Terahertz metrology with a

Three-photon coherent population trapping in $^{40}Ca^+$

Mathieu Collombon

PhD Supervisors : - Martina Knoop
- Gaëtan Hagel

PIIM Laboratory - Marseille/France

Outline

- Coherent Population Trapping in a 3-photon scheme

Experimental set-up:

- Local optical reference at 729nm
- Frequency comb and stability transfer
- Trapping setup for ions spectroscopy

- Spectroscopic study of the dark line

- Outlook

The $^{40}Ca^{+}$

A good candidate for trapping and cooling

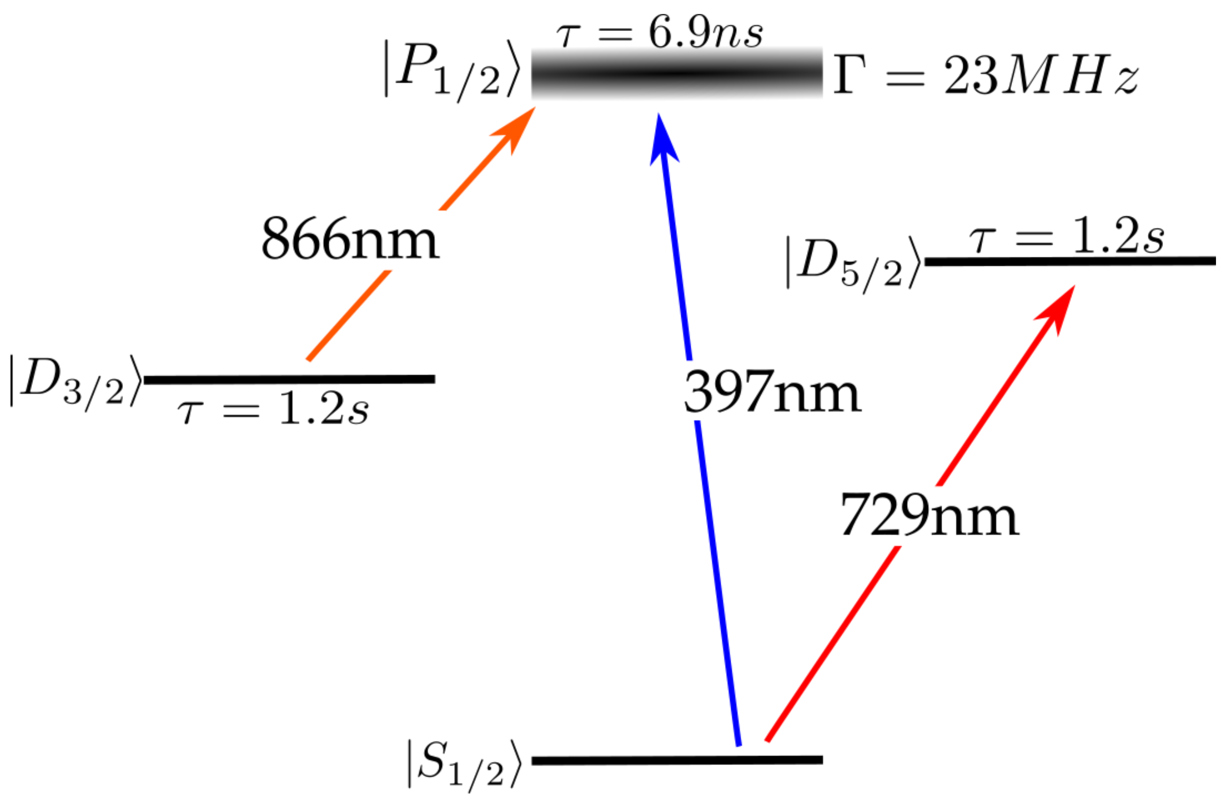
- Doppler cooling at 397nm

→ $T_{min} = 0.55mK$

- Repumping at 866nm

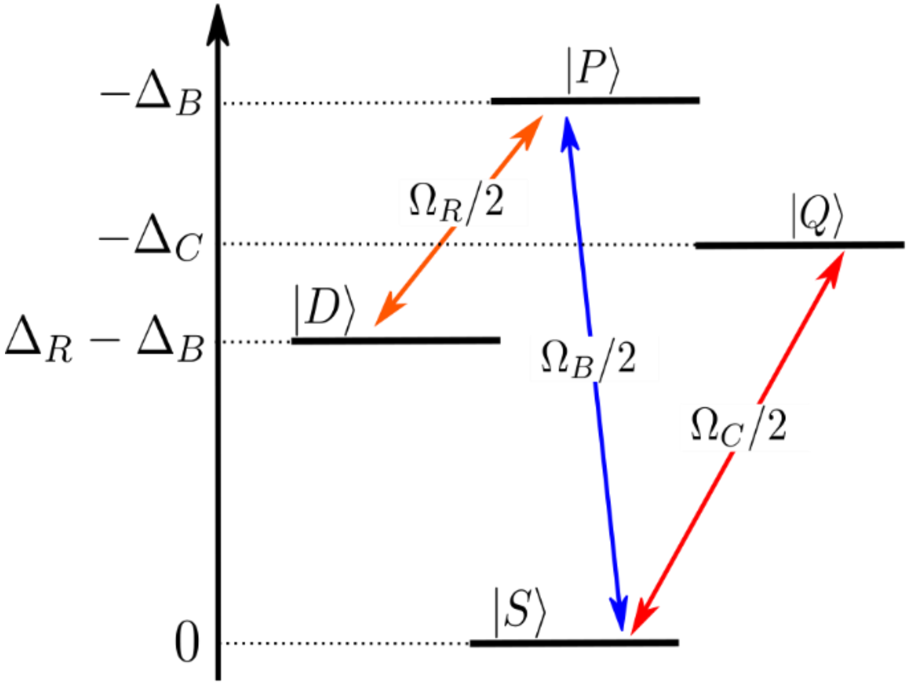
And for metrology :

- Clock transition at 729nm Natural linewidth < 1Hz



Coherent population trapping in a 3-photon scheme

Dressed state picture :



weak coupling approx.

$$\alpha_C = \frac{\Omega_C}{2\Delta_C} << 1$$

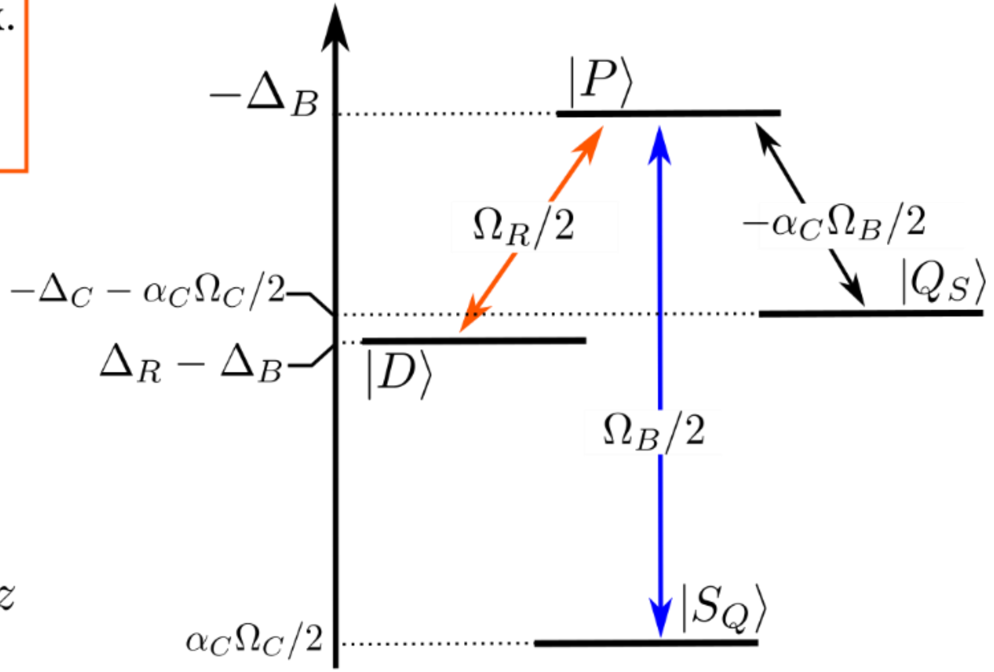
Typ.

$$\frac{\Omega_C}{2\pi} \approx 50kHz$$

$$\Delta_C \approx -25MHz$$

Light shift term

$$LS_{clock} = \frac{\Omega_C^2}{4\Delta_C} \approx 25Hz$$



Trapping when $|D\rangle$ and $|Q_S\rangle$ are degenerated

$$\Delta_R = \Delta_B - \Delta_C - LS_{clock}$$

[1] C. Champenois *et al.* PRA 74 (2006)

The THz frequency

Three photons : Allows 1st order Doppler cancelation if $\Delta k = \vec{k}_R - \vec{k}_B + \vec{k}_C$ =0

Spectroscopy on big sample

Co-propagant lasers : Doppler effect / 400

When 3-photon dark resonance condition is fulfilled : $\Delta_R = \Delta_B - \Delta_C$ →

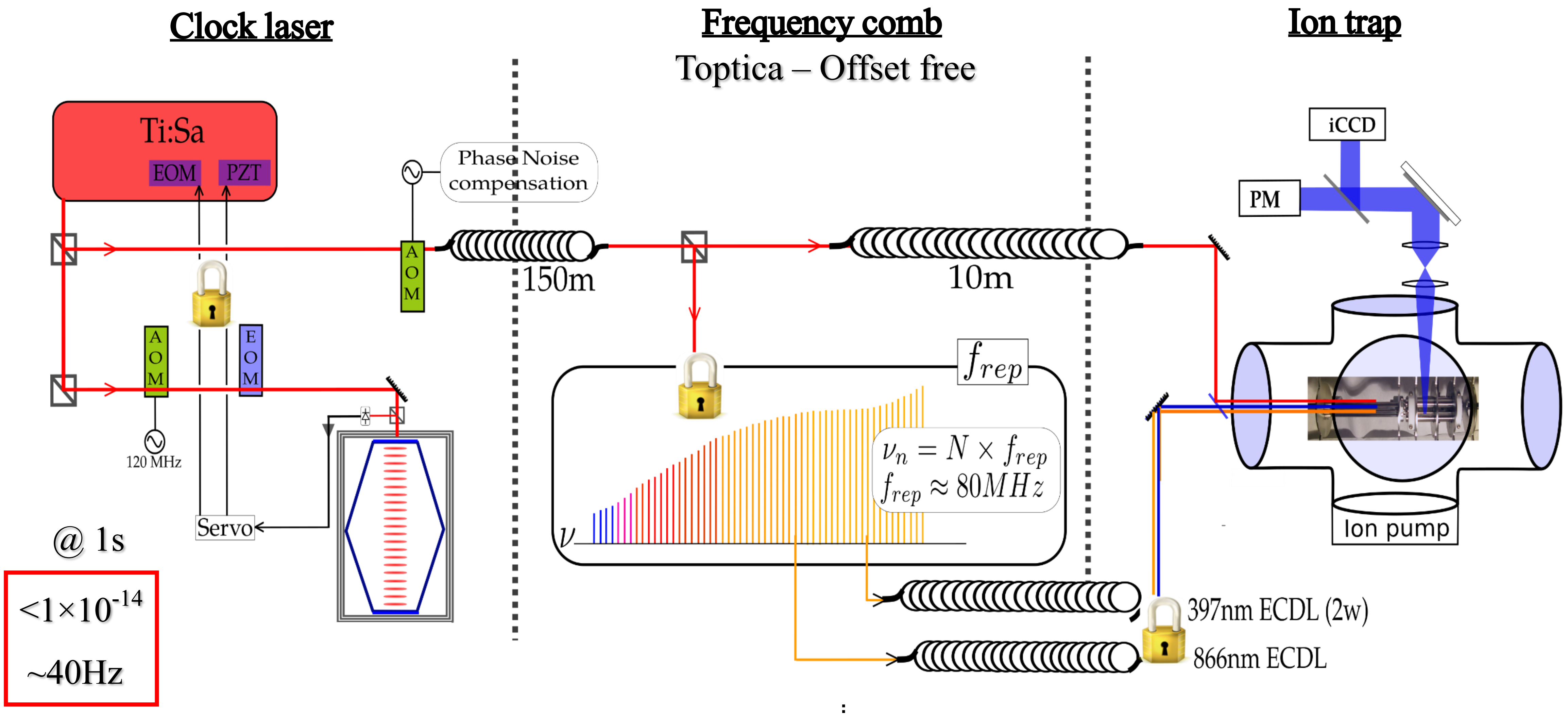
Magnetic dipolar transition

$$\nu\left(|D_{3/2}\rangle \rightarrow |D_{5/2}\rangle\right) = \nu_R^0 - \nu_B^0 + \nu_C^0$$

Raman DFC : 1 819 599 021 534 +/- 8Hz *Solaro et al. PRL (2018)*

Raman CW : 1 819 599 021 504 +/- 37Hz *Yamazaki et al. PRA (2008)*

Experimental set-up



◆ Trapping the ions

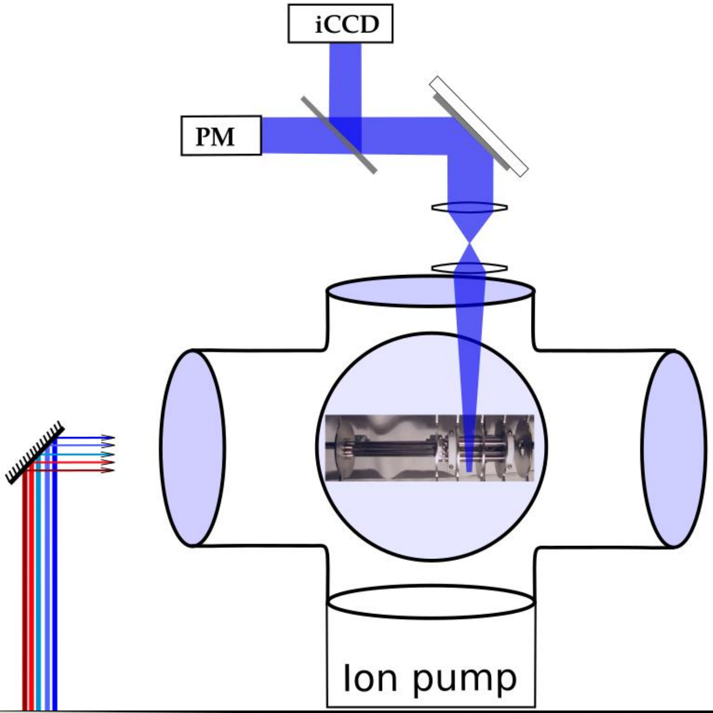
Segmented trap :

-Quad. 1 : ions creation

-Quad. 2 : probing

-Oct. 1 : under improvement

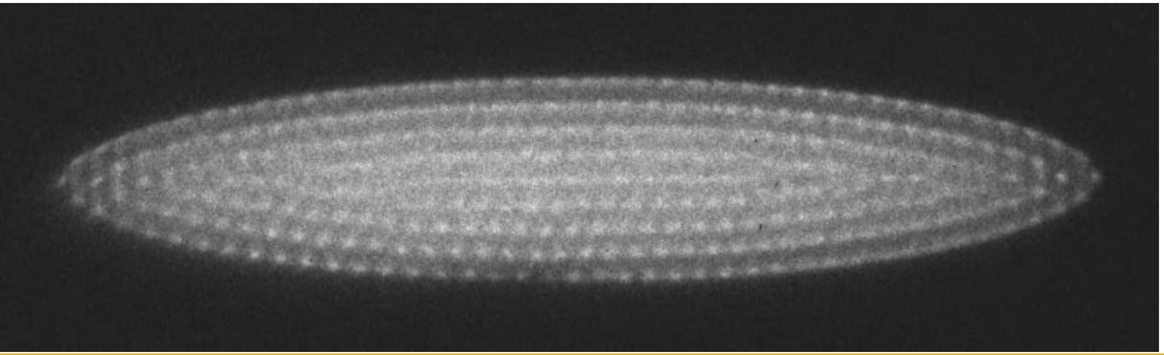
$$L_{quad} = 20 \text{ mm } *2$$
$$r_0 = 3.93 \text{ mm}$$
$$\Omega_{RF}/2\pi = 5.2 \text{ MHz}$$
$$V_{RFmax} = 1200V_{pp}$$
$$V_{DCmax} = 2000V$$
$$DC_{efficiency} = 0,013$$

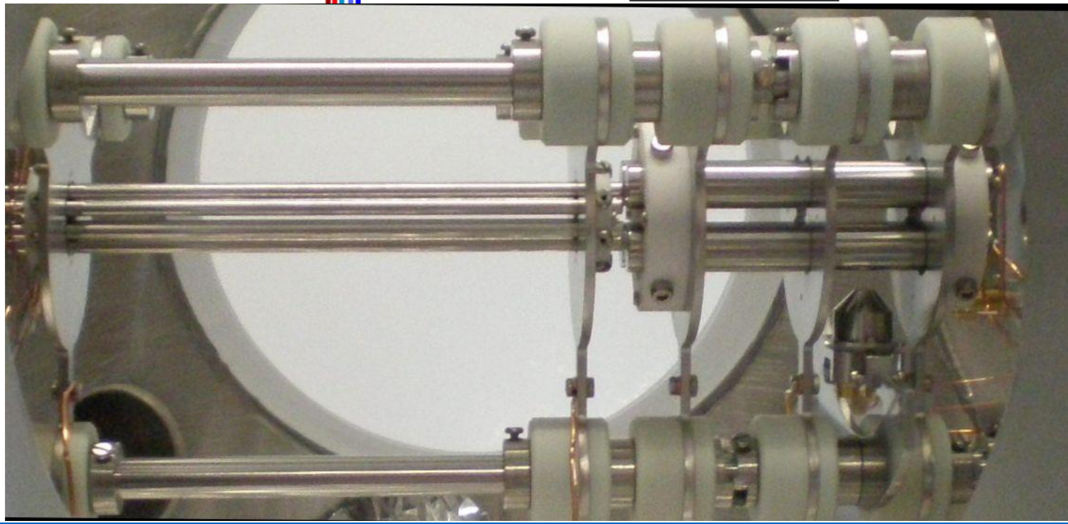


PMT : photon counting

iCCD : picture for ions counting

A typical cloud in Quad. 2 : 2535 ions +/- 10



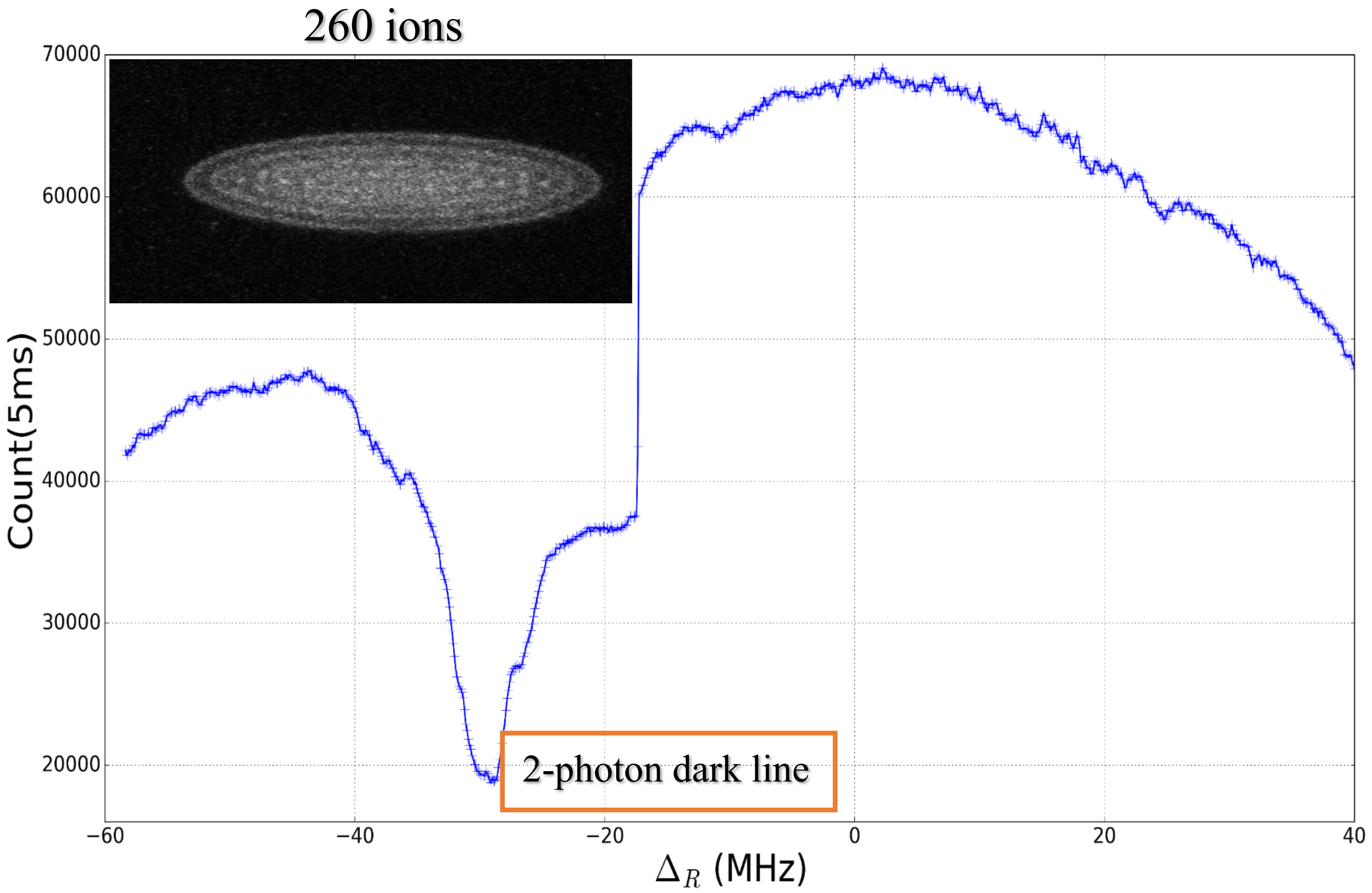


Spectroscopic study of the dark line

-Scanning the frequency of the 866 laser

-Recording the number of photons detected at 397nm

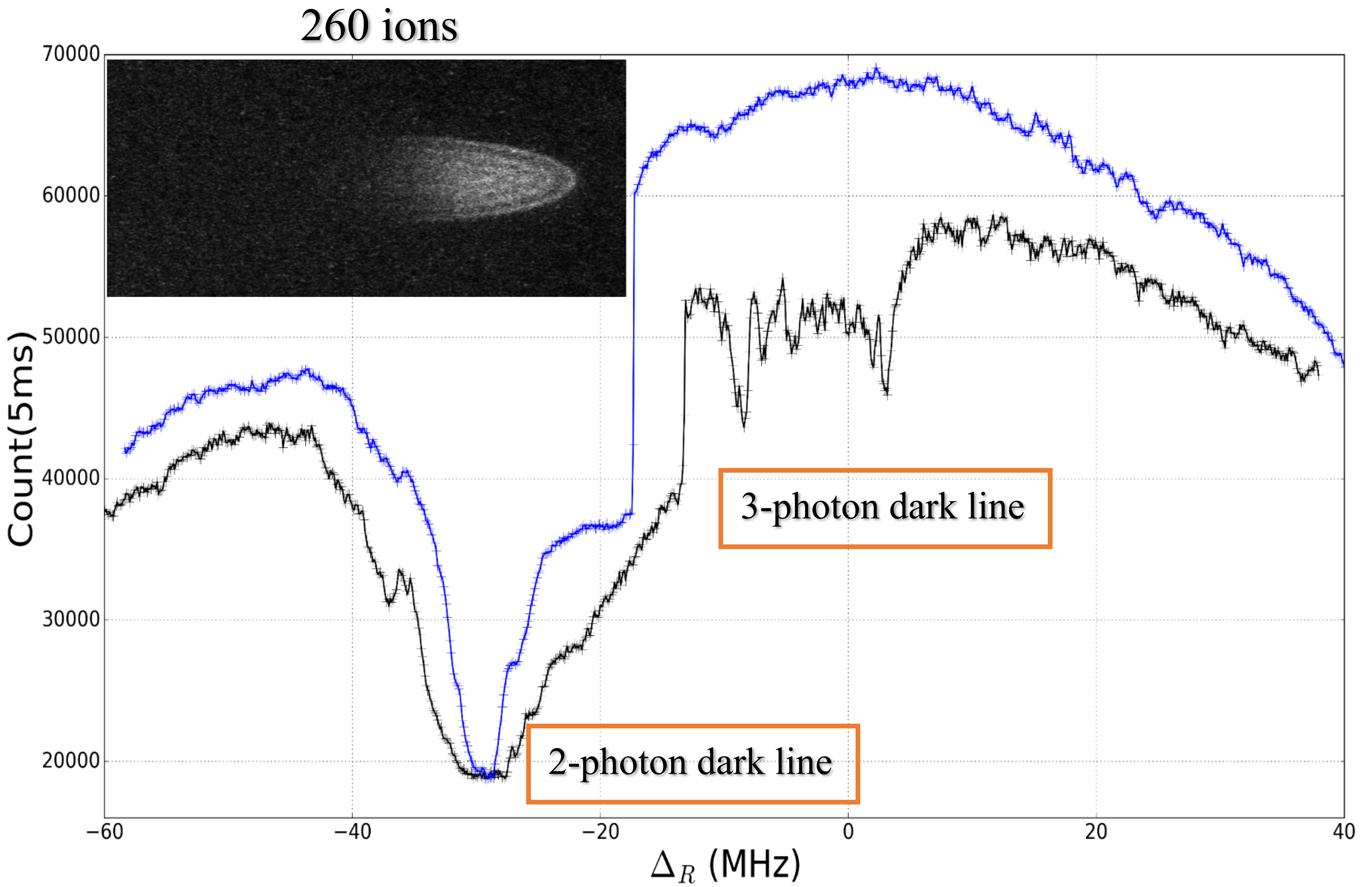
: 397 and 866 free-running, 729nm is OFF



Spectroscopic study of the dark line

-Scanning the frequency of the 866 laser

-Recording the number of photons detected at 397nm



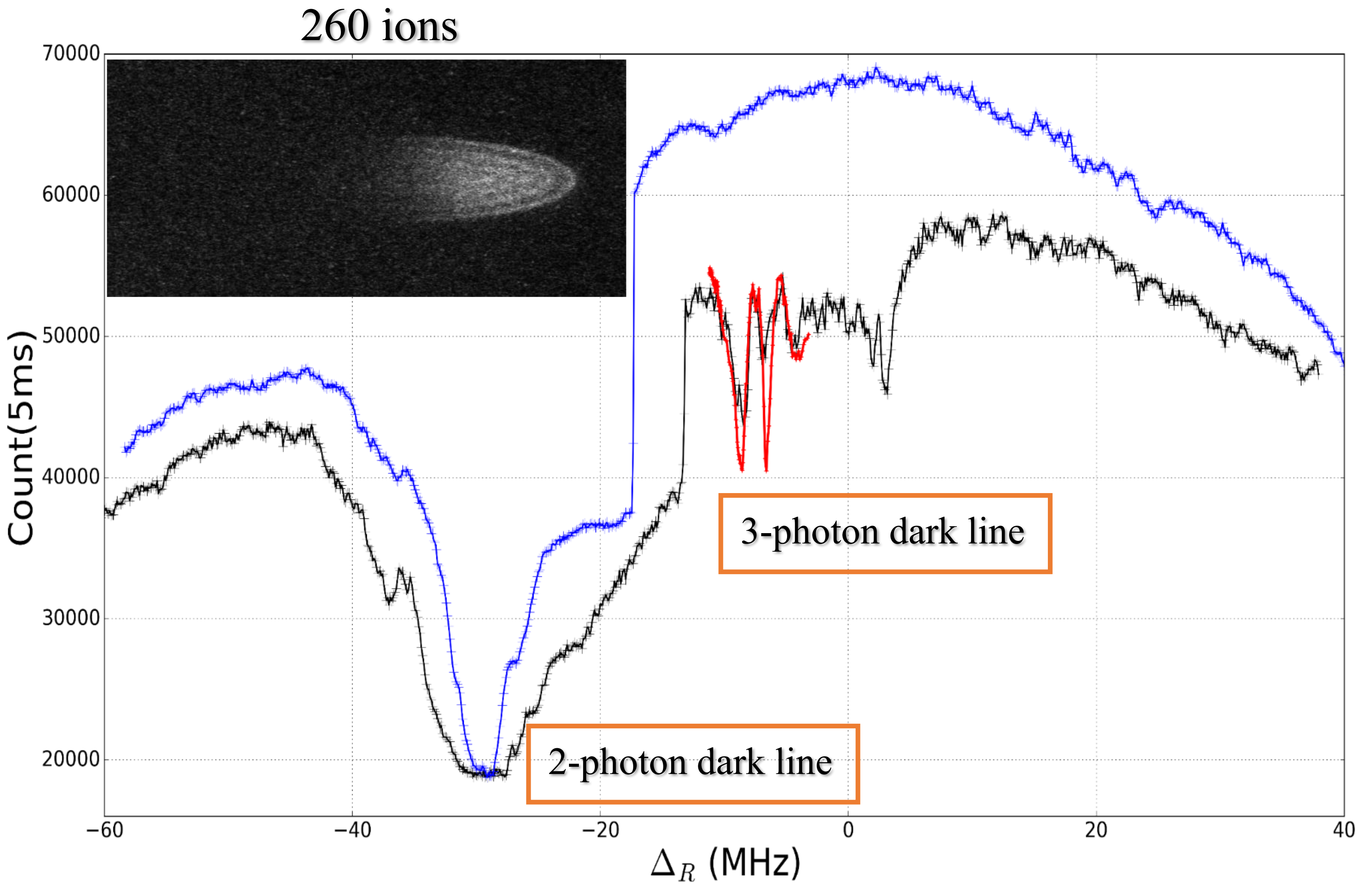
: 397 and 866 free-running, 729nm is OFF

: 397 and 866 free-running, 729nm is ON

Spectroscopic study of the dark line

-Scanning the frequency of the 866 laser

-Recording the number of photons detected at 397nm



: 397 and 866 free-running, 729nm is OFF (blue)

: 397 and 866 free-running, 729nm is ON (black)

: 397 and 866 locked to the comb, locked to the 729 (red)

Typical spectra

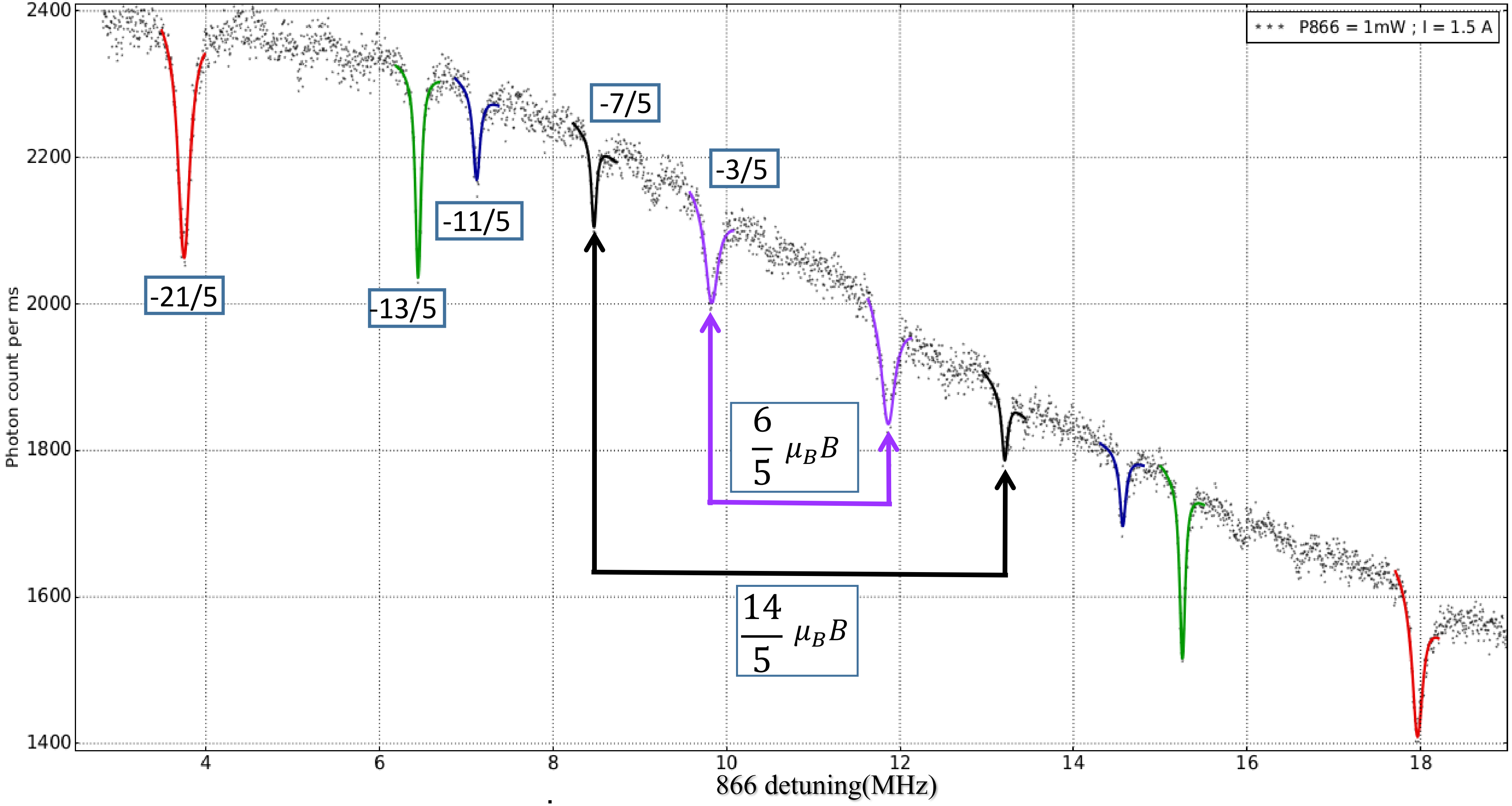
Physical quantities of interest :

- -FWHM
- -Contrast
- -THz frequency

- -Center of each Zeeman couple

↓

THz frequency



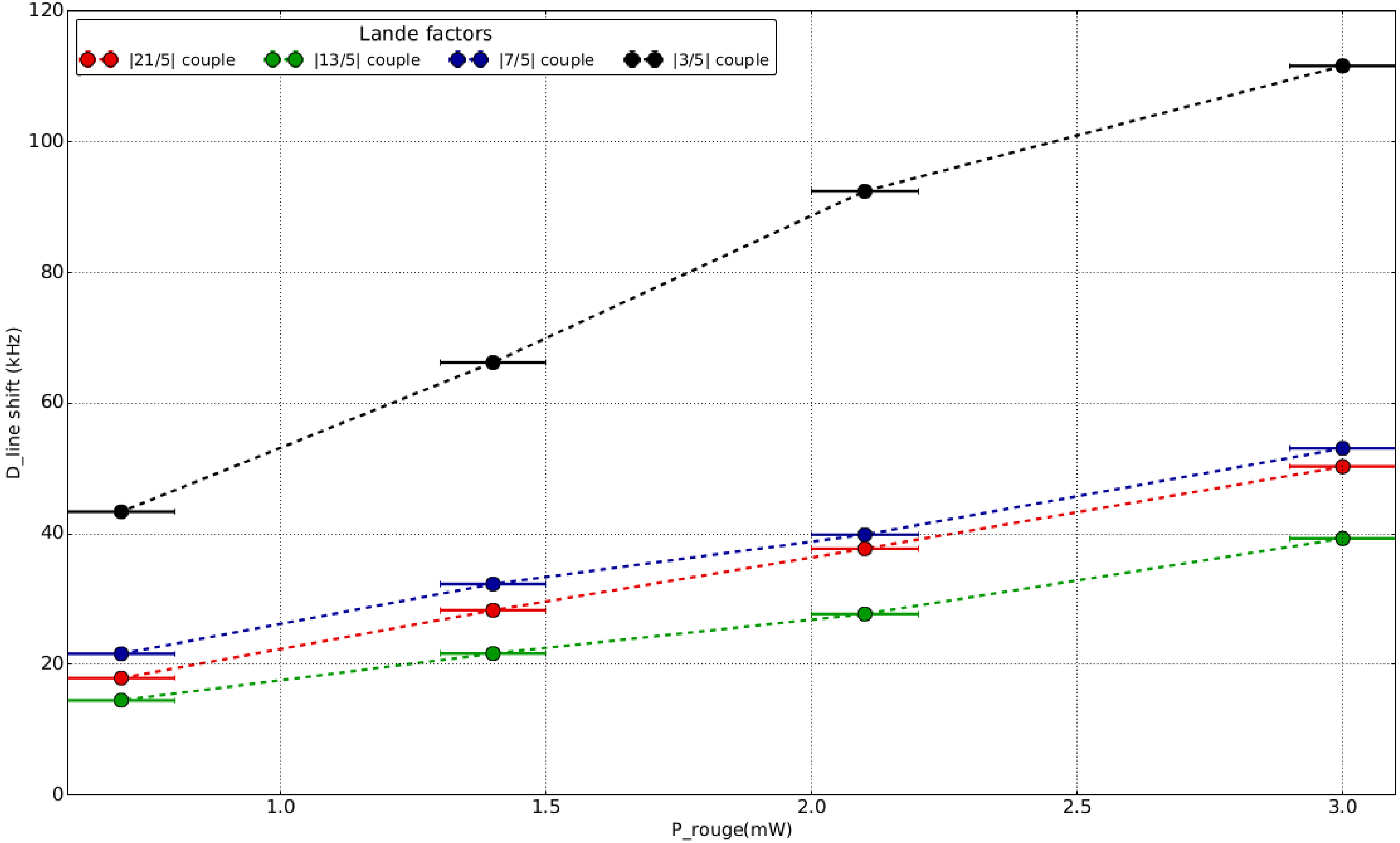
Systematic study : 866 laser power

Centre of each couple

↓

THz frequency

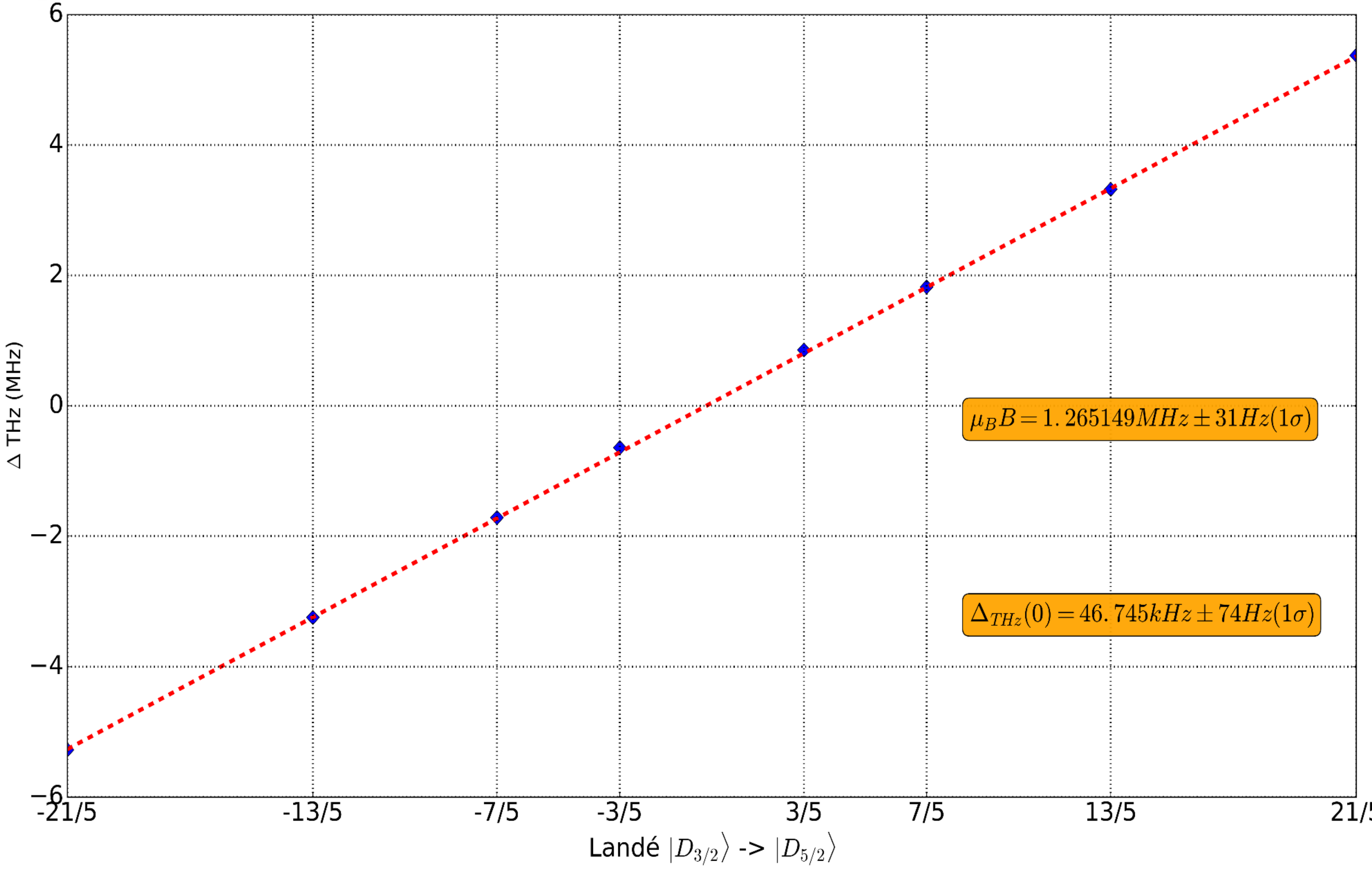
X Averaging the shift of each line



Systematic study : 866 laser power

Extraction of local B field

Offset @ g=0



Systematic study : 866 laser power

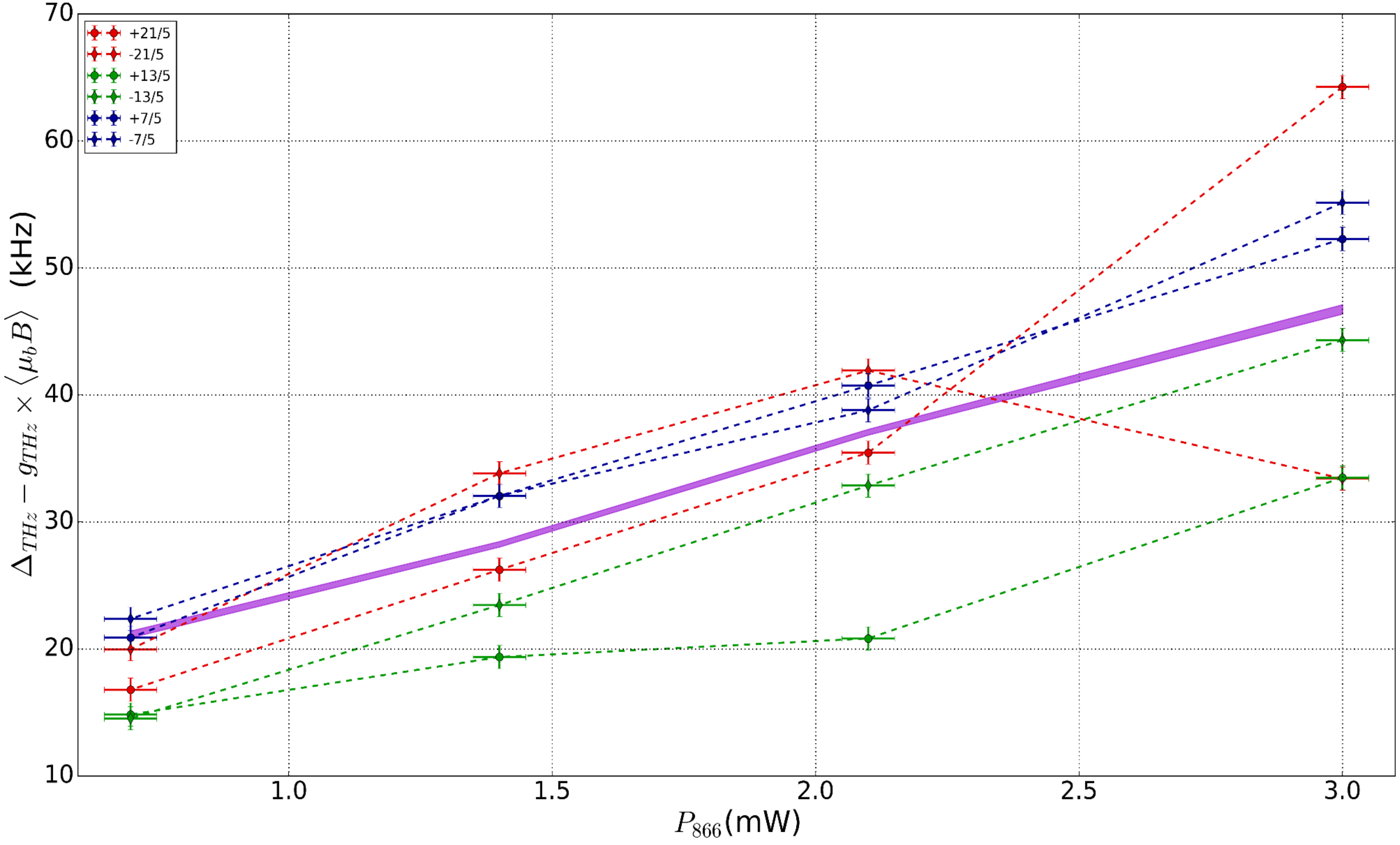
Extraction of local B field

Offset @ g=0

Depend on 866 power

Most likely triggered by decoherence

Zanon-Willette et al. PRA (2011)



Systematic study

No measurable shift yet

Coherence influence

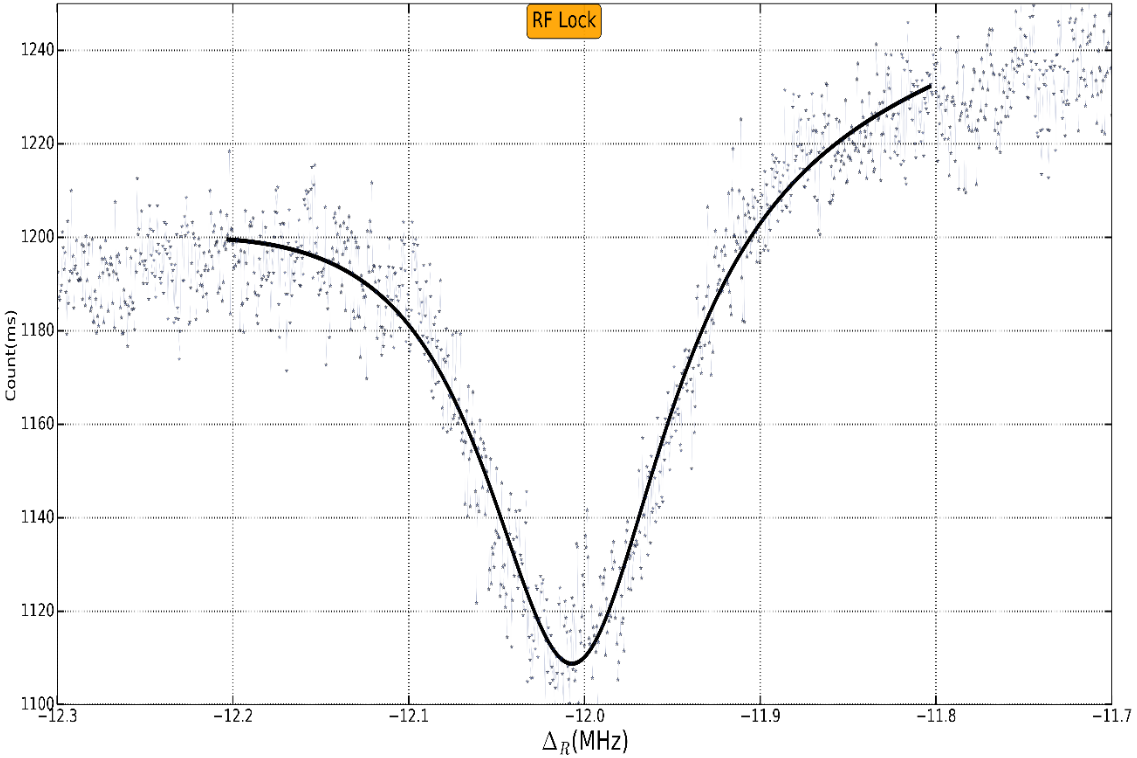
FWHM = 130kHz

Contrast = 13%

397 and 866 locked to

comb RF referenced

729 to ULE



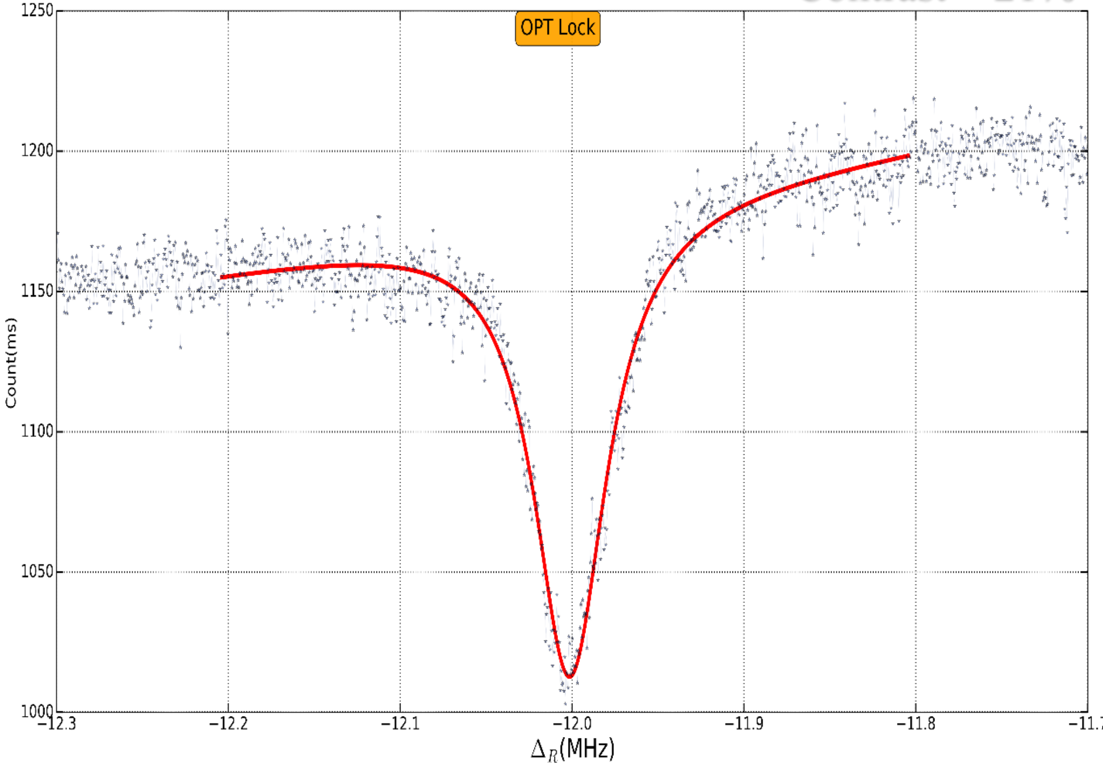
397 and 866 locked to

comb OPT referenced

729 to ULE

FWHM = 50kHz

Contrast = 21%



Conclusion and ongoing work

-Magnetic field improvement (10kHz broadening in today's set-up) → New system almost ready

-Need to precisely point out the dependence in laser linewidth → Artificially broadening the lasers

-Find the correct shift behaviour : multiple effect (Doppler, light shift…)

-Best measurement so far :FWHM = 50kHz

Contrast = 21%

D-line measurement error = 1kHz

-Stable set-up but needs improvement on laser power stabilization

→ Promising for the study of 2nd order Doppler effect

→ THz standard

Thank you very much

The CIML team (permanent) :

- Martina Knoop
- Caroline Champenois
- Gaëtan Hagel
- Marie Houssin
- Aurika Janulyte
- Jofre Pedregosa

…and PhD student :

- Adrien Poindron (1st)
- Marylise Marchenay(2nd)
- Cyril Chatou (2nd)

and me ...