Accelerator Activities at PITZ

Plasma acceleration etc.

Outline

- Motivation / Accelerator Research & Development (ARD)
- Plasma acceleration
  - Basic Principles
  - Activities
  - SINBAD
- ps-fs electron and photon beams
  - Ellipsoidal laser, RF gun, Undulator

Matthias Groß
Klausurtagung Schloss & Gut Liebenberg
20. September 2013

HELMHOLTZ ASSOCIATION

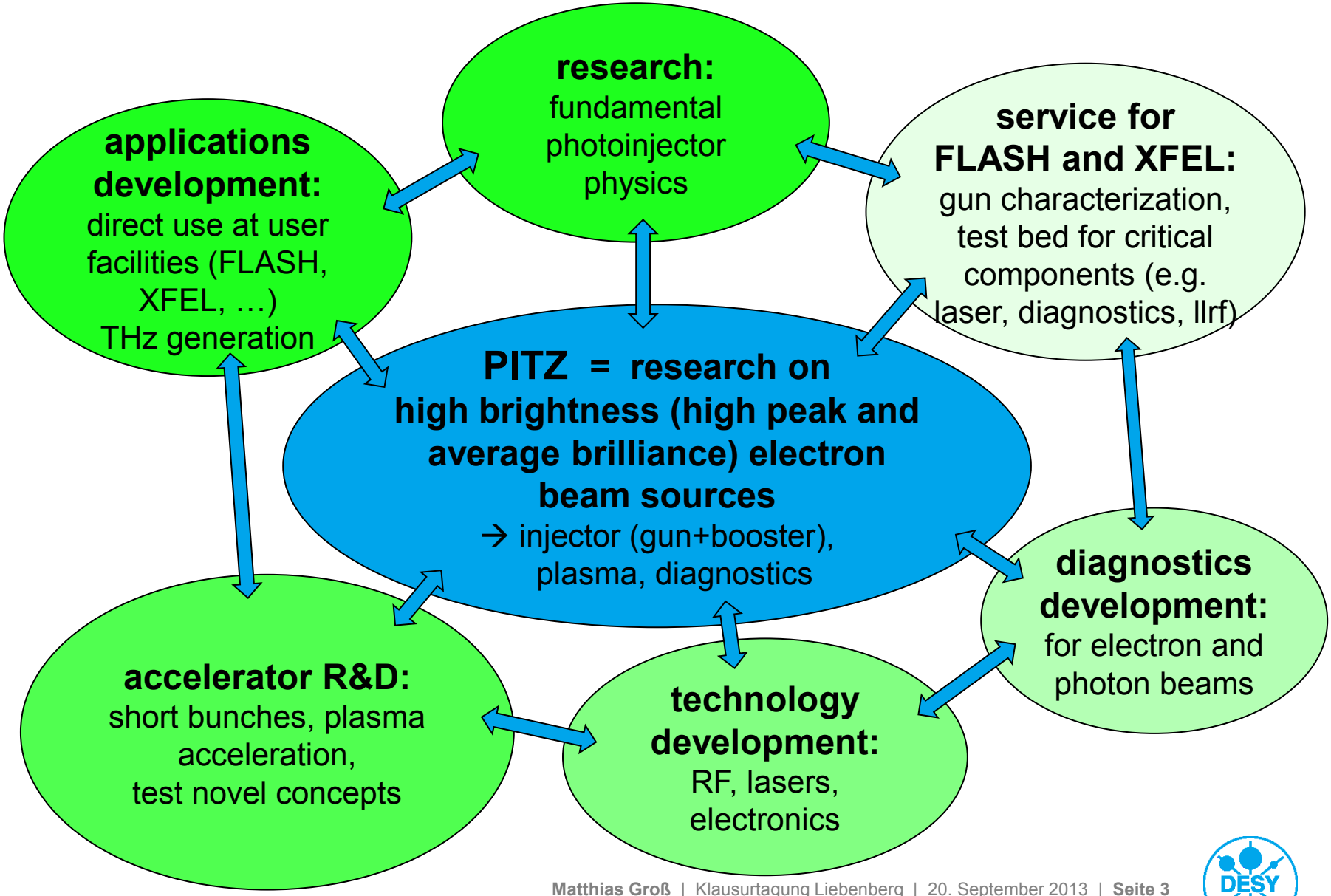
PITZ Photo Injector Test Facility Zeuthen

DESY

Accelerator Technology

- Light sources to investigate materials. Applications in
  - Life Sciences (Biology, Chemistry, Medicine)
  - Material Technology
  - Fundamental Research
  - etc.
- Accelerators for particle- and nuclear physics
  - Constitution of matter
  - Fundamental forces
  - etc.
- For this we need
  - High beam energy
  - High particle density
  - Very short particle bunches

PITZ activities



Helmholtz ARD Program – Accelerator R&D as a Research Field

> Accelerator physics:

- Originally part of
  - high energy physics
  - nuclear physics
  - research with photons, neutrons, ions (PNI)
- Since 2010: ARD is part of HGF portfolio program → extra funding for ARD
- **Starting 2015: own topic in HGF program (POF III) – recognized as a future oriented research field**
- Significant, stable funding (base budget) for accelerator R&D; independent of big science projects

Coordinator: Reinhard Brinkmann

Helmholtz ARD – Research Topics and DESY Involvement

Superconducting RF Technology

Concepts and Technologies for Hadron Acc.

HELMHOLTZ ASSOCIATION ACCELERATOR Research & Development

PITZ is involved

ps – fs Electron and Photon Beams

Novel Acceleration Concepts

Courtesy:
Ralph Aßmann

Motivation for Developing Plasma Acceleration

- Why novel accelerators? – we are already very good in accelerator technology!

- Conventional accelerators work well but they are very large

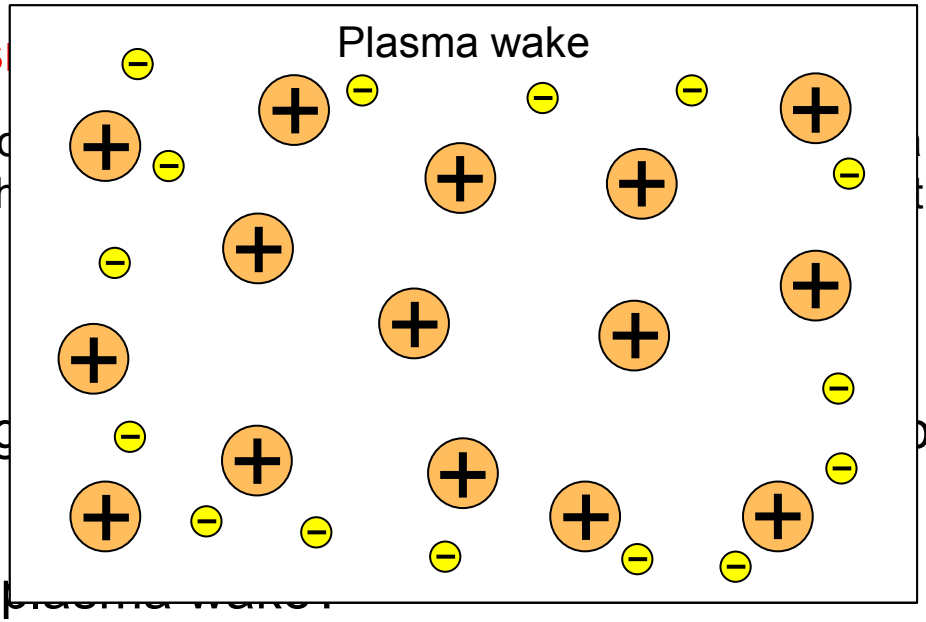
Name	Final energy	Size
HERA	27.5 GeV	2 km diameter
SLAC (SLC linac)	50 GeV	3.2 km length
European XFEL (linac)	17.5 GeV	2.1 km length

- Conventional accelerator cavities: about 100 MV/m
- Possible with plasma acceleration: up to 1 TV/m !!!

} **10.000x**

Problem of Conventional Accelerators

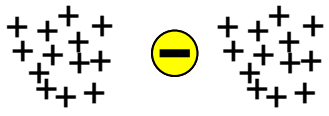
- Basic problem: microscopic particles are accelerated with macroscopically generated fields
  - Small field gradient → Large accelerator
- New Idea: Plas
  - Utilize microsc plasma) – these are big since the ch the building materials



- Ionization of a g ous properties for acceleration
- How to drive a p
  - With a strong **laser** pulse (laser driven plasma wakefield accelerator – LDPWA)
  - With a **particle** beam (particle driven plasma wakefield accelerator – PDPWA)

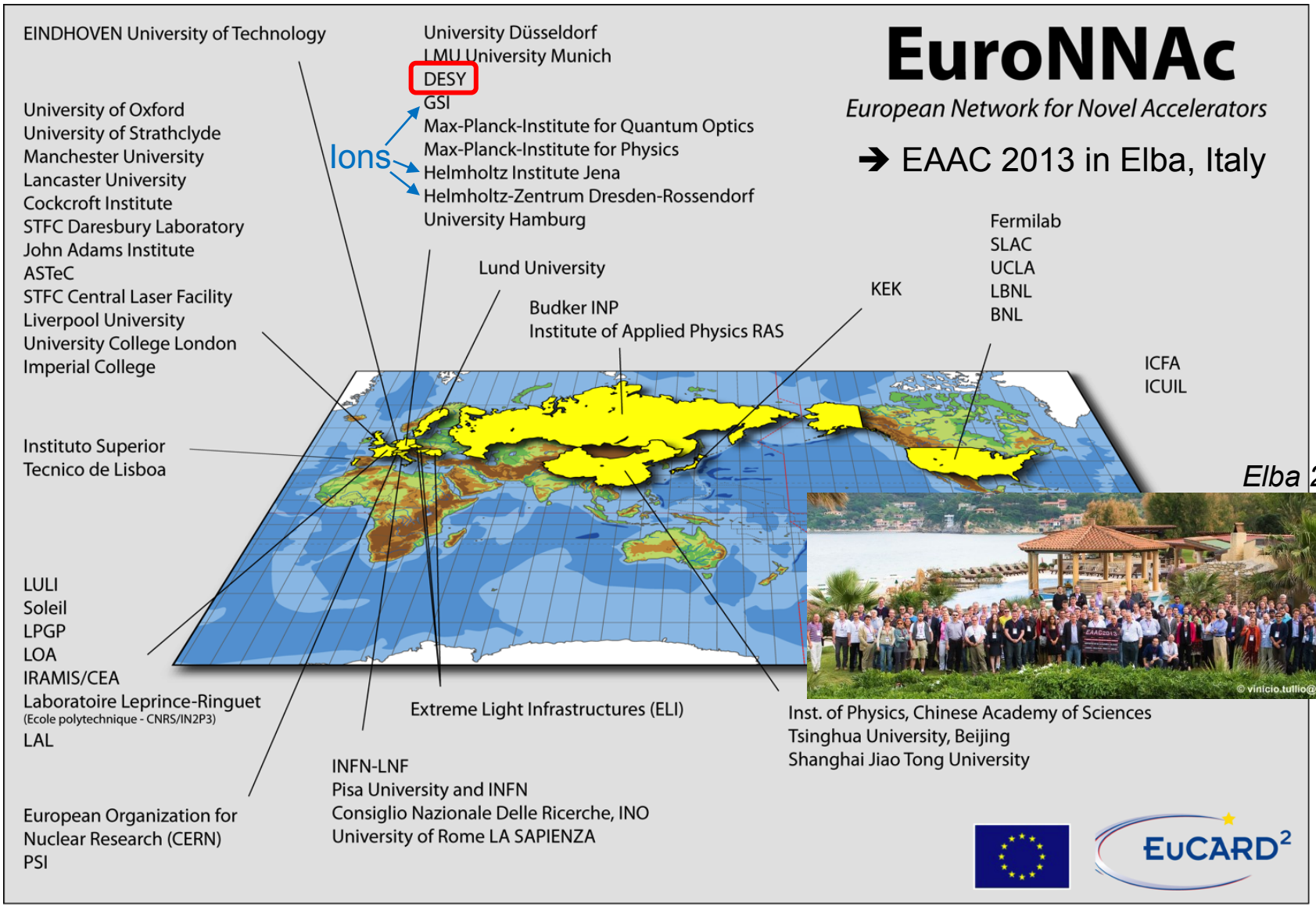
Plasma Wakefield Accelerator

- Acceleration of an electron with a (travelling) wakefield



- With optimal utilization of non-linearities we can achieve extremely strong acceleration

Players in Novel Accelerators: World Wide with High Concentration in Europe



Courtesy:
Ralph Aßmann

ARD Research Activities at DESY

SC Technology
(R&D on CW, cryo module test bench, ongoing)

SC Processes
(large series production & testing of sc cavities and modules, AMTF, ongoing)

FEL Seeding
(sFLASH, FLASH2 seeding, ongoing)

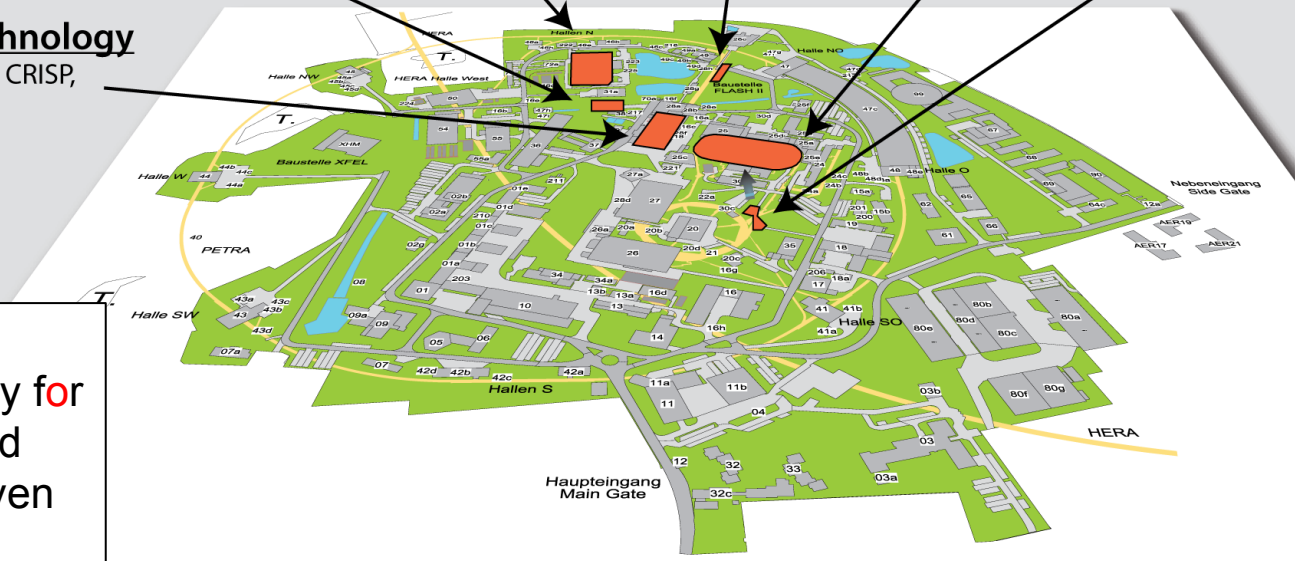
FLASHForward
(beam-driven plasma acceleration, 2016+)

SINBAD (ultra-short bunches, LAOLA, proto-type table-top FEL, 2017+)

AXSIS (atto-second bunches, ICS, 2014+)

LAOLA at REGAE
(laser-driven plasma acceleration, 2013-2016)

Surface Technology
(cavity surfaces, CRISP, ongoing)



Zeuthen Campus

Photo-Injector
(ongoing)

LAOLA at PITZ
(bunch modulation in plasma, 2013+)

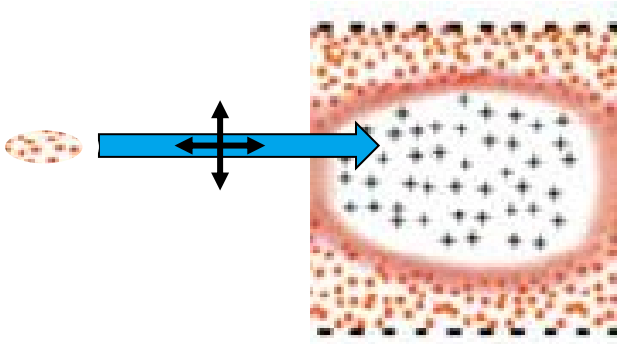
LAOLA:
Laboratory for
Laser- and
beam-driven
plasma
Acceleration

Courtesy:
Ralph Aßmann

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

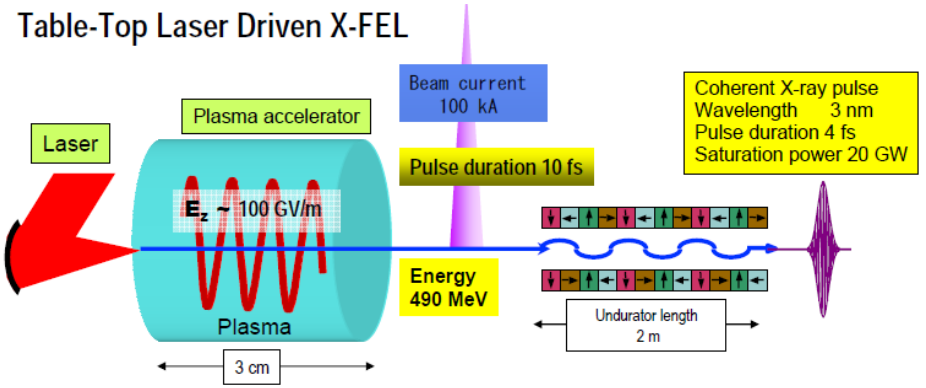
REGAE (laser driven)

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



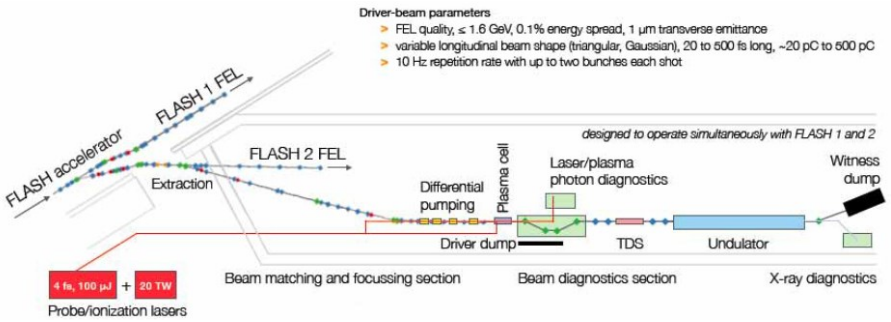
LUX (laser driven)

- Laser driven light source



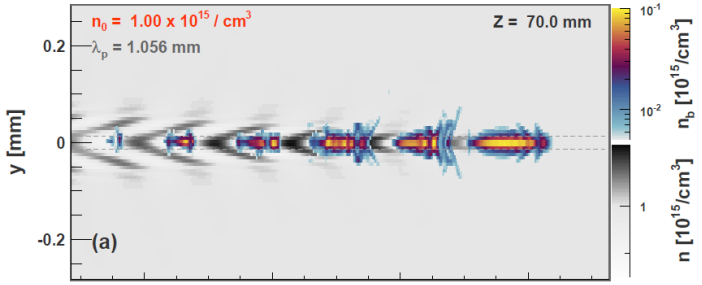
FLASHForward (particle driven)

- Energy boosting of FLASH bunch to utilize special pulse shapes



PITZ (particle driven)

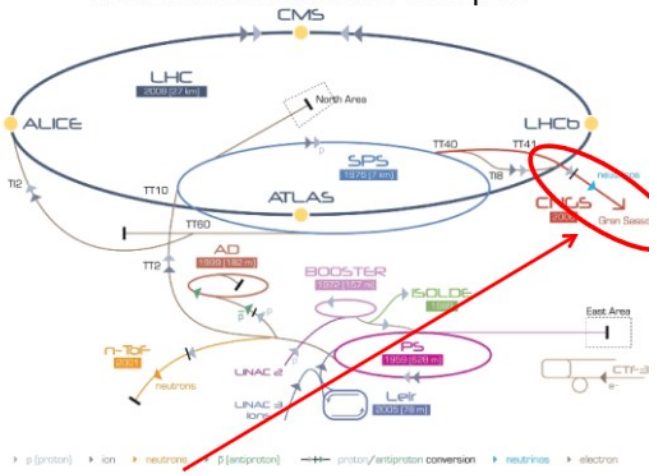
- Self-modulation of electron beam
- High transformer ratio



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

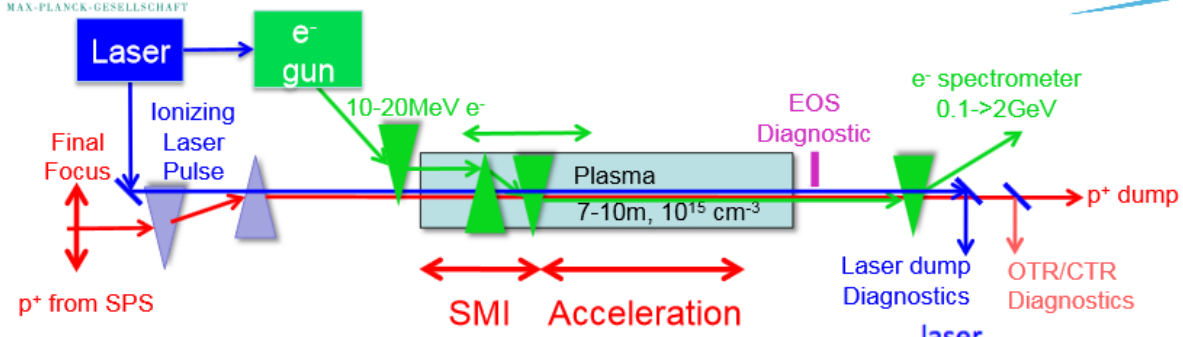
CERN Industrial Beam Complex



CNGS experimental area

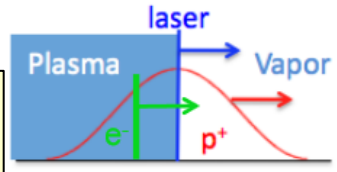
BASE-LINE EXPERIMENTAL SETUP

AWAKE



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

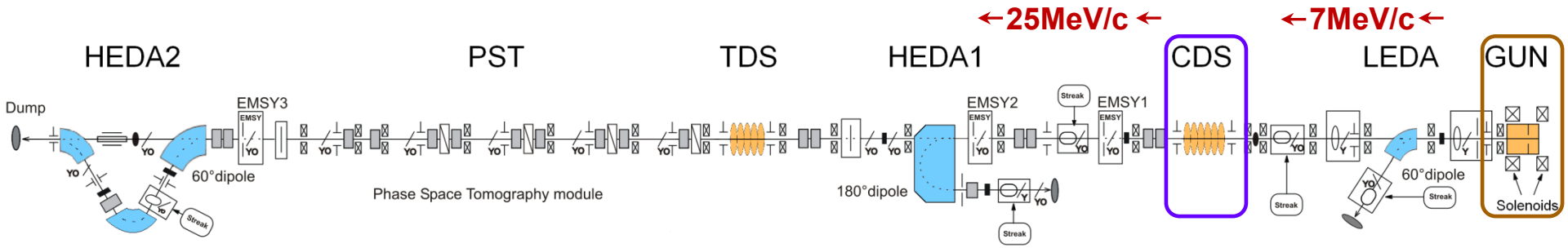
Why Experiments at PITZ?

- 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

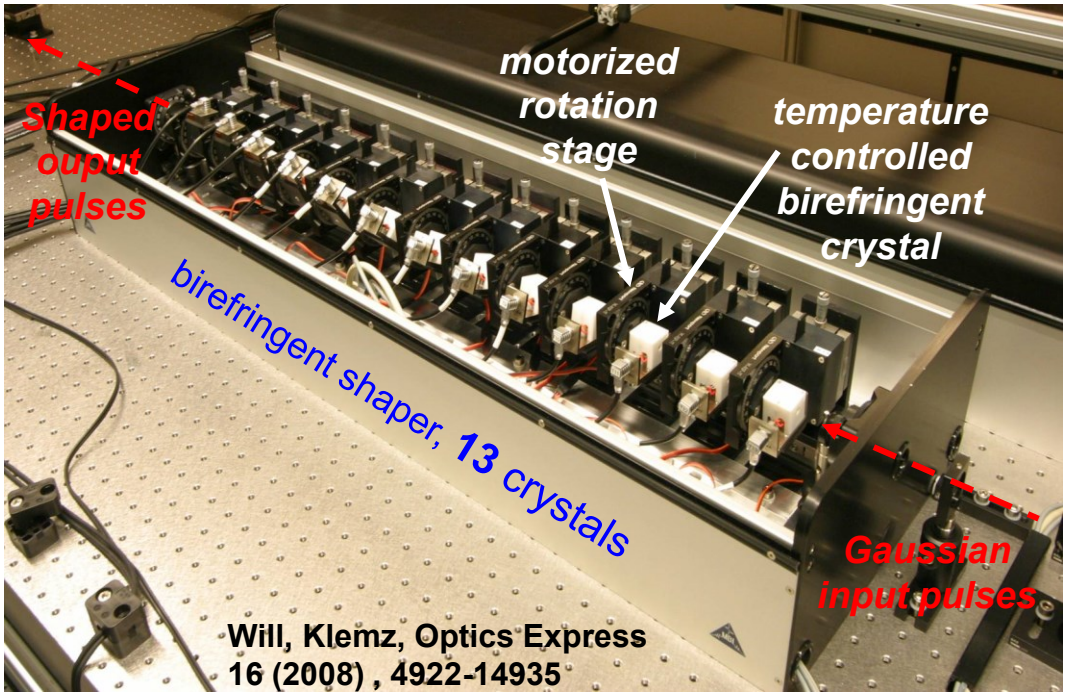
PITZ Overview

- UV Photocathode Laser
- RF Gun, Booster
- Diagnostics
  - Slit scan (Transverse emittance)
  - Streak camera, soon TDS (Longitudinal emittance)
  - Screen stations (beam shape and position)
  - Tomography (Transverse emittance)
- New developments (plasma acceleration etc.)

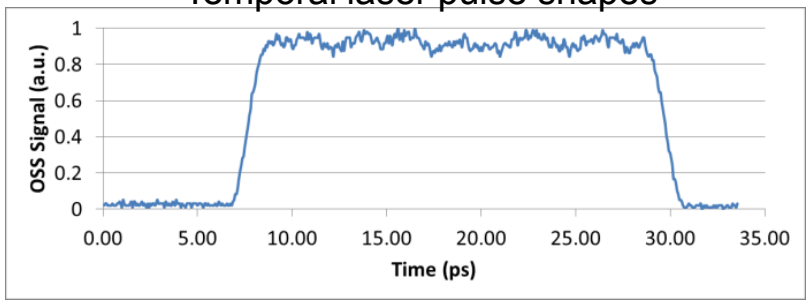


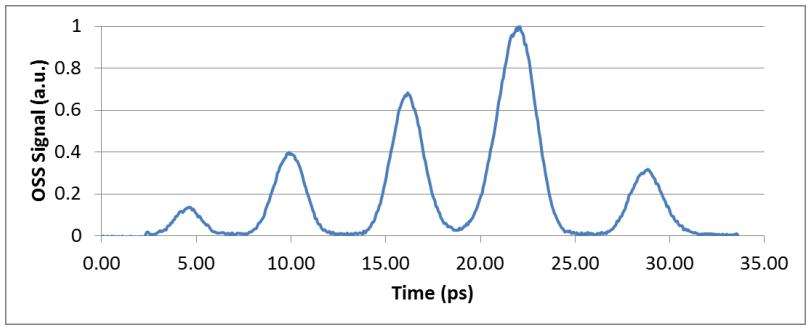
Flexible Laser Pulse Formation at PITZ

- 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

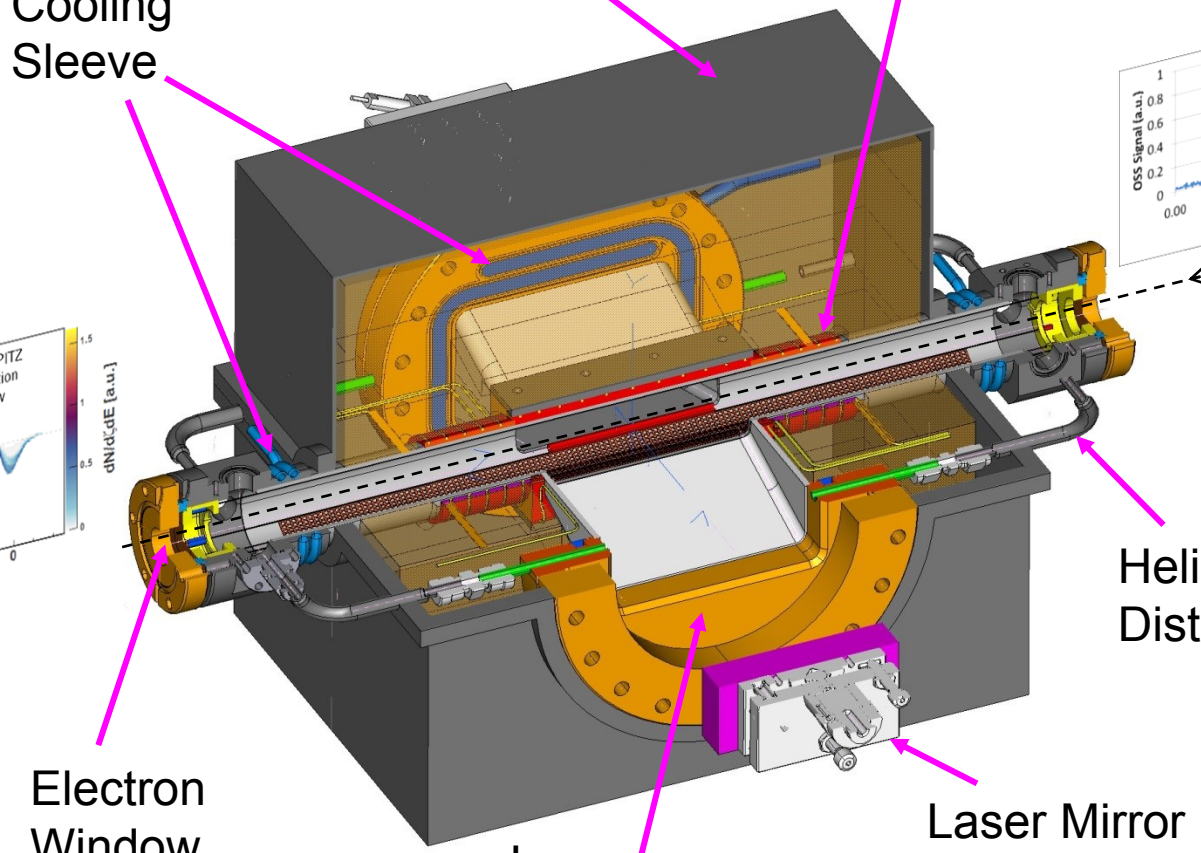


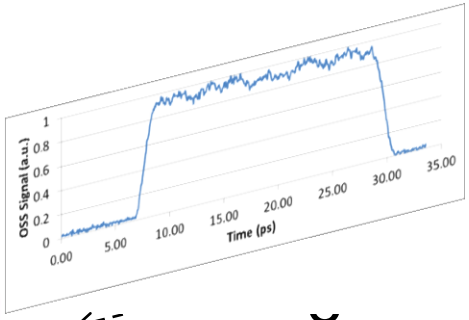


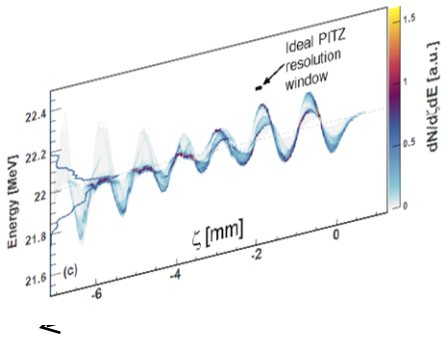
Electron bunch ≙ Laser pulse

Plasma Cell Design – Currently in Fabrication

Design:
Gerald Koss



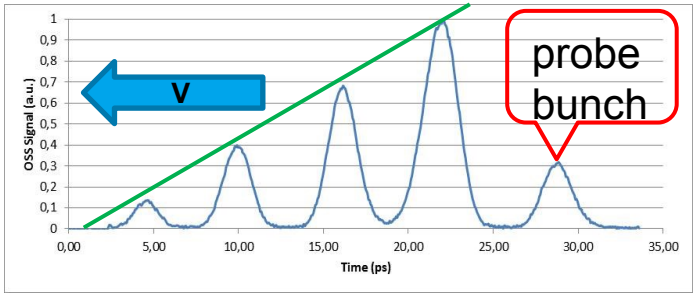




LAOLA@PITZ: High Transformer Ratio (TR) studies

- 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:



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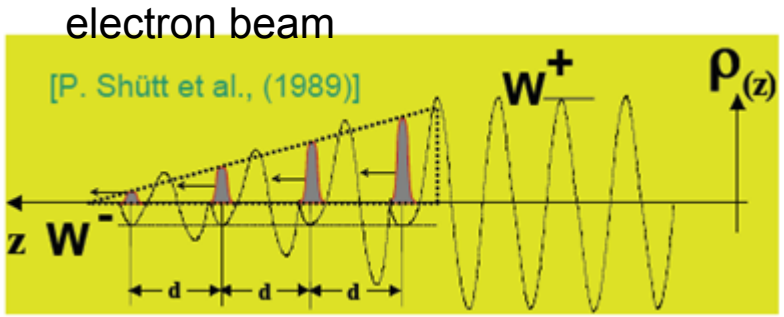
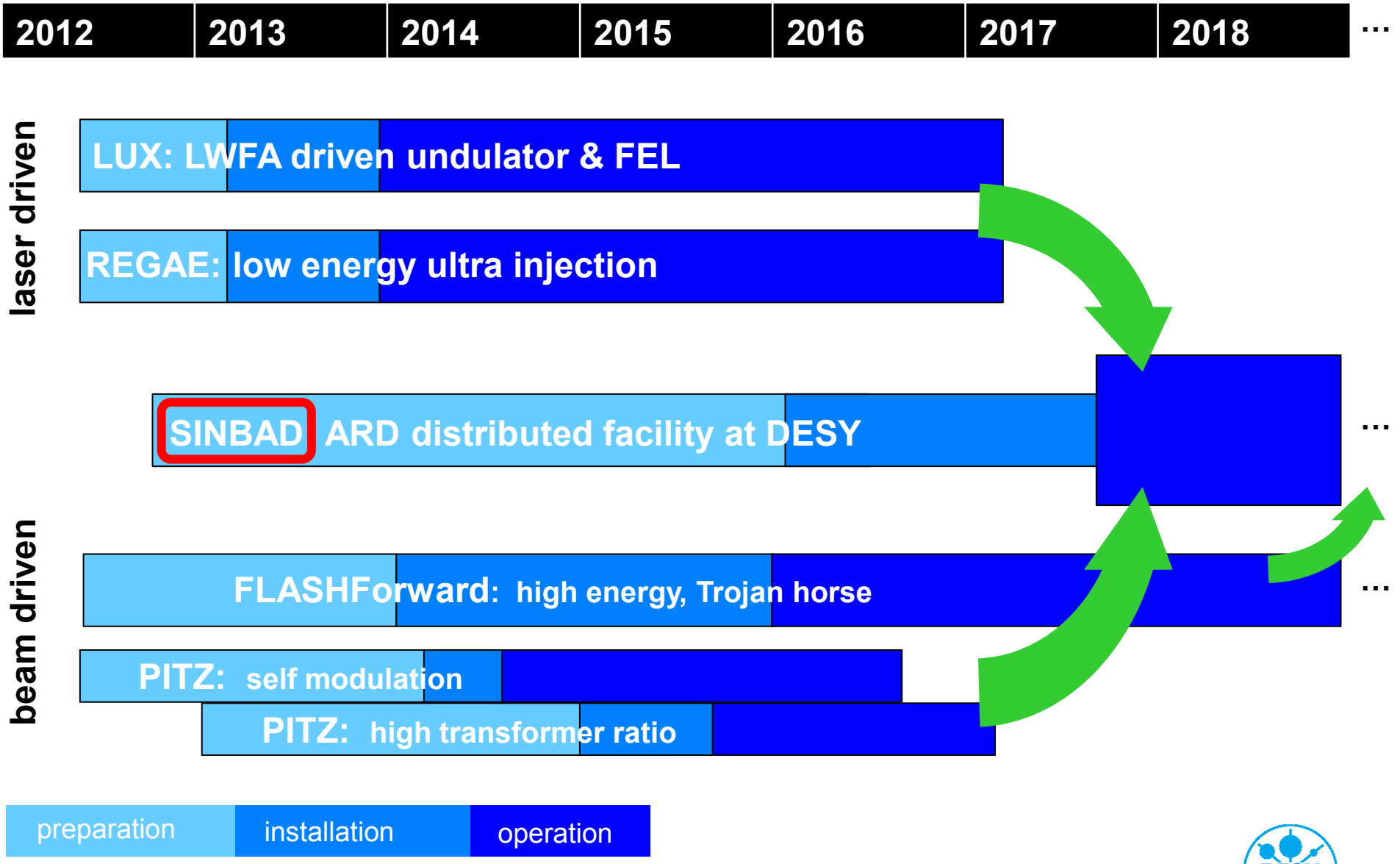


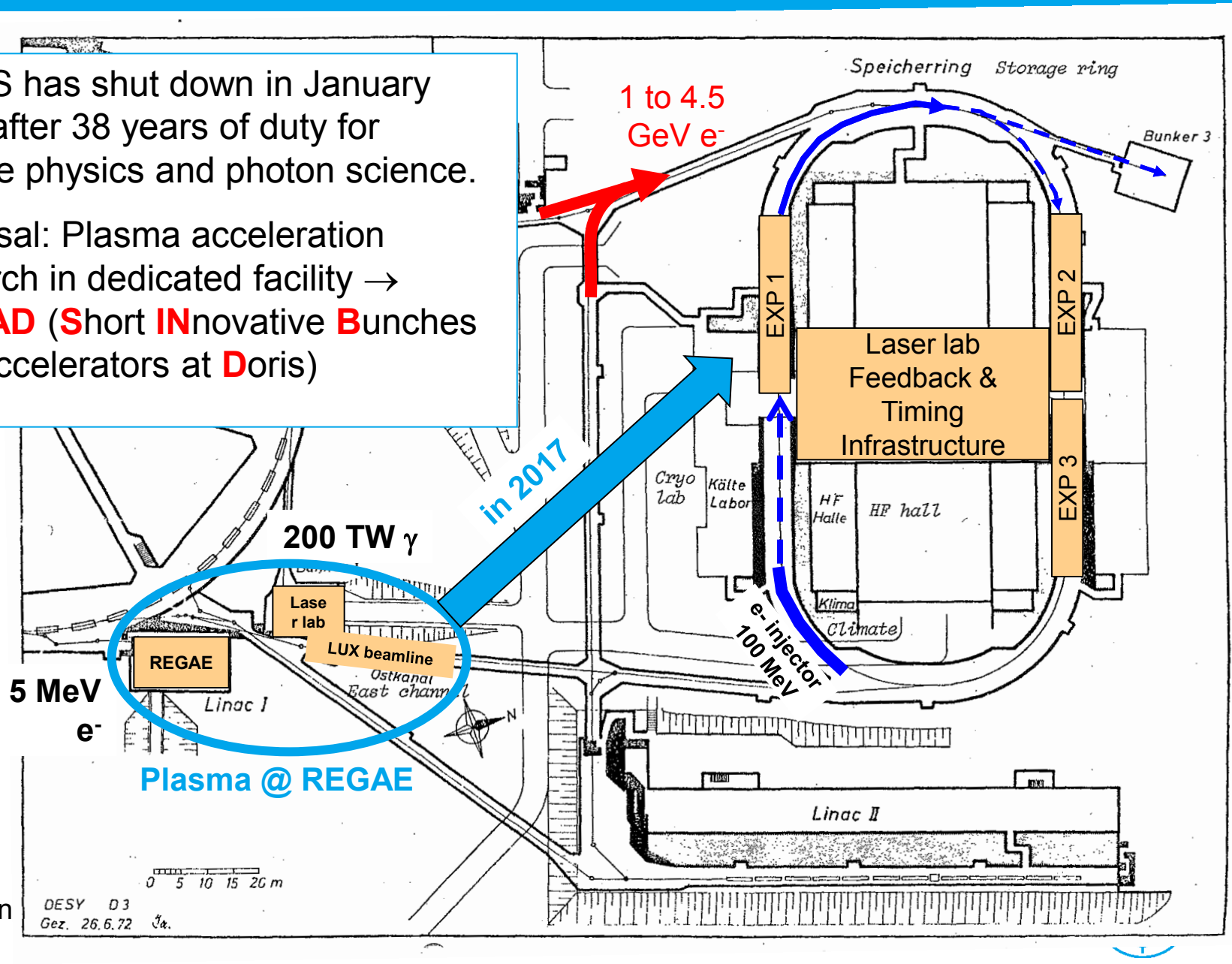
- Significant plasma acceleration of a probe bunch could be possible
  - Transformer Ratio up to 8 with matched plasma wavelength
- Needs bunch compressor for high absolute energy gain

Roadmap for Novel Accelerator Research at DESY



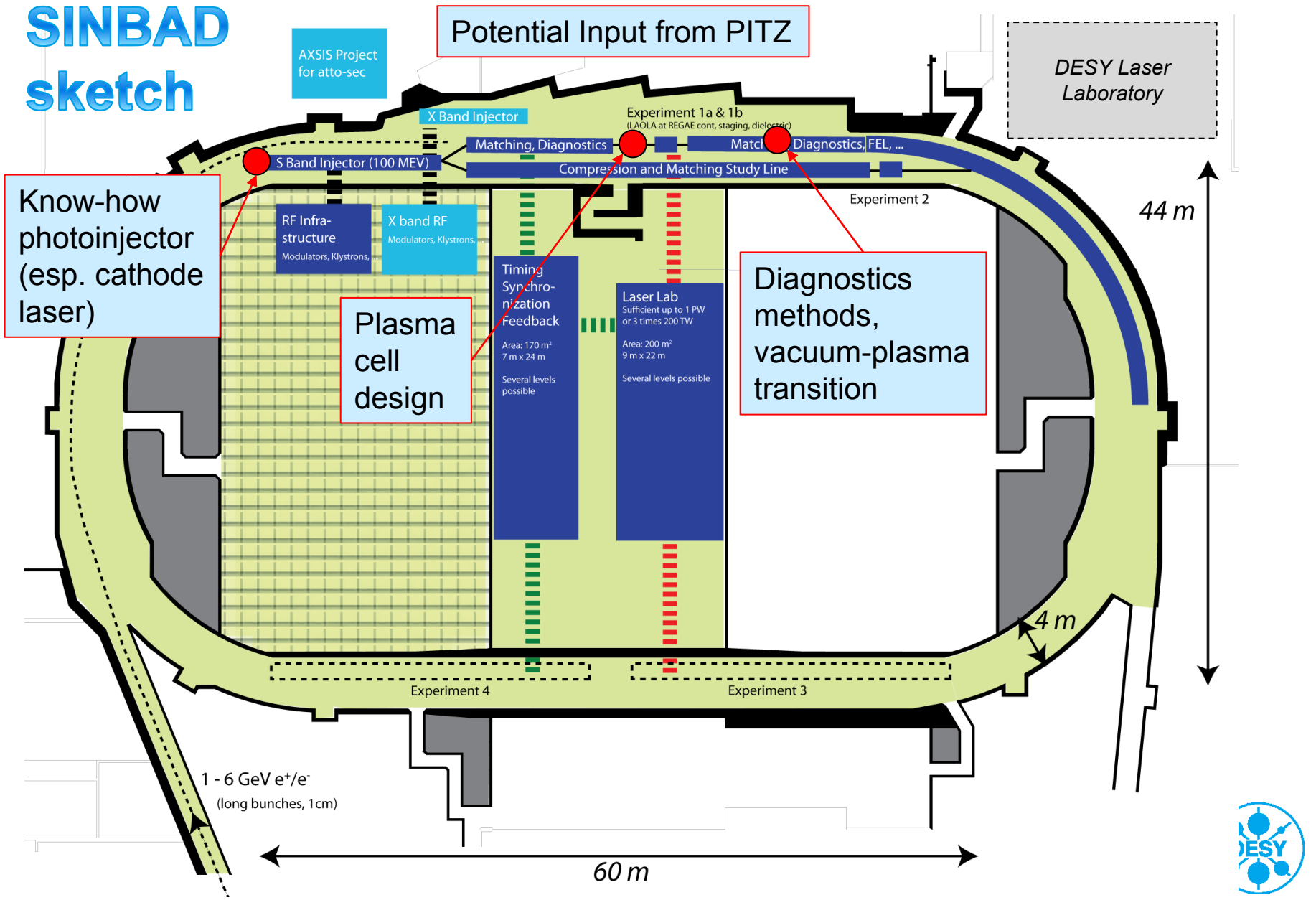
The Plasma @ DORIS Proposal…: SINBAD

- DORIS has shut down in January 2013 after 38 years of duty for particle physics and photon science.
- Proposal: Plasma acceleration research in dedicated facility → **SINBAD** (**S**hort **IN**novative **B**unches and **A**ccelerators at **D**oris)



Courtesy:
Ralph Aßmann

Knowledge Transfer: PITZ to SINBAD



Helmholtz ARD – Research Topics and DESY Involvement

Superconducting RF Technology

DESY | HZB Helmholtz Zentrum Berlin | HZDR

Concepts and Technologies for Hadron Acc.

GSI | JÜLICH FORSCHUNGSZENTRUM

HELMHOLTZ ASSOCIATION ACCELERATOR Research & Development

PITZ is involved

ps – fs Electron and Photon Beams

DESY | KIT Karlsruhe Institute of Technology

Novel Acceleration Concepts

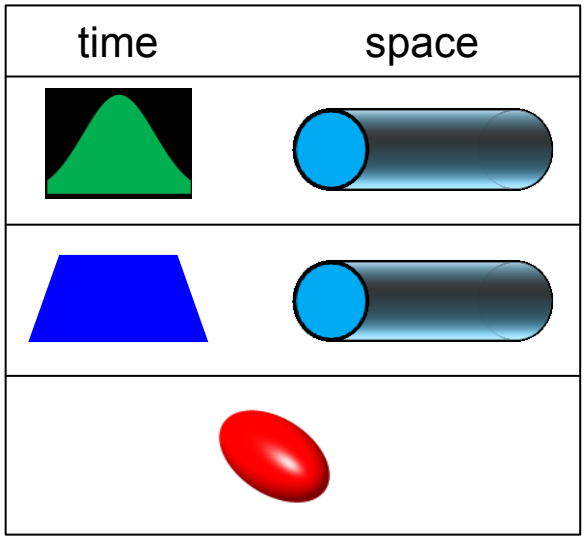
DESY | GSI | HZDR

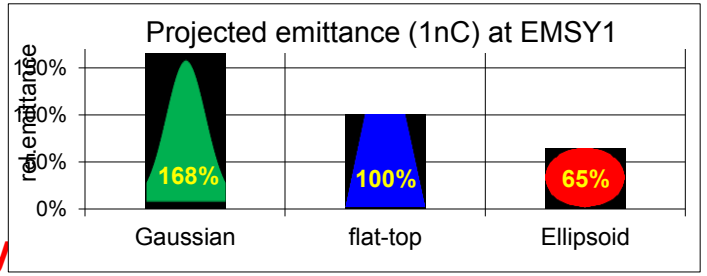
Courtesy:
Ralph Aßmann

DESY

Ellipsoidal Laser

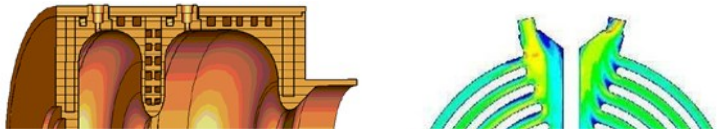
- Expertise at PITZ: Optimizing electron bunch properties
- Fundamental parameter: shape of laser pulse
- Standard: temporal Gaussian
- Developed for European XFEL: temporal flat-top
- New project: ellipsoidal
- Benefits for linac driven light sources:
  - Lower emittance → higher **brilliance**
  -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



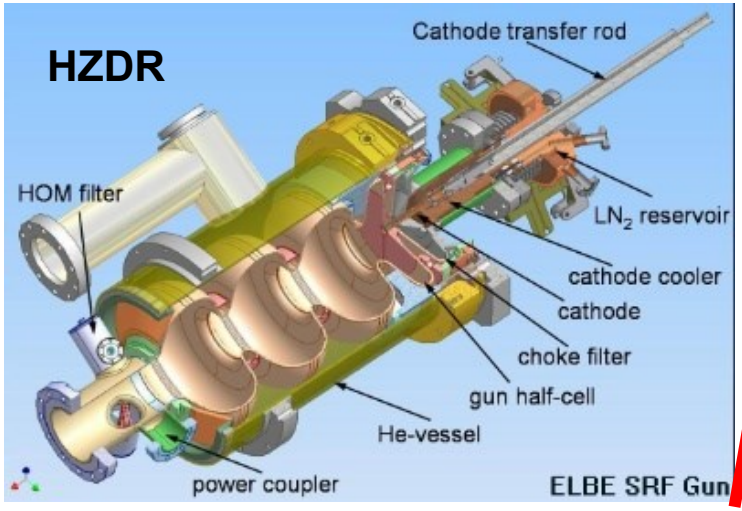


Electron Gun Development

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



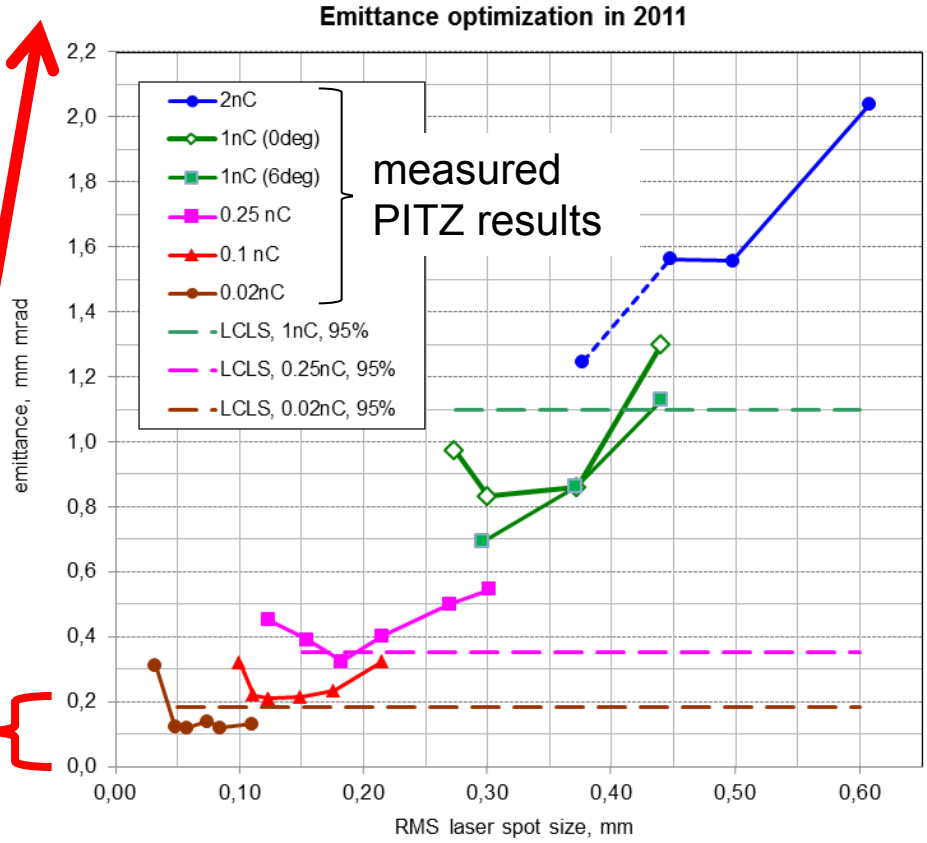
- **Problem:**
  - Current state-of-the-art in SC RF guns:



measured emittance: 3±1 mm mrad @80pC

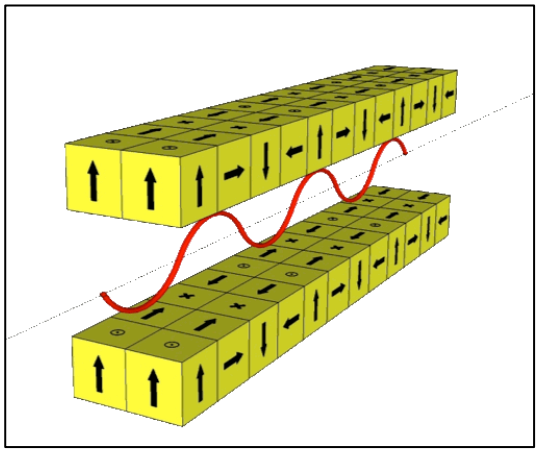
required for CW XFEL

➔ **only NC guns reach goal region**



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

- Accelerator research is important for many applications and is conducted in many places around the world
- Plasma acceleration has the potential to revolutionize the way to build accelerators
- PITZ is working in plasma acceleration within the ARD environment in LAOLA collaboration
  - Current work: Self-modulation and high transformer ratio
  - Mid-term view: Important contributions to ARD test facility SINBAD
- 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