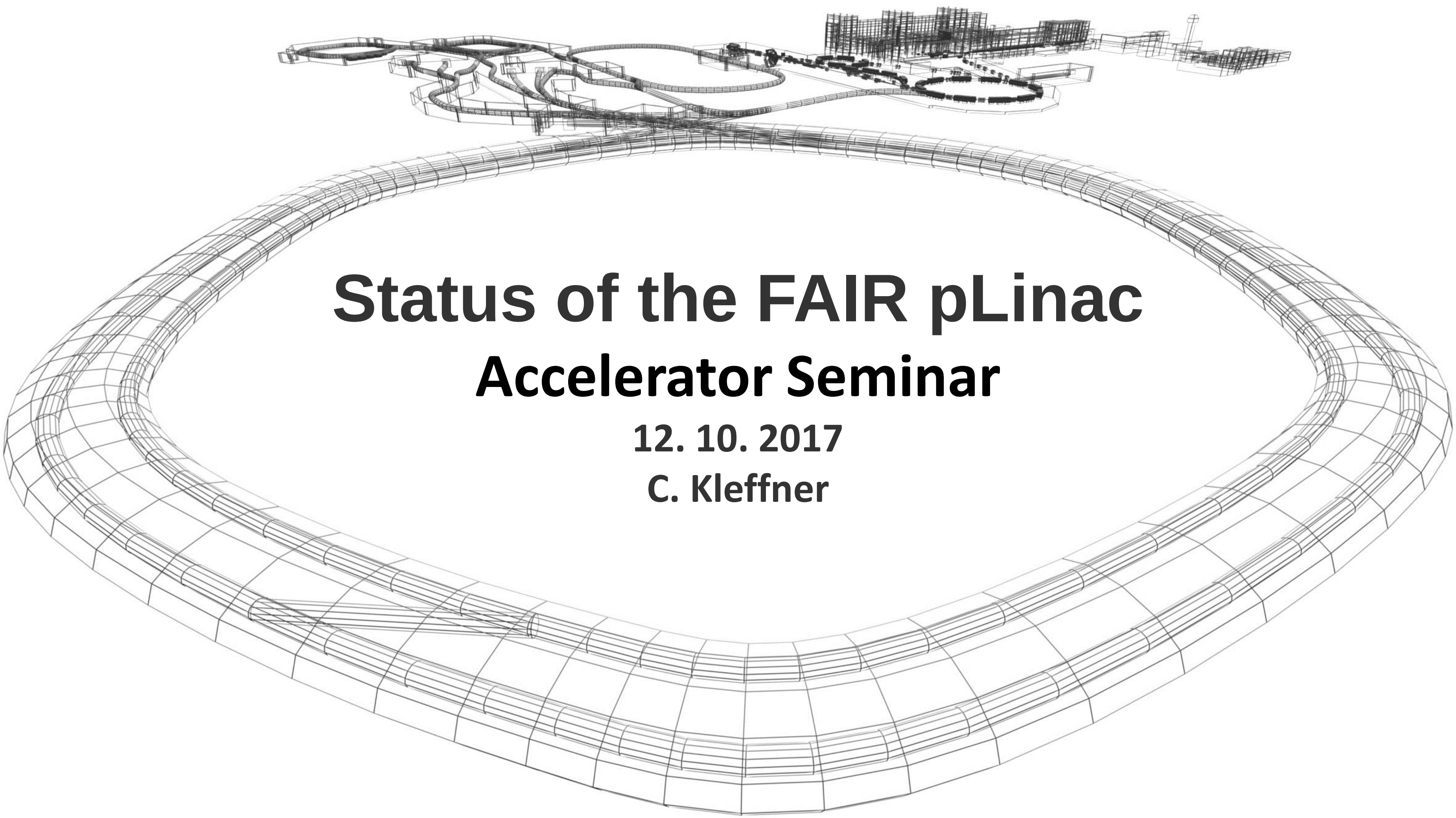


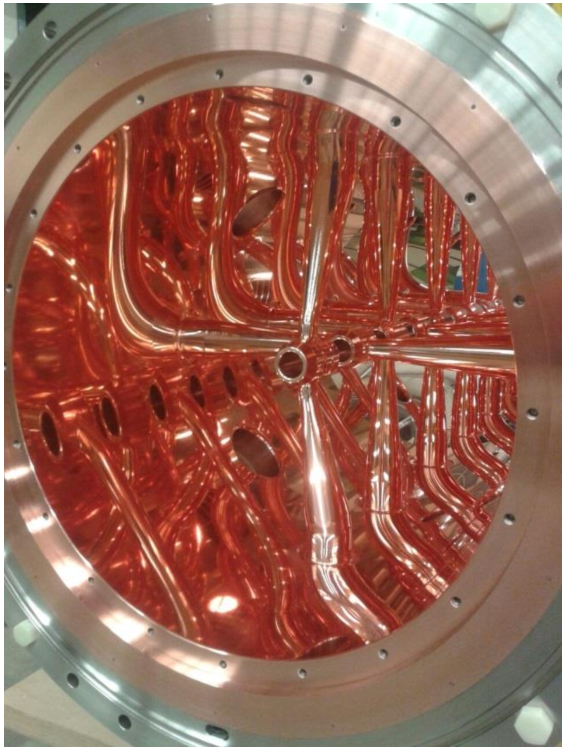
Status of the FAIR pLinac

Accelerator Seminar

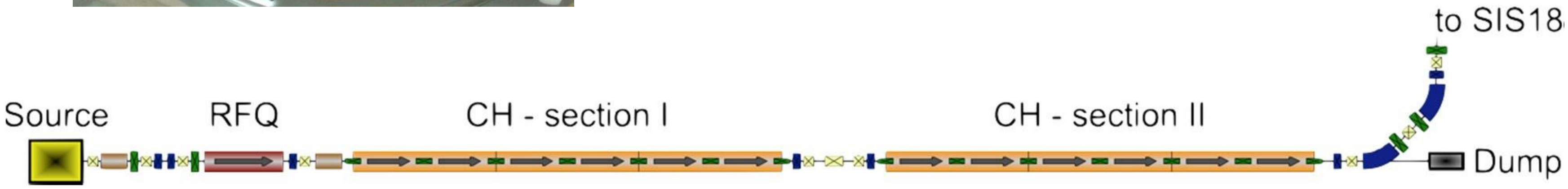
12. 10. 2017

C. Kleffner

pLinac - overview

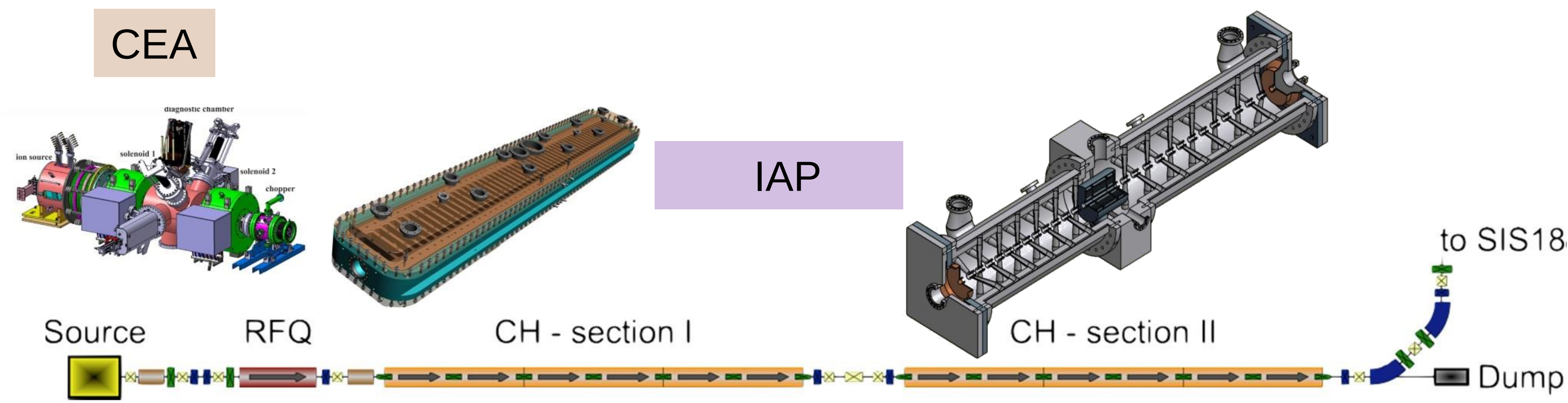


Beam Energy (MeV)	70 → **68**
Design Current (mA)	70
Beam Pulse (µs)	36
Repetition Rate (Hz)	4
Frequency (MHz)	325.224
Beam Loading (peak) (MW)	4.9
RF Power (peak) (MW)	2.2
Klystron (3 MW Peak Power)	7
Solid State Amplifier	3
Total Length (RFQ + CH)	≈ 27 m



pLinac overall design

- 2.45 GHz ECR source generating 100 mA of 95 keV protons
- LEBT & diagnostics chamber:
  faraday cup / allison scanner / wien filter
- ladder 4-Rod RFQ with chopper and a beam dump in front
- Six normal conducting crossbar cavities of CCH and CH type aranged in two sections with intermediate diagnostic section

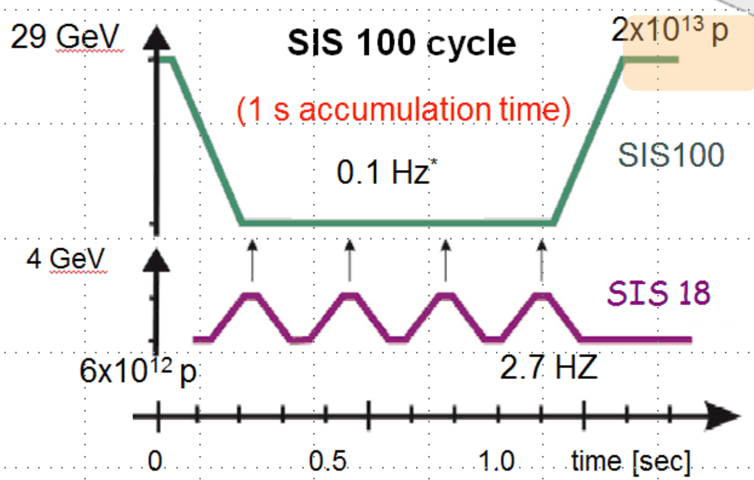


reasons for a new proton linac

FAIR primary beam chain: Protons

SIS100 injection:
4 injection from SIS18

SIS100 extraction:
Single, short (50 ns) bunch



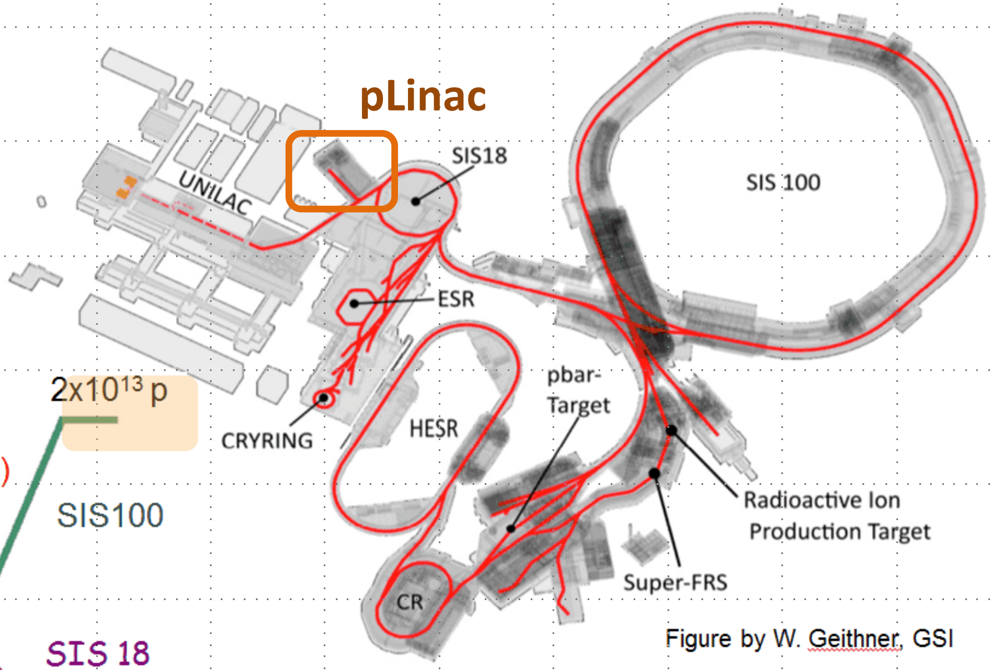


Figure by W. Geithner, GSI

*adapted to CR cooling rate

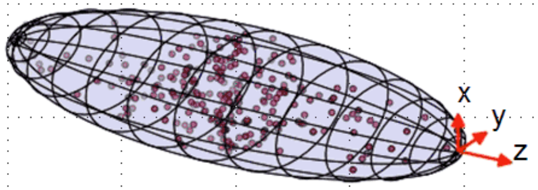
reasons for a new proton linac

Intensity limitations: Space charge (SC)

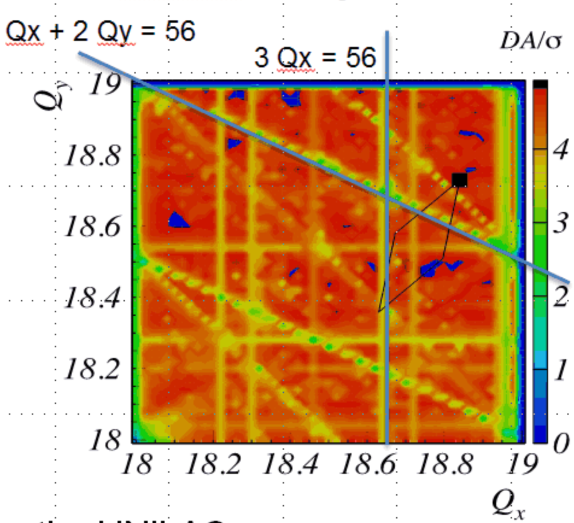
Concept:

- Space charge is the inter-particle Coulomb force.
- In the beam frame SC force be evaluated with the Poisson's equation.

$$\nabla^2\Phi = \frac{\rho}{\epsilon_0\gamma^2}$$



G. Franchetti, S. Sorge, Proc. IPAC11



Space charge effects:

- SC limited or/and determine beam parameters and accelerator components (CERN LHC injector chain + FAIR)
- SC is a major intensity limitation for synchrotrons expressed by tolerable SC tune shift

Energy depending!

$$\Delta Q_y^{sc} = -\frac{NZ^2 g_f}{2\pi A \beta_0^2 \gamma_0^3 B_f \epsilon}$$

➢ Reason why the p-linac have a higher final energy as the UNILAC

reasons for a new proton linac

Comparison of estimated intensities

		p-linac	UNILAC
Linac	Energy in MeV	68	20
	Current in mA	35	3
	Emittance in µrad (4 rms)	7	3
SIS18	Protons per cycle	6E12*	1.5E12*
SIS100	Protons per cycle	2E13	5E12
CR	Antiprotons per cycle	2E8	5E7
	Relative	100%	25%

CH4 cracked & pulsed gas stripper

factor 4 gain

* limited by space charge (dQ=0.5)

- **Assumption for both cases**
  Design cycles as well as design loss budget (Injection, Extraction, Space charge, ...)

W. Barth et al, Heavy ion linac as a high current proton beam injector, PRST-AB 18, 050102 (2015)

IAP pLinac design

A ladder RFQ will be build @ **IAP** after the successful prototype test (BMBF support)
copper plating foreseen Q4 2017
beam tests foreseen @ GSI in 2020

RFQ beam dynamic IAP design

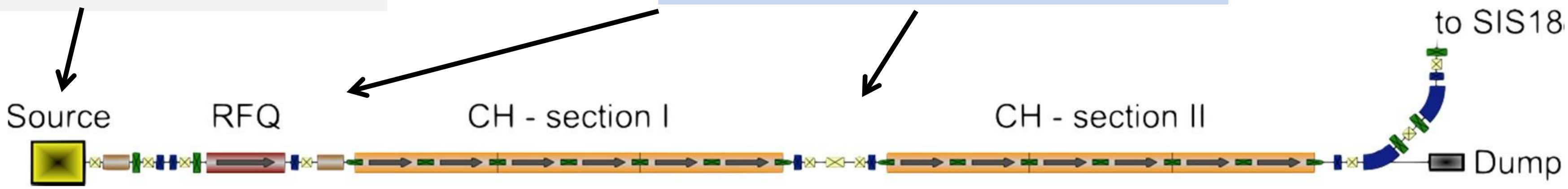
reworked beam dynamics (IAP)
70 MeV fixed since 2015-04
changed to 68 MeV 2017-02

reworked RF design of CH, CCH
final report expected Q4 2017 **(IAP)**

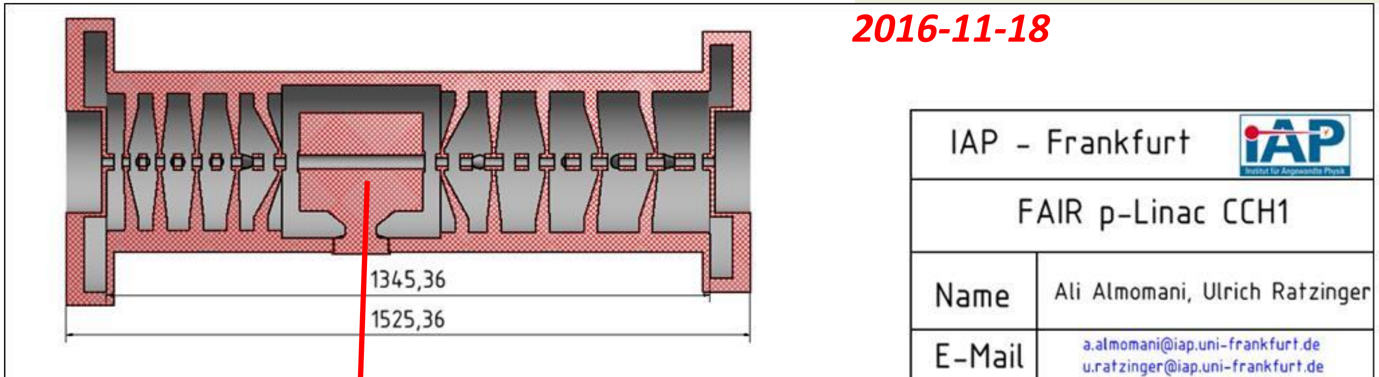
triplets already ordererd
design of housings still has to be approved
delivery in 2018?

ion source CEA
beams tests 2017/18
Q3 2017 100 kV
SAT @ CEA

rebuncher sections
update of the draft rf design is needed



IAP pLinac design



@ IAP
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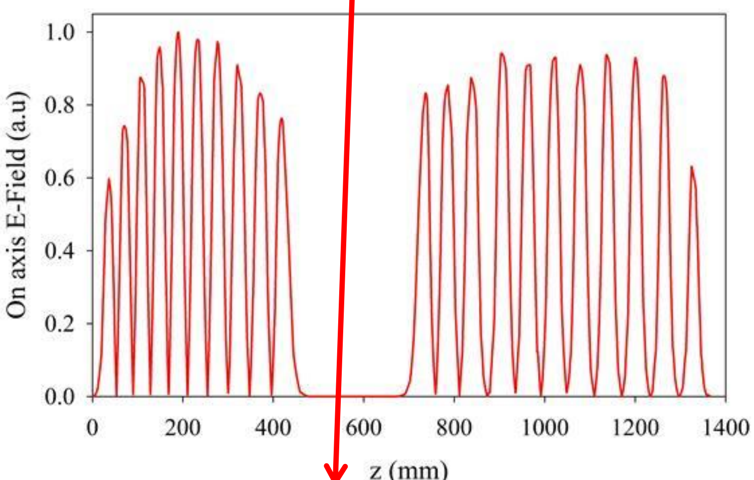
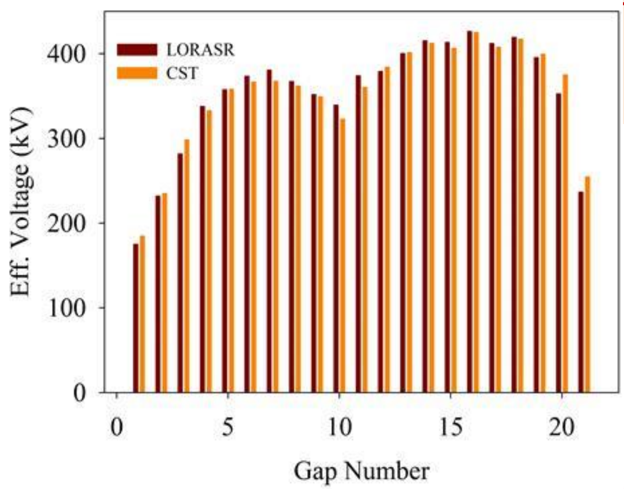
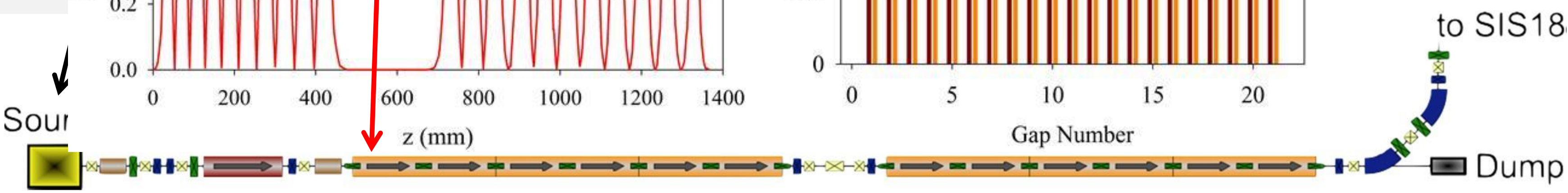
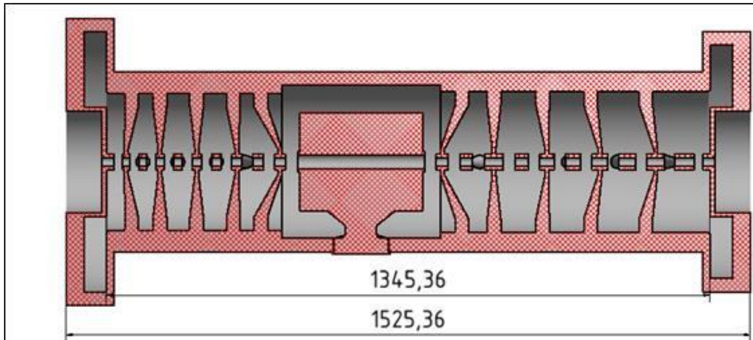






IAP pLinac design



2016-11-18

IAP – Frankfurt	
FAIR p-Linac CCH1	
Name	Ali Almomani, Ulrich Ratzinger

@ IAP
e test

2017
2020

gn

rd
s to be

be

2017-02-17 final geometry
2017-10 final rf-design

IAP, Frankfurt, 15.02.2017

U. Ratzinger

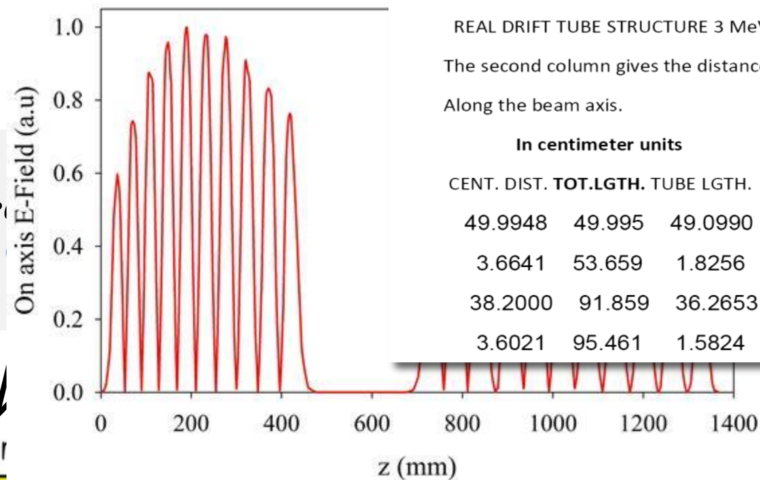
REAL DRIFT TUBE STRUCTURE 3 MeV to 68 MeV

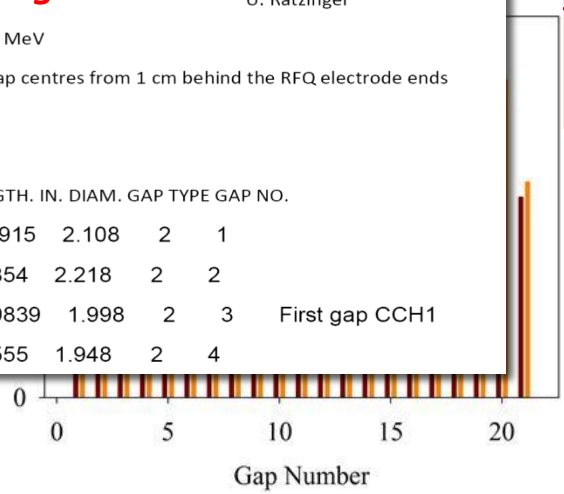
The second column gives the distances of gap centres from 1 cm behind the RFQ electrode ends

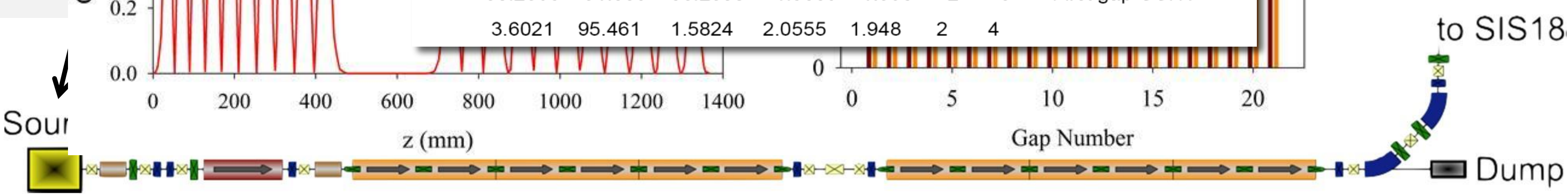
Along the beam axis.

In centimeter units

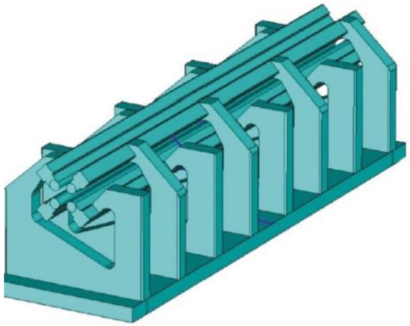
CENT. DIST.	**TOT.LGTH.**	TUBE LGTH.	GAP LGTH.	IN. DIAM.	GAP TYPE	GAP NO.	
49.9948	49.995	49.0990	1.7915	2.108	2	1	
3.6641	53.659	1.8256	1.8854	2.218	2	2	
38.2000	91.859	36.2653	1.9839	1.998	2	3	First gap CCH1
3.6021	95.461	1.5824	2.0555	1.948	2	4	

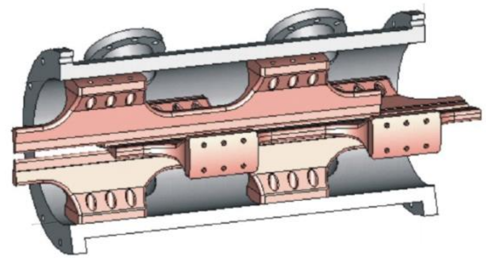


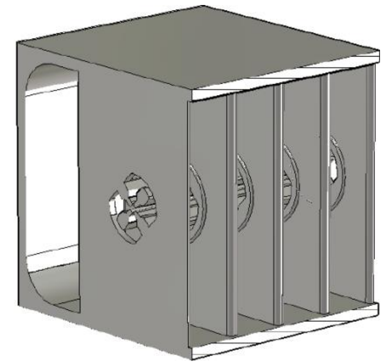




325 MHz RFQ – history







- **MAC11:** ***The MAC recommends the four-vane structure,*** *more reliable and better exploited ... However, being the RFQ a typically delicate piece of equipment in linacs, it would be advisable to* ***build a cheaper four-rod structure too*** *... and treat it as a spare component.*

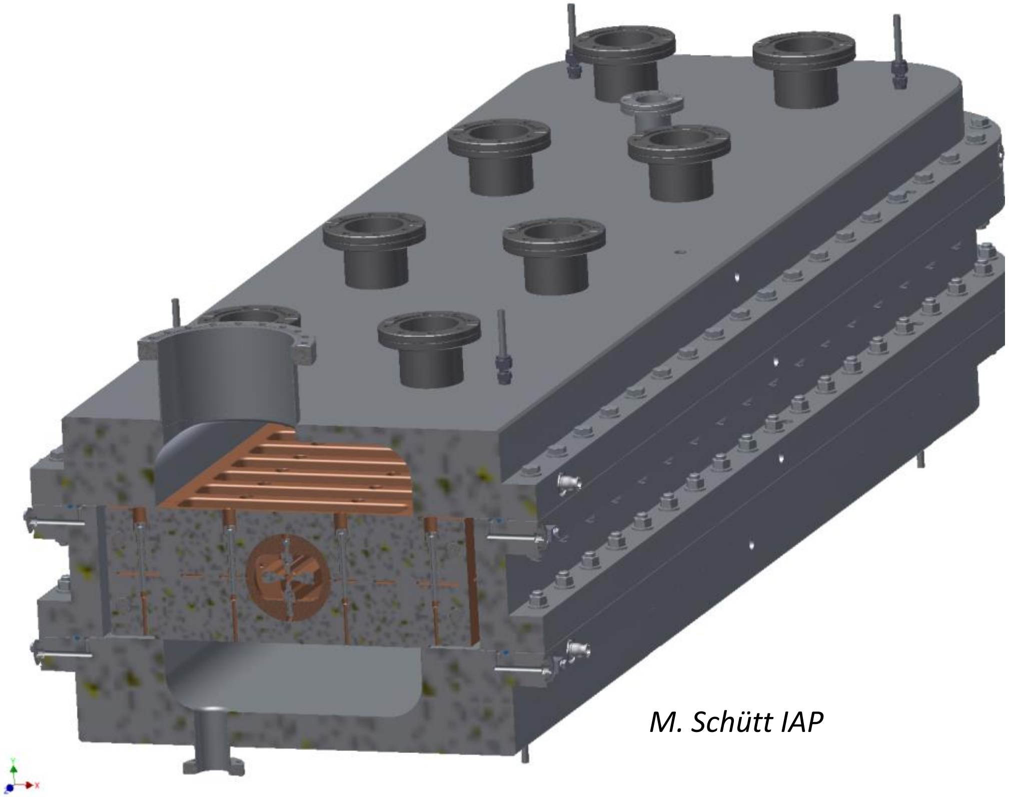
- **MAC12:** ***The strategy to build two RFQs,*** *one of the 4-rod and one of the 4-vane type,* ***has been confirmed and the MAC supports it.***

- **MAC13:** ***Building an additional 4-rod RFQ*** *profiting from a supplementary R&D budget* ***is a wise decision*** *that could provide a spare solution during operation and in case of delays in the production of the baseline 4-vane RFQ ...*
  It should be noted that the 3-year construction time of the RFQ brings it clearly on the critical path.

- **MAC15:** ***Schedule additional testing of the ladder RFQ, if possible with beam and prepare a mitigation plan based on the construction of a four-vane RFQ in case of problems with the ladder design.***

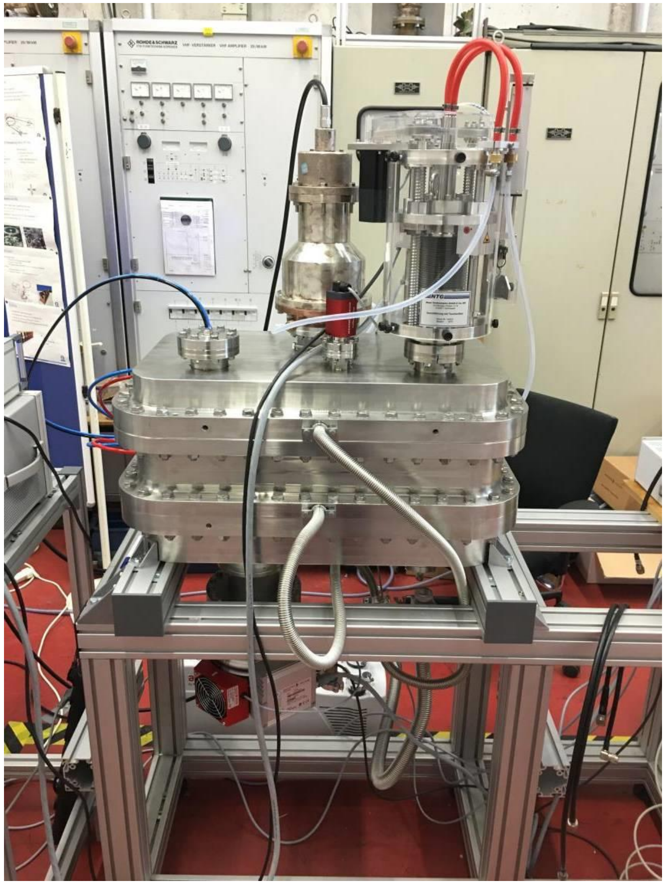
- ***to be continued ..***

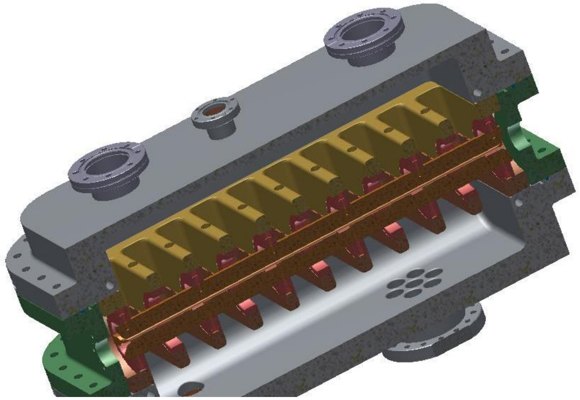
ladder RFQ – mechanical design (BMBF support)



modular mechanical layout
2 half shelves & middle section
RFQ mini-vane electrodes with rings jammed between upper and lower ladder
copper parts made of oxygen free stiff material (no thermal treatment)
no mechanical adjustment for the RFQ electrodes needed
mechanical solidity

ladder RFQ – prototype





prototype summary	time-line
manufactoring started	2014
First low level rf measurements	2015
Final tuning	02/2016
IAP conditioning	03/2016
successful GSI high power test	04/06 2016

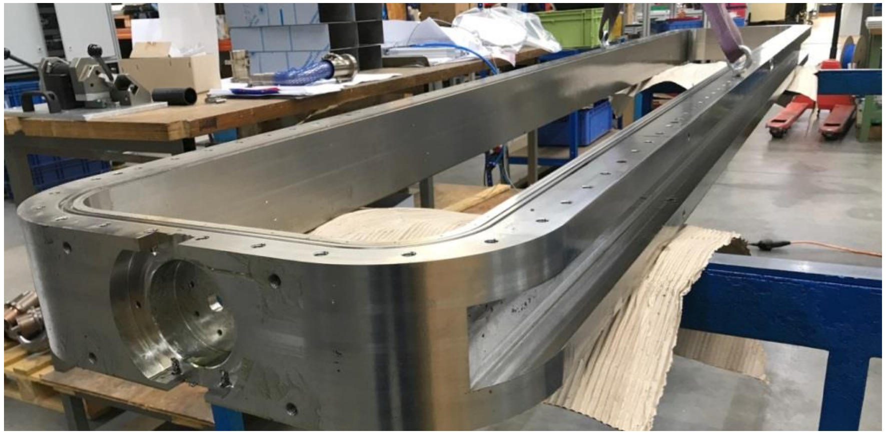
ladder RFQ - advantages and open questions

advantages	Open questions
expenses in between 4-Rod and 4-Vane RFQ (400 k€ ... 450 k€)	LEBT – RFQ beam dynamic review needed
middle section (ladder / electrodes) exchangable / no mechanical alignment required	High amount of dimensional accuracy in the manufacturing process required
no dipole field error (*compared to 4-Rod*)	coupling loop for full size ladder RFQ needs galvanic contact to the support structure
good flatness properties possible (< 2%)	
proven vacuum properties (prototype test)	**POP Test with beam mandantory**

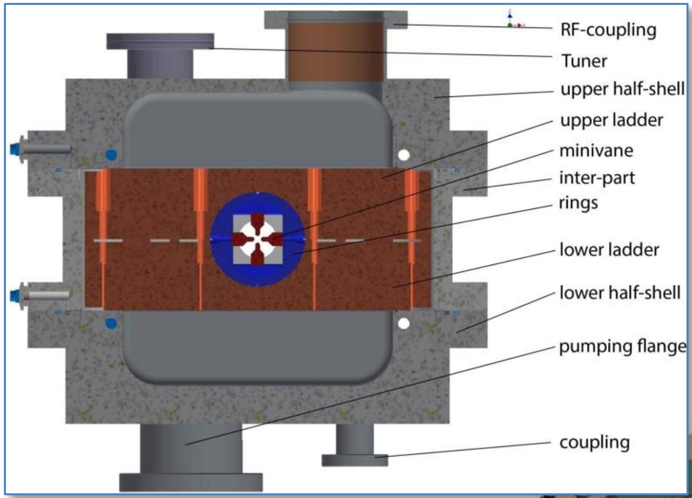
ladder RFQ – status

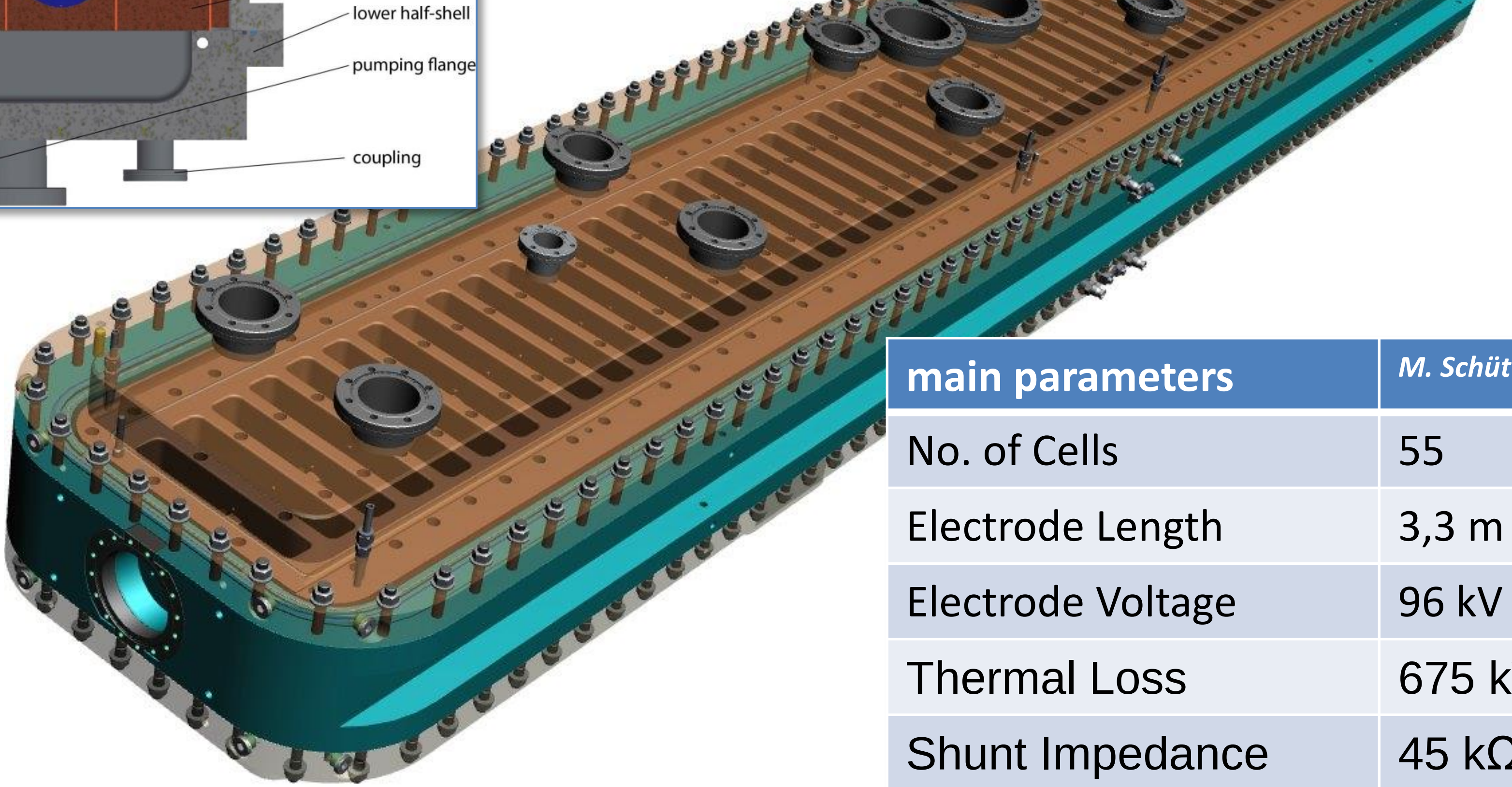
MAC 16:
(R11) Pursue the option of testing the RFQ in its final position in the new building and provide a comprehensive schedule that leaves sufficient time after the early beam tests for building a 4-vane RFQ in industry.
MAC17:
Copper plating in Q4/2017 of the two RFQ half-shell is, before the refurbishing of the GSI galvanic workshop, is essential to achieve this goal.

2017-10-13	**acceptance test of vacuum chamber parts of the ladder RFQ**
2017 Q4	**copperplating ladder RFQ vacuum chamber**



325 MHz IAP ladder RFQ – parameters

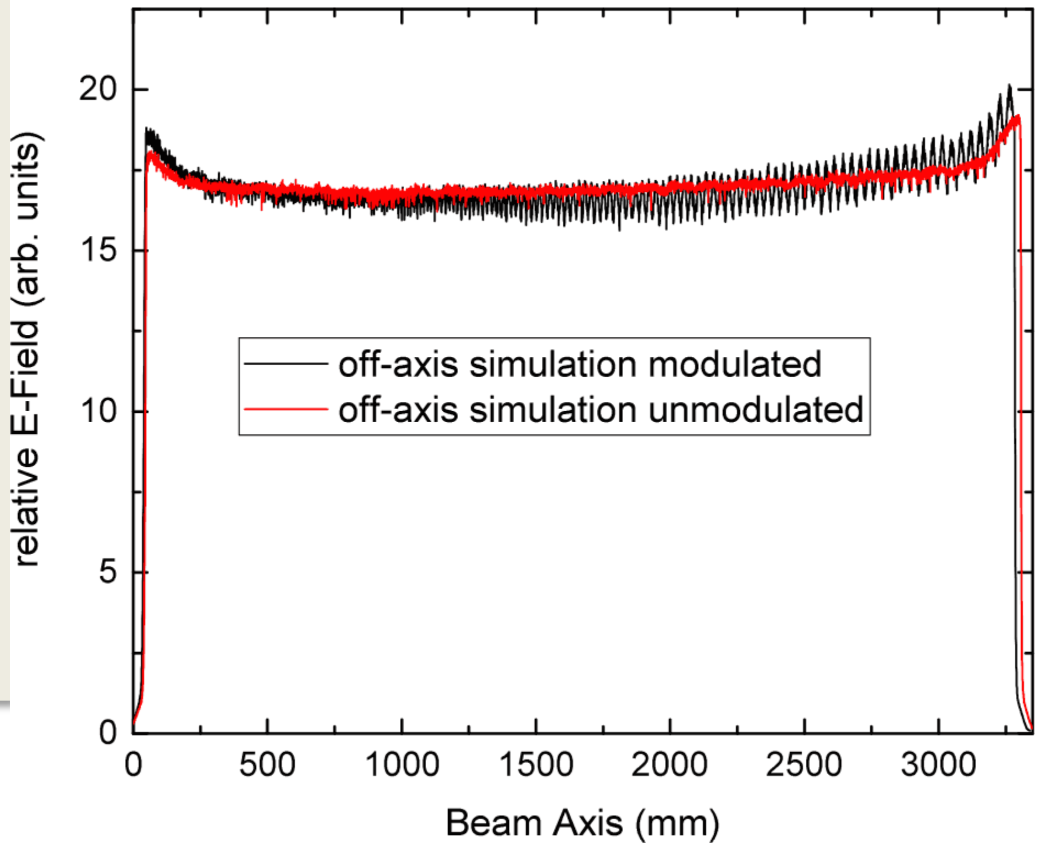




main parameters	*M. Schütt IAP*
No. of Cells	55
Electrode Length	3,3 m
Electrode Voltage	96 kV
Thermal Loss	675 kW
Shunt Impedance	45 kΩm

ladder RFQ - tuning concept (R11)

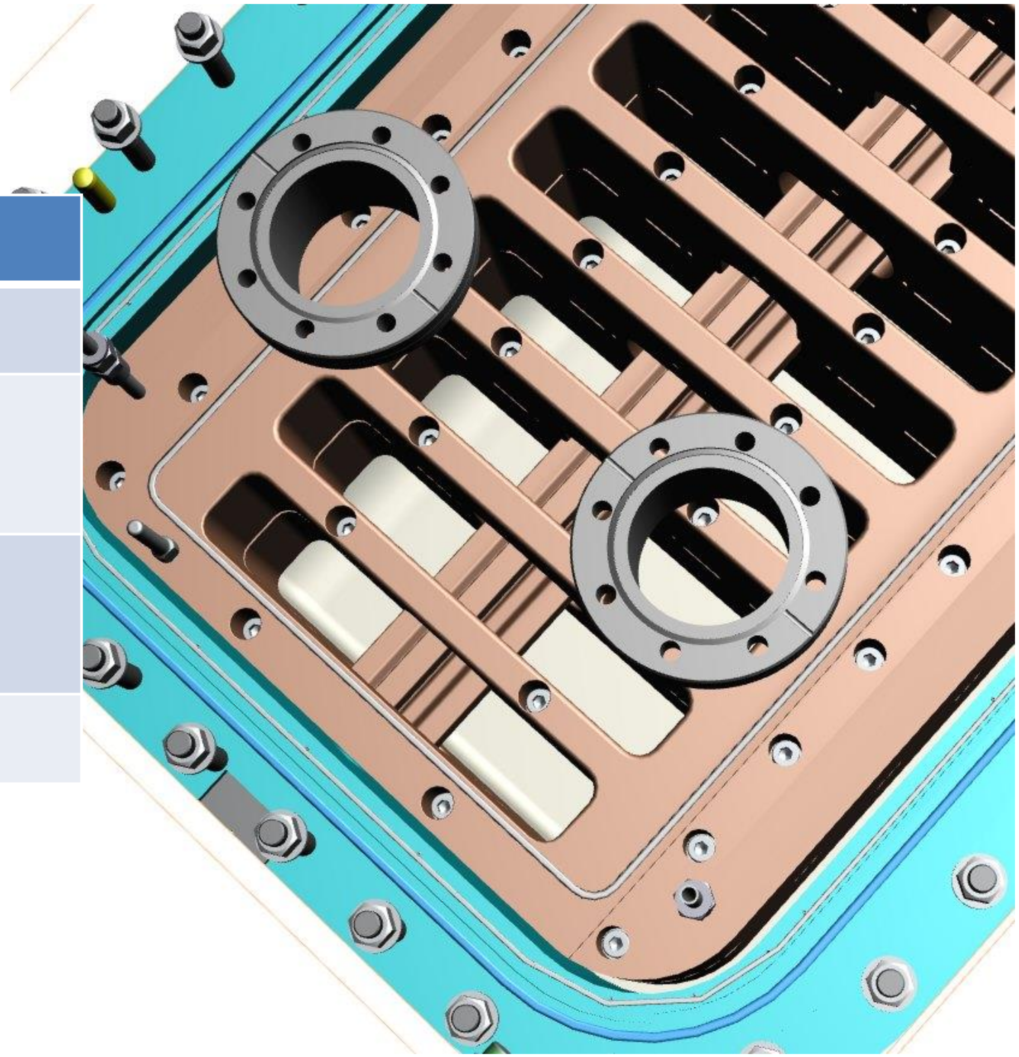
- *NO use of additional tuning plates*
- Fabricate *oversized* Ladder Structure
- Bead pull & frequency measurements combined with iterative milling of the ladder geometry.
- Fine tuning with plungers



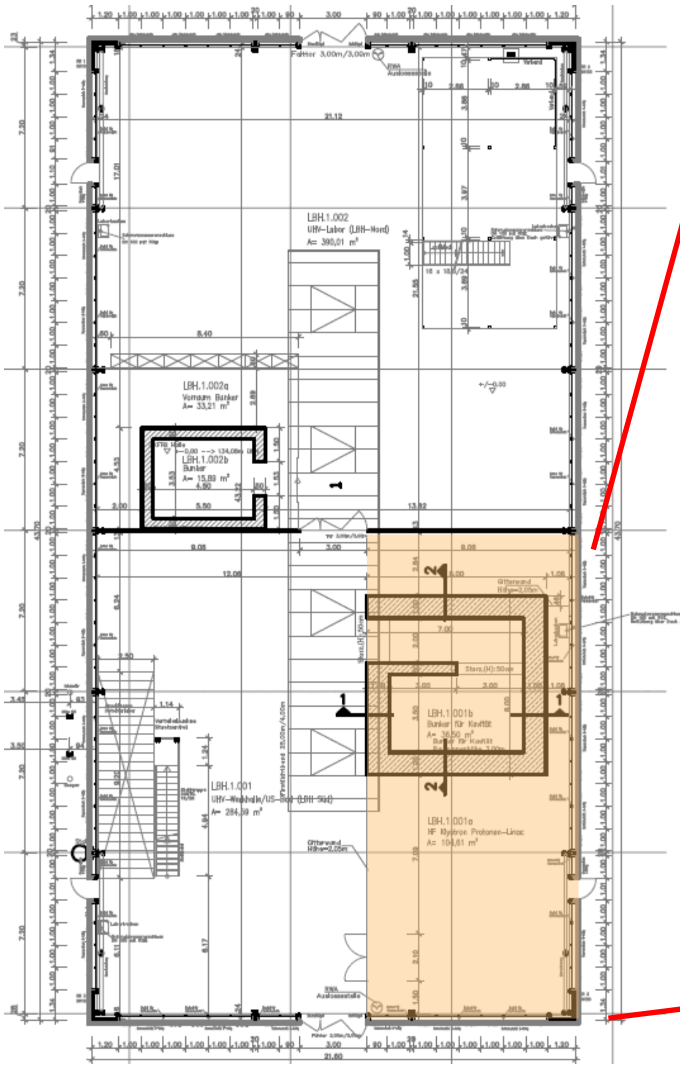
M Schuett IAP, TUPVA0P74, IPAC2017, Copenhagen

RFQ Schedule

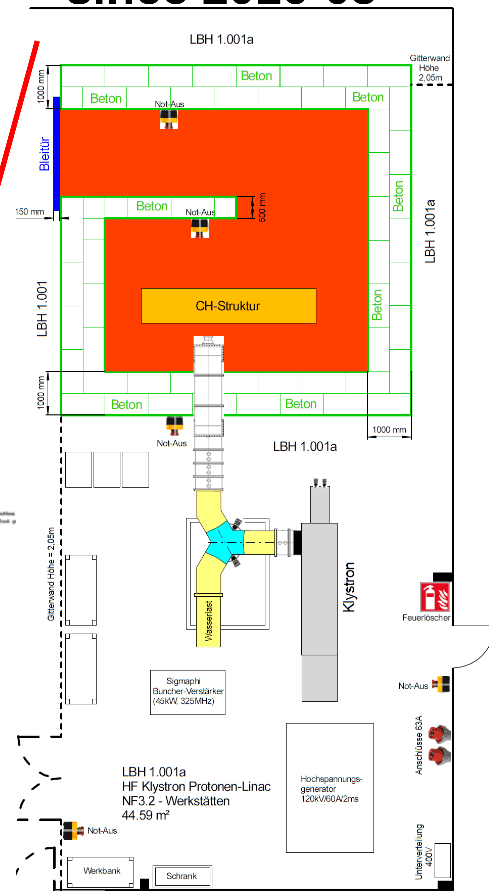
Schedule	
Q3/ 2017	Fabrication
Q4 / 2017	Copper Plating tank
2018	RF Tuning Low Level Tests
2018-2019	RF Power Test

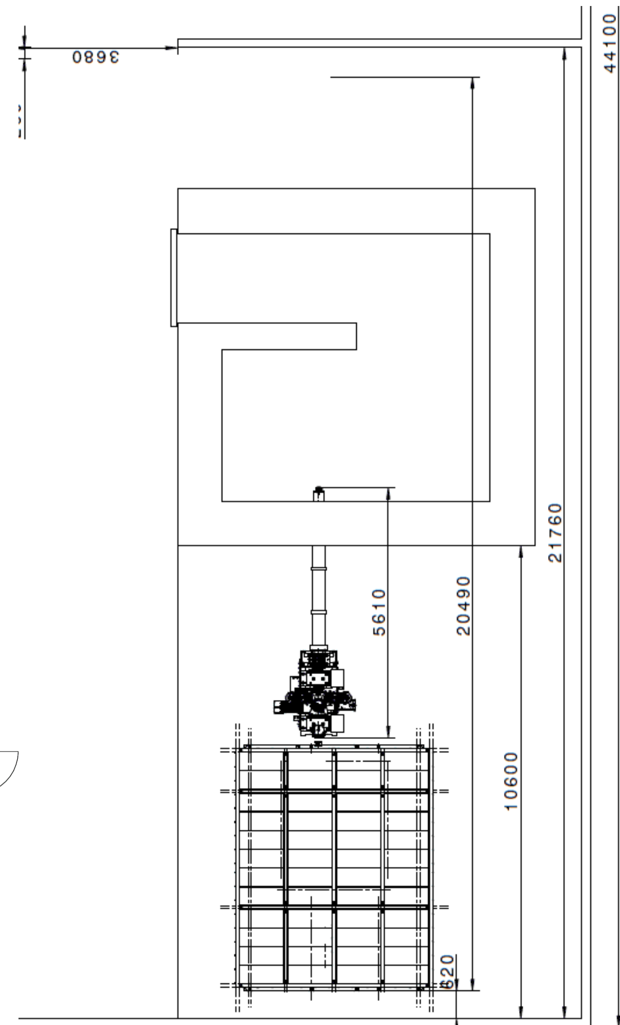


ladder RFQ – beam test in LBH ?

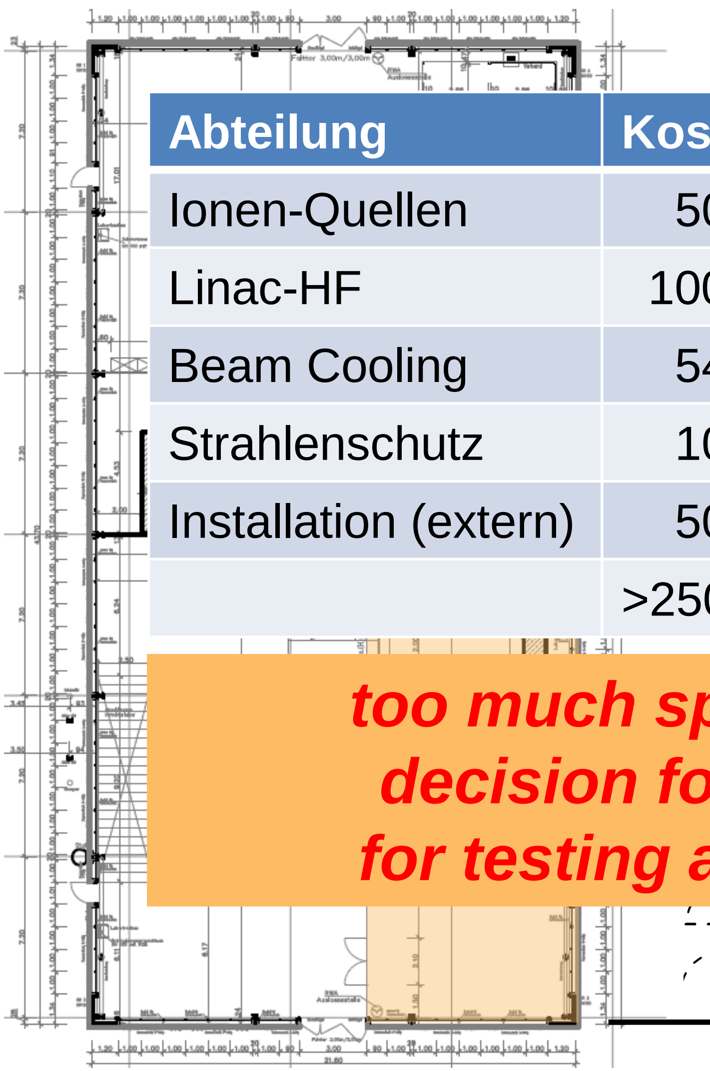


LRF testbench since 2016-05





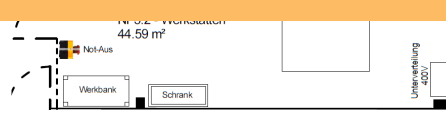
ladder RFQ – beam test in LBH ?



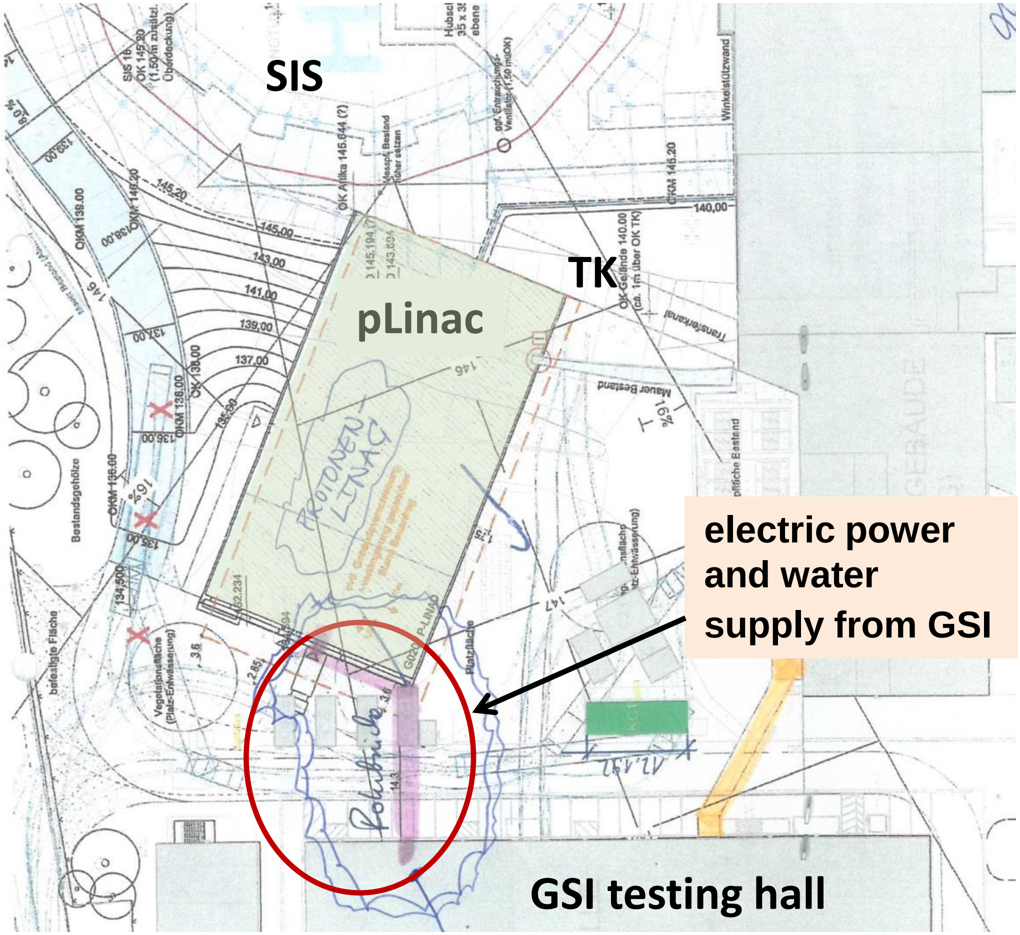
LRF testbench

Abteilung	Kosten	Ressourcen
Ionen-Quellen	50 T€	36 MM
Linac-HF	100 T€	50 MM
Beam Cooling	54 T€	8 MM
Strahlenschutz	10 T€	3 MM
Installation (extern)	50 T€	12 MM
	>250 T€	> 100 MM

too much space needed inside LBH
decision for early pLinac building
for testing all structures with beam



pLinac building



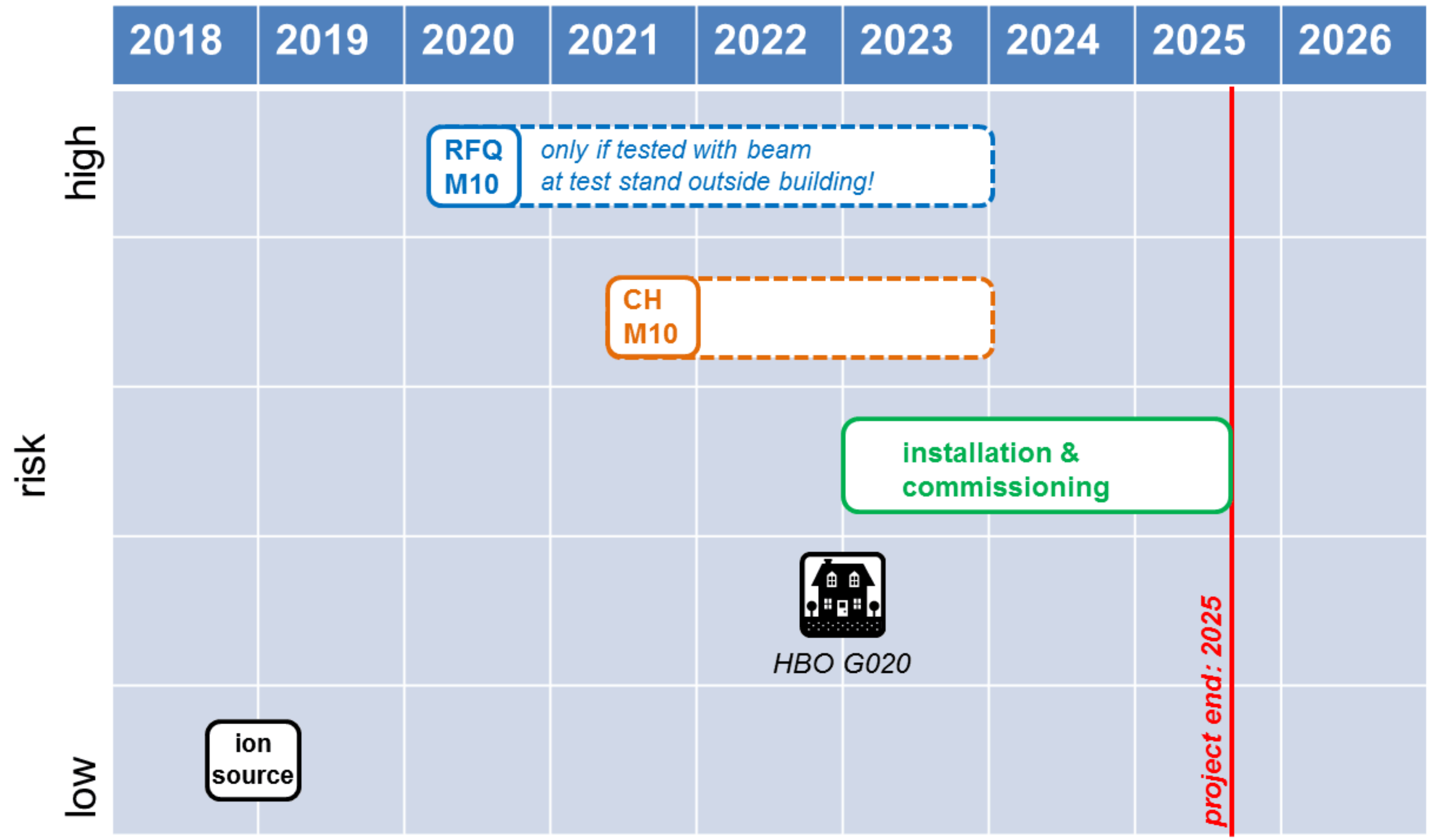
GSI GA/VTK

MAC: ***It is desirable to get the building ready for installation before end of 2020***

pLinac building will then be used for the beam test rather the LBH LRF Testbench

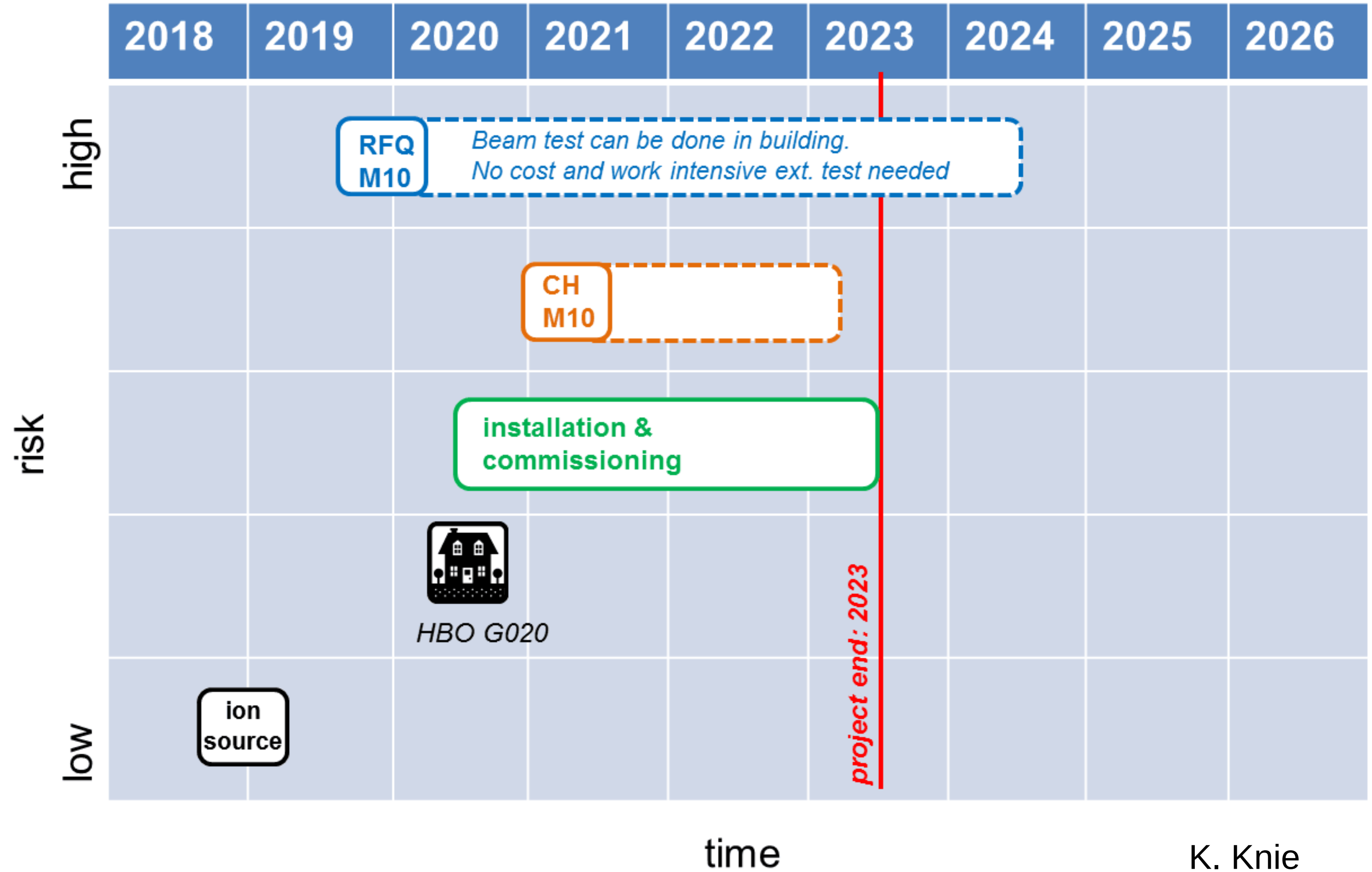
→feasability study 2017-02

pLinac building – FAIR planning



MAC16: ***The Committee strongly supports the testing of the RFQ in the pLinac building that should become available before end of 2020.***

pLinac building – revised planning



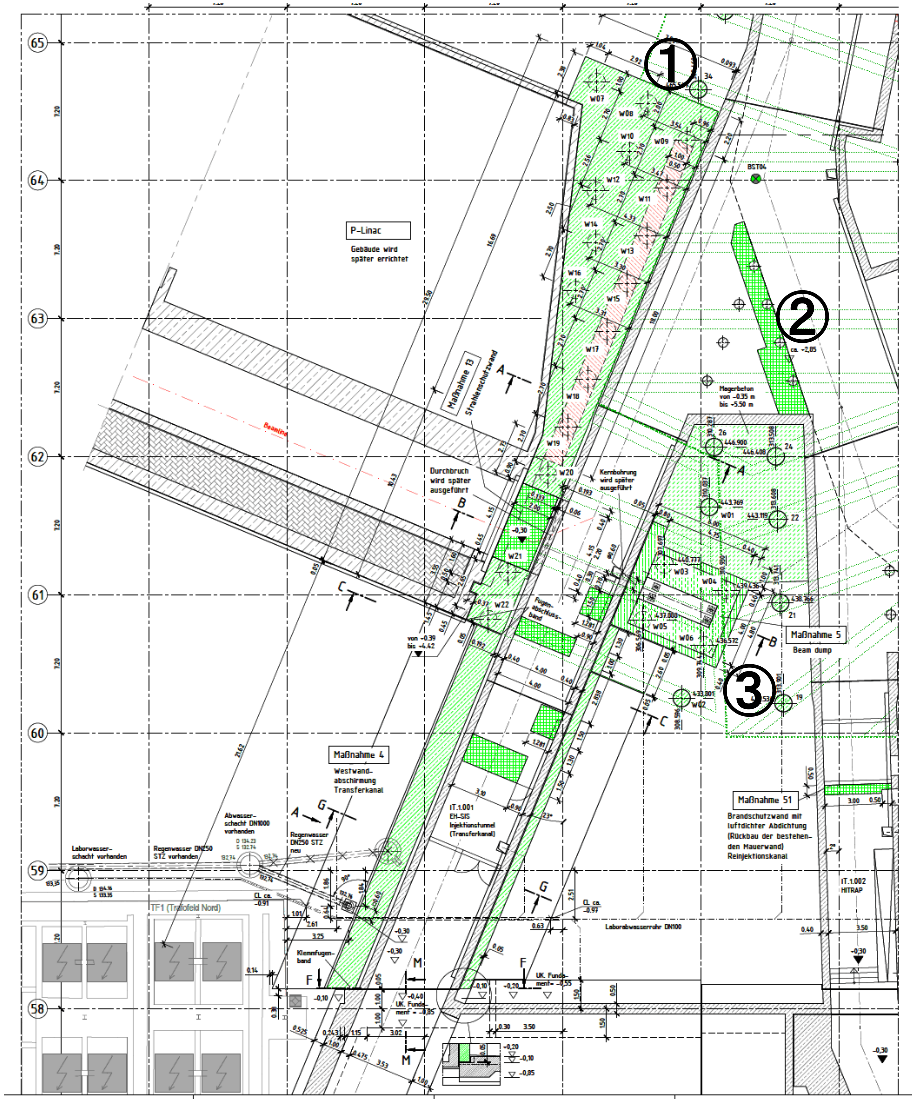
K. Knie

pLinac building

The pLinac building has already started three years ago!

pLinac building

pLinac building / GAF



GAF / WTK actions

① WTK shielding wall with hematite inlay (only E10)

② ~~hematite „lamda“~~ simplified:
→ concrete shielding wall

③ beam dump

WTK building activity:
2017-12 ... 2018-01

pLinac building activity: Q4 2018
HBO pLinac building: Jan 2020

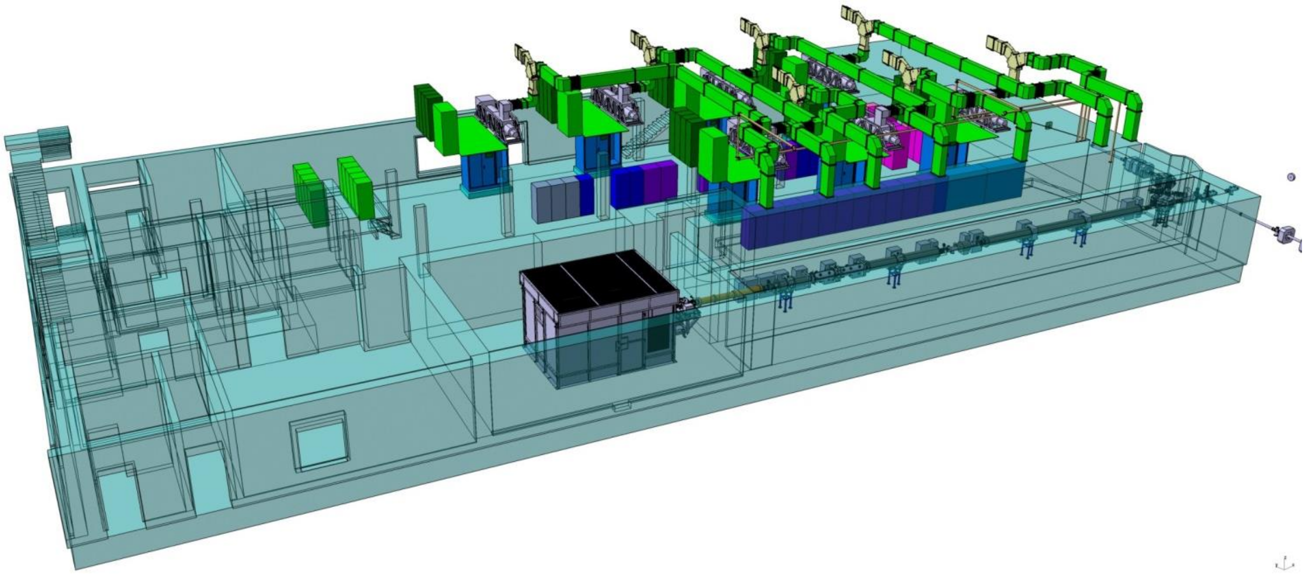
excavation work – TK tunnel

aug 2017

excavation work now (oct 2017) finished

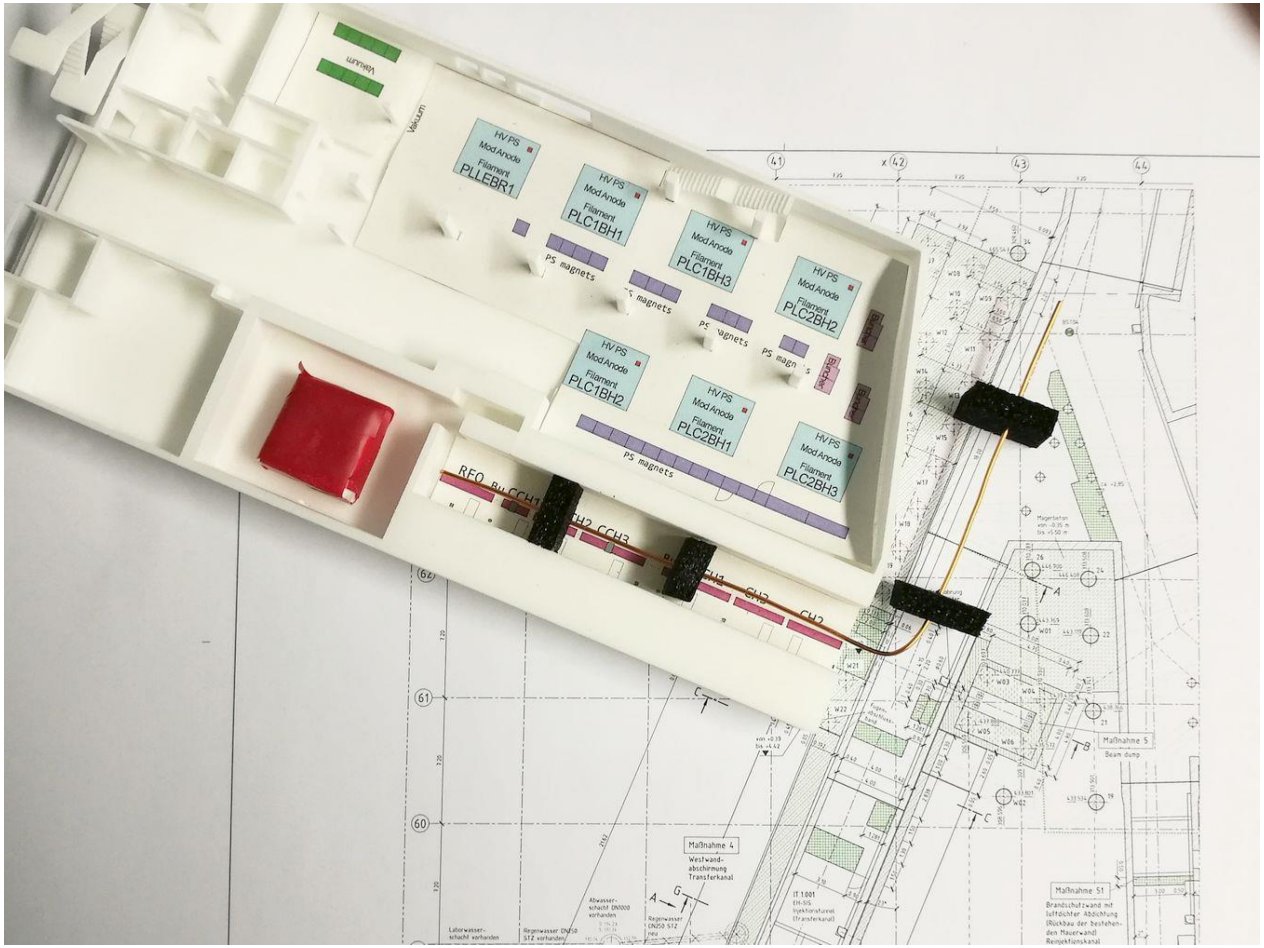
pLinac building status

freeze design planning / sign building application   2017-10-13



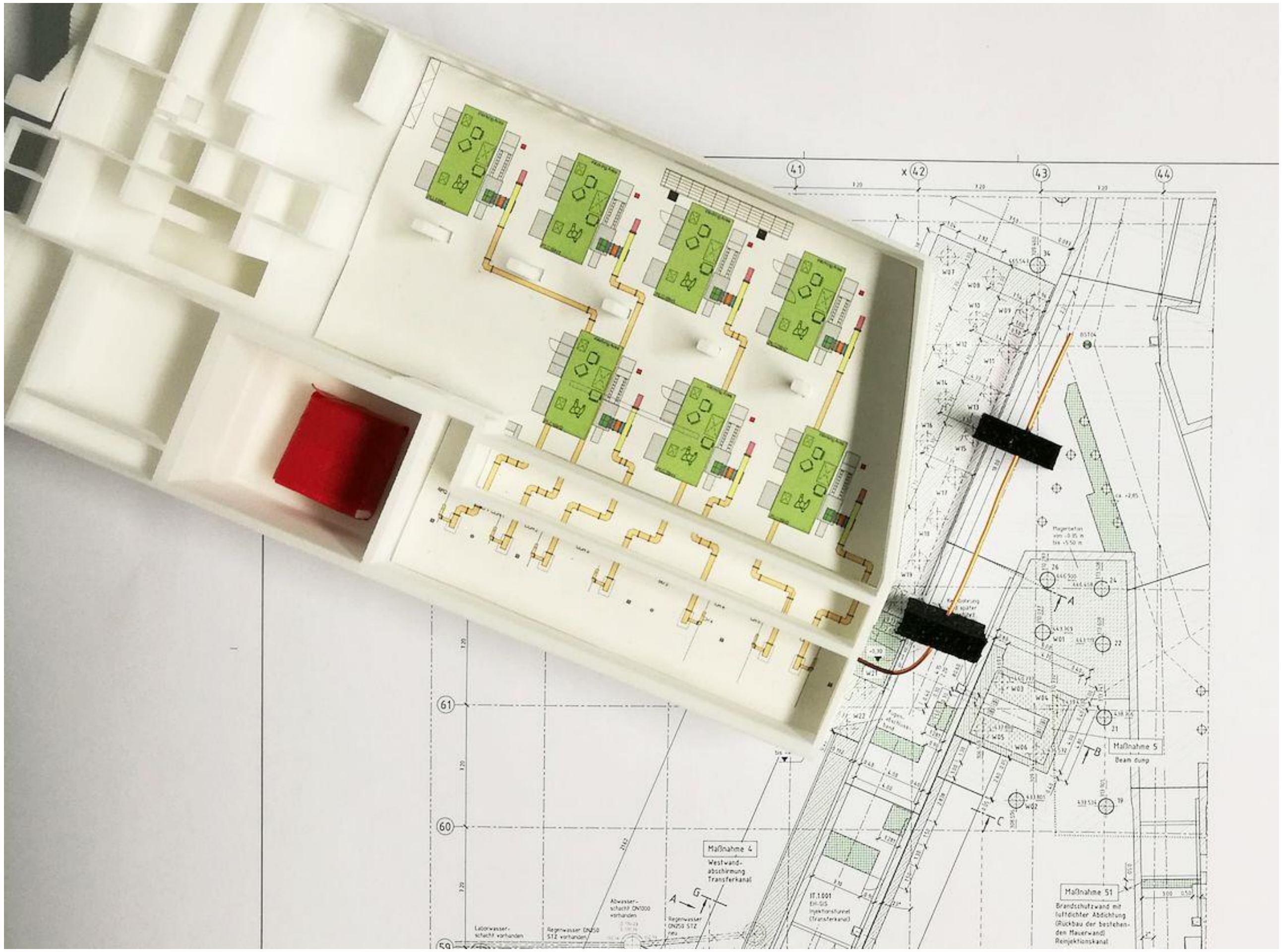
pLinac building status

freeze design planning / sign building application 2017-10-13



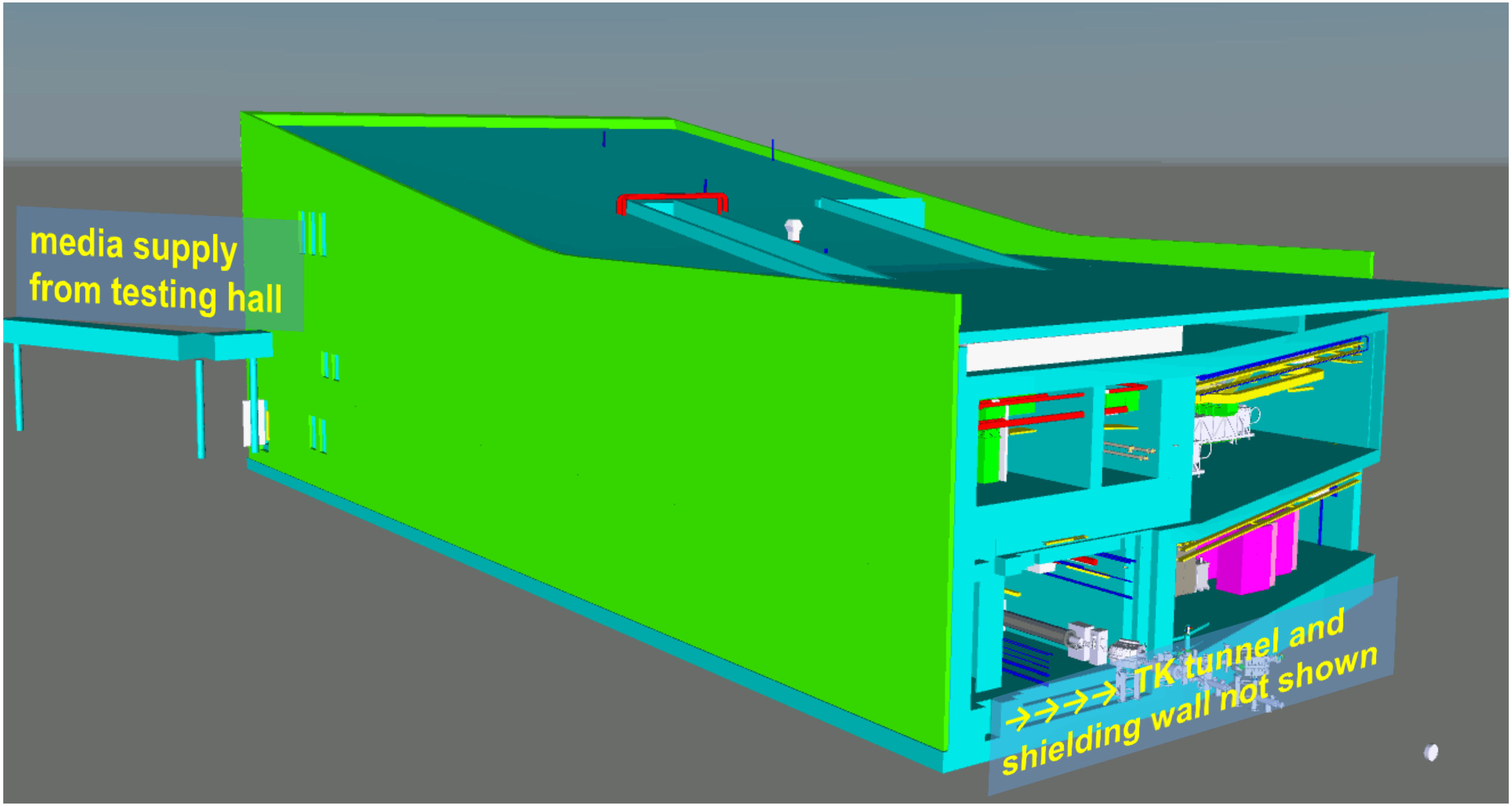
pLinac building status

freeze design planning / sign building application 2017-10-13



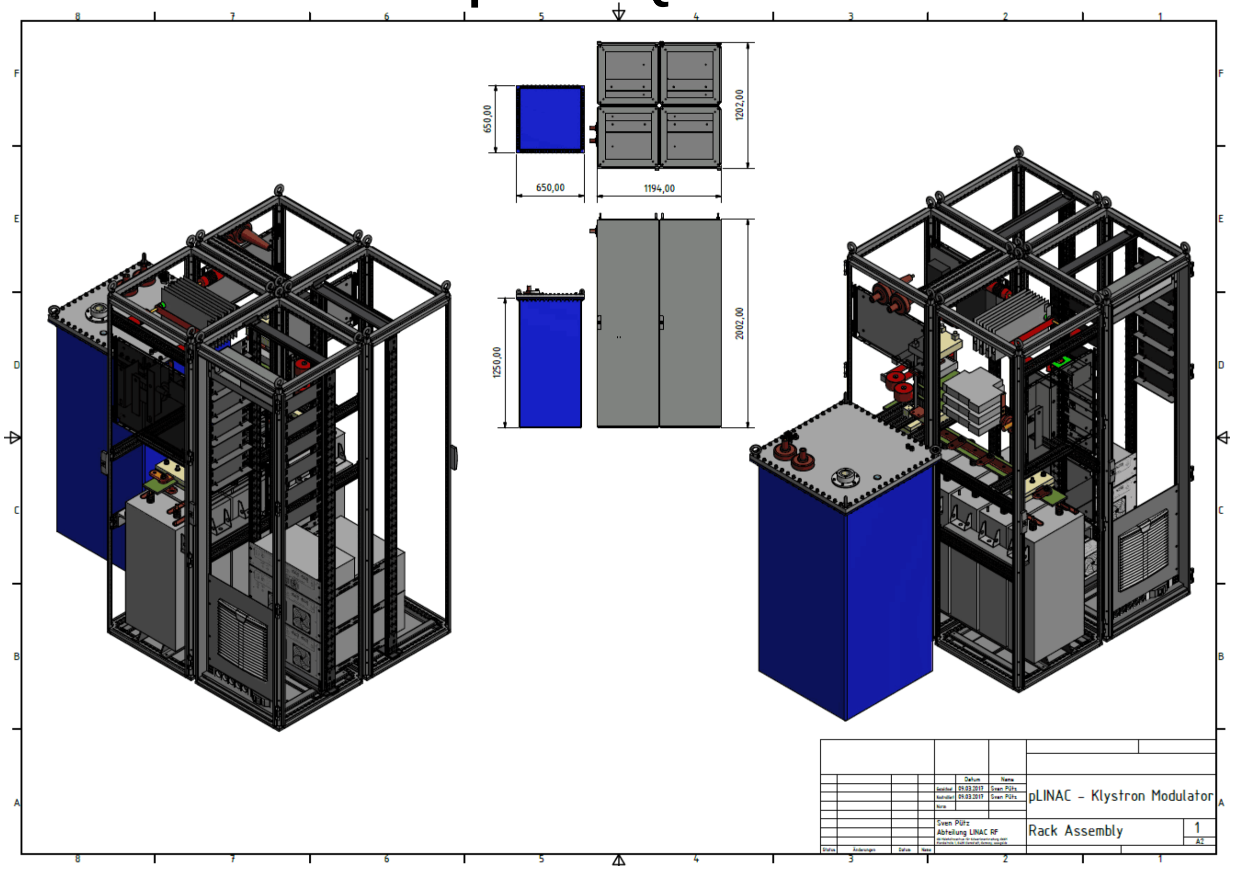
pLinac building status

freeze design planning / sign building application 2017-10-13



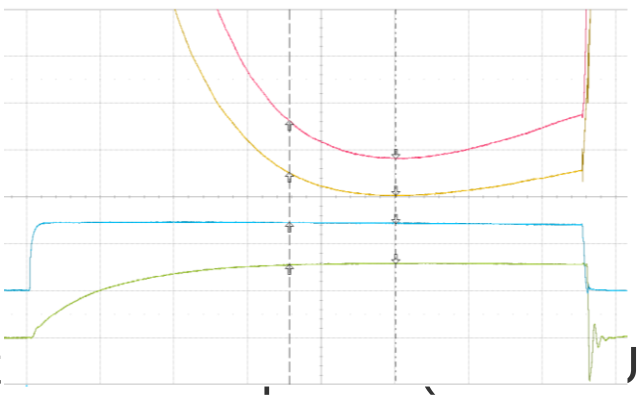
status modulator

start of commissioning with full power operation expected Q4 2018



status modulator

- decision in favour of in-house design
- demonstrated operation at the pLINAC operating point
- proven high reliability
  - topology in use at LINAC4
  - 14+2 systems, >100k operating hours w/o fault in the power train



100 us/div
360us flat top ($\Delta U/Uk$ < 1%; $\Delta I/Ik$ < 1.5%)

- meet [illegible] R/system)
- 50% of cheapest viable commercial (turn-key) offer

M. Pütz

CH / CCH prototype

- manufactoring
- copper plating
- tuning
- RF high power

successfully tested 2016

CCH prototype
(without dummy lens)

dummy lens

CH / CCH cavity manufactoring

welding procedure of the stems has to be redeveloped
(welding from the outside of the tank is preferable)

monolithic RF-structure - irrecoverable damages of the structure possible in **case of major surface damages**

copper plating issues now solved by engineers and technicians with a major, additional development expense @ galvanic shop:
copperplating at GSI mandantory
Additional dummy tests for CCH1 type mandantory

Konus type beam dynamic call for precision manufacturing of all tanks as well as careful tuning between all cavities

CH / CCH next steps

2017-02 pLinac kickoff : decision to reduce the design energy: 68MeV
2017-10 IAP final design (report not yet published)

Geometry of Triplett housings finalized (review needed)

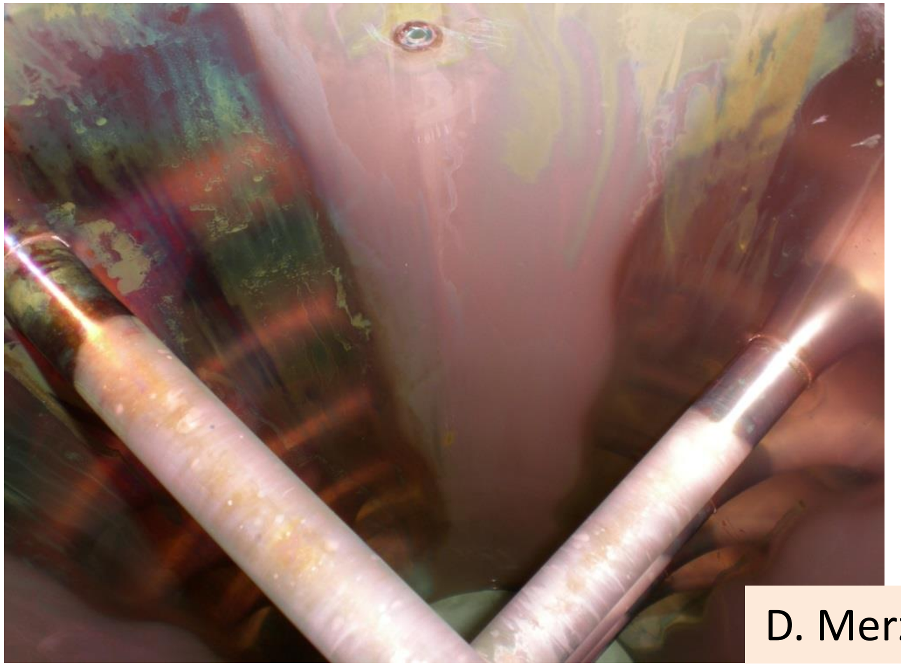
New CH CCH Spec has to be written.

Mechanical integration with all pLinac devices
(GSI DMU together with IAP)

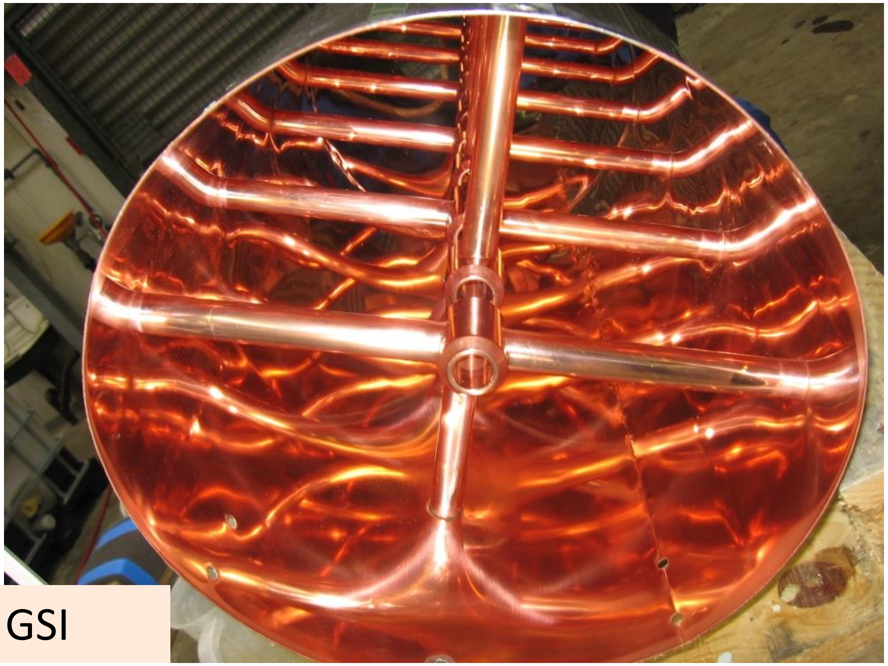
CH / CCH galvanic plating

- 3 dummy CH tanks needed for successful copperplating
- complex anode shapes developed
- ensure electrolte flow at the surface
- reconditioned electrolyte bath
- **CCH1 tank (*dwarf*): additional dummy test mandantory**

first test



sucessful test

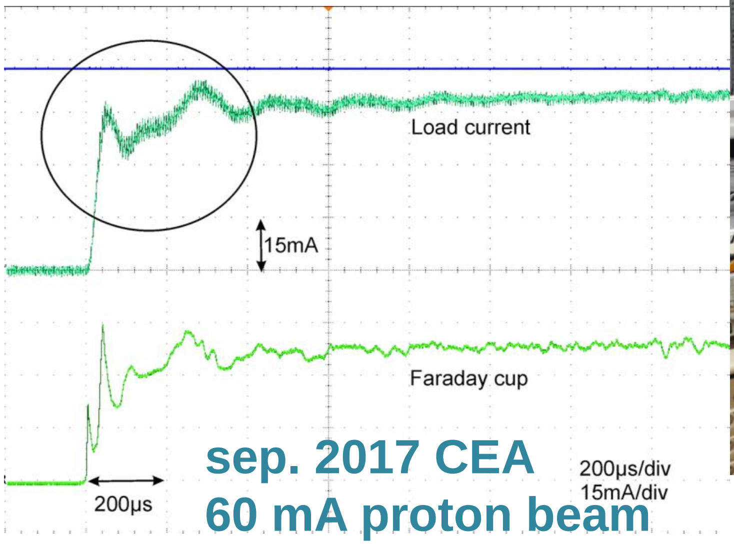


D. Merz GSI

Power Converter GSI Inkind

100 kV	Main Power Converter
-50 kV	Puller Power Converter
-5 kV	Repeller Power Converter
2x PC	Solenoide
2x PC	Source Coils
4x PC	Steerer Typ S1
PC	Electrostatic Chopper
	Control Rack

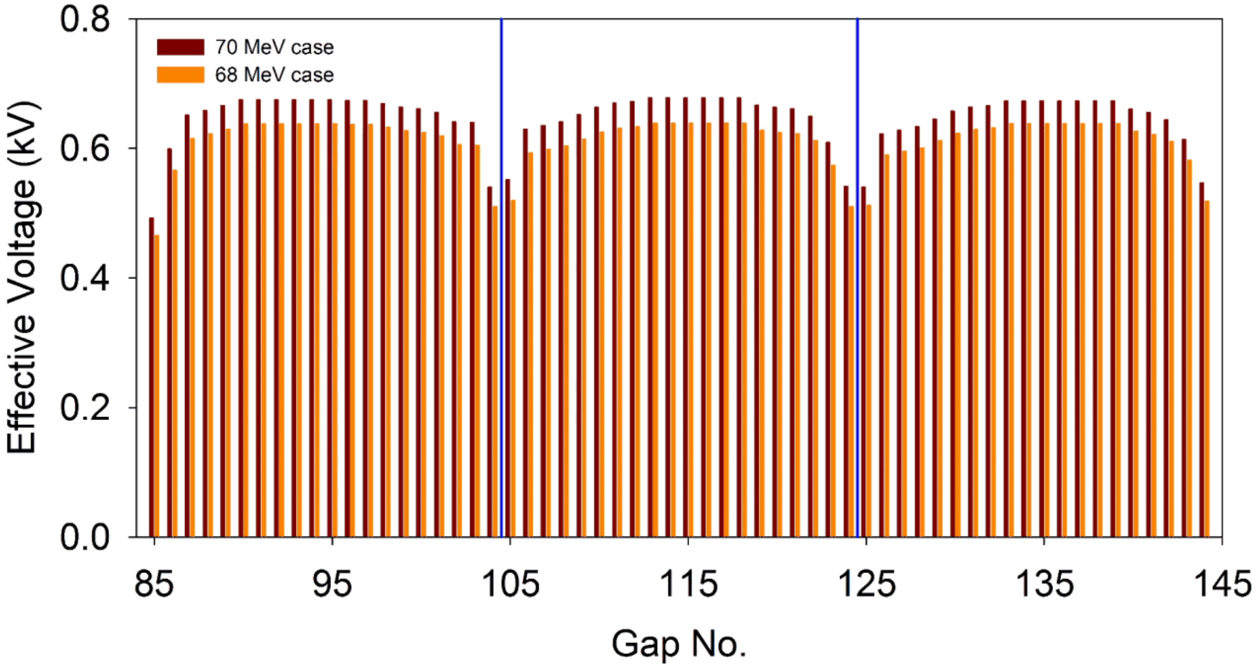
FuG 100 keV power conv. sucessful SAT Q3 2017 @ CEA



sep. 2017 CEA
60 mA proton beam

pLinac – gap voltage reduction

Voltage Comparison: 70 MeV and 68 MeV



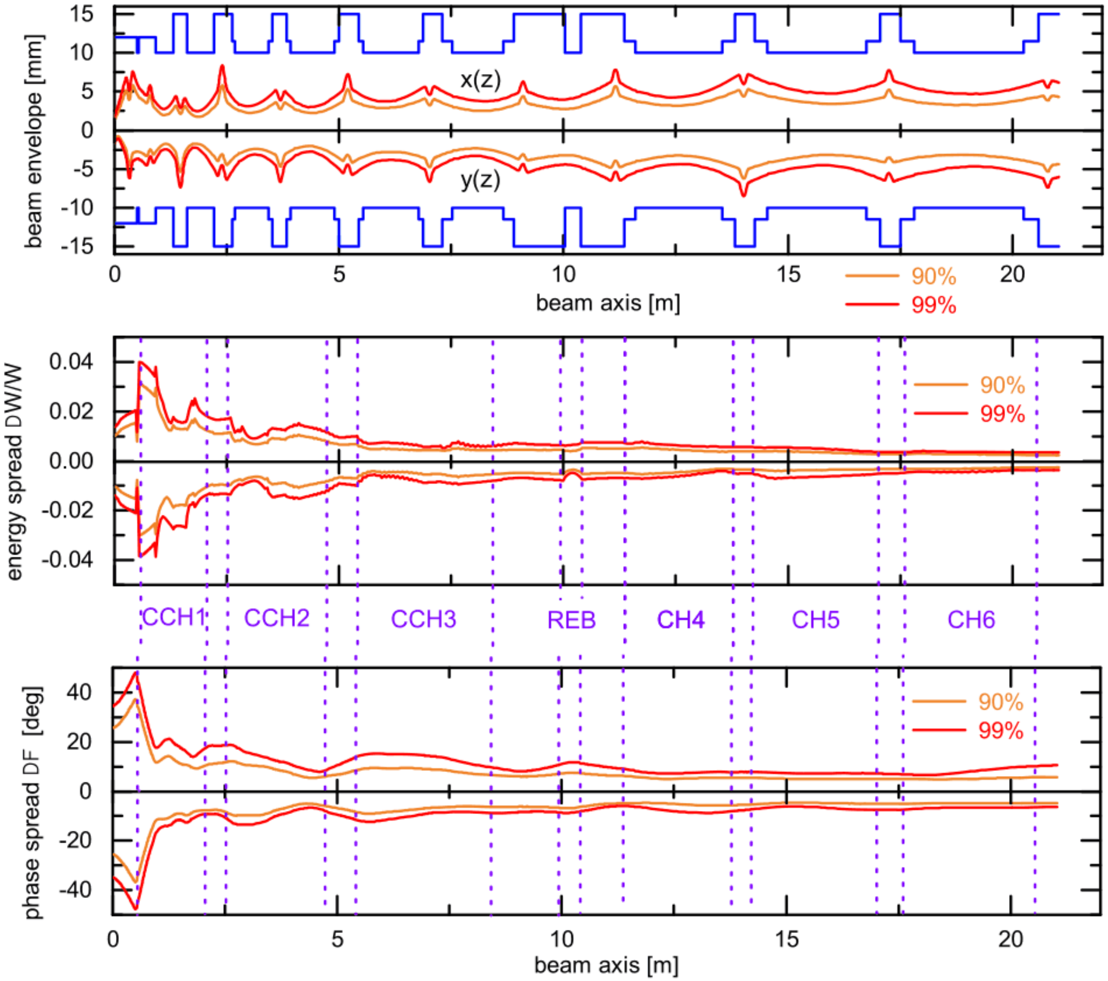
Cavity	CCH1	CCH2	CCH3	CH4	CH5	CH6
ΣV_{70} (MV)	7.419	11.894	12.866	12.932	12.971	12.887
ΣV_{68} (MV)	7.419	11.894	12.866	12.221	12.219	12.217
ΔV	0.0	0.0	0.0	0.711	0.752	0.670

Ali Almomani, IAP - Frankfurt / Friday Seminar 10.02.2017

beam dynamic (IAP)

2016 LINAC moprc018

beam envelopes



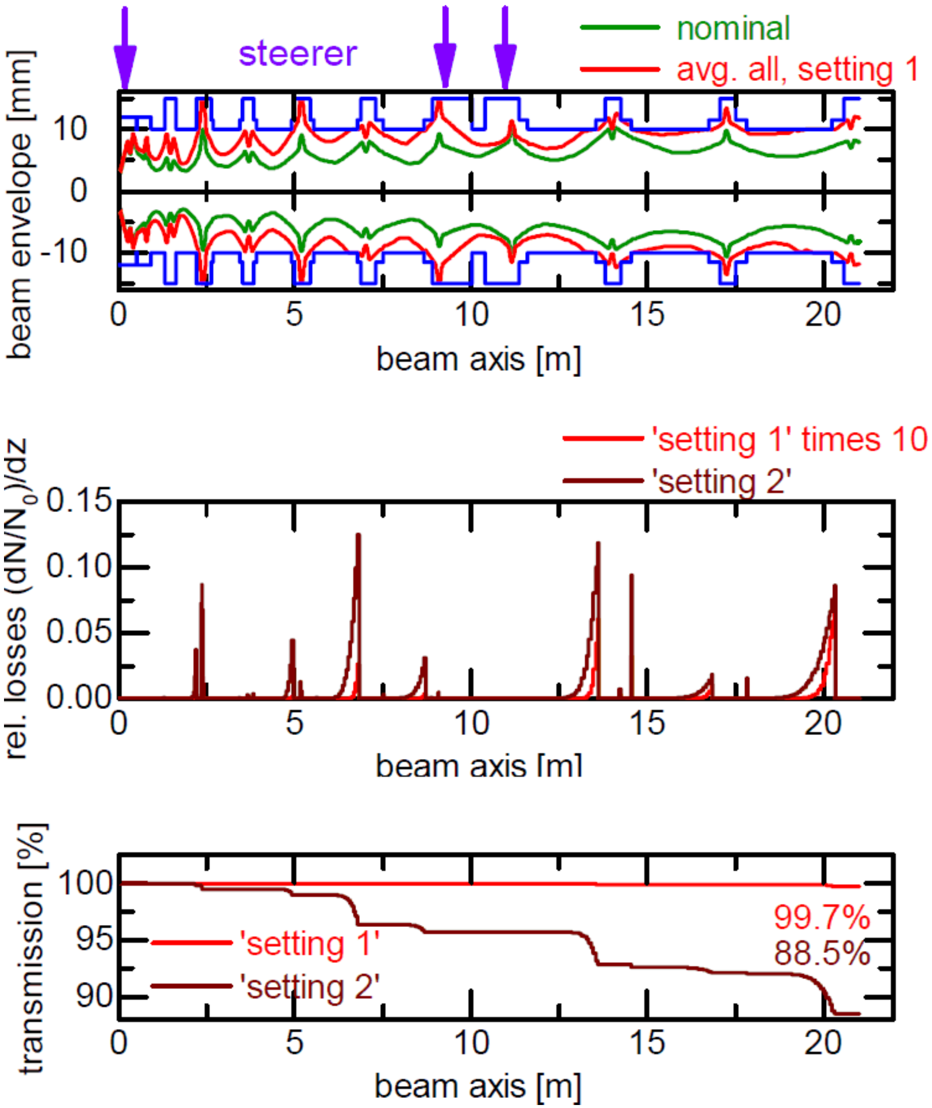
R. Tiede, Institute for Applied Physics (IAP), Goethe-University Frankfurt
MOPRC018 LINAC 2016

error studies (IAP)

2016 LINAC moprc018

lens displacement

1. **100 µm (setting 1)**
2. **200 µm (setting 2)**



beam dynamic on site

MAC 17:
(R7) Complete a set of end-to-end beam dynamics simulations for the p-linac, including RFQ, CCH/CH and the transfer line to SIS18. Use this set of simulations to analyse the sensitivity of the beam optics (losses and emittance growth) to the errors on the main linac components (position and rotation of quadrupoles, etc.).

build up beam dynamics know how on site:

2017-Q4	**support from GSI** **WPL beam dynamics S. Appel (70%)** **O. Boine-Frankenheim (dep.)**
2017-10-20	**kickoff meeting at IAP Frankfurt**

thank you for your attention