GOETHE UNIVERSITÄT FRANKFURT AM MAIN

FAIR Injector Linacs II

Innerhalb des Verbundprojekts 05P2015, R&D Beschleuniger Teilprojekt am IAP Ffm “ Weiterentwicklung der FAIR – Injektoren bei GSI”

Uli Ratzinger, IAP Frankfurt

KHUK Jahrestreffen 2016, Bad Honnef

01./02. 12. 2016

IAP Institut für Angewandte Physik

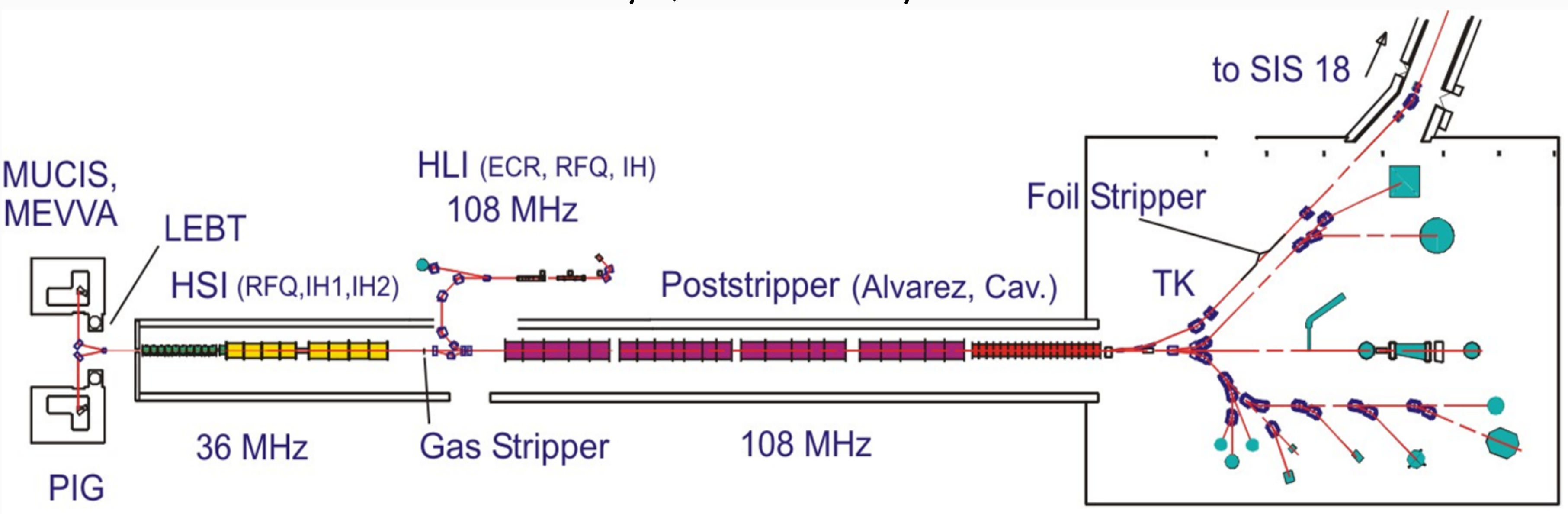
GSI Linac Situation in 2016

Unilac only - in operation with short and long duty factors, energy variable.

HSI (short pulse) → Stripper → Alvarez-DTL (short pulse) → SIS18

at 11.4 AMeV: relevant for FAIR only

$$t_{beam} < 100 \mu s, \quad t_{RF} < 500 \mu s.$$



Envisaged Scenario for FAIR around 2022 as seen by our group

- Unilac, short pulse operation only (4 Hz, 500 μs RF pulse or similar)
- Proton linac, short pulse operation only (4 Hz, 500 μs RF pulse or similar)
- CW linac to continue the traditional research fields on nuclear chemistry, material sciences, biophysics

Those three linacs are the best choice, because:

- Provides highest injector capability and operation safety
- Offers low cost versions for p-linac and Unilac-modifications
- Optimum solution for traditional „high duty factor users“

Status of GSI/FAIR Linacs development

- Modified Unilac

  High Current HSI and High Charge state HLI injector upgrades
  Improved gas stripper (pulsed hydrogen, W. Barth et al., great success)
  High current capable charge state separator (U. R. et al.)
  Alternative approach: Plasma stripper development by J. Jacoby et al., IAP
  New high energy linac with energy upgrade option

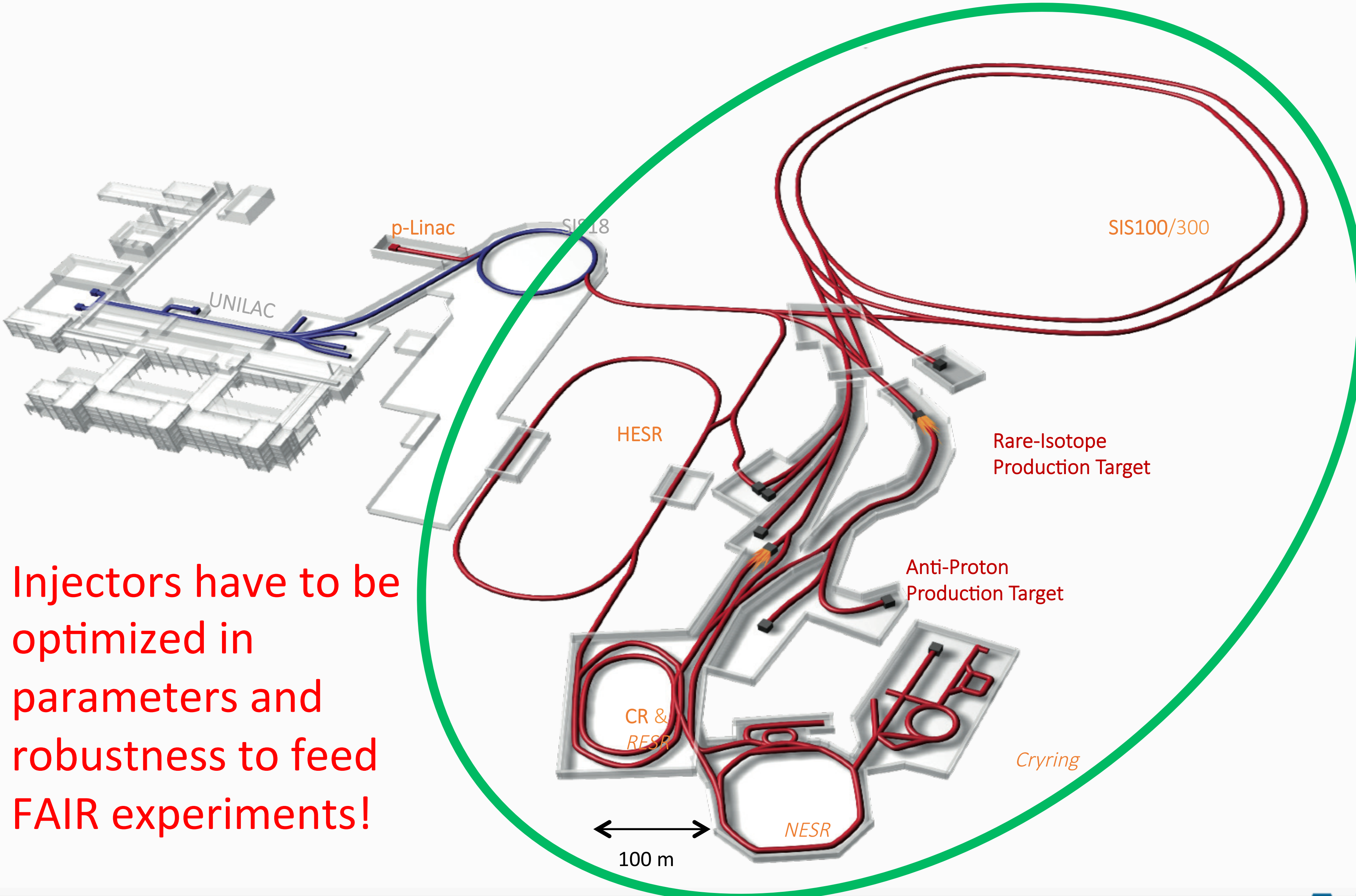
- p –Linac (Development at IAP since 2001, with GSI support)

  Ion source (CEA), lenses and rf amplifiers under construction.
  RFQ and CH-DTL development underway (U.R. et al., IAP Frankfurt).
  13 MV CCH2 and prototype - RFQ power tests were very successful in 2016 at GSI with the 3 MW klystron test stand.

- CW Linac (Developed at IAP since 2000, with BMBF, GSI and HIM support)

  Demonstrator - sc cavity with two sc solenoids in cryostat successfully testet at GSI.
  Beam test behind HLI in preparation, two next sc cavities under construction
  (H. Podlech et al., IAP).

The Future with FAIR (after 2022?)



Injectors have to be optimized in parameters and robustness to feed FAIR experiments!

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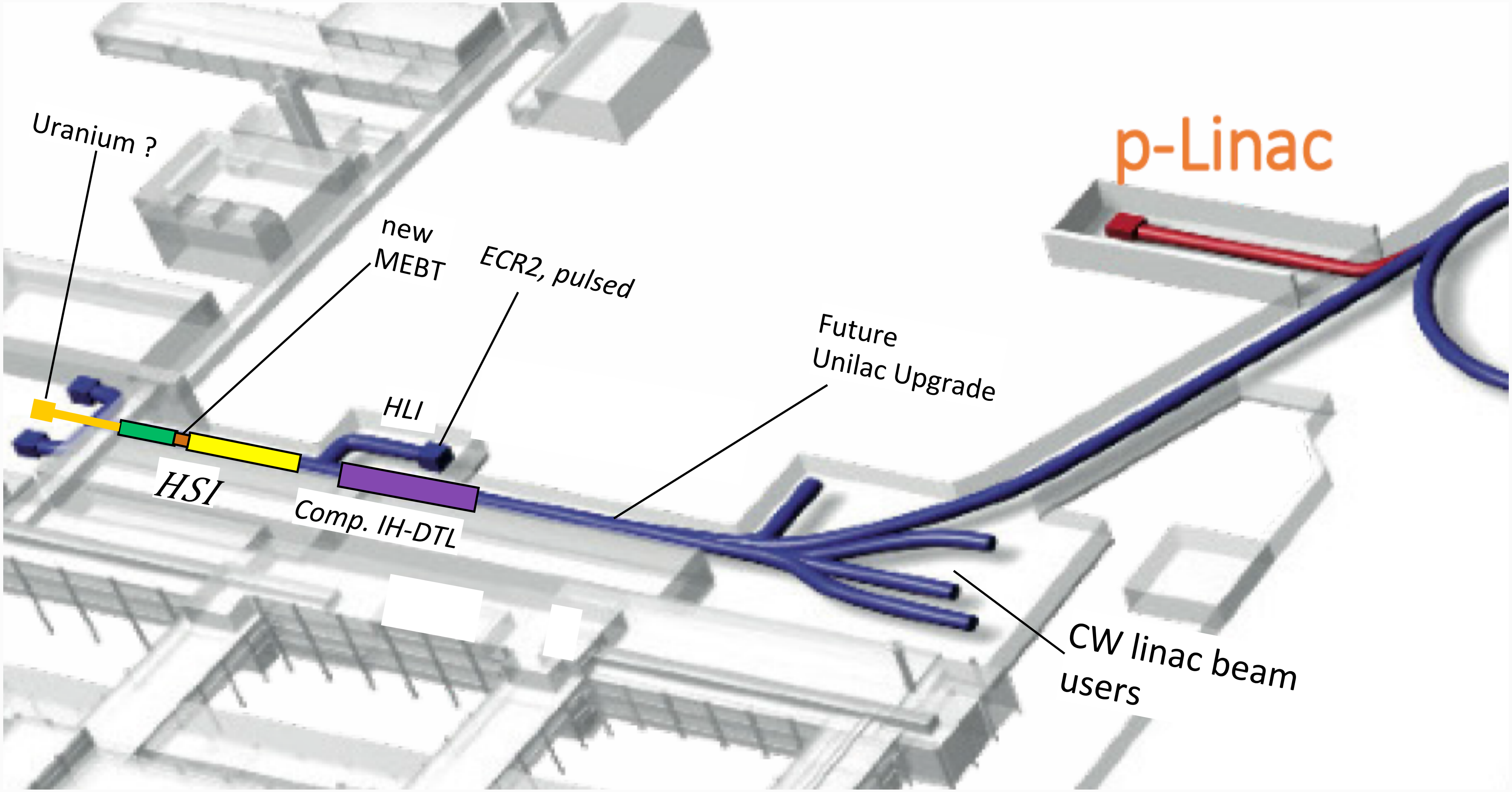
The Future with FAIR (after 2022?)

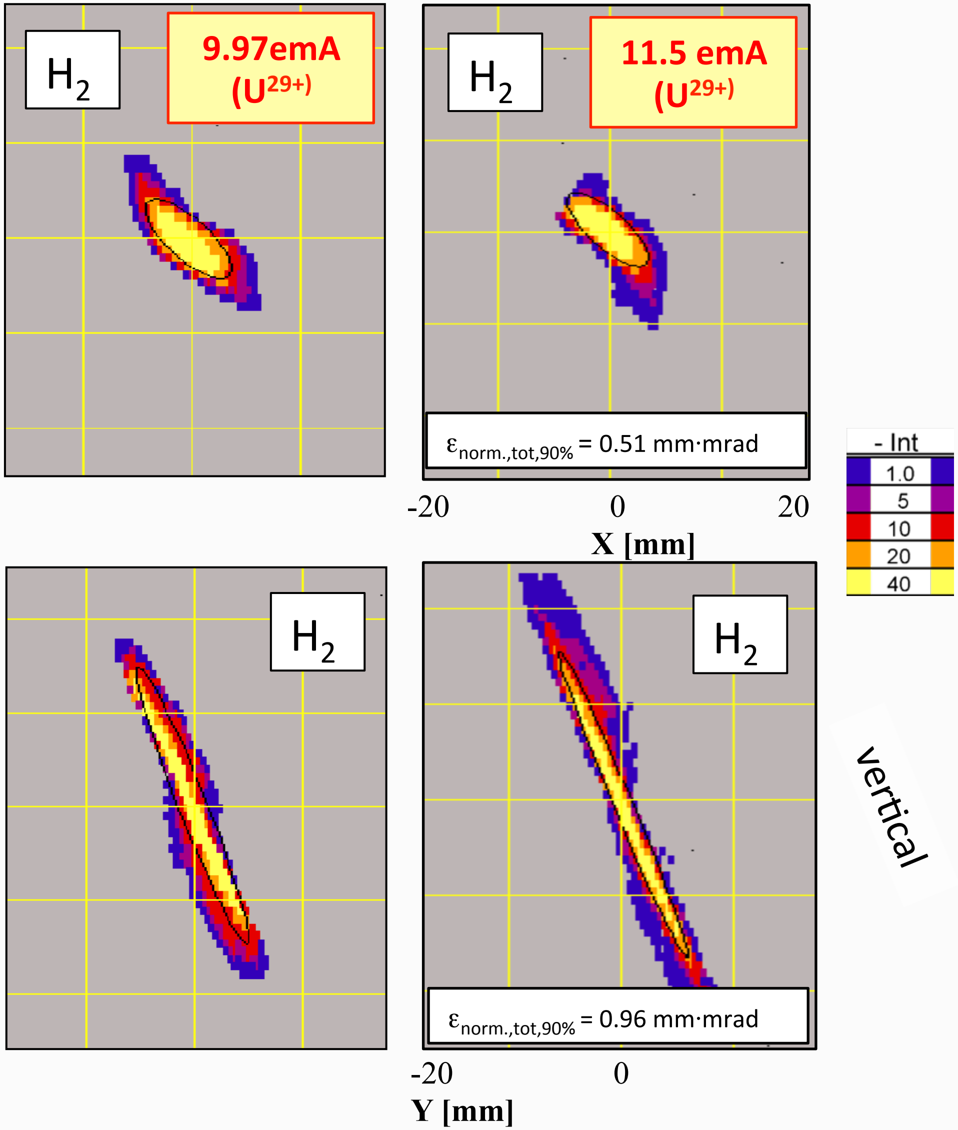


Modified Unilac, p–Linac (and CW Linac)

Latest Stripping Results with U^{4+} from HSI, July 2016

W. Barth et al., C. Düllmann et al.
MEPHI-Seminar, Sept. 2016:

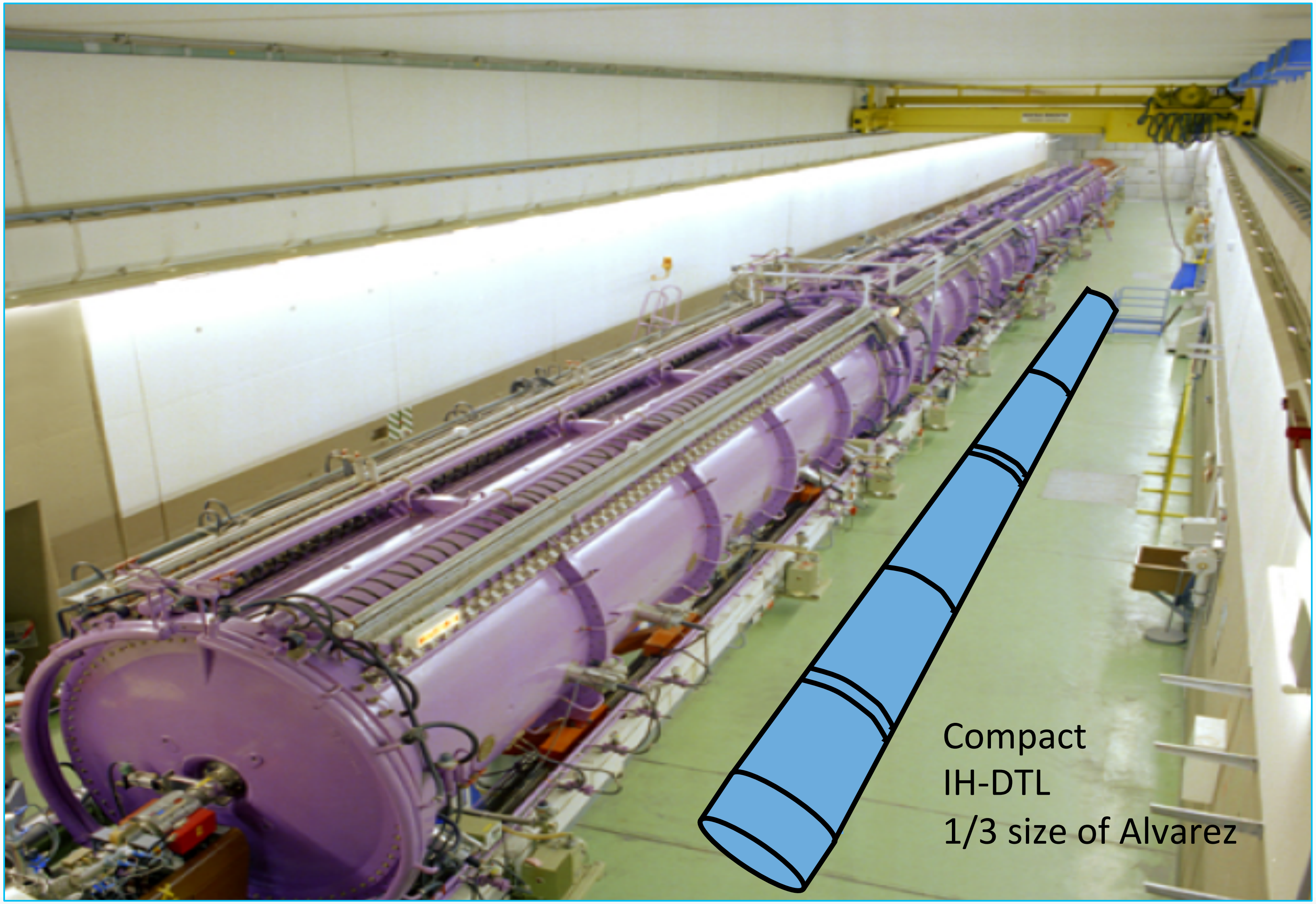
- 14.7 emA in front of RFQ
- 11.0 emA U^{29+} behind pulsed H_2 gas stripper !



Facit: The HSI with minor improvements is well suited for FAIR

Unilac - 11.4 AMeV - Compact IH – DTL Proposal

Alvarez-DTL against Compact IH – DTL, Size comparison



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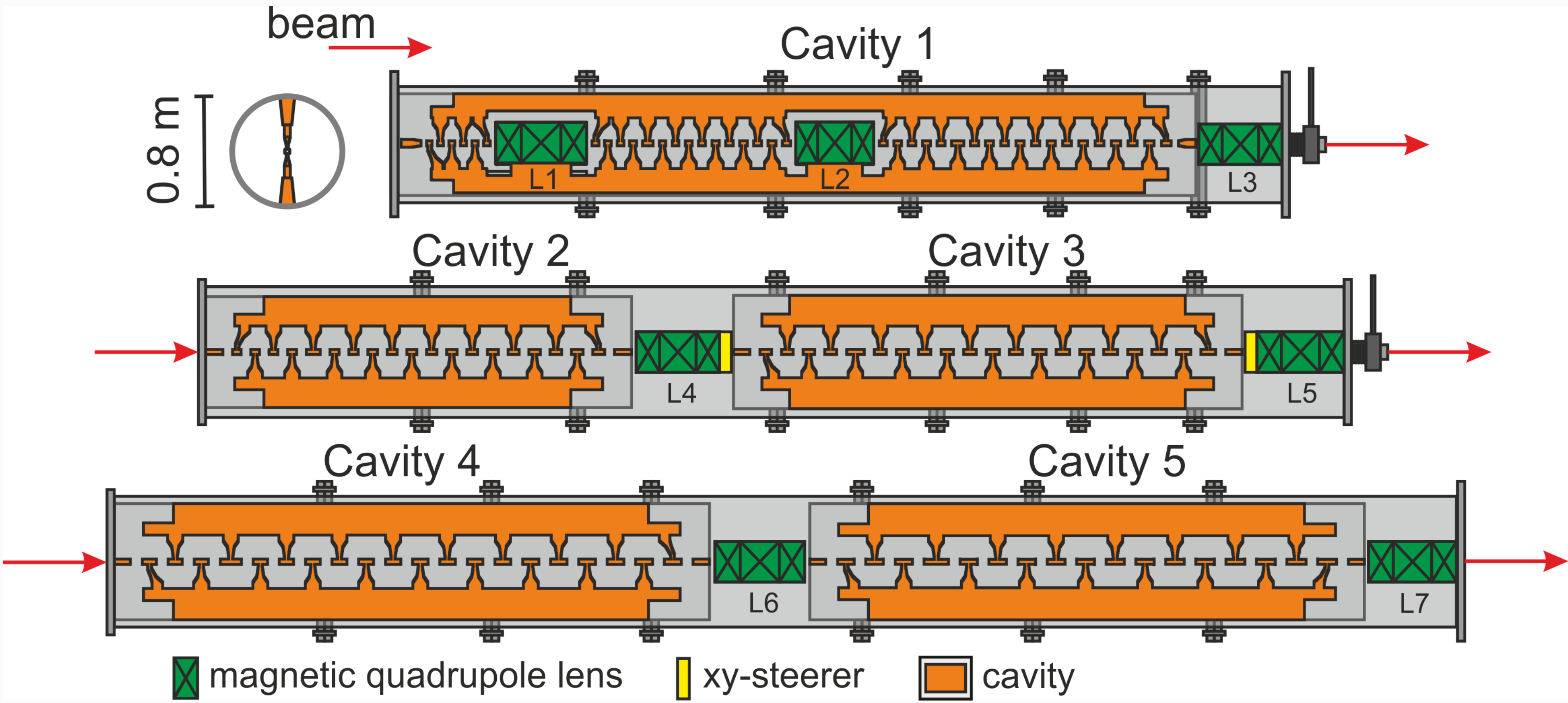
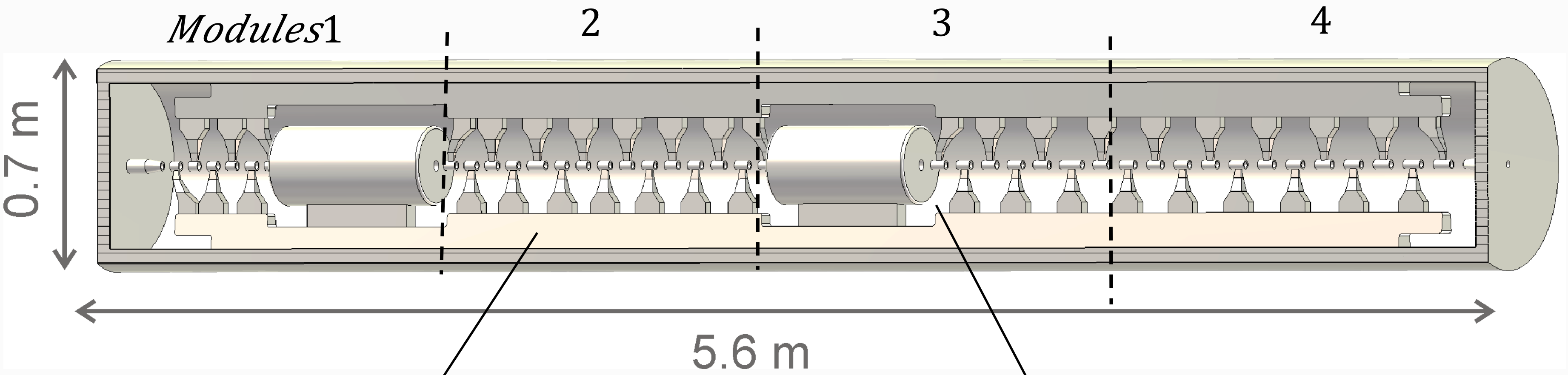
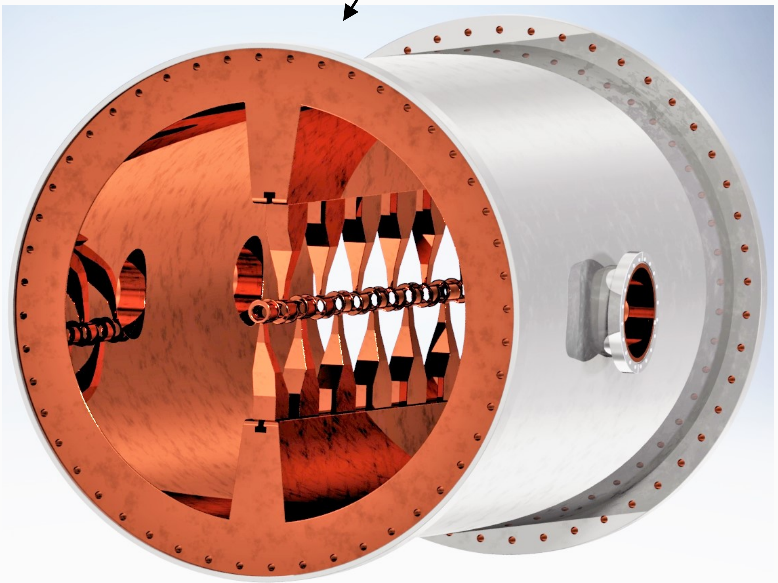
IH-DTL mechanical concept

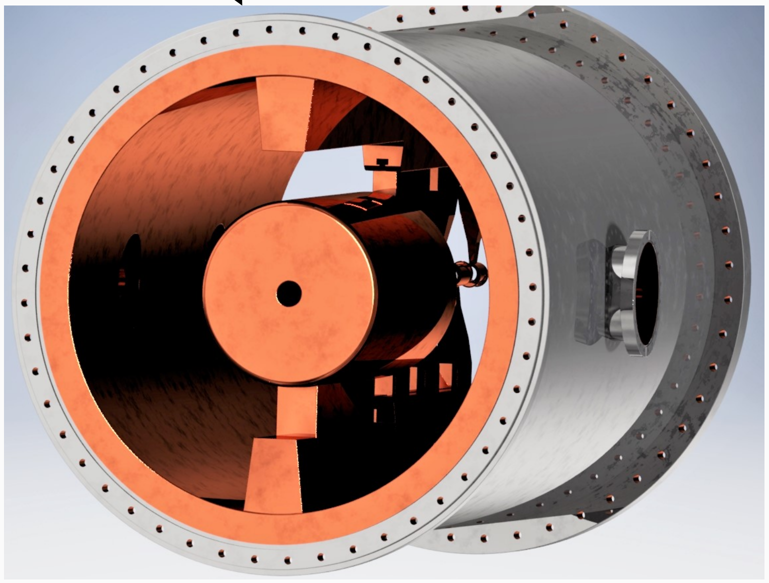


Compact IH-DTL made of three mechanically rigid sections. Cavities divided into cylindrical modules (1-1.5 m long) to ease production, copperplating and installation.

IH-DTL, CST cavity models

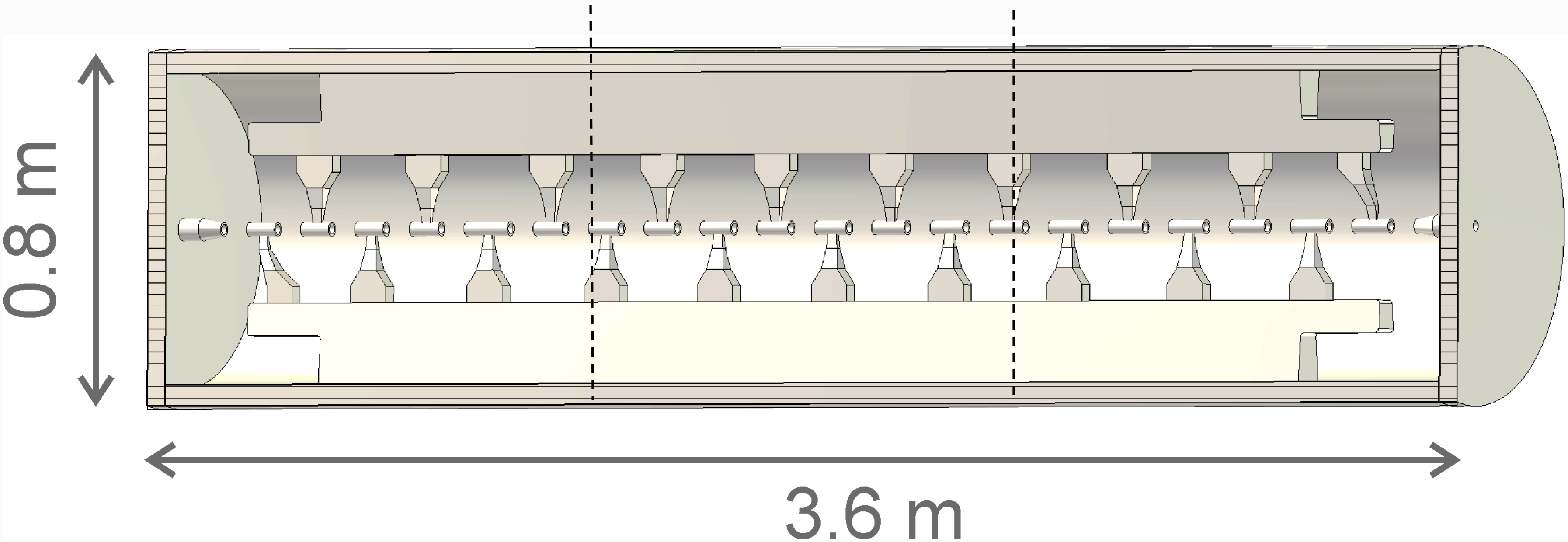






Cavity 1, two internal lenses

IH-DTL, CST cavity models



Cavities 2-5 (cavity 3 shown), external lenses

Along the IH-DTL:

Drift tube aperture:	**25 mm**
Lens aperture:	**36 mm**
Pole tip field:	**1.03 T**

Optimization steps in conjunction with beam dynamics and cost reduction are necessary.

Multi Turn Injection of U^{28+} into SIS18

The compact IH-DTL approach gives transverse effective exit emittance values for nominal benchmark case1 in units [mmmrad] of

$$\varepsilon_{x,\ abs.,80\%} = 5 \text{ mmmrad;}$$

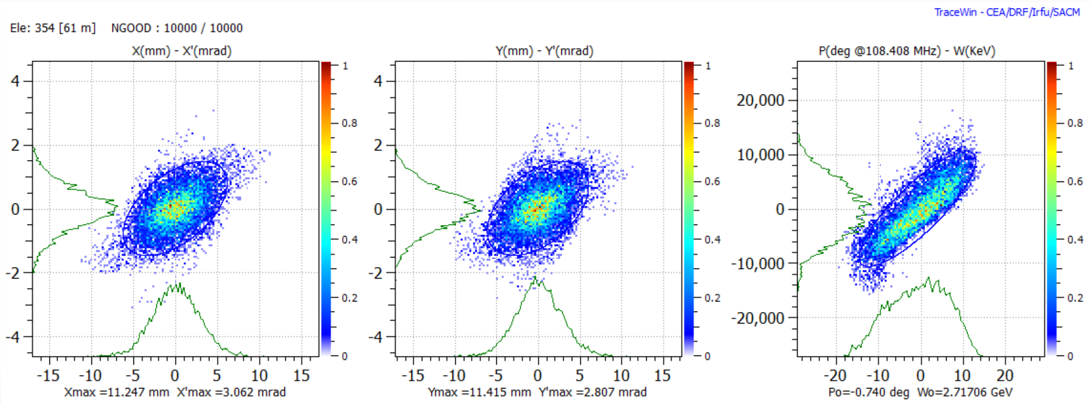
$$\varepsilon_{x,\ norm.,80\%} = 0.78 \text{ mmmrad;}$$

$$I_{80\%} = 13 \text{ mA.}$$

This gives $3\cdot 10^{11}$ *particles per SIS* 18 cycle at 20 turn injection!

Collimators at the end of the transfer channel will allow an optimum choice of injected emittances in xx‘ and yy‘.

Simulated particle distr. at 11.4 AMeV



Suggestions from our investigations

No cavities for energy variation into the future Unilac:

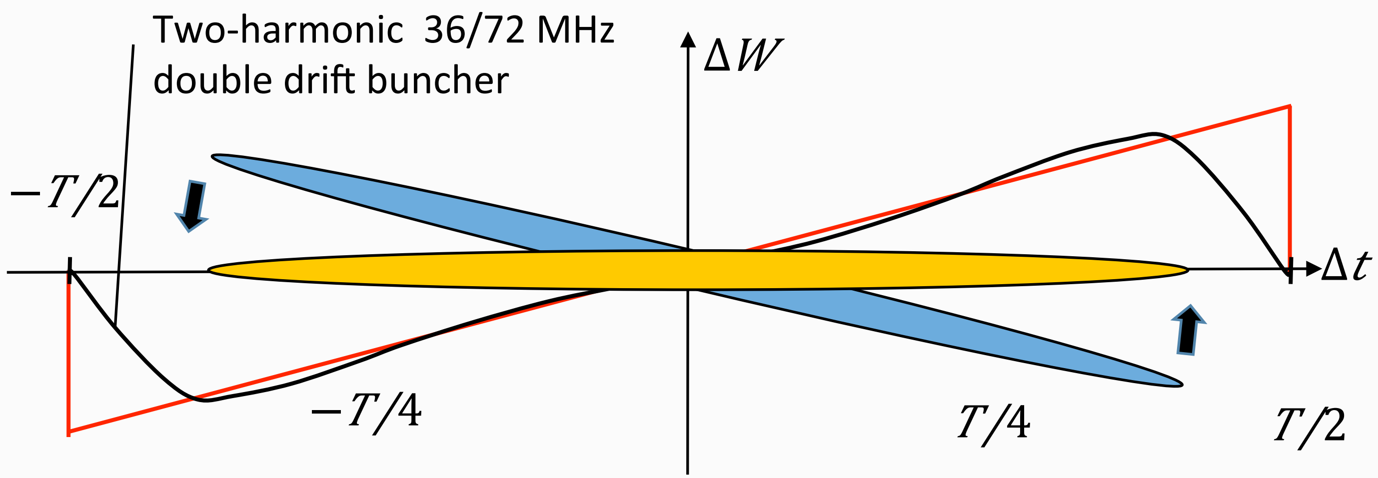
These cavities are excited by the klystron principle and will cause substantial emittance growth at high current beam operation for FAIR

No long pulses at the Unilac

Cavity and stripper performance suffer seriously with respect to FAIR needs

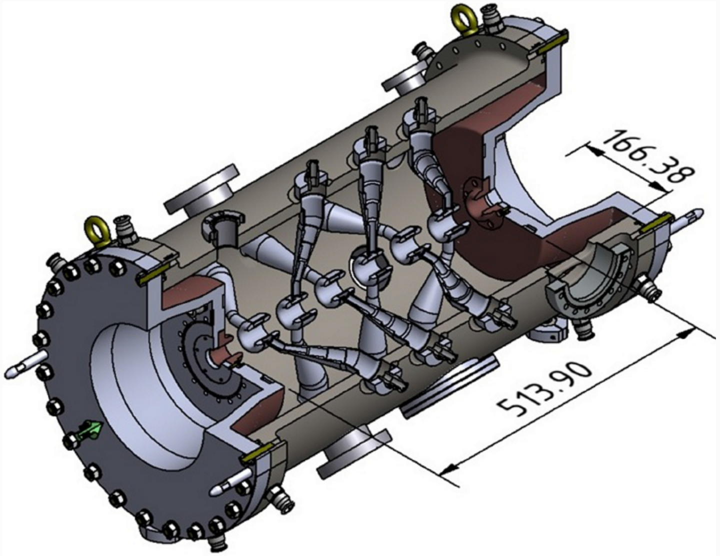
Longitudinal phase space matching into SIS18

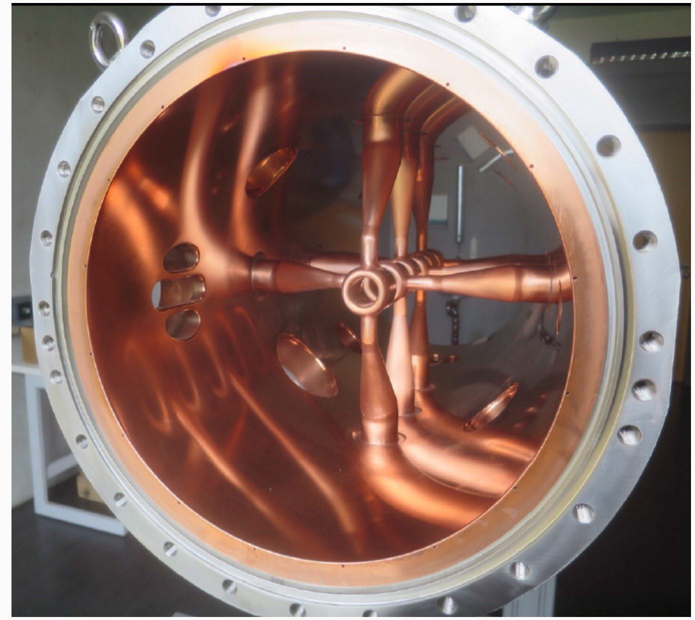
Approach to a dc beam at synchrotron injection minimizes space charge effects from micro bunches



Long linac bunches at synchrotron injection, T=27.7 ns.

Option „325 MHz, 50 – 60 AMeV linac for direct SIS100 injection“



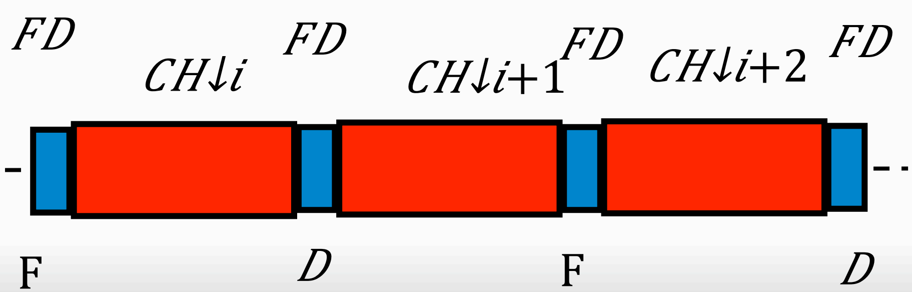


A 325 MHz prototype cavity has been built for β=0.16; ready for RF power testing at GSI.

Negative synchronous phase.

Assumed linac structure (to be investigated):

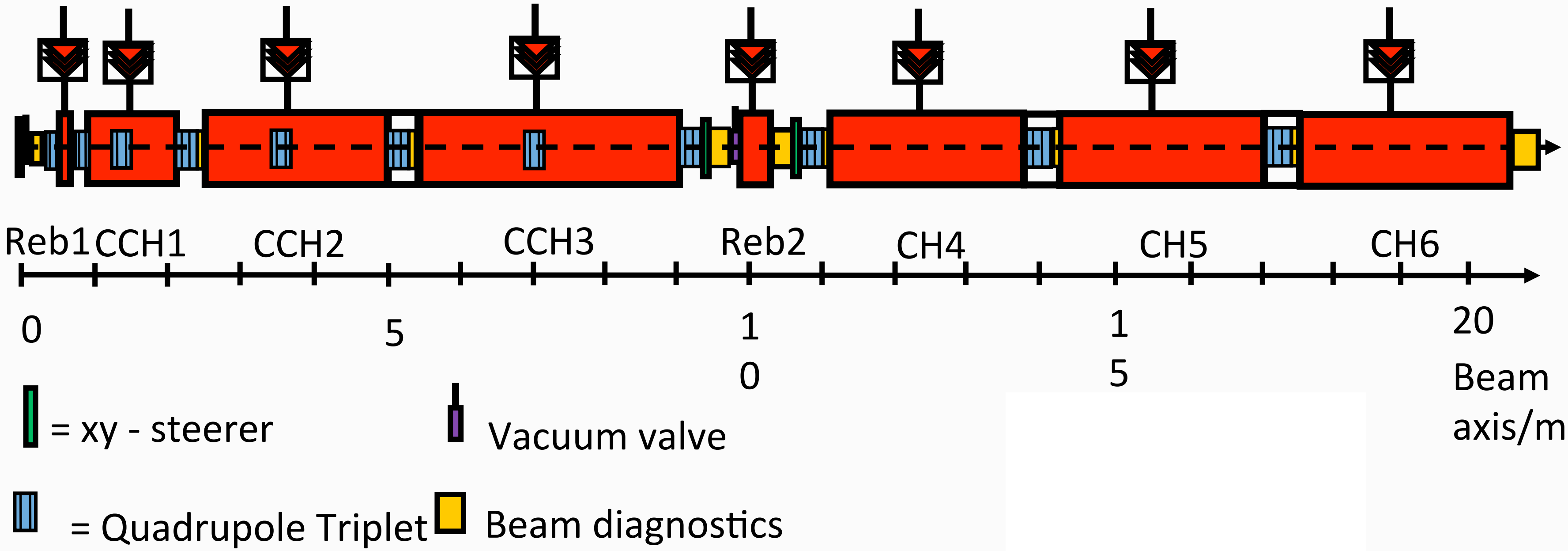
- FDOFD – focusing along the front end
- FODO   – focusing along the high energy end



Number of Gaps	7
Frequency (MHz)	325.2
Voltage Gain (MV)	6
Eff. Accel. Length (mm)	513.90
Eff. Accel. Field (MV/m)	13.3
Power Loss (MW)	1.76
Q_0 – value	12500
Effective Shunt impedance (MΩ/m)	52.15
Aperture (mm)	27

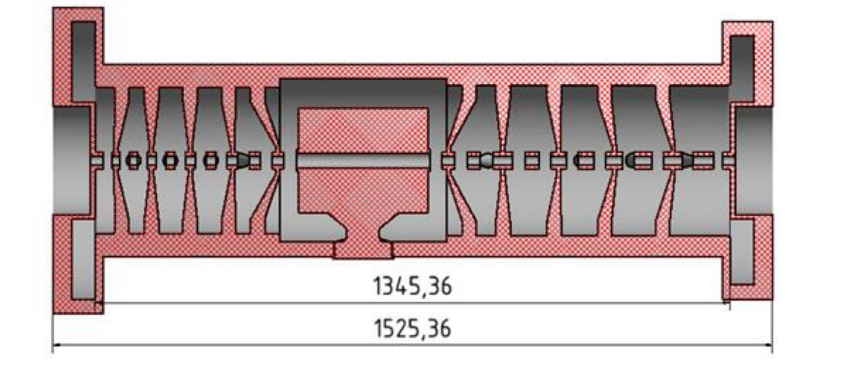
FAIR Proton Linac Development

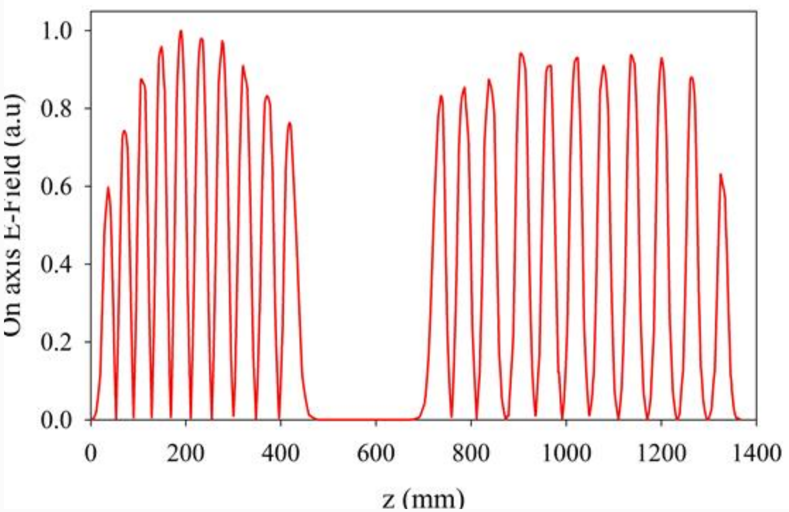
- Detailed cavity layout in progress at IAP
- Triplet lenses and RF power amplifiers ordered by GSI/CEA

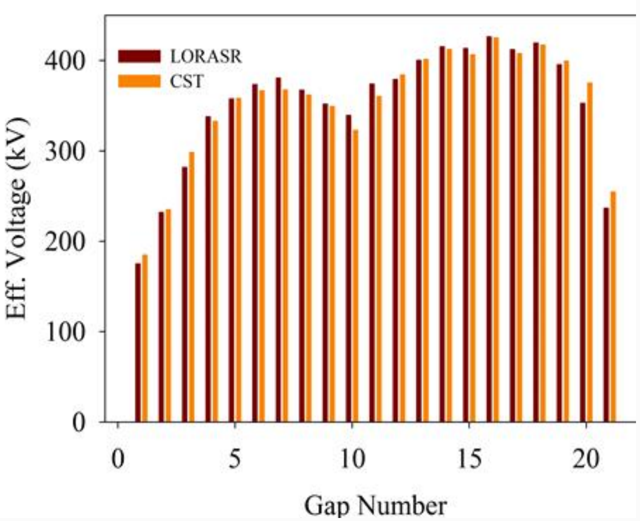


Scheme of the 70 MeV FAIR proton CH - DTL

Detailed CH – Cavity Layout going on



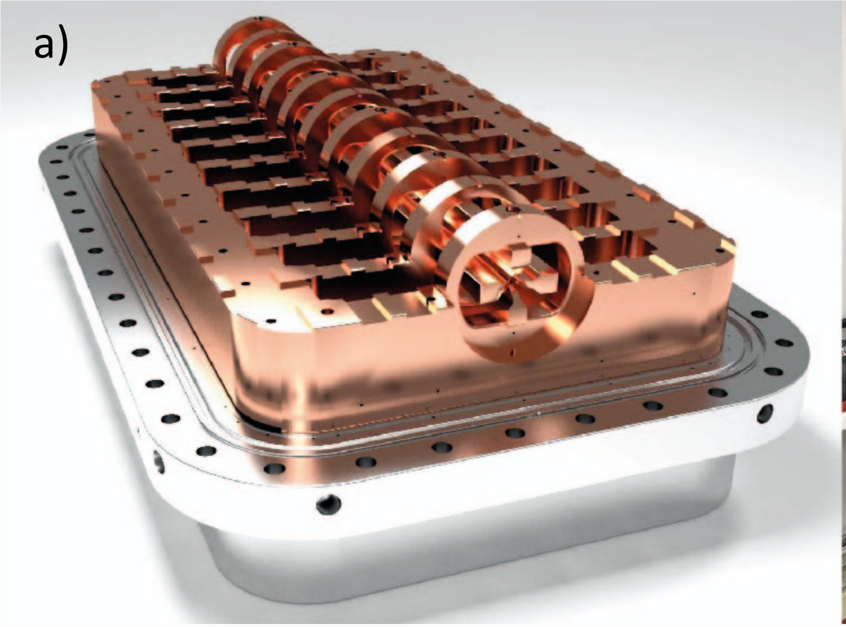


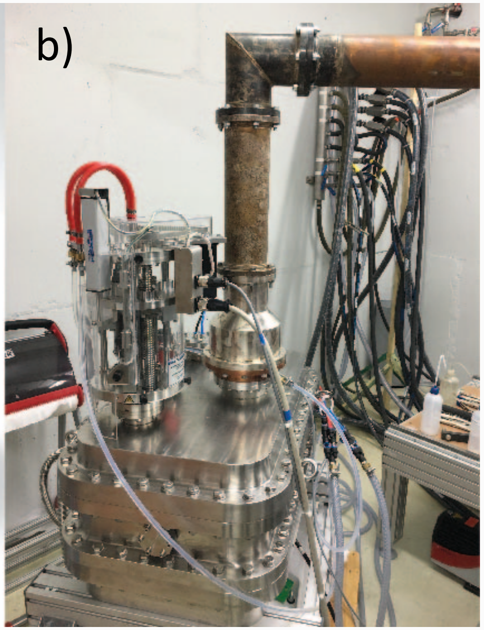


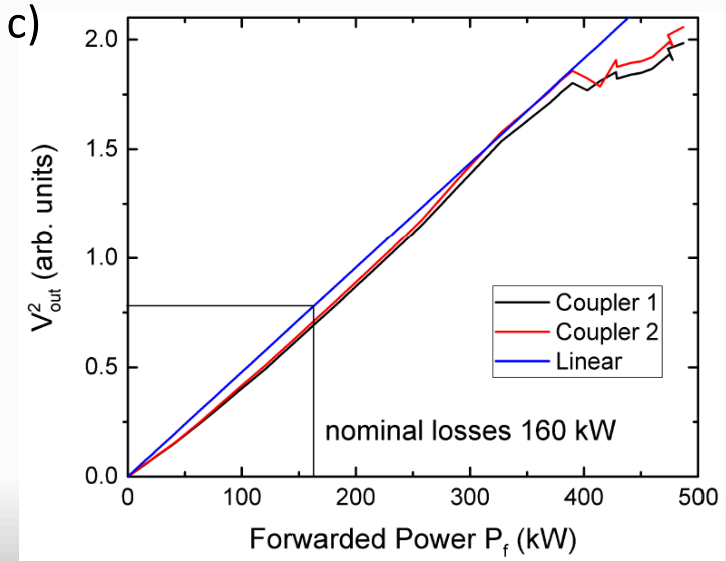
CCH1 Cavity design, yz- cut, 3D view with triplets, E-field and gap voltage distribution

FAIR p-Linac RFQ Development

- Short 325 MHz prototype was developed and RF power testet successfully







a) View on the ladder structure;
b) RF power test at GSI Darmstadt;
c) Resulting behaviour of stored field energy against input power.

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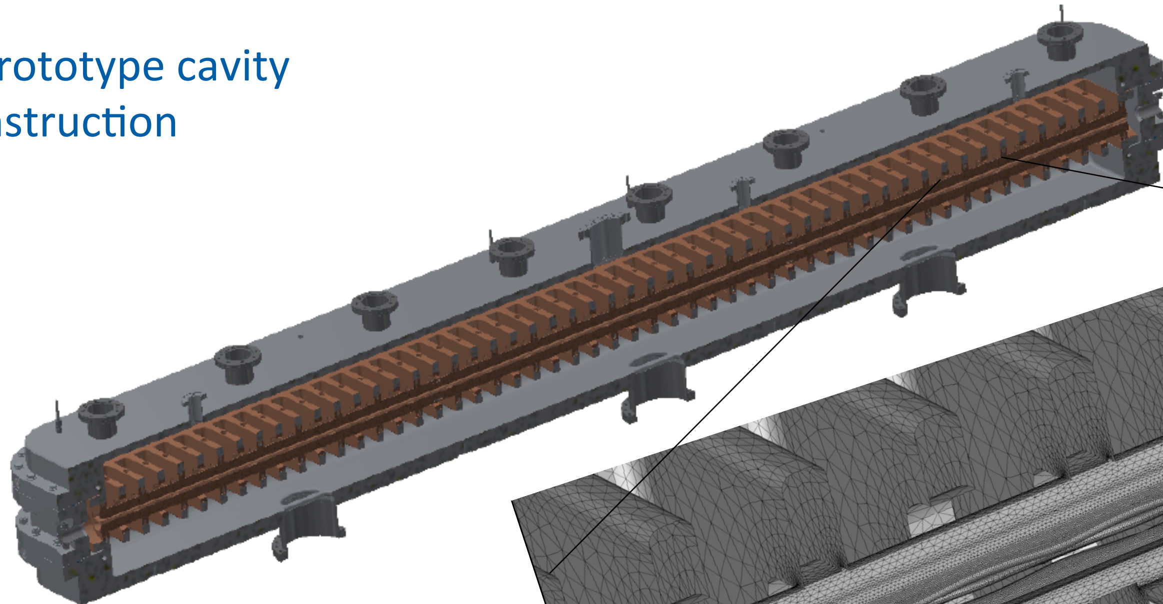
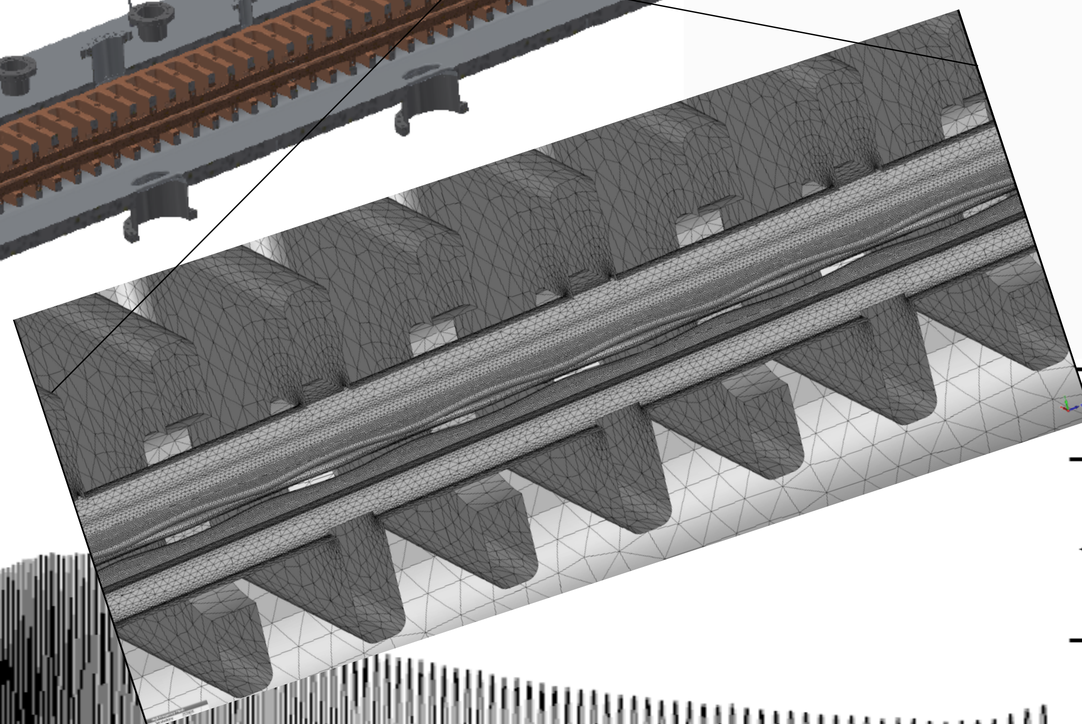
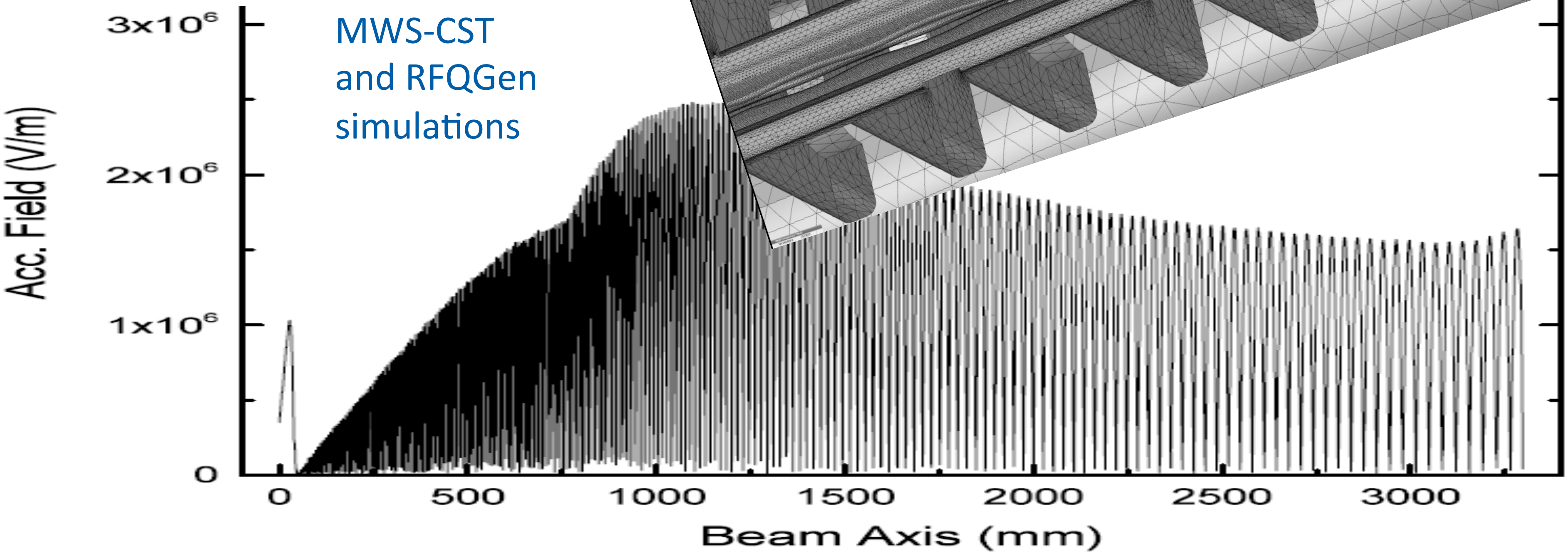
FAIR p-Linac RFQ Development

Full size prototype cavity
under construction





MWS-CST
and RFQGen
simulations



Summary

- IAP Frankfurt is heavily involved in the GSI/FAIR injector design and upgrade program
- A closer collaboration between GSI/FAIR and IAP for the next years is definitely needed in that field

Unilac – Alvarez replacement:

- Beam dynamics and RF design approach for a 16.5 mA, 11.4 AMeV $U\uparrow 4+$ - linac for FAIR successfully done
- All applied linac technologies known at GSI and IAP from former projects. Highest safety in time and money.
- Keeps the option for a substantial energy upgrade with direct injection into SIS100 open: More then 50 m Unilac tunnel are still available behind the compact IH-DTL.
- An additional CW linac would allow to continue traditional GSI – research like Nuclear Chemistry (with Superheavy Elements), Material Research, Biophysics. CW linac demonstrator project showing promising results

Proton Linac:

- CCH2 cavity was successfully power tested up to 2.5 MW (nominal power loss: 1.5 MW)
- Design and construction phase running
- Accelerator community shows high interest on that novel, compact proton linac approach

Involved key persons from IAP on the presented topics

- Ali Almomani (Postdoc, CH cavity development)
- Hendrik Hähnel (Doctorand, IH – DTL beam dynamics and cavity design)
- Uli Ratzinger
- Rudolf Tiede (permanent scientific IAP staff, beam dynamics)
- Daniel Bänsch (Technician)
- Jan Kaiser (master student, high energy linac layout)
- Martin Droba (Postdoc, LASEP)
- Qizheng Yan (master student, LASEP magnets)
- Max Schütt (Doctorand, Ladder RFQ cavity design)
- Marcus Obermayer (Doctorand, Ladder RFQ beam dynamics)
- Holger Podlech (Professor, CW super conducting linac development)
- Marco Busch (Postdoc, CW super conducting linac development)
- Malte Schwarz (doctorand, CW super conducting linac development)
- Markus Basten (doctorand, CW super conducting linac development)