HRJRG-400: Application of 3D ellipsoidal cathode laser pulses for high brightness photo injector optimization

DEVELOPMENT OF A PHOTO CATHODE LASER SYSTEM FOR QUASI ELLIPSOIDAL BUNCHES AT A HIGH BRIGHTNESS PHOTO INJECTOR

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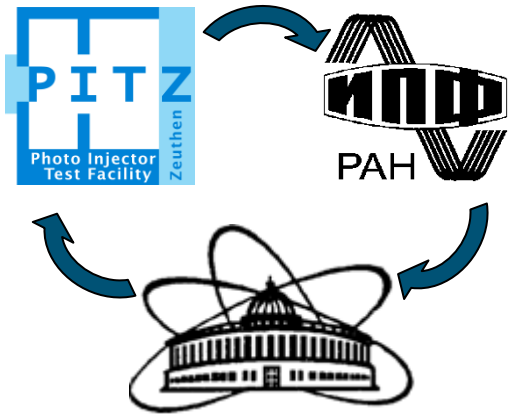
HRJRG Workshop, March 3, 2014, Moscow



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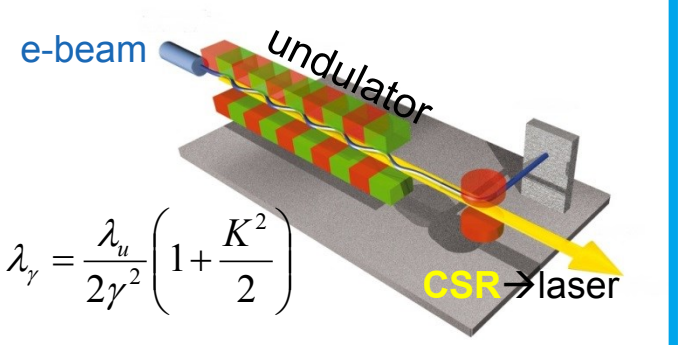
HELMHOLTZ ASSOCIATION

DESY

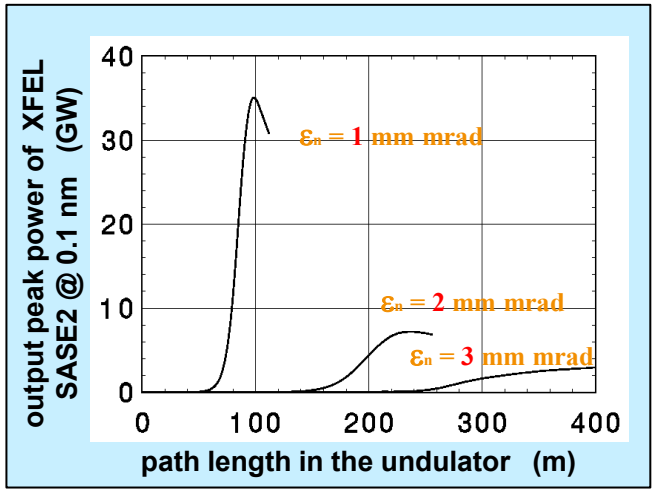
Motivation: European XFEL - a next generation light source



$$\lambda_\gamma = \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$

FEL = **F**ree **E**lectron **L**aser

SASE = **S**elf **A**mplified **S**pontaneous **E**mission



The European X-ray FEL (DESY, Hamburg)

- L > 3km
- Superconducting linac
- E=17.5GeV
- I=5kA
- 1.15 billion Euro (DE~58%;RU~27%)

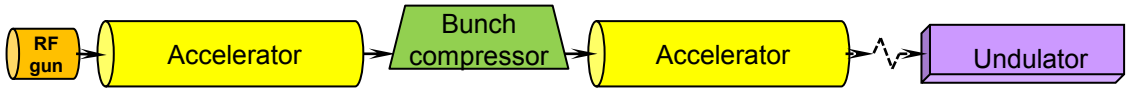
The XFEL will deliver:

>wavelength down to 0.1 nm➔
➔**atomic-scale resolution**

>ultra-short pulses (≤ 100 fs) ➔
➔ **ultra-fast dynamics**, "molecular movies"

>ultra-high peak brilliance ➔ investigations of matter under **extreme conditions** (Xe^{21+})

>transverse spatial coherence ➔ imaging of single nanoscale objects, possibly down to individual macromolecules (**no crystallisation needed !!**)



Why electron injector is so important …. ???

property of linacs: beam quality will DEGRADE in acc. linac

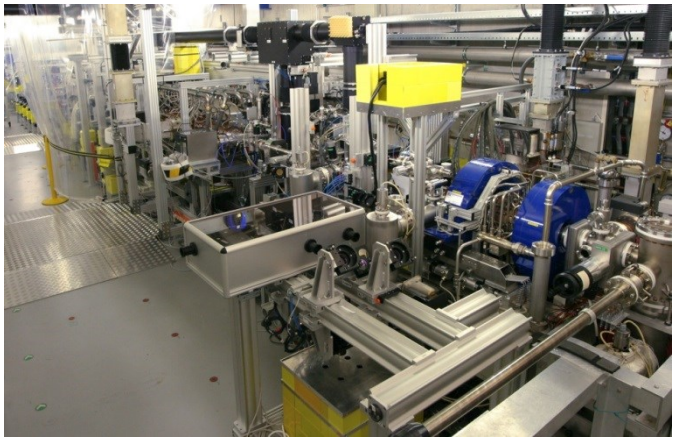
e-beam emittance ε = phase space volume ➔
➔measure of beam quality:➔ the smaller, the better !

➔ electron source has to produce lowest possible emittance ➔ high brightness !!

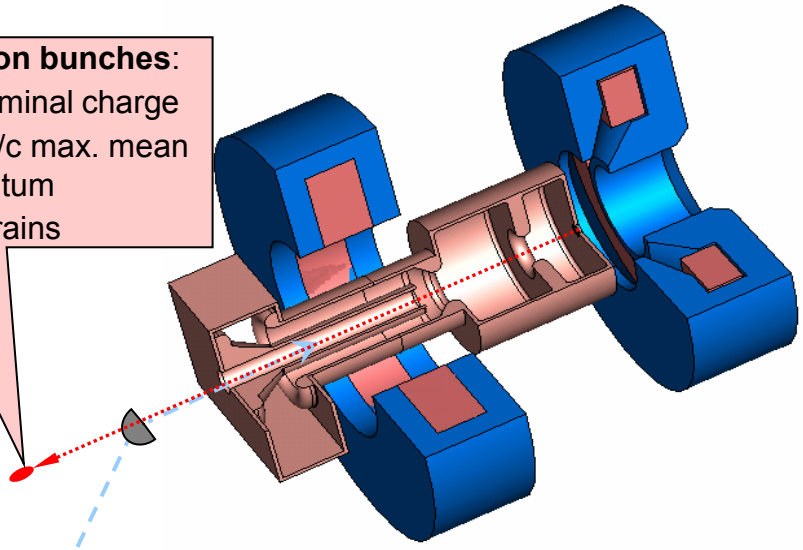
Specs for XFEL Injector ε =0.9 mm mrad (1nC)

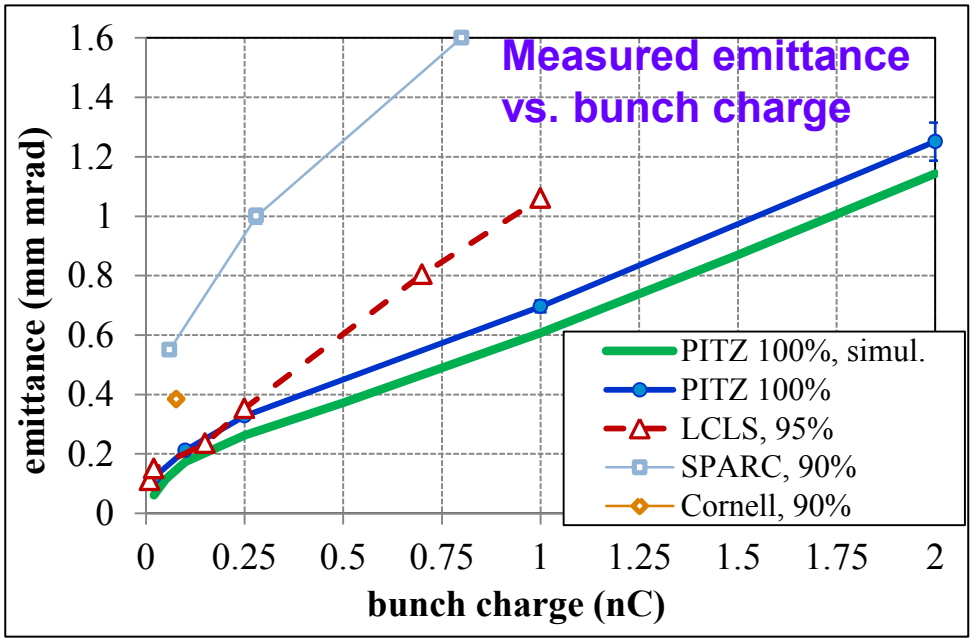
High Brightness Photo Injector Developments at PITZ

The **Photo Injector Test facility at DESY in Zeuthen (PITZ)** focuses on the development, test and optimization of high brightness electron sources for superconducting linac driven SASE FELs



Electron bunches:
- 1nC nominal charge
- ~7MeV/c max. mean momentum
- Pulse trains



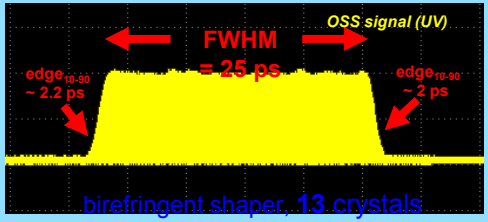


Photocathode laser λ=257nm

Trains with up to **800 pulses (1MHz) at 10Hz** repetition rate

Temporal (micro) pulse shaping

Flattop (nominal)



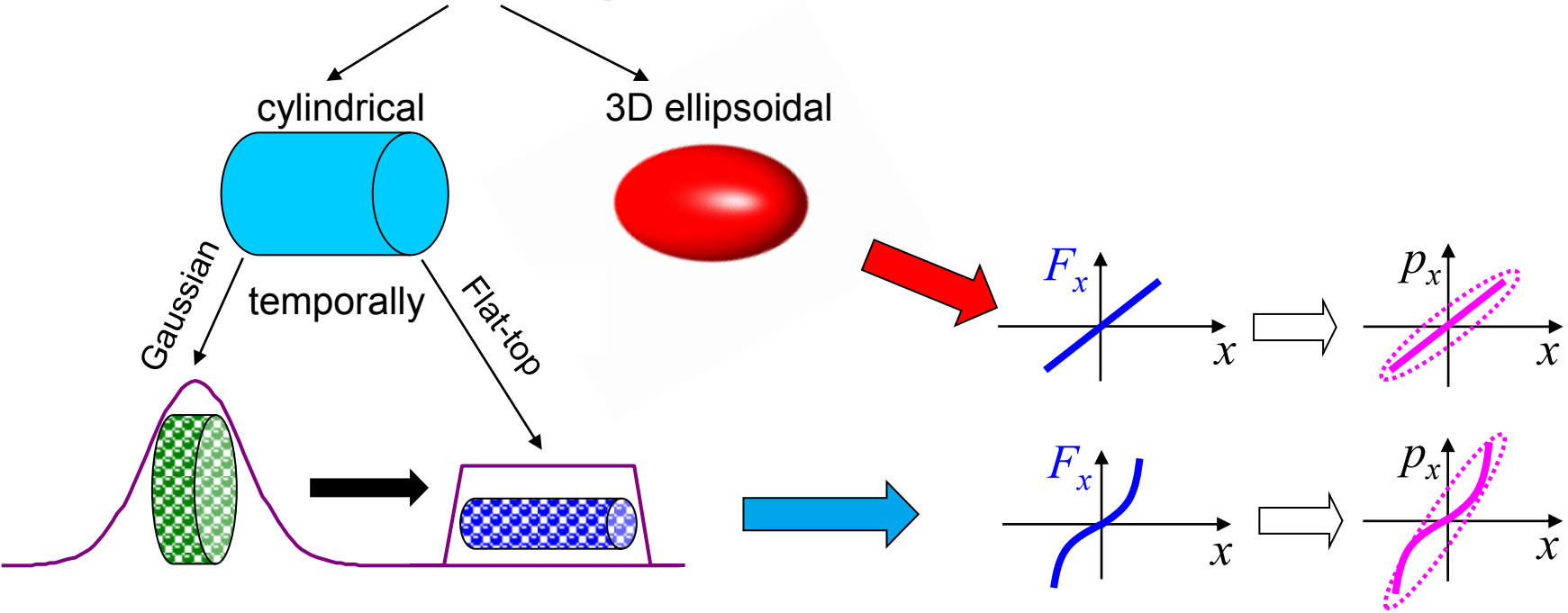
M. Krasilnikov, F. Stephan et al., PRST-AB 15, 1000701 (2012).

Photo cathode laser shaping → 3D ellipsoid: motivation

- **Motivation:** Further improvement of the electron beam quality by reduction of the transverse projected beam emittance.
- **Main idea:** Optimization of the cathode laser pulse shape in order to minimize the impact of the space charge on the transverse emittance.

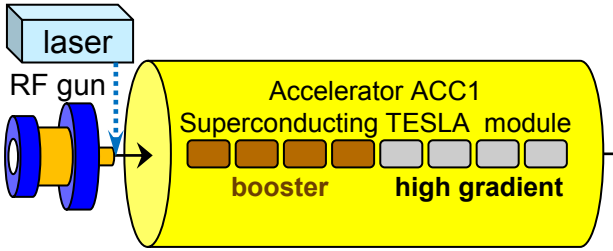
$$\varepsilon = \sqrt{\varepsilon_{cath}^2 + \varepsilon_{RF}^2 + \varepsilon_{SpCh}^2}$$

$$\text{cathode laser shape}: \varepsilon_{SpCh} \rightarrow \min$$



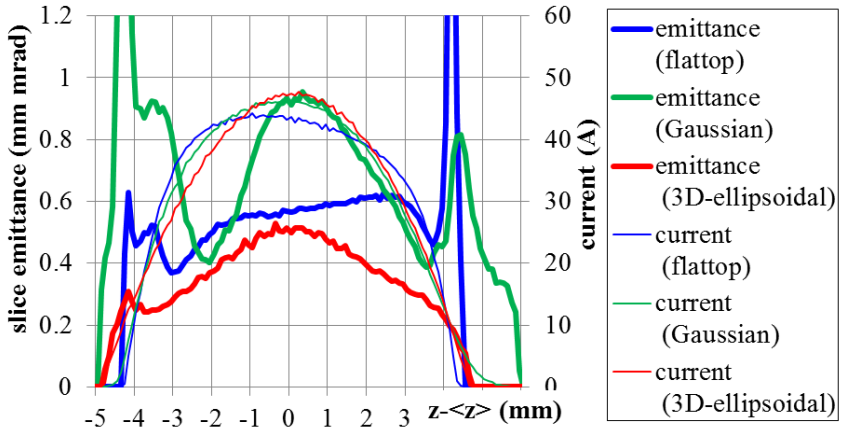
Beam Dynamics Simulations: XFEL Photo Injector (1nC)

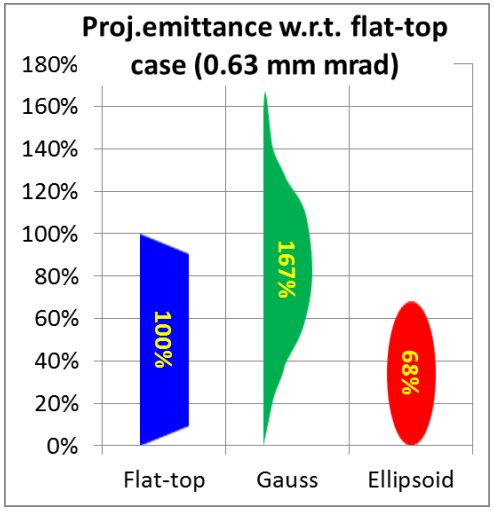
➔Various shapes of the photocathode laser pulse (Gaussian and Flattop temporal profiles vs. 3D-ellipsoid)

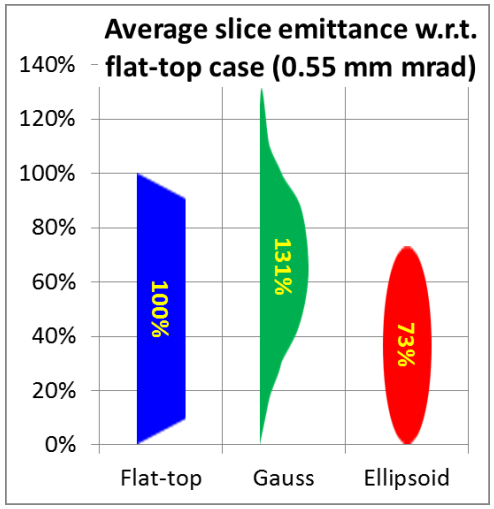


z=15m
E_{beam}~150MeV
σ_t ~7ps

Bunch current profiles and slice emittance at z=15m







Benefits of using of 3D ellipsoidal pulses compared to conventional cylindrical ones:

- ~no beam halo → better signal/noise, reduced **radiation damage**
- ~pure sinusoidal longitudinal phase space +3rd harm. →simplify/allow required **compression**
- less sensitive to machine settings → higher **stability**

3D ellipsoidal cathode laser pulses ➔ Major improvements on electron beam performance

Photo cathode laser shaping → 3D ellipsoid: Practical Realization

Goal – develop a photo cathode laser system with following parameters:

parameter	value	unit
wavelength	258	nm
micropulse energy	15	μJ
pulse train frequency	1	MHz
pulse train length	**0.3**	ms
pulse train rep.rate	10	Hz
micropulse rms duration	6±2	ps
transverse rms size	0.5±0.25	mm

Collaboration:

DESY (Zeuthen) – **IAP**(Nizhny Novgorod) – **JINR** (Dubna)

- **DESY (PITZ)** → more than a decade experience of the **electron source** development and experimental optimization, photo injector infrastructure is ready for tests
- **IAP** → high level expertise level on **laser** system developments, extended laser infrastructure
- **JINR** → significant experience in applied and fundamental accelerator science, radiation based **diagnostics**

BMBF project "Development and experimental test of a laser system for producing quasi 3D ellipsoidal laser pulses"

HRJRG-400 project "cathode laser pulses for high brightness photo injector optimization"

→ Laser system development at IAP, further improvement of the pulse shaping

→ Installation at PITZ for tests with e- beam, dedicated e-beam diagnostics

HGF-RFBR support:

- Individ.grants → manpower (PITZ = 2 PhD stud., IAP = 4 researchers + 2 PhD stud., JINR = 2 researchers + 2 engineers)
- Consumables for installation at PITZ ➔ laser room reconstruction is in progress
- Travel expenses (knowledge and skills exchange)

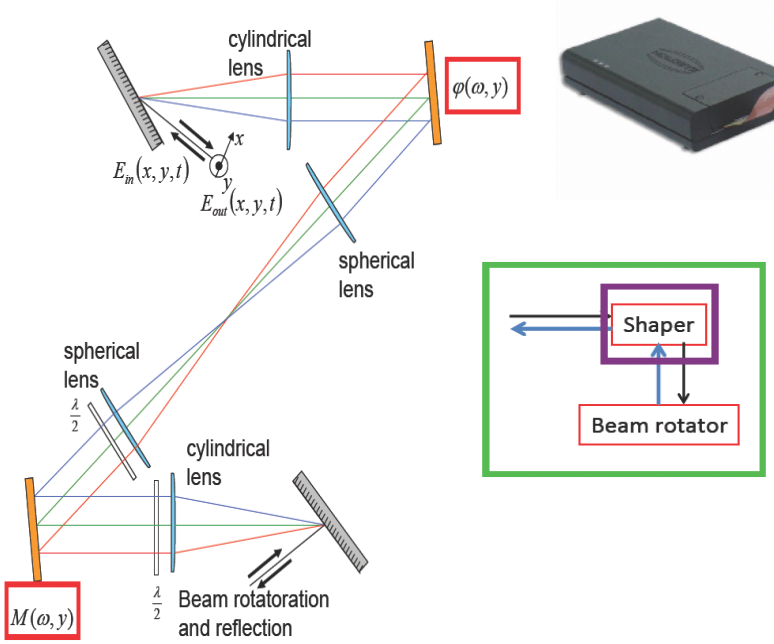
HRJRG-400 project: young researchers contribution

- **IAP** → major part of developments is performed by young scientists:
  - Andrianov Alexey (researcher) : femtosecond fiber laser seeding system
  - Gacheva Ekaterina (PhD student) : Multipass broadband Yb:KGW amplifier
  - Zelenogorsky Victor (researcher): laser pulse shaper, automation of the pulse shaping algorithm, cross-correlator for 3D shape diagnostics
  - Mironov Sergey (researcher): general coordination, numerical simulations of the laser pulse properties, harmonics (SH and UV) generation

- **PITZ**
  - Rublach Tino (Postdoc): PITZ laser room reconstruction for parallel operation of 2 laser systems
  - Khojoyan Martin (Postdoc): Beam dynamics simulations for 3D ellipsoidal laser pulses for the PITZ setup, numerical simulations of the impact of possible imperfections of the laser pulses onto electron beam performance
  - Prach Bornpoornprasert (PhD student): Simulation of possible IR/THz option for PITZ, simulation of benefit of usage of 3D ellipsoidal pulses
  - NN (PhD student): Development of experimental methods for 3D electron beam shape diagnostics

- **JINR**
  - Makarov Roman (engineer): Development of accelerator and diagnostic technique on base of synchrotron and undulator radiation applied to 3D ellipsoidal bunches
  - Petrov Dmitry (engineer): Development of undulator systems applied for FEL radiation from 3D ellipsoidal pulses.

3D-Ellipsoid laser system: developments at IAP



HOLOEYE Photonics AG, Germany (*www.holoeye.com)*
PLUTO-NIR: High-Resolution LCOS Phase Only Spatial Light Modulators

! Reflected signal flickering → ? Hamamatsu SLMs

Pulse Shaper Tests at IAP

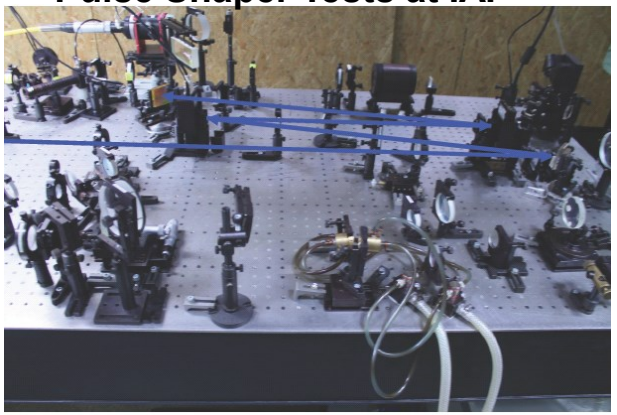
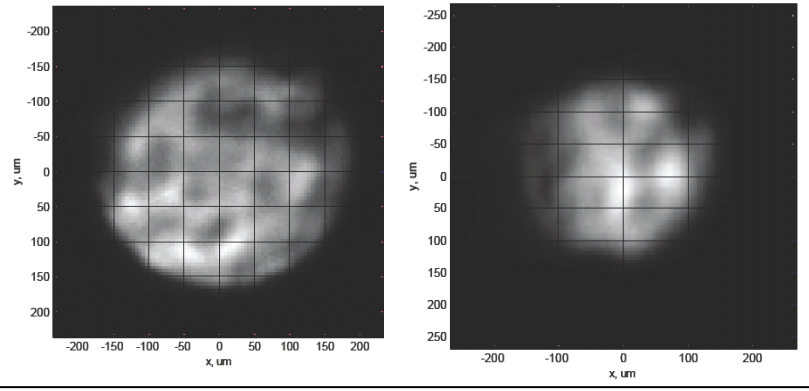
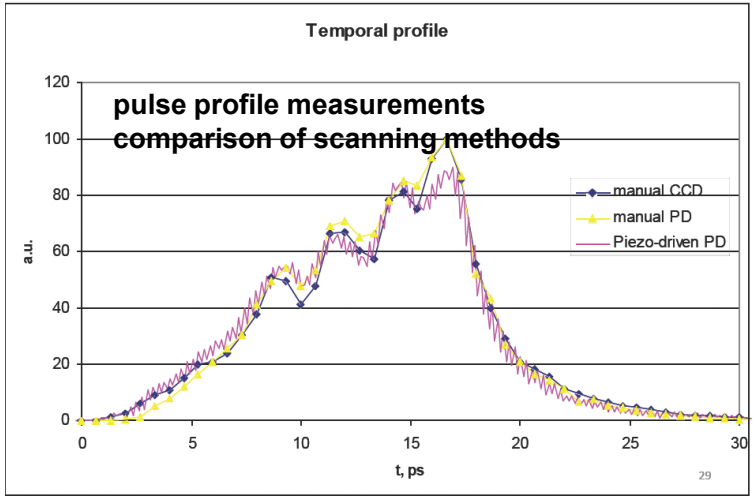


Image at nonlinear crystal of cross-correlator

1ω 2ω





Conclusions and Outlook

- **3D ellipsoidal** cathode laser pulses → next step in photo injector optimization for SASE FELs. Beam dynamics simulations → **benefits** from 3D ellipsoidal laser pulses for linac driven light sources (lower **emittance**, almost no beam halo,"more sinusoidal" LPS, less sensitive to machine settings)

- 3D ellipsoidal cathode laser pulses, **practical realization** ➔ HRJRG-400 (collaboration DESY-IAP-JINR):
  - Laser system developments at IAP RAS, Nizhny Novgorod (Russia), SLM based pulse shaper
    - All necessary equipment is installed and functioning
    - The energy of fundamental pulses close to the calculated (70μJ instead 100μJ)
    - The conversion efficiency of the SH of ~50% achieved by using of the angular chirped pulse technique
    - Improvement of the conversion into UV is ongoing (currently up to 20%)
    - Shaper is ready for managing spatial-temporal parameters. New SLMs (Hamamatsu) are under commissioning
    - Works on fast camera for the 3D pulse shape diagnostics are planned in the nearest future
  - Delivery and installation at PITZ for tests with e-beam → from September 2014, preparation for the installation have been started
  - Developments on diagnostics at JINR are ongoing

- Further intensive extended studies on the revealed effects (like SLM stability, harmonics generation efficiency etc.) are highly desirable in order to improve the laser system performance. Also more studies in electron beam dynamics for more precise and reliable diagnostics are required. R&D on IR/THz option at PITZ is under consideration.

Thank you for your attention!