PETRA IV

Status of the Conceptual Design

Rainer Wanzenberg

Three-Way Meeting , May 3, 2018

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY

Outline

- PETRA IV schedule and timeline
  - CDR preparation phase
- Status of the Lattice Design
- PETRA IV Injector
- Technical implications
- Collaborations

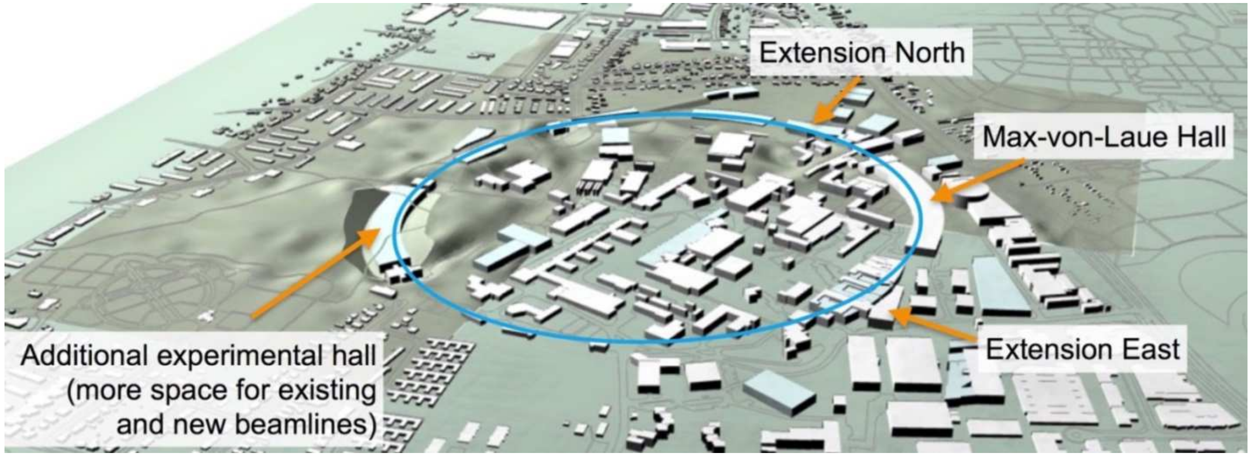
PETRA IV – first conceptual ideas in 2016

Parameters and parameter range,
status February 2016:

PETRA IV Parameter		
Energy	5 GeV	(4.5 – 6 GeV)
Current	100 mA	(100 – 200 mA)
Number of bunches	~ 1000	
Emittance horz.	20 pm rad	(10 – 30 pm rad)
vert.	20 pm rad	(10 – 30 pm rad)
Bunch length	~ 100 ps	

Goals:
2024 Start construction
2026 Start up PETRA IV

Science case:
Understanding the Complexity of Nature
Bright, Tailored X-Rays, 3D Imaging



PETRA IV – Updated schedule

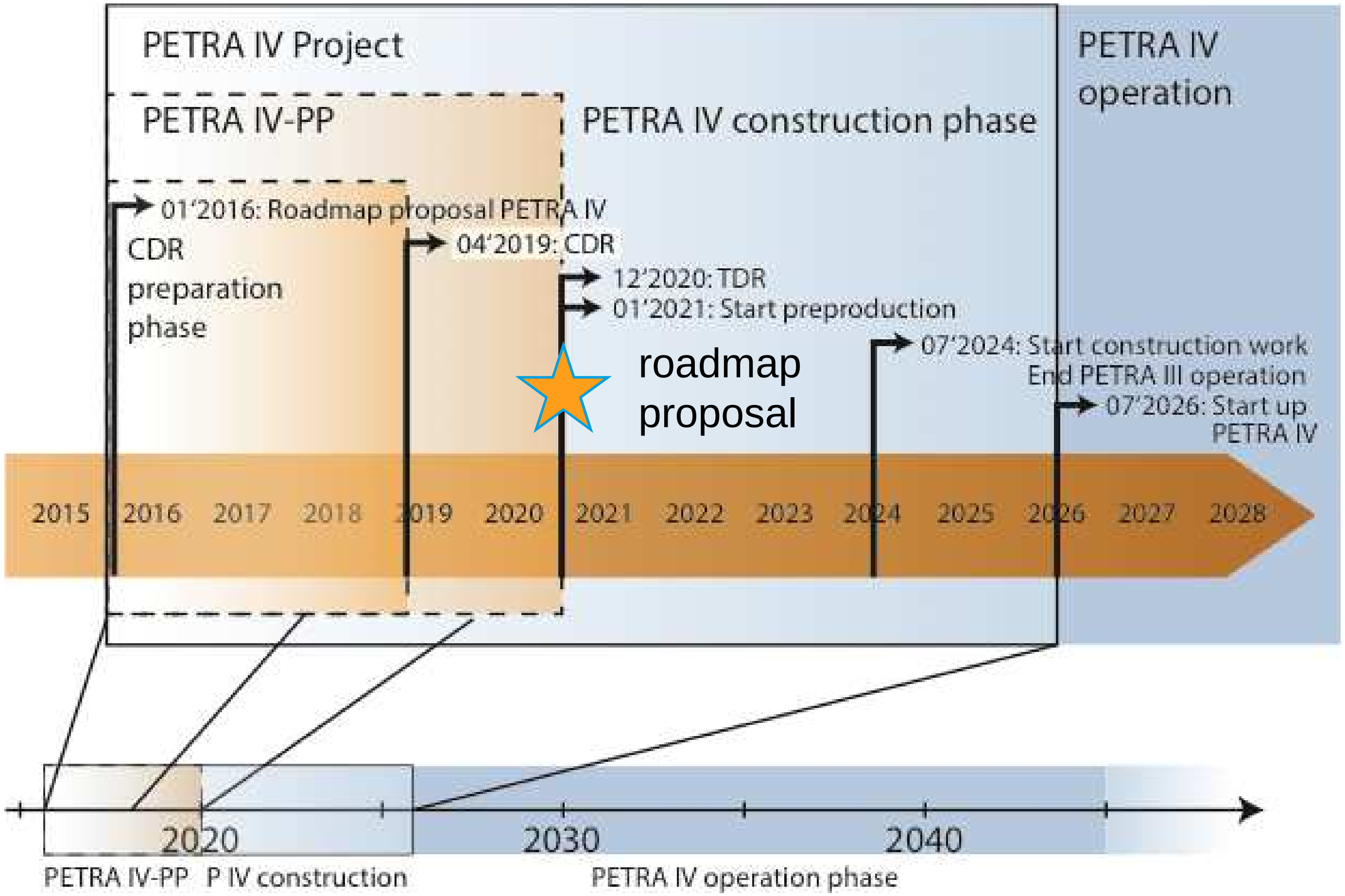
Adjustment of the schedule

- an update of the **national roadmap** - initially expected for end of 2018 / 2019 - is now scheduled for 2021
- more time for the accelerator design studies
  - ➢ evaluate promising alternative lattice concepts,
  - ➢ optimization between minimum achievable emittance and dynamic aperture, sensitivity to errors , and aspects related to a stable operation of the ring

Current activities

- CDR preparation phase
- finish CDR until spring 2019
- CDR includes science case and design concept of machine and beamlines (science case will be ready already in 2018)

PETRA IV – New Timeline



Goal: ★ **bring PETRA IV onto the national roadmap of large-scale research facilities (next call: 2021)**

Design Strategy

Lattice Design

Design goal: get an large dynamic acceptance
(ideal case: off-axis injection is possible)

- design based on a hybrid seven bend achromat (scaled from ESRF-EBS cell)
- option: DMI / FODO style undulator cell
  - arc cell with phase advance of π between sextupoles, double -I cell (DMI)

    (first approch with: double twist in 4D-phase to enable chromatic correction in both planes)
  - cell for insertion devices, FODO-like

Injectors

Design goal: reuse most parts of injector chain

- studies to improve emittance, including a new lattice for the synchrotron
- investigation of the technical requirements to maintain operation until 2045

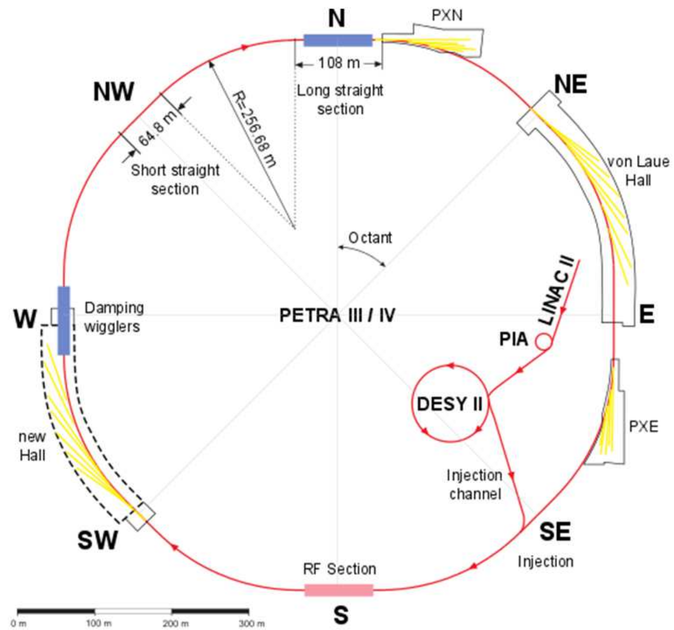
Technical design

Investigation of the *technical limits* and possibilities at an early stage before a lattice design is finalized

- magnet design: design studies of quads, sextupoles, combined function magnets and dipoles with longitudinal gradient
- girder design: investigation of concepts with new materials, studies of alignment and installation concepts
- vacuum design: modeling of the system with small chambers
- fast kickers: on axis injection

PETRA IV – Lattice design status

Parameter	PETRA III (DW)	H7BA 25.2 m (DW)
Total current	100 mA	100 mA
Nat. emittance $\varepsilon_{0,}$ *No IBS* (with DW)	5100 pm (1280 pm)	15 pm (9.3 pm)
Energy spread σ_p (with DW)	$0.82 \cdot 10^{-3}$ ($1.23 \cdot 10^{-3}$)	$0.73 \cdot 10^{-3}$ ($1.44 \cdot 10^{-3}$)
Energy loss/turn U_0 (with DW)	1.3 MeV (5.1 MeV)	1.37 MeV (4.6 MeV)
Momentum compaction factor α_c	$1.13 \cdot 10^{-3}$	$1.46 \cdot 10^{-5}$
Max. gradient g	17 T/m	100 T/m
Dispersion D_x at SF	750 cm	4.2 cm



Hybrid Seven Bend Achromat scaled and adopted from ESRF-EBS

8 cells / arc (cell length: 25.2 m / **new version ~ 26 m**),

injection in one long straight section, damping wigglers in another straight section

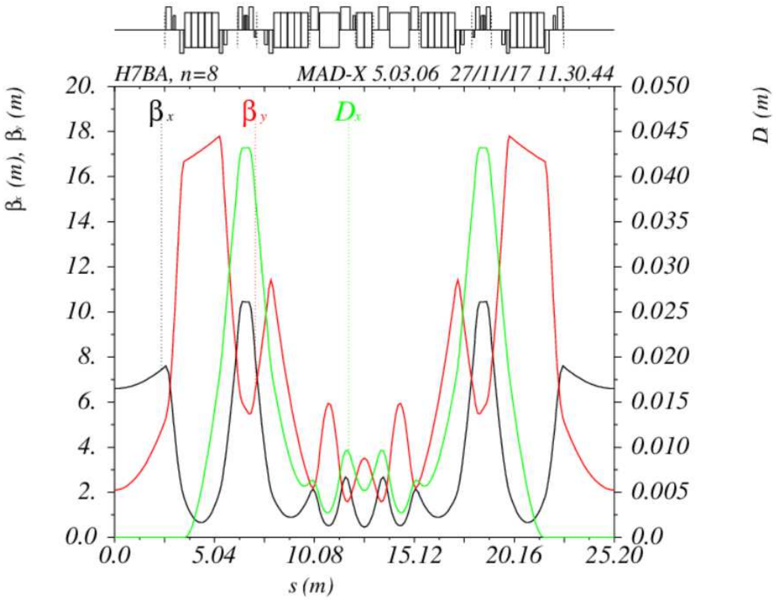
Contribution to IPAC 2018:

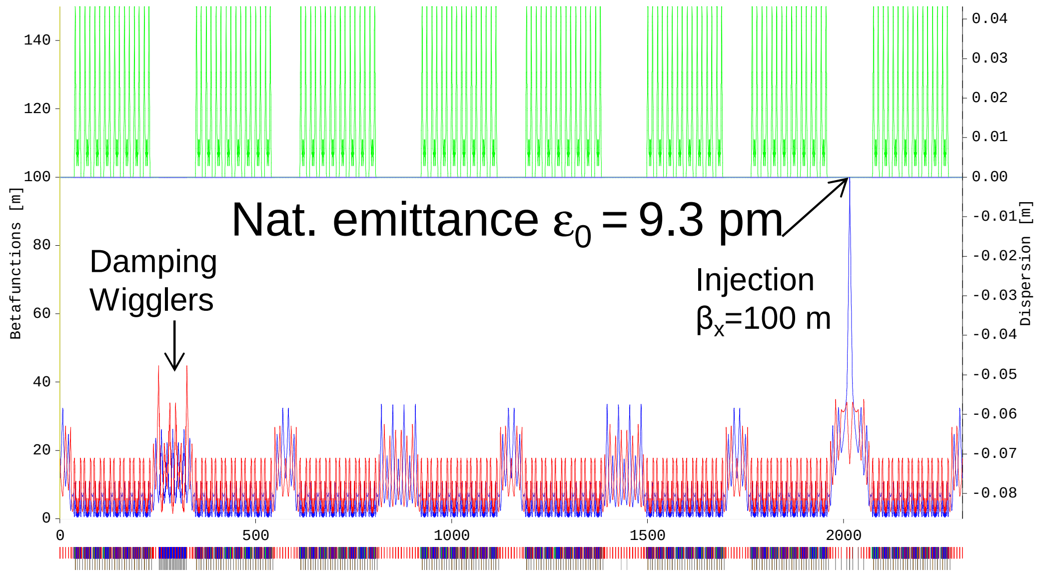
J. Keil, *et al.* *A PETRA IV LATTICE BASED ON HYBRID SEVEN BEND ACHROMATS*

Paper submitted to JSR:

C. G. Schroer, *et al.* PETRA IV: The ultra-low emittance source project at DESY

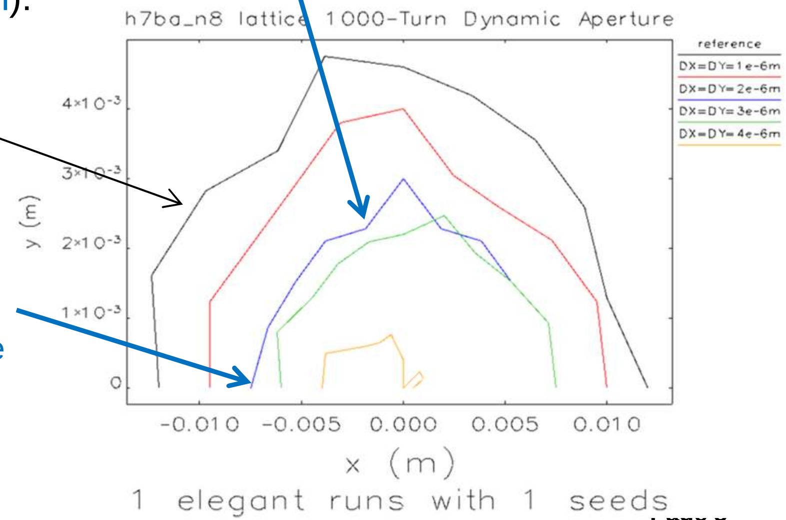
PETRA IV – "Reference lattice", H7BA





- > RF: 500 MHz, 6 MV, bucket height=3.3%
- > A_x = 1.35 mm·mrad Dynamic acceptance
- > A_y = 1.24 mm·mrad (6 D tracking, no errors)

sensitivity to errors (2 µm rms, all magnets, no correction):

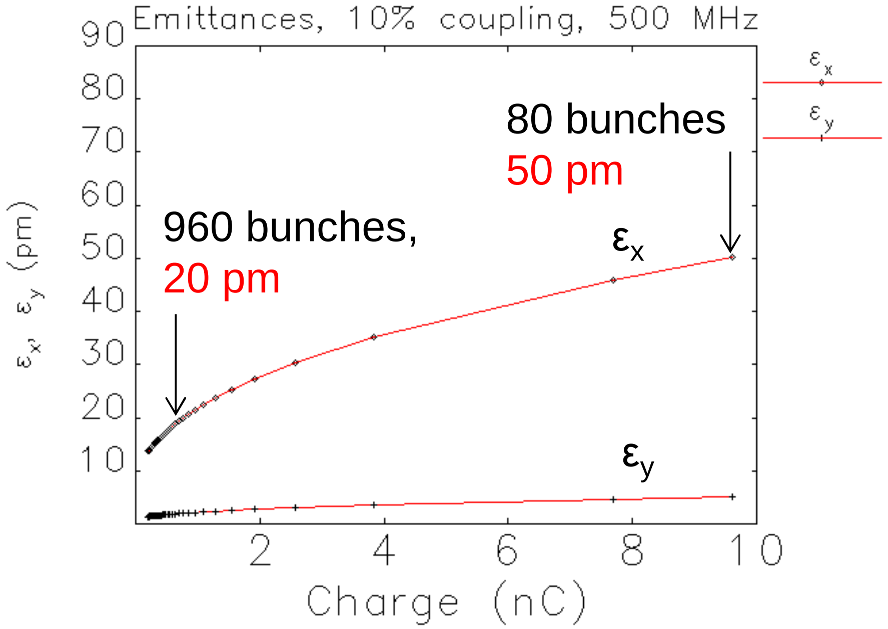


The DA is reduced by a factor 2 with respect to the ideal one

- ➢ an on axis injection seems to be required for a safe injection (with errors)

Intra beam scattering

Parameter	Continuous mode	Timing mode
Total current	100 mA	100 mA
Bunches	960	80
Bunch charge	0.77 nC	9.6 nC
Emittance (horz.) (vert.)	20 pm 2 pm	50 pm 5 pm
Energy spread	$1.5 \cdot 10^{-3}$	$1.7 \cdot 10^{-3}$
Touschek Lifetime	3.9 h	0.4 h



Intra beam scattering: Multiple Coulomb scattering, theory by A. Piwinski (1974)

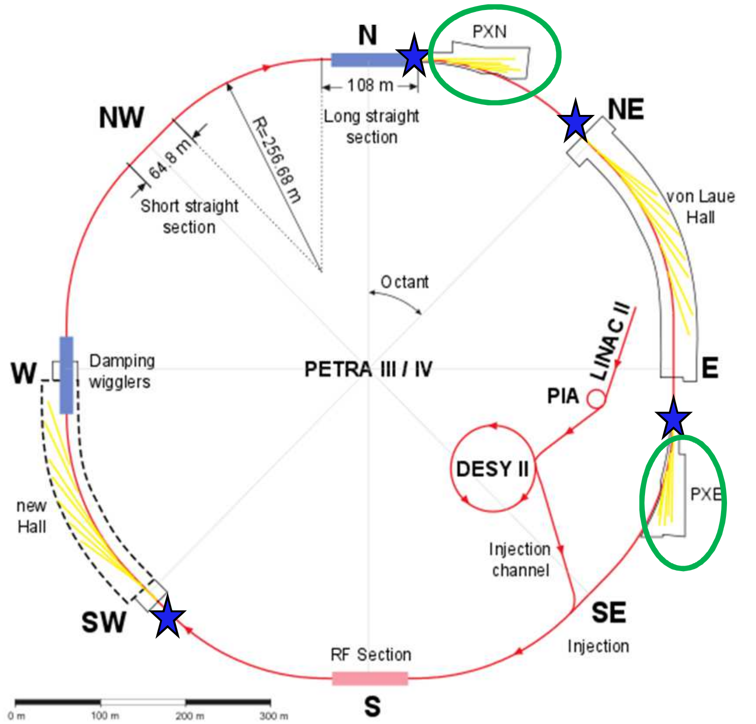
$$\frac{1}{\tau_x} = \left\langle A \left[f(1/a, b/a, q/a) + \frac{D_x^{\,2}\, \sigma_h^{\,2}}{\sigma_{x\beta}^{\,2}\, f(a,b,q)} \right] \right\rangle$$

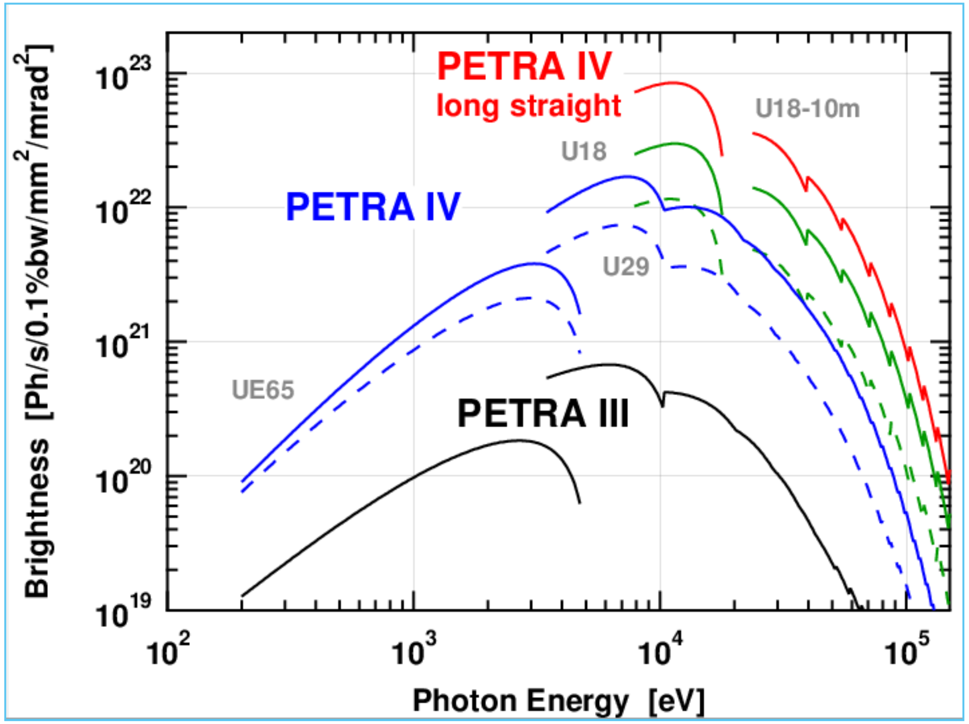
$$A \sim \frac{N_0}{\gamma^4\ \epsilon_x\, \epsilon_y\, \sigma_s\, \sigma_p}$$

← Beam intensity

- Using 1920 bunches (not equally spaced) would imply
  - 200 mA operation with the same parameters or
  - 100 mA operation with an emittance of 16 pm
- First estimates indicate that the total current in the timing mode will be only 80 mA due to collective effects

PETRA IV – recent lattice design studies



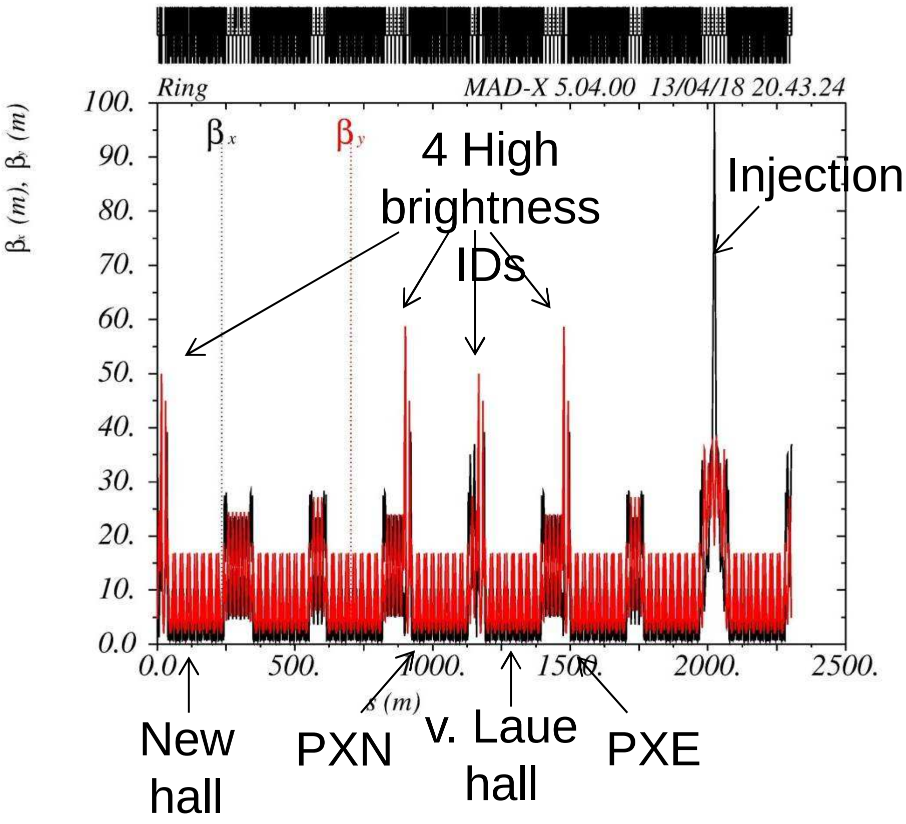


H7BA – ESRF style lattice

- 8 cell / arc , cell length 26.2 m
- + 4 undulator cells in the long straight sections
- canting in 4 insertion straigths

brightness:
10 m long undulator in the long straight section **with optimized beta-function (2 m)**.

Updated “Reference lattice” H7BA



Parameter	4 x 4 mrad canting + 26 IDs*
Energy	6 GeV
Tune	162.17 / 64.27
Beta @ ID center	6.6 / 2.1 m
Space for IDs	5 m / 2+2 m
Chromaticity	+3 / +3
Nat. Emittance	12.3 pm·rad
Energy loss per Turn	3.32 MeV
Energy Spread	$0.905 \cdot 10^{-3}$
Bunch length	6.8 ps
Damping partition numbers	1.29 / 1 / 1.71
Damping times	22 / 27 / 16 ms

without IBS

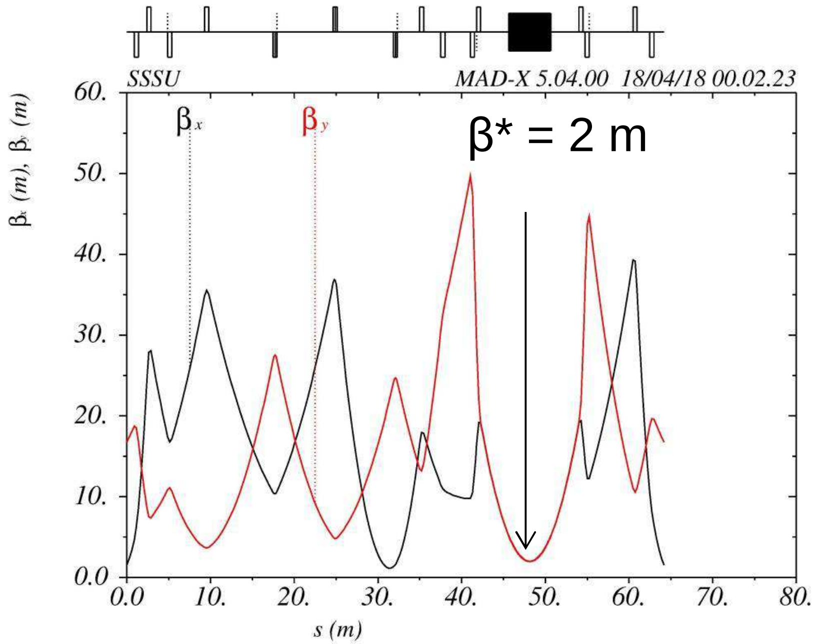
two octants: 2 x (7+1) = 16 beam lines
two extensions: 2 x (2x2+1) = 10 beam lines
undulator beam lines (total) 26 beam lines
+ side beam lines

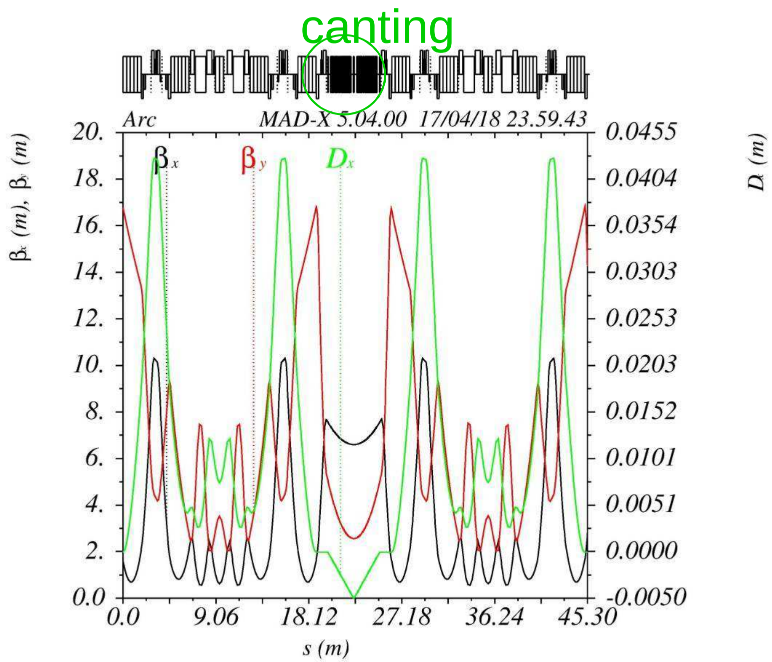
26 insertion devices:
8 x L=2 m (canted)
18 x L=5 m (straight)
λ_p = 32 mm,
B_0 = 0.91 T

<u>IBS with IDs</u>
q_b = 0.8 nC
$\varepsilon_{x,y}$ = 33 / 3.3 pm rad

2 = canting (4 mrad)   1 = straight section (low beta)

Low beta cells and canted cells



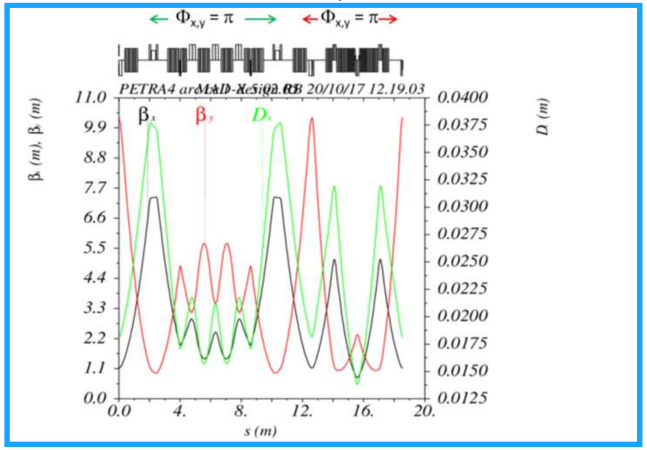


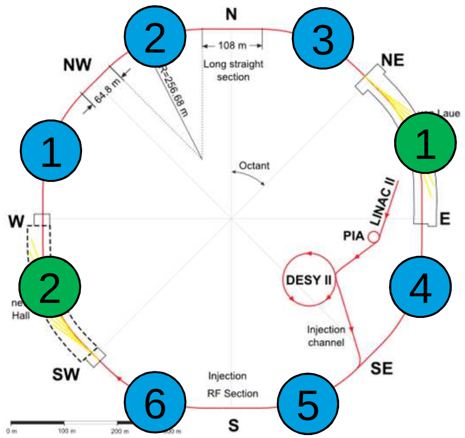
- Request by users: Four IDs in the long/short straight sections with optimized beta functions to achieve high brightness
- Upstream of the existing halls and the new hall; ID length 5 m and/or 10 m
- Additional chromaticity due to the small β* → increase in sextupole strength
- Extension halls PXE and PXN: First two ID straights are canted straights, 4 mrad

Work in progress: impact of the canting on emittance and energy spread
smaller dynamic aperture due to low beta insertion and canting

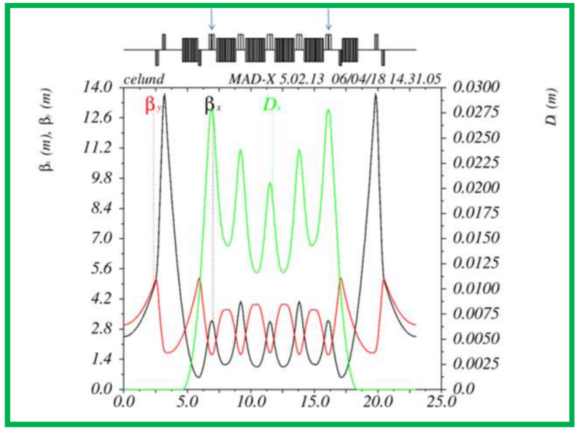
Options: DMI Lattice / FODO Type cell

DMI - cell $\Phi_{x,y} = \pi$





FODO type undulator cells



Two cell types: Non interleaved double –I cell (no IDs),
FODO type undulator cells (cells with IDs)
emittance ~ 30 pm

Work in progress:
preliminary results indicate: large dynamic aperture (~ 18 mm at β ~ 100 m)
off axis injection seems to be possible

PETRA IV – Collective effects

Impedance budget

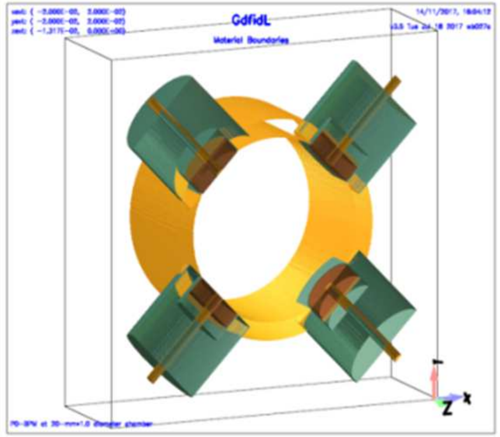
- **Timing mode TMCI threshold**
  effective impedance **budget 1.2 MΩ/m**

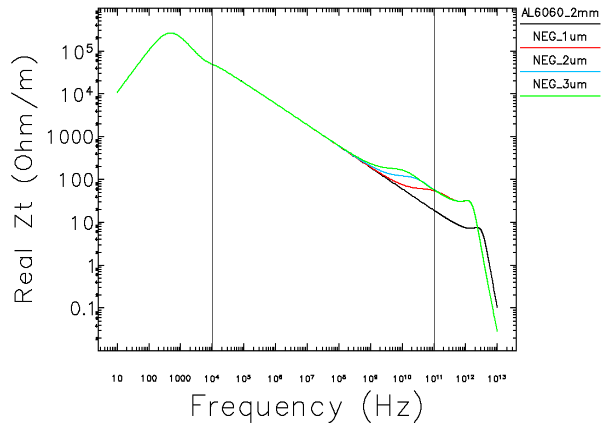
work in progress:

Impedance model

- geometric impedance
  22 insertion device sectors (low gap chambers)
  ~ 10 BPMs / cell
  ~ 5 absorbers, bellows, flanges / cell
  ~ 40 cavities ➔ ~ **0.5 MΩ/m**

- resistive wall impedance
  NEG coated chamber
  modelling with IW2D code *), CERN





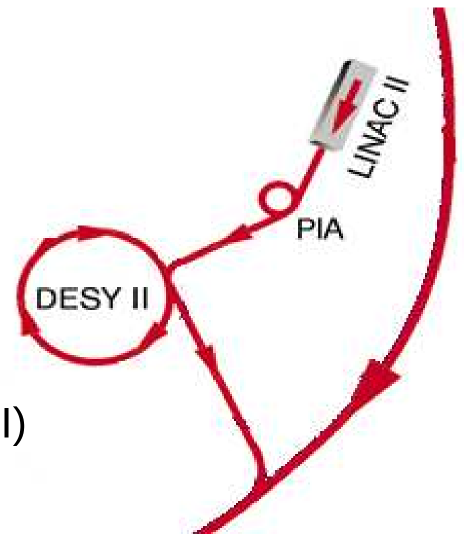
*) N. Mounet, "The LHC transverse coupled-bunch instability", Ph.D thesis, Lausanne, EPFL, 2012.

Contribution to IPAC 2018:
Yong-Chul Chae , *et al.* Status of Impedance Modeling for PETRA IV

PETRA IV – Injector

Linac II
S-Band Linac (450 MeV)
PIA (accumulator ring)

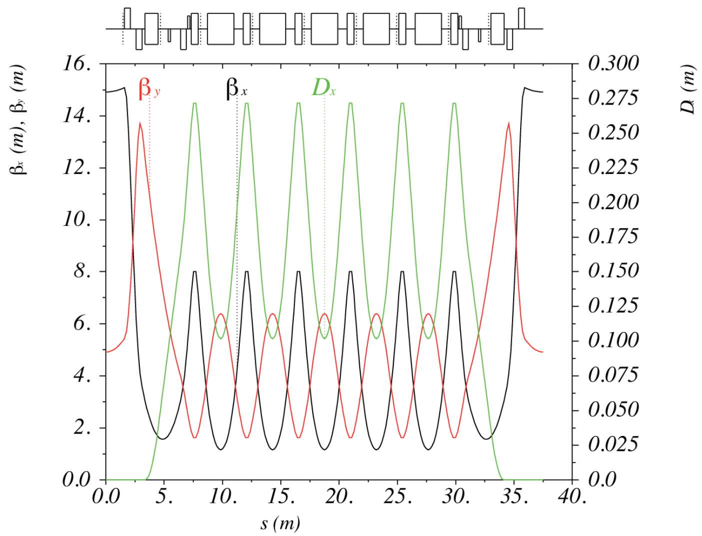
DESY II 450 MeV → 7 GeV,
Emittance (6 GeV) x/y ~ 350/15 nm
Intensity: max. **2 x 10^{10}**, (bunch current in **0.42 mA** in PETRA III)



Study: new booster DESY IV

Parameter	DESY IV
Energy	450 MeV -> 6 GeV
Circumference	300 m
Straight length	3.2 m
Tune	17.17 / 12.38
Equilibrium Emittance	10.7 nm·rad
Energy loss per Turn	6.67 MeV
Energy Spread	$2.03 \cdot 10^{-3}$
Damping times	0.8 / 1.8 / 2.44 ms

One octant of DESY IV



Contribution to IPAC 2018:
Hung-Chun Chao, *et al.* Lattice Studies of a Booster Synchrotron for PETRA IV

Technical implications

Design Strategy

Investigation of the technical limits and possibilities at an early stage before a lattice design is finalized

Magnets, Girder

- Collaboration with Efremov Institute
- design of high gradient magnets
- Contacts to industry (Thyssen Krupp) concerning magnet materials
- Collaboration with Alfred Wegener Institute master thesis on bionic girders, Ph. D. thesis

Vacuum System

- Simulations, using: MAX IV chamber profile + NEG
- *Plans for an experiment at PETRA III delayed due to a lack of resources*

RF System

- Collaboration with Technische Universität Darmstadt, TEMF, investigation of 500 MHz single cell cavities (master thesis is planned)

**Diagnostics …
Power supplies**

- high precision BPMs, …, hot swap power supplies, study of conceptual ideas

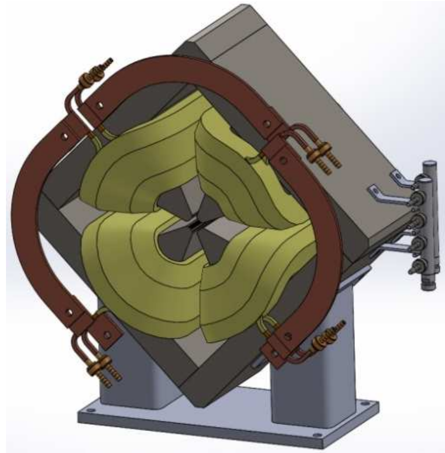
Magnets

- Collaboration with Efremov Institute
- Design study for Sextupole magnets presently factor 2.5 stronger as ESRF-EBS
- Building of prototypes QHG20 with different materials

One quarter of an iron joke of a QHG20 prototyp quadrupole build at DESY (pole design from Efremov Inst.)

The coils are build at Efremov Inst. (delivery at end of May)

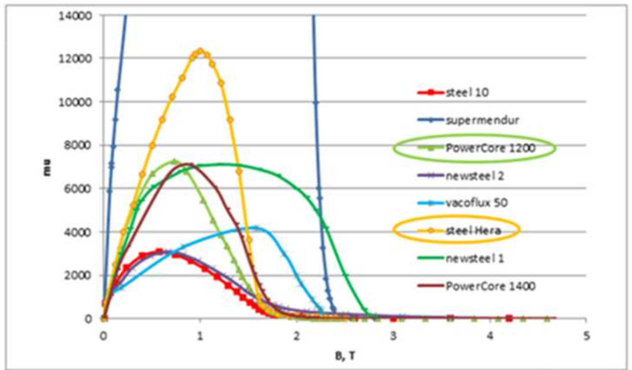
Goal: first prototype ready in summer 2018



QHG20

HERA steel

Parameters	Units	**QHG20**
Air gap	mm	**20**
Field gradient, G	T/m	**149,7**
Field quality at R= 0.6a		$3{,}7\text{x}10^{-4}$
Core length	mm	200
Number of turns per coil		56
Number of coils		4
Nominal current	A	200

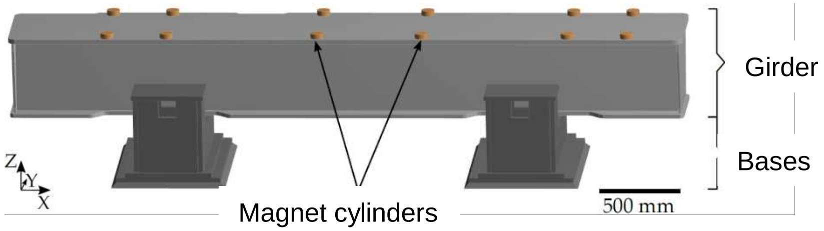


Girders

- Collaboration with Alfred Wegener Institute: Bionic Lightweight Design of Girders

The AWI explores the principles that turn the exoskeletons (shells) of unicellular planktonic organisms into extremely light and stable constructions. (https://www.awi.de/en/science/special-groups/bionics.html)

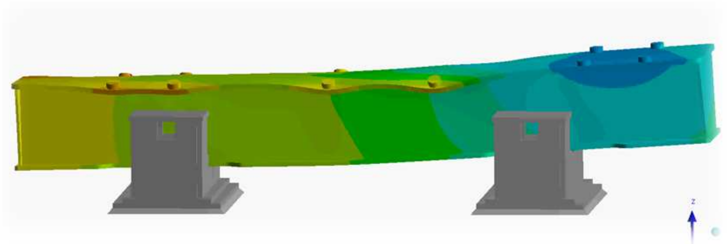
master thesis by Simone Andresen: investigation of a reference girder, simplified model of a PETRA III girder



Optimization of the structure using an evolution strategy to improve the stiffness and vibration characteristics

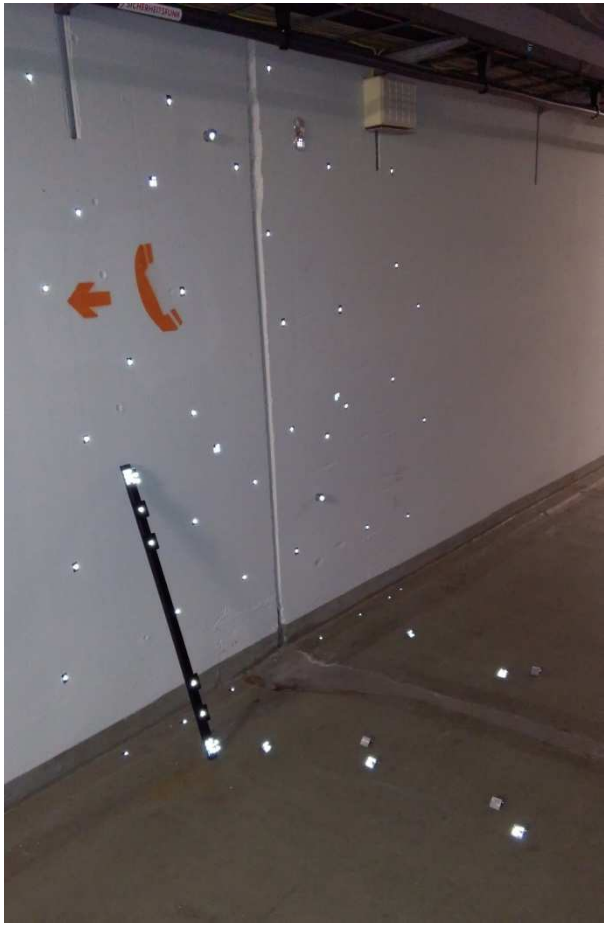
Topological optimized structure:

Modal analysis



Mechanical stability

Building monitoring



At five positions in the PETRA tunnel
reflecting marks have been placed at the tunnel walls
(WR20, NR60, OR60, SOL85, SWR20).

photogrammetry is used to determine
long-term movement of the tunnel building

preliminary results:

difference 6.2.18 (shut down) → 4.4.2018
dZ longt., dX horz., dY vert

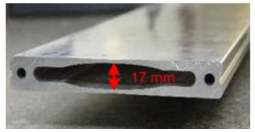
- NR60, dZ = 2.0mm, dX = 0.1mm, dY = 0.3 mm
- OR60, dZ = 1.2mm, dX = 0 mm, dY = 0 mm

- SOL86, dZ = 1.7mm, dX = 0.2 mm, dY = 0.3mm
- SWR20, dZ = 1.7mm, dX = 0.2 mm, dY = 0.3mm
- WR20, dZ = 0.5mm, dX = 0.0 mm, dY = 0.0 mm

Vacuum System

Experience at DESY:
-MVS- NEG-sputtering facility

80 m of damping wigglers
with NEG coated low gap chambers



PLANNED EXPERIMENTS: PETRA III ARC SECTION

- Install NEG-coated chambers in standard arc-section in PETRA III
  - 13 sputter coated standard dipole chambers
  - optionally: 8 NEG-coated quadrupol-chambers

To study:

- Photons hitting the walls may lead to a self-activation of the NEG material ? Could avoid in situ heating of the chambers.
- How fast will this provide sufficient pressure level ?
- Conditioning of vented section?
- different coatings: standard columnar-film and density-film

The installation of the chambers into PETRA III is planed for the winter shut-down 2018/19

RF System

Two variants have been considered 500 MHz or 100 MHz System

Many bunches are advantageous for the brightness mode
500 MHz ←→harmonic number h = 3840

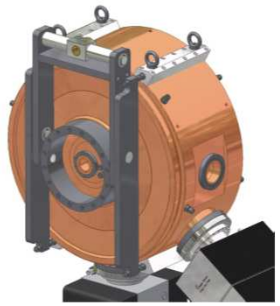
1920 bunches (4 ns bunch to bunch spacing)
seems to be possible.

One cell cavity (BESSY), $R_S = 3\ M\Omega$, 30 kW, 0.4 MV
Total voltage 6 MV requires at least 15 cavities

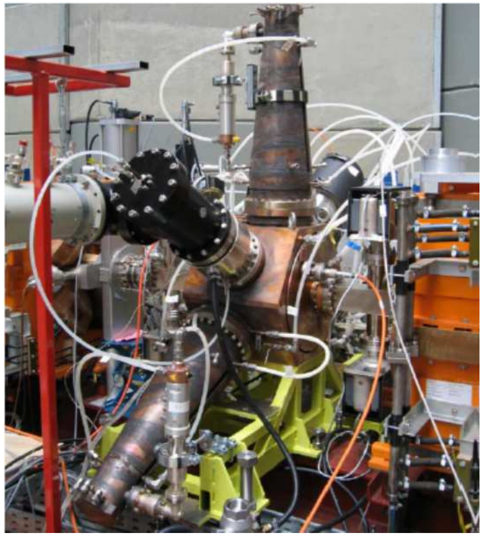
3rd harmonic cavities, ~ 2 MV, → 22 mm long bunches
mitigation of IBS for the timing mode (80 bunches x 1 mA)

Collaboration with Technische Universität Darmstadt, TEMF
Herbert De Gersem,
Wolfgang Ackermann,
Wolfgang O. Müller

Cavity parameters,
HOM calculations,
etc.
now also for the
500 MHz cavity



100 MHz cavity MAX IV design



Damped single cell 500 MHz cavity
F. Marhauser, E. Weihreter,
BESSY II

Collaborations

- ESRF
  supporting the lattice design, sharing lattice files
  visit to ESRF (June) , visitor (Simone Liuzzo) from ESRF at DESY (Aug.)

- Mikael Eriksson
  joined the PETRA IV project preparation as a generalist from June 2016

- SLAC – DESY collaboration
  visit to SLAC in Oct 2016
  Yunhai Cai visited DESY in April 2017, LEGO, lie algebra methods

- Efremov institute - DESY collaboration: magnet design

- Alfred Wegener institute - DESY collaboration: girder design, Ph.D. thesis

- Technical University of Darmstadt: RF calculation, 500 MHz cavity,
  master thesis

Thank you for your attention !