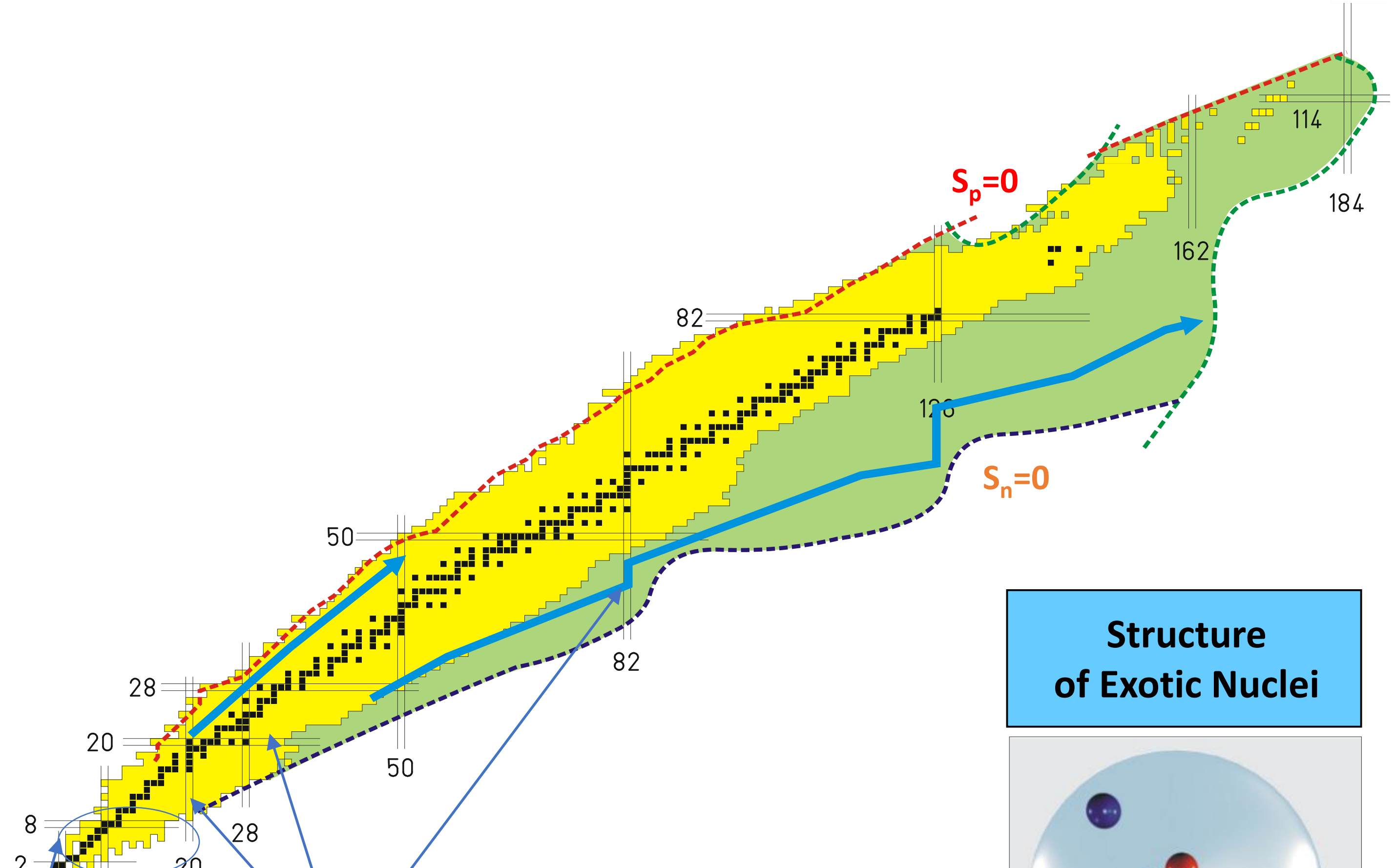
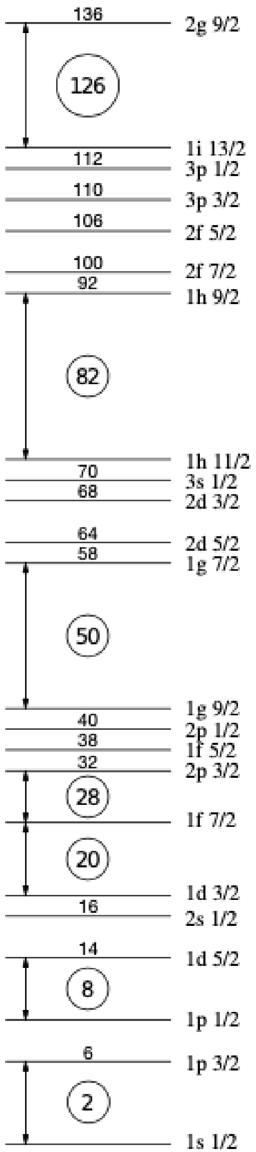
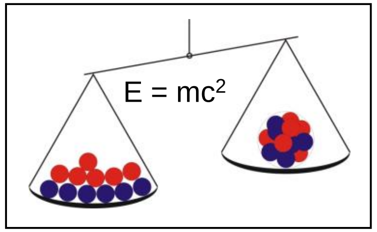
Ion Trapping Developments at Edinburgh University, for Precise Mass Measurement of Light Exotic Nuclei at TITAN, TRIUMF

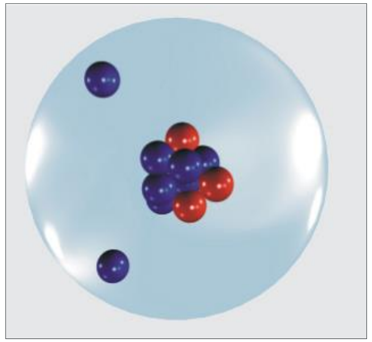
Callum Brown





Structure of Exotic Nuclei





$\delta m/m \approx 10^{-6} - 10^{-7}$

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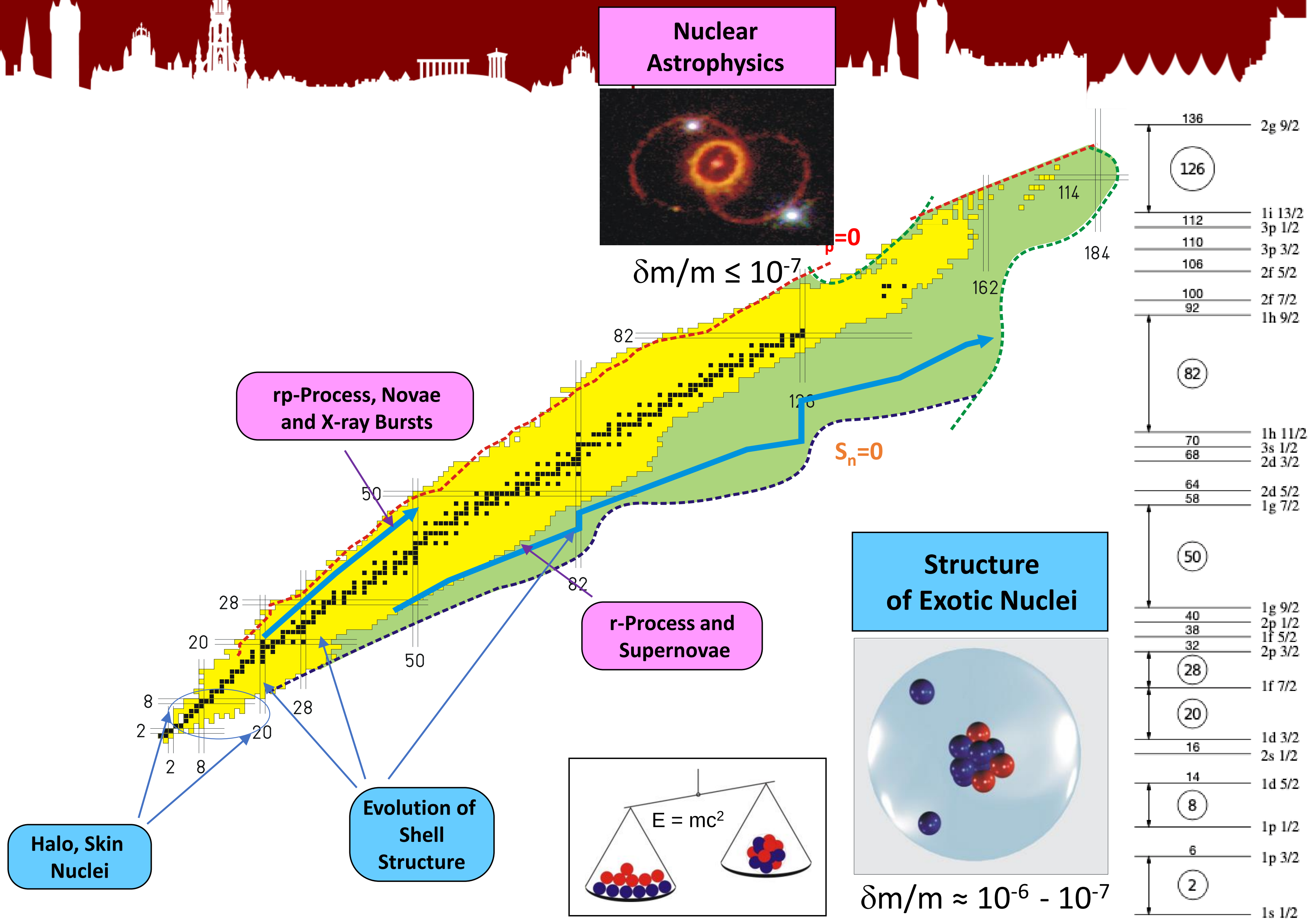

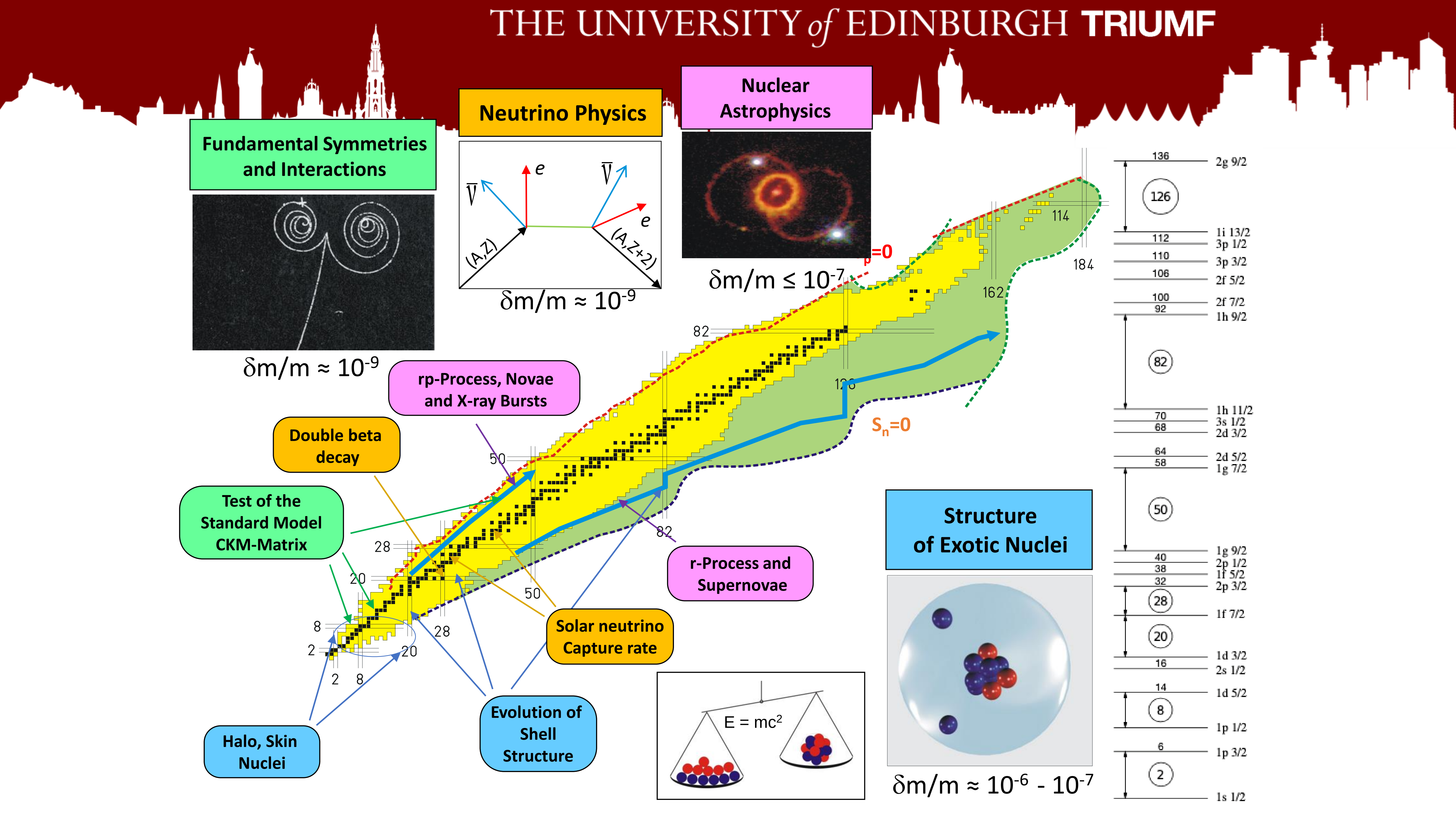
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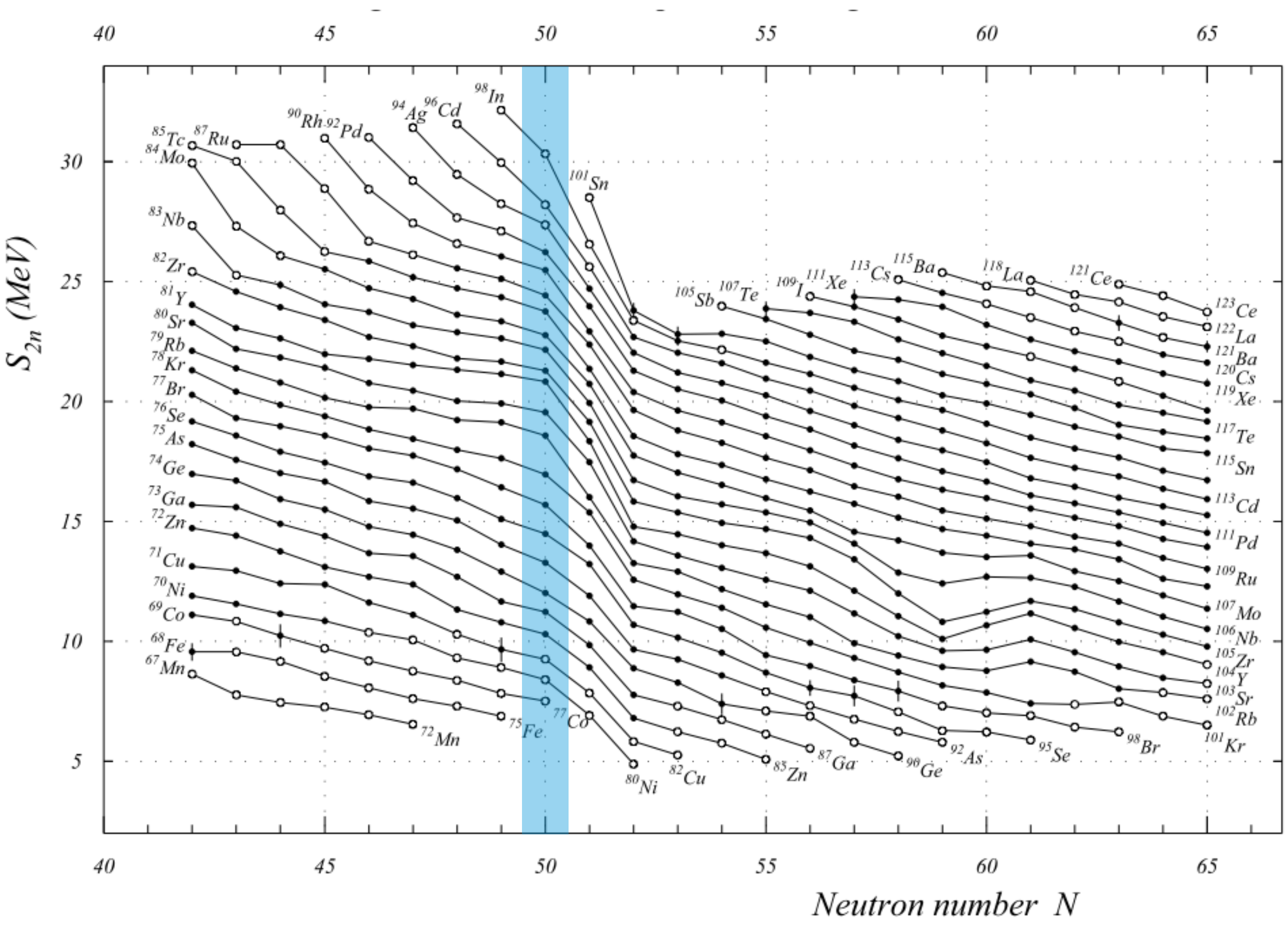
Fundamental Symmetries and Interactions
δm/m ≈ 10-9
Neutrino Physics
(A,Z)
(A,Z+2)
e
δm/m ≈ 10-9
Nuclear Astrophysics
δm/m ≤ 10-7
rp-Process, Novae and X-ray Bursts
Double beta decay
Test of the Standard Model CKM-Matrix
Halo, Skin Nuclei
Evolution of Shell Structure
Solar neutrino Capture rate
r-Process and Supernovae
Sn=0
Structure of Exotic Nuclei
E = mc2
δm/m ≈ 10-6 - 10-7
2
8
20
28
50
82
126
114
162
184
136
112
110
106
100
92
70
68
64
58
40
38
32
16
14
6
2g 9/2
1i 13/2
3p 1/2
3p 3/2
2f 5/2
2f 7/2
1h 9/2
1h 11/2
3s 1/2
2d 3/2
2d 5/2
1g 7/2
1g 9/2
2p 1/2
1f 5/2
2p 3/2
1f 7/2
1d 3/2
2s 1/2
1d 5/2
1p 1/2
1p 3/2
1s 1/2

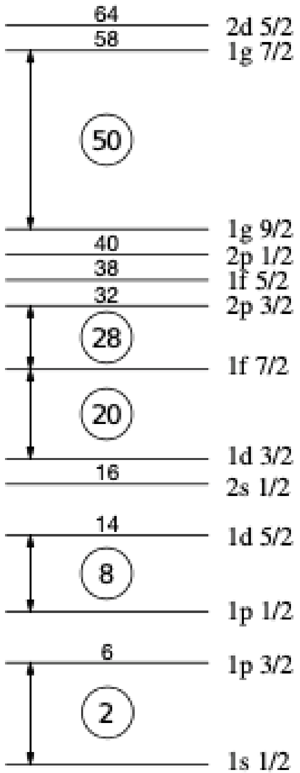
Masses for Nuclear Structure

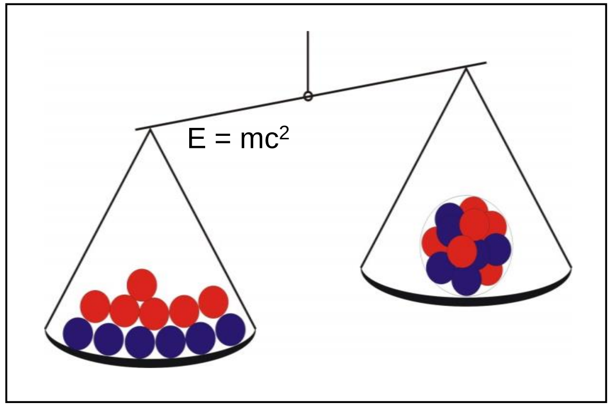


$$E_{\mathrm{B}}(N,Z) = [M_{\mathrm{a}}(N,Z) - Nm_{\mathrm{n}} - Z(m_{\mathrm{p}} + m_{\mathrm{e}})]c^2$$

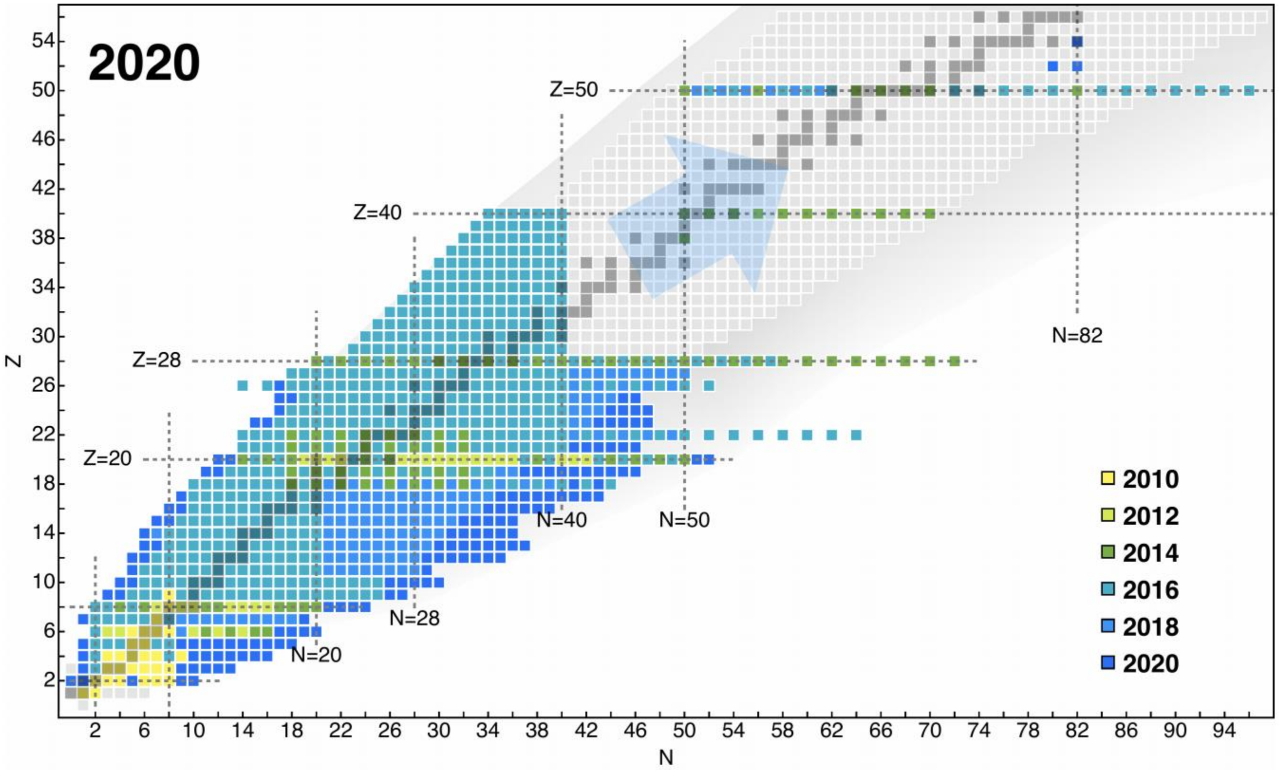
$$S_{2\mathrm{n}}(N,Z) = M_{\mathrm{a}}(N-2,Z) + 2M_{\mathrm{n}} - M_{\mathrm{a}}(N,Z)$$

$$S_{2\mathrm{p}}(N,Z) = M_{\mathrm{a}}(N,Z-2) + 2M_{\mathrm{p}} - M\mathrm{a}(N,Z)$$





Masses for Nuclear Structure



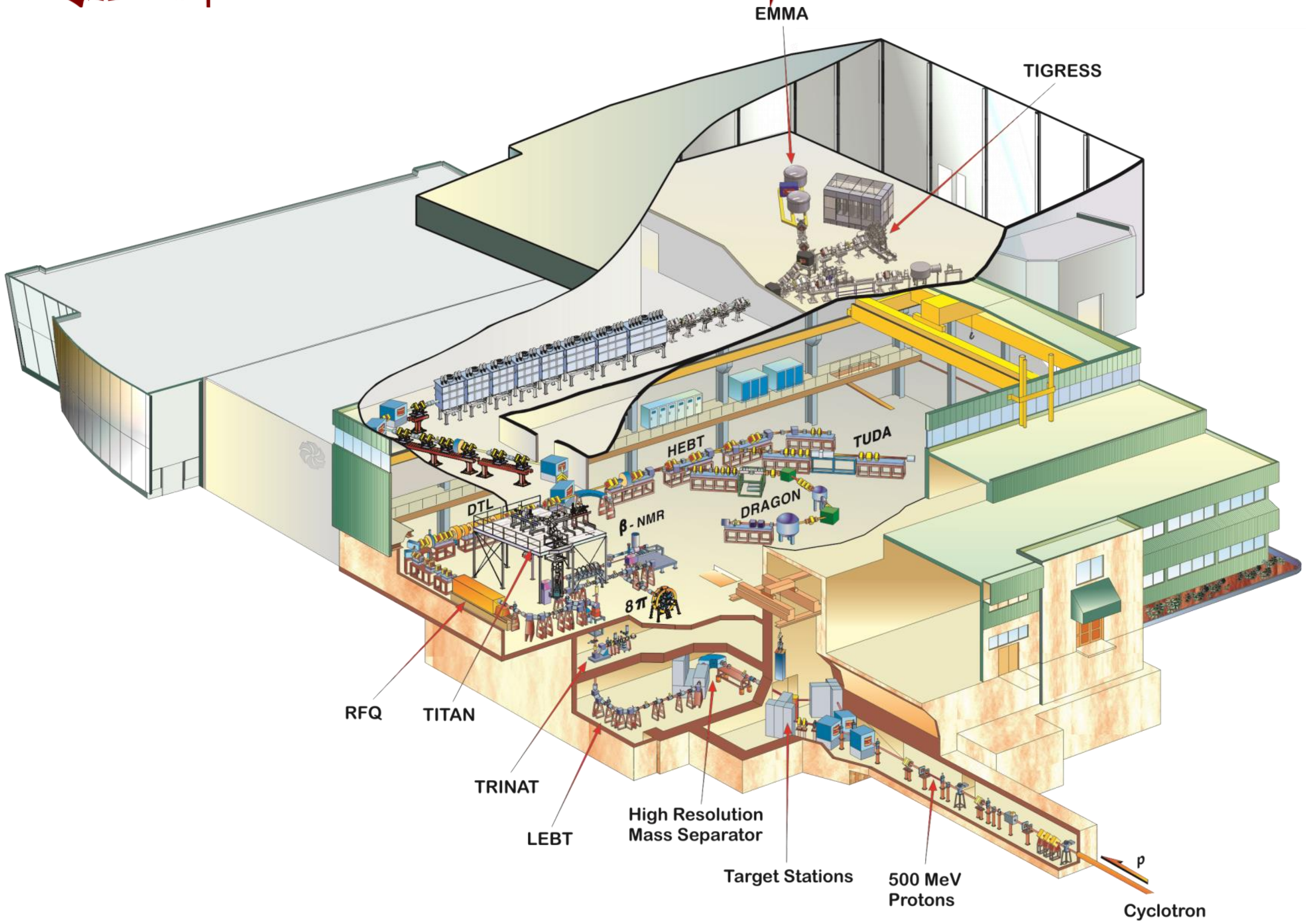
Evolution of Shell Structure:

- Deformation, Inversion
- Developing theoretical models (ab-initio)

ISAC

TRIUMF's Isotope Separator and Accelerator (ISAC)

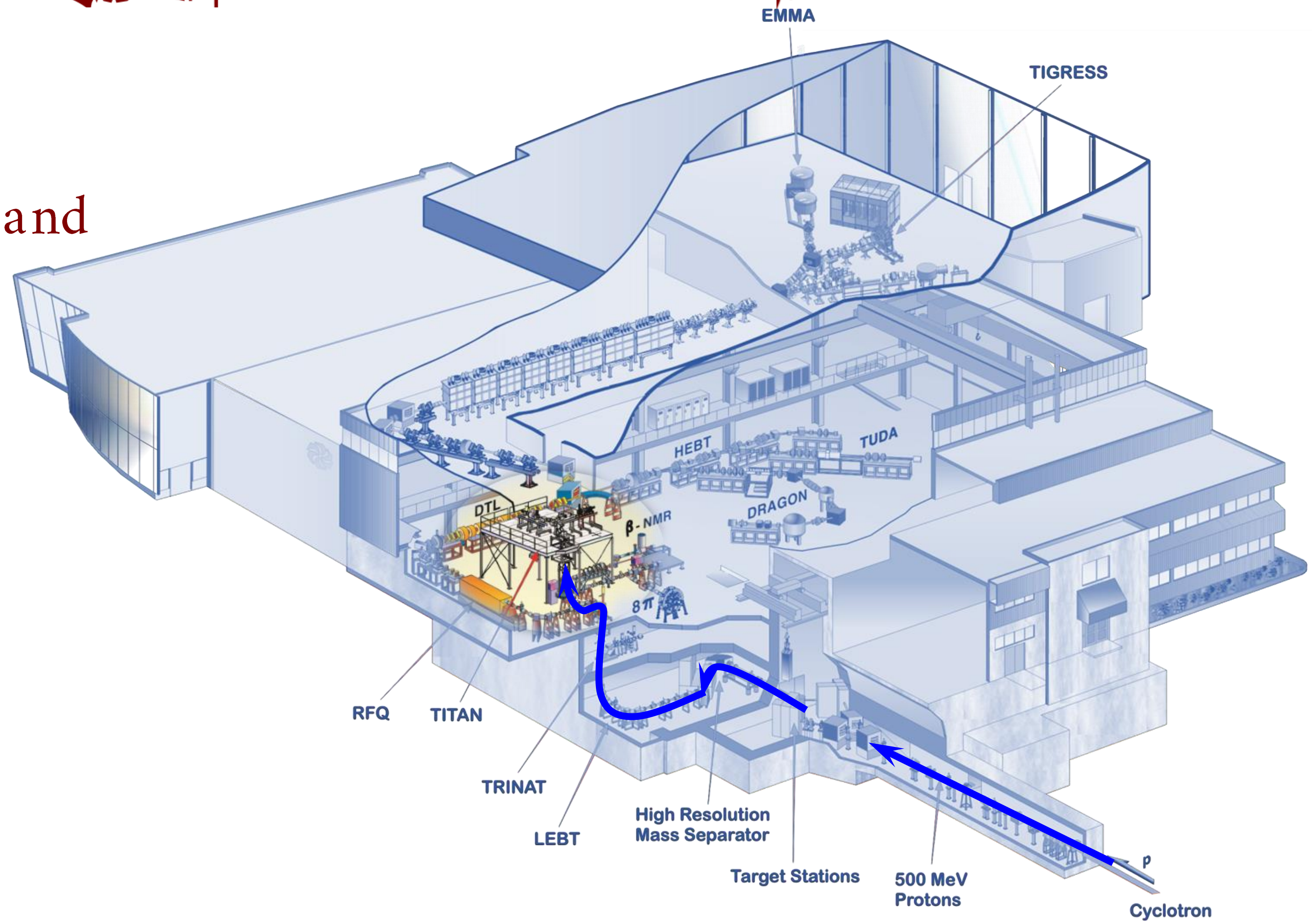
- Isotope Separation On-Line (ISOL)
- 500 MeV p @ 100μA
- Resonant Ionisation Laser Ion Source (TRILIS)



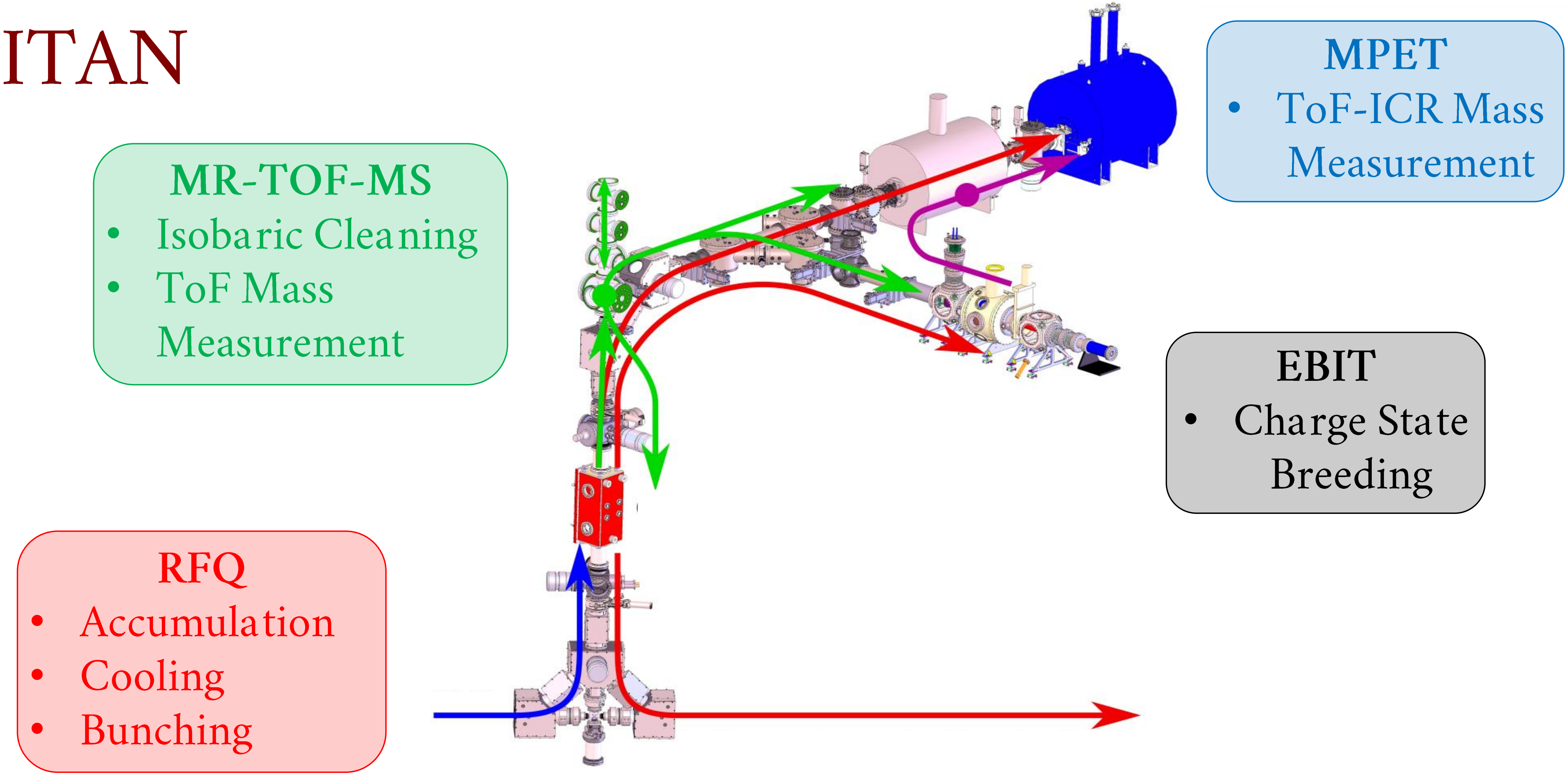
TITAN

TRIUMF's Ion Trap for Atomic and Nuclear Science (TITAN)

- Decay Spectroscopy
- High Precision Mass Measurements



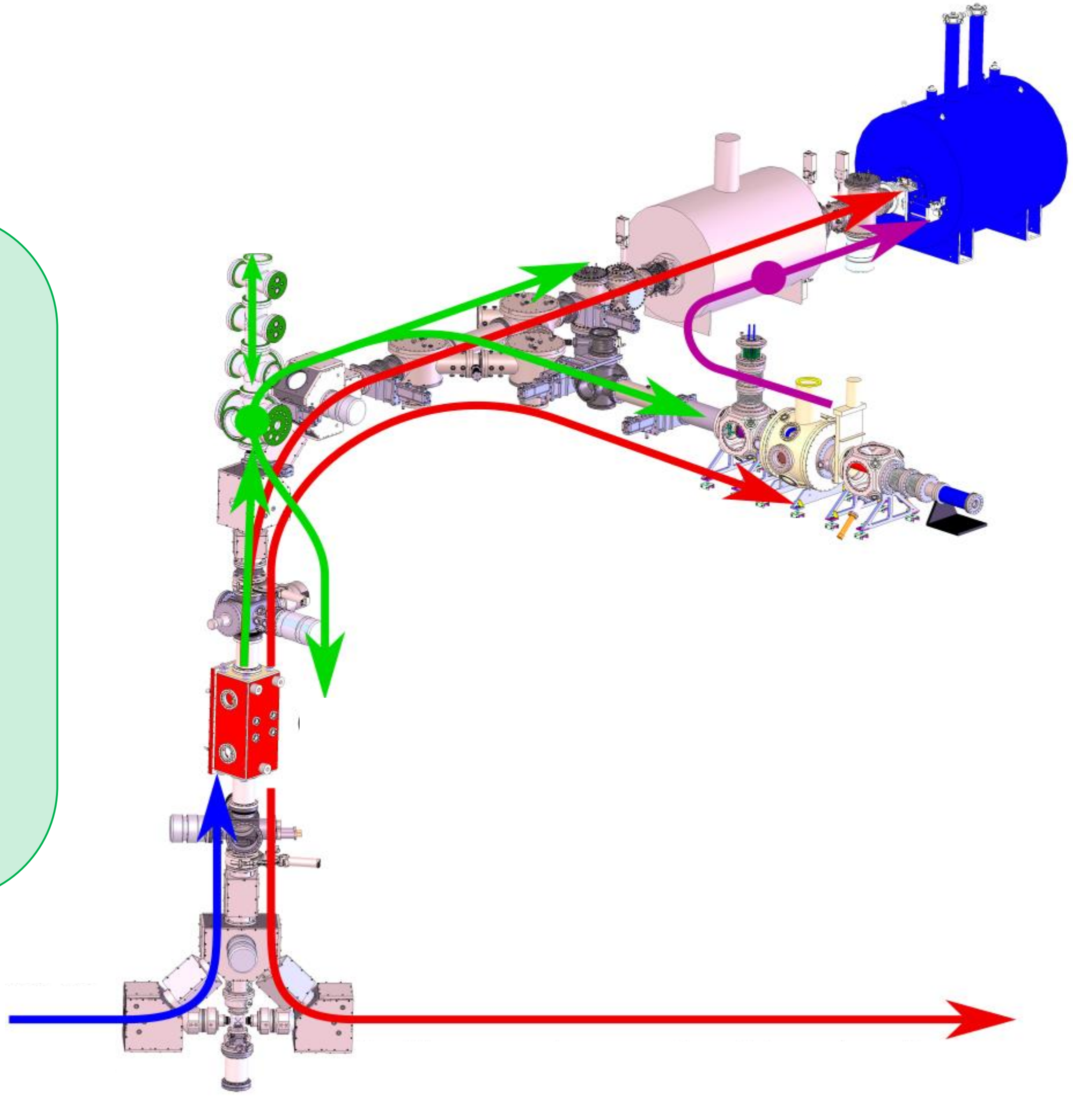
TITAN



J. Dilling *et al.*, NIMB 204 (2003) 492, C. Jesch et al., Hyperfine Interact. 235 (2015) 97

TITAN

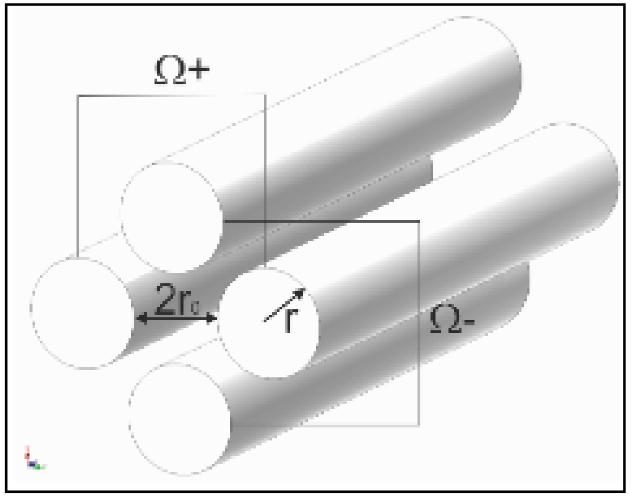
MR-TOF-MS
- Isobaric Cleaning
- ToF Mass Measurement
- 10^{-7} precision
- Very high sensitivity
- Short measurement times



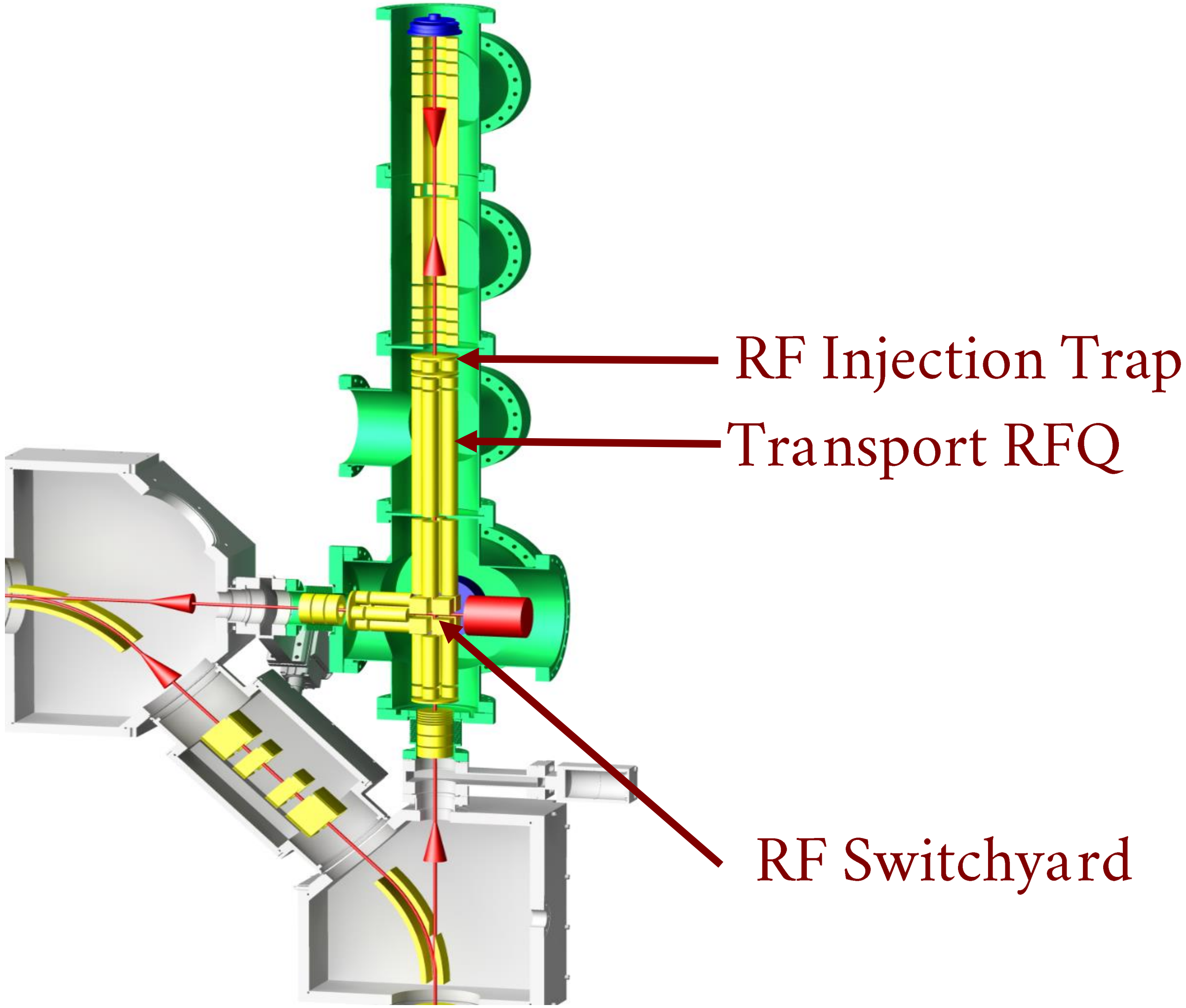
MPET
- ToF-ICR Mass Measurement
- 10^{-9} precision

TITAN MR-TOF-MS

Low energy transport and preparation with gas-filled radio-frequency quadrupoles (RFQs)



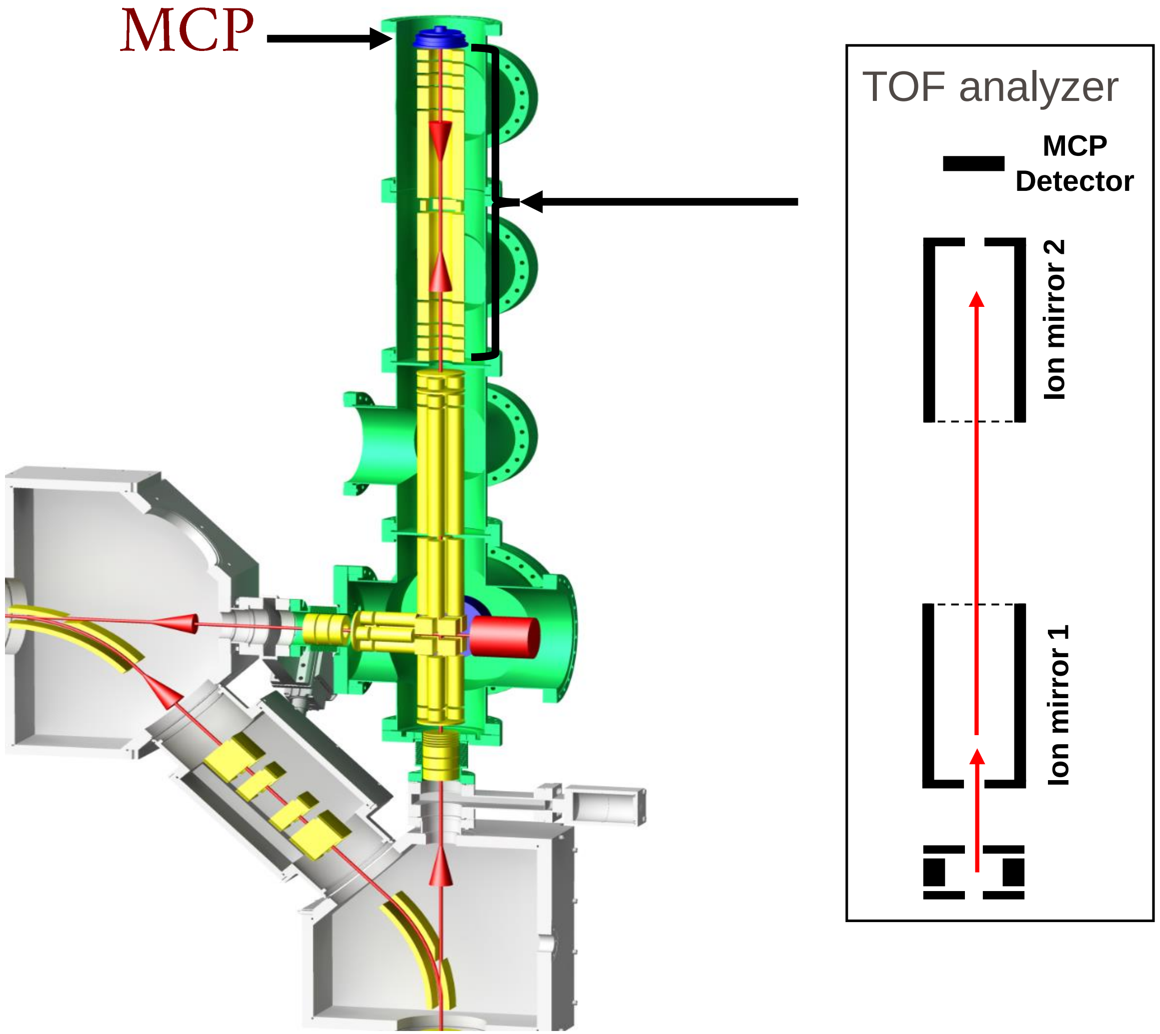
C. Jesch et al., Hyperfine Interact. 235 (2015) 97
W. Plass et al., Phys. Scr. T166 (2015) 014069



TITAN MR-TOF-MS

- Time-of-flight (ToF) measurement
- Isochronicity:

$$\frac{m}{q} \propto t^2$$



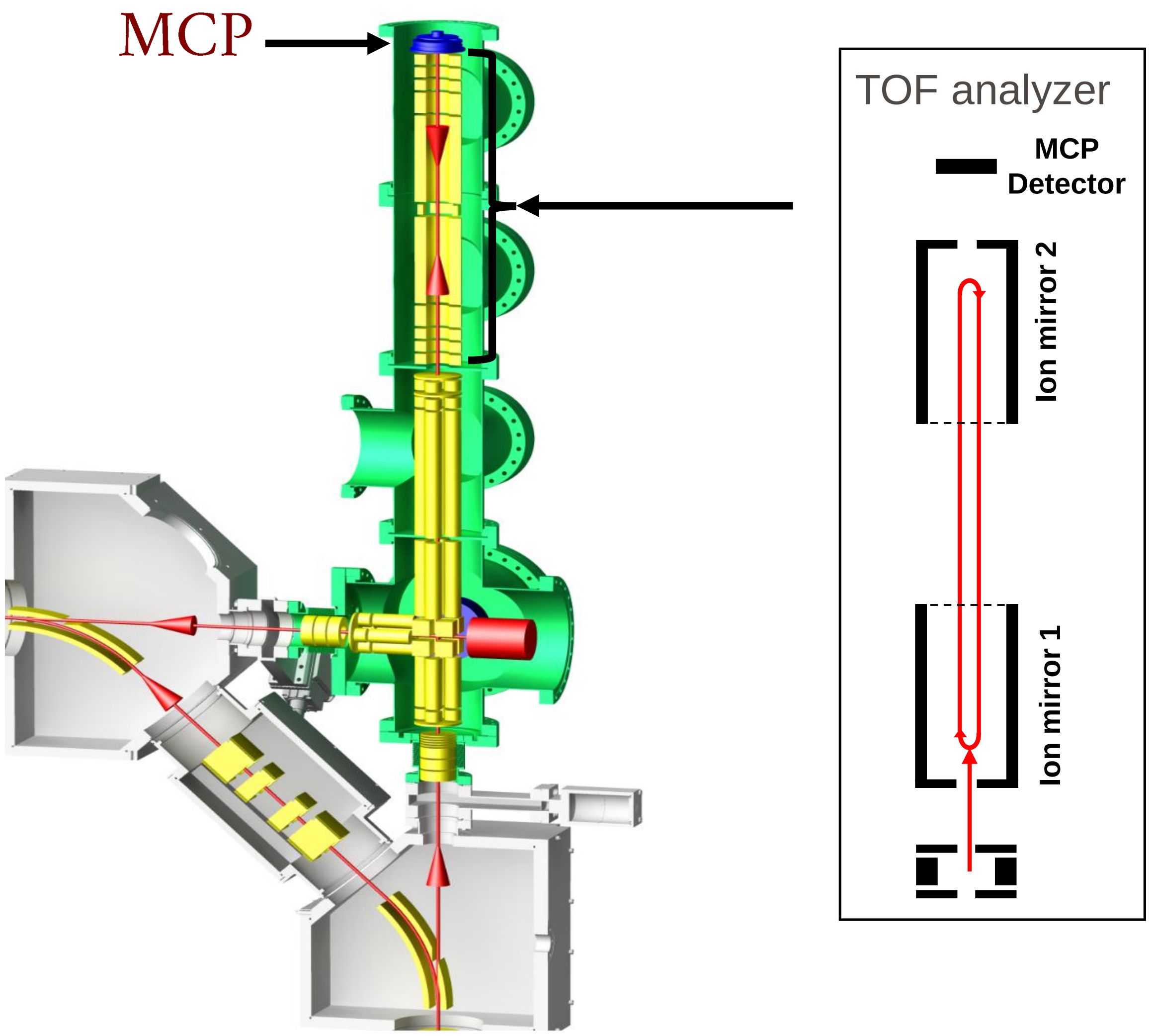
C. Jesch et al., Hyperfine Interact. 235 (2015) 97
M. Yavor et al., Int. J. Mass Spec. 381 (2015) 1-9
T. Dickel et al., J. ASMS 28 (2017) 1079
T. Dickel et al., IJMS 412 (2017) 1-7

TITAN MR-TOF-MS

- Time-of-flight (ToF) measurement
- Isochronicity:

$$\frac{m}{q} \propto t^2$$

- Multiple Reflection
- Path length boosts resolving power



C. Jesch et al., Hyperfine Interact. 235 (2015) 97
M. Yavor et al., Int. J. Mass Spec. 381 (2015) 1-9
T. Dickel et al., J. ASMS 28 (2017) 1079
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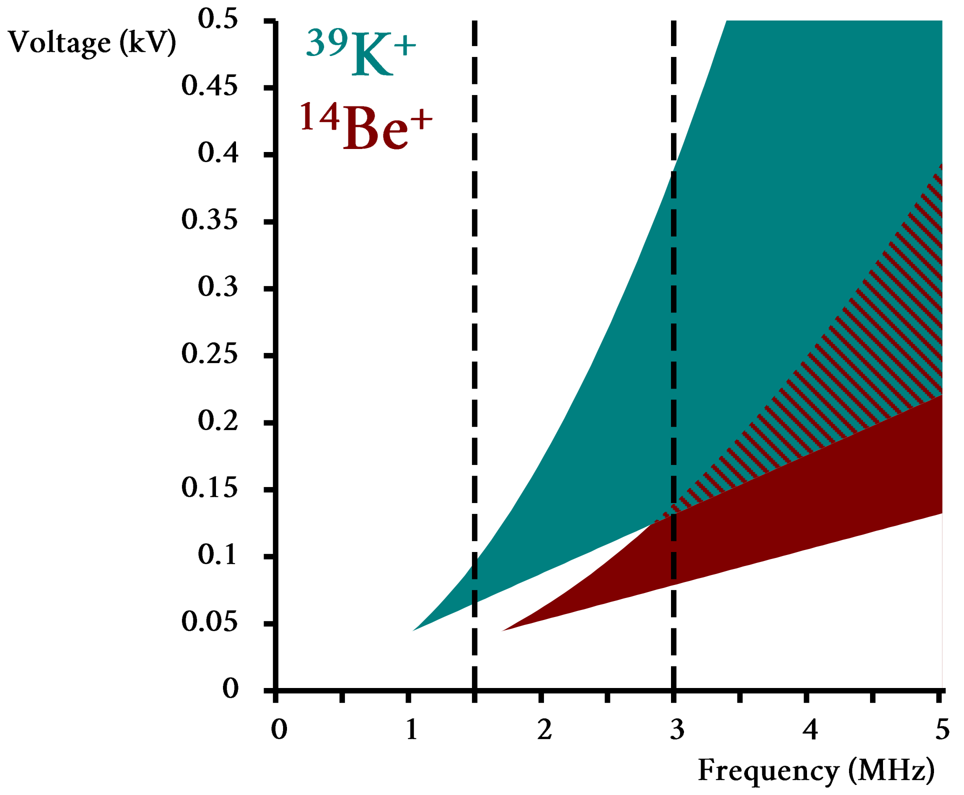
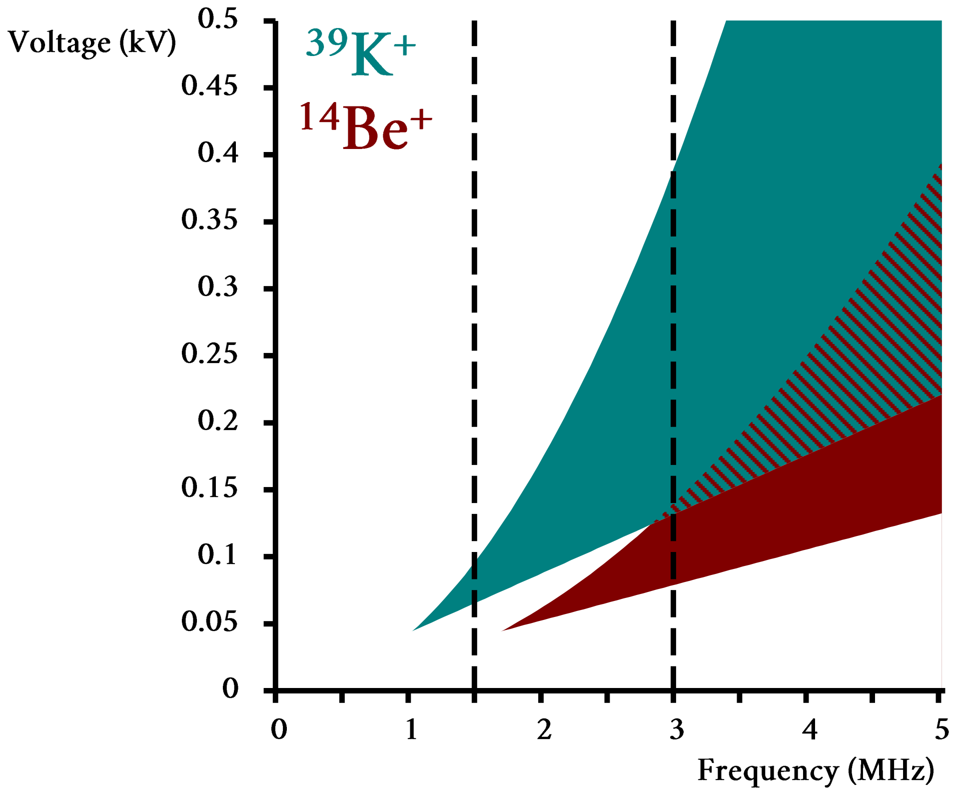
Upgraded RF

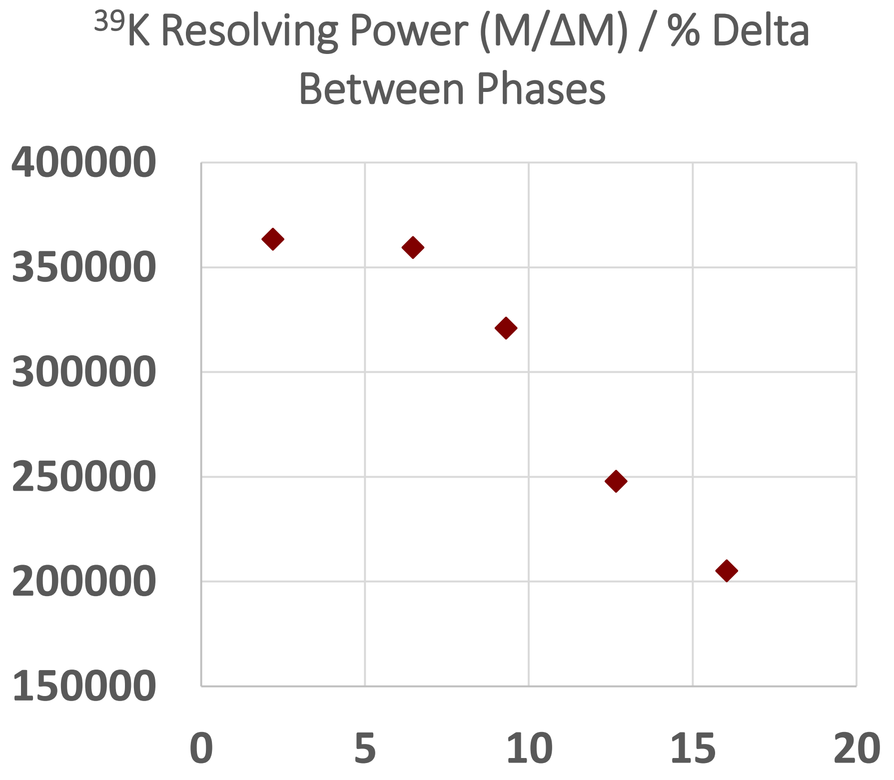
- Appropriate V, f necessary for transport



Upgraded RF

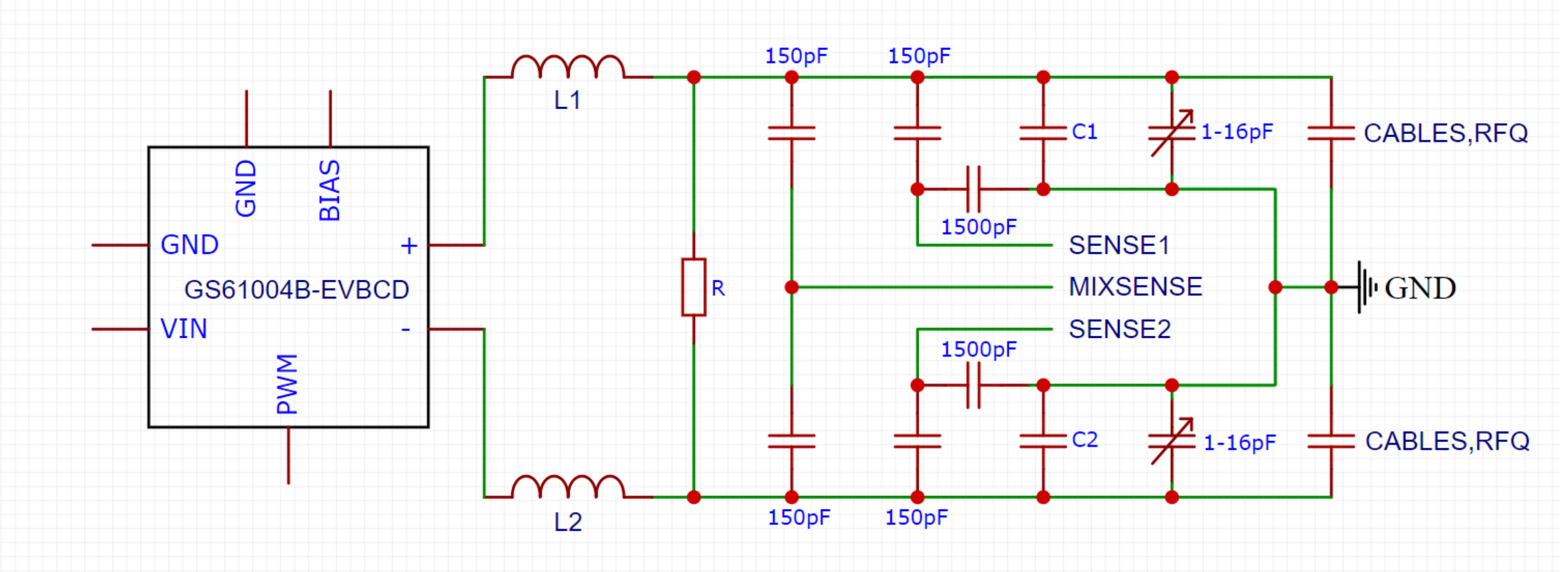
- Appropriate V, f necessary for transport
- Matched phases maximise resolving power

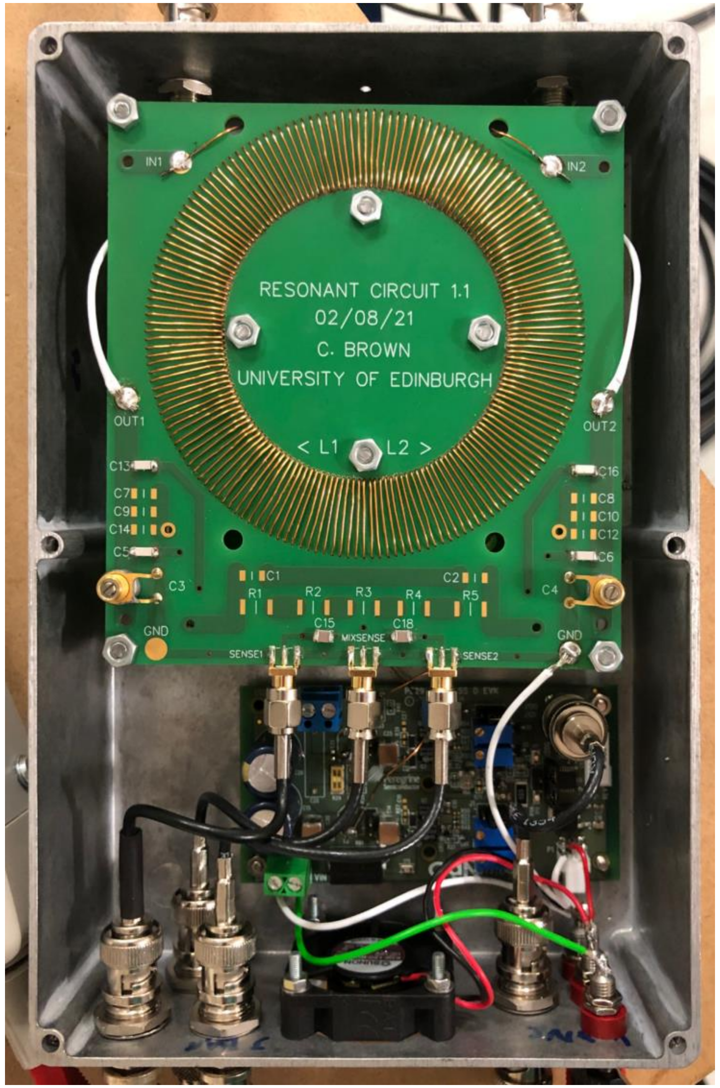




Edinburgh RF Drivers

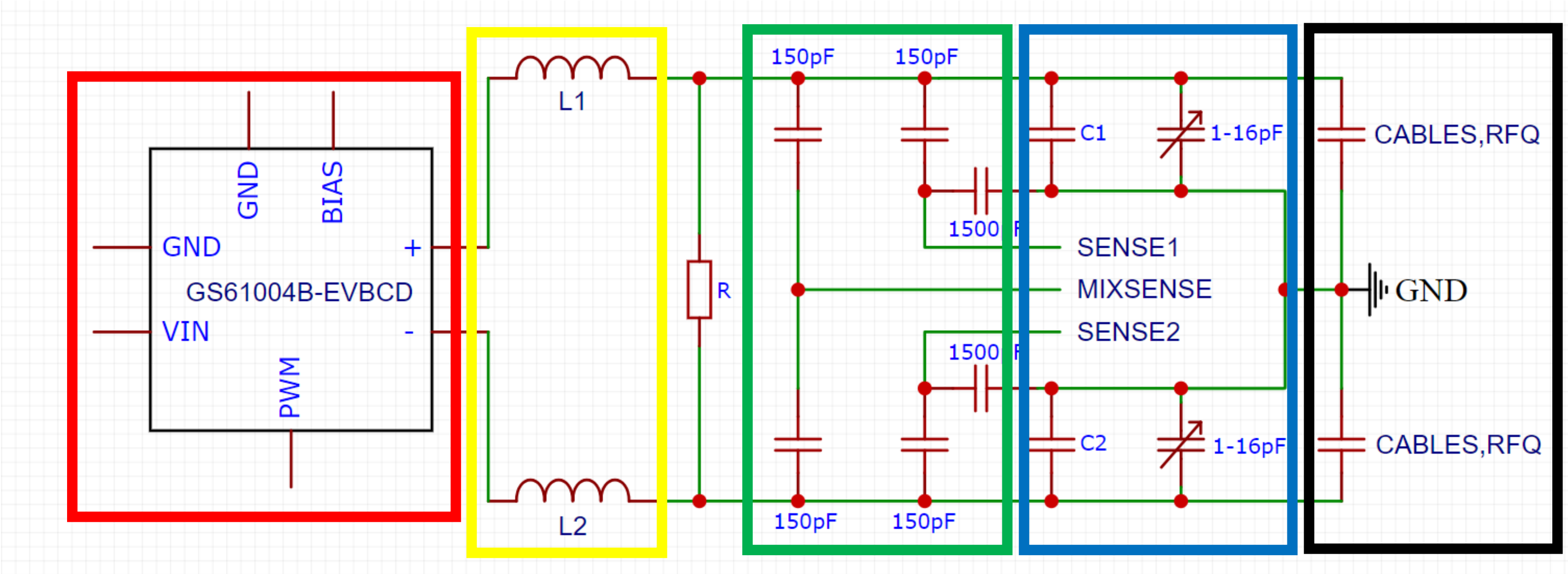
- Resonant LC design
- High frequency
- High amplitude
- Well-matched phases





Edinburgh RF Drivers

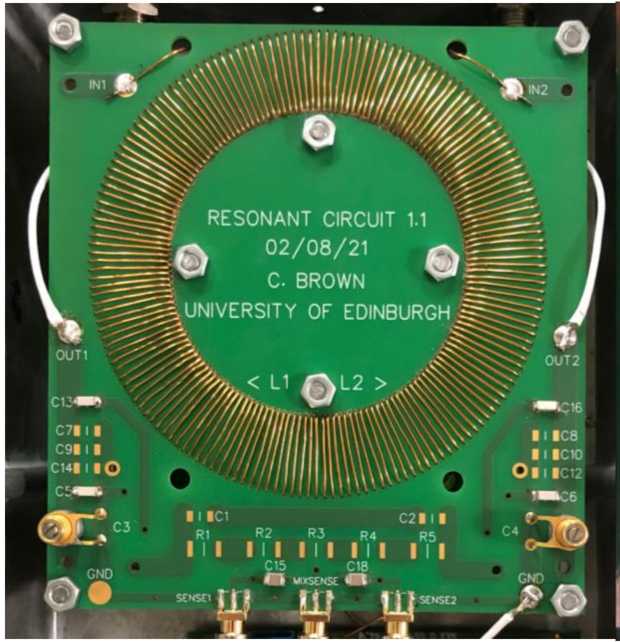
- Square wave provided by modified commercial driver board (GaN FETs)
- SENSE1,2: monitor phase amplitudes
- MIXSENSE: monitor phase differential
- Capacitive load: RFQ, cabling
- Inductive load: custom inductor
- Variable caps: match phases
- SMD caps: tune frequency

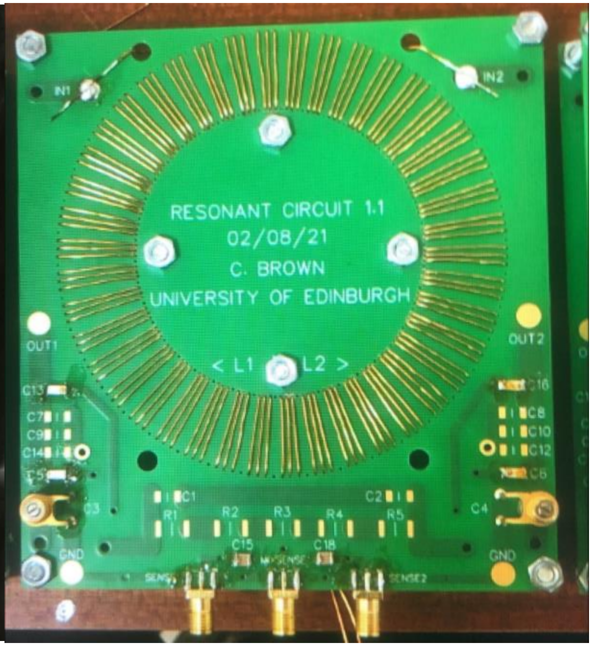


Edinburgh RF Drivers

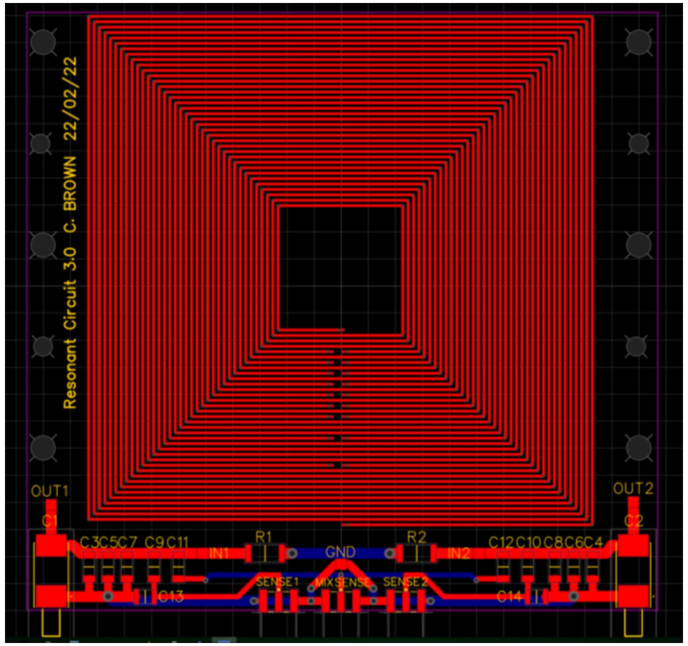
- Two different inductor-on-pcb designs

- Toroidal inductor: lower resistance, field confinement





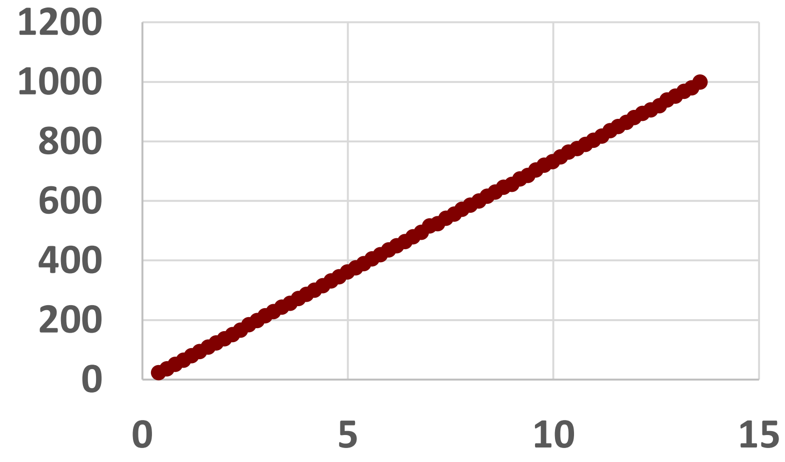
- Planar spiral inductor: faster production, tunable inductance



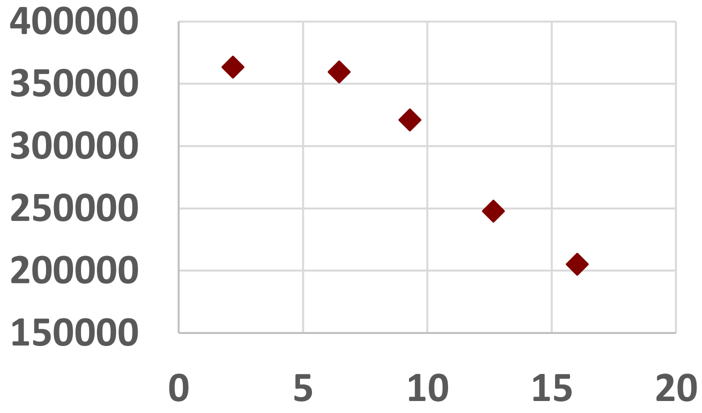
Edinburgh RF Drivers

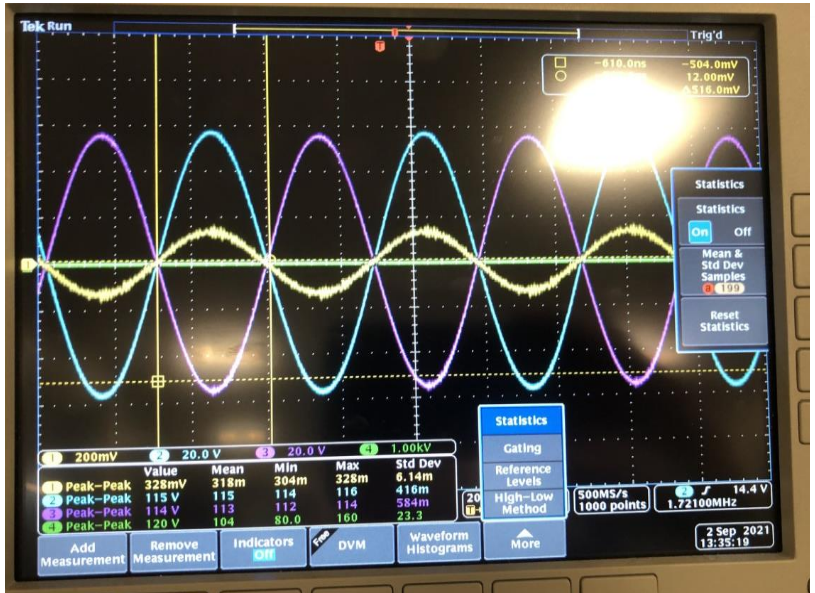
- 0.5 – 5 MHz @ <2kV pp
- Trimmer circuit matches phases <5%
- Successfully installed at TITAN

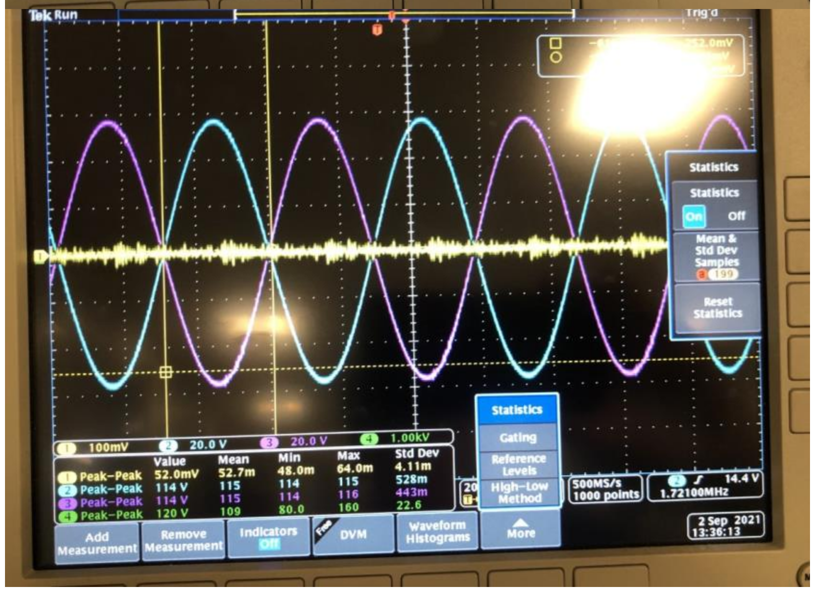
RF Out / DC In, Vpp



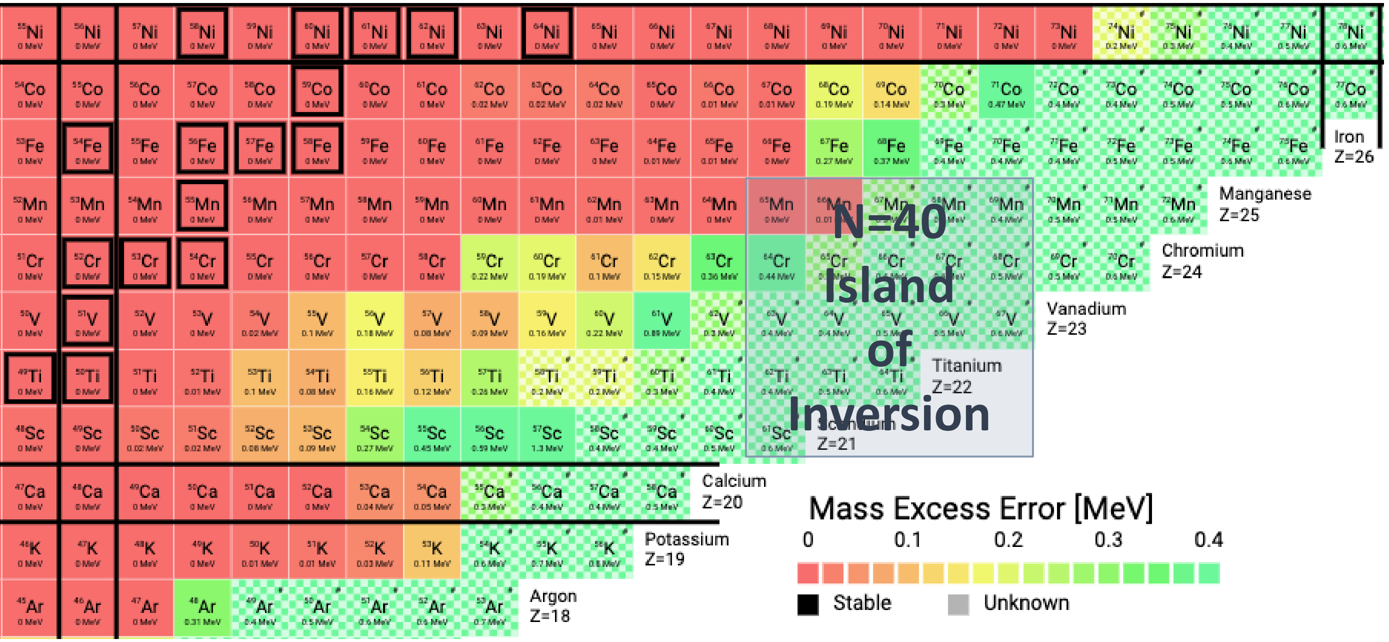
^{39}K Resolving Power (m/Δm) / % Delta Between Phases

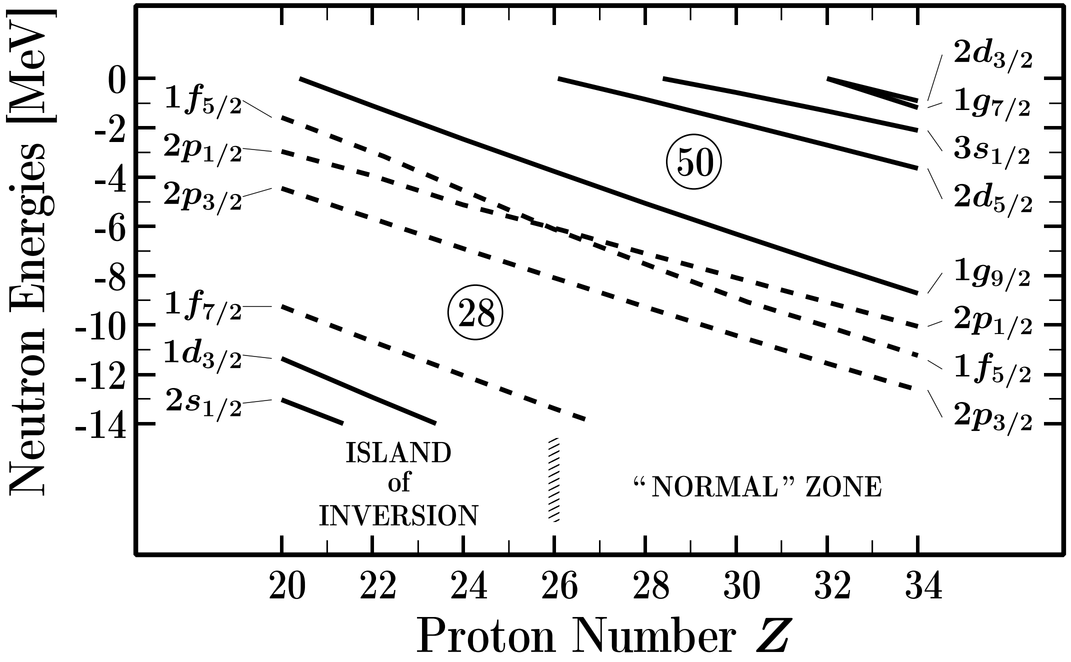






N = 40 Island of Inversion





W. S. Porter et al., PRC 105 (2022) 041301

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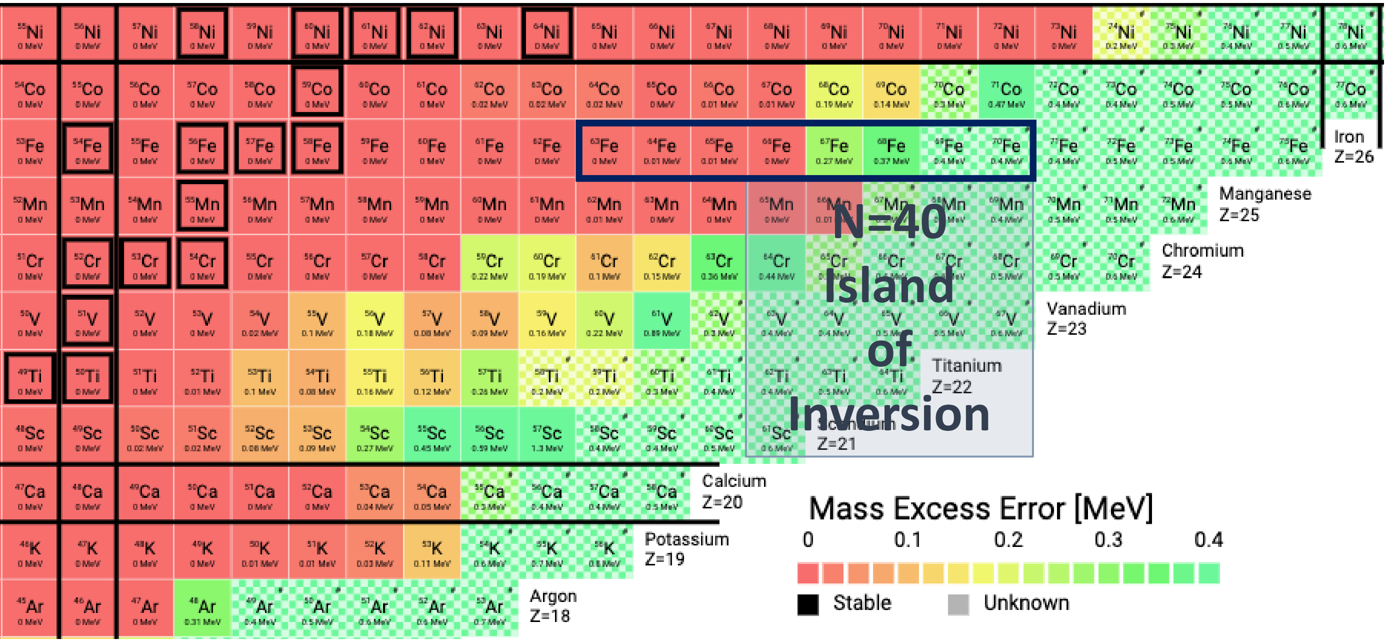

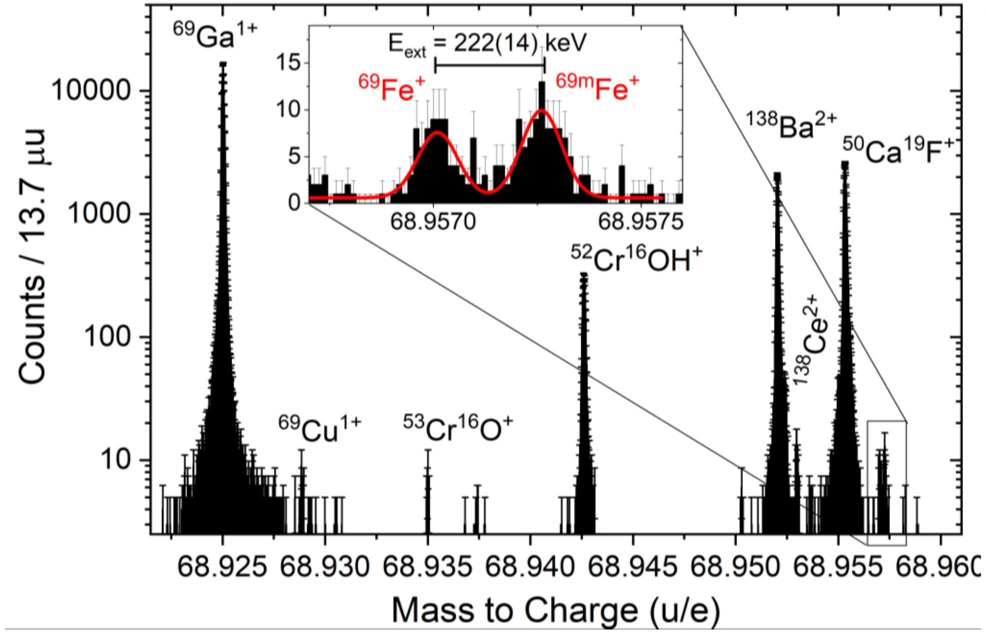

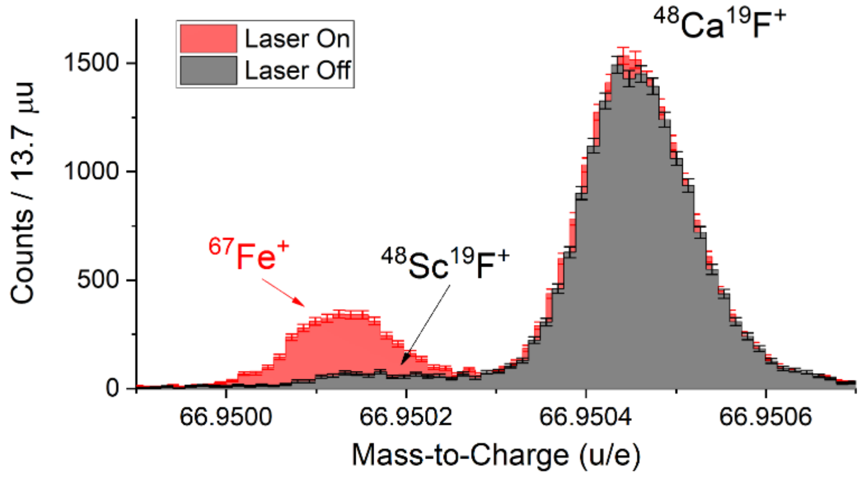

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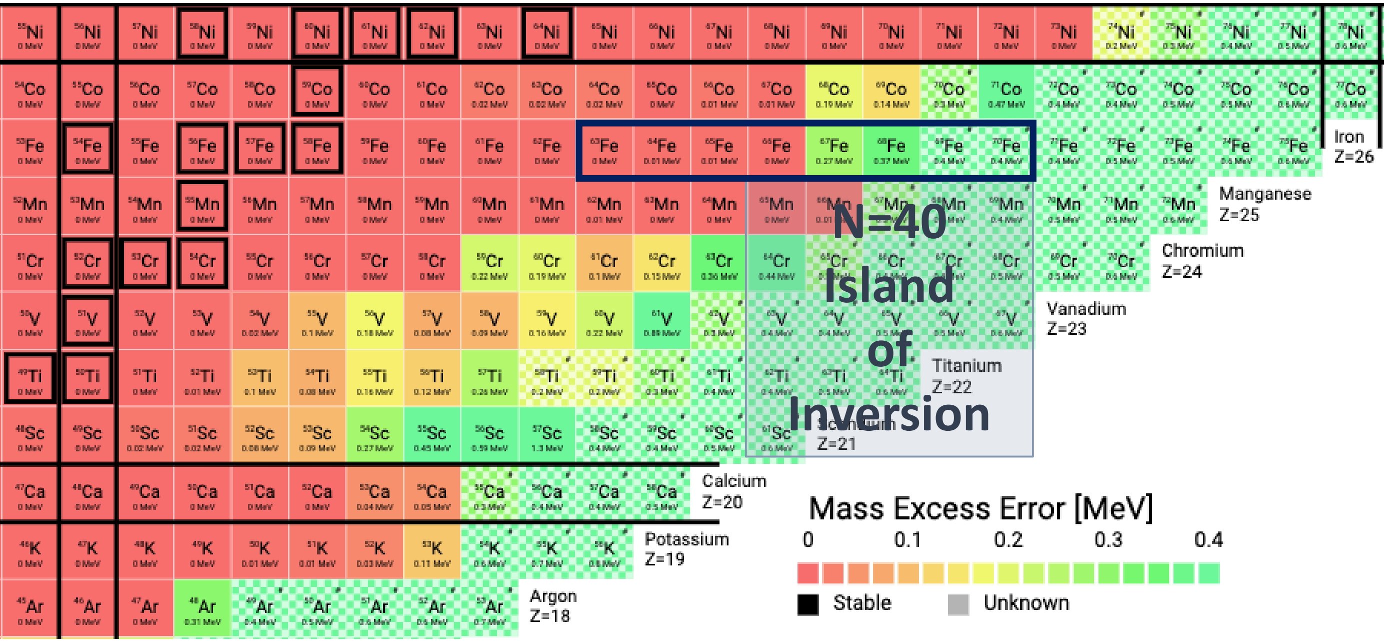
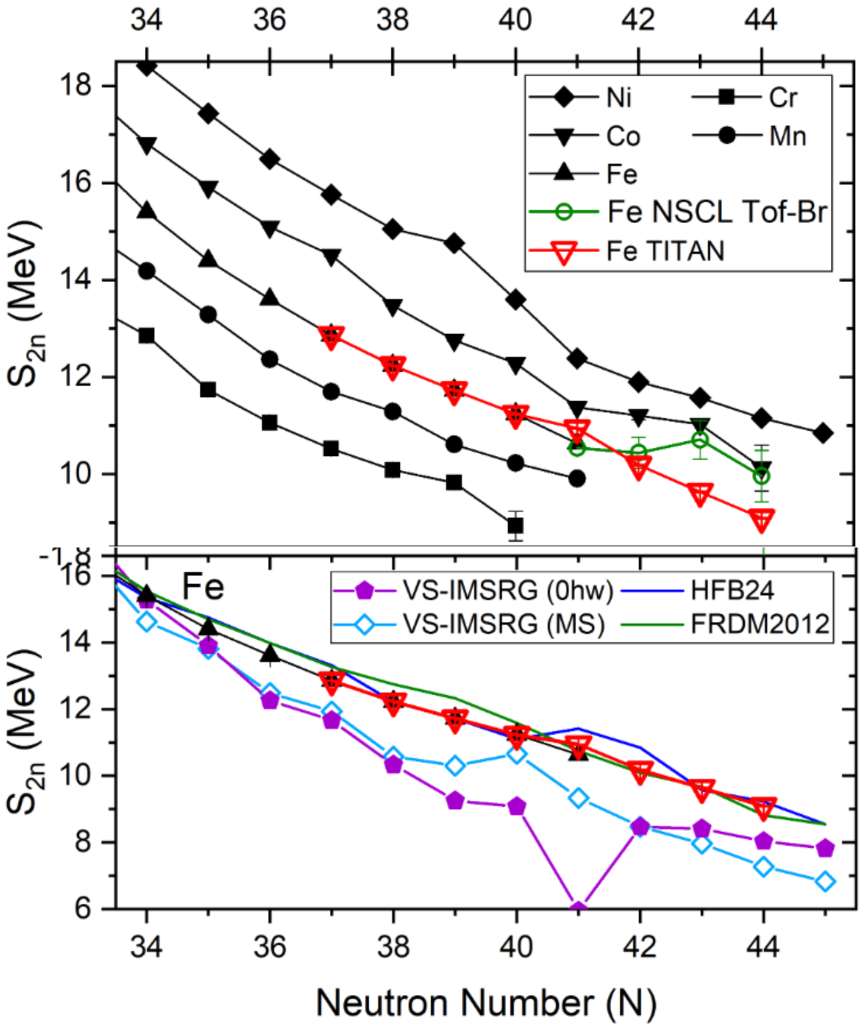
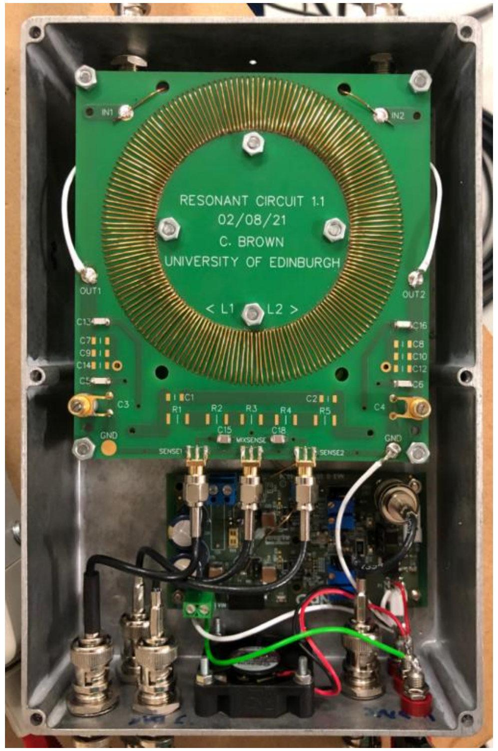
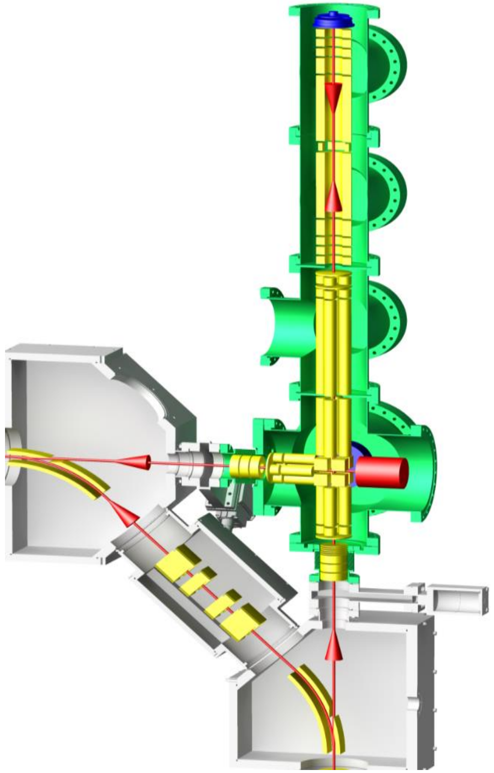


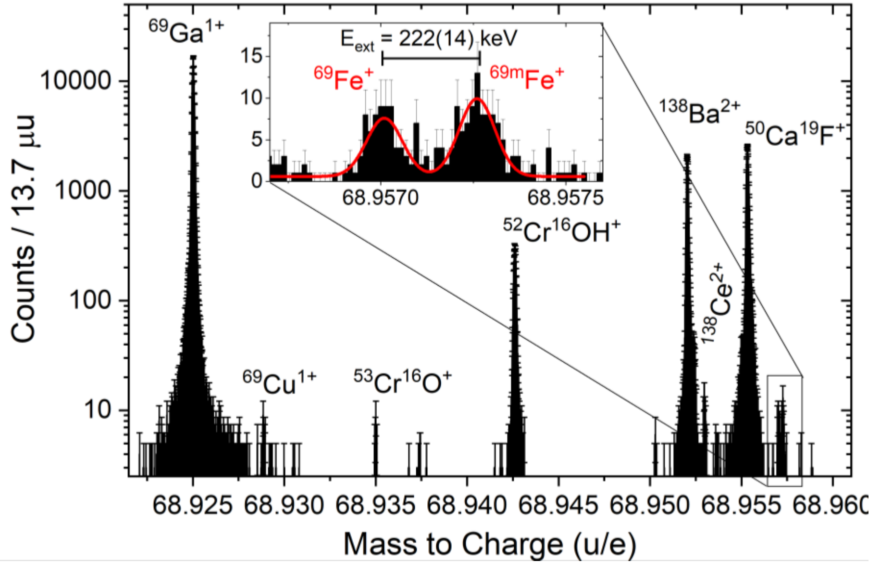


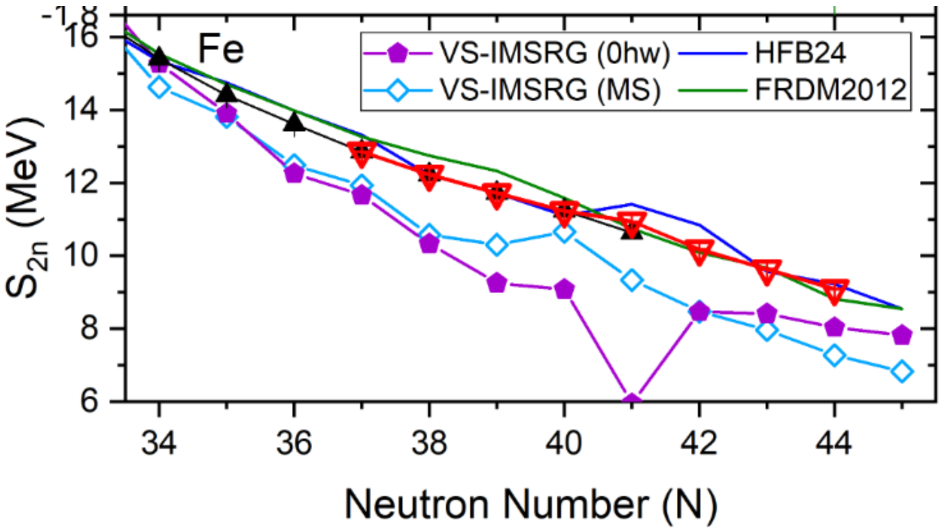
W. S. Porter et al., PRC 105 (2022) 041301

Questions?


RESONANT CIRCUIT 1.1
02/08/21
C. BROWN
UNIVERSITY OF EDINBURGH
< L1 L2 >




E_{ext} = 222(14) keV
$^{69}Fe^{+}$
$^{69m}Fe^{+}$
68.9570
68.9575
$^{69}Ga^{1+}$
$^{69}Cu^{1+}$
$^{53}Cr^{16}O^{+}$
$^{52}Cr^{16}OH^{+}$
$^{138}Ba^{2+}$
$^{138}Ce^{2+}$
$^{50}Ca^{19}F^{+}$
Counts / 13.7 μu
Mass to Charge (u/e)


Fe
VS-IMSRG (0hw)
VS-IMSRG (MS)
HFB24
FRDM2012
S_{2n} (MeV)
Neutron Number (N)