DeLLight *(Deflection of Light by Light)*

Probing vacuum non linearity in presence of strong fields with the DeLLight experiment

F. COUCHOT, X. SARAZIN, S. ROBERTSON, A. MAILLIET, E. BAYNARD,
J. DEMAILLY, M. PITTMAN, S. KAZAMIAS, A. DJANNATI-ATAI, M. URBAN

Aurélie Mailliet
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Scientific motivations

- **Classical ED** : $c = universal\ cte$!
- **QED** : *the vacuum must behave like a non linear « optical » medium when subjected to strong electromagnetic fields (e. m.)* (W. Heisenberg and H. Euler, *Z. Phys.* **98**, 714 (1936))

$$n_{vide} = f(E^2, B^2, E \times B) \neq 1 \ \rightarrow c \neq cte$$

State of the art expriment

- **Birefringence induced by magnetic field**

Best sensitivity achieved by PVLAS ⟶ F. Della Valle *et al.*, *Eur. Phys. J. C* **76**, 24 (2016):

  - Change of polarization state
  - Current sensitivity $\approx 10^{-2}\,\sigma\,\sqrt{T_{obs}(days)}$ $(10^{-1}\,\sigma \text{ in } 100 \text{ days})$
  - Limitation: magnetic field (B~2.5 T)

DeLLight experiment in vacuum

- **Goal** : variation of vacuum refraction index measurement caused by strong laser fields

- **Kerr effect in medium** :

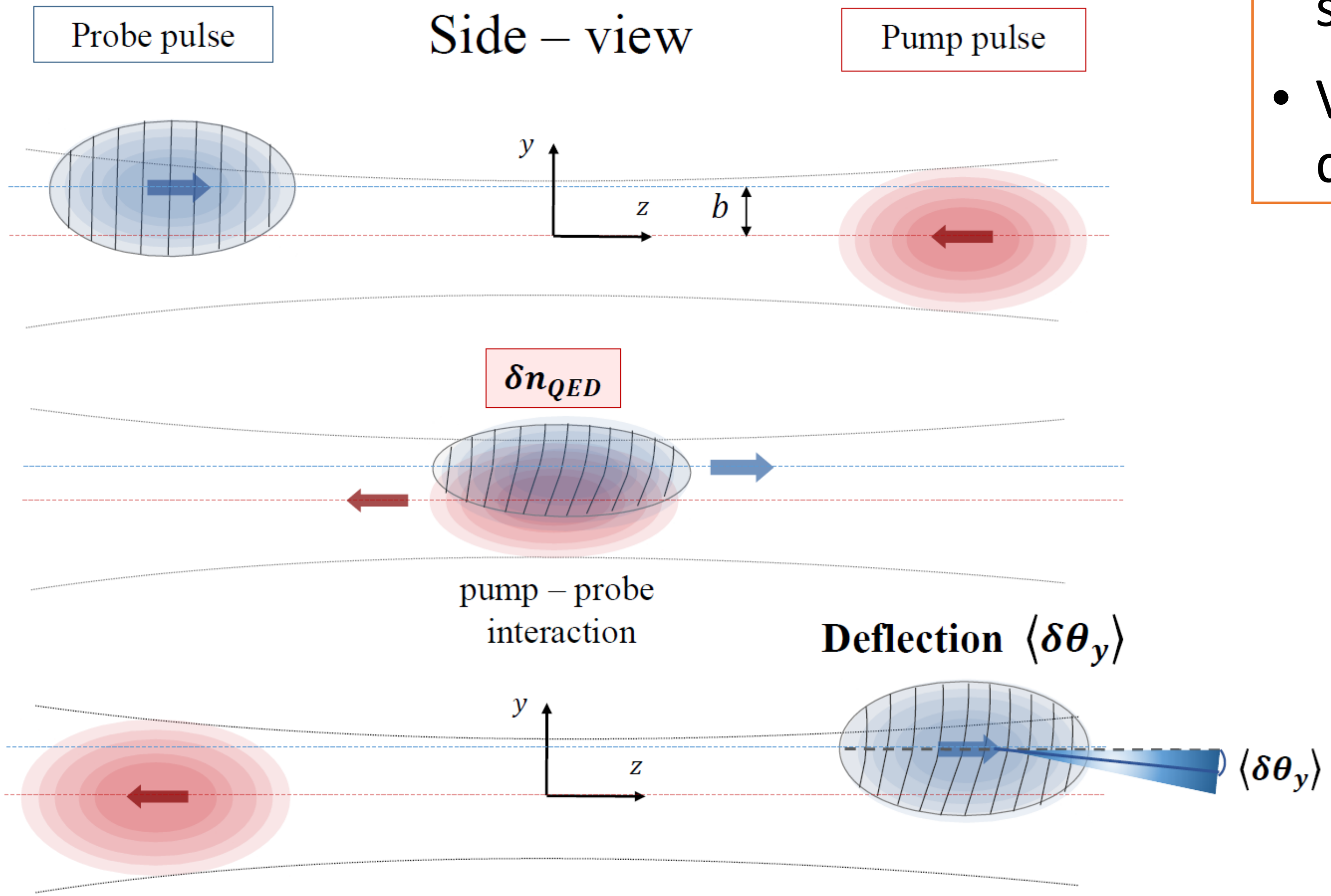
$$n = n_0 + n_2 \times I$$

  - QED induces **nonlinear index** n_2 of vacuum: $n_2 \sim 10^{-33} cm^2/W$
  - Kerr index of silica: $n_2 \sim 10^{-16} cm^2/W$
  - Kerr index of air: $n_2 \sim 10^{-19} cm^2/W$

- **DeLLight** : intense laser pulse produced by LASERIX

$$\begin{cases} \mathrm{E} = 2.5\ \mathrm{J} \\ \tau_{\mathrm{imp}} = 50\ \mathrm{fs} \\ \mathrm{w}_0 = 5\ \mu\mathrm{m} \end{cases} \Rightarrow \begin{cases} \mathrm{B} \sim 10^5\ \mathrm{T} \\ \mathrm{I} \sim 10^{20}\ \mathrm{W/cm^2} \\ \Delta n = n_2 \times I \sim 10^{-13} \end{cases}$$

DeLLight experiment in vacuum



- Highly focused laser pulses to achieve strong fields: $I_{pump} \gg I_{probe}$
- Vacuum index gradient $\Rightarrow$ probe pulse deflected

LASERIX :

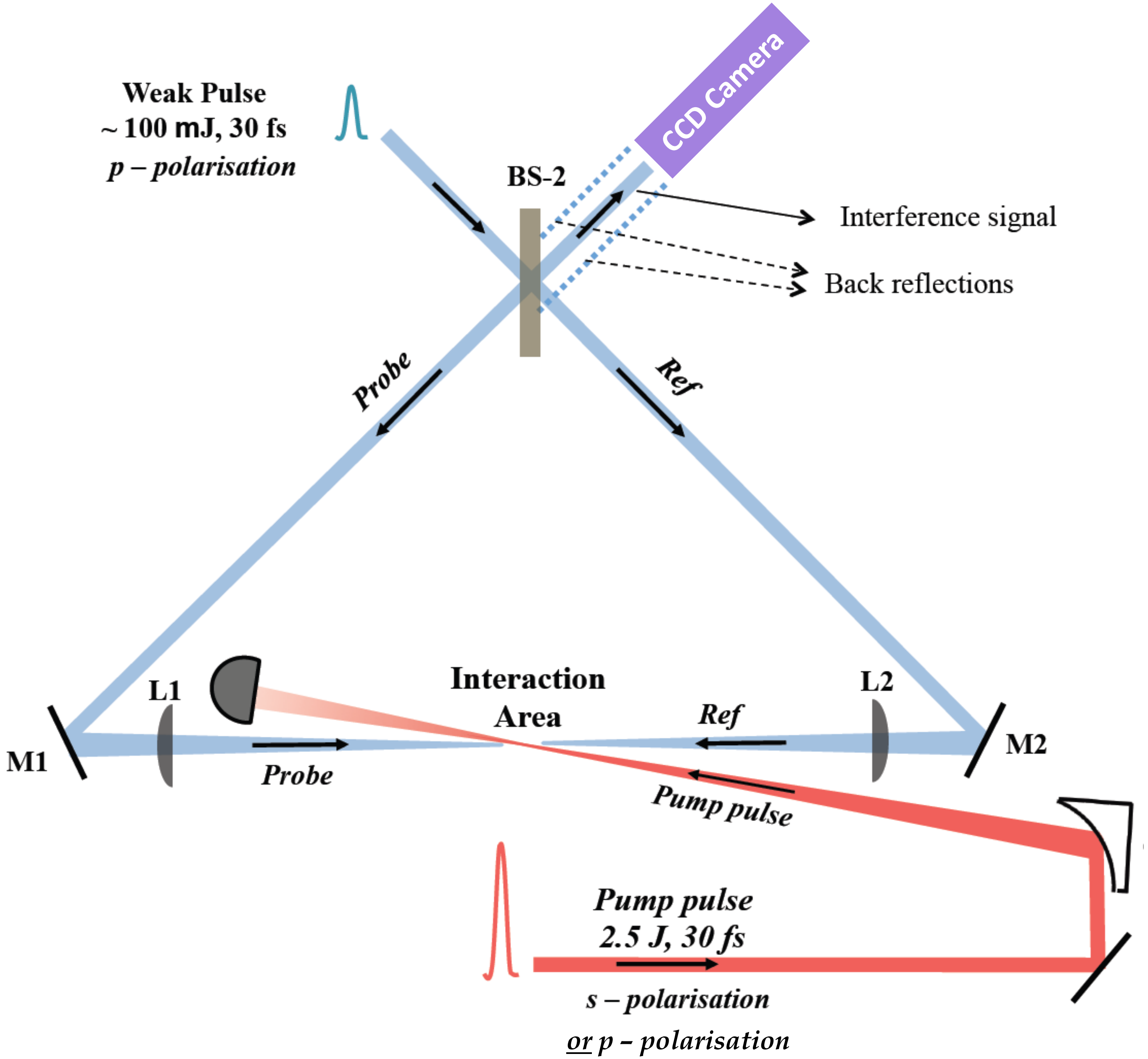
- $\mathrm{E} = 2.5\ \mathrm{J}$
- $\tau_{imp} = 50\ \mathrm{fs}$
- $\mathrm{w}_0 = 5\ \mu\mathrm{m}$ *(width at focus)*

$\Rightarrow B \sim 10^5\ T$

$\Rightarrow \delta\theta \sim 10^{-13}\ rad$

$(\Delta n \sim 10^{-13})$

DeLLight experiment in vacuum



Sagnac interferometer
⇒ **amplification** of expected signal

Extinction factor:

$$F = \frac{I_{out}}{I_{in}} \sim 10^{-5} \left(with\ A\ \alpha\ \frac{1}{\sqrt{F}} \right)$$

Expected signal with focal lenght $f = 50\ cm$:

$$\Delta y_{QED} = \frac{f \times \delta\theta}{2\sqrt{F}} \sim 0{,}01\ nm$$

- **Stability** against movement of optical components
- Back reflections at beamsplitter allow **monitoring and suppression of beam pointing fluctuations**

- **ON-OFF measurement:** succession of probe-pump interaction and no probe-pump interaction to aquire statistics
  - $f_{rep,laser} = 10\ Hz$ and $f_{rep,ON-OFF} = 5\ Hz$

Expected sensitivity

$$N_{sd} \propto \frac{\sqrt{T_{obs}} \times f}{\sigma_y \times \sqrt{F} \times (w_0^2 + W_0^2)^{\frac{3}{2}}}$$

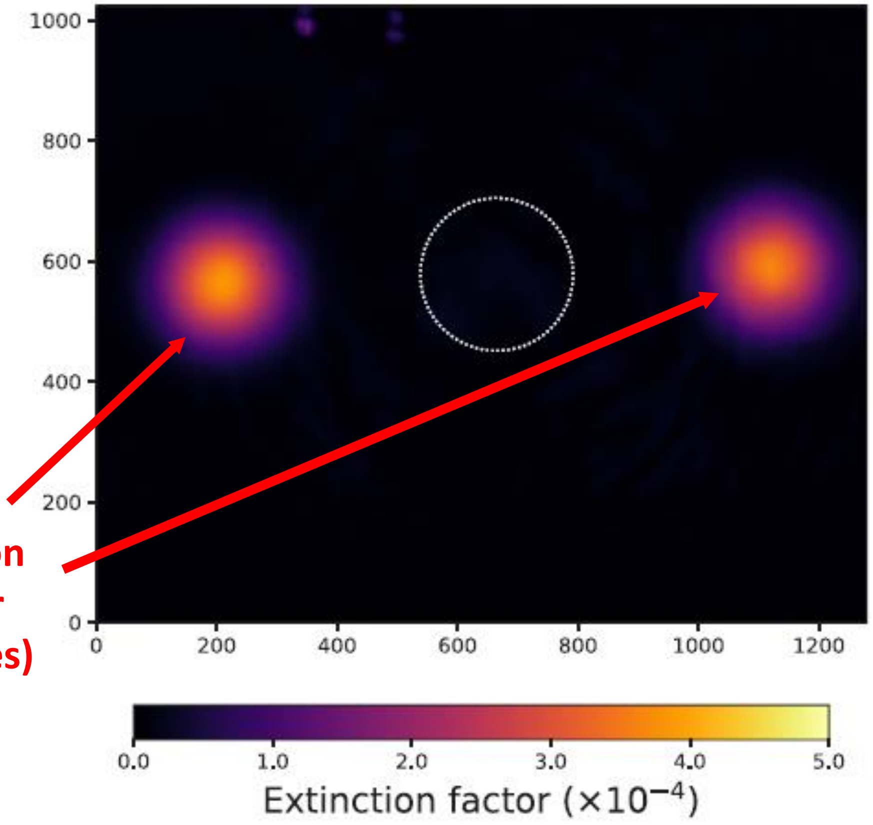
N_{sd} : number of standard deviation
σ_y : spatial resolution of intensity profile barycenter measurement
F : extinction factor
w_0 *and* W_0 : waist of the probe and pump beam at focus
T_{obs} : integrated duration of measurement
f : focal length (lenses inside the interferometer)

$$\begin{cases} \sigma_y = 10\, nm\ (shot\ noise) \\ F = 10^{-5} \\ w_0 = W_0 = 5\ \mu m \end{cases} \Rightarrow N_{sd} = 5\ (5\sigma\ \text{measurement})\ \text{for one month of data}$$

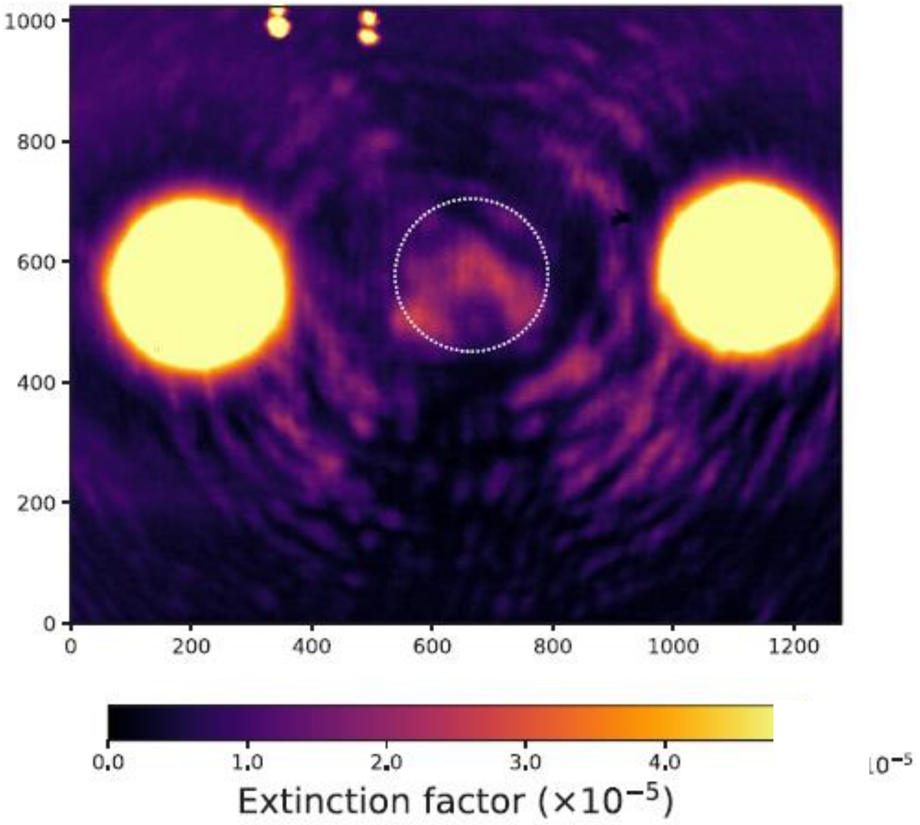
DeLLight Prototype

Main results achieved with the first DeLLight prototype and published in:
S. Robertson, A. Mailliet, X. Sarazin *et al.*, “*Experiment to observe an optically induced change of the vacuum index*”, Phys. Rev. A **103**, 023524 (2021)

1. **Extinction: residual phase noise ~ few 10^{-5}**
   Induced by surface defects of the mirrors and lenses



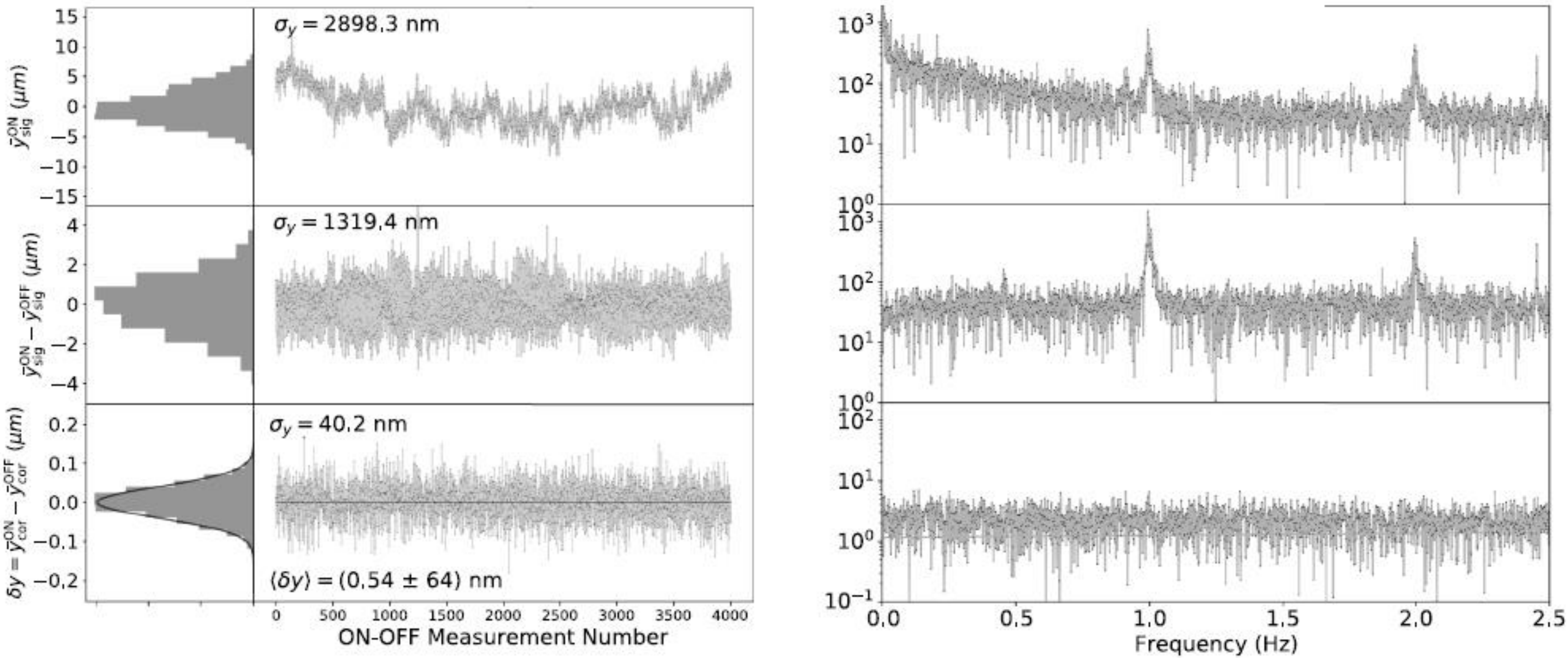
Back reflections on the beamsplitter (used as references)



DeLLight Prototype

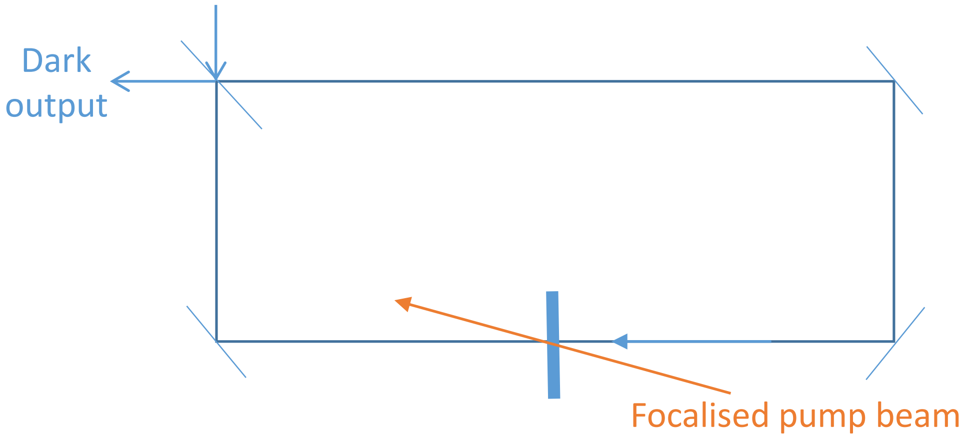
2. Spatial resolution ~ 40 nm (limited by quantum shot noise of the current CCD camera)

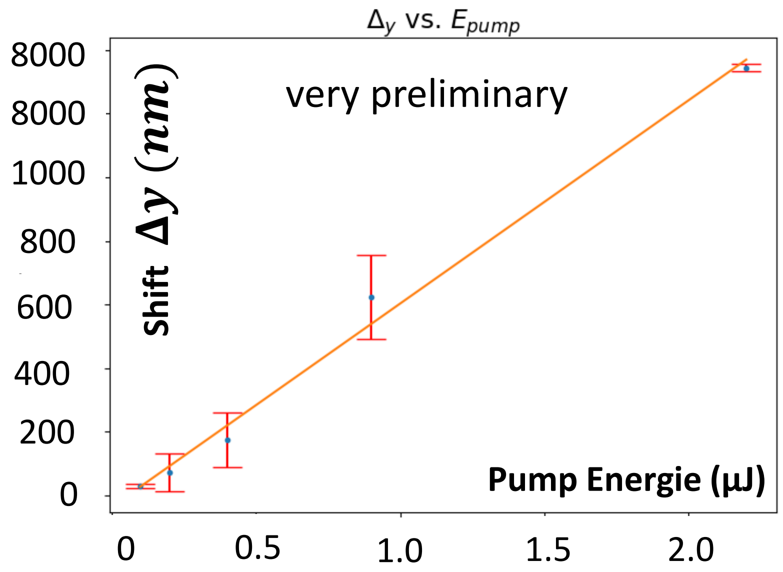
↳ Suppression of the beam pointing fluctuations



Demonstration/validation of the prototype: Kerr effect in medium

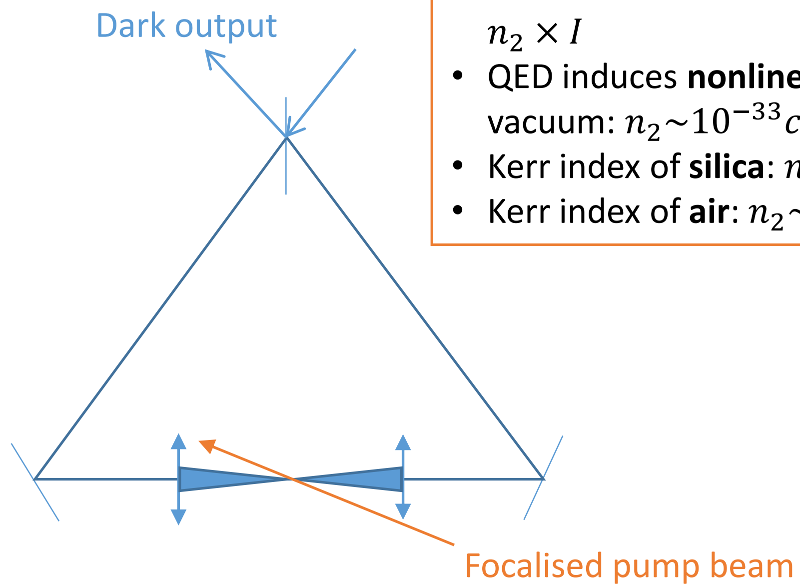
1. Kerr effect in silica SiO_2

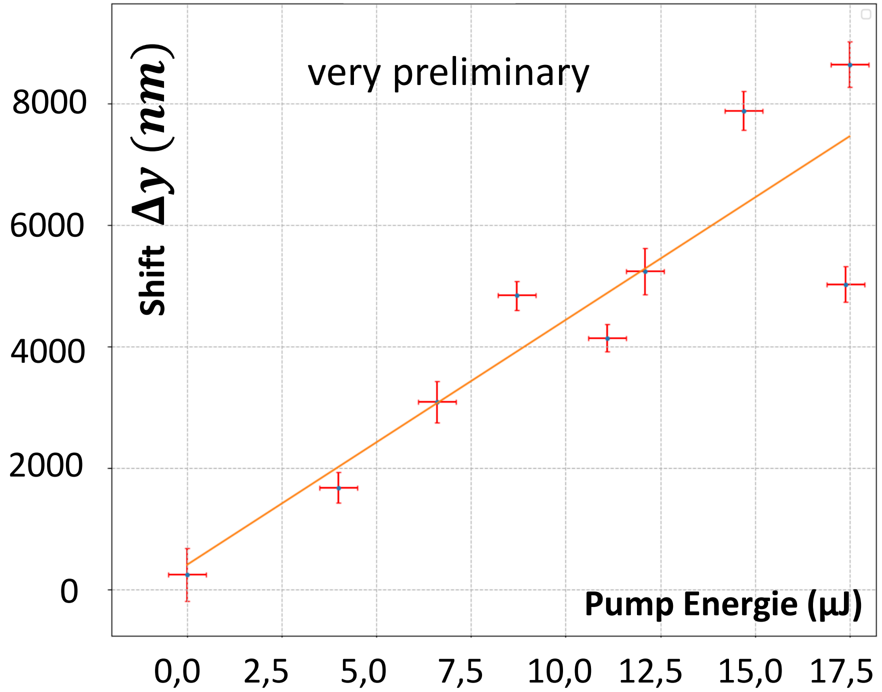




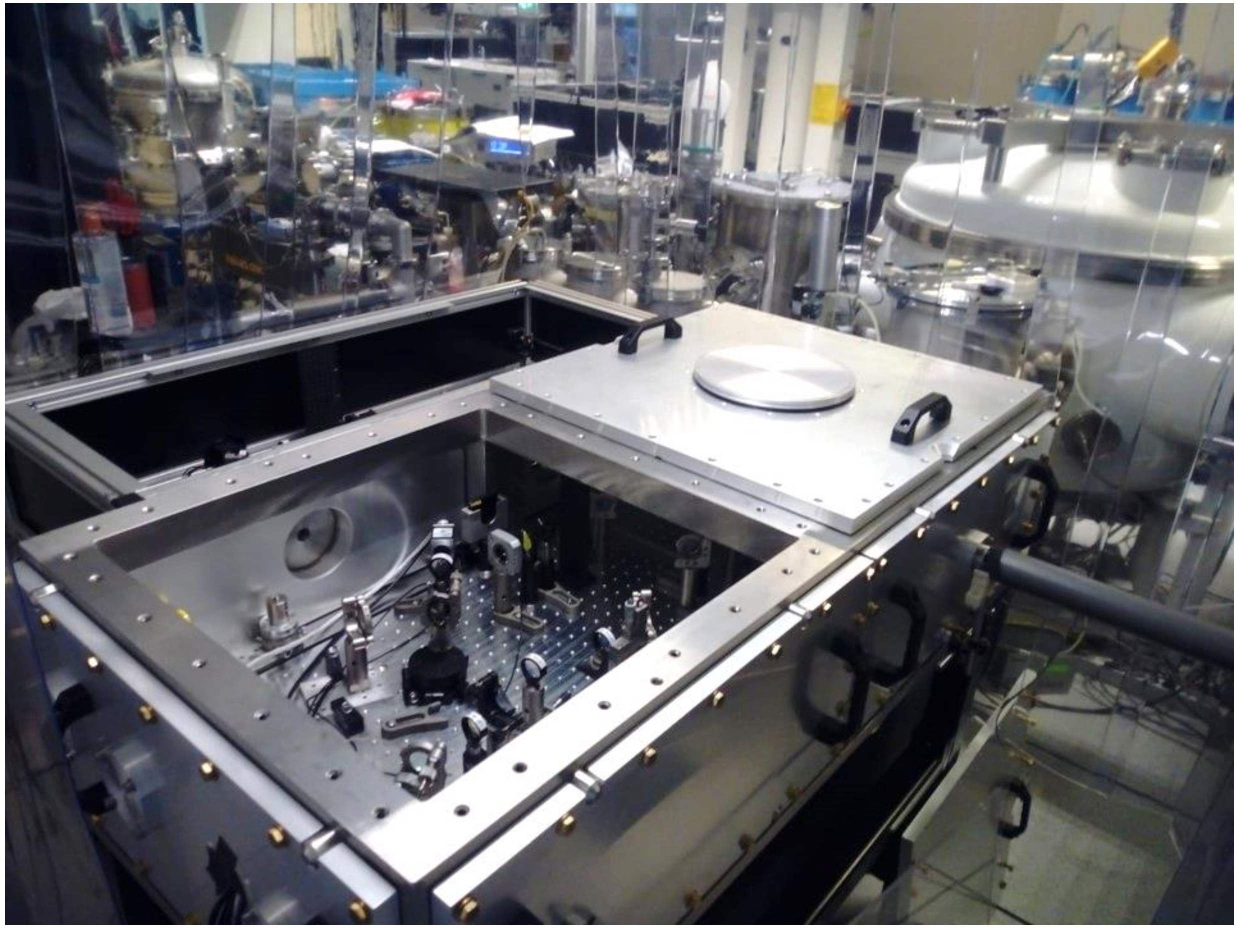
2. Kerr effect in air

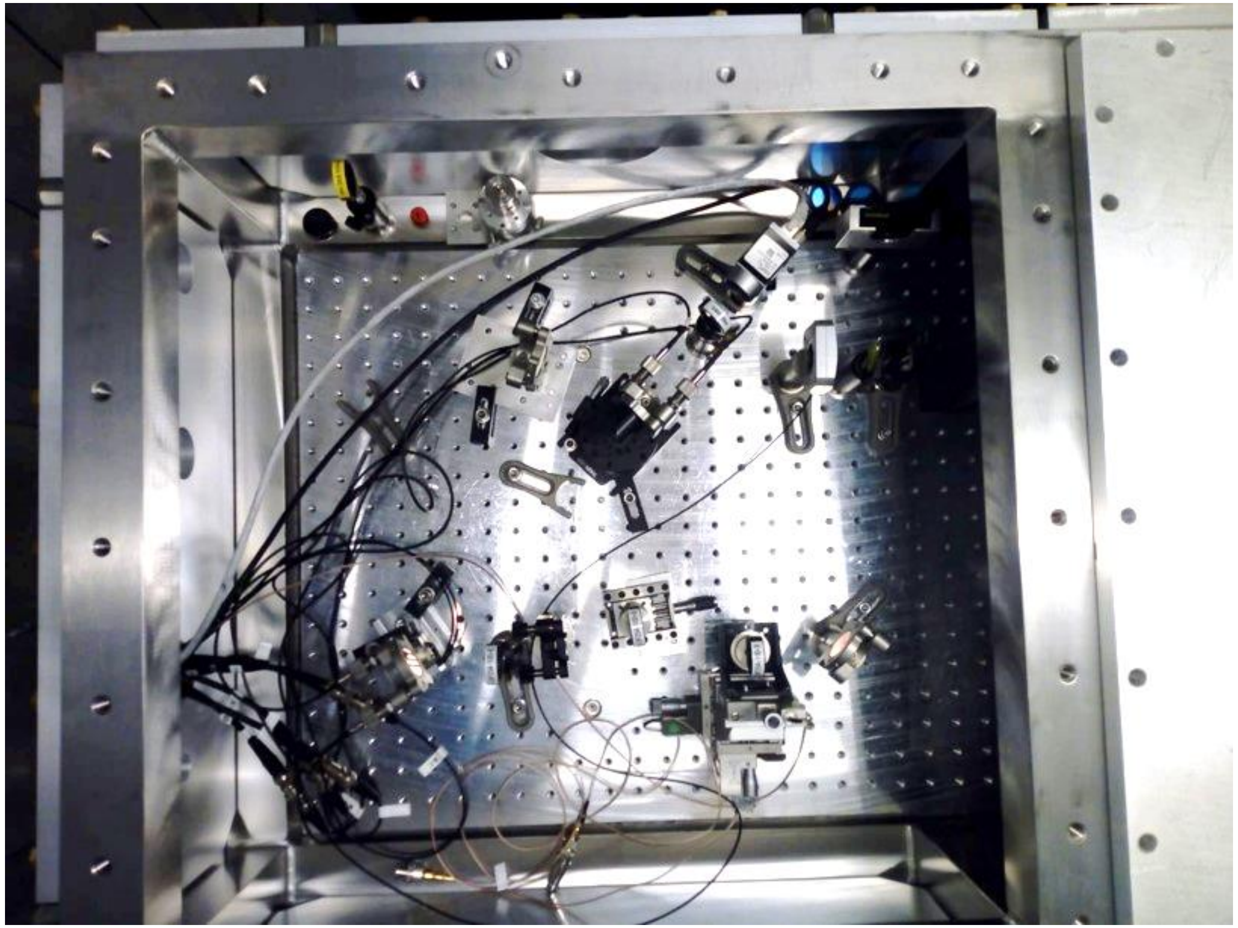
- **Kerr effect in medium** : $n = n_0 + n_2 \times I$
- QED induces **nonlinear index** $n2$ of vacuum: $n_2 \sim 10^{-33} cm^2/W$
- Kerr index of **silica**: $n_2 \sim 10^{-16} cm^2/W$
- Kerr index of **air**: $n_2 \sim 10^{-19} cm^2/W$





Current experimental setup





Summary

- Objective : Kerr effect measurement in vacuum using intense laser fields
  - Sagnac interferometer: intense pump pulse ($I \sim 10^{20}\ W/cm^2$) + low probe pulse

- 1st year of PhD:
  - Prototype in **silica** and experimental method validation (Kerr effect in silica at low intensity $I \sim 10^8 - 10^9\ W/cm^2$)
  - Data analysis
  - Other studies (extinction study, intensity profile analysis, beam stabilization, etc)

- 2nd year of PhD:
  - Prototype in **air** and experimental method validation (Kerr effect in air at low intensity $I \sim 10^{10}\ W/cm^2$)
  - Ongoing improvement of beam stabilization
  - Installation in vacuum chamber

- 3rd year of PhD:
  - First measurements in vacuum
  - Publication of Kerr effect results in air

Thanks for listening ☺