多核子移行反応によるr−過程A=195ピーク滞留核領域の原子核・天体核研究

- How are the elements of Gold and Platinum synthesized –

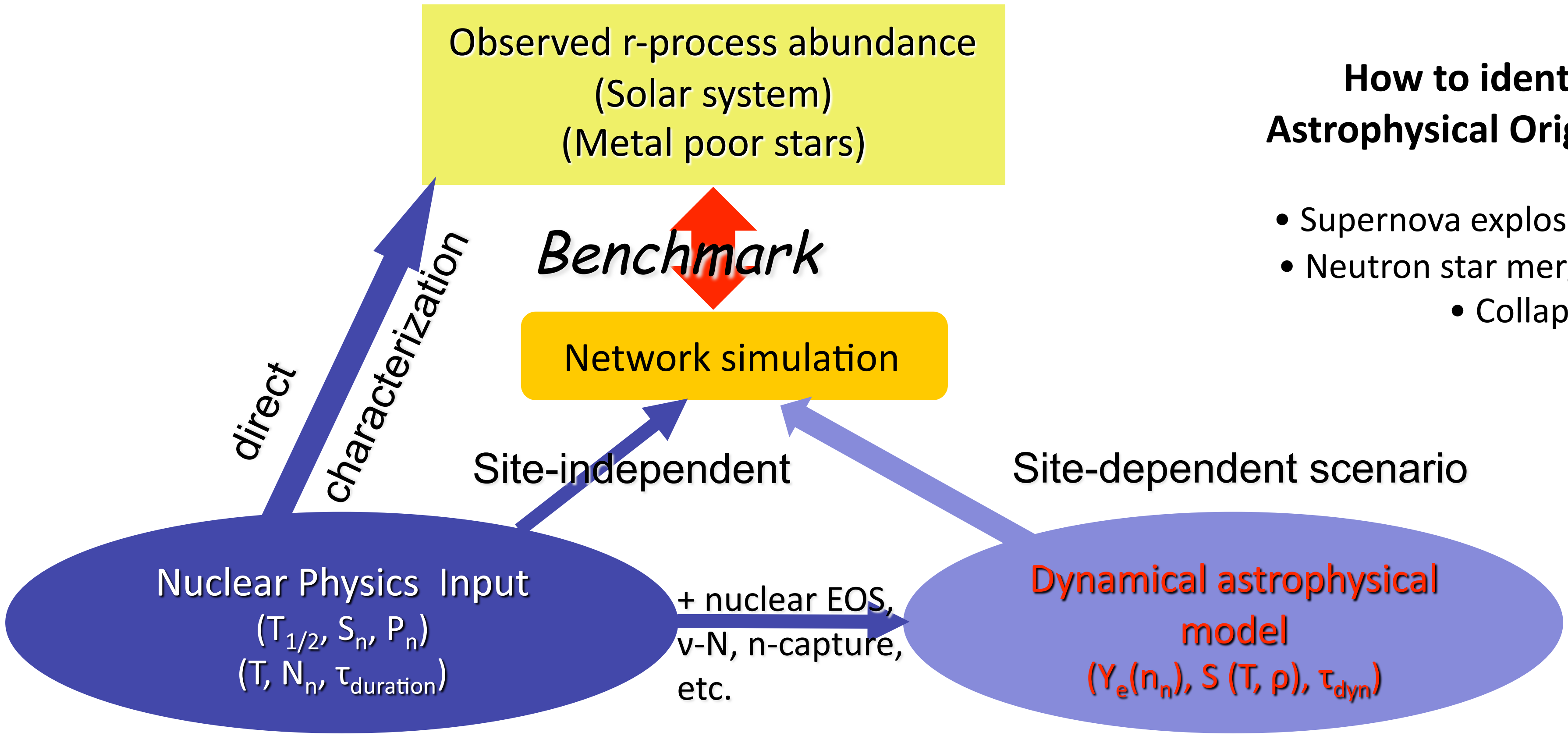
- Nuclear Physics Approach -

TRIAC Tokai Radioactive Ion Accelerator Complex

2009.7.28 宇核連WS H.M.
for RNB group, KEK

B²FH&Cameron (1957!!);

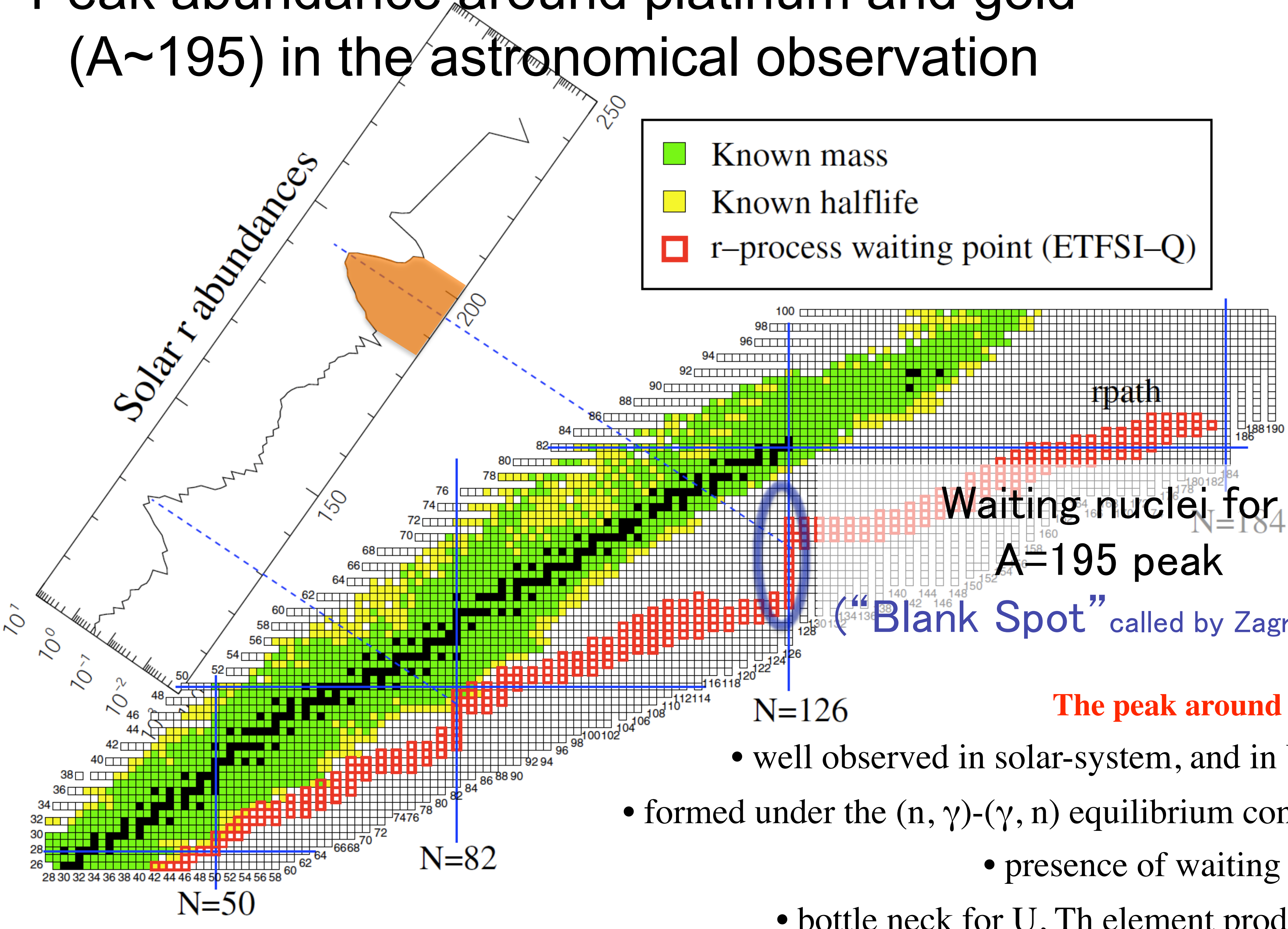
They are synthesized in a rapid neutron capture (r-) process through the path consisting of numerous neutron-rich nuclei under explosive astrophysical condition (s) .



How to identify Astrophysical Origin

- Supernova explosion
- Neutron star merger
- Collapsar
-
-

Peak abundance around platinum and gold (A~195) in the astronomical observation



The peak around A=195

- well observed in solar-system, and in UMPs
- formed under the (n, γ)-(γ, n) equilibrium condition
- presence of waiting nuclei
- bottle neck for U, Th element production
- no experimental information so far

H. Grawe et al., Rept. Prog. Phys. 70(2007)1525.

Nuclear physics origin of the A=195 peak

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Decay scheme, mass of waiting nuclei: At first, LIFE-TIME ($T_{1/2}$)

- confirmation of the (n, γ)-(γ, n) equilibrium:

  $Y_{r,\ prog} / T_{1/2}$(waiting) ~ const.←→determination r-process path

- minimum duration time to form the 3rd peak:

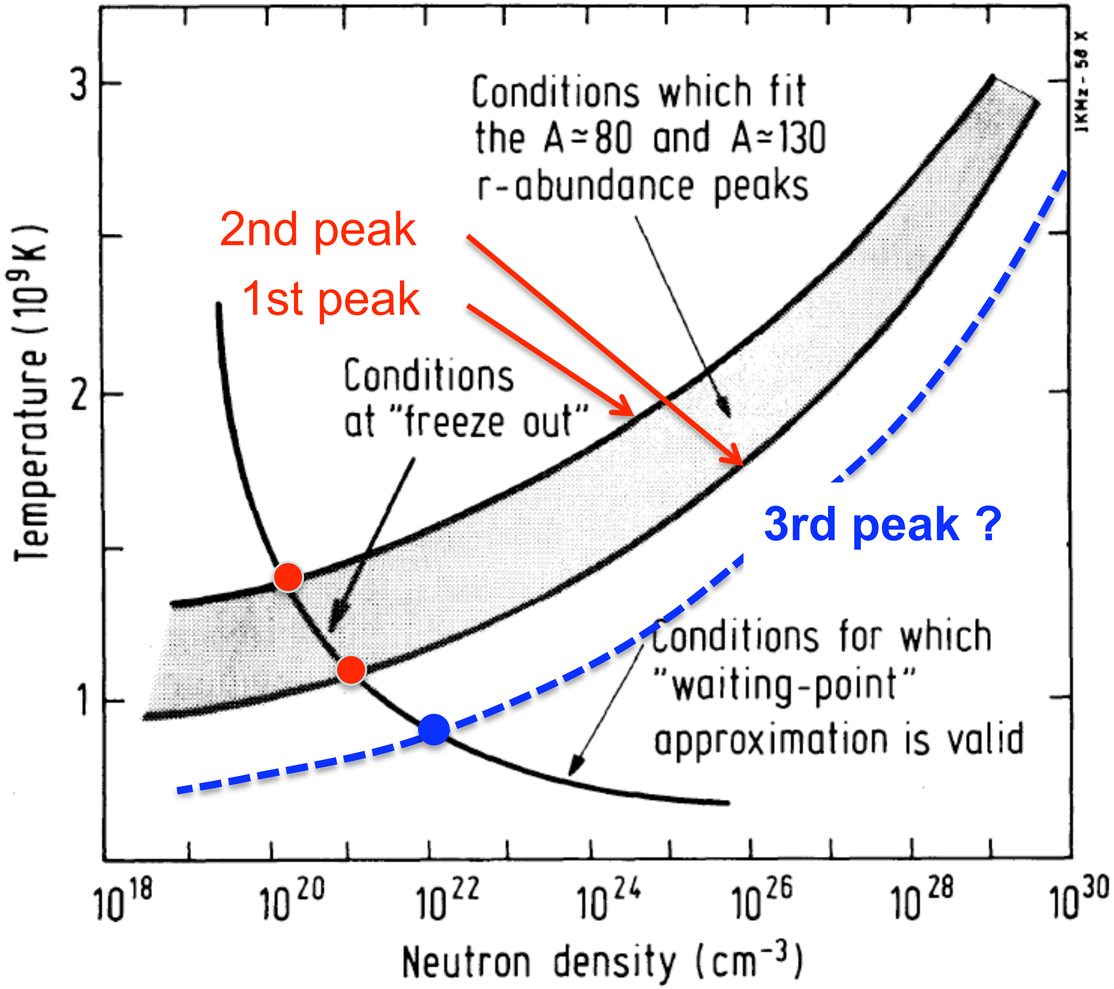
  ~ $\Sigma\ T_{1/2}$(waiting)

- determination astrophysical circumstance:

  $N_n - T_9$ correlation

- freeze-out conditions: T_9 and N_n

- sensitive test for mass-flow toward U, Th element synthesis



from K. –L. Kratz, et al., Ap. J. 403('93)216.

How to reach the “Blank spot” ?

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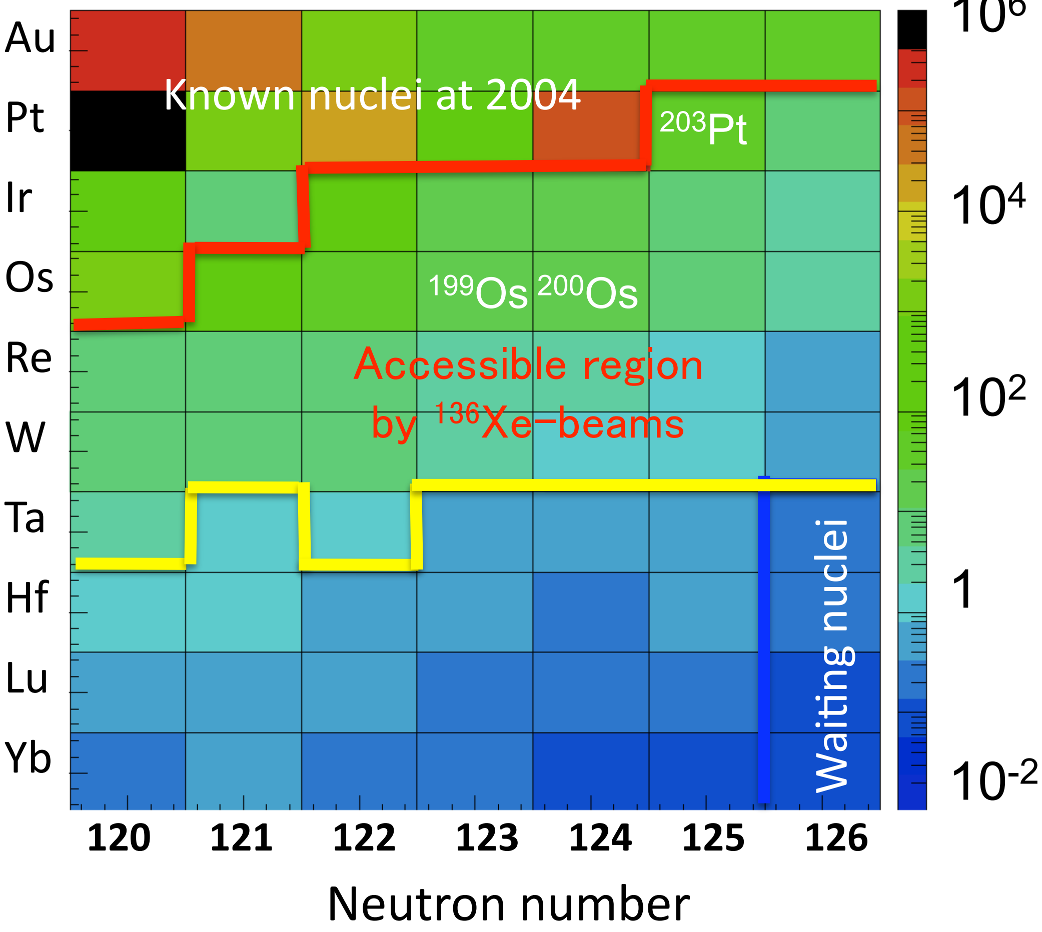
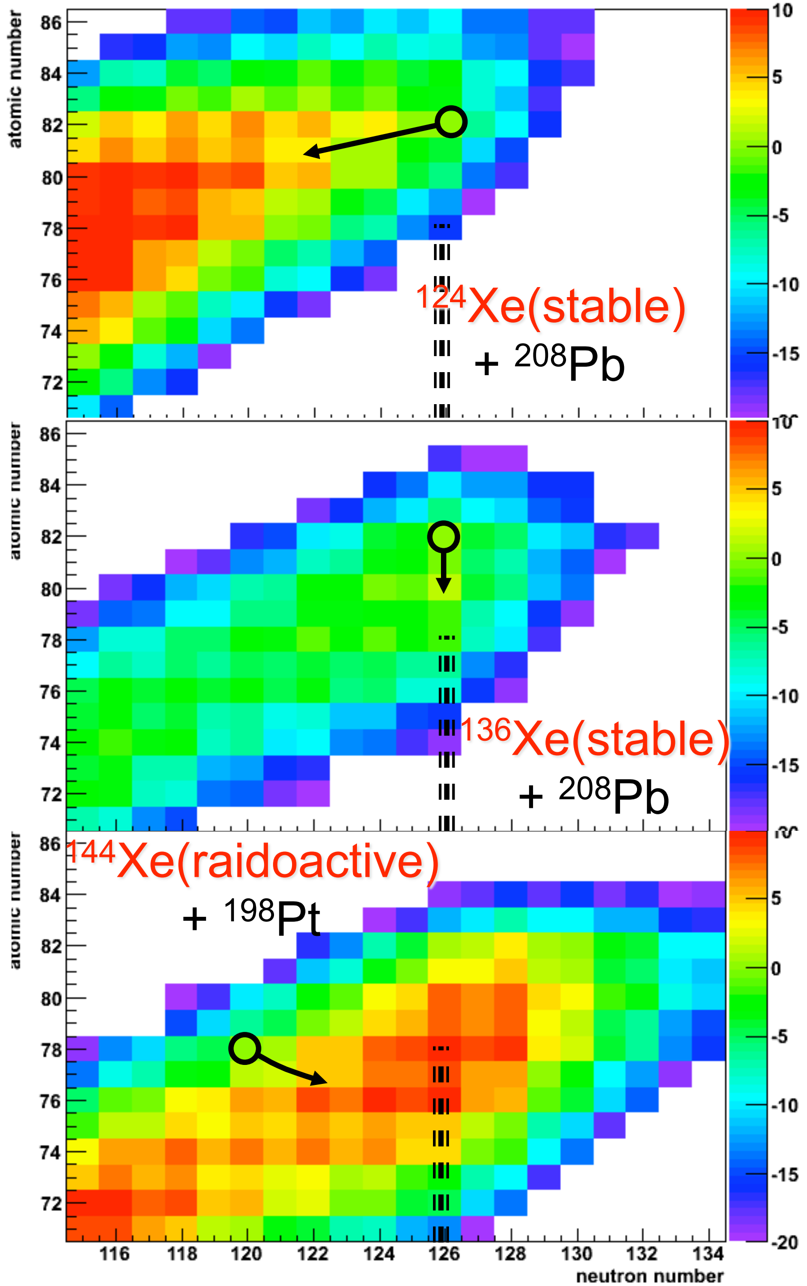
Multi-nucleon transfer reactions by
n-rich RIBs (~10 MeV/u)

proposed by C.H. Dasso et al., PRL73(‘94)1907.

$T_{1/2}$ (s) from KUTY





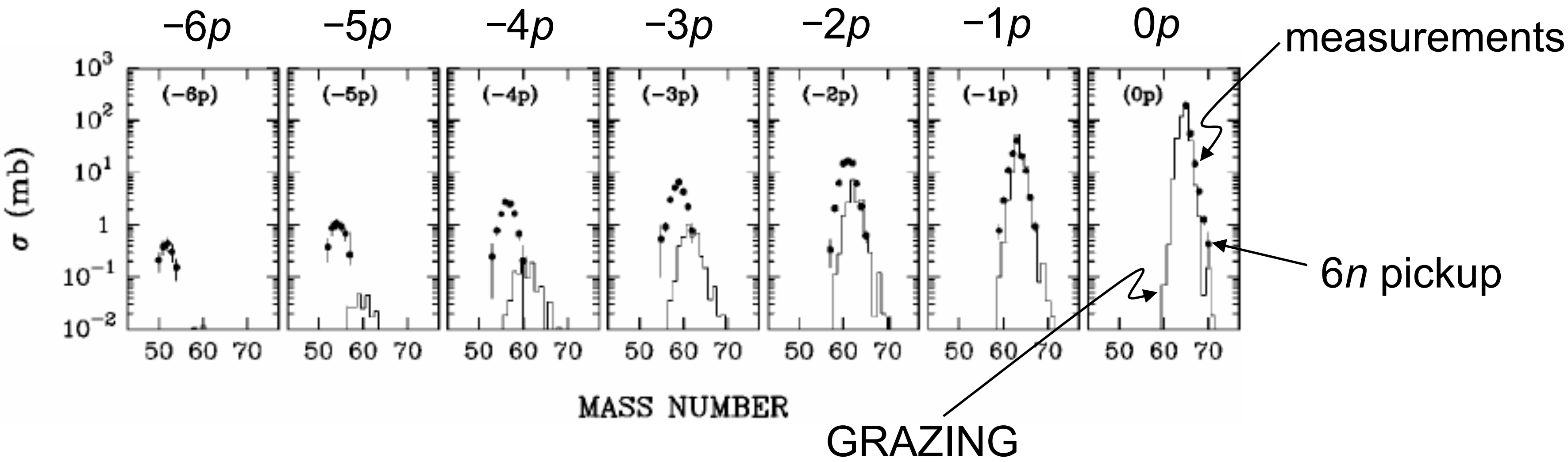
^{144}Xe-RNB + ^{198}Pt seems to be the best

But, ^{136}Xe + ^{198}Pt is realistic.

Multi-Nucleon Transfer (MNT) reaction

$^{64}Ni+^{238}U$

L. Corradi et al., Physical Review C59, 261 (1999).



A. Winther, Nuclear Physics A572, 191 (1994);
A. Winther, Nuclear Physics A594, 203 (1995).

- rather large cross sections (~1 mb) for the stripping channel of 6*p*
- pickup channels up to 6*n* for the pure neutron transfer channel (0*p*)

⟶ experimental evaluation for $^{136}Xe+^{198}Pt$

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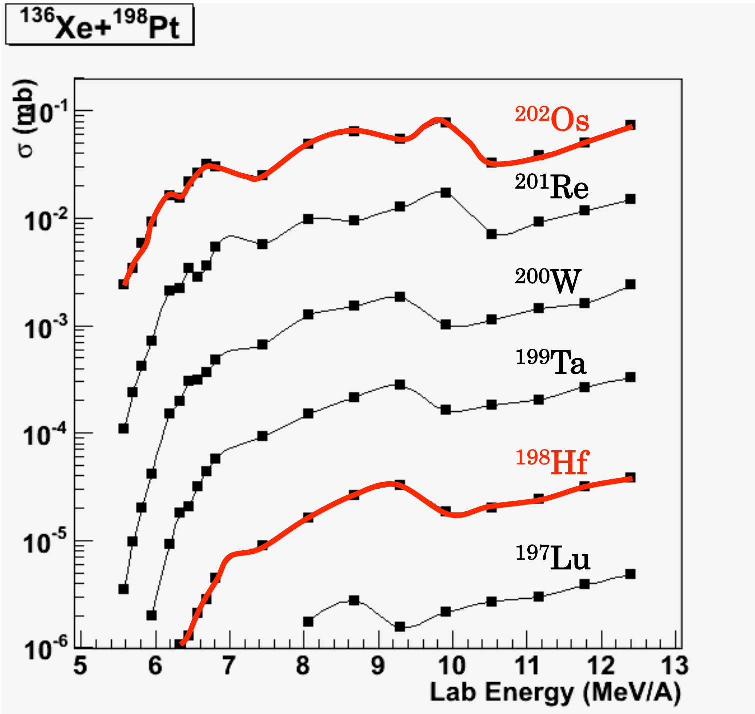
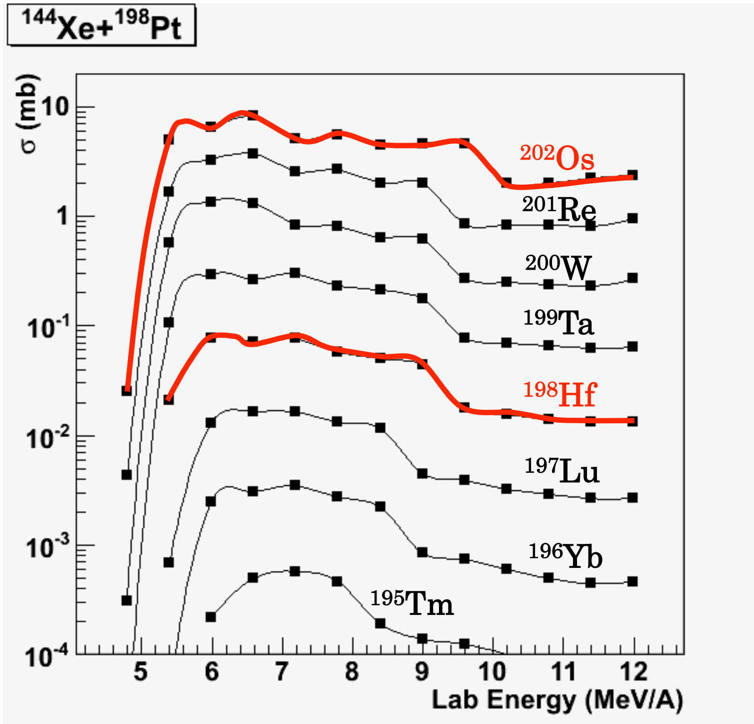
MNT reactions of ^{136,144}Xe + ^{198}Pt

excitation functions for the production of *N*=126 isotones

^{136}Xe (stable) + ^{198}Pt



^{144}Xe (RNB) + ^{198}Pt



stable beam	^{136}Xe + ^{198}Pt	σ~10^{-1} mb for ^{202}Os	σ~10^{-5} mb for ^{198}Hf
neutron-rich RNB	^{144}Xe + ^{198}Pt	σ~10^{+1} mb for ^{202}Os	σ~10^{-1} mb for ^{198}Hf

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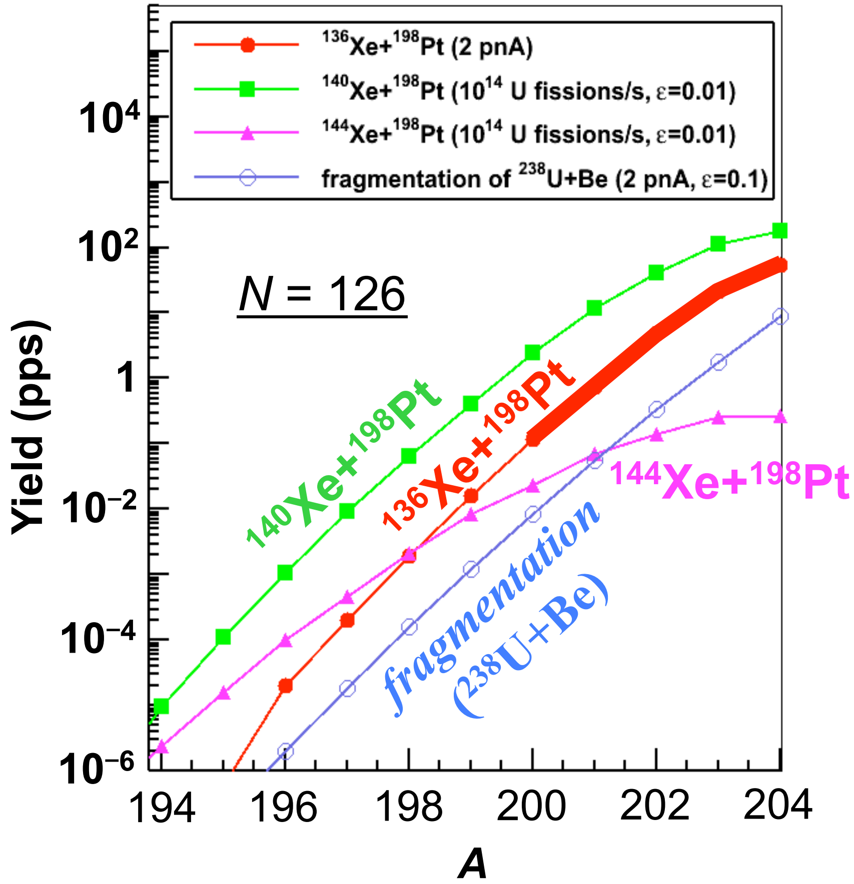
Estimated yields

proton-induced fission of U at the total fission rates of 10^{14} Hz.

isotope	beam intensity
^{137}Xe	2.2×10^{10} pps
^{138}Xe	1.8×10^{10} pps
^{139}Xe	1.0×10^{10} pps
^{140}Xe	4.2×10^{9} pps
^{141}Xe	1.3×10^{9} pps
^{142}Xe	2.7×10^{8} pps
^{143}Xe	4.2×10^{7} pps
^{144}Xe	4.7×10^{6} pps
^{145}Xe	3.8×10^{5} pps
^{146}Xe	1.8×10^{4} pps



RNB ^{140}**Xe** is superior to other nuclei for the investigation of the 3rd peak waiting nuclei. Stable ^{136}**Xe** is the second best choice for A > 198.

Characterization of the A=195 peak

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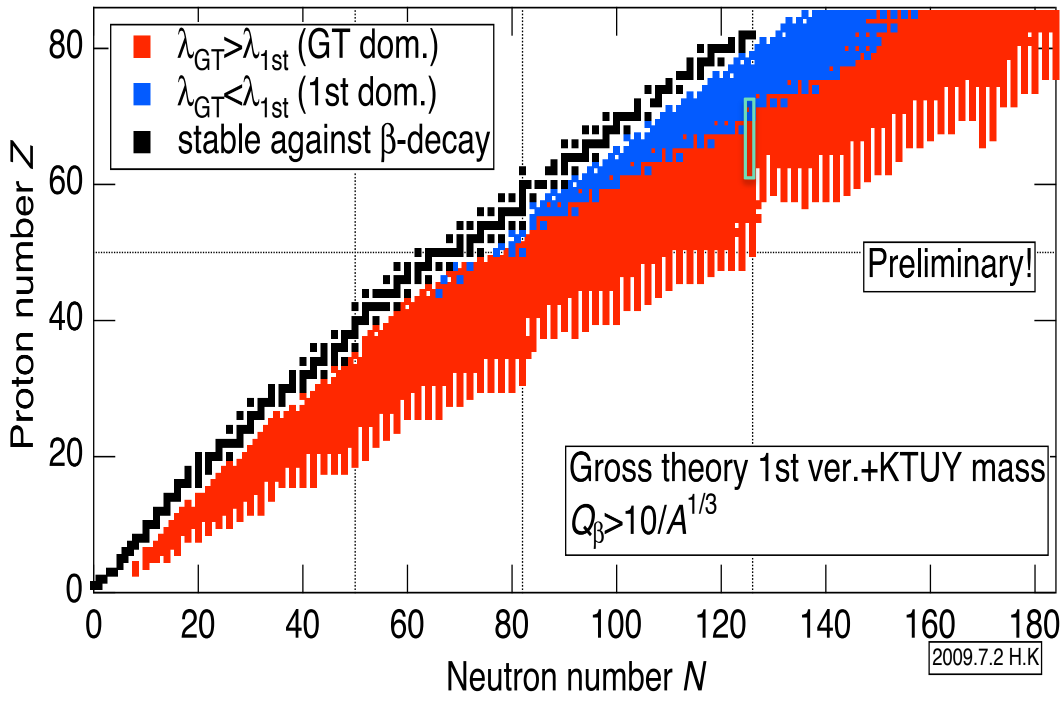
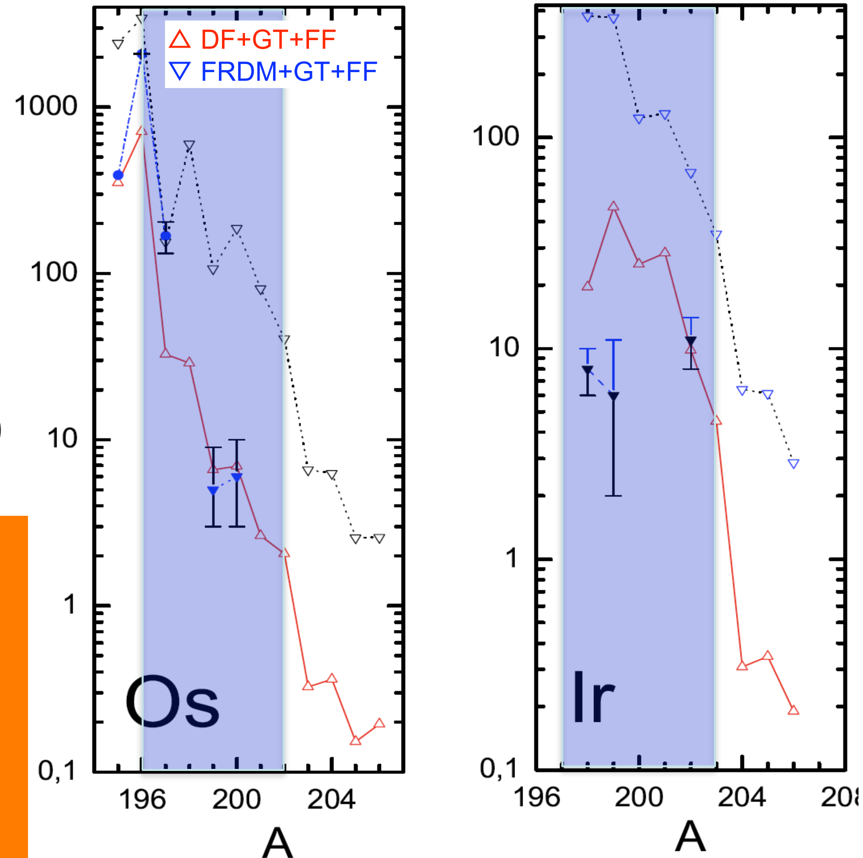
LIFE-TIME ($T_{1/2}$) of waiting nuclei: ultimate goal of physics motivation

- actual r-process path,
- astrophysical N_n – T condition,
- duration time passing through waiting nuclei
- sensitive test for actinide element production rate



First forbidden β-transitions will compete to the allowed transitions according to the shell evolution



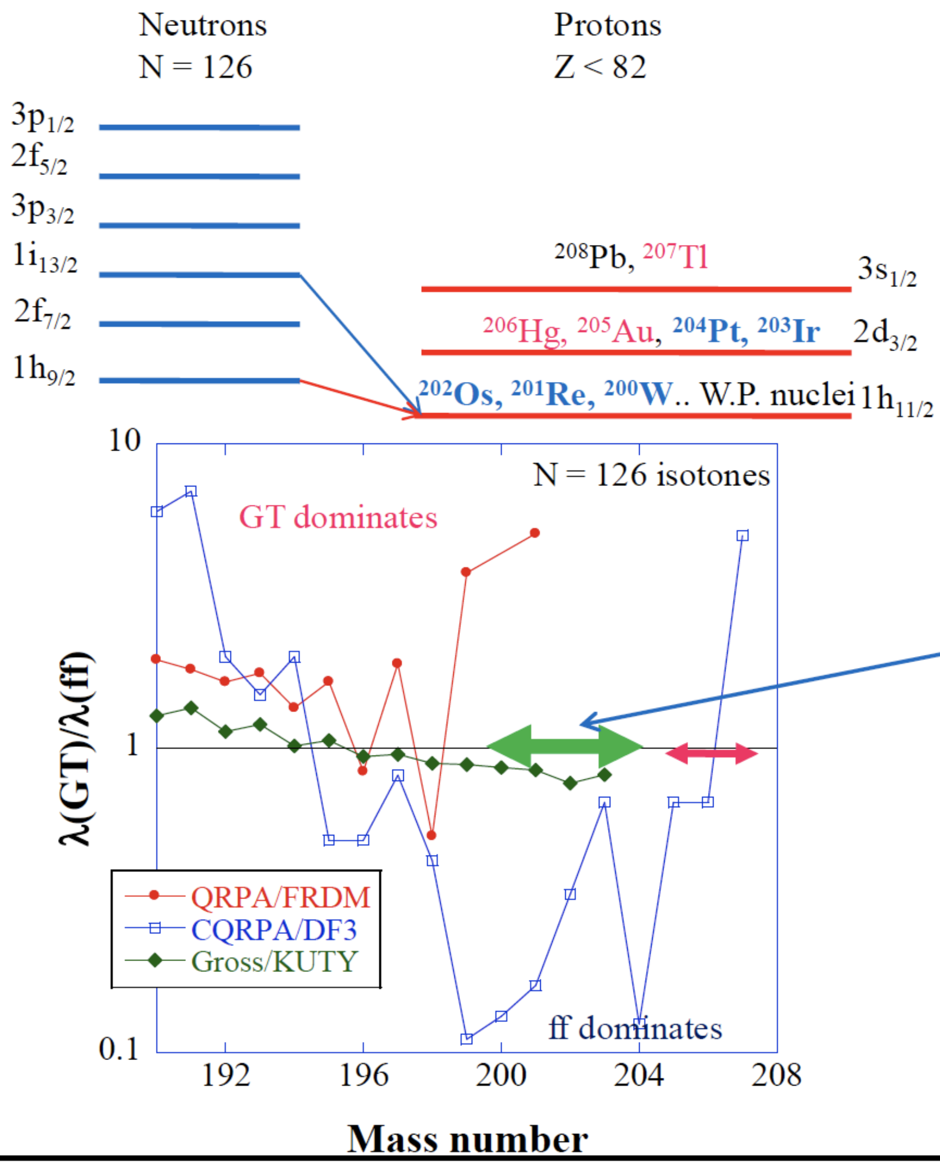
from I. N. Borzov et al., Rept. NUSTAR-THEORY-08

Measurements of nuclei in "Blank Spot"

- dominant weak decay mode and shell evolution in the "south region" from Z = 82, N = 126
- sensitive test for lifetime predictions

: specific aim of this experimental proposal

GT vs. FF on N = 126 shell closures



$\pi h_{11/2}$ is open from ^{201}Re
(all w.p. nuclei locate in $\pi h_{11/2}$)

FF ($\nu i_{13/2} \Rightarrow \pi h_{11/2}$)
GT($\nu h_{9/2} \Rightarrow \pi h_{11/2}$)

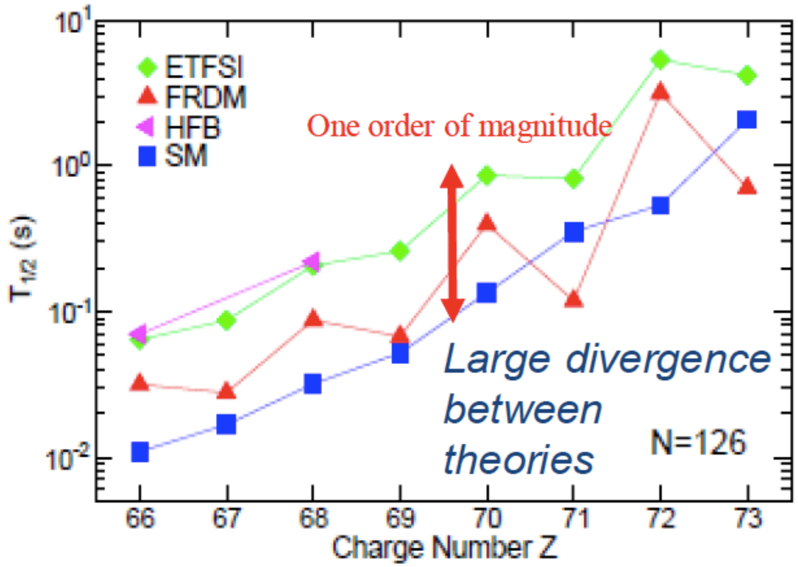
competition
between GT and FF transitions

^{204}Pt-^{202}Os vs. ^{201}Re, ^{200}W
$T^{\beta}_{1/2}$, log ft

- **experimental hint for reliable treatment of β-decay mode**

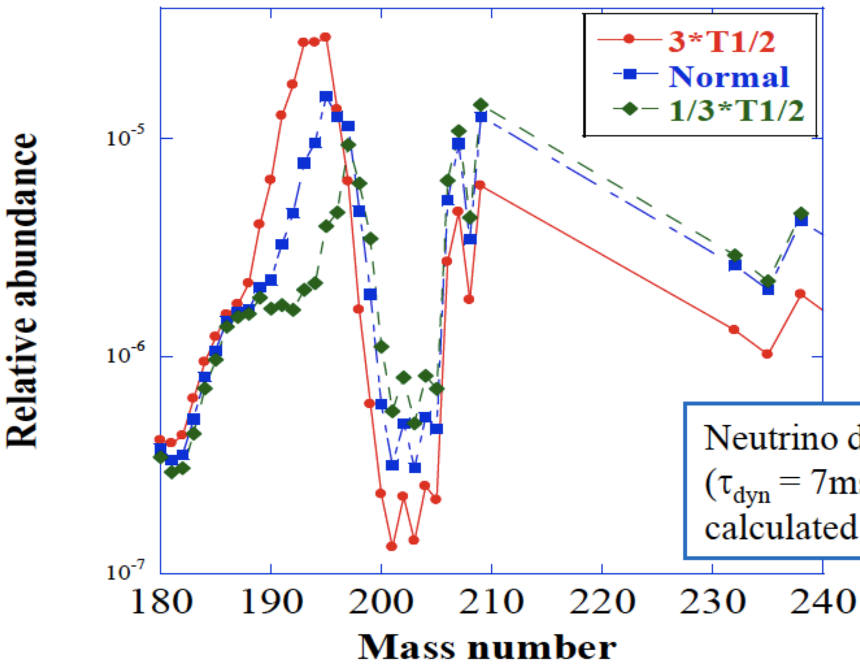
$T^{\beta}_{1/2}$ vs. abundance pattern

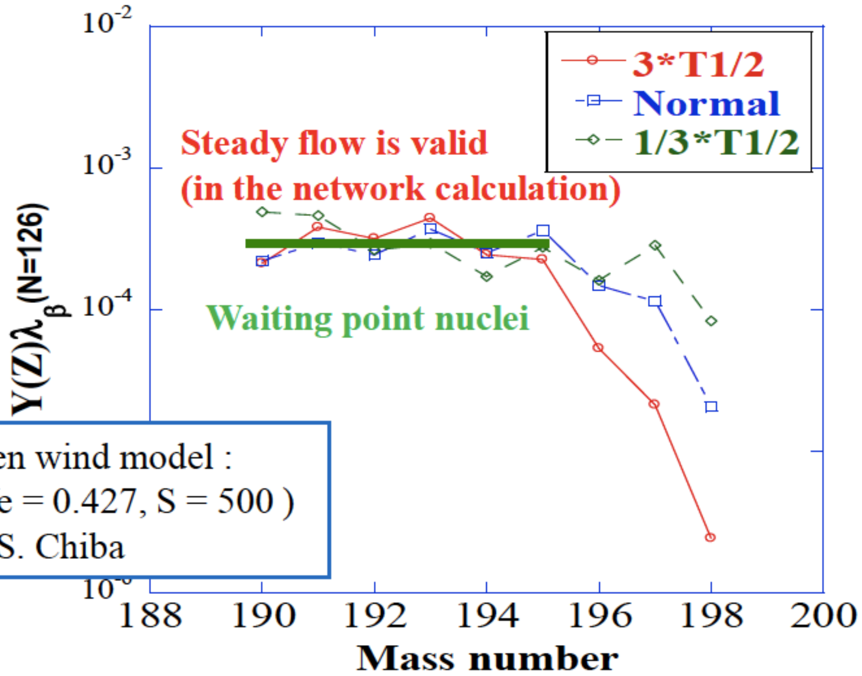
- peak height
- peak width
- peak position
- Pb abundance
- Actinoids abundance



$T^{\beta}_{1/2}$ of ^{190}Gd ~ ^{196}Yb
$\Rightarrow 3 \times T^{\beta}_{1/2}$ or $1/3 \times T^{\beta}_{1/2}$

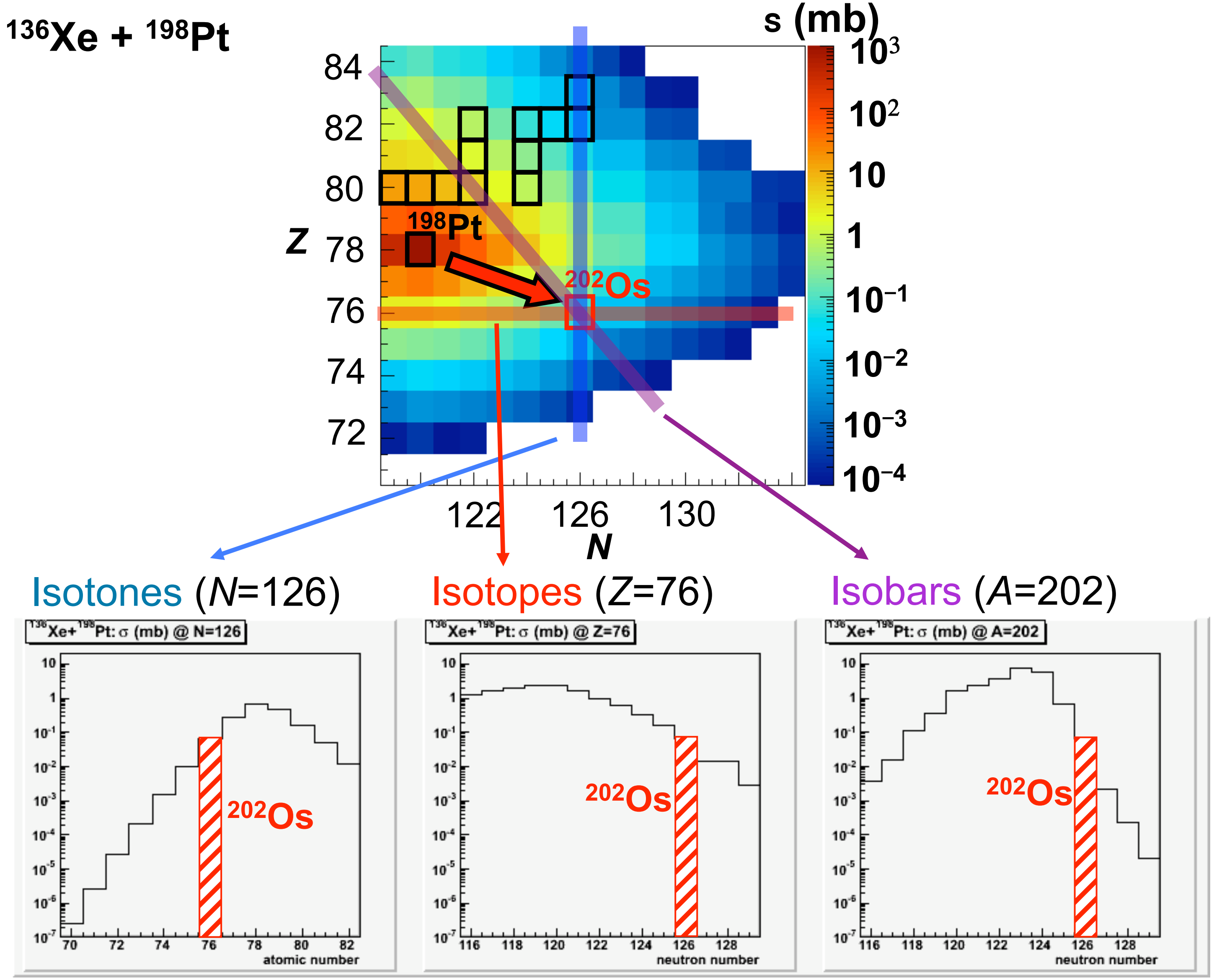
In fact, waiting point analysis is…



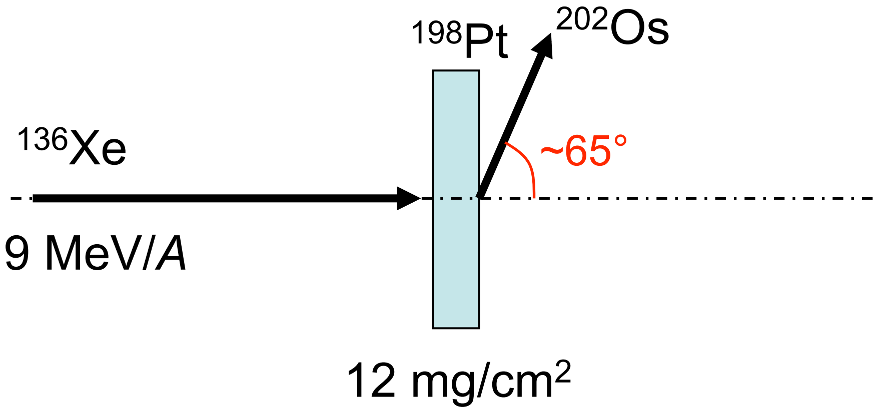


Neutrino driven wind model :
(τ_{dyn} = 7ms, Ye = 0.427, S = 500)
calculated by S. Chiba

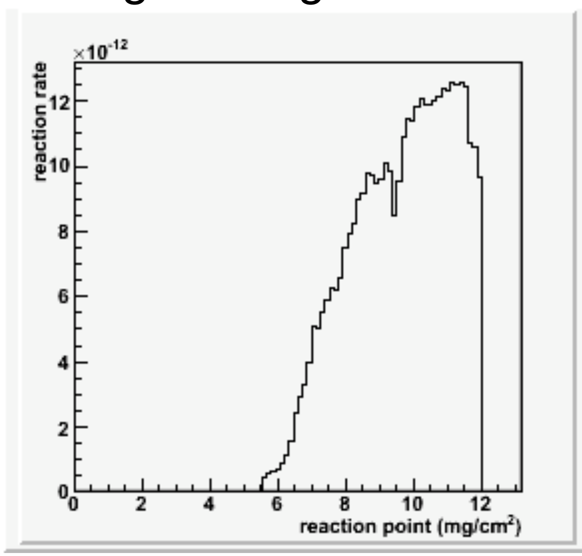
Contaminations



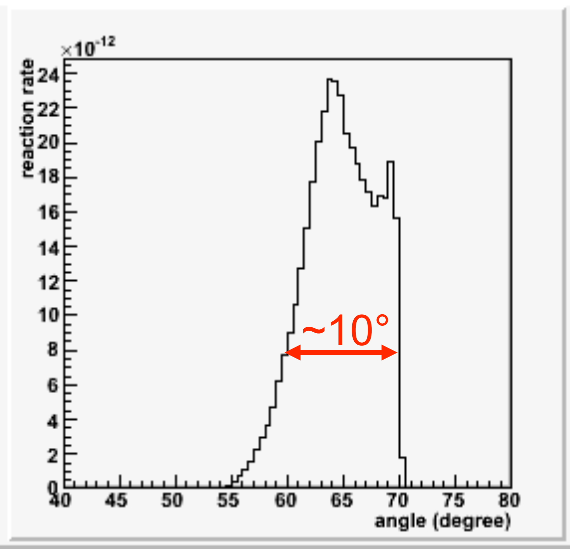
Kinematics



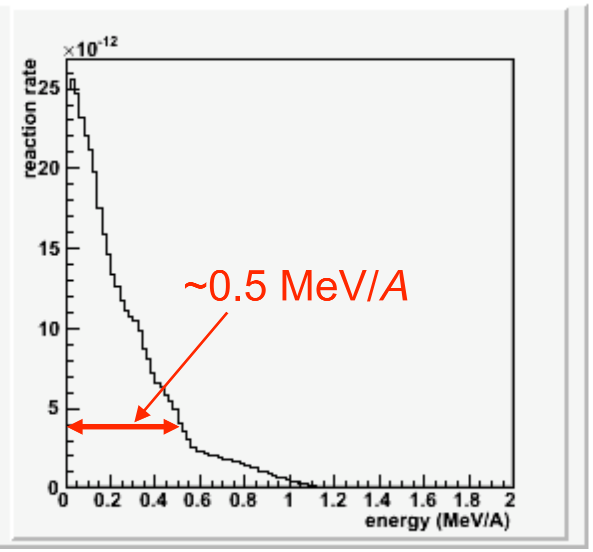
reaction points
along the target thickness



angular distributions
of ^{202}Os



energy distributions
of ^{202}Os



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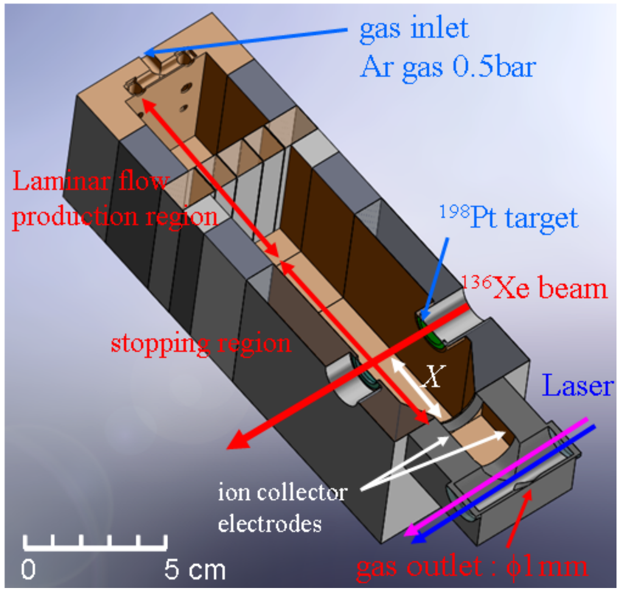
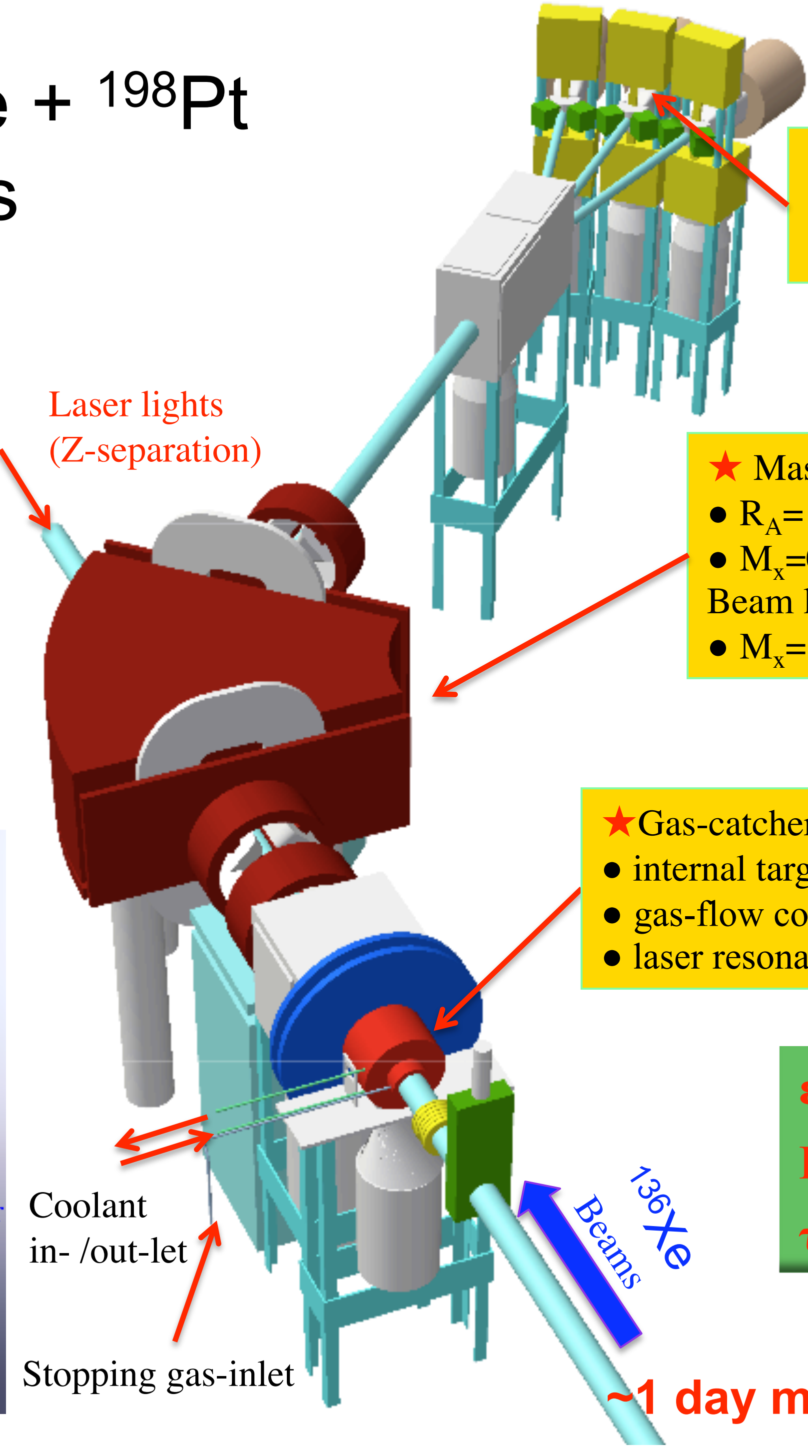
Set-up for ^{136}Xe + ^{198}Pt reactions

A-, Z-spearation
with
high collection efficiency

Gas-catcher
+ Resonance ionization (*Z*)
+Mass separator (*A*)
+Detection system
called as *KEK GC-LISOL*
at E2-Hall of RIBF





★ Detection system
- β-decay measurement
- tape transport system

★ Mass (A) separator
- R_A= 840
- M_x=0.85, M_y=1.3

Beam line
- M_x=1.7, M_y=2.05

★Gas-catcher system
- internal target
- gas-flow collection/extraction
- laser resonance-ionization

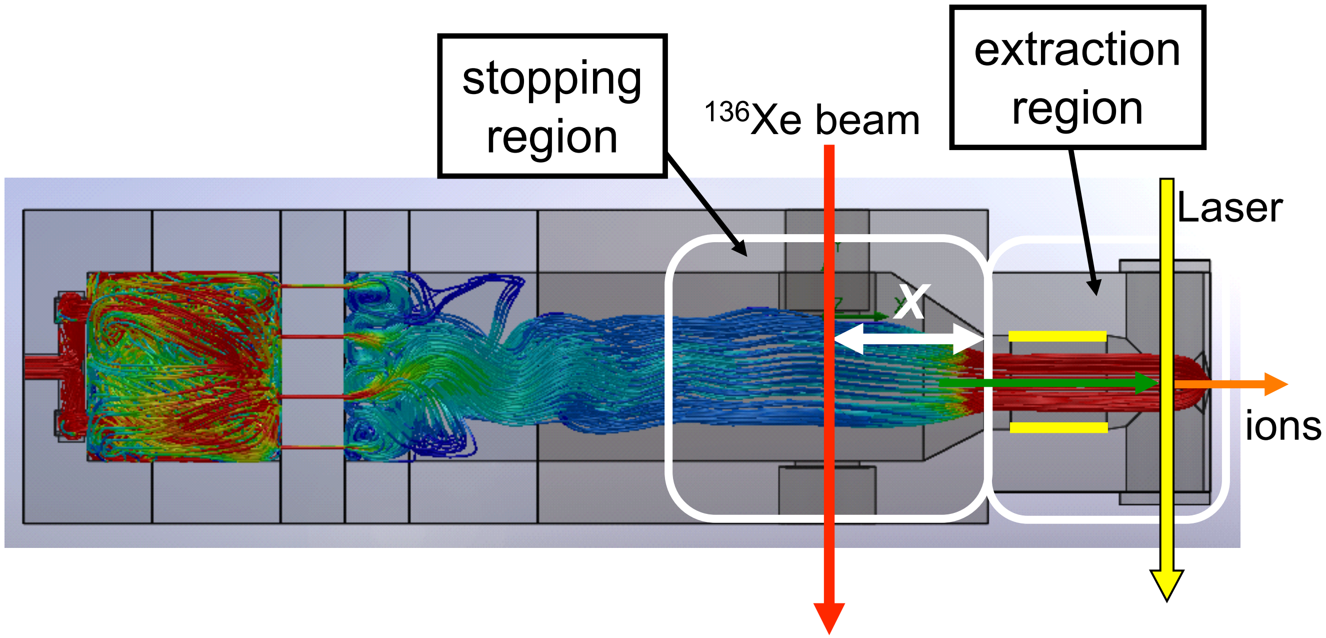
$\varepsilon_{tot.}$~ 3% ($t_{1/2}$=100 ms)

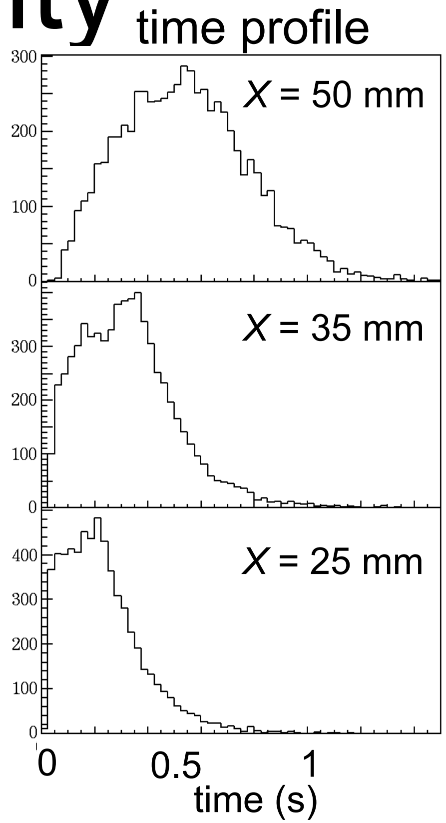
R_Z~ 1000, R_A~ 840

$\tau_{extr.}$~ 200 ms

~1 day machine time for ^{200}W

Extraction probability



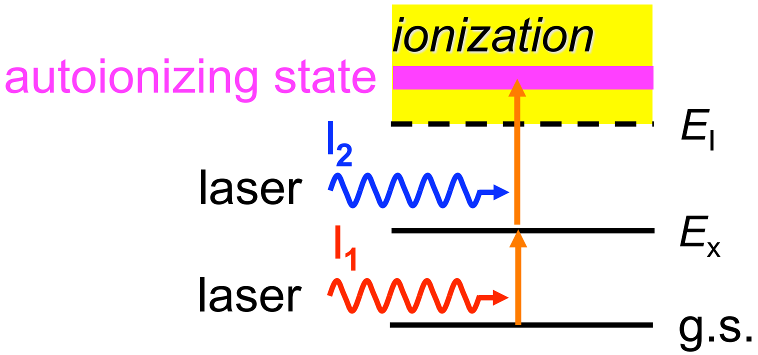


We need to study the optimum *X* experimentally.

X	Volume of gas cell	Stopping efficiency (e_s)	Transport efficiency (e_t)	$e_s \times e_t$	Mean tranportation time	Extraction probability ($T_{1/2}$ = 100 ms)
25 mm	261 cm^3	86%	70%	60%	235 ms	29%
35 mm	288 cm^3	90%	67%	60%	330 ms	19%
50 mm	329 cm^3	92%	67%	62%	540 ms	6.7%

Laser resonance ionization

atomic energy level



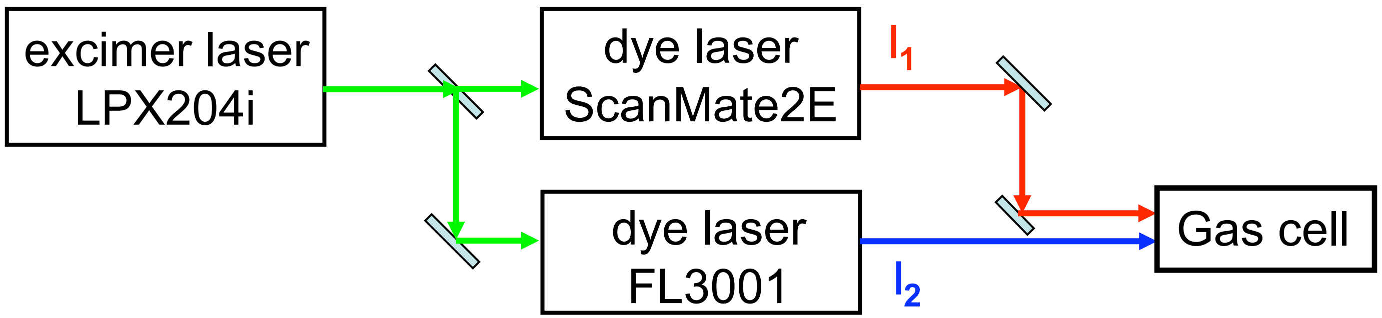
laser wavelength

for ionization of stable isotopes (Z=69~78)

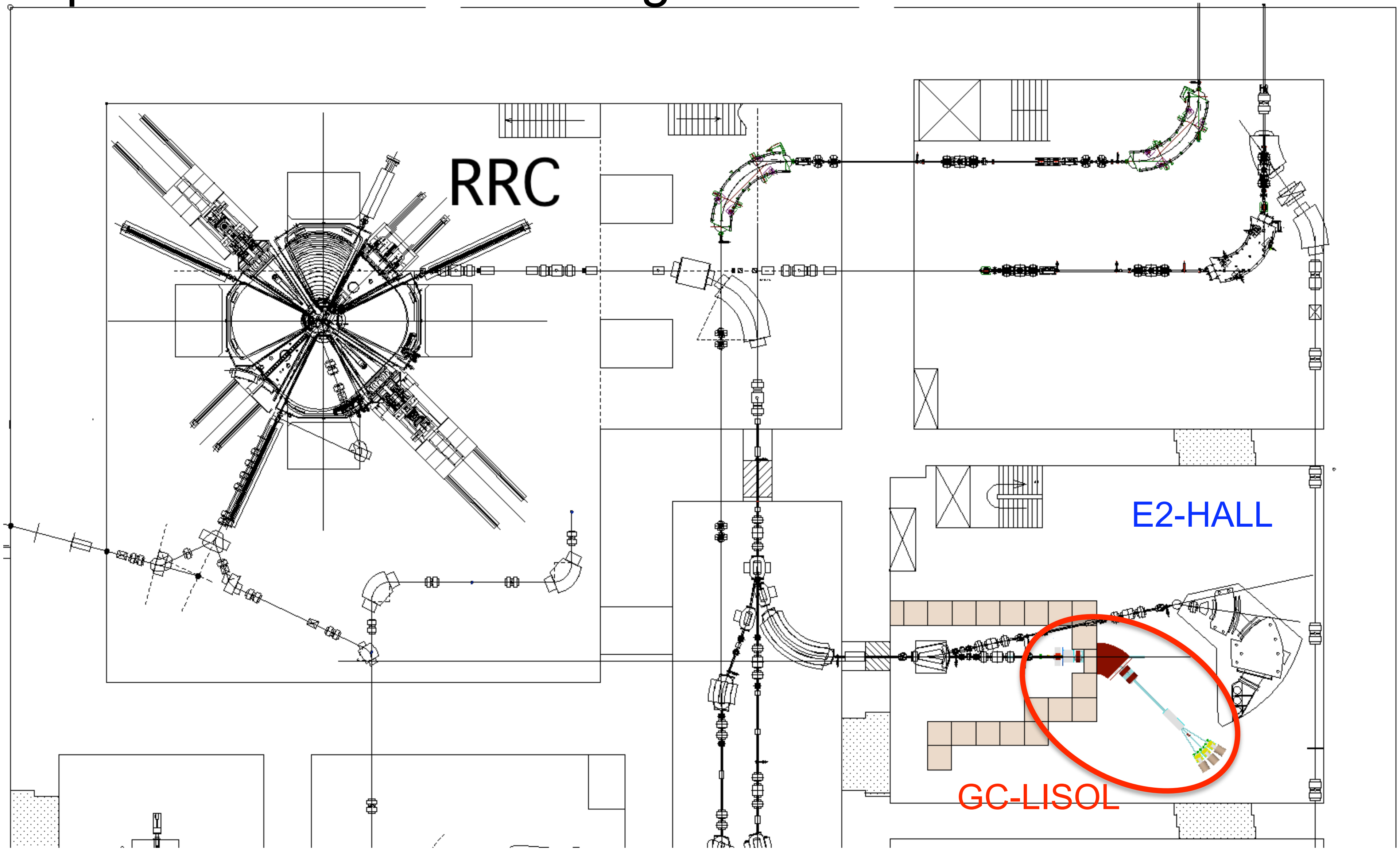
l_1 : 250 – 590 nm ← Z separation

l_2 : 220 – 460 nm ← ionization

l_1 and l_2 are known,
but we need to confirm and search
the most efficient ionization-schemes



A possible site for installing the KEK GC-LISOL



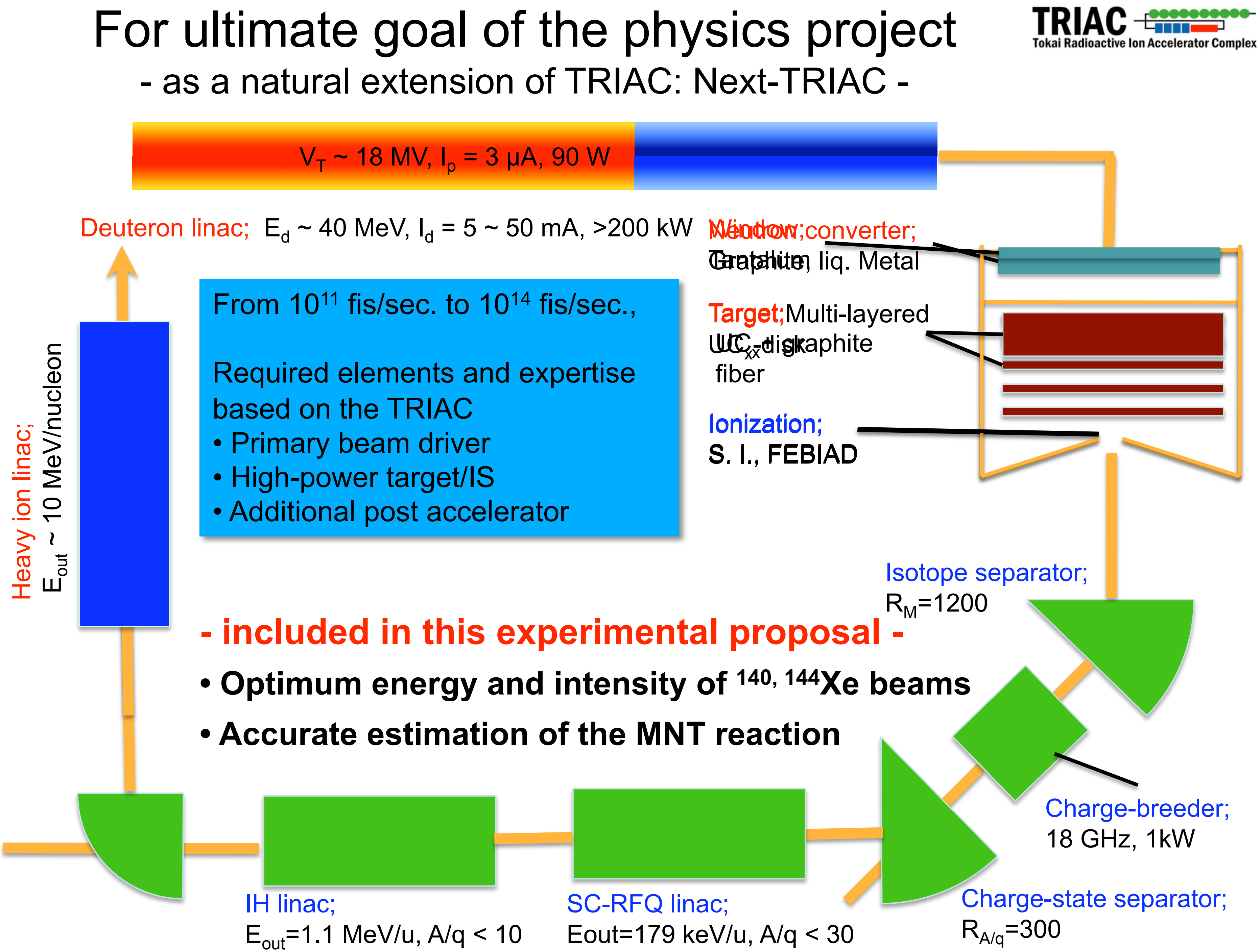
Summary of experimental proposal

Find out dominant decay mode and shell evolution in the vicinity of waiting nuclei through the lifetime measurements of nuclei in the "Blank spot" in the experimental proposal during five years

- *MNT reactions of Xe beams of stable isotope (^{136}Xe)*
- *A sensitive test and an important opportunity for improvement of the lifetime predictions*
- *A new method for decay spectroscopy of MNT fragments*
- *Optimum energy and intensity of $^{140,\,144}$Xe beam for future's MNT reactions*

For ultimate goal of the physics project

- as a natural extension of TRIAC: Next-TRIAC -



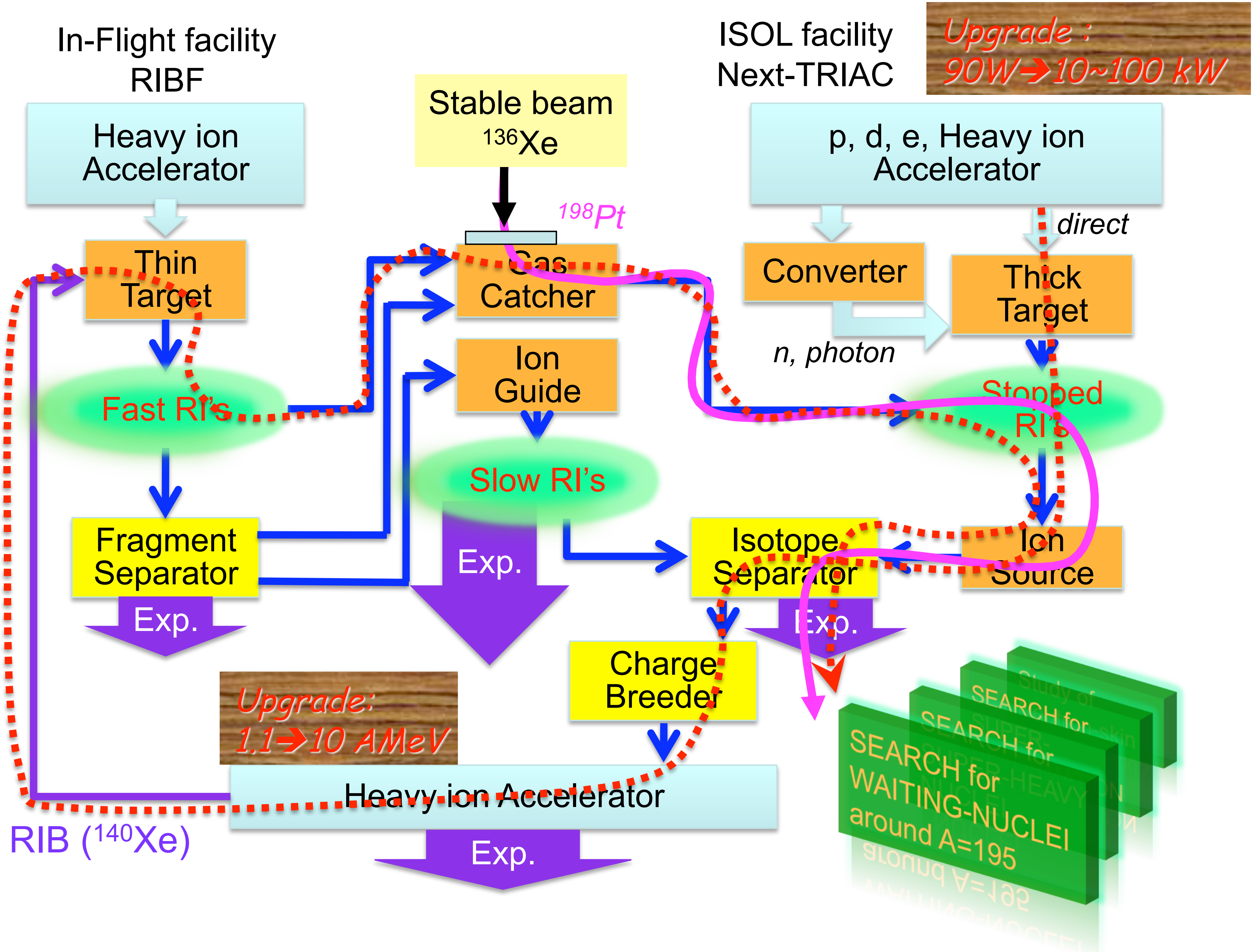
From 10^{11} fis/sec. to 10^{14} fis/sec.,

Required elements and expertise based on the TRIAC
- Primary beam driver
- High-power target/IS
- Additional post accelerator

- included in this experimental proposal -

- **Optimum energy and intensity of $^{140, 144}$Xe beams**
- **Accurate estimation of the MNT reaction**

Combined scheme of Next-TRIAC and RIBF



Conceptual layout of the TRIAC facility plan in POST-RIBF

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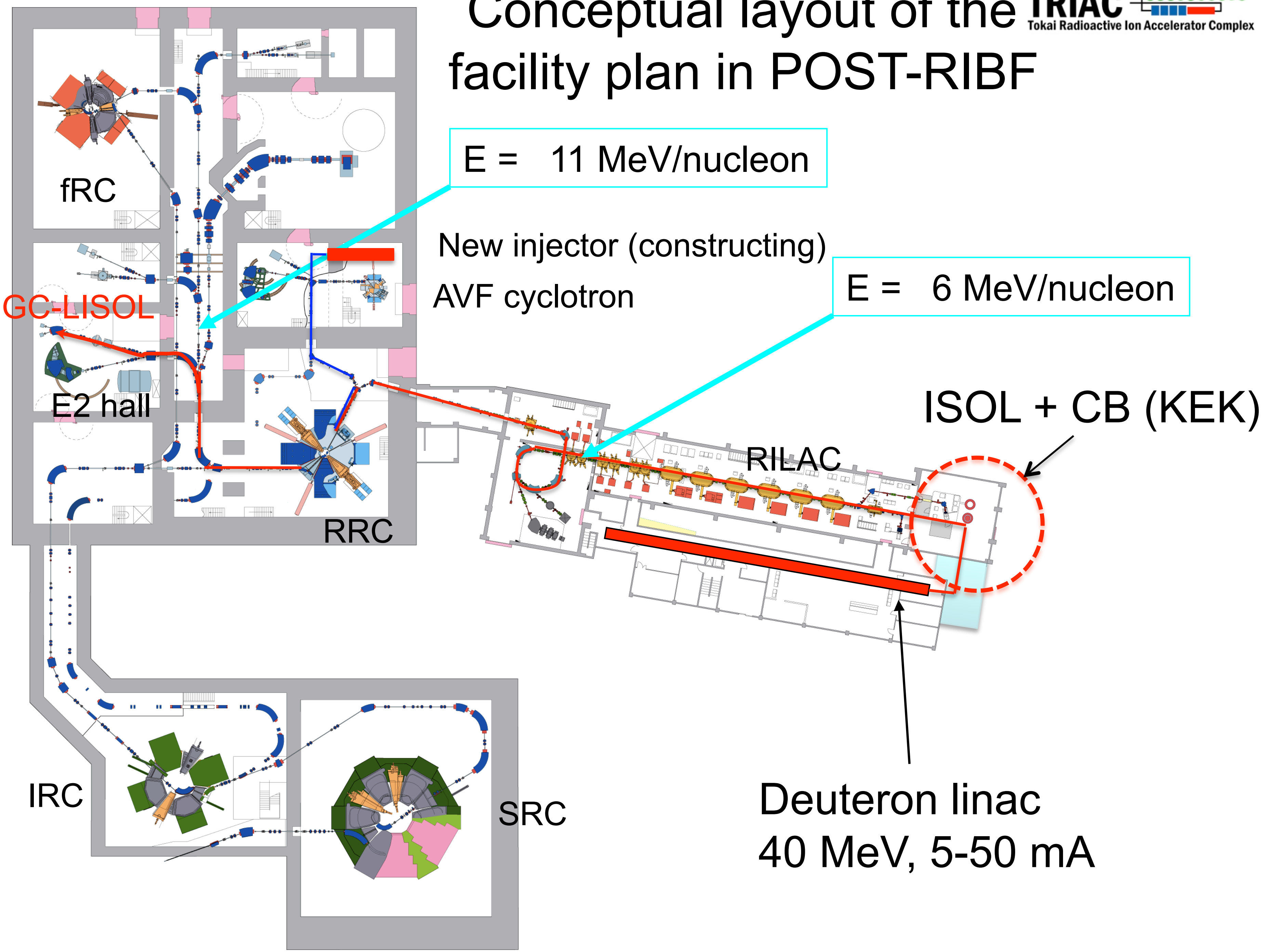

Thank you !!

梶野さん、住吉さん、和南城さん、大槻さん、
西村さん、千葉さん、小浦さん、宇津野さん