Tuning of ion beams and measurements at the LABEC TANDEM

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per il gruppo LABEC Università&Sezione

III Seminario Nazionale Rivelatori Innovativi
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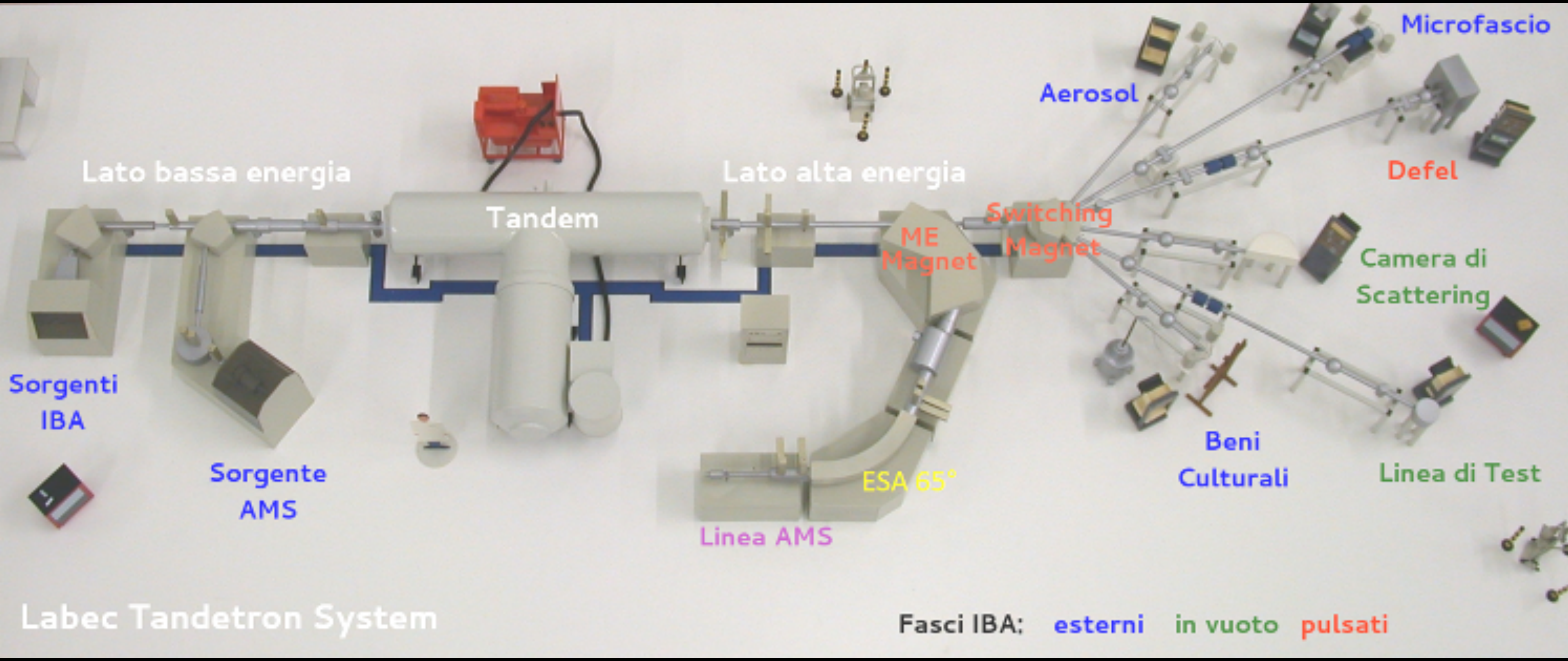
Measurements at LABEC



Outline

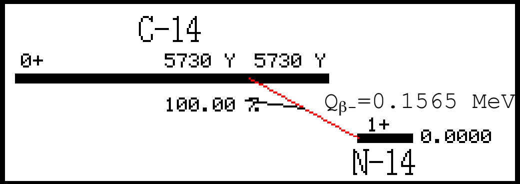
- ✓ Why measuring by Accelerator Mass Spectrometry (AMS)
  - The example of radiocarbon
- ✓ How to perform an AMS measurement by a Tandem accelerator facility
  - The example of LABEC accelerator
- ✓ **Laboratory session**
  - Beam transport
  - Data analysis

Accelerator Mass Spectrometry (AMS)

- ✓ AMS technique has been introduced to measure the relative abundance of **rare isotopes**
  - Radioactive isotopes of medium-long half life
  - Isotopes characterized by a very low abundance

^{14}C ($t_{1/2}$ = 5730 yrs)	^{129}I ($t_{1/2} = 1.6 \cdot 10^7$ yrs)	^{10}Be ($t_{1/2} = 1.5 \cdot 10^6$ yrs)	^{36}Cl ($t_{1/2} = 3 \cdot 10^5$ yrs)
Archaeometry *Geology* *Palaeoclimate*	*Environmental science* *Nuclear safeguards*	*Environmental science* *Geology*	*Environmental science* *Geology*

The example of ^{14}C



- ✓ Radiocarbon is the only natural radioactive carbon isotope
- ✓ It is produced in the atmosphere and enters in all the biosphere

→ **equilibrium condition**:

$$^{14}R = \frac{^{14}\mathrm{C}}{\mathrm{C}_{totale}} \approx \frac{^{14}\mathrm{C}}{^{12}\mathrm{C}} \approx 1.2 \cdot 10^{-12}$$

- ✓ After the death of an organism, its ^{14}C co starts to decrease due to the radioactive

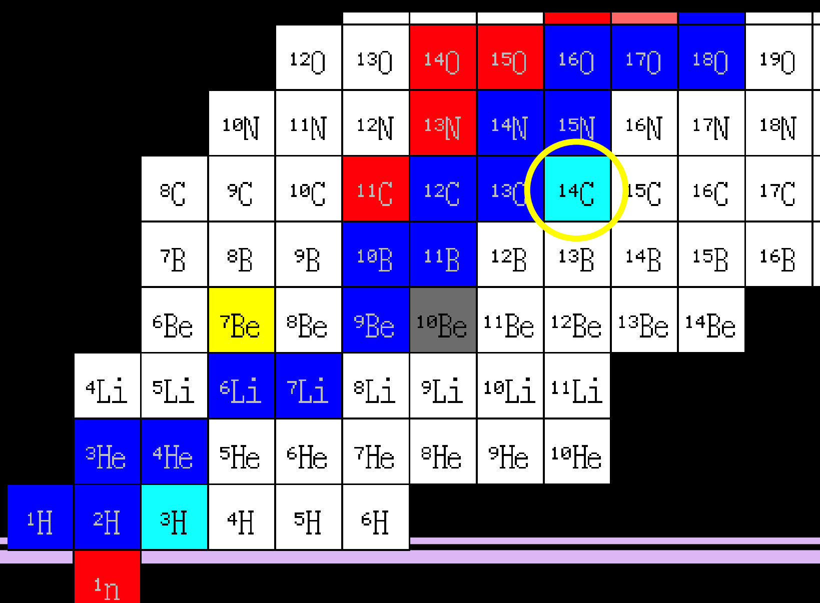
Dating of organic findings

$$^{14}R(t) = {}^{14}R_0 \, e^{-t/\tau}$$

$$t = \tau \cdot \ln\left(\frac{^{14}R_0}{^{14}R(t)}\right)$$

How to measure rare isotopes

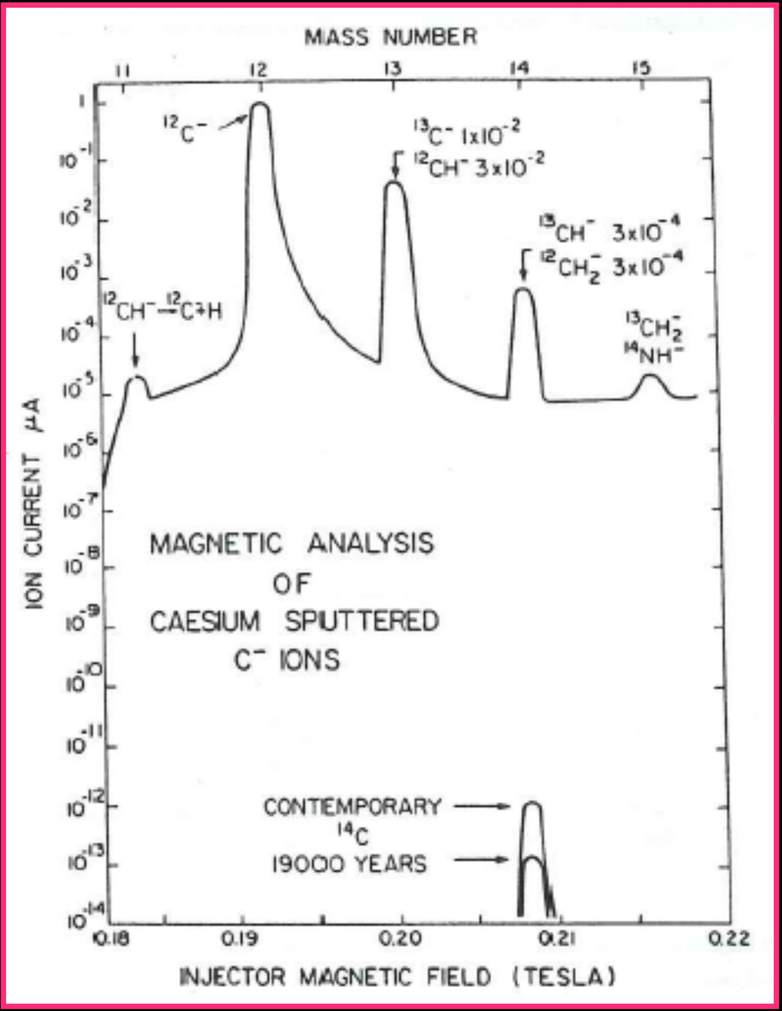
- ✓ By counting the decays
  - however, this cannot be convenient: very low activities → very long measuring time or pretty big samples
- ✓ By counting the atoms
  - however, their discrimination is not easy due to the presence of **isobars**



ISOBARI DEL ^{14}C

	^{14}N	$^{12}CH_2$	^{13}CH
$\Delta m/m$	0.000012	0.0009	0.0003

^{14}C: a needle in a haystack

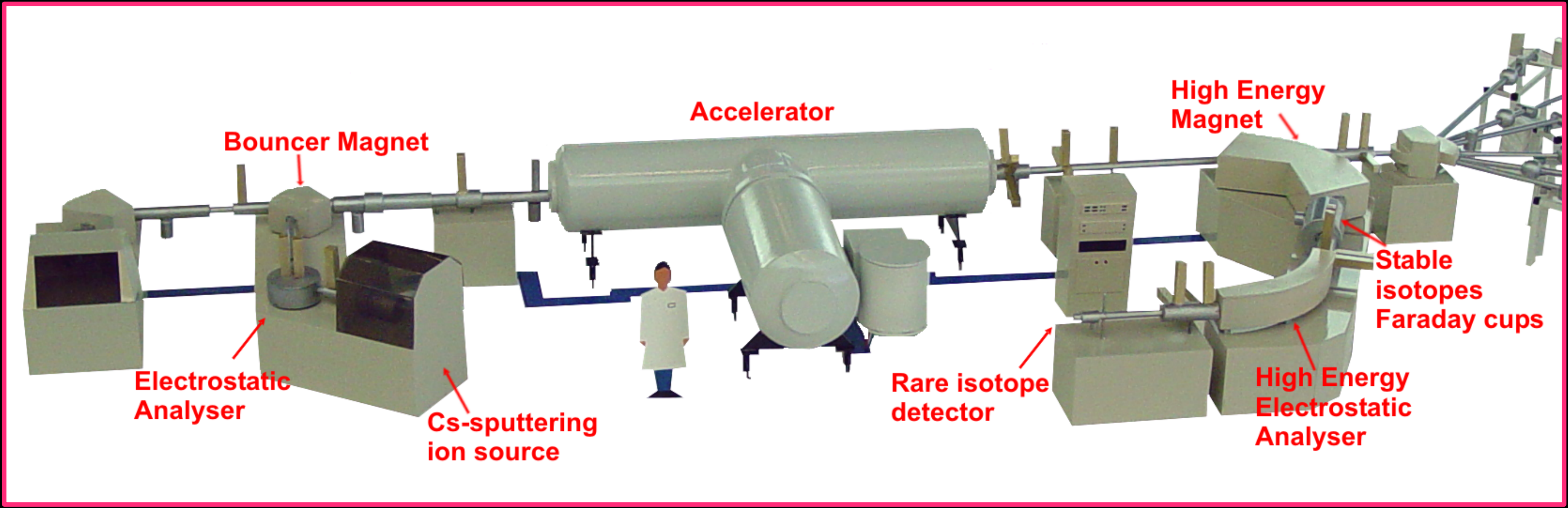


- ✓ The typical sensitivity of traditional mass spectrometry is not sufficient

In AMS, electrostatic and magnetic “filters” are coupled to a Tandem electrostatic accelerator

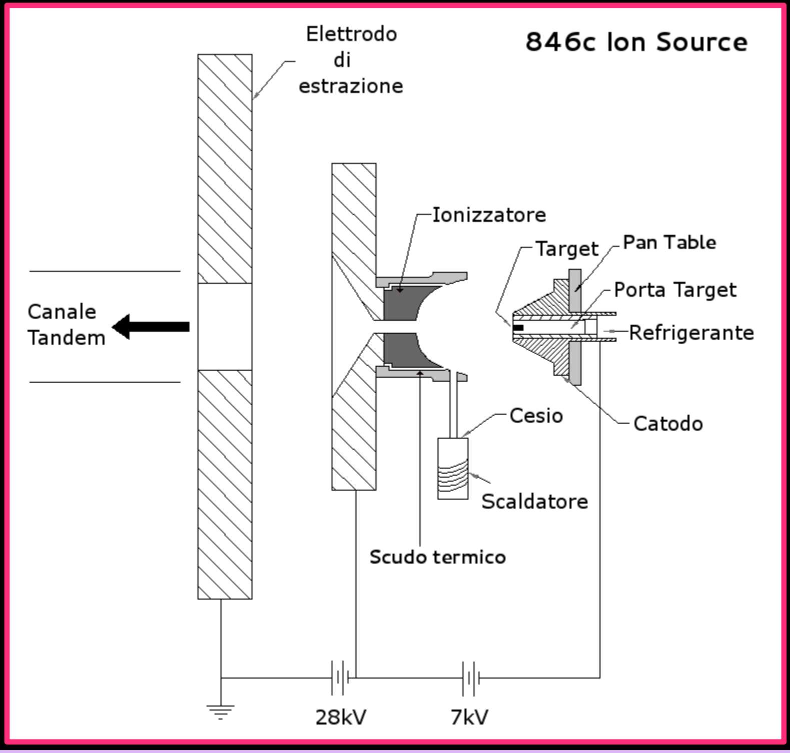
The accelerator itself is used as a sort of high sensitivity detector

The AMS beam line at LABEC



From the sample to the ions: the source

- ✓ Samples are inserted in the Cs-sputtering ion source as graphite pellets (*m<1 mg*)



Negative ions are extracted from the source → the isobar ^{14}N is suppressed

Suppression of ^{14}N

Ionization Potentials and Electron Affinities of the Elements

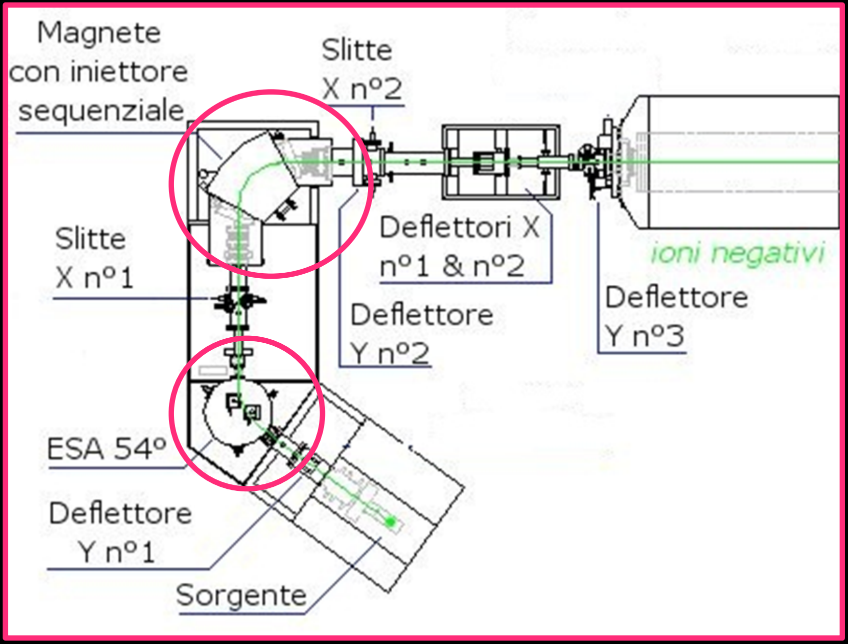
IA	IIA	IIIA	IVA	VA	VIA	VIIA	VIIIA
$_{1}$H 13.59 0.754	Ionization Potential Electron Affinity						$_{2}$He 24.48 0.078*
$_{3}$Li 5.39 0.618	$_{4}$Be 9.32 0.195*	$_{5}$B 8.30 0.277	$_{6}$C 11.26 1.263	$_{7}$N 14.53 -0.07	$_{8}$O 13.61 1.461	$_{9}$F 17.42 3.399	$_{10}$Ne 21.56 < 0
$_{11}$Na 5.14 0.548	$_{12}$Mg 7.64 < 0	$_{13}$Al 5.98 0.441	$_{14}$Si 8.15 1.385	$_{15}$P 10.48 0.747	$_{16}$S 10.36 2.077	$_{17}$Cl 13.01 3.617	$_{18}$Ar 15.76 < 0
$_{19}$K 4.34 0.501	$_{20}$Ca 6.11 0.043	$_{31}$Ga 6.00 0.30	$_{32}$Ge 7.90 1.2	$_{33}$As 9.81 0.81	$_{34}$Se 9.75 2.021	$_{35}$Br 11.81 3.365	$_{36}$Kr 14.00 < 0
$_{37}$Rb 4.18 0.486	$_{38}$Sr 5.70 < 0	$_{49}$In 5.79 0.3	$_{50}$Sn 7.34 1.2	$_{51}$Sb 8.64 1.07	$_{52}$Te 9.01 1.971	$_{53}$I 10.45 3.059	$_{54}$Xe 12.13 < 0
$_{55}$Cs 3.89 0.472	$_{56}$Ba 5.21 < 0	$_{81}$Tl 6.11 0.2	$_{82}$Pb 7.42 0.364	$_{83}$Bi 7.29 0.946	$_{84}$Po 8.42 1.9	$_{85}$At 9.5 2.8	$_{86}$Rn 10.75 < 0

*Metastable

R. Middleton, A negative-ion cookbook

- ✓ ^{14}N does not form negative ions in the stable state
- ✓ Lifetime of negative excited states are too short with respect to the time needed to travel to the injection into the accelerator
- ✓ Possible fragments from molecules (e.g.NH) are discriminated thanks to the following charge-energy-mass analysis

The analysis on the low energy side



- ✓ First selection according to **energy/charge**

$$\varepsilon r = 2\frac{E}{q}$$

q=-1
E= 35 keV

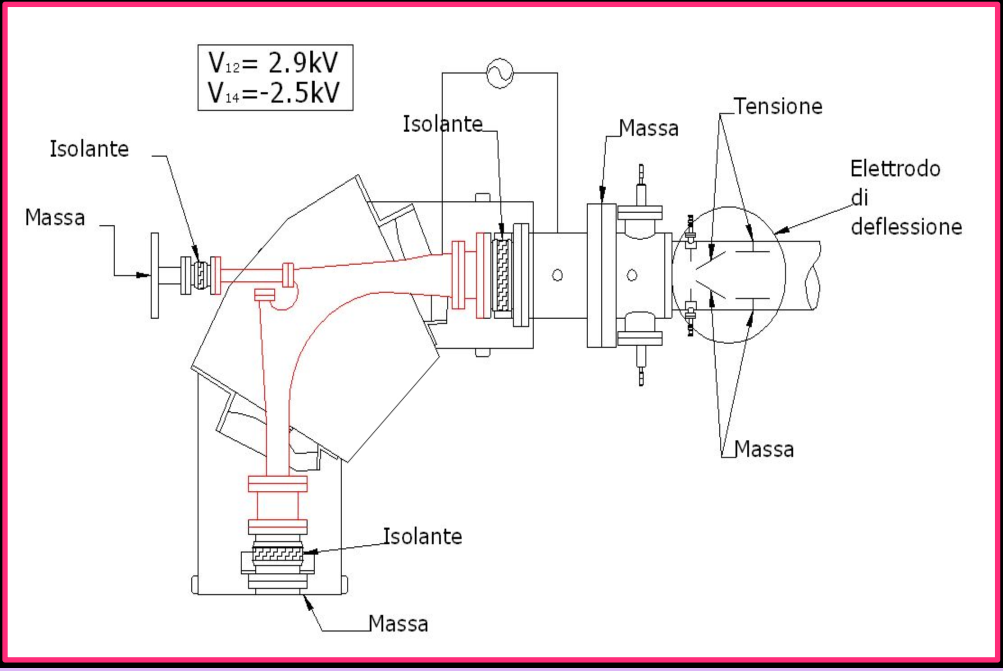
- ✓ Second selection according to **impulse/charge**

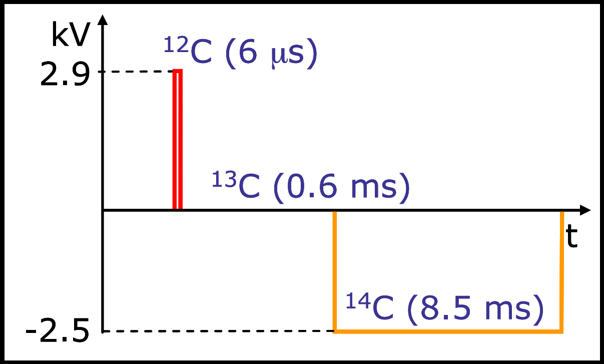
$$Br = \frac{\sqrt{2mE}}{q}$$

→ *to select the three masses 14, 12 and 13*

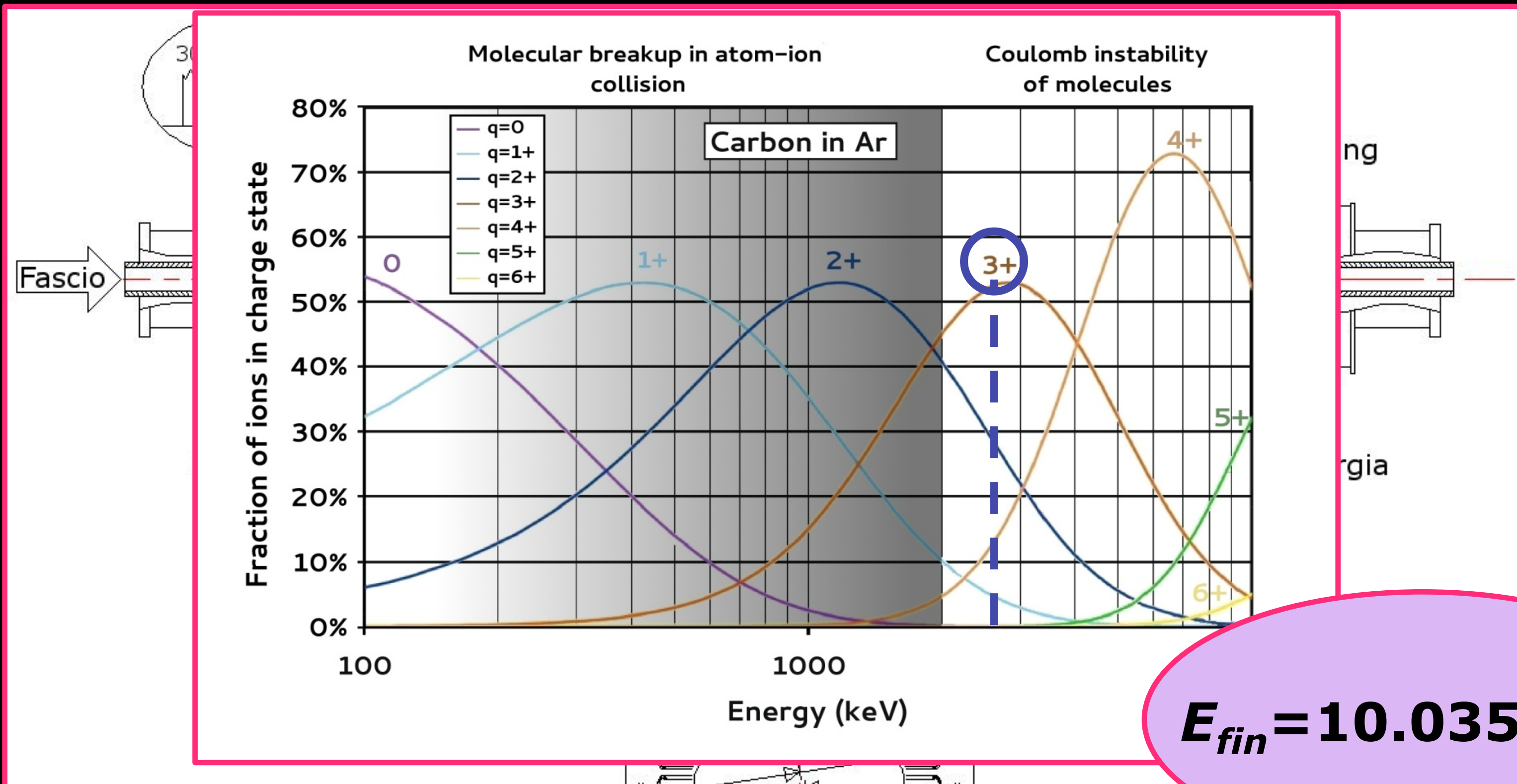
Sequential injection…

- ✓ The magnetic field is kept fixed to optimize the transmission of a mass (m=13)
- ✓ The other masses are transmitted by changing their energy inside the magnet chamber





...into the accelerator

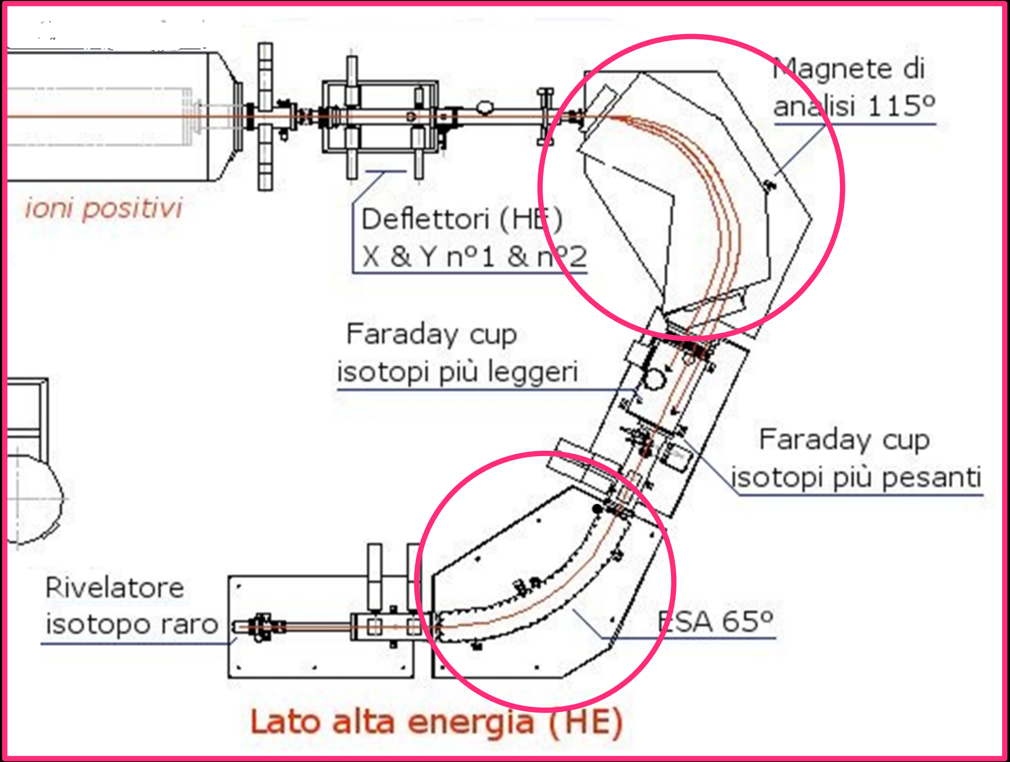


E_{fin}=10.035 MeV

$$E_{fin} = \left(E_{inj} + e \cdot V_t\right) \cdot \frac{m_i}{m_{tot}} + q \cdot e \cdot V_t$$

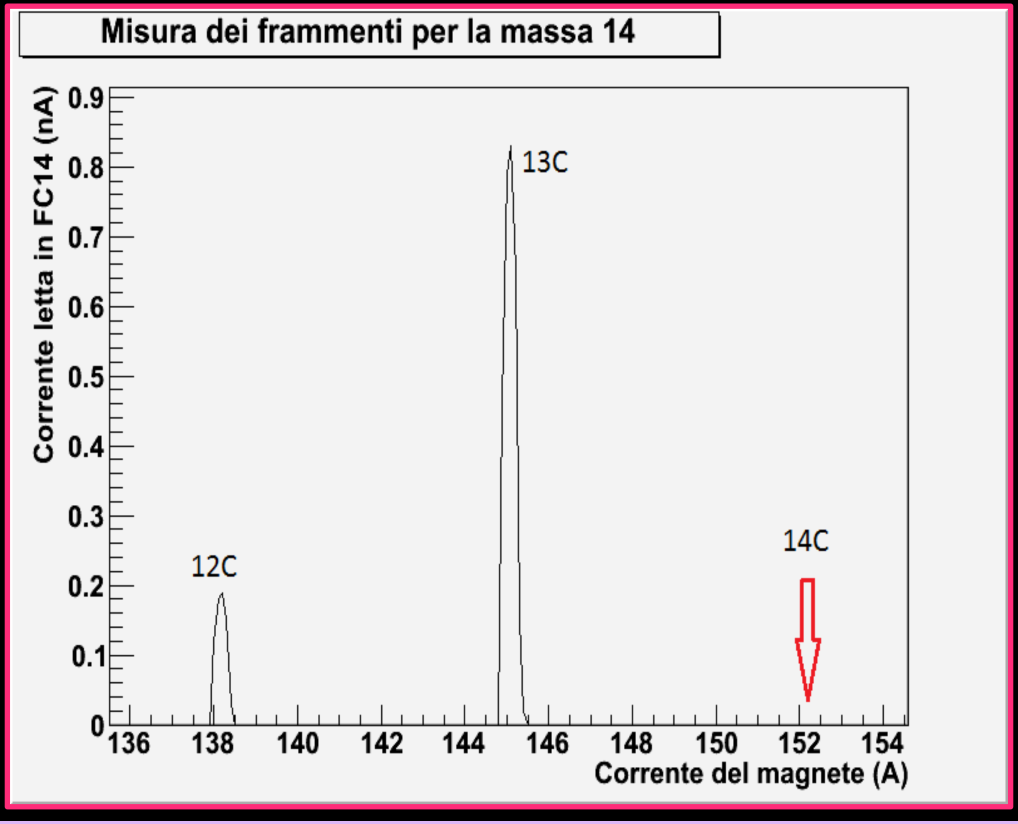
The analysis on the high energy side

- ✓ First selection according to impulse/charge
  → **discrimination of $^{14}C^{3+}$ ions**
- ✓ Second selection according to energy/charge
  → rejection of possible residual interferences

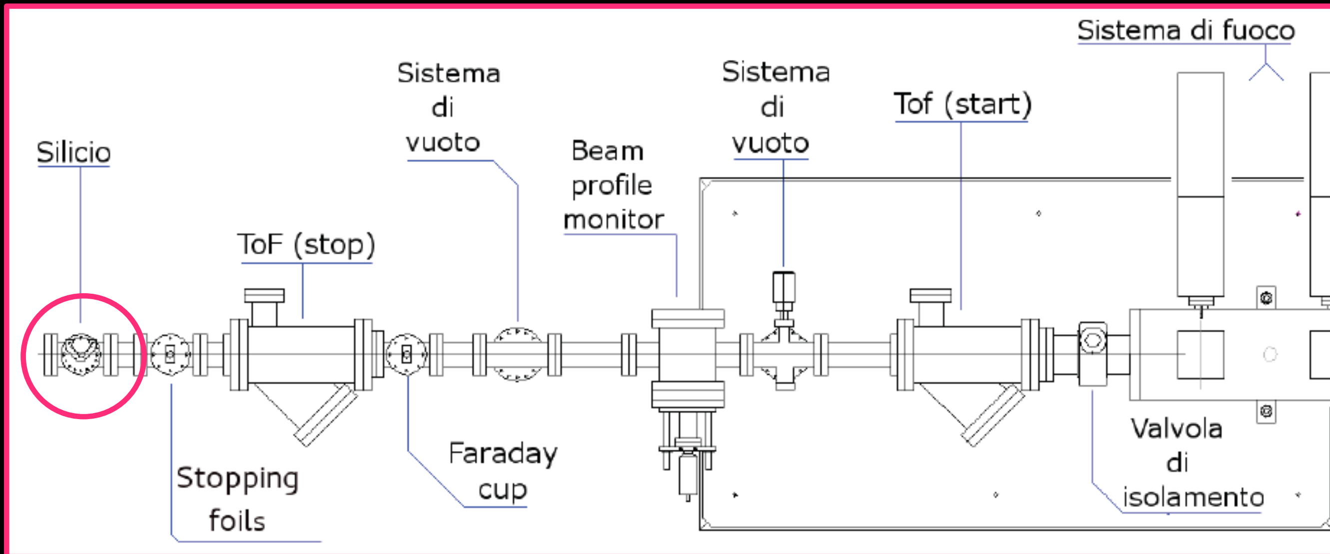


What happens to molecular isobars?

- ✓ As a consequence of the stripping process, molecules can be split into their atomic constituents



Counting the radiocarbon ions

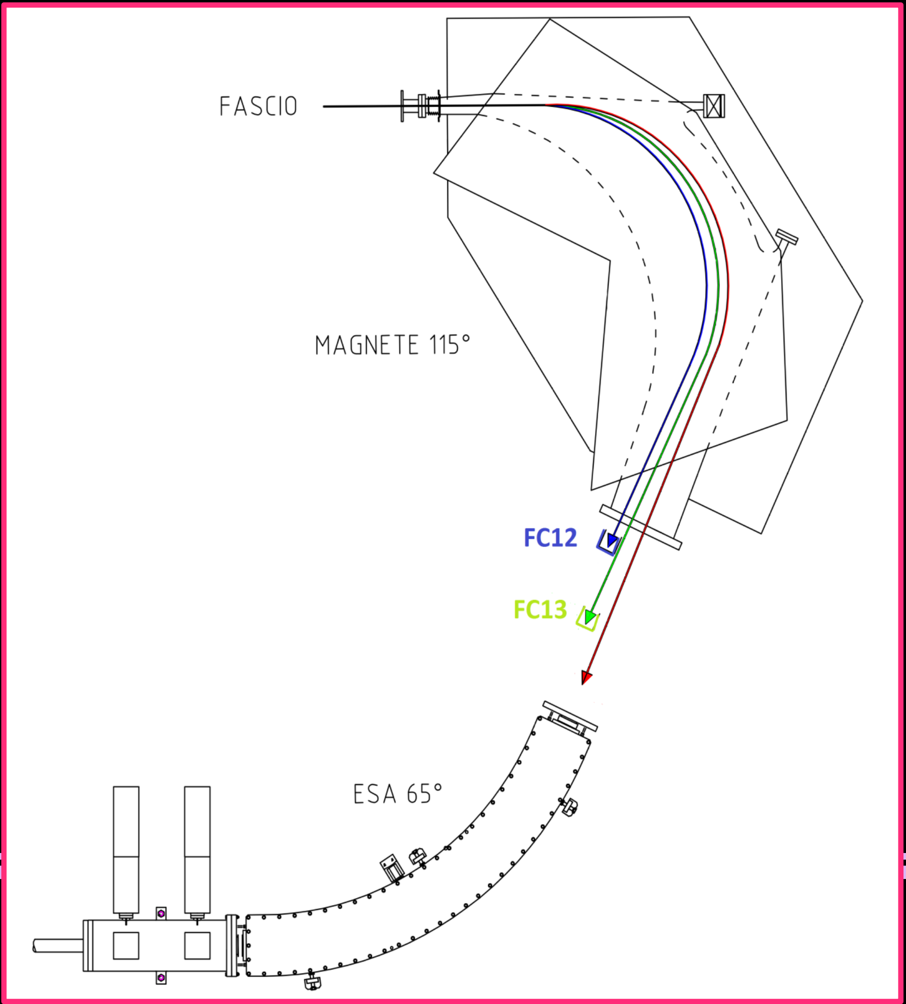


Hamamatsu Si-photodiode → **CAEN A422A Charge-sensitive preamplifier** → **ORTEC 570 Amplifier** → **ORTEC 550A SCA** → **ORTEC 661 Ratemeter**

ORTEC 570 Amplifier → **ADC - PC**

What about the stable isotopes?

✓ $^{12}C^{3+}$ and $^{13}C^{3+}$ are measured in offset Faraday cups at the exit of the high-energy magnet



Measurement of ^{12}C → measurement of the **isotopic ratio** $\frac{^{12}C}{^{14}C}$

Measurement of ^{13}C → measurement of **isotopic fractionation correction**

The importance of beam transport

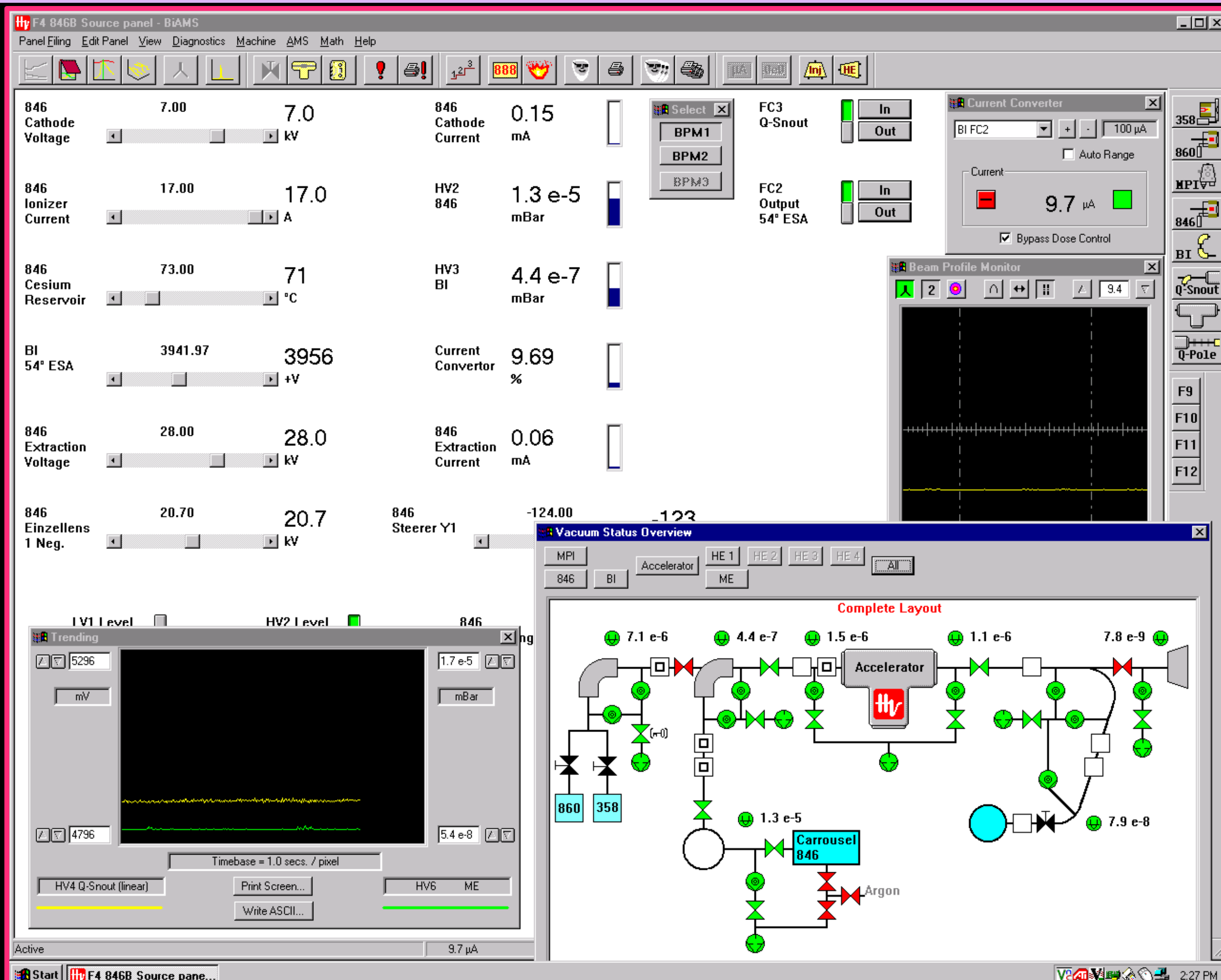
- ✓ The expected ^{14}C counting rate is low (few tens of Hz at maximum) → the transmission has to be optimized
- ✓ A good analysis of the beam depends on the stability of machine parameters (e.g. energy of the beam, i.e. terminal voltage) → we can exploit feedback systems

Set focusing elements (Einzel lens and quad doublets) and steerers to optimize the transmission

Set electrostatic analysers and magnets to efficiently discriminate the components of the beam

Check Faraday cups, Beam Profile Monitors (BPM) and ^{14}C counting rate to monitor the beam transport

Working with the beam



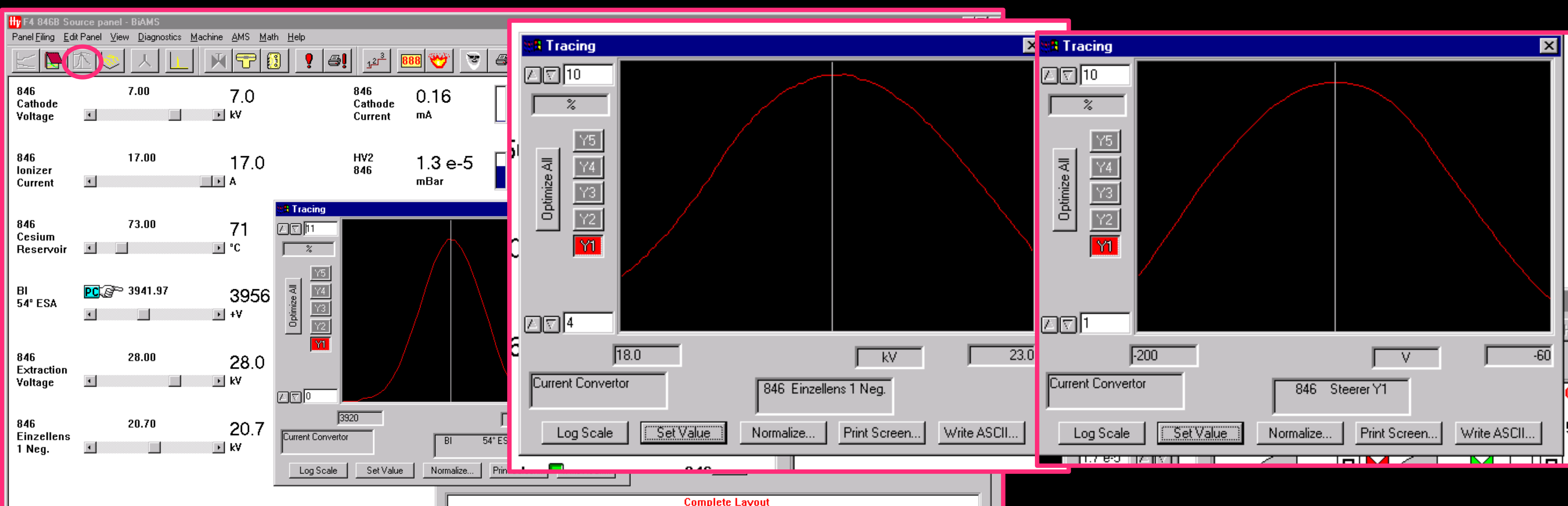
Beam in FC2

✓ Three elements to set

Electrostatic Analyser (ESA)

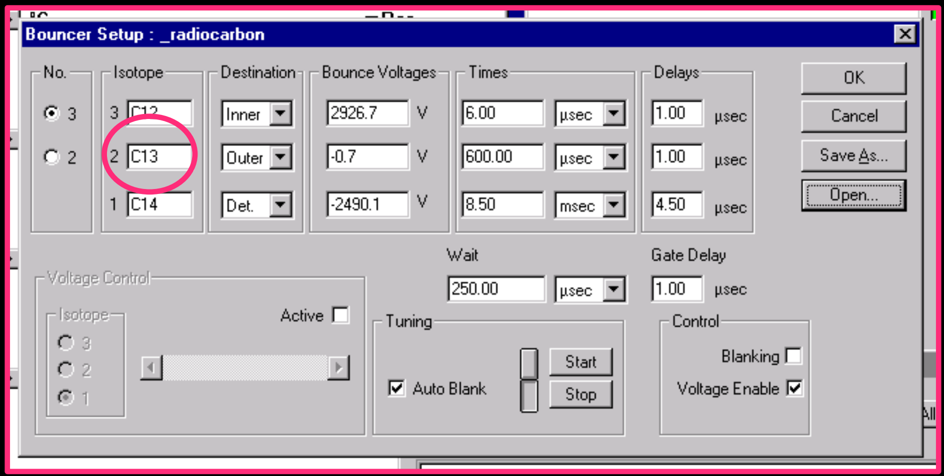
Einzel Lens

Steerer Y



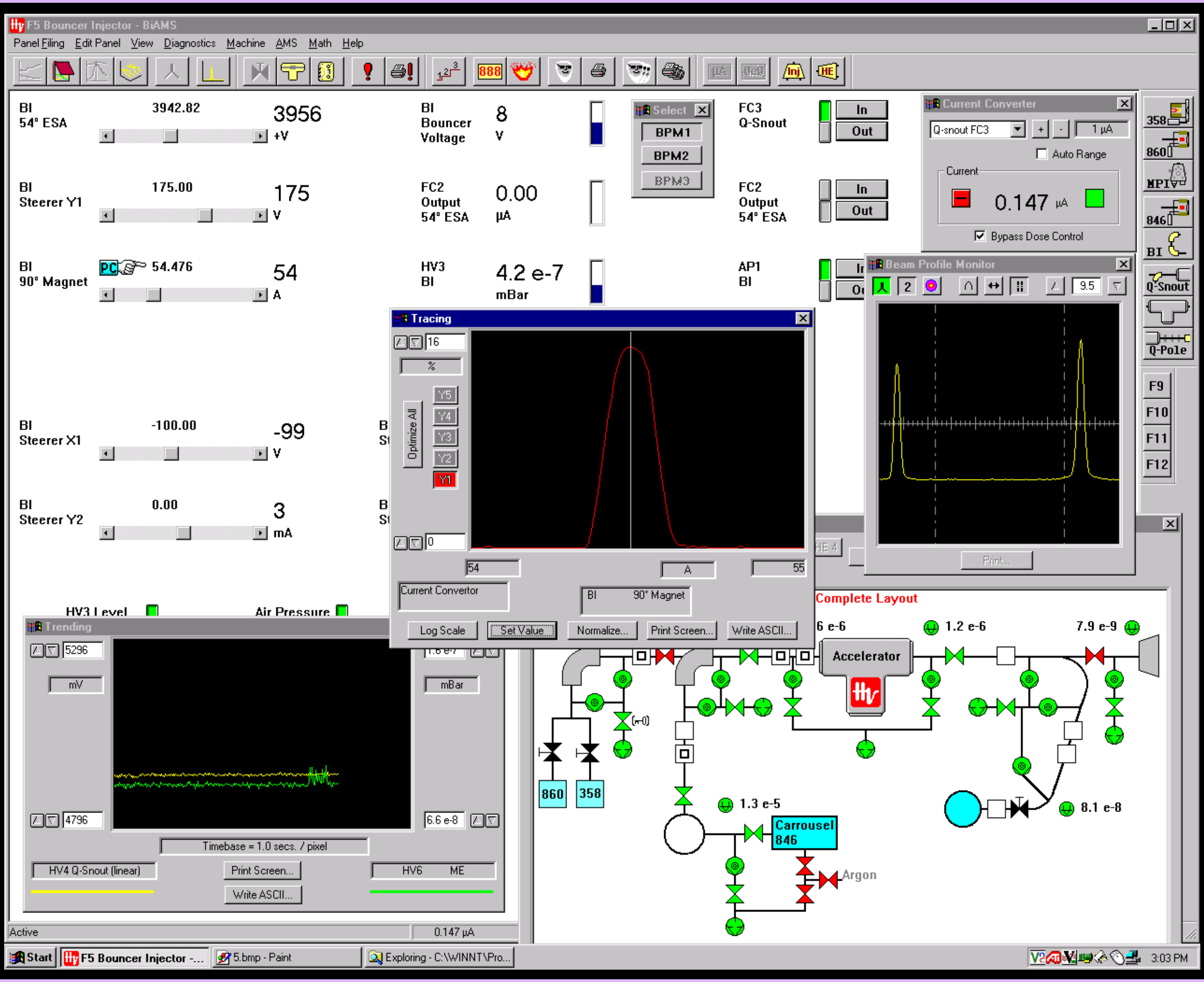
Beam in FC3

✓ Set the magnet → which mass?



Optimize the current in the Faraday cup and monitor beam spatial distribution in the BPM

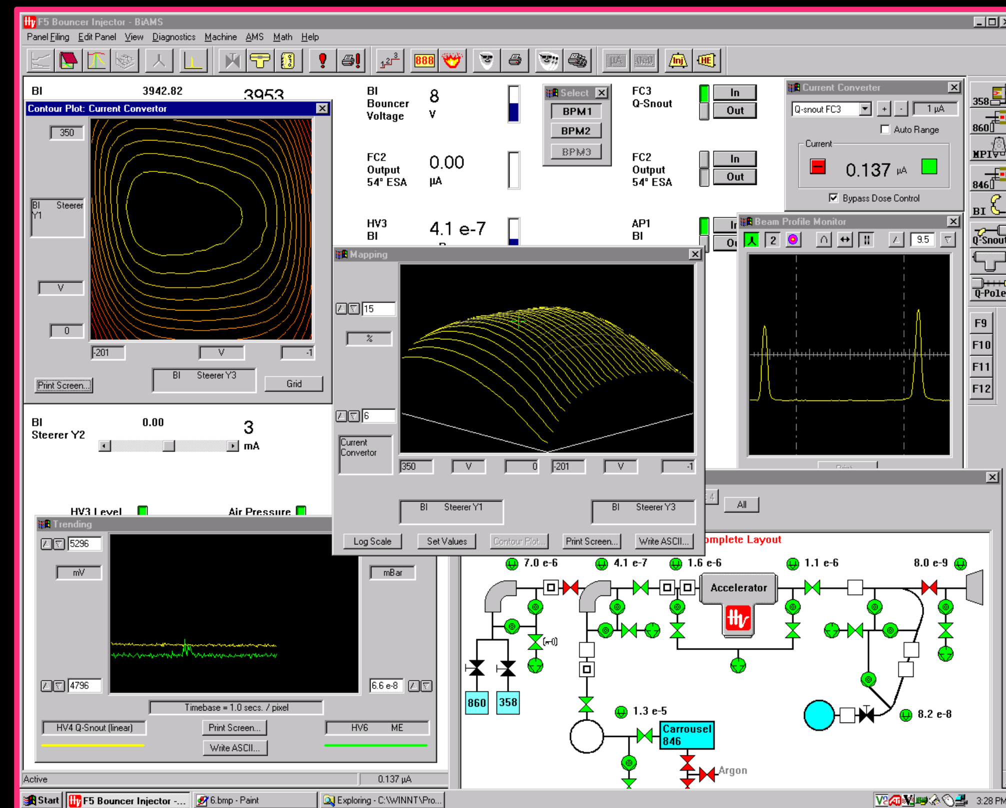
Beam in FC3



F5 Bouncer Injector - BiAMS
Panel Filing Edit Panel View Diagnostics Machine AMS Math Help
BI 54° ESA 3942.82 3956 +V
BI Steerer Y1 175.00 175 V
BI 90° Magnet 54.476 54 A
BI Steerer X1 -100.00 -99 V
BI Steerer Y2 0.00 3 mA
BI Bouncer Voltage 8 V
FC2 Output 54° ESA 0.00 µA
HV3 BI 4.2 e-7 mBar
Select BPM1 BPM2 BPM3
FC3 Q-Snout In Out
FC2 Output 54° ESA In Out
AP1 BI
Current Converter
Q-snout FC3
Auto Range
Current
0.147 µA
Bypass Dose Control
Beam Profile Monitor
Tracing
Current Convertor
BI 90° Magnet
Log Scale Set Value Normalize... Print Screen... Write ASCII...
Trending
HV3 Level Air Pressure
Timebase = 1.0 secs. / pixel
HV4 Q-Snout (linear) Print Screen... Write ASCII... HV6 ME
Complete Layout
Accelerator
Carrousel 846
Argon
860 358
1.2 e-6 7.9 e-9 1.3 e-5 8.1 e-8
Active 0.147 µA
Start F5 Bouncer Injector -... 5.bmp - Paint Exploring - C:\WINNT\Pro... 3:03 PM

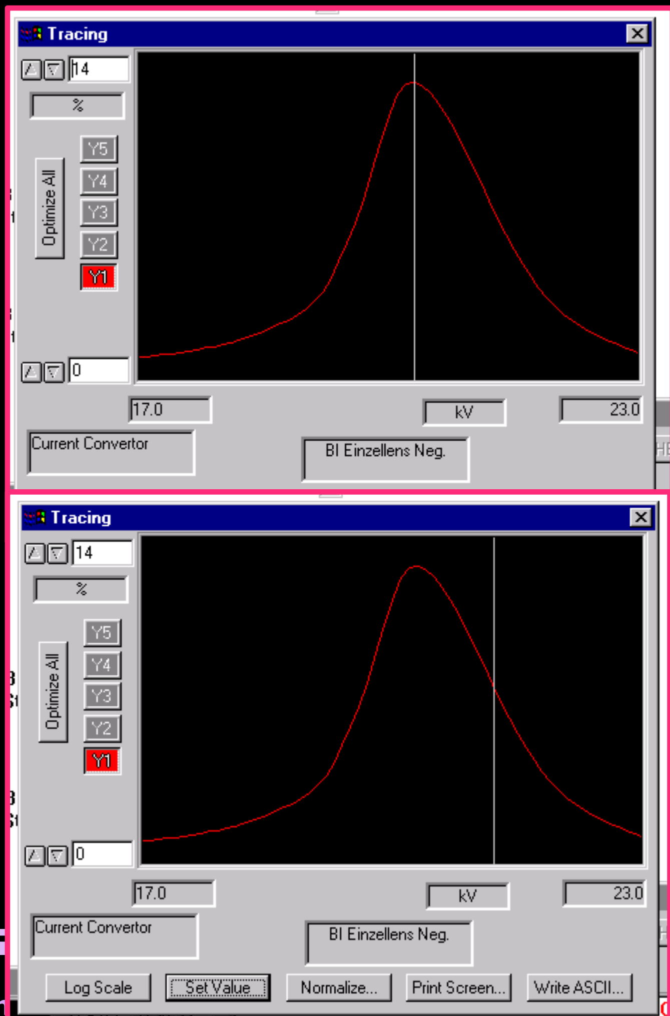
Beam in FC3

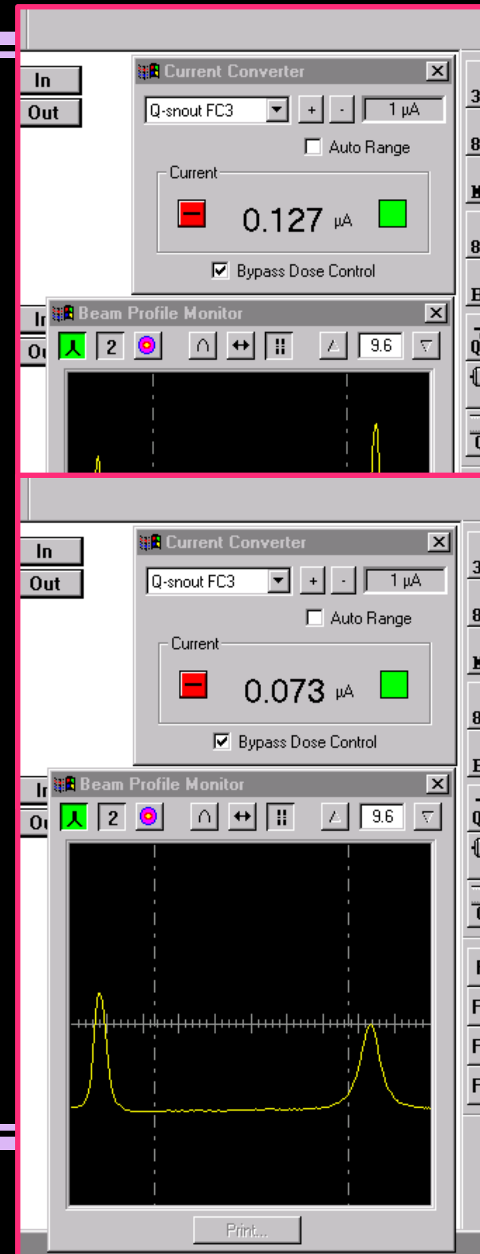
- ✓ A couple of Y steerers
- ✓ A couple of X steerers



Beam in FC3

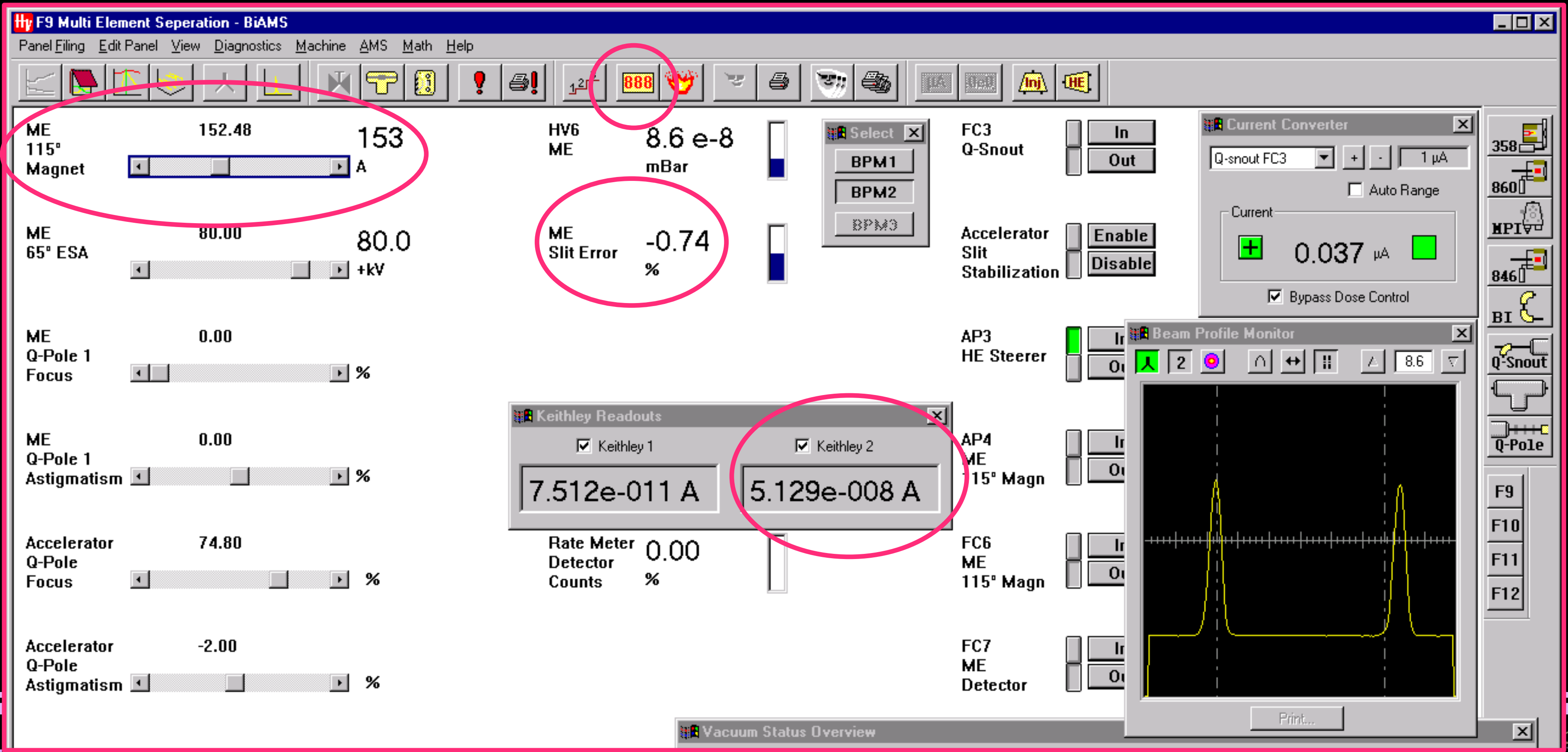
✓ Einzel lens to focus





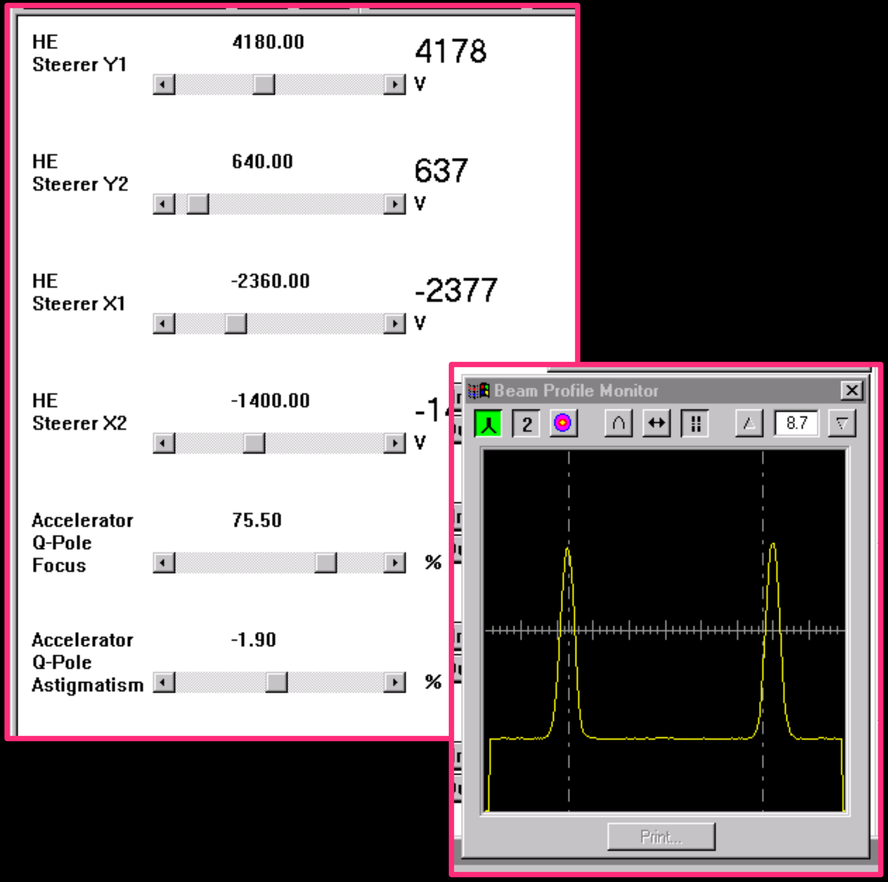
At the exit of the accelerator

- ✓ Roughly set the magnet on the high energy side → monitor $^{13}C^{3+}$ current in the dedicated offset Faraday cup



At the exit of the accelerator

- ✓ Set Q-snout
- ✓ Set quadrupoles (focus and astigmatism) and high energy steerers



Downstream the high-energy magnet

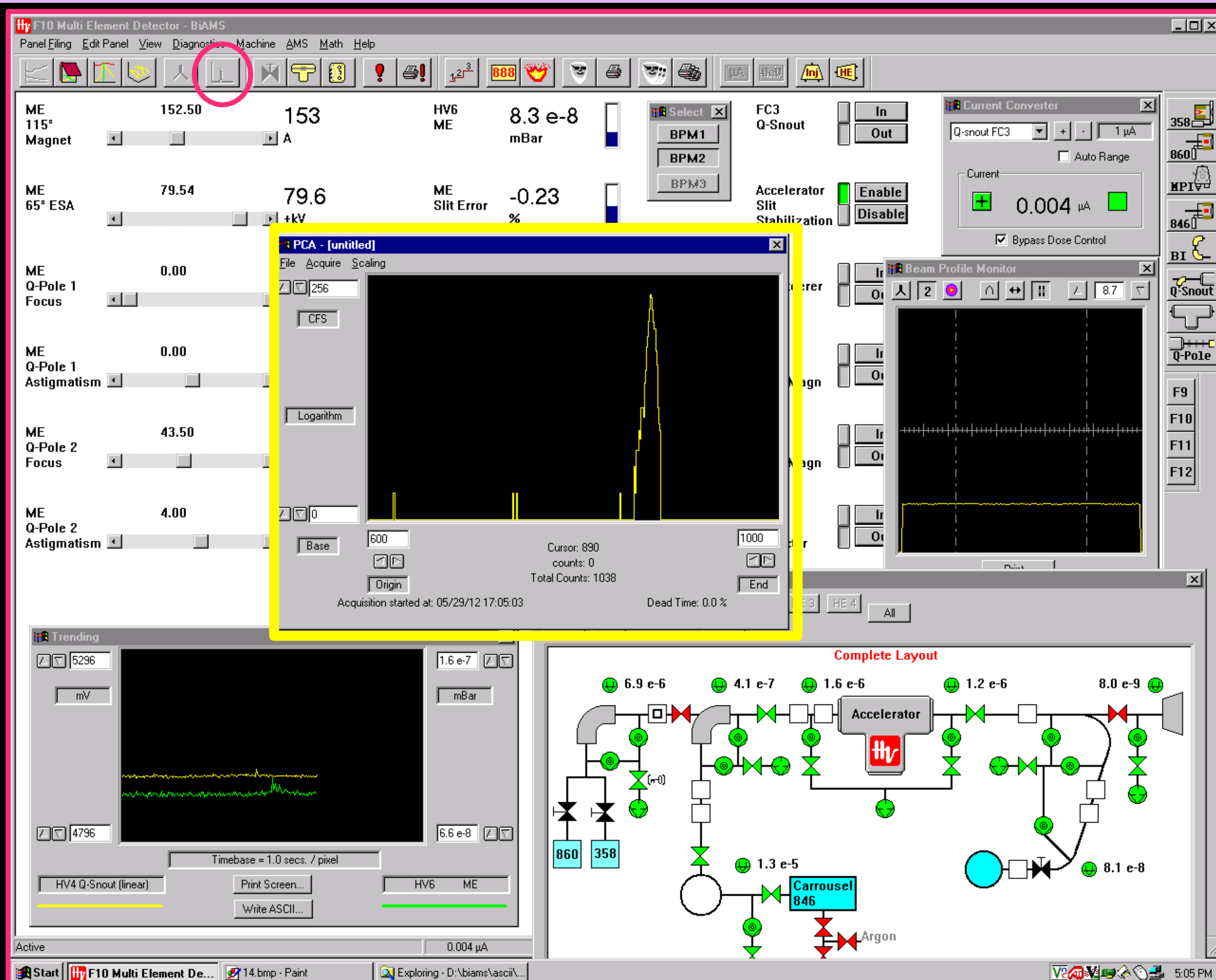
- ✓ Typical beam currents are too low to use Faraday cup or BPM

Check the counting rate in the $^{14}C^{3+}$ silicon detector (roughly, looking at the output signal of SCA)

- ✓ Set high-energy electrostatic analyser and quadrupoles

Final check of the three isotopes

Our goal



F10 Multi Element Detector - BiAMS
Panel Filing Edit Panel View Diagnostics Machine AMS Math Help
ME 115° Magnet 152.50 153 A
ME 65° ESA 79.54 79.6 +kV
ME Q-Pole 1 Focus 0.00
ME Q-Pole 1 Astigmatism 0.00
ME Q-Pole 2 Focus 43.50
ME Q-Pole 2 Astigmatism 4.00
HV6 ME 8.3 e-8 mBar
ME Slit Error -0.23 %
Select BPM1 BPM2 BPM3
FC3 Q-Snout In Out
Accelerator Slit Stabilization Enable Disable
Current Converter
Q-snout FC3
1 µA
Auto Range
Current
0.004 µA
Bypass Dose Control
PCA - [untitled]
File Acquire Scaling
256
CFS
Logarithm
0
Base
600
Origin
Cursor: 890
counts: 0
Total Counts: 1038
1000
End
Acquisition started at: 05/29/12 17:05:03
Dead Time: 0.0 %
Beam Profile Monitor
8.7
358 860 MPI 846 BI Q-Snout Q-Pole
F9 F10 F11 F12
Trending
5296
mV
4796
1.6 e-7
mBar
6.6 e-8
Timebase = 1.0 secs. / pixel
HV4 Q-Snout (linear)
Print Screen...
Write ASCII...
HV6 ME
All
Complete Layout
6.9 e-6
4.1 e-7
1.6 e-6
1.2 e-6
8.0 e-9
Accelerator
860
358
1.3 e-5
Carrousel 846
Argon
8.1 e-8
Active
0.004 µA
Start
F10 Multi Element De...
14.bmp - Paint
Exploring - D:\biams\ascii\...
5:05 PM

The AMS measurement

- Your set of samples to be measured:
  - **Standard** samples → to normalize measured isotopic ratio
  - **Blank** samples → to subtract background counts (due to machine and sample preparation)
  - **Unknown samples**
- What is measured:
  - **^{14}C counts**
  - **^{12}C and ^{13}C currents**

Data Analysis

$$^{14}R_{norm,sample}(pMC) = {}^{14}R_{cert,std}(pMC) \cdot \left(\frac{^{13}R_{meas,std}}{^{13}R_{meas,sample}} \right)^2 \cdot \left(\frac{^{14}R_{meas,sample} - {}^{14}R_{meas,blk}}{^{14}R_{meas,std} - {}^{14}R_{meas,blk}} \right)$$

Certified concentration of standard

Isotopic fractionation correction

Normalization to standard and subtraction of background

$$t_{RC}(yrs\ BP) = 8033\, yrs \cdot \ln \left(\frac{100\ pMC}{^{14}R_{norm,sample}} \right)$$

Calibration → *Most probable calendar age*

Lab practice

14:30 – 15:40	*Beam transport and optimization of measurement parameters*
15:40 – 15:50	*Start of AMS measurement*
15:50 – 16:10	*Sample preparation laboratory*
16:10 – 17:00	*Improvements on detection of molecular isobars*
17:00 – 18:00	*Data analysis*

Have a good job!