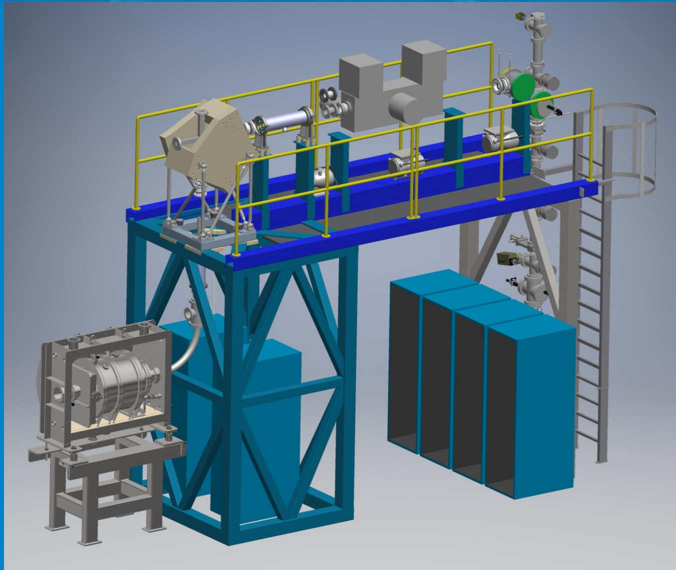
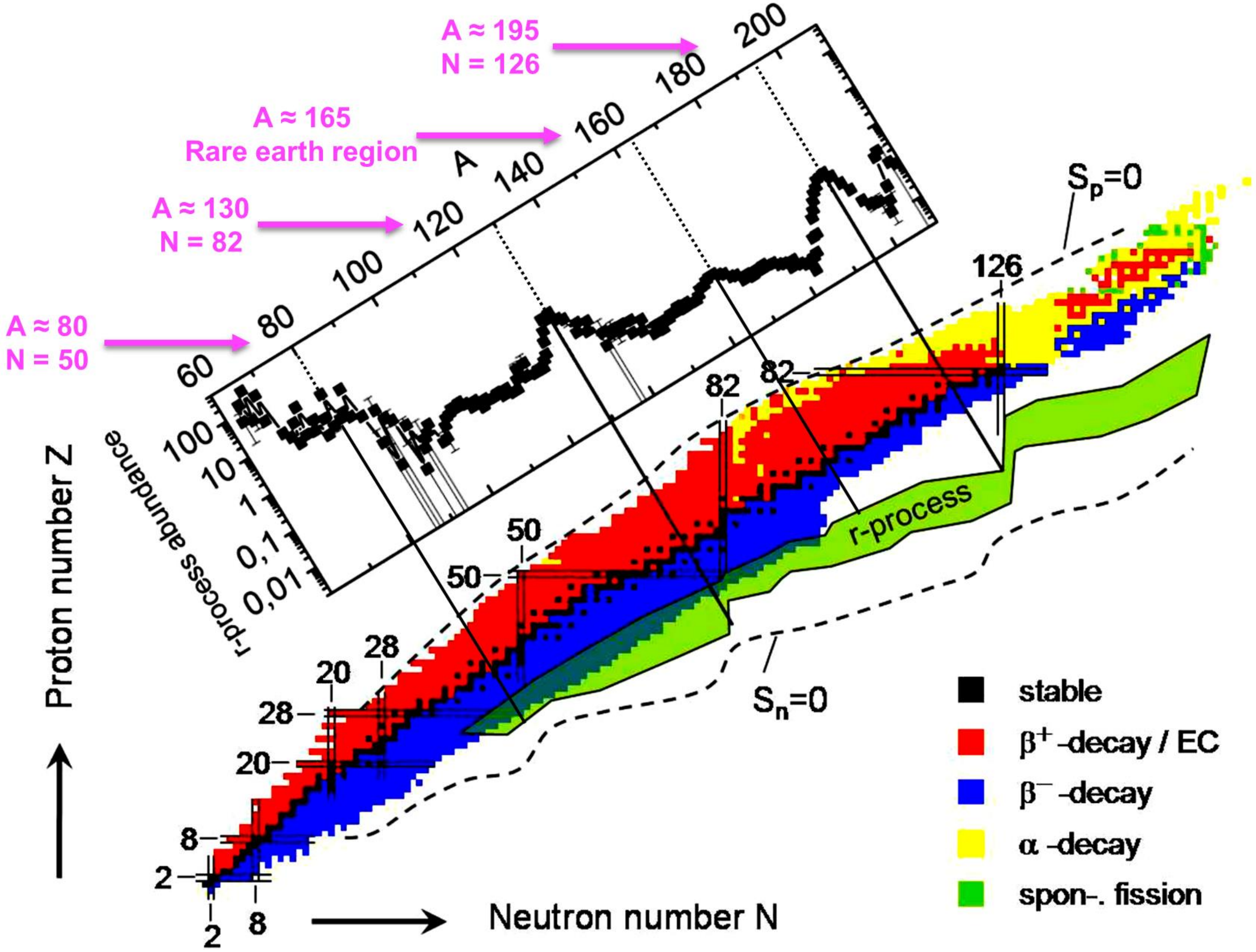
THE N=126 FACTORY AT ANL



ADRIAN VALVERDE
Argonne National Laboratory/University of Manitoba

JULY 19 2019

R-PROCESS STUDIES AT ANL



A ≈ 195
N = 126

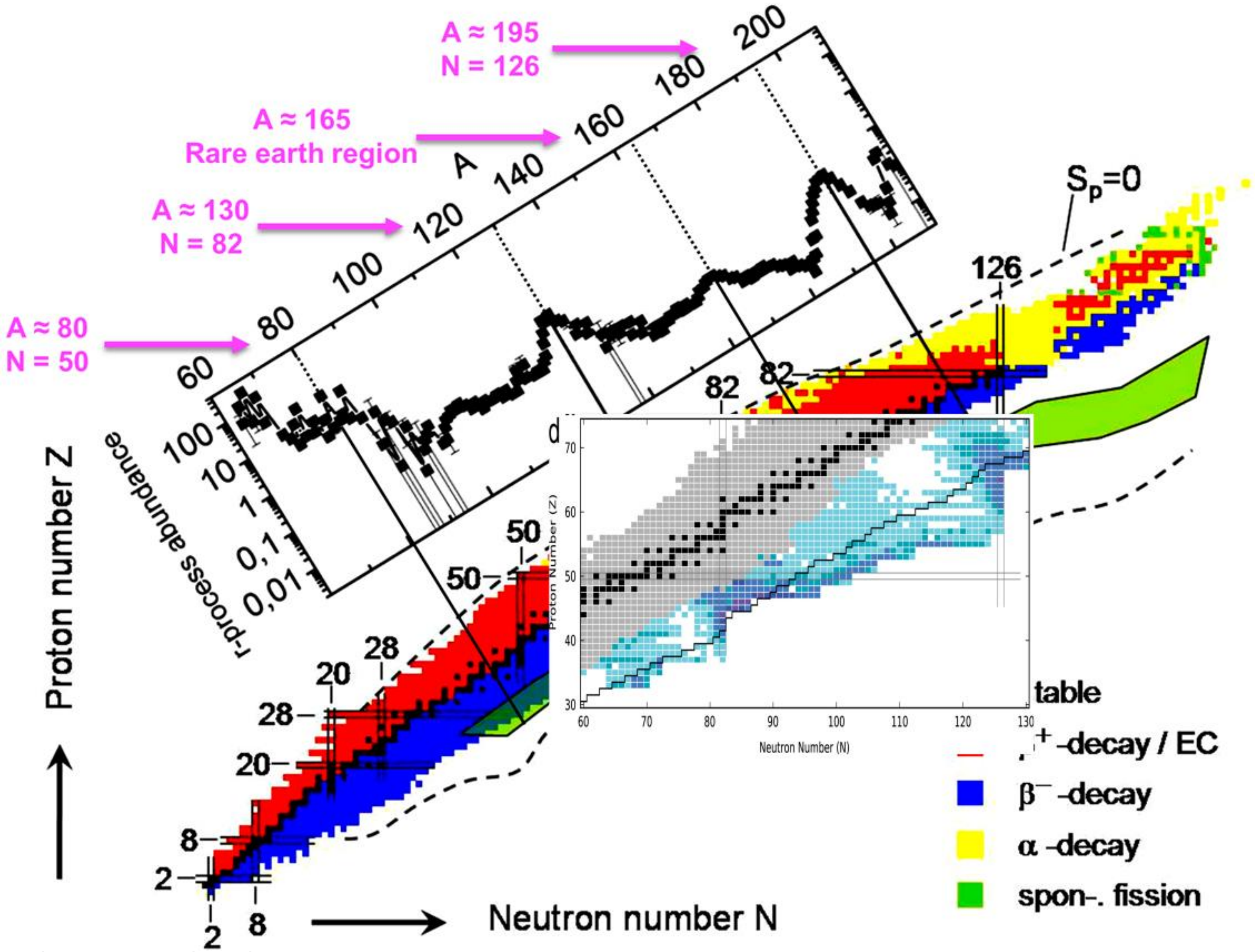
A ≈ 165
Rare earth region

A ≈ 130
N = 82

A ≈ 80
N = 50

R. Kruecken, arXiv:1006.2520 (2010)

R-PROCESS STUDIES AT ANL

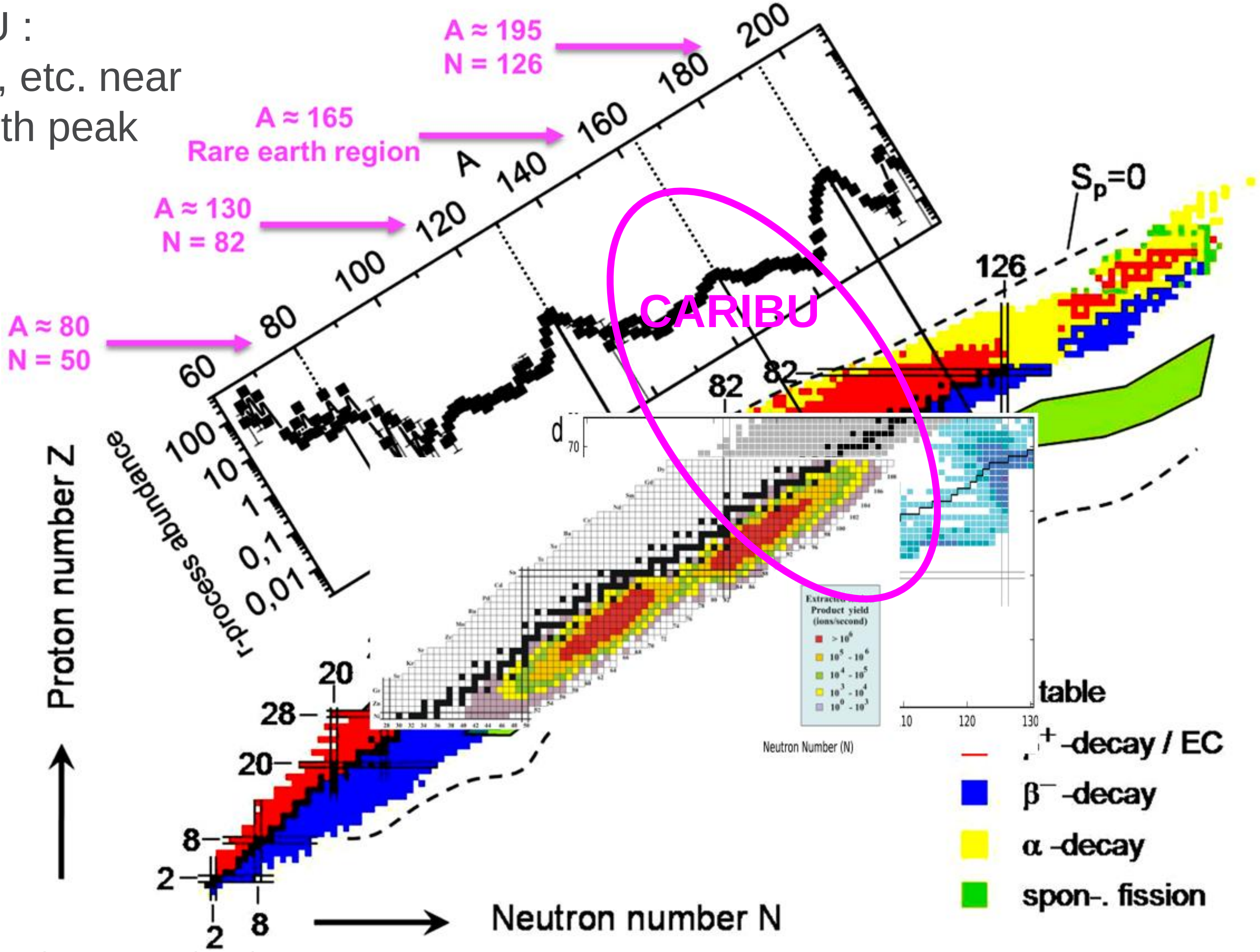


R. Kruecken, arXiv:1006.2520 (2010),

M.R. Mumpower et al., PPNP, 86 (2016)

R-PROCESS STUDIES AT ANL

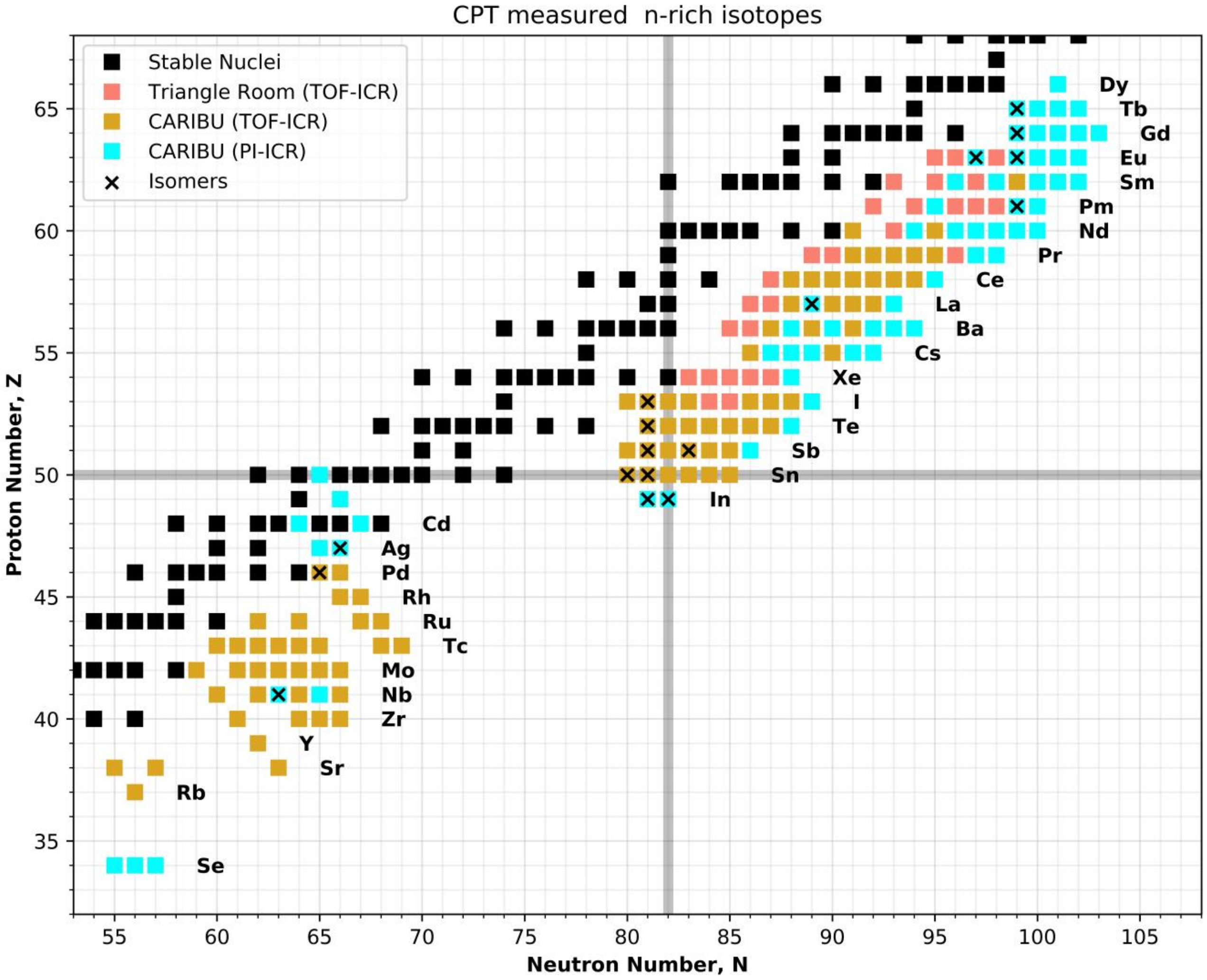
CARIBU :
Masses, etc. near
rare-earth peak



R. Kruecken, arXiv:1006.2520 (2010),

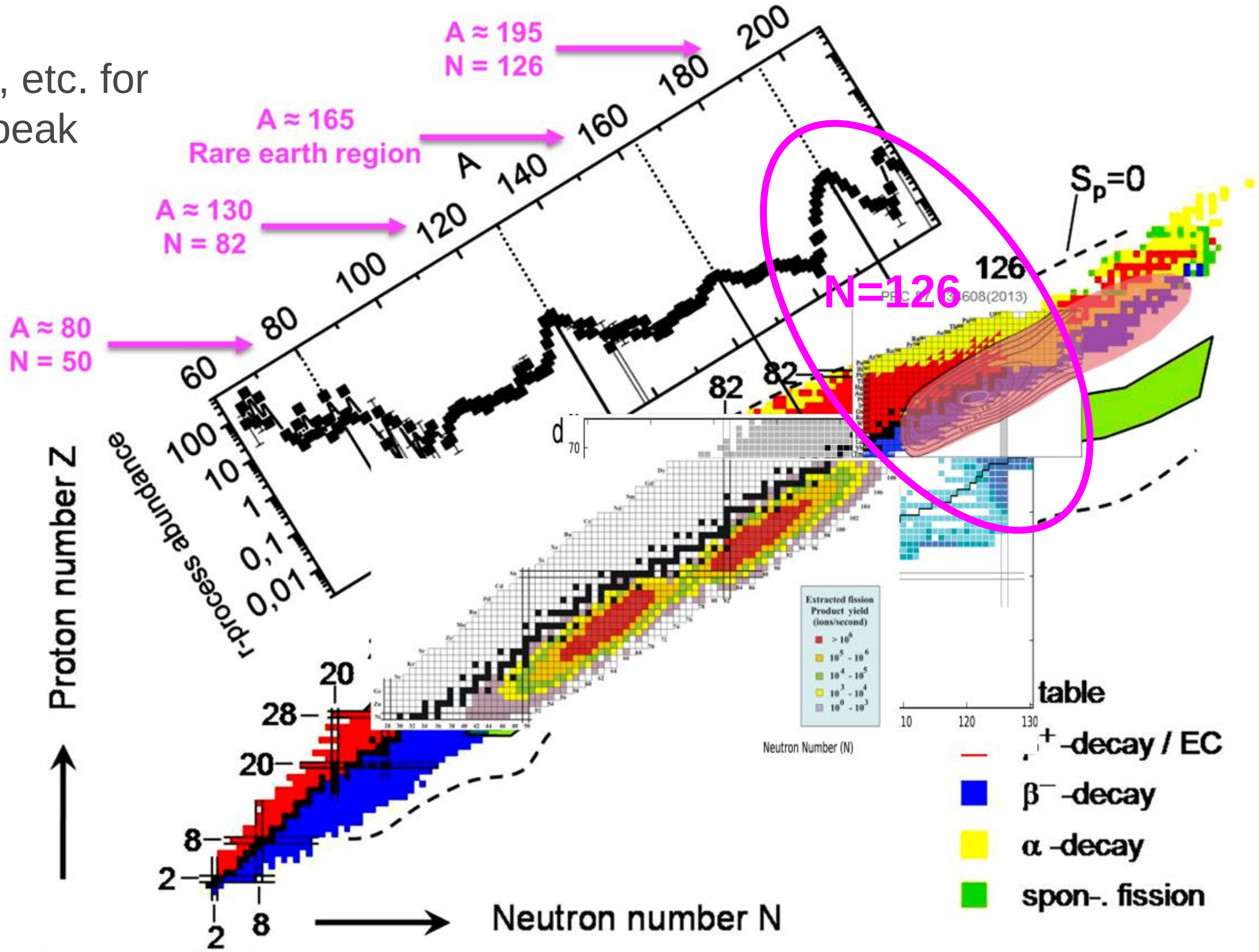
M.R. Mumpower et al., PPNP, 86 (2016)

R-PROCESS AT CARIBU



R-PROCESS STUDIES AT ANL

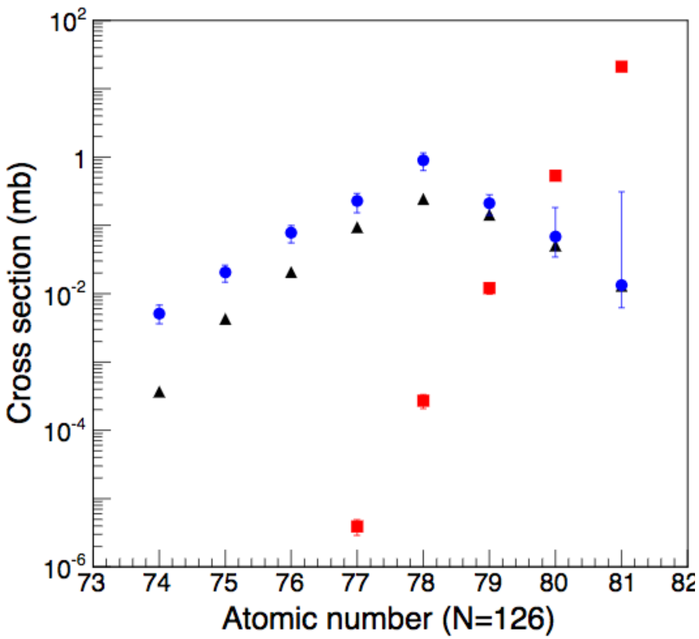
N=126:
Masses, etc. for
A~195 peak



R. Kruecken, arXiv:1006.2520 (2010),

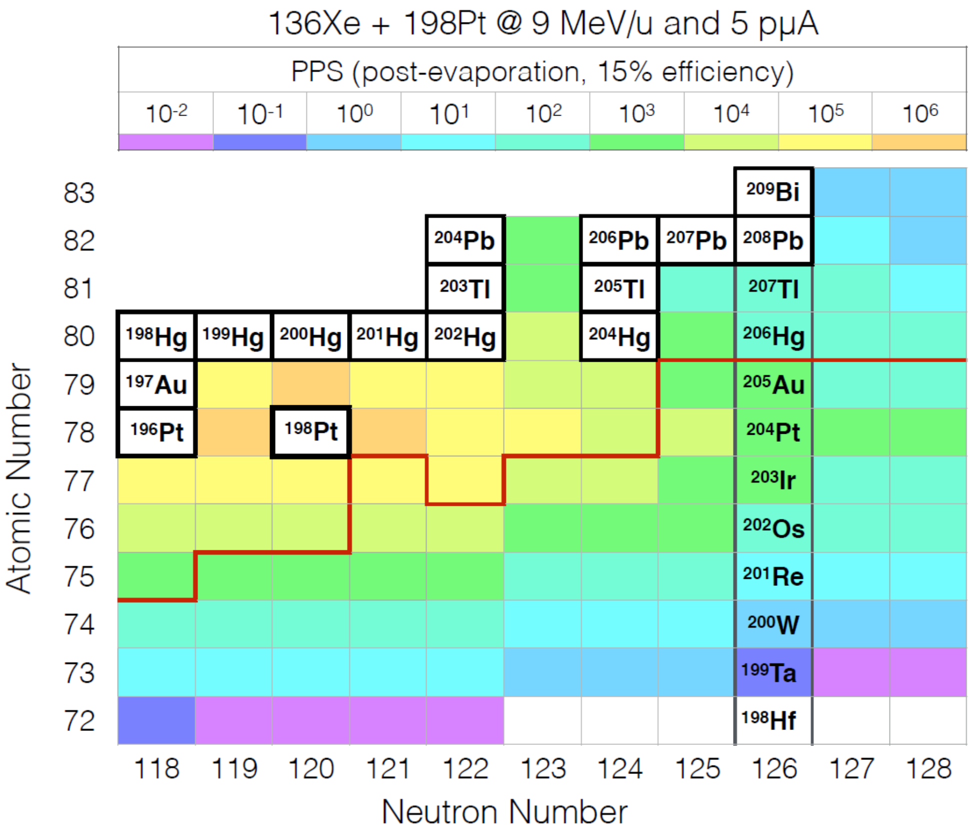
M.R. Mumpower et al., PPNP, 86 (2016)

ACCESSING *N*=126 PEAK



^{208}Pb + ^{9}Be at 1 GeV
(fragmentation reaction with best cross-sections for *N* = 126)

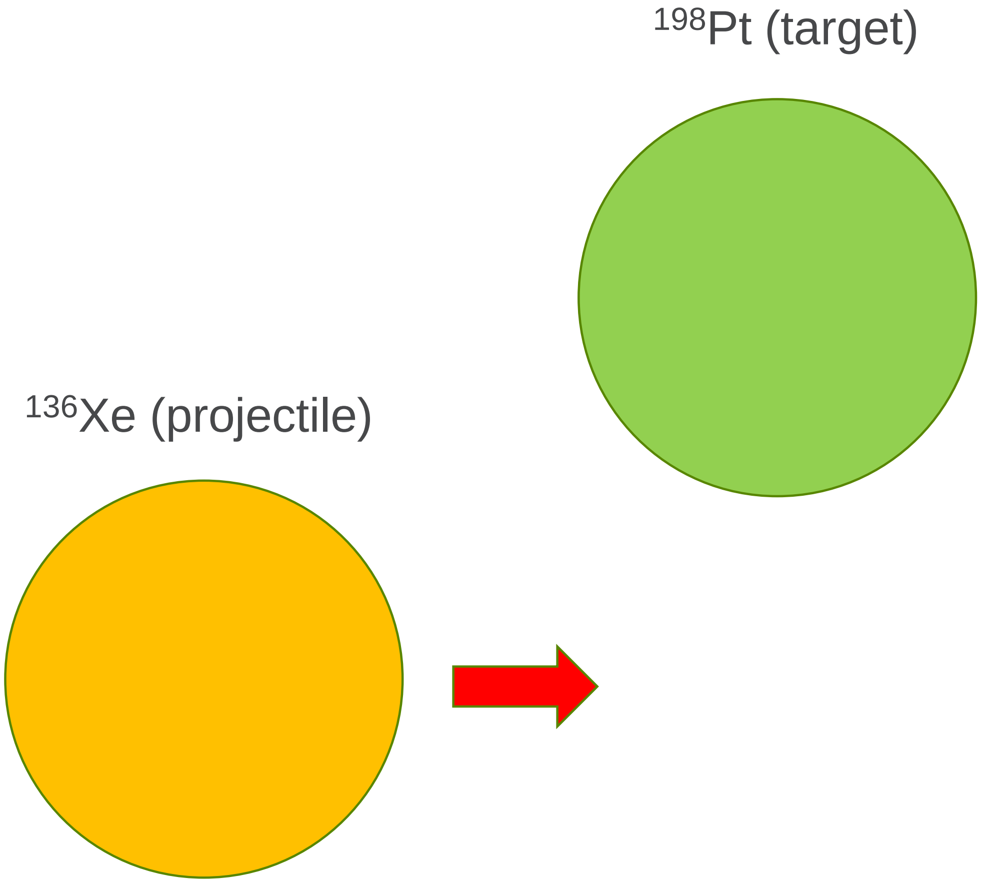
^{136}Xe + ^{198}Pt at 8 MeV/u
(best multi-nucleon transfer (MNT) reaction)



Hirayama et al., EPJ Web Conf. **109**, 08001 (2016)

N=126 rate figure courtesy J.M. Kelly

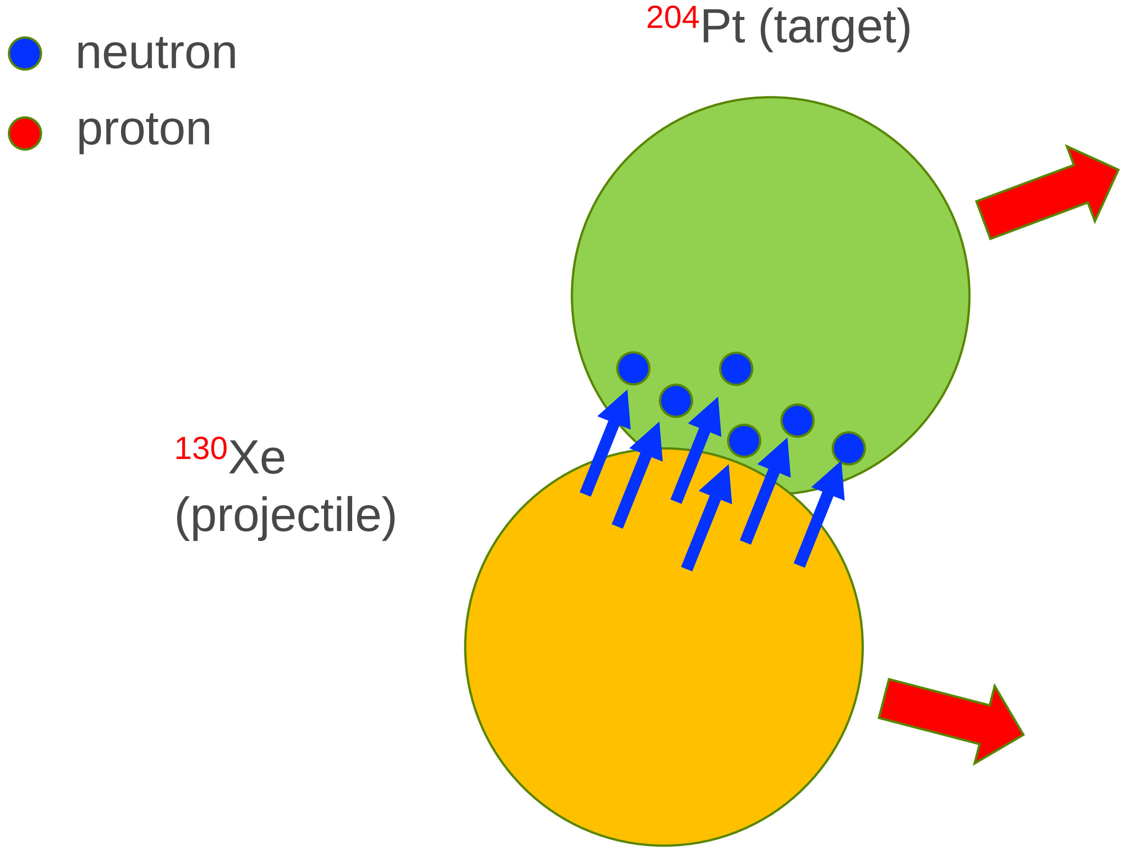
ACCESSING *N*=126 PEAK: MNT REACTIONS



^{198}Pt (target)

^{136}Xe (projectile)

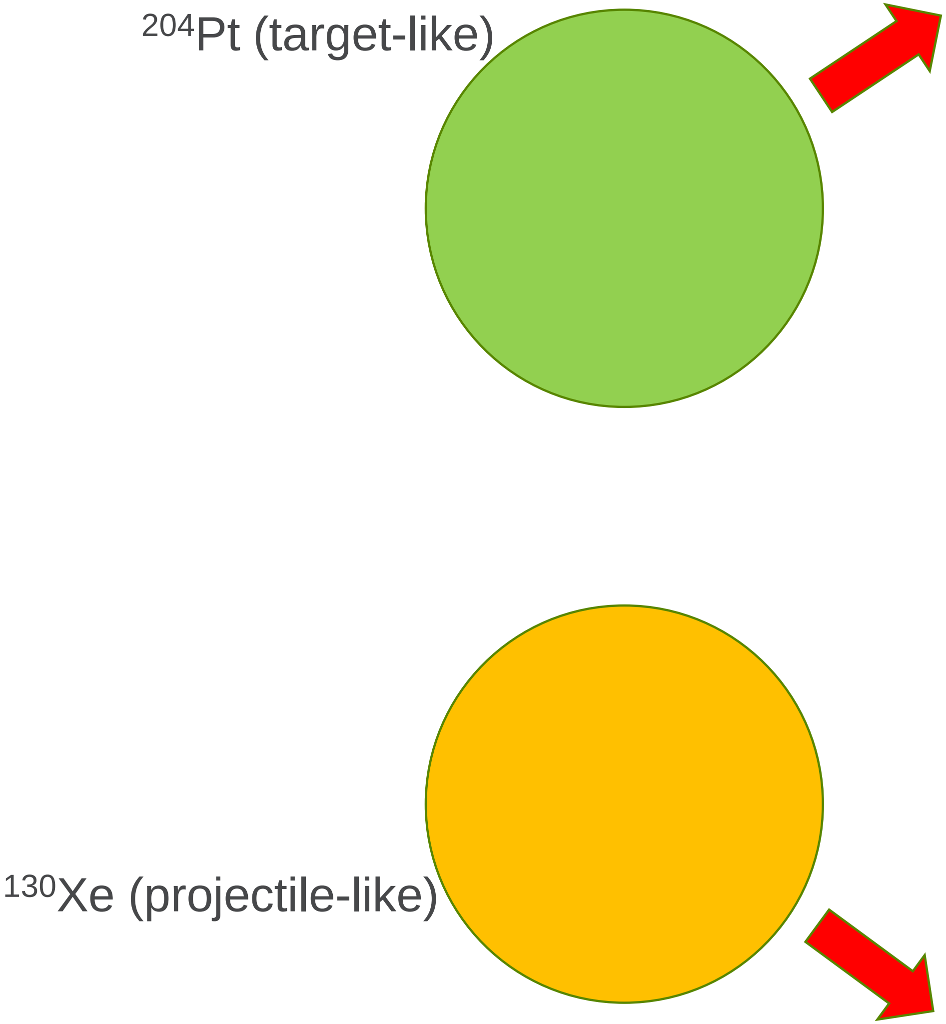
ACCESSING *N*=126 PEAK: MNT REACTIONS


- 🔵 neutron
- 🔴 proton

^{204}Pt (target)

^{130}Xe
(projectile)

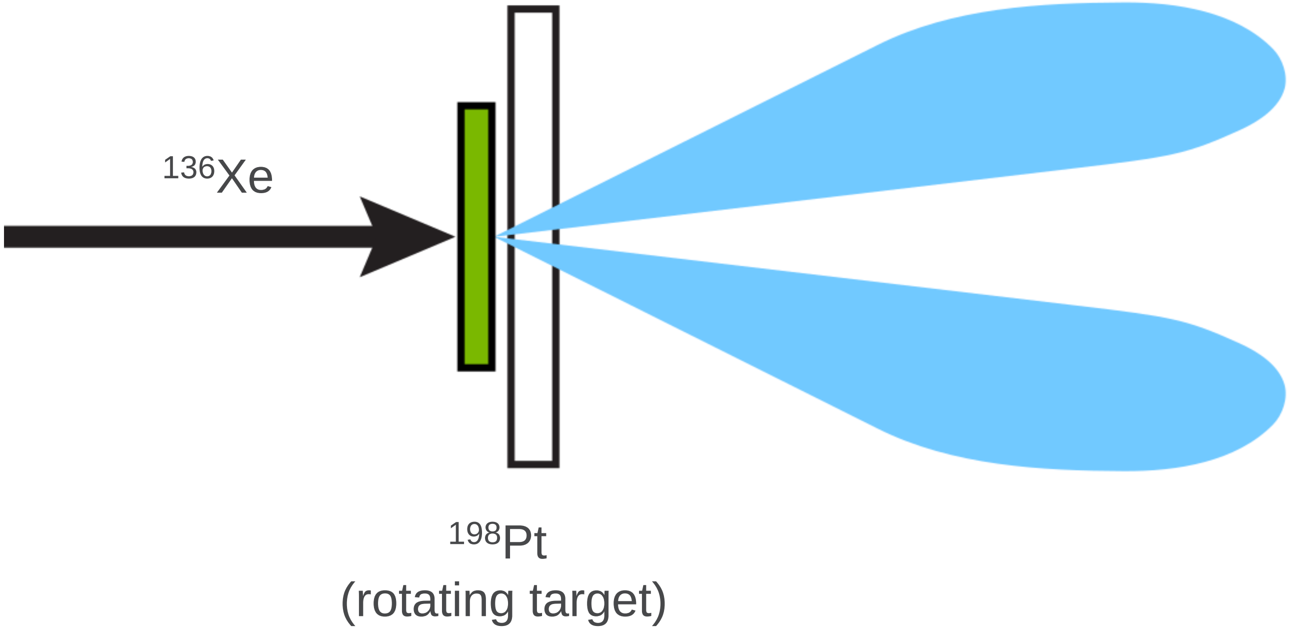
ACCESSING *N*=126 PEAK: MNT REACTIONS



^{204}Pt (target-like)

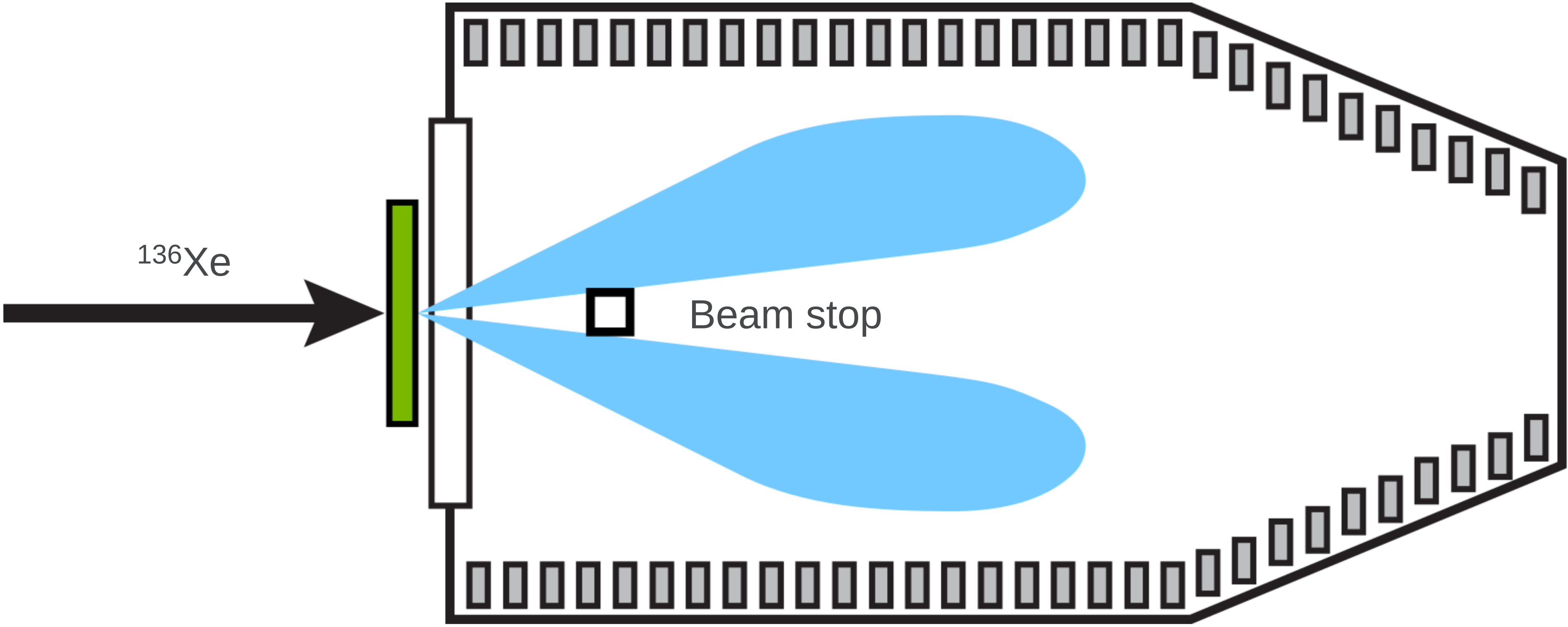
^{130}Xe (projectile-like)

MNT REACTIONS: COLLECTION



MNT REACTIONS: COLLECTION

- Thermalize fragments in He gas
- Transport to end using gas flow, electric fields

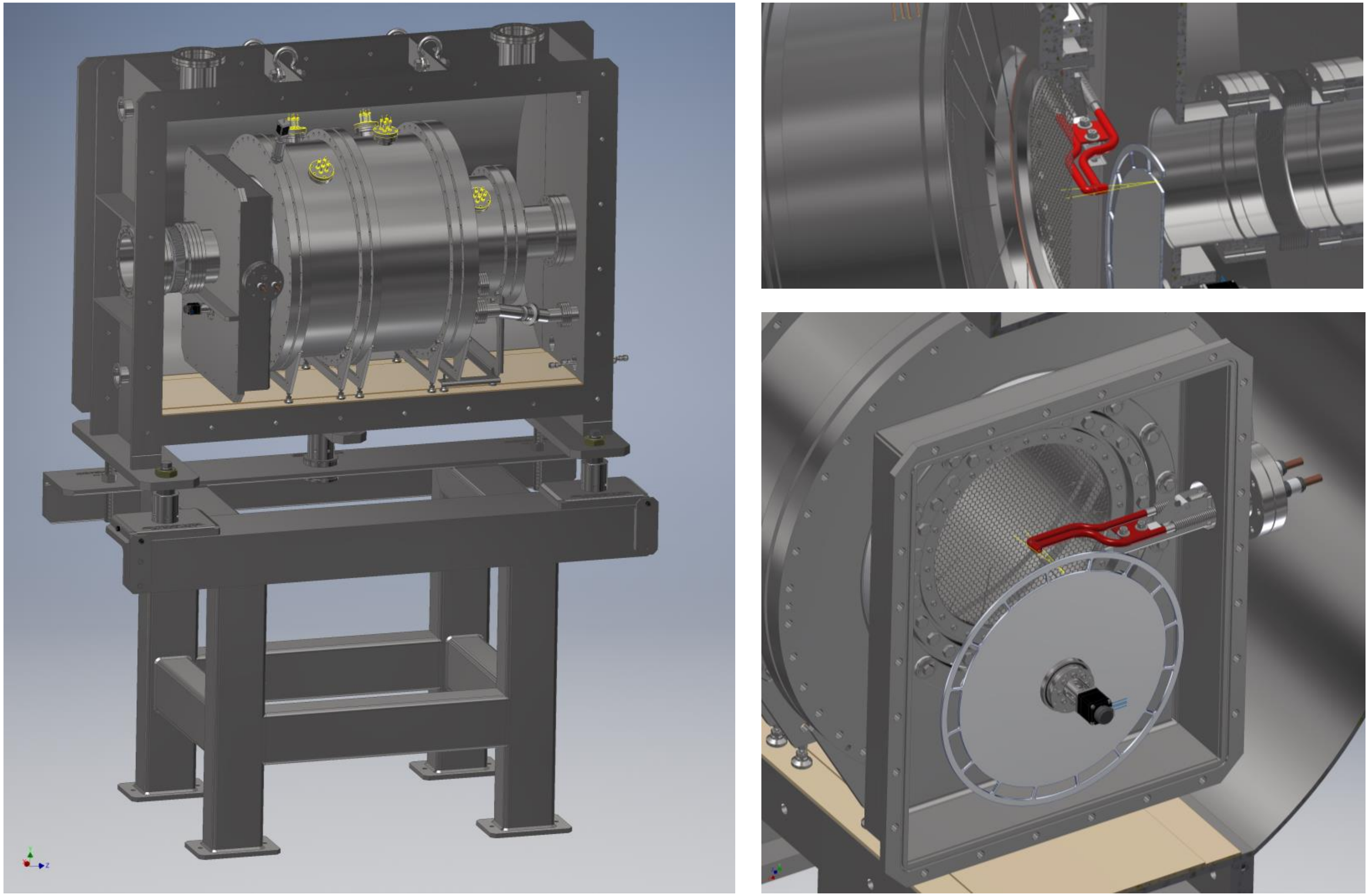


^{198}Pt
(rotating target)

GAS CATCHER

X. Yan, B.J. Zabransky

GAS CATCHER

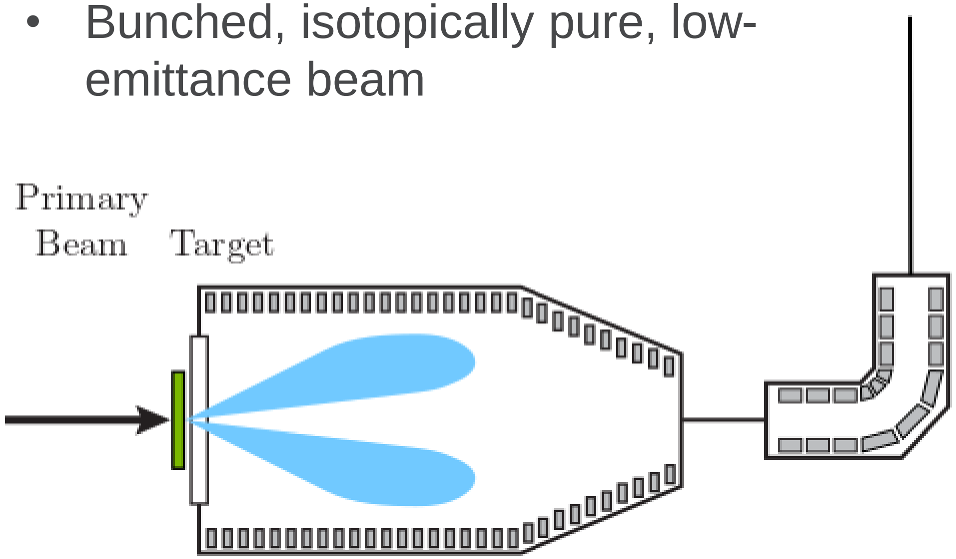


R. Knaack

GAS CATCHER

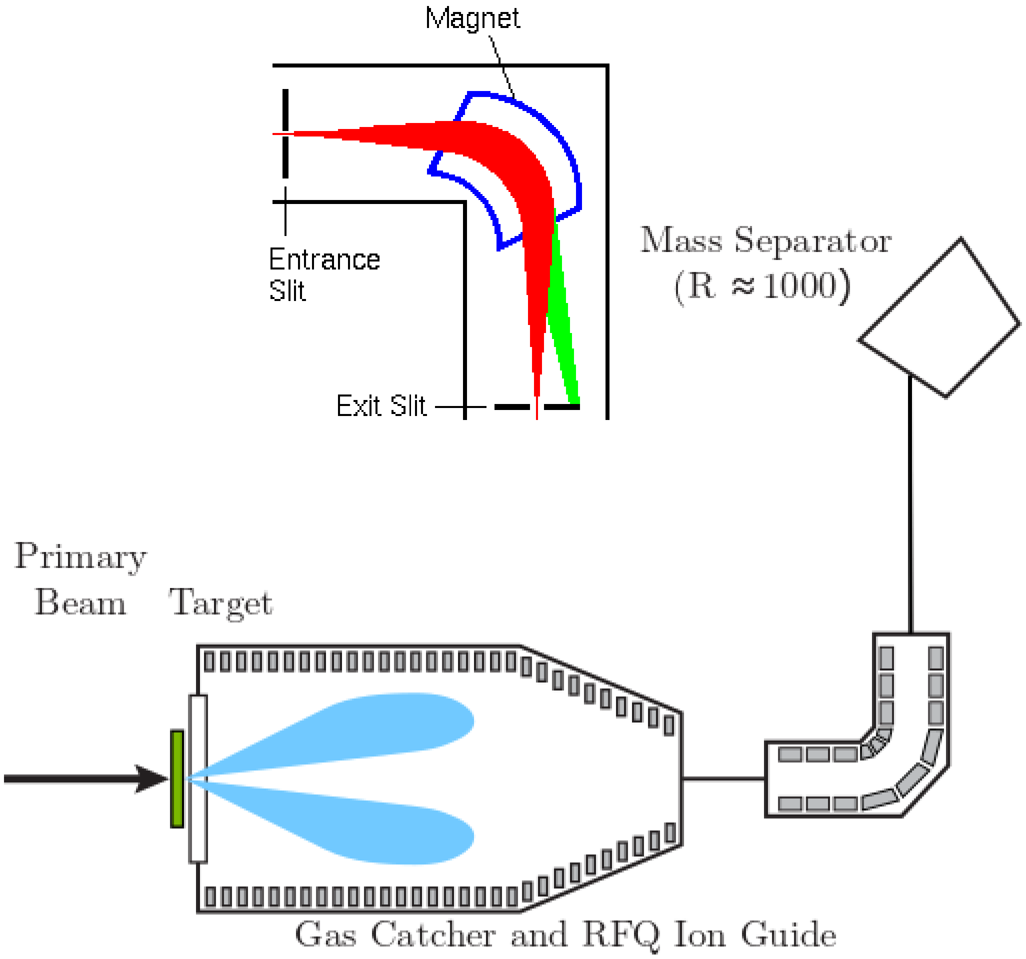
- Continuous, isotopically mixed, low energy beam

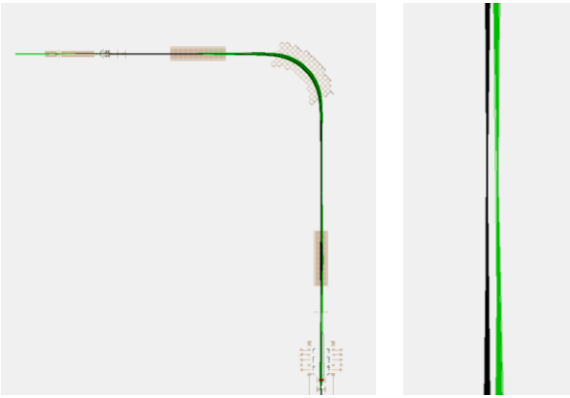
- Bunched, isotopically pure, low-emittance beam



Gas Catcher and RFQ Ion Guide

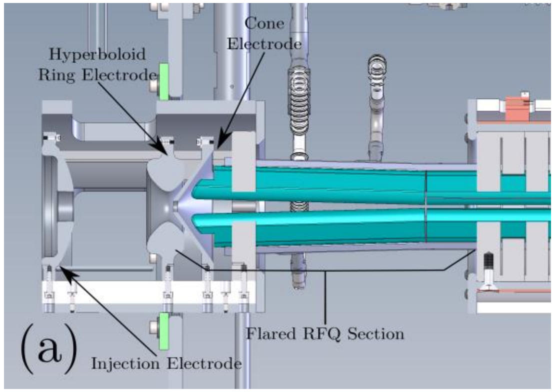
ISOBAR SEPARATING MAGNET

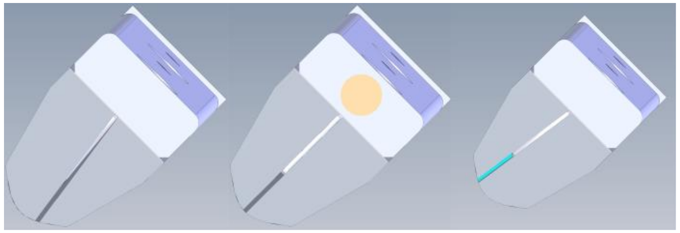


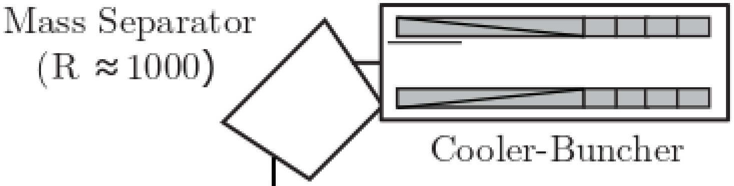


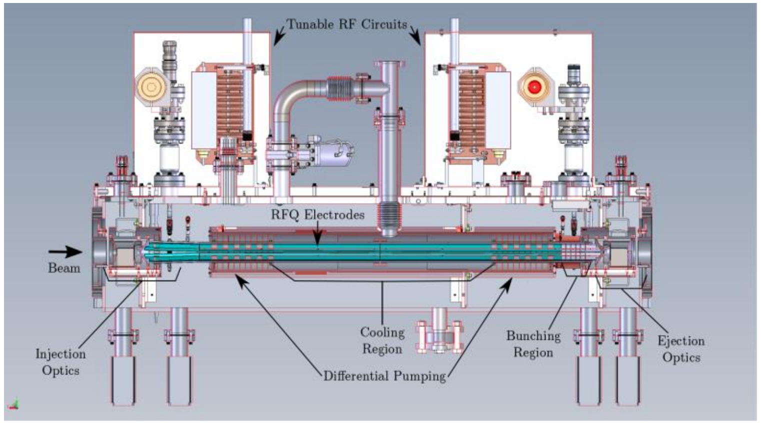
- Resolution high enough ($M/\Delta M$~1000) to separate into isobars

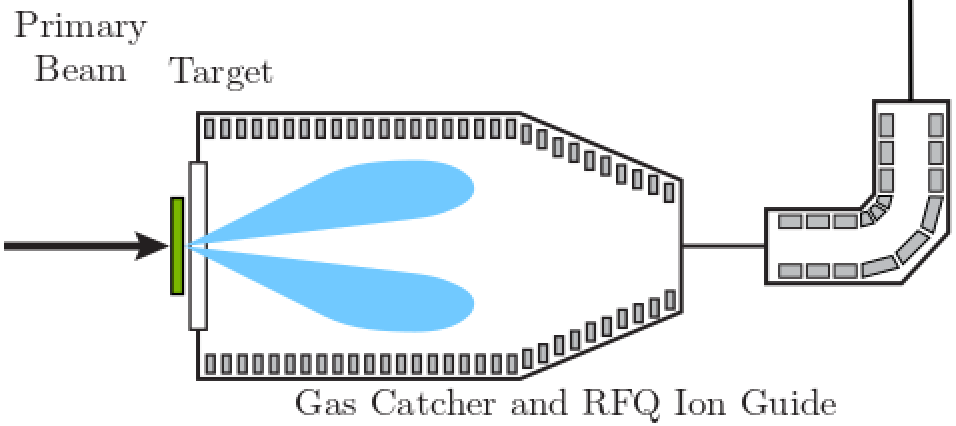
COOLER-BUNCHER





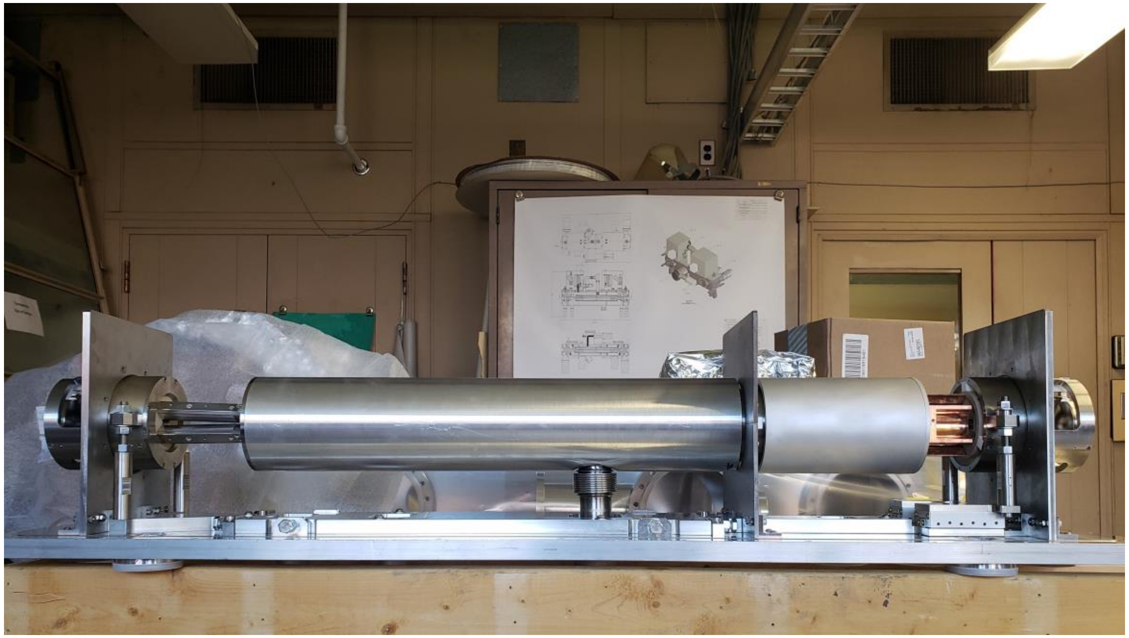


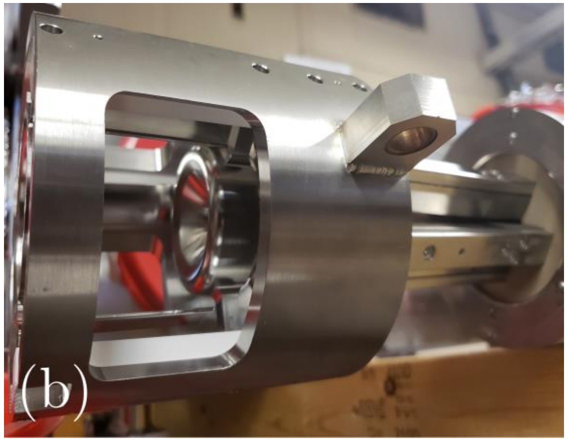




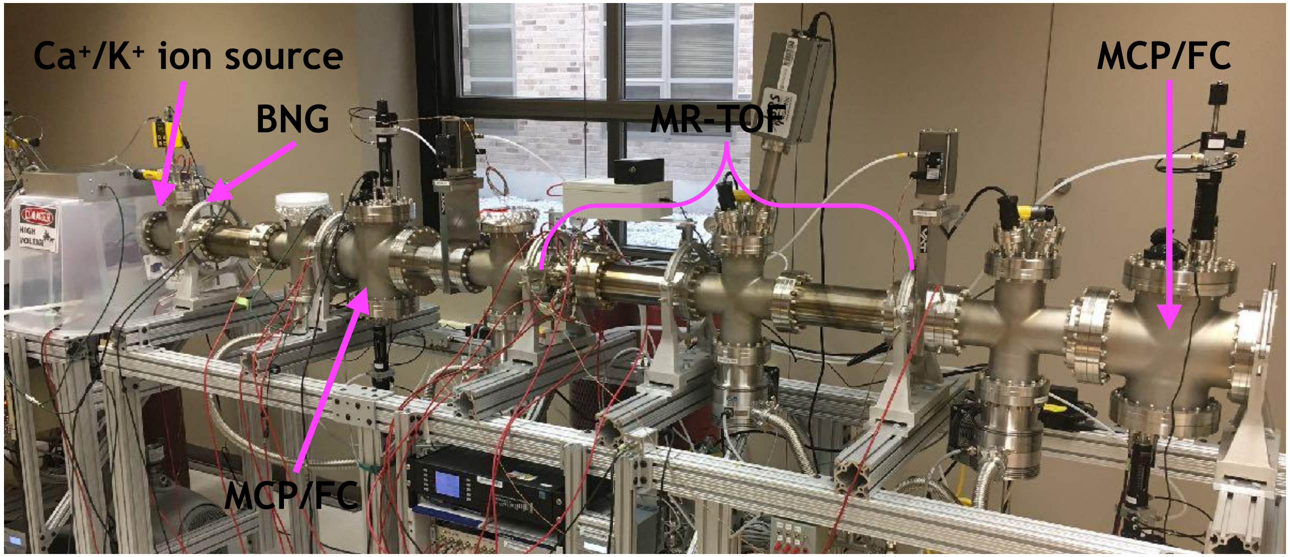
- Separated cooling and bunching sections, simplified electrode construction, optimized injection optics
- Design used for NSCL EBIT Cooler-Buncher

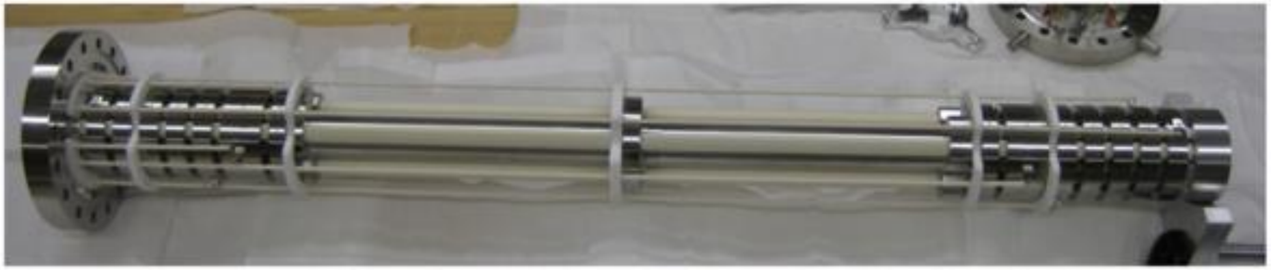
COOLER-BUNCHER





NOTRE DAME MR-TOF

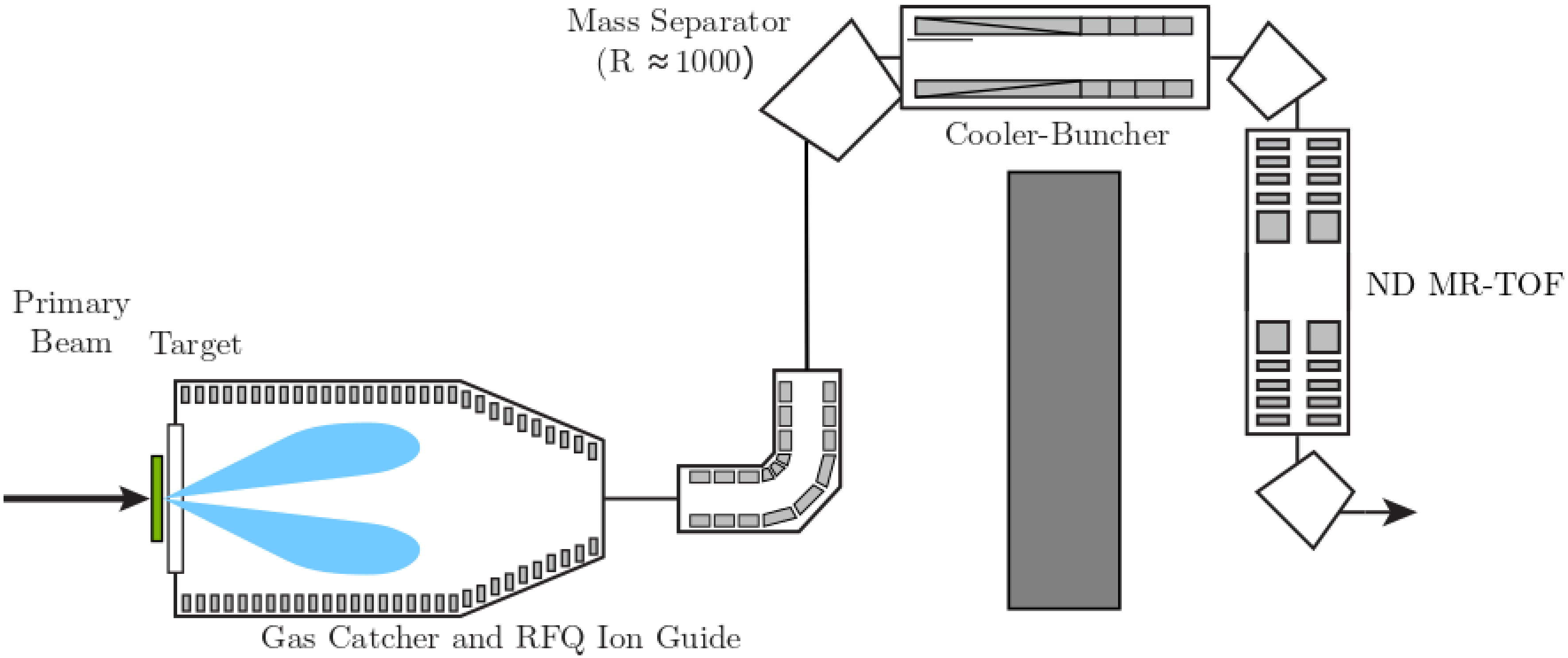




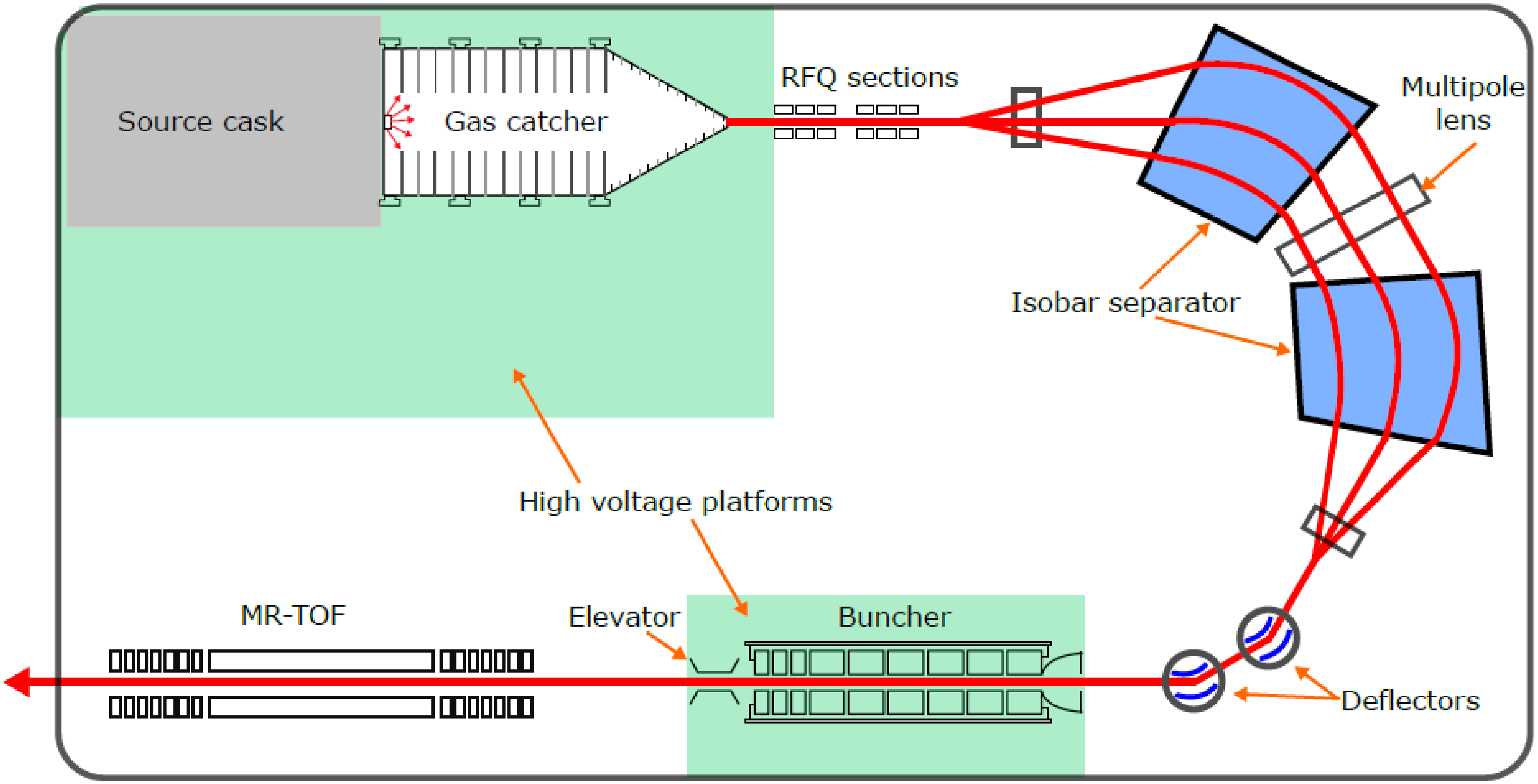
M. Brodeur, J.M. Kelly ,B. Liu

NOTRE DAME MR-TOF

- Mass Resolution in $M/\Delta M > 10^5$
- Deliver isotopically pure beams to experiments

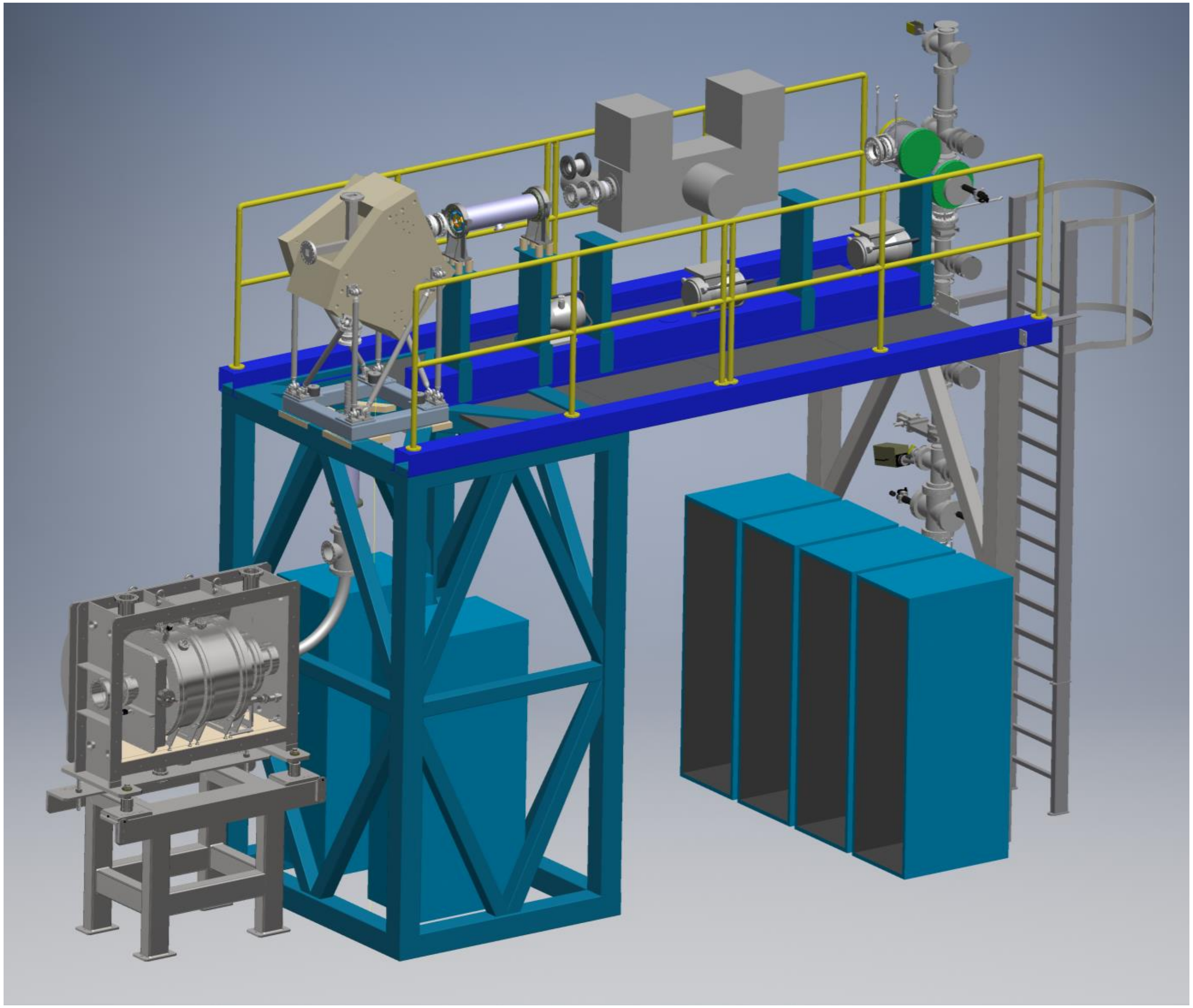


CARIBU FACILITY



R. Orford. McGill University, PhD thesis, 2018

N=126 OVERVIEW

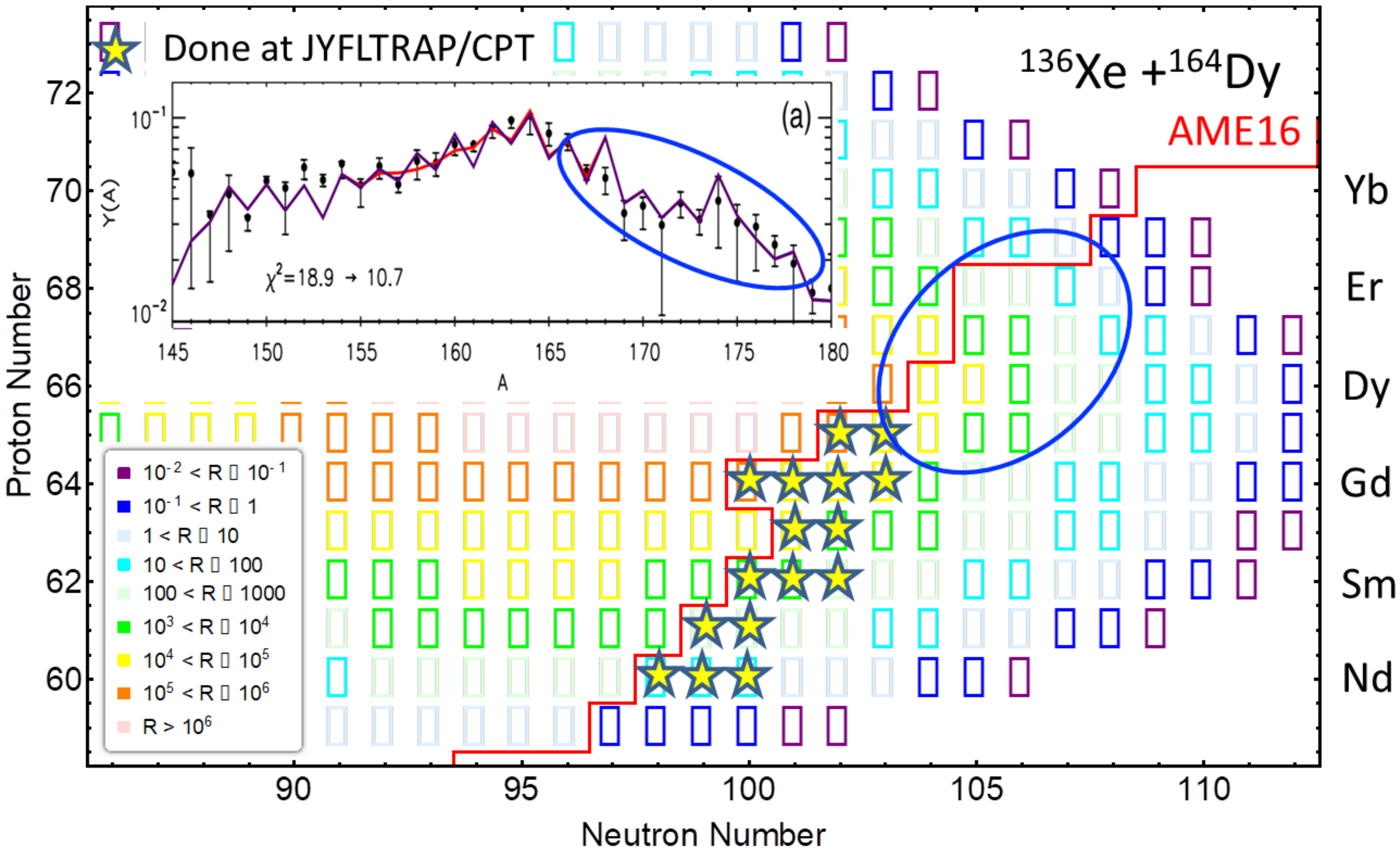


EXPERIMENTS

- Mass measurements using the CPT
  → PI-ICR offers access to low rate isotopes
  → D. Ray’s talk yesterday

- Decay Spectroscopy using X-array

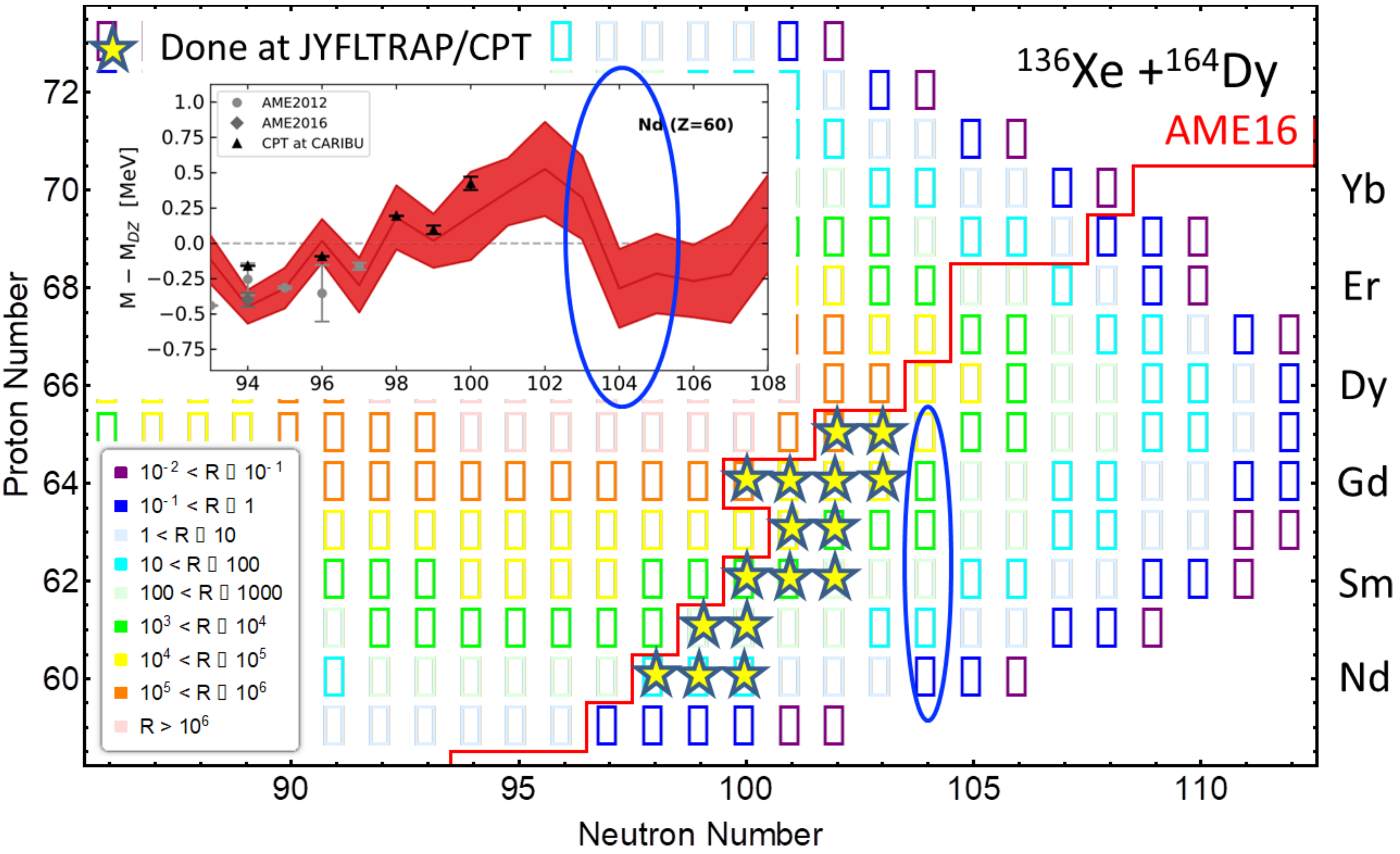
N=126: RARE EARTH PEAK



M. Vilen et al., PRL 120, 262701 (2018)

GRAZING calculations courtesy M. Brodeur

N=126: RARE EARTH PEAK

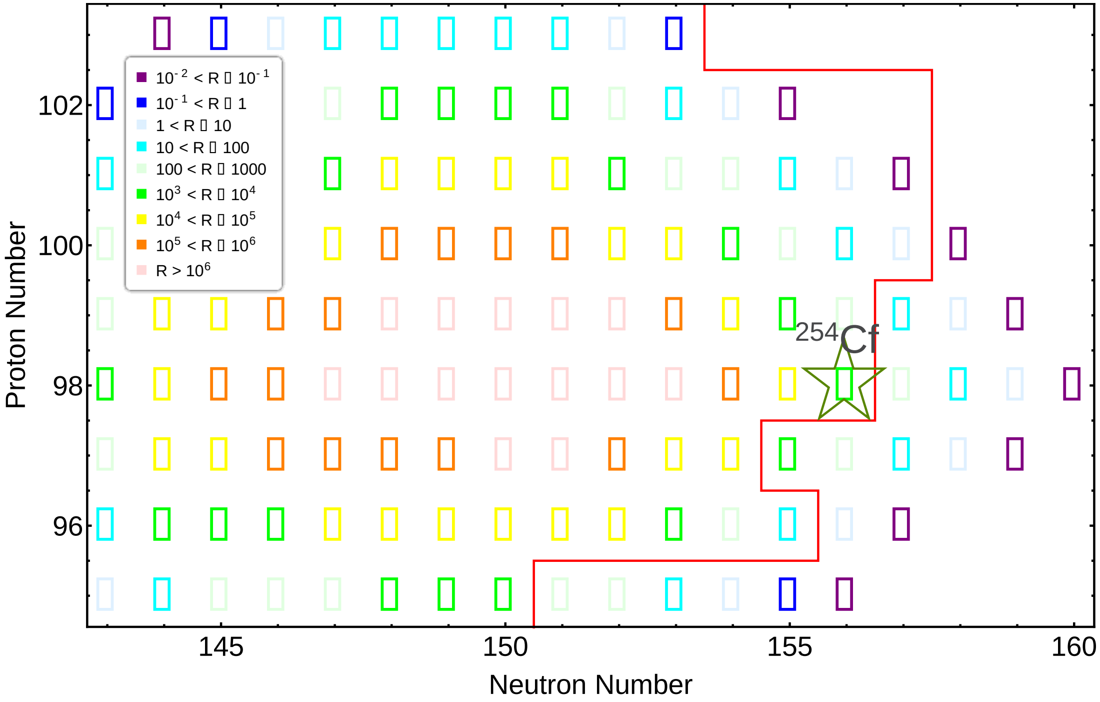


R. Orford et al., PRL 120, 262702 (2018)

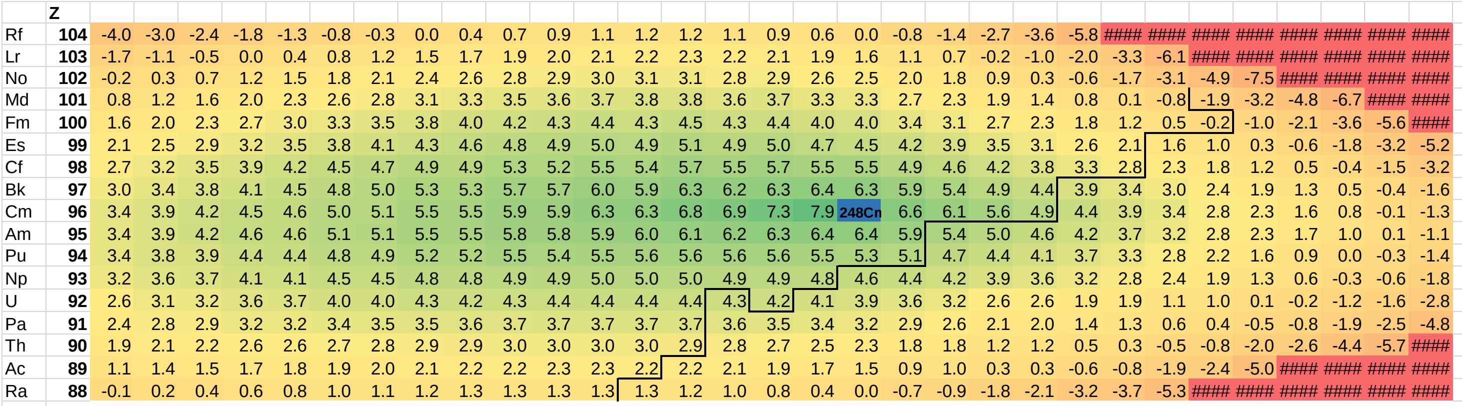
GRAZING calculations courtesy M. Brodeur

N=126: VERY HEAVY NUCLEI

^{136}Xe + ^{251}Cf (50 mCi)



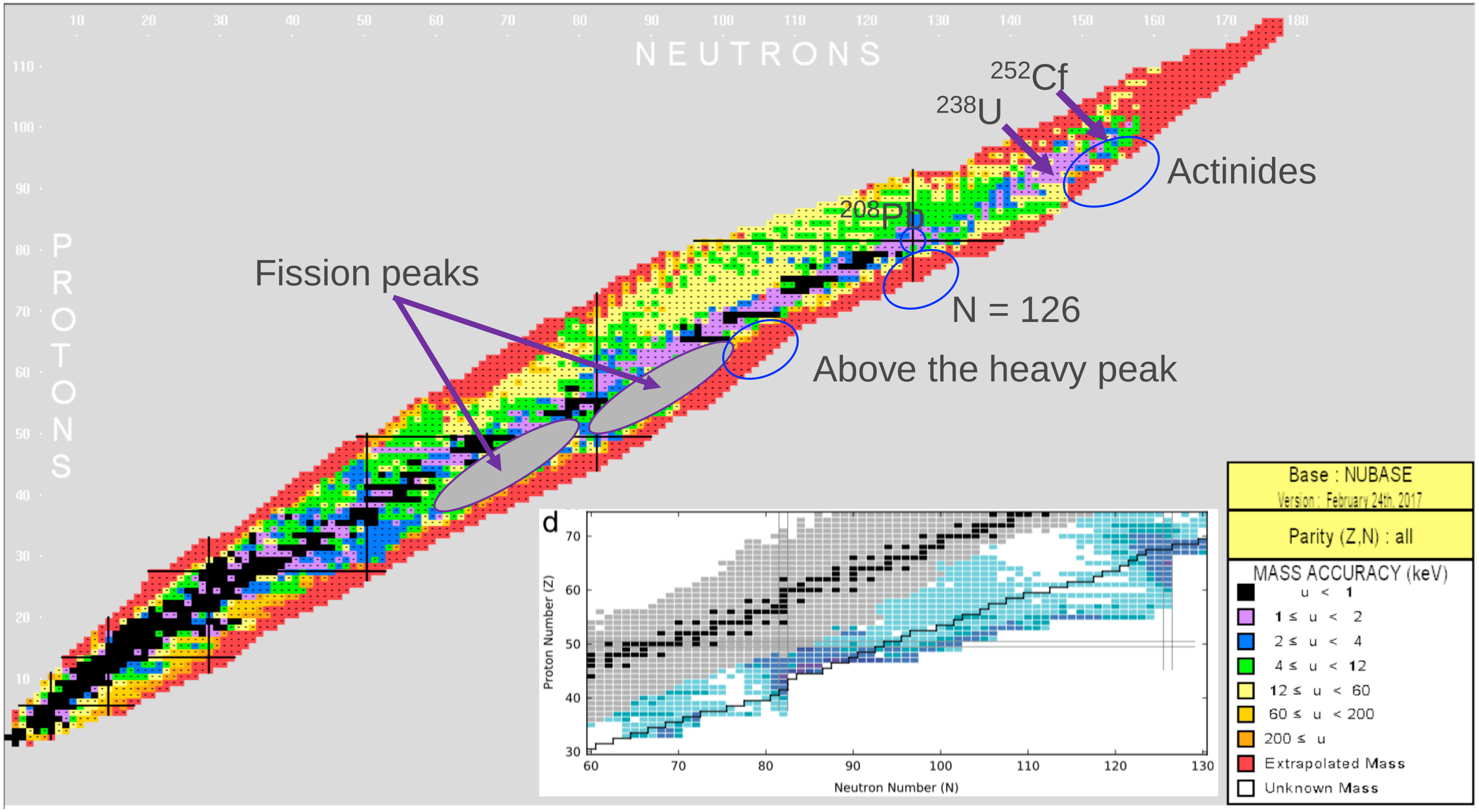
^{238}U + ^{248}Cm
for very n-rich Z~100



	Z																																
Rf	**104**	-4.0	-3.0	-2.4	-1.8	-1.3	-0.8	-0.3	0.0	0.4	0.7	0.9	1.1	1.2	1.2	1.1	0.9	0.6	0.0	-0.8	-1.4	-2.7	-3.6	-5.8	####	####	####	####	####	####	####	####	
Lr	**103**	-1.7	-1.1	-0.5	0.0	0.4	0.8	1.2	1.5	1.7	1.9	2.0	2.1	2.2	2.3	2.2	2.1	1.9	1.6	1.1	0.7	-0.2	-1.0	-2.0	-3.3	-6.1	####	####	####	####	####	####	
No	**102**	-0.2	0.3	0.7	1.2	1.5	1.8	2.1	2.4	2.6	2.8	2.9	3.0	3.1	3.1	2.8	2.9	2.6	2.5	2.0	1.8	0.9	0.3	-0.6	-1.7	-3.1	-4.9	-7.5	####	####	####	####	
Md	**101**	0.8	1.2	1.6	2.0	2.3	2.6	2.8	3.1	3.3	3.5	3.6	3.7	3.8	3.8	3.6	3.7	3.3	3.3	2.7	2.3	1.9	1.4	0.8	0.1	-0.8	-1.9	-3.2	-4.8	-6.7	####	####	
Fm	**100**	1.6	2.0	2.3	2.7	3.0	3.3	3.5	3.8	4.0	4.2	4.3	4.4	4.3	4.5	4.3	4.4	4.0	4.0	3.4	3.1	2.7	2.3	1.8	1.2	0.5	-0.2	-1.0	-2.1	-3.6	-5.6	####	
Es	**99**	2.1	2.5	2.9	3.2	3.5	3.8	4.1	4.3	4.6	4.8	4.9	5.0	4.9	5.1	4.9	5.0	4.7	4.5	4.2	3.9	3.5	3.1	2.6	2.1	1.6	1.0	0.3	-0.6	-1.8	-3.2	-5.2	
Cf	**98**	2.7	3.2	3.5	3.9	4.2	4.5	4.7	4.9	4.9	5.3	5.2	5.5	5.4	5.7	5.5	5.7	5.5	5.5	4.9	4.6	4.2	3.8	3.3	2.8	2.3	1.8	1.2	0.5	-0.4	-1.5	-3.2	
Bk	**97**	3.0	3.4	3.8	4.1	4.5	4.8	5.0	5.3	5.3	5.7	5.7	6.0	5.9	6.3	6.2	6.3	6.4	6.3	5.9	5.4	4.9	4.4	3.9	3.4	3.0	2.4	1.9	1.3	0.5	-0.4	-1.6	
Cm	**96**	3.4	3.9	4.2	4.5	4.6	5.0	5.1	5.5	5.5	5.9	5.9	6.3	6.3	6.8	6.9	7.3	7.9	**248Cn**	6.6	6.1	5.6	4.9	4.4	3.9	3.4	2.8	2.3	1.6	0.8	-0.1	-1.3	
Am	**95**	3.4	3.9	4.2	4.6	4.6	5.1	5.1	5.5	5.5	5.8	5.8	5.9	6.0	6.1	6.2	6.3	6.4	6.4	5.9	5.4	5.0	4.6	4.2	3.7	3.2	2.8	2.3	1.7	1.0	0.1	-1.1	
Pu	**94**	3.4	3.8	3.9	4.4	4.4	4.8	4.9	5.2	5.2	5.5	5.4	5.5	5.6	5.6	5.6	5.6	5.5	5.3	5.1	4.7	4.4	4.1	3.7	3.3	2.8	2.2	1.6	0.9	0.0	-0.3	-1.4	
Np	**93**	3.2	3.6	3.7	4.1	4.1	4.5	4.5	4.8	4.8	4.9	4.9	5.0	5.0	5.0	4.9	4.9	4.8	4.6	4.4	4.2	3.9	3.6	3.2	2.8	2.4	1.9	1.3	0.6	-0.3	-0.6	-1.8	
U	**92**	2.6	3.1	3.2	3.6	3.7	4.0	4.0	4.3	4.2	4.3	4.4	4.4	4.4	4.4	4.3	4.2	4.1	3.9	3.6	3.2	2.6	2.6	1.9	1.9	1.1	1.0	0.1	-0.2	-1.2	-1.6	-2.8	
Pa	**91**	2.4	2.8	2.9	3.2	3.2	3.4	3.5	3.5	3.6	3.7	3.7	3.7	3.7	3.7	3.6	3.5	3.4	3.2	2.9	2.6	2.1	2.0	1.4	1.3	0.6	0.4	-0.5	-0.8	-1.9	-2.5	-4.8	
Th	**90**	1.9	2.1	2.2	2.6	2.6	2.7	2.8	2.9	2.9	3.0	3.0	3.0	3.0	2.9	2.8	2.7	2.5	2.3	1.8	1.8	1.2	1.2	0.5	0.3	-0.5	-0.8	-2.0	-2.6	-4.4	-5.7	####	
Ac	**89**	1.1	1.4	1.5	1.7	1.8	1.9	2.0	2.1	2.2	2.2	2.3	2.3	2.2	2.2	2.1	1.9	1.7	1.5	0.9	1.0	0.3	0.3	-0.6	-0.8	-1.9	-2.4	-5.0	####	####	####	####	
Ra	**88**	-0.1	0.2	0.4	0.6	0.8	1.0	1.1	1.2	1.3	1.3	1.3	1.3	1.3	1.2	1.0	0.8	0.4	0.0	-0.7	-0.9	-1.8	-2.1	-3.2	-3.7	-5.3	####	####	####	####	####	####	
		135	**136**	**137**	**138**	**139**	**140**	**141**	**142**	**143**	**144**	**145**	**146**	**147**	**148**	**149**	**150**	**151**	**152**	**153**	**154**	**155**	**156**	**157**	**158**	**159**	**160**	**161**	**162**	**163**	**164**	**165**	**N**

N=126 FACTORY REACH

What regions can it cover for the r-process?



^{252}Cf

^{238}U

Actinides

^{208}Pb

Fission peaks

N = 126

Above the heavy peak

→ longer term, insight into fissionability of heaviest neutron-rich nuclei

CONCLUSION

- Nuclear physics inputs needed to better understand astrophysical *r* process
  - Large ongoing project at ATLAS/CARIBU for measurements on N=82 and rare-earth peak regions.
  - Next step is the N=126 abundance peak

- Atomic masses are the most important nuclear data input for r-process abundance calculations; PI-ICR at the CPT means they can be measured with very low yield.

- The N = 126 beam factory aim to produce nuclei of importance for the r-process that are difficult to access: N = 126 shell, above fission peaks, and actinides.

- Beam factory gas catcher, isobar separator, cooler-buncher and MR-TOF are under assembly or commissioning.

- The N=126 factory can do a lot more than N=126 nuclei.

ACKNOWLEDGEMENTS

Thanks for listening

Collaboration :

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NATIONAL LABORATORY

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G. Savard,
X. Yan ,
B.J. Zabransky

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CHICAGO

University of Manitoba

D. Ray,
K.S. Sharma,
A.A. Valverde

UNIVERSITY OF
NOTRE DAME

M. Brodeur,
B. Liu

MNT REACTIONS: COLLECTION

- Thermalize fragments in He gas
- Transport to end using gas flow, electric fields