Accelerator Mass Spectrometry (AMS) at ATLAS

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ATLAS 25th Anniversary Celebration

Physics Division, Argonne National Laboratory

22-23 October 2010

AMS at ATLAS over the years

Year	Radioisotope	Accelerator	Topic
1979	^{14}C, ^{26}Al, ^{32}Si, ^{36}Cl	Tandem	Detection with split-pole spectrograph
1980	^{32}Si	Tandem	Half-life measurement (101 yr)
1980	^{26}Al	Tandem	Cross section $^{26}Mg(p,\gamma)^{26}Al$
1983	^{44}Ti	Tandem	Half-life measurement (54 yr)
1984	B^{--}, C^{--}, O^{--}	Tandem	No evidence found (<10^{-15})
1984	^{60}Fe	Tandem+Linac	Half-life measurement (1.5×10^6 yr)
1984	Free quarks	Injector Fermi Lab	Cryogenic search for free quarks
1987	^{41}Ca	Tandem+Linac+GFM	Developing a ^{41}Ca dating method
1993	^{59}Ni	Tandem+Linac+FS	Solar CR alphas in moon rocks
1994	^{39}Ar, ^{81}Kr	ECR+Linac+GFM	Developing a detection method
2000	^{81}Kr	NSCL (MSU)+FS	Groundwater dating
2000	^{236}U	ECR+Linac+FMA	^{236}U from ^{235}U (n,γ)
2004	^{39}Ar	ECR+Linac+GFM	Dating of ocean water (circulation)
2005	^{63}Ni	ECR+Linac+GFM	Cross section of $^{62}Ni(n,\gamma)^{63}Ni$
2008	^{39}Ar	ECR+Linac+GFM	Ar with “no“ ^{39}Ar (dark matter search)
2009	^{146}Sm	ECR+Linac+GFM	Half-life meas. (~10^8 yr), p-process

People from Argonne involved with AMS over the years

I. Ahmad, D. Berkovits, P. J. Billquist, F. Borasi, J. Caggiano, **P. Collon**, C. N. Davids, D. Frekers, B. G. Glagola, J. P. Greene, R. Harkewicz, B. Harss, A. Heinz, D. J. Henderson, **W. Henning**, C. L. Jiang, W. Kutschera, M. Notani, **R. C. Pardo**, N. Patel, **M. Paul**, **K. E. Rehm**, R. Rejoub, J. P. Schiffer, R. H. Scott, D. Seweryniak, K.W. Shepard, S. Sinha, A. Sozogni, E. J. Stephenson, X, Tang, J. Unsitalo, **R. Vondrasek**, J. L. Yntema

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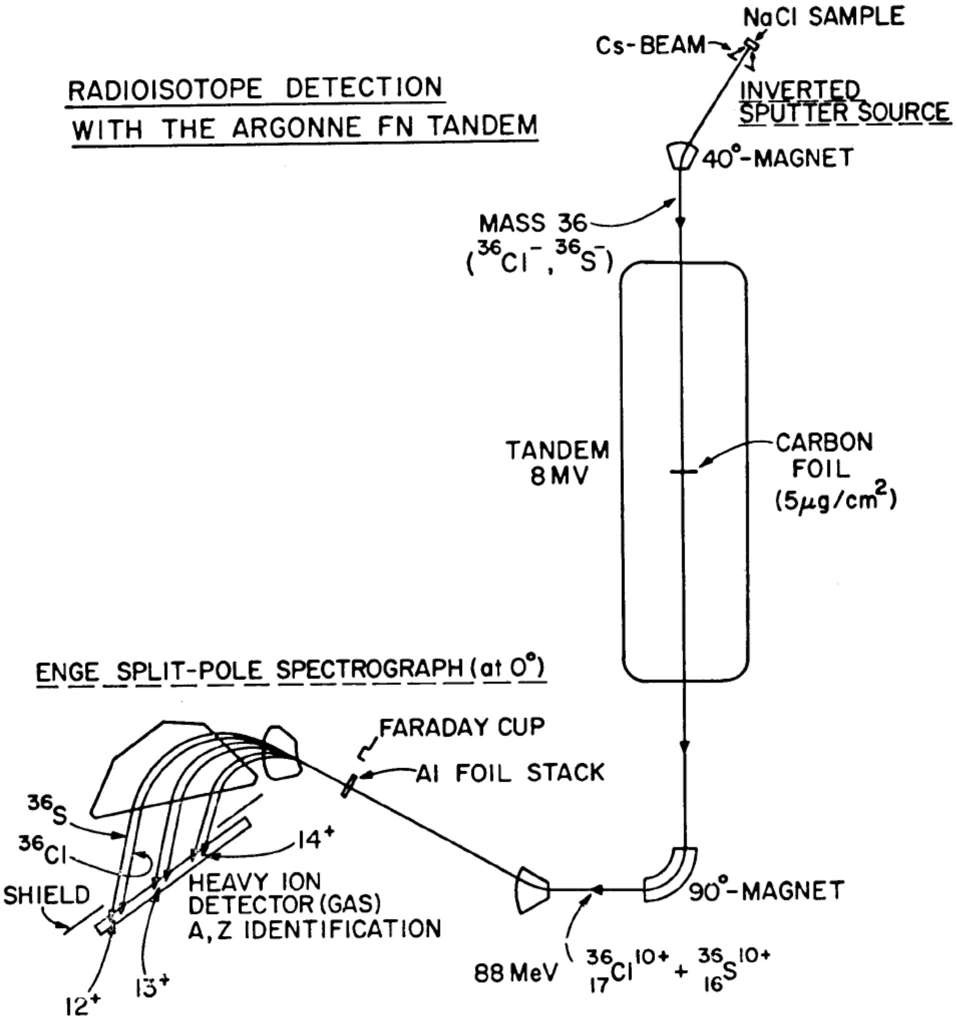
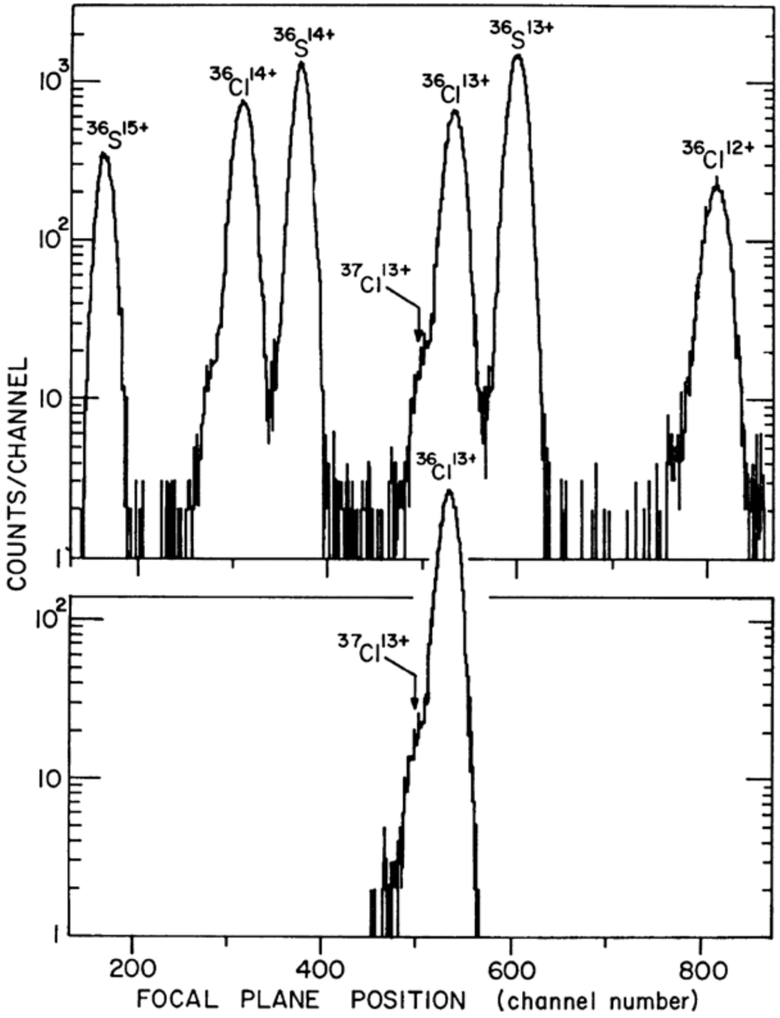
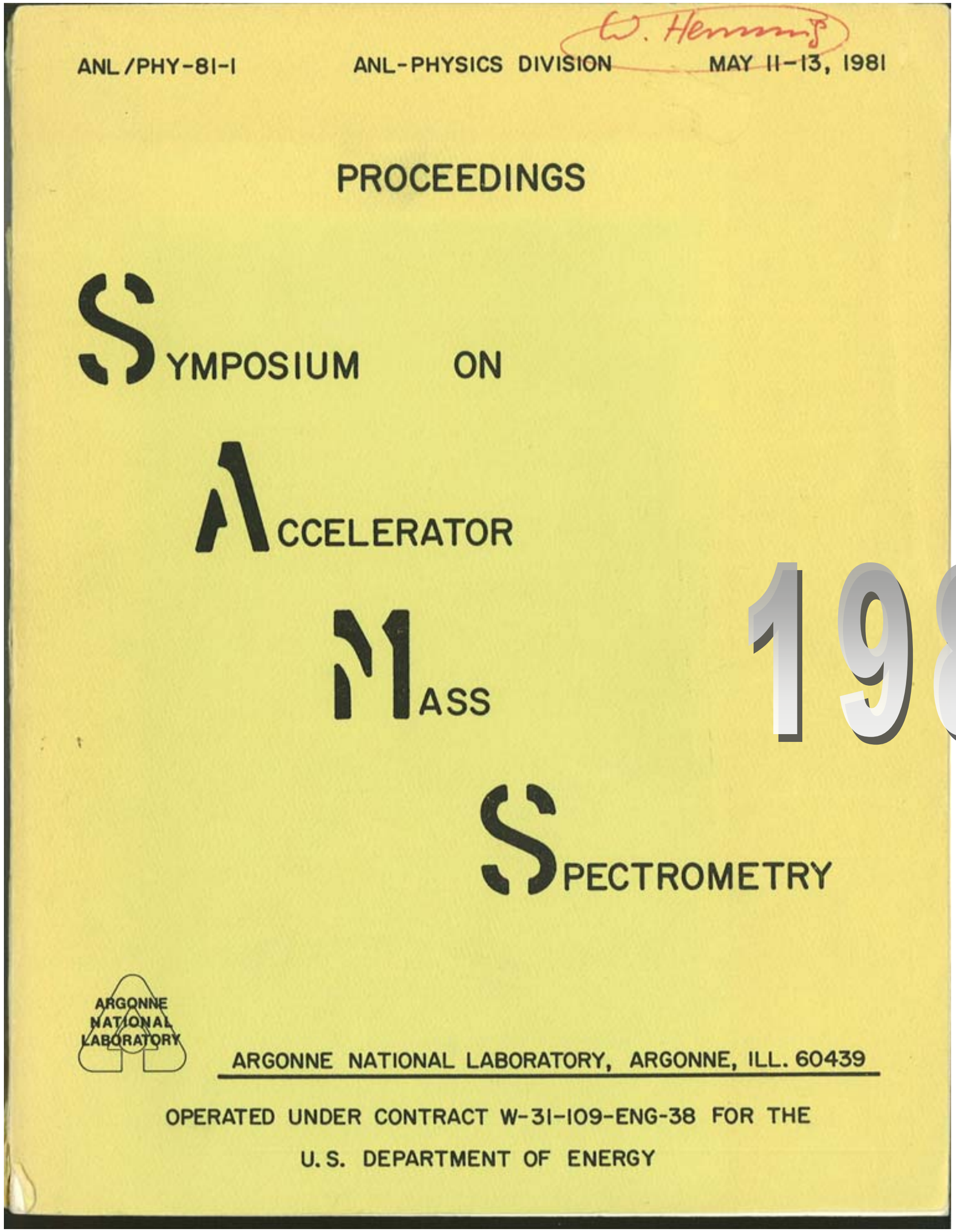




First AMS Paper from Argonne: W. Kutschera, W. Henning, M. Paul, E.J. Stephenson, J. L. Yntema, *Radiocarbon* 22/3 (1980) 807



ANL/PHY-81-1 ANL-PHYSICS DIVISION MAY 11-13, 1981

W. Henning

PROCEEDINGS

SYMPOSIUM ON

ACCELERATOR

MASS

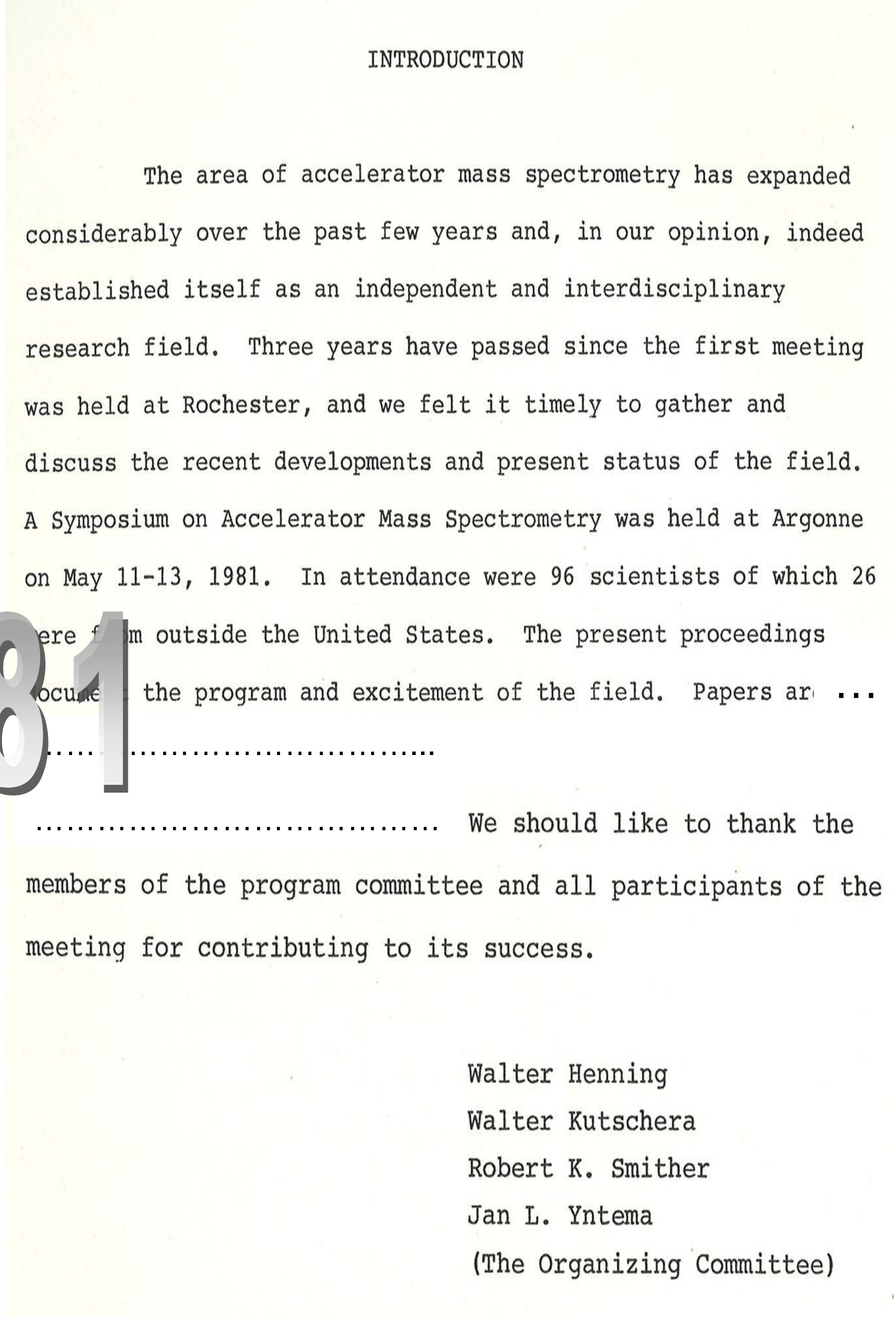
SPECTROMETRY

ARGONNE NATIONAL LABORATORY

ARGONNE NATIONAL LABORATORY, ARGONNE, ILL. 60439

OPERATED UNDER CONTRACT W-31-109-ENG-38 FOR THE
U. S. DEPARTMENT OF ENERGY

1981



INTRODUCTION

The area of accelerator mass spectrometry has expanded considerably over the past few years and, in our opinion, indeed established itself as an independent and interdisciplinary research field. Three years have passed since the first meeting was held at Rochester, and we felt it timely to gather and discuss the recent developments and present status of the field. A Symposium on Accelerator Mass Spectrometry was held at Argonne on May 11-13, 1981. In attendance were 96 scientists of which 26 ere f m outside the United States. The present proceedings ocume the program and excitement of the field. Papers ar ...

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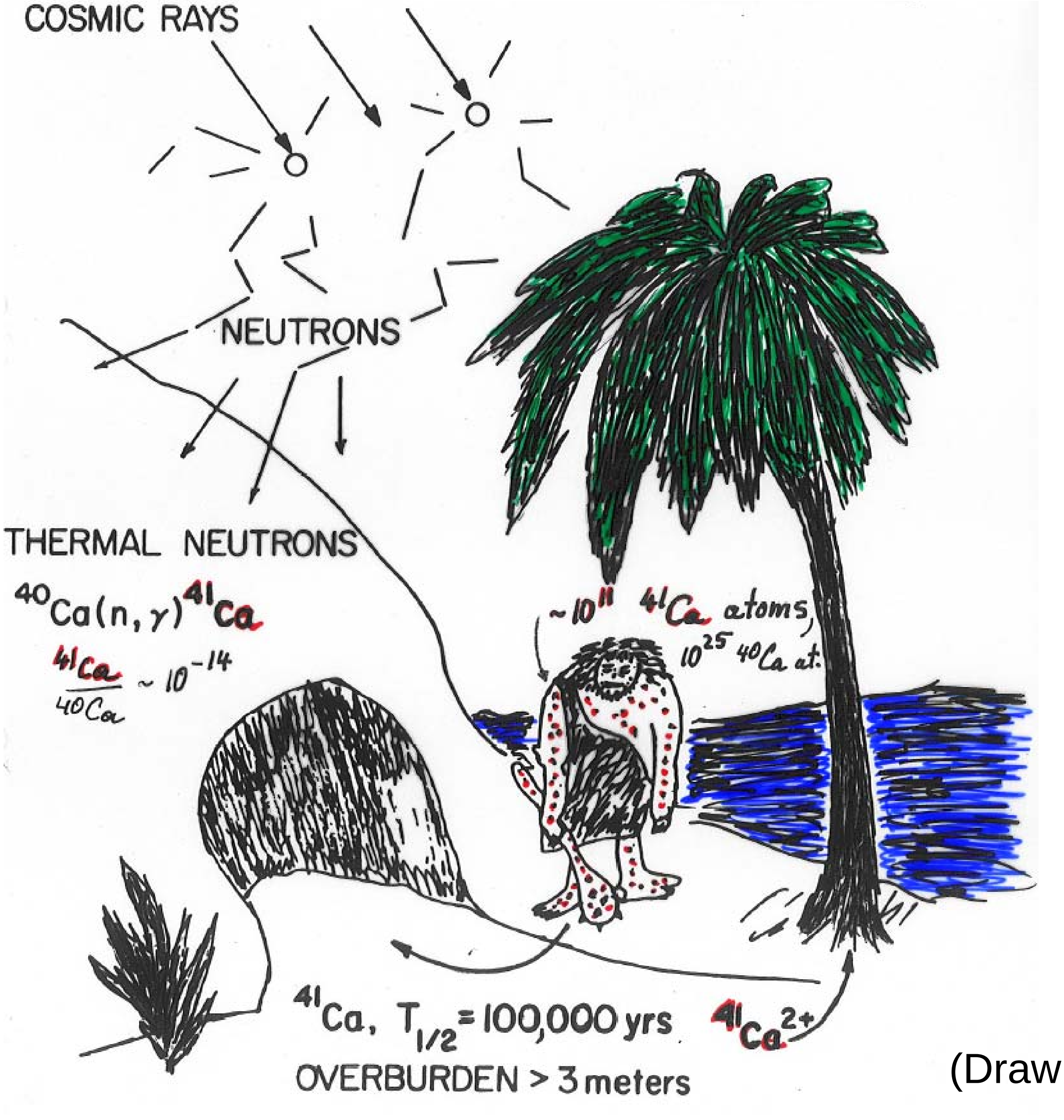
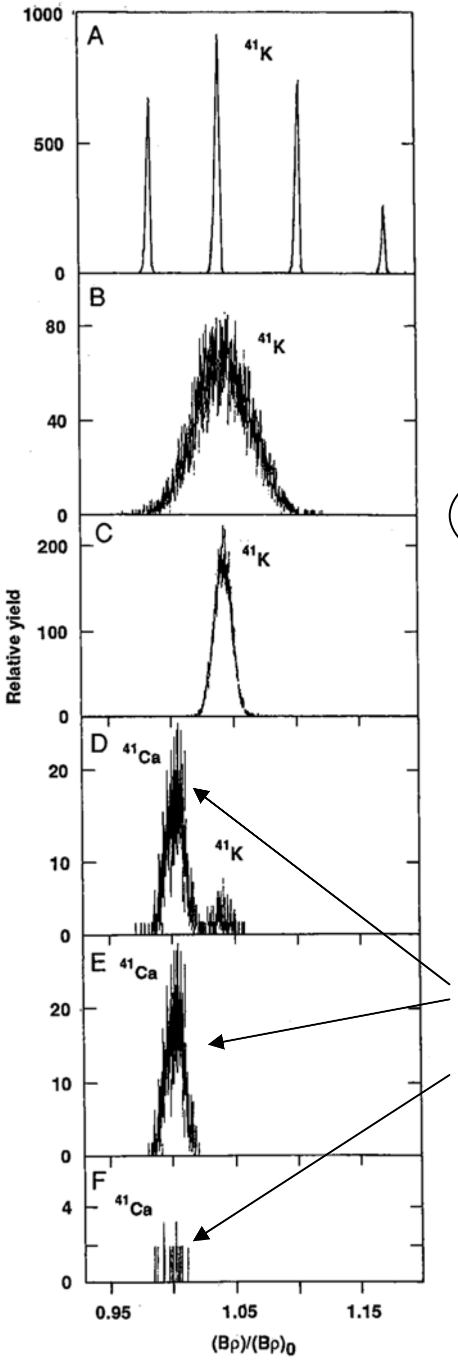
.... We should like to thank the members of the program committee and all participants of the meeting for contributing to its success.

Walter Henning
Walter Kutschera
Robert K. Smither
Jan L. Yntema
(The Organizing Committee)

The Concept of Radiocalcium Dating



(Drawing: W. Henning)



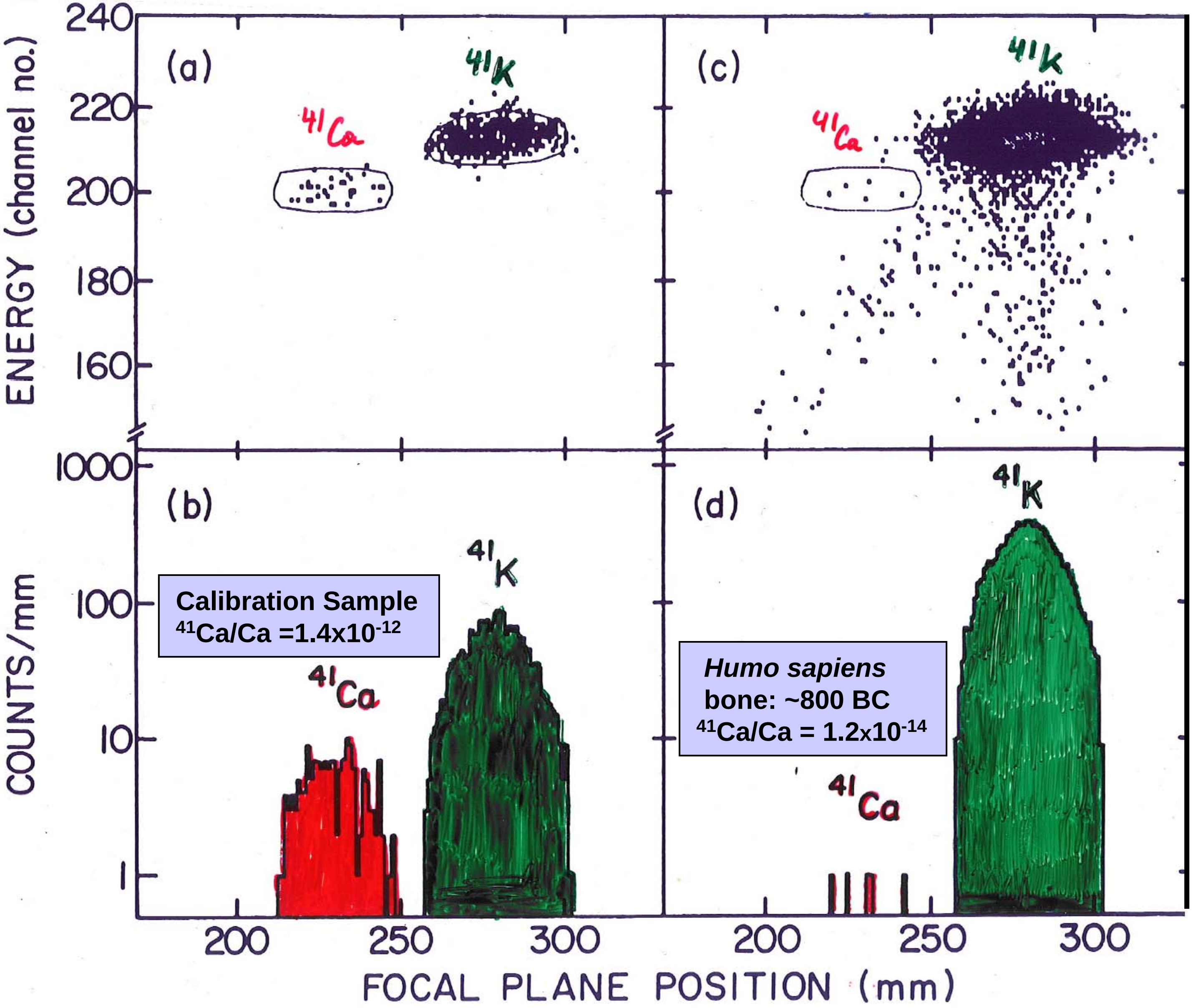
Calcium-41 Concentration in Terrestrial Materials: Prospects for Dating of Pleistocene Samples

W. Henning, W. A. Bell, P. J. Billquist, B. G. Glagola,
W. Kutschera, Z. Liu, H. F. Lucas, M. Paul, K. E. Rehm,
J. L. Yntema, *Science* 236 (1987) 725

Detection of natural ^{41}Ca/Ca ratio using an enrichment process similar to the first detection of ^{14}C by W. F. Libby 40 years earlier [Phys. Rev. 72 (1947) 931].

Table 2. Summary of the results of ^{41}Ca abundances. The values measured with AMS were divided by the pre-enrichment factor to obtain the original ^{41}Ca abundances.

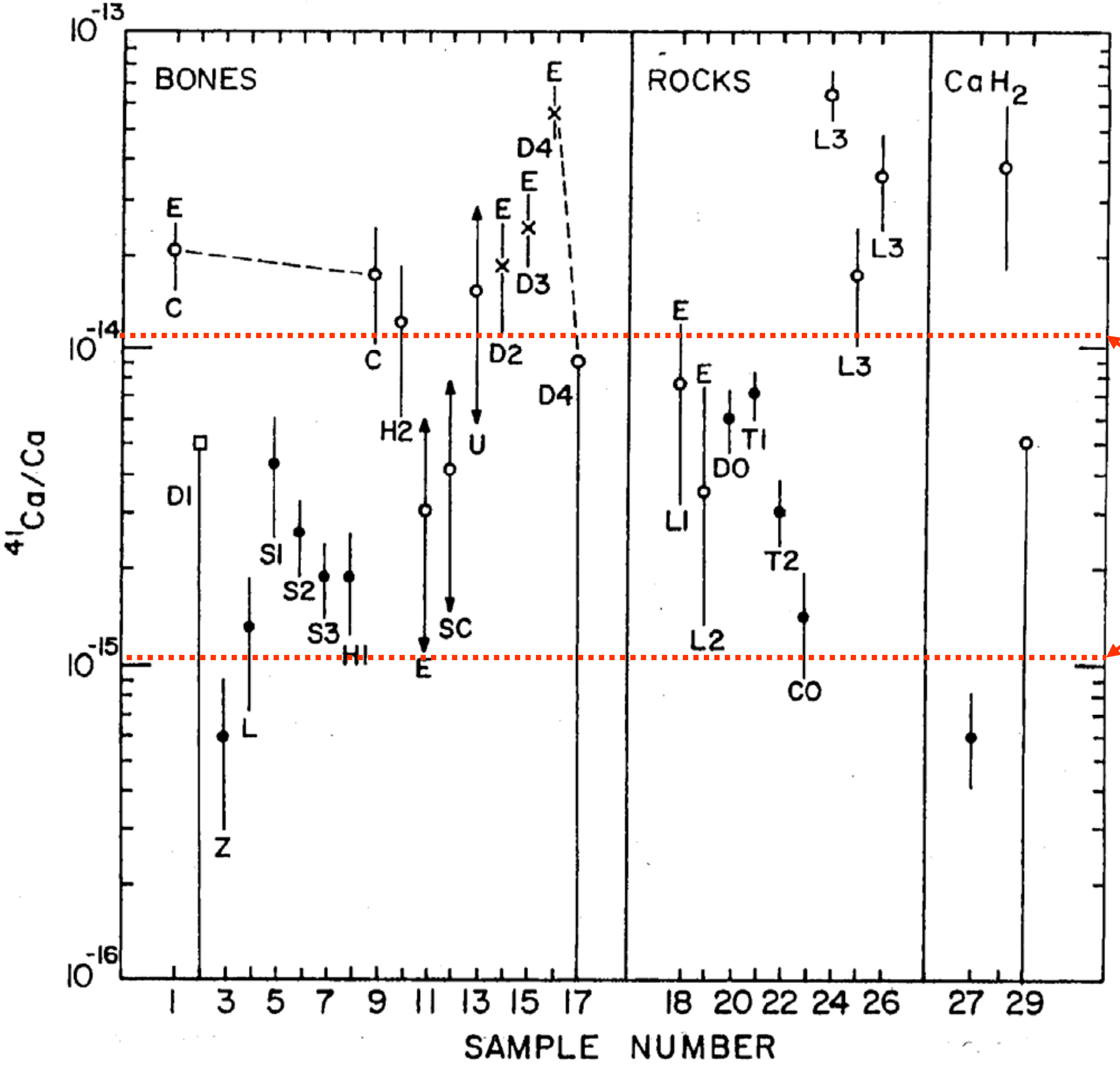
Sample	^{41}Ca/Ca ratio measured with AMS	Pre-enrichment factor	Original ^{41}Ca/Ca ratio
Calibration sample (nonenriched)	$(4.4 \pm 1.0) \times 10^{-12}$	1	$(4.4 \pm 1.2) \times 10^{-12}$
Calibration sample (pre-enriched)	$(5.2 \pm 0.2) \times 10^{-10}$	152	$(3.4 \pm 0.5) \times 10^{-12}$
Contemporary bovine bone	$(3.0 \pm 0.6) \times 10^{-12}$	151	$(2.0 \pm 0.5) \times 10^{-14}$
Limestone (surface)	$(8.8 \pm 4.4) \times 10^{-13}$	116	$(7.6 \pm 4.5) \times 10^{-15}$
Limestone (11 m depth)	$(4.0 \pm 1.9) \times 10^{-13}$	117	$(3.4 \pm 2.1) \times 10^{-15}$
Limestone (11 m depth) (nonenriched)	$\leqslant 5.8 \times 10^{-14}$	1	(3.4×10^{-15})



Calibration Sample
^{41}Ca/Ca =1.4x10^{-12}

Humo sapiens
bone: ~800 BC
^{41}Ca/Ca = 1.2x10^{-14}

W. K. et al., Studies Towards a Method for Radiocalcium of Bones,
Radiocarbon **31/3** (1989)311-323



Estimated range of $^{41}Ca/Ca$ values

Overview of ^{41}Ca measurements at Argonne, GSI, Penn, Rehovot

W.K. , *Nucl. Instr. Meth.* **B50** (1990) 252-261

A possible solution:

Absolute ^{41}Ca dating?

^{41}Ca decays by electron capture:	$^{41}\mathrm{Ca} + e^- \rightarrow {}^{41}\mathrm{K}^* + \nu_e$
Exponential decay of ^{41}Ca:	$^{41}\mathrm{Ca}_t = {}^{41}\mathrm{Ca}_o \times e^{-\lambda/t}$
The sum of parent and daughter is:	$^{41}\mathrm{Ca}_o = {}^{41}\mathrm{Ca}_t + {}^{41}\mathrm{K}_t^*$(radiogenic)
The **age** is then **independent** of $\mathbf{^{41}Ca_o}$:	$t = 1/\lambda \times \ln(1 + \mathbf{{}^{41}C_t/{}^{41}K_t^*})$
The problem which has to be solved:	How to distinguish ^{41}K* from ubiquitus environmental ^{41}K
Perhaps this may work:	The recoil energy of ^{41}K* after EC due to the emission of ν_e is only +2.2 eV.
In bone, Ca forms apatite crystals:	$\mathrm{Ca_5(PO_4)_3(OH)}$

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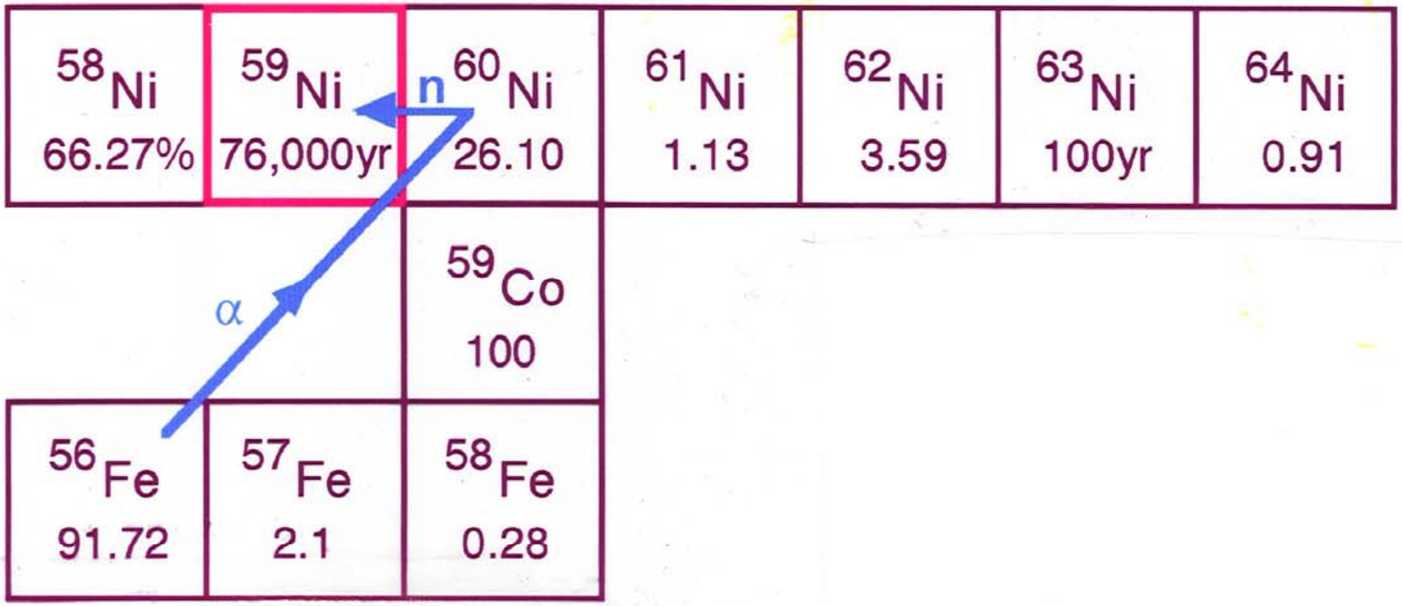
In bone, Ca forms apatite crystals: $\mathrm{Ca_5(PO_4)_3(OH)}$

Perhaps ^{41}K* will stay inside the apatite crystals, and can thus be detected after selective chemistry has dissolved everything else of the bone matrix.

Measuring the interaction of soft alpha particles from solar cosmic rays with the surface of the moon

W.K. et al., *Nucl. Instr. Meth*. **73** (1993) 403

Production of ^{59}Ni by solar cosmic ray alpha particles from iron in lunar surface rocks



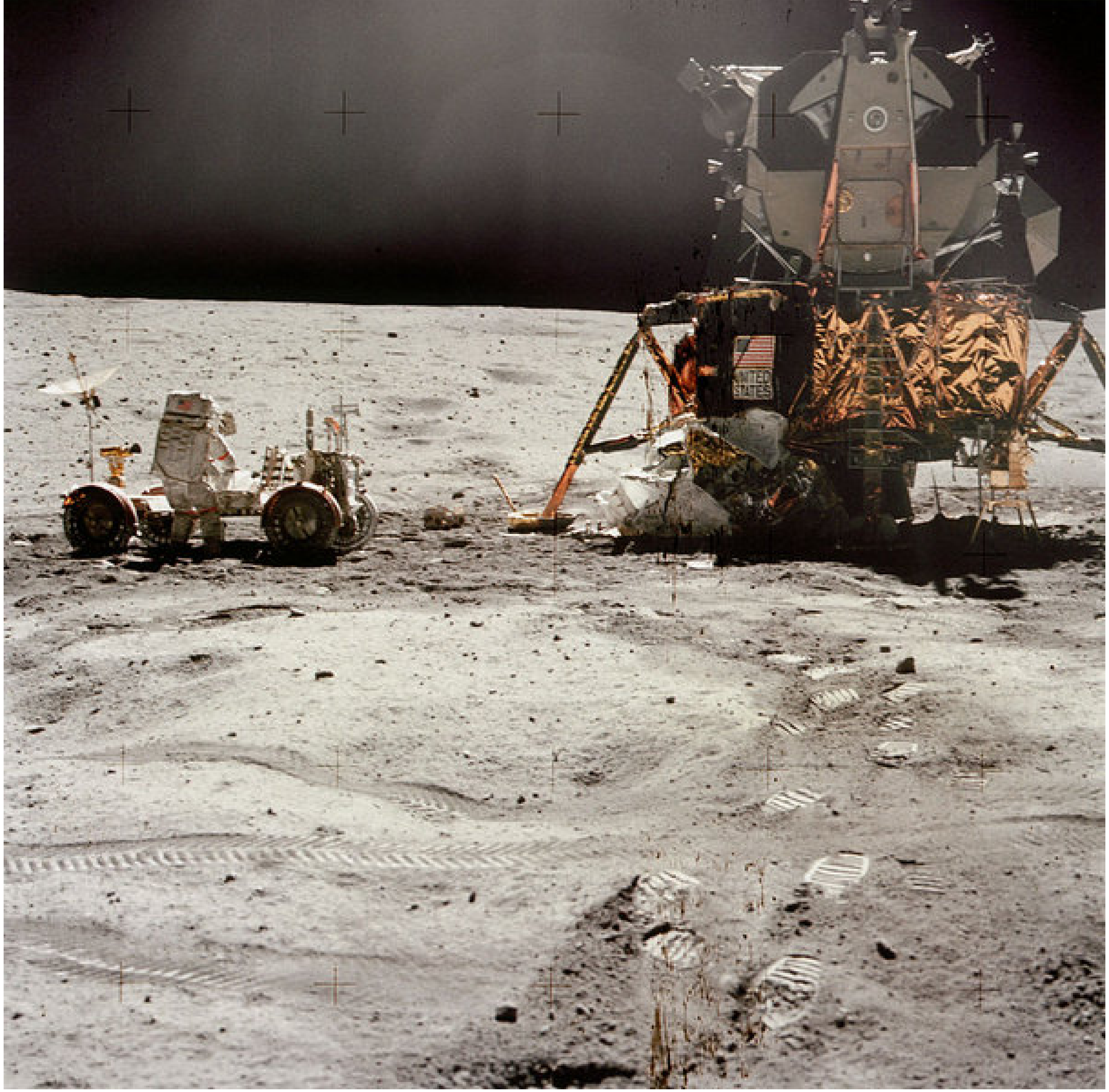
^{58}Ni 66.27%	^{59}Ni 76,000yr	^{60}Ni 26.10	^{61}Ni 1.13	^{62}Ni 3.59	^{63}Ni 100yr	^{64}Ni 0.91
		^{59}Co 100				
^{56}Fe 91.72	^{57}Fe 2.1	^{58}Fe 0.28				

avoid:

$^{59}Co(p,n)^{59}Ni$

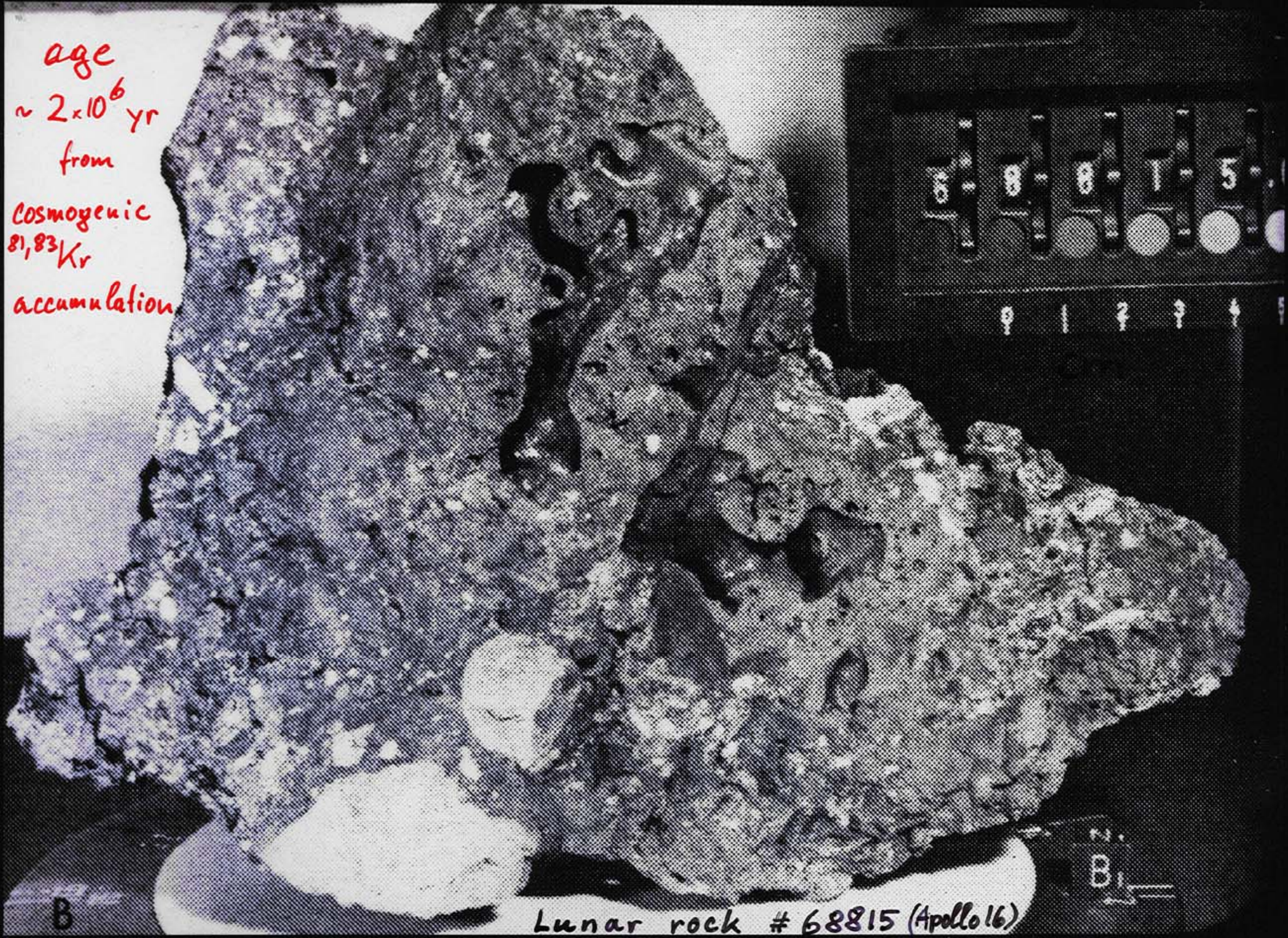
$^{60-64}Ni(p, spall)^{59}Ni$

through low Co, Ni content



Apollo 16 flight to the Moon (16-27 April 1972)

Lunar Module Orion, with John W. Young working at the Lunar Rover



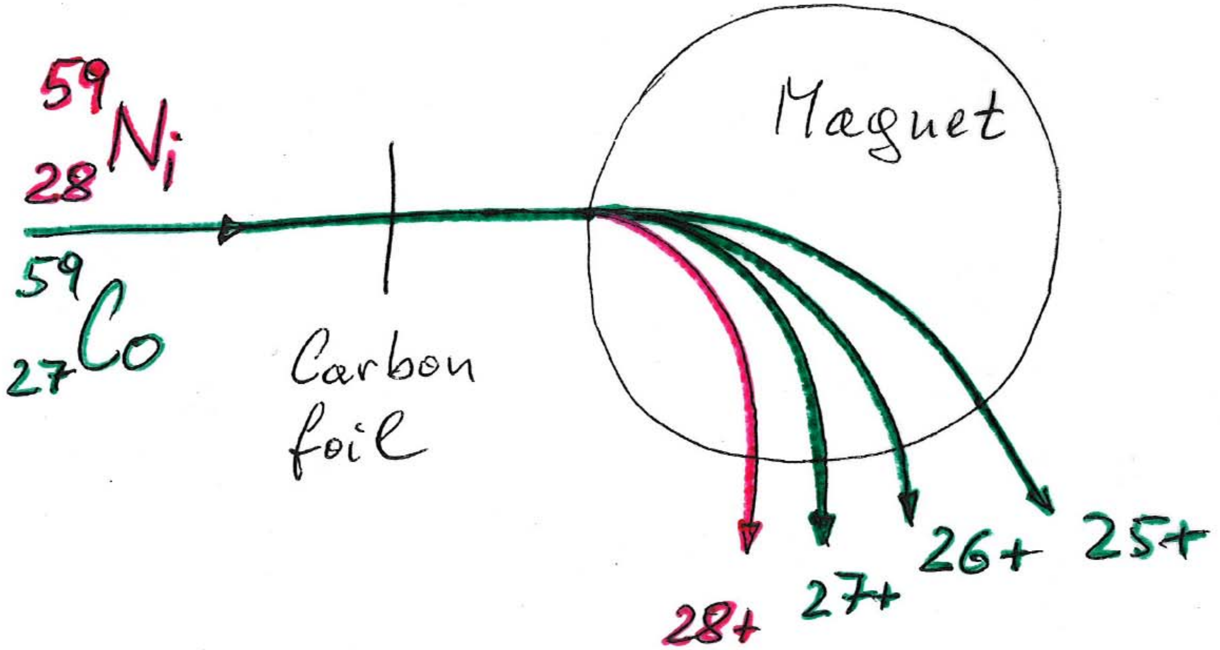
age
~ 2×10^6 yr
from
cosmogenic
^{81,83}Kr
accumulation

Lunar rock # 68815 (Apollo 16)

Separation of ^{59}Ni from ^{59}Co

by full stripping

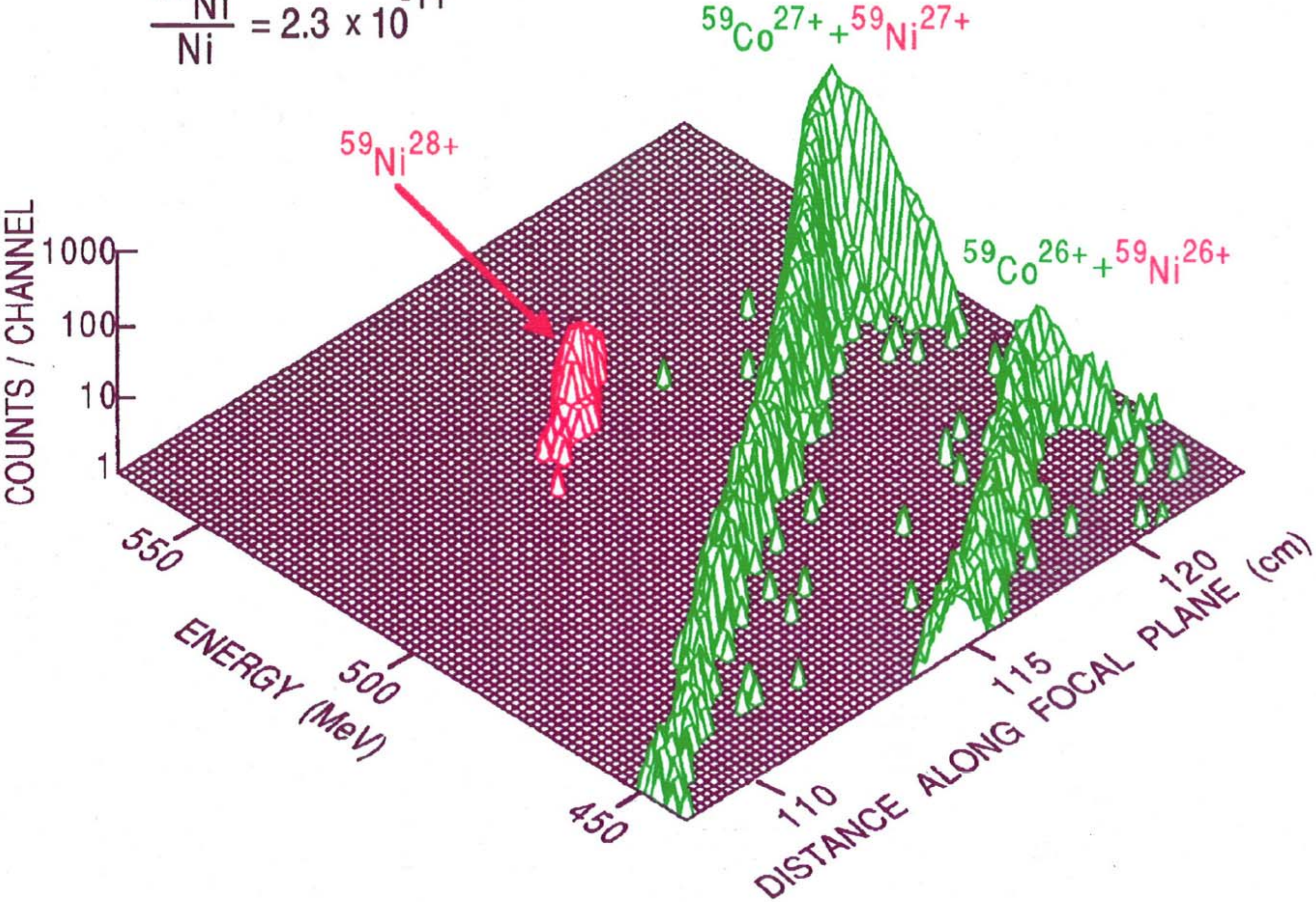
W. K. et al. NIM B 73 (1993) 403-412



ANL-P-20,714

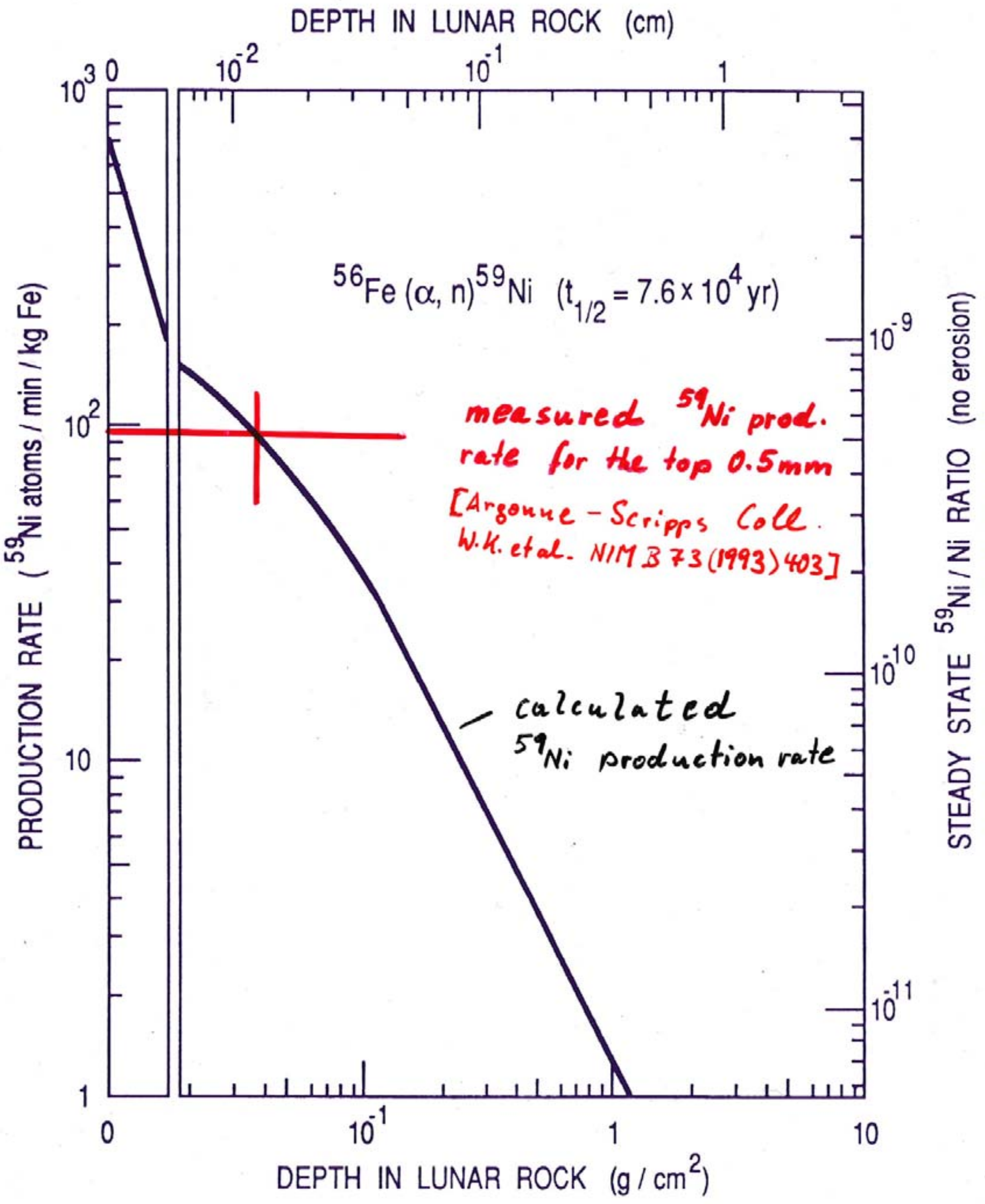
ADMIRE METEORITE

$$\frac{^{59}\mathrm{Ni}}{\mathrm{Ni}} = 2.3 \times 10^{-11}$$



Separation of ^{59}Ni from ^{59}Co
by full stripping at E = 640 MeV

ANL-P-20,485



measured ^{59}Ni prod. rate for the top 0.5mm

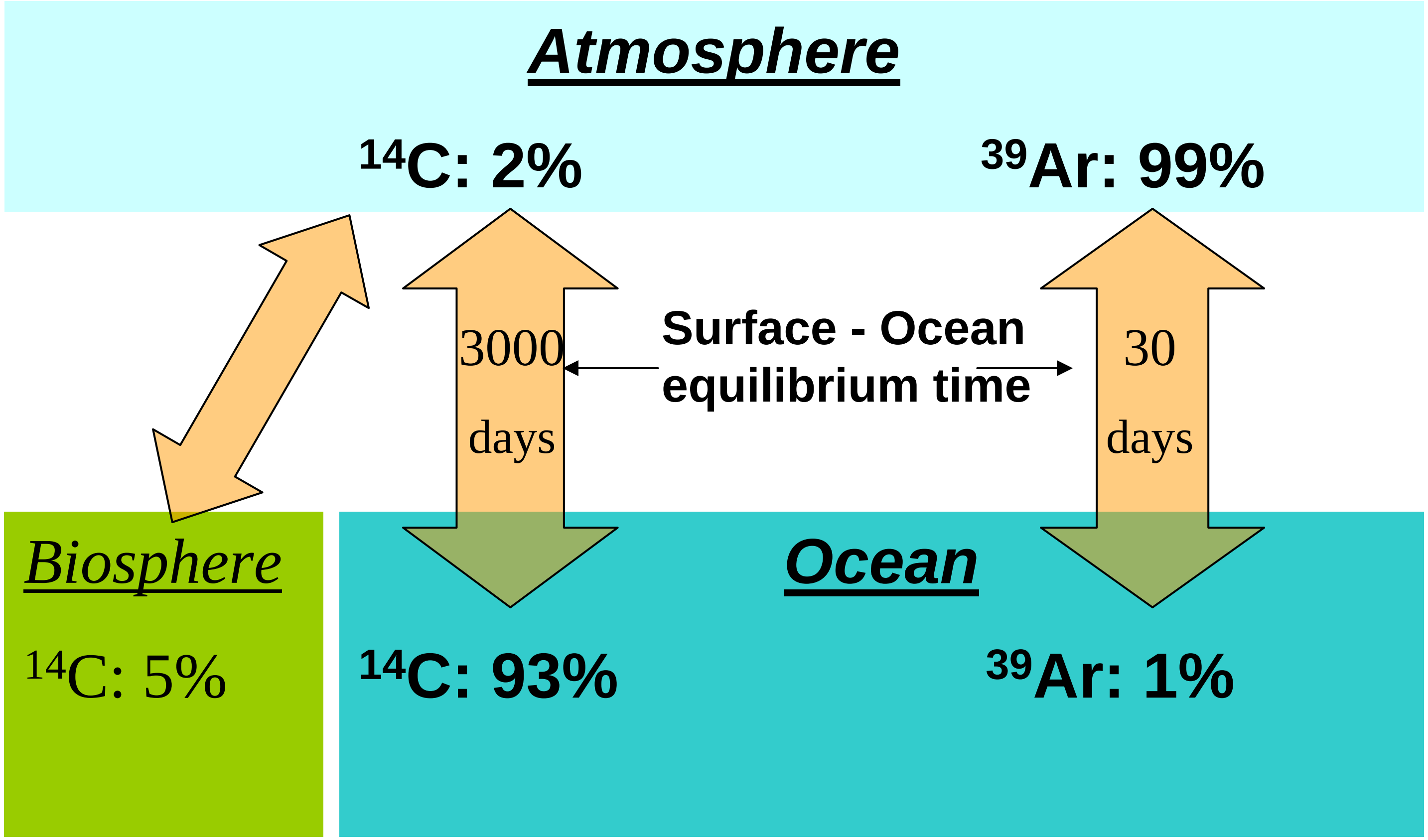
[Argonne - Scripps Coll. W.K. et al. NIM B 73 (1993) 403]

calculated ^{59}Ni production rate

^{39}Ar ($t_{1/2}$ = 269 yr)

the ideal tracer to study ocean dynamics

Studying the Dynamics of the Oceans with two different cosmogenic radioisotopes



Atmosphere

^{14}C: 2%

^{39}Ar: 99%

3000 days

Surface - Ocean equilibrium time

30 days

Biosphere

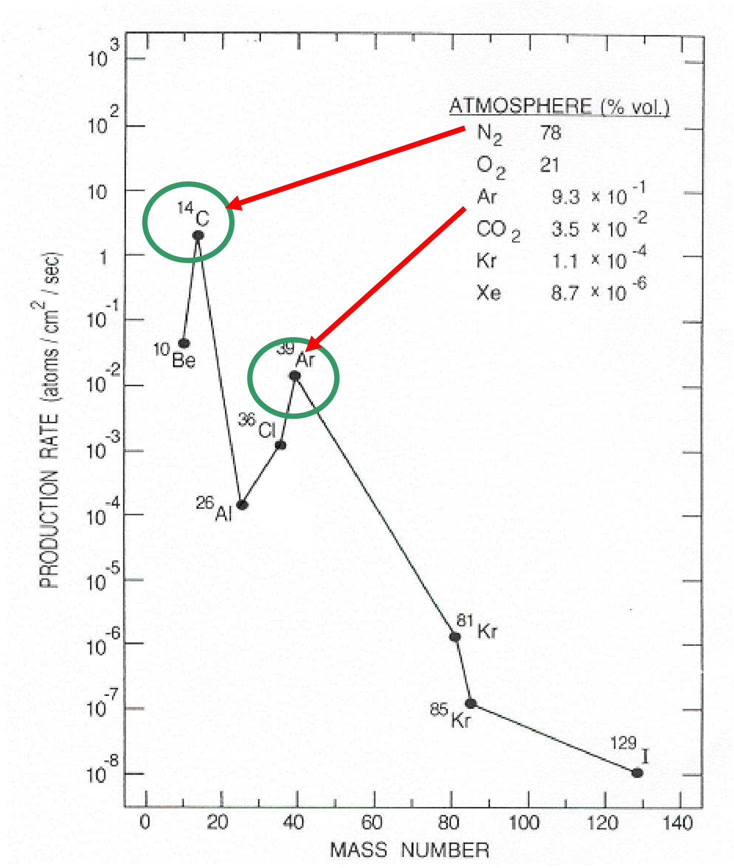
^{14}C: 5%

Ocean

^{14}C: 93%

^{39}Ar: 1%

^{14}C and ^{39}Ar key data



Production rate of long-lived cosmogenic radionuclides

Half-life

^{14}C: 5730 years
^{39}Ar: 269 years

Atmospheric isotope ratios

$^{14}C/ ^{14}C = 1.2\text{x}10^{-12}$
$^{39}Ar/ ^{40}Ar = 8.1\text{x}10^{-16}$

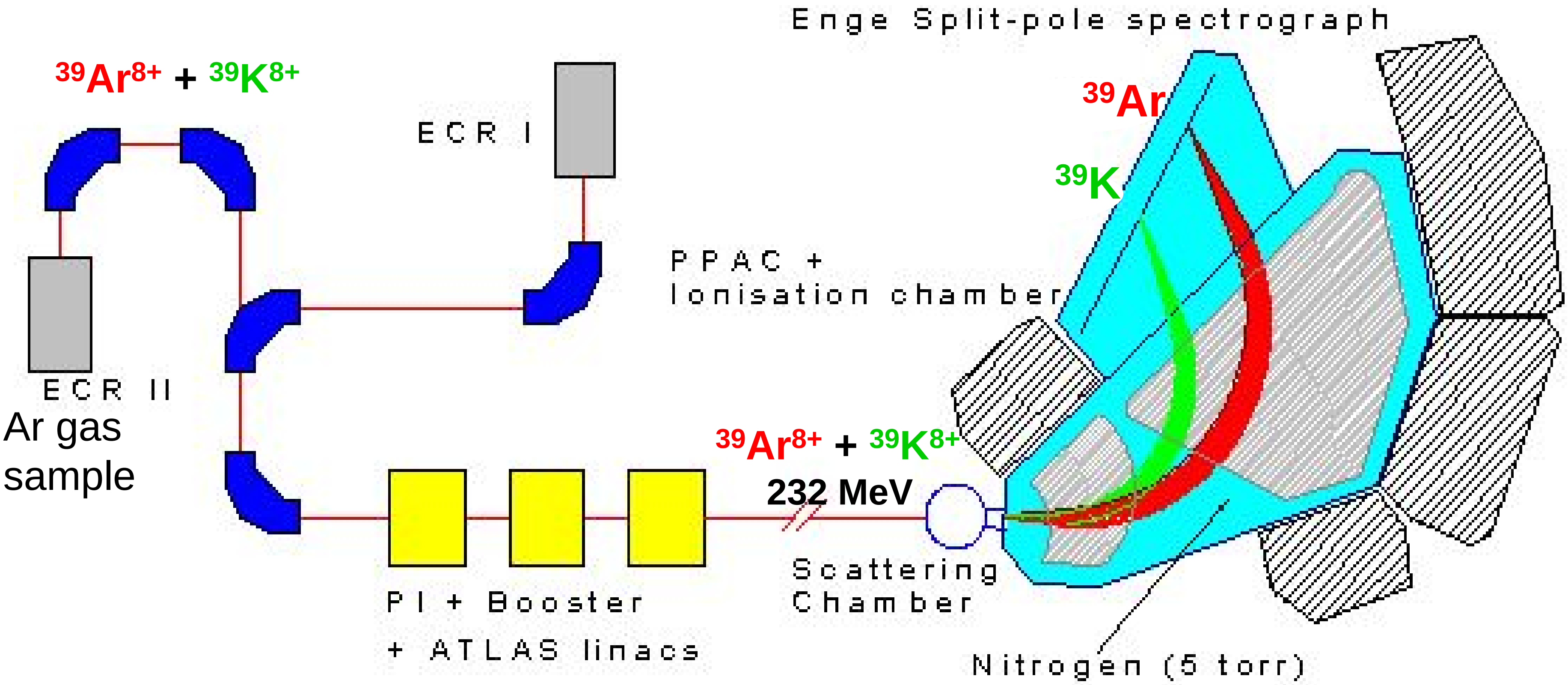
Ocean water concentrations

^{14}C: $1.8\text{x}10^{9}$ atoms/litre → 0.4 decays/min
^{39}Ar: $6.5\text{x}10^{3}$ atoms/litre → 17 decays/year

Low Level Counting	AMS
^{14}C: 250 litre H_2O	0.5 litre H_2O
^{39}Ar: 1500 litre H_2O	20 litre H_2O ?

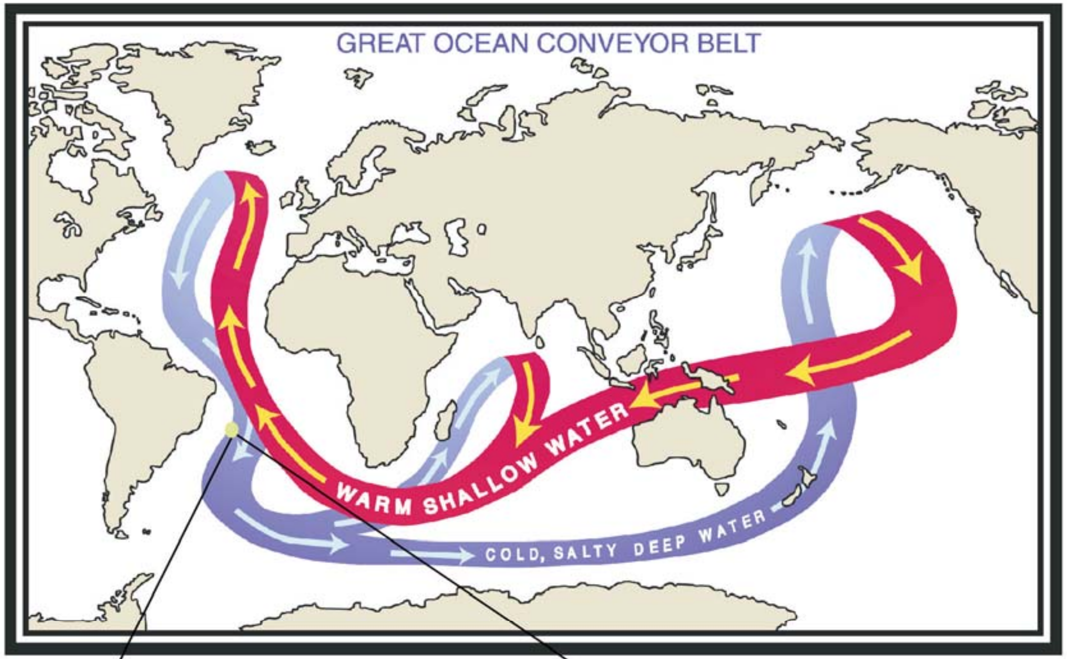
^{39}Ar detection with ATLAS

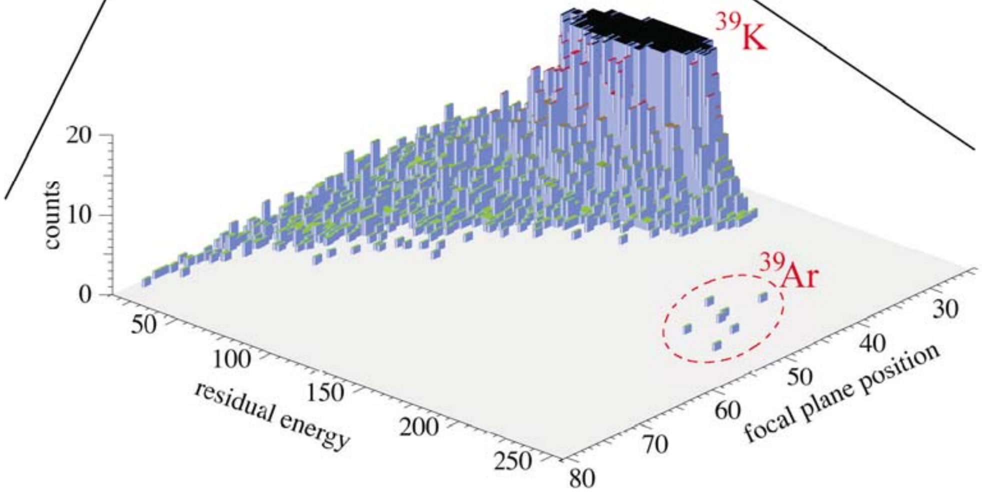
[P. Collon et al., *Nucl. Instr. Meth.* B 223-224 (2004) 428]



Isobar separation of ^{39}Ar(Z=18) from ^{39}K (Z=19) in the gas-filled magnetic spectrograph

Dating of deep ocean water with ^{39}Ar ($t_{1/2}$ = 269 a) using AMS





Sample: SAVE #95
Water depth = 4717 m
^{39}Ar/^{40}Ar = $(2.6 \pm 0.6) \times 10^{-16}$
= 32% atmospheric Ar
“Age“ (decay) = 440 years

P. Collon, T.-Z. Lu, W. K.
Ann.Rev. Nucl.Part. Sci.
54 (2004) 39-67

Results of ^{39}Ar/^{40}Ar measurements at Argonne

Sample	^{39}Ar/^{40}Ar (10^{-16})	Fraction of atm. argon*	“Decay age“ (years)
Neutron activated argon	580 ± 40		
Atmospheric argon	7.7 ± 0.9	95%	
South Atlantic Ventilation Experiment			
#294, water depth = 850 m	5.2 ± 0.7	65%	170
#294, water depth = 5000 m	3.5 ± 0.6	44%	320
#95, water depth = 4717 m	2.6 ± 0.6	32%	440
Great Artesian Basin, Australia, Watson creek well, ground water (0.4 Myr)	0.4 ± 0.2	5%	1200
Atmospheric argon*	8.5 ± 1.2	105%	
Neutron activated argon	600 ± 40		

*Normalized to ^{39}Ar/^{40}Ar = 8.1×10^{-16} = 100%, measured by Low Level Counting (Loosli)

Collon et al., Nucl. Instr. Meth. B 223-224 (2004) 428-434

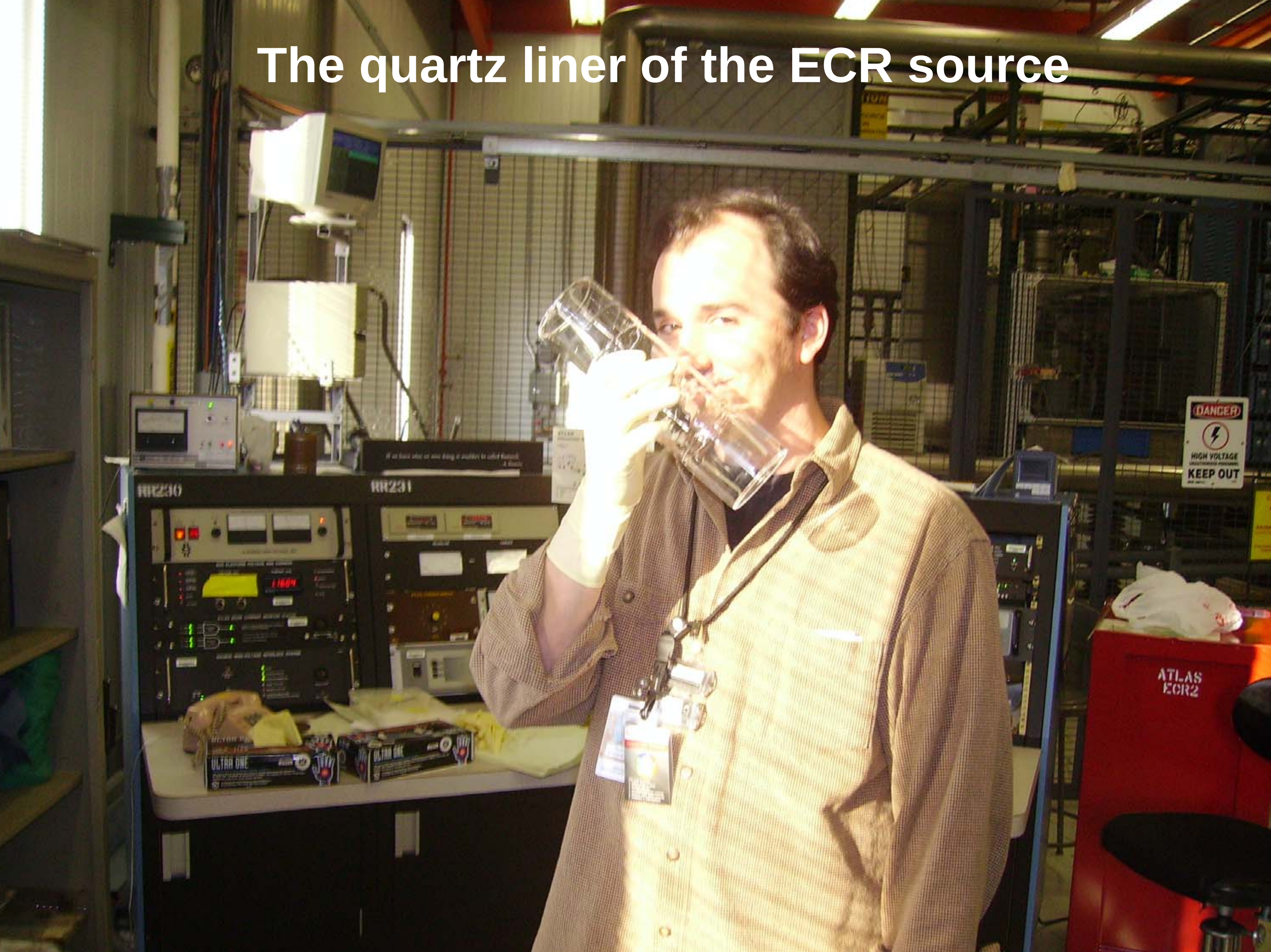
Pushing the detection limit of ^{39}Ar into the realm of interest for dark matter searches with liquid argon

Desired (F. Calaprice, Princeton):

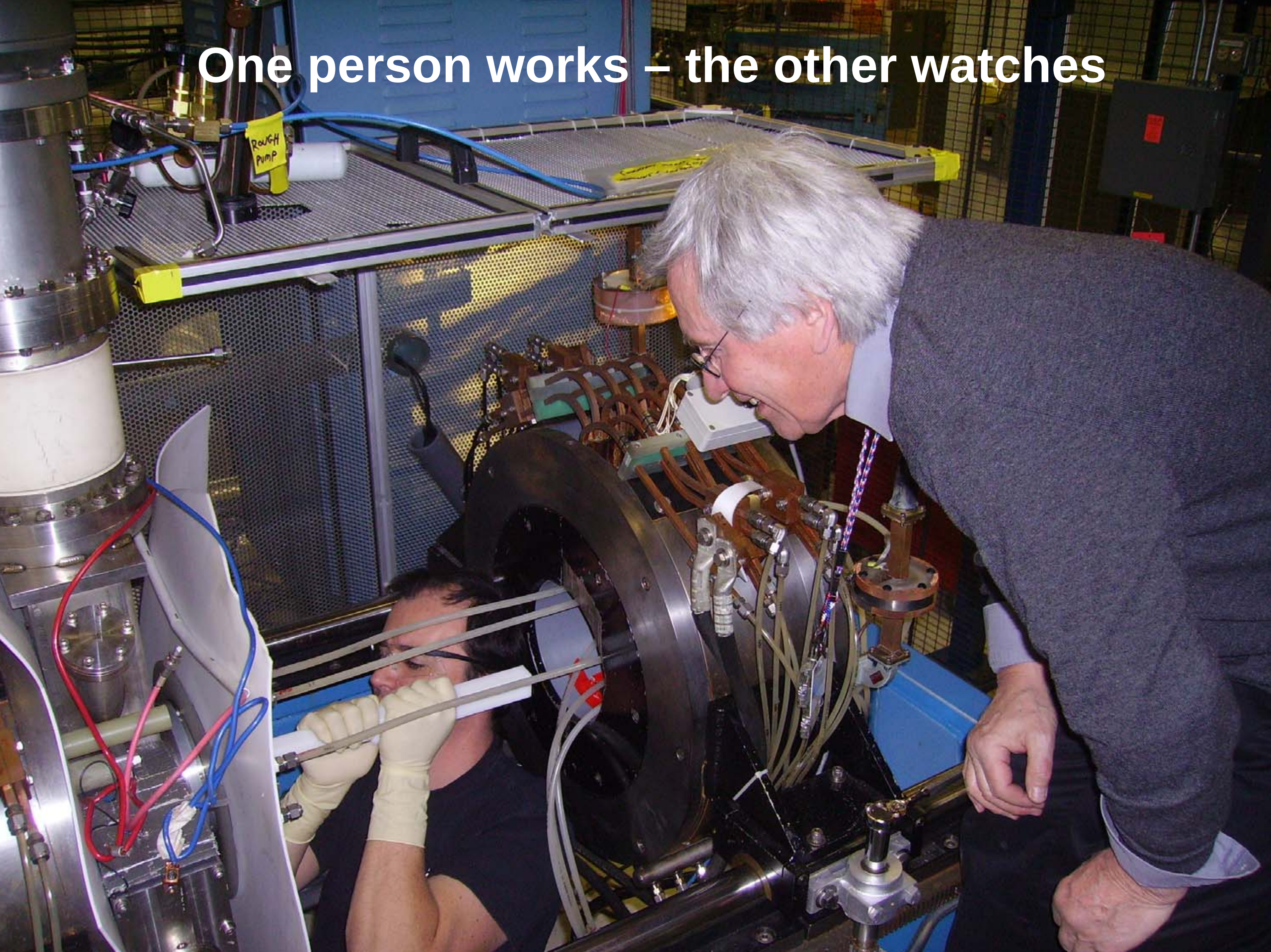
$^{39}\mathrm{Ar/Ar} \sim 10^{-3} \times (^{39}\mathrm{Ar/Ar})_{\mathrm{atmosphere}} \sim 1\mathrm{x}10^{-18}$

A lost battle against the isobaric background of ^{41}K

The quartz liner of the ECR source



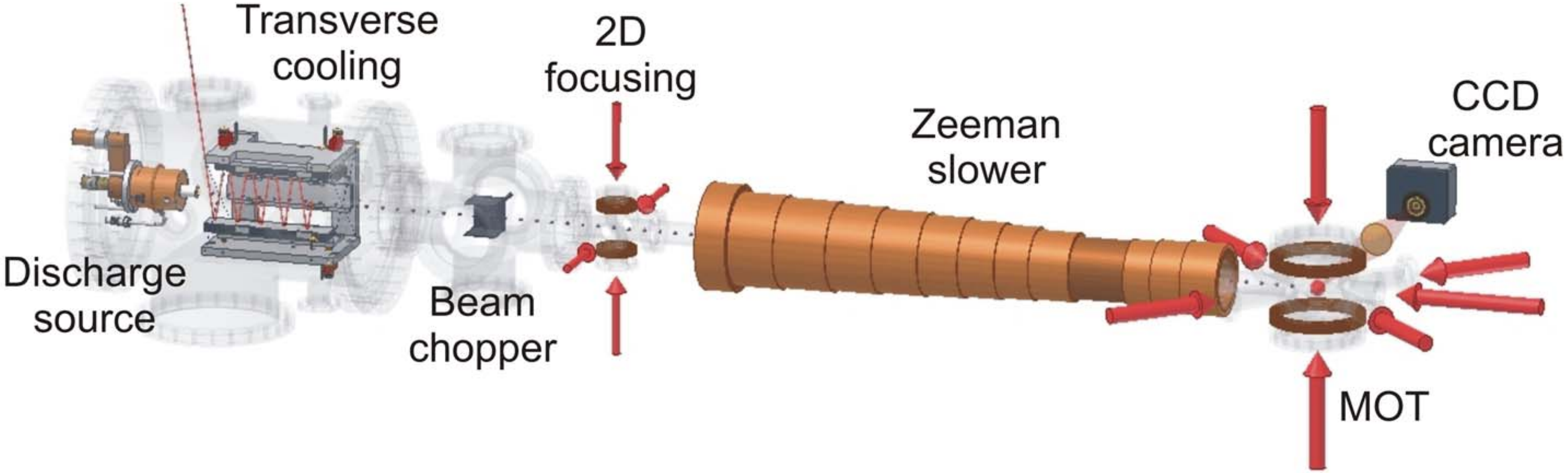
One person works – the other watches



Sometimes things just don‘t work out

The future:

^{39}Ar detection with the magneto optical trap technique (P. Mueller, Z.-T. Lu et al.)



Once you cross the ocean,

You are forever on the wrong side.

Victor Weisskopf