Nuclear Astrophysics with **A**ccelerator **M**ass **S**pectrometry (**AMS**)

Georg Rugel
working (now) at
Helmholtz-**Z**entrum **D**resden-**R**ossendorf (HZDR)
@ FWIR: Accelerator Mass Spectrometry & Isotope Research
measuring (now) @DREAMS (**DRE**sden **AMS**)

17th Rußbach School on Nuclear Astrophysics, 2022 March 13th-19th

Overview

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

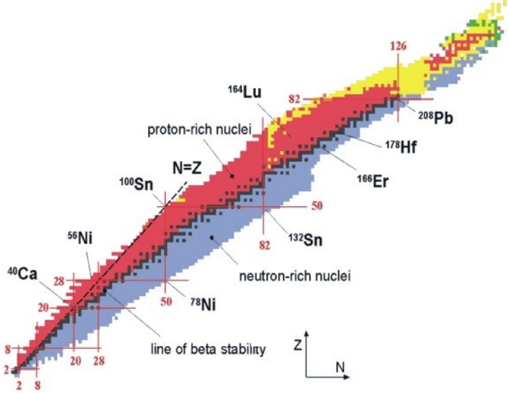
- Applications of AMS to Astrophysics
  some examples (only very brief)

Application
Astrophysics

HST Crab Nebula

Crab nebula ~ 2000 pc

Near-Earth Supernova
~ 100 pc   1 pc ~ 3 Lyr



Messengers:

Radionuclides

DREAMS
(**DRE**sden **AMS**)

Detectives:

Accelerator **M**ass **S**pectrometry
(measure rare isotopes)

MLL
AMS
at TU Munich

Accelerator **M**ass **S**pectrometry

Counting individual atoms (like conventional **MS**)

But

Logo of operators Rossendorf

- accelerator (mostly a tandem – but new developments)
- molecules destroyed by stripping
- challenge: isobar separation

techniques: e.g. gas-filled magnet (GFM), degrader foil, + detector (ionisation chamber)

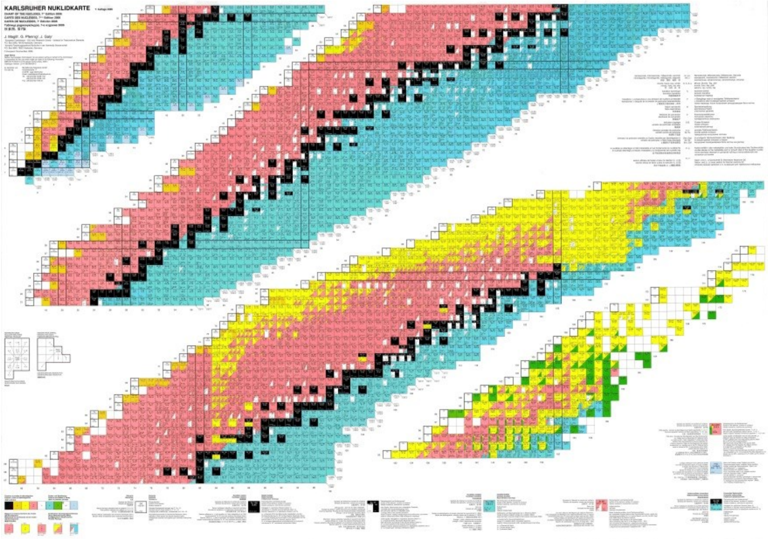
- mostly for radionuclides
- extremely sensitive (isotopic ratio ~ 10^{-16})

Historical

1939 Alvarez and Cornog discovered accidentally ^{3}He (cyclotron).
From 1939 until 1977, for around 40 years, dark and silent!

1977 Muller proposed to measure ^{14}C or ^{10}Be by means of a cyclotron.
Independently, Gove, Litherland, and Purser suggested the use of a Tandem accelerator for ^{14}C measurements.

2020 Much more than 100 AMS laboratories worldwide.
From small table top accelerators until large facilities with more than 10 MV terminal voltage.
Isotopes of interest from ^{3}H until the heaviest nuclides like ^{244}Pu.



The majority of AMS laboratories is dedicated to ^{14}C and ^{10}Be.

Every 3 years AMS conference:
2021 online (Sydney) –
A lot of new ideas, developments!

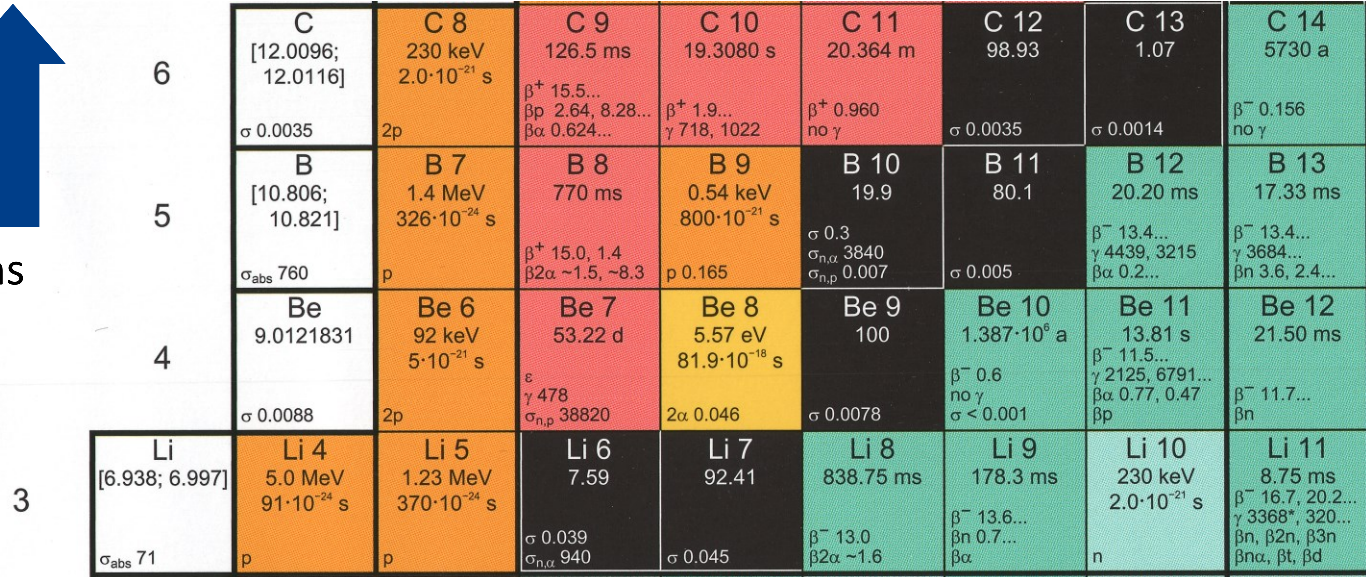
Why Accelerator Mass Spectrometry (AMS)? We are impatient scientists …

- Long-lived radionuclides ($T_{1/2}$ ~ millions of years)
- Isotopic ratios (radio/stable)
- Decay counting too long
- Count atoms instead
- AMS most sensitive technique

# of neutrons

# of protons

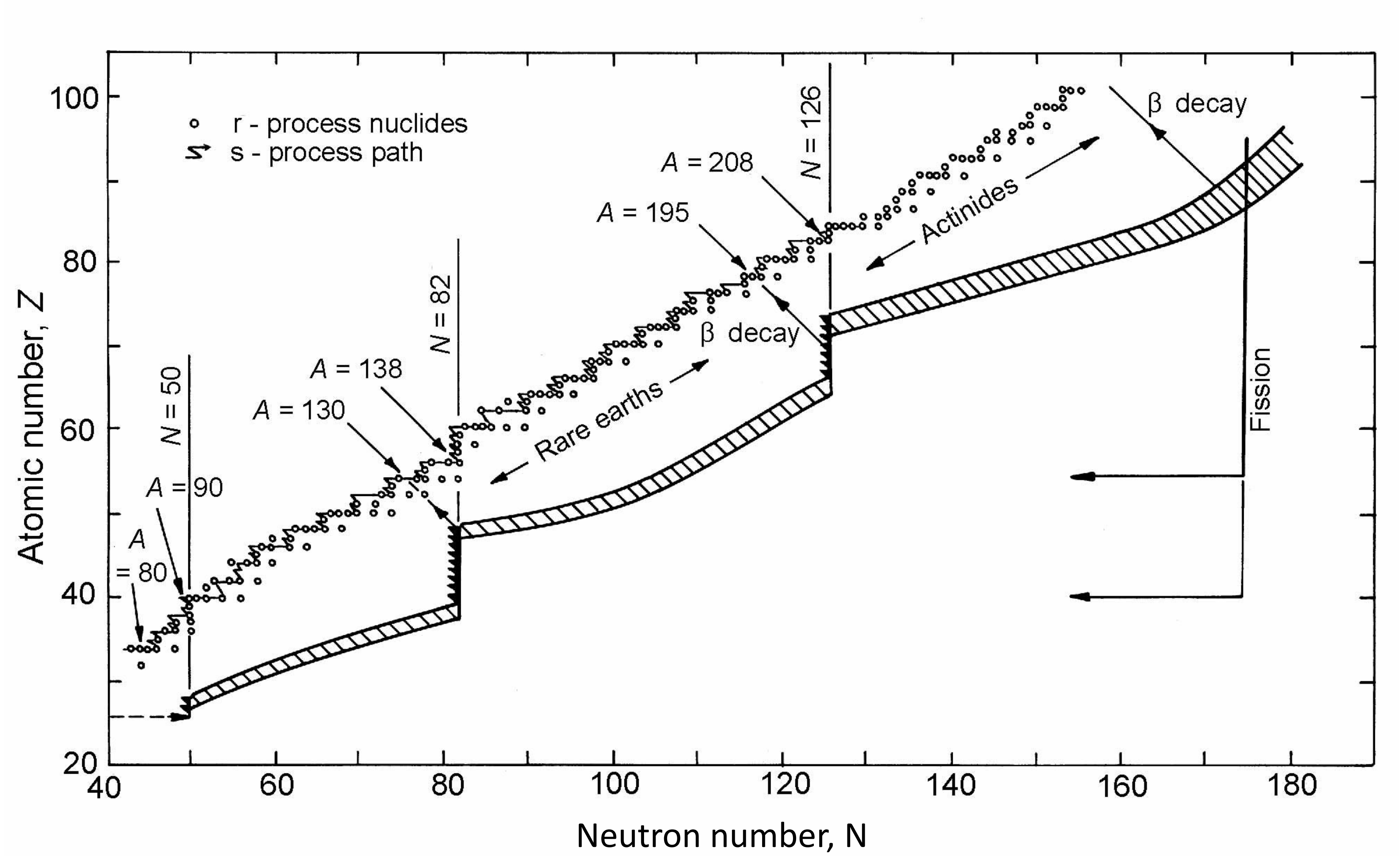
Mass #



	6	C [12.0096; 12.0116] σ 0.0035	C 8 230 keV $2.0\cdot10^{-21}$ s 2p	C 9 126.5 ms β^+ 15.5... βp 2.64, 8.28... $\beta\alpha$ 0.624...	C 10 19.3080 s β^+ 1.9... γ 718, 1022	C 11 20.364 m β^+ 0.960 no γ	C 12 98.93 σ 0.0035	C 13 1.07 σ 0.0014	C 14 5730 a β^- 0.156 no γ
	5	B [10.806; 10.821] σ_{abs} 760	B 7 1.4 MeV $326\cdot10^{-24}$ s p	B 8 770 ms β^+ 15.0, 1.4 $\beta2\alpha$ ~1.5, ~8.3	B 9 0.54 keV $800\cdot10^{-21}$ s p 0.165	B 10 19.9 σ 0.3 $\sigma_{n,\alpha}$ 3840 $\sigma_{n,p}$ 0.007	B 11 80.1 σ 0.005	B 12 20.20 ms β^- 13.4... γ 4439, 3215 $\beta\alpha$ 0.2...	B 13 17.33 ms β^- 13.4... γ 3684... βn 3.6, 2.4...
	4	Be 9.0121831 σ 0.0088	Be 6 92 keV $5\cdot10^{-21}$ s 2p	Be 7 53.22 d ε γ 478 $\sigma_{n,p}$ 38820	Be 8 5.57 eV $81.9\cdot10^{-18}$ s 2α 0.046	Be 9 100 σ 0.0078	Be 10 $1.387\cdot10^{6}$ a β^- 0.6 no γ $\sigma < 0.001$	Be 11 13.81 s β^- 11.5... γ 2125, 6791... $\beta\alpha$ 0.77, 0.47 βp	Be 12 21.50 ms β^- 11.7... βn
3	Li [6.938; 6.997] σ_{abs} 71	Li 4 5.0 MeV $91\cdot10^{-24}$ s p	Li 5 1.23 MeV $370\cdot10^{-24}$ s p	Li 6 7.59 σ 0.039 $\sigma_{n,\alpha}$ 940	Li 7 92.41 σ 0.045	Li 8 838.75 ms β^- 13.0 $\beta2\alpha$ ~1.6	Li 9 178.3 ms β^- 13.6... βn 0.7... $\beta\alpha$	Li 10 230 keV $2.0\cdot10^{-21}$ s n	Li 11 8.75 ms β^- 16.7, 20.2... γ 3368*, 320... βn, $\beta2n$, $\beta3n$ $\beta n\alpha$, βt, βd

Part of the chart of nuclides, 9th edition, 2015

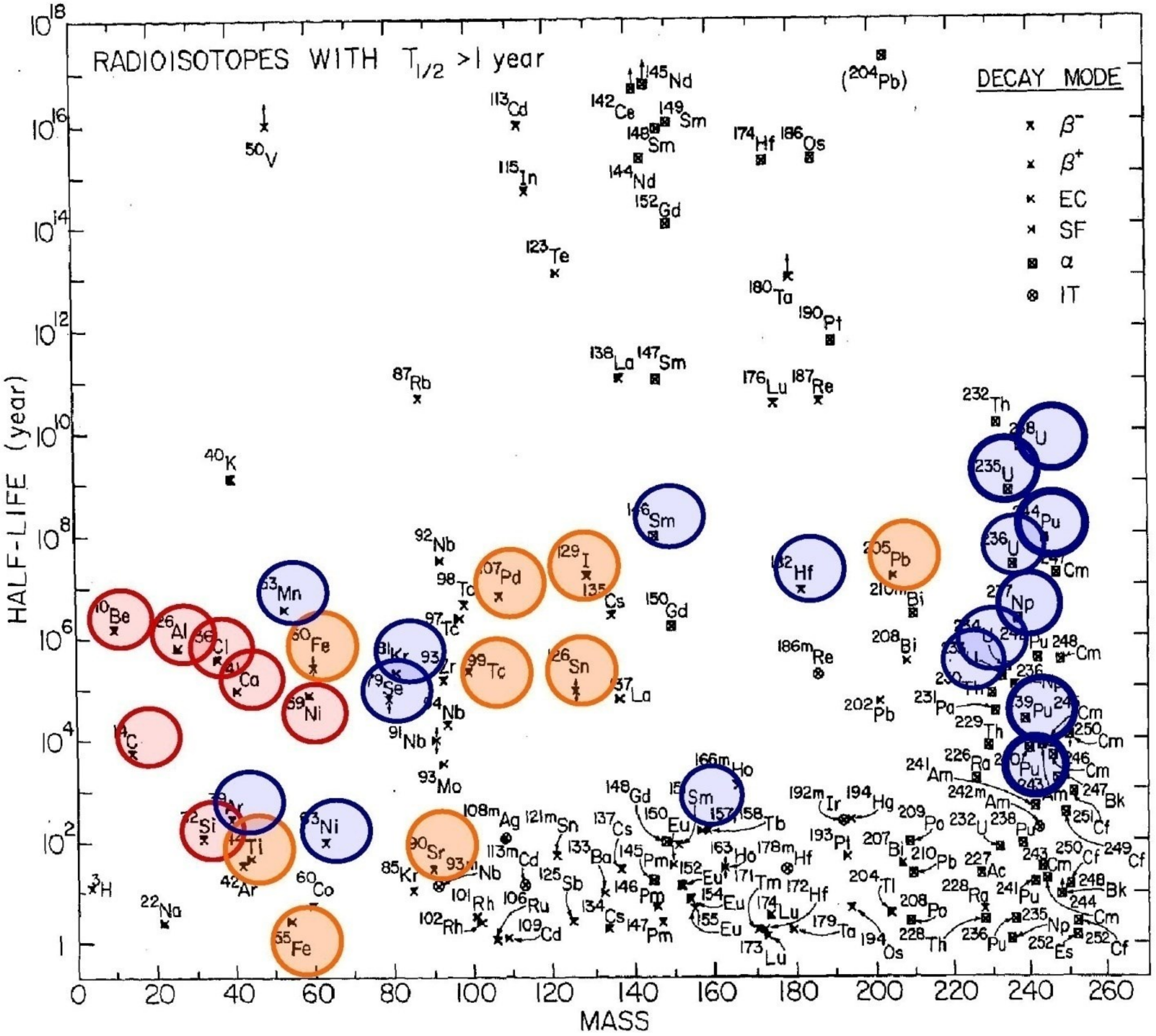
Nucleosynthesis



Radiogenic Isotope Geology
Alan P. Dickin, Cambridge University Press; radiogenic.com

after Seeger et al. (1965)

Radionuclides detected by AMS



Status
1981
^{10}Be, ^{14}C, ^{26}Al,
^{32}Si, ^{36}Cl,
^{41}Ca, ^{59}Ni

Status
1996
+9 new
isotopes

Status
2008
+17 more
new isotopes

Fig. 4 from D.Fink, NIM B 268, 2010
modified/updated from W. Kutschera 1981

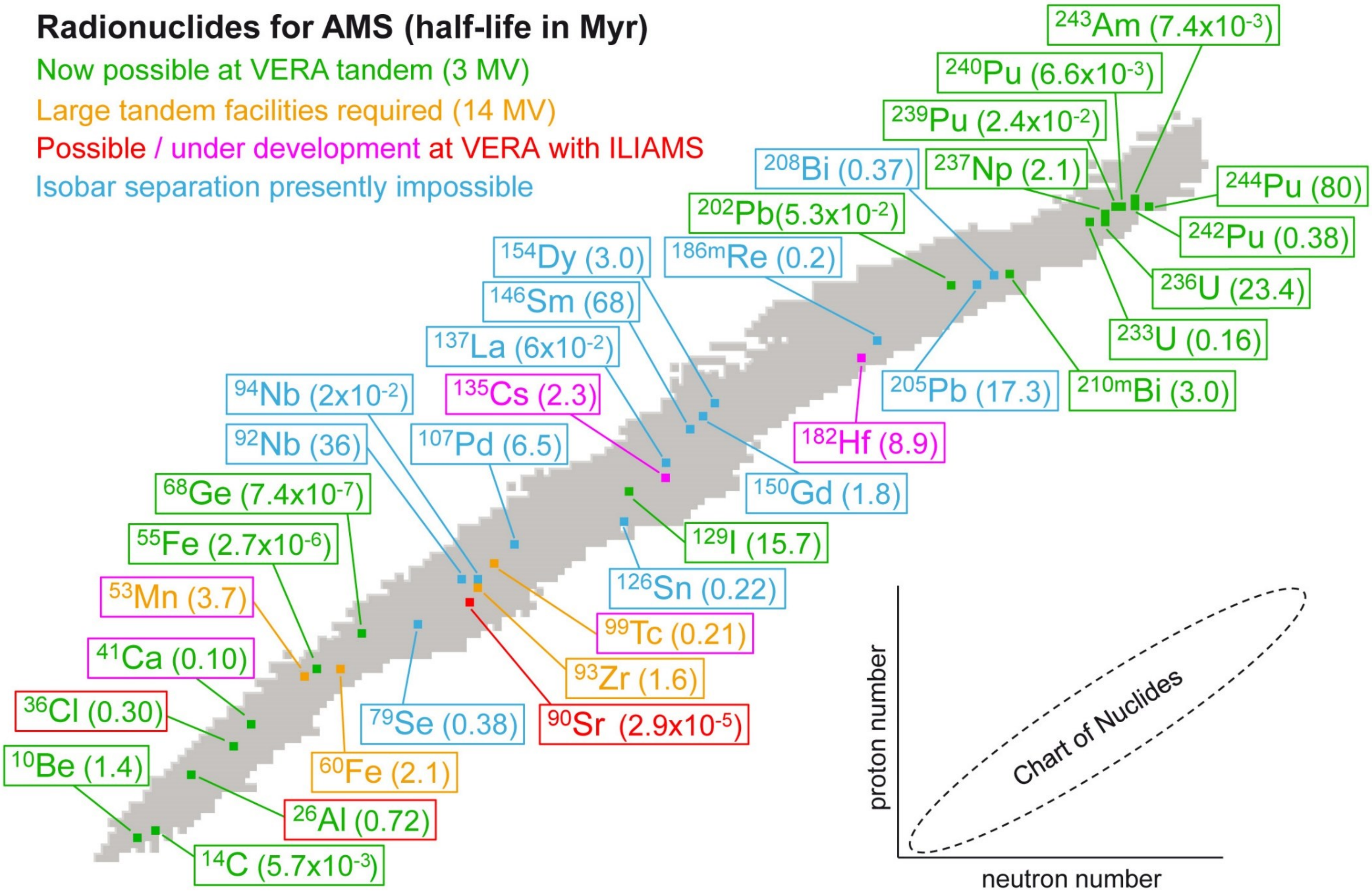
Radionuclides for AMS (half-life in Myr)

Now possible at VERA tandem (3 MV)

Large tandem facilities required (14 MV)

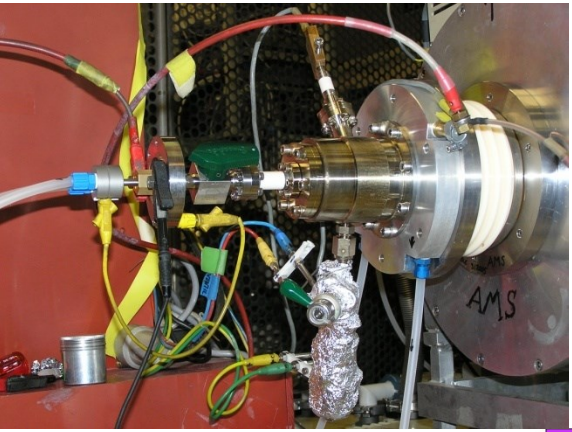
Possible / under development at VERA with ILIAMS

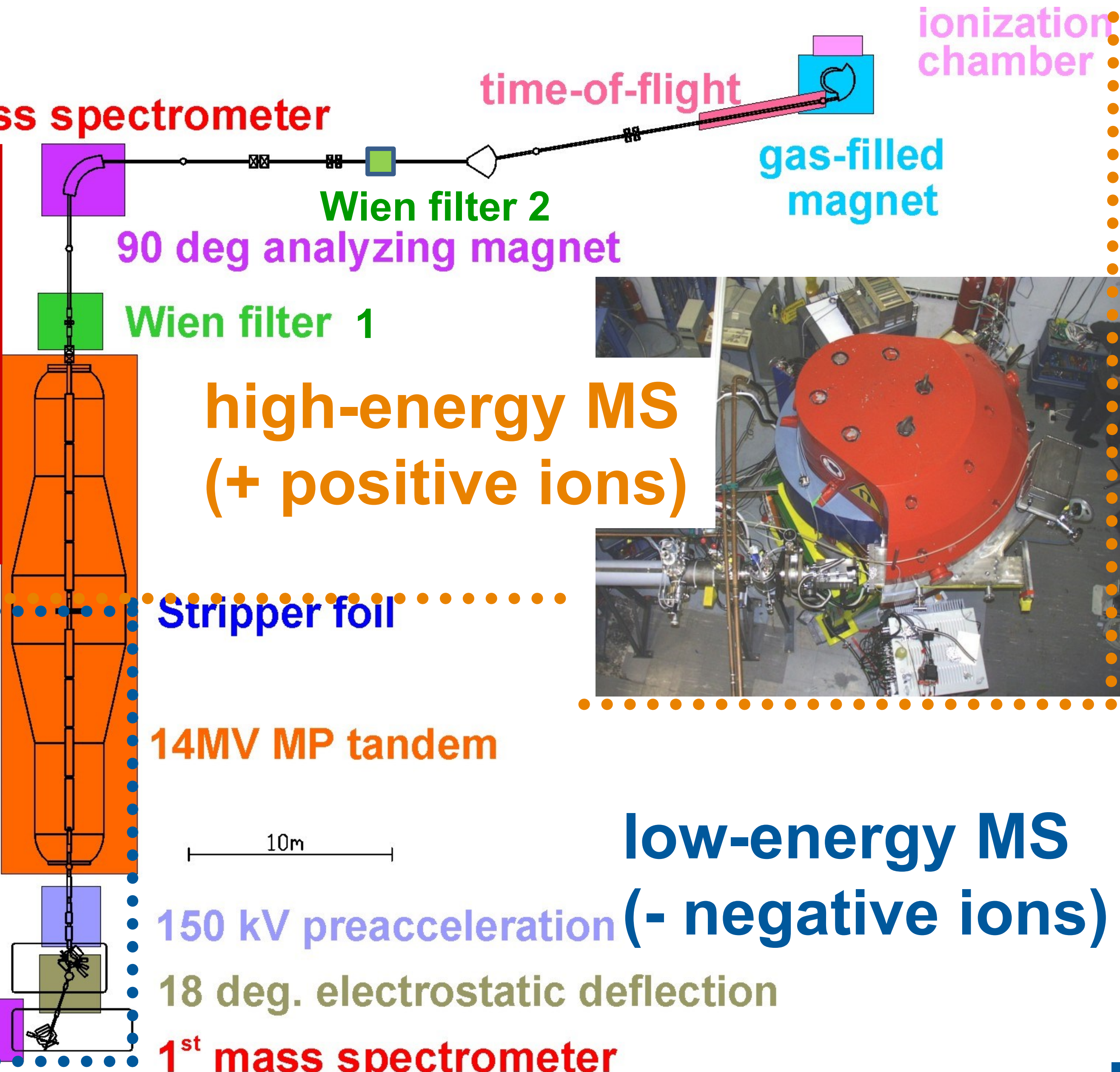
Isobar separation presently impossible



From VERA

AMS Setup at Munich





ionization chamber

time-of-flight

2nd mass spectrometer

gas-filled magnet

Wien filter 2

90 deg analyzing magnet

Wien filter 1

high-energy MS
(+ positive ions)

Stripper foil

14MV MP tandem

10m

low-energy MS
(- negative ions)

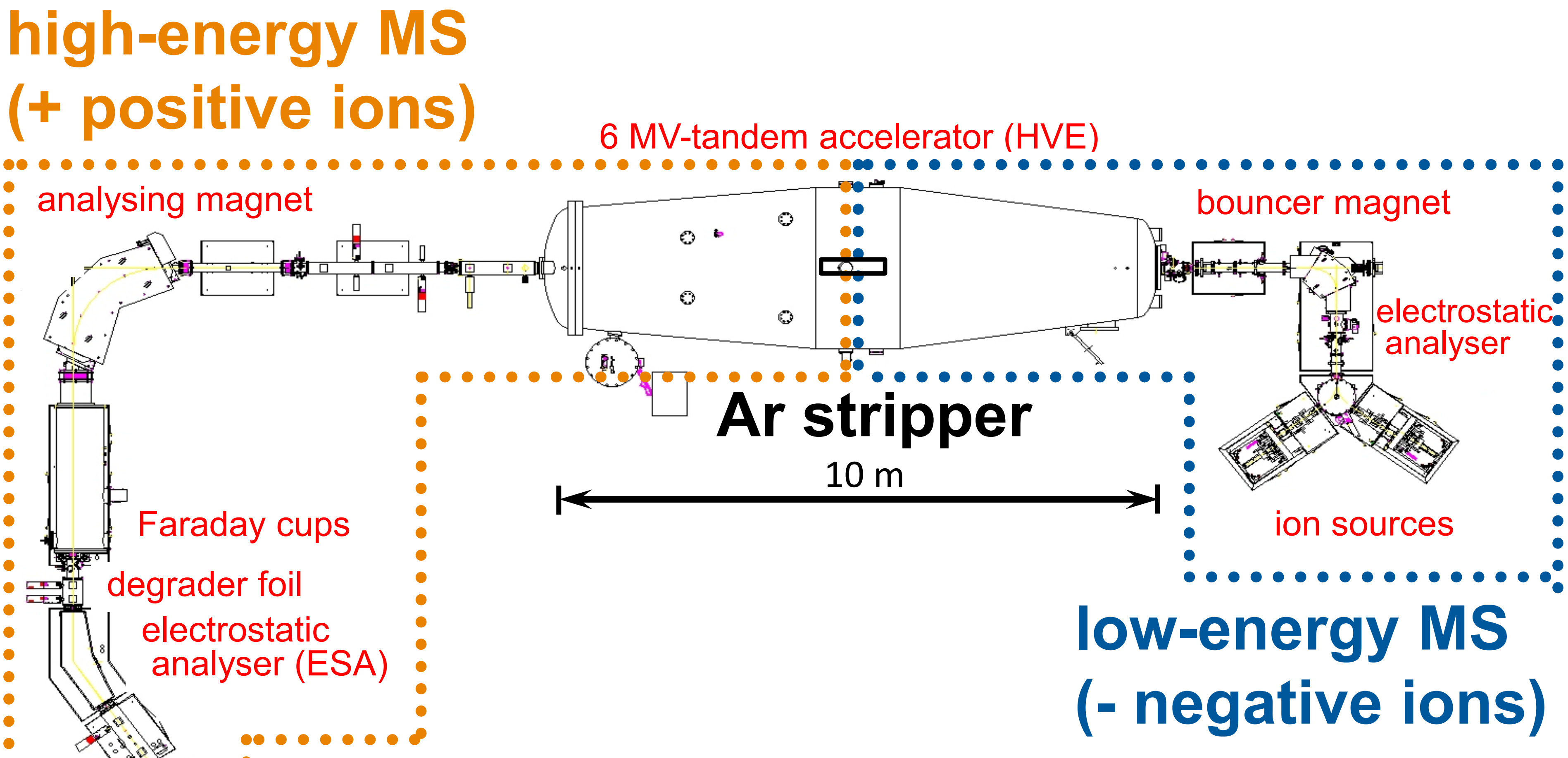
150 kV preacceleration

18 deg. electrostatic deflection

Negative ion source

1st mass spectrometer

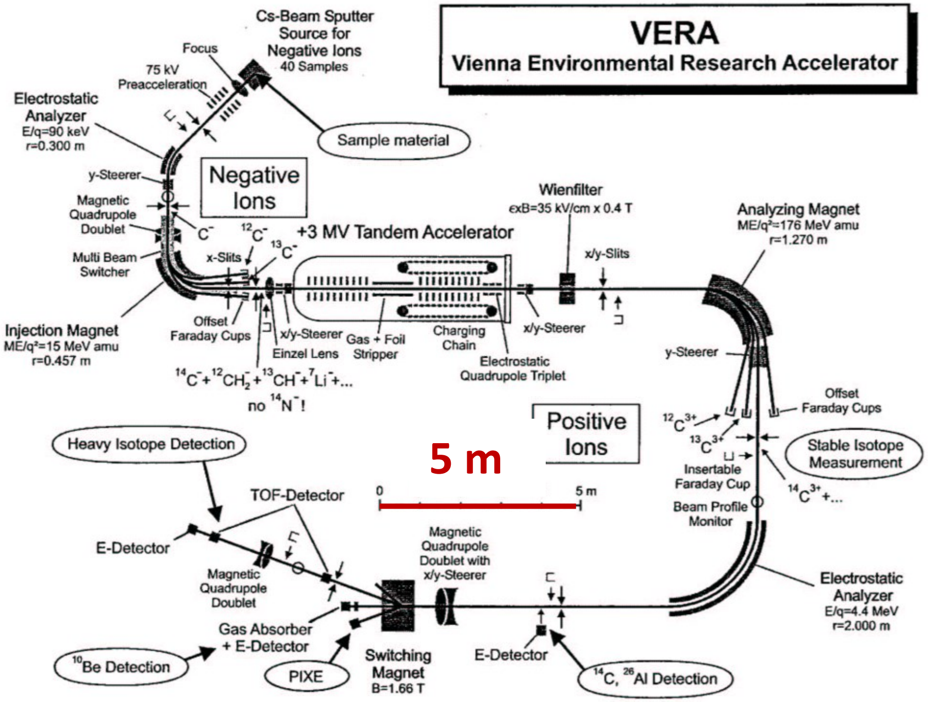
DREAMS - DREsden AMS



Separation by
nuclear charge and mass
no ~~molecules~~ no ~~isobars~~

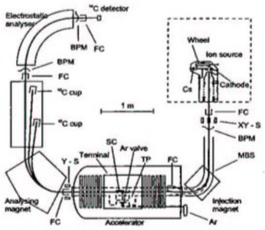
Akhmadaliev et al., NIMB, 2013.; Rugel et al., NIMB, 2016.

AMS Facilities
max. voltages: 3 MV; 0.5 MV; 0.2 MV



Standard AMS, TV = 3 MV
16 m x 12 m = 192 m²

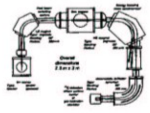
Vienna



Compact AMS, TV = 0.5 MV
6 m x 5 m = 30 m²

Poznan

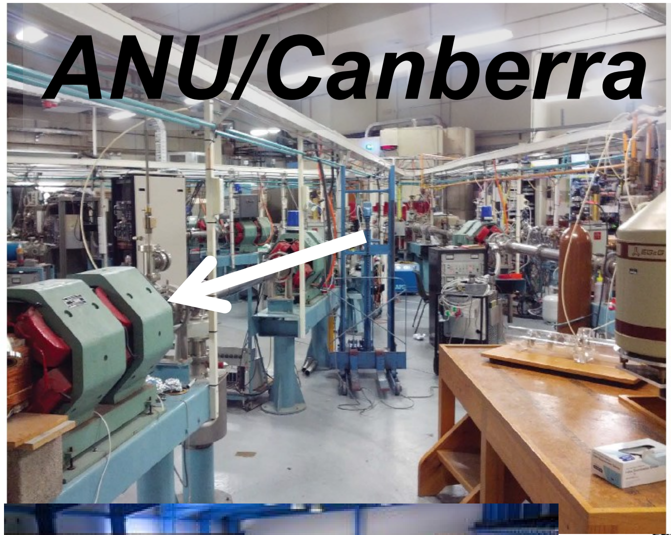
→



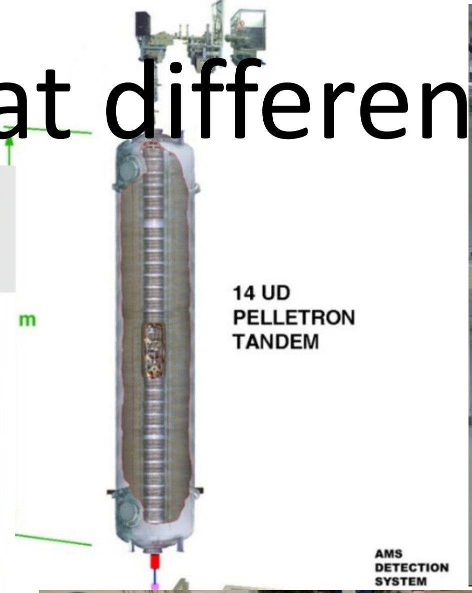
Mini AMS, TV = 0.2 MV
3.0 m x 2.3 m = 6.9 m²

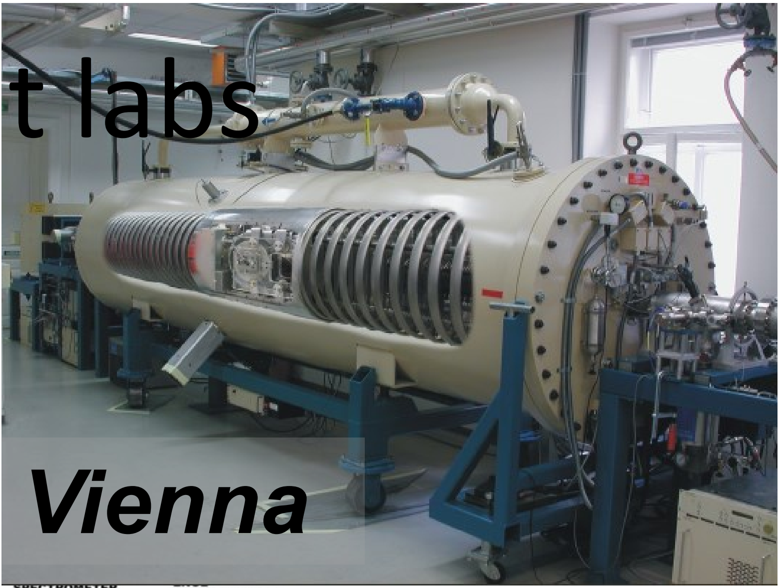
Zurich

AMS at different labs



ANU/Canberra





Vienna

ANSTO Sydney

ETH Zurich

Slide from Anton Wallner

New dedicated AMS
@ HZDR

Building Construction started 2022

max. voltage: 1 MV

Novel projects – like:

Isobar suppression at low energy side

“Laser”

contact:

Anton Wallner, Johannes Lachner

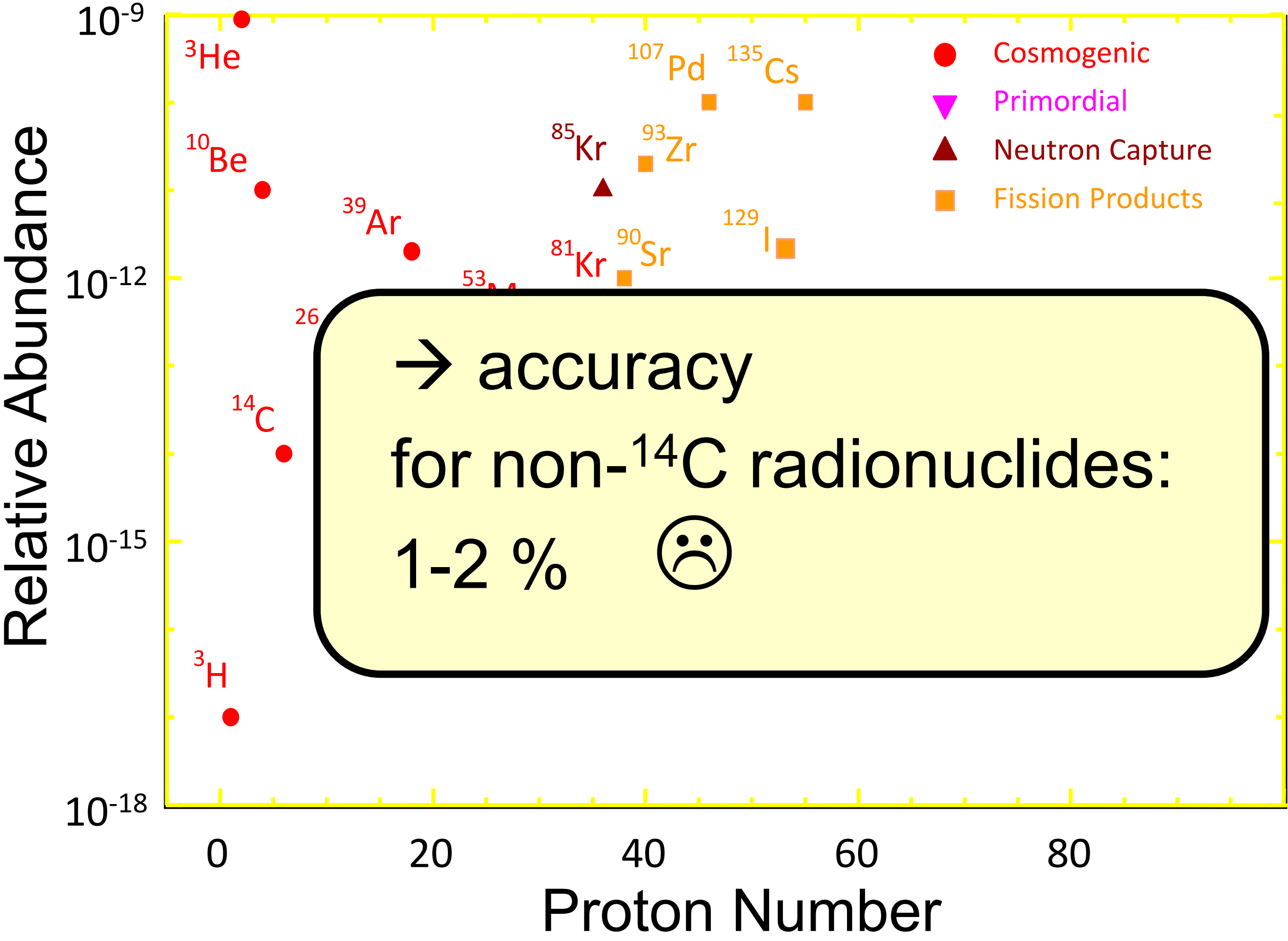
NEW Street

NEW Building

2022-02

2022-03-10

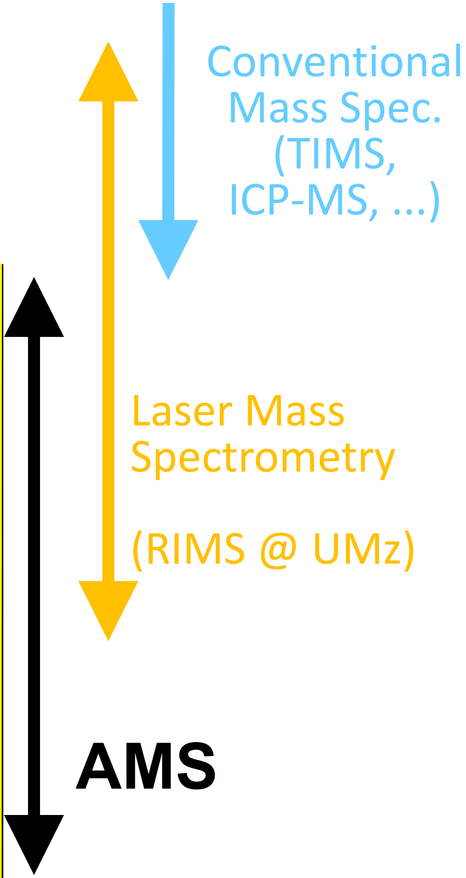
Typical isotopic ratios



→ accuracy

for non-^{14}C radionuclides:

1-2 % ☹



Conventional Mass Spec. (TIMS, ICP-MS, ...)

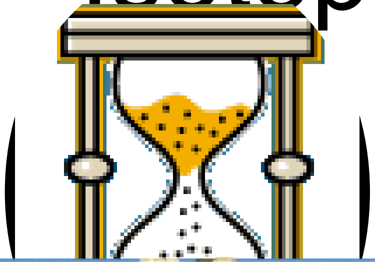
Laser Mass Spectrometry

(RIMS @ UMz)

AMS

adapted from Klaus Wendt

Isotopic ratios @ 10^{-15} ?



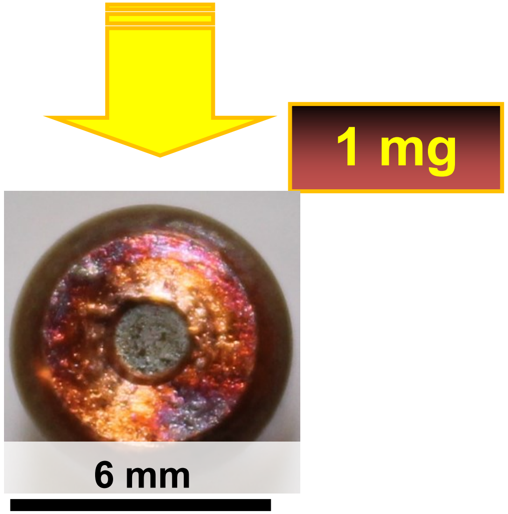
Frauenkirche Dresden, Germany

e.g. sand grain Ø 0.44 mm

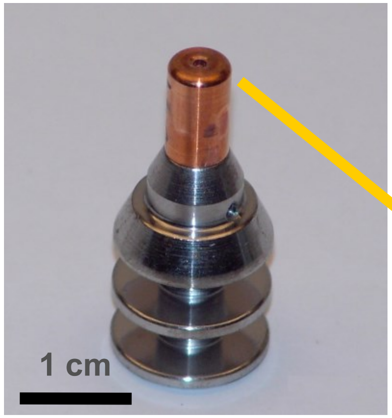
One black grain : ~ 10^{-15}

AMS needs chemistry (sample material into an ion source!)

Careful extraction of RN
(quantitative, no contamination,
1st isobar separation)



AMS needs a high performance negative ion source



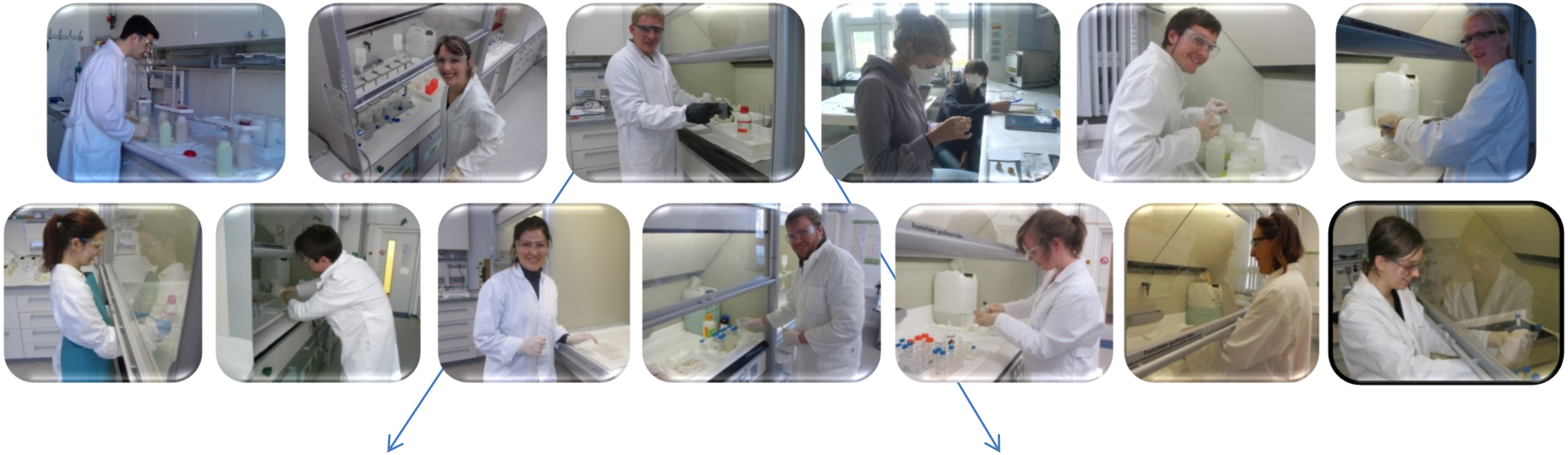
AMS target holder

Wheel for 200 samples (4 x 50)

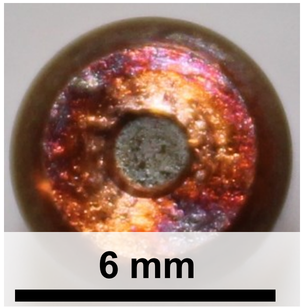
Sometimes possible to avoid chemistry;
e.g. cross section measurements

Chemical AMS sample preparation @ DREAMS

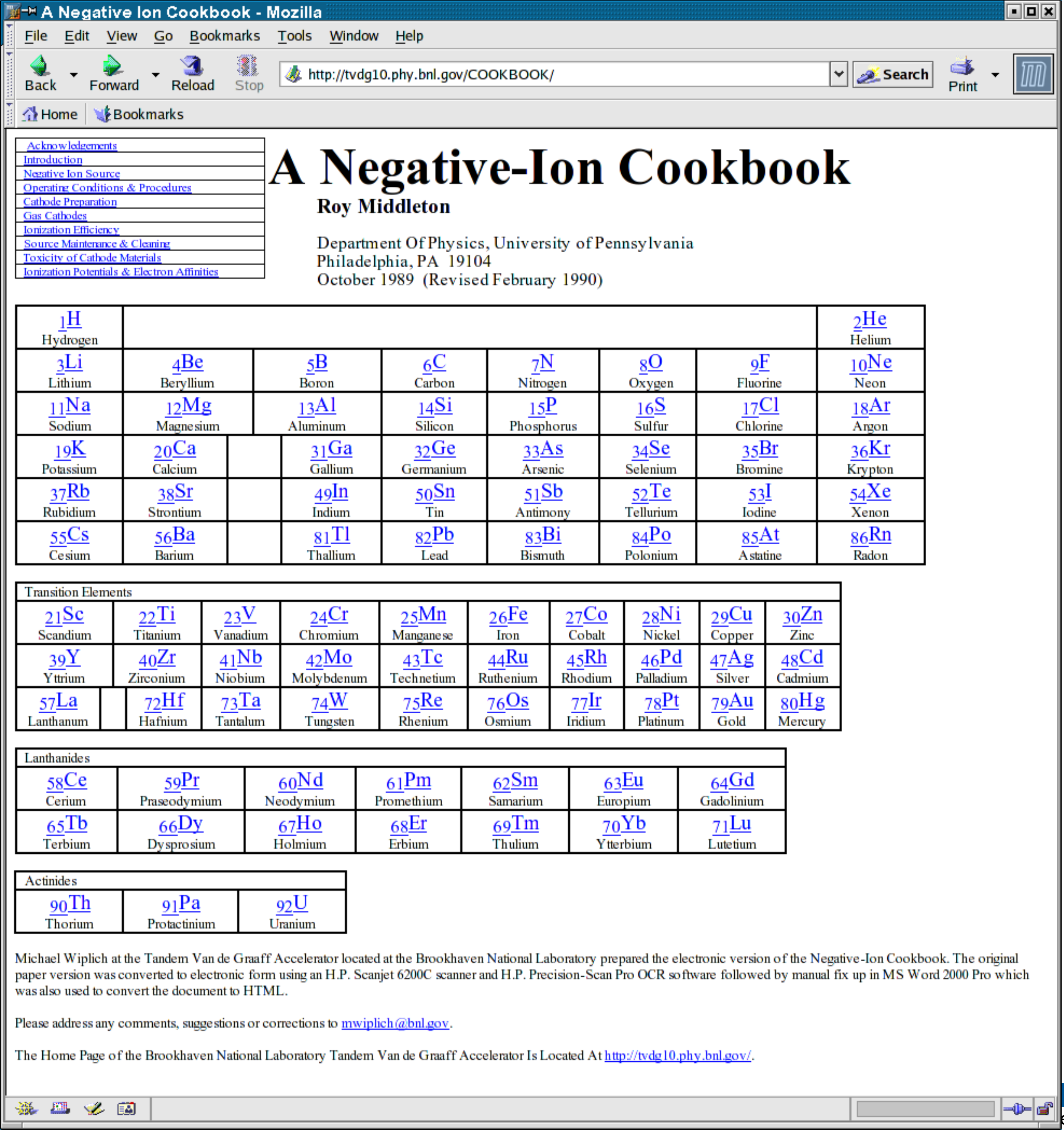
(operational since September 2009)
many users; two laboratories



Volatile elements:
^{36}Cl, ^{129}I



Other elements:
e.g. ^{10}Be, ^{26}Al, ^{41}Ca
(^{53}Mn, ^{60}Fe, …)



A Negative-Ion Cookbook

Roy Middleton

Department Of Physics, University of Pennsylvania
Philadelphia, PA 19104
October 1989 (Revised February 1990)

1H Hydrogen								2He Helium
3Li Lithium	4Be Beryllium		5B Boron	6C Carbon	7N Nitrogen	8O Oxygen	9F Fluorine	10Ne Neon
11Na Sodium	12Mg Magnesium		13Al Aluminum	14Si Silicon	15P Phosphorus	16S Sulfur	17Cl Chlorine	18Ar Argon
19K Potassium	20Ca Calcium		31Ga Gallium	32Ge Germanium	33As Arsenic	34Se Selenium	35Br Bromine	36Kr Krypton
37Rb Rubidium	38Sr Strontium		49In Indium	50Sn Tin	51Sb Antimony	52Te Tellurium	53I Iodine	54Xe Xenon
55Cs Cesium	56Ba Barium		81Tl Thallium	82Pb Lead	83Bi Bismuth	84Po Polonium	85At Astatine	86Rn Radon

Transition Elements										
21Sc Scandium		22Ti Titanium	23V Vanadium	24Cr Chromium	25Mn Manganese	26Fe Iron	27Co Cobalt	28Ni Nickel	29Cu Copper	30Zn Zinc
39Y Yttrium		40Zr Zirconium	41Nb Niobium	42Mo Molybdenum	43Tc Technetium	44Ru Ruthenium	45Rh Rhodium	46Pd Palladium	47Ag Silver	48Cd Cadmium
57La Lanthanum		72Hf Hafnium	73Ta Tantalum	74W Tungsten	75Re Rhenium	76Os Osmium	77Ir Iridium	78Pt Platinum	79Au Gold	80Hg Mercury

Lanthanides						
58Ce Cerium	59Pr Praseodymium	60Nd Neodymium	61Pm Promethium	62Sm Samarium	63Eu Europium	64Gd Gadolinium
65Tb Terbium	66Dy Dysprosium	67Ho Holmium	68Er Erbium	69Tm Thulium	70Yb Ytterbium	71Lu Lutetium

Actinides		
90Th Thorium	91Pa Protactinium	92U Uranium

Michael Wiplich at the Tandem Van de Graaff Accelerator located at the Brookhaven National Laboratory prepared the electronic version of the Negative-Ion Cookbook. The original paper version was converted to electronic form using an H.P. Scanjet 6200C scanner and H.P. Precision-Scan Pro OCR software followed by manual fix up in MS Word 2000 Pro which was also used to convert the document to HTML.

Please address any comments, suggestions or corrections to mwiplich@bnl.gov.

The Home Page of the Brookhaven National Laboratory Tandem Van de Graaff Accelerator Is Located At http://tvdg10.phy.bnl.gov/.

Working horse:

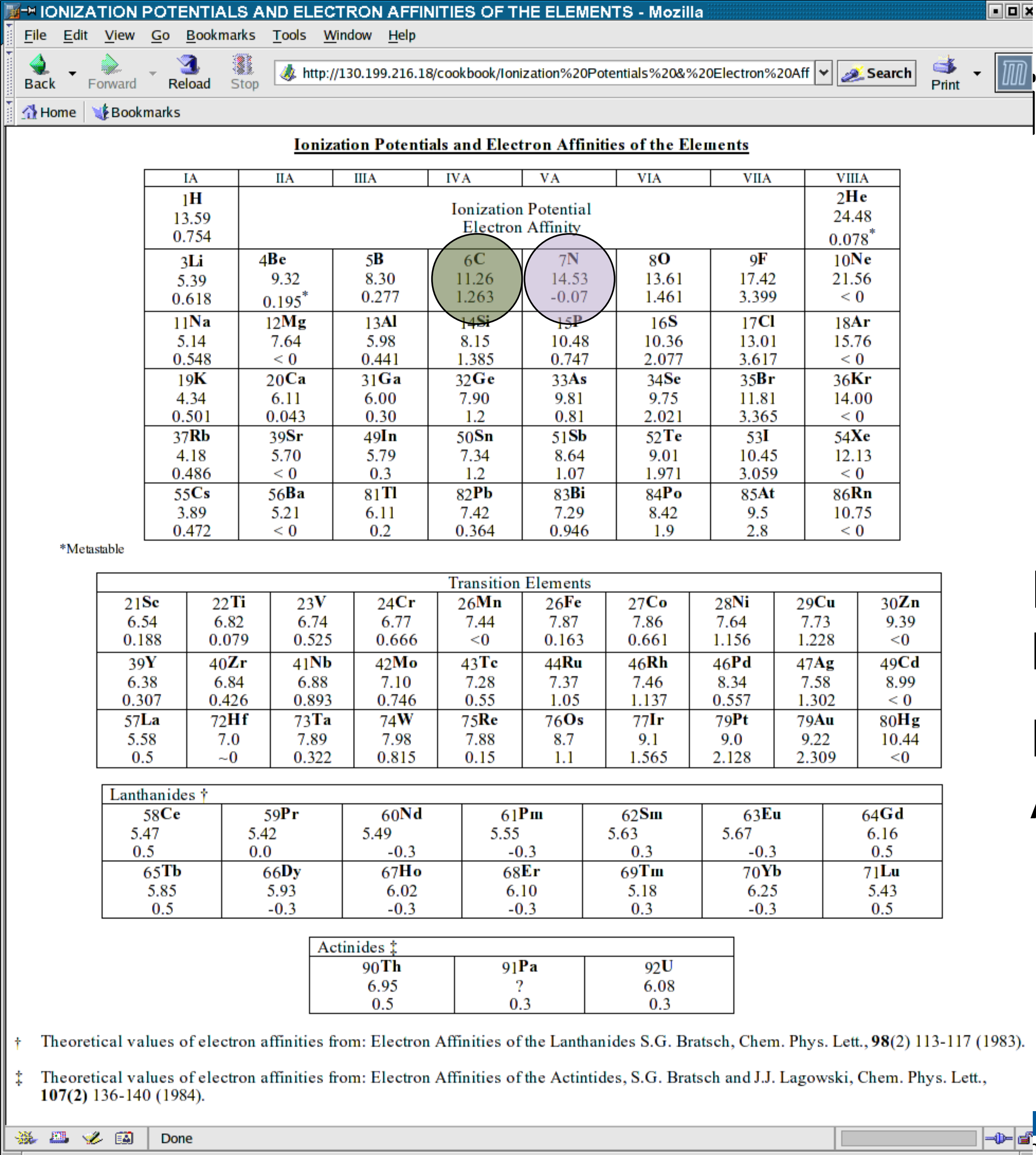
Sputter ion sources Middleton type

No double or triple charged negative ions!

Scanned version available under:

http://tvdg10.phy.bnl.gov/COOKBOOK/

ionisation



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	39**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

Transition Elements									
21**Sc** 6.54 0.188	22**Ti** 6.82 0.079	23**V** 6.74 0.525	24**Cr** 6.77 0.666	26**Mn** 7.44 <0	26**Fe** 7.87 0.163	27**Co** 7.86 0.661	28**Ni** 7.64 1.156	29**Cu** 7.73 1.228	30**Zn** 9.39 <0
39**Y** 6.38 0.307	40**Zr** 6.84 0.426	41**Nb** 6.88 0.893	42**Mo** 7.10 0.746	43**Tc** 7.28 0.55	44**Ru** 7.37 1.05	46**Rh** 7.46 1.137	46**Pd** 8.34 0.557	47**Ag** 7.58 1.302	49**Cd** 8.99 < 0
57**La** 5.58 0.5	72**Hf** 7.0 ~0	73**Ta** 7.89 0.322	74**W** 7.98 0.815	75**Re** 7.88 0.15	76**Os** 8.7 1.1	77**Ir** 9.1 1.565	79**Pt** 9.0 2.128	79**Au** 9.22 2.309	80**Hg** 10.44 <0

Lanthanides †						
58**Ce** 5.47 0.5	59**Pr** 5.42 0.0	60**Nd** 5.49 -0.3	61**Pm** 5.55 -0.3	62**Sm** 5.63 0.3	63**Eu** 5.67 -0.3	64**Gd** 6.16 0.5
65**Tb** 5.85 0.5	66**Dy** 5.93 -0.3	67**Ho** 6.02 -0.3	68**Er** 6.10 -0.3	69**Tm** 5.18 0.3	70**Yb** 6.25 -0.3	71**Lu** 5.43 0.5

Actinides ‡		
90**Th** 6.95 0.5	91**Pa** ? 0.3	92**U** 6.08 0.3

† Theoretical values of electron affinities from: Electron Affinities of the Lanthanides S.G. Bratsch, Chem. Phys. Lett., **98**(2) 113-117 (1983).

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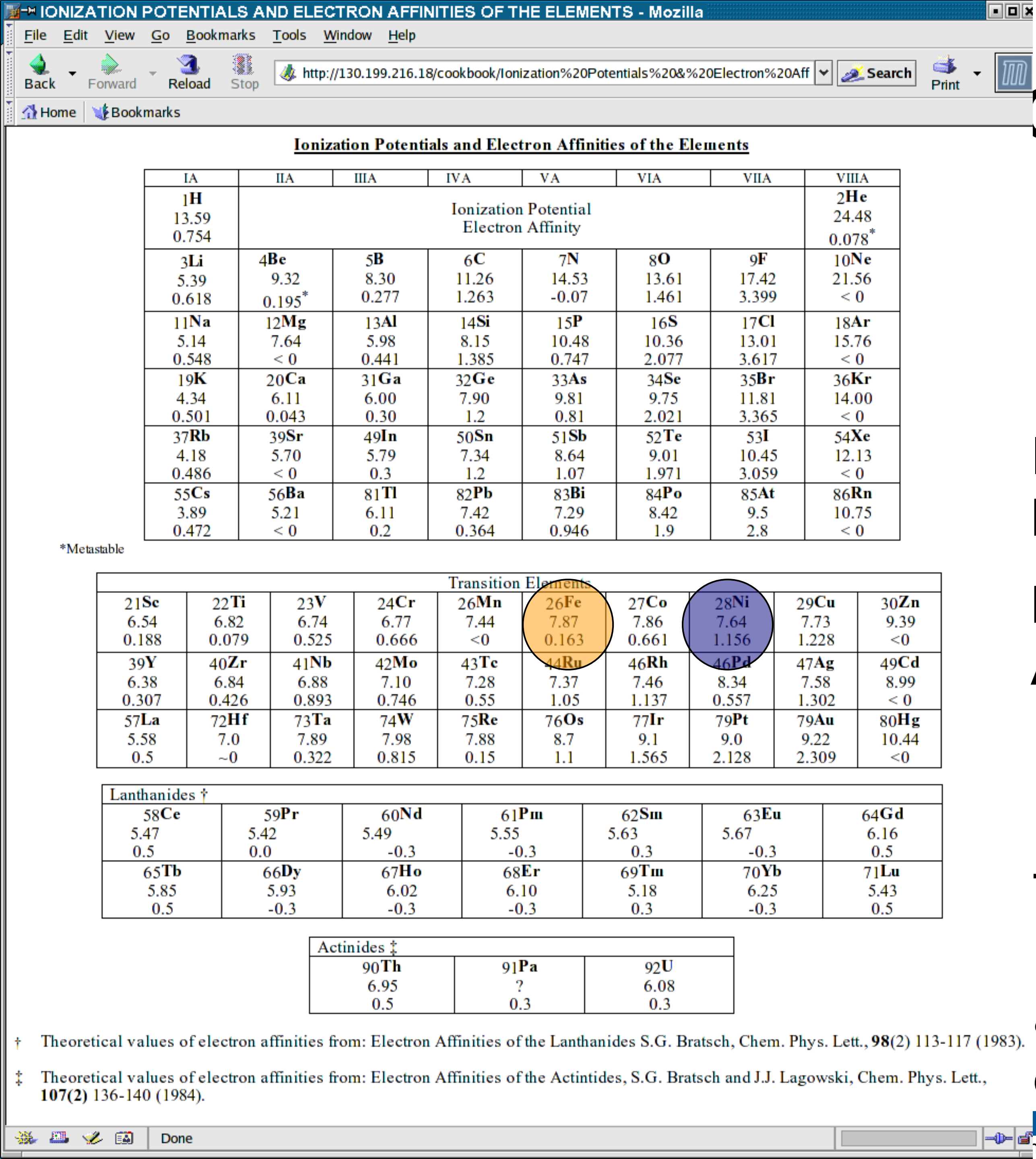
[eV]	$^{14}C^-$	$\cancel{^{14}N}^-$
Ionisation Potential	11.26	14.53
Electron Affinity	1.263	-0.07

Complete suppression in the ion source

onisation



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† Theoretical values of electron affinities from: Electron Affinities of the Lanthanides S.G. Bratsch, Chem. Phys. Lett., **98**(2) 113-117 (1983).

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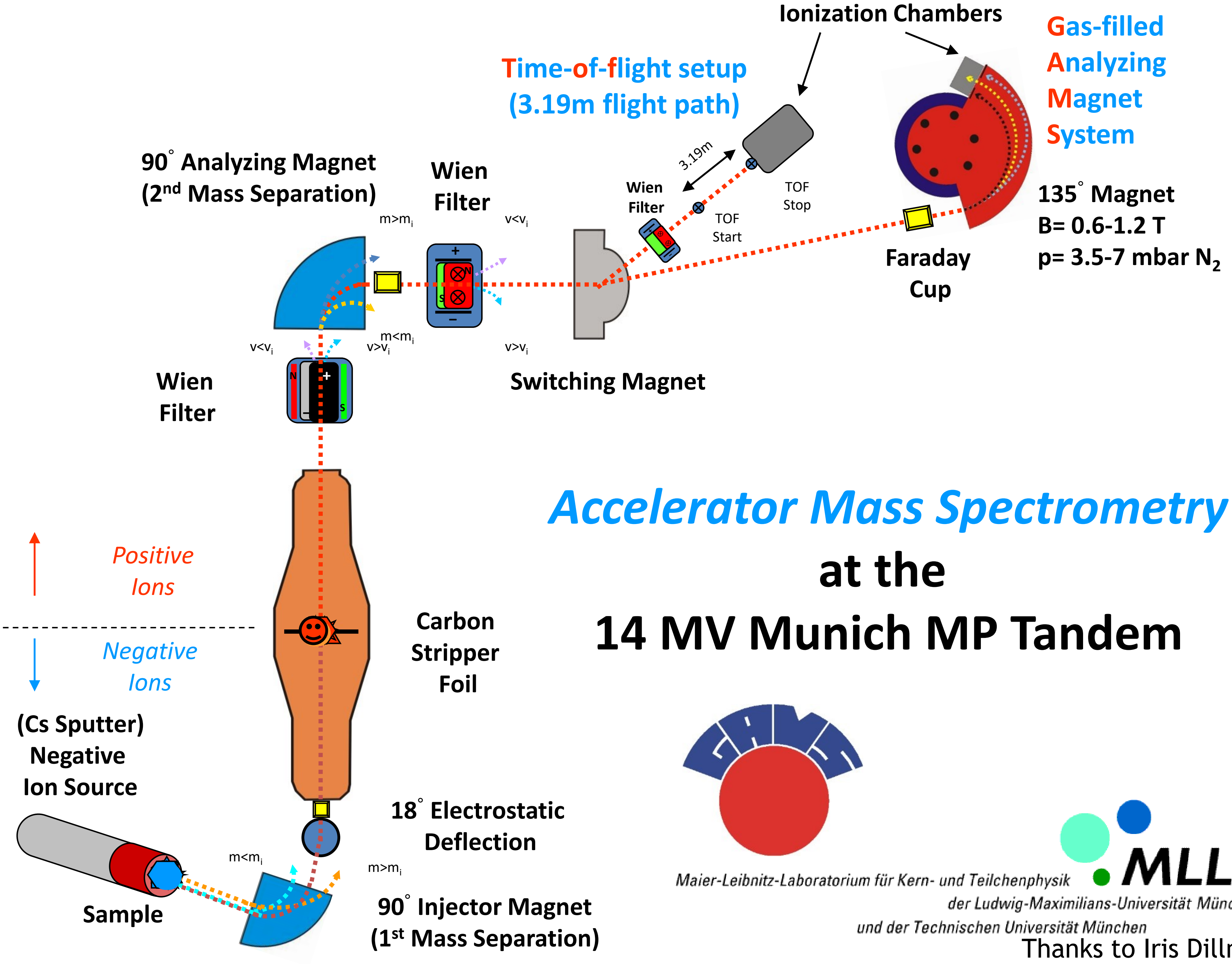
[eV]	^{60}**Fe**	^{60}**Ni**
Ionization Potential	7.87	7.64
Electron Affinity	0.163	1.156

Ni makes much more likely neg. ions!

Trick:
FeO$^-$ and NiO$^-$ have about the same (high) electron affinity

Accelerator Mass Spectrometry at the 14 MV Munich MP Tandem



Ionization Chambers

Gas-filled Analyzing Magnet System

Time-of-flight setup (3.19m flight path)

90° Analyzing Magnet (2nd Mass Separation)

Wien Filter

Wien Filter

135° Magnet
B= 0.6-1.2 T
p= 3.5-7 mbar N_2

Faraday Cup

Wien Filter

Switching Magnet

Positive Ions

Negative Ions

Carbon Stripper Foil

(Cs Sputter) Negative Ion Source

18° Electrostatic Deflection

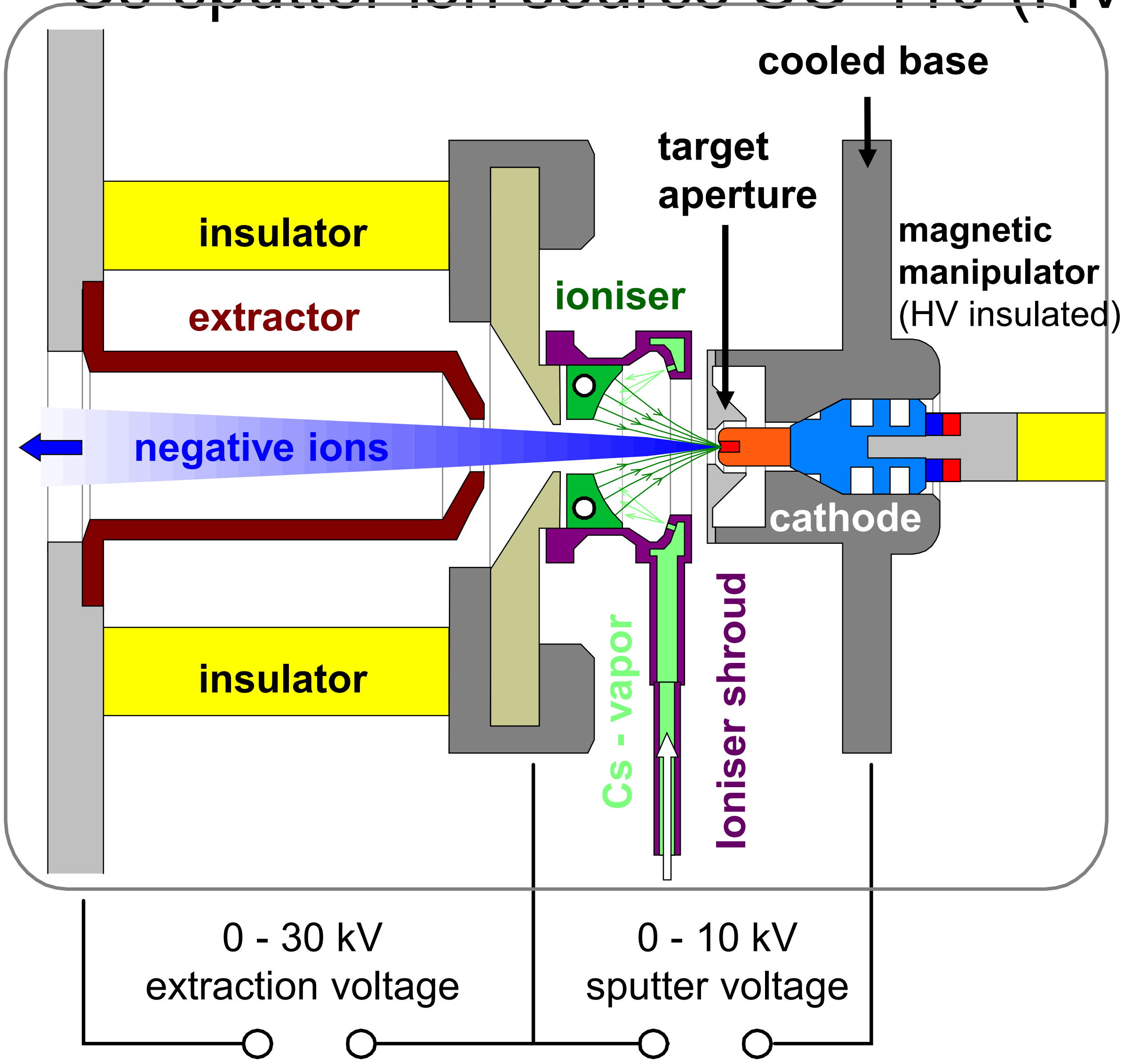
Sample

90° Injector Magnet (1st Mass Separation)

Maier-Leibnitz-Laboratorium für Kern- und Teilchenphysik der Ludwig-Maximilians-Universität München und der Technischen Universität München

Thanks to Iris Dillmann

AMS ion source:
Cs sputter ion source SO-110 (HVEE)



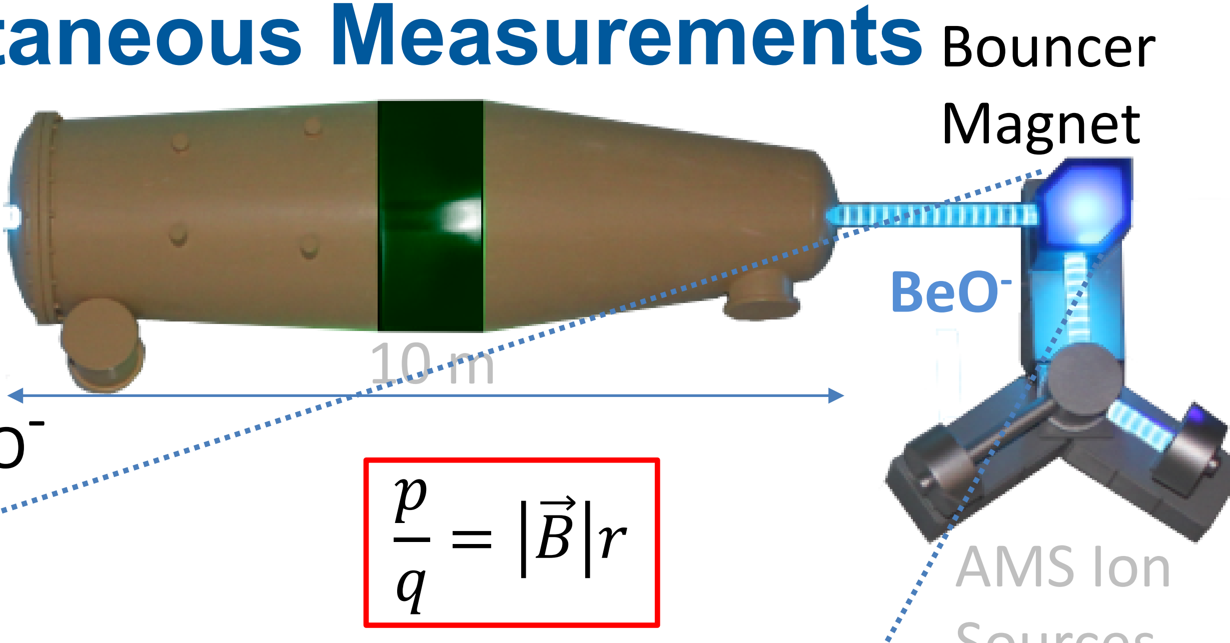
AMS target holder

Wheel for 200 samples

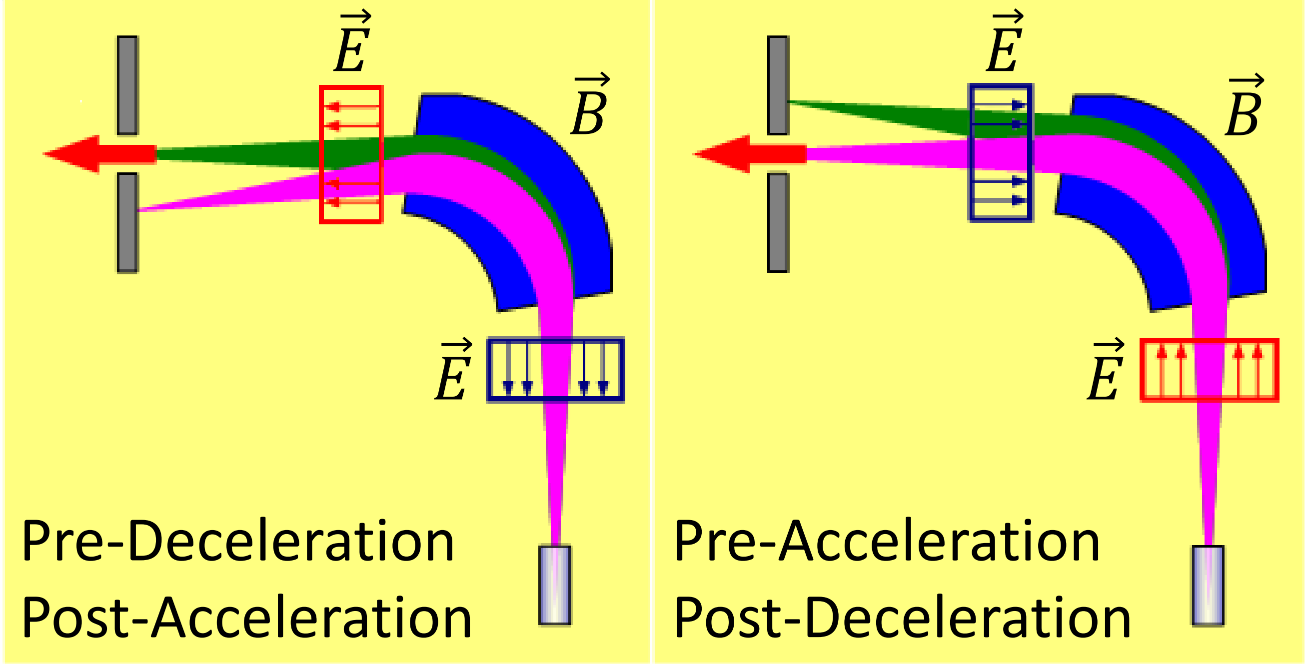
Quasi-Simultaneous Measurements

Fast Sequential Injection

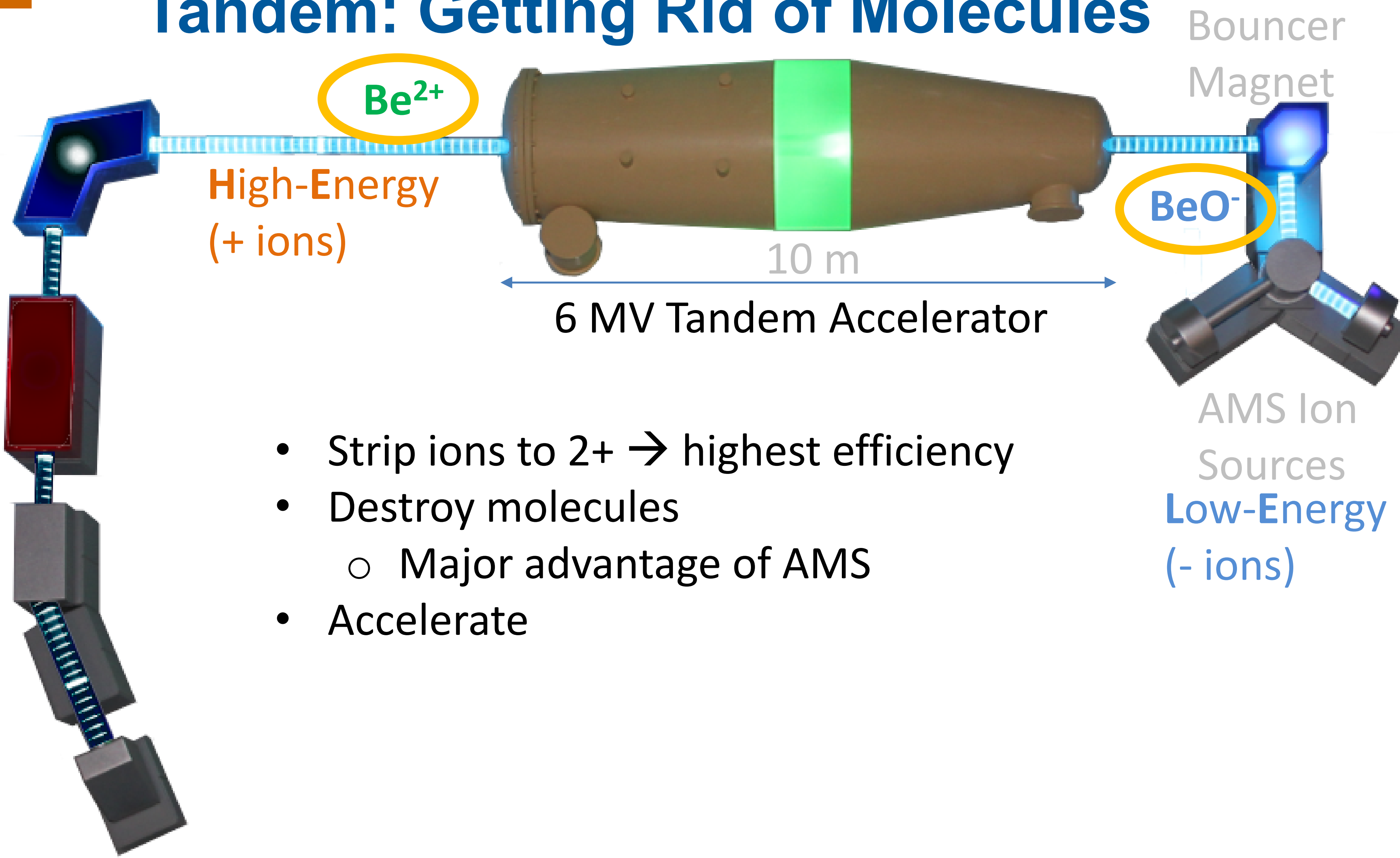
- Quasi-simultaneous stable and radio-nuclides
- E.g. $^{9}Be^{16}O^{-}$ and $^{10}Be^{16}O^{-}$
- **Change $\vec{E}$ not $\vec{B}$**



$$\boxed{\frac{p}{q} = |\vec{B}|r}$$

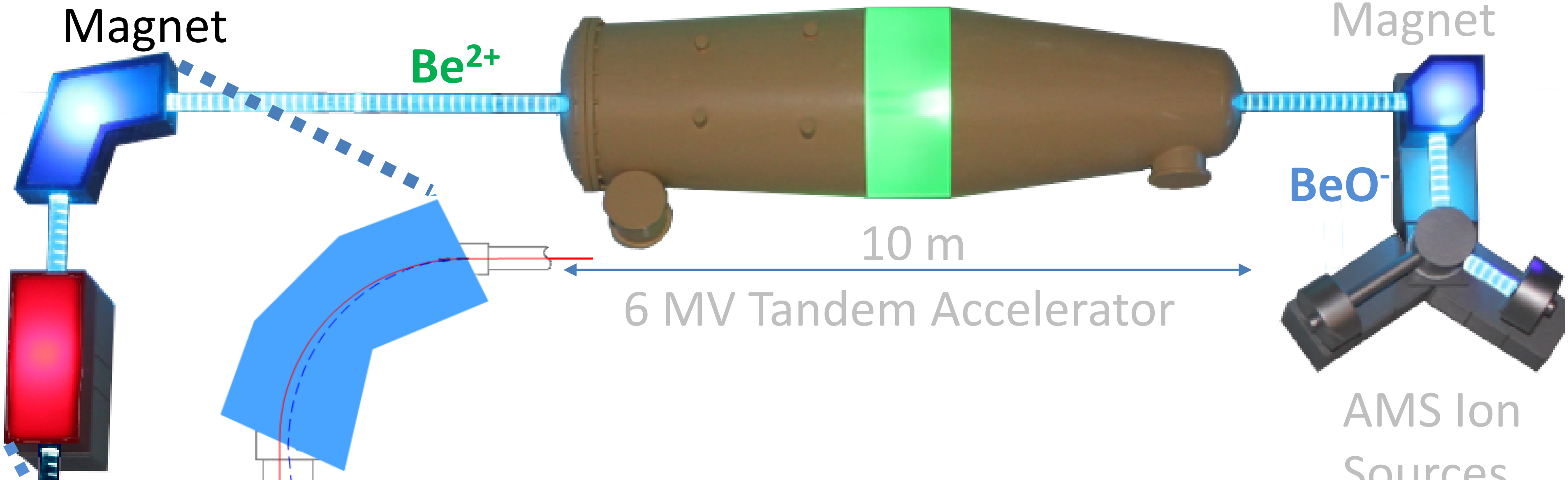


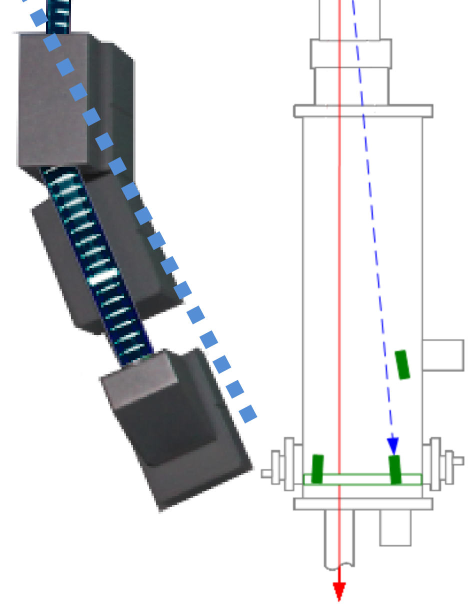
Tandem: Getting Rid of Molecules



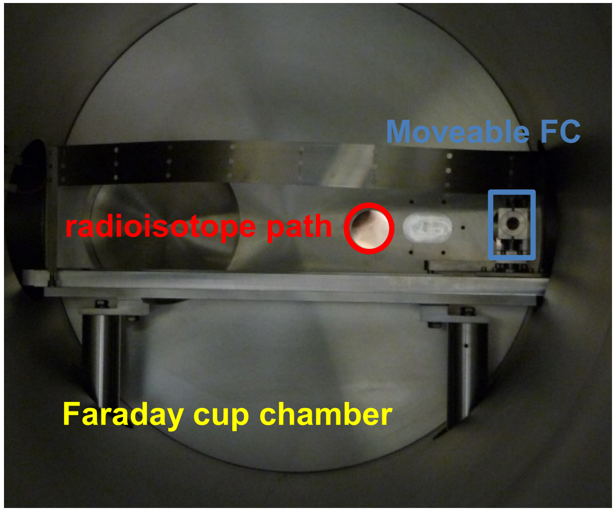
- Strip ions to 2+ → highest efficiency
- Destroy molecules
  - Major advantage of AMS
- Accelerate

Measure Stable ^{9}Be

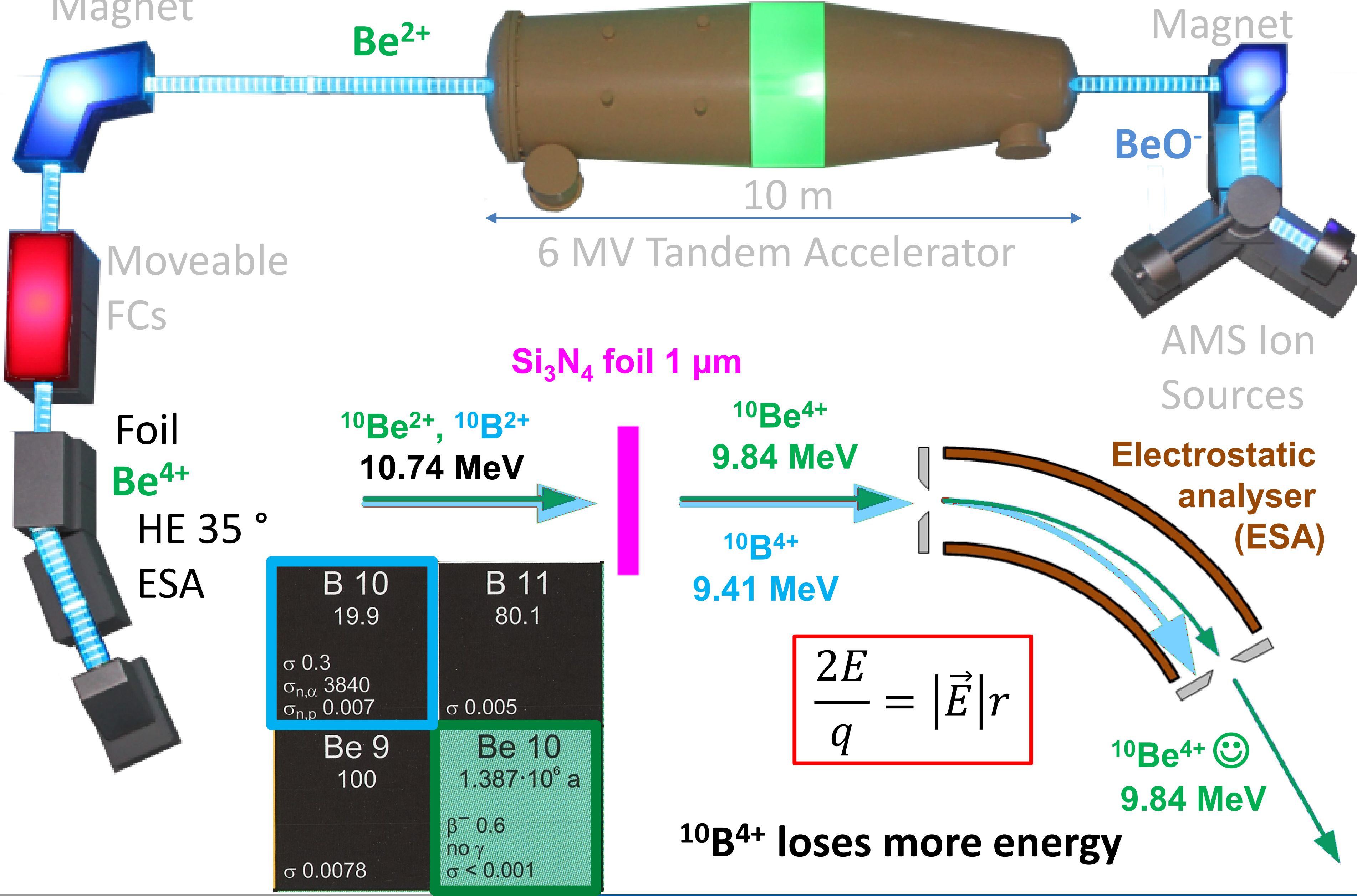




- ^{9}Be measured at Faraday Cup - - - →
- ^{10}Be go to radioisotope path →



^{10}Be into detector - no ^{10}B

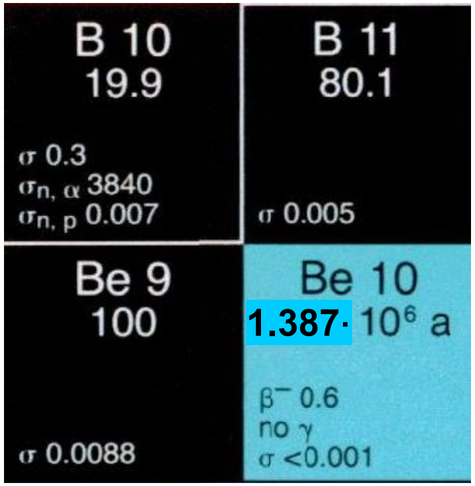


B 10 19.9 σ 0.3 $\sigma_{n,\alpha}$ 3840 $\sigma_{n,p}$ 0.007	B 11 80.1 σ 0.005
Be 9 100 σ 0.0078	Be 10 $1.387 \cdot 10^{6}$ a β^{-} 0.6 no γ σ < 0.001

$$\boxed{\frac{2E}{q} = \left|\vec{E}\right| r}$$

^{10}B^{4+} loses more energy

Typical performance data DREAMS



B 10 19.9 σ 0.3 $\sigma_{n,\alpha}$ 3840 $\sigma_{n,p}$ 0.007	B 11 80.1 σ 0.005
Be 9 100 σ 0.0088	Be 10 $1.387 \cdot 10^6$ a β^- 0.6 no γ σ <0.001

0.5 mg BeO

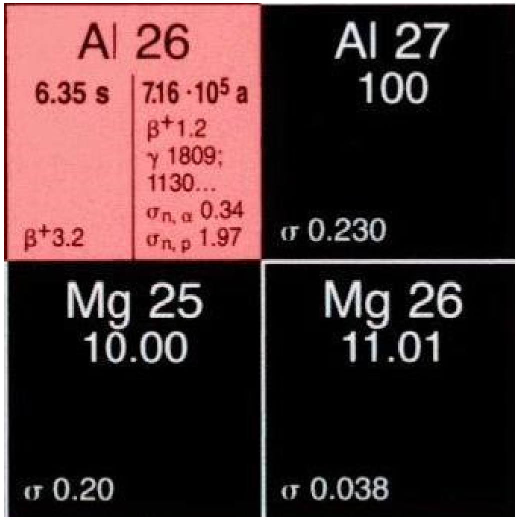
$^{10}Be/^{9}Be$: 10^{-12} at/at

→ 1.2 * 10^7 at ^{10}Be

Total efficiency: 1:1400

→ 6.6 * 10^3 cts ^{10}Be at detector

Blank: 5 * 10^{-16} ($^{10}Be/^{9}Be$)



Al 26 6.35 s β^+3.2 $7.16 \cdot 10^5$ a β^+1.2 γ 1809; 1130... $\sigma_{n,\alpha}$ 0.34 $\sigma_{n,p}$ 1.97	Al 27 100 σ 0.230
Mg 25 10.00 σ 0.20	Mg 26 11.01 σ 0.038

0.3 mg Al_2O_3

$^{26}Al/^{27}Al$: 10^{-12} at/at

→ 7 * 10^5 at ^{26}Al

Total efficiency: 1:2000

→ 350 cts ^{26}Al at detector

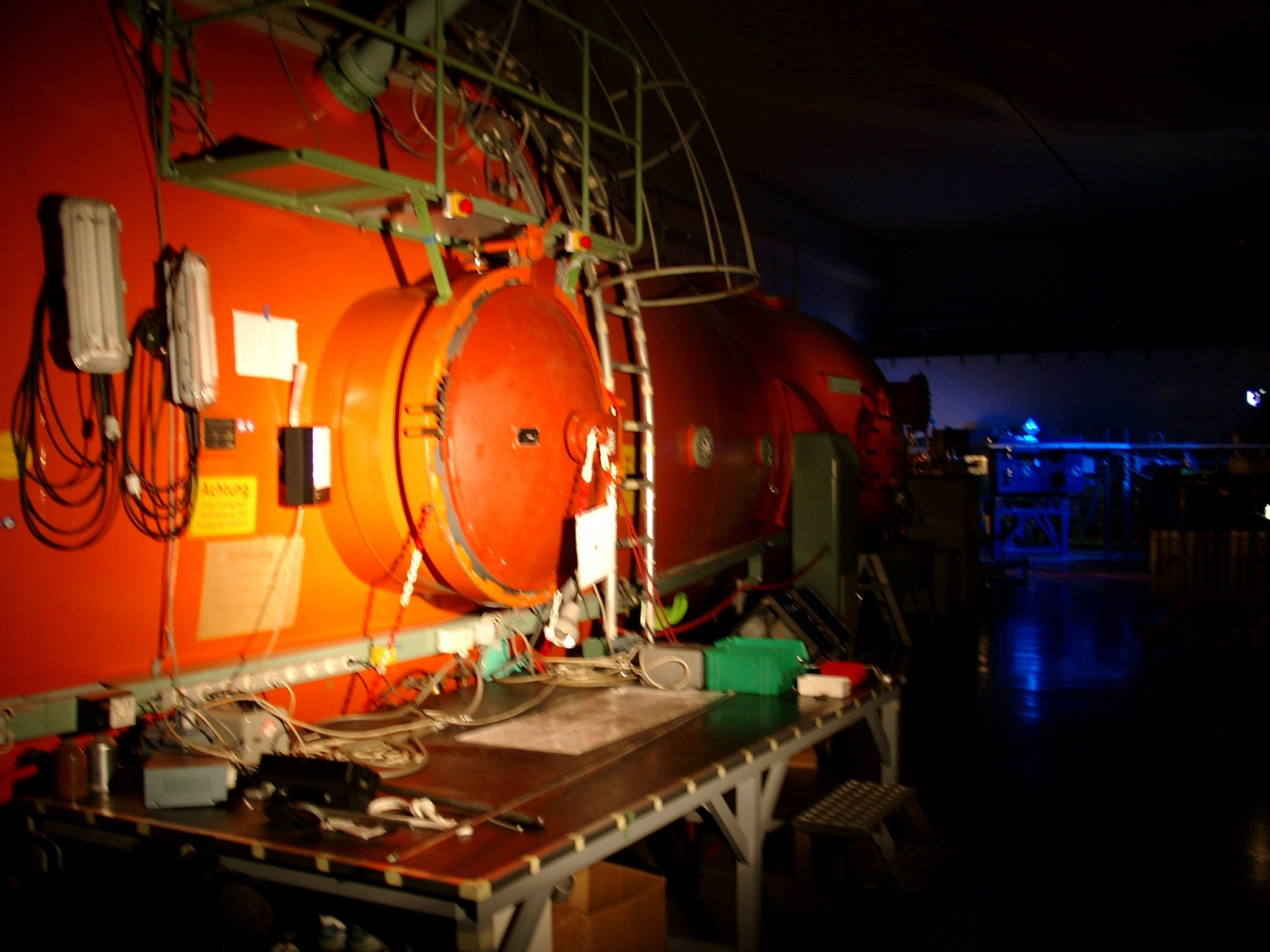
Blank: 6 * 10^{-16} ($^{26}Al/^{27}Al$)

Tandem Accelerator Laboratory Garching
Part of the MLL (Maier Leibnitz Laboratory)
Ludwig Maximilians Universität and Technische Universität München

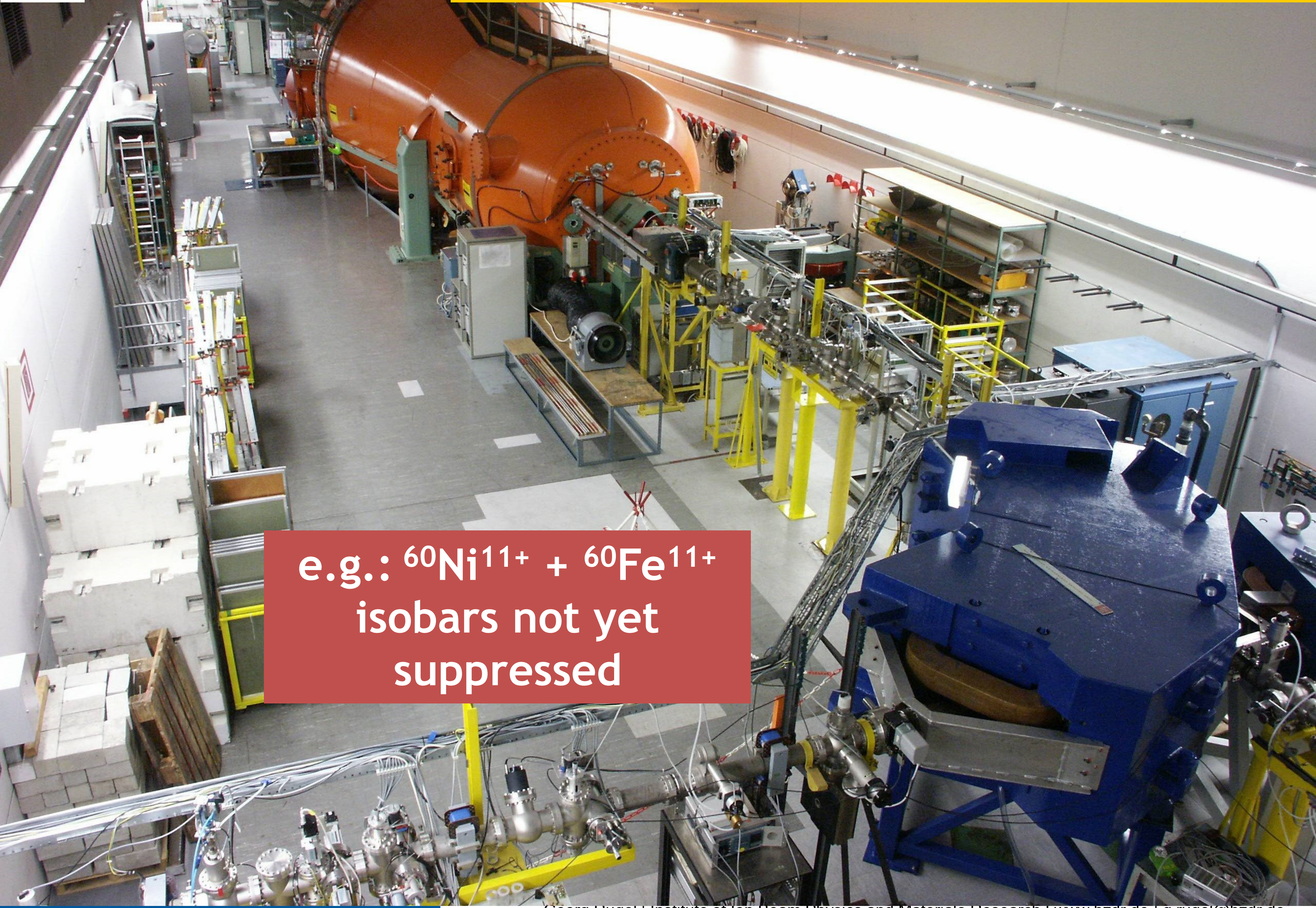
Length: about 76 m

Closed end 2019

Low-energy side of the Tandem


Achtung

High-energy side of the Tandem

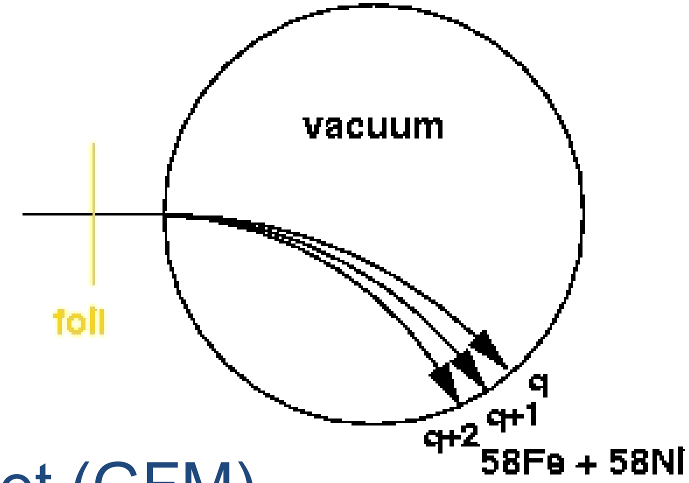


e.g.: $^{60}Ni^{11+}$ + $^{60}Fe^{11+}$ isobars not yet suppressed

Isobar Separation in a Gas-filled Magnet

magnetic rigidity

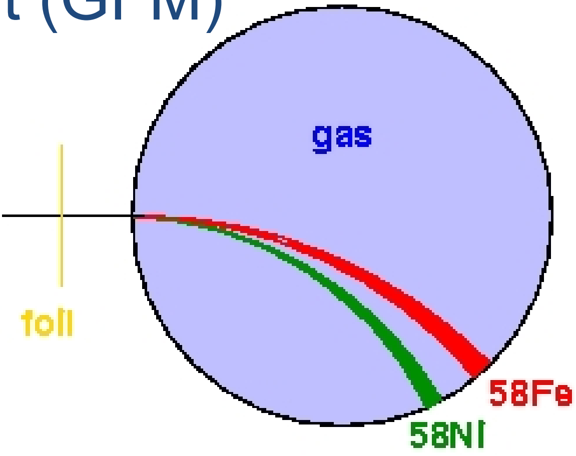
$$B\rho = \frac{Mv}{qe_0}$$

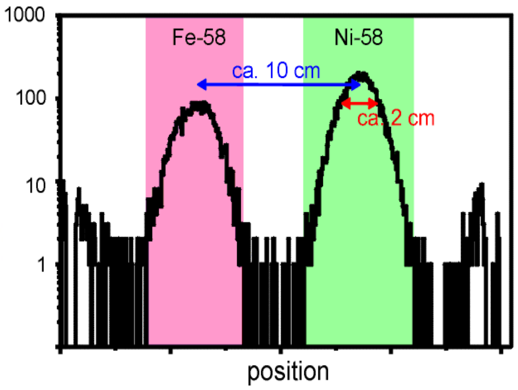


in a gas-filled magnet (GFM)

$$\langle q \rangle \sim vZ^{0.4}$$

$$B\rho \sim \frac{M}{Z^{0.4}}$$



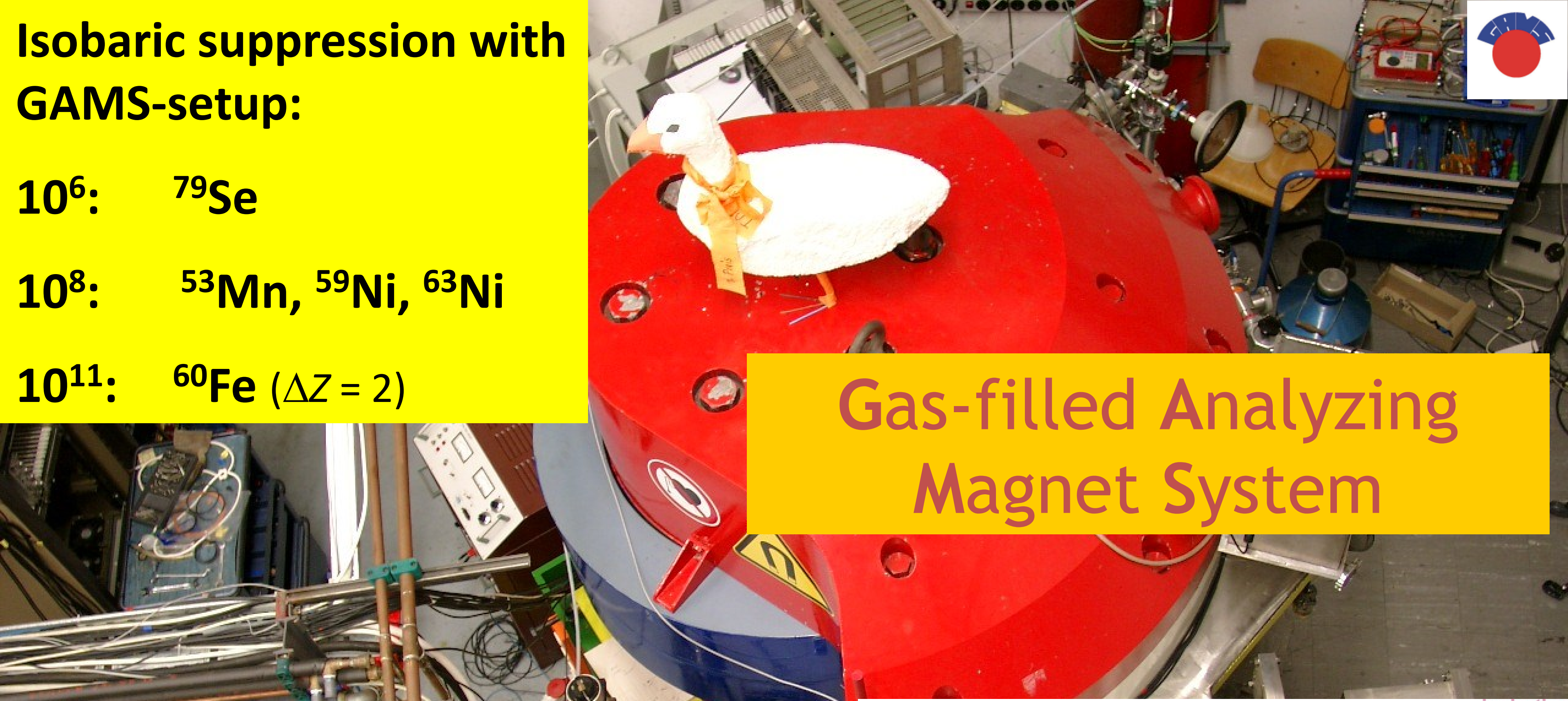


Isobaric suppression with GAMS-setup:

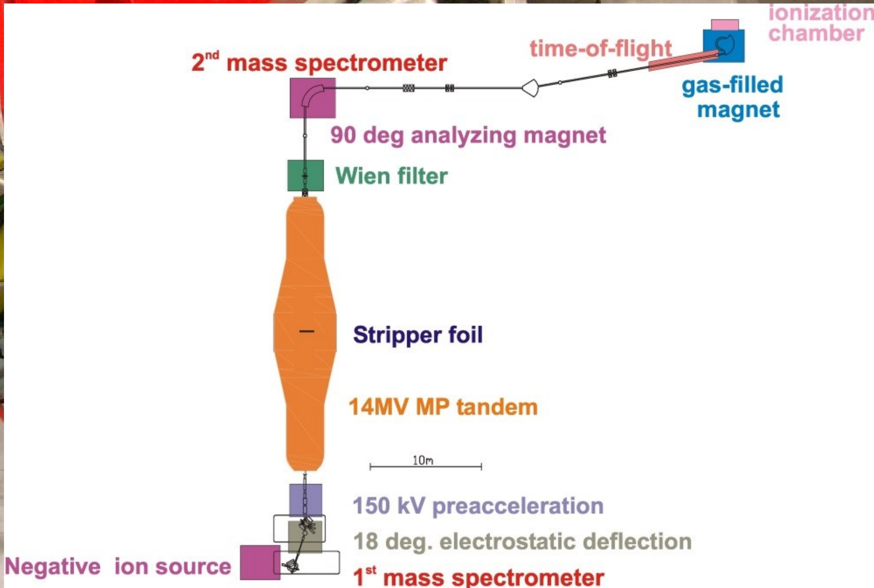
10^6: ^{79}Se

10^8: ^{53}Mn, ^{59}Ni, ^{63}Ni

10^{11}: ^{60}Fe (ΔZ = 2)



Gas-filled Analyzing Magnet System



ionization chamber

time-of-flight

2nd mass spectrometer

gas-filled magnet

90 deg analyzing magnet

Wien filter

Stripper foil

14MV MP tandem

10m

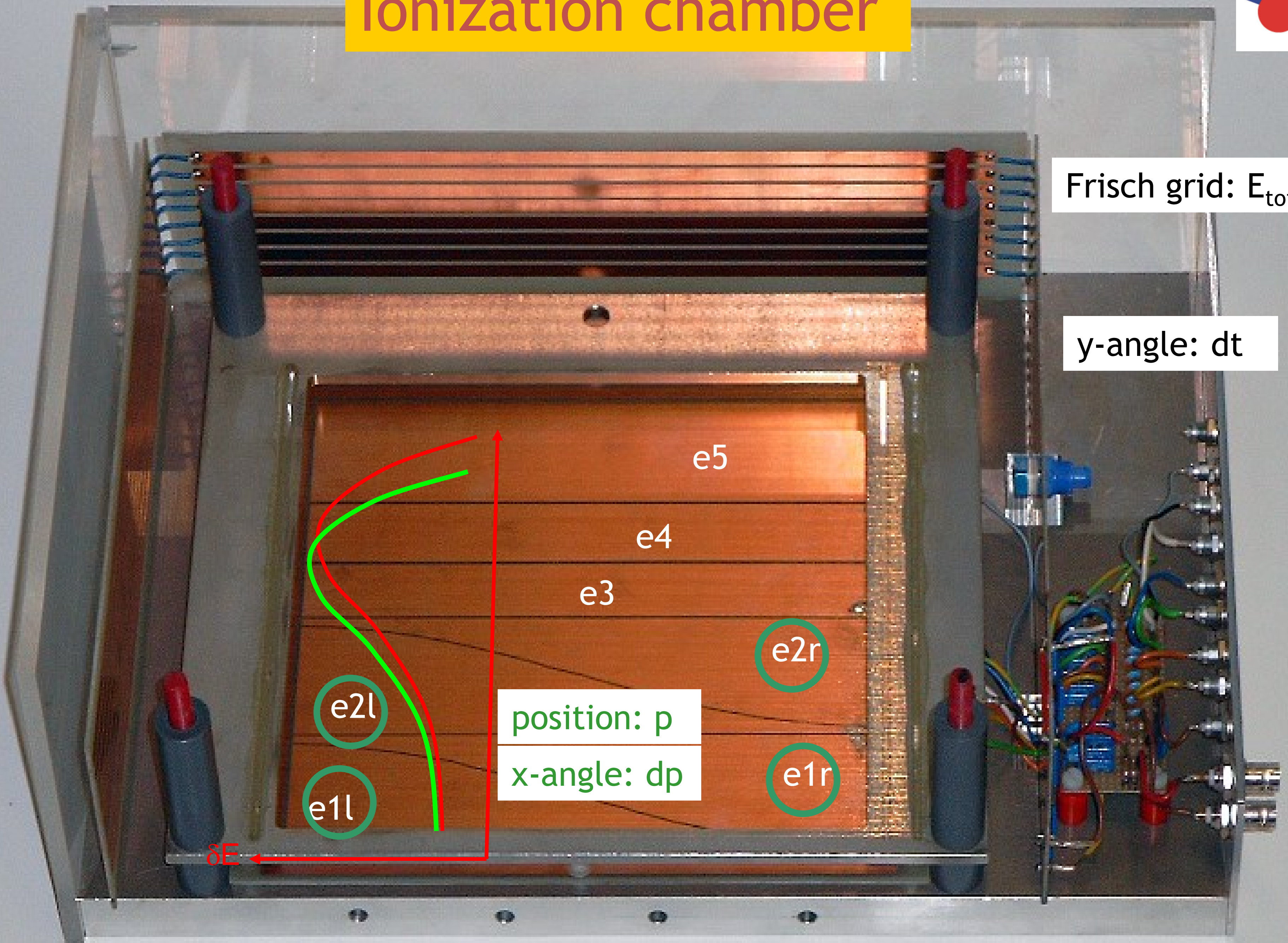
150 kV preacceleration

18 deg. electrostatic deflection

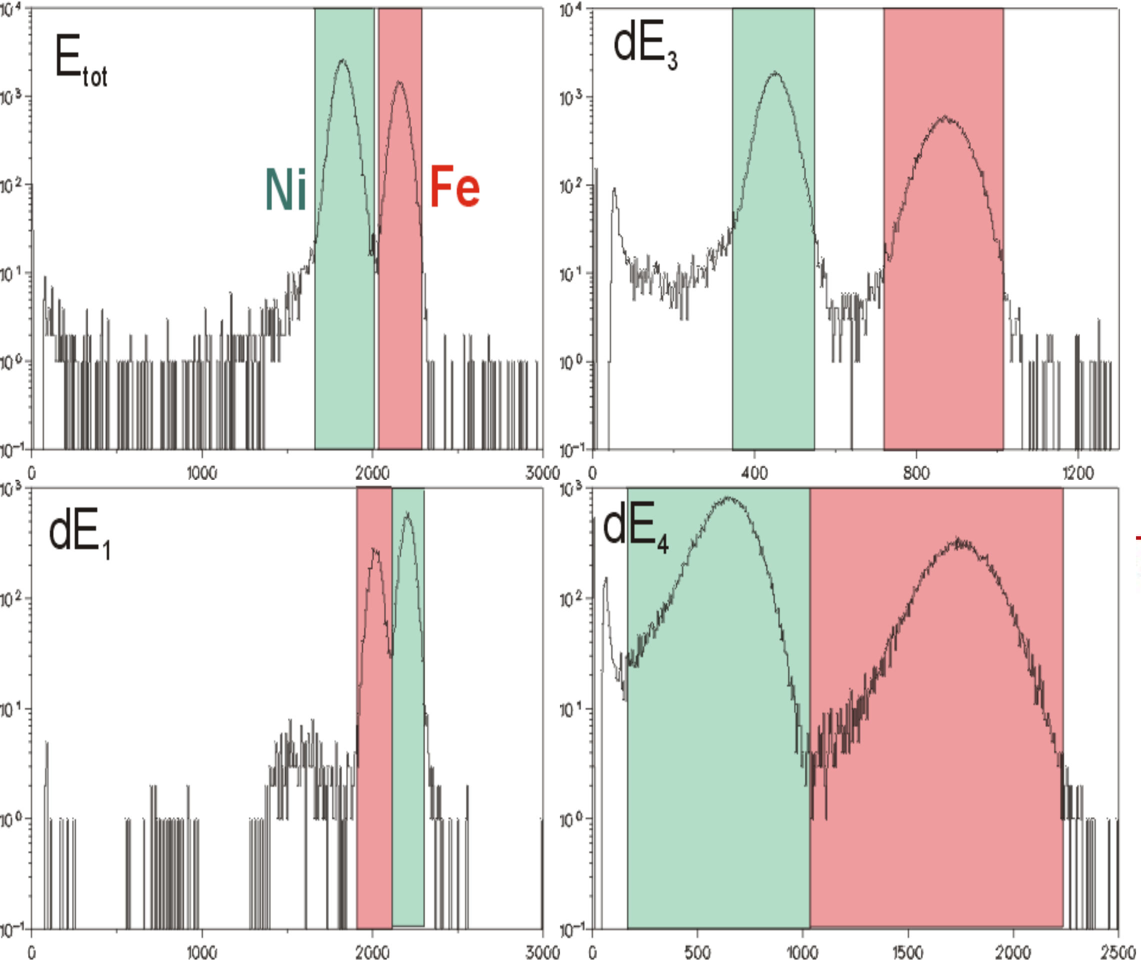
Negative ion source

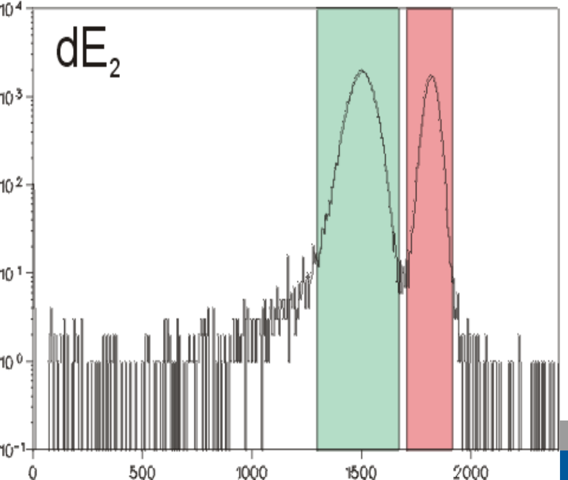
1st mass spectrometer

Ionization chamber



9 „independent“ signals



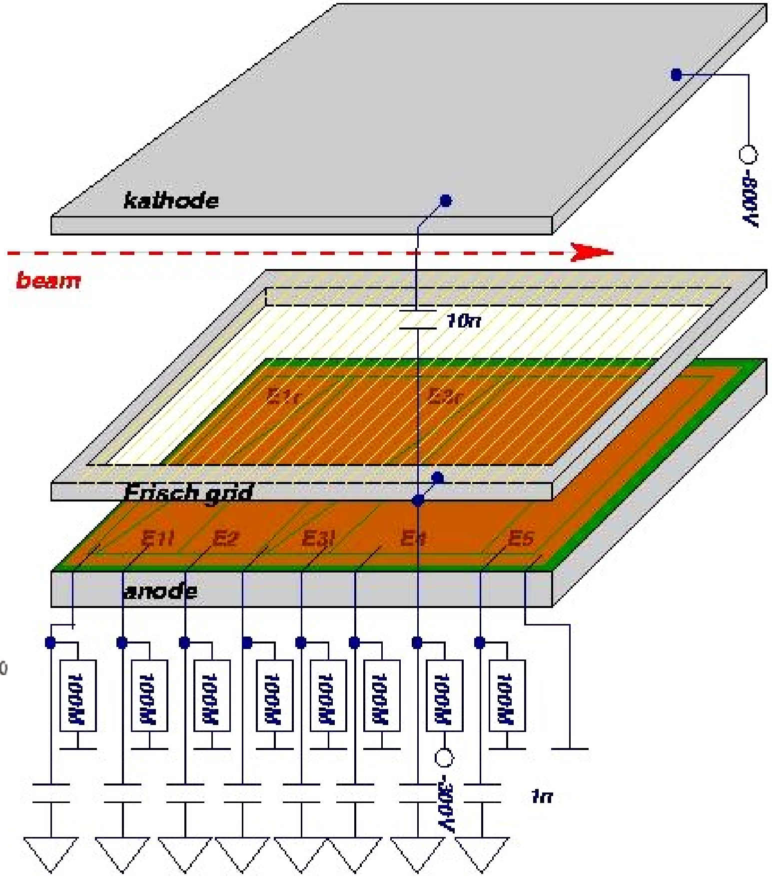


+ dE_5

+ x angle

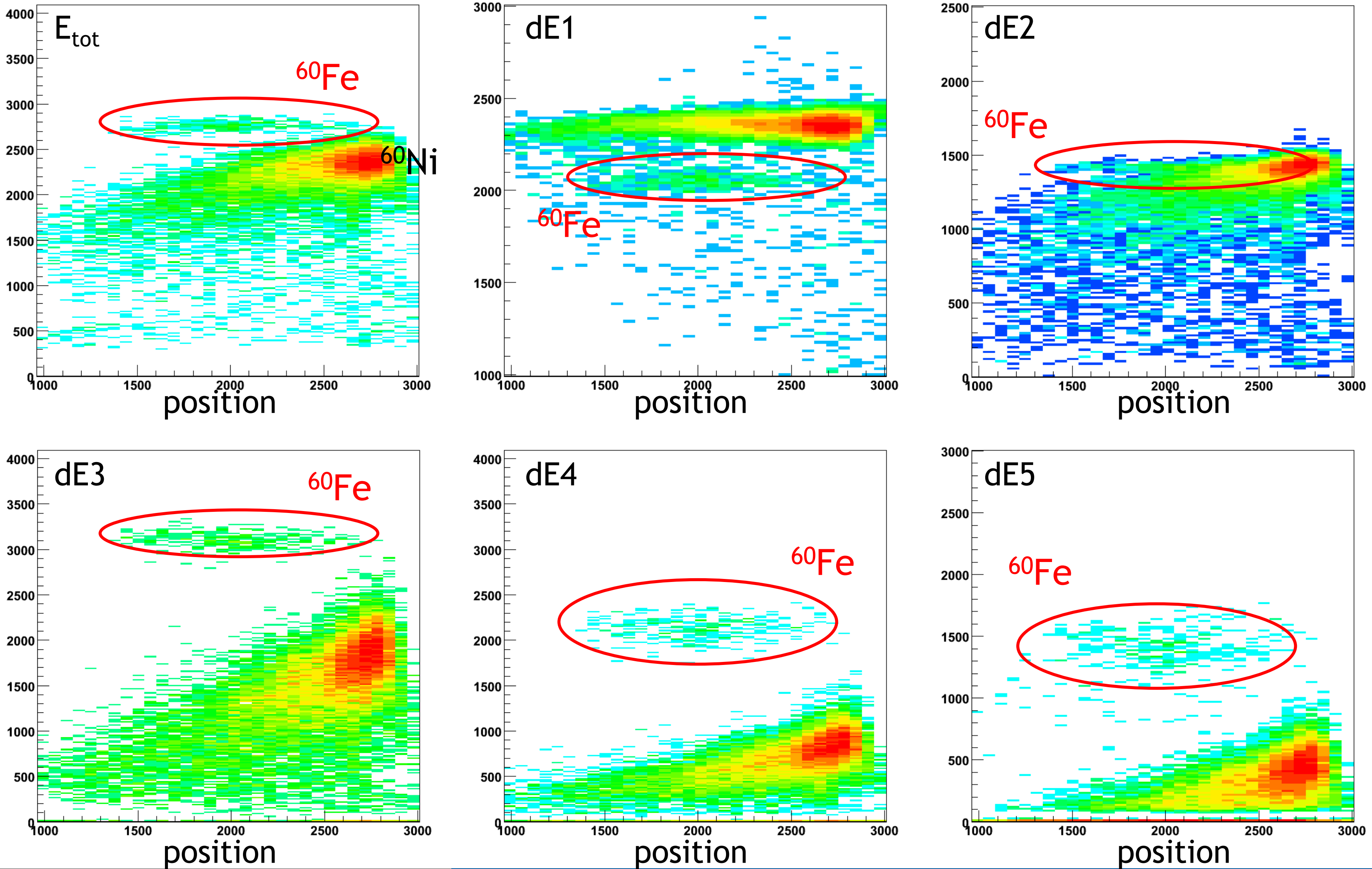
+ y angle

+ pile up rejection



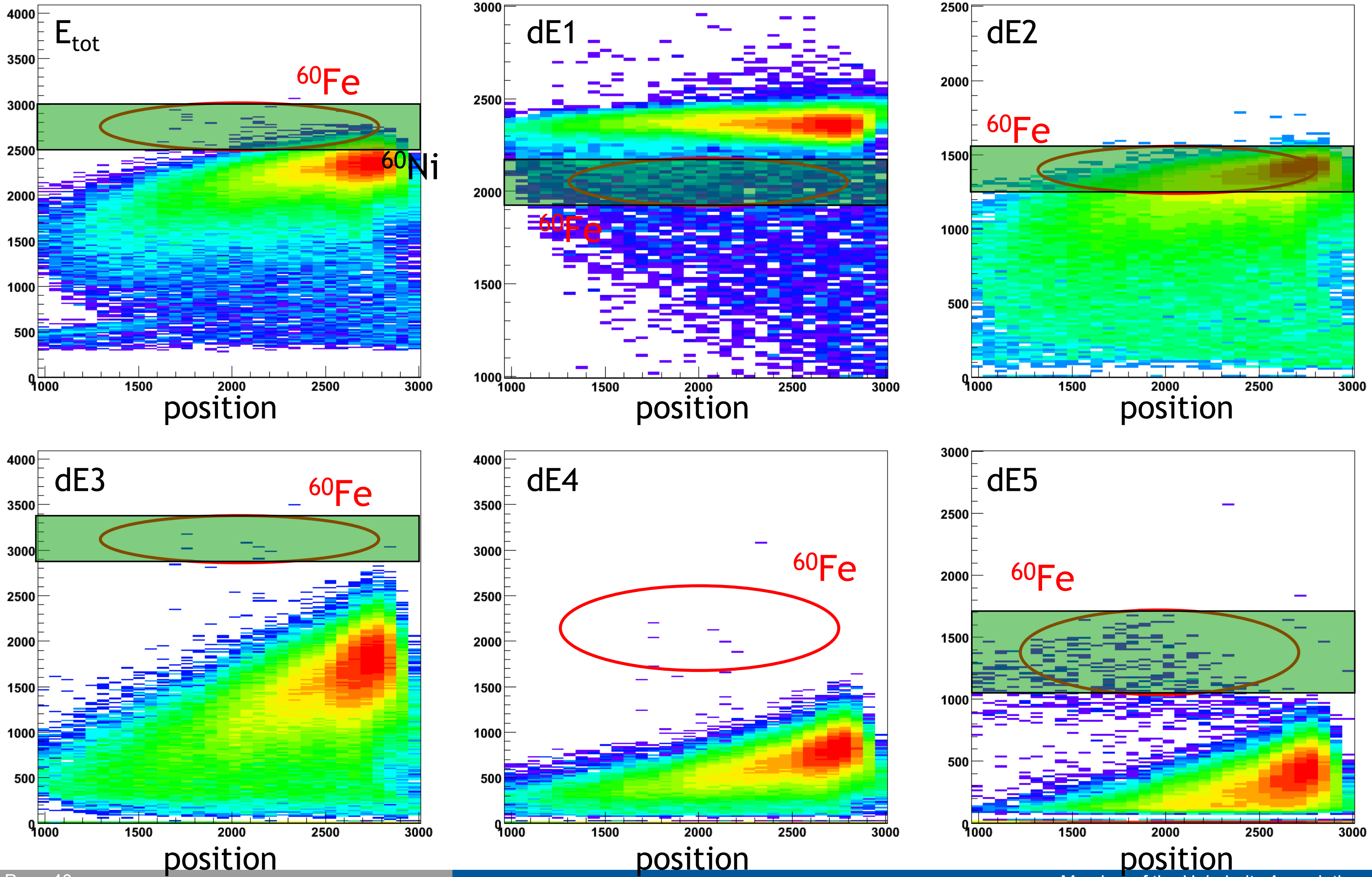
spectra for calibration; sample: ^{60}Fe/Fe = 5 ·10^{-12}

Ni/Fe ≈ 10^{-5} => ^{60}Ni/^{60}Fe ≈ 10^{6}



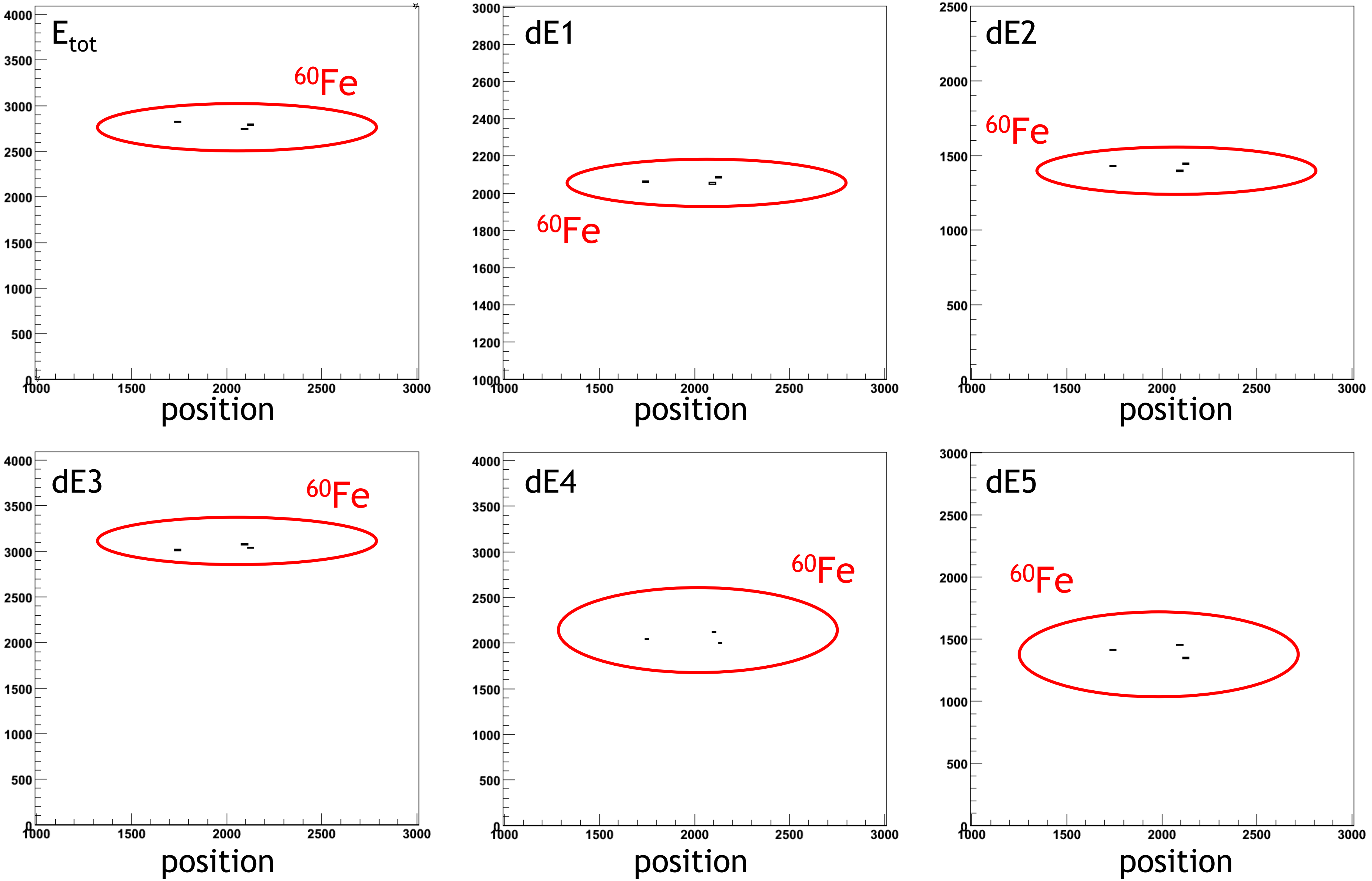
spectra for crust sample: ^{60}Fe/Fe ~ 2·10^{-15}

with windows



spectra for crust sample: $^{60}Fe/Fe = 1.4 \cdot 10^{-15}$

with windows



some numbers

1 μA $^{56}FeO^-$ => $6 \cdot 10^{12}$/sec
transmission 5% => $3 \cdot 10^{11}$/sec
for $^{60}Fe/^{56}Fe = 10^{-15}$ => $3 \cdot 10^{-4}$/sec = 1event/hour

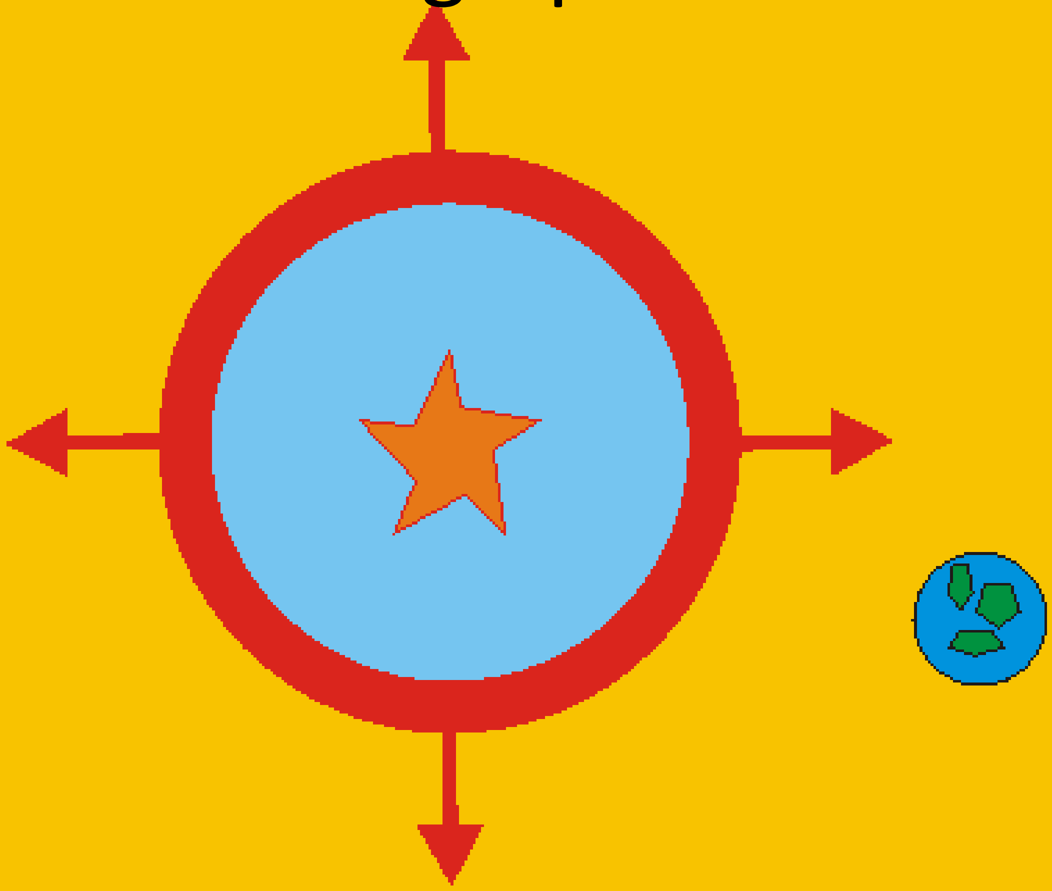
10 mg ^{56}Fe => 10^{20} atoms
1 μA $^{56}FeO^-$ => $6 \cdot 10^{12}$ atoms/sec
neg. ion yield 10^{-3} => $6 \cdot 10^{15}$ atoms/sec used
sample lasts for => $1.5 \cdot 10^{4}$ sec = 4 hours

Slide from Thomas Faestermann

Supernova fingerprints on Earth?

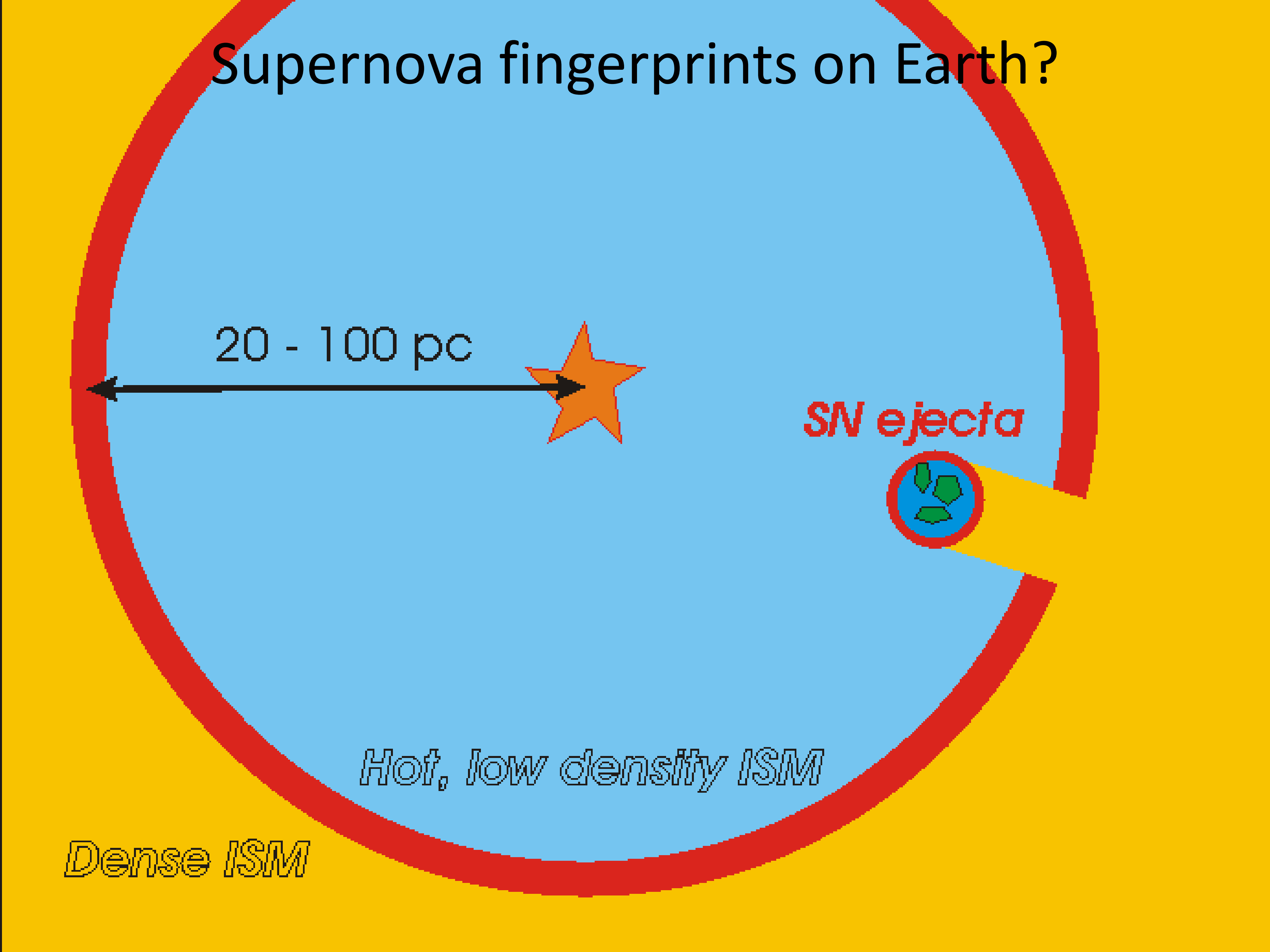
Supernova fingerprints on Earth?

Supernova fingerprints on Earth?

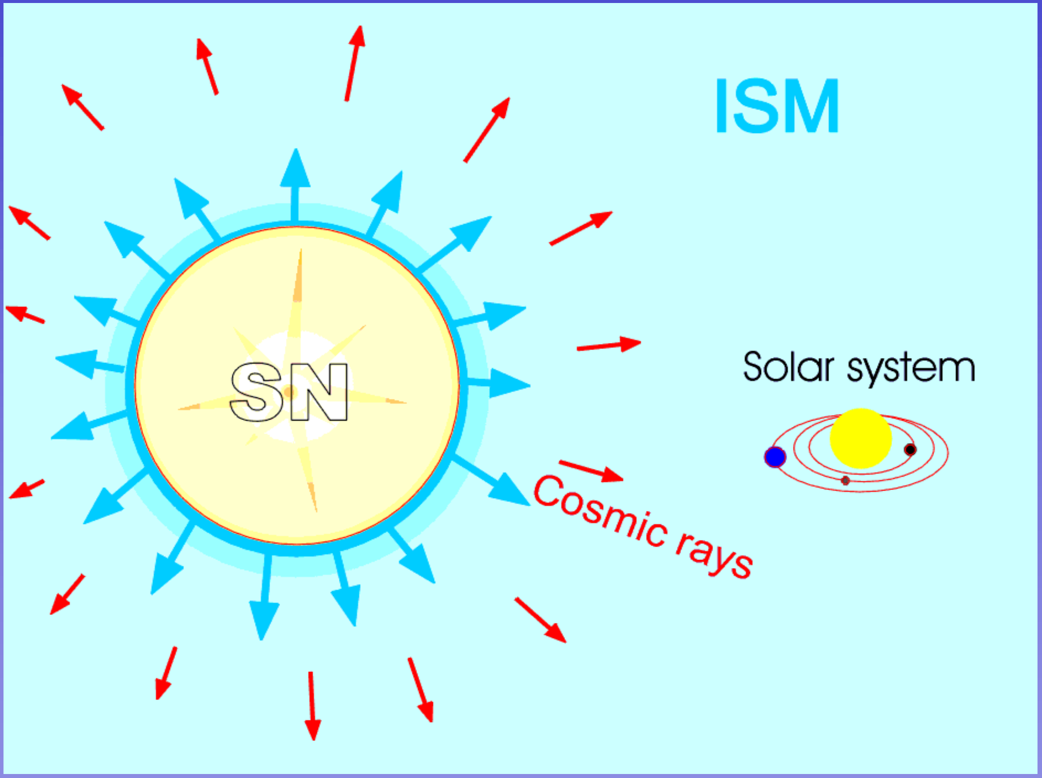


Supernova fingerprints on Earth?

Supernova fingerprints on Earth?



Live radioactivity as signature of nearby SNe



Search for long-lived,
SN produced radionuclides with negligible abundance inside the solar system:

***^{10}Be, ^{26}Al, ^{36}Cl, ^{53}Mn, ^{59}Ni,
^{60}Fe, ^{129}I, ^{146}Sm, ^{244}Pu***

*Ellis et al. ApJ 470(1996)1227,
Korschinek et al., Radiocarbon 38(1996)68*

Slide from K. Knie, <2000

Some radionuclides measured with AMS

^{55}Fe	2.7 years
^{3}H	12.3
^{44}Ti	60
^{63}Ni	100
^{32}Si	140
^{14}C	5 730
^{59}Ni	75 000
^{81}Kr	230 000
^{79}Se	280 000
^{36}Cl	301 000
^{26}Al	720 000
^{10}Be	1 388 000
^{60}Fe	2 600 000
^{53}Mn	3 600 000
^{182}Hf	8 900 000
$^{239-244}$Pu, ^{247}Cm	- 81 000 000

Independent of half-life

fundamental ph

Independent of sample mass

applied sciences

atom counting of radionuclides via isotope ratio measurements

new: ^{55}Fe, ^{68}Ge, ^{93}Zr, ^{106}Pd, ^{135}Cs, ^{146}Sm,
^{202}Pb, ^{210}Bi, ^{226}Ra, ^{229}Th, stable, …

Slide from Anton Wallner

Measurement of Cross Sections

online method

- detection of prompt γ-rays of reaction product (characteristic)
- or: recoil separator technique
- if continous E-distribution: + TOF
- all reaction products accessible
- radioactive beams

offline method

- activation technique:
  - Sample irradiation
  - Determination of reaction product
- quasi-stellar spectrum at once
- sensitive technique
  - detects decay products
  - needs radioactive samples (not too long half-life)
  - atom counting (AMS)
  - related to few applications
  - most sensitive

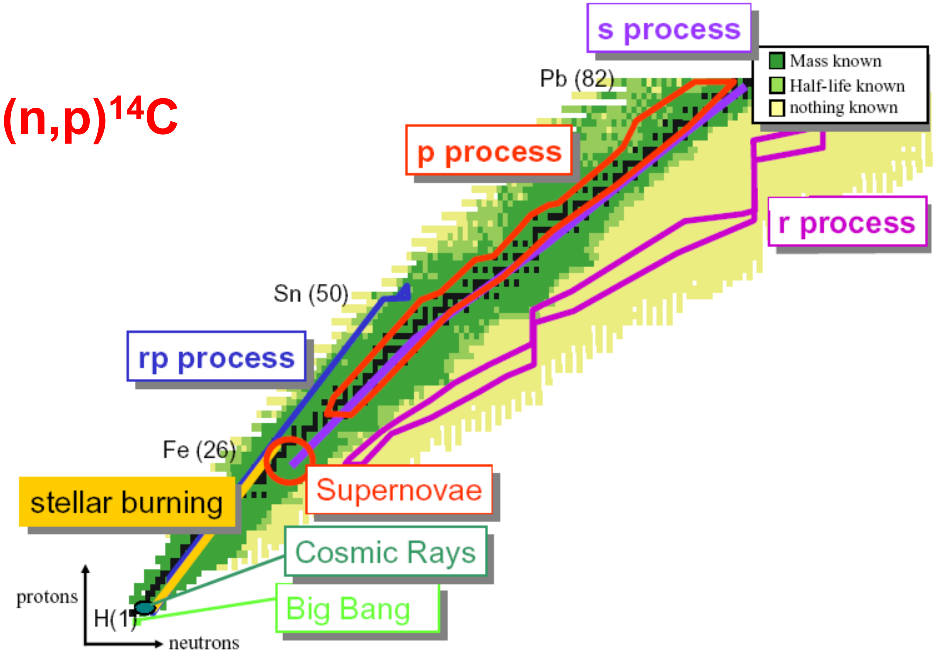
Different systematic uncertainties involved

Slide from Anton Wallner

Applications of AMS to Astrophysics

Nuclear reaction data - cross-section measurements

- **^{9}Be(n, γ)^{10}Be, ^{13}C(n, γ)^{14}C, ^{14}N(n,p)^{14}C**
- **^{35}Cl(n, γ)^{36}Cl, ^{40}Ca(n, γ)^{41}Ca**
- **^{54}Fe(n, γ)^{55}Fe, ^{58}Ni(n, γ)^{59}Ni, ^{62}Ni(n, γ)^{63}Ni, ^{78}Se(n, γ)^{79}Se,**
- **^{209}Bi(n, γ) ^{210}Bi,**
- **....**



Nucleosynthesis of elements in stars

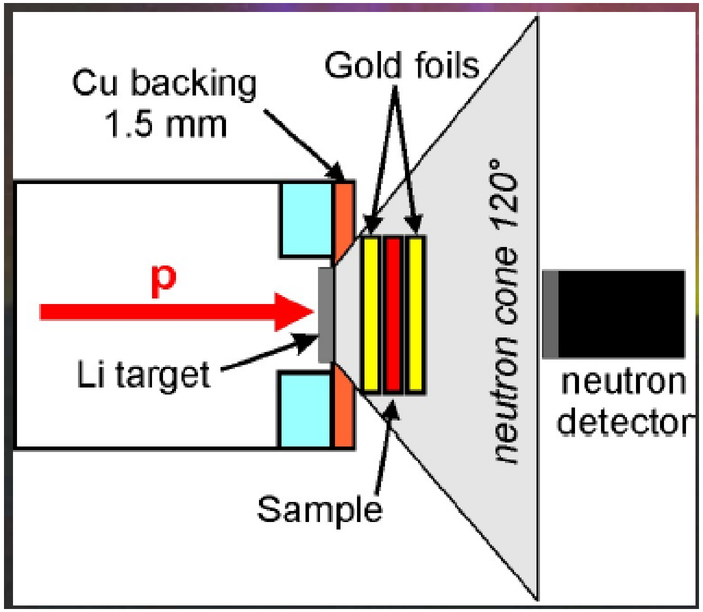
all reactions: identical irradiation geometry

Slide from Anton Wallner

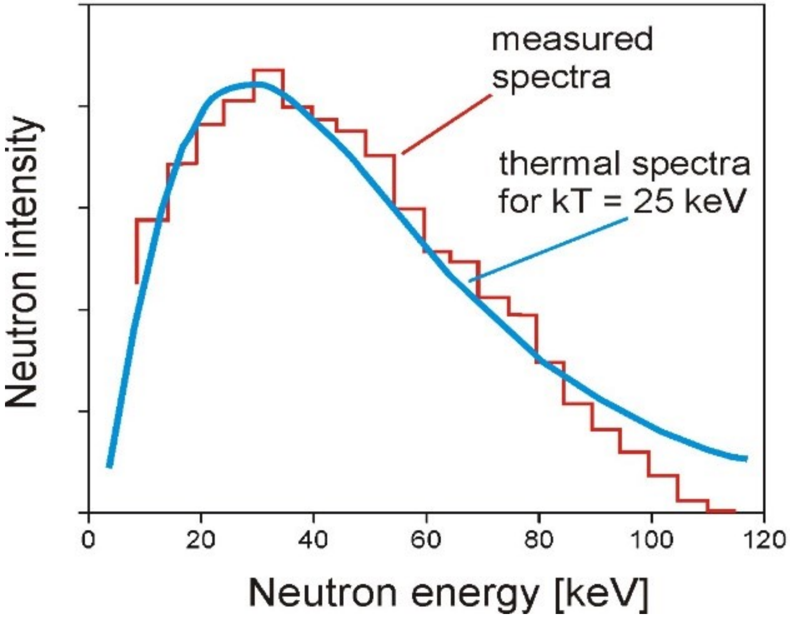
Maxwellian averaged cross sections

Experiment KIT

(1) Activation
(2) Offline – AMS measurement



same conditions for all experiments

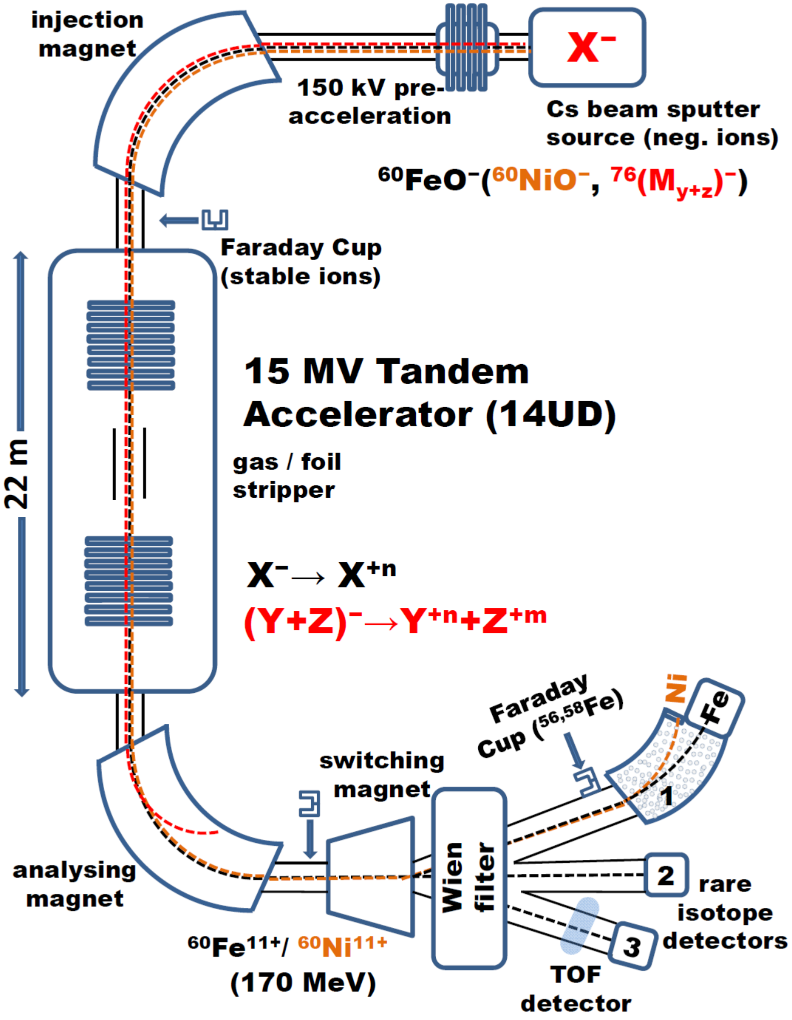


Slide from Anton Wallner

AMS basics

- ***AMS determines isotope ratios – atom counting technique***
- ***$^{14}C/^{12}C$ – radiocarbon dating***
- ***highest sensitivity: $10^{-12} – 10^{-16}$***
- ***no isobaric background (<-> ICPMS) (molecules are completely destroyed)***
- ***isotopic background clearly identified***

…radionuclides



Slide from Anton Wallner

New group
Prof. Anton Wallner at TU Dresden
with focus on
AMS
and astrophysics

Anton Wallner's group at HZDR