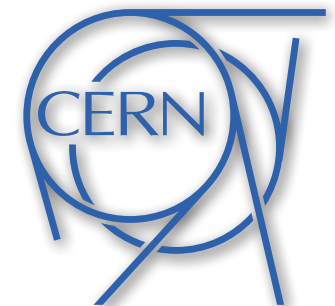


# Angular correlation studies on $^{172}\text{Lu}(^{172}\text{Yb})$ in GaN and measurements at low temperatures

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and the ISOLDE Collaboration

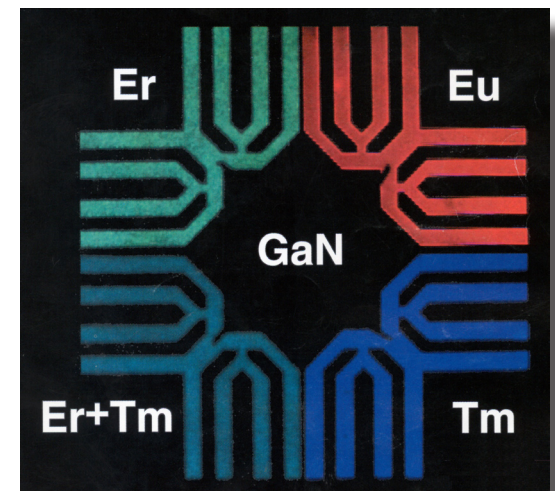
Helmholtz – Institut für Strahlen- und Kernphysik, Universität Bonn, Germany  
ISOLDE facility, CERN, Genève, Switzerland

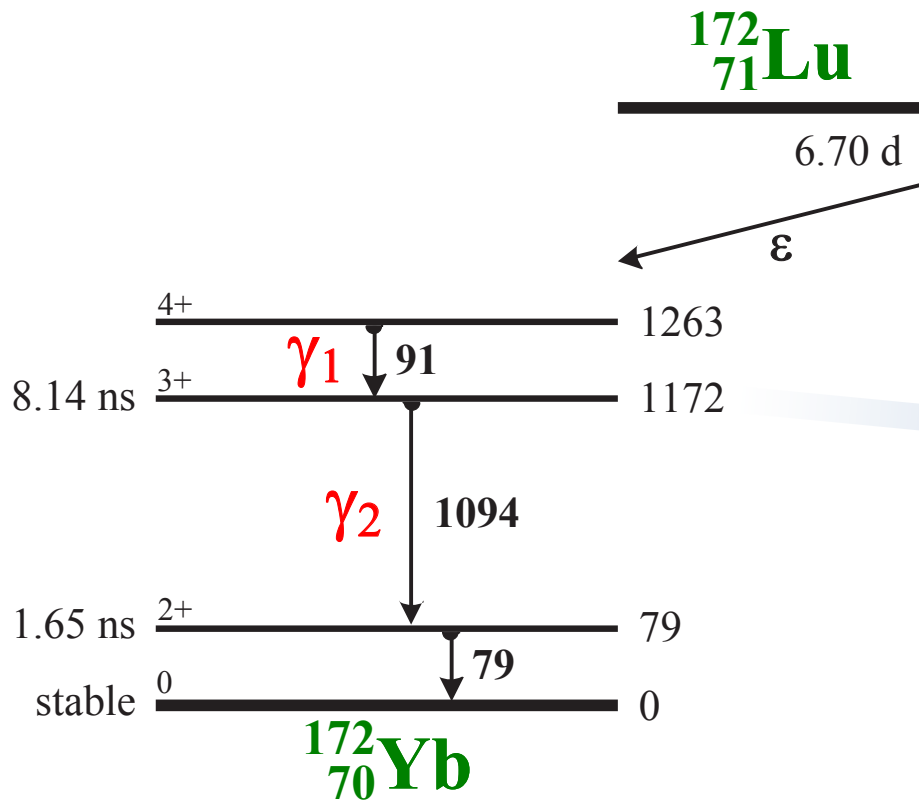


- gallium nitride is a III-V semiconductor with large direct bandgap
- electroluminescence observed at room temperature by doping GaN with rare earths
- lateral structuring of devices by ion implantation (subsequent annealing required)
- investigation of the behaviour of rare earths in GaN
- $\gamma$ - $\gamma$  perturbed angular correlation (PAC) technique well suited



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 A.J. Steckl and J.M. Zavada

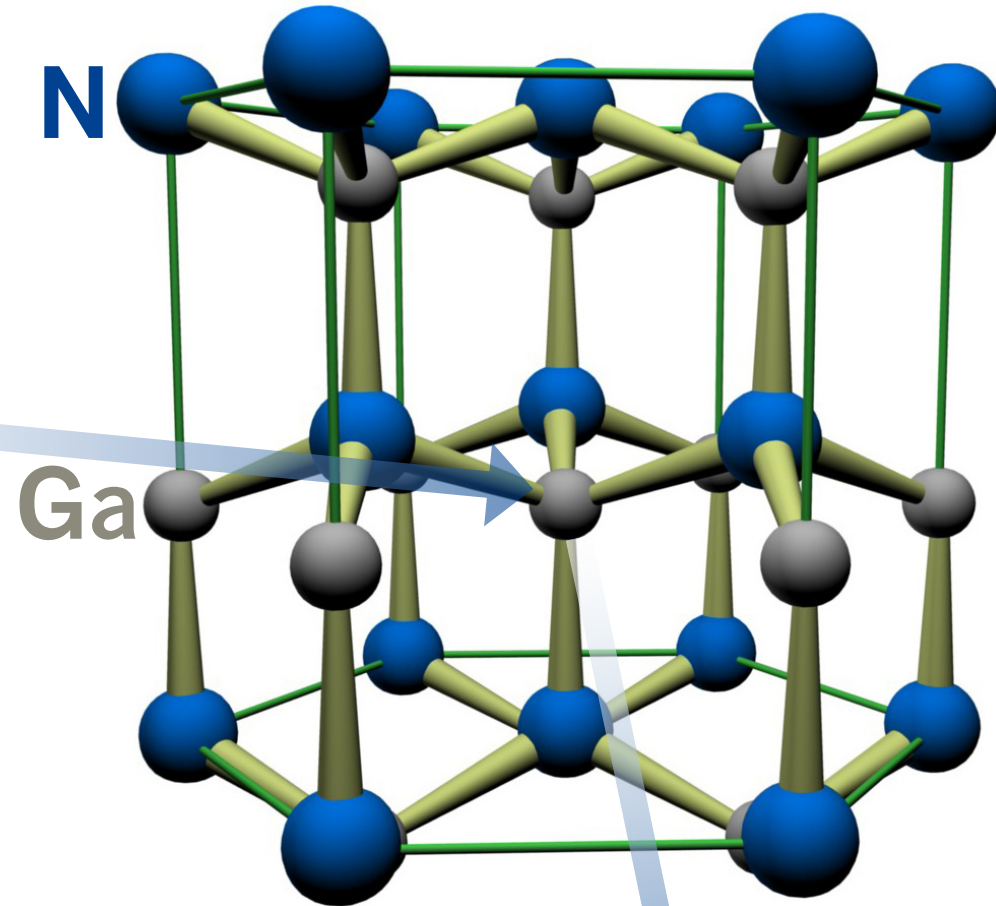




$$Q = 2.87 b$$

$$A_{22} = 0.367$$

- $\nu_Q$  : quadrupole interaction frequency
- $Q$  : quadrupole moment
- $V_{zz}$  : electric field gradient



Electric field gradient

$$V_{zz} = \frac{h}{e \cdot Q} \nu_Q$$

## **Production and implantation at CERN**

(ISOLDE facility, *Isotope Separator OnLine*)

- it works well and the samples are strong
- the isotope  $^{172}\text{Lu}$  is rarely available at ISOLDE (twice a year)
- 7 – 10 days from CERN to Bonn
- the beam is frequently contaminated with molecules of the same mass

## **Production and implantation on site (Bonn)**

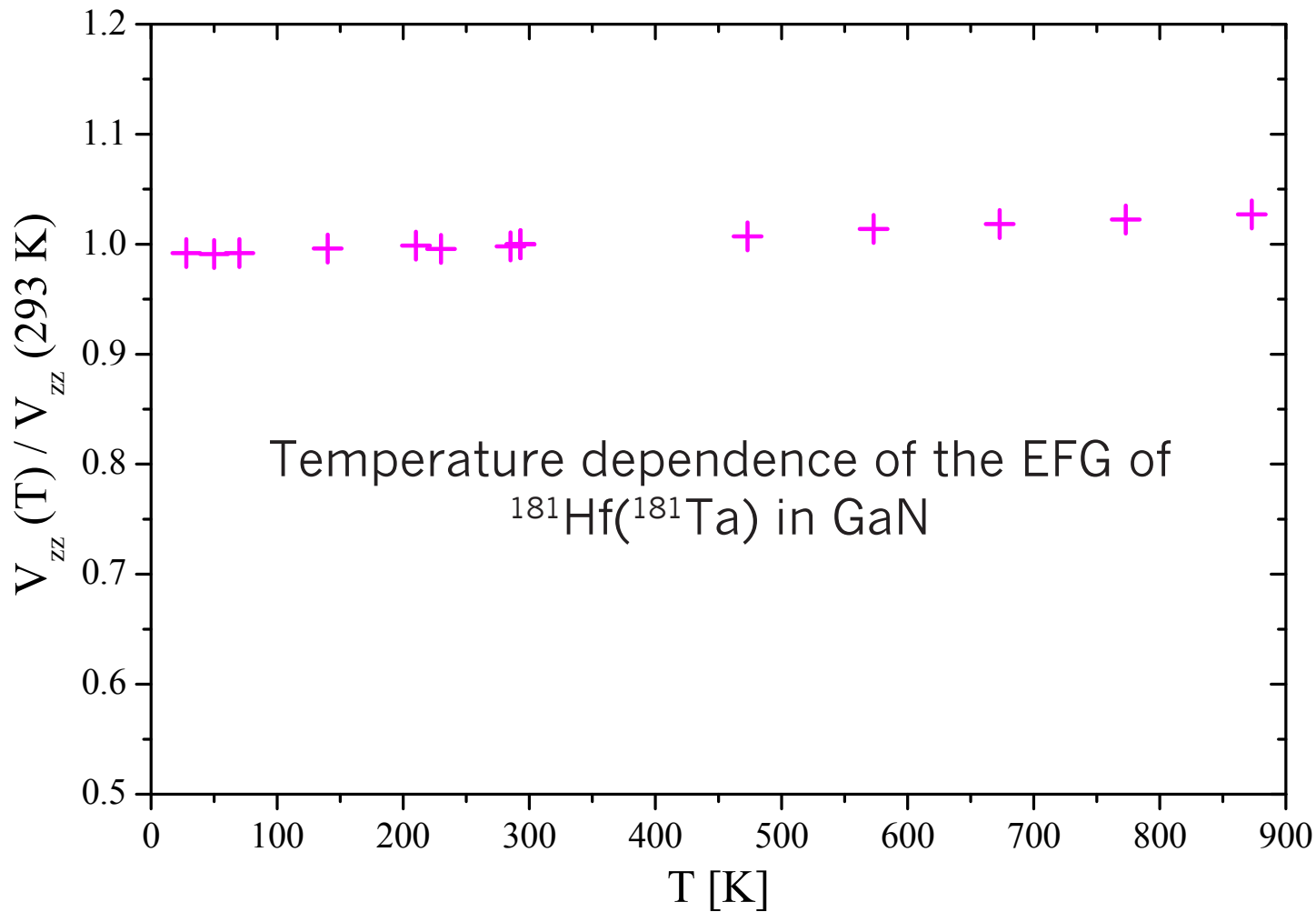
- irradiation of a thulium foil with  $^4\text{He}$  at the cyclotron, reaction  $^{169}\text{Tm}(\alpha, n)^{172}\text{Lu}$
- implantation at the Bonn isotope separator
- weak samples but frequent production

## Implantation procedure

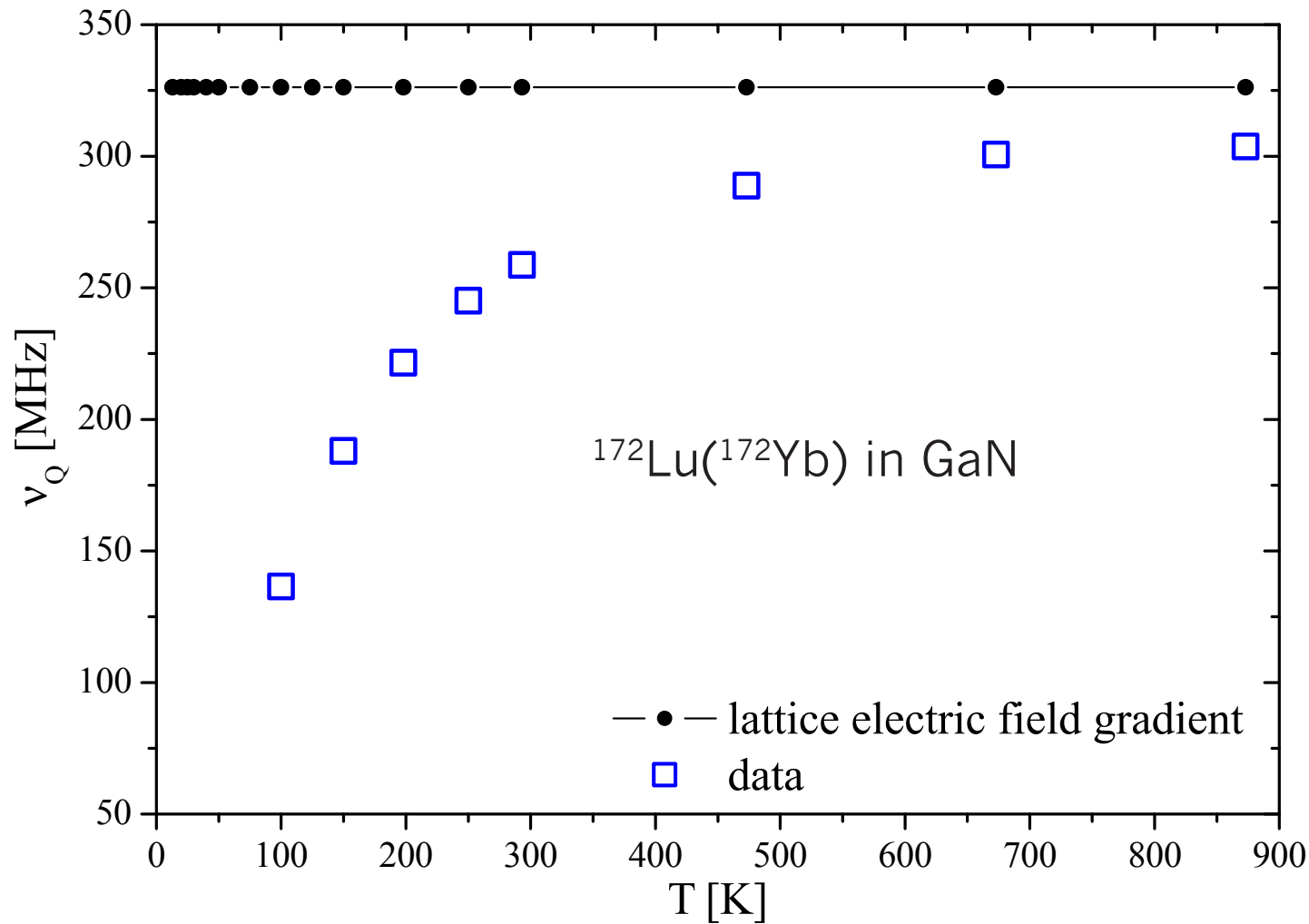
- probe:  $^{172}\text{Lu}$  is implanted in a  $5\times 5\text{ mm}^2$  sample
- sample: single crystalline GaN layer ( $11\text{ }\mu\text{m}$ ), with surface (0001), grown on a sapphire substrate
- implantation energy: 160 keV
- mean implantation depth: 30 nm

## Annealing procedure

- in a RTA-furnace (Rapid Thermal Annealing)
- at 1300 K for 2 min under nitrogen atmosphere
- with a proximity cap (here: pure GaN)

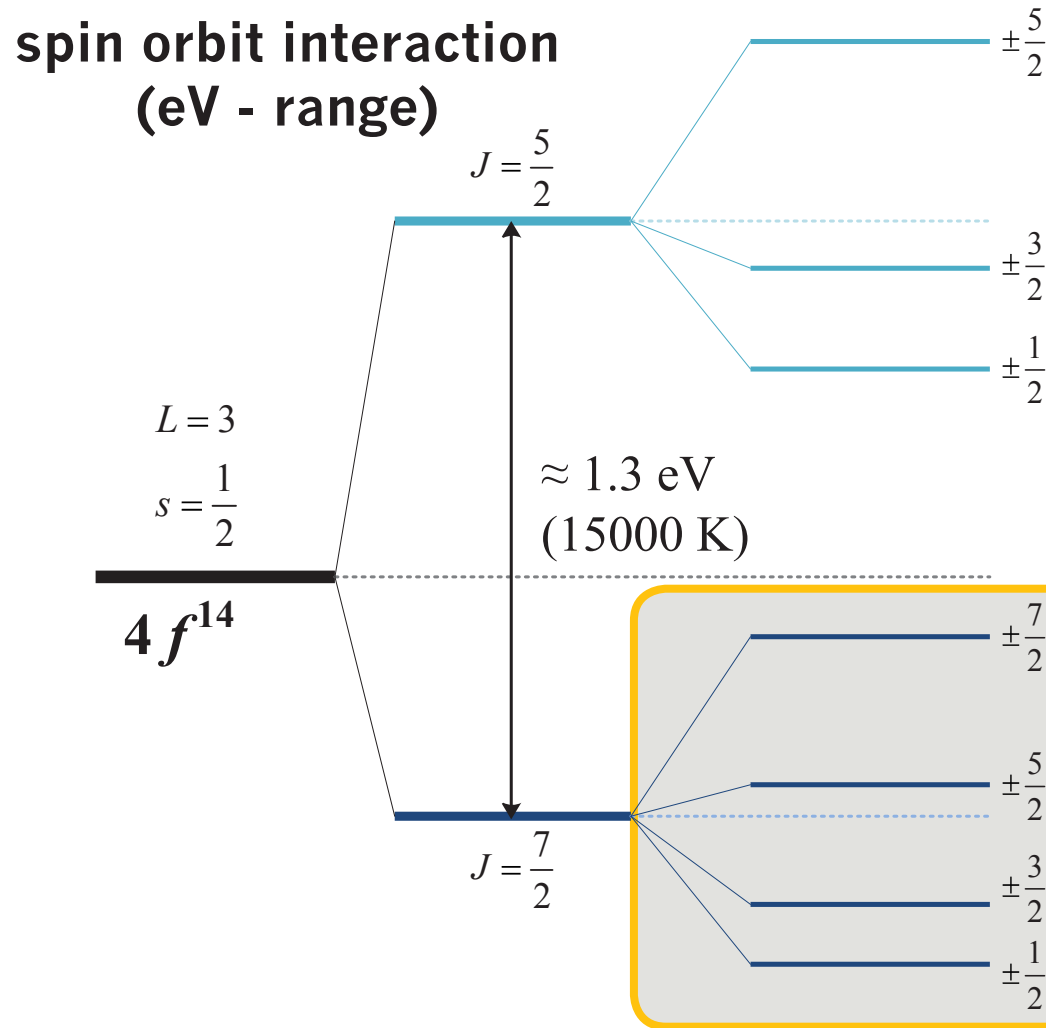


- Expected: nearly constant EFG
- lattice parameters are barely temperature dependent
- example:  $^{181}\text{Hf}$  ( $^{181}\text{Ta}$ )



- $\text{EFG} = \text{EFG}_{\text{lattice}} + \text{EFG}_{4f}$
- preferentially found state:  $\text{Yb}^{3+}$
- has a hole in the 4f shell
- $\text{EFG}_{\text{lattice}}$  and  $\text{EFG}_{4f}$  have opposite signs

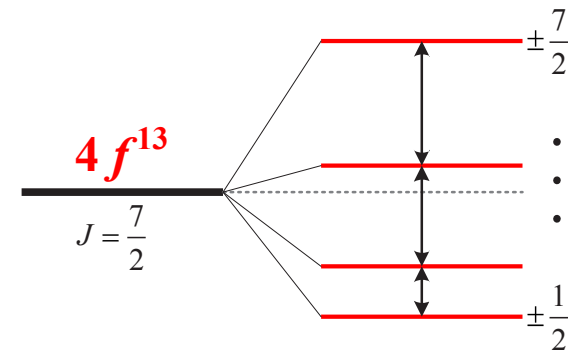
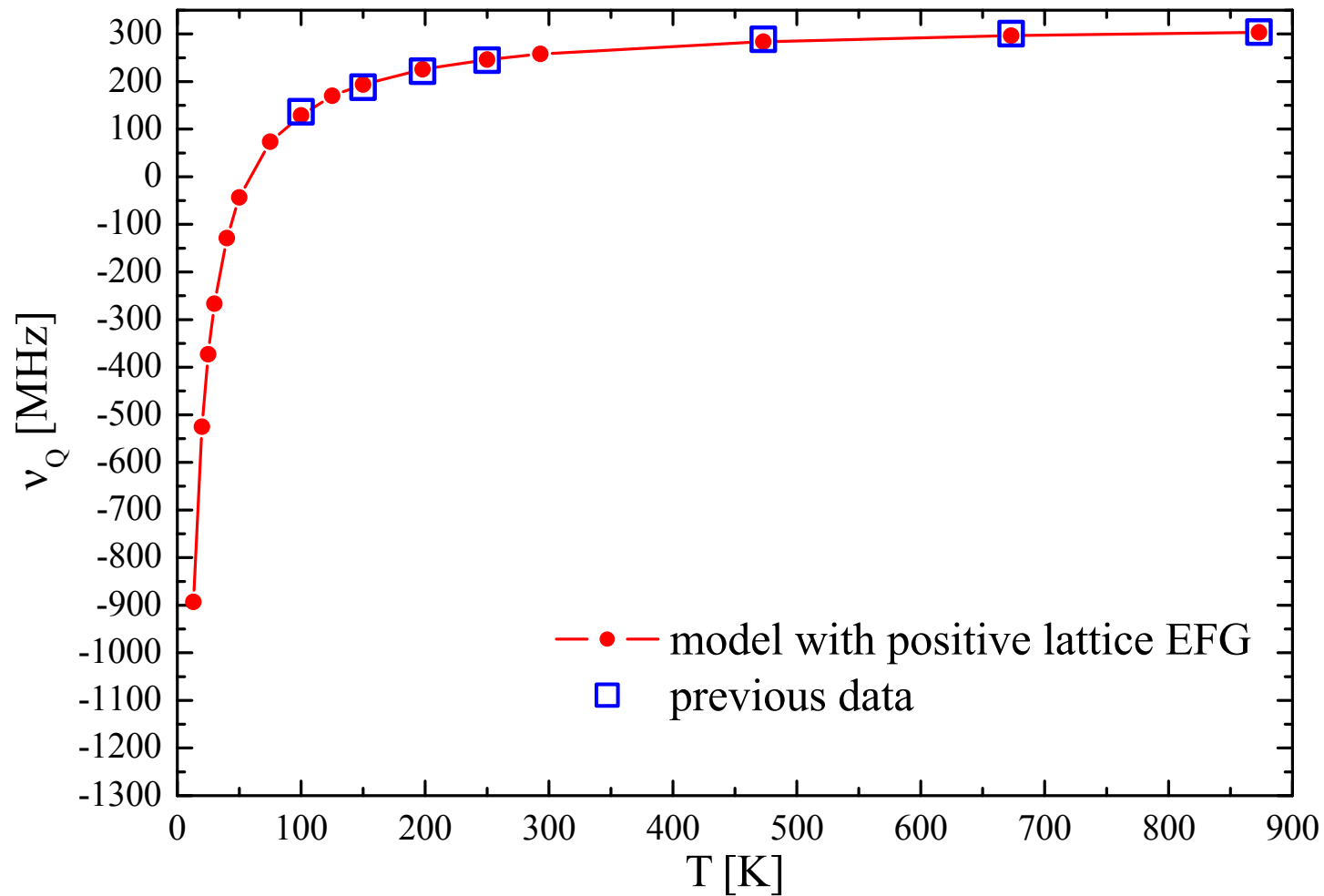
PhD thesis  
**Dr. Ronan Nédélec**  
 Bonn 2007



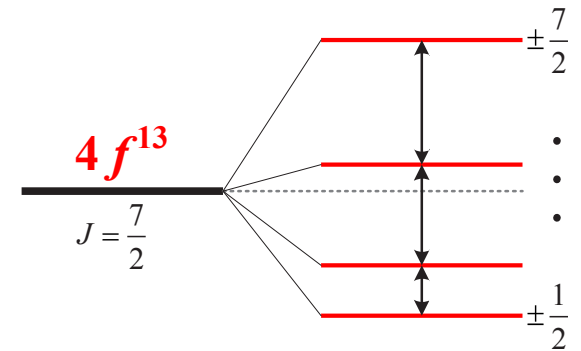
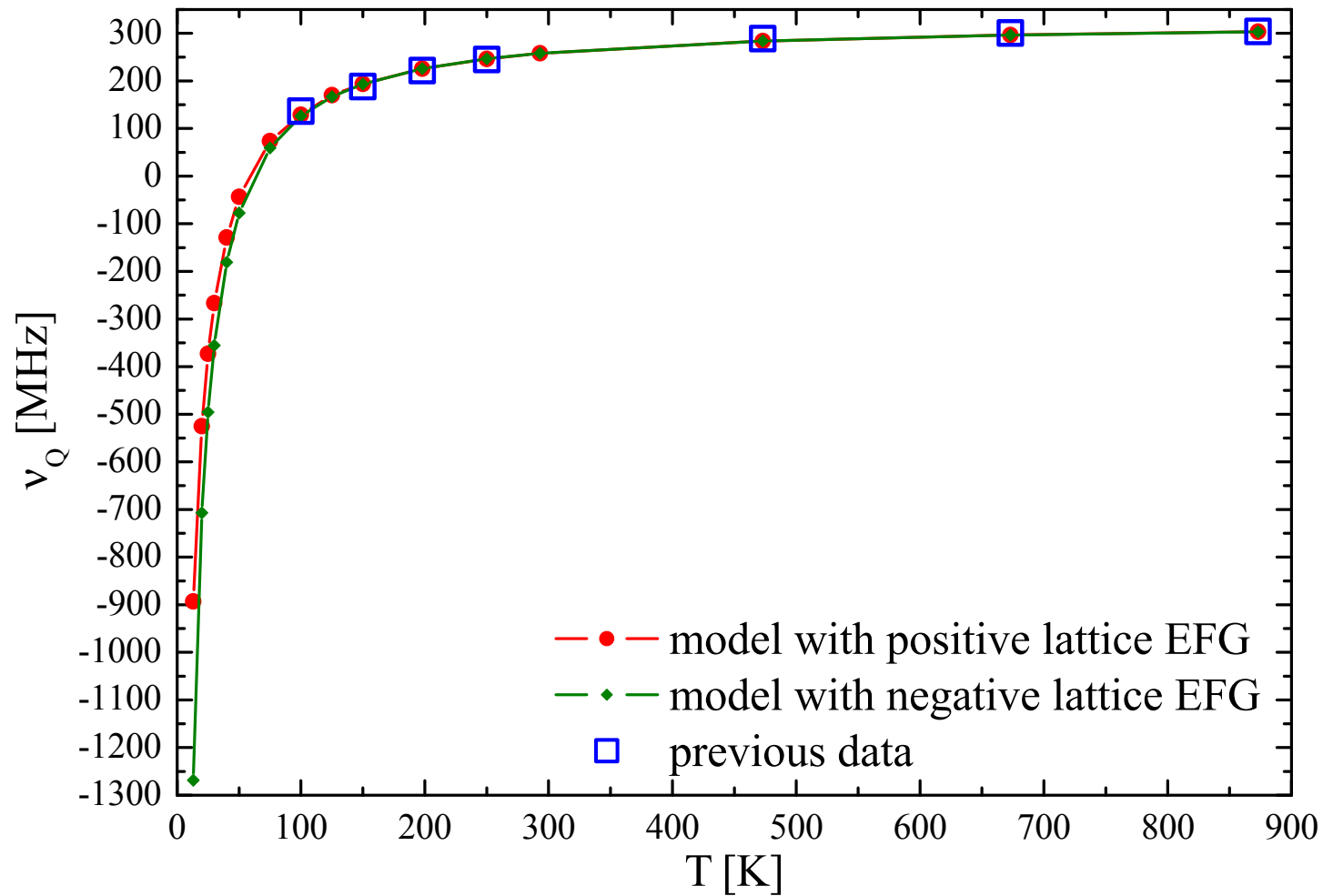
**Kramer doublets  
(meV - range)**

$$\Delta^{4f} = -\frac{1}{4\pi\epsilon_0} e^2 Q_{nuc} (1 - R_Q) \alpha \langle r^{-3} \rangle_{4f} \cdot \sum_{m_j} n_{m_j}(T) \cdot \langle m_j | 3\hat{m}_j^2 - \hat{J}^2 | m_j \rangle$$

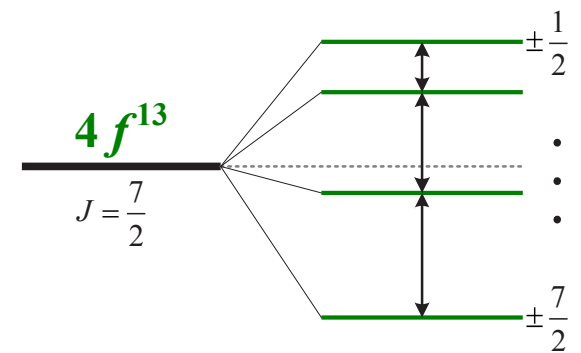




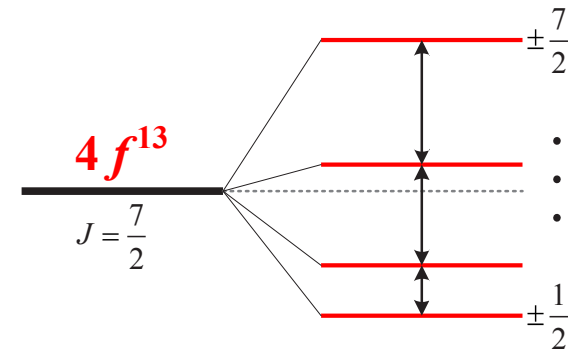
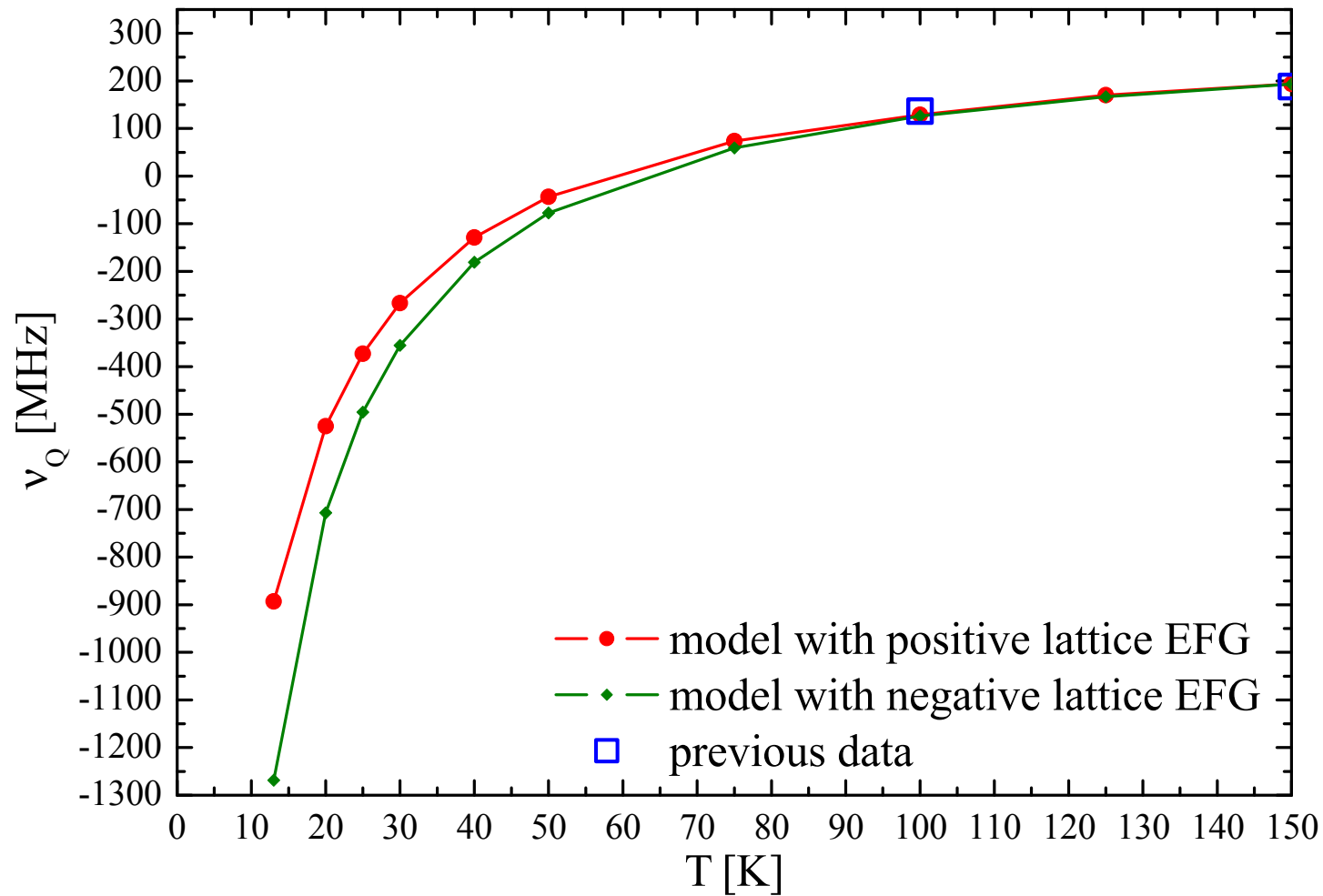
Splitting of the 4f shell with **positive** lattice EFG



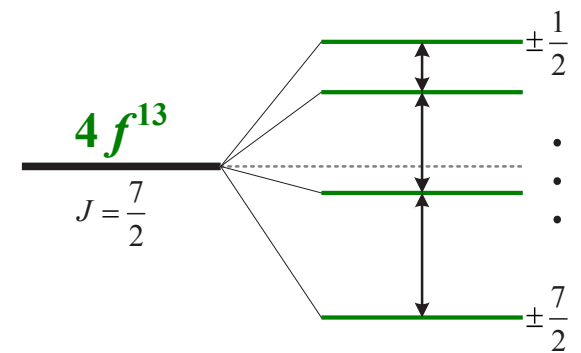
Splitting of the 4f shell with **positive** lattice EFG



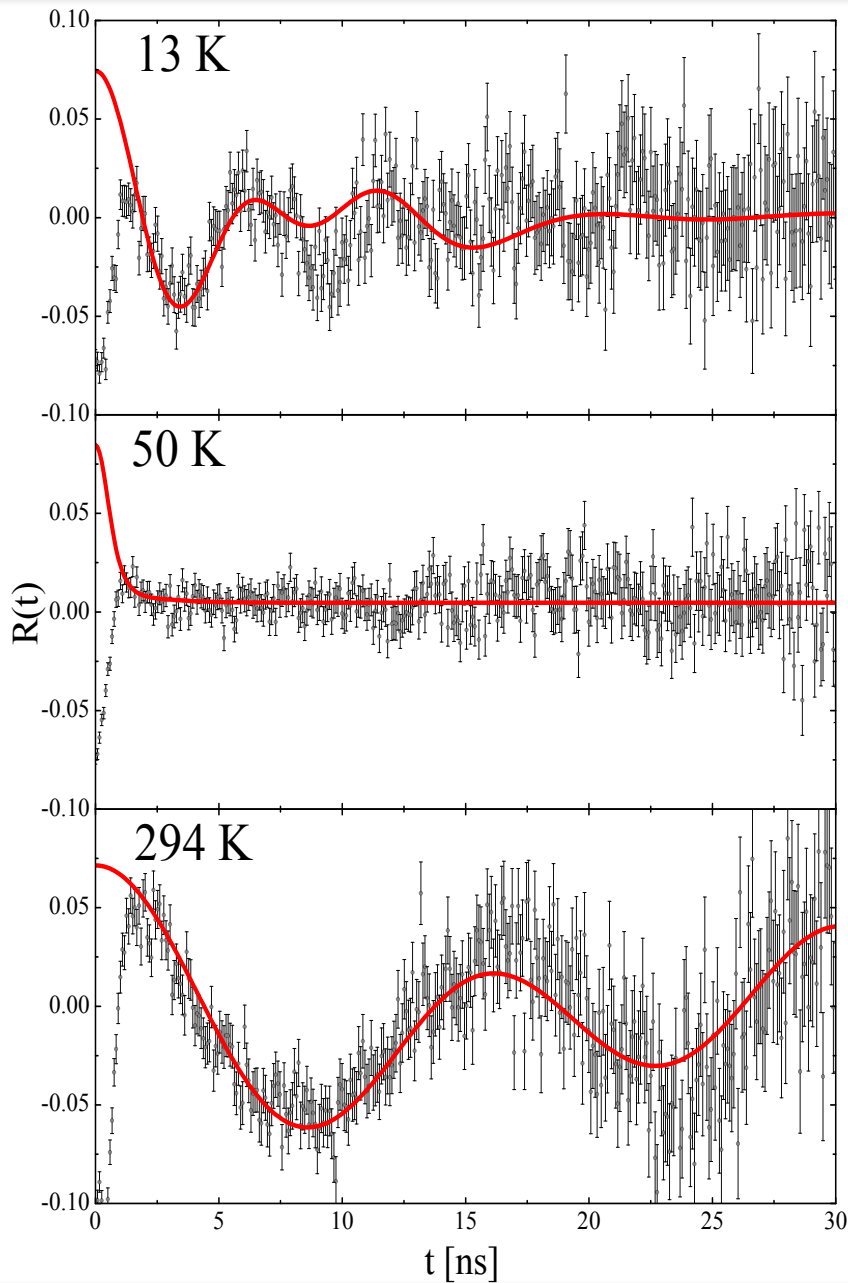
Splitting of the 4f shell with **negative** lattice EFG



Splitting of the 4f shell with **positive** lattice EFG



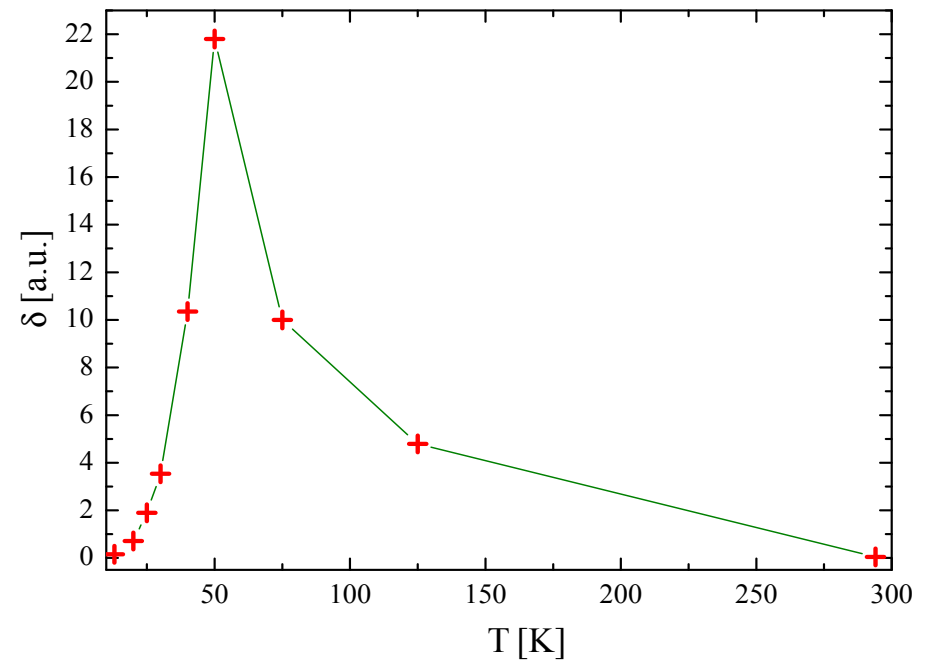
Splitting of the 4f shell with **negative** lattice EFG

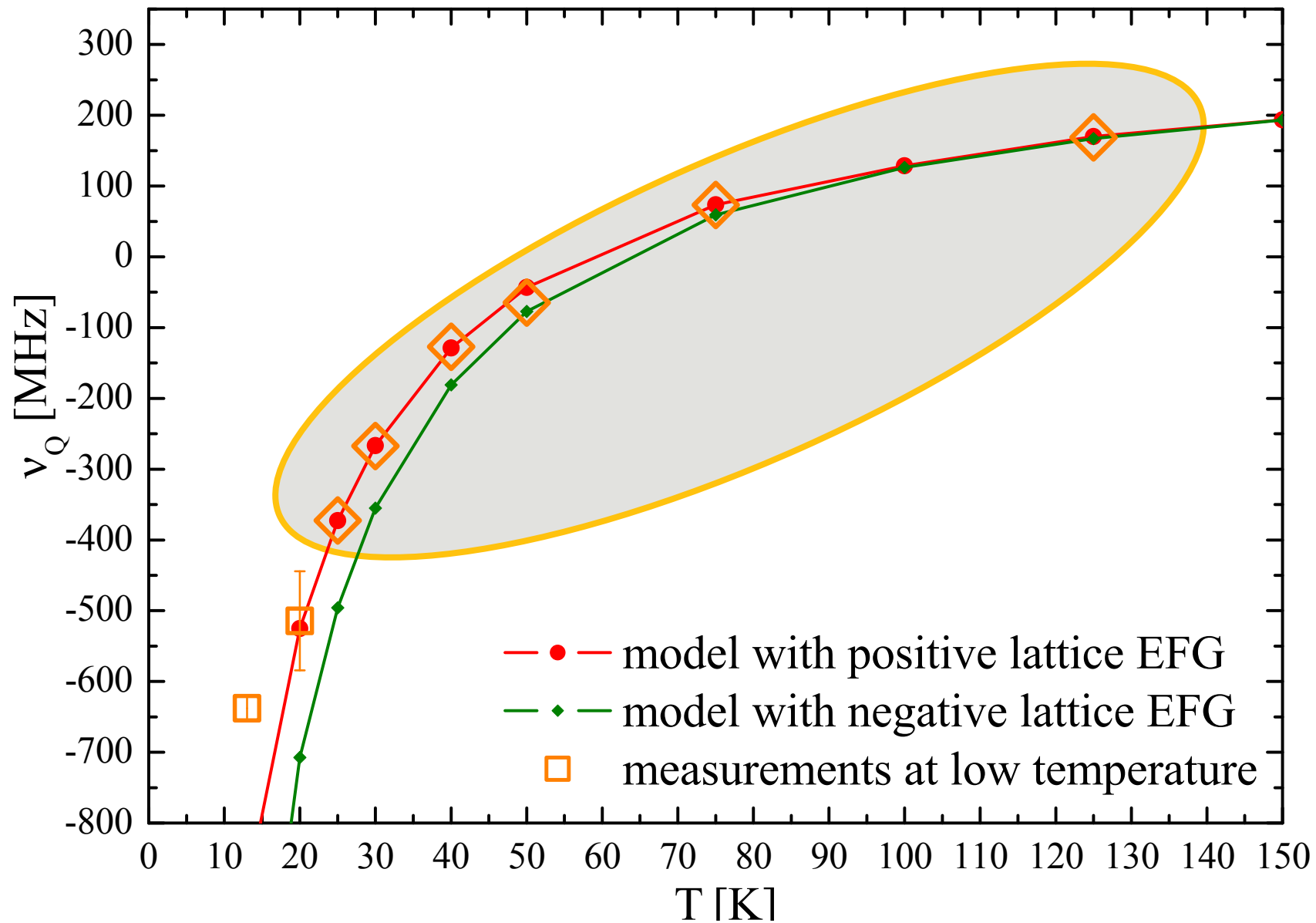


## PAC spectra of $^{172}\text{Lu}(^{172}\text{Yb})$ in GaN

- annealed at 1300 K for 2 min
- measured from 13 K to 294 K

## Temperature dependence of the damping





- the EFG at site of  $^{172}\text{Lu}$ ( $^{172}\text{Yb}$ ) in GaN was measured between 13 K and 294 K
- the strong temperature dependence of the 4f shell EFG at low temperatures could be explained with a simple model
- the current measurements support the assumption of a positive lattice EFG in GaN



**Thank you for your attention.**

**Grazie.**