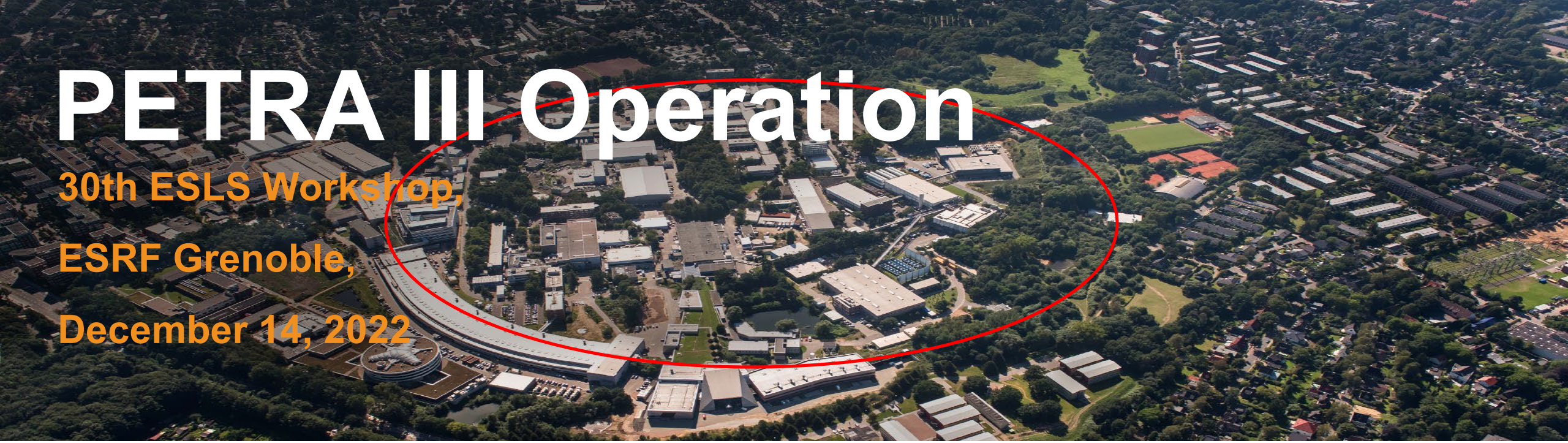


PETRA III Operation

30th ESLS Workshop,

ESRF Grenoble,

December 14, 2022

Michael Bieler
for the PETRA III / PETRA IV Team

Thank you for the support and discussions:
R. Wanzenberg, M. Schaumann, G. Kube, D. Haupt,
H. Ehrlichmann, J. Keil, G. Sahoo, R. Onken, R. Bartolini.

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

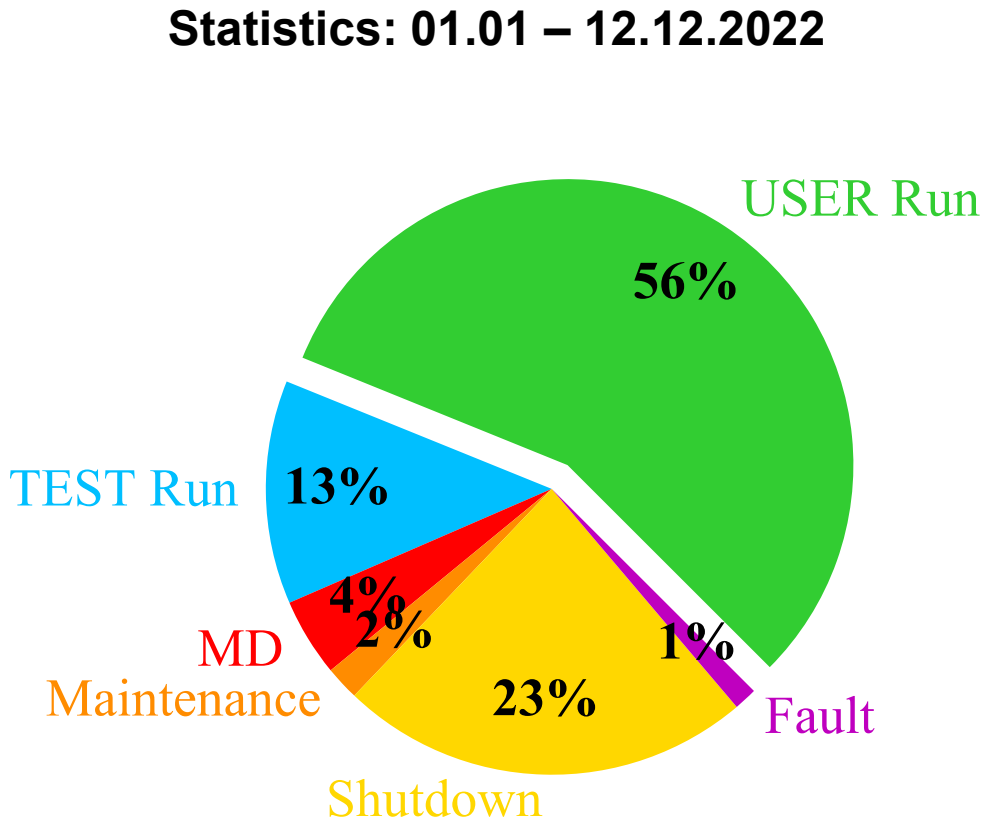
DESY.

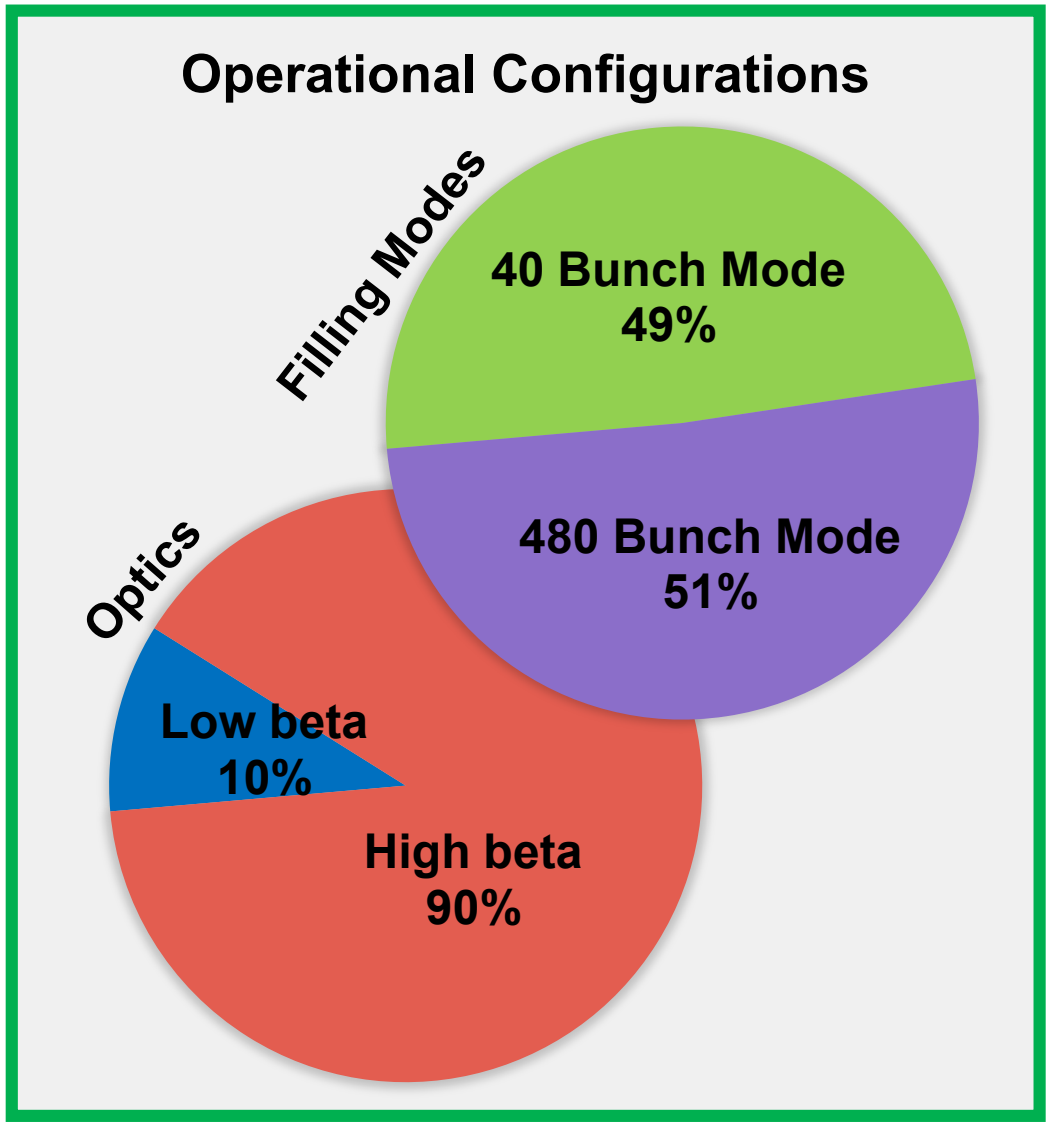
Contents

- Operation, Availability & Failure Analysis for Feb-Dec 2022
- PETRA-IV studies at PETRA III
- Energy saving options and studies
- Upgrade plans, PETRA IV

4640 h of User Time Delivered 16.2. – 12.12.2022

144 h more planned between 13.12.-18.12.2022

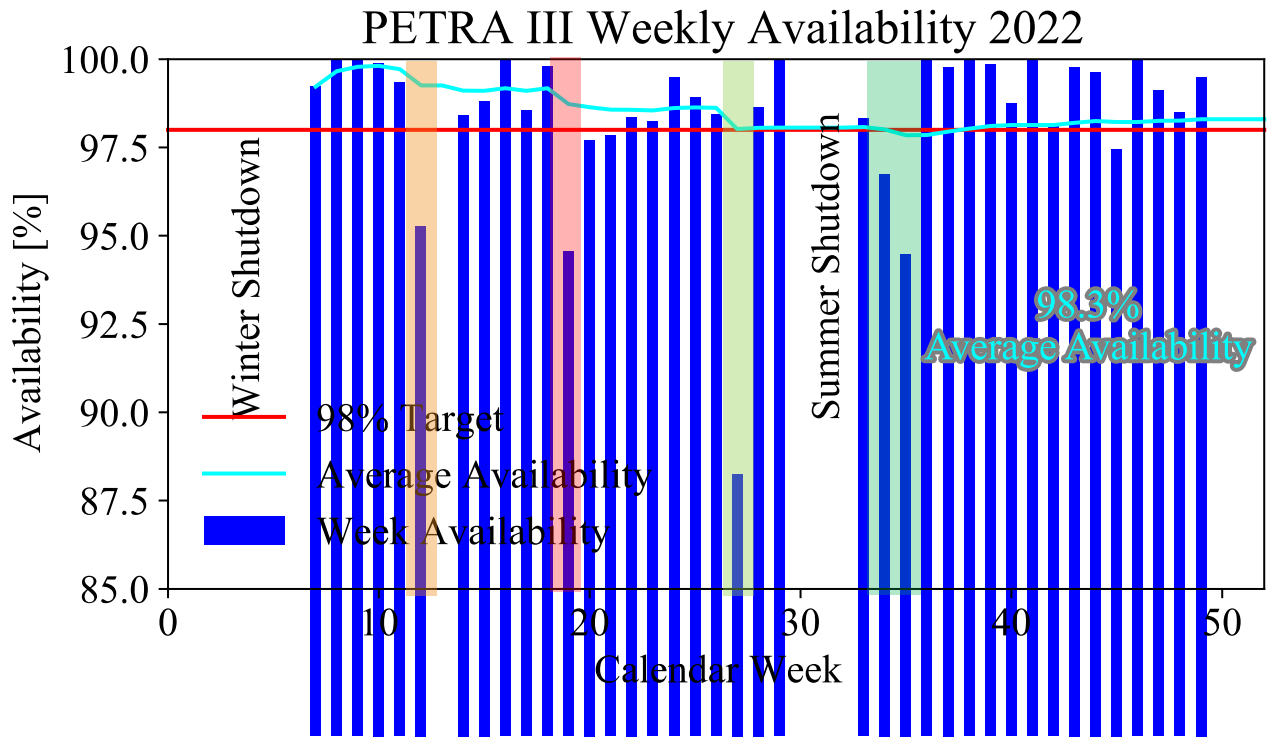




2022: Availability of 98.3%

Few major failures and troublesome period of 2 weeks after summer shutdown

MTBF: **57.3 h**
MTTR: **1 h**



W12: Power Glitch *(duration 3h30)*

W18: Faulty triggers of injection kicker *(duration 4h05)*

W27: Main power station B over-voltage problem *(duration 16h20)*

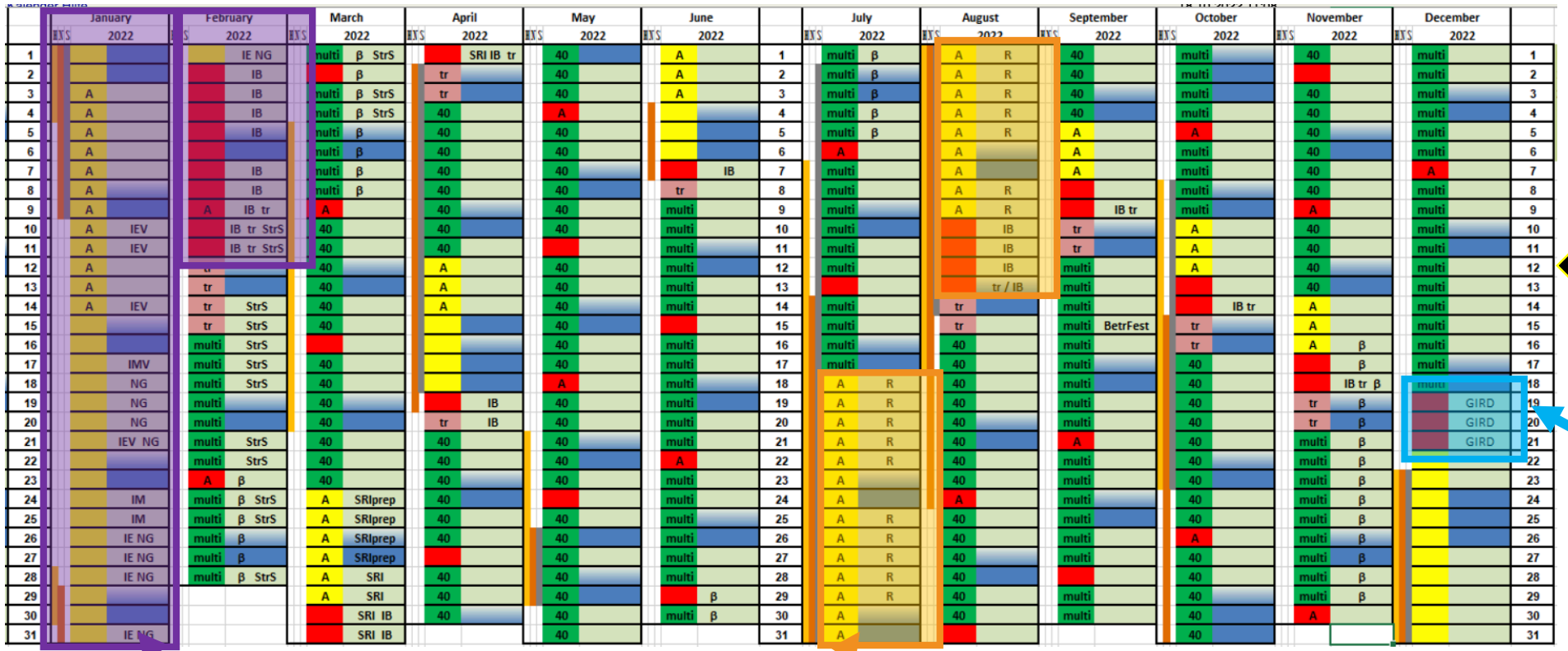
W34-35: Several independent failures:

- Power supplies
- Top up stops
- Cavity trips
- Cooling water
- Vacuum at experiments

5 Weeks of User Run remain in 2022

3 days of PETRA IV study time before winter shutdown

Studies/Commissioning
Test run
No operation
User run
Working day
Saturday
Sunday/ Bank holiday



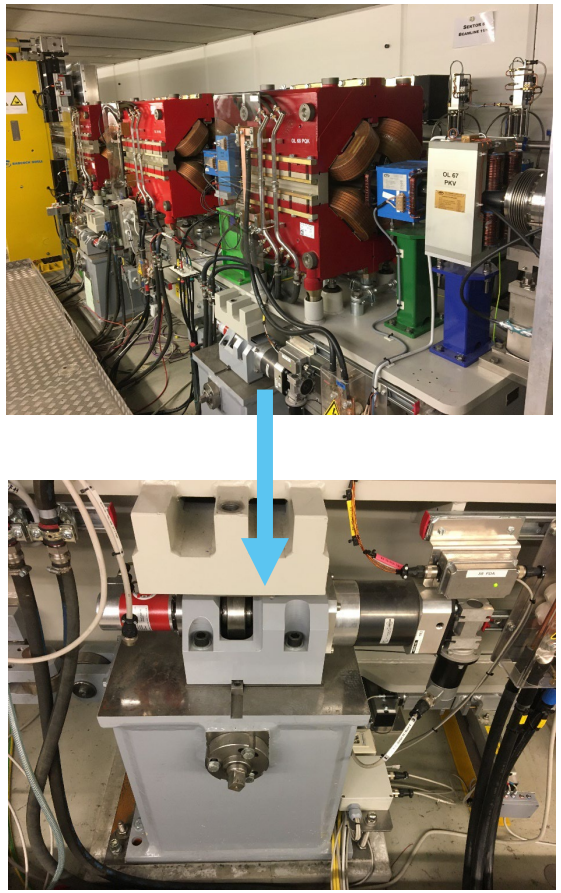
Shortest possible winter shutdown:
→ 4896 h of user run scheduled

Summer shutdown:
Repair of cooling tower

Girder movement experiment in Max von Laue Hall.

3 Days of Study for PETRA IV Girder Alignment System

Girder Movement Test in PETRA III Max von Laue hall planned for 19.-21.12.2022



PLAN

Move **ONE** girder in Max von Laue hall with the remote-controlled motors up to +/- 300 μm.

GOALS

a) Study girder movement to orbit correction response
b) Input for design of PETRA IV automatic girder alignment system
   - Identify technical requirements and limitations
   - Gaining experience and confidence in remotely moving girders
   - Development of required procedures for PETRA IV

CHALLENGES

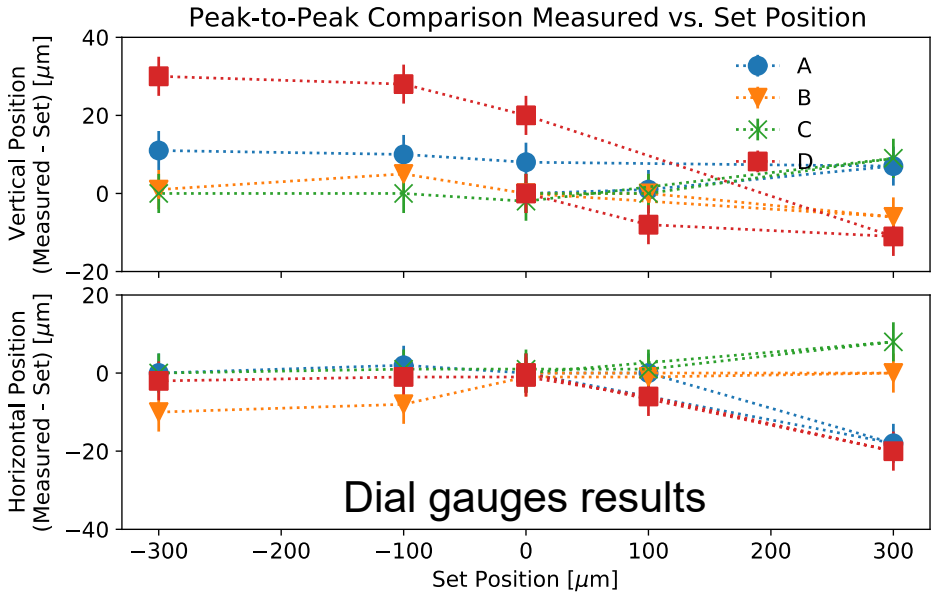
Girder alignment system not intended for movements after the initial installation phase of PETRA III (2009)

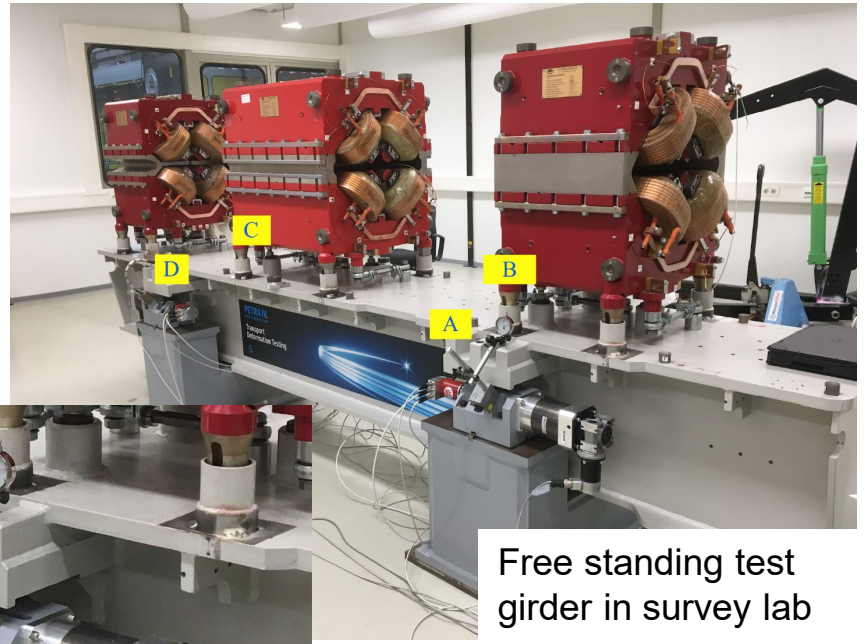
- *Fixed vacuum joints* between girders
- System *unused* and not connected since 2009
- Movement and verification *procedure not performed for many years*.

Successful Dry Run for Girder Movement Test on 19.10.2022

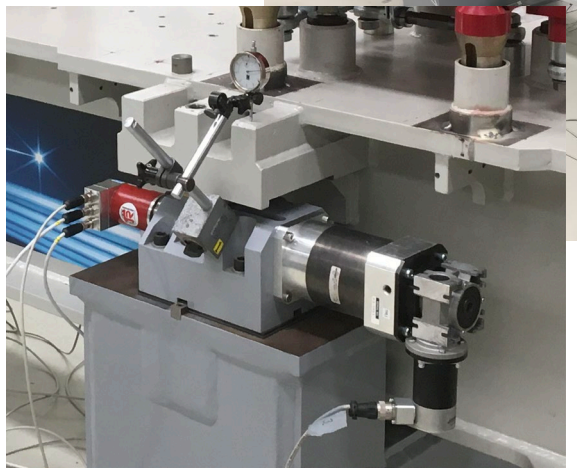
Initial tests confirmed practicability & accuracy of planned procedure

- Laser tracker and dial gauges measured the movement.
- Input of **signs and units** have been crosschecked.
- Accuracy of requested position within **+/- 20 μm - 30μm** (peak-to-peak).
- For only transverse movement (no rotations, longitudinal fixation) **starting position is recovered** within the same accuracy.





Free standing test girder in survey lab

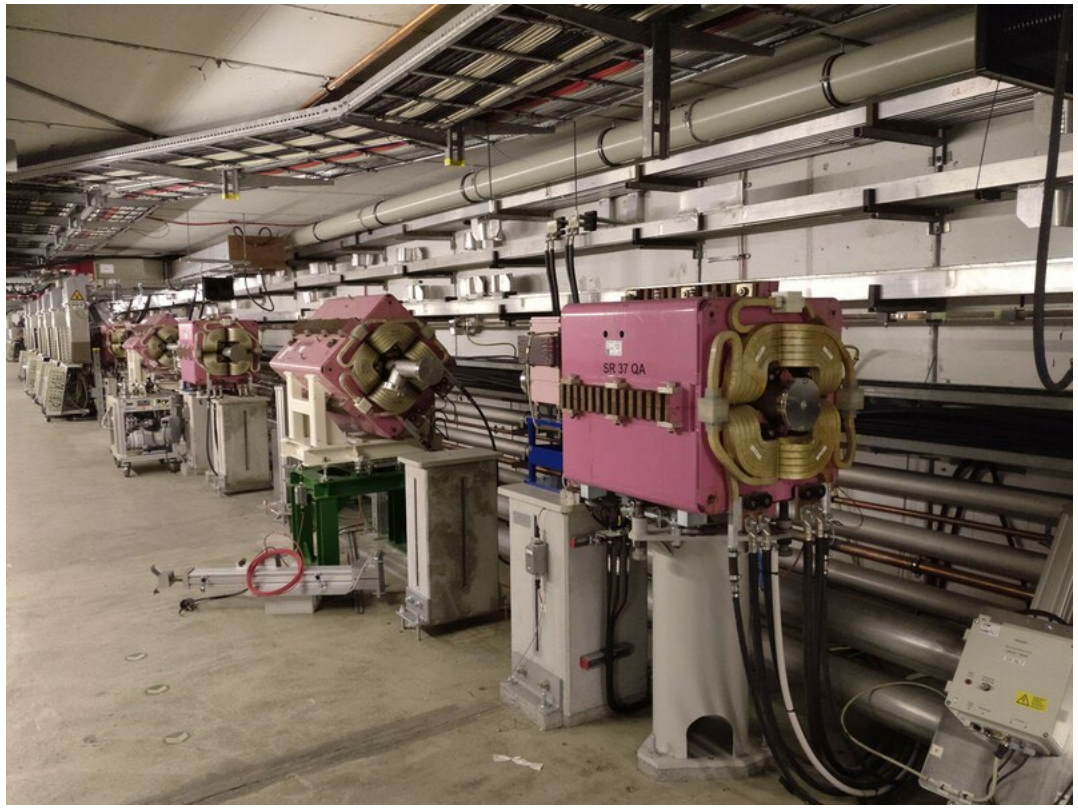


Motors installed on support feet with dial gauge measuring vertical movement

Analysis of dry test and planning of tunnel test are ongoing.

PETRA VI Prototype Test Program continues in PETRA III

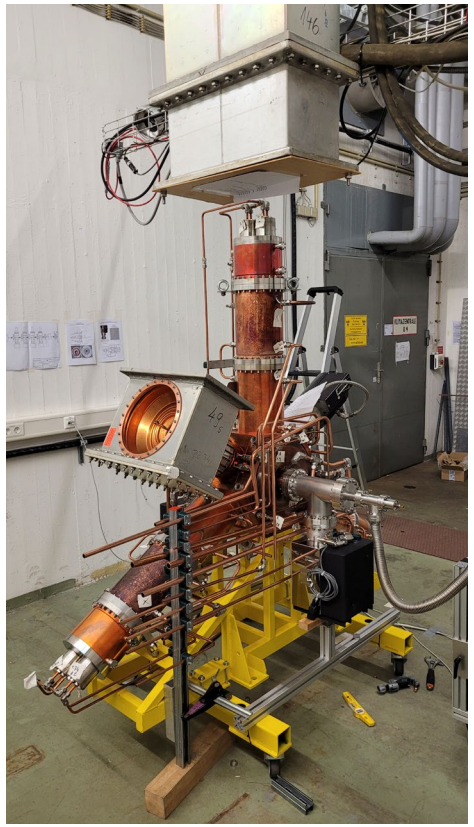
Successful preparation and installation work ongoing



Installation work during summer shutdown Jul/Aug 2022 in South Right (SR).

- **SR cavity section** had to be **vented**
- New beam pipes and valves installed

- Preparation for the PETRA IV prototype cavity (installation in coming winter shutdown).
- Installation of two current monitor types.



WP 2.12:
RF Systems

WP 2.05:
Diagnostics

Progressing Studies of PETRA IV Diagnostics

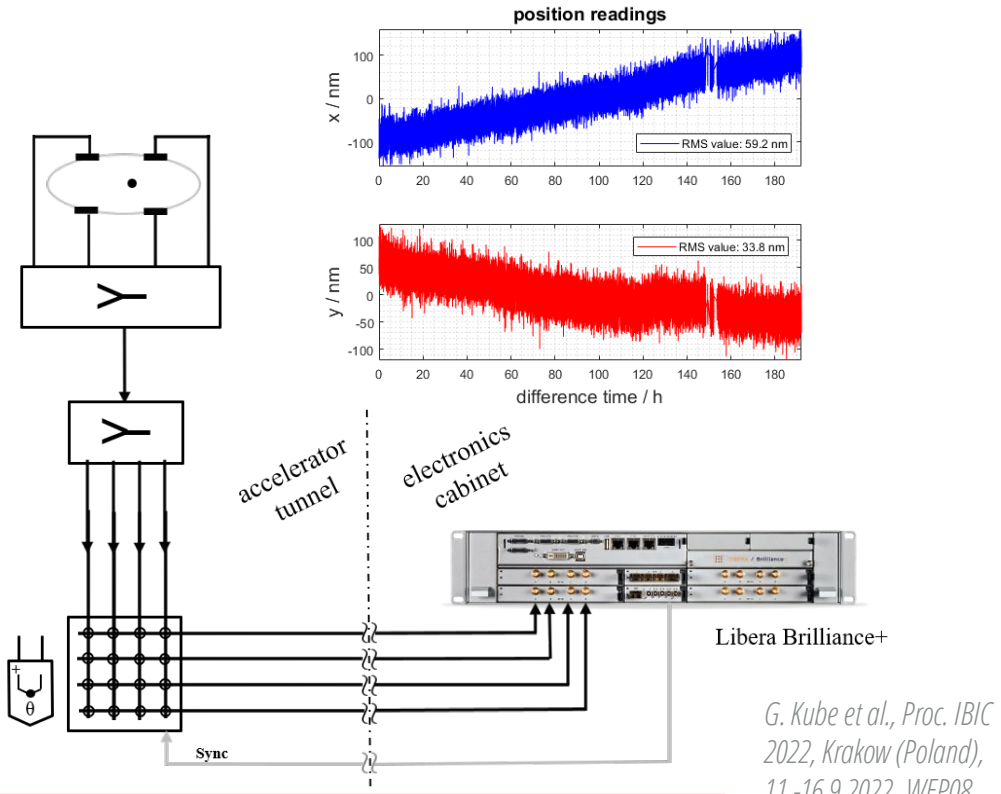
BPM electronics and Beam Current Monitors are being tested

G. Kube

PETRA IV. NEW DIMENSIONS

BPM electronics performance study at PETRA III

Evaluation of long term drifts
with e.g. 40 bunches @ 100 mA

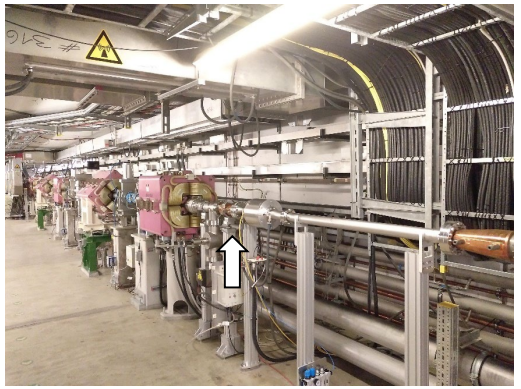


G. Kube et al., Proc. IBIC 2022, Krakow (Poland), 11.-16.9.2022, WEP08

➡ Well within specifications < 1 µm

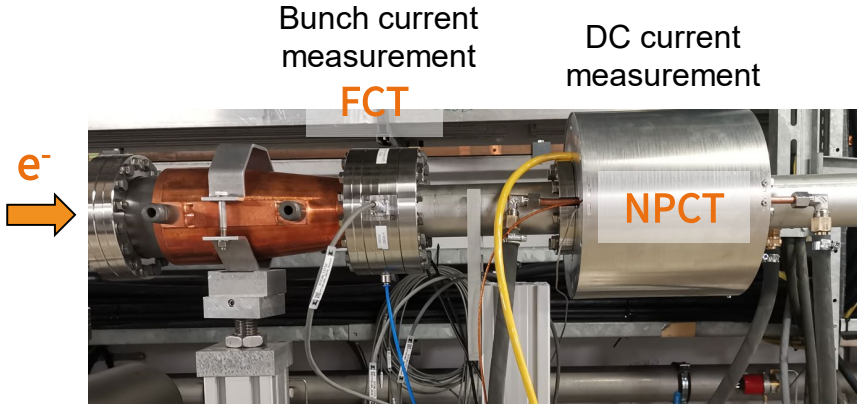
New Diagnostic Section in PETRA III

Test section (Ø 60mm) installed in PETRAIII SR during summer shutdown (July/August 22)



➡ FCT developed small vacuum leak
→ removed 21.9.2021

➡ Further improvements planned



Low Beam-Energy Operation could Reduce Energy Consumption

PETRA III: ~85% of the energy is consumed by magnets and RF

Options to reduce energy consumption for the PETRA III complex:

- Increase time between top up injections, meanwhile switch off injectors
  → *Test beam operation at DESY-II*
  → *Operationally challenging if LINAC is not in thermal equilibrium, degradation of reliability expected*

- Reduce RF power consumption by reduction of beam current and/or RF voltage
  → *needs optimization of working point*

- Reduced energy operation
  → *operation @ 5 GeV could save ~20%*

- Extend shutdown periods (no beam operation)

5 GeV Operation with 480 Bunches seems Feasible

Lifetime Reduction at 5 GeV prevents 40 Bunch Operation

Achieved Beam Performance

PETRA III	Standard Parameter	Studien 09.09.2022
Strahlenergie / GeV	**6**	**5**
Emittanz / pm rad	1300	ca. 850
HF Spannung / MV	19	15
Multibunch Mode		
Anzahl der Bunche	480	480
Strahlstrom / mA	120	100
Strahllebensdauer / h	10	**3.5**
Timing Mode		
Anzahl der Bunche	40	
Strahlstrom / mA	100	
Strahllebensdauer / h	1.5	

Tests done with 480 bunches, 100mA for 2 days

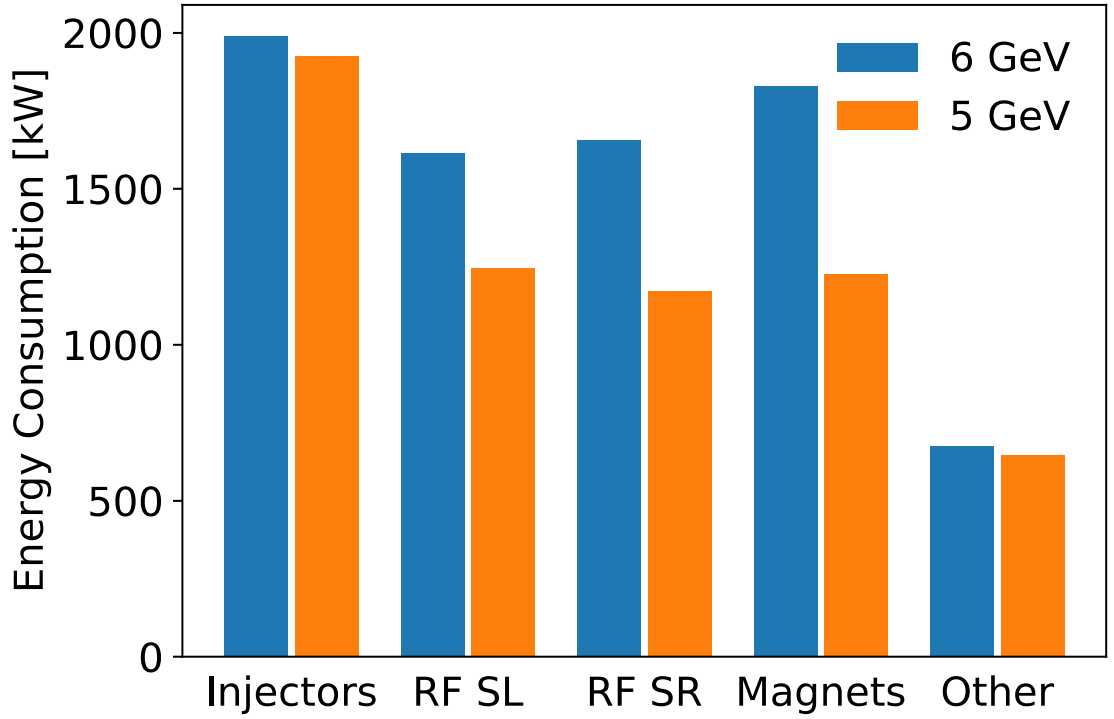
*Significant **lifetime** reduction at 5 GeV observed*
→ *Expected lifetime with 40 bunches too low for reasonable operation*

Reduction of **emittance** confirmed:

- *Horizontal emittance*: theoretical 750 pm rad
  measured ~800 pm rad
  @ 6 GeV, ~1300 pm rad
- *Vertical emittance*: uncertain
  (limitation of measurement)

5 GeV Operation Requires ~1.5 MW less Power than 6 GeV

This corresponds to ~20% of the used power of the whole PETRA III complex



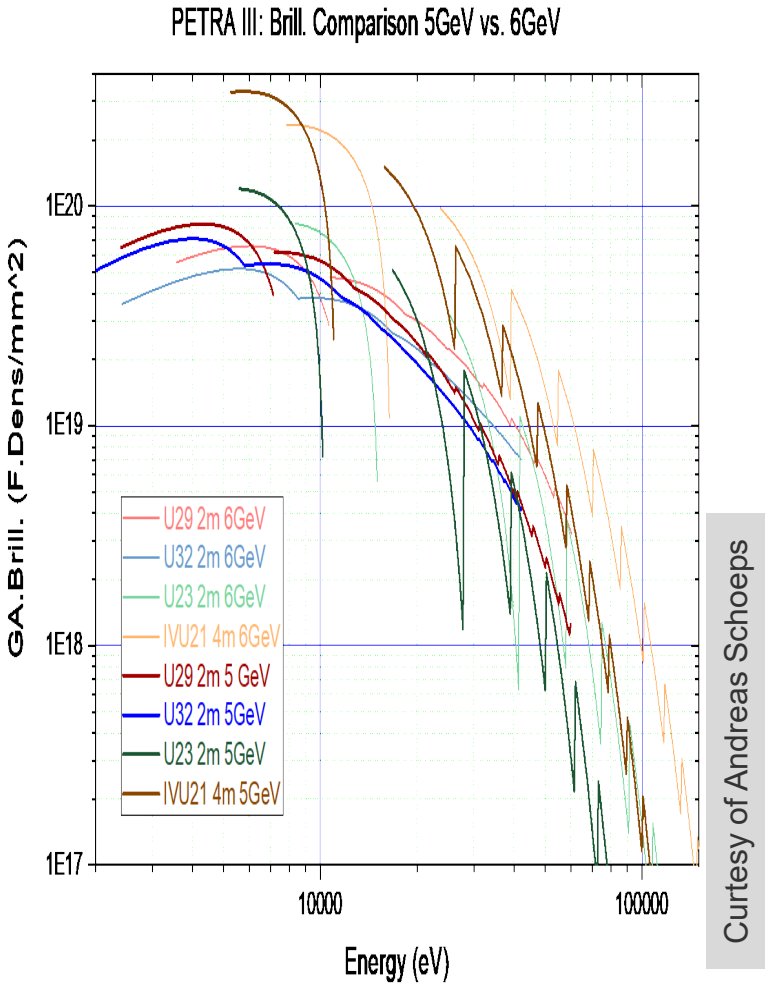
Energy saving potential of reducing the beam energy from 6 GeV to 5 GeV:

→ ~25% only PETRA III
→ ~20% all PETRA III complex

Based on data taken
- 6 GeV: 15.08.2022 09:55
- 5 GeV: 09.09.2022 12:35

Drastic Reduction of High Energy Photon Intensity at 5 GeV

Successfully delivered 22 h of 5 GeV Test Run to Beamlines



Calculation for photon beam brilliance at PETRA III 5 GeV vs. 6 GeV

Observations

Photon energies

- 2 < E < 5 keV a small increase of intensity, factor 1.25
- 8 < E < 20 keV: losses of factor 2 to 5
- E > 20keV: losses of factor 10

Conclusion from beamlines

→ Almost all beamlines would suffer
→ Loss for beamlines vs. saving is unreasonable
→ 5 GeV is **NO** option for the user run.

Injectors Power Consumption Reduced by up to 150kW

Further options are being investigated

H. Ehrlichmann
D. Haupt

Implemented measures:

- Reduction PIA energy 450MeV → 400MeV: *-25 kW*

→ Switch off LINAC-II redundancy (≤5/12 klystrons off): *-5x25 kW* = *-125 kW*

→ no hot-spares, could influence availability

-150 kW

Measures under investigation:

- Reduction DESY-II peak cycle energy 6.3 GeV → 6.0 GeV ???

→ Negative for test beam users: need high energies

- Optimization of klystron working point: ???

- Reduction LINAC-II rep-rate 50Hz → 10Hz ???

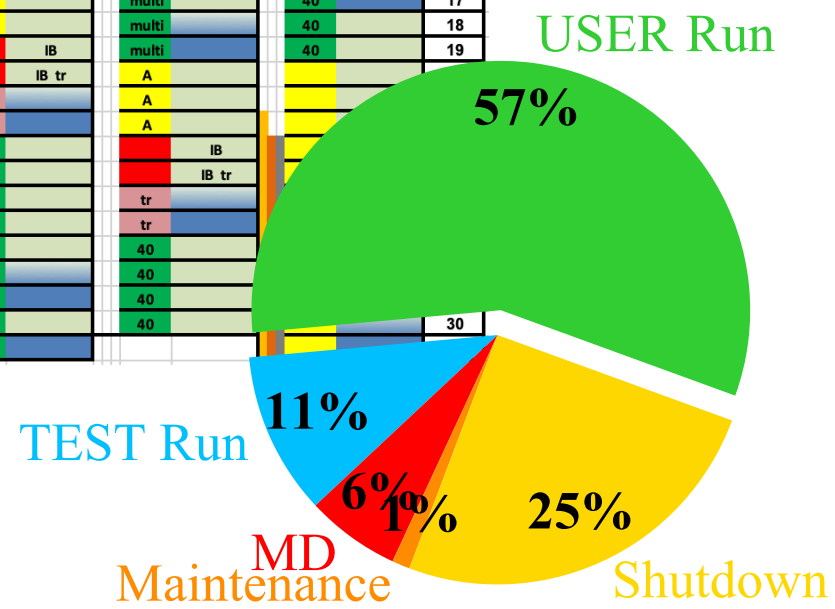
→ Influence on PIA accumulation

Draft Schedule for 2023 foresees 4992 h of User Time

Installation of new undulator and PETRA IV test cavity

	January		February		March		April		May		June		July		August		September		October		November		December	
	HNS	2023	HNS	2023	HNS	2023	HNS	2023	HNS	2023	HNS	2023		HNS	2023	HNS	2023	HNS	2023	HNS	2023	HNS	2023	
1				NG	A		multi		40		multi		1	40		A		multi		40		A		40	1
2	A	CAV		NG	multi		multi		40		multi		2	40		A		multi		40		multi		40	2
3	A	CAV		IE NG	multi		A		A		multi		3	40			IB	multi		40		multi		40	3
4	A	CAV			multi		A		40		multi		4	40			IB	multi				multi		40	4
5	A	CAV PU25			multi		A		40		multi		5				IB tr	multi		40		multi		40	5
6	A	CAV PU25		IM	multi		A		40		multi		6	40			IB tr	A		40		multi		A	6
7	A			IM	multi				40				7	40			IB	multi		40		multi		40	7
8	A			IB					40		multi		8	40			IB tr	multi		40				40	8
9	A	IEV PU25		IB	multi				40		multi		9	40		tr		multi		40		multi		40	9
10	A	IEV PU25		IB	multi						multi		10	40		multi		multi		40		multi		40	10
11	A	PU25		IB (tr)	multi			IB	40		multi		11	40		multi		A		A		multi		40	11
12	A	PU25		IB (tr)	multi		tr	IB tr	40		multi		12			multi		A		40		multi		40	12
13	A	PU25		IB	multi		40		40		multi		13	40		multi		A		40		multi		A	13
14	A			IB	multi		40		40		A		14	40		multi	AU-UUH		IB	40		multi		40	14
15	A		A	IB tr	A		40		40		multi		15	40		multi	AU-UUH		IB tr	40		A		40	15
16	A			IB tr	multi		40		A		multi		16	40			AU-UUH	tr		A		multi		40	16
17	A	IEV		IB tr	multi		40		40		multi		17	A		multi	AU-UUH	tr		A		multi		40	17
18	A		tr		multi		40		40		multi		18	A		multi	AU-UUH	40		A		multi		40	18
19	A		tr		multi		A		40		multi		19	A		multi		40			IB	multi		40	19
20	A			IB tr	multi	HERCULES	40		40		multi		20	A		multi		40			IB tr	A			20
21			tr		multi	HERCULES	40		40				21	A		multi		40		tr		A			21
22			multi			HERCULES	40		A		40		22	A		multi		40		tr		A			22
23		IMV	multi		multi	HERCULES	40		A		40		23	A		A		40		multi			IB		23
24		IEV	multi		multi	HERCULES	40		A		40		24	A		multi		40		multi			IB tr		24
25		IE NG	multi		multi		40		A		40		25	A		multi		40		multi		tr			25
26		IE NG	multi		multi				A		40		26	A		multi		40		multi		tr			26
27		IE NG	multi		multi		40				40		27	A		multi		A		multi		40			27
28			multi		multi		40				A		28	A		multi		40		multi		40			28
29					A		40				40		29	A		multi		40		multi		40			29
30		IE NG			multi		40			IB	40		30	A				40		multi		40			30
31		IE NG			multi				tr	IB tr			31	A		multi				multi					31

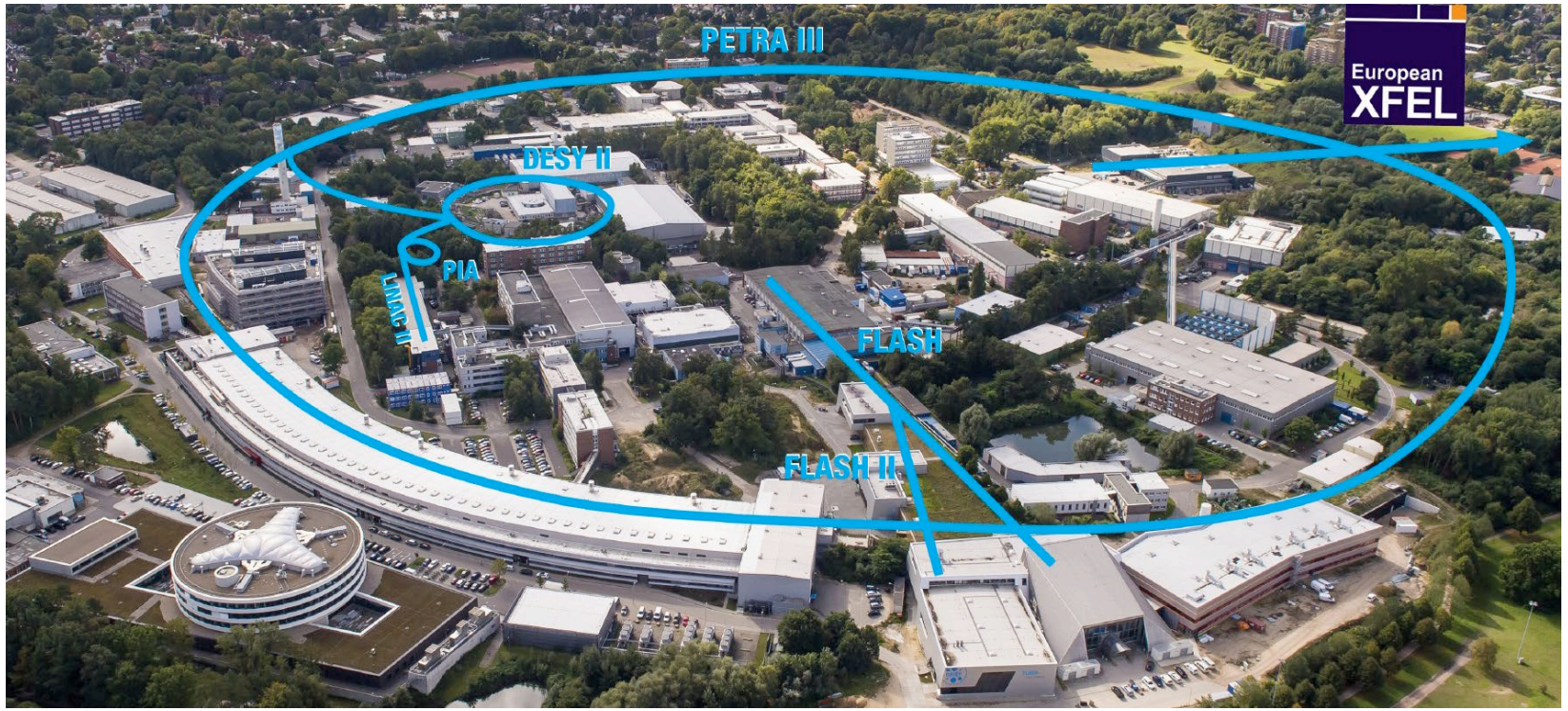
Studies/Commissioning A (A)
Test run tr
No operation A (A)
User run
Working day
Saturday
Sunday/ Bank holiday



Installation of
- Undulator for PU25 (Ada Yonath hall)
- Test cavity for PETRA IV

PETRA III is one of the core facilities at DESY

Each year ~5000h users operation serve more than 2000 users

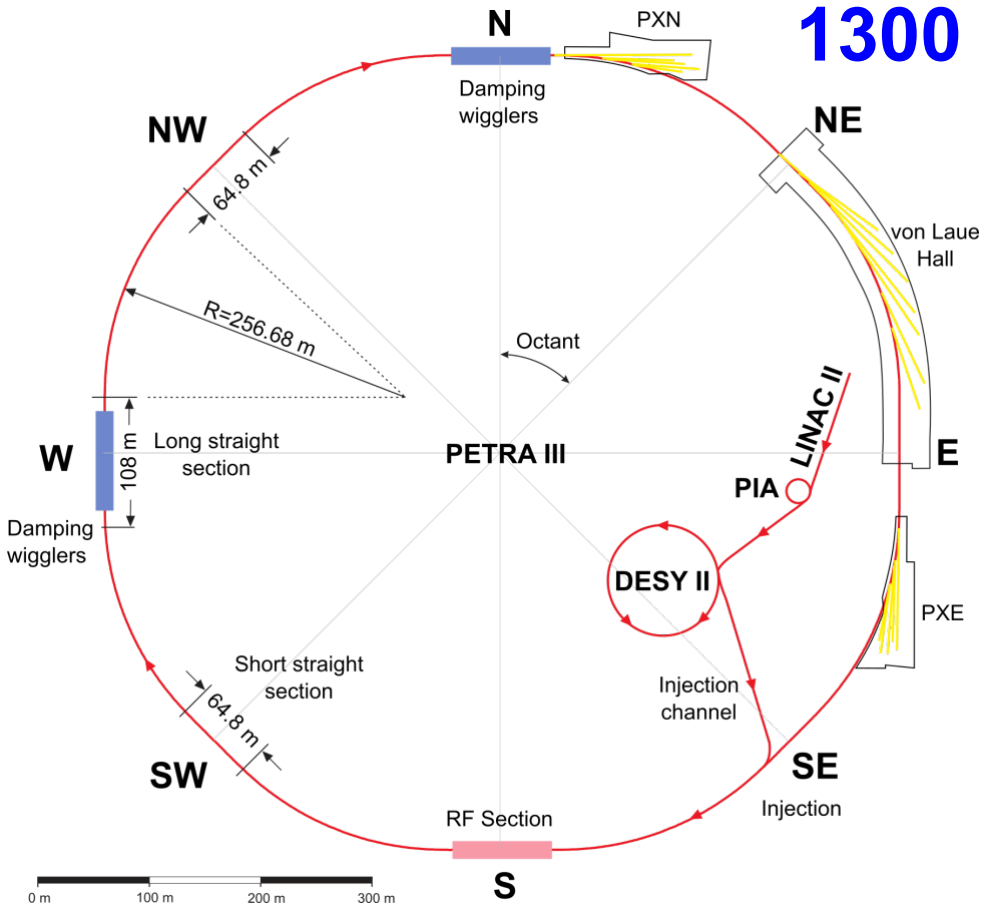


Parameter	PETRA III
Energy [GeV]	6
Circumference [m]	2304
Emittance (hor./vert.) [nm]	1.3 / 0.013
Total current [mA]	100

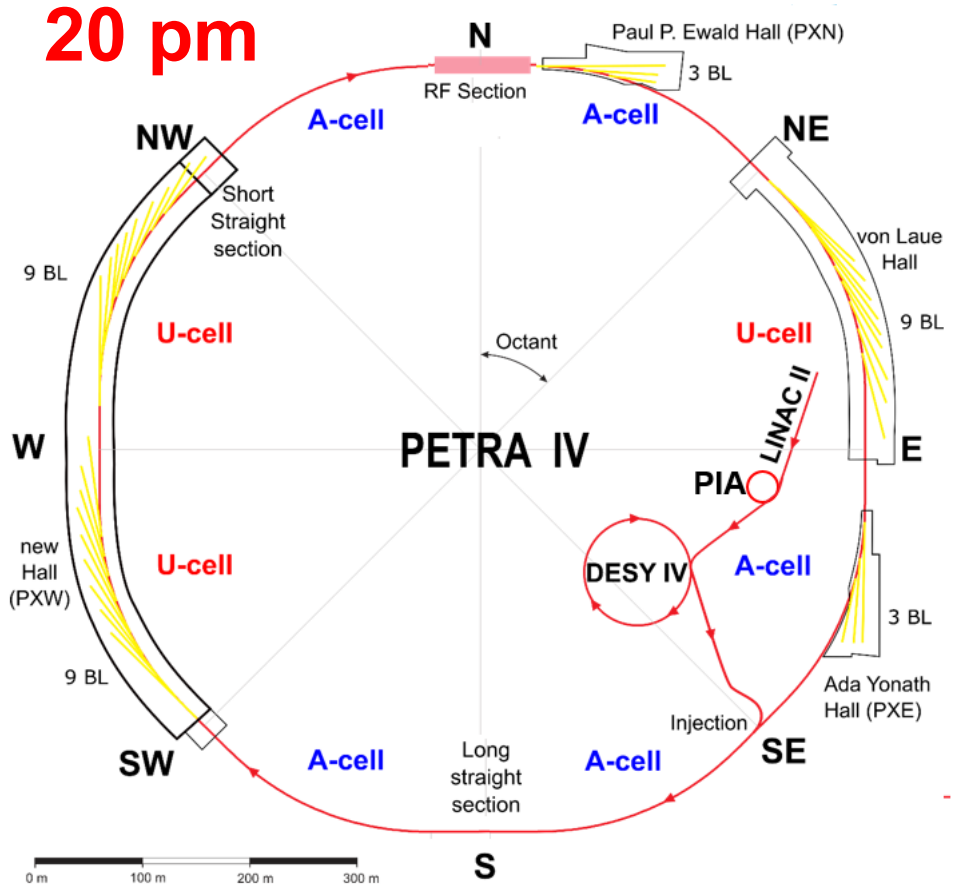
PETRA IV project:

replacing PIII with an ultra low emittance ring (20 pm) adding a new Experimental Halls in two more octants

From PETRA III to PETRA IV



1300 pm → **20 pm**



Eight Arcs (45°), 201.6 m long

One arc build from 9 ***DBA cells*** L_{cell} = 23 m, 5 m ID straight sections

5 pure FODO-arcs + 2 modified FODO arcs with 2 ***DBA cells***

Beamlines

Max von-Laue Hall:14; PXN:5; PXE: 7

Eight Arcs (45°), 201.6 m long

72 cells ESRF-EBS ***H6BA cells***

9 cells per arc L_{cell} = 22.75 m, 4.3(TBC) m ID straight sections

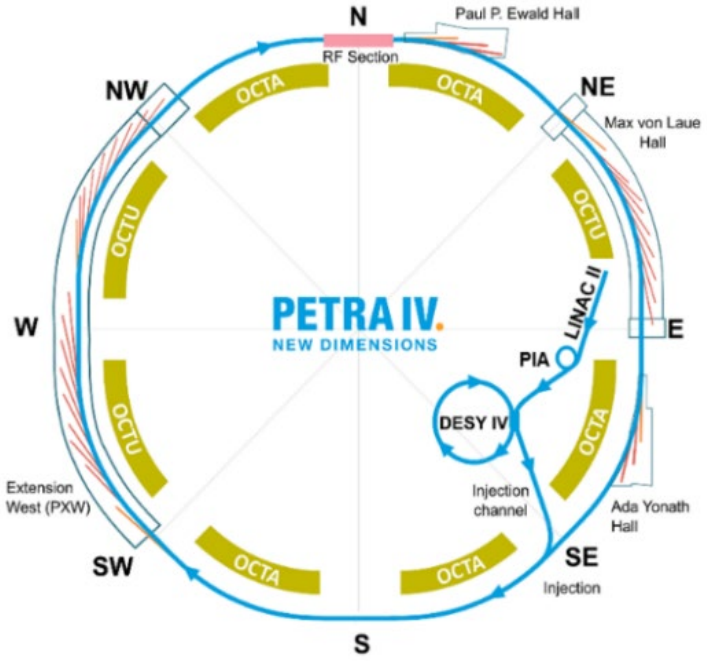
Straights for Beamlines

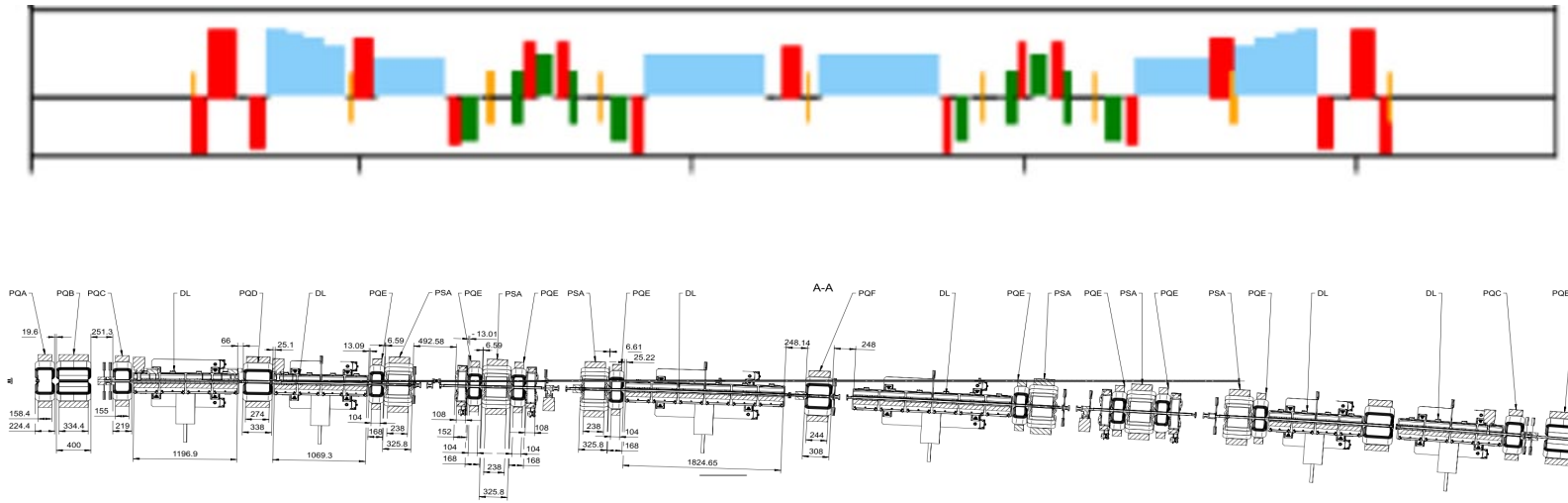
Max von-Laue Hall: 9; PXN: 3; PXE: 3 + New Hall: 9 + 9(8)

PETRA IV accelerator lattice

The PETRA IV accelerator lattice fulfills all the requirements to produce X-ray beams with unprecedented brightness. PETRA IV will be the world leading machine.

The lattice is based on a novel cell structure (H6BA) that is replicated identical across all octants (72 cells) achieving 20 pm electron beam emittance with >10h beam lifetime and off axis injection.

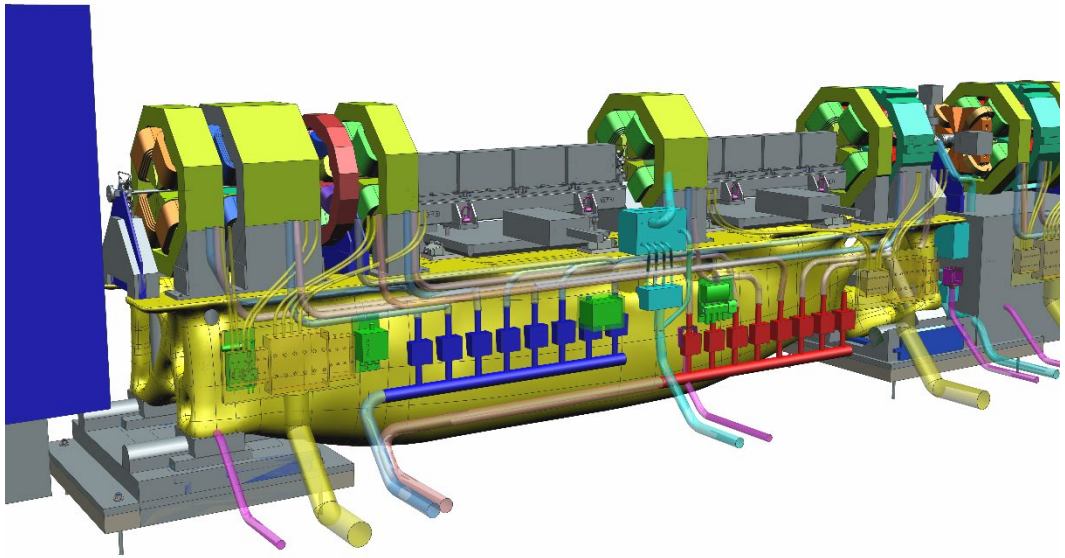


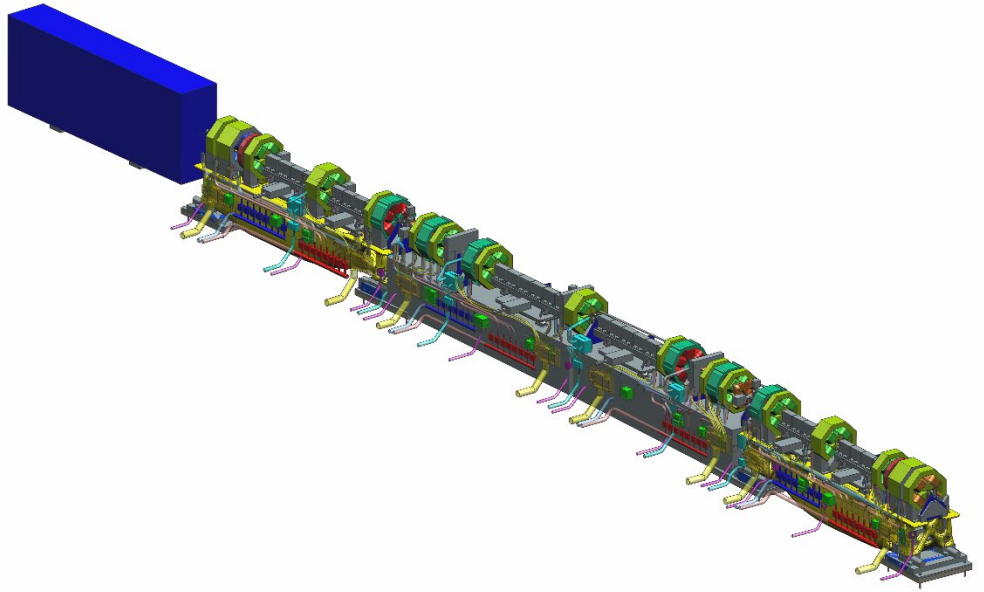


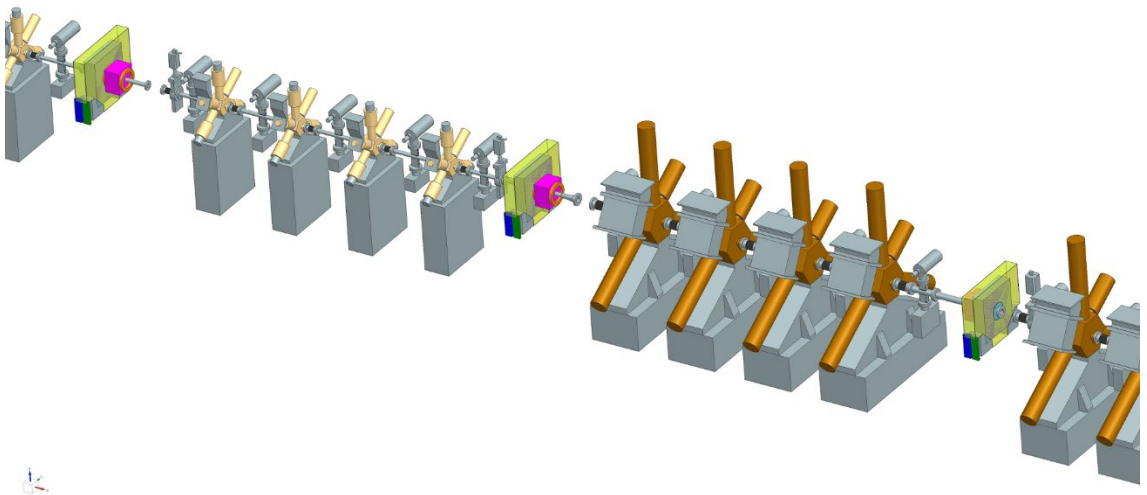
Engineering integration of the cell in progress (TDR)

Ongoing work:

- engineering integration of all components in the cell on the girders
- check on space envelope and clashes
- design of the extraction photon pipe
- implementation of the canted photon beamlines
- implementation of RF section
- implementation of services



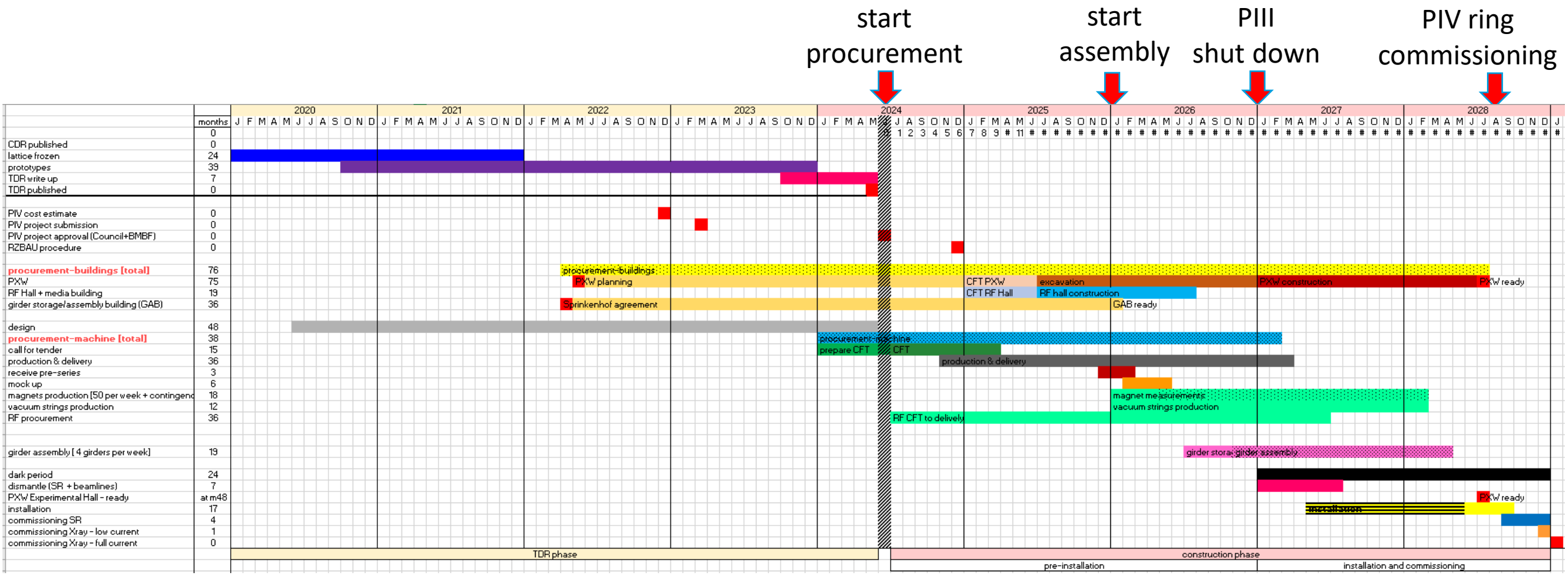




PETRA IV project schedule

The draft breakdown below hinges on

- Project approval in mid 2024
- Call for tender placed in mid 2024
- Dark period ~24 months
- First light in Jan 2029



Conclusions

- PETRA III operates with high availability
- PETRA III supports development of PETRA IV with study beam time wherever possible
  - RF and diagnostics installations done in summer shutdown
- Beam operation @ 5 GeV could reduce the PETRA III complex power consumption by ~20%, however performance loss vs. saving potential seems unreasonable for beamlines and users.
- The PETRA IV project is in the TDR phase, approval in 2024?

Thank you for your attention

Contact

DESY. Deutsches
Elektronen-Synchrotron

www.desy.de

Michael Bieler
MBB
bieler@desy.de
0049 40 8998 3805

Comparison Energy Consumption: 6 GeV vs. 5 GeV

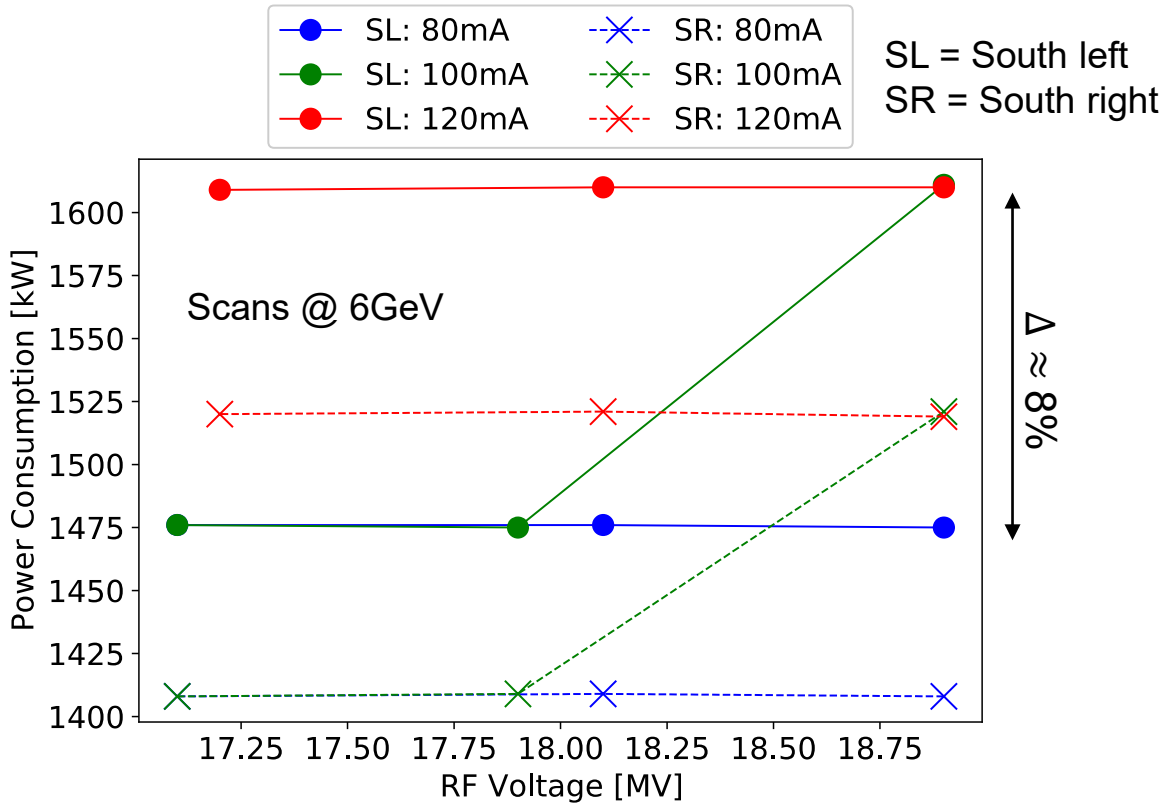
Main contributions are magnet current reduction and required RF power

Power consumption at 6 GeV vs. 5 GeV

	PETRA III 15.08.2022 9:55	PETRA III 09.09.2022 12:35	Differenz 15.08-09.09	relative Differenz
Energie / GeV	6	5	1.0	16.7%
Strahlstrom / mA	100	100	0.0	
HV-Spannung / MV	19	15	4.0	21.1%
Leistungsaufnahme / kW				
Geb 47c Sektoren	204.4	200.0	4.4	
Geb 47c Halle	314.4	282.0	32.4	
Geb 47 c Tunnelelektrante	156.0	163.8	-7.8	
Geb 47 c Magnetstrom	135.2	94.0	41.2	
Sender SL	1614.1	1244.8	369.3	
Sender SR	1657.0	1173.0	484.0	
Magnete	1695.3	1131.0	564.3	
Summe PETRA III	**5776.4**	**4288.6**	**1487.8**	25.8%
Vorbeschleuniger				
LINAC II	973.9	910.2	63.7	
DESY Sender	516.4	516.0	0.4	
DESY Magnete (geschätzt)	500.0	500.0	0.0	
Total	**7766.7**	**6214.8**	**1551.9**	20.0%

Comparison Energy Consumption: 6 GeV vs. 5 GeV

RF Voltage and Beam current scan



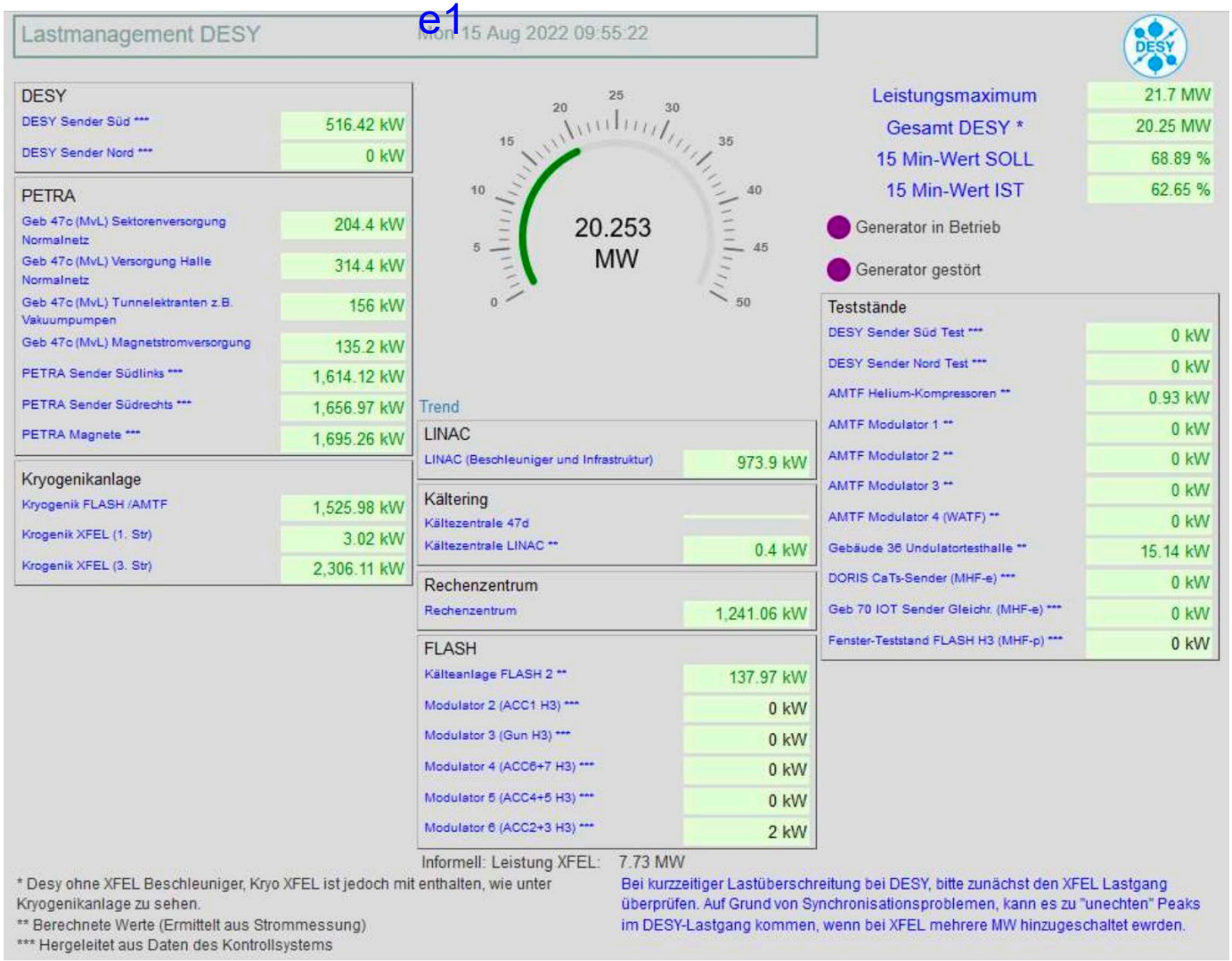
Power consumption of RF transmitter at 6 GeV with 480 bunches for different beam currents and RF voltages

PETRA III, 6 GeV, 480 Bunche				
21.09.22			Senderleistung	
Zeit	Strom/mA	Spannung/MV	P_SL/kW	P_SR/kW
16:00	80	**18.9**	1475	1408
16:05	80	18.1	1476	1409
16:10	80	17.1	1476	1408
16:20	100	17.1	1476	1408
16:23	100	17.9	1475	1409
16:26	100	**18.9**	1611	1521
16:32	120	18.9	1610	1519
16:36	120	18.1	1610	1521
16:39	120	17.2	1609	1520

Power Consumption at DESY

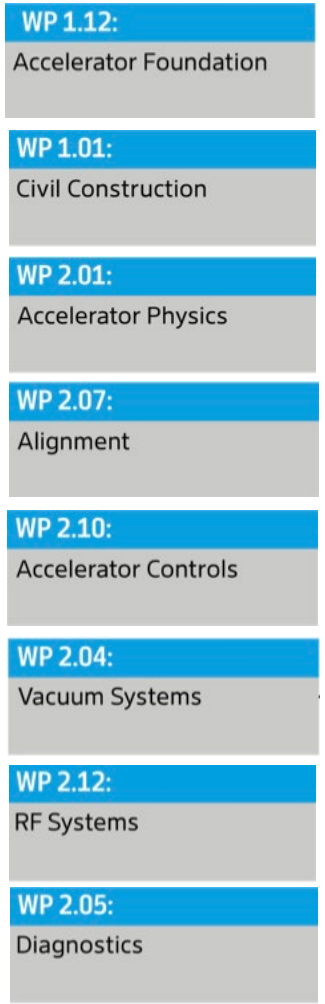
15.08.2022, 40 bunches, 100 mA (Reference)

http://cssweb.desy.de:8084/sdsweb/display/LastmanagementVariante1



PETRA III is Study Framework for PETRA IV Development

Diverse studies involve several groups and work packages



Beam stability concepts

- Monitoring of environmental parameters
- Evaluation of ground vibrations
- Orbit analysis
- Modelling of data
- Girder movers

Accelerator physics / beam dynamics

- Test of commissioning strategies
- High level software
- Test of algorithms
- Impedance model

Technical subsystems

- RF system
- Diagnostics

Selection of studies planned for 2022

Implementation of alternative methods to measure optics, chromaticity and coupling

Impact on orbit when moving a girder (December 2022)

Vibrations due to civil construction (mid 2022)

Installation of diagnostic components: Current monitor, BPM (summer shutdown 2022)

Preparation for PETRA IV test cavity (installation in 2023)

For a more complete list see back-up slides

Diverse Studies at PETRA III support PETRA IV TDR

PETRA IV resources support studies at PETRA III

Performed 2021

Truck movement → impact on orbit

Correlation of temperatures with mechanical measurements in the tunnel

Correlation with orbit data

First turn threading, test of software interface

Collaboration with SLAC
robust conjugate direction search (RCDS)

Collimator wakefields

Installation of waveguides for the cavity test
Preparation for the solid state amplifier

Test of new BPM electronics (new Libera hardware)
Diagnostic test with 2 ns bunch filling pattern

Planned for 2022

Implementation of faster methods for optics, coupling and chromaticity measurements

Development of machine learning tasks

Test to move a girder → impact on orbit

Vibration test for PXW Hall construction

Installation of a solid state amplifier

Preparation for the installation of a single Cell 500 MHz PETRA IV cavity

Installation of cavity postponed to 2023, due to delayed delivery of components

Installation of diagnostic components:
Current monitor, BPM
(summer shut down 2022)

Curing of crack between tunnel segments in SWR 37