Study of the neutron-rich tellurium isotopes by laser spectroscopy

- What kind of nuclear information from laser spectroscopy ?
- Why measurements on the tellurium isotopes ?
- Experimental methods and difficulties overcome
- Some experimental results
- Comparison with nuclear models

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ISOLDE Workshop February 6-8, 2006

Nuclear data obtained from laser spectroscopy : μ, Q_s, $\delta\langle r^2\rangle$

- by studying atomic transitions through long isotopic chains :
  - the hyperfine structure → μ, Q_s
  - the isotope shift → $\delta\langle r^2\rangle$

- atomic properties used to obtain information on the nucleus

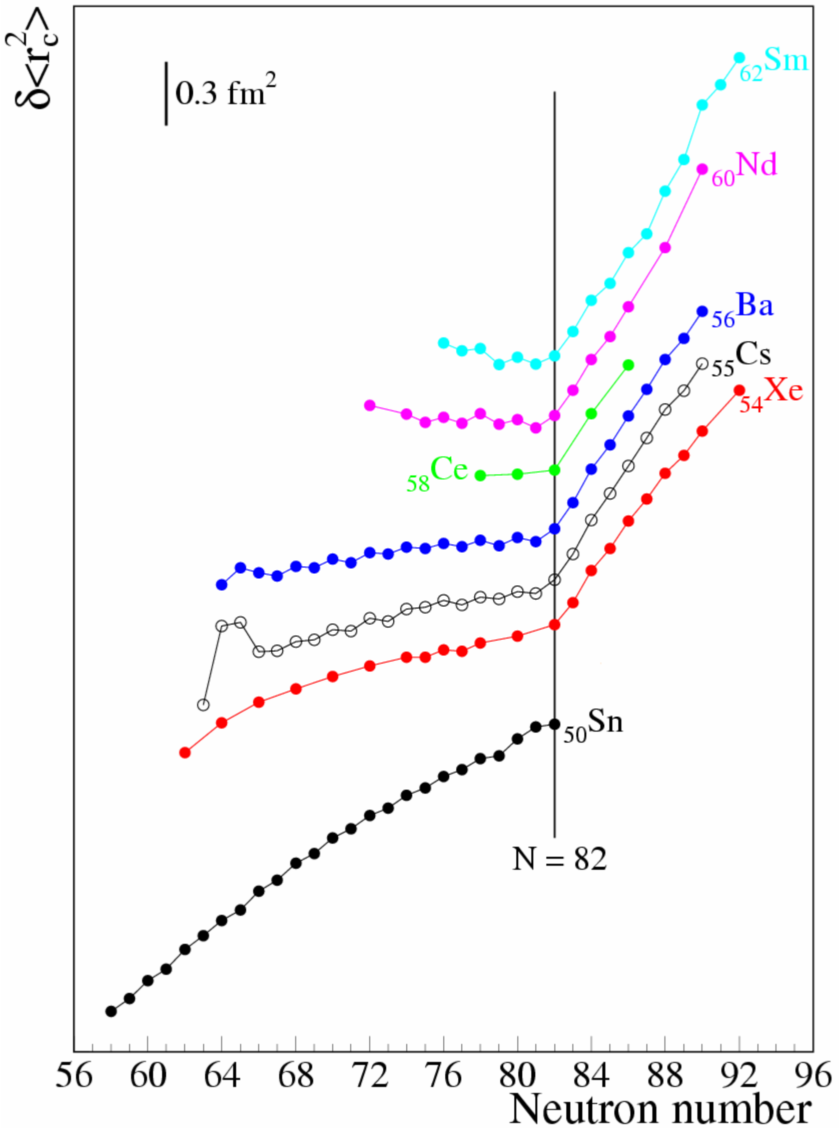
- high resolution is required :

  for tellurium isotopes, $\lambda = 214$ nm $\Leftrightarrow$ $\nu \sim 10^6$ GHz $\Leftrightarrow$ $E \sim 6$ eV

  $\Delta\nu_{A,A+1} \sim 100$ MHz

  thus we want to measure an effect $< 10^{-7}$

  → such resolution is obtained by laser spectroscopy



kink at N = 82

- observed in all isotope series with $Z \geq 54$
- in the proton-magic tin nuclei, still an open question

⇨ neutron-rich Te isotopes

dynamic effects

- observed in Cd, In and Sn (Z=48, 49, 50)
- associated with a parabolic behaviour of $\delta\langle r^2 \rangle$
- not observed in isotope series with $Z \geq 54$ (quadrupole deformation)

⇨ neutron-deficient Te isotopes

Refs. Sm, Nd, Ce: ADNDT 37(1987)455; J. Phys. G18(1992)1177; J. Phys. G29(2003)2479
Ba: NPA403(1983)234; Phys. Let. B211(1988)272 Cs: NPA367(1981)1
Xe: Phys. Lett. B216(1989)7
Sn: PRC34(1986)1052; Z.Phys.A326(1987)419; PRC 72(2005)034305

COMPLIS at ISOLDE

resonance ionization spectroscopy on laser-desorbed atoms

resolution ~ 200 MHz

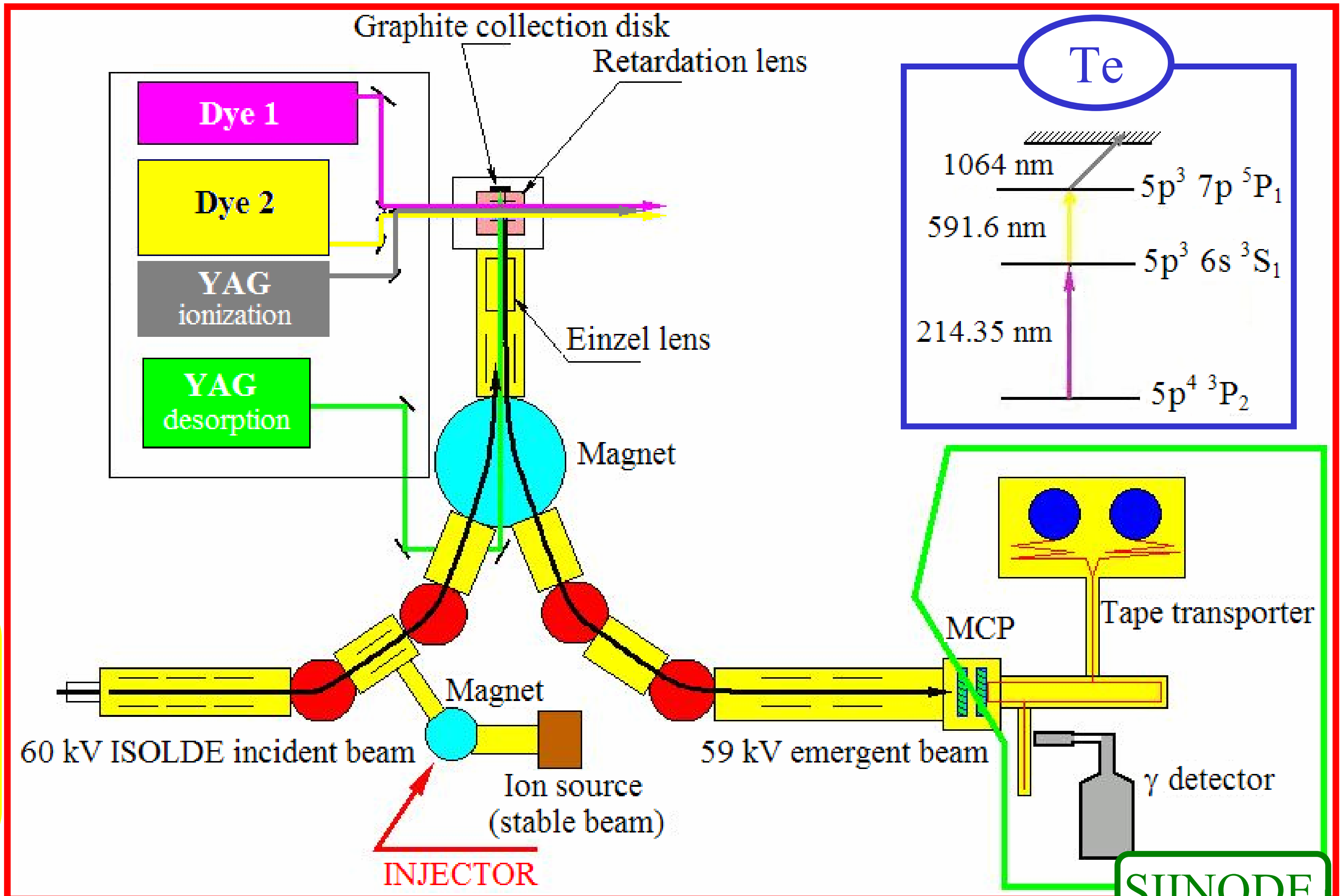
10^8 atoms/frequency point

Neutron-rich Te isotopes :

UC_x+hot plasma ion source

4×10^7 atoms/mC for ^{136}Te

⇨ A = 127 to 136



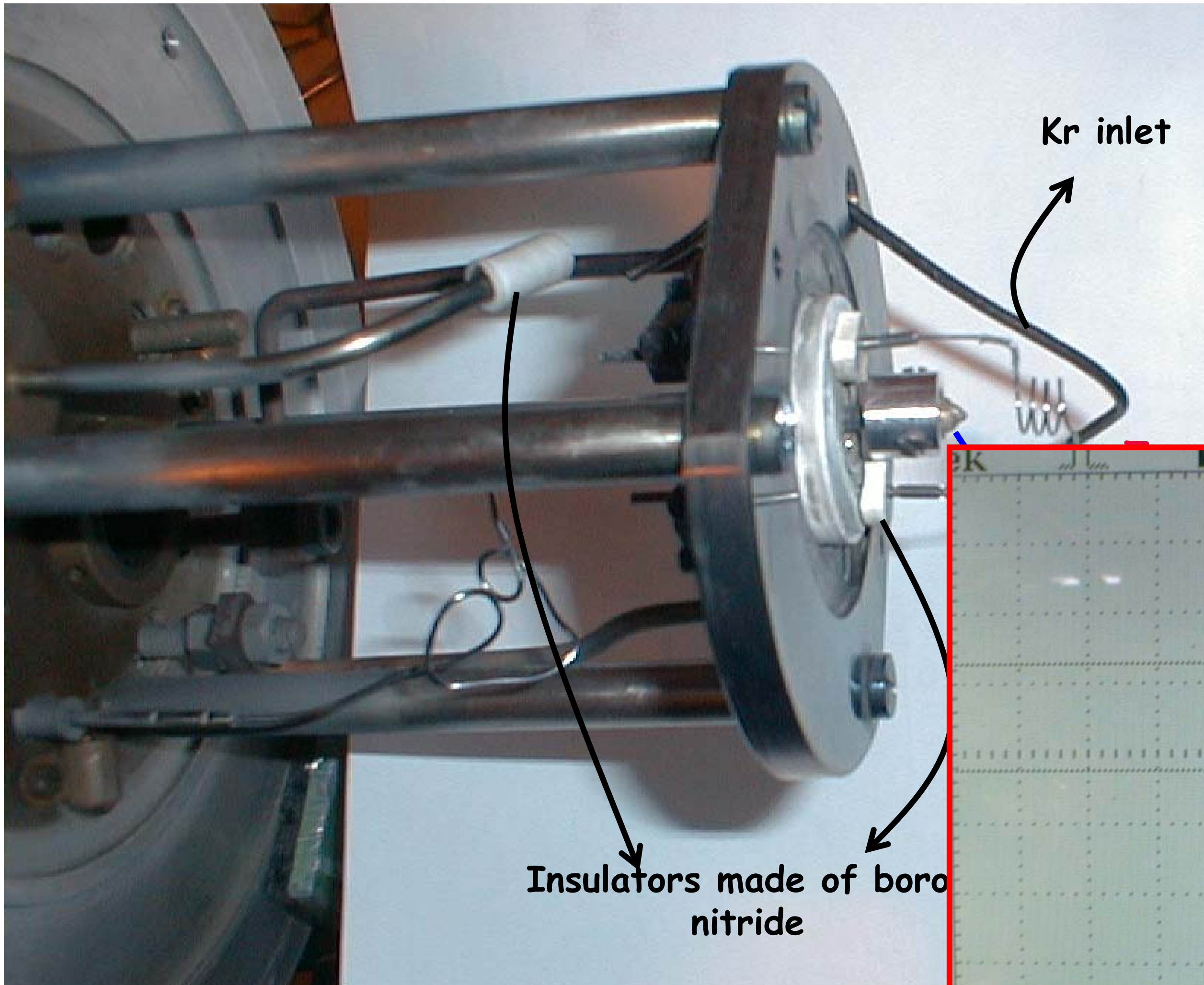
COMPLIS

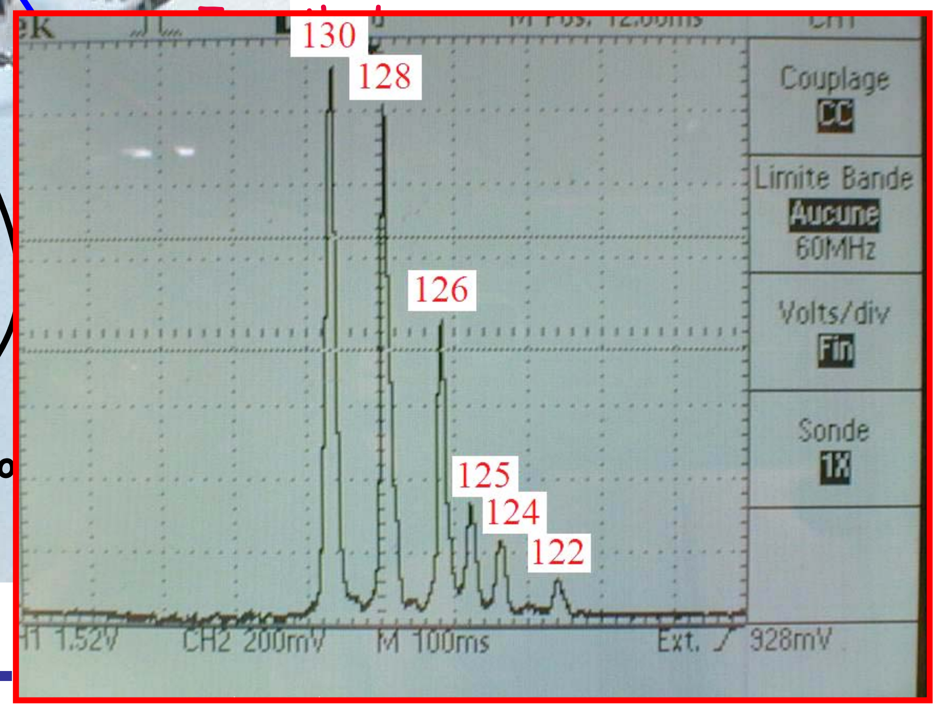
- frequency scan of the first excitation step
- mass identification by TOF
- delay between collection and desorption, to discriminate between m and g when $T_{1/2}$ are different → ^{129,131,133}Te

SIINODE

- fixed frequency set on a resonant transition
- ions collected on the tape and transported in front of a γ-detector
- to discriminate between m and g, when $T_{1/2}$ similar or both long, but γ-rays observed in the m and g decay different

Ion source designed and built to produce stable beams of tellurium





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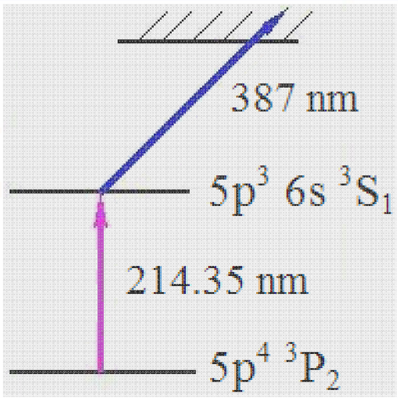
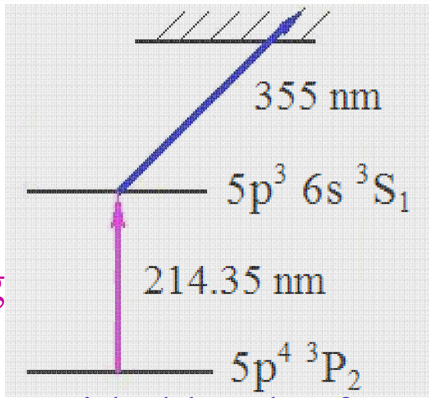
Ionization schemes



obtained by frequency tripling



387 nm : doubling the frequency delivered by a pulse dye laser

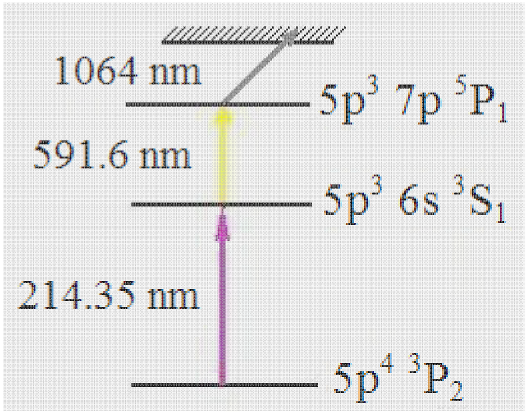
no auto-ionizing level has been found

☹ efficiency very low : 5×10^{-9}

355 nm : provided by the frequency tripling of a YAG laser

☺ efficiency : 5×10^{-7}

☹ isobars ionized directly by this intense UV laser beam

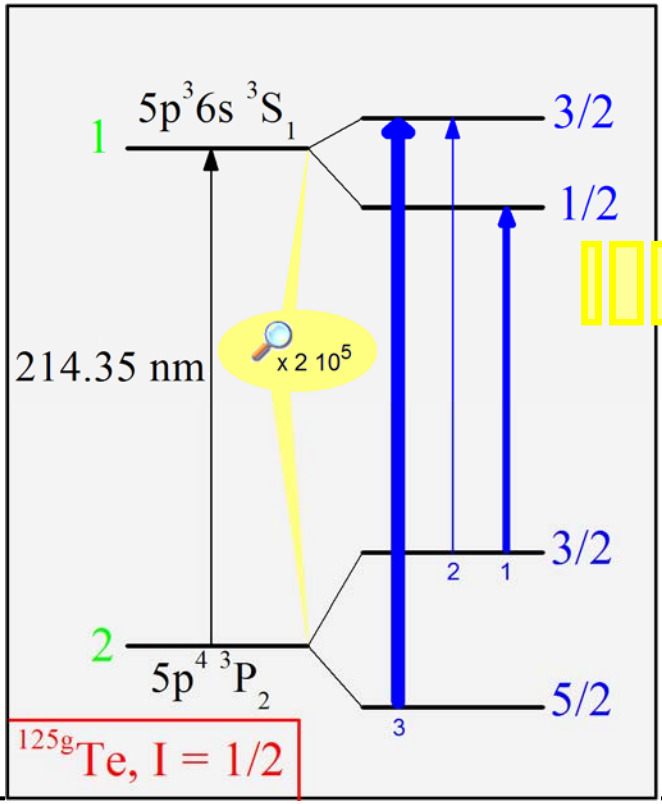


Ionization scheme in three steps :

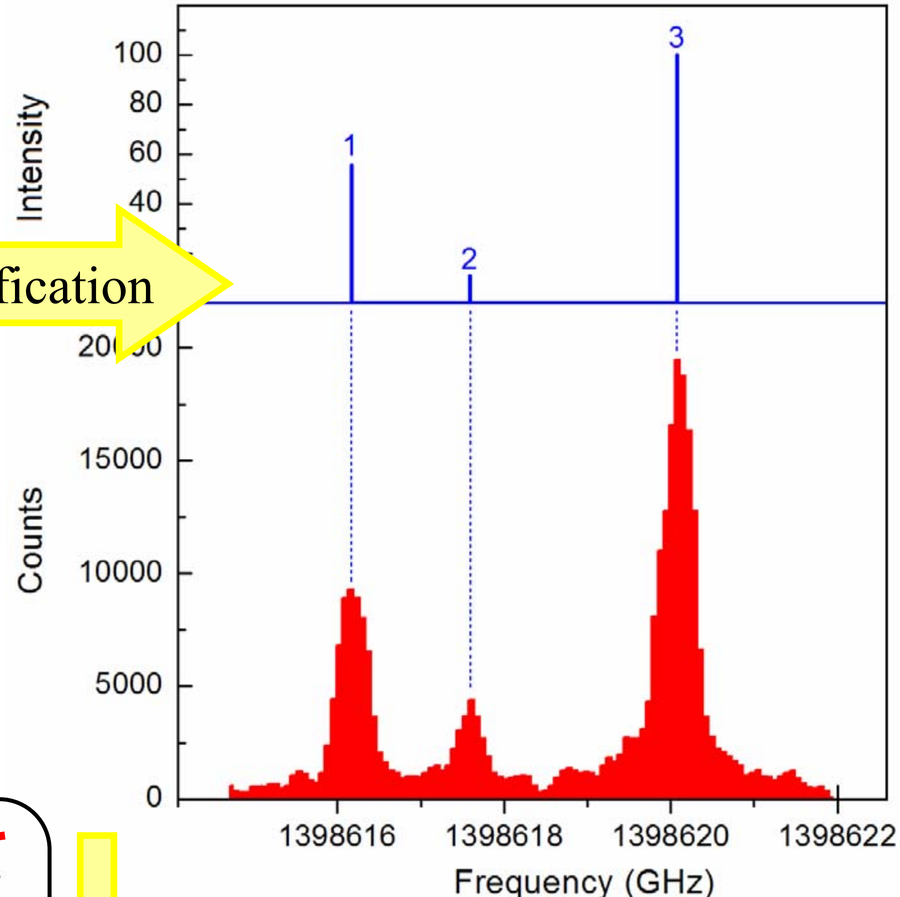
☺ good efficiency

☺ isobar ionization suppressed

Hyperfine structure of ^{125g}Te



Identification



$$W_F = W_J + \frac{AC}{2} + \cancel{\frac{B[3C(C+1) - 4I(I+1)J(J+1)]}{8I(2I-1)J(2J-1)}}$$

$$\vec{F} = \vec{I} + \vec{J} \quad \text{and} \quad C = F(F+1) - I(I+1) - J(J+1)$$

$$\text{with} \quad A = \mu_I \frac{\overline{H_0}}{IJ} \quad \text{and} \quad B = eQ_S\overline{\Phi_{JJ}(0)}$$

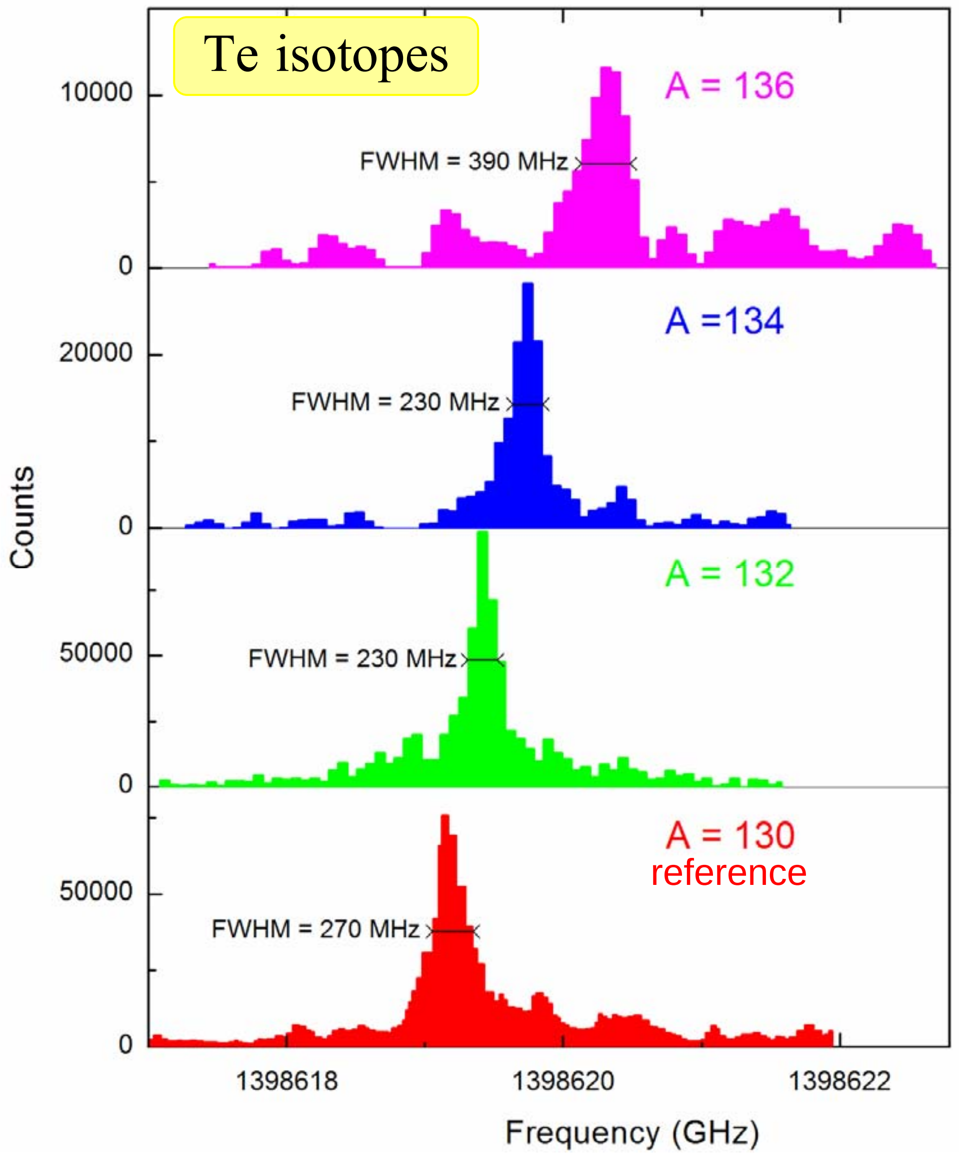
A = – 0.995 (19) GHz

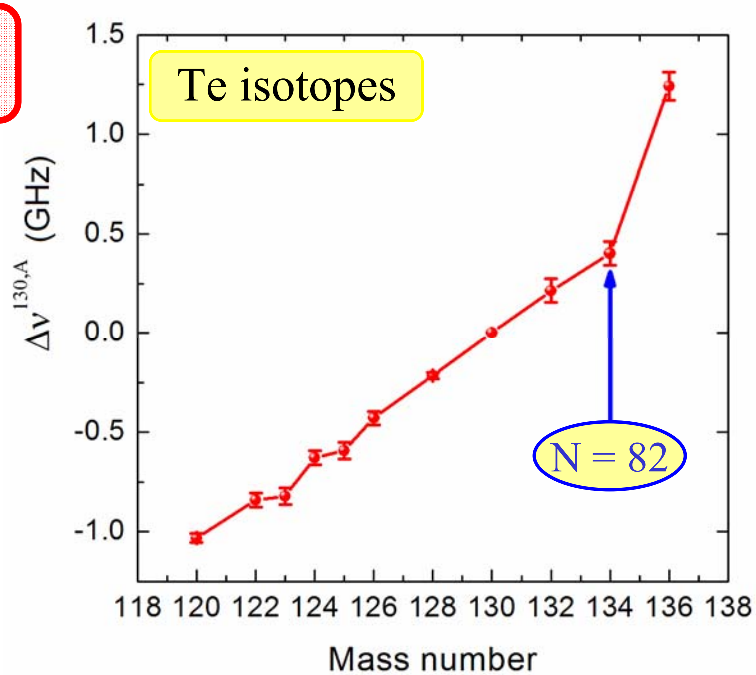
A' = + 0.951 (35) GHz

μ = – 0.885051 (4) μ_N

⇨ $\overline{H_0}$

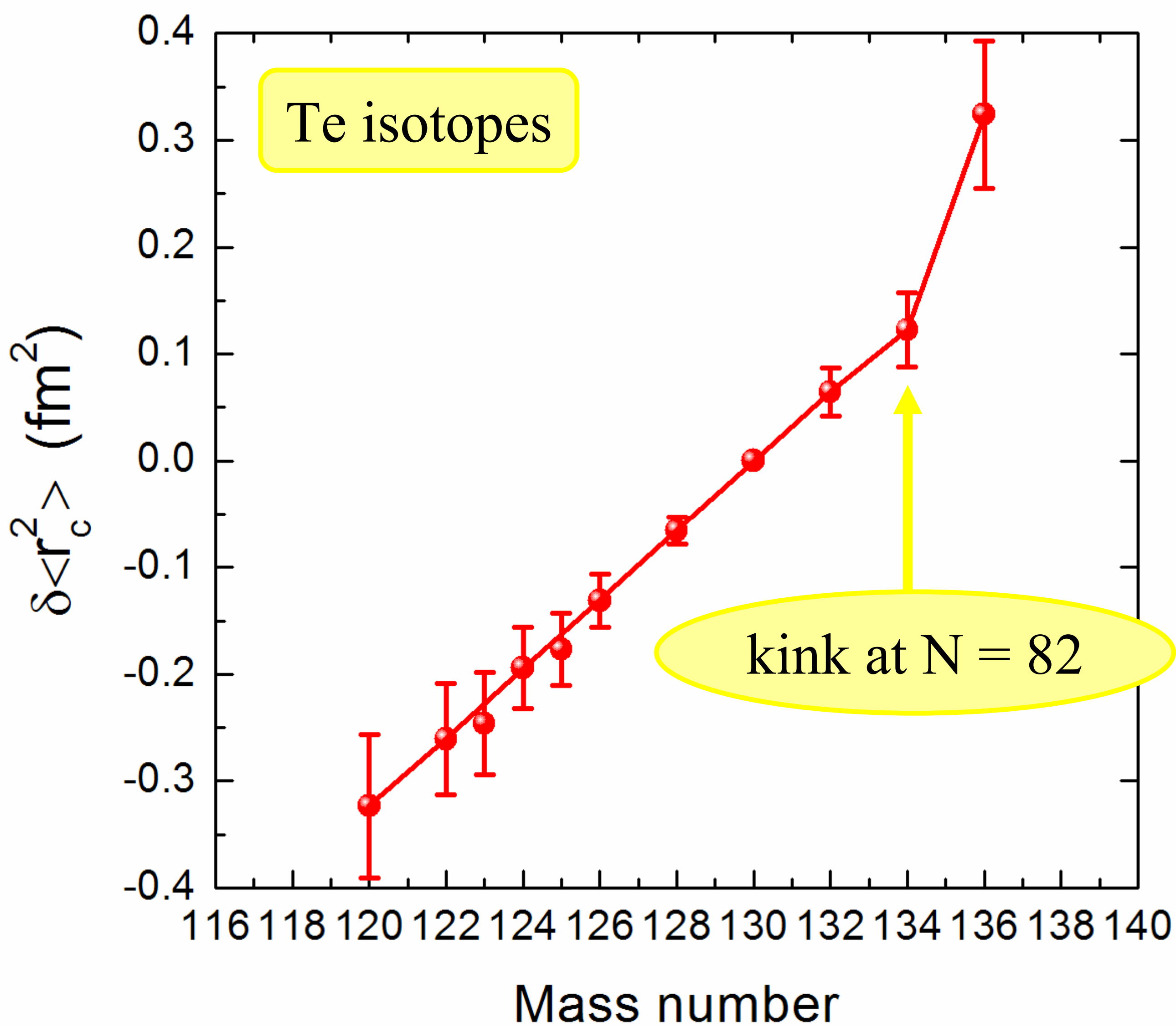
Isotope shift



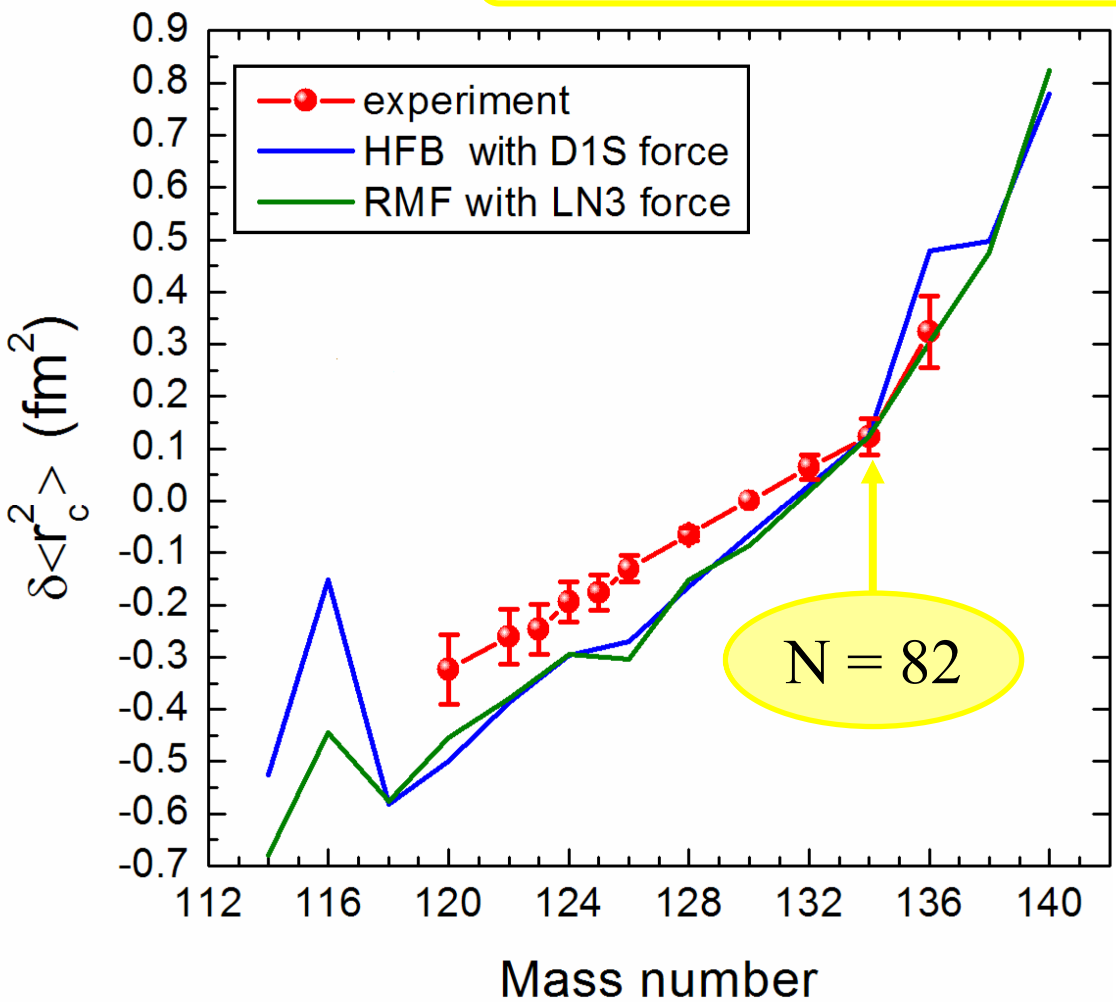


$$\Delta\nu = \Delta\nu_{NMS} + \Delta\nu_{SMS} + \Delta\nu_{FS}$$

- when A changes ⇨ changes in the atom:
  - the reduced mass → $\Delta\nu_{NMS}$
  - the correlations between the e^- → $\Delta\nu_{SMS}$
  - the charge distribution in the nucleus
    → $\Delta\nu_{FS} = F\times\lambda = F\times k\times\delta\langle r^2\rangle$
- F and $\Delta\nu_{SMS}$ obtained from a King plot between our $\Delta\nu$ values and the r_c values from muonic atom experiments [PRC39(1989)195]
  → $F = 4.66 \pm 0.86$ GHz/fm^2
  → $\Delta\nu_{SMS} = -1.89 \pm 0.33 \times \Delta\nu_{NMS}$


Te isotopes
kink at N = 82
0.4
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
δ<r$_c^2$> (fm^2)
116 118 120 122 124 126 128 130 132 134 136 138 140
Mass number

$\delta\langle r^2\rangle$: comparison with static models



$r_c(^{134}Te)_{exp} = 4.752 \pm 0.004$ fm

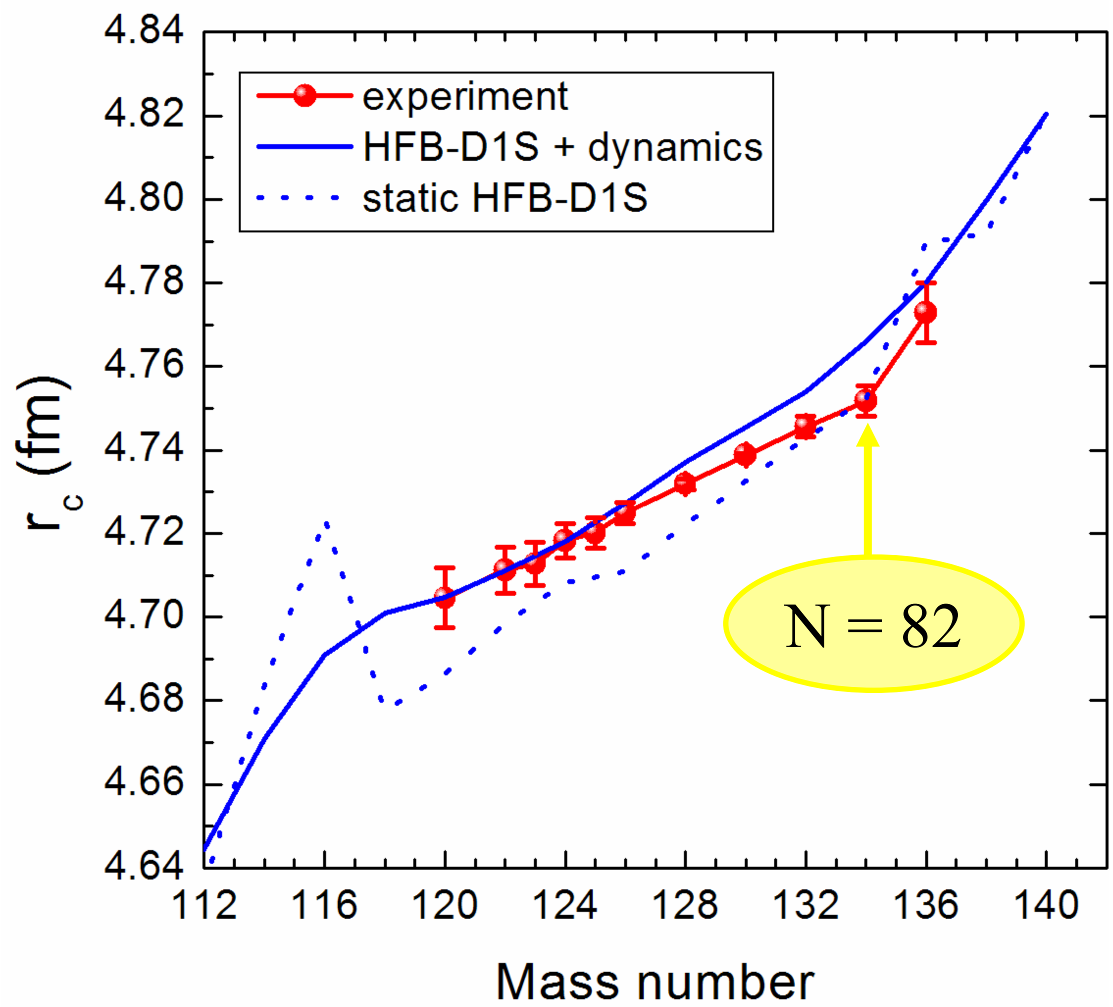
$r_c(^{134}Te)_{HFB} = 4.753$ fm

$r_c(^{134}Te)_{RMF} = 4.761$ fm

- theoretical $\delta\langle r^2\rangle$ very similar except for ^{116}Te and ^{136}Te
- slope before N = 82 overestimated by both static models
- slope after N = 82 well reproduced by RMF

Refs : - HFB with D1S force, J. Libert, private communication
- RMF with LN3 force, G. A. Lalazissis et al., ADNDT71(1999)1

r_c : comparison with HFB calculations including dynamic effects



Ref : J. Libert, private communication

- r_c slightly overestimated for $^{128\text{-}136}$Te close to N = 82
- perfect agreement from ^{126}Te down to ^{120}Te

⇨ what happens in the neutron deficient isotopes ?

COMPLIS collaboration for the tellurium study

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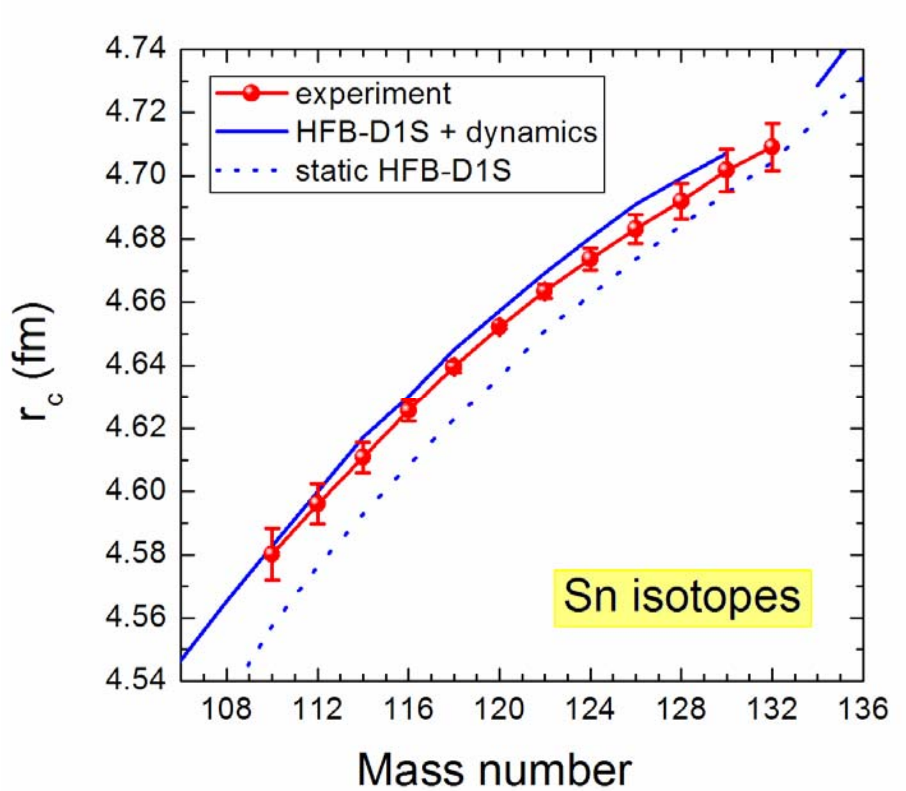
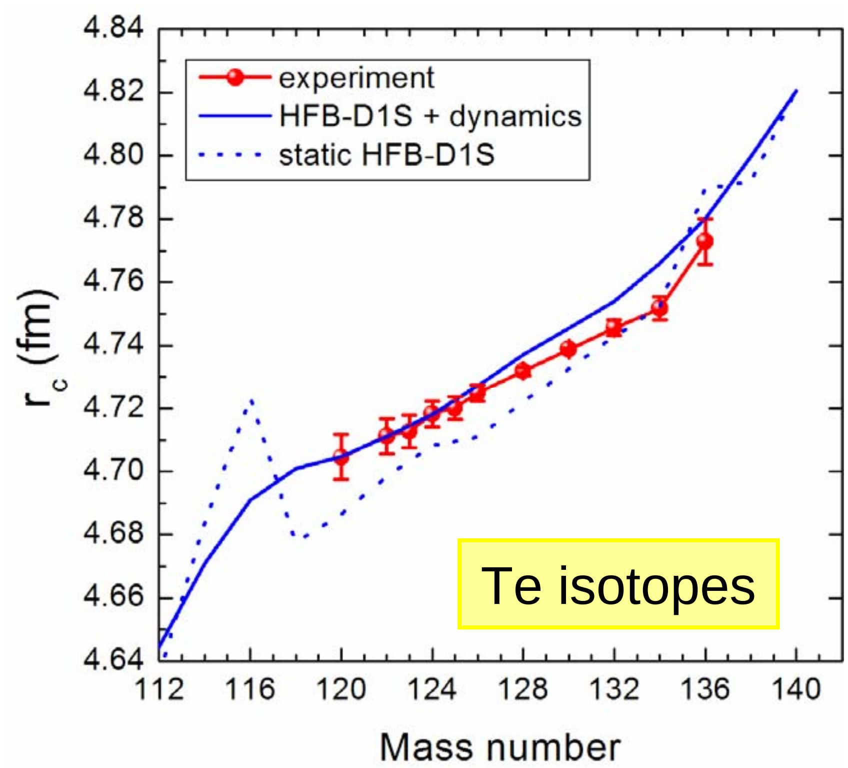
Mainz University : R. Horn, G. Huber, M. Seliverstov

LPSC Grenoble : J. Genevey

McGill University : J. Crawford, J.K.P. Lee

New York University : H. Stroke


experiment
HFB-D1S + dynamics
static HFB-D1S
Sn isotopes
r_c (fm)
Mass number
4.54
4.56
4.58
4.60
4.62
4.64
4.66
4.68
4.70
4.72
4.74
108
112
116
120
124
128
132
136


experiment
HFB-D1S + dynamics
static HFB-D1S
Te isotopes
r_c (fm)
Mass number
4.64
4.66
4.68
4.70
4.72
4.74
4.76
4.78
4.80
4.82
4.84
112
116
120
124
128
132
136
140