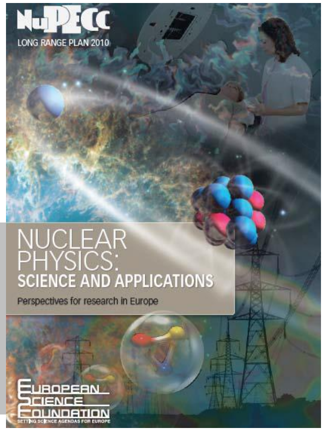
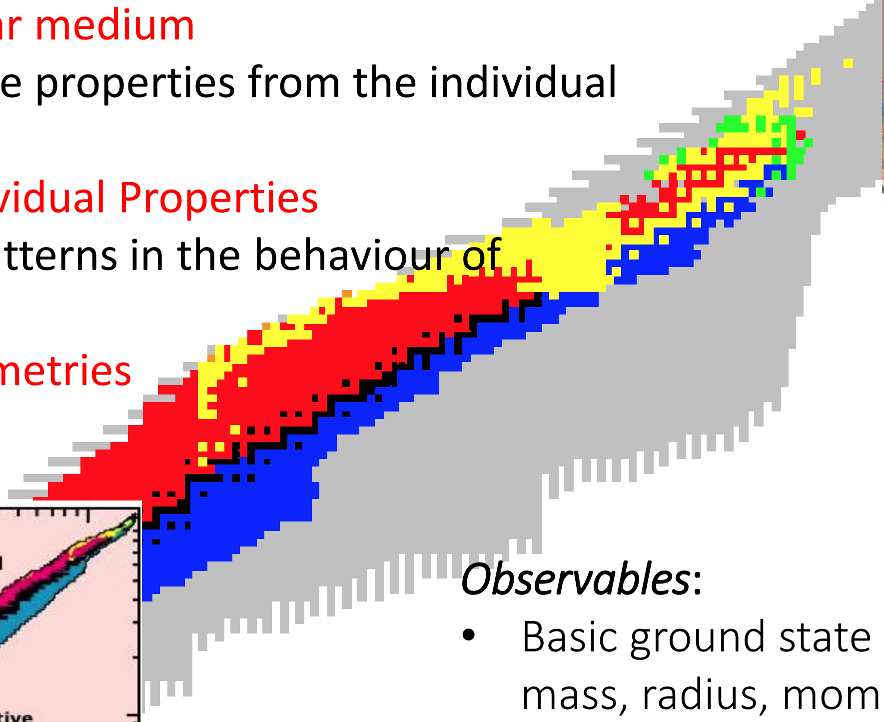
ISOLDE LIEBE review: 21st March 2019
Interesting beams for physics

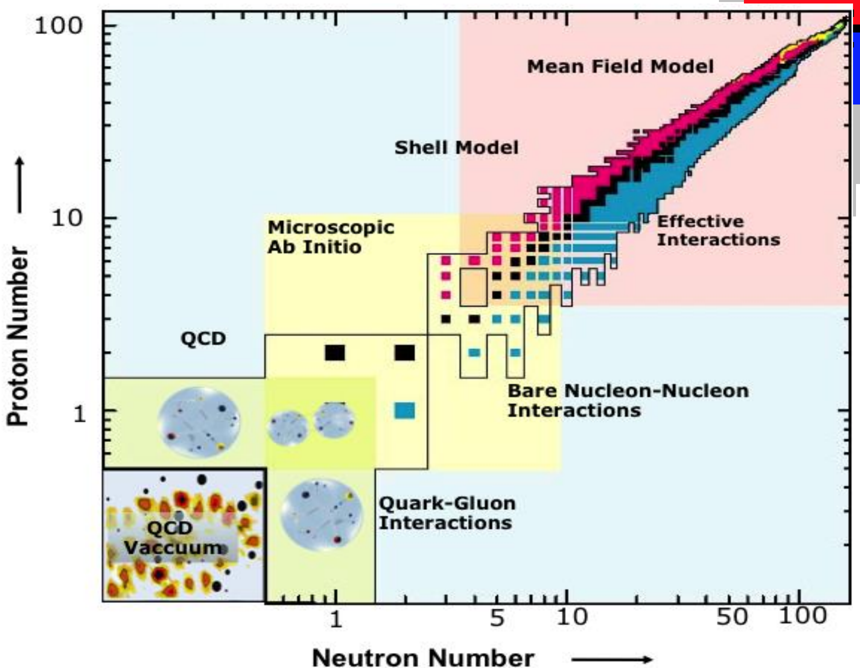
Karl Johnston

Open Questions

- How a nucleus is formed from their constituents
  - ➢ Strong force in nuclear medium
- How to explain the collective properties from the individual behaviour
  - ➢ Collective versus individual Properties
- Why do we have regular patterns in the behaviour of nuclei?
  - ➢ Identification of Symmetries







Observables:

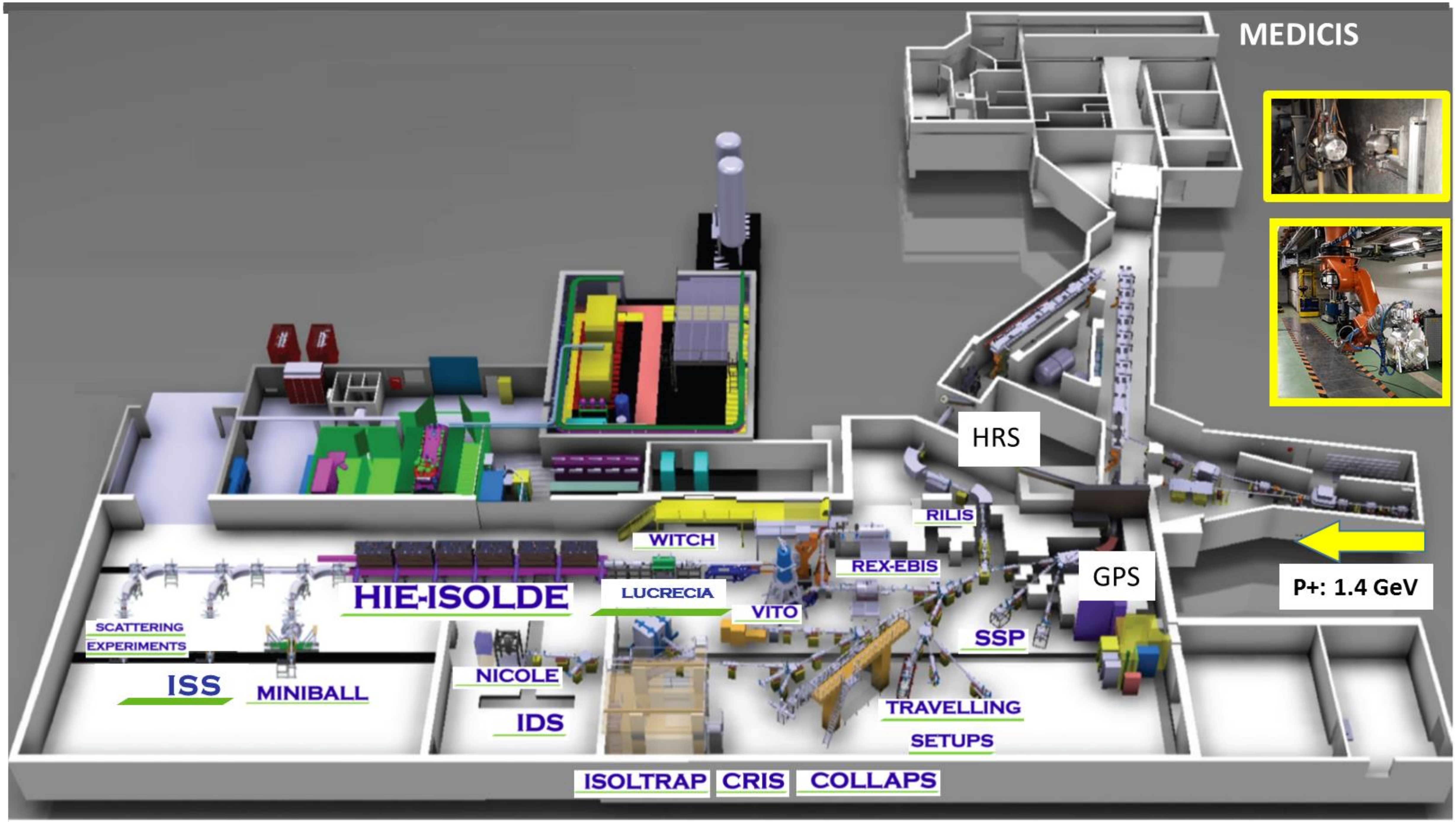
- Basic ground state properties: mass, radius, moments J, μ, Q
- Half-life y decay process
- Transition probabilities

Theoretical Models:

Shell Model (magic numbers)

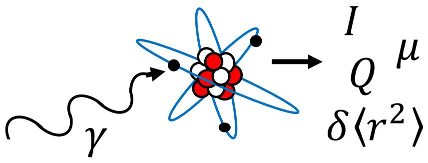
Mean field Calculations (collective properties)

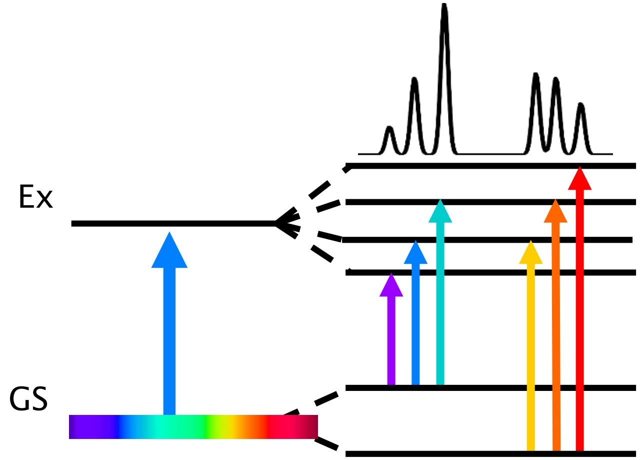
Ab Initio Calculations (light nuclei)


MEDICIS
HRS
RILIS
WITCH
REX-EBIS
GPS
P+: 1.4 GeV
HIE-ISOLDE
LUCRECIA
VITO
SSP
SCATTERING
EXPERIMENTS
ISS
MINIBALL
NICOLE
IDS
TRAVELLING
SETUPS
ISOLTRAP
CRIS
COLLAPS

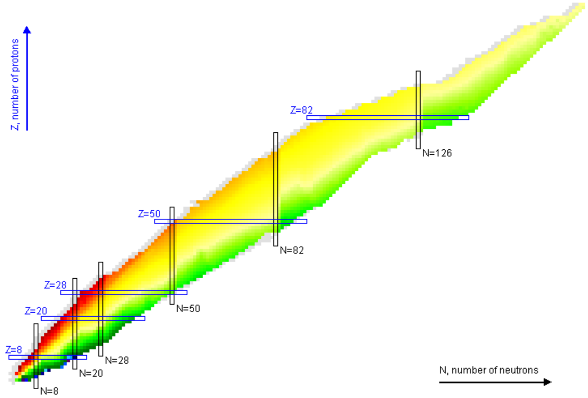
Studying nuclear structure

- The atomic hyperfine structure gives you information on:
  - Nuclear spin
  - Magnetic moment
  - Quadrupole moment
  - Relative charge radii
- Method: COLLAPS, CRIS (laser spectroscopy)

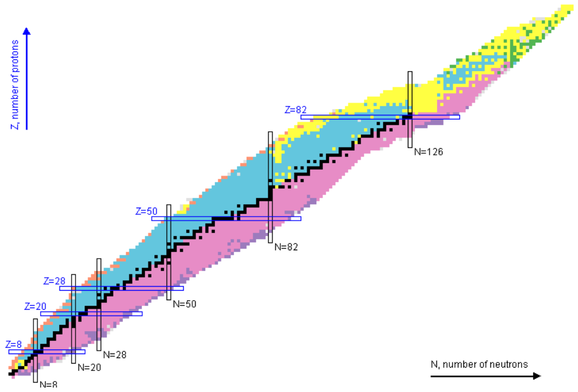




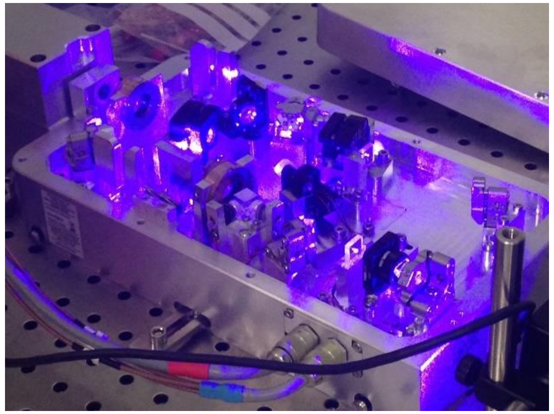
- The mass of the nucleus gives you information on:
  - Binding energy
  - Proton and neutron separation energy
- Method: ISOLTRAP (mass spectrometry)

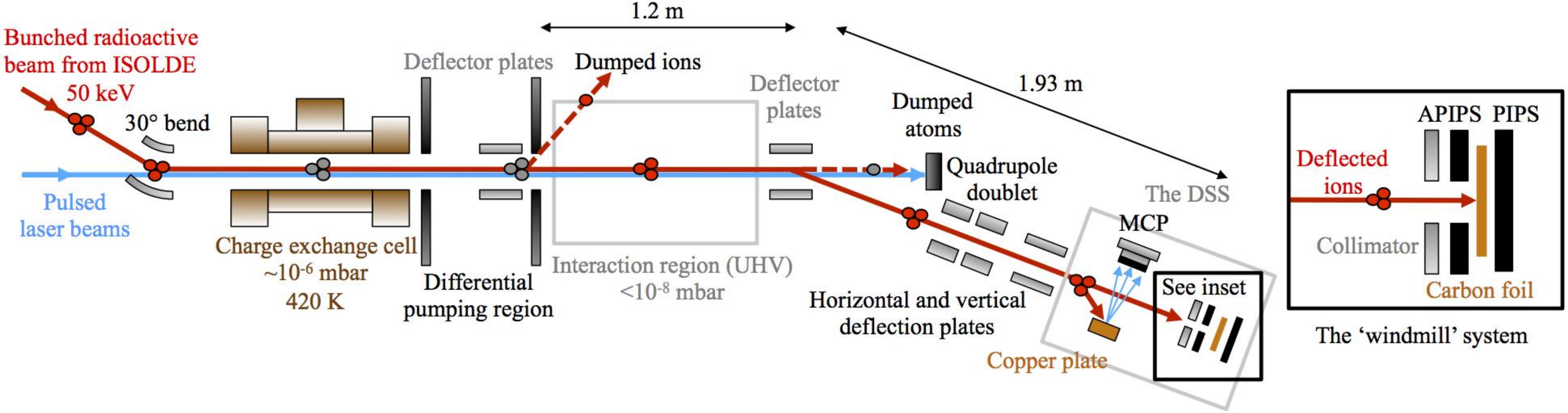


- Spectroscopy of the nucleus gives you information on:
  - Life time
  - Decay mechanism
  - Branching ratio
  - Nuclear reactions, …
- Method: IDS, MINIBALL, ISS, SEC, TAS



CRIS





1.2 m
1.93 m
Bunched radioactive beam from ISOLDE
50 keV
30° bend
Pulsed laser beams
Charge exchange cell
~10^{-6} mbar
420 K
Deflector plates
Dumped ions
Differential pumping region
Interaction region (UHV)
<10^{-8} mbar
Deflector plates
Dumped atoms
Quadrupole doublet
Horizontal and vertical deflection plates
The DSS
MCP
See inset
Copper plate
APIPS
PIPS
Deflected ions
Collimator
Carbon foil
The ‘windmill’ system

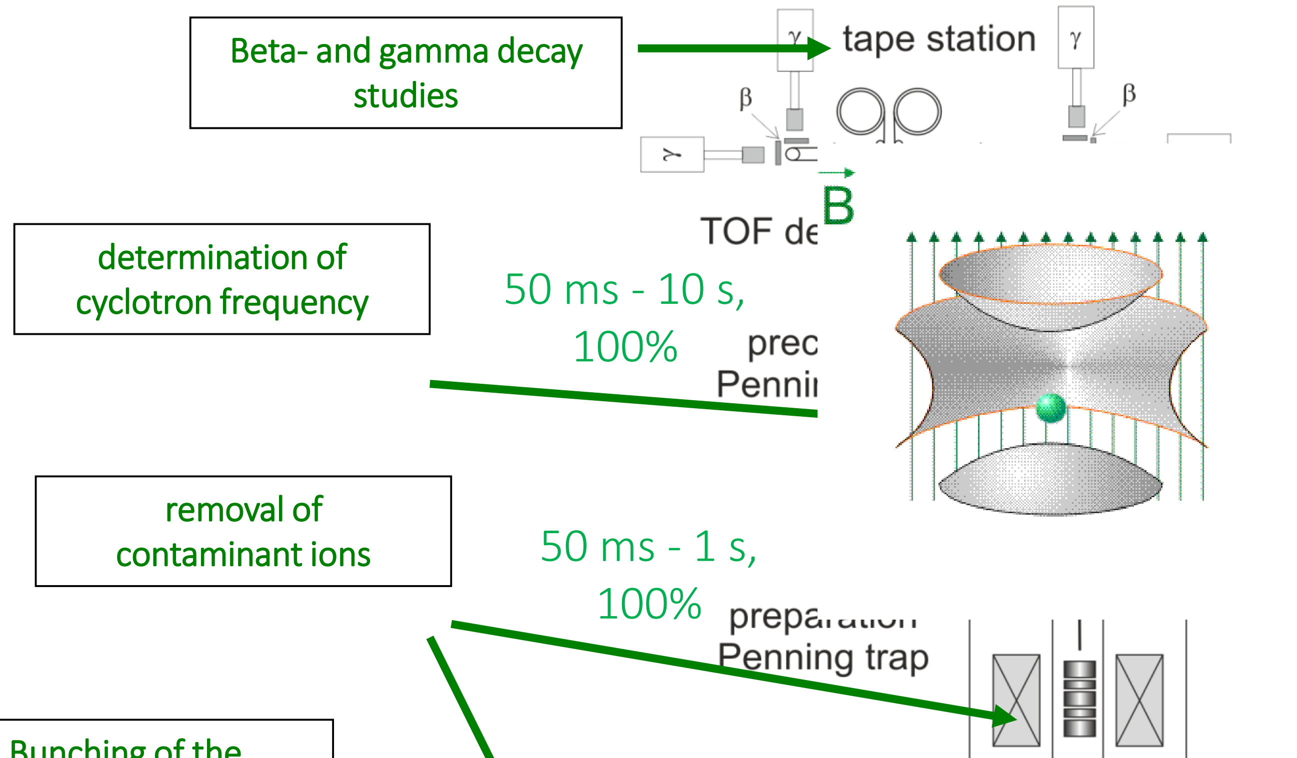
Penning-trap mass spectrometry

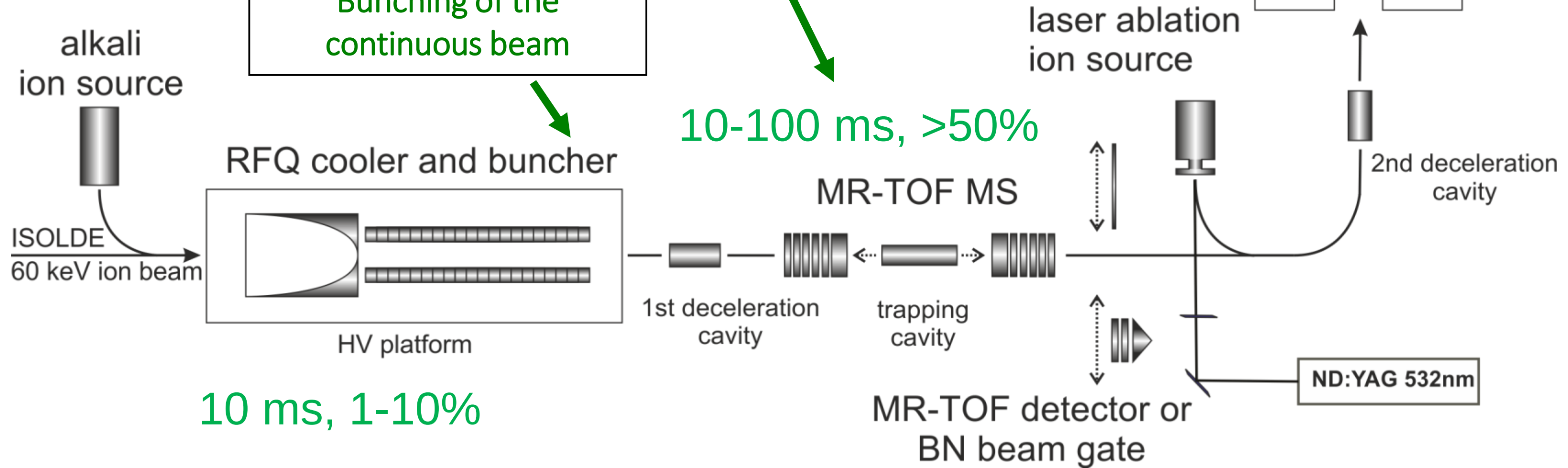
ISOLTRAP setup

From cyclotron frequency to mass

$$\nu_c = \frac{1}{2\pi}\frac{q}{m}B$$

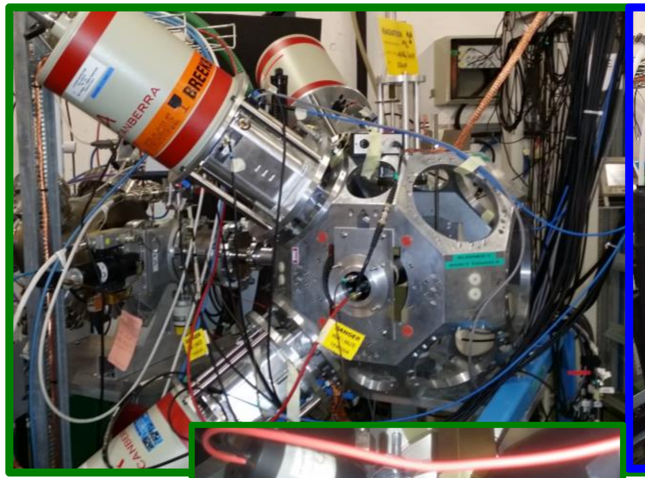
Relative mass uncertainty around 10^{-8}





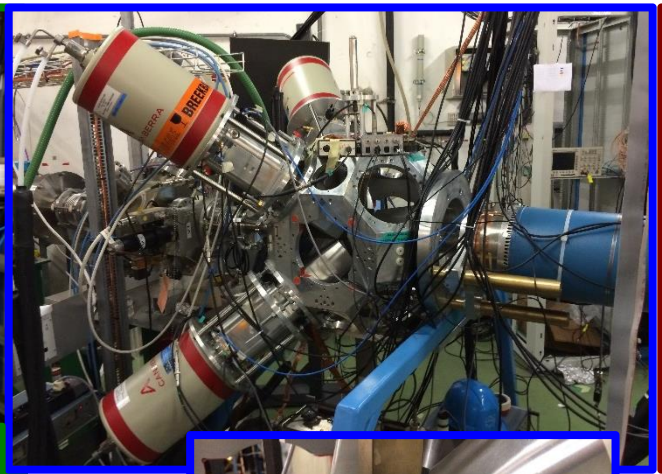
Versatile ISOLDE Decay Station (IDS)

Life Time Measurements



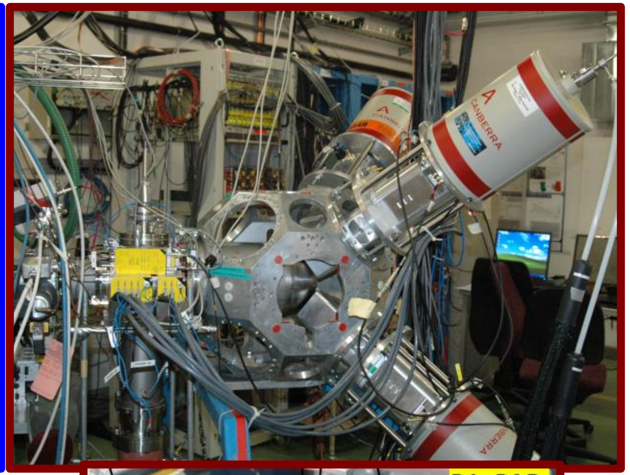

- Implantation on Tape
- 4 Ge Clovers at Backward angles
- 2 LaBr3
- 1 plastic scintillator
- Data on ^{129}In, 34Mg, 34Al..

High efficiency Gamma Spectroscopy

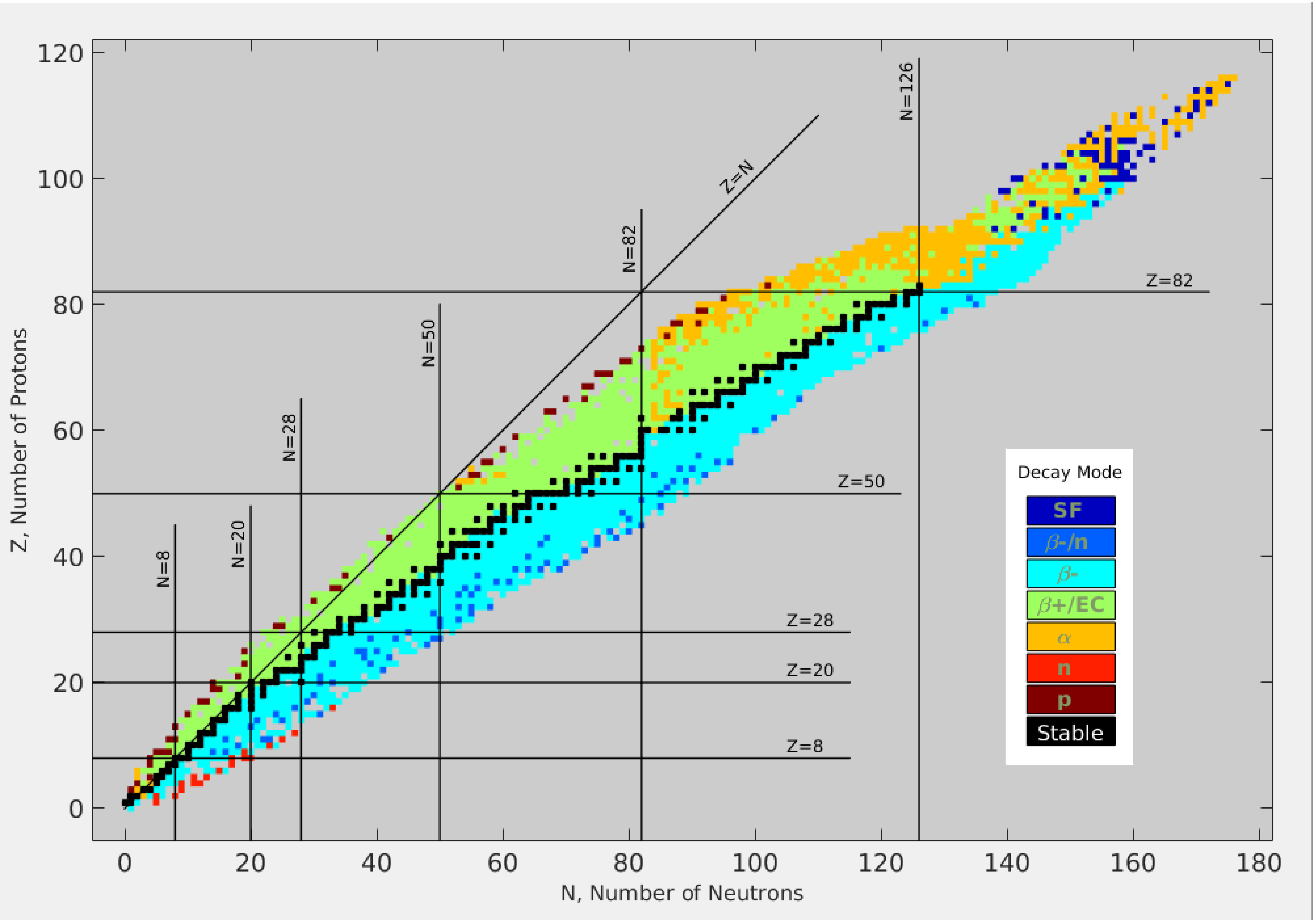


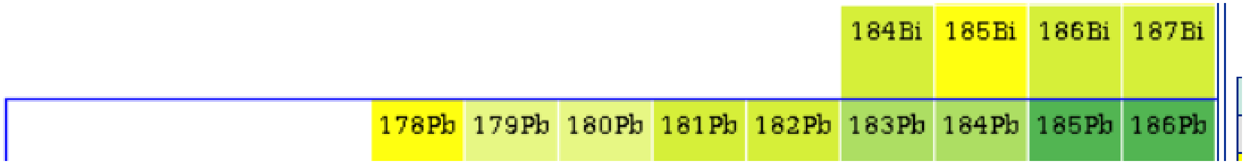

- Implantation on Tape
- 4 Ge Clovers at Backward angles
- 1Miniball Detector (triple cluster)
- 3 plastic scintillators
- ^{207,208}Hg, Mn

Charged Particle Spectroscopy




- Implantation on C foil
- 4 Ge Clovers at Forward angles
- Si box


Decay Mode
SF
β-/n
β-
β+/EC
α
n
p
Stable
Z=N
N=8
N=20
N=28
N=50
N=82
N=126
Z=8
Z=20
Z=28
Z=50
Z=82
Z, Number of Protons
N, Number of Neutrons



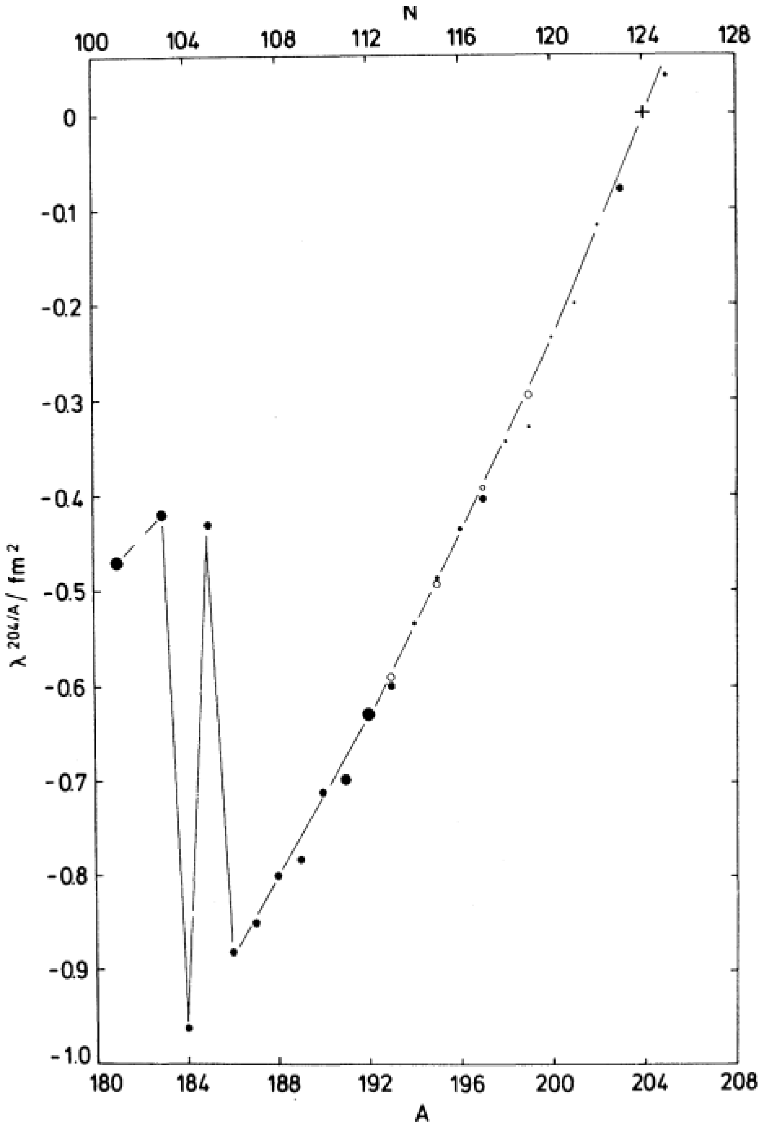
nature physics

LETTERS

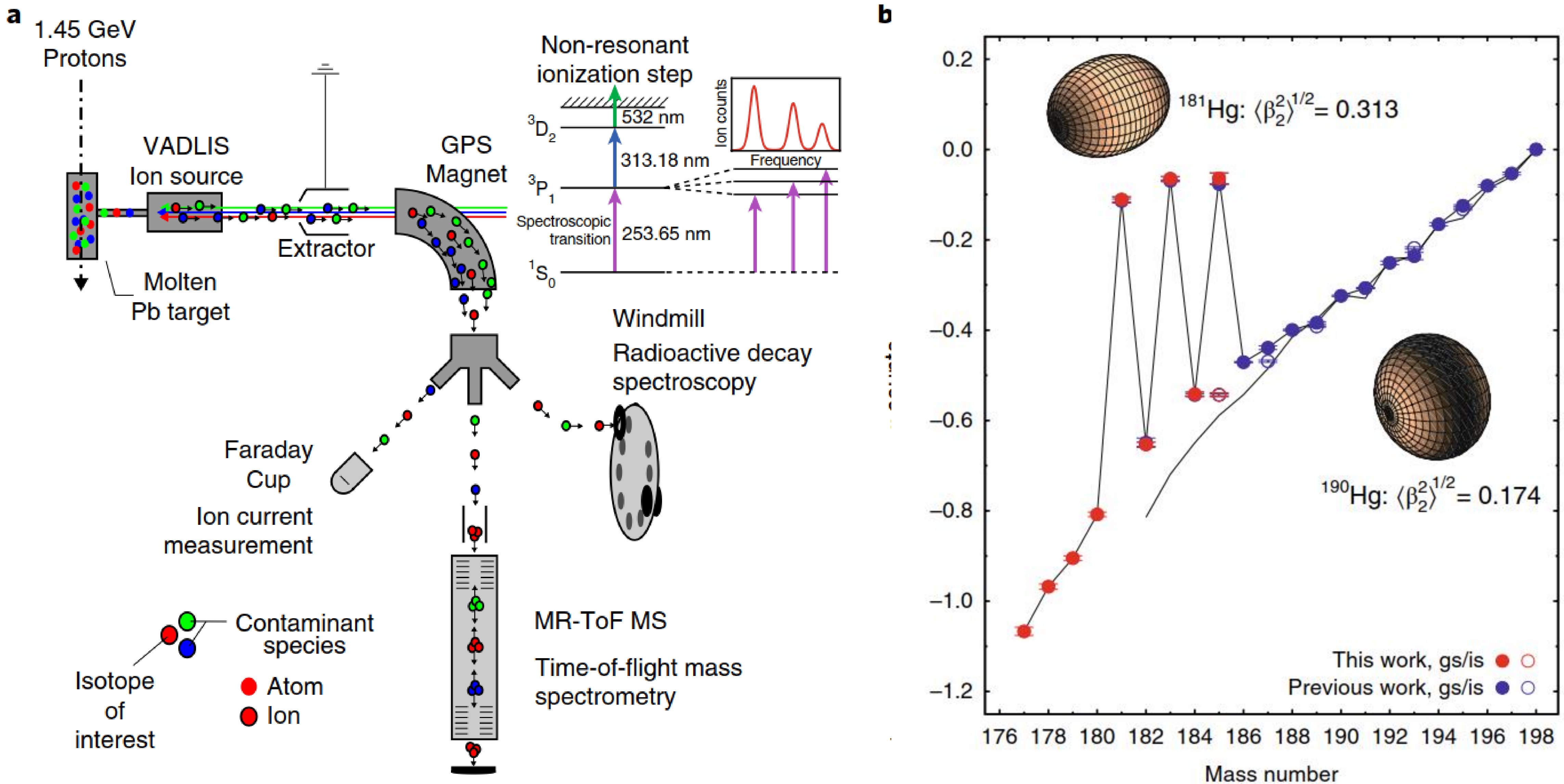
https://doi.org/10.1038/s41567-018-0292-8

Characterization of the shape-staggering effect in mercury nuclei

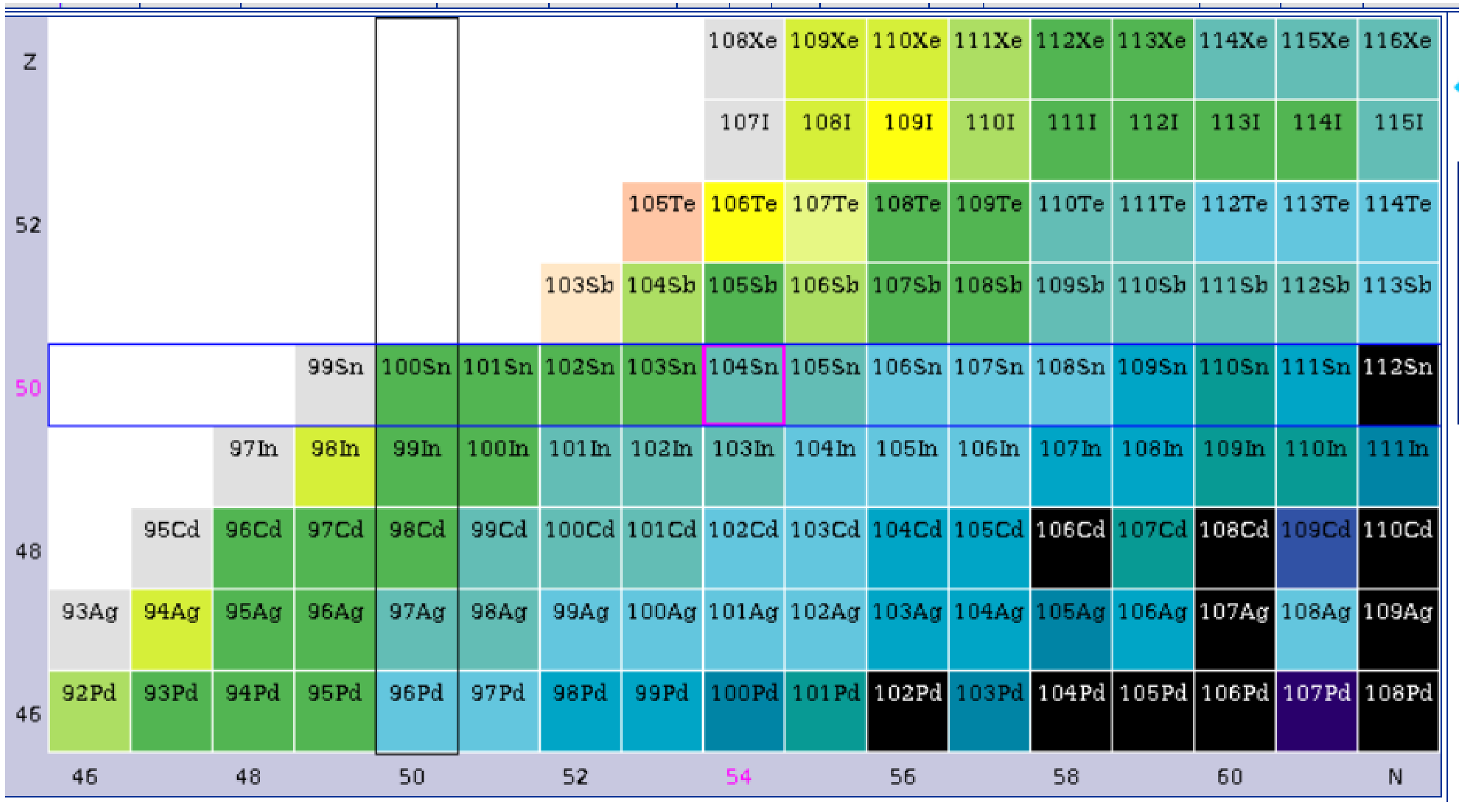
B. A. Marsh[1]*, T. Day Goodacre[1,2,18], S. Sels[3,18], Y. Tsunoda[4], B. Andel[5], A. N. Andreyev[6,7], N. A. Althubiti[2], D. Atanasov[8], A. E. Barzakh[9], J. Billowes[2], K. Blaum[8], T. E. Cocolios[2,3], J. G. Cubiss[6], J. Dobaczewski[6], G. J. Farooq-Smith[2,3], D. V. Fedorov[9], V. N. Fedosseev[1], K. T. Flanagan[2], L. P. Gaffney[3,10], L. Ghys[3], M. Huyse[3], S. Kreim[8], D. Lunney[11], K. M. Lynch[1], V. Manea[8], Y. Martinez Palenzuela[3], P. L. Molkanov[9], T. Otsuka[3,4,12,13,14], A. Pastore[6], M. Rosenbusch[13,15], R. E. Rossel[1], S. Rothe[1,2], L. Schweikhard[15], M. D. Seliverstov[9], P. Spagnoletti[10], C. Van Beveren[3], P. Van Duppen[3], M. Veinhard[1], E. Verstraelen[3], A. Welker[16], K. Wendt[17], F. Wienholtz[15], R. N. Wolf[8], A. Zadvornaya[3] and K. Zuber[16]



Neutron deficient Hg


a
1.45 GeV Protons
VADLIS Ion source
Molten Pb target
Extractor
GPS Magnet
Non-resonant ionization step
532 nm
313.18 nm
Spectroscopic transition
253.65 nm
$^3D_2$
$^3P_1$
$^1S_0$
Ion counts
Frequency
Windmill
Radioactive decay spectroscopy
Faraday Cup
Ion current measurement
MR-ToF MS
Time-of-flight mass spectrometry
Contaminant species
Isotope of interest
Atom
Ion
b
^{181}Hg: $\langle\beta_2^2\rangle^{1/2}$= 0.313
^{190}Hg: $\langle\beta_2^2\rangle^{1/2}$= 0.174
This work, gs/is
Previous work, gs/is
Mass number
0.2
0.0
−0.2
−0.4
−0.6
−0.8
−1.0
−1.2
176
178
180
182
184
186
188
190
192
194
196
198

Neutron deficient Sn



- **Shell evolution around N=Z=50** [Faestermann *et al.*, Prog. Part. Nucl. Phys. 69, 85 (2013)]
- **Heaviest self-conjugate doubly magic nucleus?** [Guastalla *et al.*, PRL 110, 172501 (2013)]
- **Proton-neutron correlations, pairing correlations** [Dean and Hjorth-Jensen, RMP 75, 607 (2003)]
- **Superallowed beta decay** [Hinke *et al.* Nature 486, 341 (2012)]
- **End of the rp process** [Schatz *et al*. PRL 86, 0031-9007 (2001)]

Open questions

- Shell evolution towards N=Z=50 ?
- Ordering of shell model orbits ?
- Robustness of N=Z=50 shell closures?

N=Z=50 shell closures?

Robust ?

- **Super-allowed beta decay of ^{100}Sn**
  [Hinke *et al.* Nature 486, 341 (2012)]
- **Coulomb Excitation of ^{104}Sn**
  [Guastalla *et al.*, PRL 110, 172501 (2013)]

Sof?

- **Coulomb Excitation of $^{106-112}Sn$**
  [Vaman *et al.*, PRL 99, 162501 (2007)]
- **Microscopic shell model studies**
  [Coraggio *et al.* PRC 91, 041301(R) (2015)]

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Laser Spectroscopy of neutron-deficient Sn isotopes

January 11, 2016

Ground state properties of neutron deficient Sn towards 100Sn.

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Letter of Intent to the
ISOLDE and Neutron Time-of-Flight Experiments Committee
for experiments with HIE-ISOLDE

Transfer Reactions and Multiple Coulomb Excitation in the ^{100}Sn region

J. Cederkall[1], D. Di Julio[1], C. Fahlander[1], R. Hoischen[1], J. Gellanki[1], P. Golubev[1], D. Rudolph[1], S. Siem[2], A. Goergen[2], G. Tveten[2] , P. A. Butler[3], D. T. Joss[3], M. Scheck[3], A. Blazhev[4,], J. Jolie[4] , N. Braun[4], P. Reiter[4], N. Warr[4], D. G. Jenkins[5], R. Wadsworth[5], S. Freeman[6], J. Iwanicki[7], P. Napiorkowski[7], M. Zielinska[7], M. Huyse[8], P. van Duppen[8] , R. Krucken[9], J.van de Walle[10], T. Davinson[11], Th. Kroll[12], J. Leske[12] , N. Pietralla[12], T. Grahn[13], D. Voulot[14], F. Wenander[14]

Excited state properties of neutron deficient Sn towards 100Sn

GPS schedule 2018

WK	Month	MO	Schedule	Notes
15	April	9	#513/ #650	
16	April	16	TISD; TISD; IS633	8B: IDS
17	April	23	#534/567 Sn VD5; IS611, IS640, IS647, IS652, IS653	111Cd
18	April	30	May-01; #599 Ti foils	
19	May	7	IS634; Ascension	RILIS: Mg
20	May	14	MD: FTS; MD:FTS; #653 UC-Ta n	
21	May	21	IS622	RILIS: Cu
22	May	28		
23	June	4	IS610; #634 LIST	RILIS: In
24	June	11	ISBM; ^{22}Mg to LA1; IS614	RILIS: Mg
25	June	18	Tech Stop; #655 Ta - W; IS528	RILIS: Dy (night-time)
26	June	25	Medical isotopes; IS528, IS638	RILIS: Dy (night-time)
27	July	2	#659 UC VD7	
28	July	9	IS644 (LOI205)	96Kr / 212Rn
29	July	16	IS644: 4.8MeV/u (IS506)	96Kr / 212Rn
30	July	23	#665 53Mn; #632 ThC VD7	
31	July	30	IS552: 4.1MeV/u	22x Rn
32	August	6	#650/513 MWCNT	
33	August	13	XT03; IS616: 4.5MeV/u	8B
34	August	20	#635 UC Ta	
35	August	27	IS629: 11Be @ 7MeV/u (IS655); XT03	RILIS: Be
36	September	3	IS629; IS634; Jeune	RILIS: Be
37	September	10	#641 UC Ta; IS576, IS578, IS630, IS648, IS653	RILIS: Mn
38	September	17	Tech stop; (IS655); (IS604)	
39	September	24	#619 Pb VD5; IS585, IS602, IS638, IS640	199Hg
40	October	1		
41	October	8	IS631 206Hg @ ~ 7.5MeV/u	RILIS: Hg
42	October	15	#633Th; Gandalph; Negative run: IS615	RILIS: At; MD on HIE
43	October	22	#534 Sn VD5; IS611, IS640, IS647, IS652, IS653	111Cd; MD on HIE
44	October	29	#638 UCW; XT03; IS561 9Li @ 7.5MeV/u	
45	November	5	(IS655); LOI198; IS637	RILIS: Ac (GLM/GHM/LA1)
46	November	12	p⁺ off 0600; Prep for winter Physics (separate file)	

Cu FT
In FT
Bi FT/in-source
Tl/Hg SPEDE

Sc/In
70Br

n-def In
n-rich K
n-def Sn

Ge + S
Sc
n-rich Sb

Medical Biophysics

119Sb for biopac
149Tb/152Tb
199Hg
Ac beam development

β-NMR on liquids

ISOLDE Solid State Physics

Parallel Hg/Cd

Mg,Be
Mn, Ac

Good Mn run

Travelling

8B @ LA1
22Mg @ LA1
Ac development
(2 setups)
GANDALPH (-ve)

TISD/MD

-ve beams
LIST
New n-conv
RFQ MD
HIE MD
FTS commissioning
(no LIEBE)

Later....

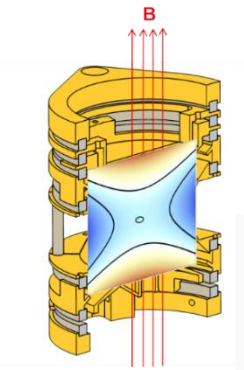
XT03

HRS schedule 2018

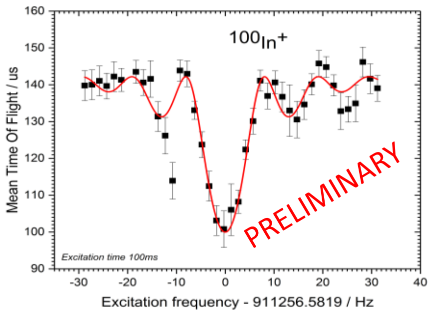
WK	Month	MO	Schedule	Notes
15	April	9	IS639	In RILIS; (#640 LaC - n)
16	April	16	#627 Ta -W	
17	April	23	IS532	Sc RILIS; In RILIS
18	April	30	#651 ZrO HP; May-01; TISD; IS623	RILIS test; Ge 34S
19	May	7	#652 ZrO HP; Ascension; IS642	70Br
20	May	14	#618 UC- Ta/W; IS645	26Na
21	May	21	#654 UC - W	
22	May	28	IS620	K beams
23	June	4	#626 Ta - W; IS649	Sc RILIS
24	June	11	TBC	
25	June	18	Tech Stop; Machine development	
26	June	25	Machine development	
27	July	2	#658 UC Ta (+CF4); IS650, IS637, IS608	RILIS: Bi
28	July	9		
29	July	16	#637 UC W (+CF4)	
30	July	23	IS552, IS553: 4.1MeV/u	22xRa/142Ba
31	July	30	#631 LaC Ta	
32	August	6	IS562: 4.4MeV/u	Sn RILIS
33	August	13	#639 LaC Ta	
34	August	20	IS613	Sn RILIS
35	August	27	#643 UC+34S	
36	September	3	Jeune; 134Sn @ 7.33MeV/u	134Sn+34S
37	September	10	IS654; #623 SiC	
38	September	17	Tech stop; IS651 28Mg @ 9.5MeV/u	RILIS: Mg
39	September	24	IS621 28Mg@9.5 MeV/u	RILIS: Mg
40	October	1	#662 UC n; IS635	RILIS: Sb
41	October	8	IS638	
42	October	15	(tbc) UC; tuning IDS VITO	MD on HIE
43	October	22	IS645; IS641 (end Sat night)	RILIS: Tl; MD on HIE
44	October	29	#642 UC n(ew)-conv; TISD	
45	November	5	TISD; TISD; #672 CaO VD7; WISArD LOI172	RILIS: for TISD
46	November	12	p⁺ off 0600; Prep for winter Physics (separate file)	

ISOLTRAP : experimental campaigns in 2018

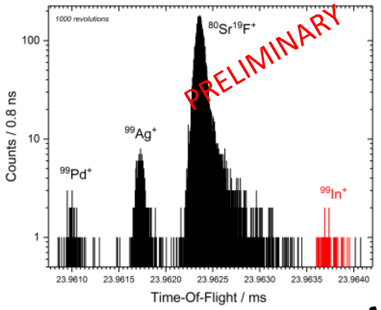
April 2018 – LaC_x + RILIS: high-quality Indium beams.

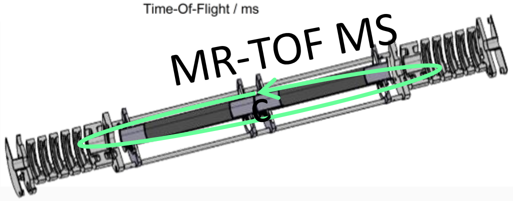


Precision Penning trap



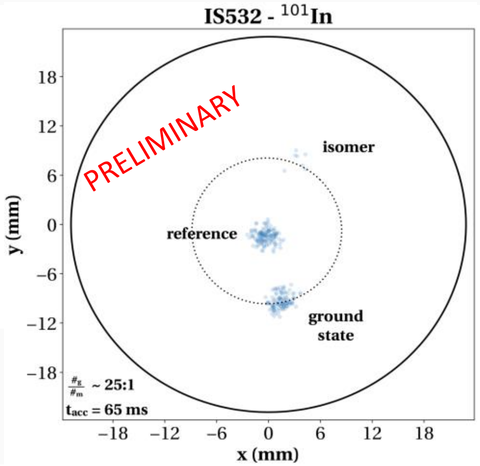
Penning trap measurements improve the mass uncertainty of ^{100}In by a factor 100.





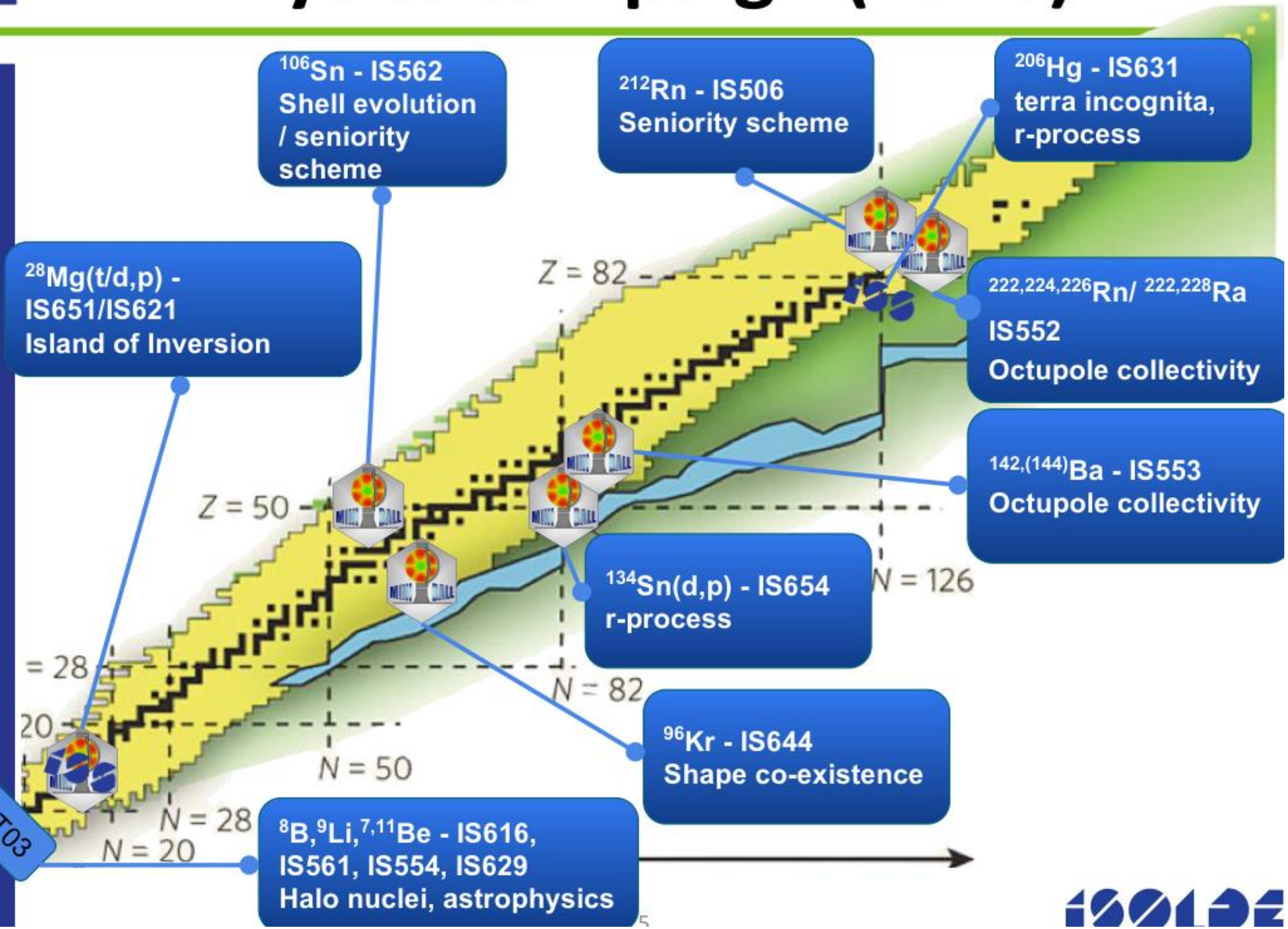
MR-TOF MS allows first mass measurement of ^{99}In

PI-ICR technique allows first mass measurement of $^{101}In^{g,m}$.



- $^{52\text{-}55}Sc$ run (RILIS+Ta-foil target)
  - Confirms that neutron rich Sc up to *A*=52 are produced ☺
  - Stable Ti-V-Cr isobaric contamination too strong ☹
  - Impossible to measure the Sc isotopes of interest
  - Run redirected to In ☺☺☺
- ^{70}Br Q_{ec} value : Mai 2018
  - lower production rate and higher than expected contamination ☹

Physics campaign (2018)



ISOLDE

MB: IS562 - ^{106}Sn

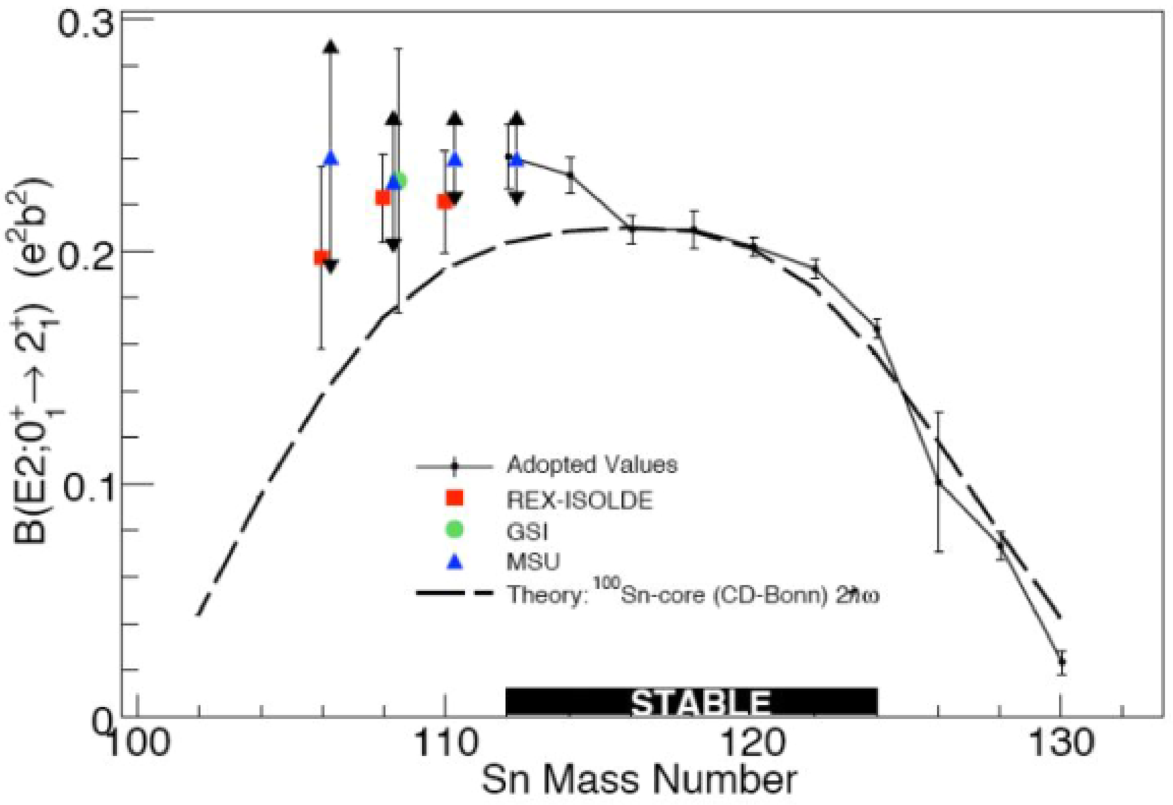
Transfer Reactions and Multiple Coulomb Excitation in the ^{100}Sn Region,

J. Cederkäll *et al.*

- Study discrepancies of B(E2)s in light Sn isotopes (textbook seniority scheme example!)

Experiment 8.-13.8.2018:

- ^{106}Sn @ 4.404 MeV/u on ^{206}Pb target
- Contamination from ^{106}In
- Obtained very good statistics on $2^+ \to 0^+$
- $4^+ \to 2^+$ overlaps with ^{206}Pb transition but may be recovered using more careful particle selection by reaction kinematics



Sensitivity, yield and impurities

All the aforementioned techniques have their own specific limitations/requirements:

- CRIS sensitive to ~100 ions / s
- Requires bunched beam (i.e. HRS)
- ISOLTRAP sensitive to ~0.5 ions/s (if clean)
- Coulex requires at least 100 ions/s at setup i.e. at least 1000/s yield (ideally x10 more both ends)
- Impurities can always be a problem either isobaric, double-charged etc etc from target or products of ion source
- Release information can be crucial for experiments: detailed yield analysis required.