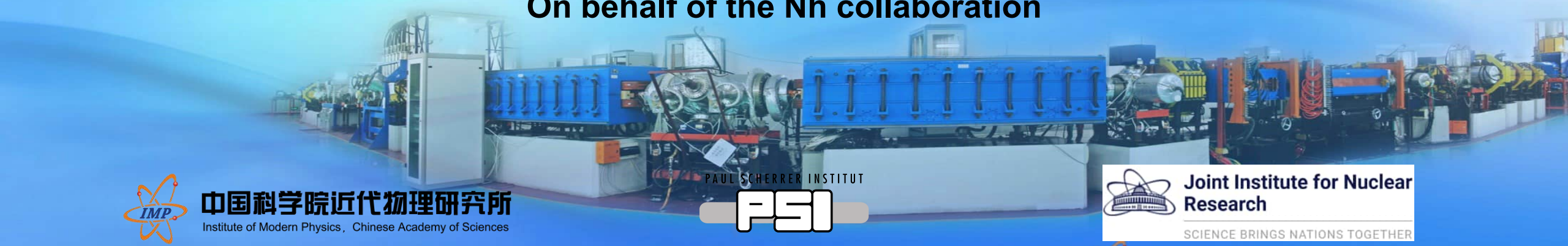
Status of chemical investigation of Nh at IMP

Yang WANG

On behalf of the Nh collaboration



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

PAUL SCHERRER INSTITUT
PSI

Joint Institute for Nuclear Research
SCIENCE BRINGS NATIONS TOGETHER

Contents

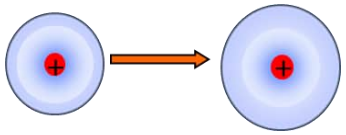
Background

Chemistry of SHEs

Periodic Table of Elements

1 IA												13 IIIA	14 IVA	15 VA	16 VIA	17 VIIA	18 VIIIA
1 H	2 IIA																2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg	3 IIIB	4 IVB	5 VB	6 VIB	7 VIIB	8	9 VIIIB	10	11 IB	12 IIB	13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71 La-Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103 Ac-Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs				112 Cn						
								109 Mt	110 Ds	111 Rg		113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

$$m = m_0 \left[(1 - (v/c)^2\right]^{-1/2}$$

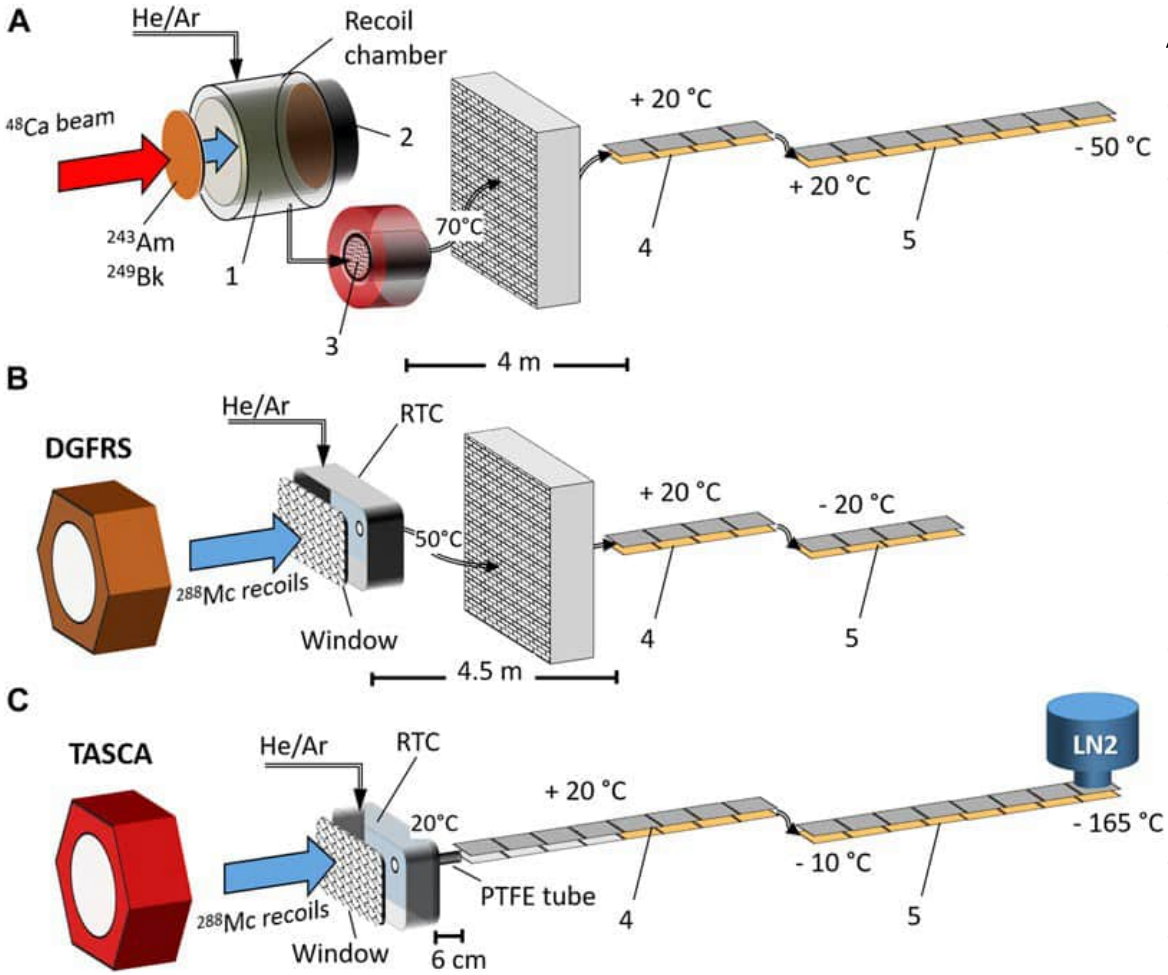


Relativistic effects on SHEs?

Background

Previous chemical study with Nh

(I)：Dubna & GSI, 2014~2017



A. Dubna (*Mendeleev Commun.* ***24,*** *2014*)

- **^{48}Ca+^{243}Am, U-400+RTC, 5 events**
- **Confirmed the synthesis of E115 and E113 by ^{48}Ca+^{243}Am**
- **No physical pre-separation, high background**
- **$-\Delta H > 60$ kJ/mol**

B. Dubna (*Eur. Phys. J. A.* ***53,*** *2017*)

- **^{48}Ca+^{243}Am, U-400 + DGFRS + RTC， 0 events**
- **PTFE capillary (4.5 m)**
- **$-\Delta H > 45$ kJ/mol**

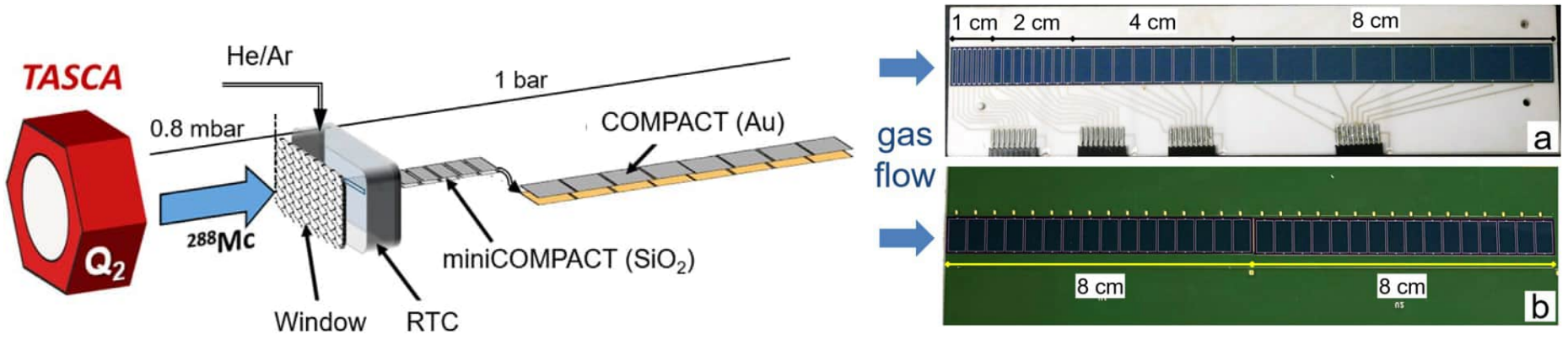
C. GSI (*Frontiers in Chemistry* ***9,*** *2021*)

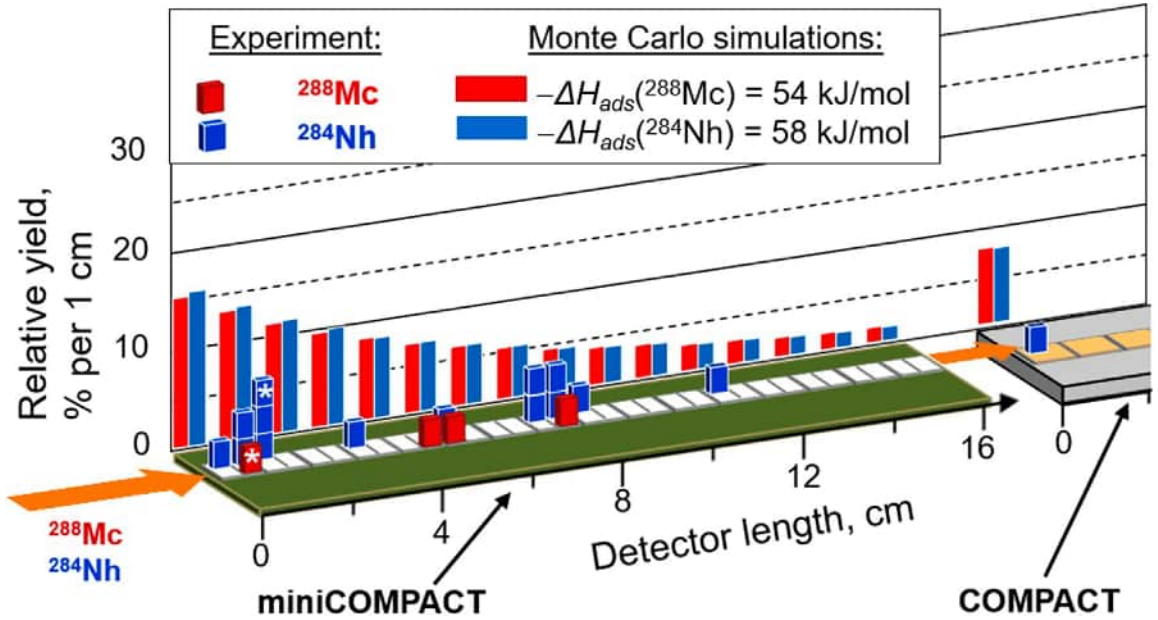
- **^{48}Ca+^{243}Am, TASCA + RTC, 20 days， 0 events**
- **PTFE capillary (6 cm)**
- **$-\Delta H > 50$ kJ/mol**

Background

Previous chemical study with Nh

(II)： GSI, 2020~2024 (*Frontiers in Chemistry* ***12,*** *2024*)

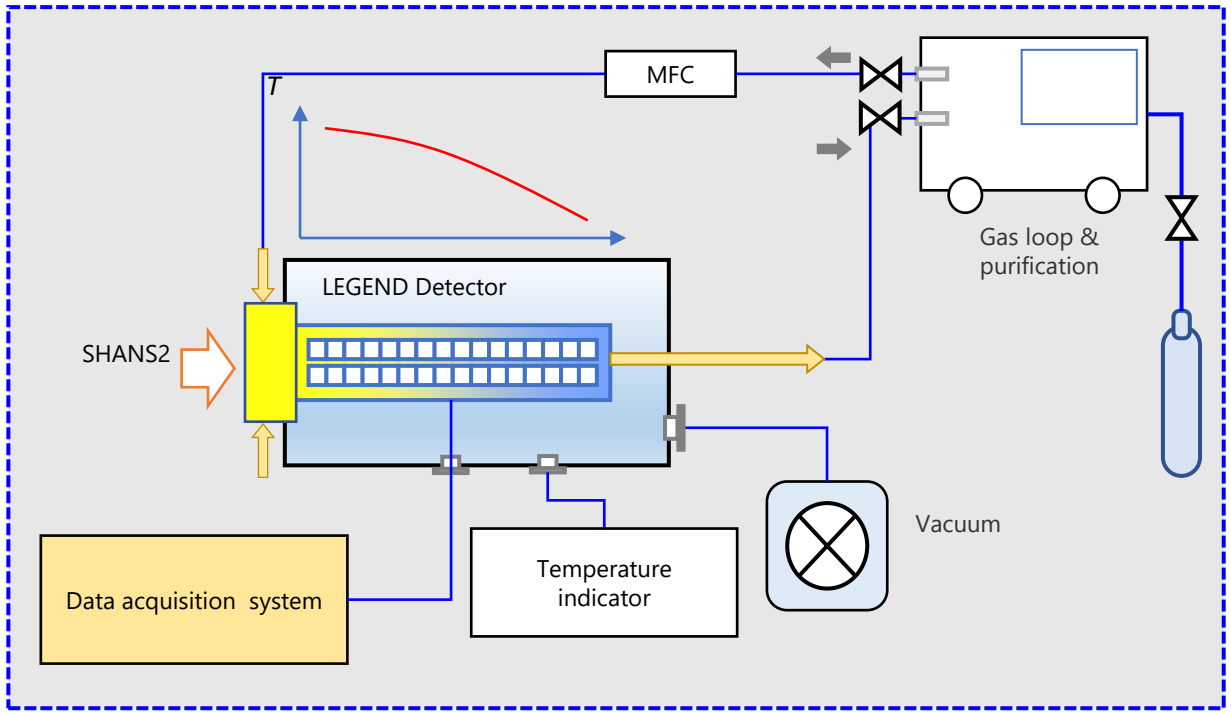


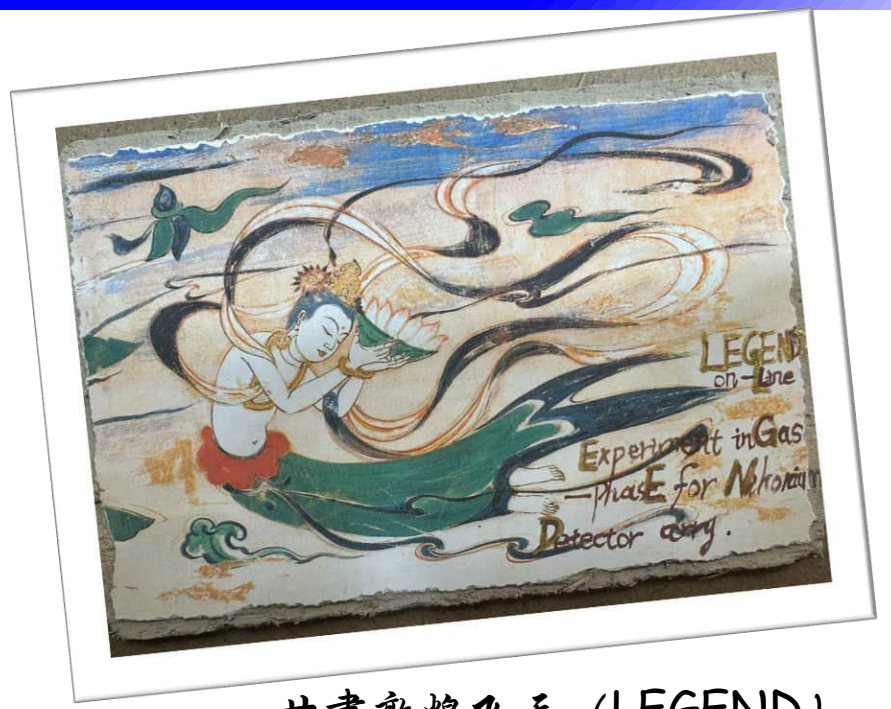


No Teflon capillary! 18 long decay chains of Nh within 6 weeks ≈ ***40%***

Background

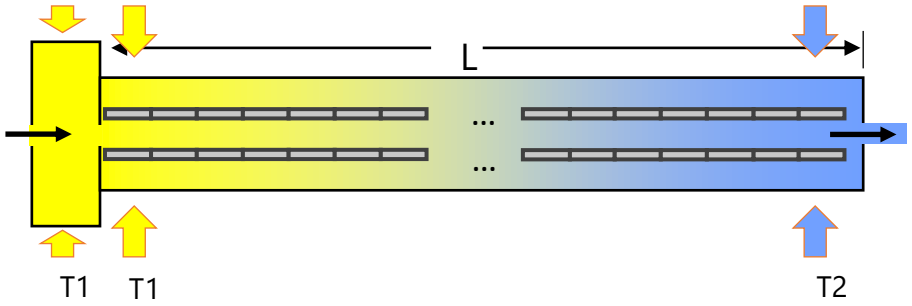
LEGEND: on-Line Experiment in Gas-phasE for Nihonium Detector array



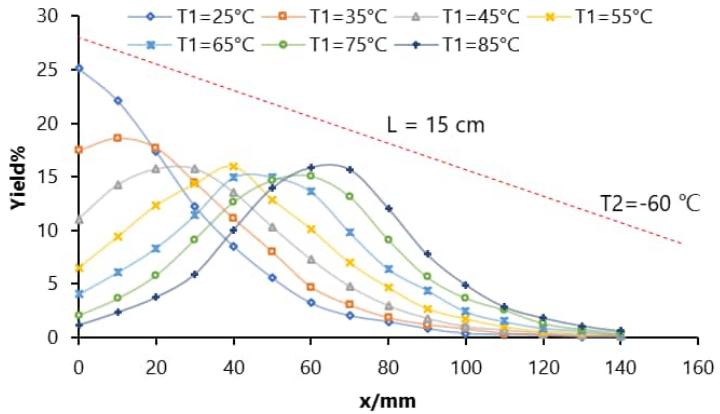


甘肃敦煌飞天（LEGEND）

Legend with temperature gradient



Monte Carlo simulation [$-\Delta H_{ads}$(Nh)=58 kJ/mol]



Background

Superheavy elements research facility @ IMP

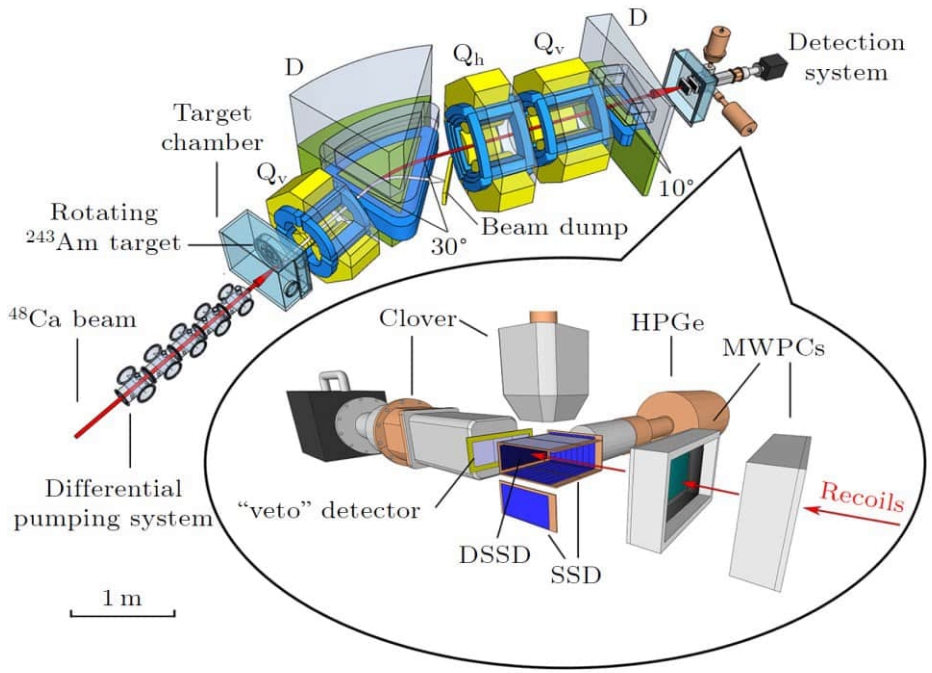
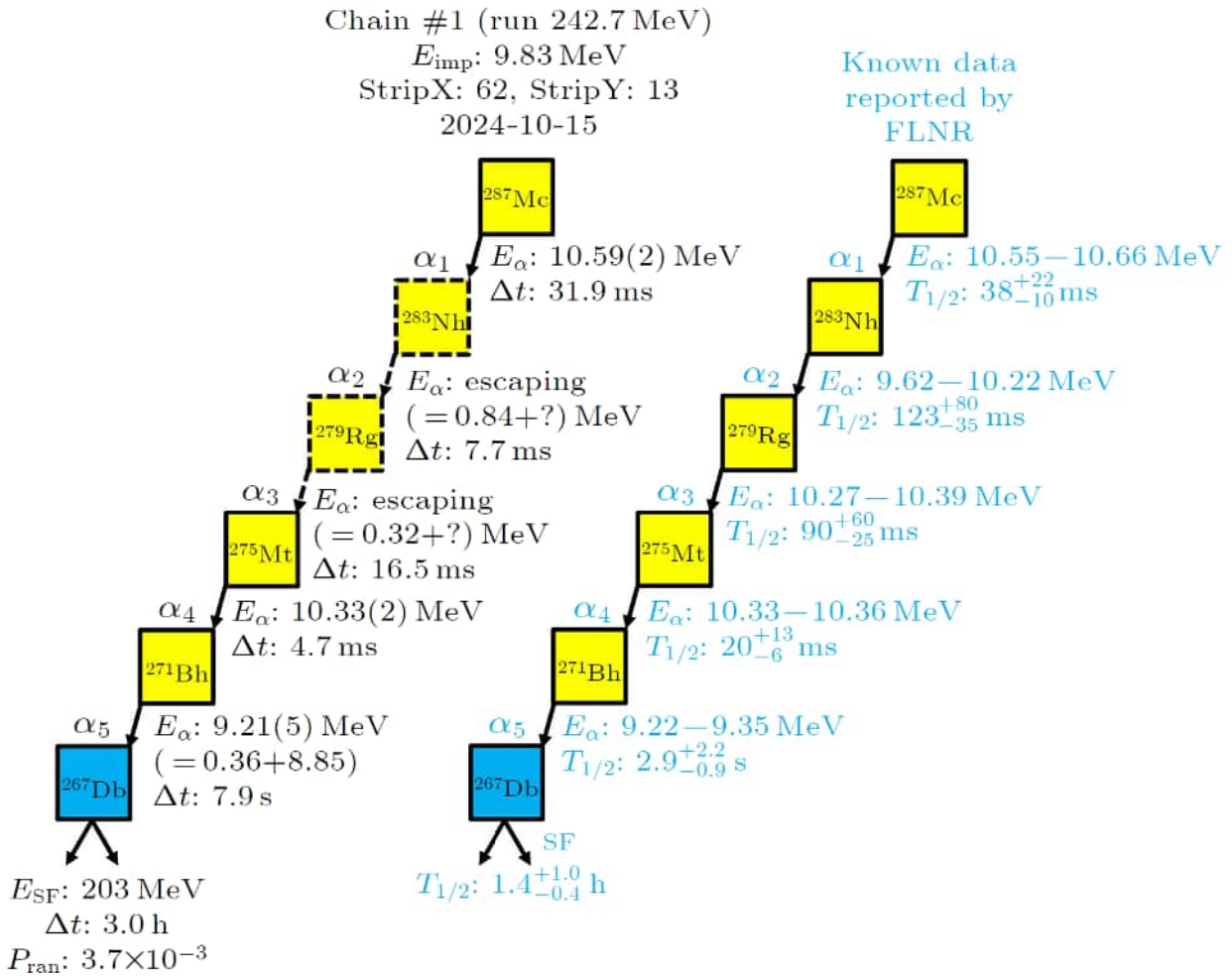


Table 1. The year of run, number of used targets (N_{target}), target thickness, energy (laboratory-frame) of ^{48}Ca in the middle of the target layer, resulting excitation energy intervals (with use of mass table [32,33]), magnetic rigidity of the dipole magnets, total beam doses, number of chains assigned to ^{288}Mc (3n) and ^{287}Mc (4n), and the corresponding cross sections.

Year of run	N_{target}	Target thickness (mg/cm^2)	E_{lab} (MeV)[a]	E^* (MeV)[b]	$B\rho$ (Tm)	Beam dose $\times10^{17}$	No. of chains 3n/4n	σ_{3n} (pb)	σ_{4n} (pb)
2023	4	0.57(6)[c]	241.6	33.1–36.4	2.102/2.091	8.8	5/0	$6.1^{+4.1}_{-3.0}$	
2024	10	0.48(5)[c]	240.2	32.2–34.9	2.100/2.096	3.9	4/0	$13.0^{+10.2}_{-7.1}$	
			242.7	34.2–37.0	2.093	7.8	3/1	$4.9^{+4.6}_{-3.0}$	$1.6^{+3.8}_{-1.4}$
2025	10	0.50(5)[c]	235.0	27.7–30.6	2.095	4.8	0/0	<4.7	
			238.1	30.2–33.2	2.095	6.0	3/0	$6.1^{+5.7}_{-3.7}$	
			240.2	32.0–34.9	2.095	7.3	3/0	$5.0^{+4.7}_{-3.1}$	
			244.3	35.3–38.3	2.095	8.8	2/0	$2.8^{+3.7}_{-1.9}$	
			248.4	38.9–41.7	2.095	8.2	0/0	<2.7	



X. Y. Huang et al 2026 Chinese Phys. Lett. 43 010101

"Recent results of SHANS2"
Zaiguo Gan, 19th May 2026

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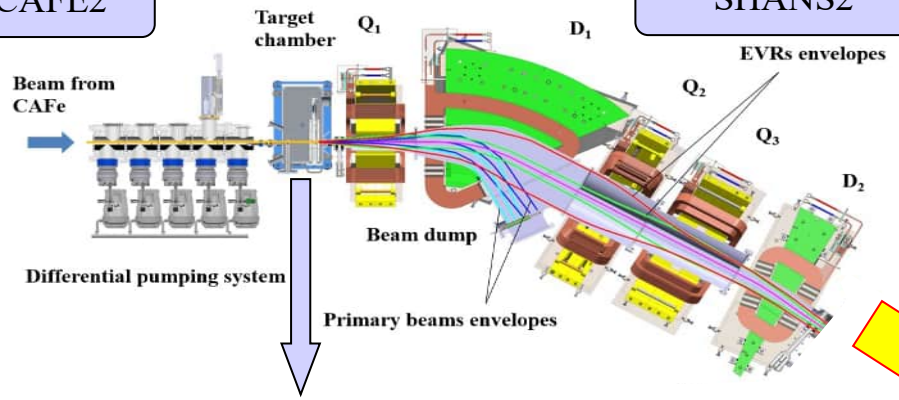
Production and identification of Nh

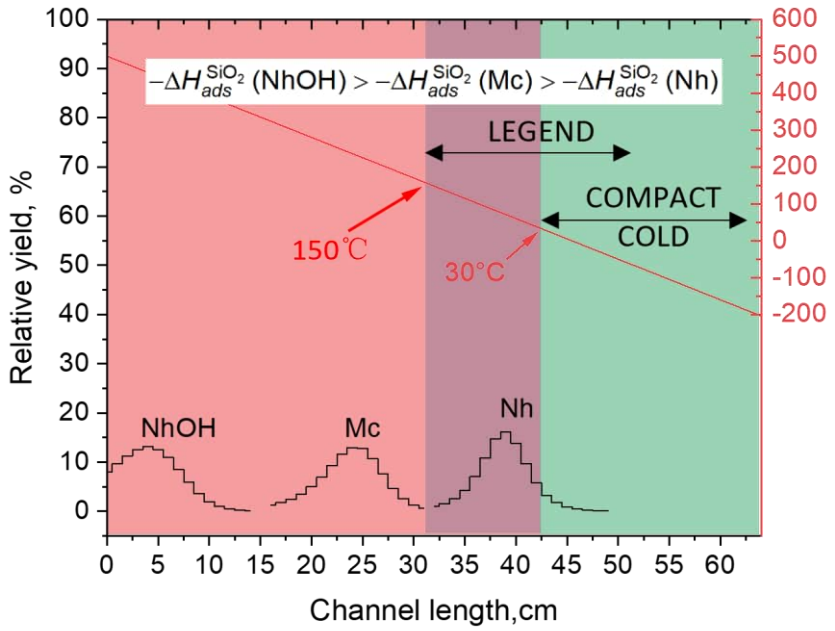
CAFE2

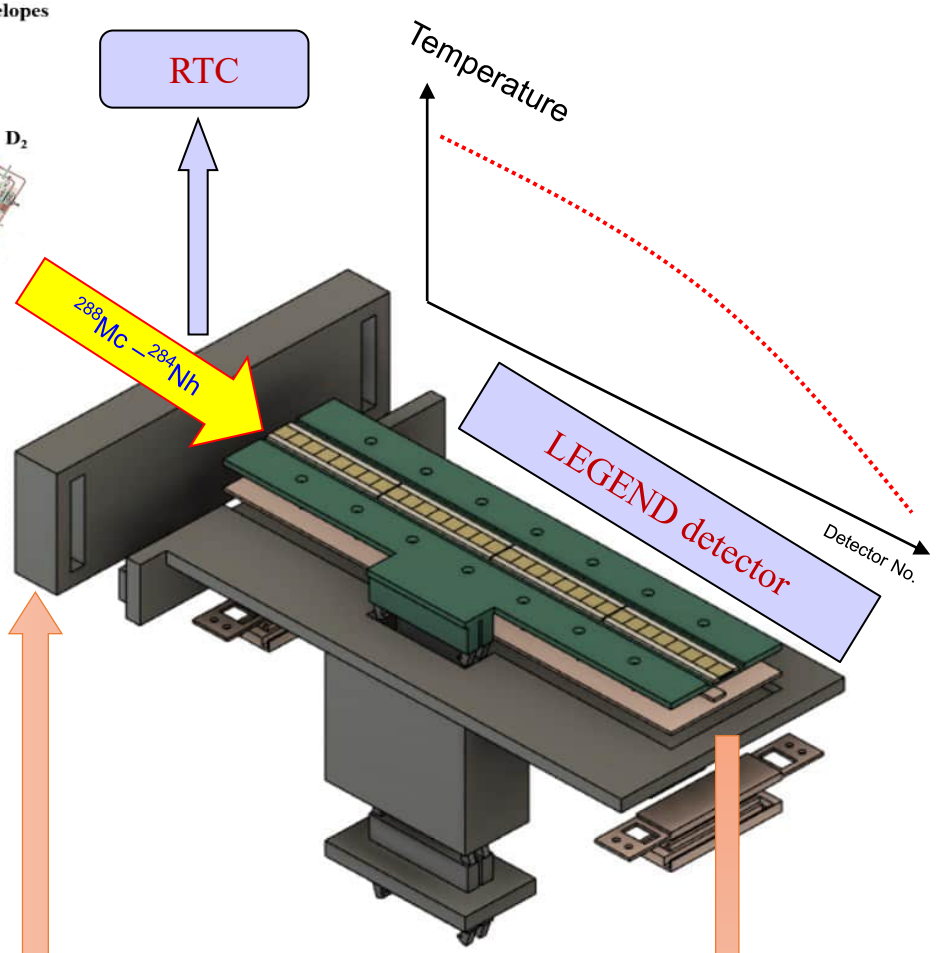
SHANS2



RTC

$^{243}Am(^{48}Ca,3n)^{288}Mc$ (Z=115)

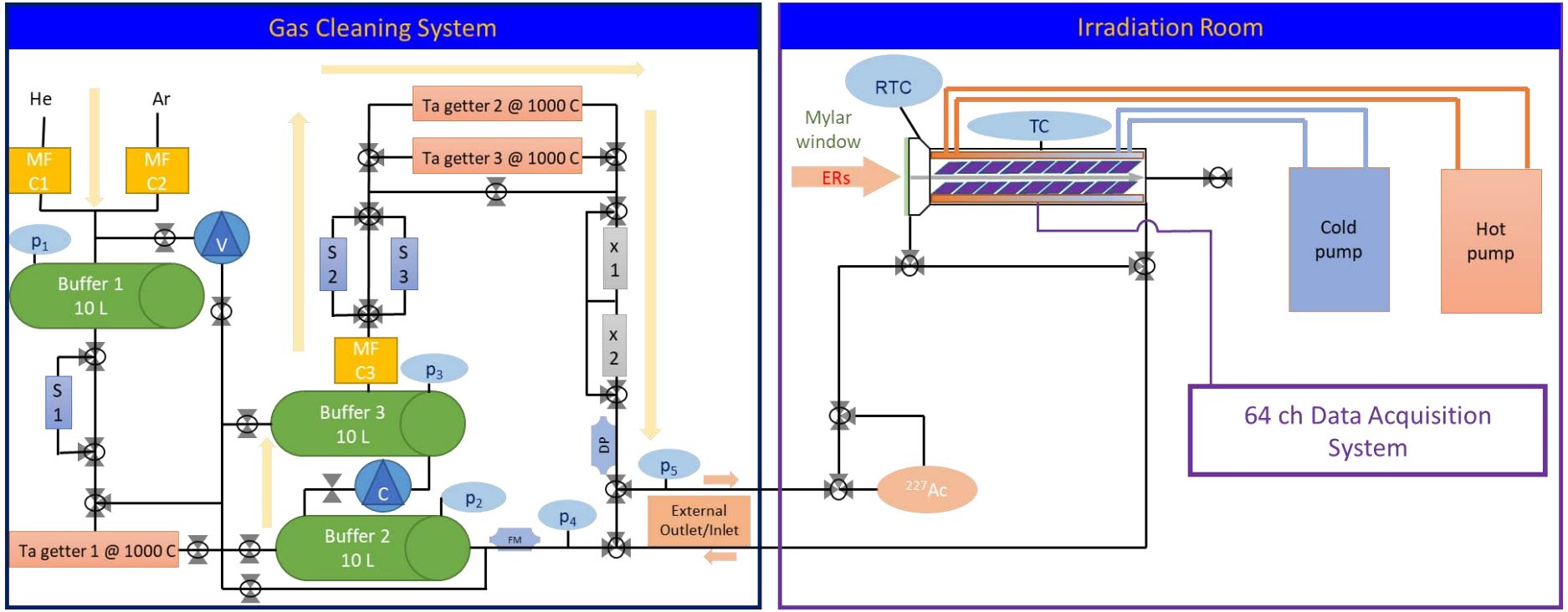




Gas loop

Development of the LEGEND system

LEGEND system



1. Gas Cleaning system

Gas purification and circulation loop (remove H_2O, O_2, H_2……)

2. Vacuum Window

Mylar foils, honeycomb-hole grids (high transparency)

3. RTC

Small volume with high efficacy (short transport time)

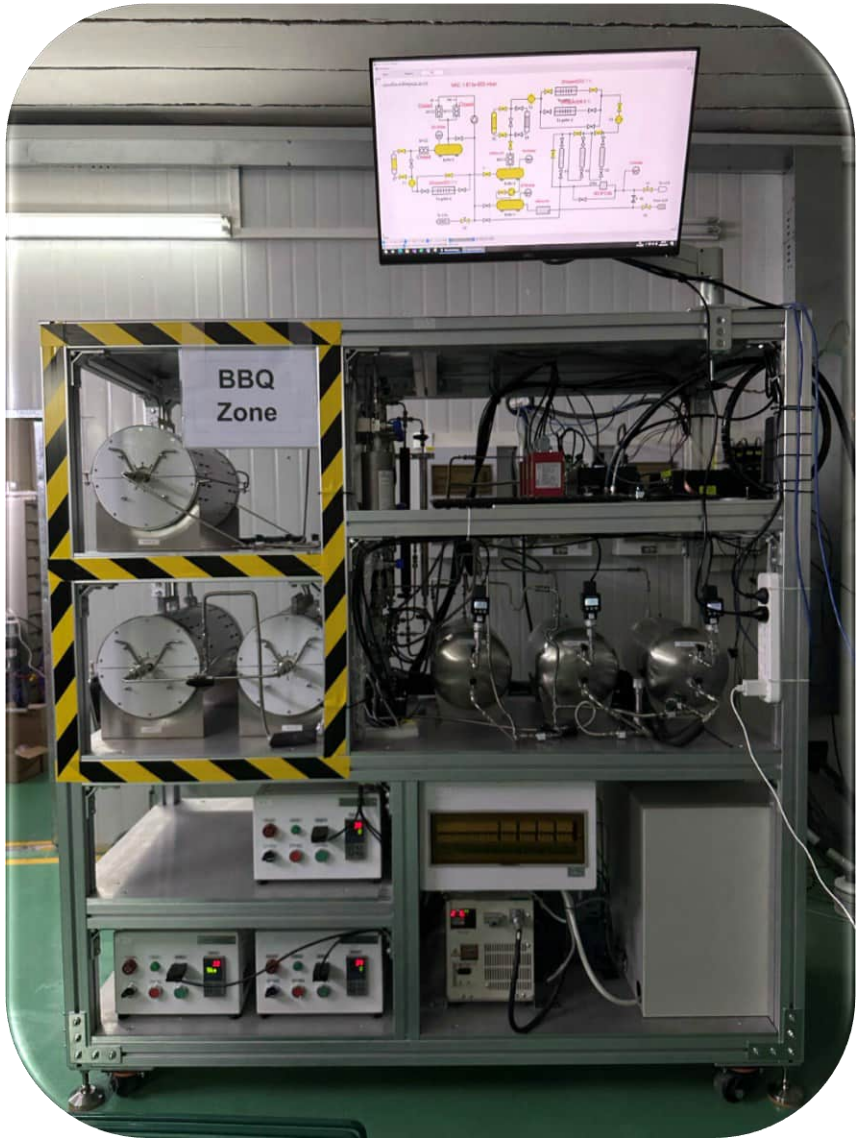
4. TC

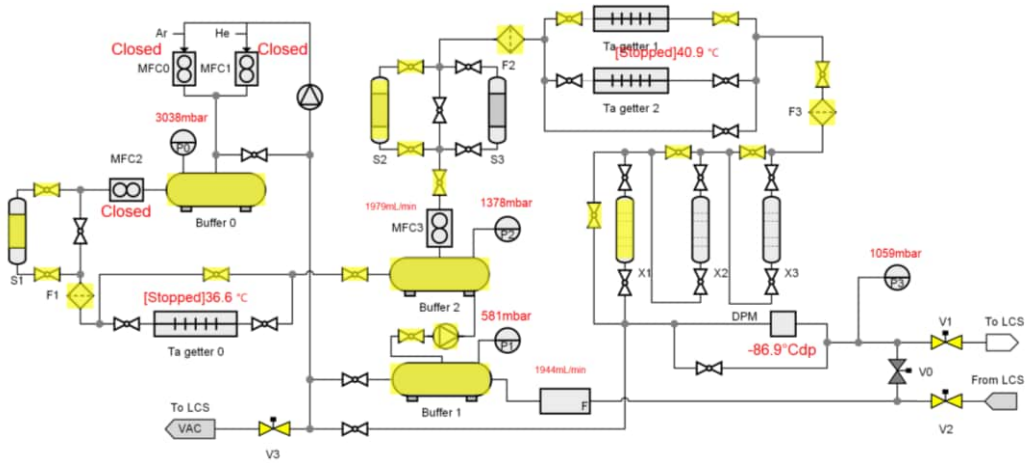
Direct connected with RTC (Si-detectors array with negative temperature gradient)

Development of the LEGEND system

GCS (gas cleaning system)

20 L; 0.5~3 L/min (Ar/He); 0.5~2 bar





Buffer 1~3: 10 L tank (SUS316,EP-level clean)

S 1~3: Drying column (P_2O_5)

Ta getter 1~3: Ta metal @ 1000℃

X 1~3: GateKeeper® gas purifiers

(H_2O, O_2, CO, CO_2, H_2< 100 pptV; 1.5 nm filter)

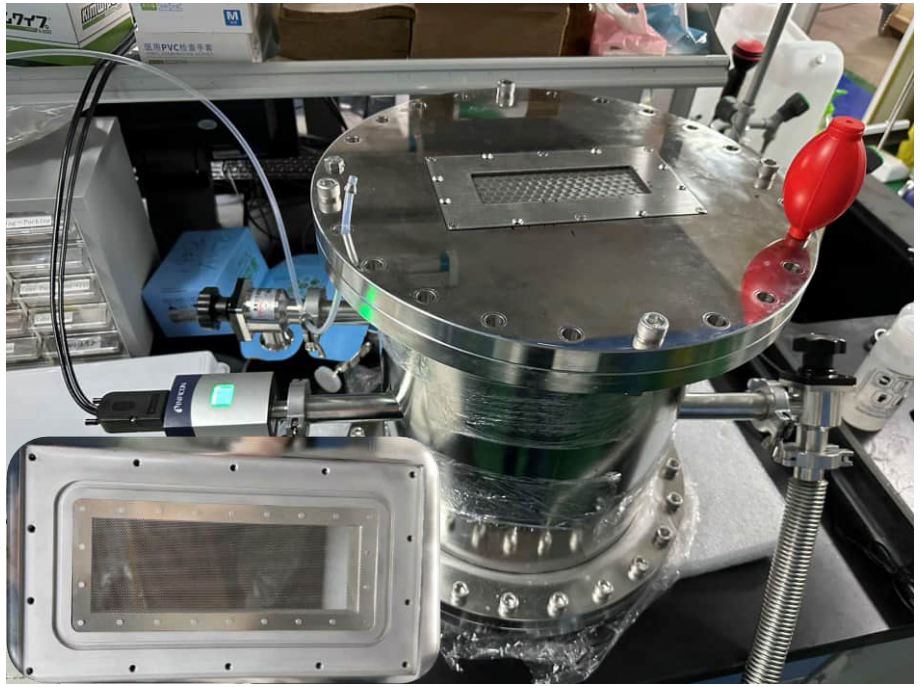
DPM: -109℃, 3 ppbV

On-line operation and auto-control !

Development of the LEGEND system

Vacuum window

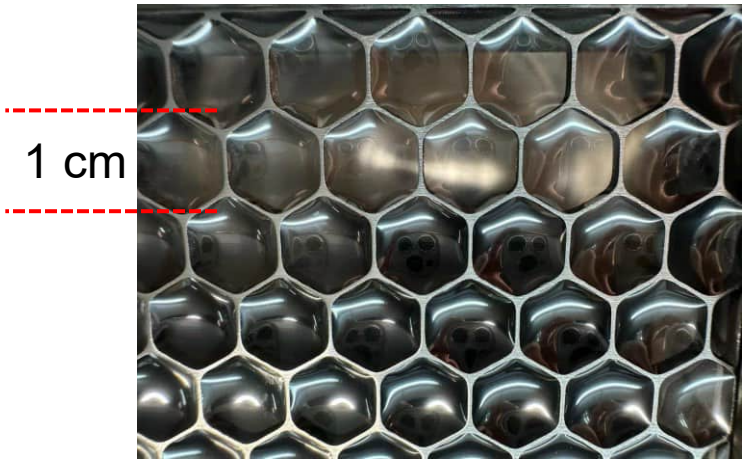
Adapter with vacuum window (15×5 cm^2)



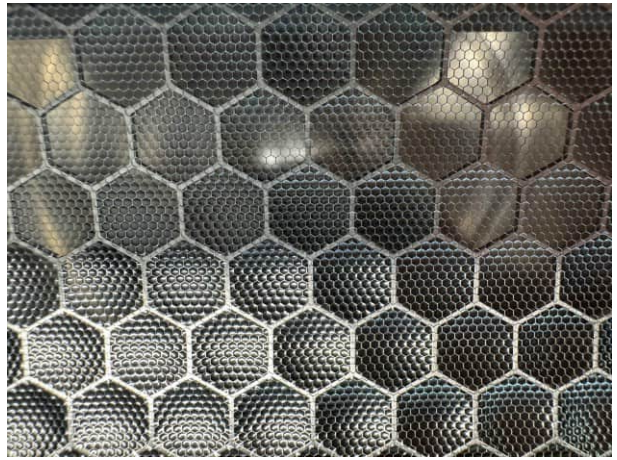
The adapter connects SHANS2 and RTC.

The window is located in the focal plane of SHANS2.

Honeycomb grids: 2+0.1 mm-thick SUS



Grid1: 88.7% (2.5~6 μm Mylar foils)



Grid1+2: 74.1% (0.7~2.5 μm Mylar foils)

Development of the LEGEND system

RTC (recoil transfer chamber)

Position distribution of ERs on the focal plane of SHANS2

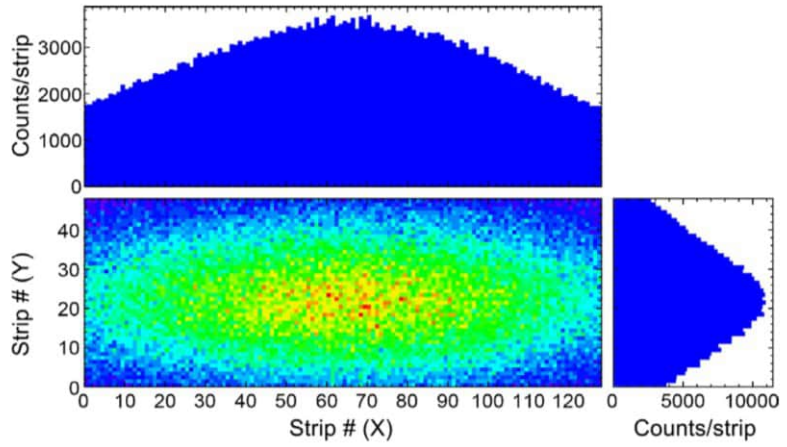


Fig. 5. Position distribution of ^{205}Fr produced in the ^{40}Ar + ^{169}Tm reaction with an incident energy of 178.5 MeV in the focal plane of SHANS2 and corresponding projections in the horizontal (X) and vertical (Y) directions, respectively on the top and right of the position distribution. The magnetic rigidity was set as 1.595 T m for both dipole magnets.

The standard deviations in the horizontal (σ_x) and vertical (σ_y) directions are 50.7 mm and 15.0 mm respectively.

Nucl. Instrum. Methods A. ***1050*** *(2023) 168113*

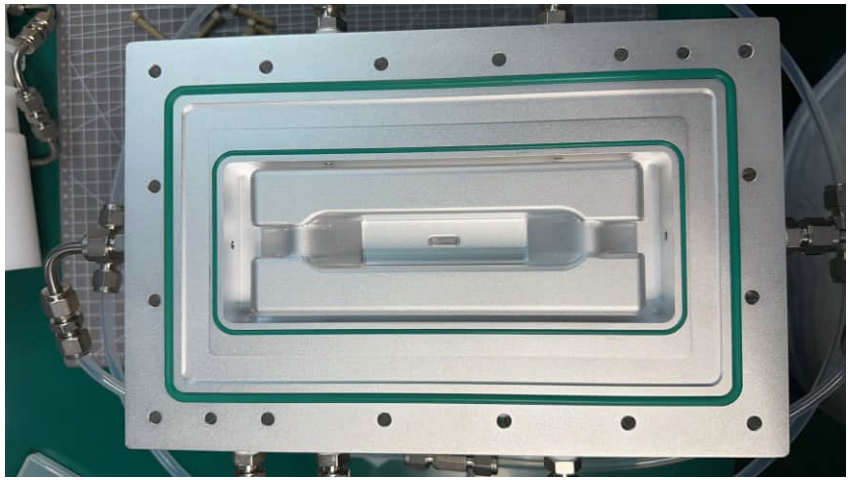
Design of the RTC

RTC #1: **91%** ($2\sigma_x \times 2\sigma_y$)
X=101.4 mm; Y=30 mm; D=20 mm **V=60.84 mL**
Time=1.8 s (2 L/min Ar)

RTC #2: **75%** ($1.5\sigma_x \times 1.5\sigma_y$)
X=76.0 mm; Y=22.5 mm; D=20 mm **V=34.2 mL**
Time=1.0 s (2 L/min Ar)

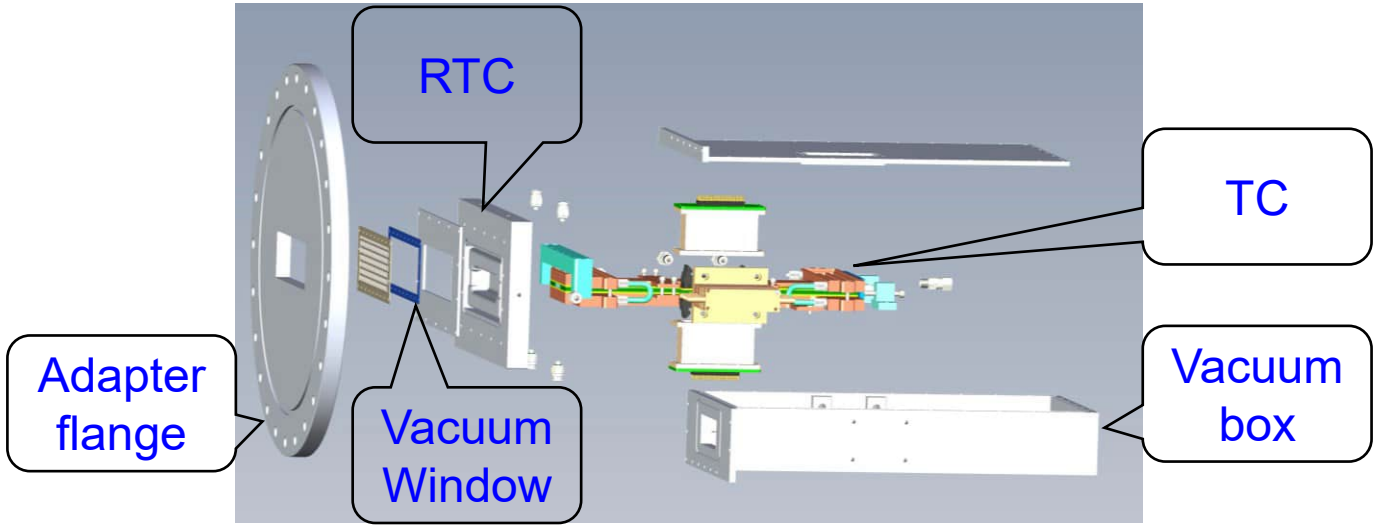
RTC #3: **75%** ($1.5\sigma_x \times 1.5\sigma_y$)
X=76.0 mm; Y=22.5 mm; D=15 mm **V=25.6 mL**
Time=0.8 s (2 L/min Ar)

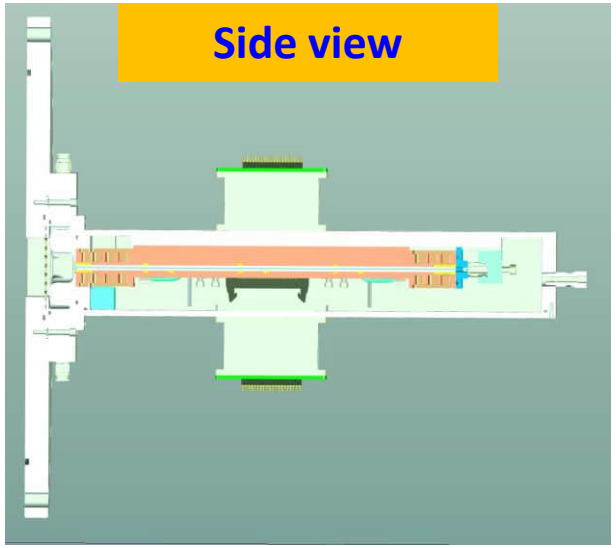
^{284}Nh $T_{1/2}$= 0.77s

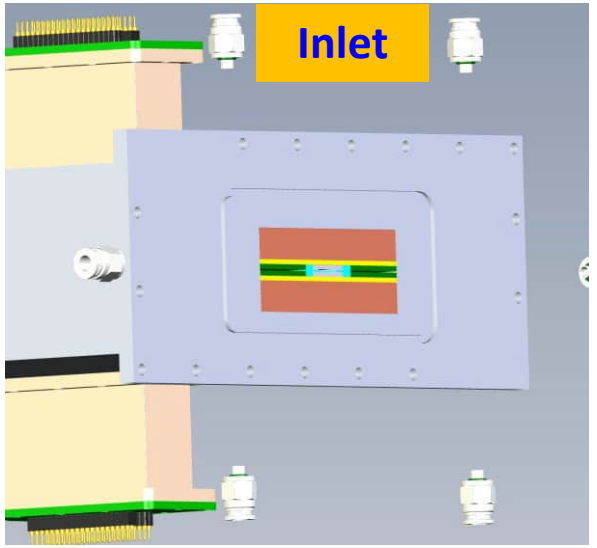


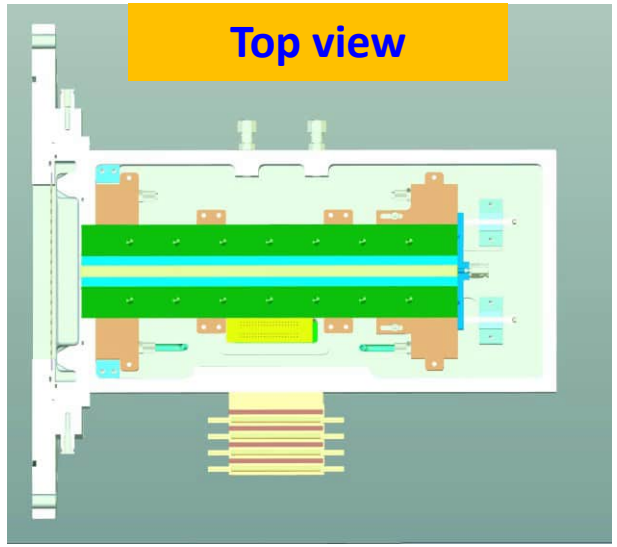
Development of the LEGEND system

TC (Thermochromatography)





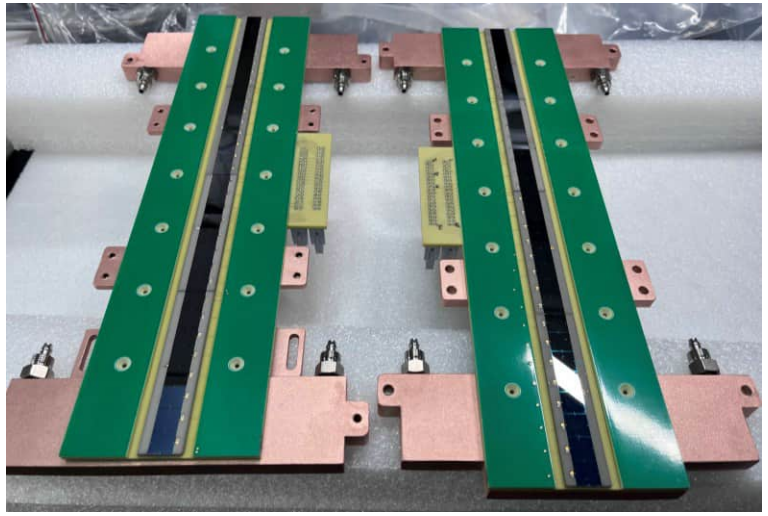


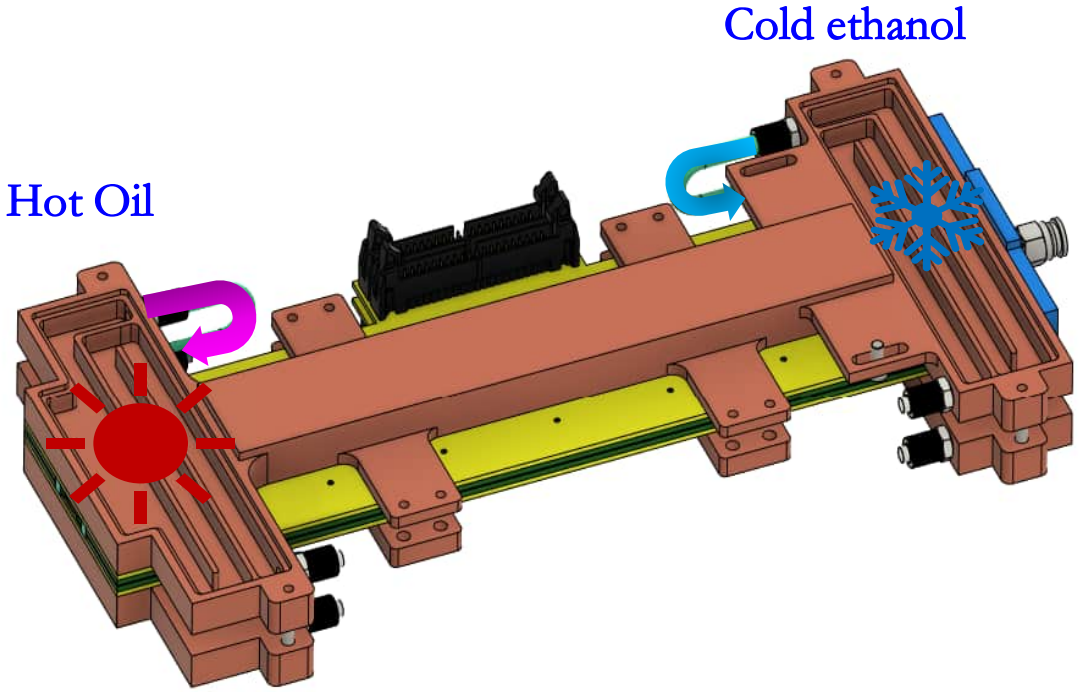


Development of the LEGEND system

TC (Si-detector array)

32 (4 × 8) pairs of Si-detectors—64 ch

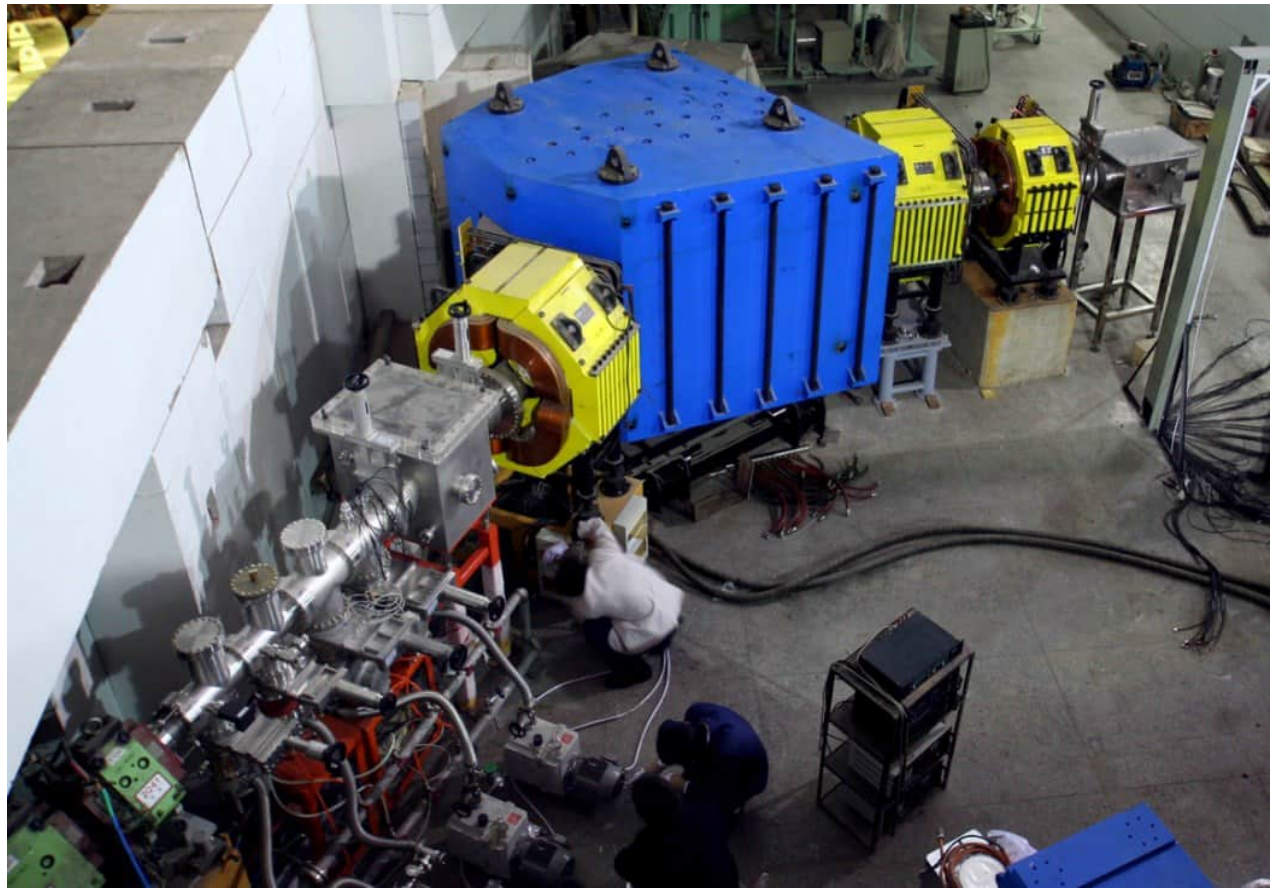


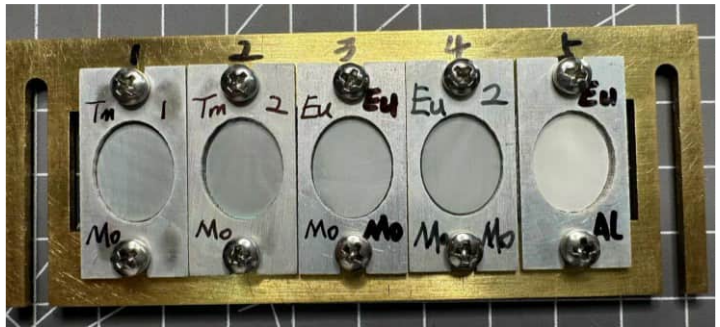


Length mm	Width mm	Height mm	Efficiency -α	Efficiency -SF
321.28	10.04	0.80	89.10%	78.20%

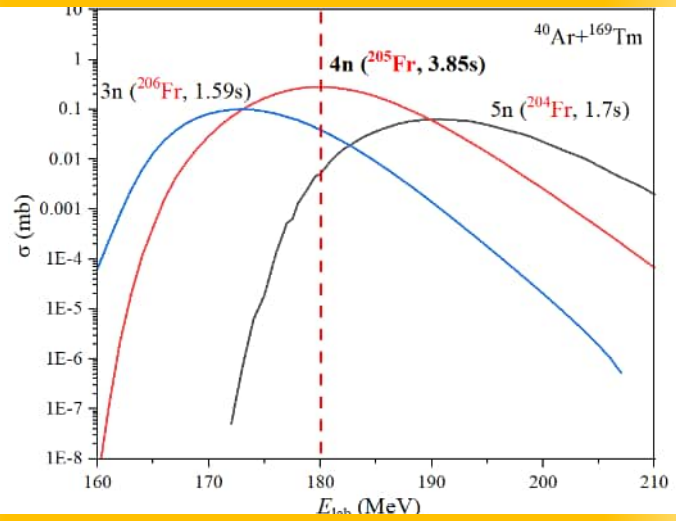
Development of the LEGEND system

Test of LEGEND system with Fr and Tl at SHANS, IMP (15th—30th July 2023)

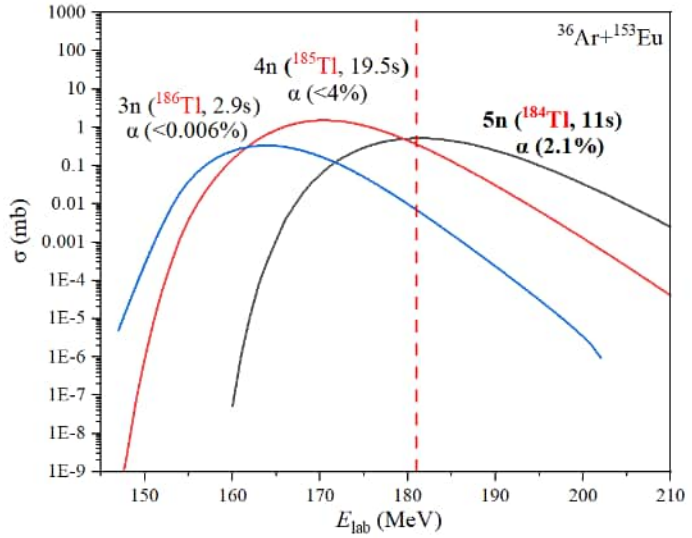




^{169}Tm(^{40}Ar,4n)^{205}Fr @ 180 MeV & 0.7 pμA



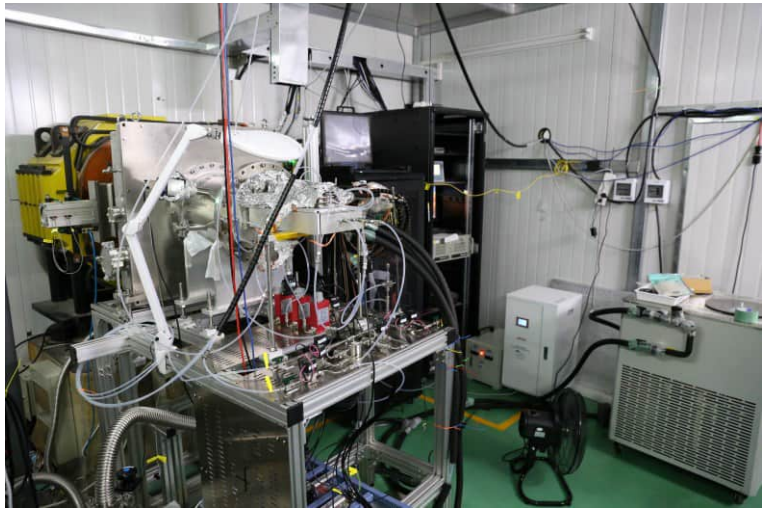
^{153}Eu(^{36}Ar,5n)^{184}Tl @ 181 MeV & 0.8 pμA



Development of the LEGEND system

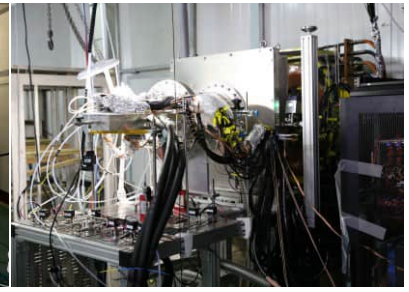
Test of LEGEND system with Fr and Tl at SHANS, IMP

LEGEND @ SHANS

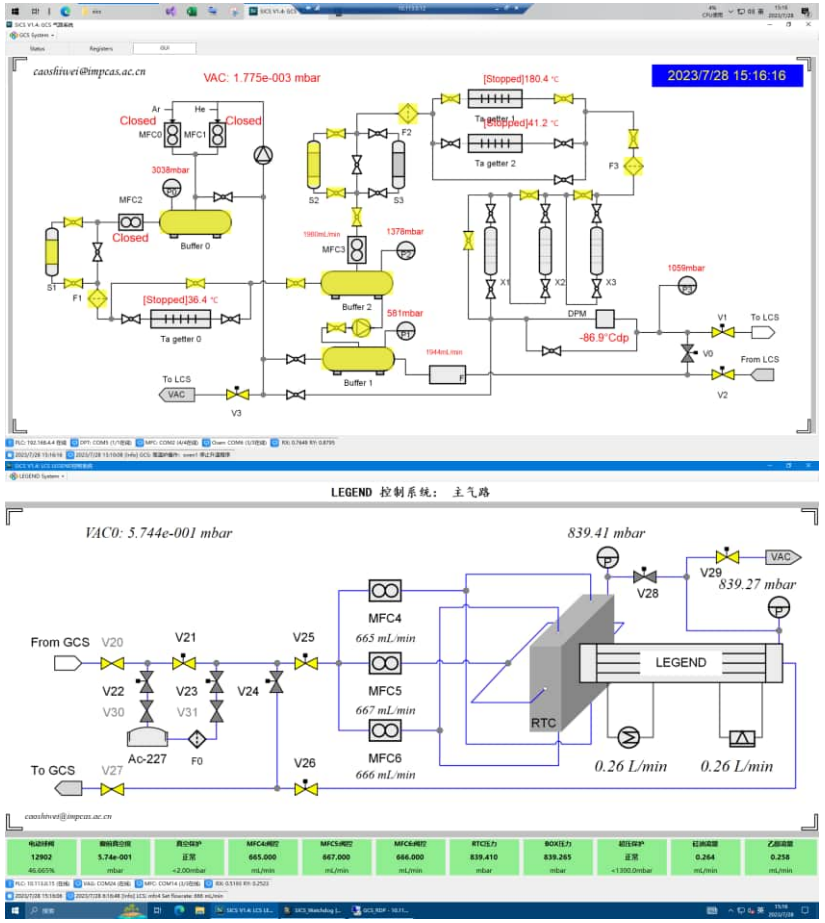


GCS

LCS



LEGEND Control System



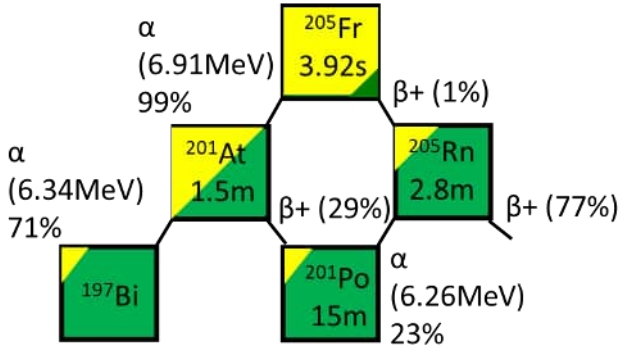
The LEGEND system is very stable with good performance!

Suitable for Nh experiments with long beam time!

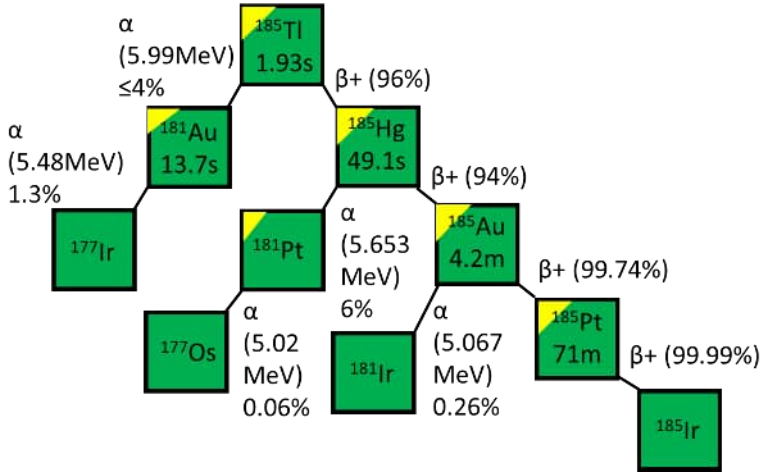
Development of the LEGEND system

Test of LEGEND system with Fr and Tl at SHANS, IMP

Distribution of Fr on SiO_2

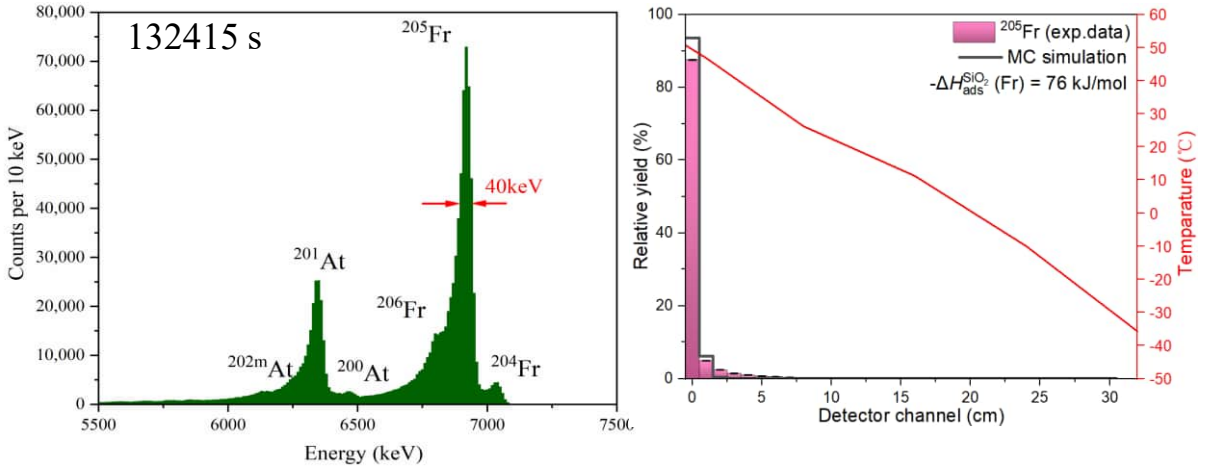


Distribution of Tl on SiO_2



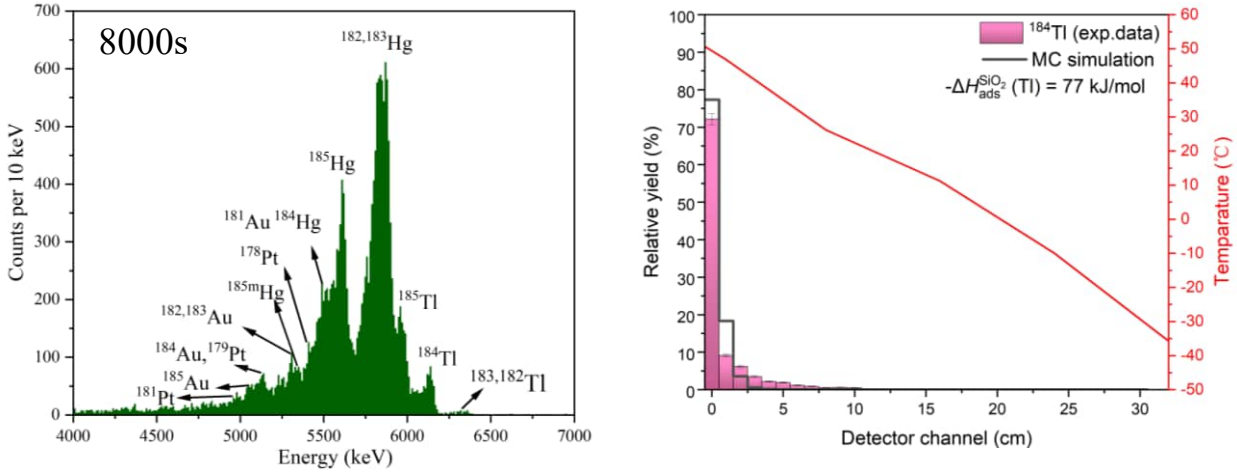
Bottom #1

Upper limit: ΔH_{ads}(Fr) > -76 kJ/mol



Bottom #1

ΔH_{ads}(Tl) > -77 kJ/mol

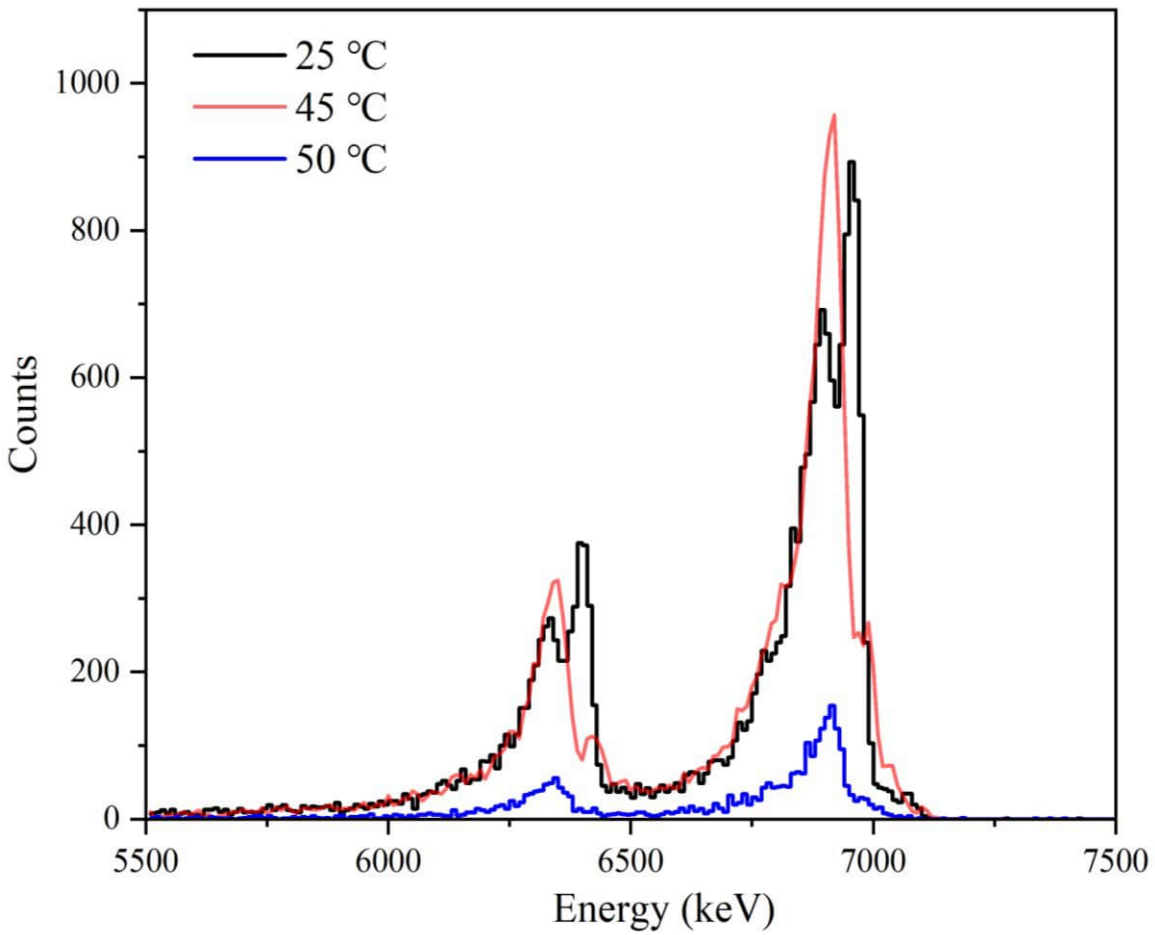


The LEGEND system is fast enough to obtain short-lived isotopes!

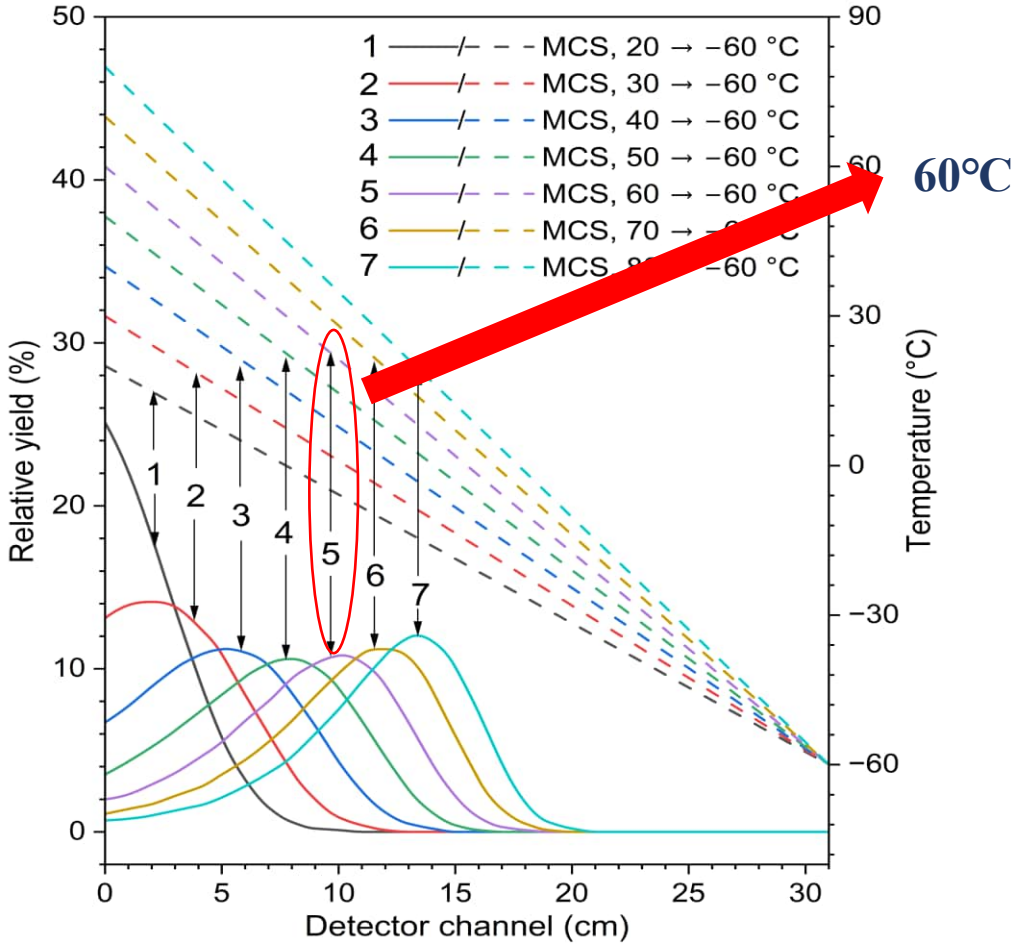
Development of the LEGEND system

Test of LEGEND system with Fr and Tl at SHANS, IMP

Spectrum obtained with Si detector



Distribution of Nh on SiO_2 by MCS



High performance 4H-SiC detectors are needed!

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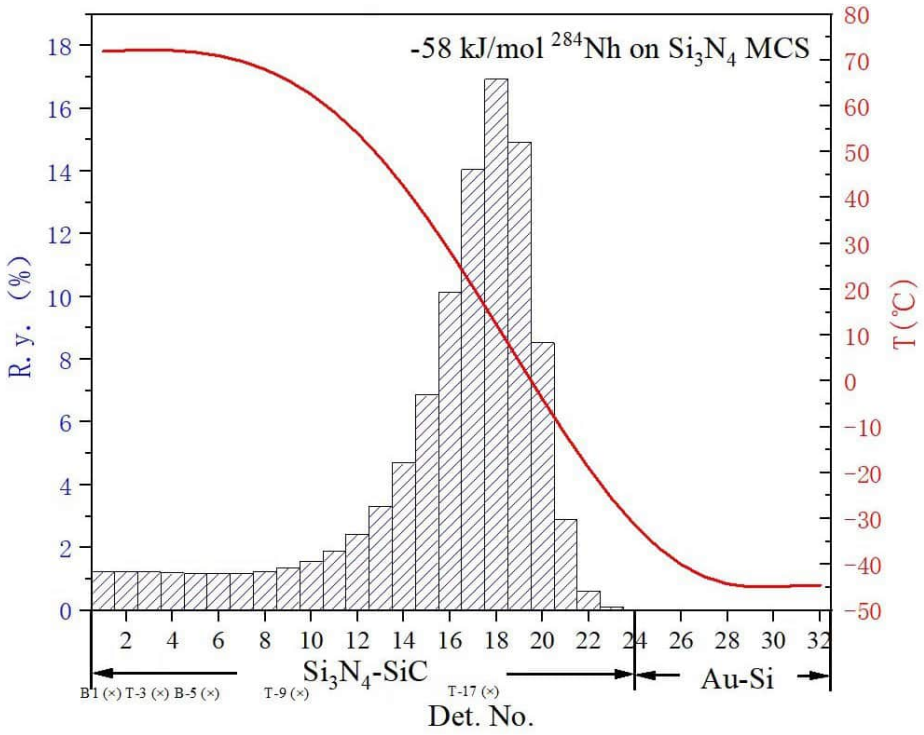
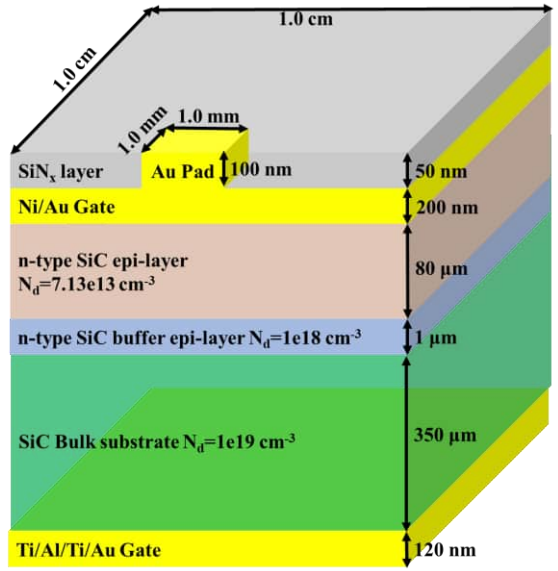
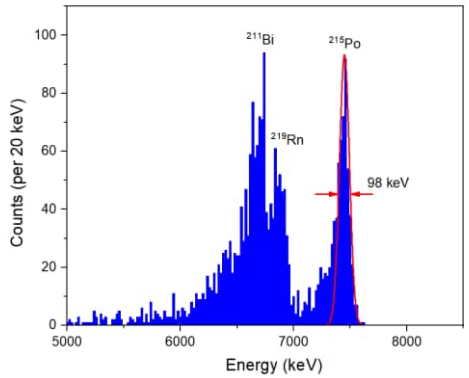
Improvement of LEGEND

Development of SiC detectors

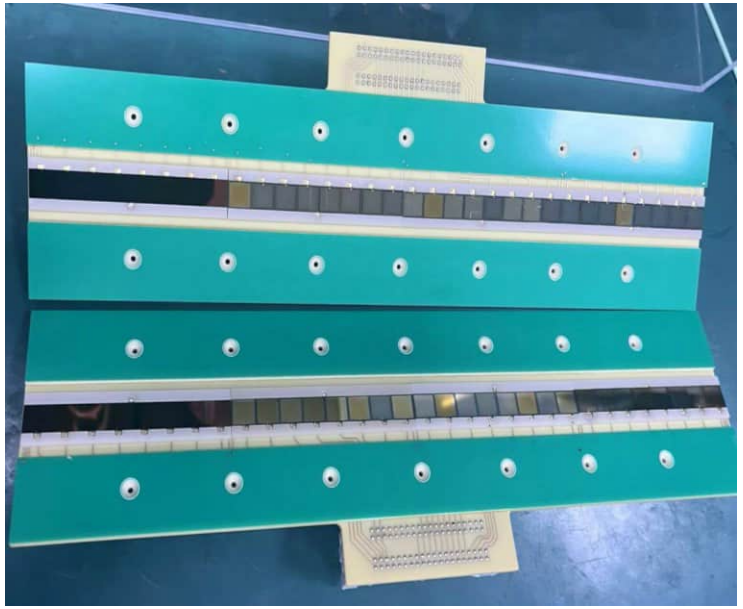


Distribution of ^{284}Nh on Si_3N_4 surface with the temperature gradient: +65 ~ -45 ℃
(MCS: -58 kJ/mol for Nh)





98 keV @ 7386 keV at 65℃



First 24 pairs
4H-SiC Detectors
(+65~-20 ℃)
Covered with Si_3N_4
75 nm or 50 nm

Last 8 pairs
Si detectors
(-20~-45 ℃)
covered with Au
50 nm

First chemical experiment of Nh at IMP

^{243}Am targets were prepared by molecular electrodeposition method

^{243}Am targets

	ug/cm^2	err
target 1	501.19	17.54
target 2	486.13	17.03
target 3	499.49	17.48
target 4	465.85	16.31
target 5	453.64	15.88
target 6	458.24	16.06
target 7	467.28	16.39
target 8	471.90	16.51
target 9	473.95	16.58
target 10	472.62	16.54
	475.03	15.19

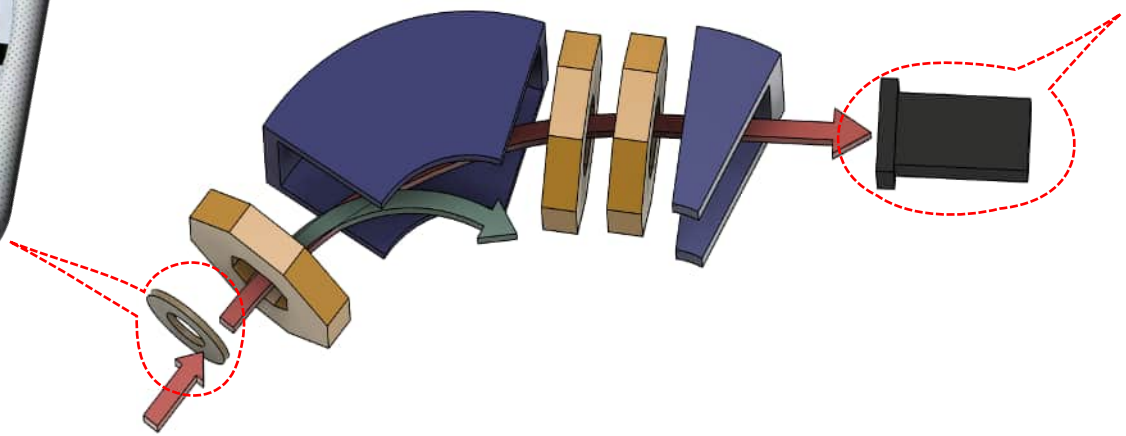
10 sectors on a 20 cm wheel
^{243}Am: 475 μg/cm^2
Ti foil: 2.28 μm

First chemical experiment of Nh at IMP

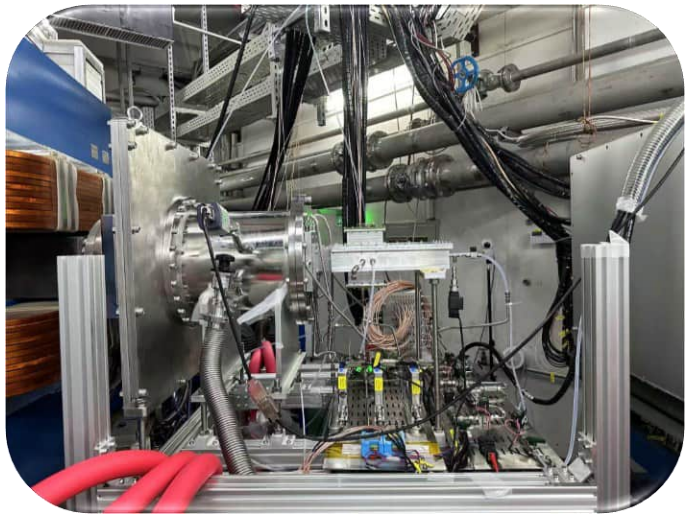
First Nh experiment at SHANS2, IMP, (23th Sep. -- 14th Oct. 2024)

SHANS2 @ CAFE2

^{243}Am targets



$^{48}Ca^{14+}$ beam from CAFE2



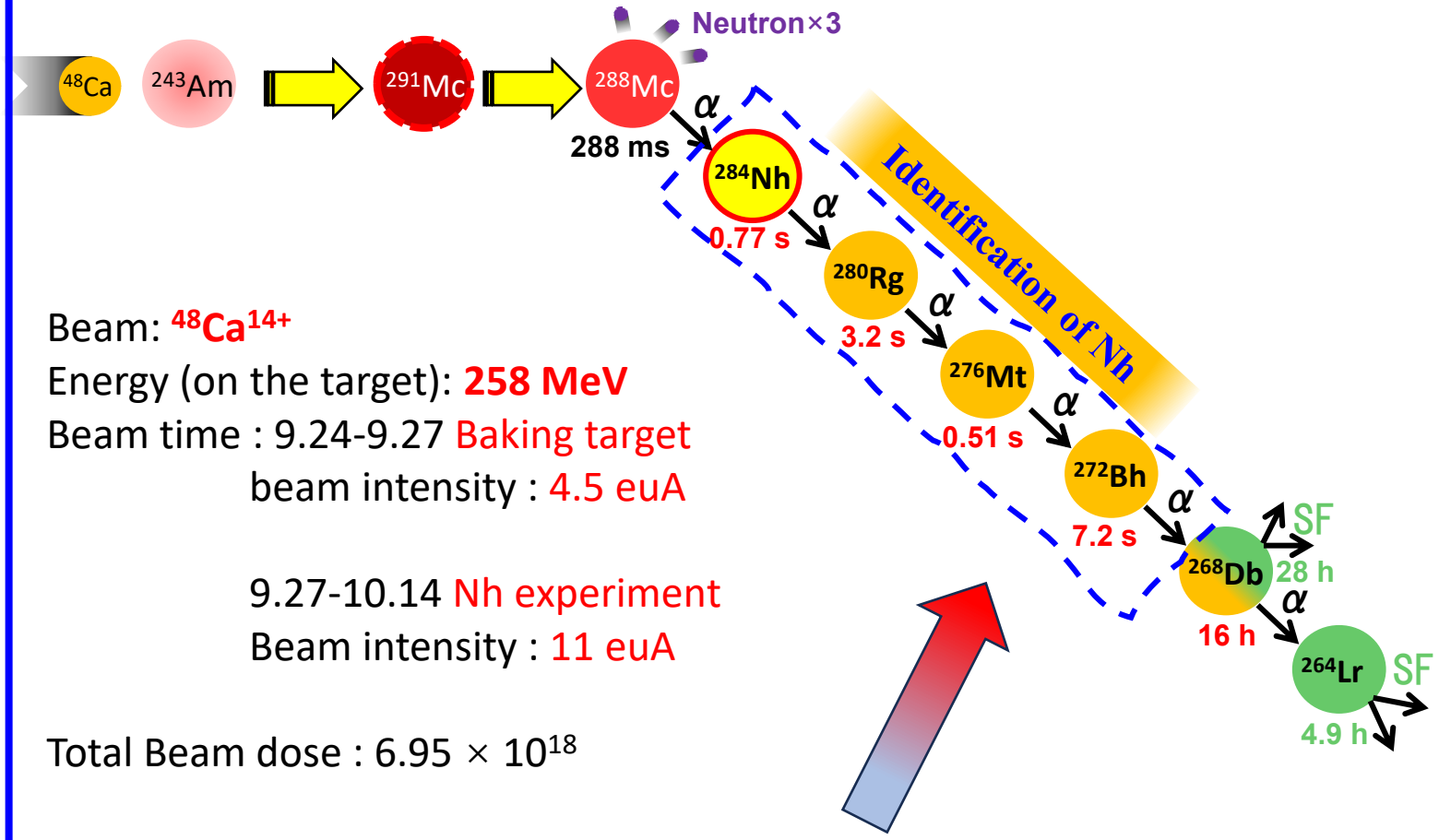
Improved LEGEND system

E_{cot} = 241.3 MeV**σ** (^{288}Mc) ≈ **10 pb**

First chemical experiment of Nh at IMP

Online experiment with ^{48}Ca beam and ^{243}Am targets

$^{243}Am(^{48}Ca,3n)^{288}Mc$



Beam: $^{48}Ca^{14+}$

Energy (on the target): **258 MeV**

Beam time : 9.24-9.27 Baking target

beam intensity : 4.5 euA

9.27-10.14 Nh experiment

Beam intensity : 11 euA

Total Beam dose : 6.95×10^{18}

Decay chains expected to be observed

Nh Collaboration

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

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SCIENCE BRINGS NATIONS TOGETHER

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PAUL SCHERRER INSTITUT
PSI

R. Eichler, P. Steinegger, G. Tiebel, J. Wilson

First chemical experiment of Nh at IMP

First observation of SHES on 4H-SiC detectors

One ^{288}Mc was Observed!

TOP-0 (65℃)

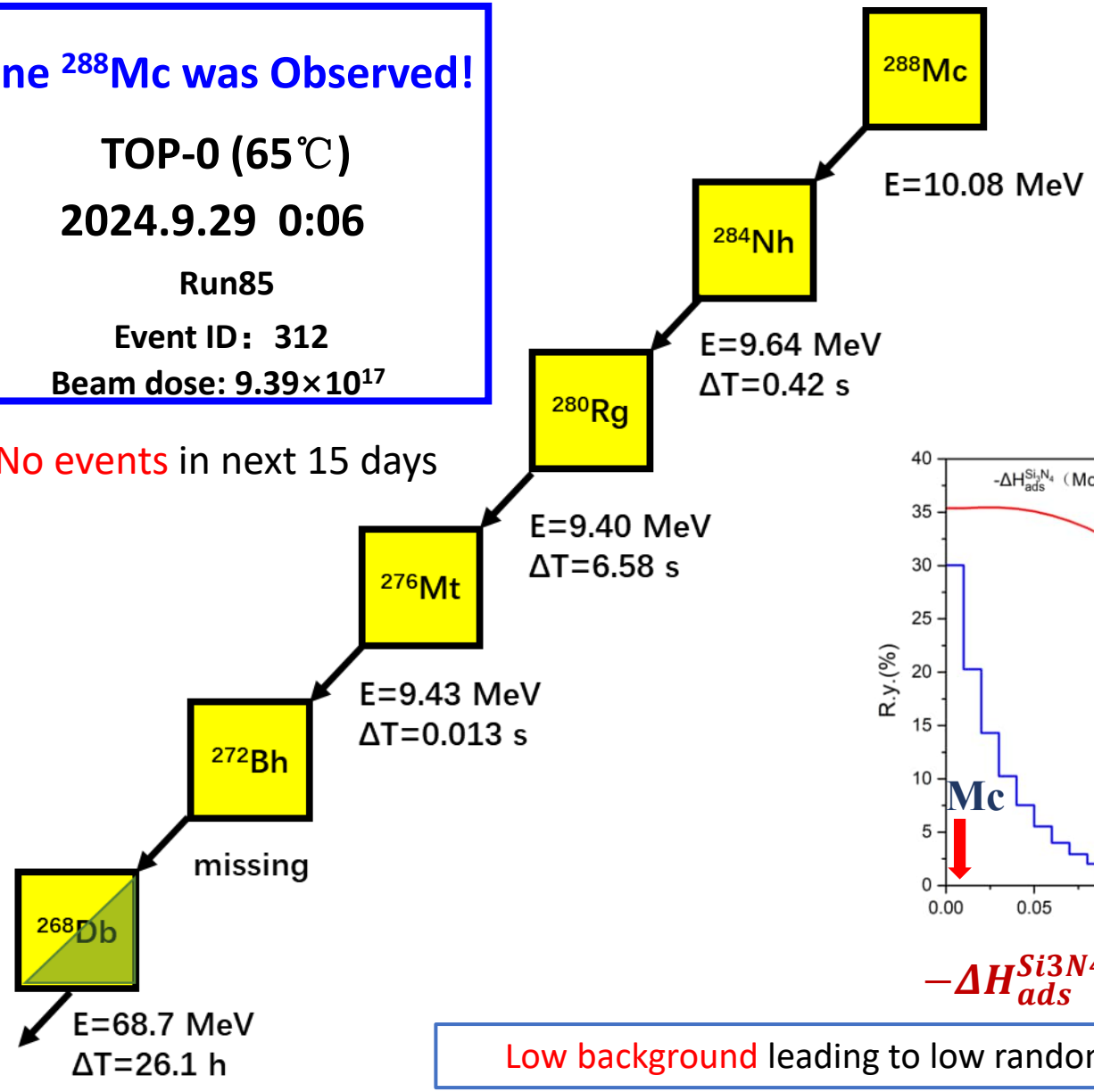
2024.9.29 0:06

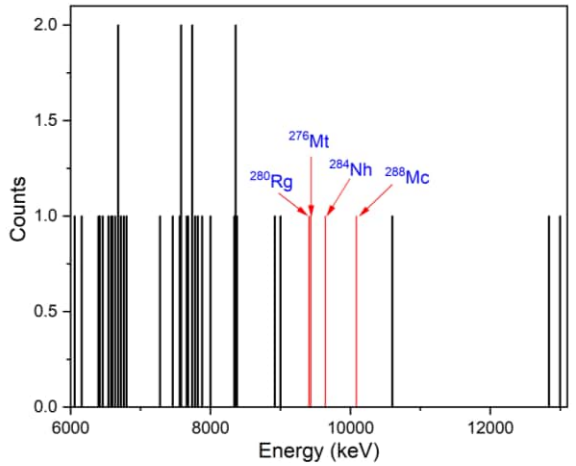
Run85

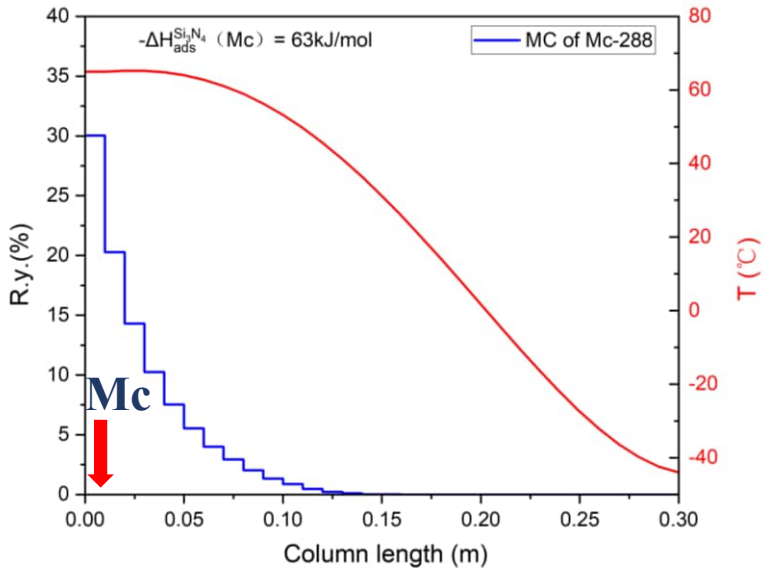
Event ID: 312

Beam dose: 9.39×10^{17}

No events in next 15 days







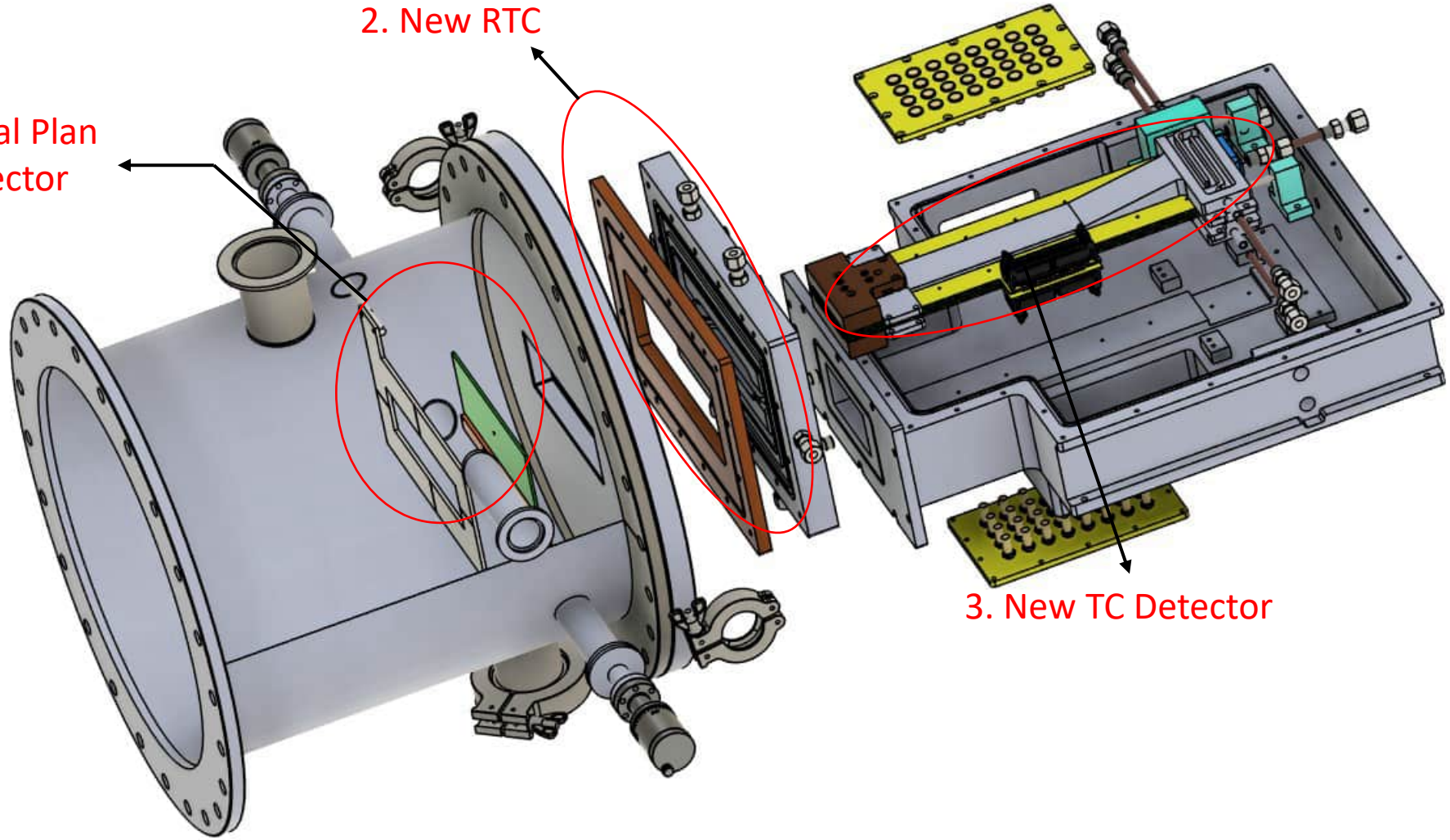
$-\Delta H_{ads}^{Si3N4}$ (Mc) > 63 kJ/mol

Low background leading to low random probabilities of 4.9×10^{-7}

Contents

Upgrading of the LEGEND system

Overview

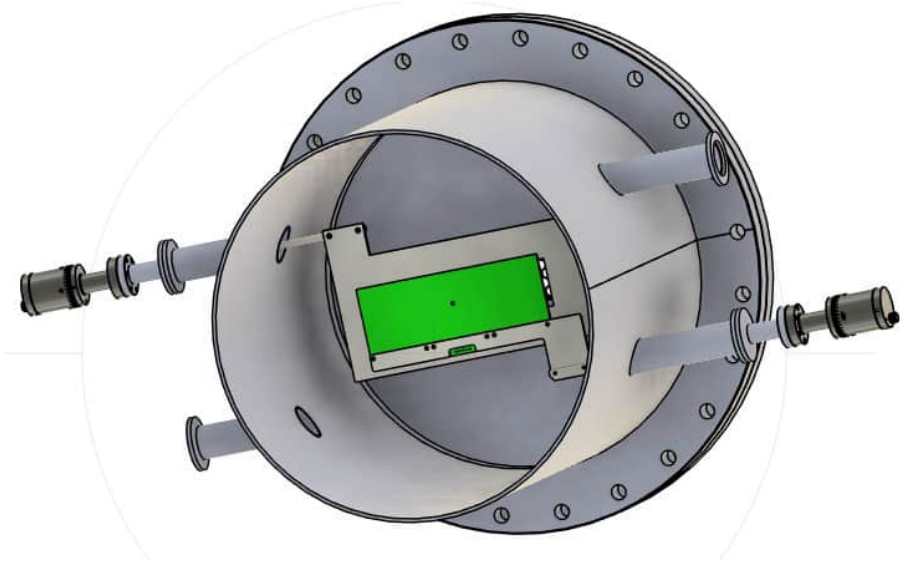


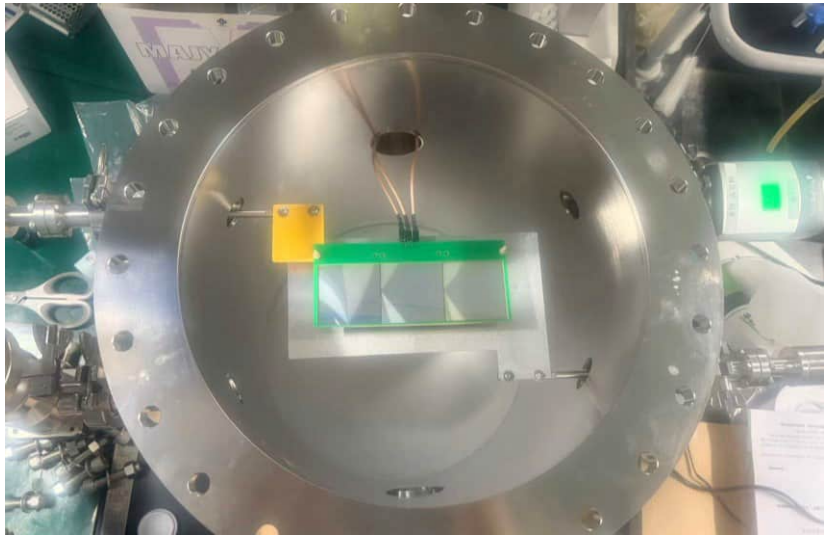
4. Improvement of MCS

5. Improvement of Am-243 target

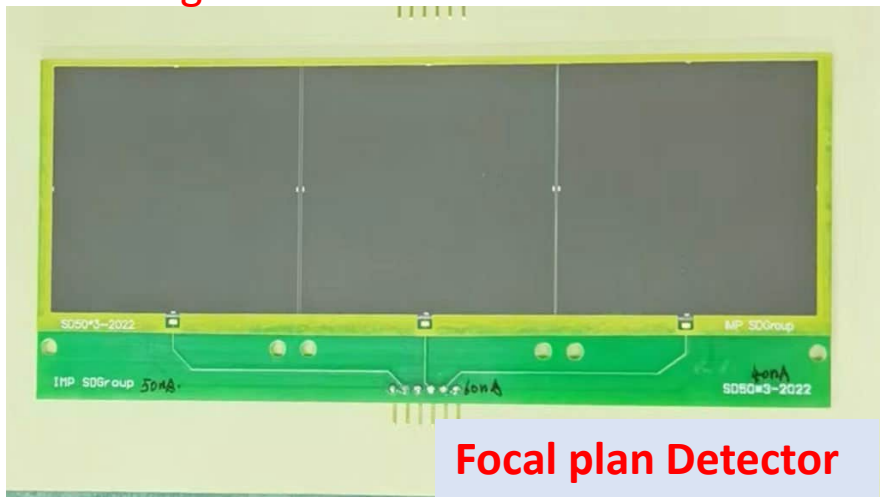
Upgrading of the LEGEND system

Focal Plane Detector



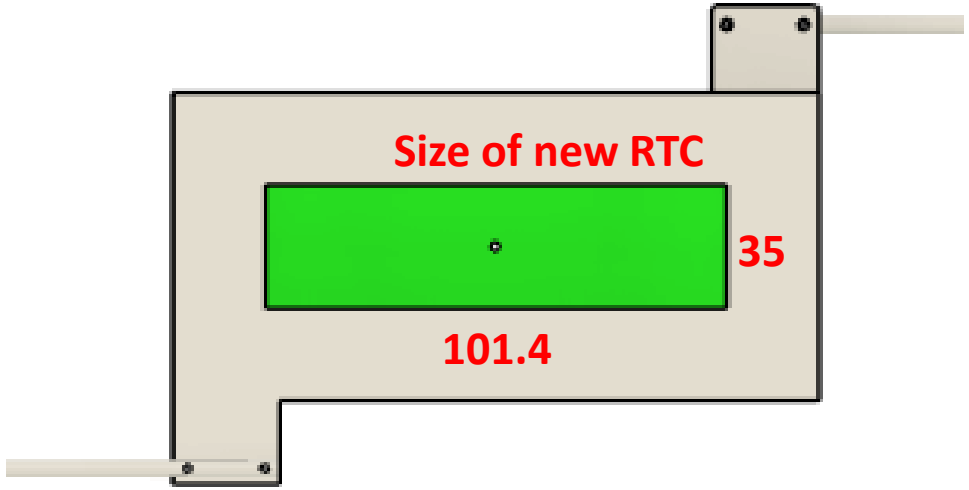


Length： 157 mm Width： 69 mm



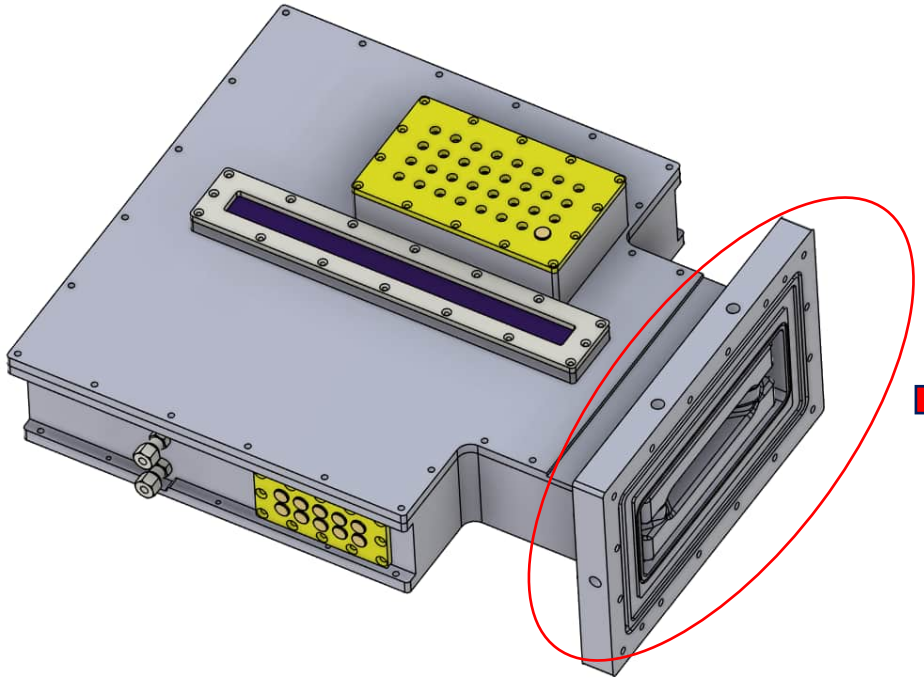
Focal plan Detector

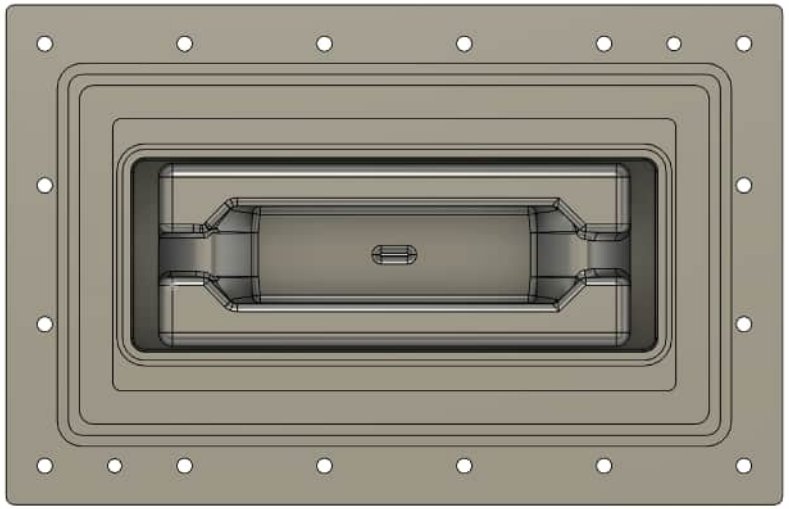
Detector unit： 50×50 mm



Upgrading of the LEGEND system

New RTC



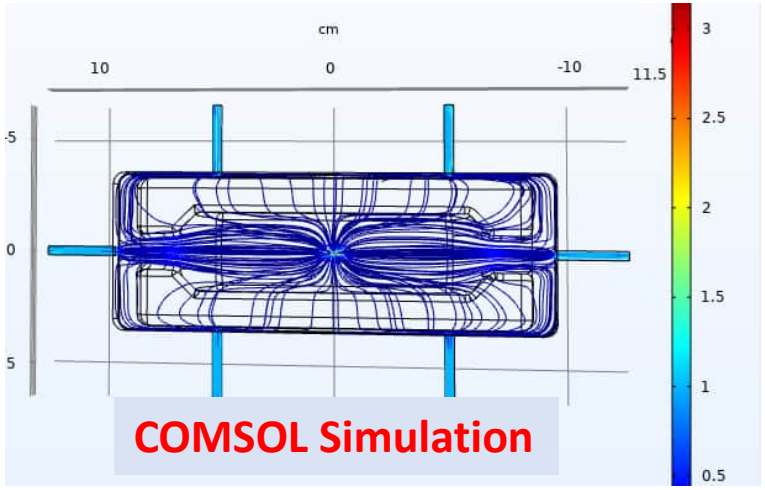


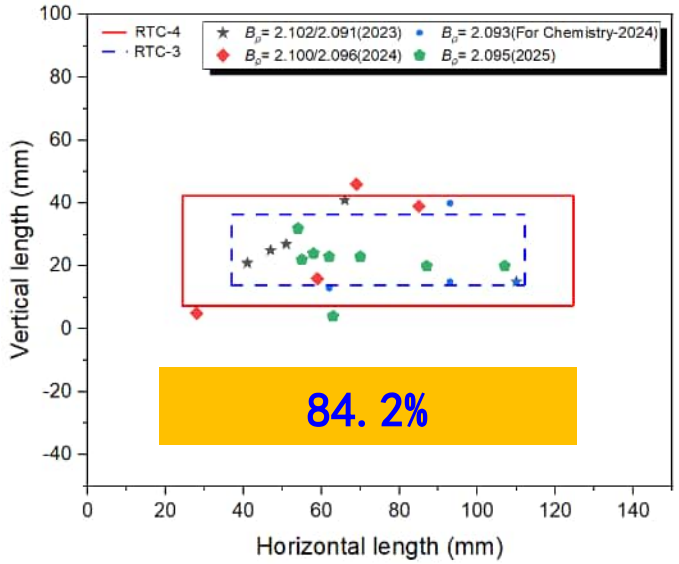
➢IMP RTC 4

X = 101.4 mm Y = 35 mm

D = 20 mm

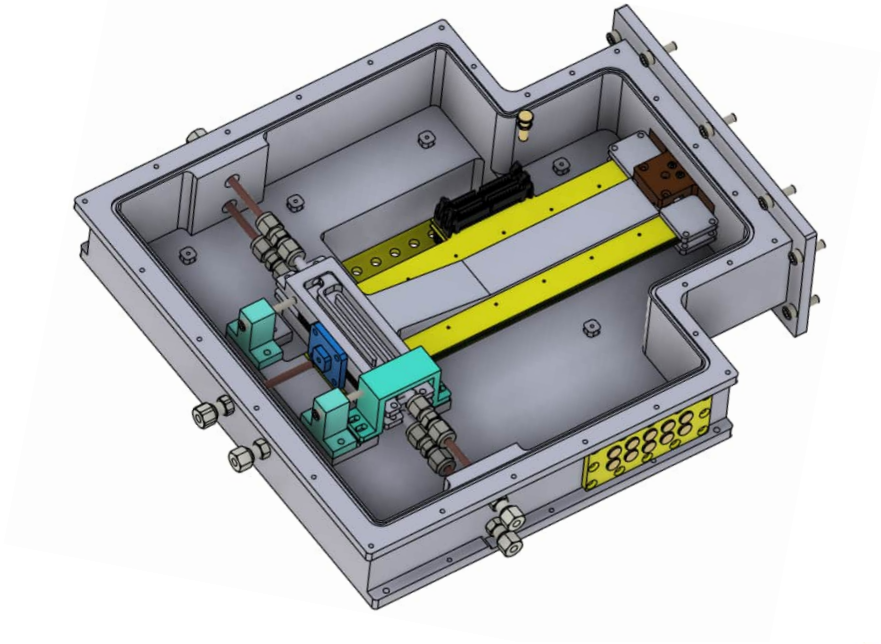
V = 70.98 mL

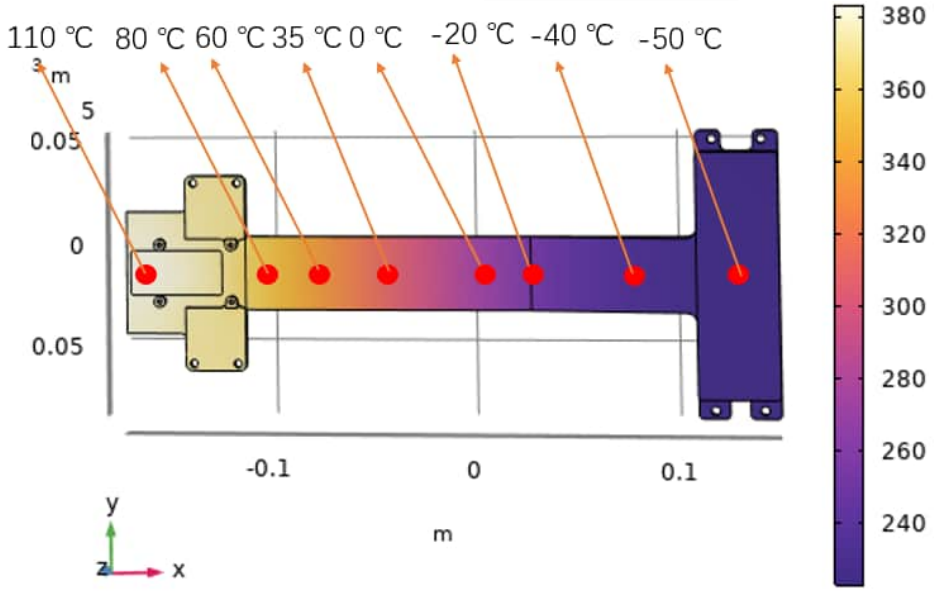


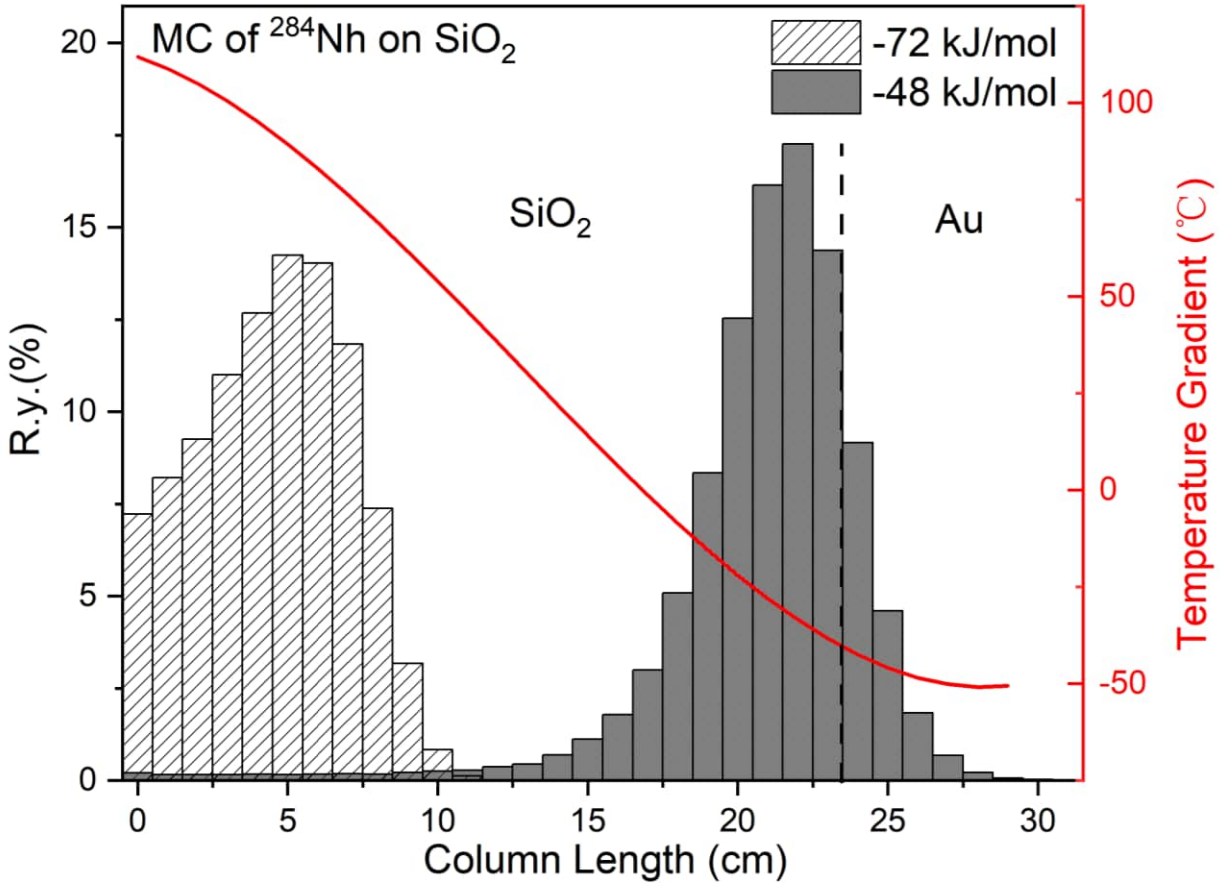


Upgrading of the LEGEND system

From Sg to Bh







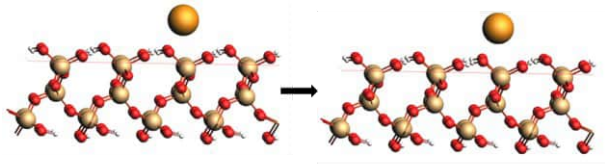
$$-72\ kJ/mol \leq \Delta H_{ads}^{SiO_2}(Nh) \leq -48\ kJ/mol$$

Upgrading of the LEGEND system

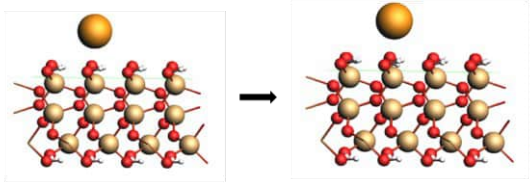
Identification of the detector surface

4H-SiC detector (made @ IMP)

Physical adsorption √

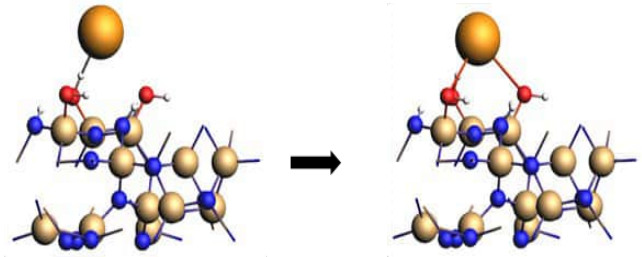


Optimized Structure of Adsorption Model (view 1)



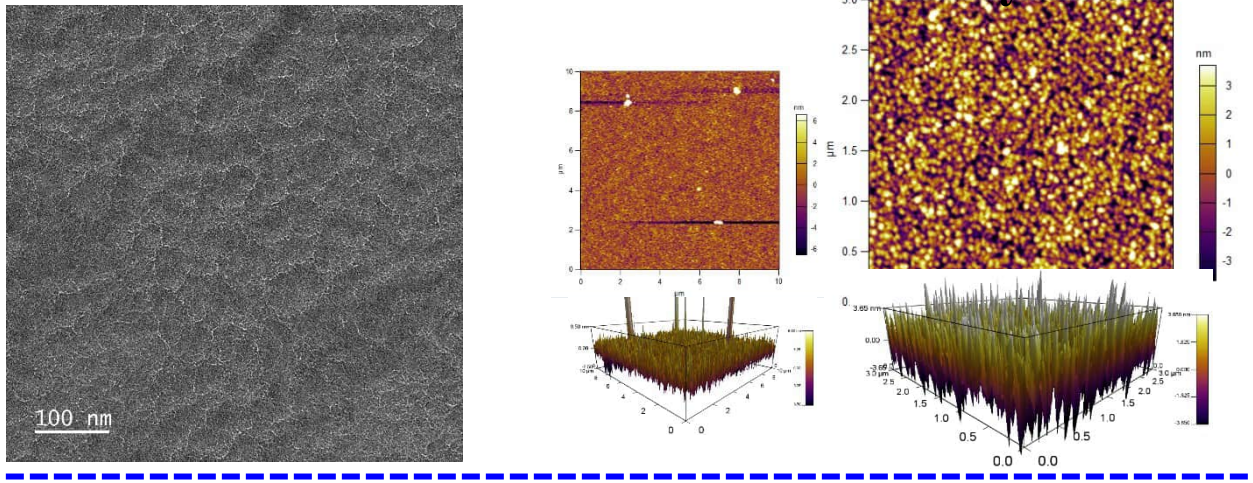
Optimized Structure of Adsorption Model (view 2)

Chemical adsorption ×

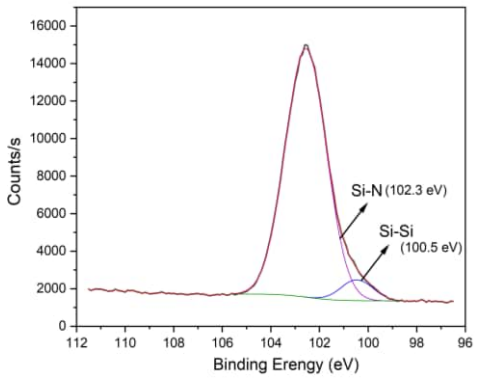


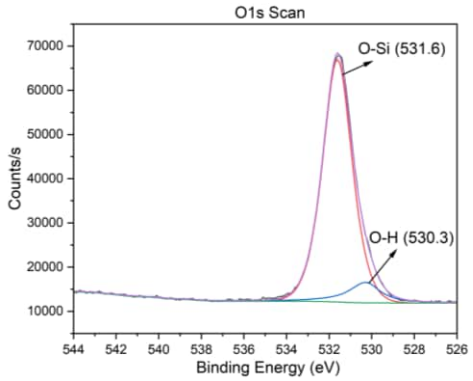
Optimized Structure of Adsorption Model (Along Y-axis)

SEM 、TEM、AFM surface analysis



XPS chemical speciation analysis





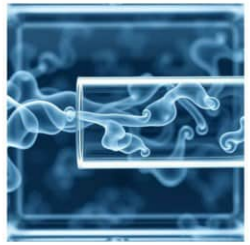
Upgrading of the LEGEND system

Improvement of MCS

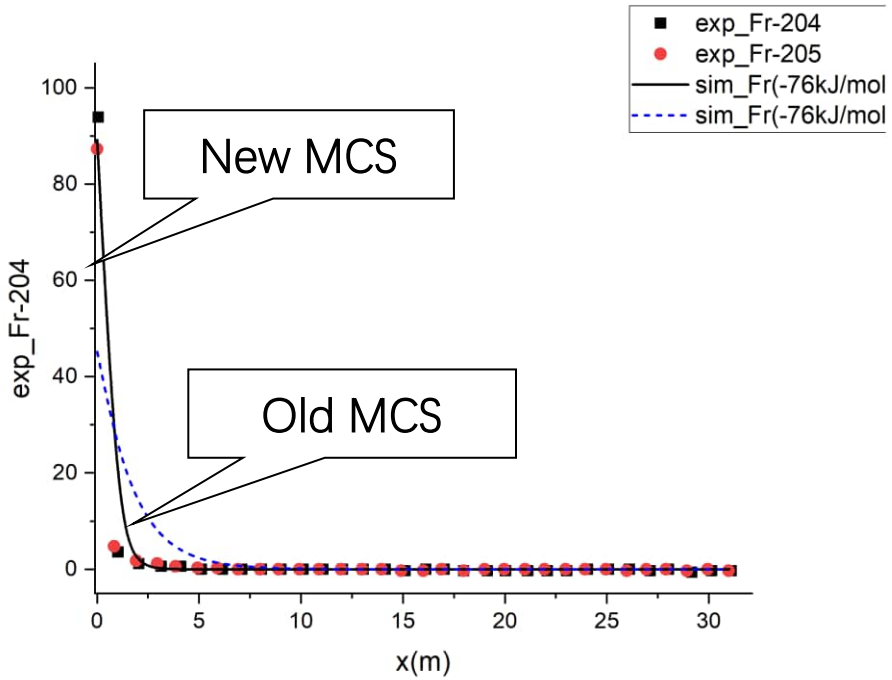
PSI

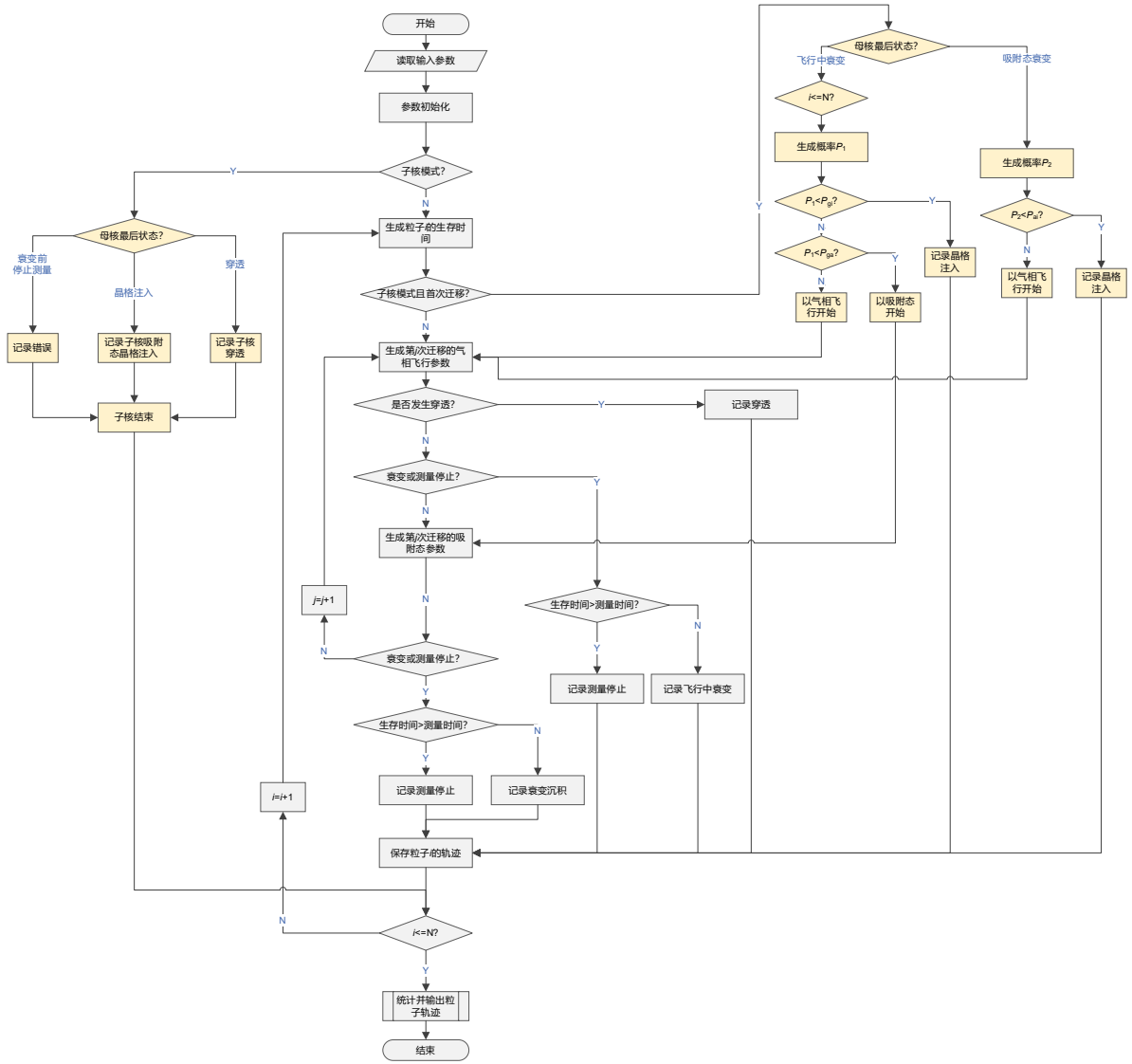
Diffusion Control

as part of Monte-Carlo simulation of gas chromatography



Robert Eichler & Patrick Steinegger :: Laboratory of Radiochemistry PSI-NES & ETHZ & UniBern)
10th Workshop on the Chemistry of the Heaviest Elements (CHE10) Dunhuang, China from September 6.-13, 2025

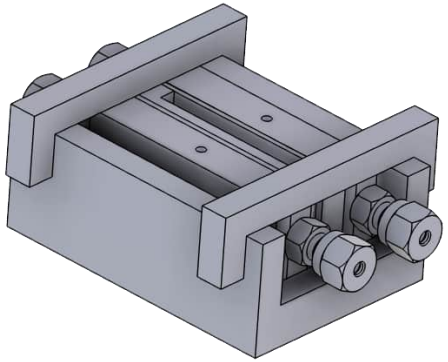




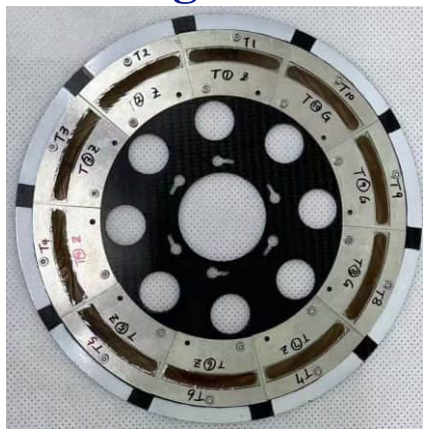
Upgrading of the LEGEND system

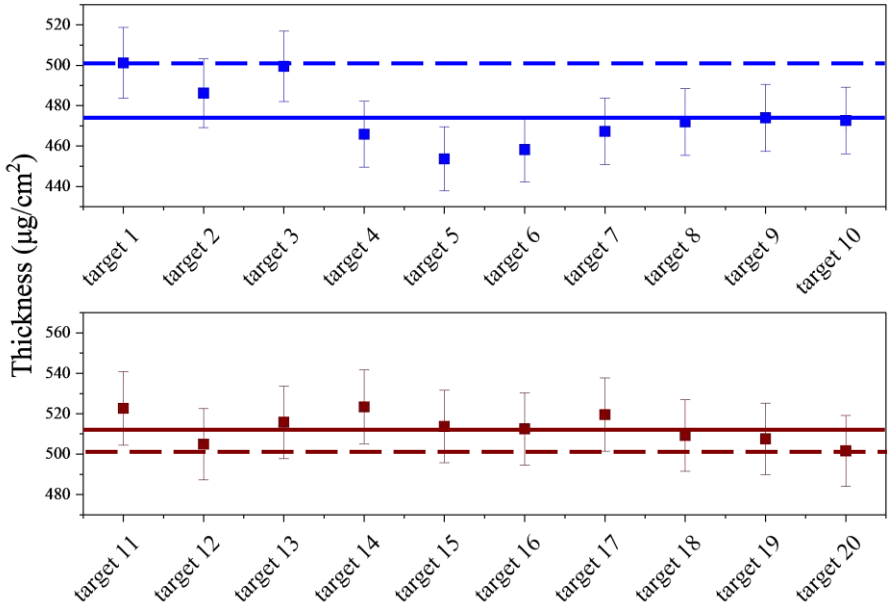
Improvement of Am-243 target

Manual apparatus



Target 1-10

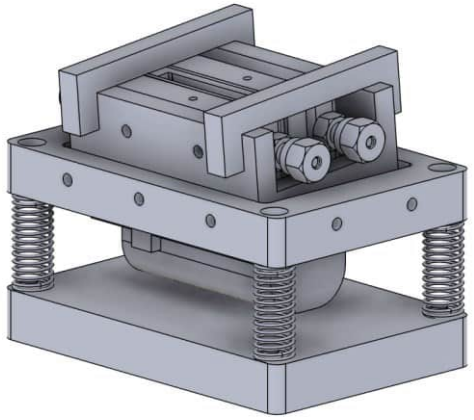




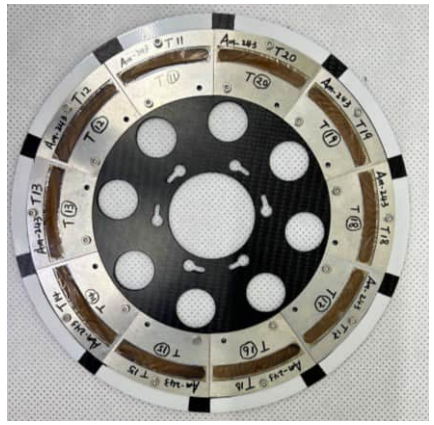
Thickness
(475 ± 15 μg/cm²)

Thickness
(513 ± 7 μg/cm²)

Automated apparatus



Terget 11-20



Target No.	Thickness (μg/cm²)	Beam current (pμA)	Irradiation time (d)	Beam dose
1 - 10	475 ± 15	0 ~ 1 pμA	81	2.3×10^{19}
11 -20	513 ± 7	0 ~ 1 pμA	138	4.65×10^{19}

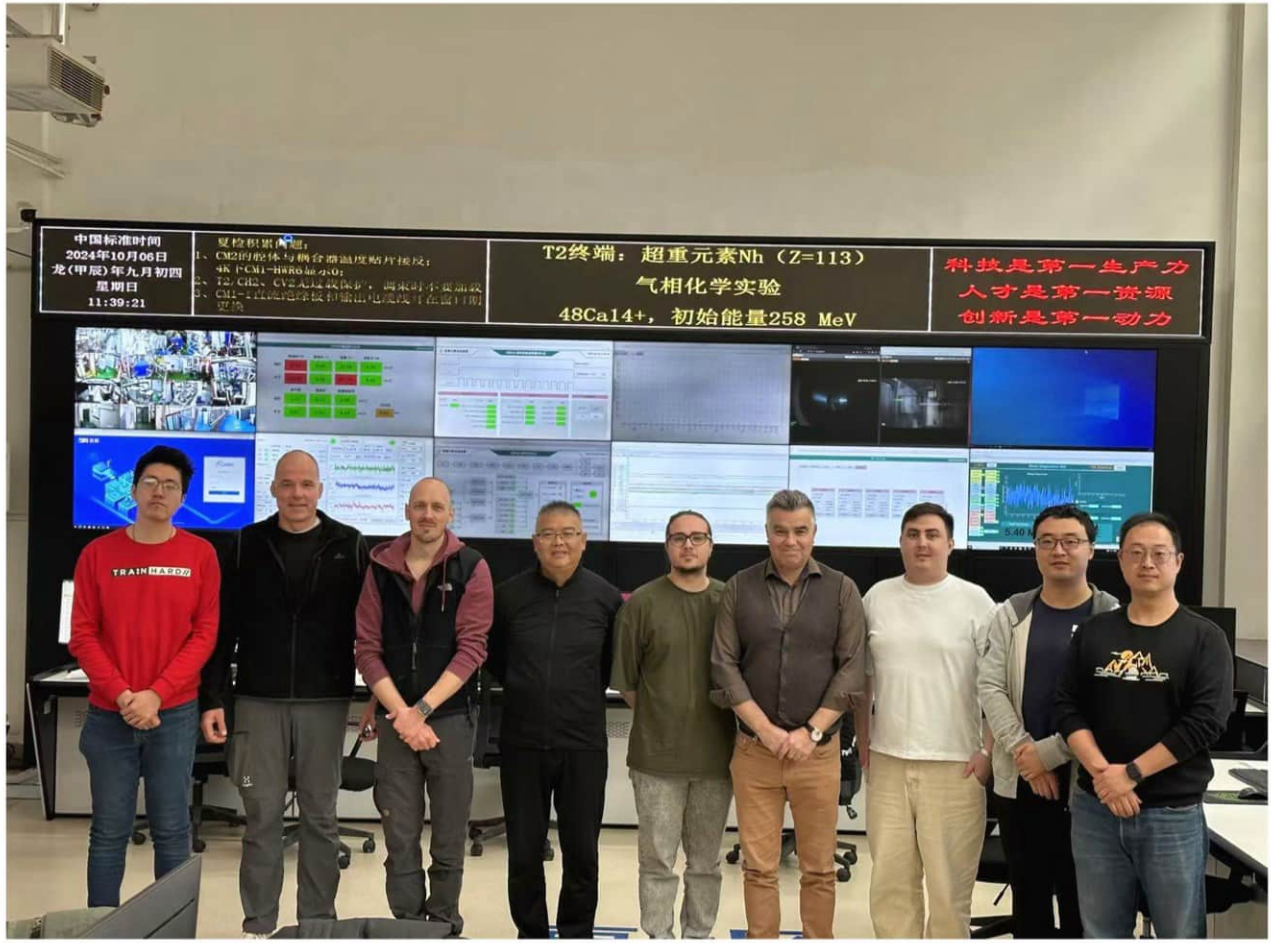
Contents

Summary

Gas-phase chemistry for Nh & Mc

1. IMP is available for chemistry study for SHEs .
2. Experimental apparatus for Nh chemistry is established.
3. High performance 4H-SiC detectors is developed.
4. Next experiment on Nh chemistry will be performed in 2026 @ IMP.

Thank you for your attention!



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