Plasma Acceleration at PITZ

Self-modulation; high transformer ratio

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Nishny Novgorod
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HELMHOLTZ ASSOCIATION

PITZ Photo Injector Test Facility Zeuthen

DESY

Plasma Acceleration 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)

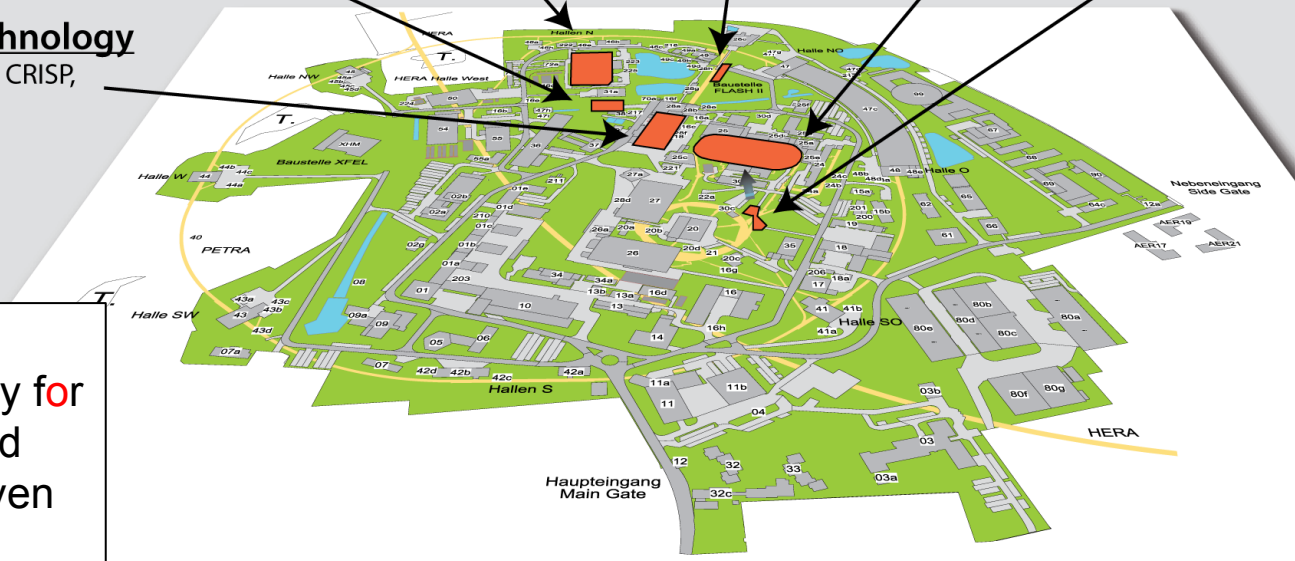
FLASHForward
(beam-driven plasma acceleration, 2016+)

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+)

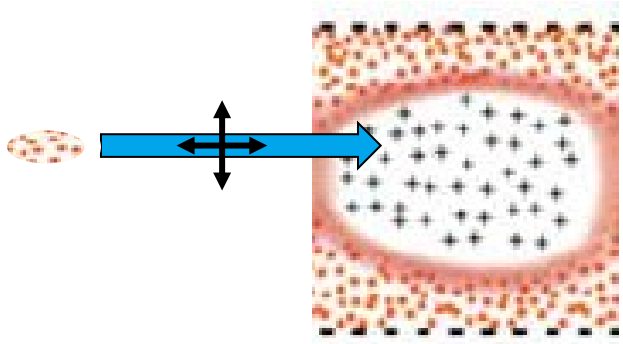
LAOLA:
Laboratory for Laser- and beam-driven plasma Acceleration

Courtesy:
Ralph Aßmann

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

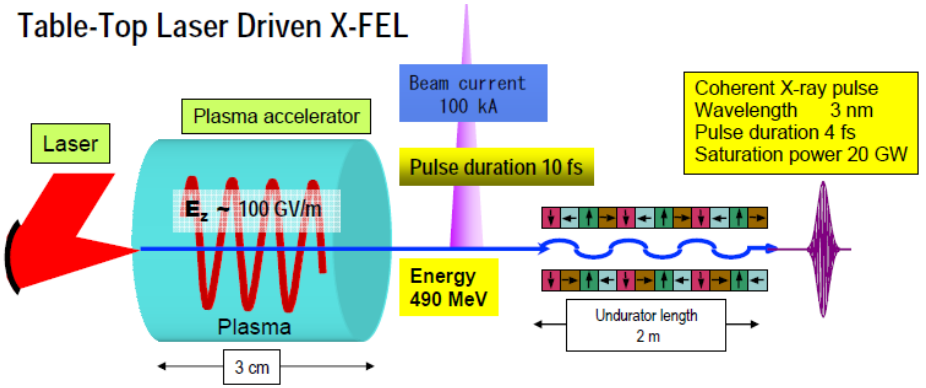
REGAE (laser driven)

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



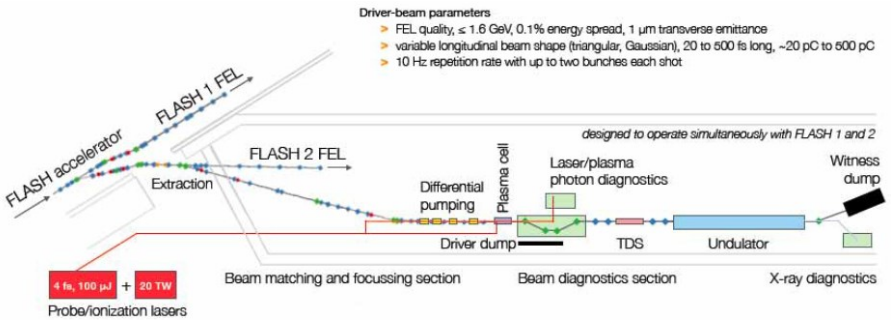
LUX (laser driven)

- Laser driven light source



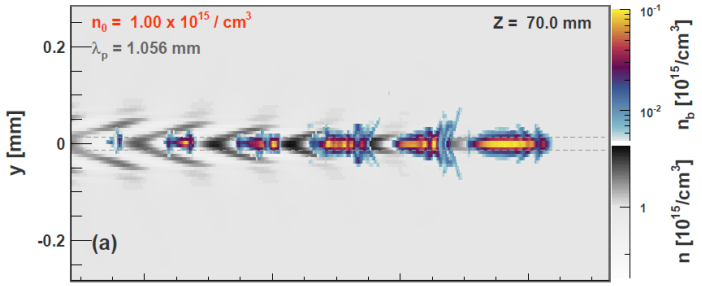
FLASHForward (particle driven)

- Energy boosting of FLASH bunch to utilize special pulse shapes



PITZ (particle driven)

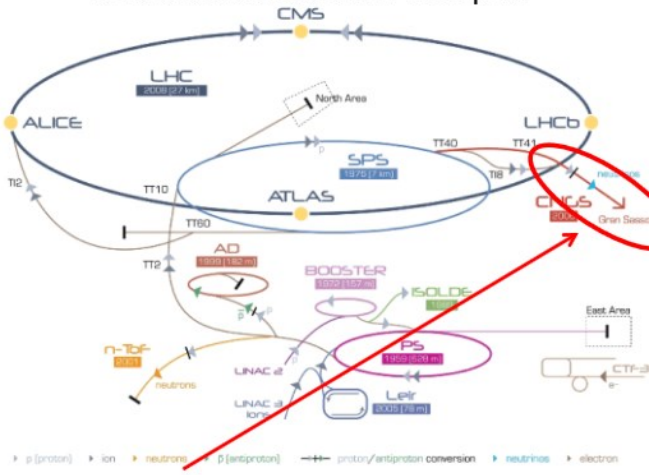
- Self-modulation of electron beam
- High transformer ratio



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

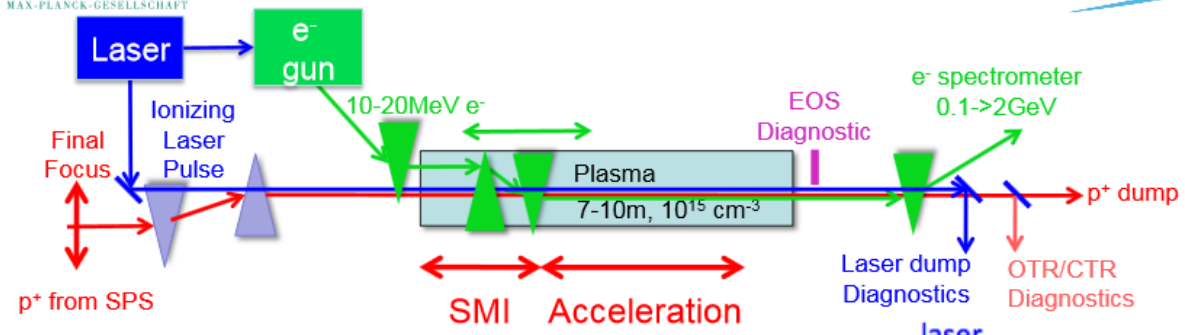
CERN Industrial Beam Complex



CNGS experimental area

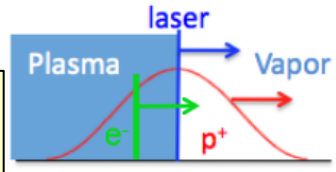
BASE-LINE EXPERIMENTAL SETUP

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

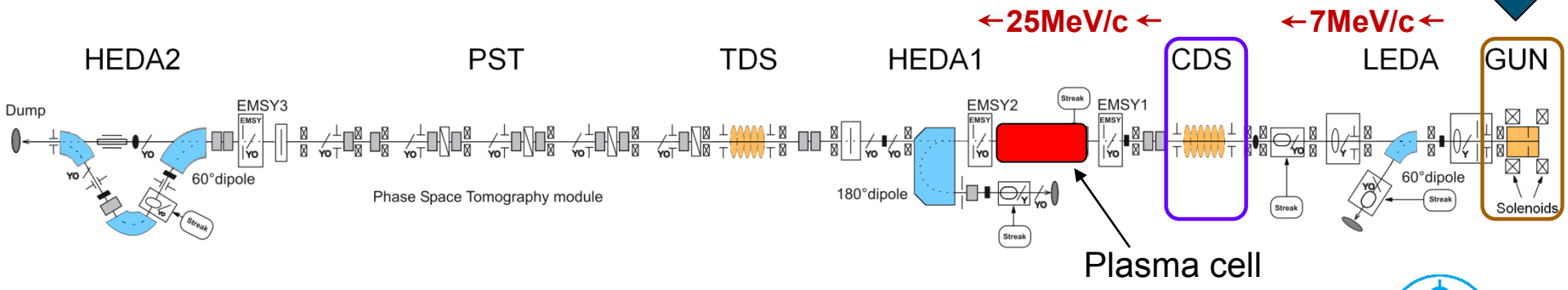
Why Experiments at PITZ?

- 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

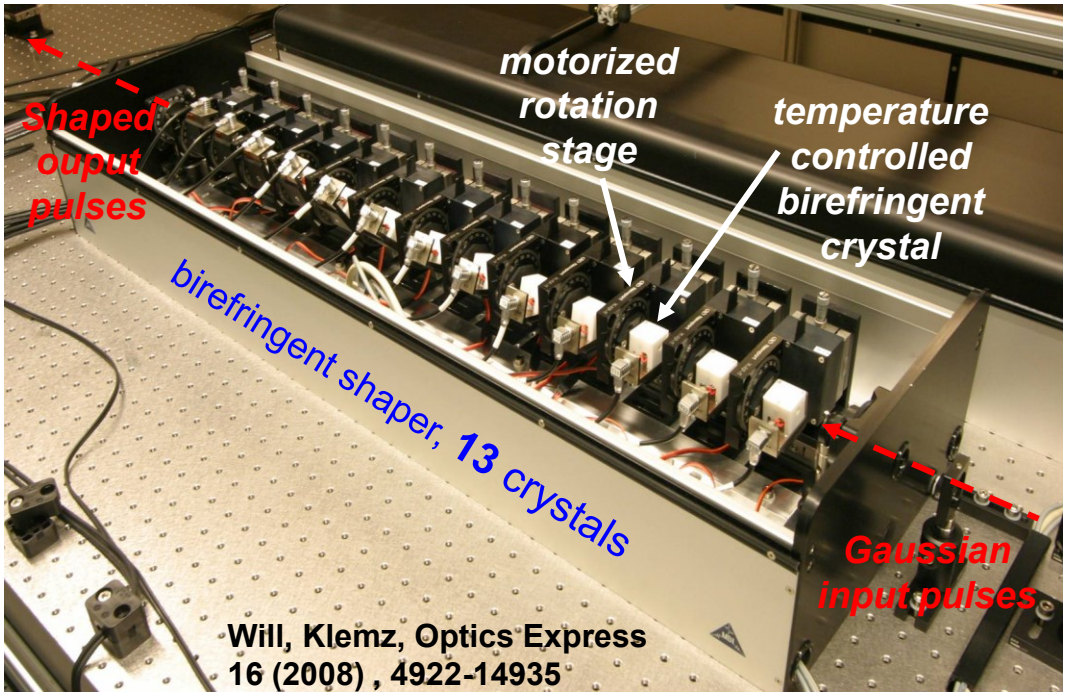
PITZ Overview

- 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.)

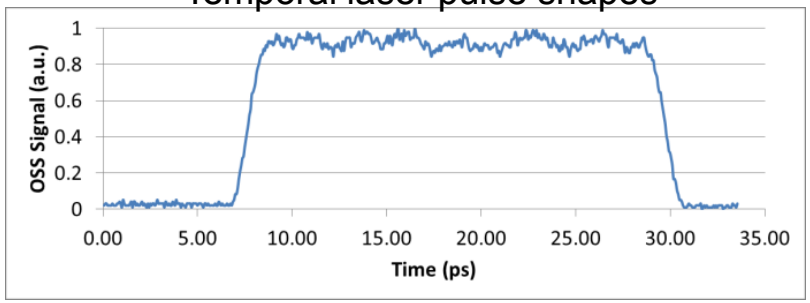


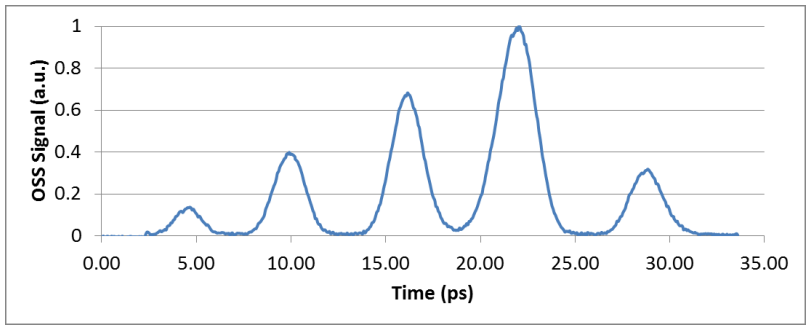
Flexible Laser Pulse Formation at PITZ

- 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

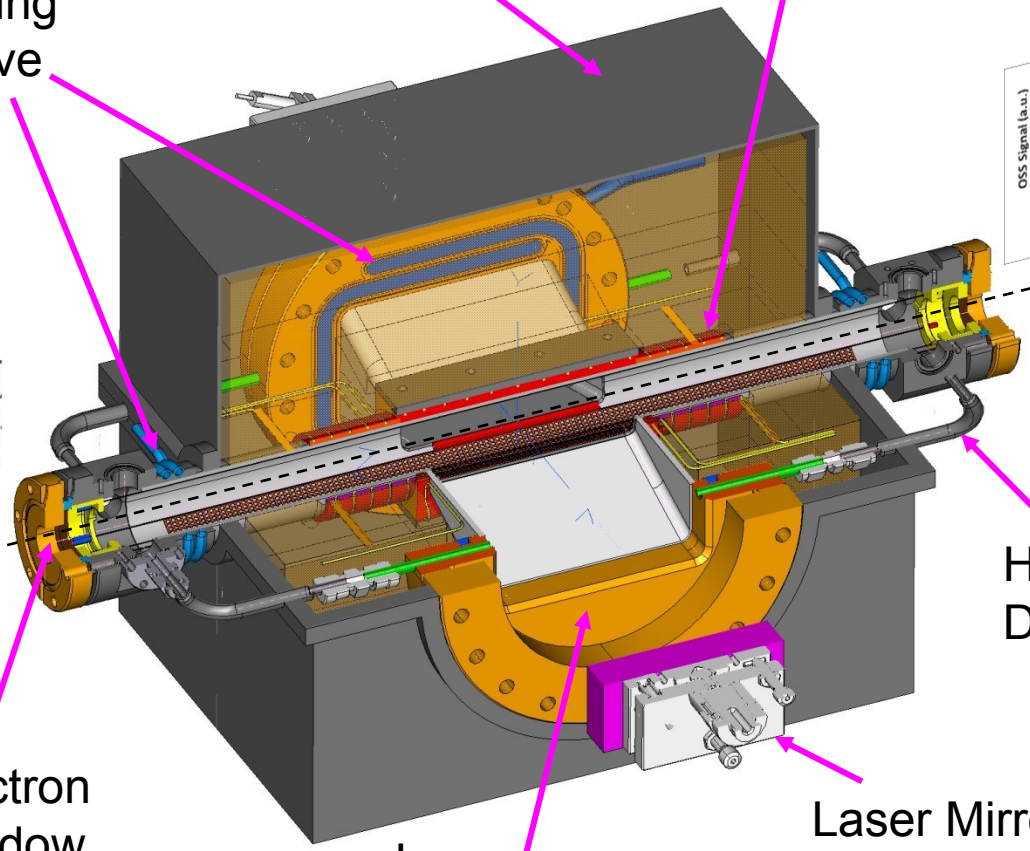


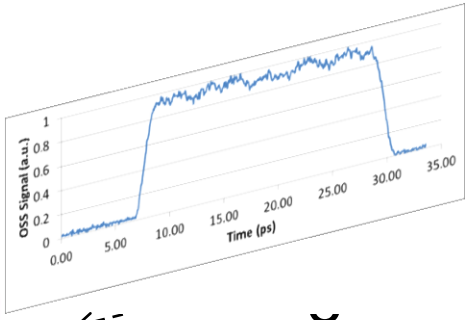


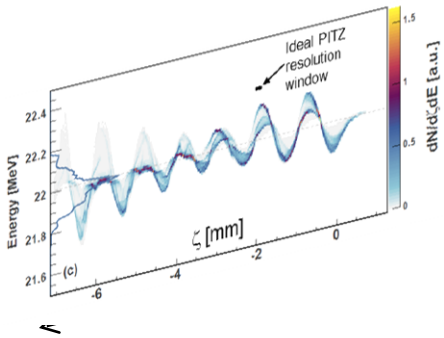
Electron bunch ≙ Laser pulse

Plasma Cell Design – Currently in Fabrication

Design:
Gerald Koss







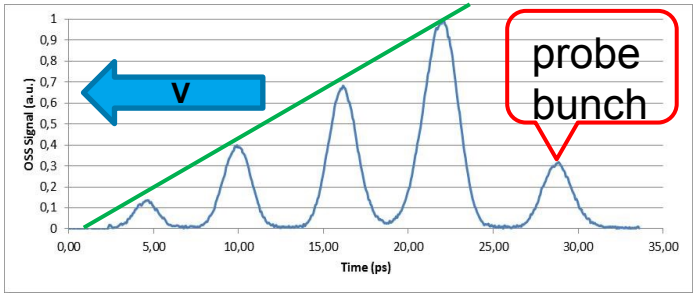
LAOLA@PITZ: High Transformer Ratio (TR) studies

- 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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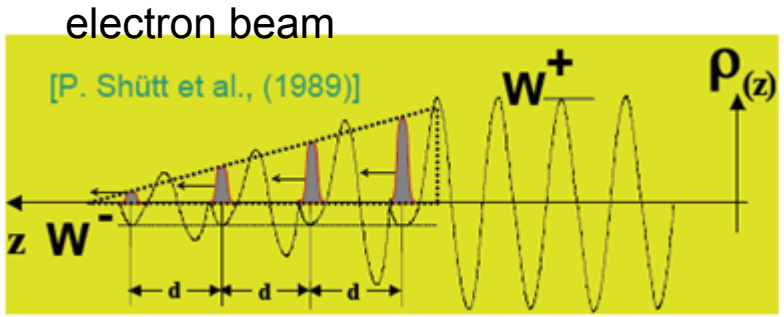
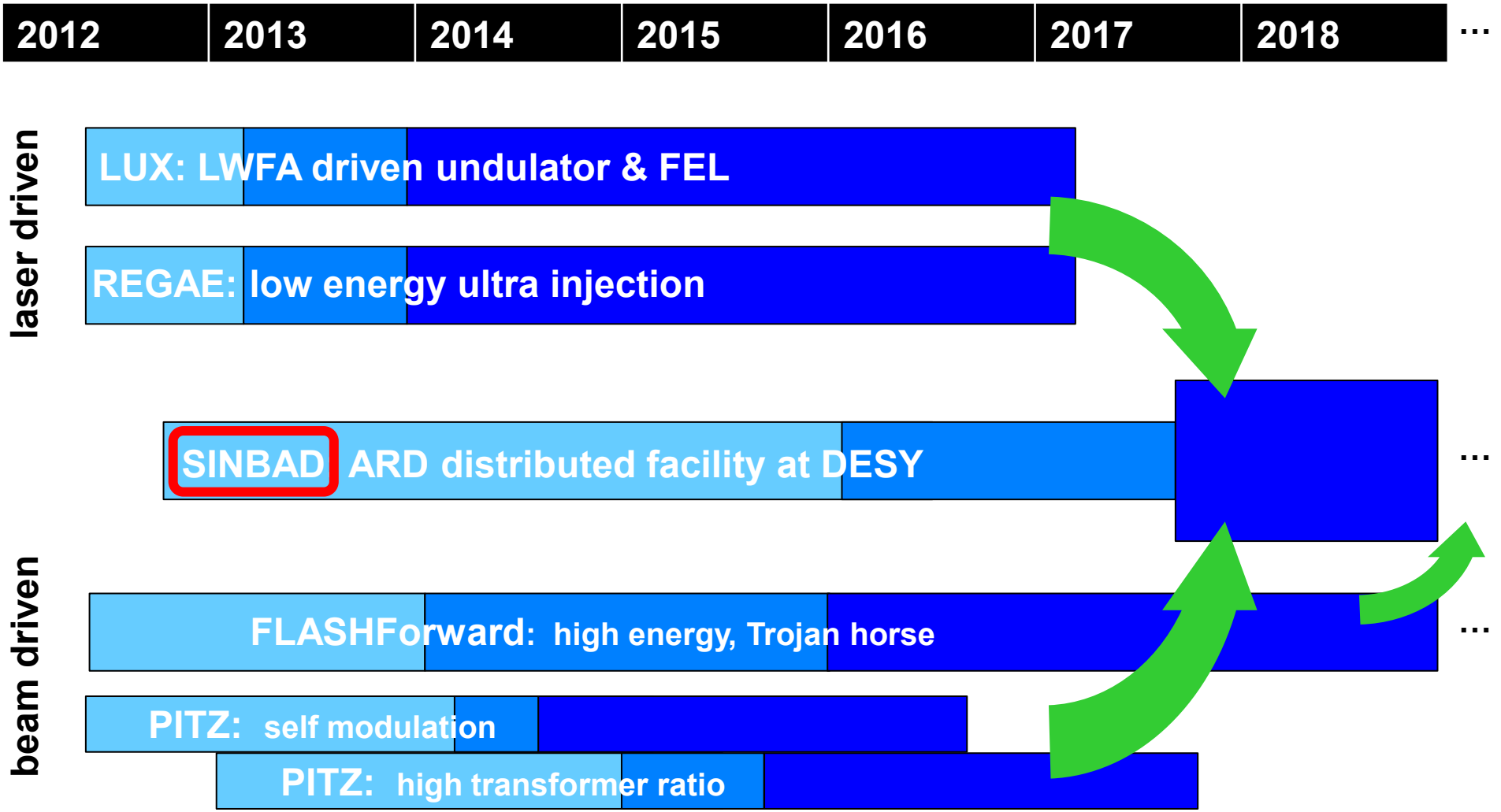


- Significant plasma acceleration of a probe bunch could be possible
  - Transformer Ratio up to 8

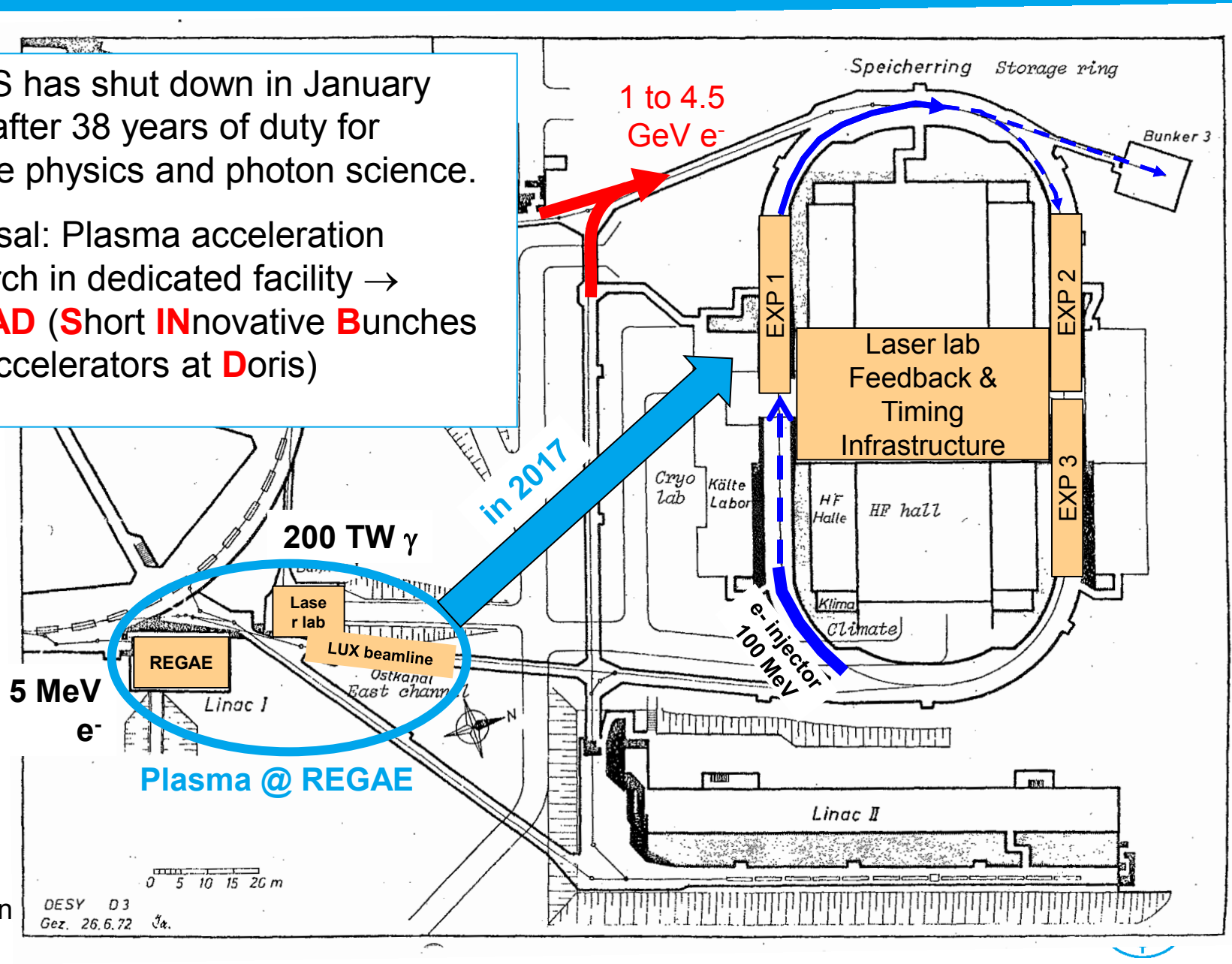
- Needs bunch compressor for high absolute energy gain

Roadmap for Novel Accelerator Research at DESY



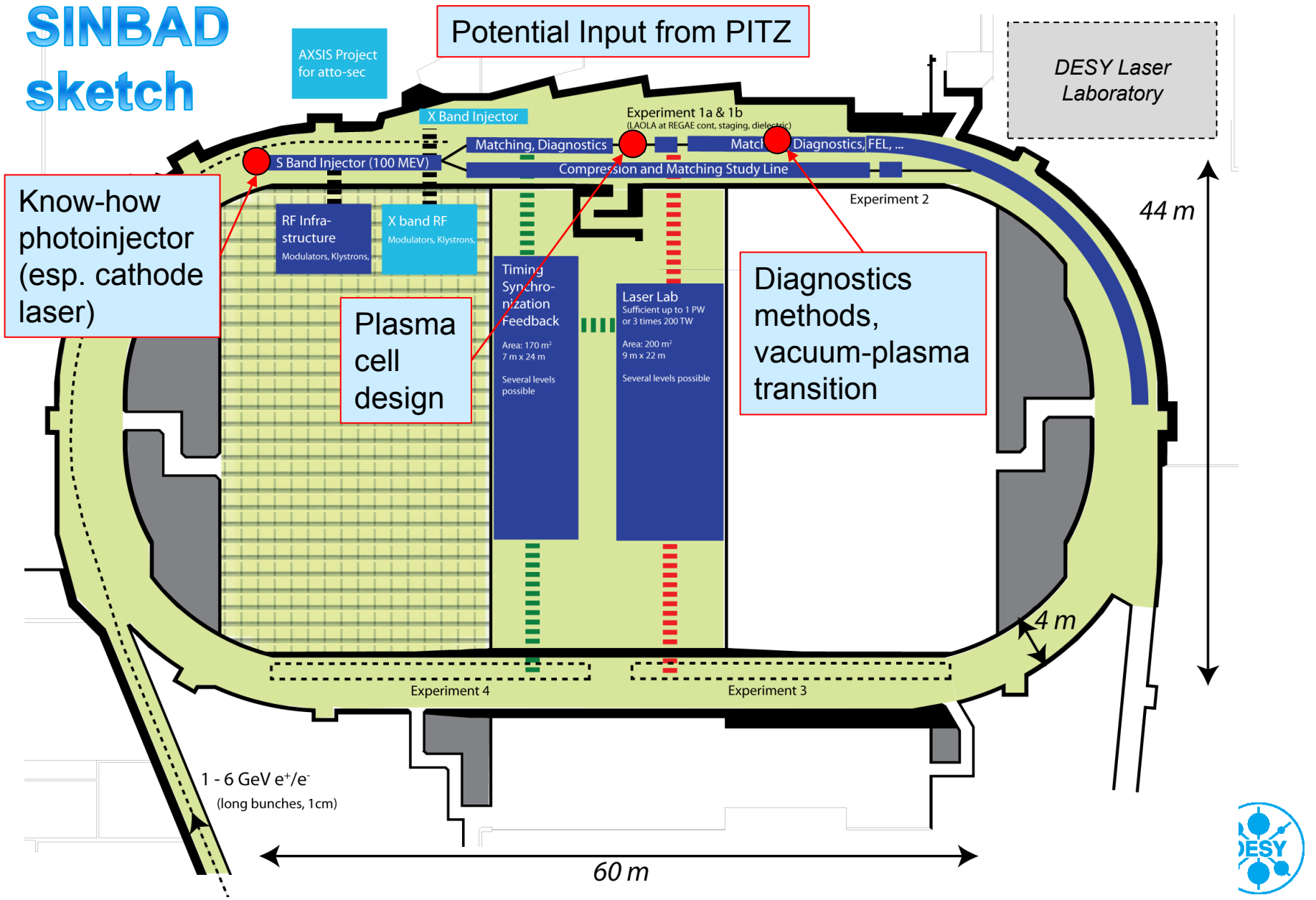
The Plasma @ DORIS Proposal…: SINBAD

- 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



Summary

- Plasma acceleration research at DESY is organized in LAOLA collaboration
- PITZ is working in plasma acceleration utilizing its unique facility
  - Current work: Self-modulation and high transformer ratio
  - Mid-term view: Important contributions to ARD test facility SINBAD
- Self modulation
  - Plasma cell was designed and is in fabrication