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Opportunities for laser spectroscopy with MNT reaction products

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Outline

- Laser spectroscopy of radioactive isotopes

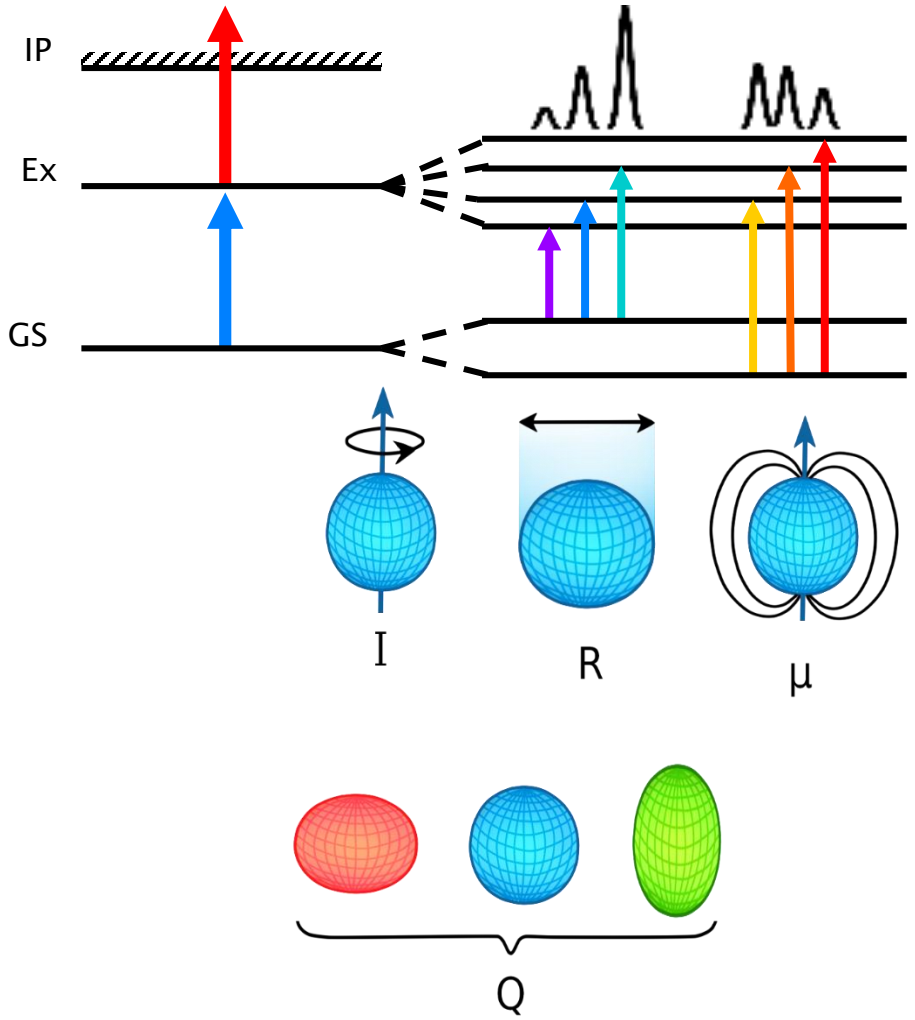
- Some examples of new possibilities
  - Refractory isotopes near Z=82: investigating shape phenomena
  - Study of high-spin isomers in W region

- Conclusions

Laser spectroscopy of radioactive isotopes

Collinear laser spectroscopy and derivatives:

- ‘Fast’ beam (order of magnitude 10 keV)
- Usually requires singly charged beam
- Ground- and excited states (>ms lifetime)
- Yields spectroscopy at the natural linewidth
- **VERY** element-specific!
- Main limitations in terms of required rates:
  - Efficiency of signal detection
  - Background due to e.g. laser scatter or contaminants in the ion beam



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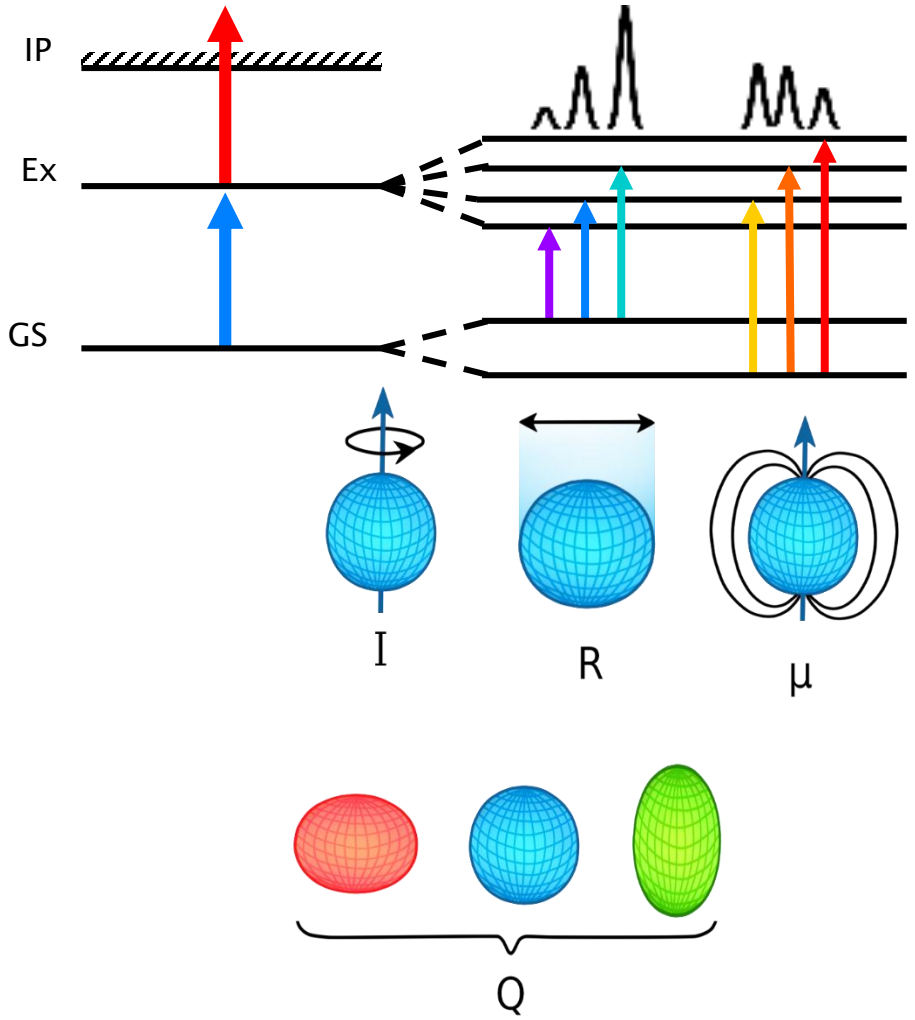
- => Beam rates below 10^4-1000/s are challenging (but sometimes possible)



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- Main limitations in terms of required rates:
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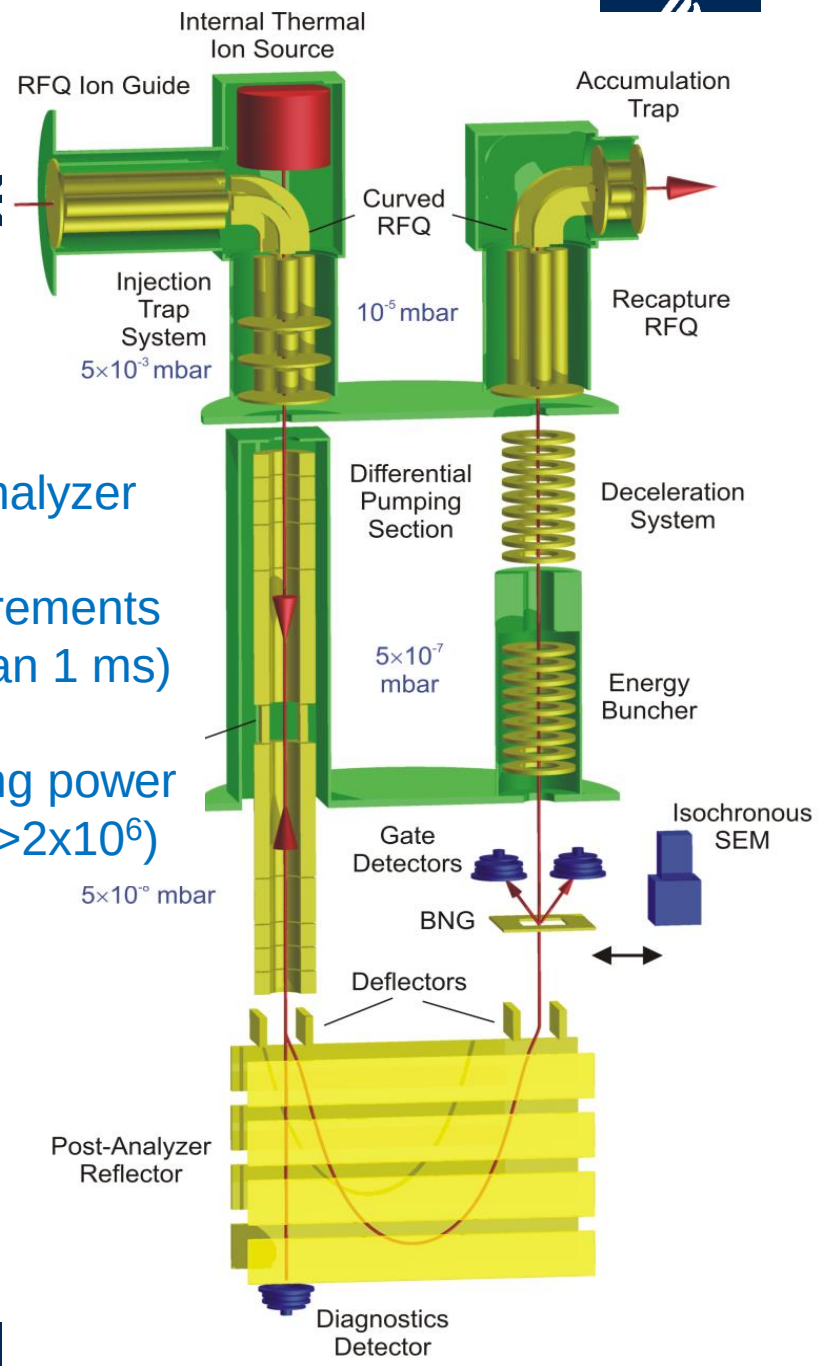
- => With ultra-clean beam:
  Rates below 100-1000/s are still challenging (but possible, e.g. with coincidence techniques, collinear RIS, …)

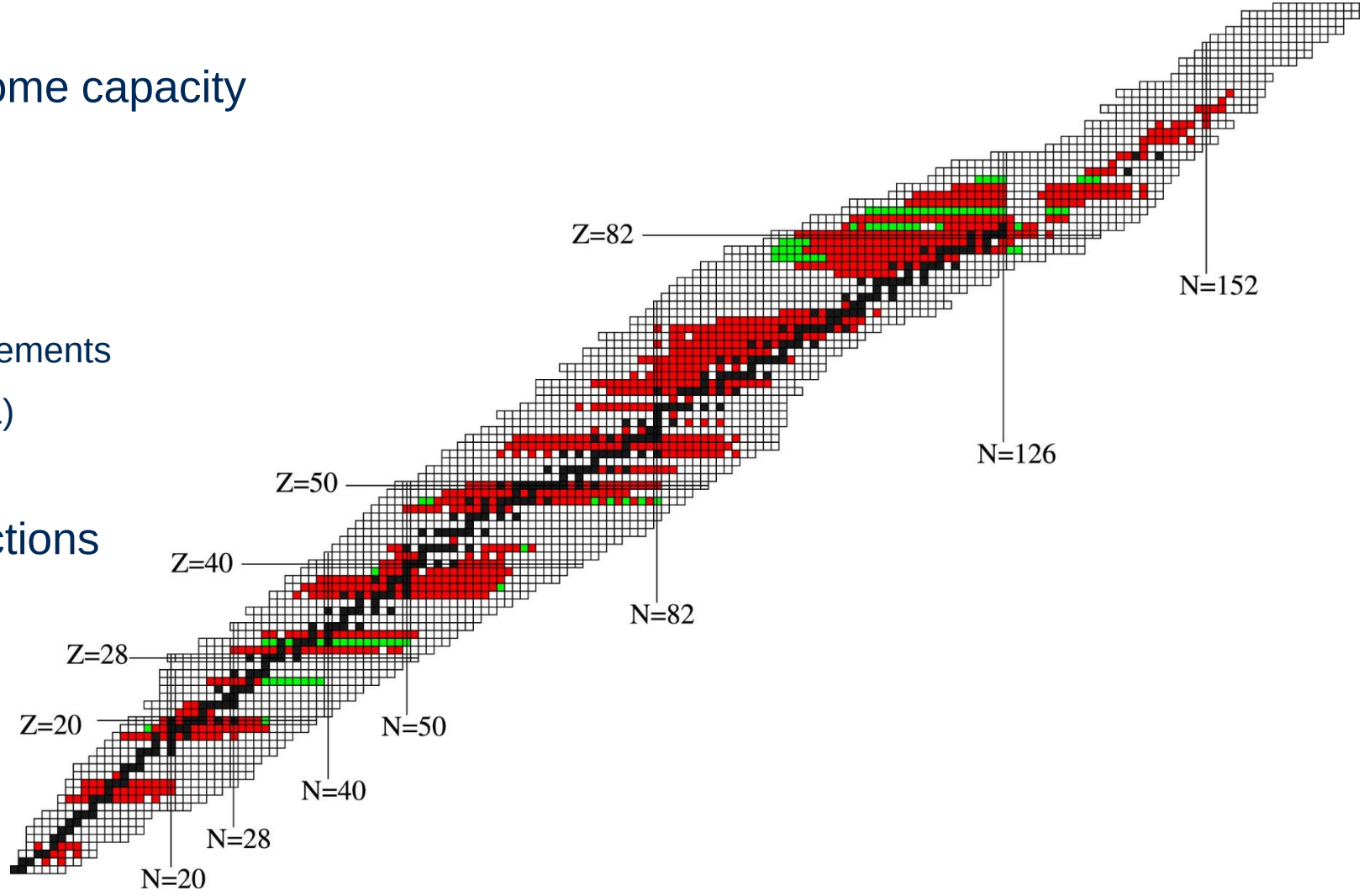
Next gen. Analyzer
→
faster measurements
(10^5 in less than 1 ms)
&
higher resolving power
(ion optically >$2x10^6$)



Courtesy of Timo Dickel

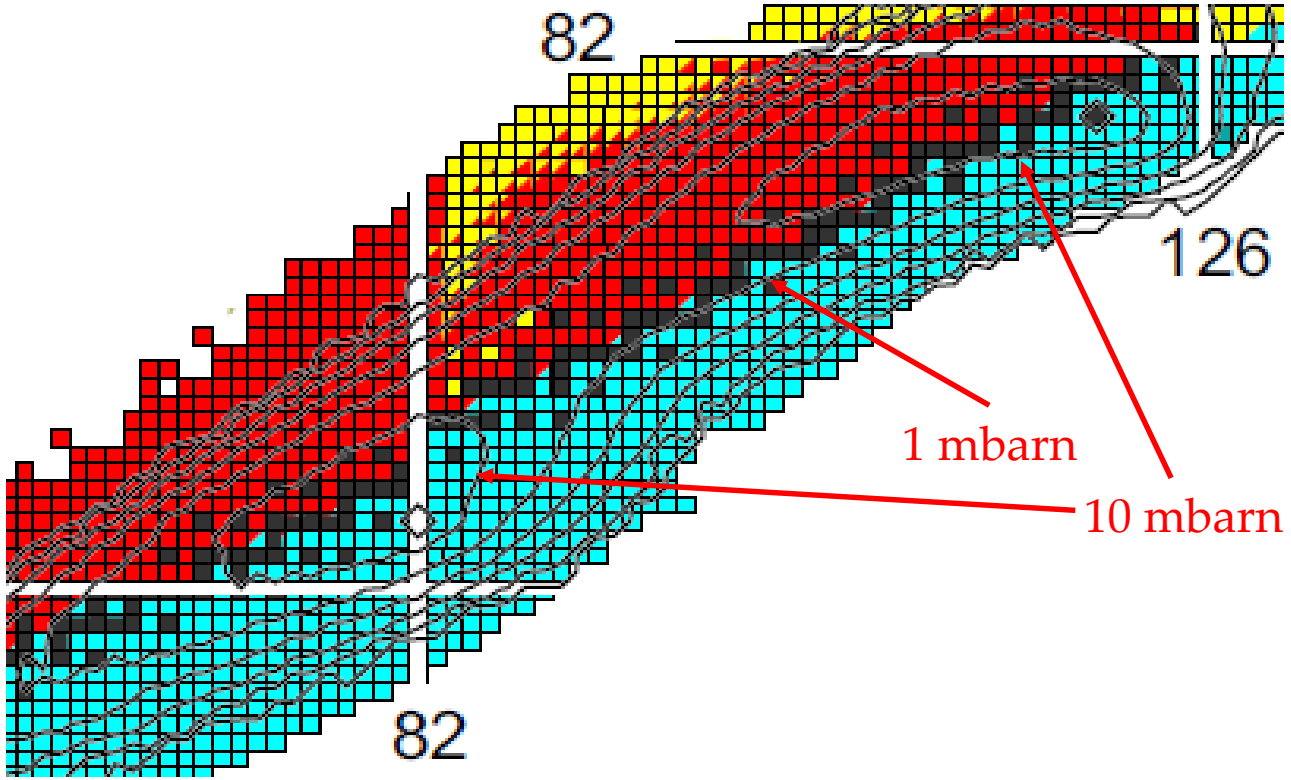
Optical landscape

- Coloured squares: studied in some capacity using laser spectroscopy
- Clear gaps can be seen
  - Due to atomic structure of those elements
  - Due to production limitations (ISOL)
- Exploring novel production reactions is crucial for the future!
  - IGISOL
  - NSCL/FRIB
  - GSI



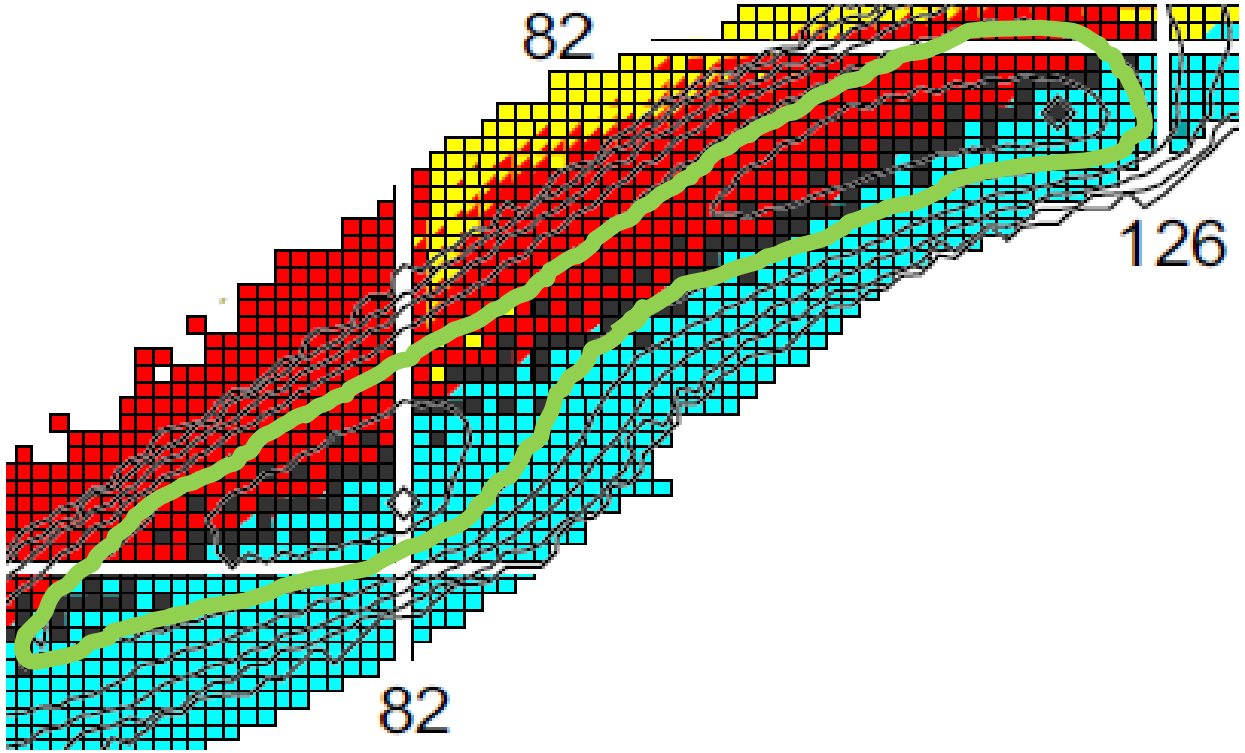
Example using Xe+Pt

- Let’s take a 1 mbarn cross section as a kind of ‘feasibility limit’
  - Cutoff in reality is less clear



V. V. Saiko et al., PRC 99, 014613 (2019)

example: Xe+Pt



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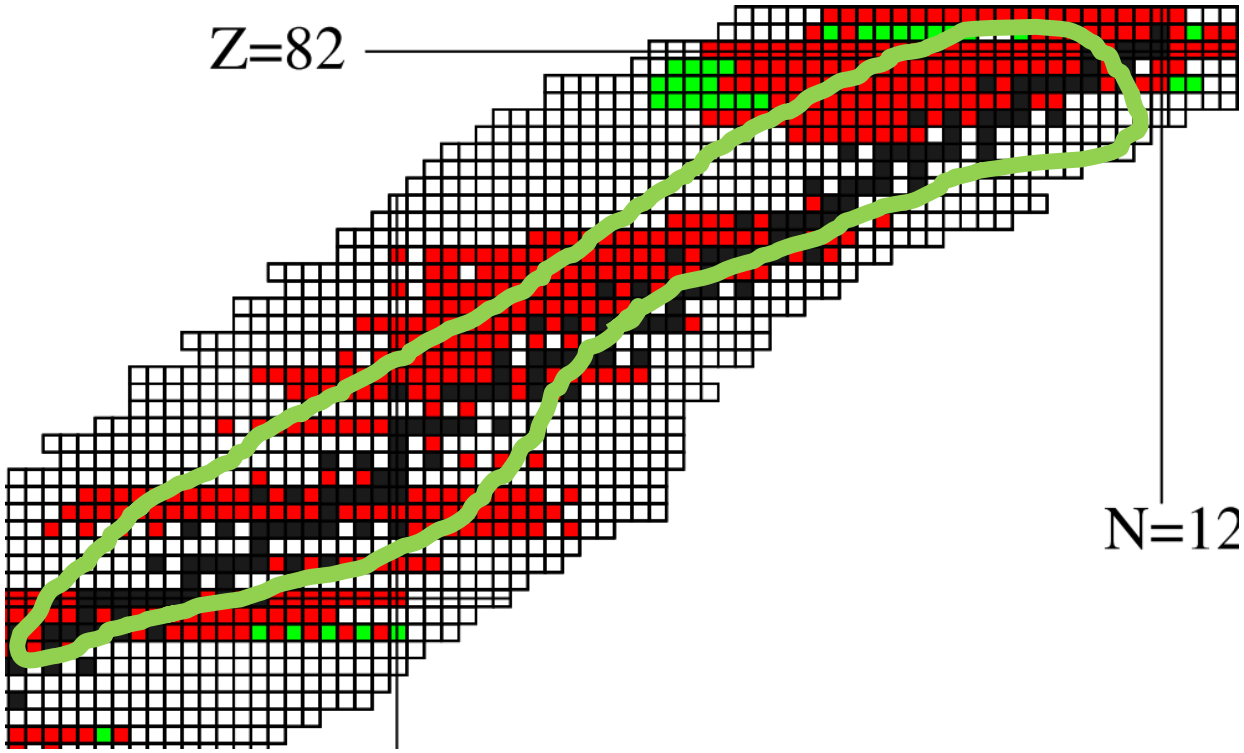


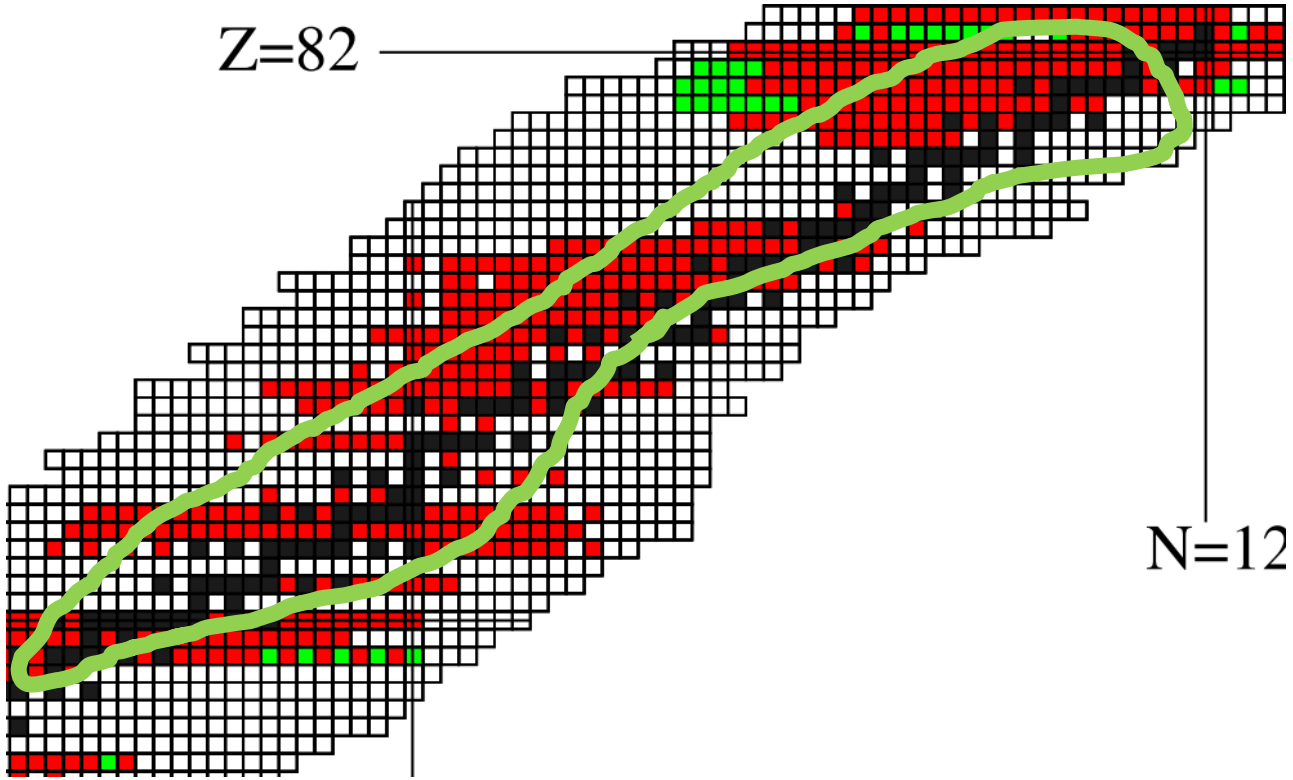
'Optical landscape': white squares have not been studied at all using laser spectroscopy.
e.g.we don't know the nuclear radius or dipole moment!

Example using Xe+Pt

- Let’s take a 1 mbarn cross section as a kind of ‘feasibility limit’
  - Cutoff in reality is less clear

- Clear gaps in our optical datasets exist which would be filled!
- Especially neutron-rich isotopes are difficult to access

- + Different targets could give access to other gaps in the landscape



Refractory isotopes near Z=82: investigating shape phenomena

- Pb region features dramatic examples of shape changes and shape staggering
- Hg: shape staggering around N=104
  B.A. Marsh, Nature Physics **14**, 1163–1167 (2018)
- Au, Pt, Ir: jump to deformed state around N=104
- ^{184}Os: no effect?

- Furthermore, with MNT reactions neutron-rich isotopes can also be produced

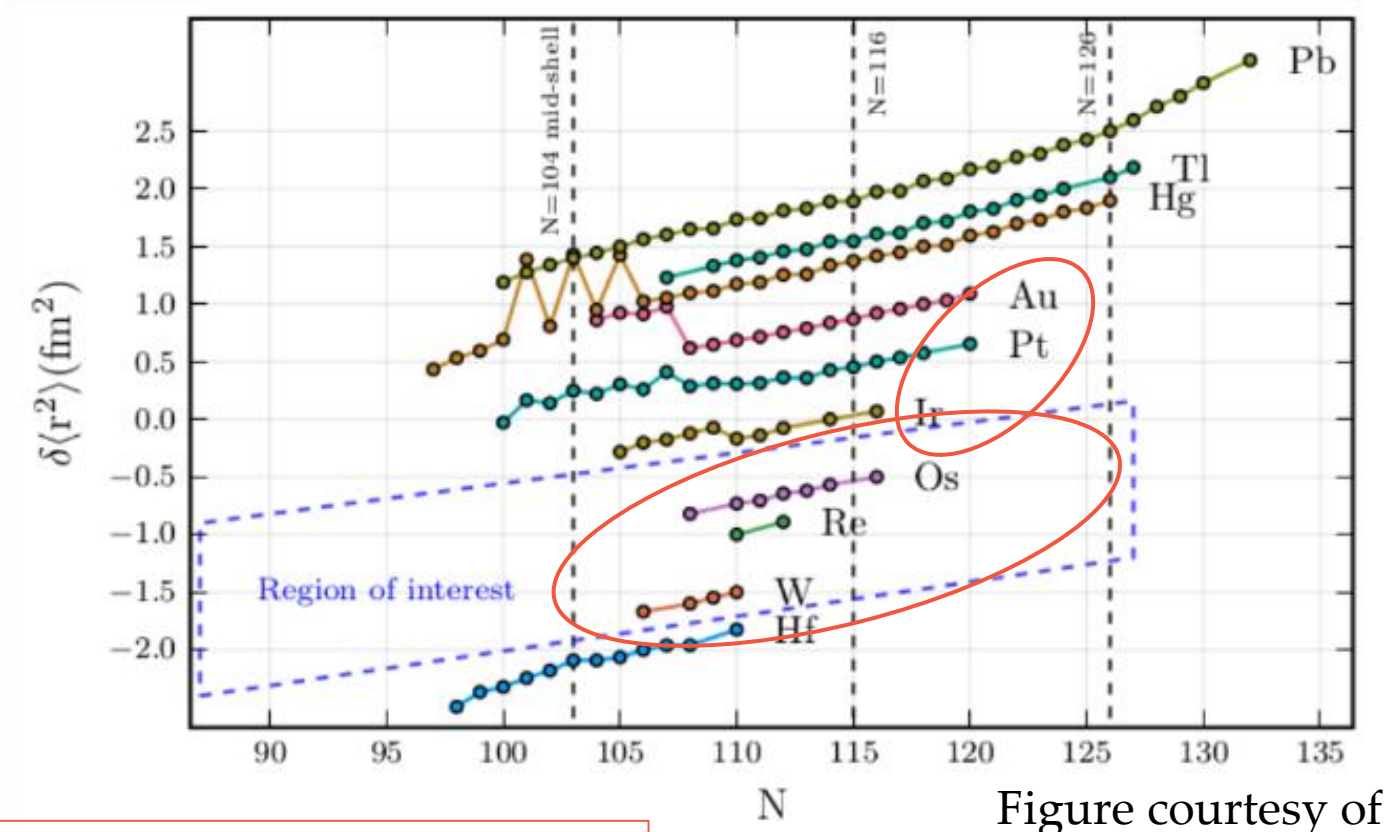


Figure courtesy of M. Reponen

The use of MNT reactions would enable the first study of shapes, sizes and configurations, from below the N=104 midshell and approaching N=126!

A note on optical spectroscopy of these elements…

- Atomic structure gets more complicated for f- and d-shell elements
- Atomic level density gets larger
- Angular momenta increase
- Hyperfine structures span wider and contain more peaks

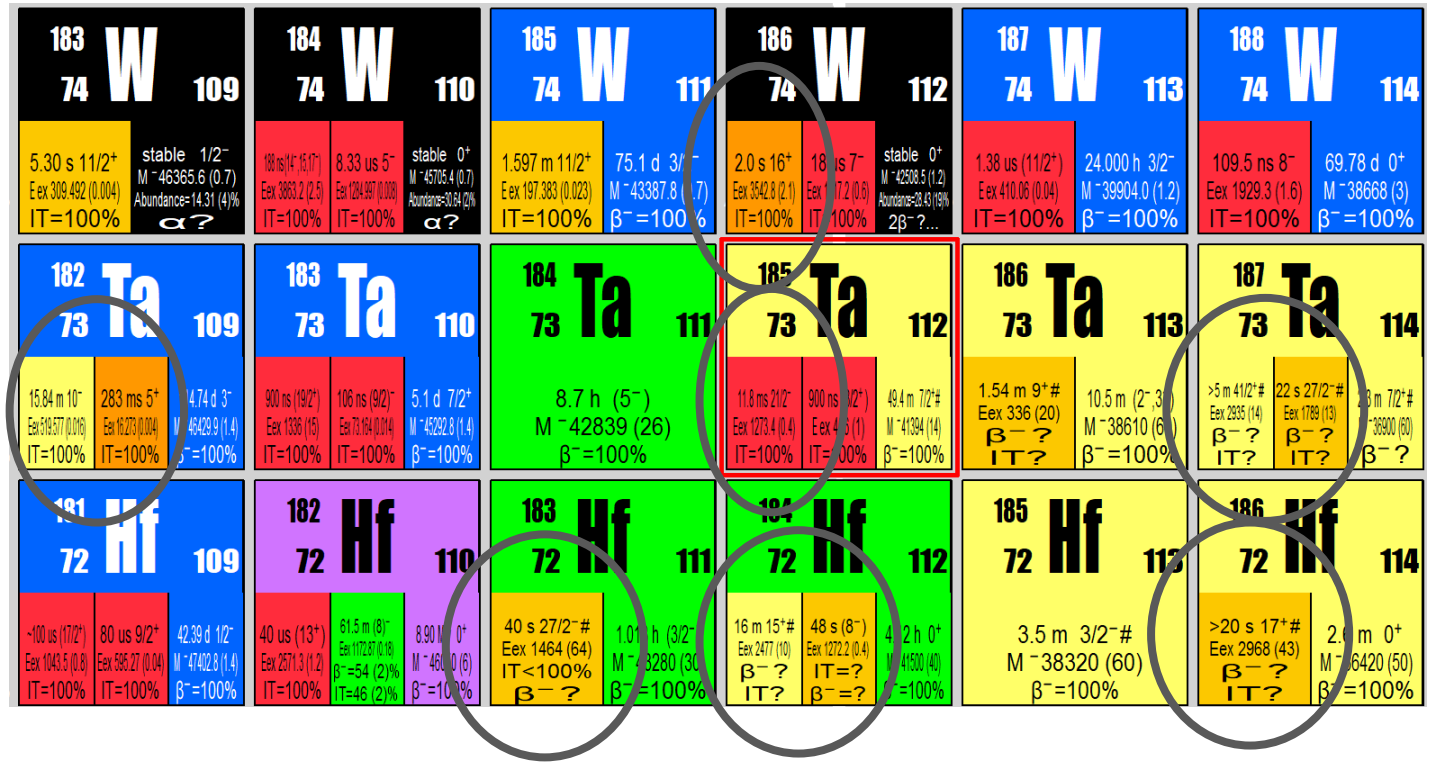
A lot of prior offline studies are required to find optimal spectroscopy schemes

- Much work has already been carried out at IGISOL laboratory and at KISS for e.g. Ir, Pt, Os, Ta, … Experience exists.

Further exploring advantages of MNT reactions

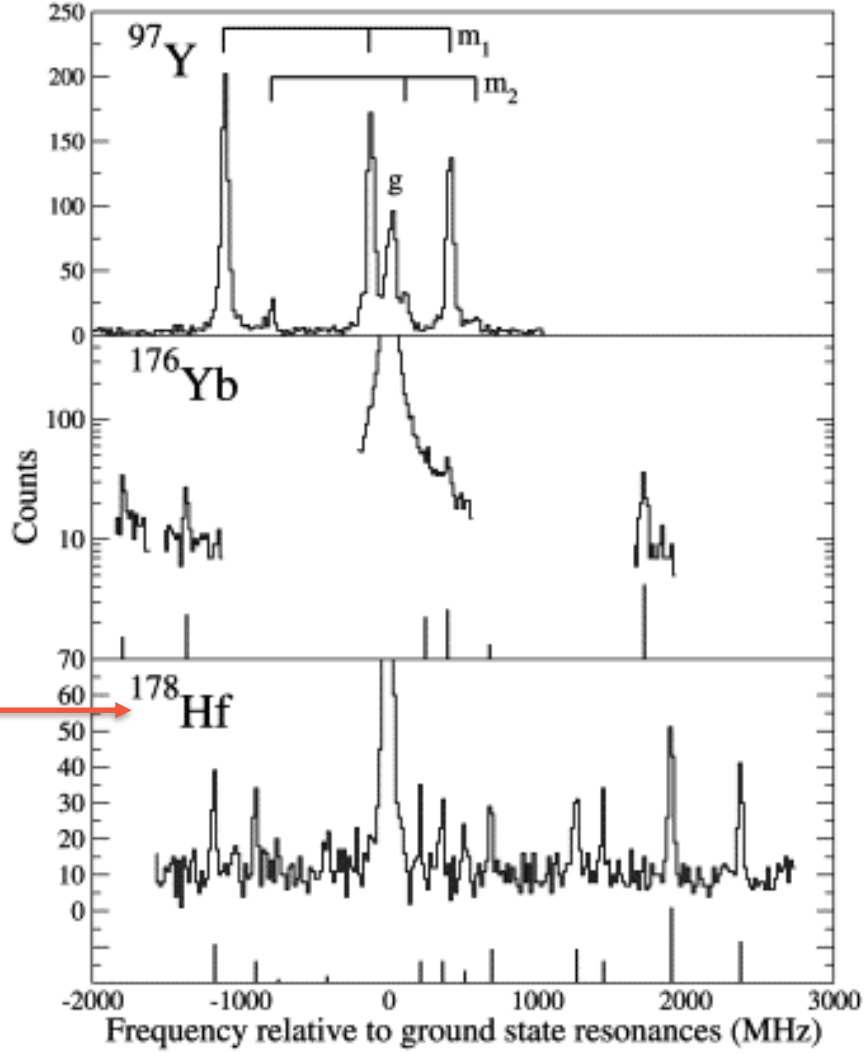
- Short-lived + refractory + high-spin multi-quasiparticle isomers
- mqp isomers have been observed to systematically have a smaller charge radius than the g.s., despite having a larger quadrupole deformation
- Theoretical explanation is still lacking
  - In part because there are only a handful of cases studied…

- Examples:
(there are others in the region e.g. ^{191}Ir)



Further exploring advantages of MNT reactions

- MNT reactions are a great tool to access these neutron-rich, highly refractive isotopes
- Furthermore: use of MR-TOF to clean away one of the higher-produced states (see e.g. examples on the right)
- ^{178}Hf at IGISOL: produced at 100 ions/s
- photo-ion coincidence enabled by cleanliness of the beam will allow even lower rates



Conclusion

- Laser spectroscopy uniquely bridges atomic and nuclear structure to reveal structural and shape information

- MNT reactions provide unique access to uncharted regions of the nuclear chart
  - In this talk, I discussed two examples, but many more cases can surely be identified
  - The presence of a high-resolution (isomeric) separator is a great advantage for laser spectroscopy

- Intriguing physics cases await to be tackled!

Thanks!