PETRA IV

Overview and Technical Implications

Rainer Wanzenberg
Travemünde, Feb 20, 2018

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

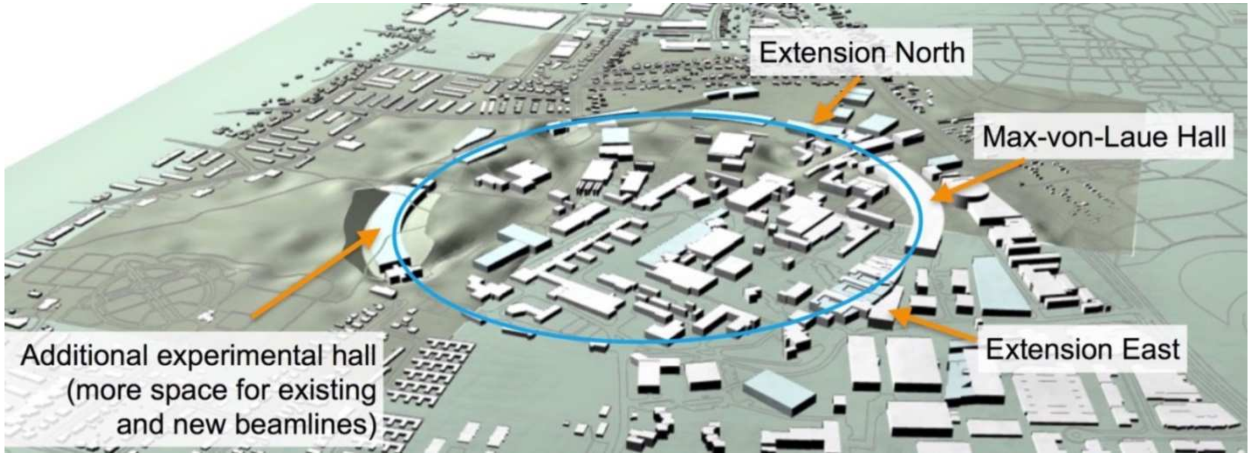
DESY

PETRA IV – 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

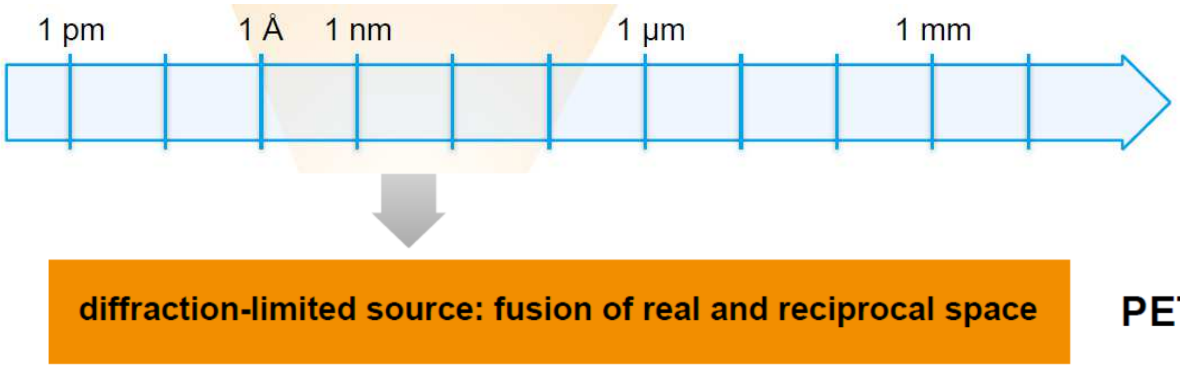


PETRA IV – Science case

PETRA IV - Decoding the Complexity of Nature
The ultimate 3D process microscope

http://photon-science.desy.de/facilities/petra_iv_project/index_eng.html

Closing the Gaps in the Complexity Window



PETRA IV

Photon emittance:

$$\epsilon_\lambda = \frac{\lambda}{4\,\pi} = \frac{1}{2}\hbar\,c\,\frac{1}{E_\lambda}$$

= 8 pm

for photons
0.1 nm or 12.3 keV

Diffraction limited source ←→ **beam emittance ~ photon emittance**

Brilliance

Brillance: > 10^{22} Photons / (sec mrad^2 mm^2 0.1 % BW)

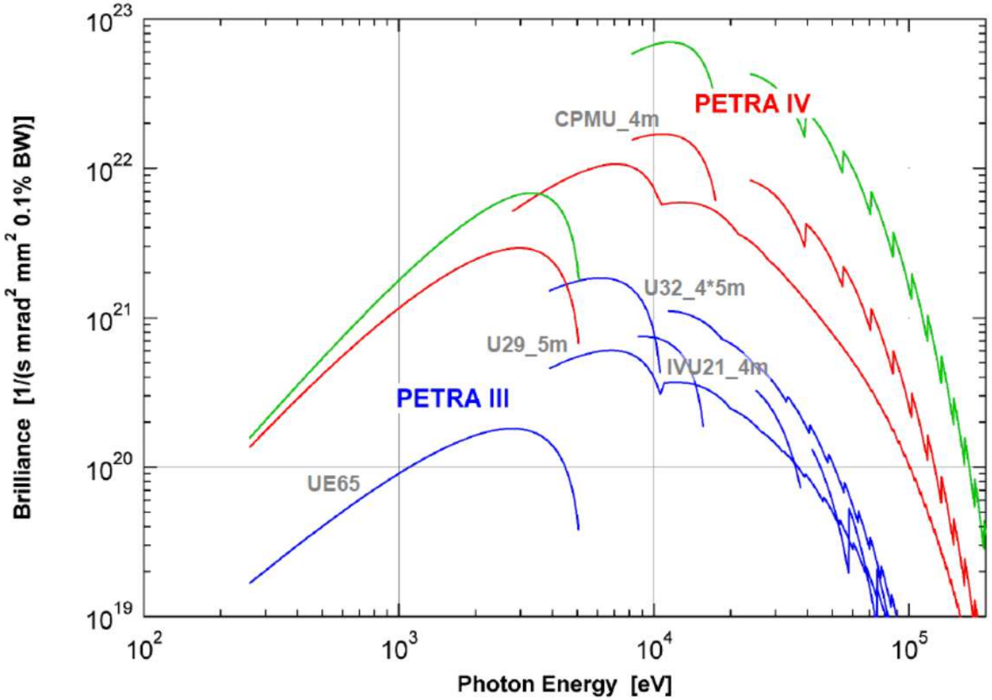
angle integrated photon spectral flux (undulator, beam intensity)

$$\mathcal{B}_n = \frac{\mathcal{F}_n}{4\pi^2 \Sigma_x \Sigma'_x \Sigma_y \Sigma'_y},$$

photon beam convoluted with the electron beam

$$\Sigma_{x,y} = \sqrt{\sigma^2_{x,y} + \sigma^2_{\lambda}},$$

$$\Sigma'_{x,y} = \sqrt{\sigma'^2_{x,y} + \sigma'^2_{\lambda}}.$$



(Courtesy Markus Tischer)

PETRA III
ε_x = 1.2 nm, κ =0.25 %
β_x = 10 m, β_y = 2.5 m

PETRA IV
ε_x = 15 pm, κ =100 %
β_x = 5 m, β_y = 2.5 m

PETRA IV
ε_x = 10 pm, κ =50 %
β_x = 1 m, β_y = 1 m

Accelerator – Beam Line Interface

Joint meeting: photon science and accelerator physics

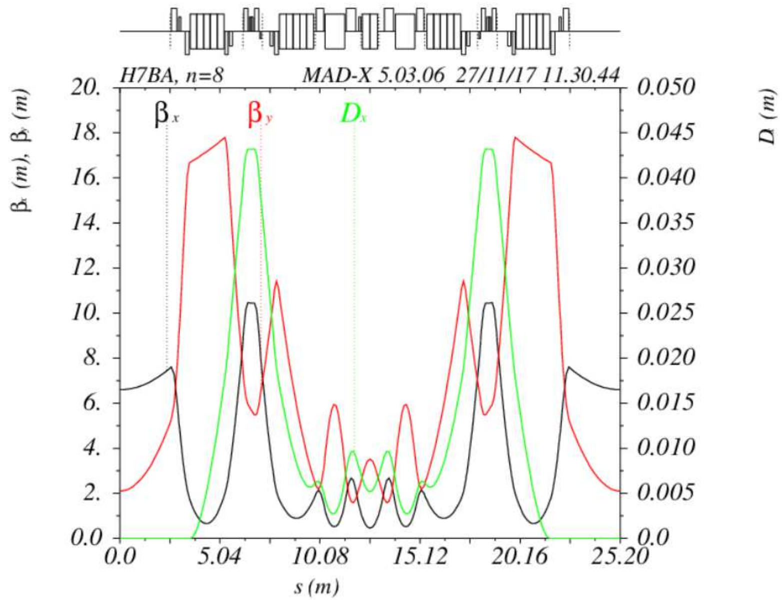
PETRA IV Workshop in Jesteburg, July 12-13, 2017

Sessions:

- Science Case and Lattice Design Status
- Brilliance and Flux
- Design and Technical Implications (Accelerator)
- Design and Technical Implications (Photon Beamlines)

PETRA IV – Lattice design status

Parameter	PETRA III (DW)	H7BA 25.2 m (DW)
Total current	100 mA	100 mA
Nat. emittance ε_0 (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



A_x = 1.35 mm·mrad Dynamic acceptance

A_y = 1.24 mm·mrad (6 D tracking, **no errors**)

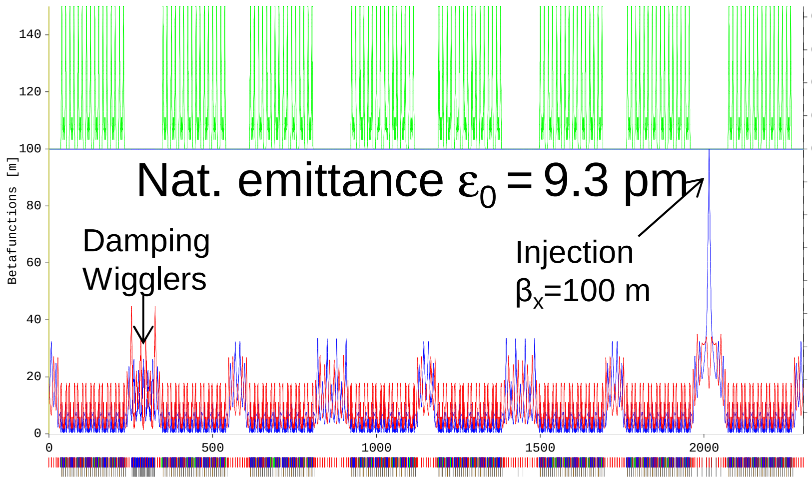
"Reference Lattice"

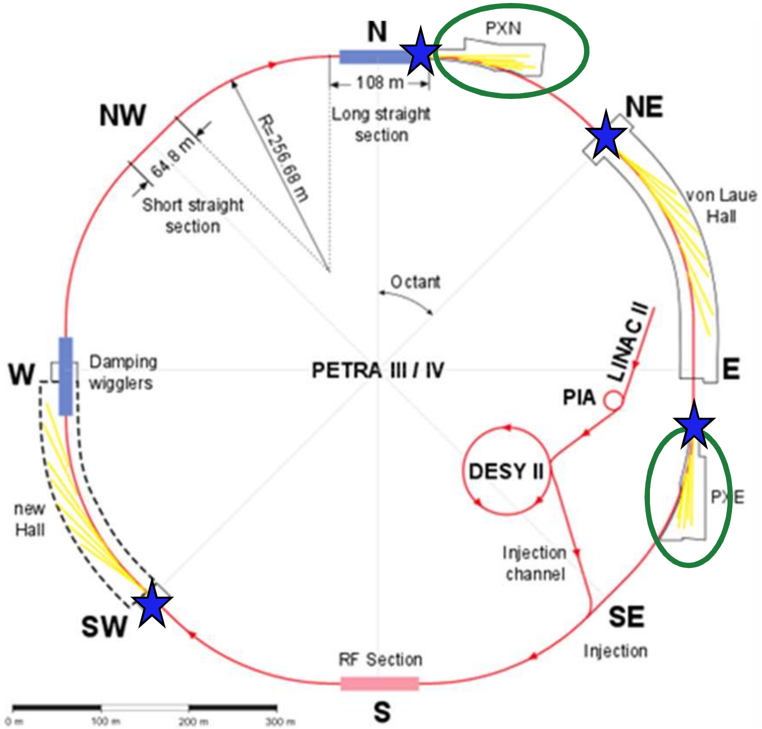
Hybrid Seven Bend Achromat scaled and adopted from ESRF-EBS
8 cells / arc (cell length: 25.2 m / new version ~ 26 m),
injection in one long straight section,
damping wigglers in another straight section

Next steps

Lattice design:

- optimize the cell length with respect the tunnel geometry
- design of cells with canted IDs
- special low beta section in the straight sections
- investigation of lattice options (double –I cells)





Goals:

Summer 2018:

Publication on the Design Status

First prototype of a high gradient qudrupole

Spring 2019: CDR

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 Institutemagnet design of high gradient magnets
- Contacts to industry (Thyssen Krupp) concerning magnet materials
- Collaboration with Alfred Wegener Institutemaster thesis on bionic girders,
  Ph. D. student has started in Dec. 2017

Vacuum System

- Simulation of synchrotron radiation in small gap chambers using: MAX IV chamber profile + NEG
- Plans for an experiment at PETRA III

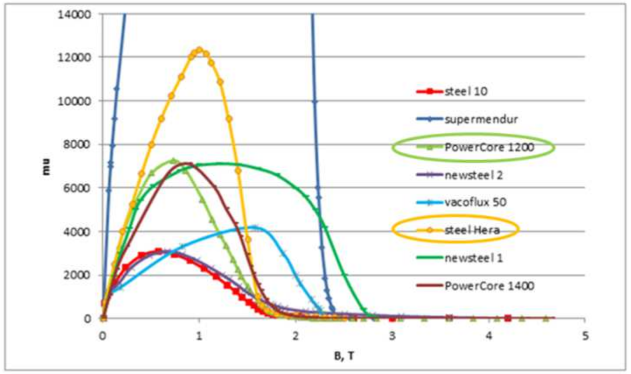
RF System

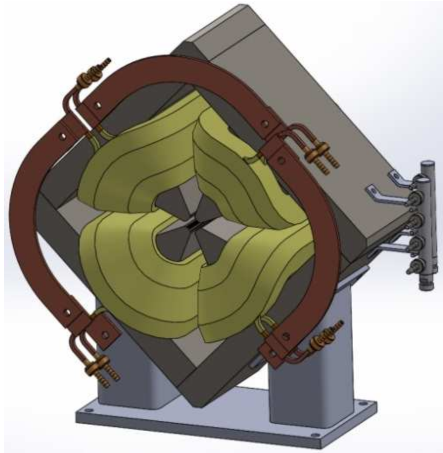
500 MHz or 100 MHz (option 125 MHz) System

- Collaboration with
  Technische Universität Darmstadt, TEMF

Technical concepts:

- Collaboration with Efremov Institute
  compact magnet design
  of high gradient magnets
- Contacts to industry (Thyssen Krupp)
  concerning magnet materials
- Building of prototypes QHG20
  with different materials (summer 2018)





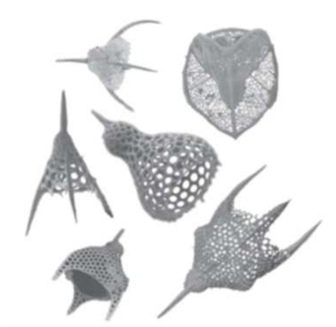
QHG20

HERA steel

Parameters	Units	**QHG20**
Air gap	mm	**20**
Field gradient, G	T/m	**149,7**
Field quality at R= 0.6a		$3{,}7\times10^{-4}$
Core length	mm	200
Number of turns per coil		56
Number of coils		4
Nominal current	A	200
Conductor	mm	6x6-d3.5
Total weight	kg	250

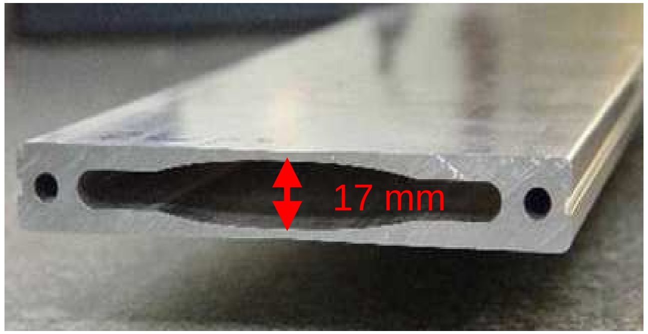
- Design study for Sextupole magnets
  presently factor 2.5 stronger as ESRF-EBS
- Collaboration with Alfred Wegener Institute: Bionic Lightweight Design of Girders

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)



Vacuum System

Experience at PETRA III:
80 m of damping wigglers
with NEG coated low gap chambers



Simulations have started based on MAX IV and ESRF-EBS vacuum systems

MAX IV chamber profile + NEG $(56\frac{l}{s\,m}$ at tube ∅ 15mm)

$<2 \cdot 10^{-12}\ \frac{\text{mbar}}{\text{mA}}$ for activated NEG (20 Ah)

$<5 \cdot 10^{-12}\ \frac{\text{mbar}}{\text{mA}}$ for activated NEG (1 Ah)

$\sim 1 \cdot 10^{-6}\ \frac{\text{mbar}}{\text{mA}}$ for unactivated NEG (1 Ah)

Multi-Step Simulation

- Ray-Tracing & 1-D transfer-Matrix pressure calculation (Mathematica, CALCVAC/VACLINE)
- Monte-Carlo simulations with SynRad and Molflow+ using 3-D geometries

Activities for PETRA IV:

- simulation of synchrotron radiation in small gap chambers including the reflectivity of the NEG material
- calculation of gas desorption
- pressure profiles

- plans for an experiment in 2018

> Install NEG-coated chambers in standard arc-section in PETRA III

  - Sputter coat standard dipole chambers

To study:

> Self-activation by hitting chamber walls with photons possible?

> How fast this will provide sufficient pressure level ?

> Conditioning of vented section?

RF System

Two variants are considered

500 MHz or 100 MHz (option 125 MHz) System

Cavities:

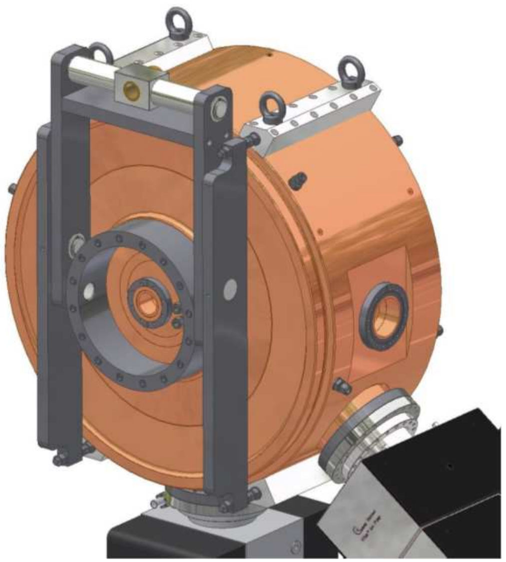
500 MHz single cells

100 MHz single cells, based on MAX IV design

Collaboration with
Technische Universität
Darmstadt, TEMF

Herbert De Gersem,

Wolfgang Ackermann



Cavity parameters,
HOM calculations,
etc.

Next steps: technical subsystem

- **Diagnostics:**
  First turn orbit measurements
- **Controls**

high precision BPMs (XFEL)
have a large impedance !
single shot data acquisition,
automatic first turn steering, …

- **Alignment and Stability**

bionic girders
magnet blocks ?
vibration measurements

- **Tunnel ventilation, thermal stability**

passive system / heating of the
tunnel (see MAX IV) ?

- **Orbit feedback**

requirements from the
beamlines: stability
2 % of beam size

- **Power supplies**

many power supplies:
new infrastructure
hot swap

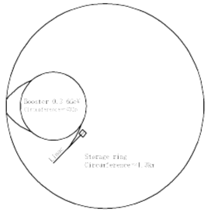
Future competition

ESRF
E = 6 GeV
C = 844 m
ε = 130 pm

start
construction
2019

APS
E = 6 GeV
C = 1104 m
ε = 41 pm

on axis
injection
with fast kicker



HEPS, Beijing
E = 6 GeV
C = 1360 m
ε = 58 pm
(33 pm option)

PETRA IV
E = 6 GeV
C = 2304 m
(arcs 1612 m)
ε ~ 15 pm

http://www.esrf.eu/home/UsersAndScience/Accelerators/ebs---extremely-brilliant-source.html

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 (host Bob Hettel)
  discussing on lattice theory, impedance and collective effects
  Yunhai Cai visited DESY in April 2017, LEGO, lie algebra methods

- Efremov institute - DESY collaboration: magnet design

- Alfred Wegener institute - DESY collaboration: girder design

- Technical University of Darmstadt: RF calculation, 100 MHz cavity

Thank you for your attention !