Accelerator Activities at PITZ

Plasma acceleration etc.

Outline

- Introduction of PITZ (**P**hoto **I**njector **T**est facility at **Z**euthen)
- Plasma acceleration
  - Motivation
  - Self-modulation experiment
  - Further development
- ps-fs electron and photon beams
  - RF gun, Ellipsoidal laser, Undulator

Matthias Groß
LA3NET Workshop, HZDR
29. April 2014

HELMHOLTZ ASSOCIATION

PITZ Photo Injector Test Facility Zeuthen

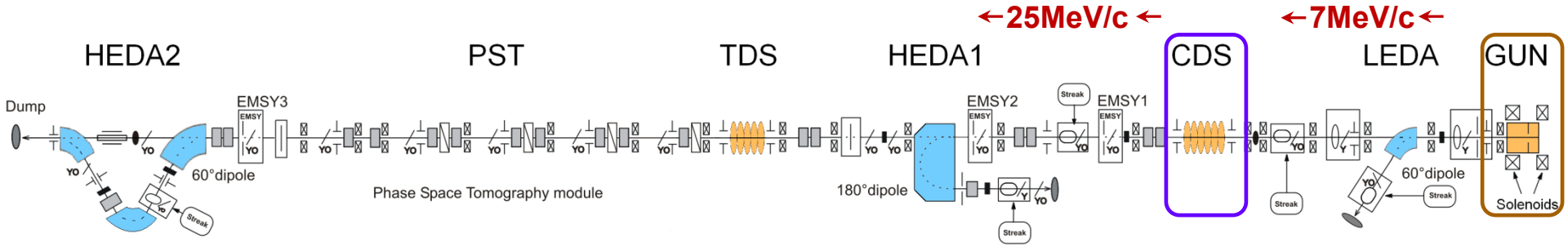
DESY

DESY, Location Zeuthen

- Former Institute for High Energy Physics in Zeuthen (Academy of Sciences of the GDR). Was merged with DESY on 1st January 1992
- 200 employees of which 50 are scientists

Photo Injector Test facility at Zeuthen – PITZ

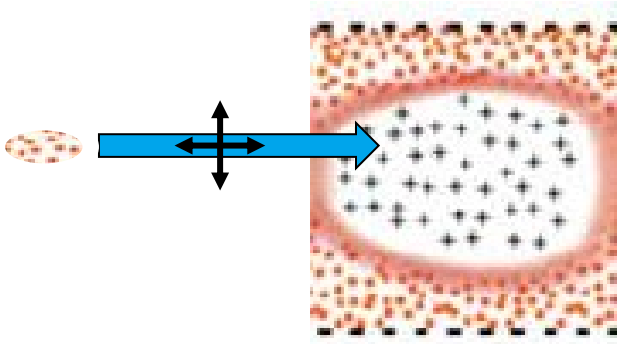
- Goals & research activities
  - Study, development, characterization and conditioning of electron beam sources for FLASH and the European XFEL
  - Testing new developments e.g. laser system, accelerating structures (e.g. PWA), deflecting structure, cathodes, and beam diagnostics
- History – some highlights
  - 1999: DESY directorate decision to build PITZ in Zeuthen
  - 2002: 1st photoelectrons produced
  - 2008: New Yb:YAG photocathode laser system
  - 2013: First electron gun delivered to European XFEL



Novel Accelerator Research in LAOLA (laola.desy.de)

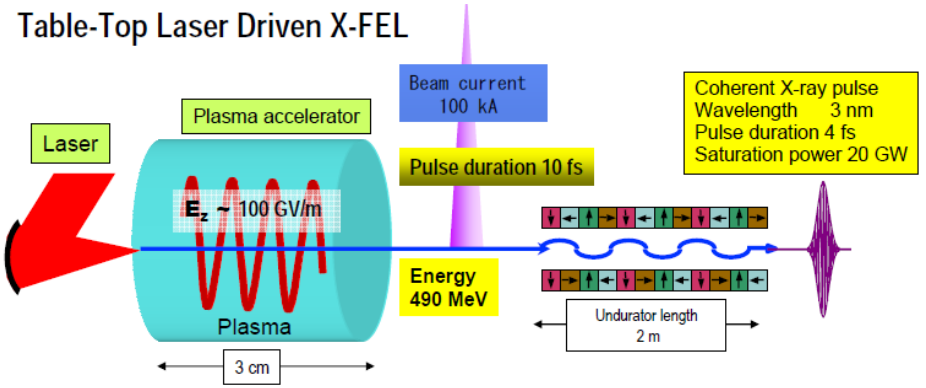
REGAE (laser driven)

- Probing of electrical fields with test beam (external injection)



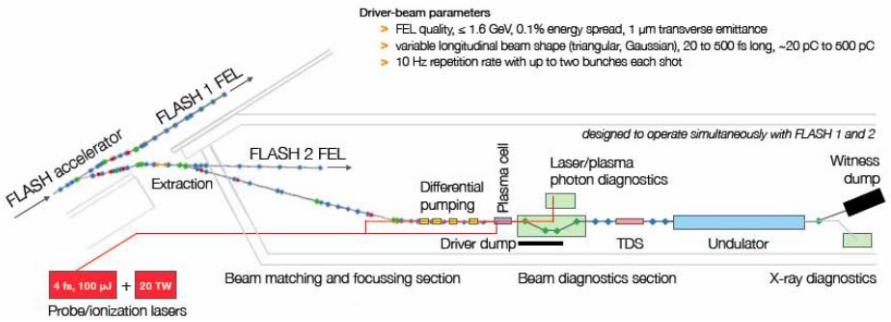
LUX (laser driven)

- Laser driven light source



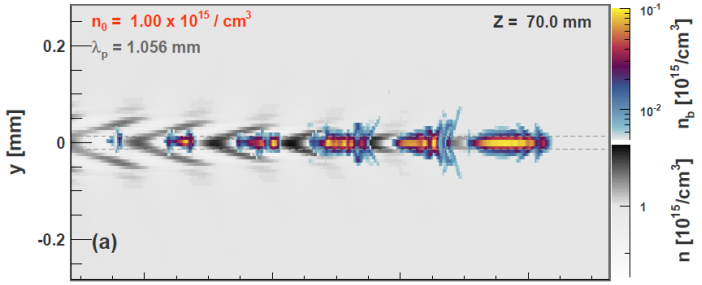
FLASHForward (particle driven)

- Energy boosting of FLASH bunch to utilize special pulse shapes



PITZ (particle driven)

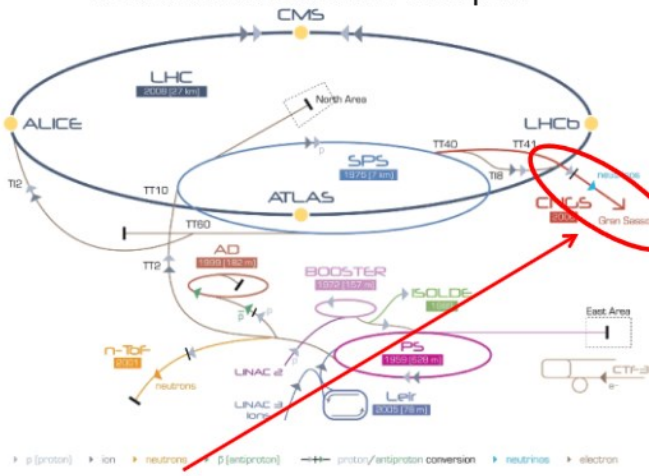
- Self-modulation of electron beam
- High transformer ratio



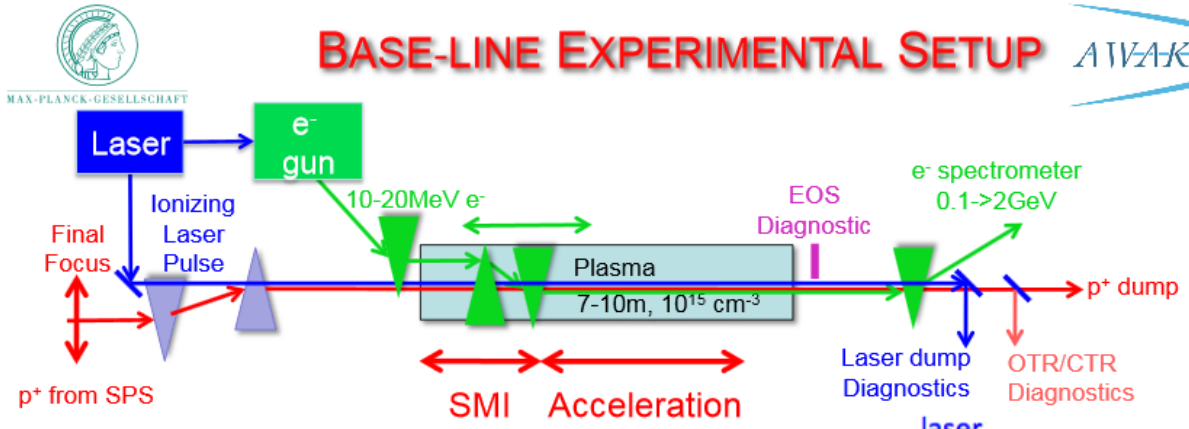
EAAC Workshop 2013: Patric Muggli, AWAKE: A Proton-Driven Plasma Wakefield Experiment at CERN

- Use high energy proton beams from SPS to drive plasma wave
- Convert proton beam energy to accelerate electron beam in single stage

CERN Industrial Beam Complex

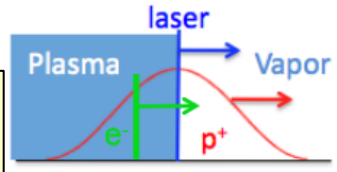


CNGS experimental area



Caldwell et al., Nature Physics (2009):

$$E_{z,max} = 240(MV\ m^{-1})\left(\frac{N}{4x10^{10}}\right)\left(\frac{0.6}{\sigma_z(mm)}\right)^2$$



- High accelerating gradient requires **short** bunches (σ_z less than 100μm)
- Existing proton machines produce **long** bunches (10cm)

Self-modulation!

gli, 06/04/2013, EAAC 2103

Courtesy:
Patric Muggli

DESY

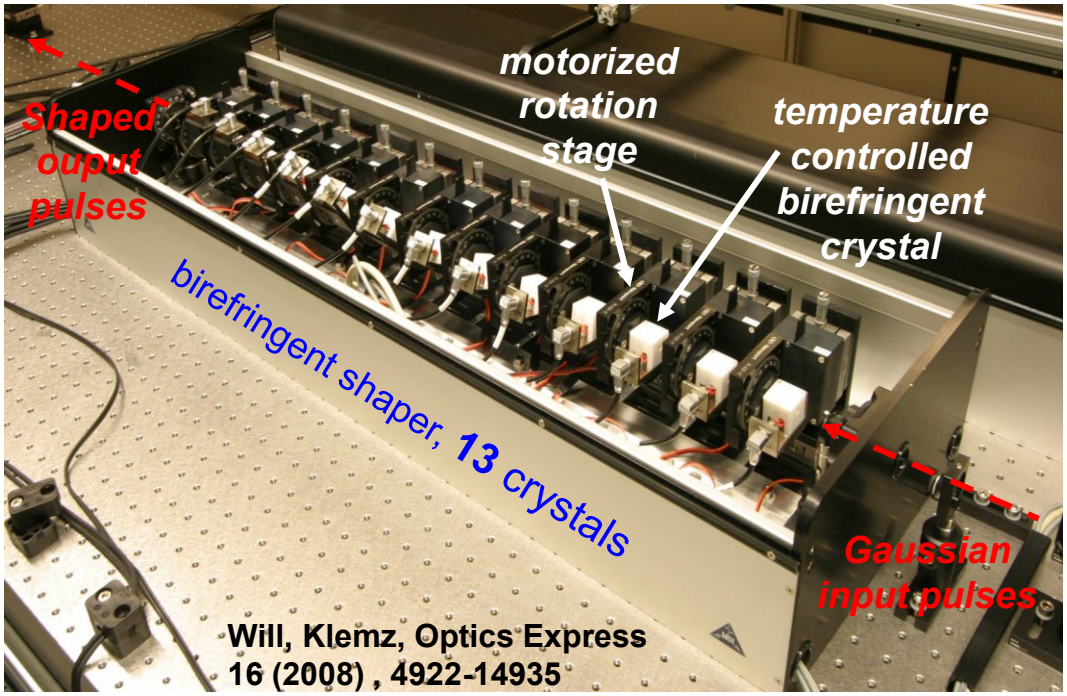
Why Experiments at PITZ?

- Favorable circumstances
  - Very high level photo injector test facility
  - Worldwide unique laser system (pulse shaper)
  - Well developed diagnostics (high resolution electron spectrometer, etc.); soon: transverse deflecting cavity + dispersive section for longitudinal phase space measurements
  - High flexibility (Pure R&D facility)

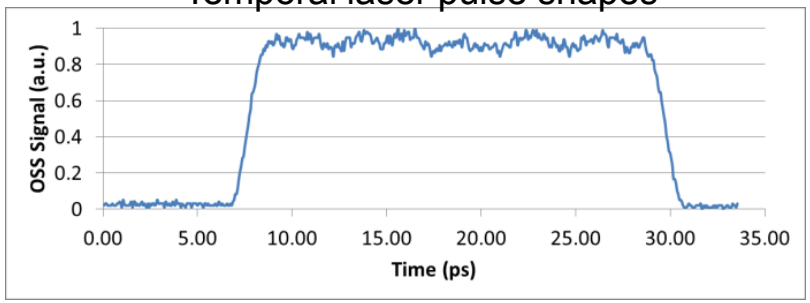
- Possible contribution from PITZ:
  - Self-modulation of electron beam (same principle as for proton beam!)
  - Later: High transformer ratio (multiplying beam energy by factor up to 8) – needs bunch compressor for high absolute energy gain

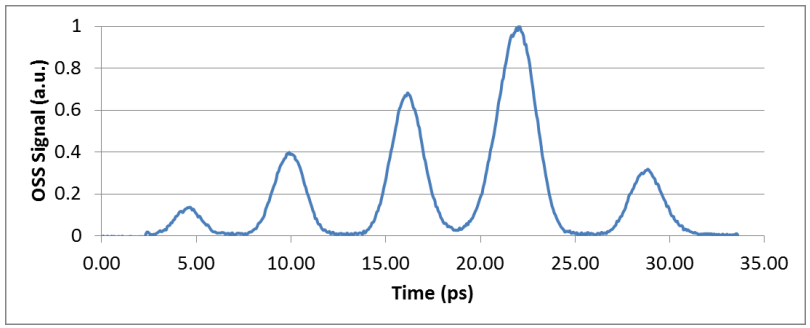
Flexible Laser Pulse Formation at PITZ

- Photoinjector laser
- Developed and built by Max-Born Institute Berlin
- **Key element**: the **pulse shaper**
  - Contains 13 birefringent crystals. Pulses are split according to polarization. Delay is given by crystal thickness; relative amplitude can be varied freely by adjusting relative angle between crystals



Temporal laser pulse shapes

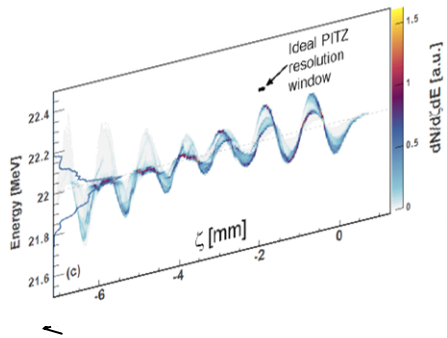


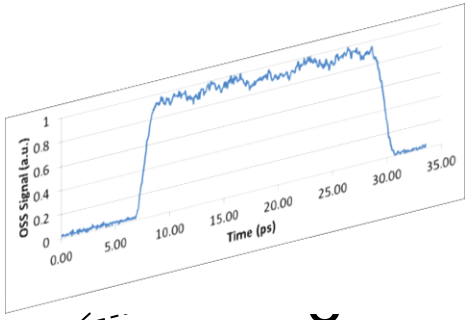


Electron bunch ≙ Laser pulse

Plasma Cell Design – Currently in Fabrication

Design:
Gerald Koss





Thermal Insulation

Heating Coils

Cooling Sleeve

Helium Distribution

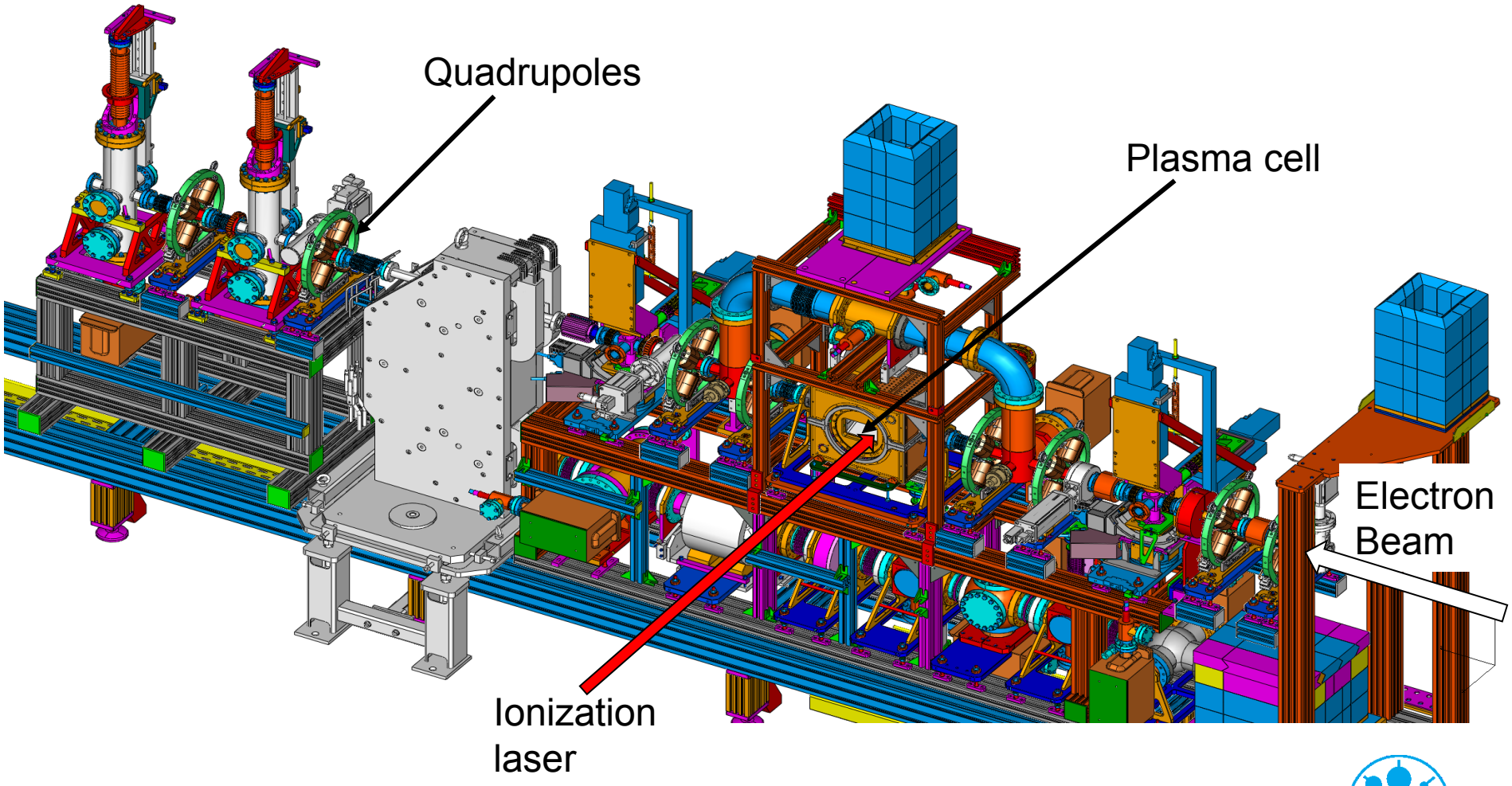
Electron Window

Laser Window

Laser Mirror

Plasma Cell Assembly: Sketch of Beam Line

Design: Gerald Koss / Alexander Donat / Sebastian Philipp

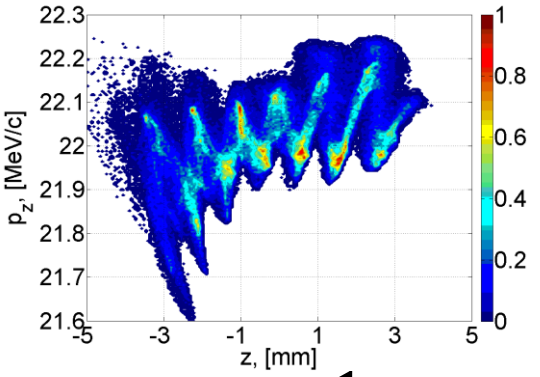


Simulated Self-modulation Experiment

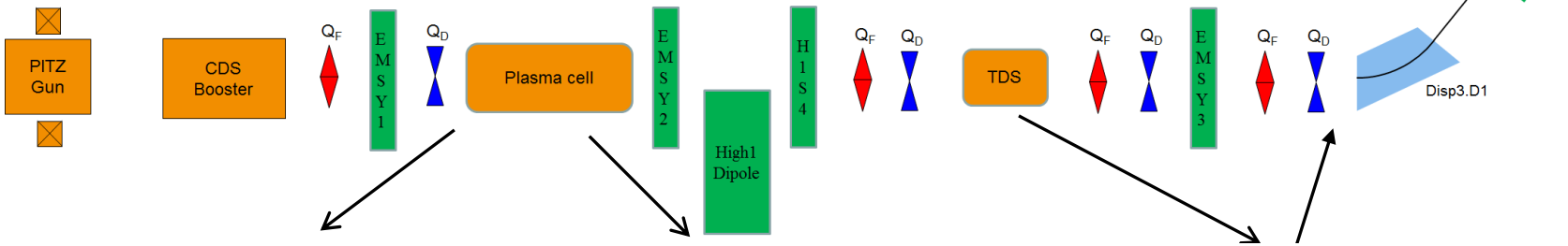
Longitudinal Phase-space studies

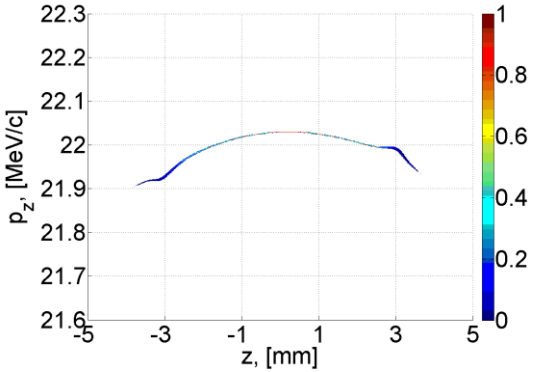
Simulations:
Martin Khojoyan /
Dmitriy Malyutin

Expected phase space ←

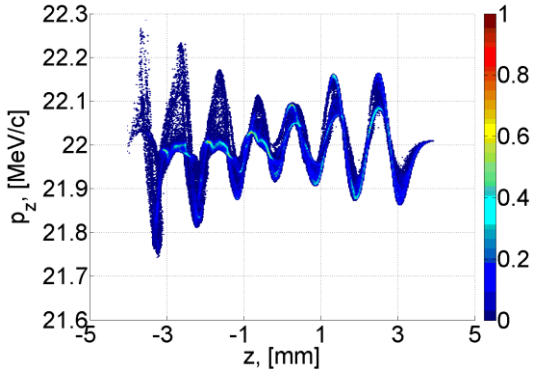


Not optimized

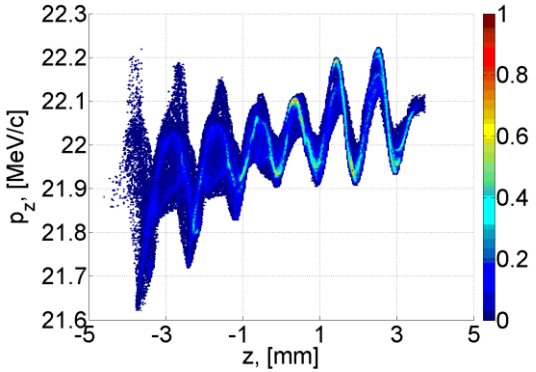




In front of plasma cell



After plasma cell
(assuming zero initial energy spread)



In front of dipole

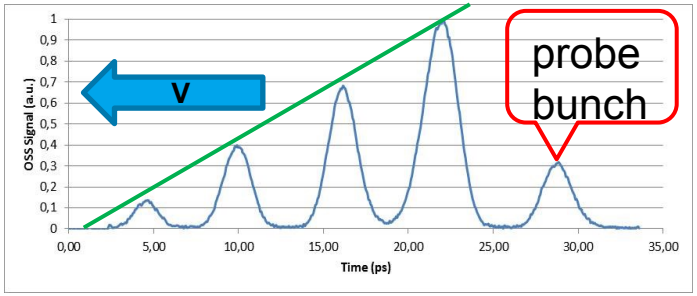
LAOLA@PITZ: High Transformer Ratio (TR) studies

- TR is defined as $R = \frac{\hat{W}(\zeta)}{\tilde{W}(\zeta)}$ ← accelerating field behind bunch ← decelerating field within bunch

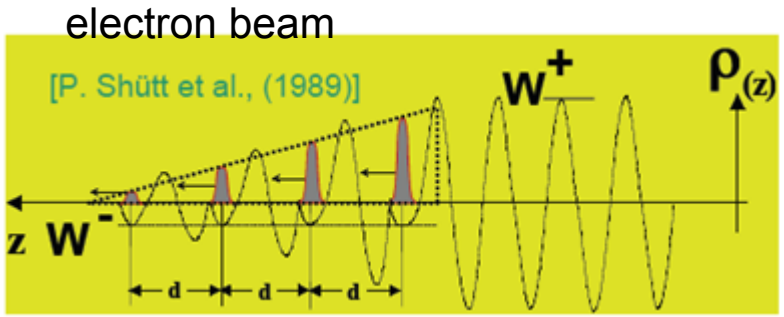
- Fundamental beam loading "theorem": $R \leq 2$ for bunches with symmetric current profile

- Idea: Tailored bunch current profile (asymmetric bunch)

PITZ Laser capability:



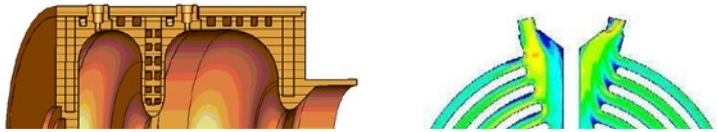
⇒



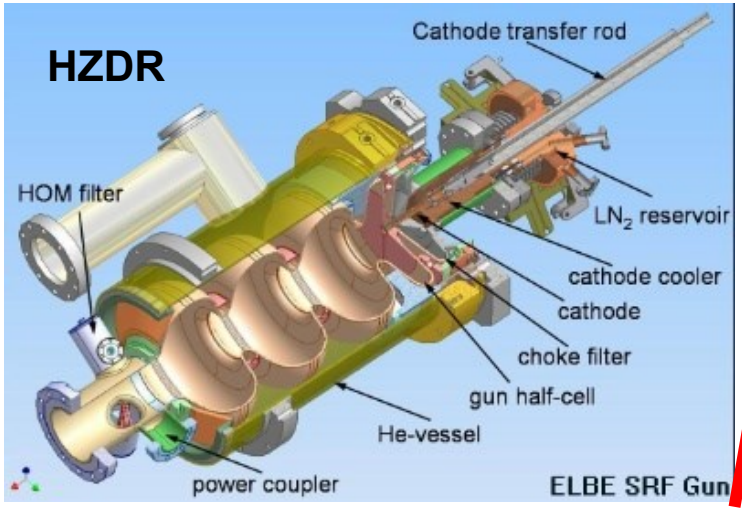
- Significant plasma acceleration of a probe bunch could be possible
  - Transformer Ratio up to 8 with matched plasma wavelength
- Needs bunch compressor for high absolute energy gain

Electron Gun Development

- Expertise at PITZ: Gun development to increase performance
- Fundamental issues: cooling / stability



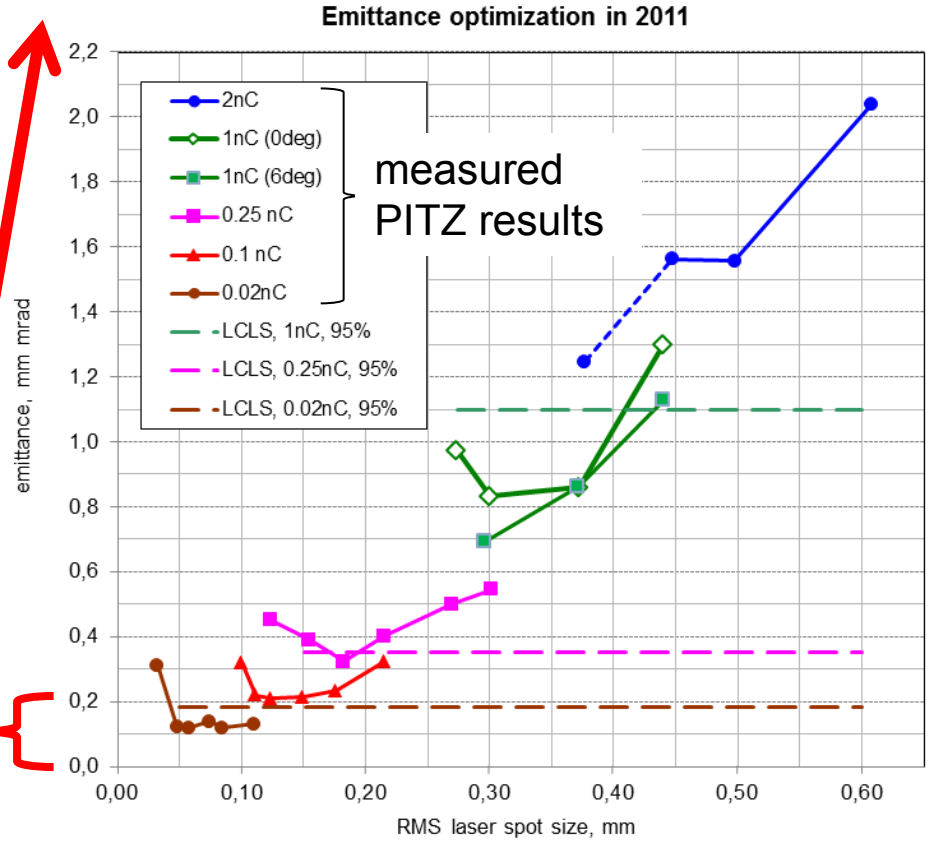
- **Problem:**
  - Current state-of-the-art in SC RF guns:



measured emittance: 3±1 mm mrad @80pC

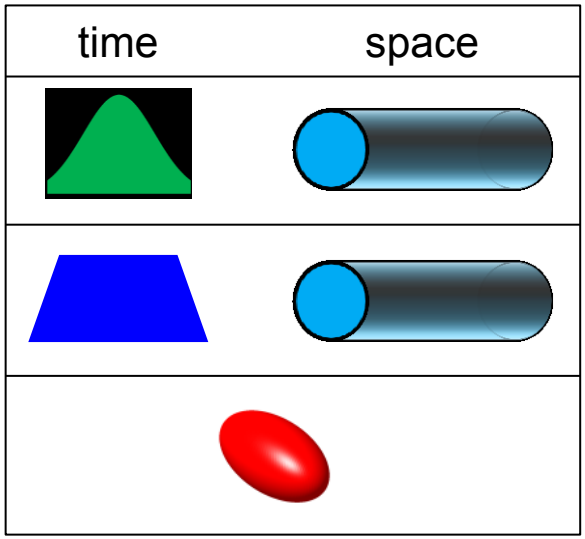
required for CW XFEL

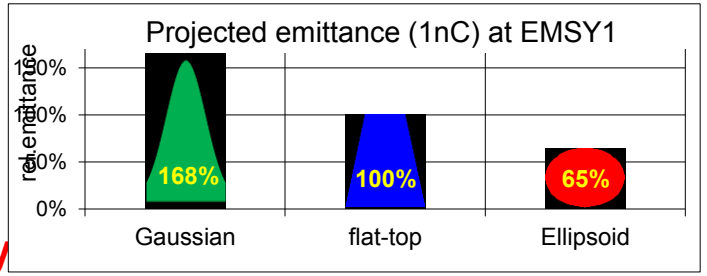
➔ **only NC guns reach goal region**



Ellipsoidal Laser

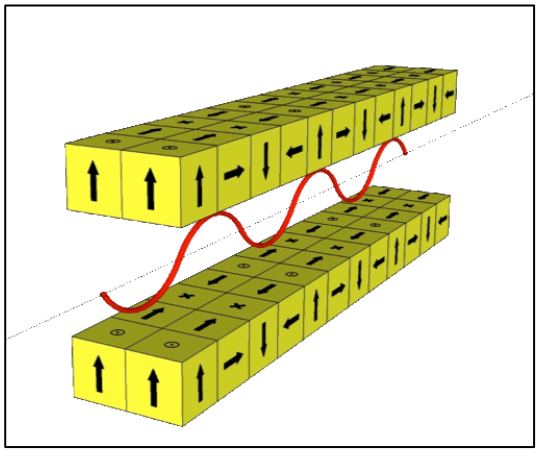
- Expertise at PITZ: Optimizing electron bunch properties
- Fundamental parameter: shape of laser pulse
- Standard: temporal Gaussian
- Developed for European XFEL: temporal flat-top
- New project: ellipsoidal
- Benefits for linac driven light sources:
  - Lower emittance → higher **brilliance**
  - More linear phase space → better **compression**
  - Almost no beam halo → reduced **radiation damage**
  - Less sensitive to machine settings → higher **stability**





Development of IR/THz Source

- Asset of PITZ: High charge, high quality electron beam available
- Need: tunable THz source for pump-probe experiments at European XFEL
- Realization:
  - Use existing undulator design
  - APPLE: Choose polarization by moving magnets
  - Insert into PITZ beam line
  - **High power, tunable** FEL operation in IR/THz
  - Add on: low charge beams for electron diffraction (like REGAE)



- Other possibilities:
  - Use undulator radiation for **electron beam diagnostics**
  - **IR/THz radiation source for users** (+ preparation for beam time at XFEL)

→ Connection to users in Berlin / Brandenburg region

Summary

- PITZ: conventional and novel accelerator research
- PITZ is working in plasma acceleration in the LAOLA collaboration
  - Current work: Self-modulation and high transformer ratio
- PITZ expertise will also be driving force in several other accelerator developments

- PITZ plays a significant role in the highly relevant field of accelerator R&D