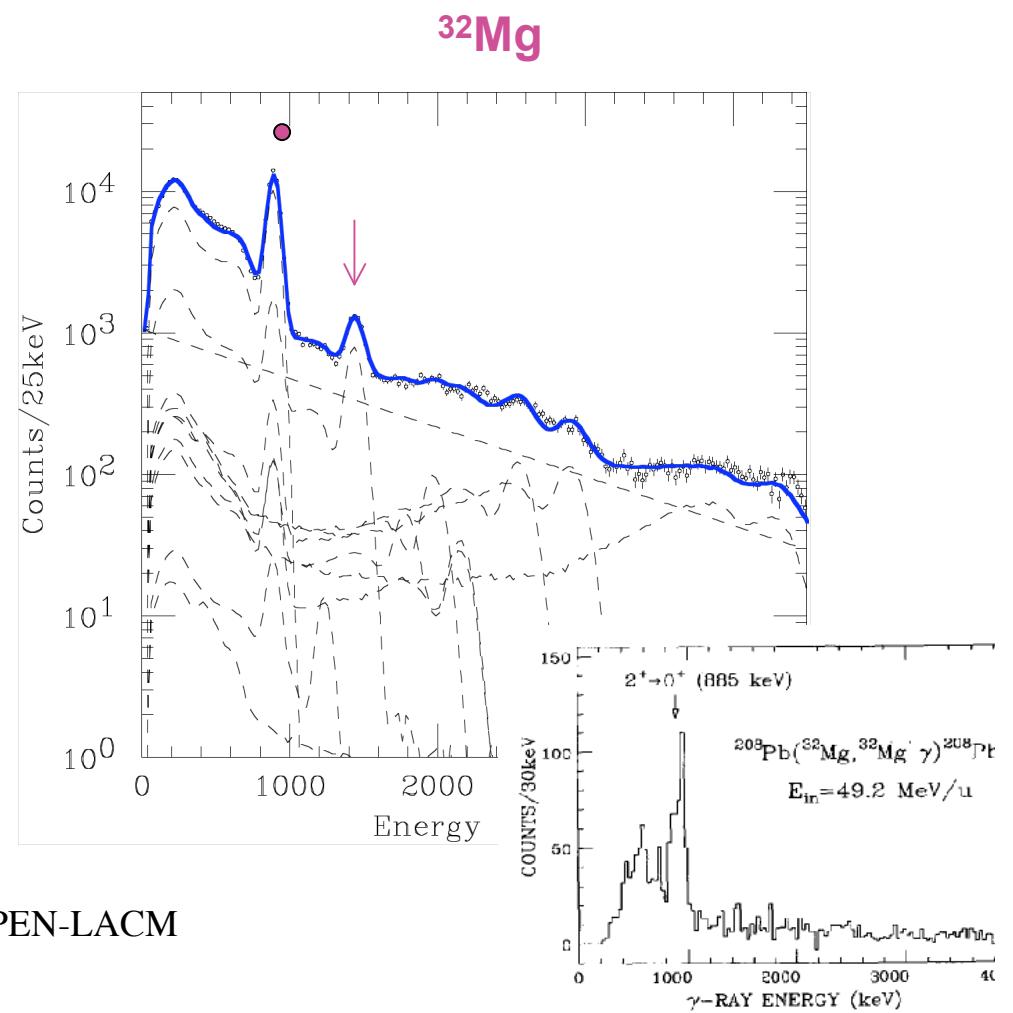
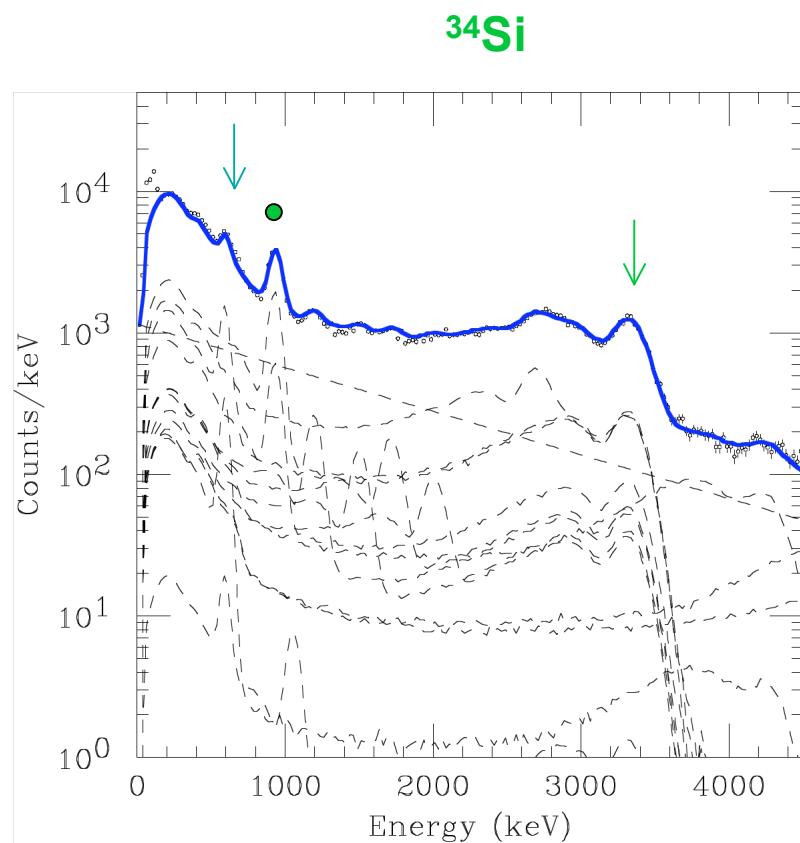


JUSTIPEN-LACM

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γ -rays associated with $^1\text{H}(\text{Si}, \text{Si}^*)^1\text{H}$ and $^1\text{H}(\text{Mg}, \text{Mg}^*)^1\text{H}$

(p,p') -- neutron transition (M_n)
high statistics - $\gamma\gamma$ or $\gamma\gamma\gamma$ coincidence



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JUSTIPEN-LACM

Decoupling of n- and p-distributions in ^{16}C ?

In-beam γ measurements with fast ^{16}C RI beams

γ -decay lifetime measurement - new recoil-shadow method

$$\tau \sim 75 \pm 23 \text{ ps}, B(\text{E}2: 2^+ \rightarrow 0^+) \sim 0.3 \text{ W.U.}$$

- the slowest ? E2 transition

Imai *et al.* (2003)

award talk tomorrow

$^{16}\text{C} + ^{208}\text{Pb}$ inelastic

Coulomb-nuclear interference

$$M_n/M_p = 7.6 \pm 1.0$$

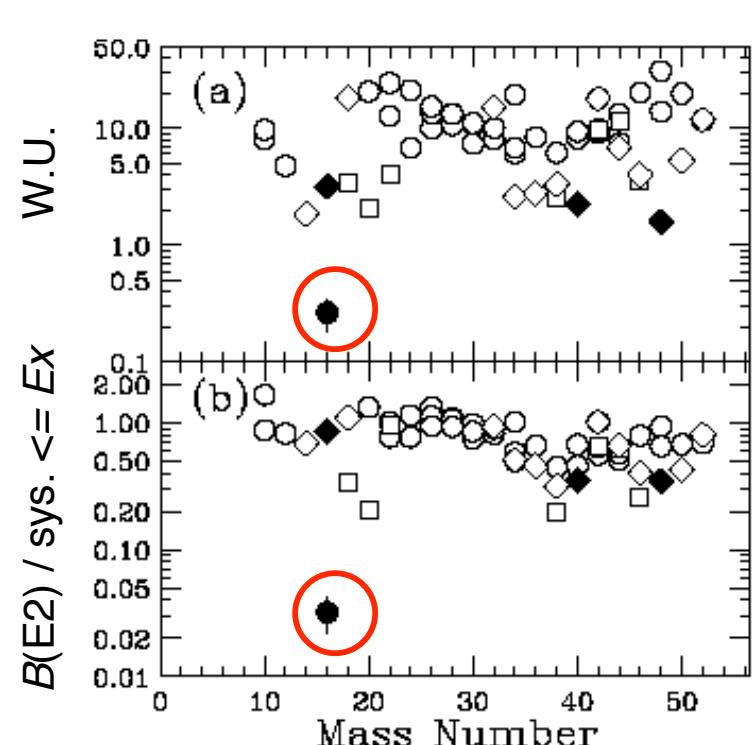
Elekes *et al.* (2003)

$^{16}\text{C} + ^1\text{H}$ inelastic

neutron-sensitive

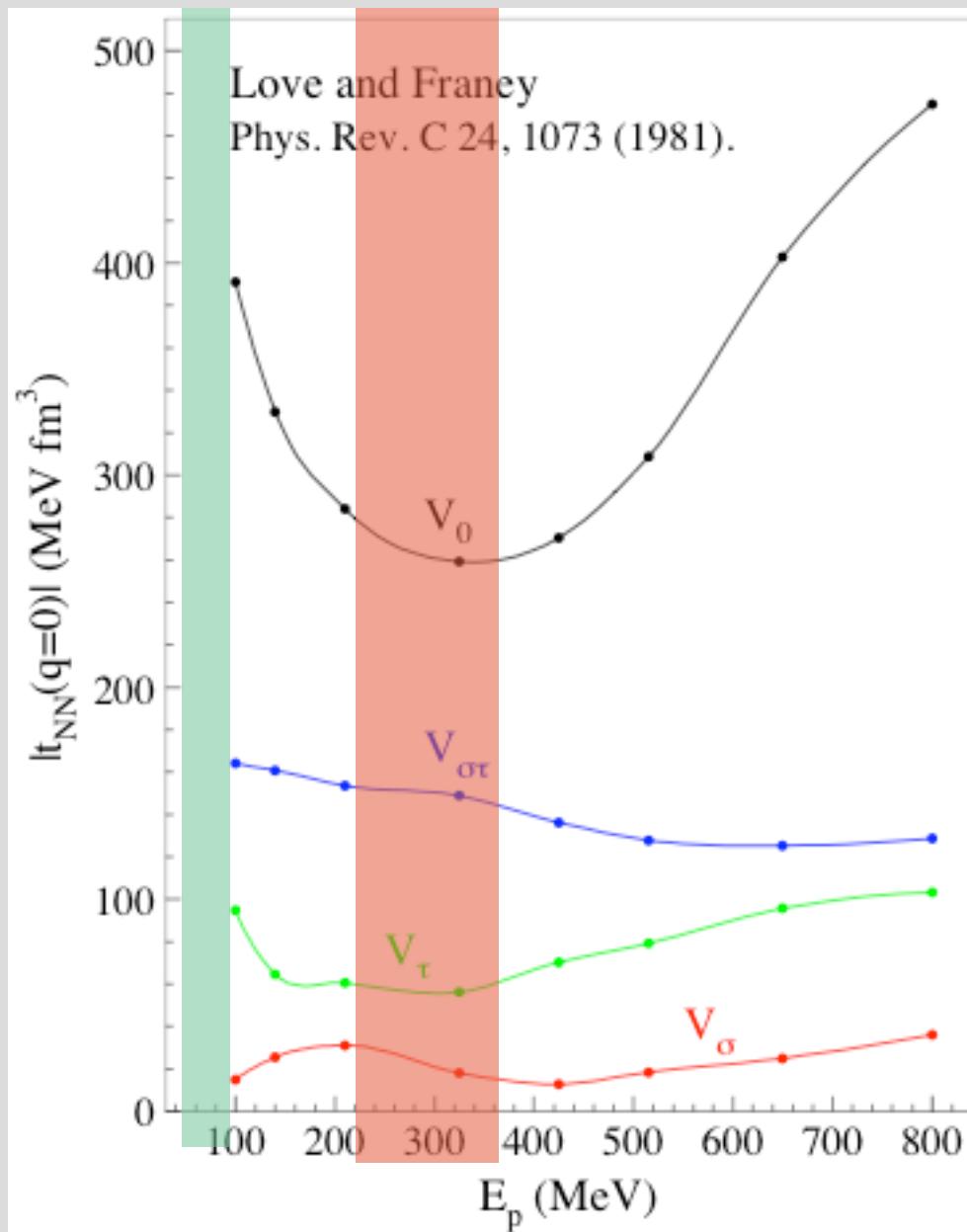
a large β

$M_n \gg M_p \sim B(\text{E}2) \text{ for } 0^+ \rightarrow 2^+$



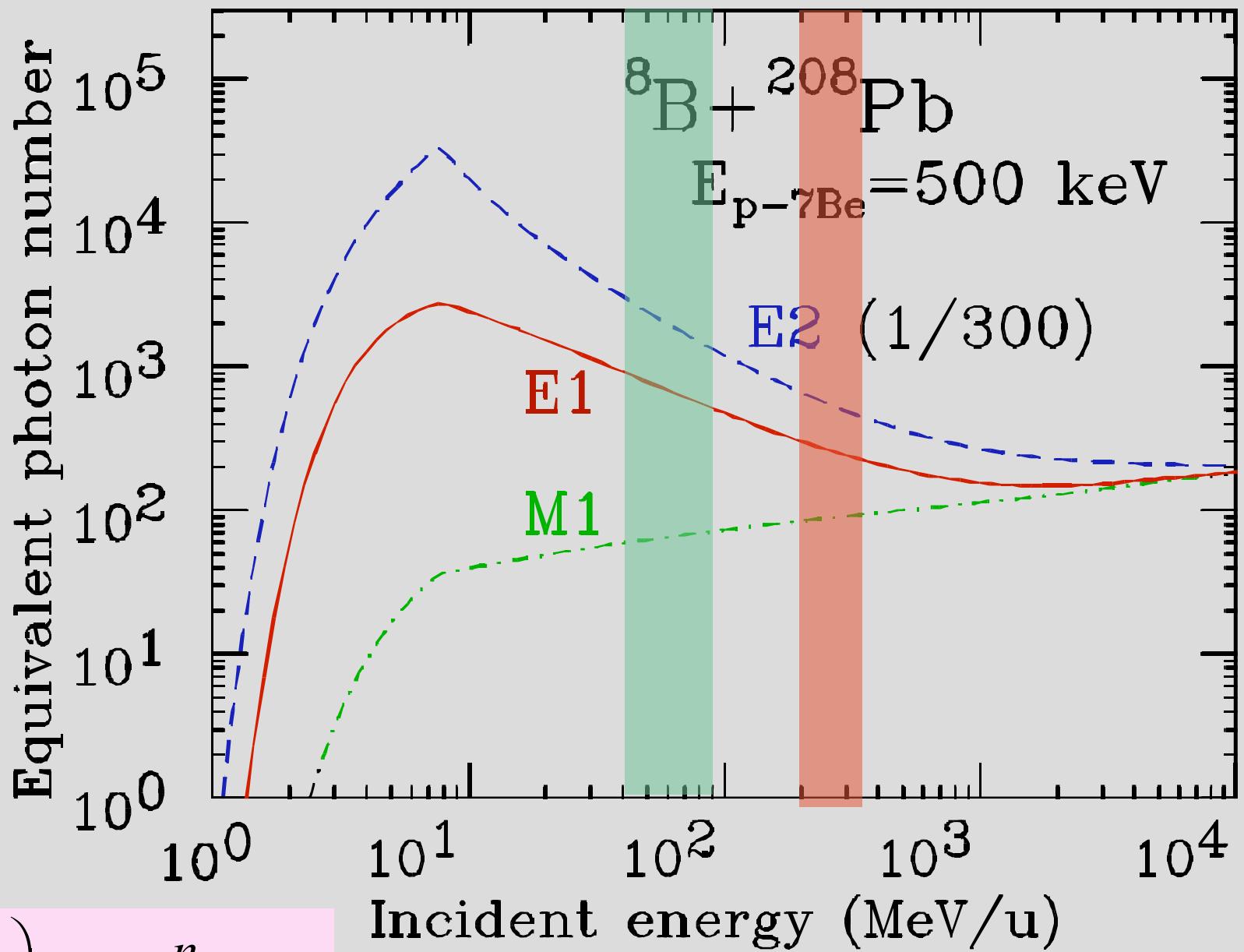
c.f. ^{15}B : Q , ^{12}C inel., (p,p')

NN effective interaction



Transparent
nucl. Interior
single scattering
p-elastic \Rightarrow density

large $V_{\sigma\tau}/V_0$
spin-isospin modes
GT, spin dipole ...



$$\left(\frac{d\sigma}{dE_\gamma} \right)_{\text{C.D.}} = \frac{n}{E_\gamma} \sigma_{(\gamma, p)}$$

JUSTIPEN-LACM

M1/E2: factor of ~5 increase

世界初の超伝導リングサイクロトロン (SRC)

$K = 2,500 \text{ MeV}$

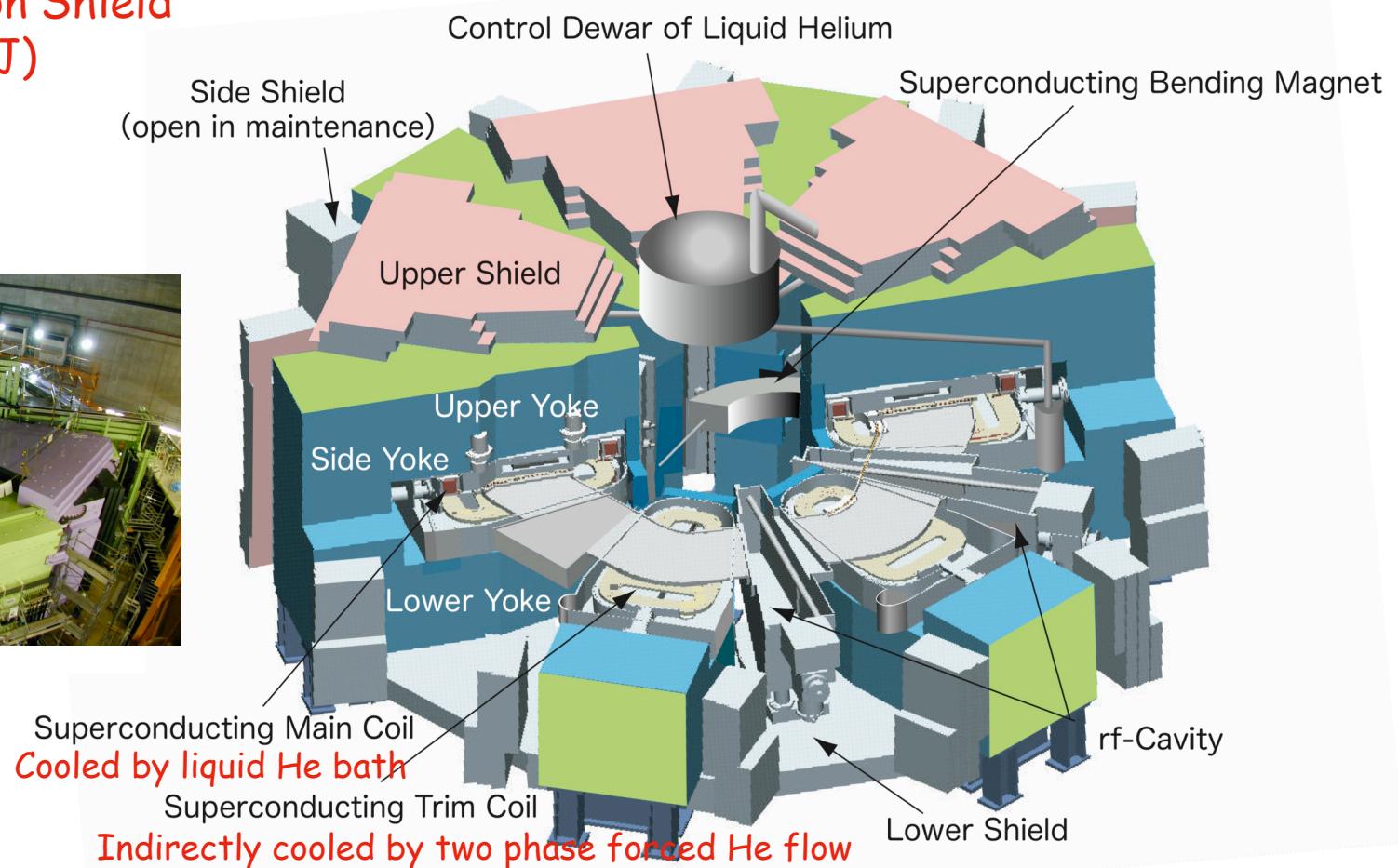
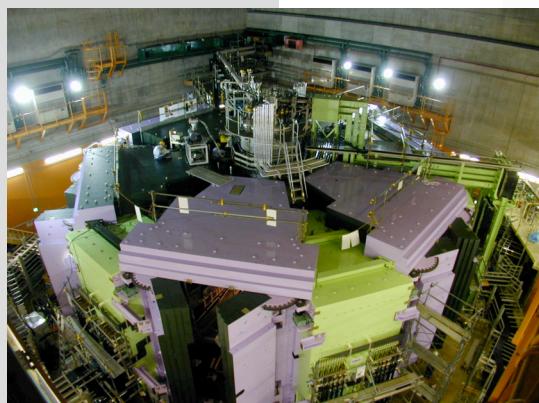
Self Magnetic Shield

Self Radiation Shield

$3.8\text{T} (240 \text{ MJ})$

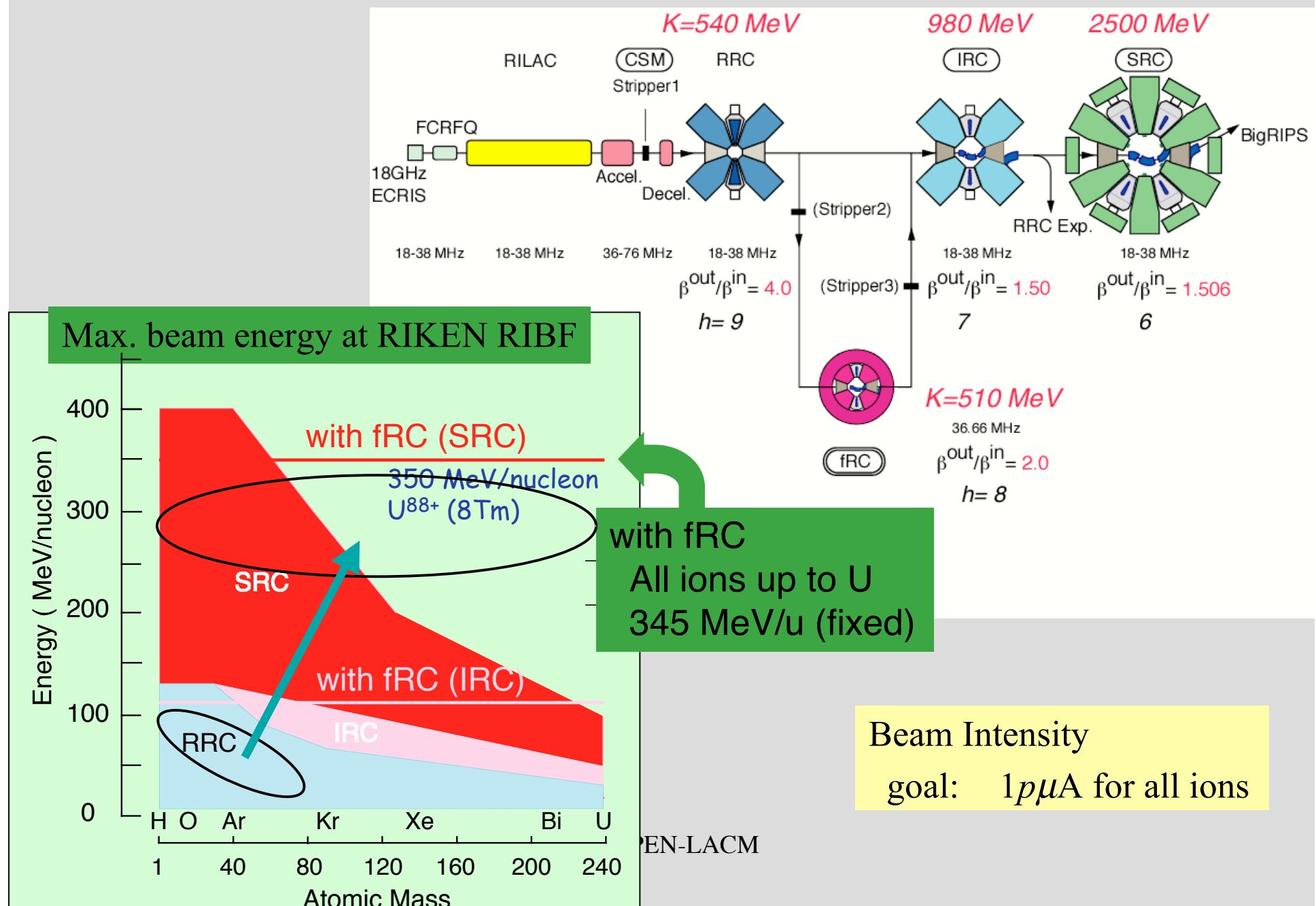
$18\text{-}38 \text{ MHz}$

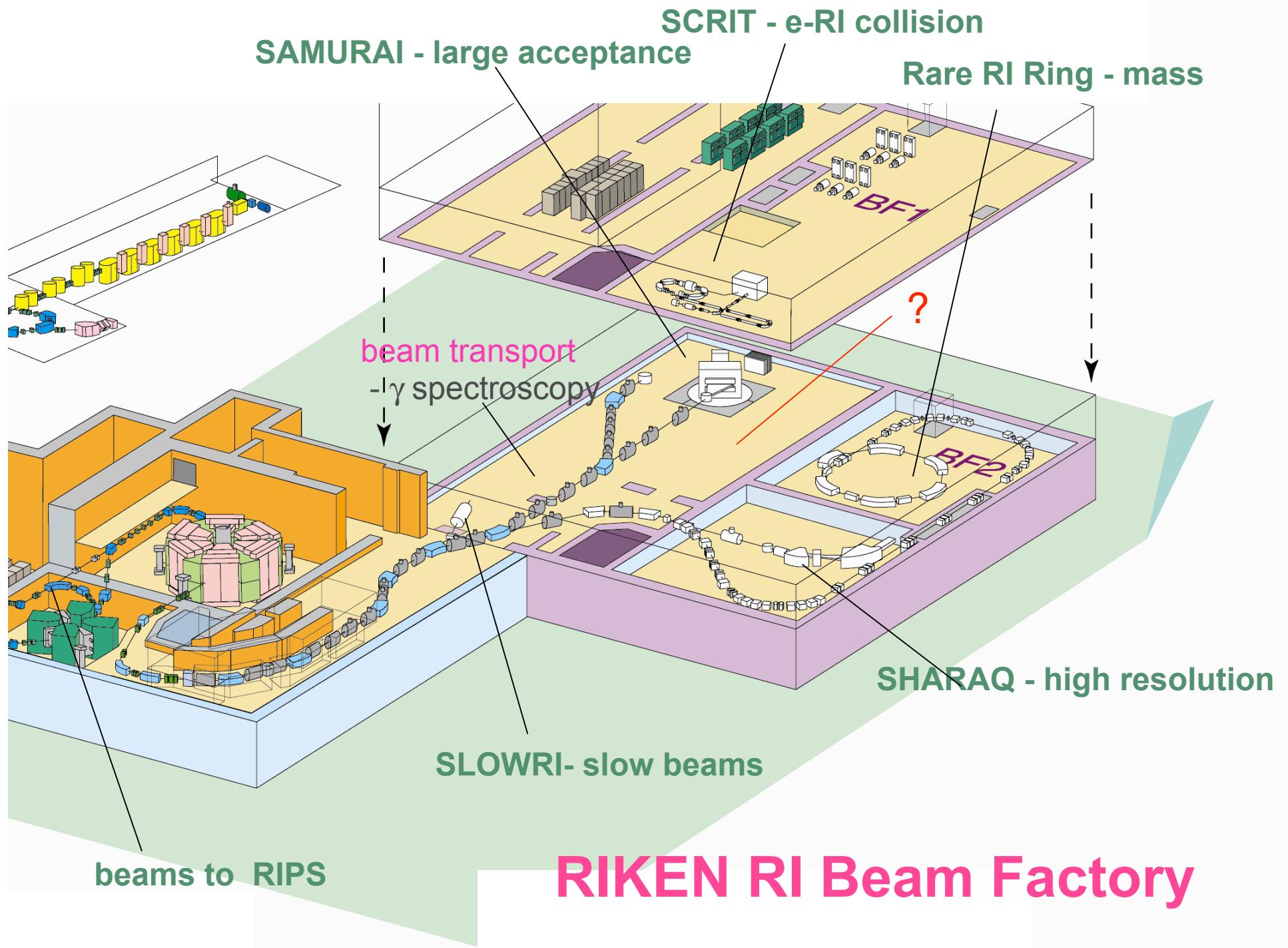
$8,300 \text{ tons}$



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RIBF Accelerator Complex





Major Facilities for Nuclear Physics (Science) in Japan

1. J-PARC

2. RIKEN (RIBF)

3. RCNP
(+SPring8)

