PITZ Activities for FLASH and European XFEL

Frank Stephan for the PITZ team, Travemünde, February 21st, 2018

Content:

- New contributions to the PITZ Collaboration
- Report on operation of Gun 4.6
- Progress in modelling the photoemission process
- Installation and test of gun quads at XFEL
- Status of Gun 5 development
- Developing 3D ellipsoidal laser pulses → improved beam quality
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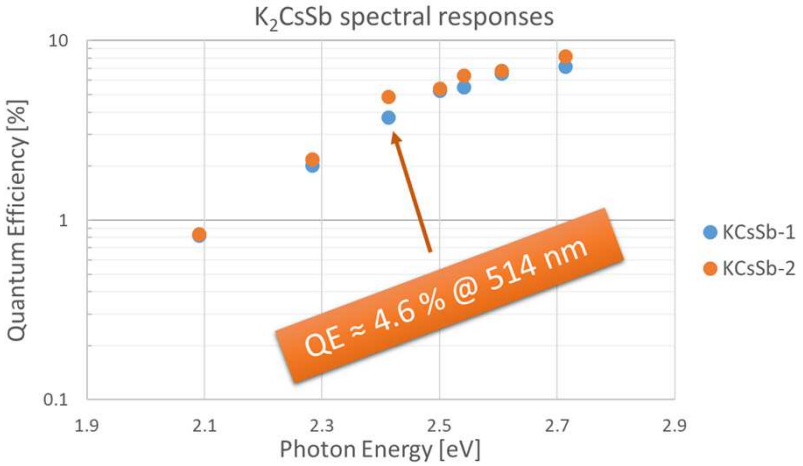
- Summary & Outlook (Gun 4.5)

New contributions to the PITZ collaboration

- **XFEL participation in PITZ has started**
  - Part of personnel and operation costs are covered by **XFEL funding** (XFEL operation and R&D)

- **INFN Milano (LASA) started working on the development of green cathodes on the LASA plug design (in operation at PITZ / XFEL / FLASH / REGAE / SINBAD / LBNL / FNAL)**
  - First **sequential deposition** on test sample in week 47/2017 (“proof of principle”)
    - Sb 10 nm
    - K until max QE
    - Cs until max QE
  - Second sequential deposition 1 Dec 2017
    - Growth as before
  - Next steps
    - Improve temperature control
      - Not uniform cathode growth
    - Design new source layout in view of **co-evaporation in the near future**

View into the prep chamber



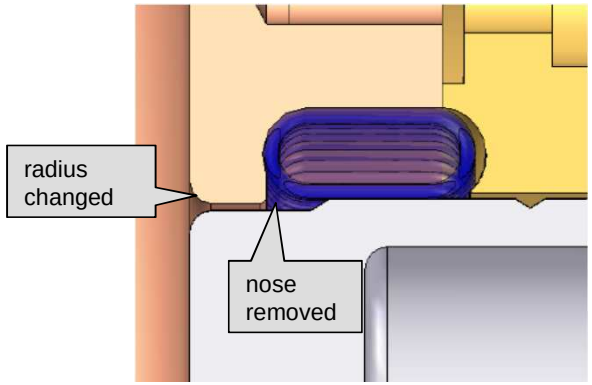
Operating experience with Gun 4.6

More than 1.6 years of operation

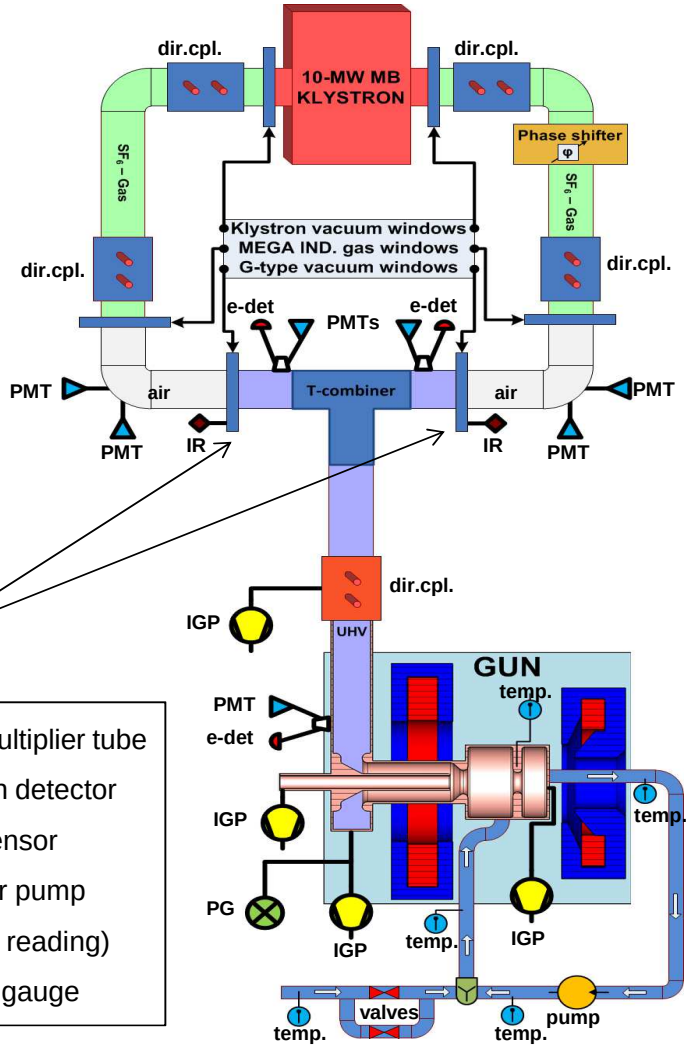
Operating experience with Gun 4.6: current setup at PITZ

Features of the Gun 4.6 setup (reminder)

- Gun 4.6 with new type of cathode spring holder design (watchband-reloaded)



- two conditioned DESY-type windows for the 2-window setup (similar as in 2011)
- T-Combiner with optimized RF design for best window positioning for reflections
- gun conditioning started on 7.3.2016



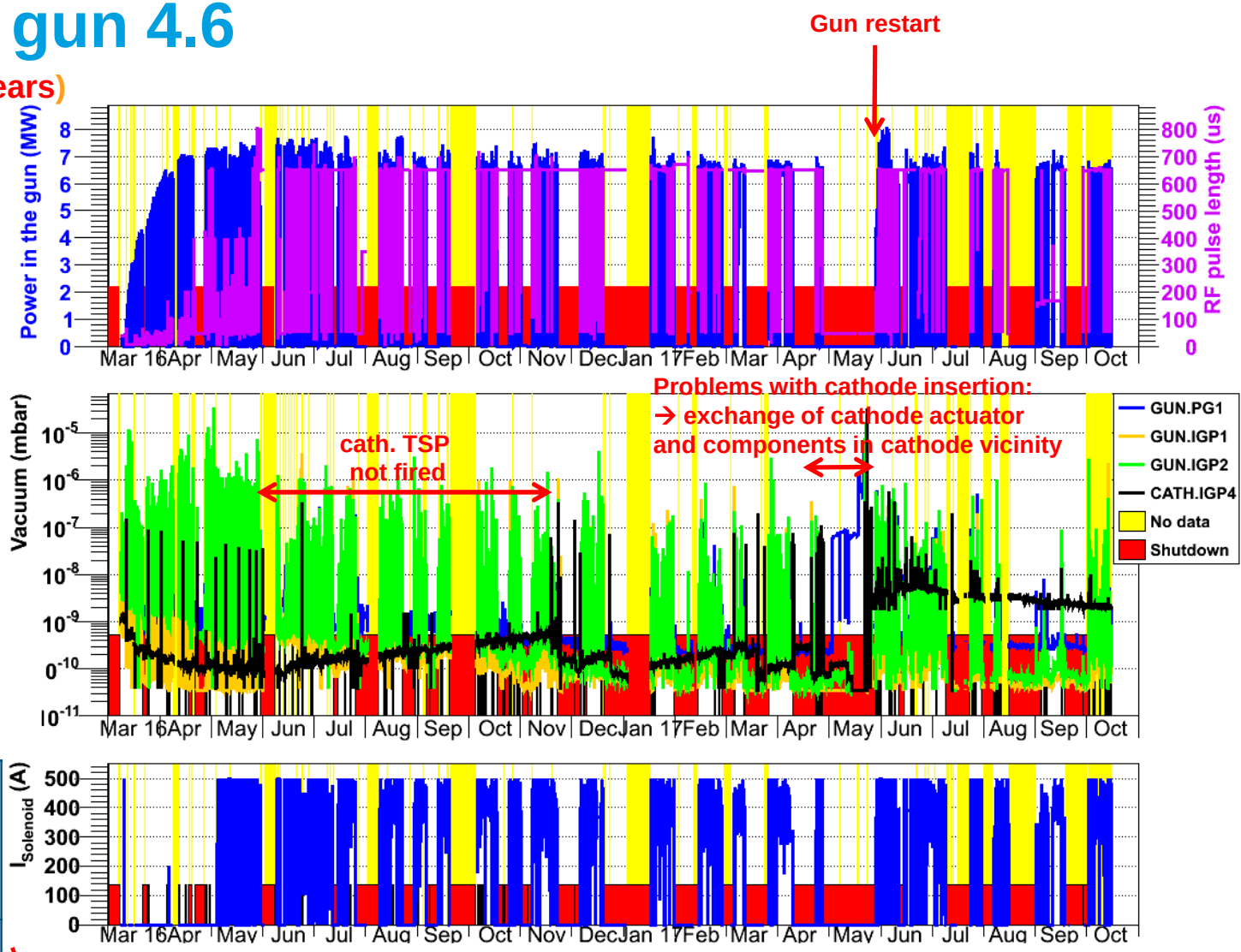
PMT – Photomultiplier tube
e-det – Electron detector
IR – Infrared sensor
IGP – Ion getter pump (pressure reading)
PG – Pressure gauge

Operation history of gun 4.6

(from 07.03.2016 to 16.10.2017 → >1.6 years)

- ~1 month to reach full power @100 us.
- Initial conditioning slow, but everything was new: gun, directional coupler, T-combiner.
- Slow increase of pressure in the cathode region: TSP has not been fired from May to November 2016.
- Problems with the cathode insertion on 21.04.2017:
  - Resonance temperature difference 7deg
  - Strongly increased dark current

  → Exchange of the Cathode Box, Cathode Spring, Cathode Spring Holder, Bellow, **z-Actuator (guilty)**.
- 30.05.2017 Gun Restart. Nominal operational **parameters recovered within 1 week**. Stable operation reached in ~4 weeks. **No problem observed afterwards.**

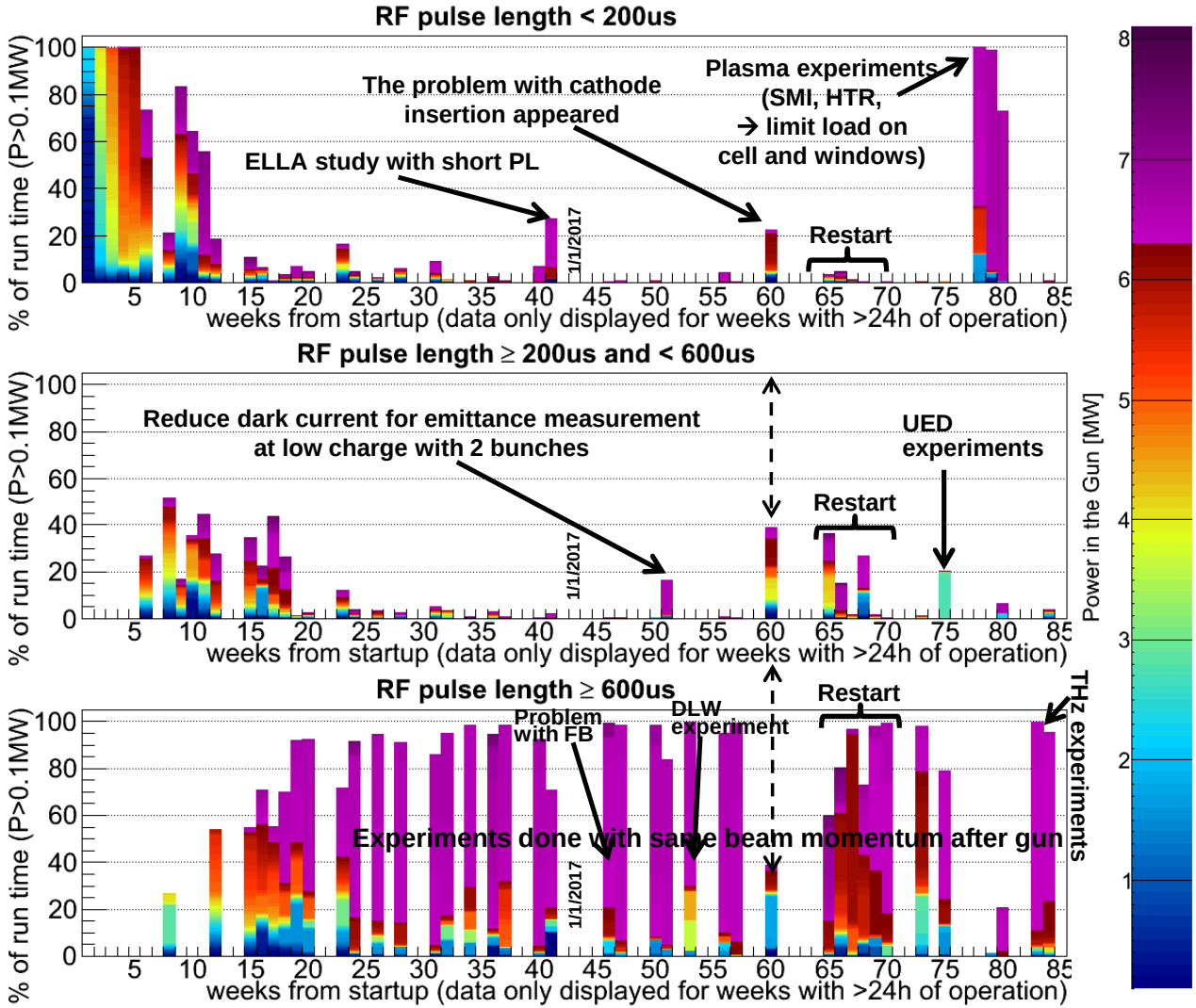


DC at the end of run. The data is measured as amplitude of the signal.	**PITZ:** Max. DC @ Power=**6.4MW**, Imain=**0A**, FC@1379mm	**FLASH:** DC= **6.5µA** @ Power=**5MW**, Imain=**312A**, FC@1540mm	**XFEL:** DC= **25µA** @ Power=**5.2MW**, Imain=**336A**, DCM@2250mm
DC from the Gun4.6 @ **PITZ**	**41µA**	**1.4µA**	**2µA** ~confirmed

Power and pulse length usage during operation of gun 4.6

(all data with >100kW in gun taken into account)

- 11 weeks spent to reach 6MW at 650µs at the beginning (similar to gun 4.2 which had 2 Thales vacuum windows)
- **At restart: after only 5 days reached 6.5MW at 650µs**
- Before the cathode insertion problem:
  → 73..99% of weekly run time above 6MW and 650µs since week 24 (weeks 41 and 53 excluded).
  After the cathode insertion problem and reconditioning (since week 69) the corresponding weekly run time was 60..94% (weeks 78..80 excluded).
- **When aiming for >6 MW and >600 µs we had run weeks were for ~97% of the time (and more) these parameters were met (before and after the gun restart).**



Summary of Gun 4.6 operation (>1.6 years)

- No problems with „**watchband reloaded**“ cathode spring design
  ➔ **seems to work !**
- No problem anymore with DESY-type RF windows when operating with 2 vacuum windows at optimized position at 6.5 MW, 650µs, 10 Hz (>24 weeks of full operation mainly at these parameters)
  ➔ **two RF vacuum window solution seems to work !**
- In between (after 13 months successfull operation of Gun4.6 at PITZ) problems to correctly **insert cathode** have shown up on 21.4.2017. Most probable explanation: ➔ **malfunctioning, damage** and **misalignment** of **z-actuator** of cathode system (~10 years old) ! → actuator was exchanged together with cathode spring, its holder, bellow, and cathode box. Operation of **Gun4.6 restarted** on 29.5.2017 **without problems**; standard run parameters reached in **~1 week**; stable operation reached in ~4 weeks.
  5 cathode extractions/insertions without problems since May 2017.

Next steps:

- Gun 4.6 was sent to XFEL on 14. 11. 2017. Single Thales windows at optimum position was mounted (increase of gun gradient currently not needed). Previous XFEL gun serves as full functioning spare gun.
- Gun 4.4 (contact stripe cathode spring design) will be equipped with DESY-type window at optimum position to have a 1:1 spare for FLASH in case current FLASH gun has a problem
- **Gun 4.5** (contact stripe cathode spring design) will be equipped with **2 Thales windows at optimized position** for conditioning and operation at PITZ

Progress in modelling the photoemission process

Progress in modelling the photoemission process

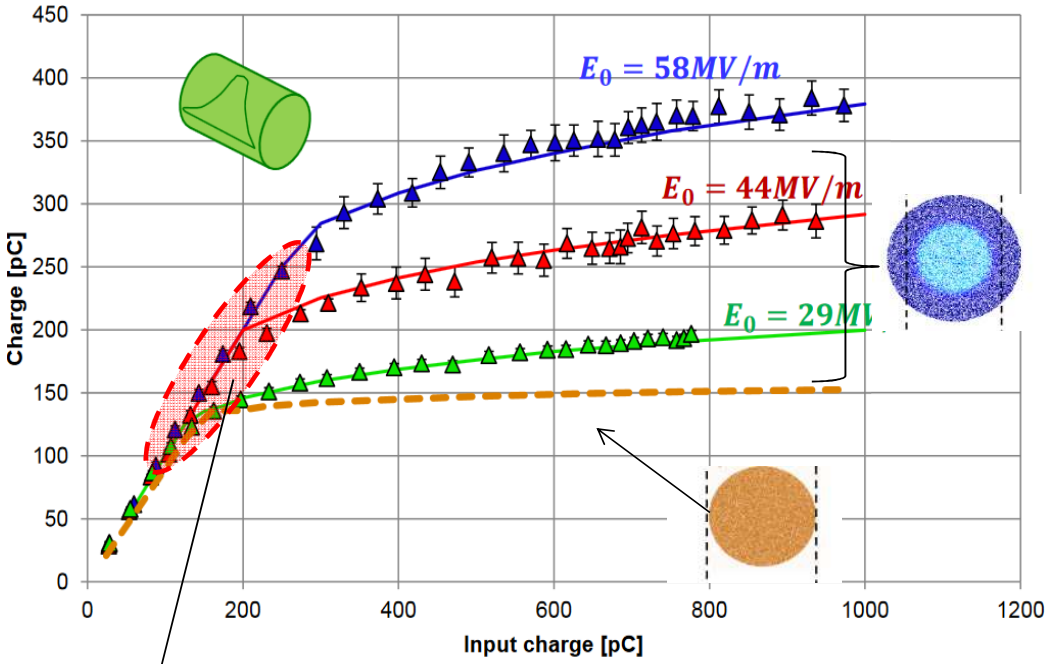
Collaboration with TU Darmstadt and colleagues at DESY in HH

- Photoemission beyond linear region is not well simulated.
- Short Gaussian laser case is improved using Core + Halo model.
- For long laser pulses more relevant to FELs (e.g. Flattop), agreement is worse → **work needed**.

Collaborations with TU Darmstadt

- o 3D photoemission modeling using full EM Lienard-Wiechert approach.
- o Cathode surface barrier correction due to Schottky effect and laser potential.
- o Cathode physics model determines 3D QE distribution.

→ Ye Chen et al., NIM A 889 (2018) 129-137.
→ C. Hernandez-Garcia et al., NIM A 871 (2017) 97-104.



Best beam emittance located in transition region, needs more accurate photoemission modeling.

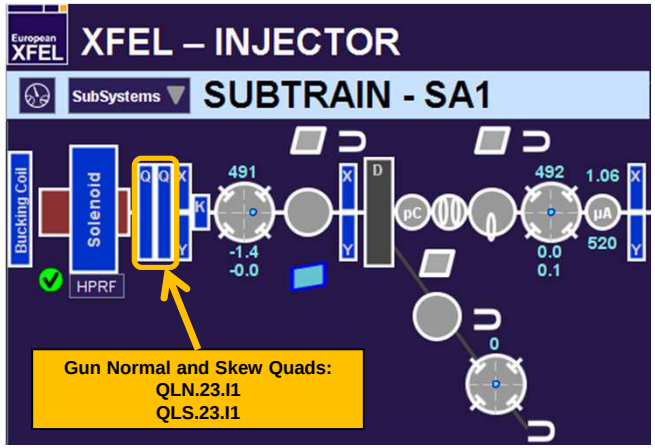
Gun quads

→ correct quadupole effects from gun coupler and solenoid

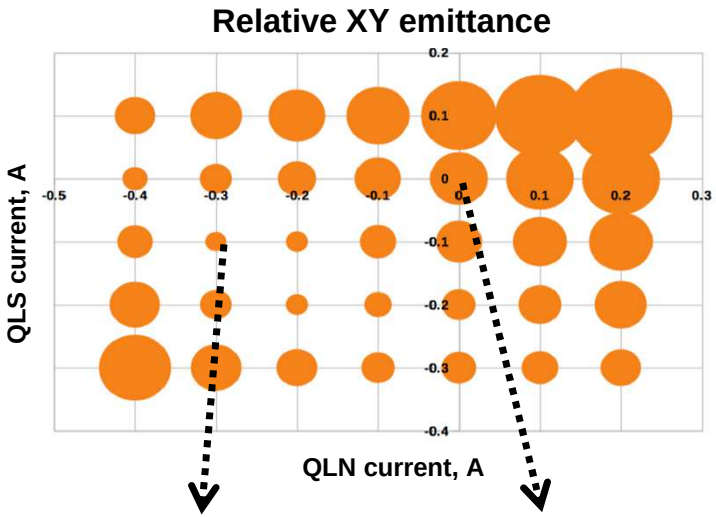
Installation (Aug 2017) & test (Oct 2017) of gun quads at XFEL

The injector settings for the tests:

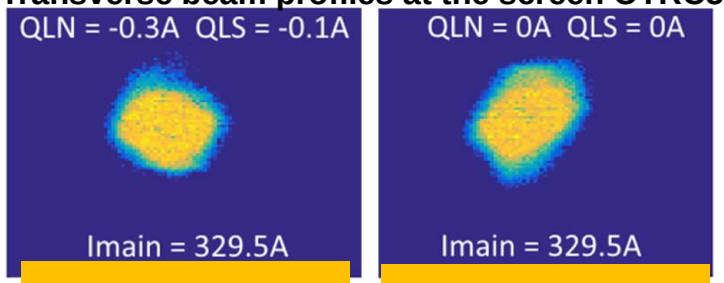
- Gun power: 5.13MW (53MV/m)
- RF pulse length: 70 µs
- Gun RF phase: -43deg (w.r.t. zero-charge phase)
- BSA: 1.2 mm
- Beam momentum after the gun: unknown
- Beam momentum after AH1: 130 MeV/c
- Number of pulses: 1
- Gun main solenoid current 329.5 A
- Gun bucking solenoid current 17.7 A
- Bunch charge: 500 pC
- A1 and AH1 adjusted for MMMG phase



Results of the tests:



Transverse beam profiles at the screen OTRC59



ε_n = 0.97 mm mrad

ε_n = 1.20 mm mrad

PITZ experience with fully optimized setups w/o/ ↔ w/ gun quads ➔ 10% reduction

➔ **~20% reduction**
(solenoid was not optimized beforehand)

Installed gun quads have Design 2: two quads at a single frame

Quads design parameters:

- Combination of a normal and a skew quad
- Aluminum frame
- 0.56 mm copper cable
- 140 windings per coil
- Q_grad = 0.0117 T/m @ 1A

Update: Compact gun quads at more optimized position – Design 3

Design parameters:

- Combination of a normal and a skew quad
- Aluminum frame (**more narrow than for design 2**)
- 0.56 mm copper cable
- **300** windings per coil

→ will be tested at PITZ with gun4.5

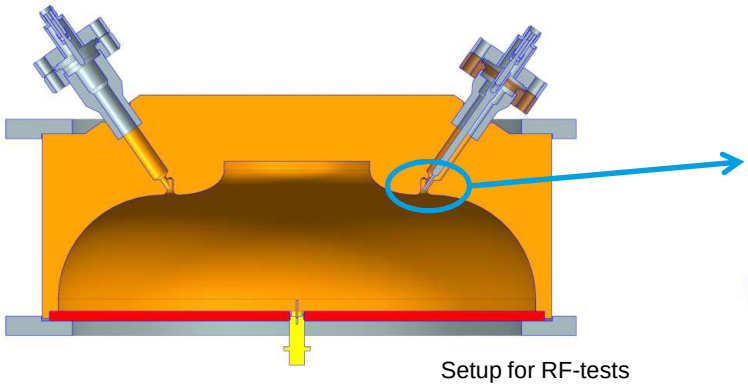
Gun 5 development

Status of Gun 5 development

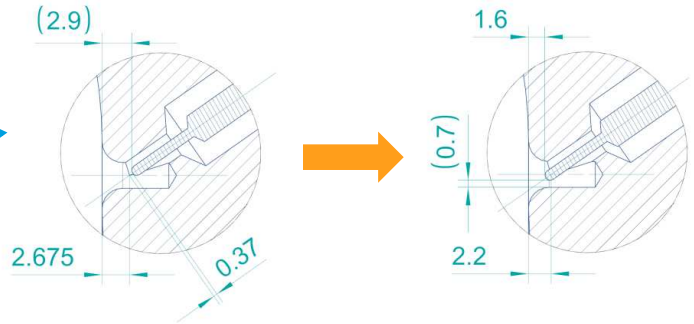
Gun 5 includes RF probe (stability, symmetric power coupler), improved geometry (reduced heating & surface field), better water cooling and reduced deformation (more reliable operation at high duty cycle)

Gun 5 design: V. Paramonov et al., NIM A 854 (2017) 113-126.

- Experiments on test piece showed the need of an improved probe position
  → second probe hole was machined on existing test piece
  → low power **RF-tests successful !**



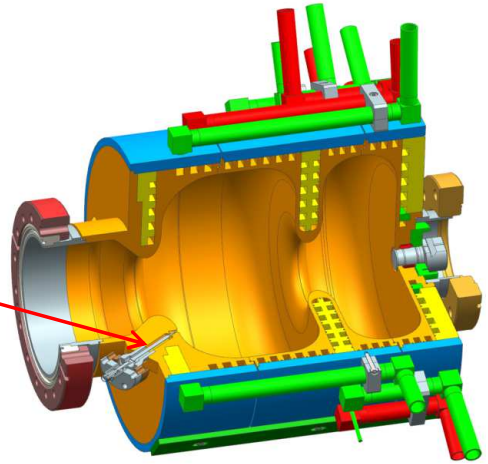
Setup for RF-tests

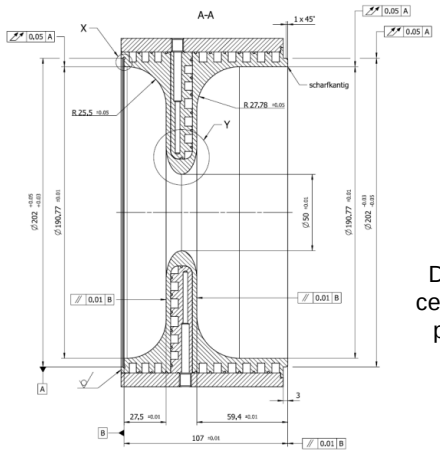


first approach

new design

- Technical design of Gun 5 is settled
  → **production was started (MVS)**
  → final cavity expected to be ready in about week 36/37
  (~Sept.'18, but still several hurdles to take)



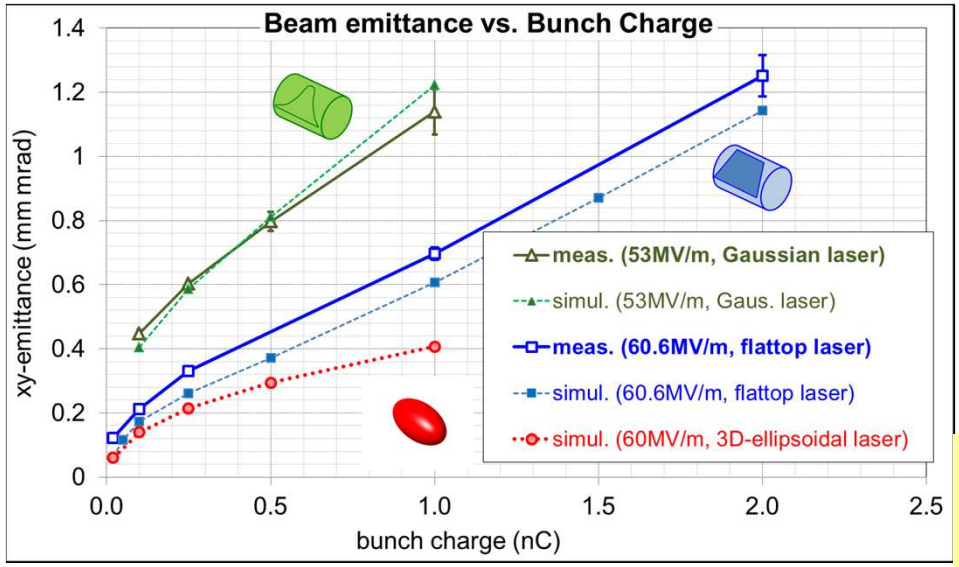


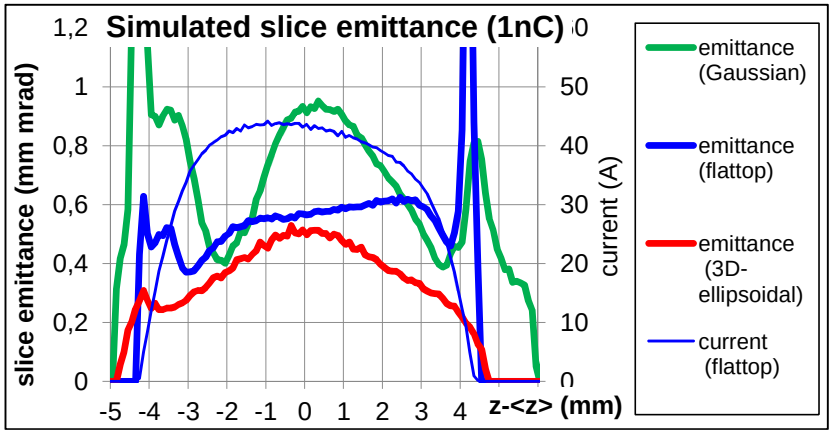
Drawing of the center part to be produced first

Developing 3D ellipsoidal laser pulses

→ improved beam quality

Developing 3D ellipsoidal laser pulses → improved beam quality

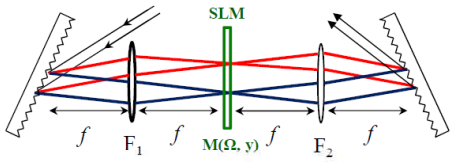




- Laser shaping → **key** for optimizing photoinjector **brightness**.
- Ellipsoidal laser shaping benefits **high bunch charge** beams or **CW guns** (lower gun gradients).

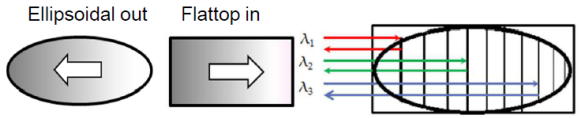
- Two methods to generate 3D ellipsoidal photo cathode laser pulses are under study:

Spatial Light Modulator (SLM) shaper

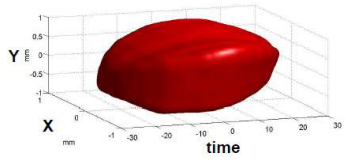


Collaboration with IAP, JINR

NEW: 3D Volume chirp Bragg grating

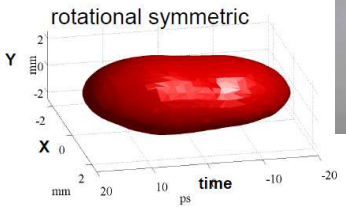


no rotational symmetry



IR cross correlation measurements

rotational symmetric

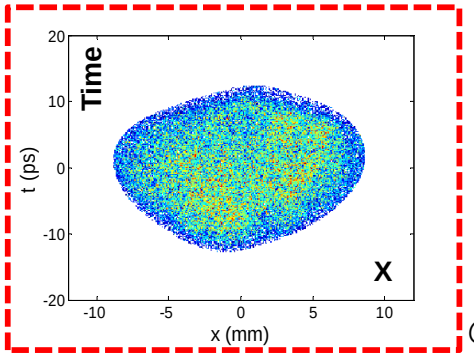


Developing 3D ellipsoidal laser pulses → result of 2017

First experimental results using SLM shaper and the laser system from IAP (Nizhny Novgorod, Russia)

- Laser diagnostics not yet complete
- Limited performance of oscillator + disc amplifier (stability, synchronization, spectrum)
- Limited pockels cells contrast + flatness

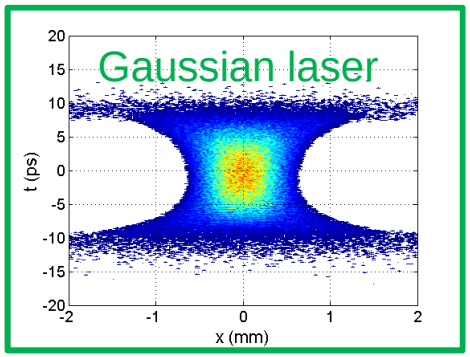
BUT: **electron beam measurements have been performed with SLM pulse shaper !**

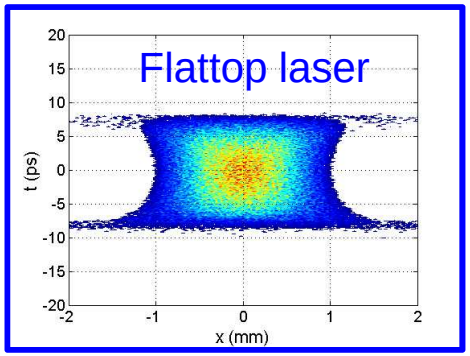


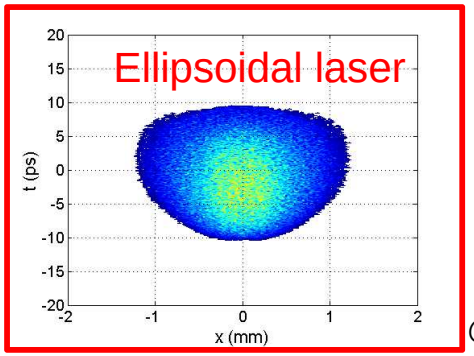
@PST.SCR1

similarity in shape

Comparison with simulated beam shapes (500pC):





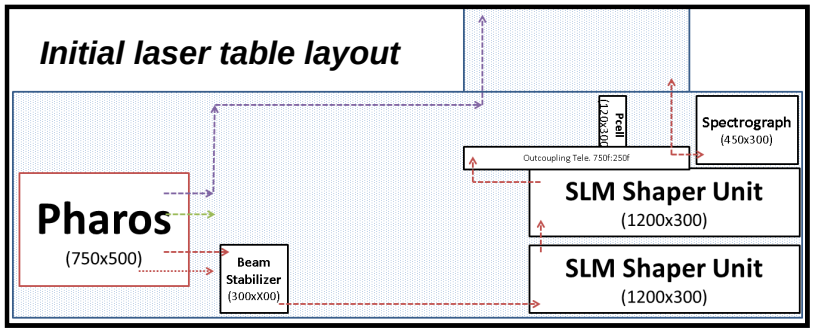


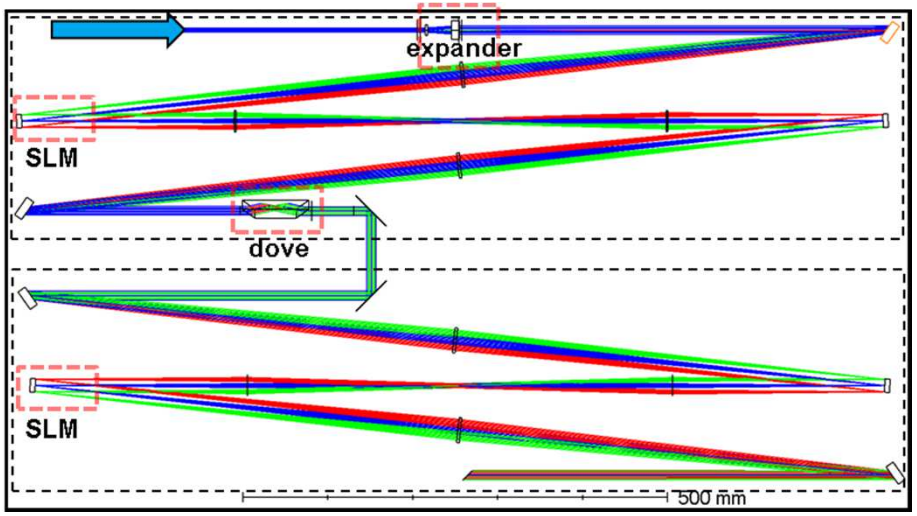
@EMSY1

Ellipsoidal Laser System (ELLA 2.0)

Simplified, linear, robust pulse shaping scheme with new PHAROS frontend

- 20 W, 1 MHz IR commercial laser system
  - 20 µJ @ 1.0 MHz, 40 µJ @ 0.5 MHz, 100 µJ @ 0.2 MHz… etc
- IAP system dismounted, PHAROS frontend installed, uTCA integration and mounting of optical elements on laser table ongoing
- Basic RF synchronized photoelectrons already tested during last run period (→ simplified backup for MBI laser)
- Pulse shaping experiments with **SLMs** (1st) & **Volume Bragg Grating** (2nd) under preparation
- Laser transport beamline concept to be reconsidered

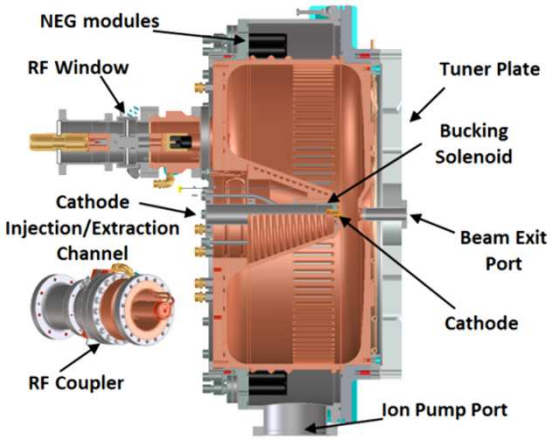




First steps towards NC and hybrid CW gun designs

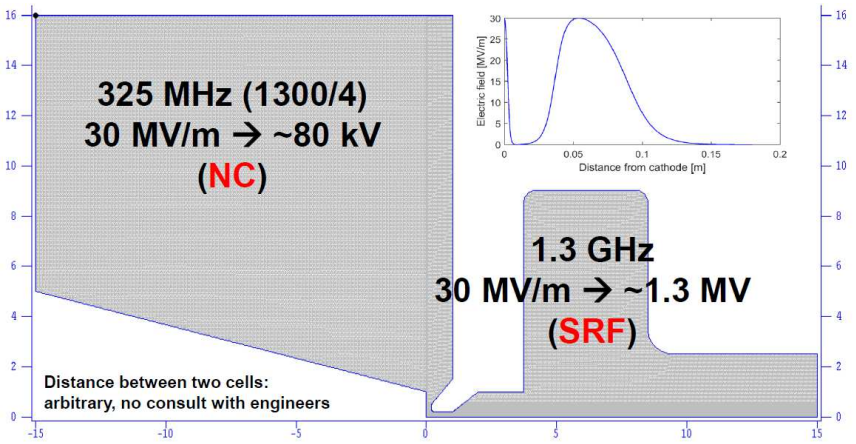
High brightness CW gun developments

- **Next generation** CW NC gun (LBNL type)
  - A **backup solution** for DESY CW electron source.
  - **Cavity re-optimization** based on LBNL gun operation experience
    - compatible frequency, higher shunt impedance, higher gradient…
  - NC gun physical design will be sponsored by XFEL, postdoc (India) did not get visa (>6month), position to be filled from current job announcement.
  - Looking for collaboration with LBNL/SLAC.



PITZ can also support SRF gun development when needed:
- RF simulations
- photoinjector optimizations
- …

- **NC-SC hybrid gun**
  - **New concept:**
    - High gradient, low voltage, NC cathode cell, compatible with high QE semiconductor cathode.
    - SC capture cell close-by for bunching and higher beam energy.
  - **Preliminary design** and simulations show promising results, further investigations to be done.
  - **First discussions done with DESY SRF experts**, feedback expected.



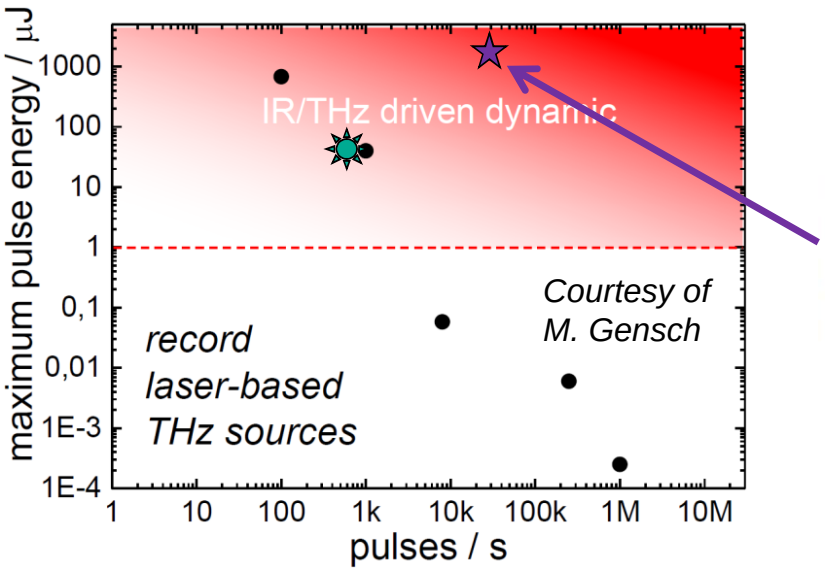
Recent THz Studies at PITZ

Recent THz Studies at PITZ

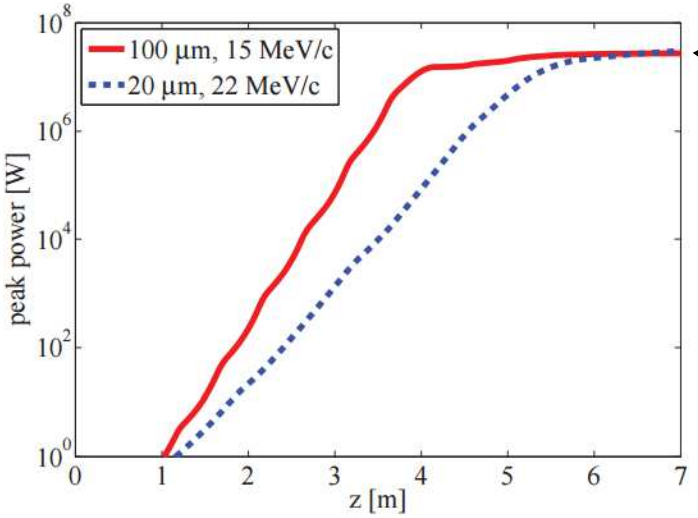
PITZ ←→ prototype THz source for pump-probe experiments for XFEL users

XFEL (~3.4 km) — PITZ-like accelerator based THz source (~20 m) → X-ray, THz — Pump & probe

"Tunable IR/THz source for pump probe experiments at the European XFEL", E.A. Schneidmiller et al., FEL 2012, Nara, Japan, August 2012



Laser based THz is limited at high repetition rate, while most IR/THz driven dynamics needs pulse energy above 1 µJ.



~mJ THz pulse @ MHz train (SASE simulation with PITZ beam, ~4 nC, I_{peak} ~200A)

PITZ like accelerator close to the XFEL end station will allow **unique combination** of **X-ray** and **THz** for **every pulse** in the train (average power, tunability).

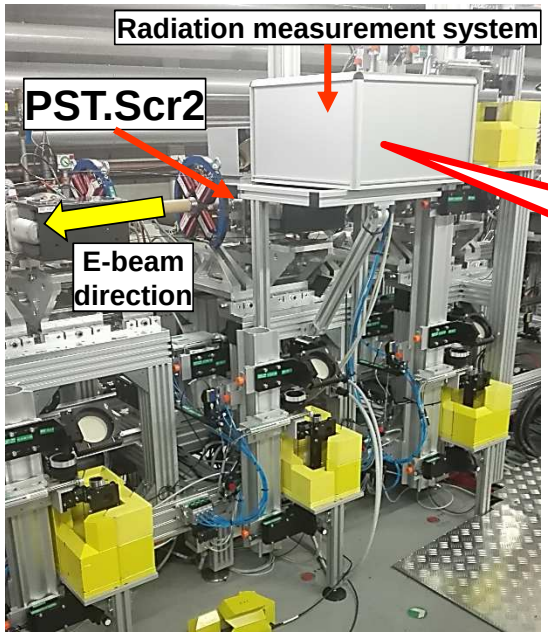
➔ Concept was presented at XFEL THz user workshop
→ interest → considered as long-term solution

Recent THz Studies at PITZ

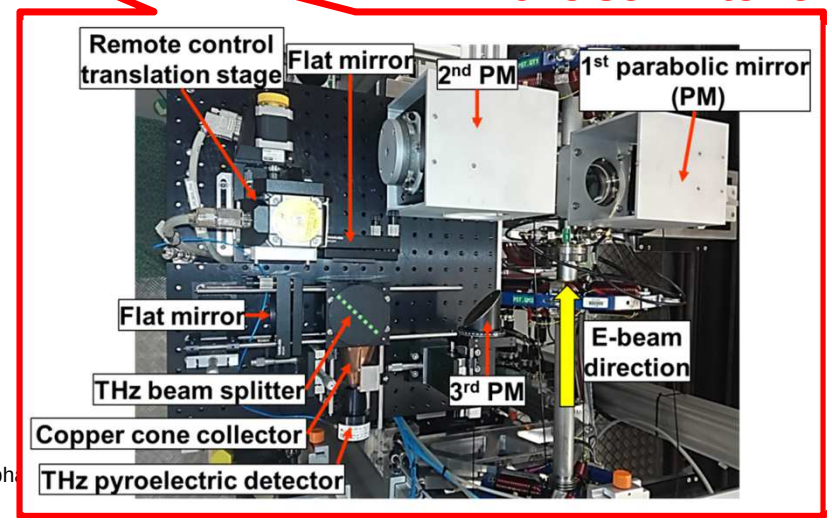
PITZ ← → prototype THz source for pump-probe experiments for XFEL users

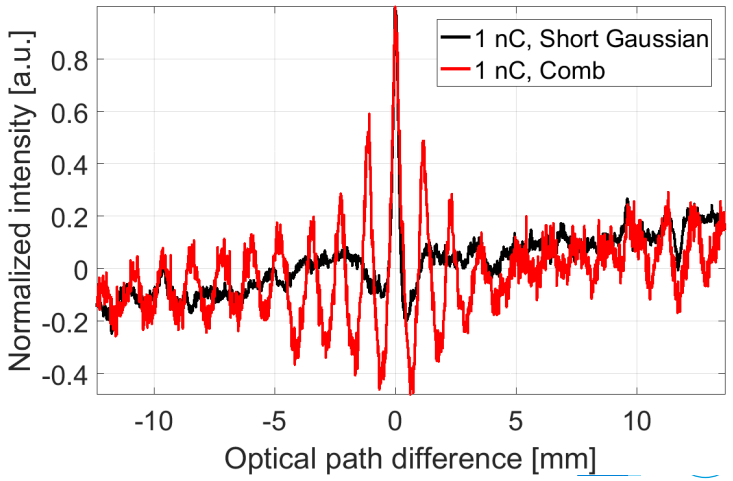
- Successful beam tests at PITZ:
  - 2016: successful **characterization** of **4 nC beams** for THz SASE FEL ☺
  - 2017: first CTR THz radiation generated and characterized

Photo cathode laser shape	Short Gaussian	Comb with 4 uniform peaks
Laser t_{FWHM}	~ 2.5 ps	?
Bunch charge	1 nC	1 nC
Bunch compression	$\Phi_{booster}$ off-crest at -80°	-
Average CTR pulse energy	1.972 µJ	0.164 µJ



THz Michelson interferometer set up & measurement





Summary & Outlook

Summary & Outlook

- Collaboration: **XFEL** participation in PITZ has started
  INFN Milano (LASA) started activity on producing "**green cathodes**"
- Gun 4.6 was in operation at PITZ for >1.6 years:
  → „**watchband reloaded**" cathode spring design and **2 DESY-type RF vacuum windows** operated at optimized position with XFEL specs (6.5 MW, 650µs, 10 Hz) **seem to work reliably!**
- **Gun quads** installed and tested at XFEL and FLASH
- **Gun 5** production has **started** and first thoughts on **NC and hybrid CW guns**
- Successful experiments with 3D shaped pulses, installation of ELLA2.0 ongoing: **PHAROS** front end with pulse shapers of **SLM** and **VBG** type
- Successful **beam experiments** for **THz source for pump-probe experiments** at **XFEL** →
  2016: **4nC** beams for THz SASE FEL, 2017: first **THz measurements** from CTR at PITZ

- Gun4.5:
  - Delivery of T-combiner from MEGA industries was significantly delayed, installation on gun on 31.1.2018
  - Setup equipped with 2 Thales windows at optimum position and as compact as possible
  - Start of conditioning is planned for March 2018.