High Transformer Ratio PWFA using cathode laser based bunch shaping.

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DESY

LAOLA @ PITZ

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Outline

1. High Transformer Ratio PWFA
2. Photo Injector Test facility at DESY Zeuthen – PITZ
3. Plasma cell
4. PITZ case in simulation
5. Experimental results
6. Prospects

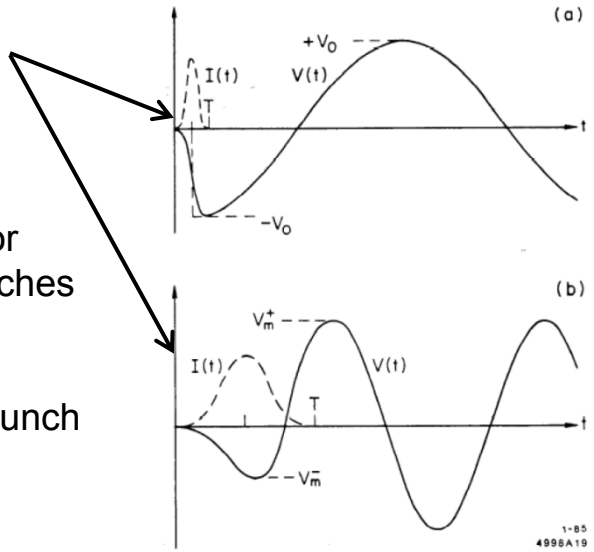
High Transformer Ratio PWFA

Collinear wakefield acceleration (linear theory):

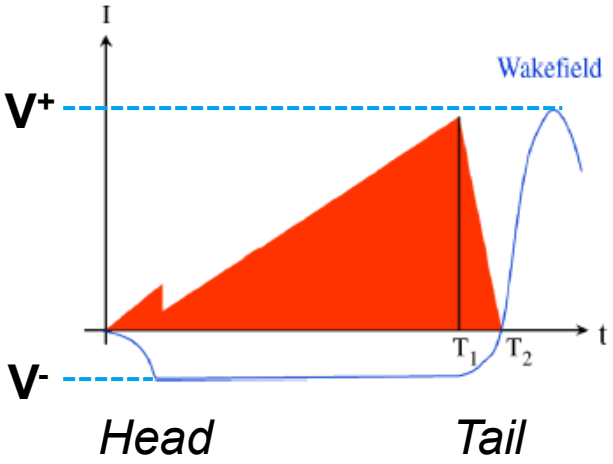
Fundamental theorem of beamloading: $E_{acc}/E_{dec} \leq 2$

→ Only true for symm. bunches

→ Various proposed bunch shapes



Bane, Wilson, Weiland, SLAC-PUB-3528, 1984



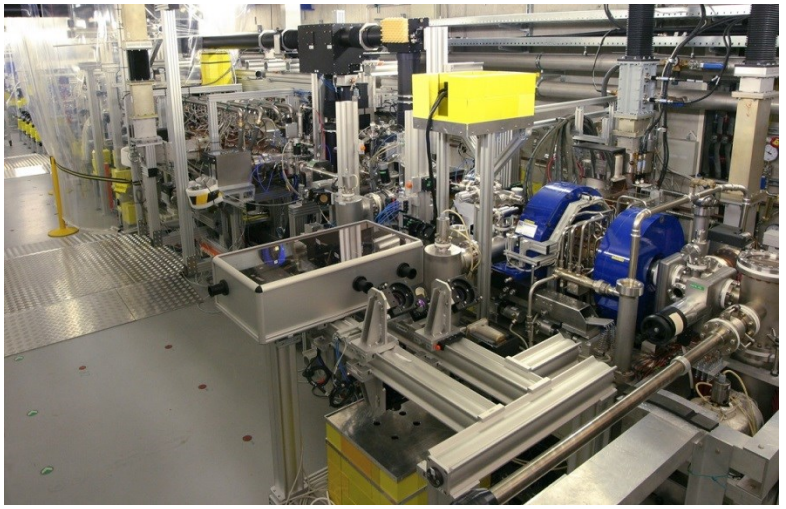
Jiang, Jing, Schoessow, Power, Gai, PRSTAB 15, 011301, 2012

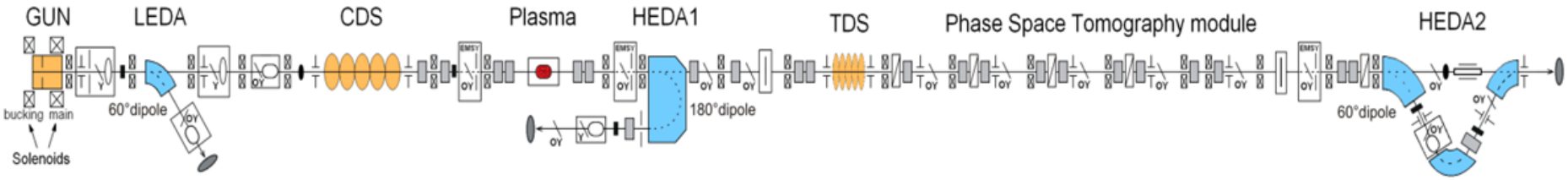
High Transformer Ratio:

$$\frac{V^+}{V^-} > 2$$

> Allows trade-off between max. acceleration gradient, max. efficiency & max. witness energy gain per driver energy

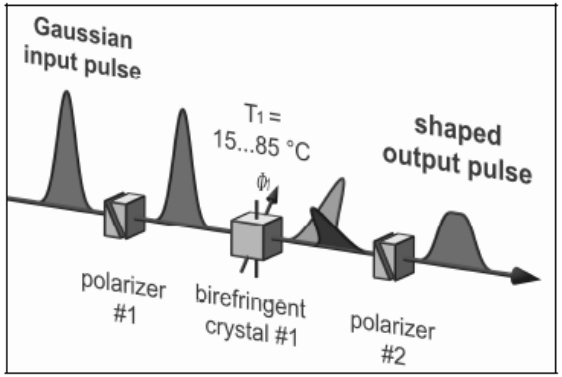
- Test bed & preparation of electron guns for FLASH and Eu-XFEL
- 20 m Linac
- 1.3 GHz RF gun
- Max. 25 MeV after CDS booster cavity
- 1 pC – 5 nC bunch charge
- Various diagnostics including transverse deflecting cavity
- Highly flexible photocathode laser…

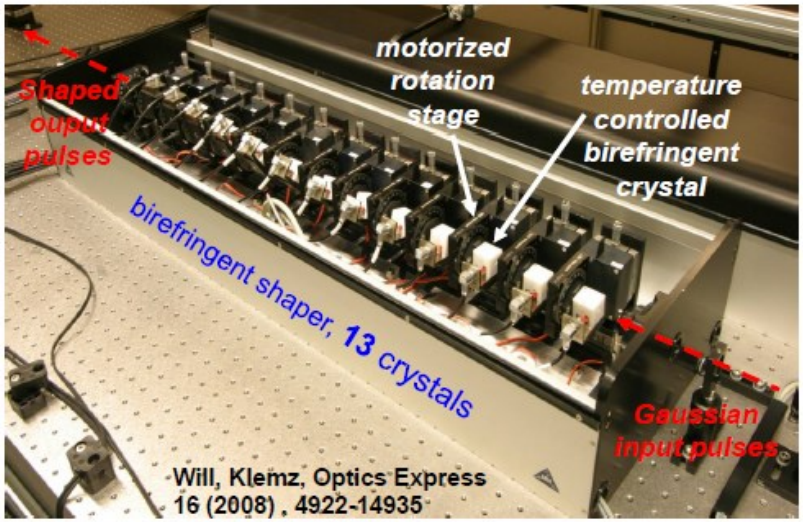


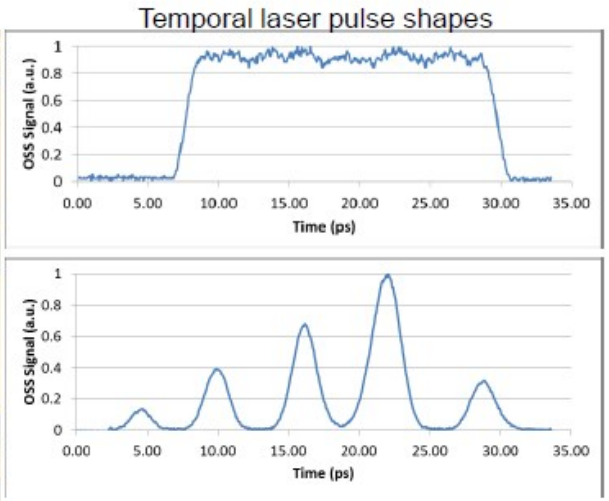


Bunch shaping @ PITZ

- Photocathode laser based bunch shaping
- Laser pulse shape → electron bunch shape
- Tunable pulse shaper of 13 birefringent crystals → addition of **14 amplitude-tunable Gaussian virtual pulses**
- Additional pulse added via delayline as witness

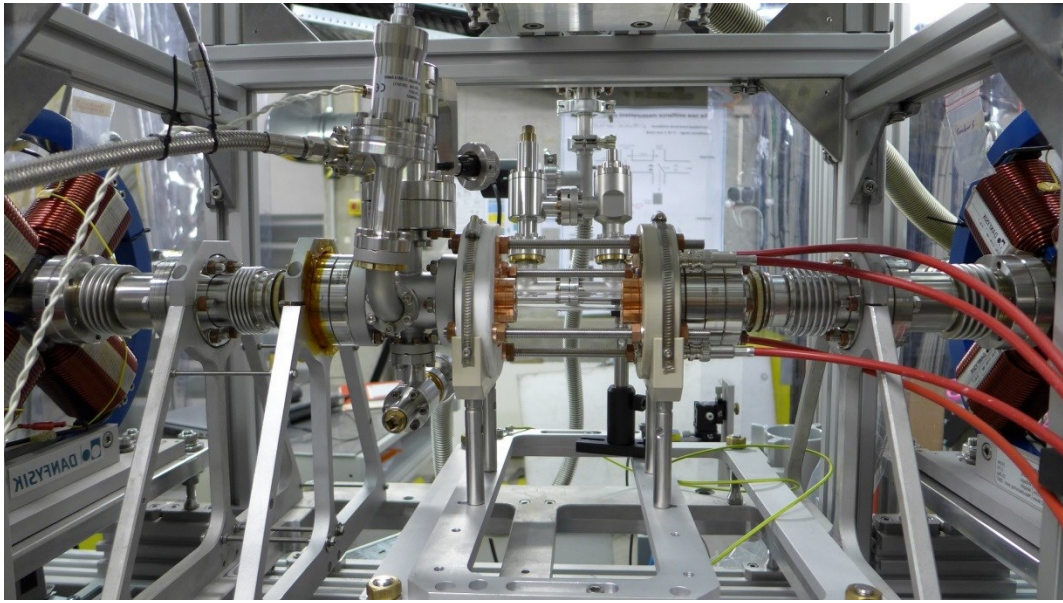






PITZ gas discharge plasma cell

- Gas discharge in **Argon**
- 10mm diameter, **100mm length** discharge channel
- 2-10µs pulses of 200 – 1000A
- Electron windows for vacuum separation
- Densities of **up to 5×10^{16} cm^{-3}**



Transformer Ratio definition for measurements

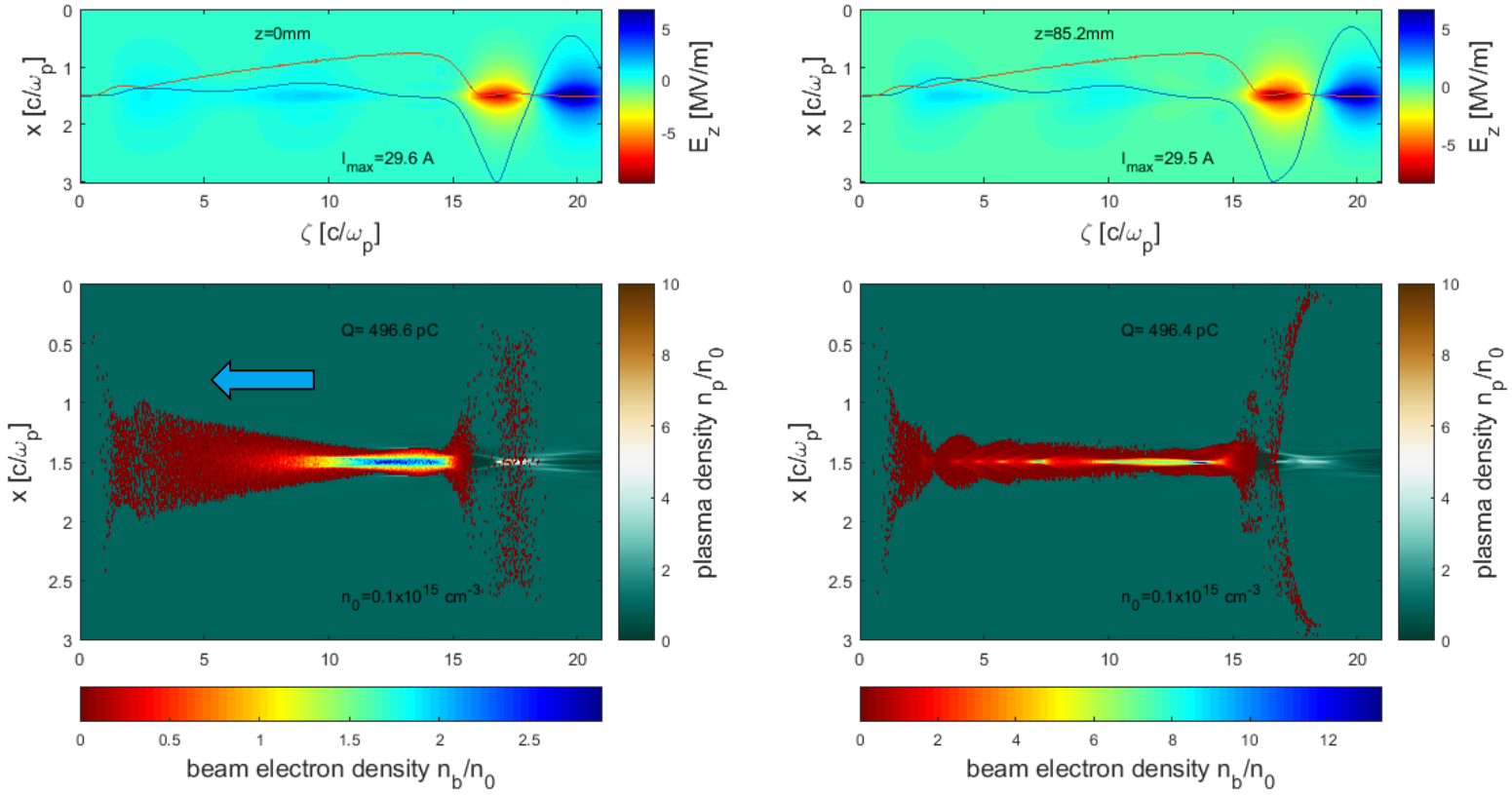
- No direct field measurement
- No controlled injection of witness bunch (witnessing wide phase range)
- Measuring & simulating “effective Transformer Ratio“:

$$\frac{E_{\text{slice\_max, witness, Plasma On}} - E_{\text{slice\_max, witness, Plasma Off}}}{\max\left(E_{\text{(mean-slice-energy), driver, Plasma Off}} - E_{\text{(mean-slice-energy), driver, Plasma On}} \right)}$$

- Worst case underestimating TR: highest energy witness electrons with plasma not necessarily at highest energy without plasma

HTR PWFA @ PITZ simulation

- ASTRA electron beam simulation
- HiPACE simulation of Plasma Wakefield Acceleration
- Transformer Ratio ~ 5.5 (calculated from field amplitudes)



ASTRA HiPACE

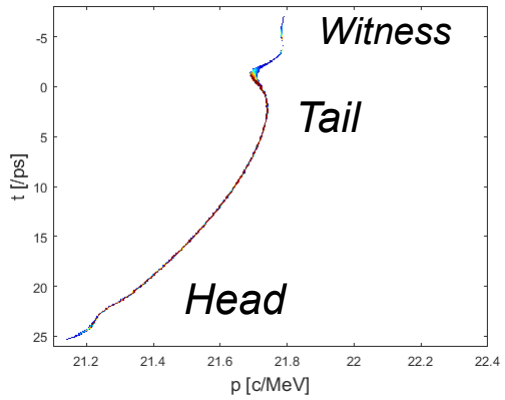
HTR PWFA @ PITZ simulation

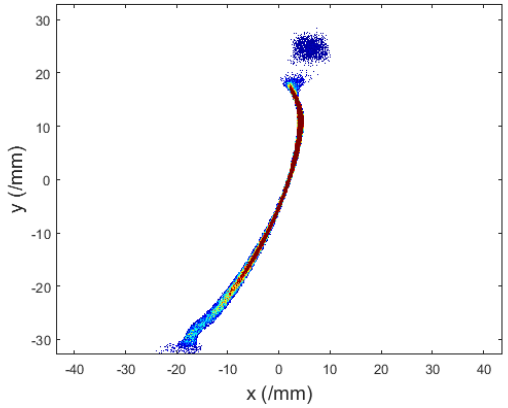
- Simulated effective TR ~ 6.2

Simulated phase space

Simulated measurement in dispersive section

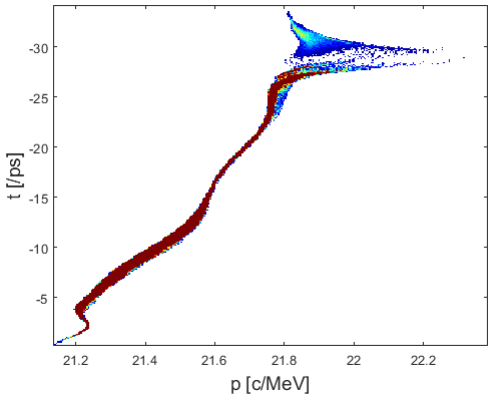
Without plasma

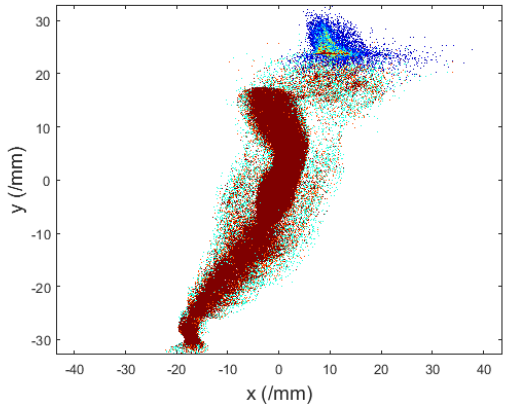




time

With plasma





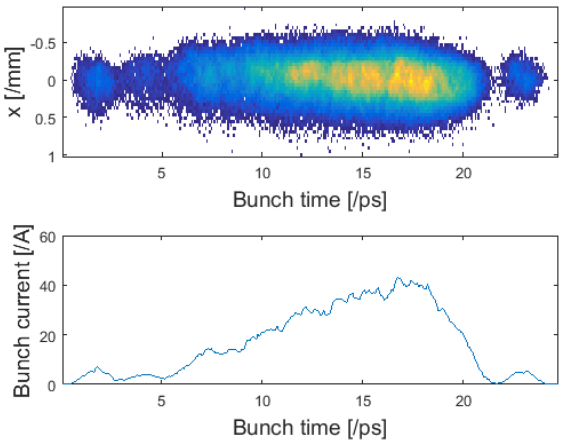
energy

ASTRA HiPACE

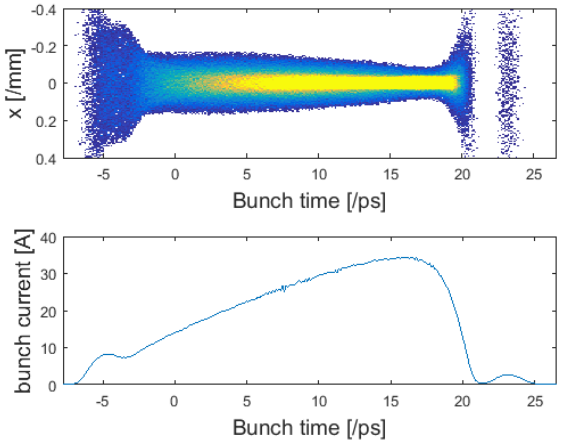
Experimental results – bunch shaping

- Demonstrated various bunch shapes
- Witness bunch delay, total charge and driver-witness charge ratio tunable

Measurement 550 pC



Simulation 500 pC



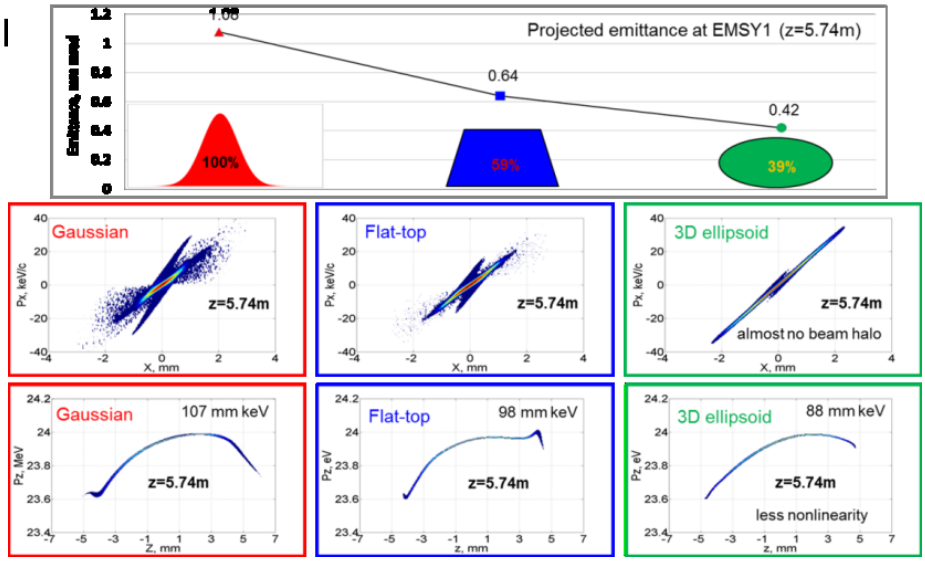
Preliminary Experimental Results – Transformer Ratios

PRELIMINARY RESULTS; DETAILED ANALYSIS & PUBLICATION PENDING

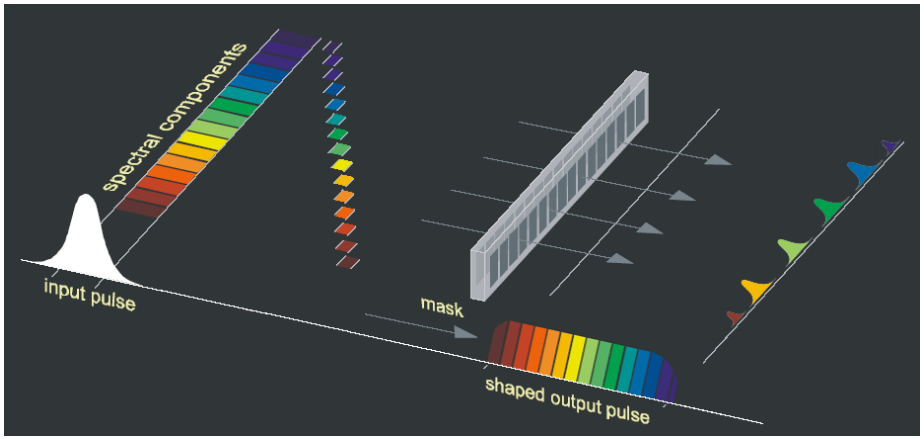
- 100 mm Argon gas discharge plasma (n_p = ~10^{12}–10^{16} cm^{-3})
- No stable driver transport at densities above ~10^{15} cm^{-3}
- Measured TR= -1.5 – 4.9 (preliminary analysis)
- Driver charges 400 - 900 pC, witness/driver charge ratio 1-5%
- max. energy gain ~1MeV

Future advanced bunch shaping @ PITZ

- 3D-shaping of bunches using SLMs or dispersed photocathode laser
- Designed for production of quasi-ellipsoidal electron bunches for emittance minimisation
- Independent xz and yz shaping
- Under assembly @ PITZ

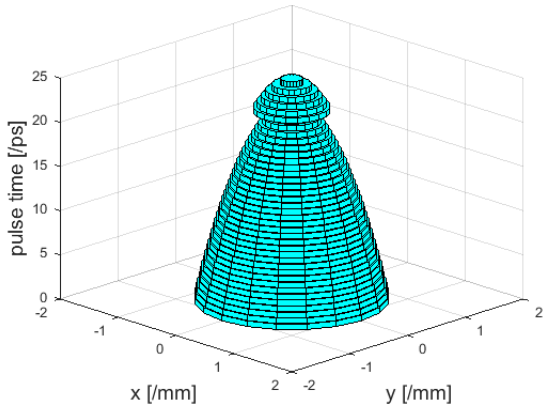


Simulated emittance minimisation for PITZ case



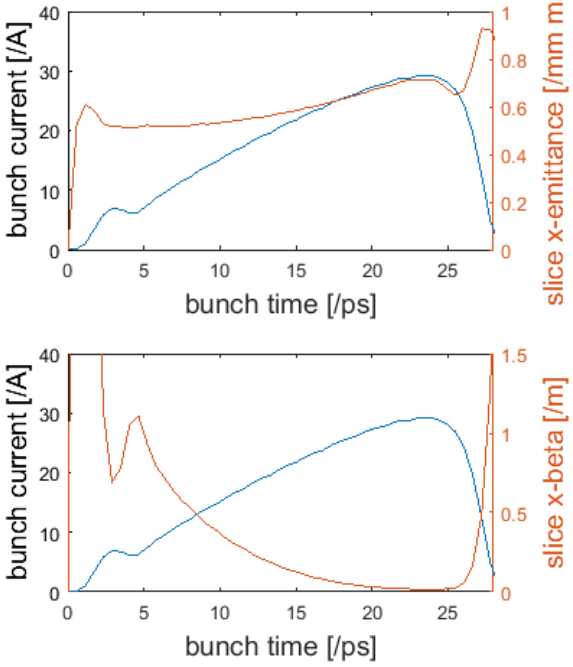
SLM based shaping principle

Future advanced bunch shaping @ PITZ

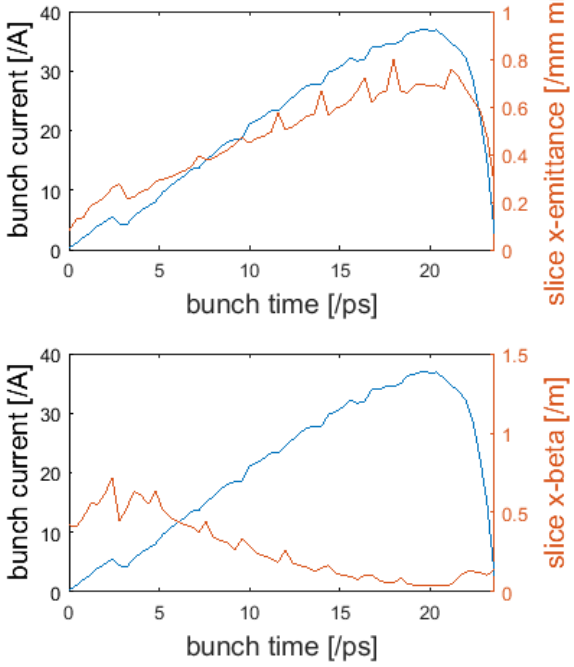


- Compensate space charge effects at photocathode
- Improve bunch slice mismatch
- Better tunability of bunch shape

Current, crystal based shaping



SLM based shaping



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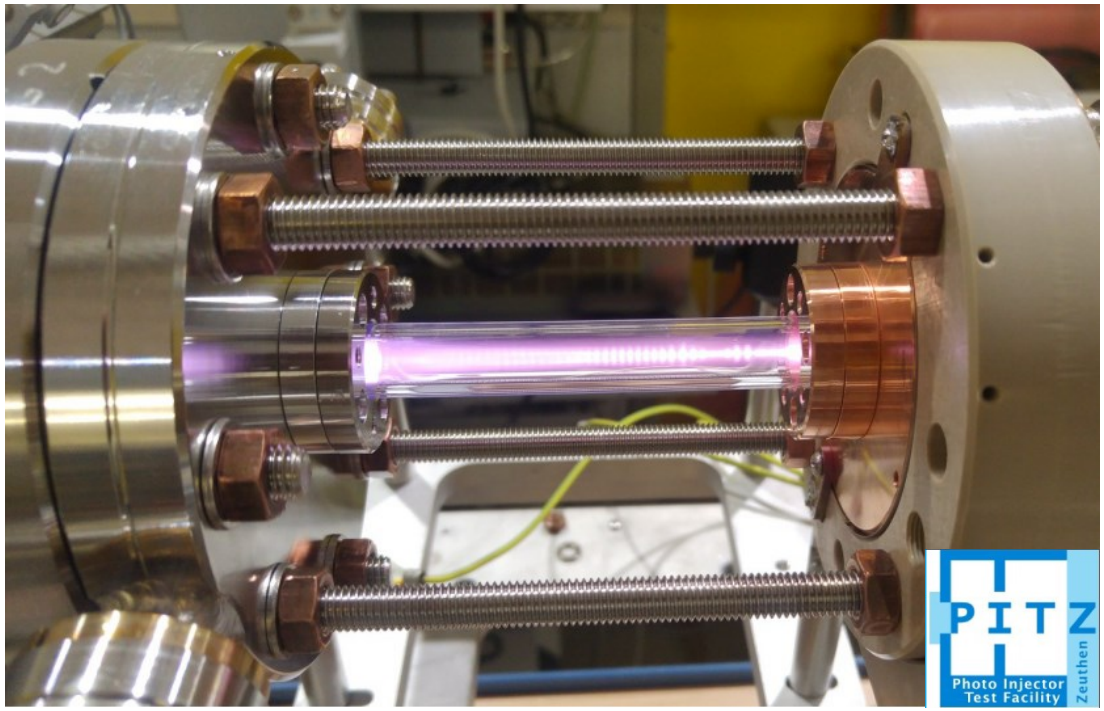
Conclusions

- **High Transformer Ratios > 2 (preliminary results ≤ 4.9)** measured in a PWFA for the first time
- Stable **transport for bunchlength ~ λ_p** observed
- No experimental differences for triangular and double triangular beam observed
- Measurements done at **low gradients** (≤ 10 MV/m)
- Electron bunch **cathode laser shaping demonstrated** for various shapes
- Experiments with **upgraded shaping capabilities** will continue

Thank you very much for your attention!



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