

# High-Brightness Beam Developments at PITZ

Ye Chen for the DESY PITZ Team

The 5th annual meeting of the programme "Matter and Technologies"  
Helmholtz Institute Jena, March 5-7, 2019

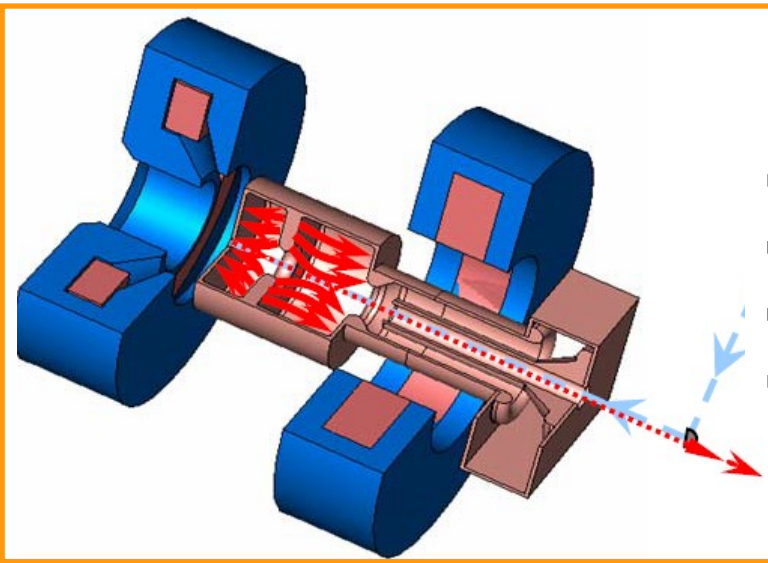
## Contents

- **PITZ facility**
- **Laser:** towards ultimate low emittance beams → 3D ellipsoidal bunches
- **Cathode:** development of "green" photocathodes
- **Emission:** photoemission of space-charge dominated beams
- **NC CW gun:** first results towards upgraded design
- **Applications:**
  - **THz source:** proof of principle experiments for a high power, tunable THz source for pump-probe experiments at European-XFEL by using LCLS I undulators
- **Summary**



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

Development, test and optimization of high brightness electron sources for FLASH and European XFEL + applications



## RF Gun

- **L-band** (1.3 GHz) 1.6-cell copper cavity
- $E_{cath} \geq 60 \text{ MV/m} \rightarrow 7 \text{ MeV/c e-beams}$
- $650 \mu\text{s} \times 10 \text{ Hz} \rightarrow \text{up to } 45 \text{ kW av. RF power}$
- **Cs<sub>2</sub>Te** PC (QE~5-10%)  $\rightarrow \text{up to } 5 \text{ nC/bunch}$

Test-bed for FEL injectors, gun cavities and photo injector subsystems  $\rightarrow$  e.g. lasers

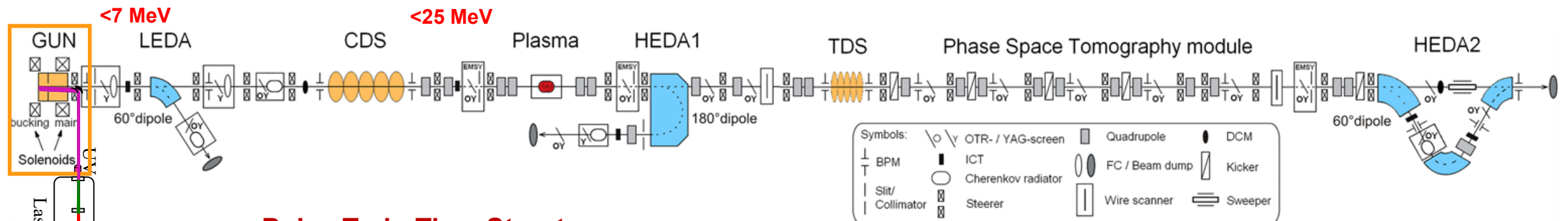
High brightness  $\rightarrow$  small  $\epsilon_{tr}$  (projected and slice), a variety of beam diagnostics

Tackling injector operation issues at FELs

Further studies

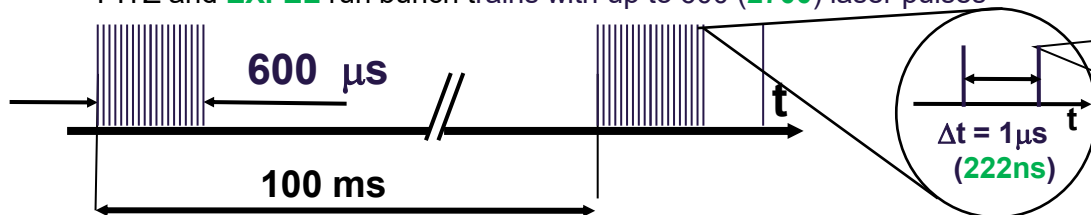
$\rightarrow$  e.g. cathodes: dark current, photoemission, QE, thermal emittance, ...

$\rightarrow$  applications like plasma acceleration, THz, UED, ...

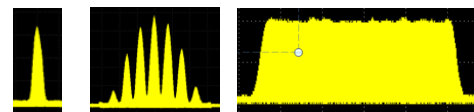


## Pulse Train Time Structure:

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



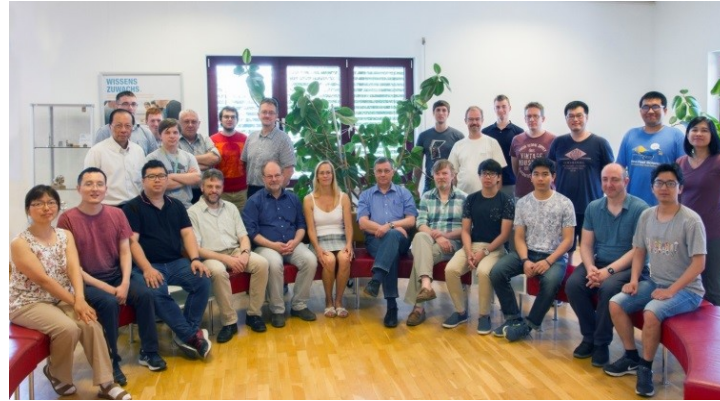
## flexible shapes



# PITZ Collaboration Partners

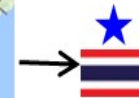
## Founding partners:

- **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:

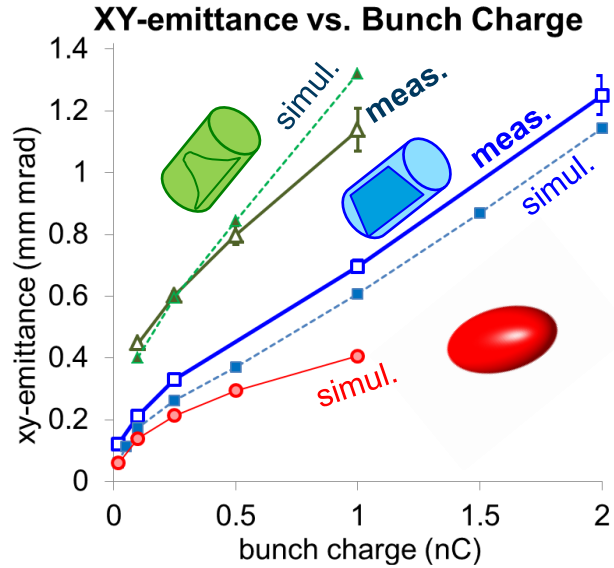
- **Hamburg university:**
  - most PhD students;
  - HGF-Vernetzungsfond;
  - generation of short pulses
  - plasma experiments
- **HZDR:**
  - BMBF-PC-laser-project between MBI, DESY and HZDR, until ~2009;
  - Collaboration between HZB, HZDR, MBI and DESY in SC-gun-cluster



## 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

# Developing 3D ellipsoidal laser pulses



**Proof of principle demonstrated with IAP system at PITZ in 2016 (single SLM → dual path)**

Comparison with **simulated e<sup>-</sup> beam shapes (500pC):** similarity in shape

Gaussian laser

Flattop laser

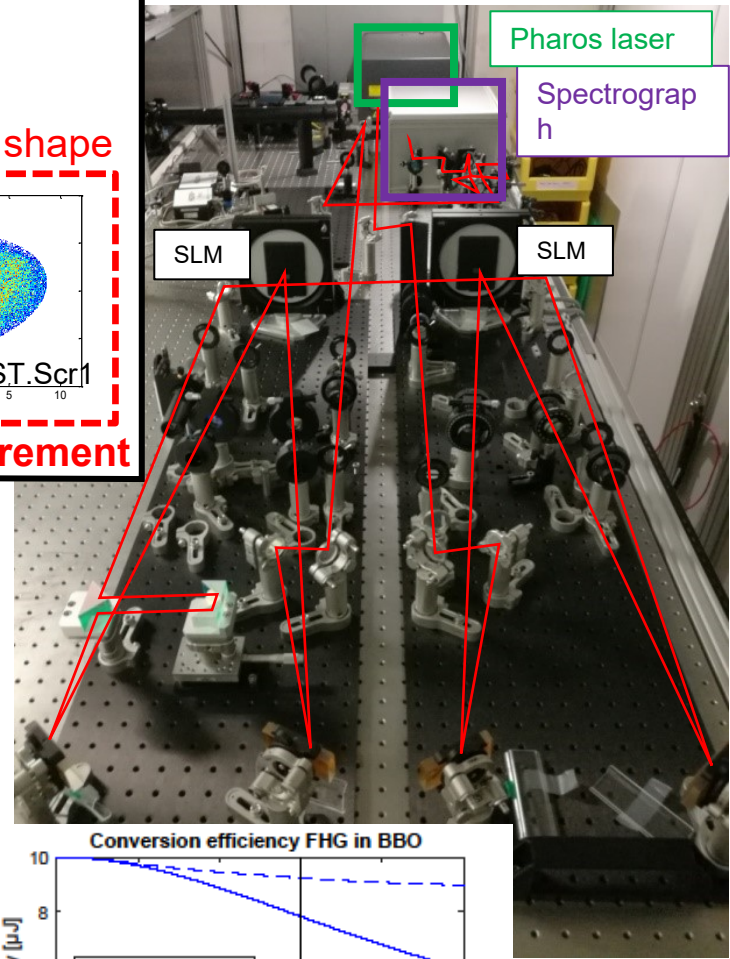
Ellipsoidal laser

@EMSY1

@PST.Scri

J. Good et al., Proc. 38<sup>th</sup> FEL Conf., WEP006 (2017)

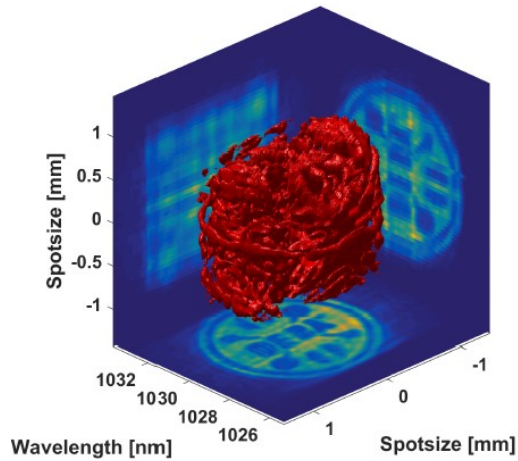
**First Measurement**



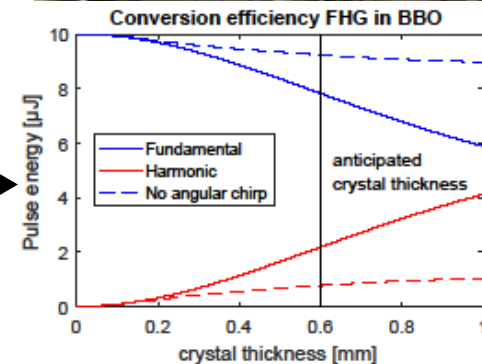
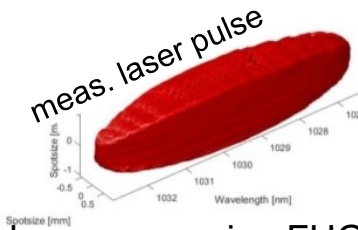
## Redesign to true double SLM setup based on commercial Pharos laser:

- Improved **stability**
- Improved shaping capabilities: independent masking in x-y, spectrograph feedback

- **Next:**
- experiments to quantify shape preserving FHG conversion with **angular chirp**
- true 3D shaping with Volume Bragg Gratings → work ongoing



SLM capabilities at proper transport

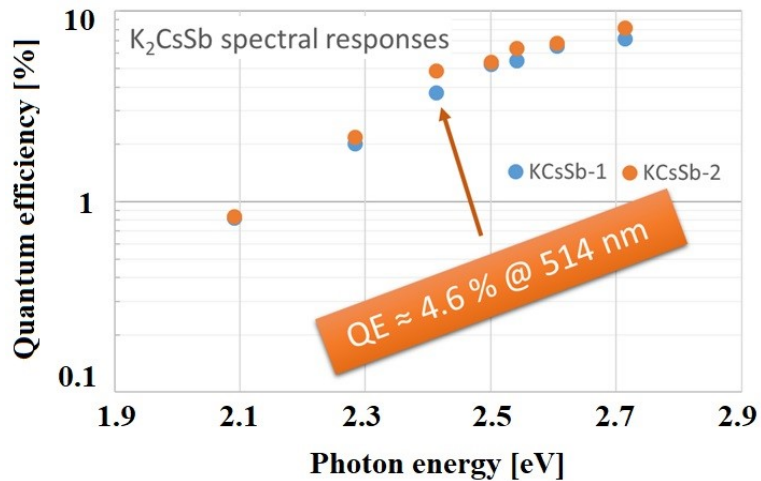


Simulation

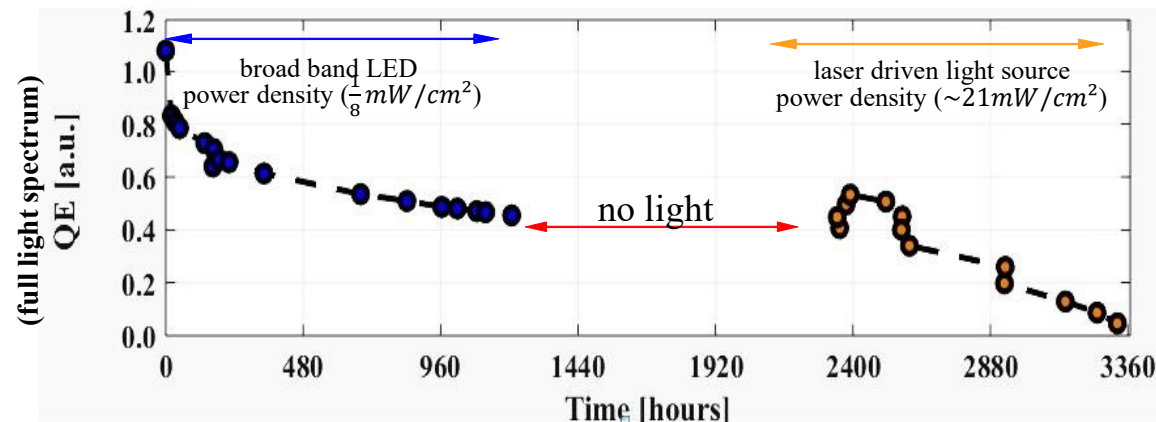
# Development of green cathodes on INFN LASA plug design

**Aim:** → better beam quality → simplified photo cathode laser → especially needed for CW operation

- Grow reliable "green" cathodes (K-Cs-Sb compound) on 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
  - Sb 10 nm → K until max QE → Cs until max QE



## Long term measurement

total extracted **charge** over more than **3 months**

QE versus time

- Base system pressure: low  $10^{-10}$  mbar
- QE decrease depends on light power density (fatigue effect?)

→ still reasonable QE

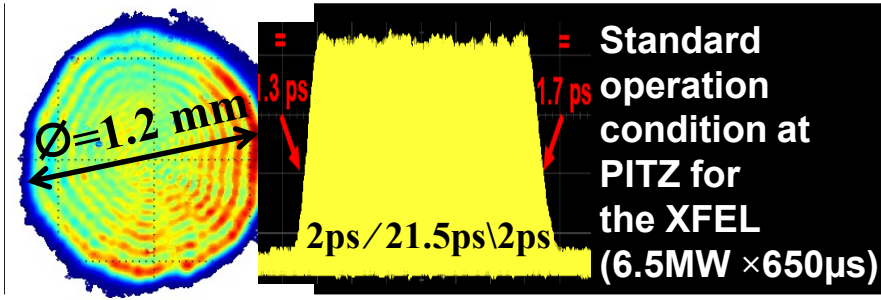
- Design new source layout in view of **co-evaporation**; **PhD student just started**



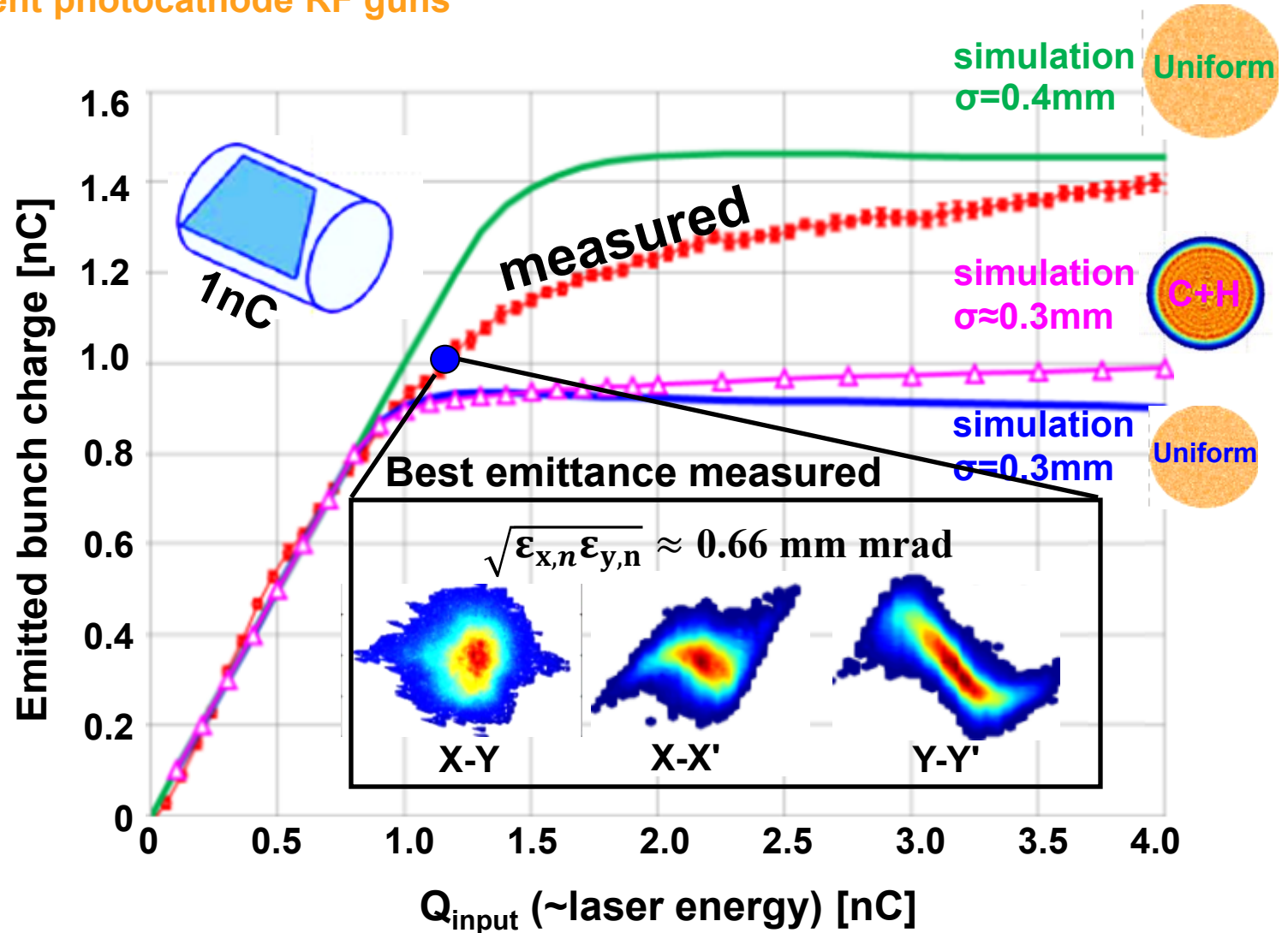
View into the prep chamber

# Space-Charge Dominated PhotoEmission (SCDPE)

and associated beam dynamics in high-gradient photocathode RF guns

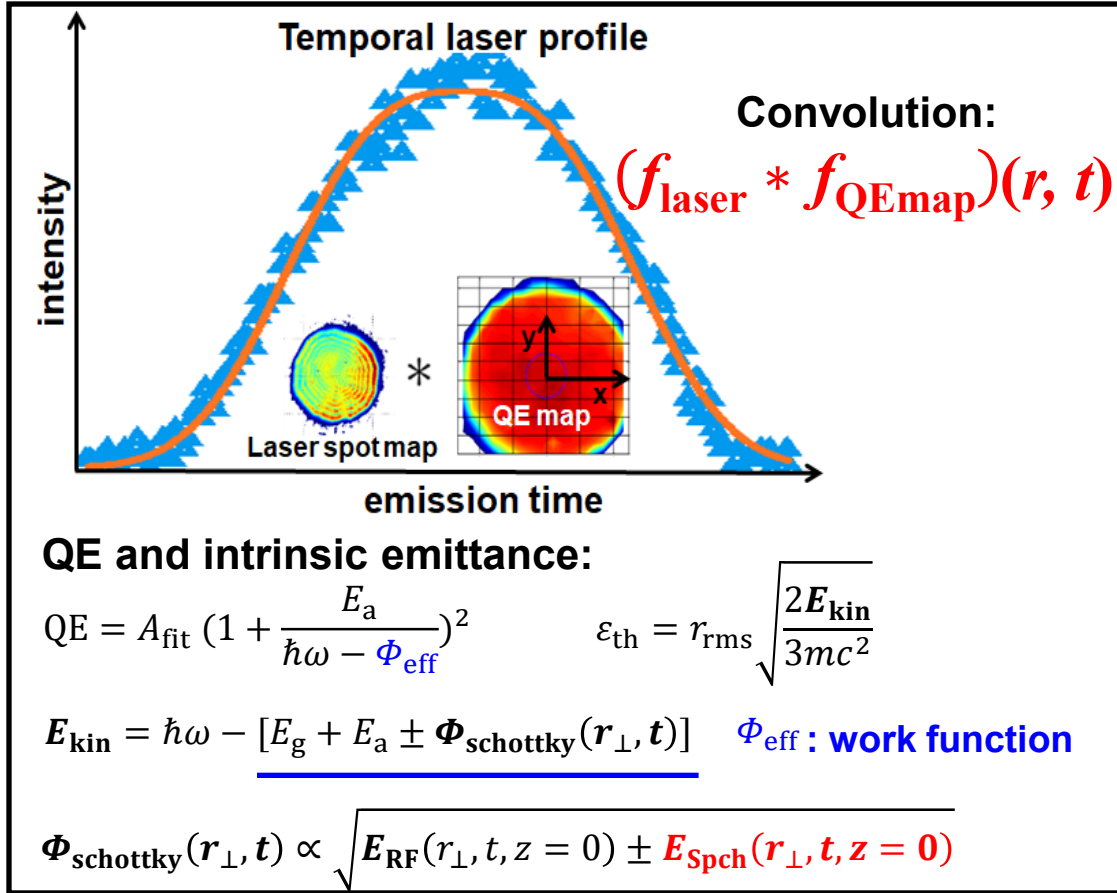


**At working point:  
beam extraction at cathode  
strongly influenced  
by space-charge effects  
and cannot be well  
reproduced by simulations**



# First simulation results

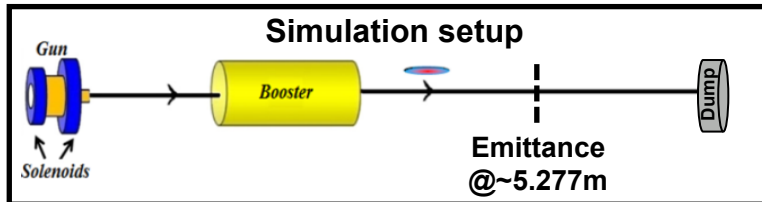
On intrinsic surface emittance



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DARMSTADT

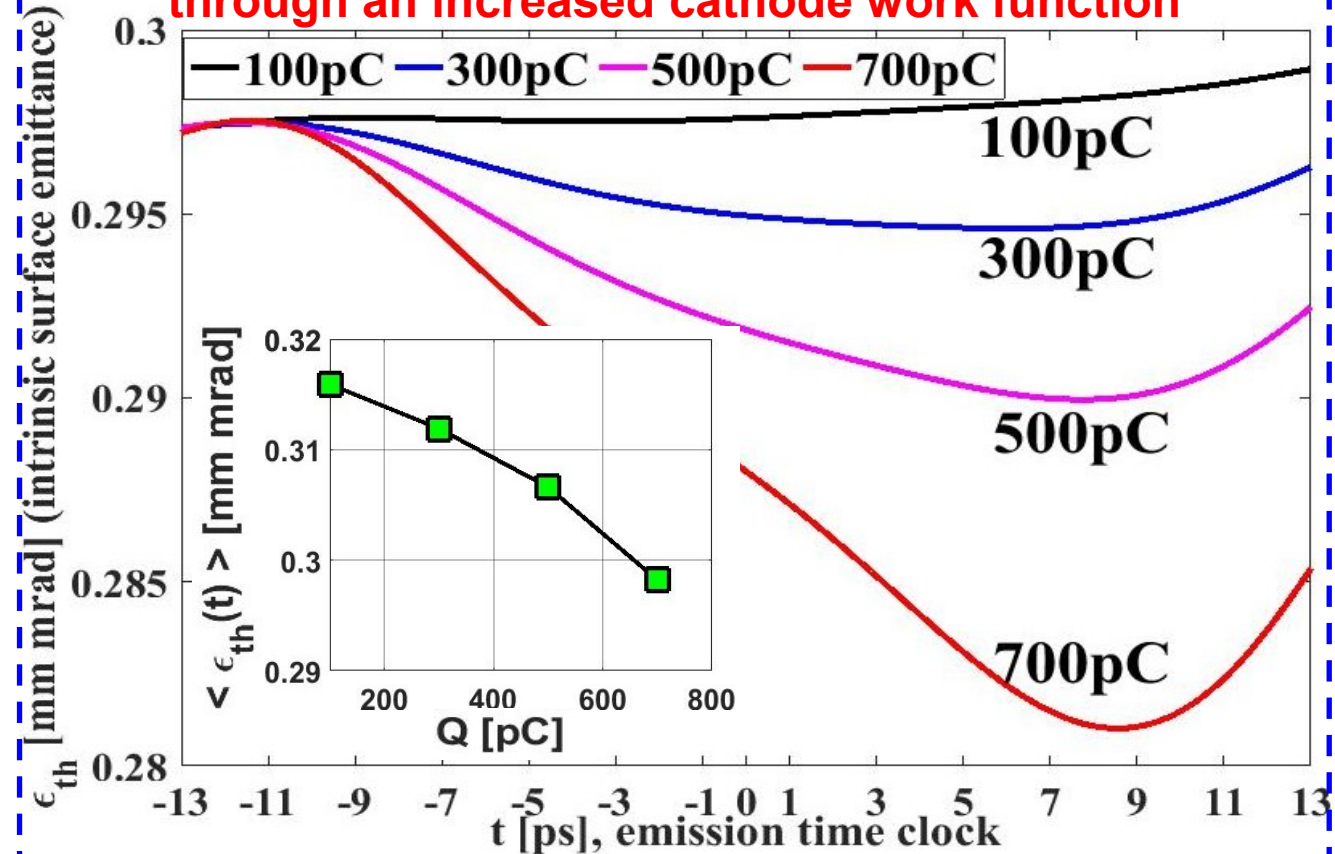


DESY

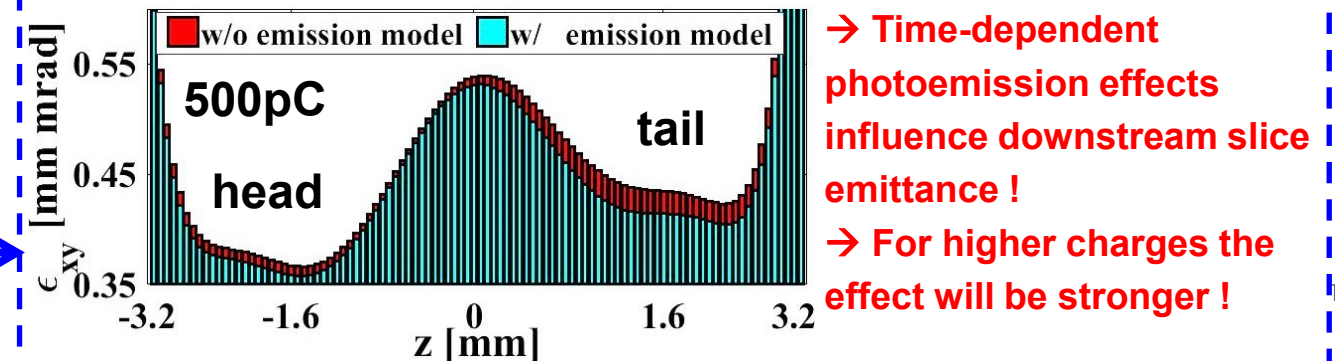


At cathode

Space-charge fields cooling down cathode surface through an increased cathode work function



Simulated slice emittance at  $z \approx 5.3\text{m}$



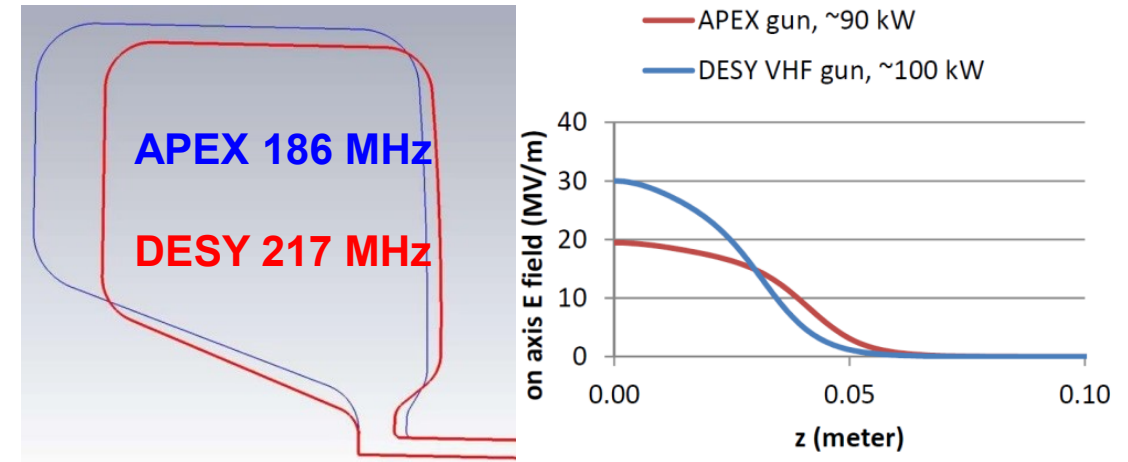
# Towards upgraded NC CW gun design: first results



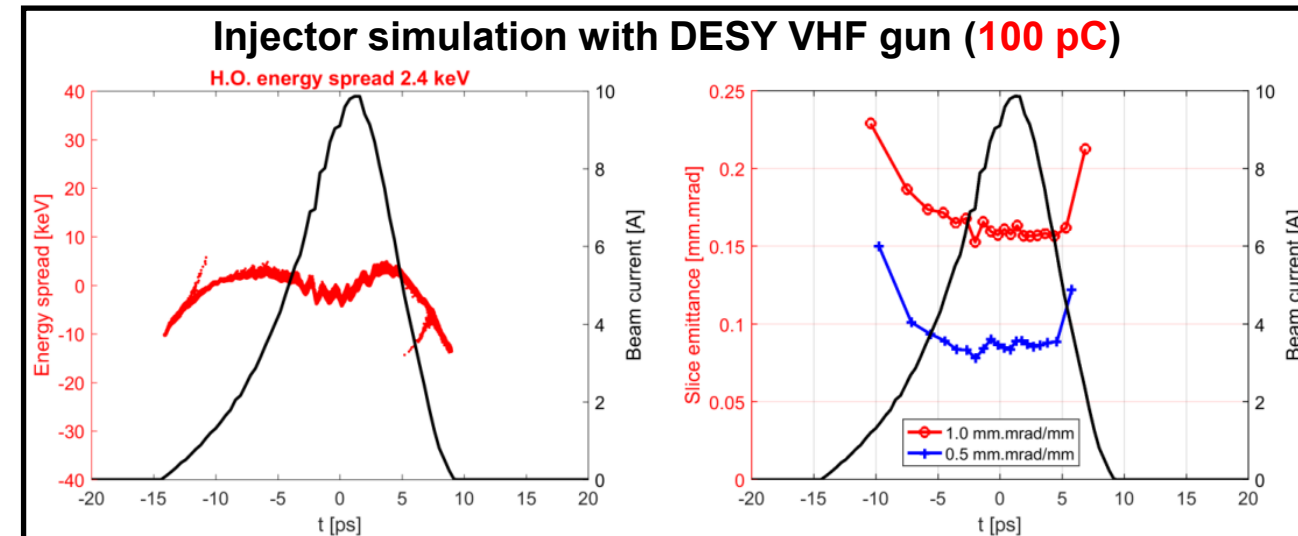
Backup gun design for European XFEL CW upgrade, in collaboration with LBNL

- 1<sup>st</sup> DESY VHF gun with high gradient optimized.
  - Current gun design plugged into LCLS-II injector model shows improvement on emittance (**0.09~0.16  $\mu\text{m}$** ) and high order energy spread (**<3 keV rms**) @ 100 pC with  $I_{\text{peak}}=10\text{A}$ .
  - High gradient mode ( $\sim 30 \text{ MV/m}$ ) faces uncertainties of dark current and breakdown.
- 2<sup>nd</sup> design with higher voltage under studies

## DESY VHF gun (217 MHz) vs APEX gun (186 MHz)



Parameter	APEX	DESY gun Mode1	DESY gun Mode2	Unit
Frequency	186	217	217	MHz
<b>Voltage</b>	<b>750</b>	<b>860</b>	<b>690</b>	<b>kV</b>
<b>Cathode gradient</b>	<b>19.8</b>	<b>30.0</b>	<b>24</b>	<b>MV/m</b>
Intrinsic quality factor, Q0	3.1E4	3.2E4	3.2E4	
Shunt impedance	6.2	7.4	7.4	M $\Omega$
<b>Nominal RF power for Q0</b>	<b>90</b>	<b>100</b>	<b>64</b>	<b>kW</b>
Stored energy	2.4	2.3	1.9	J
<b>Maximum surface E field</b>	<b>24 (1.7kilp)</b>	<b>38 (2.5kilp)</b>	<b>30 (2kilp)</b>	<b>MV/m</b>
Maximum wall power density	25	35	22	W/cm <sup>2</sup>

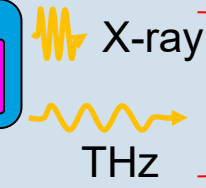




# THz studies towards pump-probe experiments at European XFEL

**European XFEL (~3.4 km)**

PITZ-like accelerator based THz source (~20 m) →

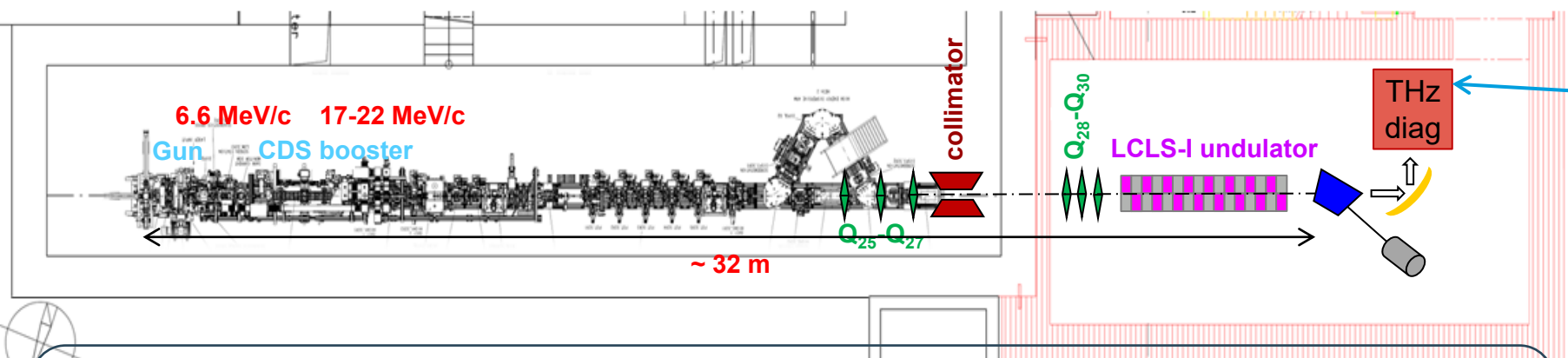


X-ray

THz

Pump & probe

*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"*



### Motivation

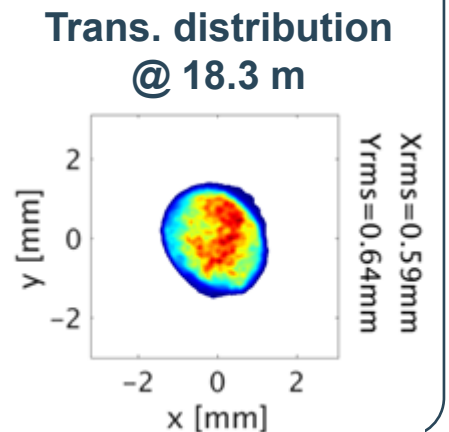
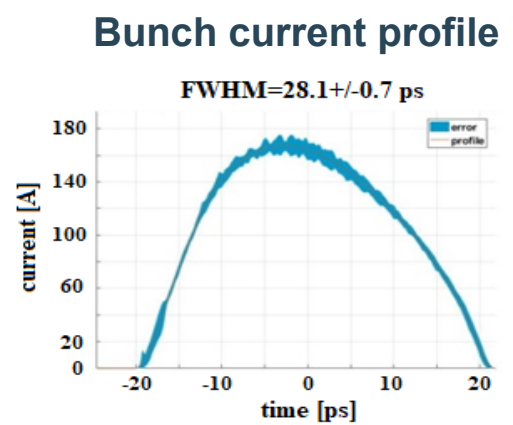
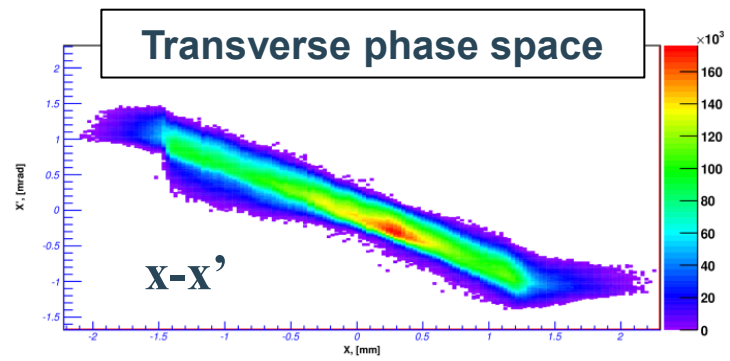
**Pulse energy vs. rep.rate for modern THz sources**

1,3-5: Optical rectification[1]  
 2: photoconductive antenna [1]  
 6: CTR (LCLS/FACET) [2]  
 7: UR (FLASH) [3]  
 8: UR (TELBE) [4]

[1]B. Green, et al, Sci.Rep.V. 6, Article number: 22256 (2016)  
 [2]M. Gensch, Proceedings of FEL 2013, 474 (2013)  
 [3]<https://flash.desy.de/>  
 [4]<https://www.hzdr.de/db/Cms?pOid=34100&pNid=2609&pLang=de>

## Experiment with Gaussian photocathode laser

- Bunch charge **4.7 nC**; peak current **~ 170 A**
- Best emittance **5.5 mm mrad**



# Summary

- **PITZ:** - well developed **photo injector test facility** with detailed beam **diagnostics** available
  - **broad scientific program** very relevant for **DESY 2030 strategy**
  - **largest part of activity related to European XFEL** (current operation and future upgrades)
    - can tackle **XFEL injector operation issues**
    - **open for new collaborations**
- One of leading institutes on optimizing **beam emittance**
  - next step: generate high charge **quasi 3D ellipsoidal electron beams** for ultimate beam quality  
(see **Poster #XX** by **C. Koschitzki**)
- Developments towards "**green**" **photocathodes** have started at INFN LASA Milano
- Work on improving the **photoemission modeling**
- Work on **thermal momentum imaging** (see **Poster #29** by **P.-W. Huang**)
- Design for **NC CW guns** ongoing (see **Poster #XX** by **G. Shu**)
- Conceptual Design study for **high power, tunable THz source** for P&P experiments at European XFEL received funding (see **Poster #28** by **X.-K. Li**)

**Thank you for your time!**