Status and future plans of PITZ

Photo Injector Test Facility at DESY in Zeuthen

Mikhail Krasilnikov for PITZ team

Virtual ARD ST3 Workshop, 23.09.2020

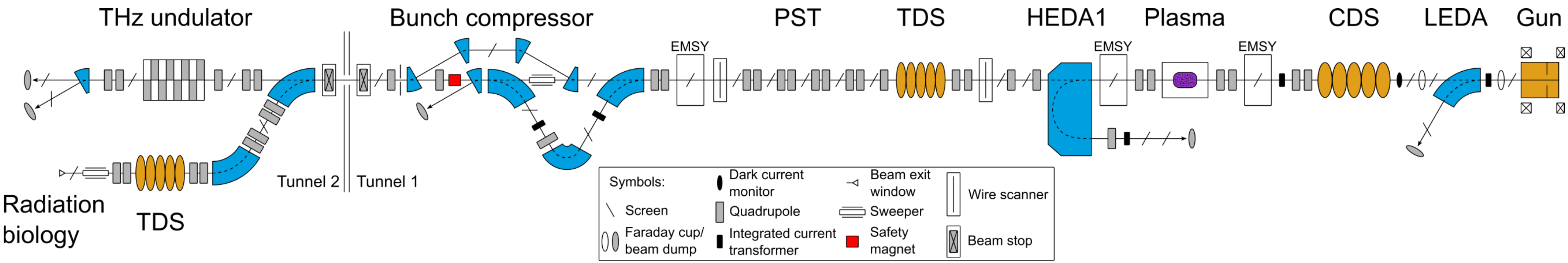


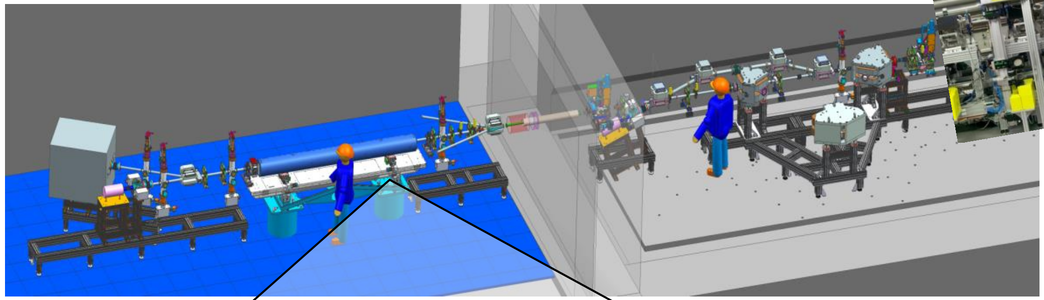
Photo Injector Test Facility at DESY in Zeuthen (PITZ)

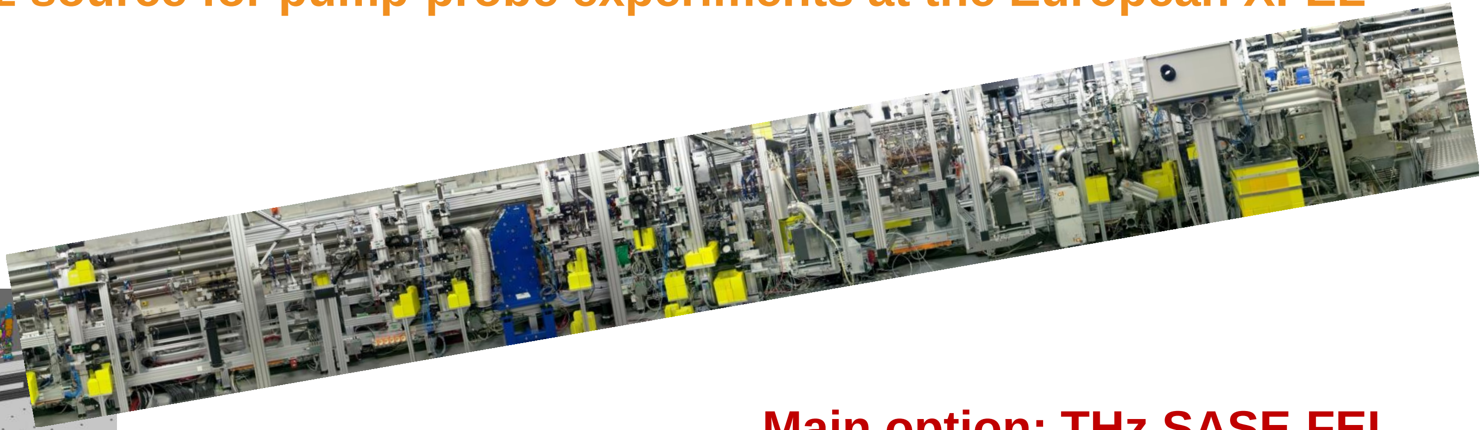
High brightness photo injector development, optimization and applications

- As one of **first machines @DESY: restarted operation** after COVID19 lock-down on 20.4.2020: efficiency of shift work is lower than before, e.g. due to separation of both shift persons, but → several run periods with extensive measurement program:
  - **Gun4.2** is running **stably**, (200 µs, ~60 MV/m, >92% up time)
  - Emittance reduction with **truncated Gaussian**
  - **THz@PITZ** → several beam measurements
  - Progress on new **ELLA photocathode laser system**
  - **Cathode response time** measurements
  - **Thermal emittance** measurements at fresh and used Cs_2Te cathodes
  - …
- **TDS (RF deflector) klystron** was **exchanged** and put back into **operation**
- Further installations in the PITZ **tunnel annex** (**THz@PITZ**)

THz R&D at PITZ (PITZ4)

Developments on accelerator based THz source for pump-probe experiments at the European XFEL



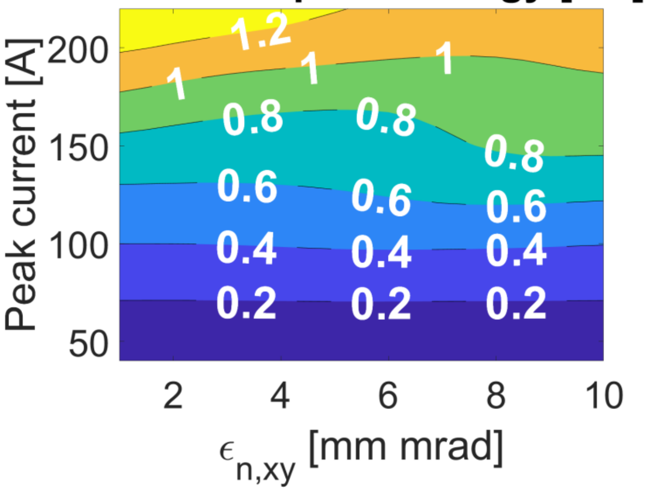


LCLS-I undulators (on loan from SLAC)

Properties	Details
Type	**fixed gap planar hybrid** (NeFeB)
Nominal gap	6.8 mm
K-value	3.49
Support diameter / length	30 cm / 3.4 m
Vacuum chamber	11 mm x **5 mm**
Period length	30 mm
Poles / a module	226 poles (= 113 periods)
Total weight w/o vac. chamber	1000 kg

Main option: THz SASE FEL

Saturation pulse energy [mJ]



Sat. pulse energy: up to 1.2 mJ
Sat. length: from 3.5 m

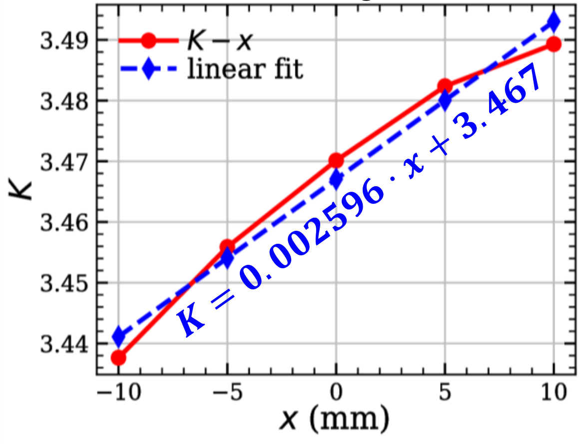
LCLS-I undulator field measurement at DESY in Hamburg

Speed talk

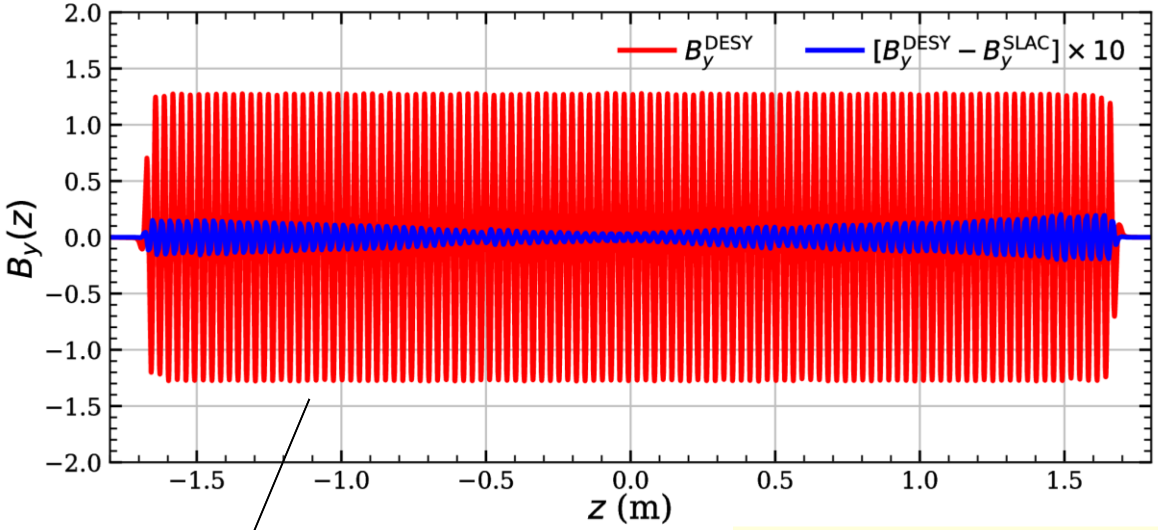
Horizontal field gradient implementation

- Two **LCLS-I** undulators have arrived at Hamburg in August 2019
- The fields of the undulator L143-112000-**26** have been re-measured at DESY Hamburg and are **consistent** with SLAC measurement (discrepancy < 0.02 T)
- However, the **transverse gradien**t will lead to an off-axis (~25 mm) trajectory in the horizontal plane; **steering coils** are considered to correct it

Horizontal gradient

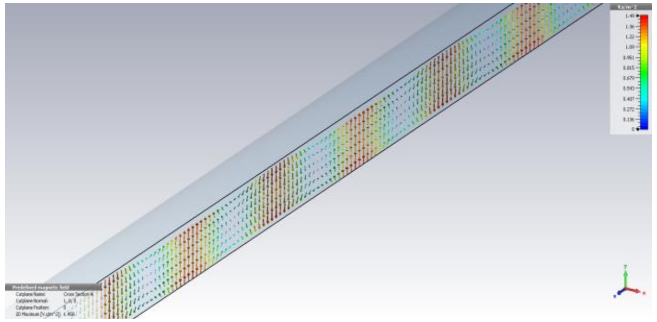


On-axis By along the 3.4 m undulator



$$\chi(x,y,z) = -\frac{\cosh[k_x(x_0+x)]}{\cosh[k_x x_0]} \cdot \sum_{n=1}^{N_h \cdot N_U} \{a_n \cos(k_{zn} z) + b_n \sin(k_{zn} z)\} \cdot \frac{\sinh(k_{yn} y)}{k_{yn}}$$

3D Field map $\vec{B} = -\frac{\partial \chi}{\partial \vec{r}}$, including horizontal gradient

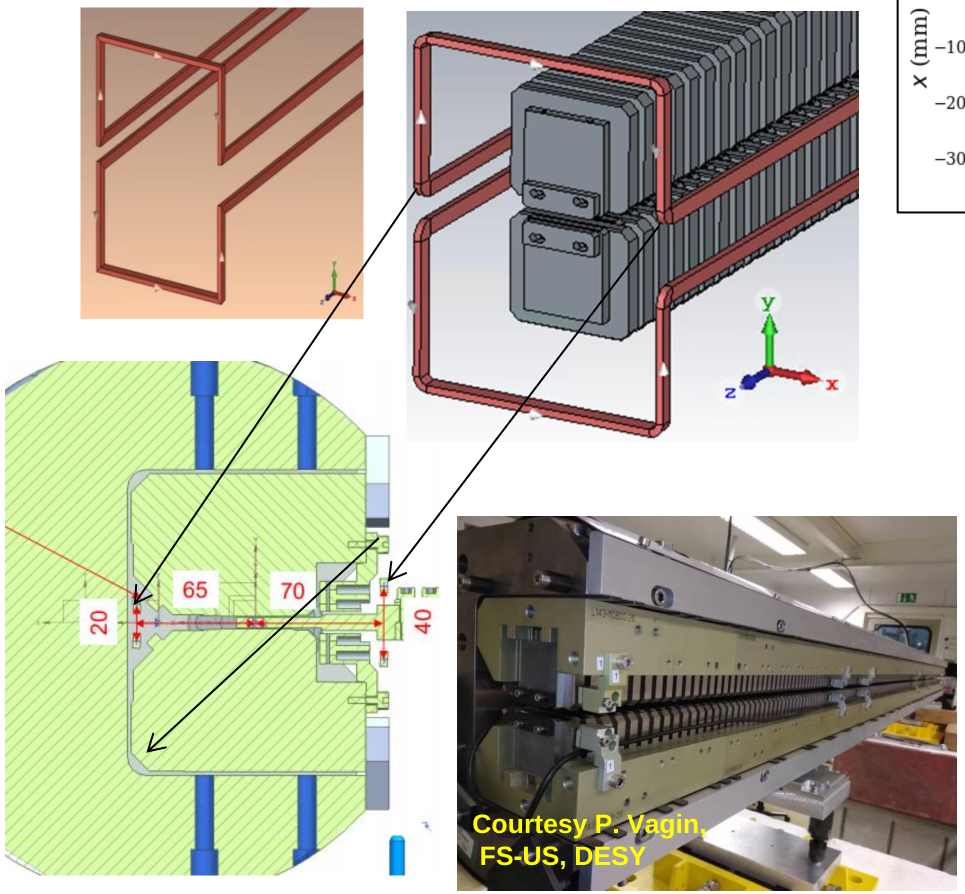


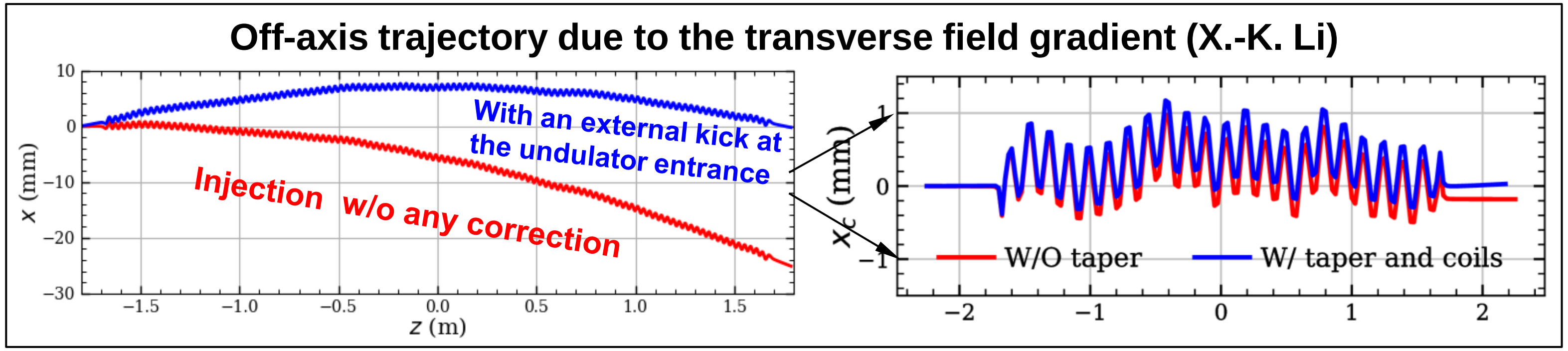
Courtesy M. Tischer, P. Vagin

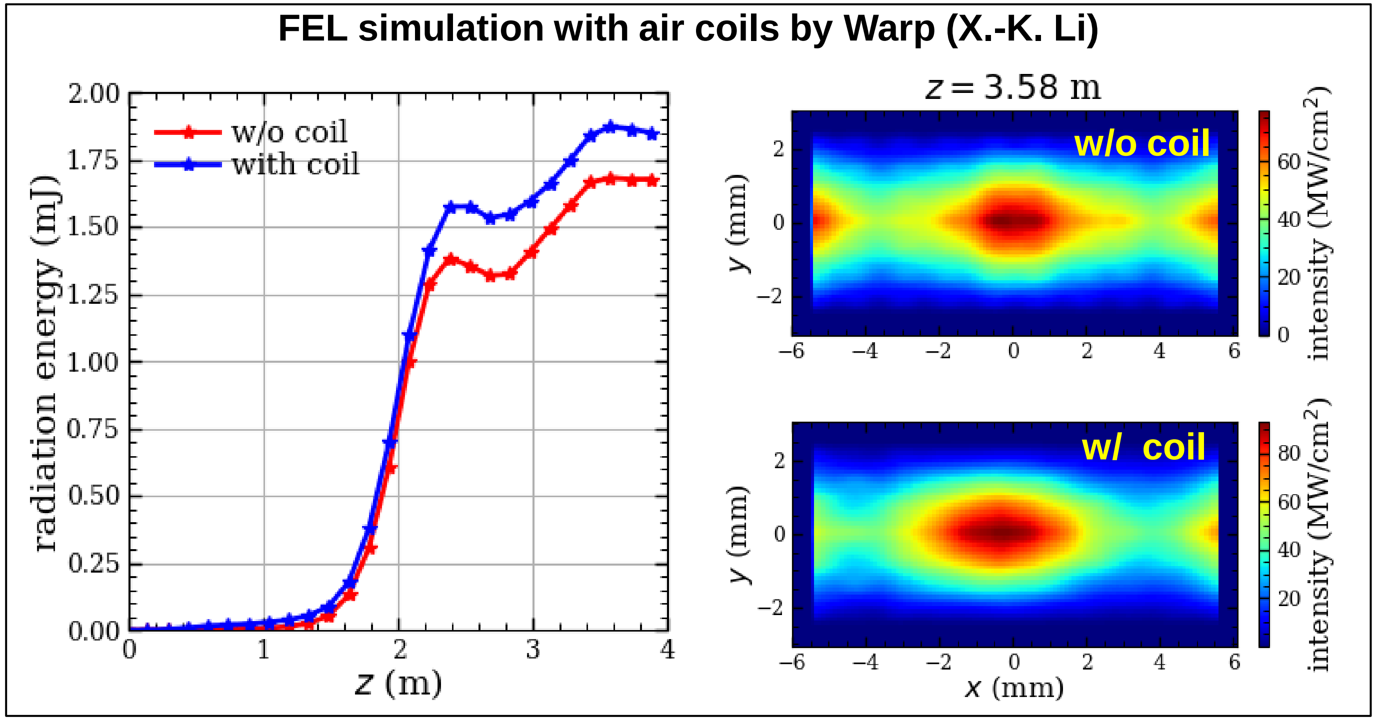
Design and modeling of correction coils

Horizontal undulator gradient impact onto beam transport and THz SASE FEL

steering coils are considered to correct **transverse gradient** impact

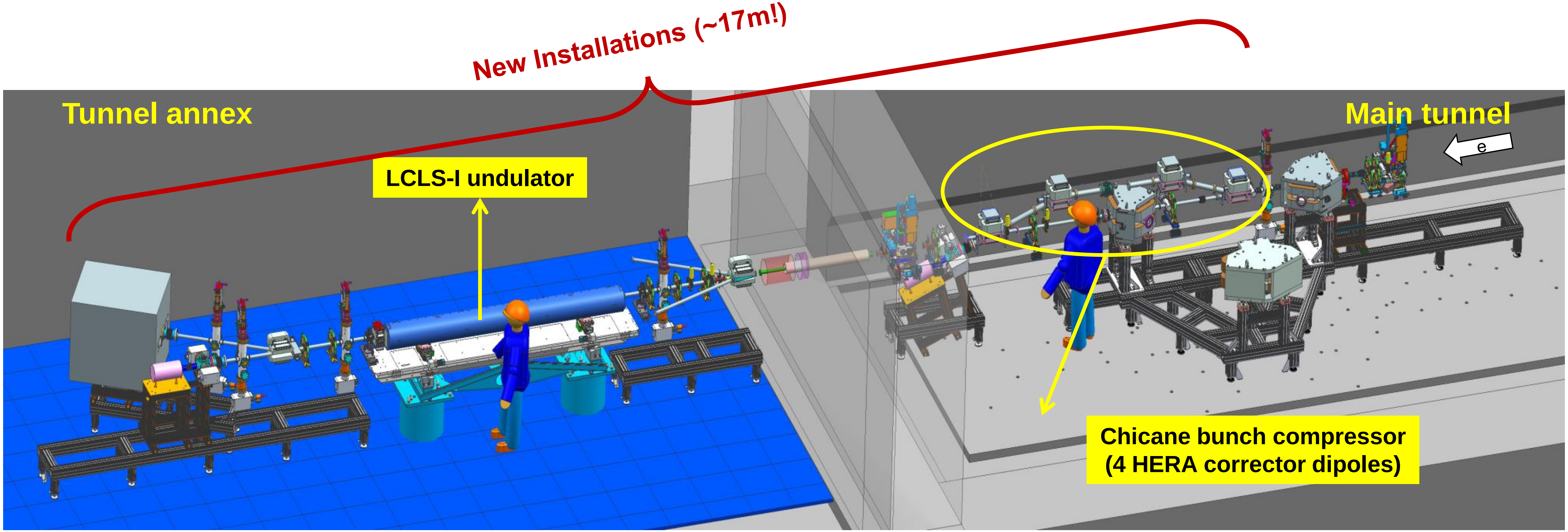






PITZ4 Setup for THz generation

PITZ Beamline Upgrade for THz Proof-of-principle Experiments

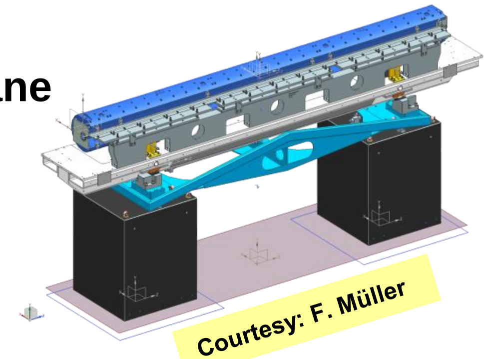


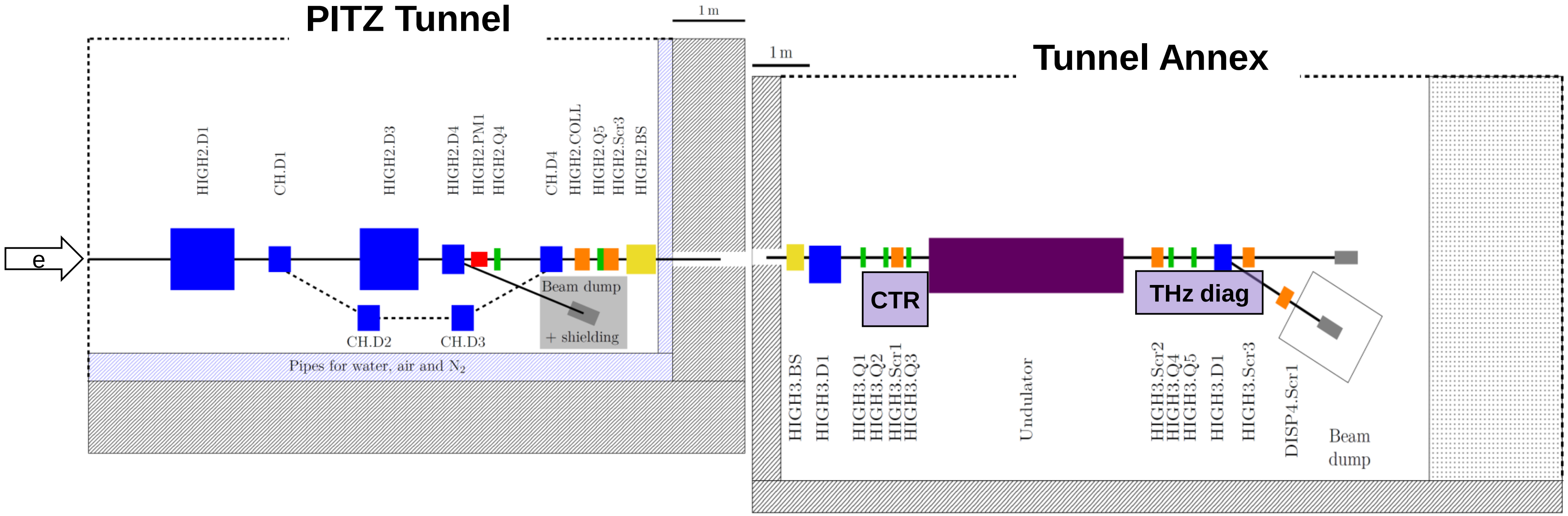
PITZ4 Setup for THz@PITZ

Courtesy T. Weilbach

Beam line technical design and Infrastructure

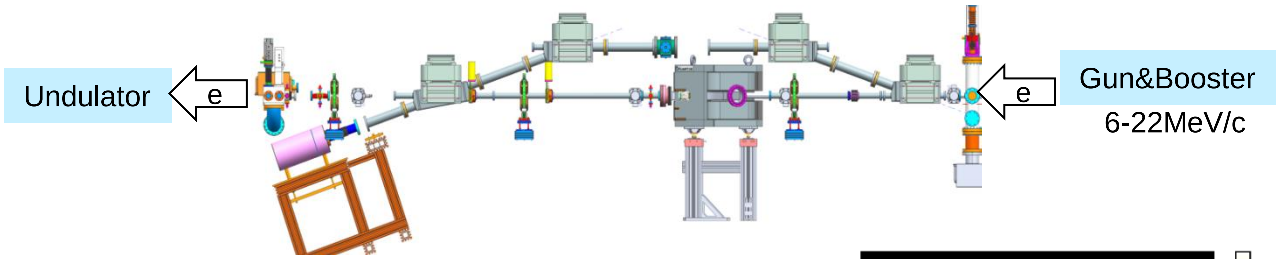
- **Layout of beam line fixed, parts are being designed / built** (screen stations, support frames, etc.)
- **Infrastructure setup finished** (power, network and gas distribution), **crane** installed and tested
- New support structure for undulator ordered and received (granite blocks and frame)
- **Personal interlock** installed & tested, waiting for TÜV approval
- Simulations on radiation safety concept for separate tunnel operation ongoing





PITZ Bunch compressor

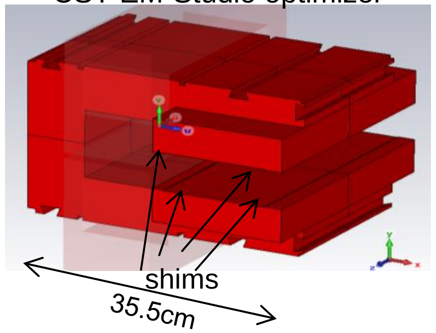
Magnetic chicane based on HERA steerers

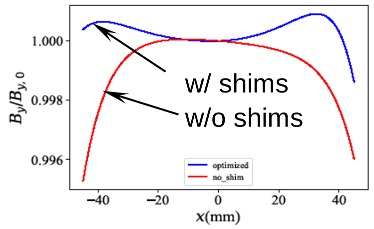


- To optimize for SASE
  - high averaged currents, longer than cooperation length
  - high charge, longitudinal *flat-top* and *Gaussian*
- To support tuning seeded FEL (by photocathode laser pulse *modulation*)
- To optimize for superradiant
  - short bunch length
  - relatively low charge 10pC-1nC, longitudinal *Gaussian*
- To optimize for low-Q sub-ps high-repetition rate applications (~1pC)

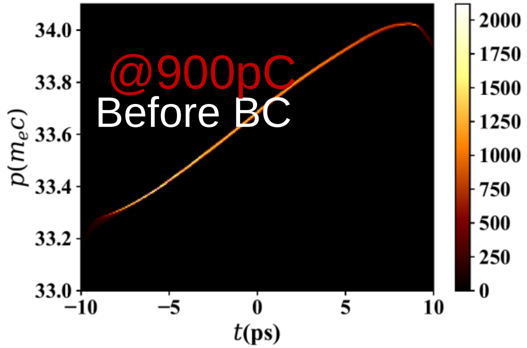
Old HERA magnet (steerer) with new pole shoe

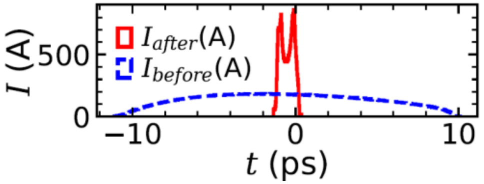
CST EM-Studio optimizer

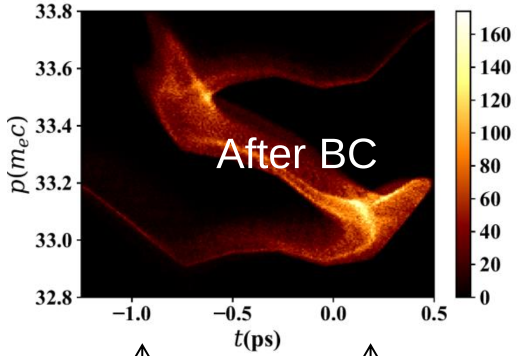




bending axis

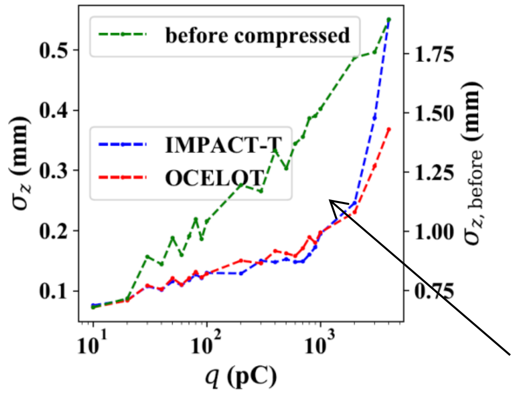


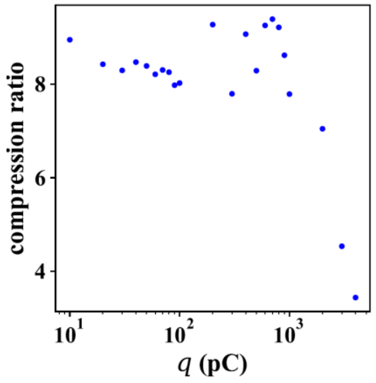




head
tail

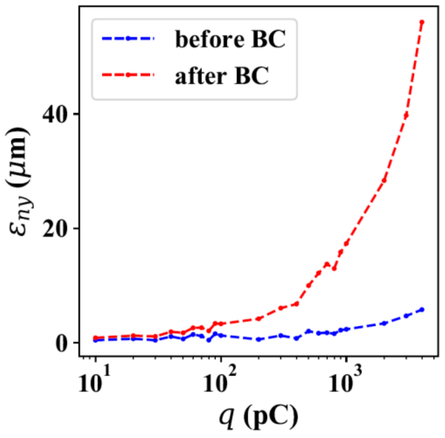
rms beam size at full compression





S2E optimization could allow compression at high charges

transverse emittance growth



Conclusions and outlook:

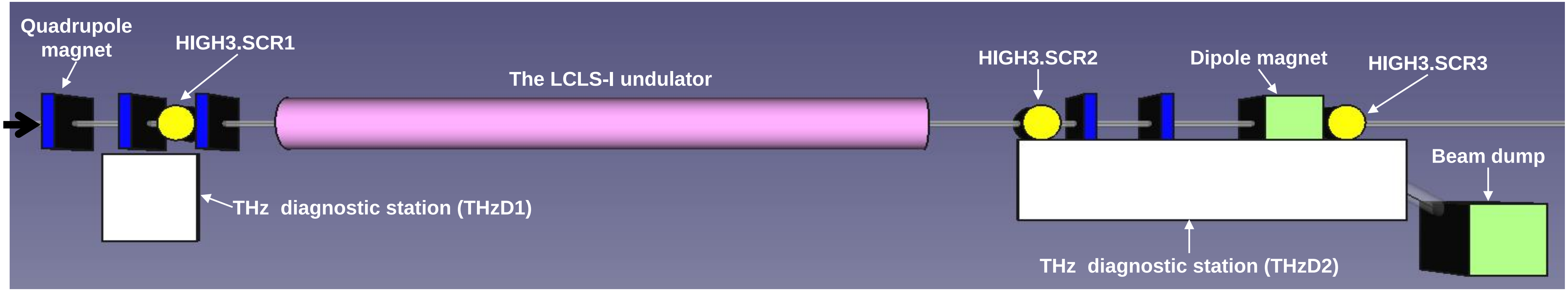
- S2E optimization of gun and booster phase has been developed for **flexibility** in tuning bunch length, current profile, etc.
- Optimized gun phase linearizes energy chirp, thereby **compression** ratio.
- **Ocelot** and **ImpactT** results are benchmarked.

Courtesy A. Lueangaramwong

Speed talk

THz Radiation Diagnostics systems for PITZ4

Design considerations are ongoing



HIGH3.SCR1 ➔THzD1

A screen station (HIGH3.SCR1) located downstream from the chicane is used as a *CTR* station for electron bunch length and compression efficiency measurements:

- *Relative* radiation power / energy
- Spectral distributions (interferometer setup)

HIGH3.SCR2 and HIGH3.SCR3 ➔ THzD2

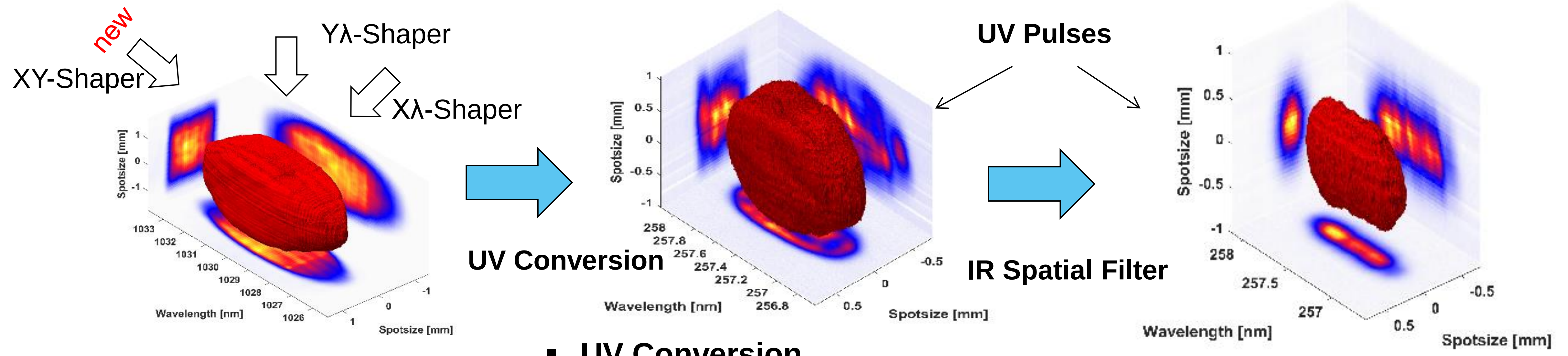
Two screen stations (High3.Scr2 and High3.Scr3) for coupling *FEL radiation* out from the beamline:

- Radiation power / energy
- Transverse distribution / polarizations
- Spectral distributions (interferometer setup)

- The THz beamlines have been designed to transport with intensity losses up to 40% for λ_{rad} between 20 and 100 µm
- The radiation transported distances are up to 2.5 m
- Considering to transport in a closed system to avoid THz absorption in air

Courtesy P. Boonpornprasert

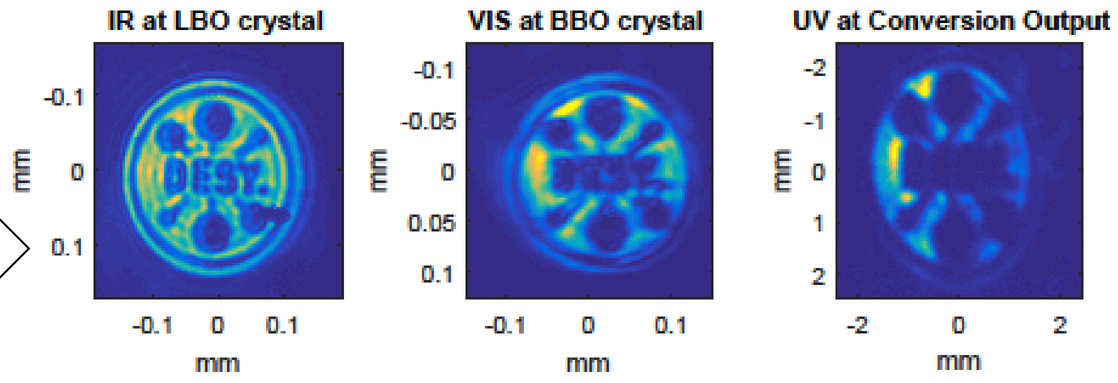
Developing 3D ellipsoidal laser pulses (photocathode laser)



- **UV Conversion**
  - 4th harmonic nonlinear conversion heavily exaggerates small non-uniformities
  - Possibly insufficient optical resolution

- **IR Shaping**
  - 3 SLMs (spatial light modulators) Shapers allow for shaping of all 3 projections
  - Direct feedback loops with IR-Spectrograph allow high quality shaping

Transverse Shaping through conversion

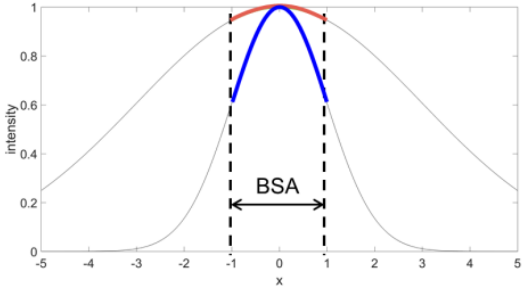


- **Spatial Filtering**
  - With spatial filtering non-uniformities are removed
  - Temporal/spectral shaping still possible. Some emittance reduction possible in this mode. Experiments have been delayed due to PITZ machine problems

Courtesy C. Koschitzki

Emittance measurements with truncated Gaussian pulses

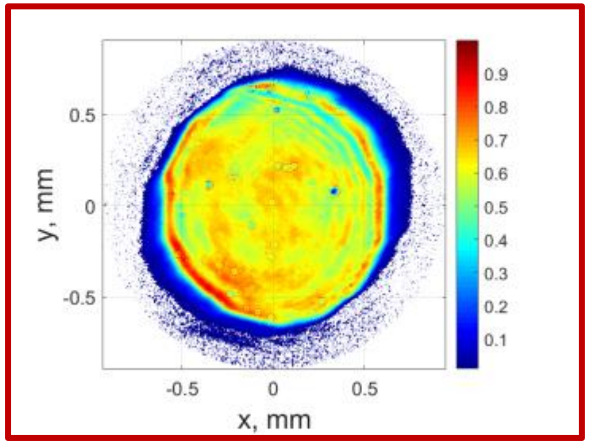
Idea: transverse truncation leads to lower emittance and better efficiency (less cutting at BSA)



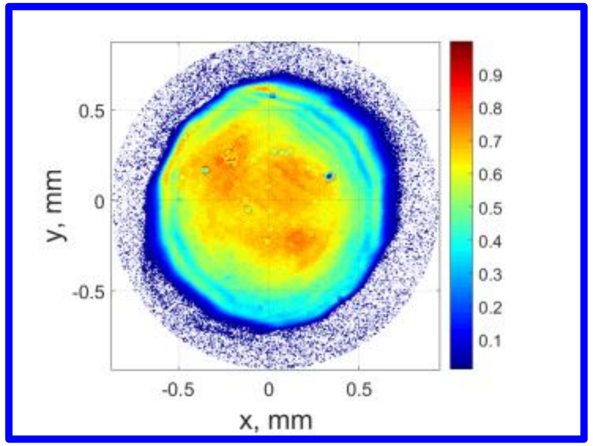
Projected emittance measurements:

- Laser temporal: 6 ps (FWHM) Gaussian
- Bunch charge: 500pC
- Gun: 6.3 MW_p (~60 MV/m)
- Electron momentum after booster: 20 MeV/c
- Beam shaping aperture (BSA) diameter: 1.3 mm

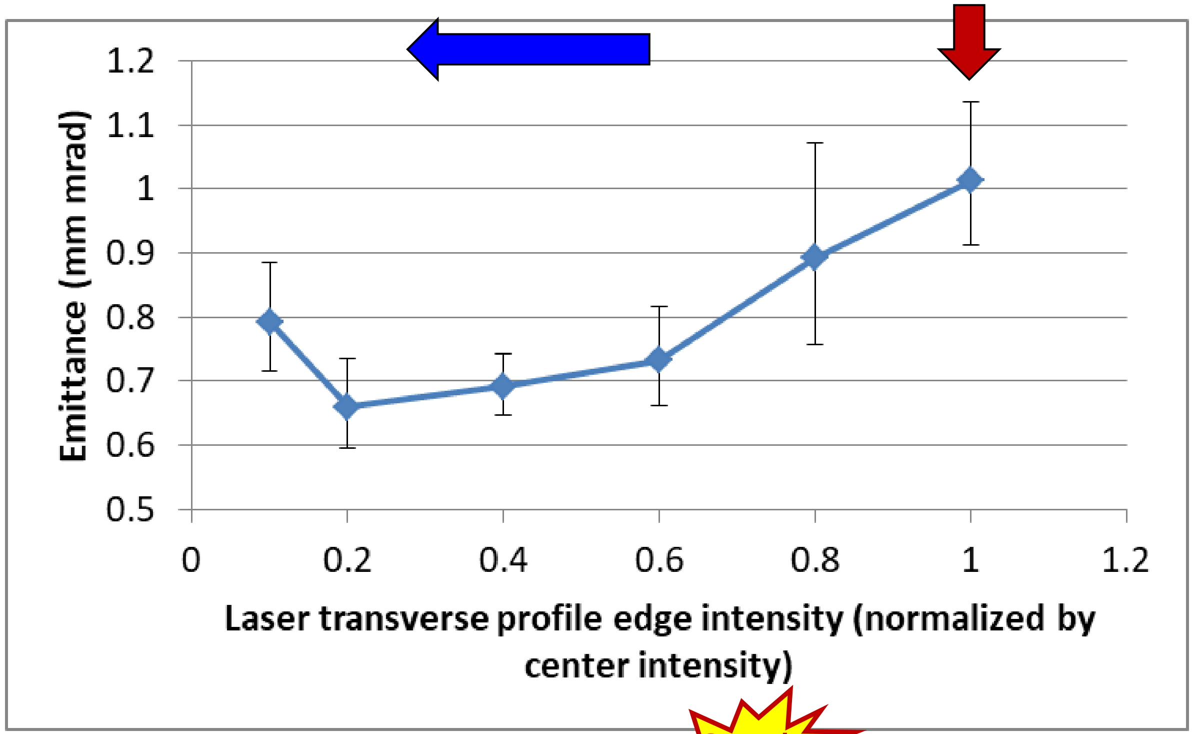
Homogeneous



Truncated Gaussian



Truncated Gaussian **Homogeneous**



34% emittance improvement!

- 15% for 250 pC bunch charge

Courtesy M. Gross

Speed talk

Cathode Response Time measurements

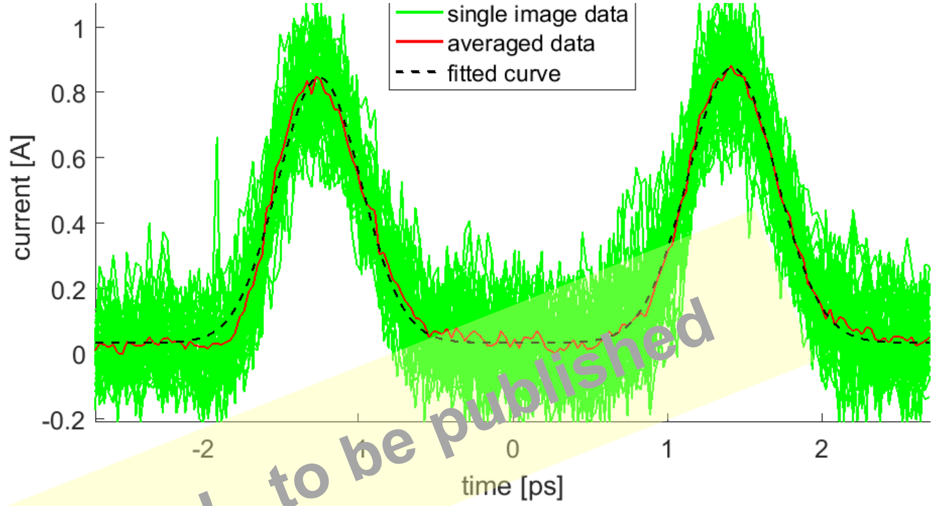
Preliminary results

Speed talk

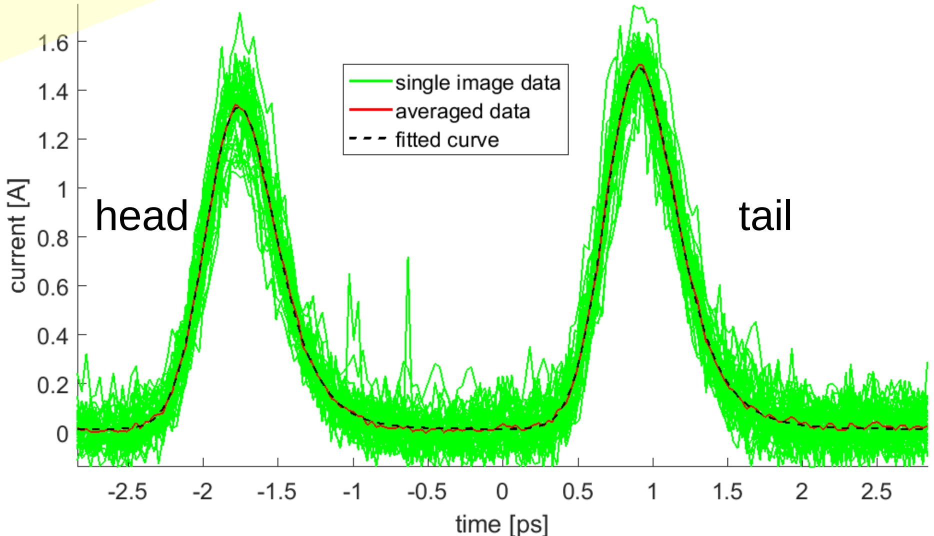
Courtesy G. Loisch

- Reference measurements with Mo and Au cathodes
- Various Cs_2Te cathodes measured:
  - Different thicknesses (5nm, 10nm, 15nm)
  - Production @INFN Milano & DESY HH
  - Fresh and used
- Preliminary results:
  - Bunch shape as predicted!
  - Shortest (exp.) response time ~180 fs ±40 fs
  - Significant differences between INFN & cathodes
  - No intuitive dependence on thickness
- Thinner cathodes and other materials being prepared (CsKSb, …)

Au, 1.34 pC *(Gaussian fit)*

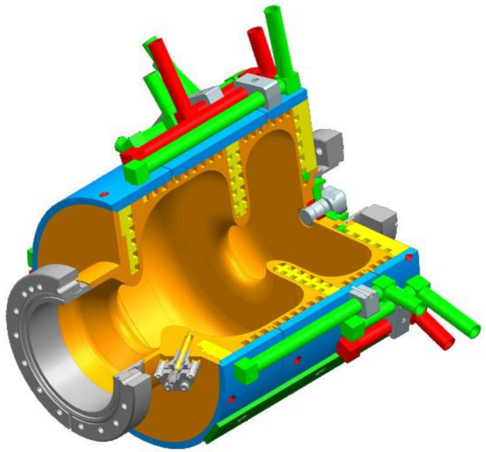


Cs2Te (10nm DESY), 1.8 pC *(Gaussian exp. fit)*



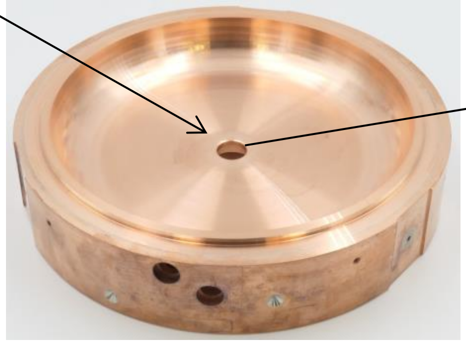
(Near) Future Plans: Gun5 at PITZ

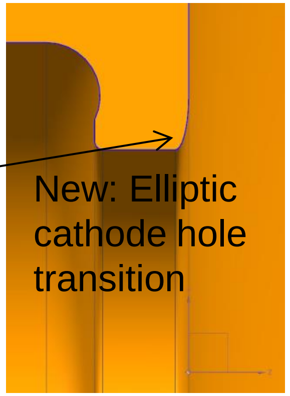
Gun5 fabrication, installation and tests



- Gun5 allowing longer bunch trains for FLASH and XFEL has high priority to reach longer RF flat-tops (up to **1 ms**) for providing more bunches to users at FLASH and European XFEL.
- New cavity **design** (**elliptic** shape including **cathode hole transition**, extended cooling)
- Further developments of the LLRF system (**RF pickup**, detuning).
- Due to COVID-19 workflows had to be reorganized (workshops, supplier, communication etc.)→ slow progress in production since mid of March.
- <u>Status:</u>
  - All gun-bodies were final machined in Zeuthen
  - Currently external optical quality control of the RF-surfaces roughness
  - In parallel welding of the vacuum flanges
  - *BUT: recently a small damage was produced on RF surface during quality control measurements in Hamburg → consequences to be analyzed*
- <u>Timeline:</u>
  - October: brazing of vacuum connections + leak check
  - November: brazing of water connections + tuning
  - December: CO_2 cleaning + start of set up in Zeuthen
  - January: set up in Zeuthen + start installation at PITZ
  - February: final installation + start conditioning

Final machined cathode body of Gun5





Final machined front body of Gun 5 with pick-up and symmetry holes

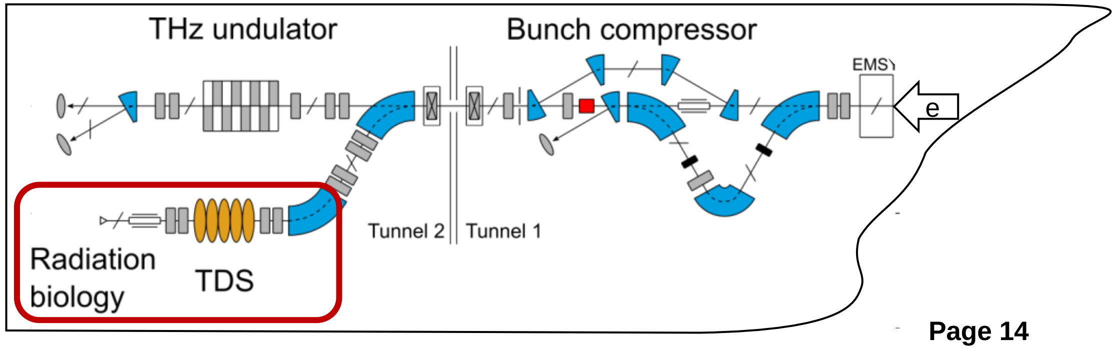
Courtesy S. Philipp

Conclusions and Outlook

☼=speed talk

Status and future plans of PITZ

- **THz@PITZ** (developments on accelerator based THz source for pump-probe experiments at the EXFEL):
  - LCLS-I undulator for proof-of-principle experiments (re-measured at HH, horizontal gradient modeled, compensation coil is under design) ☼
  - Beam line technical design and Infrastructure (setup is finished, details are under finalization, implementation is ongoing)
  - Bunch compressor (s2e simulations are performed, technical realization is ongoing) ☼
  - THz diagnostics (design is under finalization)
- Progress in **photocathode laser** developments:
  - **3D ellipsoidal** pulses (in progress → IR, UV, spatial filtering)
  - 2D transverse shaping → **truncated Gaussian** pulses → >30% emittance improvement measured for 500pC ☼
- **Slice emittance** measurements using slit scan with TDS and quads applied → test measurements
- Cathode (Mo, Au, Cs_2Te of various thickness) **response time** measurements (procedure ~mature and performed routinely) ☼
- Upcoming:
  - **Gun5** fabrication is ongoing
    → final installation and conditioning start is expected in 02/2021.
    → BUT: recently a small damage was produced on RF surface during quality control measurements in Hamburg → to be analyzed
  - Proposals on **Radiation Biology**:
    - FLASH radiation therapy promises significant increase of therapeutic window
    - BUT many effects are not understood yet!
    - Since PITZ can offer uniquely wide beam parameter range, systematic studies of FLASH radiation therapy are planned at PITZ



Thank you!

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