PETRA IV.
NEW DIMENSIONS

# Accelerators report

PETRA IV TDR Phase - Progress Review Meeting

Riccardo Bartolini

PETRA IV Machine Project Leader

Hamburg, May 11th, 2023

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

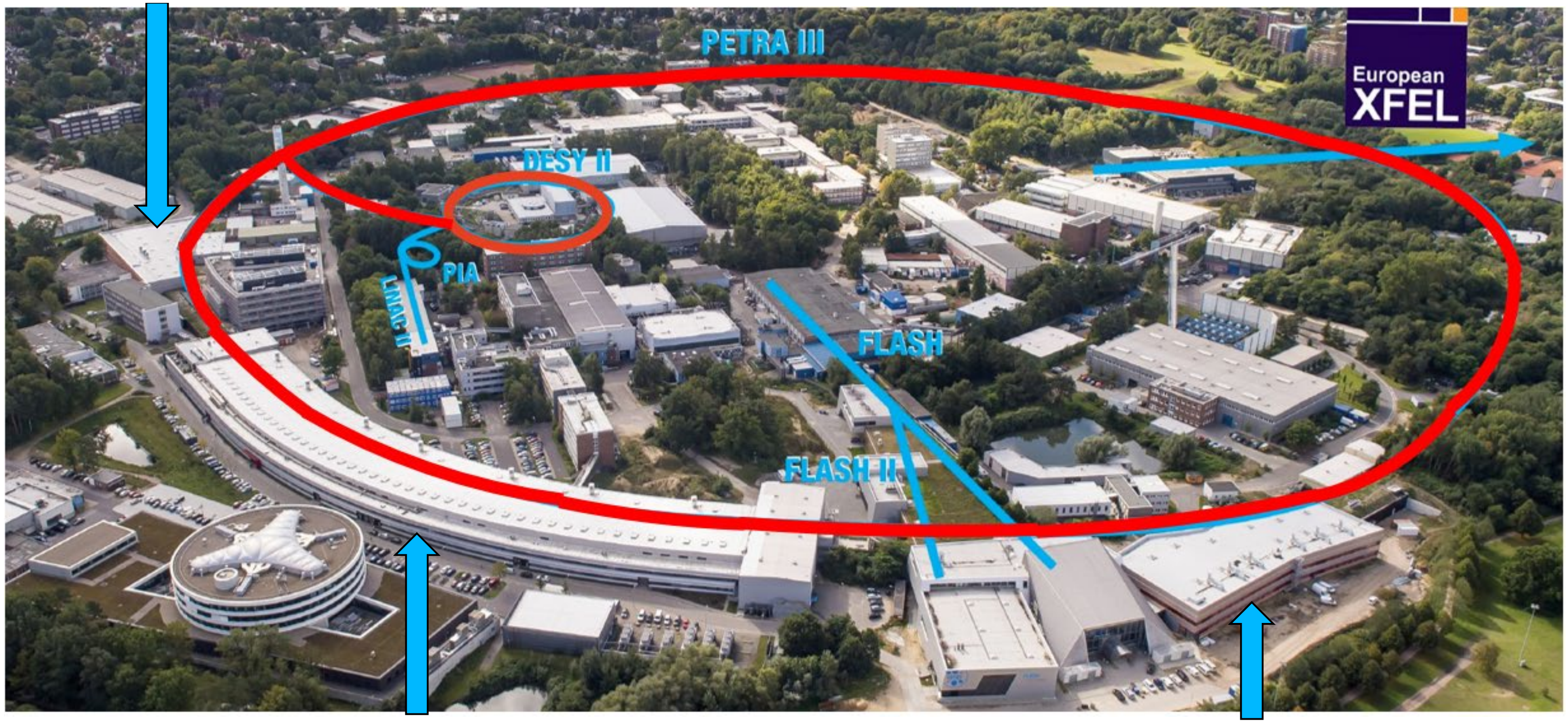
# Outline

- Present status and organization of the PETRA IV machine project
  - The TDR phase
  - The project phase
- Highlights of technical activities
  - Updates on prototype programme
  - Measures to reduce the requirements on PETRA IV infrastructure
- Conclusion and future work

# PETRA III is one of the core facilities at DESY

## Each year ~5000h of operation serve more than 3300 users

Ada Yonath Hall
Extension Hall East




Max von Laue Hall

Paul P. Ewald Hall
Extension Hall North

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

PETRA III emittance 1300 pm

65 times smaller

PETRA IV emittance 20 pm

enabling 500 times larger X-ray beams brightness

# PETRA IV project:

**replacing PIII with an ultra-low emittance ring, adding a new Experimental Hall in two more octants, replacing DESY II with a new low emittance booster**

# Status of the *PETRA IV TDR phase project*

PETRA IV. NEW DIMENSIONS

**PETRA IV TDR phase**: the organisational structure (WBS) and timeline is settled since May 22.

The WBS is based on four WPGs (civil engineering, machine, beamlines, technical coordination).

**Deliverables:**

Design and prototype activity should be completed in order to start the call for tender.
Write up of the TDR in parallel.
Project structure and cost estimates.
The timeline hinges on project approval by ~June 2024 (t=0) anm 2 years dark time.

Progress in all technical activities
- civil infrastructure: PXW, RF hall, GAB, tunnel access and service buildings
- consolidate logistic plan and first draft installation plans
- engineering integration (including DESY IV and transfer lines)
- beamline portfolio finalised

Major effort went into the write up of the project proposal to be submitted to the BMBF.

# Progress since fall 2022 – the project proposal

*We wrote a project proposal to be submitted to the funding agency (BMBF)*

*- sound cost estimate ($\pm$10% error) should be ready by December 2022*

**[completed – external(DESY) assessment planned]**

*- funding decision necessary by Q2 2024 –* ***June 2024 is fixed as time t = 0***

**[still valid]**

*- expectation for budget availability is Q1 2025.*

*The TDR project will continue for the Q2 2024 with bridging funds from DESY*
*The submission of the project proposal is decoupled from the publication of the TDR*

After the go-ahead from TAC, MAC and PSC, the project proposal was written in December 22 - March 23. Summary of the science case was submitted to the DESY Directorate on March 7th and evaluated by the DESY Scientific Council on March 15th. Evaluation by DESY Council happened on 29th March (Scope and Budget). FIAC review on May 5th 2023.

Submission to the BMBF ready by end May 2023.
*However it is still unclear what funding call or route we should follow.*

# The project proposal took a large effort from all the team!

PETRA IV. NEW DIMENSIONS

- Appendix 1: Project Budget
- Appendix 2: Financial Structure
- Appendix 3: Operation & Decommissioning Budget
- Appendix 4: Economic Risks
- Appendix 5: Project - WPG 1 Civil Construction
- Appendix 5: Project - WPG 2 Accelerators and Storage Ring
- Appendix 5: Project - WPG 3 Photon Science Experiments
- Appendix 5: Project - WPG 4 Technical Coordination and Logistics
- Appendix 6: Project - Management Concepts
- Appendix 7: Governance
- Appendix 8: Project Risks
- Appendix 9: Requirements & Stakeholder Analysis
- Appendix 10: Access Management
- Appendix 11: Business Model
- Appendix 12: Data Management
- Appendix 13: Competitors
- Appendix 14: Code of Conduct
- Appendix 15: Sustainability

The document counts ~1000 pages (~300 in the accelerators section)

It is supported by cost estimates for all WPs (subsystems)

It forms an excellent basis for the TDR

*We still maintain the starting date of the project to June 2024 (t=0).*

*All design effort in the meantime will focus on measure to reduce the power consumption and the requirements on the infrastructure.*

*The cost envelope is fixed!*

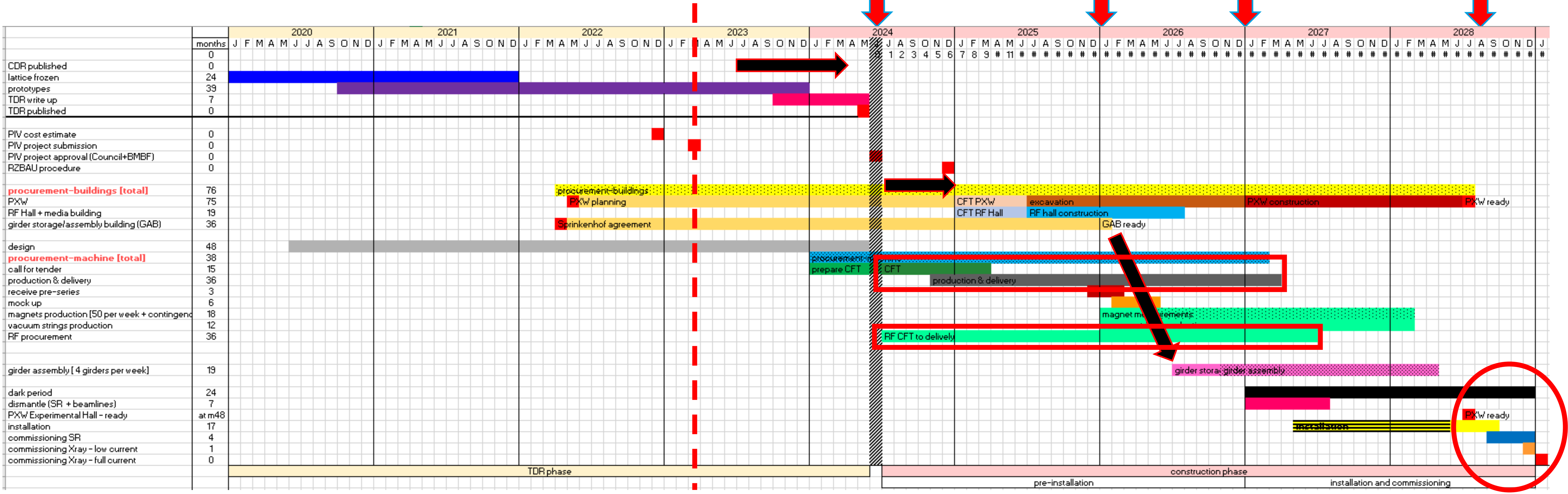
# The *PETRA IV project* timeline is still challenging

TDR extended with bridging fund from DESY
(5M per year in 2023 - 2024)
Procurement estimated to 3 years
GAB occupation by Jan 2026
PXW occupation by August 2028
Installation completed October 2028
Three months commissioning time

The draft breakdown below hinges on
- Project approval in mid 2024
- Call for tender start in mid 2024
- **Dark period 24 months**
- **First light in Jan 2029**

**the project is built on the basis of these 2 constraints**

start procurement
start assembly
PIII shut down
PIV ring commissioning



# Cost of *PETRA IV project* and operation have been estimated

PETRA IV. NEW DIMENSIONS

| PETRA IV | DESY's Own Contribution | | | Third Party Funding | | | Sum |
|---|---|---|---|---|---|---|---|
| | Personnel | | Investments | Personnel | | Investments | |
| | PY | Mio.€ | Mio.€ | PY | Mio.€ | Mio.€ | Mio.€ |
| Accelerators | 580 | 52.8 | 40.0 | 344 | 31.4 | 328.1 | **452.3** |
| Experiments | 634 | 57.7 | | 365 | 33.3 | 223.5 | **314.5** |
| Logistics | 22 | 2.0 | | 180 | 16.2 | 13.2 | **31.4** |
| Infrastructure | 109 | 9.9 | | 185 | 16.9 | 665.8 | **692.6** |
| Safety | 19 | 1.7 | | 24 | 2.4 | 20.0 | **24.1** |
| Management | 52 | 4.7 | | 219 | 19.8 | 2.4 | **26.9** |
| Sum in Mio.€ | | **128.8** | **40.0** | | **120.0** | **1,253.0** | **1,541.8** |

29.3%

PY = person/year over the project 5 years (machine project ends in 2029)

on the accelerators:
580/5 = 116 FTEs from DESY
344/5 = 69 FTEs new recruits
and 30 already hired in the TDR phase

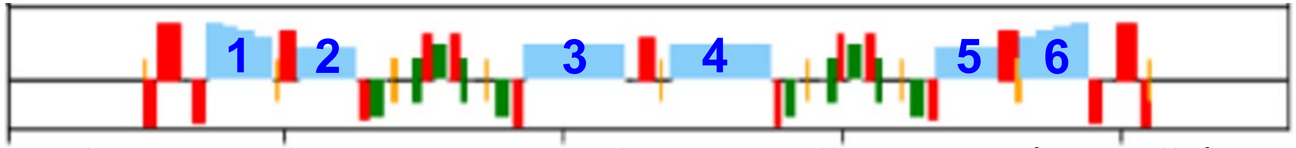
| Operation Budget in M€ | PETRA III | | PETRA IV | |
|---|---|---|---|---|
| **Personnel** | | **37.6** | | **51.3** |
| Accelerator operation | 108 FTE | | 139 FTE | |
| Experiments | 145 FTE | | 206 FTE | |
| **Recurrent** | | **14.8** | | **20.3** |
| Electricity (2022 price) | 10 M€ | | 13.3 M€ | |
| consumption | 74.3 GWh | | 98.4 GWh | |
| other recurrent costs | 4.8 M€ | | 7.0 M€ | |
| **Invest** | | **8.4** | | **21.3** |
| **Total** | | **60.8** | | **92.9** |

on the accelerators
108 → 139 FTE
mostly in controls and infrastructure groups
74.3 → 98.4 GWh
mostly due the cooling and air conditioning in the **whole tunnel + PXW**
**~ 8 MW for accelerators in routine ops (6 MW SR + 2 MW injector)**

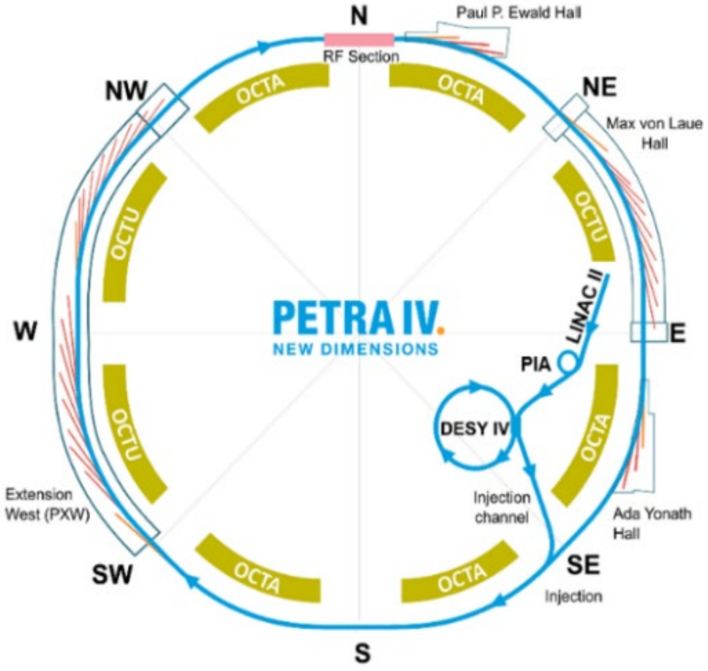
# The lattices of PETRA IV and DESY IV are frozen

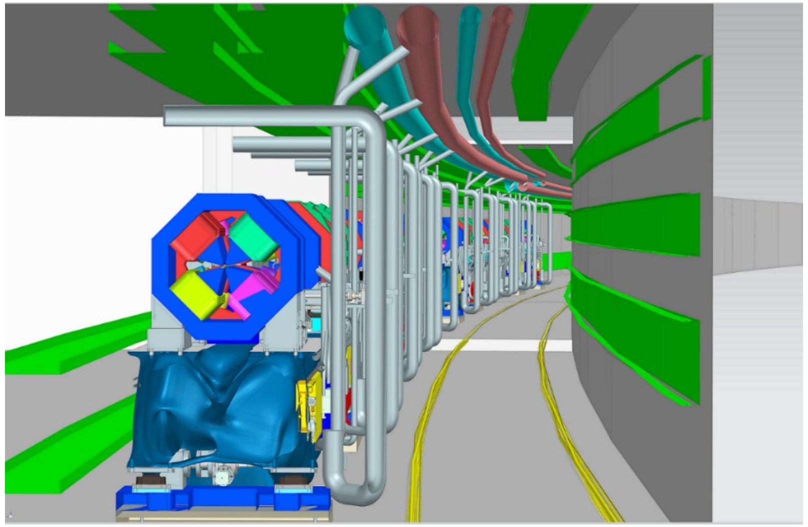
Minor chances are due only to engineering integration

The PIV lattice is based on a novel cell structure (**H6BA**)

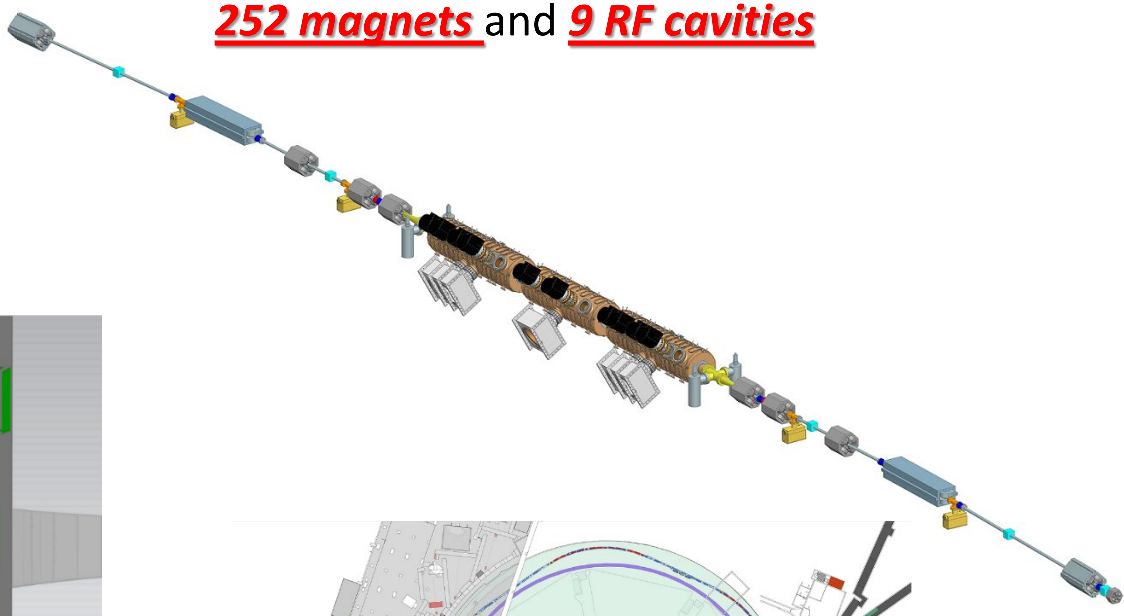


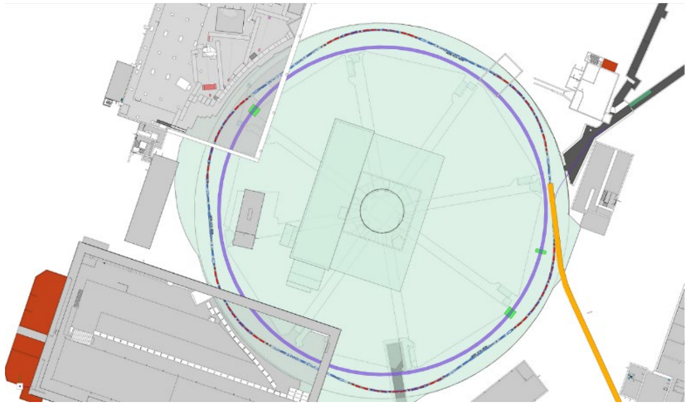

that is replicated identical across all octants (72 cells)



The DESY IV booster (316.8m) will have ***252 magnets*** and ***9 RF cavities***





# Magnets design for Storage Ring almost completed

| Accelerator | Magnet | Quantity |
|---|---|---|
| PETRA IV  | PQA | 128 |
| | PQB | 128 |
| | PQC | 128 |
| | PQD | 144 |
| | PQE | 576 |
| | PQF | 72 |
| | PQG | 162 |
| | PQH | 14 |
| | PQK | 1 |
| | PSA | 432 |
| | POA | 288 |
| | PCA | 576 |

Each arc (octant) contains 9 cells
The ring contains 8 octants

The **arcs** contains (cell*72):

| | |
|---|---|
| 432 | DLQs permanent magnet dipoles |
| 1224 | quadrupoles |
| 432 | sextupoles |
| 288 | octupoles |
| 216 | standalone correctors |

Including the straight sections, it is about 4000 magnets

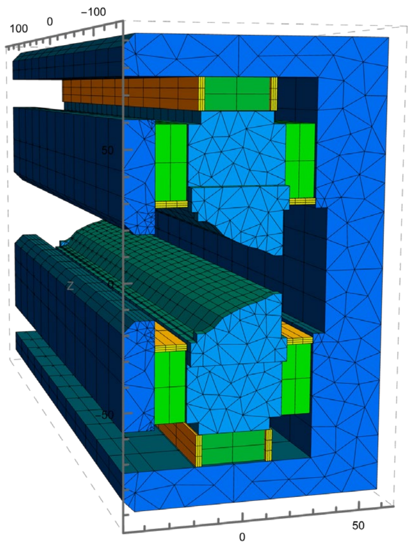
PM dipoles reduce power consumption by 1.6 MW and require no cooling.

*Measures to reduce the power consumption and the requirements on the infrastructure are being looked at*

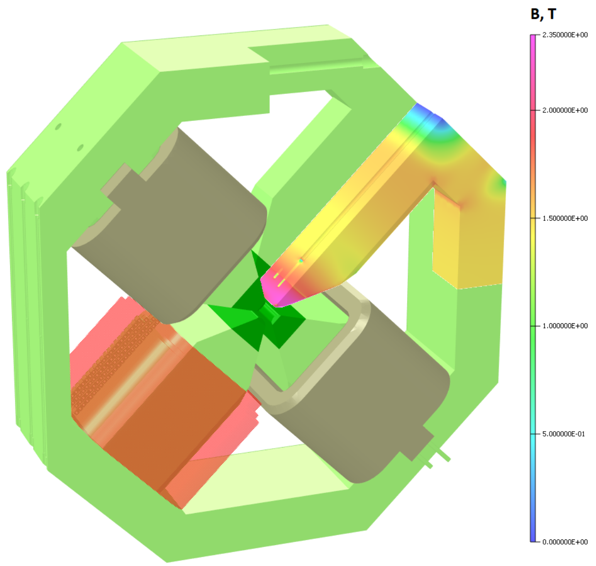
# Reducing the power consumption with PM and optimisation of the resistive magnets design

To reduce the power consumption PM are extensively used (432 dipoles) and the design of the pole materials and yoke has been optimized for all resistive magnets

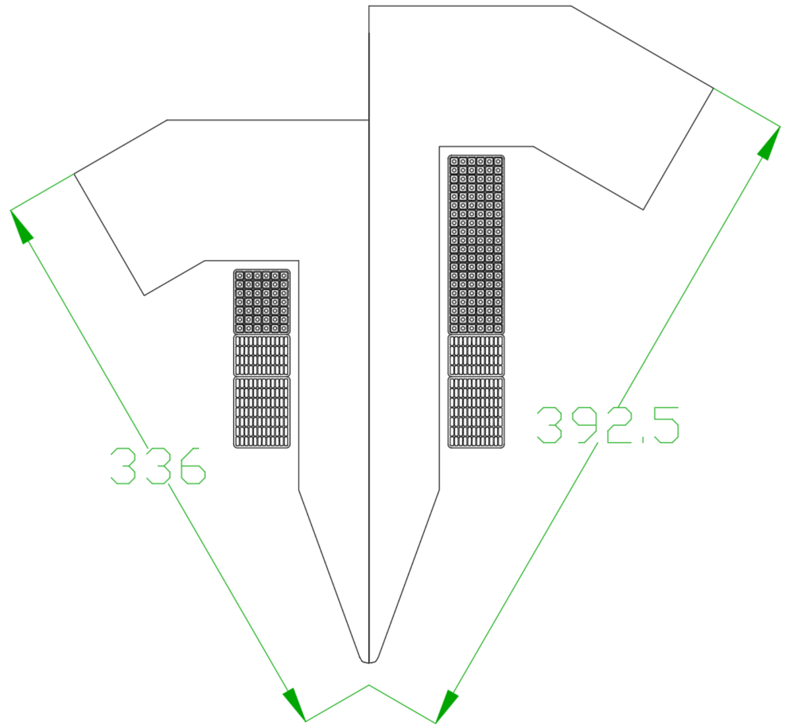
Permanent magnet dipoles DLQs




Cross section of PQA 115 T/m




Enlarged coil section of PSA sextupole

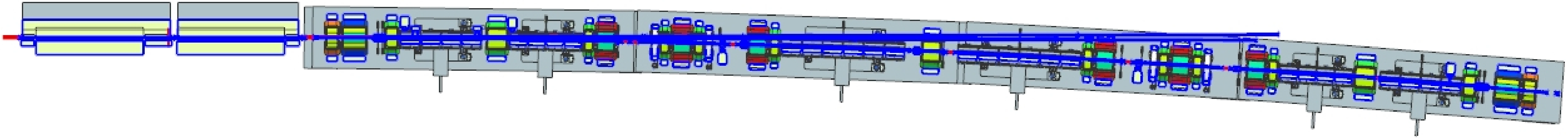



The coil size and the cooling diameter of the quadrupoles has been chosen to reduce the current density at the cost of a slight increase of the allowed temperature increase

*Courtesy M.Tischer, A. Aleov and M. Thede*

# Vacuum

The vacuum system guarantees a residual pressure < $10^{-9}$ mbar over the 2.3 km circumference in routine operation



*Extensive use of NEG eliminates the need of pumps and reduce the power consumption.*

Additional equipment and related electronics controllers, are equally distributed around the ring:

- 1000 pumps (SIPs and TSPs)

*Modern and more efficient power supplies will be installed, as compared to PETRA III*

The vacuum chambers must be cooled to take the heat load from synchrotron radiation generated by the electron beam – flow on absorbers (800 kW with a flow < 1 litre/min – 4 bar pressure).

*Correct dimensioning of the cooling system to cater for ~400 kW*

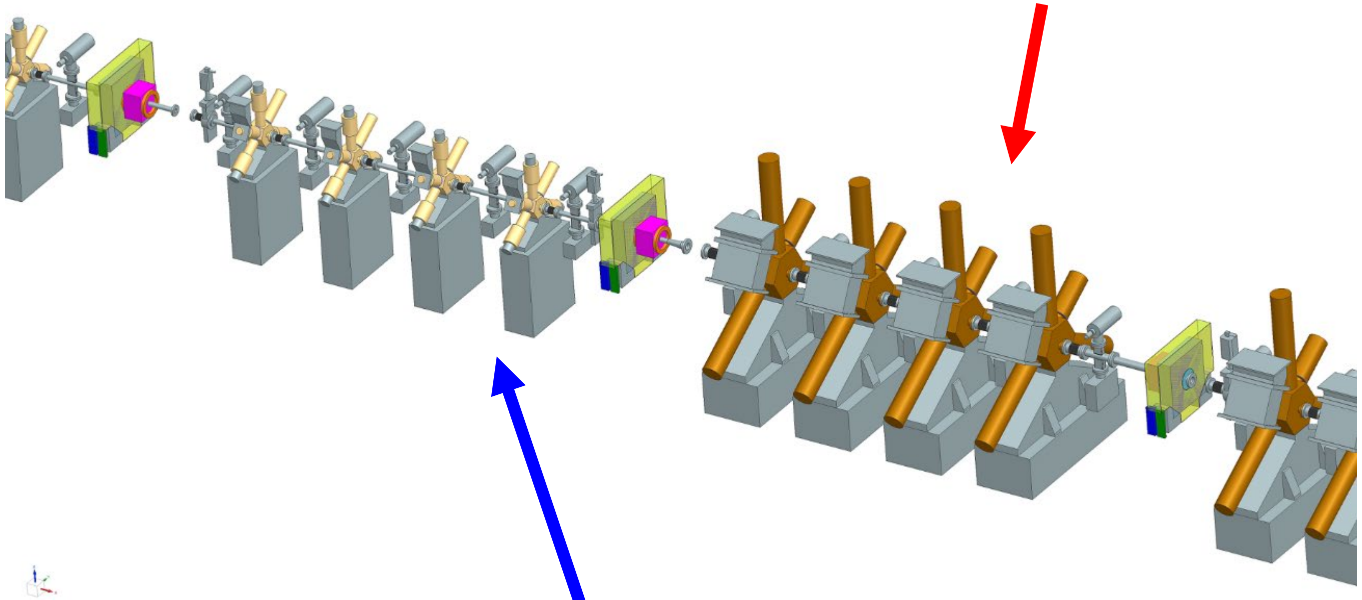
*Strict avoidance of additional cooling circuits for Aluminum chambers (in the IDs and damping wigglers)*

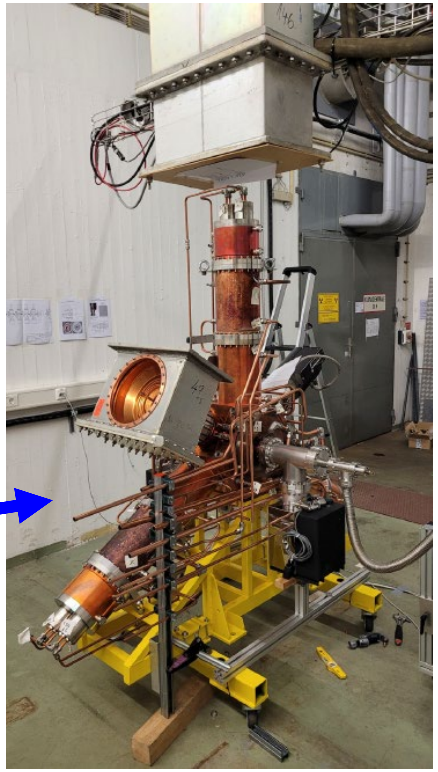
# The RF system is designed. Prototypes are on-site and tested

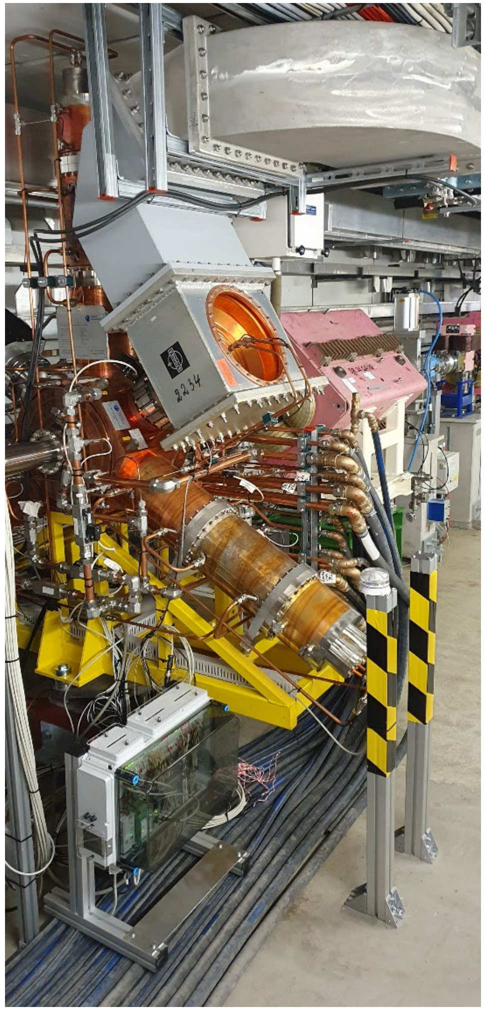
PETRA IV.
NEW DIMENSIONS

The RF system provides the voltage (8 MV) and RF power necessary to keep the beam at the right energy in the machine. It will be installed in the straight section (North) and contains

***24 RF cavities:*** 500 MHz cavities







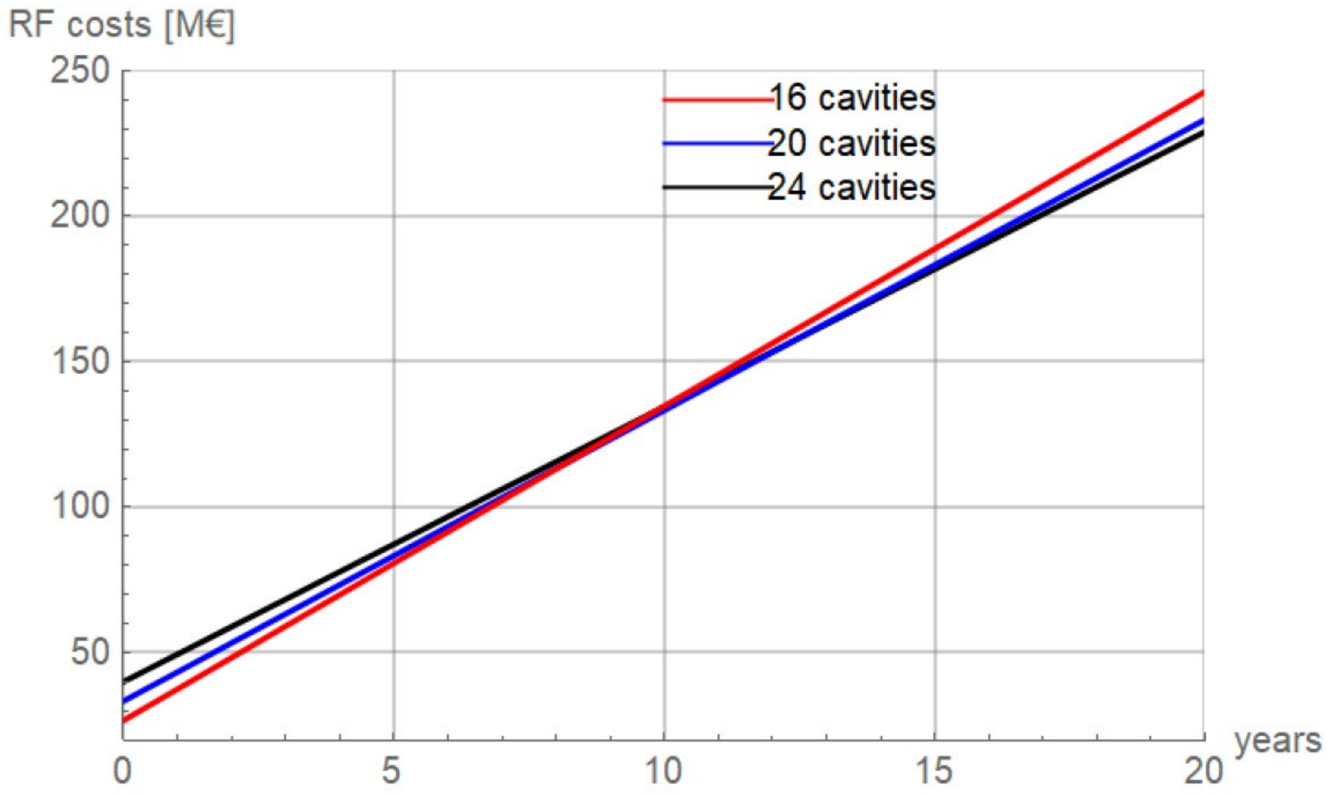
***24 harmonic RF cavities***: 1.5 GHz third harmonic cavities

Grouped in six stations of four 500 MHz cavities and four 1.5 GHz harmonic cavities

*Courtesy R. Onken and P. Huelsmann*

# RF infrastructure

The total number of RF cavities was discussed considering the trade off between construction cost operating cost and reliability. The TAC endorses the RF architecture.




The initial cost of 24 RF cavities can be re-absorbed after 10 years operation (at 400 euros/kWh)

Although the number of cavities is kept to 24 the design of the cooling circuits will be optimized to merge them as much as possible and reduce them from the 6 independent cooling circuit presently in the cost estimates.

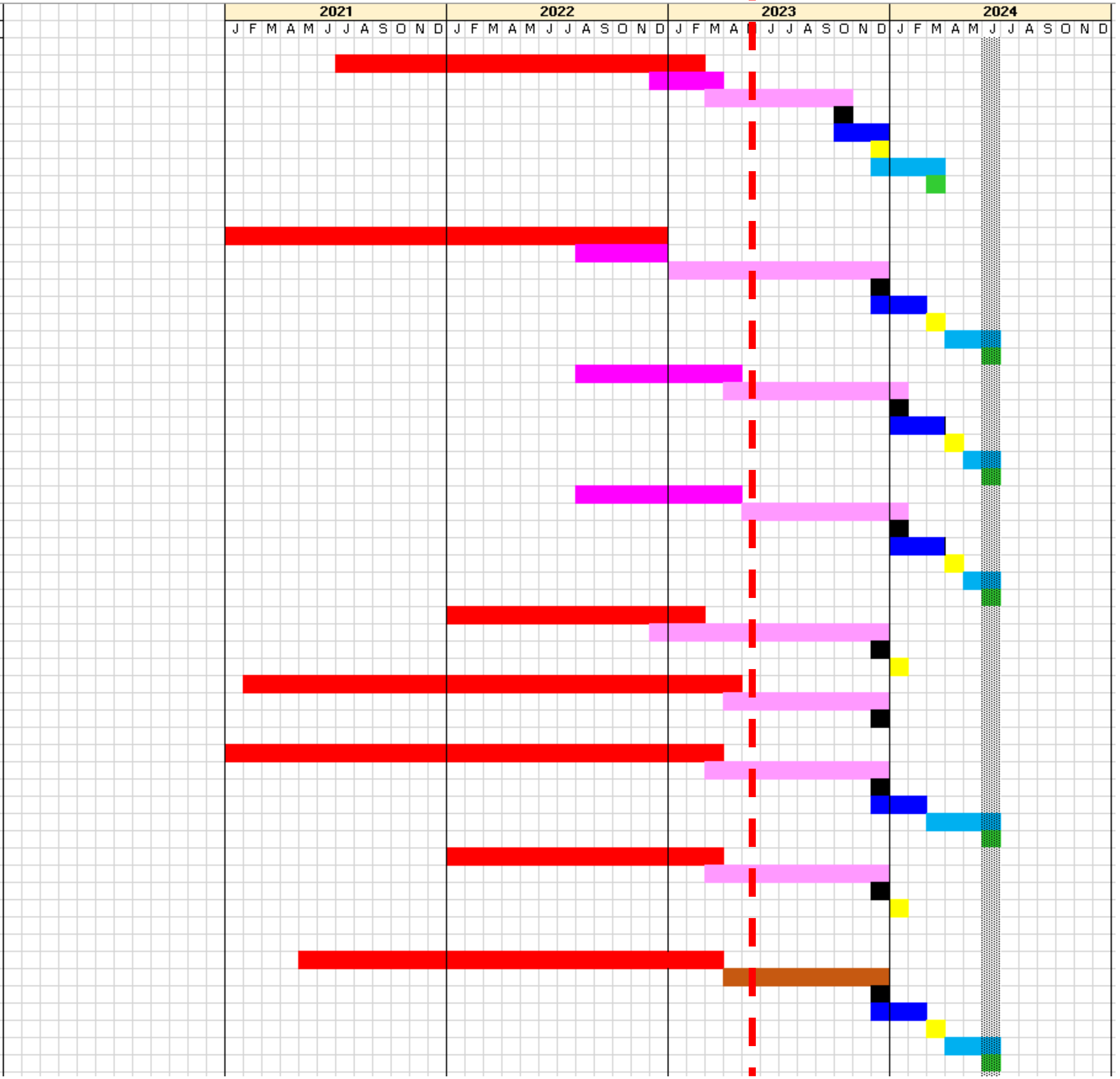
The total **power consumption** of the RF cavities is about **1.35 MW**
Including the SSAs (50% efficiency) the total RF power is about **2.7 MW**

Including conditioning mode, the total power can rise to 4.8 MW.

# Mock-up of a fully equipped girder is underway

PETRA IV. NEW DIMENSIONS

| *NEW TIMELINE for TDR girder* | months |
|---|---|
| **Girders** | |
| Design | |
| CFT for prototype | 4 |
| Order prototype | 8 |
| prototype girder delivered | 0 |
| prototype girder test complete | 3 |
| girder ready for TDR girder (b36) | 0 |
| Girder desing finalised | 3 |
| CFT for final girders | 0 |
| | |
| **Resistive Magnets** | |
| Design (magnetic and mechancal) | |
| PQA prototype CFT | 5 |
| PQA order | 13 |
| PQA prototype magnet delivered | 0 |
| PQA prototype magnets test complete | 3 |
| PQA ready for TDR girder (b36) | 0 |
| PQA desing finalised | 3 |
| PQA series CFT | 0 |
| PSA prototype CFT | 9 |
| PSA order | 10 |
| PSA prototype magnet delivered | 0 |
| PSA prototype magnets test complete | 3 |
| PSA ready for TDR girder (b36) | 0 |
| PSA desing finalised | 2 |
| PSA series CFT | 0 |
| S/F corrector prototype CFT | 4 |
| S/F corrector order | 9 |
| S/F corrector prototype magnet delivered | 0 |
| S/F corrector prototype magnets test complete | 3 |
| S/F corrector ready for TDR girder (b36) | 0 |
| S/F corrector desing finalised | 2 |
| S/F corrector series CFT | 0 |
| dummy magnets design | 14 |
| dummy magnet procurment (internal) | 13 |
| dummy magnets delivered | 0 |
| dummy magnets ready for TDR girder (b36) | 0 |
| climatic cabin CFT | 26 |
| cliamtic cabin installation | 9 |
| climatic cabin delivered | 0 |
| **Permanent Magnets DLQs** | |
| DLQ prototype magnets design | 27 |
| DQL prototypemagnet procurment (internal) | 10 |
| DLQ prototypemagnets delivered | 0 |
| DLQ prototype test | 3 |
| DLQ desing finalised | 4 |
| DLQ series CFT | 0 |
| dummy magnets design | 15 |
| dummy magnet procurment (internal) | 10 |
| dummy magnets delivered | 0 |
| dummy magnets ready for TDR girder (b36) | 0 |
| | |
| **Vacuum** | |
| Design (vacuum and mechancal) | 23 |
| manufacturing prototype vessel (DESY) | 8 |
| prototype vessels delivered | 0 |
| prototype vessels test complete | 3 |
| prototype vessel ready for TDR girder (b36) | 0 |
| Vessels desing finalised | 3 |
| CFT for final vessel | |




**Girder prototype**

specs doc written

with DESY procurement

**PQA prototype**

contract placed with SIGMAPHI

**PSA prototype**

second round of CFT

**S/F corrector prototype**

specs almost finalized

**Dummy magnet** in-house

(climatic cabin with DESY procur.)

**DLQ prototype**

specs almost finalized

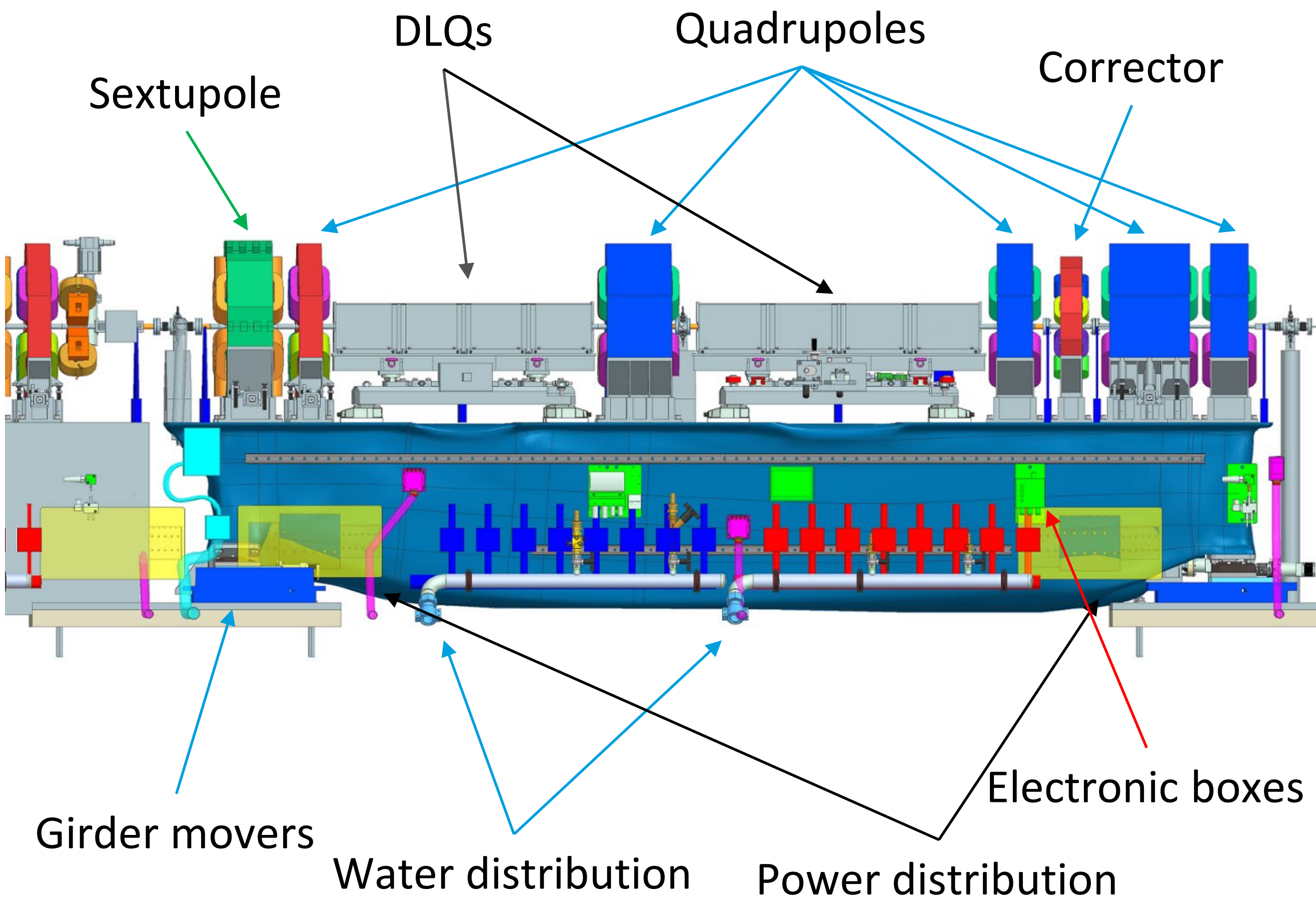
**Dummy magnet** in-house

**Vacuum chambers prototype**

in-house manufacturing

# Scope and sequences of tests is being collect

| Number | Task | Goal | responsible WP 2.xx | Duration |
|---|---|---|---|---|
| 1 | Measure EF's of the bare Girder | Same EF'S as simulation | 06 | 1 day |
| 2 | Measure transfer functions G2G | gain information for feedback | 06 | 2 days |
| 3 | Measure deflection of bare vs equipped Girder | Same EF'S as simulation | 06 | 1+1 day |
| 4 | Measure EF's of the equipped Girder | Same EF'S as simulation | 06 | 4 days |
| 5 | Measure EF's of the Magnets on the equipped Girder | gain information for feedback | 06 | 5 days |
| 6 | Measure vibrations generated on the Girder | gain information | 06 | |
| 7 | Mover Tests | see if the girder can be moved | 06,xx | 7 days |
| 8 | Magnet placement/coarse alignment | be able to align +-0,2mm | 06,07 | 5 days |
| 9 | Magnet fine alignment | | 07,06 | |
| 10 | Girder Transport test, fine aligned | | 07,06 | |
| 11 | Girder Transport test, equipped coarse aligned | see if magnets fall off | 07,06 | |
| 12 | test gluing procedure | check time needed | 07,06 | 12 days |
| 13 | Assembly test vacuum system supports | Initial verification of assembly concept | 04 | |
| 14 | Assembly test vacuum string | Verify GAB-like installation of full string | 04 | |
| 15 | Assembly test for activation configuration | Verify that activation can be done | 04 | |
| 16 | Tests on cable routing and cooling for vacuum system | Ensure access to all relevant components during operation. Ensure Maintainability. | 04 | |

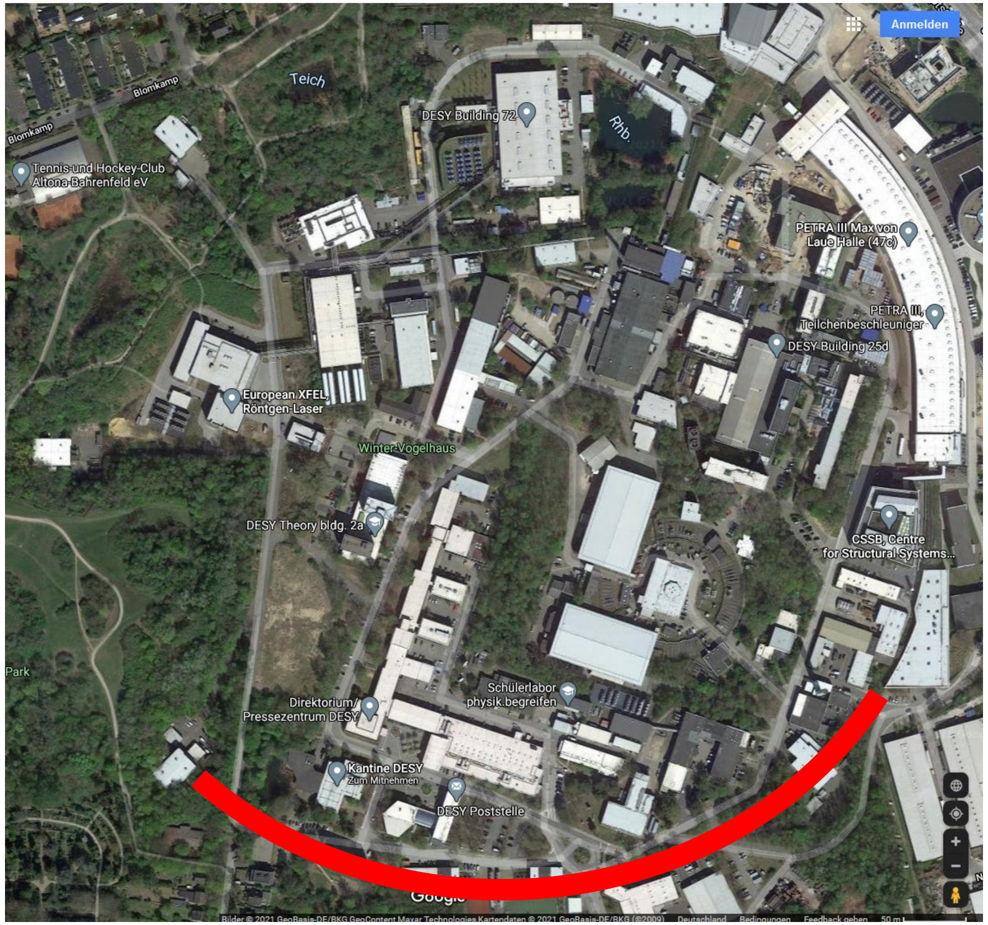


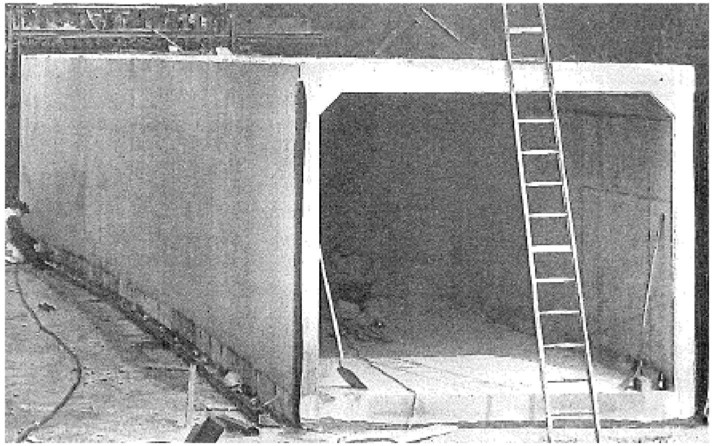

*Courtesy N. Koldrack and C. Kula*

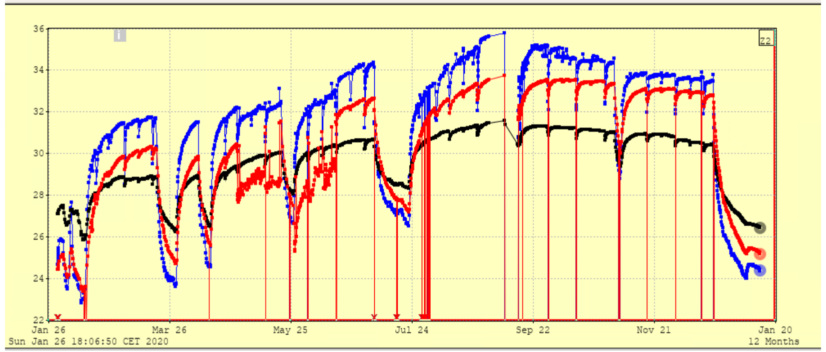
# Accelerator stability and related infrastructure

PETRA IV. NEW DIMENSIONS

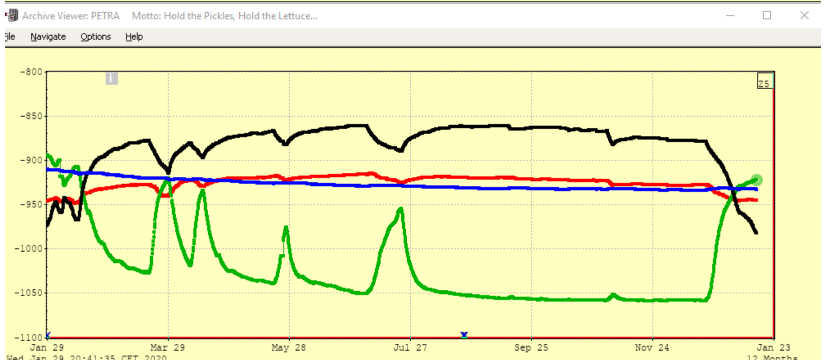
PIV will reuse a large part of the original PETRA tunnel






Temperature up to $\Delta T \sim 10$ °C



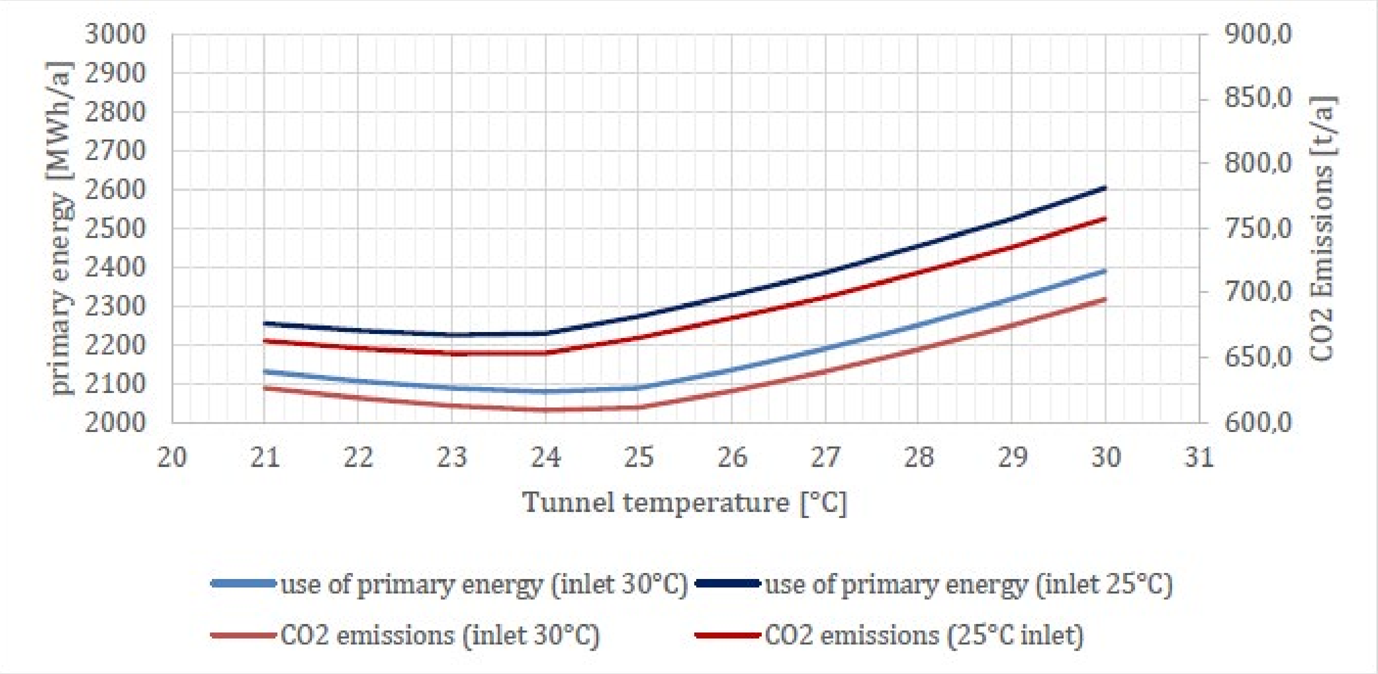

Movement up to 200 μm

*Courtesy M. Bieler*

# Power consumption and cost reduction measures

Operating temperature in the tunnel:

- definition of the operating temperature in the tunnel set to 25 °C.
- temperature stability requirements ±0.5 °C locally and ±1.5 °C across the whole tunnel as dictated by the permanent magnet temperature stability
- ongoing discussions on the inlet temperature of the water and the allowed $\Delta T$ in the magnet
- complex thermal simulations of the tunnel temperature distribution started with the collaboration of the Fraunhofer institute in Magdeburg




The power consumption of the cooling system is computed as a function of the operational tunnel temperature under different choices of the parameters above

and integrated over one year

to take into account of different external conditions balance winter/summer conditions

(rep WP104-rep-0001)

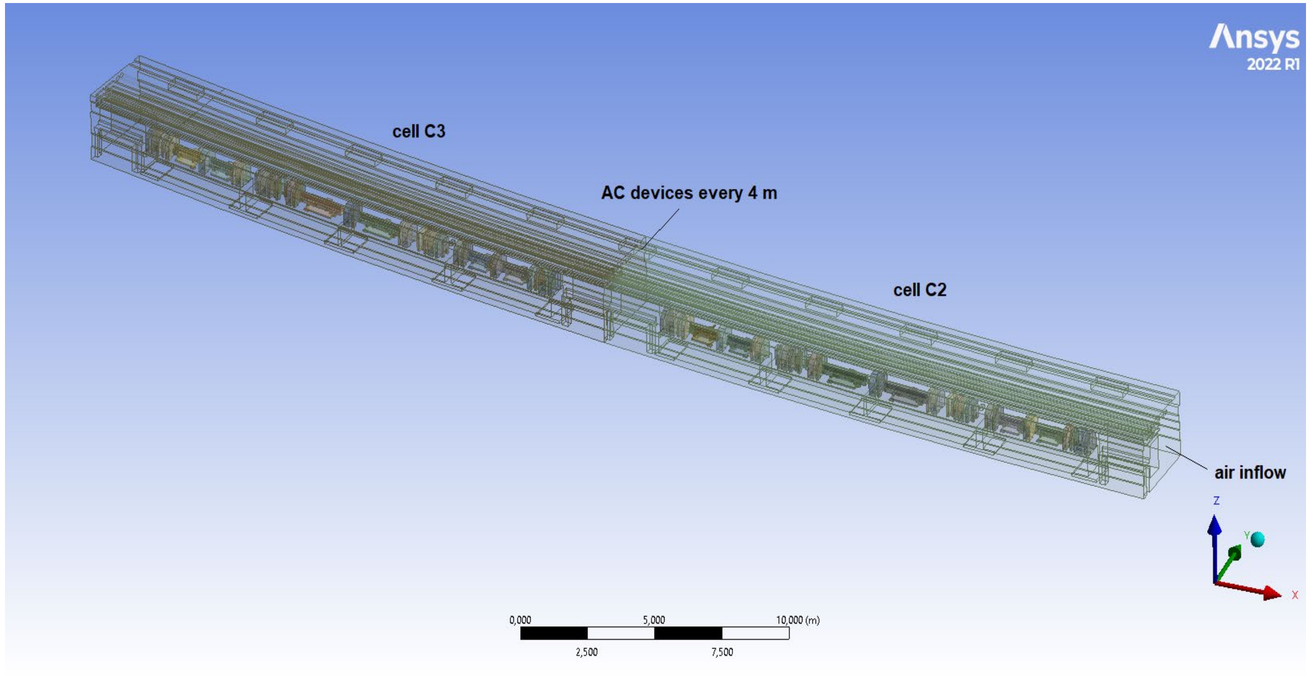
***Courtesy T. Warnecke***

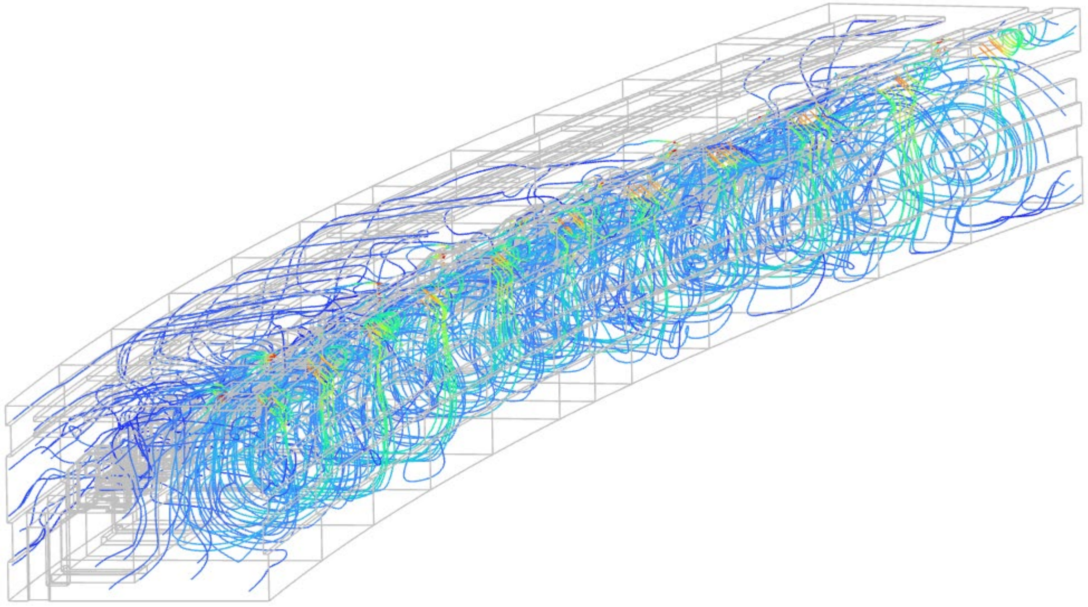
# Accelerator stability and related infrastructure

Temperature required to guarantee the stable operation of the accelerator is 0.5 °C locally (and 1.5 °C across the whole ring)

Water cooling of magnets, and vacuum system required (4 bars)
Air Handling Units (AHU) necessary to guarantee local temperature stability

Complex thermal calculation to guarantee the thermal stability are done in collaboration with Fraunhofer Institute Magdeburg

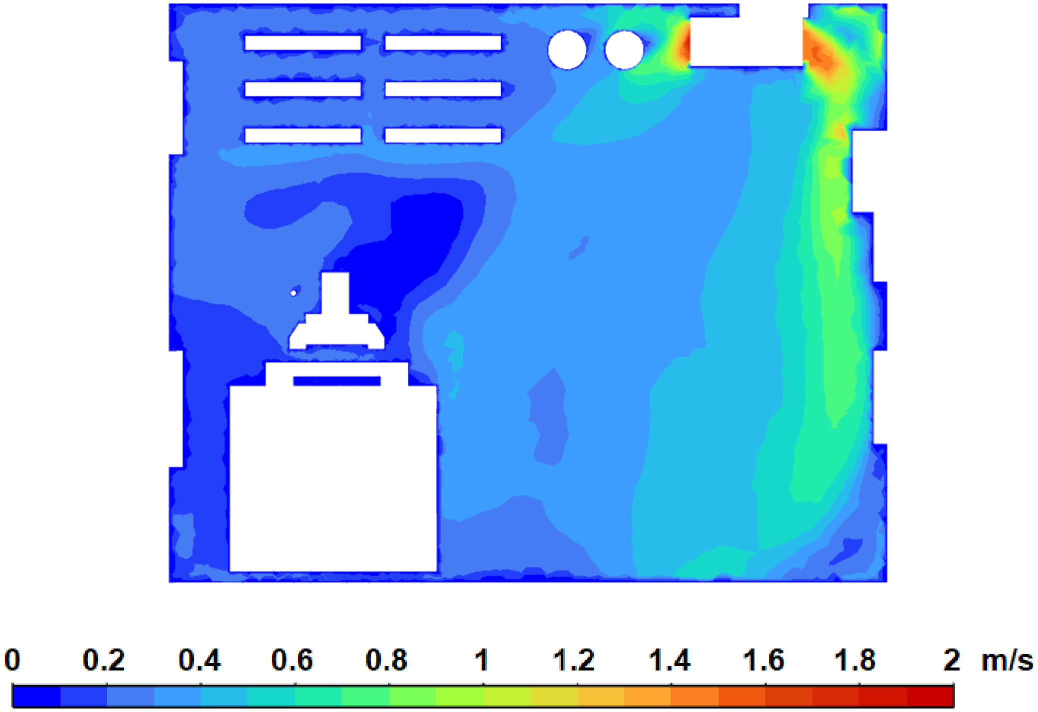


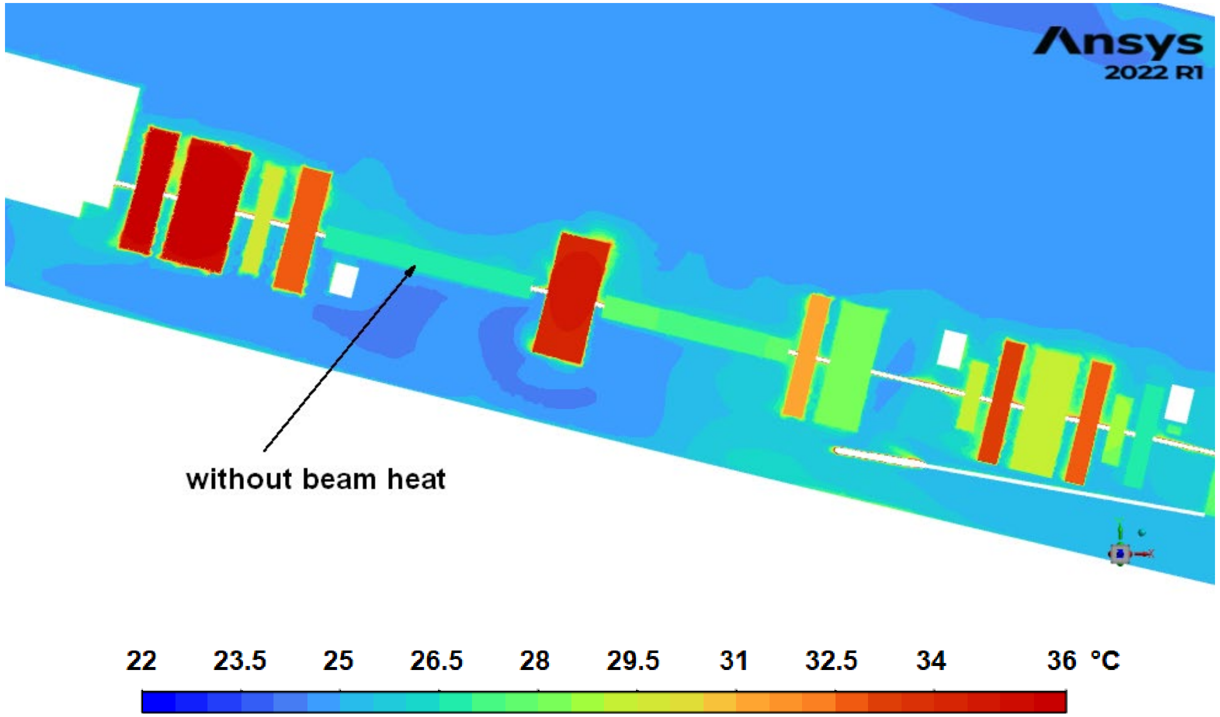



# Air flow and temperature simulations of the PETRA IV tunnel

Pattern of the AHU: presently set to one unit every 4m operating with the same power
Each delivers 600 W in normal operation but has 1.7 W installed

These simulations should tell us if the air ventilation can be simplified, e.g. reducing the number of AHU or tailoring the power profiles.



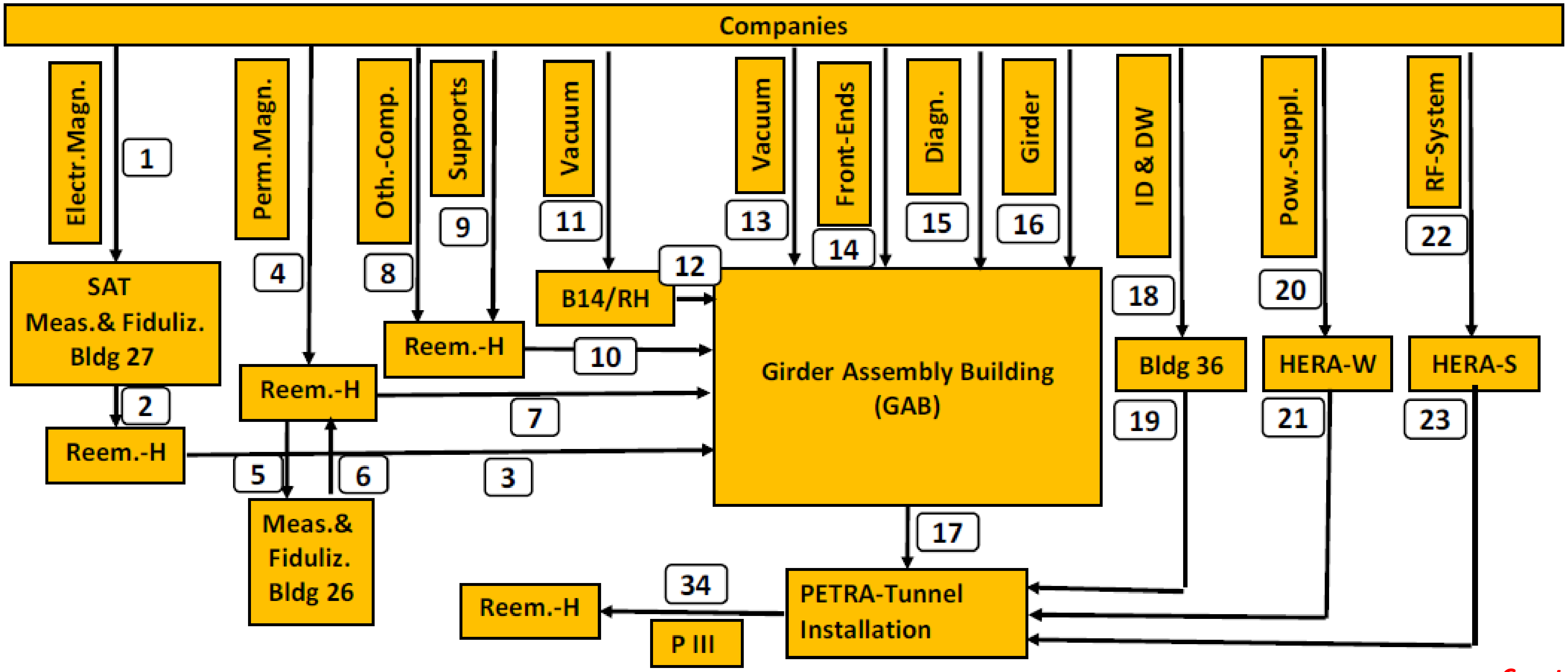




*Courtesy J. Eckoldt*

# The logistics plan for the machine assembly and installation has been developed.

PETRA IV. NEW DIMENSIONS

The activities for all the technical subsystems are identified and allocated to existing or new buildings



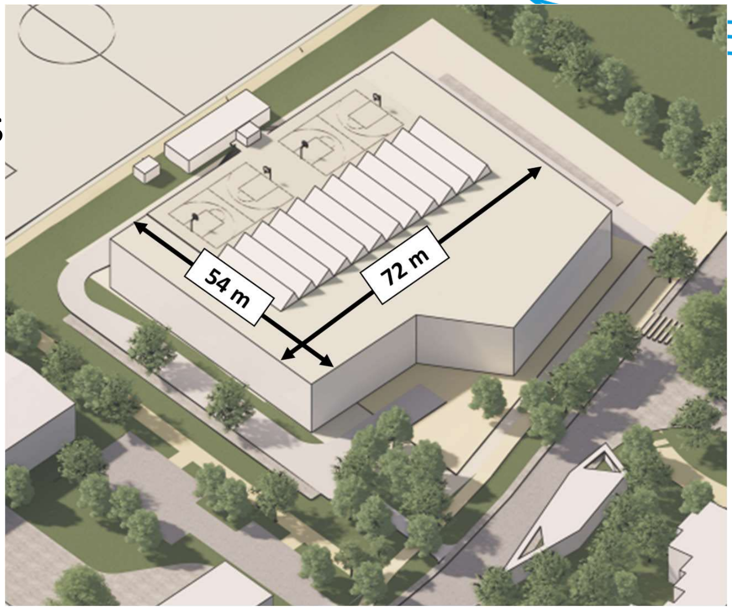

*Courtesy D. Einfeld*

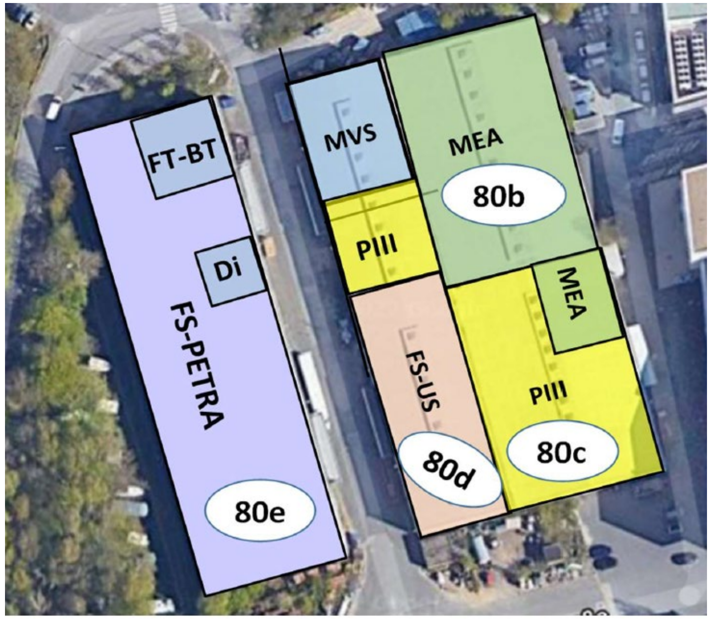
Key to the logistic plan will be the new ***Girder Assembly Building (GAB)***

# Space allocation on campus is defined

PETRA IV. NEW DIMENSIONS

The new Girder Assembly Building (GAB) is in the planning stage
The Reemtsma Halls 80b-c-d-e will be used for storage of components


Plans for decommissioning of PETRA III
and installation of PETRA IV are worked out.

*Courtesy D. Einfeld*

# Draft installation plan is being prepared

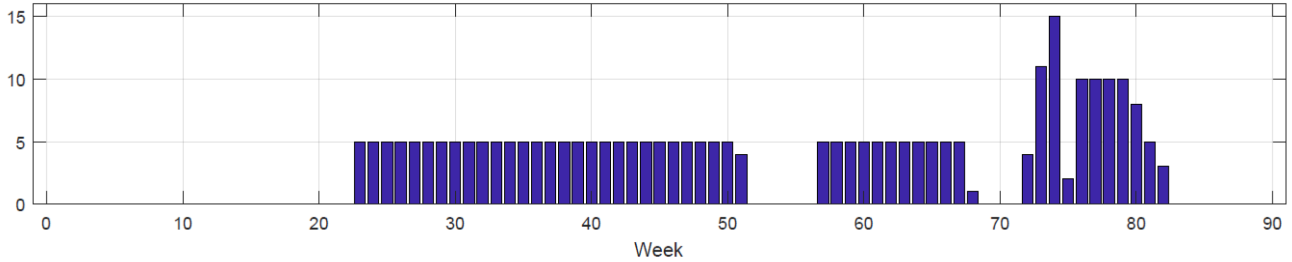
PETRA IV. NEW DIMENSIONS

Plans for decommissioning of PETRA III and installation of PETRA IV are worked out.

| Vorgar | Task Name | Dauer | Anfang | Ende |
|---|---|---|---|---|
| | P4_Installation | 450 d | Mon 28.12.26 | Fre 15.09.28 |
| | Incoming | 396 d | Mon 28.12.26 | Die 04.07.28 |
| | Outgoing | 126 d | Fre 01.01.27 | Fre 25.06.27 |
| | PETRA4 Installation | 445 d | Mon 04.01.27 | Fre 15.09.28 |
| | 1 Straight North | 337 d | Mon 04.01.27 | Die 18.04.28 |
| | 2 Arc1 | 317 d | Fre 05.03.27 | Mon 22.05.28 |
| | 3 Straight NE | 157 d | Mit 03.03.27 | Don 07.10.27 |
| | 4 Arc2 | 162 d | Mit 03.02.27 | Don 16.09.27 |
| | 5 Straight E | 263 d | Mit 17.02.27 | Fre 18.02.28 |
| | 6 Arc3 | 226 d | Fre 19.03.27 | Fre 28.01.28 |
| | 7 Straight SE | 273 d | Mit 24.02.27 | Fre 10.03.28 |
| | 8 Arc4 | 220 d | Mon 04.01.27 | Fre 05.11.27 |
| | 9 Straight South | 150 d | Mon 03.05.27 | Fre 26.11.27 |
| | 10 Arc5 | 256 d | Mon 04.01.27 | Mon 27.12.27 |
| | 11 Straight SW | 392 d | Mon 04.01.27 | Die 04.07.28 |
| | 12 Arc6 | 407 d | Mon 04.01.27 | Die 25.07.28 |
| | 13 Straight W | 417 d | Mon 11.01.27 | Die 15.08.28 |
| | 14 Arc7 | 429 d | Don 14.01.27 | Die 05.09.28 |
| | 15 Straight NW | 435 d | Mon 18.01.27 | Fre 15.09.28 |
| | 16 Arc8 | 363 d | Mon 25.01.27 | Mit 14.06.28 |
| | 20 DESY | 125 d | Mon 04.01.27 | Fre 25.06.27 |
| | 26 MvL | 379 d | Mon 04.01.27 | Don 15.06.28 |
| | 27 D-Weg | 345 d | Mon 04.01.27 | Fre 28.04.28 |


*Courtesy M. Hüning*

Girder installation rate fairly flat except rush at the end to compete the octants in the PXW



# Conclusions and future work

- PETRA IV is the highest priority project at DESY
- Lattice of the accelerators well defined. Many elements of the machine are close to their final design.
- Prototypes are on the way.
- Requirements on infrastructure are being clarified
- All effort in the remaining TDR phase will be focused on measure to reduce the investment and operation cost

## Thanks to many colleagues that provided material for this summary

# Thank you for your attention!