Nuclear reaction study for high-level radioactive waste:

Cross section measurements for proton- and deuteron-induced spallation reactions of long-lived fission products

He Wang

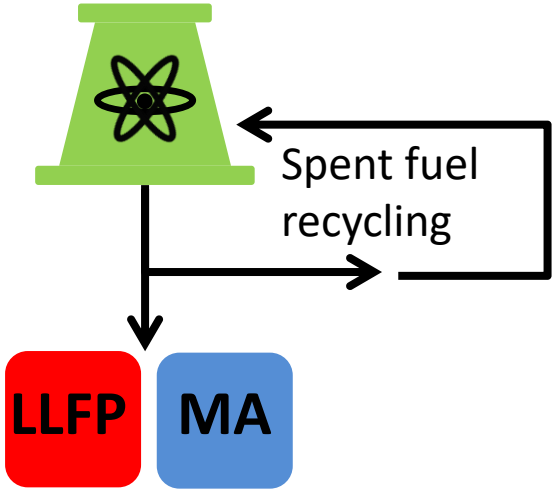
RIKEN Nishina Center

15th Varenna conference on NRM, Varenna, Italy, June 11 - 15, 2018

Content

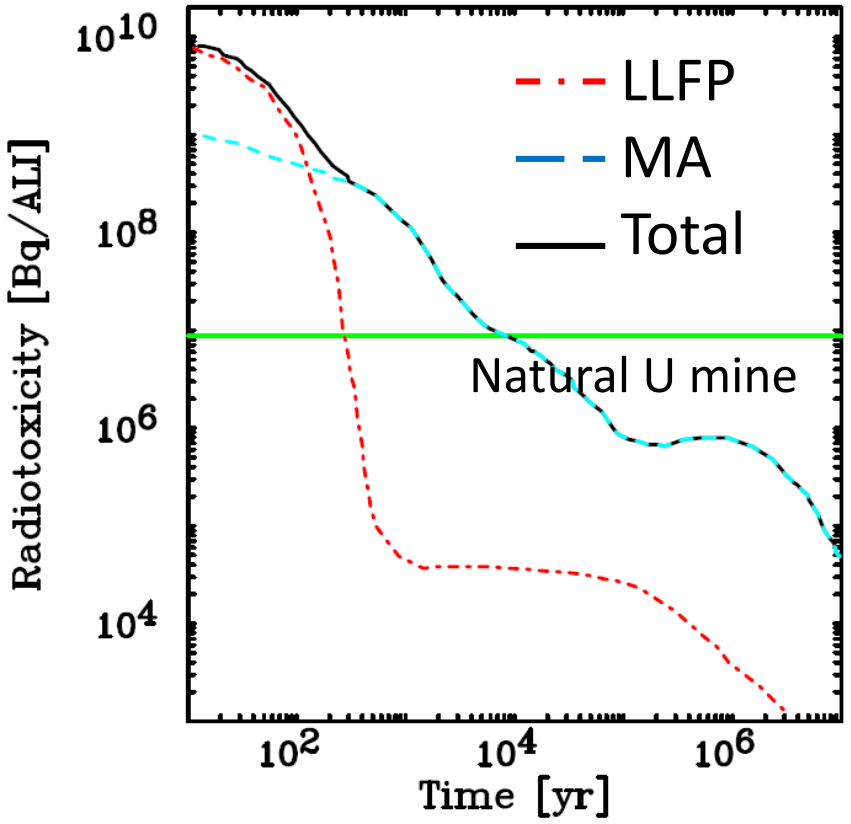
- Motivation
- Experiment details
- Results and discussion on ^{137}Cs, ^{90}Sr, ^{107}Pd
- Summary

Motivation



High-level radioactive waste

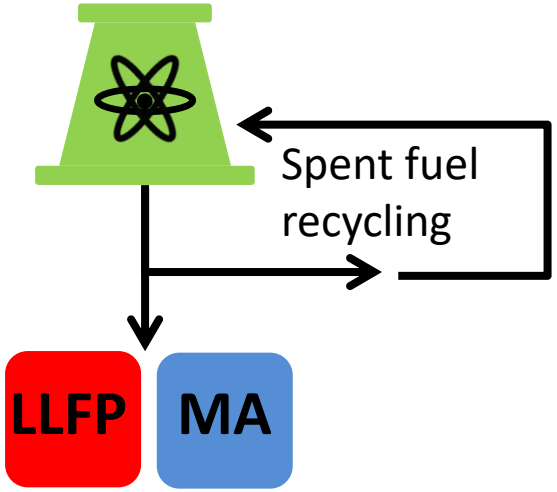
- Long-lived fission products
  e.g. ^{137}Cs, ^{90}Sr, ^{107}Pd, ^{93}Zr…
- Minor Actinide
  e.g. $^{241,243}Am$, ^{237}Np…



In Japan, ~800t U / year (~75% of 50 LWR)

1t MA and 39t LLFP in spent fuel

Further Reprocessing on LLFP nuclei



How about accelerator system to reduce radioactivity of LLFP?

Lack of nuclear reaction data for LLFP (so far, n-capture only)

- MA (Np, Am) 1t → ADS, FBR
- Platinum (Pt, Rh, Pd) 4t → re-used, except for ^{107}Pd (6.5×10^{6}y)
- Heat generator (Cs, Sr) 5t → Disposal, FBR
- Other FP 30t → Disposal, FBR

Ref: Lecture by Dr. Oigawa, CNS summer school, 2015

A challenge at RIKEN

Year	Energy [MeV/u]	LLFP	Purpose
2014	190	^{137}Cs/^{136}Xe, ^{90}Sr	Spallation
2015	100/200	^{107}Pd, ^{93}Zr, ^{90}Sr, ^{135}Cs	Spallation/Coulomb breakup
		^{93,94}Zr, ^{79,80}Se	Spallation/Exclusive cross section
2016	50	^{107}Pd,^{93}Zr	Spallation
	100/200	^{126,127}Sn	Spallation/Coulomb breakup
2017	30	^{107}Pd,^{93}Zr,^{79}Se	Low energy

- Half-life distributions of fragments from production cross section
- RIBF provides a unique opportunity to get reaction data

Nuclear Reaction study on LLFP at Varenna

- ^{137}Cs, ^{90}Sr
  First targets for study spallation
- ^{107}Pd
  Recovery of palladium metal

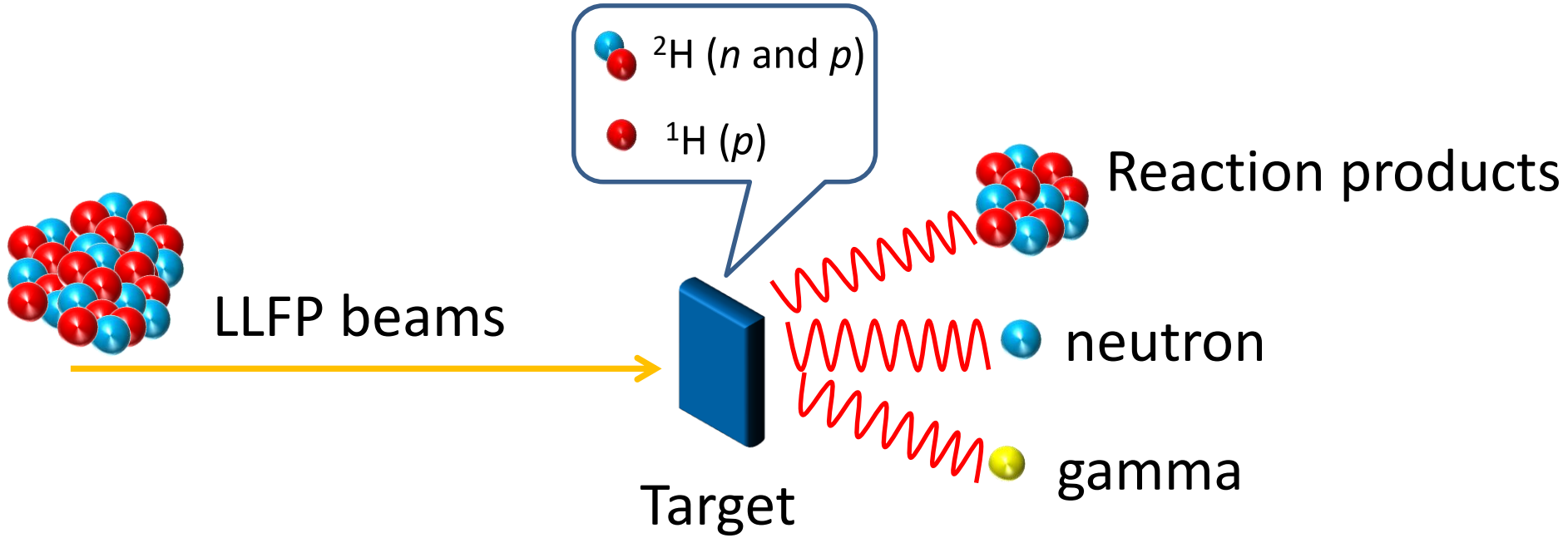
Nuclide	Half-life [year]	(*n*, *γ*) [b]
^{137}Cs	30.1	0.27
^{90}Sr	28.8	0.01
^{107}Pd	6.5×10^6	9.2

- ^{93}Zr by Y. Watanabe on June 15th
- ^{136}Xe by X.H. Sun on June 15th

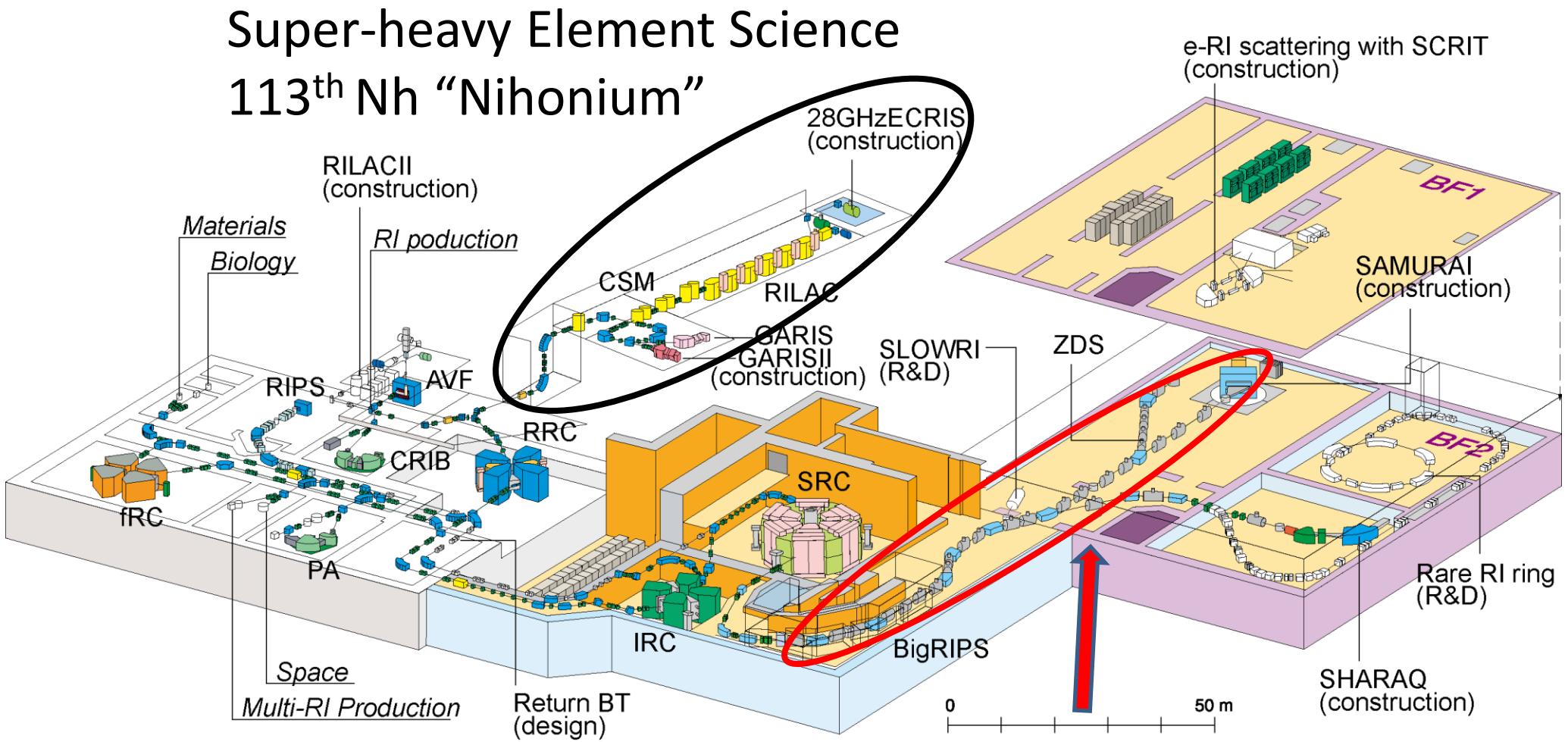
Nuclear Reaction Study via Inverse Kinematics Method

Inverse kinematics

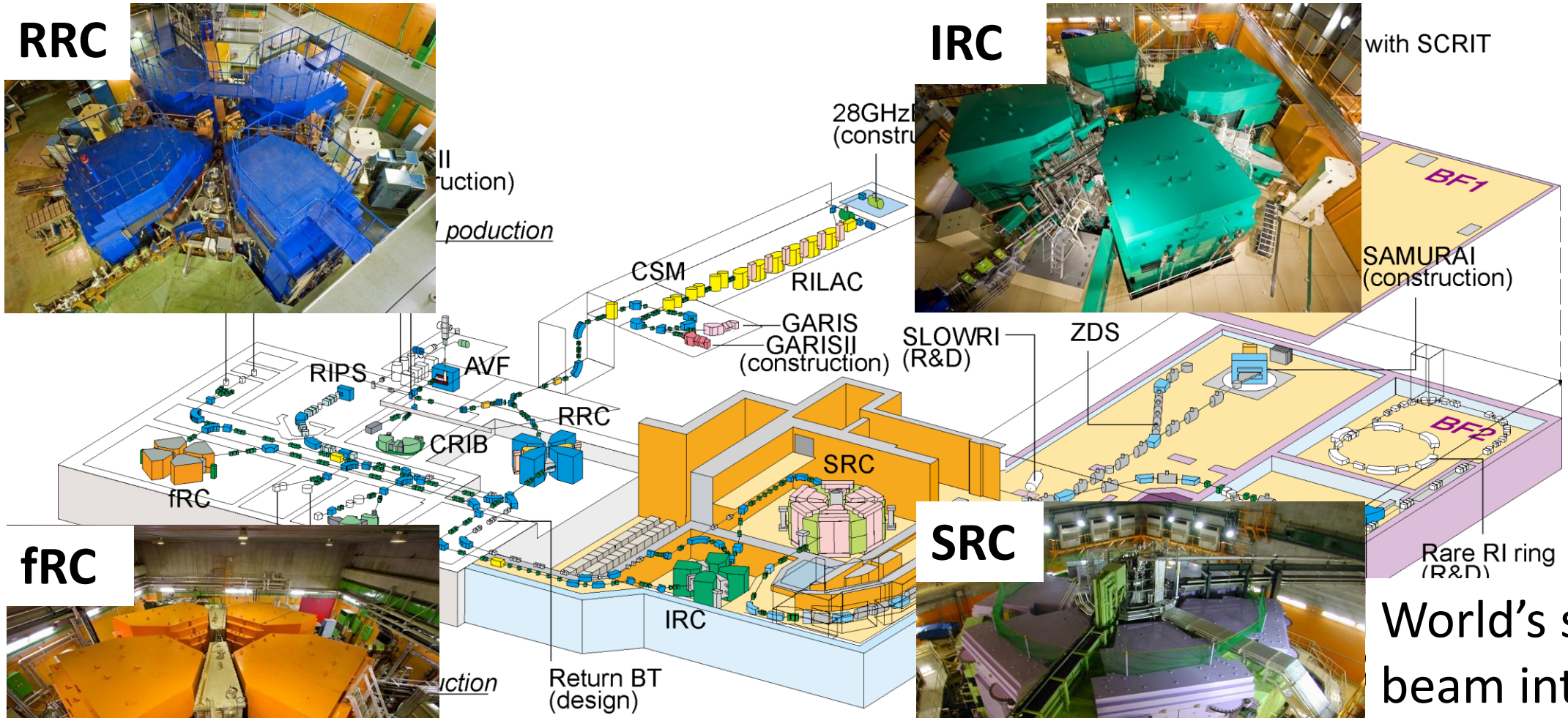
- Proton and deuteron target
- Energy dependence



RI Beam Factory



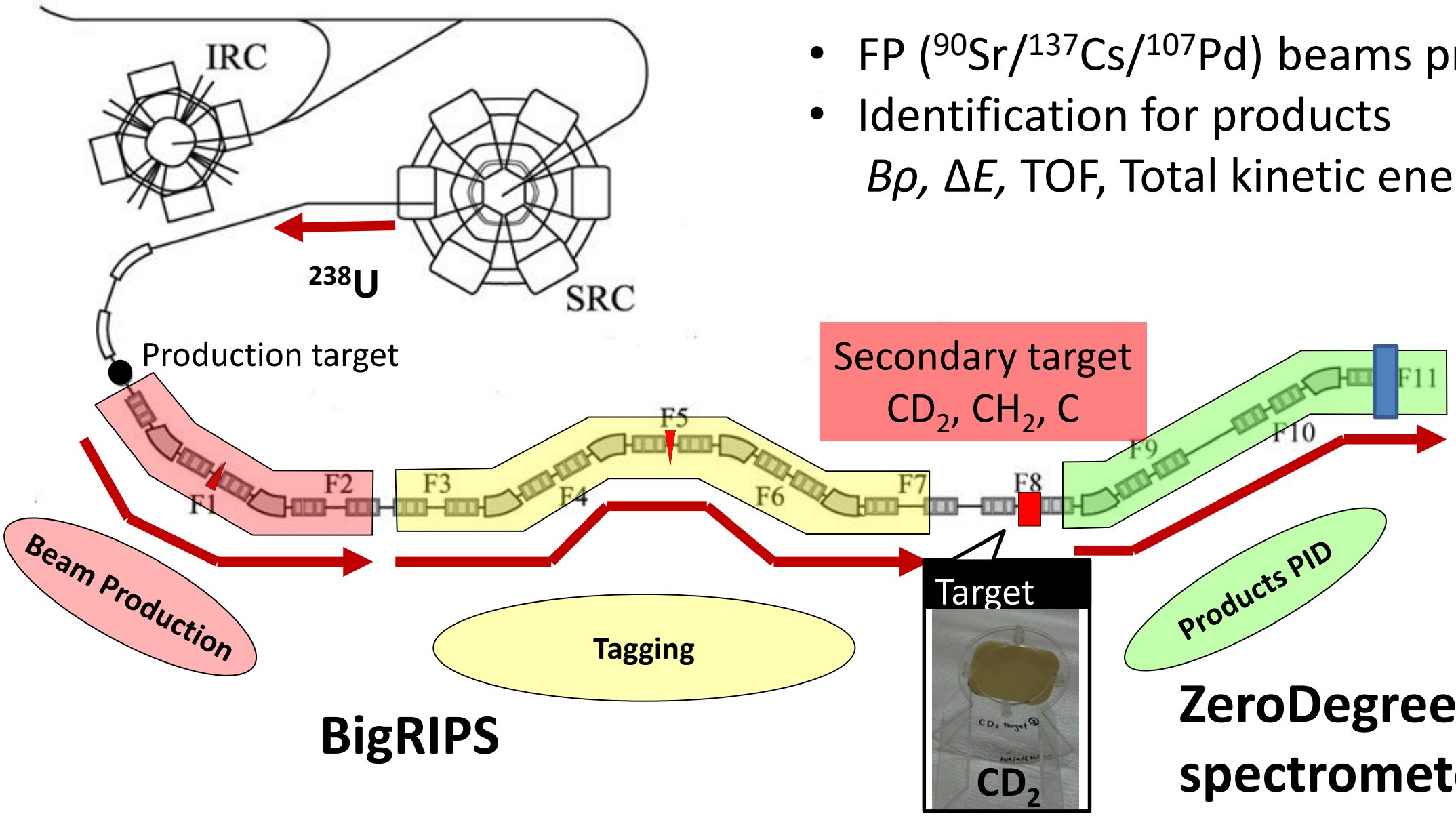
RI Beam Factory



World's strongest beam intensity

Experimental setup

- FP (^{90}Sr/^{137}Cs/^{107}Pd) beams production
- Identification for products
  Bρ, Δ*E*, TOF, Total kinetic energy



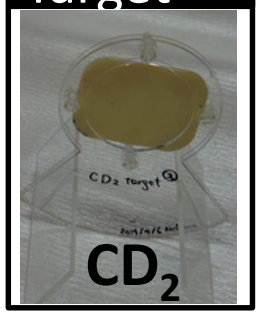
Secondary target
CD_2, CH_2, C

F1 F2 F3 F4 F5 F6 F7 F8 F9 F10 F11

Beam Production

Tagging

Target

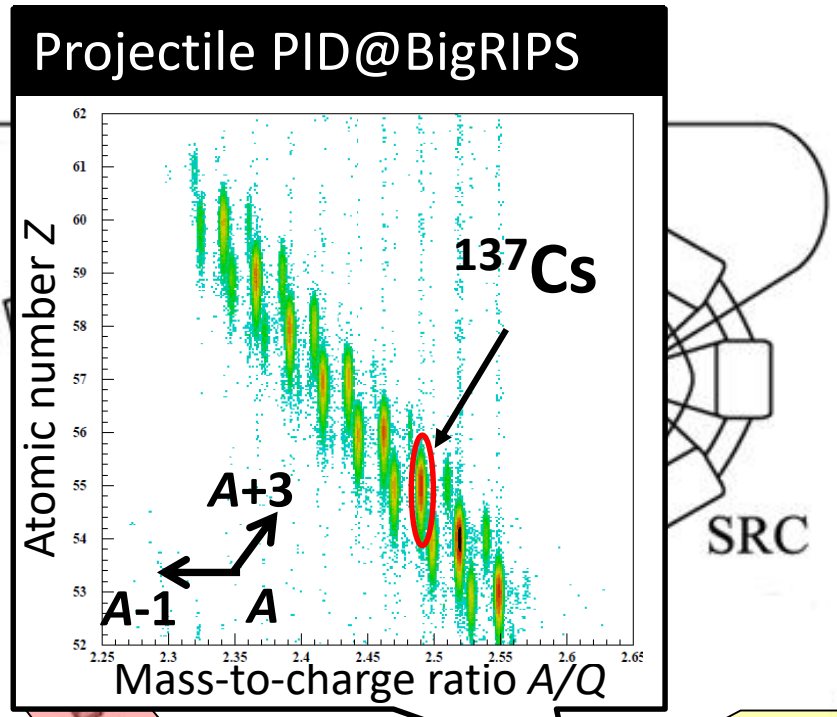


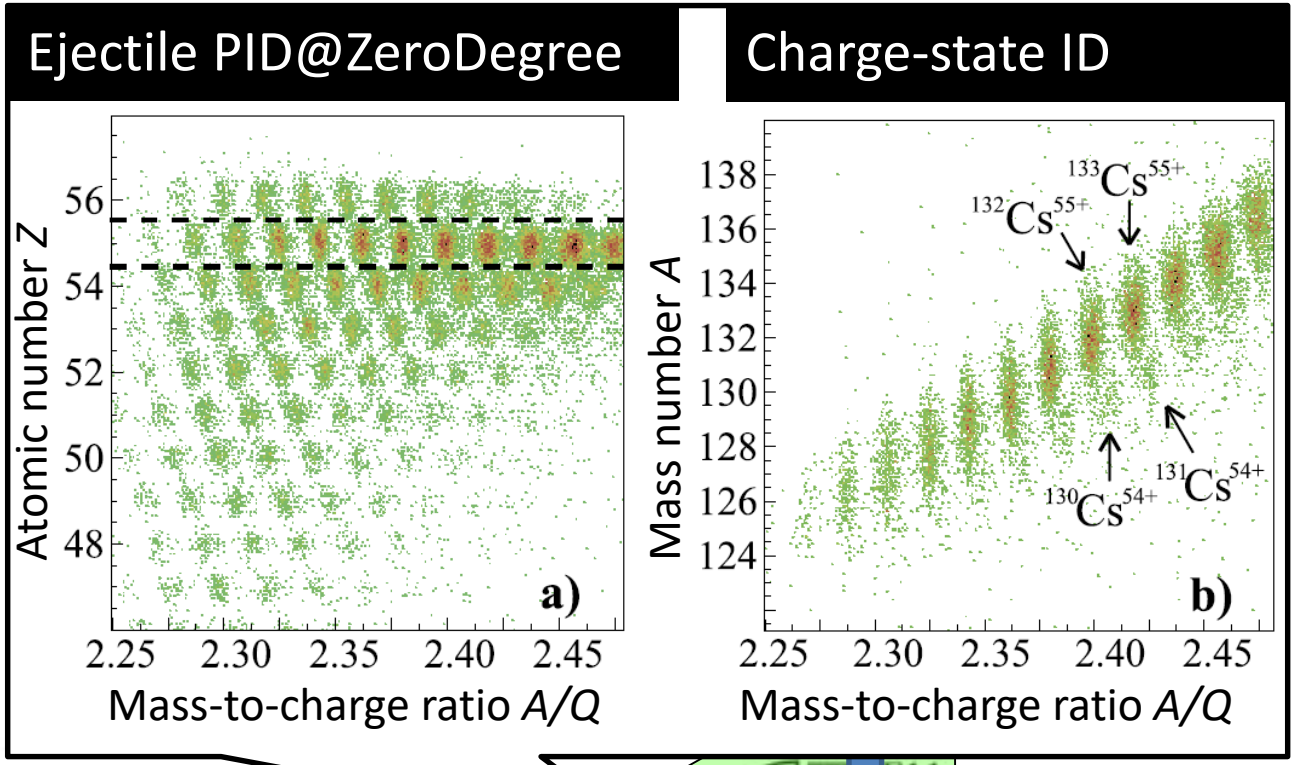
Products PID

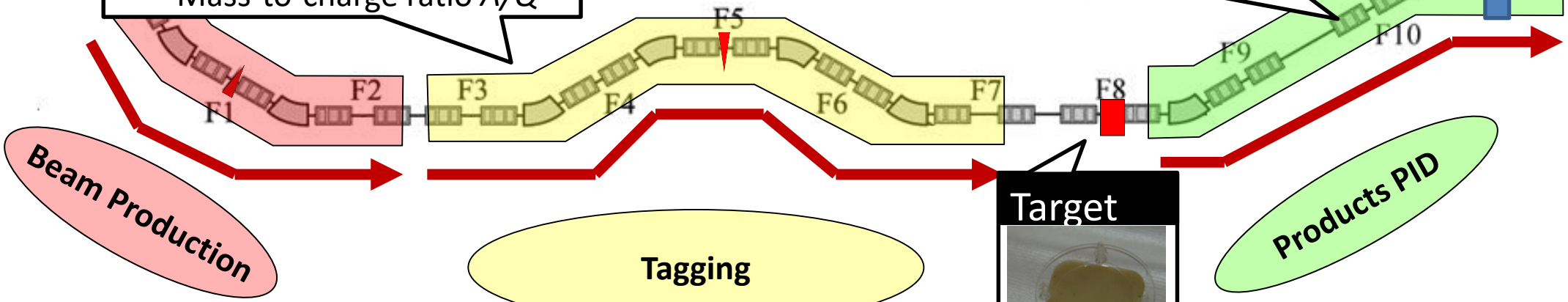
BigRIPS

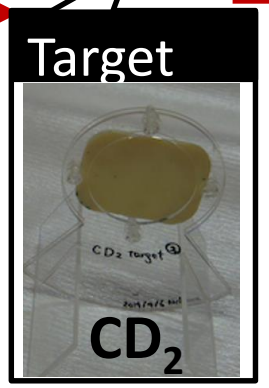
ZeroDegree spectrometer

The first challenge: ^{137}Cs





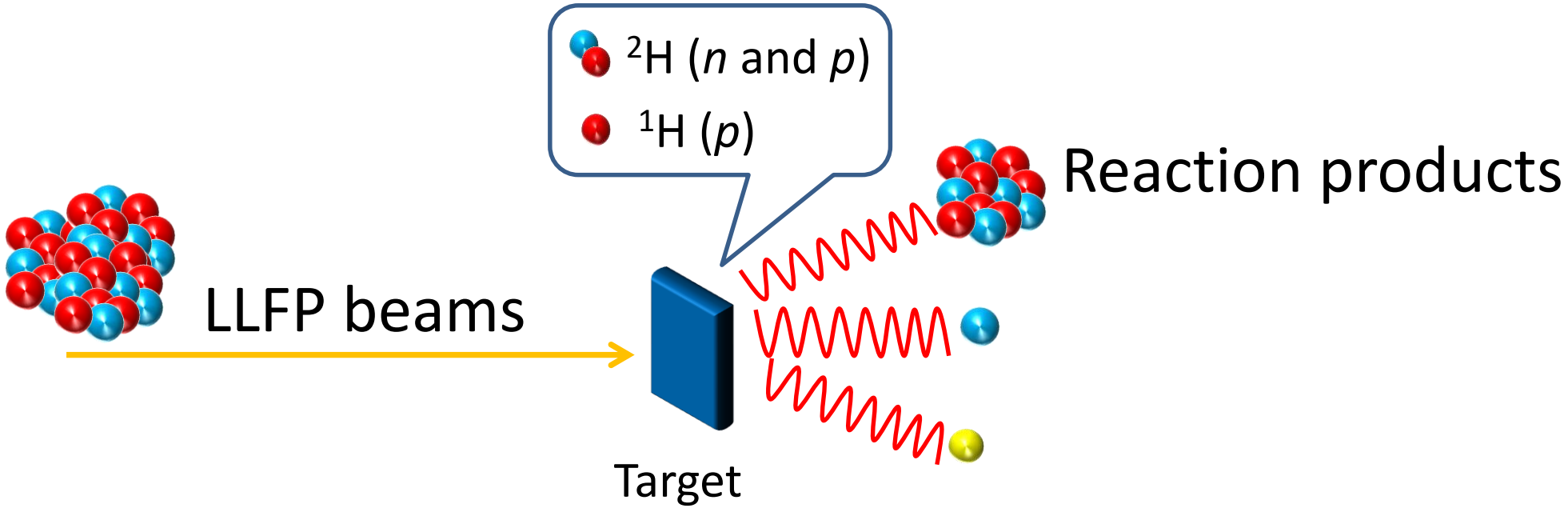




BigRIPS

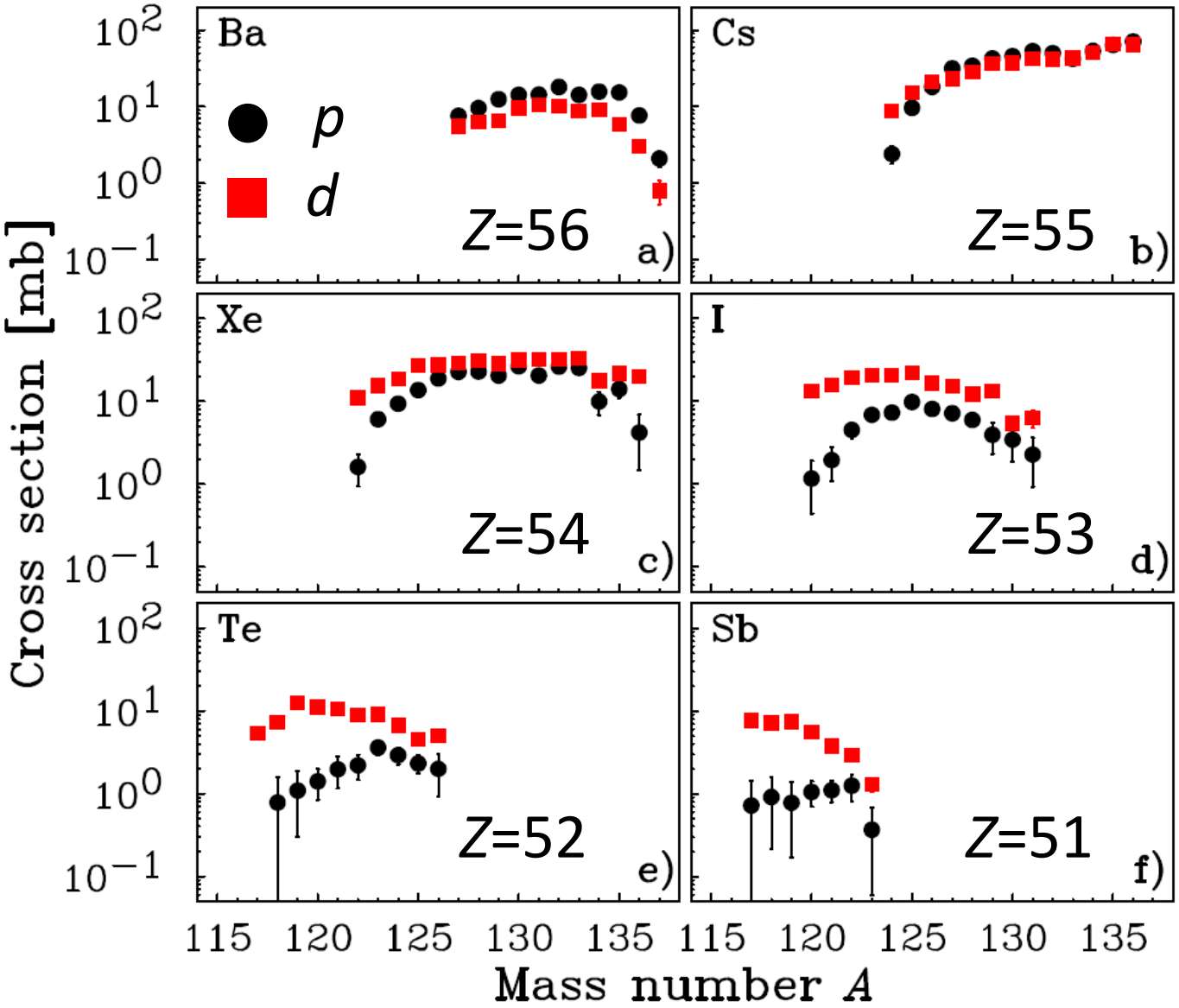
ZeroDegree spectrometer

Isotopic distribution cross section



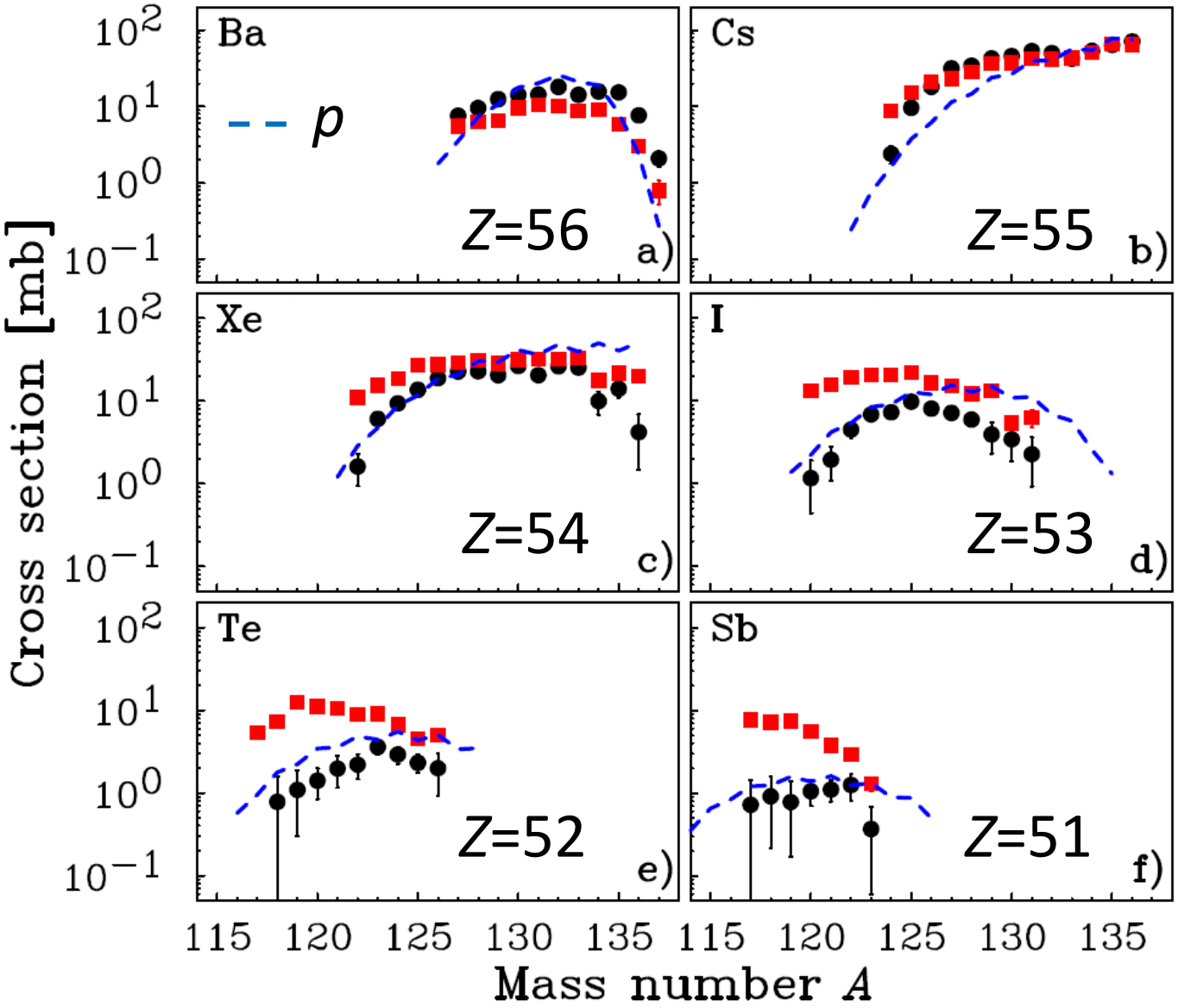
$$\sigma = \frac{N_{products}}{N_{beam} \times n_{target}}$$

Products from ^{137}Cs



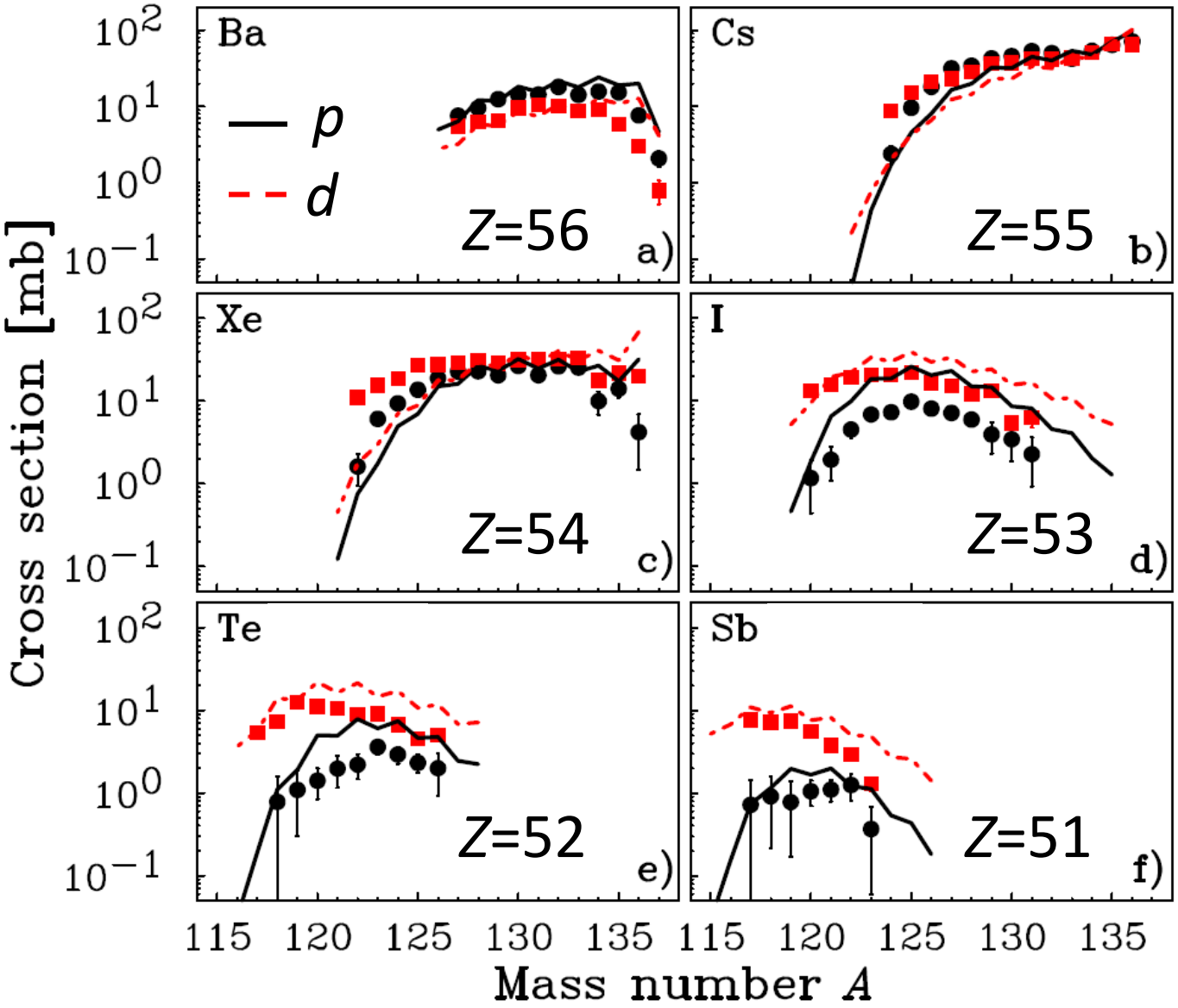
HW, H. Otsu, H. Sakurai et al., Phys. Lett. B, 754, 104(2016).

SPACS



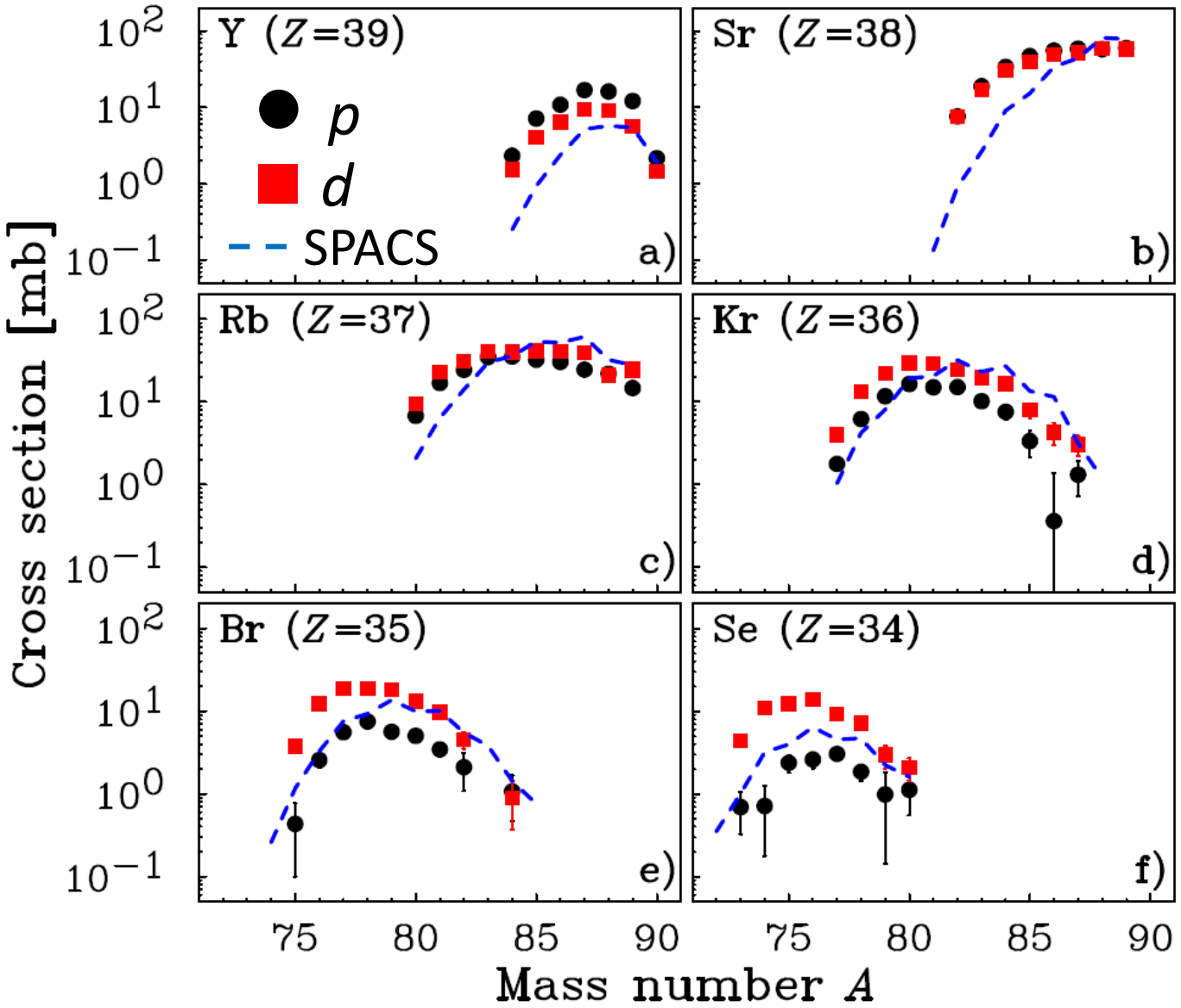
C. Schmitt, K.-H. Schmidt, and A. Kelic-Heil, Phys. Rev. C **90**, 064605 (2014)

Intra-nucleon cascade and evaporation by PHITS



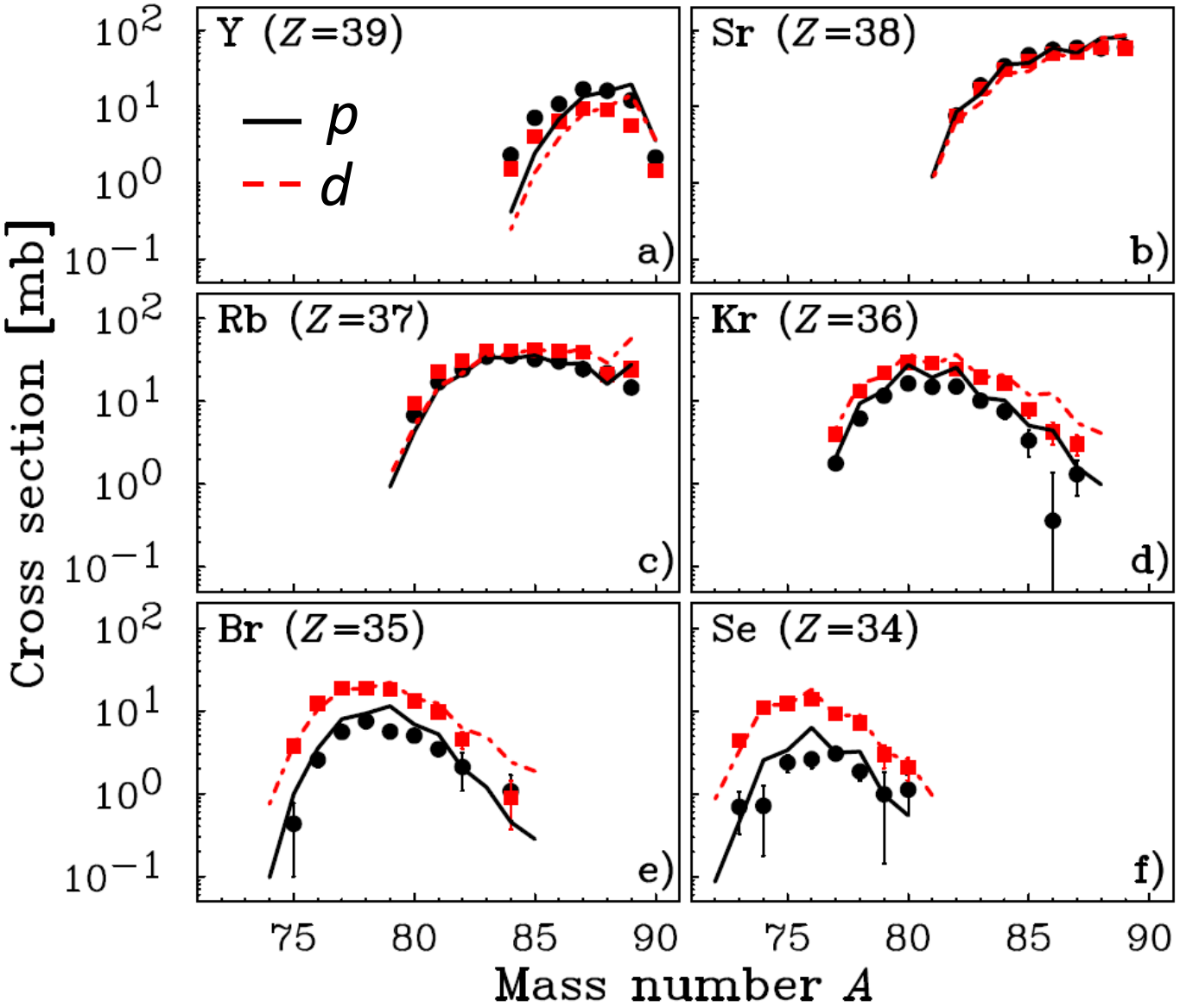
INCL4.6: Boudard et al., Phys. Rev. C 87 (2013) 014606. GEM: Furihata, NIM B 171 (2000) 251.

Products from ^{90}Sr



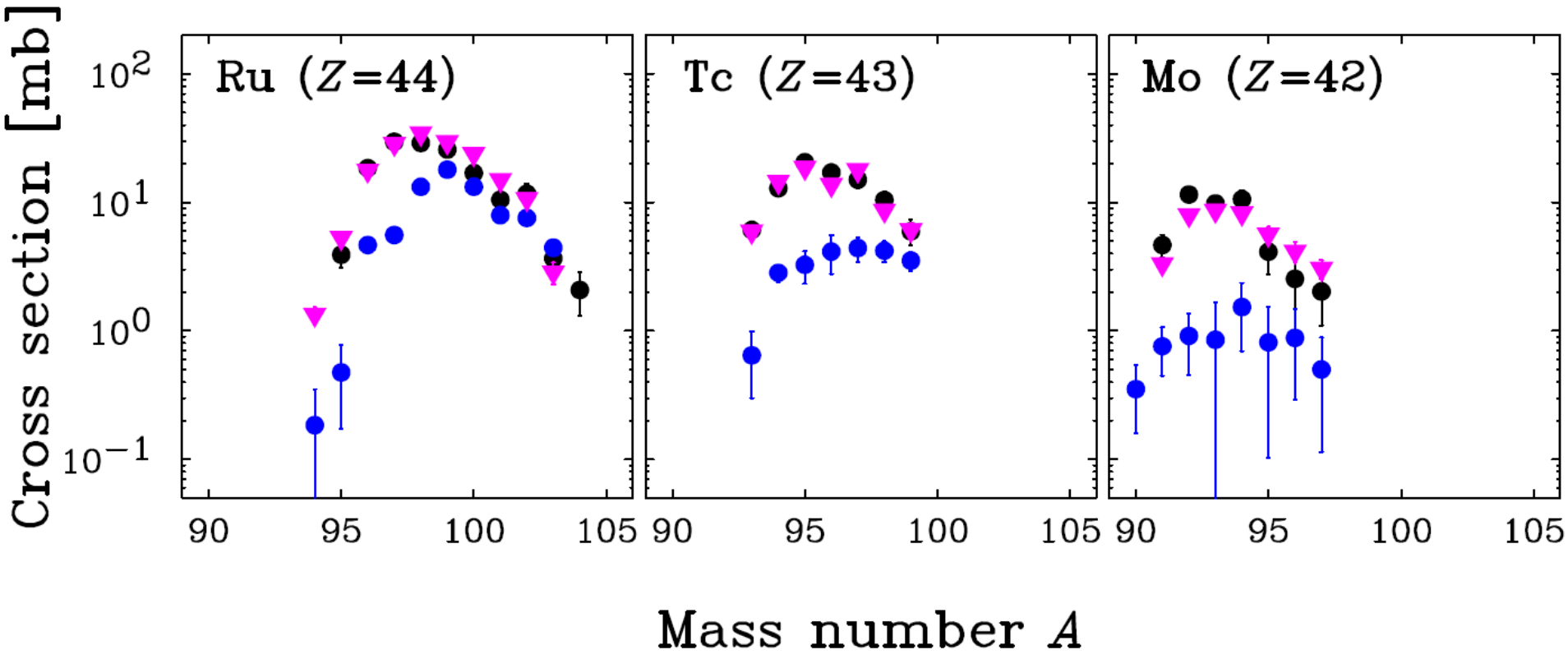
HW, H. Otsu, H. Sakurai et al., Phys. Lett. B, 754, 104(2016).

Comparison with PHITS



HW, H. Otsu, H. Sakurai et al., Phys. Lett. B, 754, 104(2016).

Energy dependence for light-mass ions (^{107}Pd)

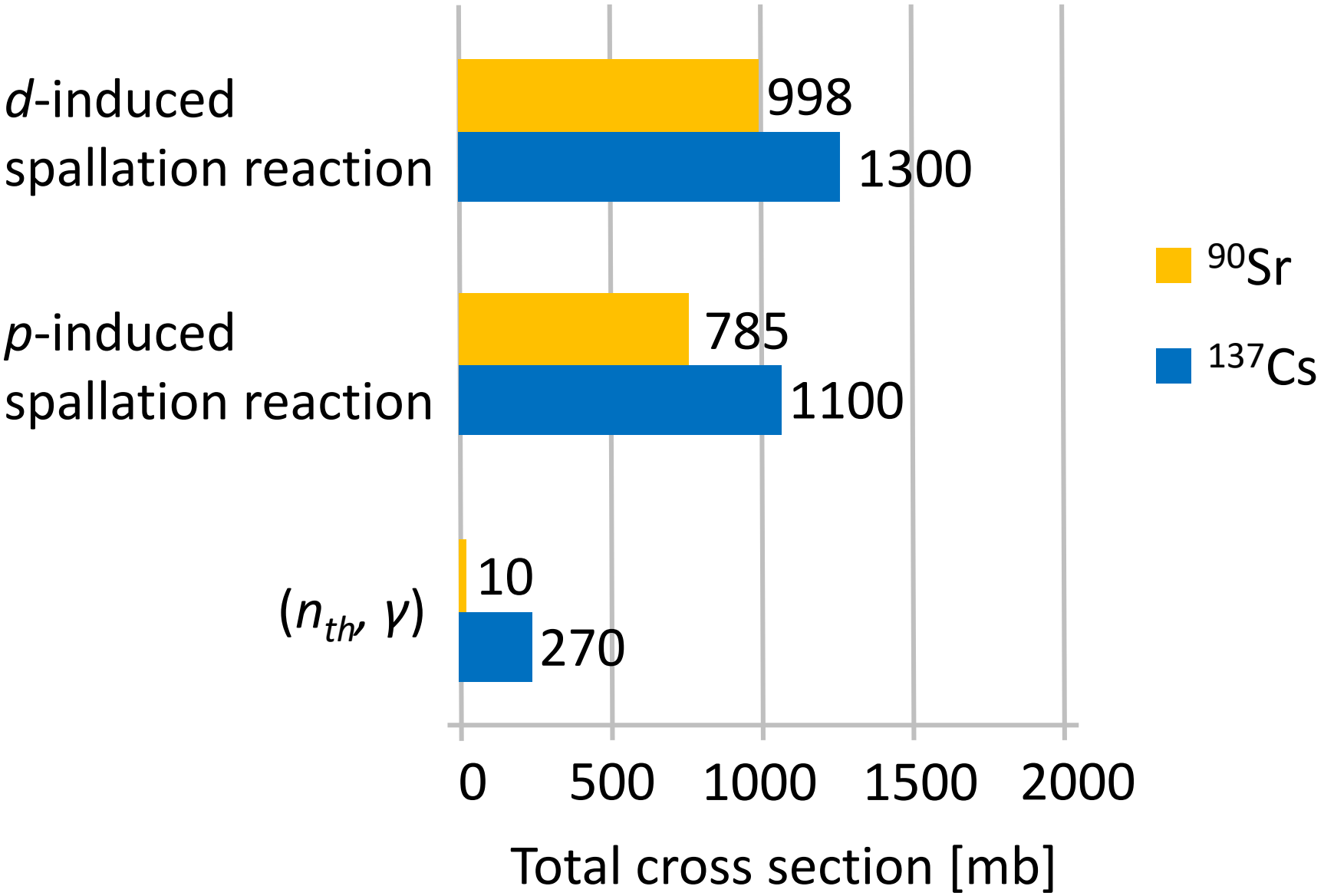


- *p*@196 MeV/*u*
- *p*@118 MeV/*u*
- *d*@118 MeV/*u*

σ_d at 118 MeV/*u* is similar to σ_p at 196 MeV/*u*

HW, H. Otsu, H. Sakurai et al., Prog. Theor. Exp. Phys. 2017, 021D01(2017)

Potential of spallation for LLFP transmutation I



Potential of spallation for LLFP transmutation I

Total cross section for ^{107}Pd

	Cross section [barn]
Spallation	1
(n,γ)	9.2

Transmutation rate depends on

Cross section and Flux

Summary

- Spallation reactions for LLFP nuclei using inverse kinematics at RIBF
- Cross sections on *p* and *d* for ^{137}Cs, ^{90}Sr and ^{107}Pd
  - Target dependence
  - Energy dependence
- Comparison with spallation models
- Potential for the transmutation on LLFP
  - Total spallation cross section
  - Production of other radioactive isotopes at different reaction energies
- Collaboration with nuclear engineering

Collaborators

RIKEN Nishina Center

HW, H. Otsu, H. Sakurai, S. Chen, N. Chiga, P. Doornenbal, T. Ichihara, T. Isobe, S. Kubono, G. Lorusso, T. Matsuzaki, Y. Shiga, P.-A. Söderström, Y. Watanabe, K. Yoshida, N. Fukuda, H. Suzuki, H. Takeda, Y. Shimizu, D. S. Ahn, T. Sumikama, H. Sato, M. Uesaka, T. Kubo

Kyushu University

Y. Watanabe, S. Kawase, K. Nakano, S. Araki, T. Kin

Tokyo Institute of Technology

Y. Togano, M. Shikata, S. Takeuchi, T. Nakamura, Y. Kondo, J. Tsubota, A. Saito, T. Ozaki

Miyazaki University

Y. Maeda, S. Kawakami, T. Yamamoto

University of Tokyo

S. Momiyama , M. Niikura, R. Taniuchi, S. Koyama, T. Ando, S. Nagamine, T. Saito, K. Wimmer

CNS, Univ. of Tokyo

S. Michimasa, M. Matsushita, S. Shimoura

Hokkaido University

A. Makinaga, M. Aikawa

Reduction and Resource Recycling of High-level Radioactive Wastes through Nuclear Transmutation

http://www.jst.go.jp/impact/en/program/08.html

This work was funded by ImPACT Program of Council for Science, Technology and Innovation (Cabinet Office, Government of Japan).

Nucleus-Nucleus Collisions 2018

Omiya, Japan (not far from Tokyo)
4-8, December 2018

Hosted by RIKEN Nishina Center
Supported by IUPAP

You can get full information at

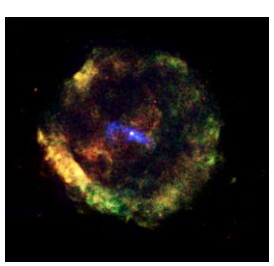
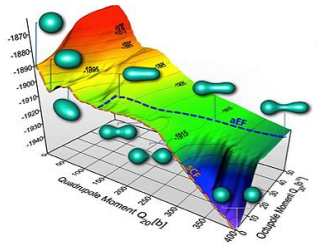
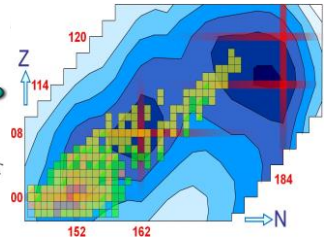
http://nn2018.riken.jp

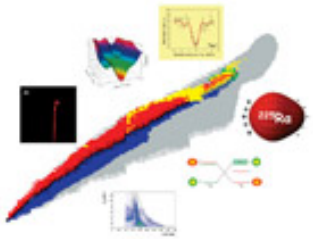
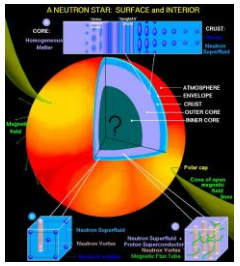
International Conference on

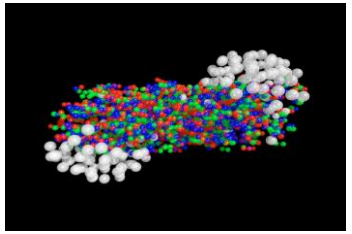
Nucleus-Nucleus Collisions

- **Organized every 3 years since the first meeting in 1982 at MSU**
- **11th at Texas (USA), 12th at Catania (Italy), 13th at Omiya (Japan)**
- **350+ participants in the 12th**
- **350—400 participants in NN2018**

Nucleo-synthesis | Fusion & fission | Superheavy elements | Unstable nuclei | EoS and strangeness | Quark-gluon plasma



Low → to → Ultra high Energy

+ Applications (Cancer therapy, nuclear transmutation, RI for other fields. . . .)

Nucleus-Nucleus Collisions 2018

Omiya, Japan (not far from Tokyo)
4-8, December 2018

Hosted by RIKEN Nishina Center
Supported by IUPAP

You can get full information at

http://nn2018.riken.jp

Abstract submission is now open!
New deadline: June 30th

Banquet (in the evening of Dec. 7)

Thank you

Looking forward to seeing you in NN2018