Mass separation and mass measurement capabilities/opportunities with PILGRIM

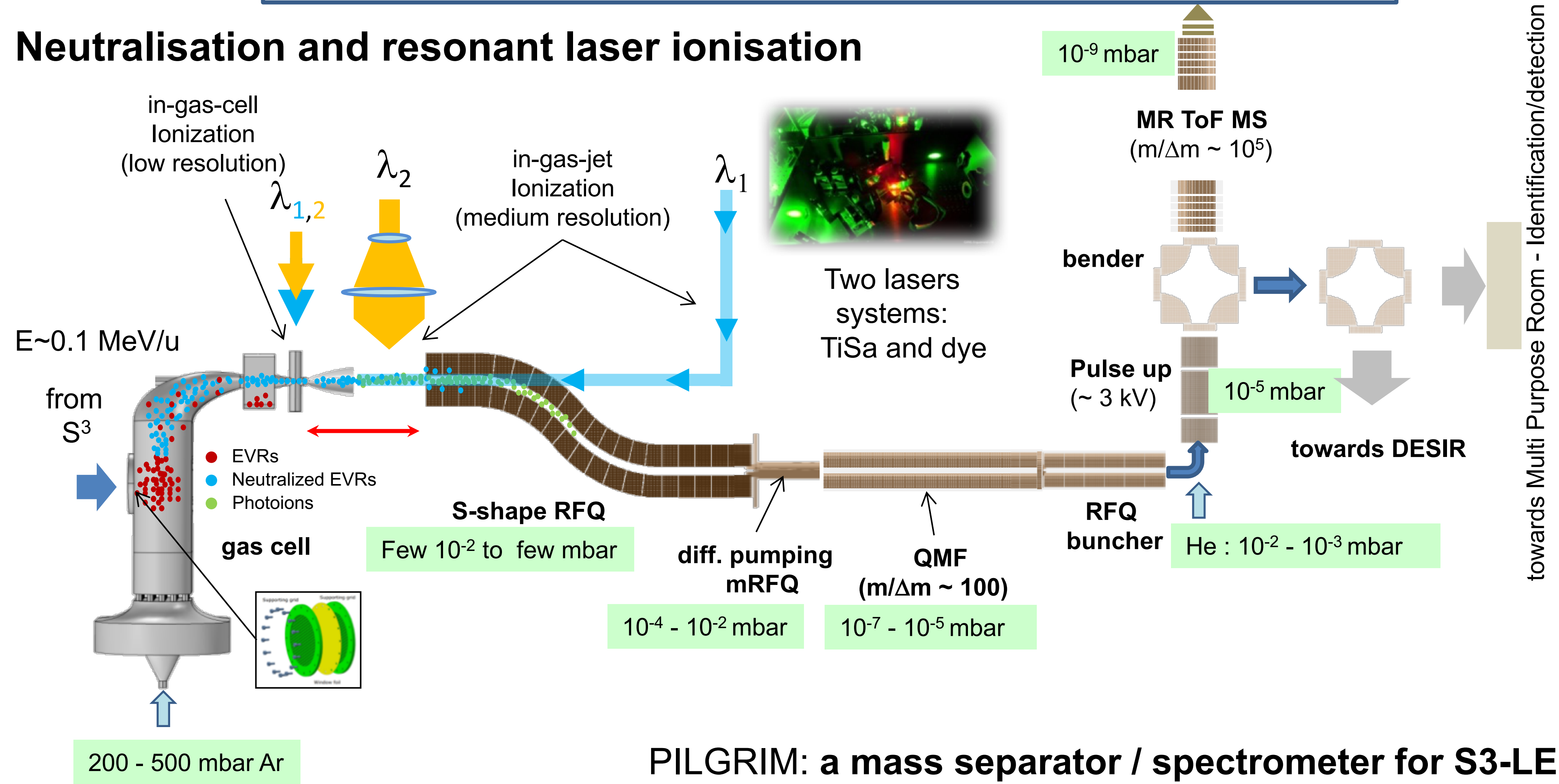
P. Delahaye

S3 physics workshop, Saclay, 2017/03/27

S³-LEB @ SPIRAL2

(Gas cell studies, laser system) — KU Leuven
(Gas cell) — IPN Orsay
(RFQs) — LPC Caen
(mr-TOF-ms, laser system, infractructure, safety) — GANIL
(narrow band-width laser pre-studies at MARA) — LARISSA, JGU, University of Jyväskylä

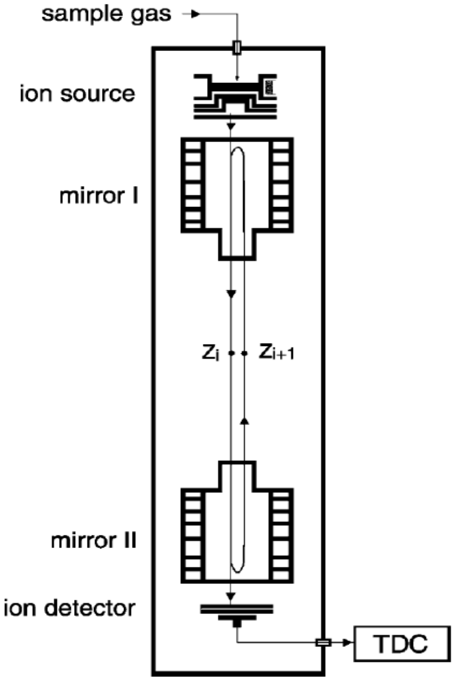
Neutralisation and resonant laser ionisation



PILGRIM: **a mass separator / spectrometer for S3-LEB**

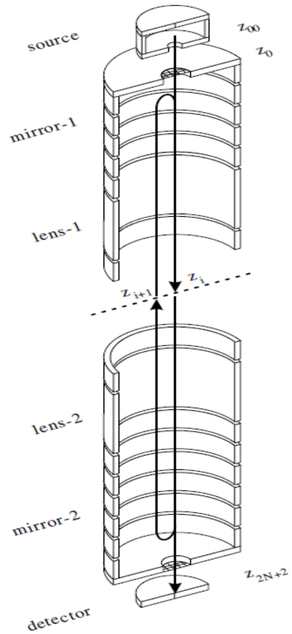
MR ToF MS : rapid history

1990 - 2003:
Original idea



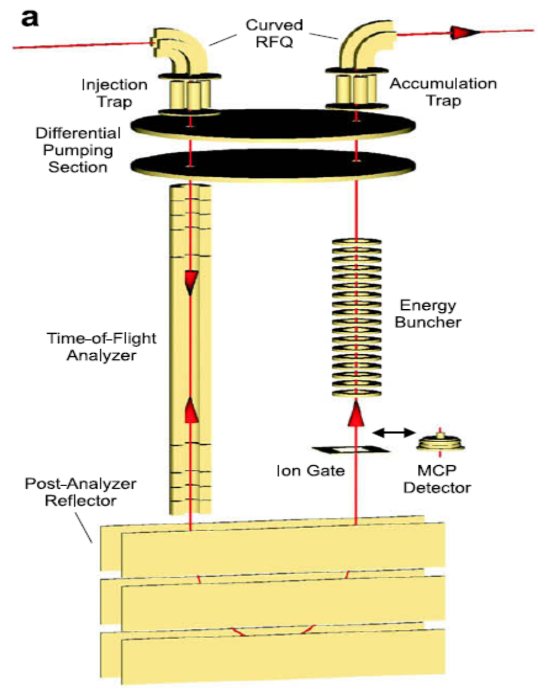
H. Wollnik and A. Casares, Int. J. Mass. Spectrom. **227**, 217 (2003)

2004-2008:
Proof of principle



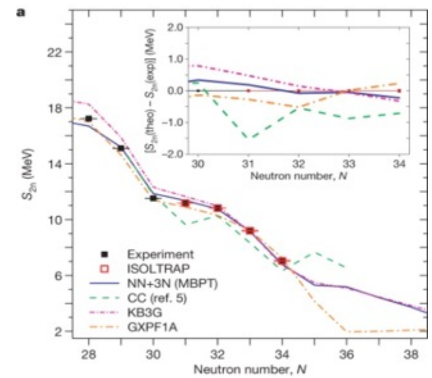
Y. Ishida *et al.*, NIM B **219-220**, 468 (2004)
H. Wollnik *et al.*, NIM A **519**, 373 (2004)
A. Piechaczek *et al.*, NIM B **266**, 4510 (2008)

2007-…
Optimization



W. R. Plaß *et al.*, NIM B **266**, 4560 (2008)
W. R. Plaß *et al.*, Eur. Phys. J. Special Topics **150**, 367 (2007)

2012
Physics results!



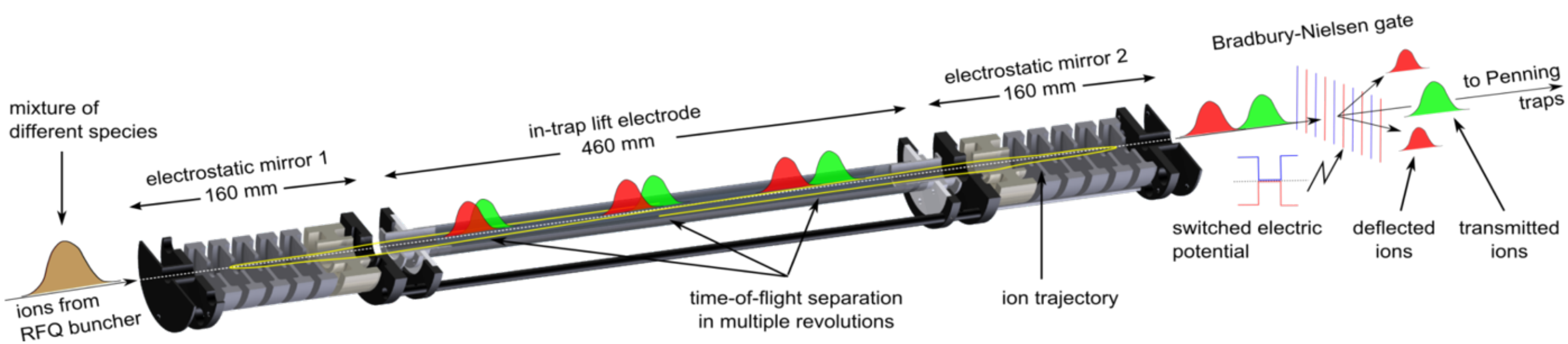
ISOLTRAP
Masses of $^{53,54}Ca$ measured with 10^{-6} accuracy
N=32 is a shell closure

F. Wienholtz et al., Nature **498** (2013) 346-349

MR ToF MS principle

- Multi-Reflection Time of Flight Mass Spectrometer
  - Two ion optical mirrors, connected through a pulsed drift tube
  - A time of flight focus can be realized inside the trap: the revolution time only depends on the mass and not on the energy
- ISOLTRAP MR-ToF-MS

R= M/δM= t/2δt



Photograph Courtesy : R. N. Wolf (University of Greifswald)

Collaboration with Greifswald University

PhD thesis *Pierre Chauveau*

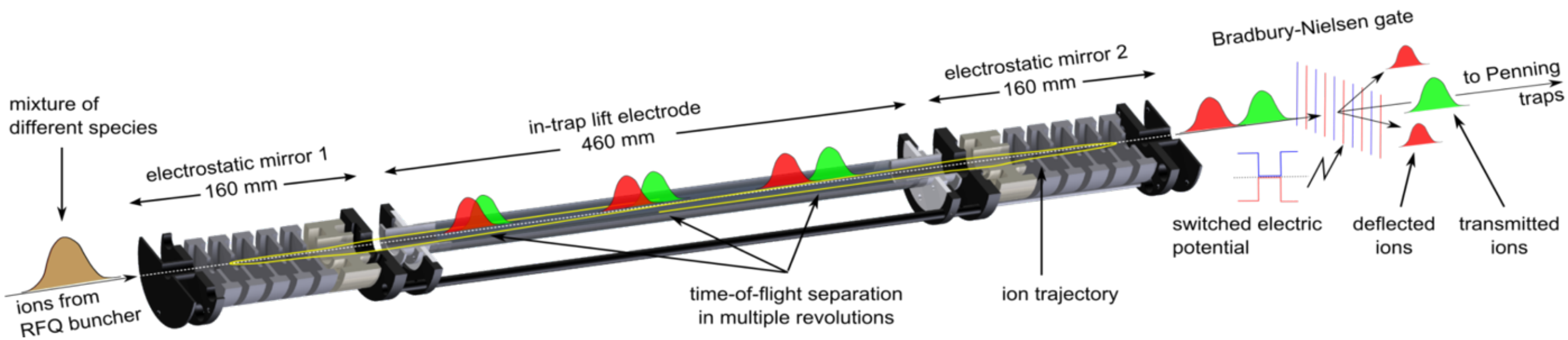
MR ToF MS performances

- Typical trapping time: 10-100 ms
- Resolving power: up to x·10^5
- Mass measurement: $\delta m/m \sim 5 \cdot 10^{-7}$

for intensities down to fractions of pps

ISOLTRAP MR ToF MS:
R. Wolf et al., IJMS 349 (2013)123 and ref therein

$^{53-54}$Ca mass measurements:
F. Wienholtz et al., Nature **498** (2013) 346-349

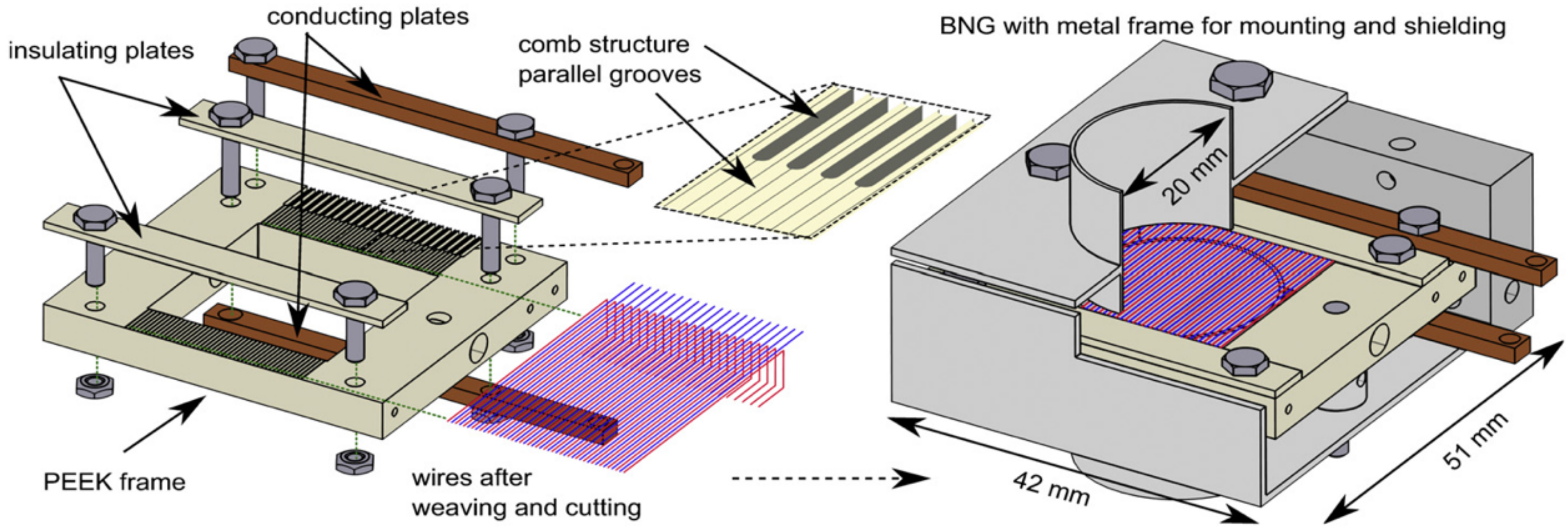


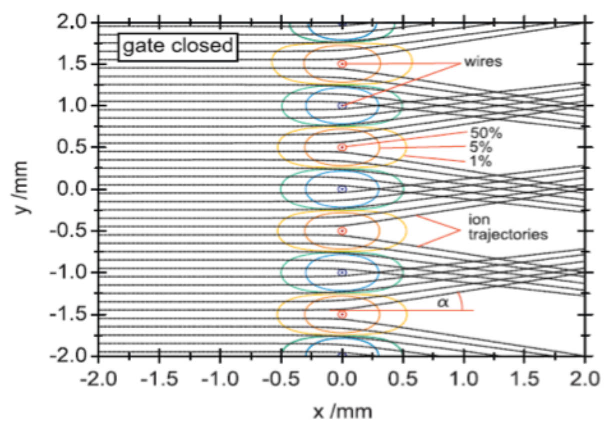
Photograph Courtesy : R. N. Wolf (University of Greifswald)

Such performances require
- Cooled and bunched beams, with δt <100ns
- High vacuum (<10^{-8} mbar)
- High precision and stability voltage supplies

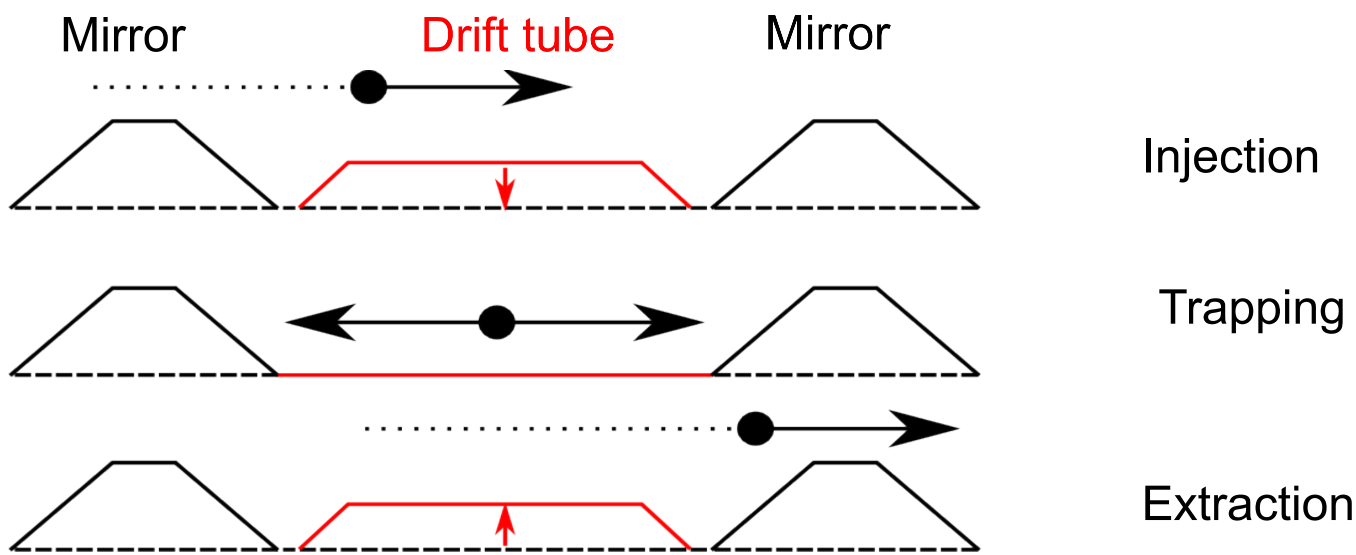
Bradbury-Nielsen Gate

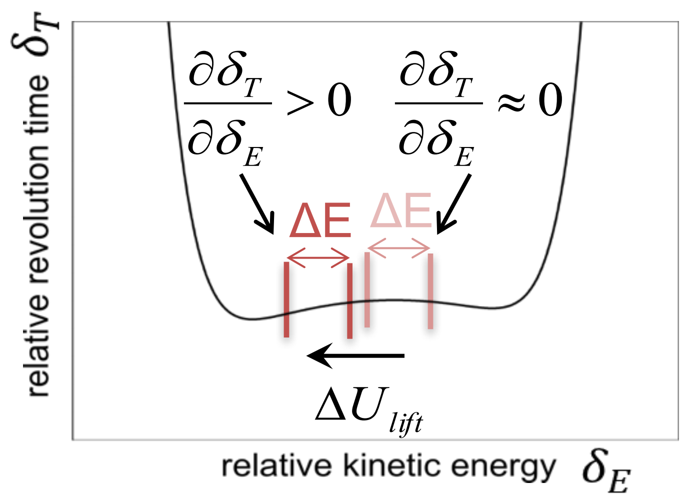
- See eg Wolf, NIM A 686(2012)82





In-trap lift





Control of the time focus!

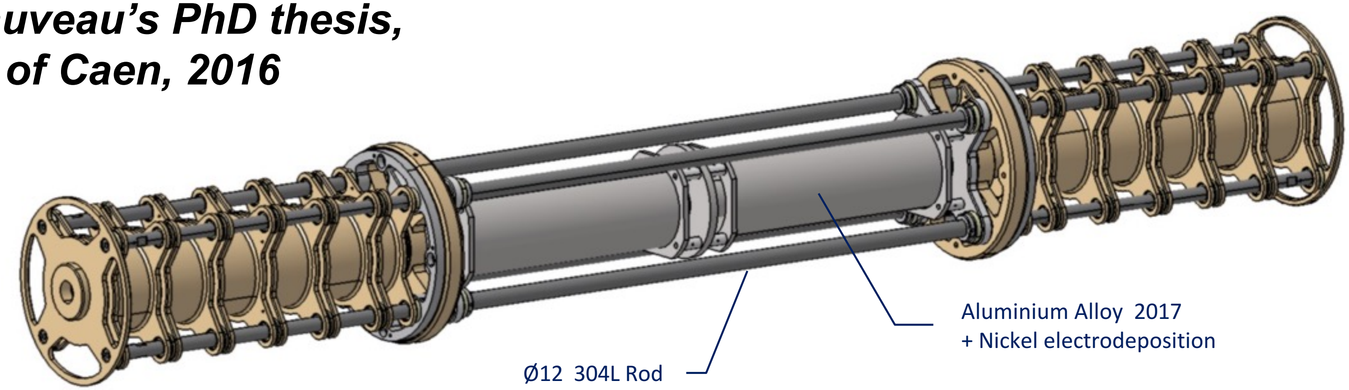
R. Wolf et al., IJMS 313(2012)8

Time focus
- at BN gate
- at detector

PILGRIM

Piège à Ions Linéaire du Ganil pour la Résolution des Isobares et la mesure de Masse

See P. Chauveau's PhD thesis, University of Caen, 2016



Features:

- Mirrors: hollow tubes configuration *minimizing the optical aberrations*
- Invar rods to support the mirrors *minimizing d(T) variations*
- Large vacuum conductance *minimizing collision spreads P<5e-9 mbar*
- Nickel coated aluminum electrodes *homogeneous potential definition*

Design, simulation and tests (GANIL)
P. Chauveau, P. Delahaye, Y Liu, A. Shornikov

Collaboration with uni – Greifswald
R. Wolf, M. Rosenbusch et L. Schweikhard

Mechanical design and construction, electronics and slow control (LPC Caen)
Y. Merrer, J. Lory, P. Desrues, J. F. com, C. Vandamme, J. Brégeault et F. Boumard

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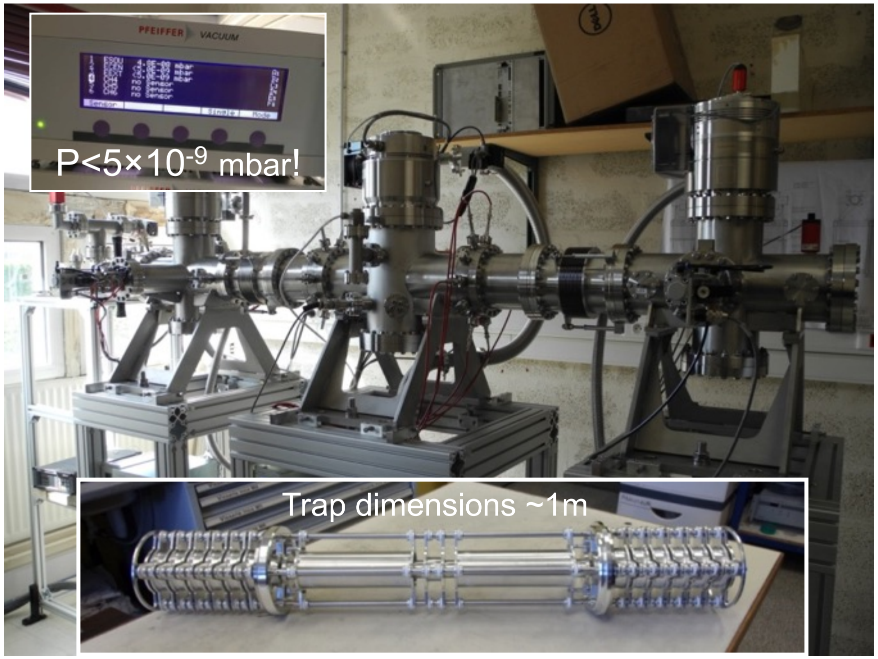

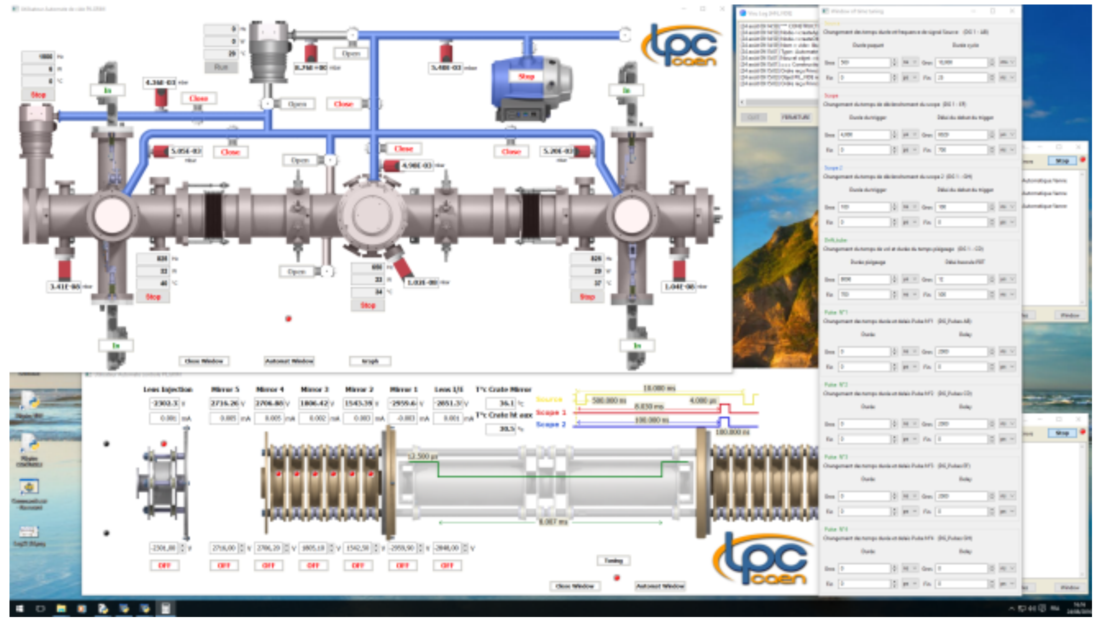

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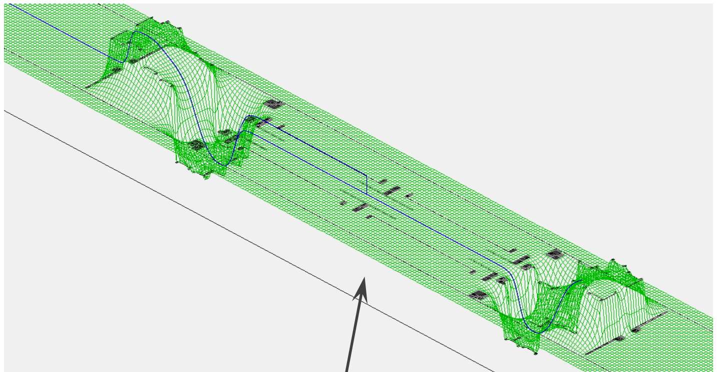
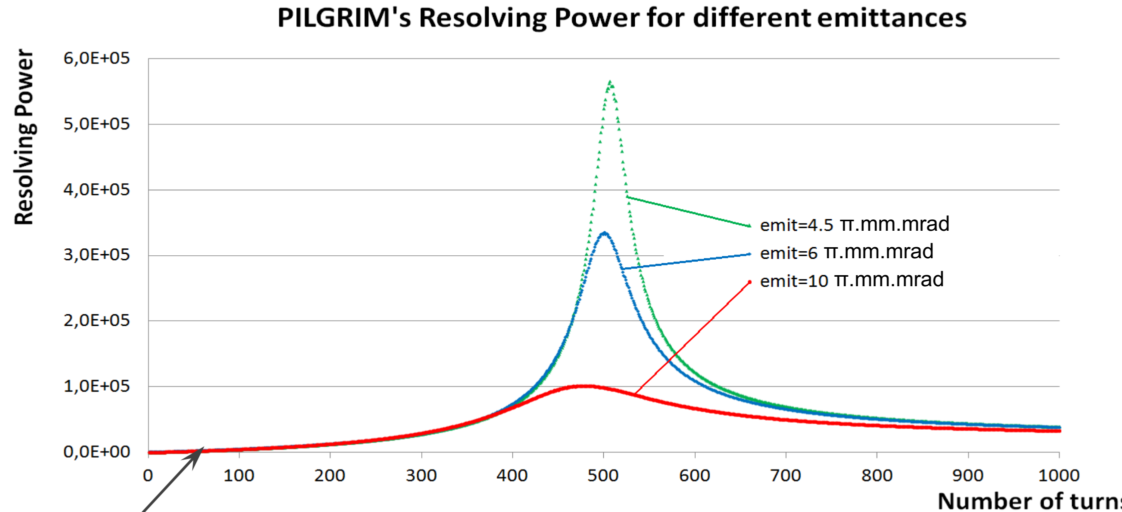
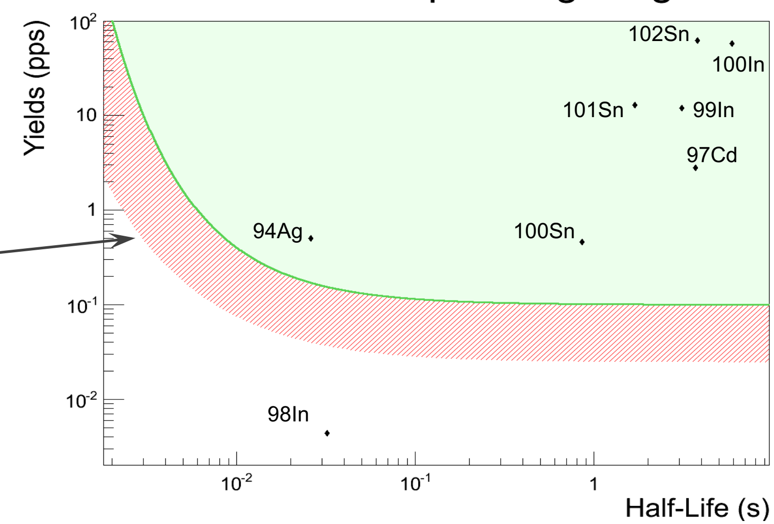
Simulations of PILGRIM





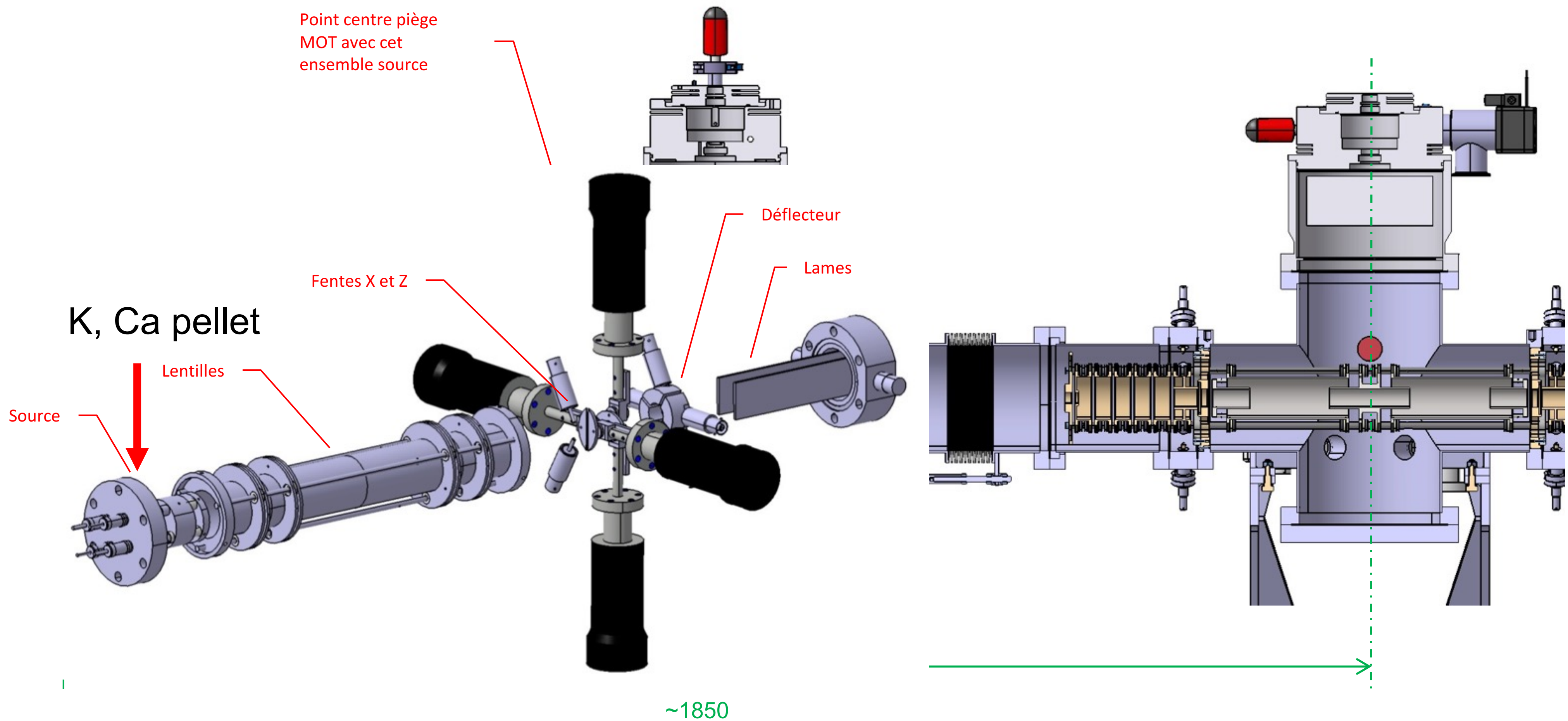
Pierre Chauveau *et al*, EMIS 2015 conference proceeding to be published in NIMB

MR-ToF-MS operating range



- Simulated with SIMION 8.1 without space-charge
- Resolving powers above 300k achieved for realistic emmitances
- Short separation time (≈10-15ms) → wide range of radioactive nuclei accessible
- Precision mass measurement ($x \cdot 10^{-7}$)

First tests of PILGRIM



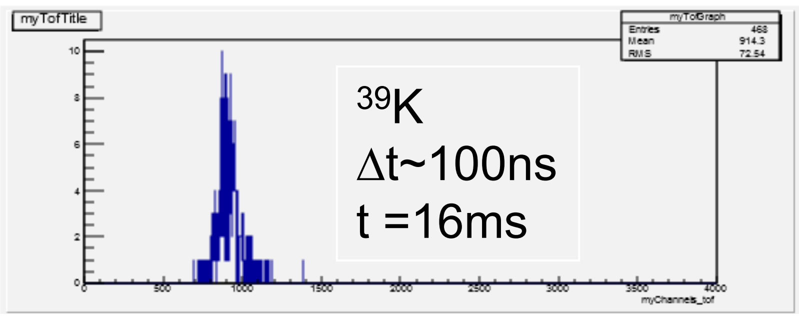
Beam chopping with deflector plate and Behlke switch:
$\delta t \sim 100 ns$
$\delta E \sim 100 eV$

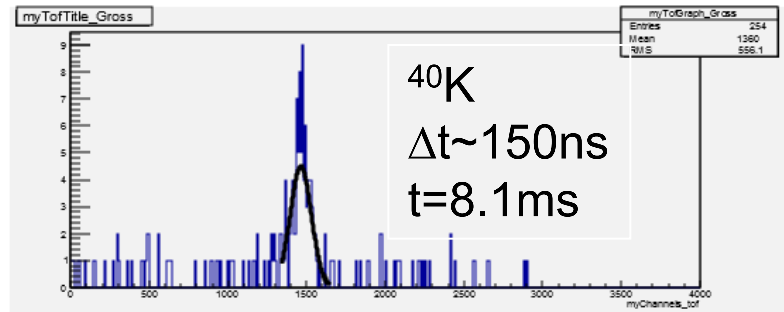
Status

Goals: R>100,000 and $\delta m/m<10^{-6}$

Summer 2016

- R=Δt/(2t)~65,000 in 5 days (!)
- No trapping losses up to t~32ms





Fall of 2016

R is limited because of:

- δE~40eV and θ~1° due to beam chopping induce an increase in Δt with the number of turns
- Large Voltage variations due to large T variations induce ToF variations $\delta t_0 \sim 2.5 \cdot 10^{-5}$ dT(K)

- Beam chopping with a BNGate for δE<10eV, θ=0°

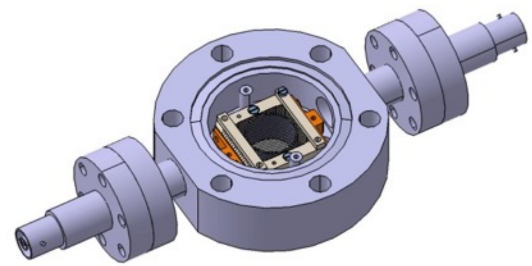
- Temperature controlled electronic rack
- HV supply with T variation active correction

Status

Goals: R>100,000 and $\delta m/m<10^{-6}$

Winter - Spring 2017

BN Gate is being constructed
- J. Lory and J. Perronel



Corrected HV power supplies ordered: delivery end of April

Temperature controlled rack by June
- internship N. Lepoul

➡ **Testing the new resolving power: summer 2017**

Slow control is being modified for mass measurement
- Fast timing switching between reference ion and test ion
- J. Brégeault and F. Boumard

➡ **Testing the mass measurement capacities: Summer – Fall 2017**

Radioactive ion beam commissioning: 2018?

Outlook, conclusions

PILGRIM is almost operational

- Ion trapping without losses during 32ms
- R~65,000 achieved

PhD P. Chauveau

Should become fully operational with

- A BN

Thanks a lot for your attention!

- T controlled rack and T corrected power supplies

Ongoing

- A slow control allowing fast switching between reference masses

Radioactive ion beam commissioning

- Possible as of 2018: LIRAT?
- In 2019 with S3-LEB

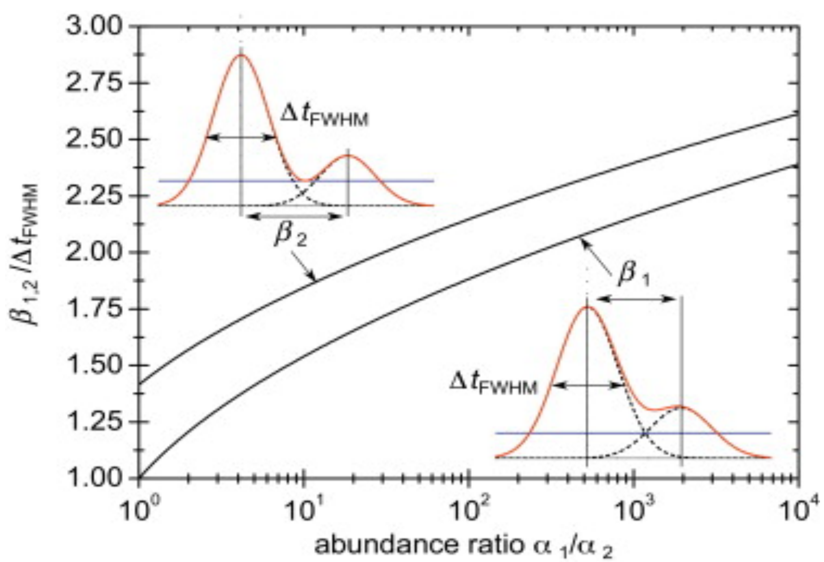
2018-

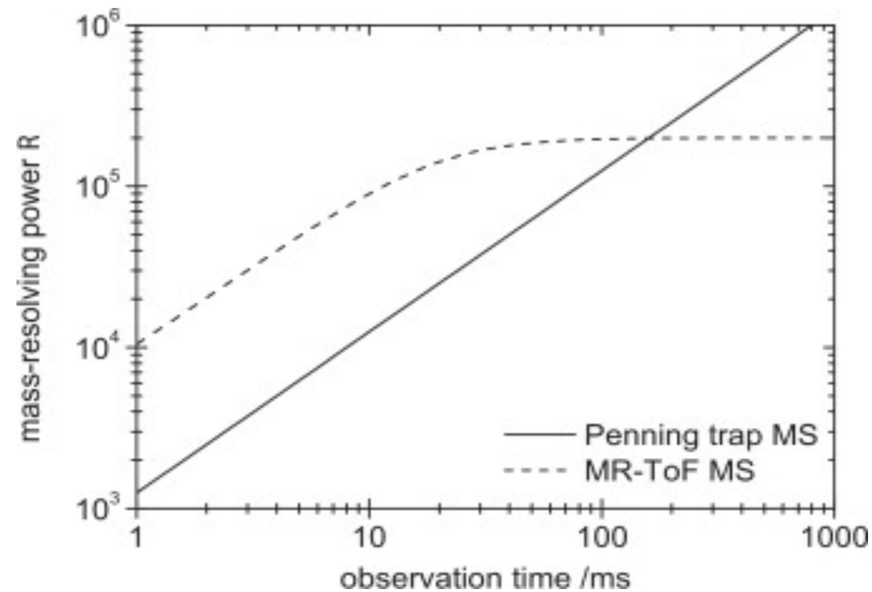
Backup

Mass measurements

Goals: R>100,000 and $\delta m/m<10^{-6}$

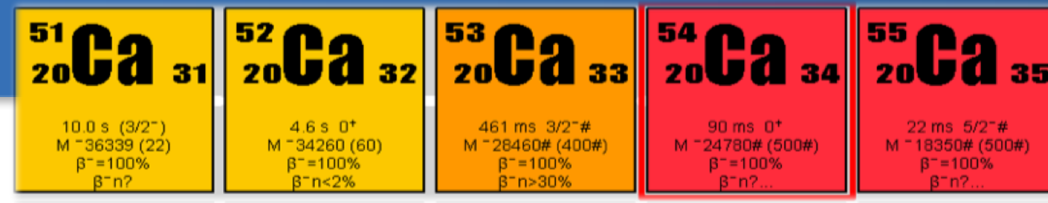
$\beta 12=R(N2=\alpha N1)/R(N2=N1)$





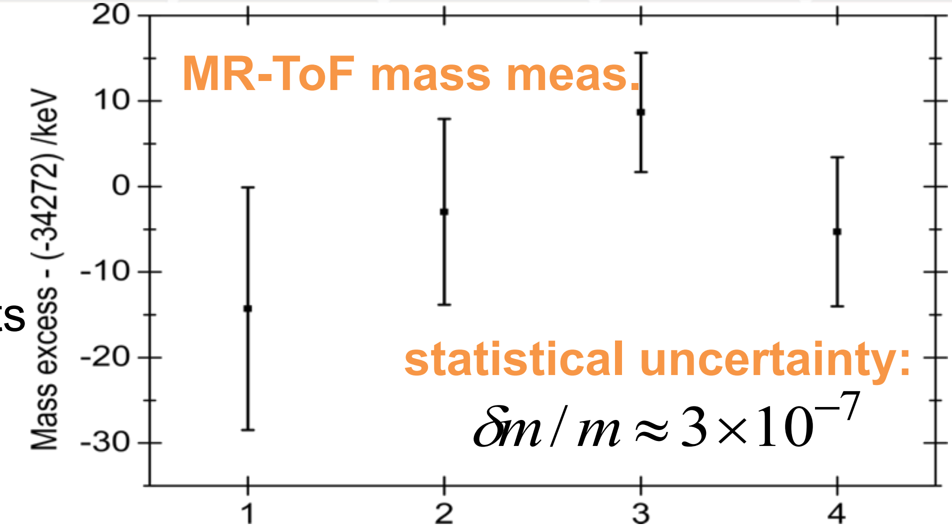
R. Wolf et al., IJMS 349 (2013)123
and ref therein

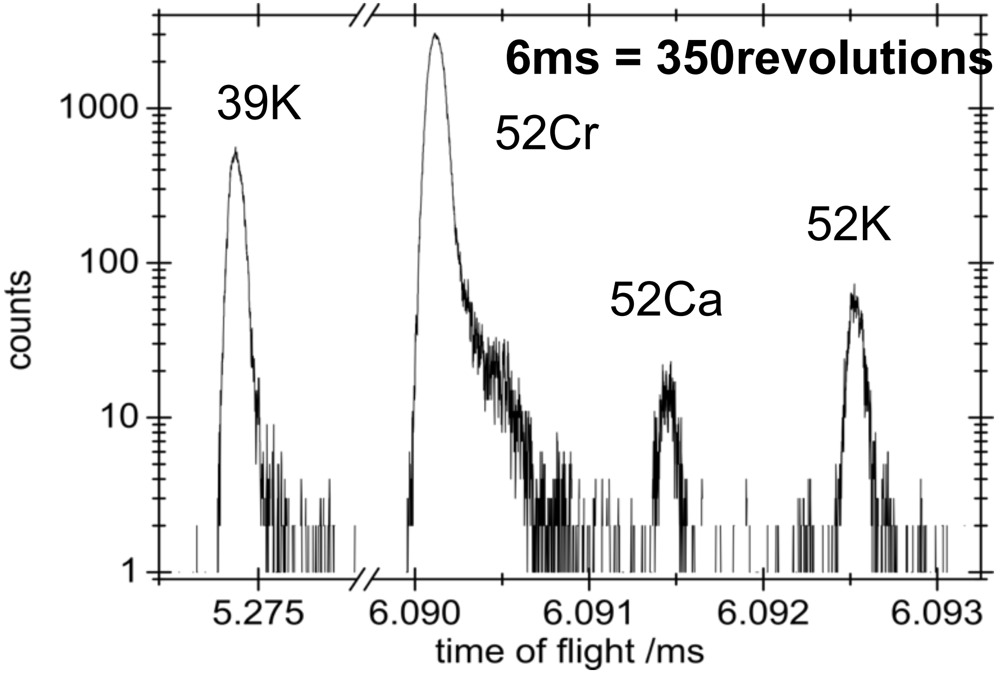
MR-ToF mass spectrometer

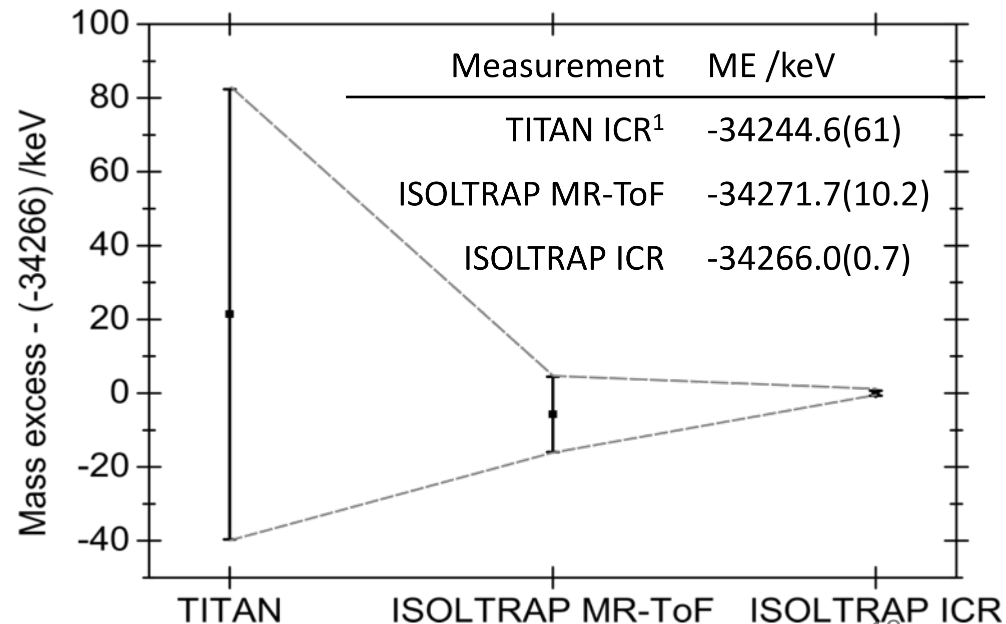


\\ n-rich Calcium isotopes: 52Ca

- TITAN/Triumf measurements of 51,52Ca[(1)]
- ISOLTRAP meas.[2] in agreement with TITAN
- 51,52Ca measured with Penning trap
- 52,53,54Ca measured with MR-ToF-MS
  - ➔ MR-TOF-MS agrees with PT measurements
  - ➔ sub-ppm mass uncertainty





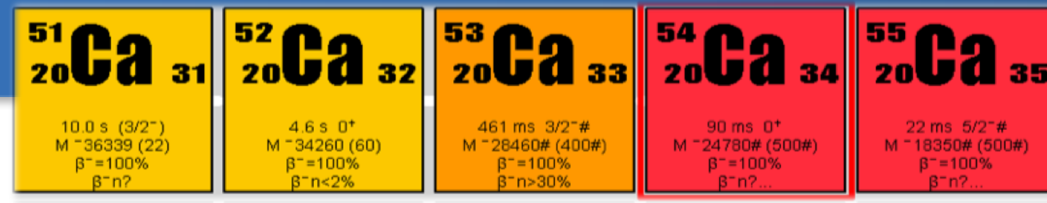


1: Gallant *et al.*, PRL 109, 032506 (2012) 2: Wienholtz *et al.*, in press

Courtesy R. Wolf

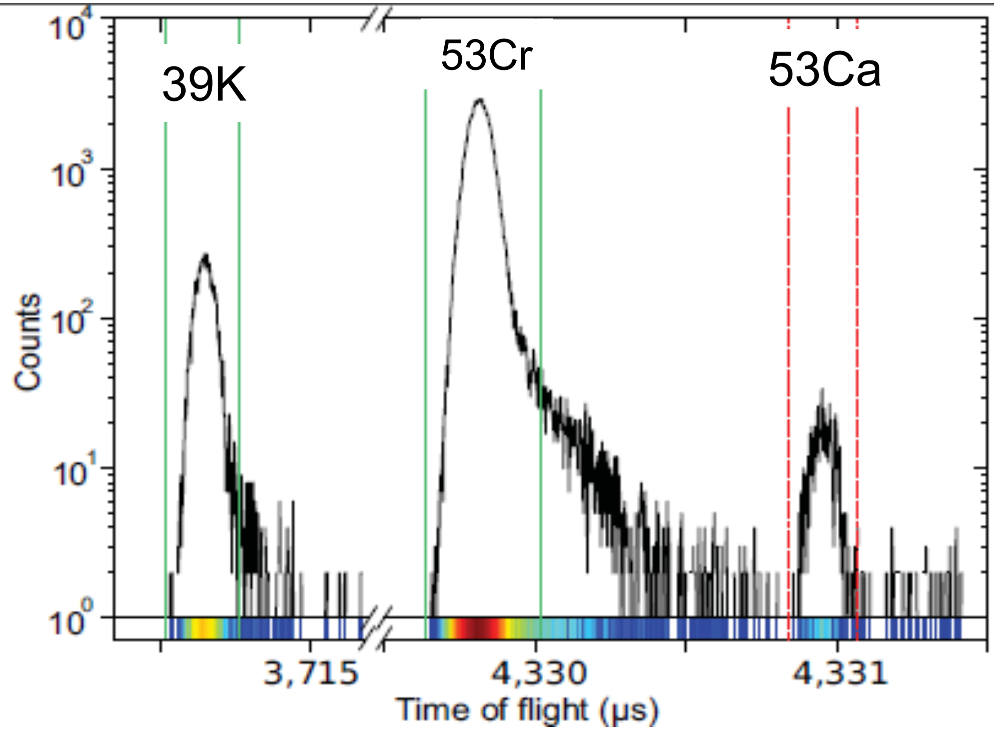
MR-ToF mass spectrometer

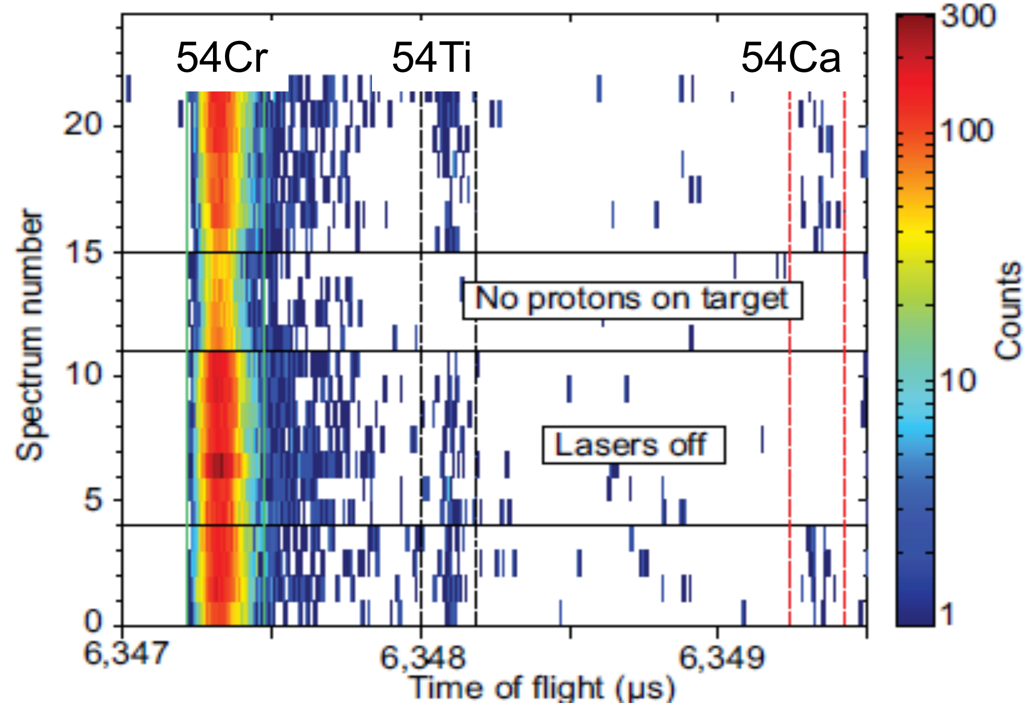
\\ n-rich Calcium isotopes: 53Ca and 54Ca



***A*=53:** measurement cycle ≈ 4ms

***A*=54:** measurement cycle ≈ 6ms





6413 counts/12.6h ➔ 9 counts/minute

2314 counts/18.2h ➔ 2 counts/minute

statistical uncertainty ≈ 45keV ➔ $\delta m/m \approx 9\times10^{-7}$

Kreim *et al.*, INTC-P-317, IS 532 (2011)   Wienholtz *et al.*, in press

Courtesy R. Wolf