^{14}C - AMS

- **Introduction**
- **Identification of ^{14}C**
- **^{14}C concentrations**
- **Remarks for users**

AMS **A**ccelerator **M**ass **S**pectrometry

a method for measuring very small isotopic ratios

„very small“ => radioisotopes

Basic Considerations

^{14}C is a radionuclide,
why not counting the radioactive decay?

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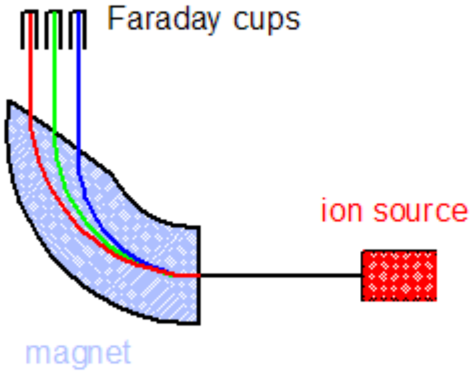
why not counting the radioactive decay?

sample with 1 mg C => $5.0 * 10^{19}$ C atoms
modern sample, i.e. $^{14}C/C = 10^{-12}$ => $5.0 * 10^{7}$ ^{14}C atoms
half life 5730 yrs => decay probability $3.9 * 10^{-12}$ s^{-1}
⇒ for the 1 mg modern sample 0.7 decays / h
low statistical error 50000 counts => 4 years

mass spectrometry (**MS**) does not wait for decay !!!
10 µA current = $6.2 * 10^{13}$ ions/s => 62 ^{14}C ions/s

Limitation of ‘classical‘ MS



- isobaric ions	$^{14}C^{+} = {}^{14}N^{+}$
- higher charged ions	$^{28}Si^{2+}$
- molecular ions	$^{12}CH_2^{+}$
- resolution (tailing)	10^{-5} level

- ^{14}C intensity
- other background

note: single ones of these problems can be overcome,

but not all of them simultaneously

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isobaric ions

higher charged ions

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Example of a mass spectra

negative ions

⇒ no $^{14}N^{-}$

⇒ no $^{28}Si^{2-}$

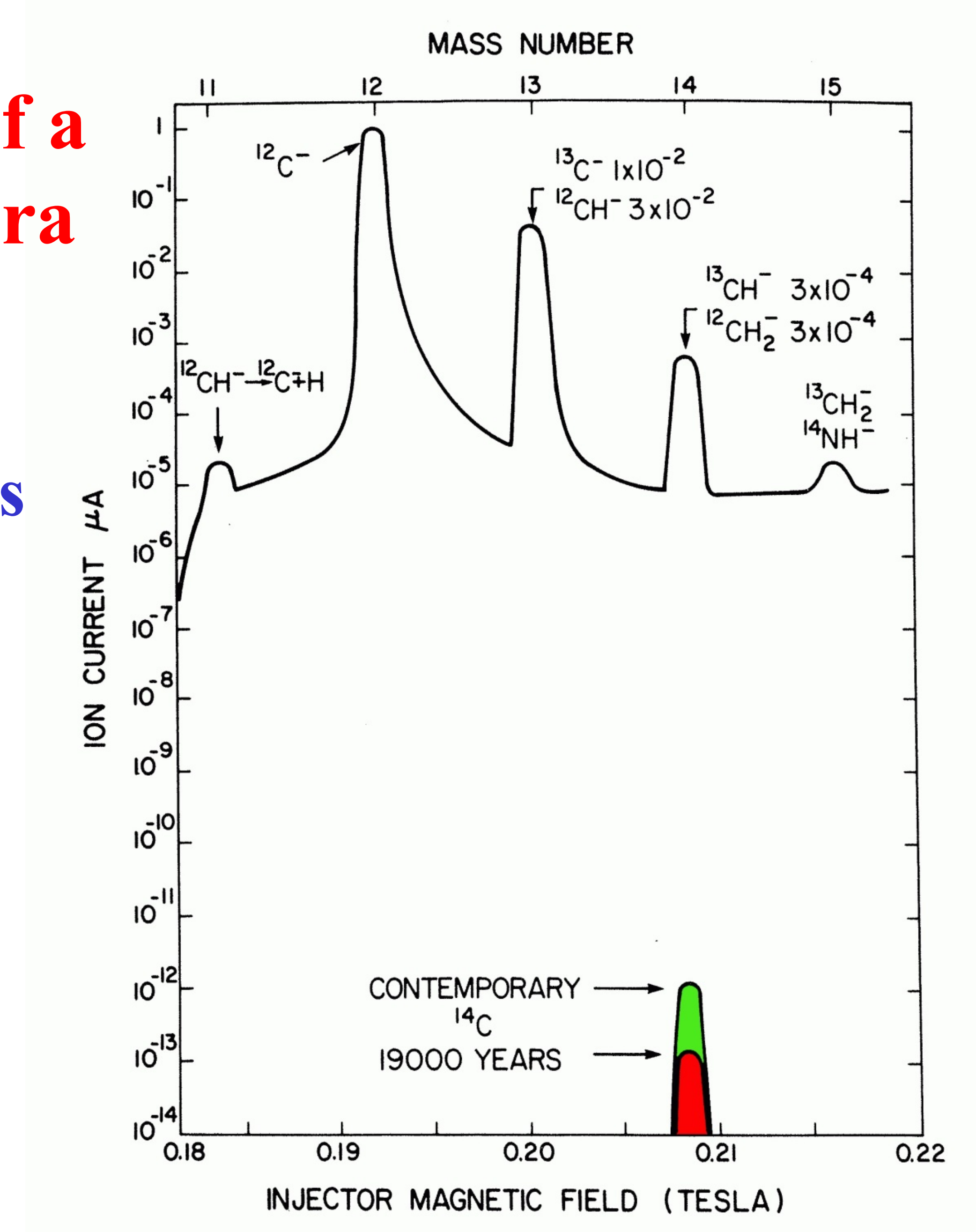


Fig. R.Beukens, Radiocarbon after four decades, Springer-Verlag, 1992

isobaric ions

higher charged ions

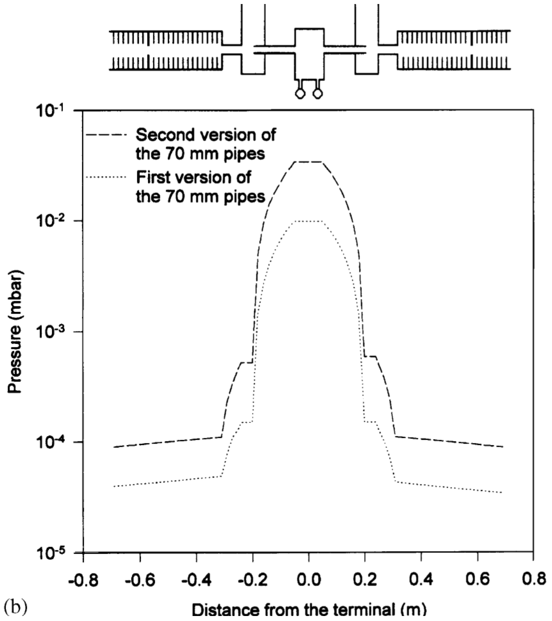
molecular ions

other background

^{14}C intensity

Molecular ions

- ions fly in vacuum (10^{-6} mbar)
- but hit matter at the stripper



(b)

Fig. from P. Person et al., NIM A500 (2003) 55

isobaric ions

higher charged ions

molecular ions

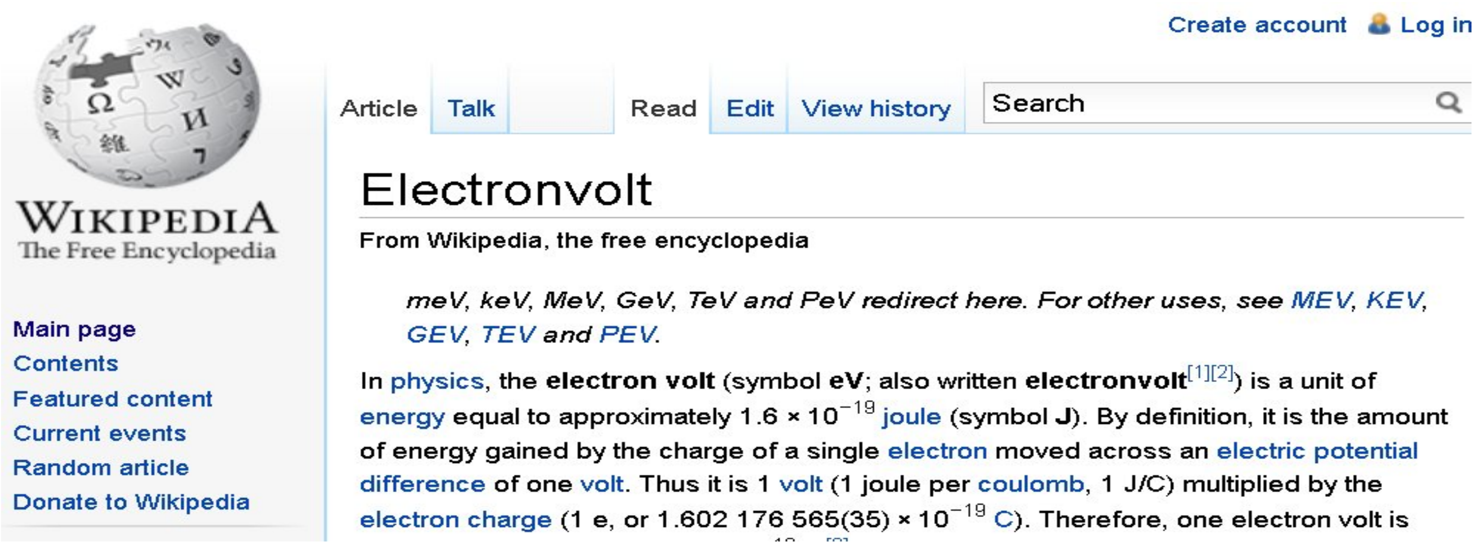
other background

^{14}C intensity

Insertion: energy of ions

Highest efficiency for $^{12}C^{3+}$ is at 2.5 MeV

1 eV = 1.6022 10^{-19} J ➔ 1 MeV = 1.6022 10^{-13} J



Electronvolt

From Wikipedia, the free encyclopedia

meV, keV, MeV, GeV, TeV and PeV redirect here. For other uses, see MEV, KEV, GEV, TEV and PEV.

In physics, the **electron volt** (symbol **eV**; also written **electronvolt**[1][2]) is a unit of energy equal to approximately 1.6 × 10^{-19} joule (symbol **J**). By definition, it is the amount of energy gained by the charge of a single electron moved across an electric potential difference of one volt. Thus it is 1 volt (1 joule per coulomb, 1 J/C) multiplied by the electron charge (1 e, or 1.602 176 565(35) × 10^{-19} C). Therefore, one electron volt is

isobaric ions

higher charged ions

molecular ions

other background

^{14}C intensity

Example ^{14}C with 2.4 MeV in argon

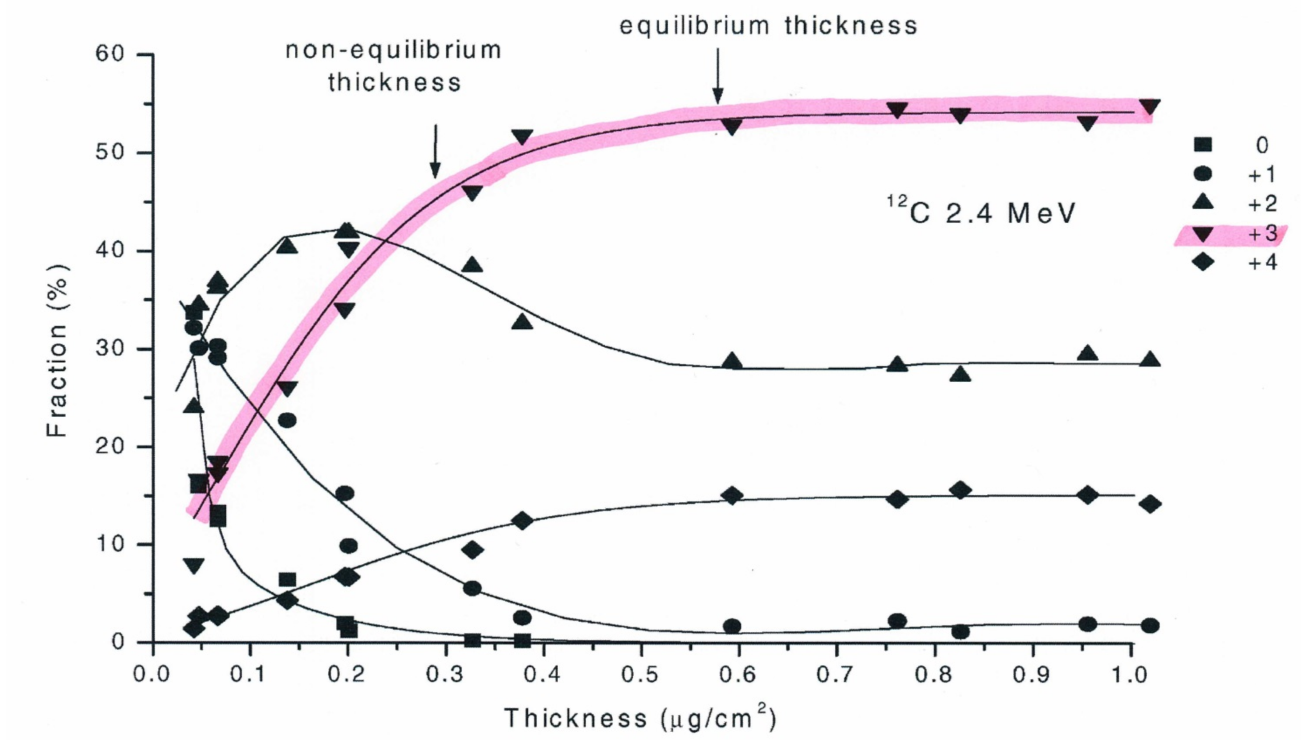


Fig. from M. Kiisk et al. NIM **A481** (2002) 1

isobaric ions

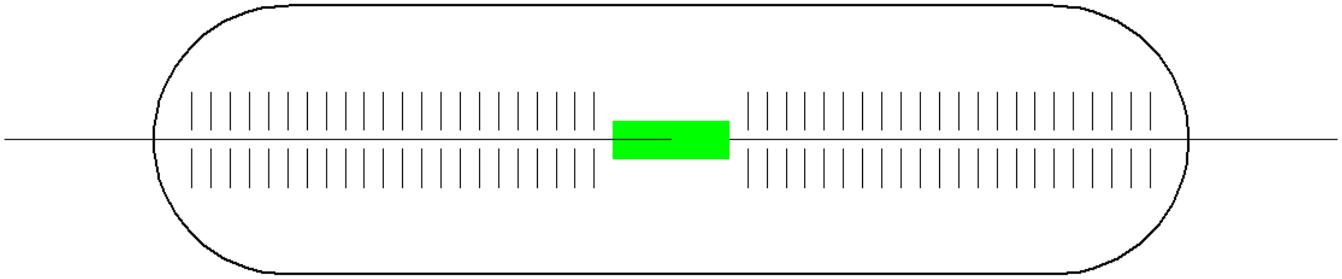
higher charged ions

molecular ions

other background

^{14}C intensity

Insertion: energy of ions



ground potential

incoming
C-
0.035 MeV

potential 2.5 MV

at the stripper
C-
2.5035 MeV

ground potential

C+	5 MeV
C2+	7.5 MeV
C3+	10.0 MeV
C4+	12.5 MeV

Second aim of the stripper:

gaining energy

isobaric ions

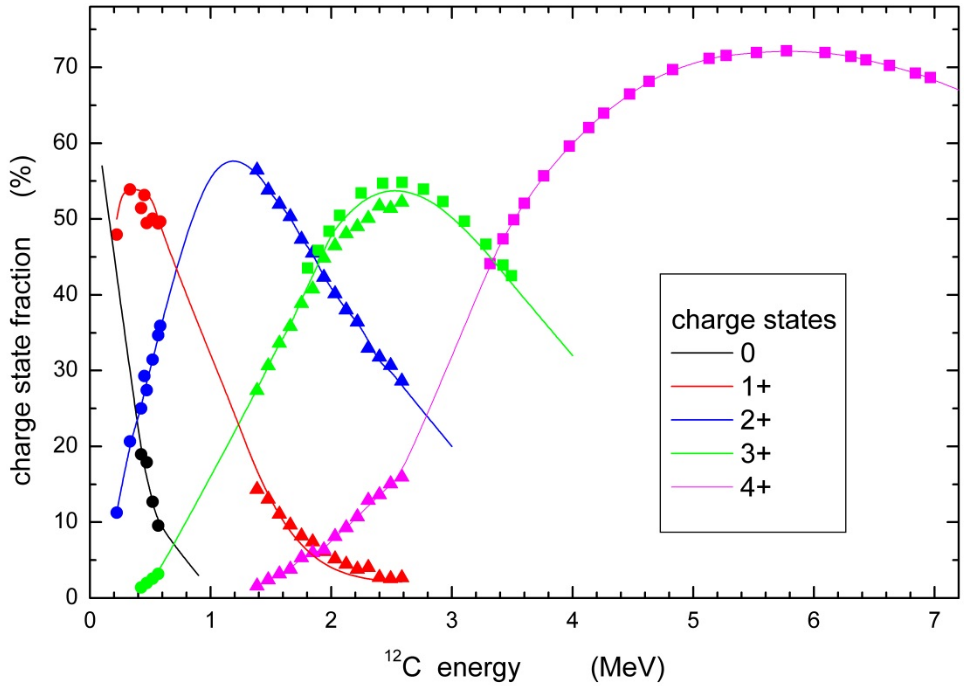
higher charged ions

molecular ions

other background

^{14}C intensity

^{12}C charge states as function of energy (equilibrium thickness)



molecular ions in 3$^+$ charge state break off

⇒ no background contribution

⇒ used at the old Jena AMS system

isobaric ions

higher charged ions

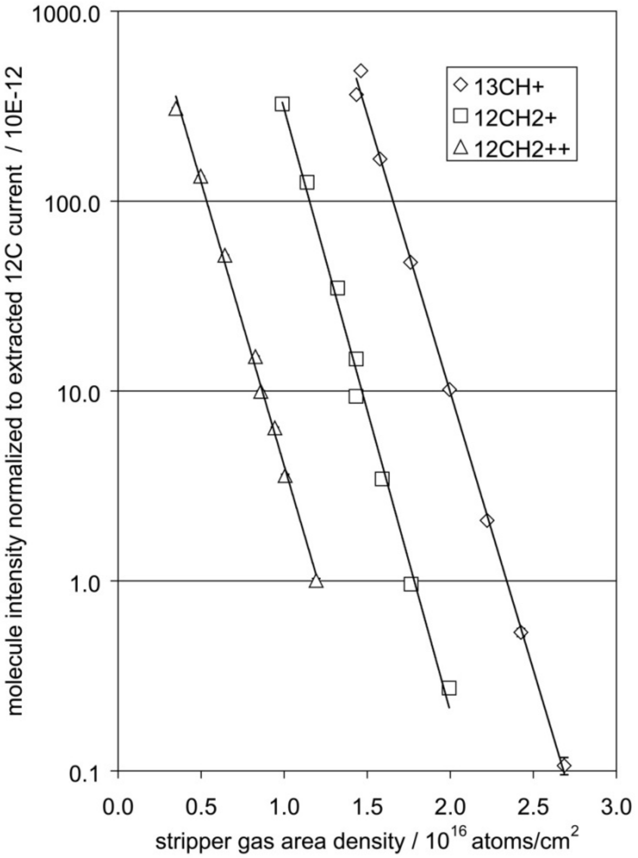
molecular ions

other background

^{14}C intensity

Second way:

molecules are also destroyed by impacts with stripper atoms/molecules



thickness > equilibrium

. thickness for q

side effects:

energy straggling

angular straggling

so why?

isobaric ions

higher charged ions

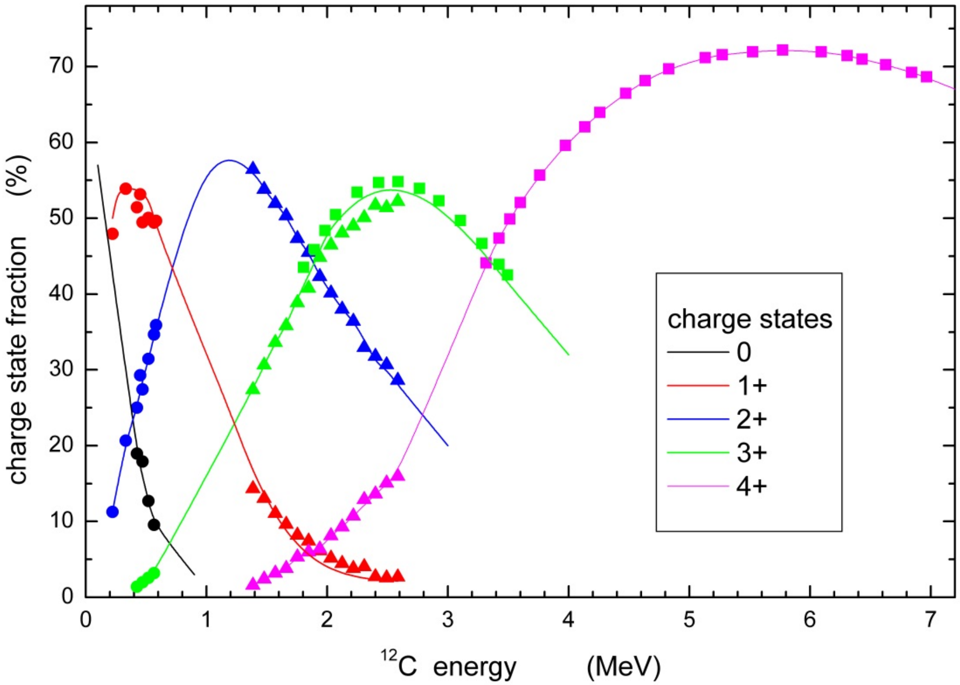
molecular ions

a) charge ≥ 3+

b) thick stripper

other background

^{14}C intensity



no molecules ➔ no 3+ charge state ➔ not 2.5 MeV

AMS systems with terminal voltages of

500 or 200 kV possible !!!

(less costs, less space, less ion optical elements)

isobaric ions

higher charged ions

molecular ions

a) charge ≥ 3+

b) thick stripper

other background

^{14}C intensity

Remark: thickness of strippers

these values have large uncertainties (± 50 % ?)

ion energy	**molecule suppression**	**stripper thickness**
2.5 MeV	3+ charge state	0.6 µg/cm²
500 keV	„thick stipper“	2.2 µg/cm²

table is for argon ➔

1 µg/cm² = 1.5 * 10^{15} atoms/cm² = 5.6 * 10^{-3} mbar m

isobaric ions

higher charged ions

molecular ions

a) charge ≥ 3+

b) thick stripper

other background

^{14}C intensity

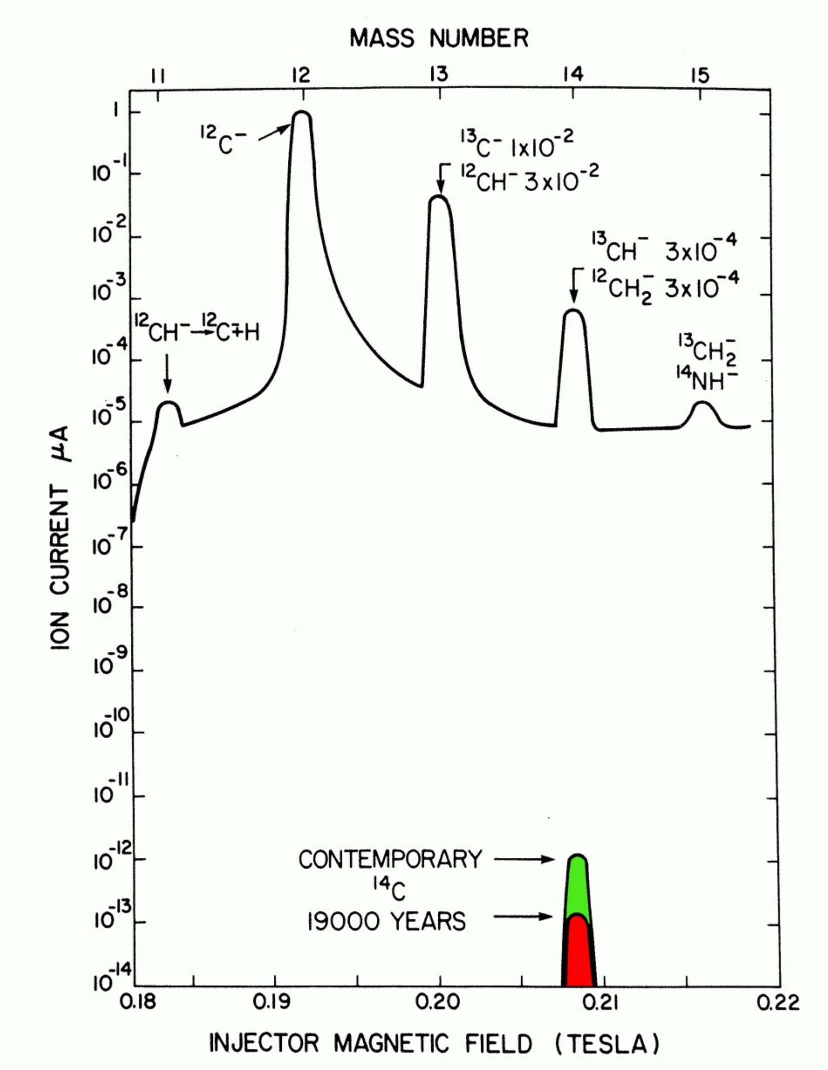
Other background contributions

the start ➔

solved up to 10^{-5}

Other processes to be considered

higher energy reduces tails of peaks



isobaric ions

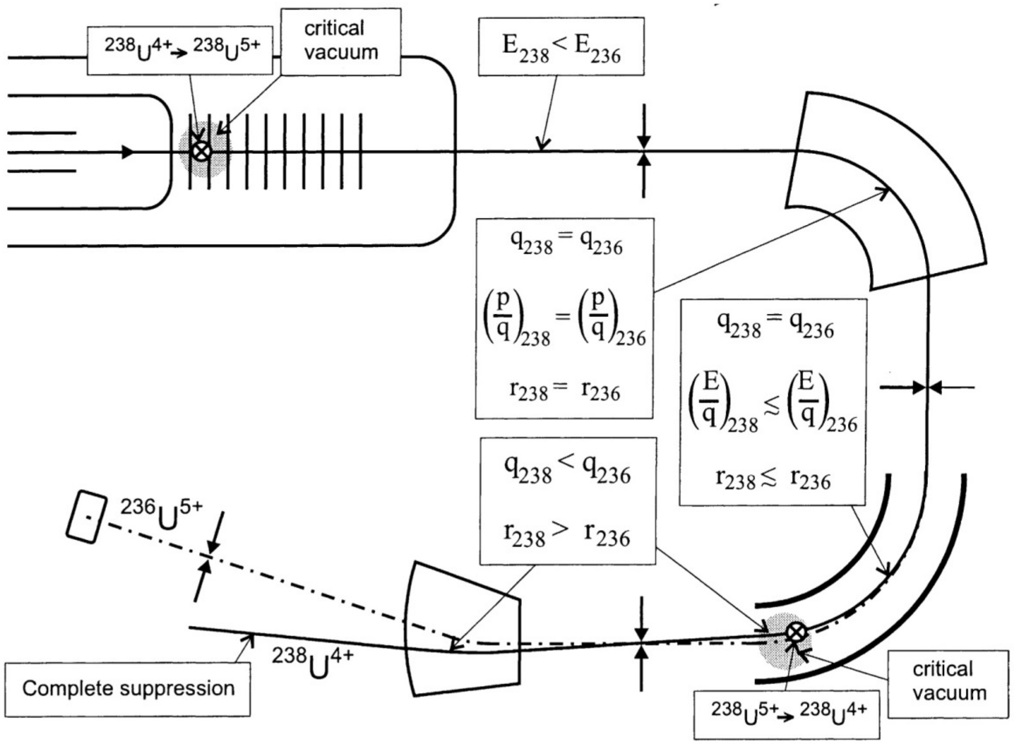
higher charged ions

molecular ions

other background

^{14}C intensity

example for background:



two „unlikely“ processes

but relevant for an *IR* of 10^{-12}

isobaric ions

higher charged ions

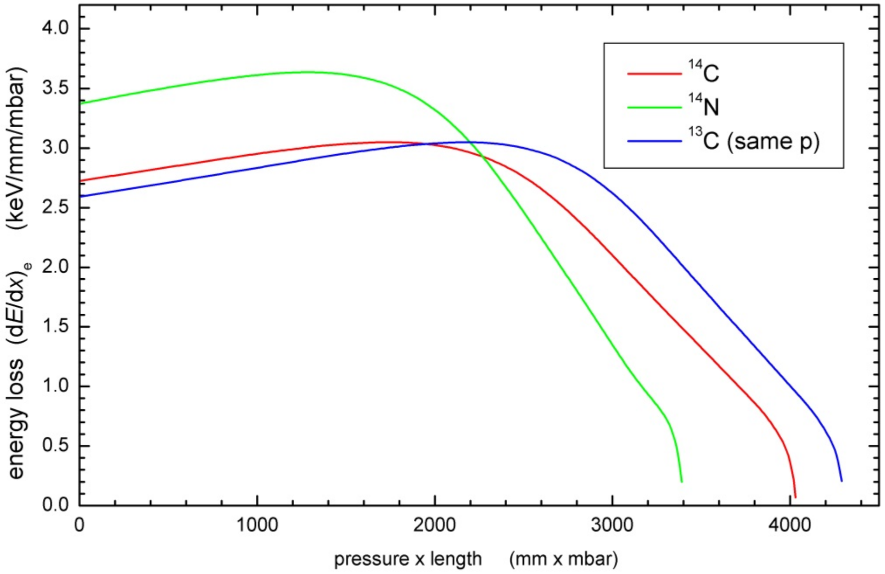
molecular ions

other background

^{14}C intensity

One solution is the detector

energy loss of ions in matter depends on the ion & its energy



isobaric ions

higher charged ions

molecular ions

other background

^{14}C intensity

Detector

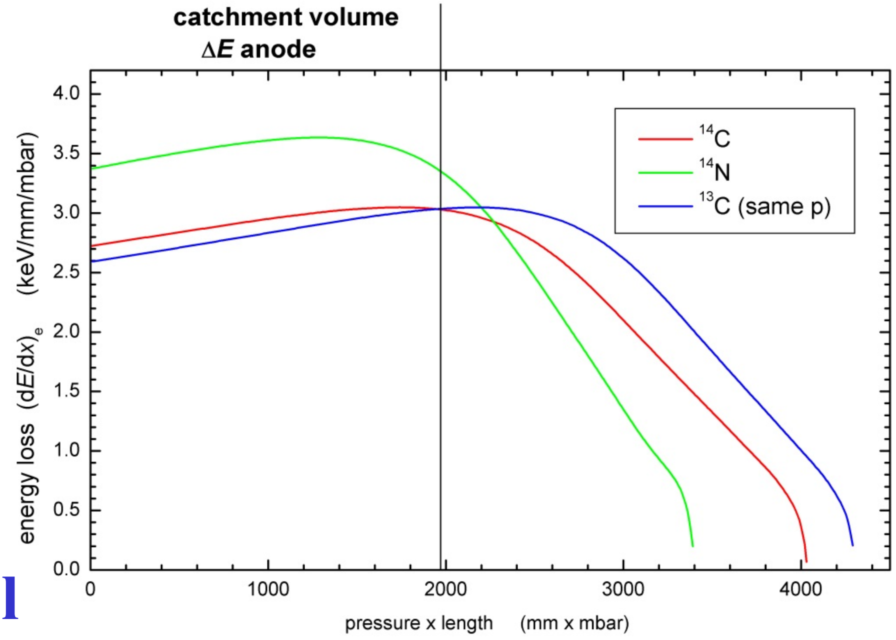
ionisation chamber

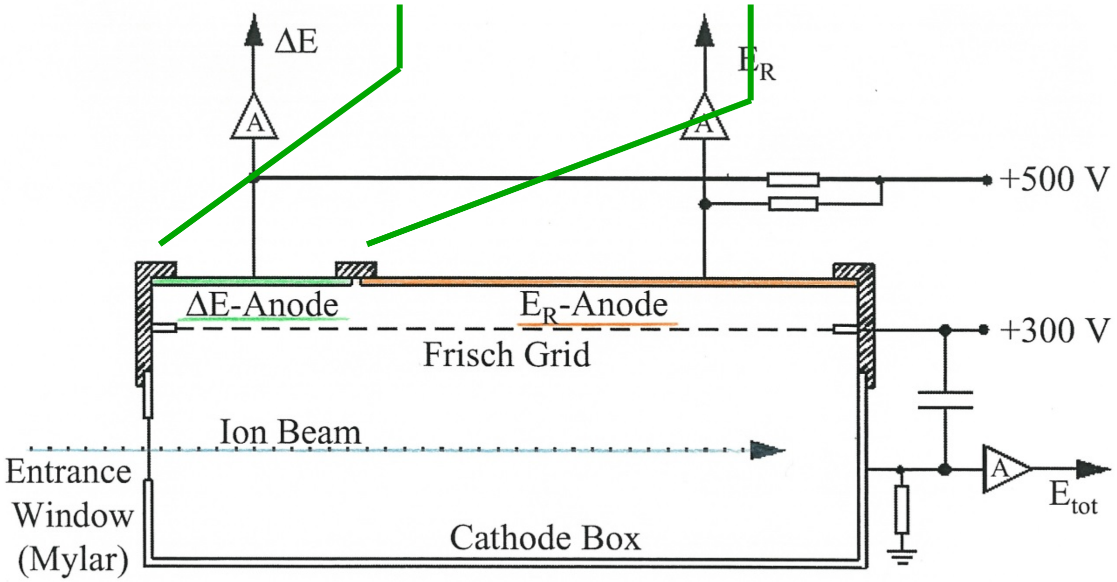
signal ~ energy loss

more precise:

signal

~ energy loss integral





isobaric ions

higher charged ions

molecular ions

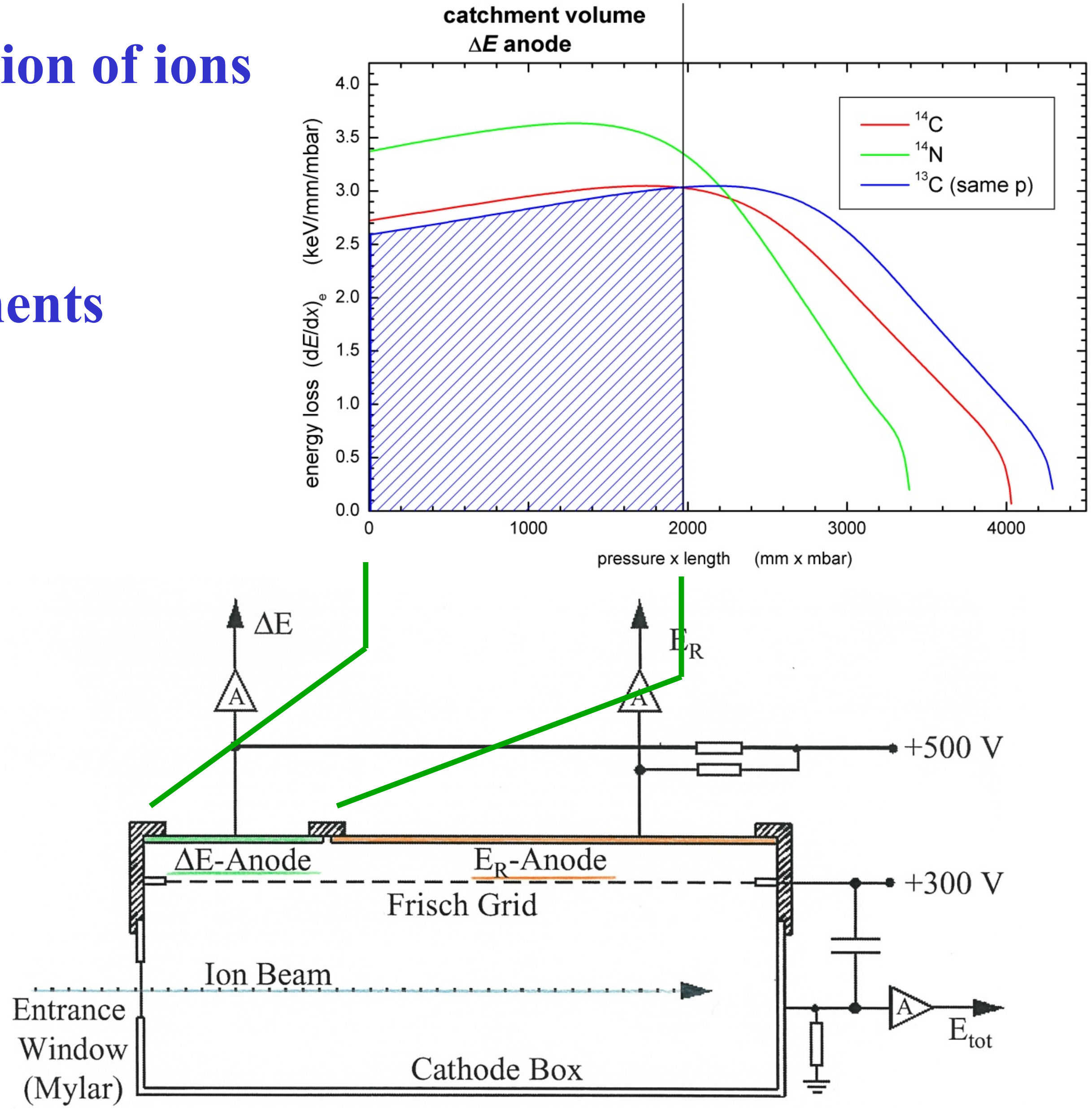
other background

^{14}C intensity

Detector

identification of ions in

$(\Delta E, E_{res})$ measurements



isobaric ions

higher charged ions

molecular ions

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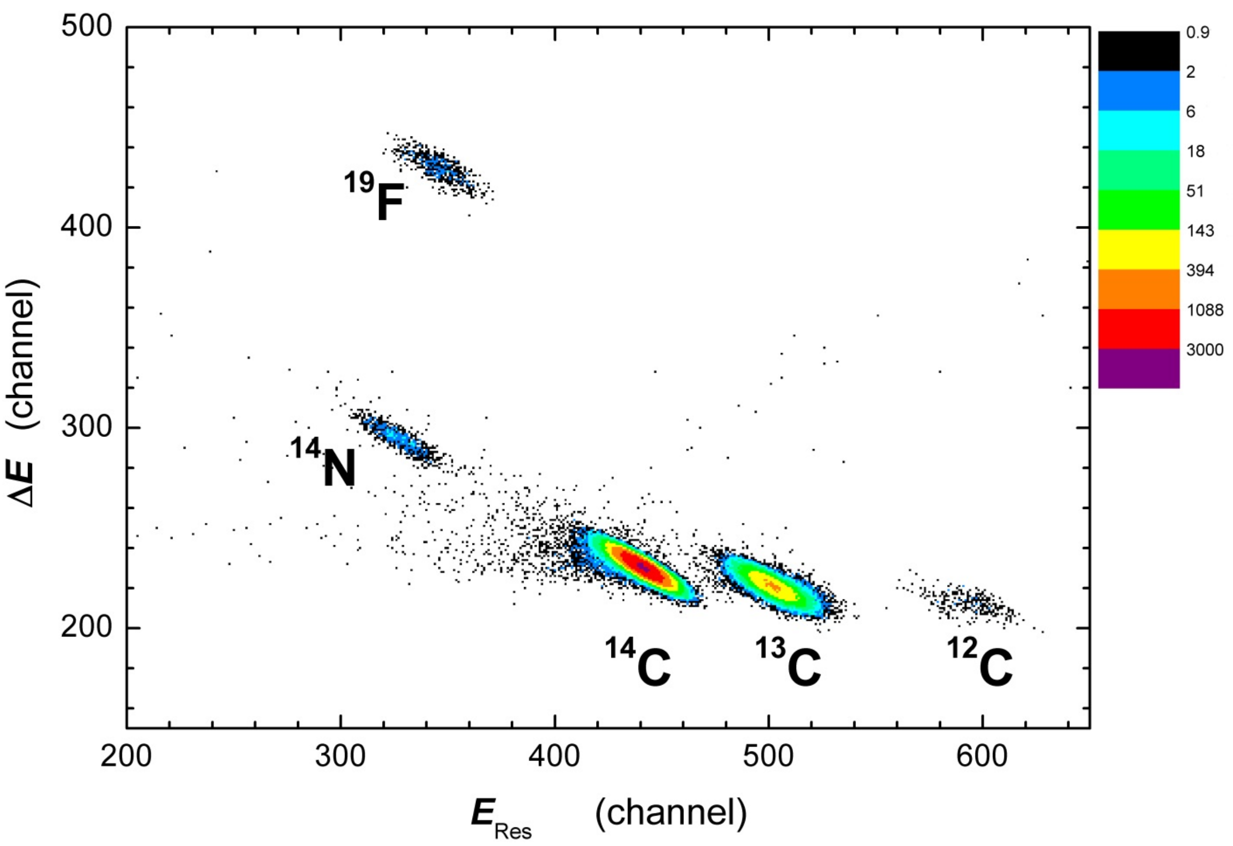
^{14}C intensity

Detector



single ion counting ➔ ^{14}C intensity no problem

(ΔE, E_{Res}) not required

isobaric ions

higher charged ions

molecular ions

other background

^{14}C intensity

14C - AMS

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^{14}C concentrations

lesson learned: identification of ^{14}C

wanted ^{14}C concentrations = ^{14}C / ^{12}C

trick: measurement of the ^{12}C current

like weighing paper-clips

instead of counting them

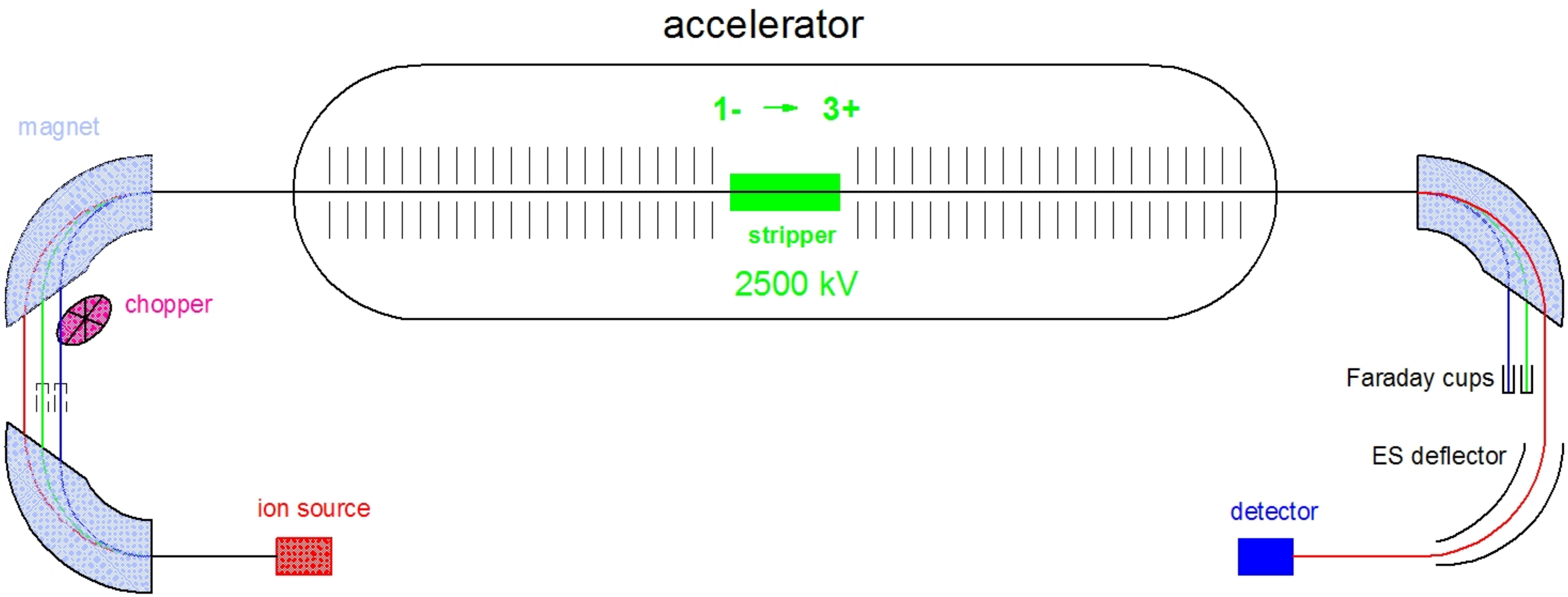
$$ {}^{14}\mathrm{C} \quad \text{concentration} \ \propto \ \frac{{}^{14}\mathrm{C} \ \ \text{events}}{\int I_{12C}(t)\,\mathrm{d}t} $$

sensitivity of AMS

10µA (q = 1) ~ 6.2 * 10^{13} ions/s = 2.2 * 10^{17} ions/h

if *IR* = 10^{-12} ➔ 2 * 10^{5} ^{14}C / h

dedicated ^{14}C-AMS set-up



this scheme correspond to the old Jena AMS facility

another dedicated ^{14}C-AMS set-up

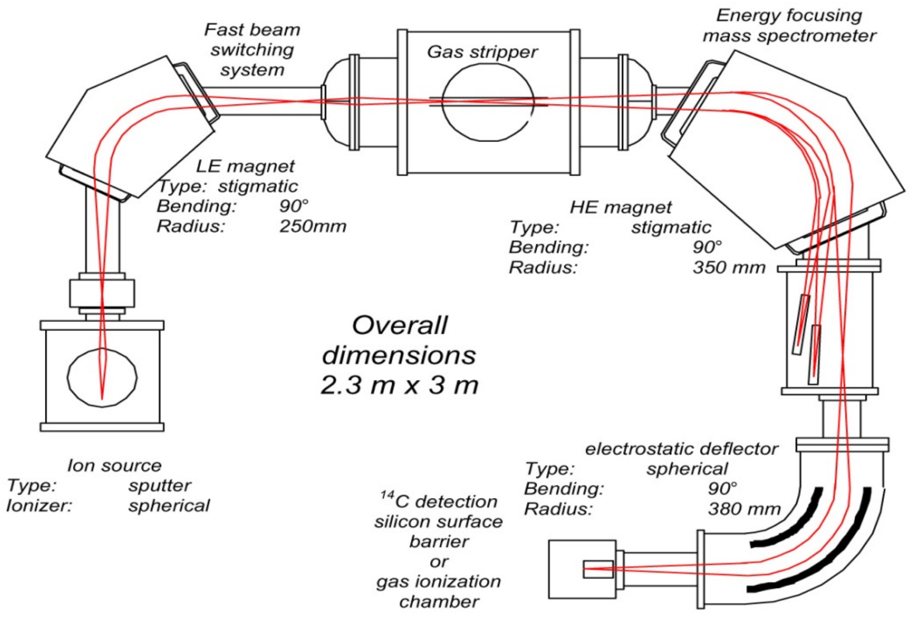


Fig. from H.A. Synal et al., NIM B259 (2007) 7

This figure shows the MICADAS, a system working with 200 kV terminal voltage

There are other major differences amoung the both AMS systems, e.g. the way to send the ^{12}C, ^{13}C, and ^{14}C ions to the high energy side:

Sequential and simultaneous injection

Indirect influence on performance through design requirements on beamline and magnets.

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Remarks for the user

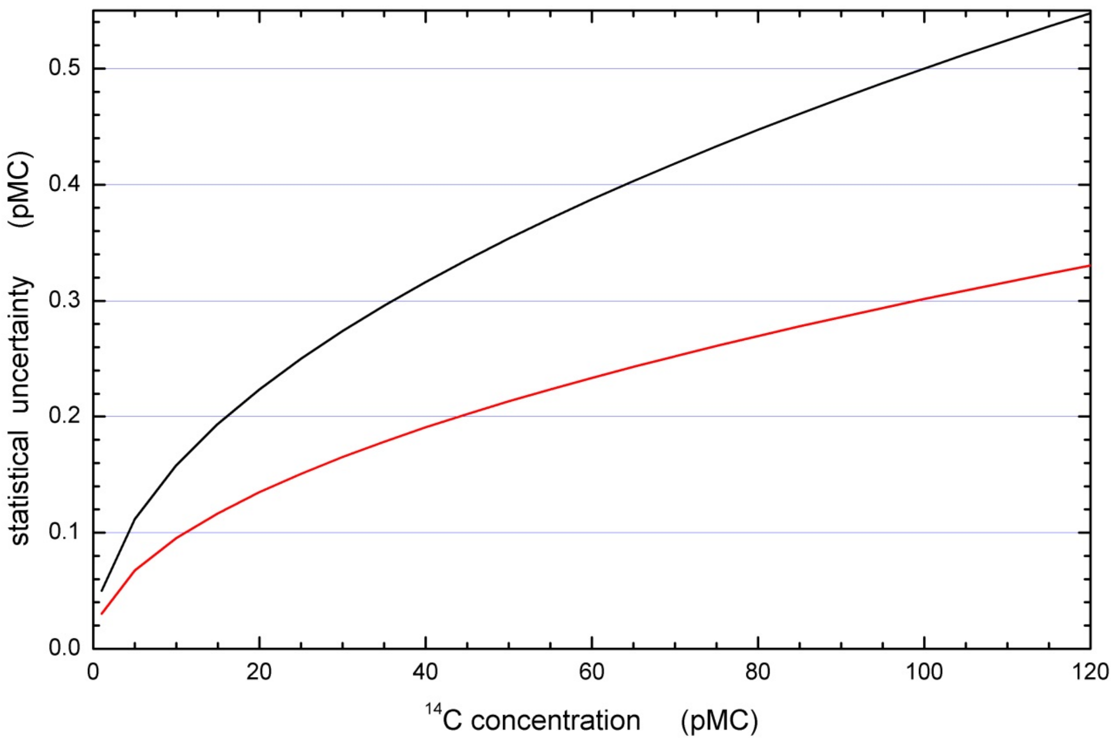
- A ^{14}C result is not a number ! Its a value and an uncertainty !!!
- Not all labs perform all chemical pretreatments
- For **normal** requirements the AMS system do not matter.
- What is „normal“ ?

feature	normal	very good
uncertainty of modern samples	0.5 pMC	0.25 pMC
background of processed sample	0.4 pMC	0.2 pMC
sample mass	1 mg	10 µg

Different (background) notations:

0.2 pMC = 0.002 F^{14}C = 2.4 10^{-15} ^{14}C/^{12}C = 50 000 yrs BP „conv. age“

Uncertainties quoted mostly for 100 pMC with simple math (only statistical uncertainty):



uncertainty based on same effort

Black 0.5 pMC @ 100pMC

Red 0.3 pMC @ 100pMC

Thank you for your attention !

Tours at combustion lab and AMS system:
at the respective dates
out of the elevator at ground floor,
to the left, door with sign „^{14}C-Analytik“