EAAC Workshop
La Biodola, Isola d'Elba
04/06/13

First single-shot and non-intercepting longitudinal bunch diagnostics for comb-like beams by Electro-Optic Sampling

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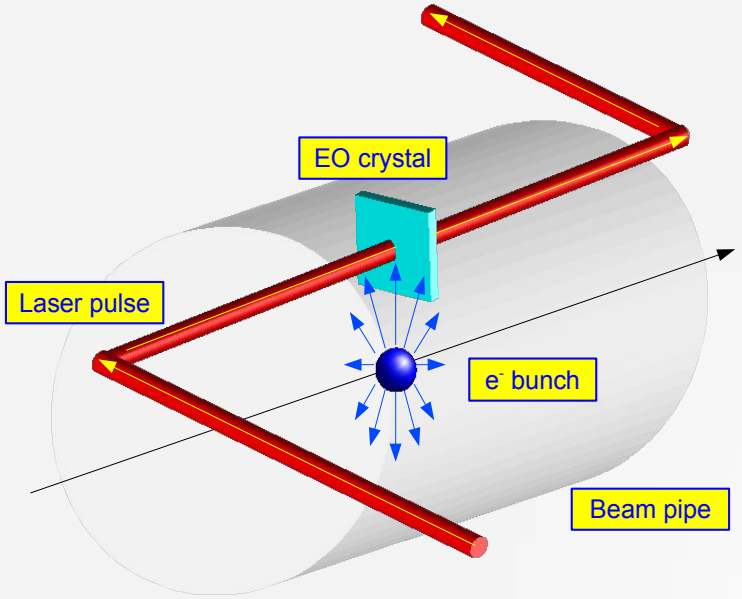
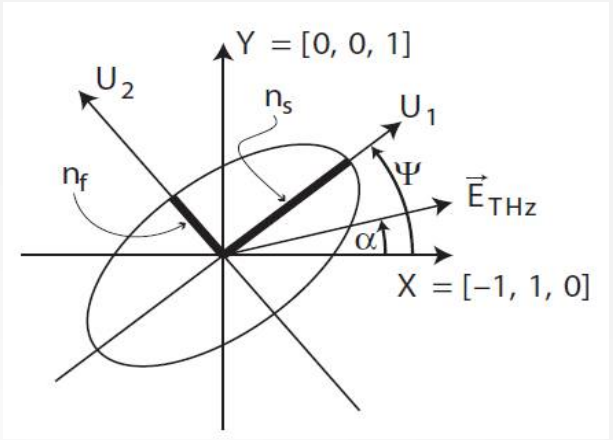
Electro-Optical Sampling

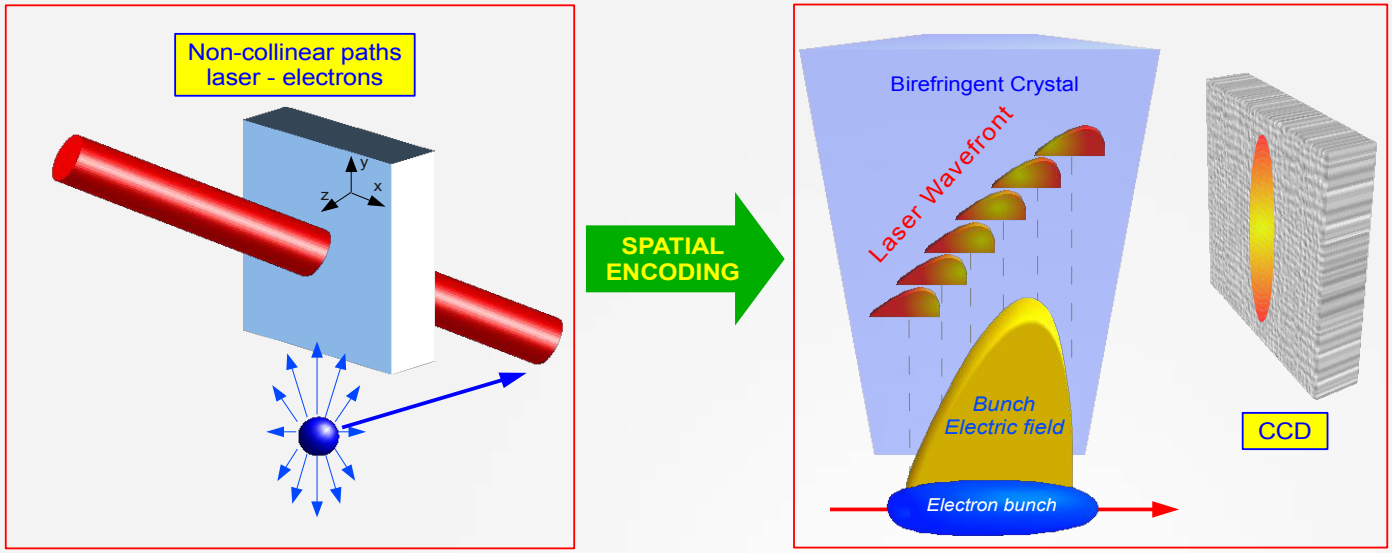




$$\Gamma(\alpha) = \frac{\omega d}{c}(n_1 - n_2) = \frac{\omega d}{2c} n_0^3 r_4 E_{THz} \sqrt{1 + 3\cos^2\alpha}$$

- **PWFA**: need to correlate **incoming** and **outgoing** beams from the plasma
  - non-intercepting & single-shot diagnostics for beams to be injected in **plasma**.
- **Electro-Optical Sampling (EOS)** to measure bunch longitudinal profile using nonlinear crystals (ZnTe, GaP)
- Benefits: **single shot, non-intercepting**, time resolution (~50 fs). Disadvantages: small signals (low SNR), complex layout, costs.

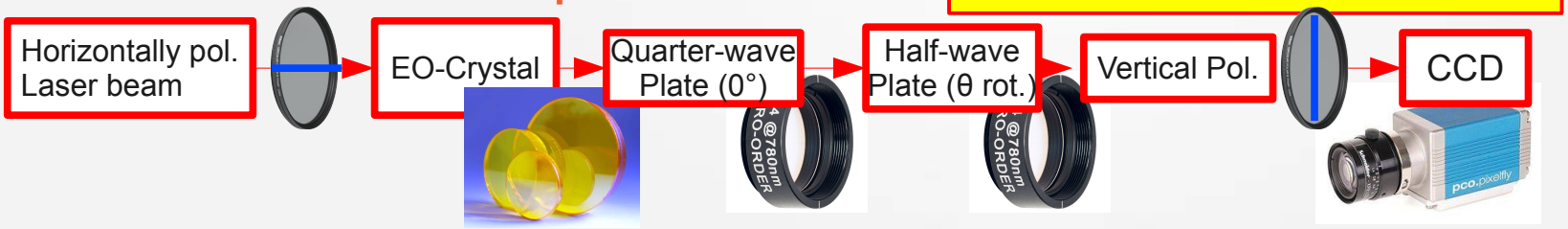
EOS Spatial Encoding Setup



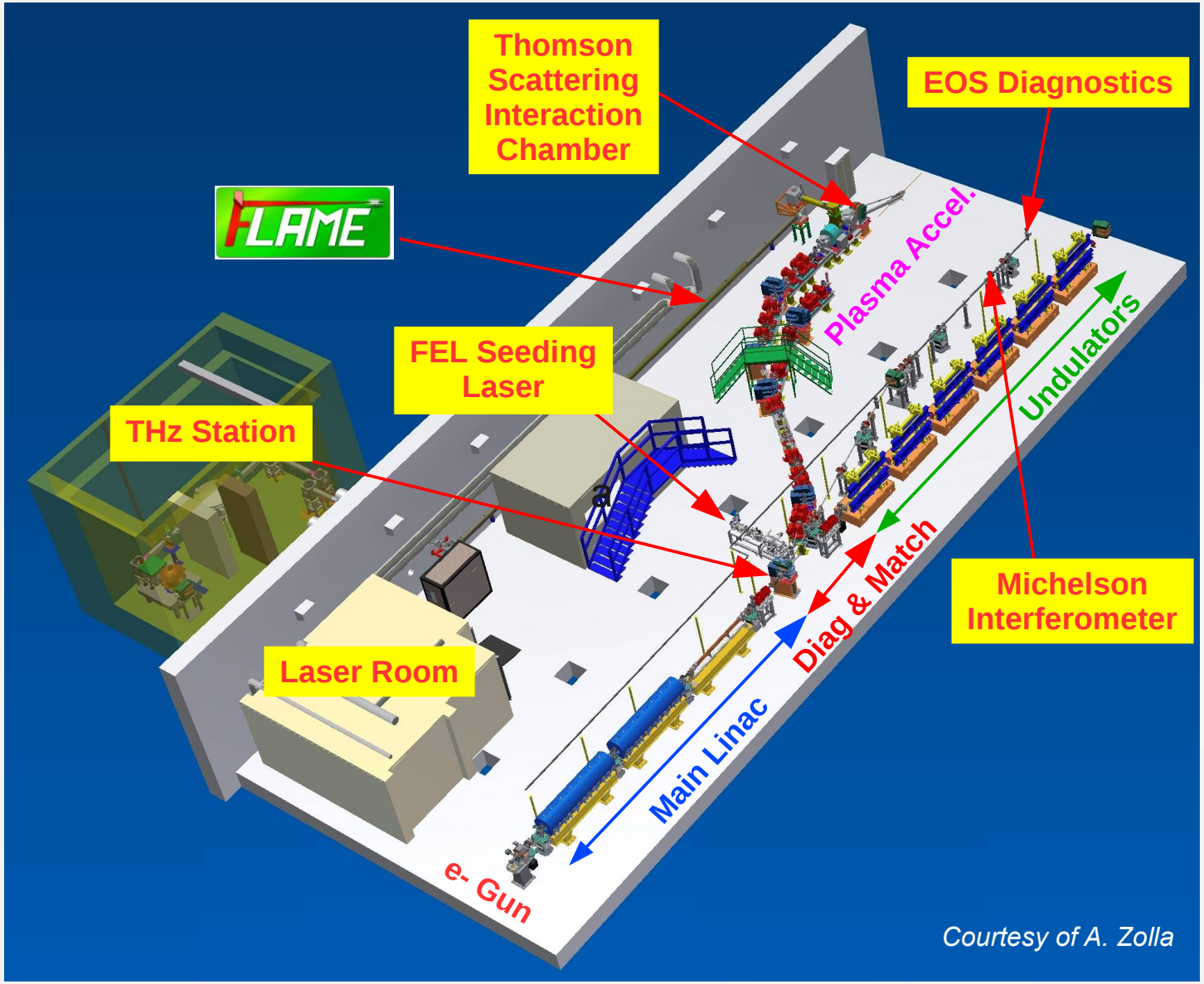
- **Laser crosses the crystal with an incident angle of 30°** → one side of the laser pulse arrives earlier on the EO crystal than the other by a time difference Δt.
- Coulomb field inducing birefringence is encoded in the spatial profile of laser pulse
- Benefits: **simple**, **no high energy laser needed**.
- Drawbacks: **poor surface quality of EO crystals.**

Near Crossed Polarizer Setup

$$I_{det} \sim I_{laser}\, 2\theta\Gamma + 4\theta^2 I_{laser} \sim E_{THz}$$



SPARC_LAB Layout



Laser-electrons synchronization

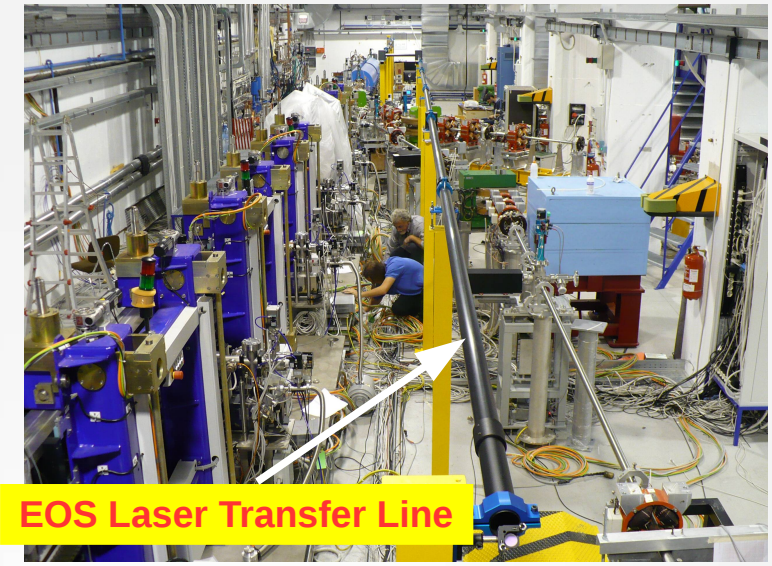
- **EOS uses the SPARC_LAB ptc. laser**
  - 800nm, 60fs (rms, **T.L.**), up to 500μJ pulse energy, 10Hz.
- **Transfer Line of 34m installed**.
- Benefits
  - Simplified EOS layout setup
  - ~~**Independent laser system**~~
  - High energy available
  - **Self-synchronized with e-beam**
    - 1 laser pulse per 1 e- bunch
    - ~~**Intensified Fast Gated CCD**~~

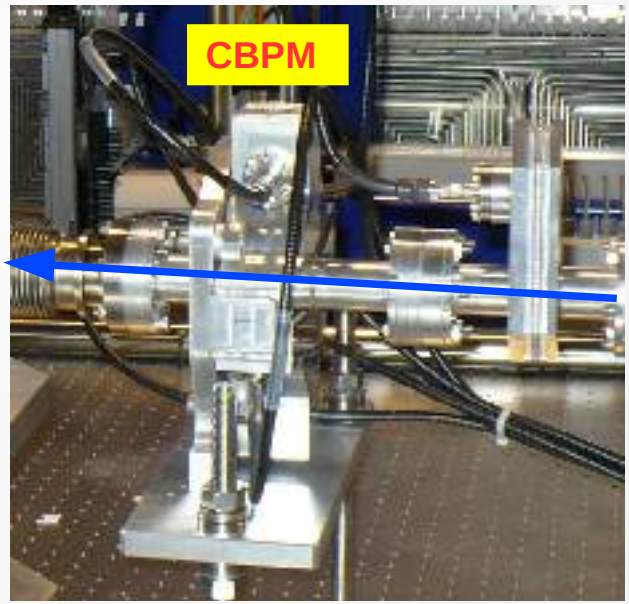
Synchronization laser-electrons

- Laser Time Arrival Monitor: 30ps risetime photodiode.

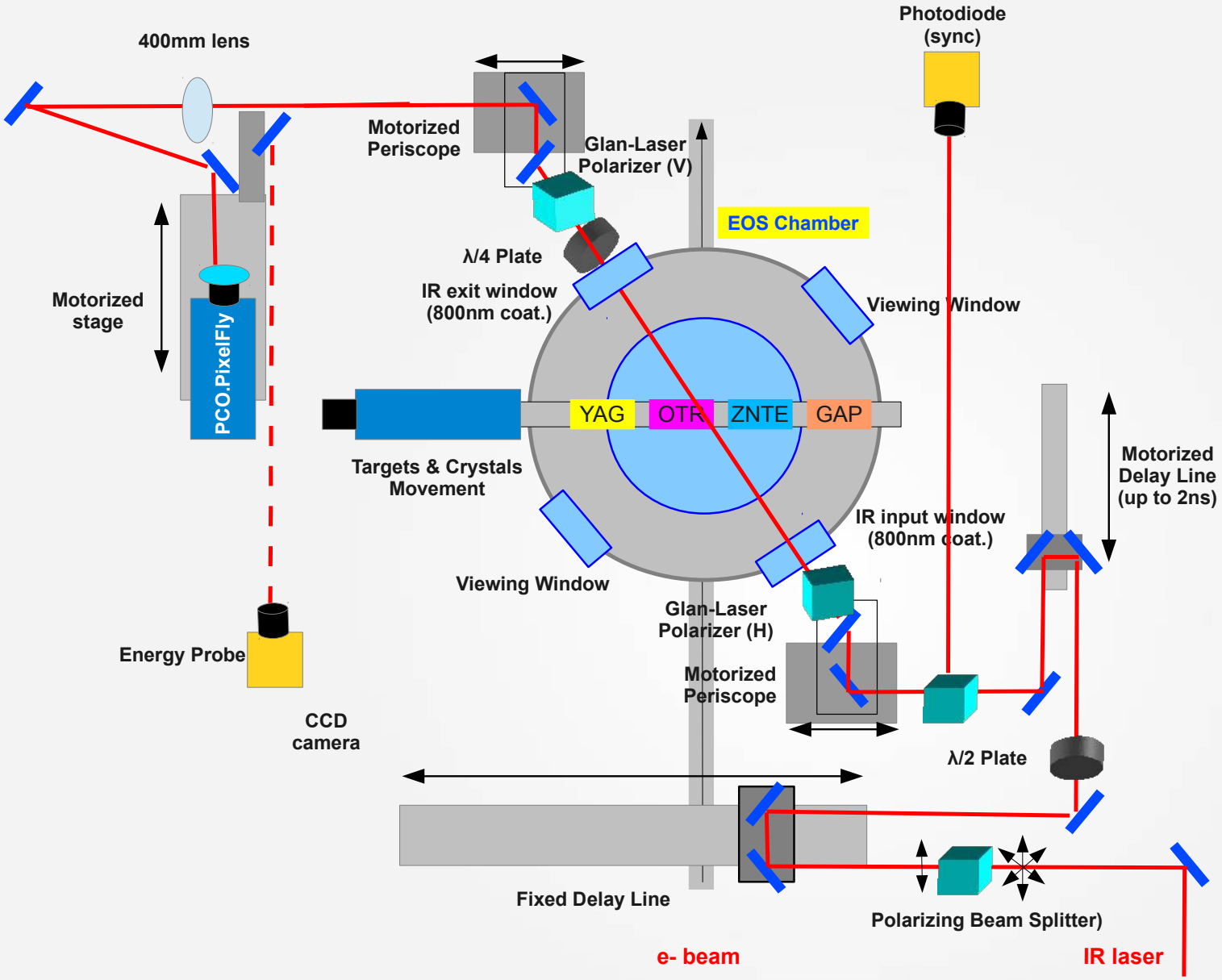
Item	Symbol	Condition	Value	Unit
Spectral Response Range	λ	V_b = 7 V	450 to 870	nm
Peak Response Wavelength	λ_p	V_b = 7 V	850	nm
Effective Sensitive Area	A		0.2 × 0.2	mm^2
Chip Size			1 × 1	mm^2

- Bunch Time Arrival Monitor: 4GHz Cavity-BPM.

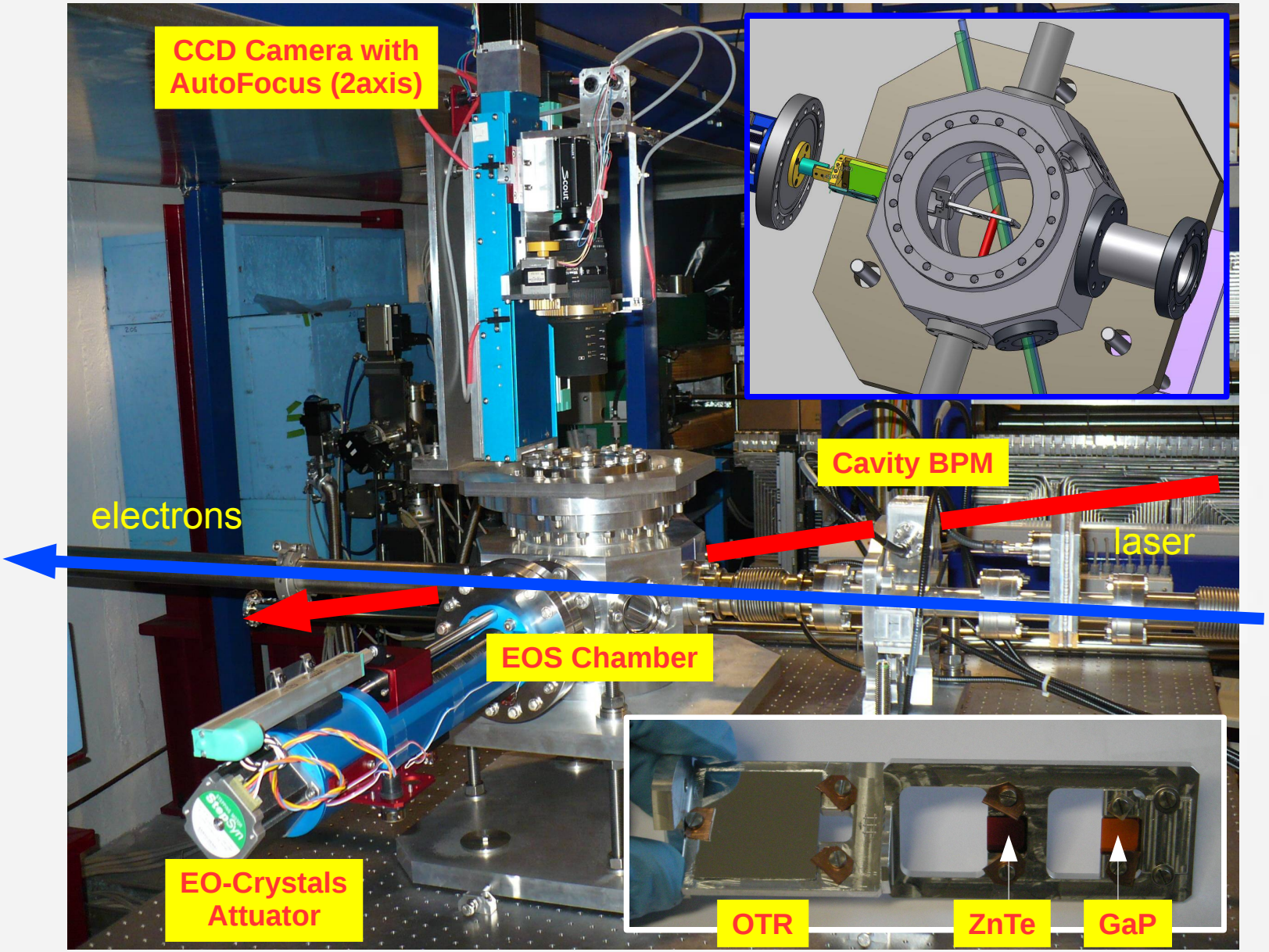




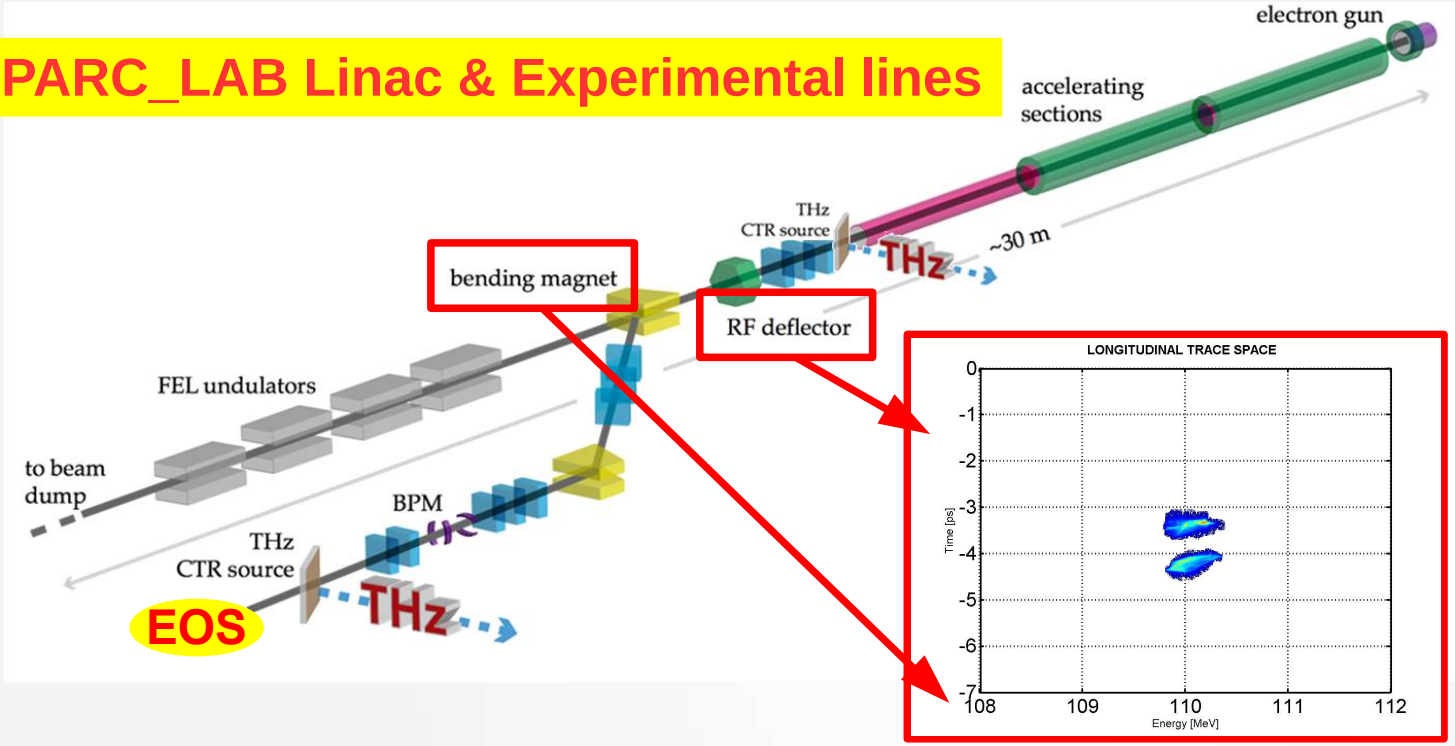
EOS optical setup



EOS diagnostics chamber

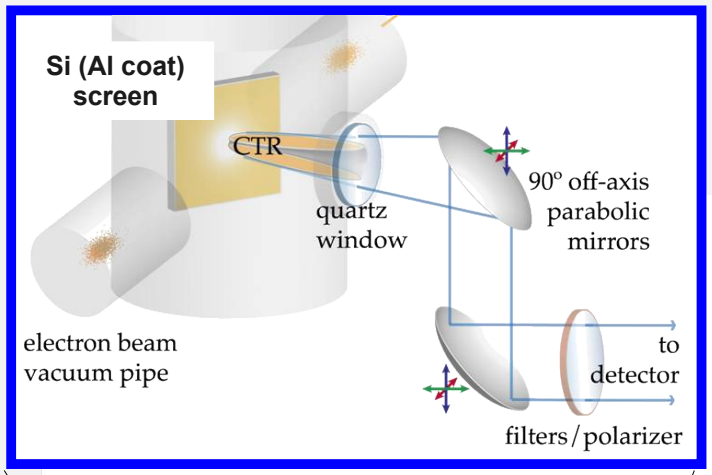


Longitudinal Phase Space



- Charge: 160pC total (80pC + 80pC)
- Energy: 110MeV
- Overall emittance: 2.29mm mrad (Y), 2.56mm mrad (X)
- 2-bunches distance: (830±30) fs (rms)
- Bunch lengths: (64±8) fs, (52±8) fs (rms)

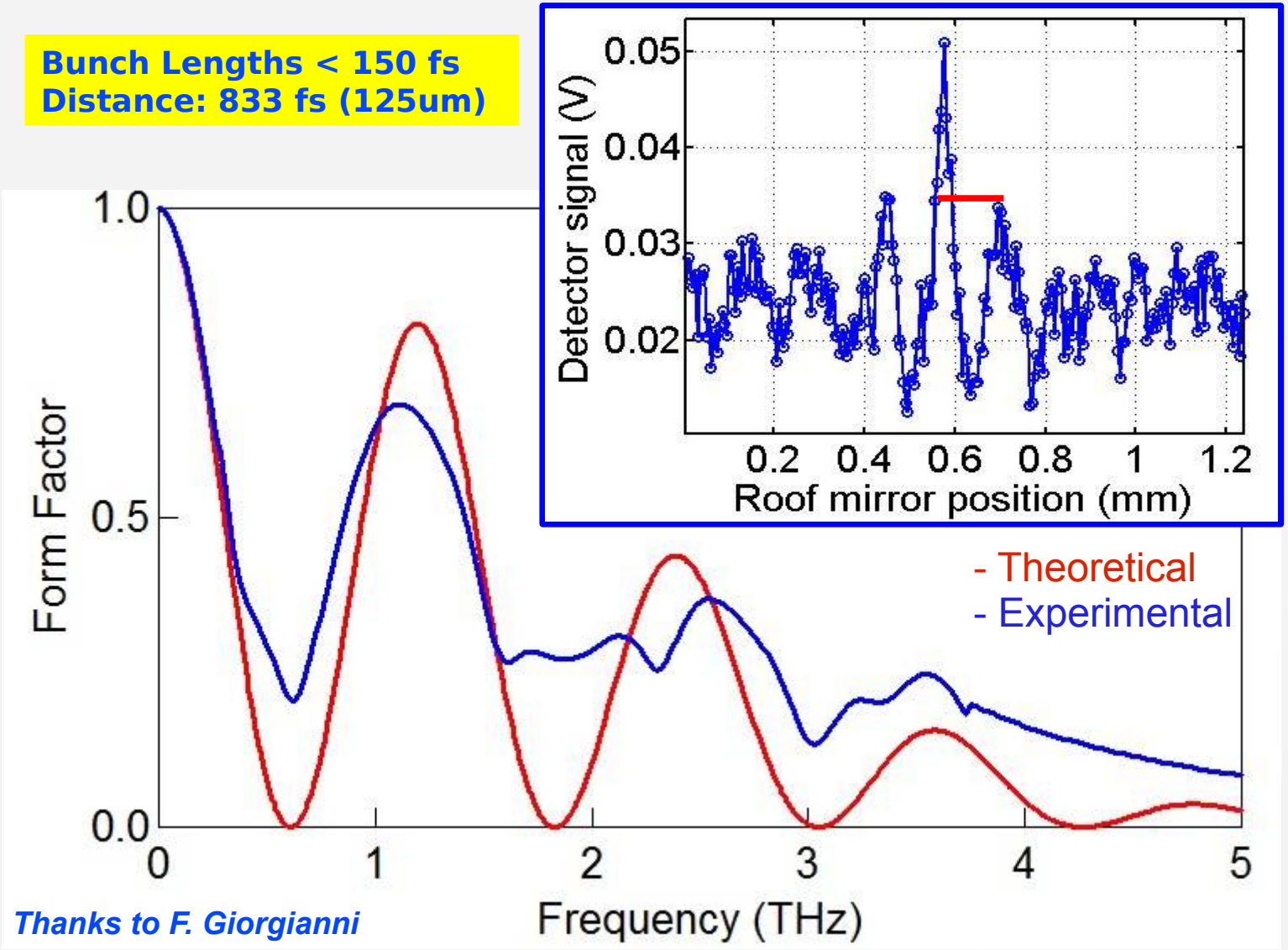
Michelson Interferometer results



THz Detector: 0.5÷30 THz
Beam Splitter: Mylar 12um
Quartz Window: <3.8 THz

Michelson Interferometer results

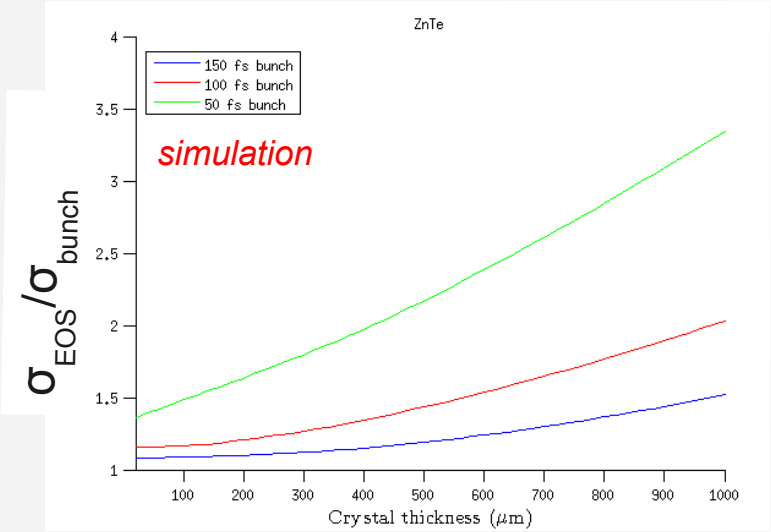
Bunch Lengths < 150 fs
Distance: 833 fs (125um)

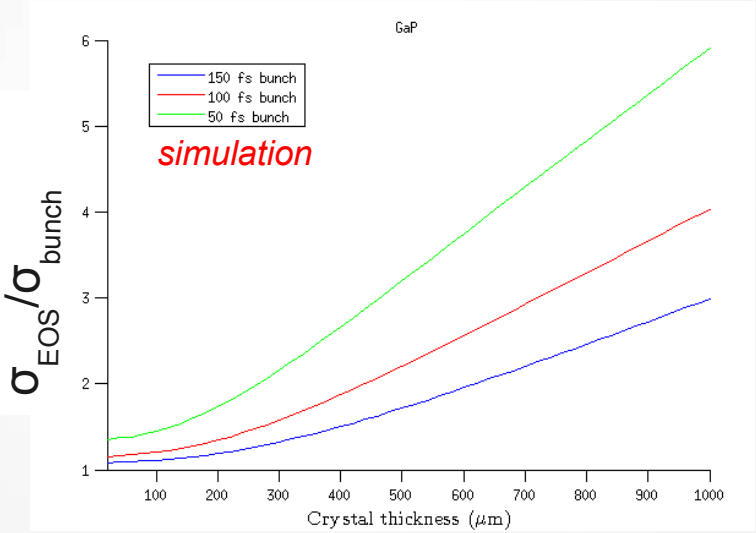


Thanks to F. Giorgianni

EOS Current Parameters

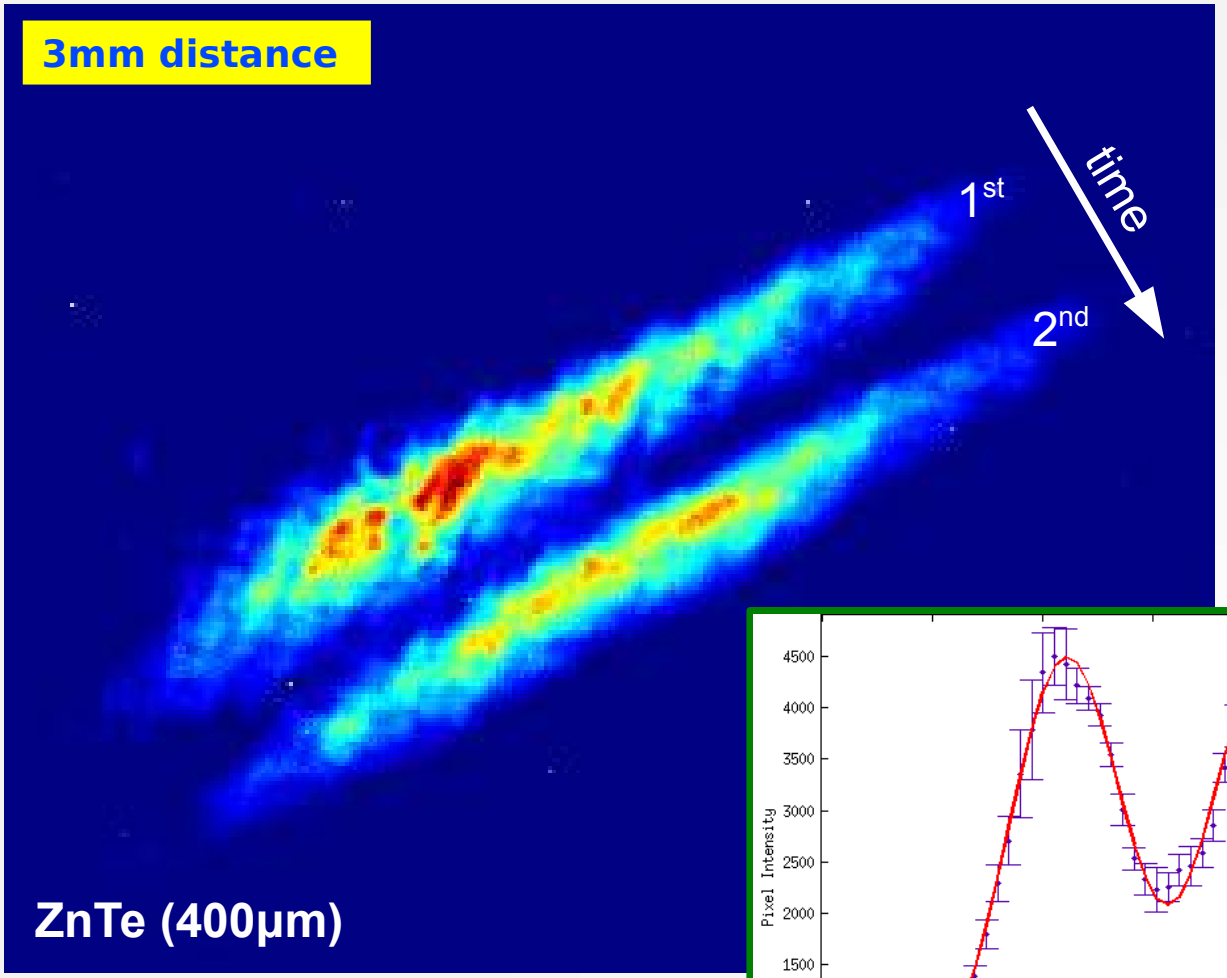
- Ti:Sa SPARC_LAB photocathode laser
  - *Pulse duration:* ***130 fs (rms)***
  - *Energy:* *200 nJ*
  - *Spot diameter:* *5 mm (**~10 ps time window**)*
- CCD resolution: **1 pixel ≈ 17 fs**
- Crystals 10x10 mm^2 (provided by IngCrys Ltd.)
  - *ZnTe (400μm), GaP (500μm)*
  - ***140 fs** (ZnTe), **250 fs** (GaP) **rms** (THz – laser velocity mismatch)*

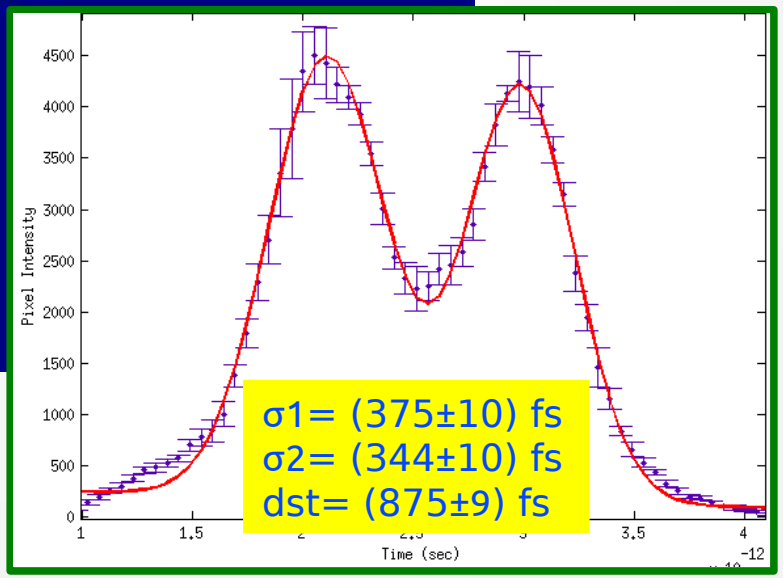




- Better resolution limit σ_{lim} with thinner crystals (but lower signals!)

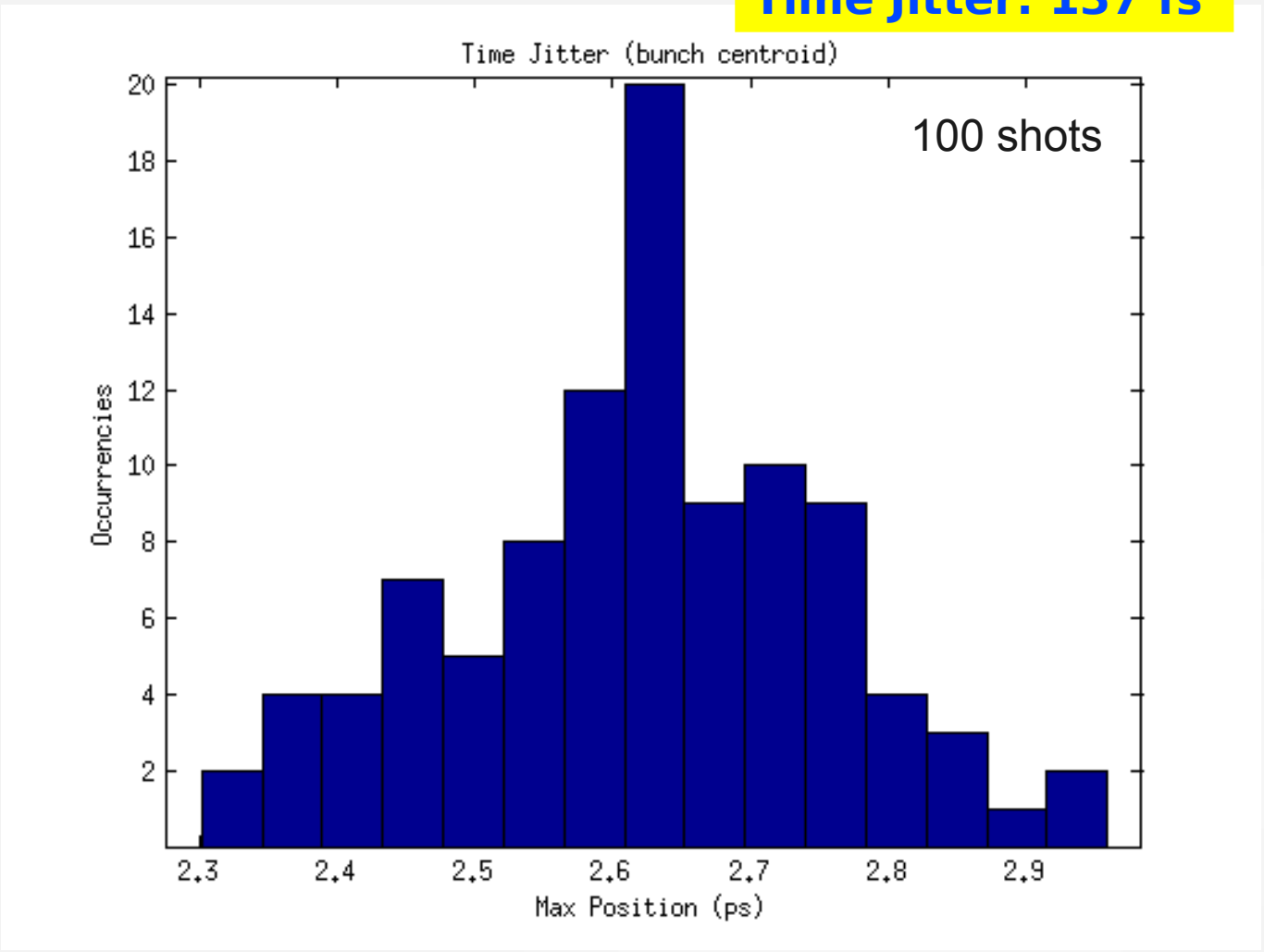
Very preliminary EOS results





Time Jitter evaluation with EOS

Time Jitter: 137 fs



Conclusions & Outlooks

- ✔ EOS Monitor is a useful diagnostics **to measure lengths and spacing** of single and multi-bunch electron beams.
- ✔ It can be used as a **time-stamp** and/or to evaluate the RF **time jitter**.
- ✔ Bunch spacing is well reproduced.
- ✗ As expected the bunch lengths were too short to be correctly measured → improvements needed for sub-100fs bunches:
  - *Shorter laser pulse* → make a pulse compressor to achieve laser TF pulse length of 60 fs (rms).
  - *Use thinner crystals* → with 100um thicknesses we have ~110 fs (ZnTe) and **~50 fs (GaP)** rms resolutions.
    - Drawback: very low signals!
  - Exploring different EO crystals...

Thank you for your attention!