The Progress of Accelerator Mass Spectrometry and their Applications in China

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1. Introduction

AMS- Leading technique for the detection of long-lived nuclides

1. Ultra high sensitivity: 10^{-15}--10^{-16} (~65Ka ^{14}C)
2. Small sample size: mg-μg
3. High throughput: ~3000 samples/yr
4. Extreme valuable for Archaeological dating, Paleo-environmental & Biomedical studies

Challenging Issue for a precise measurement

Interferences need to be eliminated as much as possible in every step of the measuring process:

- Sample collection and preparation
- Ion beam generation
- Beam transport and handling
- Gas stripping
- Data acquisition and processing

High quality AMS facility performances:

- Extremely low machine background
- Very low isotopic fractionation
- High beam transmission efficiency
- High resolution beam analysis
- High long term operation stability

- Among ~ 60 AMS facilities around the world, 5 are in China.

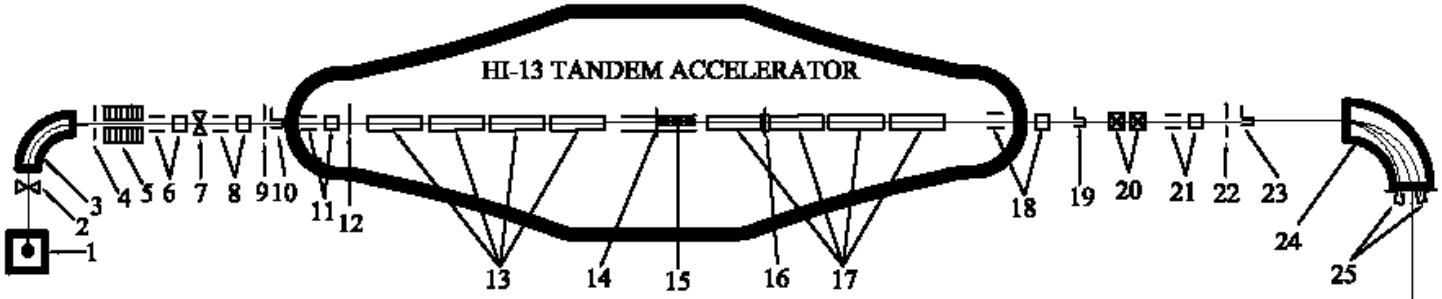
CIAE	HI-13MV Tandem	^{10}Be, ^{26}Al, ^{36}Cl, ^{41}Ca, ^{79}Se, ^{129}I…….
PKU	EN 6MV Tandem	^{10}Be, ^{14}C, ^{26}Al
PKU	0.6 MV Tandem	^{14}C
XI'AN CENTER	3 MV Tandem	^{10}Be, ^{14}C, ^{26}Al , ^{41}Ca, ^{129}I
SINR	Cyclotron	^{14}C

2. Typical AMS Facilities in China

HI-13 Tandem Accelerator

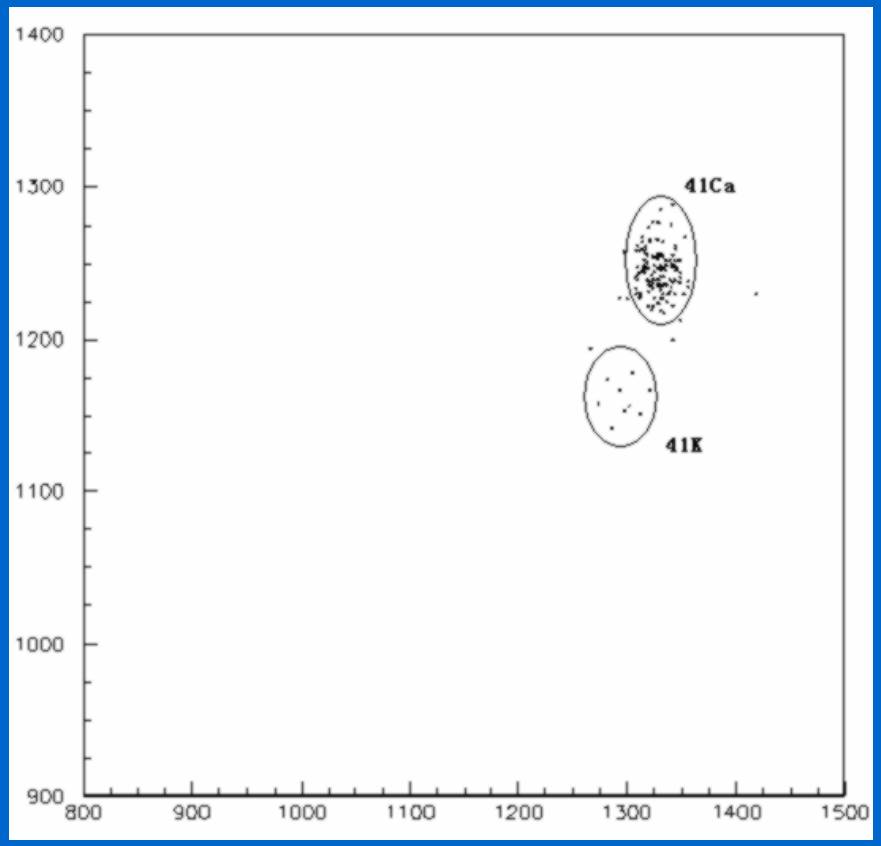
China Institute of Atomic Energy (CIAE)

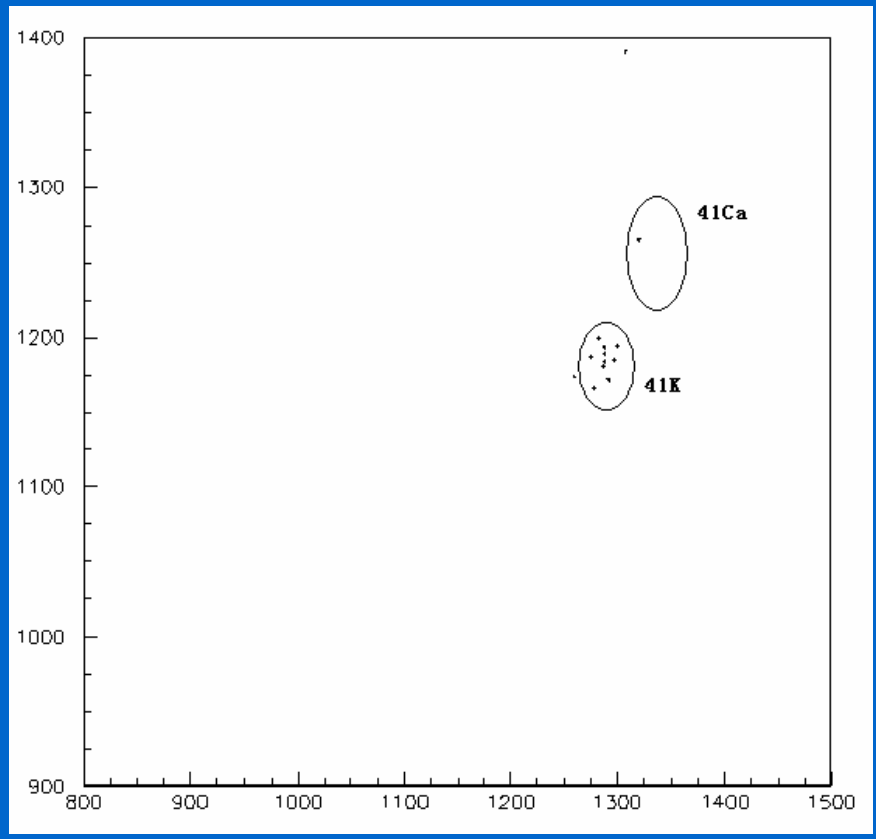
The layout of CIAE's HI-13 MV AMS system



1: ION SOURCE
2: TRIM LENS
3: DEFLECTING MAGNET
4: APERTURE
5: PRE-ACCELERATION TUBE
6: 1X.1Y STEERER
7: MATCHING LENS
8: 1X.1Y STEERER
9: APERTURE
10: L.E CUP
11: 2X.2YSTEERER
12: GRIDED LENS
13: ACCELERATIION TUBE
14: GAS OR FOIL STRIPPER
15: ELECTROSTATIC QUADRUPOLE TRIPLET
16: SECOND STRIPPER
17: H.E ACCELERATION TUBE
18: H.E 1X.1Y STEERER
19: H.E CUP
20: H.E MAGNETIC QUADRUPOLE DOUBLET
21: H.E 2X.2Y STEERER
22: OBJECT SLIT
23: OBJECT CUP
24: ANALYZING MAGNET
25: OFF-SET CUP
26: IMAGE SLIT
27: IMAGE CUP
28: MAGNETIC QUADRUPOLE DOUBLET
29: SWITCHER MAGNET
30: SLIT
31: 1X.1Y MAGNETIC STEERER
32: QUADRUPOLE DOUBLET
33: CUP
34: SLIT
35: ELECTROSTATIC DEFLECTOR
36: MICROCHANNEL PLATE DETECTOR
37: AMS TARGET CHAMBER
38: DETECTOR

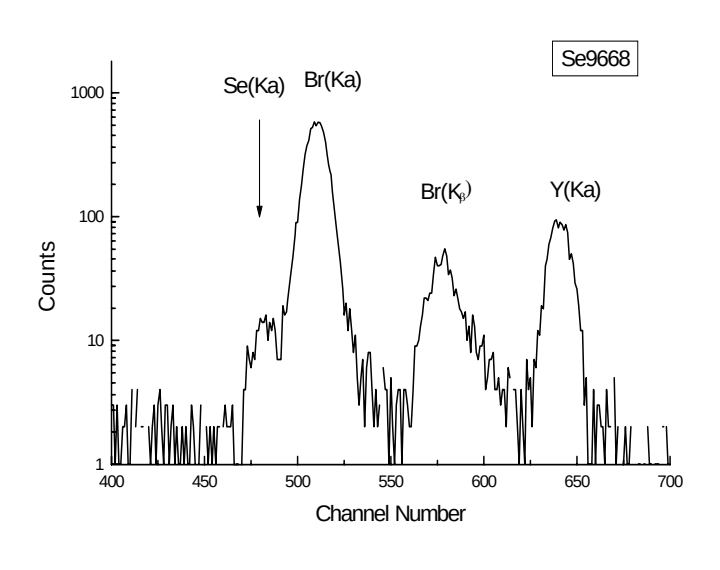
Two-dimensional spectra (ΔE1-ΔE2)of ^{41}Ca standard(10^{-11}) sample and blank sample

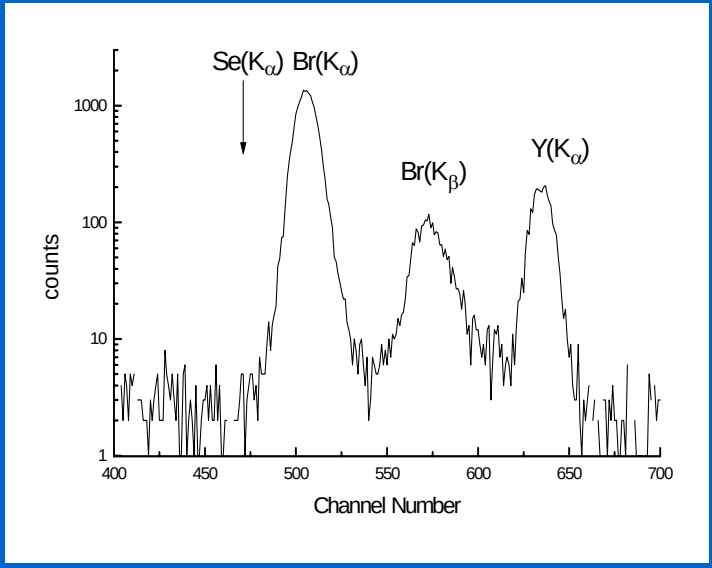




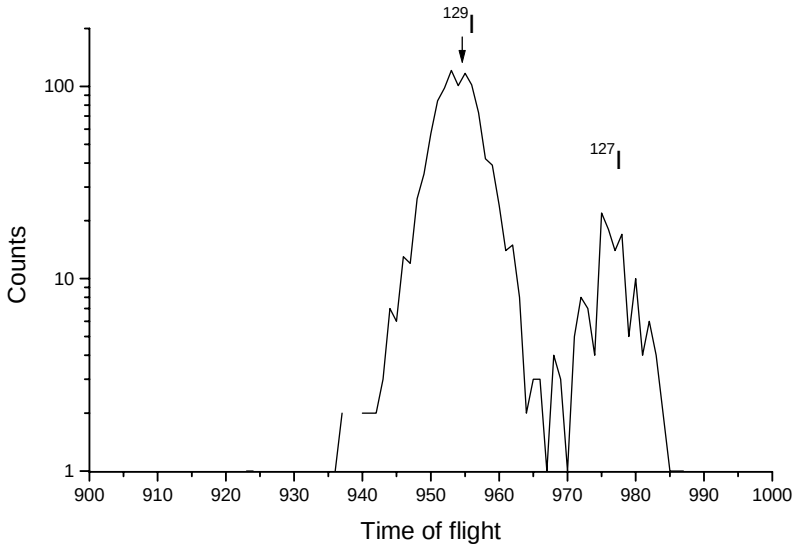
Projectile X-ray method for the identification of ^{79}Se

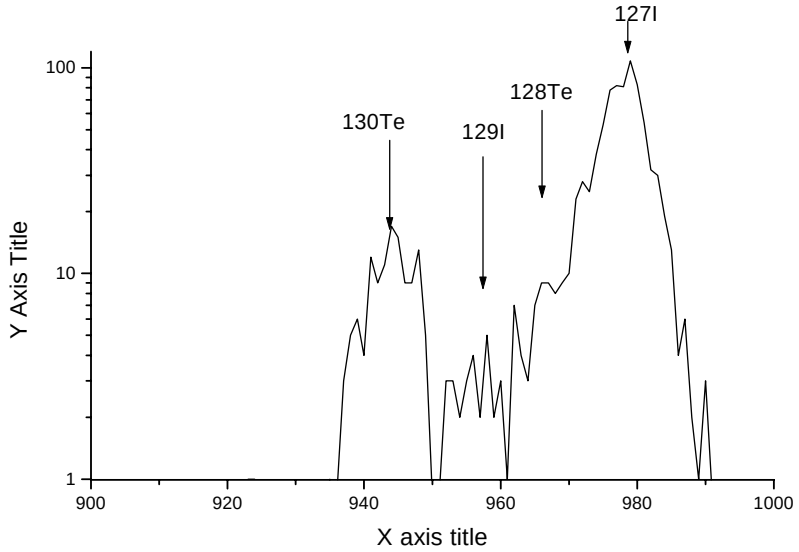
- According to different characteristic Kα ray energy, the ^{79}Se and ^{79}Br are identified .



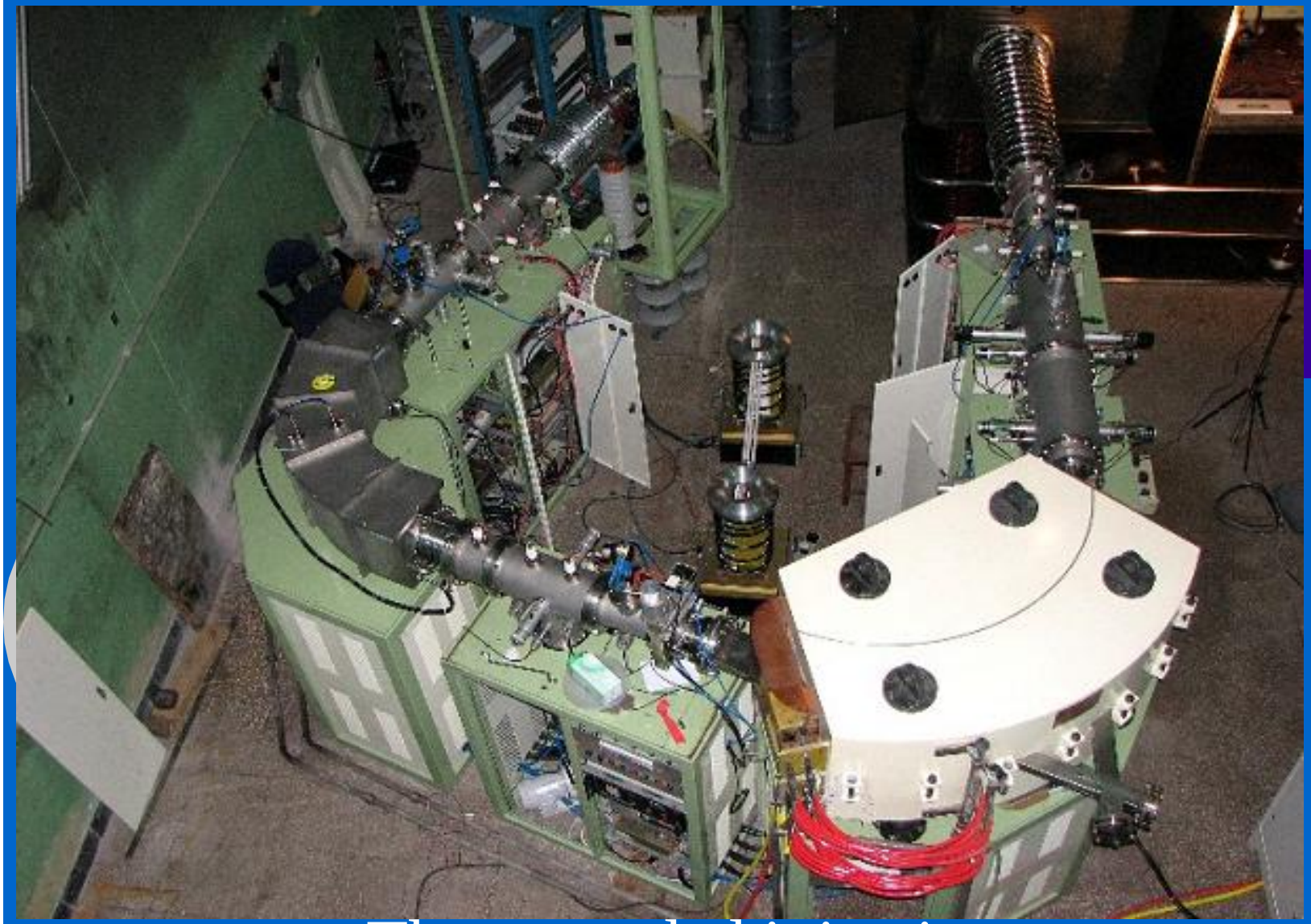


TOF method for isotope identification of ^{129}I



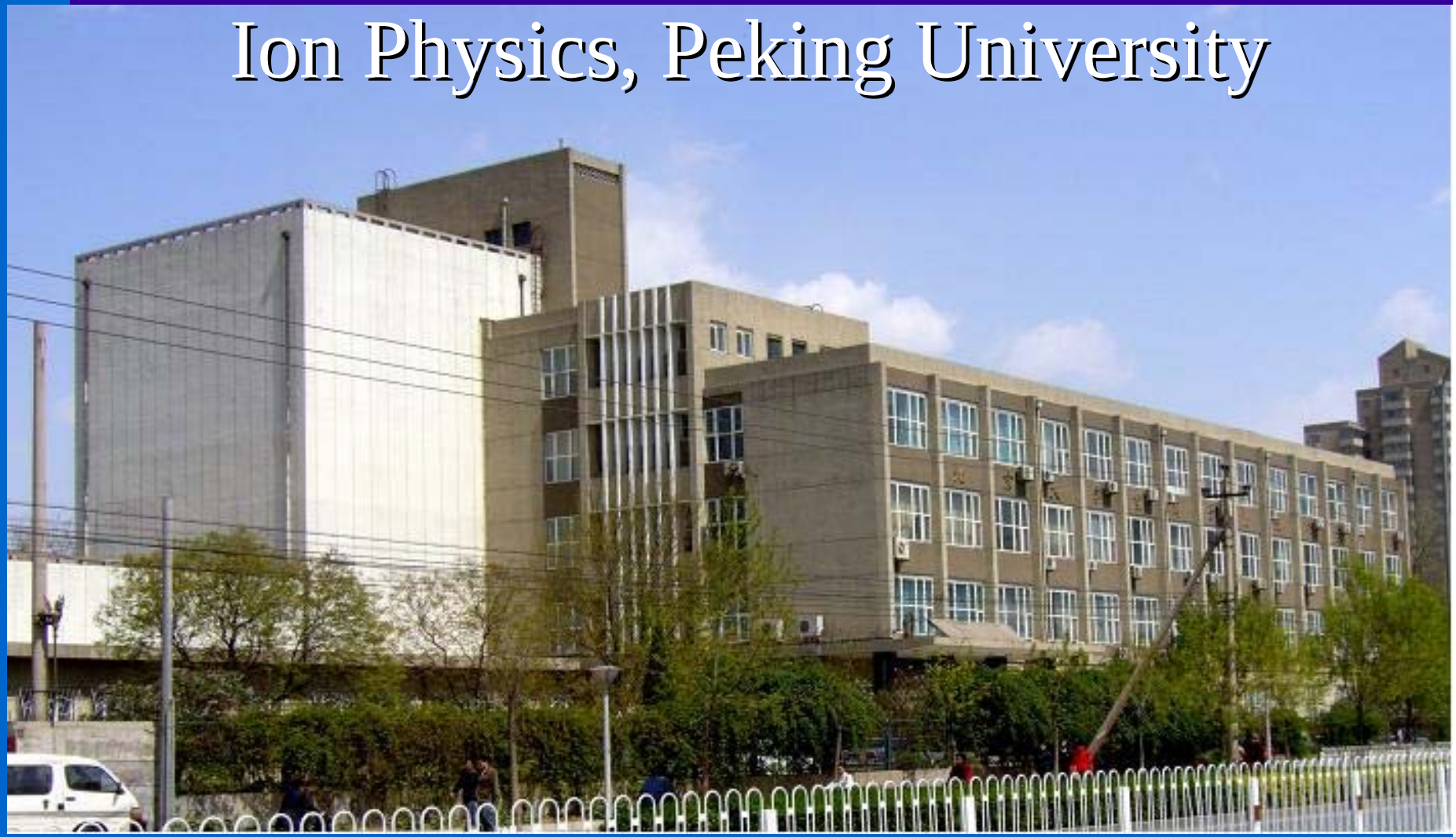


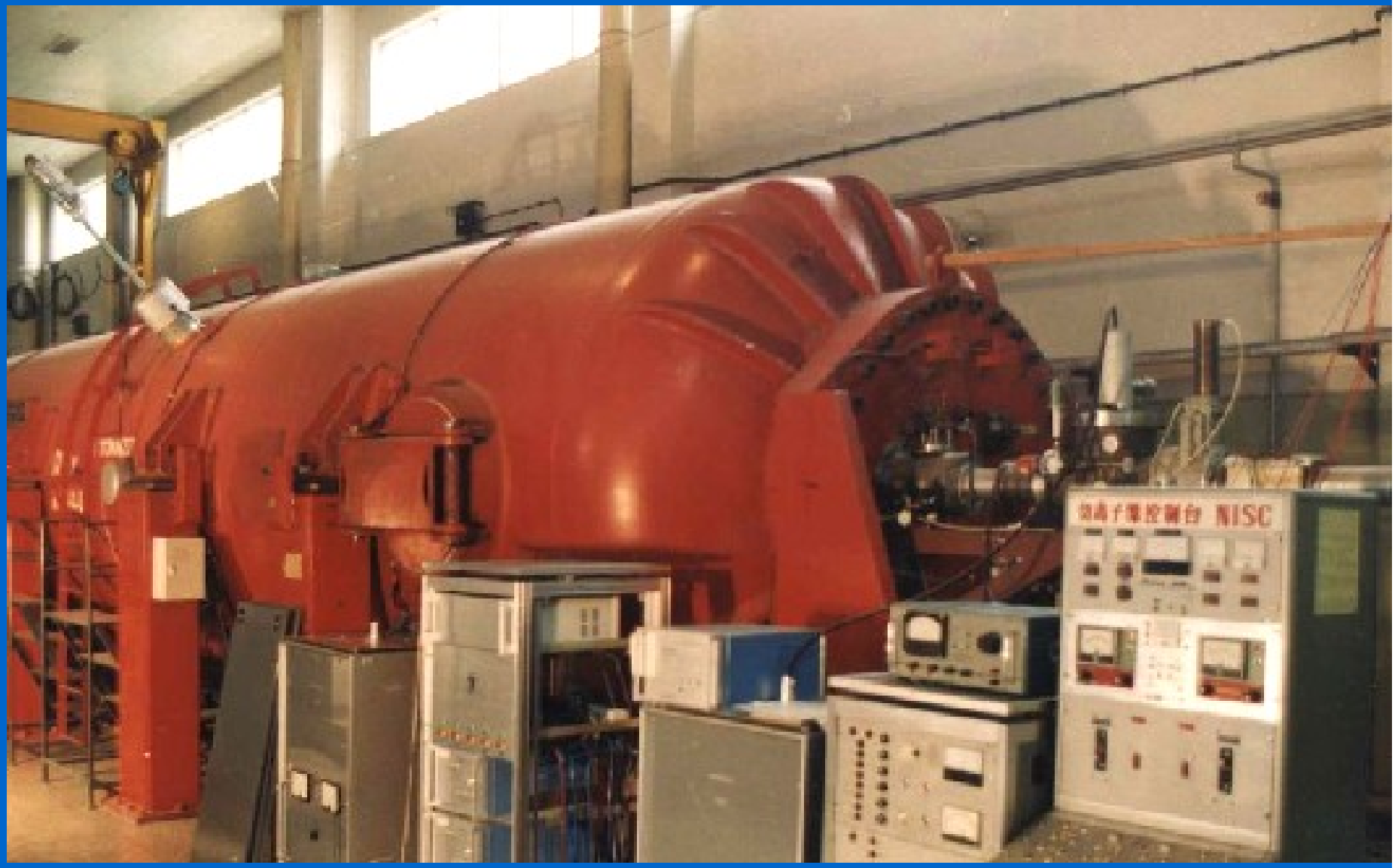
For the measurements of heavy elements (Pu, U isotopes), Mass resolution(M/ΔM) increased from 90 to 400.



The upgraded injection system

PKUAMS at the Institute of Heavy Ion Physics, Peking University



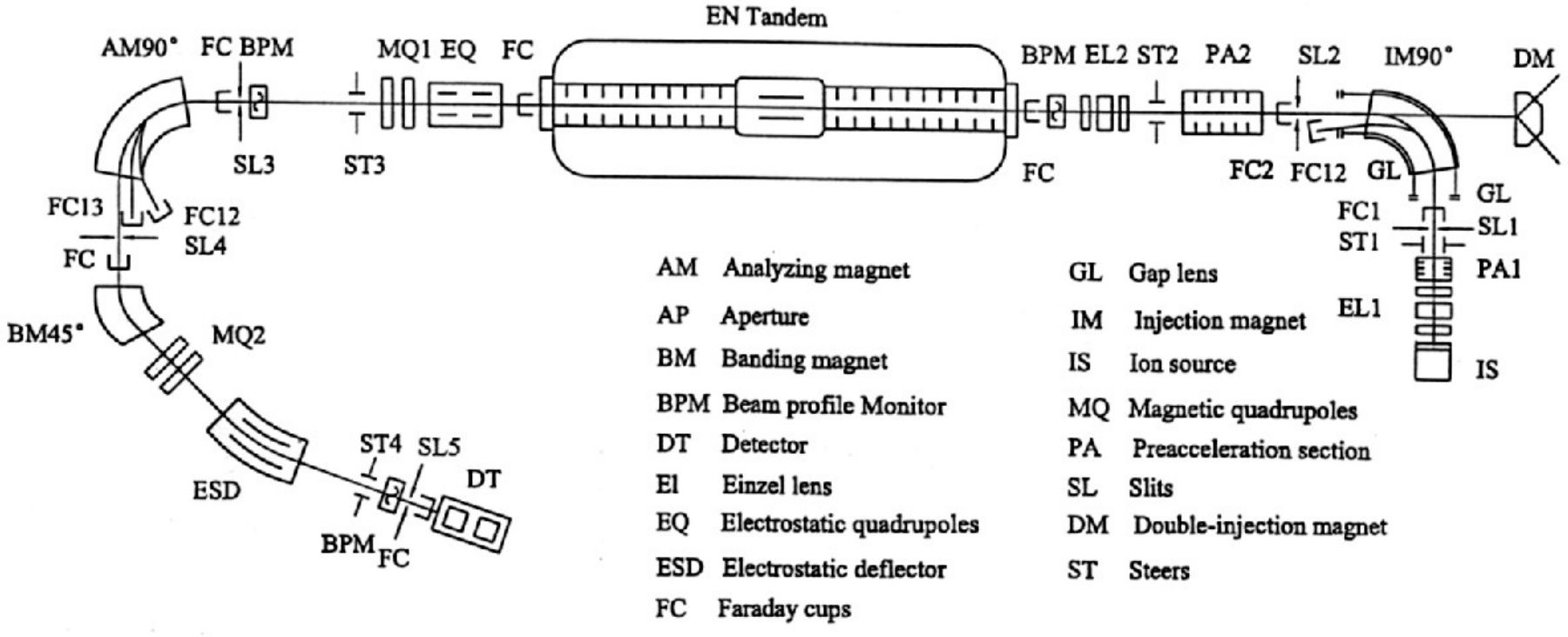


HVEC 6MV EN Tandem Accelerator

Upgraded Features of PKUAMS for the Xia-Shang- Zhou Chronology Project

- Precision of measurement : 0.4- 0.5% for ^{14}C
- Machine background : $^{14}C \sim 1\times10^{-15}$; $^{10}Be < 6\times10^{-15}$
- Beam transport efficiency: ~ 30%
- Serial sample calibration with Bayesian method developed
- Quality control for precise dating established

The Layout of the PKU-AMS

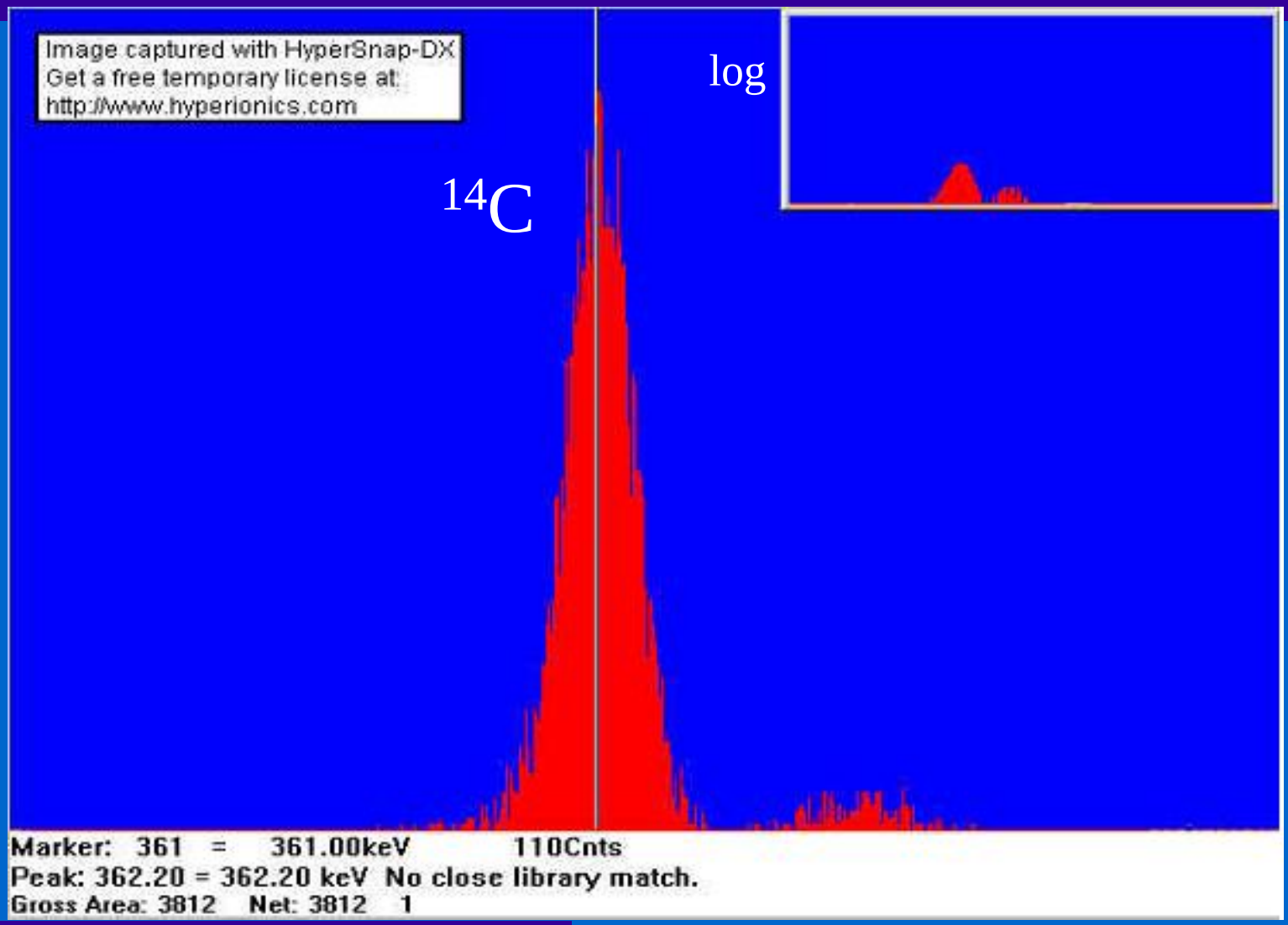


Computer Control System

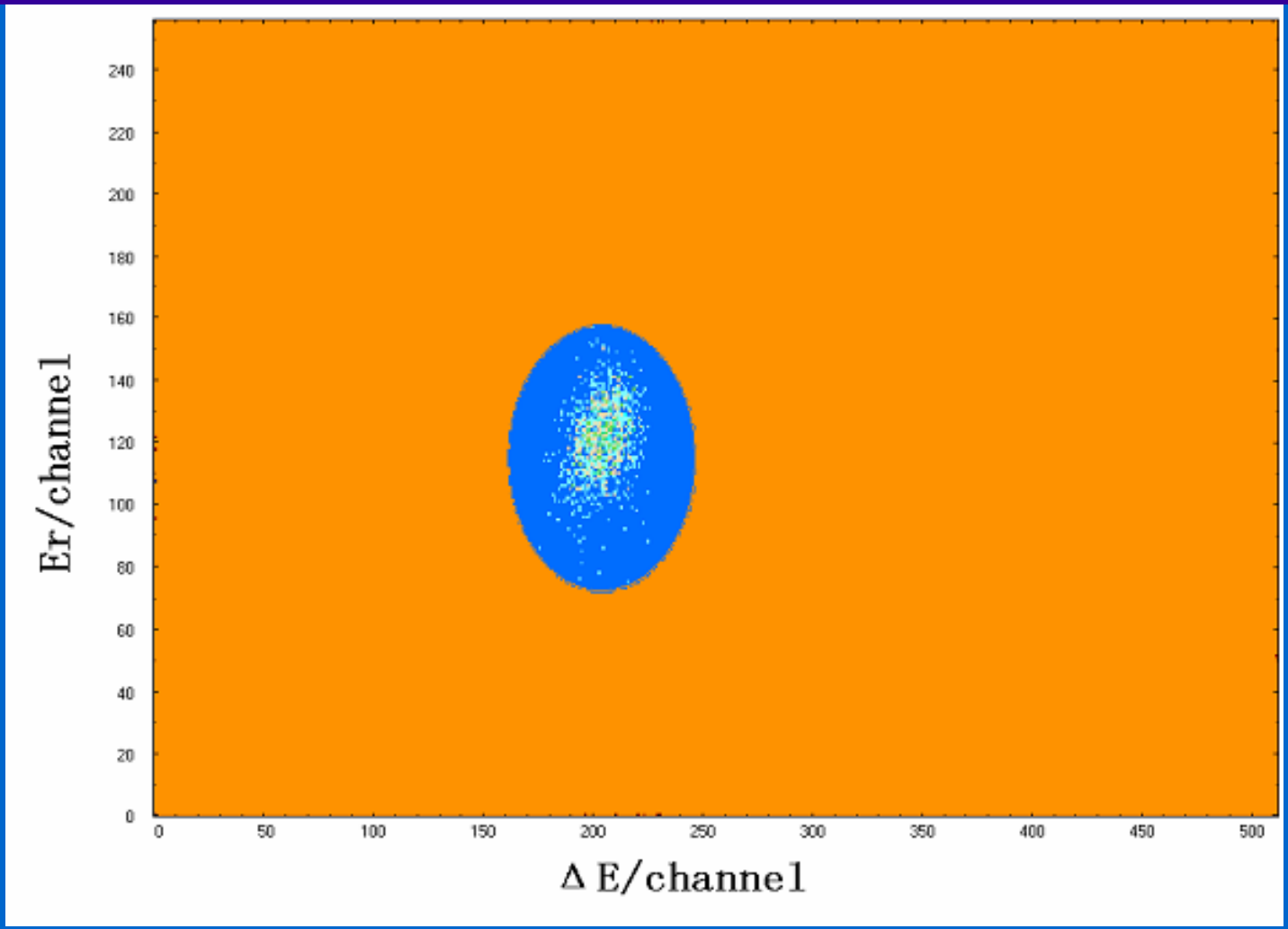
control precision 0.05%

Stability 0.1% in 8 hrs

Typical Spectrum of ^{14}C after upgrading



Typical ΔE--E Spectrum of ^{10}Be



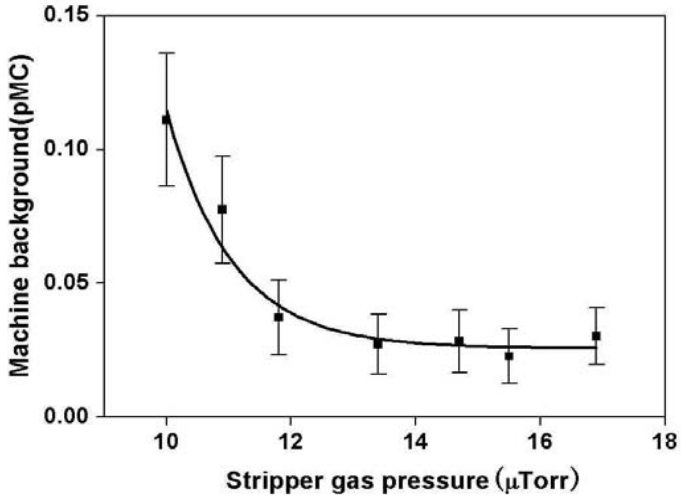
Modern Compact Facility for PKU-AMS

V_{max}=0.6MV

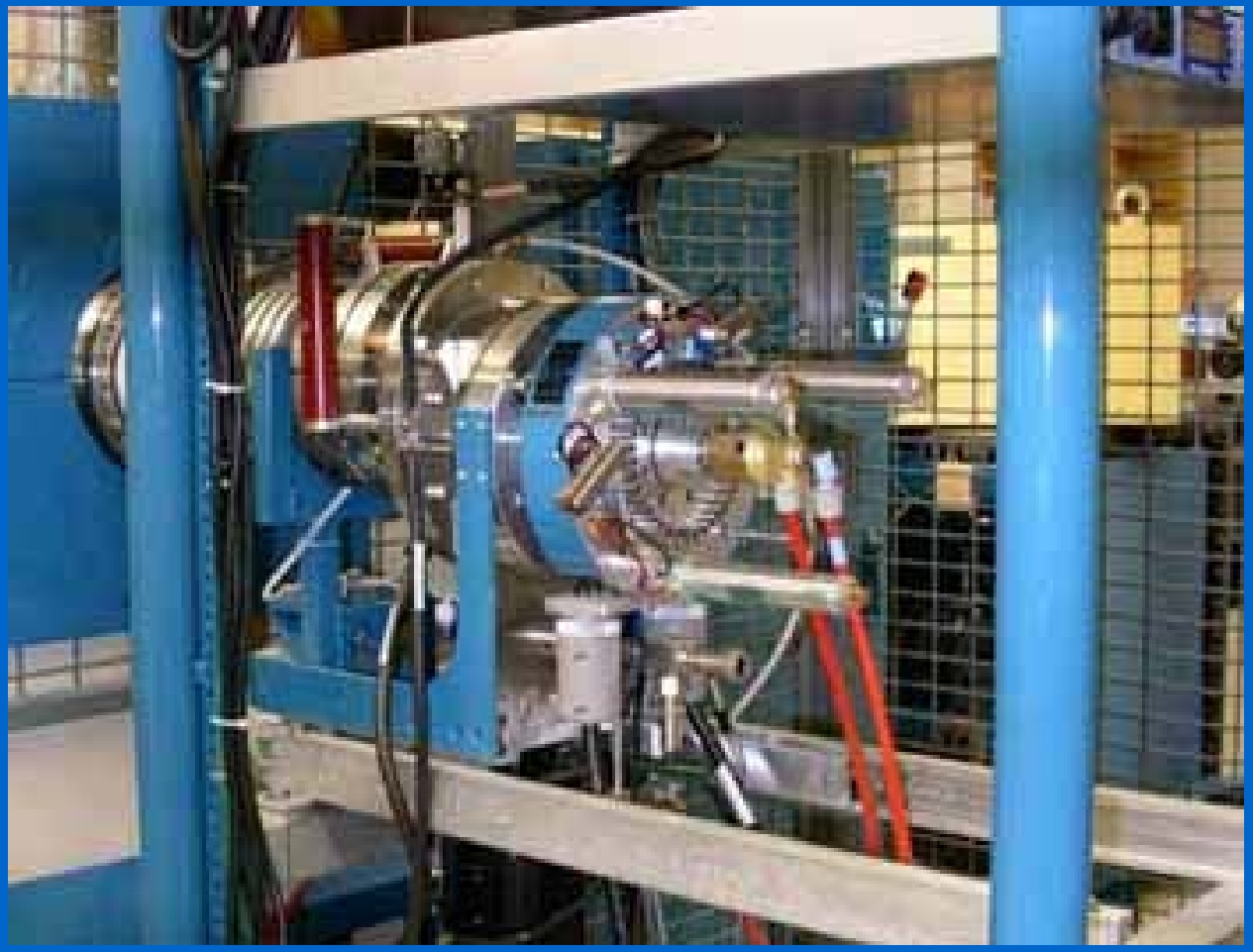
V_{op}=0.46MV

Machine Performance

- Accuracy：0.3 %, ~25 yrs
- Background: <4X10^{-16}, ~65 Ka
- Source output: 60-80 μA
- Transport efficiency：~42%
- Dating Capability：>3000/yr
- Standard sample comparison ：OXI, OXII, ANU, & IAEA standard sample
- Comparison inter Labs：UC-Irvine, ANU, IAEA



The Sputtering Ion Source with 40 targets



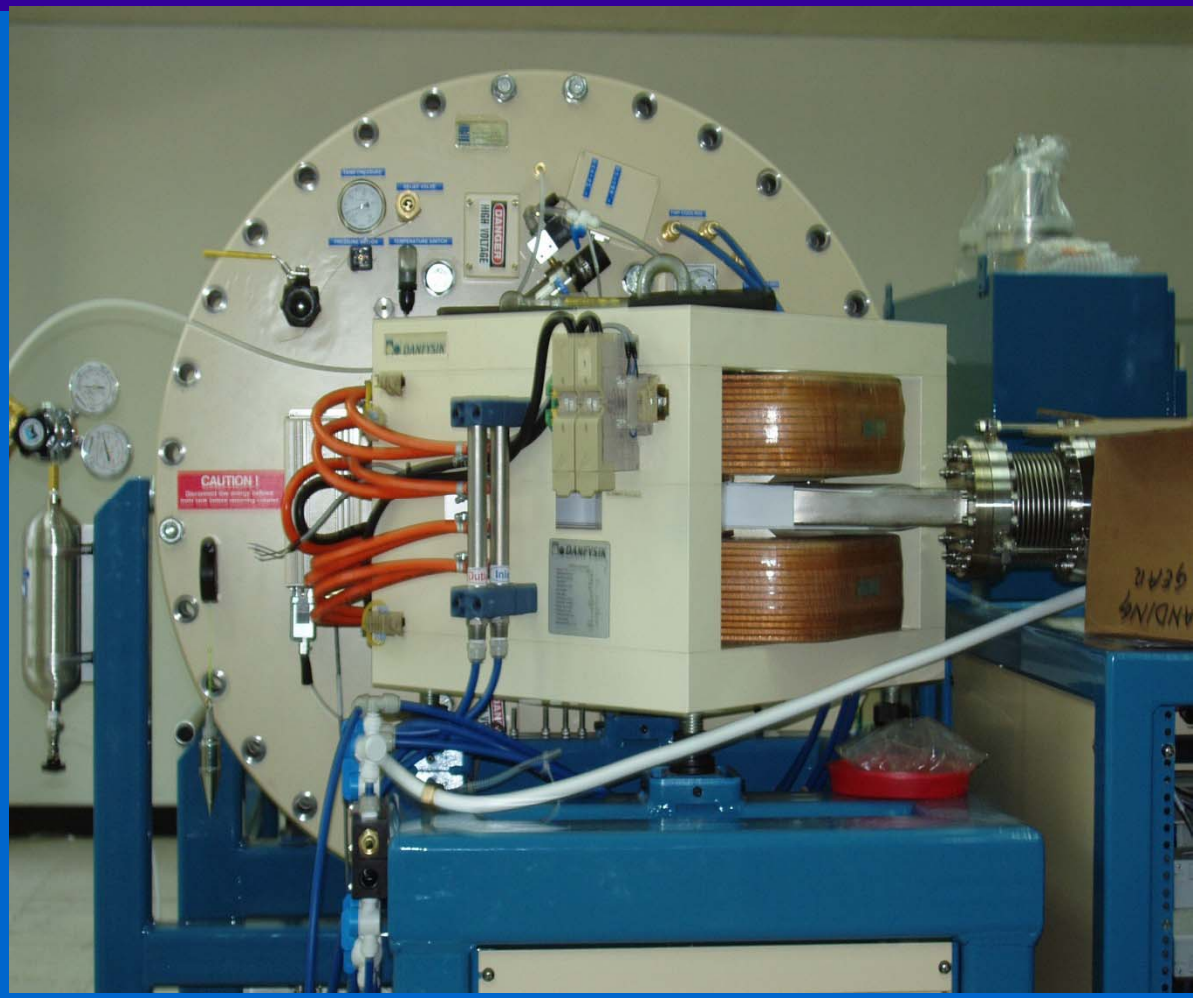
- I_{inj}=50-80 μA $^{12}C^-$ with high beam quality and stability

The Sequential Injection System

- Biased vacuum chamber for ~10 Hz cycling sequential injection

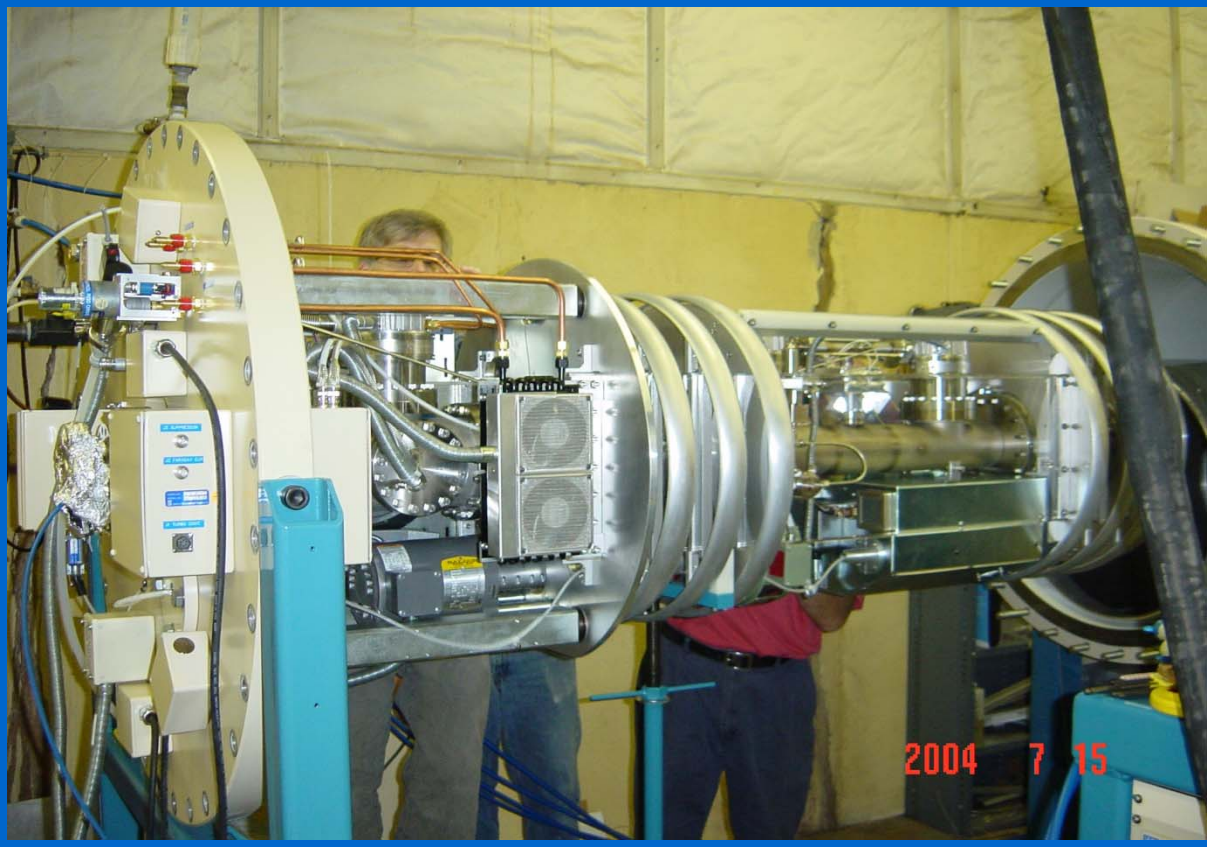
- $^{12}C^-$ 0.3 ms
  $^{13}C^-$ 1.0 ms
  $^{14}C^-$ 100 ms

- Fractionation & beam loading effect minimized



Special Recirculation Gas Stripper

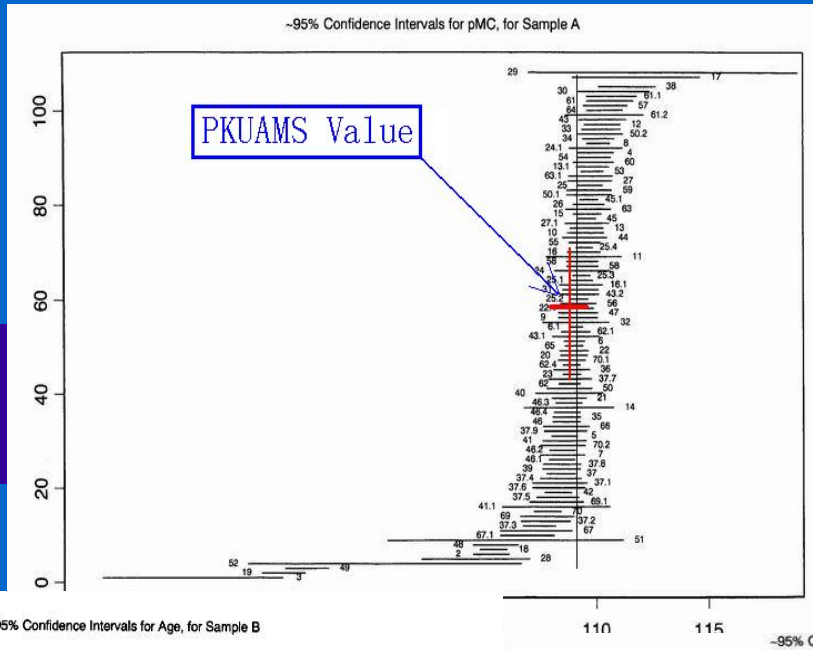
- Stripping channel
  ϕ 8X450 mm
- Pressure inside the stripping channel
  17-19X10^{-3} Tor.
- Two molecular pumps for recycling stripping gas

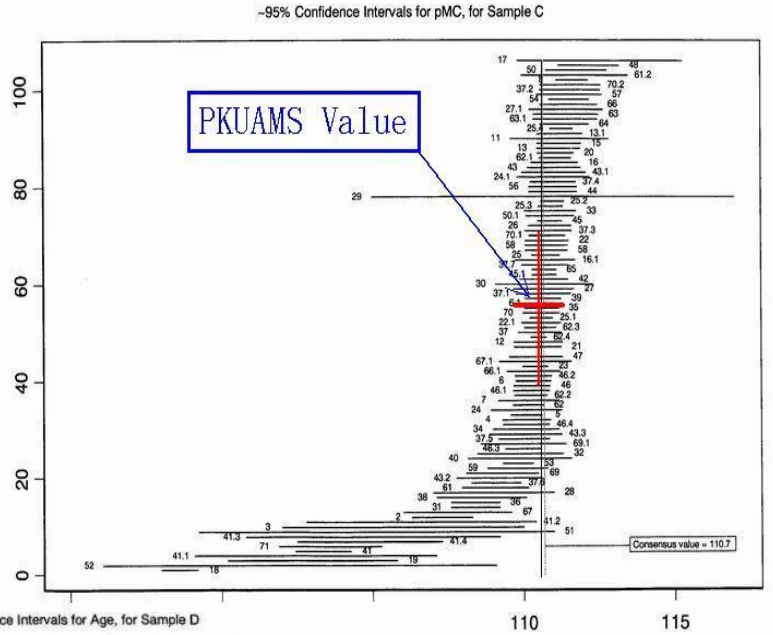


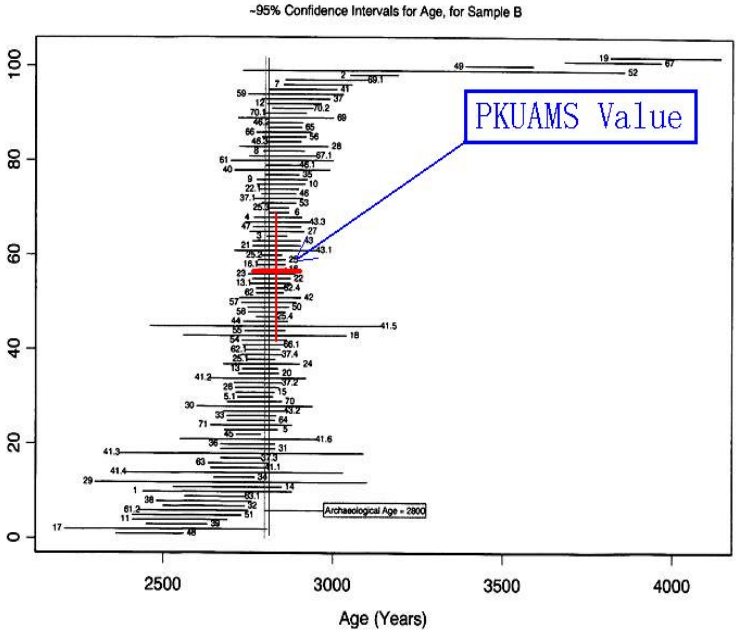
Detector & Data Acquisition

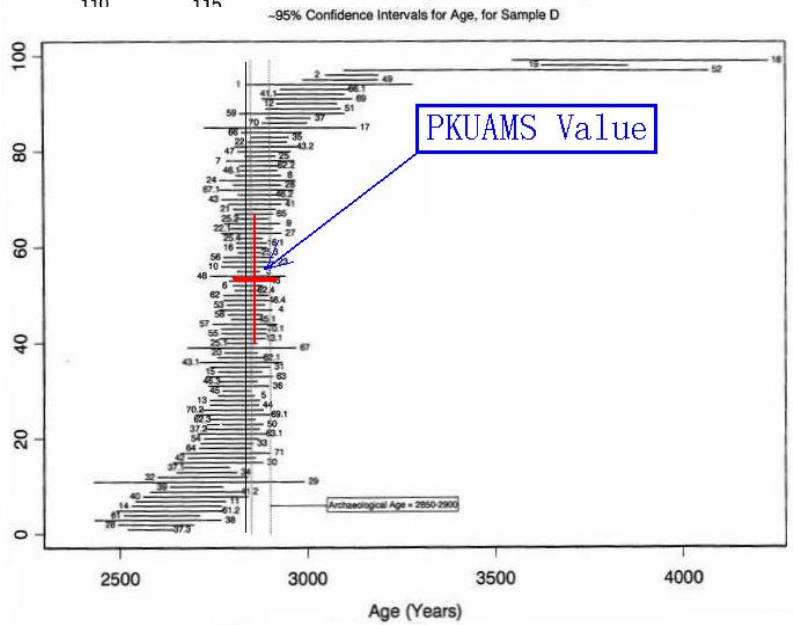
- An Au Surface Barrier Detector with a lifetime about 1500 hrs
- Clean ^{14}C spectrum can be obtained at 200 counts/sec for modern carbon sample

Comparison with IAEA Samples









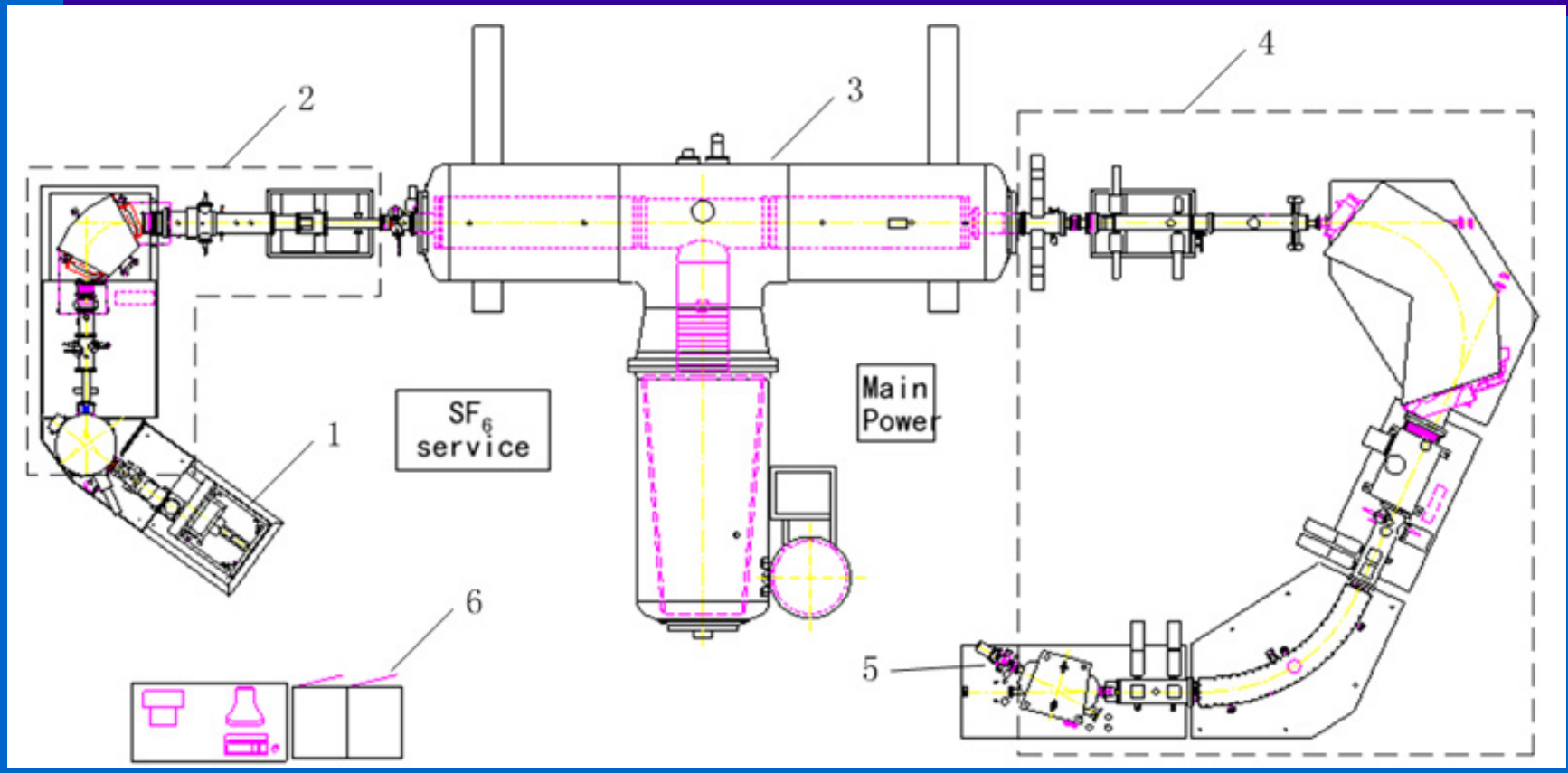
Xi'an AMS Center

Jointly established by Institute of Earth Environment, CAS and Xi'an Jiaotong University in 2004

Xi’an 3 MV Multi-element AMS

(10Be, 14C, 26Al and 129I)

Layout of the Xi'an AMS Facility



1. Ion source 2. Injector 3. HVEC 3MV Tandem
4. High energy analyzing system
5. Detector 6. Control system

Special features

- Ion source for both solid and potencially CO_2 samples
- Sequential injection at 100Hz cycling frequencies
- Low injection energy with Q-snout
- Accelerator tube with combined magnetic & electrostatic suppression results in low X radiation level
- Flat Top mass independent transmission

Injector

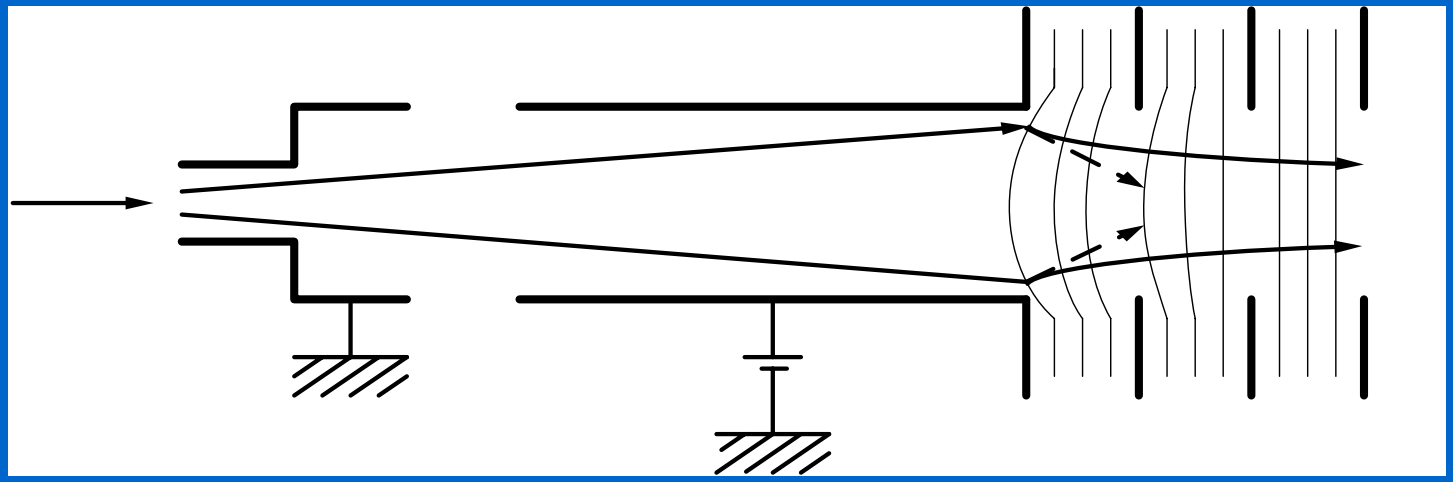
Negative ion source with 50 sample holders

- 54° electrostatic spherical analyzer (R=470mm)
- 90°bouncer magnet （ R=400mm ）
- Fast sequential injection at 100 Hz, ^{14}C 9.5 ms, ^{12}C & ^{13}C 100 μs

Low injection energy and Q-snout

Low Injecion energy 35 keV → Using small electro-magnetic components

Q-snout: solving the overfocusing on ions while entering into the accelerator with low energy



Results of the Acceptance Tests

^{10}Be、^{14}C、^{26}Al、^{129}I (2006.7)

		Sensitivity (Tested)	Statistic Precision (Tested)
^{14}C (Graphite)	$^{14}C/^{12}C$	**3.0×10^{-16}**	**0.18%**
	$^{13}C/^{12}C$		**0.070%**
^{10}Be	$^{10}Be/^{9}Be$	**3.6×10^{-15}**	**1.40%**
^{26}Al	$^{26}Al/^{27}Al$	**2.3×10^{-15}**	**0.38% (3.0MV)**
^{129}I	$^{129}I/^{127}I$	**2.0×10^{-14}**	**1.75%**

- **High ^{14}C precision reached by fast sequential injection**
- **High ^{10}Be detection sensitivity at 3MV AMS**

FUTURE POSSIBLE EARTH SCIENCES RESEARCH

- High resolution study on climate & cosmic events
- Establishing Chinese climatic history
- Studies on Chinese civilization origin
- Dating of groundwater
- Control and preventability of environmental pollution
- Physiognomy evolvement of Tibetan Plateau
- Geodynamics

3. Typical Applications

Archaeological Studies : Chronicle Dating

Si Ma-qian
145 BC-90 BC

Shi JI, written by Si Ma-qian, is the most authoritative book on the chronicle of ancient Chinese history starting from 841 BC. It also gives all the King's names and their genealogy since Xia. However, Chinese chronology has not been well established so far.

- For the date of the conquest of Shang by King Wu of Zhou, at least 44 different solutions have been offered spreading over a span of 112 years.

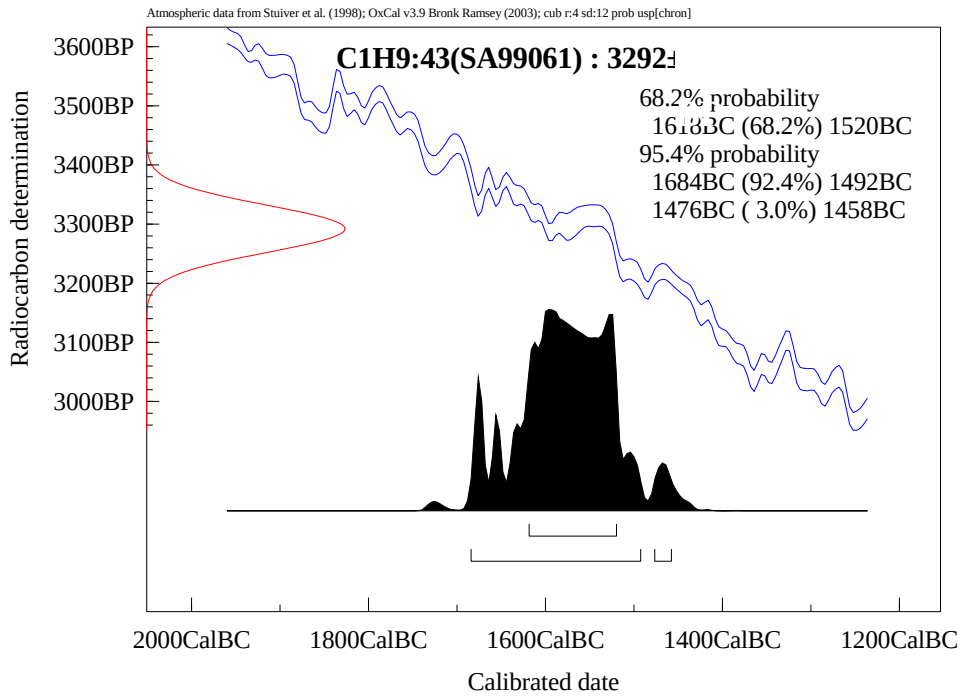
Dynasties	Dates
Xia	? BC – ? BC
Shang	? BC – ? BC
Western Zhou	? BC – 771 BC
Eastern Zhou	770 BC – 252 BC

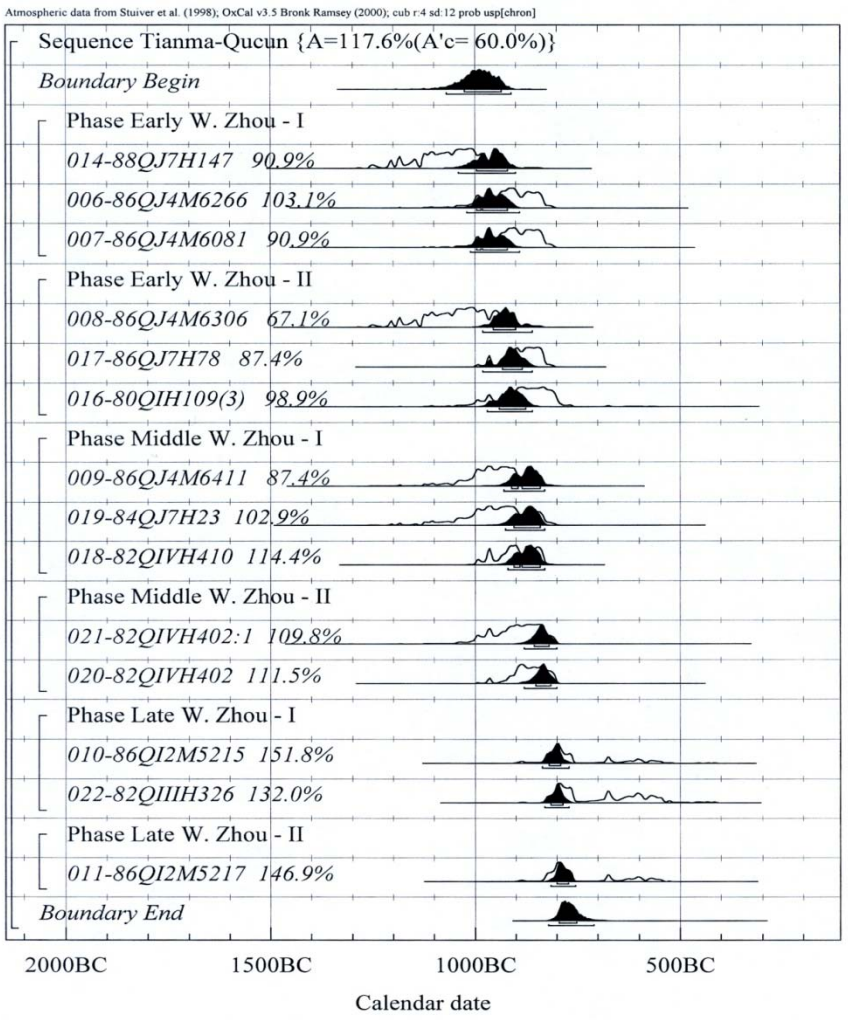
- The Xia-Shang-Zhou Chronology Project integrates Archaeological studies, Astro-chronological studies & Radiocarbon dating etc. to establish a chronicle frame for Xia, to Western Zhou on the base of scientific evidence
- Nine series of samples, including 7 sites, one tomb series and a special series of oracle bone samples, were studied with AMS ^{14}C dating
- The inscriptions on oracle bones recorded the King's name, activities, war, sacrificial offerings and important astronomical phenomena.

Oracle bones from Yinxu site of Shang Dynasty

Calibration of serial samples with Bayesian method

- Tree rings used to convert ^{14}C age into calendar years
- Calibration of serial samples using Bayesian method to reduce uncertainty





Results via synthesis of various means

Dynasties	Dates
Xia	ca. 2070 BC – ca. 1600 BC
Shang	ca. 1600 BC – 1046 BC
Western Zhou	1046 BC – 771 BC

Chronological frame of Xia, Shang & Western Zhou

Studies on Neolithic culture in North China

Donghulin Site discovered & excavated

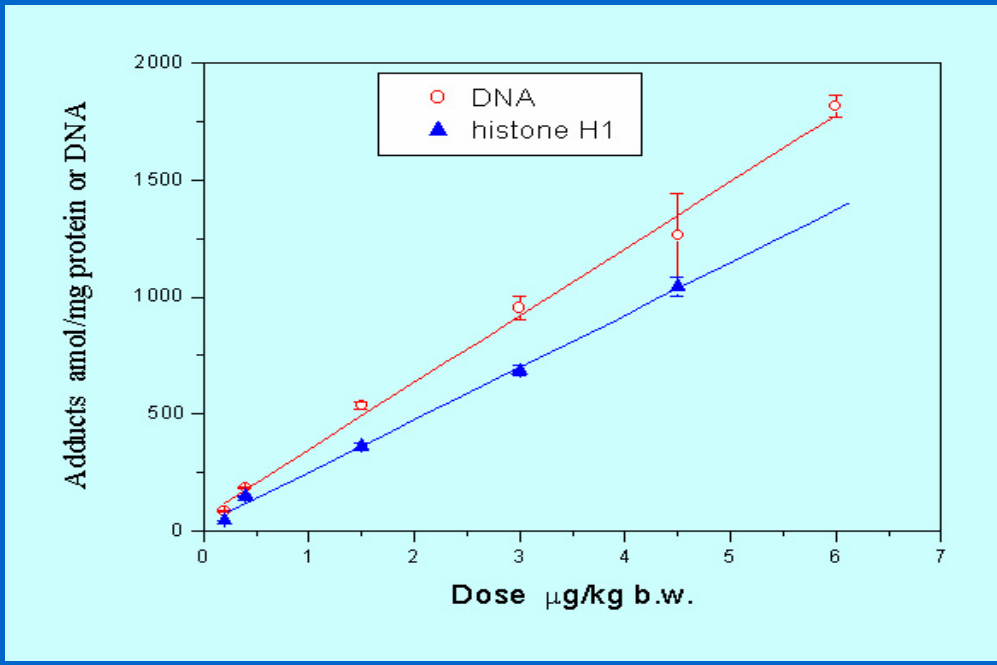
- Tombs, ash-pits, fireplaces and other vestiges along with chipped stone implements, microliths, polished stone tools and potteries were found at Donghulin site

Studies on Neolithic culture in North China

- More than 20 charcoal and bone samples were collected from this site and dated on PKUAMS.
- The results show that the Donghulin Man lived from 9000BC to 7000BC, the early Neolithic period

Bio-science studies using PKUAMS

Measurement on ^{14}C-labled nicotine-DNA adducts

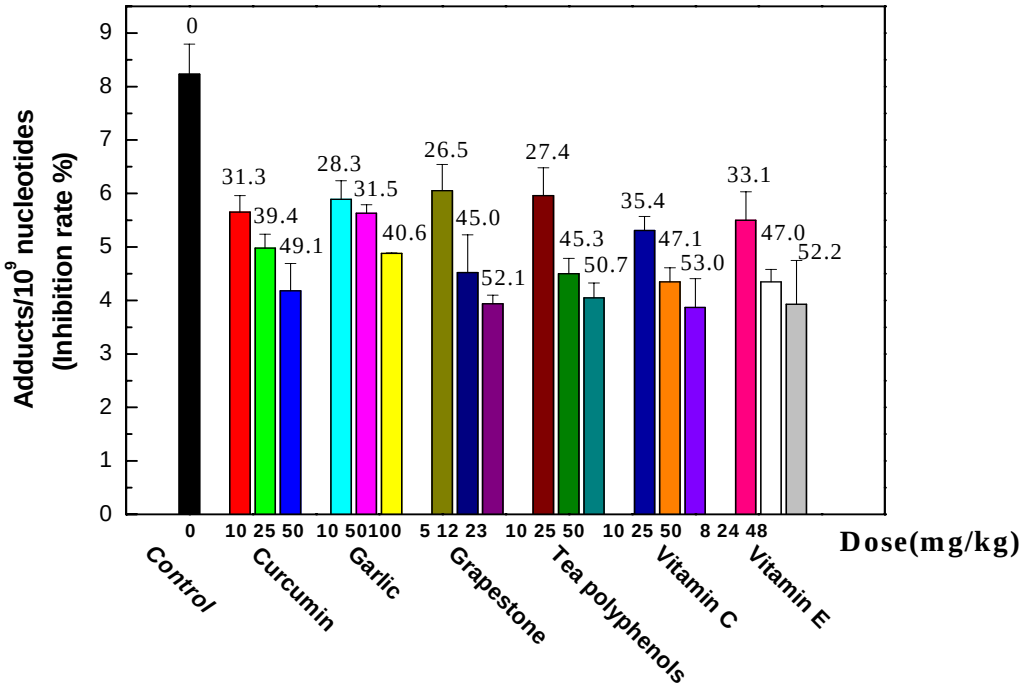


Recently, the inhibitory effects of curcumin, garlic,squeeze, grape-seed extract, tea polyphenols, vitamin C and vitamin E on nicotine-DNA adduction have been investigated.

Inhibition Effects of Adductions by Dietary Constituents

- Amongst the six agents, grape-seed extract showed the strongest inhibition to the DNA adduct formation

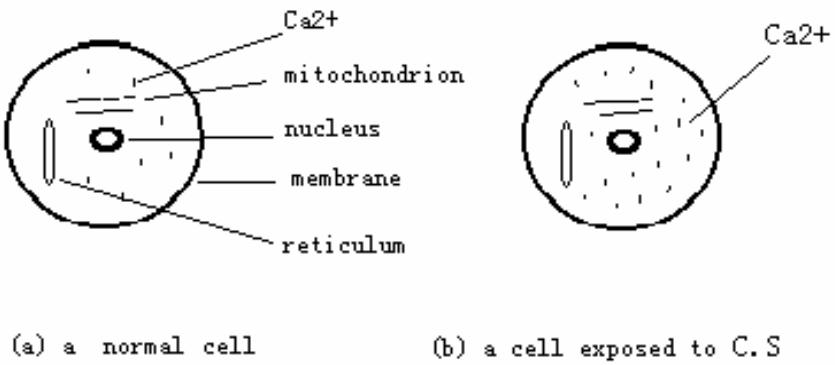
- The reduction rate reached about 50% for all agents except garlic squeeze (40%)



Biomedical applications at CIAE

- Using ^{26}Al as a tracer to study pneumoconiosis

- Using ^{41}Ca as a tracer to investigate the origin of increased free Ca^{2+} in cells when exposed to carcinogenic substance.



10^7 Ca atoms may go into each cell when the cells are exposing to carcinogenic substance 1 hour

CONCLUSIONS

- AMS technology has been well developed in China
- Each of the 4 Tandem based AMS performed successfully to meet their needs in the fields of Archaeology, Earth Science, Environmental Sciences and Biomedical sciences and etc.
- All of the facilities will be further upgraded according to the requirements of new applications


Thank you!
The Campus of
Peking University

Demands of Xia-Shang- Zhou Chronology Project

- To define the chronological frame from the start of Xia dynasty up to 841 B.C. by precise ^{14}C dating on serial samples from various historical sites and oracle bones
- Precision better than ± 30 years
- Counts of ^{14}C per measurement 100 -300k
- High long-term operation stability

Quality control for precise Dating

- Machine error analysis and reduction
- Standardized beam tuning procedure
- Well-designed measuring procedure and data manipulation program
- Statistical testing
- Multiple targets with *t*- or *F*- test
- Multi-standards (OX-I, OX-II, ANU, IAEA…)
- Inter-comparison between Laboratories

Upgraded components of PKU-AMS

- High output ion source with 40 sample-holders
- Fast cycling sequential injection system
- High efficiency, flat-topping, mass independent beam transport
- Installation of recycling stripping gas
- Highly stabilized power sources
- Computer controlled operation & data acquisition

Recirculation Stripper for EN Tandem

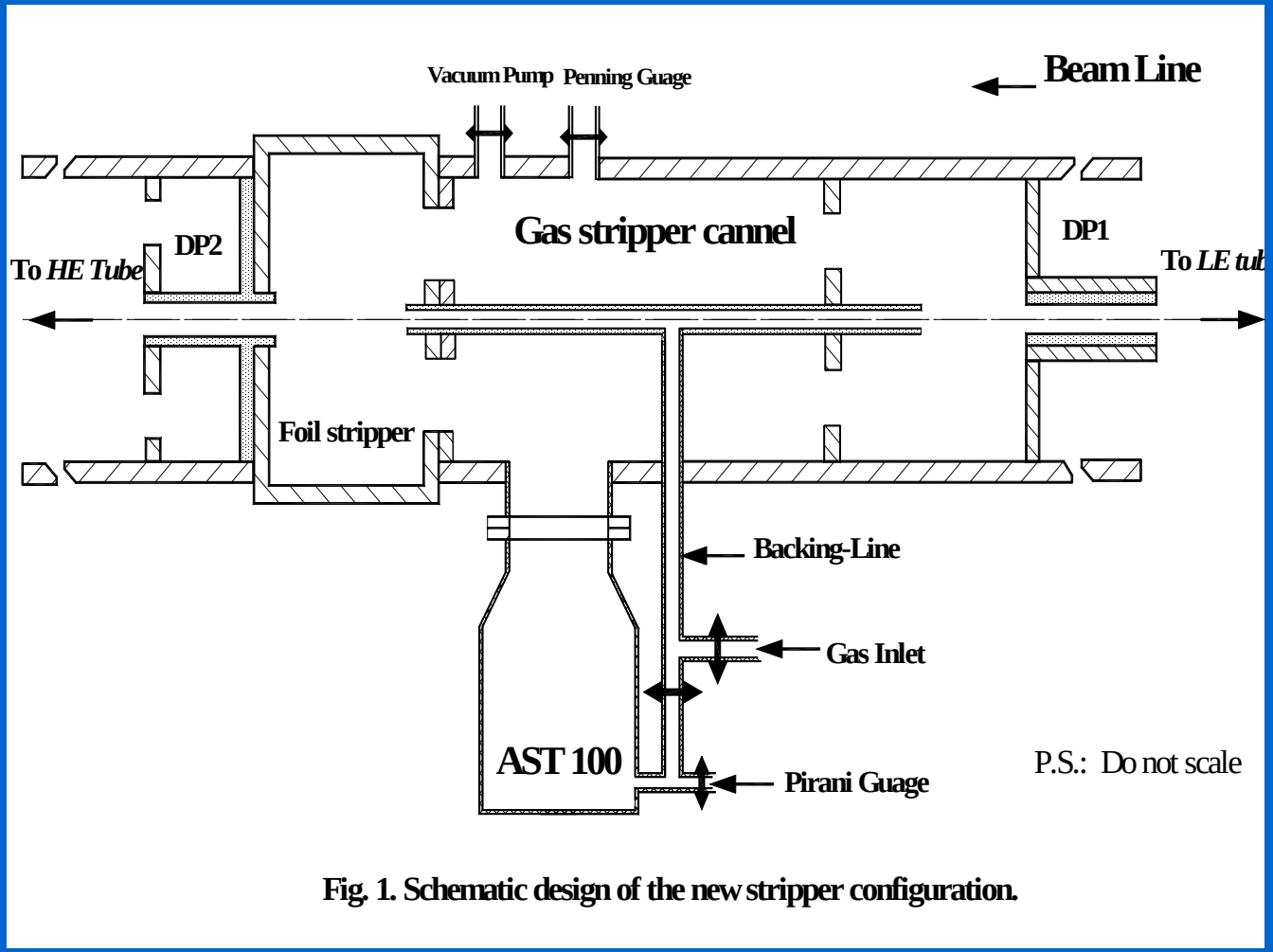


Fig. 1. Schematic design of the new stripper configuration.

The Conquest of Shang by King Wu

- A profile was found in Fengxi site (near Xi'an) with the remains from Pre-Zhou to the late Zhou
- Fengxi site was dated. It was the home of the Zhou people before the establishment of Western Zhou
- King Wen of Zhou (周文王) moved his capital to Fengxi, and KingWu (周武王), son of King Wen, conquered Shang from Fengxi

The Conquest of Shang by King Wu

- AMS results: the Conquest occurred mostly during 1060 BC – 1000 BC
- LS results: the Conquest occurred mostly during 1050 BC – 1010 BC
- Considering the dating results of Yin site and oracle bones from late Shang as well as Liulihe site and Tianma-Qucun site from early Western Zhou, the most possible intervals was 1050 BC – 1020 BC

Xinzhai site –A Study on Xia

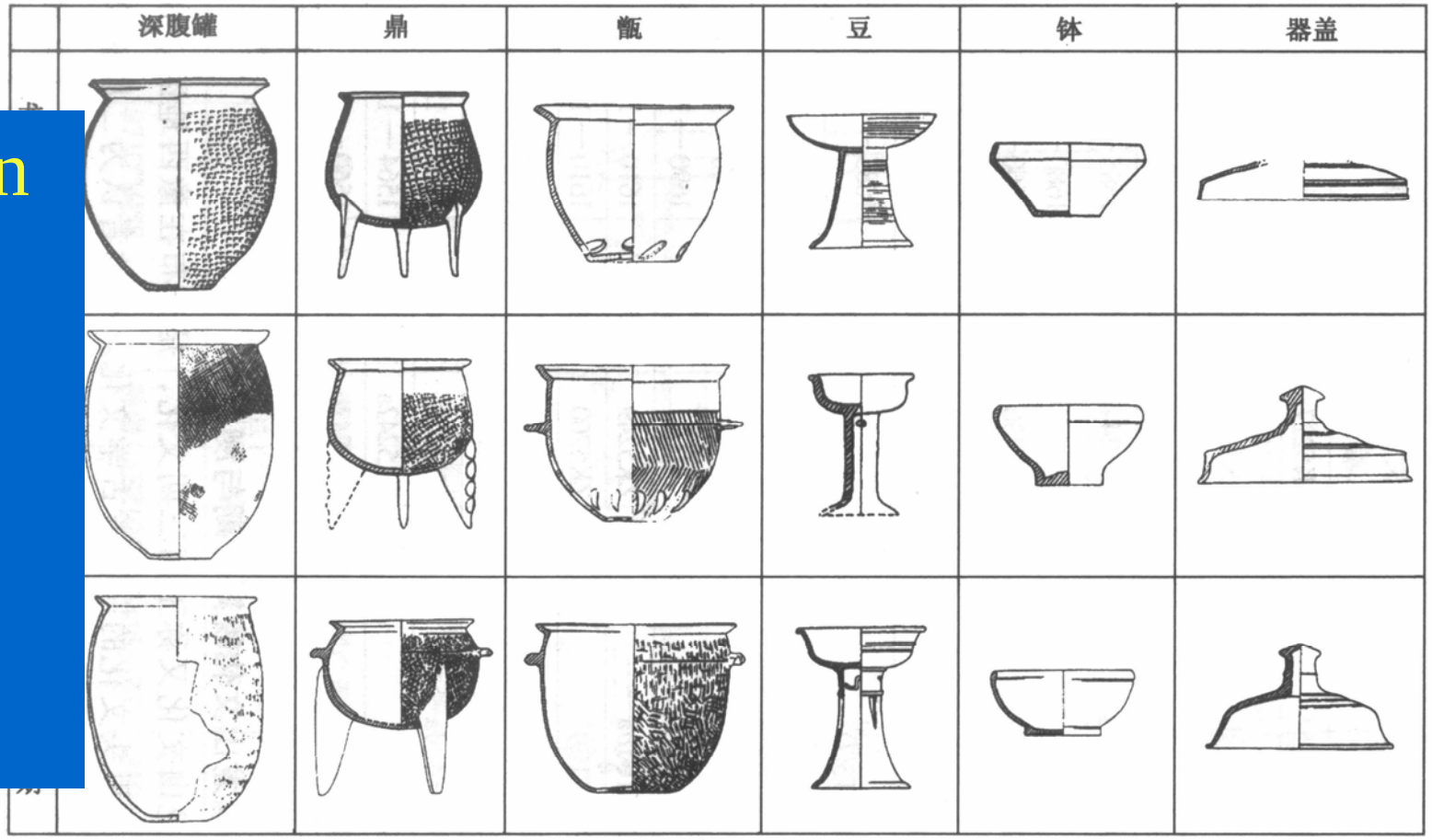
- 1000 m^2 Cultural remains in Xinzhai site contain late Longshan and early Er-li-tou.
- Bayesian method is used again for the calibration of the serial samples from 3 sites

Evolution of the form of Potteries

Longshan

Xinzai

Er-li-tou



豫西地区龙山文化晚期、新砦期与二里头文化一期
典型陶器形制演变图

Unearthed pottery from Xinzhai site

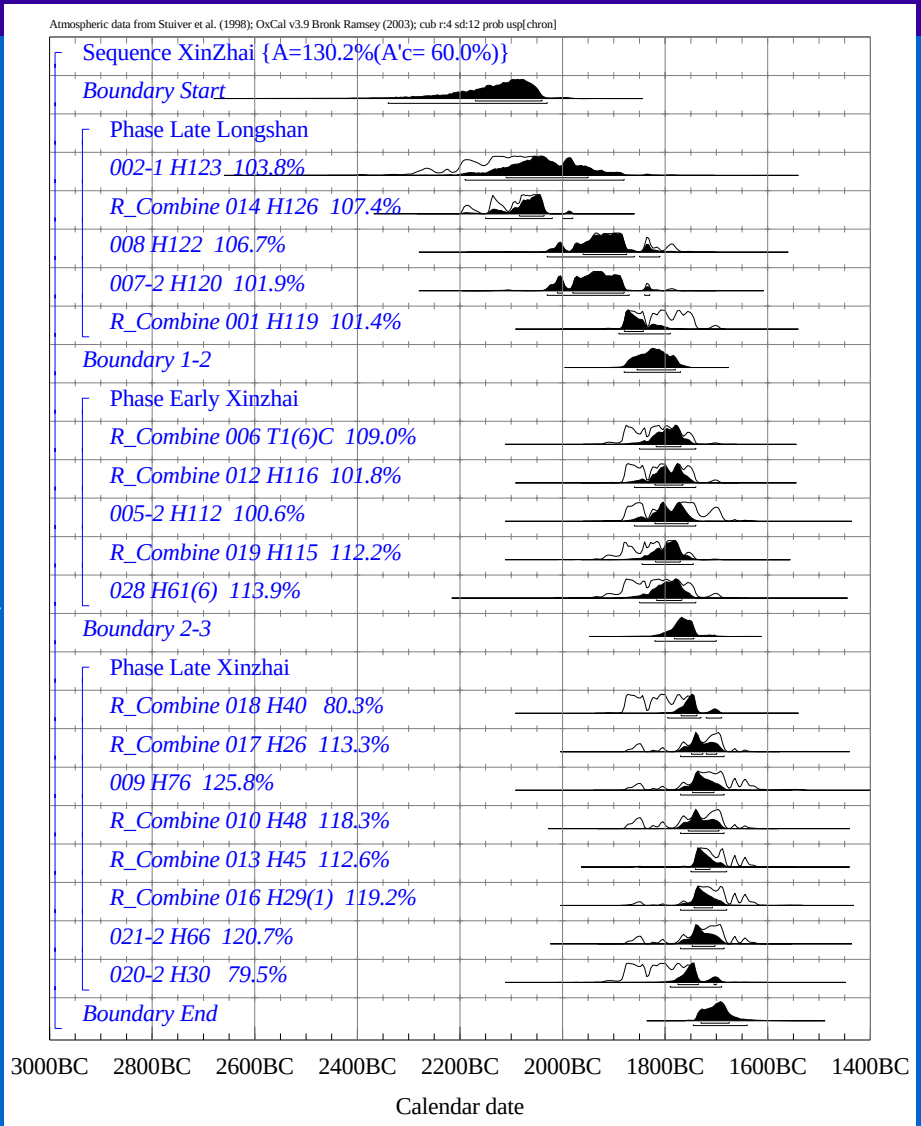
Late **Longshan** phase

Unearthed pottery from **Xinzhai** site

Xinzhai Phase

Xinzhai Phase

- It is believed Xia started from late Longshan and finished in Erlitou culture
- There was a gap between late Longshan and Erlitou culture
- Xinzhai culture filled this gap



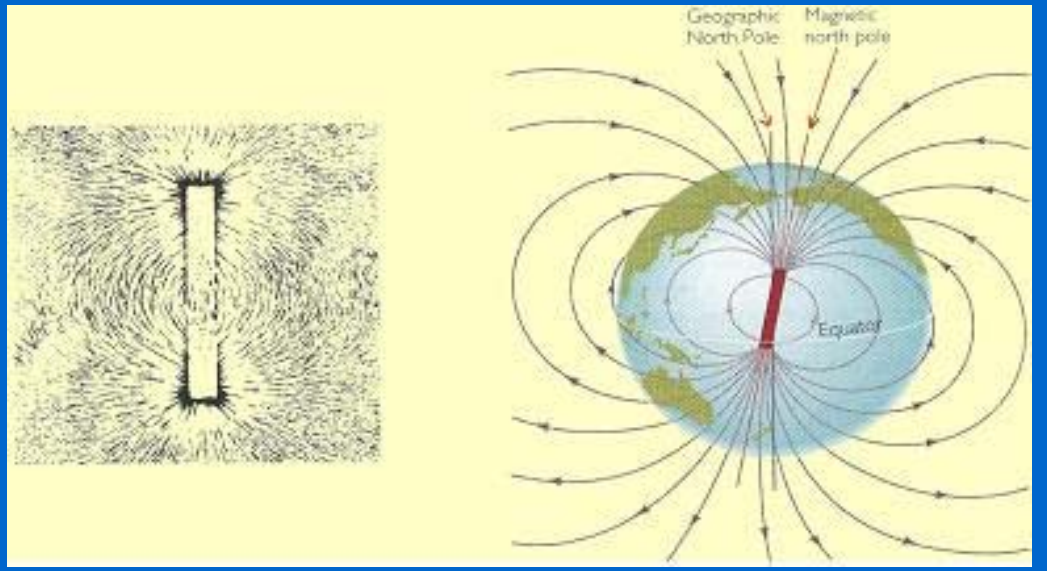
Preliminary Results of Xinzhai Site

- The transition time from **Longshan** to **Xinzhai** was about 1840BC – 1820BC
- The end age of **Xinzhai** (~ 1720BC) is about the same with the beginning of **Er-li-tou**
- It is not clear if **Longshan** culture belongs to **Xia**, but most archaeologists in China believe **Xinzhai** culture belongs to **Xia**, therefore the beginning of **Xia** dynasty was at least before 1820BC

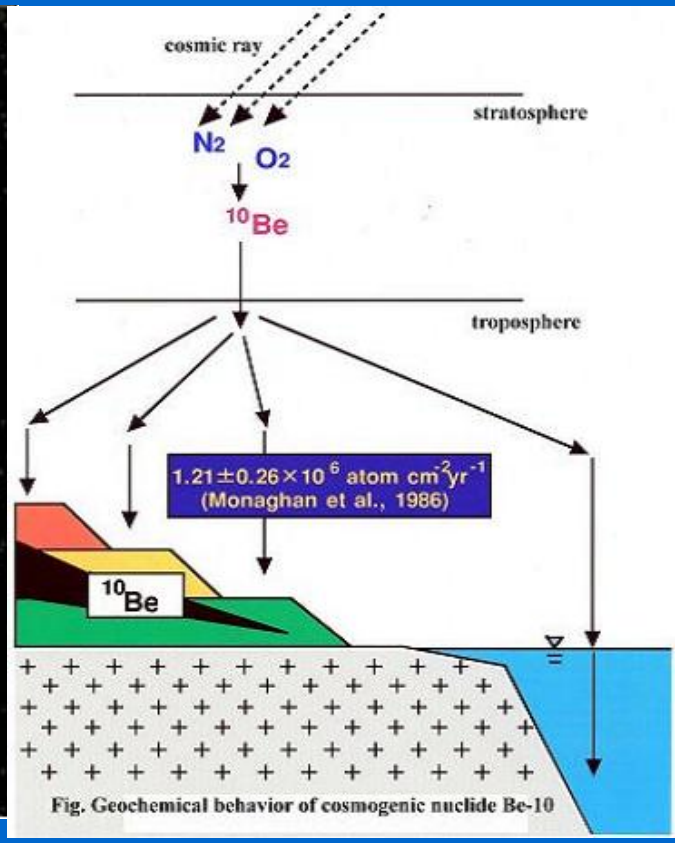
Earth Science Studies with ^{10}Be

• The Matuyama-Brunhes polarity reversal which happened 0.78 Ma ago was recorded in loess L8 in Chinese loess sequence which corresponds to a glacial period.

• The same polarity reversal boundary by the marine record was in an interglacial period



Geomagnetic field shielding of cosmic rays



^{10}Be is a useful isotopic tracer for studying the formation of Aeolian deposits and Quaternary climate evolution

Matuyama-Brunhes polarity reversal

- One explanation is that the loess record of the Matuyama-Brunhes boundary (MBB) is displaced downwards by over 100 cm
- To determine the true position of the MBB in loess, ^{10}Be concentration in loess from Louchuan, Shanxi Province is being dated, as the increase of the ^{10}Be production rate due to the reduction of geomagnetic field intensity during the polarity reversal is significant .

Matuyama-Brunhes polarity reversal

- PKUAMS was tuned to the best condition for separating ^{10}Be from ^{10}B with a gas-filled chamber. An inter-comparison with Uppsala University was in good agreement

- More than 80 loess samples have been measured and the $^{10}Be/^{9}Be$ ratios are found in the range of 10^{-11}–10^{-12}, the results will be compared & processed further.

Earth's magnetic field was reversed many times in the past. The latest reversal occurred at 780 thousand years ago, the Brunhus-Matuyama reversal. These geomagnetic polarity reversals are recorded in different types of geological sediments, e.g. deep-sea sediments and loess (the wind-blown dust widely diustributed in northern China,). However, the Brunhus-Matuyama reversal boundary (MBB) is found in different positions corresponding to glacial and interglacial times in loess and marine sediments respectively.

Someone suggested that this apparent disparity between ocean and land records is due to the delayed lock-in of reversal signals in loess. One way to test their hypothesis is to measure the Be-10 concentration in loess profiles. As the cosmogenic Be-10 production is expected to increase at the time of geomagnetic reversal due to the reduction of geomagnetic field intensity, a Be-10 peak may be detected and it should point to the true position of the reversal. This is one of the examples of our AMS application at PKU.