PETRA IV

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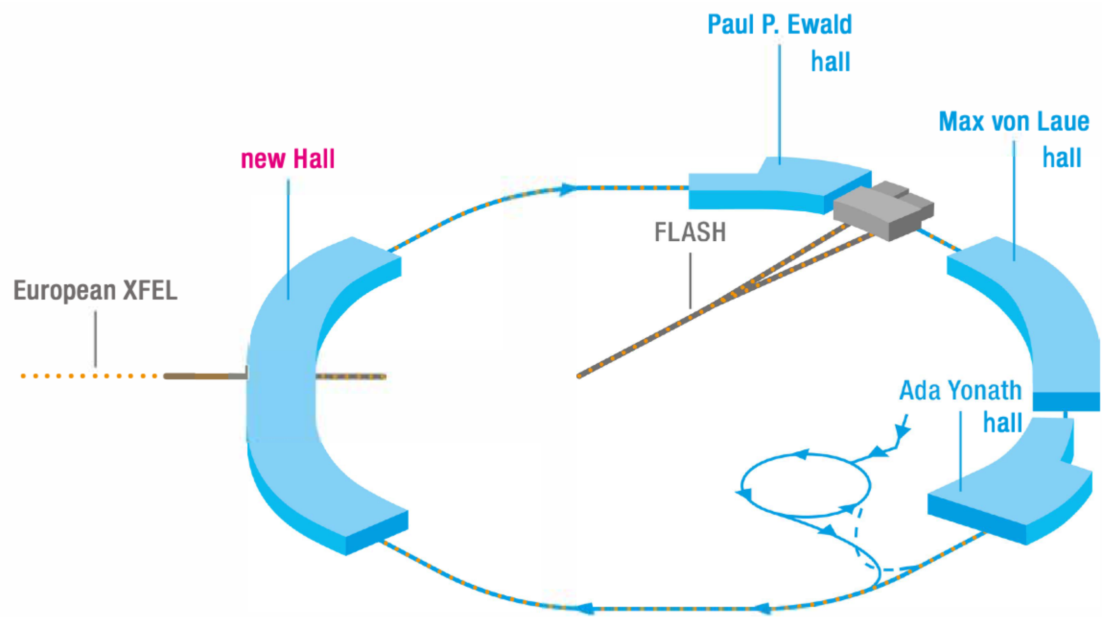
DESY M Betriebsseminar Travemünde 2020

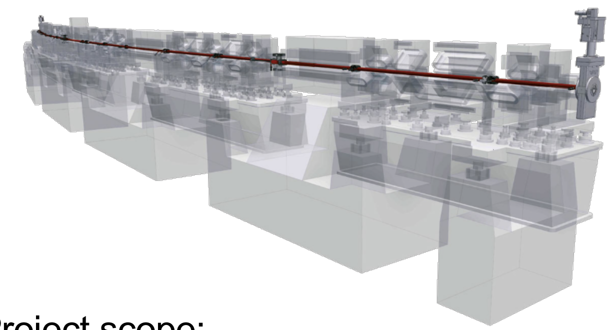
14.02.2020

PETRA IV Science & Technology Case

Analytical tool with unprecedented resolution

Conceptual Design





Project scope:

- new accelerator chain and storage ring: Hybrid 7 Bend Achromat (H7BA)
- upgrade and build new beamlines
- new experimental hall in the west

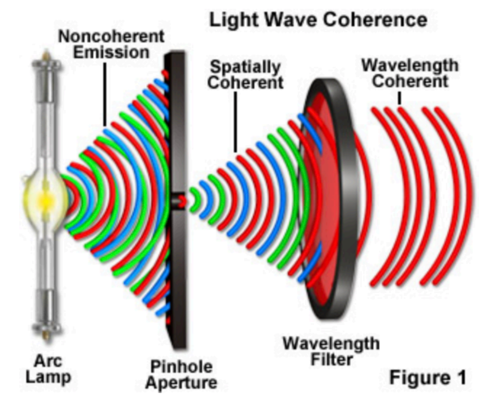
Reuse existing infrastructure as much as possible

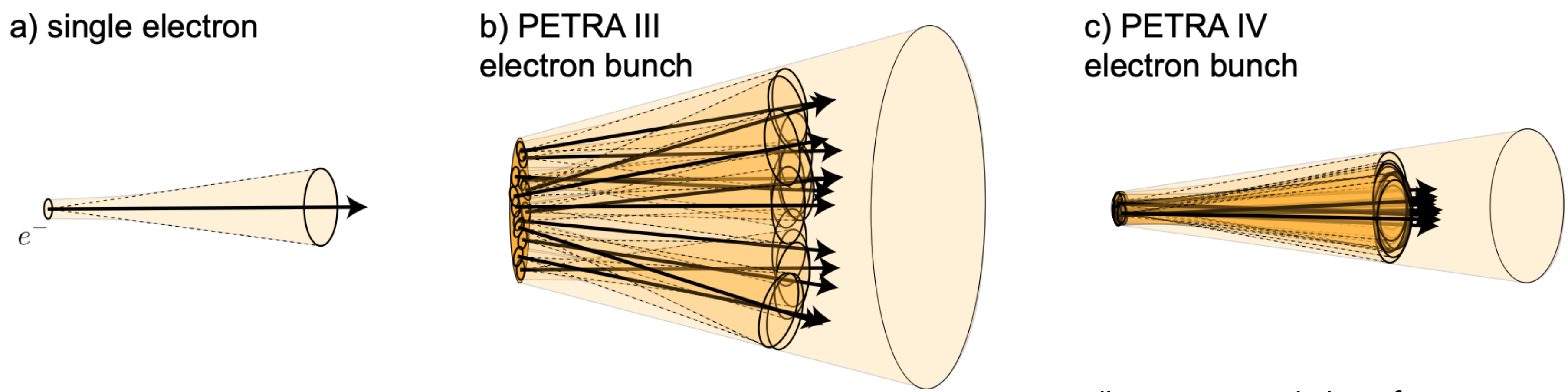
3D X-ray microscope:

- applications in all fields of science: health, energy, earth & environment, transport, information
- investigate dynamics of biological, chemical, and physical processes on all relevant length scales and under realistic conditions
- serve broad national/international user community from universities, research centres, and industry

PETRA IV.

What makes the difference …





single-electron emission cone (X-ray energy dependent)

divergence and size of electron bunches comparable to single-electron emission cone

➔ (nearly) lossless focusing of the whole beam!

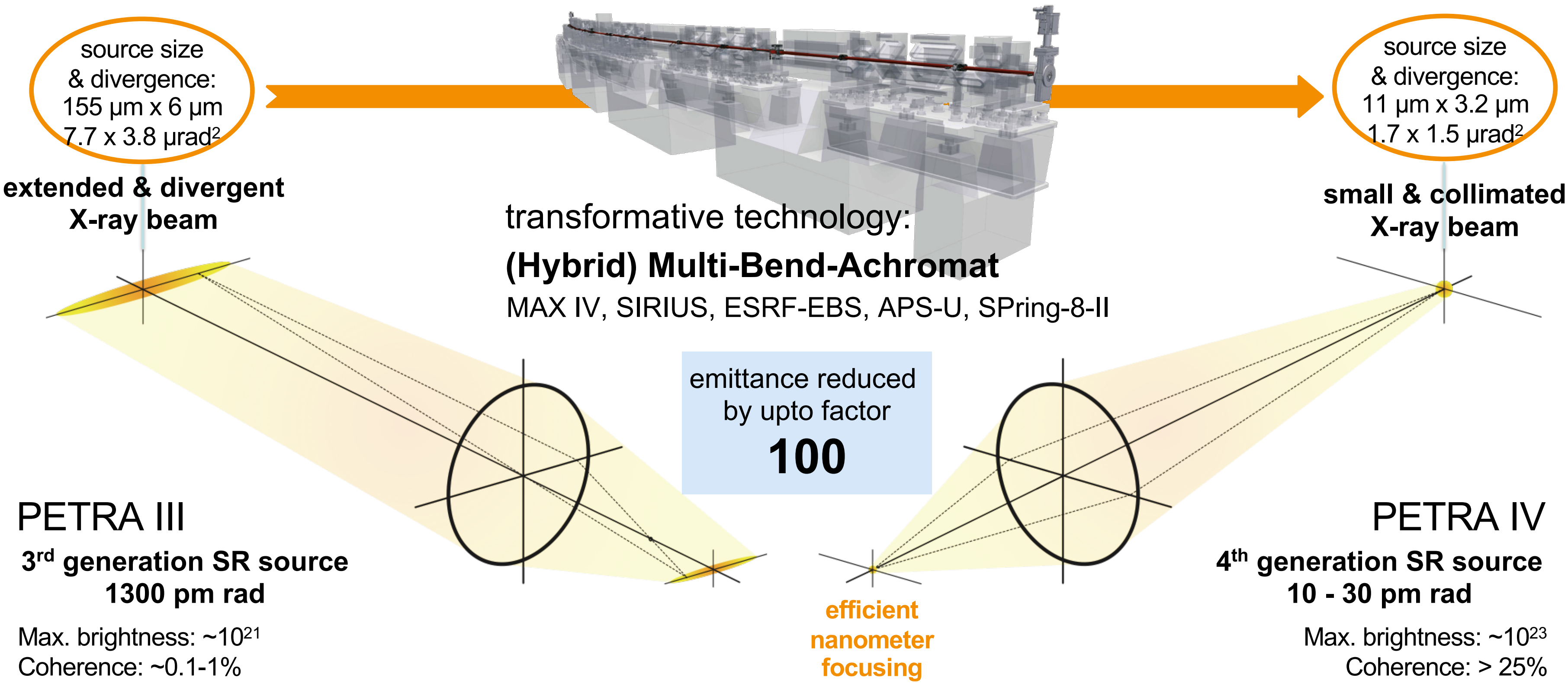
➔ **Diffraction limit**: optimal resolution in real and reciprocal space **AT THE SAME TIME**!

➔ PETRA IV can probe all length scales simultaneously, from atomic to macroscopic dimensions!

➔ ***In-situ*** 3D Microscope for **physical**, **chemical**, and **biological** processes

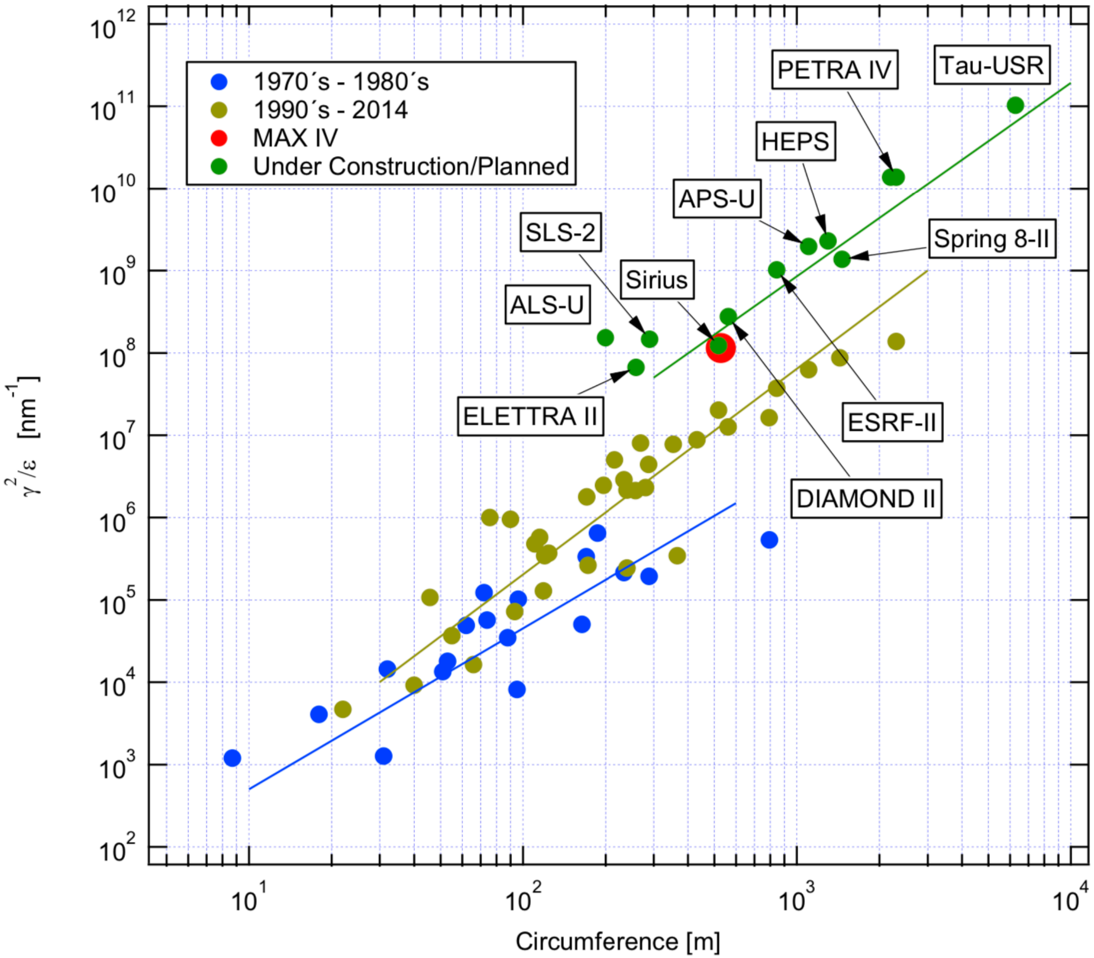
PETRA IV.

Ultra-Low Emittance Storage Ring



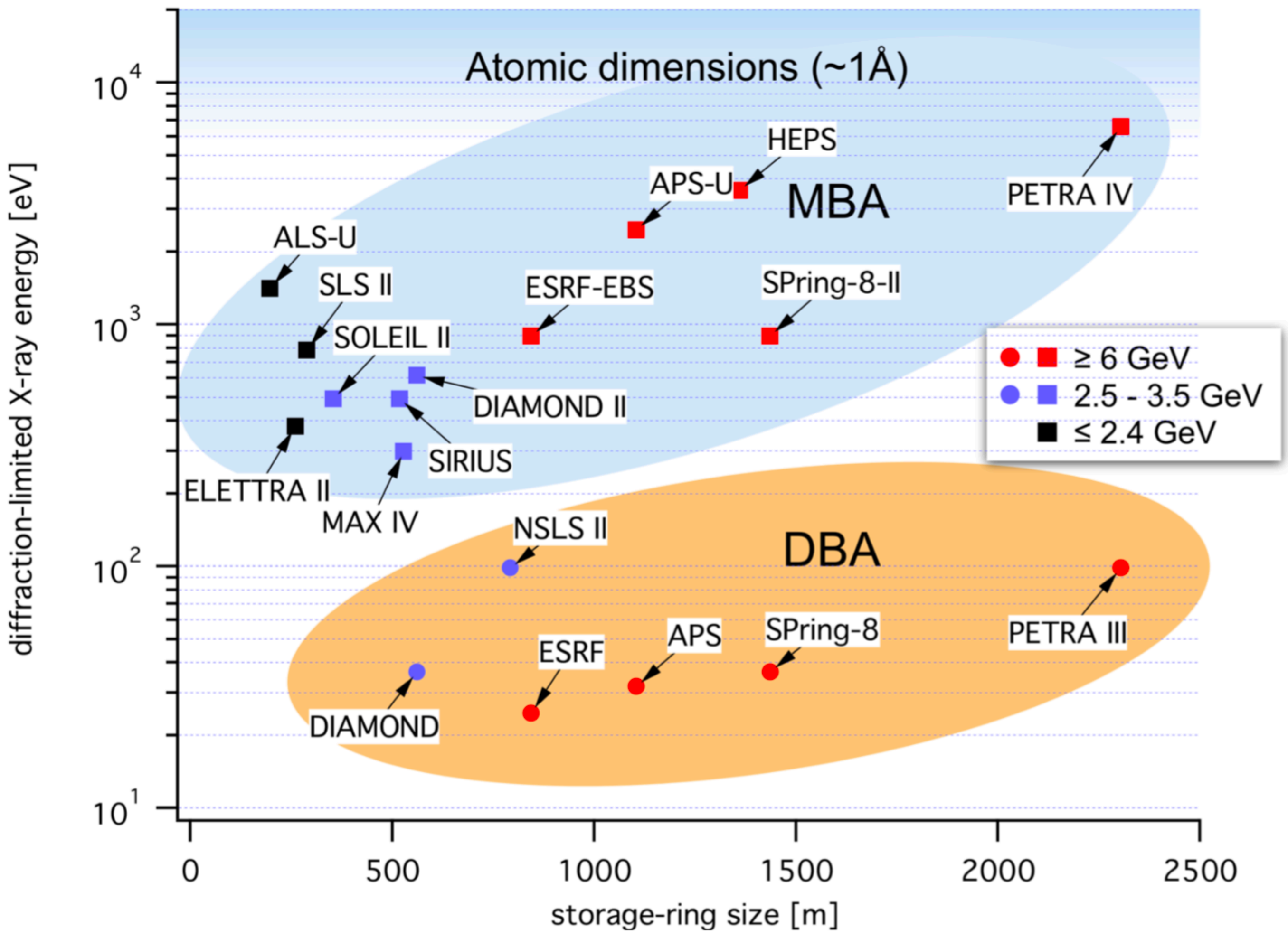
PETRA IV.

A unique Ultra-Low Emittance Storage Ring



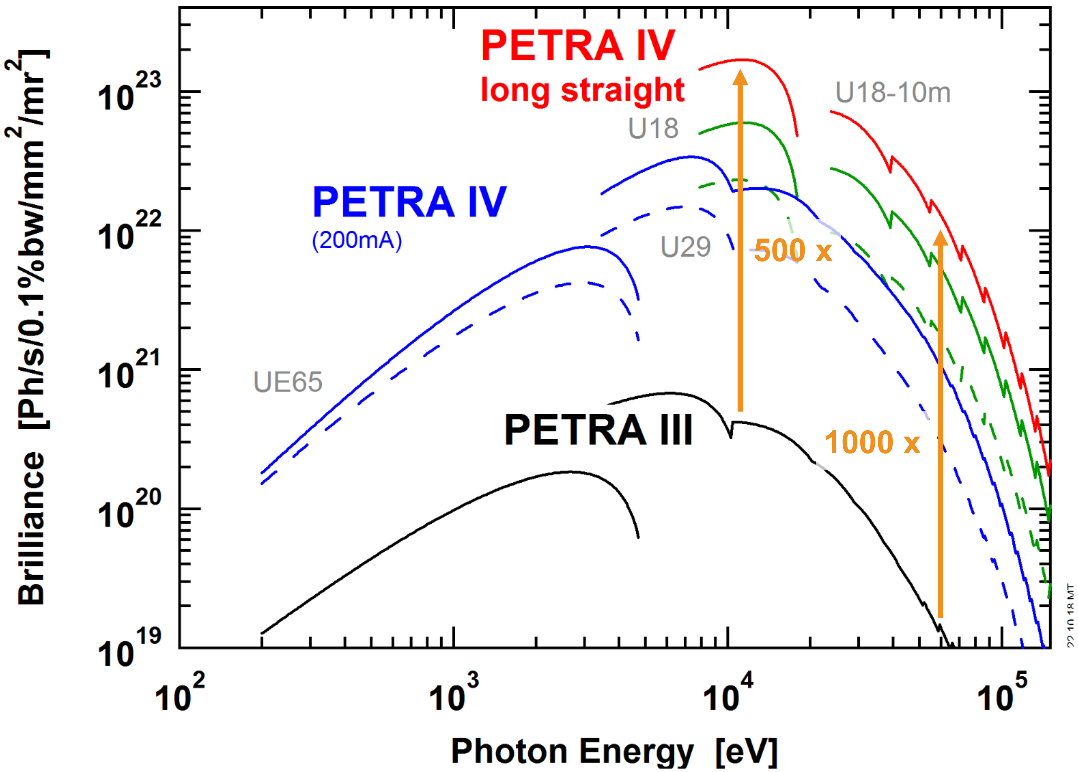
PETRA IV.

A unique Ultra-Low Emittance Storage Ring



PETRA IV.

Expected Brightness



Based on current design:

> emittance:

→ coherence mode: < 20 x 4 pmrad²

→ timing mode: < 50 x 10 pmrad²

> undulators: 5 m, 10 m

> optimised beta (in 10 m section): 4 x 4 m²

> ring current: 200 mA

Brightness increase by

→ 500 x (hard X-rays)

→ 1000 x (high-energy X-rays)

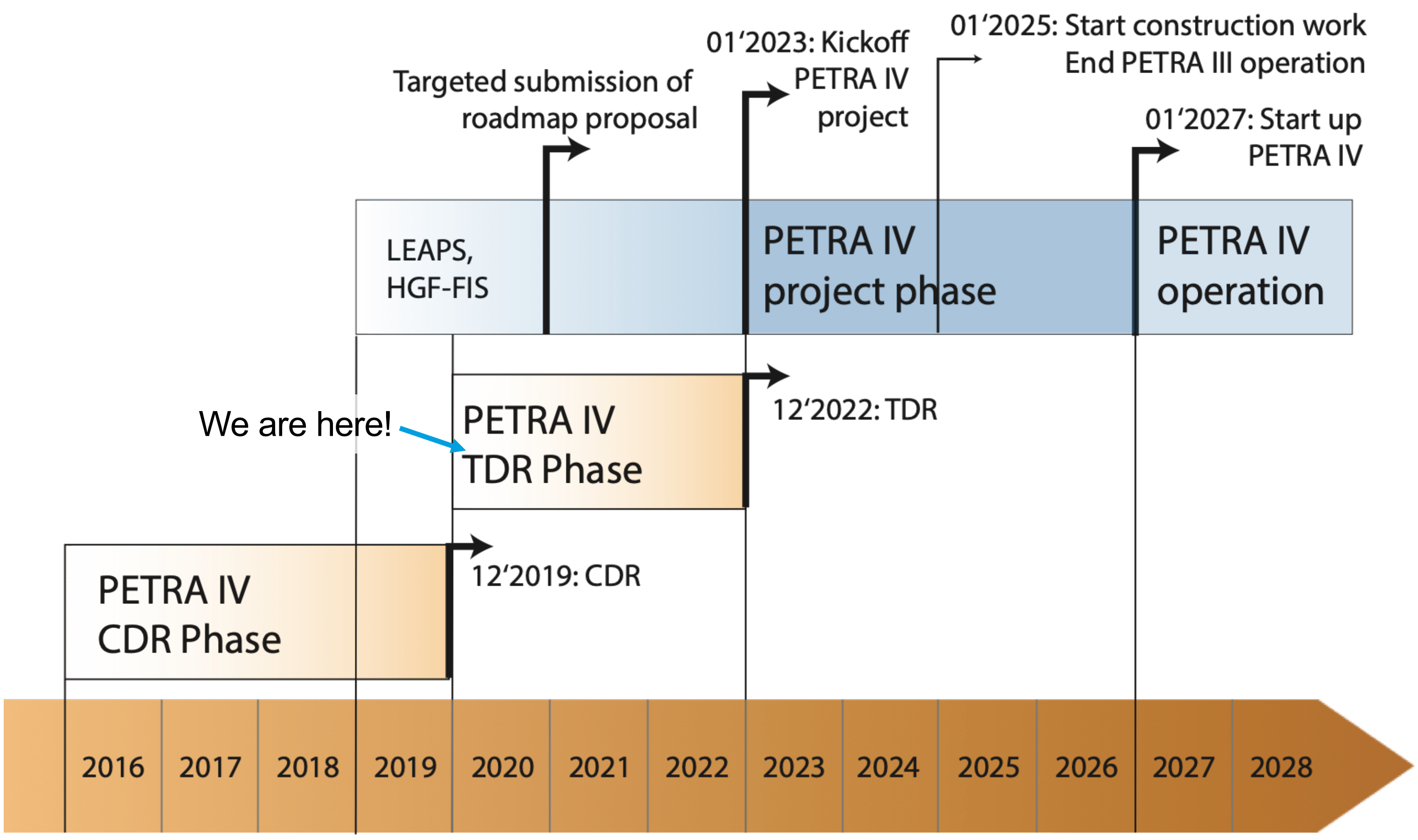
PETRA IV brightness at 100 keV same as for 10 keV at PETRA III today!!

Schroer, et al., JSR **25**, 1277 (2018).

Schroer, et al., R. Röhlsberger, et al., eds., PETRA IV CDR, DESY (2019), DOI: 10.3204/PUBDB-2019-03613

PETRA IV.

Timeline



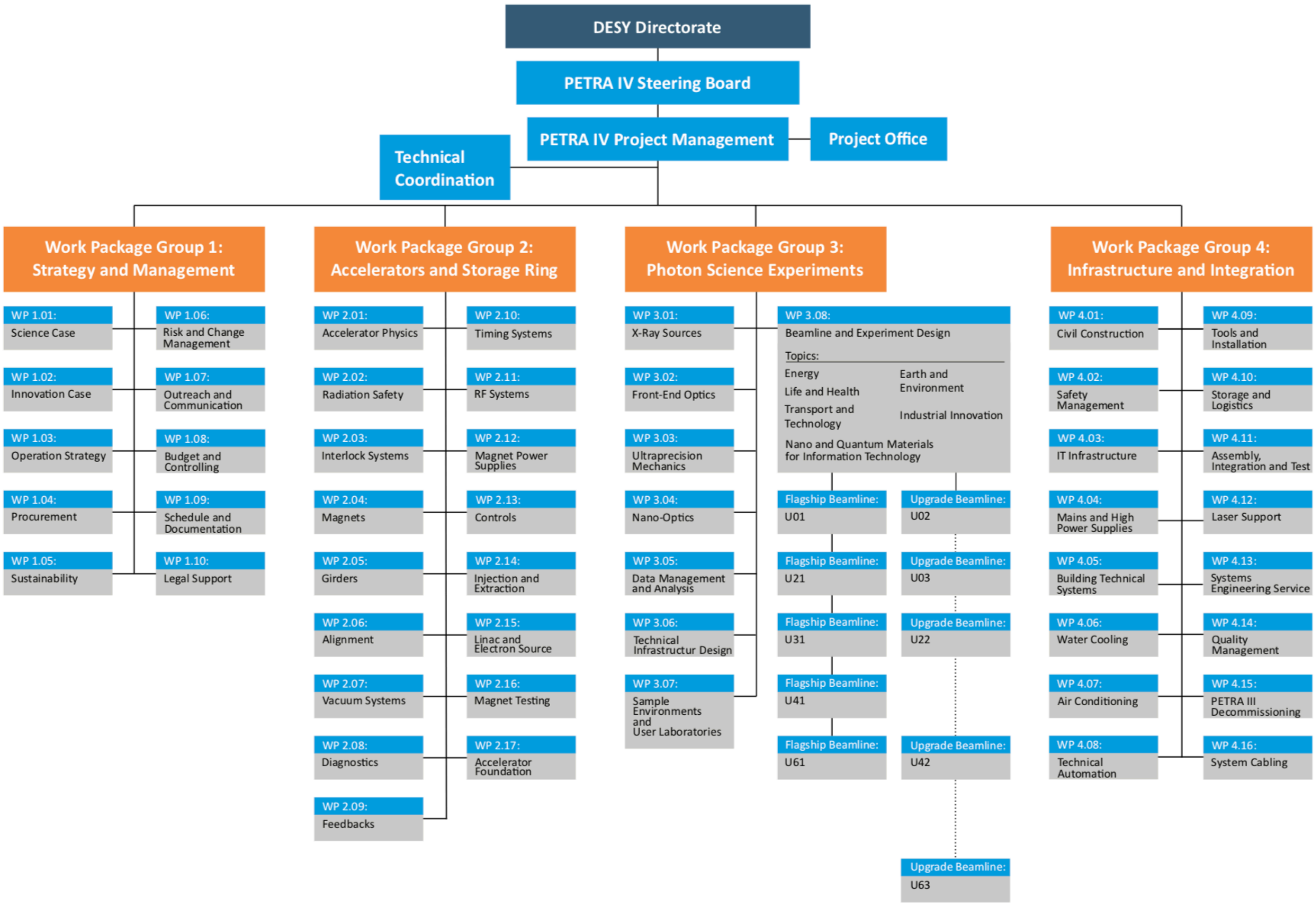
PETRA IV.

Conceptual Design Report
Focus on science and innovation case and storage ring feasibility

Now online:

PETRA IV.

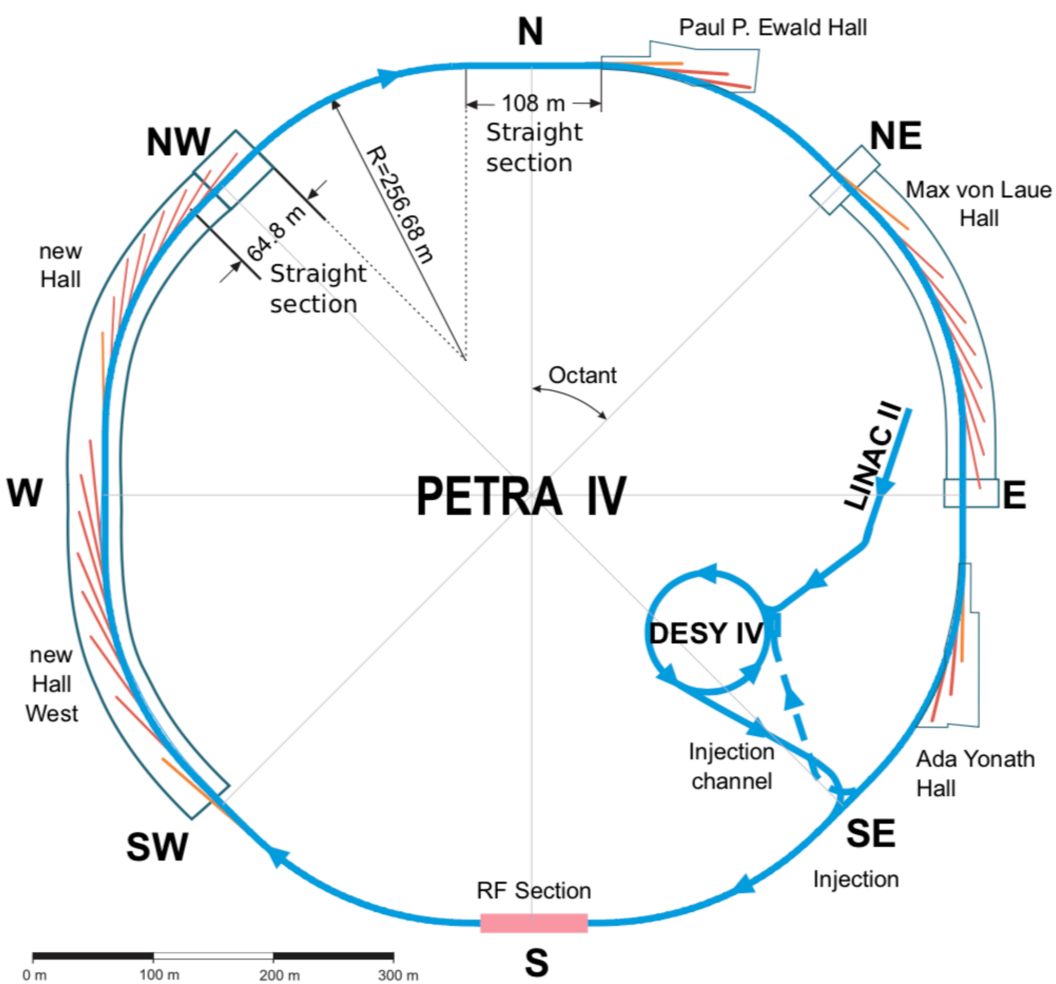
Governance and work breakdown structure



PETRA IV. in the Science City Bahrenfeld

Storage Ring and Injectors

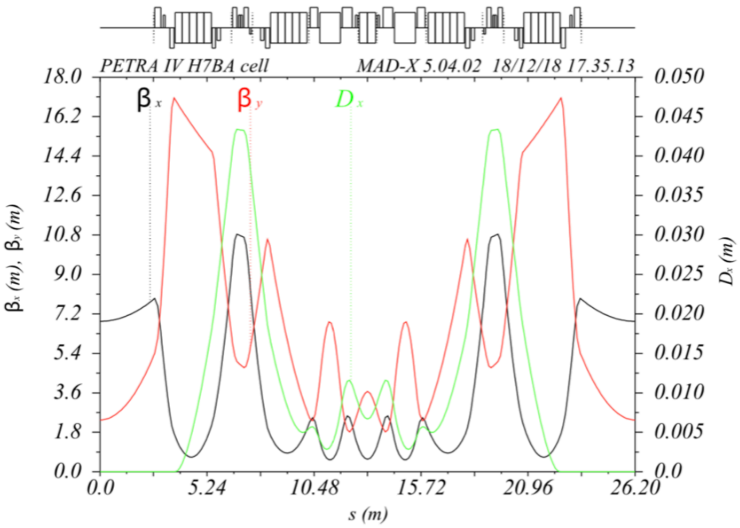
(Some) Key Concepts

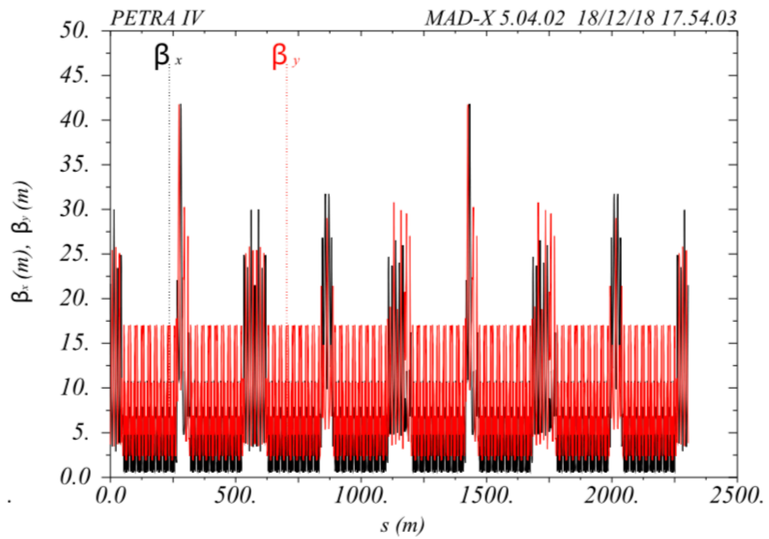


CDR Baseline Lattice (17pm)

Design parameter	PETRA III		PETRA IV	
Energy / GeV	6		6	
Circumference / m	2304		2304	
Operation mode	**Continuous**	**Timing**	**Brightness**	**Timing**
Emittance (horiz. / vert.) / pm rad	1300 / 10		$<$ 20 / 4	$<$ 50 / 10
Total current / mA	100		200	80
Number of bunches	960	40	1600*	80
Bunch population / 10^{10}	0.5	12	0.6	4.8
Bunch current / mA	0.1	2.5	0.125	1.0
Bunch separation / ns	8	192	4 / 20 (gaps)	96

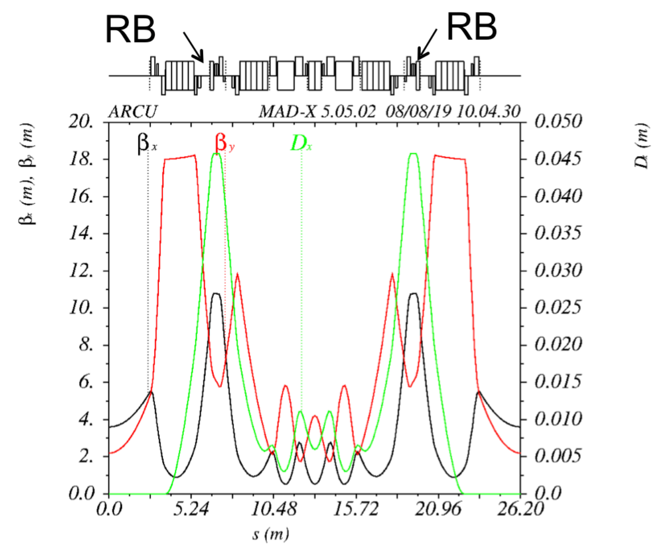
* 80 $\times$ 20 bunches

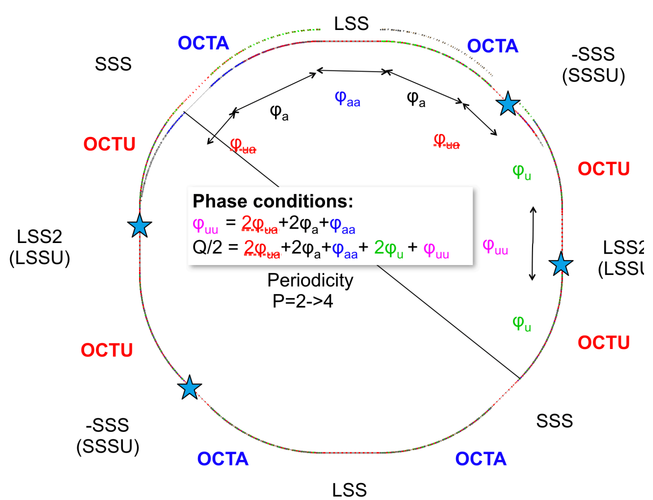


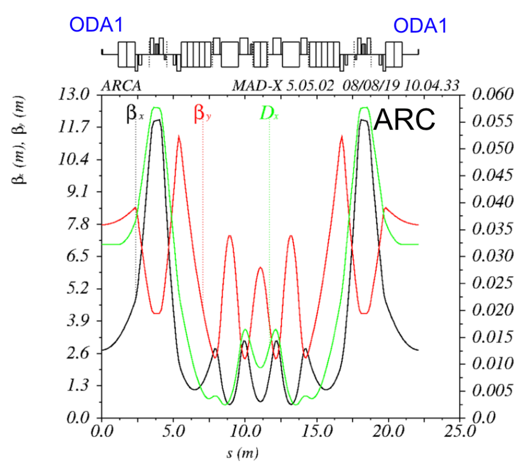


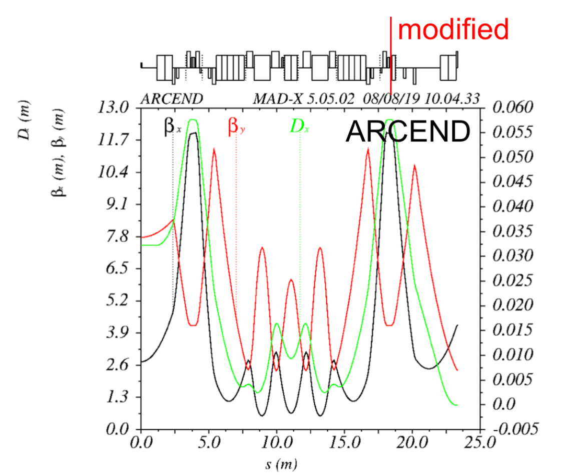
Alternative Lattice

- Goal: achieve better LMA, provide more tuning knobs, optimise cost
- Cell with undulator straights
  - 8 cells per achromat
  - Reverse bends
  - Lower β at IDs (see further slides)
- Different cell in the arc without the undulator IDs
  - 9 cells per achromat
  - Weaker sextuples
  - Additional octupoles



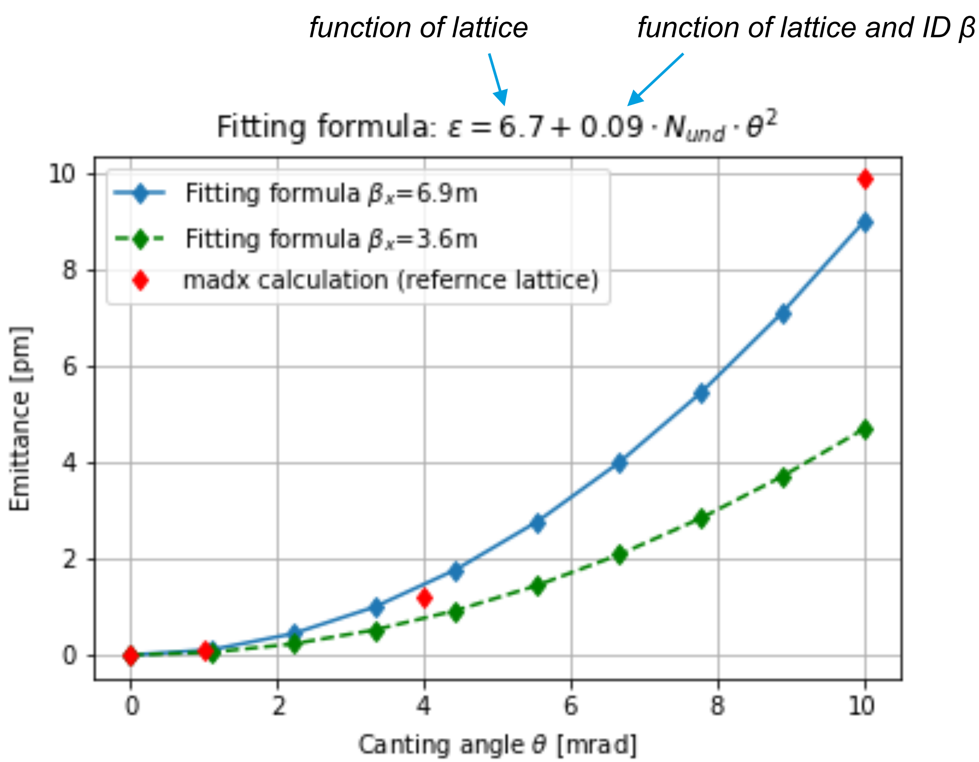




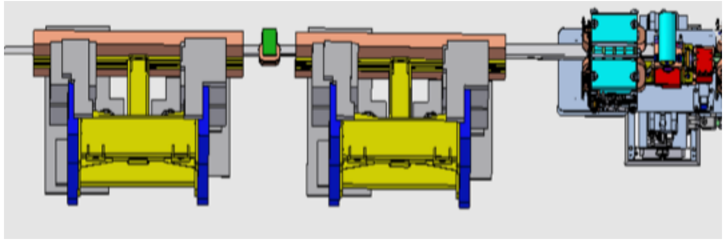


Existing Beamlines

- In-depth analysis of preservation of existing beamlines performed
- Requires a shorter (23m) cell in one of the octants (von Laue)
- Beam Dynamics properties are suffering
- Many PETRA III beamlines are canted which is not compatible with low emittance
- Joint meeting with FS with the recommendation that machine performance should be given priority



Canted undulator

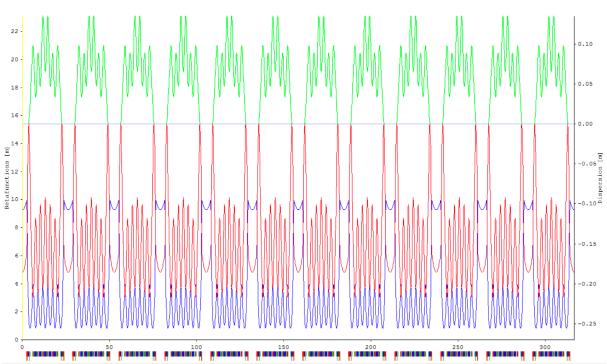


Emittance increase from one canted section (2 IDs):

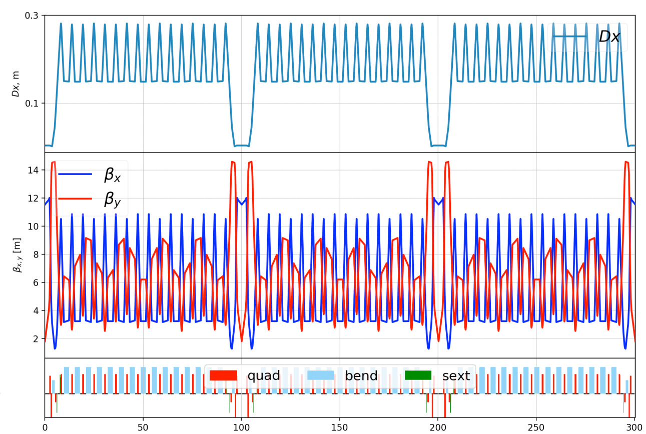
- Reference lattice with β_x=6.9m
- Combi lattice with β_x=3.6m

Booster/Accumulator

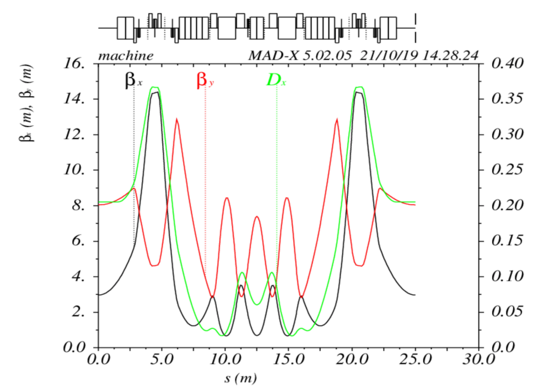
- Additional lattice considerations
  - Aim to have a booster (DESYIV) or a booster + accumulator ring (DESYII + DESYIV)
  - Injection points into DESYIV from DESYII, LINACII, PETRA IV, LPWA
- Possible lattices:
  - 4nm lattice with PETRAIV-like cell
  - 10nm lattice with TME-like arcs
  - 6nm MAXIV-type 7BA lattice also feasible



6 nm lattice



10 nm lattice



4 nm lattice

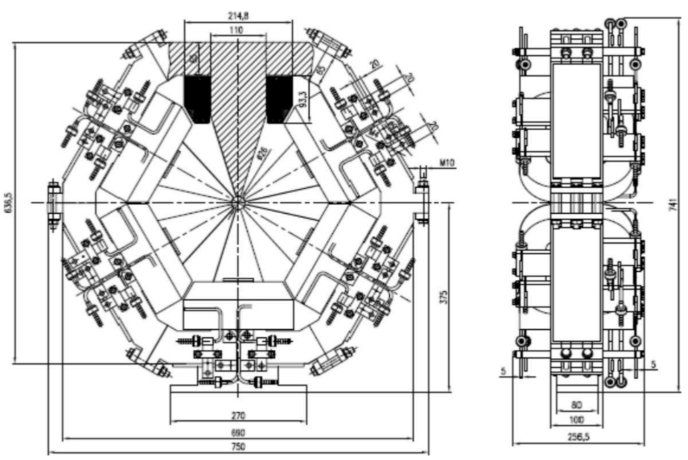
Magnets

- Sextupole and octupole magnets are challenging, the rest similar to ESRF-EBS

Quadrupole Magnets

Name	N	L / m	k_1 / m^{-2}	B' / T m^{-1}	r / mm	B_p / T	Type
QF1	2	0.293	+2.78	+55.7	13	0.72	Medium gradient
QD2	2	0.211	-3.21	-64.2	13	0.83	Medium gradient
QD3	2	0.161	-2.27	-45.4	13	0.59	Medium gradient
QF4A	2	0.211	+2.62	+52.5	13	0.68	Medium gradient
QF4B	2	0.211	+2.62	+52.5	13	0.68	Medium gradient
QD5	2	0.211	-2.97	-59.4	13	0.77	Medium gradient
QF6	2	0.385	+4.62	+92.4	13	1.20	High gradient
QF8	2	0.481	+4.39	+87.9	13	1.14	High gradient

Sextupole design Efremov Institute St. Petersburg



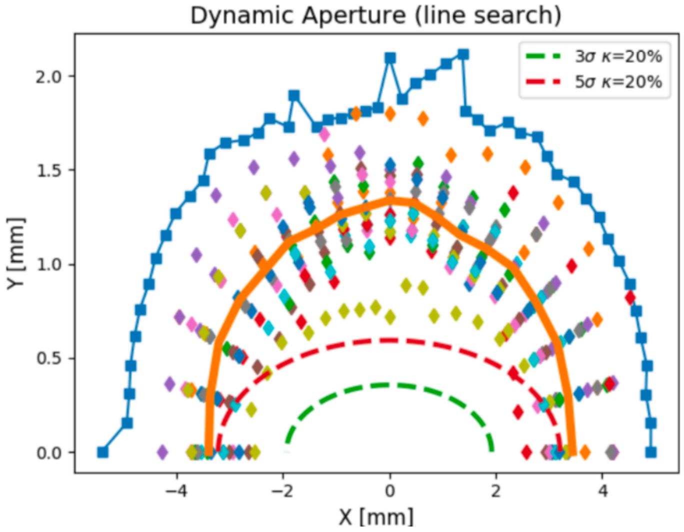
Sextupole Magnets

Name	N	L / m	k_2 / m^{-3}	$\frac{1}{2}B''$ / T m^{-2}	r / mm	B_p / T	Type
SD1A	2	0.165	-427	–4277	13	0.72	Chrom. Sextupole
SF2A	2	0.199	+379	3790	13	0.64	Chrom. Sextupole
SD1B	2	0.165	-368	–3680	13	0.62	Chrom. Sextupole

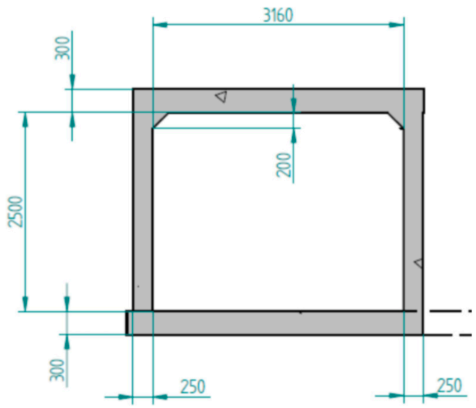
Alignment and Tunnel Stability

- Simulations indicate that aligment is critical for beam accumulation and reaching design parameters
- 30µm or better (rms) alignemnt on the girder will be required to guarantee beam accumulations

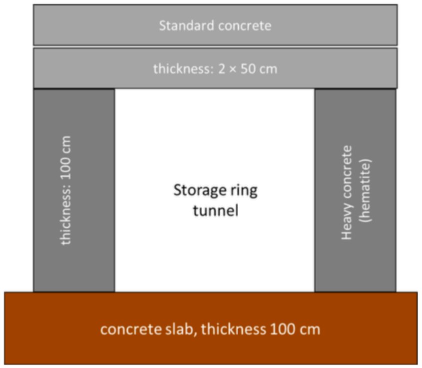
Dynamic aperture with errors



- Old tunnel segments will need aditional stabilization



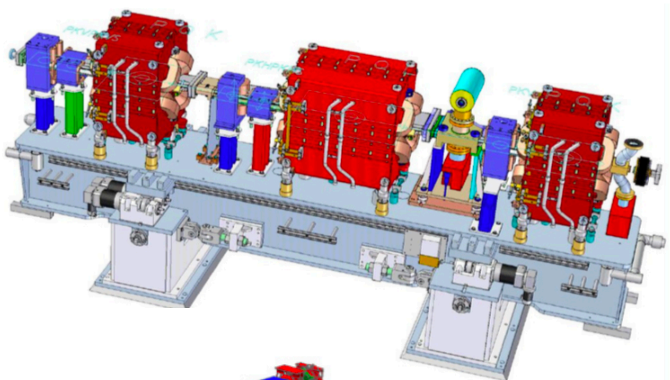
(a) *Cross section of the original accelerator tunnel, built in 1976.*

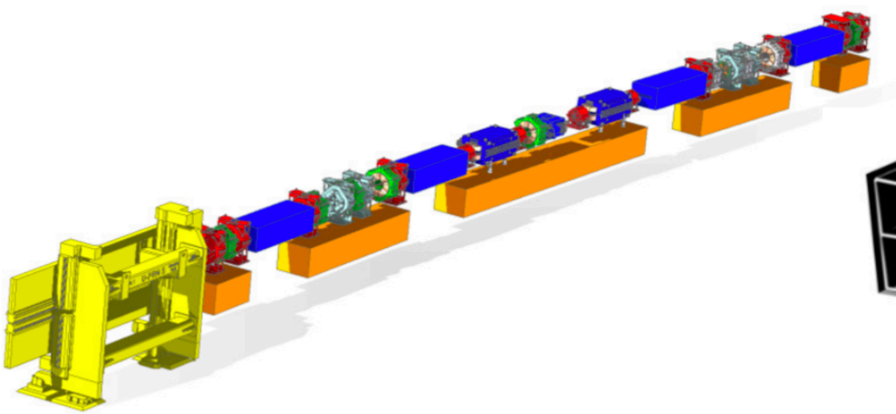


(b) *Cross section of the tunnel in the Max von Laue hall.*

Magnet Supports

- In 4th generation light sources girders are essential for beam stability, alignment and assembly
- PETRA III or ESRF girder concept can be used.
- R&D into longer and stiffer girders has been ongoing during the CDR phase

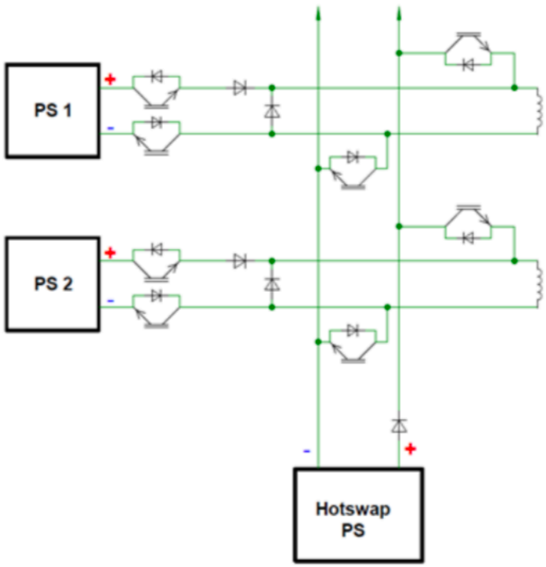




Power Supplies

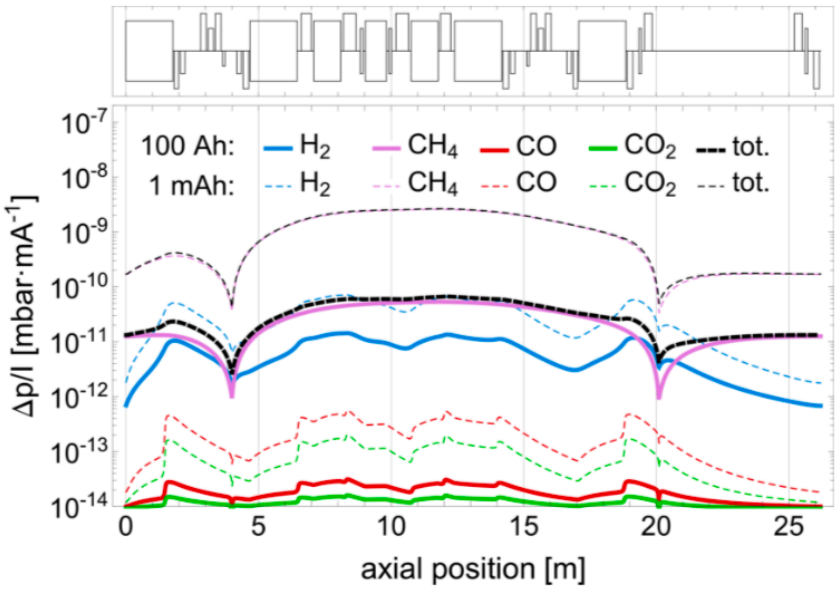
- Large number of power supplies requires improved reliablility concept

Location	Magnet type	N_{mag}	N_{PS}	Factor	N_{mag} total	N_{PS} total
Achromat	Longitudinal-gradient dipole	4	2	64	256	128
Achromat	Dipole/quadrupole	3	1	64	192	64
Achromat	Quadrupole (medium-gradient)	12	12	64	768	768
Achromat	Quadrupole (high-gradient)	4	4	64	256	256
Achromat	Chromatic sextupole	6	6	64	384	384
Achromat	Harmonic sextupole	4	3	64	256	192
Achromat	Octupole	2	1	64	128	64
Achromat	Skew quadrupole	4	4	64	256	256
SSS	Quadrupole	11	6	2	22	12
LSS	Quadrupole	17	5	2	34	10
SSSU	Quadrupole	14	14	2	28	28
LSSU	Quadrupole	20	13	2	40	26
SSS	Skew quadrupole	4	4	2	8	8
LSS	Skew quadrupole	4	4	2	8	8
SSSU	Skew quadrupole	4	4	2	8	8
LSSU	Skew quadrupole	4	4	2	8	8
Sum					2652	2220



Vacuum

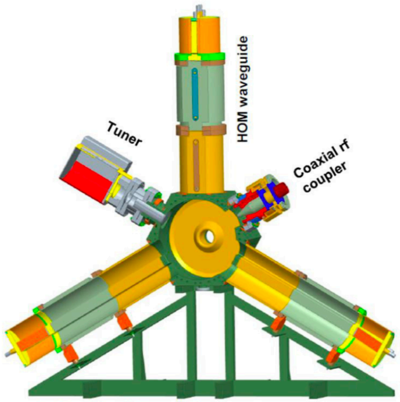
- Challenge: small chambers and tight magnet placing
- NEG coating: good experience at MAX IV. Coating and activation tests and impedance studies at PETRA III ongoing



RF

- 500 MHz single-cell HOM-damped cavities
- 3rd harmonic system for bunch lengthening
- Solid-state amplifiers

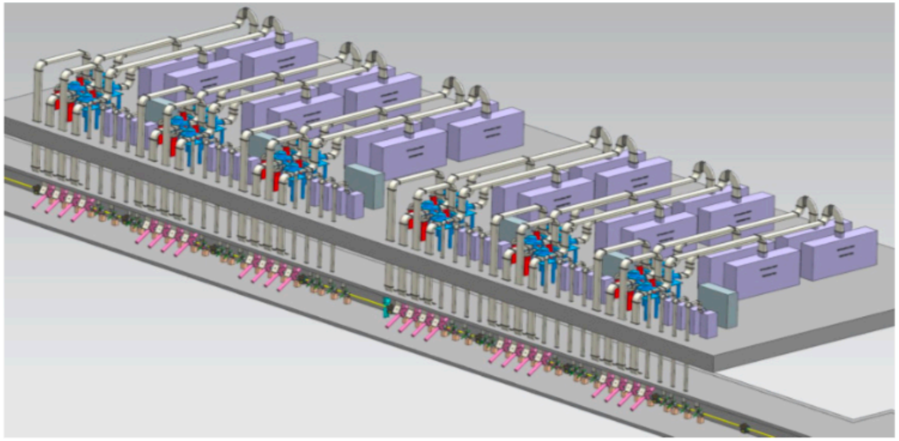
RF frequency (fundamental RF system)	499.665 MHz
RF voltage (fundamental RF system)	8 MV
Synchronous phase	30.2°
Synchrotron frequency	421 Hz
Number of RF single-cell cavities	24
RF voltage per cavity	333 kV
Shunt impedance per cavity	3.4 MΩ
Unloaded quality factor	29 000
Loaded quality factor	7400
Total wall loss in cavities	392 kW
Total beam loading power	800 kW
Cavity coupling factor	3.0
Number of RF stations	24
Nominal transmitter power per RF station	110 kW



Courtesy of Ernst Weihreter, HZB

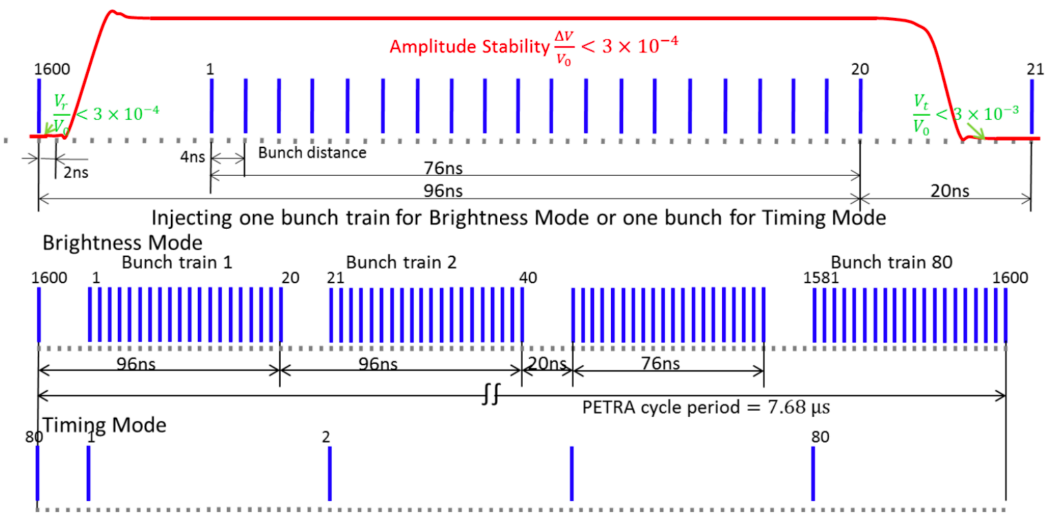

Courtesy of Wolfgang Anders, HZB

RF frequency	1498.995 MHz
RF voltage	2.26 MV
Number of single-cell cavities	24
RF voltage per cavity	94 kV
Shunt impedance per cavity	1.5 MΩ
Unloaded quality factor	17 000
Loaded quality factor	2700
Total wall loss in cavities	71 kW
Cavity coupling factor	5.3
Number of RF stations	24
Nominal transmitter power per RF station	10 kW

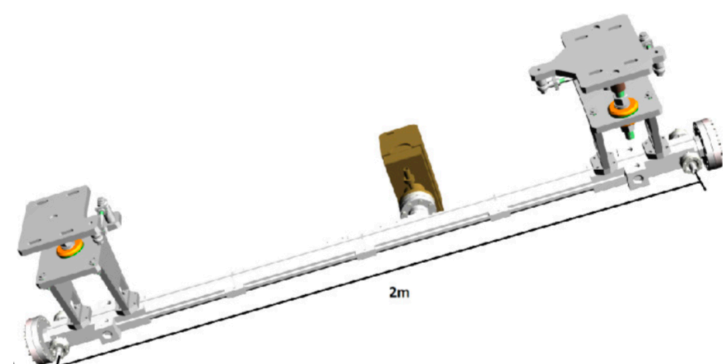


Injection, Septa, Kickers

- On-axis swap-out injection requires fast kickers
- High single-bunch charge from linac for timing mode (~10nC from 2-3 RF buckets)



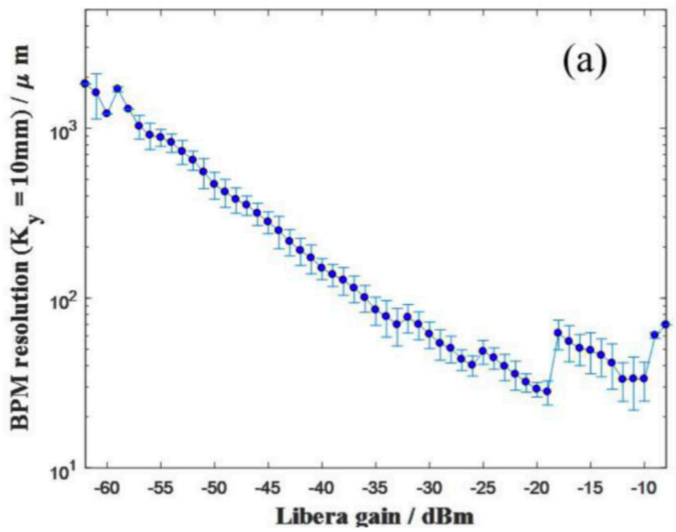
	Kicker magnet	Pulser
Impedance	50 Ω	50 Ω
Free aperture	20 mm	
Kicker length	2000 mm	
Deflection	63 μrad/kV	
Pulse waveform		80 ns rectangular
Repetition rate		1 Hz
Rise and fall time		<4 ns



Diagnostics

- Mostly standard diagnostics
- Precise BPMs with single-bunch resolution (Libera Brilliance → Libera Brilliance+)
- Reliable ultra-low emittance measurement in horizontal and vertical direction (double-slit interferometry and x-ray pinhole)

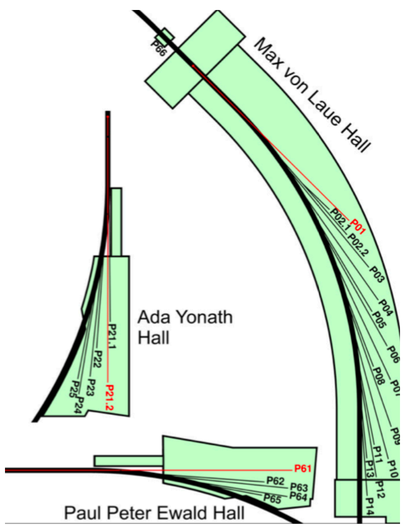
PETRA III BPM resolution studies



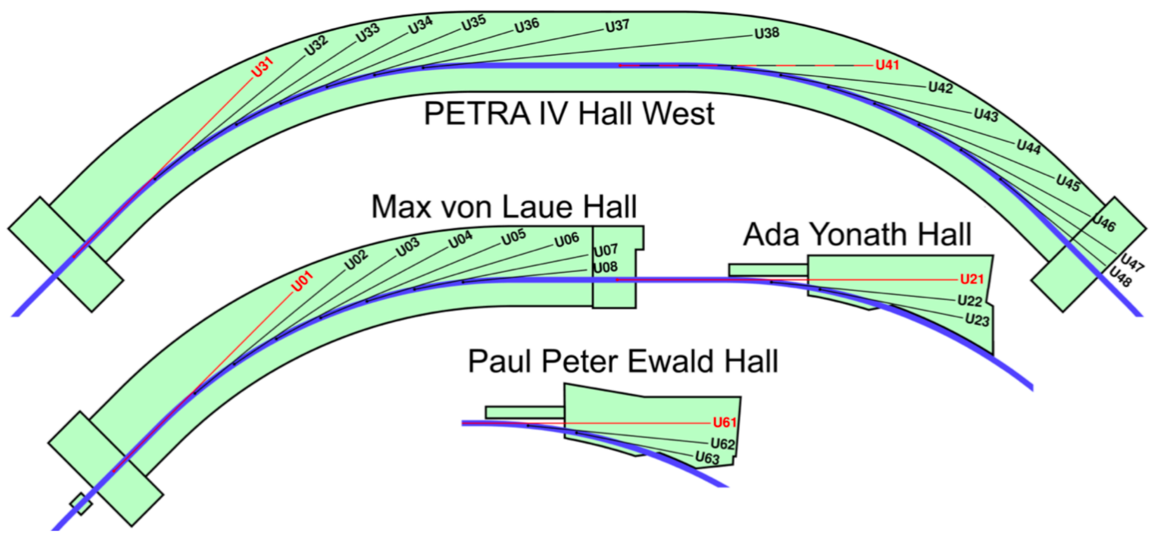
Insertion Devices and Beamlines

- 4 10m long super-IDs foreseen (5 might be possible) with 18mm undulators (IVU)
- Generally shorter-period and more compact structures
- Total of 30 beamlines foreseen
- Considering superbends in Ada Yonath/PPE Hall to replace undulator sources

PETRAIII

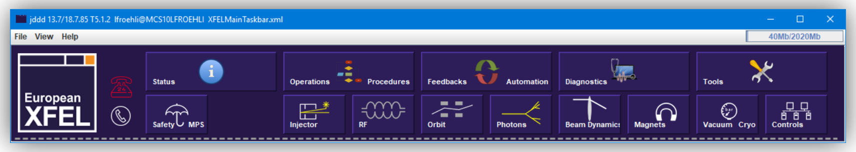


PETRAIV

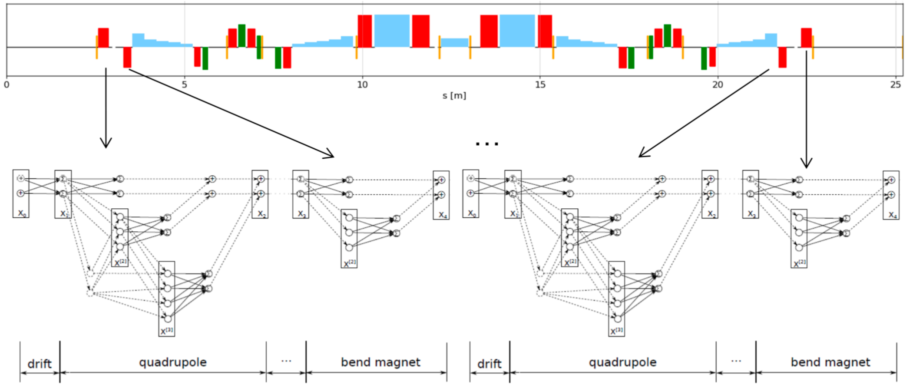


High Level Controls / Machine Learning

- PETRA IV HLC group – new high level controls, specification and prototyping started, collabo MPY/MCS
- As much as possible integrating experience and tools from XFEL



- NN-based steering for PETRA IV A. Ivanov (funded by AMALEA project) extending ocelot steering/optimizer tools



The moonshot of plasma acceleration: PETRA IV injection

Realization of challenging requirements incl. stability will advance field tremendously

Status

- discussions on concept in early stage, goal → CDR
- *several schemes considered:* swap out at full energy, booster ring, accumulator ring
- *only one option seems viable/interesting:* accumulator ring at full energy

Challenges for an LPA injector

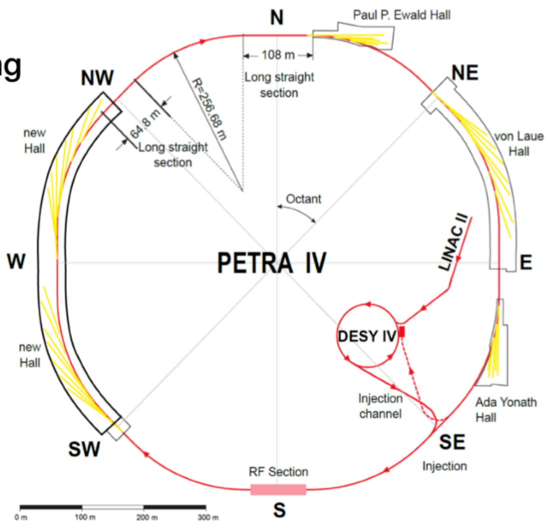
- ~10 nC / second
- bunch length ~100 ps
- 6 GeV injection energy
- sub-% energy stability
- ‰-level energy spread

Our approach

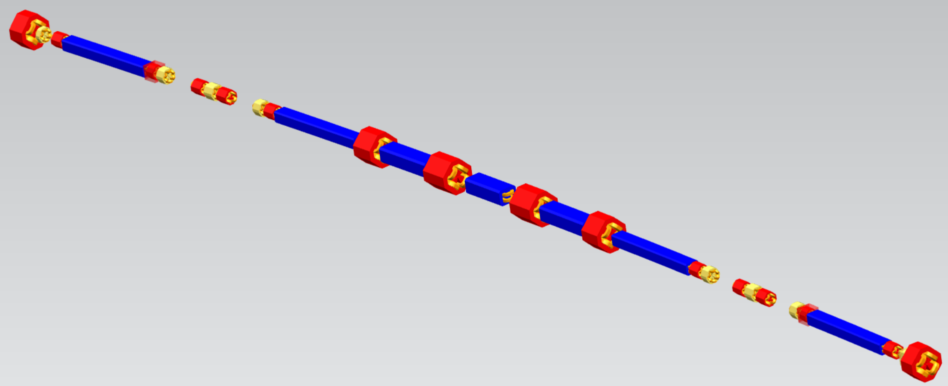
- → unrealistic for single bunch: accumulator ring
- → beam transport + accumulation, fs → ps
- → damping time: full energy at high rep. rate
- → LUX concepts + KALDERA feedbacks
- → phase space tailoring (see next slides)

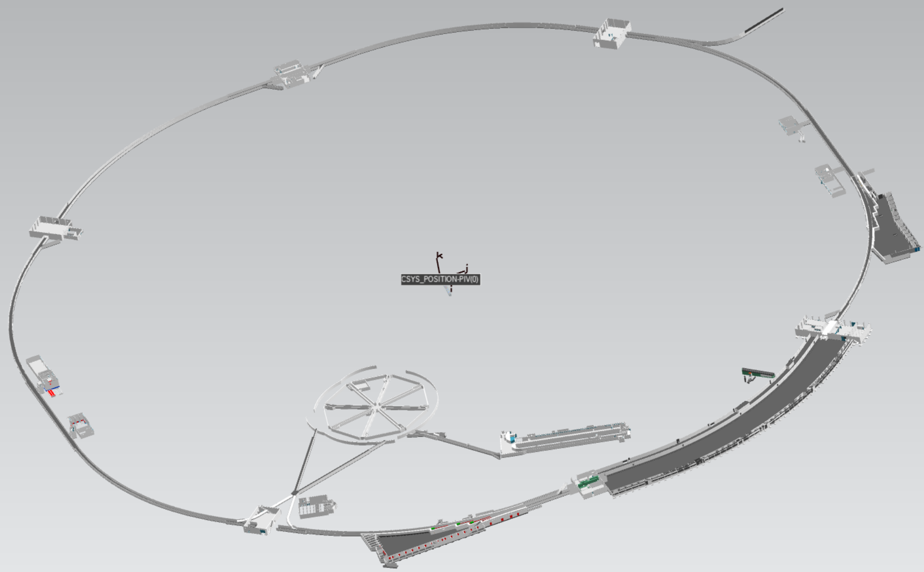
Additional requirements

- geometric emittance < 20 nm
- orbit stability < 1 mm
- 1 Hz injection rate into PETRA IV



Technical Integration





- Engineering specifications and CAD integration in progress

Thank you