# Accelerator R&D at PITZ
## (Photo Injector Test facility at DESY in Zeuthen)

Frank Stephan for the PITZ Collaboration, Hamburg, September 5th, 2018

**Content:**

- PITZ: collaboration, facility, operation parameters
- Towards ultimate low emittance beams → **talk: Christian Koschitzki**
- Development of “green” photo cathodes
- Report on gun 4.5
- Next generation of pulsed RF gun
- First considerations towards upgraded NC CW gun design → **poster: Guan Shu**
- Applications:
  - Beam driven plasma acceleration:
    - Self modulation of long particle beams
    - High transformer ratios in plasma

    → **talk: Gregor Loisch**
  - Bunch microstructure generation with dielectric lined waveguides
  - High power, tunable THz source for pump-probe experiments at European-XFEL → **talk: Prach Boonpornprasert**
  - First static UED measurements
- Summary & Outlook

# PITZ Collaboration Partners (formal contract signed)

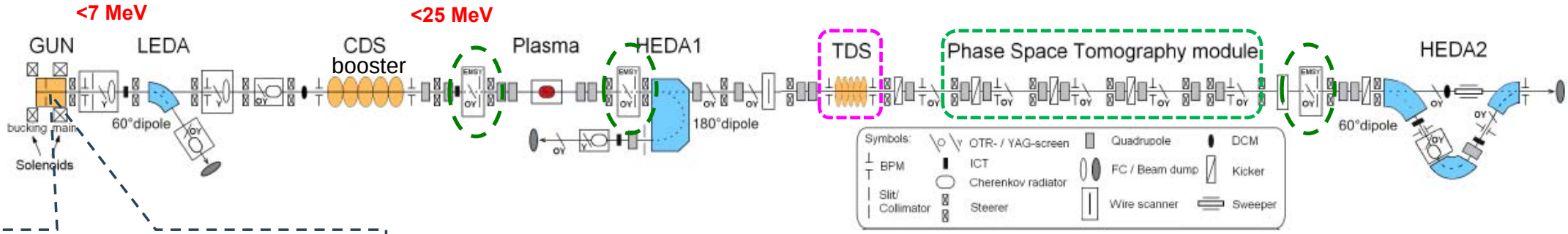
contract on **green** photocathodes

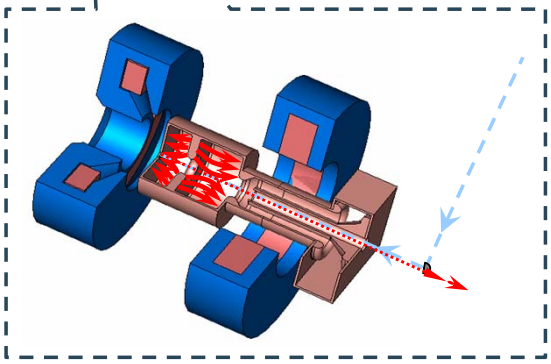
- **Founding partners of PITZ:**
  - **DESY, HH & Z** (leading institute)
  - **HZB (BESSY)** (A. Jankowiak): magnets, vacuum
  - **MBI** (S. Eisebitt): cathode laser
  - **TU Darmstadt** (TEMF, T. Weiland, H. DeGersem): simulations
- **Other national partners:**
  - **Hamburg university**:
    - most PhD students;
    - HGF-Vernetzungsfond;
    - generation of short pulses
    - plasma experiments
  - **HZDR**:
    - BMBF-PC-laser-project between MBI, DESY and HZDR, until ~2009;
    - collaboration between HZB, HZDR, MBI and DESY in SC-gun-cluster
- **International partners:**
  - **IAP Nizhny Novgorod + JINR Dubna**: 3D elliptical laser pulses, THz radiation
  - **INFN Frascati + Uni Roma II** (L. Palumbo, M. Ferrario): TDS and E-meter pre-studies
  - **INFN Milano** (C.Pagani): photocathodes
  - **INR Troitsk** (L. Kravchuk): CDS, TDS, Gun5
  - **INRNE Sofia** (D. Tonev, G. Asova): EMSY + personnel
  - **LAL Orsay** (A. Stocchi): HEDA1 + HEDA2
  - **STFC Daresbury** (D. Angal-Kalinin, B.Militsyn): phase space tomography
  - **Thailand Center of Excellence in Physics** (T. Vilaithong, Ch. Thongbai): personnel
  - **YERPHI** (V. Nikoghosyan) **+ CANDLE** (V. Tsakanov, B. Grigoryan), **Yerevan**: personnel
  - **LBNL Berkeley** (W. Leemans): PWFA, NC CW Gun
  - [**SLAC** (N. Holtkamp): LCLS-I undulators]

# Photo Injector Test facility at DESY, Zeuthen site (PITZ)

**Development, test and optimization of high brightness electron sources for SC linac driven FELs + applications:**

- test-bed for FEL injectors, e.g. **FLASH** and **European XFEL** (**gun cavities** and photo injector subsystems → e.g. **lasers**)
- **high brightness → small $\varepsilon_{tr}$** (projected and slice), **lots of beam diagnostics**
- further studies → e.g. **cathodes**: dark current, photoemission, QE, thermal emittance, …
  → applications like **plasma acceleration**, **THz**, **UED**, …



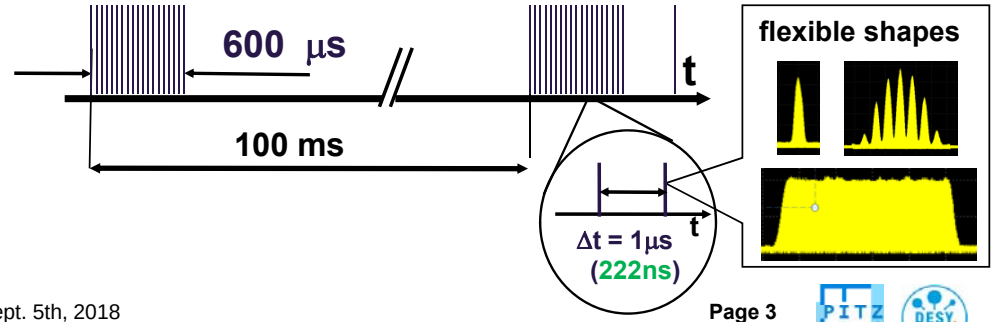



## RF gun

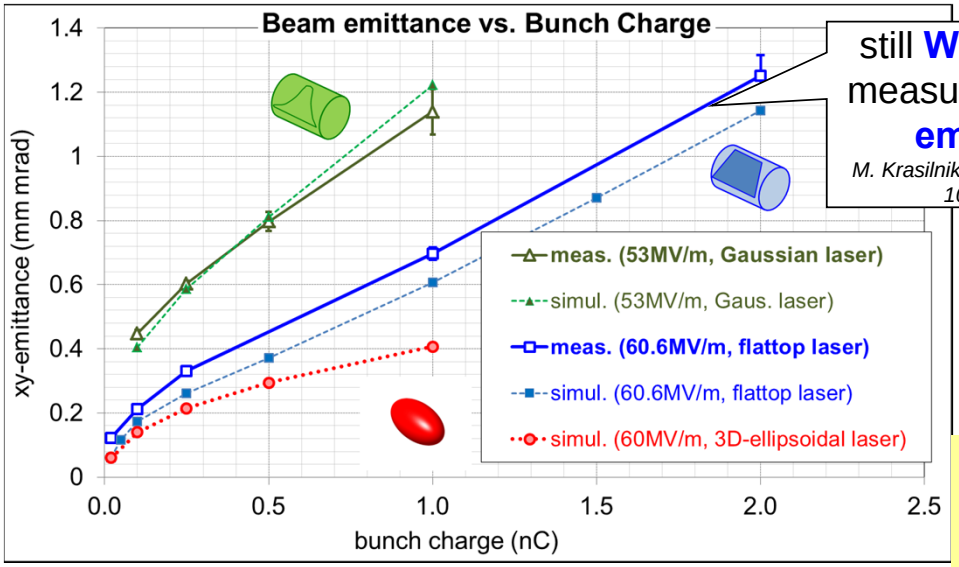
- L-band (1.3 GHz) 1.6-cell copper cavity
- Ecath **>~60MV/m** → 7MeV/c e-beams
- 650us x 10Hz → up to **45 kW** av. RF power
- $Cs_2Te$ PC (QE~5-10%) → up to 5nC/bunch
- LLRF control for amp & phase stability
- Solenoids for emittance compensation

## Pulse Train Time Structure:

PITZ and **EXFEL** run bunch trains with up to 600 (**2700**) laser pulses

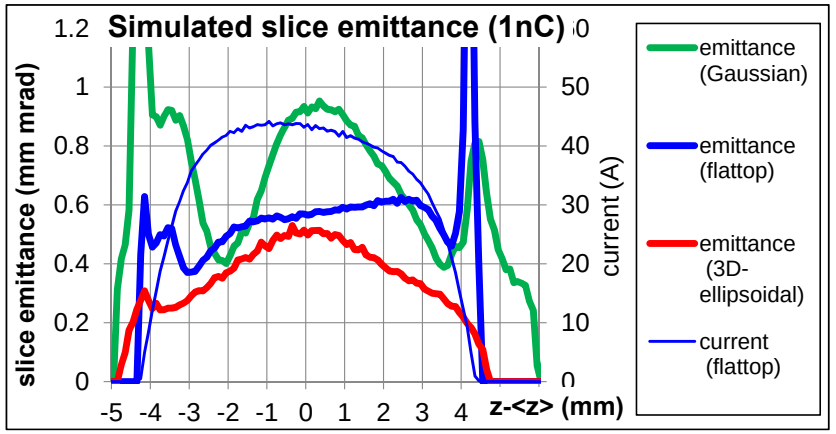


# Towards ultimately low emittance beams → 3D ellipsoidal pulses




still **WR** on **lowest** measured projected **emittances**

*M. Krasilnikov et al., PRST-AB 15, 100701 (2012)*

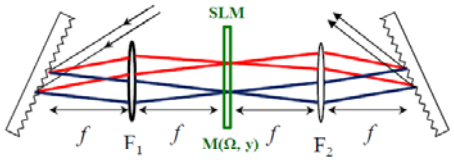



- Laser shaping → **key** for optimizing photoinjector **brightness**.
- Ellipsoidal laser shaping benefits **high bunch charge** beams or **CW guns** (lower gun gradients).

- Two methods to generate 3D ellipsoidal photo cathode laser pulses are under study:
  - Mironov et al., *Appl. Opt*. **55**, p. 1630 (2016)
  - Mironov et al., *Laser Phys. Lett.* **13**, p. 055003 (2016)

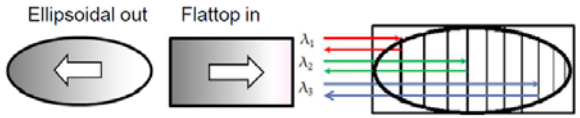
**→ highlight talk: Christian Koschitzki**

**Spatial Light Modulator (SLM) shaper**

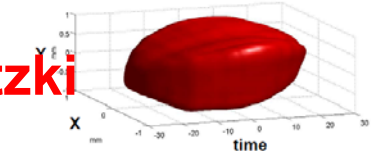



Collaboration with IAP, JINR

**NEW: 3D Volume chirp Bragg grating**

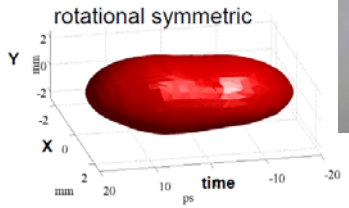



no rotational symmetry




IR cross correlation measurements

rotational symmetric



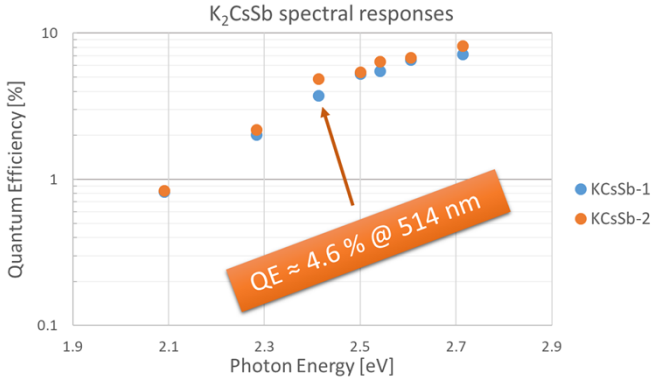

# Development of green cathodes on INFN LASA plug design

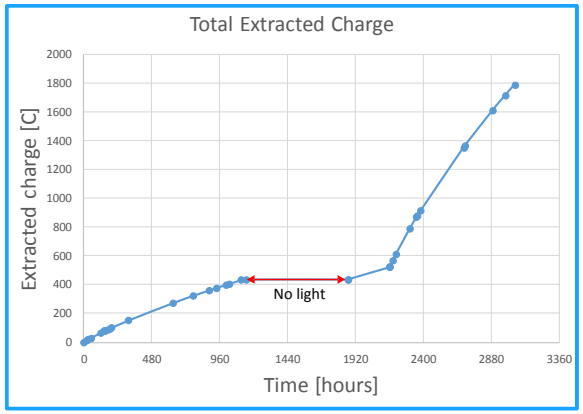
**The INFN LASA Milano plug design is in operation at PITZ / XFEL / FLASH / REGAE / SINBAD / LBNL / FNAL.**

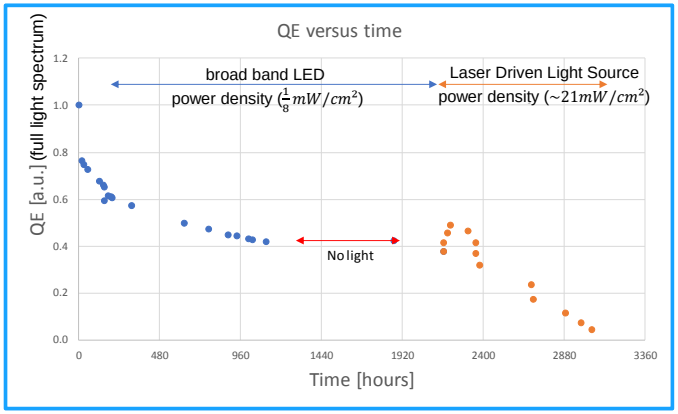
- **The aim of this activity is to grow reliable "green" cathodes (K-Cs-Sb compound) on the INFN plugs and test them in the PITZ RF-Gun** (high cathode gradient + fairly high duty cycle)
  - First **sequential deposition** on test sample in week 47/2017 ("proof of principle")
    - Sb 10 nm
    - K until max QE
    - Cs until max QE
    - Repeated on 1 Dec 2017
  - **Long term measurement**
    - Total extracted **charge** over more than **3 months**
    - QE versus time
      - Based system pressure in the low $10^{-10}$ mbar
      - QE decrease depends on light power density (fatigue effect?)

      → still reasonable QE
  - Next: Design new source layout in view of **co-evaporation in the near future**

**View into the prep chamber**

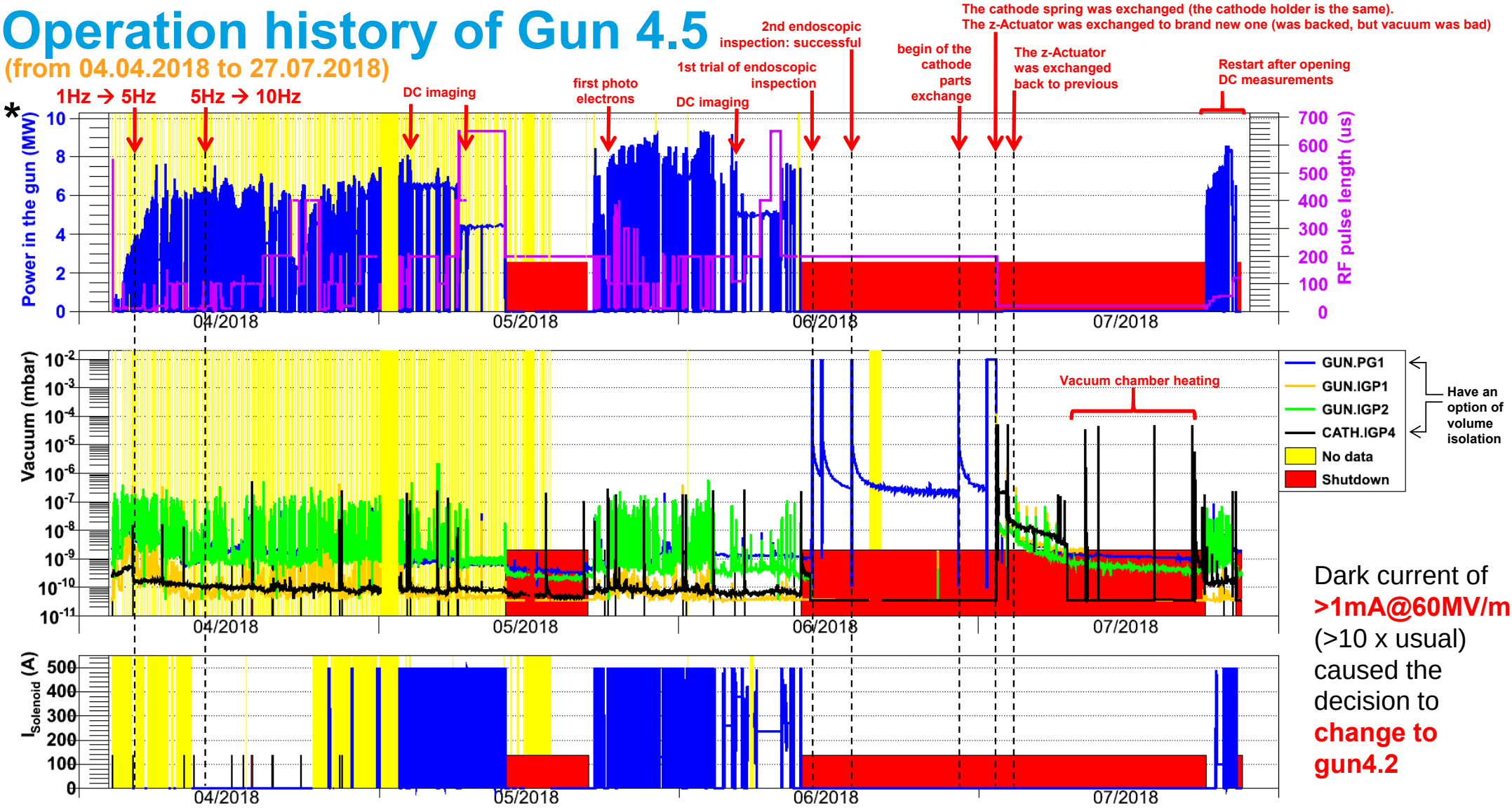


# Operation history of Gun 4.5

(from 04.04.2018 to 27.07.2018)

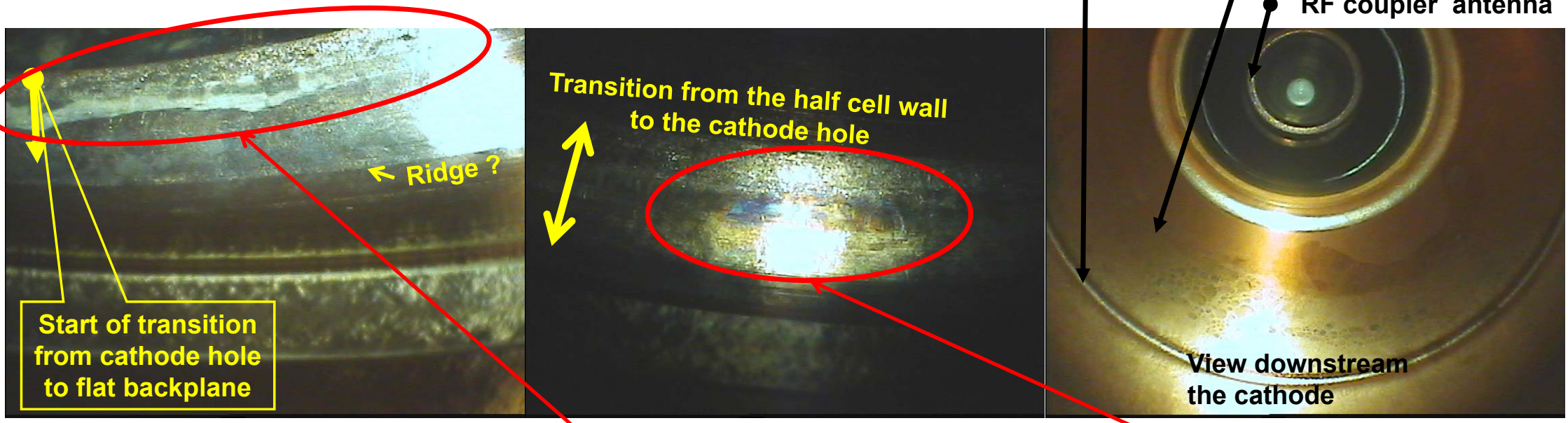


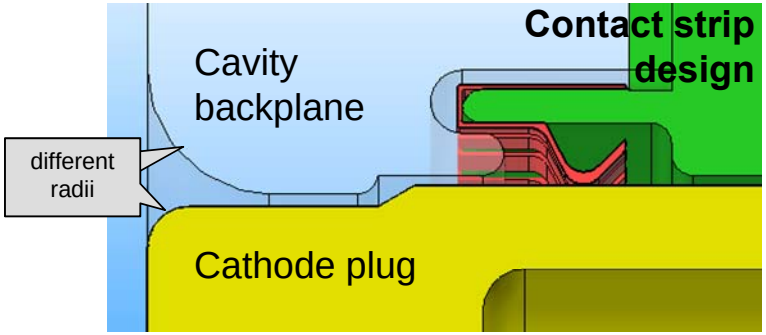

Dark current of **>1mA@60MV/m** (>10 x usual) caused the decision to **change to gun4.2**

* The power readings are presented from 10MW dir. coupler. The readings are not 100% reliable.

# Gun4.5: visual inspection on 18.06.2018

Pictures taken from the cathode side using videoscope



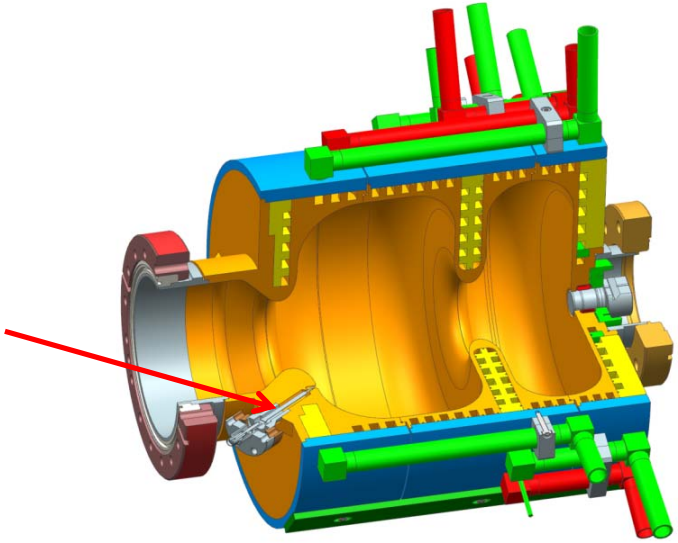

**White (calcareous-like) traces and color changes (like from high temperature gradient or from burning) was observed on the rounding between cathode hole and flat backplane**

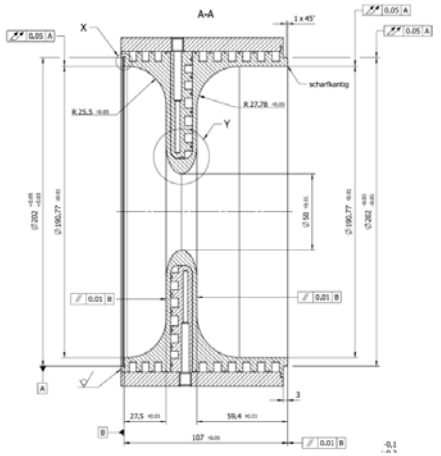
- An attempt to touch and identify a ridge edge on the gun backplane rounding was done: possible edge was not tactile detectable.

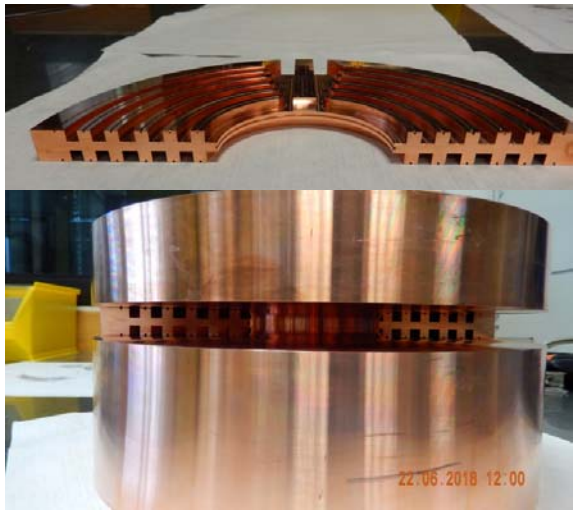
# Next generation of pulsed RF gun under production

## Fabrication of Gun 5 for higher stability & reliability has started

- New features of Gun 5 (see V. Paramonov et al., NIM A 854 (2017) 113-126.):
  - includes **RF probe** → + fine control of RF stability
    + allows symmetric power coupler (2 input arms → reduced load on RF windows)
    - possible sensitivity on pulsed heating → **experimental tests needed**
  - increased **water cooling** and reduced **deformation** over RF pulse → more reliable operation at high duty cycle
  - improved cell **geometry** + elliptical irises → reduced RF heating & surface field strength





→ **First (central) part under production now**

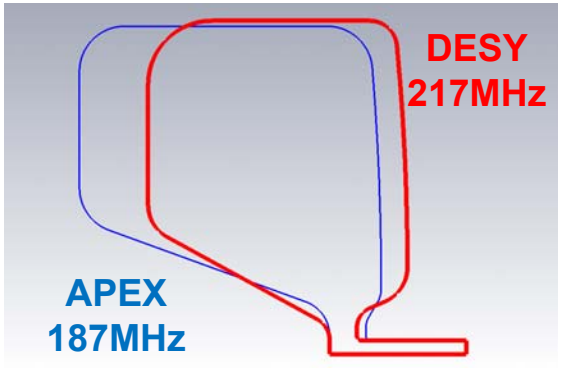
# First considerations towards upgraded NC CW gun design

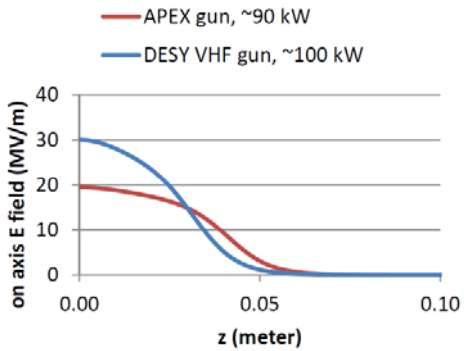
## Backup design for European XFEL CW upgrade

- CW gun design collaboration
  - DESY group visit to LBNL and SLAC (2/2018).
  - **Collaboration with LBNL** on NC CW gun development.
- PITZ design progress (**still preliminary !!!**)
  - Design tool benchmarked using APEX gun model (187 MHz).
  - RF design of a **217 MHz** gun for European XFEL started this year, targeting **~30 MV/m** at cathode, **~100 kW** RF power.
  - Current gun design plugged into LCLS-II injector model shows emittance (**0.10~0.16 µm**) and high order energy spread (**3~4 keV rms**) @ 100 pC with $I_{peak}$=10A.
  - Gun geometry, injector layout and optics are still under further optimizations.

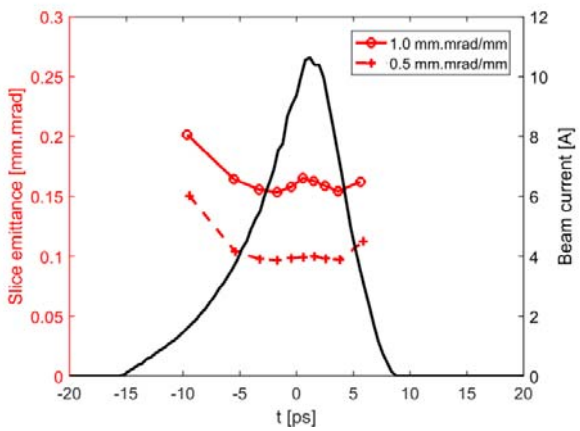
**→ poster: Guan Shu**

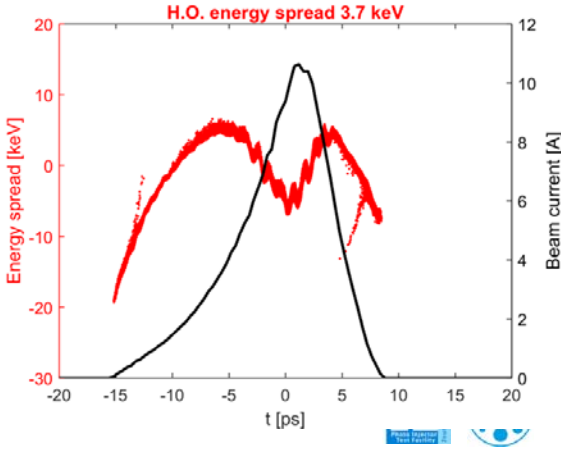
**Preliminary design of DESY VHF gun (217 MHz)**



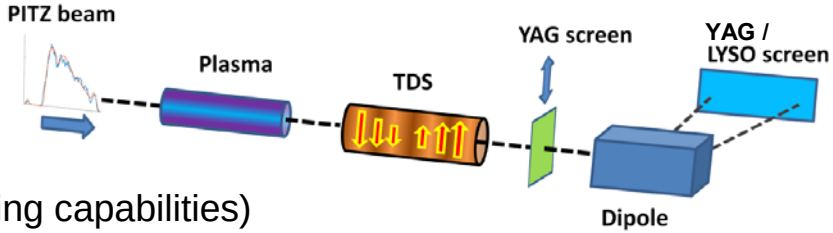

**Preliminary injector simulation with DESY VHF gun (100 pC)**



# Beam driven PWFA Research at PITZ

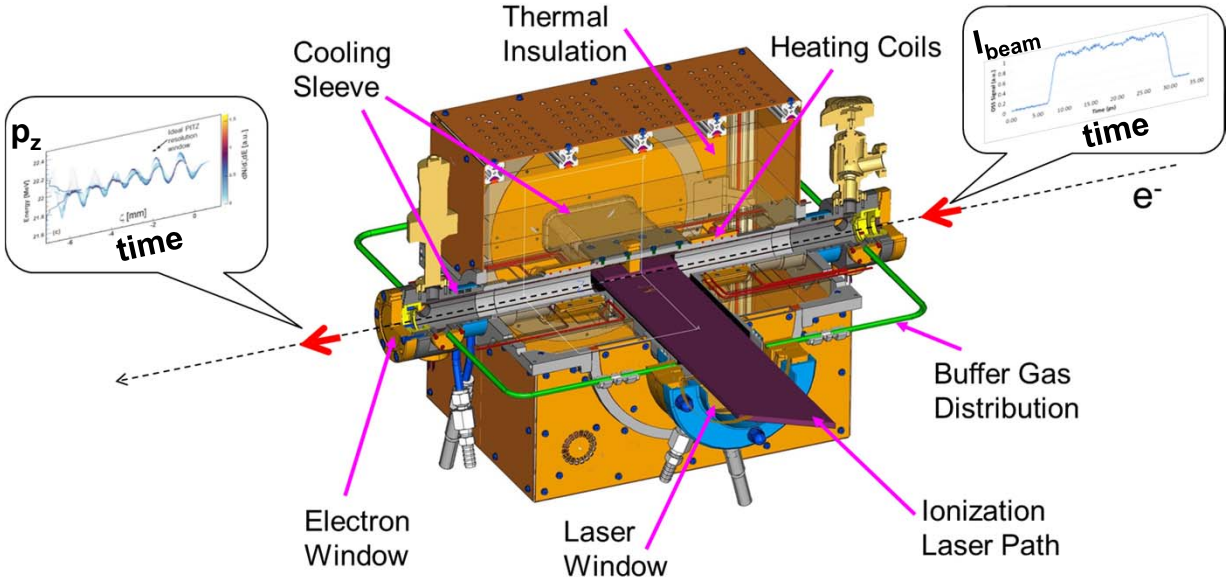
## A flexible platform for exploring beam-plasma interactions




- **Flexible temporal bunch forms** (advanced photocathode laser pulse shaping capabilities)
- Developed and **benchmarked beam diagnostics** in place (RF deflector, dipole spectrometer, …)

### Novel cross-shaped lithium heat pipe oven

- *Ionization laser is coupled in through side windows*
  *→ flexibility in plasma channel length and density profile*

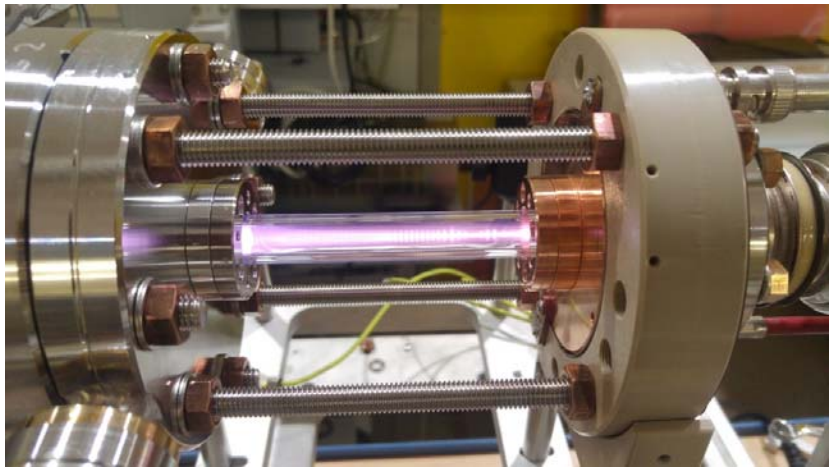



O. Lishilin *et al.*, Proc. of IPAC2017, TUPIK017

### Discharge plasma cell (argon)

- *Simple setup*
- *Scalable in plasma density*

→ highlight talk: Gregor Loisch

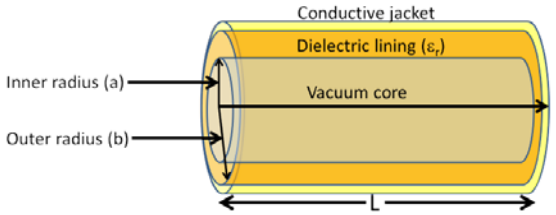


G. Loisch *et al.*, "Jitter mitigation in low density plasma sources for wakefield accelerators", NIM A, *to be published*

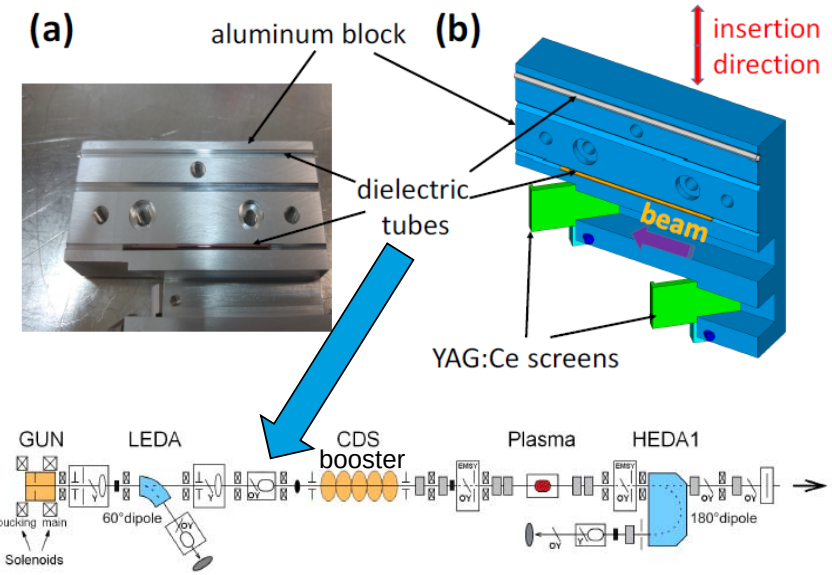
# Bunch Microstructure Generation with DLWs at PITZ

**PIs: F. Lemery (CFEL, DESY) and P. Piot (APC FNAL)**

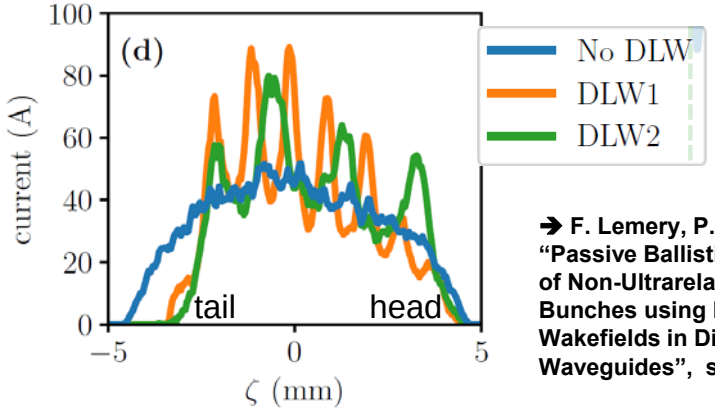
- **Using Dielectric Lined Waveguides - DLW**




| parameter | symbol | nominal | range | unit |
|---|---|---|---|---|
| laser launch phase | $\phi_l$ | 0 | – | deg |
| laser spot radius | $r_l$ | 2 | – | mm |
| laser pulse duration | $L_t$ | 13 | [10, 20] | ps |
| RF gun peak field | $E_0$ | 60 | [45, 60] | MV/m |
| linac phase | $\varphi_b$ | 0 | [-20, +10] | deg |
| linac voltage | $V_b$ | 14 | [10, 18] | MV |
| bunch charge | $Q$ | 1.1 | [0.020, 2] | nC |
| beam momentum | $\langle p \rangle$ | 21.8 | [16, 22] | MeV/c |
| DLW permittivity | $\varepsilon_r$ | 4.41 | – | – |
| DLW1 inner radius | $a_1$ | $450 \pm 50$ | – | $\mu$m |
| DLW1 outer radius | $b_1$ | $550 \pm 50$ | – | $\mu$m |
| DLW1 length | $l_1$ | $50.0 \pm 0.1$ | – | mm |
| DLW2 inner radius | $a_2$ | $750 \pm 50$ | – | $\mu$m |
| DLW2 outer radius | $b_2$ | $900 \pm 50$ | – | $\mu$m |
| DLW2 length | $l_2$ | $80.0 \pm 0.1$ | – | mm |

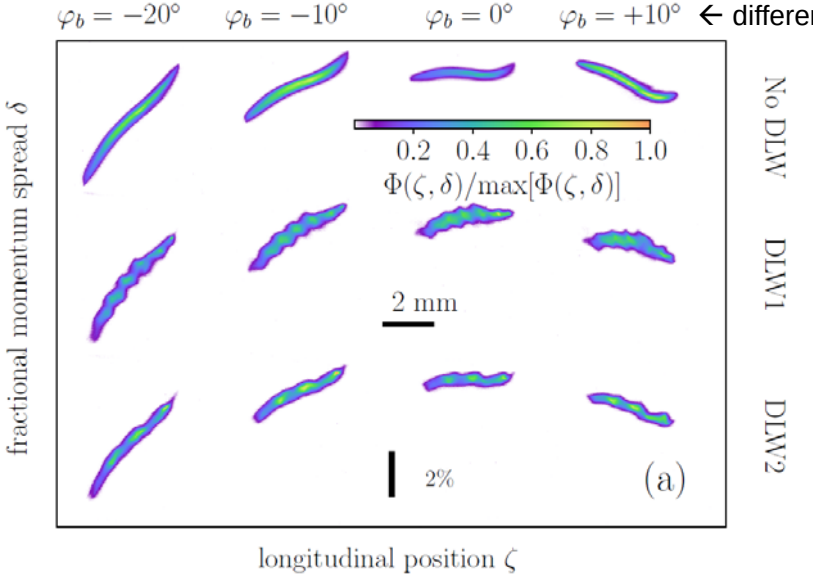



**E-beam current profiles**




➔ **F. Lemery, P. Piot, et al., "Passive Ballistic Microbunching of Non-Ultrarelativistic Electron Bunches using Electromagnetic Wakefields in Dielectric-Lined Waveguides", submitted to PRL**

**Measured Longitudinal Phase Spaces**



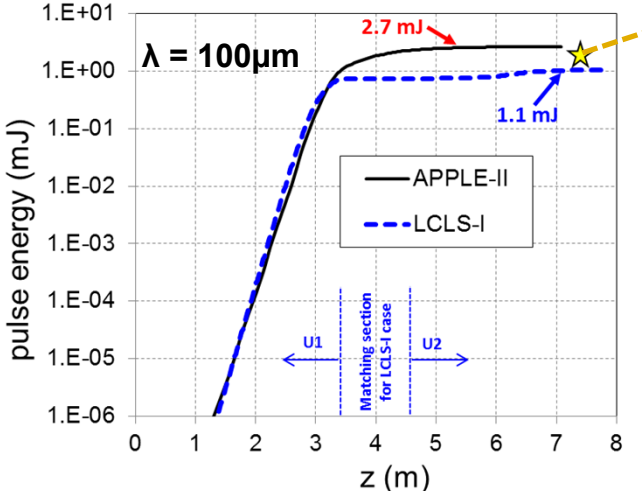
# IR/THz SASE source for pump-probe experiments @E-XFEL

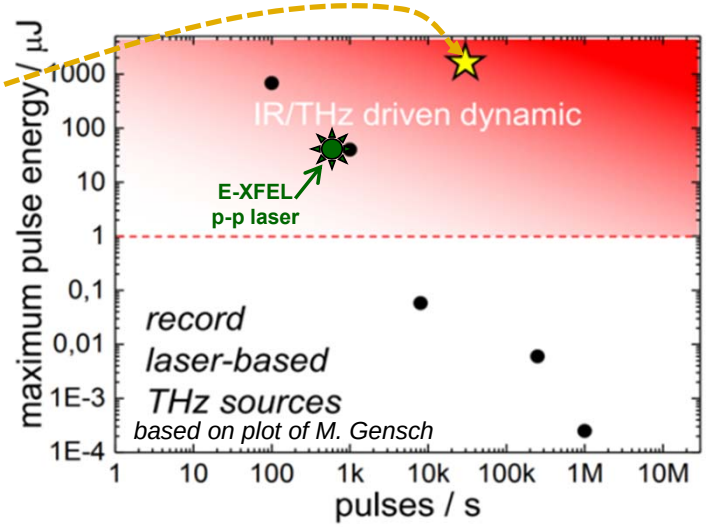
**PITZ-like accelerator can enable high power, tunable, synchronized IR/THz radiation**


*E.A. Schneidmiller, M.V. Yurkov, (DESY, Hamburg), M. Krasilnikov, F. Stephan, (DESY, Zeuthen),*
*"Tunabale IR/THz source for pump probe experiments at the European XFEL, Contribution to FEL 2012, Nara, Japan, August 2012*

- Accelerator based IR/THz source meets requirements for pump-probe experiments (e.g. the same pulse train structure !)
- Construction of radiation shielded area for installing reduced copy of PITZ is possible close to user experiments at E-XFEL
- Prototype of accelerator already exists → **PITZ** facility at DESY in Zeuthen

**Simulation of THz SASE FEL @PITZ**




e.g. in E-XFEL photon beam line tunnel:

Required beam (**~4nC, $I_{peak}$~200A**) already demonstrated at PITZ

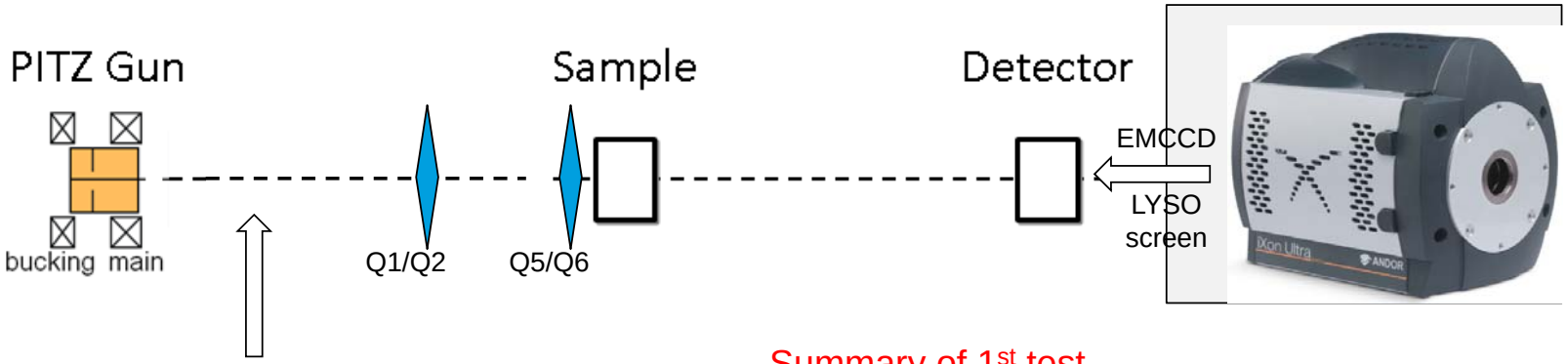
➔ **PITZ can be used for proof of principle and optimization!**

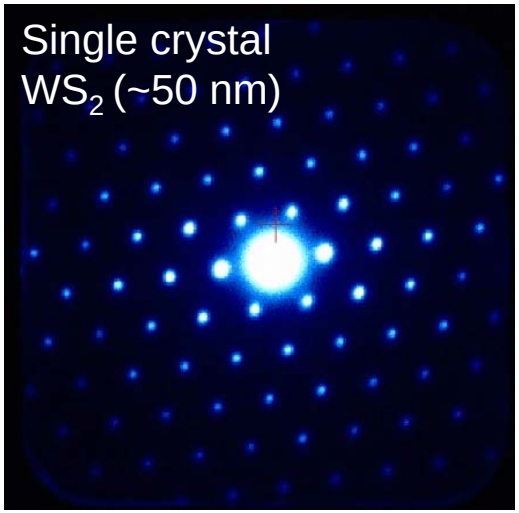
➔ **highlight talk: Prach Boonpornprasert**

# First static electron diffraction tests at PITZ

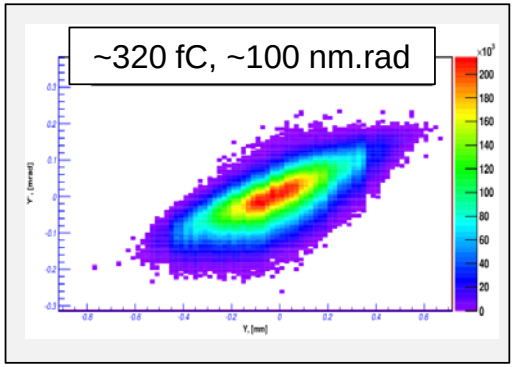
**Collaboration between PITZ, Max-Born-Institute (MBI) and Fritz-Haber-Institute (FHI)**

- PITZ bunch train (up to ~$10^4$ pulses/sec) reduces signal accumulation time for diffraction patterns for better signal to noise ratio.



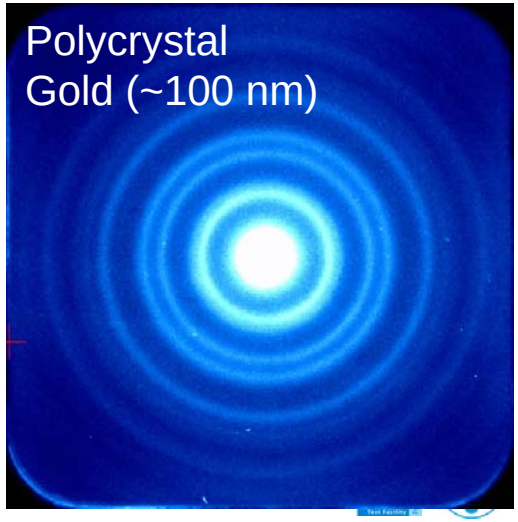

Emittance measurement




Summary of 1st test

| e⁻ beam at sample | 1st Test | Unit |
|---|---|---|
| Energy | **~4** | **MeV** |
| Electron per pulse | **~2x10$^6$** | **e⁻/pulse** |
| Bunch FWHM length | ~2* | ps |
| Normalized emittance | ~100 | nm.rad |
| RMS beam size at sample | ~200 | µm |
| Transverse coherence length | **~1.9**** | **nm** |

*Buncher off. **No beam aperture yet.



# Summary

- **PITZ:** - well developed **photo injector test facility** with detailed beam **diagnostics** available
  - already broad scientific program
  - **open for new joint work → contact frank.stephan@desy.de !**
- One of leading institutes on optimizing **beam quality**
  → next step: generate high charge **quasi 3D ellipsoidal electron beams** for ultimate beam quality
- Developments towards **"green" photocathodes** have started at INFN LASA Milano
- (Work on photoemission modeling ongoing) **→ poster: Ye Chen**
- New gun4.5 had too high dark current → exchanged with old **gun4.2** **→ poster: Houjun Qian**
- **Next generation** of **pulsed gun** under production, first thoughts on **NC** (and hybrid) **CW guns**
- Very successful experiments performed on **beam driven plasma acceleration**:
  - **self-modulation** of long particle bunches
  - **high transformer ratio** in plasma with shaped particle beam
- Successful generation of **bunch microstructure** using dielectric lined waveguides
- Promising feasibility studies for **high power, tunable THz source** for P&P experiments at European XFEL
- First successful **static electron diffraction** experiments using bunch trains
- (Simulation studies ongoing to use PITZ for Laboratory Astrophysics experiments) **→ poster: Ye Chen**
- (High gradient pulsed quadrupoles for novel accelerators) **→ poster: Gregor Loisch**