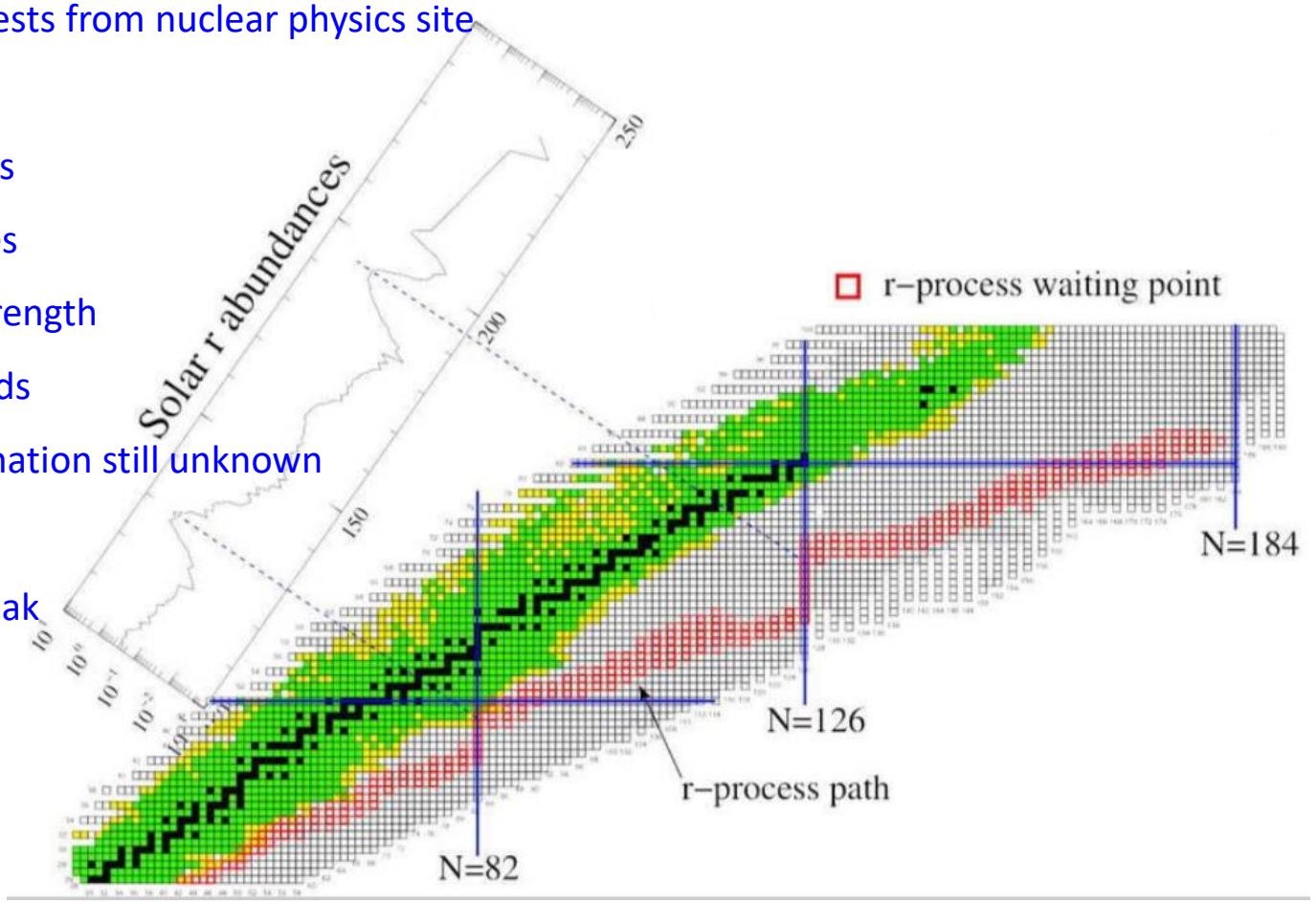
UNIVERSITY OF SURREY

Investigation of neutron-rich isotopes around N=126 using chemical separation methods

Zhiqiang Chen

Background of r-process and N=126 isotones

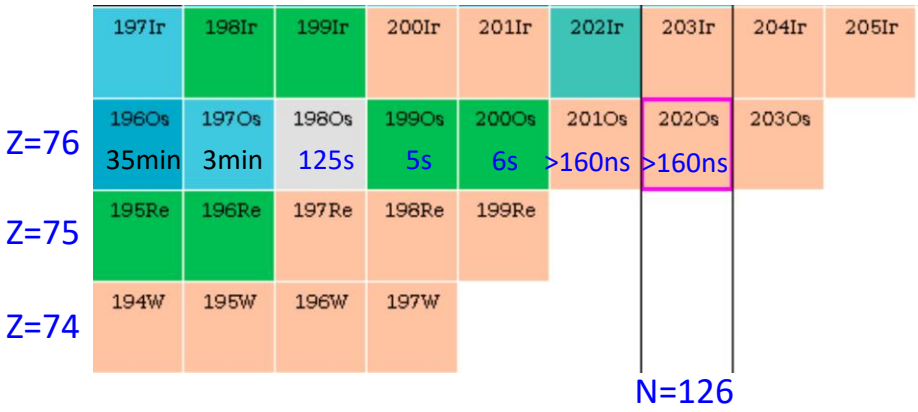
- r-process:
  - half of the elements heavier than iron
- r-process study requests from nuclear physics site
  - nuclear mass
  - beta-decay properties
  - Neutron capture rates
  - Gamma transition strength
  - Fission rates and yields
- Till now, many information still unknown
- N=126 isotones
  - A~190 abundance peak
  - Magic nature

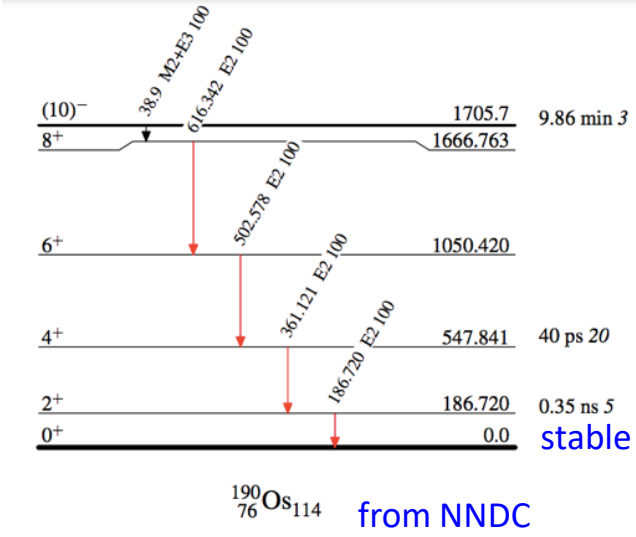


Background of neutron-rich Os isotopes

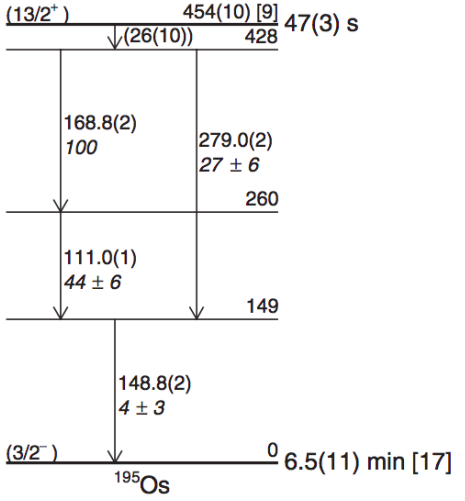
- N=126 region
  - still ‘‘terra incognita’’
- ^{202}Os:
  - last known N=126 isotopes
  - half-life is still vague
- Other light Os isotopes:
  - beta-decay information for $^{199\text{-}201}$Os not known
  - ^{199m}Os($T_{1/2}$=25.2(20)ns)
  - ^{198m}Os($T_{1/2}$=18.0(28)ns, 16.1(8)ns)
  - ^{197m}Os($T_{1/2}$=78.2(66)ns)
  - ^{195m}Os($T_{1/2}$=34.0(23)ns)

    S. J. Steer et al., PRC 84, 044313(2011).
- long live isomer in $^{190\text{-}192m}$Os, ^{195m}Os





from NNDC

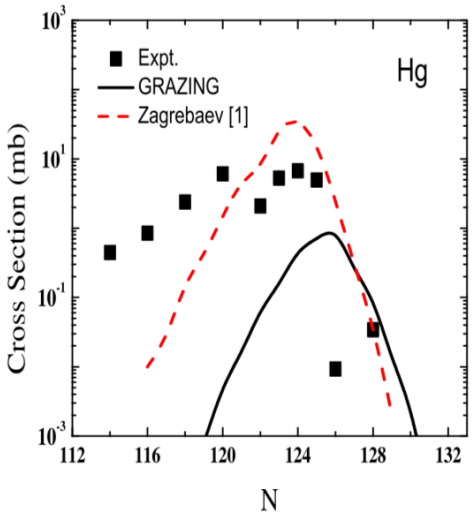


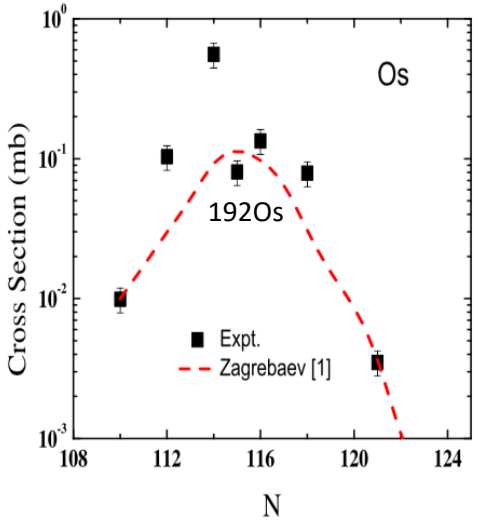
Y. X. Watanabe et al., PRC 101, 041305(R)(2020)

Study of neutron-rich Os isotopes by MNT

$^{136}Xe + ^{208}Pb$

E = 767MeV

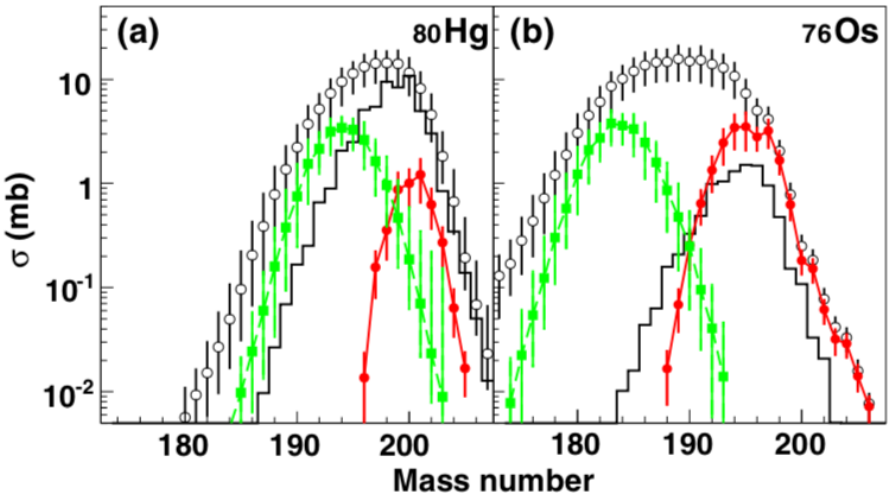




J. S. Barrett et al., PRC 91, 064615 (2015).

$^{136}Xe + ^{198}Pt$

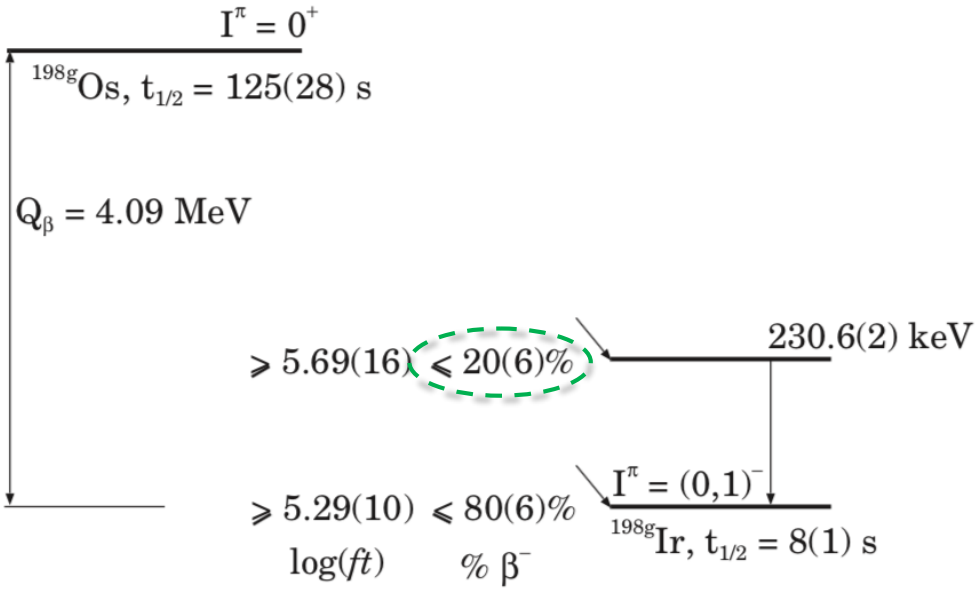
E = 1085MeV



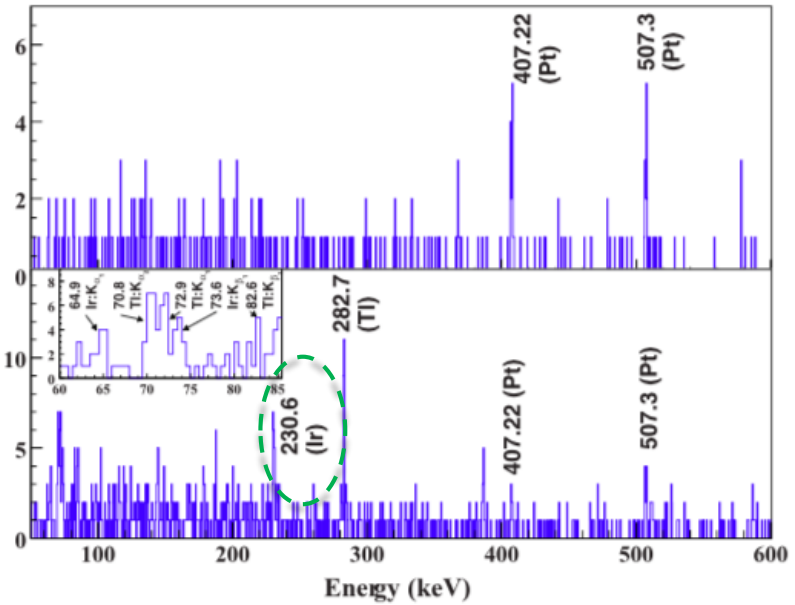
Y. X. Watanabe et al., PRL 115, 172503 (2015).

- Multinucleon transfer reaction
- $^{136}Xe + ^{208}Pb$ / ^{198}Pt with beam energy near Coulomb barrier

Study of neutron-rich Os isotopes by MNT



beta-delayed gamma spec of ^{198g}Os and ^{198g}Ir



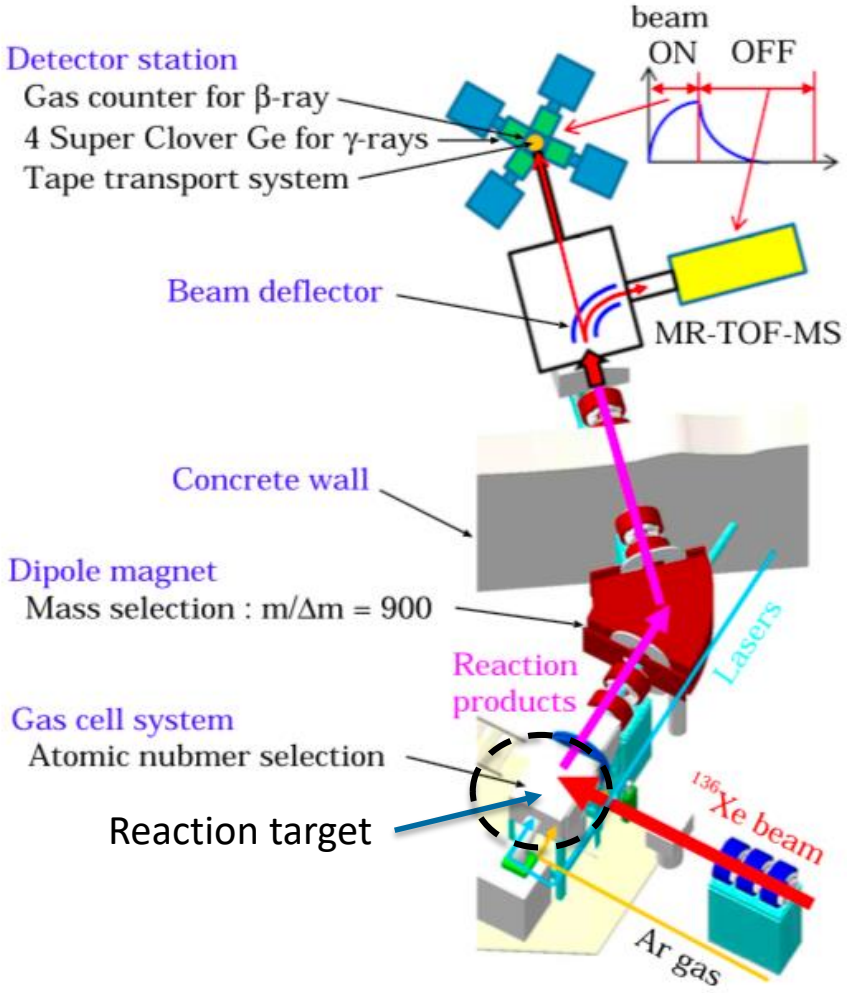
Y. Hirayama et al., PRC 98, 014321 (2018).

- KISS project in RIKEN

- ^{136}Xe (1462MeV, 50 pnA) + ^{198}Pt target with a thickness of 12.5mg/cm^2
- Half-life measured first time

Several methods to isolate the nuclei of interest

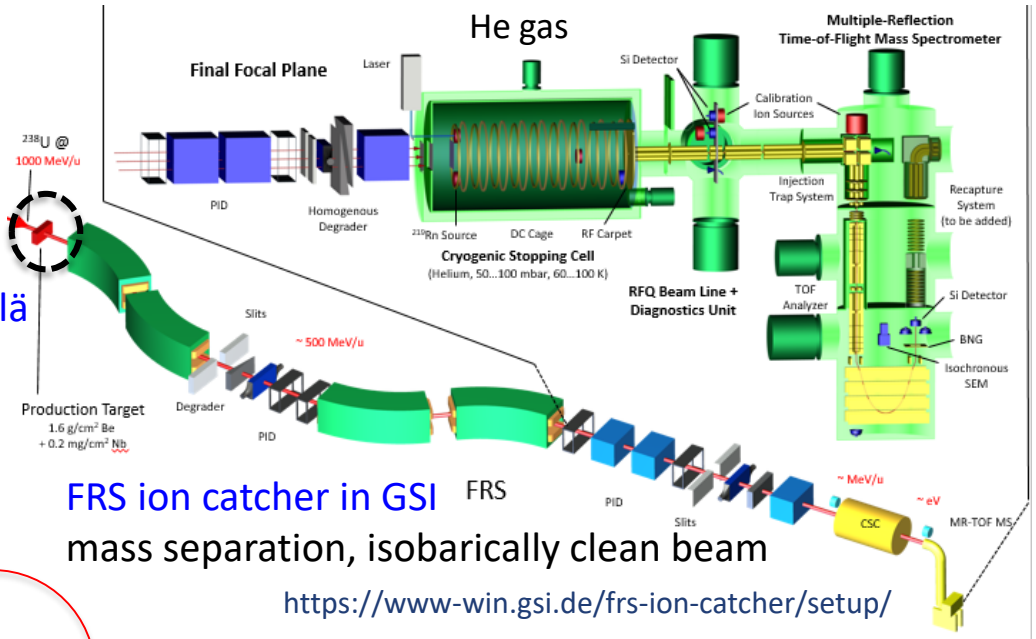
- low energy products in MNT
- △E-E-TOF (✕)
- α decay tagging, but not an universal method (e.g. neutron-rich β emitters)
- Other methods:
- laser ionization, e.g. KISS project in RIKEN
- Z selection(Gas cell)
- A/Q separation(Dipole magnet)
- lifetime > 1s



Y. Hirayama et al., NIMB 463, 425–430(2020).

Several methods to isolate the nuclei of interest

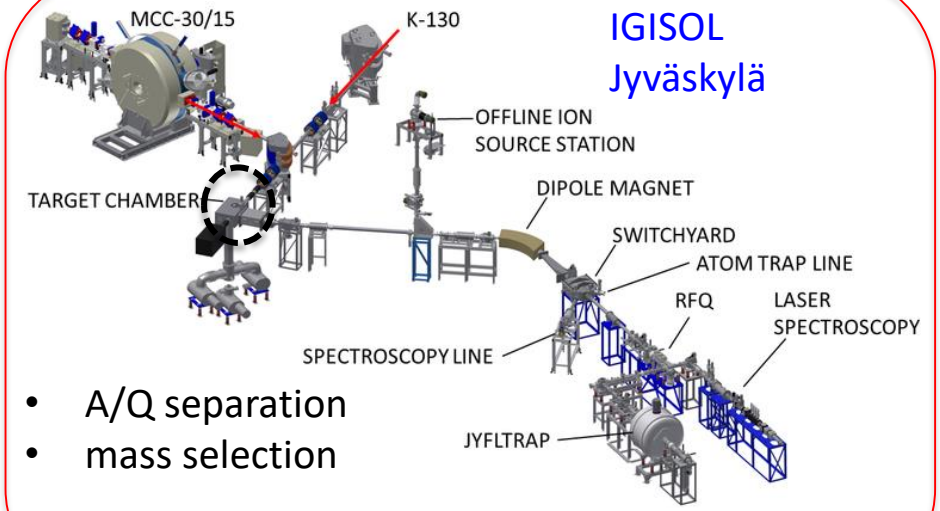
- High-precision mass measurements
  - FRS ion catcher in GSI
  - Penning traps, MAIDEN project in Jyväskylä
  - MR-TOF, N=126 factory in Argonne
- mass selection



FRS ion catcher in GSI

mass separation, isobarically clean beam

https://www-win.gsi.de/frs-ion-catcher/setup/



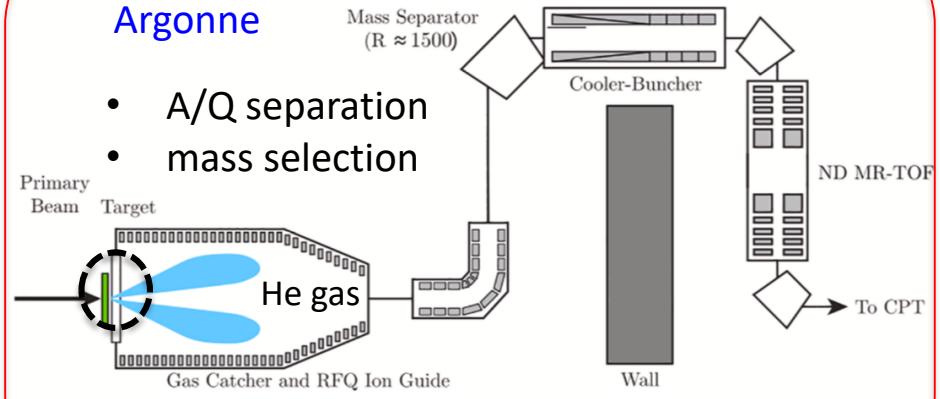
IGISOL Jyväskylä

- A/Q separation
- mass selection

I.D. Moore et al., NIMB 317, 208–213(2013).

The N = 126 factory Argonne

- A/Q separation
- mass selection

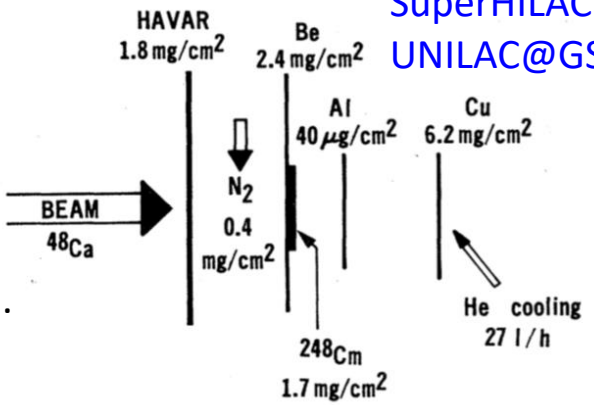


G. Savard et al., NIMB 463, 258–261(2020).

- Widely used in early study; especially in heavy / super heavy nuclei study

M. Schadel et al., PRL 48,852(1982).
D.C. Hoffman et al., Phys. Rev. C 31, 1763 (1985).
G. G. Adamian et al., Eur. Phys. J. A 56:47(2020), refs therein.

SuperHILAC@LBL
UNILAC@GSI

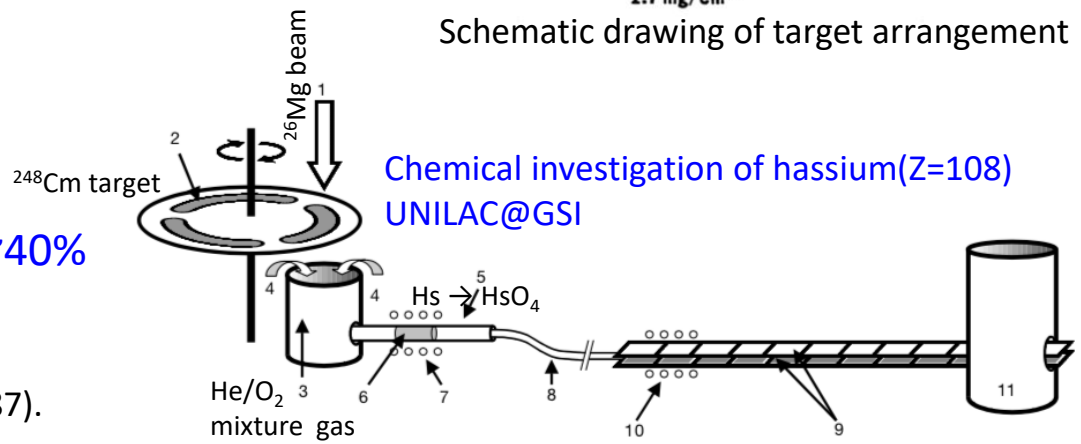


Schematic drawing of target arrangement

- Feature
- high sensitivity
- high efficiency

UNILAC@GSI, transport efficiency ~40%

K.J. Moody et al., Z. Phys. A 328, 417-422(1987).



Chemical investigation of hassium(Z=108)
UNILAC@GSI

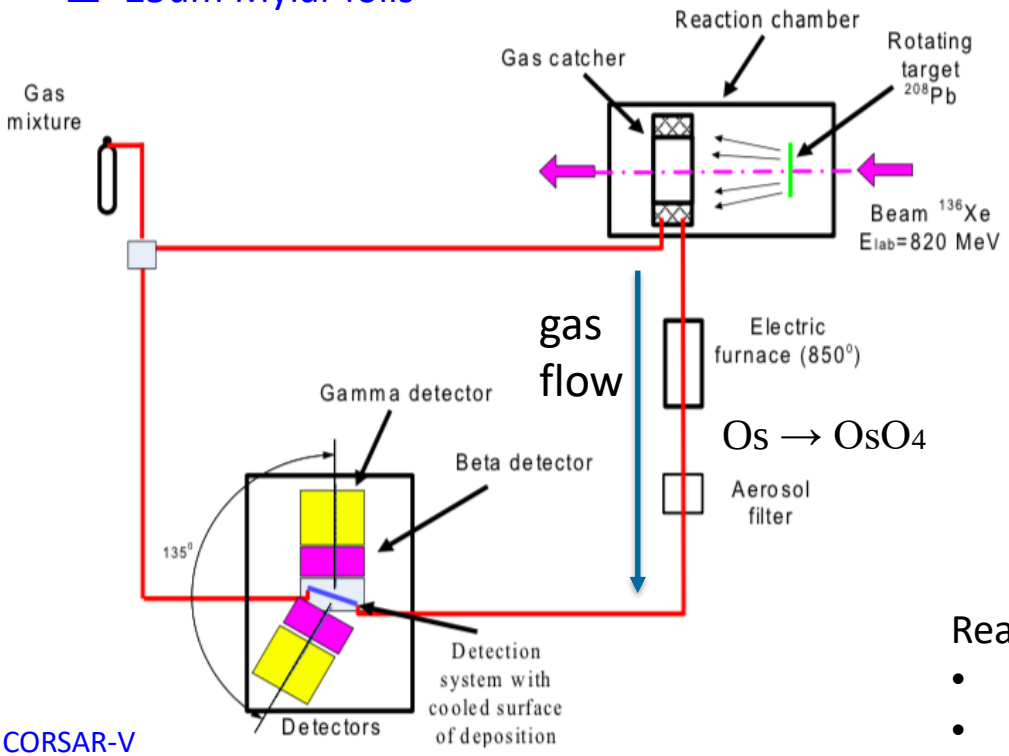
Ch. E. Dullmann et al., Nature 418 859(2002)

Technique	MNT products	Sensitivity
$B\rho$–ΔE–E	$Z = 6$–17	μb
TOF–ΔE–E	$Z = 20$–30	μb
$B\rho$ + decay tagging	$Z \leq 89$	μb
Chemical separation + decay tagging	$Z \leq 103$	20 nb
Velocity filter + decay tagging	$Z \leq 102$	1 nb

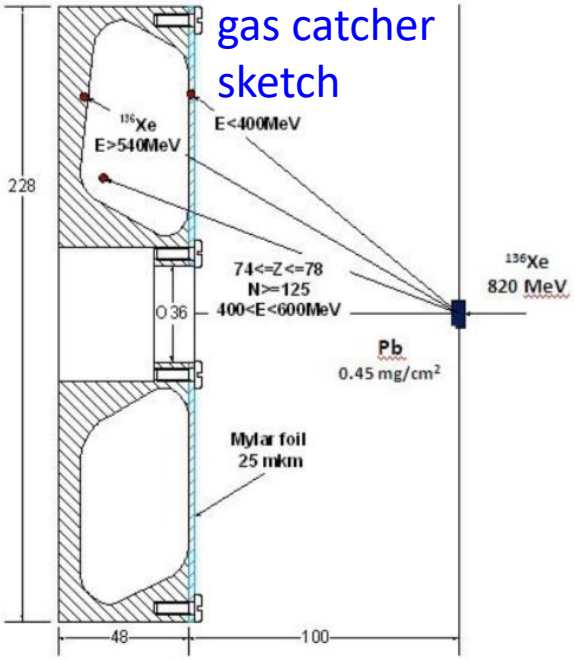
G. G. Adamian et al., Eur. Phys. J. A 56:47(2020).

Previous $^{136}Xe+^{208}Pb$ study using chemical separation methods

- $^{136}Xe+^{208}Pb$@Jyväskylä in 2012;
- proposed by E.M. Kozulin(JINR, Dubna);
- E_{lab}=820MeV;
- 80%He+20%O, 1.5atm, in Gas catcher
- 25um Mylar foils



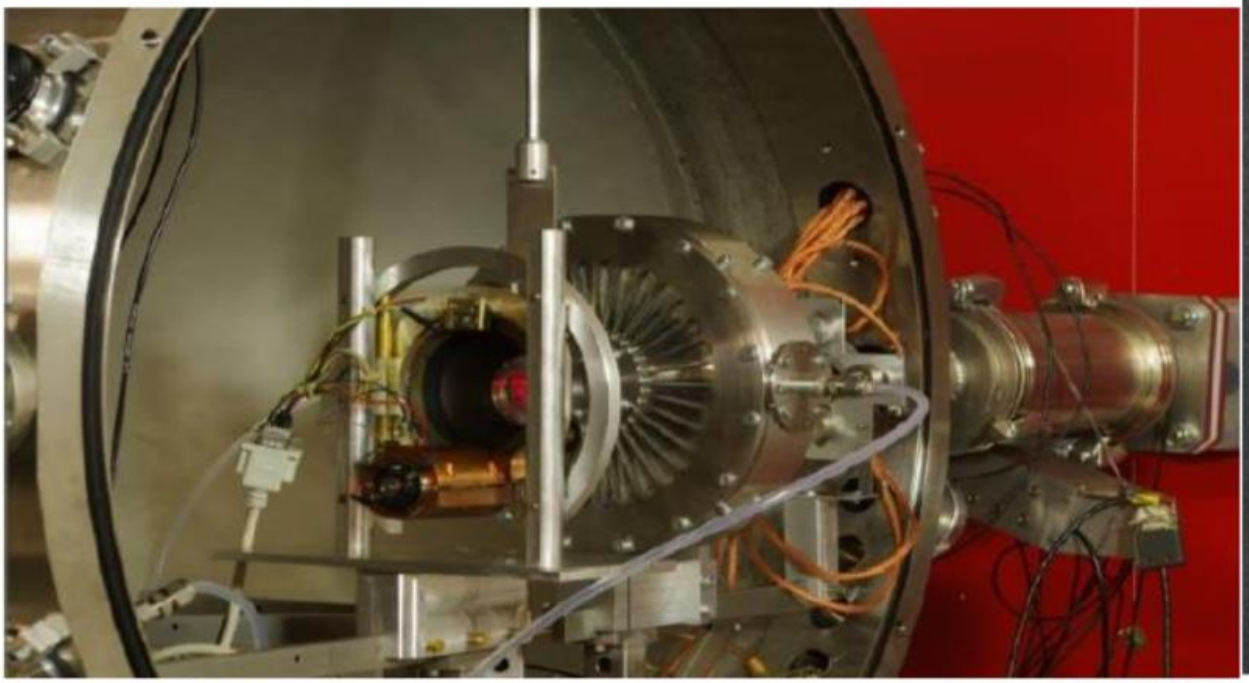
CORSAR-V
(correlation setup for the reaction products registration (volatile products))
Journal of Physics: Conference Series 515 (2014) 012016



Reaction products:

- E<400MeV: stopped in the Mylar;
- 400<E<600MeV, 74≤Z≤76: captured by the gas

Experimental setup

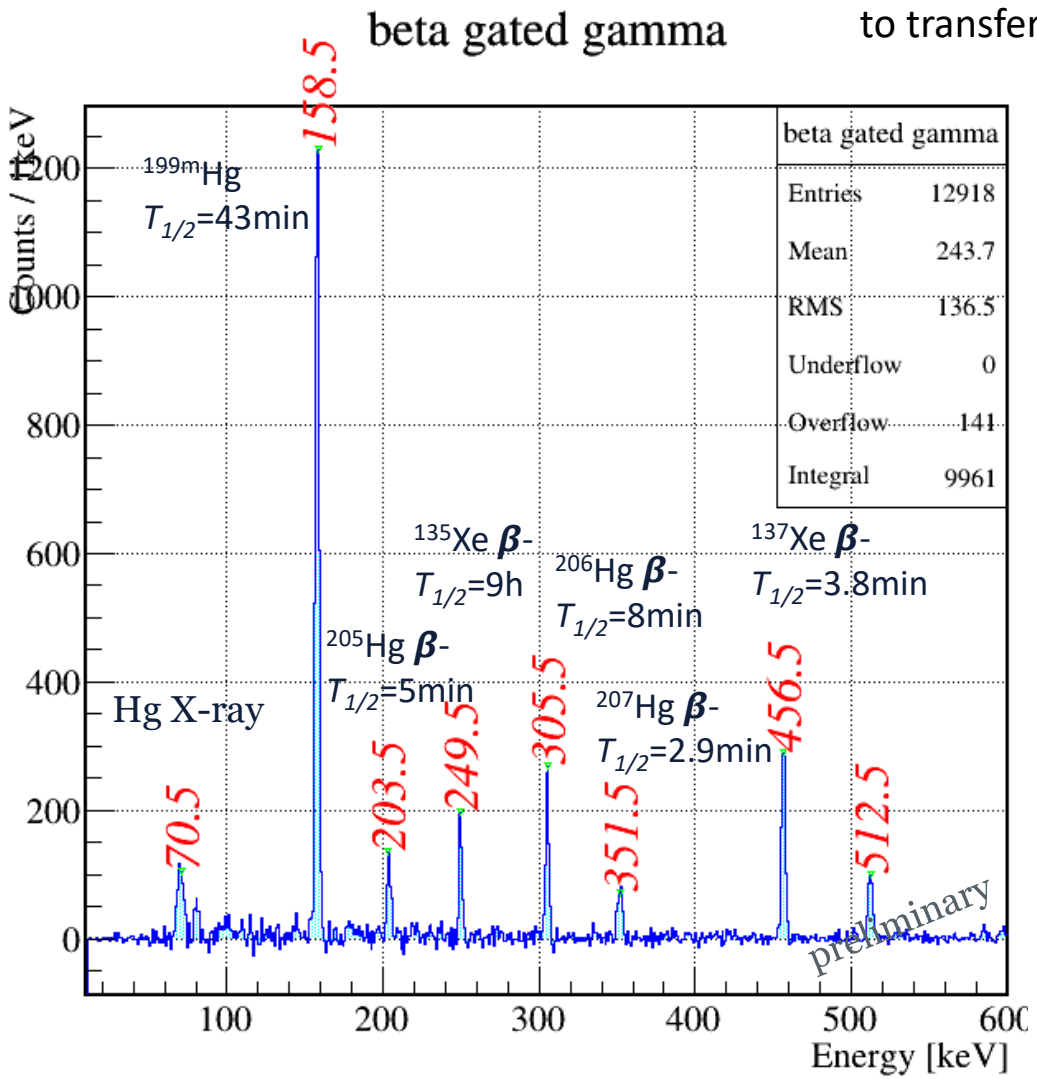


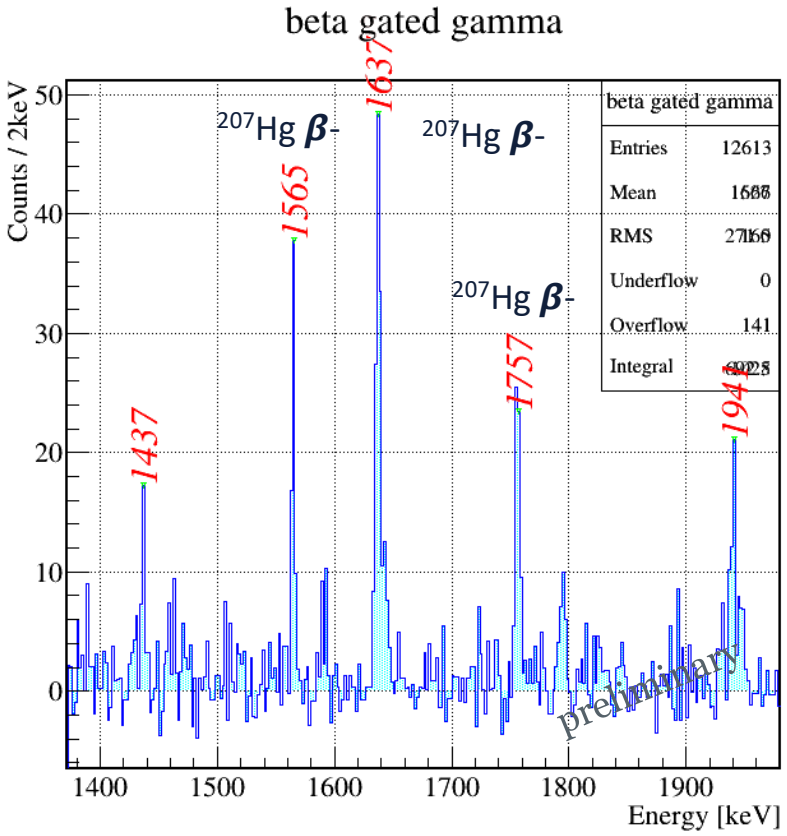
reaction chamber with a rotating ^{208}Pb target and gas catcher

liquid nitrogen cooled deposition chamber with Si beta detector installed

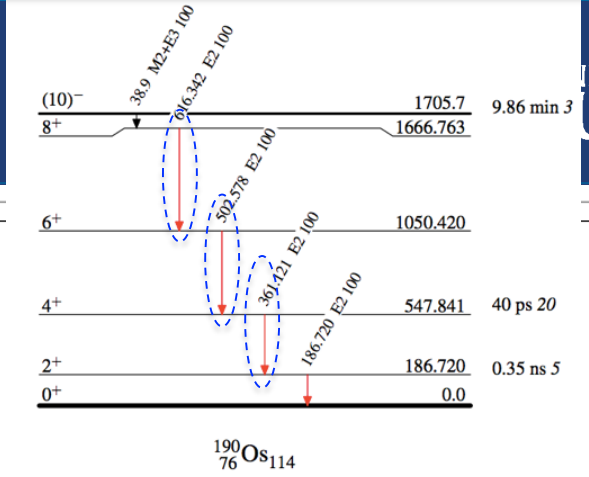
- beta-gated gamma spectra

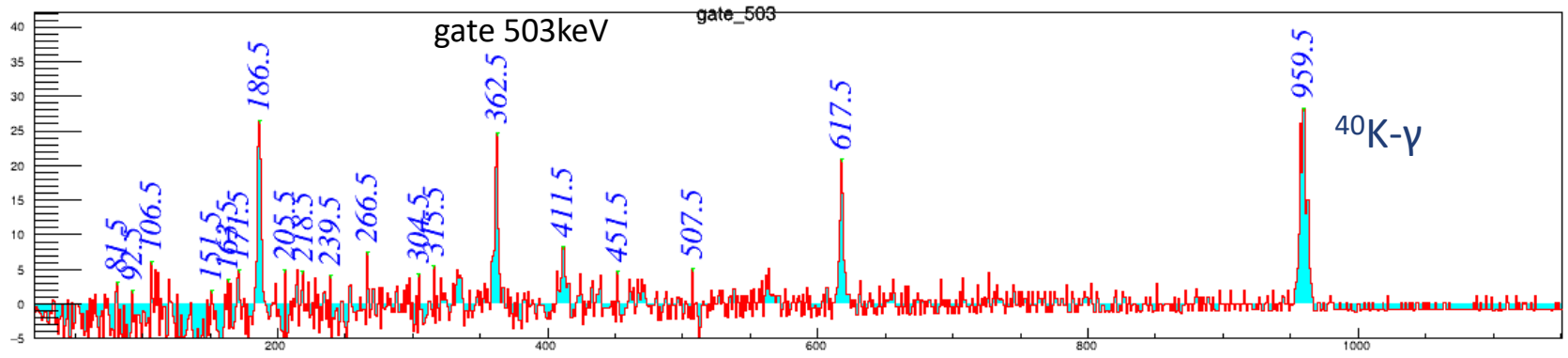
Many thanks for E.M. Kozulin and K. Novikov(JINR, Dubna) to transfer data to us

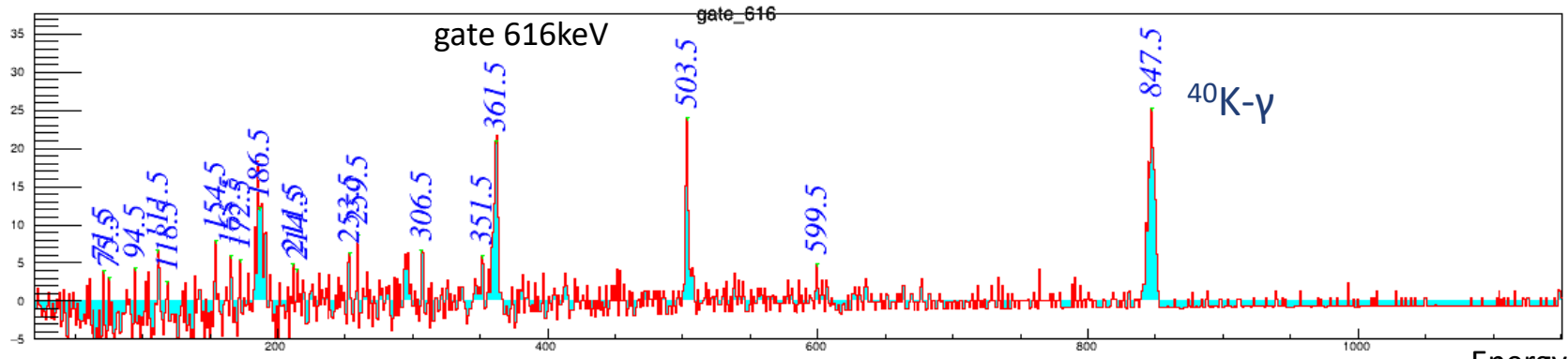




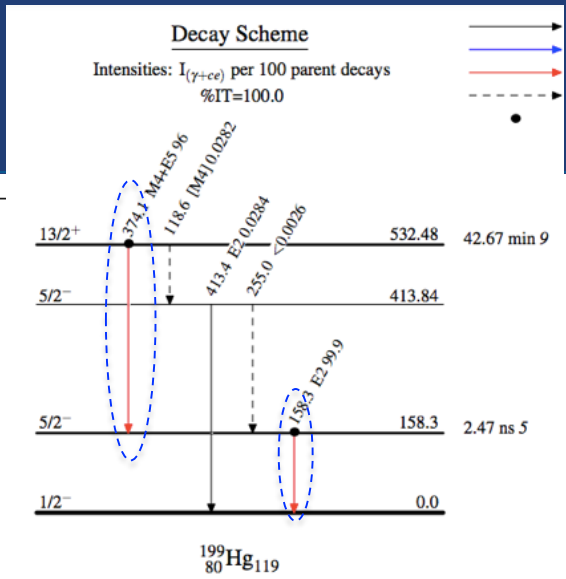
^{190m}Os(gamma-gamma coincidence)

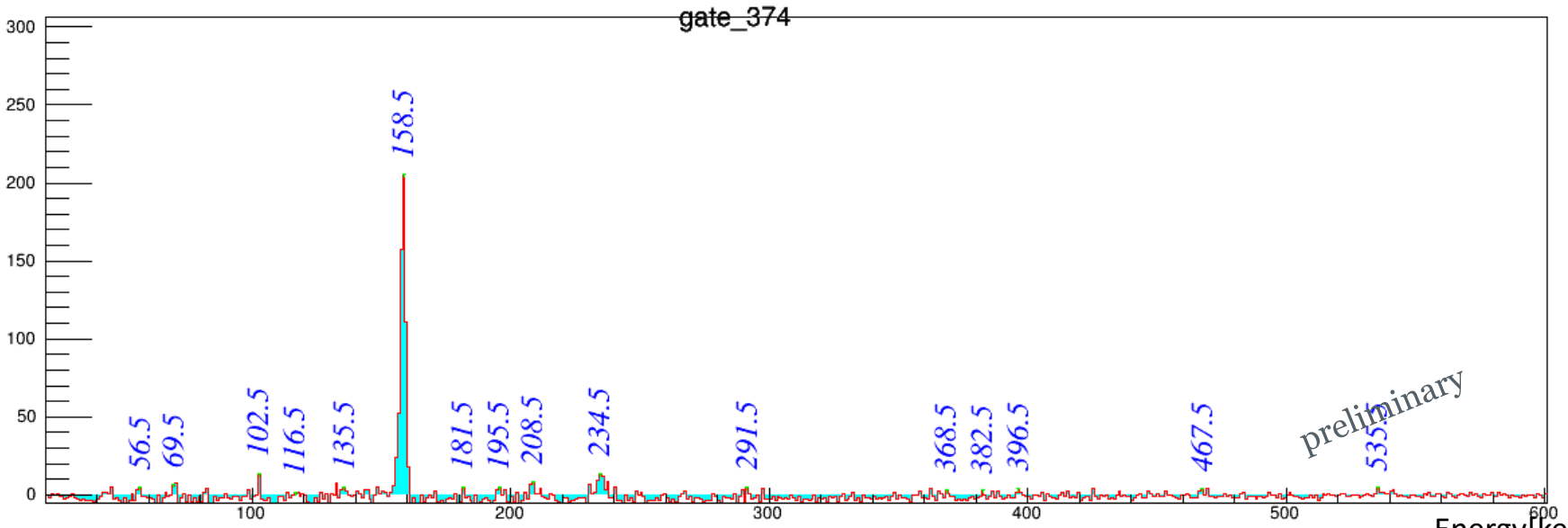






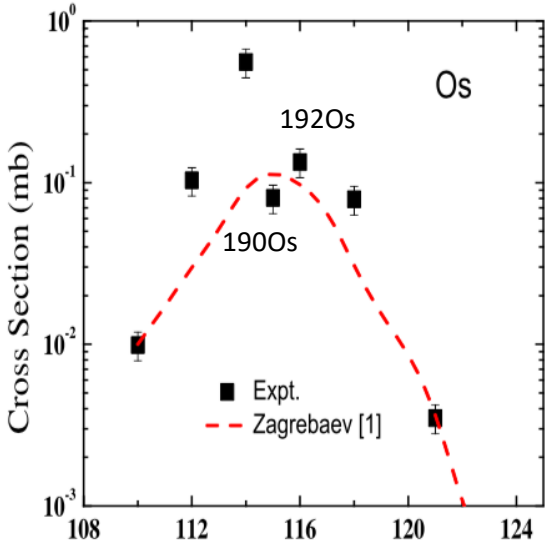
^{199m}Hg (gamma-gamma coincidence)



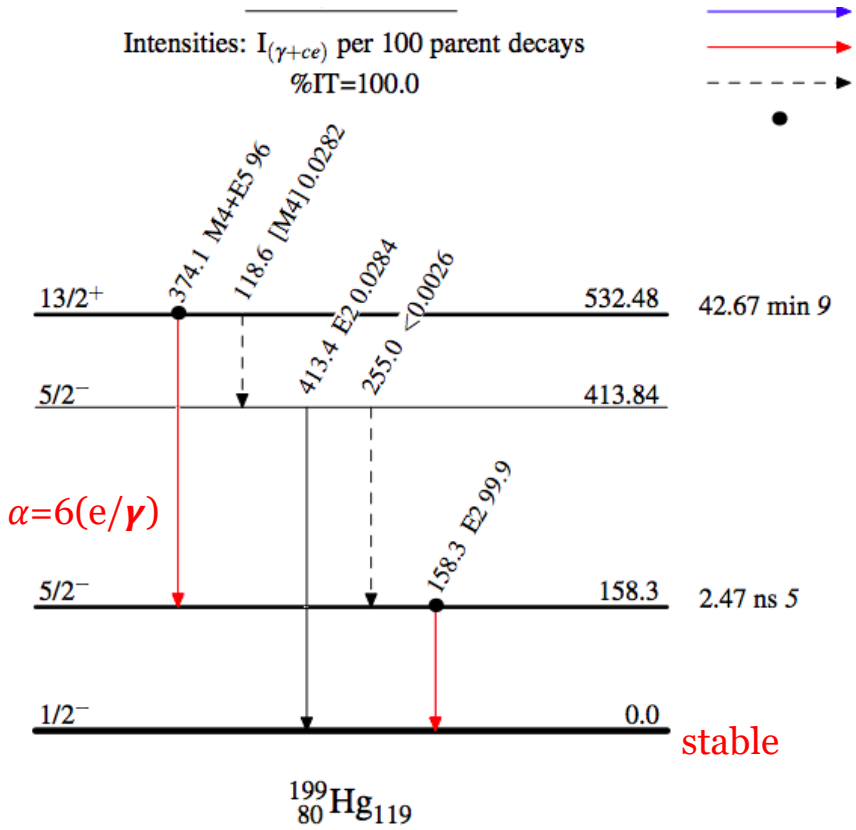


- From gamma-gamma coincidence:
- ^{190m}Os(10min) and ^{199m}Hg($T_{1/2}$=43min) were identified
- From beta-gamma coincidence:
- ^{199m}Hg($T_{1/2}$=43min), ^{205,206,207}Hg β-(<10min), ^{135,137}Xe β-(9h,3.8min) were identified
- ^{192m}Os(6s) not found
- Many Hg were also transported

^{136}Xe + ^{208}Pb

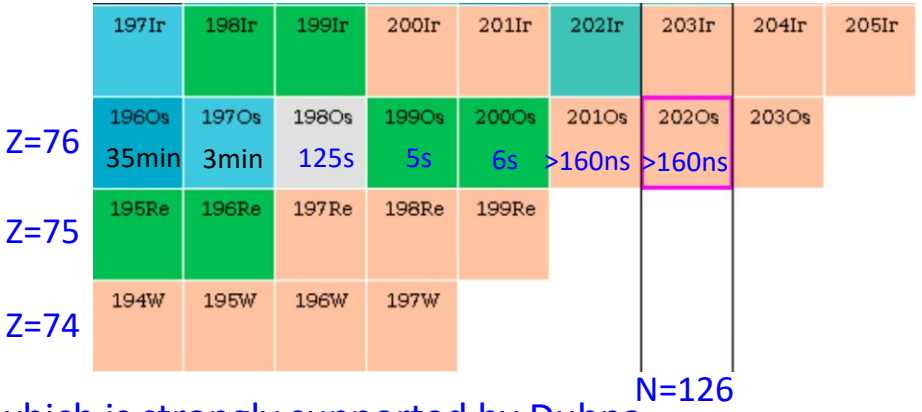


PRC 91, 064615(2015)



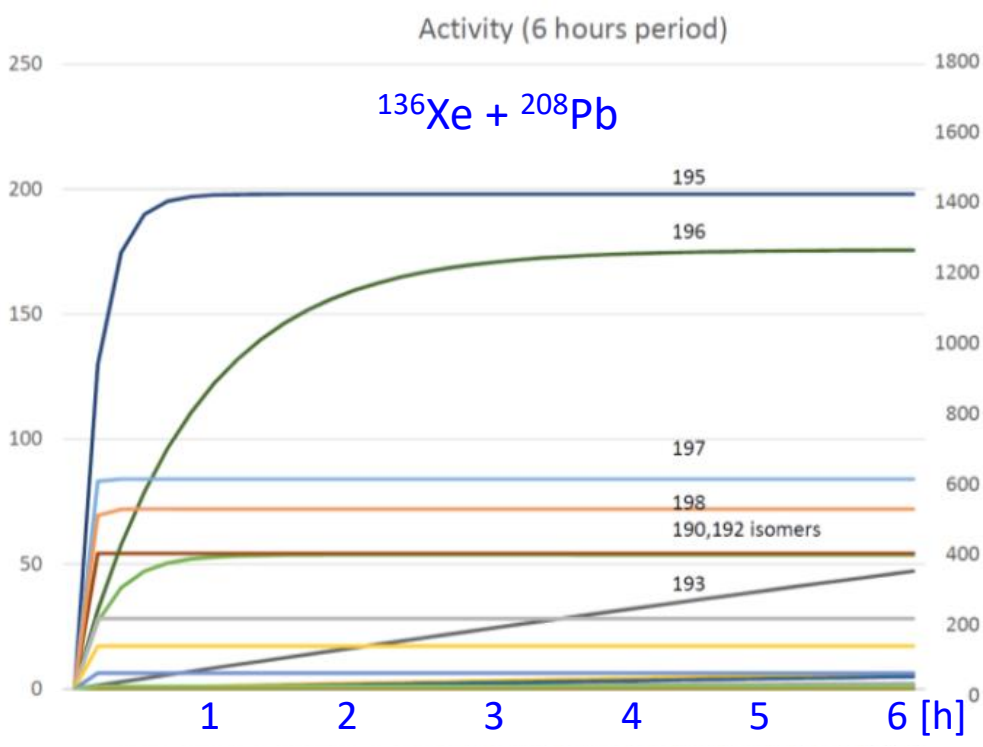
Proposal in Jyväskylä: test the chemical separation method

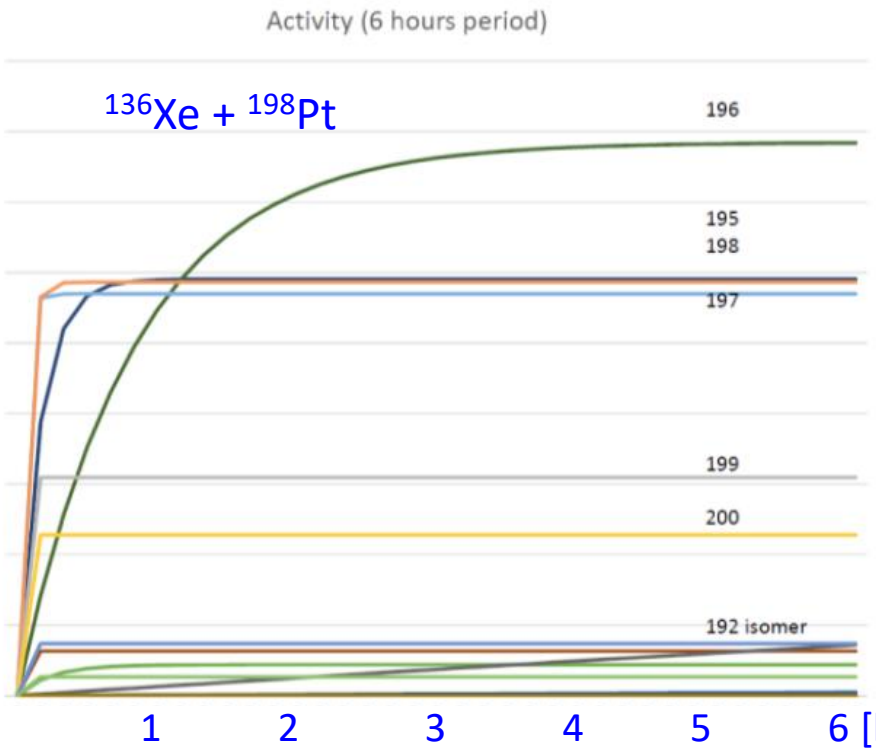
- Surrey + Dubna collaboration
- We've got 3 days of beam time from the PAC to test our setup using ^{136}Xe + ^{208}Pb / ^{198}Pt
  - speed of gas flow
  - efficiency of transport and adsorption
  - efficiency of separation on site at CORSAR;
  - efficiency of extraction for osmium isotopes
- upgrade the previous setup by
  - improving the adsorption of Hg(e.g. add Au foil), which is strongly supported by Dubna chemistry group;
  - reducing the transportation time(e.g. enlarge the speed of gas flow);
    minimum time ~1min in early experiment with radiochemical methods.
    G. G. Adamian et al., Eur. Phys. J. A 56:47(2020).
  - …
- If possible, extend to other elements such as rhenium(Z=75) and tungsten(Z=74)



Predicted activity of Os isotopes in the first 6 hours

- In the calculation
- beam intensity: 100pnA
- transmission efficiency: 50%
- cross-section calculation: θ=31-65deg, kinetic energy 400-600MeV

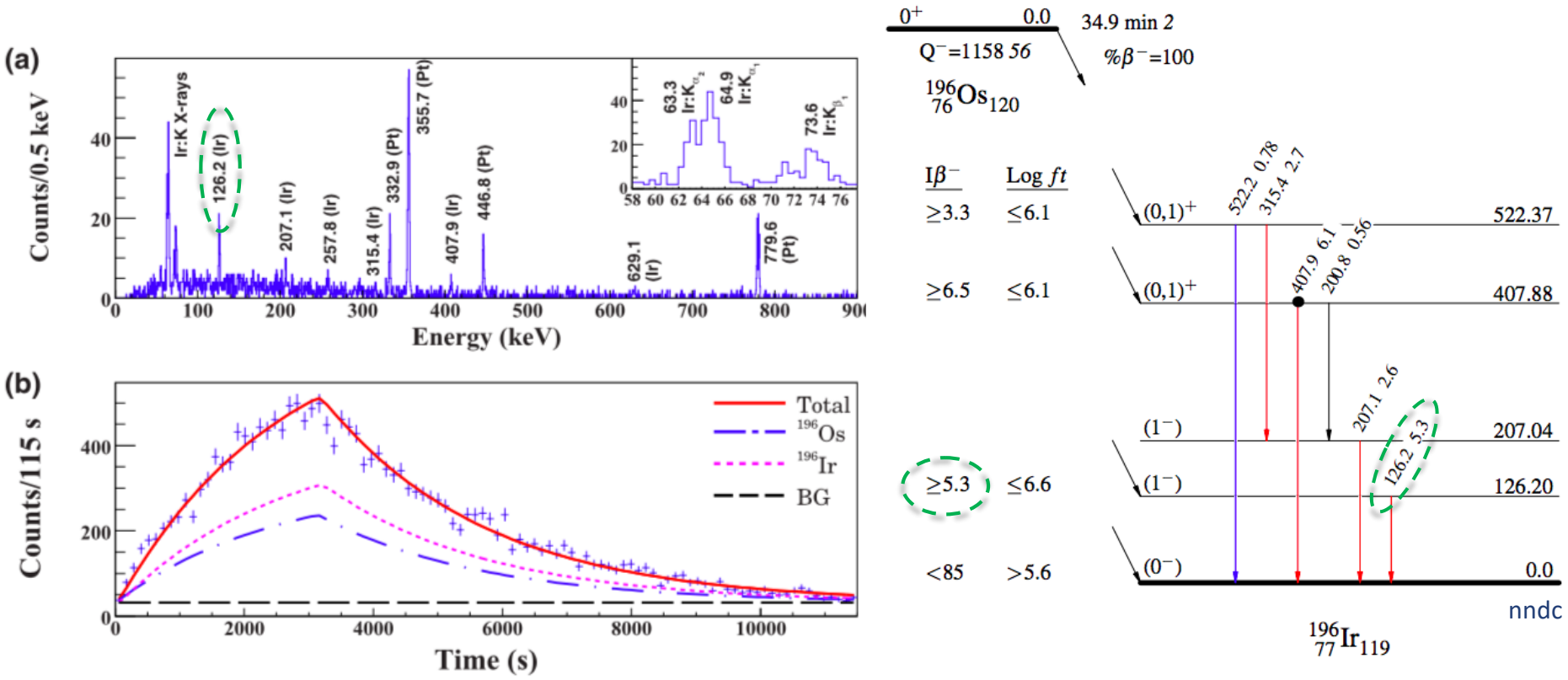




- highest activity: ^{195,196}Os.
- decay scheme of ^{196}Os is already known.

cross-section calculation from A. Karpov

Recent study of ^{196}Os decay



Y. Hirayama et al., PRC 98, 014321(2018).

- ^{136}Xe + ^{198}Pt, KISS project @ RIKEN
- beta decay of ^{196}Os will be used to check our setup

Summary

- Importance of study on r-process and N=126;
- Several methods to isolate the nuclei of interest;
- Chemical separation method;
- high efficiency and sensitivity
- Proposal in Jyväskylä

- What can we do in GSI:
- high intensity low-energy beam line is nice for MNT study with chemical separation method

Acknowledgement

N. Aksenov, Yu.V. Albin, A.Bogachev, G.A. Bozhikov, L. Canete, W. Catford, D. Doherty, T. Eronen, P. Greenlees, N.S. Gustova, J. Henderson, P. Ivanov, A. Kankainen, A. Karpov, S. Khlebnikov, G. Knyazheva, E.M. Kozulin, G. Lotay, A.S. Madumarov, I. Moore, K. Novikov, T.Parry, I.Pchelintsev, Zs. Podolyák, P.H. Regan, V.V. Saiko, J. Saren, W. Trzaska, I. Vorobev

Many thanks to E.M. Kozulin and K. Novikov(JINR, Dubna):

- transferring previous $^{136}Xe+^{208}Pb$ data to us;
- discussing about the data.

Many thanks to J. Saren and P. Greenlees(Jyväskylä) for the help during data analysis.


Thank you for your attention!