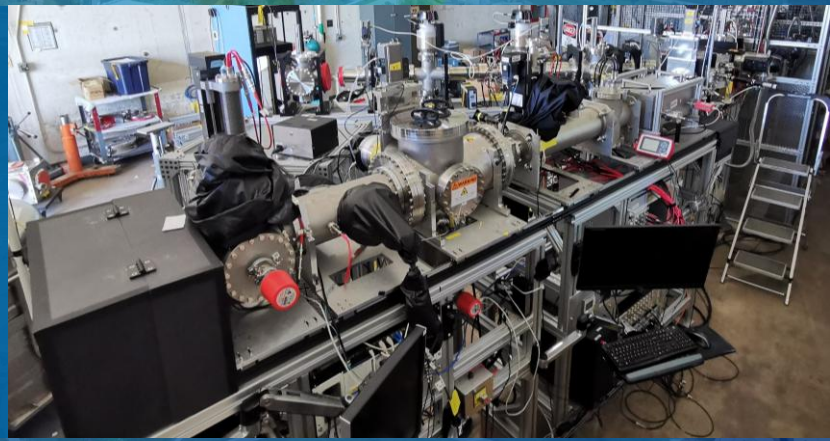
AUGUST 10TH, 2025

LASER SPECTROSCOPY AT ARGONNE NATIONAL LABORATORY



BERNHARD MAASS
Assistant Physicist

U.S. DEPARTMENT of ENERGY

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Argonne NATIONAL LABORATORY

OUTLINE

- The ATLAS accelerator facility at ANL offers a **low-energy stopped-beam** infrastructure **ready-made for laser spectroscopy** experiments

- We performed first successful measurements with our new beamline **ATLANTIS**, which is now upgraded for more versatility and new beams

- More Laser Spectroscopy for nuclear structure is planned at the **N=126 factory**, in the neutron-rich lead region

- A **new generation of laser spectroscopy** experiments can be developed at ANL

- I'm always open for proposals, ideas, collaboration!

ATLAS AT ANL

ATLAS is the world's first superconducting ion accelerator (est. 1978)

DOE user facility

- beams from hydrogen to uranium – up to 18MeV/u
- rich program on fast beams with GRETINA, Gammasphere + FMA/AGFA, HELIOS, MUSIC and more.
  - » low-energy nuclear physics

ATLAS also has a strong **stopped beams** program, mostly masses:

NuCARIBU:
- neutron-induced uranium fission
- extraction via gas cell
- ATLAS beam source via EBIS
- direct access to cooled, stopped beam in "Area 1"

status: operational

N=126 factory:
- ATLAS target inside gas cell
- extraction of MNT products at large angle
- extraction as cooled, stopped beam

status: commissioning

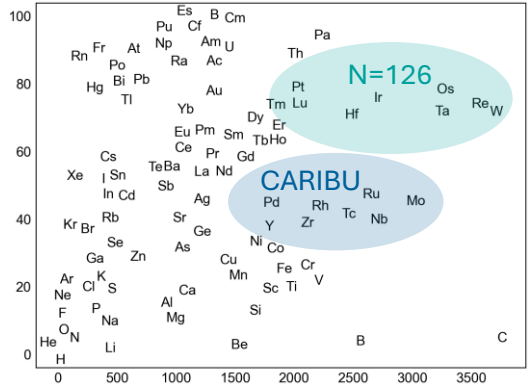
STOPPED BEAMS AT ATLAS

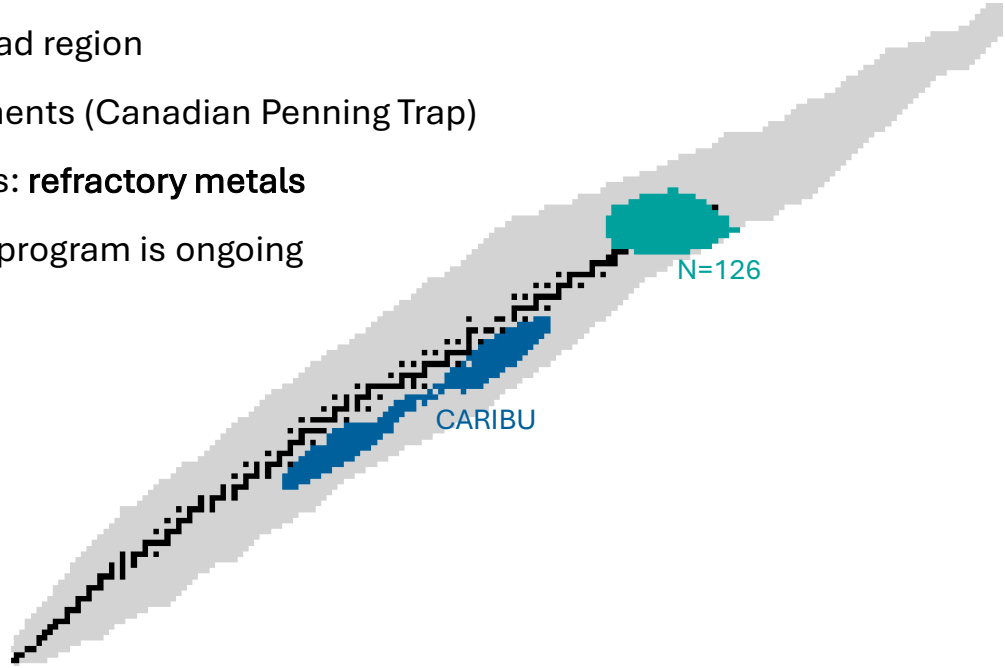
- stopped and cooled radioactice beams at ATLAS from

  NuCARIBU: n-rich beams in the tin region

  N=126: n-rich beams in the lead region

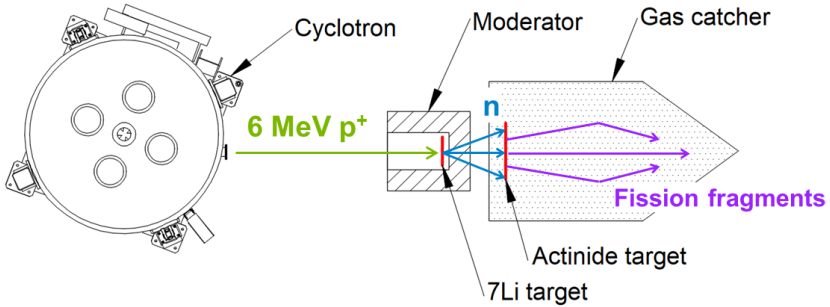
- beams have & will be used for mass measurements (Canadian Penning Trap)
- gas cells chemically different from ISOL-targets: **refractory metals**
- setup of a complementary laser spectroscopy program is ongoing

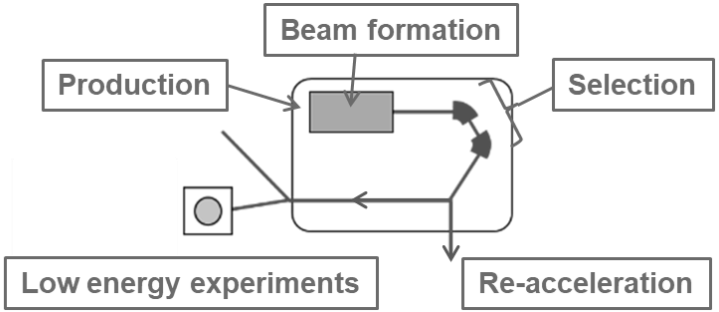




NUCARIBU

- **NuCARIBU** is a neutron-induced fission source inside a gas cell
- Peak rate ~200k/s (i.e. ^{144}Ba)
  - p^+ beam intensity can be increased further (x10)



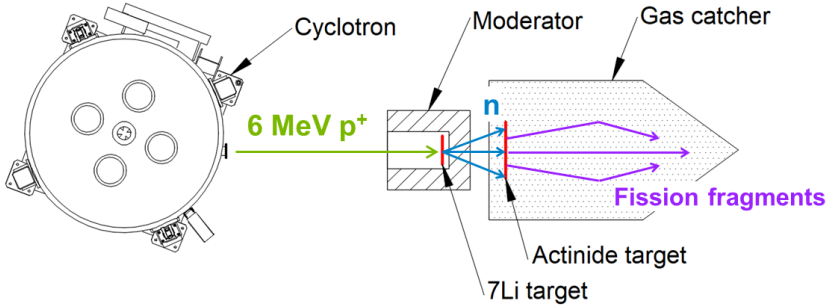


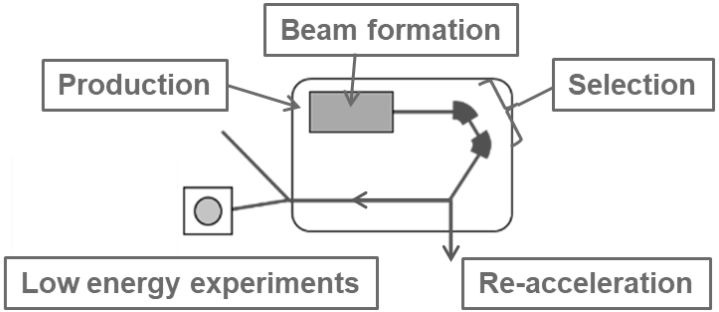
NUCARIBU

- **NuCARIBU** is a neutron-induced fission source inside a gas cell
- Peak rate ~200k/s (i.e. ^{144}Ba)
  - p^+ beam intensity can be increased further (x10)
- Previously, the setup (CARIBU) was used with spontaneous ^{252}Cf fission
  - lower intensity, continuous degradation
  - slightly shifted production: **Pd and Ru**



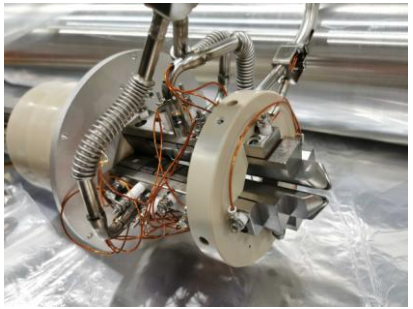
- ^{252}Cf fission fragments
- ~2 x 10^7 fissions/s
- $t_{1/2}$ ^{252}Cf 2.5 yr
- $\leq 10^6$ ions/s



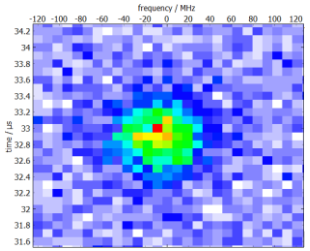


ATLANTIS & LASPEC INFRASTRUCTURE

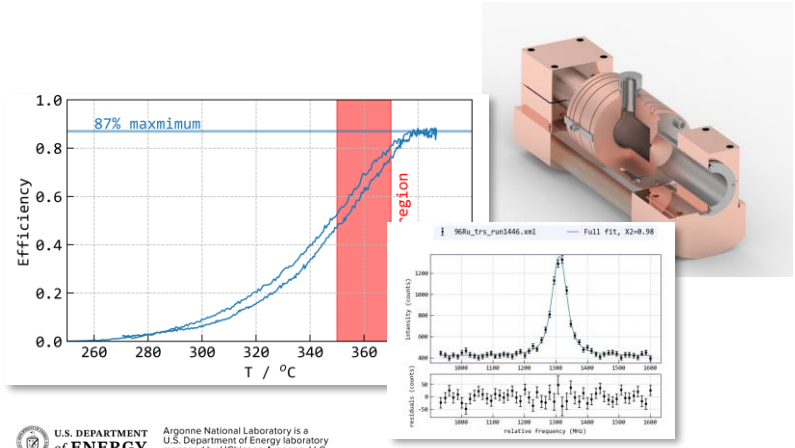
- ATLANTIS Laser Spectroscopy beamline was set up in Area 1 in 2022/2023
  - Measurements on Ru/Pd

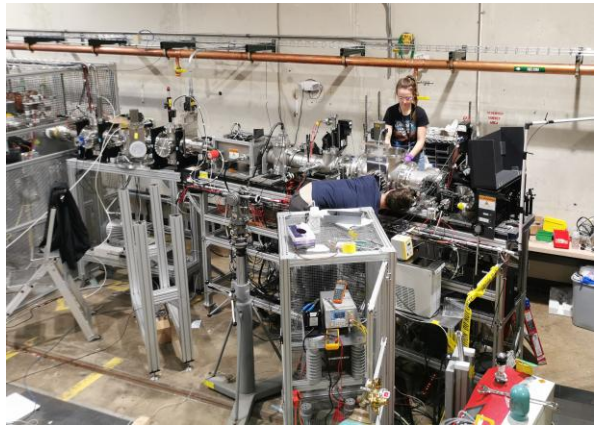


- Accompanying infrastructure:
  - RFQ Cooler & Buncher
  - Charge Exchange Cell for beam neutralization with Mg
  - Laser Ablation Offline Source
  - Laser Laboratory



$\Delta t < 1\mu s$
$\Delta E < 40MHz\ (3V)$
eff.: ~80%

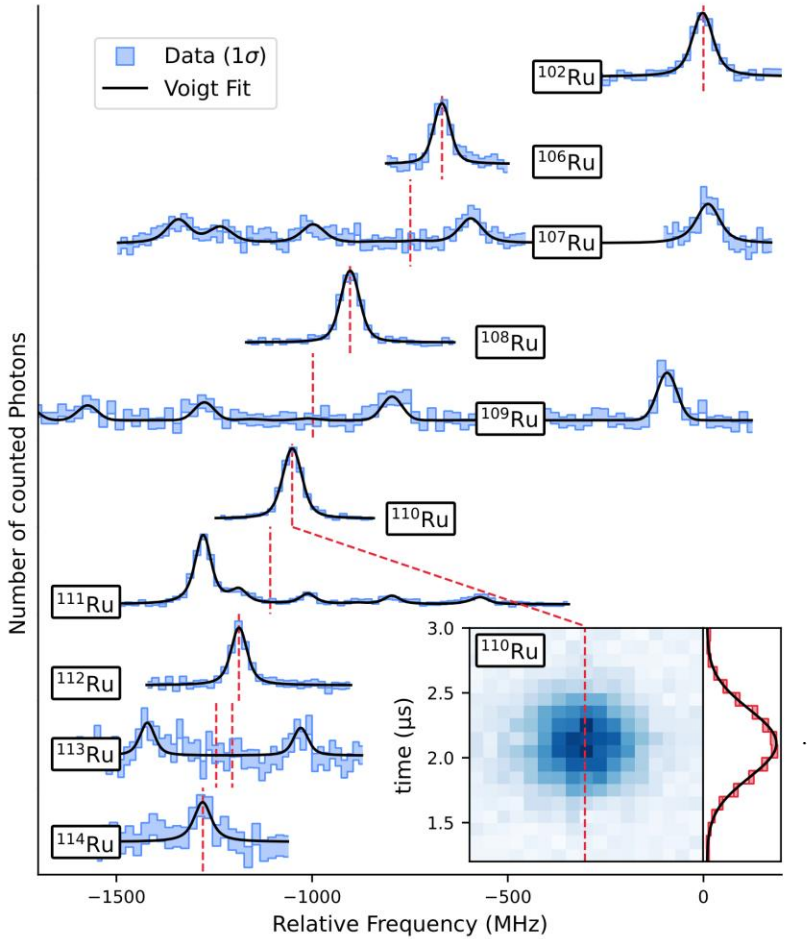




Kristian König / Laura Renth

RUTHENIUM

- Measured the optical spectra of 9 neutron-rich Ruthenium isotopes
- More data than presented here
  - search & exclude, statistics, systematics
- Referenced on stable/offline ^{102}Ru
  - Produced in laser ablation ion source
  - Similar beam properties due to bunching
- Confirmed the spin-1/2 assignment for Ru-113
- No isomers were detected
  - adds some ambiguity to some datasets where isomeric half-lives are long



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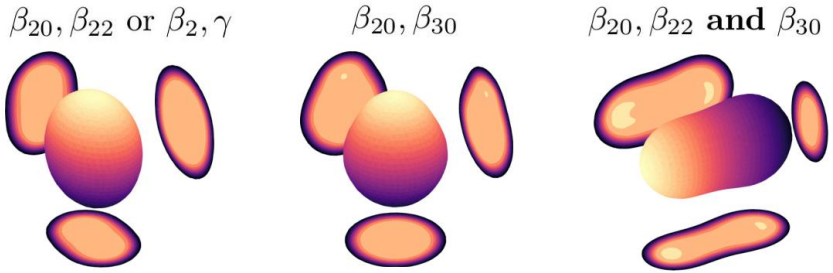
BSKGx MODELS

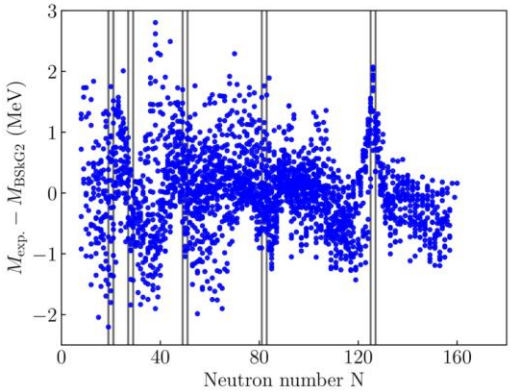
Brussels Skyrme on a grid

$$E \sim \int d^3r \left[C^\rho \rho(\mathbf{r})\rho(\mathbf{r}) + C^\tau \tau(\mathbf{r})\rho(\mathbf{r}) + \dots \right]$$

- Skyrme Energy Density Functional (EDF)
- ~25 coupling constants fitted to
  - 2457 masses: σ ~ 0.63MeV
  - 884 charge radii: σ ~ 0.025fm
- HFB wavefunctions in coordinate space without assumptions on axial symmetry:

  triaxiality, reflection-asymmetry, octupole deformation is possible

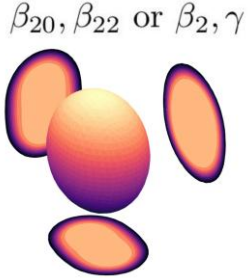




G. Scamps, S. Goriely, E. Olsen, M. Bender, and W. Ryssens, Eur. Phys. J. A **57**, 333 (2021)
W. Ryssens, G. Scamps, S. Goriely, and M. Bender, Eur. Phys. J. A **58**, 246 (2022)
G. Grams, W. Ryssens, G. Scamps, S. Goriely, and N. Chamel, Eur. Phys. J. A **59**, 270 (2023)
W. Ryssens, G. Scamps, S. Goriely, and M. Bender, Eur. Phys. J. A **59**, 96 (2023)

RUTHENIUM IN BSKG

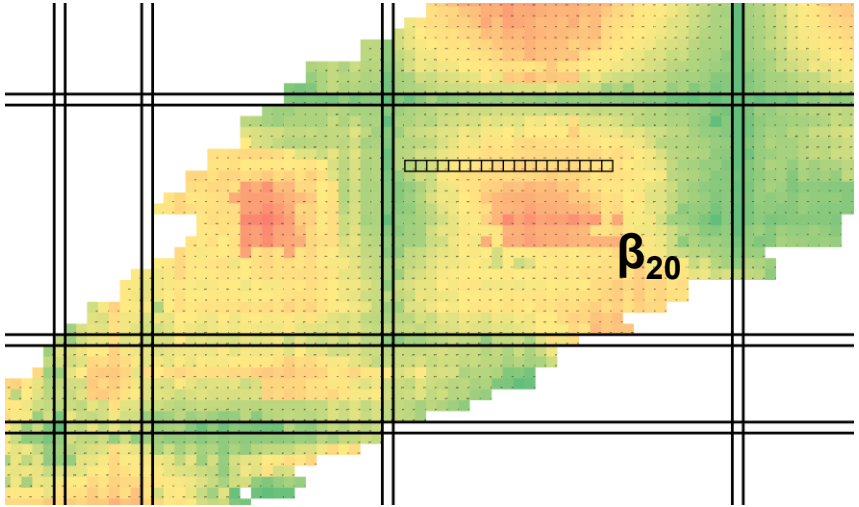
- Ruthenium g.s. are in the region of (static) quadrupole deformation
- COULEX experiments show hints of triaxiality
- BSkG predict triaxial deformations

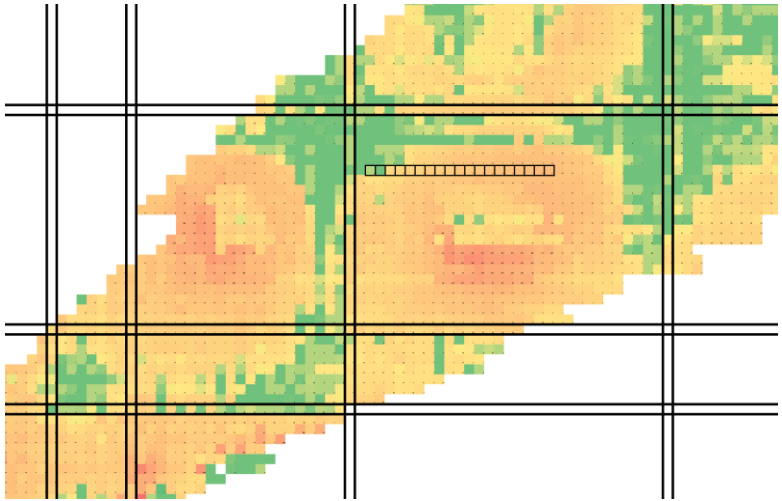


$$\beta_{\ell m} = \frac{4\pi}{3R^{\ell}A}\langle Q_{\ell m}\rangle$$

$$\beta_2 = \sqrt{\beta_{20}^2 + 2\beta_{22}^2}$$

$$\gamma = \text{atan}(\sqrt{2}\beta_{22}/\beta_{20})$$



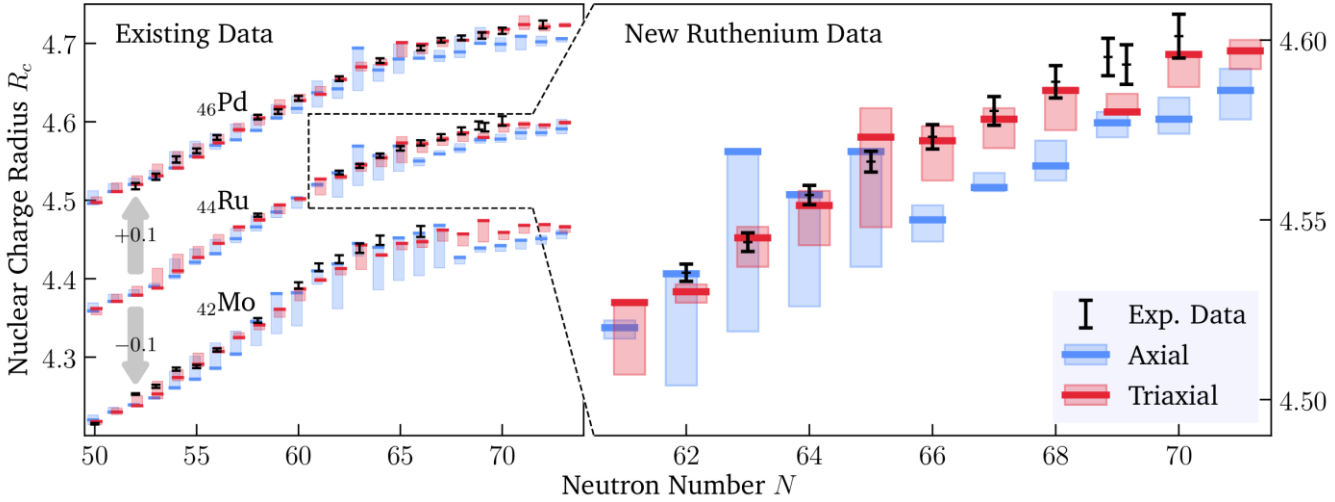


RUTHENIUM IN BSKG

Triaxiality *does not* enlarge or shrink the nuclear size.

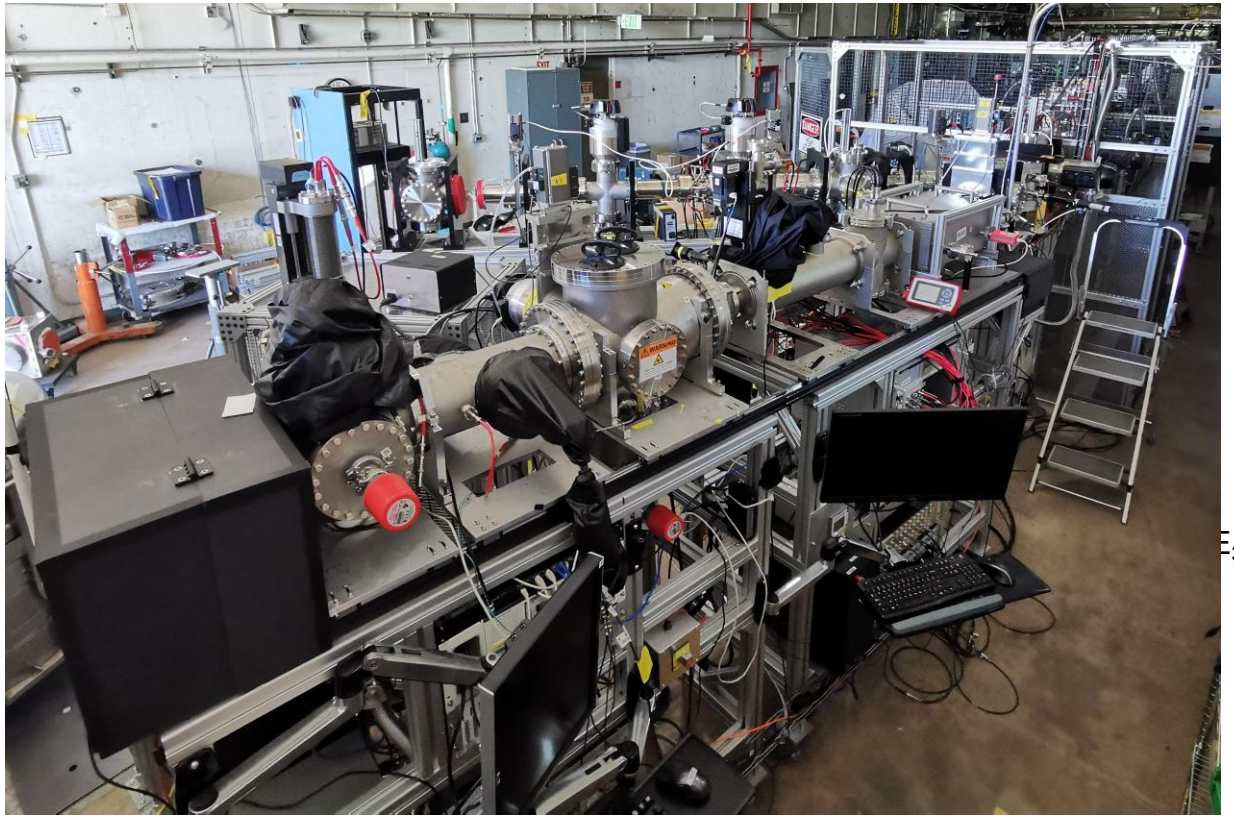
But it is necessary to produce a complete and consistent picture of a nucleus, where triaxiality is known to be prevalent.

arxiv: 2503.07841 waiting on referees decision



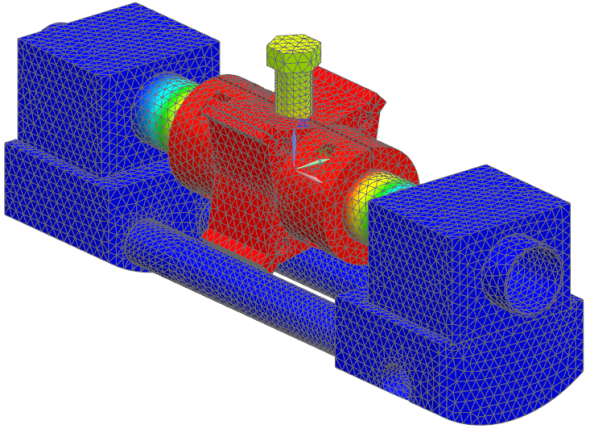
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QUO VADIS, ATLANTIS?



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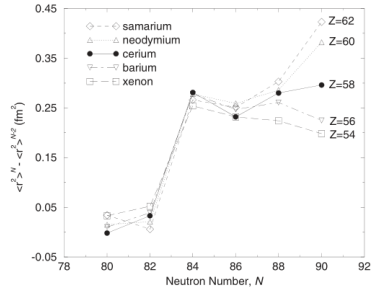
QUO VADIS, ATLANTIS?

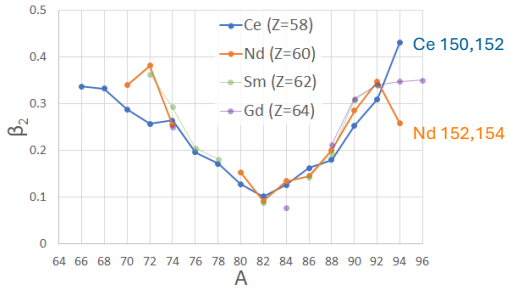


- Major upgrade ongoing:
  - Implementing resonance ionization for isomer separation
  - keeping fluorescence detection capabilities

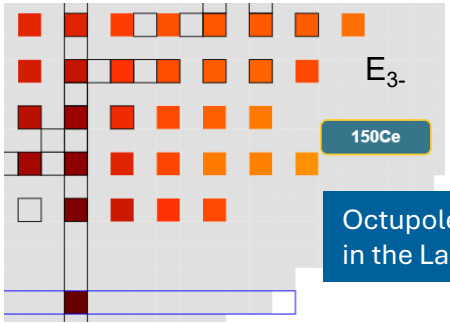
- Investigating & manipulating charge state distributions in the RFQ trap & charge exchange cell
- PAC-Approved experiments on Tc, Zr, La, Nd, Ce:
  - investigating open-shell nuclei & (beyond-QP) deformation

theory input





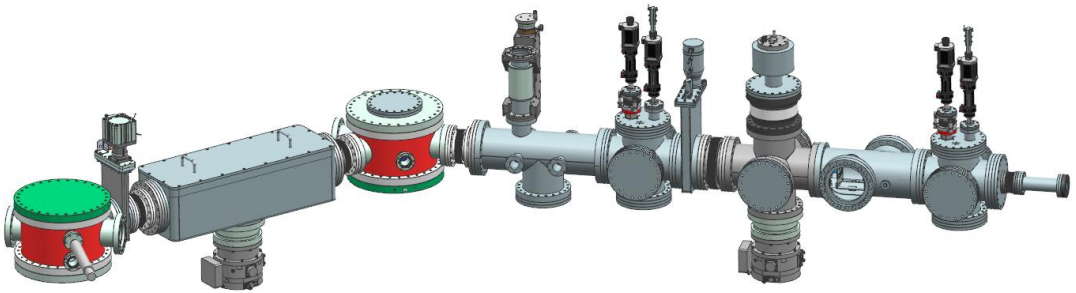
B. Cheal *et al.*, J. Phys. G: Nucl. Part. Phys. **29**, 2479 (2003)

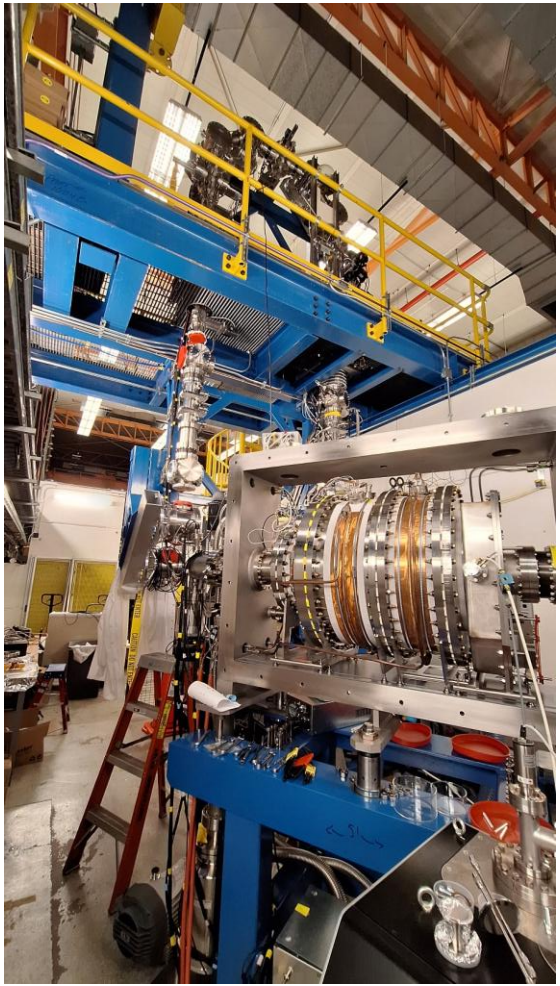


Octupole deformation in the La region

N=126 FACTORY

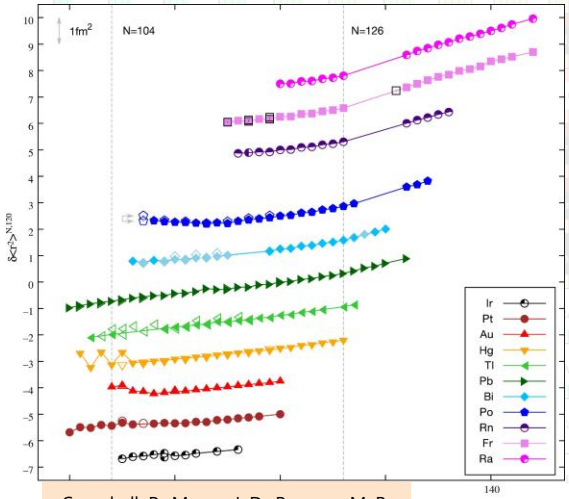
- Generate rare isotopes via multi-nucleon transfer (MNT) reactions
- Heavy beam (e.g., ~ 10 MeV/N Xe) on heavy target (e.g., Pt)
- Stop beam-like or target-like product in gas catcher
- Provide beams to low-energy experiments via mass separation + bunching
  - decay station (X-Array)
  - mass measurements (CPT)
  - laser spectroscopy (RIS + Fluorescence)





LASPEC AT N=126

- Implemented a copy of the offline source
- target Pt isotopes (production peak)



Campbell, P.; Moore, I. D.; Pearson, M. R.
Prog. Part. Nucl. Phys. 86 (2016)

red top bar:
previous l.s. investigation

Ir 196

k vertical lines:
production of 10^k /s
(here: $1.2 \cdot 10^6$)

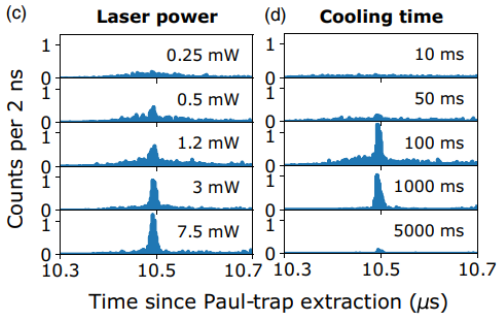
theory input

N=126 INSTRUMENTATION

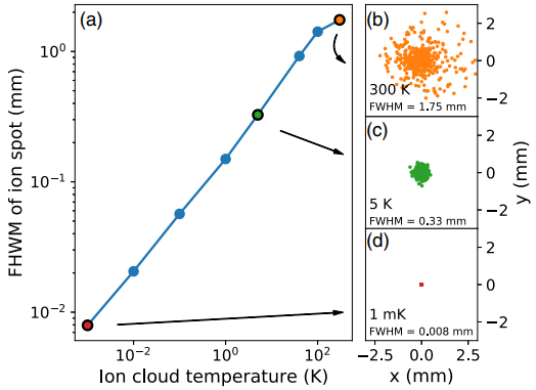
N=126 beams will be used for

MRTOF masses → Decay / Penning Trap → Laser Spec (2026-27)

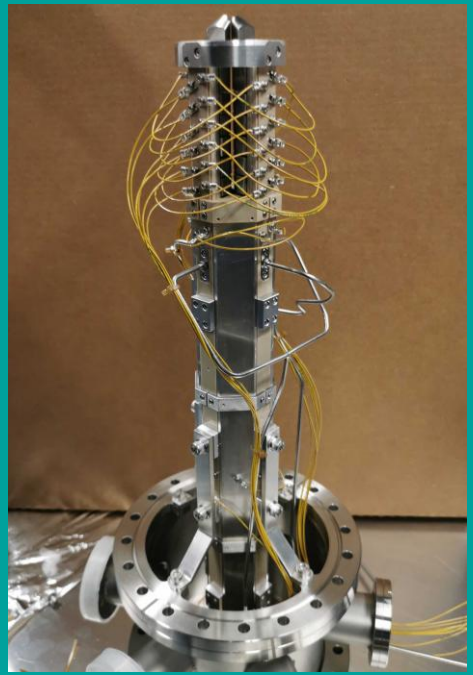
- Implement sympathetic cooling in designated trap
- support mass measurements (MRTOF/Penning Trap)



S. Sels et al. Phys. Rev. Res. 4, 033229 (2022)



New RFQ prototype (set up at TU Darmstadt) - operational



BEYOND CLS

Increase the sensitivity and the resolution of laser spectroscopy of short-lived isotopes:

mK-beam spectroscopy:

- long & precise particle/laser overlap
- optimized charge exchange process (energy & reagent)
  - » or state-selective charge exchange
- conditional ejection (only eject when RI is present)
  →increase in sensitivity

fundamental limitation: optical cycling & repumping

Goal: Move towards sub-Hz beam rate sensitivity in a versatile setup

BEYOND CLS

Increase the sensitivity and the resolution of laser spectroscopy of short-lived isotopes:

identify interesting physics cases

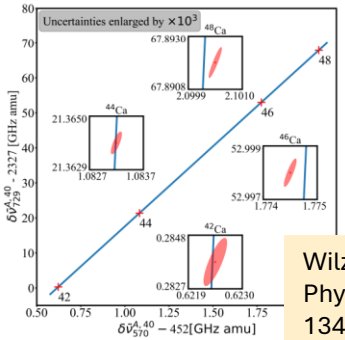
theory input

in-trap spectroscopy:

- longer interrogation times → longer-lived states → higher resolution
  - » Bohr-Weisskopf effect (magnetization distribution) (MHz)
  - » Breit-Rosenthal (charge distribution & shape) (kHz-MHz)
  - » magnetic octupole moment Ω (higher-order currents & l=3 mixing) (Hz-KHz)

- high-precision isotope shift (& masses)

  → king-plot nonlinearities → RI's increase the resolution



Wilzewski et al, Phys. Rev. Lett. 134, 233002

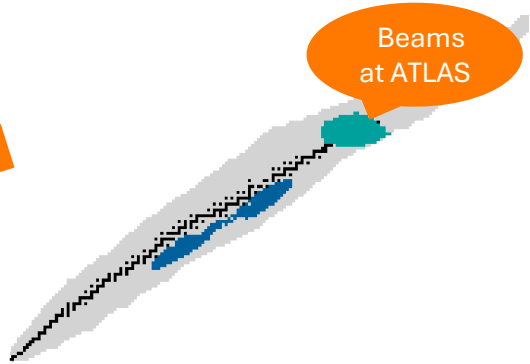
nuclear polarizability,

higher-order moments $\delta\langle r^4\rangle$

deformation, pairing

new bosons that couple e-n

theory input



SUMMARY & CLOSING

✓ The ATLAS accelerator facility at ANL offers a **low-energy stopped-beam** infrastructure **ready-made for laser spectroscopy** experiments:

NuCARIBU & N=126

✓ We performed first successful measurements with our new beamline **ATLANTIS**, which is now upgraded for more versatility and new beams

Triaxiality in Ruthenium, RIS & more experiments to come

✓ More Laser Spectroscopy for nuclear structure is planned at the **N=126 factory**, in the neutron-rich lead region

Platinum & sympathetically cooled beams for masses

✓ A **new generation of laser spectroscopy** experiments can be developed at ANL

mK-beams and in-trap spectroscopy

✓ **I'm always open for proposals, ideas, collaboration, questions!**

THANK YOU FOR YOUR ATTENTION!

Bernhard Maass[1,2], Alex Brinson[4,5], Daniel Burdette[1], Jason Clark[1], Adam Dockery[5], Max Horst[2,7], Phillip Imgram[8], Finn Köhler[2], Kristian König[2], Jeremy Lantis[1], Imke Lopp[2], Kei Minamisono[5], Patrick Müller[2], Peter Müller[1], Wilfried Nörtershäuser[2,7], Julian Palmes[2], Skyy Pineda[5], Simon Rausch[2,7], Laura Renth[2], Brooke Rickey[5], Daniel Santiago-Gonzalez[1], Guy Savard[1], Felix Sommer[2], Julien Spahn[2], Adrian A. Valverde[1]

BSkG Model calculations: Michael Bender[3], Guilherme Grams[6], Wouter Ryssens[6]

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