SINBAD-ARES

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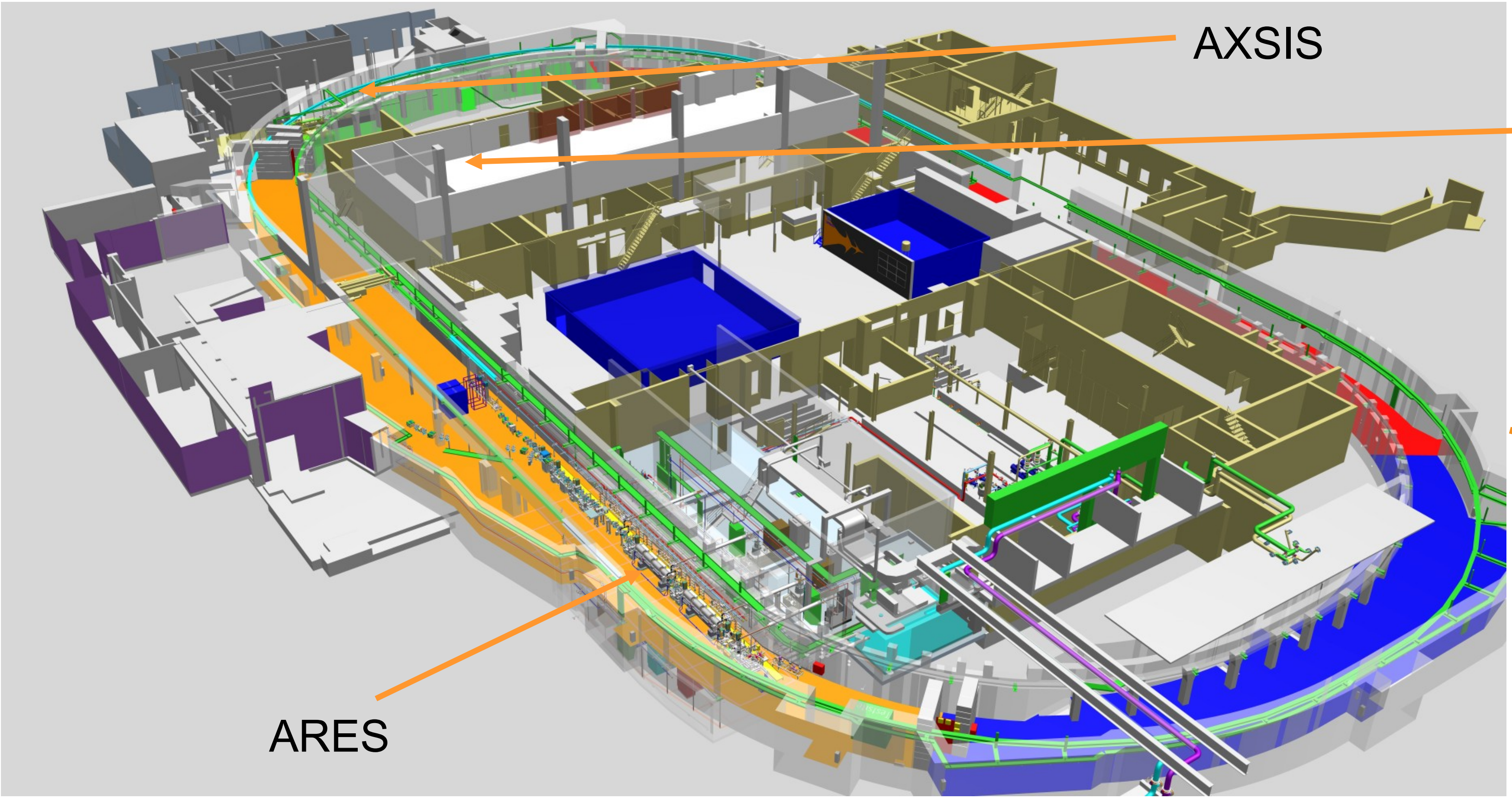
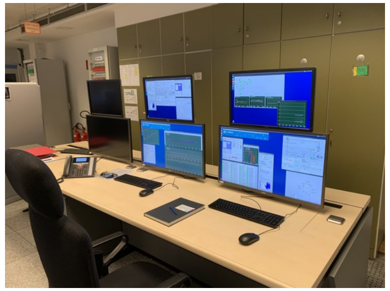
02.07.2019

SINBAD is a new, dedicated accelerator R&D facility at DESY

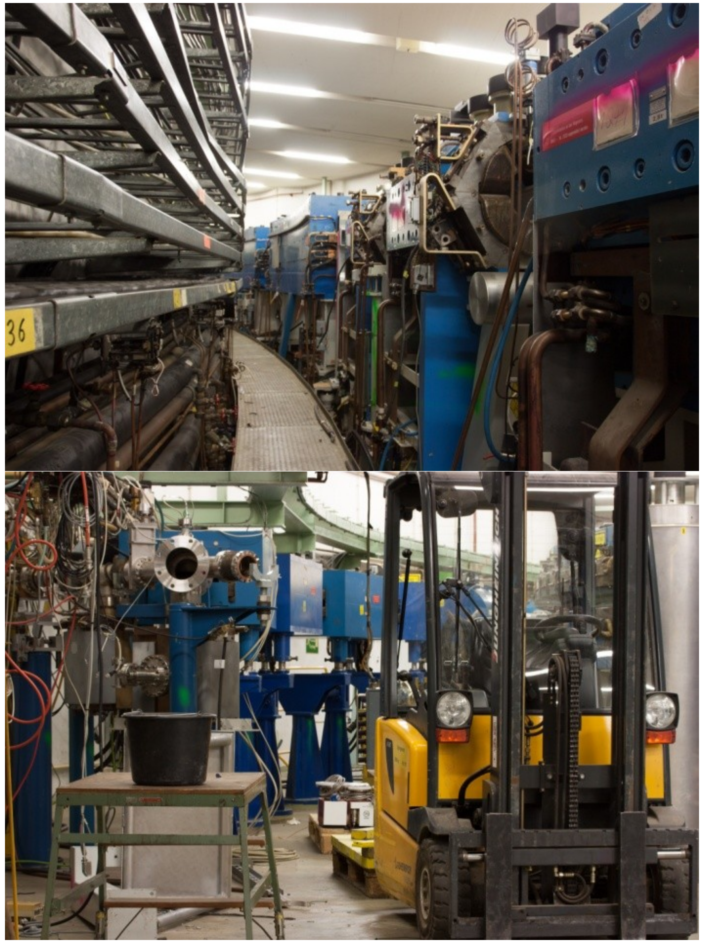
- SINBAD = Framework for all ARD activities in the former DORIS tunnel & associated areas
- It focuses on Research and Development on ultra-fast Science and high gradient Accelerators
- Based on DESY know-how and many collaborations!
- Multiple independent experiments



SINBAD-ARES space in BKR

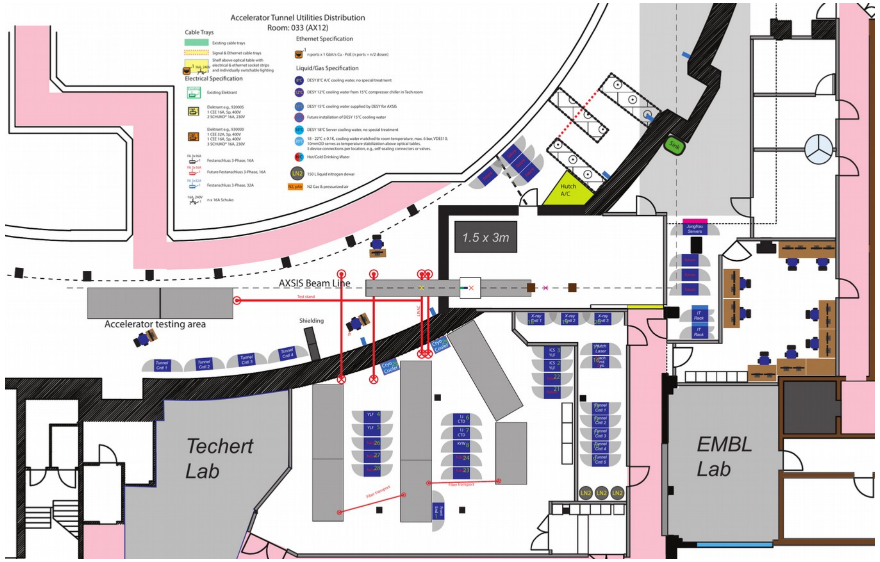


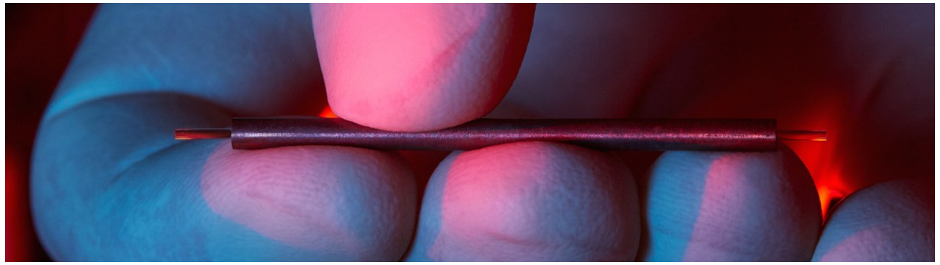
The first step...

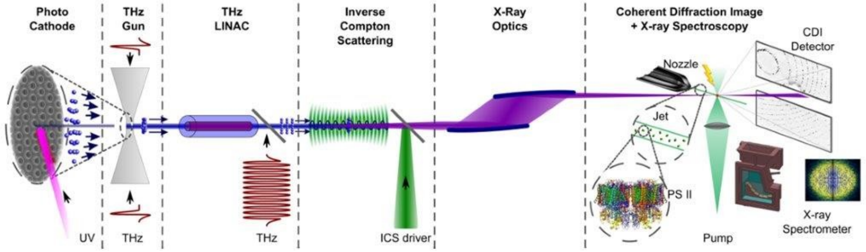


AXSIS

- Collaboration of the groups of 4 Pis
  - Lasers & Accel.: F. Kaertner, R. Assmann
  - X-ray & Bio.: H. Chapmann, P. Fromme
- Funded by an ERC synergy grant (ends summer 2020)
- Lasers → THz → Electrons → X-rays → Users
- Hosted at SINBAD & neighboring former Hasylab user-areas.
- Target electron beam parameters: 10 -20 MeV, sub pC charge
- Laser lab construction about to be completed

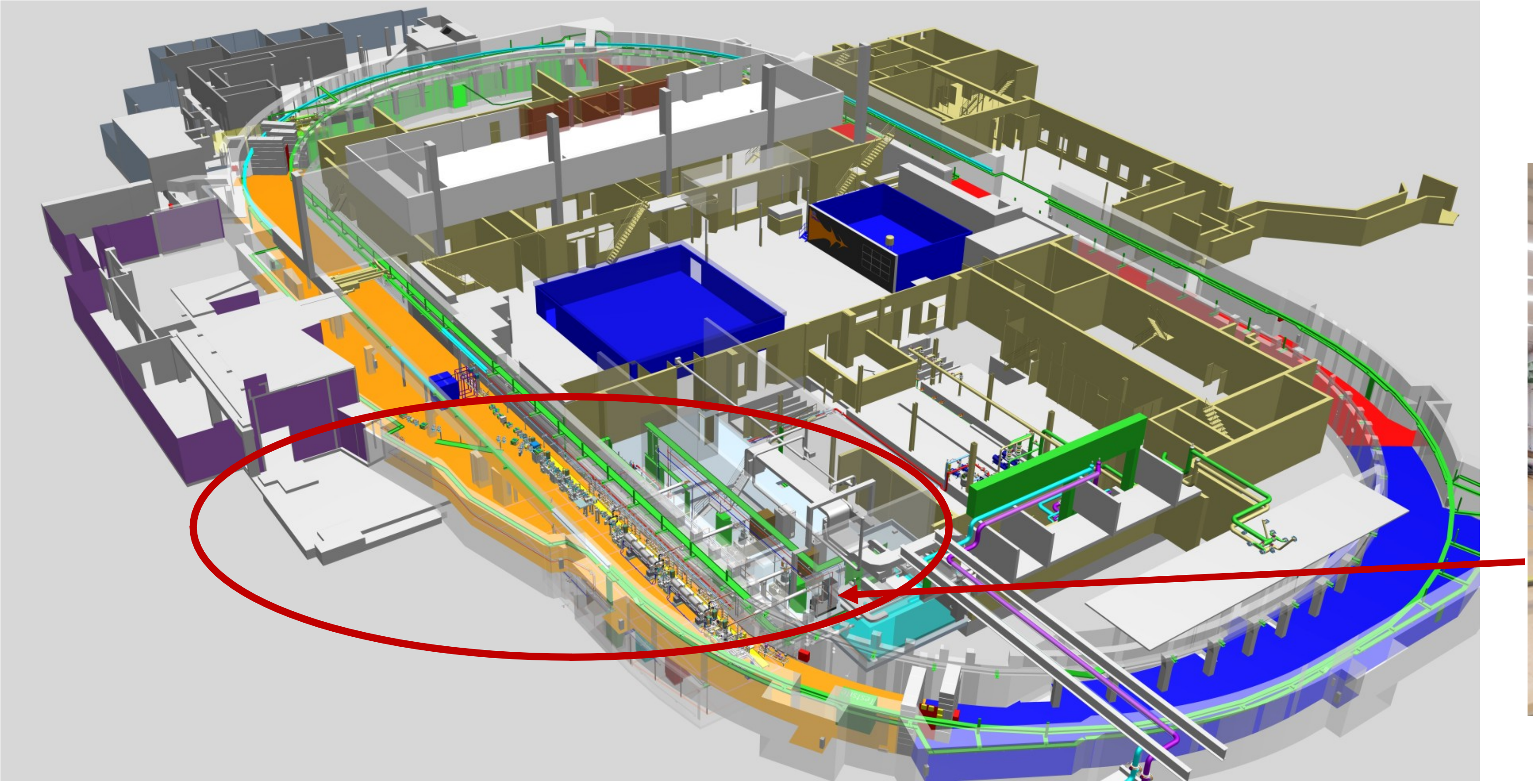






ARES is one of the Experiments located at SINBAD

It is a conventional RF Photo-Injector for the Production of high Brightness fs electron Bunches with Energy around 100MeV



ARES Linac at SINBAD

Motivation

Why a “conventional” Photo-Injector for SINBAD?

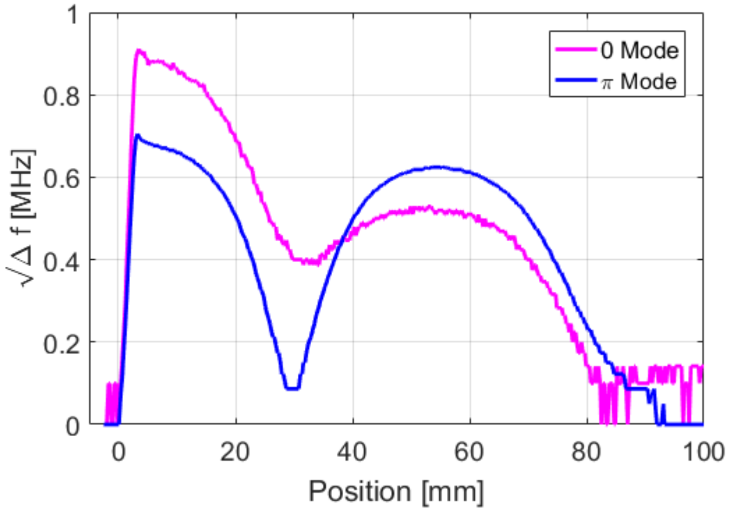
- Conventional S-band RF technology allows to produce **stable and reproducible electron bunches** (good tradeoff gradient versus bucket volume – extensive experience at DESY).
- **R&D** on producing **high brightness e-bunches with bunch length at fs/sub-fs and excellent arrival time stability**: important research in its own right, enables understanding ultimate limitations in photo injectors.
- Characterization of ultra-short (~fs), low charge (~pC to sub-pC) bunches is technically challenging -> **R&D on novel diagnostics devices and fs-level synchronization.**
- Short bunches fit into very compact (novel) accelerators with **short accelerating field wavelength**. They constitute excellent **probes** to measure energy gain.
- The chosen **electron bunch energy (100-150MeV)** :
  - helps with damping the **space charge effect**, thus allowing reaching >1kA local peak current;
  - minimizes **de-phasing issues** at injection point for typical plasma densities;
  - allows excellent **energy resolution** when measuring the energy gain of the beam (goal energy gain typically ≥ 1% initial beam energy).
- The beam quality in novel accelerators depends on the detailed parameters and quality of the injected beam (e.g. bunch shape, bunch length, emittance, arrival time stability, energy) -> **flexible widely tunable Working Points and bunch shapes for novel accelerator R&D.**

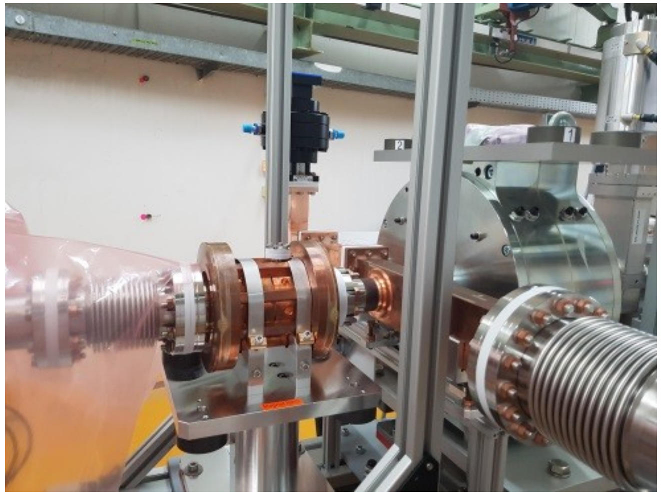
ARES Stage 0: Gun

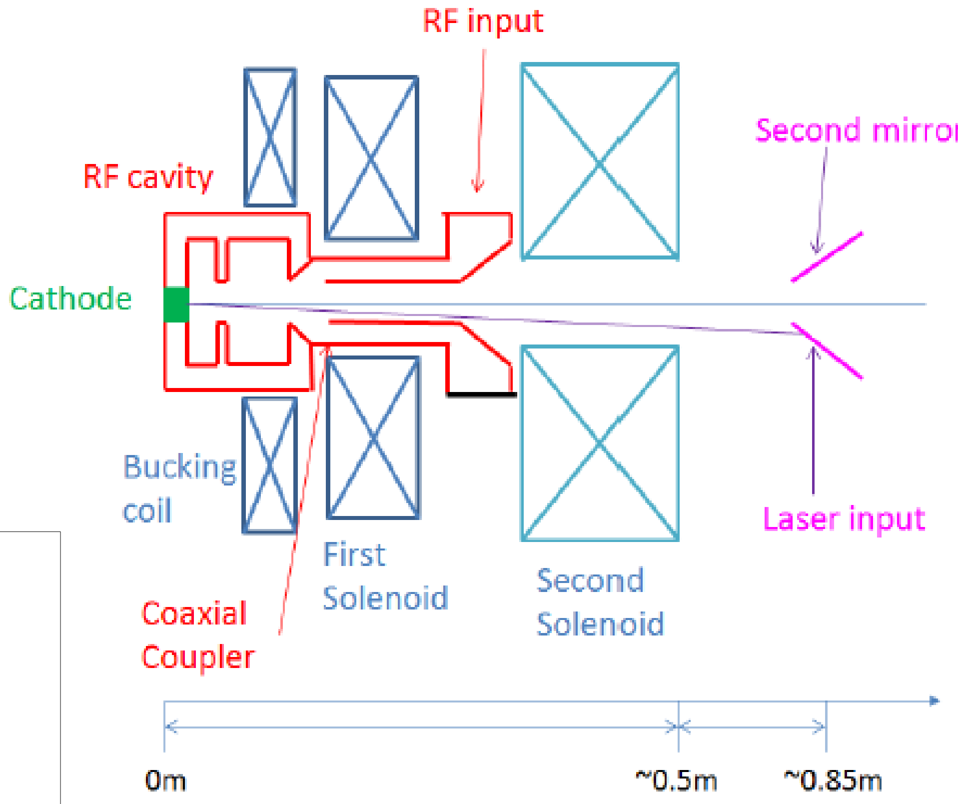
Currently being commissioned

The Design of the ARES Photo-Injector allows broad Tuning of the longitudinal Phase-Space of the Beam at the Cathode (1/3)

REGAE-like Gun Cavity- 1.5 Cells Standing Wave – exchangeable Cathode-Plugs





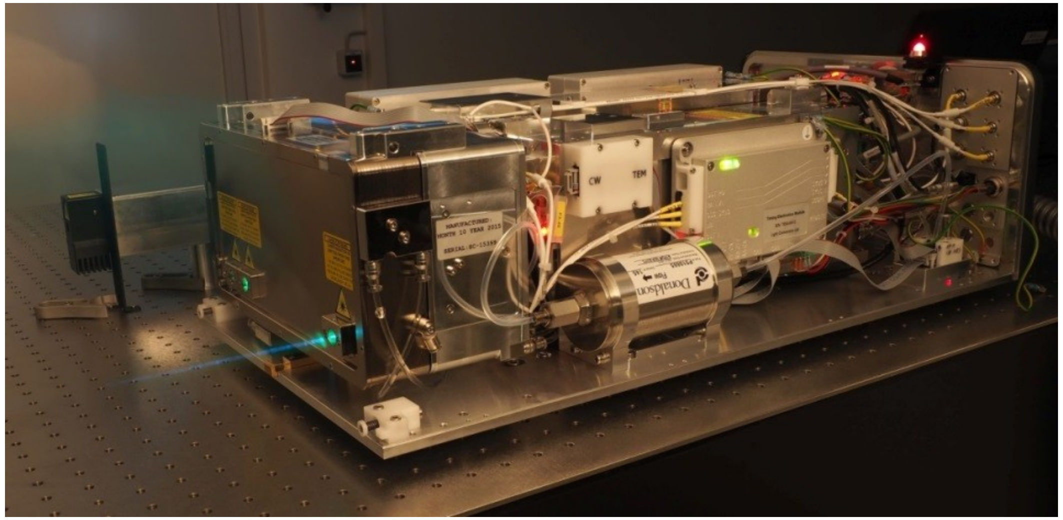


Peak gradient: 117 MV/m for 6MW input power
RF pulse length: 6μs

Why use different cathode-types ?
- Semiconductors, (e.g. Cs_2Te) :
  - High QE (e.g. 4%-11%)
  - Slow response time ~ ps
- Metals (e.g. Cu):
  - Lower QE (e.g. 0.014%)
  - Faster response time < ps

B. Marchetti et al., TUPMF086, IPAC18

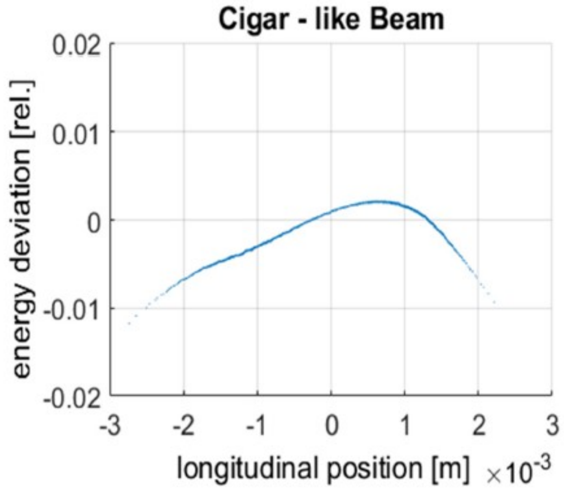
The Design of the ARES Photo-Injector allows broad Tuning of the longitudinal Phase-Space of the Beam at the Cathode (2/3)



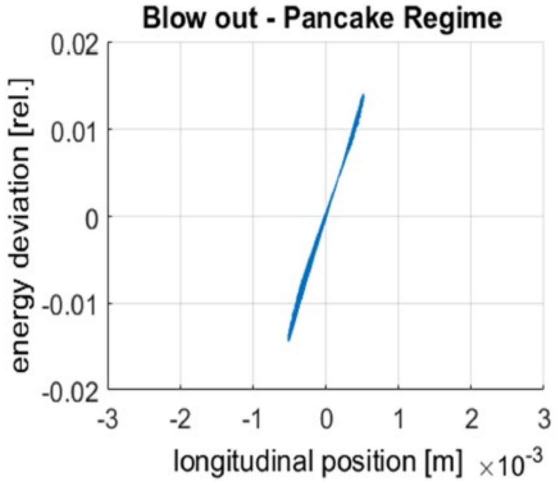
- **Yb doped laser** (PHAROS from Light Conversion)
- Pulse energy ≥1mJ
- Central wavelength: 1030 nm (4th harmonic 257 nm)
- Pulse length range tunable: 180fs-10ps FWHM

- **DESY-developed transverse flat-top shaping system**
- Range for flat-top shaping: 20µm-0.2mm RMS

Design by **Lutz Winkelmann & Sebastian Pumpe**



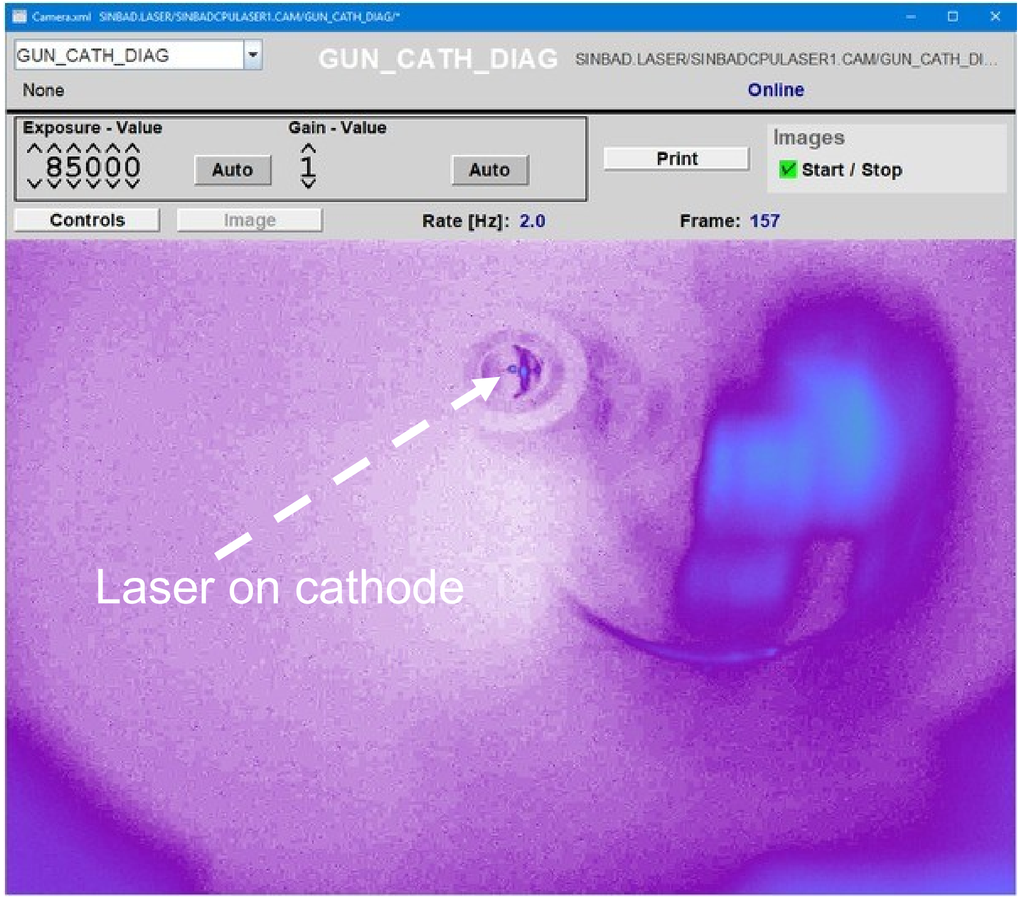
Slice_Emittance and Slice-Energy Spread minimized

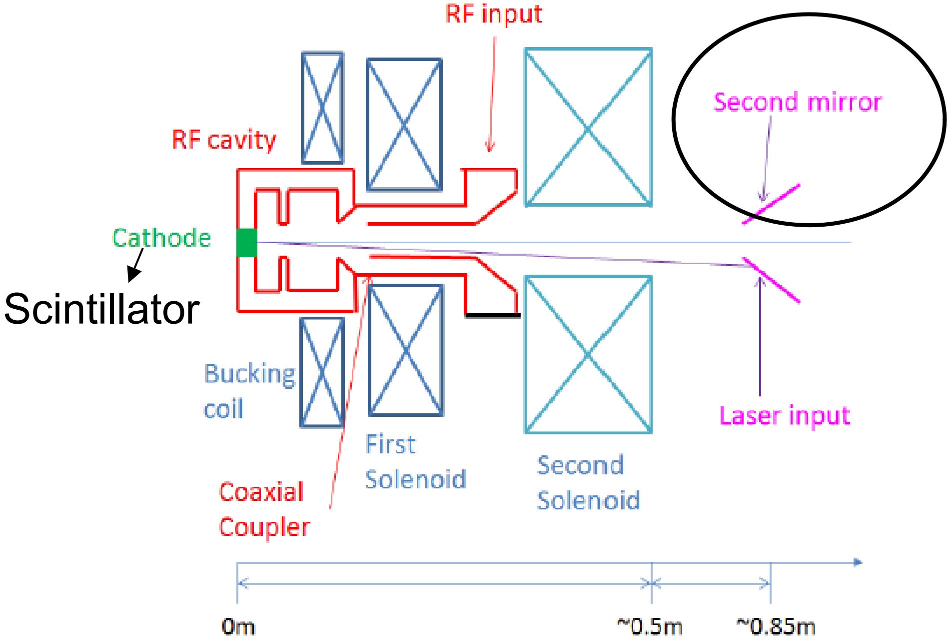


Linear Longitudinal Phase-Space

B. Marchetti et al., Appl. Sci. ***2018****, 8, 757*

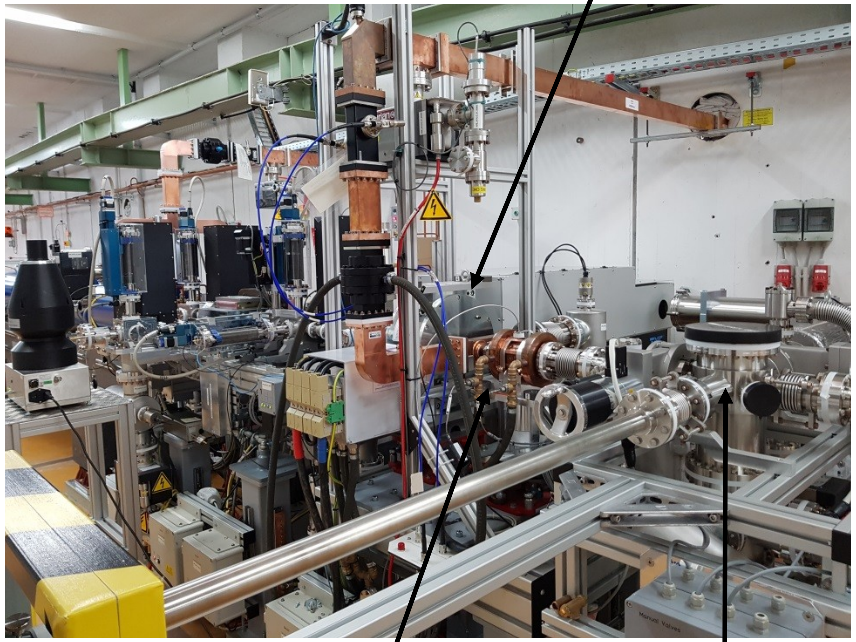
The Photo-Cathode Transverse Shaping System has been succesfully commissioned in January 2019



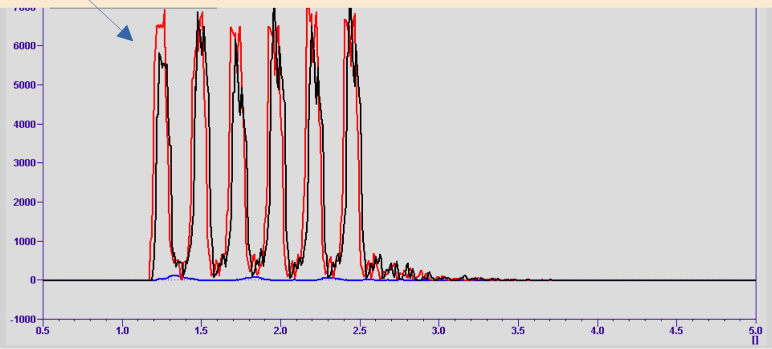


Measured data (Lutz Winkelmann, Christoph Mahnke):
Aligned and characterized two flat-top laser sizes at the scintillator cathode:
- 320µm diameter (FWHM)
- 54 µm diameter (FWHM)

The Photo-Injector has been installed and the Conditioning of the RF-Gun is ongoing



- **First RF-gun** cavity and related diagnostics installed
- **Conditioning** ongoing (so far reached 6.3MW in forward peak power with very short RF pulses at 50Hz)
- Ongoing procurement of **second RF-gun** cavity with modified cooling channels allowing integration of **second solenoid.**
- RF-conditioning was very problematic
  - Resonance temperature changed from 18 to 63 degree C (tuned to 42)
  - Sparking in waveguide limited for a long time to 2MW, 0.5 us forward power
- Intermediatly successful strategy
  - Very short pulses (100ns)
  - Reflection compensation (no circulator)
  - “Train” of short-pulses
  - Automation tool…
    - e.g. detection of increase in reflected power to ramp down the RF (and not wait for vacuum)
- **<u>Currently stuck at 1.6MW → hardware exchanges needed</u>**



ARES Stage 1: linac

Installation was completed end Mai

The Linac Cavities have been procured and installed

Installation of the Beamline Components for Matching and Diagnostics is not yet completed

- **RF cavities embedded in solenoids**
- 20 MV/m for 45MW input power

→ About **75MeV energy gain per cavity** expected with our RF station

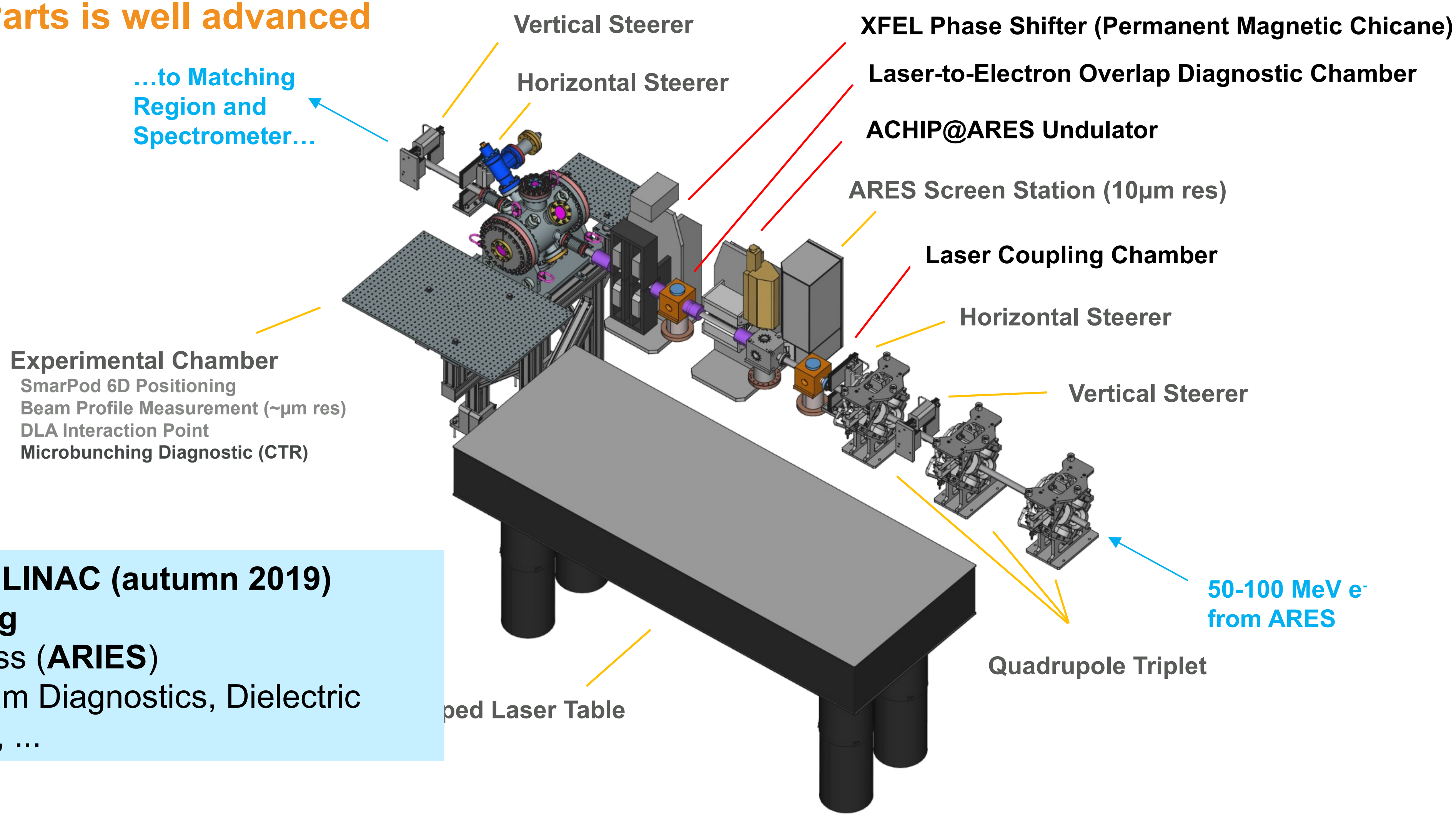
The third linac cavity, necessary for the energy upgrade, has been already ordered.

ARES Stage 2: experimental area

detail planning ongoing, many parts available, installation fall 2019

The Technical Design of the temporary Experimental Area is almost completed

The Procurement of the Parts is well advanced

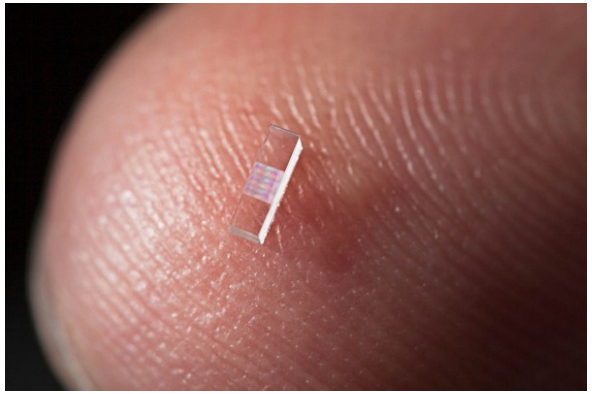


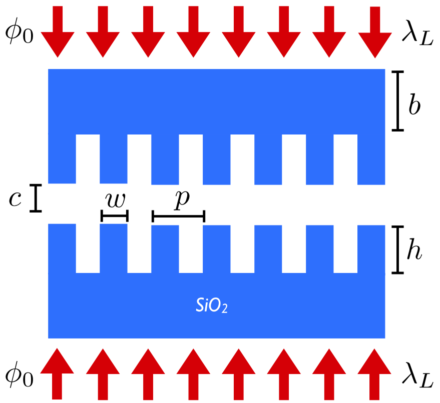
- To be installed at the **ARES LINAC (autumn 2019)**
- Will later move to the **Dogleg**
- Open for transnational access (**ARIES**)
- Possible users: **ACHIP**, Beam Diagnostics, Dielectric Structures, medical imaging, ...

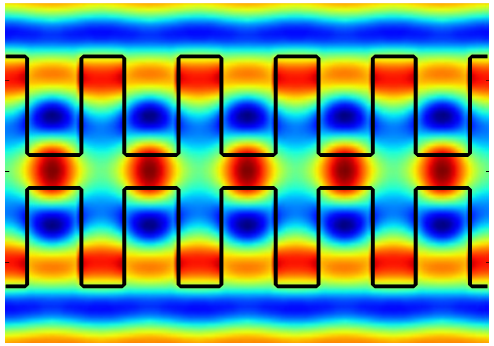
Planned DLA experiments

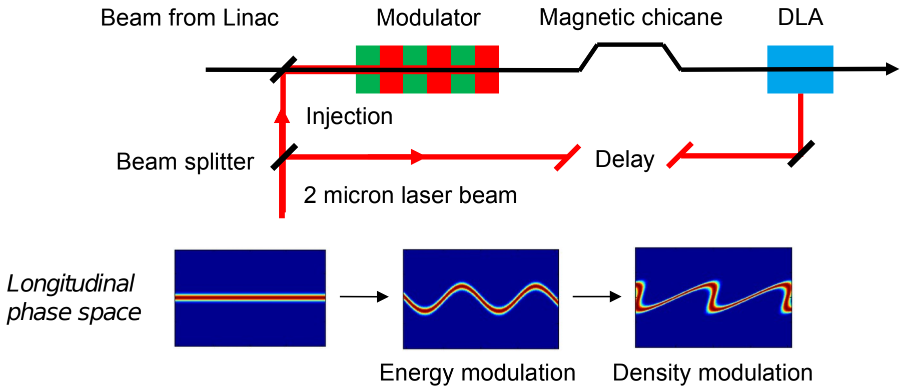
Installation of the Beamline Components for Matching and Diagnostics is not yet completed

- Efforts part of the ACHIP collaboration & support by ARIES WP 18.4
- 2 um Laser currently installed photo cathode-laserlab
  - Laser from Kaertner group, sync by Hartl group
- Laser beam line etc in production
- Samples on Hexapod
- Laser-damage tests of samples currently ongoing.









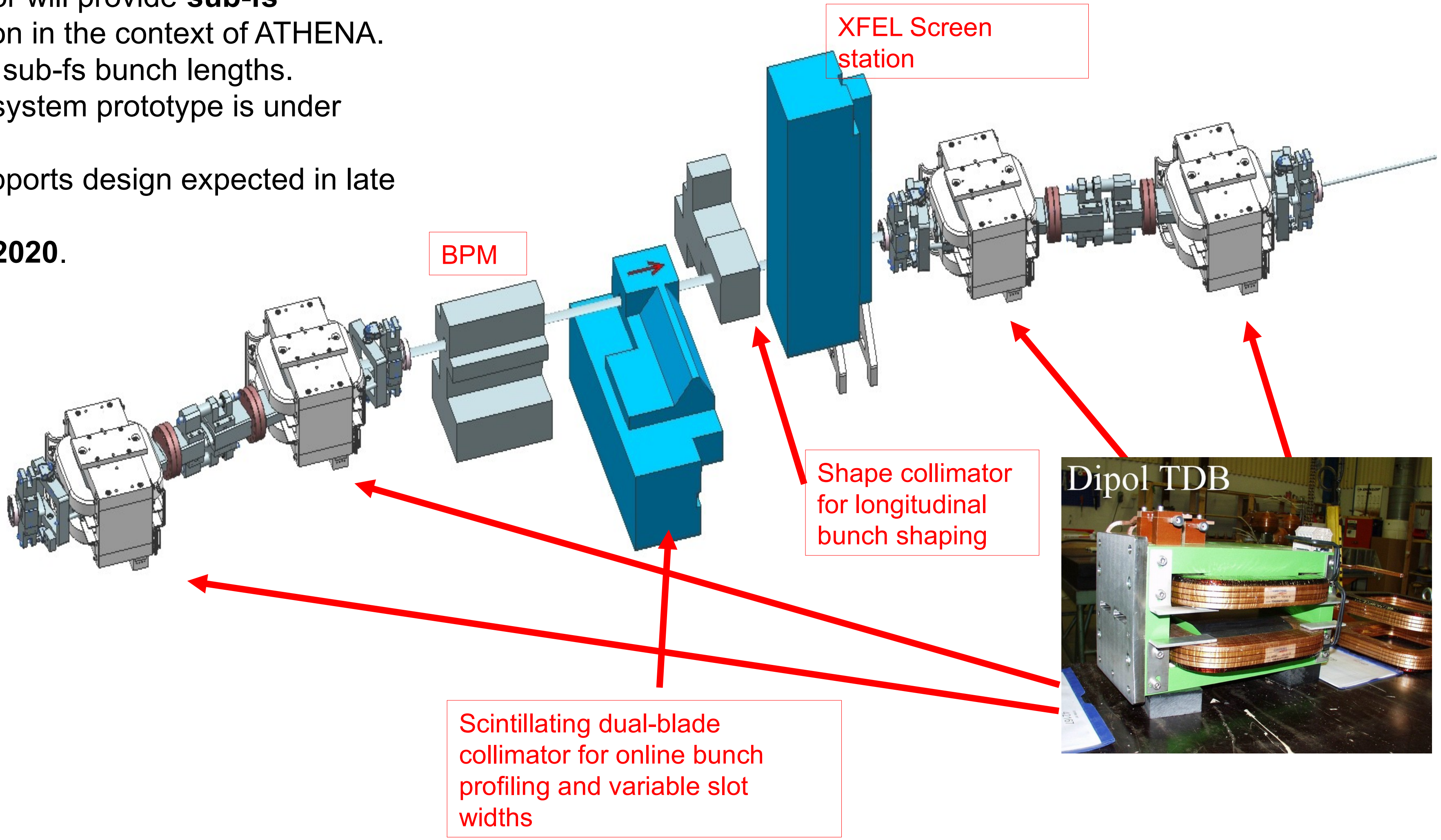
ARES Stage 3: magnetic bunch compressor

detail planning ongoing, many parts available, installation 2020

The Technical Design of the Bunch Compressor is ongoing

The bunch compressor will allow the production of attosecond bunches for external injection into ATHENA

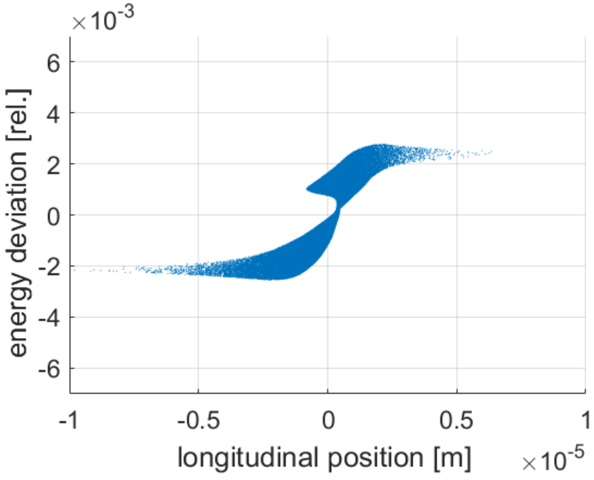
- The ARES bunch compressor will provide **sub-fs bunches** for external injection in the context of ATHENA.
- Collimator approach to yield sub-fs bunch lengths.
- The mechanical movement system prototype is under construction.
- Vacuum and mechanical supports design expected in late summer 2019.
- **Installation is foreseen in 2020**.



Compression via Velocity Bunching and Magnetic Compression have different Advantages/Disadvantages

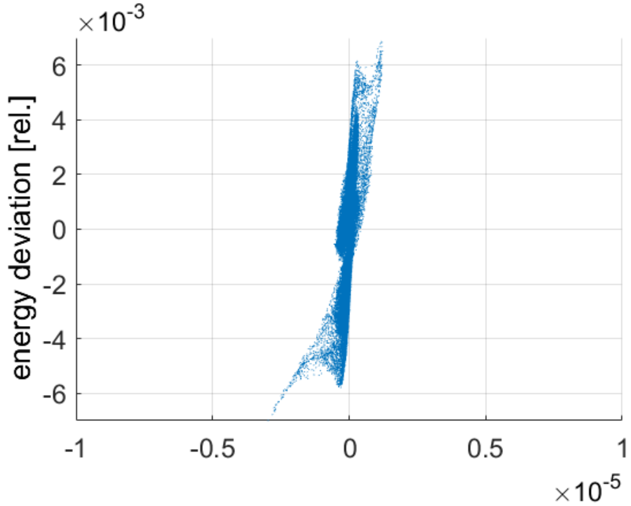
Velocity Bunching

- No CSR → very good transverse emittance
- Non-linearity in longitudinal phase space
- Tighter tolerances on phase of the RF-compressor



Magnetic Compression

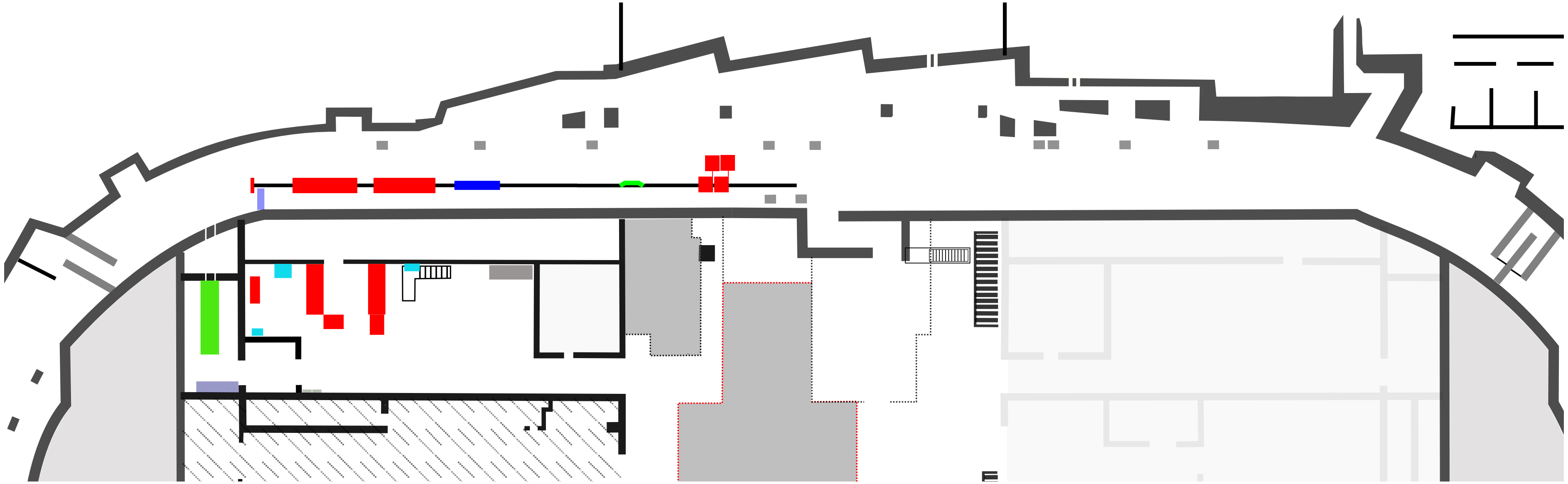
- Ultra-short beams (remove non-linearity)
- Affordable tolerances on RF phase
- CSR spoils the beam
- Much charge lost in the slit



Hybrid Compression is also possible

ARES Stage 4: X-band transverse deflecting structure

Main parts ordered, PolariX collaboration, installation 2020



PolariX TDS Project

- Novel design of TDS with **tunable direction of the streaking field** invented at **CERN**
- First prototype cavity has **been produced** and **characterized** at **PSI**
- Performed **high power conditioning at CERN**
- Prototype cavity **will be tested with beam at DESY** (FLASHForward beamline) in **2019**
- Novel beam diagnostics techniques will be tested: e.g. **3D beam charge distribution reconstruction** through tomography
- **PolariX TDS cavities for SINBAD-ARES** will be available in **2020.**

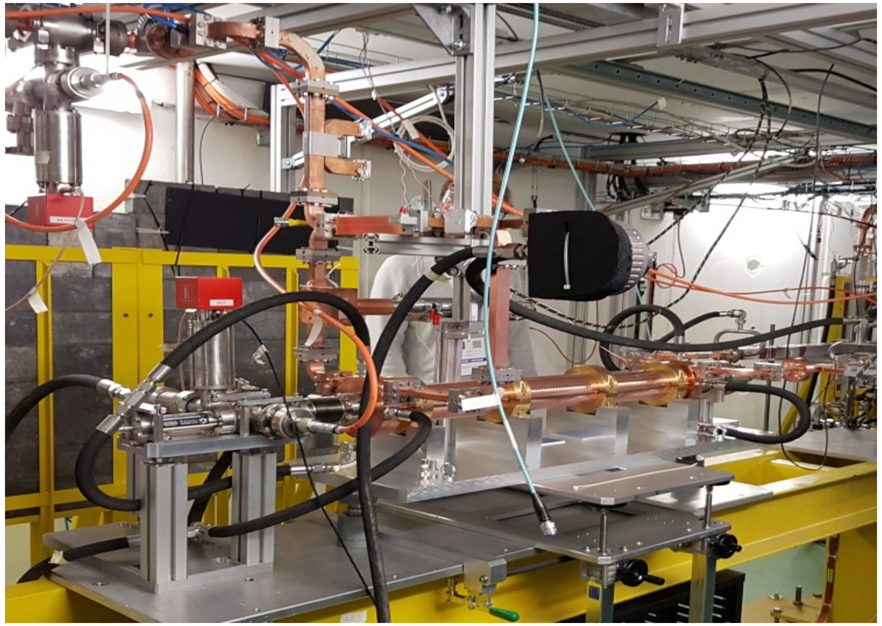
Collaboration between:

DESY

PAUL SCHERRER INSTITUT

CERN

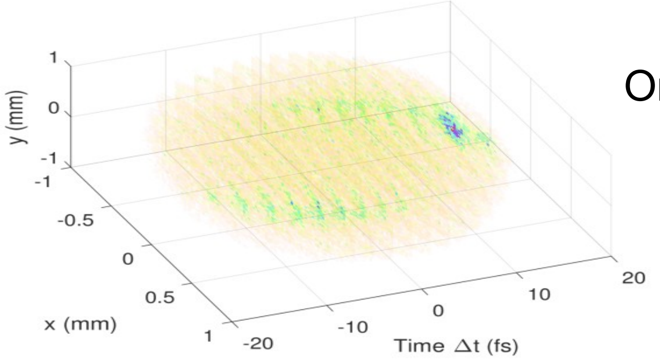
Coordinated by:
Alexej Grudiev (CERN)
Paolo Craievich (PSI)
Barbara Marchetti (DESY)



PolariX TDS Prototype at CERN for high power Conditioning

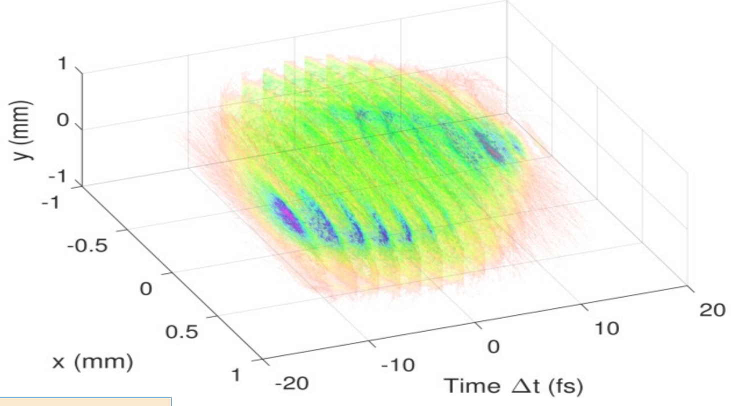
The PolariX-TDS Beamline

**Reconstruction of
3D charge density distribution**



Original

Reconstructed



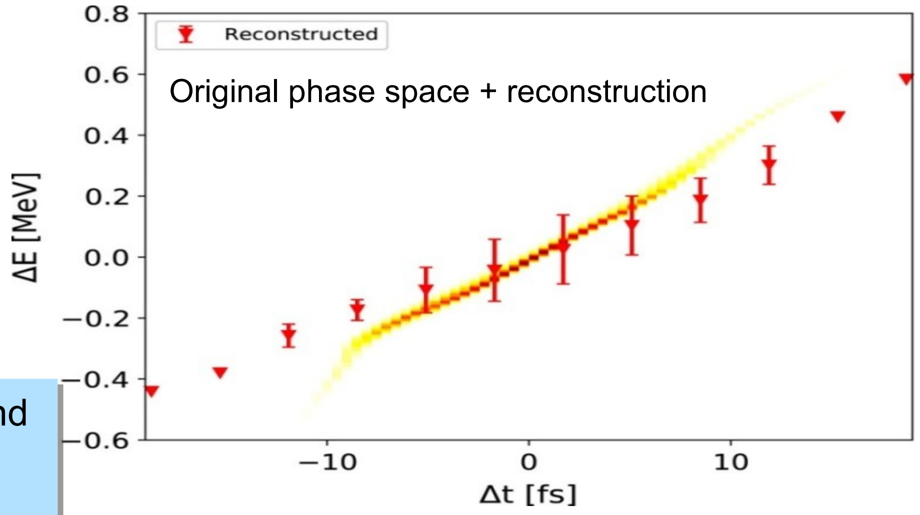
Longitudinal Resolution = 2 fs

D. Marx et al., J. Phys.: Conf. Ser., vol. 874, (2017) 012077

Longitudinal Phase Space

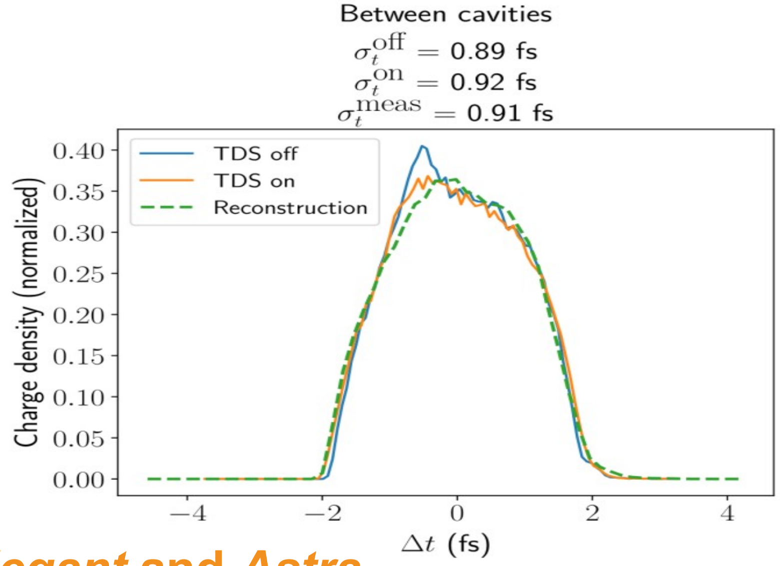
Longitudinal Resolution = 3.4 fs

D. Marx et al., Nucl. Inst. and Methods in Physics Res., A 909 (2018) 374–378



Longitudinal Charge Profile

Longitudinal Resolution = 0.18 fs



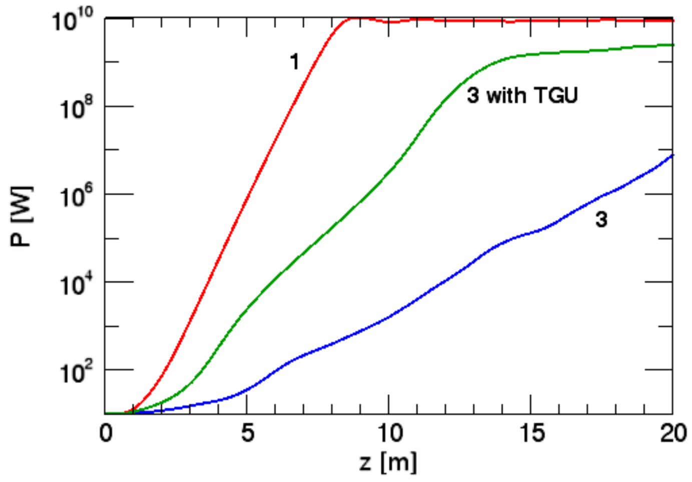
Simulations performed with *elegant* and *Astra*

ARES Stage 5: dogleg

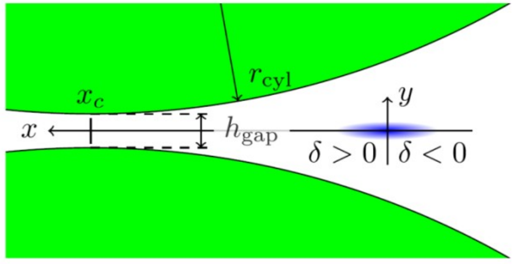
Main parts ordered
will host transverse gradient undulator experiment

Transverse Gradient Undulator Experiment

- The major problem of the LPA beam for FEL radiation is the relatively large energy spread (up to 1%).
- Transverse Gradient Undulator (TGU) is designed to minimize the energy spread effect leading to an improvement of FEL gain and radiation power substantially.
- Collaboration with KIT and HI Jena.
- Installation of a TGU at the Dogleg (mid 2020) proof-of-principle experiment.



Power gain in three cases with an ideal undulator with zero energy spread (1), TGU (2) and without TGU (3) for 1,5% energy spread.



*A. Bernhard, PHYSICAL REVIEW ACCELERATORS AND BEAMS 19, 090704 (2016)

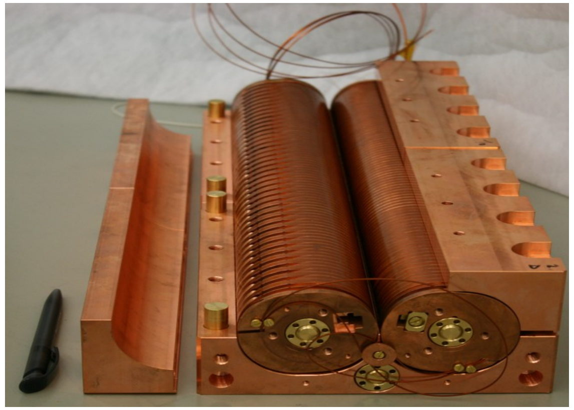
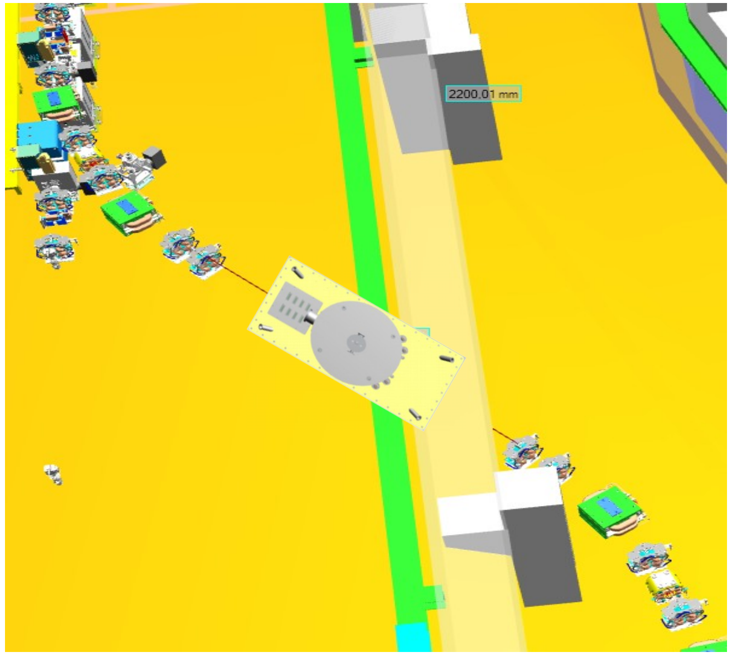


TABLE I. Parameters of the example TGU.

Period length	λ_u	[mm]	10.5
Number of full periods	N_u		40
Pole radius	r_{cyl}	[mm]	30
Gap width on symmetry axis	g	[mm]	1.1
Shift symmetry axis—beam center	x_c	[mm]	6.47
Gap width at beam center	g_c	[mm]	2.4
Flux density amplitude at beam center	$\tilde{B}_{y0}$	[T]	1.10
Undulator parameter at beam center	K_0		1.07
Transverse gradient	α_K	[m^{-1}]	149.5
Relative transverse gradient	α	[m^{-1}]	139.7

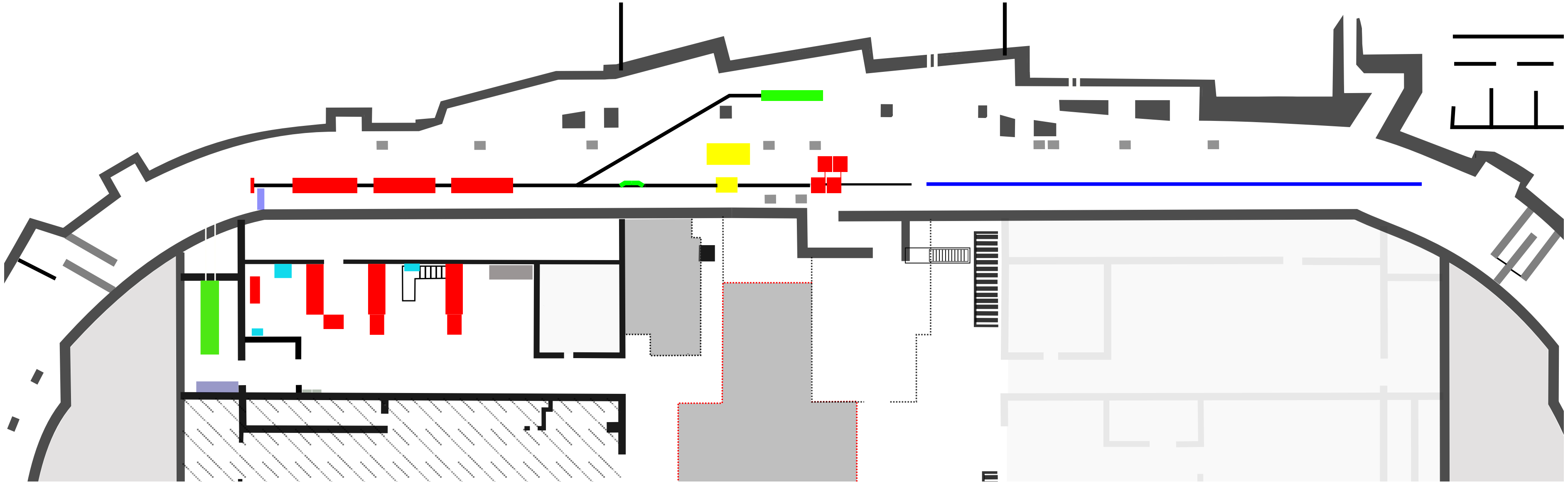


ARES Stage 6: linac energy upgrade

RF structure ordered, RF-station tender not started yet

ARES Stage 7-9: plasma, FEL,...

no detailed planning yet, plasma originally assumed to be based on REGAE



+ laser lab (location, size tbd)

SINBAD hall

Looking south

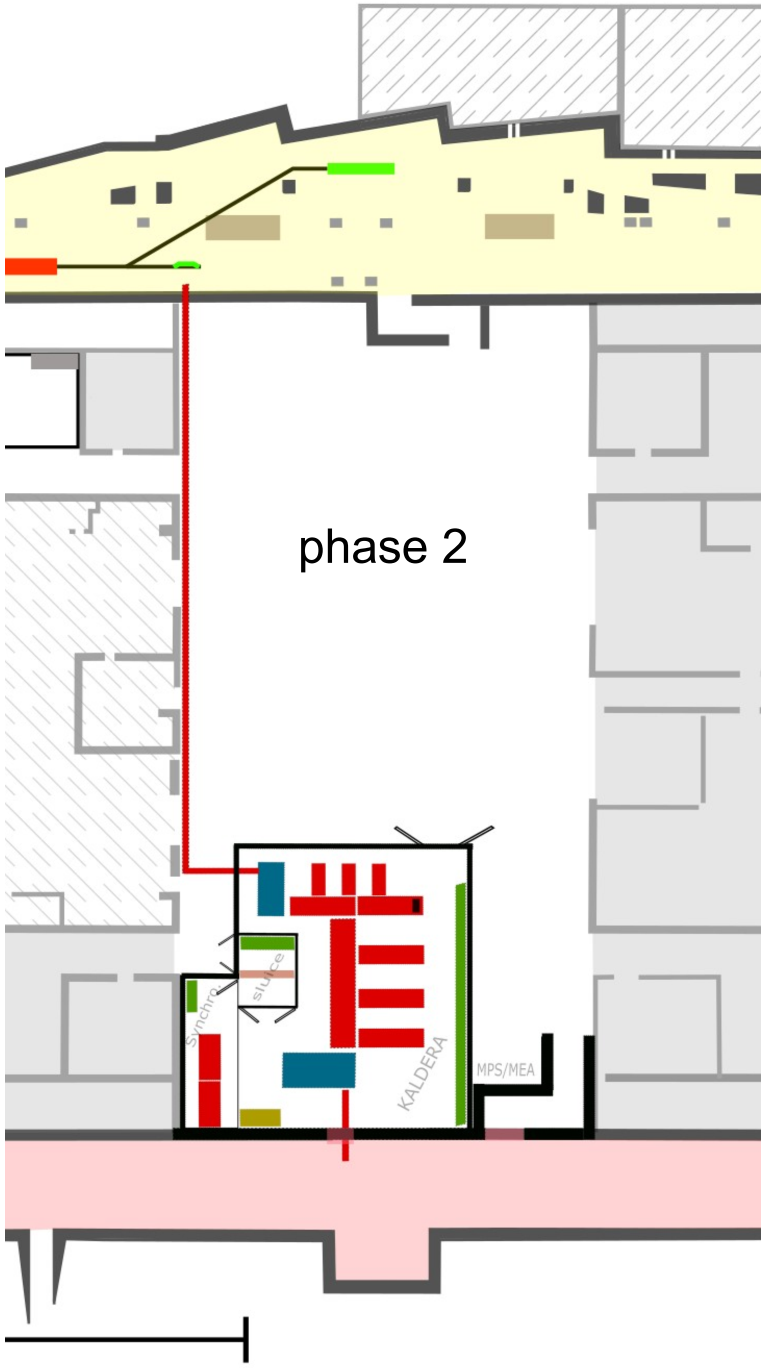
SINBAD hall

Looking south

Location and size of laser lab

- The lab will be located where the SINBAD box is located currently. (SINBAD box moves to other hall side)
- Location offers basement space and space for air cond. equipment. Some space above laser lab is needed for air cond. (only ½ footprint can be used due to crane.)

- 300 qm = total size of laser lab/clean room:
  - **180**qm: KALDERA; **100**qm for: KIT (40), prep. (35), synch (25); **20**qm: sleuce.
  - From the sleuce, all labs can be accessed independently.
  - Separators for lab space can be removed, if KIT is moving out.



Thank you

Many colleagues contributed to the work presented in this talk.
In particular I would like to thank:

- The technical groups of DESY
- The collaboration partners in Polarix, ARIES, ACHIP,…
- Klaus Floettmann, Reinhard Brinkmann
- The persons in MPY-1 involved in ARES & ARES experiments.