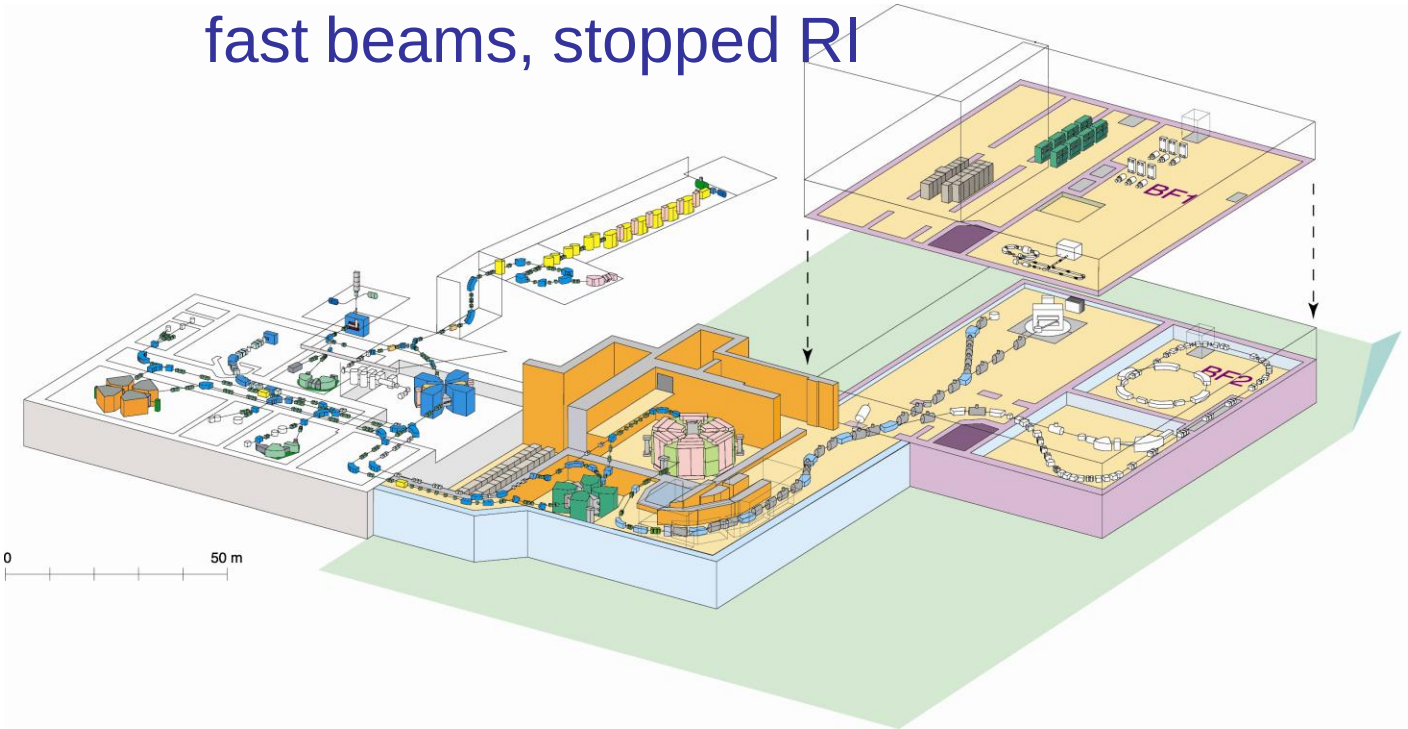
DREB Studies at RIKEN RI Beam Factory

Tohru Motobayashi
(RIKEN Nishina Center)

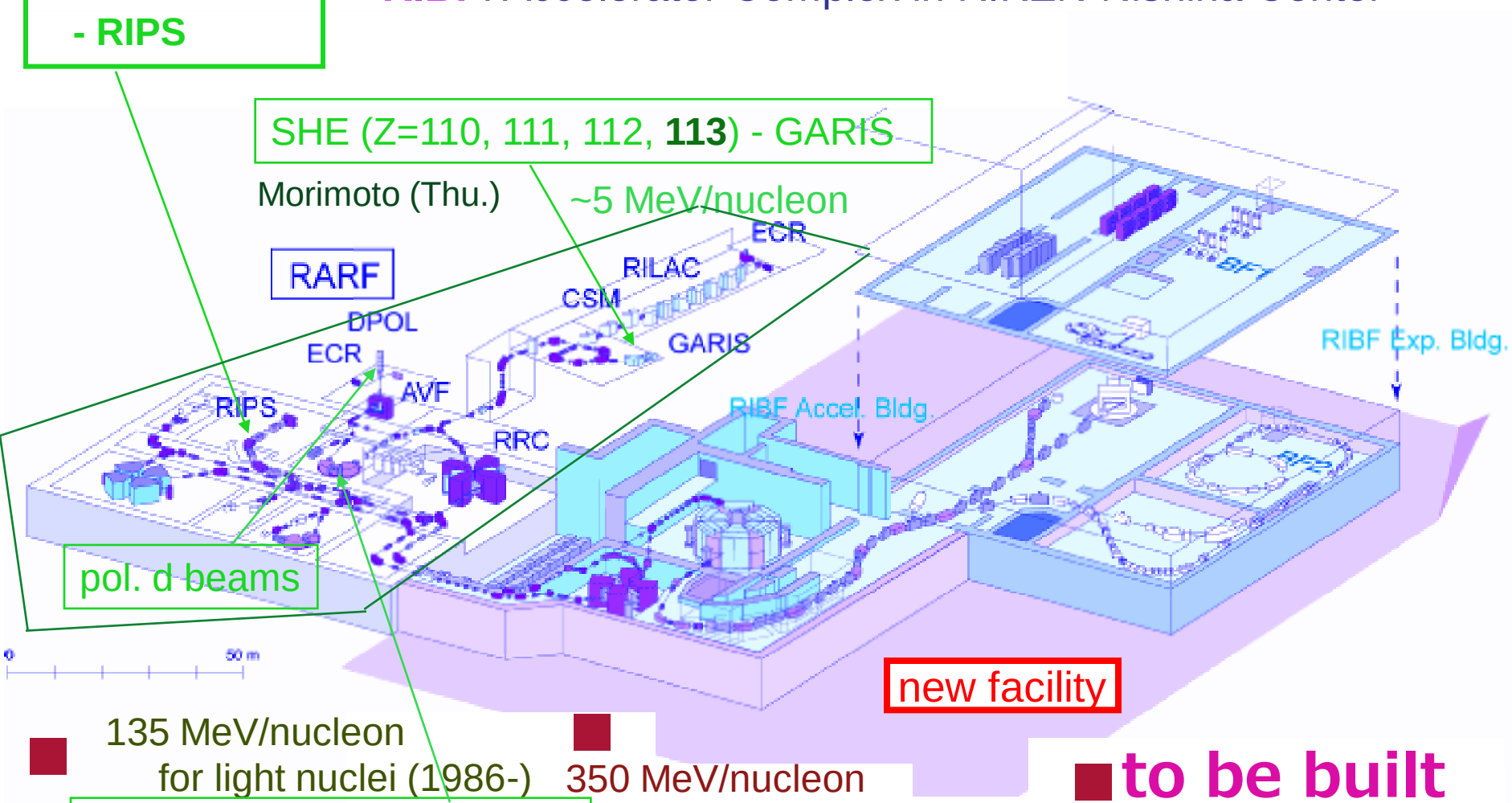
* radioactive isotope

-a ~~next~~ new-generation exotic beam facility
<= projectile fragmentation / in-flight U-fission
fast beams, stopped RI



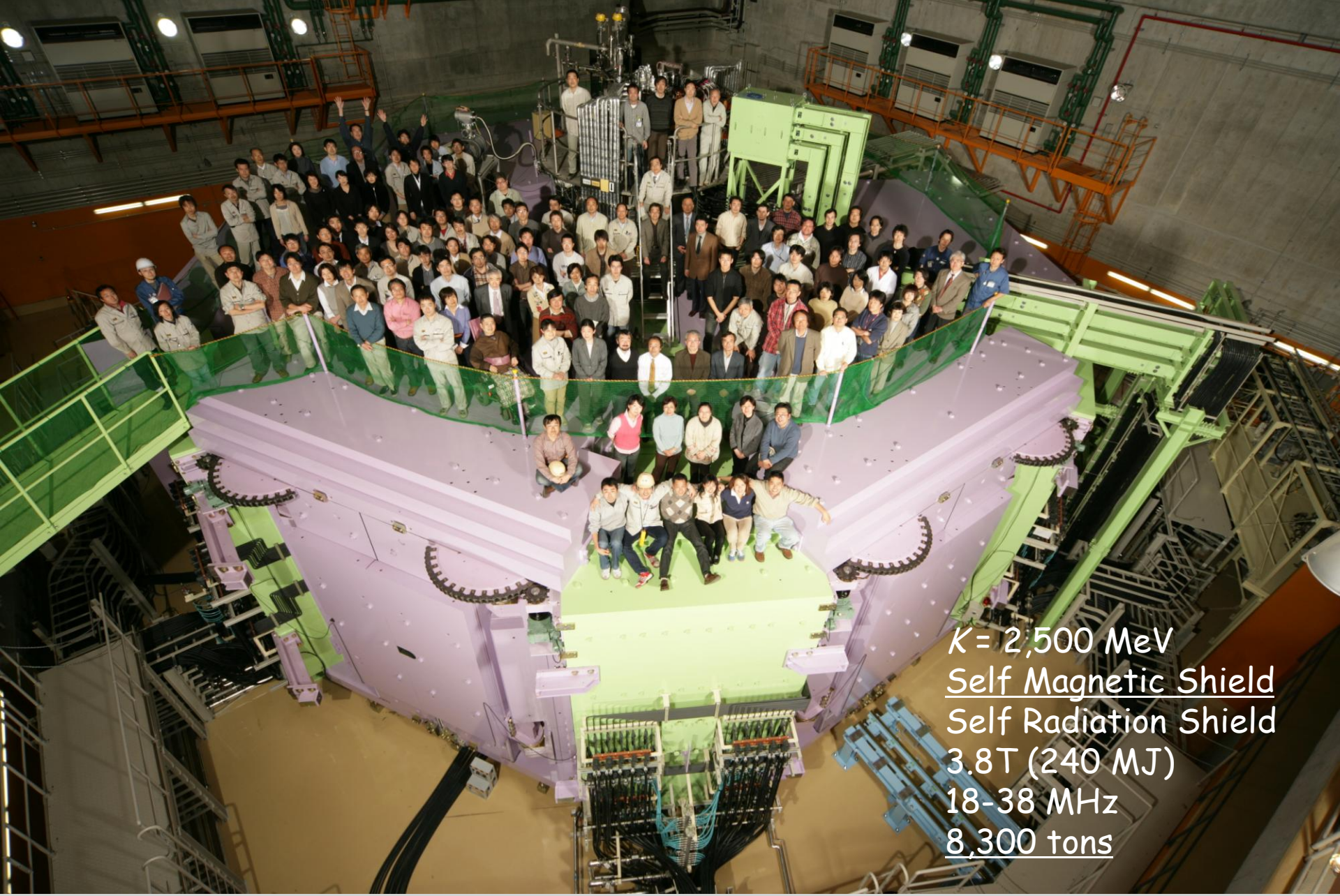
May 2007

RIBF: Accelerator Complex in RIKEN Nishina Center

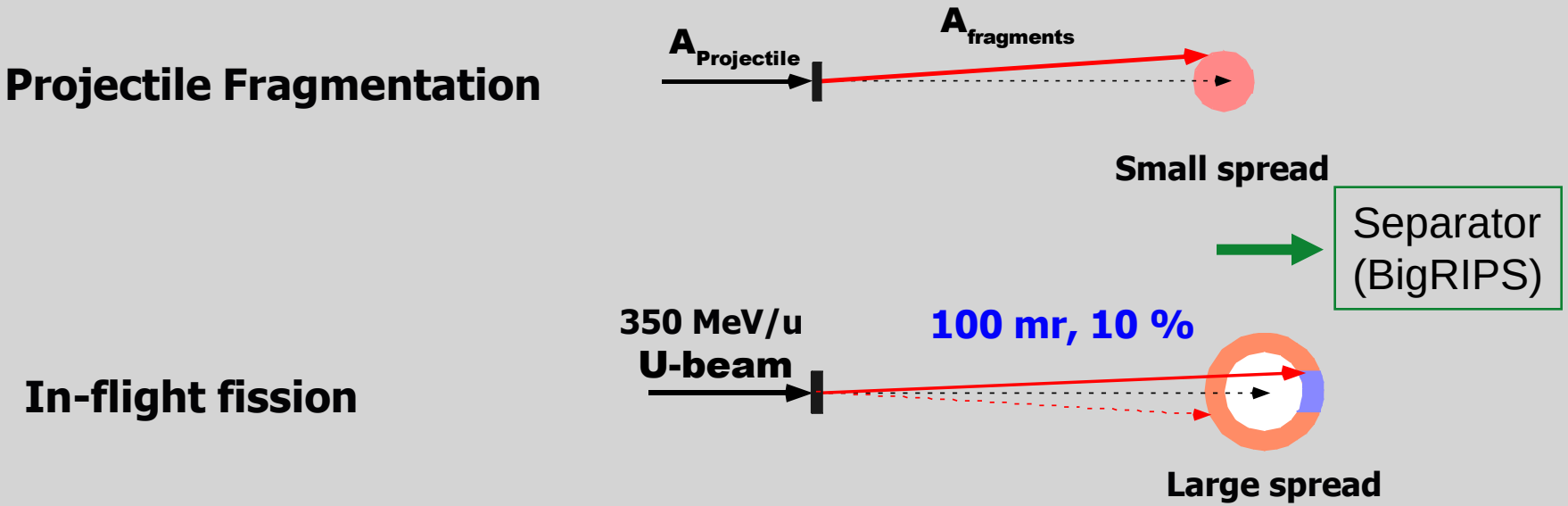


1st beam in Dec. 2006
U beam in Mar. 2006
RI production with U-fission NOW!

May 2007


K = 2,500 MeV
Self Magnetic Shield
Self Radiation Shield
3.8T (240 MJ)
18-38 MHz
8,300 tons

Two mechanisms of RI beam production



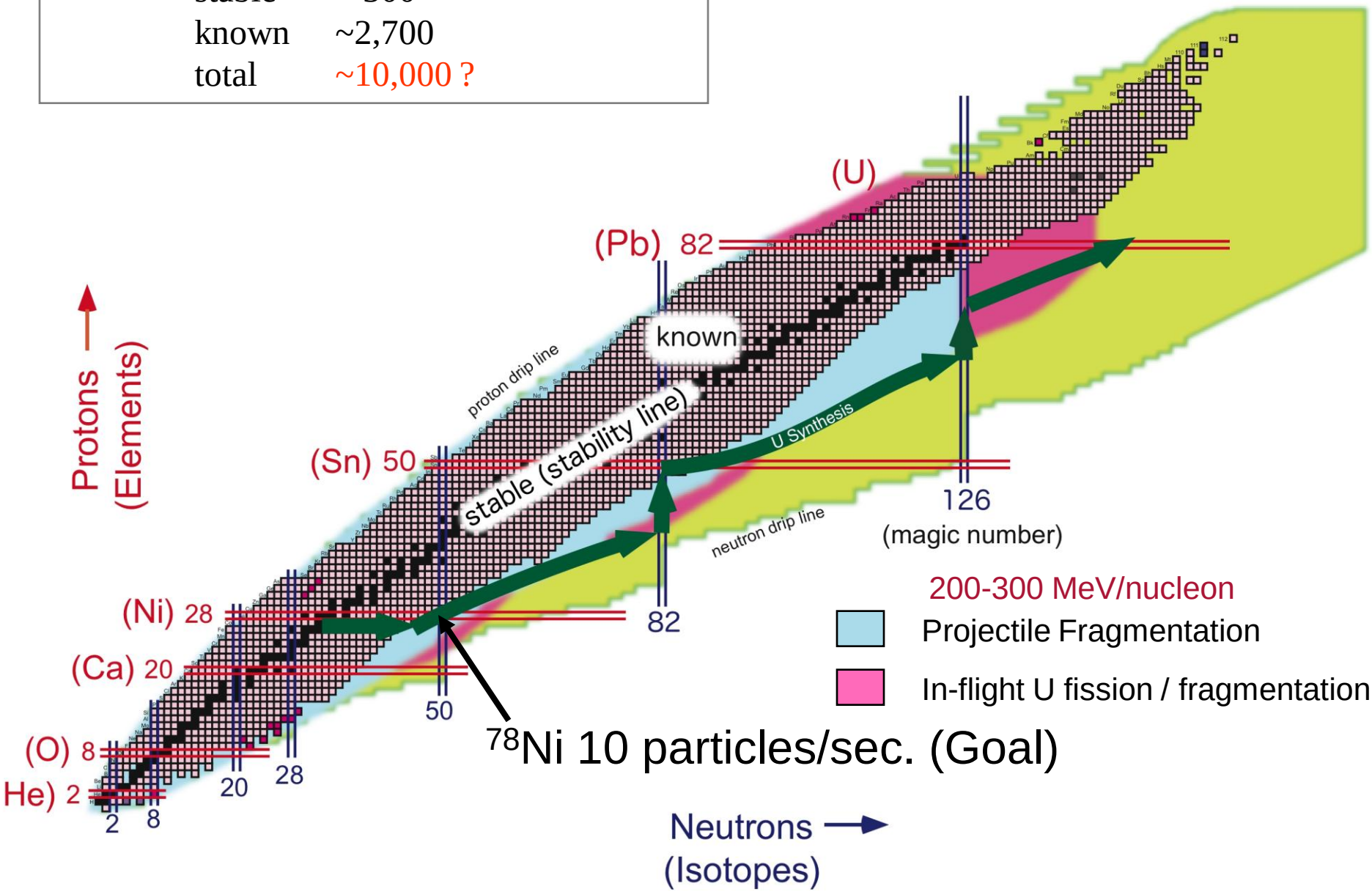
Large acceptance of the separator (Big RIPS):

<= large-aperture superconducting quadrupoles

=> accepting RI beams by in-flight fission of U

Atomic nuclei (isotopes)

stable	~300
known	~2,700
total	~10,000 ?



use of beams -- DREB

fast RI beams very far from stability

fast (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, …..

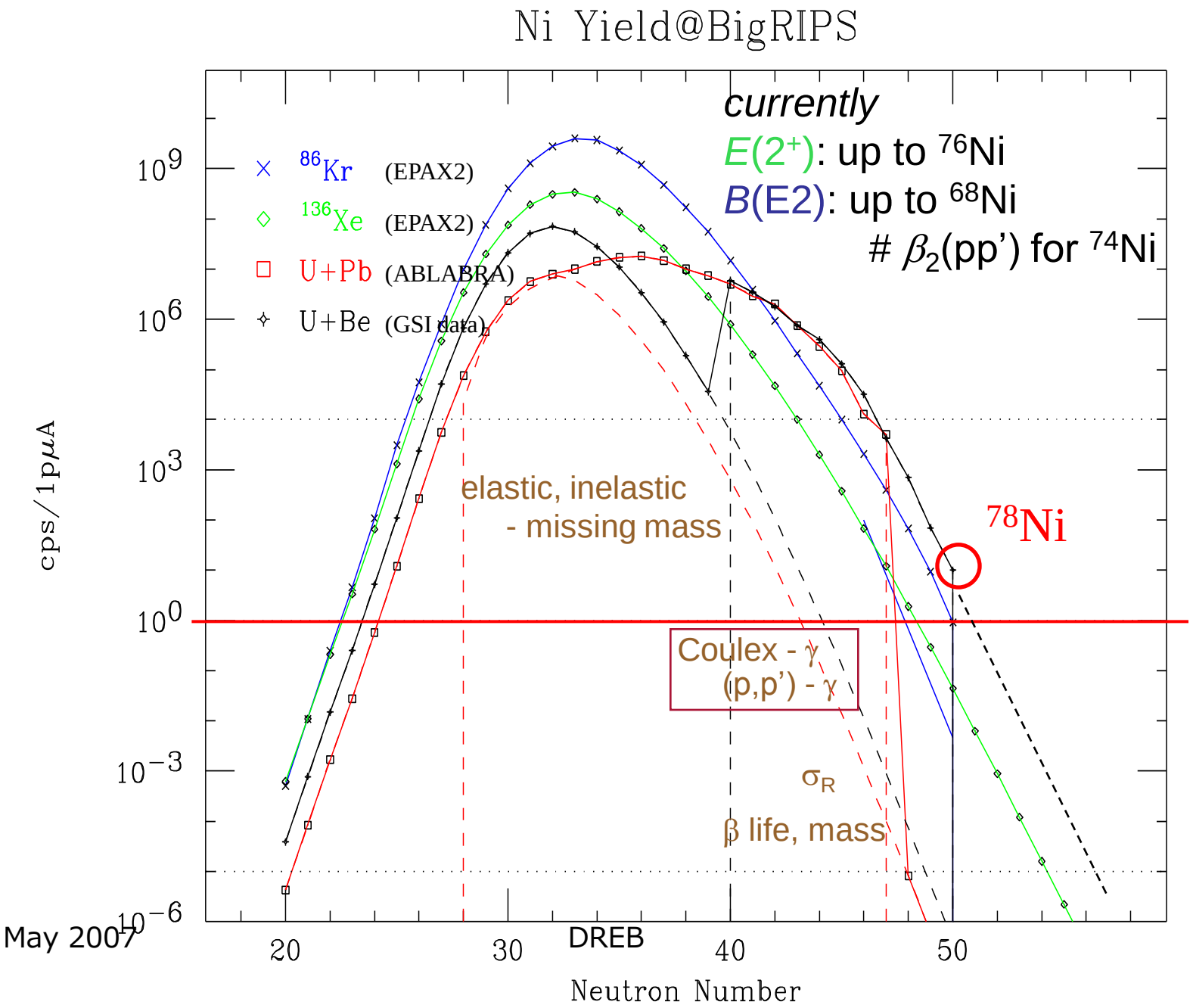
SLOWRI, (SCRIT)

degraded (< 50 MeV/nucleon)

reactions with mass transfer
fusion (spectroscopy), transfers, …

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

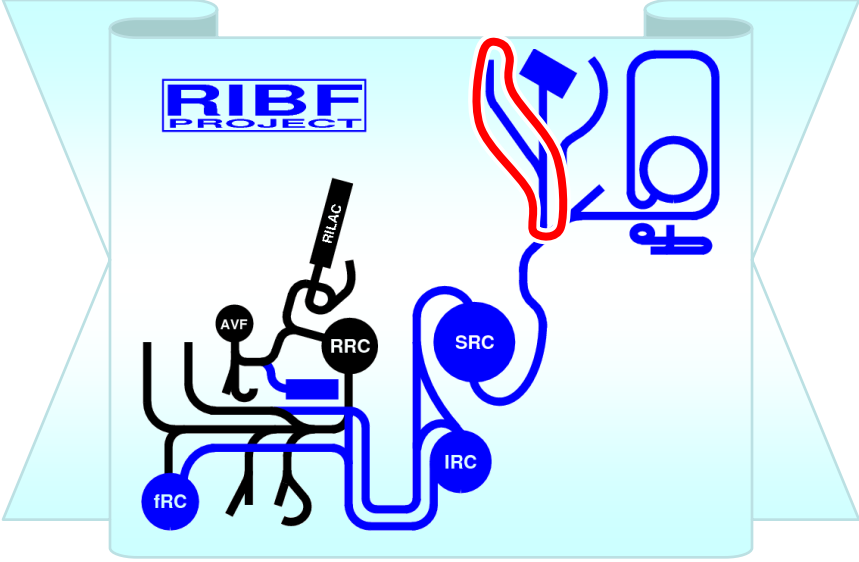
Intensity of Ni isotopes (350 *A*MeV, 1pμA)



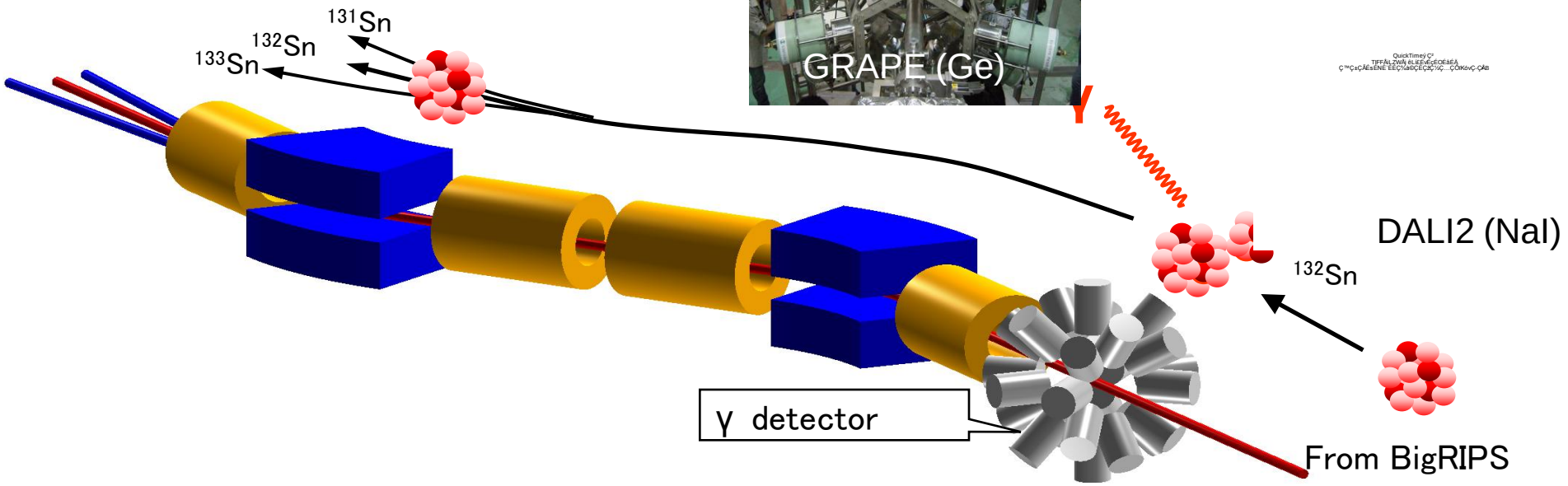
Zero-degree spectrometer

particle ID / momentum analysis

e.g. Doppler shifted γ-ray measurements
with identification of products



GRETA ?



What are necessary ? (RIBF)

- spectroscopy / nuclear astrophysics with DREB

reaction calculations with poor experimental information

sophisticated (microscopic) theoretical treatments

more theoretical control for parameters

e.g. optical pot. (imaginary part)

good “parametrization” for nuclear structure <=> unknown

ANC instead of *S* ?

deformation, M_n M_p, …

Theories suitable for 200-300 *A*MeV

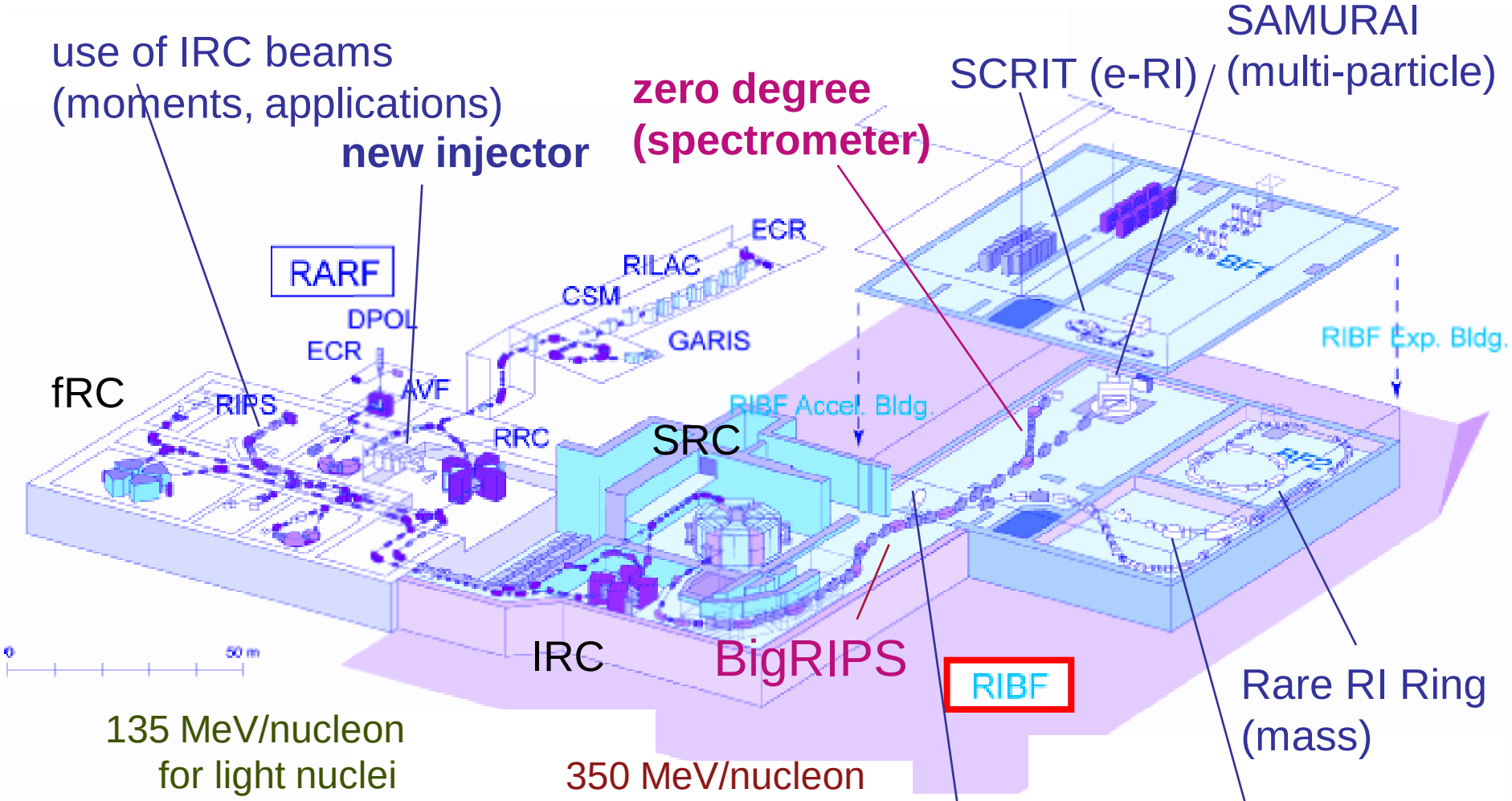
Glauber, eikonal (CDCC), relativisitic impulse,…

Schoroedinger + relativistic kinematics, …

New methods

New equipment

RIBF (2007 -)


use of IRC beams
(moments, applications)
new injector
zero degree
(spectrometer)
SCRIT (e-RI)
SAMURAI
(multi-particle)
RARF
DPOL
ECR
AVF
RIPS
RRC
ECR
RILAC
CSM
GARIS
fRC
RIBF Accel. Bldg.
SRC
RIBF Exp. Bldg.
IRC
BigRIPS
RIBF
Rare RI Ring
(mass)
135 MeV/nucleon
for light nuclei
350 MeV/nucleon
up to U
SHARAQ
(high-resolution)
Slow RI
(gas stopper)

PAC for RIBF

1st: 9, 10 Feb. 2007

19 (5) proposals for BigRIPS (+ ZeroDegree)

<DR(EB) experiments approved / differed>

Measurements of reaction cross sections	T. Ohtsubo
Proton elastic scattering	H. Sakaguchi
(p,2p) Knockout Reactions	T. Kobayashi
Production of spin-aligned RI beams	H. Ueno
3N force via dp elastic scattering	K. Sekiguchi
2+ states of heavy tin and tellurium nuclei -(p,p')	Zs. Dombrádi
Pionic Atoms in (d,^{3}He)	K. Itahashi
Magicity in ^{42}Si and ^{54}Ca - coulex	S. Takeuchi
^{78}Ni and its vicinity - 2n removal / inelastic	K. Yoneda
Beyond ^{132}Sn - 2n removal / coulex	N. Aoi
"Island of Inversion" - 2p removal / (p,p') / coulex	H. Scheit

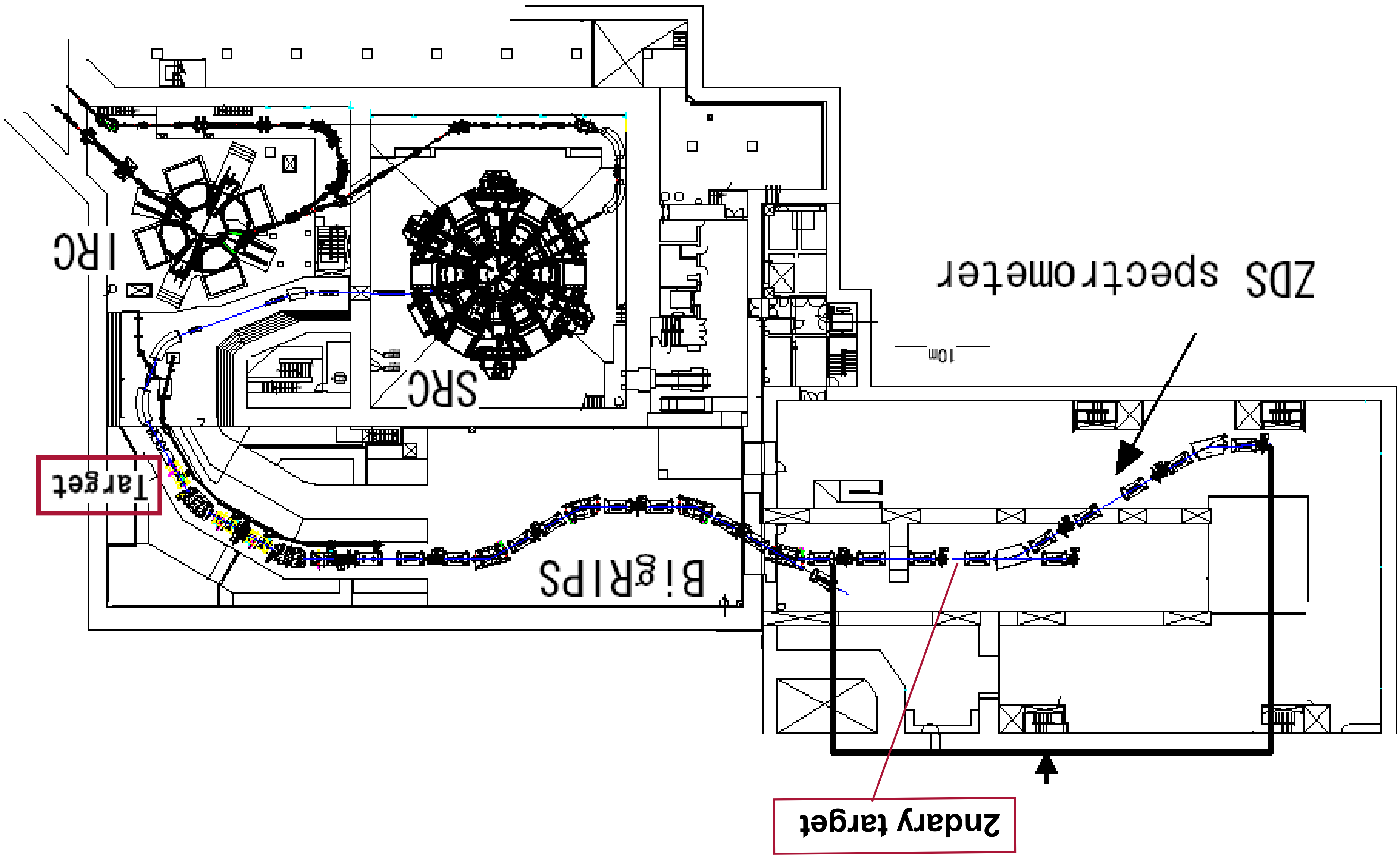
(5 LOI)

2nd: Sept.

Facility information:

http://www.nishina.riken.go.jp/UsersGuide/Nuclear/index.html

Big RIPS - RI beam separator

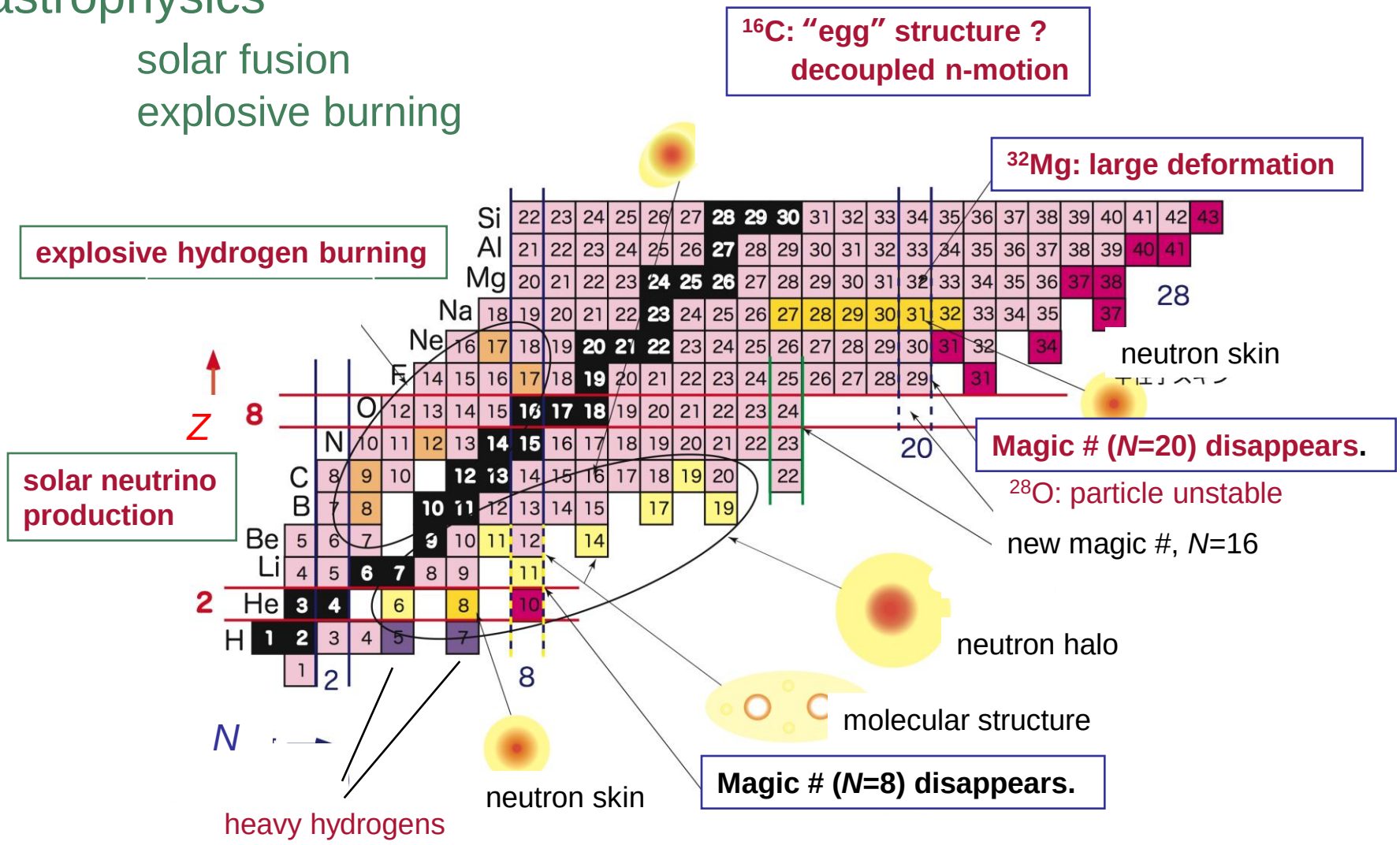


exotic nuclear structure

- shell closure
- behaviors of p & n - correlated / decoupled

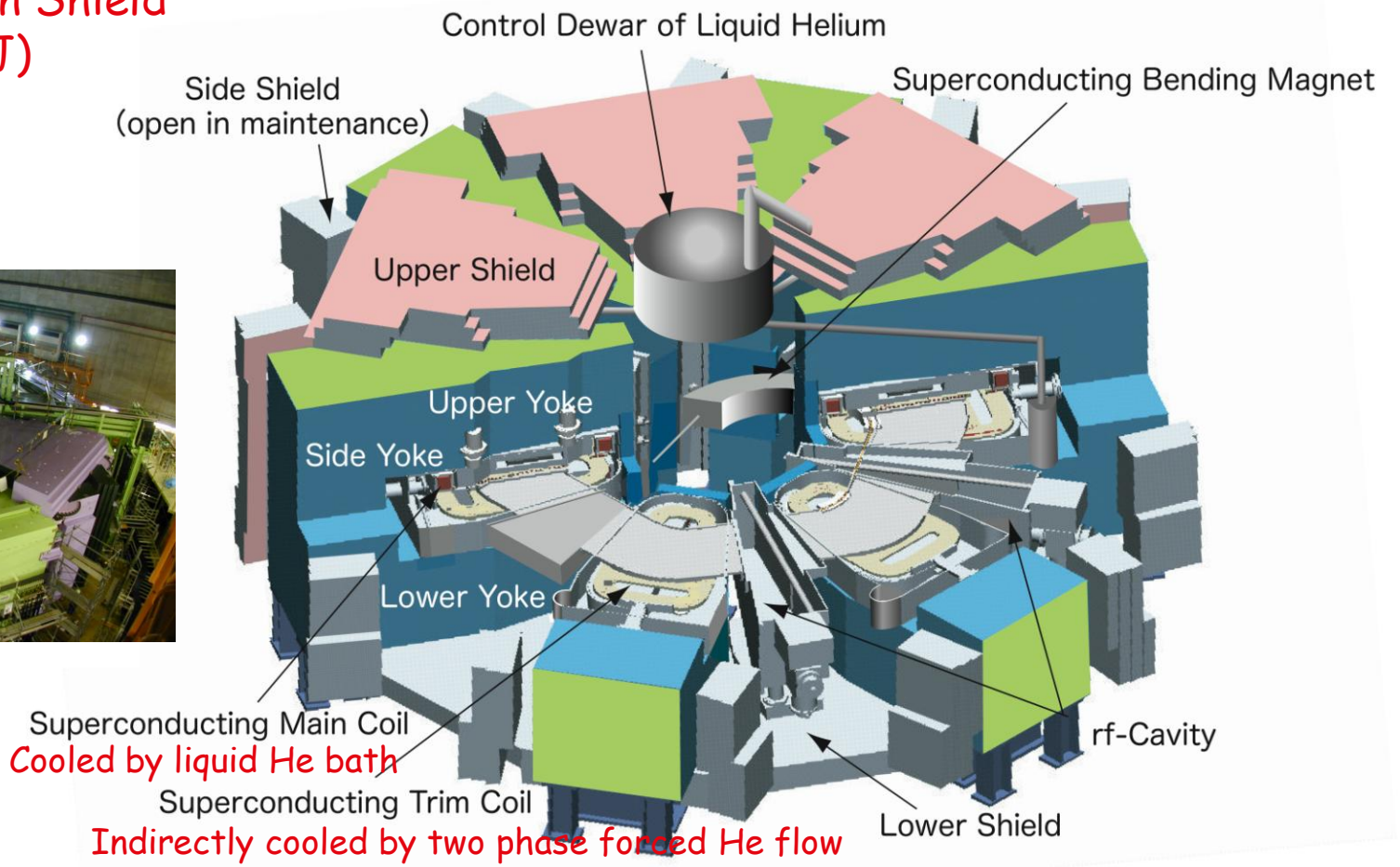
astrophysics

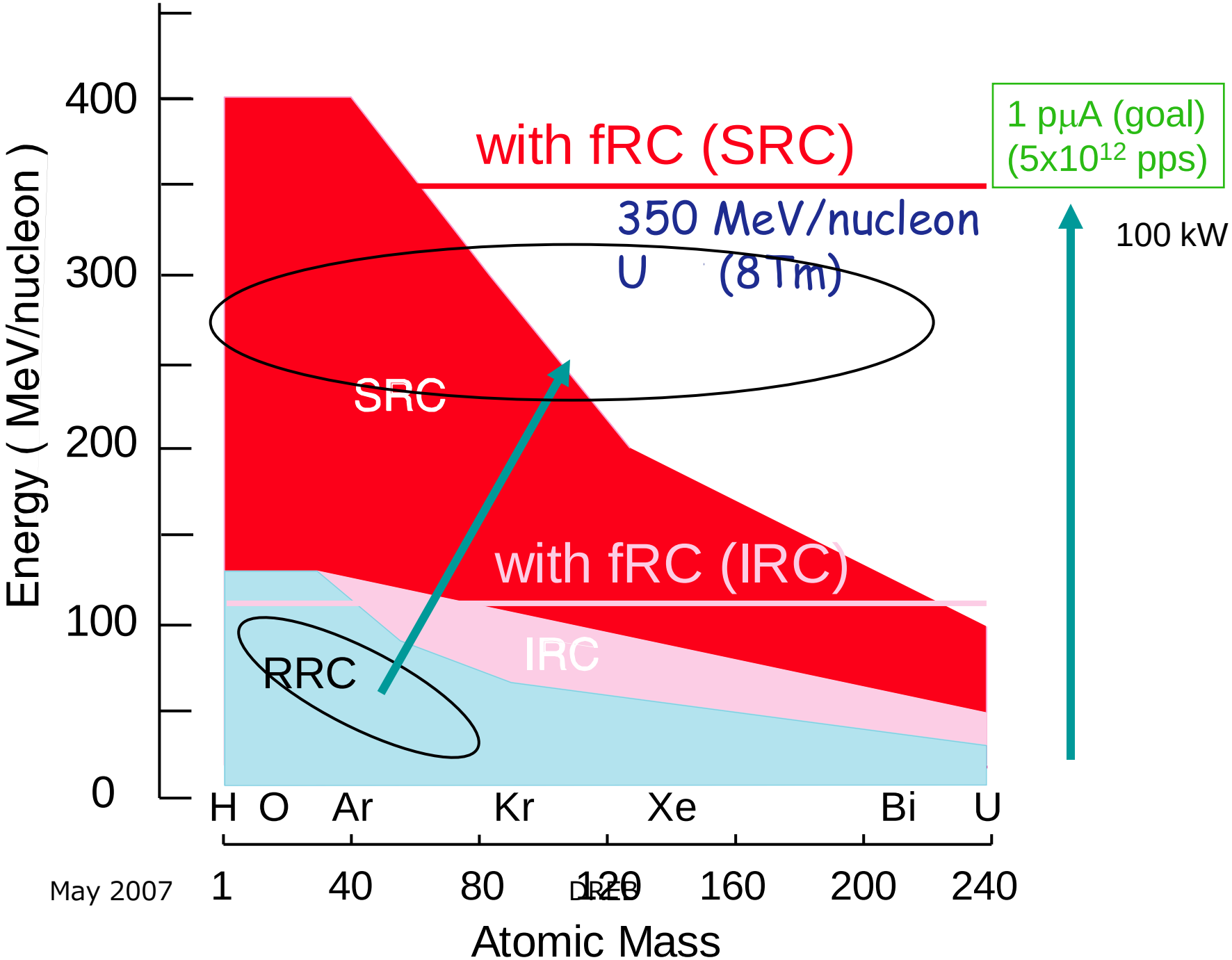
- solar fusion
- explosive burning



世界初の超伝導リングサイクロトロン (SRC)

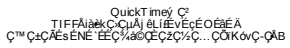
K = 2,500 MeV
Self Magnetic Shield
Self Radiation Shield
3.8T (240 MJ)
18-38 MHz
8,300 tons




Energy (MeV/nucleon)
400
300
200
100
0
with fRC (SRC)
350 MeV/nucleon
U (8Tm)
SRC
with fRC (IRC)
IRC
RRC
1 pμA (goal)
(5x10^12 pps)
100 kW
H O Ar Kr Xe Bi U
1 40 80 120 160 200 240
Atomic Mass
May 2007
DRE3

1st RI beams with U in-flight fission

ΔE



TOF

Mar. 27, 2007

RI beams at RIKEN

Ring Cyclotron (1987) + RIPS (~1990) <= LBL, GANIL (LISE)

fast "RI-beam" or "RNB" by fragmentation (< 100 *A*MeV)

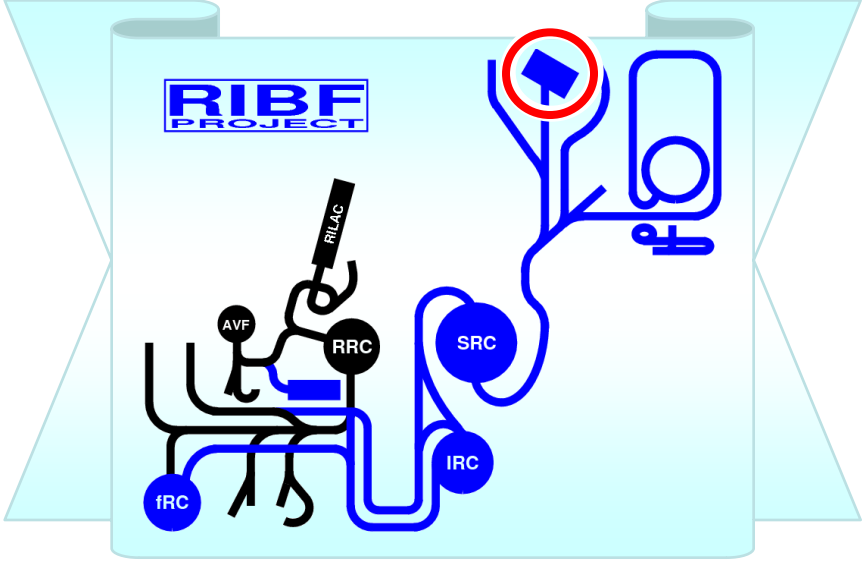
the most intense beams for some light nuclei

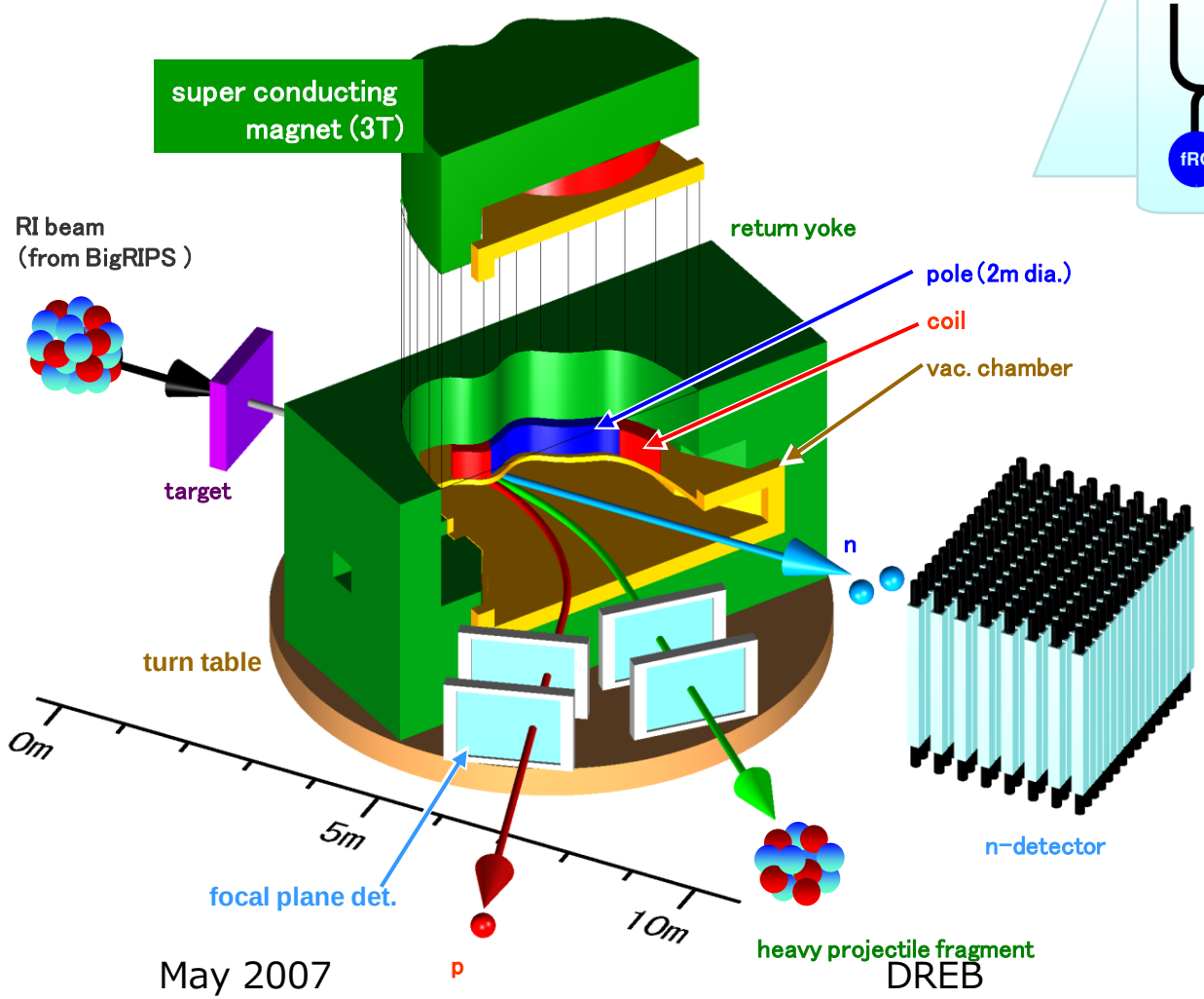
stop	μ- and Q-moments for neutron-rich nuclei
fast	new lifetime measurements (^{16}C, ⋯)
fast	Coulomb dissociation for structure of light drip-line nuclei (^{11}Li,^{11}Be, ⋯) for astrophysics (^{14}O, ^{8}B .)
fast	fast Coulomb excitation, inelastic scattering (^{32}Mg, ..)
fast	γ spectroscopy w. secondary fragmentation (^{34}Mg, ..)
fast	charge exchange, (p,p′), ⋯
deg.	low energy reactions w. degraded beams (fusion, astro.)
fast	new isotopes (^{31}F, ⋯)

RI Beam Factory (**RIBF**)

RI beams: fragmentation / in-flight fission

SAMURAI7





Large solid-angle spectrometer

particle correlation
- unbound sates
- (p,2p)
- astrophy. (p,γ)
- nucl. matter

SAMURAI7 (Superconducting Analyzer for MUlti Particles from RAdioIsotope Beams with 7 Tm)

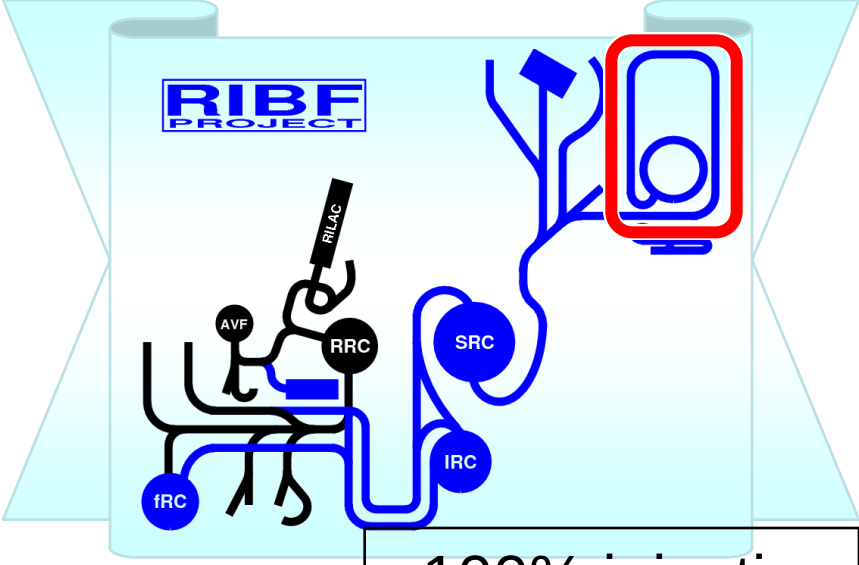
May 2007

DREB

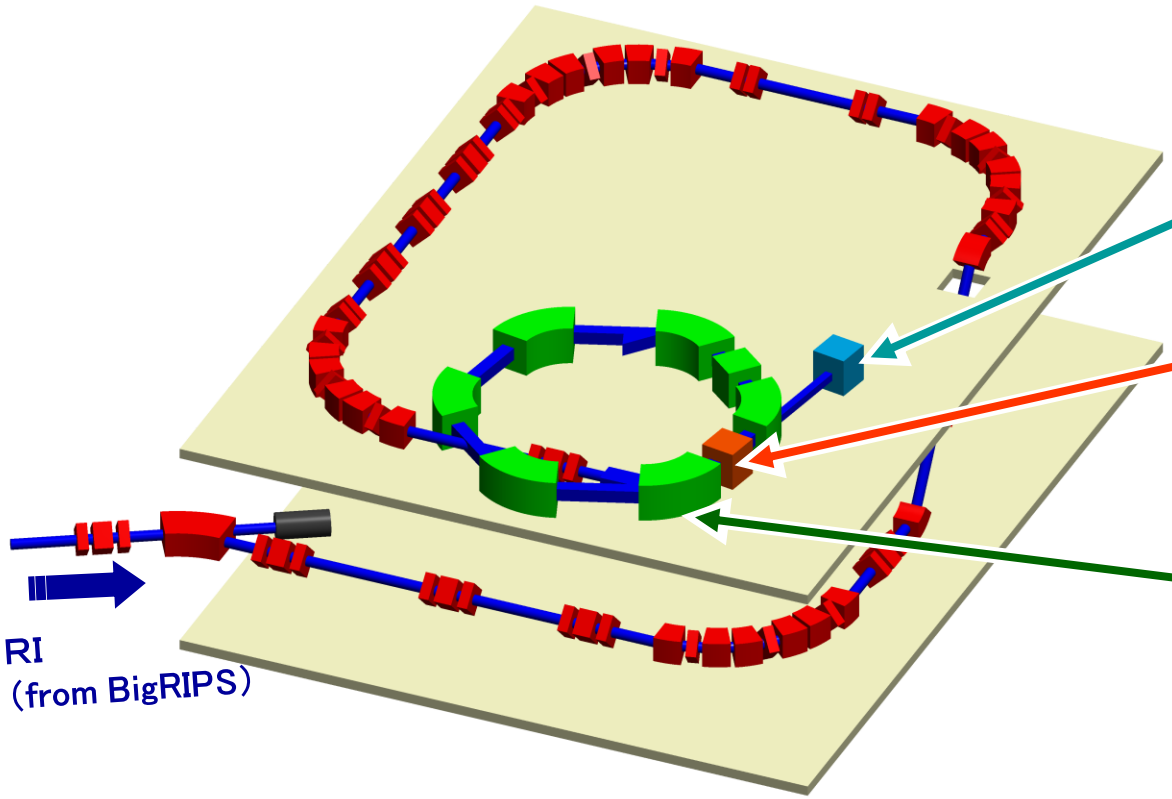
Rare RI ring

Isochronous ring
with individual injection

mass measurement for
short-lived rarely-produced
nuclei



~100% injection
< 100 s^{-1}



particle ID

kicker magnet

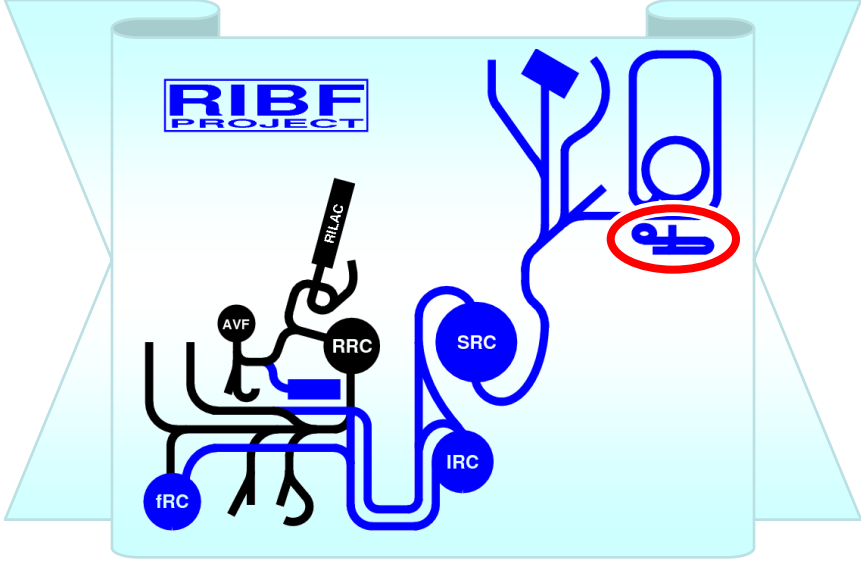
Mass $\Delta m/m$~10^{-6}
Beta decay, …

Isochronous ring

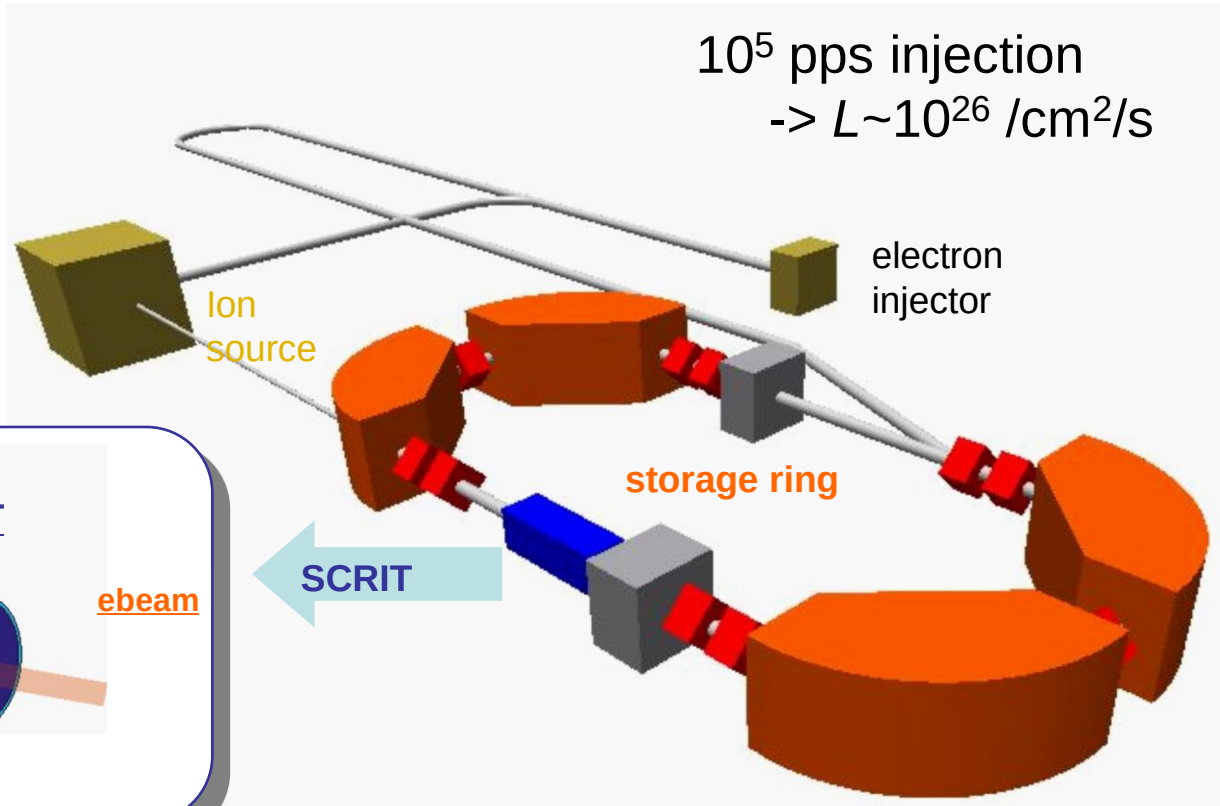
SCRIT

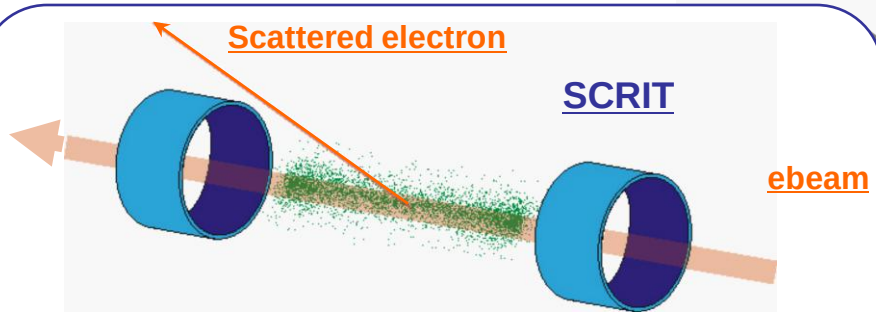
Self Confining RI Target

electron–RI scattering



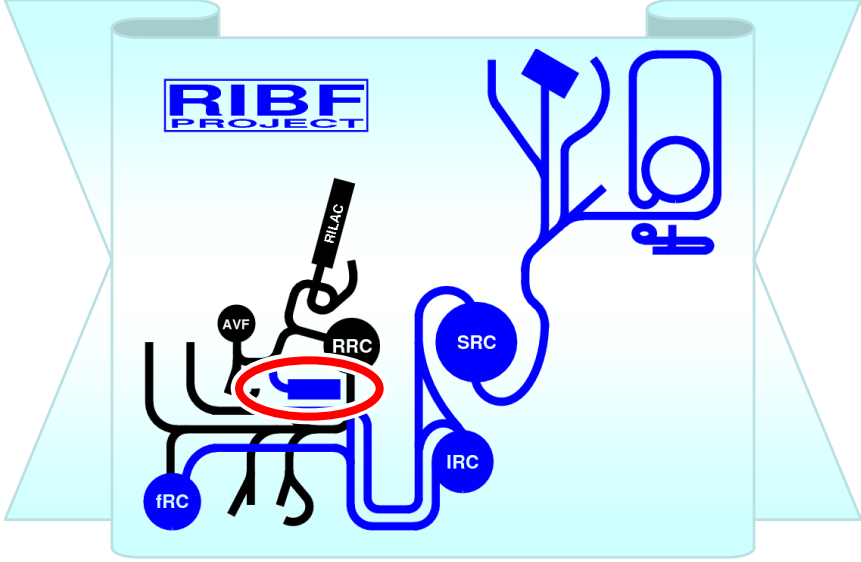
10^5 pps injection
-> L~10^{26} /cm^2/s

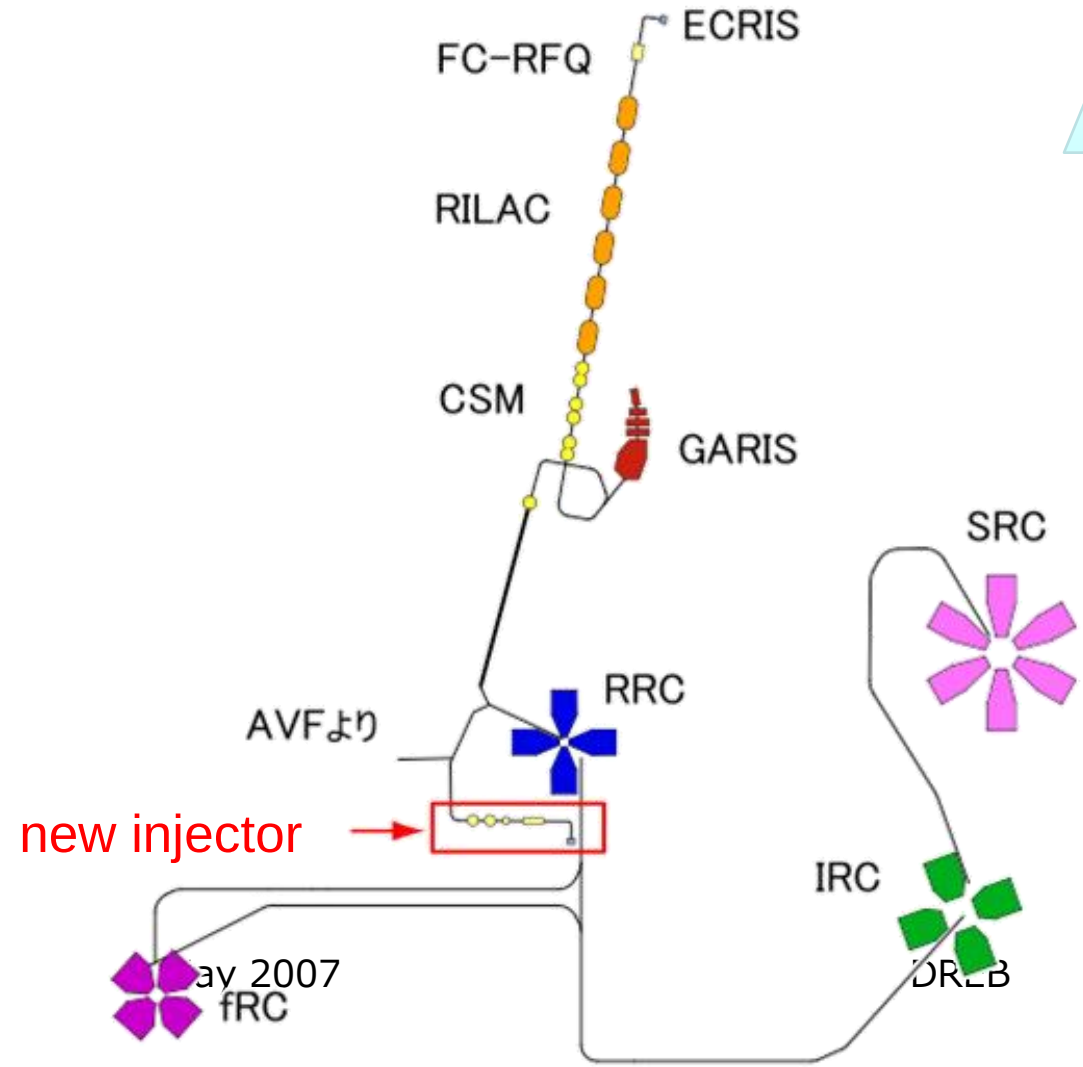




RIs trapped by the electron beam

Injector system dedicated for RIBF

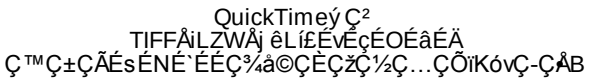




Independent operations of RILAC-GARIS (SHE, ..) and RIBF

DALI2*

High efficiency
Doppler-shift correction



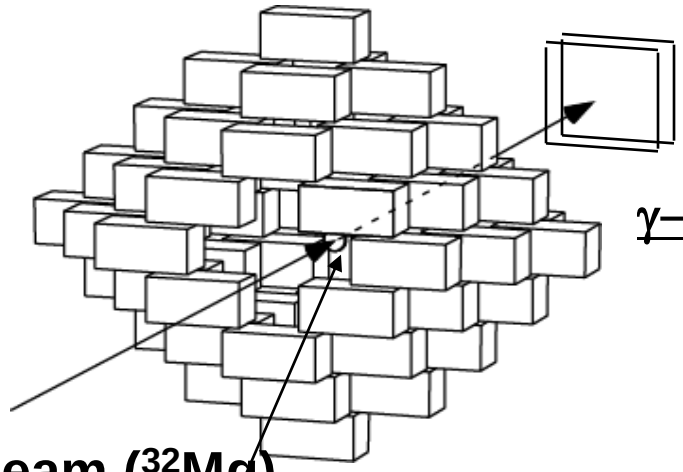
160 NaI(Tl) crystals
- 4x8x16 cm^3
- ΔE~9% (FWHM) @ 662 keV

$\Delta\theta$~9 deg.

For 1 MeV γ (β=0.3, $\Delta\beta/\beta$=10%)
- ΔE=8.7%
- ε=20%

* **D**etector **A**rray for **L**ow **I**ntensity radiation

Coulomb excitation of ^{32}Mg (N=20)

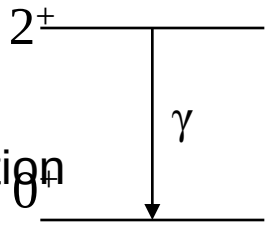


Charged particles (Si stack - ΔE-E)

particle ID for ejectiles (^{32}Mg)

γ–rays (DALI -NaI(Tl) array)

γ-ray energy => state ID
emission angle
=> Doppler correction



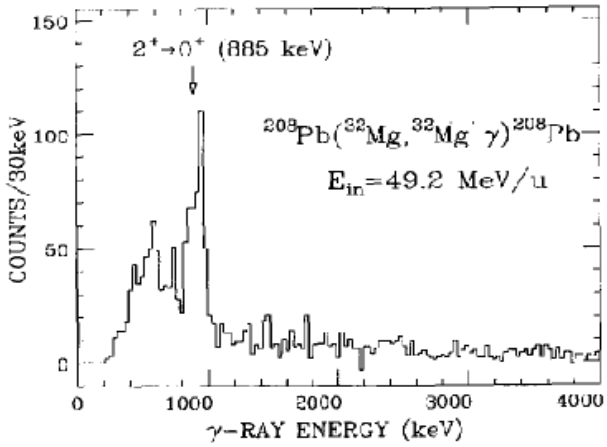
RI beam (^{32}Mg)

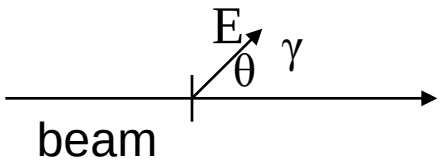
300 s^{-1}

~50 A MeV

Target (^{208}Pb)

350 mg/cm^2



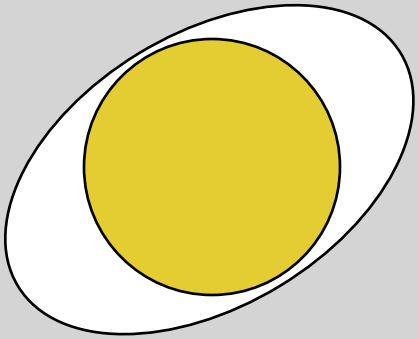


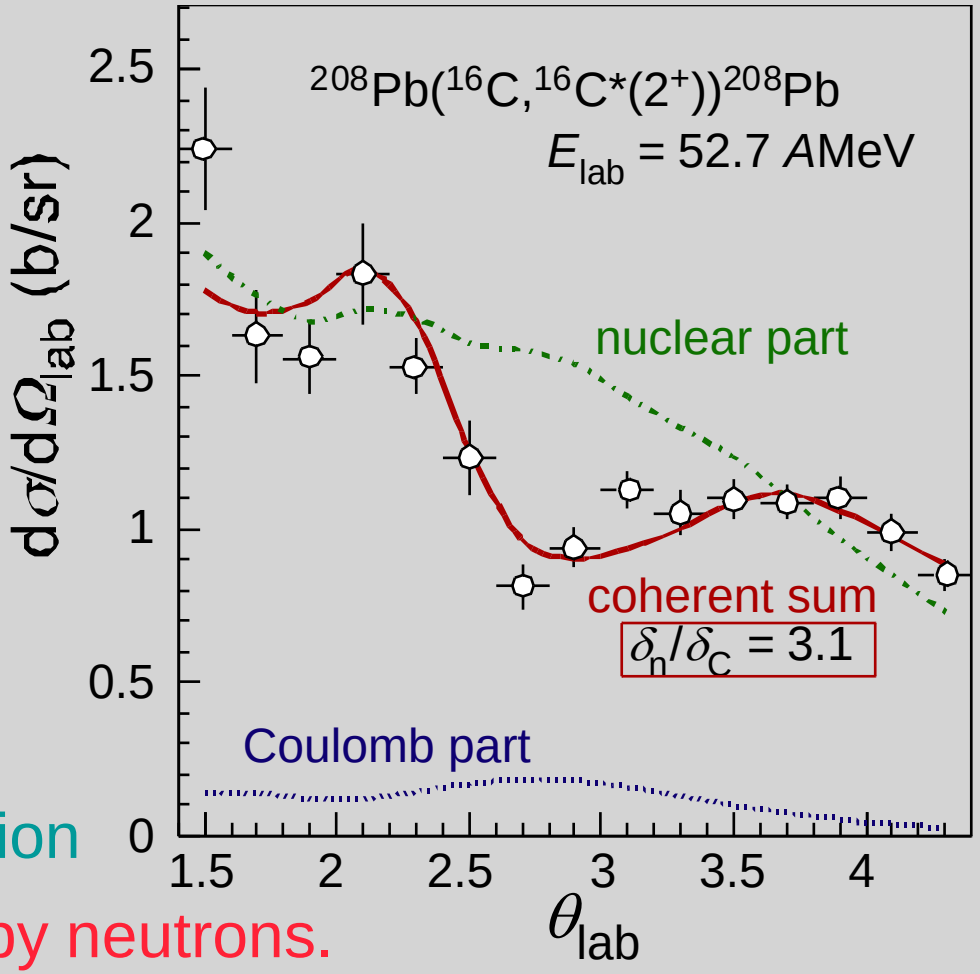
Doppler-shift corrected spectrum

$^{16}C + ^{208}Pb$

Inelastic scattering

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





"egg-like" structure ?

strong
p-n interaction

2+ excitation: almost only by neutrons.

<=> lifetime, (p,p')

Coulomb-nuclear Interference in angular distribution

ongoing collaboration programs (examples)

RIKEN-GSI

workshop (theory > experiment)
"Expert Meeting (FRS related technical issues)" w. MSU, …
for experiments / developments with common interests => regular meeting

Japan-Italy Symposium

(RIKEN-IN2P3)

Co-hosting: Beijing Summer school / EXON Symposium

new collaboration programs

Japan US Theory Institute for Physics with Exotic Nuclei (about to start)

International collaboration program (UT in collaboration w. RIKEN)

"Associated International Laboratory"

GANIL-RIKEN with institutions of both countries
common experiments / developments
nuclear structure (low energy nuclear physics)

Toward an “Asian regional center”

"Council for China-Japan Research Collaboration on Nuclear Physics"

Pekin U., CIAE Beijing, IMP Lanzhou, SIANP Shangai

RIKEN, ….

Pre-meeting : @RIKEN on 6-7th Feb. => regular meeting for Asian collaboration (future)

toward exotic nuclei farther from the stability

new-generation facilities -- RIBF, RIA, GSI-FAIR, Spiral2…

more new methods, probes

e.g. e-RI scattering

mass measurement of rarely produced RIs

two nucleon correlation in nucleus

asymmetric nuclear matter

efficient stopping / degrading fast beams

=> variety of methods, reactions …

impacts to:

understanding

many-body dynamics

nucleosynthesis - origin of matter (*e.g.* r-process)

evolution of the universe

applications to

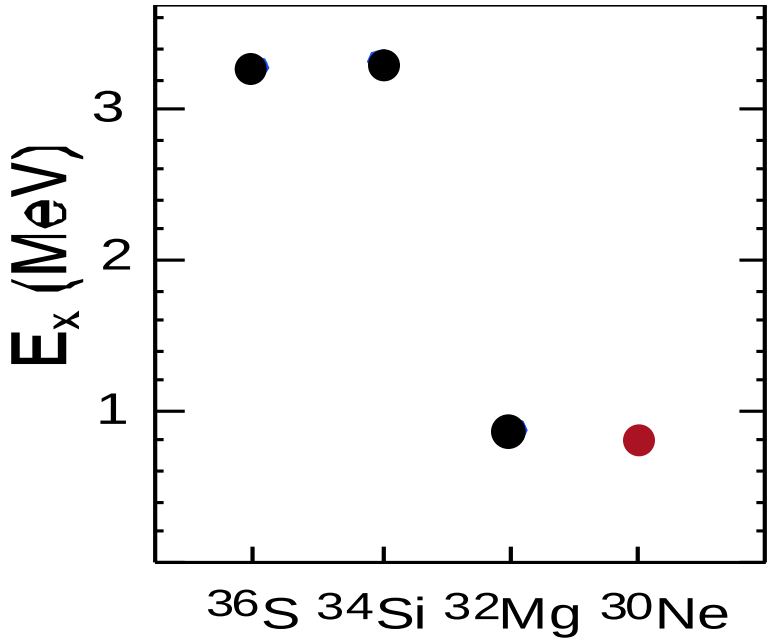
biology, medicine, chemistry, ….

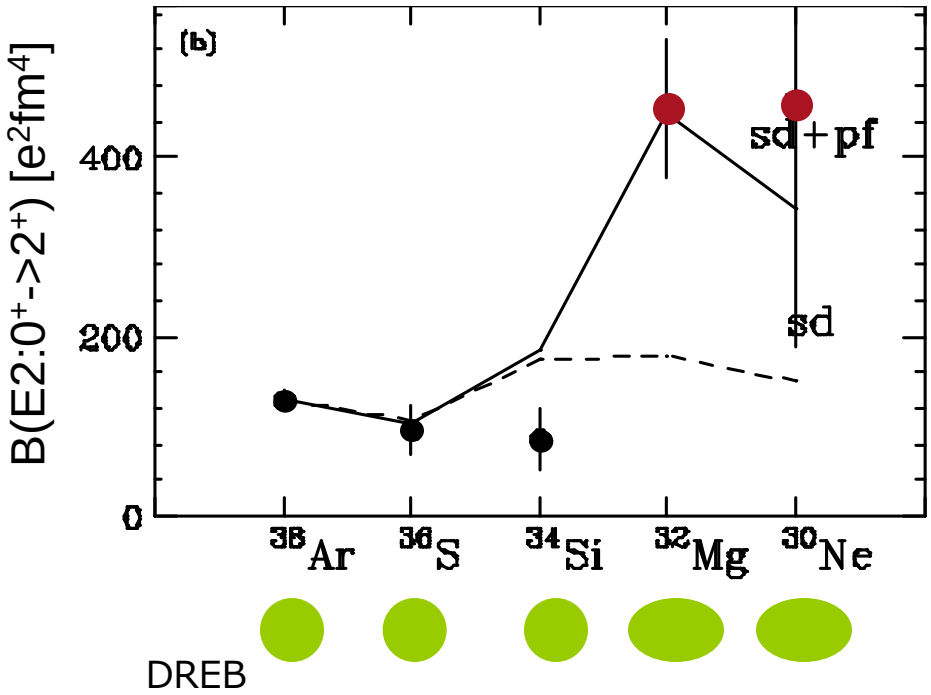
2^+ location / B(E2)
of N = 20 nuclei

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





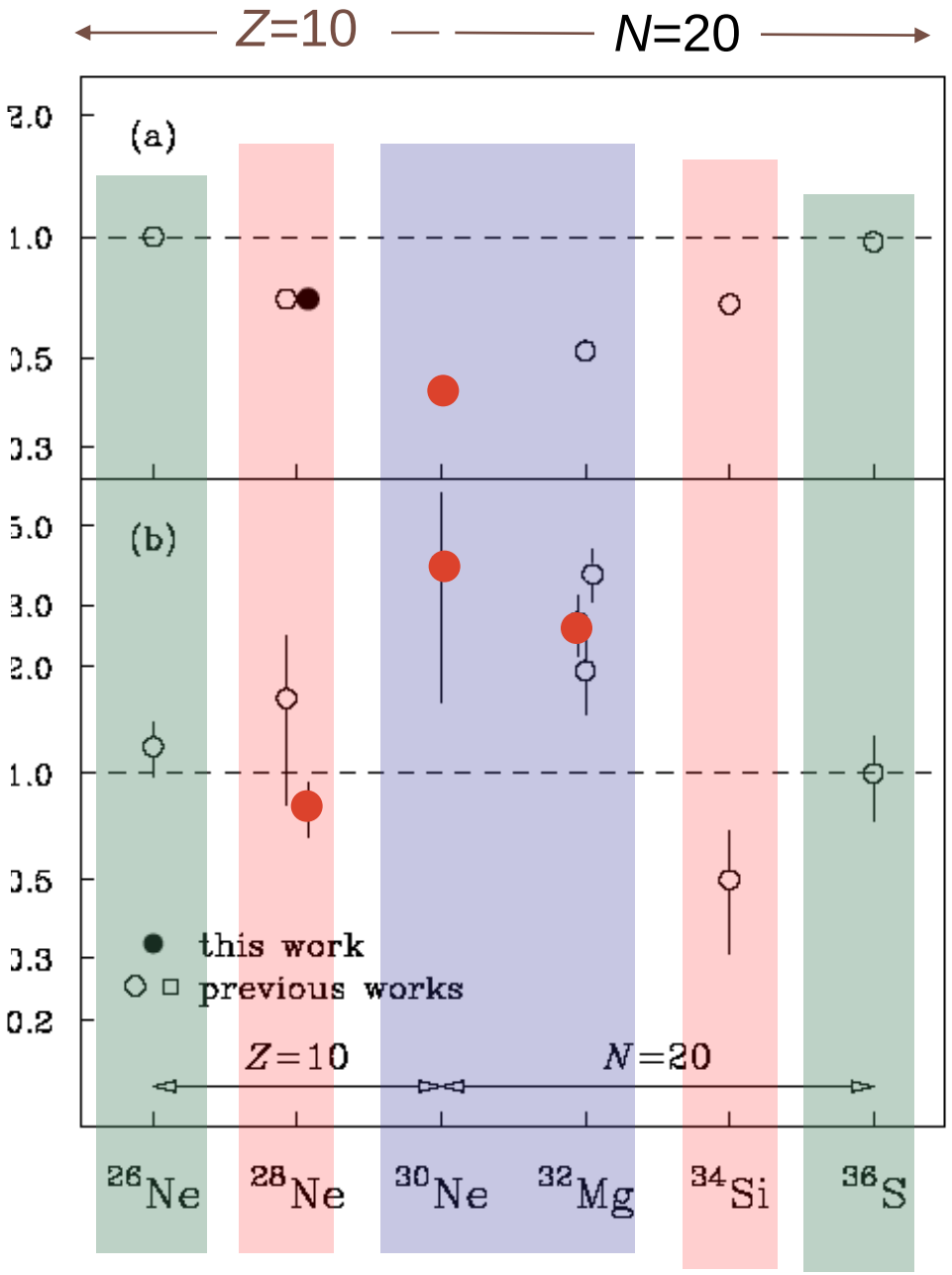
Fate of magic numbers

N=(8,) **20**

Coulomb excitation
(p,p')
2ndary fragmentation

$E(2^+)/ E(2^+)_{sd}$

$B(E2)/ B(E2)_{sd}$
(coulex)



May 2007

"normal" transitional Island of inversion transition "normal"

^{16}C

- decoupling of p/n motion (shape)

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

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

$\tau \sim 75 \pm 23$ps, B(E2: $2^+ \rightarrow 0^+$) ~ 0.3 W.U.

- the slowest ? E2 transition

Imai *et al*. (2003)

award talk tomorrow

^{16}C+^{208}Pb inelastic

Coulomb-nuclear interference

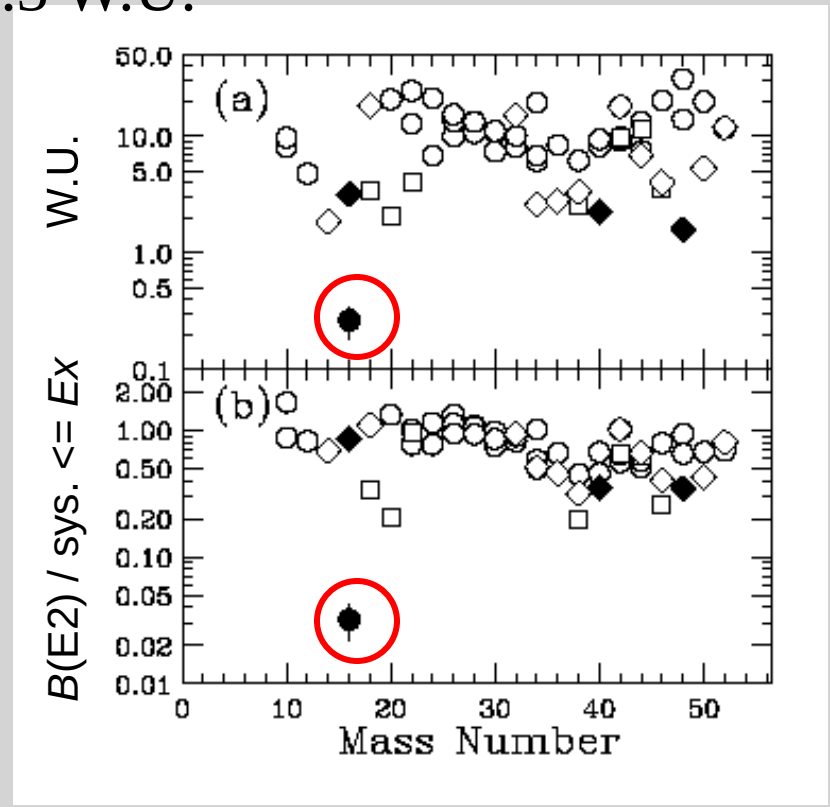
$M_n/M_p = 7.6 \pm 1.0$

Elekes *et al*. (2003)

^{16}C+^{1}H inelastic

neutron-sensitive

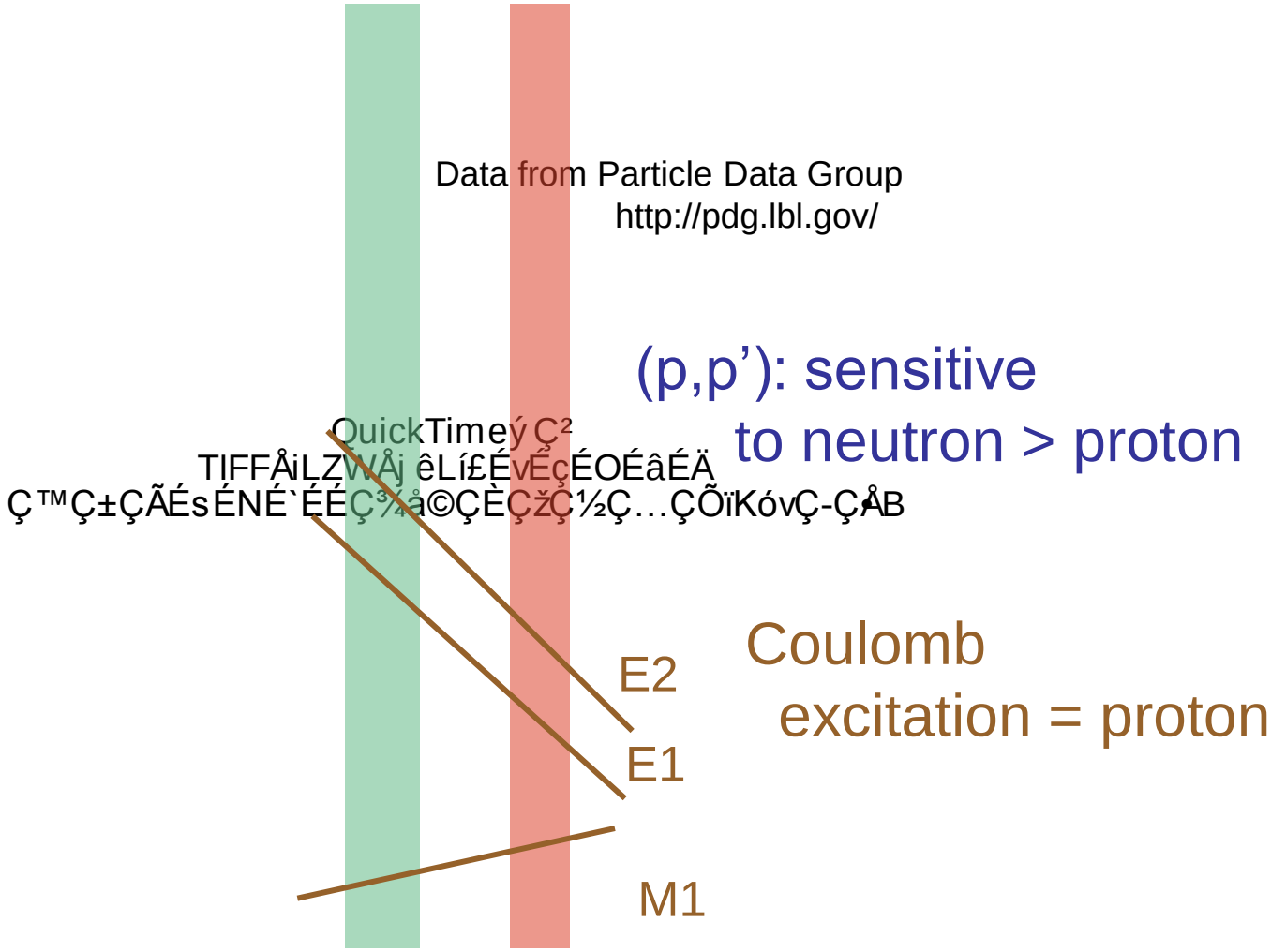
a large β



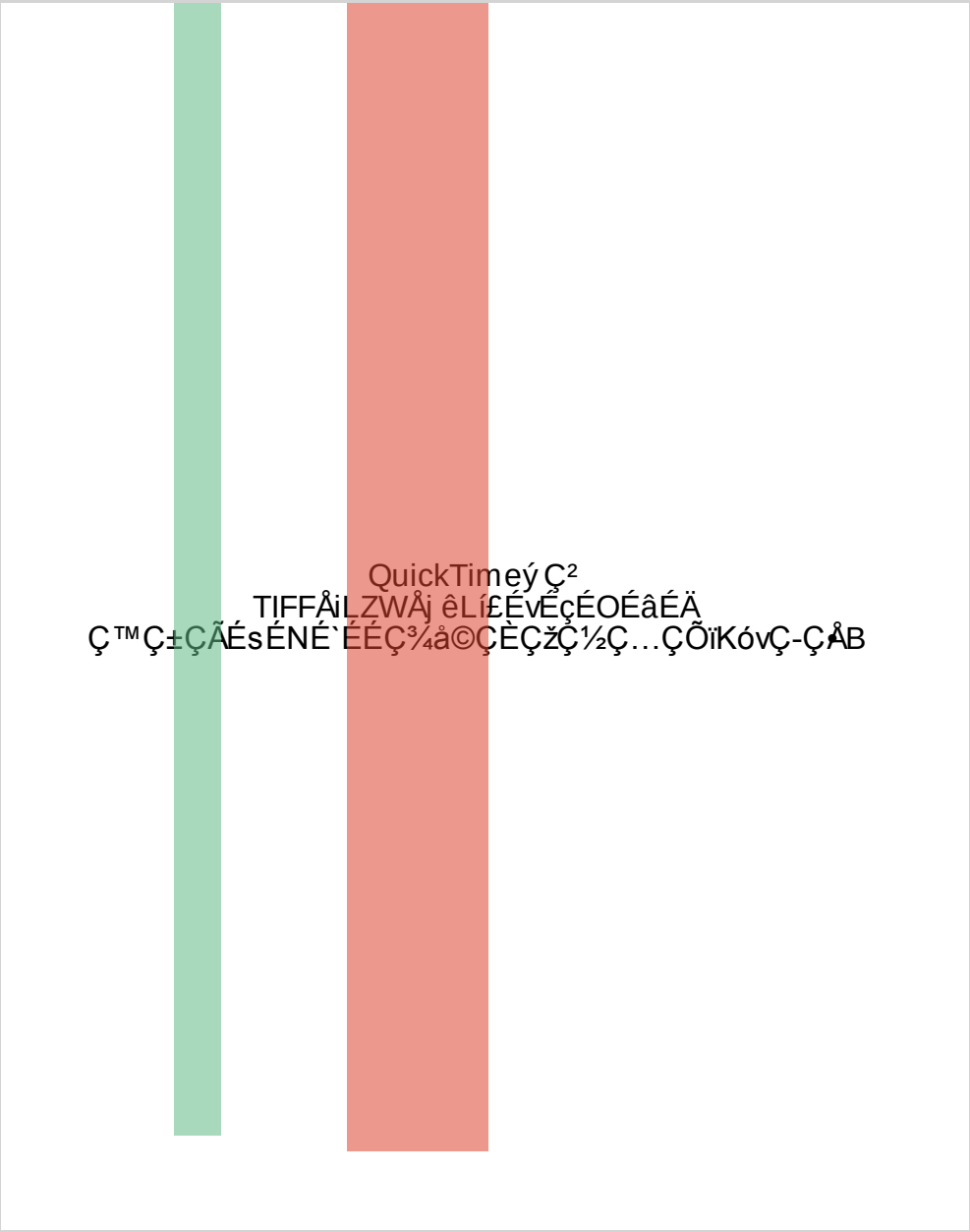
$M_n >> M_p$ ~B(E2) for $0^+ \rightarrow 2^+$

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

NN cross section

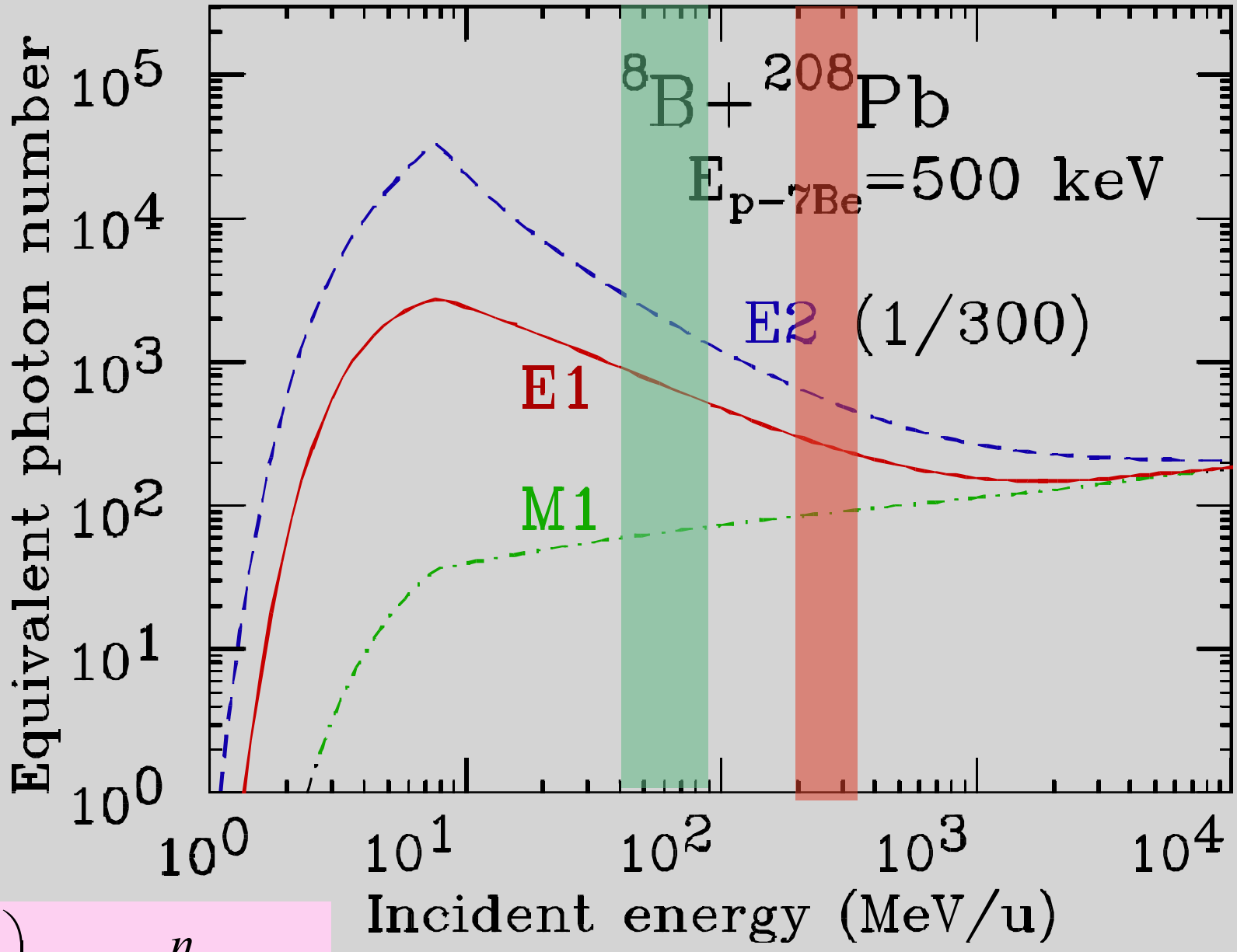


NN effective interaction



Transparent
- nucl. Interior
- single scattering
  - p-elastic => density

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



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

DREB

M1/E2: factor of ~5 increase