PETRA IV.
NEW DIMENSIONS

The PETRA IV Machine Ugrade

PETRA IV TDR-Phase Progress Review Meeting

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PETRA IV Machine Project Leader

Hamburg, November 27th, 2023

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

Outline

- Progress of the PETRA IV machine project since last project review (May 2023)

- Highlights of technical activities
  Highlights of the prototype programme
  Recent issues with DESY IV

- Conclusions and future work

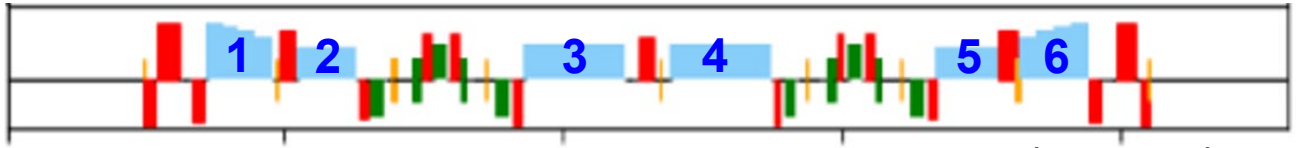
Main events since last project review (May 2023)

- The project proposal was revised/corrected with Directorate's input
- Cost estimate with internal (July) and external (September) reviews;
  TAC_06 (September), FIAC_03 (October), MAC_42 (November)
- Design and prototype activities
  TDR girder, RF, diagnostics, kickers, …
  revision of the DESY IV lattice and layout
- Definition of the next steps for 2024-2025

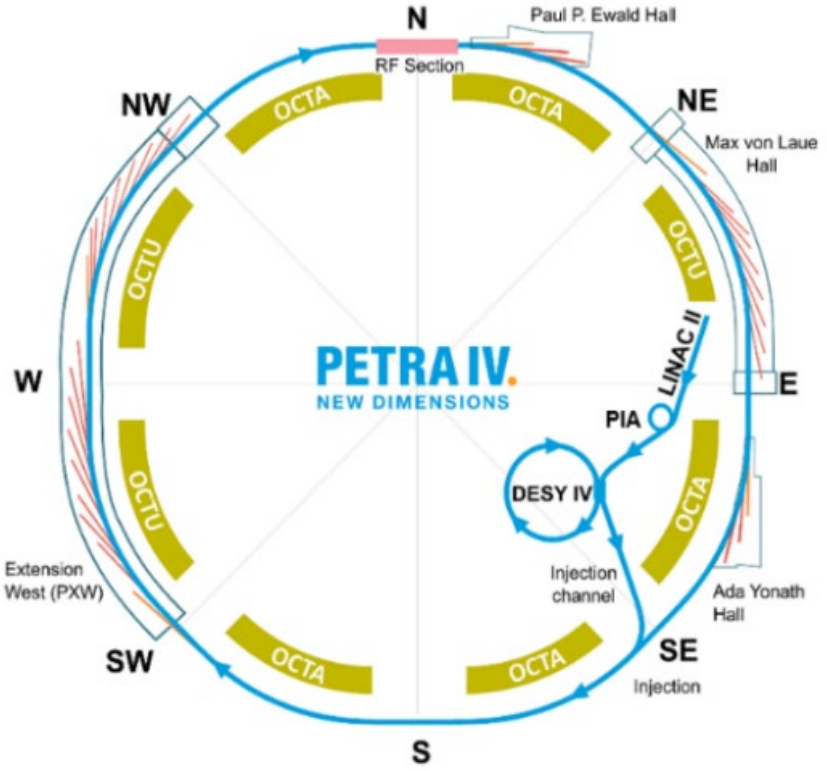
The PETRA IV storage ring: a world leading machine

The PETRA IV accelerator lattice will produce X-ray beams with unprecedented brightness.

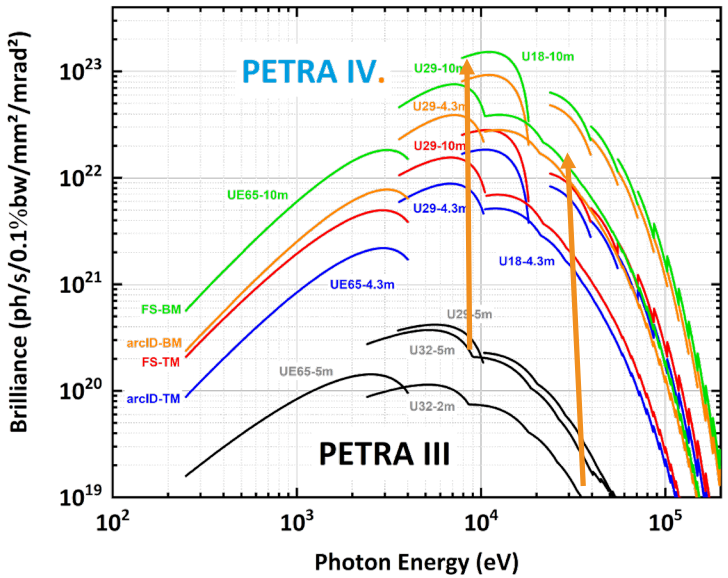
The lattice is based on a novel cell structure (**H6BA**)

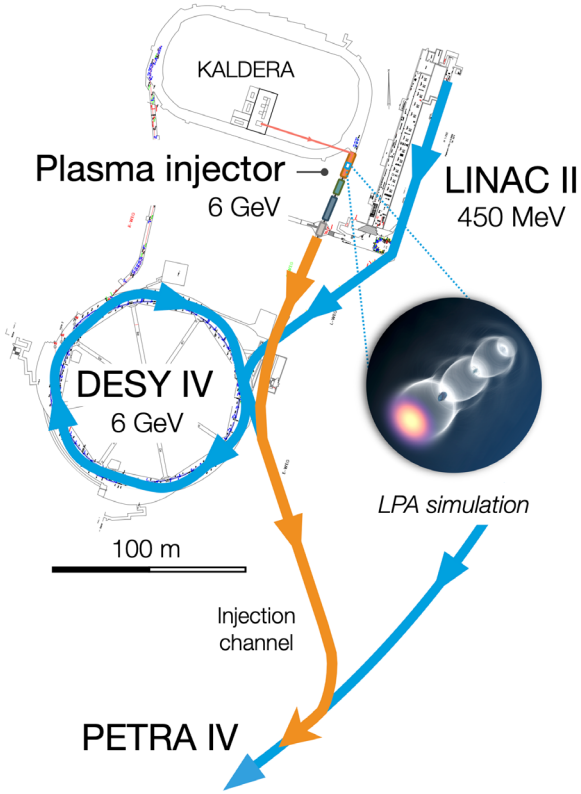


that is replicated identical across all octants (72 cells)



- emittance: : ~ 20 x 4 pmrad^2
- undulators: 4.3 m and 10 m
- **Average brightness increase: 500**





The *PETRA IV project* timeline is under revision

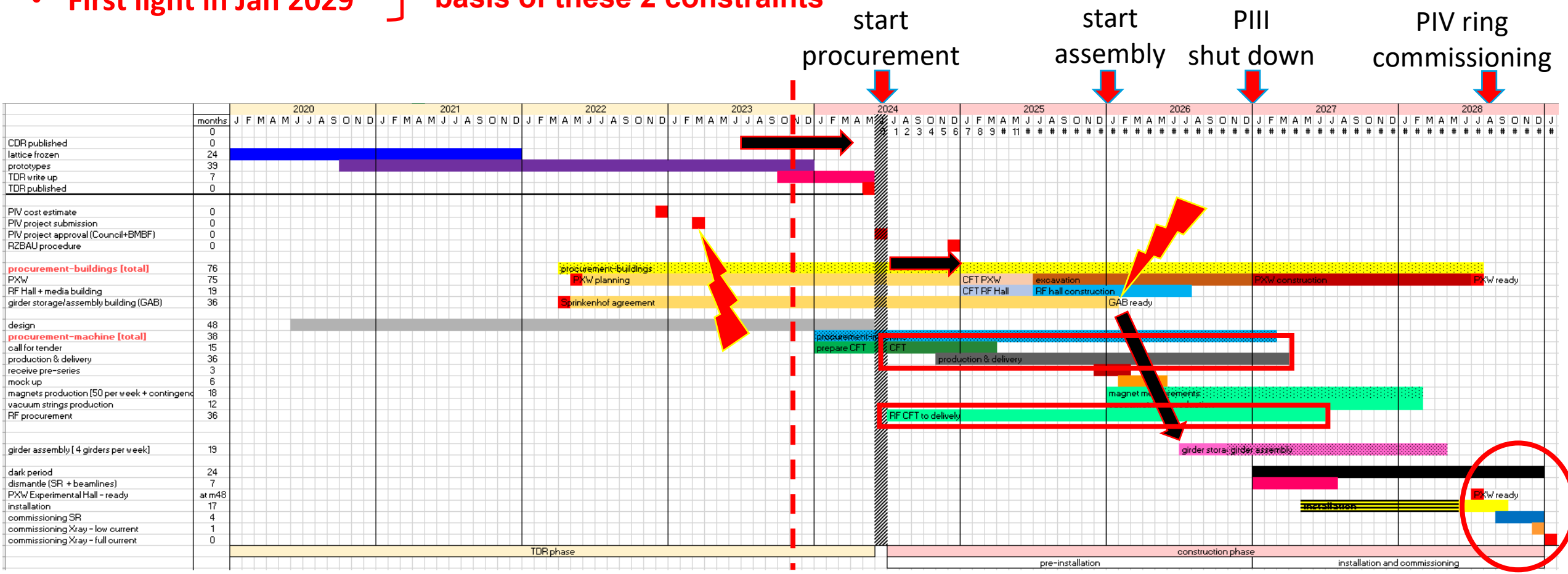
The draft breakdown below hinges on

- 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**

This timeline cannot be maintained and **at least one year shift** of t=0 is considered

Last week came the news of additional 44 M€ funding for PETRA IV R&D



The Engineering Design will continue into 2024-25

The EDR phase aims at

- completing design and write up a document to a sufficient level of details to support the call for tender
- Investigate areas where cost saving and reduction of energy consumption can be implemented
- building one fully equipped girder with magnets, vacuum strings, water and power connections as close as possible to the final configuration
- complete the full prototype programme

Recruitment programme for the TDR phase was concluded (DESY + PIV Project) 103.9 FTE (57.5 FTEs on the accelerators).

The additional funding will allow

- **the opening of ~40 position across the project (~10 on the machine)**
- **the conclusion of the prototype phase**

Large contract cannot be placed until final project approval.

Urgent manpower needs are prioritised.

PETRA IV. Project Phase

Priority Recruitment

Priority List

Rank	Work Package		Position	ID
1	WPG1	Civil Construction and Infrastructure	Work Package Group Leader	P.101.5
2	WP 1.01	Civil Construction	Civil Construction Engineer	P.101.6
3	pso01	Assembly, Integration, Test	Schedule Manager	P.pso01.1
4	pso04	Procurement	Procurement (Construction)	P.pso04.2
5	WP 1.02	Main Power Supplies / MKK	Engineer	P.102.3
6	WP 1.03	Water Cooling / MKK	Engineer	P.103.3
7	WP 1.04	Air Conditioning / MKK	Engineer	P.104.3
8	WP 1.01	Civil Construction	Civil Construction Engineer	P.101.7
9	WP 1.01	Civil Construction	Civil Construction Engineer	P.101.8
10	WP 1.01	Civil Construction	Civil Construction Engineer	P.101.9
11	WP 2.10	Machine Controls	High-Level Software	P.210.1
12	pso02	Recruitment	Recruiter	P.pso02.1
13	WP 3.02	Beamline Technology / ZM1	Design Engineer Preparation and Models	P.302.5
14	pso08	Documentation and Change Management	Junior Scientfic Manager	P.pso08.1
15	pso04	Procurement	Procurement (EKM)	P.pso04.3
16	WP 2.05	Diagnostics	Engineer	P.205.24
17	WP 2.05	Diagnostics	Engineer	P.205.25
18	WP 1.03	Water Cooling	Engineer / CAD designer	P.103.4
19	WP 1.03	Water Cooling	Engineer / CAD designer	P.103.5
20	WP 1.04	Air Conditioning	Engineer / CAD constructeur	P.104.4
21	WP 3.09	Beamline and Experiment Design	BL manager (Imaging Beamlines)	P.309.6
22	WP 4.01	Assembly, Integration, Test	CAD engineer	P.401.5
23	WP 3.09	Beamline and Experiment Design	Engineer / Leader TechTask	P.309.12
24	WP 1.01	Civil Construction	Civil Construction Engineer	P.101.3
25	WP 1.01	Civil Construction	Civil Construction Engineer	P.101.1
26	pso03	Budget Controlling	Accountant	P.pso03.1
27	WP 3.02	Beamline Technology	Design Engineer Preparation and Models (located in ZM1)	P.302.18
28	WP 2.06	Girders	Engineer	P.206.3
29	WP 2.02	Magnets	Engineer	P.202.5
30	WP 4.05	Quality Management	WPL	P.405.2
31	WP 2.03	Magnet Testing	Measurement engineer	P.203.5
32	WP 2.10	Machine Controls	High-Level Software	P.210.38
33	WP 2.08	Feedbacks	HW designer 1	P.208.6
34	WP 4.01	Assembly, Integration, Test	Requirements Engineer	P.404.2
35	WP 4.01	Assembly, Integration, Test	CAD engineer	P.401.5
36	WP 3.09	Beamline	Mechatronic Engineer	P.309.7
37	WP 3.02	Beamline Technology	Mechanical Engineer Optics	P.302.5
38	WP 2.10	Accelerator Physics	Physicist (replacement)	P.201.2
39	WP 4.04	Systems Engineering	CAD integrator	P.404.4
40	WP 4.04	Systems Engineering	BIM integrator	P.404.5

RecruitmentPriorityBundle01 | PersonnelRequirements-2023-2024

40 new FTEs are in the priority list
for the project ramp up phase

Priorities is given to activities that are already on the critical path (mostly civil engineering)

On the machine project:

- 2 diagnostics (emittance meas. – cabling)
- 2 controls (high-level software)
- 1 girders
- 1 magnets (PM/DLQ) + 1 DW
- 1 magnetic measurements (resistive)
- 1 feedback systems
- 1 accelerator physics

extension/stabilization of ~10 fixed term positions nearing the end of the contracts

Funding for remaining prototype activity assessed

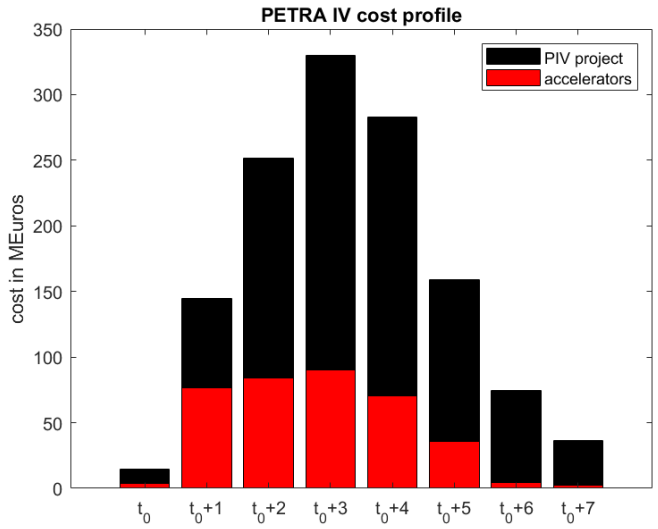
Ran	Work Package	Column1	Item	ID	funding	Volume in 2024	Volume in 2025
1	2,02	Magnets - Resistive	Slow / Fast Corrector		prototype	100.000,00 €	
2	2,02	Magnets - Resistive	Quadrupole PQD/PQE		prototype	100.000,00 €	
3	2,02	Magnets - Resistive	Benches: small equipment		prefinancing	10.000,00 €	
4	2,02	Magnets - PM	Variable gap damping wiggler (prototype)	I.202.33	prefinancing	200.000,00 €	200.000,00 €
5	2,02	Magnets - PM	Bench for DLQ (to be reused for undulators?)	I.202.40	prefinancing		250.000,00 €
6	2,02	Magnets - PM	Bench DW - stretched wire bench	I.202.34	prefinancing	150.000,00 €	
7	2,02	Magnets - PM	Magnetic Measurement Hutch DLQ	I.202.42	prefinancing	200.000,00 €	500.000,00 €
8	2,02	Magnets - PM	Cooperation ESRF (JC)		prototype	50.000,00 €	
9	2,02	Magnets - PM	8th module for DLQ		prototype	20.000,00 €	
10	2,02	Magnets - PM	DLQ prototype		prototype	30.000,00 €	
11	2,04	Vacuum Systems			prototype	400.000,00 €	200.000,00 €
12	2,05	Diagnostics	Stripline BPM Detector		prototype	50.000,00 €	
13	2,05	Diagnostics	BPM electronics and feedthroughs prototypes		prototype	300.000,00 €	100.000,00 €
14	2,05	Diagnostics	BPM mechanics prototypes		prototype	140.000,00 €	
15	2,06	Girders	Mock-up TDR steel plates		prototype	10.000,00 €	
16	2,06	Girders	Full arc cell mock-up preparatory work	I.401.3	prefinancing	100.000,00 €	90.000,00 €
17	2,07	Alignment	Acceleratometer		prototype	2.500,00 €	
18	2,08	Feedbacks	Electronic development - Fast-corrector test stand - Essential		prototype	150.000,00 €	
19	2,08	Feedbacks	Electronic development - Additional		prototype		165.000,00 €
20	2,11	Magnet Power Supplies	FOFB cables prototyping		prototype	60.000,00 €	
21	2,11	Magnet Power Supplies	Test system for hot-swap		prototype	75.000,00 €	
22	2,11	Magnet Power Supplies	Electronic racks testa, water cooled	I.211.4	prefinancing	30.000,00 €	
23	2,11	Magnet Power Supplies	Prototype power supply for FOFB		prototype	50.000,00 €	
24	2,12	RF Systems	Shintake cavity prototype including SSA		prototype	180.000,00 €	100.000,00 €
25	2,12	RF Systems	Low-level RF test system		prototype	50.000,00 €	
26	2,12	RF Systems	Circulator for main RF		prototype	70.000,00 €	
27	2,12	RF Systems	cleaning booster cavities		prototype	10.000,00 €	
28	2,14	Injection and Extraction	Prototype dump kicker		prototype	50.000,00 €	
Total						**2.587.500,00 €**	**1.605.000,00 €**

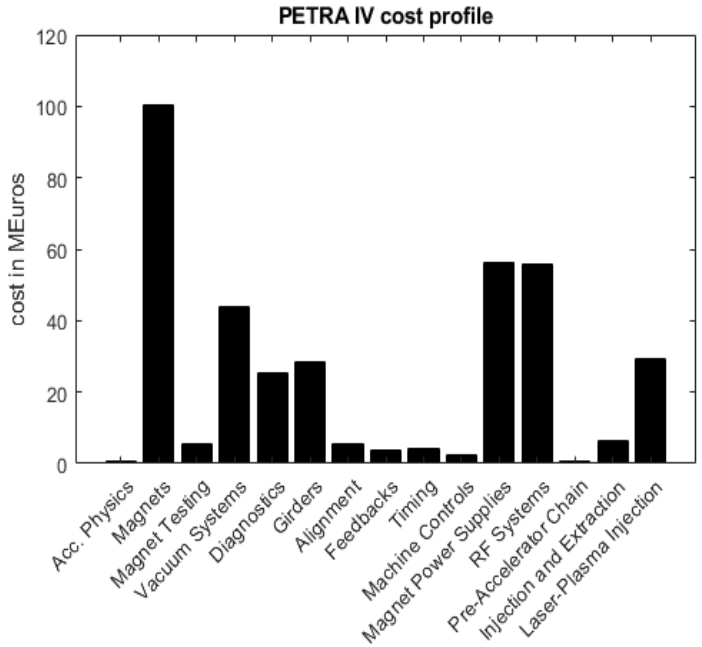
Cost of ***PETRA IV project*** has been estimated

The cost for the PETRA IV project is fixed!
Price index fixed at end 2022

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	**40.4**	344	31.4	331.4	455.6
Experiments	634	57.7		365	33.3	225.7	316.7
Logistics	22	2.0		180	16.2	13.3	31.5
Infrastructure	109	9.9		185	16.9	607.2	634.0
Safety	19	1.7		24	2.4	20.2	24.3
Management	52	4.7		219	19.8	2.4	26.9
Sum in Mio.€		**128.8**	**40.4**		**120.0**	1,200.2	1,489.4

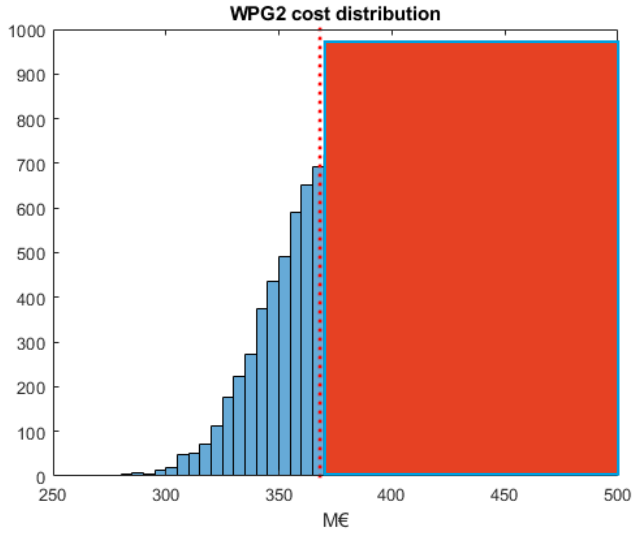
30.6%

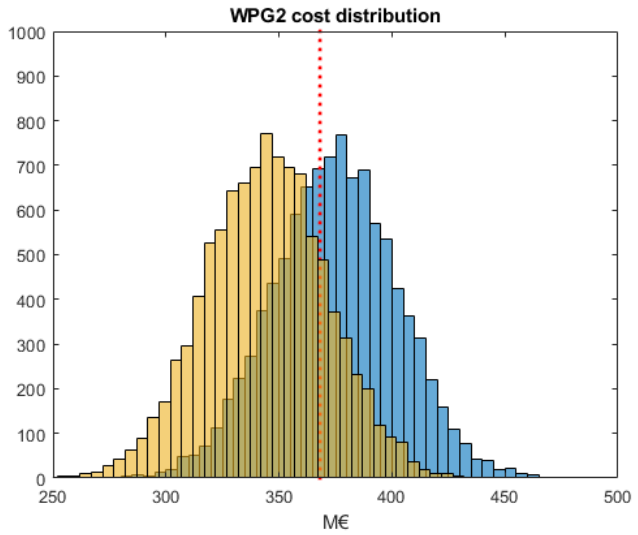




Dealing with uncertainties and errors

- Accelerator cost 371.8 M€ (error distributions from the uncertainties reported in the WP)



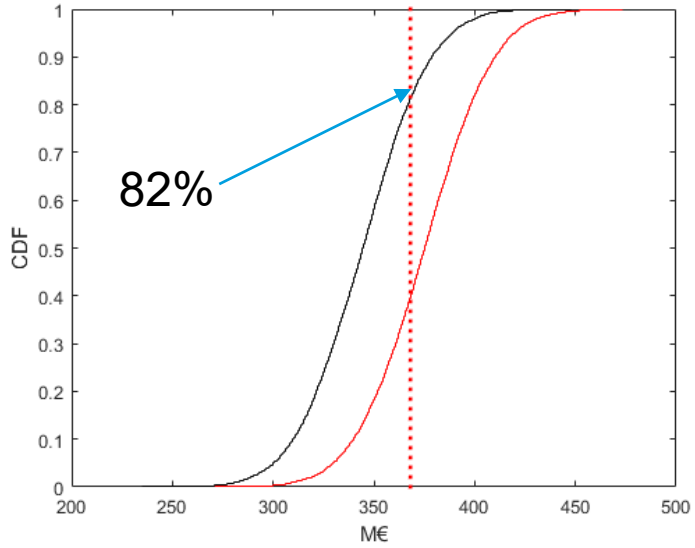


The strategy is to build to budget, allowing redundancy [not contingency]

Potential savings (***to be identified within the end of the EDR***)

- reduction in hot-swap redundancy – (here assumed 1:3)
- reduction in RF cavity stations

- corresponding cost reduction (infrastr.) racks, cooling, cables, IT cabling, size of supply building (rack space)



Status of design: hot swap system

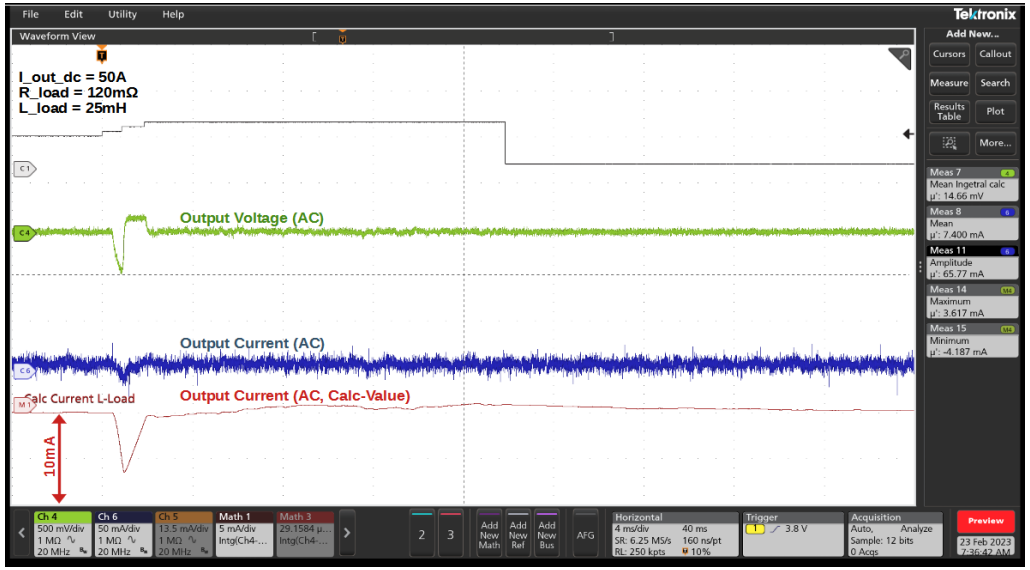
PS reliability at PIII is already very high: unlikely to improve reliability of a single unit
PIV will have 4400 PS more than PIII 859 – MTBF reduced accordingly

Hot swap is the only viable solution to further improve the reliability

Contacts with ESRF:
ESRF design had difficulties in the commissioning phase but now working fine
ESRF hot swap 1:4 – 1:6 depending on the position in the ring/racks

PIV implementation
1:1 concept - successful tests at PIII with beam
but…
large cost, large real estate and infrastructure requirements

Hot-swap tests at PETRA III were successful



Current deviation 6e-4 over 2.5 ms during the hot-swap

Under analysis: reduction of the hot-swap topology, definition of the ratio 1:n for different PS type, their size, the rack capacity required, the cooling demands.

Prototype programme and timeline

The TDR phase is supporting a number of prototypes on key subsystems:

Magnets (WP2.02):

- high gradient quadrupoles (delivery from SIGMAPHI in October 23)
- sextupole (contract awarded to Danfysik in June – deliver expected end April 24)
- combined fast/slow corrector (design finalized – prototype in house – foreseen May 24)
- permanent magnet DLQ (first module prototype in-house January 24)
- Dummy magnets for the TDR girders in fabrication at DESY (ongoing – foreseen January 24)

Vacuum (WP2.04):

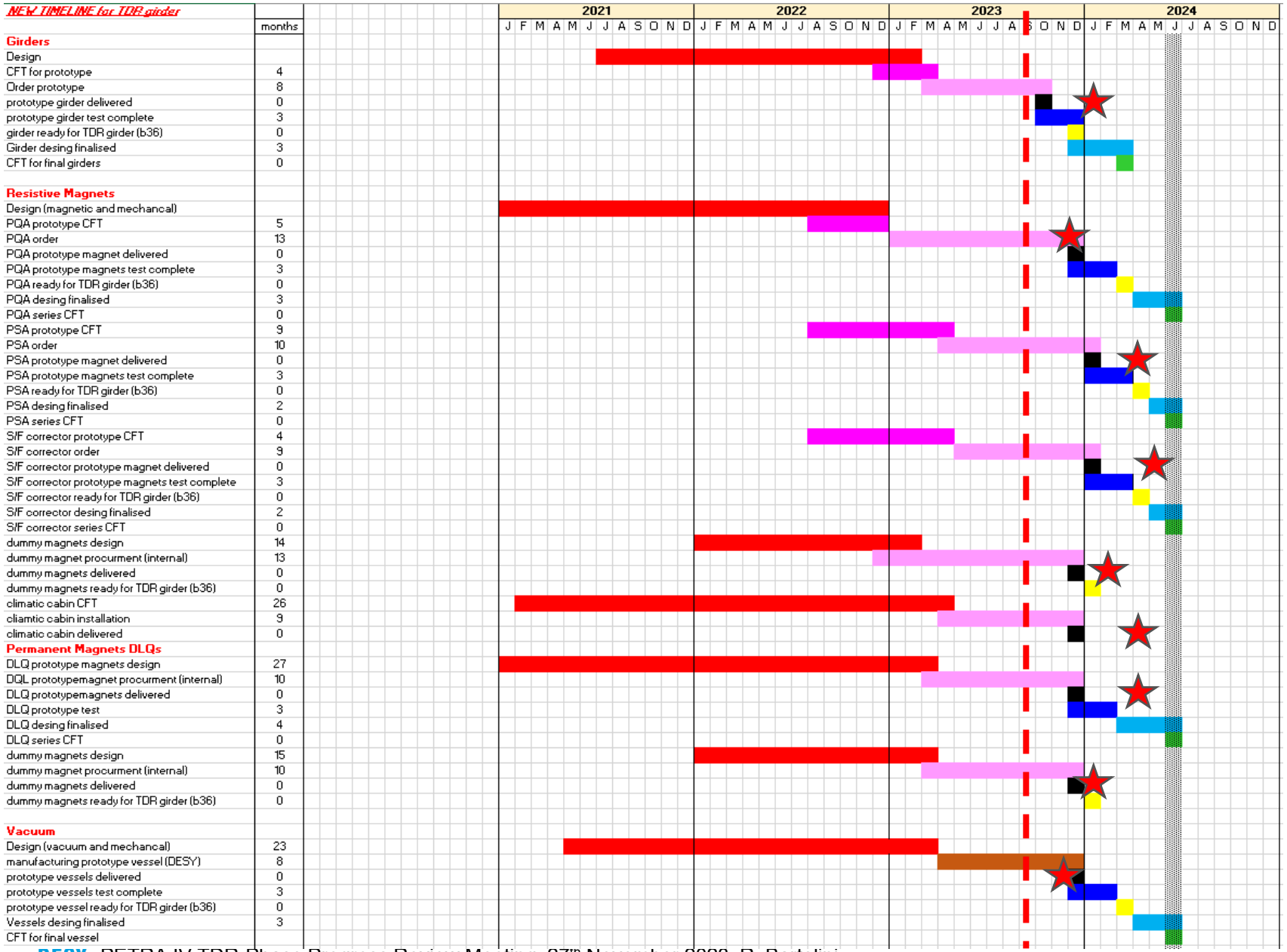
- NEG coating of long small aperture chambers (done and positive)
- vacuum string for TDR girder mock up (copper extruded profiles at DESY – foreseen November 23)
- demonstrator of PS for Ion pumps

Girders (WP2.06):

- one girder (contract placed – delivery end of January 24)
- girder movers

These will allow the construction of one mock up girder by the end of the TDR phase.

Detailed status of the TDR mock up girder programme



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
delivery January 24

PQA prototype
SIGMAPHI delivery Dec. 23

PSA prototype
Danfysik delivery April 24

S/F corrector prototype
in-house delivery May 24

Dummy magnets in-house
(climatic cabin with DESY procur.)

DLQ prototype in-house
first module January 24
full module April 24

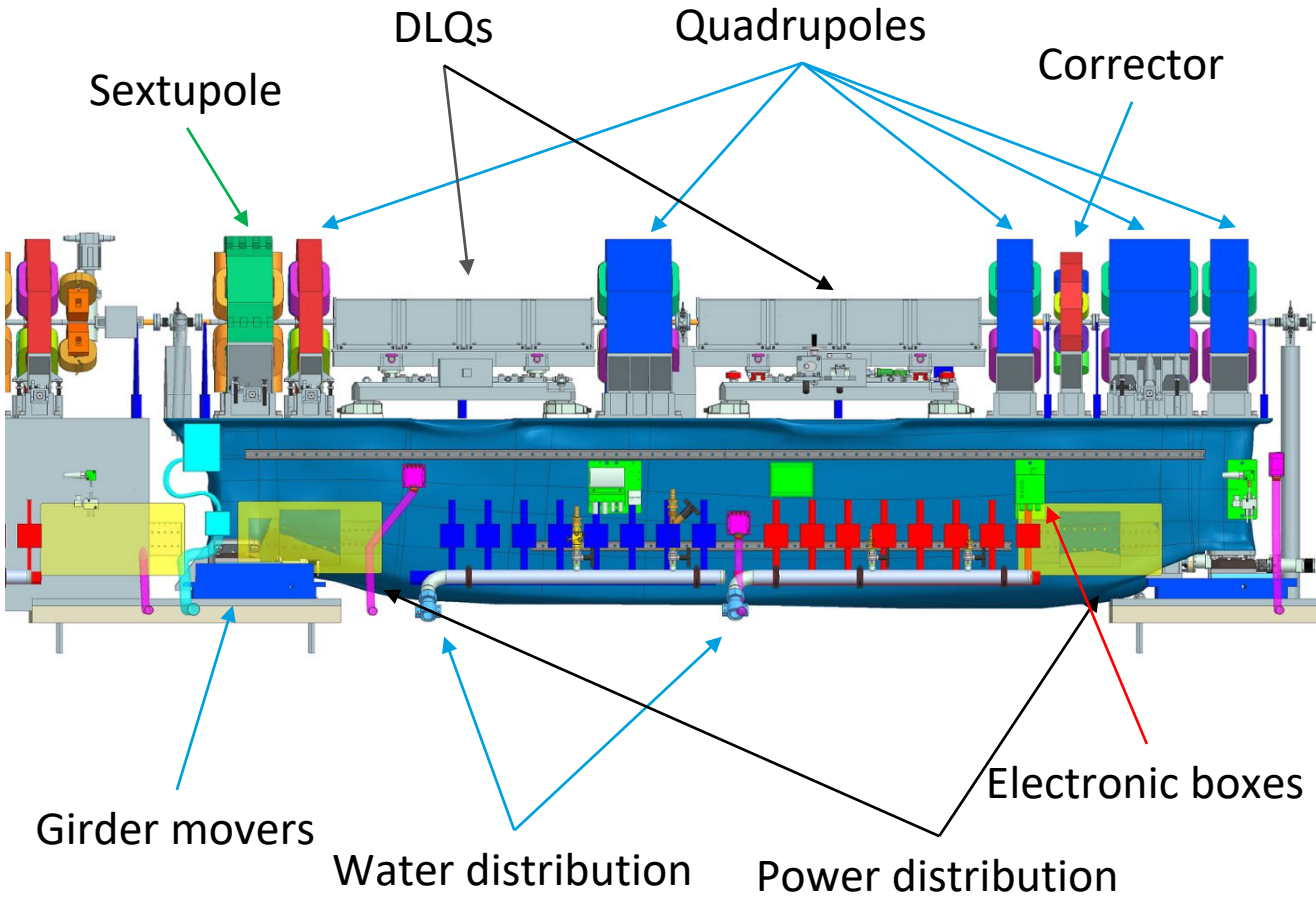
Dummy magnets
in-house end of 2023

Vacuum chambers prototype
in-house November 23

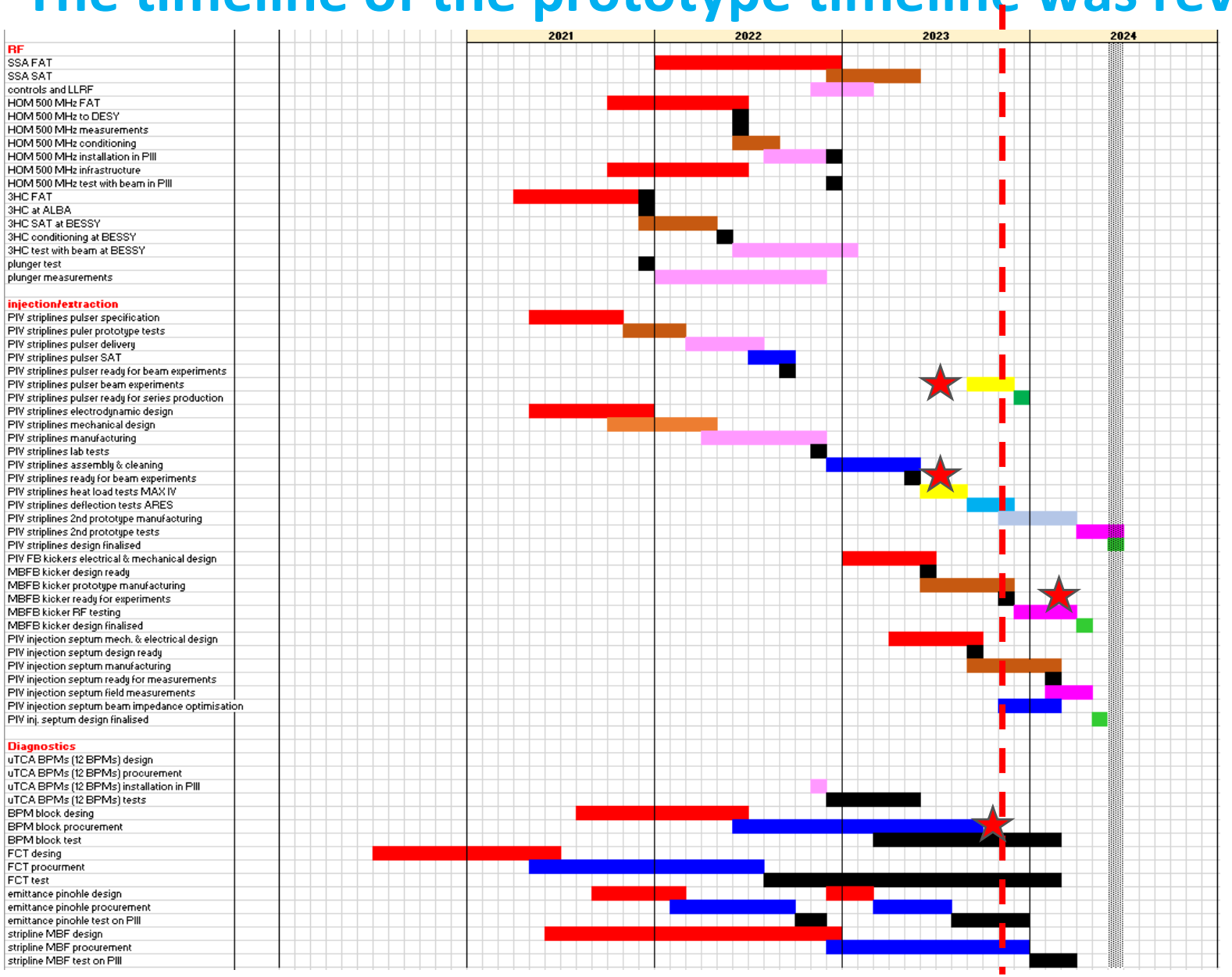
Prototype of a mock up girder is underway

A detailed list of scope and sequences of tests is being collected

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	



The timeline of the prototype timeline was revised



Prototyping activity running in many different areas

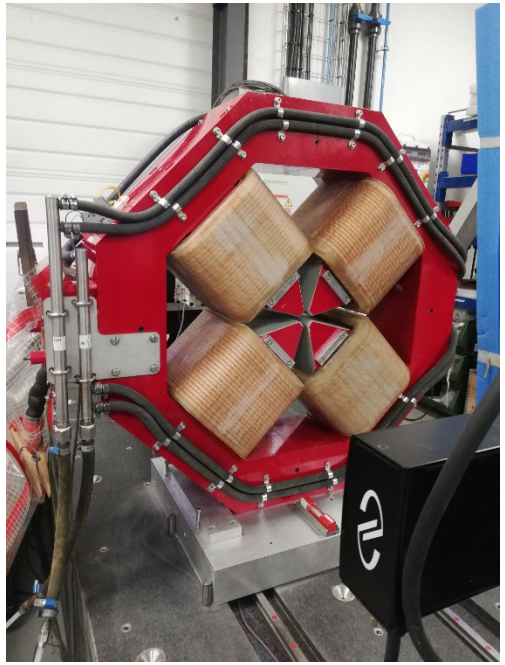
All efforts are made to support financially the ongoing activities

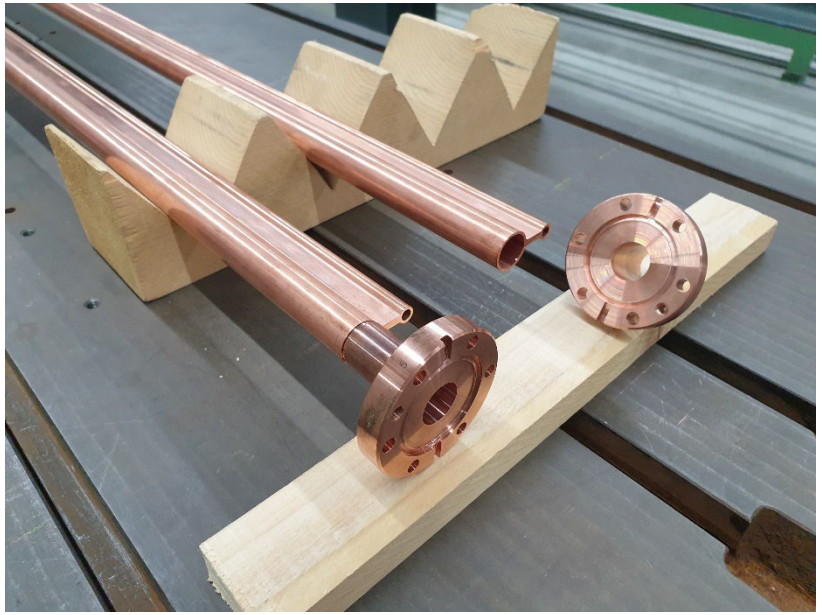
The current plan matches the TDR timeline

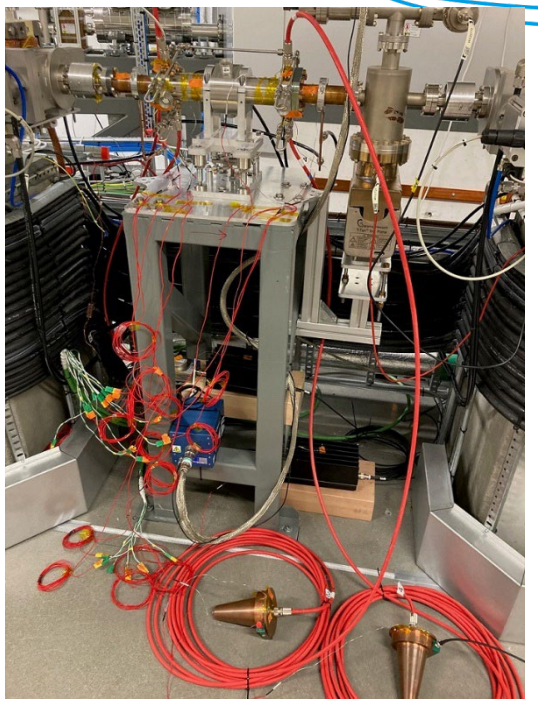
However close monitoring is required

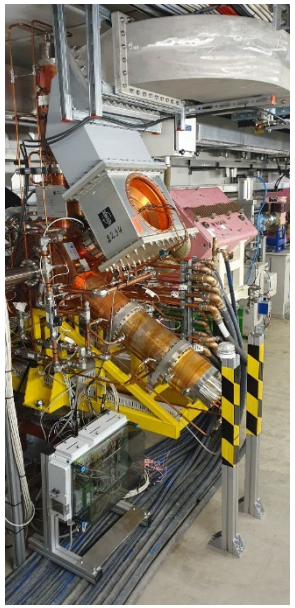
Delays in some areas (e.g. magnets, kickers) will put us beyond t=0

Prototypes are underway





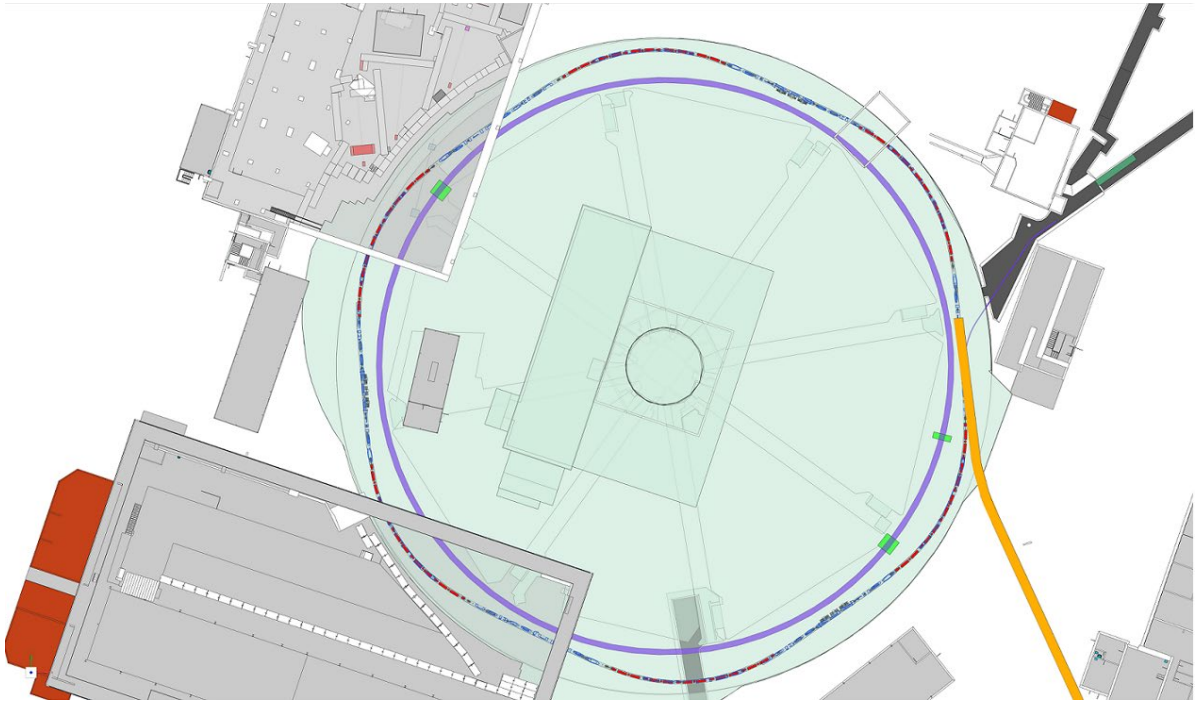




Status of DESY IV

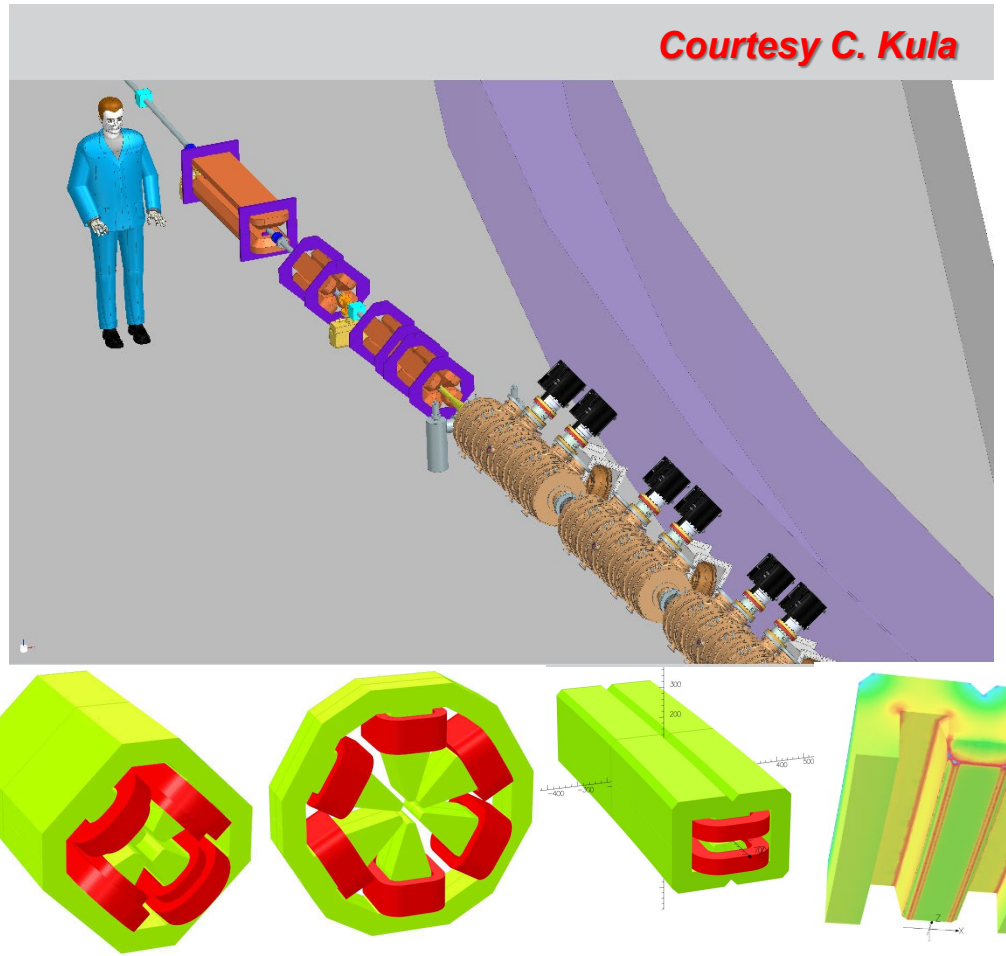
The PETRA IV project proposal includes the construction of a new booster DESY IV

The lattice was frozen last year with a design delivering 20 nm – 1 nC single bunch operation reusing the LINAC-II and PIA ring



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

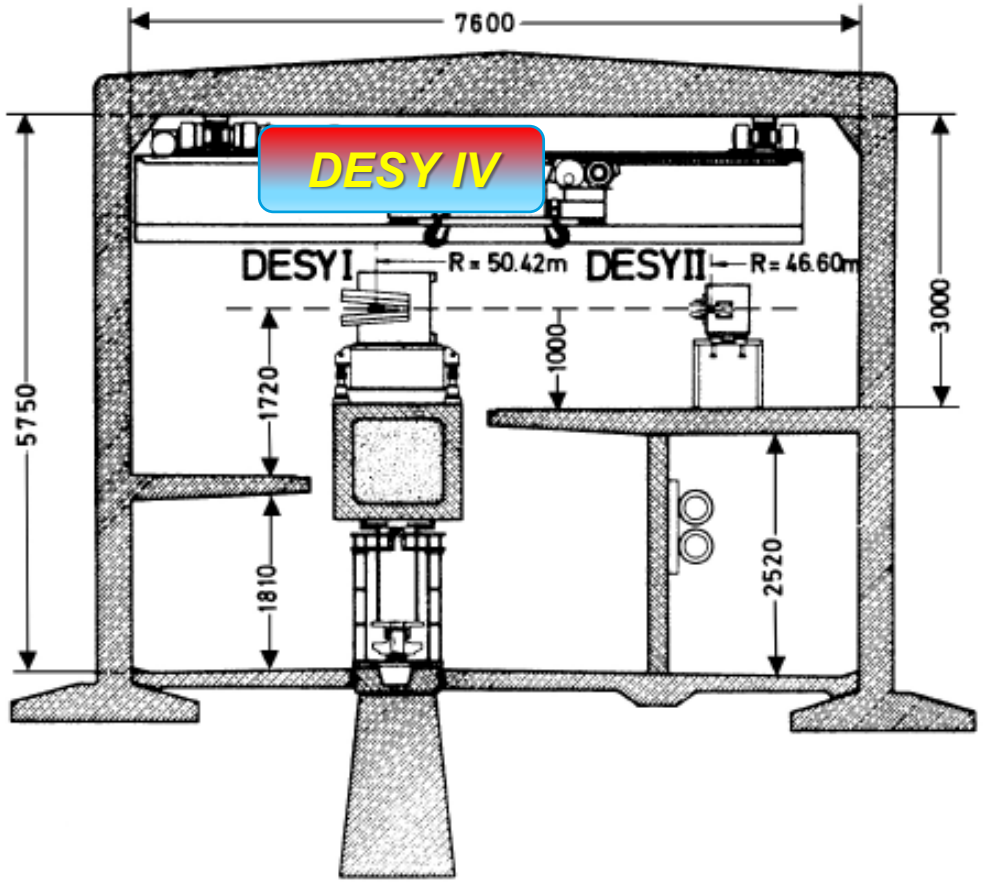
System design and
CAD integration progressed



DESY IV: installation issues

The definition of detailed installation plans highlighted several issues:

Inherited building layout poses several constraints: installation on the ceiling turns out to be more costly than planned and with a complex logistics – not impossible, but triggered a review…

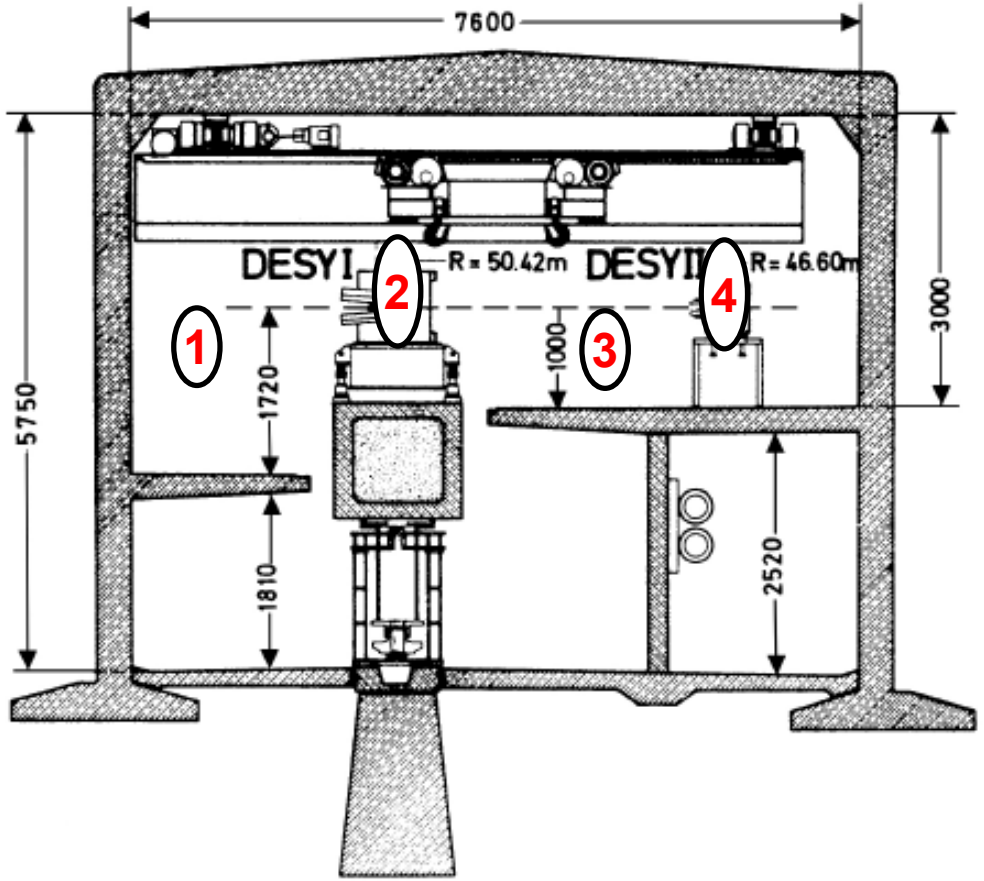


Installation issues:

- Close to the maximum load:
  1.5 tons per magnet + 1.5 tons support
- Difficulties in drilling the holes on the ceiling due to the reinforced steel rod pattern on the ceiling (no wet drilling)
- Logistic concept requires a transport and lifting system and the outer floor load must be reinforced
- The “ringtraeger” creates difficulties in providing a smooth and stable surface for transport and lifting vehicles. Such surface must be prepared and the ringtraeger ideally should be removed
- Crane removed

DESY IV analysis of different options

Different options were analysed in terms of lattice layout, stability and installation procedure:



Option 2: Ringtrager discarded on the basis of stability issues (apparently a long debated issue)

- M 7 -

Hamburg, den 25. März 1964
Dr. Stz/Sch

Aktenvermerk

Betr.: Beratungsvertrag Herrn Prof. Hauri

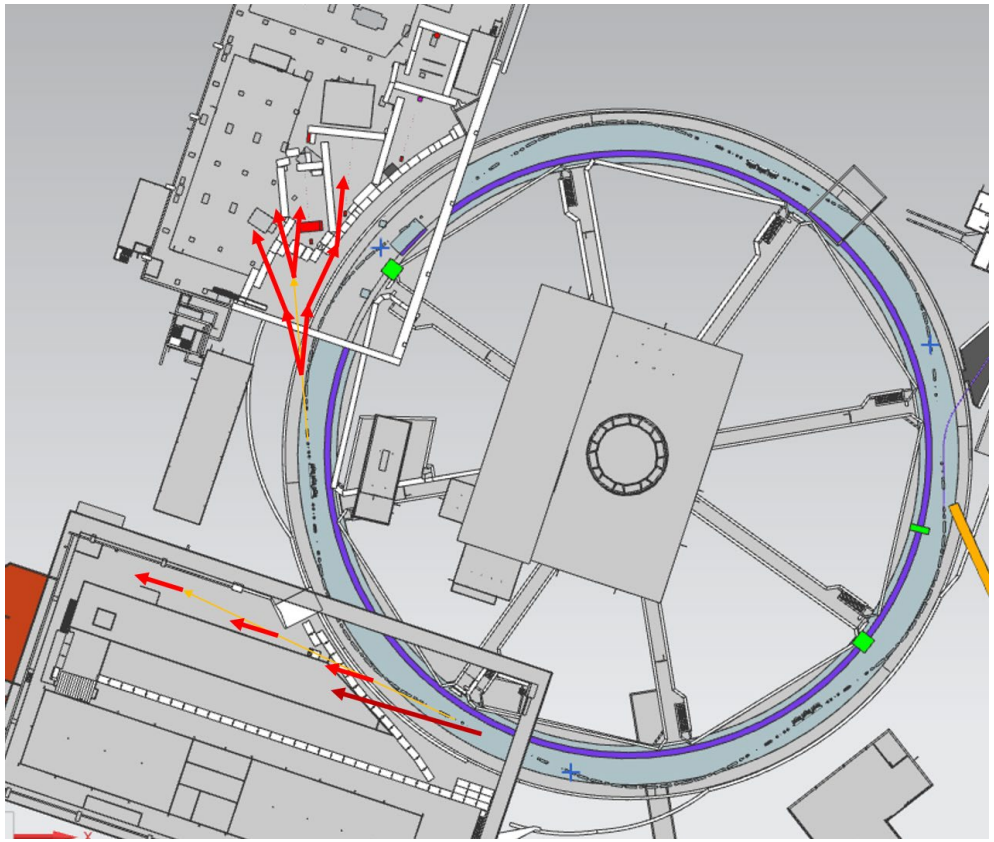
Nach Abschluß der Arbeiten am Magnet-Ringträger fand am 9.3.64 eine Besprechung zwischen Herrn Prof. Hauri und mir statt. Es wurden noch einmal die Fragen der Ringschwingungen diskutiert, insbesondere auf Grund der letzten Messungen von Herrn Dr. Degèle. Diese Messungen hatten eine Periode der Ringträgerschwingungen nach jedem 6. Magneten erkennen lassen. Da die restlichen Schwingungs-Amplituden des Ringträgers verhältnismäßig klein sind und weit unter dem ursprünglich geforderten Maß von 0,1 mm liegen, hat es nach An-

Outer wall and inner wall possible:

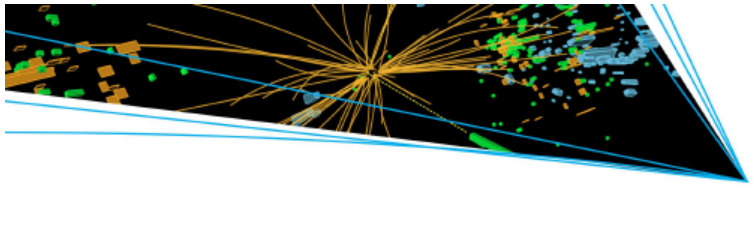
Option 1: not favoured as the outer wall has no support pillars underneath the floor
Option 4: not favoured as the removal of DESY II does not allow start of installation before the PIII shutdown

DESY IV: testbeamlines issues

DESY II runs parasitically for the production of e+/e- beam [testbeam] serving a large community (detectors)



Courtesy H. Ehrlichmann



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16. Juni 2023

Zukunft des DESY-Teststrahls

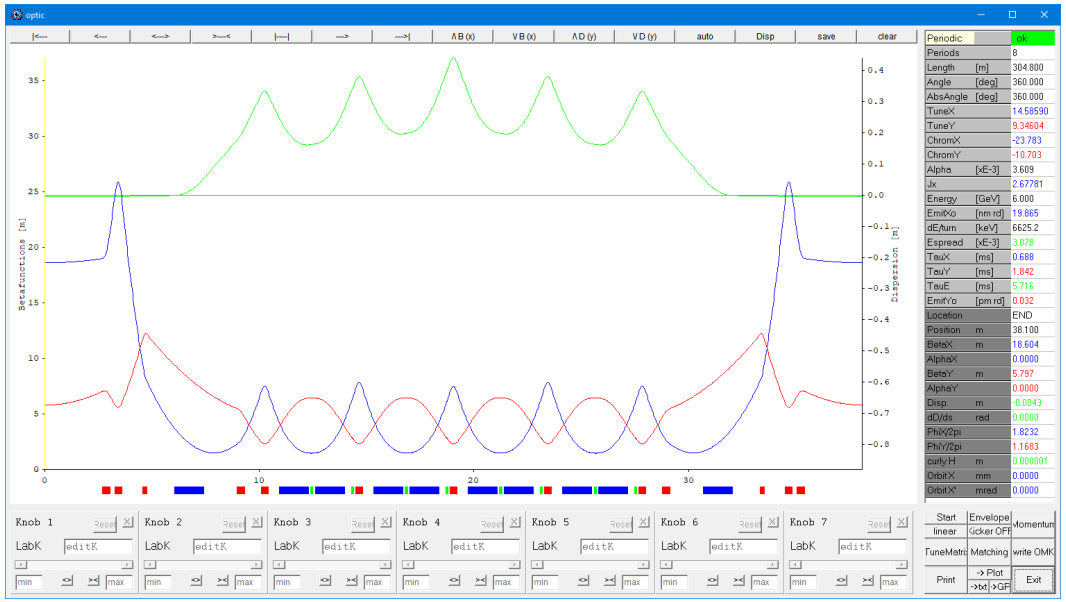
Sehr geehrter Herr Professor Dosch,

wir wenden uns an Sie mit der dringenden Bitte, das Angebot eines Elektron-Teststrahls im Bereich 1-6 GeV auch über den bevorstehenden Umbau der DESY-Beschleunigerinfrastruktur für PETRA IV hinaus fortzuführen. Die heute an DESY II bestehenden Einrichtungen für Teststrahl-Messungen sind in dieser Form weltweit einmalig und werden für laufende und zukünftige Entwicklungen von Teilchendetektoren dringend benötigt.

Working group set up with the FH division (M. Stanitski, S. Ackermann) – options for testbeamlines at DESY IV
Assess the implication of the required modification to the DESY IV baseline and the test beamline performance

DESY IV lattice revisited

The Beam Physics group provided lattices for all options with equivalent performance to the baseline DESY IV: Moving from hexagonal to octogonal symmetry to follow the floor layout (and to provide better compatibility with the test beamlines)



Parameter	3h3l-v8 ceiling	Option 3 Intermediate
Circumference C	316.8 m	304.8 m
Nat. emittance $\varepsilon_{x,0}$	19.0 nm	19.0 nm
Tune Q_x/Q_y	17.37 / 12.15	15.18 / 8.27
Nat. chromaticity ξ_x/ξ_y	-41.7 / -13.8	-24.4 / -10.9
MCF α_c	$3.2\cdot10^{-3}$	$3.2\cdot10^{-3}$
Hor. damp. par. nr. J_x	2.56	2.29
Rel. energy spread σ_E	$2.6\cdot10^{-3}$	$2.1\cdot10^{-3}$
Energy loss/turn ΔE	6.5 MeV	6.6 MeV

DESY IV parasitic operation for testbeamlines: discussion ongoing on the required modification to the baseline operation: ramped 5Hz for top-up, followed by CW operation for test beamlines

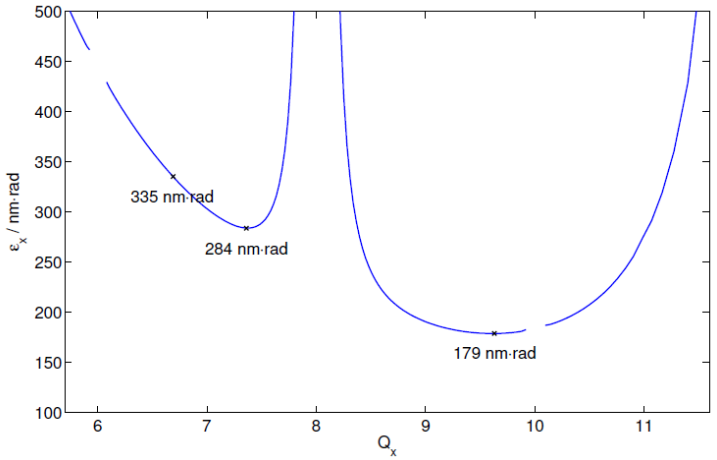
The continuation of testbeam programme will be a decision of the DESY Directorate

Alternative options for the pre-accelerator: reuse of DESY II

Analysis of reusing DESY II pointed out that the large emittance 350 nm is unsuitable for injection in PIV. However, the idea of limited modifications to DESY II, could be appealing as a measure to save on the large investment for the DESY IV booster (76 M€ including refurbishment of the DESY tunnel infrastructure).

This poses the question whether DESY II operation can be extended for few years, with limited refurbishment, until the LPA delivers a beam suitable as full injector for PETRA IV

The emittance of DESY II can be reduced with new power supplies for the quadrupoles – J. Keil IPAC17 and operating off-energy down to 120 nm.

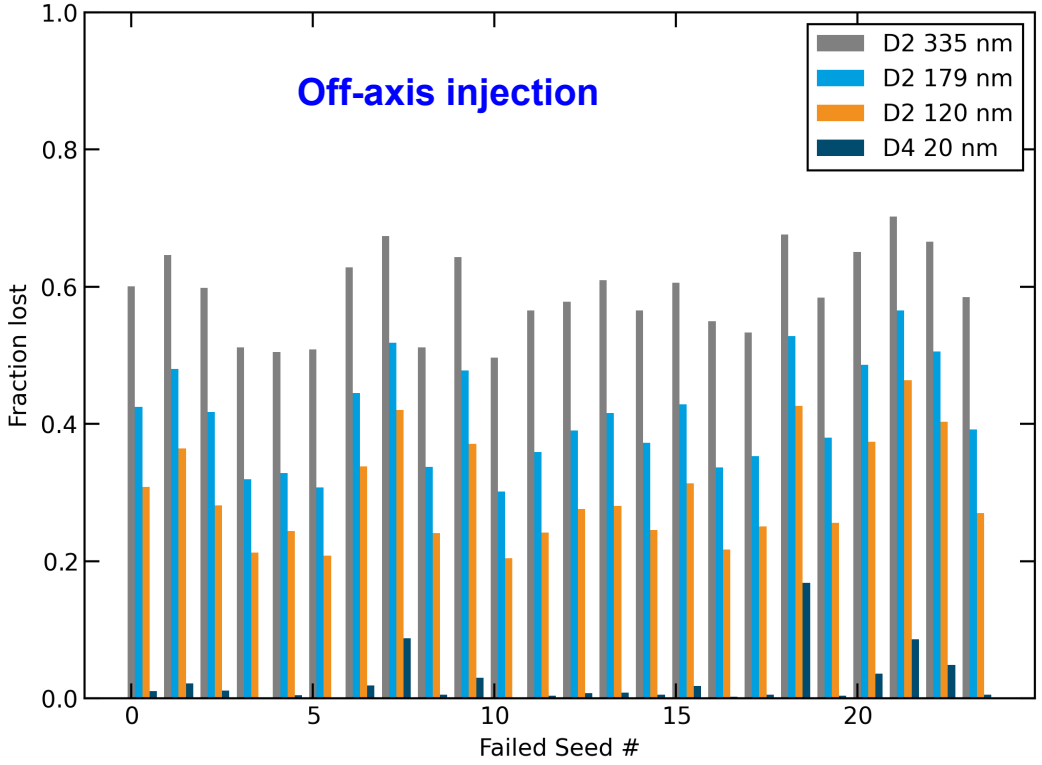


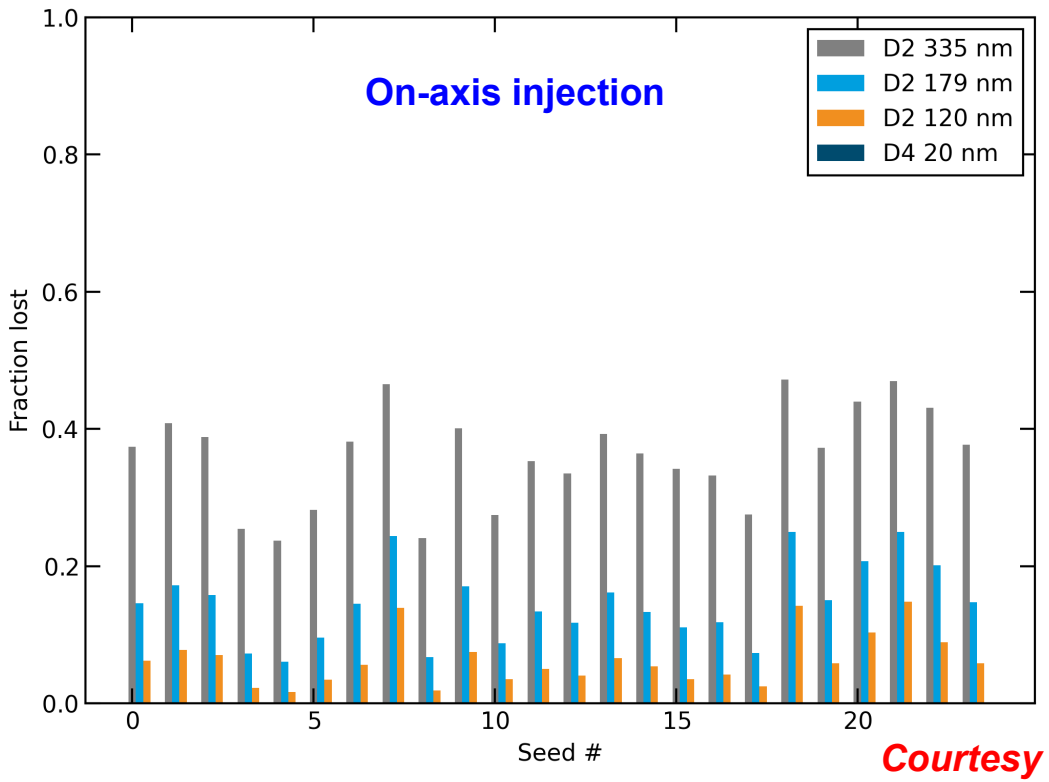
Currently a max of 3 nC can be accelerated in DESY II – this rules out operation in timing mode for PIV (7.6 nC)
However:

- collimation in the transfer lines can be used to reduce the emittance of DESY IV to the level acceptable for injection in PETRA IV and reduce radiation issue at the injection point
- can use swap-out injection in PETRA IV (collimation in transfer line still needed)

Using existing DESY II as booster for PETRA IV reevaluated

- Simulation of injection from DESY II (with/without emittance-optimized beams) into PETRA IV.
- Roughly 60% of the beam is lost during off-axis injection and 35% during on-axis (swap-out) injection
- However, with on-axis injection, timing mode parameters cannot be reached due to charge limit





Courtesy S. Antipov

DESY IV remains the baseline strategy for the pre-accelerator complex until the potential of the LPA injector is fully assessed

Conclusions and future work

- PETRA IV is the highest priority project at DESY

- Project proposal (TDR) ready
- Storage ring lattice well defined. Many elements of the machine are close to their final design.
- Prototypes are on the way
- DESY programme under revision – new lattice done – engineering integration ready to restart
  pending decisions on installation

- Personnel/Investment resources for 2024-2025 reassessed in the light of the recent news on funding

9th Low Emittance Ring workshop – CERN 12th-16th February 2024
Workshop on feedback systems – in preparation at Karlsruhe (KIT)
Workshop on injector systems – April 2024 location to be defined
(supported by the EU I-FAST project)

Special Thanks to D. Einfeld for his 3 years consultancy for PETRA IV

Thanks to many colleagues that provided material for this summary

Thank you for your attention!