Recent spectroscopic activities using multi-nucleon transfer reaction products at KISS

(KEK Isotope Separation System : KISS)

KISS was open for External User Program in 2016.
Start call-for-proposal from last RIKEN PAC

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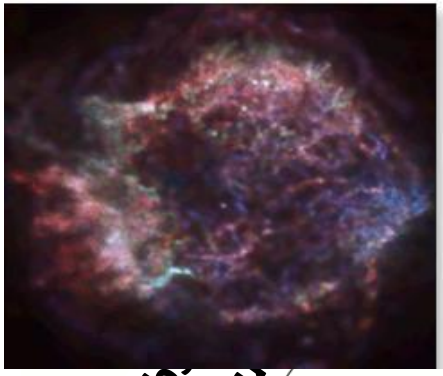
Contents :

1. KISS project : Astrophysical motivation
2. Key issues : production and separation
3. Present status of KISS
4. R&D and future plan
5. Summary

LA3NET Laser ion Source Workshop
24-25th October 2016, Paris

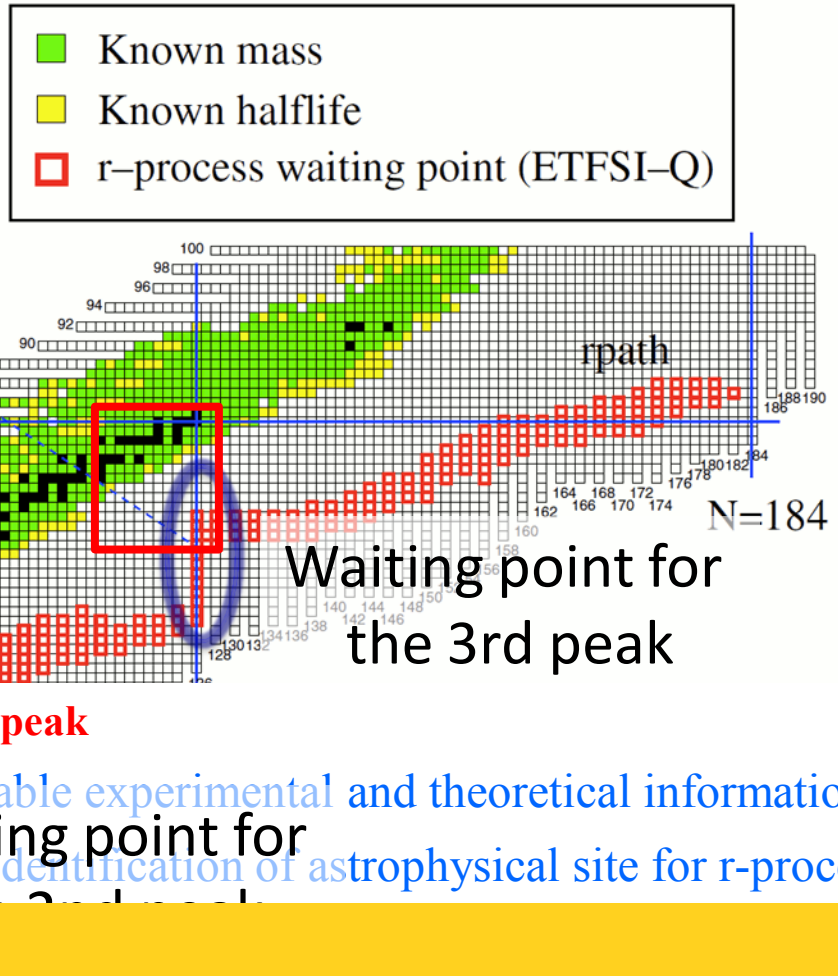
Identification of astrophysical site for r-process
~ How are the elements of Gold and Platinum synthesized ~

Type II Supernova



Neutron star merger

H. Grawe et al., Rep. Prog. Phys. 70 (2007), 1525-1582.



The 3rd peak

No reliable experimental and theoretical information so far

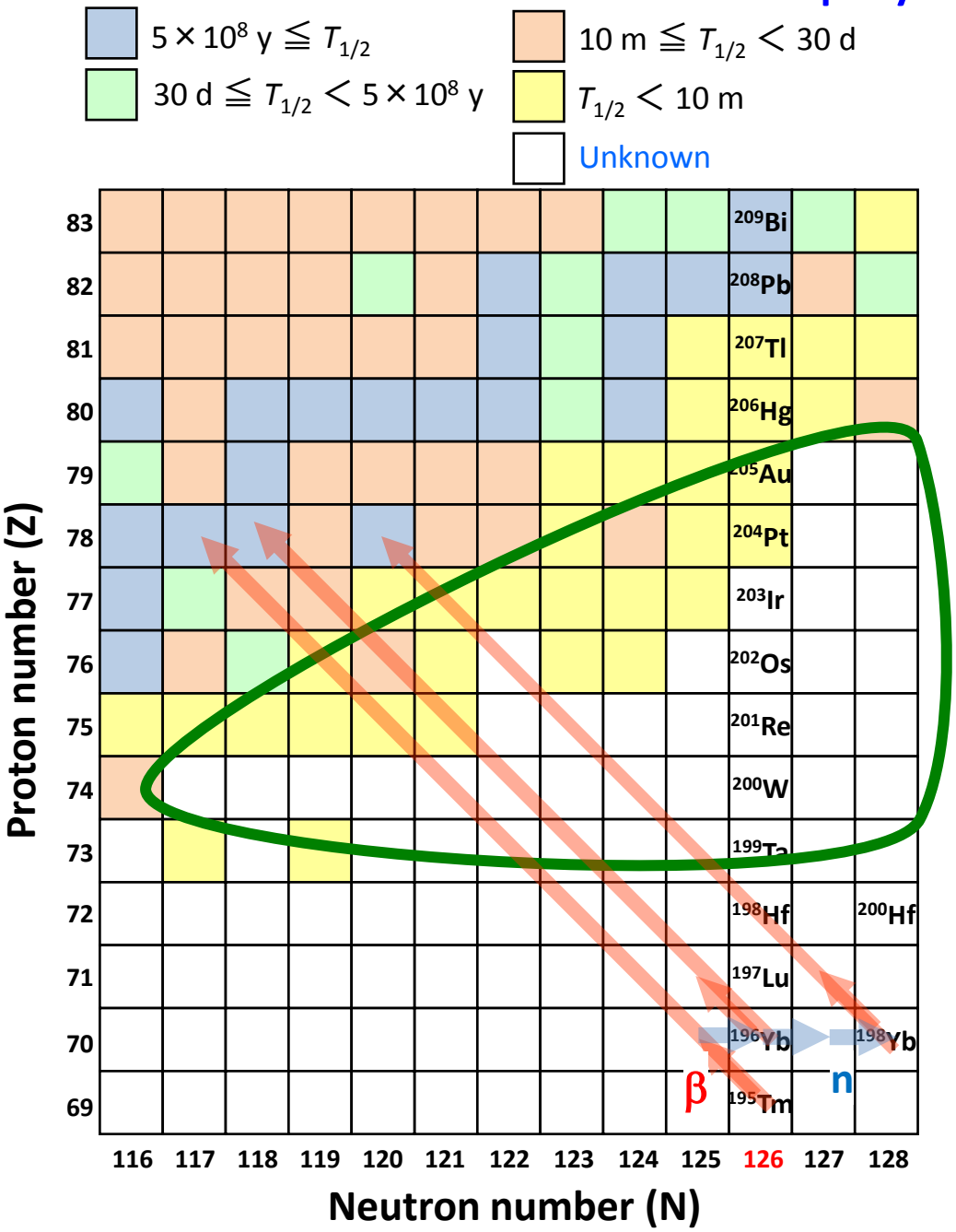
Waiting point for

→ No identification of astrophysical site for r-process

Ultimate goal of physics motivation

- Actual r-process path
- Astrophysical N_n – T condition
- Duration time passing through waiting point
- Sensitive test for actinide element production rate

Identification of astrophysical site for r-process



MNT reaction of
^{136}Xe beam + ^{198}Pt target system

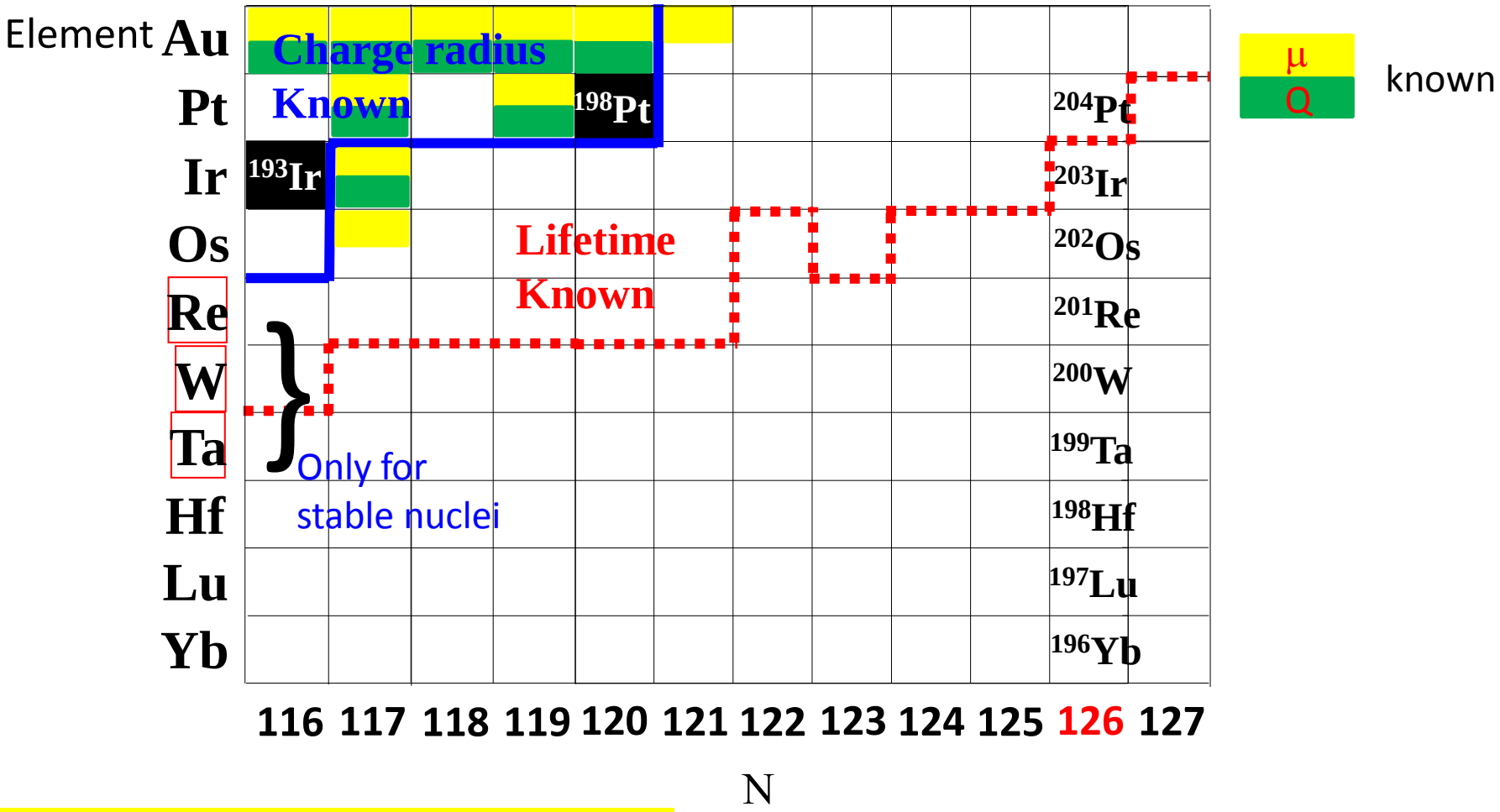
- Lifetime measurements of nuclei around N = 126
  → Actual r-process path (β-decay flow equilibrium)
- Mass measurement
  → Temperature and neutron density condition for the 3rd peak formation ((n,γ)-(γ,n) equilibrium)

1st stage: Lifetime of nuclei from ^{203}Ir to ^{200}W

- β-γ spectroscopy around N=126
  → Nuclear structure

β-decay flow equilibrium

EM moments and charge radii around N=126



Laser spectroscopy around N=126
Nuclear structure, interaction in nuclei
→ improve theoretical models
→ improve lifetime and mass predictions
for astrophysical interest

Lifetime : http://wwwndc.jaea.go.jp/CN14/index.html(2014)
Charge radii : Atomic Data and Nucl. Data Tables 99 (2013) 69
EM moments : Atomic Data and Nucl. Data Tables 90 (2005) 75

Experimental Issues:

How to access ?

Efficient production of nuclei of interest

⇨ Multi-nucleon transfer reaction

How to separate?

High efficiency and purity

⇨ Gas cell system

Laser resonance ionization + ISOL

How to access the nuclei with N=126 ?

Multi-nucleon transfer reactions (MNT) with low energy n-rich heavy ion beams (~10 MeV/*A*)

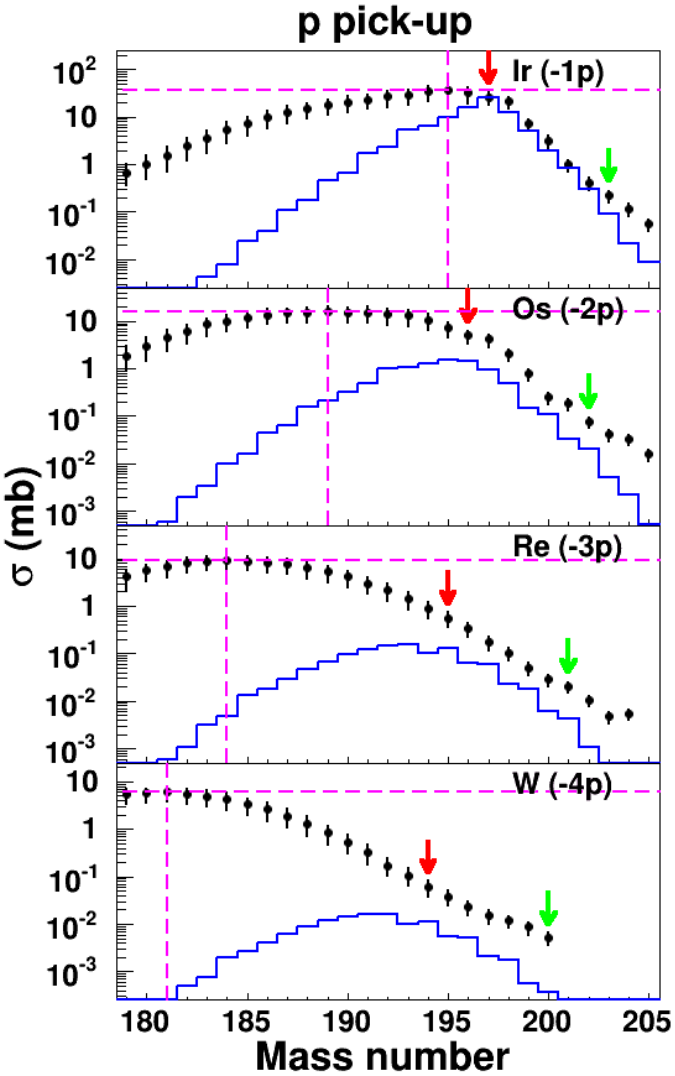
proposed by C.H. Dasso et al., PRL73(1994)1907.

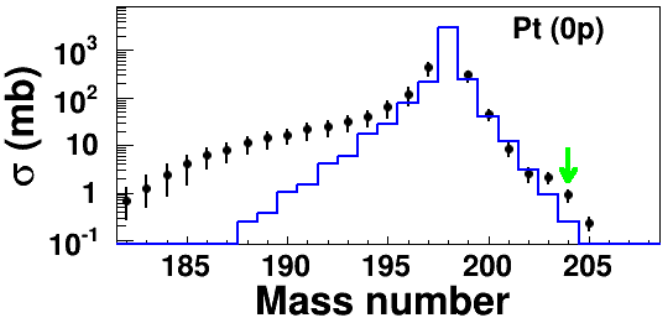
Recently revisited by V. Zagrebaev et al. ("Blank Spot " ; PRL 101 (2008) 122701)

^{136}Xe beam (10.75 MeV/A) + ^{198}Pt target (6mg/cm^2)

The production rates were estimated by using GRAZING code.

Check the feasibility by measuring the production σ of PLFs using VAMOS at GANIL





- evaluated from the measured σ of PLFs

GRAZING

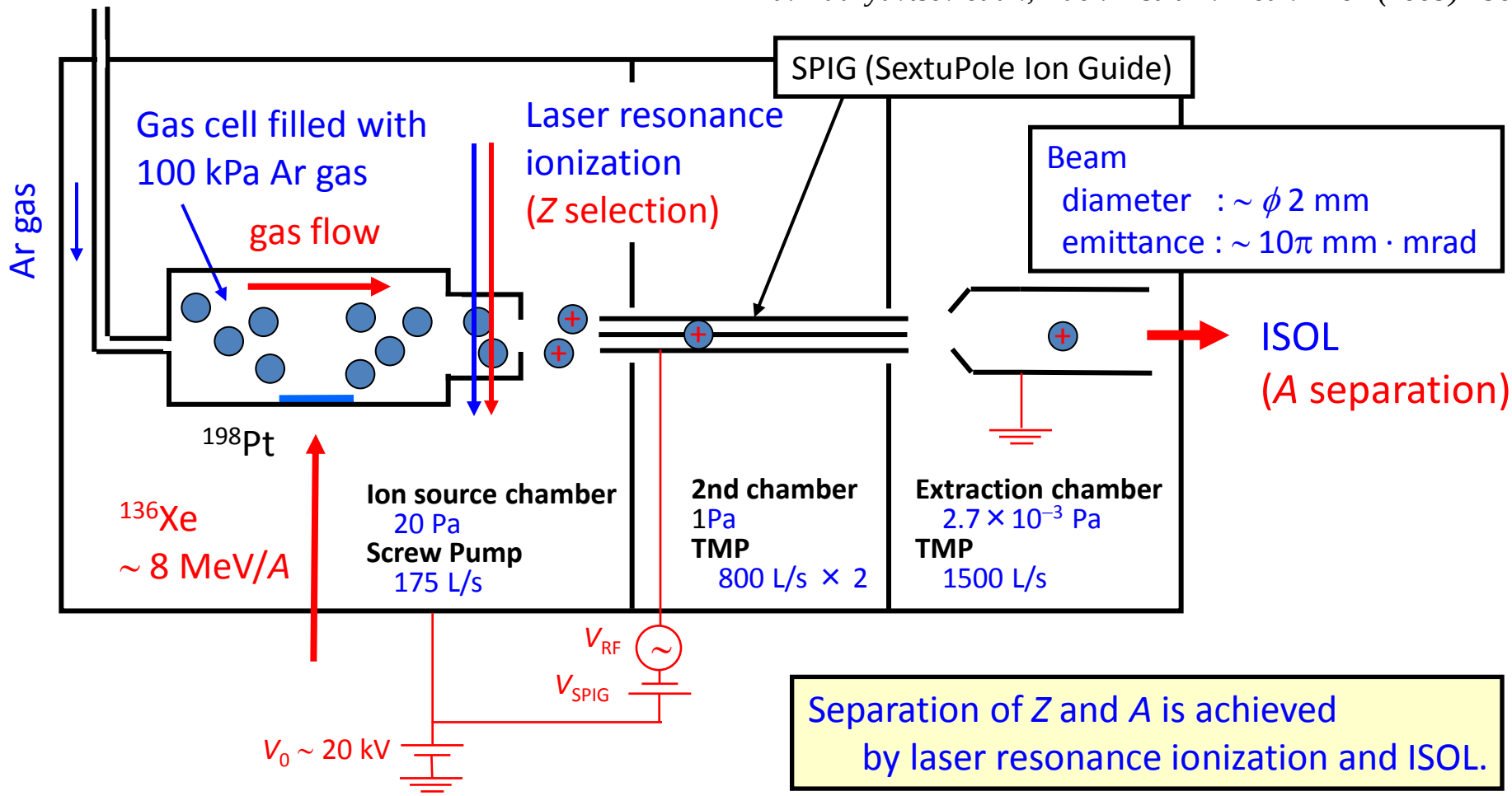
N ~ 126
Modest enhancement of σ by a factor of 2 ~ 10

Y.X. Watanabe et al.
PRL 115 (2015) 172503.

How to separate nuclei ?
Gas cell system
– Laser resonance ionization + ISOL –

Developed by KU Leuven group

P. Van Duppen, Nucl. Instrum. Meth. B126 (1997) 66.
Yu. Kudryavtsev et al., Nucl. Instrum. Meth. B267 (2009) 2908.



Separation of *Z* and *A* is achieved
by laser resonance ionization and ISOL.

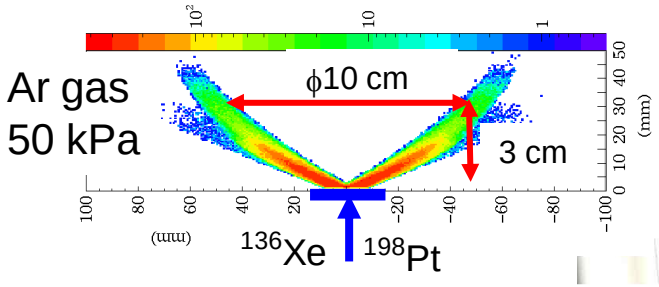
Present status

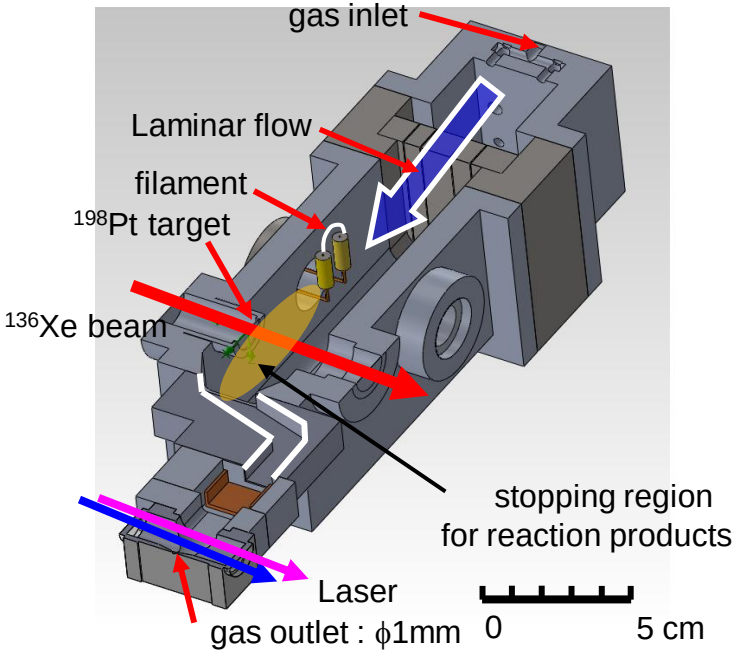
- Installation status: completed.
- On-line tests for extracting Pt-like elements : Done produced by MNT reactions between ^{198}Pt and ^{136}Xe
- Some results using ^{136}Xe beam

KISS (KEK Isotope Separation System) @ RIKEN

2011 : Construction
2012 : Off-line test
2013- : On-line test
2015- : Join RIKEN NP-PAC

MNT reaction: ^{136}Xe beam + ^{198}Pt target





Detection system
- Tape-transport system
- two-layered plastic scintillators
  ΔΩ = 75%, B.G. = 0.09 cps
- Ge detectors

Mass separator
(*A* selection)
M/ΔM ~ 900

Extraction chamber
- High voltage (~20 kV)

E3

MNT products

E2

laser@B2F

Gas cell system
- Target (^{198}Pt)
- MNT reaction
- Gas cell (Ar gas, neutralization)
- Laser resonance ionization
  (Z selection)

Lasers

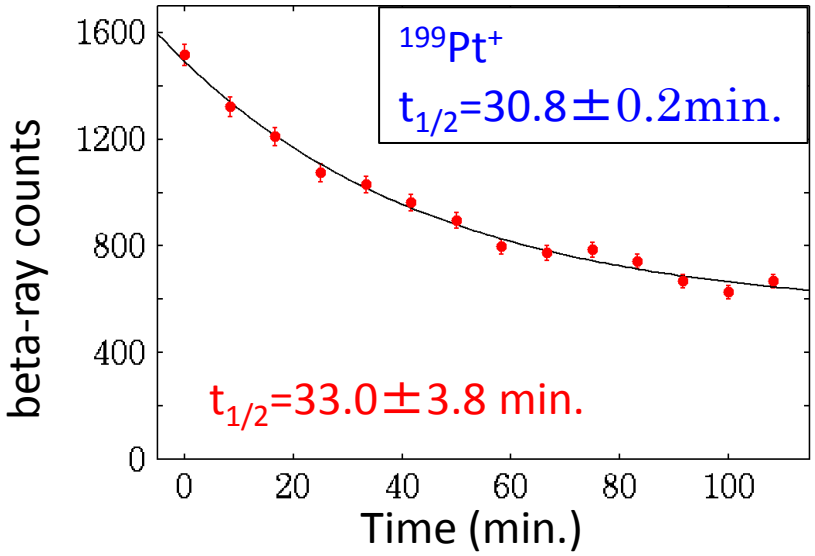
Ar gas

^{136}Xe beam

Y.H. et al. NIMB353(2015)4
NIMB376(2016)52

KISS Status

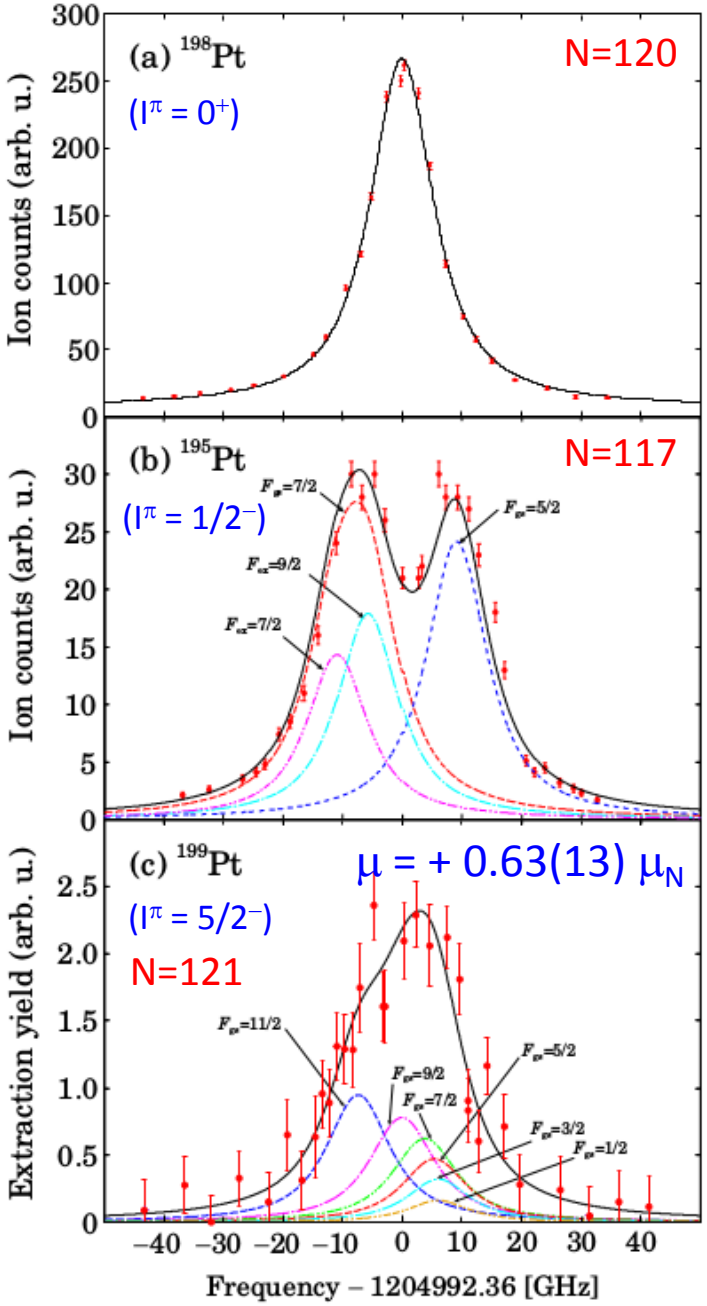
- Laser ionization : $^{198}Pt^{+}$, $^{199}Pt^{+}$, $^{196}Ir^{+}$, $^{197}Ir^{+}$, $^{198}Ir^{+}$
- Extraction efficiency : 0.15% for $^{198}Pt^{+}$, 0.01% for unstable nuclei
- Extraction time : 350 ms
- Lifetime measurement : $^{199}Pt^{+}$ and iridium isotopes



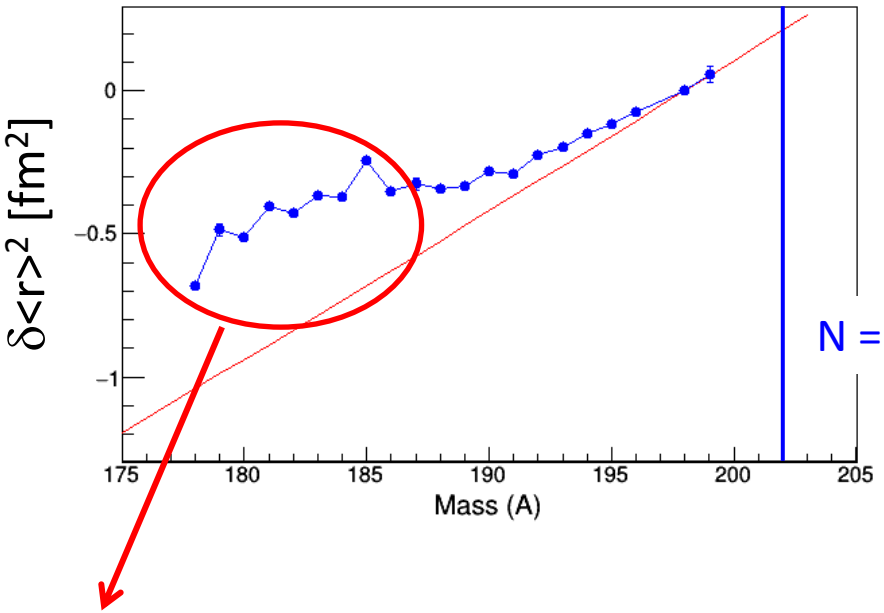
In-gas cell laser ionization spectroscopy

- Isotope shift → charge radius
- Hyperfine structure → g-factor, Q moment

Hyperfine structure of platinum isotopes



Hyperfine structure ^{199}Pt ($I^\pi = 5/2^-$) → g-factor, $\delta\langle r\rangle^2$

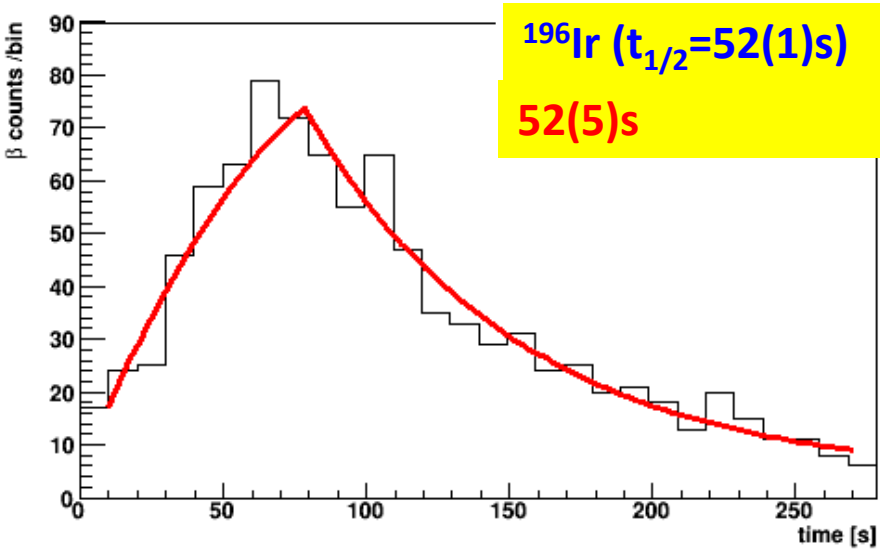


Shape transitions
Even-Pt : triaxial shape
Odd-Pt : axial shape

Spherical shape toward N = 126

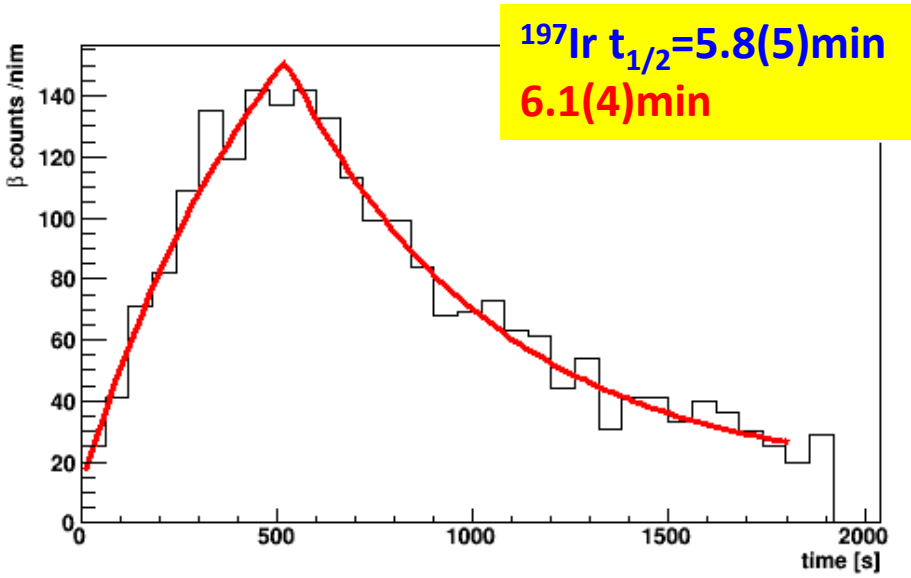
Laser spectroscopy toward N = 126

Lifetime measurements



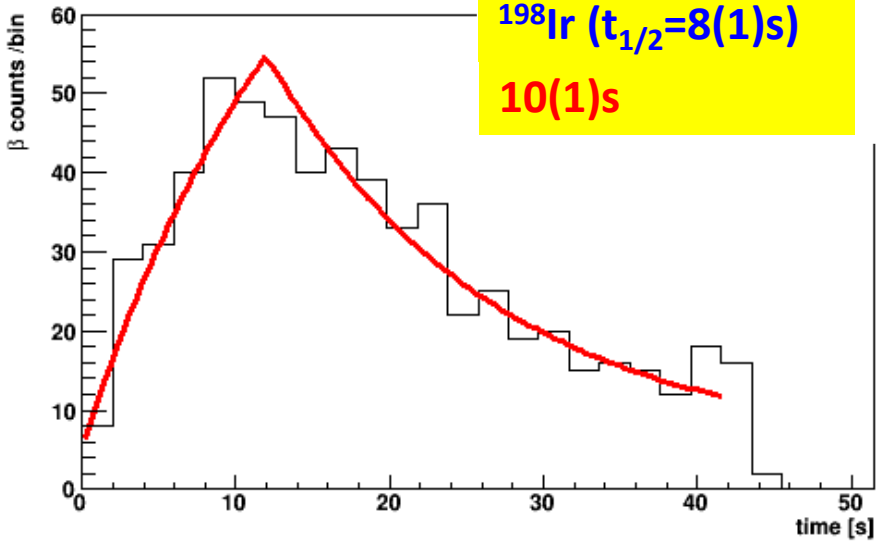
^{196}Ir ($t_{1/2}$=52(1)s)

52(5)s



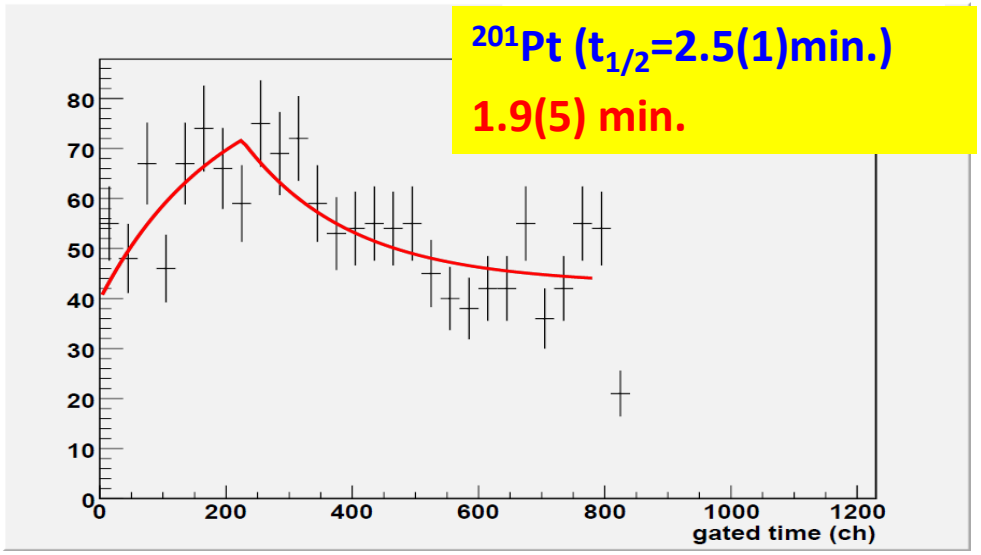
^{197}Ir $t_{1/2}$=5.8(5)min

6.1(4)min



^{198}Ir ($t_{1/2}$=8(1)s)

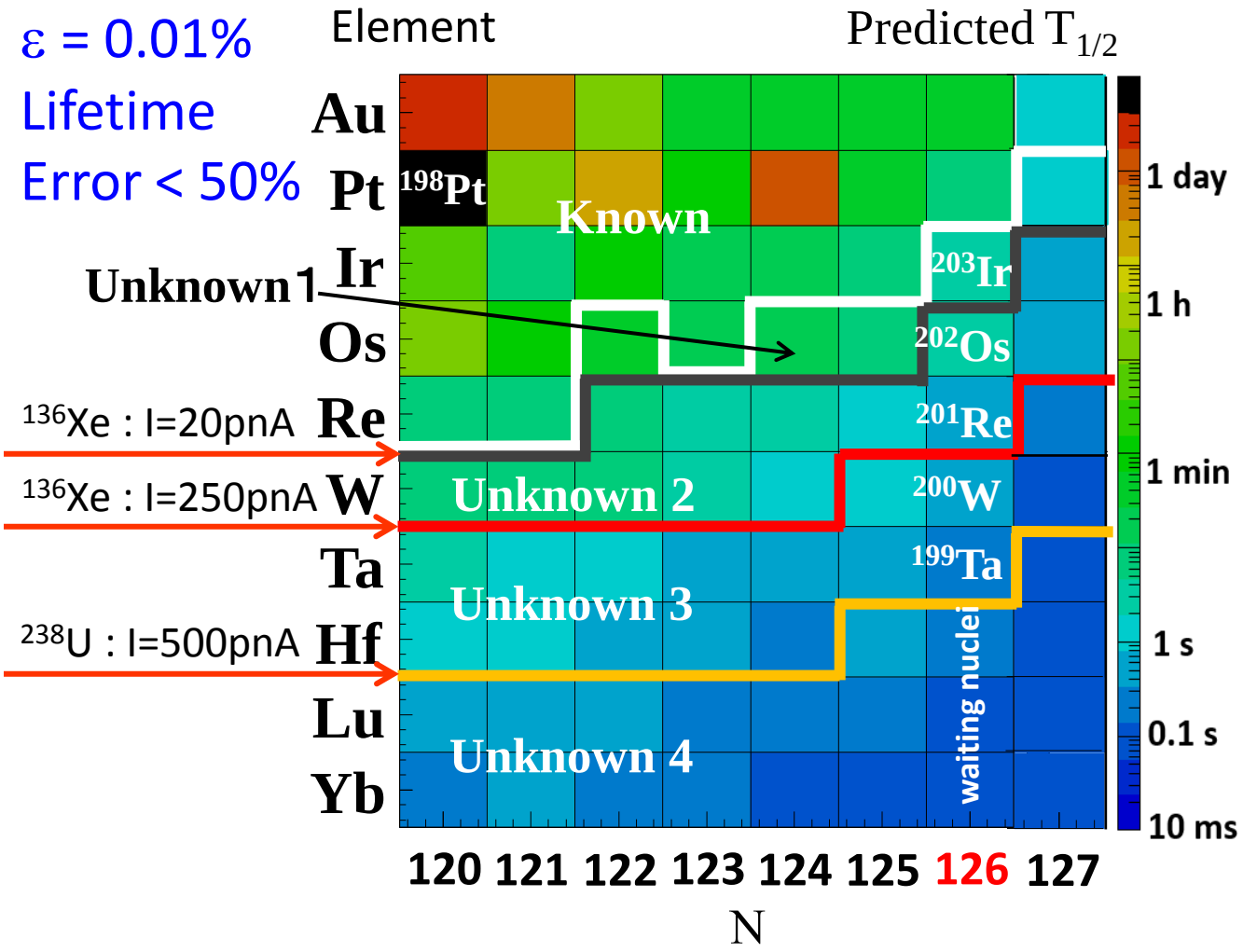
10(1)s



^{201}Pt ($t_{1/2}$=2.5(1)min.)

1.9(5) min.

Accessible region on nuclear chart for lifetime measurements



NP1512-RRC41: "Lifetime measurement of nuclei around N=126 using KISS"

KUTY : H. Koura, T.Tachibana, M. Yamada, http://wwwndc.jaea.go.jp/CN14/index.html

R&D and Future plan

1. Intense primary beam
   -> increasing the production yields
2. Low background gas counter
   -> Lifetime, β–γ spectroscopy
3. Ge arrays
   -> β–γ spectroscopy
4. MR-TOF
   -> Mass measurements

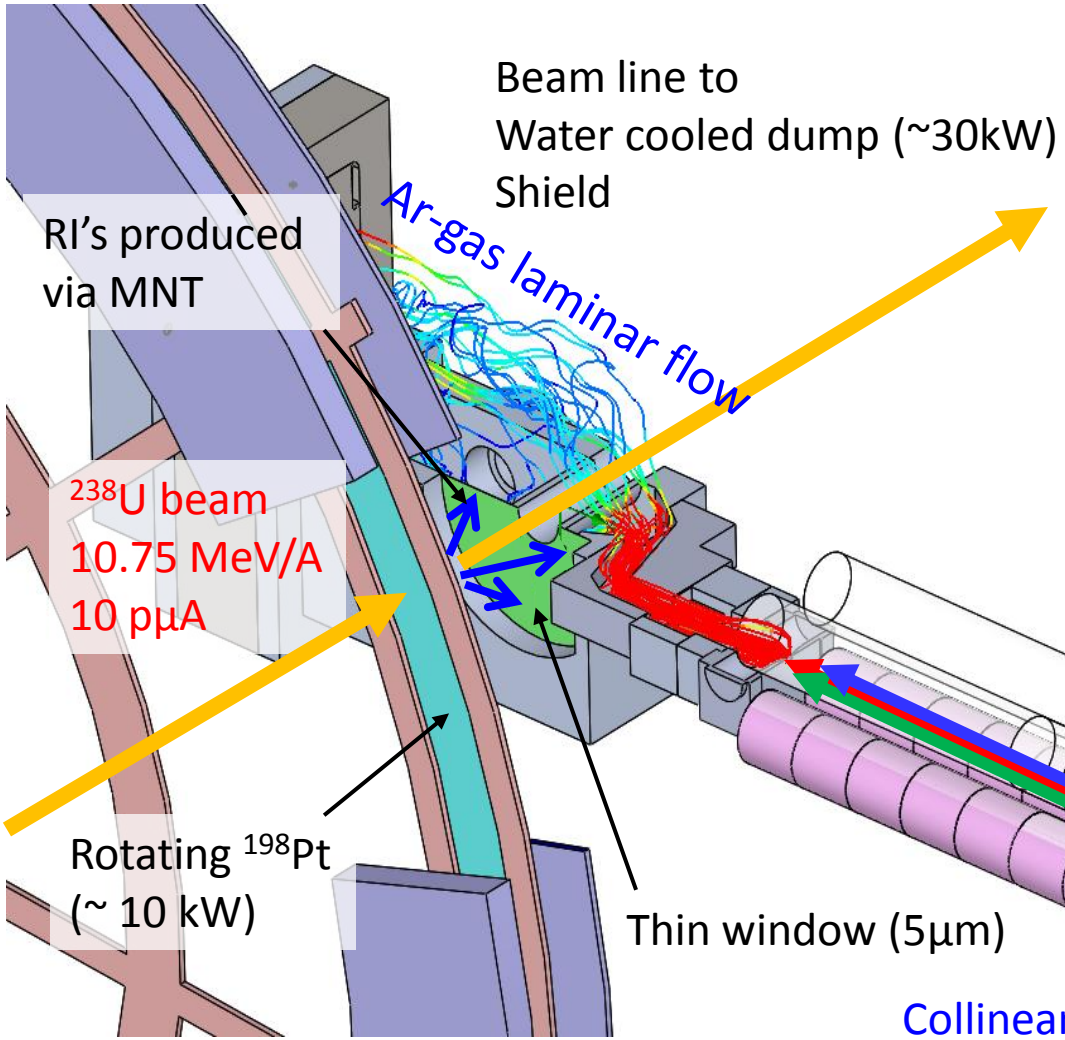
New gas cell for the use of intense primary beam

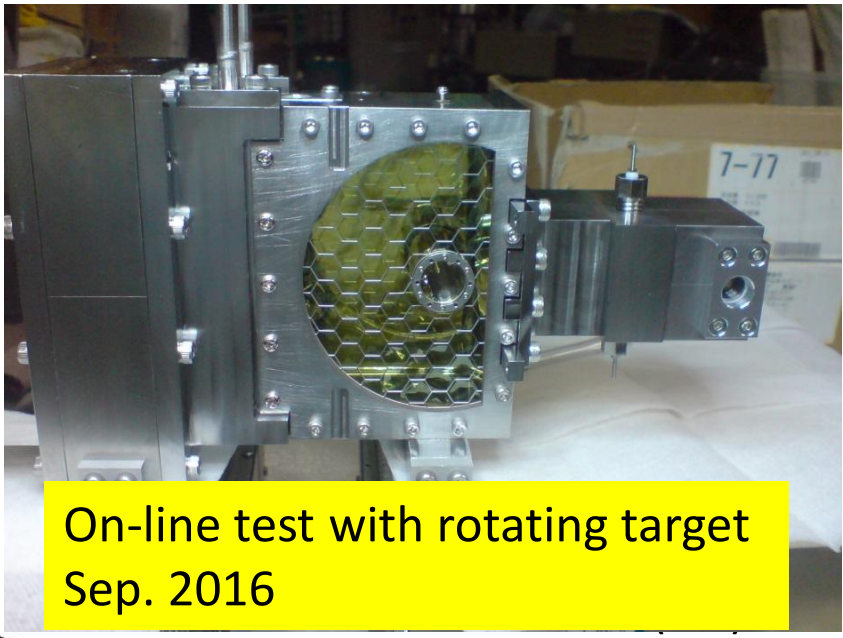
$^{136}Xe/^{238}U$ primary beam : available max intensity : 250/500 pnA, POST-RIBF : ^{238}U, 10 pμA

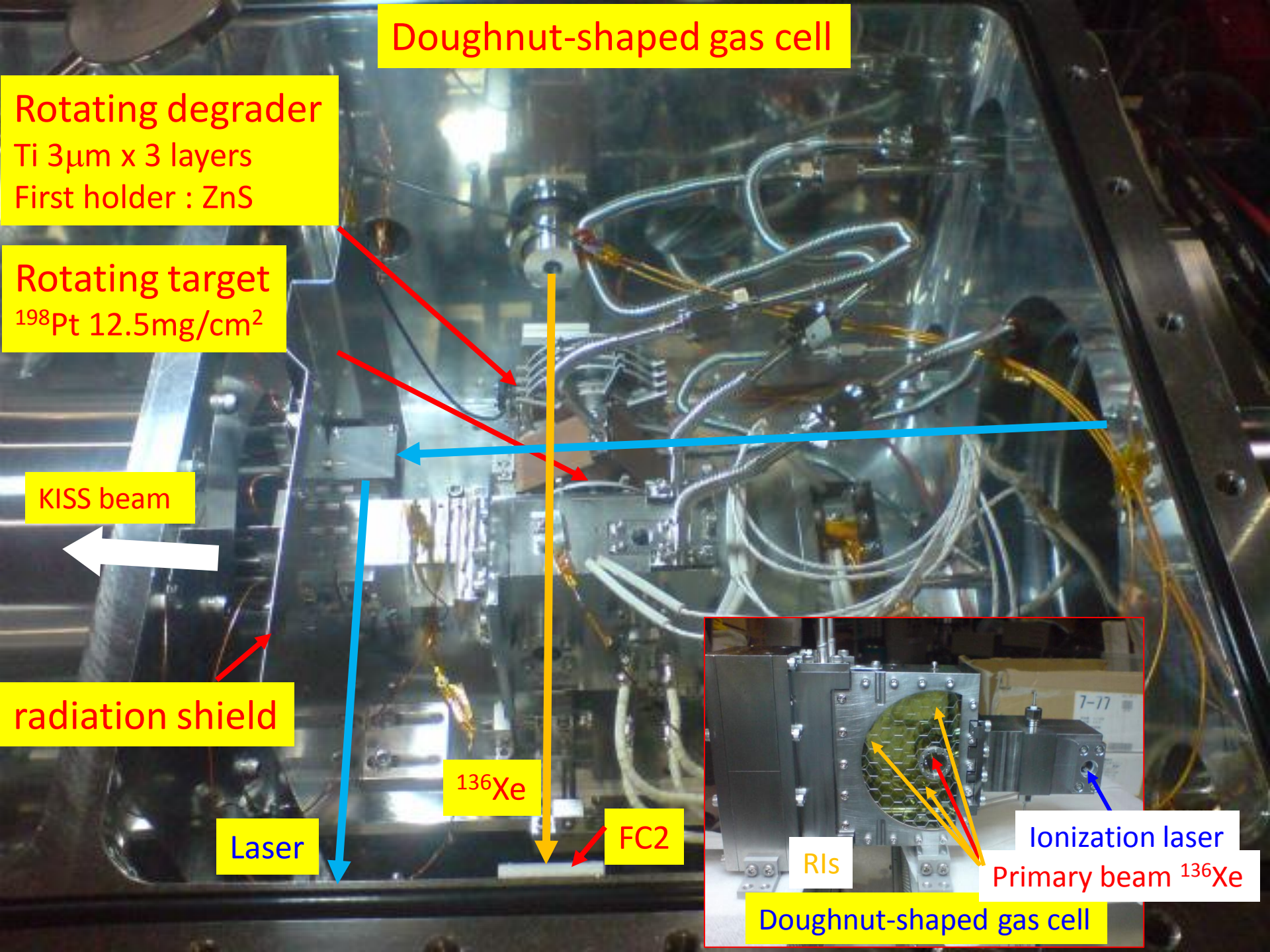
Acceptable max intensity : around 20 pnA, limited by Havar foil as gas-cell windows

➡ Doughnut –shaped gas cell (window less)

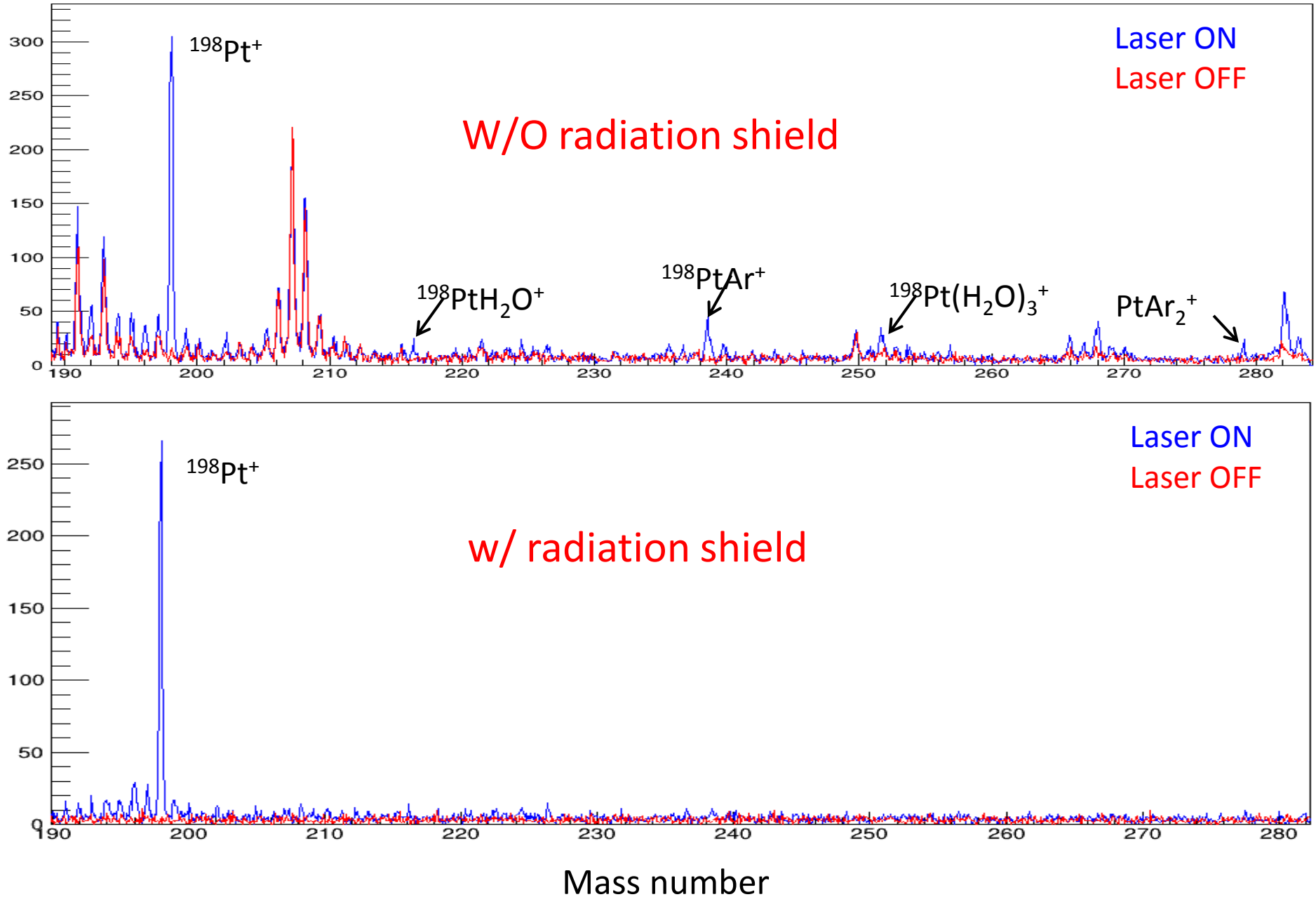
ϕ2 mm exit aperture for fast extraction of 100 ms






Doughnut-shaped gas cell
Rotating degrader
Ti 3μm x 3 layers
First holder : ZnS
Rotating target
198Pt 12.5mg/cm2
KISS beam
radiation shield
136Xe
Laser
FC2
RIs
Ionization laser
Primary beam 136Xe
Doughnut-shaped gas cell

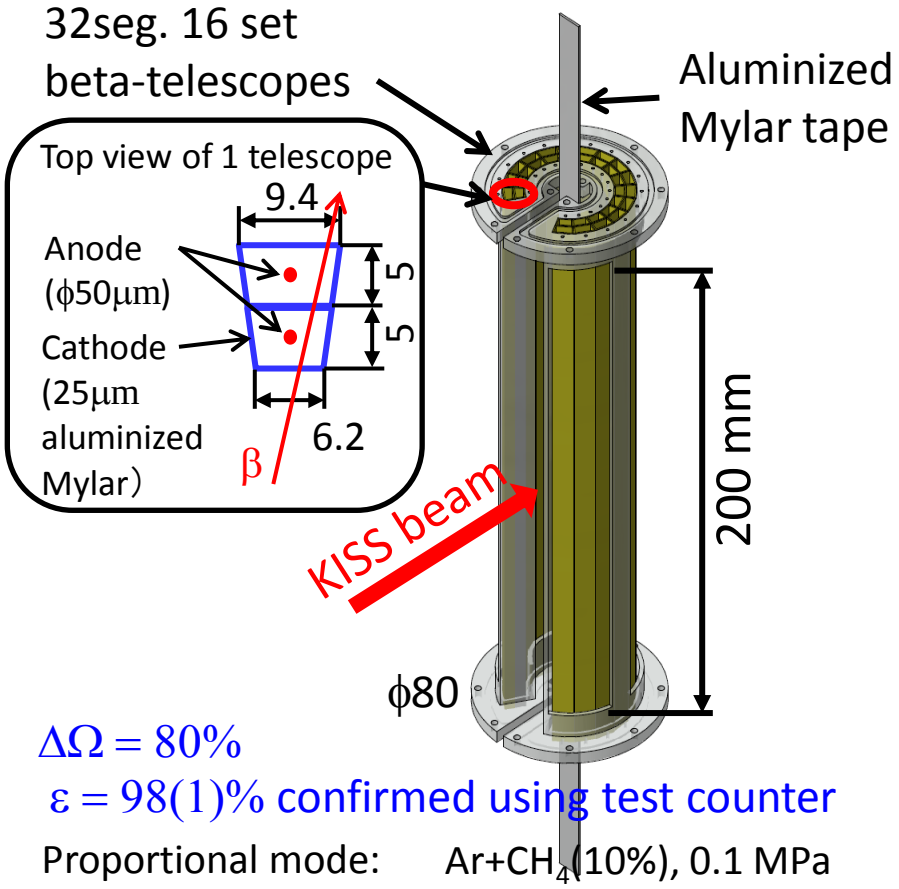
^{198}Pt mass distribution w/ and w/o laser



Low-background gas counter

For the lifetime measurements,
it is necessary to reduce background rate as low as the extraction yields (0.01 cps)

Main source of background is gamma-rays.
By replacing detector material from plastic scintillator to gas, we can reduce the thickness 1/100 (sensitivity to gamma-ray) drastically.



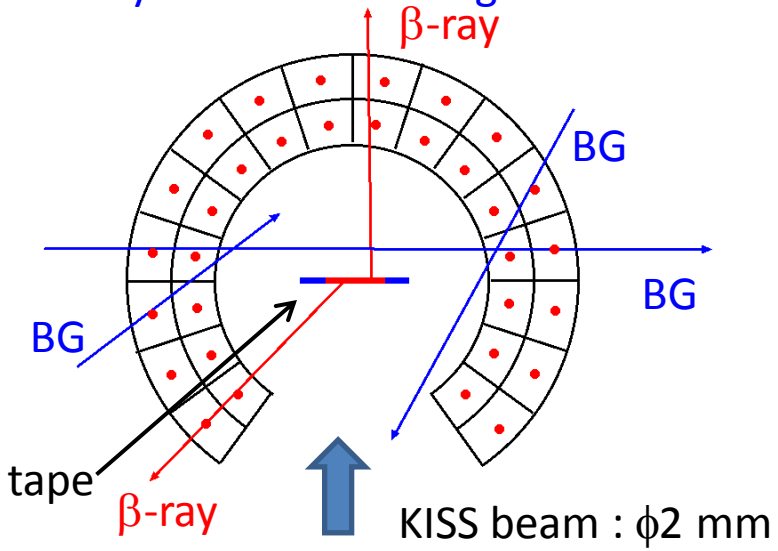
$\Delta\Omega = 80\%$

$\varepsilon = 98(1)\%$ confirmed using test counter

Proportional mode: Ar+CH_4(10%), 0.1 MPa

Top view of gas counter

From the hit pattern of telescopes, we can drastically reduce the background rate.



Combination with
veto counter for Cosmic-ray
and lead shield against room BG

Assembling and performance tests

Collaborative R&D between KEK and IBS (Korea) I

Constr 20

5 Super

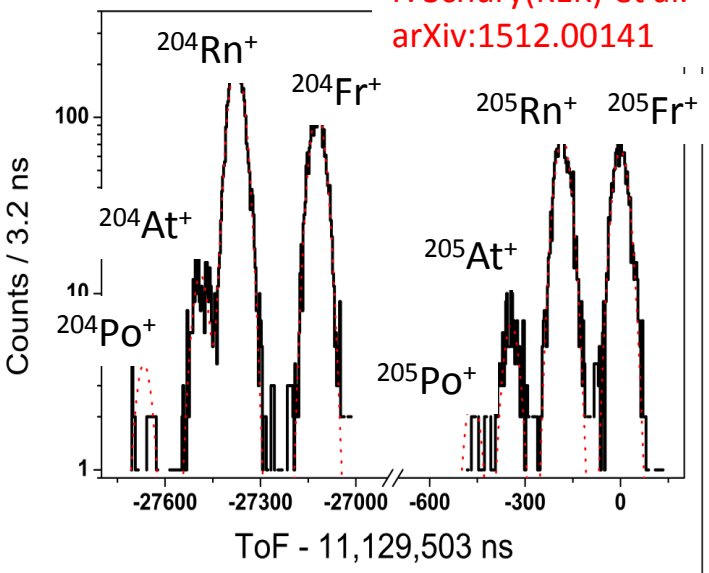
New gas c
for β-rays

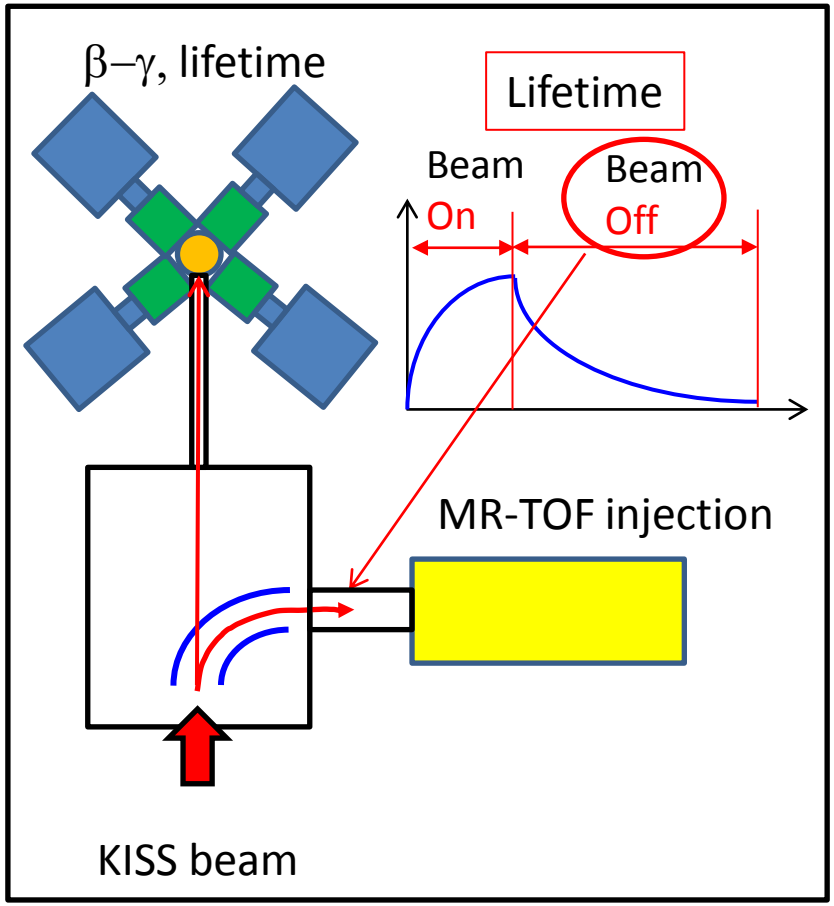
Ge detectors arrived on 10th Aug.
Performance tests
Installed on Jan.
Available for KISS external users

Collaborative R&D between KEK and IBS (Korea) II

Installing a new MR-TOF and injection system at KISS, MR-TOF developed by Wada-san group

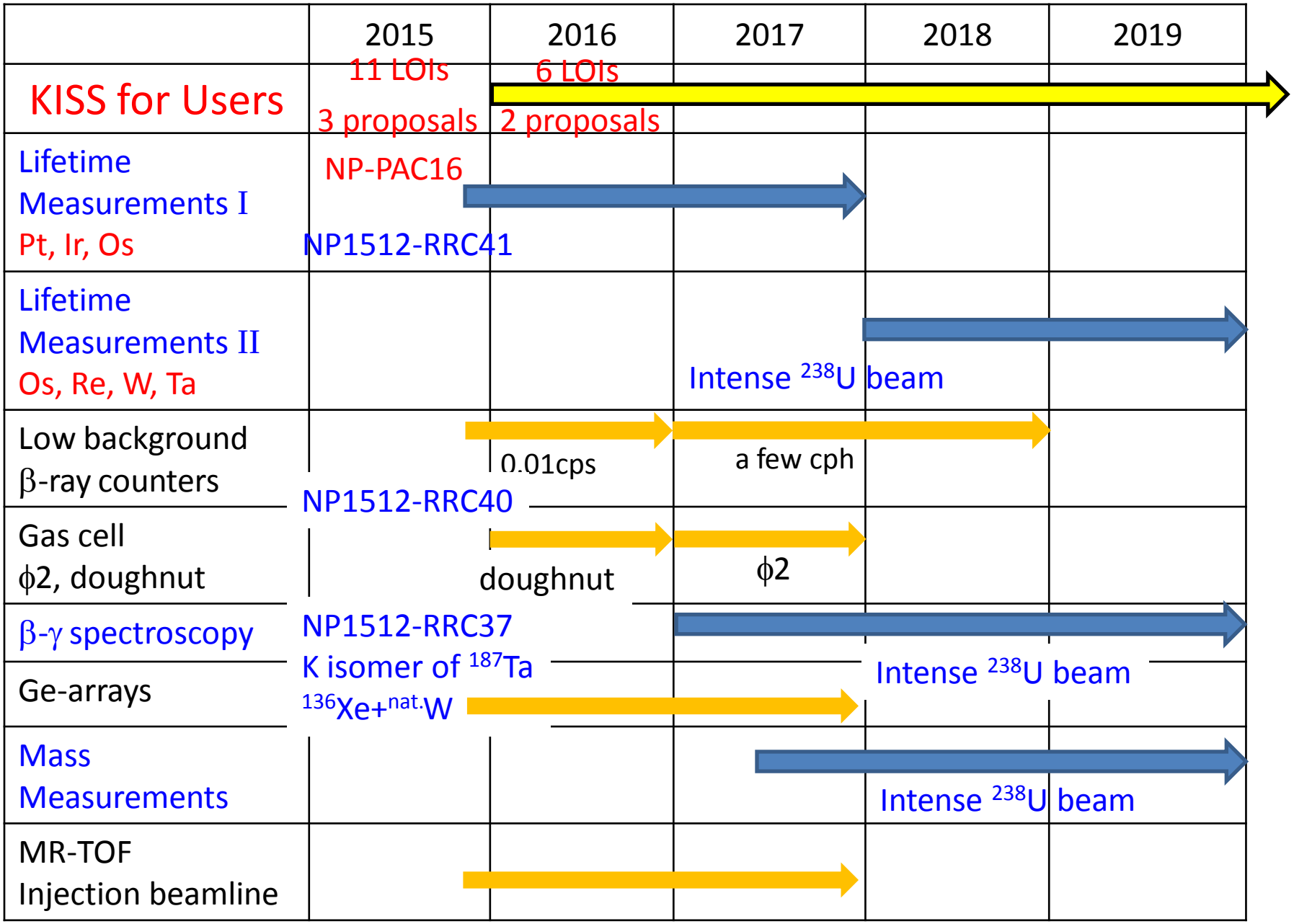
P. Schury(KEK) et al.
arXiv:1512.00141





Design work
Installed in 2017

KISS proposal submission and R&D plans



Summary

Characterize *3rd peak of* abundance pattern in terms of nuclear physics points of view through lifetime and mass measurements of the waiting nuclei as an ultimate goal of the physics motivation of the project

1st stage : Lifetime measurements of nuclei around N=126,
especially for ^{203}Ir ~ ^{200}W (*N*=126)
β-decay spectroscopy around *N* = 126 nuclei

- Installation of KISS was completed.

- Under on-line tests for extracting MNT Pt-like elements as R&D exp.

  We can start half-life measurements of nuclei around N = 126.

- Laser spectroscopy for platinum and iridium isotopes

  g-factor, charge radius

- R&Ds : increasing production rate using intense primary beam

  Installing new β-detectors, Ge-detectors and MR-TOF

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