中国科学院
CHINESE ACADEMY OF SCIENCES

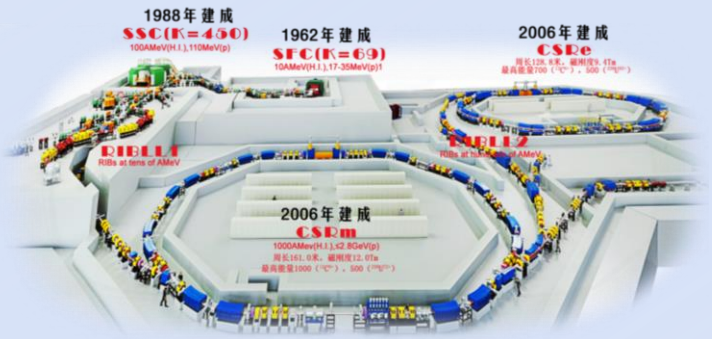
中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

14th ITP/CAS-BLTP/JINR Joint Workshop on Physics of Strong Interacting Systems

SHE studies at the gas-filled recoil separators in IMP

Zhiyuan Zhang

Institute of Modern Physics, Chinese Academy of Sciences



Oct. 18-23, 2026, Nanjing

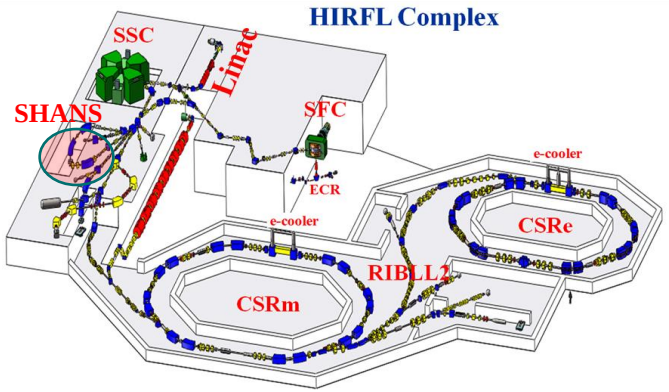


Gas-filled recoil separators in IMP

- Synthesis of heavy and superheavy nuclei
- Decay spectroscopy and nuclear structure
- Mass measurement
- Chemistry on SHEs
- …

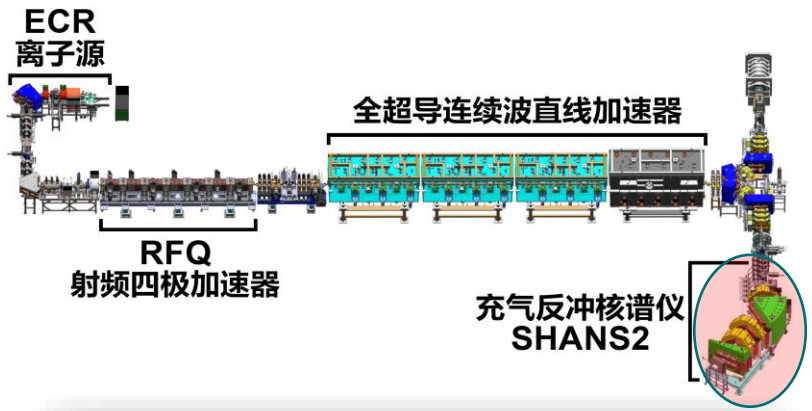
Production: Fusion evaporation reaction
Separation: Gas-filled recoil separators (DGFRS1&2, GRAND, TASCA, GARIS1&2&3, RITU, AGFA, BGS, ...)
Identification: Correlation measurement based on, e.g., α-decay chains, RDT, exc. func., ...

Heavy Ion Research Facility in Lanzhou (HIRFL)



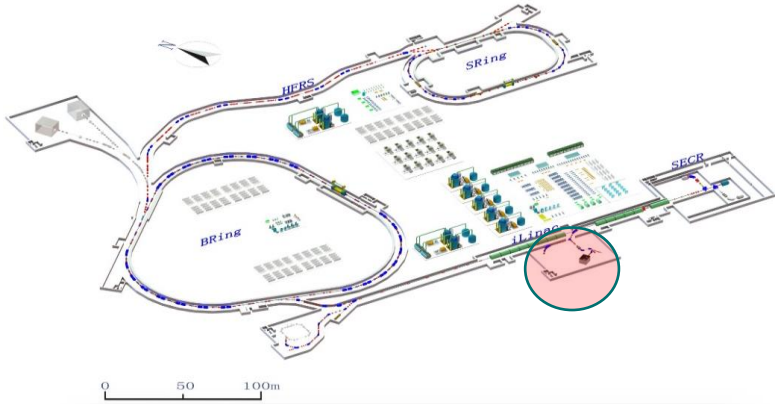


China Accelerator Facility for Superheavy Elements (CAFE2)



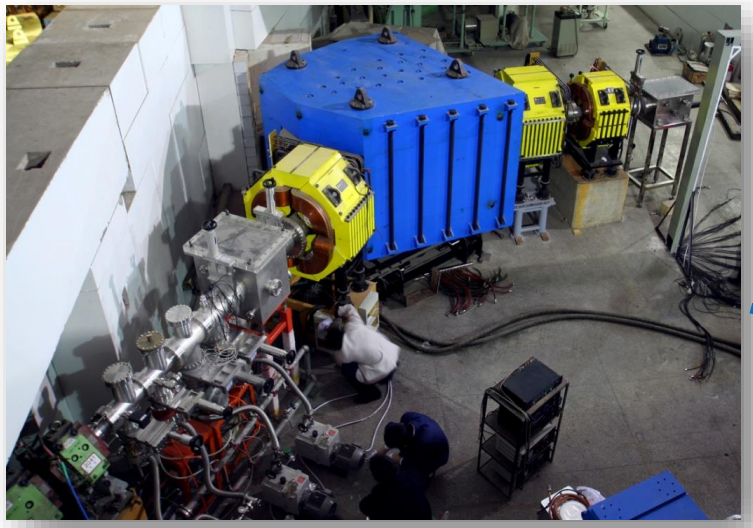


High Intensity Heavy Ion Accelerator Facility (HIAF)





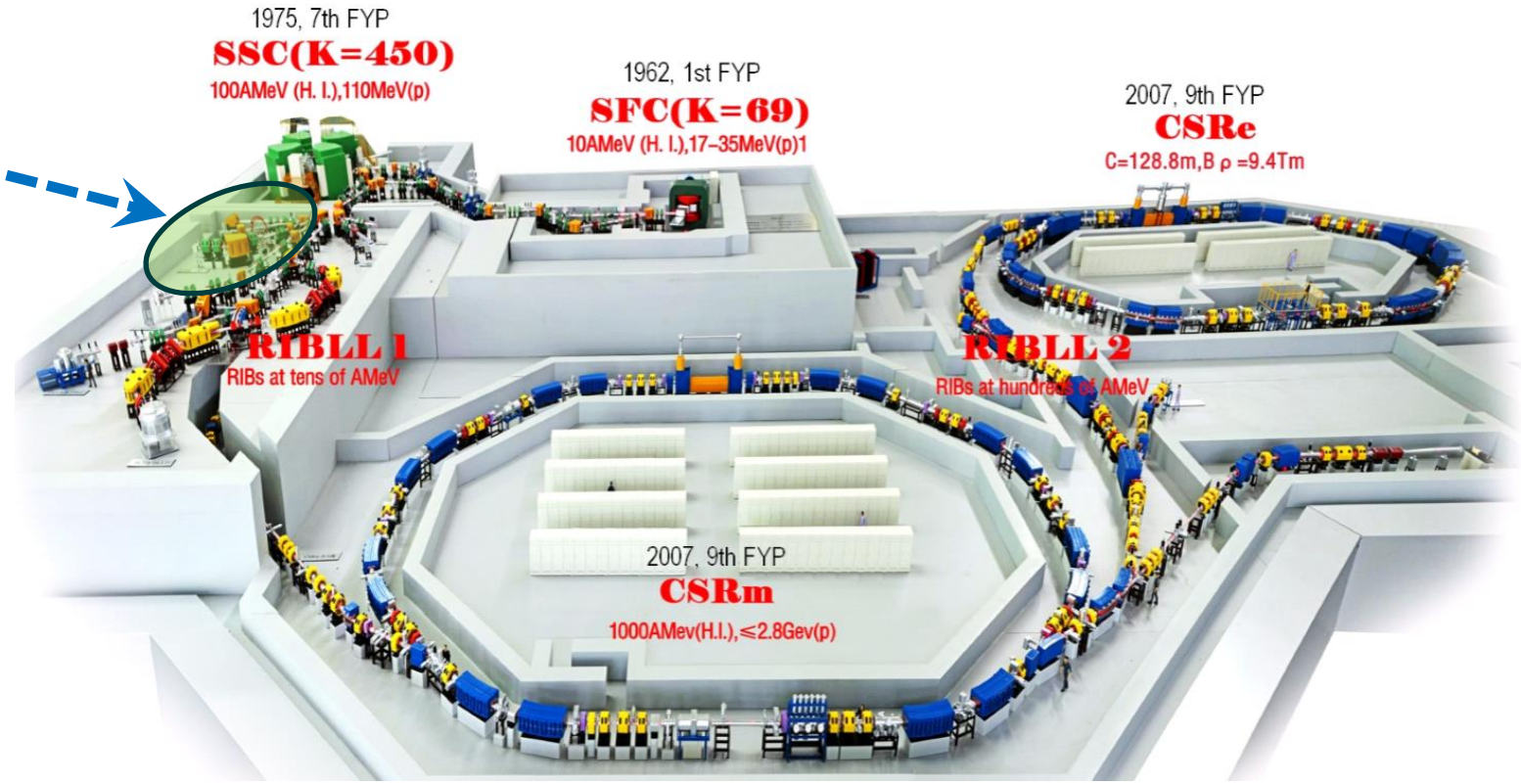
SHANS at HIRFL



***S**pectrometer for **H**eavy **A**toms and **N**uclear **S**tructure (**SHANS**)*
(2006-)

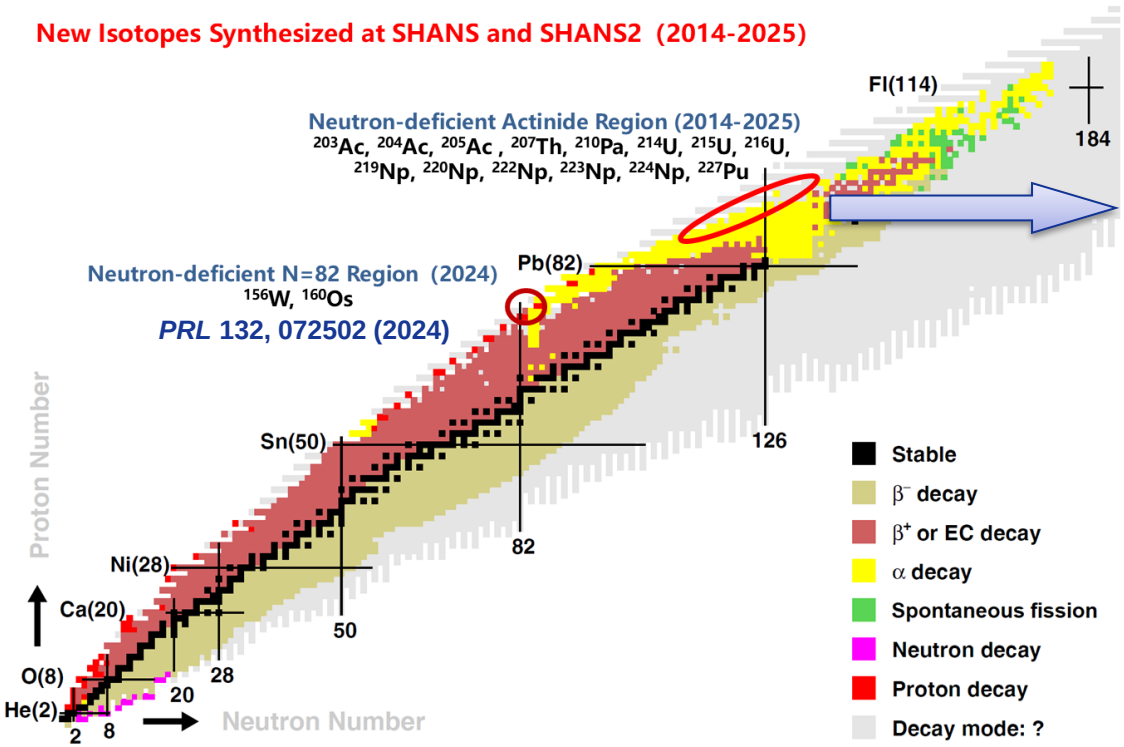
Mode: ECR/SECR + SFC
Ions: Ar, Ca, Ne, Mg, Ni, Kr, …
Energy: ~ 5 MeV/u
Typical Intensity: ~0.5 pμA (^{36,40}Ar)
0.2~0.5 pμA (^{40}Ca)

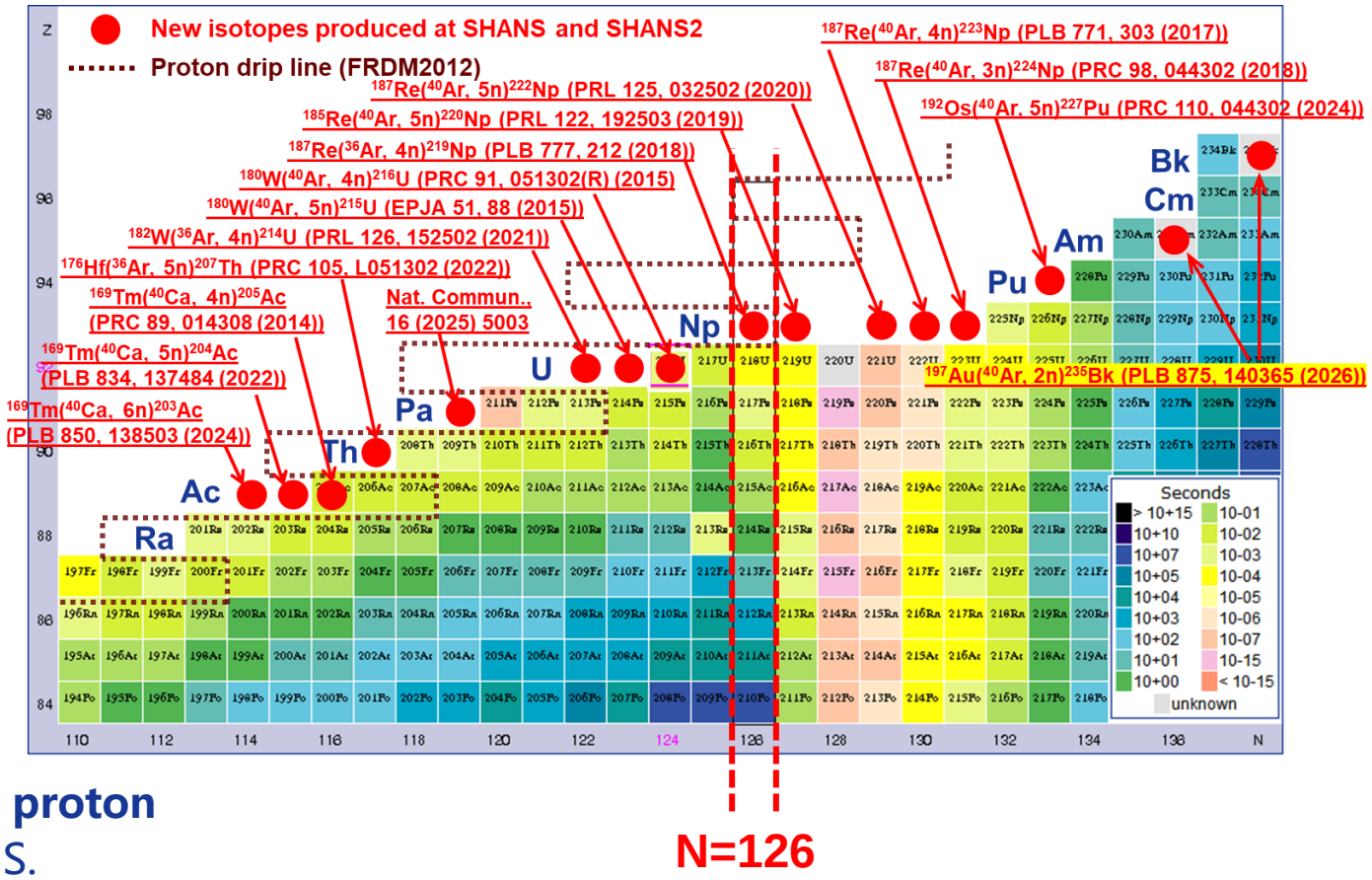
Heavy Ion Research Facility in Lanzhou (HIRFL), China



Z.Y. Zhang, L. Ma, Z.G. Gan, *et al.*, NIM B, 317 (2013) 315-318.

New isotopes discovered at SHANS





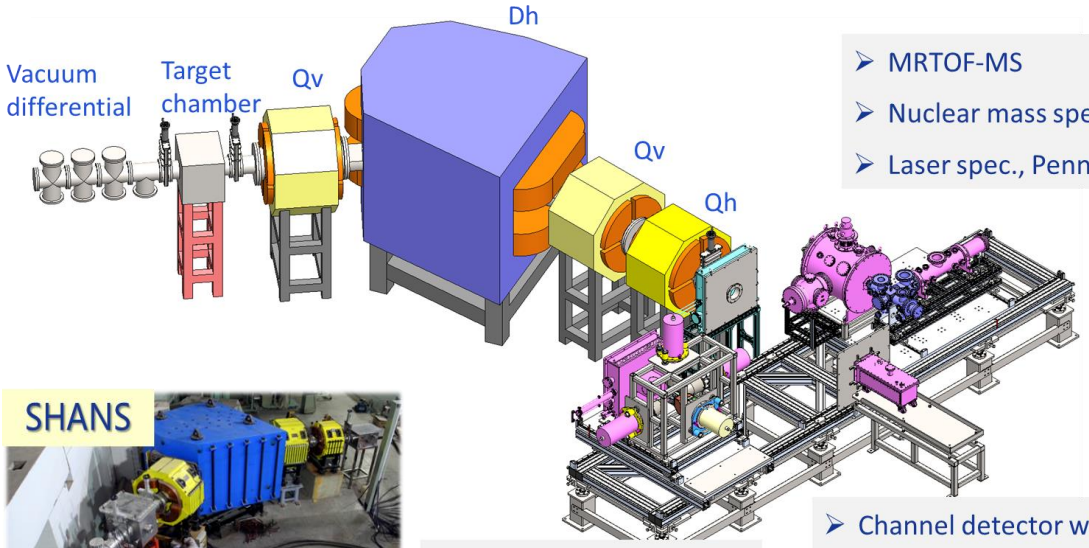
More than ten new isotopes near the **heaviest proton drip line and *N*=126** were synthesized at SHANS.

- α-decay systematics
- Limits on proton drip line
- Shell evolution at N=126
- EC-delayed fission and fission barriers
- …

Challenges:

- Low cross section (pb ~ nb)
- Short half-lives (~μs or lower)
- Multi decay modes, e.g. α, EC, ECDF, …

Progress of SHANS: MRTOF technique



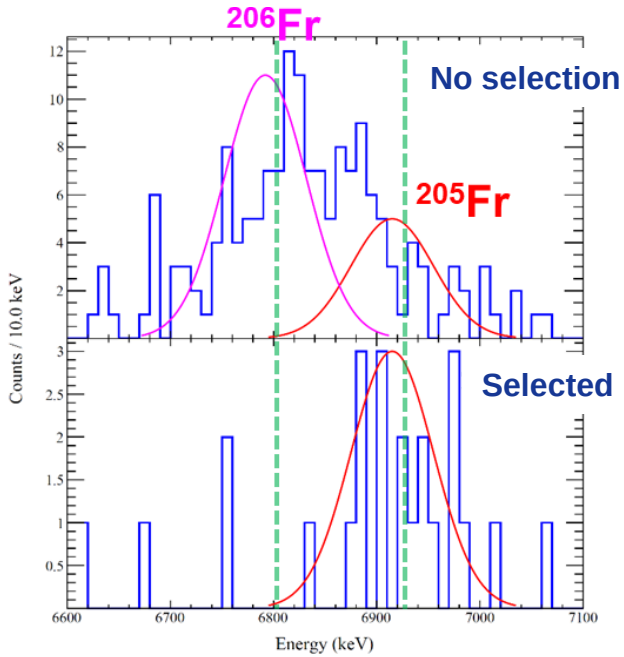
- MRTOF-MS
- Nuclear mass spectrometry
- Laser spec., Penning Trap, ….

- Si box + HPGe detectors
- Decay spectroscopy

- Channel detector with temperature gradient
- Nuclear chemistry study



α spectrum after MRTOF

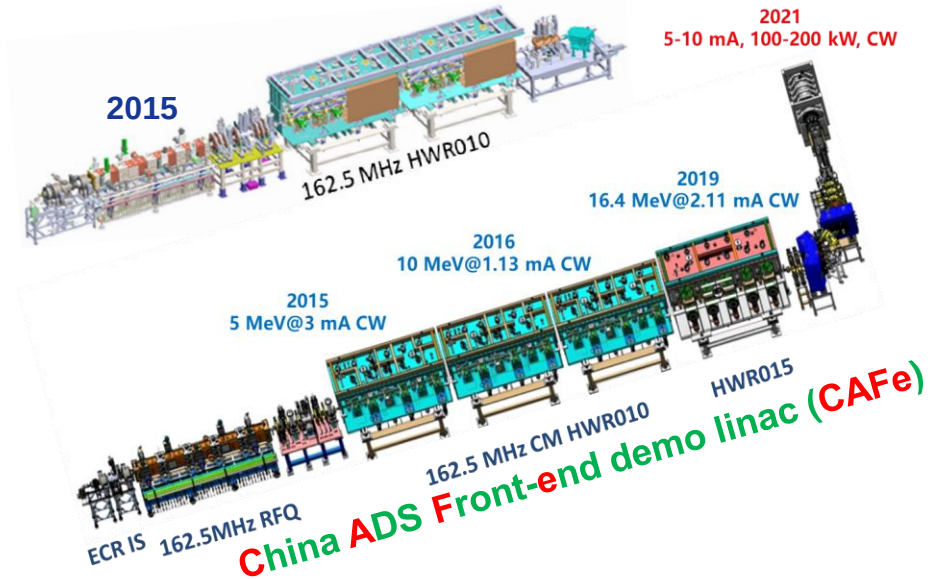


- Si-box + HpGe -> α-γ spectroscopy (J. G. Wang, …)
- Multi-Reflection TOF(MRTOF) -> Mass measurement (W. X. Huang, Y. L. Tian, Y. S. Wang, J. Y. Wang, …)
- Gas chromatography channel detector -> SHE Chemistry (Z. Qin, Y. Wang, M. H. Huang, …)

X. Kong, Y. S. Wang, Y. L. Tian, et al.,, NIMA, 1093 (2027) 172038

Courtesy to Y. L. Tian, W. X. Huang, Y. S. Wang, J. Y. Wang…

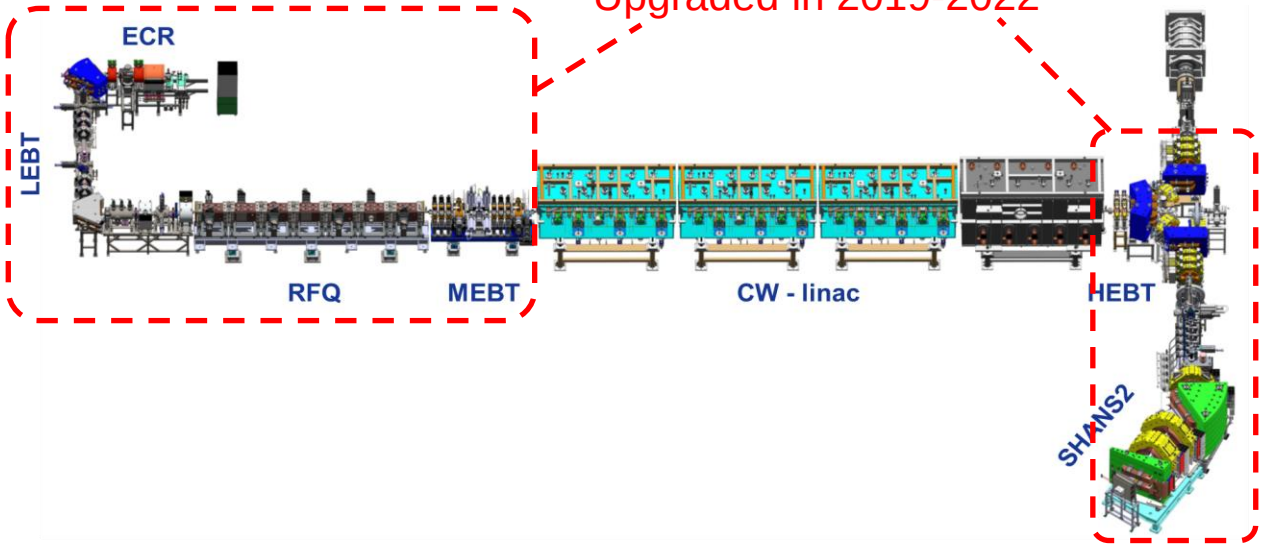
CAFe and CAFE2 at HIRFL



Z. Wang, Y. He, H. Jia, et al., Phys. Rev. Acc. Beams, 19 (2016) 120101.
S.H. Liu, Z.J. Wang, H. Jia, Y. He, et al., NIM A, 843 (2017) 11-17.
L. Gong, Z. Wang, W. Dou, W. Chen, et al., NIM A, 1058 (2024) 168819.

China Accelerator Facility for Superheavy Elements (CAFE2)

Upgraded in 2019-2022





Electron cyclotron resonance ion source (ECRIS) (14+18 GHz)



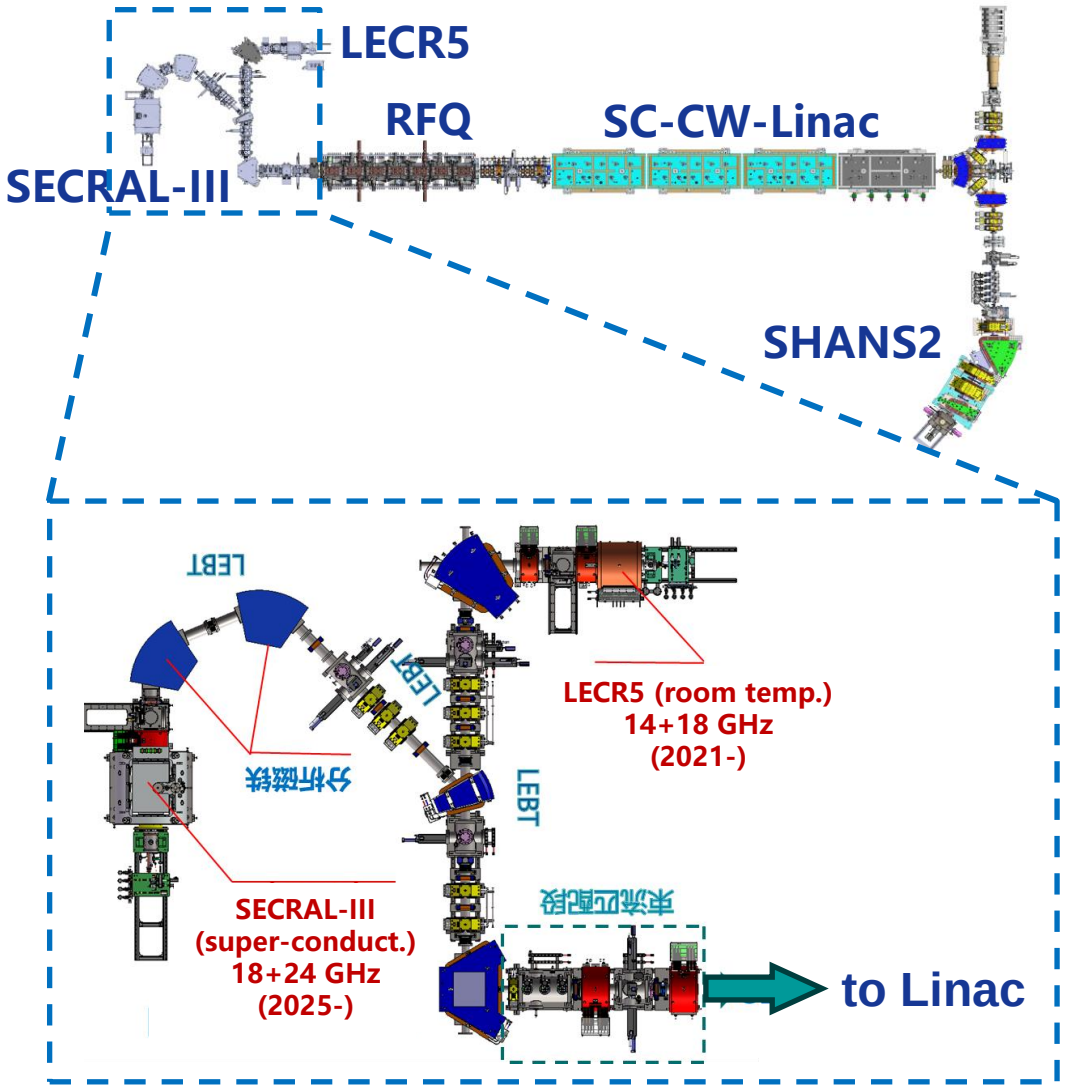
Radio frequency quadrupole accelerator (RFQ)



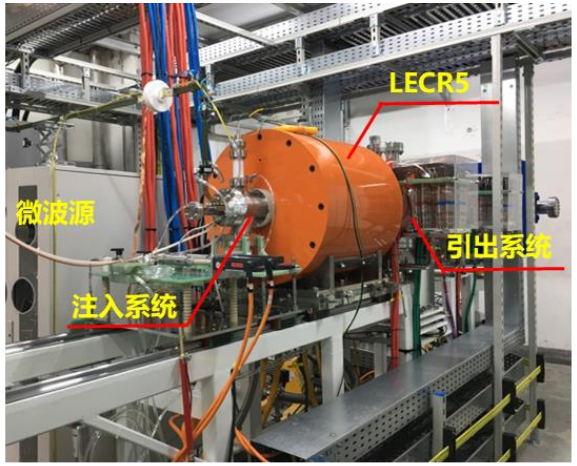
Super-conducting linear accelerator (CW - Linac)

Progress of CAFE2: New superconducting ion source

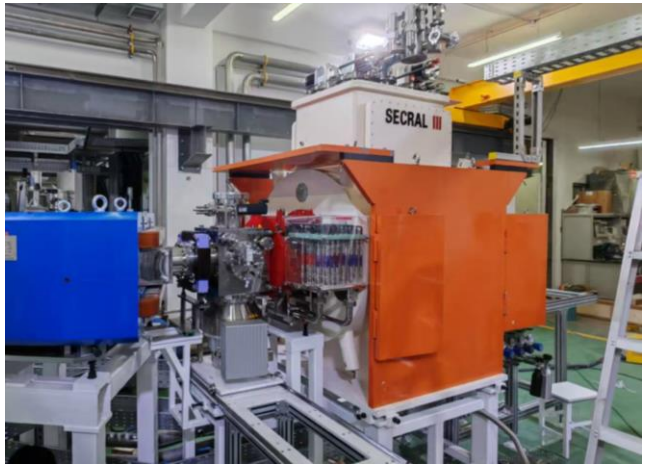
China Accelerator Facility for Superheavy Elements (CAFE2)



CAFE2 running time (2022 ~ 2025)					
Ions	Highest Intensity (pμA)	Beam time (h)	Ions	Highest Intensity (pμA)	Beam time (h)
40Ar12,13+	14.8	3083	48Ca14+	1.5	2352
40Ca13+	5	717	52Cr17+	1.5	1371
55Mn17+	2	134	54Cr17,18+	2	5143
Total beam time at SHANS2 >12000 h					



LECR5 (room temp.)
(2021-)

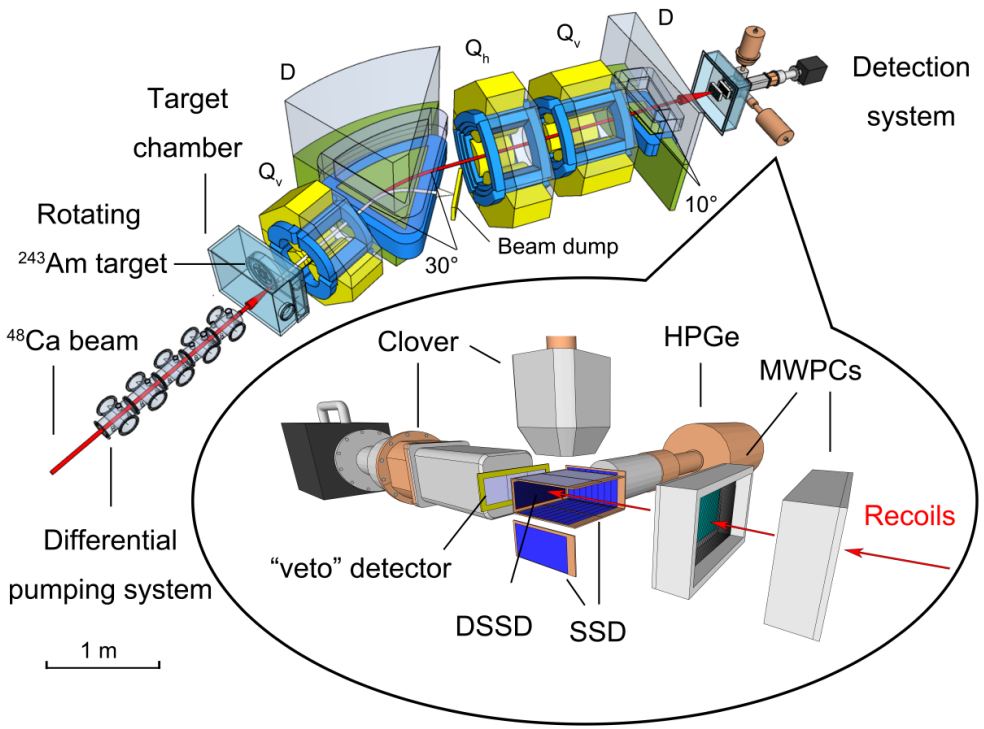


SECRAL-III (super-conduct.)
(2025-)

W. Lu, et al., NIM A, 1062 (2024) 169207

Courtesy to Wang Lu, Chen Qian, Hongyi Ma, ...

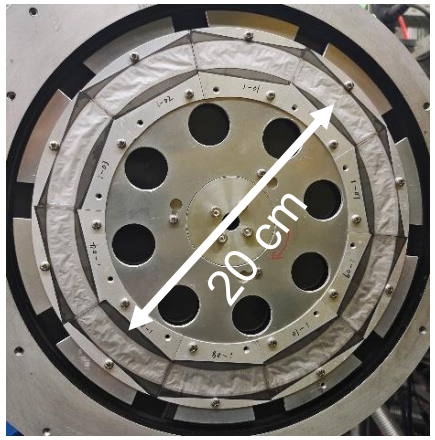
SHANS2 at CAFE2

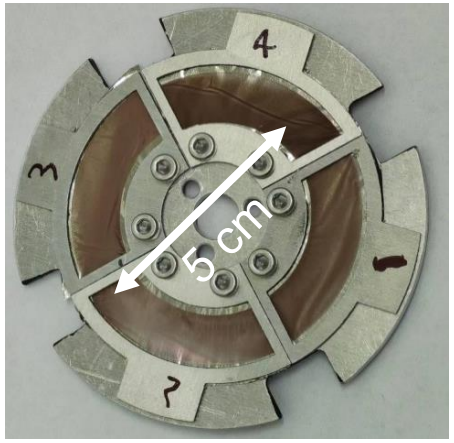


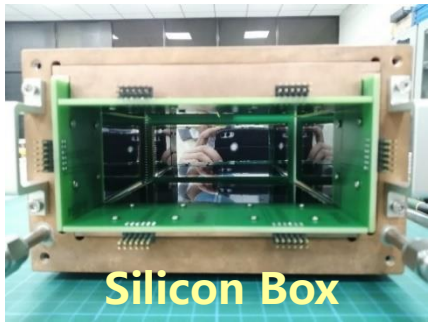


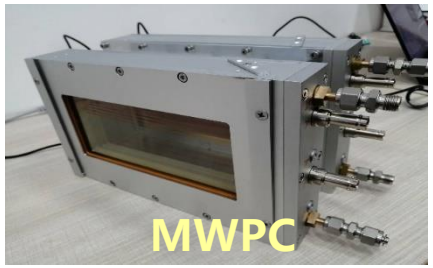
Rotating target

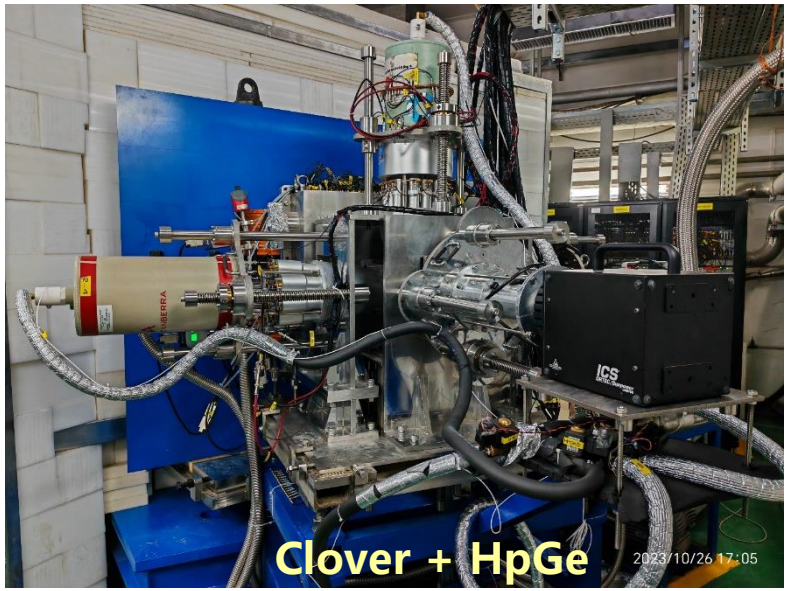








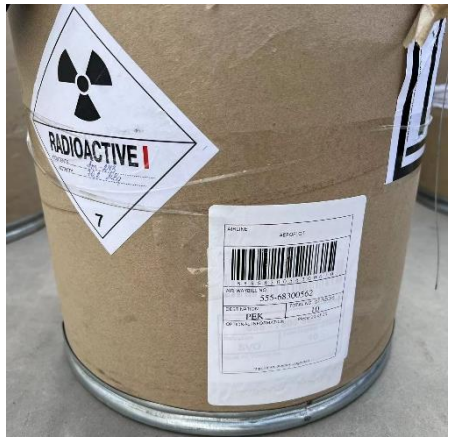




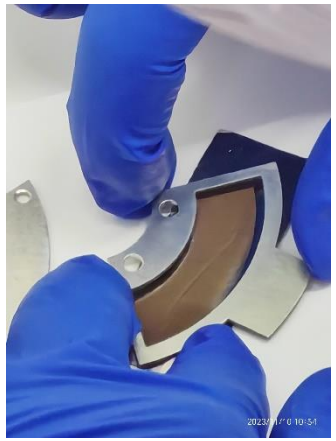
S.Y. Xu, Z.Y. Zhang, Z.G. Gan, et al., NIMA, 1050 (2023) 168113

L.N. Sheng, Q. Hu, H. Jia, et al., NIMA, 1004 (2021) 165348

Radioactive target – ^{243}Am



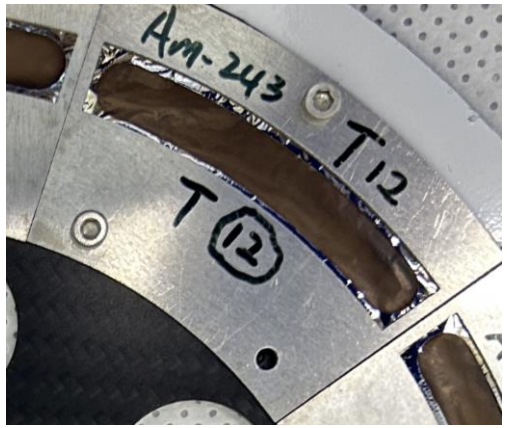












Before irradiation



After irradiation

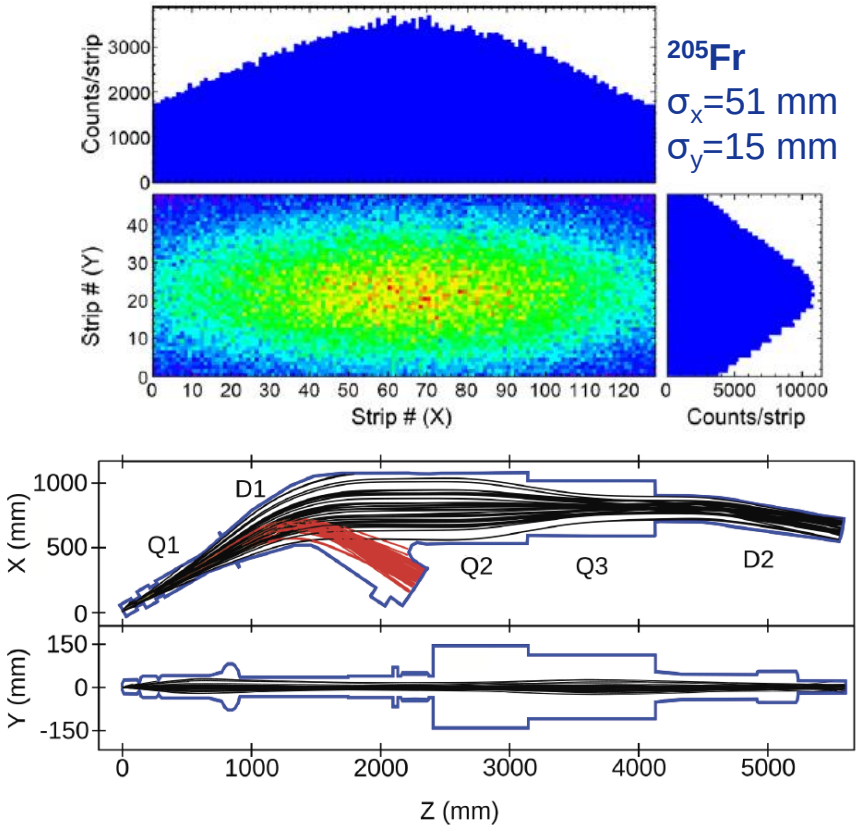
Beam	^{40}Ar, ^{54}Cr
^{243}Am Thickness	513 ± 7 μg/cm^2
Intensity	~ 1 pμA
Beam time	83 days
Beam dose	2.6 × 10^{19}

Courtesy to Xiaojie Yin, Yang Wang, Qin Zhi, Minghui Huang, Chunli Yang, Zaiguo Gan, Long Ma, …

Transmission of SHANS2

Lab	Setup	Gas	Measured Transmission	Simulated Transmission
IMP-CAS	SHANS2	He (100 Pa)	67(11)% (^{48}Ca+^{208}Pb) 58(32)% (^{40}Ar+^{169}Tm)	51% (^{48}Ca+^{208}Pb) 50% (^{40}Ar+^{169}Tm)

^{40}Ar+^{169}Tm @ 178.5 MeV



Monte Carlo simulation

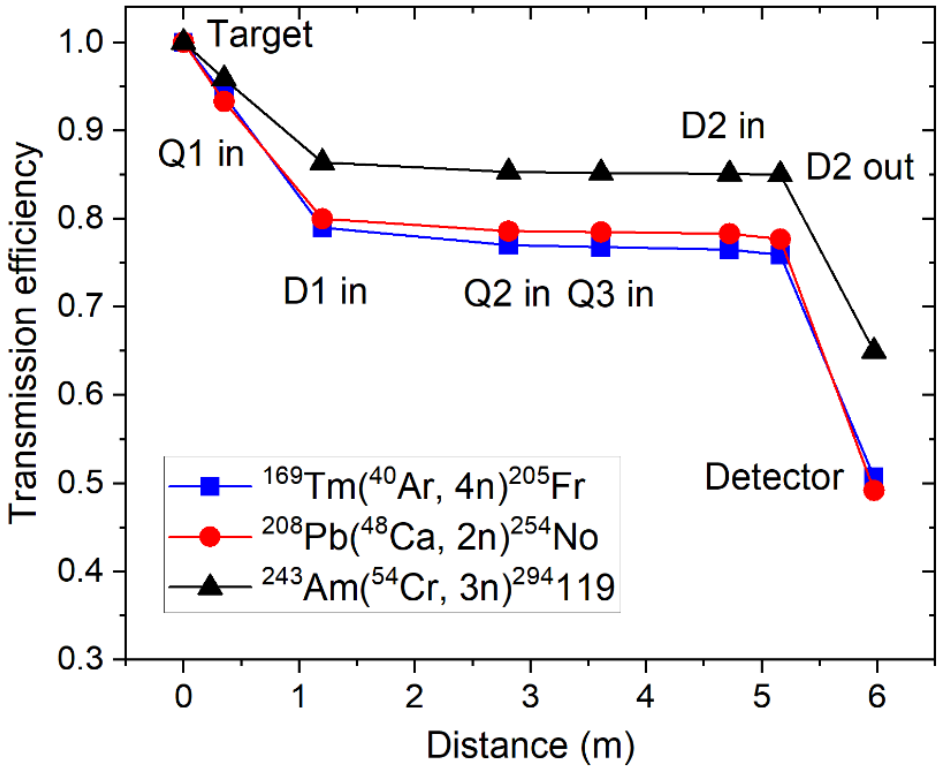


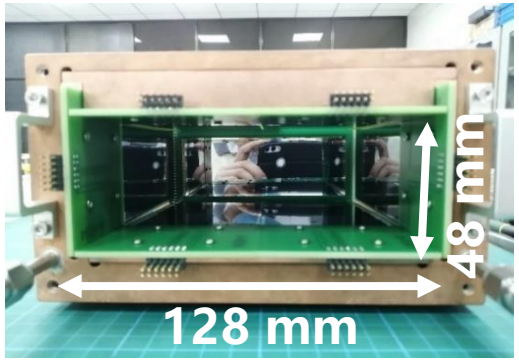
Table 1
Detailed specifications of the magnets in SHANS2.

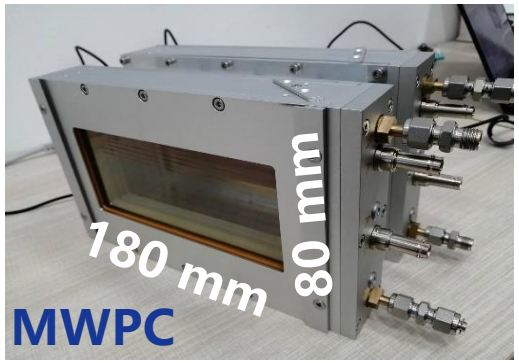
Parameters	Values
Configuration	$Q_vDQ_hQ_vD$
Total length	5.97 m
Horizontal/vertical acceptance	±70/±113 mrad
Q_1 magnet	
Distance from the target point to Q_1	0.35 m
Effective length	0.46 m
Aperture radius	81 mm
Maximum field gradient	11.85 T/m
D_1 magnet	
Distance from Q_1 to D_1	0.39 m
Effective length	0.838 m
Deflection angle	30°
Entrance angle	0°
Exit angle	−34°
Deflection radius	1.6 m
Maximum magnetic field	1.563 T
Vertical gap	±79 mm
Q_2 magnet	
Distance from D_1 to Q_2	0.77 m
Effective length	0.45 m
Aperture radius	162 mm
Maximum field gradient	4.2 T/m
Q_3 magnet	
Distance from Q_2 to Q_3	0.35 m
Effective length	0.63 m
Aperture radius	157 mm
Maximum field gradient	5.03 T/m
D_2 magnet	
Distance from Q_3 to D_2	0.48 m
Effective length	0.436 m
Deflection angle	10°
Entrance angle	−10°
Exit angle	10°
Deflection radius	2.5 m
Maximum magnetic field	1.1 T
Vertical gap	±93 mm
Distance from D_2 to the focal plane	0.81 m

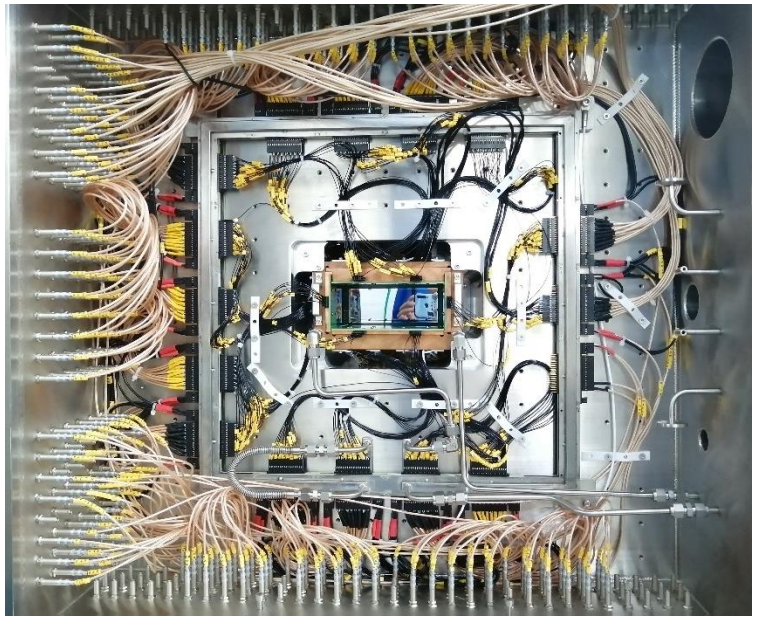
S.Y. Xu, Z.Y. Zhang, Z.G. Gan, et al., NIMA, 1050 (2023) 168113
M. M. Zhang, et al., Nucl. Instrum. Meth. A 1086, 171376 (2026)

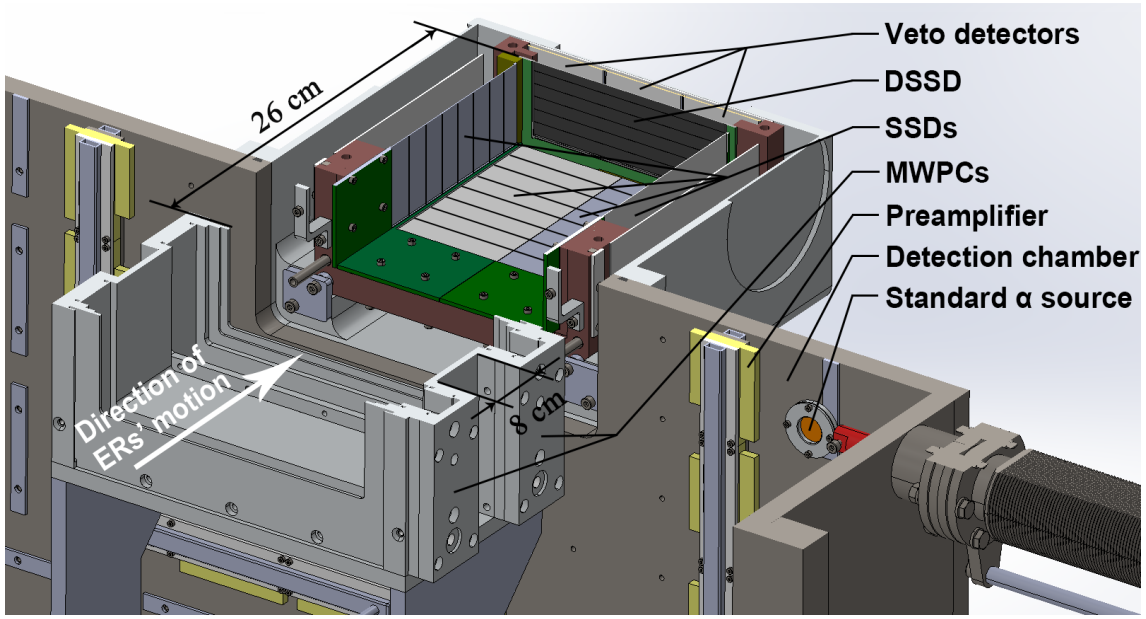
Detection System: MWPC and Si-Box

DSSD+SSD detectors

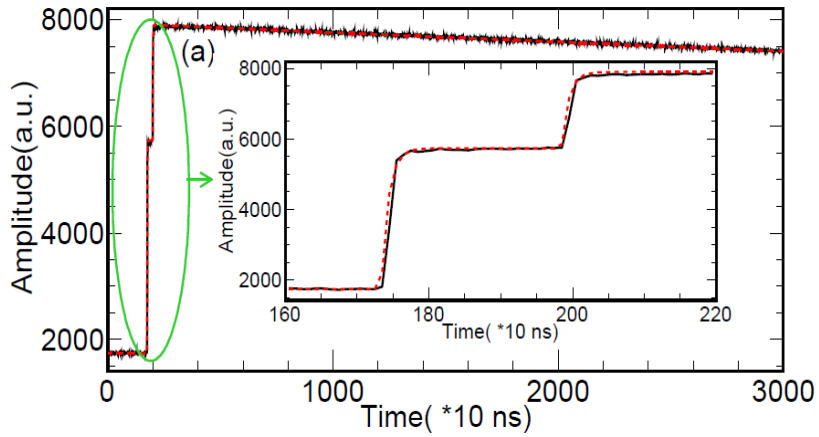






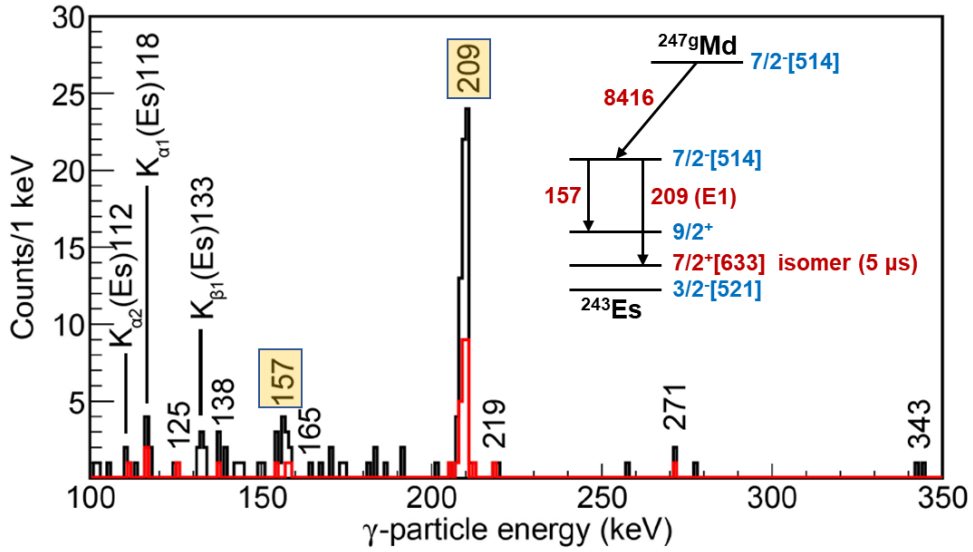


- Active area: 128 x 48 mm² (DSSD), 120 x 63 mm² x 6 (SSD), 50 x 50 mm² x 3 (Veto)
- Thickness: 300 μm (DSSD, Veto), 500 μm (SSD)
- Total detection efficiency for α's: 86(8)%
- Energy resolution: 30 keV (DSSD), 80 keV (DSSD+SSD)
- Cooling down to -20 ℃ with alcohol
- MWPC: 300 Pa isobutane; 0.9 μm-thick Mylar window
- Digital electronics: 100 MHz, 14 bit, trace + PHA (FPGA)



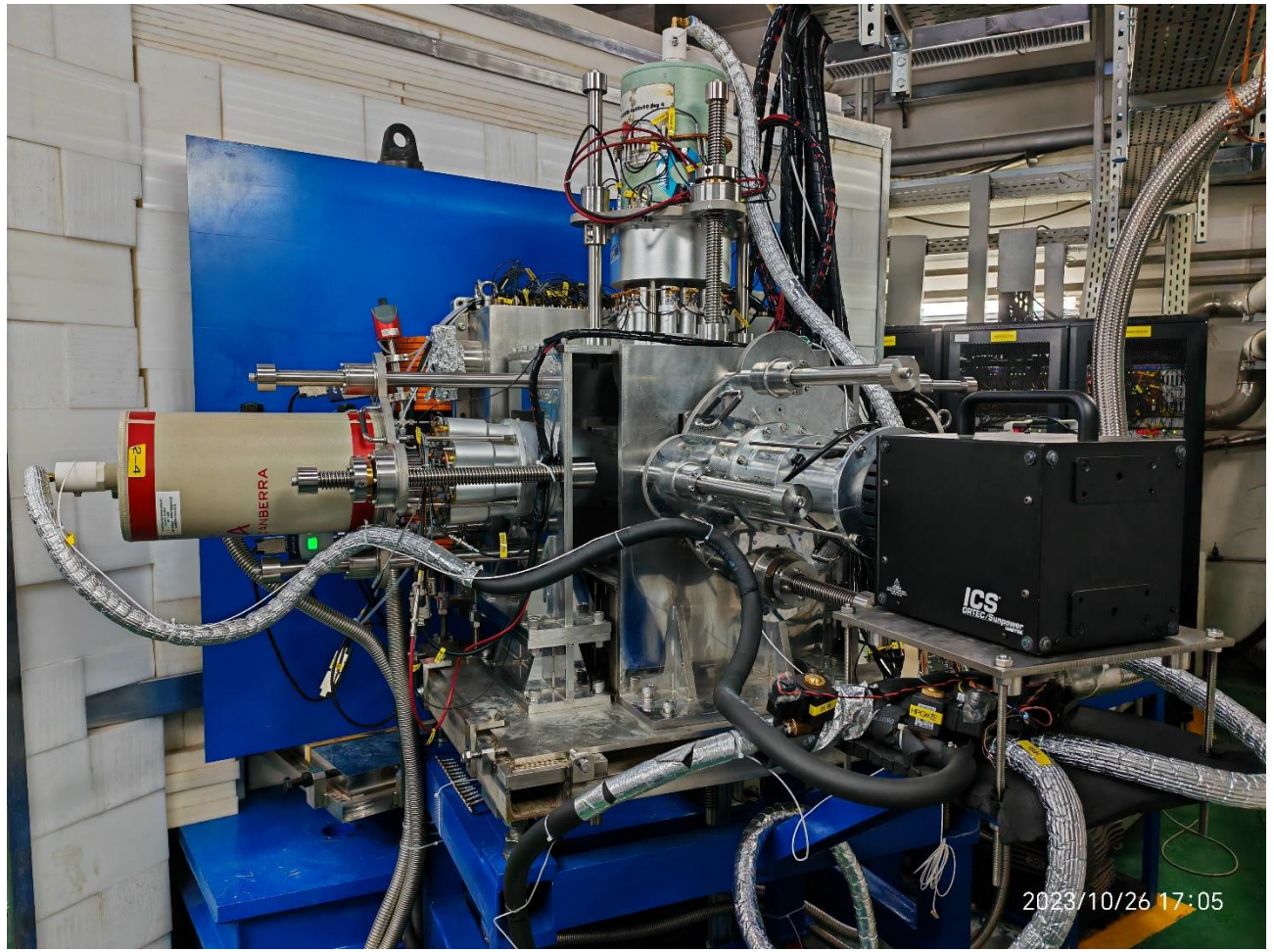
Detection System: Clover and HPGe array

- Shielding: 1.5 mm Aluminium
- Clover: 4 crystals with 60-mm diameter and 90-mm length, 40% relative efficiency for each
- HpGe: 71-mm diameter and 72 mm length, 70% relative efficiency
- Absolute eff. : ~11% (63 keV)
- Energy resolution: ~3 keV@122 keV
- Electrical cooling and liquid nitrogen cooling

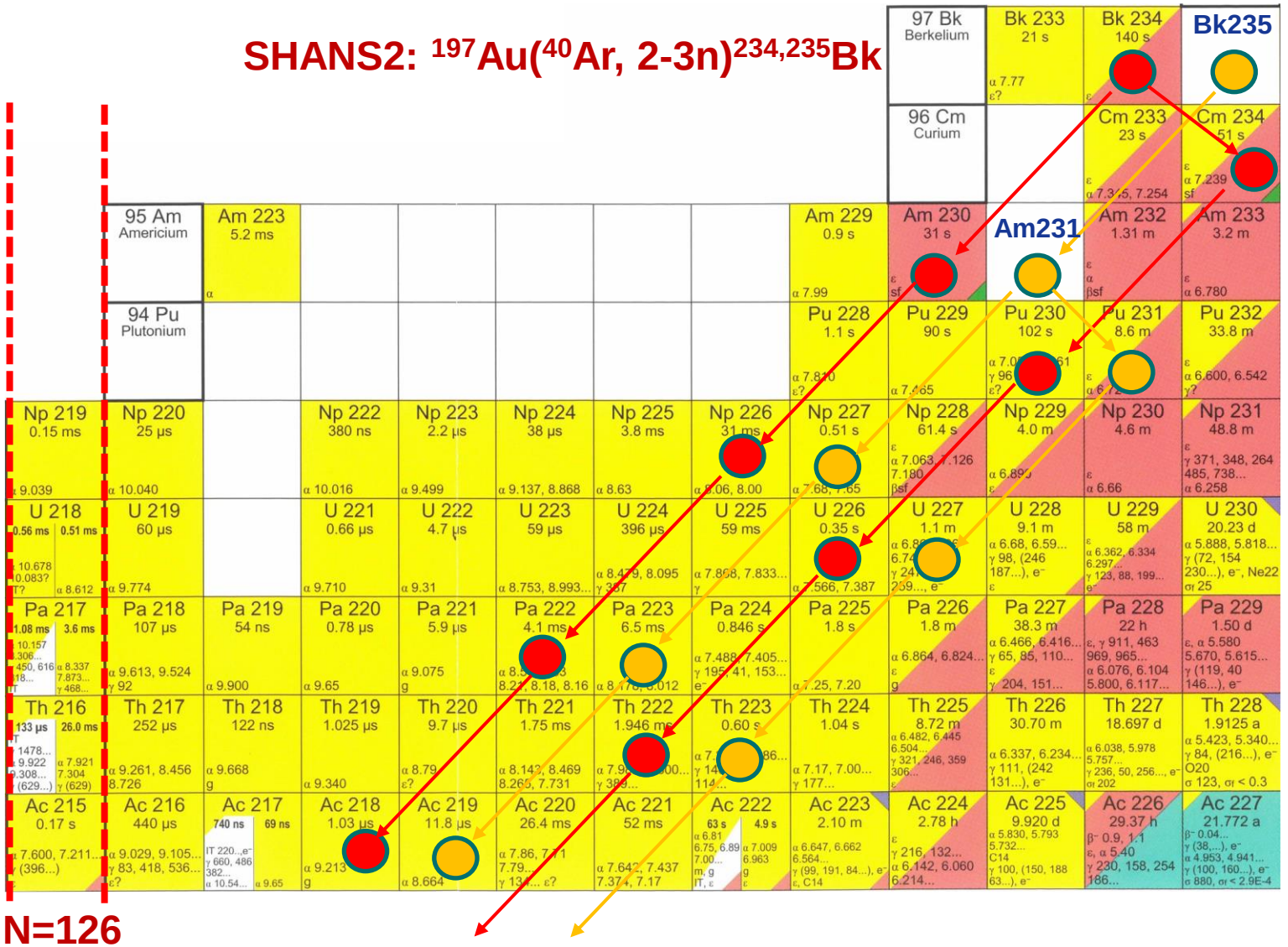


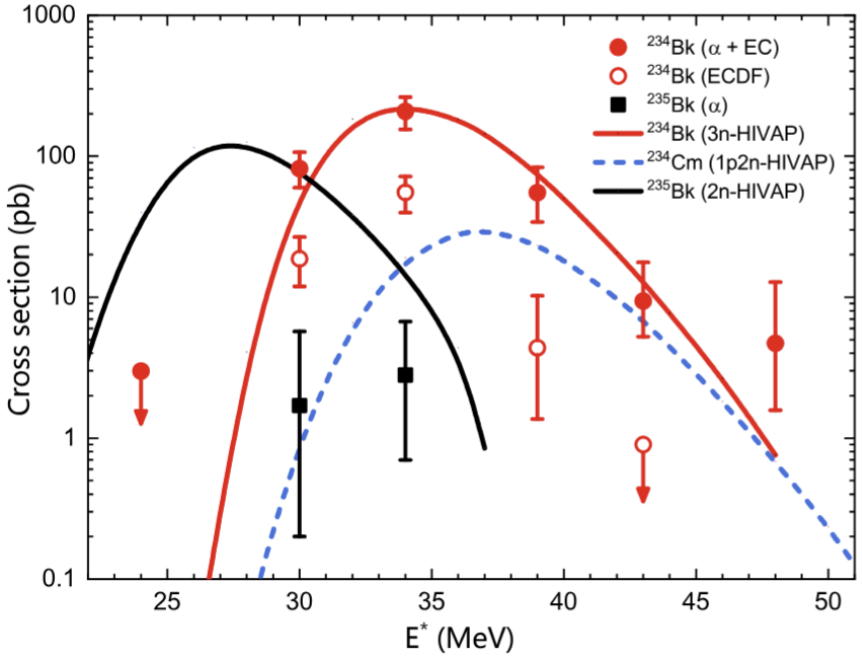
S. Y. Xu, ZYZ, et al, PRC, 112 (2025) 034315

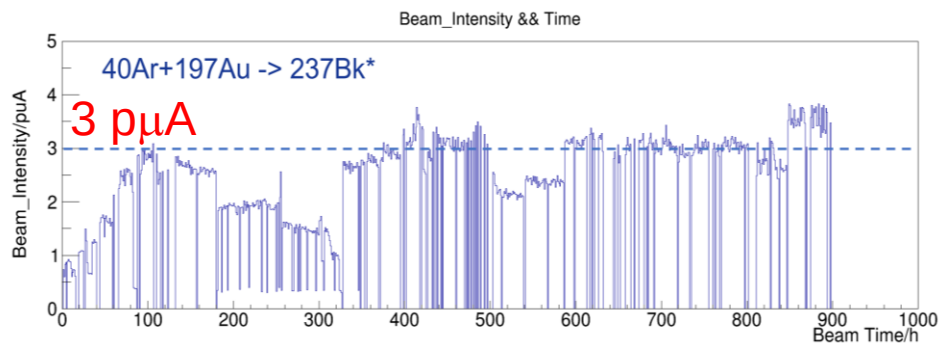
CLOVER and HPGe array



New isotopes ^{235}Bk and ^{231}Am







New isotopes ^{235}Bk and ^{231}Am

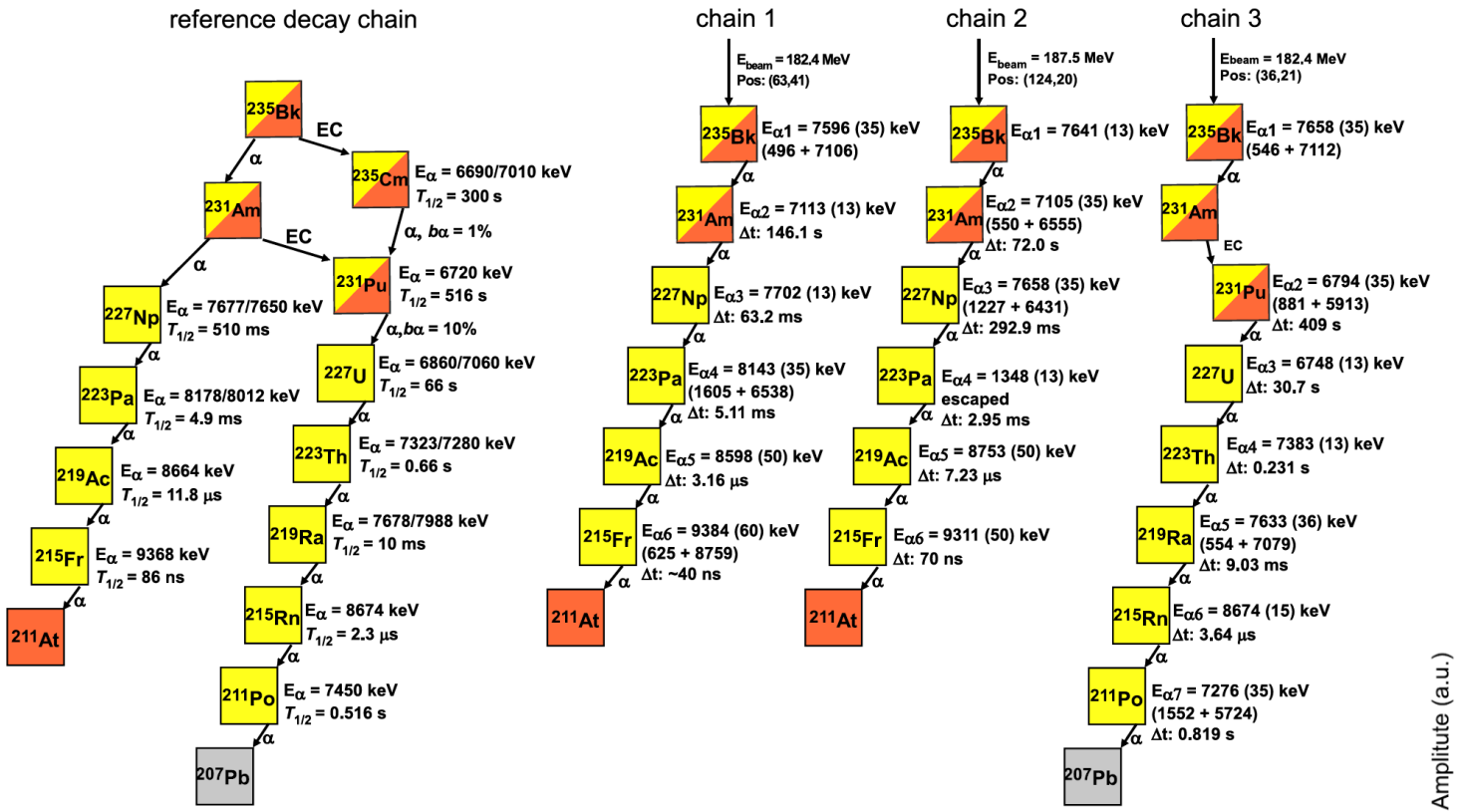


Table 1

Decay properties of ^{235}Bk and ^{231}Am. The Q_{EC} was deduced with use of the mass table [3] and Q_α in this work.

Nuclide	E_α (keV)	$T_{1/2}$(s)	Q_α (keV)	Q_{EC} (keV)
^{235}Bk	7632(17)	–	7764(17)	4417(128)
^{231}Am	7109(18)	75^{+137}_{-30}	7234(18)	3929(82)

$$b_\alpha(^{231}Am) = 17^{+65}_{-15}\%$$

Phys. Lett. B 875 (2026) 140365

Contents lists available at ScienceDirect

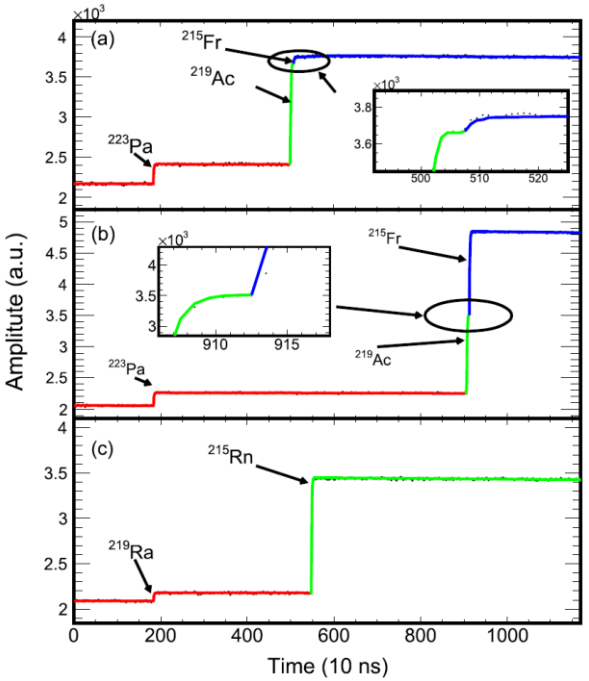
Physics Letters B

journal homepage: www.elsevier.com/locate/physletb

Letter

Decay properties of new isotopes ^{235}Bk and ^{231}Am

J.G. Wang [a,b], Z.C. Li [a,b], Z.Y. Zhang [a,b,*], Z.G. Gan [a,b,c,*], A.N. Andreyev [d,e], M.H. Huang [a,b,c], L. Ma [a,b,c], M.M. Zhang [a,b], H.B. Yang [a,b], C.L. Yang [a,b], Y.H. Qiang [a,b], Z.H. Li [a,b], X.Y. Huang [a,b], G. Xie [a,b], L. Zhu [a,b], H. Zhou [a,b], X. Zhang [a,b], J.H. Zheng [a,b], S.Y. Xu [a,b], Z. Zhao [a,b], L.C. Sun [a,f], F. Guan [a,g], X.L. Wu [a,c], W.X. Huang [a,b,c], Y.L. Tian [a,b,c], Y.S. Wang [a,c], J.Y. Wang [a,c], Z.W. Lu [a], Y. He [a,b], L.T. Sun [a,b], Z.Z. Ren [h], S.G. Zhou [b,i], V.K. Utyonkov [j], A.A. Voinov [j], Yu.S. Tsyganov [j], A.N. Polyakov [j]



Chain 1

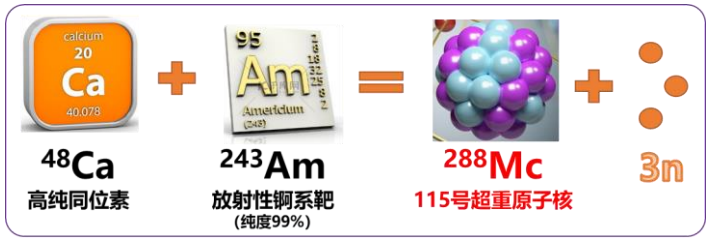
Chain 2

Chain 3

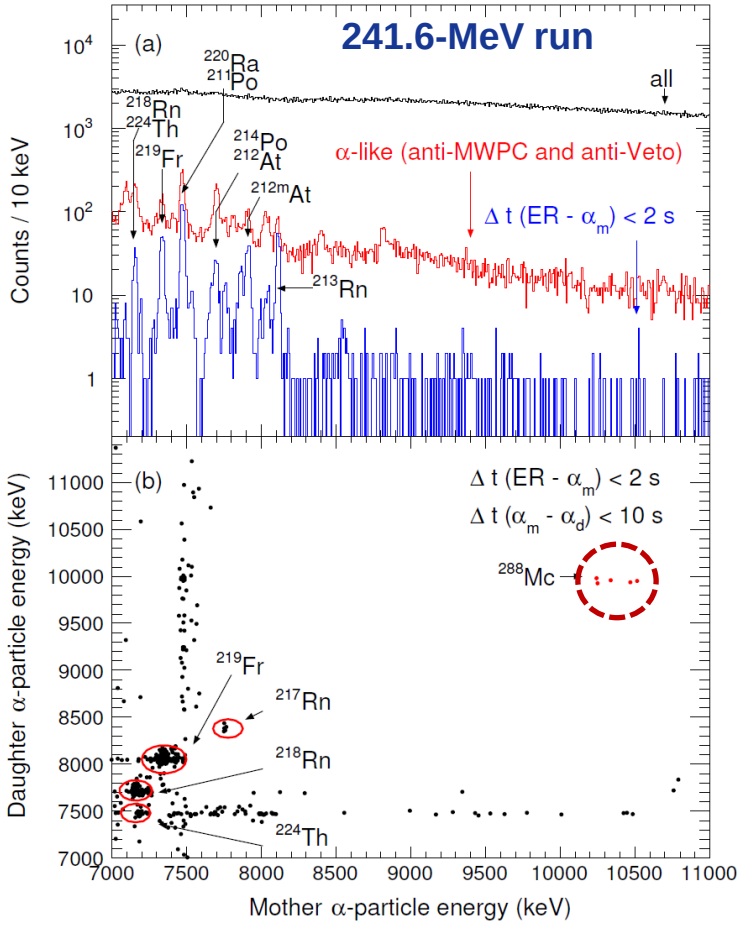
J.G. Wang, Z.C. Li, Z.Y. Zhang, *et al.*, Physics Letters B, 875 (2026) 140365.

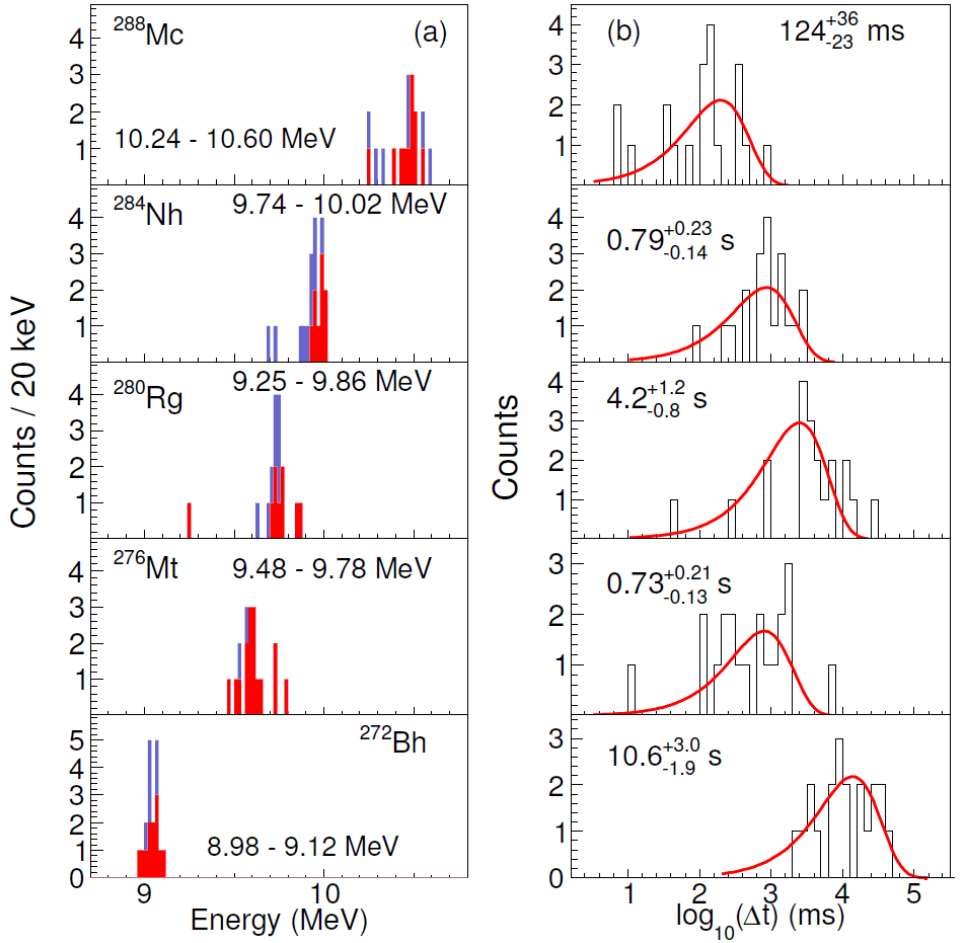
J. Khuyagbaatar, *et al.*, New isotope 231Am, Phys. Rev. C, 114 (2026) L011302.

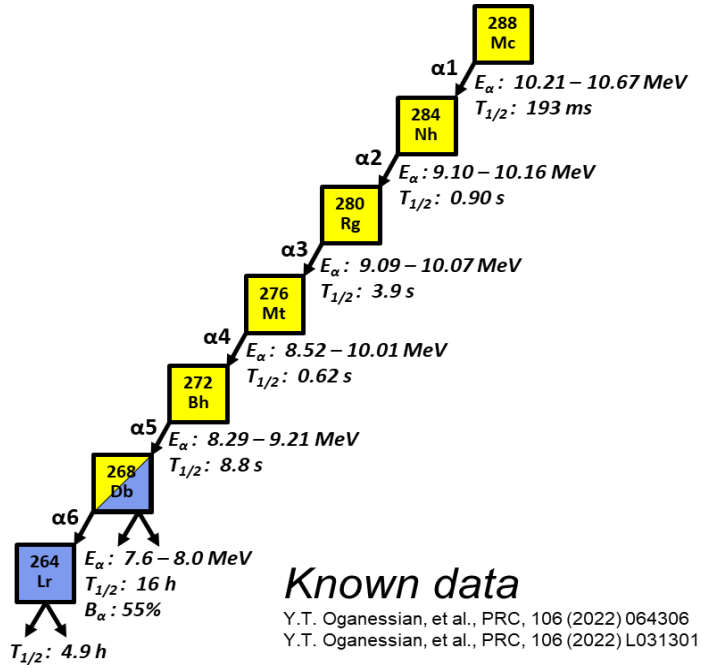
Synthesis of superheavy nuclei ^{287,288}Mc (Z=115)



^{48}Ca+^{243}Am->^{287,288}Mc+3,4n @ 235~248 MeV







Known data

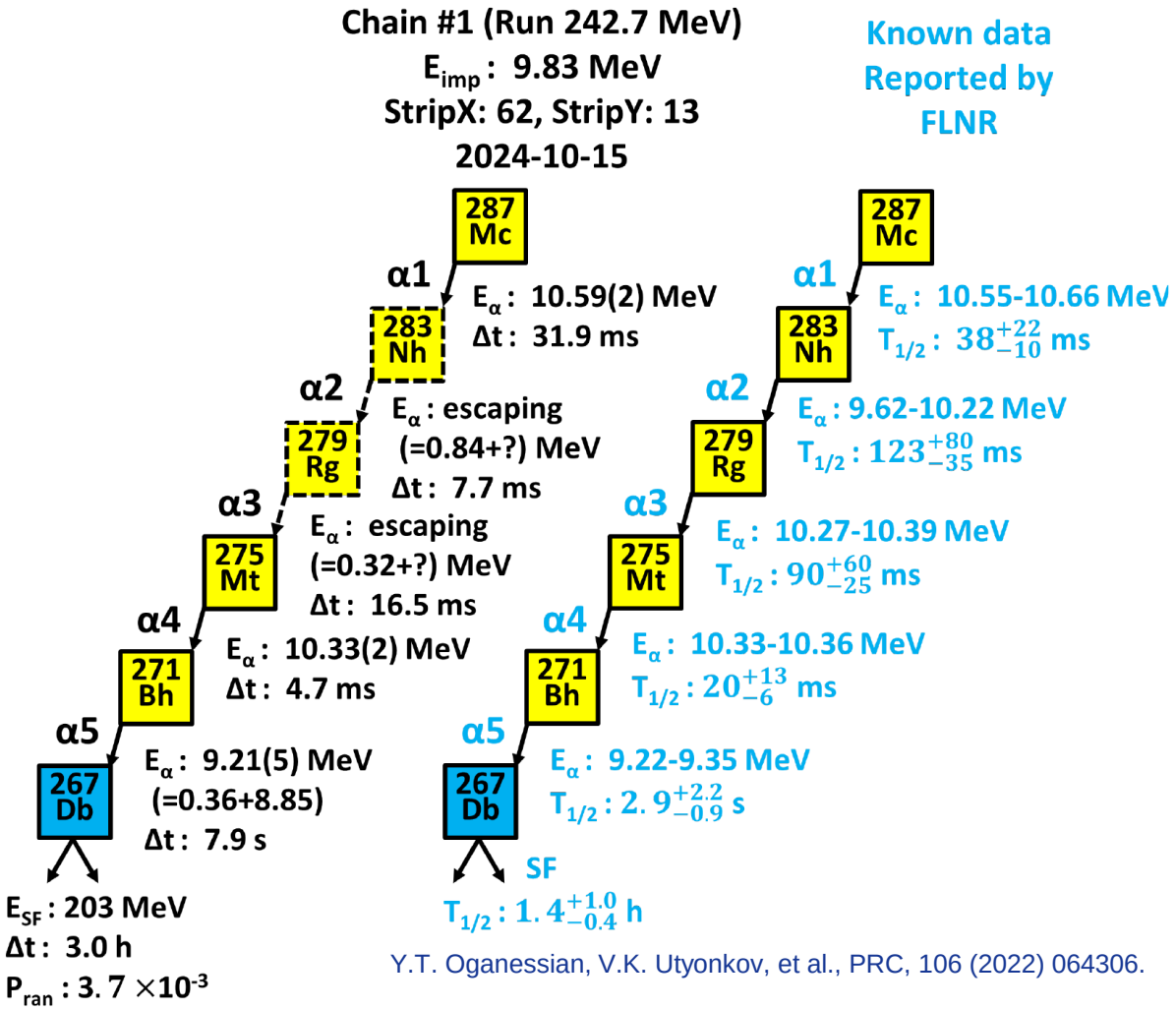
Y.T. Oganessian, et al., PRC, 106 (2022) 064306
Y.T. Oganessian, et al., PRC, 106 (2022) L031301

D. Rudolph, et al., Phys. Rev. Lett., 111, 112502 (2013)
J. M. Gates, et al., Phys. Rev. C 92, 021301 (2015)

20 events assigned to ^{288}Mc

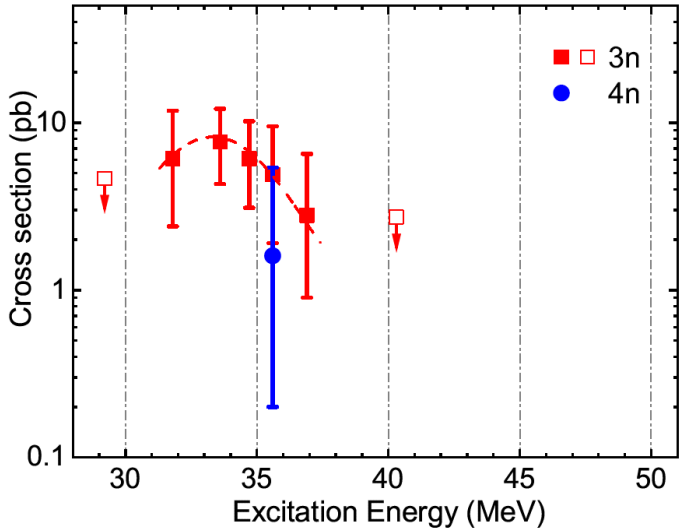
X. Y. Huang, ZYZ, et al, Chinese Physics Letters, 43, 010101 (2026)

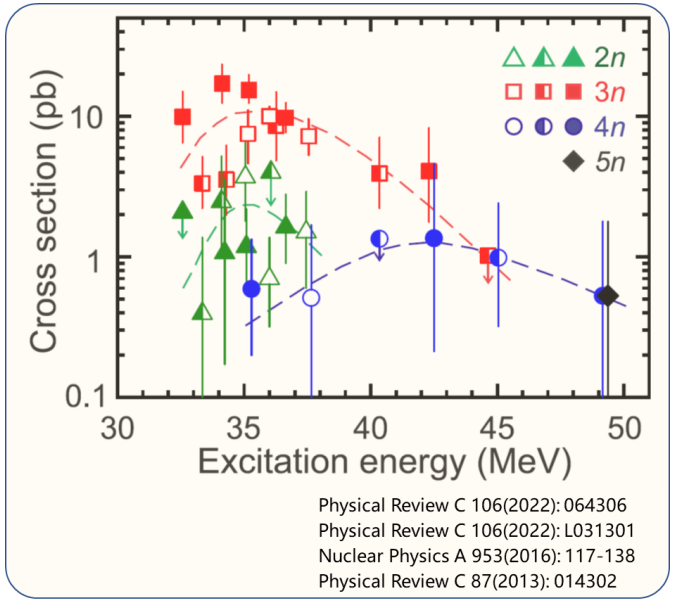
Synthesis of superheavy nuclei ^{287,288}Mc (Z=115)



Y.T. Oganessian, V.K. Utyonkov, et al., PRC, 106 (2022) 064306.

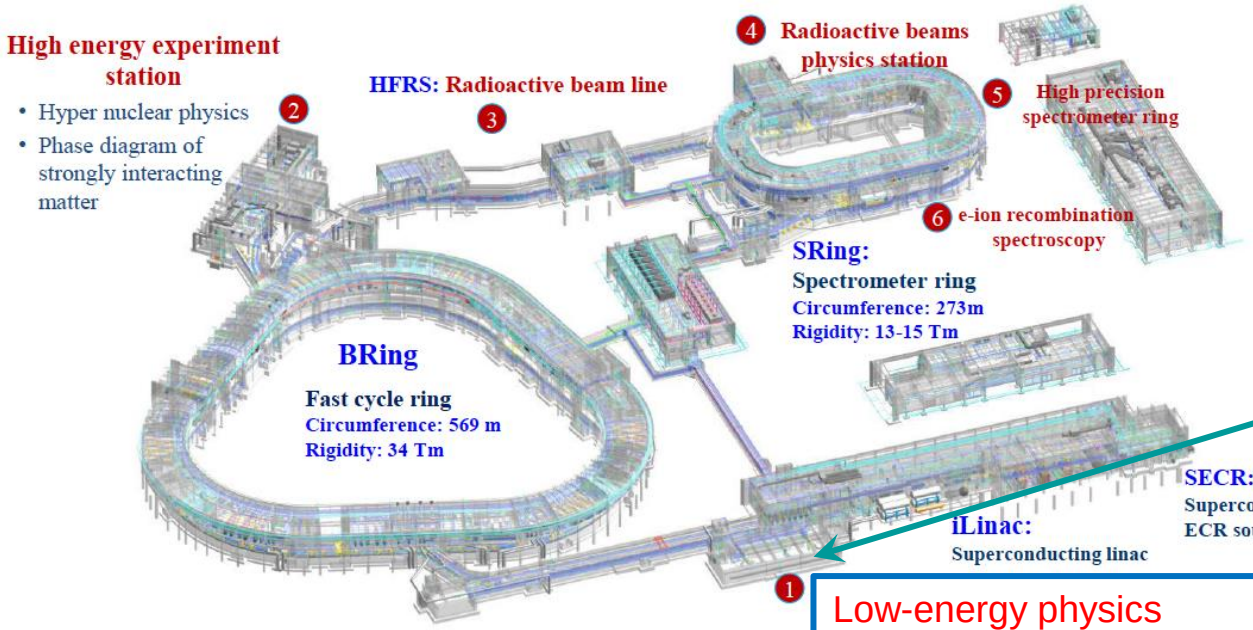
X. Y. Huang, ZYZ, et al, Chinese Physics Letters, 43, 010101 (2026)





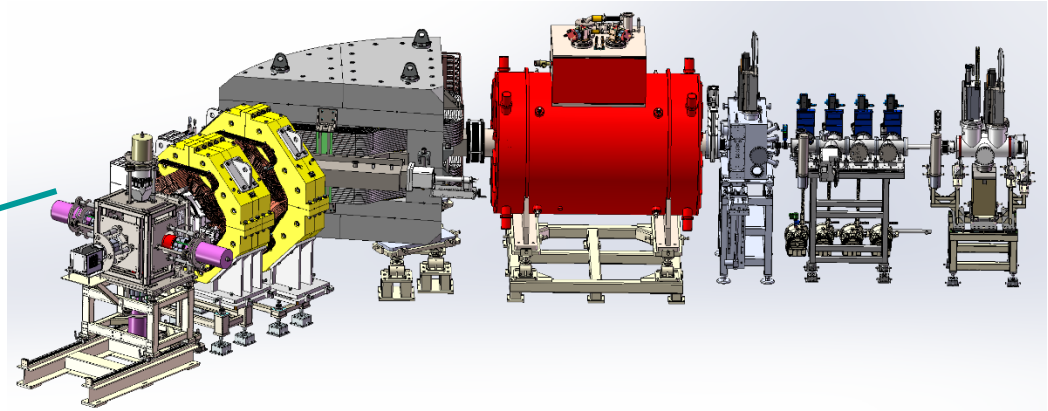
New gas-filled separator at HIAF

High Intensity Heavy-ion Accelerator Facility (HIAF)

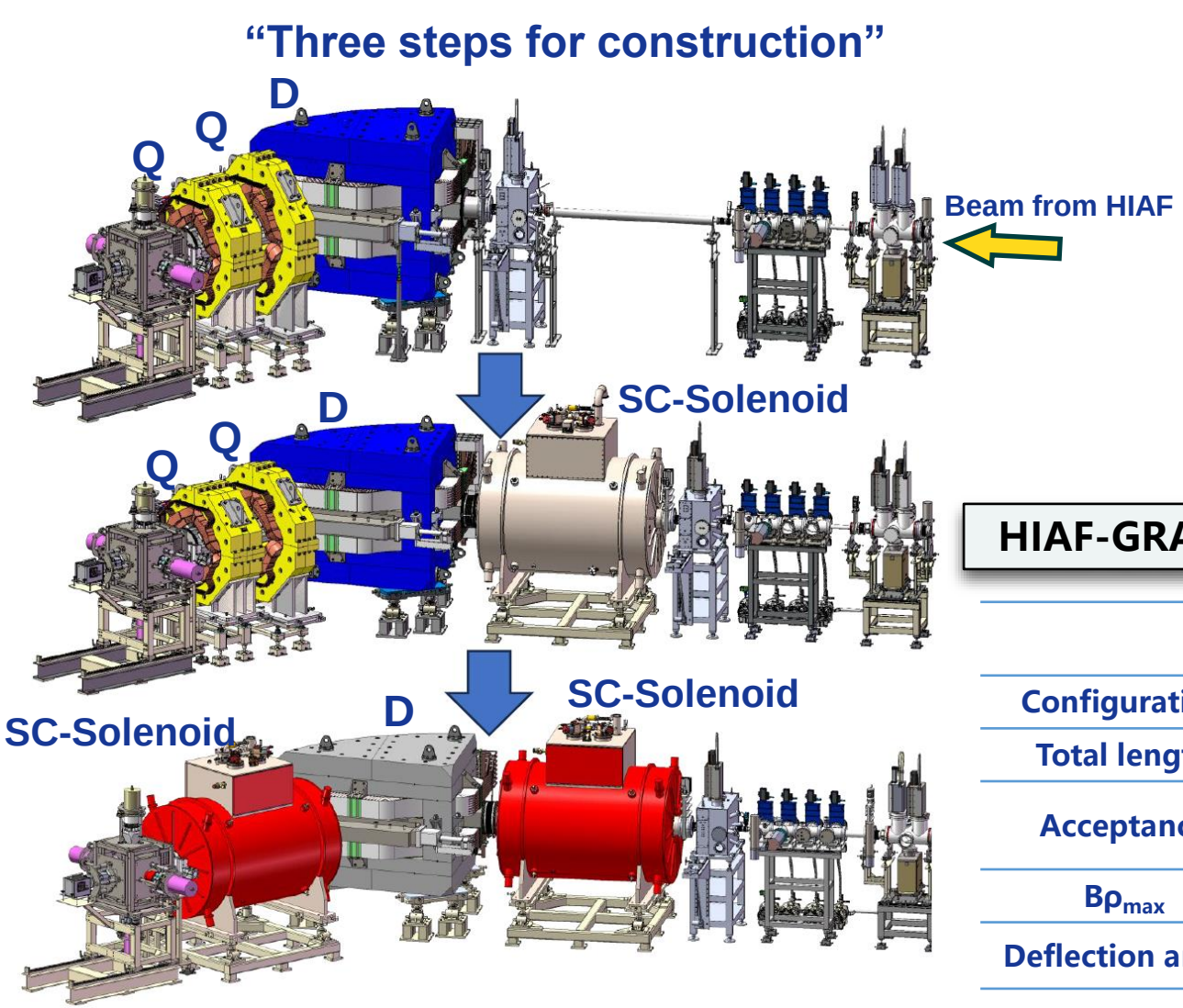


Low-energy physics
Structure/reactions, SHE
HIAF gas-filled recoil separator

Gas-filled Recoil Achromatic Solenoid Spectrometer (GRASS)



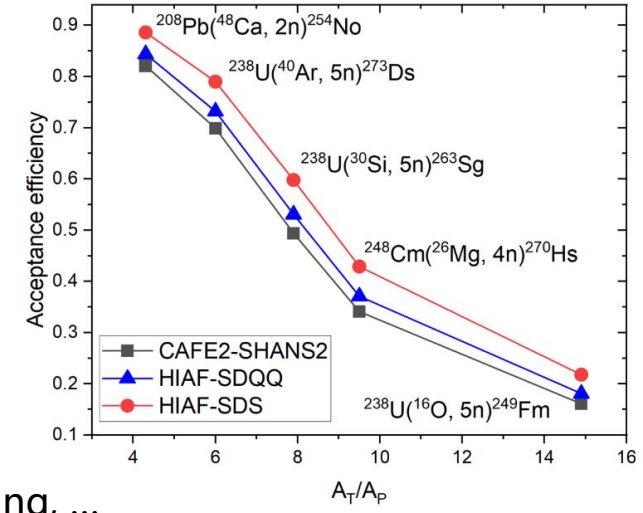
New gas-filled separator at HIAF





HIAF-GRASS is ready for DQQ config., Solenoid is under testing

	GRASS	SHANS2
Configuration	SDS	QDQQD
Total length	8.2 m	6.0 m
Acceptance	±7.5°	±4° (Hori.) ±6.5° (Vert.)
$B\rho_{max}$	2.8 Tm	2.5 Tm
Deflection angle	50°	30°+10°



Courtesy to H. B. Yang, Y. S. Qin, B. Zhao, Z. Chai, Y. Q. Chen, L. Zhu, J. G. Wang, M. H. Huang, M. M. Zhang, …

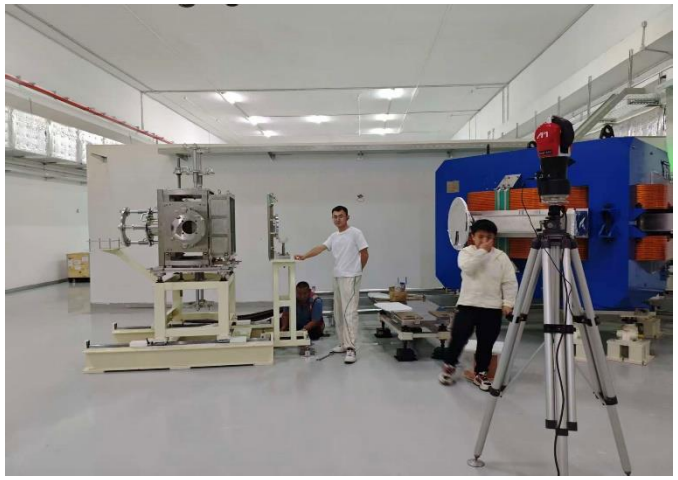
Construction for HIAF-GRASS



Feb. 17, 2025



July 9, 2025



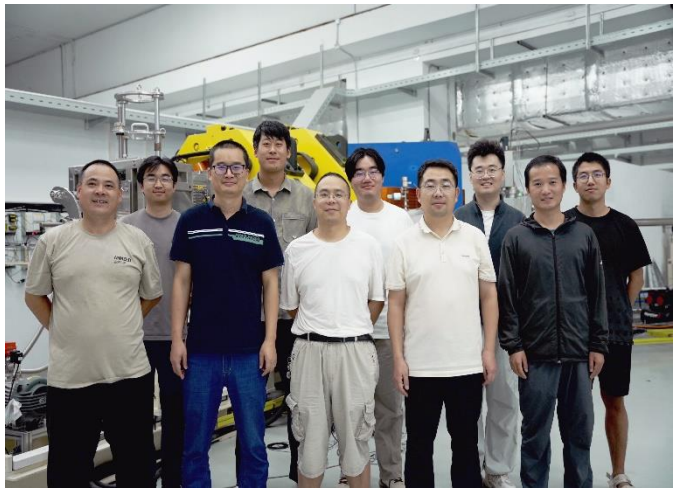
July, 24, 2025



July 27, 2025



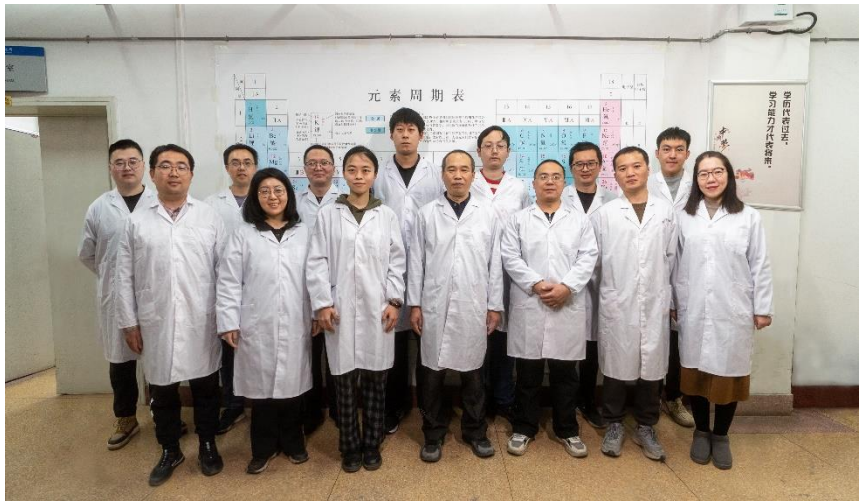
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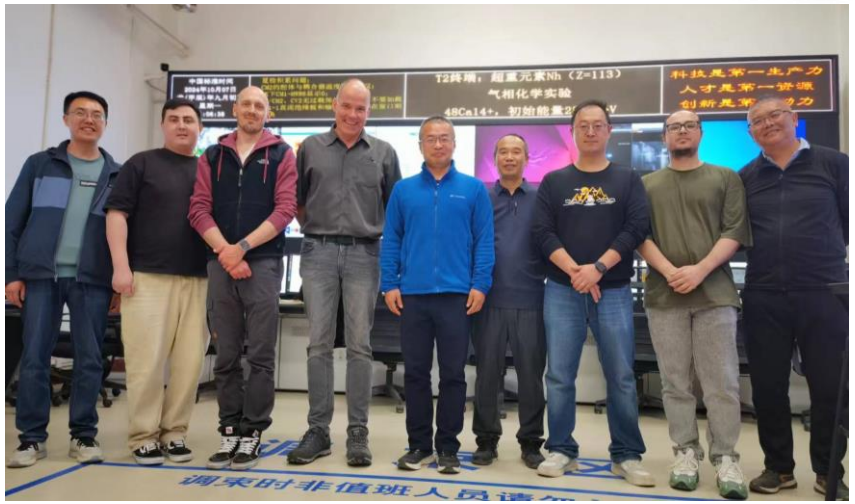


Slide from Huabin Yang

Acknowledgments







Thank you for your kind attention !



