Time Resolved UED in Sealab

Time resolution optimization with the SRF Photoinjector

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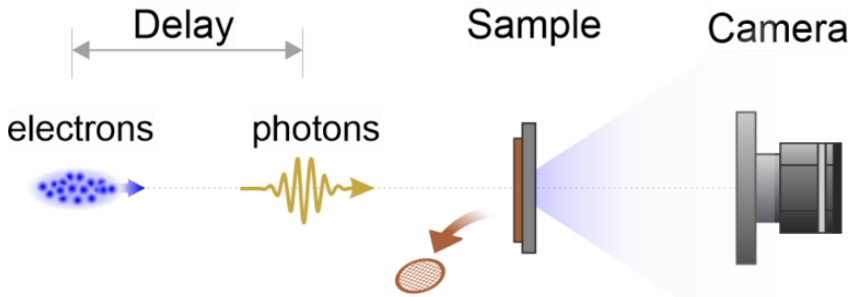
Ultrafast Electron Diffraction

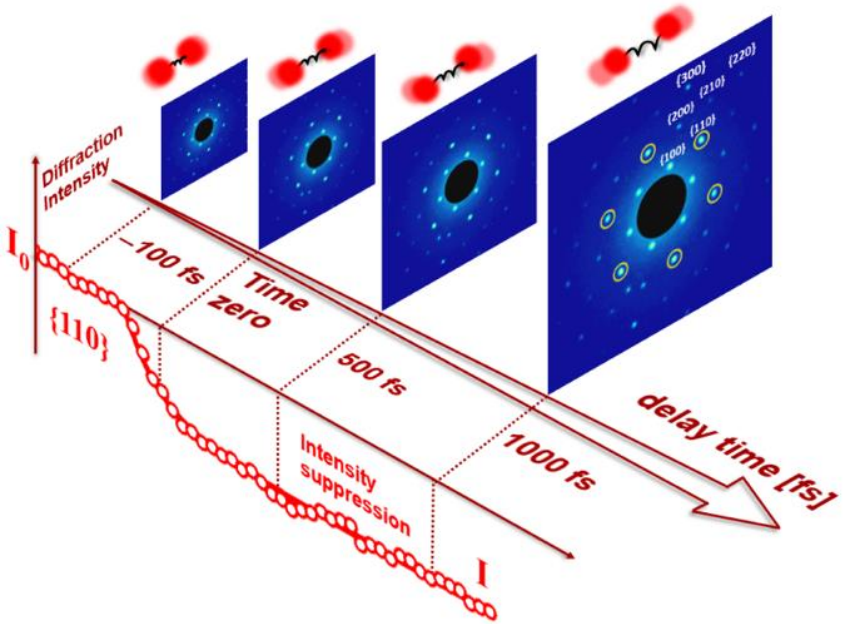
- Ultra-fast Electron Diffraction (UED) can provide of real-time imaging of structural changes in atomic scales.
- Pump photon pulse excites the target structure, while a consequent probe electron bunch generates the diffraction pattern.



- Temporal and spatial resolutions for UED are given by:

$$\Delta t^2 = \Delta t_{pump} \oplus \Delta t_{probe} \oplus \Delta t_{jitter}$$

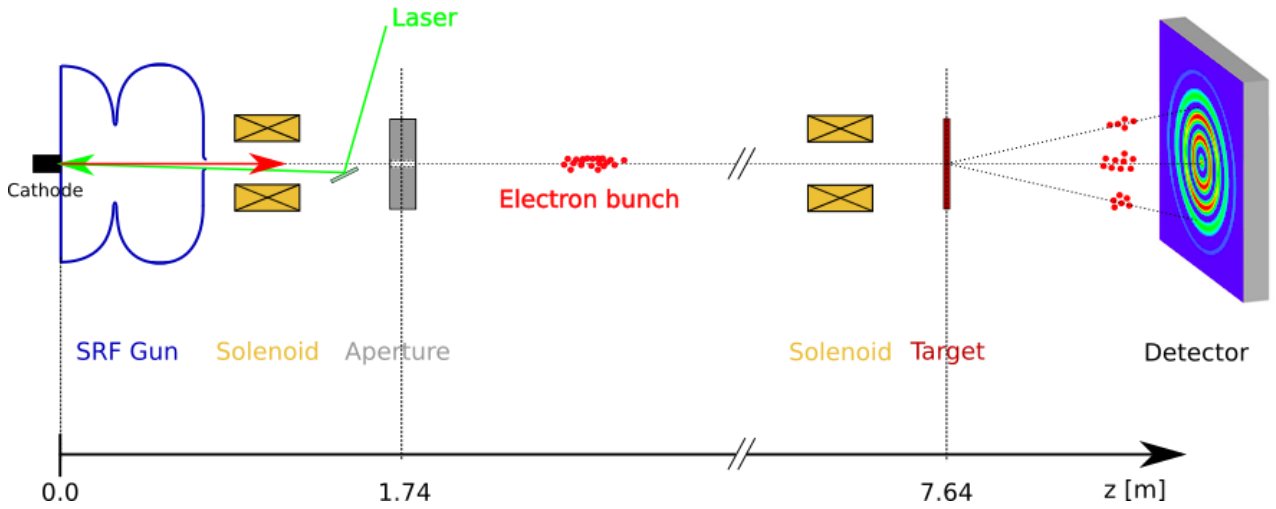
$$l_c = \Delta s^{-1} = \frac{\hbar \sigma_\perp}{m_e c \epsilon_{\perp,n}} \propto \frac{\sigma_\perp}{\epsilon_{\perp,n}}$$

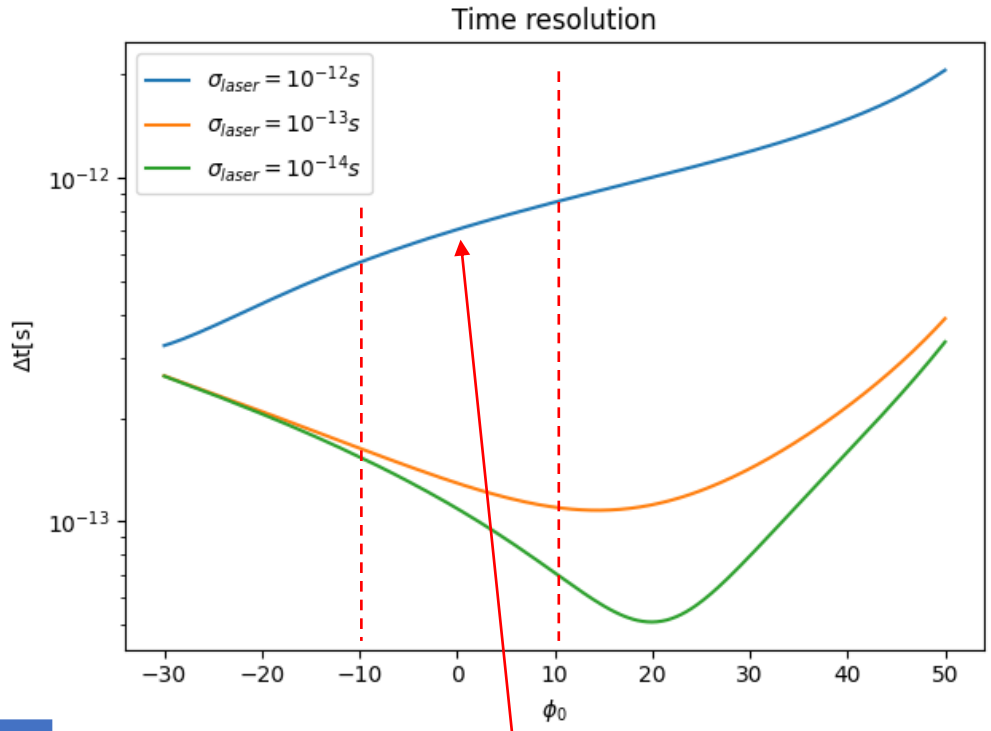


Lin, MF., Kochat, V., Krishnamoorthy, A. et al., Nat. Commun. 8, 1745 (2017).

Time Resolution for UED

- Following a **Slac MeV UED type** configuration with our RF gun:





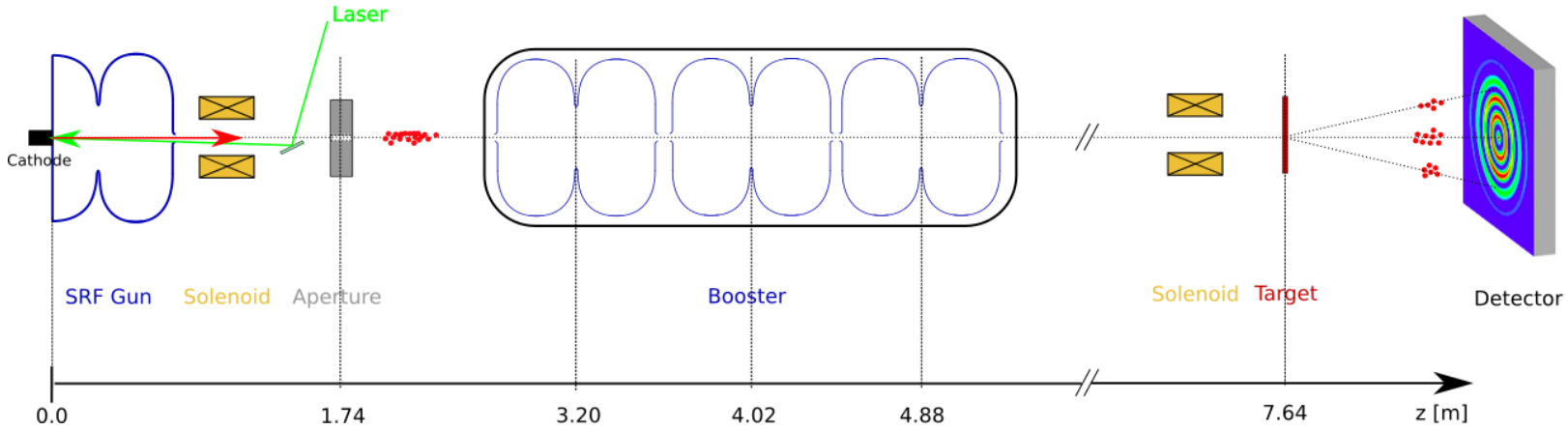
Parameter for UED mode	Value in Sealab
Gun peak on-axis field	< 25 MV/m
Laser pulse length rms	> 1 ps
Charge from cathode	1 to 10 pC -> 1 to 100 fC collimated

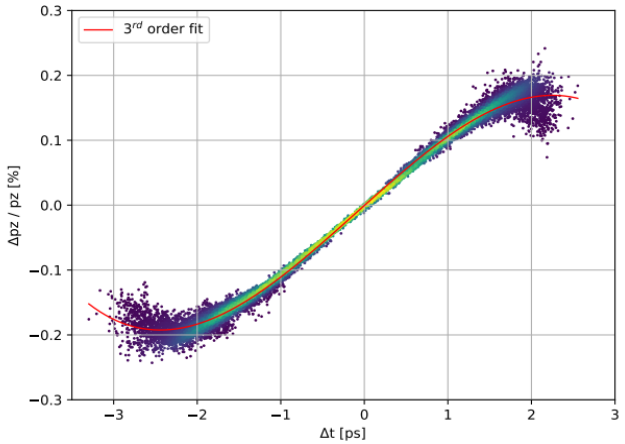
For bunch energies over 2 MeV:

$$\Delta t \geq 500 fs$$

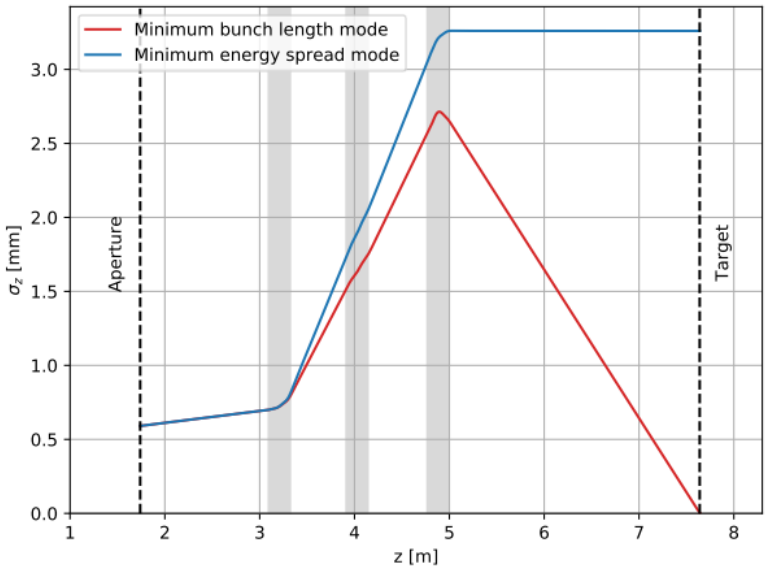
☹

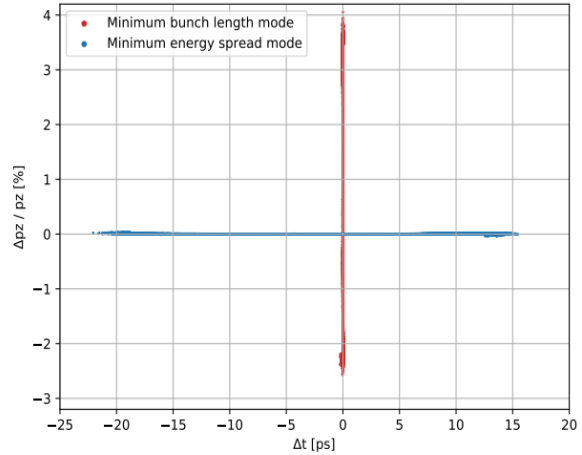
Solution: Booster Cavities





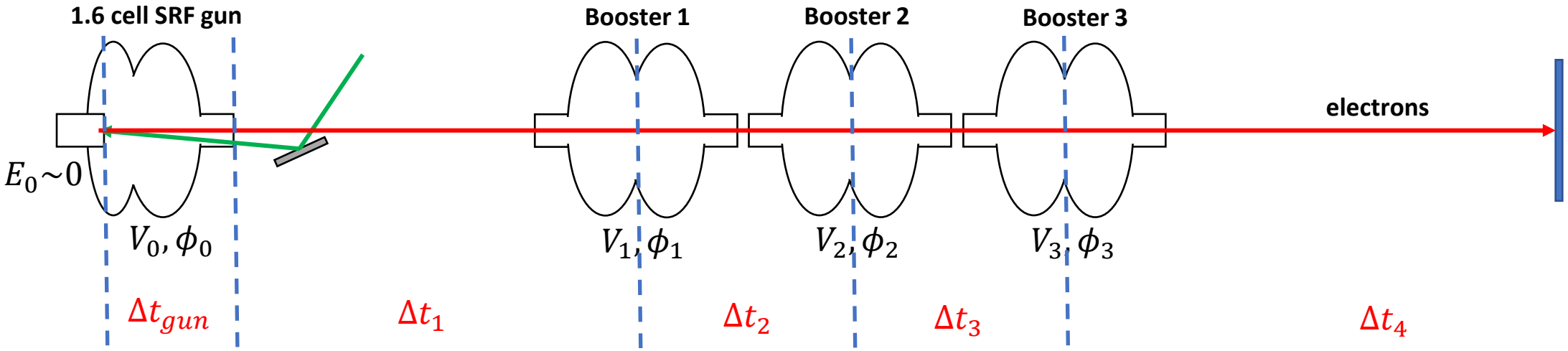
Q_{bunch}	50 fC
σ_t	$\approx$ 2 ps
$\delta E/E$	0.143 %





Q_{bunch}	50 fC	50 fC
σ_t	$\approx$ 25 fs	$\approx$ 10 ps
$\delta E/E$	1.83 %	4.8×10^{-3} %

Time of Flight Jitter



- Jitter between gun RF and laser: $\boldsymbol{\Delta t_{RL} = 300\ fs}$
- Parameter fluctuations in each cavity: $\boldsymbol{\Delta\phi_{cav} = 0.05\ °,\ \ \Delta V_{cav} = 10^{-4} V_{cav}}$

These values are educated guesses. We will only be sure once we measure them.

$$\Delta t_{jitter} = \sqrt{\sum\left(\frac{dT_{flight}}{dV_n}\Delta V_n\right)^2 + \sum\left(\frac{dT_{flight}}{d\phi_n}\Delta\phi_n\right)^2}$$

Emission from gun using on-crest phase cancels laser time jitter. Optimization of boosters -> Jitter down to 75fs rms.

Summary

→ **Beamline is currently under commissioning, first beams expected by early 2022. Experimental measurements soon…**

→ **Current status of UED in Sealab**:

- Simulations show that we are able to achieve suitable UED parameters, work is ongoing to improve time resolution to sub-100fs levels. Best optimization at the moment results in:

$$\Delta t_{bunch} \approx 60\ fs$$

$$\Delta t_{jitter} \approx 95\ fs$$

$$\Delta t \approx 115\ fs$$

This time resolution is competitive with current worldwide UED facilities.

Measuring time resolution is essential: **Arrival time and bunch length diagnostics is needed for experiments.**

Optimized transverse beam parameters at target for E = 3.0 MeV:

Collimator diameter [µm]	Q [fC]	$\sigma_\perp$ [mm]	$\epsilon_{\perp,n}$ [nm rad]	l_c [nm]	Δs [Å^{-1}]
500	50.0	0.33	19.5	6.4	0.016
200	8.1	0.15	7.0	8.2	0.012
100	2.1	0.10	3.5	11.0	0.009