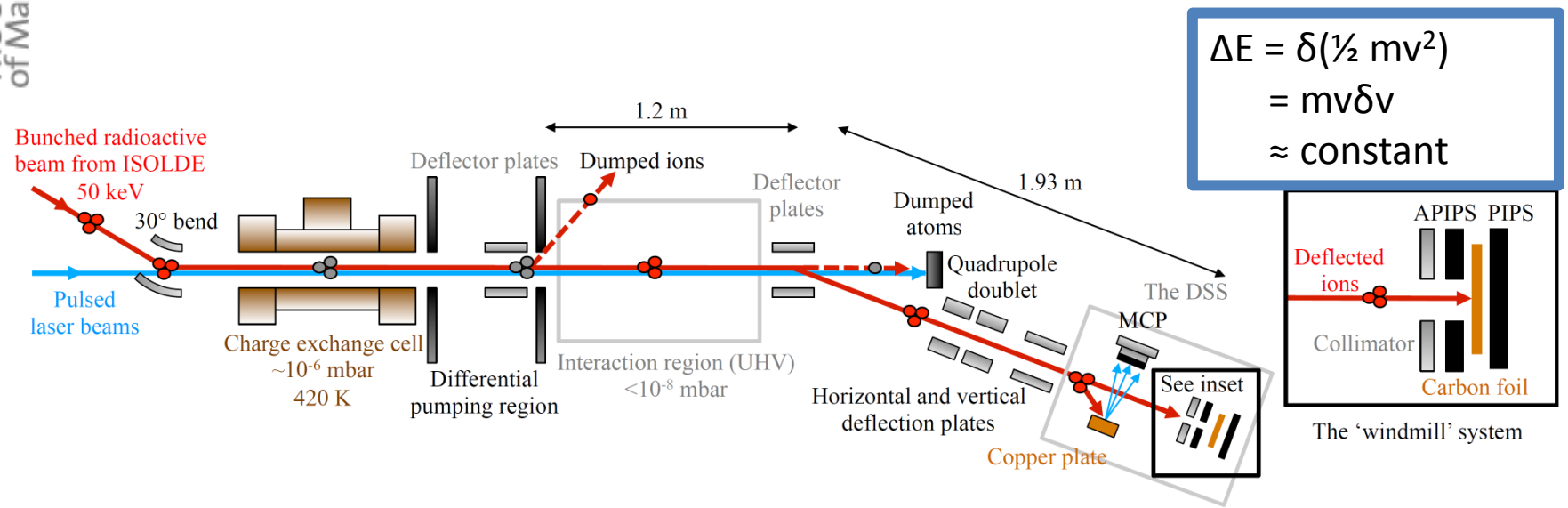
MANCHESTER 1824

The University of Manchester

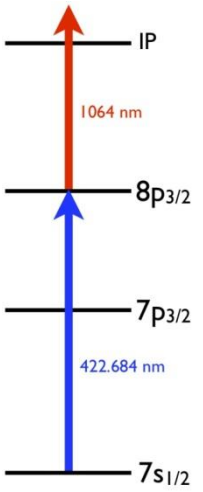
Status report for the CRIS experiment

Kieran Flanagan

CRIS experimental method

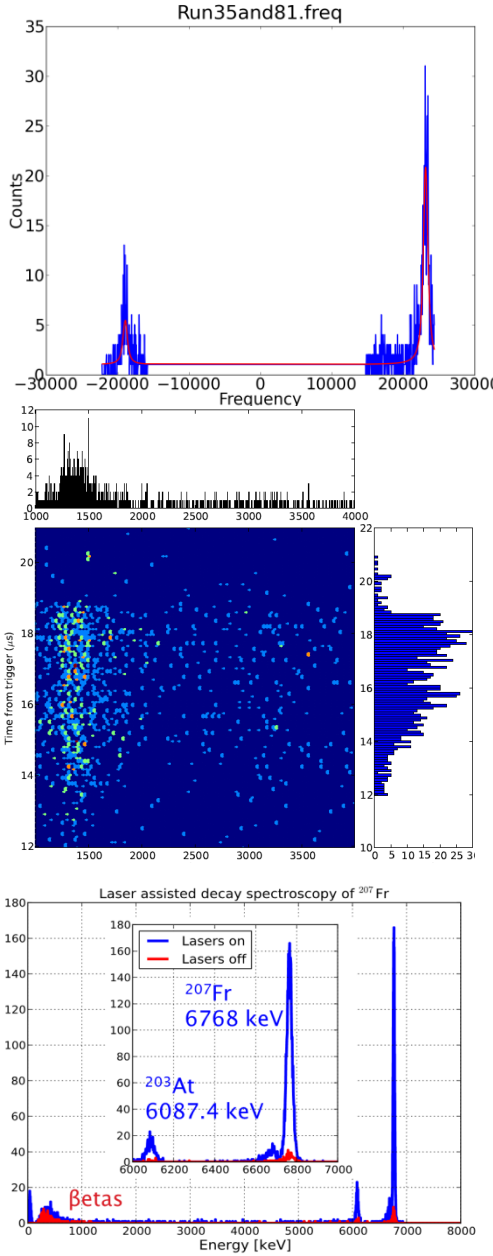


- The frequency of the laser was scanned – not the voltage
- Two step resonant ionization scheme
  - **423** nm resonant step (RILIS)
  - **1064** nm non-resonant step (CRIS)
- Measure nuclear moments, charge radii, and spin from the atomic hfs.



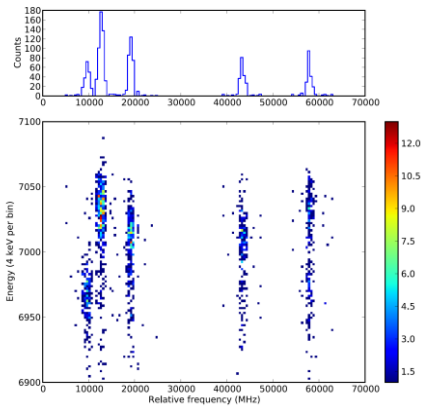
Summary of Status in 2011

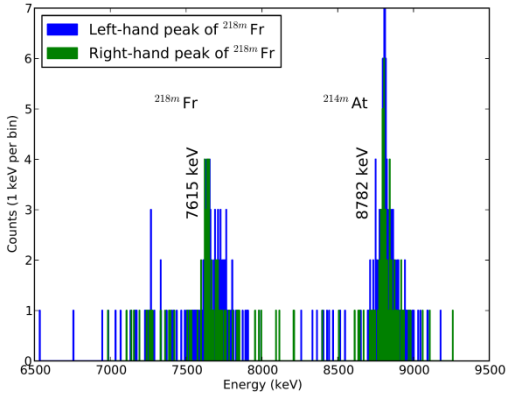
- Commissioned experiment with ^{207}Fr
- Low background: 0.05 counts/second
- Pressure in Interaction region 2.2e-8 mbar
- Charge exchange cell 50% efficiency
- Total Efficiency~1:10^6 for ion detection.
- Event-by-event data acquisition system used.
- Decay spectroscopy station installed and commissioned with ^{207}Fr: factor of 20 increase in detected alpha's with lasers on.

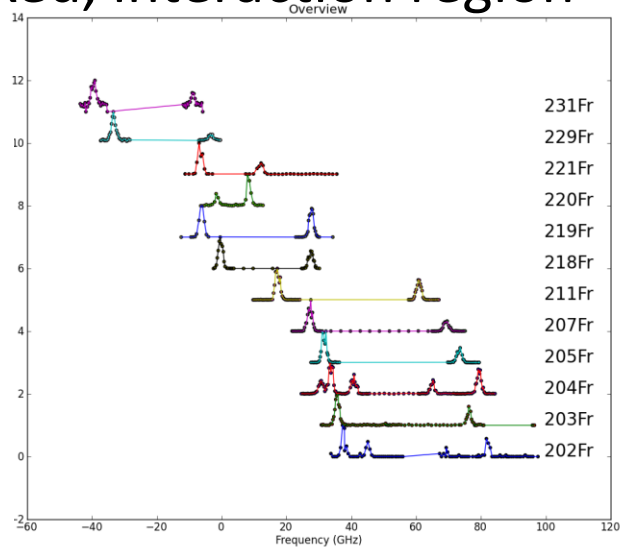


Status 2012

- Francium run completed $^{202\text{-}231}$Fr (all shifts used)
- RILIS Narrowband laser used 1.5 GHz linewidth
- ~1% total experimental efficiency estimated from ^{202,218,219}Fr
- Non-resonant ionization efficiency 0.0003%. Background rate 0.002 counts/s ^{202}Fr (cf 3-5 counts/s for fluorescence detection).
- At 9x10^{-9} mbar, 1pA of contaminant isobar reduced to 18cps
- Laser on/off ^{218}Fr alpha detection>330
- Small leak in DSS section has since been fixed, interaction region now reaches <1x10^{-9} mbar

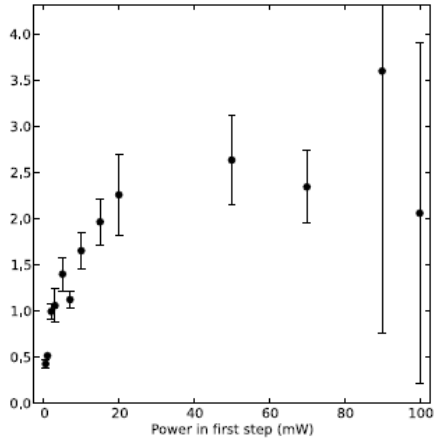


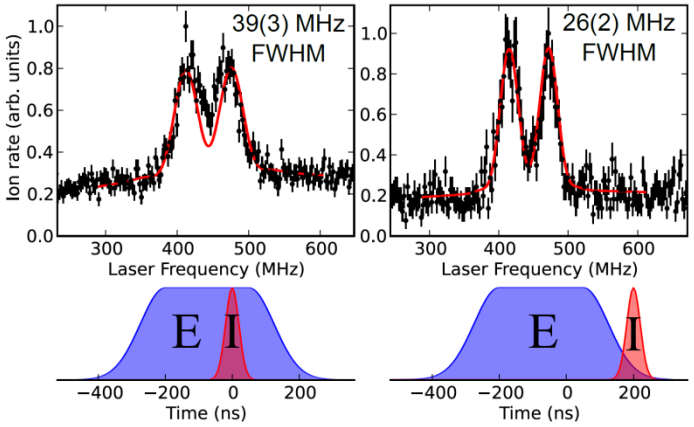


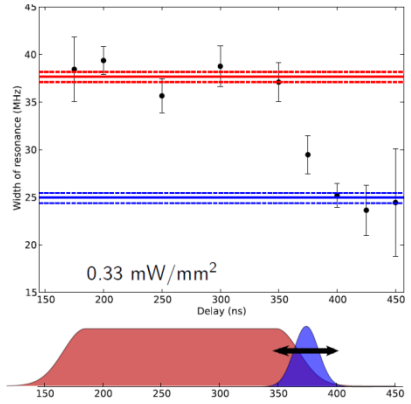


High resolution RIS

- 2013: Performed Doppler-free high resolution RIS tests on potassium.
- Tested saturating resonant step in ^{39}K with a CW laser system (769nm+355nm).
- To avoid optical pumping we also testing chopping the CW laser with a Pockels cell (100ns width)
- Were able to reach 39(3)MHz with both resonant and ionization lasers overlapped.
- Demonstrated that by separating the resonant step from the ionization step it is possible to significantly reduce coherent effects (such as AC Stark shift) and reached a linewidth of 26(2)MHz

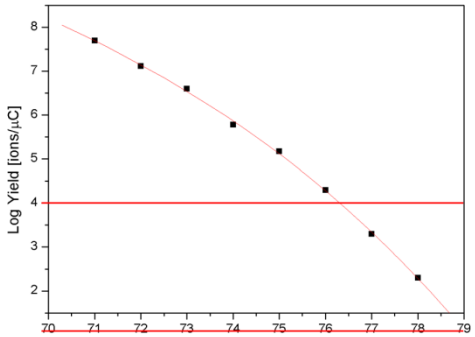


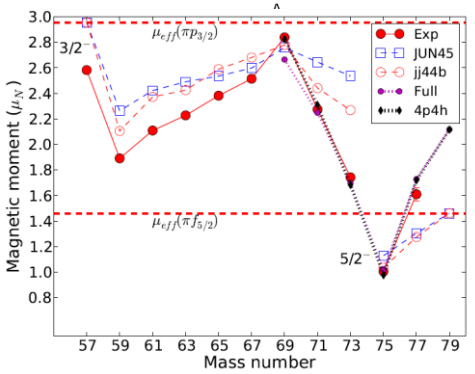




IS531: Collinear resonant ionization spectroscopy for neutron rich copper isotopes

- Study evolution of single particle levels towards ^{78}Ni. Measure spins and moments of ^{76,77,78}Cu
- Study magicity of Z=28 and N=50 in ^{78}Cu (= ^{78}Ni + 1p -1n) ?
- Search for long-lived isomers in ^{76,77,78}Cu and measure their spin and moments→ possible spin-gap isomer in ^{78}Cu, related to neutron in $\nu d_{5/2}$. Limits from in-source laser spectroscopy ^{77,78}Cu.
- Magnetic moment ^{77}Cu measured by in-source laser spectroscopy supports suggestion of significant excitation from $f_{7/2}$ orbital. Quadrupole moments are essential to better understand the evolution of nuclear structure in this region.
- 12 Shifts of radioactive beam still valid: 3 shifts for reference measurements of ^{69,71,72}Cu and 9 shifts to measure ^{76,77,78}Cu.

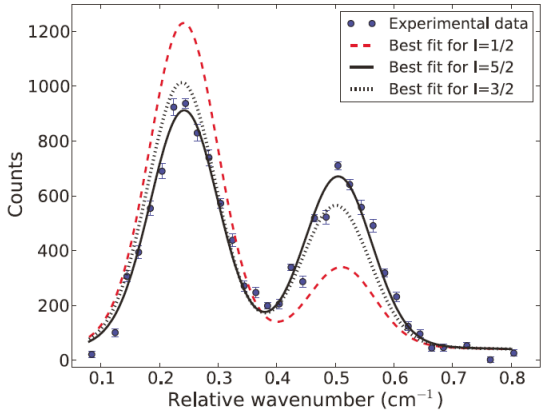




Honma
Brown } 56Ni core

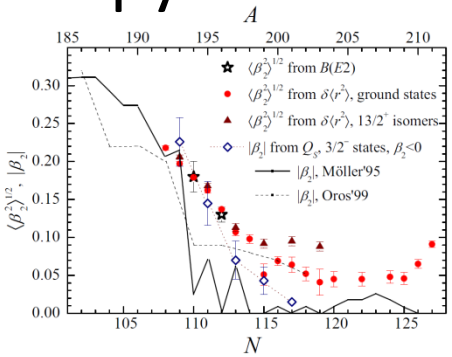
Sieja and Nowacki
48Ca core
PRC81, 061303(R),2010

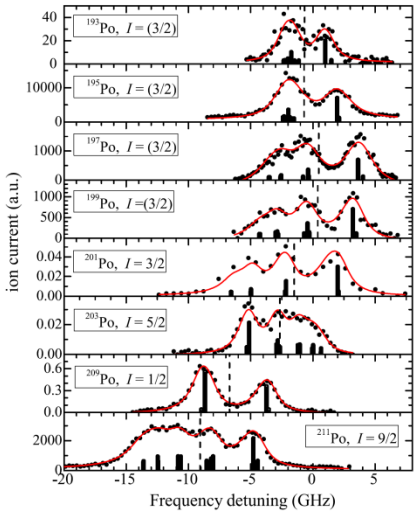
U. Koester et al.,
PRC84, 034320 (2011)

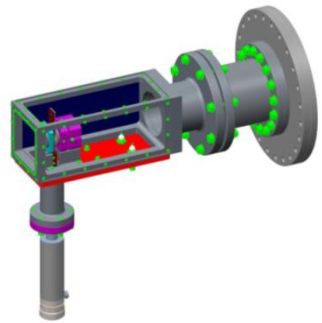


I145: Preparation for the study of the transitional nucleus ^{191}Po with high-resolution spectroscopy at CRIS

- I145 proposes to study ^{191}Po with the CRIS technique in order to measure the spin and moments.
- Feasibility study with ^{193,195,196,204}Po in order to de-risk any future proposal.
- ^{193,195}Po Spin and quadrupole measurement to understand systematic uncertainties introduced by coherent excitation to the continuum with RILIS.
- New bespoke decay spectroscopy chamber has been constructed for decay assisted laser spectroscopy of Po
- Requested 5 shifts still valid.

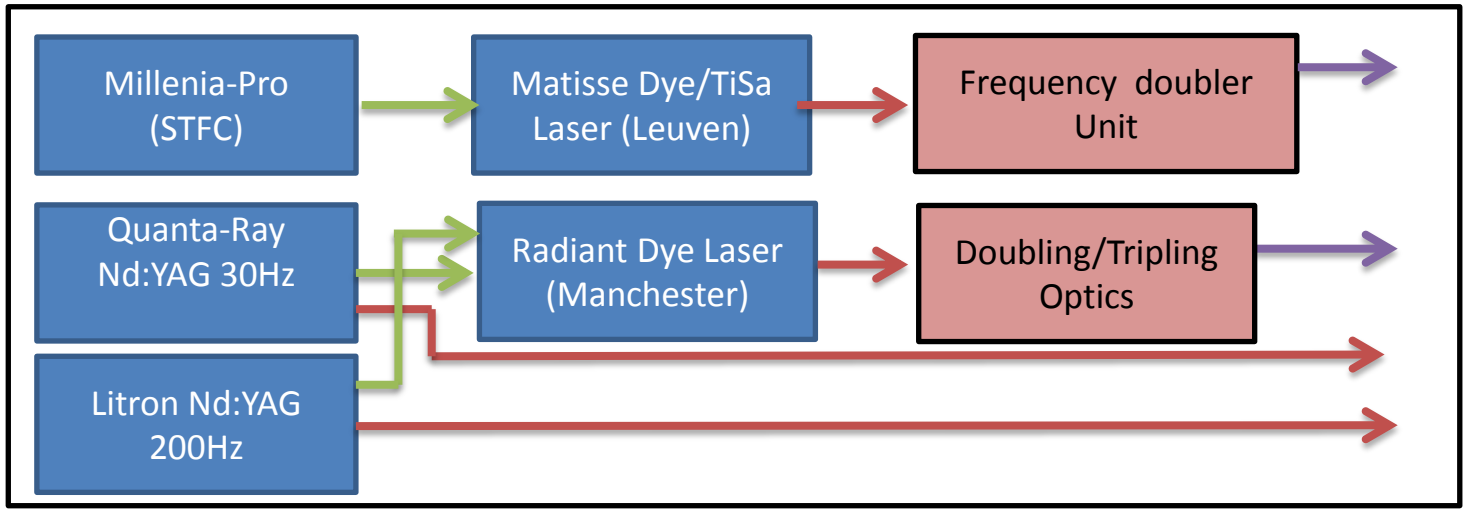




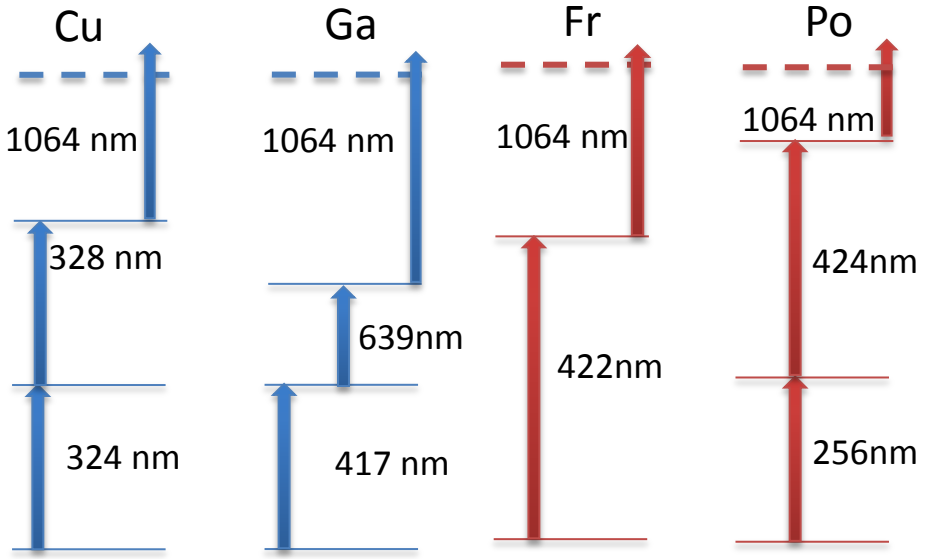


Laser setup options for 2014

Currently available CRIS resources



This laser system will allow all existing CRIS proposals and LOI to be executed during the 2014/2015 running periods with this system.



Summary

- CRIS experimental beam line has been fully installed and successfully commissioned.
- 2012 work published in PRL and accepted for publication in PRX (represents first nuclear PRX paper).
- The collaboration has all laser equipment required to execute existing proposals.
- Demonstrated ability to reach required high resolution for spin and quadrupole moment measurements.
- There is local team of sufficient strength to prepare experiments and a larger collaboration available for on-line support.
- Existing proposal and letters of intent are still compelling areas of research and should keep awarded shifts.

The CRIS Collaboration

J. Billowes, T.E. Cocolios, K.T. Flanagan, T.J. Procter, A. Smith, I. Strashnov, K.M. Lynch, S. Franchoo, V. Fedosseev, B. Marsh, G. Simpson, M. Bissell, I. Budincevic, R.P. De Groote, S. De Schepper, R.F. Garcia Ruiz, H. Heylen, J. Papuga, G. Neyens, H.H. Stroke, R.E. Rossel, S. Rothe, K. Wendt

Addendum:IS471 Collinear resonance ionization spectroscopy of rare francium isotopes

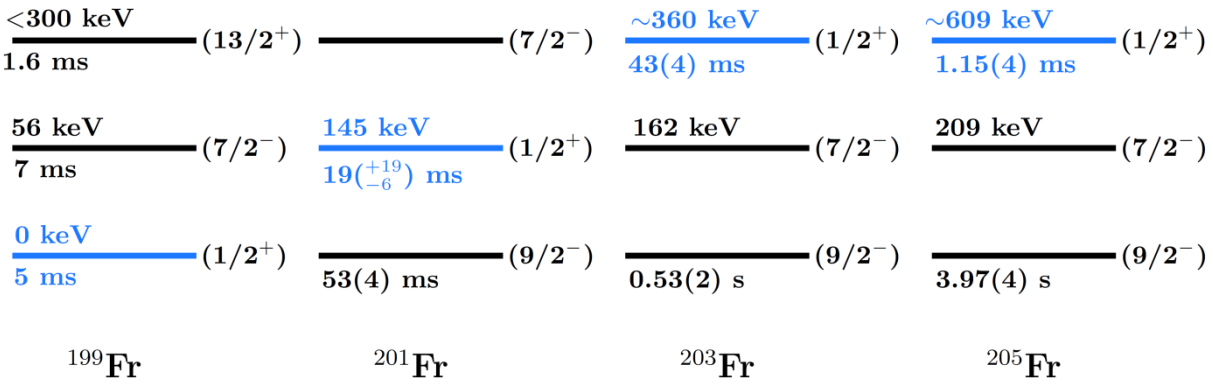
Spokesperson: K. T. Flanagan

Co-spokesperson: K.M. Lynch

Local Contact: K. M Lynch

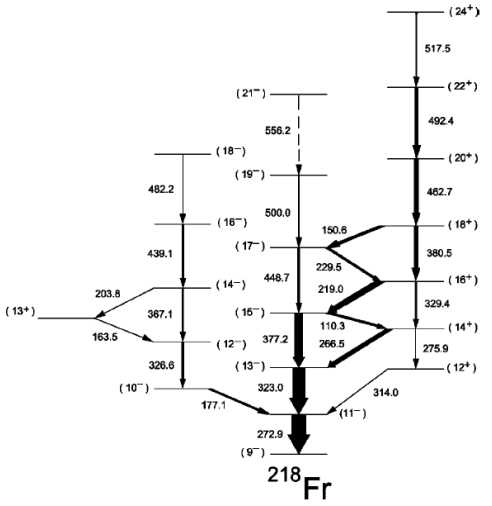
Approved Physics Case: ($\pi s_{1/2}^{-1}$) ½+ Intruder State

- Systematic reduction in energy of the deformed ($\pi s_{1/2}^{-1}$) ½+ in isotopes in this region of the chart
- ($\pi s_{1/2}^{-1}$) ½+ proton intruder state becomes the ground state in ^{195}At and ^{185}Bi
- Suggestion that ^{199}Fr has I= ½$^{+}$ ground state spin with an associated large oblate deformation
- The isomer shifts of ^{201,203}Fr and their magnetic moments will provide important information to better understand the evolution of nuclear structure in this region

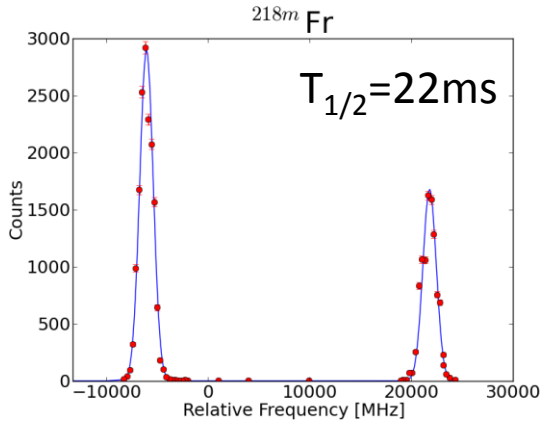


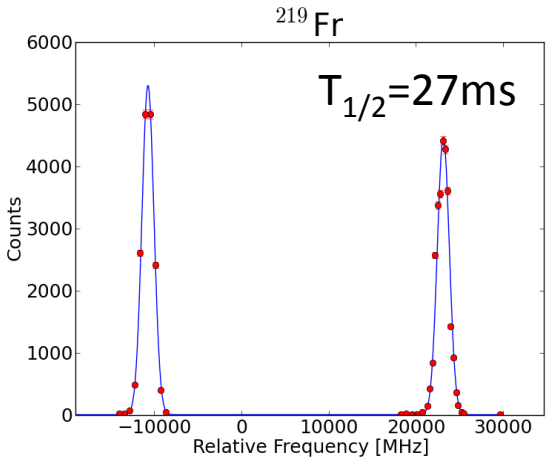
Approved Physics Case: ^{218,219}Fr

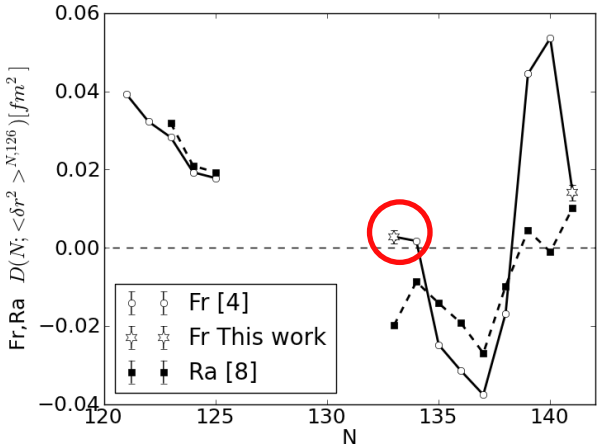
- ^{218}Fr exhibits an alternating parity band, while ^{219}Fr has parity doublet bands, which are generally associated with the presence of octupole deformations.
- The observed inversion of odd-even staggering of charge radii for $^{221\text{-}225}$Fr has been associated with octupole deformations.
- Quadrupole moments essential for understanding these transitional nuclei.



M. E. Debray et al., PRC 62, 024304 (2000)







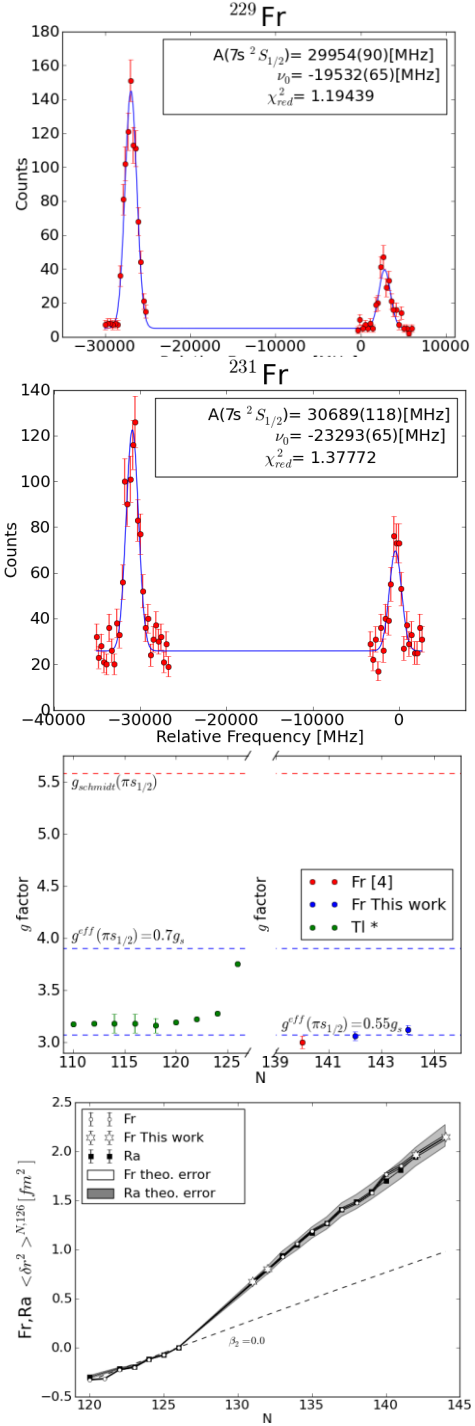
[4]A. Coc *et al.*, Phys.Lett. 163B, 66 (1985).
[8] K. Wendt *et al.*, Z. Phys. D 4, 227 (1987),

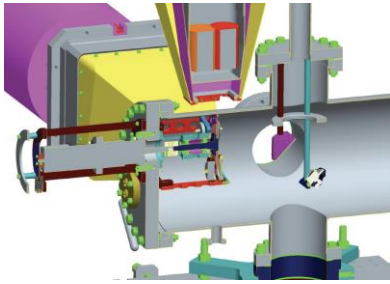
$(\pi s_{1/2}^{-1})$ ½+ intruder state ^{229,231}Fr

- Proton sharing at start of experiment was used to measure ^{229}Fr. ^{231}Fr also measured (paper in preparation)

- g-factor consistent with an interpretation of the ground state dominated by a $(\pi s_{1/2}^{-1})$ ½⁺ and closely follow trend observed in Tl isotopes.

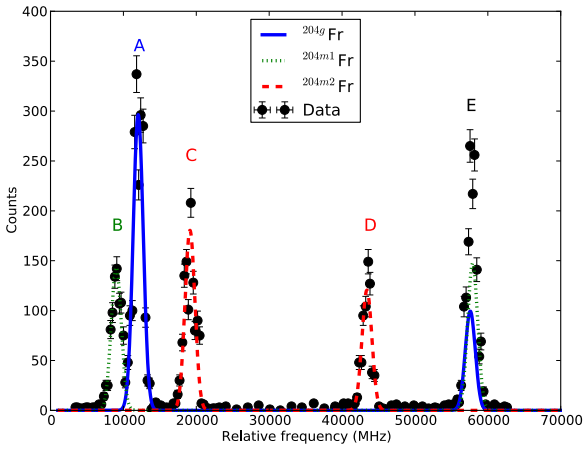
- g-factor and δ<r²> systematics will help ^{203m,201m}Fr scan regions to be heavily constrained.

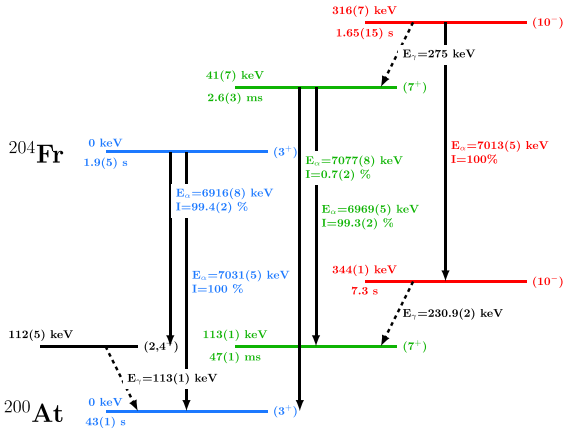


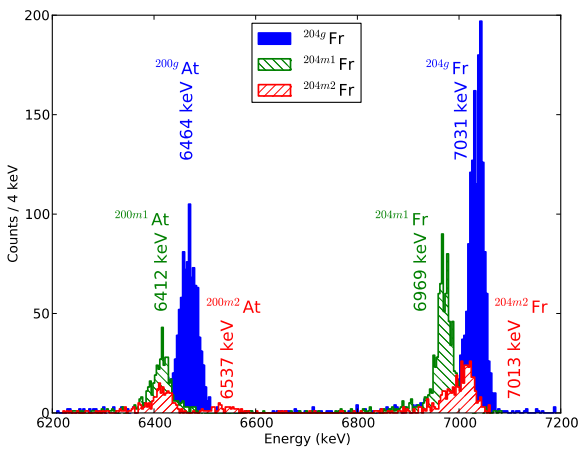


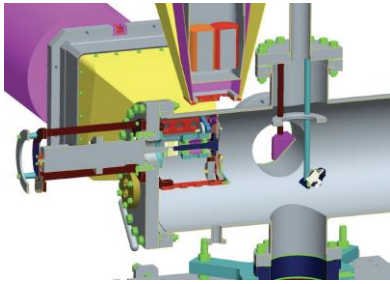
Decay Spectroscopy

- Suggestion by INTC to check the possibility of decay spectroscopy with pure beams at new setup with regard to the world-wide effort to perform trap-assisted spectroscopy.
- We constructed an alpha-decay spectroscopy station and used it to study ^{204}Fr
- Unambiguous determination of ^{204m2}Fr (I=10^{-}) state (hfs)
- System allows overlapping hfs states to studied separately.



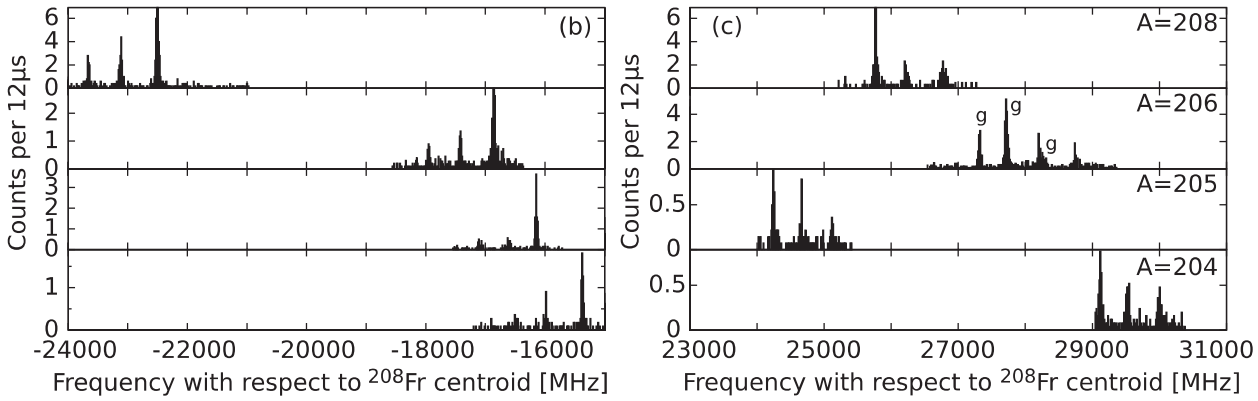


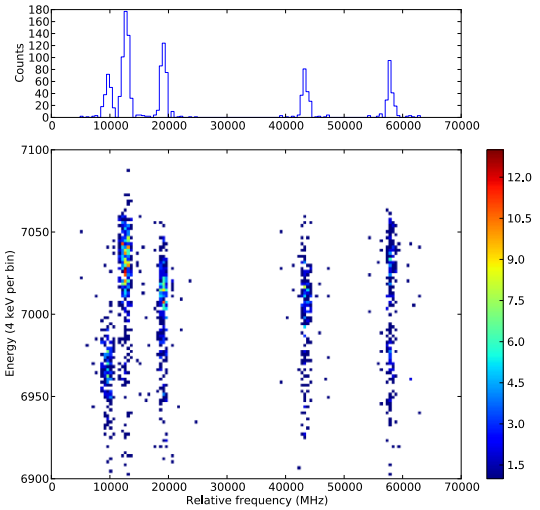




Decay Spectroscopy

- Suggestion of INTC to check the possibility of decay spectroscopy with pure beams at new setup with regard to the world-wide effort to perform trap-assisted spectroscopy.
- We constructed a UHV suitable alpha-decay spectroscopy station and used it to study 204Fr
- Unambiguous determination of ^{204m2}Fr (I=10^{-}) state
- System allows overlapping hfs states to studied separately.

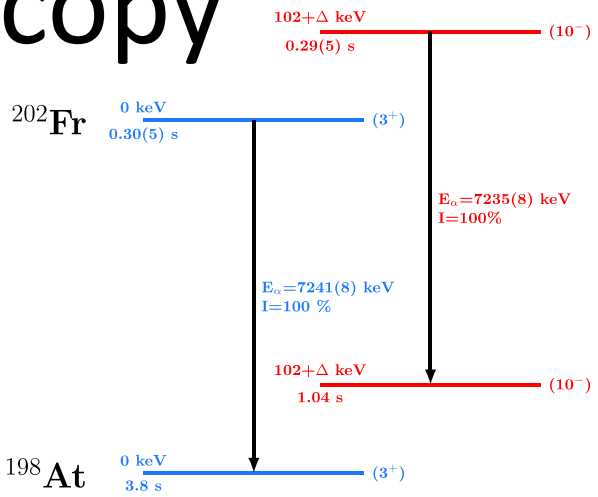


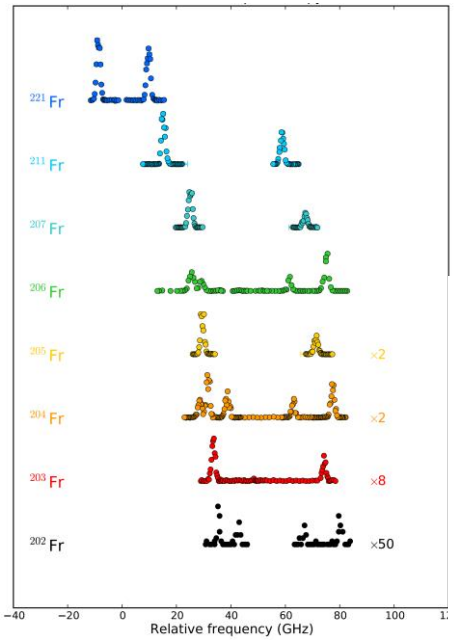


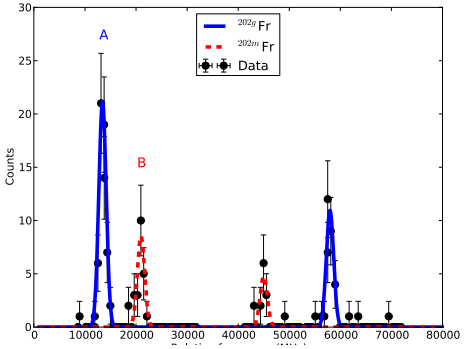
A. Voss et al., Phys. Rev. Lett. 111, 122501 (2013)

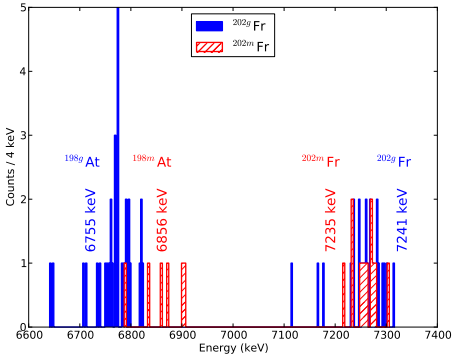
Laser Spectroscopy

- DSS used to identify ground state and isomer in ^{202}Fr
- Yield estimated to be 100 atoms/s (LA1)
- Total experimental efficiency estimated to be 1% using yield of ^{202}Fr (^{218,219}Fr also give consistent efficiency)
- 1.5hrs to produce ^{202}Fr spectrum.
- Factor 100 more sensitive than state-of-the-art bunched fluorescence spectroscopy





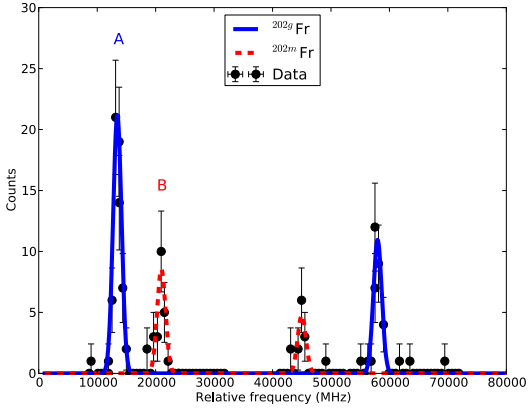


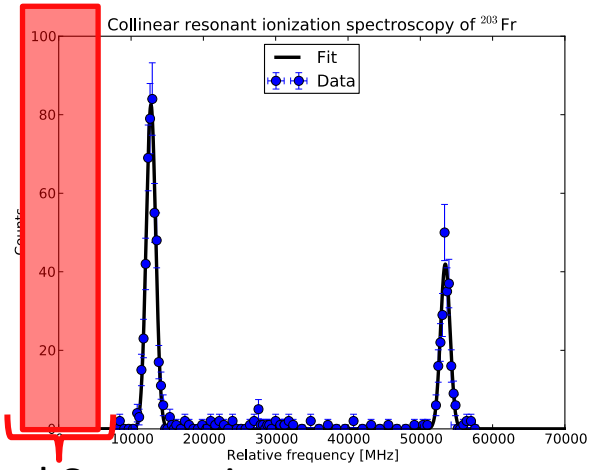


A. Voss et al., Phys. Rev. Lett. 111, 122501 (2013)

^{201,203}Fr status and expectation

- Expected yield of ½ isomer is between x10-x100 less than ^{202}Fr (shown scan took 1.5hrs)
- g-factor and $\delta\langle r^2\rangle$ systematics of ^{203,205}Fr the neutron rich ^{227,229,231}Fr used to constrain search.
- 50-60GHz scanning region will be reduced 6GHz (shown in red for ^{203}Fr).
- Scanning region for weaker right hand side hfs components will be constrained by g-factor.
- At 1 atom/s 2 shifts for each region





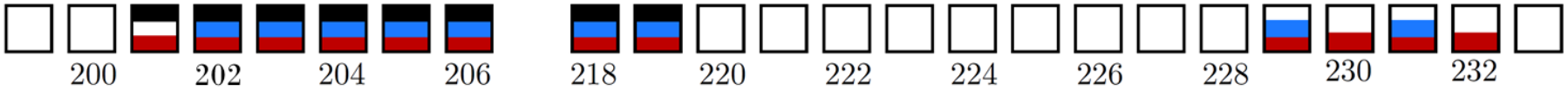
Reduced Scan region

Isotope of Fr	Half life	Spin
203g	0.53 s	(9/2) -
203m	43 ms	(1/2) +

Break down of shift request

This assumes same experimental efficiency as 2012

Request includes required time for reference scans of $^{207\text{-}221}$Fr.



Francium isotopes (black) originally proposed, (blue) measured in 2012, (red) covered by this addendum.

- ^{232,231,230,229}Fr 10 shifts are requested. Complete systematics of this region and role of ½ intruder state. Presence of isobar that is ionized by 1064nm light will be removed with second Nd:YAG.
- ^{218,219}Fr 6 shifts are requested: quadrupole moment and spin measurements of 20ms states (slow because full supercycle per step required).
- $^{206\text{-}204}$Fr 3 shifts: quadrupole moment measurements with decay tagging systematic measurements of 7S-8P transition.
- ^{203}Fr 6 shifts: quadrupole moment of ground state, hunting for isomer.
- ^{202}Fr 3 shifts: quadrupole moment of ground state and isomer.
- ^{201}Fr 6 shifts: ground and isomeric state, scan regions heavily constrained by ^{203}Fr measurement allowing measurement of 1 atom/s yield.

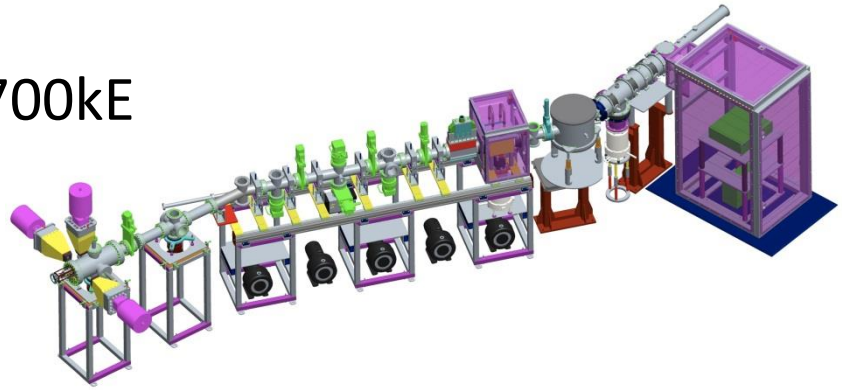
Total: 34 Shifts

Scholarly Output and Awards

- Publications: 3 Publications: PRL, NIMA, NIMB (1 accepted PRX & 1 in preparation) 8 Conference proceedings.
- General Interest Articles: 3: Nuc. Phys. News, CERN Bulletin, Brits@CERN
- Completed PhDs: 2 Students (TJ Procter and KM Lynch). Masters Students: 3
- Prizes and Awards: KM Lynch

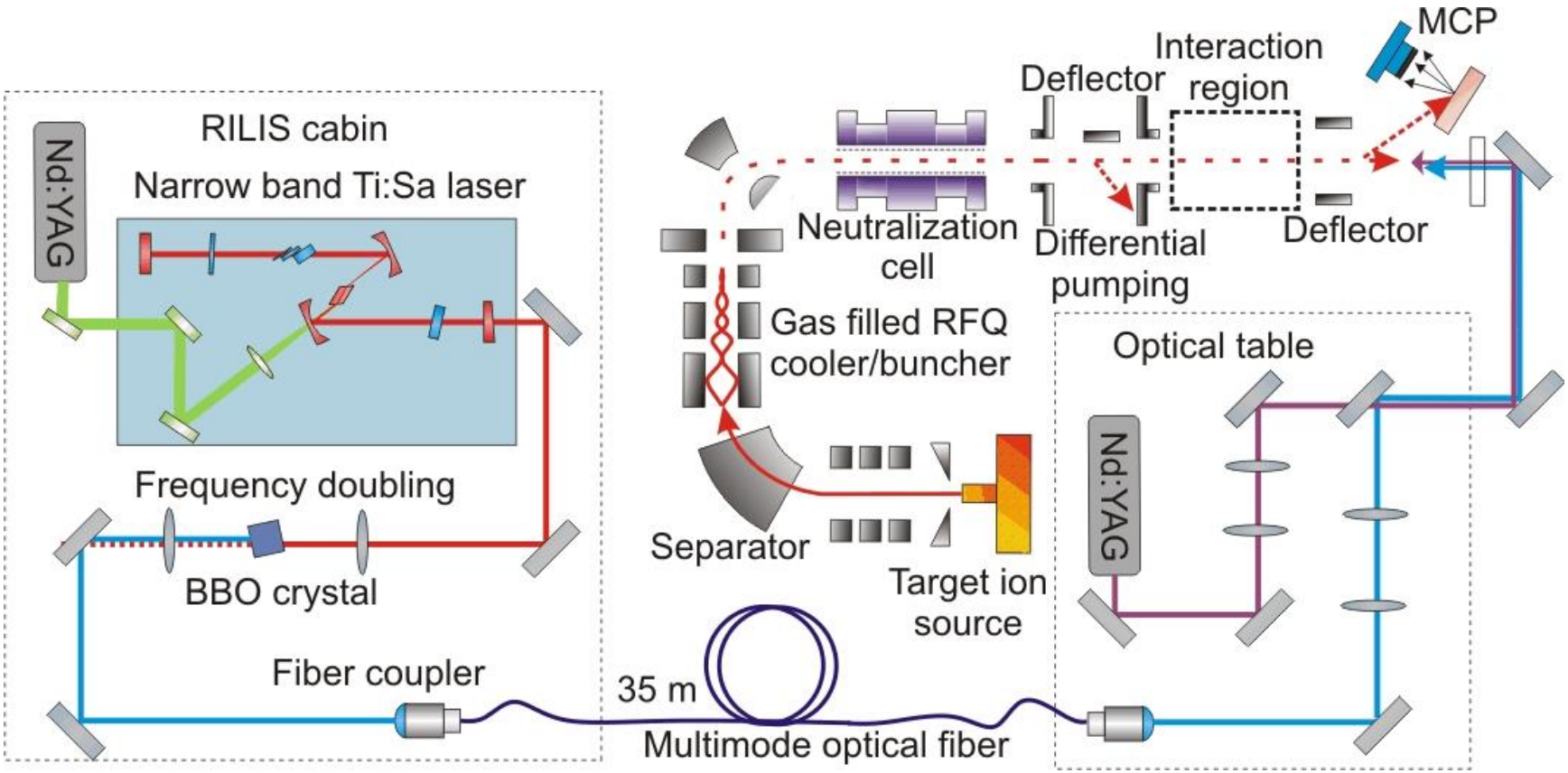
has won the IOP Nuclear Physics Group Prize 2013

Investment and Human Resources

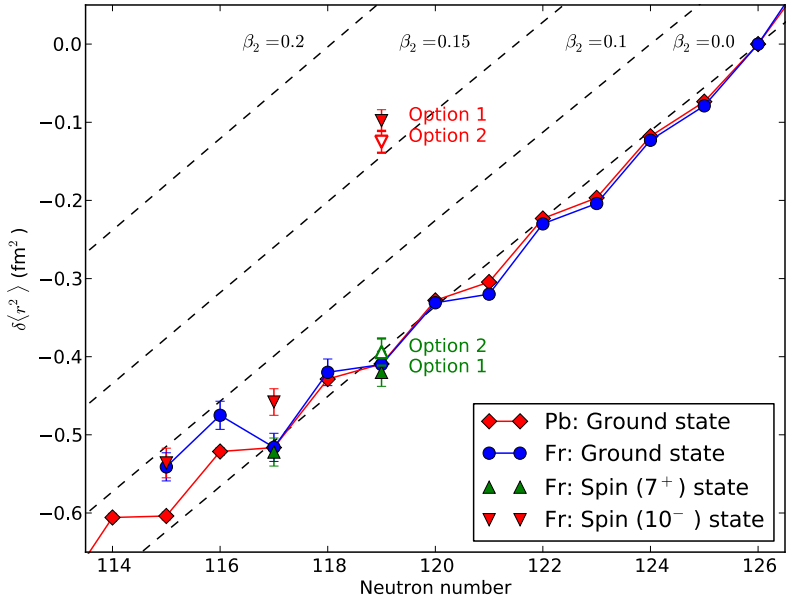


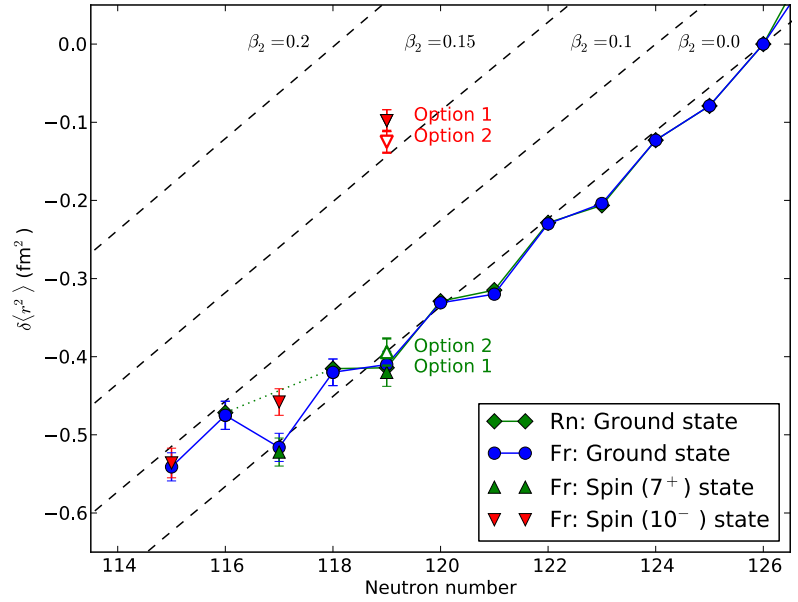
- Total Capital Investment in CRIS: 700kE
  - Laser Equipment: 270kE
  - Vacuum pumps: 91kE
  - Beam line equipment: 178kE
  - General Infrastructure: 280kE
- 2 STFC funded research fellows and a new FWO funded research fellow
- University of Manchester: 2 Academics, 1 Research Fellow, 1 PDRA, 2 new PhD students.
- KU Leuven: 1 Academic, 1 Research Fellow, 2 PhD students
- **Total FTE 2014: 7**
- Additional support for on-line experiments from collaboration 3 Academics, 1 PDRA, 4 PhD students (Leuven, Mainz, Manchester, Orsay, UWS, ILL)

CRIS Experiment 2012



Charge radii





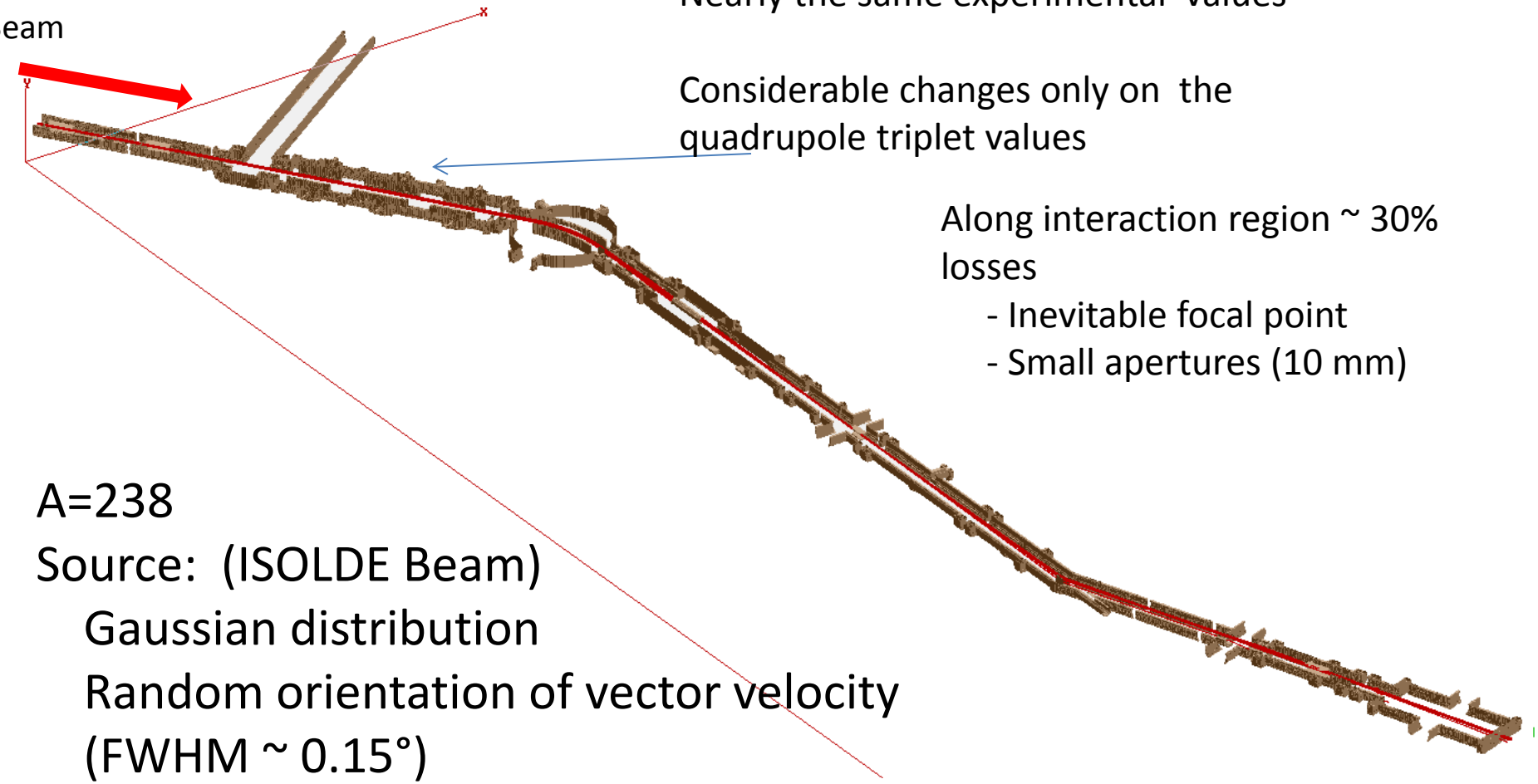
- Deviation from Pb charge radii trend at ^{203}Fr (N=116)
  - Marks onset of collective behaviour
  - Measure quadrupole moment to determine static deformation (laser linewidth < 100 MHz)
- Good agreement with Rn charge radii
  - Calibrated to $\delta\langle r^2 \rangle^{211,213}$ to account for uncertainty in F and M atomic factors
  - Original isotope shifts are only presented graphically
  - Proton acts as a spectator particle

SIMION Simulations: ISOLDE Beam

30 keV
Beam

SIMULATIONS:
Nearly the same experimental values

Considerable changes only on the quadrupole triplet values

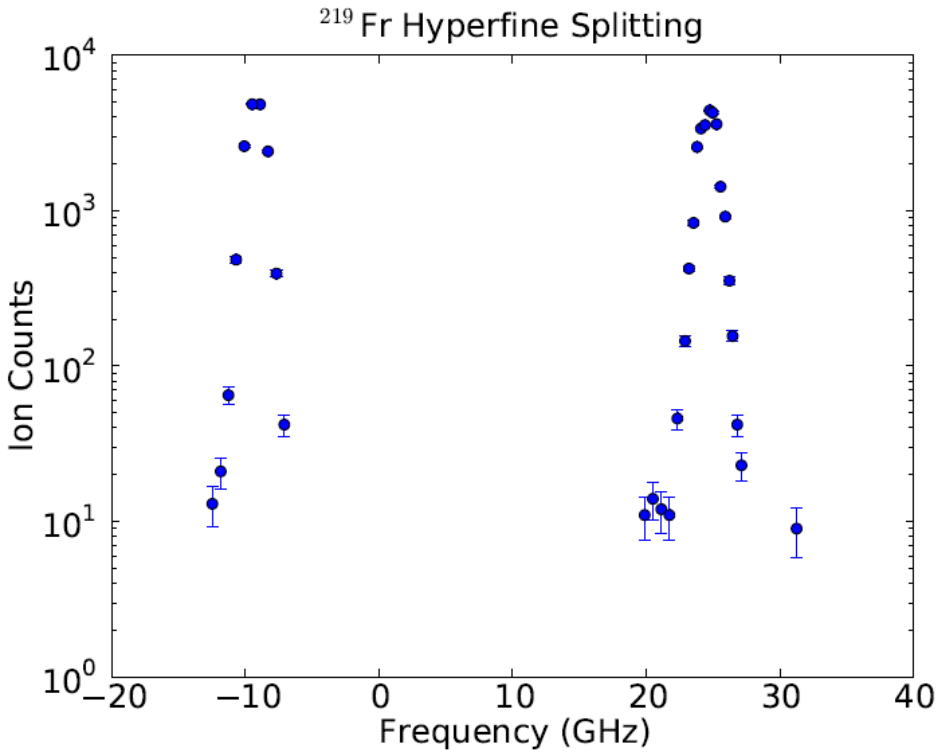


Along interaction region ~ 30% losses
- Inevitable focal point
- Small apertures (10 mm)

A=238
Source: (ISOLDE Beam)
Gaussian distribution
Random orientation of vector velocity
(FWHM ~ 0.15°)
5-10 mm initial diameter

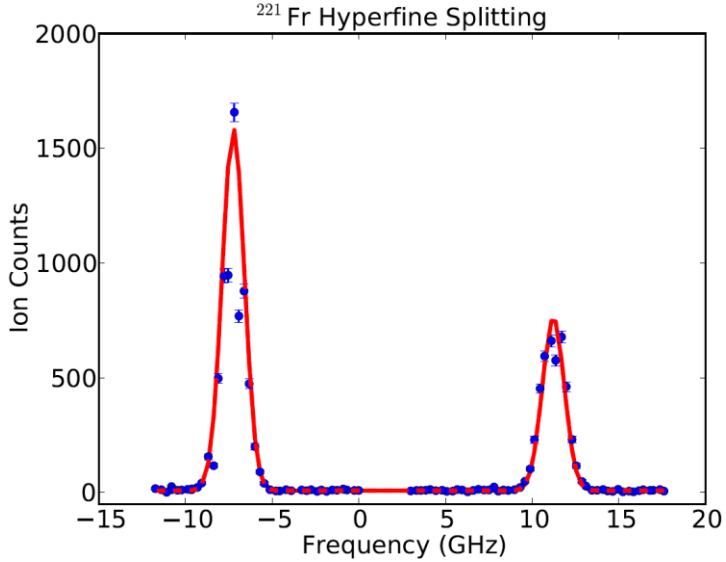
~ 70% transmission

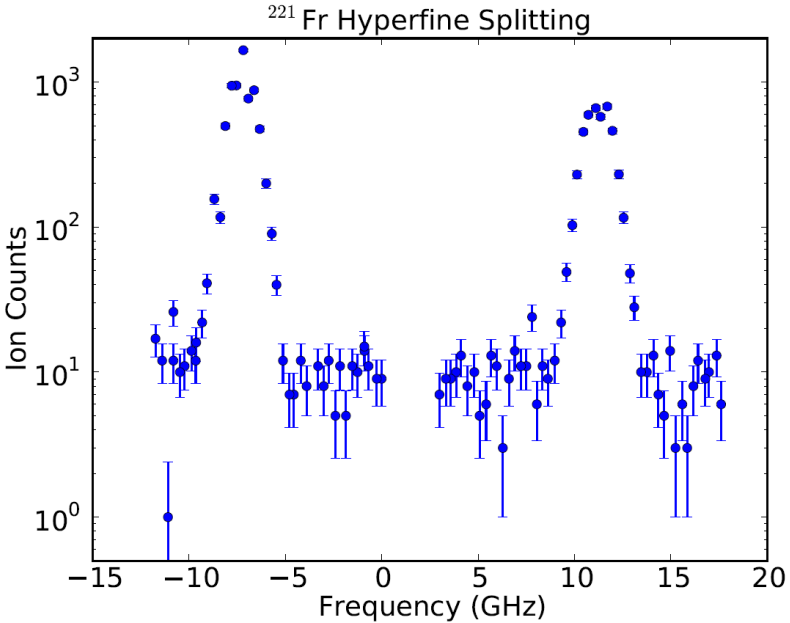
Experimental efficiency from ^{219}Fr



- 1 super cycle/step with an average of 18 proton pulses per step.
- The yield of ^{219}Fr from data base is 1.8×10^4 ppp
- Efficiency 1:70
- Laser power at measured next to the fiber launch was 95mW
- Charge exchange cell working properly

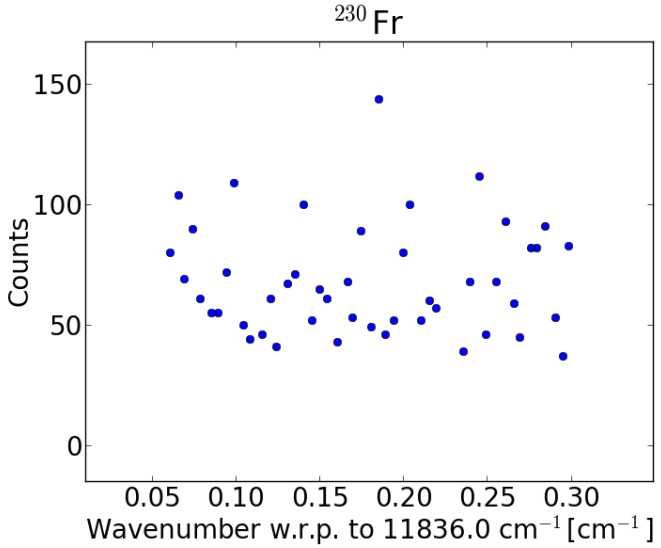
Background

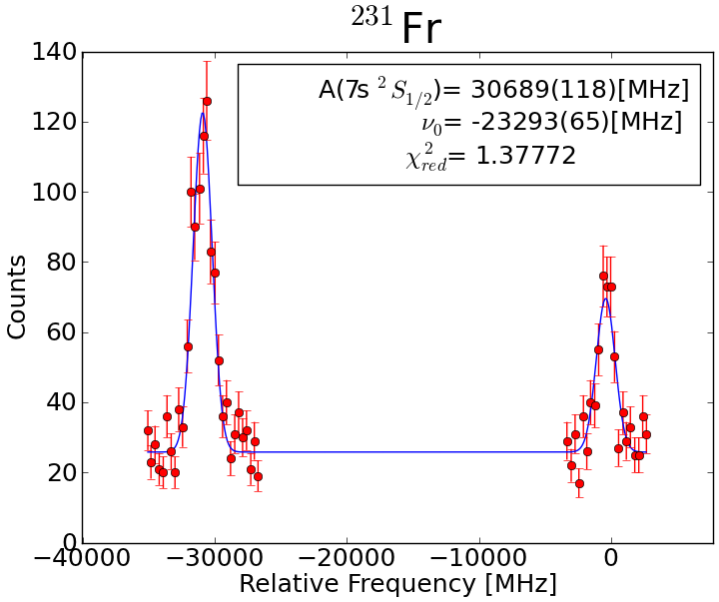




- Sources of background counting: non-resonant ionization, activity in front of MCP, MCP dark count rate, noise.
- During the run daughter activity built up in front of the MCP leading to a background rate of ~10cts/super cycle.
- Reduced window around bunch from 20us to 4us, we also waited for activity to reduce before studying ^{202}Fr

Background Part II





- 1064nm light responsible for observed rate.
- Assumption that highlying metastable/Rydberg state in Ra (or other isobar) is populated in charge exchange cell
- Anything greater than 3us would be a problem!
- Solution: Second Nd:YAG laser