Longitudinal beam profile diagnostics using coherent Cherenkov diffraction radiation at CLARA accelerator

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Coherent Cherenkov Radiation (CCR):

- Allow noninvasive diagnostic
- Relatively high intensity
- Highly directional
- New technique

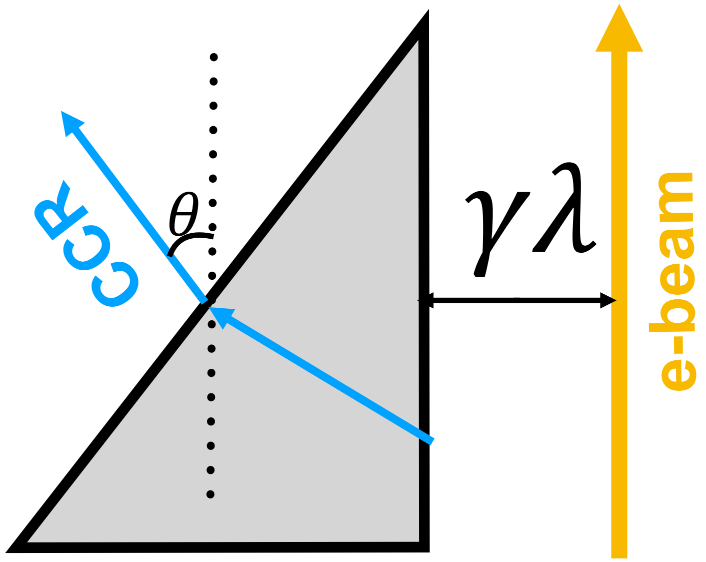


Fig.1 Schematic of CCR generation

Coherent Transition Radiation (CCR):

- Well studied

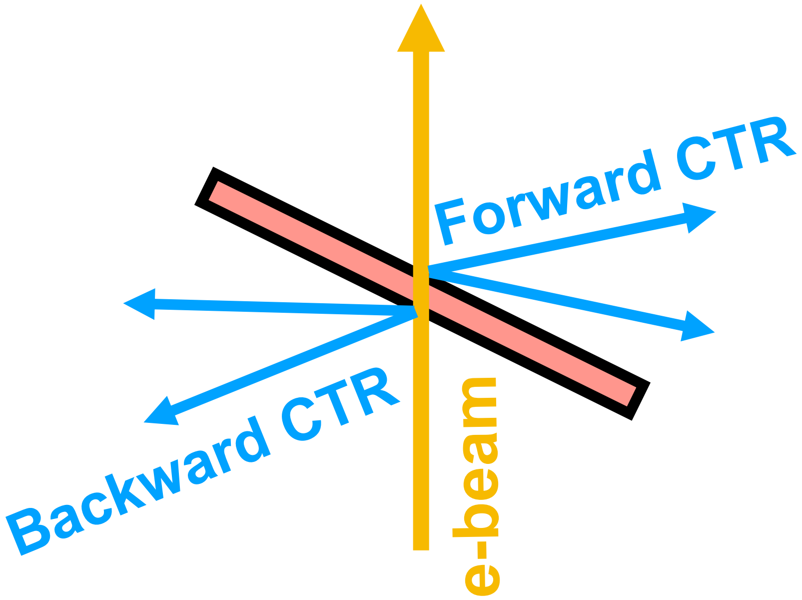


Fig.2 Schematic of CTR generation

How does CCR and CTR diagnostic work?

- The coherent spectral energy density produced by a bunch of N electrons is the product of the spectral energy density from by a single electron, the number of electrons squared and the absolute square of the form factor:

$$[\frac{d^2U}{dwd\Omega}]_{coh} = N^2[\frac{d^2U}{dwd\Omega}]_{single}|\sum_{j=1}^{N} exp(iwc^{-1}z_j)|^2 = [\frac{d^2U}{dwd\Omega}]_{single}\sum_{j=1}^{N} exp(iwc^{-1}z_j)\sum_{i=1}^{N} exp(-iwc^{-1}z_i) =$$

$$= [\frac{d^2U}{dwd\Omega}]_{single}(N + \sum_{j=1}^{N} exp(iwc^{-1}z_j)\sum_{\substack{j=1\\ j=i}}^{N} exp(-iwc^{-1}z_i)) = [\frac{d^2U}{dwd\Omega}]_{single}](N + N(N-1)|\int \rho(z)exp(iwc^{-1}z)|$$

$$[\frac{d^2U}{dwd\Omega}]_{coh} = N^2[\frac{d^2U}{dwd\Omega}]_{single}|F(w)|^2 \qquad [\frac{d^2U}{dwd\Omega}]_{coh} = N^2[\frac{d^2U}{dwd\Omega}]_{single}[\int p(z)\cos(z\frac{w}{c})dz]^2$$

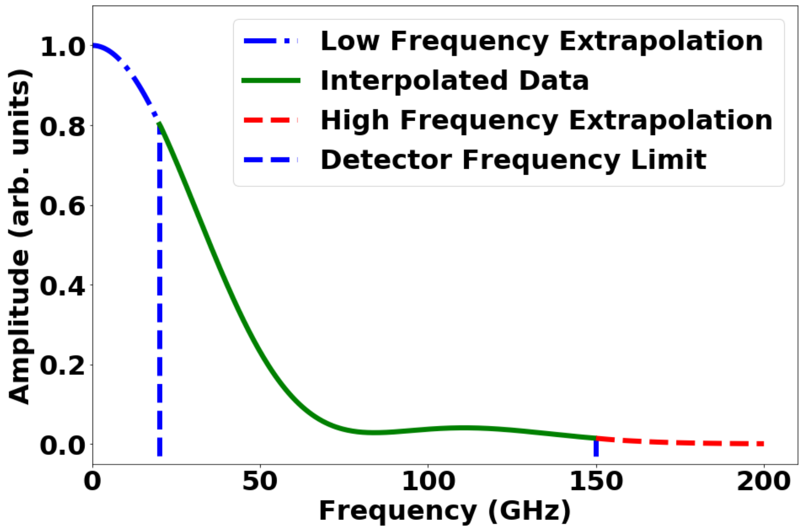
experimental data

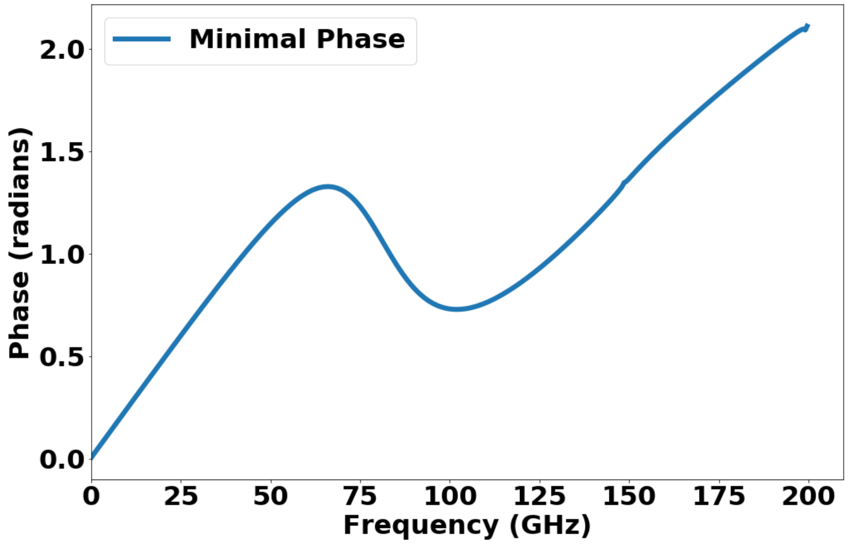
$$p(z) = \frac{1}{\pi c}\int_0^\infty \sqrt{\frac{[\frac{d^2U}{dwd\Omega}]_{coh}}{[\frac{d^2U}{dwd\Omega}]_{single}}}\cos(\psi(w) - z\frac{w}{c})dw$$

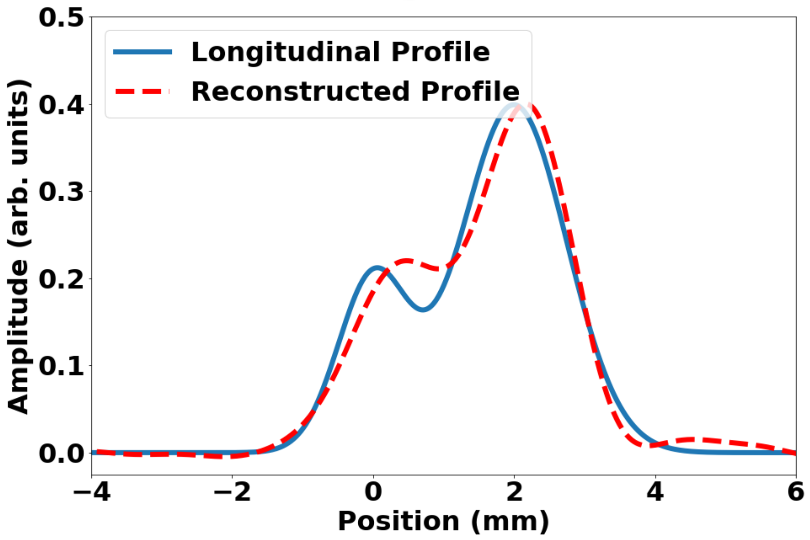
mathematical approach

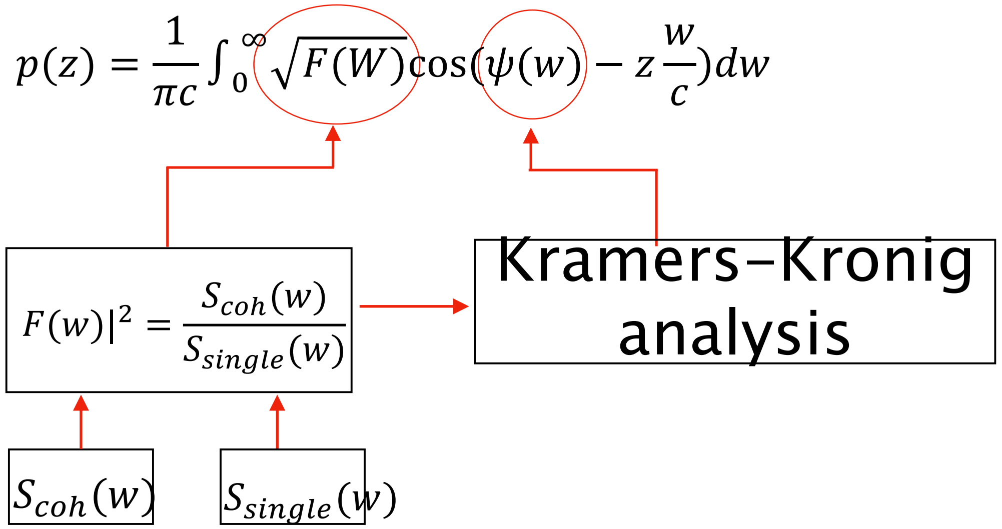
How diagnostic is works?

$$\sqrt{\frac{[\frac{d^2U}{dwd\Omega}]_{coh}}{[\frac{d^2U}{dwd\Omega}]_{single}}}$$









$$p(z)=\frac{1}{\pi c}\int_0^\infty \sqrt{F(W)}\cos(\psi(w)-z\frac{w}{c})dw$$

$$F(w)|^2=\frac{S_{coh}(w)}{S_{single}(w)}$$

Kramers−Kronig analysis

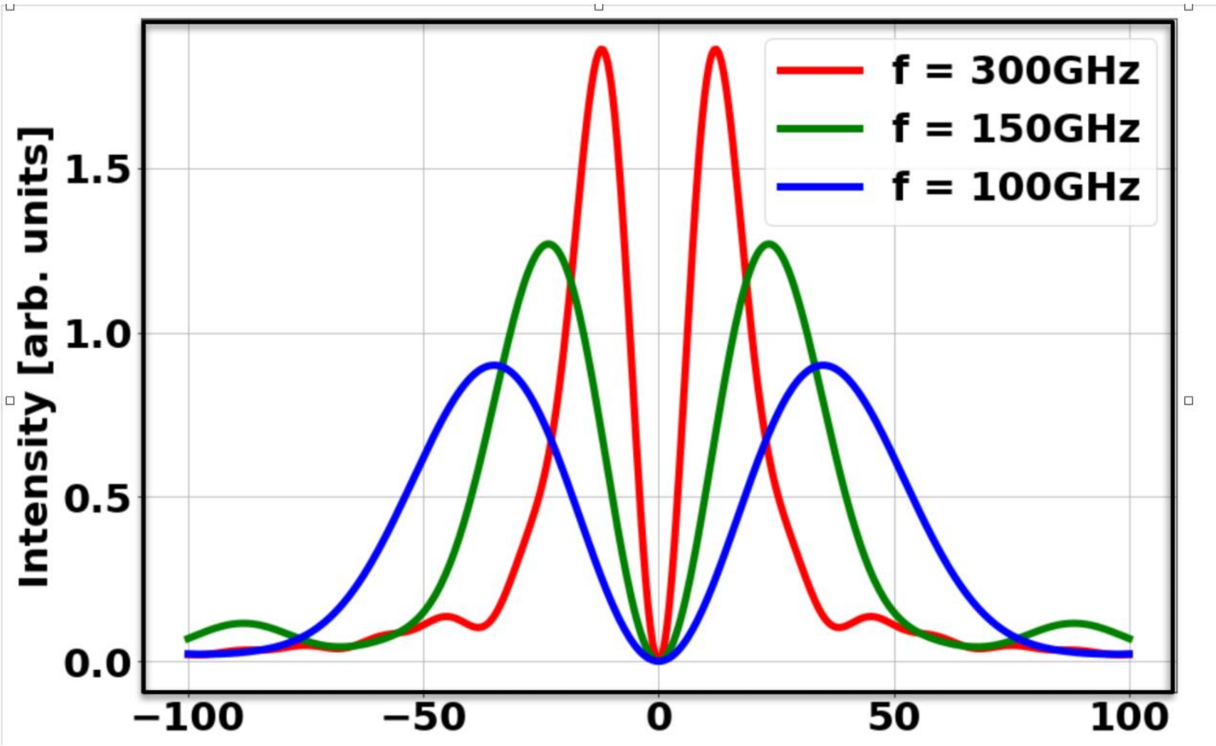
$S_{coh}(w)$

$S_{single}(w)$

Transition radiation spectrum from a single electron

Models takes into account the following parameters:

- Energy
- TR target size
- Distance between target and detector
- Detector aperture



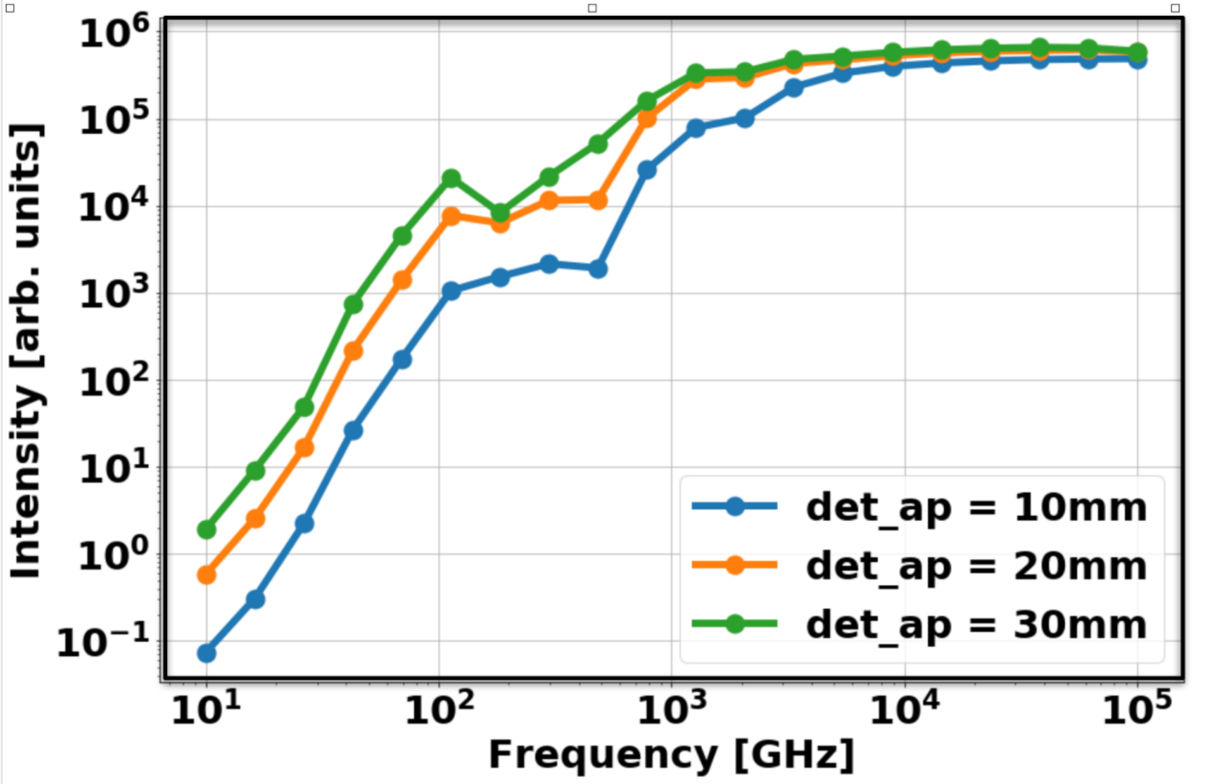


Fig.3 TR Spectral angular distribution from a single electron

Fig.4 TR Spectrum for different detector apertures

Karataev Physics Letters A, Volume 345, Issue 4-6, p. 428-438., Jul 2005

Cherenkov radiation spectrum from a single electron

Models takes into account the following parameters:

- Energy
- Cherenkov target dimensions (prismatic target)
- Cherenkov target refractive index
- Distance between target and detector
- Detector aperture
- Impact parameter (distance between beam and target)
- Angle between target and particle direction

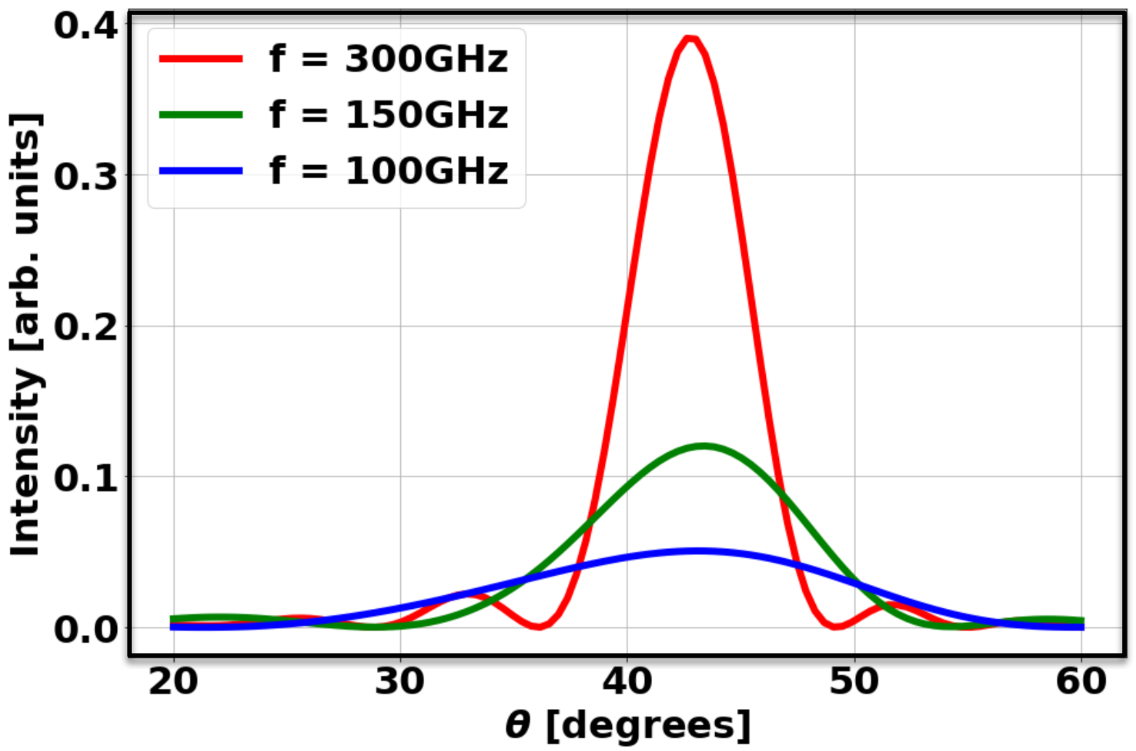


Fig. 5 VCR Spectral angular distribution from a single electron

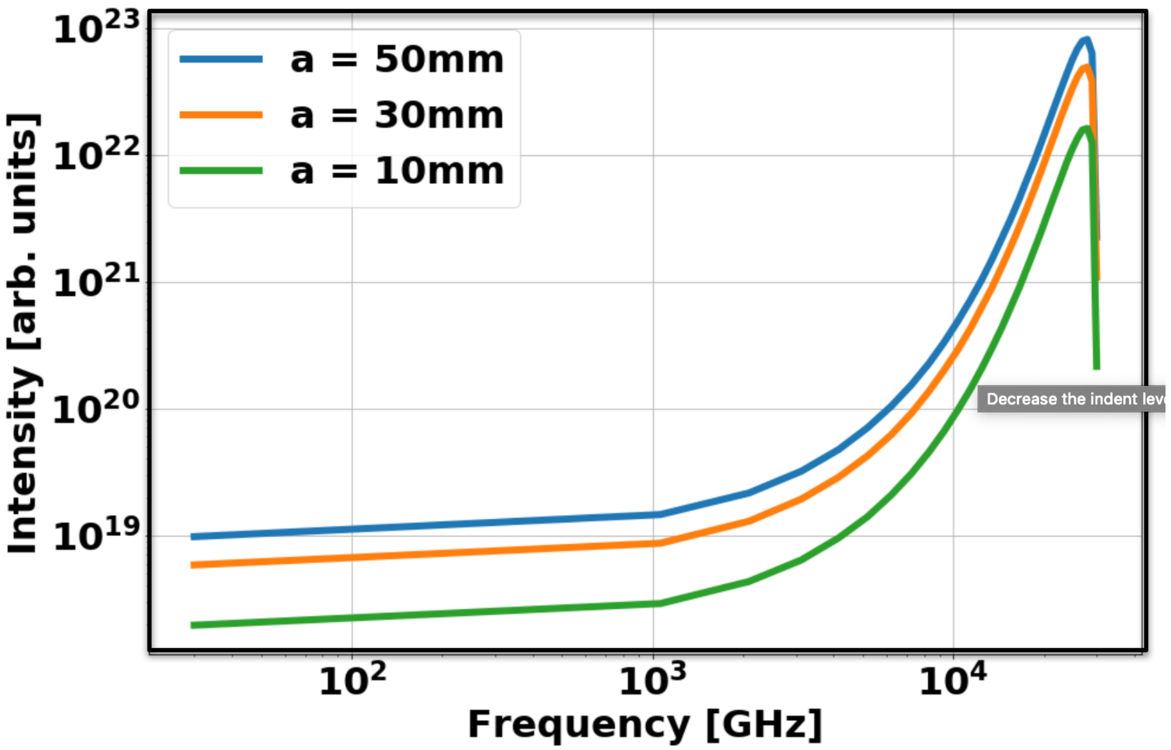
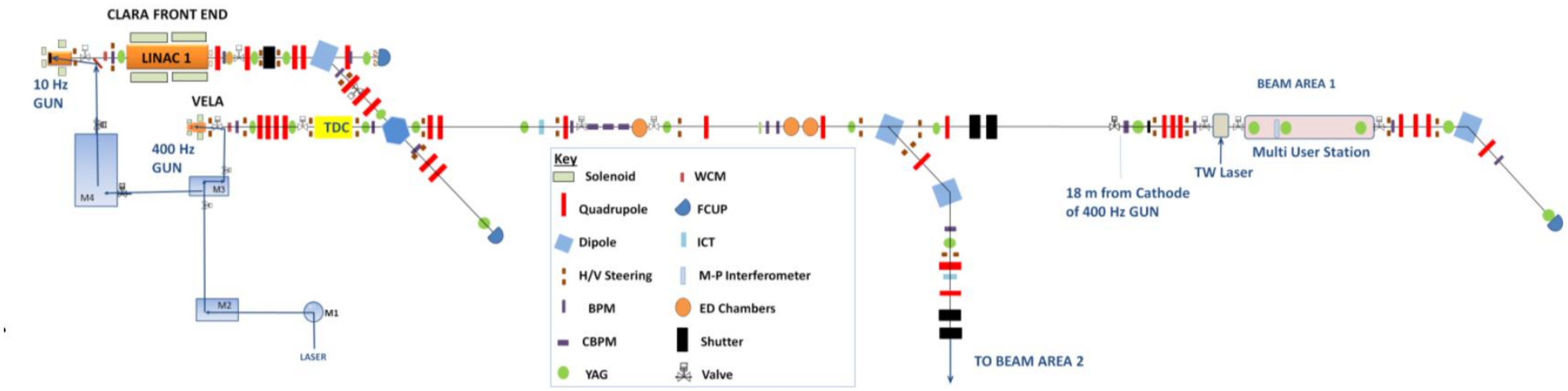
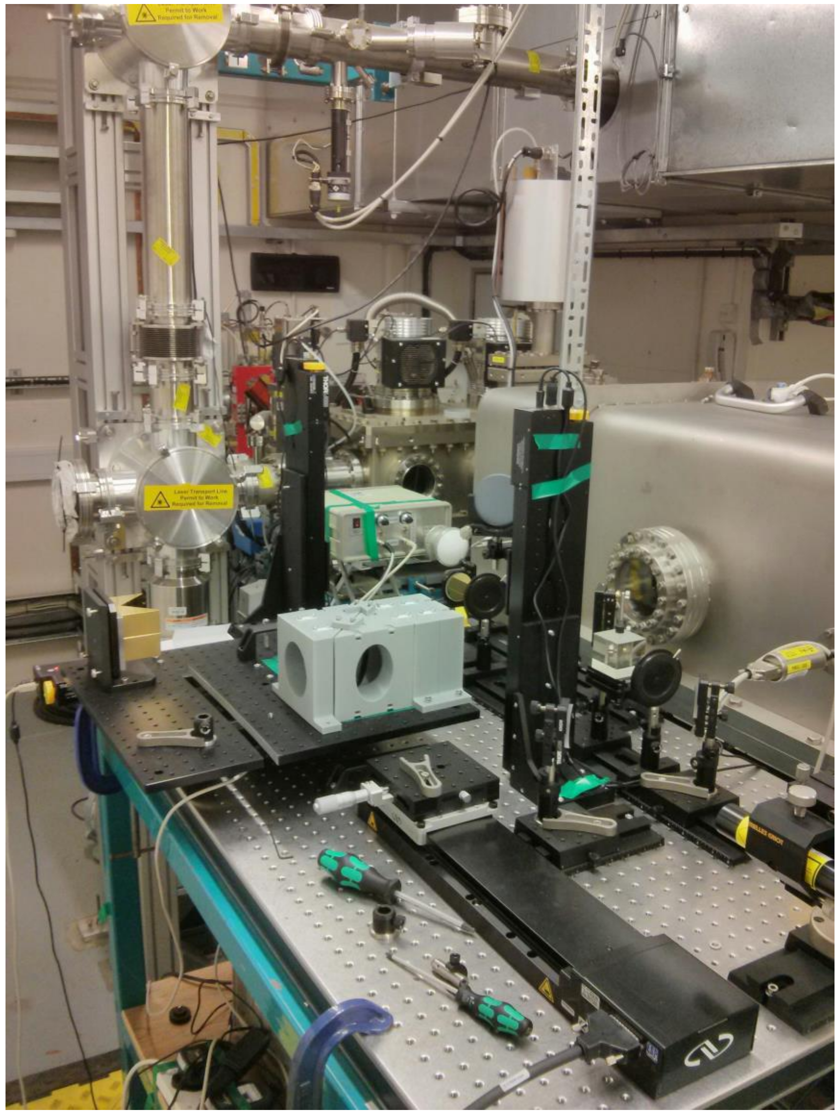


Fig. 5 VCR Spectrum for different detector apertures

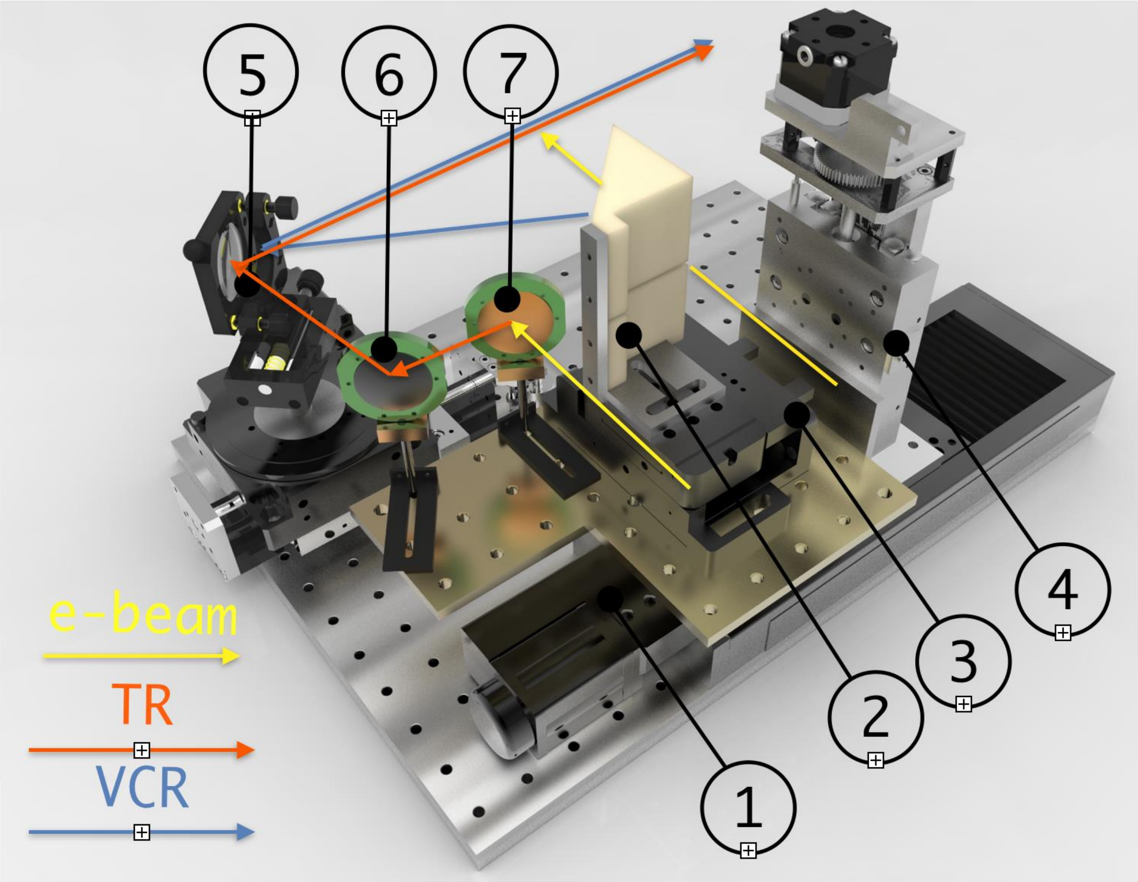
M.V. Shevelev and A.S. Konkov, J. Exp. Theor. Phys. (2014) 118: 501.

Experimental work at CLARA

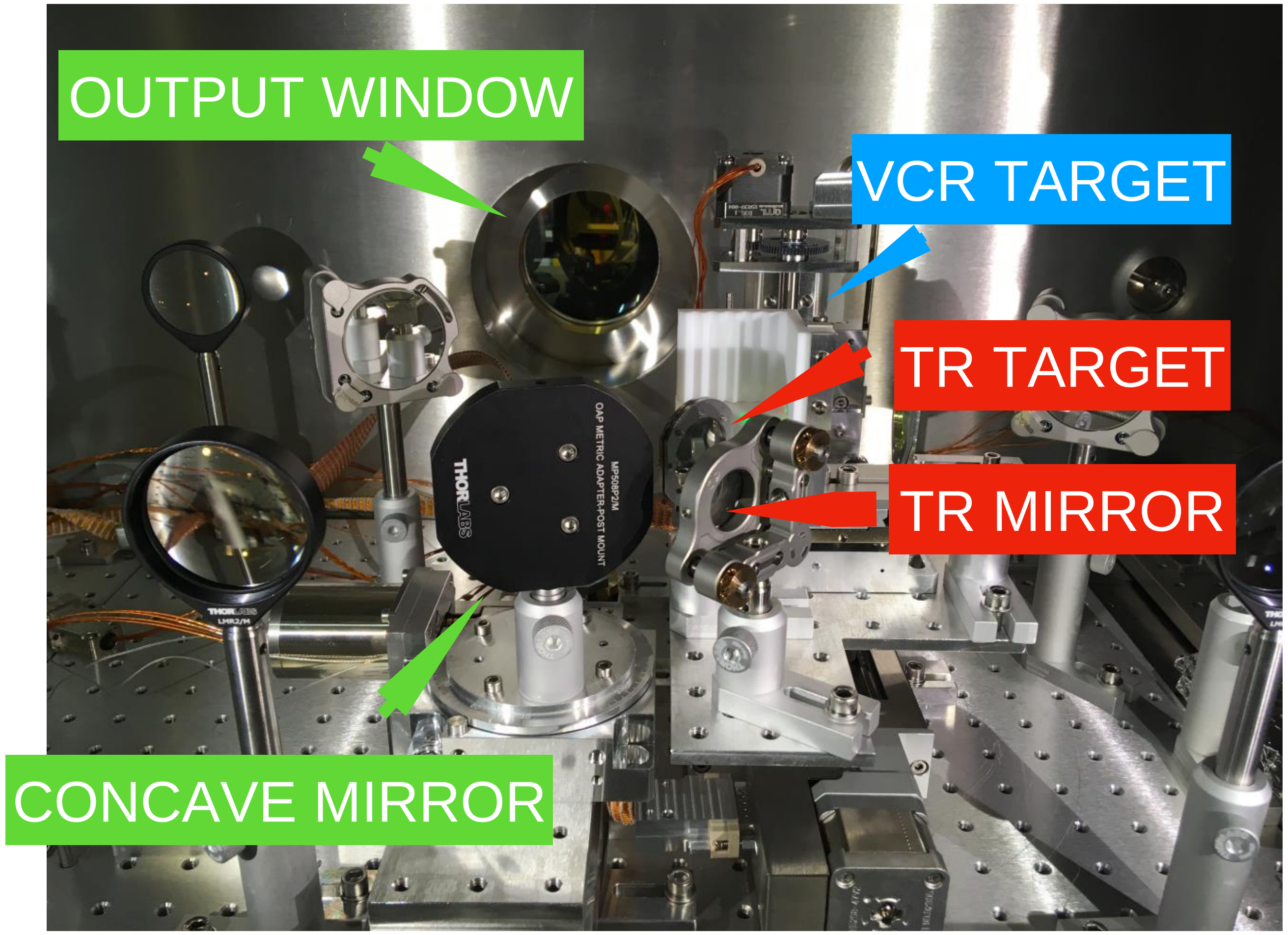




Setup inside of chamber

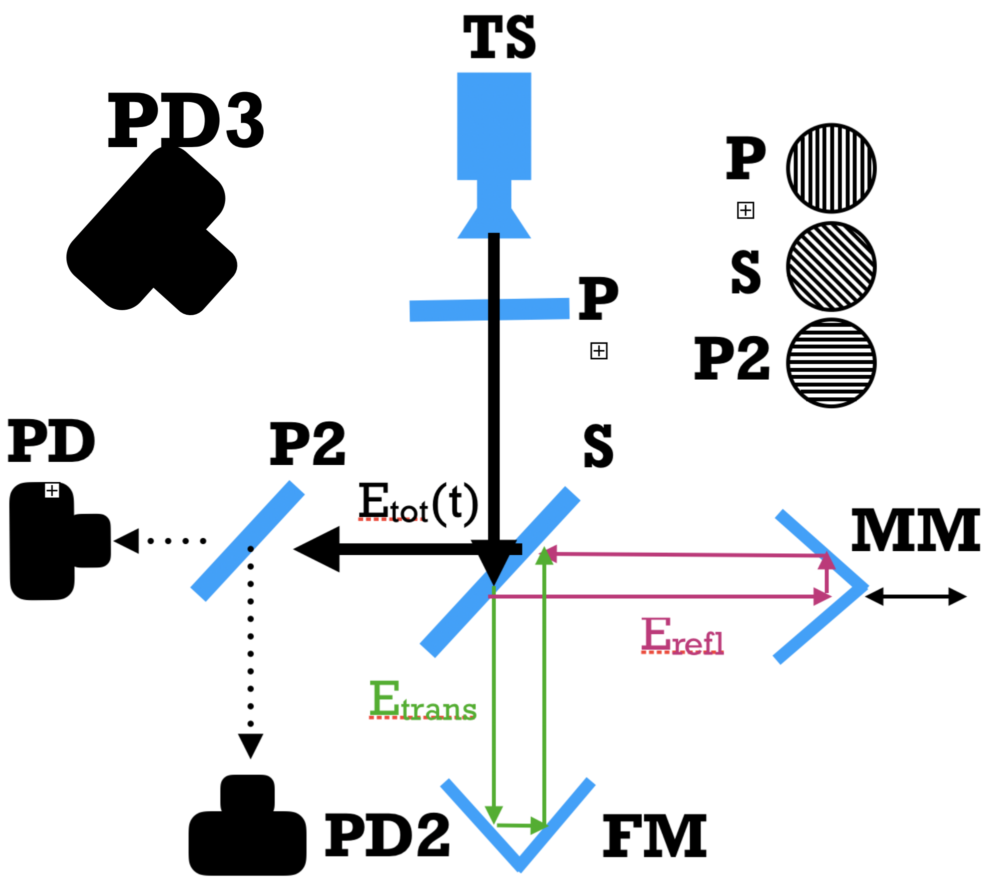


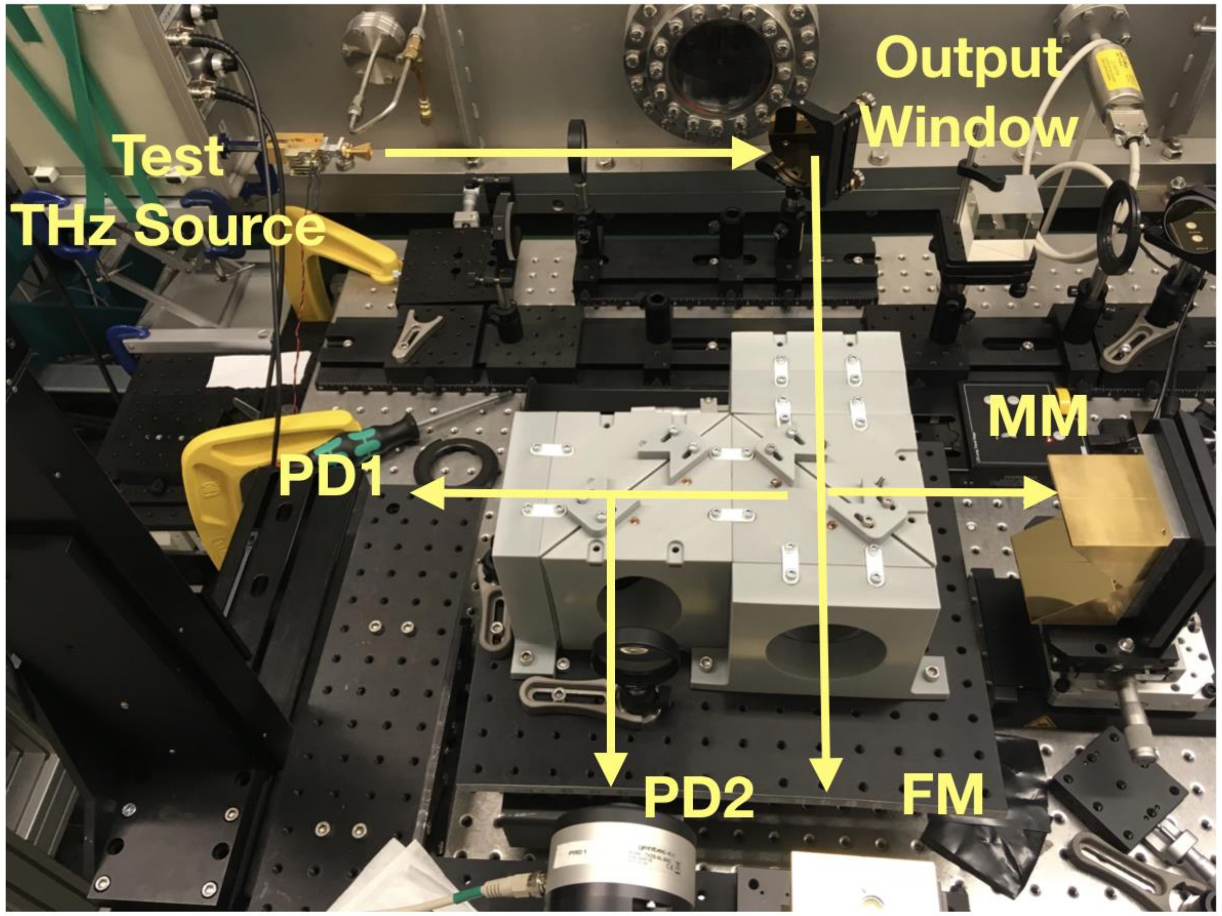
1 — Horizontal positioning stage
2 — Teflon (VCR) target
3 — Tip-Tilt stage
4 — Vertical positioning stage
5 — Concave mirror
6 — mirror
7 — Foil (TR) target



- Setup inside of vacuum chamber allows us to register VCR and TR during single accelerator run.

MPI Interferometer



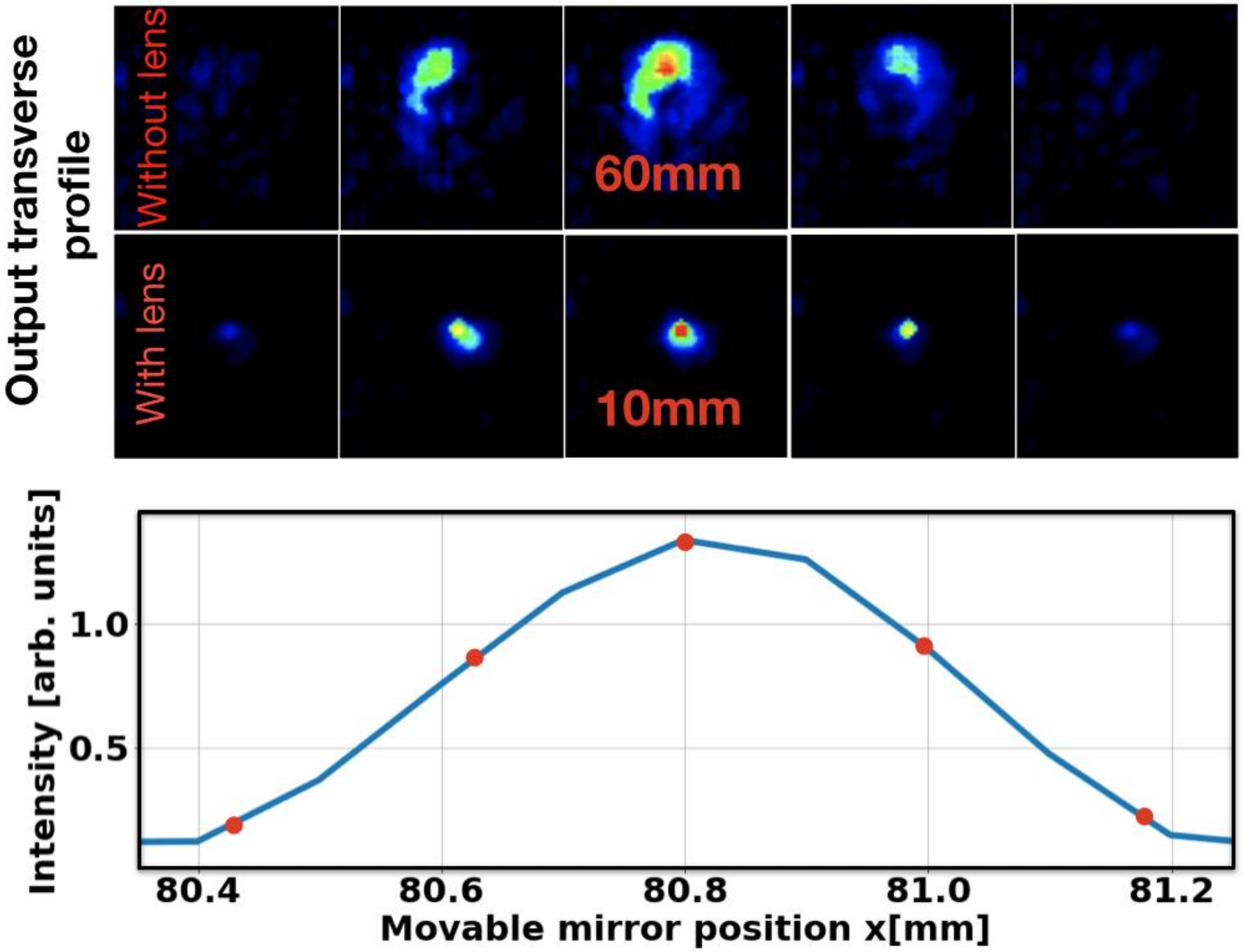


Martin–Pupplet interferometer has a higher signal to noise ration and there is possibility to use two different output and make a noise normalisation:

$$I(x) = \frac{U_h(x) - U_v(x)}{U_h(x) + U_v(x)}$$

MPI precise alignment

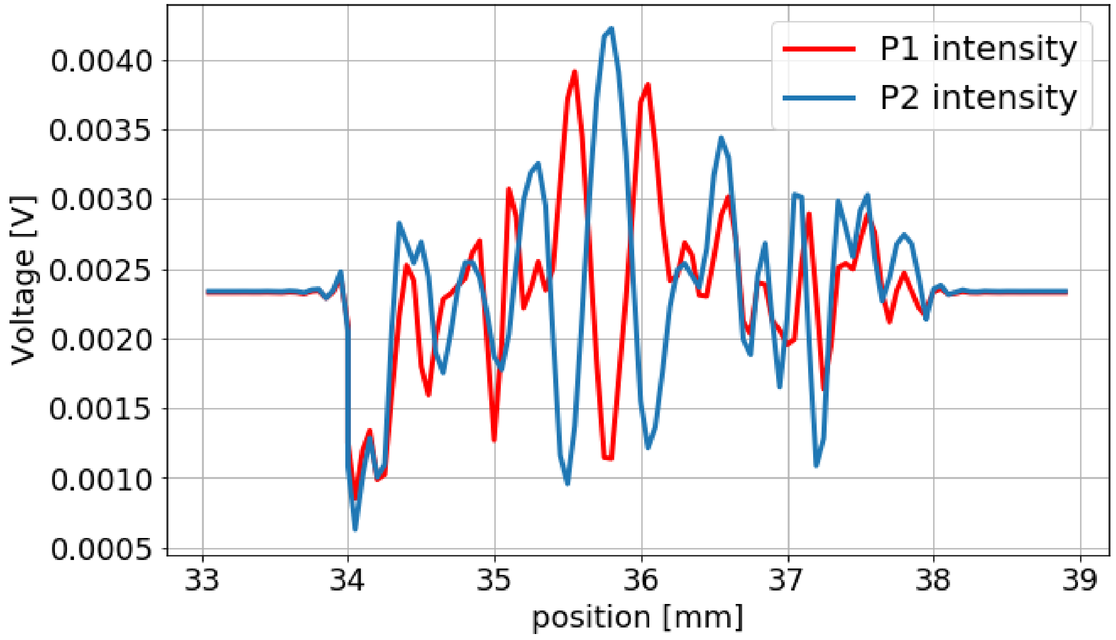
By using THz camera and test THz source we were able to align interferometry system with good precision.

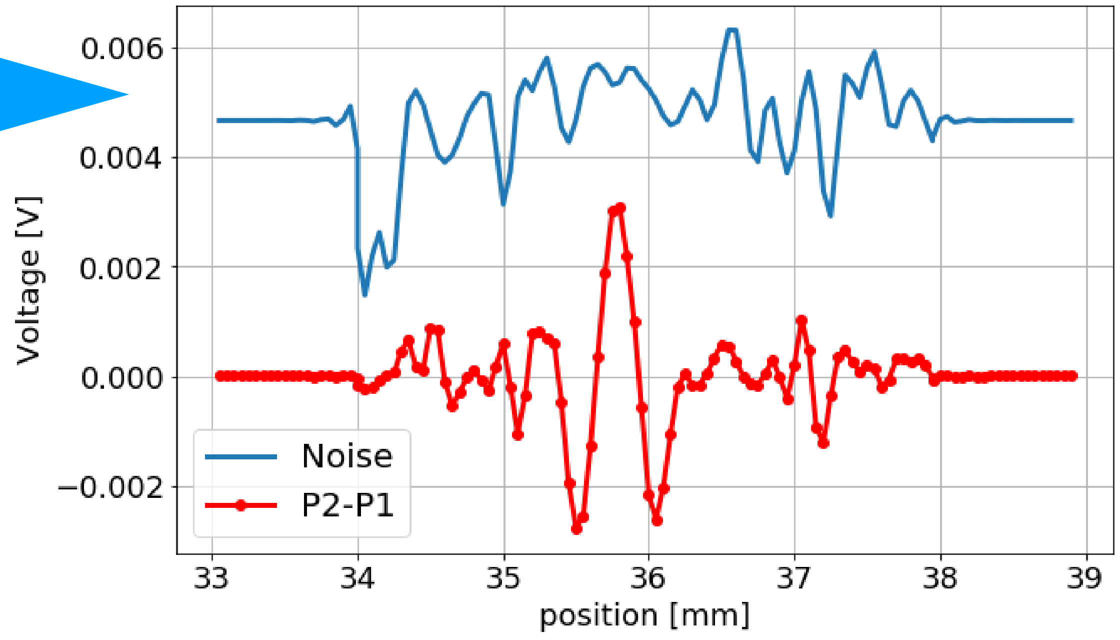


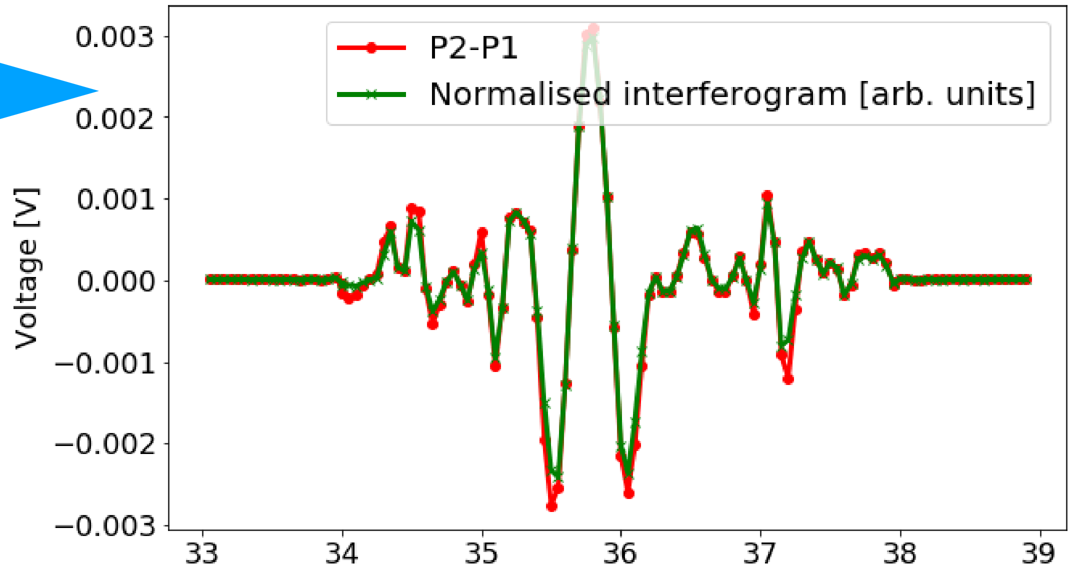
- ·Frequency range: 10 GHz — 1THz;
- ·4096 pixels (64 x 64 array)
- ·1.5mm pixel pitch
- ·Framerate, exposure and accumulation control
- ·NEP=1nW/sqrt(Hz)

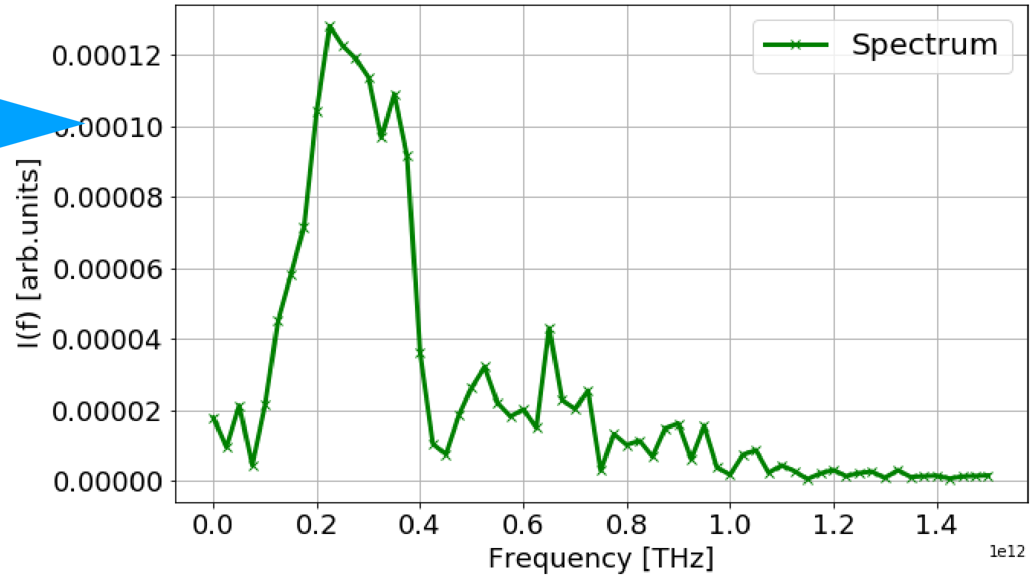
Experimental results:

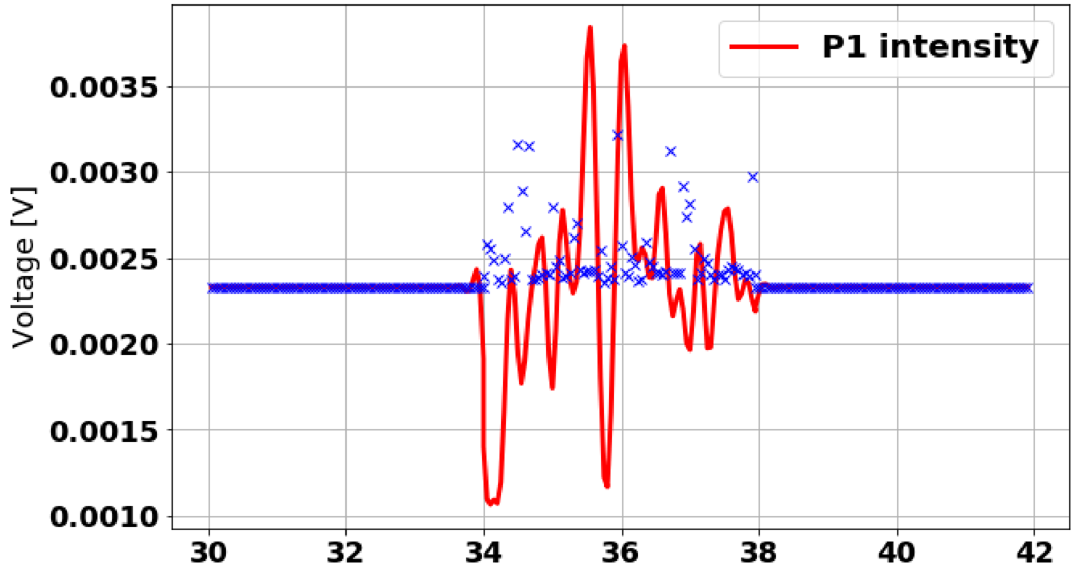
CCR, h=2mm, 80-70pC, 200 microns RMS transversal bunch size, E=40MeV





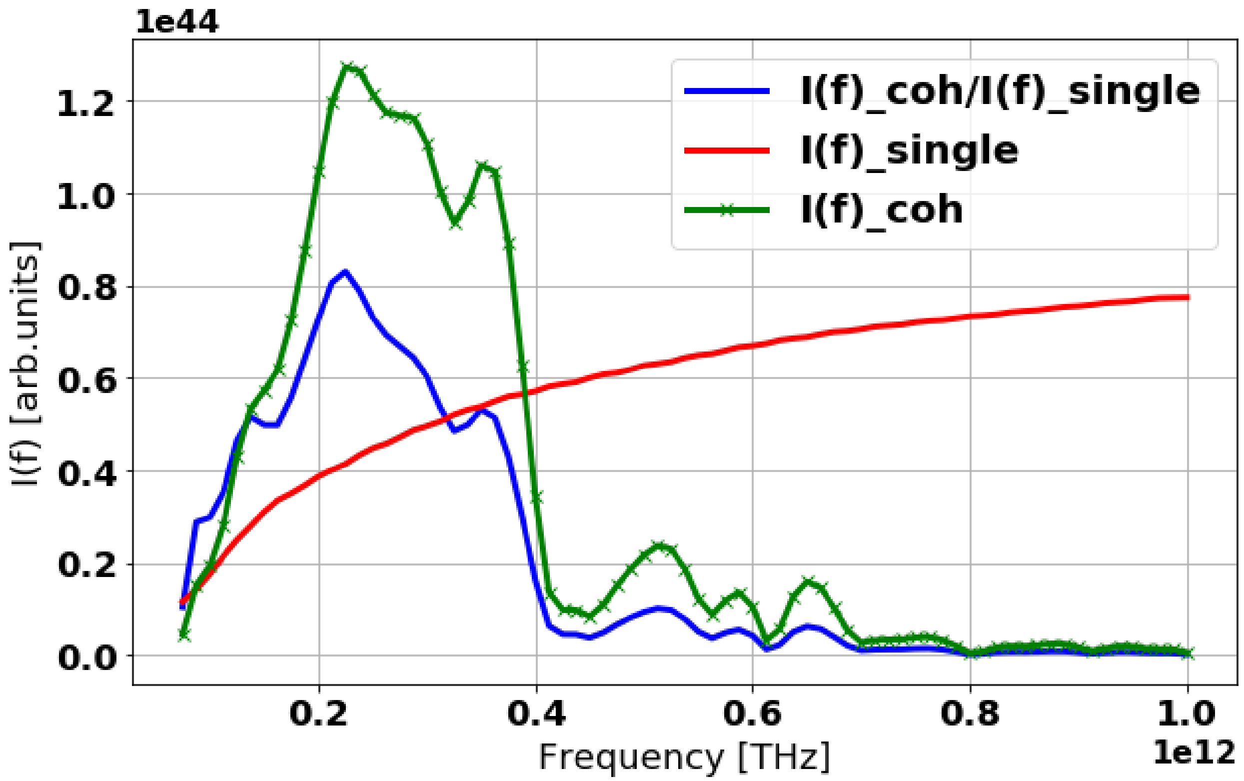


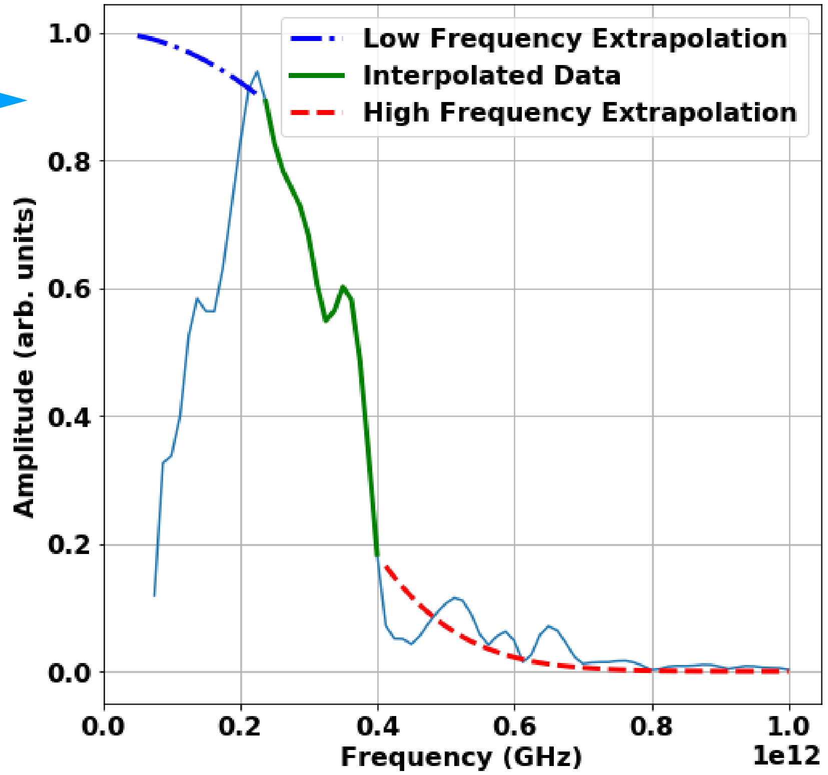


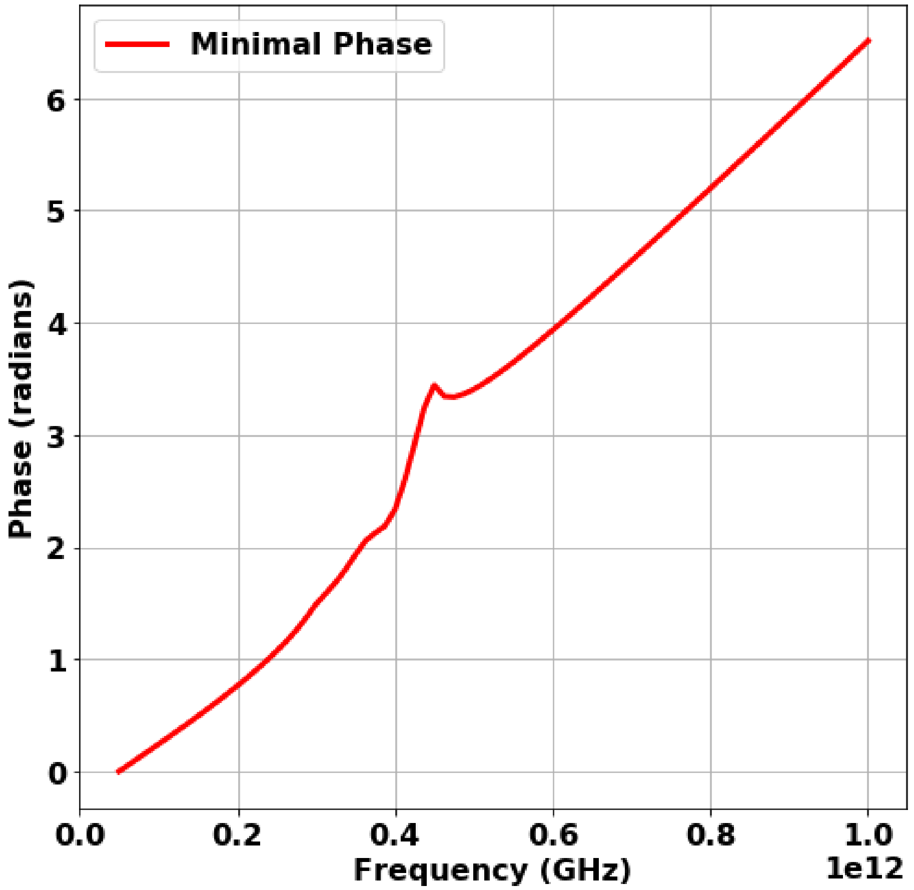


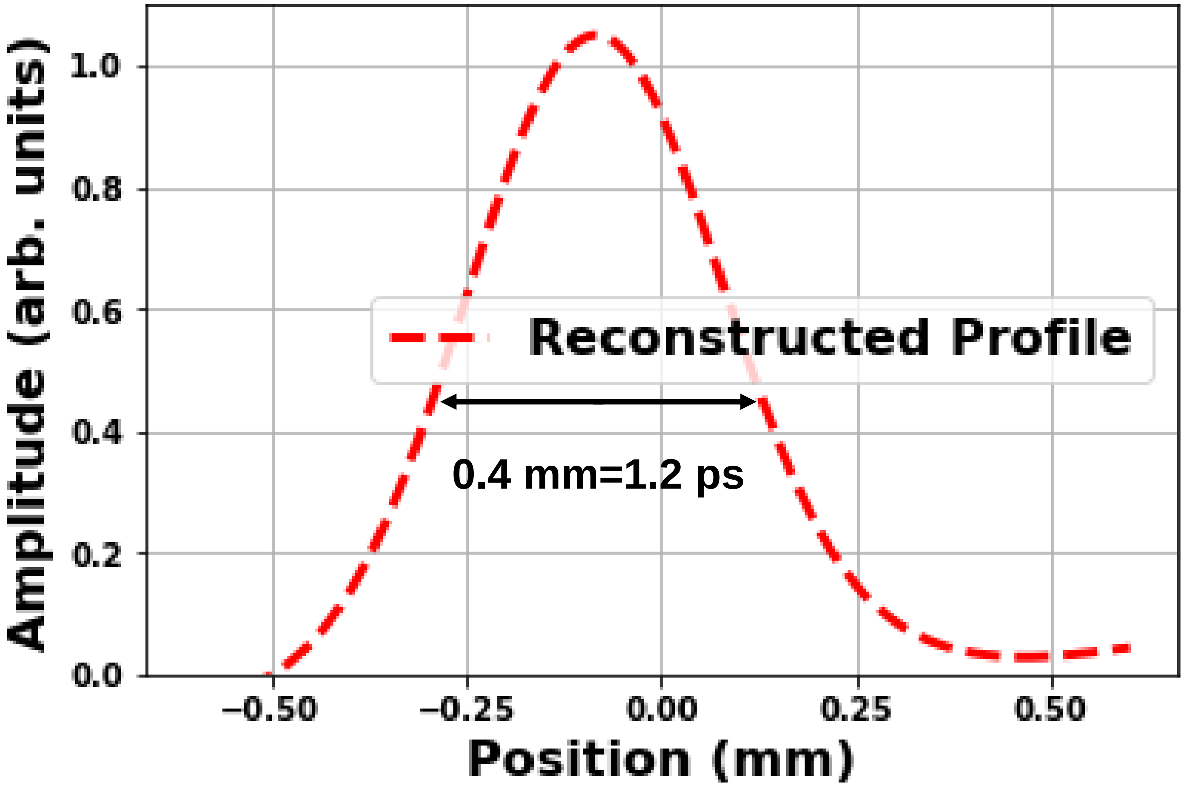
- **Error bar**
- **Appodization**
- **Filtering**

Experimental results

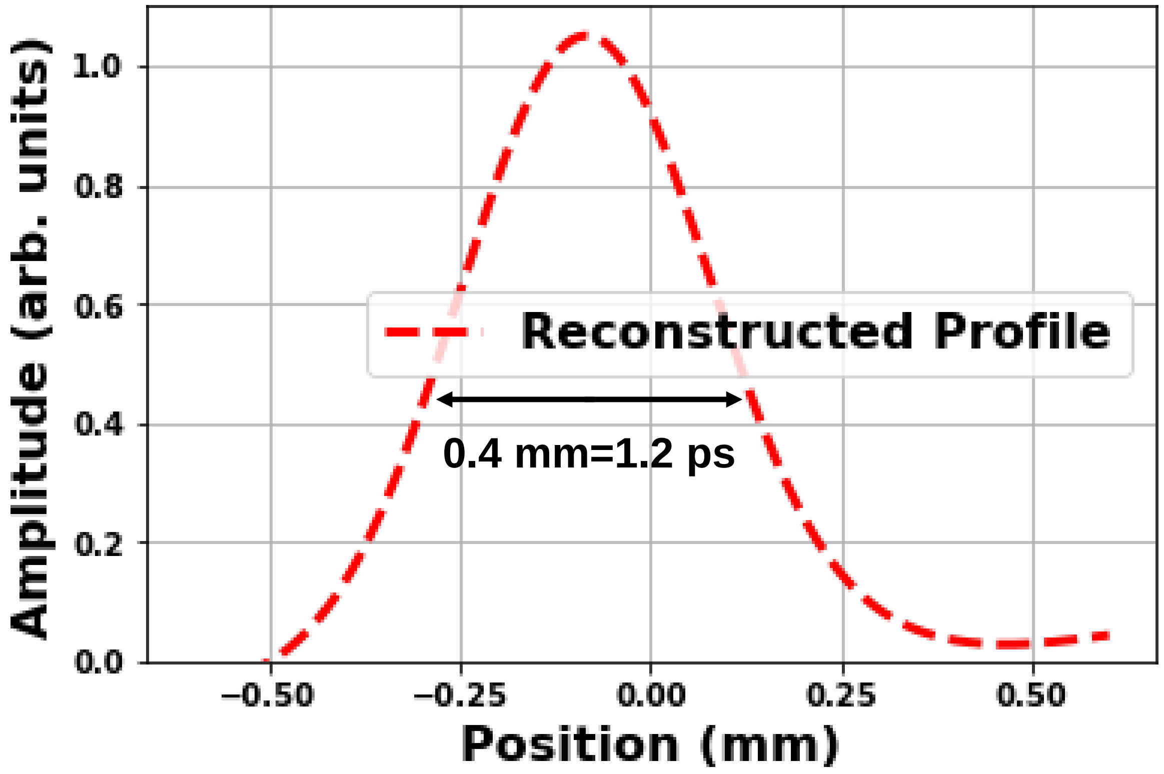




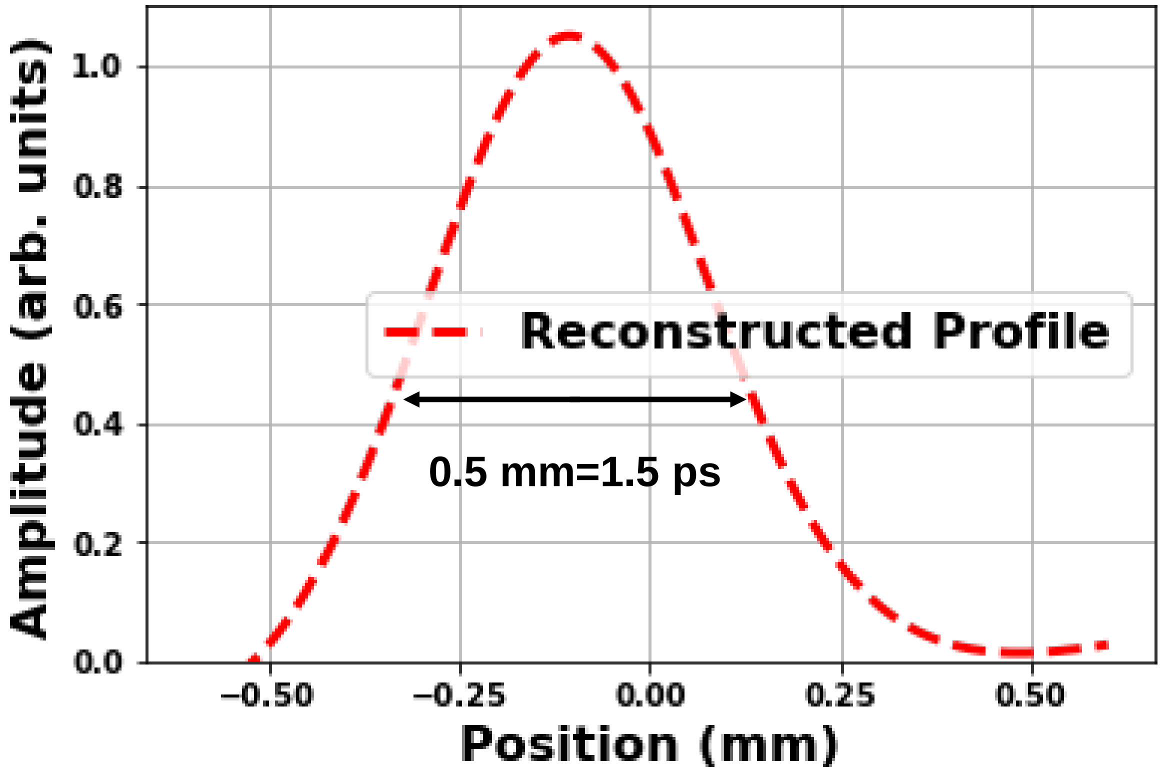




Experimental results. Two different klystron phase



-6deg



-11deg

Conclusion

- **Set of data for CTR for different klystron phases**
- **Set of data for CCR for different klystron phases**
- **CCR vs impact parameter (distance between target and beam)**
- **CCR vs target-beam angle**

- **Improve optical alignment**
- **Optics for lower frequencies**
- **Quasi-optical detector (with higher sensitivity)**

Thank you for your attention!