

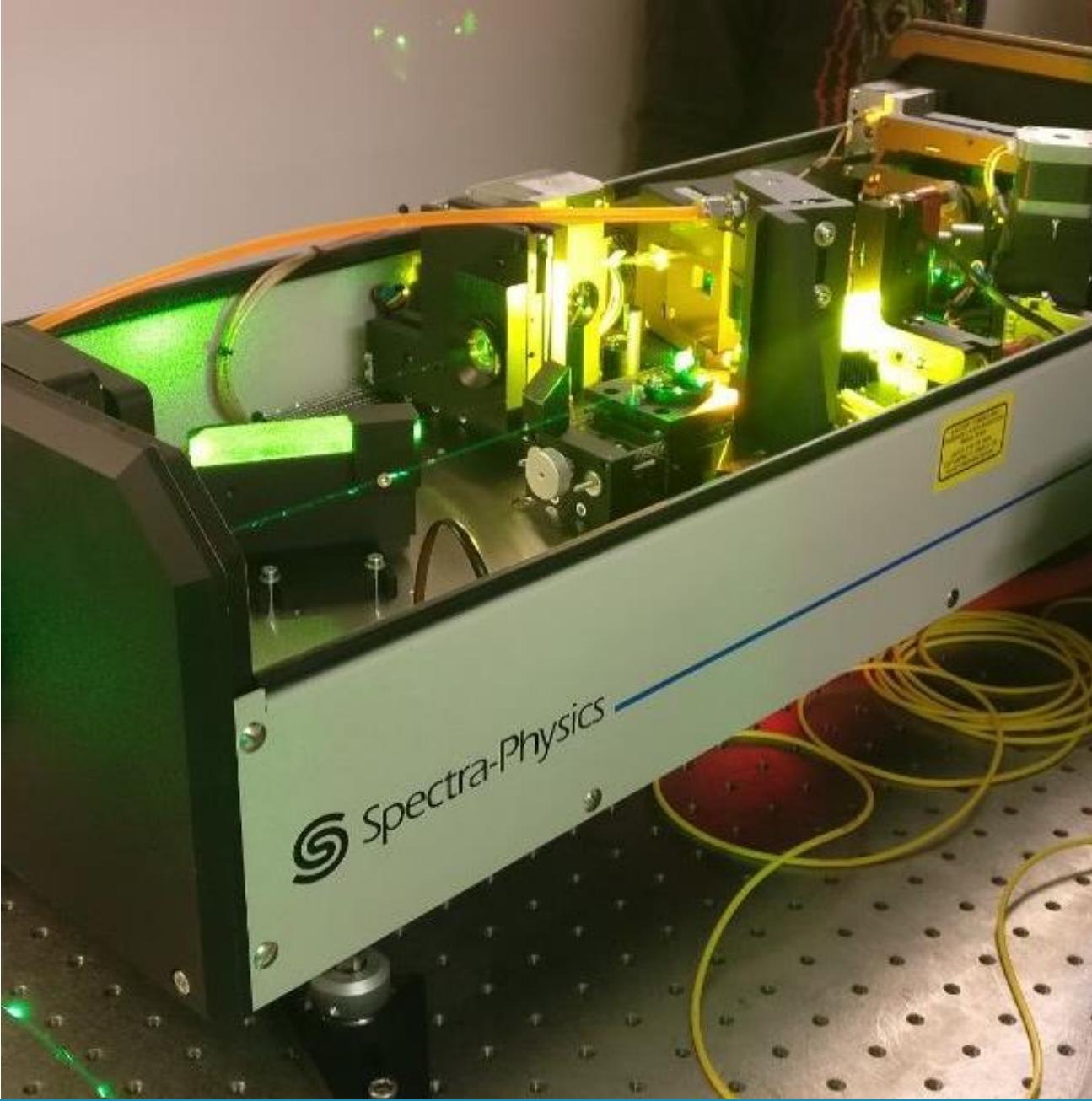
<sup>101</sup> In β+	<sup>102</sup> In β+	<sup>103</sup> In β+	<sup>104</sup> In β+	<sup>105</sup> In β+	<sup>106</sup> In β+	<sup>107</sup> In β+	<sup>108</sup> In β+	<sup>109</sup> In β+	<sup>110</sup> In e- capture	<sup>111</sup> In β+	<sup>112</sup> In Stable	<sup>113</sup> In β-	<sup>114</sup> In Stable	<sup>115</sup> In β-	<sup>116</sup> In Stable	<sup>117</sup> In β-	<sup>118</sup> In β-	<sup>119</sup> In β-	<sup>120</sup> In β-	<sup>121</sup> In β-	<sup>122</sup> In β-
Cd β+	<b>KU LEUVEN</b>				<sup>107</sup> Cd Stable	<sup>108</sup> Cd Stable	<sup>109</sup> Cd e- capture	<sup>110</sup> Cd Stable	<sup>111</sup> Cd Stable	<sup>112</sup> Cd Stable	<sup>113</sup> Cd Stable	<sup>114</sup> Cd Stable	<sup>115</sup> Cd β-	<sup>116</sup> Cd Stable	<sup>117</sup> Cd β-	<sup>118</sup> Cd β-	<sup>119</sup> Cd β-	<sup>120</sup> Cd β-	<sup>121</sup> Cd β-	<sup>122</sup> Cd β-	
Ag β+	<sup>102</sup> Ag β+	<sup>103</sup> Ag β+	<sup>104</sup> Ag β+	<sup>105</sup> Ag β+	<sup>106</sup> Ag β+	<sup>107</sup> Ag Stable	<sup>108</sup> Ag β-	<sup>109</sup> Ag Stable	<sup>110</sup> Ag β-	<sup>111</sup> Ag β-	<sup>112</sup> Ag β-	<sup>113</sup> Ag β-	<sup>114</sup> Ag β-	<sup>115</sup> Ag β-	<sup>116</sup> Ag β-	<sup>117</sup> Ag β-	<sup>118</sup> Ag β-	<sup>119</sup> Ag β-	<sup>120</sup> Ag β-	<sup>121</sup> Ag β-	
Pd capture	<sup>101</sup> Pd β+	<sup>102</sup> Pd Stable	<sup>103</sup> Pd e- capture	<sup>104</sup> Pd Stable	<sup>105</sup> Pd Stable	<sup>106</sup> Pd Stable	<sup>107</sup> Pd β-	<sup>108</sup> Pd Stable	<sup>109</sup> Pd β-	<sup>110</sup> Pd Stable	<sup>111</sup> Pd β-	<sup>112</sup> Pd β-	<sup>113</sup> Pd β-	<sup>114</sup> Pd β-	<sup>115</sup> Pd β-	<sup>116</sup> Pd β-	<sup>117</sup> Pd β-	<sup>118</sup> Pd β-	<sup>119</sup> Pd β-	<sup>120</sup> Pd β-	
Rh β+	<sup>100</sup> Rh e- capture	<sup>101</sup> Rh e- capture	<sup>102</sup> Rh β+	<sup>103</sup> Rh Stable	<sup>104</sup> Rh β-	<sup>105</sup> Rh β-	<sup>106</sup> Rh β-	<sup>107</sup> Rh β-	<sup>108</sup> Rh β-	<sup>109</sup> Rh β-	<sup>110</sup> Rh β-	<sup>111</sup> Rh β-	<sup>112</sup> Rh β-	<sup>113</sup> Rh β-	<sup>114</sup> Rh β-	<sup>115</sup> Rh β-	<sup>116</sup> Rh β-	<sup>117</sup> Rh β-	<sup>118</sup> Rh β-	<sup>119</sup> Rh β-	
Ru stable	<sup>99</sup> Ru Stable	<sup>100</sup> Ru Stable	<sup>101</sup> Ru Stable	<sup>102</sup> Ru Stable	<sup>103</sup> Ru β-	<sup>104</sup> Ru Stable	<sup>105</sup> Ru β-	<sup>106</sup> Ru β-	<sup>107</sup> Ru β-	<sup>108</sup> Ru β-	<sup>109</sup> Ru β-	<sup>110</sup> Ru β-	<sup>111</sup> Ru β-	<sup>112</sup> Ru β-	<sup>113</sup> Ru β-	<sup>114</sup> Ru β-	<sup>115</sup> Ru β-	<sup>116</sup> Ru β-	<sup>117</sup> Ru β-	<sup>118</sup> Ru β-	
Tc	<sup>98</sup> Tc	<sup>99</sup> Tc	<sup>100</sup> Tc	<sup>101</sup> Tc	<sup>102</sup> Tc	<sup>103</sup> Tc	<sup>104</sup> Tc	<sup>105</sup> Tc	<sup>106</sup> Tc	<sup>107</sup> Tc	<sup>108</sup> Tc	<sup>109</sup> Tc	<sup>110</sup> Tc	<sup>111</sup> Tc	<sup>112</sup> Tc	<sup>113</sup> Tc	<sup>114</sup> Tc	<sup>115</sup> Tc	<sup>116</sup> Tc	<sup>117</sup> Tc	

# Collinear laser spectroscopy of exotic Pd isotopes at the IGISOL facility

Sarina Geldhof

ISOLDE Workshop and Users meeting 2020



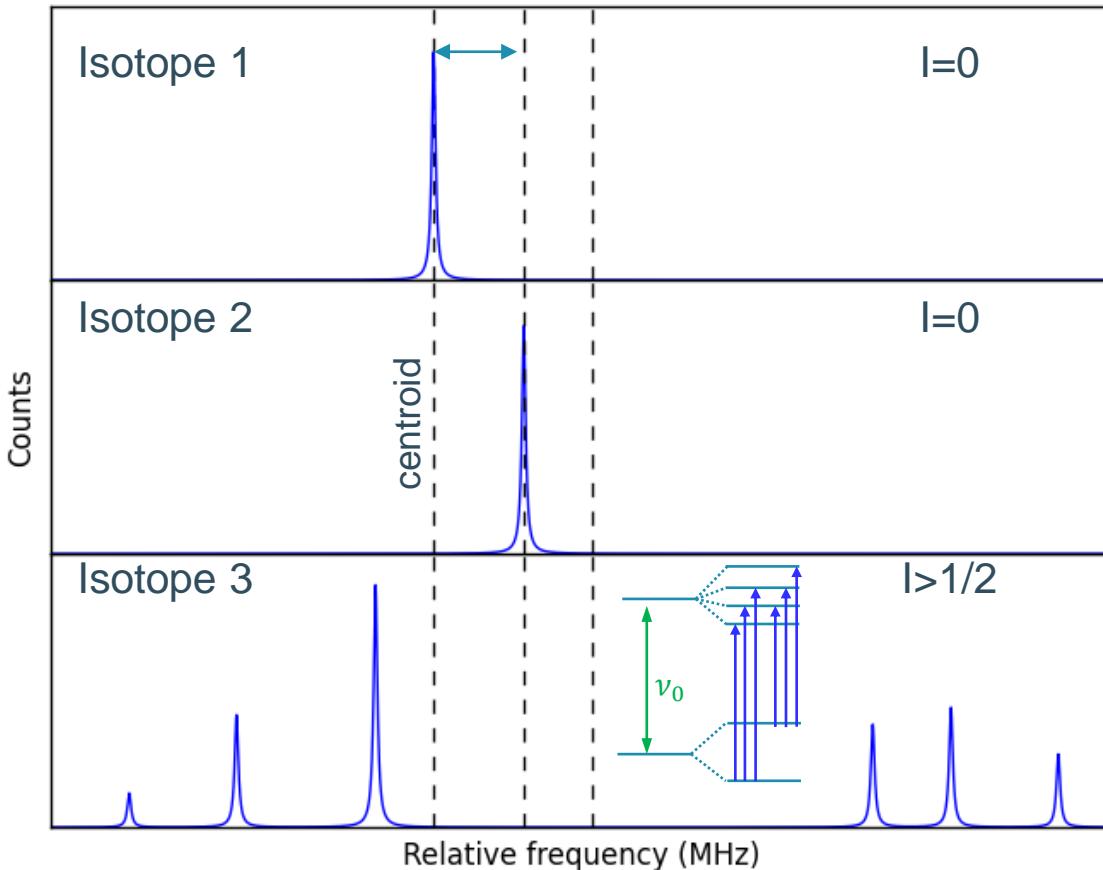


# Outline

- Atomic spectra
- The IGISOL facility
- Motivation
- Preparation
- Overview
- Charge radii
- Conclusion & outlook

# Atomic spectra

Nuclear configuration/  
shell model states



- Isotope shifts
  - Changes in RMS charge radii
- Hyperfine structures
  - Nuclear spin
  - Magnetic dipole moment
  - Electric quadrupole moment
- Identification of nuclear states

Static and dynamic  
deformation

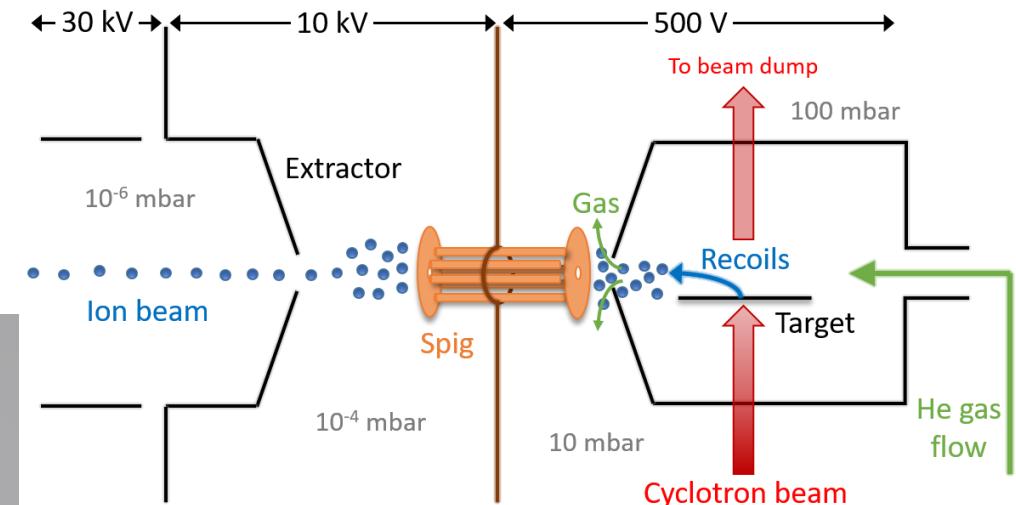
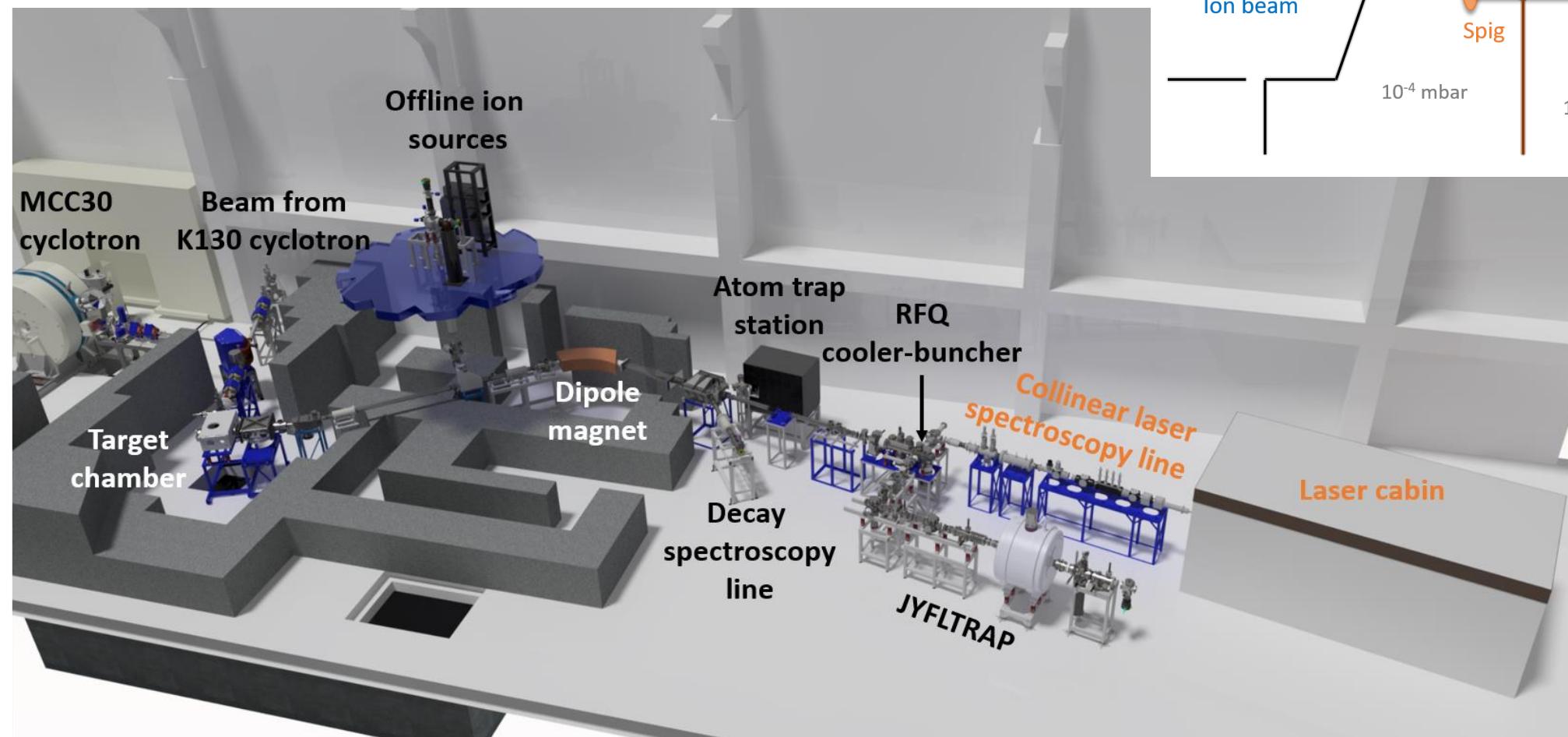


$$B = e Q_s \left\langle \frac{\partial^2 V}{\partial z^2} \right\rangle$$

$$\nu_F = \nu_0 + Af(I, J, F) + Bg(I, J, F)$$

$$A = \mu \frac{B_e}{|IJ|}$$

# The IGISOL facility

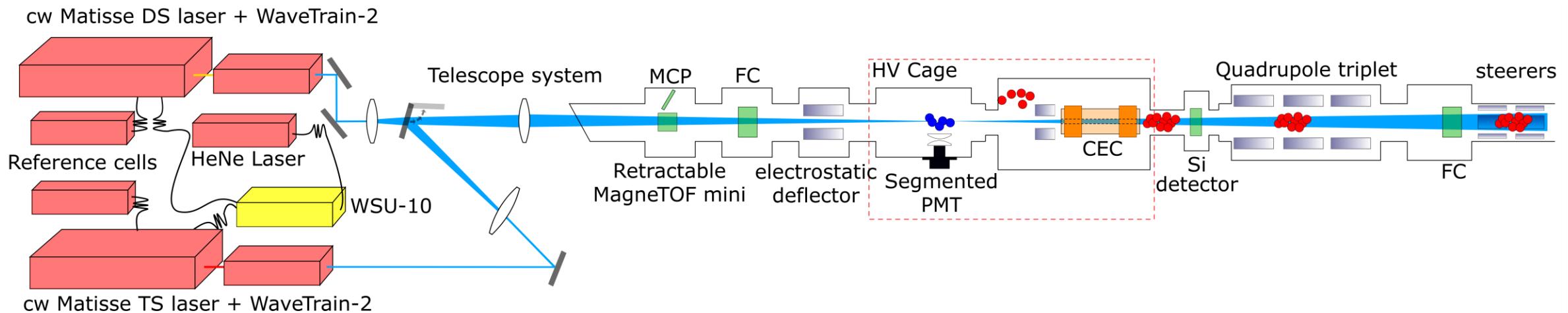


- Cyclotron beam hits thin target
- Recoils stopped in He buffer gas
- Supersonic jet guides into an ion guide
- Fast and chemically insensitive  
→ universal

# The IGISOL facility

Recent additions to the collinear laser spectroscopy beamline:

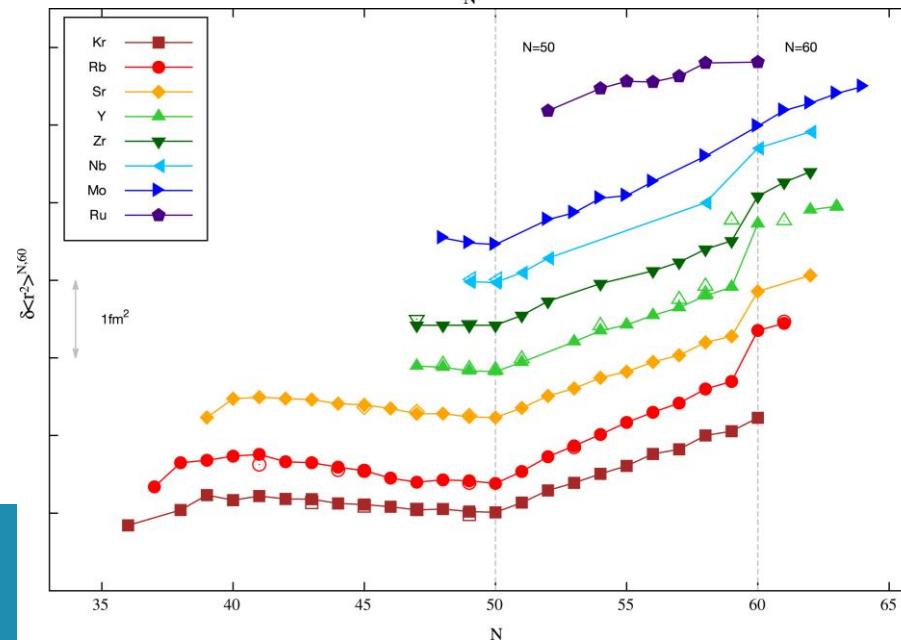
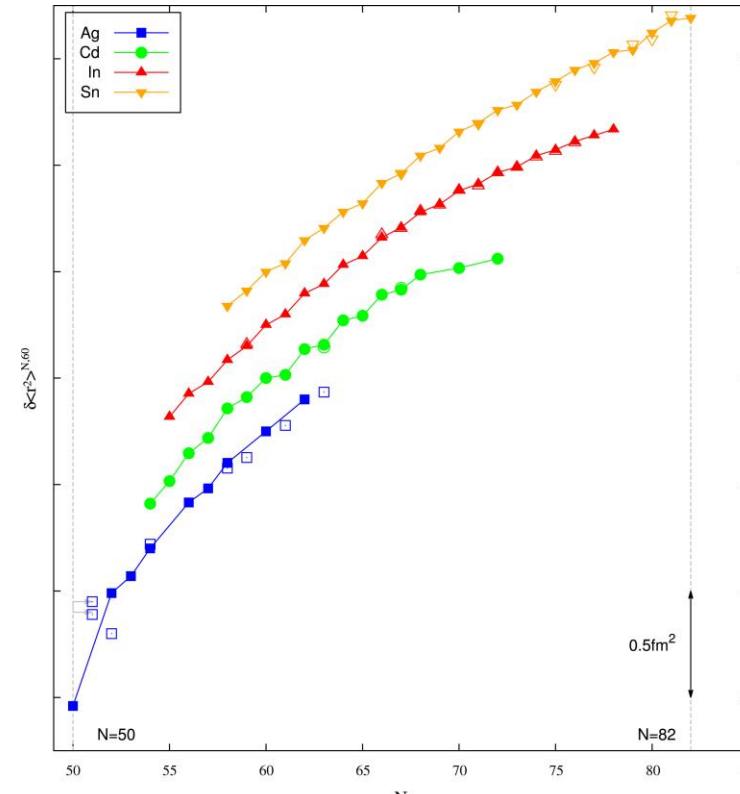
- Charge-exchange cell\*
- New laser system



\* Courtesy of W. Nörtershäuser, TU Darmstadt

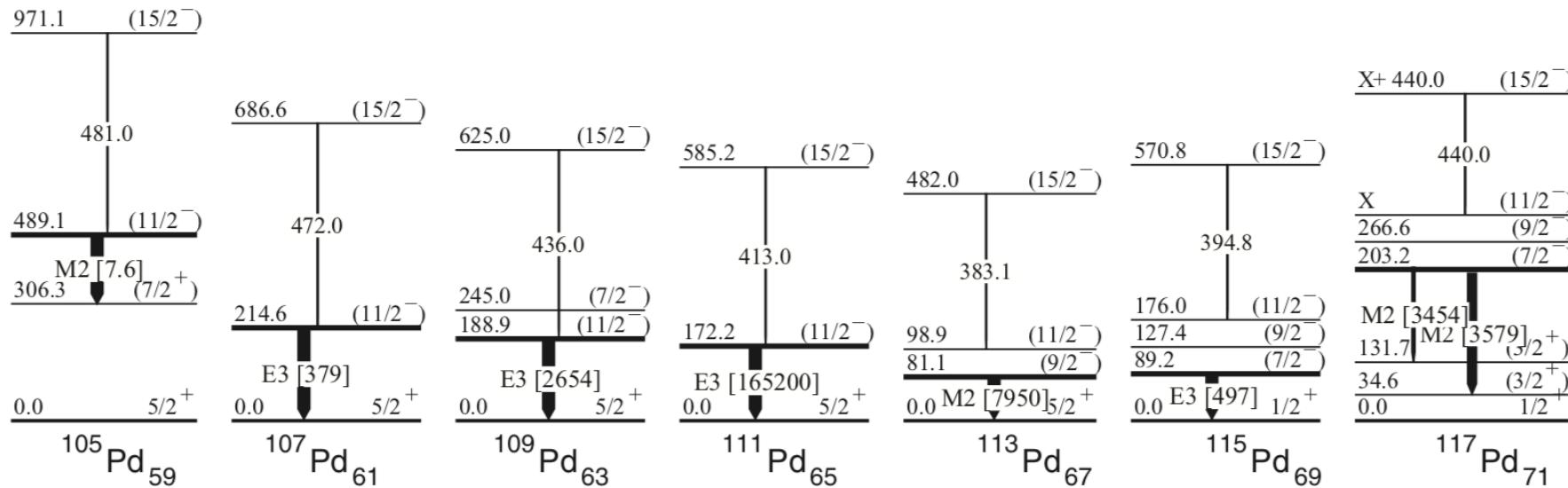
# Motivation

- Gap in optical spectroscopy data: Tc, Ru, Rh, Pd and some Ag isotopes ‘missing’
  - Refractory elements
  - Complex atomic structure
- Accessible at IGISOL thanks to chemical insensitivity and installation of charge-exchange cell
- Measurements of charge radii powerful for testing nuclear Density Functional Theory (DFT) and ab-initio approaches

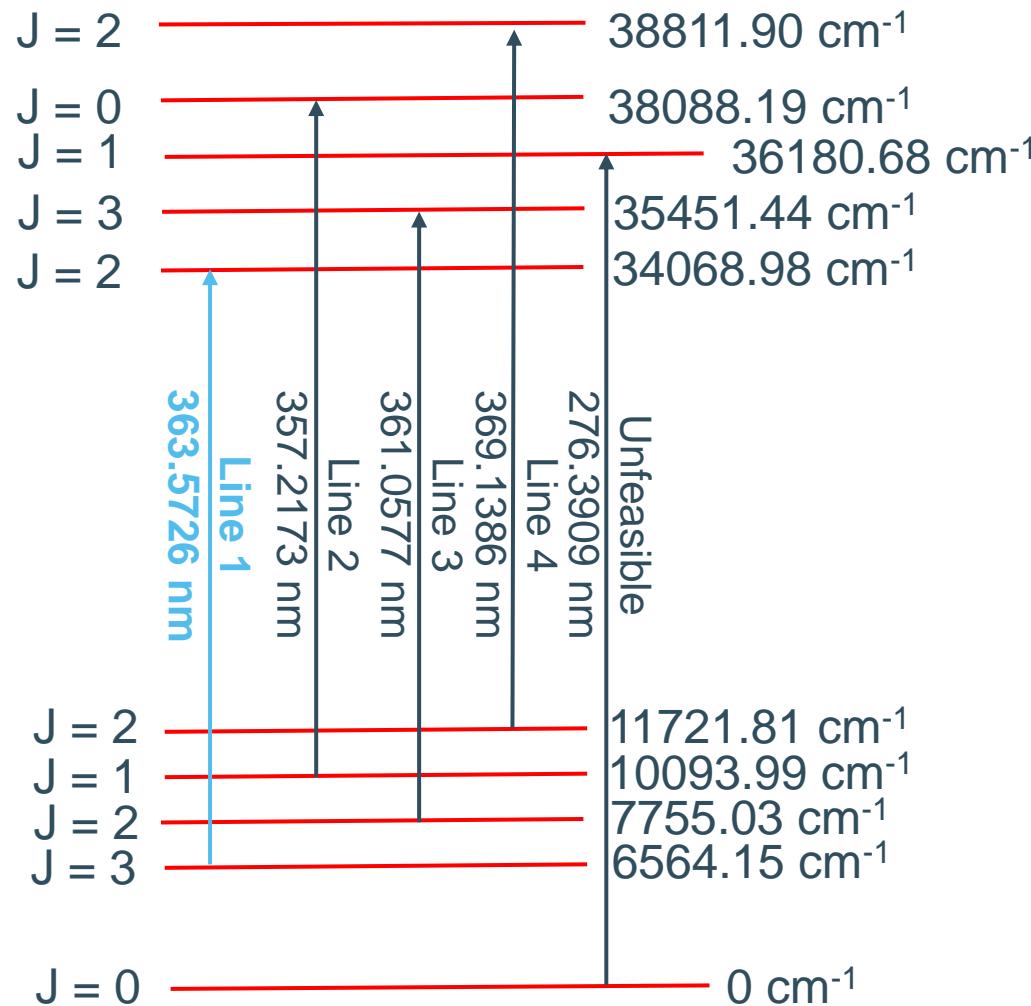


# Motivation

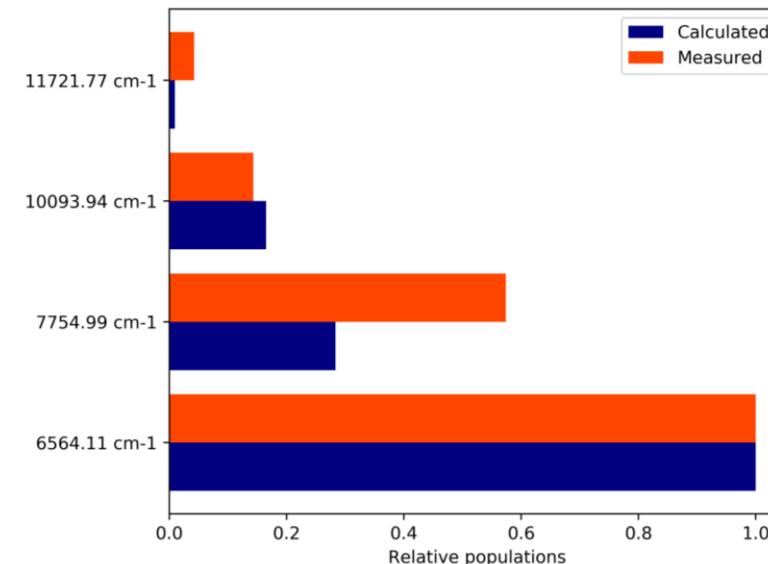
- Charge radii and nuclear moments needed to clarify various phenomena in region
  - Rapid changes in deformation, shape coexistence,...
- Ground state and isomer properties important to underpin decay spectroscopy studies
  - Firm spin assignments missing: important to understand evolution of shell-model orbits



# Preparation

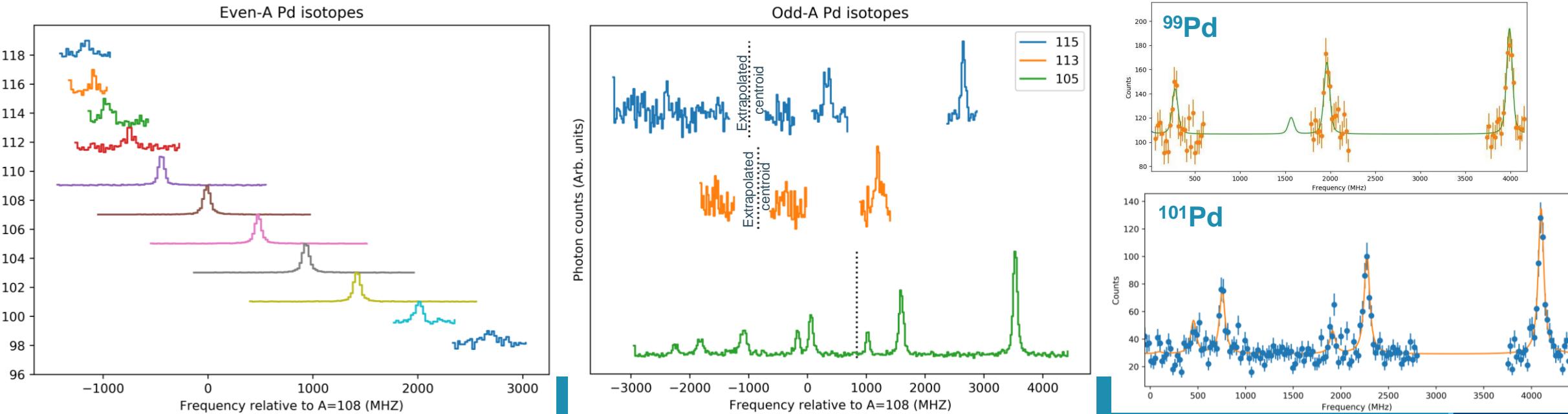


4 tested transitions from different metastable states populated in charge exchange



# Overview

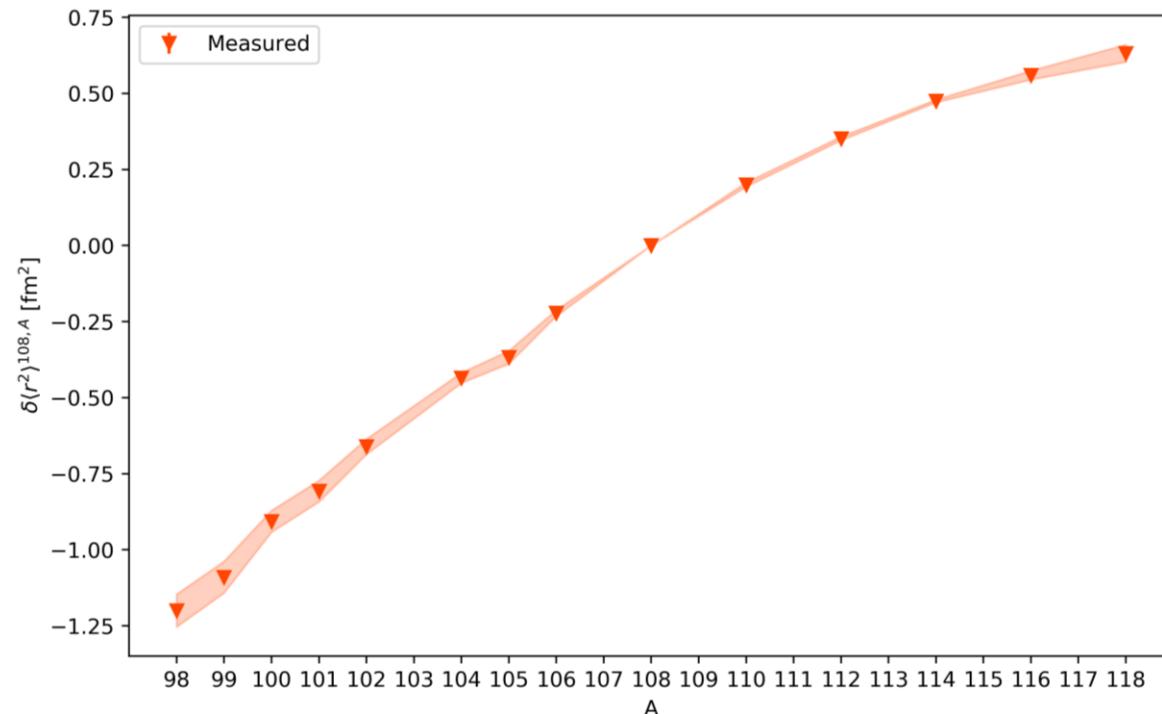
- Isotopes in the range  $A = 98\text{-}118$ 
  - 98-101: fusion-evaporation reactions; 102-110: stable, spark source; 112-118: fission on Th target
- Even- $A$ : spin zero gs, no isomers  $\rightarrow$  only one resonance
- Odd- $A$ : high nuclear spins, some isomers  $\rightarrow$  complex structure, analysis ongoing



# Charge radii

King plot technique for calibration of atomic factors

- Charge radii from muonic X-rays
- $F = -2.9(5)$  GHz/fm<sup>2</sup>,  $M = 845(669)$  GHz amu

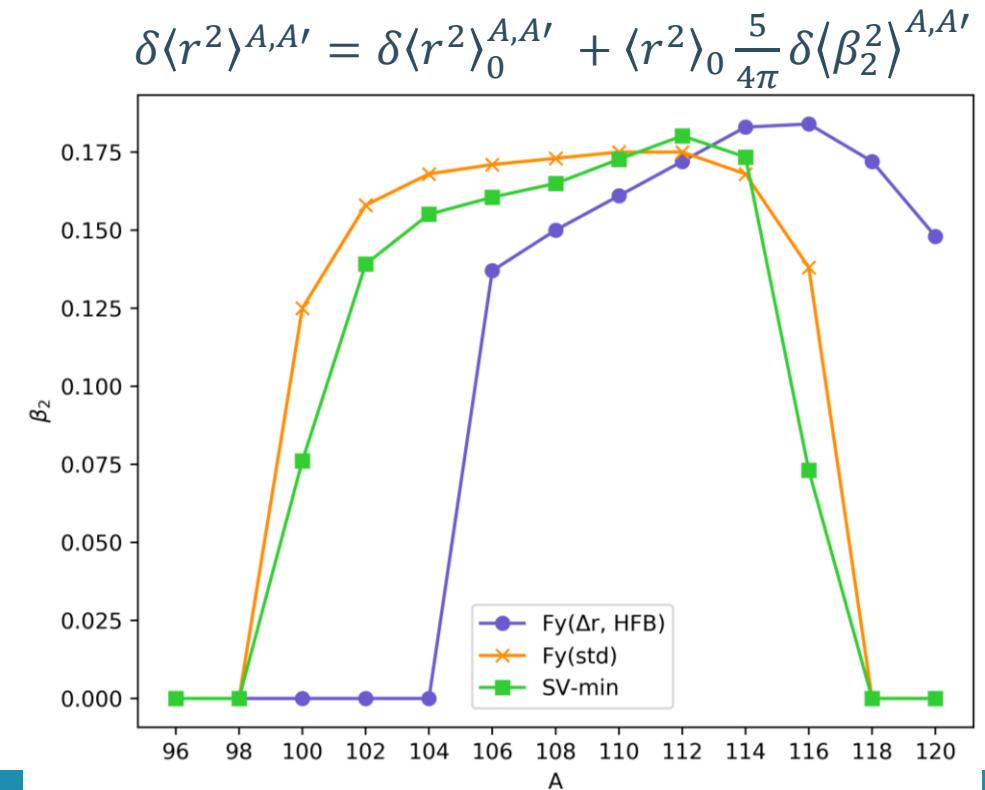
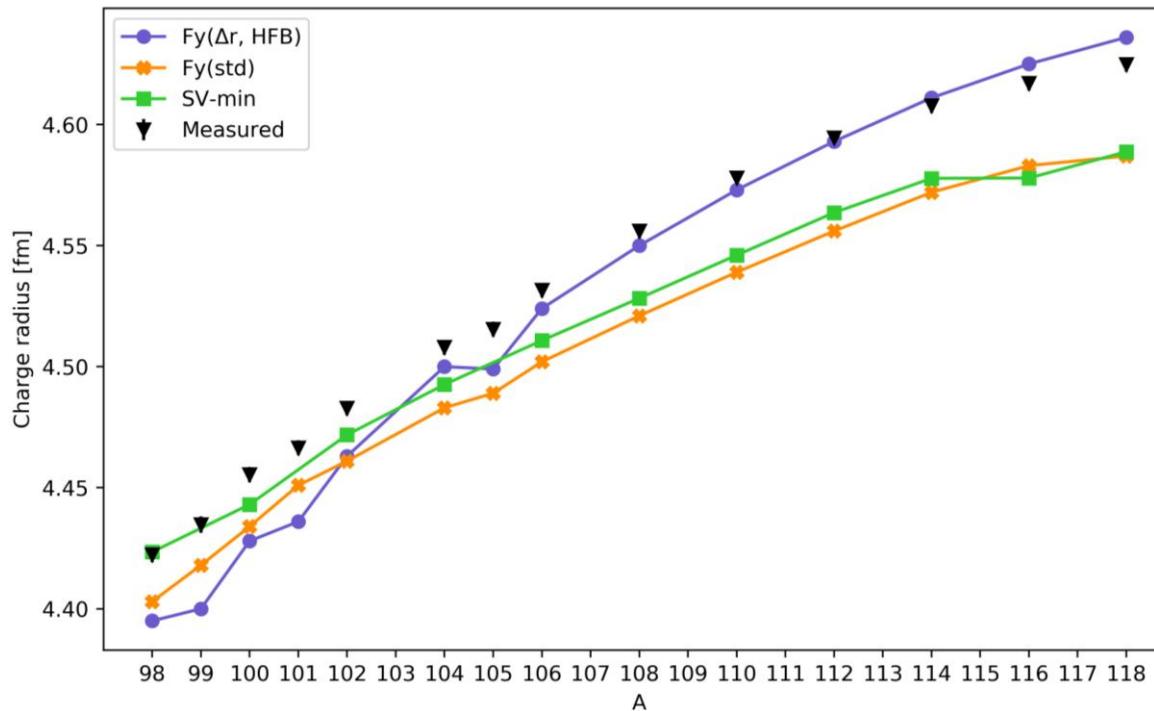


$$\delta\nu^{A,A'} = F \delta\langle r^2 \rangle^{A,A'} + M \frac{(A - A')}{AA'}$$

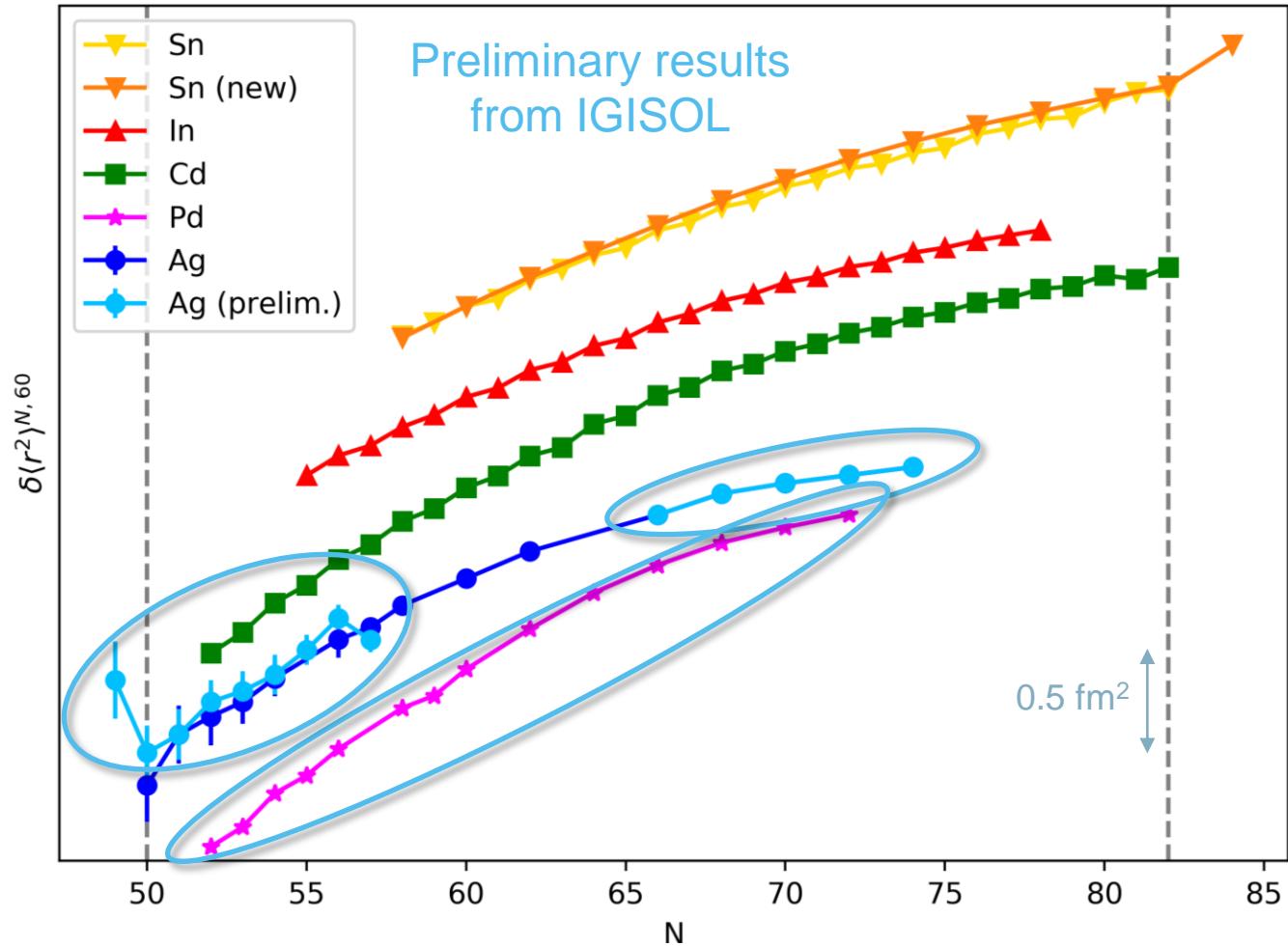
No sign of sudden change(s) in deformation,  
electric quadrupole moments needed to verify

# Charge radii

- Comparison to nuclear DFT calculations
  - Skyrme EDF SV-min, two forms of Fayans EDF which feature particular pairing functional
  - $Fy(\Delta r, HFB)$  exhibits strong pairing correlations → larger charge radius, enhanced OES



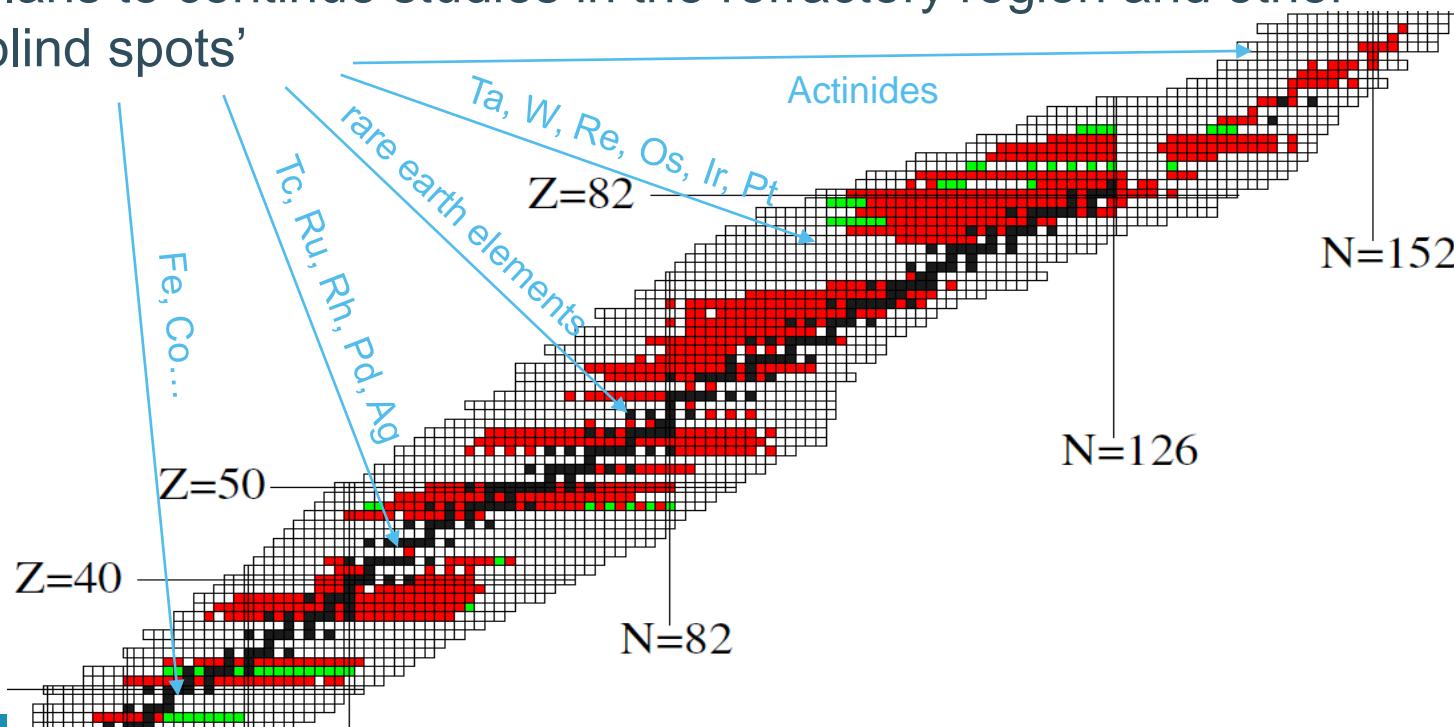
# Charge radii in the region



- More pronounced parabolic curvature down from Sn
- Fayans EDF used for Sn and Cd previously
- First optical spectroscopy of Pd, first application of Fayans EDF to deformed nuclei
- $Fy(\Delta r, HFB)$  performs well, but overestimates OES

# Outlook at IGISOL

- Push towards n-deficient (Pd) isotopes using hot-cavity ion source
- Development of RAPTOR (Low-energy, medium resolution RIS) which will give higher sensitivity → more exotic nuclei
- Plans to continue studies in the refractory region and other 'blind spots'



And at CRIS (ISOLDE): recent results on/  
plans for Sn, In, Ag,...



# Thank you!



JYVÄSKYLÄN YLIOPISTO  
UNIVERSITY OF JYVÄSKYLÄ



L. Caceres  
A. Ortiz-Cortes



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C. Devlin  
A. Koszorus

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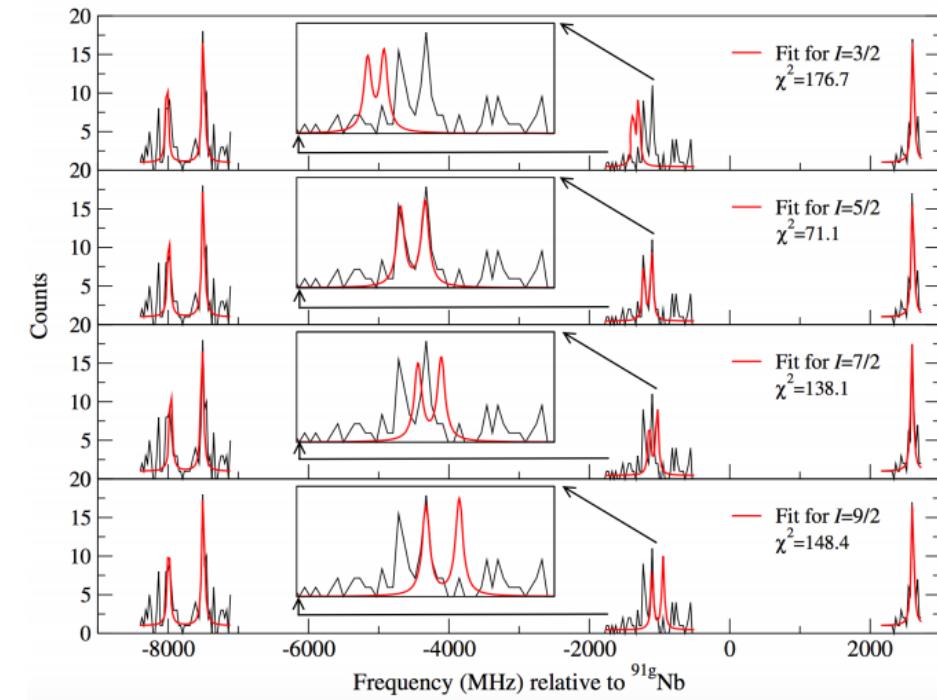
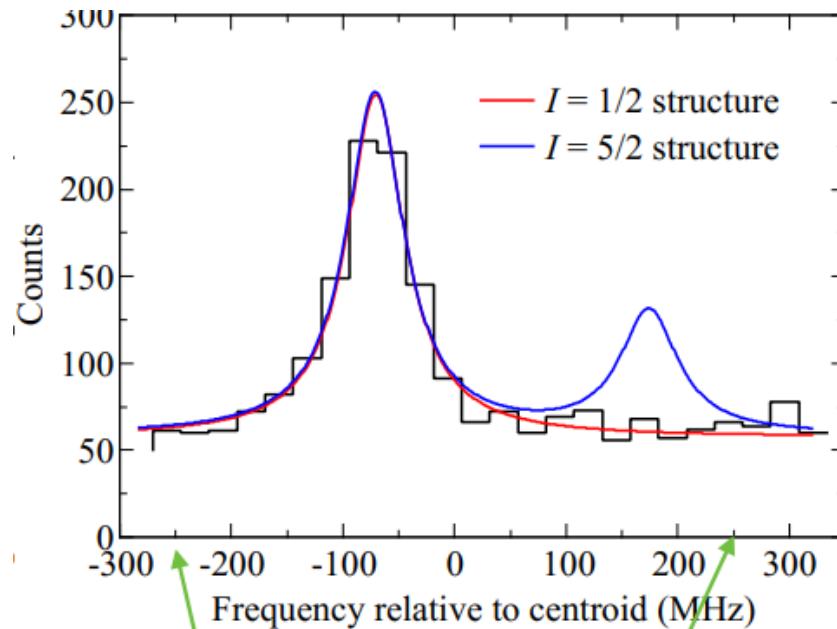


W. Nörtershäuser  
F. Sommer

KU LEUVEN

# Measuring spins

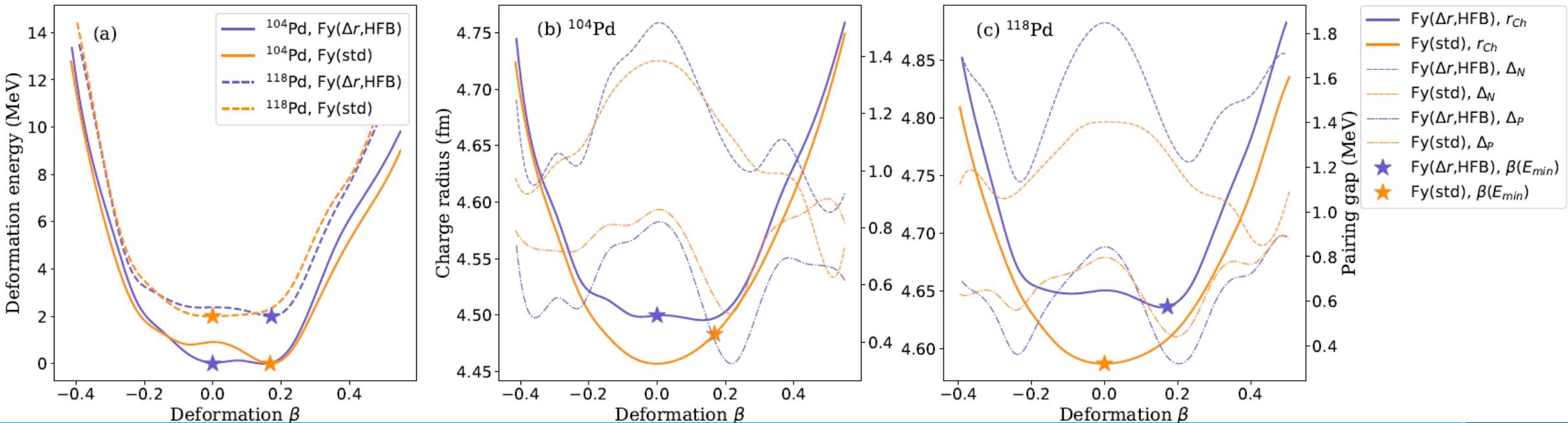
- Some cases quite easy
- Other cases a bit more tricky



- In general: higher nuclear spins are harder to tell apart
- Higher atomic spins make the assignment easier, but measurement harder

# Fayans EDF calculations

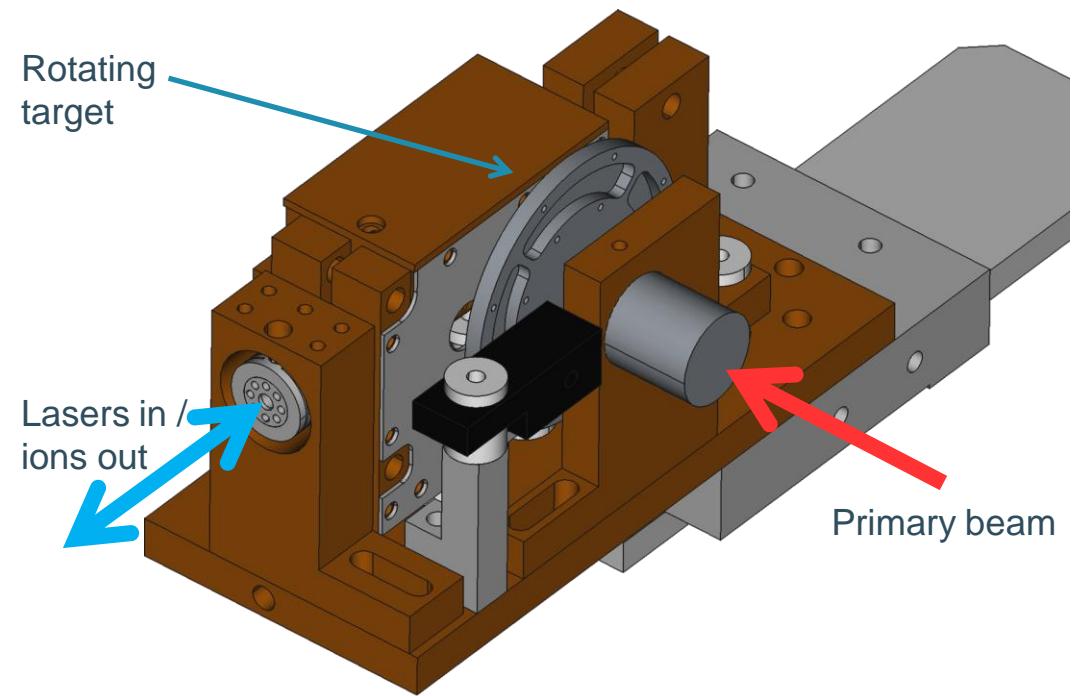
- Soft deformation predicted
- $F_y(\text{std})$  follows parabolic trend,  $F_y(\Delta r, \text{HFB})$  doesn't.
  - Also seen in calculated pairing gaps, a good measure of the pairing correlations.
  - Strong pairing correlations in  $F_y(\Delta r, \text{HFB})$  modify nuclear mean-field more at surface → larger charge radius and enhanced OES



# Hot-cavity ion source

An inductively-heated hot cavity graphite catcher for in-source laser ionisation spectroscopy

- Laser-ionisation
  - **High efficiency**
- Broadband conditions
- Injecting beam into Penning traps
  - Ultra-clean (bkg rate <<1/hr)
  - Use PI-ICR for identifying resonances



*Based on an upgraded design of M. Reponen et al.,  
Rev. Sci. Instrum. 86 (2015) 123501.*