中国原子能科学研究院
中核集团 CHINA INSTITUTE OF ATOMIC ENERGY

Status of Accelerator Mass Spectrometry & HI-13 accelerator at CIAE

China Institute of Atomic Energy

Ming He

中国原子能科学研究院
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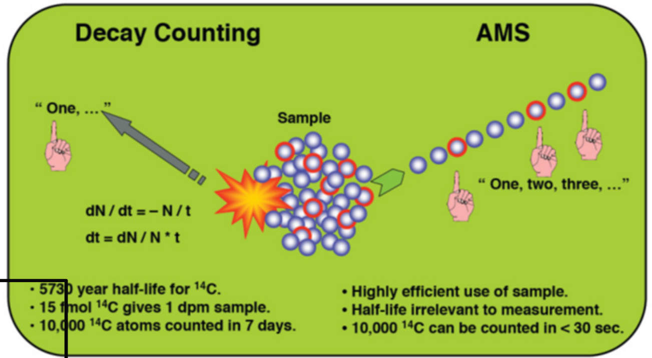
Outline

- **1. Status of AMS at CIAE**
  - 1.1 HI-13 AMS system
  - 1.2 Single stage AMS system
  - 1.3 Small tandem AMS for heavy nuclides
- **2. Status of HI-13 tandem Accelerator**
  - 2.1 HI-13 tandem accelerator
  - 2.2 Experimental terminals
  - 2.3 Beijing rare ion beam facility (BRIF)

Accelerator mass spectrometry(AMS)

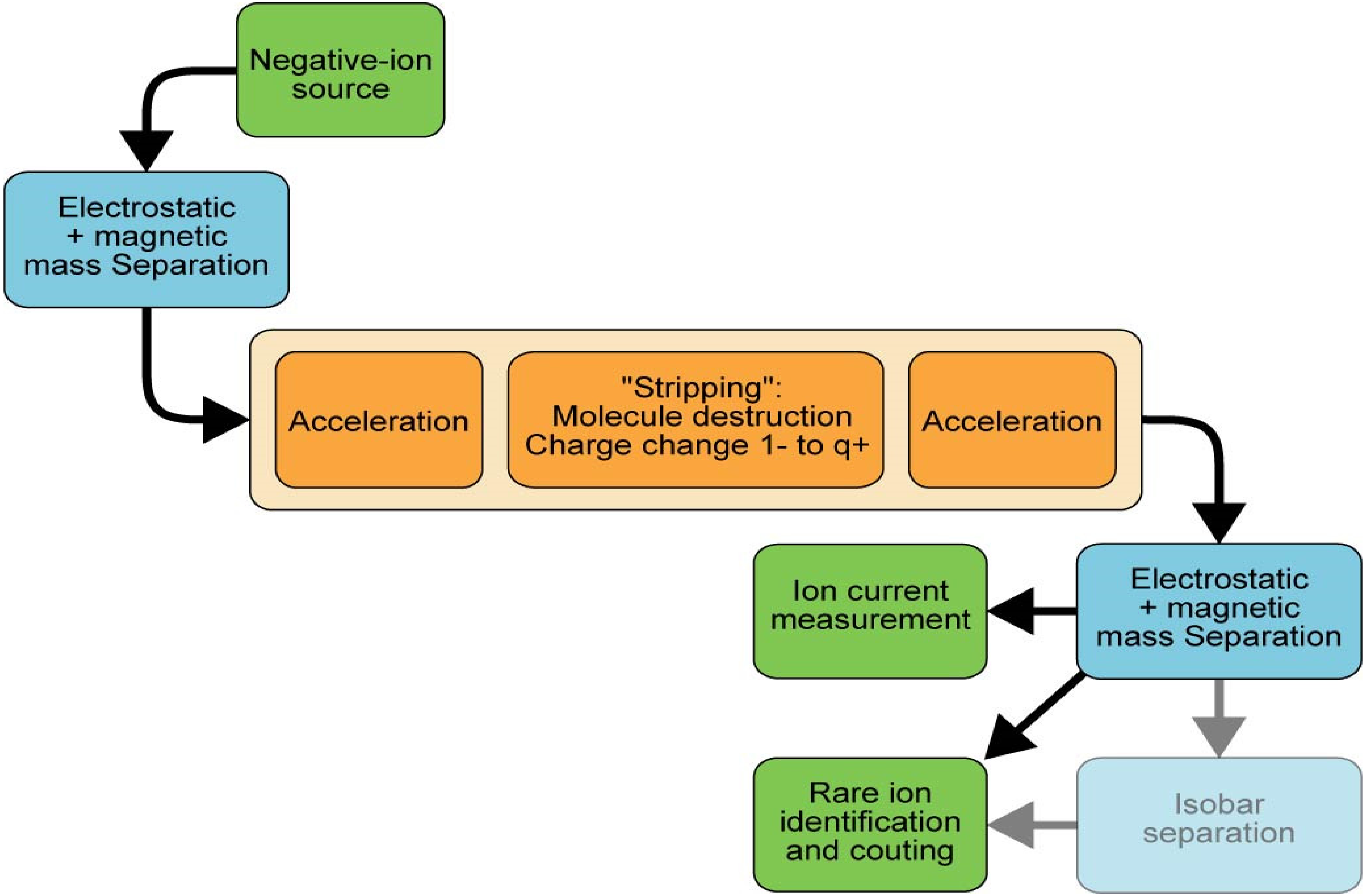
Ultra sensitivity:10^{-15}(isotopic ratio)
Long-lived isotopes(10^{2}-10^{7}years)



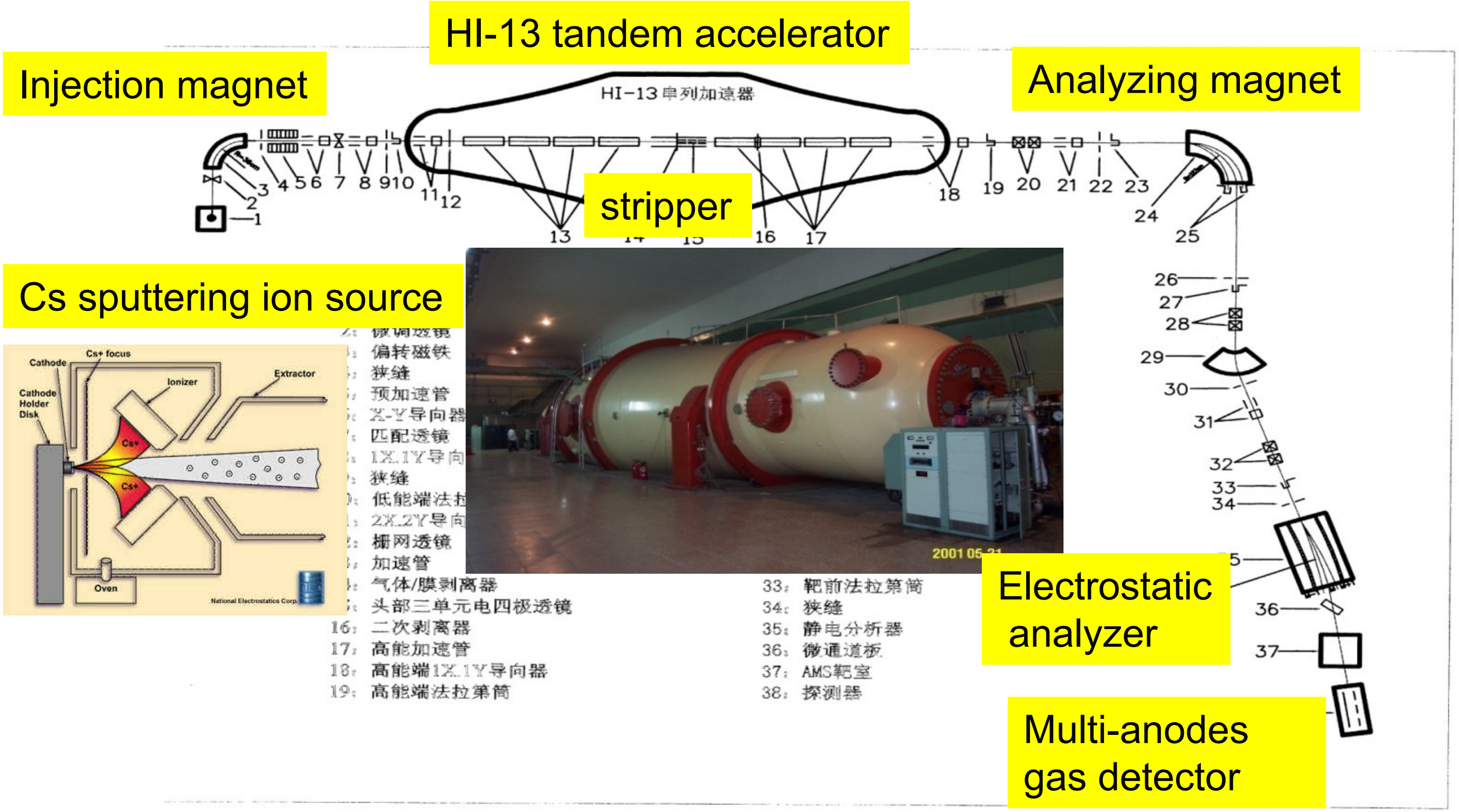
Negative ion source :decreasing background
Accelerator: high ion energy
Stripper: molecule destruction , charge change
Analyzing system: remove background
Detector: ion identification
Beam transport system: transport efficiency

Applications

Environment
Geoscience
Archeology
Physics …


Negative-ion source
Electrostatic + magnetic mass Separation
Acceleration
"Stripping": Molecule destruction Charge change 1- to q+
Acceleration
Electrostatic + magnetic mass Separation
Ion current measurement
Rare ion identification and couting
Isobar separation

1.1 HI-13 AMS System



The first AMS system in China established in 1989

^{10}Be， ^{36}Cl， ^{129}I

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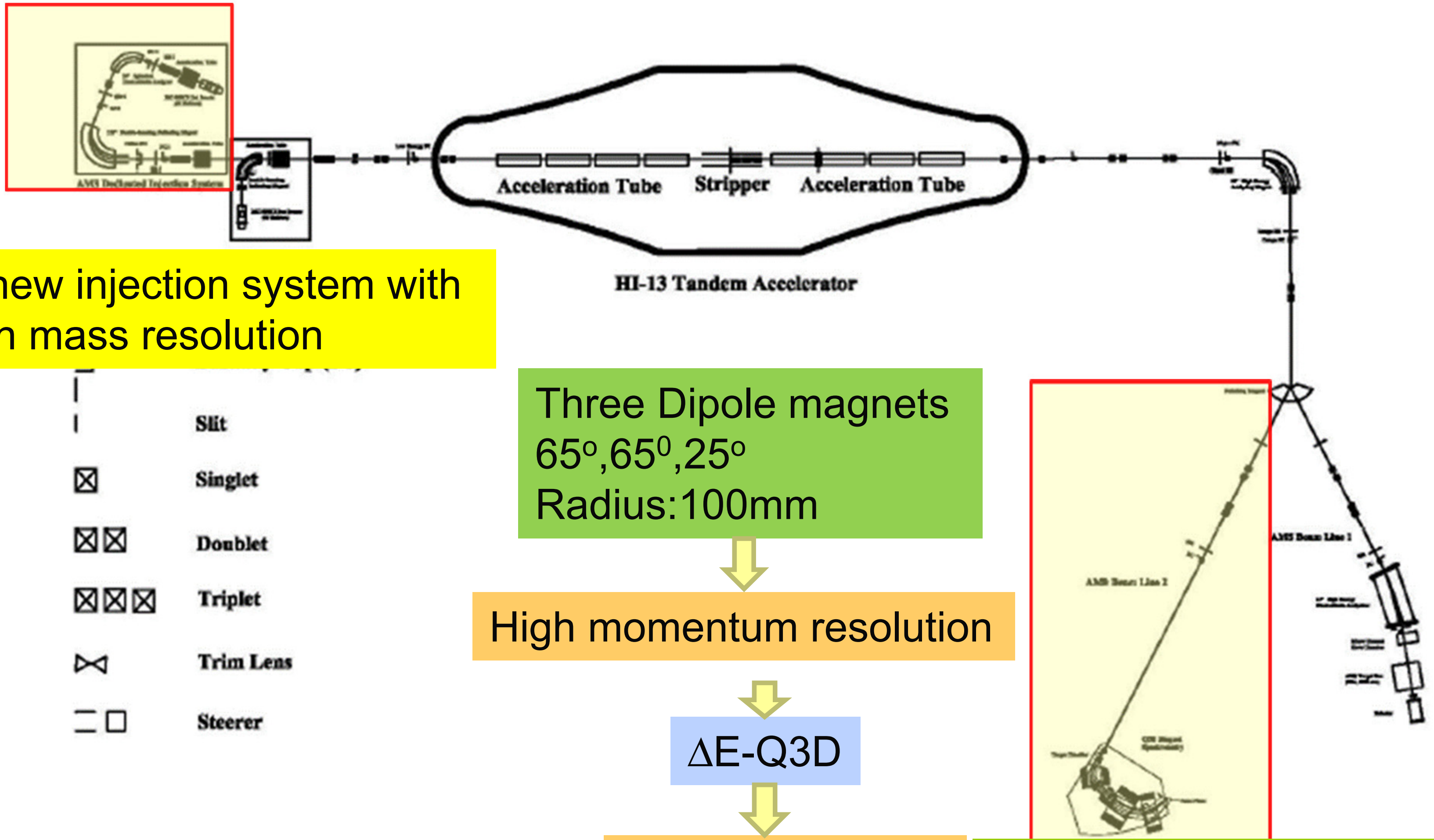
Updated HI-13 AMS system



A new injection system with high mass resolution

Three Dipole magnets
65°,65°,25°
Radius:100mm

High momentum resolution

ΔE-Q3D

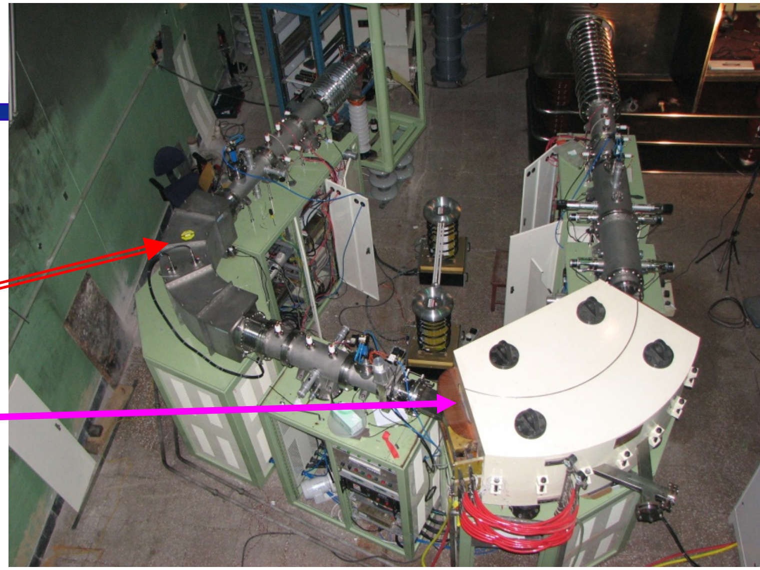
Isobar separation

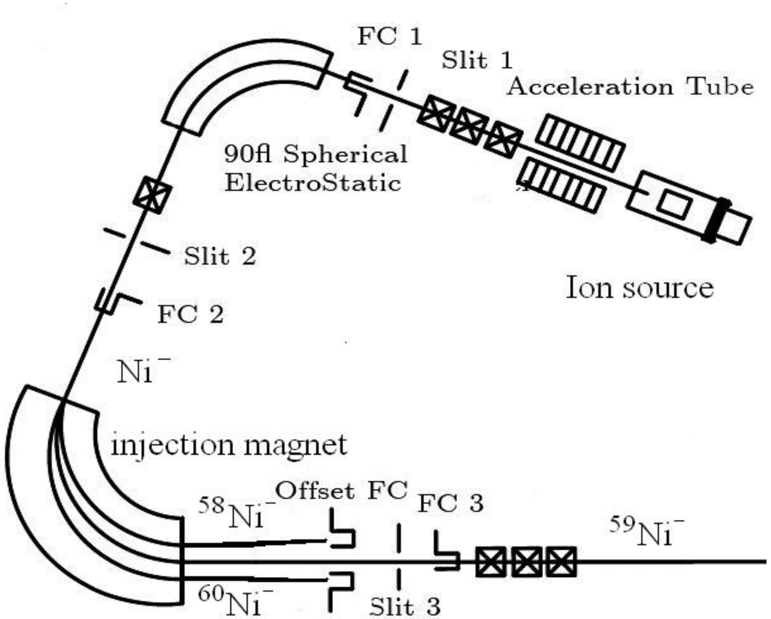
Q3D magnetic spectrometry

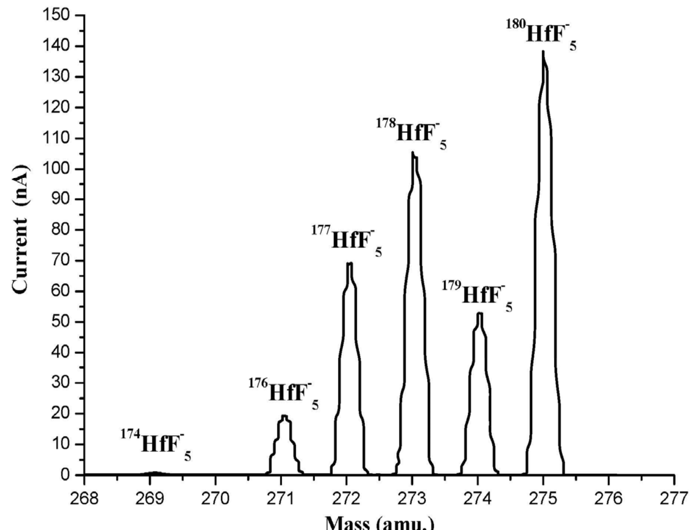
A Q3D beam lines

Injection system

- 90^0 Spherical electrostatic deflector (ρ=75cm)
- 112^0 double focusing magnet (ρ=80cm)



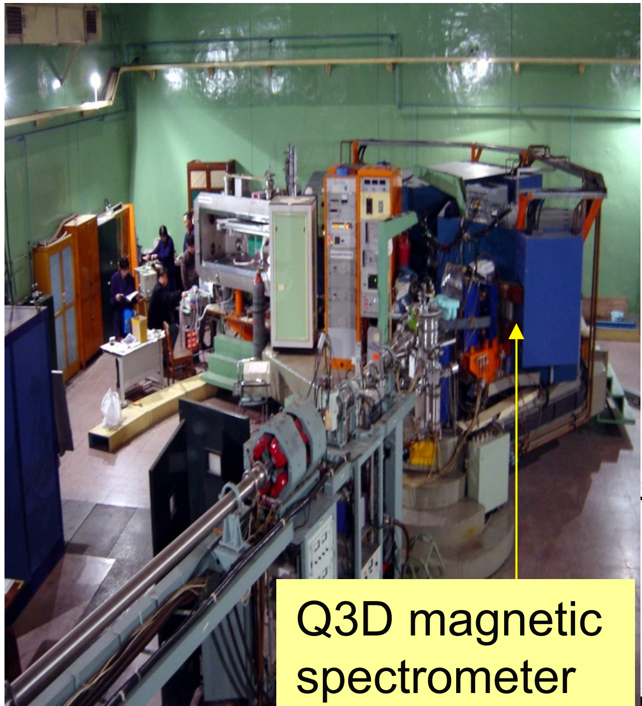


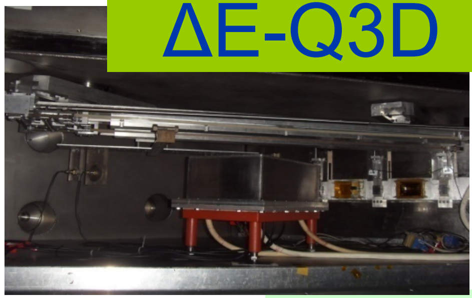


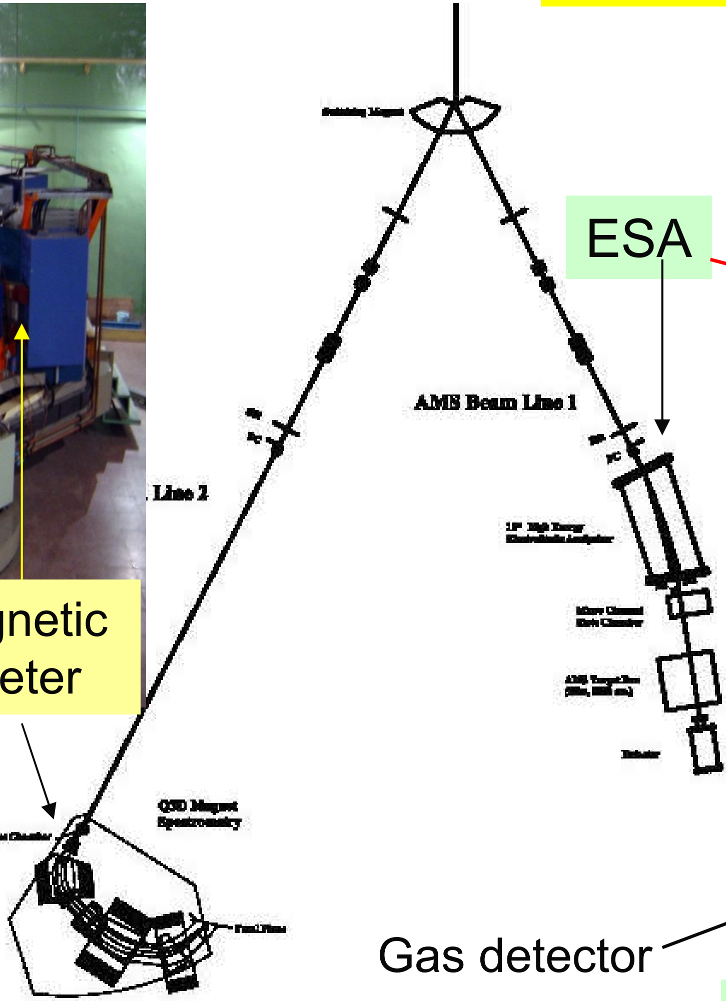
M/ΔM=450

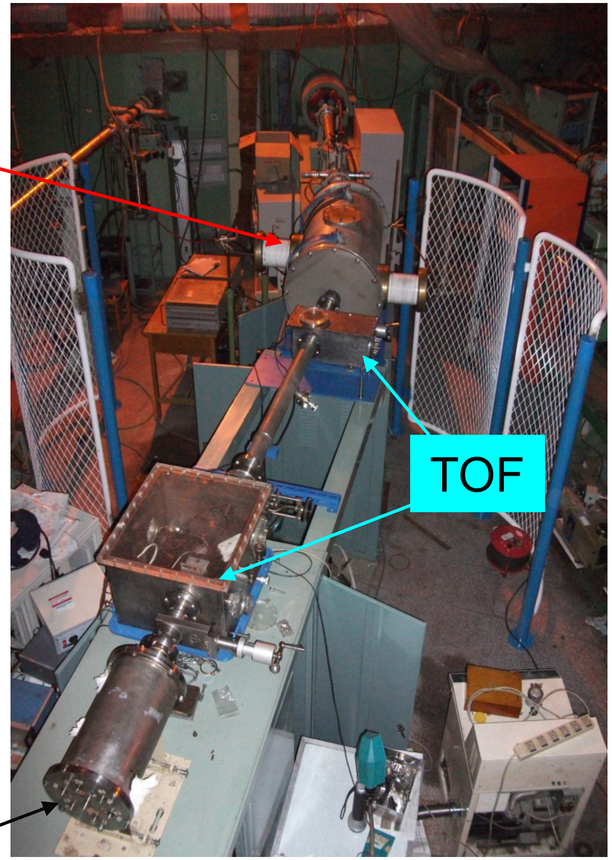
Two beam lines are used for AMS measurement

20% beam time for AMS









^{26}Al , ^{32}Si, ^{36}Cl, ^{53}Mn, ^{59}Ni, ^{60}Fe

^{10}Be, ^{41}Ca, ^{79}Se, ^{129}I, ^{236}U

HI-13 AMS performance

nuclide	Target	Injection ion	Terminal voltage	Detection method	sensitivity
^{10}Be	BeO+Nb	BeO^-	7.5MV	Absorb+ΔE-E	$^{10}Be/^9Be \sim 1\times10^{-14}$
^{26}Al	Al_2O_3+Ag	AlO^-	9.0MV	**ΔE-Q3D+ΔE-E**	$^{26}Al/^{27}Al=2\times 10^{-15}$
^{32}Si	SiO_2+Fe	Si^-	10.5MV	ΔE-Q3D+ΔE-E	$^{32}Si/Si<5\times10^{-15}$
^{36}Cl	AgCl+Ag	Cl^-	10.5MV	ΔE-Q3D+ΔE-E	$^{36}Cl/Cl<1\times10^{-15}$
^{41}Ca	CaF_2+Ag	CaF_3^-	8.0MV	ΔE-E	$^{41}Ca/Ca=2\times10^{-14}$
^{53}Mn	MnF_2+Ag	MnF^-	11.5MV	ΔE-Q3D+ΔE-E	$^{53}Mn/Mn=1\times10^{-13}$
^{59}Ni	NiO+Ag	Ni^-	11.5MV	ΔE-Q3D+ΔE-E	$^{59}Ni/Ni=8\times10^{-14}$
^{60}Fe	Fe_2O_3+Ag	FeO-	11MV	ΔE-Q3D+ΔE-E	$^{60}Fe/Fe \sim 1\times10^{-15}$
^{129}I	AgI+Ag	I^-	7.8MV	E	$^{129}I/^{127}I=2\times10^{-13}$
^{236}U	UO_2+Nb	UO^-	7.8MV	E	$^{236}U/U=1\times10^{-11}$

Applications

- （1） **Nuclear physics**

nuclear reaction cross section and half life of radioisotopes measurement

Stable isotope

$^{238}U(n,3n)^{236}U$;(***PRC87(2013)***

$^{60}Ni(n,2n)^{59}Ni$;(***NIMB294(2015)***

$^{14}N(^{16}O,^{4}He)^{26}Al$(***NIMB240(2005)***)

Short lived radioisotope

$^{128}I(n,\gamma)^{129}I$ ($^{129}I/^{127}I$);

$^{59}Fe(n,\gamma)^{60}Fe$ ($^{60}Fe/^{58}Fe$)

$^{127}I(n,\gamma)^{128}(n,\gamma)^{129}I$

$^{58}Fe(n,\gamma)^{59}(n,\gamma)^{60}Fe$

$$\sigma_2=\left[\frac{N_{129}}{N_{127}}\right]\frac{\lambda^2}{\phi^2\sigma_1\left(\lambda t-1+e^{-\lambda t}\right)}\cong\left[\frac{N_{129}}{N_{127}}\right]\frac{2}{\sigma_1\Phi^2}$$

half life measurement with AMS

$$dN/dt = N\frac{ln2}{T_{1/2}}$$

dN/dt: liquid scintillation detector

N: AMS

^{79}Se	[NIMB194(2002)]
^{151}Sm	[PRC84(2011)]
^{32}Si	[NIMB294(2013)]

- （2） **Geology**

geological exposing age and erosion rate （^{36}Cl)
the age of underground water (^{36}Cl)
The growth rate of ocean sediment(^{10}Be)

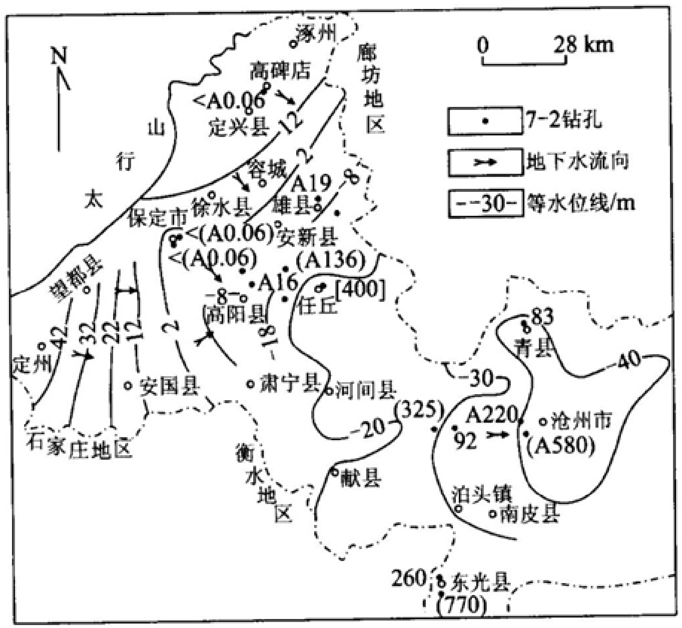
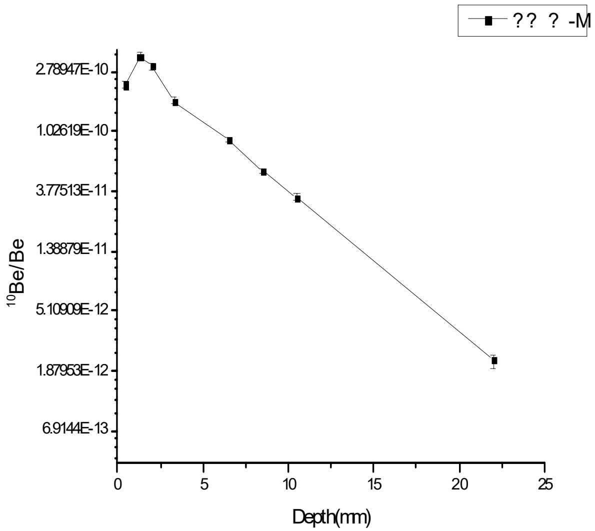


图 3 河北平原第四系深层地下水^{36}Cl同位素年龄和地下水动力学年龄对比



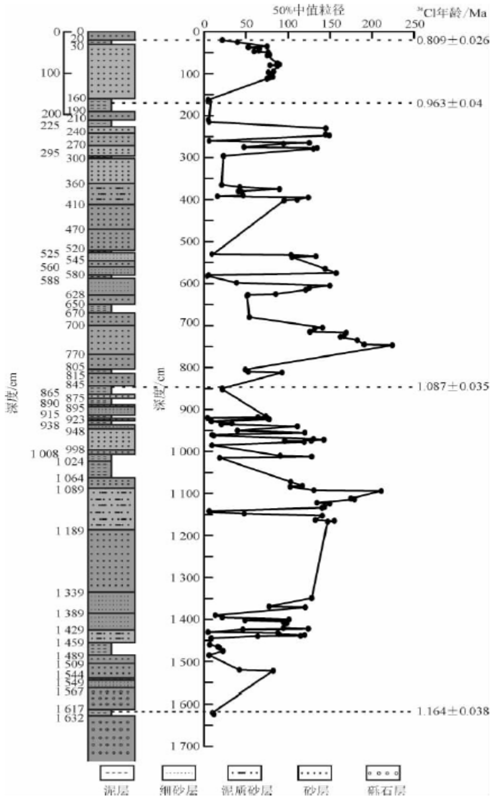


图 4 敦煌盆地早更新世地层、粒度分析和^{36}Cl年龄剖面

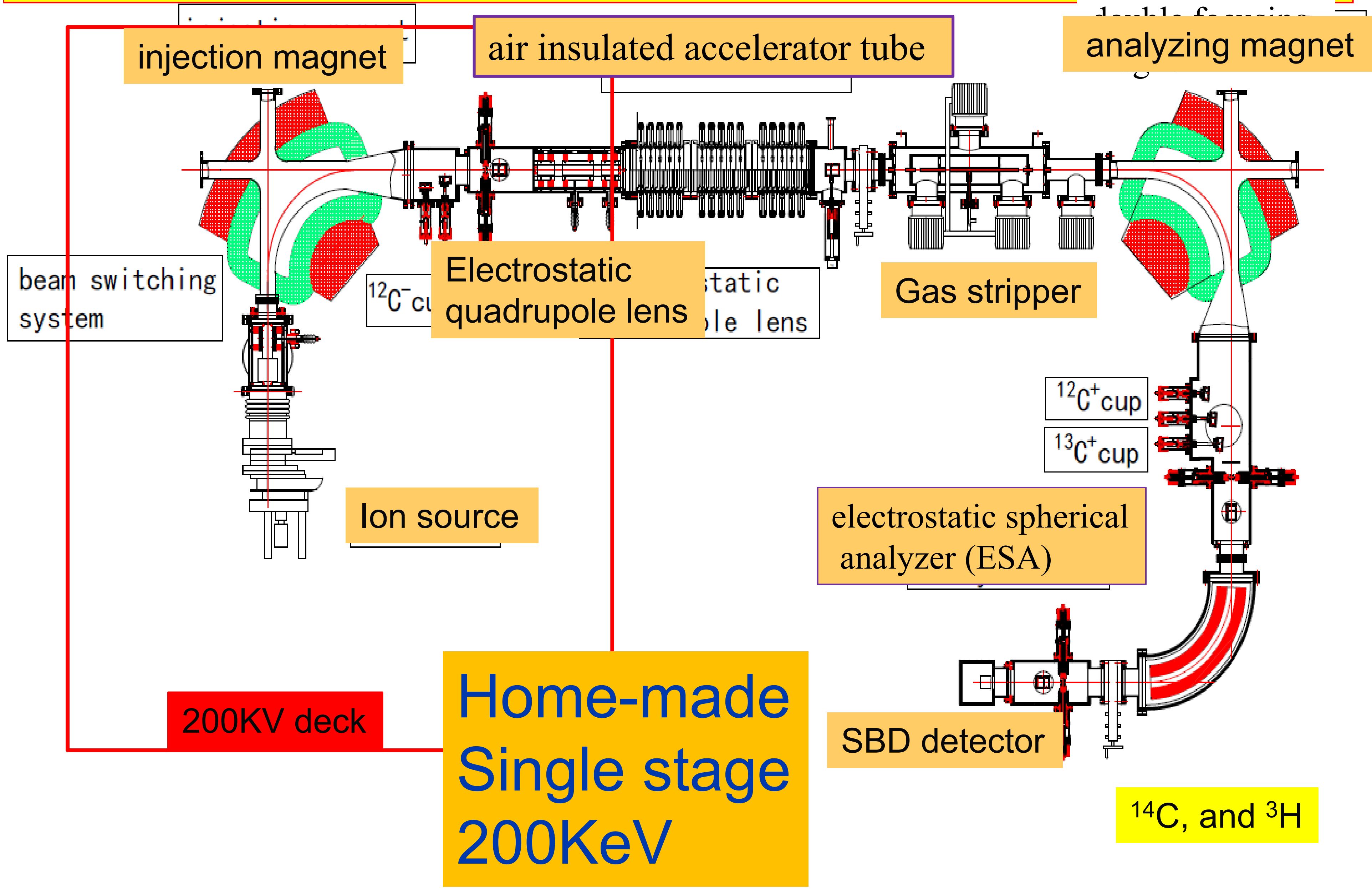
- **(3) Environment**

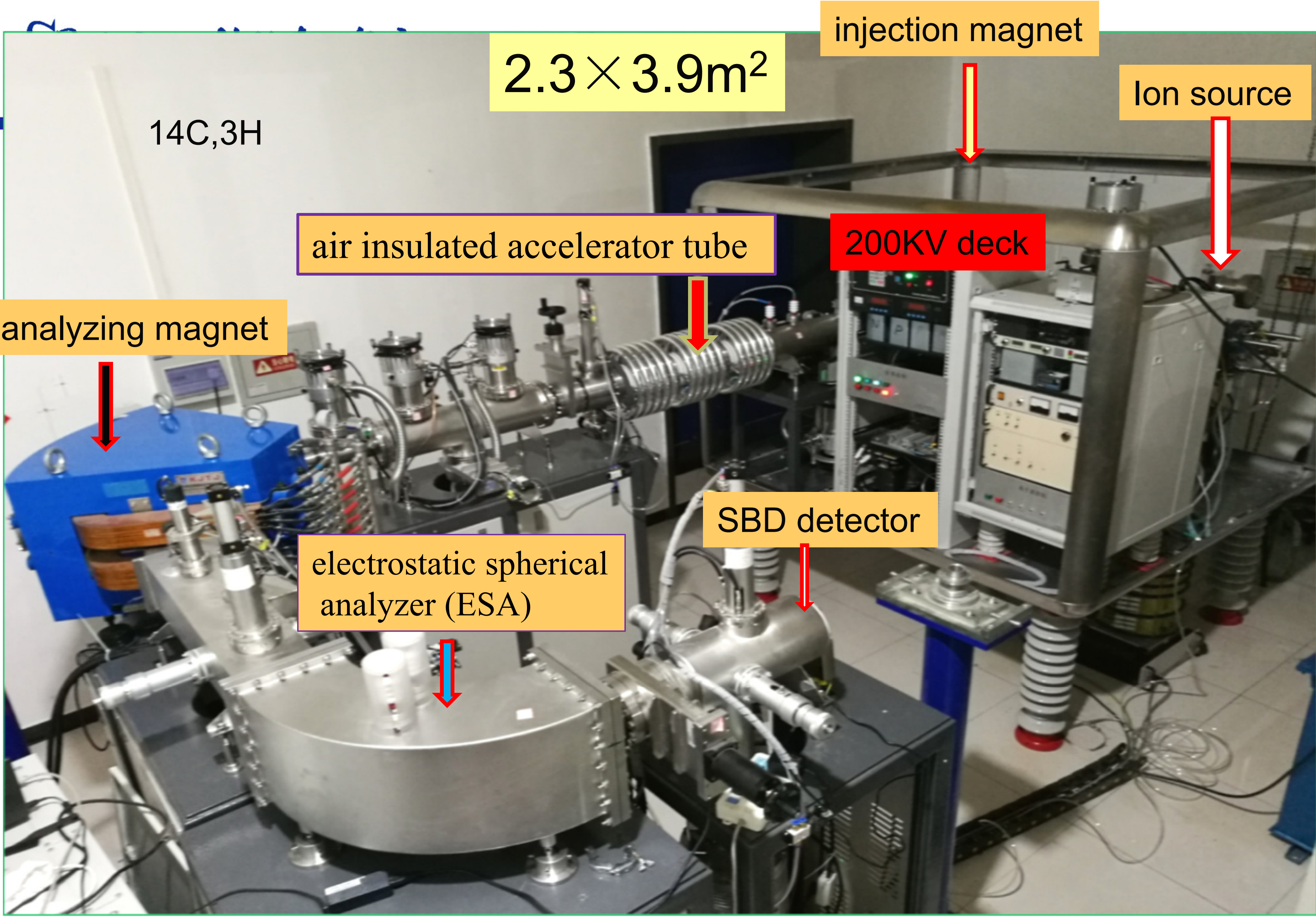
  ^{129}I and ^{36}Cl distribution (soil, tree, river, aerosole) near nuclear facility

- **(4) Biology**

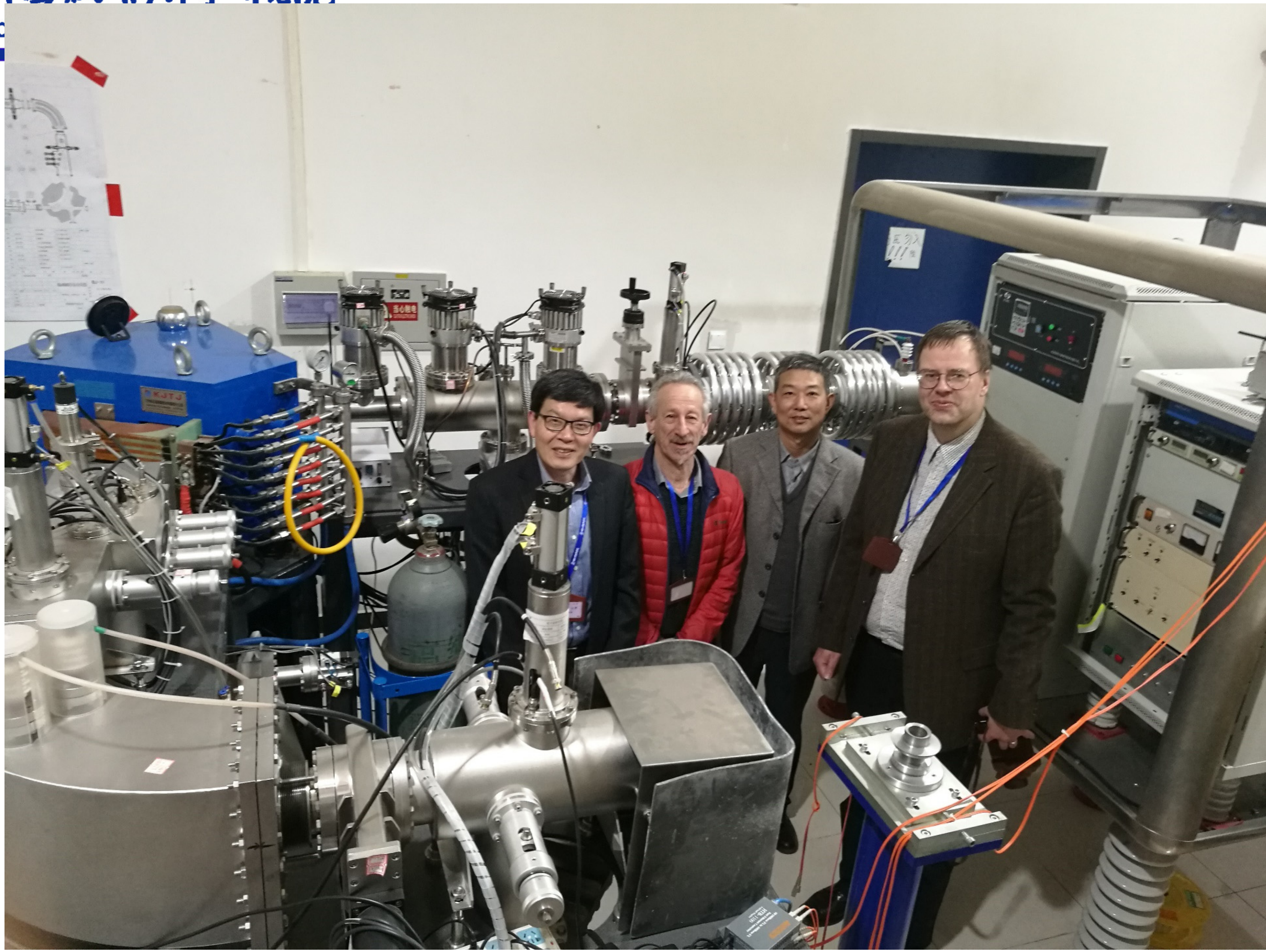
  Calcium absorptivity ,bone resorption behavior and calcium kinematics using ^{41}Ca tracer

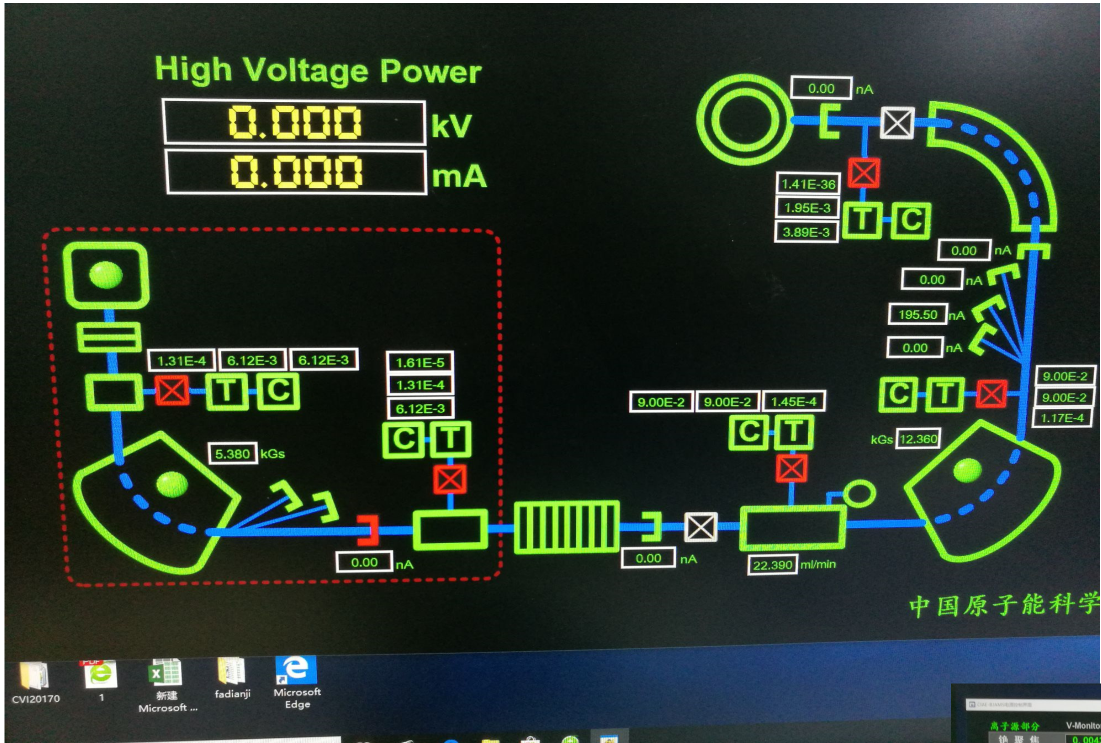
1.2 Single stage AMS





2.3×3.9m²
injection magnet
Ion source
14C,3H
air insulated accelerator tube
200KV deck
analyzing magnet
SBD detector
electrostatic spherical analyzer (ESA)




High Voltage Power
0.000 kV
0.000 mA
1.31E-4
6.12E-3
6.12E-3
1.61E-5
1.31E-4
6.12E-3
5.380 kGs
0.00 nA
0.00 nA
9.00E-2
9.00E-2
1.45E-4
22.390 ml/min
12.360 kGs
9.00E-2
9.00E-2
1.17E-4
0.00 nA
0.00 nA
195.50 nA
0.00 nA
0.00 nA
1.41E-36
1.95E-3
3.89E-3
0.00 nA
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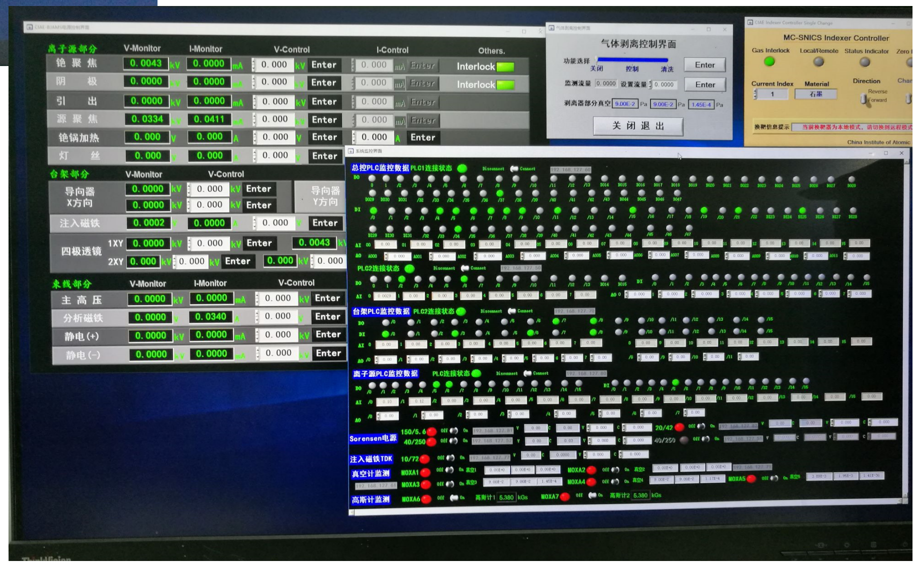
CVI20170
Microsoft Edge


V-Monitor
I-Monitor
V-Control
I-Control
Others.
Interlock
Interlock
气体剥离控制界面
MC-SNICS Indexer Controller
关 闭 退 出

Transmission efficiency and background are the key points for AMS measurement

- The structure of gas stripper, the type of stripped gas, the thickness of stripped gas are strongly related to the transmission efficiency and background , **especially in low-energy AMS systems**

Stripper gas	Transmission efficiency	
	$^{12}C^{+}$	$^{12}C^{2+}$
Ar	15%	2.5%
N_2	20%	3.2%
He	42%	6.8%

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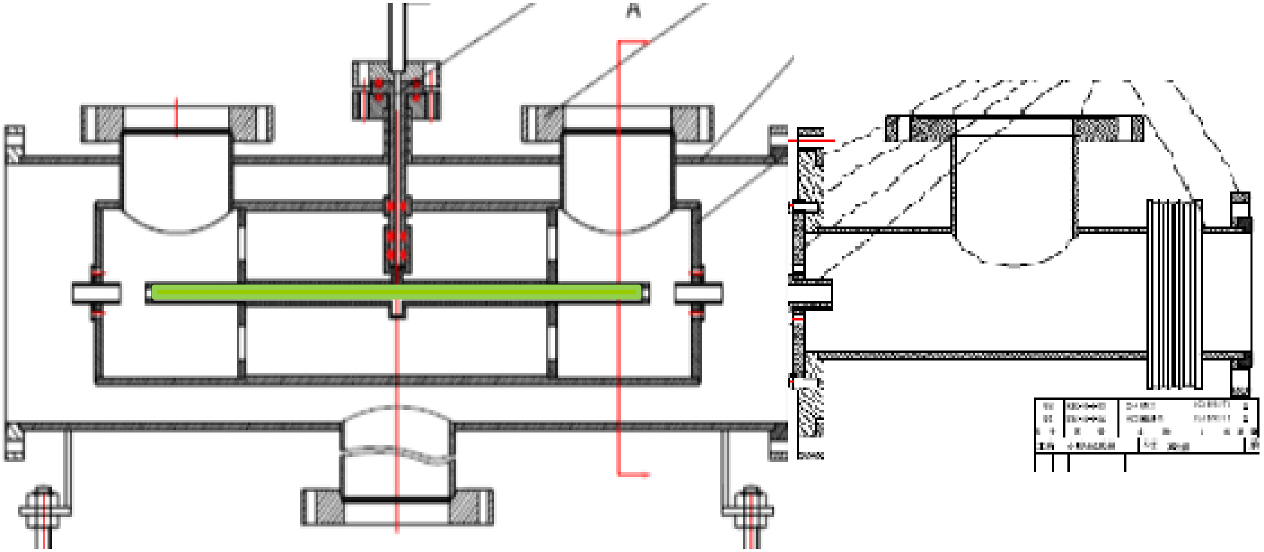
The structure of gas stripper

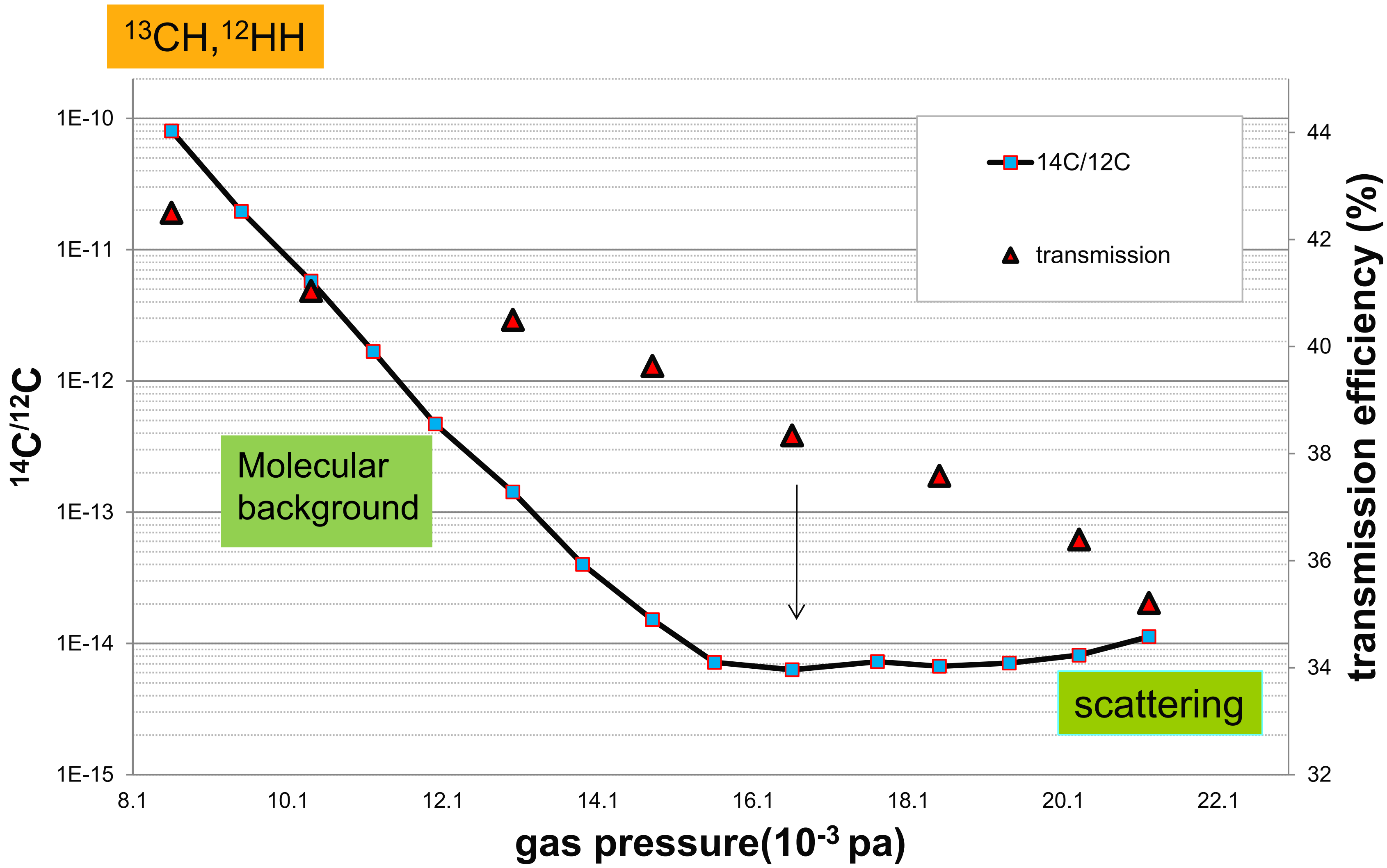


For improving the **stability of the stripper gas pressure (improving accuracy)** and the **vacuum of outside** the stripper (decreasing scattering background),

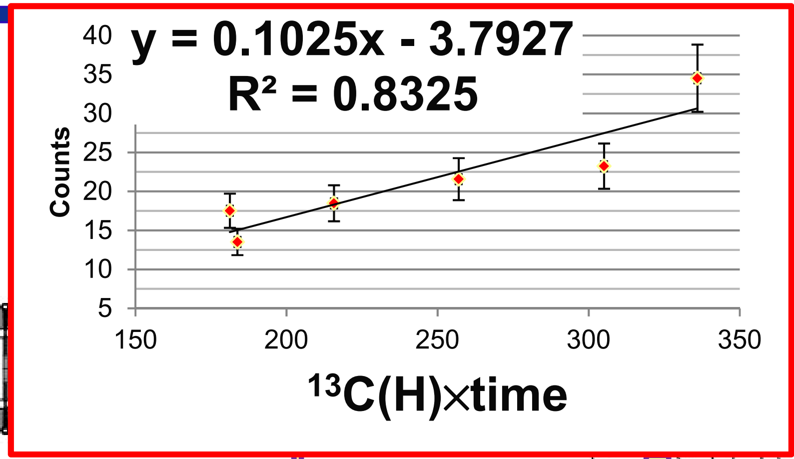
(1) Stripper gas canal is located inside a differentially pumped housing.

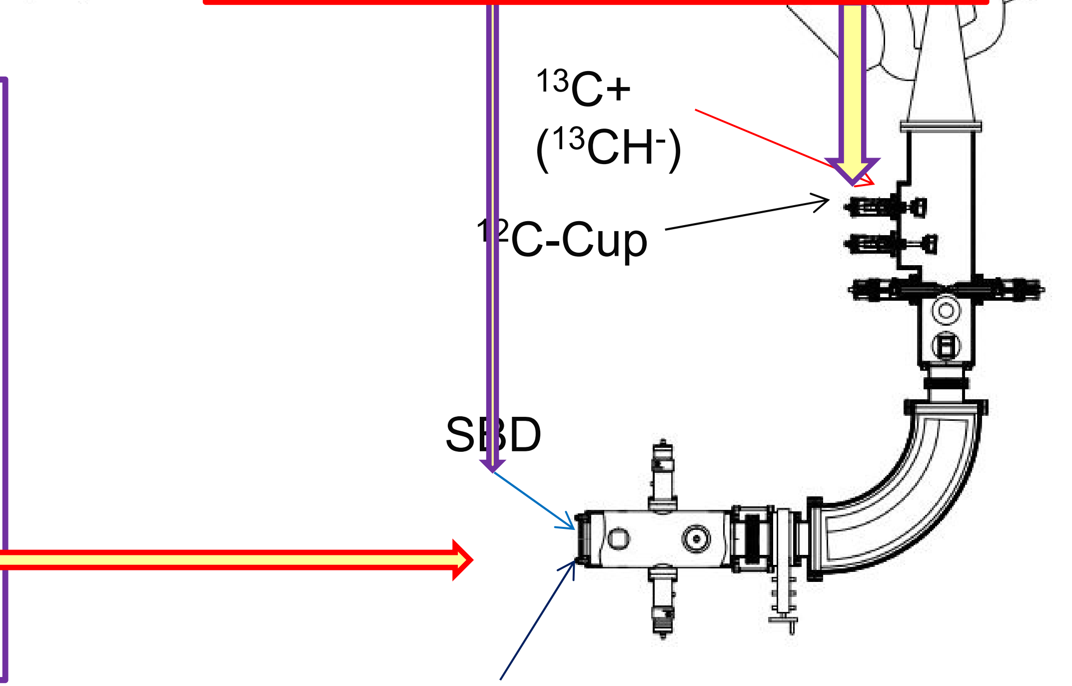
(2) Another pump is mounted between the cannel and analyzing magnet

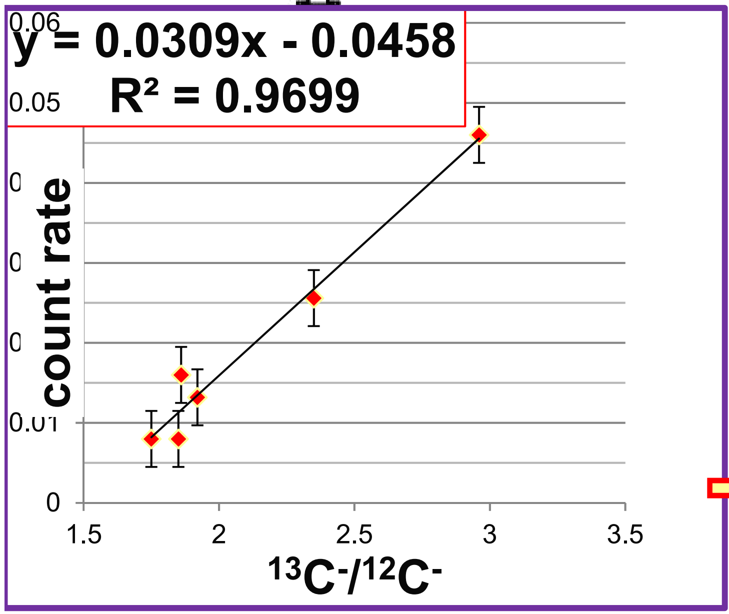
Transmission and background



Relationship of Background with $^{13}C(H)$

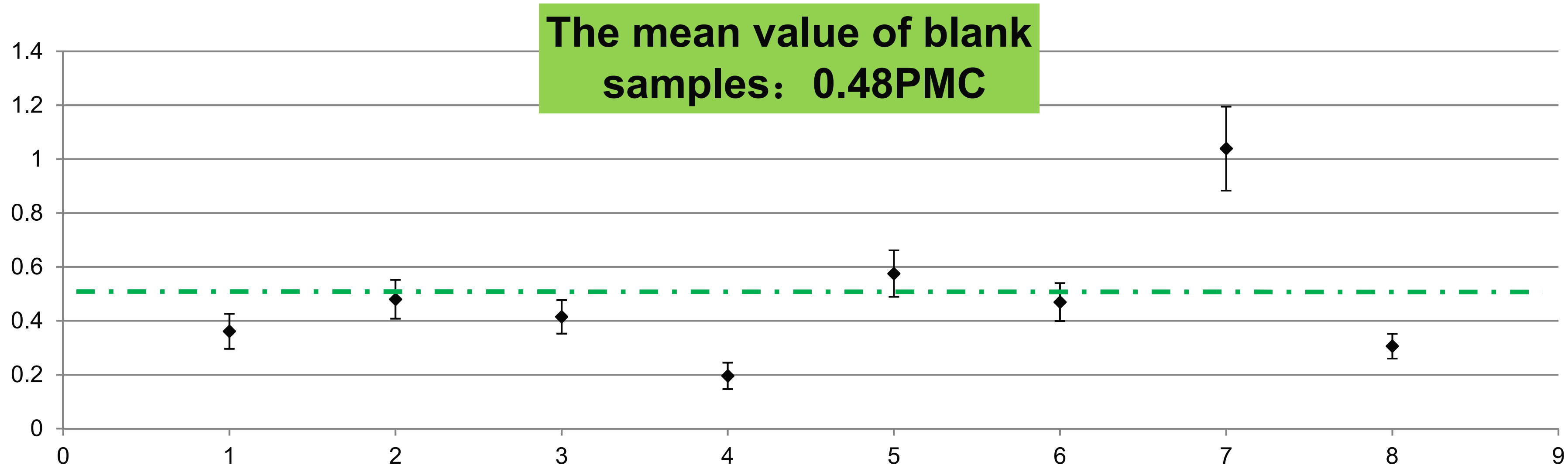






Relationship of background with $^{13}C^-/^{12}C^-$

Sensitivity

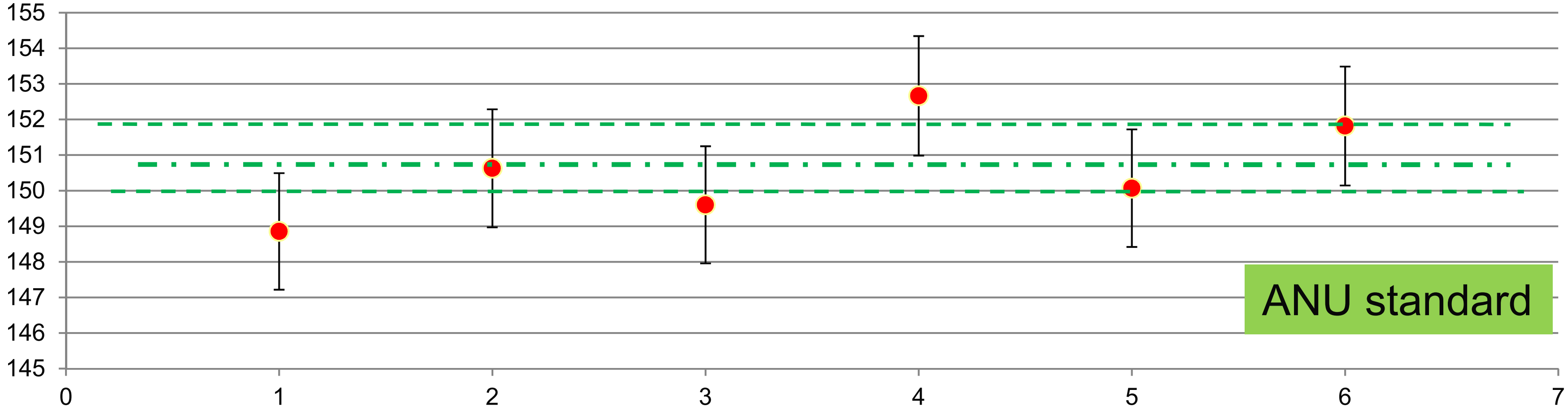


Blank samples

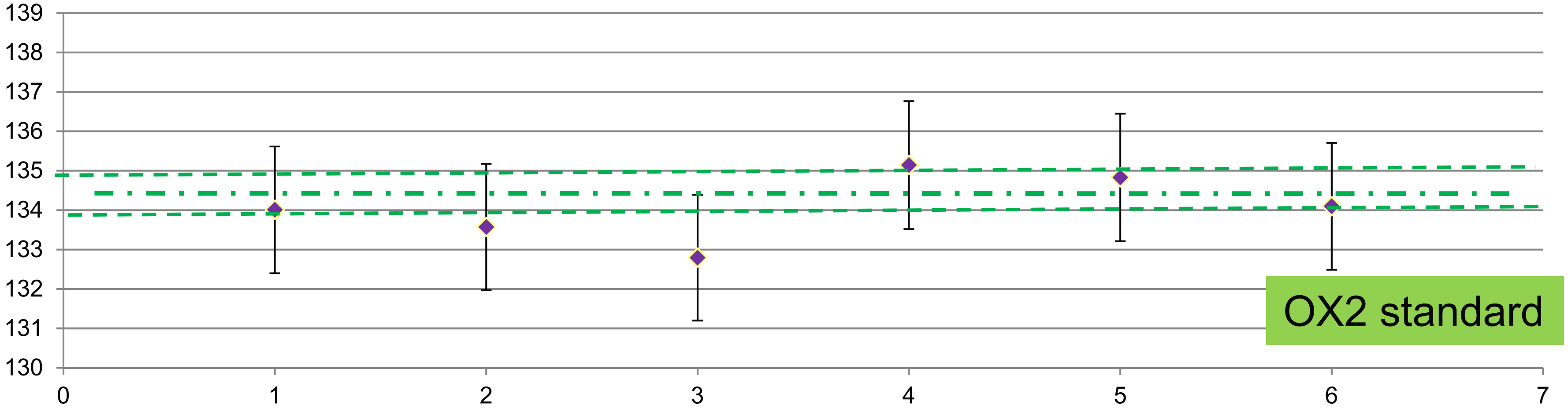
sensitivity：$^{14}C/^{12}C=5.8\times10^{-15}$

Precision

External uncertainty 0.38%，internal uncertainty：0.4%



External uncertainty：0.33%， internal uncertainty: 0.4%



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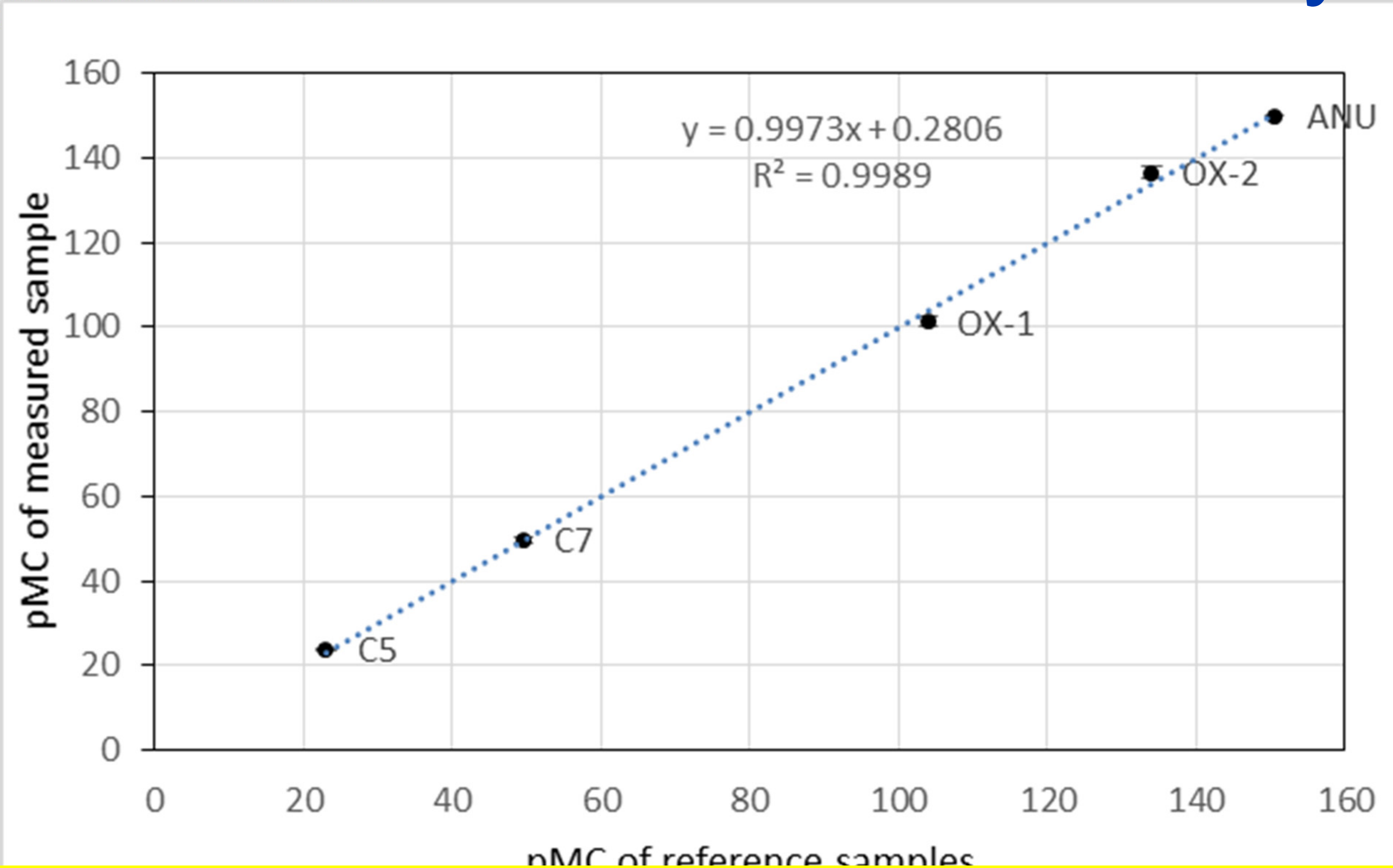
Accuracy

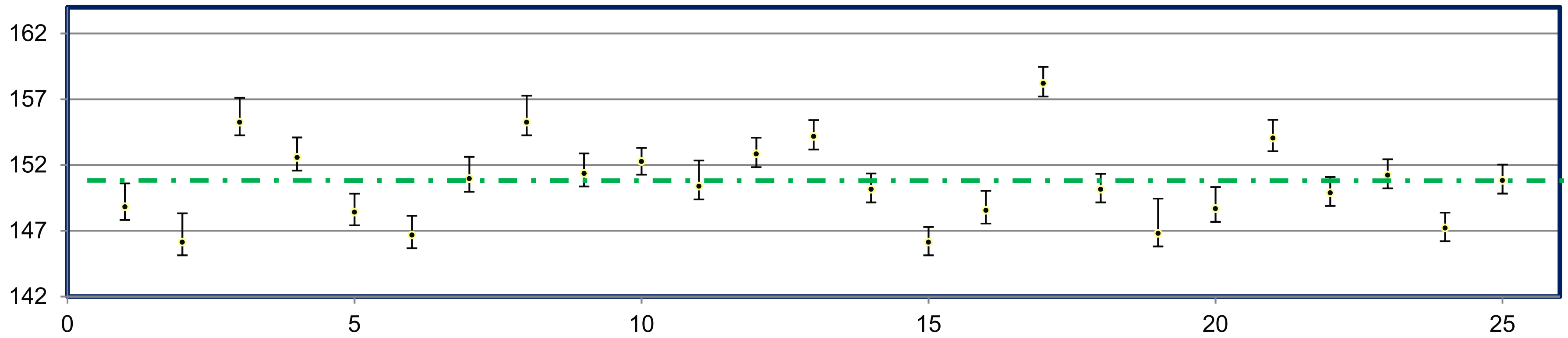


the measured values are consistent with their nominal values and they have nice linearity among the standard samples

Long term stability

One month measurement values

ANU mean value: 150.78±0.76



ANU normal value：150.61 pMC

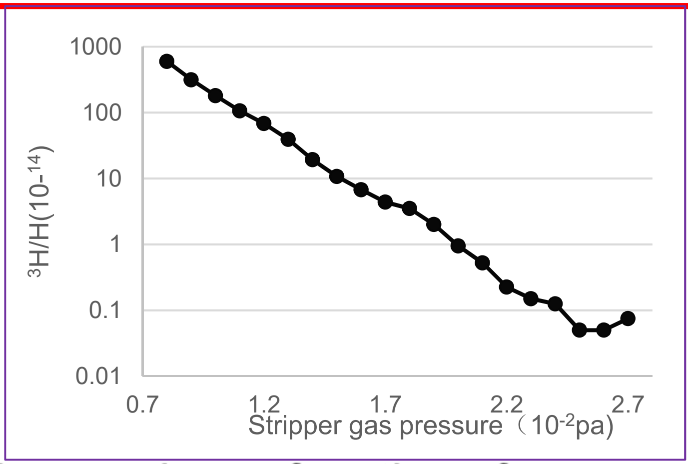
Experimental conditions and performance of ^{14}C measurement

Ion energy: 200keV
(extracting:20KV, main accelerator:180KV)
Extracting ions: C^-
Charge state after stripper: 1+
Gas stripper: Helium
Gas pressure: 1.66×10^{-2} Pa
Transmission efficiency:36%

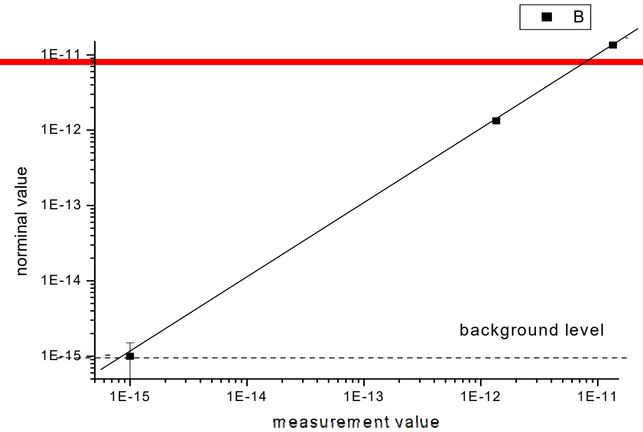
Precision : 0.3--0.5% (modern carbon)
Background level : 5.8×10^{-15} ($^{14}C/^{12}C$)

Performance of ^{3}H measurement

- Ion energy: 200keV
- Extracting ion:H^{-}
- Charge state after stripper: 1+
- Gas stripper: Helium
- Gas pressure: 2.6×10^{-2}pa (outside the stripper)
- Transmission efficiency:65%
- Background： $^{3}H/H<1\times10^{-15}$



Background as a function of gas pressure



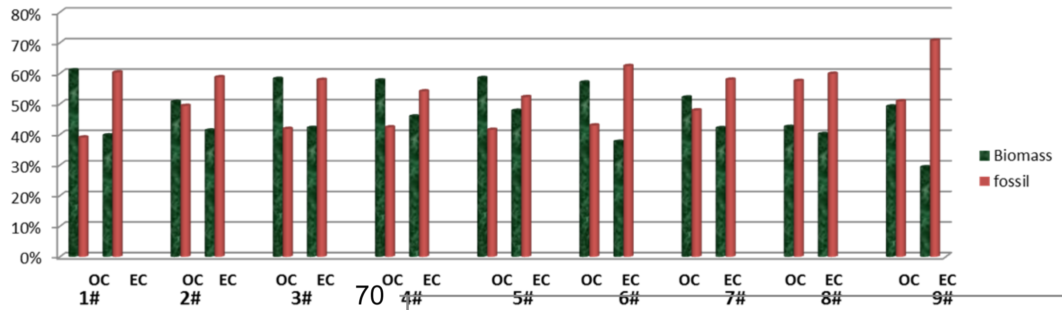
The relationship of nominal values of measurement values

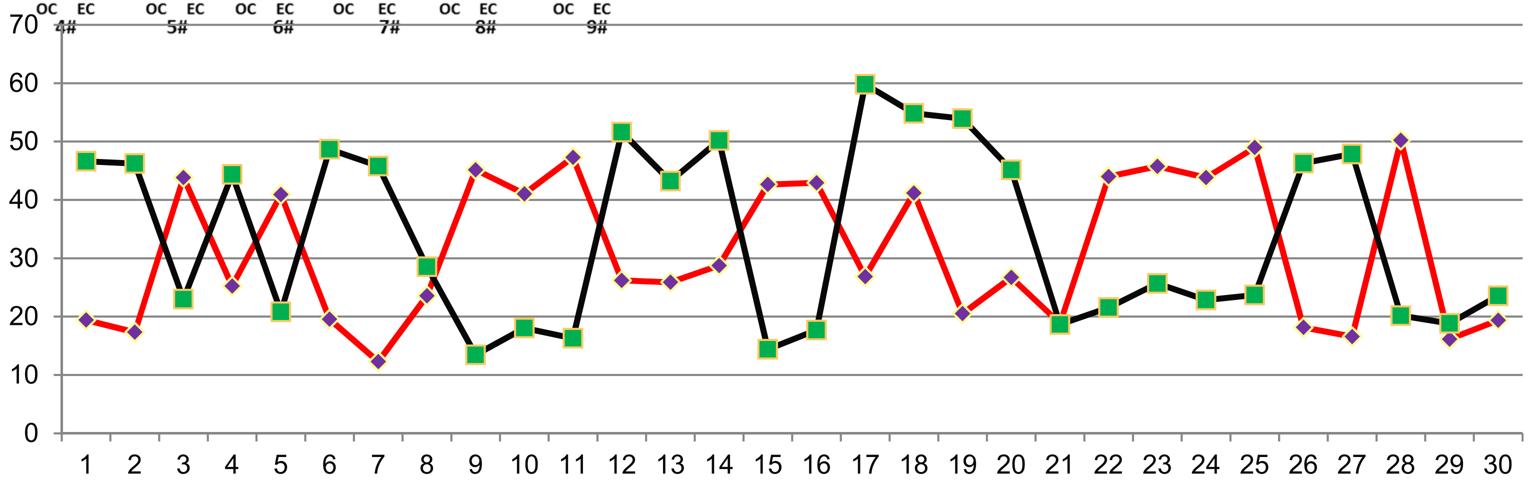
Applications

Environment

Determination the source of the aerosol using ^{14}C.

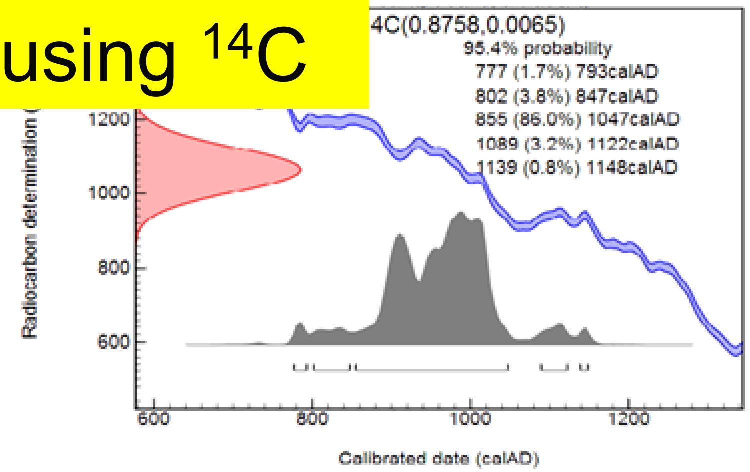
Information on the environmental effect from nuclear facilities(^{14}C,^{3}H)





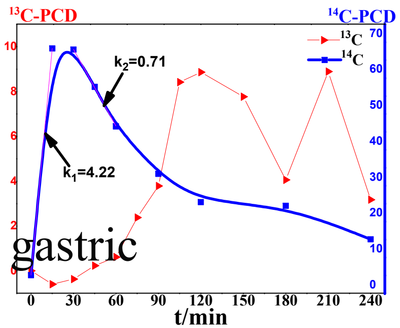
▪ Archaeology

Buddhist scripture from Tibet using ^{14}C

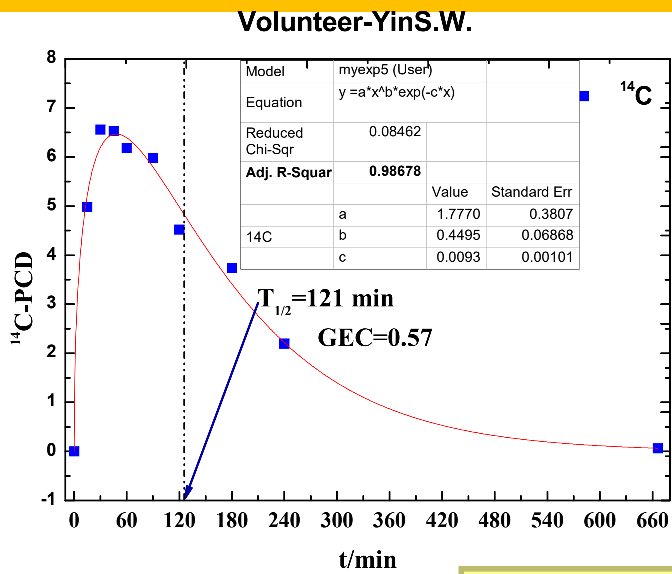


• Biomedical

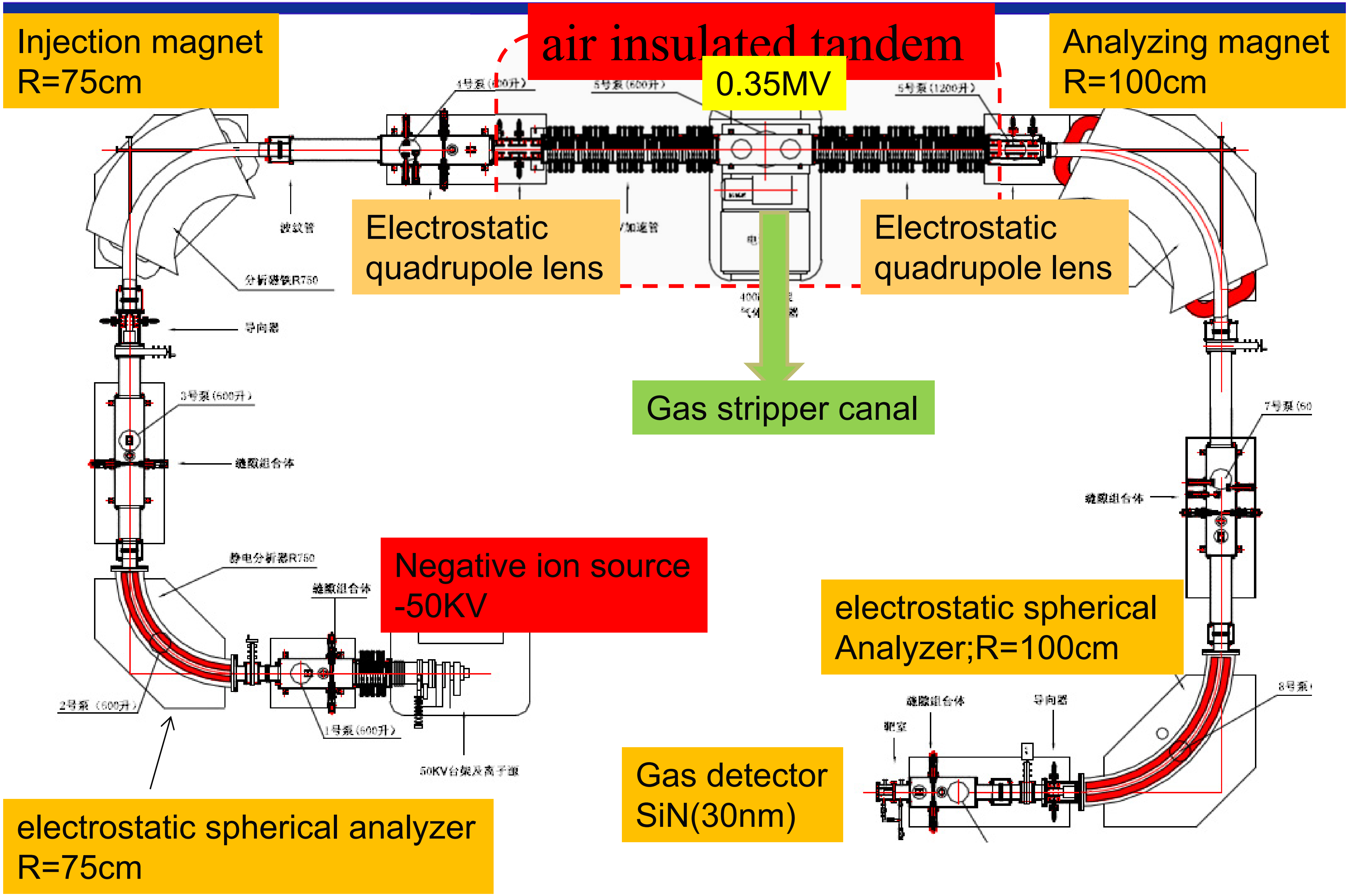
Diagnosis diseases of digestive using ^{14}C tracer
Pharmacokinetic study using ^{14}C tracer

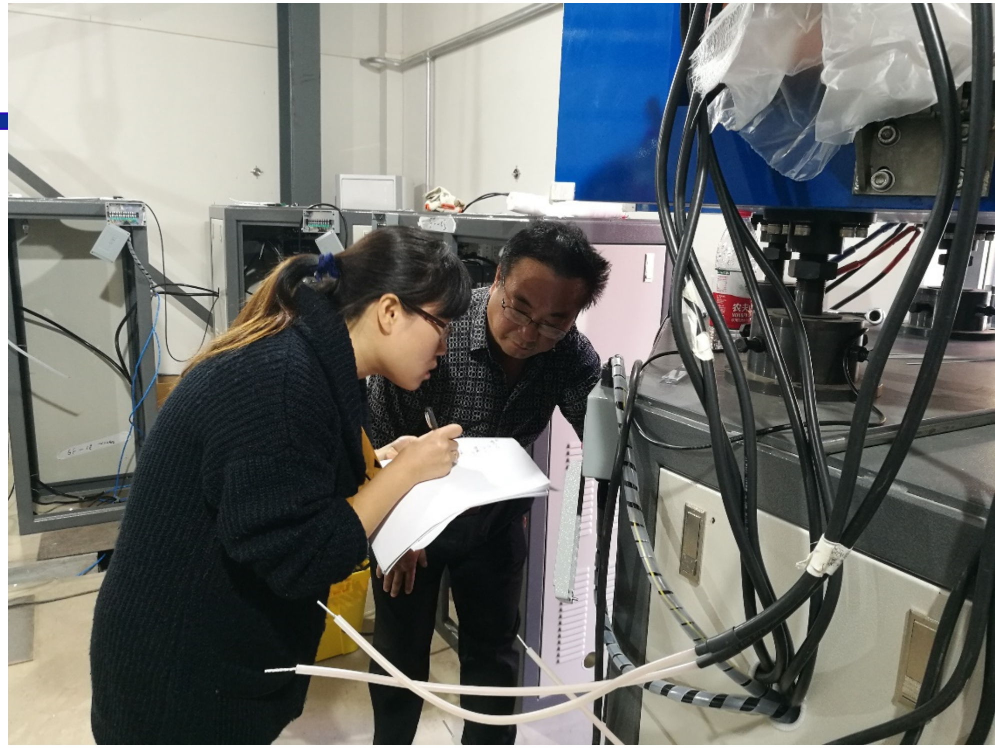


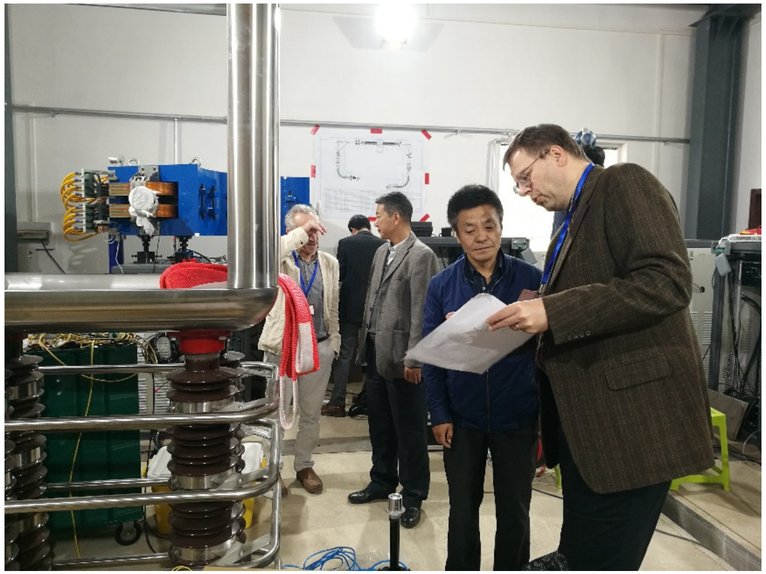
^{14}C-octanoic breath test (^{14}C-OBT) gastric emptying test



1.3 Small tandem AMS for heavy nuclides







Home-made
Accelerator :Air insulated tandem
Terminal voltage :0.35MV
Interesting nuclei: ^{26}Al, ^{129}I, ^{236}U, ^{239}Pu
Charge states: ^{129}I :2+;Actinide: 3+
Detector: gas detector, **30nm SiN window**
Applications:
environment, nuclear safeguard,…

- HI13-AMS system(12MV)

^{32}Si, ^{36}Cl, ^{41}Ca, ^{53}Mn, ^{59}Ni, ^{60}Fe, ^{90}Sr

- 0.2MV-SSAMS(0.2MV)

^{14}C, ^{3}H

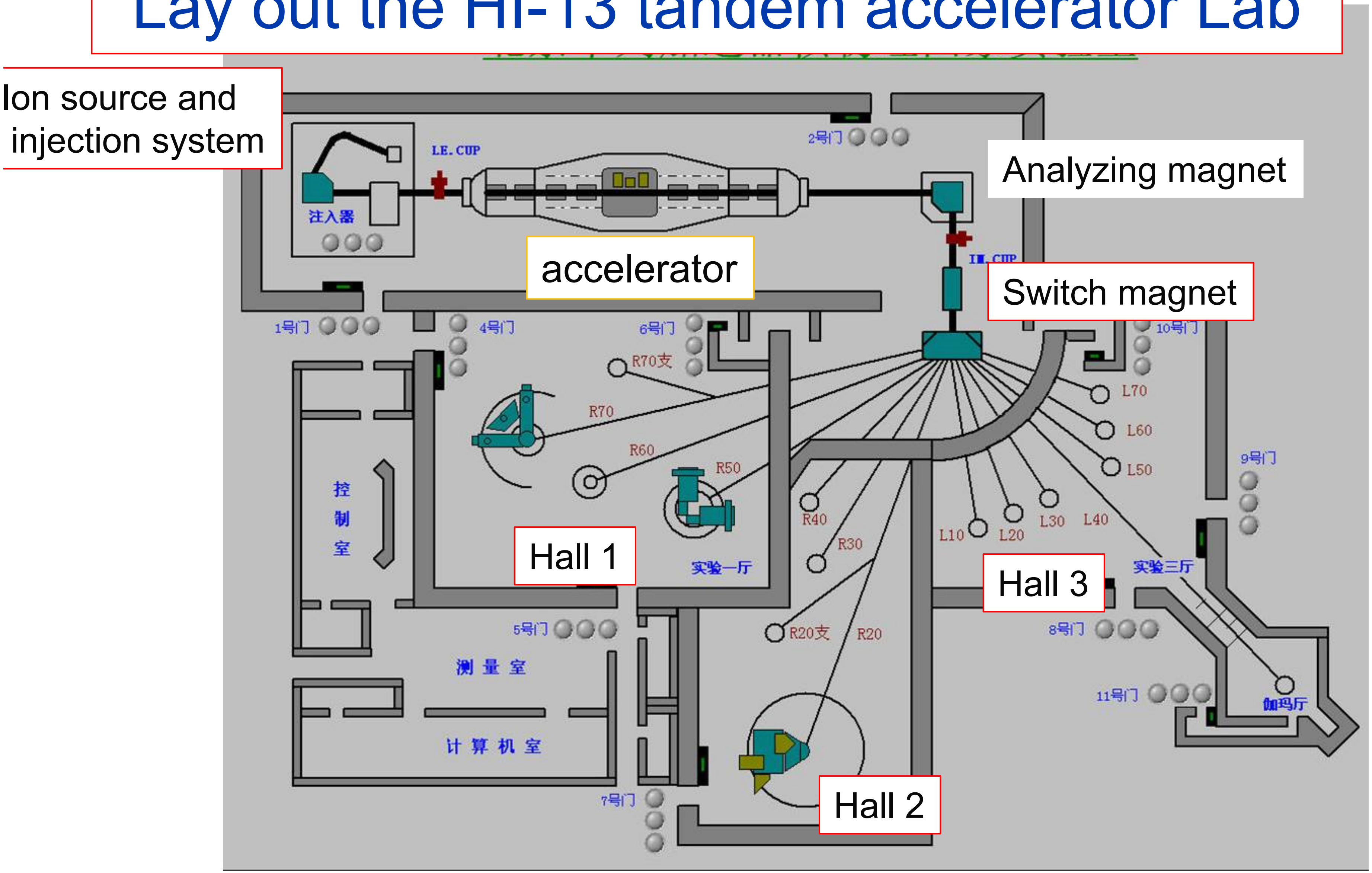
- 0.35MV tandem-AMS

^{26}Al, ^{129}I, ^{210}Pb, ^{236}U, ^{239}Pu,

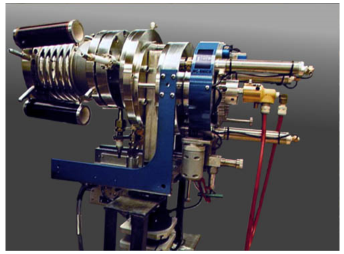
Outline

2.1 HI-13 tandem accelerator

Lay out the HI-13 tandem accelerator Lab



Three kinds of ion source



Cs sputtering negative ion source

(MC-SNICS)

(Most of the nuclides in the periodic table of elemen

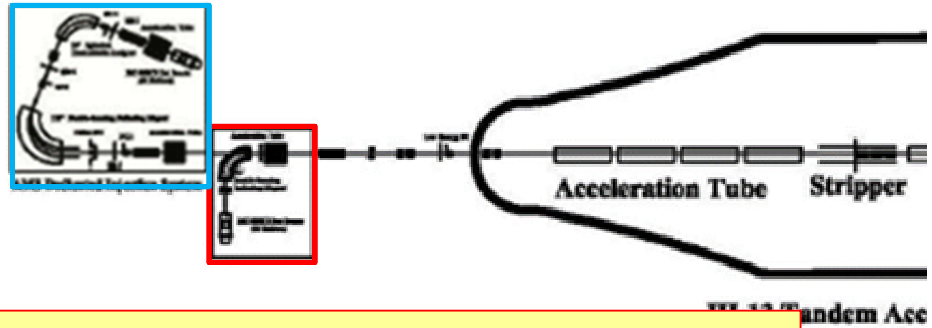
Duoplasmatron ion source

(H,D) pulse beam

RF Charge Exchange Ion Source

(He^-)

Injection system



- Two injection system

(a) Common used injection system

(Double focusing magnet R=50cm)

(b)AMS injection system

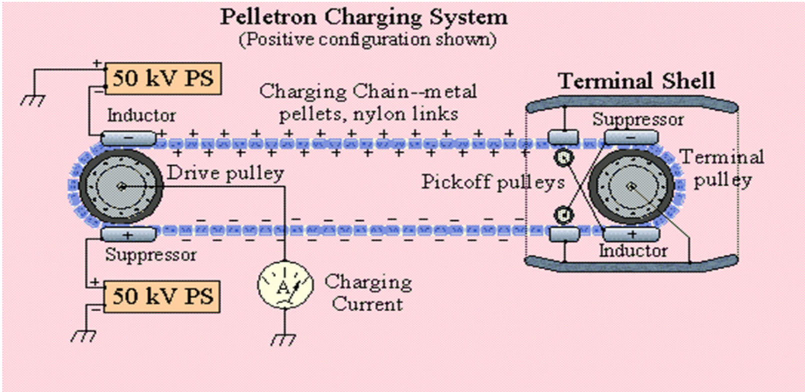
(Electrostatic spherical analyzer 90^0,R=75cm

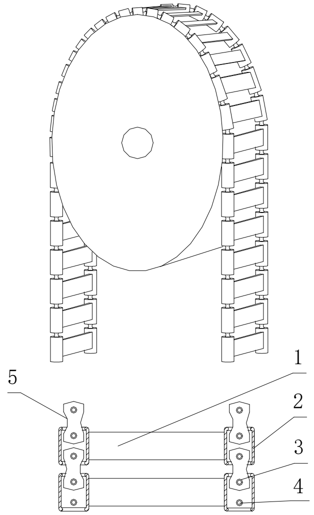
(Double focusing magnet 112^0,R=80cm

Accelerator

- Tandem accelerator
- Working terminal voltage: 12MV
- Tank length: 25m ; Maximum diameter:5.5m
- Insulating gas: SF_6(6.4×10^5Pa)

- Charging system: Laddertron chain





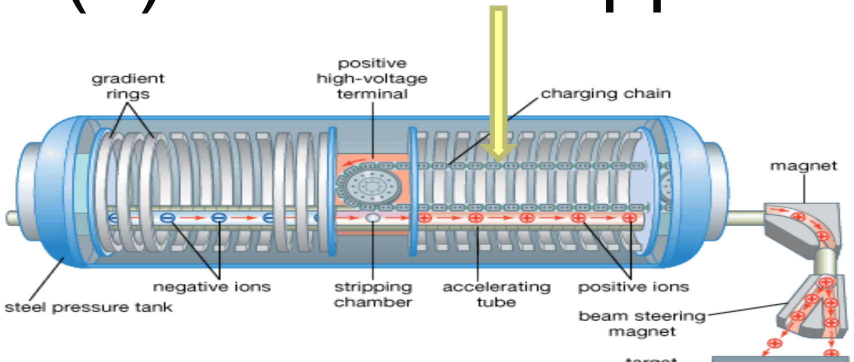
1. 联接钢板 2. 不锈钢圆筒
3. 无油轴承 4. 芯轴 5. 绝缘子

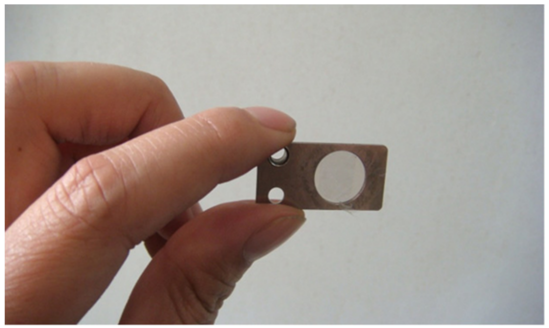
输电梯结构及工作原理示意图

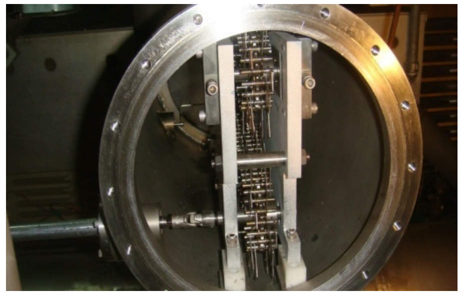
- Two Strippers:

(a) terminal stripper :Carbon foil and gas

(b) second stripper :Carbon foil(1/3 length of aceeletor tube)







Analyzing magnet and switch magnet

- Double focus analyzing magnet:

($R=127cm$ $ME/q^2=200$； $\alpha=90^0$)

- Switch magnet: ($\pm 70^0$; 14 beam lines)

Beam optical system

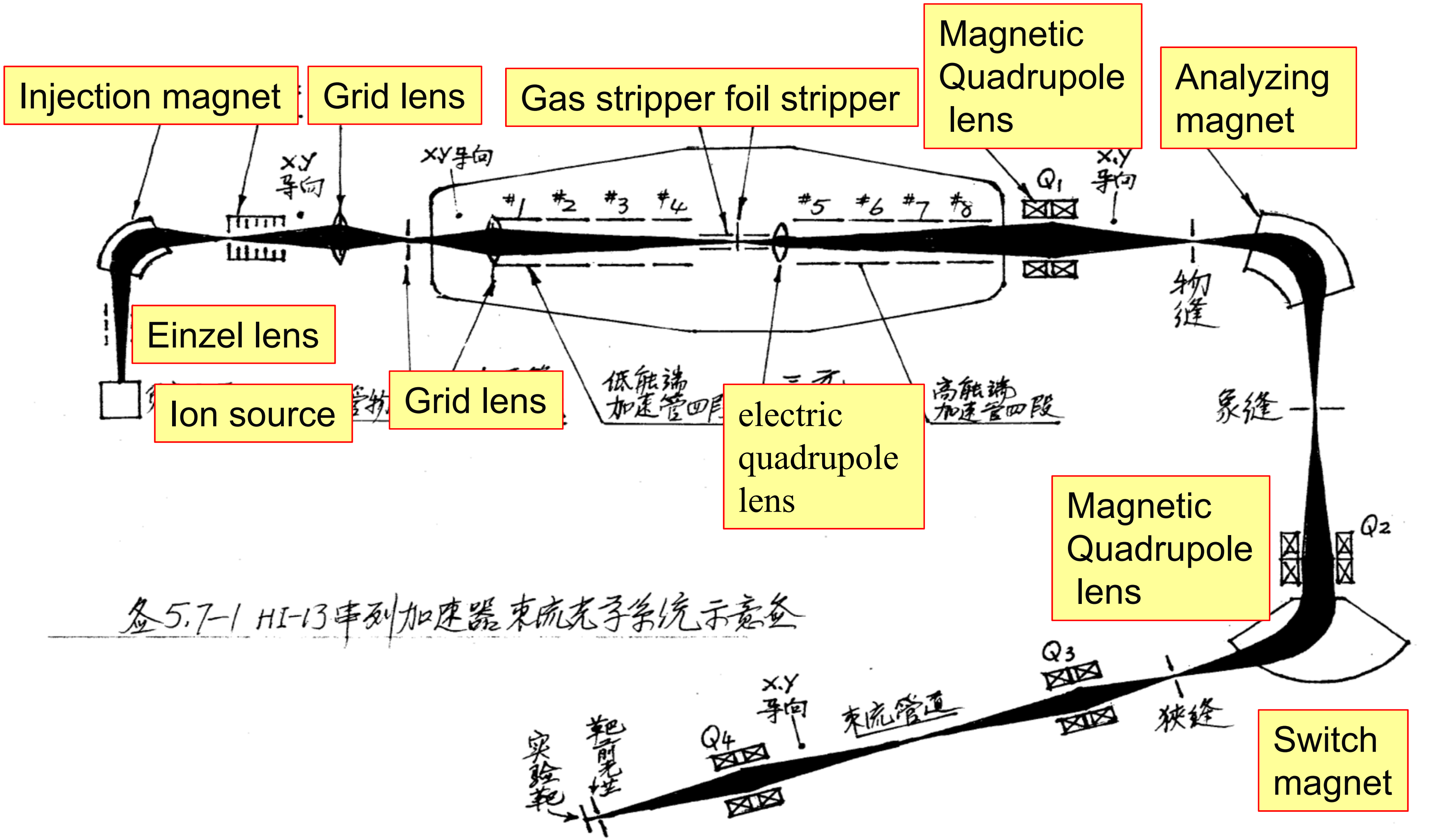
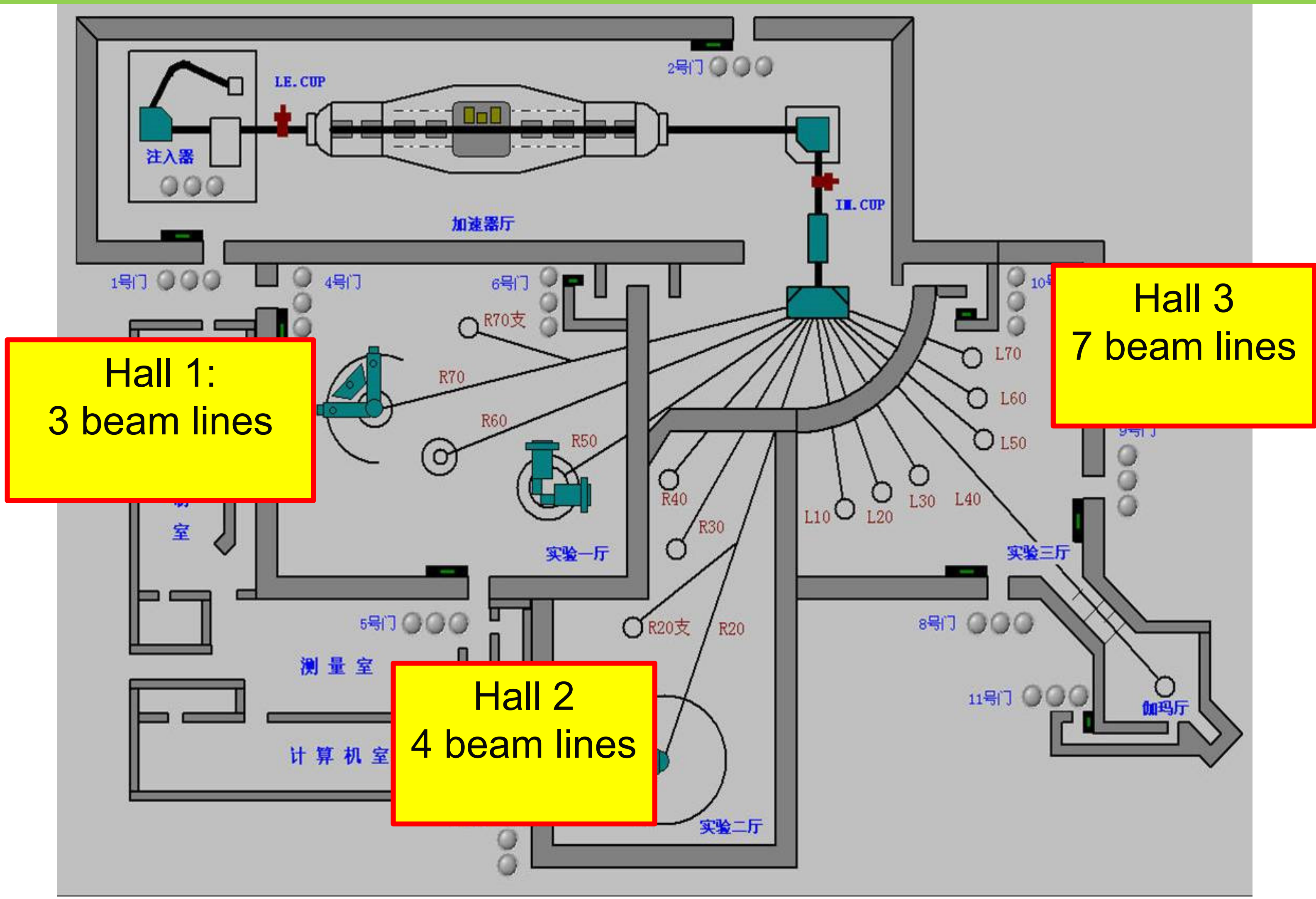


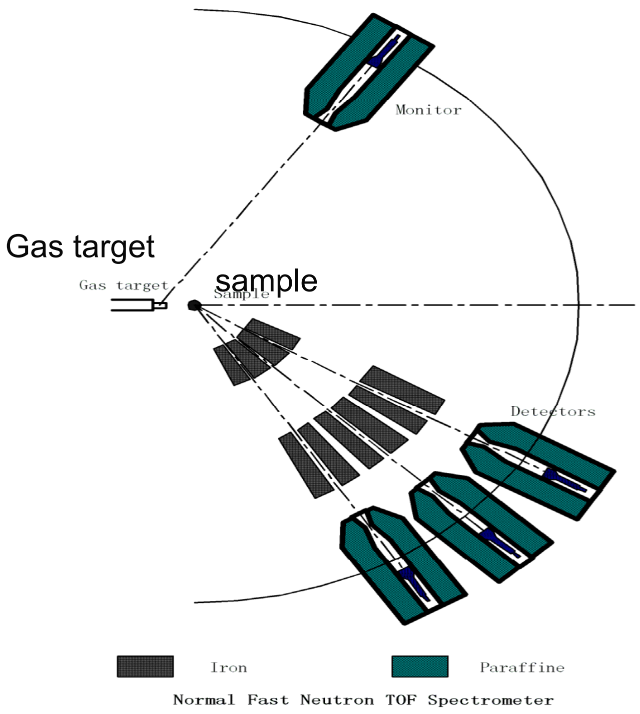
图5.7-1 HI-13串列加速器束流光学系统示意图

2.2 Experimental terminals

- Three experimental halls ,14 beam lines



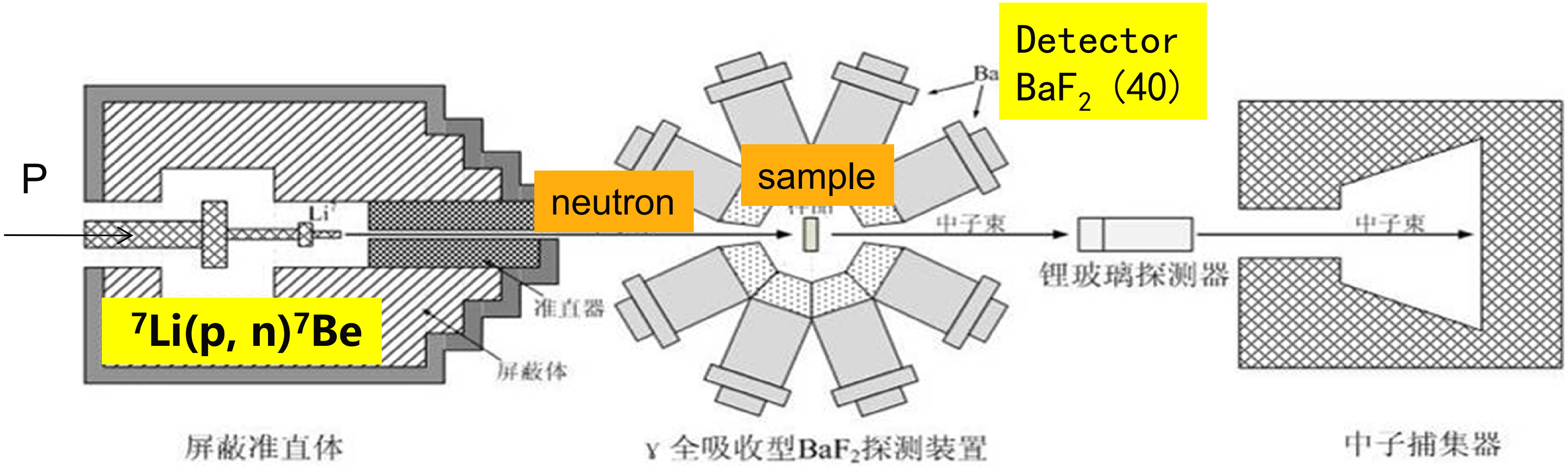
(1) Fast neutron time of flight spectrometer

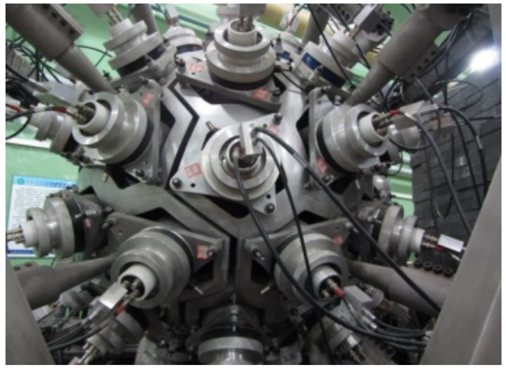


Flight length:	~6m
Measuremental angle:	-30^0--155^0
pulse beam(FWHM)	~2.5ns
pulse frequency	fundamental frequency 6 MHz，(fractionable)
Neutron energy:	5-40 MeV
Detector size:	$\phi180\times100$ mm $\phi130\times50$ mm
Detector angle interval:	10^0

Neutron double differential cross sections

(2) Gamma ray total absorption facility (GTAF)

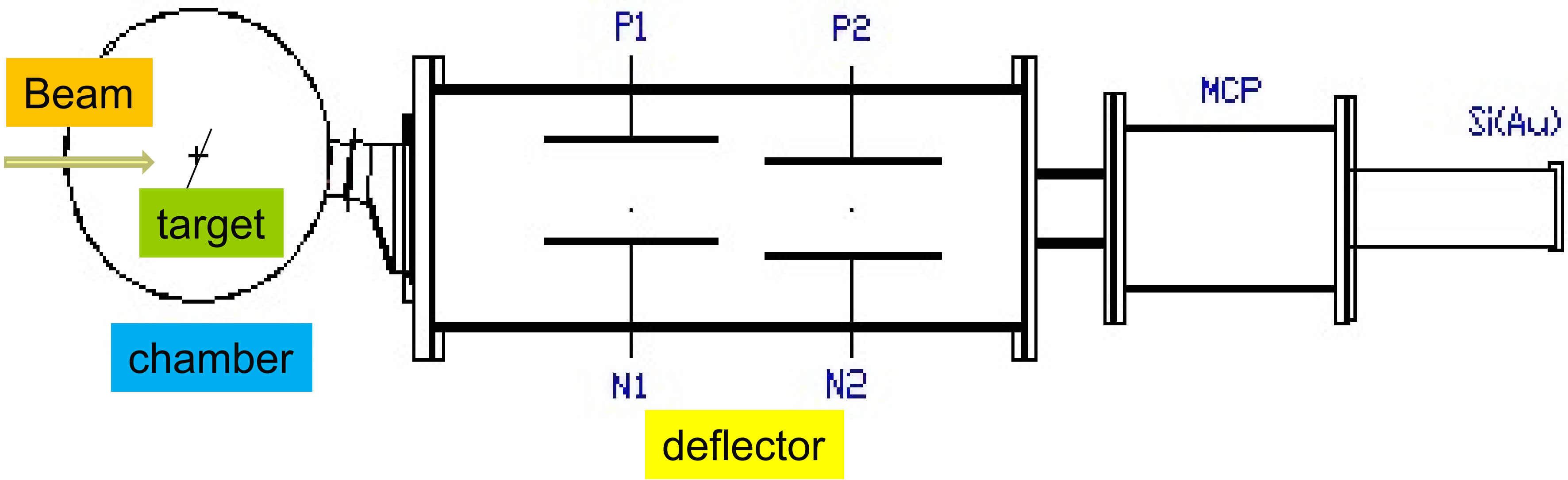




Online (n,r) prompt-gamma

(3) Heavy ion nuclear reaction

Near-barrier Fusion, elastic scattering etc.



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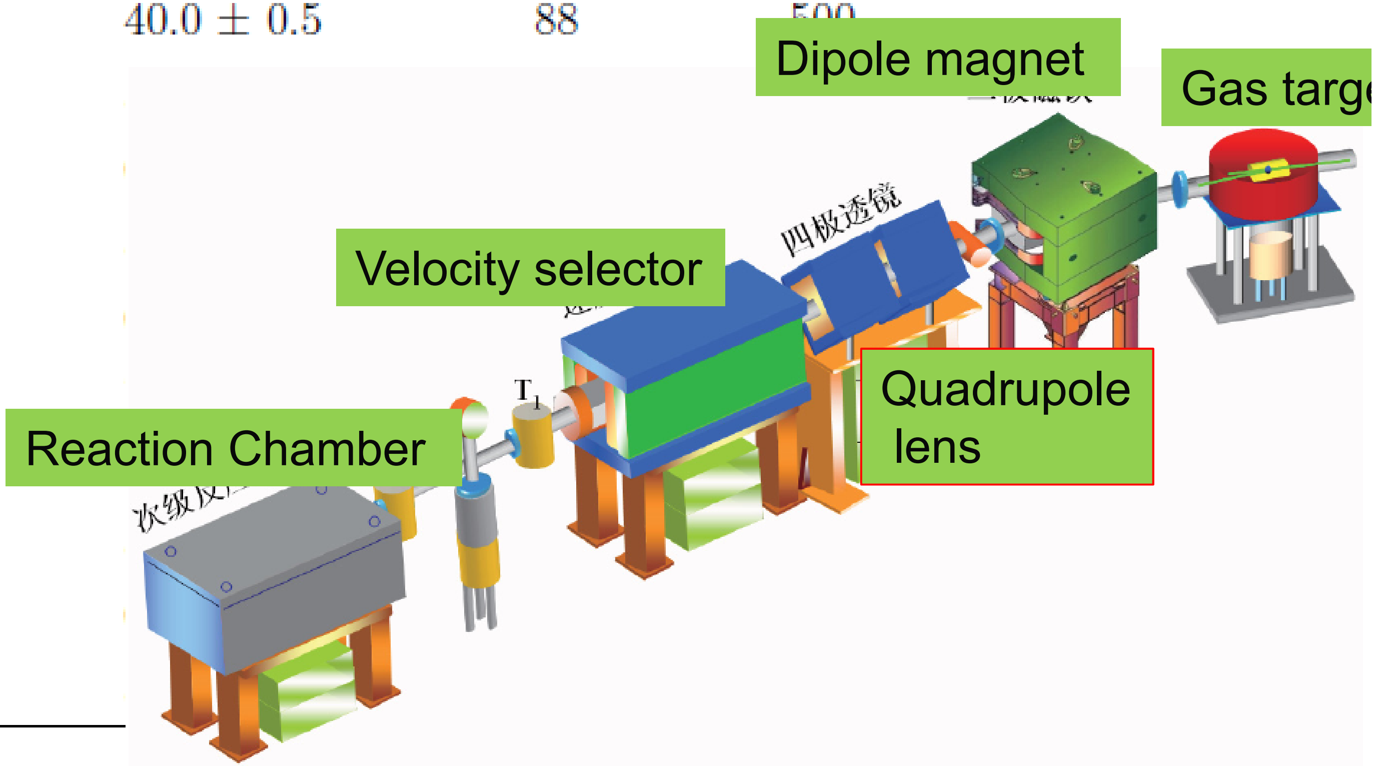
中核集团 CHINA INSTITUTE OF ATOMIC ENERGY

astrophysics

(4)Radioactive Ion Beam Line

次级束	产生反应	能量±半宽（MeV）	纯度（%）	强度（pps）†
^{6}He	$^{2}H(^{7}Li,^{6}He)^{3}He$	35.7 ± 0.5	92	500
^{7}Be	$^{1}H(^{7}Li,^{7}Be)n$	30.8 ± 1.3	99	900
^{8}Li	$^{2}H(^{7}Li,^{8}Li)^{1}H$	40.0 ± 0.5	88	500
^{10}C	$^{1}H(^{10}B,^{10}C)n$			
^{11}C	$^{1}H(^{11}B,^{11}C)n$			
^{13}N	$^{2}H(^{12}C,^{13}N)n$			
^{15}O	$^{2}H(^{14}N,^{15}O)n$			
^{17}F	$^{2}H(^{16}O,^{17}F)n$			
^{18}F	$^{3}He(^{16}O,^{18}F)^{1}H$			
^{19}Ne	$^{4}He(^{16}O,^{19}Ne)n$			
	$^{3}He(^{19}F,^{19}Ne)^{3}H$			
^{22}Na	$^{4}He(^{19}F,^{22}Na)n$			



(5) In-beam Gamma Spectroscopy

Nuclear Structure
high spin structure
Lifetime of excited States

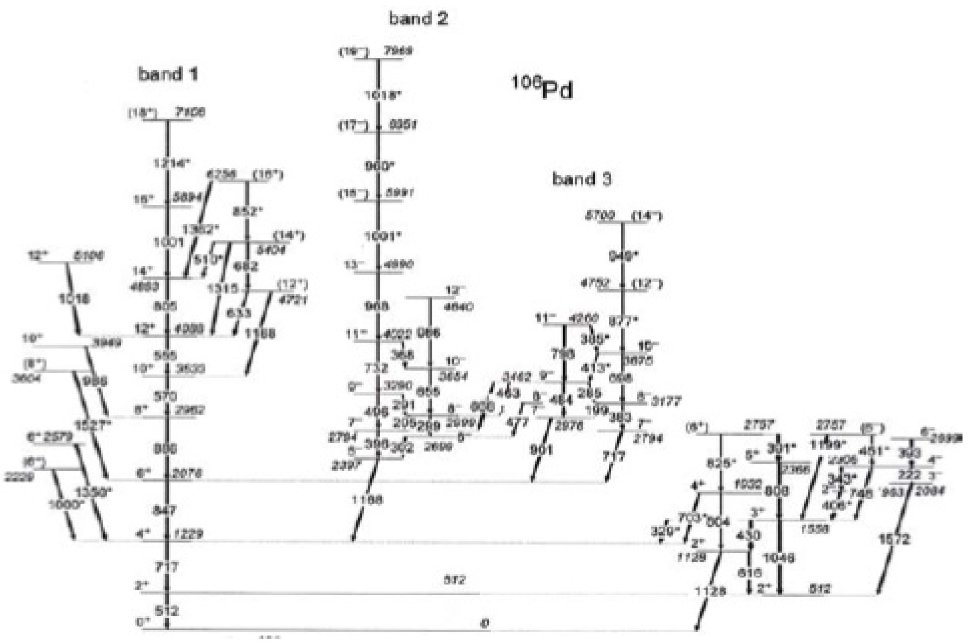
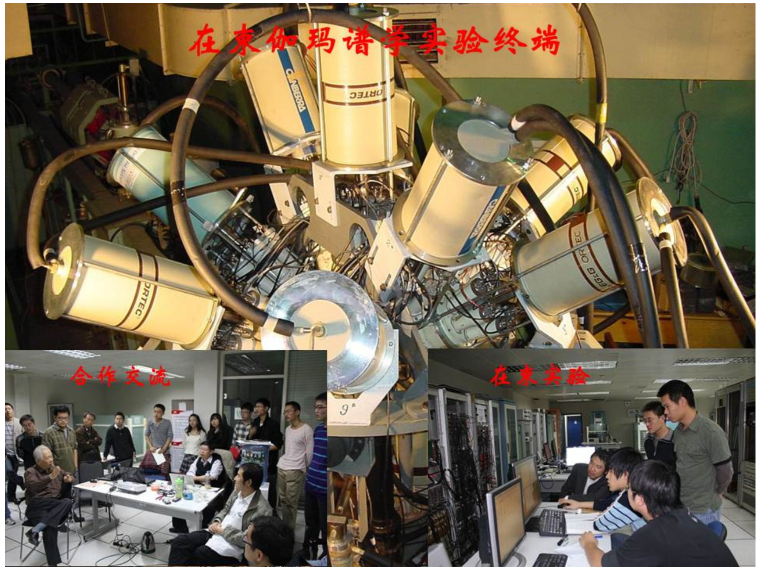


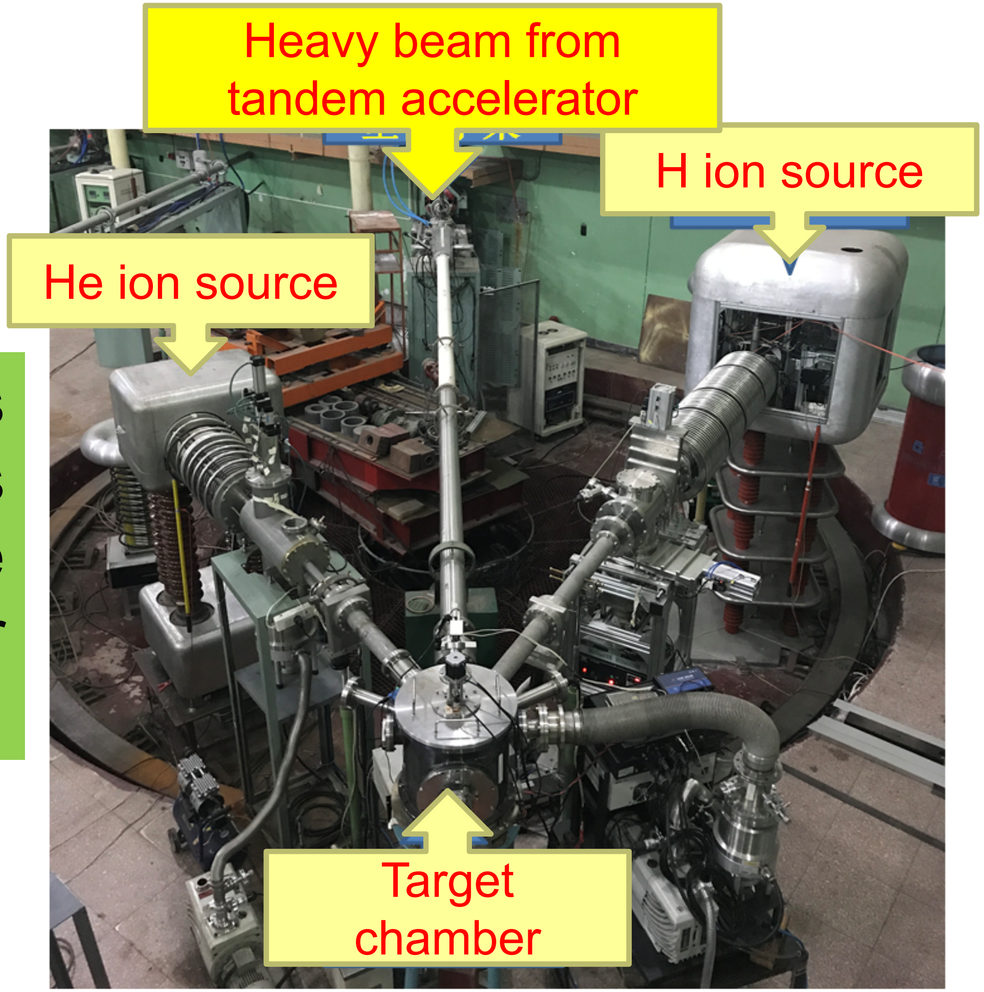
Fig.2 The level scheme of ^{106}Pd from the present experiment (*stand for new γ transitions)



(6) Triple Beam Irradiation platform

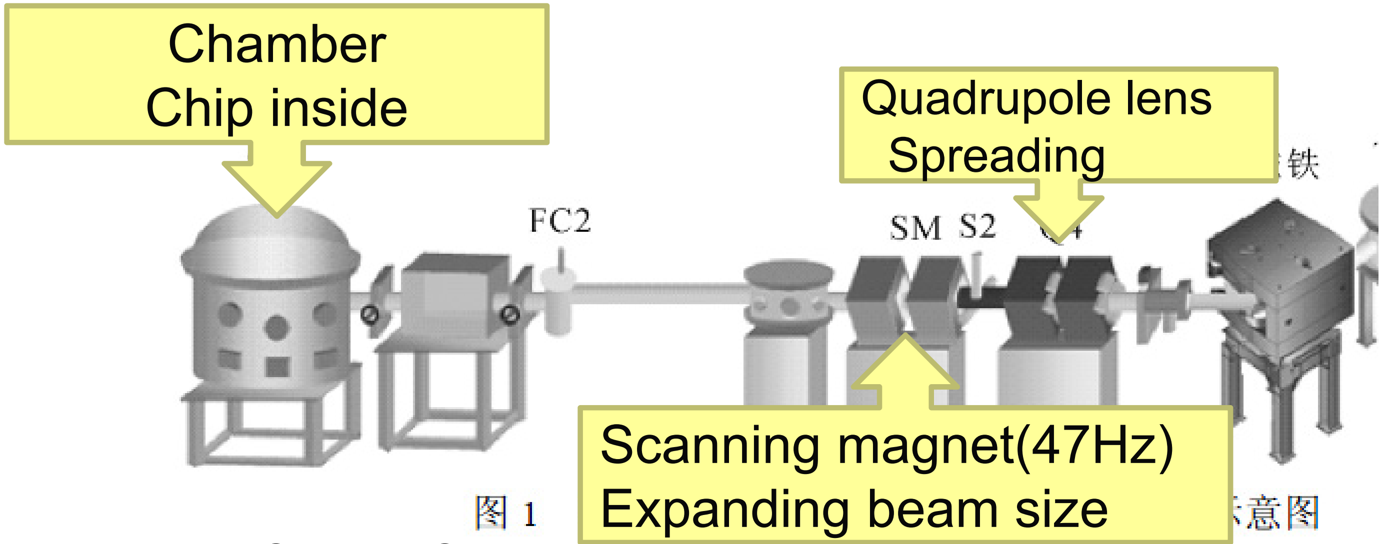
- Irradiation Effects of Materials

Simulating radiation properties of structural materials irradiated by high dose neutron irradiation in nuclear power plant



Irradiation Effects

(7) Single event effects platform

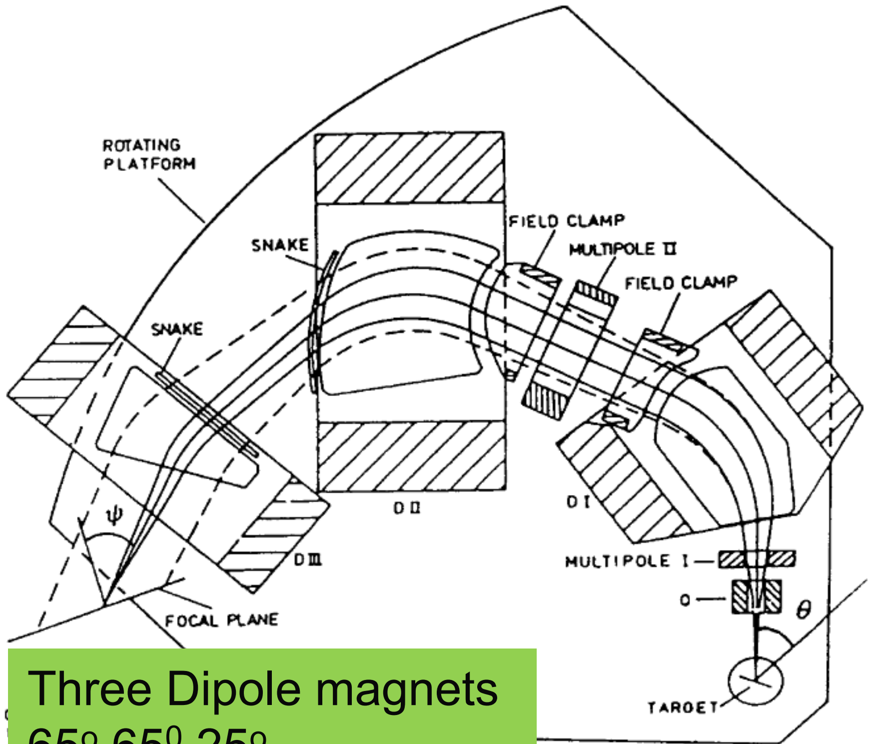


Ion flux density :1×10^{2} /cm^{2}·s

Beam Size:100 mm×100mm

avoiding the anomalies and malfunctions of some spacecrafts induced by single event effects in the chip or circuit systems.

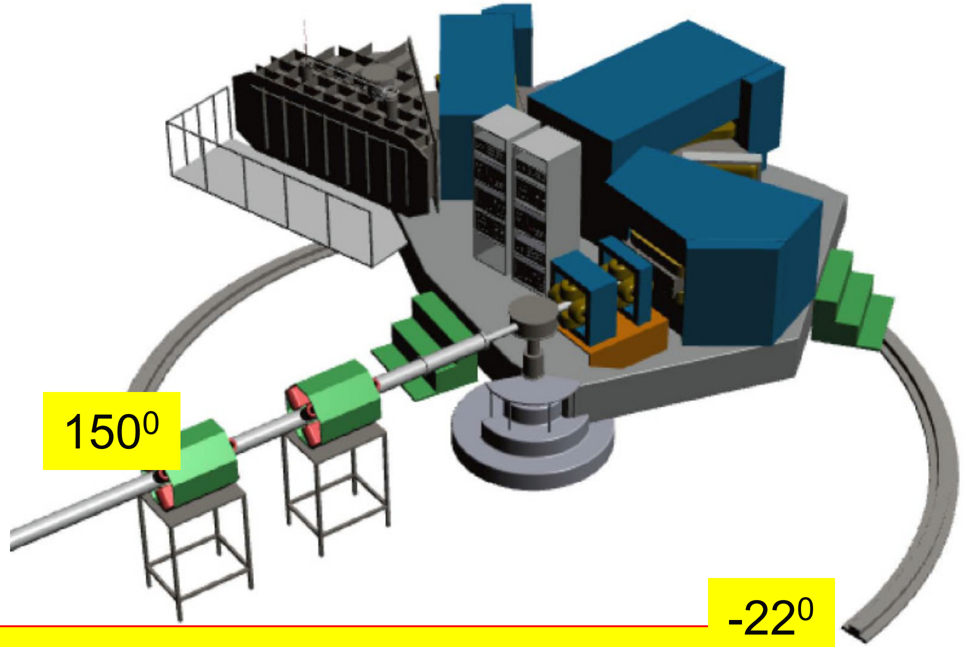
（8）Q3D magnetic spectrometry



Three Dipole magnets
$65^o, 65^0, 25^o$
Radius:100mm

High momentum resolution

Dispersion(along focal plane)
$\Delta X/(\Delta P/P)$: 11.36cm/%



Nuclear reaction
Accelerator Mass Spectrometry
Biologic Irradiation Effects

Hall 3

(9) accelerator mass spectrometry (AMS)

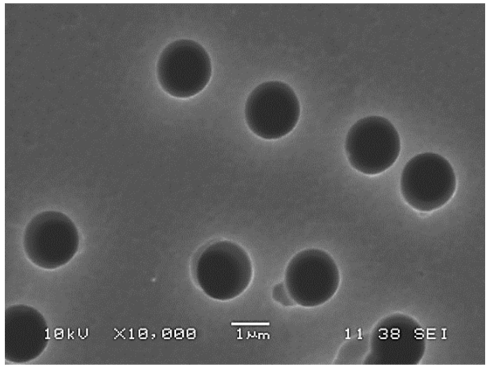
nuclide	Injection ion	Detection method	background
^{10}Be	BeO$^-$	Absorb+ΔE-E	^{10}Be/^{9}Be~1×10^{-14}
^{26}Al	AlO$^-$	**ΔE-Q3D+ΔE-E**	^{26}Al/^{27}Al=2× 10^{-15}
^{32}Si	Si$^-$	ΔE-Q3D+ΔE-E	^{32}Si/Si<5×10^{-15}
^{36}Cl	Cl$^-$	ΔE-Q3D+ΔE-E	^{36}Cl/Cl<1×10^{-15}
^{41}Ca	CaF_3^-	ΔE-E	^{41}Ca/Ca=2×10^{-14}
^{53}Mn	**MnF$^-$**	**ΔE-Q3D+ΔE-E**	**^{53}Mn/Mn=1×10^{-13}**
^{59}Ni	**Ni$^-$**	**ΔE-Q3D+ΔE-E**	**^{59}Ni/Ni=8×10^{-14}**
^{60}Fe	**FeO-**	**ΔE-Q3D+ΔE-E**	**^{60}Fe/Fe~1×10^{-15}**
^{129}I	I$^-$	E	^{129}I/^{127}I=2×10^{-13}
^{236}U	UO$^-$	E	^{236}U/U=1×10^{-11}

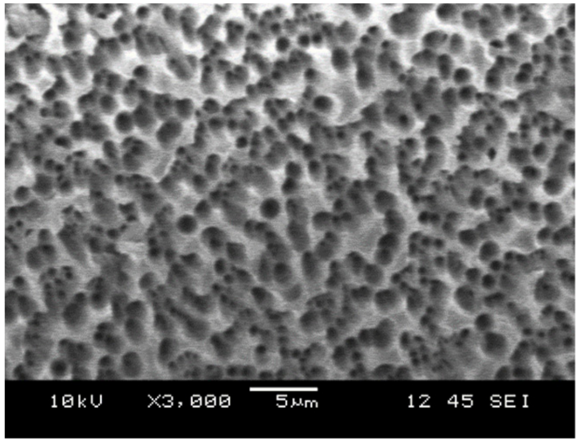
(10) Nuclear Track Membrane Irradiation platform

- Nuclear pore membrane

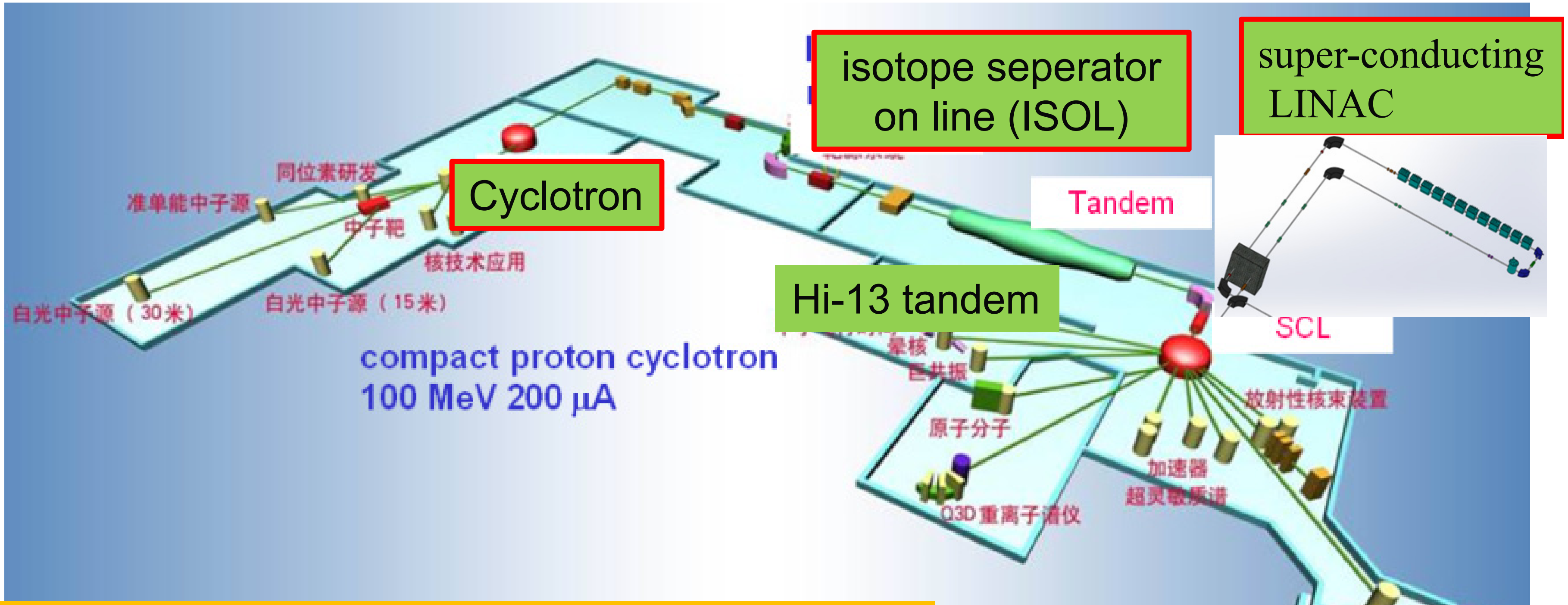
filtration membrane (gas ,liquid)

Anti-counterfeit marking images



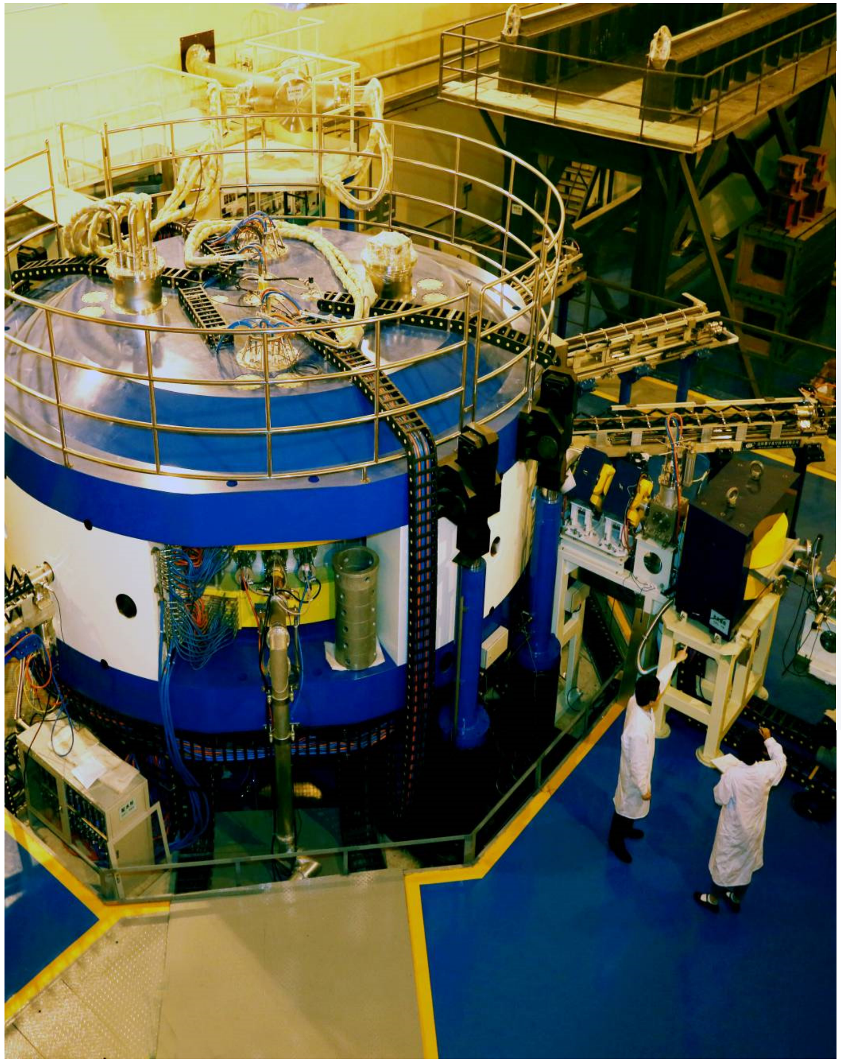


2.3 Beijing rare ion beam facility (BRIF)

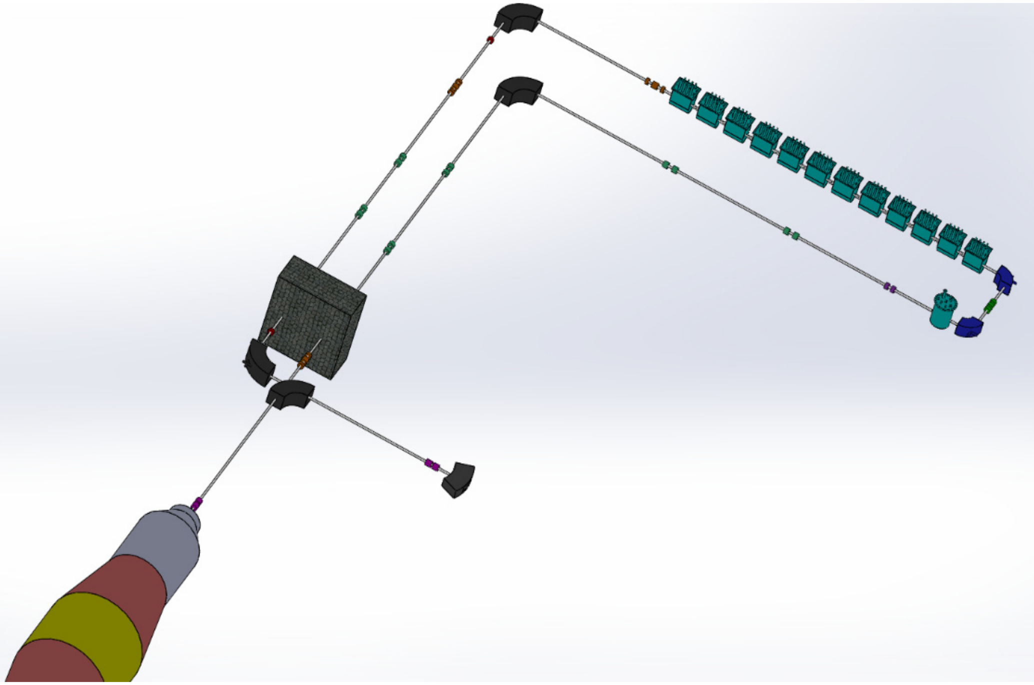


BRIF is under constructing

The BRIF is composed of a 100 MeV proton cyclotron, an isotope separator on line (ISOL) with mass resolution of 20000, and a super-conducting LINAC of 2 MeV/q



100 MeV proton cyclotron



super-conducting LINAC

Thank you!