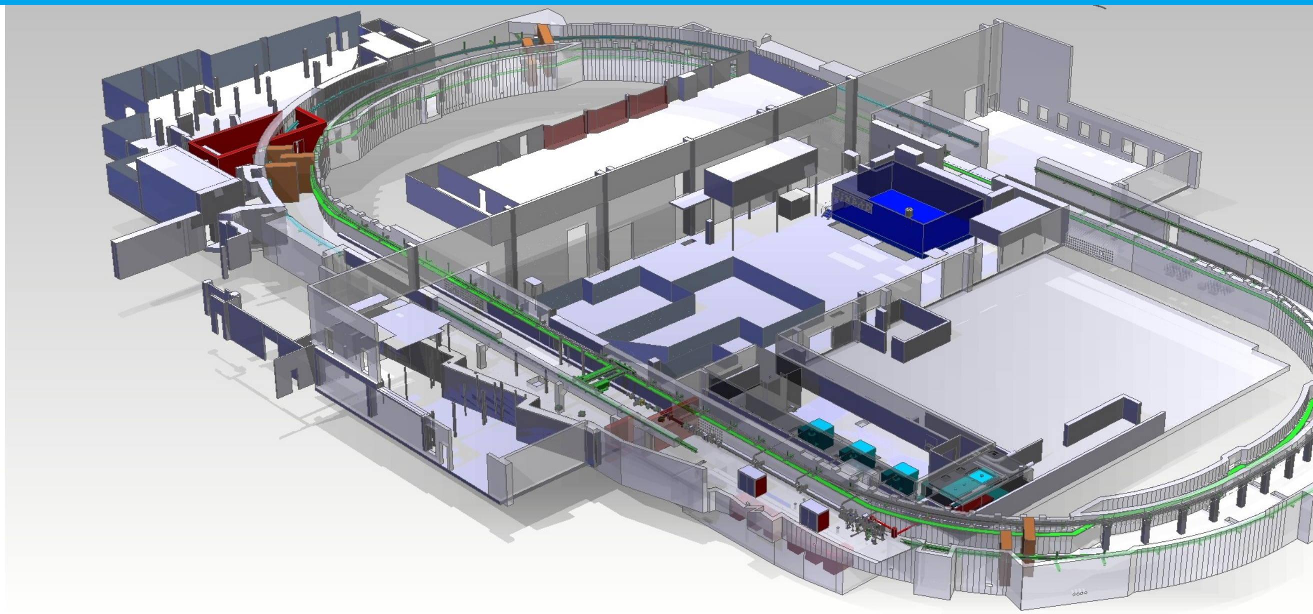
SINBAD & ATHENA

The ARD facility under construction at DESY & the proposal for a Helmholtz strategic investment in plasma acceleration



U. Dorda for the DESY MPY-1 group

EuPRAXIA yearly meeting

Paris, 28.10.2016

HELMHOLTZ ASSOCIATION

SINBAD

DESY

Overview

- SINBAD overview
- AXSIS
- ARES
  - ARES – linac
  - ARES – experiments

- ATHENA

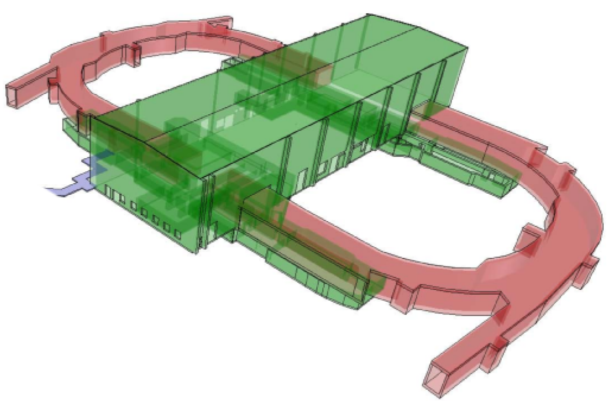
SINBADs idea

Where, who, why, when, what

SINBADs IDEA

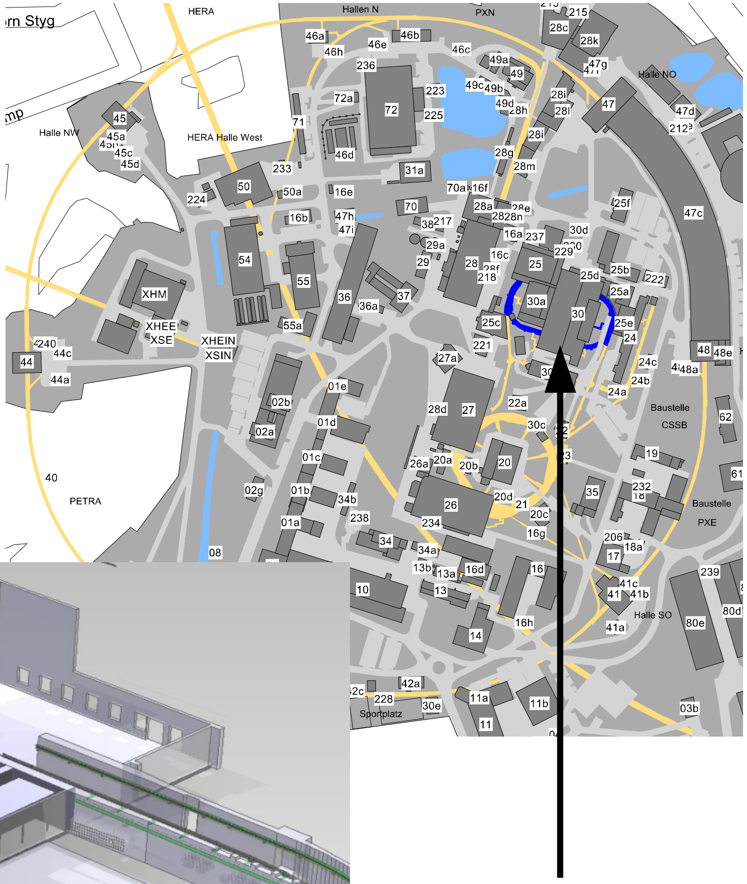
- Turn the facilities of the old DORIS storage ring plus associated halls into a dedicated multi-purpose accelerator R&D facility with several, independent experiments from ultra-fast science and high gradient accelerator modules.
- Based e.g. on the ongoing LAOLA activities, it is intended to provide the space for long-term dedicated accelerator R&D with multiple experiments using a common infrastructure.
- Project goals:
  - Production of ultra-short electron bunches for ultra-fast science.
  - Setup of an attosecond radiation source with advanced technology (AXSIS collaboration).
  - ATHENAe: Construction of a plasma accelerator module with usable beam quality for applications.

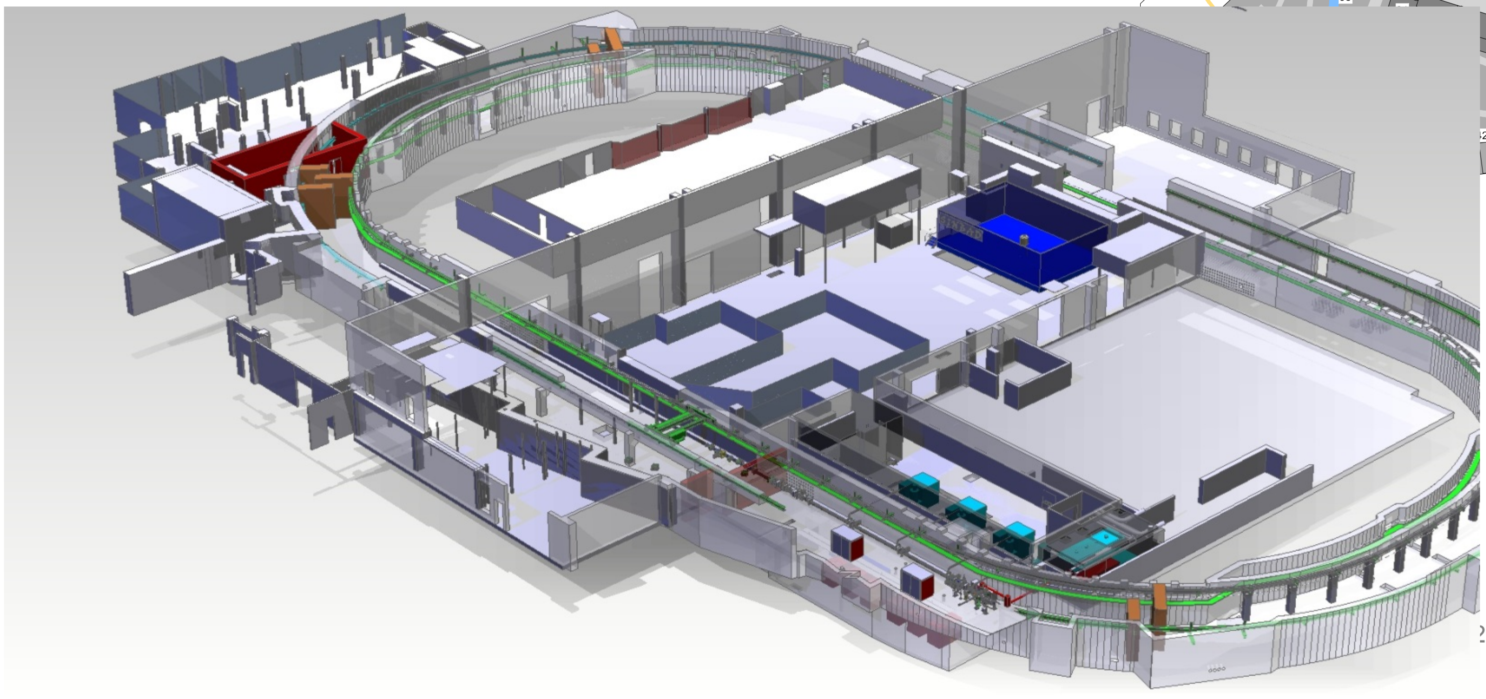
Short
INnovative
Bunches and
Accelerators at
DESY



SINBAD at DESY, Hamburg – location

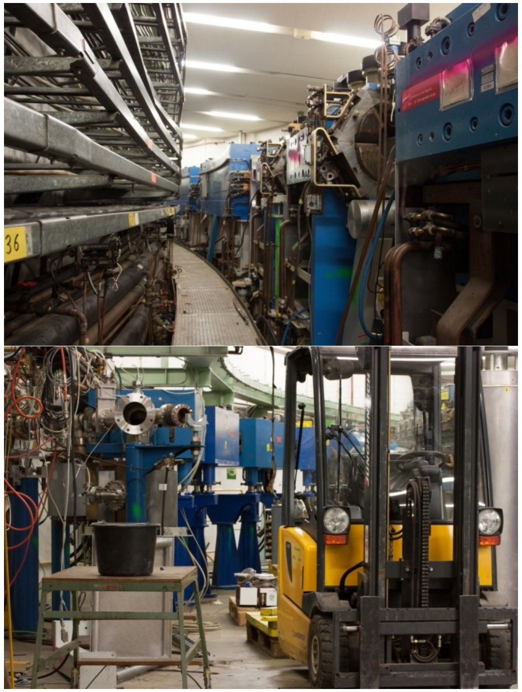
- In the old DORIS facilities
- Next to the central DESY control room
- Beam line to DESY II synchrotron (currently deactivated, but still installed)
- 290 m long, 5-9 m wide RP-shielded tunnel in racetrack shape
- 2 long straight sections of >70m length
- Central hall (650m2) + additional side rooms & cellars
- 1m thick shielding
- Multiple laser labs directly adjacent





Current clean-up status

- Removal of old DORIS beam line completed
- Removing of cabling & piping done
- Structural refurbishment finished
- Installation of technical infrastructure starting



from DORIS
to SINBAD

SINBAD will initially host 2 experiments:

ARES

- "**A**ccelerator **R**eseach **E**xperiment at **S**inbad"
- 1st step: Build A 100MeV electron linac for ultra-short bunches
  - Target: operational 2019
- 2nd step: Optimize performance and compare various compression techniques
- 3rd step: Use beam to inject into advanced acceleration concepts
  - DLA → ACHIP
  - THz driven dielectric loaded waveguides
  - ATHENAe: External injection into plasma

AXSIS

- "**A**ttosecond **X**-ray **S**cience: **I**maging and **S**pectroscopy"
- THz acceleration in dielectric loaded waveguides
- ICS for X-ray generation

SINBAD layout is chosen to allow future upgrades (e.g. ATHENAe) and has significant free space left in the tunnel!

Who: The MPY-1 TEAM

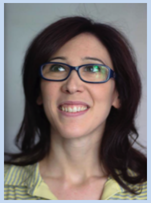
R. Aßmann


SINBAD

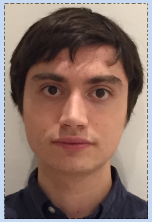

U. Dorda


S. Baark
(parttime, MEA)

ARES


B. Marchetti


J. Zhu
PhD student


D. Marx
PhD-student

ACHIP


F. Mayet
PhD-student


W. Kuropka
PhD-student

AXSIS

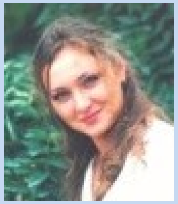

K. Galaydych
PostDoc


G. Vashchenko
PostDoc


T. Vinatier
PostDoc

Plasma (Eupraxia)


A. Walker
PostDoc


E. Svystun
PostDoc


A. Pousa
PhD-student


M. Weikum
PhD-student

FLASH


J. Bödewadt


C. Lechner

Admin. support


R. Mundt


S. Schaefer

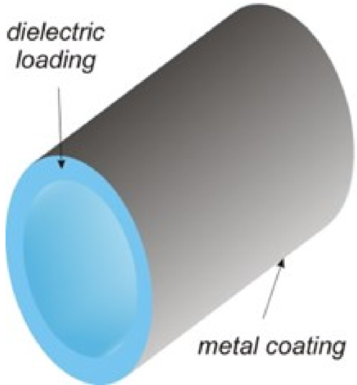
With the technical support of the DESY M-division!

AXSIS

THz-laser acceleration in dielectric loaded waveguides

- Collaboration of 4 PIs: F. Kaertner, R. Assmann, P. Fromme, H. Chapman
- funded by an ERC-synergy grant
- Using the TM01 mode in circular waveguides
- Phase-velocity is reduced by dielectric loading
- Separate THz-gun test stand starting up
- Target parameters:
  - ≈ 200MeV/m, f = 300GHz
  - E: 15 / 25 MeV (4 &12keV photons)
  - Q: 0.1 – 3pC
  - T: fsingle fs.
  - kHz rep rate

→ EuPRAXIA WP 10



ARES

Accelerator **R**esearch **E**xperiment at **S**inbad:
Electron linac for ultrashort bunches
for advanced acceleration schemes

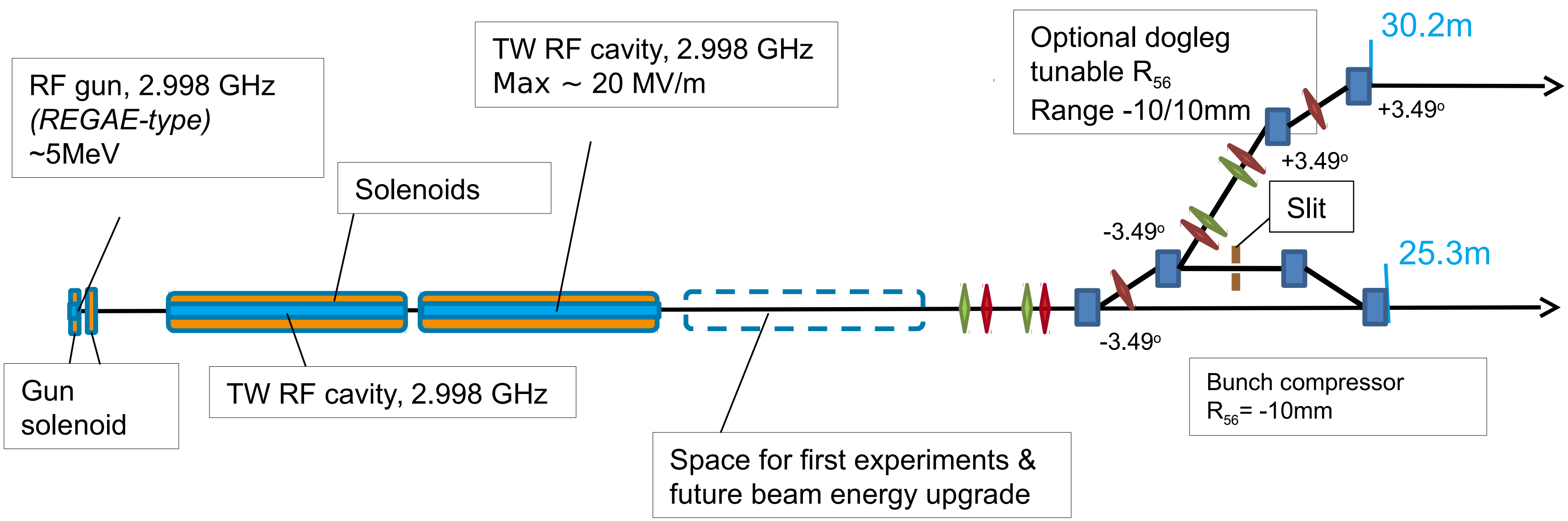
ARES-linac

Electron linac for ultrashort bunches

ARES-linac

- **Conventional linac (S-band norm. cond.) for the production of ultra-short bunches:**

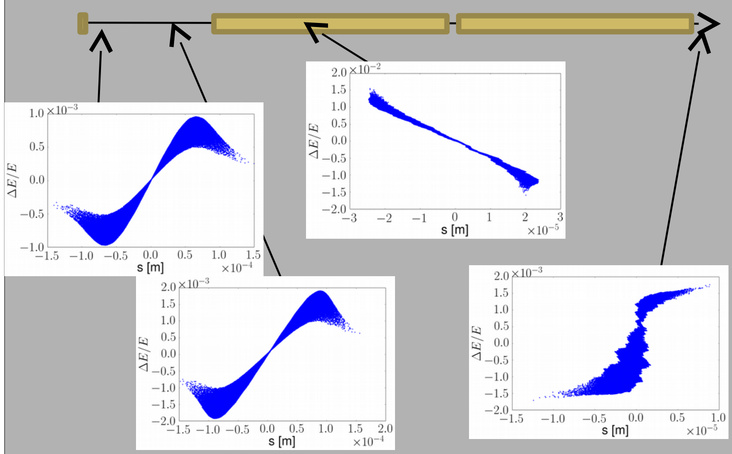
  → Charge: 0.5-20 pC (up to 1nC)
  → Energy ~ 100 MeV
  → Bunch length: few fs / sub-fs
  → Transverse norm. emittance < 0.5 mm*mrad
  → Arrival time jitter stability < 10 fs RMS



Comparisson of Compression Techniques

The linac will allow to directly compare different bunch compression techniques

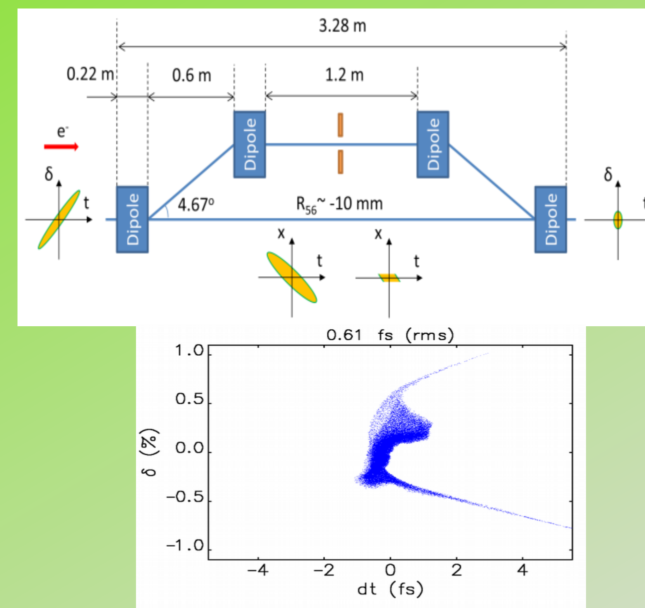
RF compression



Pro: very good transverse emittance, no CSR, no charge loss, small spot size at the exit

Contra: tight phase tolerances on the RF compressor, long. non-linearity

magnetic “compression”



Pro: high current & short beam (non-linearity cut out), distributed RF phase tolerances
Contra: charge loss

And a hybrid version of the two...

Summary of the working points for the main beamline

	VB (Velocity Bunching)	MC (Magnetic Compression)	VB+MC
Q final [pC]	0.5	0.7	2.7
Q initial [pC]	0.5	20	10
t_{RMS} [fs]	2.486	0.21 (0.27)	0.66 (0.87)
t_{FWHM} [fs]	4.1	0.14 (0.29)	1.53 (1.42)
E [MeV]	110.9	100.2 (100.2)	101.6 (101.8)
ΔE/E	0.3%	0.20% (0.18%)	0.18% (0.16%)
x_{RMS} [mm]	0.009	0.058 (0.057)	0.084 (0.083)
y_{RMS} [mm]	0.009	0.059 (0.058)	0.092 (0.088)
$n\varepsilon_x$ [µm]	0.054	0.068 (0.072)	0.19 (0.21)
$n\varepsilon_y$ [µm]	0.054	0.063 (0.065)	0.16 (0.15)
Peak current I [A]*	57	953 (759)	1173 (879)
Local peak current I_L [A]**	85	2390 (1487)	1432 (1358)
B [A/m²]***	1.97 * 10^{16}	2.13 (1.63) * 10^{17}	3.74 (2.71) * 10^{16}

*Peak current:

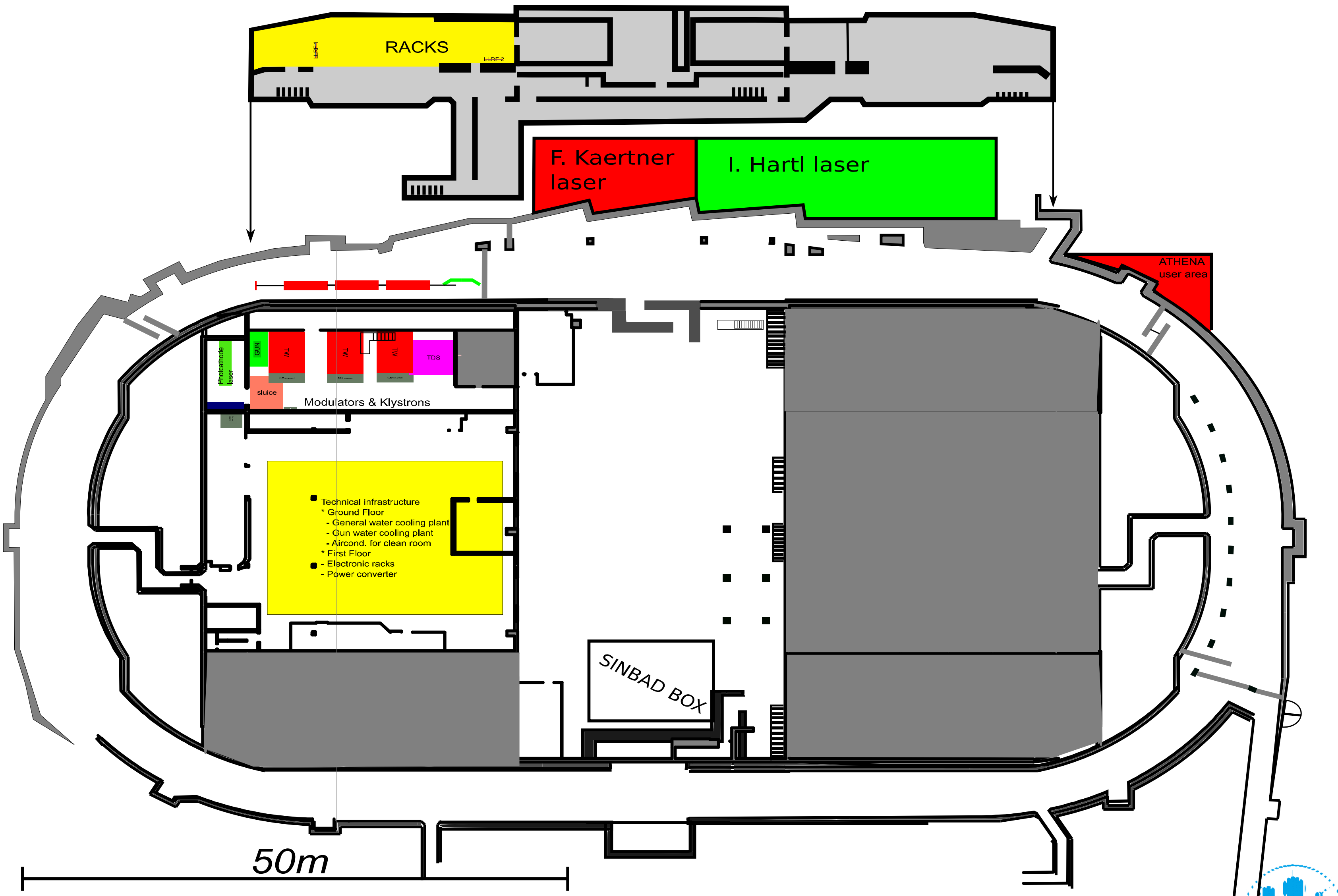
$$I = \frac{Q_{tot}}{3.5 t_{RMS}}$$

**Local peak current:

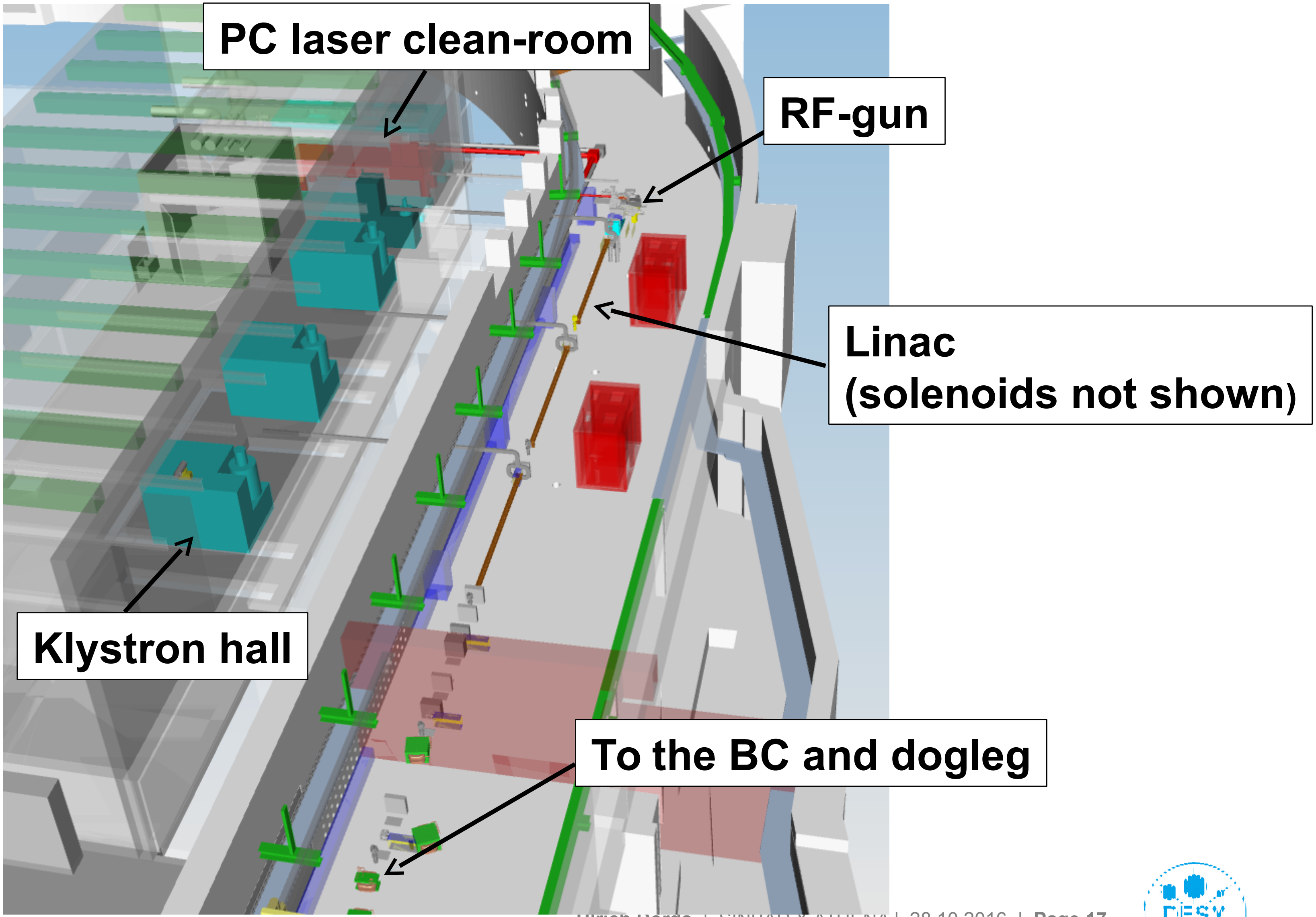
$$I_L = \frac{Q_{tot}}{t_{FWHM}}$$

*** Brightness:

$$B = \frac{I}{n\varepsilon_x n\varepsilon_y}$$


RACKS
F. Kaertner laser
I. Hartl laser
ATHENA user area
Photcathode laser
GUN
TW
TW
TW
TDS
sluice
Modulators & Klystrons
Technical infrastructure
* Ground Floor
- General water cooling plant
- Gun water cooling plant
- Aircond. for clean room
* First Floor
- Electronic racks
- Power converter
SINBAD BOX
50m

Integration of the linac in the SINBAD tunnel



Tolerances

Jitter source	Unit	Sensitivity for 10-fs timing jitter			RMS tolerance		
		0.7 pC MC	2.7 pC VB+MC	0.5 pC VB	0.7 pC MC	2.7 pC VB+MC	0.5 pC VB
Laser-to-RF	fs	42437.1	159.8	125.1	200.0	50.0	50.0
Gun charge	%	5.8	301.6	1010.1	1.0	4.0	4.0
Gun phase	deg	1.75	0.61	0.49	0.06	0.06	0.06
Gun voltage	%	0.61	0.72	0.40	0.06	0.06	0.06
TWS1 phase	deg	**0.021**	**0.011**	**0.0098**	0.013	0.009	0.009
TWS2 phase	deg	**0.022**	0.13	4.21	0.013	0.011	0.011
TWS1 voltage	%	0.055	0.073	0.10	0.013	0.009	0.009
TWS2 voltage	%	0.064	0.040	1.2	0.013	0.011	0.011
BC B-field	%	0.030	0.030	\	0.01	0.01	0.01
	fs	\	\	\	9.98	9.72	10.24

Technical “details” will decide on success: Water cooling, LLRF, EMI, ...

Time line etc.

- Target time line:
  - First beam from gun end 2017
  - First beam from linac 2018
  - Available for experiments mid 2019
  - → Depending to a large extend on X-FEL
- Access will be possible via ARIES transnational access!

ARES-experiments

Injection into advanced acceleration schemes

Towards higher frequencies → Lasers!

High Gradients (1-100 GV/m)	→	High Frequencies (> 100 GHz)	→	Small Dimensions (< 1 mm)

- No klystrons for high frequencies! → Use particle bunches or laser pulses as drivers.
- Material limitations → dielectric materials, plasma cavities, …

Two main directions:

1 Microstructure Accelerator
Laser- or beam driven
Vacuum accelerators
'Conventional' field design

2 Plasma Accelerator
Laser- or beam driven
Dynamic Plasma Structure
Plasma field calculations

→ **Use ARES-linac as injector & to probe the acceptance**

SINBAD-ARES linac - general philosophy for future experiments

- **Who will be the „users“ of the SINBAD linac?**

Experiments involving Novel High Gradient Acceleration Techniques: e.g. LPWA, Dielectric Wake-Field Acceleration, THz laser acceleration in dielectric-loaded structures…

- **What types of e-beam will such experiments need?**

Initially: **characterization of the acceleration method** and optimization of the beam quality of the accelerated beam

- **Ultra-short probes** → time resolution
- **Ultra-high stability** → synchronization
- **Small transverse focus (tens of µm – few µm)**

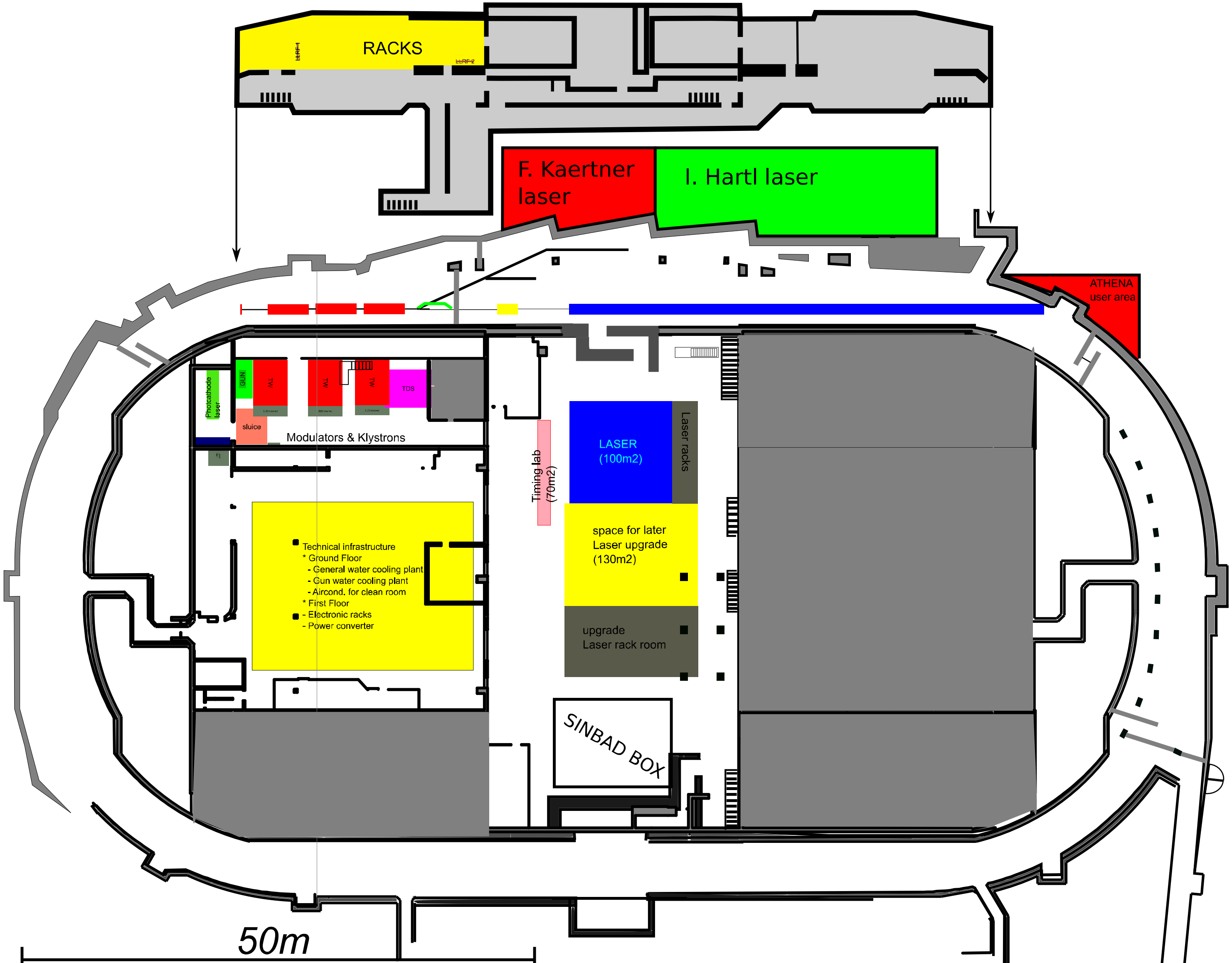
At a later stage: pilot user experiments involving e.g. **radiation production** (via FEL, ICS …)

- **Sufficiently high brightness** → radiation generation
- The **e-bunch duration has to be tuned**, according to the requirements for the production of radiation.

Research plans using the ultra-short bunches

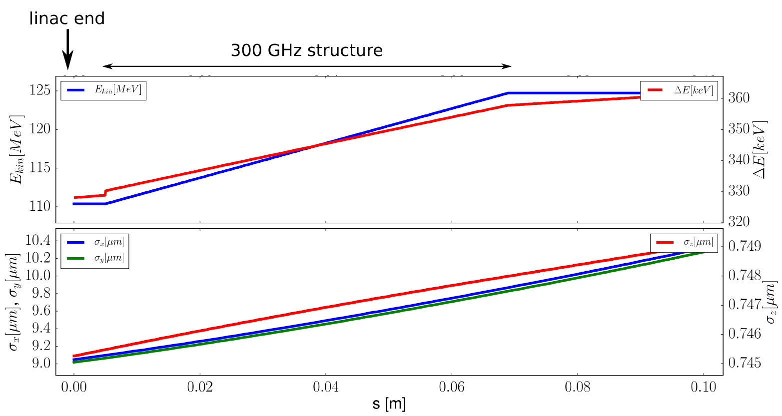
- On the long run, we aim for multiple research beam lines
  - Keeping option to add a beam line into the hall in the far future
- Envisaged topics:
  - Laser plasma wake field acceleration with external injection and demo-FEL
    - Extent depending on approval of the ATHENA proposal
  - Laser driven dielectric structures
    - Laser labs of I. Hartl and F. Kaertner adjacent
  - Imaging beam line (ICS)
    - Comparing conventional beams to LPWA, depending on approval of the ATHENA proposal
  - Beam diagnostic test stand, ...
- Relying/ planning on strong collaborations
  - Current: LAOLA, AXSIS, ACHIP, EuroNNAC, EuPRAXIA, ARIES, ...
  - Hope for: ATHENA, ….

ARES – Stage 2: experiments

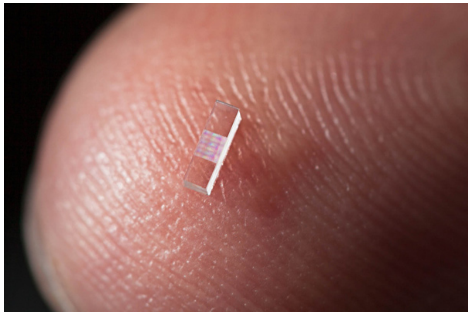


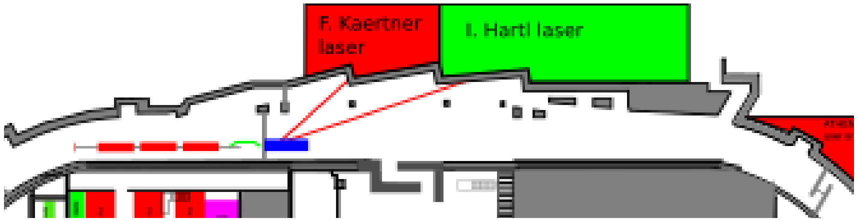
Accelerator on a Chip International Program

- 3 DESY groups are involved in ACHIP
  - I. Hartl → Lasers
  - F. Kaertner → Lasers, experiments,..
  - MPY-1 → Simulations & access to ARES-linac
- AXSIS @ ARES to test acceleration only (THz guns are tricky...)
- ARES will be an ideal injector for relativistic acceleration tests



Simulated injection into a 300GHz dielectric structure



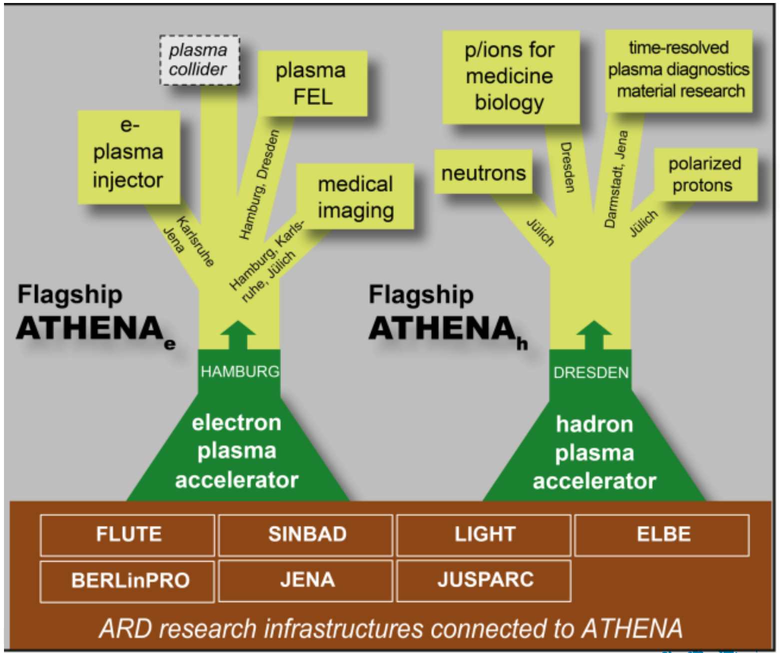


ATHENA

A collaborative proposal for Helmholtz strategic investment funds

ATHENA – proposal

- Joint **request** of 7 Helmholtz centers for Helmholtz strategic investment funds
- *"ATHENA provides the infrastructure required for* ***bringing compact and cost-effective plasma accelerators to user readiness****. Flagship projects will be set up in Hamburg (electrons) and Dresden (hadrons). Applications for science, medicine and industry will be developed in all centers."*
- ATHENAe flagship would be hosted at SINBAD.
- Total request 30ME/4years
- Submission done, waiting for decision
  - reviewed with result 'outstanding'
  - novel, compact accelerators are one of the top 7 priorities of the agenda of the Helmholtz president
- Would add a plasma stage and allow upgrading the linac with e.g. X-band RF systems, upgrade synchronization, add linac stage, ...

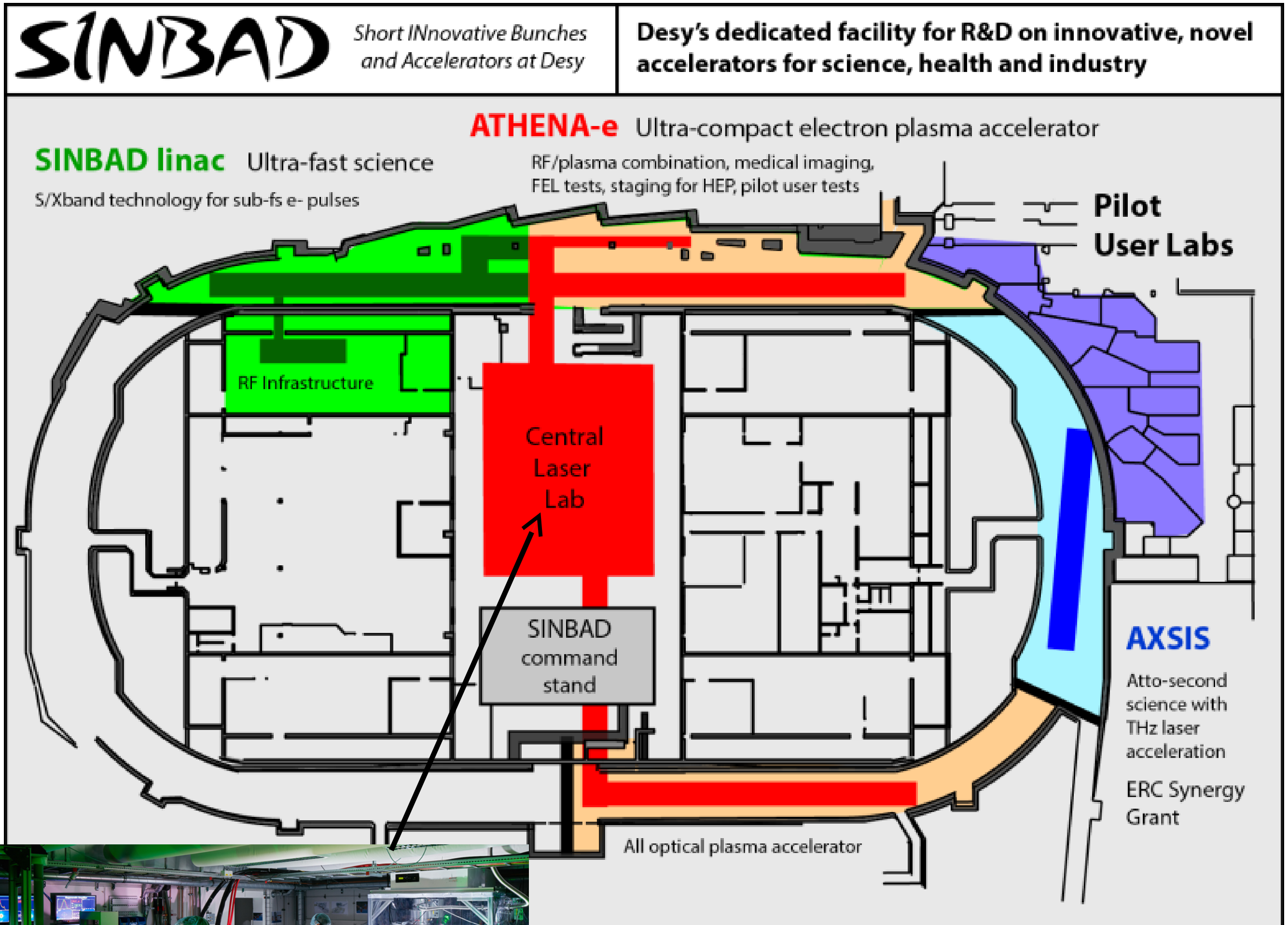


Athena is a Helmholtz-initiative, but we will strongly rrely on our partners, e.g. UHH

Ulrich


SINBAD Short INnovative Bunches & Accelerators at DESY
ARD Spitzenforschung im alten DORIS Komplex
durch optimale Nutzung der Infrastruktur
Kompakte Atto-Sekunden Lichtquelle
50 as, ICS
ERC Synergy Grant, DESY, Uni HH, Arizona
Ultrakurzer Elektronenpuls
< 1 fs mit konventioneller Technologie
ARD, DESY, Uni HH, KIT
Nutzbarkeitsstudien Plasmabeschleuniger, Skalierbarkeit
> 1 GeV/m, nutzbare Strahlqualität, FEL?
LAOLA, ARD, DESY, Uni HH
Raum für weitere Phasen und Nutzer
Drittmittel Interessensbekundung ELI
PIER
Coordinating PI
bERLinPro centre for high power cw beams in sc accelerators
bERLinPro = Berlin Energy Recovery Linac Project
100 mA / low emittance technology demonstrator
bERLinPro Helmholtz-Zentrum Berlin
beam dump
6.5 MeV, 100 mA = 650 kW
linac module
44 MeV
booster
4.5 MeV
srf-gun
1.5-2 MeV
merger
dogleg
50MeV, 100mA, 2ps (5 MW of virtual beam power)
50MeV, 10mA, <100fs (500kw of virtual beam power)
both modes normalized emittance < 1mm mrad
Jülich Short-Pulse Particle and Radiation Centre
JÜLICH
Particle physics
Synchrotron radiation
JuSPARC
Material research
Markus Büscher
ELBE center for high power radiation sources
Dual beam Petawatt / 150 TW ultrashort pulse laser facility
Diode pumped Petawatt laser development
Synchronized operation with ELBE accelerator
Dedicated shielded target areas (~1000m² laser lab space)
Beam driven sources (THz, FEL, …) at ELBE
ELBE
150TW
Draco PW
HZDR
The LIGHT test-stand at GSI: coupling of laser-accelerated ions into conventional accelerators
Principle: manipulation of laser-accelerated ions
HI Jena GSI HZDR
1. Laser-driven ion acceleration
2. beam conditioning (collimation)
3. drift line and phase-space rotation
Current results:
proton spectrum
proton beam
FLUTE: ARD-Forschung am KIT
KIT
Ultrakurze Elektronenpulse (1 fs bis 300 fs)
Grosser Bereich an Ladungen (1 pC bis 3 nC)
Kohärente Strahlung für Materialwissenschaften und biologische Anwendungen
Entwicklung/Tests von Kurzpuls-Strahldiagnose und Instrumentierung
Kooperation KIT, PSI, DESY
Ferninfrarot Linac-
FLUTE
FLUTE, a Linac-Based THz Source at KIT
Helmholtz-Institute Jena
Development and application of novel plasma diagnostics:
few-fs and 1-µm resolution,
first direct visualization of the laser-driven plasma wave in a laser-electron accelerator.
M. Schwab et al., Applied Phys. Lett (2013)
A. Sävert et al., submitted (2013)
relative z-position (µm)
Kiel
Rostock
Lübeck
Hamburg
Bremerhaven
Bremen
Berlin
Hanover
Bielefeld
Brunswick
Magdeburg
Halle
Leipzig
Dresden
Essen
Dusseldorf
Germany
Chemnitz
Frankfurt
Nuremberg
Stuttgart
Augsburg
Ulm
Munich

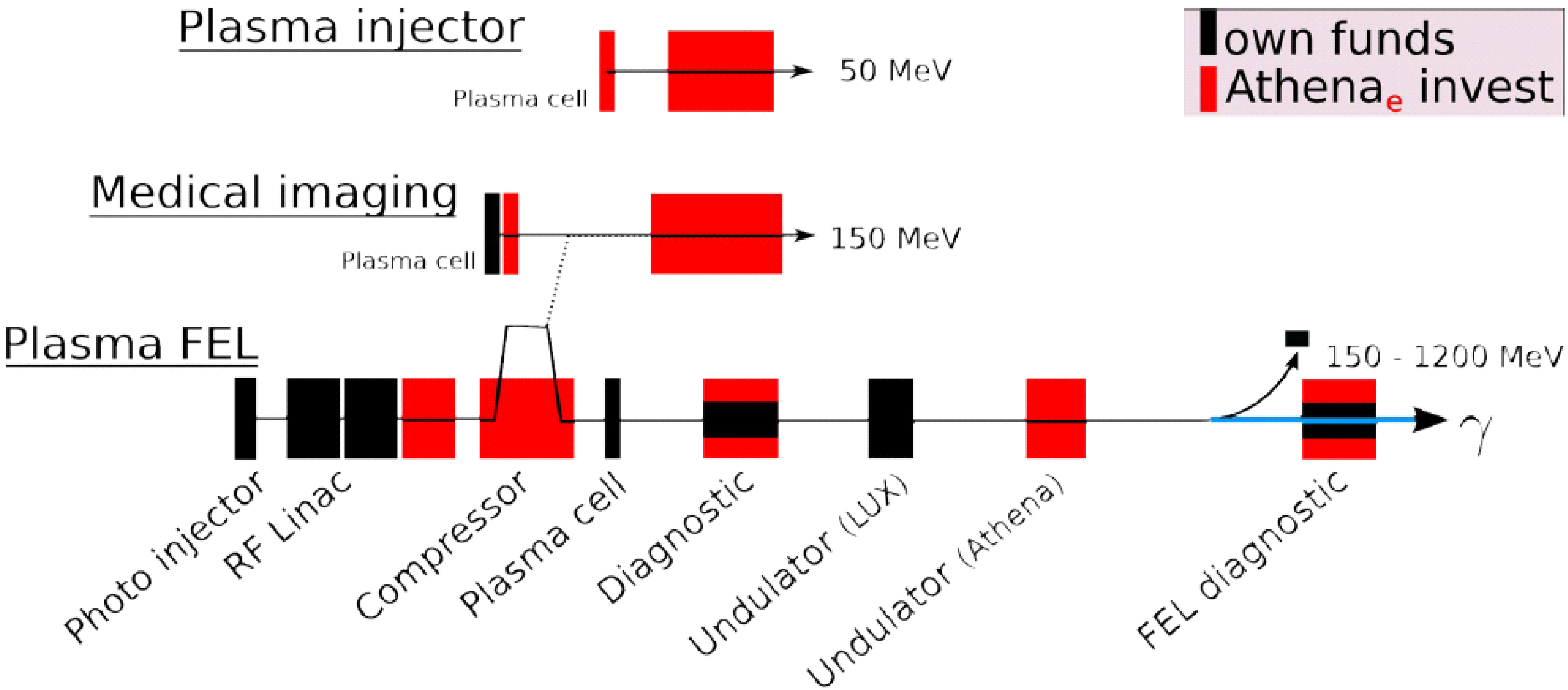
SINBAD as host to ATHENA$_e$



DESY-M University HH Laser Lab Angus

Currently operated by A. Maier's group

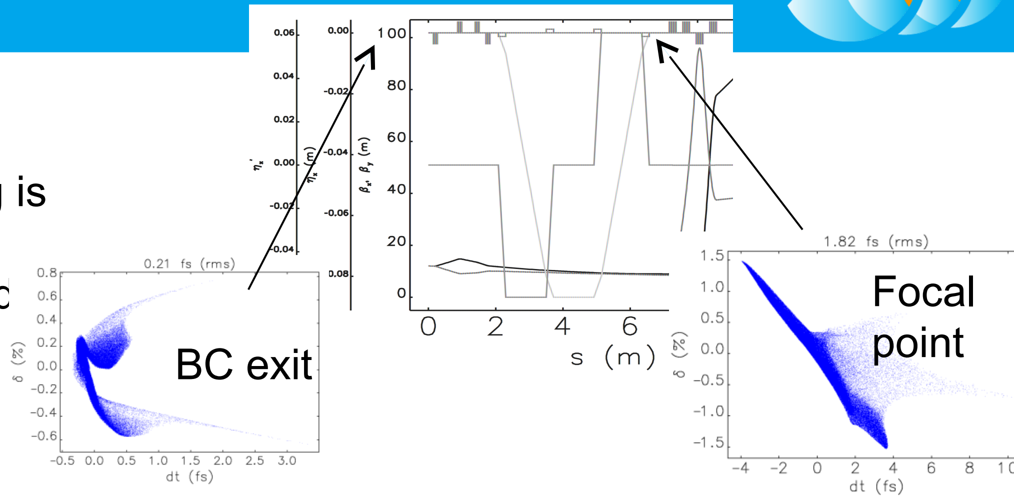
- One of the 2 **flag-ship projects**
- Relying on collaboration with **ATHENA & LAOLA partners**
- Substantial **extension** of the **SINBAD-ARES linac**
- Direct **comparison** of performances of **conventional acceleration** vs **PWFA** (internal + external injection).
- Pilot user experiments involving **plasma based FEL**



Direct **comparison** of performances of **conventional acceleration vs PWFA** (internal + external injection), both driven by lasers (baseline) and e-beams

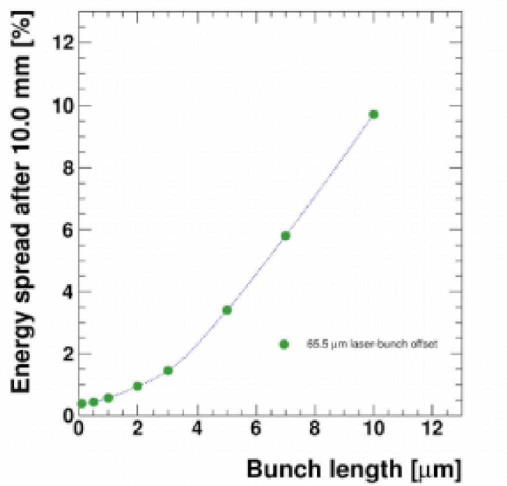
Plasma injector to be later setup at KIT for injection into test storage ring

Linac working points for injection into advanced acceleration schemes



Matched ß functions range from cm to mm ($n \sim 10^{14}$ to $n \sim 10^{17}$). While for VB, the focusing is done along the linac, in case of a bunch compressor (BC), a focusing optics is needed

Example: Simulations at $n = 10^{17}$



Bunch length < 5 fs (small final energy spread)

Preliminary studies for a working point for FEL radiation generation in soft X-rays has been done by A. Maier in the context of the ATHENA proposal.

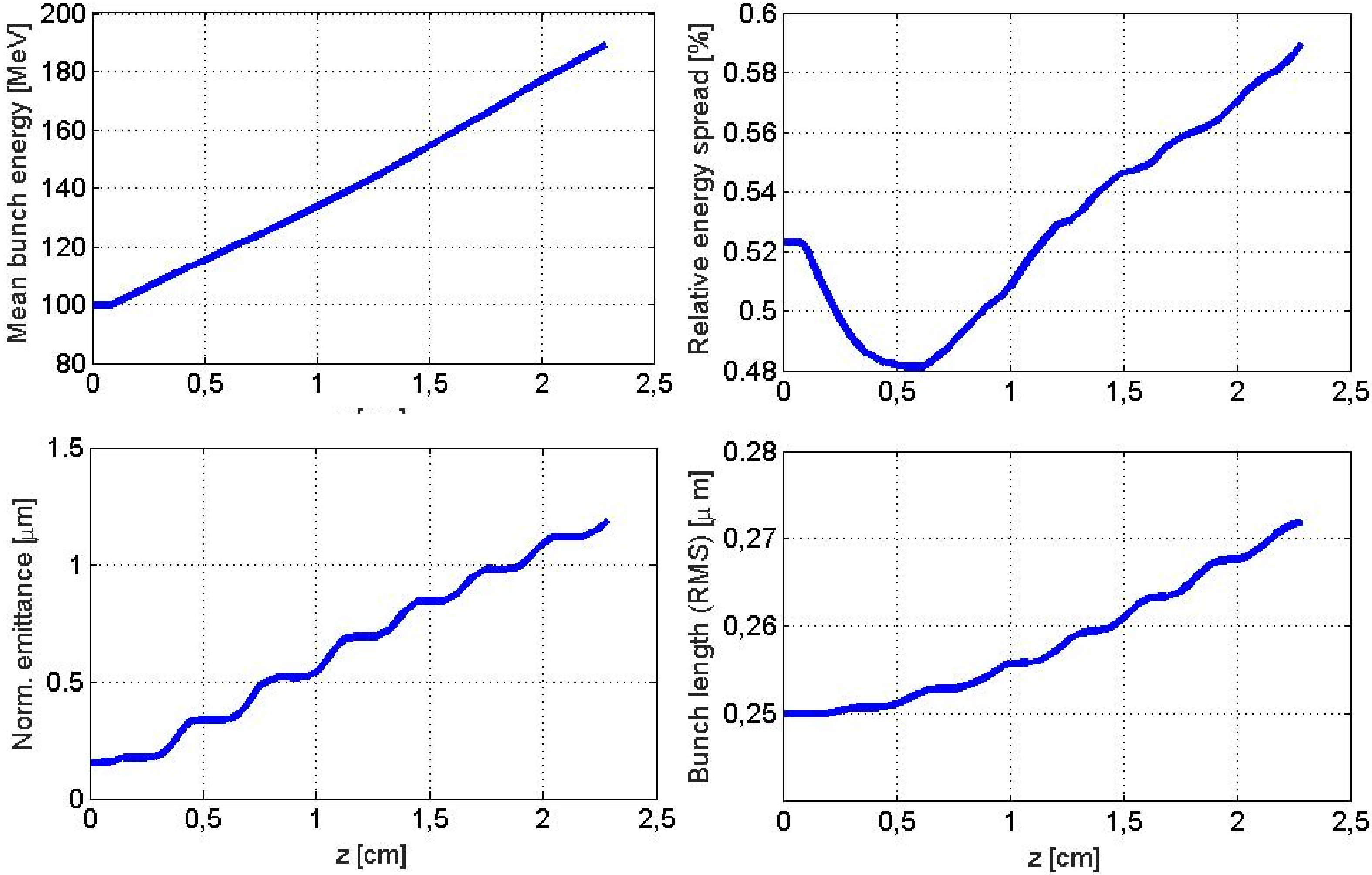
Plasma density [cm^{-3}]	10^{18}	10^{17}	10^{16}	0.5×10^{16}
Skindepth, k_p^{-1} [μm]	5.31	16.8	53.1	75.2
Plasma wavelength, λ_p [μm]	33.4	106	334	472
Injection beam energy [MeV]	100	100	100	100
Laser pulse duration [fs]	25	25	25	25
Field gradient (OSIRIS) [GV/m]	62	7.58	0.46	0.21
Accelerating region, $\lambda_p/4$ [μm]	8.35	26.5	83.5	118
200 MeV stage length [m]	1.6×10^{-3}	13.2×10^{-3}	0.22	0.48
1 GeV stage length [m]	16×10^{-3}	0.13	2.2	4.8
Matched β [mm]	0.1	0.3	1	1.5

First simulations using the ARES beam

Simulations by
Maria Weikum

Almost hard-edge plasma
model + laser guiding

$n=4.25*10^{16}$ cm^{-3}



osiris
v2.0

INSTITUTO SUPERIOR TÉCNICO

UCLA

DESY

Summary

SINBAD & ATHENA in one page

Summary

- SINBAD will be a dedicated accelerator R&D facility at DESY
- The SINBAD-ARES-linac is based on proven technology, trying to push the bunch length to a minimum & minimize the arrival time jitter.
- Several experiments on dielectric acceleration are foreseen.
- ATHENA is a collaborative proposal for a Helmholtz investment. If approved SINBAD would host one flagship program allowing to upgrade the linac and add a plasma stage incl. Undulators.
- To some extend, access will be possible via the ARIES transnational access program..

- We strongly rely on our collaborators in LAOLA, EuPRAXIA, ATHENA, AXSIS, ARIES, ACHIP,… and the support of the DESY technical groups!

Backup slides

Even more?

LAOLA Collaboration Hamburg

F. Grüner

A. Maier

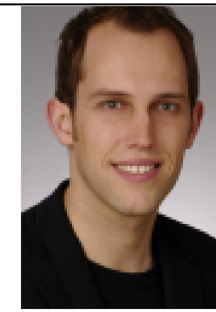
Laser: Ti:Sa 200 TW, 25 fs pulse length, 5 Hz repetition rate

- *Initially: Laser-driven wakefields in REGAE. LUX exp. towards FEL*
- *Later: Move to SINBAD facility.*

Beams:

- REGAE: *5 MeV, fC, 7 fs bunch length, 50 Hz*

FLASHForward



J. Osterhoff

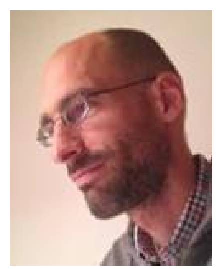
- FLASH: *1.25 GeV, 20 – 500 pC, 20 - 200 fs bunch length, 10 Hz.*
  Beam-driven plasma wakefields. Beam-driven plasma wakefields with shaped beams and innovative injection methods. Helmholtz VI with UK collaboration.

F. Stephan

- PITZ: *25 MeV, 100 pC, 20 ps bunch length, 10 Hz.*
  Beam modulation experiment in a plasma cell, preparation to CERN experiment AWAKE

- SINBAD: dedicated R&D, multi purpose, *150 MeV, 0.01 – 3 pC, down to < 1 fs bunch length, pulse rate 10 – 1000 Hz*
  - **Home of AXSIS ERC Synergy Grant**
  - **Home of ATHENA$_e$**

R. Aßmann



U. Dorda

B. Marchetti

Similarly strong teams in other Helmholtz centers!

Beam compression along the dogleg with partial RF phase jitter compensation

- Basic idea:
  compressing the e-bunch via VB+MC while compensating the arrival time jitter caused by the phase jitter in TW1 at the dogleg exit.

- Analytical approach proposed in:
  R. Brinkmann, Ideenmarkt Beschleuniger Seminar, DESY 2012.

- Developed a semi-analytical approach to study the best working point at ARES:
  B. Marchetti et al. doi:10.1016/j.nima.2016.03.041