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Progress of an accelerator mass spectrometry system on the Tsukuba 12UD Pelletron tandem accelerator

-11th International Conference on Heavy Ion Accelerator Technology - Venezia (Italy) – 8-12, June, 2009

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Outline of presentation

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- **Introduction**
  - 12UD Pelletron tandem at the University of Tsukuba
  - AMS and facilities
- **AMS system on the 12UD Pelletron tandem**
  - Description of the Tsukuba AMS system
  - Recent progress
  - Performance of ^{26}Al, ^{36}Cl and ^{129}I AMS
- **Summary and future plans**

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- **Introduction**
  - **12UD Pelletron tandem at the University of Tsukuba**
  - **AMS and facilities**

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University of Tsukuba, Tandem Accelerator Complex

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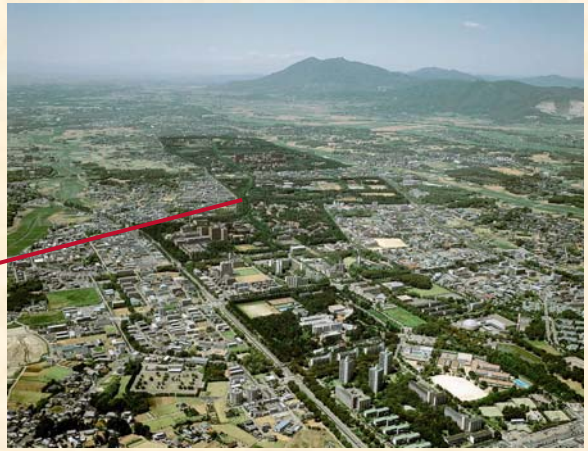


University of Tsukuba, Tsukuba science city

60 km from Tokyo in the northeast

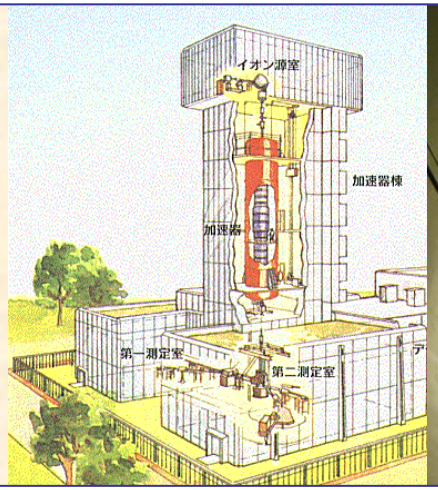
2 accelerator facilities

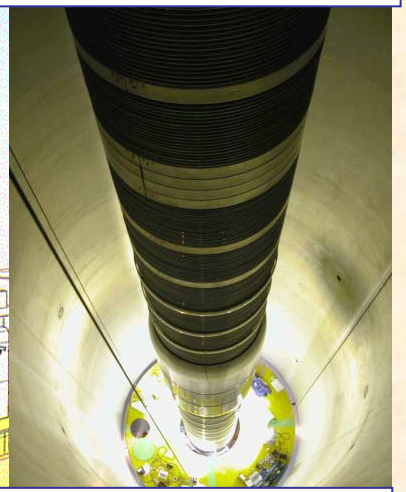
Proton Medical Research Center: PMRC

- 250 MeV Proton Synchrotron (2001)

➡ Proton Beam Radiotherapy

Tandem Accelerator Complex: UTTAC





- 12UD Pelletron Tandem Accelerator (1975)
- 1MV Tandetron Accelerator (1987)

12UD Pelletron tandem accelerator (1975)

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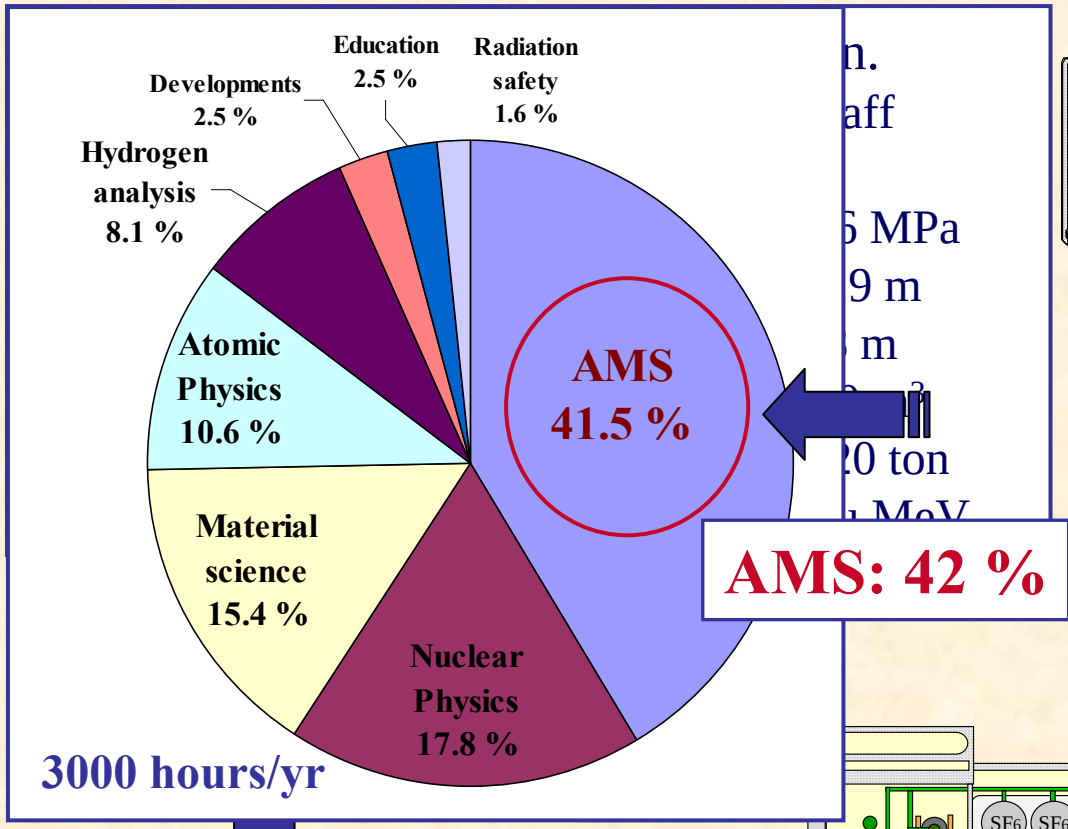

AMS: 42 %

Now

- AMS
- IBA
- Material science

Upgrade of the 12UD Pelletron tandem

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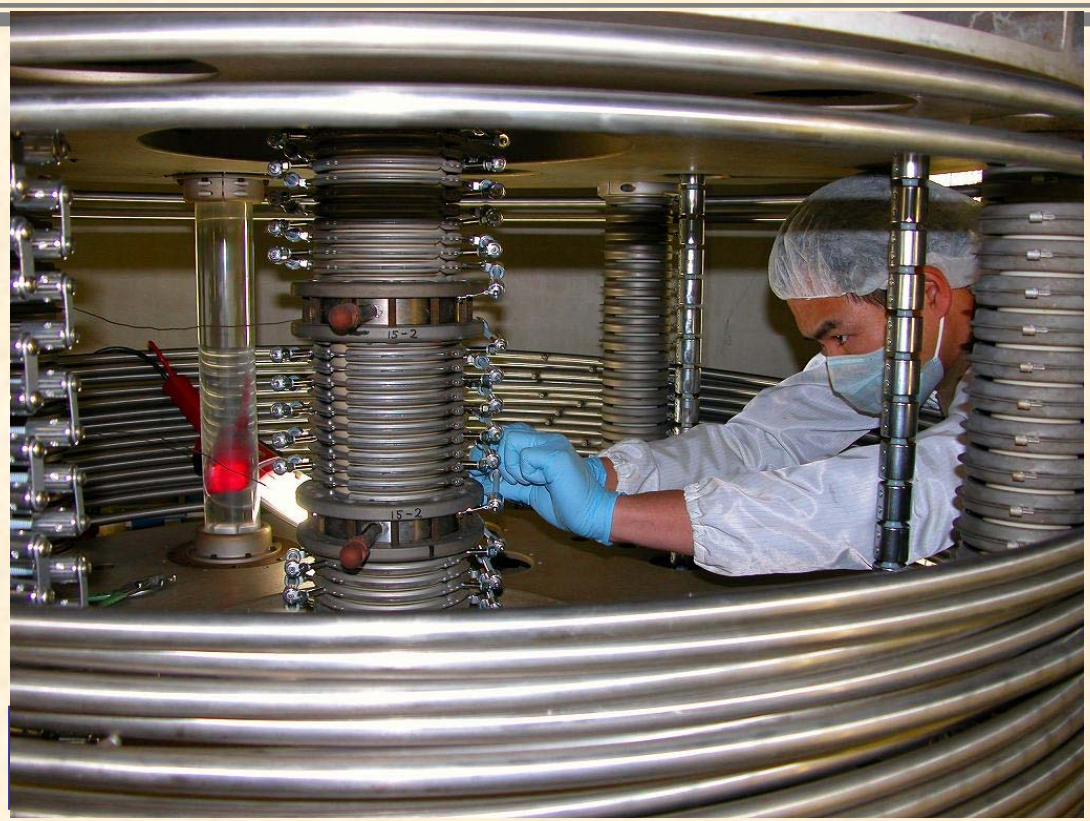
12UD at Tsukuba University, 1975



2009 Divided resistor system

We replaced the old corona needles with the divided resister system.

Variable terminal voltage (No shorting column) ⇨ $V_t = 1 \sim 12$ MV

Beam energy for the 12UD Pelletron

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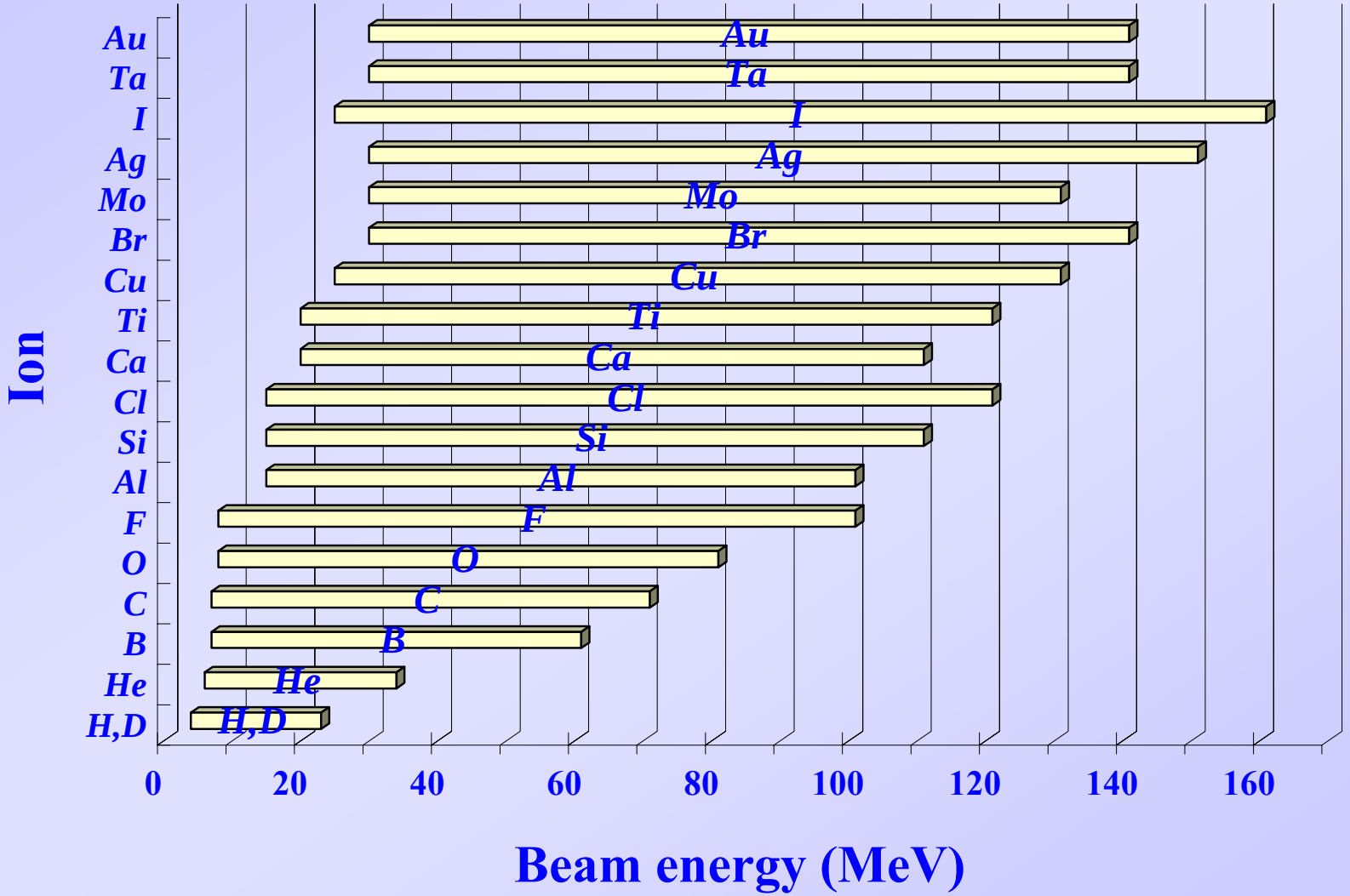
Terminal voltage: 1 - 12 MV



Accelerator Mass Spectrometry

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Targets of AMS

^{10}Be ($T_{1/2}$=1.36×10^6 yr)
^{14}C (5730 yr)
^{26}Al (7.1×10^5 yr)
^{36}Cl (3.0×10^5 yr)
^{129}I (1.57×10^7 yr)
…

Isobar, Isobaric Molecular suppression

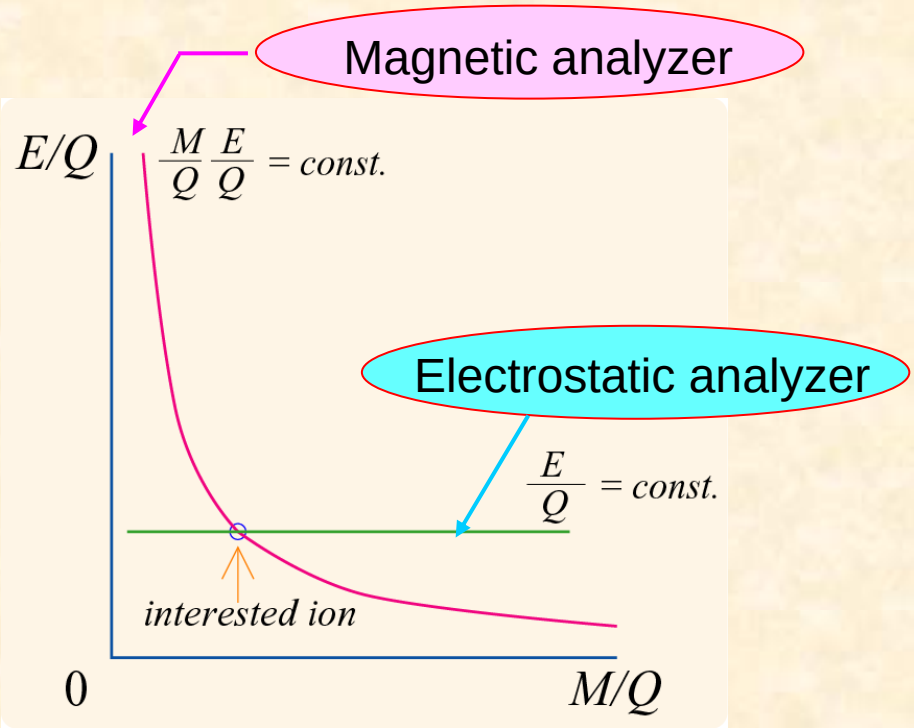
Accelerator

High energy part

Mass analysis
- Momentum analysis
- energy analysis

Detectors

~1 MeV/amu



AMS facilities

^{14}C-AMS

LLNL, KIGAM…

3MV → 1MV → 500 kV

Oxford, Groningen, Kiel, Arizona, NOSAMS, Nagoya, SNU, …

ETH, Georgia, UC-Irvine, Posnan, Peking, Paleo-labo, …

Multi Nuclides AMS

^{10}Be, ^{14}C, ^{26}Al, ^{36}Cl, ^{129}I, …

5MV and higher (← originally for nuclear physics)

LLNL(10MV), PRIME-Lab(8MV), ANSTO(9MV), ANU(14MV), ETH(6MV), Tokyo(5MV), Tsukuba(12MV), SWERC(5MV)

3MV VERA, LUND, JAEA-Mutsu, …

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- **AMS on the 12UD Pelletron tandem**
  - **Description of the Tsukuba AMS system**
  - **Recent progress**
  - **Performance of ^{26}Al, ^{36}Cl and ^{129}I AMS**

Tsukuba AMS system

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Progress of the Tsukuba AMS system

1993-1996	Trial AMS measurement for ^{14}C.
1996-1998	Development of AMS system
	^{14}C-AMS
	AMS ion source (original)
	Mass separator beam line
1999-	Development of ^{26}Al, ^{36}Cl-AMS
	Pilot beam methods (Instead of GVM control)
2002-	Development of ^{129}I-AMS
2007-	^{36}Cl AMS 9 MV→10 MV (Improved beam line)
	Background: $^{36}Cl/Cl < 1 \times 10^{-15}$
	Repetition accuracy: ± 3 %
2009-	Upgrade of the 12UD Pelletron (Resister system)
	⇨ GVM terminal control system

Tsukuba AMS system

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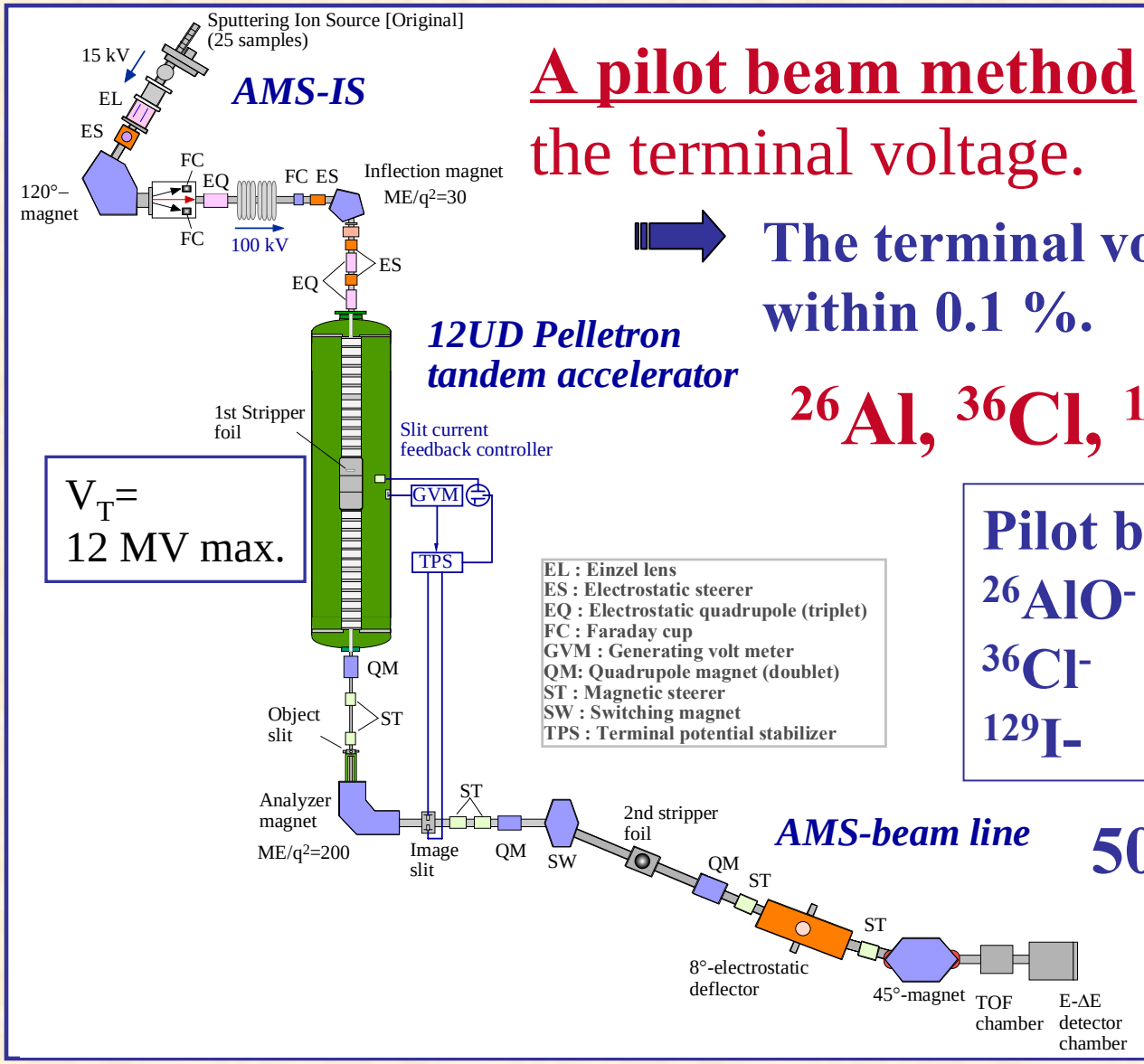

V_T=
12 MV max.

EL : Einzel lens
ES : Electrostatic steerer
EQ : Electrostatic quadrupole (triplet)
FC : Faraday cup
GVM : Generating volt meter
QM: Quadrupole magnet (doublet)
ST : Magnetic steerer
SW : Switching magnet
TPS : Terminal potential stabilizer

A pilot beam method is used to stabilize the terminal voltage.

➡ **The terminal voltage is kept stable within 0.1 %.**

^{26}Al, ^{36}Cl, ^{129}I - AMS

Pilot beams (isobar)

$^{26}AlO^- \rightarrow {}^{26}MgO^-$

$^{36}Cl^- \rightarrow {}^{12}C_3^-$

$^{129}I^- \rightarrow {}^{97}MoO_2^-$

500 samples/year.

^{36}Cl-AMS by the Tsukuba AMS system

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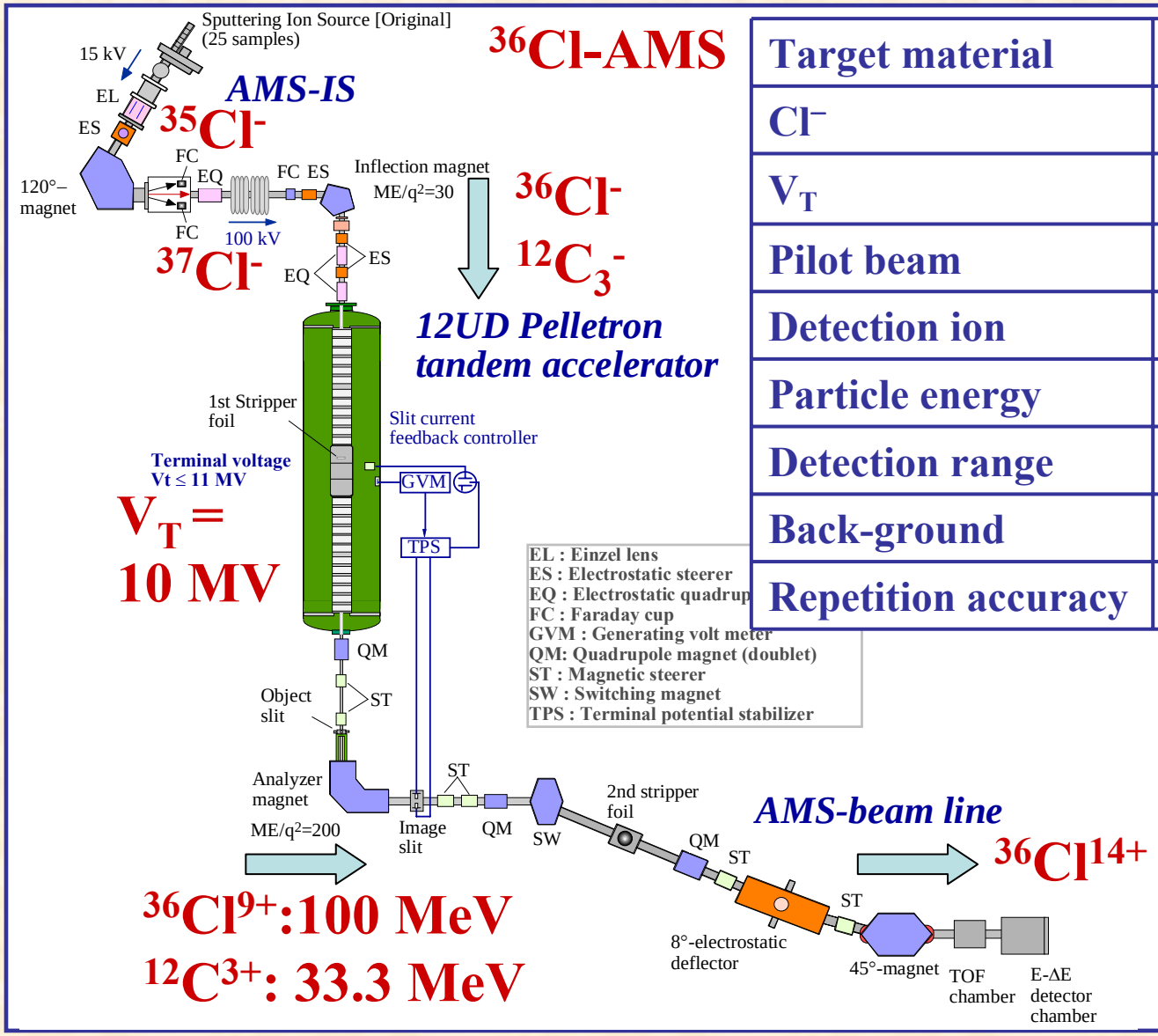

Target material	AgCl + C_{60}
Cl^-	~ 20 μA
V_T	10 MV
Pilot beam	$^{12}C_3^-$
Detection ion	$^{36}Cl^{14+}$
Particle energy	100 MeV
Detection range	$^{36}Cl/Cl = 10^{-10} \sim 10^{-14}$
Back-ground	$^{36}Cl/Cl < 10^{-15}$
Repetition accuracy	± 3 % ($^{36}Cl/Cl \sim 10^{-12}$)

AMS Cs sputtering ion source

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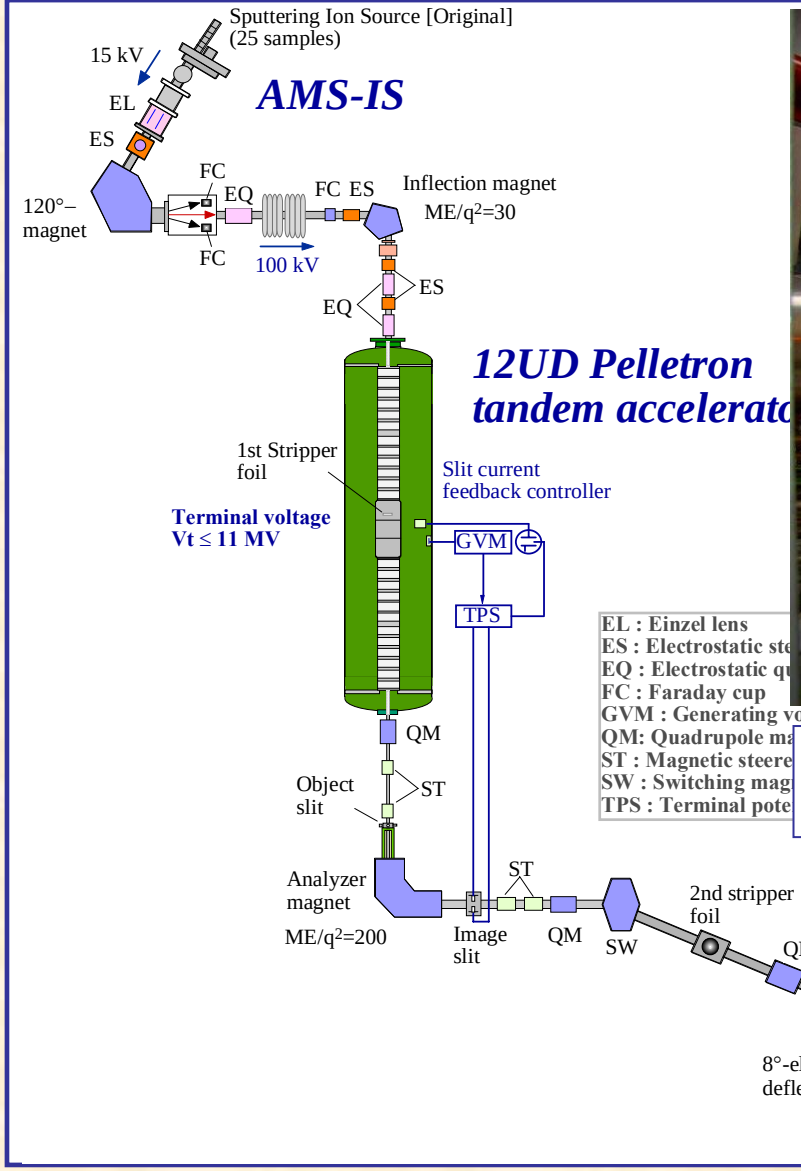

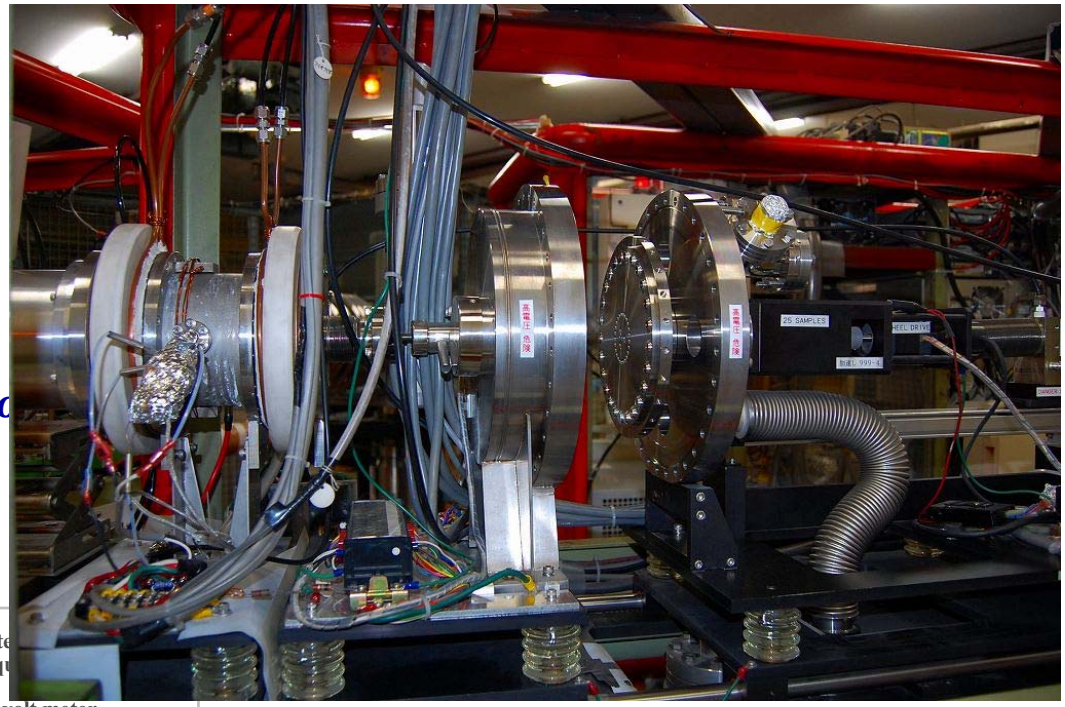

Original 25-sample changer

AMS Cs sputtering ion source

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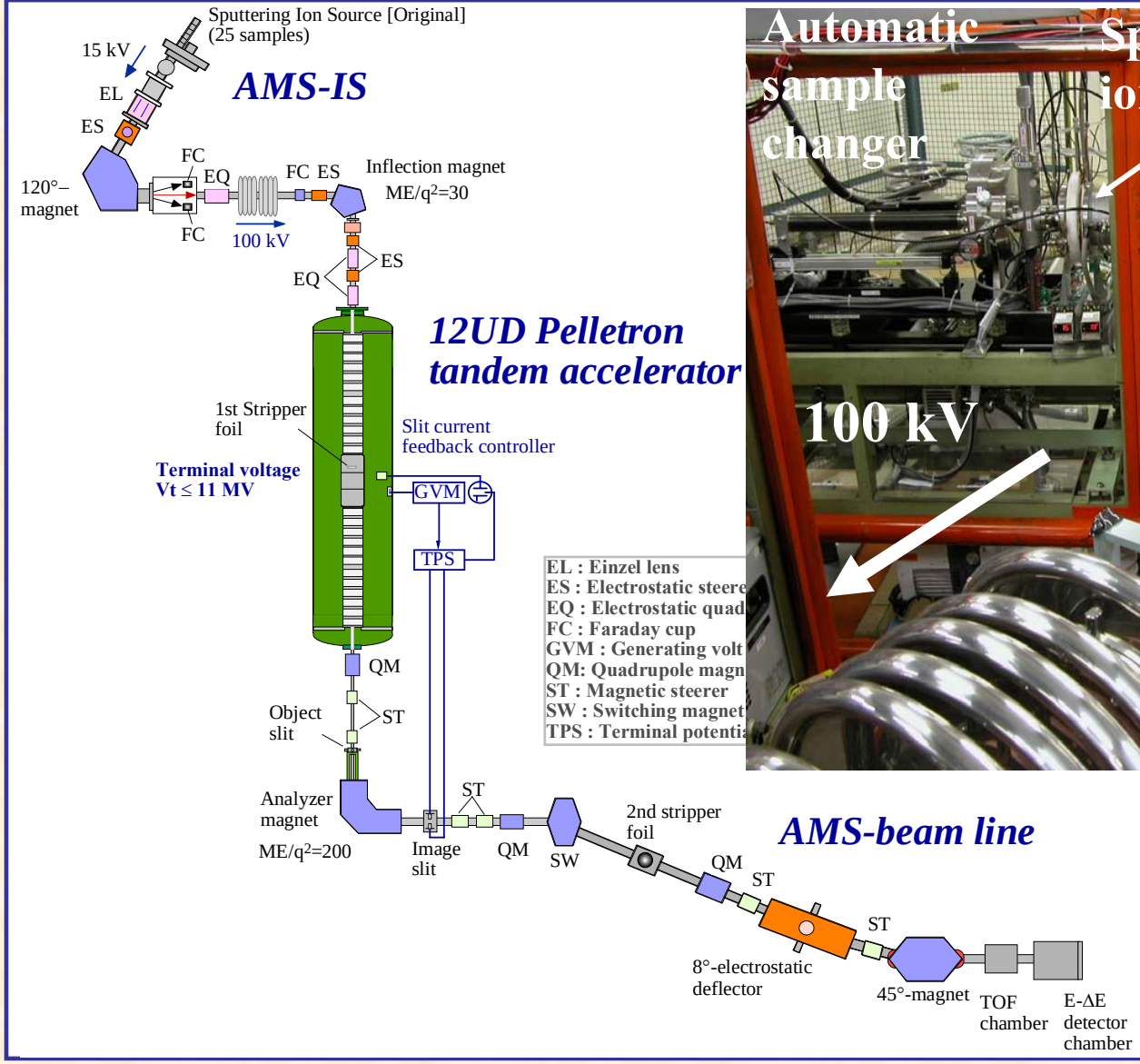

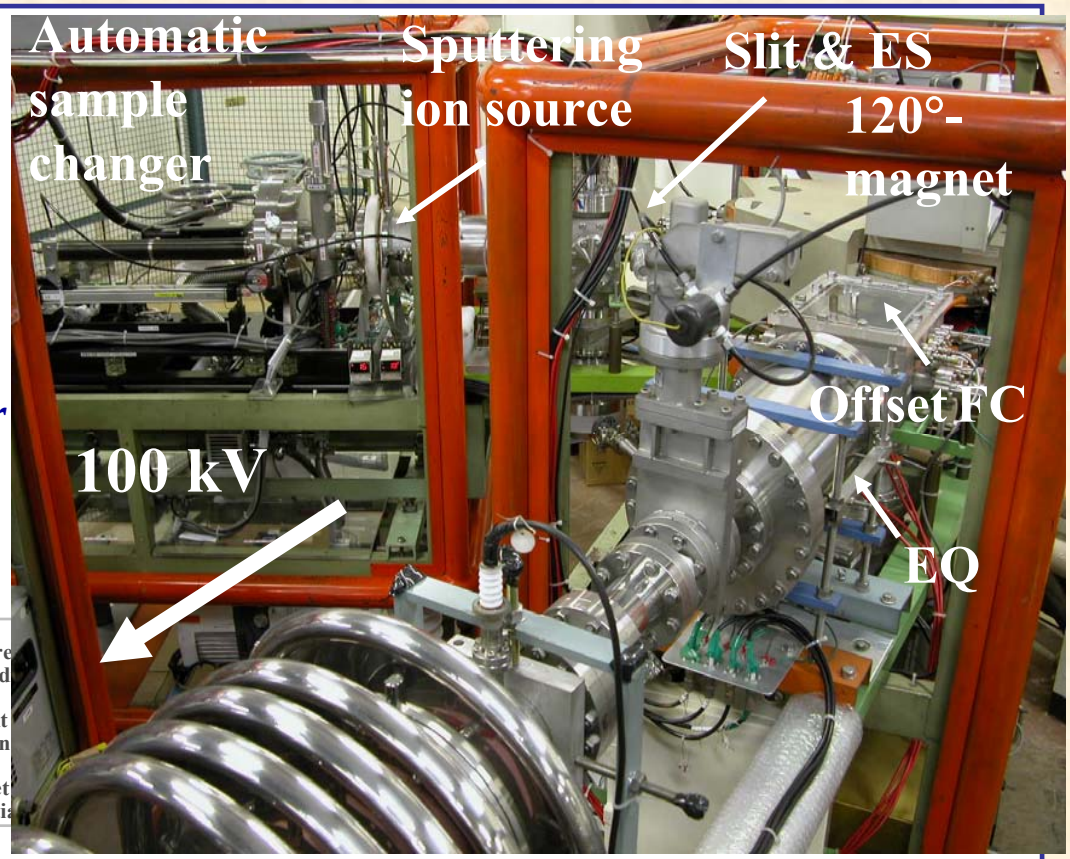

AMS Cs sputtering ion source

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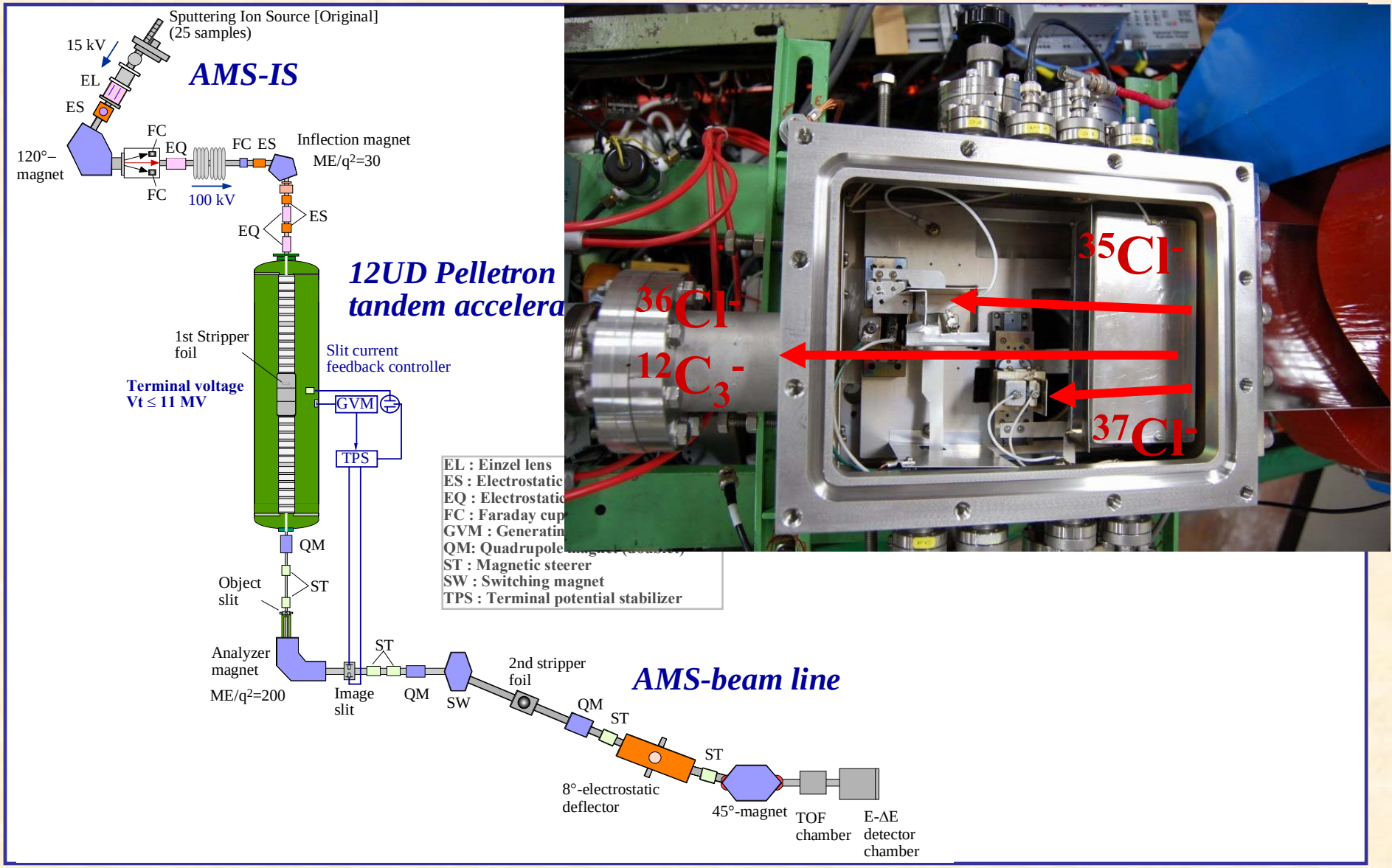

AMS Cs sputtering ion source

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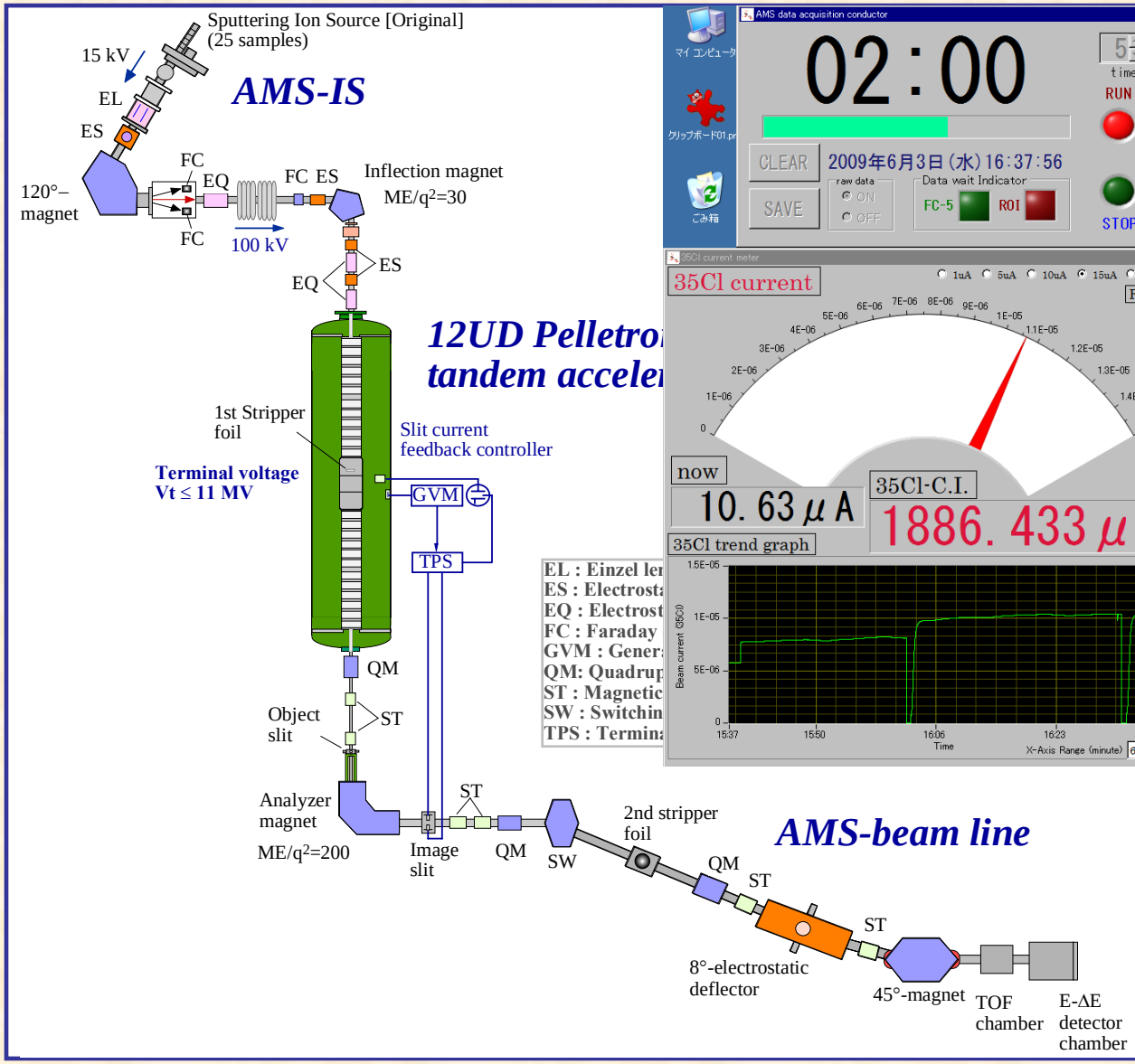
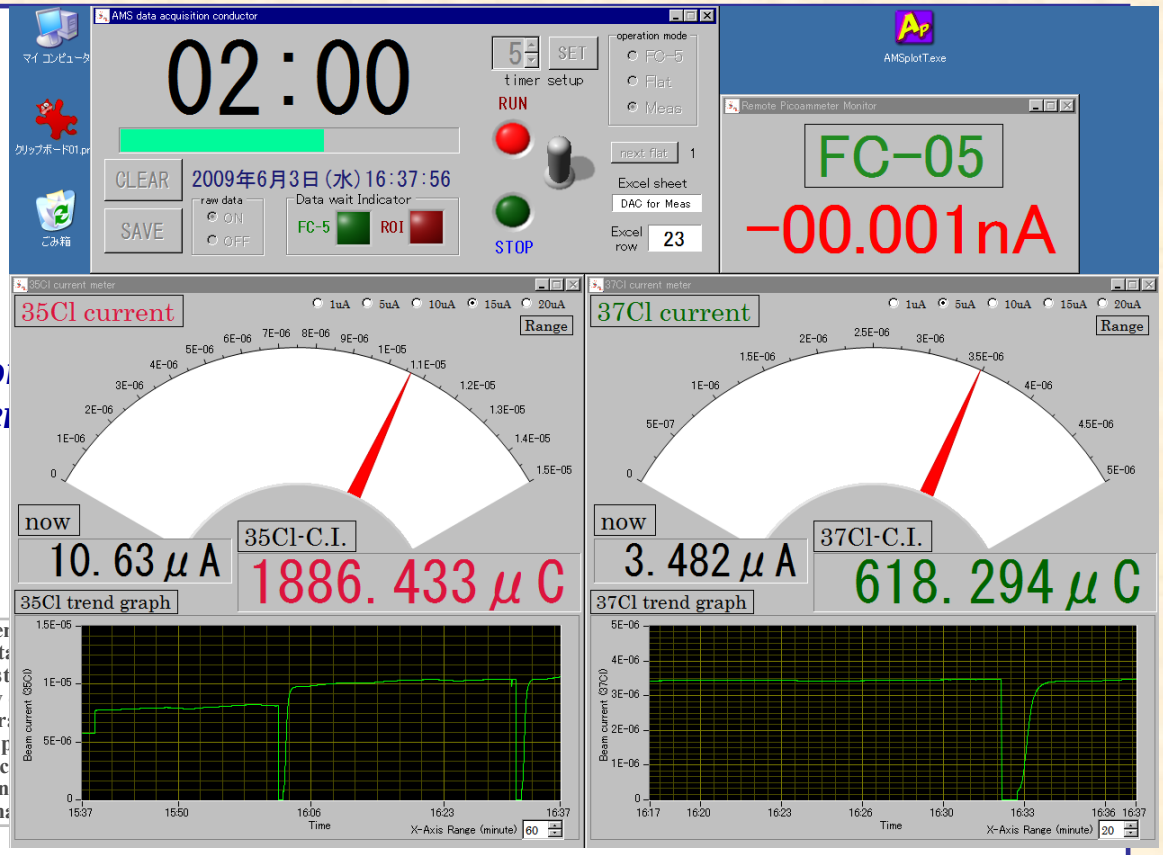
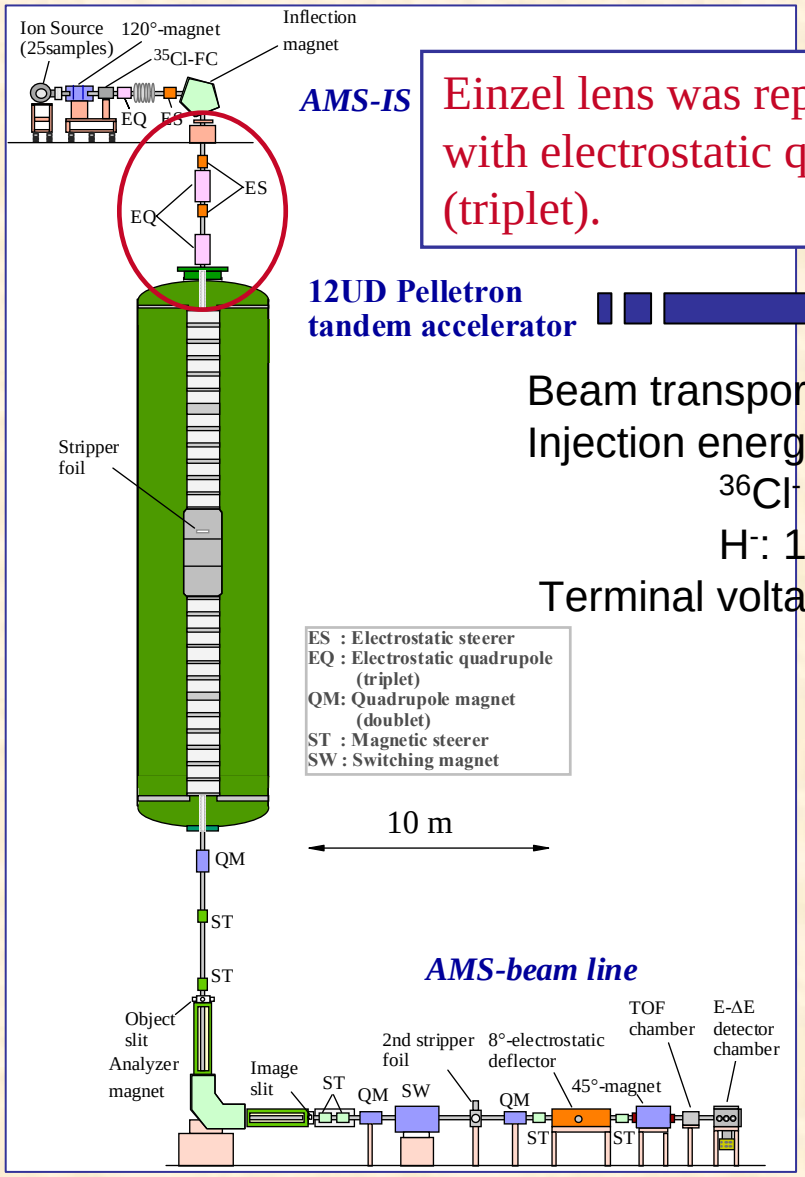


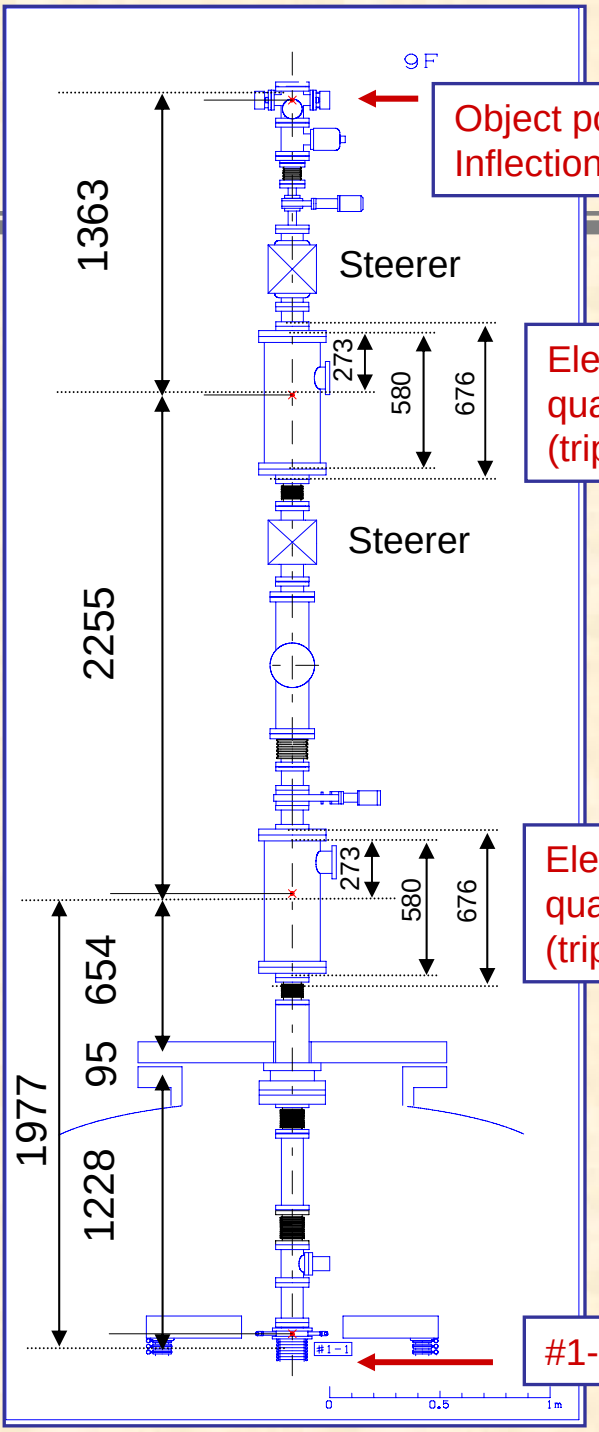


Upgrade of LEBT
for 12UD Pelletron tandem accelerator



Einzel lens was replaced with electrostatic quadrupole (triplet).

Beam transport
Injection energy
$^{36}Cl^{+}$: 103 kV
H^{-}: 120 kV
Terminal voltage: 10 MV



Tsukuba 12UD first unit (2009)

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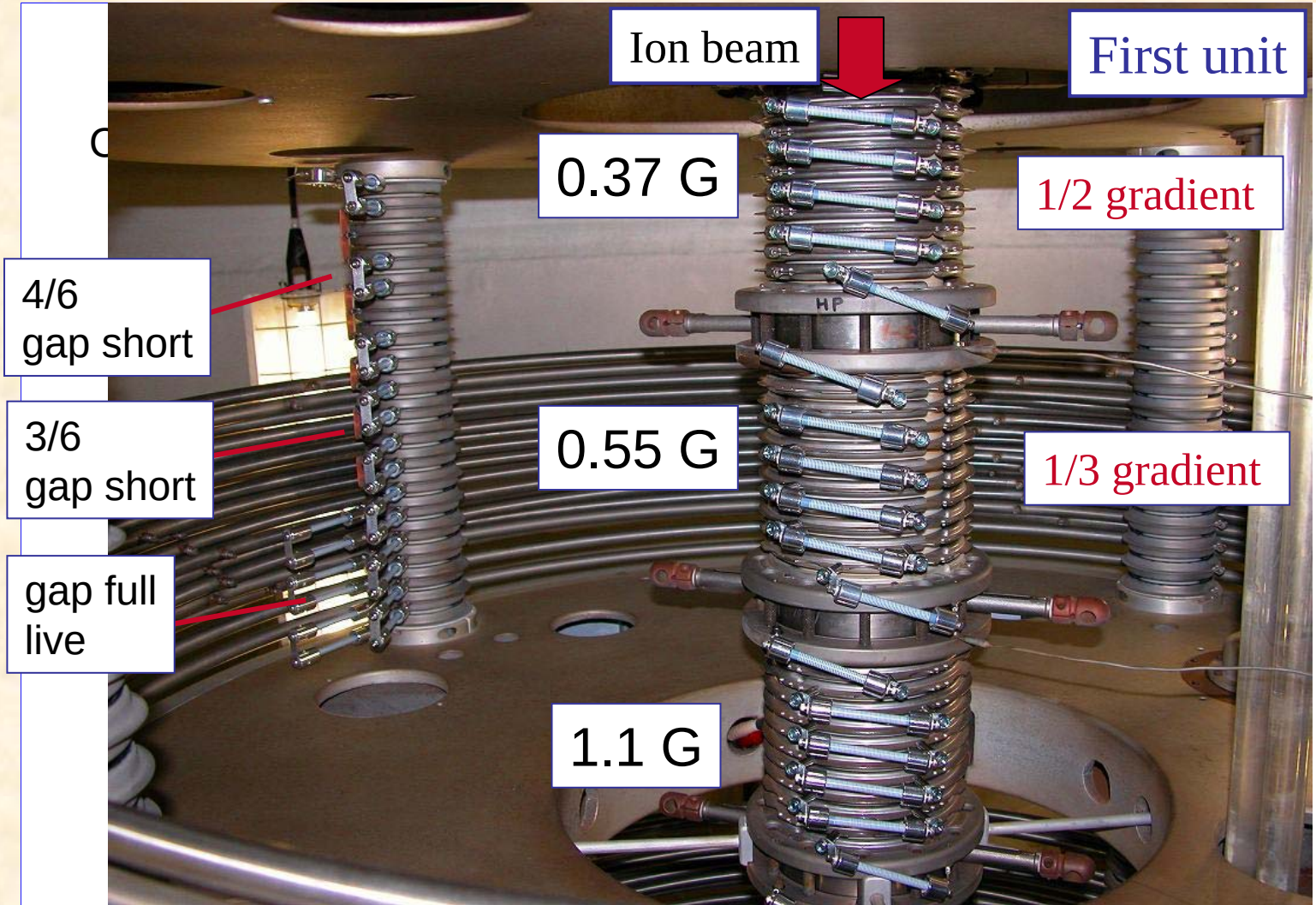
Lower resistance at the entrance.

⇨ Adjustment for the focusing effect



Terminal section (Charge exchange)

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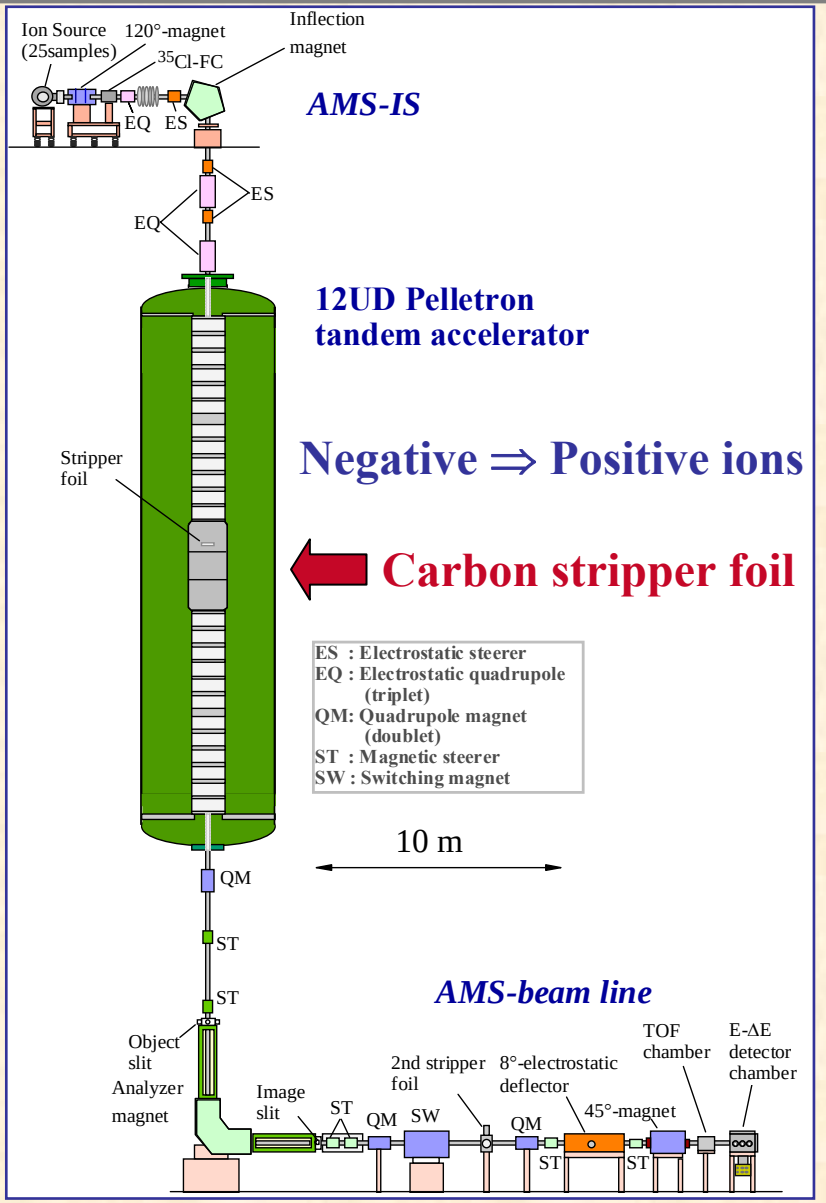
Terminal section was modified to the large aperture canal (ϕ20) in 2004.

2 foil units



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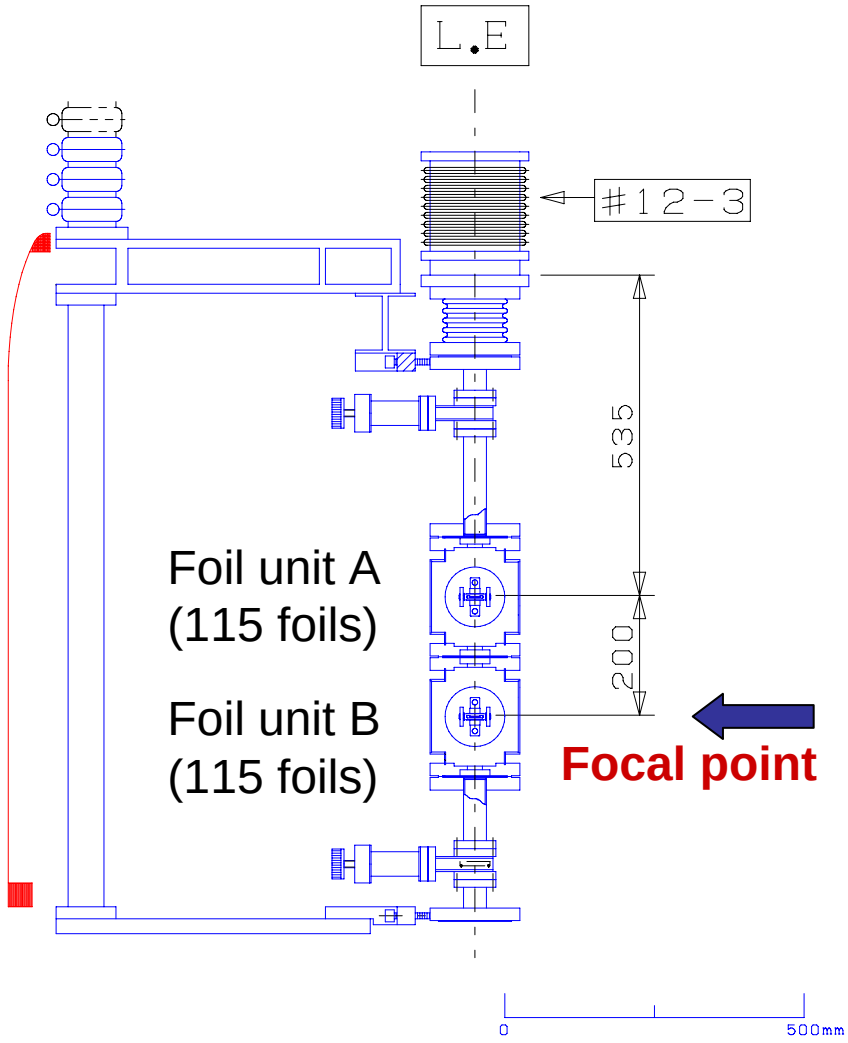

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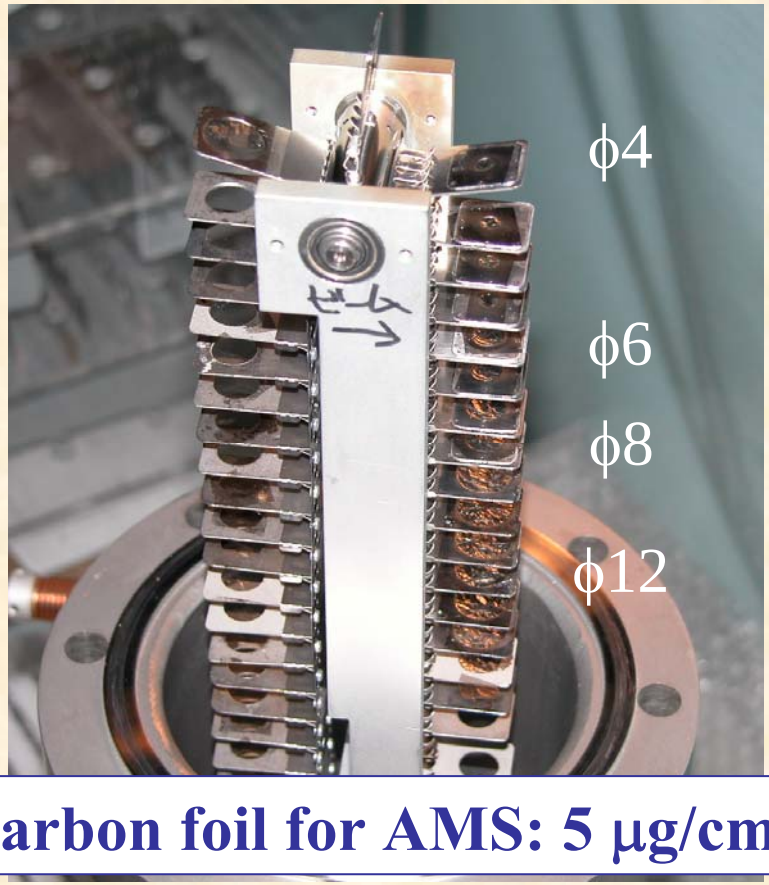
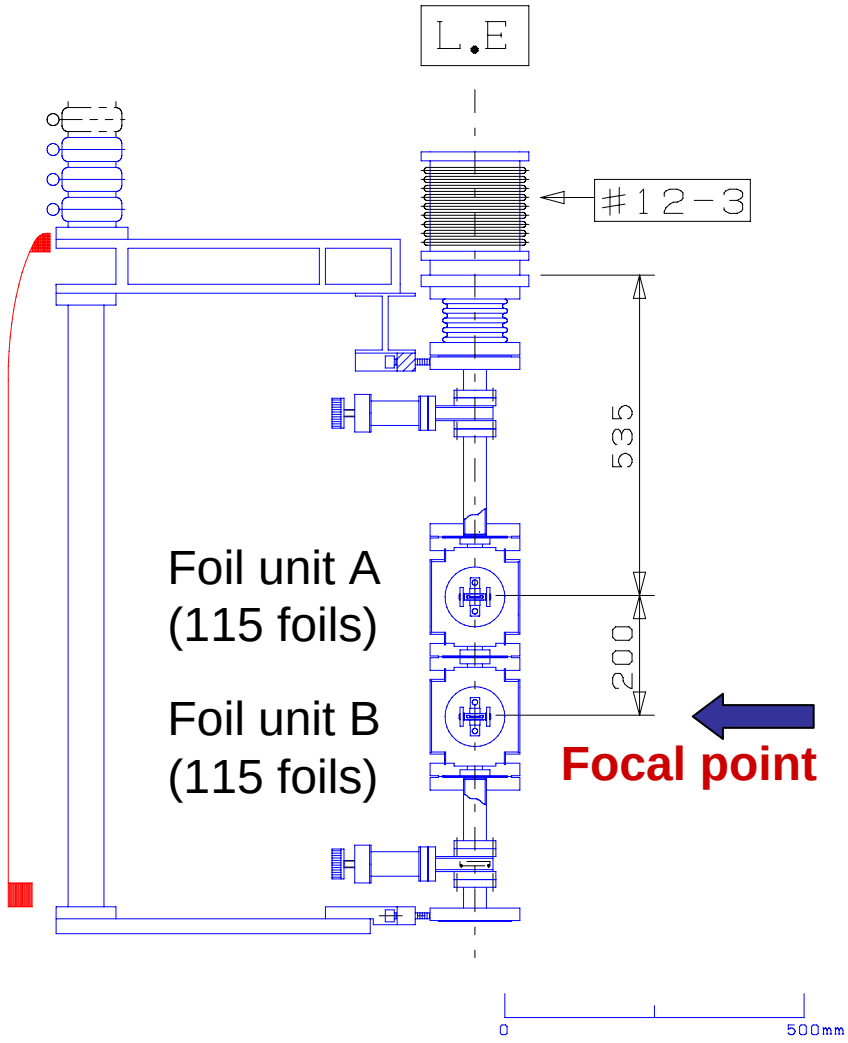


Carbon foil for AMS: 5 μg/cm²



Terminal section (Charge exchange)

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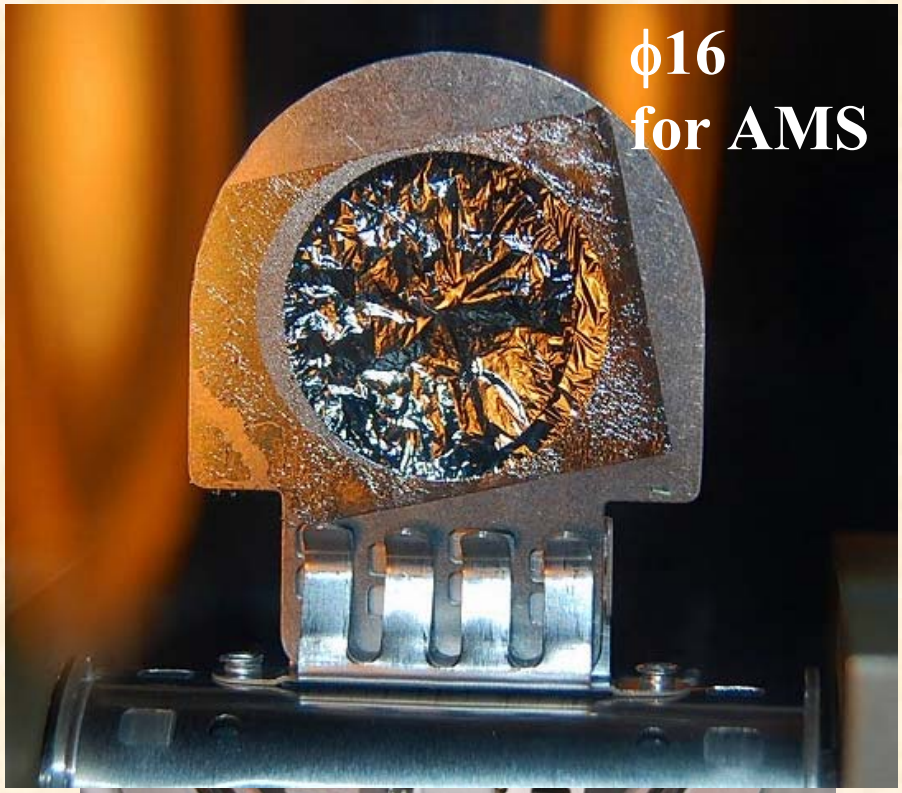

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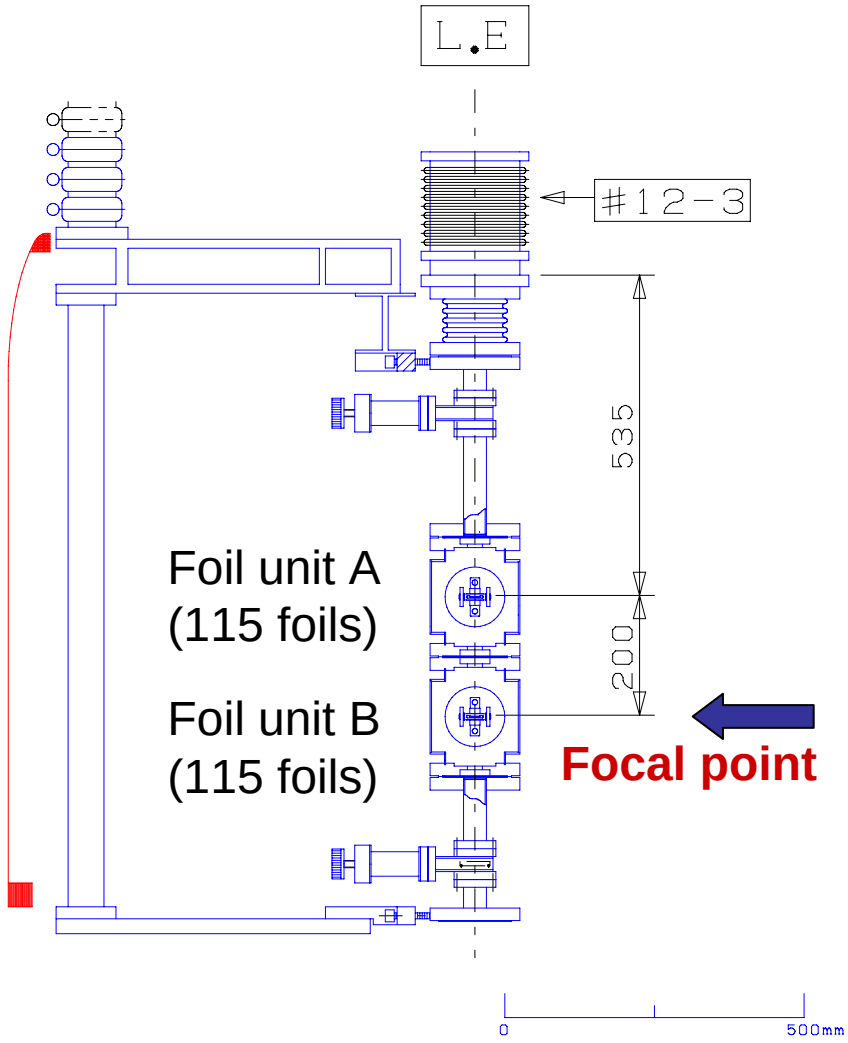

Beam transport of the 12UD Pelletron

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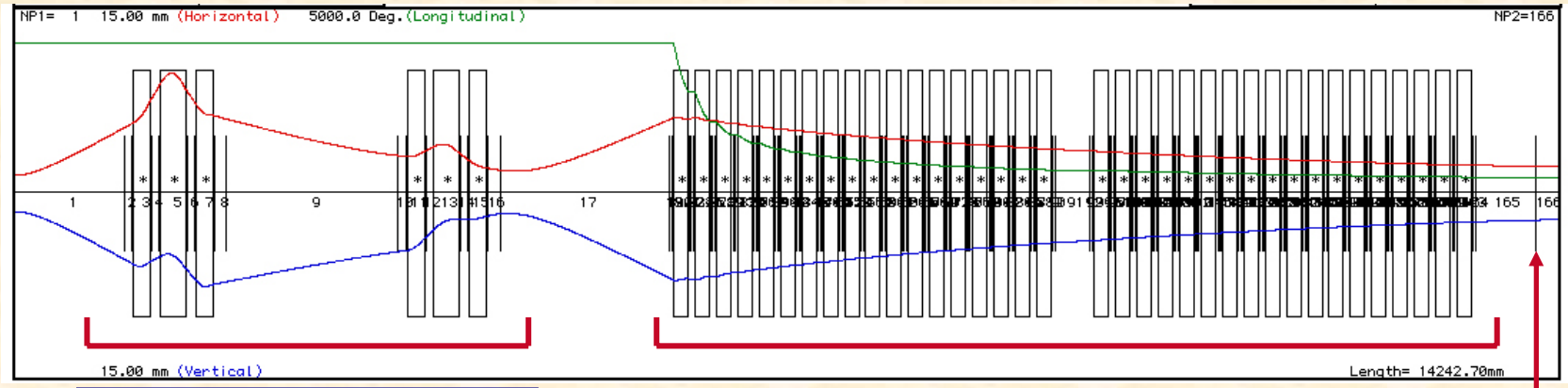
2009



15 mm

Electrostatic Q-triplet

12UD accelerator tubes

Object point

Acceptrance
~ 5 mm mrad

LEBT

$^{36}Cl^-$
Injection energy: 103 kV
V_T:10 MV

Terminal
Carbon stripper foil

Magnification: 1.5 times
on the Terminal stripper.

Beam spot on the stripper foil: ϕ 6 mm

Mass separator beam line

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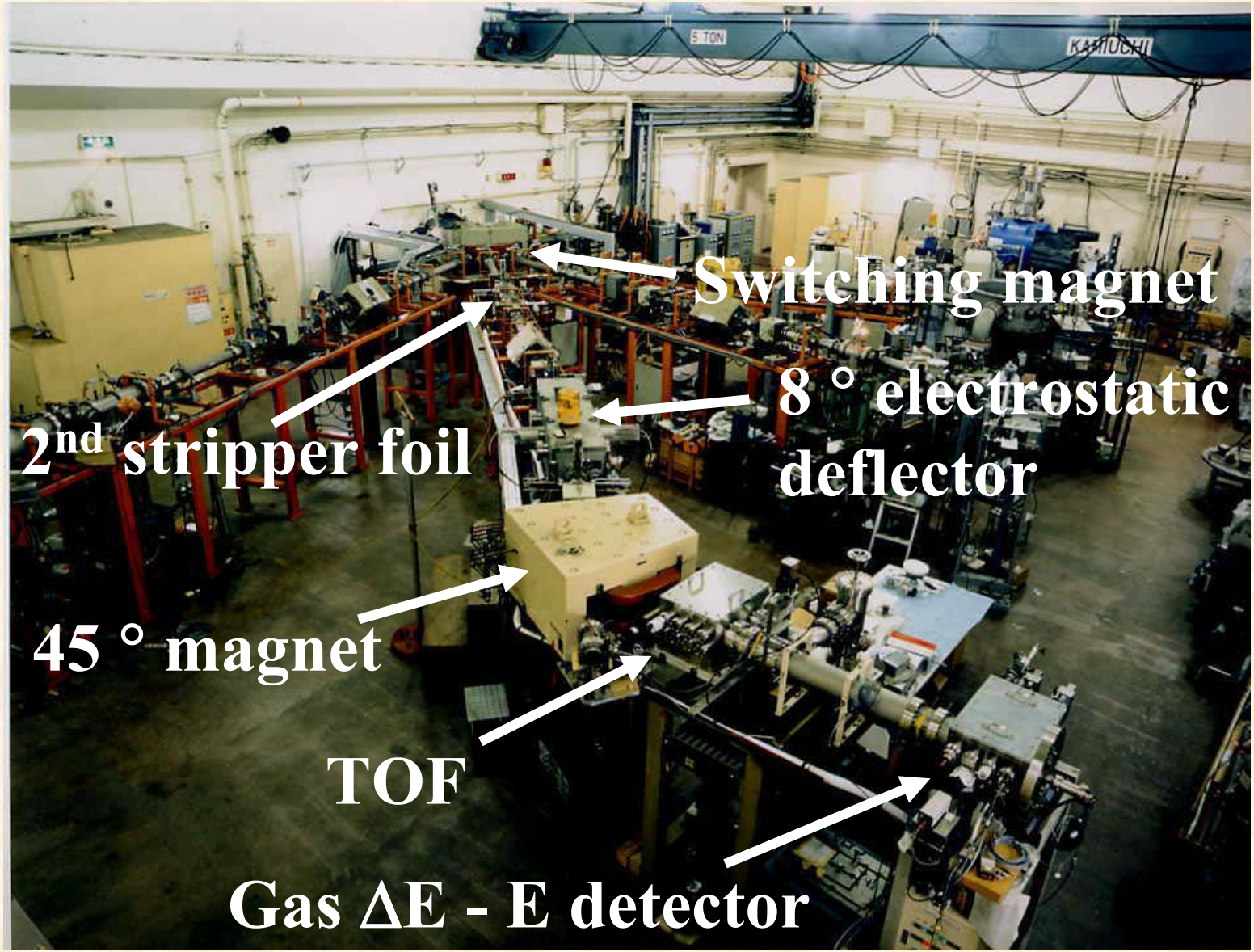

Gas E-ΔE detector

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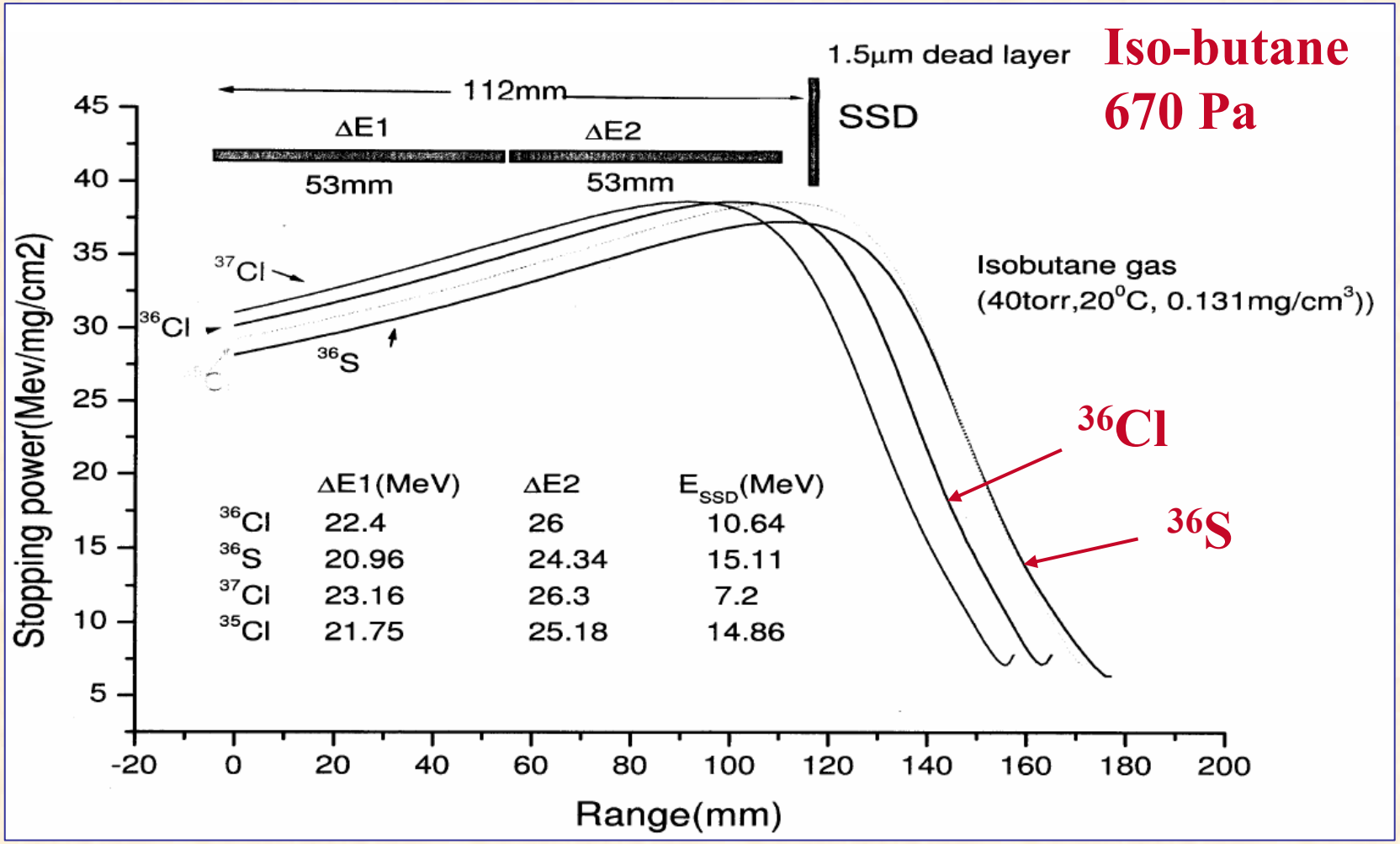

100 MeV ^{36}Cl in the gas detector.

^{36}Cl-AMS (2-dimensional spectrum)

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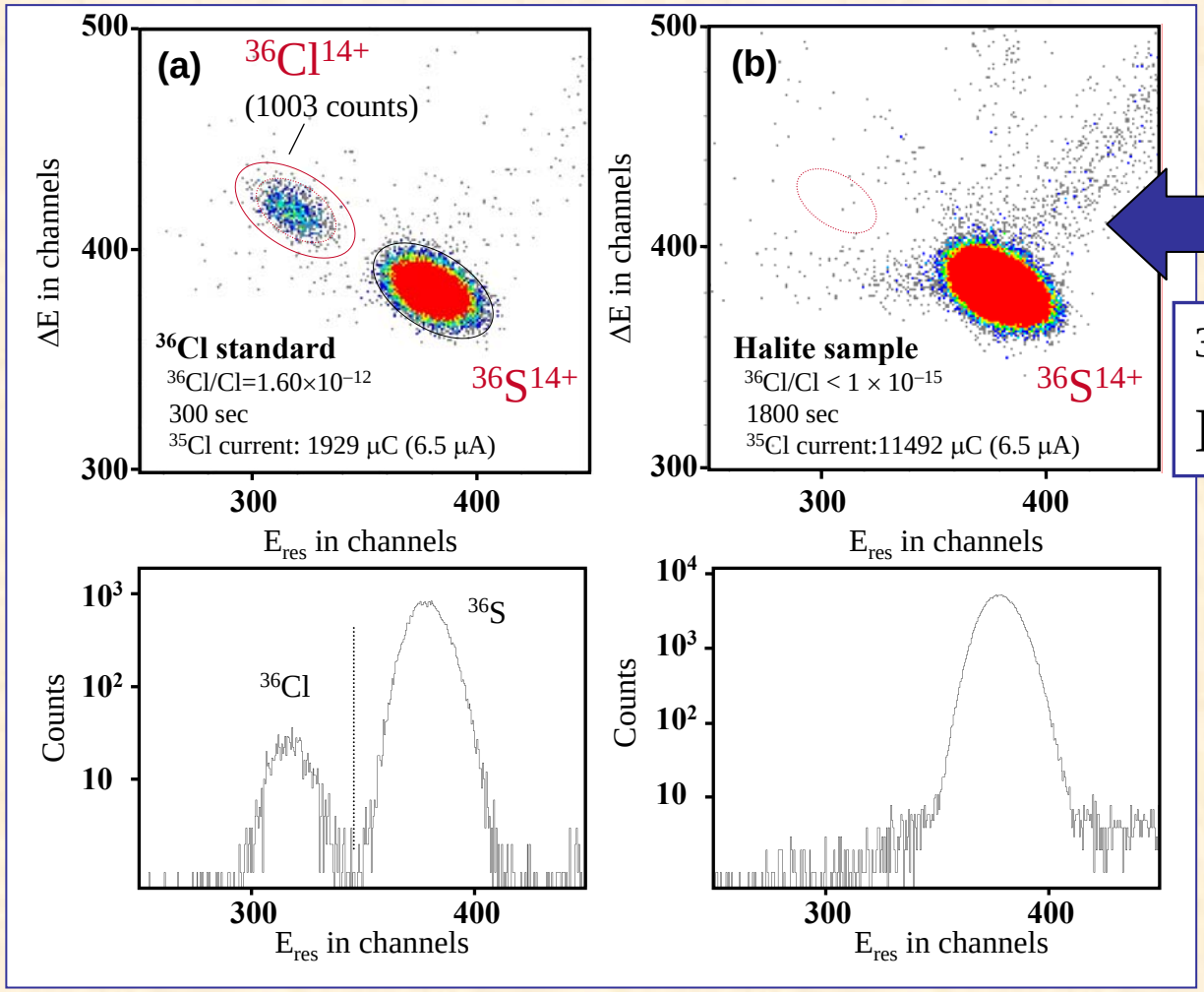

^{36}Cl/Cl
Background: ~ 1 × 10^{-15}

Standard sample
^{36}Cl/Cl=1.60 × 10^{-12}

Blank sample

^{26}Al-AMS (2-dimensional spectrum)

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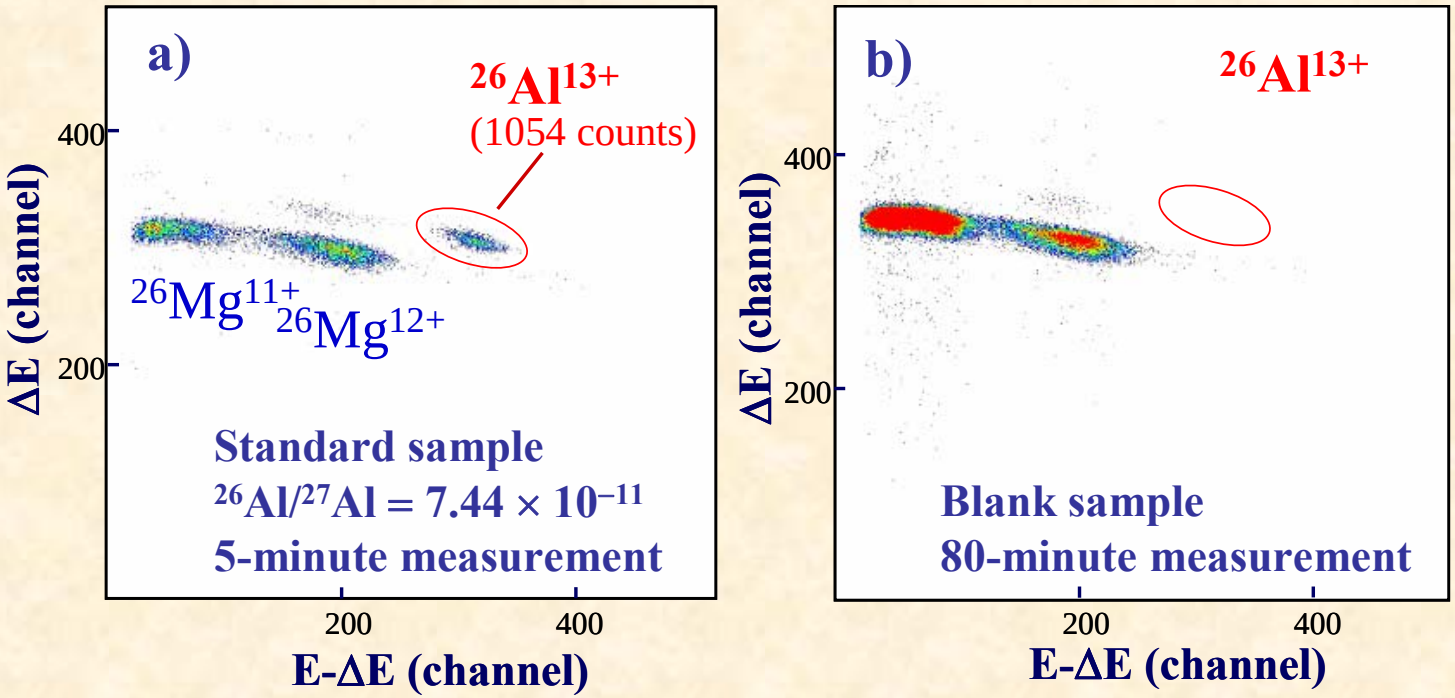

-Full stripping technique
- Pilot beam: $^{26}MgO^-$
- Beam current of AlO^- from Al_2O_3 sample : ~1.5 μA

- ^{26}Al is very clearly separated from ^{26}Mg.
- Background of the ^{26}Al-AMS: $< 1 \times 10^{-15}$.

Performance of the Tsukuba AMS system

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A pilot beam method is used to stabilize the terminal voltage.

^{26}Al-AMS

Target material	V_T	Injection ion	Pilot beam	Detection ion	Particle energy	Back-ground
Al_2O_3+$^{26}MgO_2$+Ag	10.2 MV	$^{26}AlO^-$	$^{26}MgO^-$	$^{26}Al^{13+}$	78 MeV	$< 1 \times 10^{-15}$

^{36}Cl-AMS

Target material	V_T	Injection ion	Pilot beam	Detection ion	Particle energy	Back-ground
AgCl+C_{60}	10 MV	$^{36}Cl^-$	$^{12}C_3^-$	$^{36}Cl^{14+}$	100 MeV	$<1 \times 10^{-15}$

^{129}I-AMS

Target material	V_T	Injection ion	Pilot beam	Detection ion	Particle energy	Back-ground
AgI+MoO_2+Nb	9.7 MV	$^{129}I^-$	$^{97}MoO_2^-$	$^{129}I^{26+}$	126 MeV	$< 1 \times 10^{-13}$

Applications by the Tsukuba AMS system

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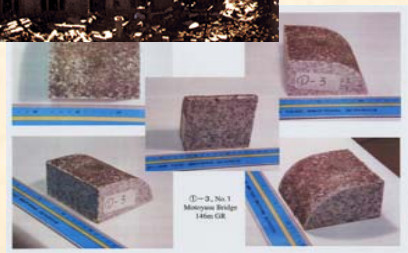
Mainly for earth and environmental sciences.

Nuclear safety research
Atomic bomb, neutron fluence



Hiroshima A-bomb sample

Soil
sediment

Soil

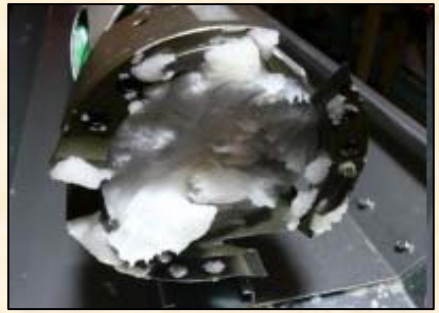
Rock
meteorite

Limestone

Meteorite

Groundwater, rain, ice

Rain water



Ice core

Biological sample

Human hair

Summary and future plans

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- **12UD Pelletron tandem at the University of Tsukuba**

  We have upgraded the 12UD Pelletron tandem.

  ⇨ LEBT, divided resister system, terminal stripper.

  The beam time for AMS research has increased to about 42% of the total operation time.

- **Tsukuba AMS system**

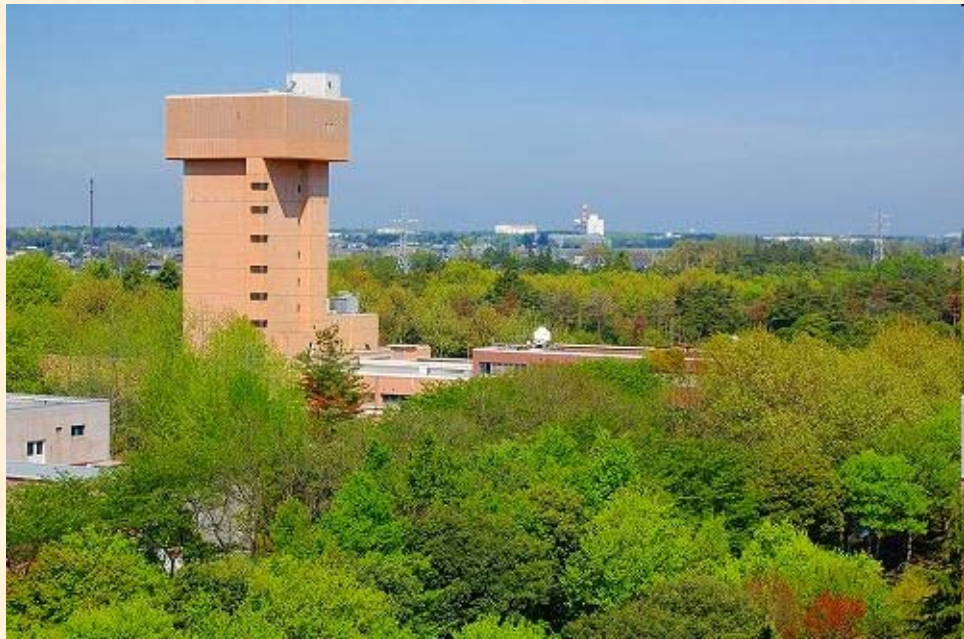
  We are able to measure long-lived radioisotopes of ^{26}Al, ^{36}Cl and ^{129}I by employing a molecular pilot beam method that stabilize the terminal voltage with 0.1% accuracy.

  ⇨ Main research fields are earth and environmental sciences.

Future plans

- GVM control system
- New injection beam line (MC-SNICS)

Thank you for your kind attention.



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Appendix

^{26}Al-AMS

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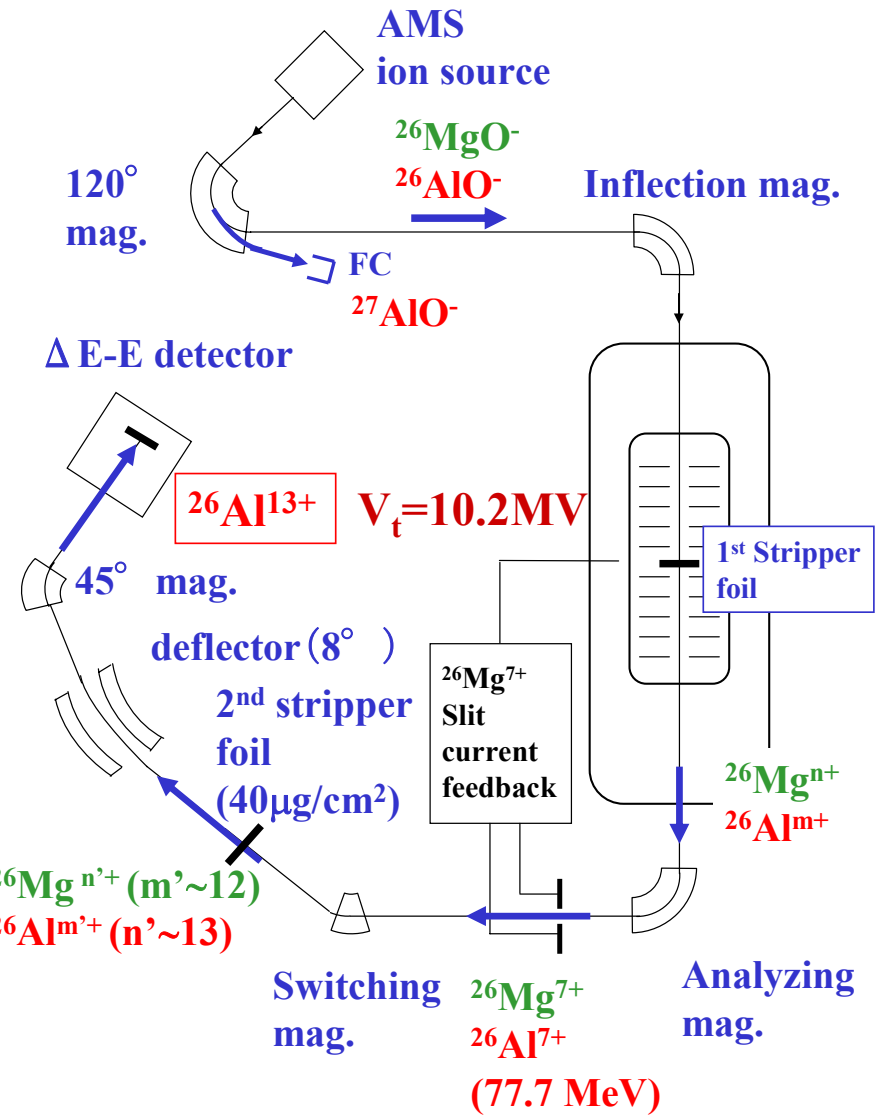

- **Full stripping technique:**
  ^{26}Al^{13+}/^{27}AlO$^-$ [counts/μC]
- **Pilot beam: ^{26}MgO$^-$**
- **Beam current of AlO$^-$ from Al_2O_3 sample : ~1.5μA**

The beam transmission of full stripped Al^{13+} : 10%.

AMS facilities in JAPAN

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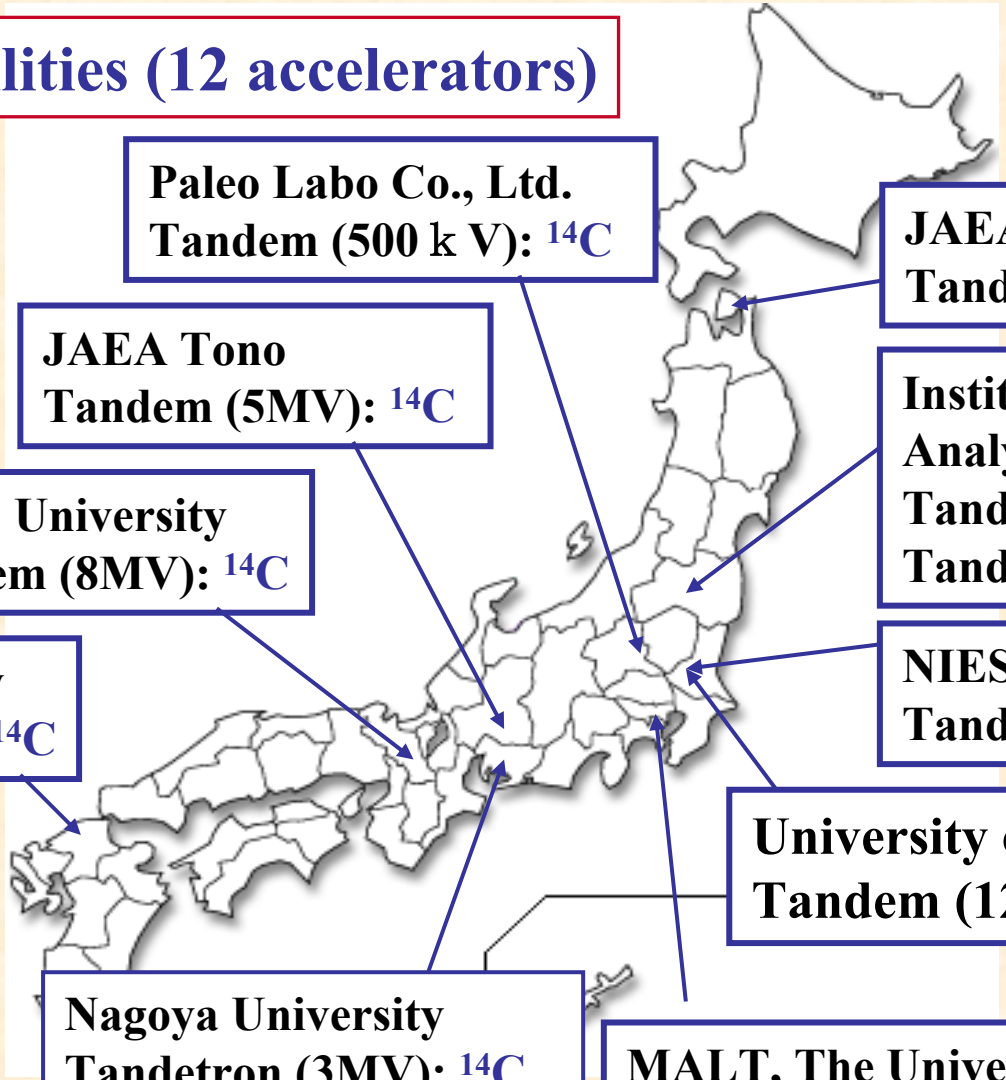
10 AMS facilities (12 accelerators)



Paleo Labo Co., Ltd.
Tandem (500 k V): ^{14}C

JAEA Mutsu
Tandetron (3MV): ^{14}C, ^{129}I

JAEA Tono
Tandem (5MV): ^{14}C

Institute of Acceleratory Analysis Ltd.
Tandem (3MV): ^{14}C
Tandem (500kV): ^{14}C

Kyoto University
Tandem (8MV): ^{14}C

Kyushu University
Tandem (10MV): ^{14}C

NIES-TERRA
Tandem (5MV): ^{14}C

University of Tsukuba
Tandem (12MV): ^{26}Al, ^{36}Cl, ^{129}I

Nagoya University
Tandetron (3MV): ^{14}C
Tandetron (2.5MV): ^{14}C

MALT, The University of Tokyo
Tandem (5MV): ^{10}Be, ^{14}C, ^{26}Al, ^{36}Cl, ^{129}I

AMS data acquisition and control system

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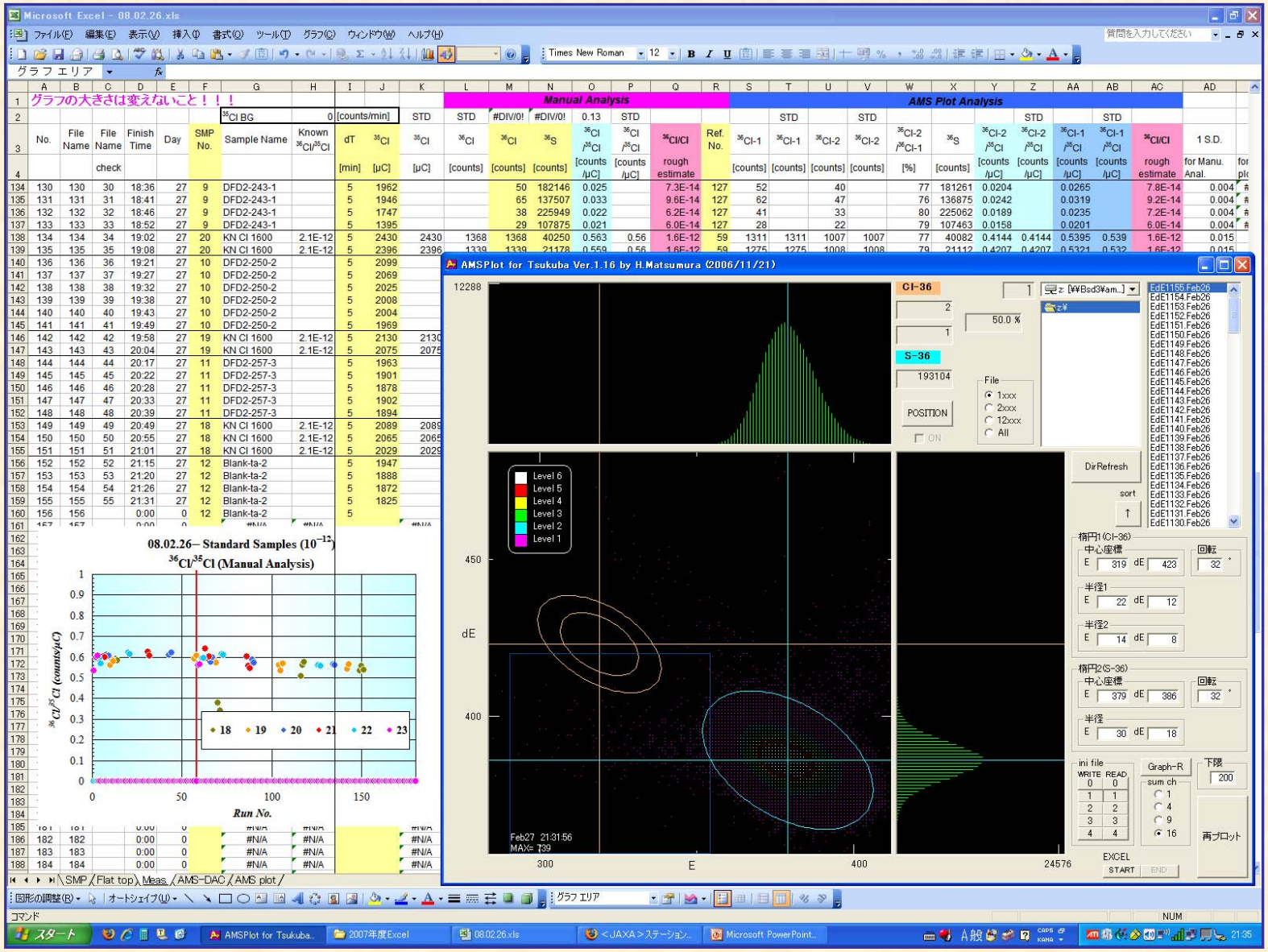
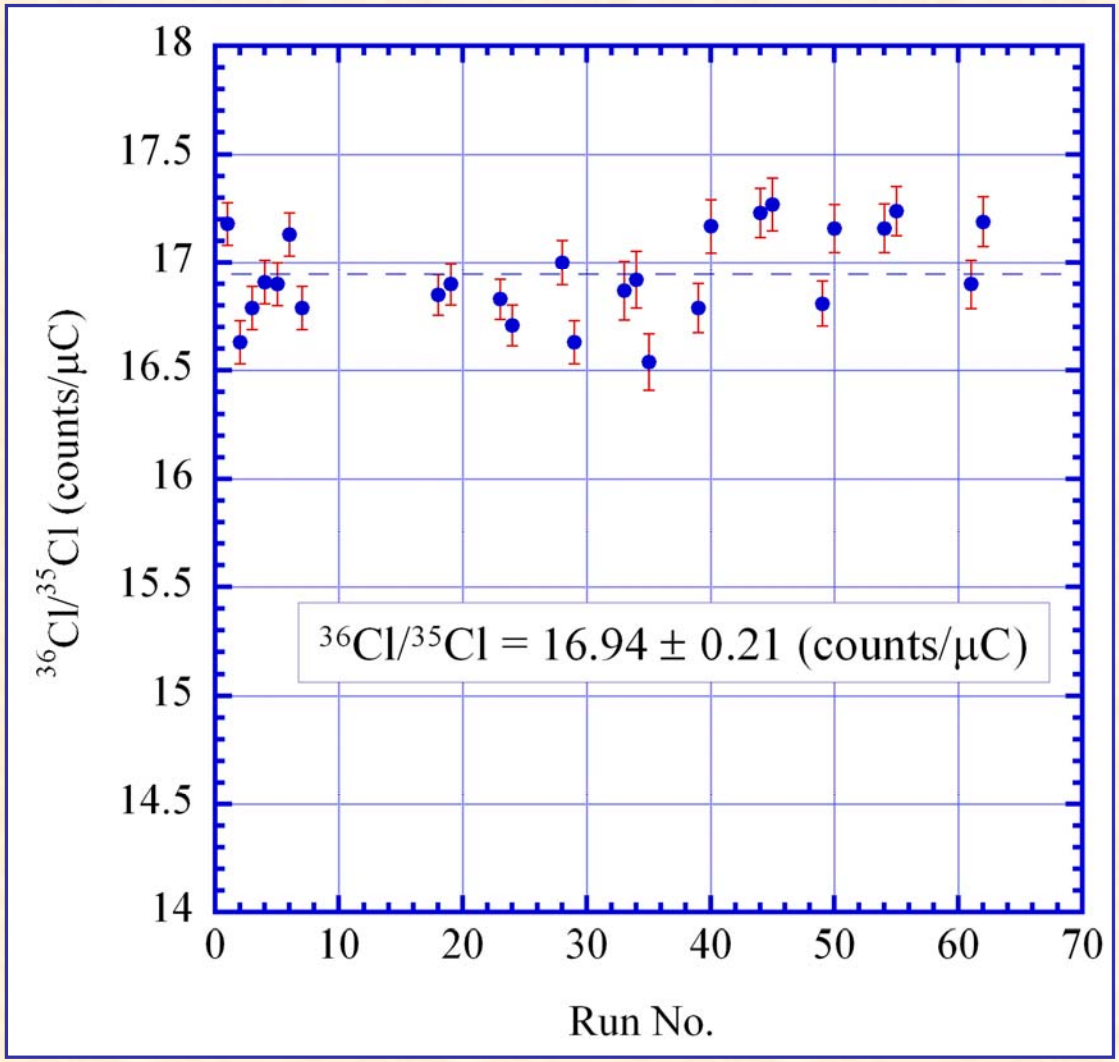


Replicated ^{36}Cl standard measurements



Standard sample:

$^{36}Cl/^{35}Cl = 5.90 \times 10^{-11}$

It takes 3 minutes for each measurement.

The standard deviation of the fluctuation of the $^{36}Cl/^{35}Cl$ ratio is kept within ± 3 %.

^{36}Cl production

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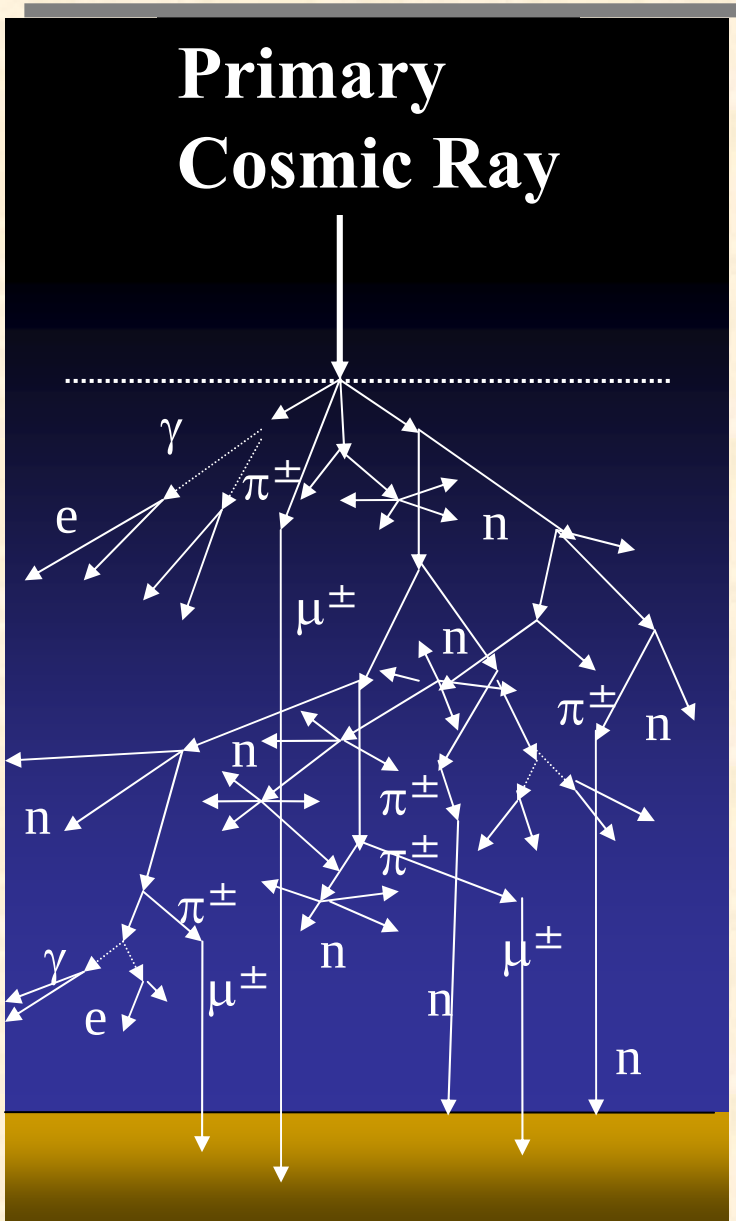

^{36}Cl ($T_{1/2}$=301 kyr): β-decay ^{36}Ar (98 %)

Natural－Cosmic rays

^{40}Ar(p, nα) ^{36}Cl

^{36}Ar (n, p) ^{36}Cl

- - -

~20 atoms/m^2/s

Neutron capture (U, Th)

^{35}Cl (n, γ) ^{36}Cl

Human activities

^{35}Cl (n, γ) ^{36}Cl (44 barn)

Nuclear explosion tests in the sea (1952-1958)

Atomic power plant,
Nuclear fuel cycle facilities, etc.

^{36}Cl-AMS

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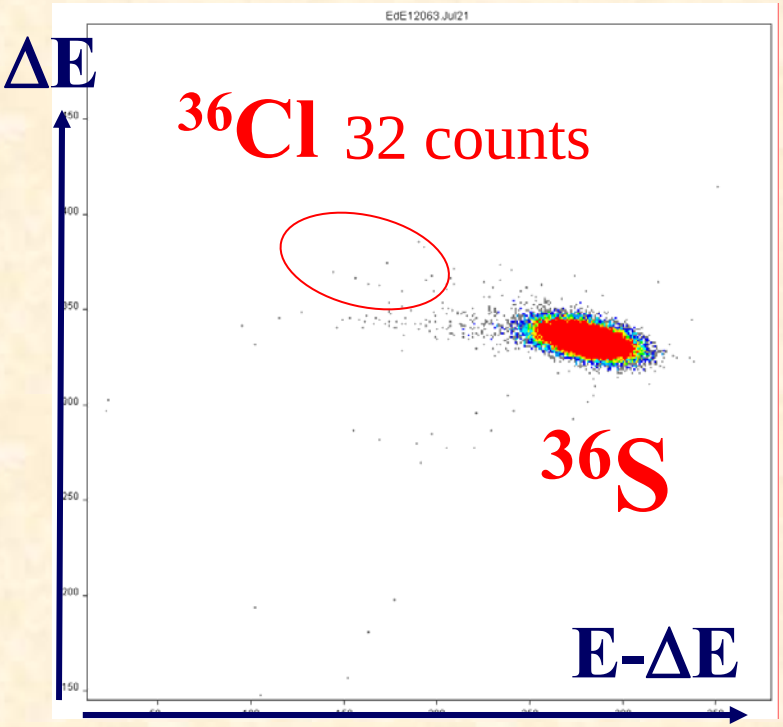

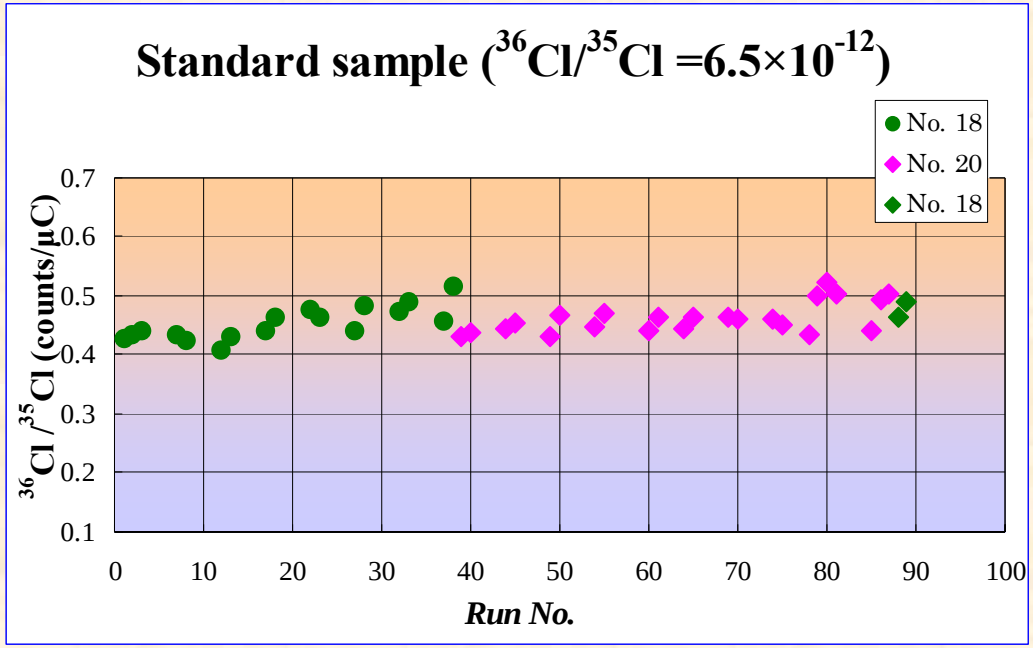

Reproduction in replicated measurements

Blank sample:

^{36}Cl / ^{35}Cl=2.4×10^{-14}

5 minutes measurement

^{36}Cl-AMS (Vt:10MV)

Beam energy: ^{36}Cl^{14+} 100MeV

Background: ^{36}Cl/Cl=~1×10^{-15}

Detection range: ^{36}Cl/Cl=10^{-10}~10^{-14}

Accuracy: ± 3 % (^{36}Cl/Cl~10^{-12})

Charge state distribution of Cl ions

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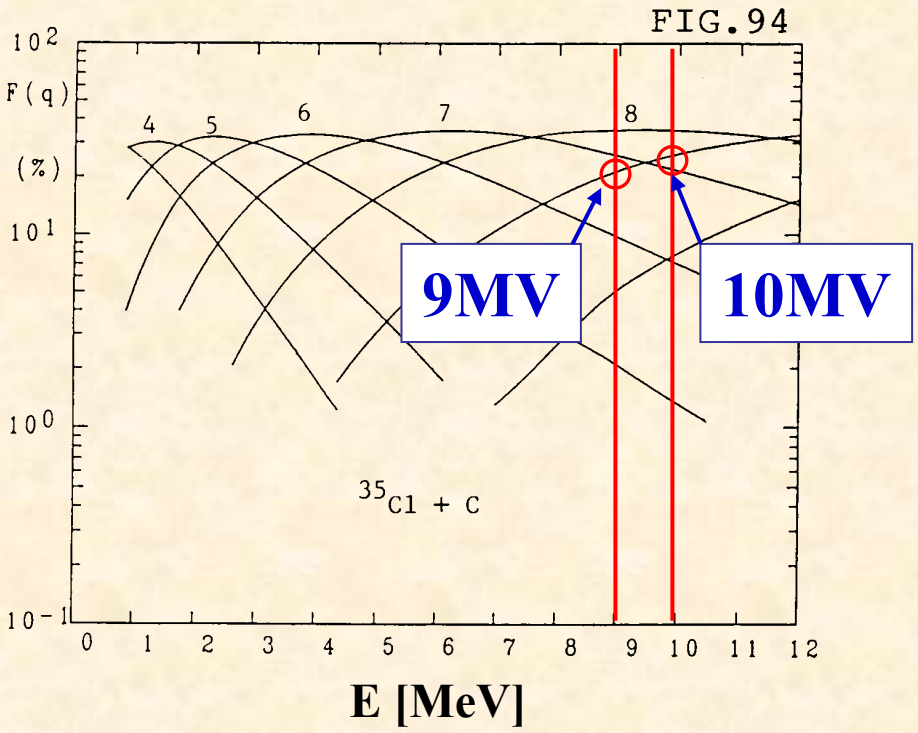
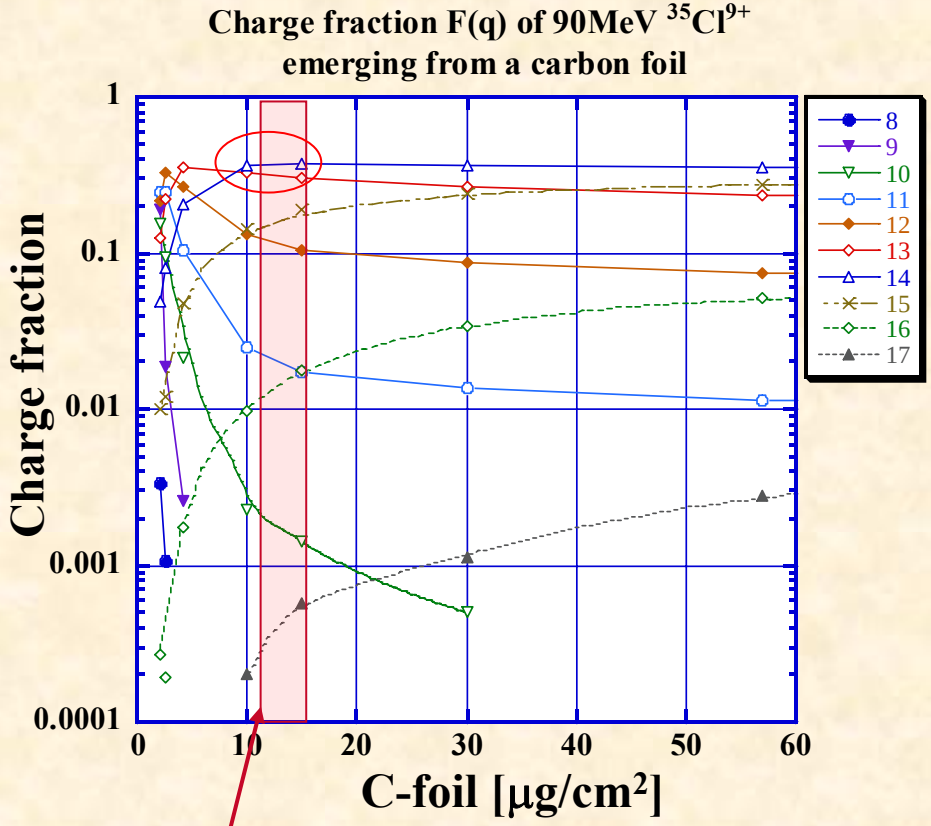
Charge state distribution of ^{35}Cl and ^{37}Cl ions after the passage through a carbon foil. [by Dr. Shima et al.]

1st stripper foil



2nd stripper foil



Charge fraction F(q) of $^{35}Cl^{9+}$ increased 1.5 times from 20% to 30%.

The optimum thickness of 2nd stripper foil: 12-15μg/cm² [F(14+)]

Sample preparation

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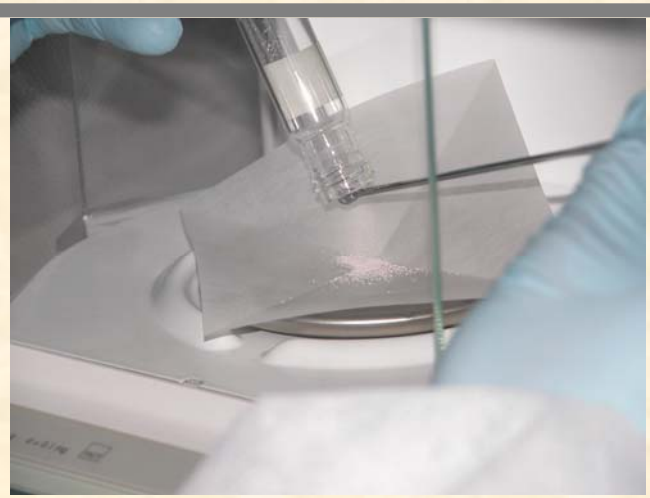
Sample (10–20 mL)
← 30% H_2O_2 (1 mL)
← 13 M HNO_3 (1 mL)
← 0.3 M $AgNO_3$ (1 mL)
Centrifugation (2500 rpm, 10 min)
Supernatant | Precipitate (AgCl)
Sulfur Reduction (2 times)
← 3 M NH_4OH (2 mL)
← sat. $Ba(NO_3)_2$ (3 mL)
Filtration (Filter Paper)
Filtrate ($[Ag(NH_3)_2]^+ Cl^-$) | Precipitate ($BaSO_4$)
← 13 M HNO_3 (0.5 mL)
Centrifugation (2000 rpm, 15 min)
Supernatant | Precipitate (AgCl)
Washing (with 0.01 M HNO_3, 2 times)
Washing (with 99.5% C_2H_5OH)
Drying (130°C, 3 h)



Sample: AgCl 1~5mg

A benzene saturated solution of fullerene (C_{60}) for $^{12}C_3^-$ pilot beam. [7.6 μl / AgCl: 1 mg]