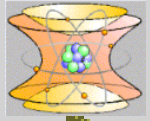
# 30 years of ISOLTRAP at ISOLDE



David Lunney
CNRS (CSNSM)
Universite Paris Sud, Orsay

ISOLDE Workshop
CERN, 4 Dec 2017

# ISOLTRAP

Time-of-flight detector

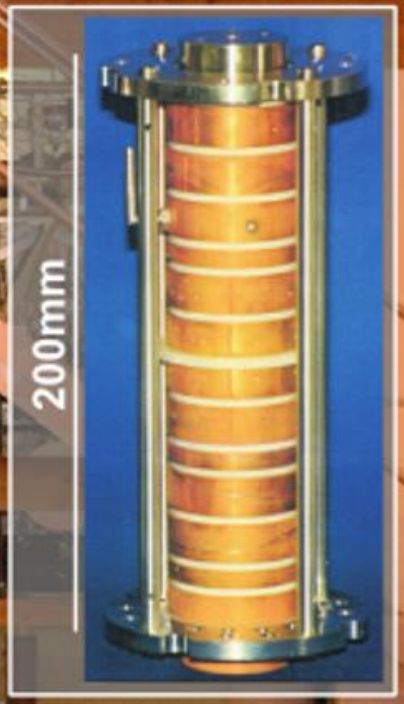
1986-1990


Precision Penning trap
*B*=5.9T

2010



Preparation Penning trap
*B*=4.7T




1994

1999

RFQ
cooler and buncher

MR-ToF-MS
BNG


## H.- Jürgen Kluge

GSI/Darmstadt and University of Heidelberg


ISOLDE Workshop
December 17, 2007

# Twenty Years of ISOLTRAP

## Many thanks to the long-term collaborators

| | | | |
|---|---|---|---|
| 1982 - 2003 | | | Bob Moore |
| 1983 - 1990 | and 2000 | up to now | Lutz Schweikhard |
| 1987 | | up to now | Georges Audi |
| 1984 - 2005 | | | Georg Bollen |
| 1993 | | up to now | Dietrich Beck |
| 1994 | | up to now | Stefan Schwarz |
| 1995 | | up to now | Dave Lunney |
| 1997 | | up to now | Frank Herfurth |
| 1999 | | up to now | Alban Kellerbauer |
| 2000 | | up to now | Klaus Blaum |

Z. Physik A – Atoms and Nuclei 297, 35–39 (1980)

Zeitschrift für Physik A Atoms and Nuclei



# 1979: The Starting Point

## A Direct Determination of the Proton Electron Mass Ratio

G. Gräff, H. Kalinowsky, and J. Traut*
Institut für Physik der Johannes Gutenberg-Universität, Mainz, Federal Republic of Germany

Received June 10, 1980

The cyclotron frequencies of free protons and electrons in a magnetic field of 5.81 Tesla with superimposed electrostatic quadrupole field have been measured. The increase of energy connected with a transition at cyclotron frequency is detected by the measurement of the time of flight through an inhomogeneous magnetic field. From the ratio of the measured cyclotron frequencies of both particles the proton electron mass ratio is deduced. The result $m_p/m_e = 1{,}836.1527(11)$ agrees within the limits of error (0.6 ppm) with the value of the indirect determination.

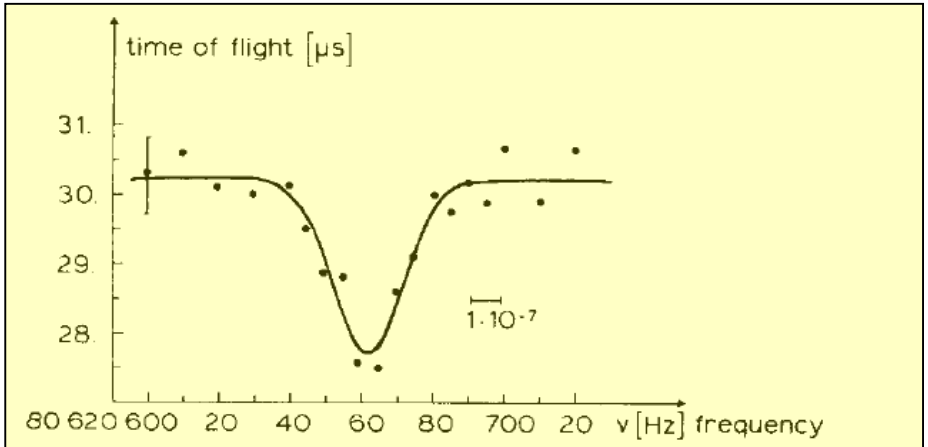



**Fig. 4.** Proton time of flight as a function of frequency (fitted by Gauss function)

# 1980: LoI to the ISOLDE Committee

HIGH PRECISION DIRECT MASS DETERMINATION OF ISOTOPES
FAR AWAY FROM STABILITY

LETTER OF INTENT

by

G.Gräff, H.Kalinowsky, H.-J.Kluge

Institut für Physik, Universität Mainz,
Federal Republic of Germany

.An ideal technique for measuring the masses of short-lived isotopes produced at an on-line mass separator should fulfill the following requirements:

(i), universal applicability to all elements produced at an ISOL - facility
(ii), direct, absolute determination of the mass
(iii), accuracy better than 100 keV
(iv), resolving power better than 100 keV in order to distinguish between ground and isomeric states
(v), high sensitivity

# 1981:Conceptual Design
# One Penning Trap in a Superconducting Magnet
# Grant Application to the BMFT

JOHANNES GUTENBERG-UNIVERSITÄT MAINZ
Fachbereich Physik
Institut für Physik

universität mainz

Prof. Dr. H.-J. Kluge

Anlage zu AZA6

Teilprojekt 5

Direkte Massenbestimmung kurzlebiger Isotope an der ISOLDE/CERN

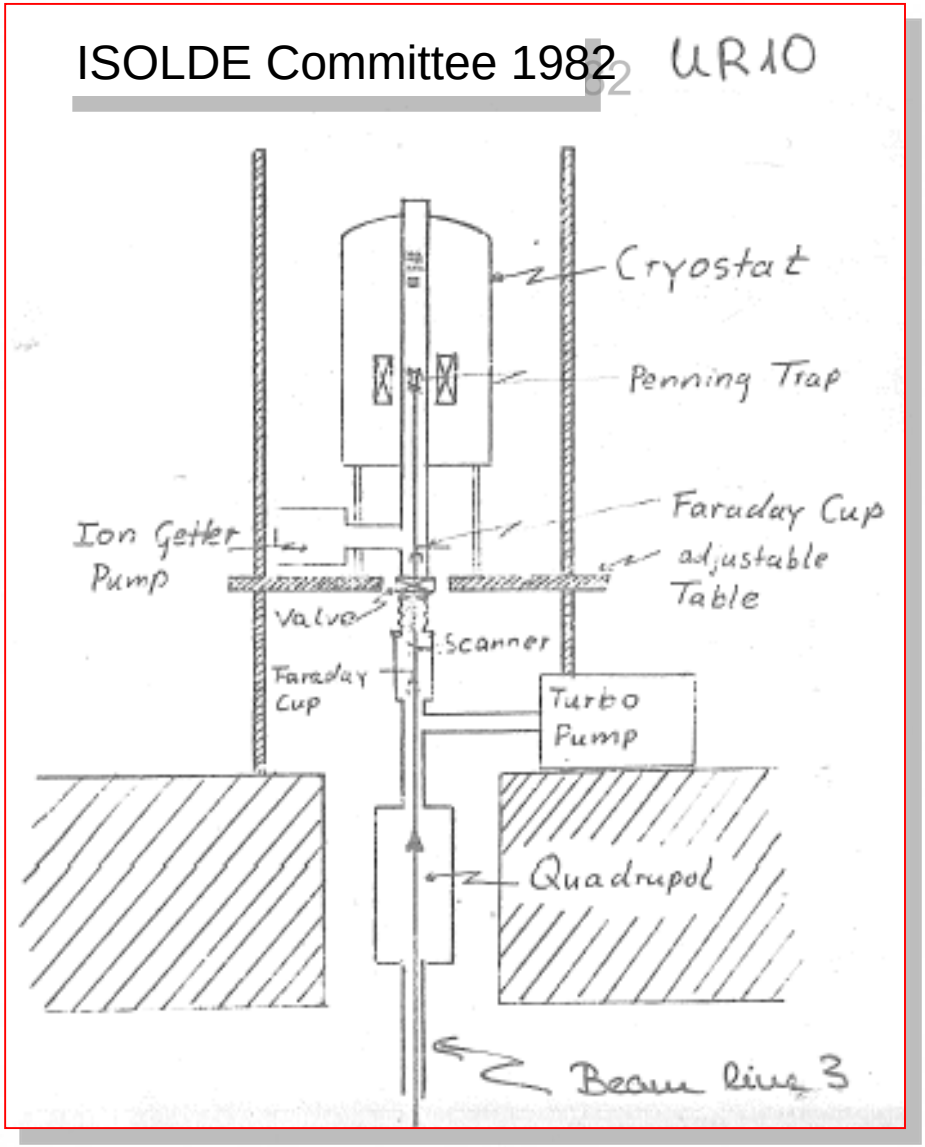
1. Vorhabenbeschreibung

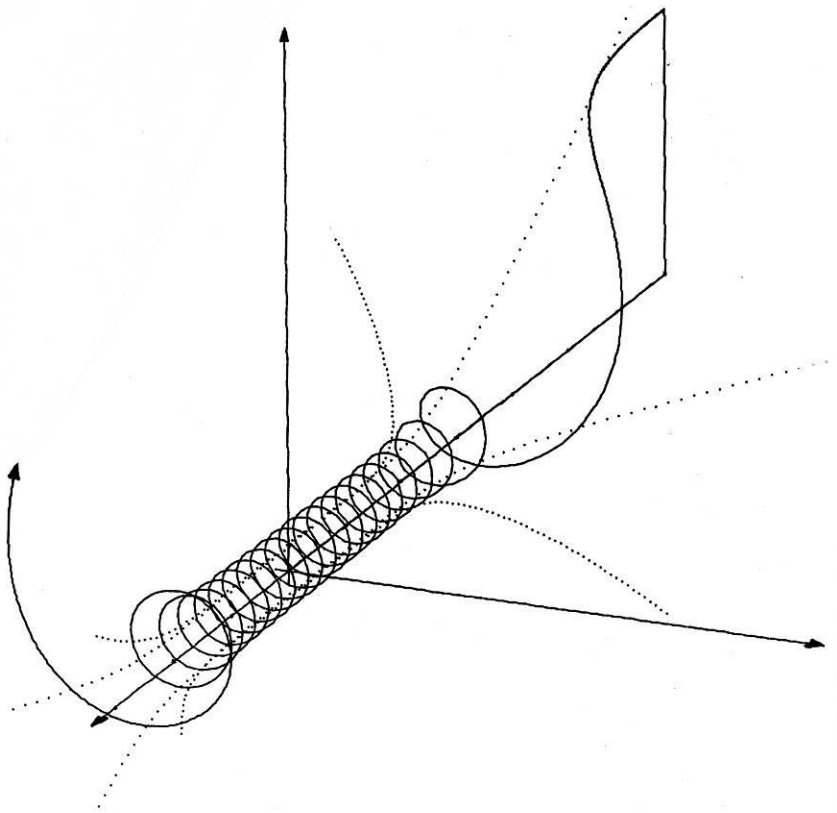
Gräff
Kalinowsky
Kluge

10/1982 Dipl. Stürmer
12/1982 Dipl. Kern
Postdoc Kalinowsky
03/1982 Postdoc Dabkiewicz
Prof. Gräff 11/1982
03/1982 Prof. Moore

# 1982: Problems to be Solved: Injection into a Penning trap

ISOLDE Committee 1982



Hildegard Stürmer, 1983

# 1983: The Concept of Separating Functions

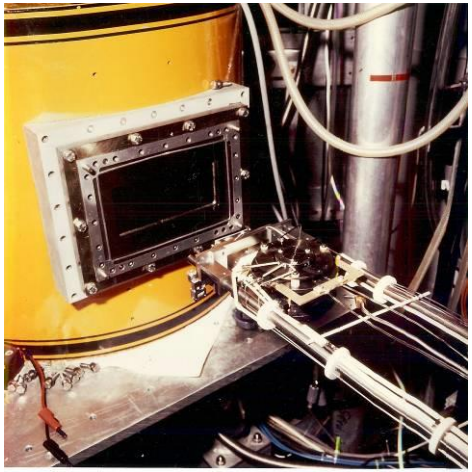
Construction and set up of preparation trap in an electromagnet with B = 0.7 T

Design and construction of precision trap (old version) in a superconducting magnet with B = 5.7 T

**Precision trap copy of the trap used by Gräff et al. for e/p mass ratio**


Dipl. Schweikhard 1985

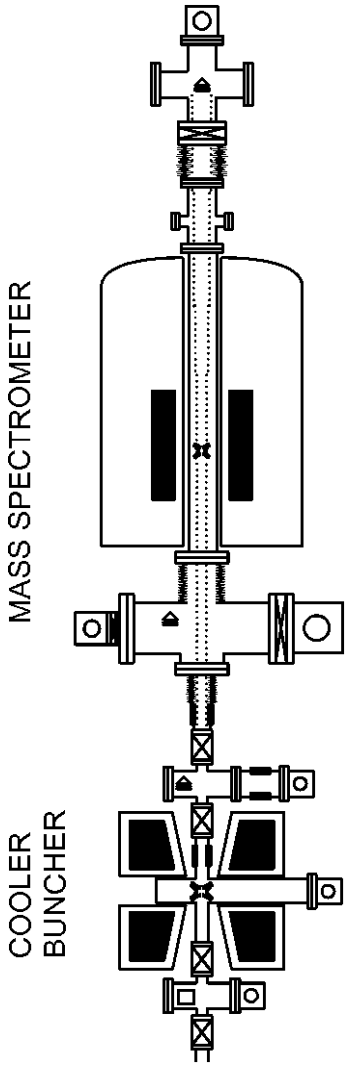
**Preparation trap in an electromagnet**

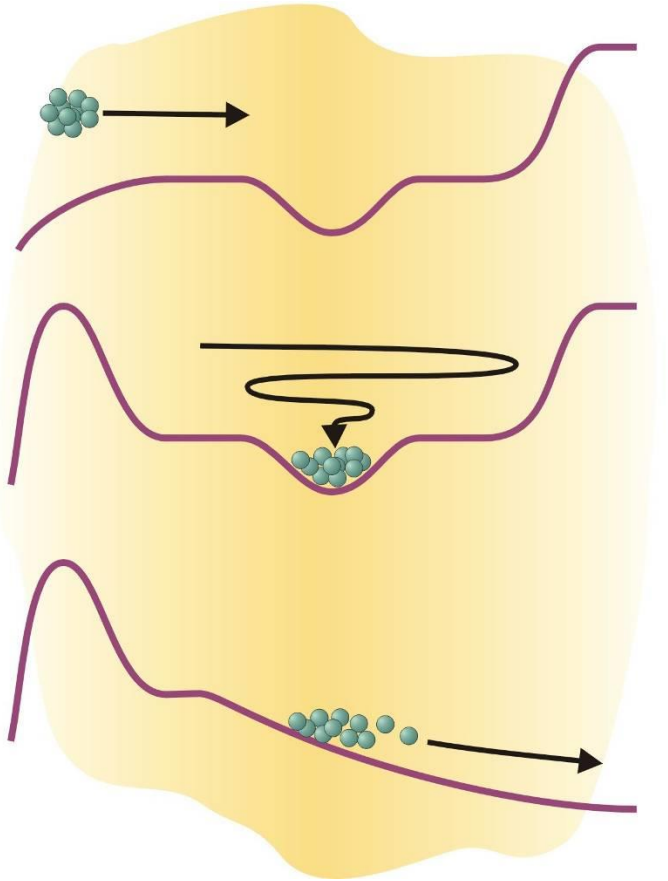


PhD Schnatz 1986

Dipl. Stürmer
Dipl. Kern
01/1983 PhD Schnatz
08/1983 Dipl. Schweikard
Postdoc Dabkiewicz
Postdoc Kalinowsky 12/1983
Prof. Moore 02/1984

# 1984: Problems to be Solved: In-Flight Capture – the Mousetrap Trick



Dipl. Kern
Dipl. Schweikhard
Dipl. Stürmer ??/1984
10/84 Dipl. Stolzenberg
PhD Schnatz
09/1984 PhD Bollen
Postdoc Dabkiewicz 07/1984

# 1985: Proposal to the PSSC

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/PSCC/85-31
PSCC/P84
19 April 1985

PROPOSAL TO THE PSCC

HIGH-PRECISION DIRECT MASS DETERMINATION

OF UNSTABLE ISOTOPES

CERN[1] - Mainz[2] - Montreal[3] - Collaboration

G. Bollen[2], G.J. Fokker[1], H. Kalinowski[2], F. Kern[2],
H.-J. Kluge[1], E. Kugler[1], R.B. Moore[3], H. Schnatz[2], G. Ulm[1]

Spokesman : H.-J. Kluge
Contactman : H.-J. Kluge

BEAM TIME REQUEST

&

SCHEDULE

installation at ISOLDE : end of 1985

first investigations:

isotopic chain of Ba (La, U - target)
" " " Ra (U - target)
eventually rare earth (Ta foil target)

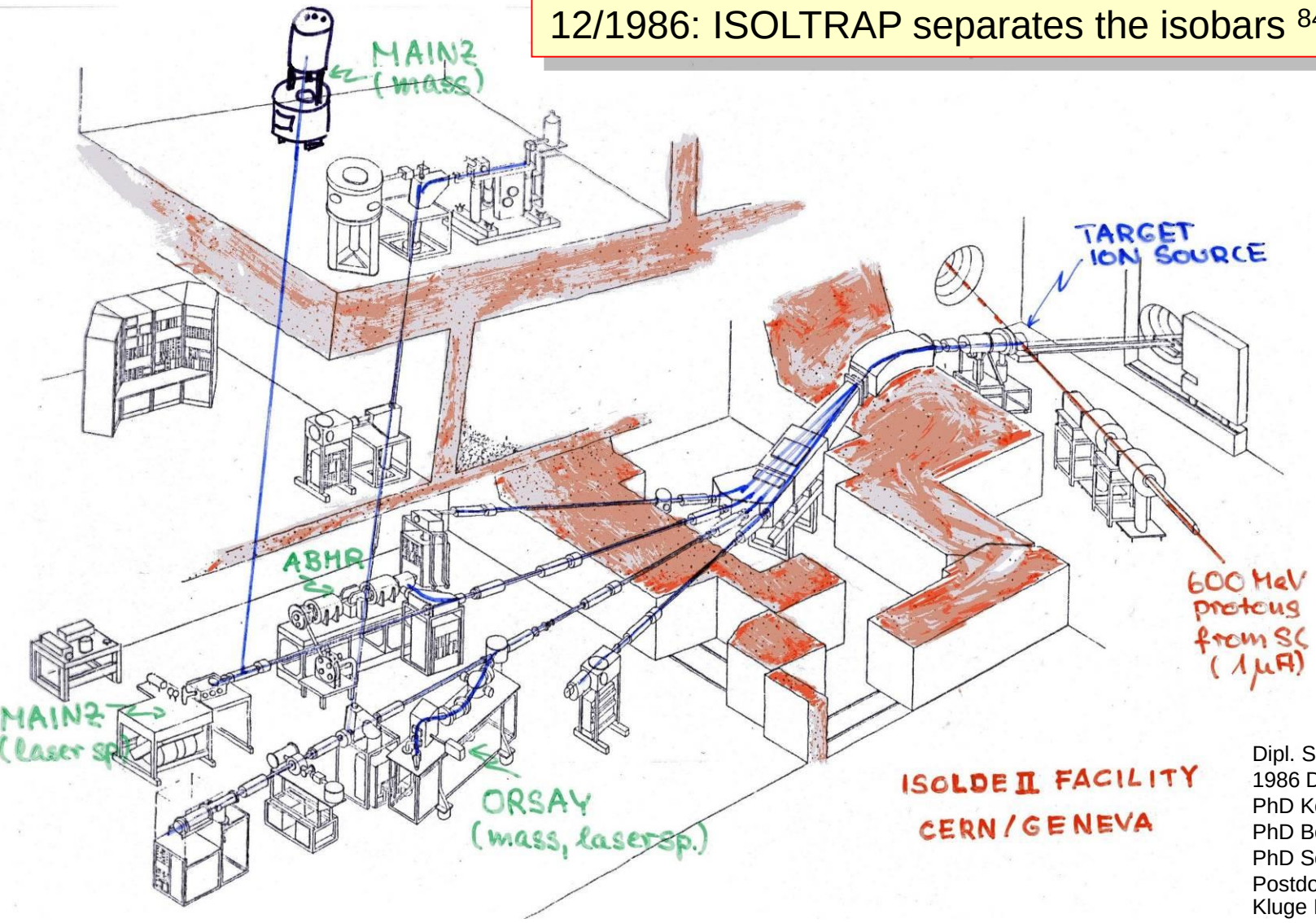
beam time request :

50 shifts for 1986 and 1987

Dipl. Stolzenberg
Dipl. Schweikard ??/1985
Dipl. Kern 02 /1985
03/1985 PhD Kern
PhD Schnatz
PhD Bollen
??/1985 Postdoc Egelhof
03/85 Kluge ISOLDE Group Leader

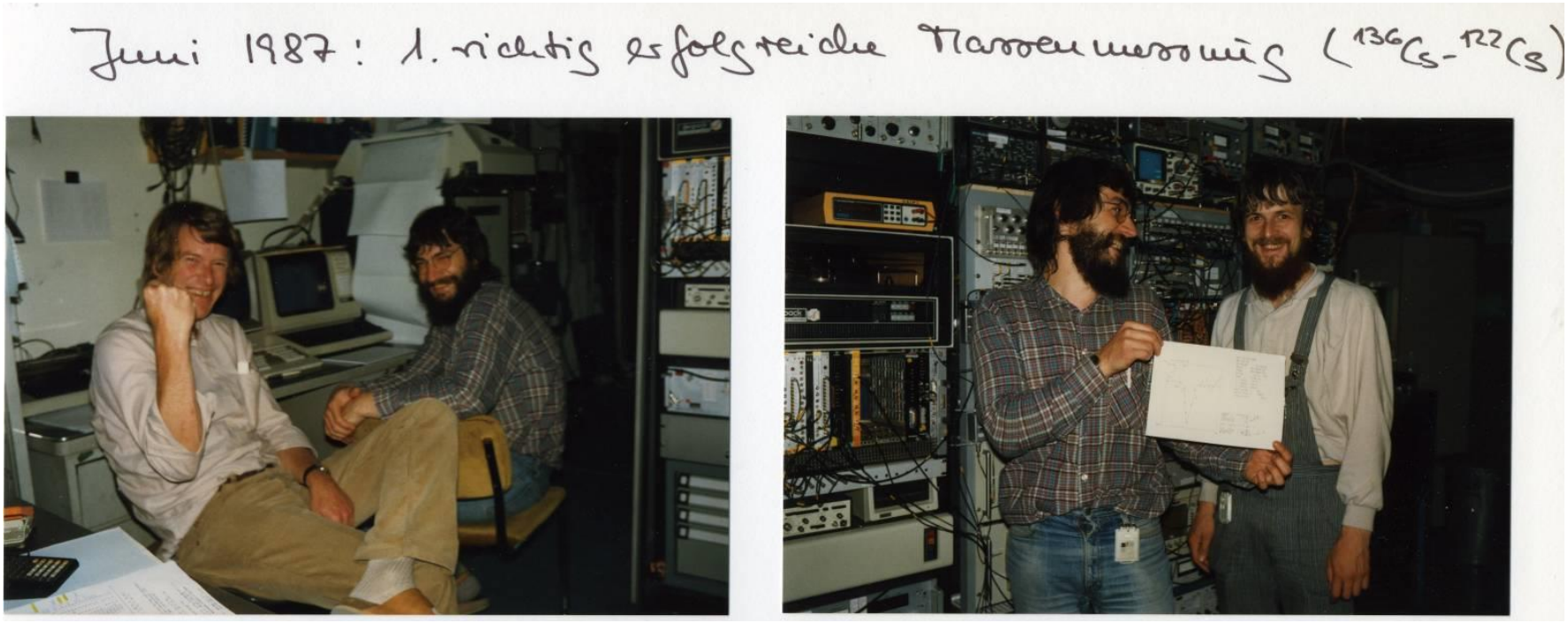
# 1986: Transport to CERN and Installation of ISOLTRAP in UR10 at ISOLDE-II

12/1986: ISOLTRAP separates the isobars $^{84}$Sr and $^{84}$Sr




Dipl. Stolzenberg
1986 Dipl. Kunz
PhD Kern
PhD Bollen
PhD Schnatz 1986
Postdoc Egelhof
Kluge ISOLDE Group Leader

# June 1987: The First Very Successful ISOLTRAP Mass Measurement

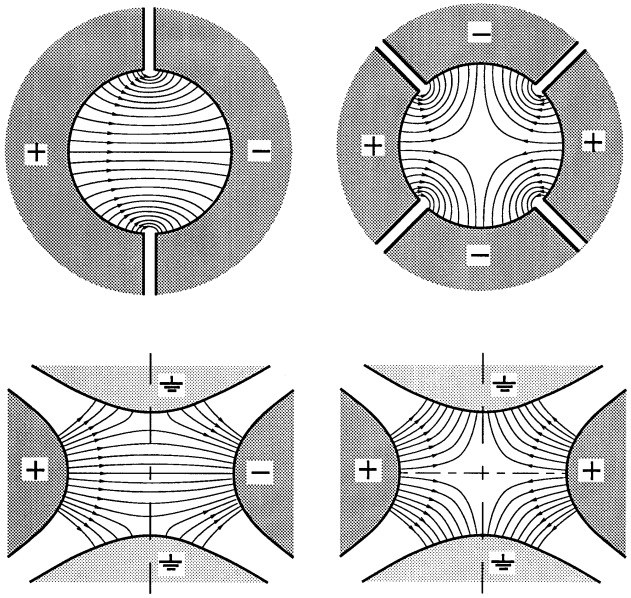


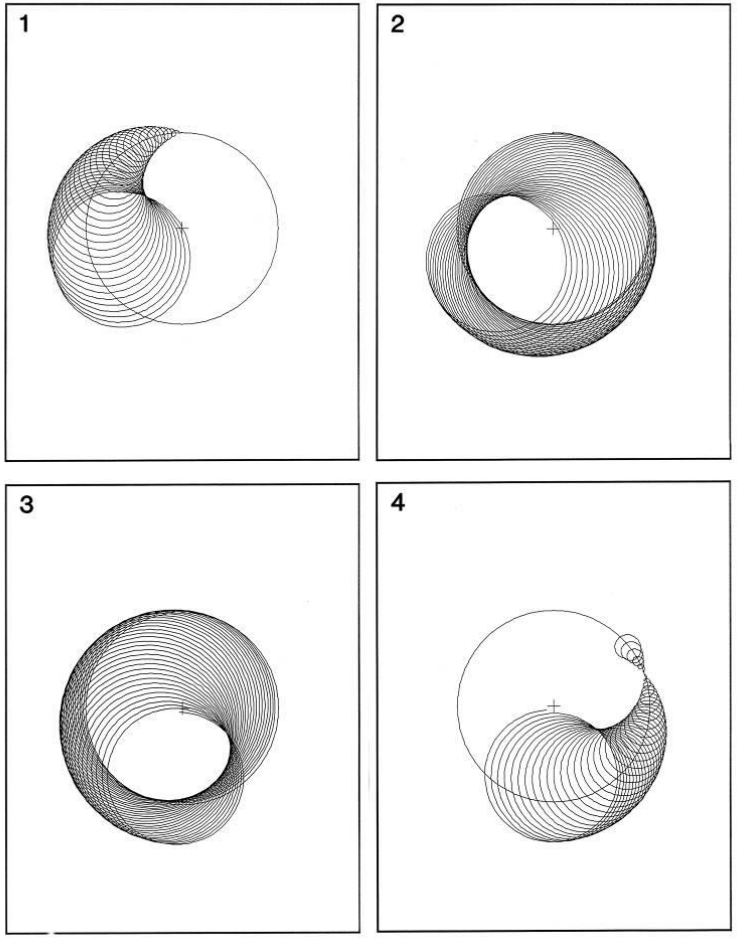

Cs: 122,124,125,127, 135,136
(Thesis Bollen 1989)

On-line: m/Δm(FWHM) = 300 000 for Cs
Off-line: m/Δm(FWHM) = 1 100 000 for Cs

Dipl Stolzenberg 09/1987
Dipl. Kunz
PhD Kern
03/1987 PhD Bollen CERN Fellow
10/1987 PhD Stolzenberg
Postdoc Egelhof ??/1987
Kluge ISOLDE Group Leader 02/87

# 1988: Understanding the Excitation in Penning Traps - from Dipolar to Quadrupolar Excitation



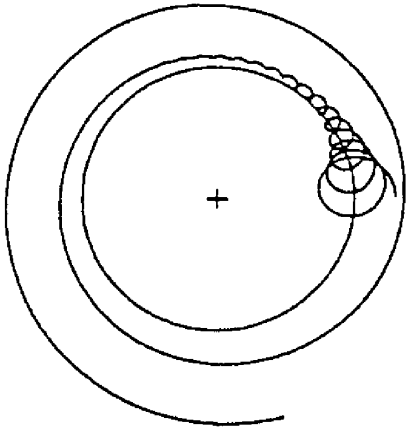



m/Δm(FWHM) = 1 700 000 for Cs
100 x smaller RF power
but 03/1988 frequency jumps
(B-inhomogeneity of precision trap)
decision for a new trap

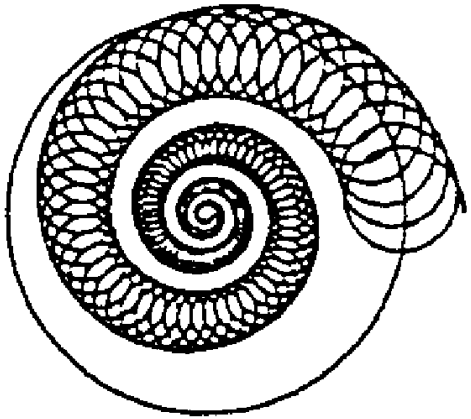
Dipl Kunz ??/1988
??/1988 Dipl. Wieß
PhD Bollen CERN Fellow
PhD Stolzenberg
PhD Kern
??/1988 Postdoc Savard
09/1988 Prof. Moore

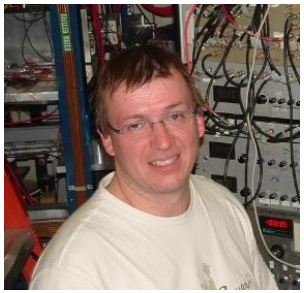
# 1989: A New Cooling Schemes is Invented: Mass-Selective Centering and Cooling

**with buffer gas**



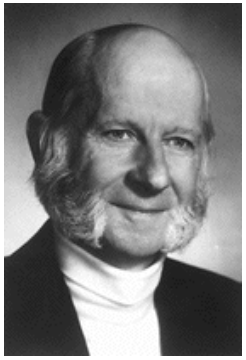
**with additional RF at $\omega_c$**





**Storage and Cooling of Ions**

**Nobel Prize 1989: H. Dehmelt & W. Paul**

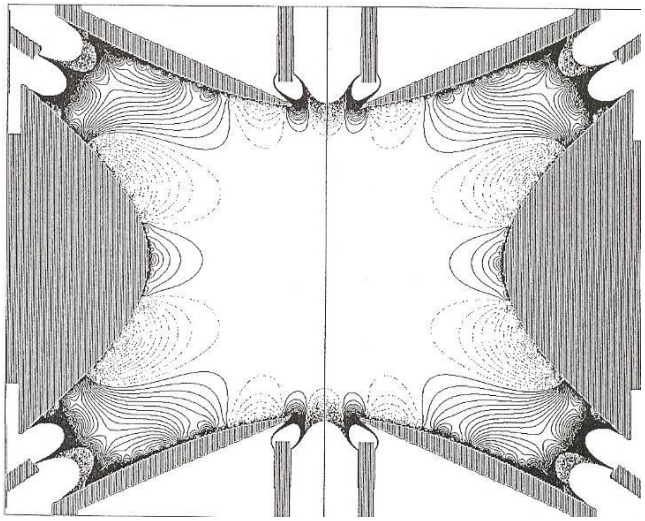


10 x higher efficiency
m/Δm(FWHM) = 160 in the preparation trap
BMBF application for extra funding concerning superconducting magnet for preparation trap

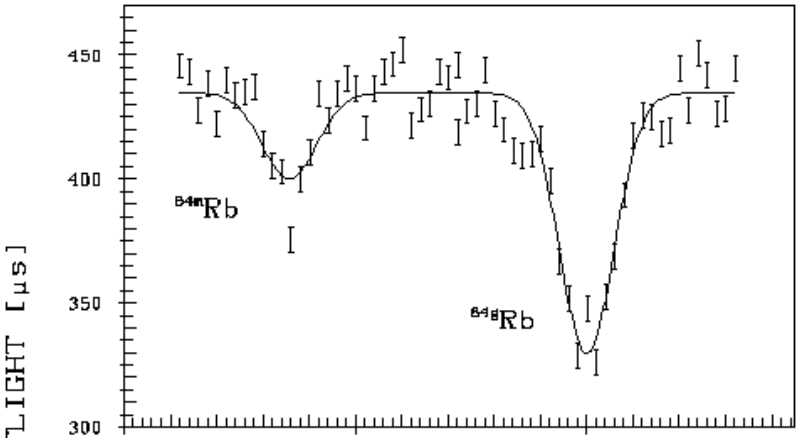
Cs: 118,119,120,121,122,122m,123,124,125,126, 127,128,129,130,131,132,133,134,135,136,137
(Thesis Stolzenberg 1992, Thesis König 1995)

Dipl. Wieß 1989
PhD Bollen CERN Fellow 11/1989
PhD Becker
1989 PhD Kern
Postdoc Savard
Sci Assoc Moore 12/1989

# 1990: ISOLTRAP Achieves $10^{-7}$ Accuracy with New Precision Trap & First Isomer Separation



Rb: 75,76,77,78,78m,79,80,81,82m,
83,84,84m,86,87 (Thesis Rouleau 1992)
Rb-78, Rb-84: (Diploma thesis König 1991)
Sr: 78,79,80,81,82,83,87 (Thesis Rouleau 1992)
Ba: 124,126,128,138,139,140,141,
142,143,144 (Thesis Stolzenberg 1992, Thesis König 1995)
Cs: 123,126,127,129,130,137,138,
139,140 (Thesis Stolzenberg 1992, Thesis König 1995)
Fr: 209,210,211,212,221,222
Ra: 226,230




12/1990 Shut-down of SC

Dipl. Wieß
??/1990 Dipl. König
??/1990 PhD Rouleau

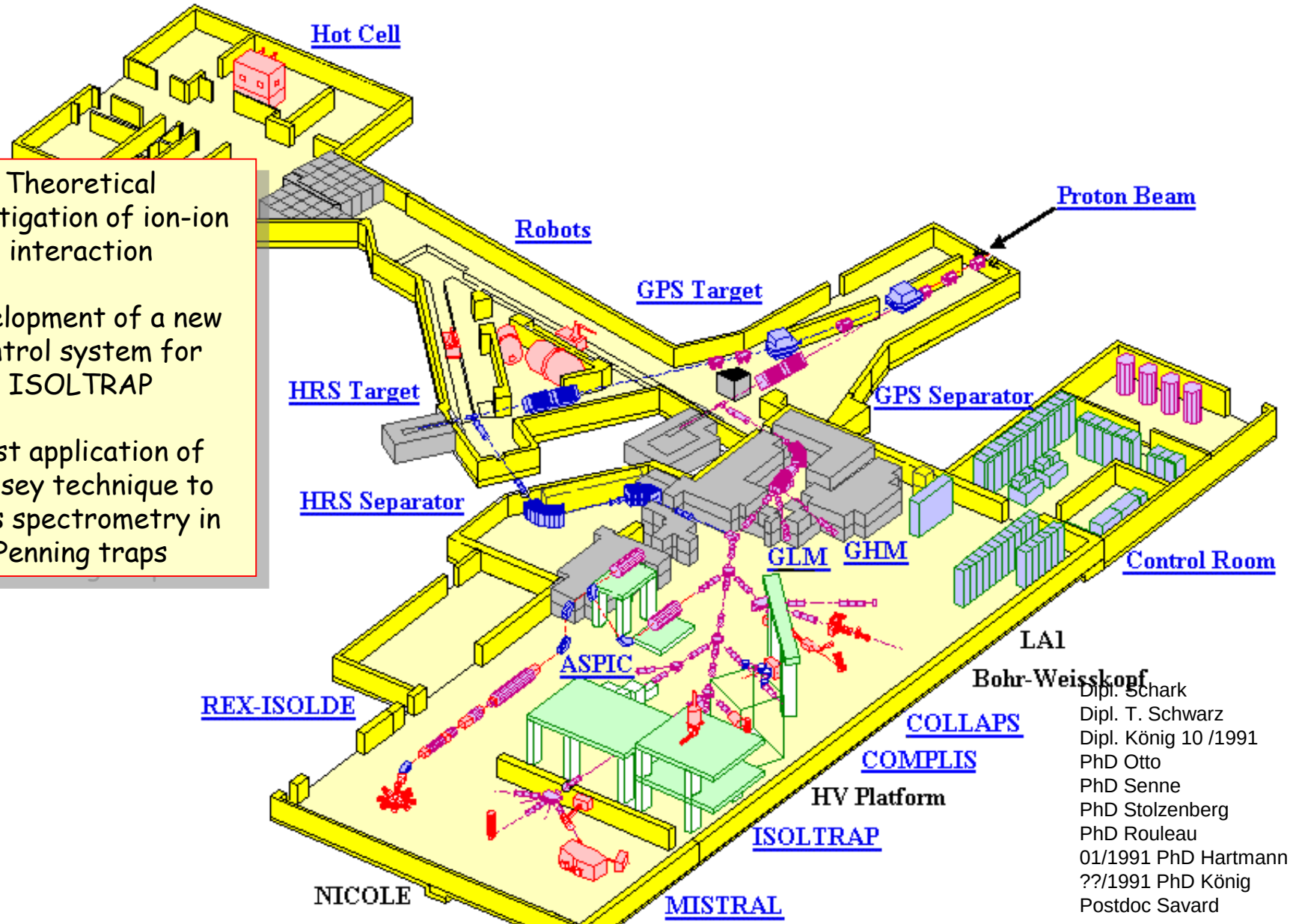
??/1990 PdD Stolzenberg
PhD Becker
Postdoc Savard

# 1991: Transfer of ISOLTRAP to the PS-Booster ISOLDE

Theoretical investigation of ion-ion interaction

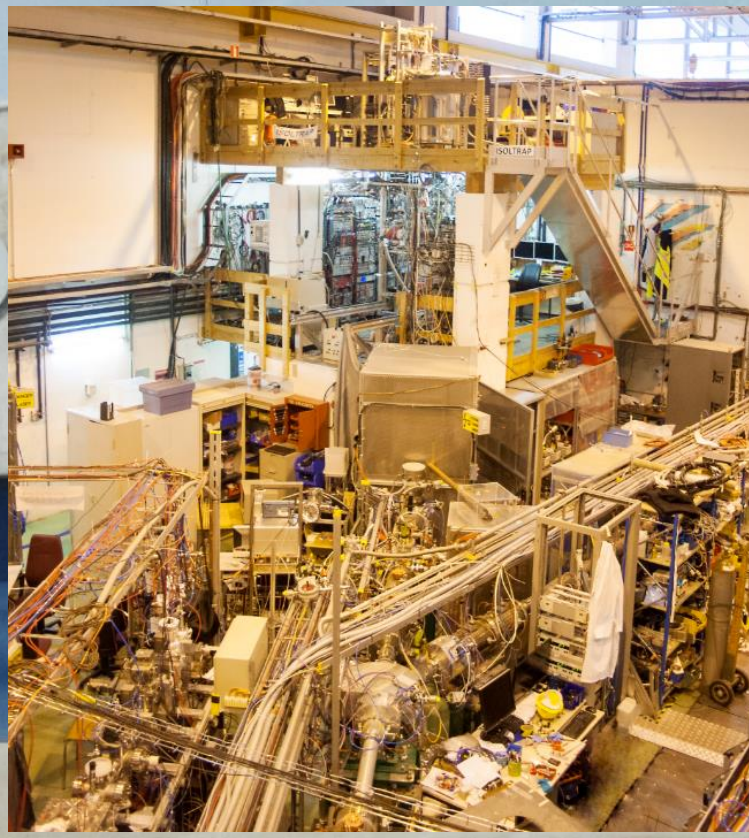
Development of a new control system for ISOLTRAP

First application of Ramsey technique to mass spectrometry in Penning traps



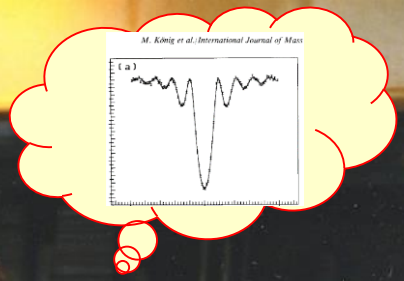

Dipl. Schark
Dipl. T. Schwarz
Dipl. König 10 /1991
PhD Otto
PhD Senne
PhD Stolzenberg
PhD Rouleau
01/1991 PhD Hartmann
??/1991 PhD König
Postdoc Savard

# 1992: Commissioning of PS-Booster ISOLDE & ISOLTRAP



10/1992 Dipl. Rohde
12/1992 Dipl. Beck
??/1992 Dipl. S. Schwarz
PhD Otto
PhD Hartmann
PhD König
05/1992 PhD Schark
PhD Rouleau 07/1992
PhD Stolzenberg ??/1992
02/1992 Szerypo CERN Associate

# August 1993: First ISOLTRAP beam time at ISOLDE-PSB



**First combination of γ-spectroscopy with PT mass spectrometry**

**Rb: 88,89,90m,91,92,93,94 (Thesis Hartmann, Diploma thesis Rohde)**
**Sr: 91,92,93,94,95 (Thesis Hartmann, Diploma thesis Rohde)**
**Cs: 140,142 (Thesis König 1995)**
**Ba: 141,142 (Thesis König 1995)**
**Ra: 226 (Thesis Hartmann)**

Dipl. Rhode 11/1993
Dipl. Beck 11/1993
Dipl. S. Schwarz
PhD Hartmann
PhD König
PhD Schark
PhD Otto 05/1993
12/1993 PhD Beck
Szerypo CERN Sc. Associate 09/1993

# 1994: Magnet of Preparation Trap Becomes Superconducting – the Most Powerful Isobar Separator

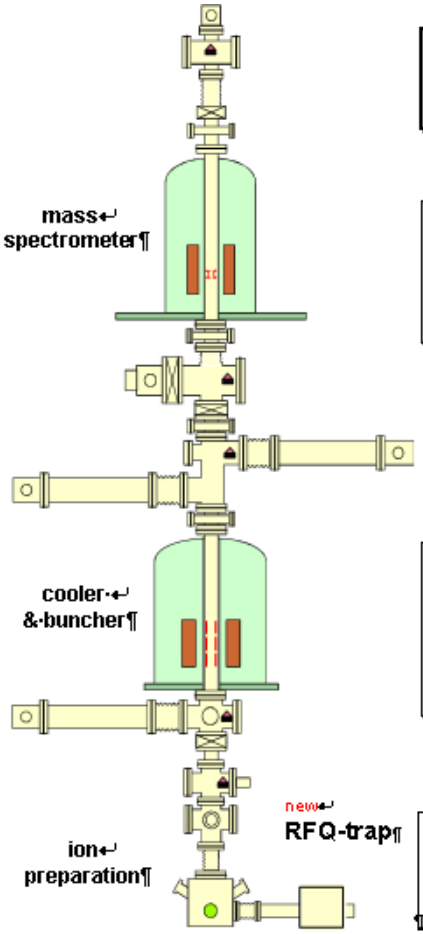
01/1994 Installation of the superconducting magnet for the new cylindrical preparation trap at ISOLDE
Foil for stopping and re-ionizing the ISOLDE beam
10/1994 Test of the new set-up with stable beams from ISOLDE
Cs: 117,119,120,122,125 (Thesis König 1995)
Overall efficiency increases by factor 10 - 100
m/Δm = 100 000 reached in preparation trap
PC-VME-bus system as control system


Dipl. S. Schwarz 03/1994
PhD Beck
PhD König
PhD Schark
06/1994 PhD. S. Schwarz
09/1994 PhD Hartmann CERN Fellow

# 1995: ISOLTRAP Measures Masses of Alkaline Earths Isotopes (Still Surface-Ionizable Elements)

06/1995
First run with
alkaline earth isotopes

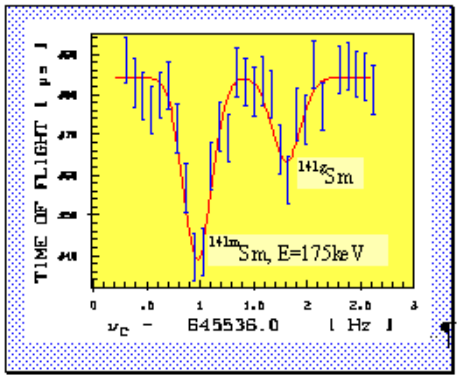
Essential:
Dipole excitation in
preparation trap for
isobaric cleaning




**ISOLTRAP**
IS302

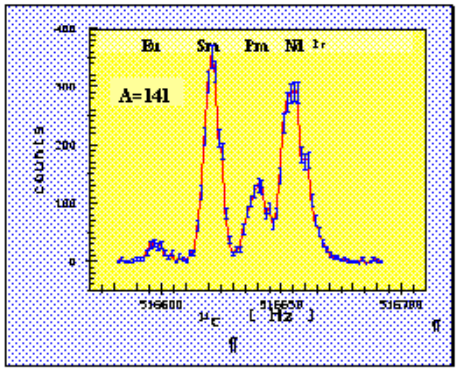
determination of
cyclotron frequency

$$R = \frac{m}{\Delta m} = 5 \cdot 10^6$$




accumulation
bunching
isobar separation

$$R = \frac{m}{\Delta m} = 1 \cdot 10^5$$



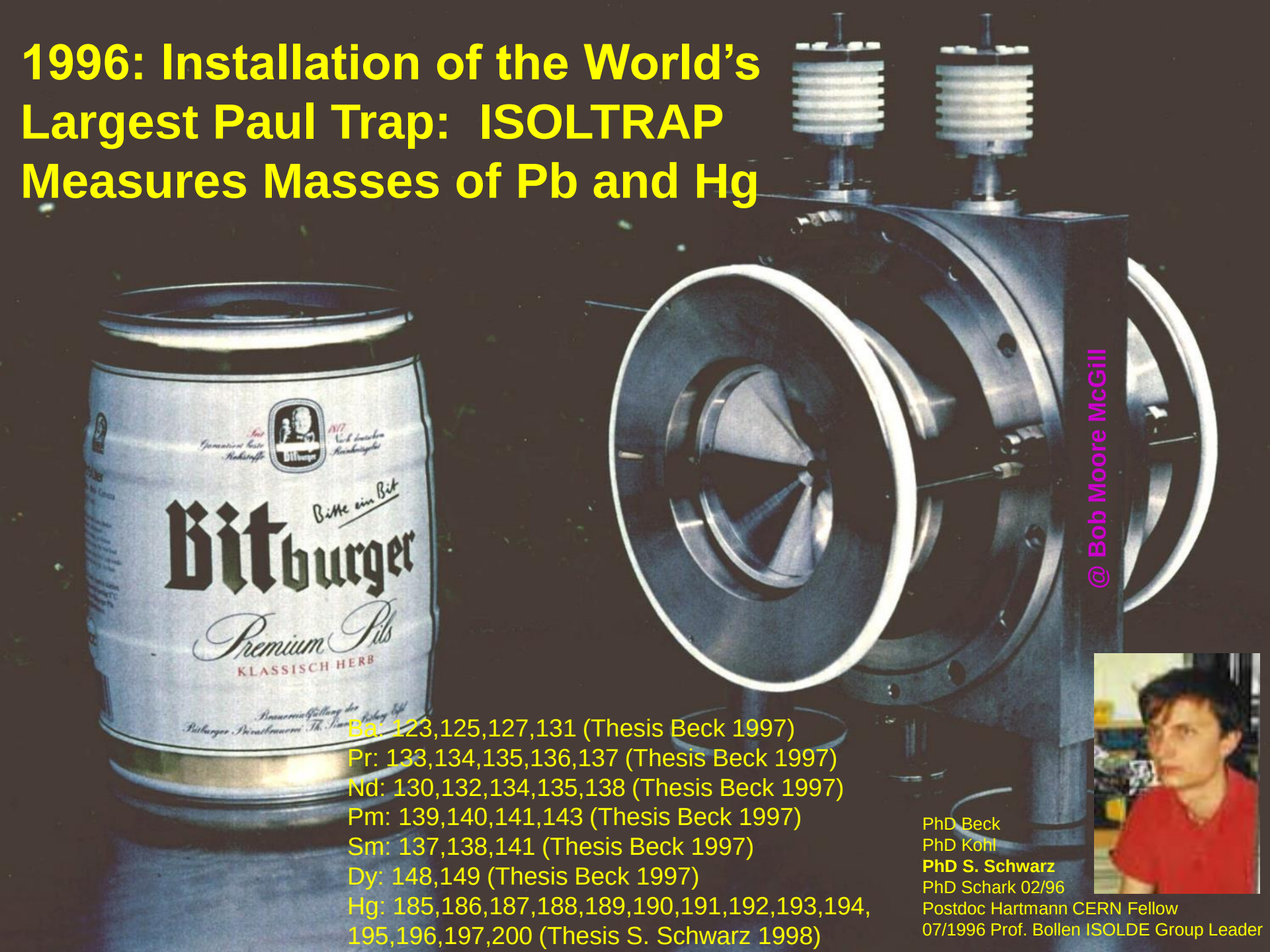

→ stopping and continuous or pulsed re-ionization /

→ direct bunching with RFQ-trap

Eu: 143,151,153 (Thesis Beck 1997; 143: thesis Schark 1997)
Cs: 133 (Thesis Beck 1997)
Sm: 136,137,138,139,140,142,143 (Thesis Beck 1997, partly thesis Schark 1997)
Pm: 136,137,138,143 (Thesis Beck 1997; 143: thesis Schark 1997 )
Dy: 148,154 (Thesis Beck 1997; 154: thesis Schark 1997)
Nd: 134,136,137,138 (Thesis Beck 1997)
Ho: 150 (Thesis Beck 1997)

**PhD Beck**
PhD Schark
PhD. S. Schwarz
PhD Hartmann 01/1995
PhD König 10/1995
11/1995 PhD Kohl
02/1995 Postdoc Hartmann CERN Fellow

# 1996: Installation of the World's Largest Paul Trap: ISOLTRAP Measures Masses of Pb and Hg



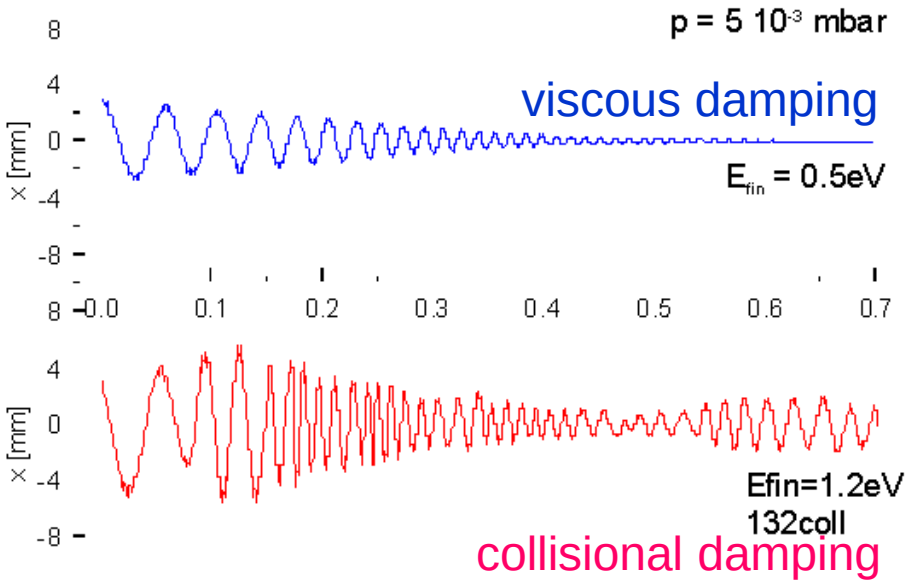

Ba: 123,125,127,131 (Thesis Beck 1997)
Pr: 133,134,135,136,137 (Thesis Beck 1997)
Nd: 130,132,134,135,138 (Thesis Beck 1997)
Pm: 139,140,141,143 (Thesis Beck 1997)
Sm: 137,138,141 (Thesis Beck 1997)
Dy: 148,149 (Thesis Beck 1997)
Hg: 185,186,187,188,189,190,191,192,193,194, 195,196,197,200 (Thesis S. Schwarz 1998)



PhD Beck
PhD Kohl
**PhD S. Schwarz**
PhD Schark 02/96
Postdoc Hartmann CERN Fellow
07/1996 Prof. Bollen ISOLDE Group Leader

# 1997: Use of Hyperboloidal Paul Trap & Preparing for a Linear Segmented RFQ Cooler and Buncher

**$Cs^+$ in Ar**

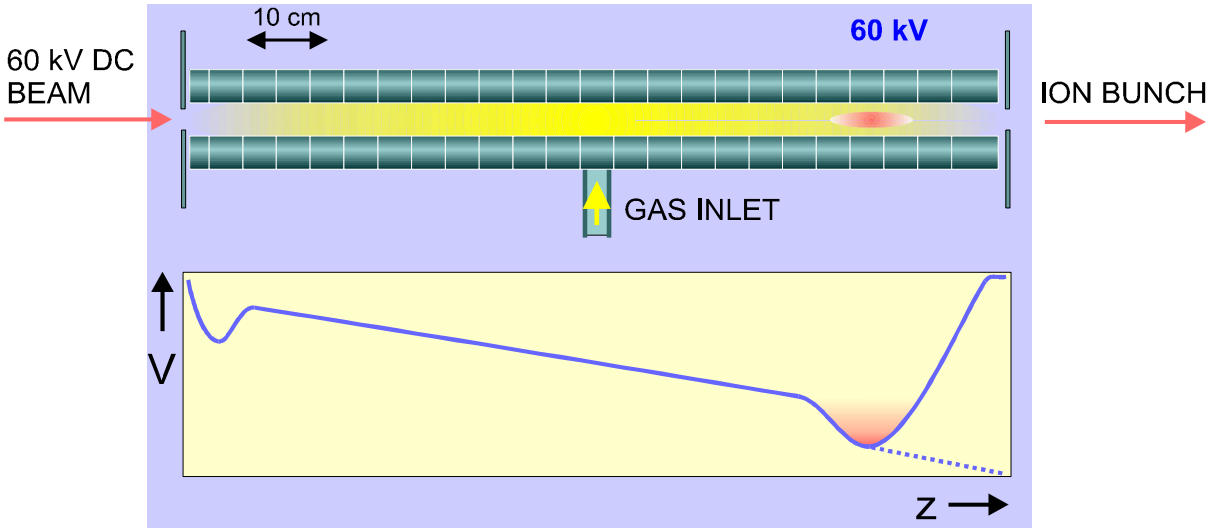


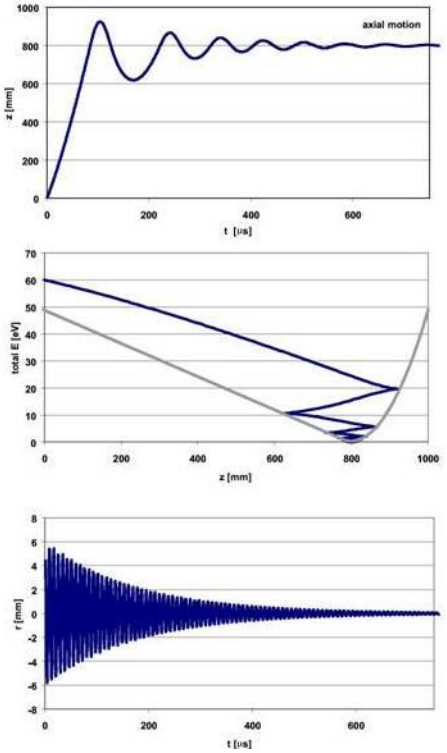

CeO: 132,133,134 (Thesis Kohl 1999)
Eu: 147,148,149 (Thesis Kohl 1999)
Dy: 149 (Thesis Kohl 1999)
Yb:158,159,160,161,162,163,164 (Thesis Kohl 1999)
Tm: 165 (Thesis Kohl 1999)
Pb:196,198 (Thesis Kohl 1999)
Bi: 197 (Thesis Kohl 1999)
Po:198 (Thesis Kohl 1999)
At:203 (Thesis Kohl 1999)
Hg: 184,185,186,191,193,194,197 (Thesis S. Schwarz 1998)

Investigation of the AC Stark effect in a Penning trap
Calculation of cooling in Paul trap
Calculation of ejection out of Paul trap

PhD Beck
PhD Kohl
PhD S. Schwarz
02/1997 PhD Herfurth Postdoc Hartmann CERN Fellow
07/1996 Bollen ISOLDE group Leader

# 1998: Simulation, Construction and Implementation of Gas-Filled Linear Segmented RFQ Cooler and Buncher






introduced to Penning trap mass spectrometry by Bob Moore

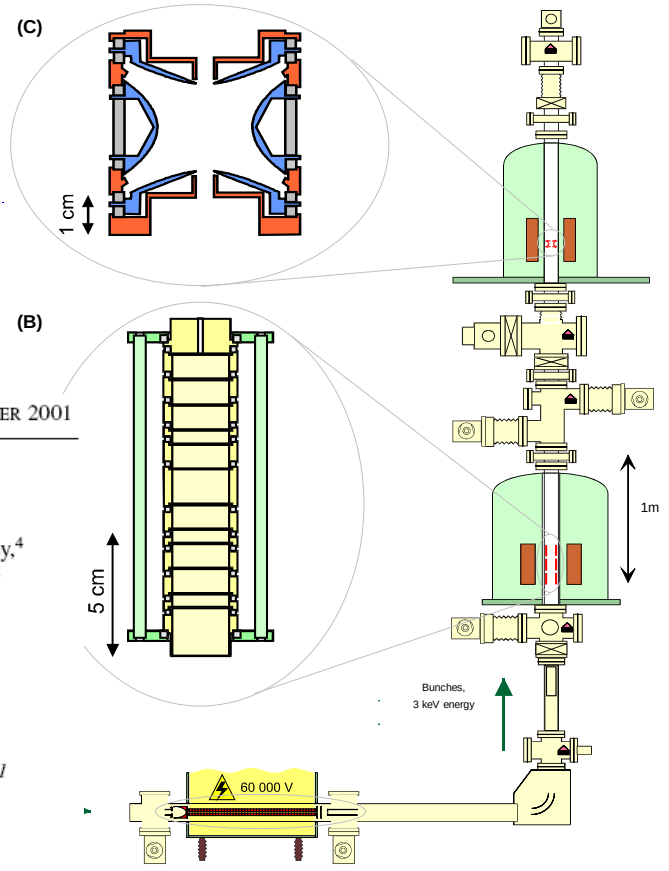
IJMS 190 (1999) 153-160

NIMA 469 (2001) 276–285

PhD Herfurth
PhD Kohl
PhD S. Schwarz
PhD Beck 01/1998
7/98 Postdoc Lamour 11/98 MC Fellow

# 1999: ISOLTRAP Becomes an Universal Mass Spectrometer

Precision Penning trap
mass measurement
isomer separation




VOLUME 87, NUMBER 14 PHYSICAL REVIEW LETTERS 1 OCTOBER 2001

**Breakdown of the Isobaric Multiplet Mass Equation at $A = 33, T = 3/2$**

F. Herfurth,[1,3,*] J. Dilling,[1] A. Kellerbauer,[2,5] G. Audi,[4] D. Beck,[6,1] G. Bollen,[3,8] H.-J. Kluge,[1] D. Lunney,[4] R. B. Moore,[5] C. Scheidenberger,[1] S. Schwarz,[2,8] G. Sikler,[1] J. Szerypo,[7] and ISOLDE Collaboration[2]

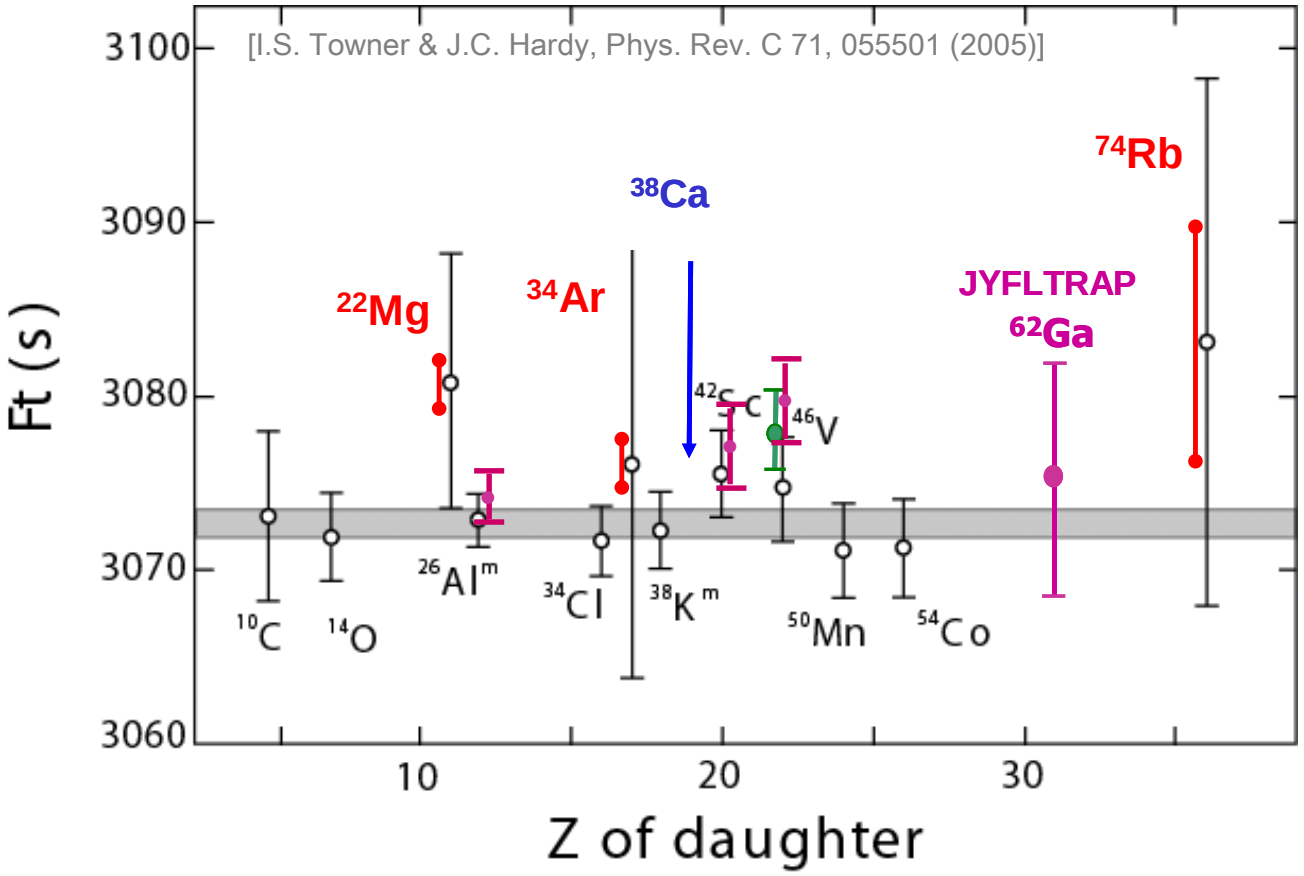
[1]*GSI, Planckstraße 1, D-64291 Darmstadt, Germany*
[2]*CERN, CH-1211 Geneva 23, Switzerland*
[3]*Sektion Physik, Ludwig-Maximilians Universität München, D-85748 Garching, Germany*
[4]*CSNSM-IN2P3-CNRS, F-91405 Orsay-Campus, France*
[5]*Department of Physics, McGill University, Montréal, Québec H3A 2T8, Canada*
[6]*Instituut voor Kern- en Stralingsfysica, Celestijnenlaan 200 D, B-3001 Leuven, Belgium*
[7]*Department of Physics, University of Jyväskylä, PB 35 (Y5), FIN-40351 Jyväskylä, Finland*
[8]*National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824-1321*
(Received 6 November 2000; published 13 September 2001)

Mass measurements on $^{33,34,42,43}$Ar were performed using the Penning trap mass spectrometer ISOLTRAP and a newly constructed linear Paul trap. This arrangement allowed us, for the first time, to extend Penning trap mass measurements to nuclides with half-lives below one second ($^{33}$Ar: $T_{1/2}$ = 174 ms). A mass accuracy of about $10^{-7}$ ($\delta m \approx 4$ keV) was achieved for all investigated nuclides. The

Ar: 33,34,42,43 (Thesis Herfurth 2001)
Xe: 114,115,116,117,118,119,120,121,122,123,124,130 (Thesis Dilling 2001)
Hg: 183,184

**PhD Herfurth**
PhD S. Schwarz ??/1999
PhD Kohl 02/1999
10/1999 PhD Kellerbauer??/1999
??/1999 PhD Dilling
Postdoc S. Schwarz
Bollen ISOLDE Group Leader 08/1999

# 2000: Application of ISOLTRAP to Specific Cases as CVC Hypothesis and Test of the Unitarity of the CKM Matrix




An accuracy of the Q-value by some few 100 eV is reached by mass measurements.

In addition required:
Half life
Branching ratio

Ar: 34 (Thesis Herfurth 2001)
Sr: 76,77,80,81
Sn: 129,130,131,132
(Thesis Sikler 2003)
Hg: 178,179,180,181,182
Kr: 73,74,75,76,77,78,80,82
Ga: 74
Rb: 74,76 (Thesis Kellerbauer 2002)

**ISOLTRAP: Mg-22, Al-26, Ar-34, Ca-38, Rb-74**
F. Herfurth *et al*., Eur. Phys. J. A 15, 17 (2002)
A. Kellerbauer *et al*., Phys. Rev. Lett.93, 072502 (2004)
M. Mukherjee *et al*., Phys. Rev. Lett. 93, 150801 (2004)
S. George et al. Phys. Rev. Lett. 98, 162501 (2007)

**JYFL-TRAP: Al-26m, Sc-42, Ga-62**
T. Eronen et al., Phys. Rev. Lett. 97 (2006) 232501
T. Eronen et al., Phys. Lett. B 636 (2006) 191;
B. Hyland et al., Phys. Rev. Lett. 97(2006) 102501

**CPT: Mg-22, V-46**
G. Savard et al., Phys. Rev. Lett. 95, 102501 (2005)
Phys. Rec. C 70, 042501(R) (2004)

**LEBIT: Ca-38**
G. Bollen et al., Phys. Rev. Lett. 96 (2006) 152501

PhD Herfurth
**PhD Kellerbauer**
Postdoc S. Schwarz ??/2000
11/2000 Postdoc Blaum
4/2000 Postdoc Scheidenberger 10/2000

# 2001: Application of ISOLTRAP to Specific Cases as Waiting Point Nuclei in Astrophysics

VOLUME 93, NUMBER 16 PHYSICAL REVIEW LETTERS week ending 15 OCTOBER 2004

## Mass Measurement on the *rp*-Process Waiting Point $^{72}$Kr

D. Rodríguez,[1,*] V. S. Kolhinen,[2] G. Audi,[3] J. Äystö,[2] D. Beck,[1] K. Blaum,[1,4] G. Bollen,[5] F. Herfurth,[1] A. Jokinen,[2] A. Kellerbauer,[4] H. -J. Kluge,[1] M. Oinonen,[6] H. Schatz,[5,7] E. Sauvan,[4,†] and S. Schwarz[5]

[1]*GSI, Planckstraße 1, 64291 Darmstadt, Germany*
[2]*University of Jyväskylä, P.O. Box 35, 40351 Jyväskylä, Finland*
[3]*CSNSM-IN2P3-CNRS, 91405 Orsay-Campus, France*
[4]*CERN, Physics Department, 1211 Geneva 23, Switzerland*
[5]*NSCL and Dept. of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824-1321, USA*
[6]*Helsinki Institute of Physics, P.O. Box 64, 00014 University of Helsinki, Finland*
[7]*Joint Institute for Nuclear Astrophysics, Michigan State University, East Lansing, Michigan 48824-1321, USA*

(Received 19 June 2004; published 14 October 2004)

The mass of one of the three major waiting points in the astrophysical *rp* process $^{72}$Kr was measured for the first time with the Penning trap mass spectrometer ISOLTRAP. The measurement yielded a relative mass uncertainty of $\delta m/m = 1.2 \times 10^{-7}$ ($\delta m = 8$ keV). $^{73,74}$Kr, also needed for astrophysical calculations, were measured with more than 1 order of magnitude improved accuracy. We use the ISOLTRAP masses of $^{72-74}$Kr to reanalyze the role of $^{72}$Kr ($T_{1/2} = 17.2$ s) in the *rp* process during x-ray bursts and conclude that $^{72}$Kr is a strong waiting point delaying the burst duration with at least 80% of its $\beta$-decay half-life.

Development of phase-locked magnetron excitation
Kr: 72,73,74,78,86 (Thesis Rodriguez 06/2003)
Ar: 32,33,36,44,45,46

01/2001 Dipl. Kuckein
PhD Kellerbauer
PhD Dilling 05/2001
PhD Herfurth 05/2001
PhD Rodriguez
06/2001 Postdoc Herfurth CERN Fellow
Postdoc Blaum
10/2001 Postdoc Sauvan

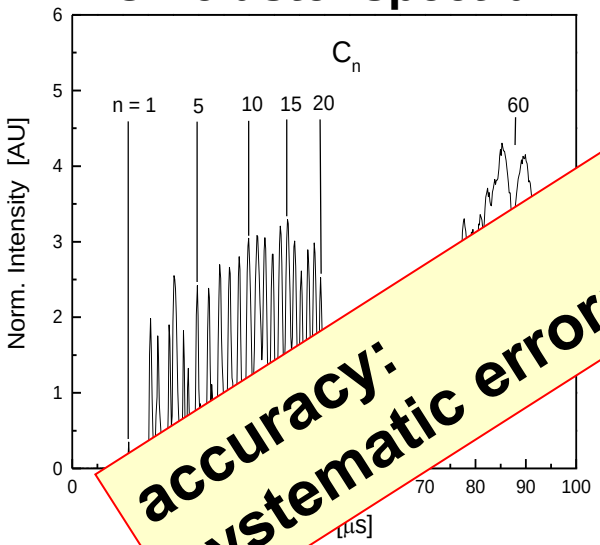
# 2002: Absolute Mass Measurements and Accuracy Check by Use of Carbon Clusters

**① desorption, fragmentation, and ionization from a $C_{60}$ pellet induced by 6 ns, 5 mJ laser pulses at 532 nm**

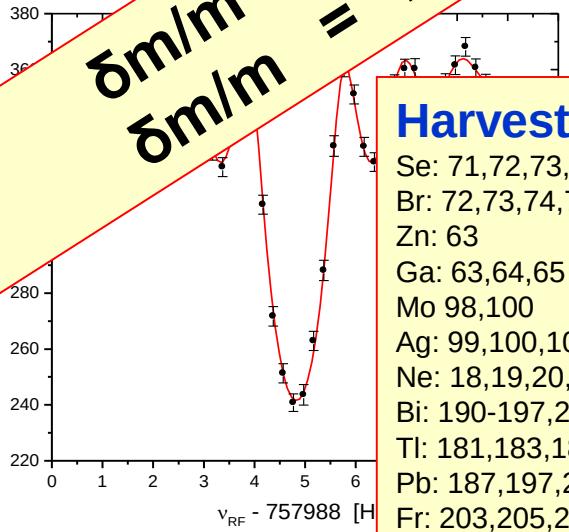
**② determination of the cyclotron frequency $\omega_c$ of the ion in the pr… Penni…**

**…rmination of the …ic error and the …evable accuracy by carbon clusters**

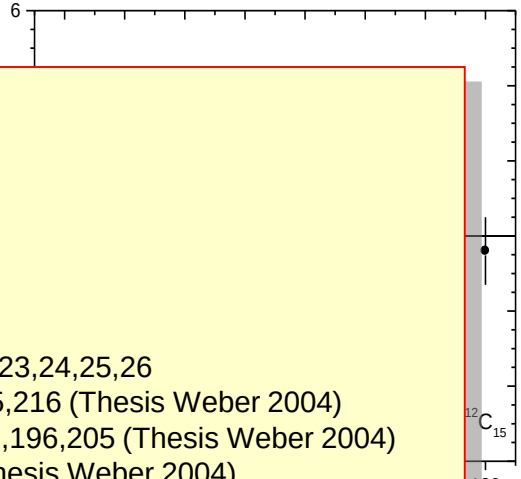
**TOF cluster spectrum**




**Cycl… …ice**




**Mass-dependent error**




**δm/m ≤ 8·10⁻⁹**

**δm/m = 1.7(6)·10⁻¹⁰ / u**

**accuracy:**

**systematic error:**

## Harvest

Se: 71,72,73,74
Br: 72,73,74,75
Zn: 63
Ga: 63,64,65
Mo 98,100
Ag: 99,100,101,103
Ne: 18,19,20,21,22,23,24,25,26
Bi: 190-197,209,215,216 (Thesis Weber 2004)
Tl: 181,183,186,187,196,205 (Thesis Weber 2004)
Pb: 187,197,208 (Thesis Weber 2004)
Fr: 203,205,229 (Thesis Weber 2004)
Ra: 214,228,229,230 (Thesis Weber 2004)
Cs: 145,147 (Thesis Weber 2004)
Rb: 74,75,76
Zn: 64

SWIFT cleaning – concept and first measurements

PhD Mukherjee
**PhD Kellerbauer 07/2002**
Postdoc Herfurth CERN Fellow
10/2003 Postdoc Blaum CERN Fellow

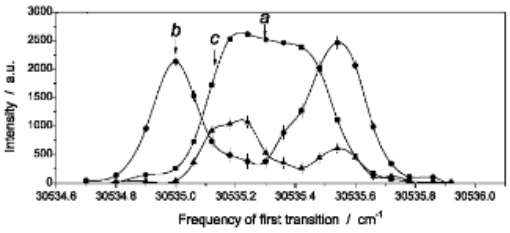
# 2003: Combination of RILIS, Nuclear and Mass Spectroscopy for Solving the Cu-70 Puzzle

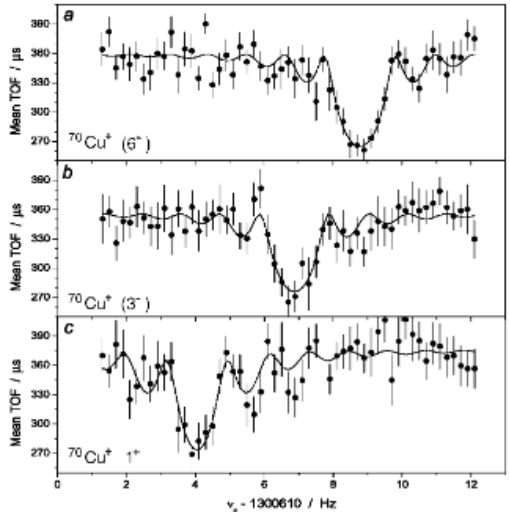
VOLUME 92, NUMBER 11 PHYSICAL REVIEW LETTERS week ending 19 MARCH 2004

**Unambiguous Identification of Three $\beta$-Decaying Isomers in $^{70}$Cu**

J. Van Roosbroeck,[1] C. Guénaut,[2] G. Audi,[2] D. Beck,[3] K. Blaum,[3,4,*] G. Bollen,[5] J. Cederkall,[4] P. Delahaye,[4] A. De Maesschalck,[6] H. De Witte,[1] D. Fedorov,[7] V. N. Fedoseyev,[4] S. Franchoo,[4] H. O. U. Fynbo,[4,†] M. Górska,[1,3] F. Herfurth,[4] K. Heyde,[6] M. Huyse,[1] A. Kellerbauer,[4] H.-J. Kluge,[3] U. Köster,[4] K. Kruglov,[1] D. Lunney,[2] V. I. Mishin,[8] W. F. Mueller,[1] Sz. Nagy,[9] S. Schwarz,[5] L. Schweikhard,[10] N. A. Smirnova,[6] K. Van de Vel,[1] P. Van Duppen,[1] A. Van Dyck,[6] W. B. Walters,[11] L. Weissman,[1,4,‡] and C. Yazidjian[3]

[1]*IKS, University of Leuven, Celestijnenlaan 200D, 3001 Leuven, Belgium*
[2]*CSNSM-IN2P3-CNRS, 91405 Orsay-Campus, France*




- Design of a MCP & channeltron detector
- Improvement of overall efficiency by 100 (alignment, detector)
- Implementation of a new control system based on LABVIEW
- Cu-70: first combination of RILIS, γ-spec and PT mass spec
- Cu-68: isolation of either ground or isomeric state

Cu: 65-68,68m,69,70,70m,70n,71-74,76 (Thesis Guénaut 2005)
Ga: 63,64,65,68,69,70-78 (Thesis Guénaut 2005)
Ni: 57,60,64,65,66,67,68,69 (Thesis Guénaut 2005)
Cr: 56,57 (Thesis Guénaut)
Mn: 56,57 (Thesis Guénaut 2005)
Rb: 82 (Thesis Guénaut 2005)
Sr: 92 (Thesis Guénaut 2005)
Cs: 124,127 (Thesis Guénaut 2005)
Ba: 130 (Thesis Guénaut 2005)
Fr: 230 (Thesis Rahaman 2005)
Ra:229-232 (Thesis Rahaman 2005)

*…21, USA*
*…9000 Gent, Belgium*
*…sia*
*…k, Russia*
*…, Sweden*
*…fswald, Germany*
*…nd 20742, USA*

…measurements, three
…−62 976.1(1.6) keV
…l energies of the (3$^-$)
…n $T_{1/2} = 6.6(2)$ s are
…ulated in the decay of
…ations, and the wave
…le the closed $Z = 28$
…exhibits a particular

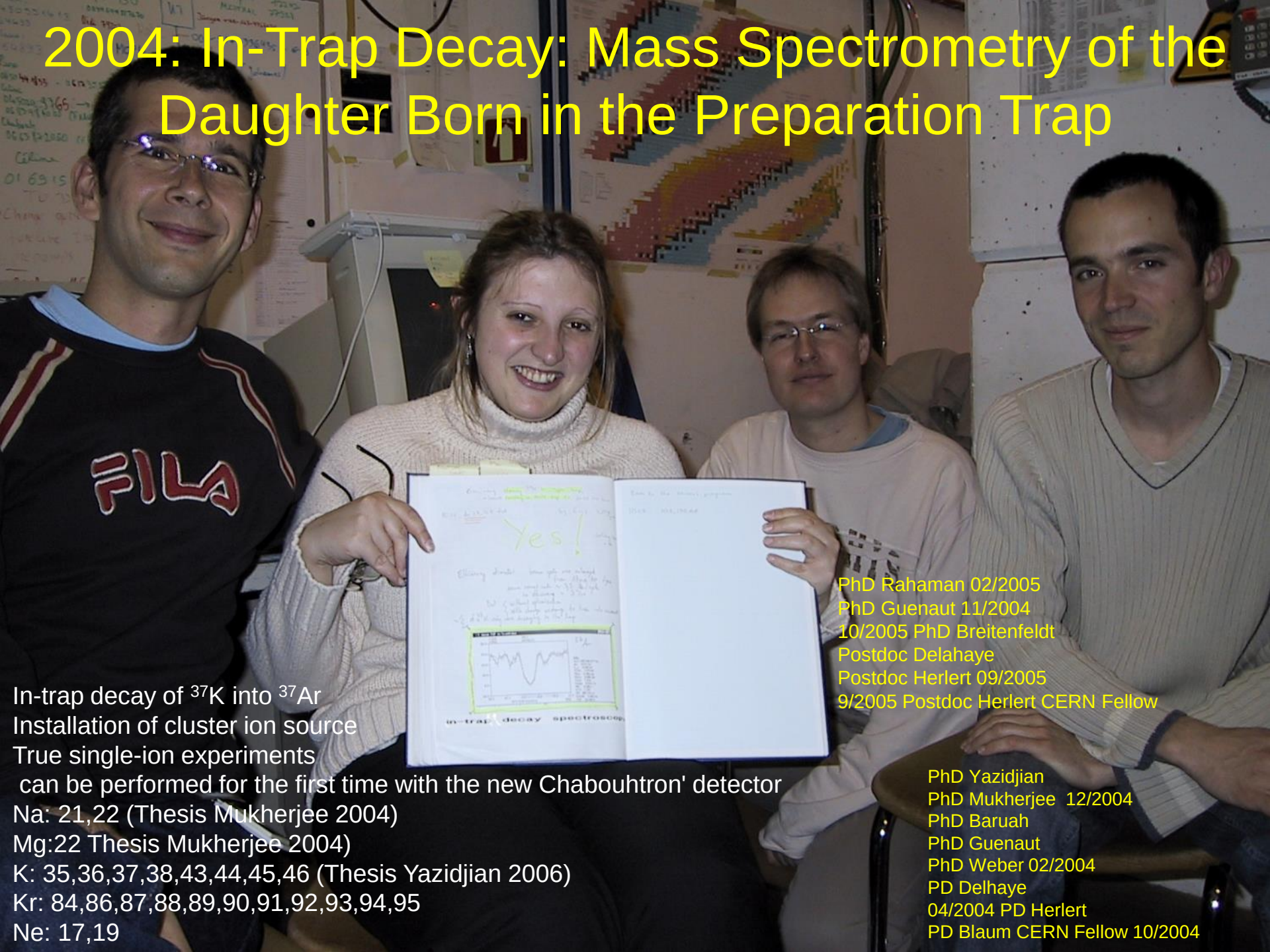
03/2003 Dipl. Yazidjian 08/2003 PhD Mukherjee

04/2003 PhD Guenaut
09/2003 PhD Yazidjian

PhD Weber
PhD Sikler 02/2003

PhD Rodriguez 06/2003
Postdoc Blaum CERN Fellow
Postdoc Herfurth CERN Fellow 12/03

# 2004: In-Trap Decay: Mass Spectrometry of the Daughter Born in the Preparation Trap




In-trap decay of $^{37}K$ into $^{37}Ar$
Installation of cluster ion source
True single-ion experiments
can be performed for the first time with the new Chabouhtron' detector
Na: 21,22 (Thesis Mukherjee 2004)
Mg:22 Thesis Mukherjee 2004)
K: 35,36,37,38,43,44,45,46 (Thesis Yazidjian 2006)
Kr: 84,86,87,88,89,90,91,92,93,94,95
Ne: 17,19

PhD Rahaman 02/2005
PhD Guenaut 11/2004
10/2005 PhD Breitenfeldt
Postdoc Delahaye
Postdoc Herlert 09/2005
9/2005 Postdoc Herlert CERN Fellow

PhD Yazidjian
PhD Mukherjee 12/2004
PhD Baruah
PhD Guenaut
PhD Weber 02/2004
PD Delhaye
04/2004 PD Herlert
PD Blaum CERN Fellow 10/2004

# 2005: Strengthening the Shell Gap at N = 82

Development of new reference ion source
Development of a two-dimensional detector
investigation of doubly charged Xe ions
Ramsey technique (Sebastian George)
First ions from cluster source to preparation-trap
Temperature and pressure stabilization

Cd: 114,118,120,122,123,124
Sn: 127,128,128m,131,132,133,134 (molecular)
(Diploma thesis Dworschak 01/2006)
Zn: 71,71m,72,73,74,75,76,77,77m,78,79,80,81
Xe: 126,136 (doubly charged)

Restoration of the $N = 82$ shell gap from direct mass measurements of $^{132,134}$Sn

M. Dworschak[1*], G. Audi[2], K. Blaum[1,3,4], P. Delahaye[5], S. George[1,3], U. Hager[6], F. Herfurth[1], A. Herlert[5], A. Kellerbauer[4], H.-J. Kluge[1,7], D. Lunney[2], L. Schweikhard[8], and C. Yazidjian[1]
[1] *GSI, Planckstraße 1, 64291 Darmstadt, Germany*
[2] *CSNSM–IN2P3–CNRS, Université de Paris Sud, 91405 Orsay, France*
[3] *Johannes Gutenberg-Universität, Institut für Physik, 55099 Mainz, Germany*
[4] *Max Planck Institute for Nuclear Physics, P.O. Box 103980, 69029 Heidelberg, Germany*
[5] *CERN, Physics Department, 1211 Geneva 23, Switzerland*
[6] *University of Jyväskylä, Department of Physics, P.O. Box 35 (YFL), 40014 Jyväskylä, Finland*
[7] *Ruprecht-Karls-Universität, Physikalisches Institut, 69120 Heidelberg, Germany and*
[8] *Ernst-Moritz-Arndt-Universität, Institut für Physik, 17487 Greifswald, Germany*

Dipl. Marie-Jeanne
02/2005 Dipl. Dworschak
05/2005 Dipl.George
PhD Yazidjian
PhD Baruah
PhD Hager

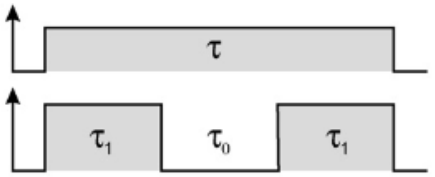
# 2006: Ten Times Faster to a Mass Spectrum

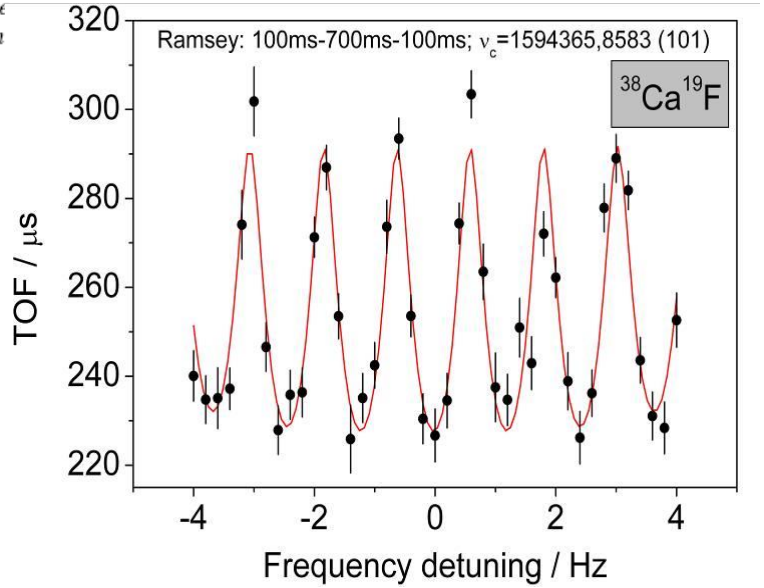
PRL 98, 162501 (2007) PHYSICAL REVIEW LETTERS week ending 20 APRIL 2007

**Ramsey Method of Separated Oscillatory Fields for High-Precision Penning Trap Mass Spectrometry**

S. George,[1,2,*] S. Baruah,[3] B. Blank,[4] K. Blaum,[1,2] M. Breitenfeldt,[3] U. Hager,[5] F. Herfurth,[1] A. Herlert,[6] A. Kellerbauer,[7] H.-J. Kluge,[1,8] M. Kretzschmar,[2] D. Lunney,[9] R. Savreux,[1] S. Schwarz,[10] L. Schweikhard,[3] and C. Yazidjian[1]

[1]*GSI, Planckstraße 1, 64291 Darmstadt, Germany*
[2]*Institut für Physik, Johannes Gutenberg-Universität, 55099 Mainz, Germany*
[3]*Institut für Physik, Ernst-Moritz-Arndt-Universität, 17487 Greifswald, Germany*
[4]*Centre d'Etudes Nucléaires de Bordeaux-Gradignan, 33175 Gradignan Cedex, France*
[5]*Department of Physics, University of Jyväskylä, P.O. Box 35 (YFL), 40014 Jyväskylä, Fin*
[6]*Physics Department, CERN, 1211 Geneva 23, Switzerland*
[7]*Max-Planck Institut für Kernphysik, 69117 Heidelberg, Germany*
[8]*Physikalisches Institut, Ruprecht-Karls-Universität, 69120 Heidelberg, Germany*
[9]*CSNSM-IN2P3-CNRS, 91405 Orsay-Campus, France*
[10]*NSCL, Michigan State University, East Lansing, Michigan 48824-1321, USA*




- Development of new reference ion source
- Implementation of Ramsey technique
- In-trap decay to produce Fe isotopes (61-63Fe)
- First design of tape station system

Al: 26,27 (Ramsey)
Ca: 38,39 (Ramsey, molecular beam)
Mn: 56,57,58,59,60,61,62,63
Fe: 61,62,63 (in-trap decay)

Dipl. Dworschak 01/2006
Dipl.George 07/2006
PhD Yazidjian
PhD Baruah
PhD Breitenfeldt

PhD Hager
08/2005 PhD George
PhD Guenaut 11/2004
Postdoc Delahaye
Postdoc Herlert CERN Fellow

# 2007: The ISOLTRAP crew at ISOLDE

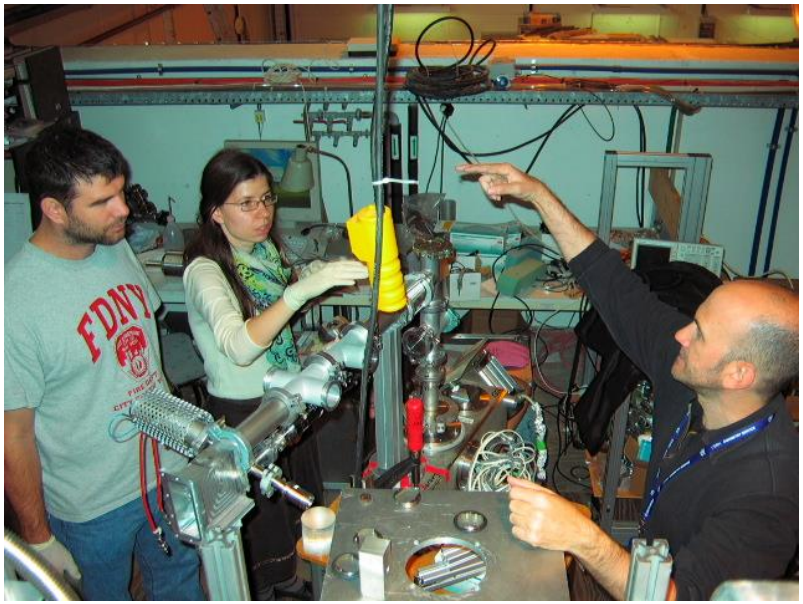

PhD Baruah
PhD Breitenfeldt
PhD George
01/2007 PhD Neidherrr
10/2007 PhD Naimi
1/2007 Kowalska Marie Curie Fellow
Postdoc Herlert CERN Fellow 9/2007

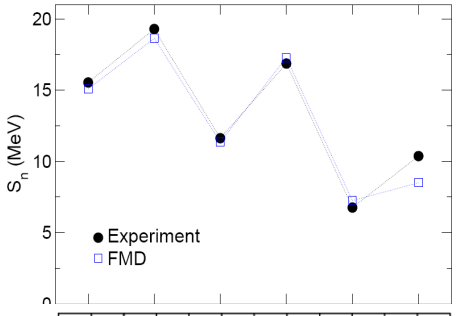
**Development of new reference ion source**
**Implementation of GSI tape station**
**Preparations for $H_2$ cooling in the buncher**

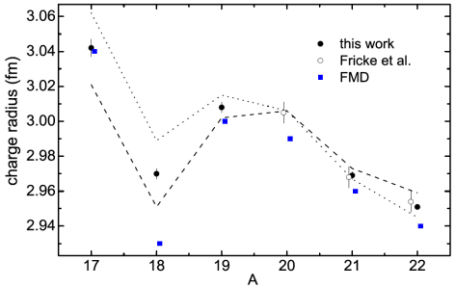
**Cd: 99,100,101,102,103,104,105,106,107,108,109**
**Ag: 117,119,120,121**
**Ra: 211**
**Fr: 211,212,213**

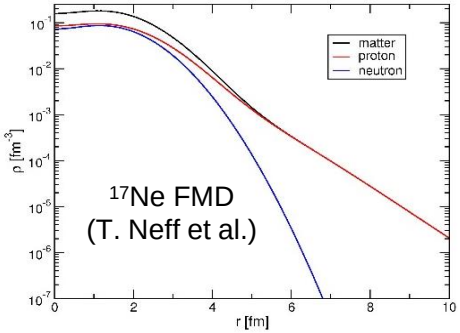
- High-precision masses of neutron-deficient rubidium isotopes from ISOLTRAP, A. Kellerbauer et al., Phys. Rev. C 76, 024308 (2007)
- Evidence for a breakdown of the isobaric multiplet mass equation: A study of the A=35, T=3/2 isospin quartet, C. Yazidjian et al., Phys. Rev. C 76, 024308 (2007)
- Die Ramsey-Methode in der Prazisions-Massenspektrometrie, S. George, K. Blaum, M. Kretzschmar, L. Schweikhard, Physik in unserer Zeit 38, 163-164 (2007)
- Ramsey method in precision mass spectrometry with Penning traps: Experimental results, S. George et al., Int. J. Mass Spectrom. 264, 110-121 (2007)
- Ramsey method of separated oscillatory fields for high-precision Penning trap mass spectrometry, S. George et al., Phys. Rev. Lett. 98, 162501 (2007)
- High-precision mass measurements of nickel, copper, and gallium isotopes and the purported shell closure at N=40, C. Guenaut et al., Phys. Rev. C 75, 044303 (2007)

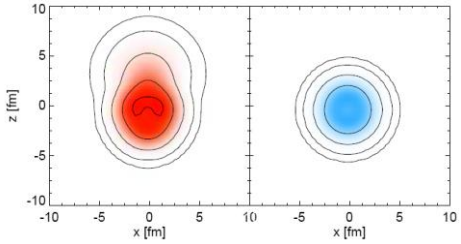
# 2008: tape station / $^{17}$Ne proton halo





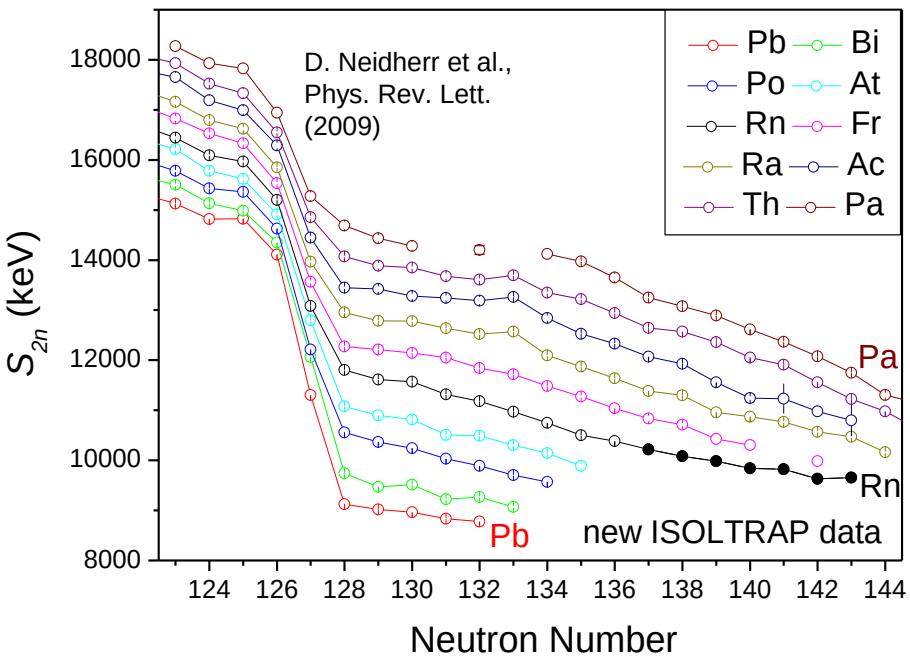




Mass Harvest:
Cd: 126,128
Rn: 220,223-229
194Hg-194Au for neutrino mass

Contact: M. Kowalska
Crew: S. Naimi, M. Breitenfeldt, D. Neidherr, C. Borgmann
Support: C. Boehm, S. George, E. Minaya + Valencia group
A. Herlert (ISOLDE Coordinator)
PhD thesis: S. Baruah (Greifswald)


- Electric and magnetic field optimization procedure for Penning trap mass spectrometers
  D. Beck et al., Nucl. Instr. and Meth. A 598, 635 (2008)
- Mass measurements beyond the major r-process waiting point **80Zn**
  S. Baruah et al., Phys. Rev. Lett. 101, 262501 (2008)
- Masses and charge radii of 17-22Ne and the two-proton-halo candidate **17Ne**
  W. Geithner et al., Phys. Rev. Lett 101, 252502 (2008)
- Time-separated oscillatory fields for high-precision mass measurements on **26Al** and **38Ca**
  S. George et al., Europhys. Lett. 82, 50005 (2008)
- Atomic mass measurements of short-lived nuclides around the doubly-magic **208Pb**
  C. Weber et al. Nucl. Phys. A 803, 1-29 (2008)
- Towards B-field stabilization at ISOLTRAP for high-accuracy mass measurements on exotic nuclides, M. Marie-Jeanne et al., Nucl. Instr. and Meth. A 587, 464 (2008)
- Mass measurements and evaluation **A=22**, M. Mukherjee et al., Eur. Phys. J. A 35, 1 (2008)
- ISOLTRAP: An on-line Penning trap for mass spectrometry on short-lived nuclides
  M. Mukherjee et al., Eur. Phys. J. A 35, 1-29 (2008)
- Restoration of the N=82 Shell Gap from Direct Mass Measurements of **132,134Sn**
  M. Dworschak et al., Phys. Rev. Lett. 100, 072501 (2008)

# 2009: discovery of the isotope $^{229}$Rn





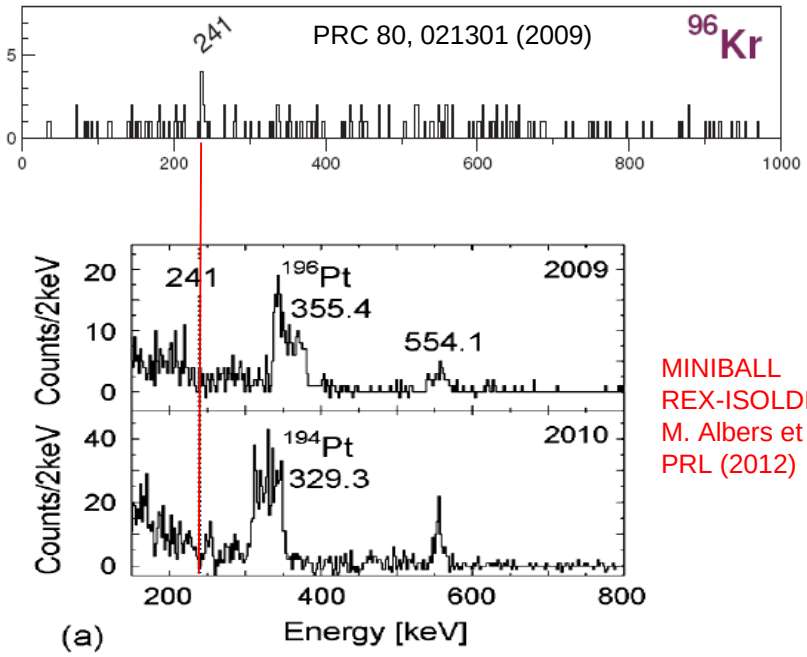
Liviu Penescu

Mass Harvest:
Mn: 63-66
Kr: 96,97

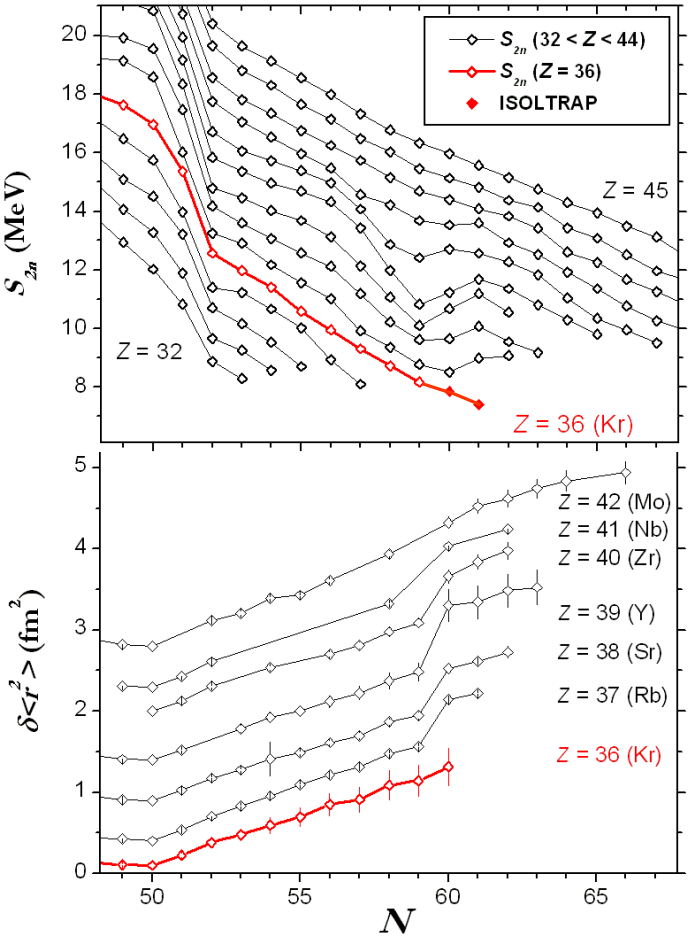
Contact: M. Kowalska
Crew: S. Naimi, D. Neidherr, C. Borgmann, S. Kreim
Support: M. Rosenbusch, S. George, C. Boehm, M. Breitenfeldt
A. Herlert (ISOLDE Coordinator)
PhD thesis: S. George (Heidelberg), M. Breitenfeldt (Greifswald)

- High-precision Penning-trap mass measurements of n-rich **136-146Xe** for nuclear structure studies, D. Neidherr et al., Phys. Rev. C 80, 044323 (2009)
- Penning trap mass measurements of **99-109Cd** with the ISOLTRAP mass spectrometer, and implications for the rp process, M. Breitenfeldt et al., Phys. Rev. C 80, 035805 (2009)
- Neutron Drip-Line Topography, E. Minaya Ramirez et al., AIP Conf. Proc. 1165, 94 (2009)
- Preparing a journey to the east of 208Pb with ISOLTRAP, M. Kowalska et al., Eur. Phys. J. A 42, 351 (2009)
- Investigation of Space-Charge Phenomena in Gas-Filled Penning Traps, S. Sturm et al., AIP Conf. Proc. 1114, 185-190 (2009)
- Discovery of **229Rn** and the Structure of the Heaviest Rn and Ra Isotopes from Penning-Trap Mass Measurements, D. Neidherr et al., Phys. Rev. Lett. 102, 112501 (2009)

# 2010: Helping spectroscopists with $^{96}$Kr

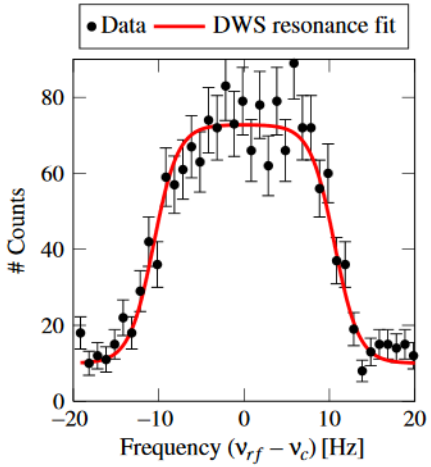



MINIBALL
REX-ISOLDE
M. Albers et al.
PRL (2012)




ISOLTRAP:
S. Naimi et al.
PRL (2010)

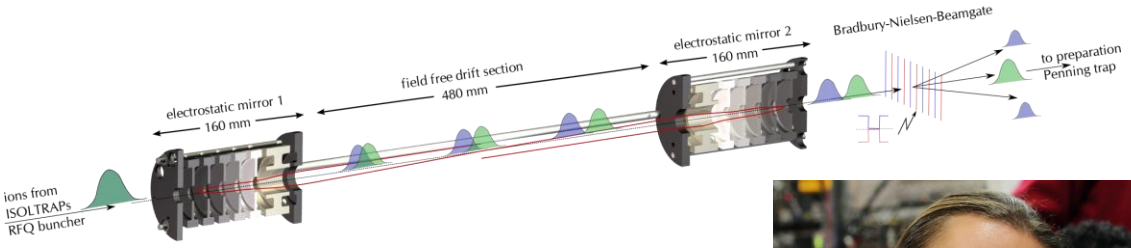
COLLAPS:
M. Keim et al.
NPA (1995)

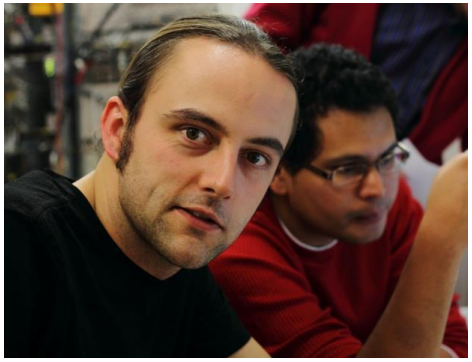


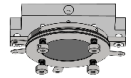


- Direct mass measurements of **194Hg and 194Au**: A new route to the neutrino mass determination? S. Eliseev et al., Phys. Lett. B. 693, 426–429 (2010)
- Critical-Point Boundary for the Nuclear Quantum Phase Transition Near A=100 from Mass Measurements of **96,97Kr**, S. Naimi et al., Phys. Rev. Lett. 105, 032502 (2010)
- Approaching the **N = 82** shell closure with mass measurements of **Ag and Cd** isotopes, M. Breitenfeldt et al., Phys. Rev. C 81, 034313 (2010)
- ISOLTRAP results 2006–2009, M. Kowalska for the ISOLTRAP collaboration, Hyperfine Interact. 196, 199-203 (2010)

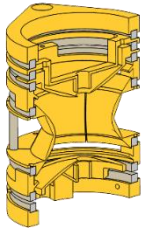
# 2010: MR-ToF ushers in a new era



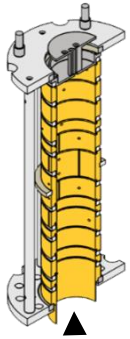





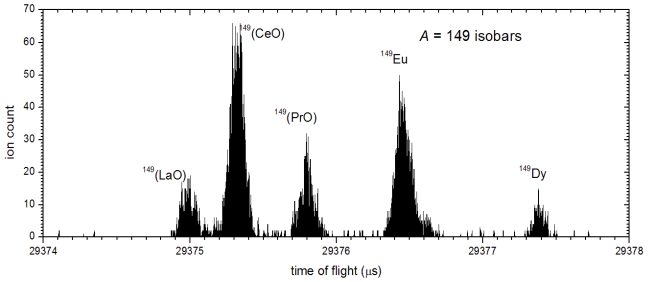
MCP

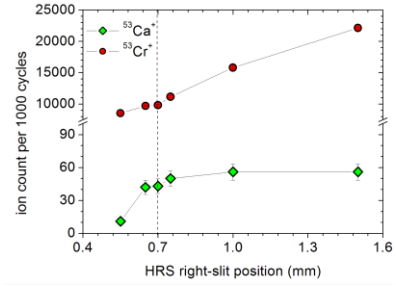


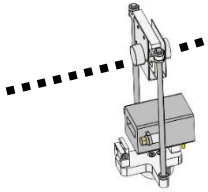
hyp trap



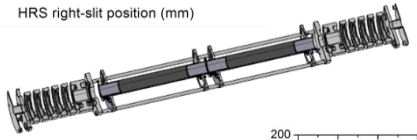
prep trap



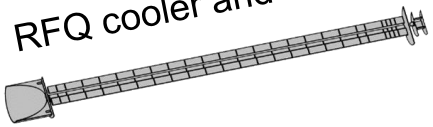



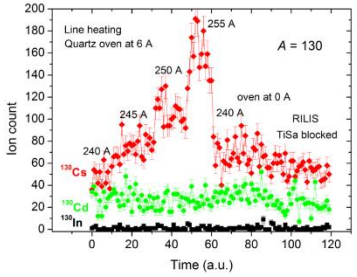
Bradbury-Nielsen beam gate



MR-TOF MS

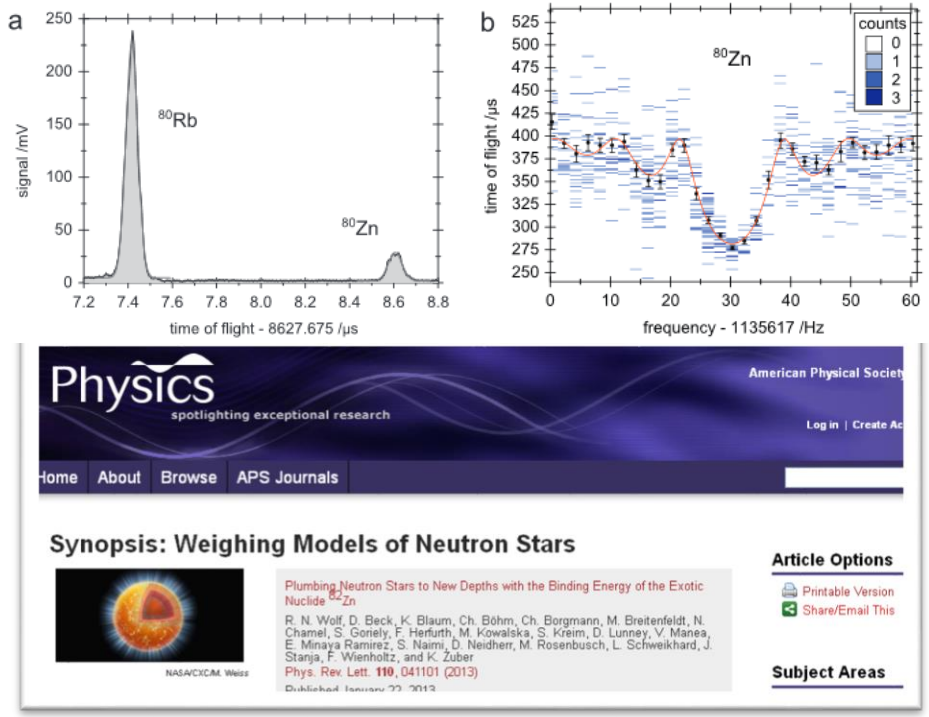
RFQ cooler and buncher





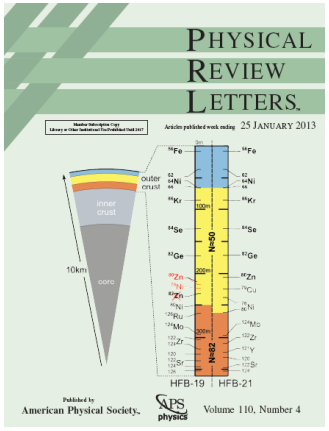

Contact: M. Kowalska → S. Kreim
Crew: C. Borgmann, D. Fink, M. Rosenbusch, R. Wolf
Support: S. George, E. Minaya, M. Breitenfeldt,
A. Herlert → M. Kowalska (ISOLDE Coordinator)
PhD thesis: S. Naimi (Orsay), D. Neidherr (Mainz)

# 2011: zinc chain revisited

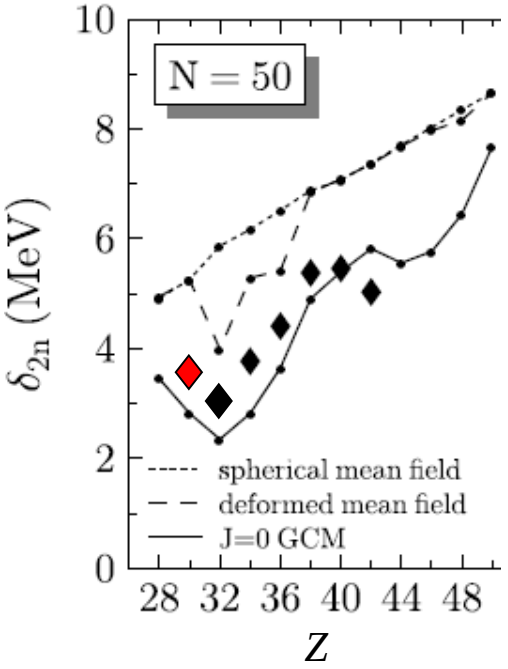












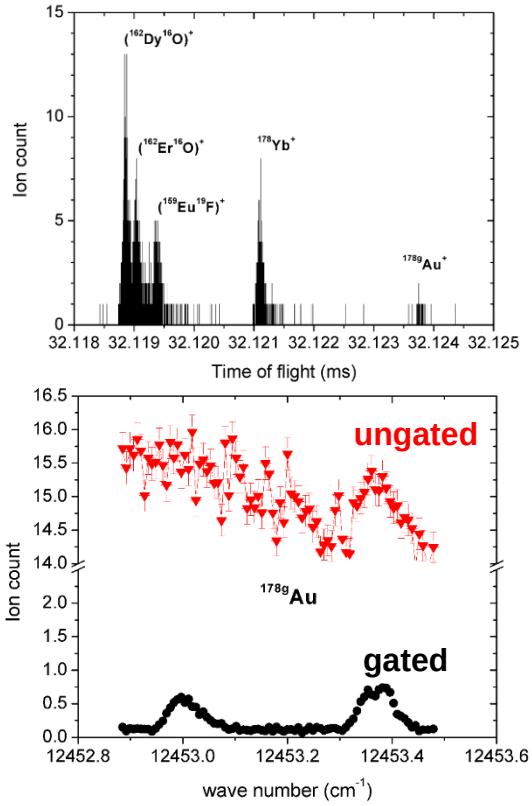

Shell gap calculations from Bender, Bertsch, Heenen PRC (2006)
$^{78,80,82}$Zn from ISOLTRAP

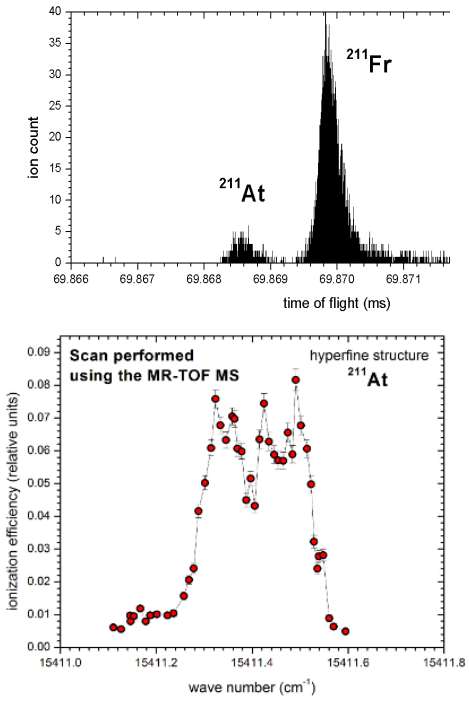
ISOLDE Workshop: S. Kreim
Harvest (despite LT magnet quench):
Ra: 233,234
Fr: 222,224,226-233
Tl: 184,186,190,202
168Lu; 202Pb
Zn: 80,81,82

Contact: S. Kreim
Crew: C. Borgmann, V. Manea, M. Rosenbusch, F. Wienholtz, R. Wolf
Support: S. George, E. Minaya, M. Breitenfeldt, D. Fink,
M. Kowalska (ISOLDE Coordinator)
PhD thesis:

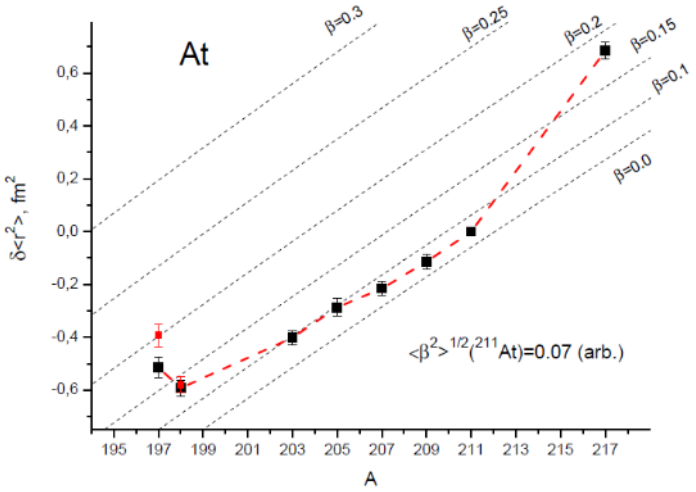

- Cadmium mass measurements between the neutron shell closures at N = 50 and 82, Ch. Borgmann et al., AIP Conf. Proc. 1377, 332-334 (2011)
- Measurements of ground-state properties for nuclear structure studies by precision mass and laser spectroscopy, K. Blaum et al., J. Phys. Conf. Ser. 312, 092001 (2011)
- New mass data for the rp-process above Z = 32, F. Herfurth et al., Eur. Phys. J. A 47, 75 (2011)
- Mass measurements of short-lived nuclides using the Isoltrap preparation Penning trap, S. Naimi et al., Hyperfine Interactions, 199, 231–240 (2011)
- Effects of space charge on the mass purification in Penning traps, A. Herlert et al., Hyperfine Interactions, 199, 211-220 (2011)
- Damping effects in Penning trap mass spectrometry, S. George et al., Int. J. Mass Spectrom. 299, 102-112 (2011)

# 2012: MR-TOF teams up with RILIS/WM




J. Cubiss et al.
PRX (2017) sub




51-54Ca, 51-53K (MRTOF)
99-100Rb, 146-148Cs, 198Tl
178m,178-182,185,188,190Au (IS)
205,207,209,211At (IS)

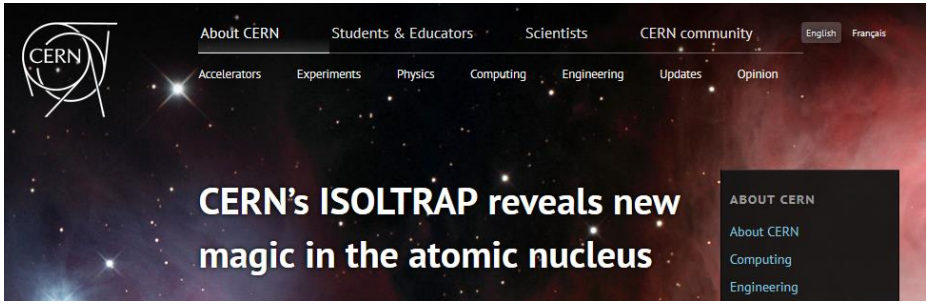
Contact: S. Kreim
Crew: V. Manea, F. Wienholtz, D. Atanasov
Support: C. Boehm, M. Rosenbusch, R. Wolf
M. Kowalska (ISOLDE Coordinator)
PhD thesis: C. Borgmann (Heidelberg)

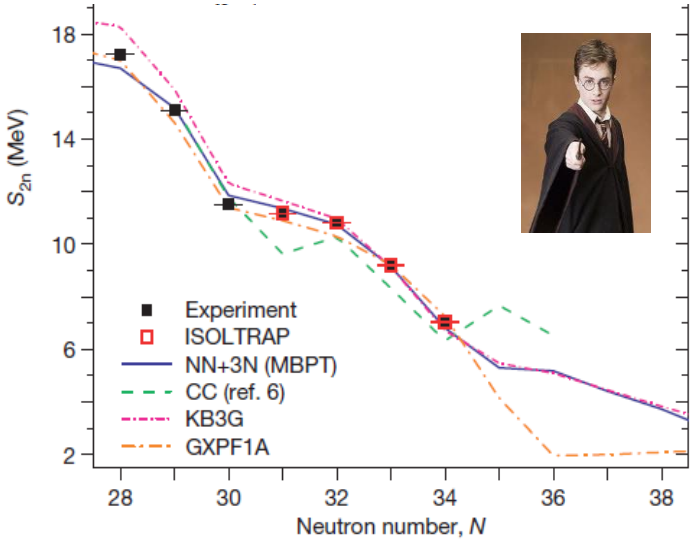

- Recoil-ion trapping for precision mass measurements, A. Herlert et al., Eur. Phys. J. A 48, 97 (2012)
- Surveying the **N=40** island of inversion with new **Mn** masses, S. Naimi et al., Phys. Rev. C 86, 014325 (2012)
- Buffer-gas-free mass-selective ion centering in Penning traps by simultaneous dipolar excitation of magnetron motion and quadrupolar excitation for interconversion between radial motion, M. Rosenbusch et al., Int. J. Mass Spectrom. 325-327, 51 (2012)
- Trap-assisted decay spectroscopy with ISOLTRAP, M. Kowalska et al., Nucl. Instr. and Meth. A 689, 102-107 (2012)
- On-line separation of short-lived nuclei by a multi-reflection time-of-flight device, R.N. Wolf et al., Nucl. Instr. and Meth. A 686, 82-90 (2012)
- Q Value and Half-Lives for the Double-β-Decay Nuclide **110Pd**, D. Fink et al., Phys. Rev. Lett. 108, 062502 (2012)
- A study of octupolar excitation for mass-selective centering in Penning traps, M. Rosenbusch et al., Int. J. Mass Spectrom. 314, 6-12 (2012)

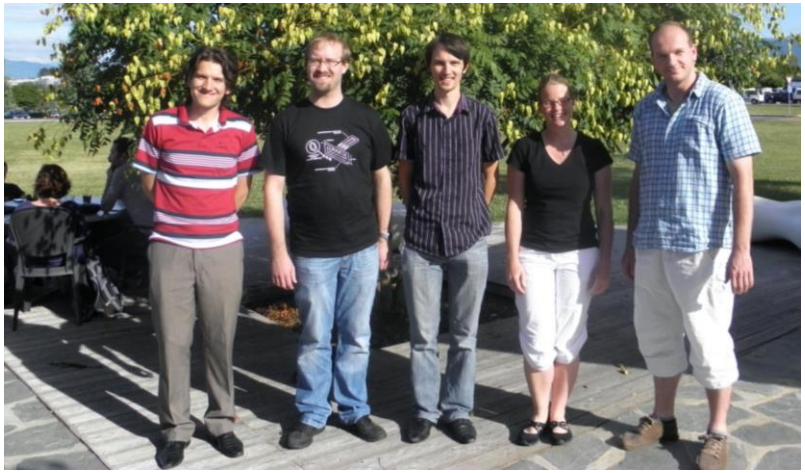
# 2013: ISOLTRAP's first article in *Nature*

## Masses of exotic calcium isotopes pin down nuclear forces

F. Wienholtz[1], D. Beck[2], K. Blaum[3], Ch. Borgmann[3], M. Breitenfeldt[4], R. B. Cakirli[3,5], S. George[1], F. Herfurth[2], J. D. Holt[6,7], M. Kowalska[8], S. Kreim[3,8], D. Lunney[9], V. Manea[9], J. Menéndez[6,7], D. Neidherr[2], M. Rosenbusch[1], L. Schweikhard[1], A. Schwenk[7,6], J. Simonis[6,7], J. Stanja[10], R. N. Wolf[1] & K. Zuber[10]



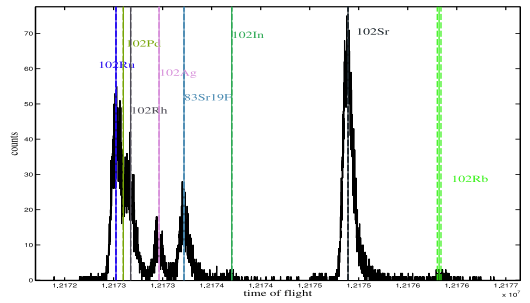



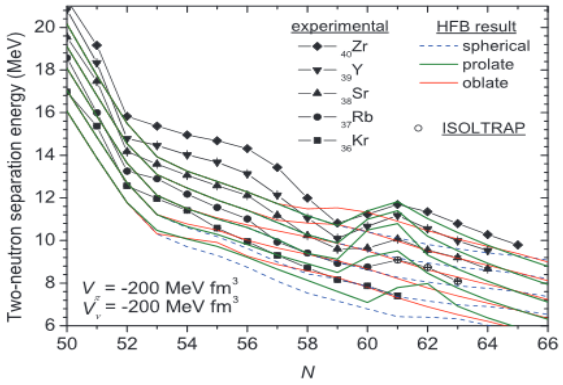
Contact: S. Kreim → V. Manea
Crew: D. Atanasov, V. Manea, F. Wienholtz
Support: P. Ascher, C. Boehm, M. Rosenbusch, R. Wolf
M. Kowalska (ISOLDE Coordinator), T. Cocolios (CERN Fellow)
PhD thesis: J. Stanja (Dresden), R. Wolf (Greifswald)

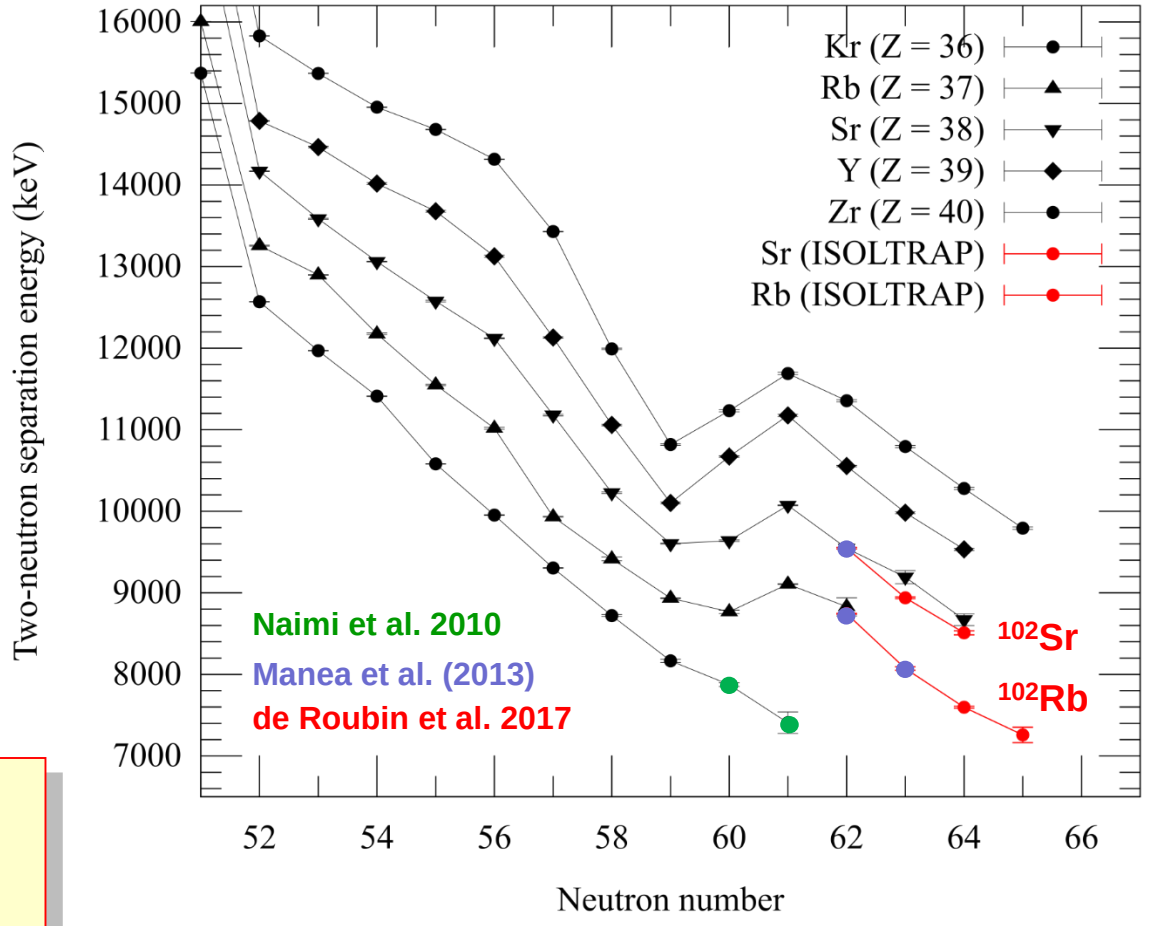
CERN LS1 (ISOLTRAP overhauled)


- Recent exploits of the ISOLTRAP mass spectrometer, S. Kreim et al., Nucl. Instrum. Methods B 317, 492–500 (2013)
- Collective degrees of freedom of neutron-rich A≈100 nuclei and the first mass measurement of the short-lived nuclide **100Rb,** V. Manea et al., Phys. Rev. C 88, 054322 (2013)
- Mass spectrometry and decay spectroscopy of isomers across the Z=82 shell closure, J. Stanja et al., Phys. Rev. C 88, 054304 (2013)
- ISOLTRAP's multi-reflection time-of-flight mass separator/spectrometer, R.N. Wolf et al., Int. J. Mass. Spectrom. 349-350, 123-133 (2013)
- Masses of exotic **calcium** isotopes pin down nuclear forces, F. Wienholtz et al., Nature 498, 346 (2013)
- Plumbing Neutron Stars to New Depths with the Binding Energy of the Exotic Nuclide **82Zn,** R. N. Wolf, Phys. Rev. Lett. 110, 041101 (2013)

# 2014: back to *A* = 100 (Sr and Rb masses)



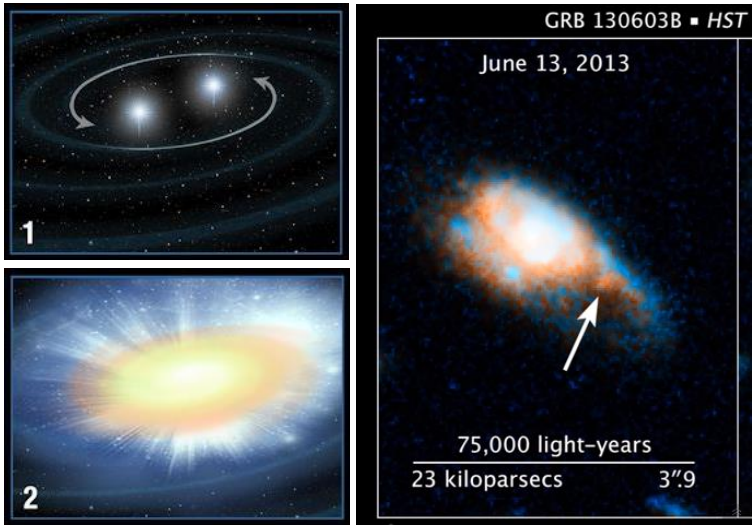




129-131Cd + half-lives
160Yb; 55-59Cr
100-102Sr; 101-102Rb + half-lives
At (IS)
Target support (B and Sc beams)
Medical isotopes (149Tb and 149Dy)

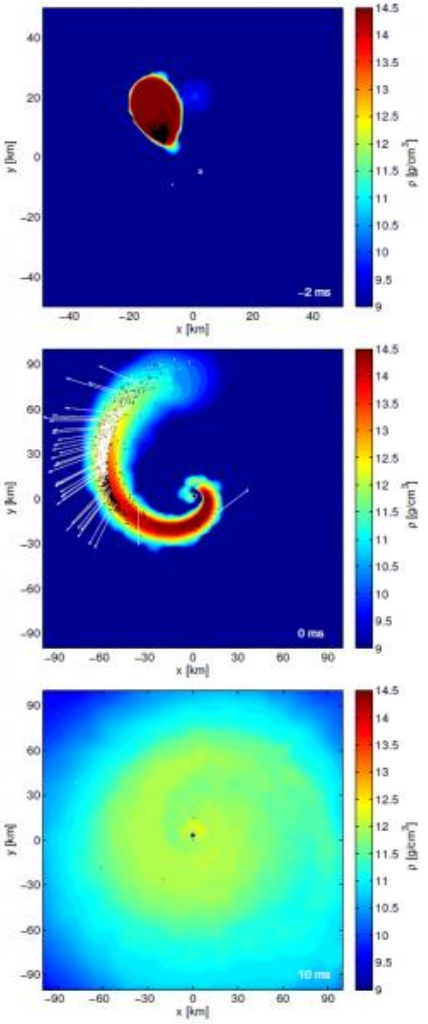
Contact: V. Manea
Crew: D. Atanasov, D. Kisler, V. Manea, F. Wienholtz
Support: P. Ascher, C. Boehm, S. George, M. Rosenbusch, R. Wolf
M. Kowalska (ISOLDE Coordinator), T. Cocolios (CERN Fellow)
PhD thesis: V. Manea (Orsay)


- Evolution of nuclear ground-state properties of neutron-deficient isotopes around Z=82 from precision mass measurements, Ch. Böhm et al., Phys. Rev. C 90, 044307 (2014)
- Competition between pairing correlations and mean-field effects in heavy, deformed nuclei, S. Kreim, Phys. Rev. C 90, 024301 (2014)
- Ion bunch stacking in a Penning trap after purification in an electrostatic mirror trap, M. Rosenbusch et al., Appl. Phys. B 114, 147-155 (2014)

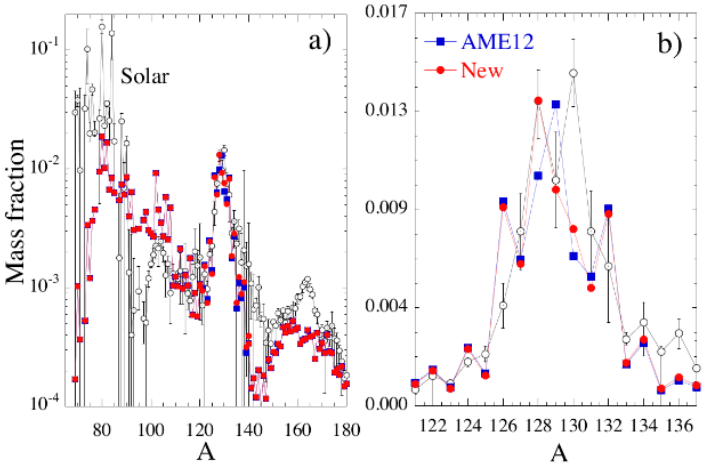
# 2015: the *r*-process waiting point $^{130}$Cd




**Neutron Star – Black Hole Merger Hydrodynamics by O. Just et al. MNRAS (2014)**



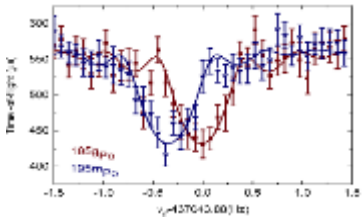
**Masses of $^{129\text{-}131}$Cd**
**D. Atanasov et al. PRL (2015)**
**Nucleosynthesis by S. Goriely**

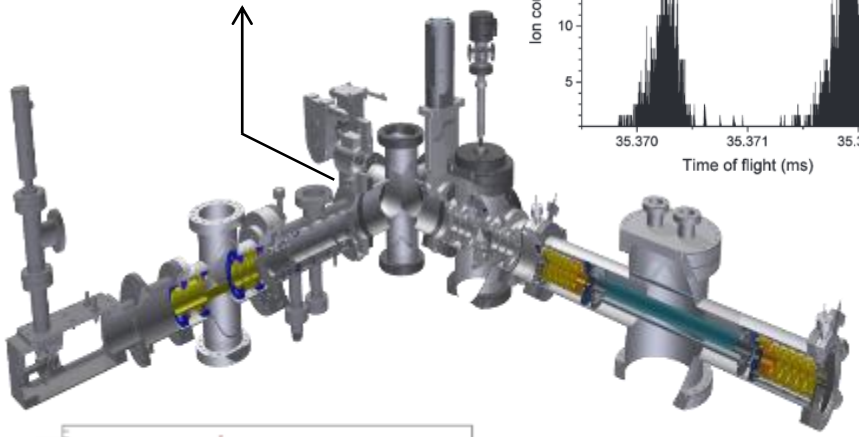

Contact: V. Manea
Crew: D. Atanasov, F. Wienholtz
Support: N. Althubiti, P. Ascher, M. Rosenbusch, R. Wolf
T. Cocolios (CERN Fellow)
PhD thesis: C. Boehm (Heidelberg)

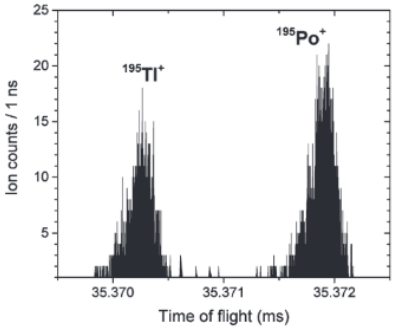
- Precision Mass Measurements of **129–131Cd** and Their Impact on Stellar Nucleosynthesis via the Rapid Neutron Capture Process, D. Atanasov et al., Phys. Rev. Lett. 115, 232501 (2015)
- Probing the N=32 Shell Closure below the Magic Proton Number Z=20: Mass Measurements of the Exotic Isotopes **52,53K**, M. Rosenbusch et al., Phys. Rev. Lett. 114, 202501 (2015)

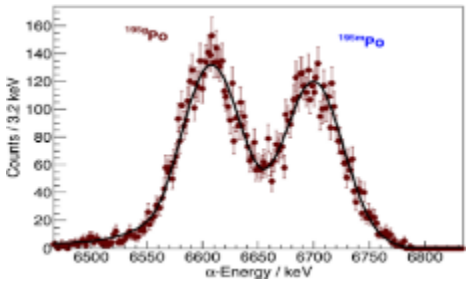
# 2016: isomer studies in Po and Cr masses

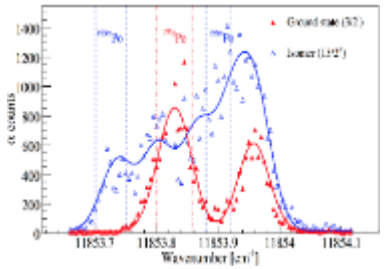


to Penning traps

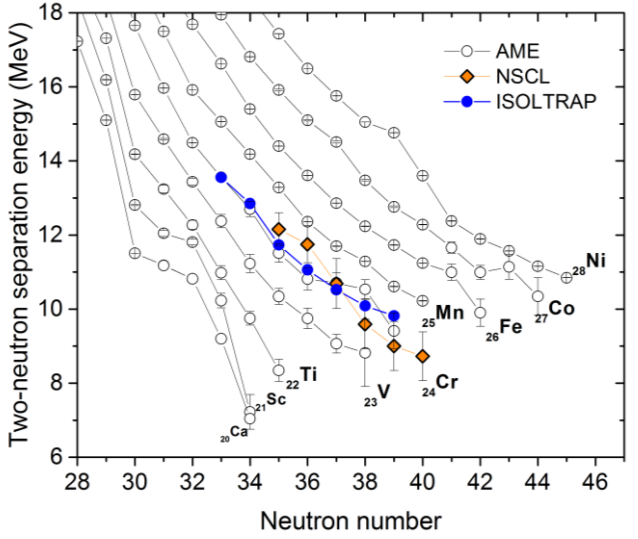




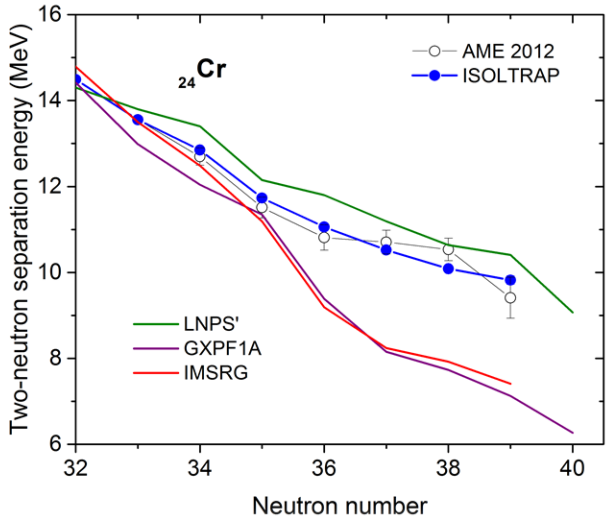




N. Althubiti et al. PRC (2017)



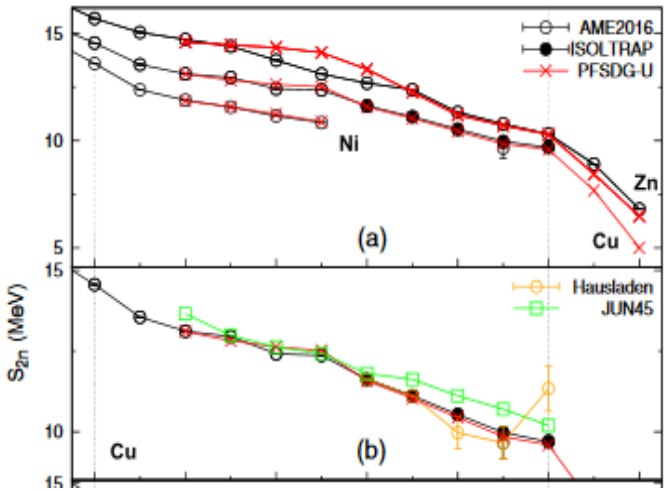

M. Mougeot et al. (PRL) submitted

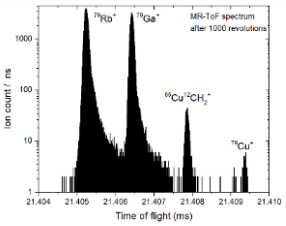


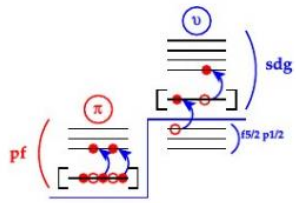

Contact: V. Manea
Crew: D. Atanasov, M. Mougeot, A. Welker,
Support: P. Ascher, M. Rosenbusch, F. Wienholtz, N. Althubiti
PhD thesis: D. Atanasov (Heidelberg), M. Rosenbusch (Griefswald)

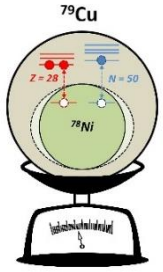
- Background-free beta-decay half-life measurements by in-trap decay and high-resolution MR-ToF mass analysis, R.N. Wolf et al., Nucl.Instrum. Meth. B (in press)

# 2017: $^{79}$Cu – only one proton from $^{78}$Ni



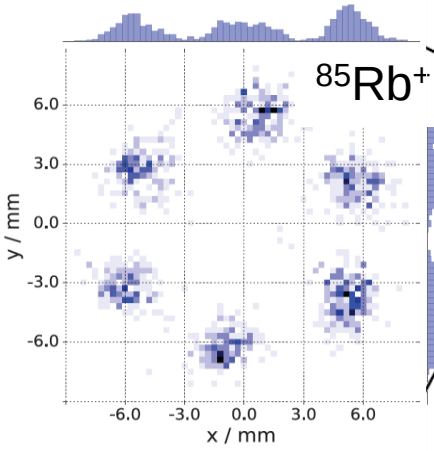




**A. Welker et al., PRL (2017)**
**+ *Viewpoint***


**Phase-imaging ion-cyclotron resonance**



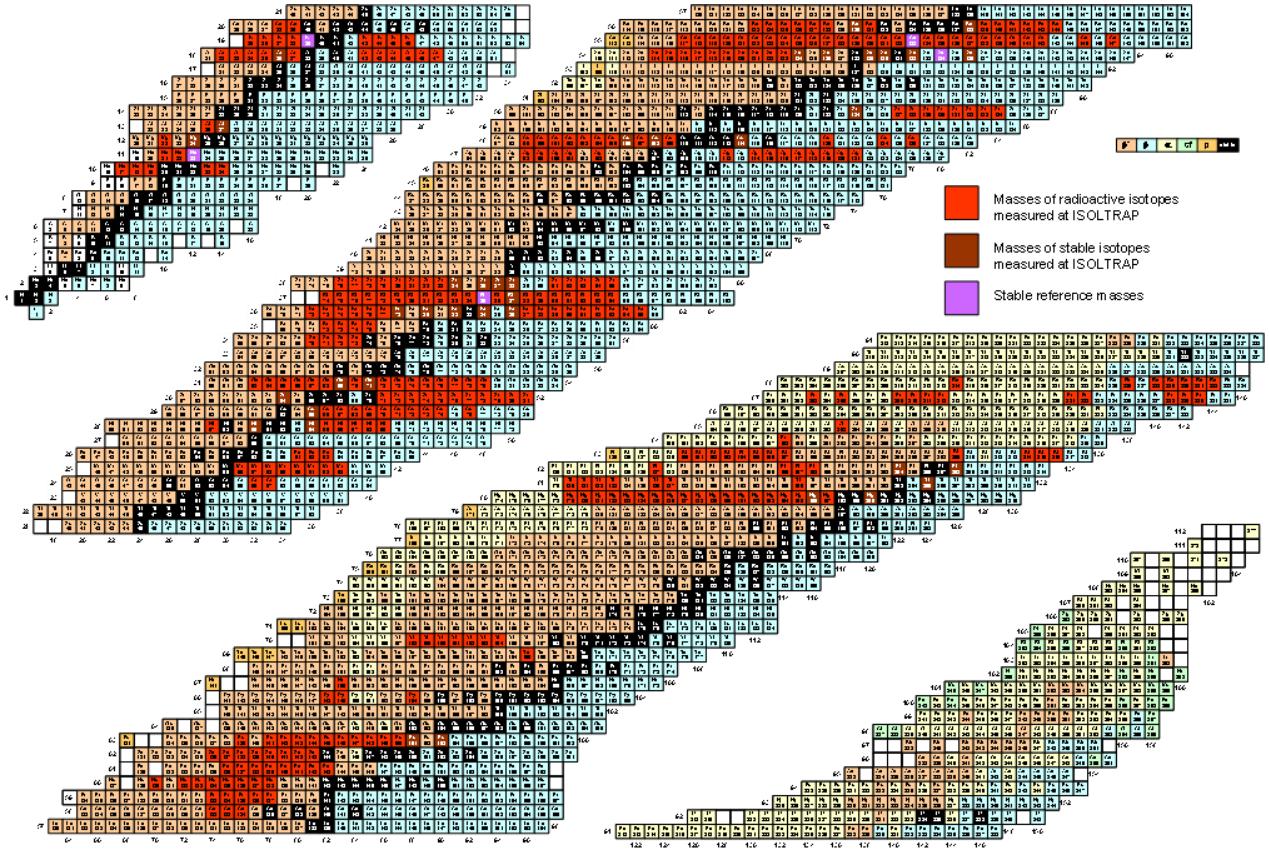

**see D. Atanasov's talk & J. Karthein's poster!**

NEW: 48Ar, 98Kr, 132Cd → D. Atanasov's talk

Contact: V. Manea
Crew: D. Atanasov, J. Karthein, M. Mougeot, T. Steinsberger
Support: A. Welker, F. Wienholtz, W. Huang, D. Neidherr, N. Althubiti
PhD thesis: A. Welker (Dresden), N. Althubiti (Manchester)


- Study of long-lived isomers in the n-deficient **195,197,199Po** by high-precision mass measurements, N. Althubiti et al., Physical Review C 96, 044325 (2017)
- Binding energy of **79Cu**: probing the structure of the doubly magic 78Ni from only one proton away," A. Welker et al., Phys. Rev. Lett. 119, 192502 (2017) + Viewpoint
- Nuclear deformation in the **A ~ 100** region: Comparison between new masses and mean-field predictions, A. de Roubin et al., Phys. Rev. C 96, 014310 (2017)
- A. Welker et al., "Precision electron-capture energy in **202Pb** and its relevance for neutrino-mass determination," Eur. Phys. J. A 53, 153 (2017)
- V. Manea et al., "Penning-trap mass spectrometry and mean-field study of nuclear shape coexistence in the n-deficient **Pb** region," Phys. Rev. C 95, 054322 (2017)
- Precision mass measurements of **Cs** isotopes – new entry in the ISOLTRAP chronicles, D. Atanasov et al., J. Phys. G: Nucl. Part. Phys. 44, 044004 (2017)

# Masses measured by ISOLTRAP:
# 669 data in AME2016, 520 are not “u” (unweighted)
# 407 unique nuclides (compared to ~300 in 2007)




over the last decade:

32 physics papers
(nuclear structure, weak-interaction nucleosynthesis)
13 of which, Letters
17 technical papers
13 doctors

# ISOLTRAP has Many Children

2007

Frans Michel Penning

Wolfgang Paul

Hans Dehmelt

Gernot Gräff

SCIENCE

EUROTRAPS

EXOTRAPS

HITRAP

NIPNET

Seattle

Mainz

MIT

Harvard

ISOLTRAP

ATRAP

ATHENA

SMILETRAP

CLUSTER TRAP

RETRAP

CPT

REXTRAP

g-factor trap

$e^+$ TRAP

TITAN

LEBIT

SHIPTRAP

JYFL TRAP

WITCH

SPECTRAP

SPIRAL TRAP

HITRAP

TRIGA TRAP

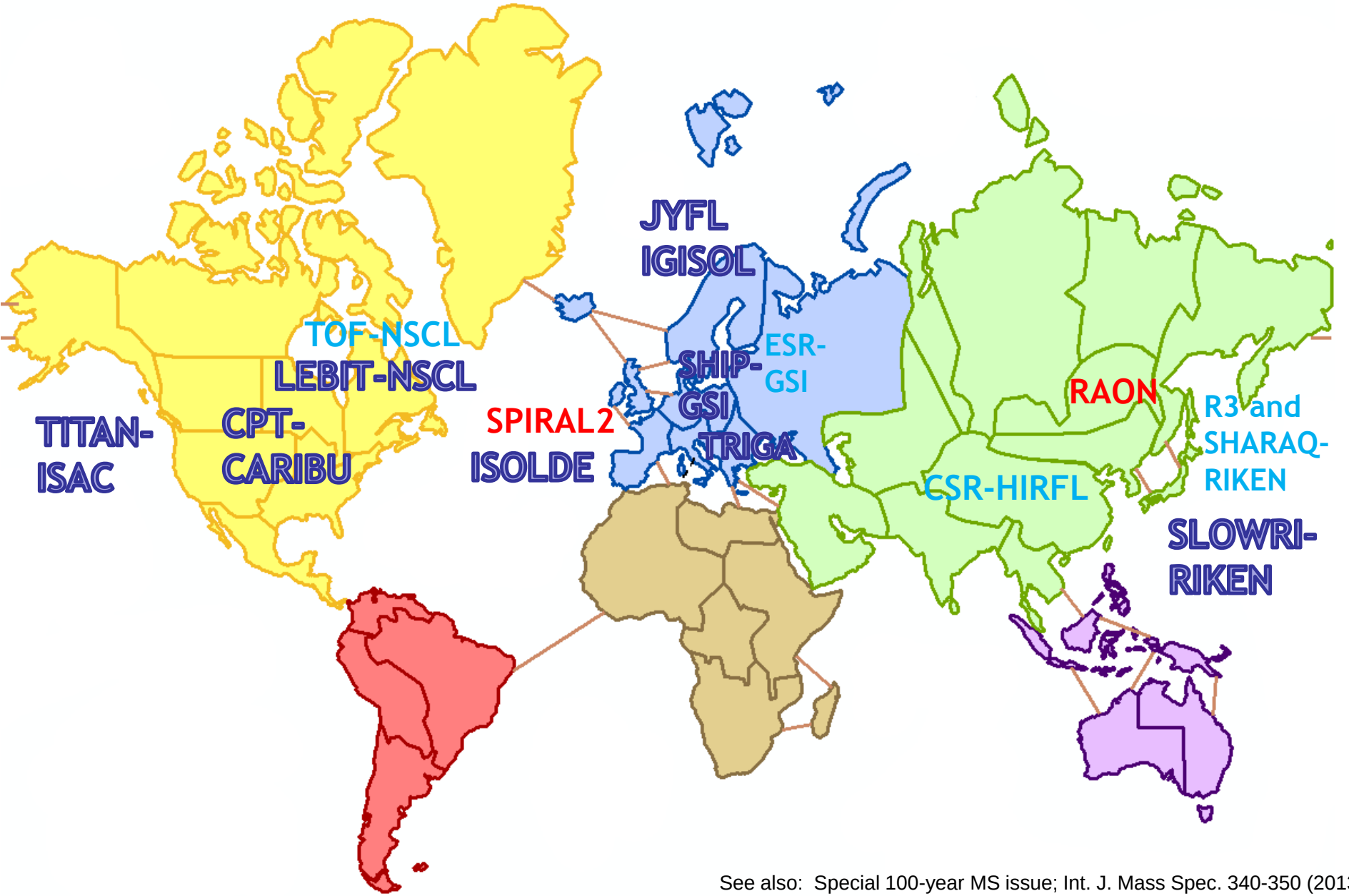
MATS

**New or recent projects**

- under construction
- or planned

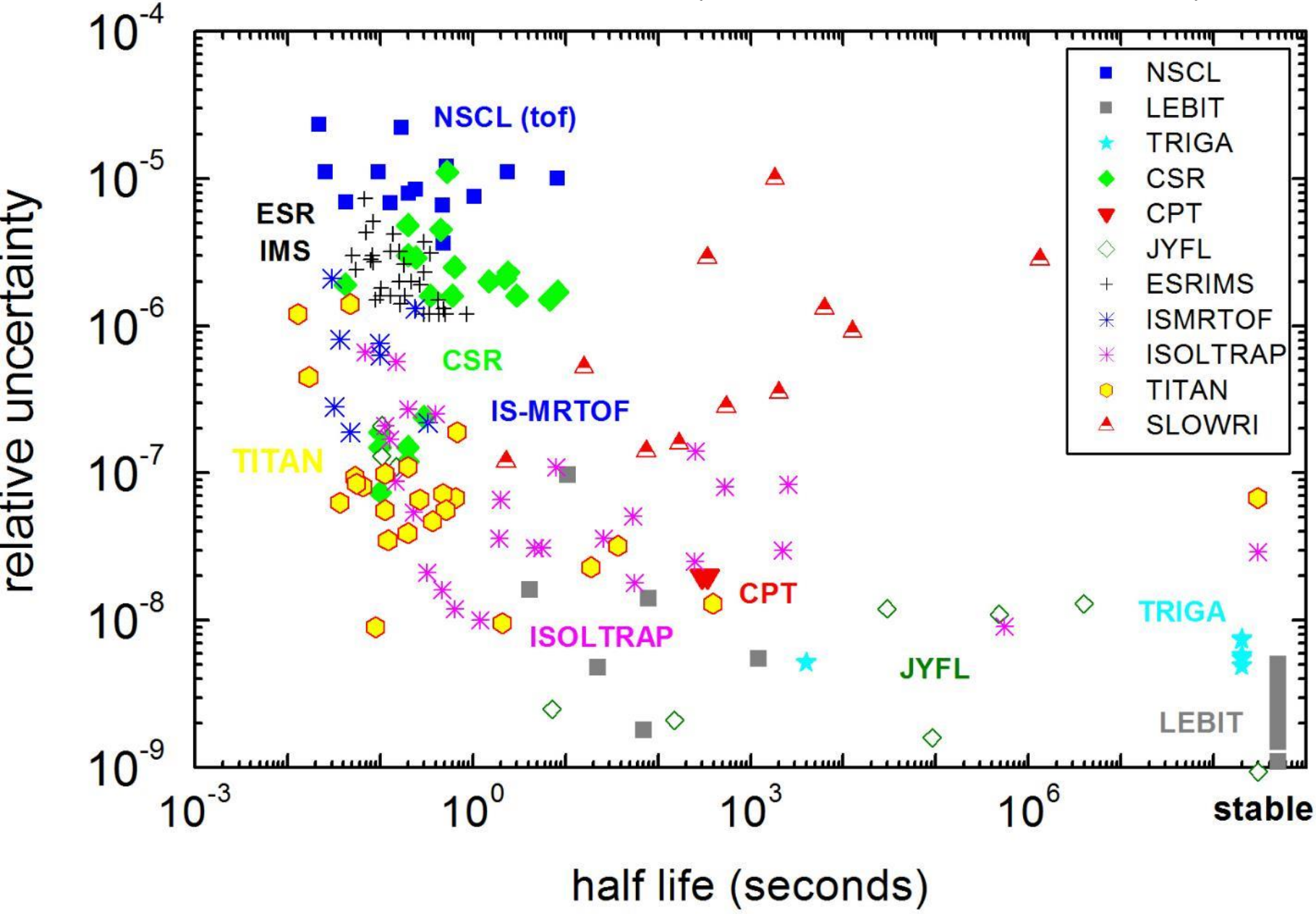
# Direct Mass Measurement Programs Worldwide

In-flight ISOL/gaswerks Future




See also: Special 100-year MS issue; Int. J. Mass Spec. 340-350 (2013)

# ARIS 2017 (since ARIS 2014)



2007

# ISOLTRAP has Many Fathers.
# Mainly Students!

| | | |
|---|---|---|
| 12 old diploma thesis x 2 years | ≈ | 24 years |
| 7 new diploma thesis x 1 years | ≈ | 7 years |
| 27 finished PhD theses x 3 years | ≈ | 81 years |
| 4 PhD theses on its track x 1.5 years | ≈ | 6 years |
| Scientific visitor & postdoc years | ≈ | 6 years |
| Total effort | ≈ | 142 years |

esis
er Ionenoptik zur Massenmessung an instabilen

berg-Universität

esis
ung in einer Penningfalle
Johannes Gutenberg-Universität
Mainz, Germany

1988 Diploma Thesis
Aufbau und Test einer Apparatur zur präzisen Massenbestimmu
F. Kern
Johannes Gutenberg-Universität
Mainz, Germany

1986 PhD Thesis
Aufbau und Test einer Apparatur zur direkten Massenbestimmung kurzlebiger Isotope
H. Schnatz
Johannes Gutenberg-Universität
Mainz, Germany

1987 Diploma Thesis
Aufbau und Test einer Apparatur zur direkten Massenbestimmung kurzlebiger Isotope am on-line Massenseparator ISOLDE/CERN
H. Stolzenberg

1988 Diplom
Untersuchu
Penningfalle
K. Kunz
Johannes G
Mainz, Germ
Mainz, Germ

1989 Diplom
Massensele
U. Wiess
Johannes G
Mainz, Germ

1989 PhD T
Erste Masse
Penningfalle
G. Bollen
Johannes G
Mainz, Germ

1989 PhD T
Massenbest
Experiments
F. Kern
Johannes G
Mainz, Germ

1991 Diplom
Massenspektrometrische Auflösung von Isomer und Grundzustand in der Penningfalle und Untersuchungen zur Coulombwechselwirkung gespeicherter Ionen
M. König
Johannes Gutenberg-Universität
Mainz, Germany

1992 PhD Thesis
Präzisionsmassenbestimmung instabiler Cäsium- und Bariumisotope mit Hilfe einer Penningfalle
H. Stolzenberg
Johannes Gutenberg-Universität
Mainz, Germany

1993 PhD Thesis
Penningfallen-Massenspektrometrie an neutronenarmen Rubidium und Strontiumisotopen
T. Otto
Johannes Gutenberg-Universität
Mainz, Germany

1993 Diploma Thesis
Präzisionsmassenspektrometrie in der Penningfalle
J. Emmes
Johannes Gutenberg-Universität
Mainz, Germany

1993 Diploma Thesis
Aufbau einer zylindrischen Penningfalle [illegible] und Kühlen von Ionen
D. Beck
Johannes Gutenberg-Universität
Mainz, Germany

1994 Diploma Thesis
Aufbau [illegible] Laserdesorptionsquelle für das CERN-Massenexperiment
S. Schwarz
Johannes Gutenberg-Universität
Mainz, Germany

1994 Diploma Thesis
Mainz, Germany

1997 PhD Thesis
Erste direkte Massenmessung radioaktiver Isotope seltener Erden am ISOLTRAP-Experiment
E. Schark
Johannes Gutenberg-Universität
Mainz, Germany

1998 PhD Thesis
Manipulation radioaktiver Ionenstrahlen mit Hilfe einer Paulfalle und direkte Massenmessungen an neutronenreichen Quecksilberisotopen mit dem ISOLTRAP-Spektrometer
S. Schwarz
Johannes Gutenberg-Universität
Mainz, Germany

1999 PhD Thesis
Direkte Massenbestimmung in der Bleigegend und Untersuchung eines Starkeffekts in der Penningfalle
A. Kohl
Ruprecht-Karls-Universität
Heidelberg, Germany

2001 PhD Thesis
Piégeage et refroidissement d'ions exotiques pour la mesure de masse
S. Henry
Université Louis Pasteur
Strasbourg, France

2001 PhD Thesis
Direct mass measurements on exotic nuclei with SHIPTRAP and ISOLTRAP
J. Dilling
Ruprecht-Karls-Universität
Heidelberg, Germany

2001 PhD Thesis
A new ion beam cooler and buncher for ISOLTRAP and mass measurements of radioactive argon isotopes
F. Herfurth
Ruprecht-Karls-Universität
Heidelberg, Germany

2001 PhD Thesis
A study of the accuracy of the Penning trap mass spectrometer ISOLTRAP and standard-model tests with superallowed beta decays
A. Kellerbauer
Ruprecht-Karls-Universität
Heidelberg, Germany

Valencia, Spain

2003 PhD Thesis
Massenspektrometrie kurzlebiger Sr- und Sn-Isotope und Aufbau der SHIPTRAP-Penningfallen
G. Sikler
Ruprecht-Karls-Universität
Heidelberg, Germany

2003 Diploma Thesis
Simulation et caractérisation d'un détecteur Channeltron pour des mesures de masse au CERN avec ISOLTRAP
C. Yazidjian
ENSI de Caen et Université de Caen
Caen, France

2004 Diploma Thesis
Améliorations des performances d'ISOLTRAP
F. Carrel
ENSI de Caen et Université de Caen
Caen, France

2004 PhD Thesis
The mass of 22Mg and a concept for a novel laser ion source trap
M. Mukherjee
Ruprecht-Karls-Universität
Heidelberg, Germany

2004 PhD Thesis
Konzeption eines kryogenen Penningfallenaufbaus für SHIPTRAP und Massenbestimmung von Radionukliden um den Z=82–Schalenabschluss an ISOLTRAP
C. Weber
Ruprecht-Karls-Universität
Heidelberg, Germany

2005 PhD Thesis
Optimized ion trapping of exotic nuclides for mass measurements in the N=40 (magic?) region

du champ magnétique dans le piège à ions de précision d'ISOLTRAP au CERN
M. Marie-Jeanne
ENSI de Caen et Université de Caen
Caen, France

2006 Diploma Thesis
Optimierung der Zyklotronfrequenzbestimmung und Hochpräzisionsmassenmessungen an neutronenreichen Zinnisotopen mit ISOLTRAP
M. Dworschak
Bayerische Julius-Maximilians-Universität
Würzburg, Germany

2006 PhD Thesis
A new detector setup for ISOLTRAP and test of the isobaric multiplet mass equation
C. Yazidjian
Université de Caen
Caen, France

| Year | Name | Thesis title |
|---|---|---|
| 1986 | H. Schnatz | Design and testing of equipment for direct mass measurement of short-lived nuclides |
| 1989 | F. Kern | Development of experiment control, data analysis and mass determination of radioactive Cs isotopes |
| 1989 | G. Bollen | First mass measurement on unstable isotopes using a Penning trap |
| 1992 | G. Rouleau | A tandem Paul-Penning trap mass measurement system for radionuclides |
| | H. Stolzenberg | Precision mass determination of unstable isotopes cesium and barium using a Penning trap |
| 1993 | T. Otto | Penning trap mass spectrometry of neutron-deficient rubidium and strontium isotopes |
| 1994 | H. Raimbault-Hartmann | Precision mass determination of neutron-rich rubidium and strontium isotopes and development and testing of a new concept for ion accumulation and cooling for ISOLTRAP |
| 1995 | M. Koenig | Precision mass determination of unstable isotopes of Cs & Ba in a Penning trap and investigation of azimuthal-quadrupole ion excitation |
| 1997 | D. Beck | Mass determination of unstable isotopes of the rare earths to $^{146}$Gd with the ISOLTRAP spectrometer |
| | E. Schark | |
| 1998 | S. Schwarz | |
| 1999 | A. Kohl | |
| 2001 | F. Herfurth | |
| 2001 | J. Dilling | |
| | S. Henry | |
| 2002 | A. Kellerbauer | |
| 2003 | G. Sikler | |
| | D. Rodriquez | |
| 2004 | C. Weber | |
| | M. Mukherjee | |
| 2005 | C. Guénaut | |
| | S. Rahaman | |
| 2006 | C. Yazidjian | |
| 2008 | S. Baruah | Precision mass measurements on neutron-rich Zn isotopes and their consequences on the astrophysical r-process |
| 2009 | M. Breitenfeldt | Mass measurements on short-lived Cd and Ag nuclides at the online mass spectrometer ISOLTRAP |
| | S. George | First Ramsey-type mass measurements with ISOLTRAP and design studies of the new PENTATRAP project |
| 2010 | S. Naimi | Onsets of nuclear deformation from measurements with the ISOLTRAP mass spectrometer |
| | D. Neidherr | Nuclear structure studies in the xenon and radon region and the discovery of a new radon isotope by Penning trap mass spectrometry |
| 2012 | C. Borgmann | Mass measurements of exotic ions in the heavy mass region for nuclear structure studies at ISOLTRAP |
| 2013 | J. Stanja | Synergy of decay spectroscopy and mass spectrometry for the study of exotic nuclides |
| | R. Wolf | First on-line applications of a multi-reflection time-of-flight mass separator at ISOLTRAP and the mass measurement of $^{82}$Zn |
| 2014 | V. Manea | Penning-trap mass measurements of exotic rubidium and gold isotopes for a mean-field study of pairing and quadrupole correlations |
| 2015 | C. Boehm | High-precision masses of n-deficient Tl isotopes at ISOLTRAP & development of an ultra-stable voltage source for PENTATRAP |
| 2016 | M. Rosenbusch | Development of new ion-separation techniques and the first mass measurement of $^{52,53}$K |
| | D. Atanasov | Precision mass measurements for studies of nucleosynthesis via the rapid neutron-capture process |
| 2017 | A. Welker | Phase-imaging ion cyclotron resonance for ISOLTRAP and mass measurements of exotic copper |
| | F. Wienholtz | How to procrastinate the writing of a doctoral thesis after publishing an article in Nature magazine |
| | N. Althubiti | Decay spectroscopy and mass spectrometry of neutron-deficient polonium isomeric states |
| 2018 | M. Mougeot | Nuclear collectivity studied by high-performance mass spectrometry |

| | | |
|---|---|---|
| Total (2007) | ≈ | 142 years |
| 13 finished PhD theses x 3 years | ≈ | 39 years |
| 3 PhD theses ongoing x 2 years | ≈ | 6 years |
| Scientific visitor & postdoc years | ≈ | 12 years |
| Total (2017) | ≈ | 199 years! |


physic-club.ch

# ISOLTRAP Collaboration Meeting, Heidelberg (2017)


Missing: Burcu, Numa, Enrique, Sergey, Yuri, Frank H., Kai (!)


Zum Jubiläum
ISOL
TRAP
30


ISOL
TRAP
30

International Journal of Mass Spectrometry 349–350 (2013) 26–37

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International Journal of Mass Spectrometry

journal homepage: www.elsevier.com/locate/ijms

# Penning trap mass spectrometry of radionuclides

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[b] Universität Heidelberg, D-69117 Heidelberg, Germany

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Radioactive nuclei
Ion beam manipulation

ABSTRACT

Trapping and cooling techniques play an increasingly impo
lication focuses on high-accuracy mass spectrometry of r
storing and cooling is also essential. The pioneering set-u
radioactive-beam facility was ISOLTRAP, still in operation
tope separator ISOLDE at CERN. This publication describes
as a high-performance mass spectrometer. In the meantin
spectrometry of short-lived nuclei became very popular so
nearly all radioactivebeam facilities worldwide.

IOP Publishing — Journal of Physics G: Nuclear and Particle Physics

J. Phys. G: Nucl. Part. Phys. **44** (2017) 064008 (18pp) https://doi.org/10.1088/1361-6471/aa6752

ISOLDE Laboratory Portrait

# Extending and refining the nuclear mass surface with ISOLTRAP

D Lunney (on behalf of the ISOLTRAP Collaboration)

CSNSM-IN2P3/CNRS, Université de Paris Sud, Orsay, France

E-mail: david.lunney@csnsm.in2p3.fr

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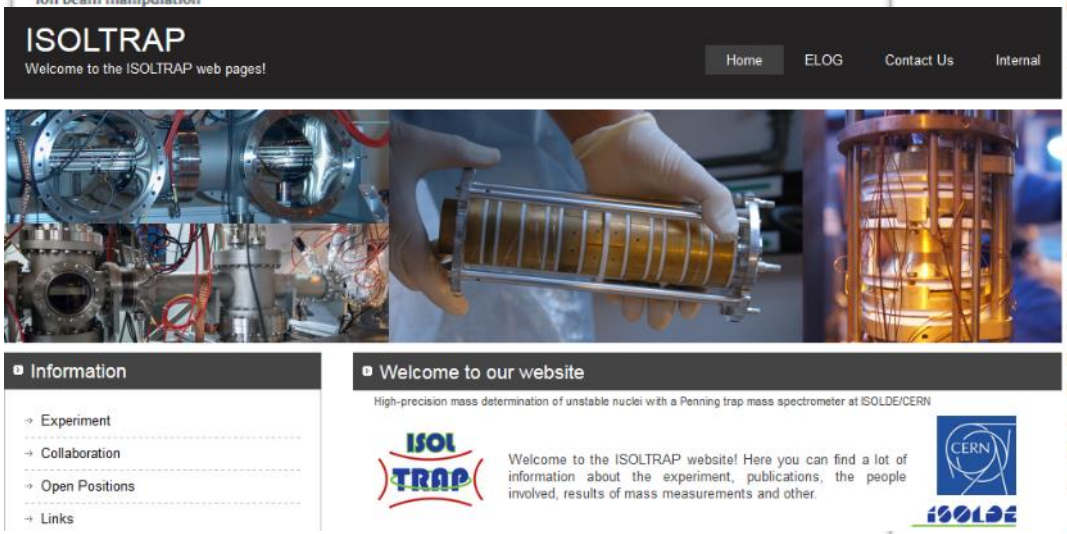
Accepted for publication 17 March 2017
Published 3 May 2017

**Abstract**

The Penning-trap mass spectrometer ISOLTRAP has received ISOLDE beams for the past 30 years! Following the move of ISOLDE to the proton-synchrotron booster site, ISOLTRAP has pioneered almost all of the techniques now associated with on-line ion trapping and manipulation for precision measurements of atomic masses. After an introduction on physics motivation, a brief history and description of the ISOLTRAP spectrometer is given, followed by an overview of the numerous developments and scientific results achieved since the previous ISOLDE Laboratory Portrait.

Keywords: nuclear physics, mass spectrometry, ion trapping, trans-plutonian planets




http://isoltrap.web.cern.ch

# H.- Jürgen Kluge with D. Lunney

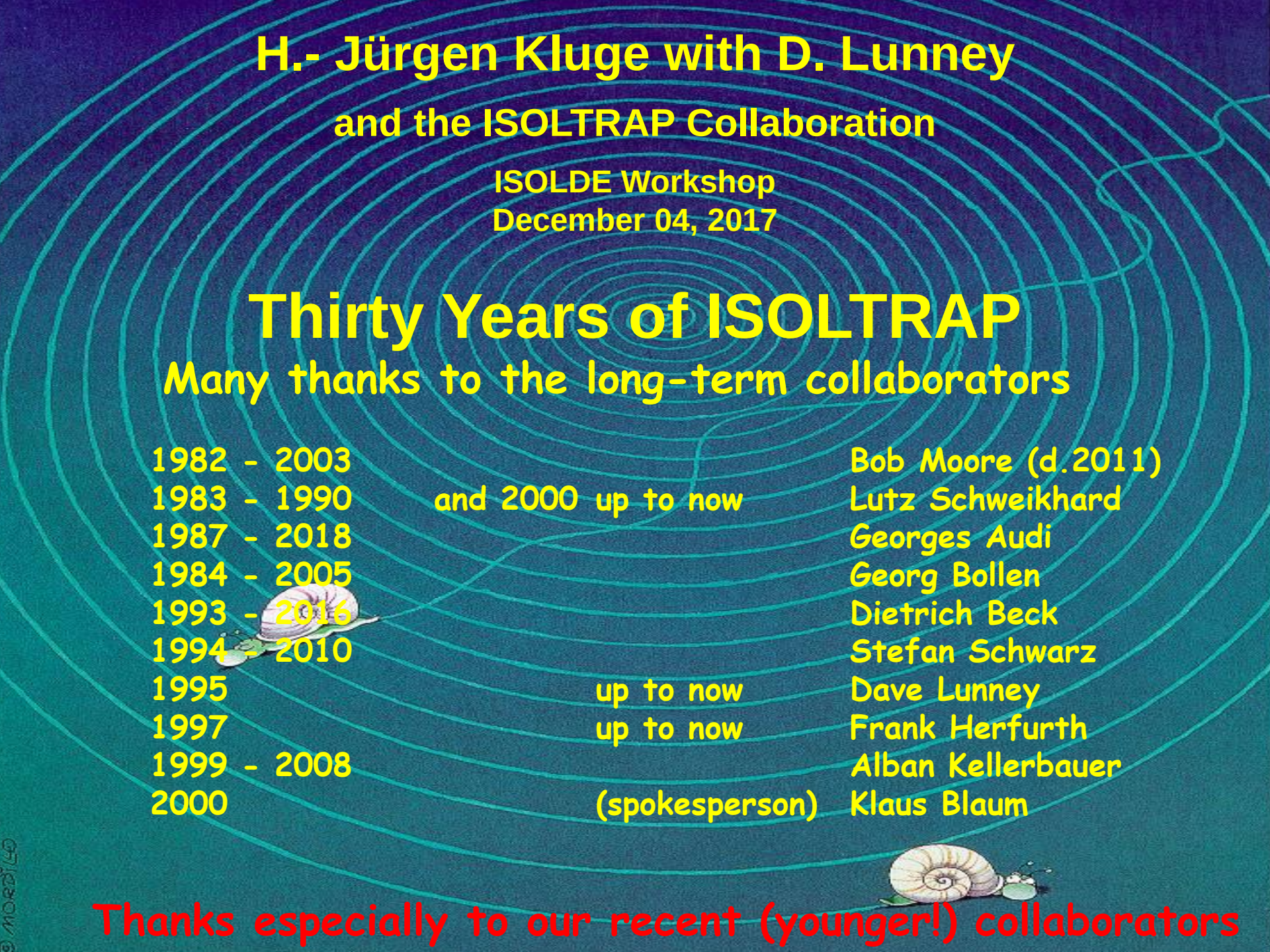
## and the ISOLTRAP Collaboration

ISOLDE Workshop
December 04, 2017

# Thirty Years of ISOLTRAP

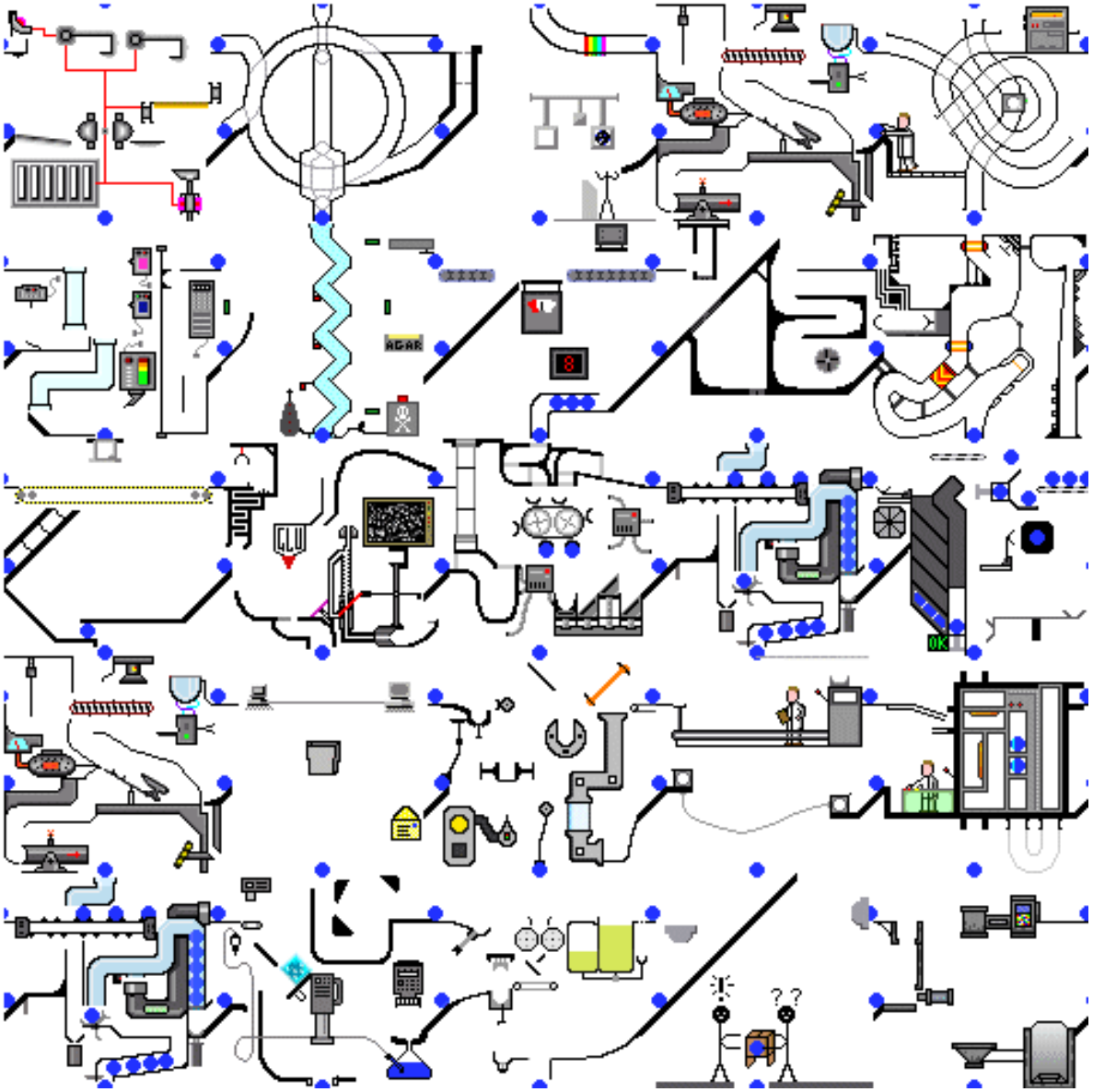
## Many thanks to the long-term collaborators

| | | |
|---|---|---|
| 1982 - 2003 | | Bob Moore (d.2011) |
| 1983 - 1990 | and 2000 up to now | Lutz Schweikhard |
| 1987 - 2018 | | Georges Audi |
| 1984 - 2005 | | Georg Bollen |
| 1993 - 2016 | | Dietrich Beck |
| 1994 - 2010 | | Stefan Schwarz |
| 1995 | up to now | Dave Lunney |
| 1997 | up to now | Frank Herfurth |
| 1999 - 2008 | | Alban Kellerbauer |
| 2000 | (spokesperson) | Klaus Blaum |



Thanks especially to our recent (younger!) collaborators

# ISOLTRAP – for the public (and spectroscopists…)



Thank you (for your patience)!