TRIUMF

Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

Towards N=82 r-process waiting point: precision atomic mass measurement of $^{125\text{-}127}$Cd

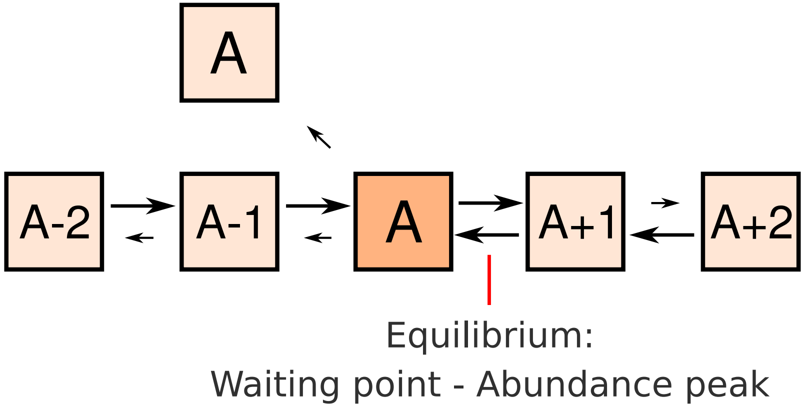
Erich Leistenschneider
for TITAN Collaboration

WNPPC, February 2017

Explosive Nucleosynthesis

r-Process (rapid neutron capture)

Neutron capture (n,γ) competes with photodesintegration (γ,n) and β-decay



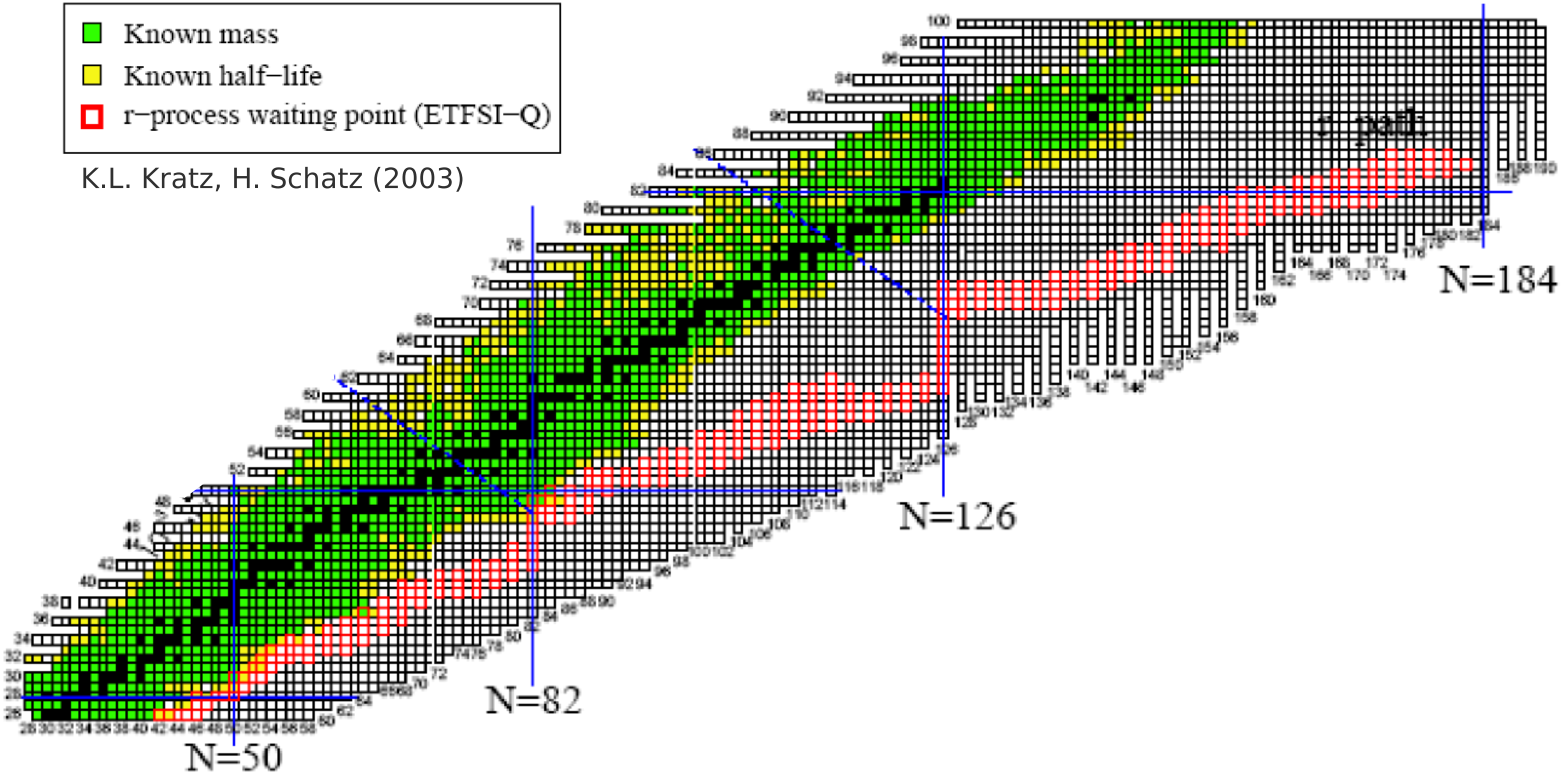
Hot temperatures (~10^9K)

High neutron densities (>10^{20} n/cm^3)

Neutron separation energies required → nuclear masses (~10keV/c^2 precision)

Explosive Nucleosynthesis

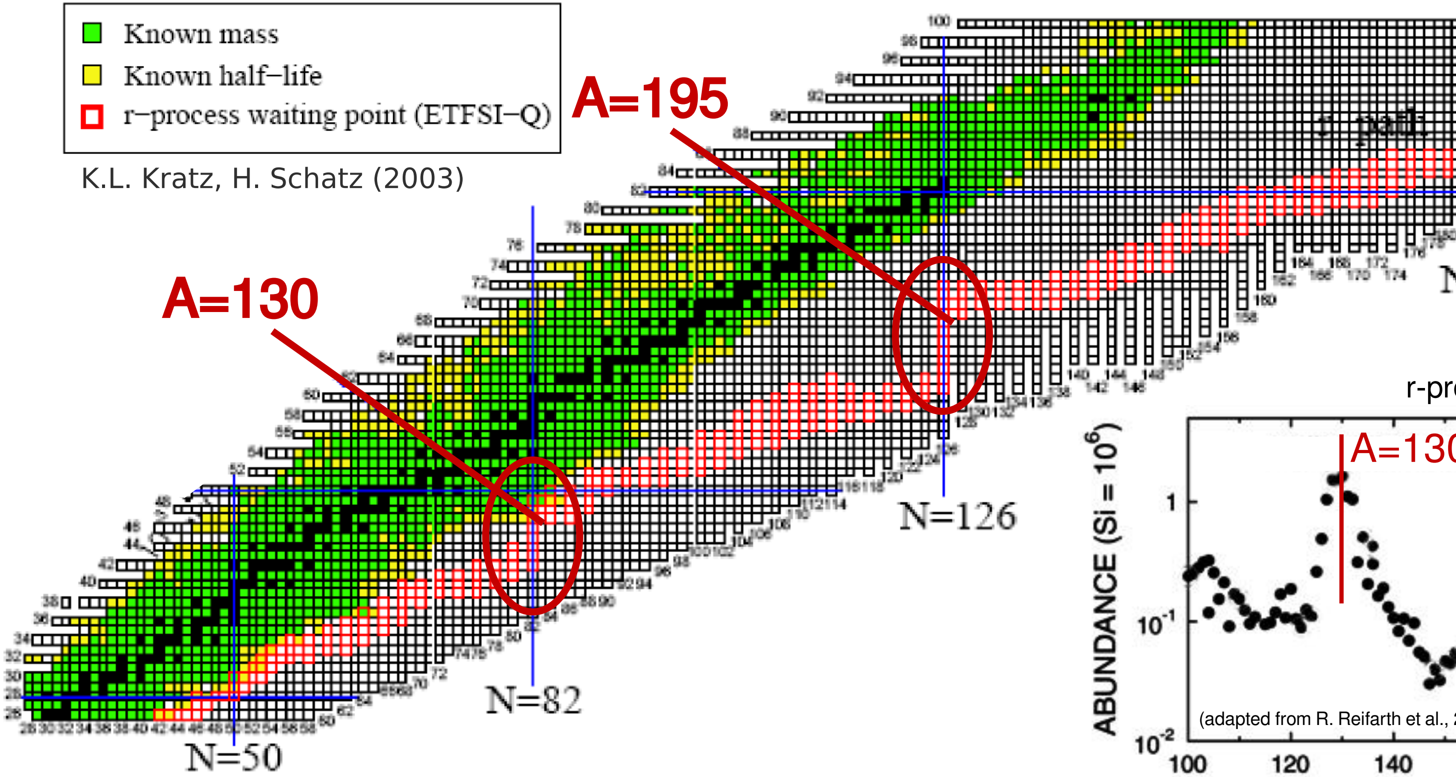
r-Process (rapid neutron capture)



K.L. Kratz, H. Schatz (2003)

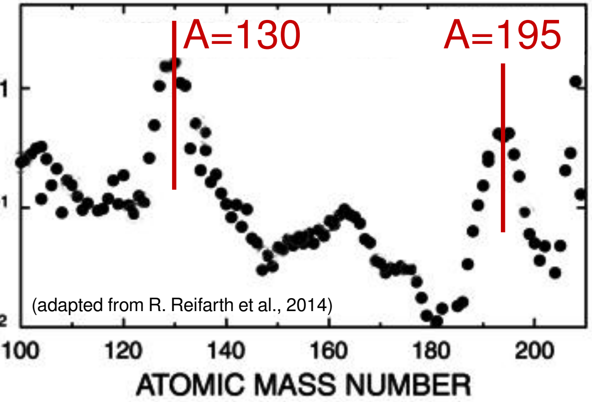
Explosive Nucleosynthesis

r-Process (rapid neutron capture)

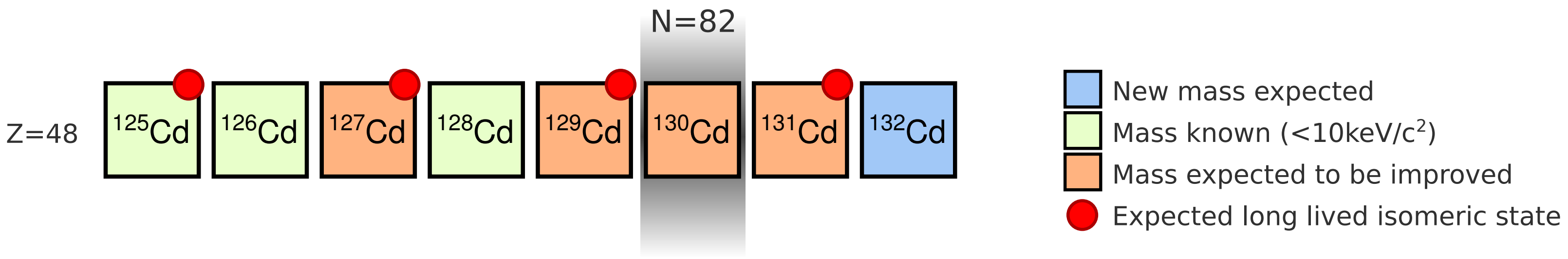


K.L. Kratz, H. Schatz (2003)

r-process Abundances



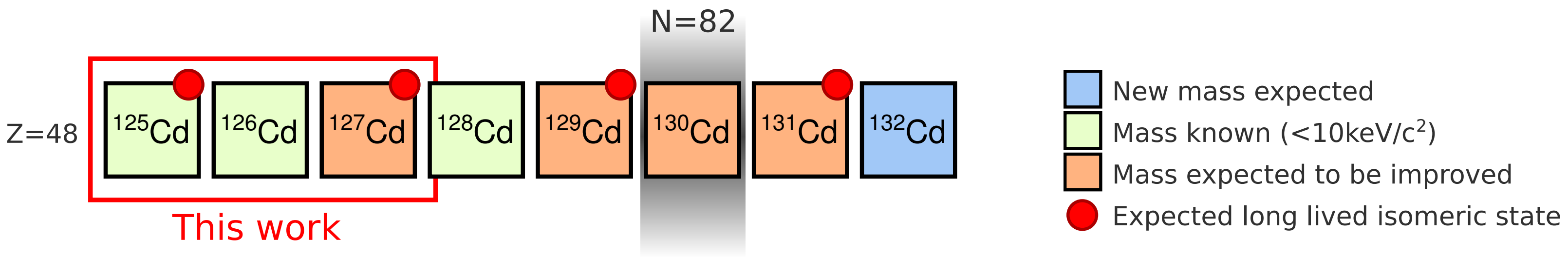
Waiting point ^{130}Cd and surroundings



"Wish-list":

- Evolution of one and two neutron separation energies around ^{130}Cd
- Improve masses to < 10 keV/c^2 for accurate r-process calculations
- Resolve long lived isomeric states

Waiting point ^{130}Cd and surroundings

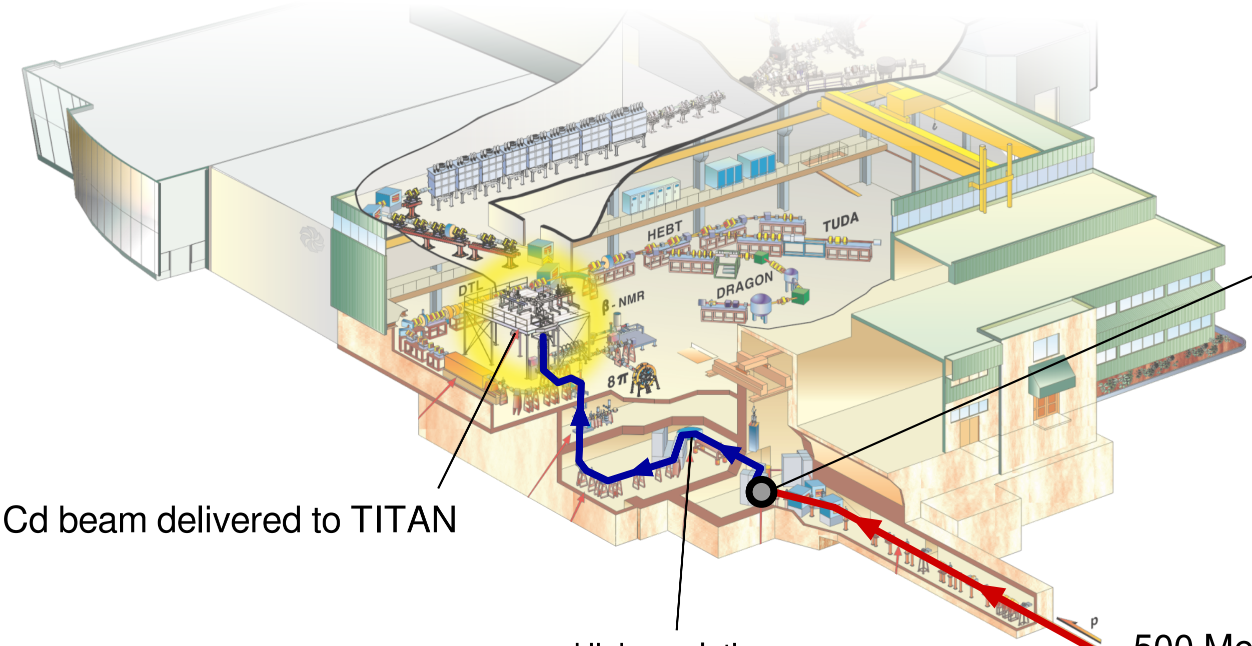


"Wish-list":

- Evolution of one and two neutron separation energies around ^{130}Cd
- Improve masses to < 10 keV/c^2 for accurate r-process calculations
- Resolve long lived isomeric states

Cd Beams

ISAC I at TRIUMF



UCx target + Ion-Guide Laser Ion Source (IG-LIS)

Element selective laser ionization
Suppresses isobaric contaminantion

Cd beam delivered to TITAN

High resolution mass separator

500 MeV proton beam from cyclotron

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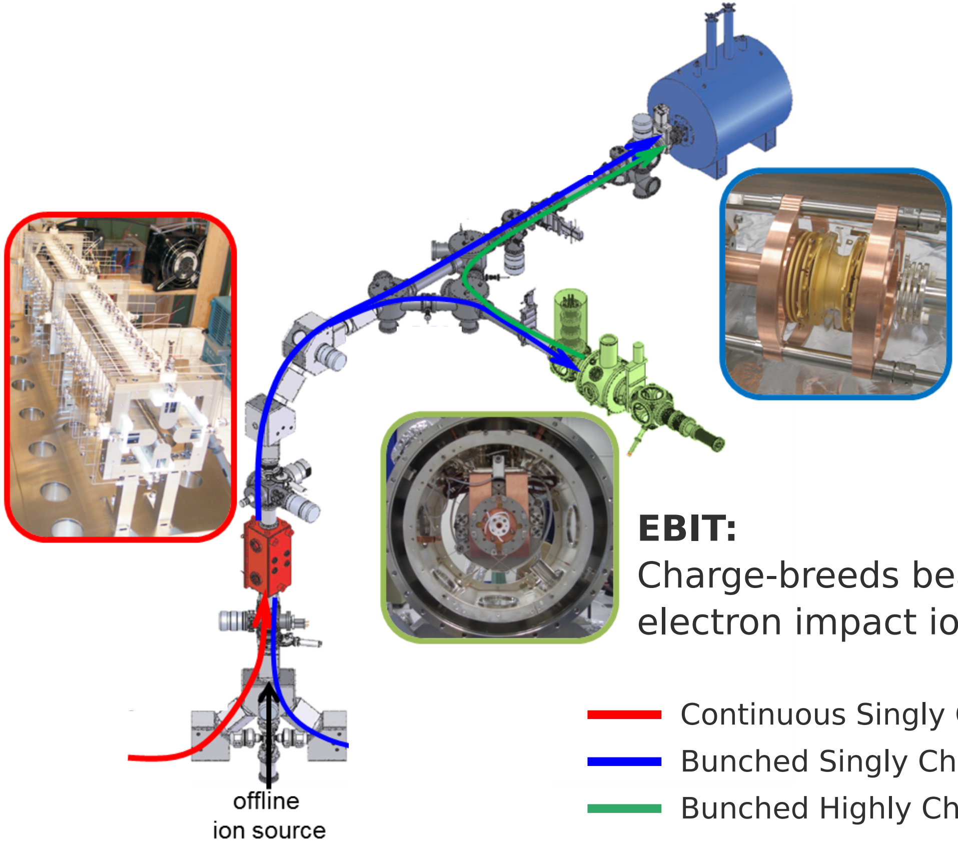
TITAN Facility

TRIUMF Ion Traps for Atomic and Nuclear Science

RFQ:
Cools 20keV ISAC beam and bunches to TITAN at 2keV



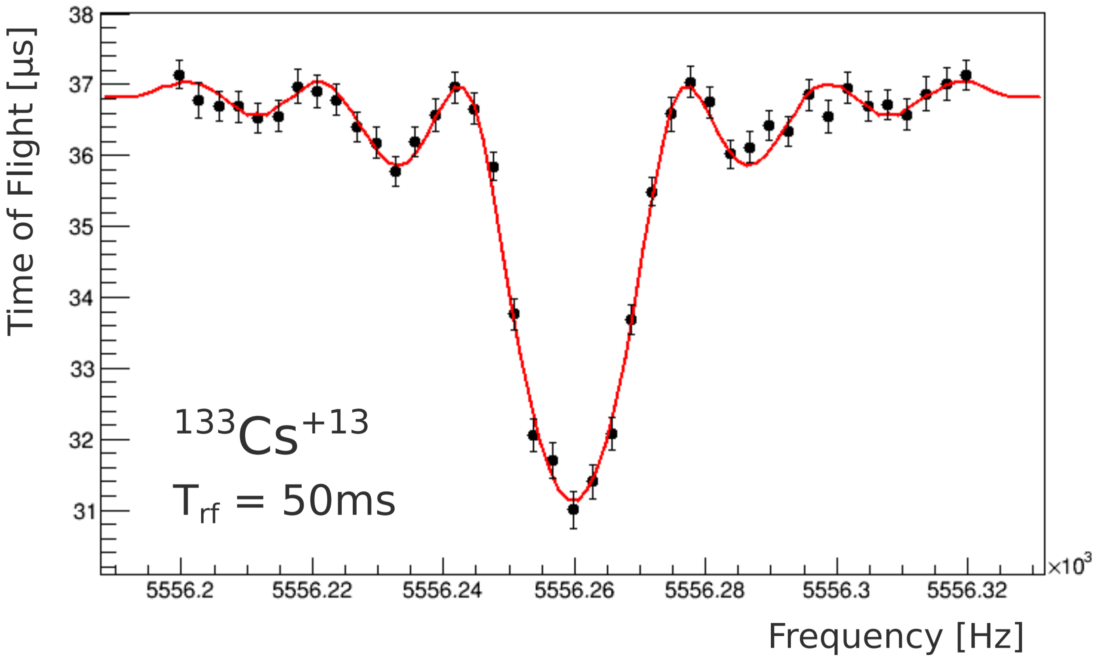
MPET:
Precision mass spectrometer

EBIT:
Charge-breeds beam through electron impact ionization

- Continuous Singly Charged Ion Beam
- Bunched Singly Charged Ion Beam
- Bunched Highly Charged Ion Beam

Measurement Principle

Time-of-Flight Ion Cyclotron Resonance



Cyclotron frequency:

$$\nu_c = \frac{q\,B}{2\pi\,m}$$

Excitation:

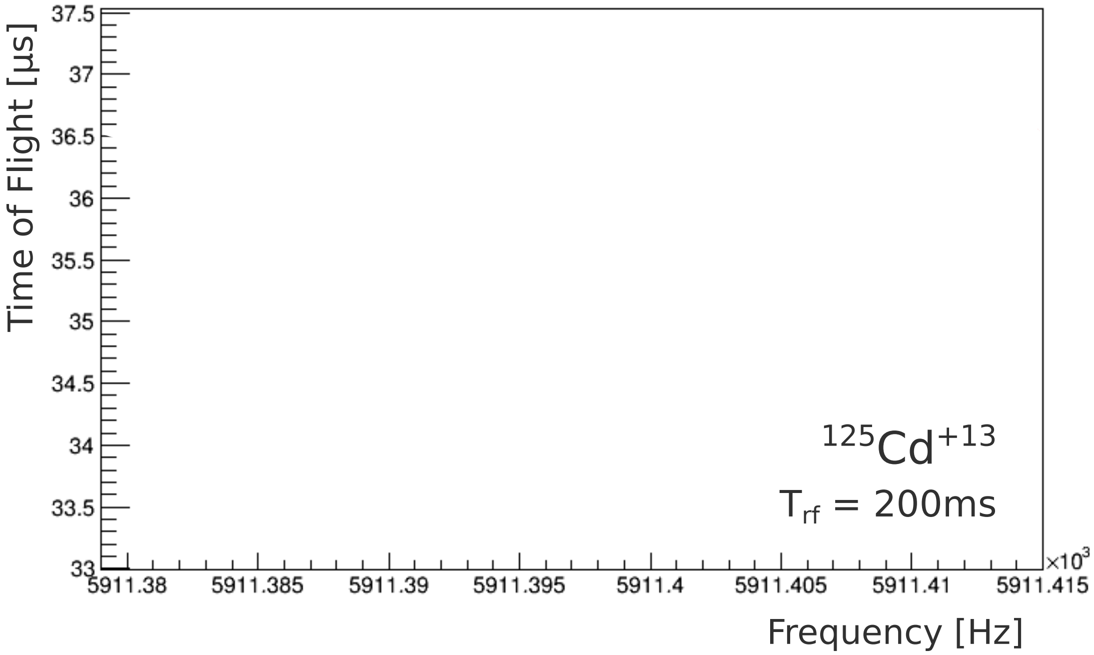
External driving field applied with frequency ν_{rf}

A lot of energy will be given to the ion`s motion, but only if $\nu_{rf} = \nu_c$

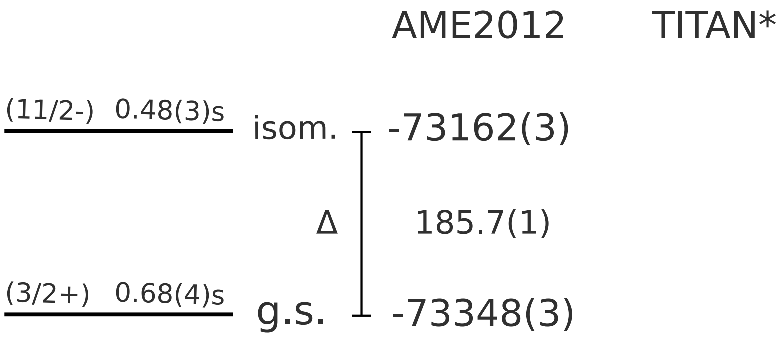
Gain in energy translates into a faster time-of-flight to detector

Results

^{125}Cd

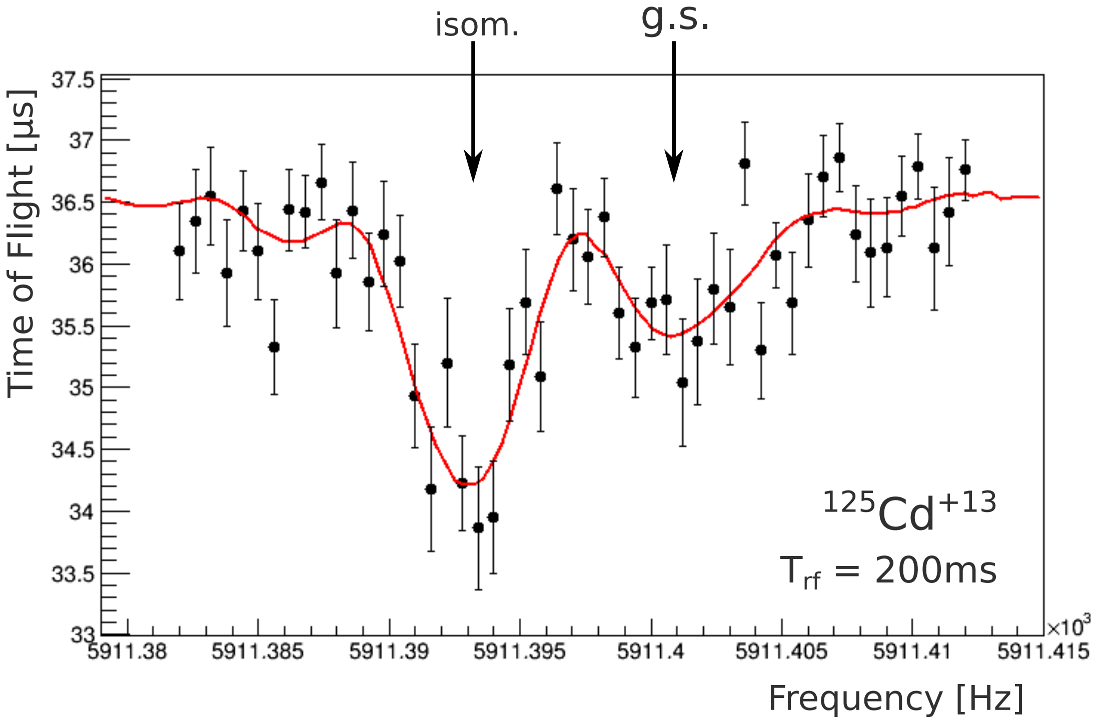


Mass Excesses [keV]

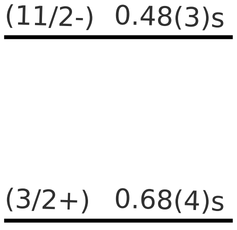


Results

^{125}Cd



Mass Excesses [keV]



	AME2012	TITAN*
isom.	-73162(3)	-73158(9)
Δ	185.7(1)	190(26)
g.s.	-73348(3)	-73347(24)

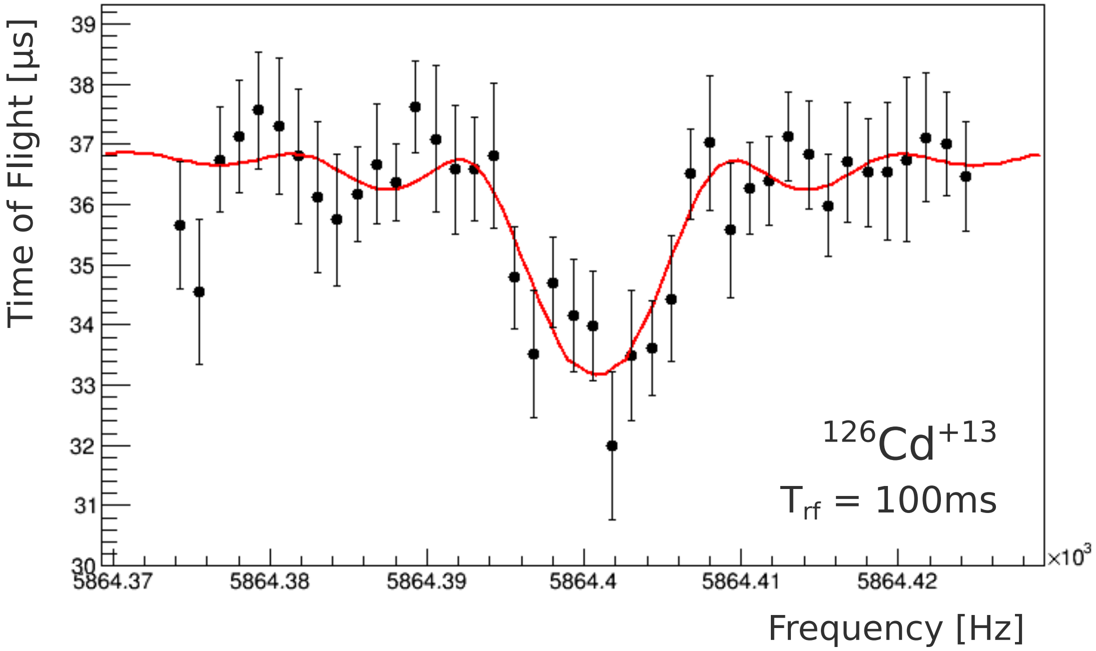
PRELIMINARY

In good agreement with literature

* analysis still in progress!

Results

^{126}Cd



Mass Excesses [keV]

			AME2012	TITAN*
0+	0.52(2)s	g.s.	-72257(3)	-72261(7)

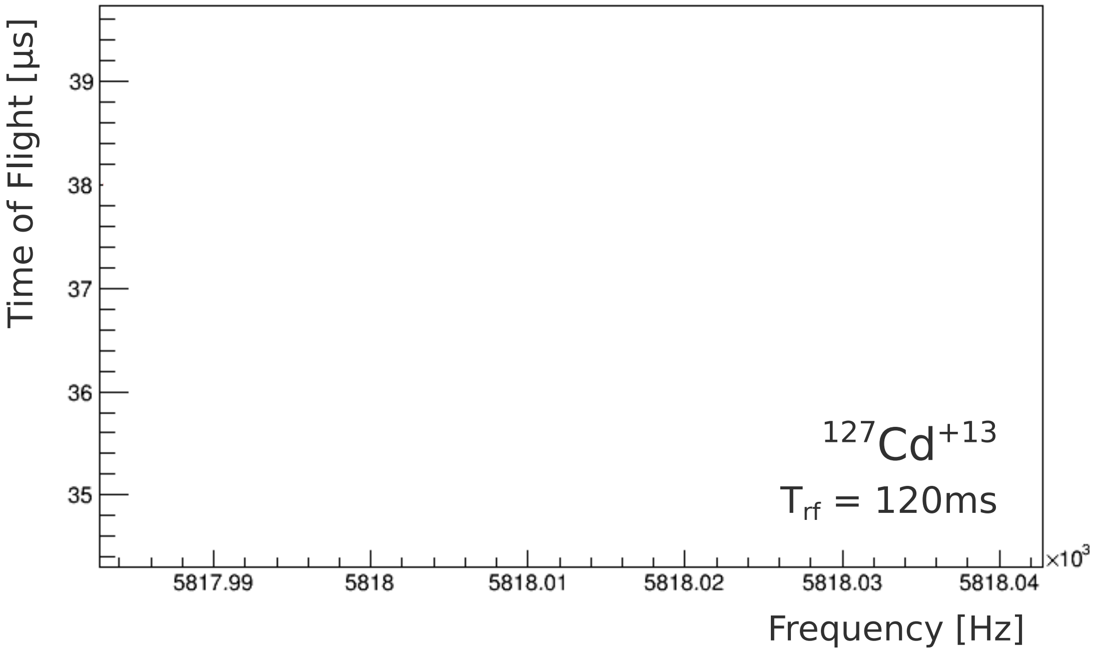
PRELIMINARY

In agreement with literature

* analysis still in progress!

Results

^{127}Cd

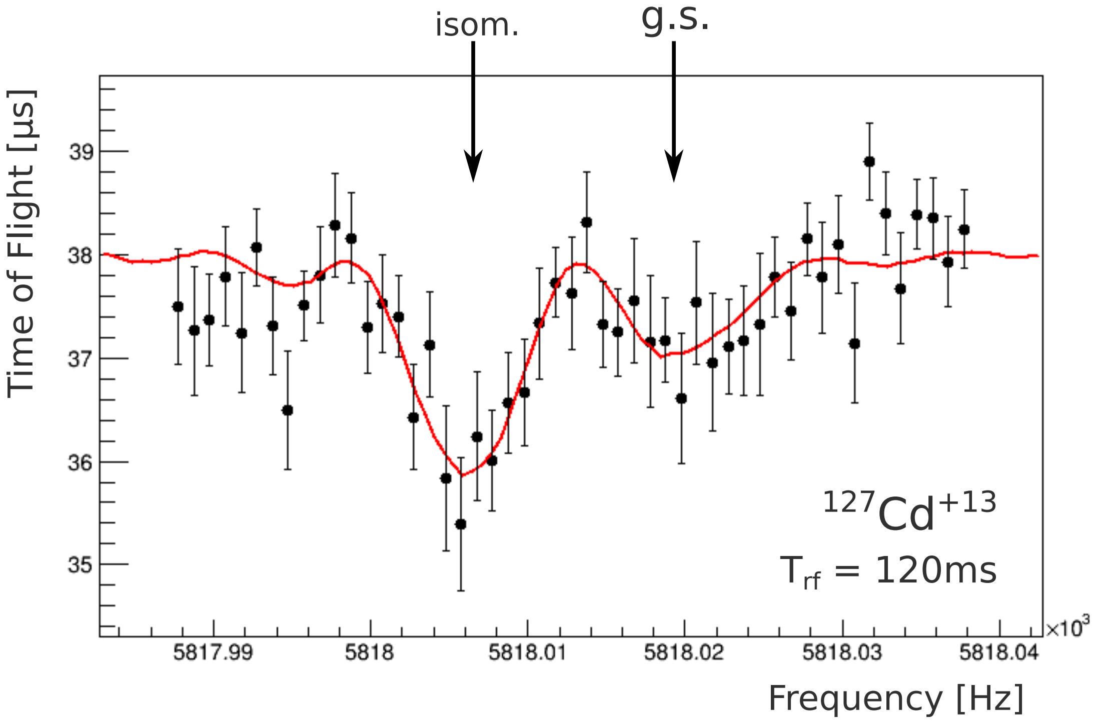


Mass Excesses [keV]

			AME2012	TITAN*
(11/2-)	(0.2s)	isom.	(?)	
		Δ	(?)	
(3/2+)	0.37(7)s	g.s.	-68493(13)	

Results

^{127}Cd



Mass Excesses [keV]

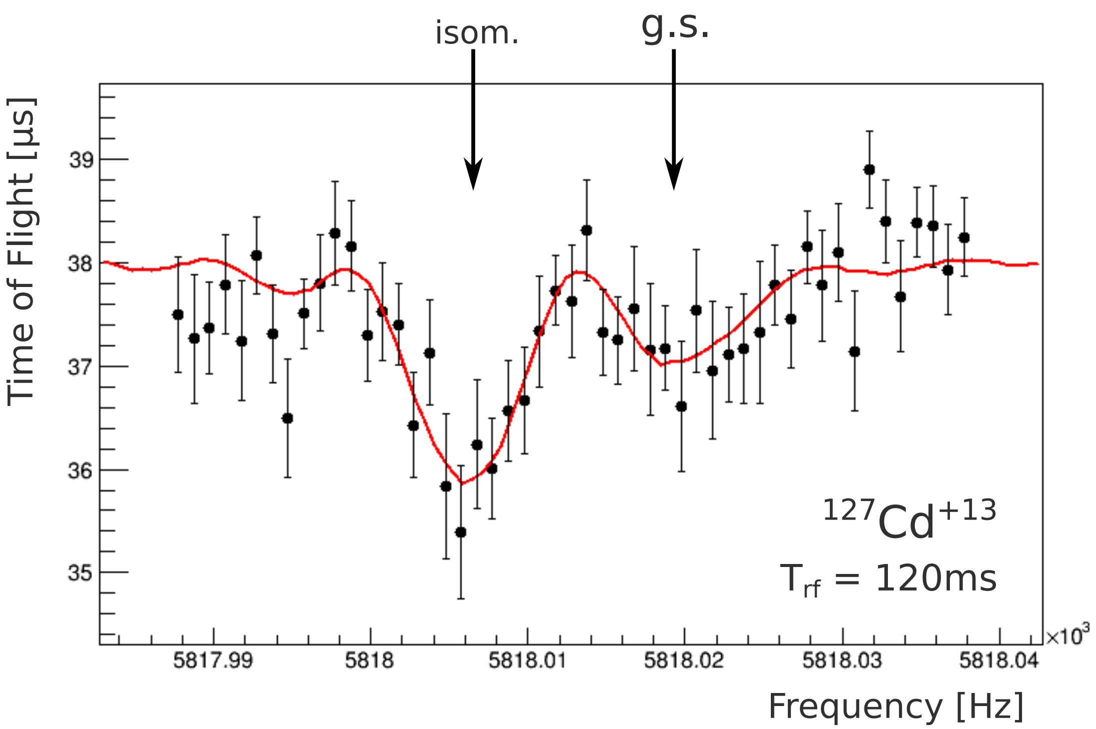
			AME2012	TITAN*
(11/2-)	(0.2s)	isom.	(?)	-68460(5)
		Δ	(?)	283(7)
(3/2+)	0.37(7)s	g.s.	-68493(13)	-68743(6)

PRELIMINARY

* analysis still in progress!

Results

^{127}Cd



Mass Excesses [keV]

Level			AME2012	TITAN*
(11/2-)	(0.2s)	isom.	(?)	-68460(5)
		Δ	(?)	283(7)
(3/2+)	0.37(7)s	g.s.	-68493(13)	-68743(6)

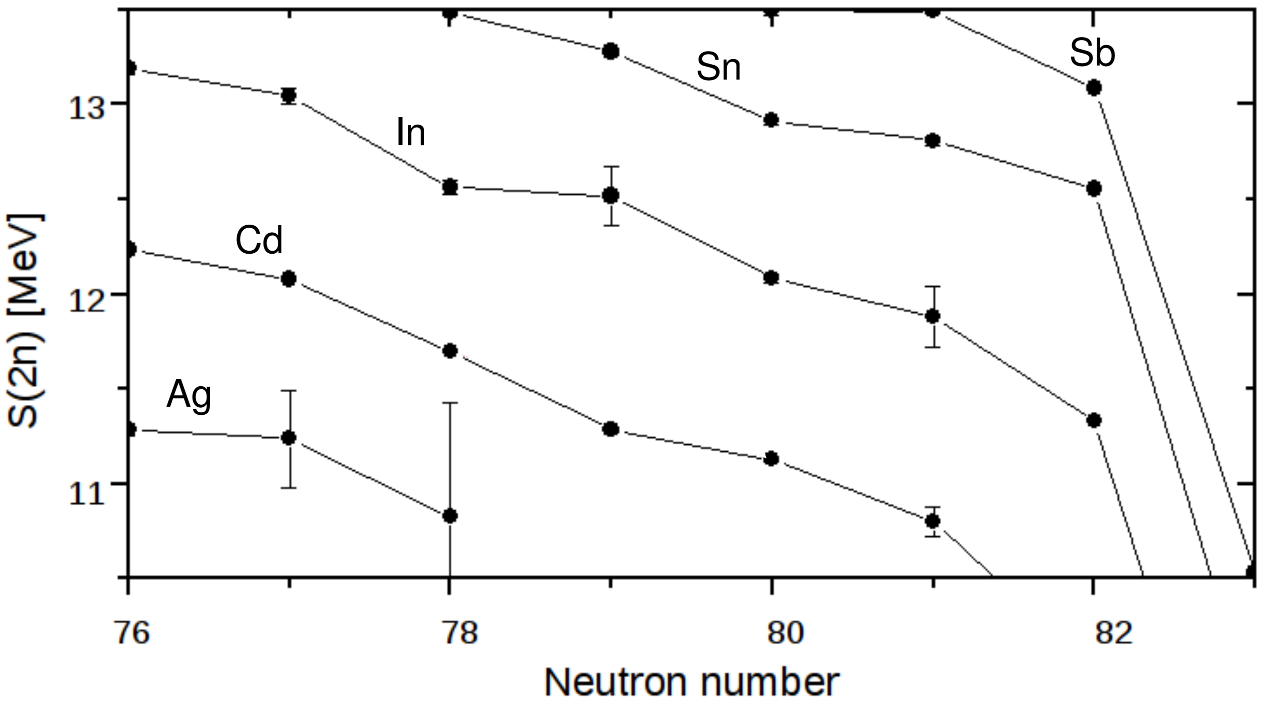
PRELIMINARY

Isomer misidentification in previously reported measurement!

* analysis still in progress!

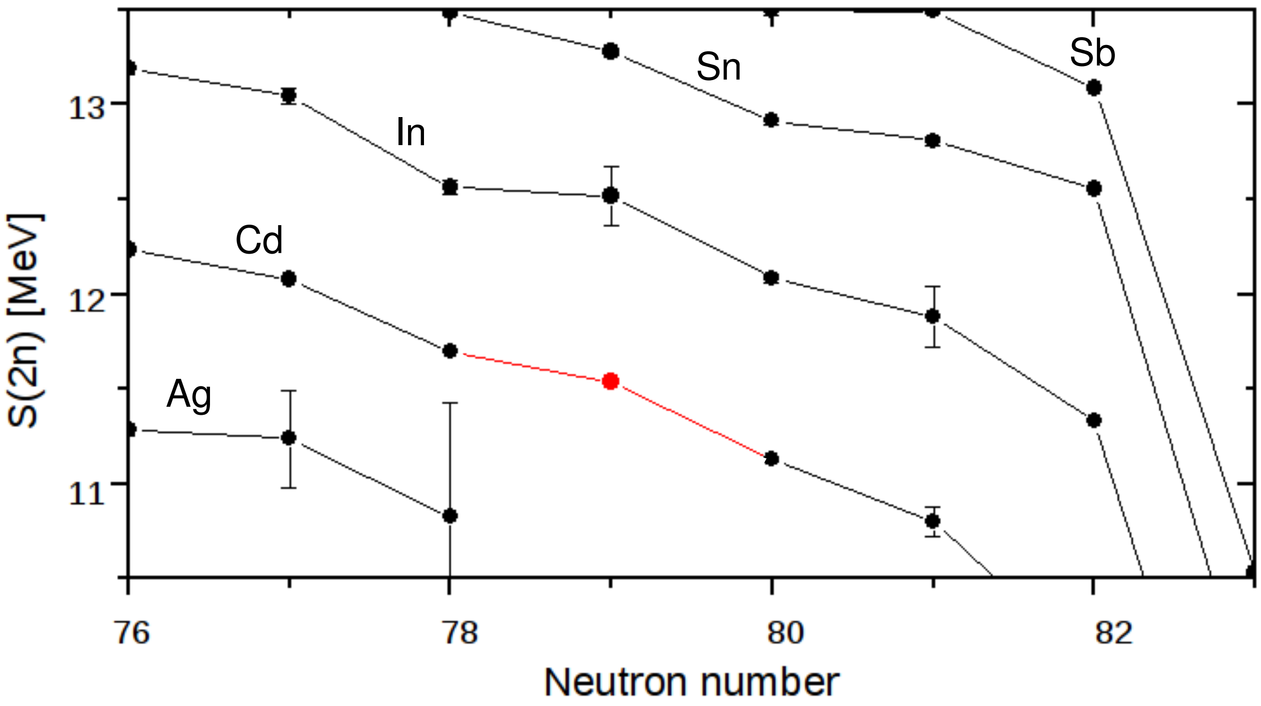
Results

Cd 2-neutron separation energies



Cd 2-neutron separation energies

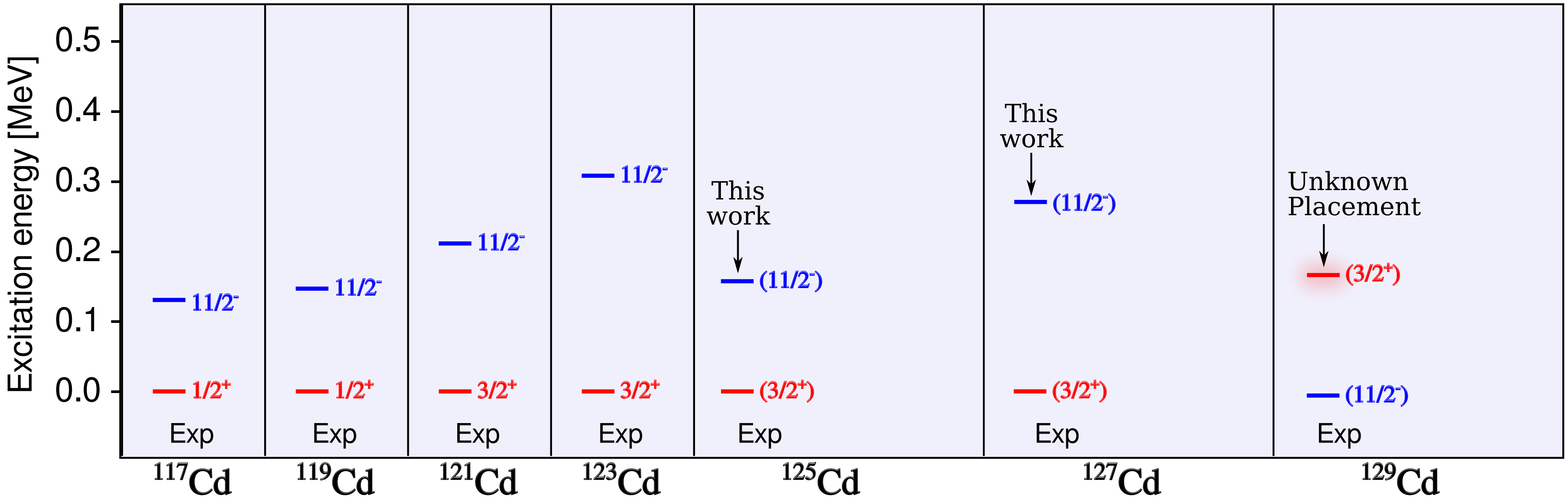
PRELIMINARY



Results

Structure Evolution

PRELIMINARY

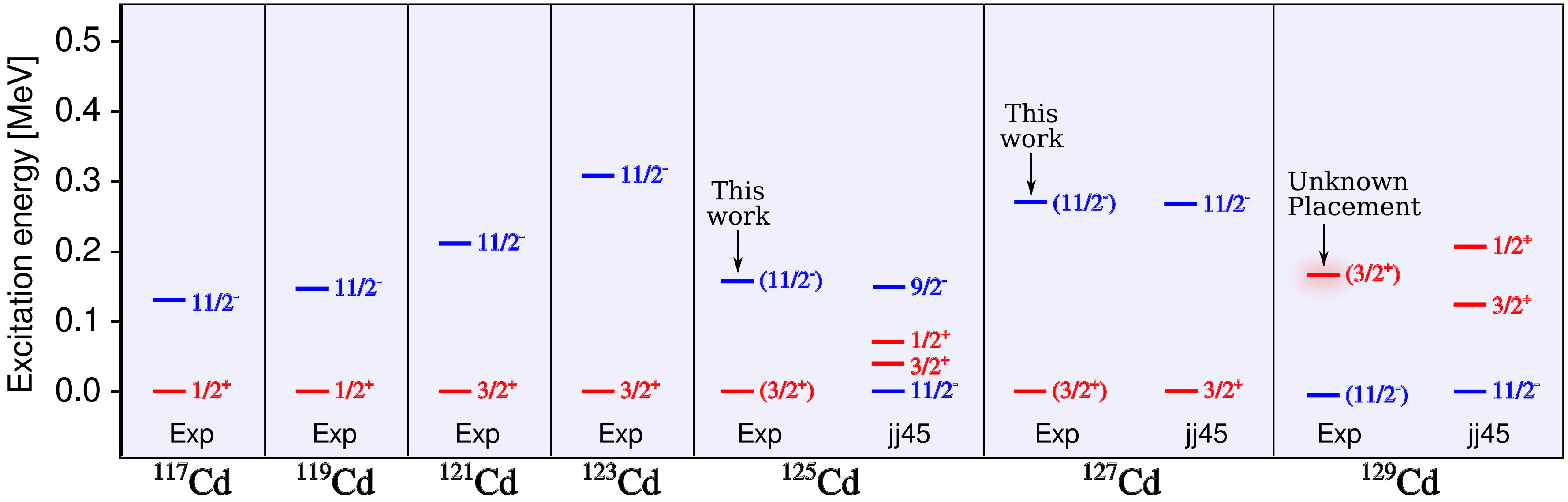


Most spins & parities assigned based on systematic arguments

Results

Structure Evolution

PRELIMINARY



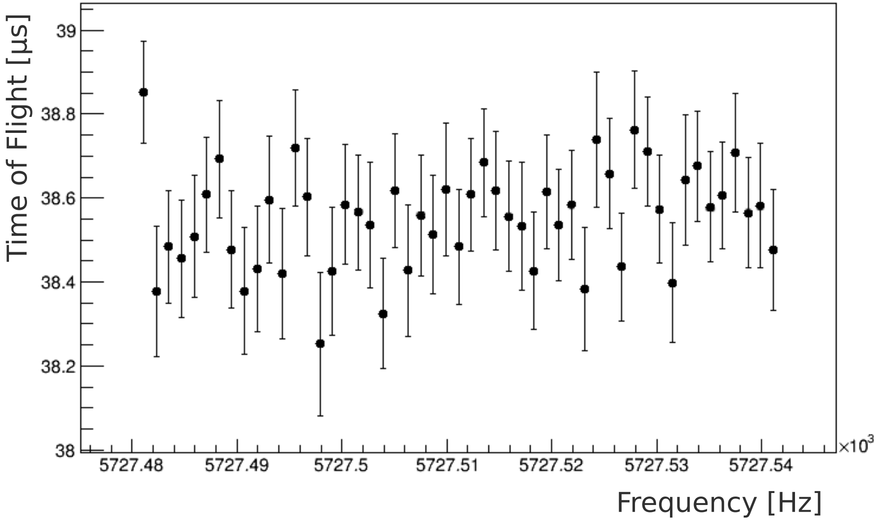
Most spins & parities assigned based on systematic arguments

Shell model calculations point out non-trivial systematics, assignments are not reliable

Future

How can we go further?

Attempt to measure mass of ^{129}Cd failed.



No clear resonance found, too large isobaric contamination

Multi-reflection Time-of-Flight (MR-TOF)

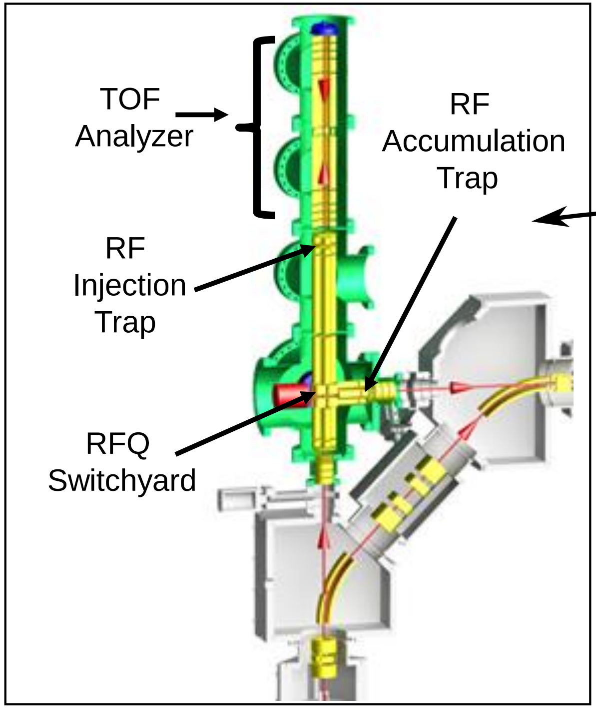
Isobar separator is required!

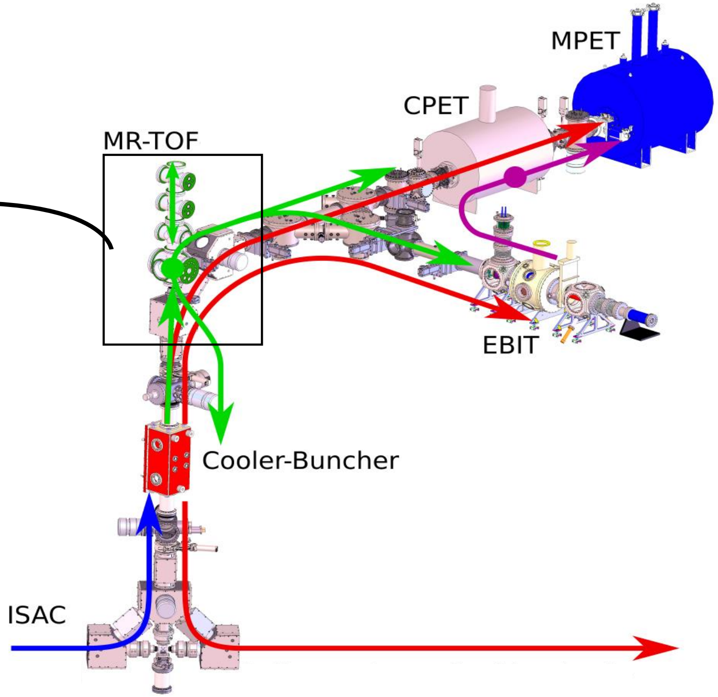
Offline comissioned, ready for online installation (in a few weeks)

~100k resolving power after 2.0 ms

How can we go further?

Multi-reflection Time-of-Flight (MR-TOF) Isobar separator





Summary

Successfully verified previous mass measurements of $^{125}Cd^{gs,m}$ and ^{126}Cd

Measured masses of both $^{127}Cd^{gs,m}$

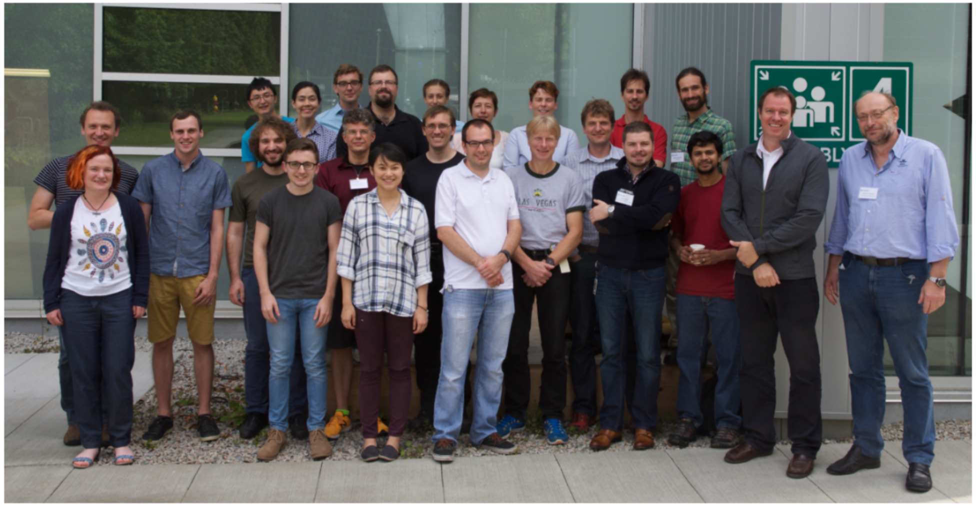
- Found isomer misidentification in previous measurements
- Ongoing theoretical calculations to inspect impact on nuclear structure and on r-process abundances
- New data should be included in the next AME

Too large isobaric contamination to probe masses beyond A=128

- Future measurements will require combined IG-LIS + MR-TOF

Thank you!

TITAN
Collaboration



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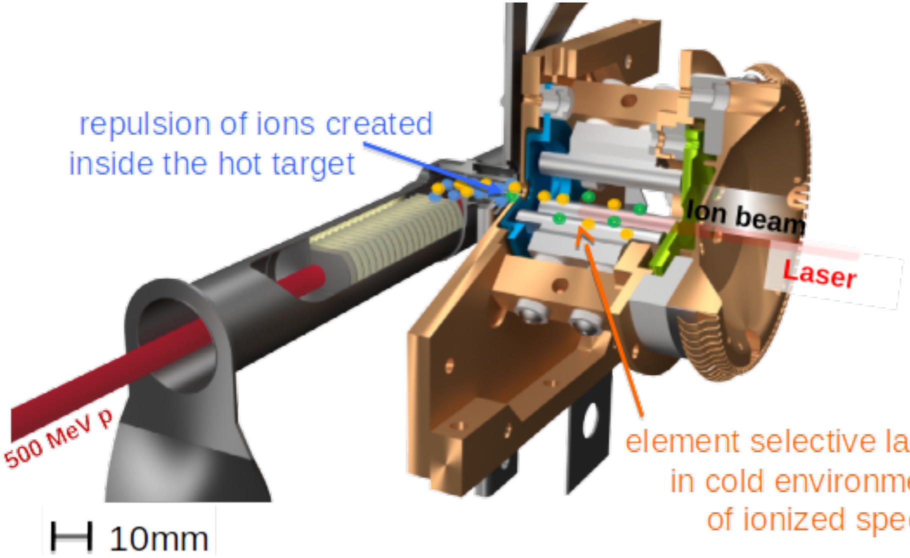
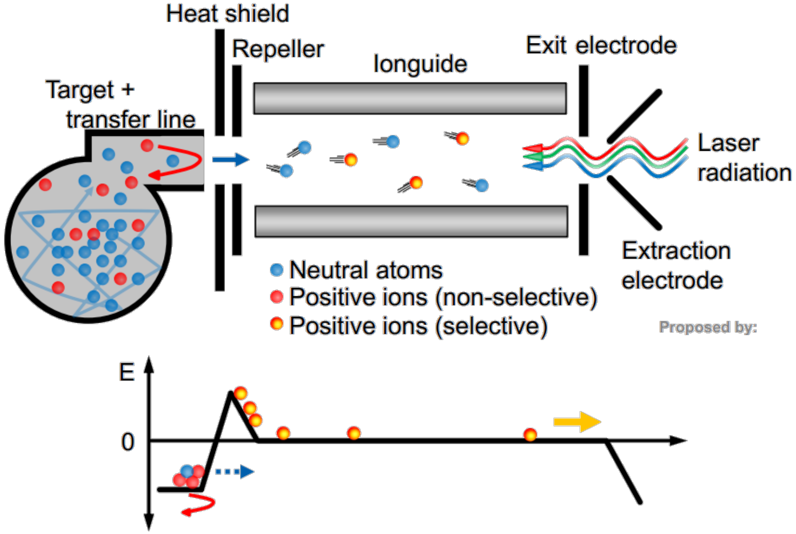
SFU
McGill University
Westfälische Wilhelms-Universität Münster
University of Calgary
Justus-Liebig-Universität Giessen
university of groningen
kvi - center for advanced radiation technology
University of Notre Dame
Technische Universität Dresden
cnrs IN2P3 Les deux infinis

Production of Cd Beams

Ion-Guide Laser Ion Source (IG-LIS)



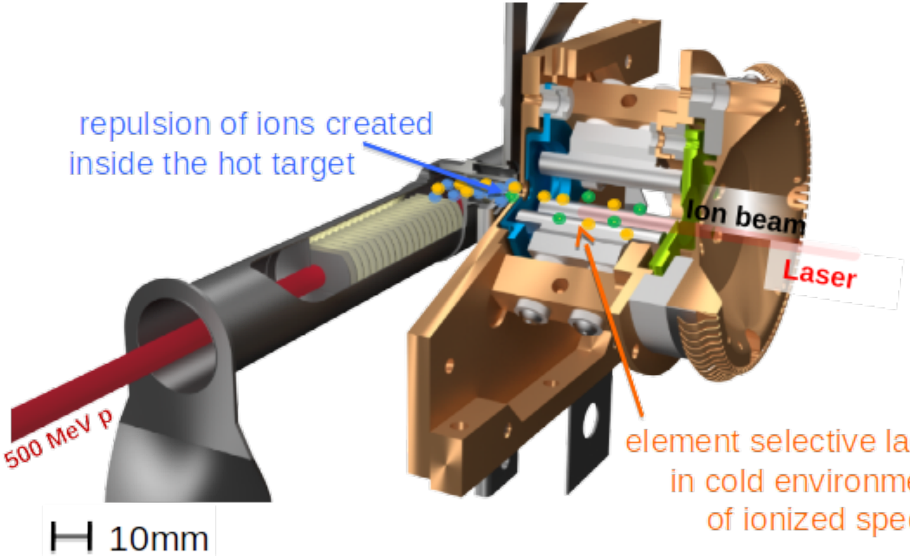
S. Raeder et al. (2014)

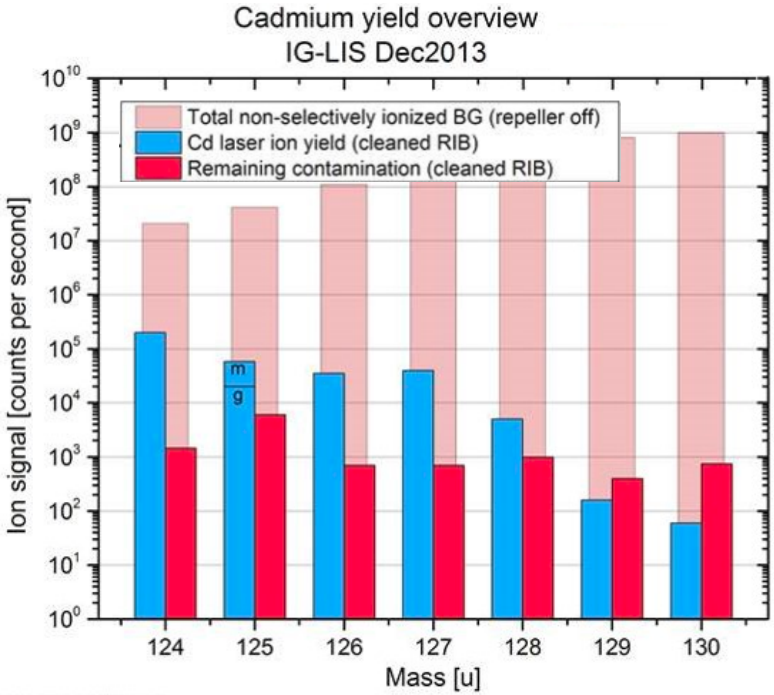


K. Blaum et al. (2003)

Production of Cd Beams

Ion-Guide Laser Ion Source (IG-LIS)

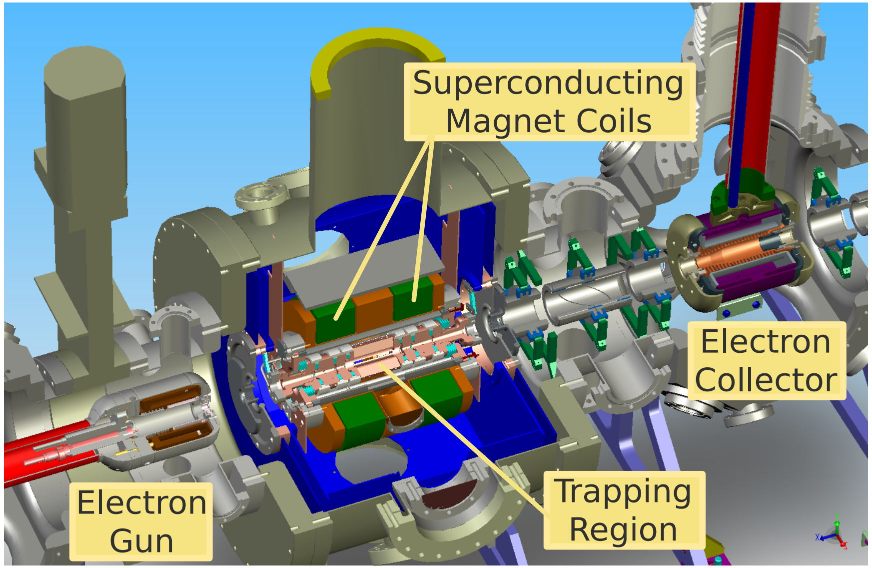


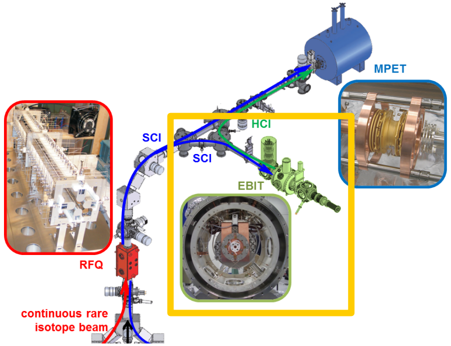


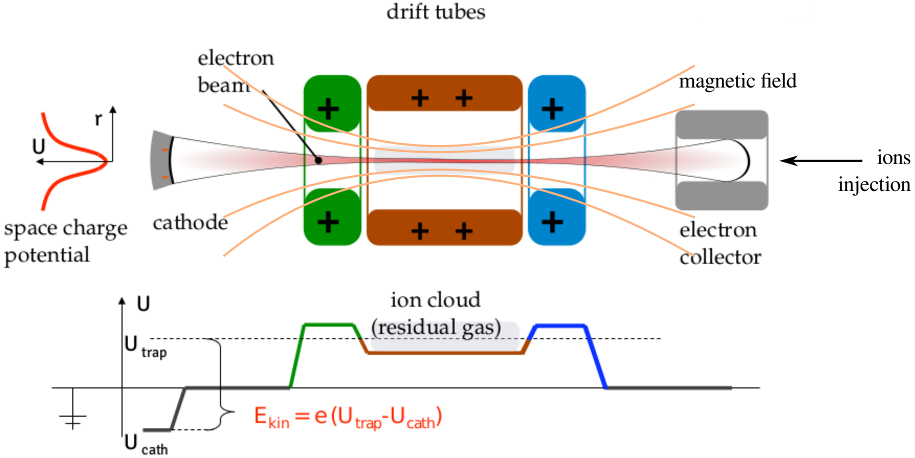
UCx target (9.8μA p+)

S. Raeder et al. (2014)

EBIT - Electron Beam Ion Trap





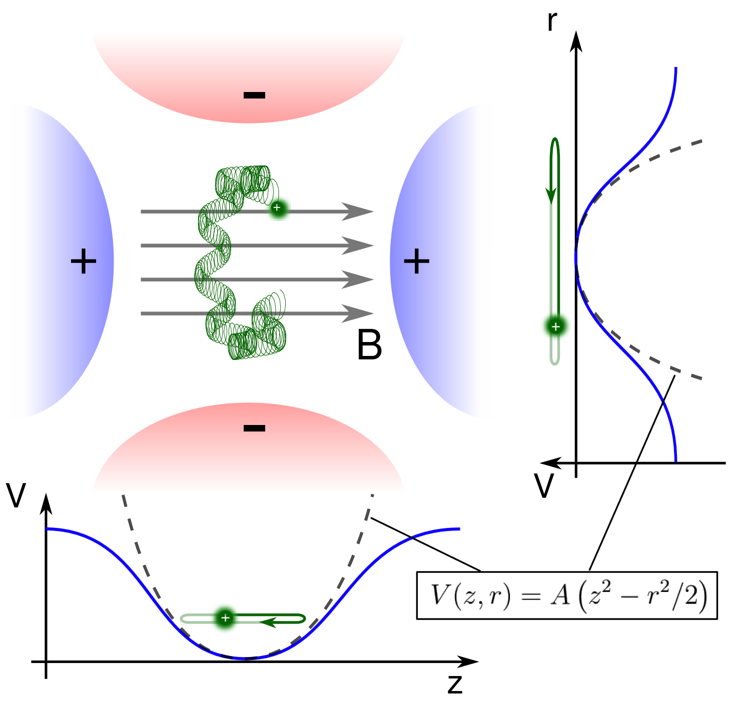


Charge breeds ions through electron impact ionization

Measurement Principle

Time-of-Flight Ion Cyclotron Resonance

Confinement in a Penning Trap:



Cyclotron frequency:

$$\nu_c = \frac{q\,B}{2\pi\,m}$$

Excitation:

External quadrupole RF field applied with frequency ν_{rf}

A lot of energy will be given to the ion`s motion, but only if $\nu_{rf} = \nu_c$

Measurement Principle

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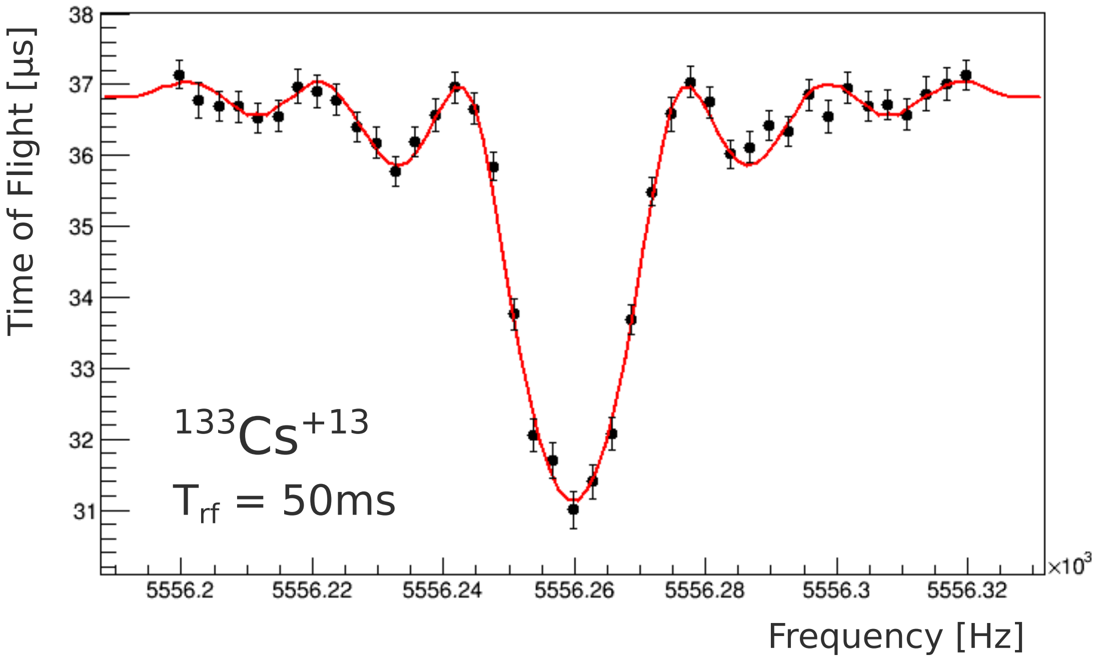


Cyclotron frequency:

$$\nu_c = \frac{q\,B}{2\pi\,m}$$

Precision:

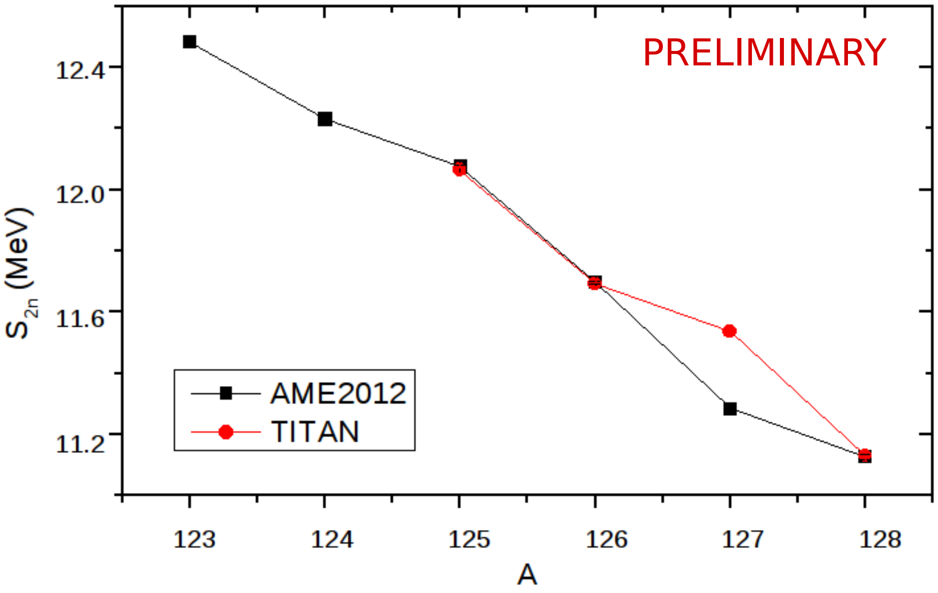
$$\frac{\delta m}{m} \propto \frac{1}{q\;T_{rf}\;B\sqrt{N}}$$

Gain in precision by increasing excitation time and charge state...

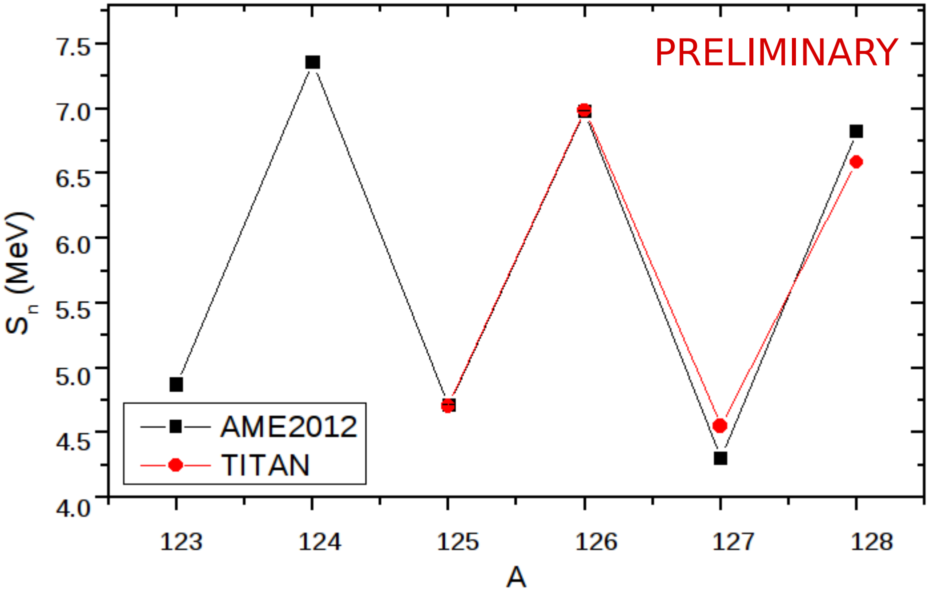
Results

Cd neutron separation energies

Two neutrons:



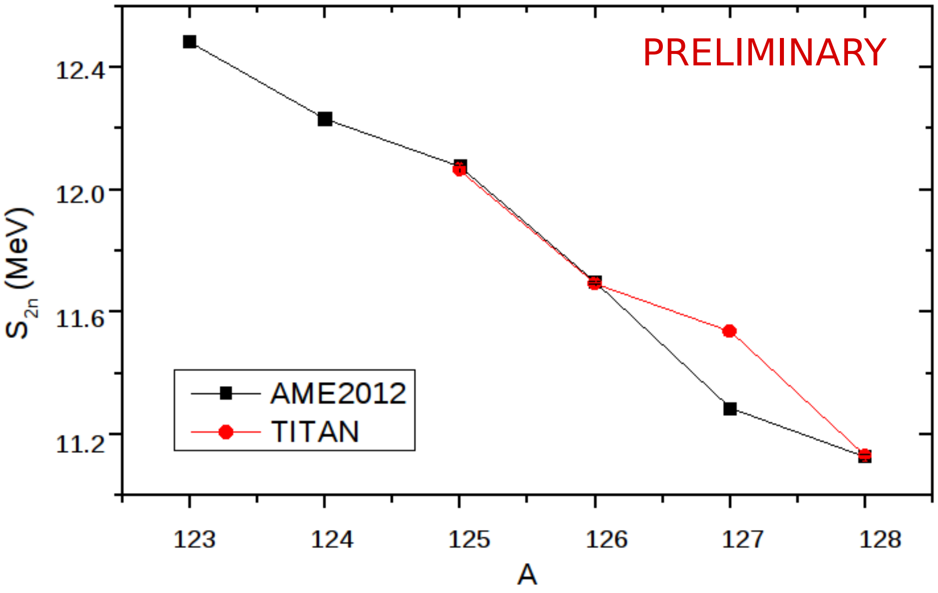
One neutron:



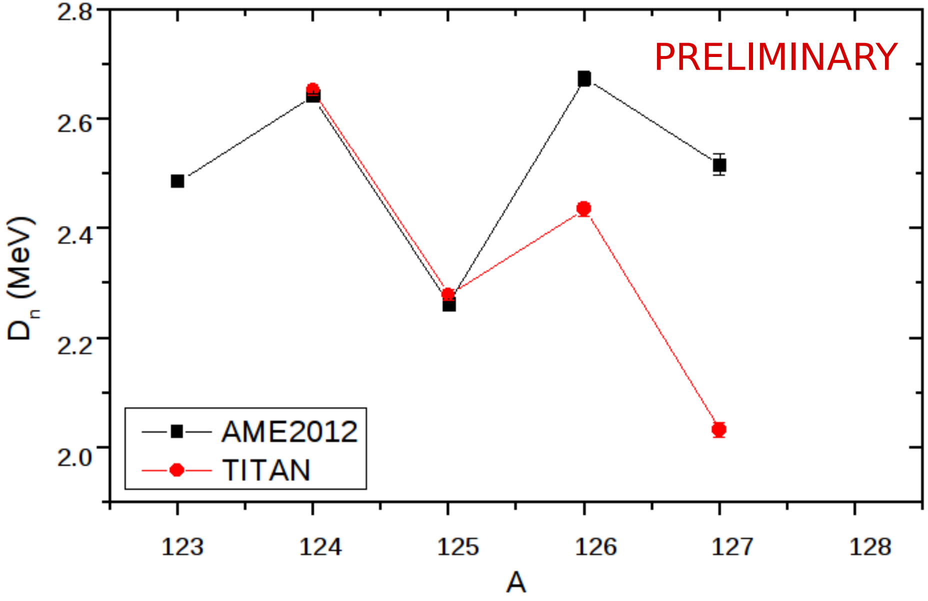
Results

Cd neutron separation energies

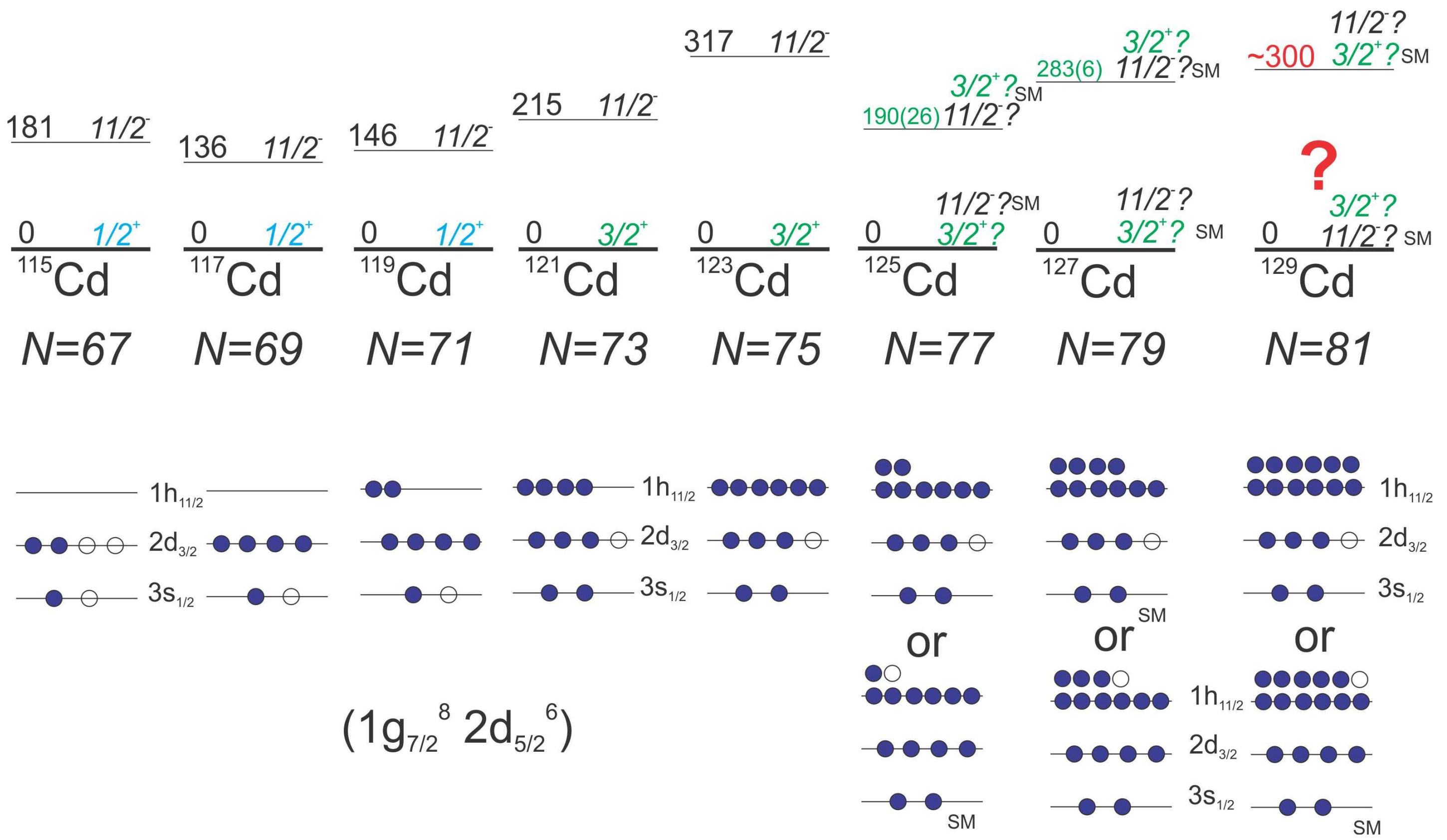
Two neutrons:



Pairing gap:

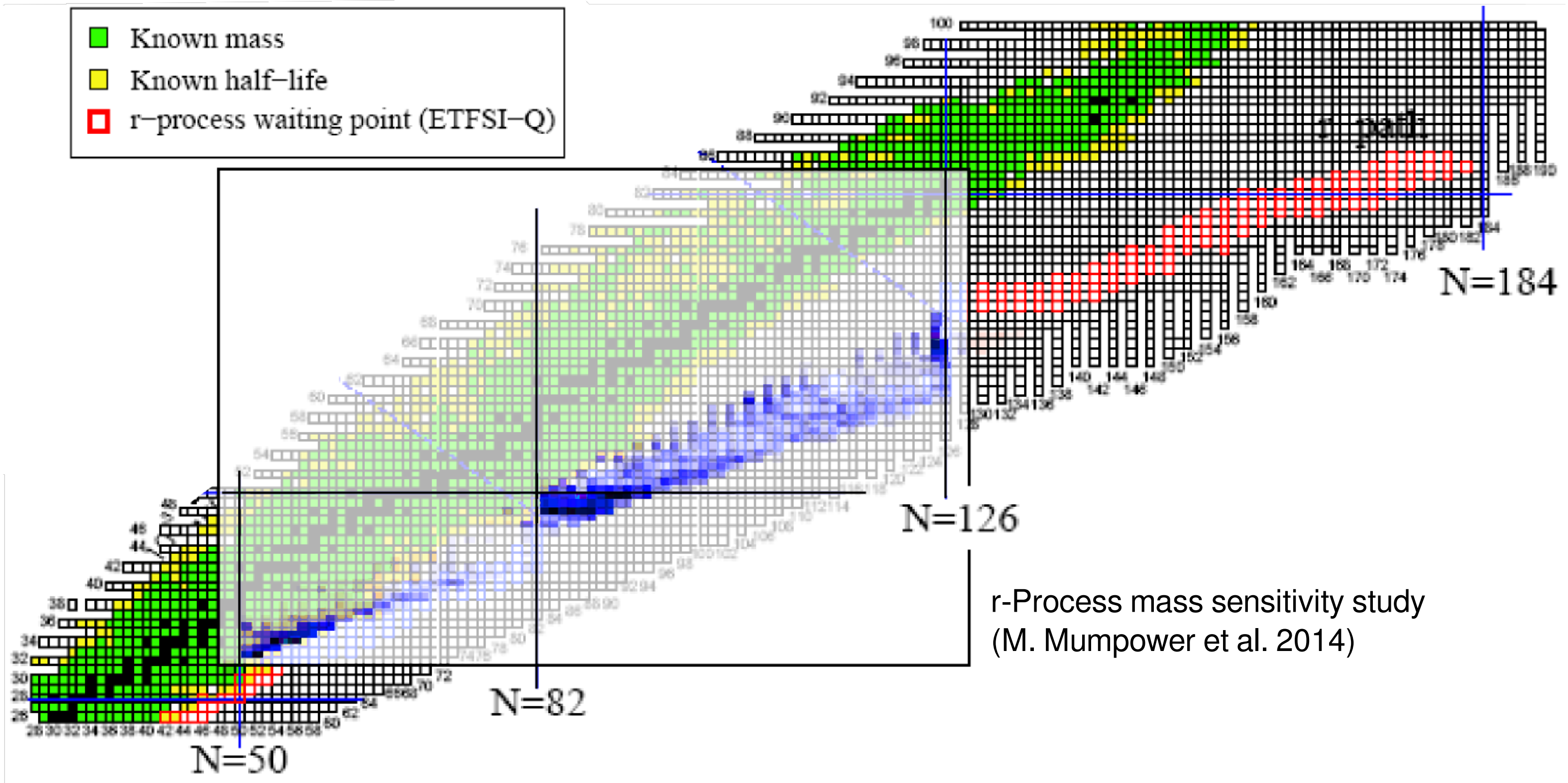


Structure Evolution



Explosive Nucleosynthesis

r-Process (rapid neutron capture)



r-Process mass sensitivity study
(M. Mumpower et al. 2014)