Cavity Designs for the CH3 to CH11 and Bellow Tuner Investigation of the Superconducting Heavy Ion Accelerator HELIAC at GSI

LINAC AG

Thorsten Conrad

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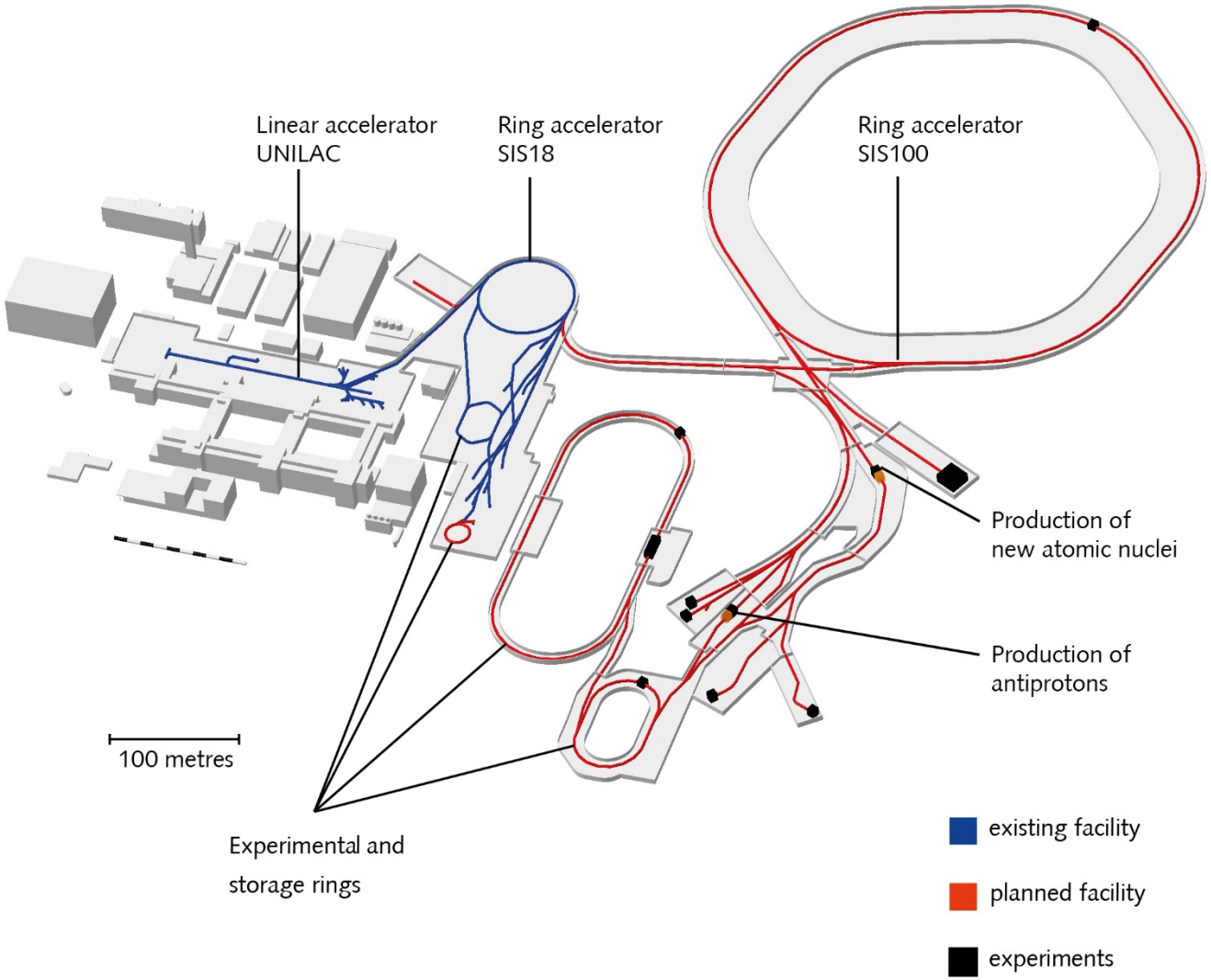
HIAT 2022 | Darmstadt

Superheavy Element Synthesis at GSI



Superheavy Element Synthesis at GSI

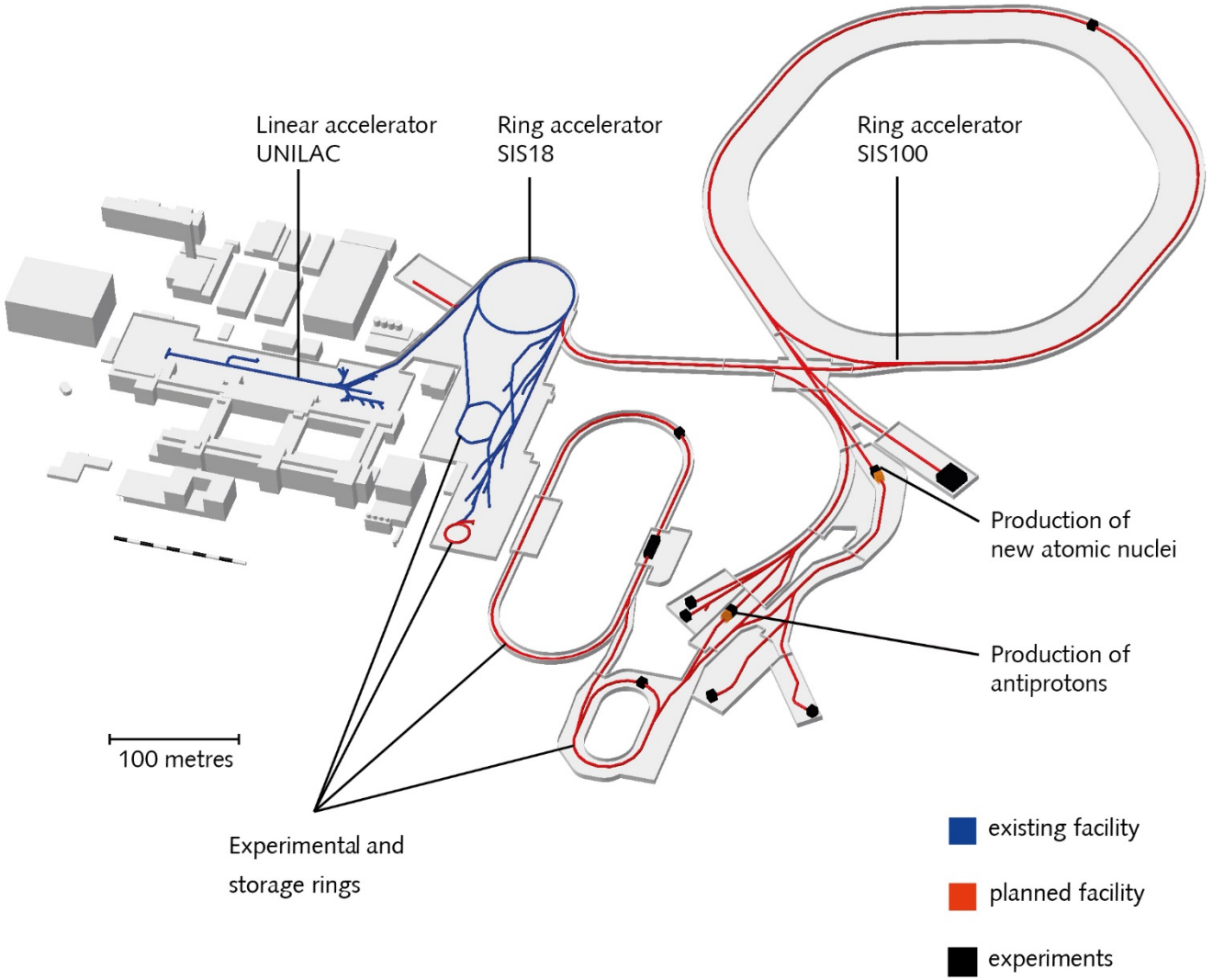
Periodic table of the elements

Alkali metals · Alkaline-earth metals · Transition metals · Other metals · Other nonmetals · Halogens · Noble gases · Rare-earth elements (21, 39, 57–71) and lanthanoid elements (57–71 only) · Actinoid elements

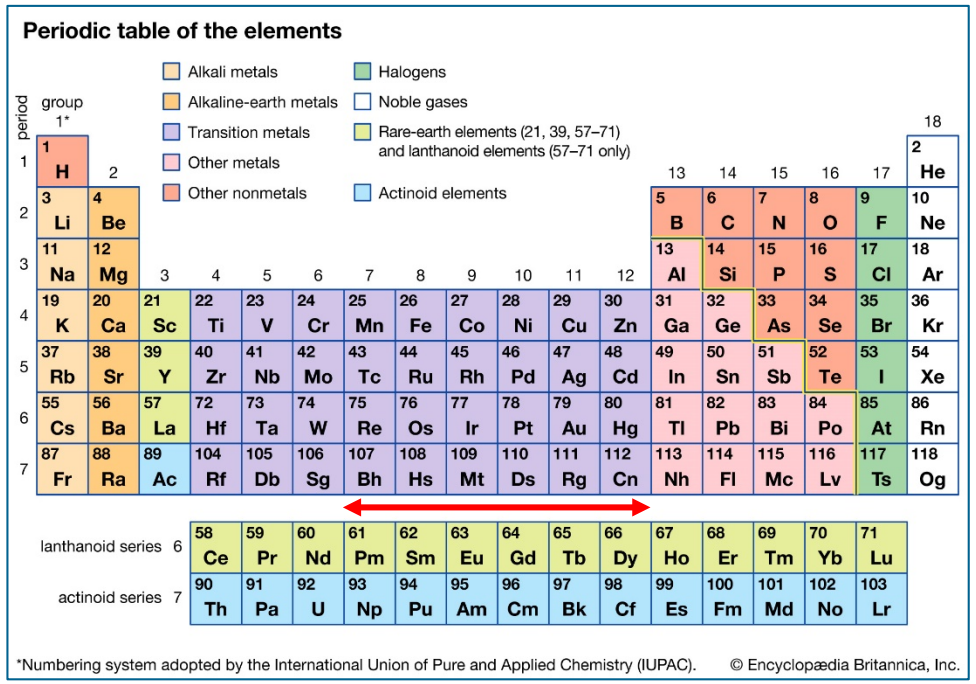
period	group 1*	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																	2 He
2	3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og

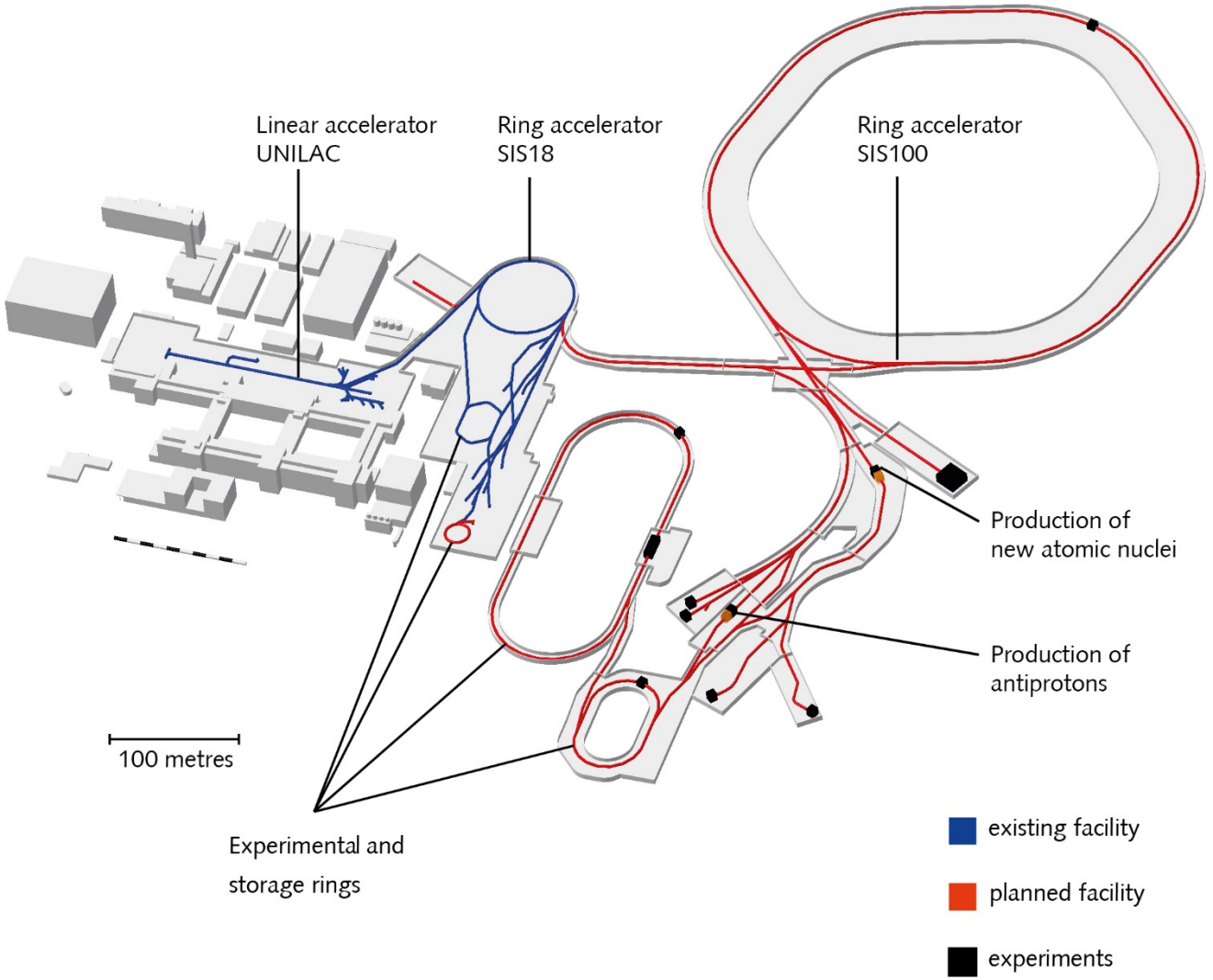
lanthanoid series	6	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
actinoid series	7	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

*Numbering system adopted by the International Union of Pure and Applied Chemistry (IUPAC). © Encyclopædia Britannica, Inc.



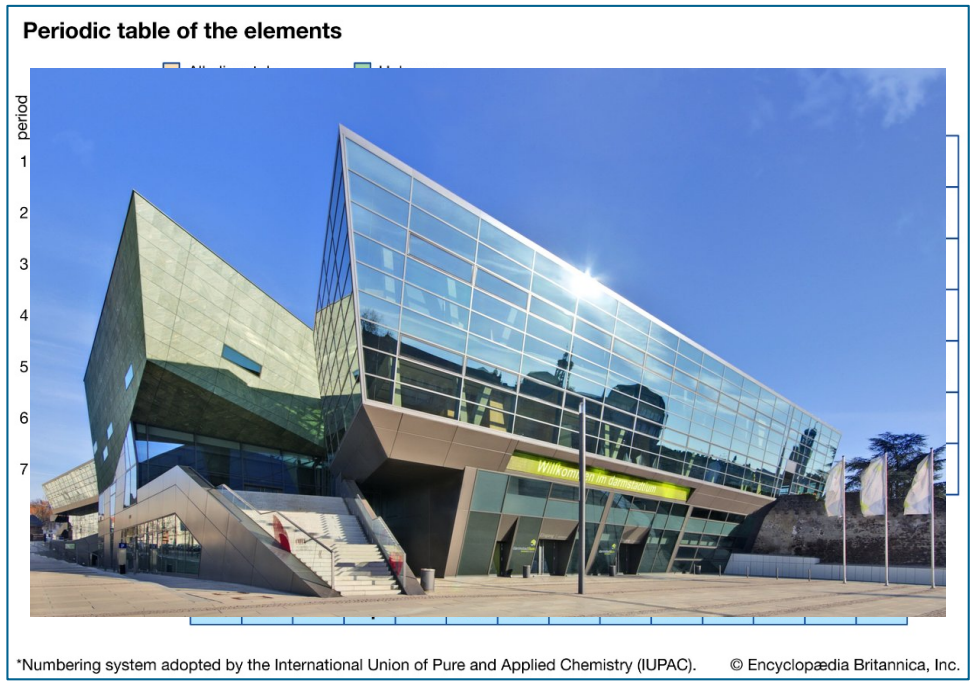
Superheavy Element Synthesis at GSI

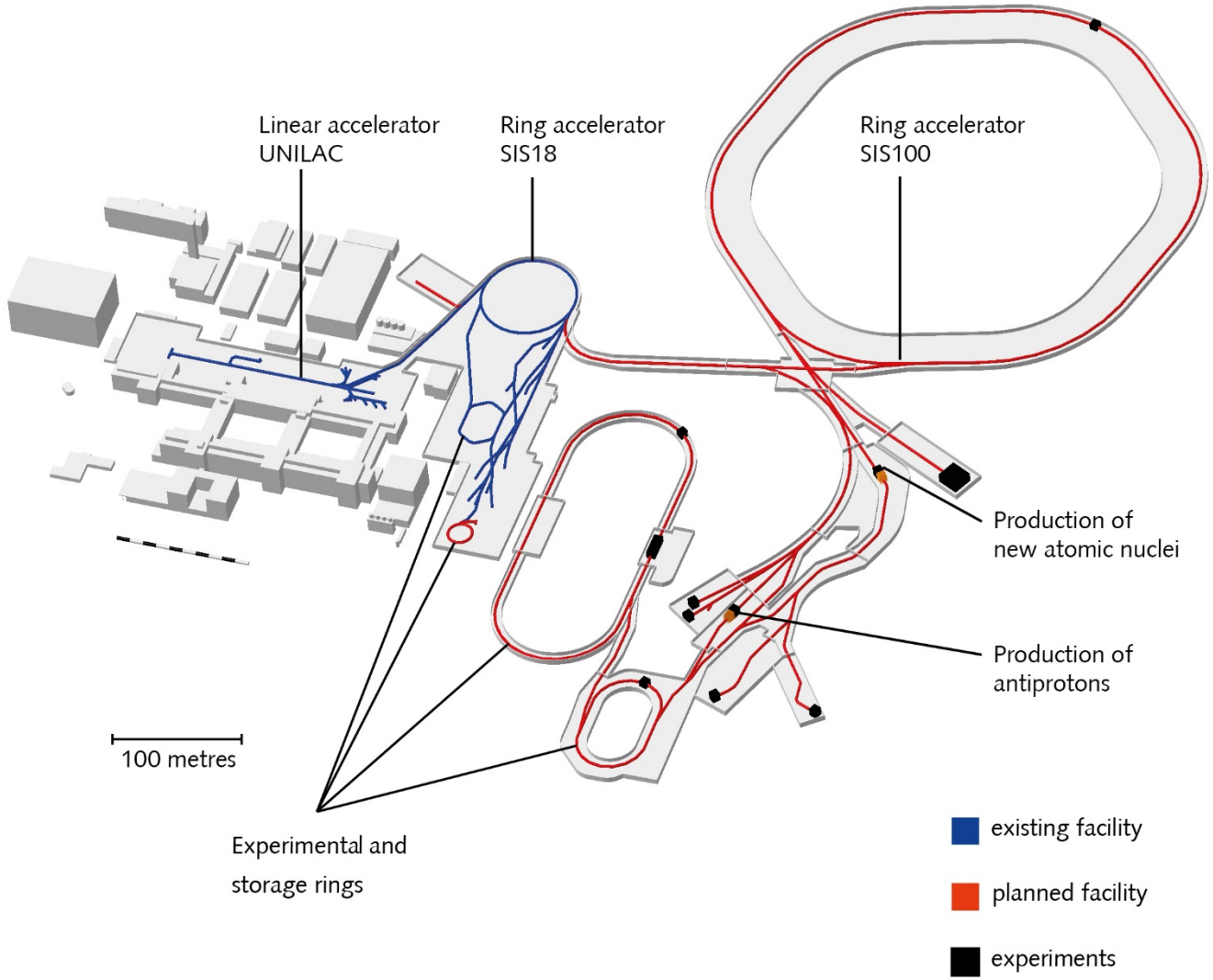




^{107}Bh ^{108}Hs ^{109}Mt

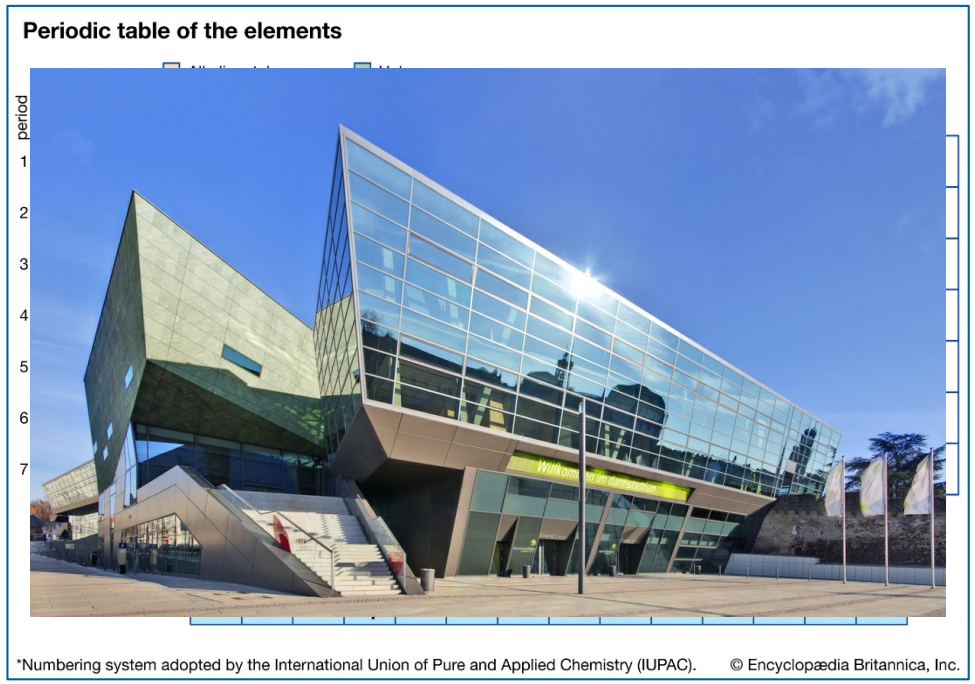
Superheavy Element Synthesis at GSI

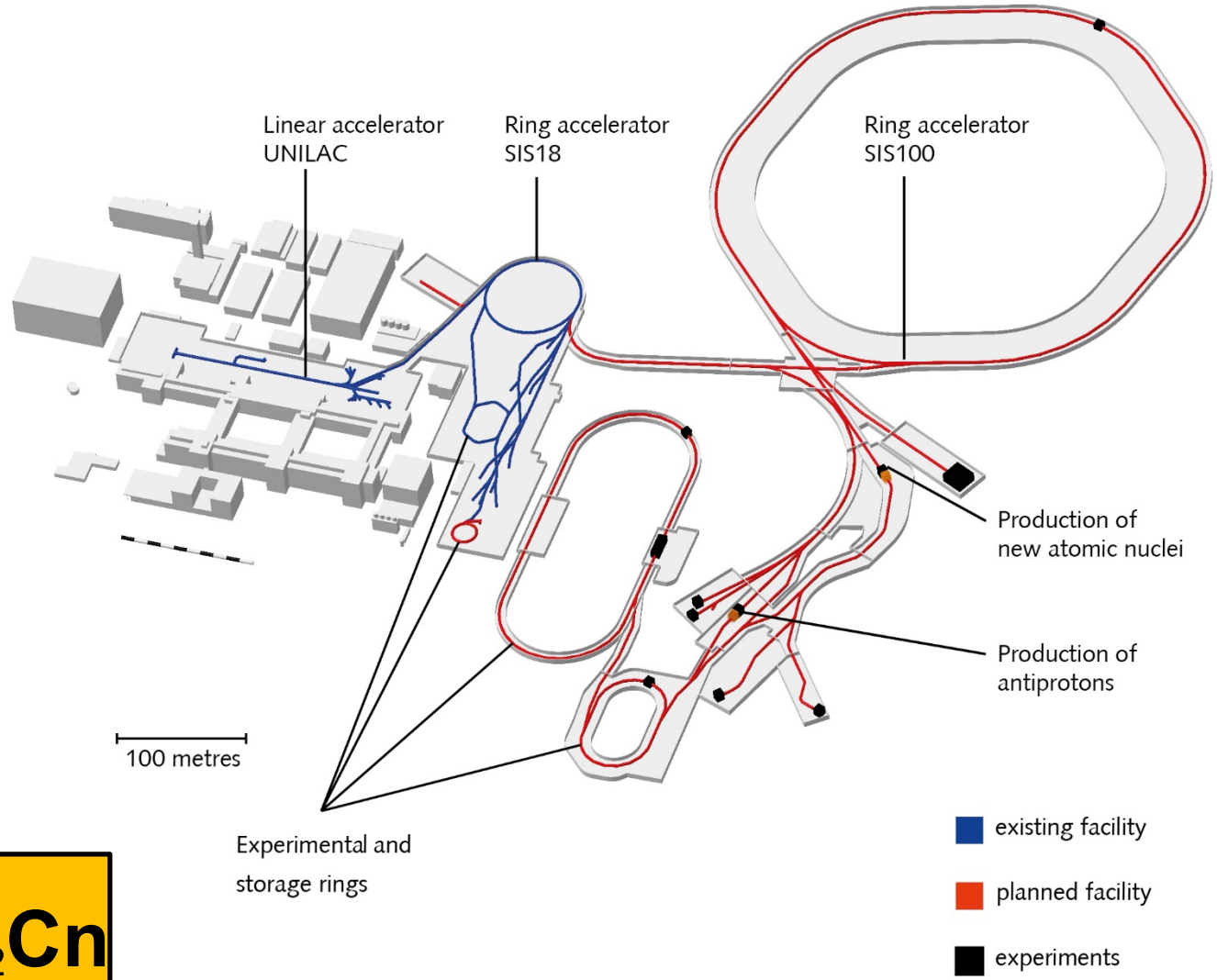




^{107}Bh ^{108}Hs ^{109}Mt ^{110}Ds

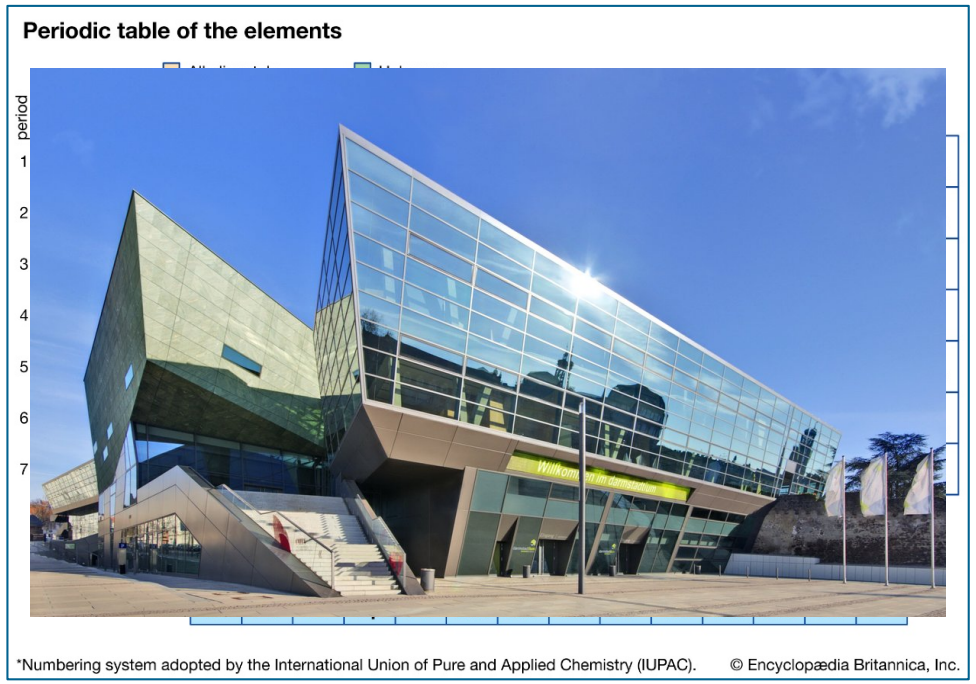
Superheavy Element Synthesis at GSI

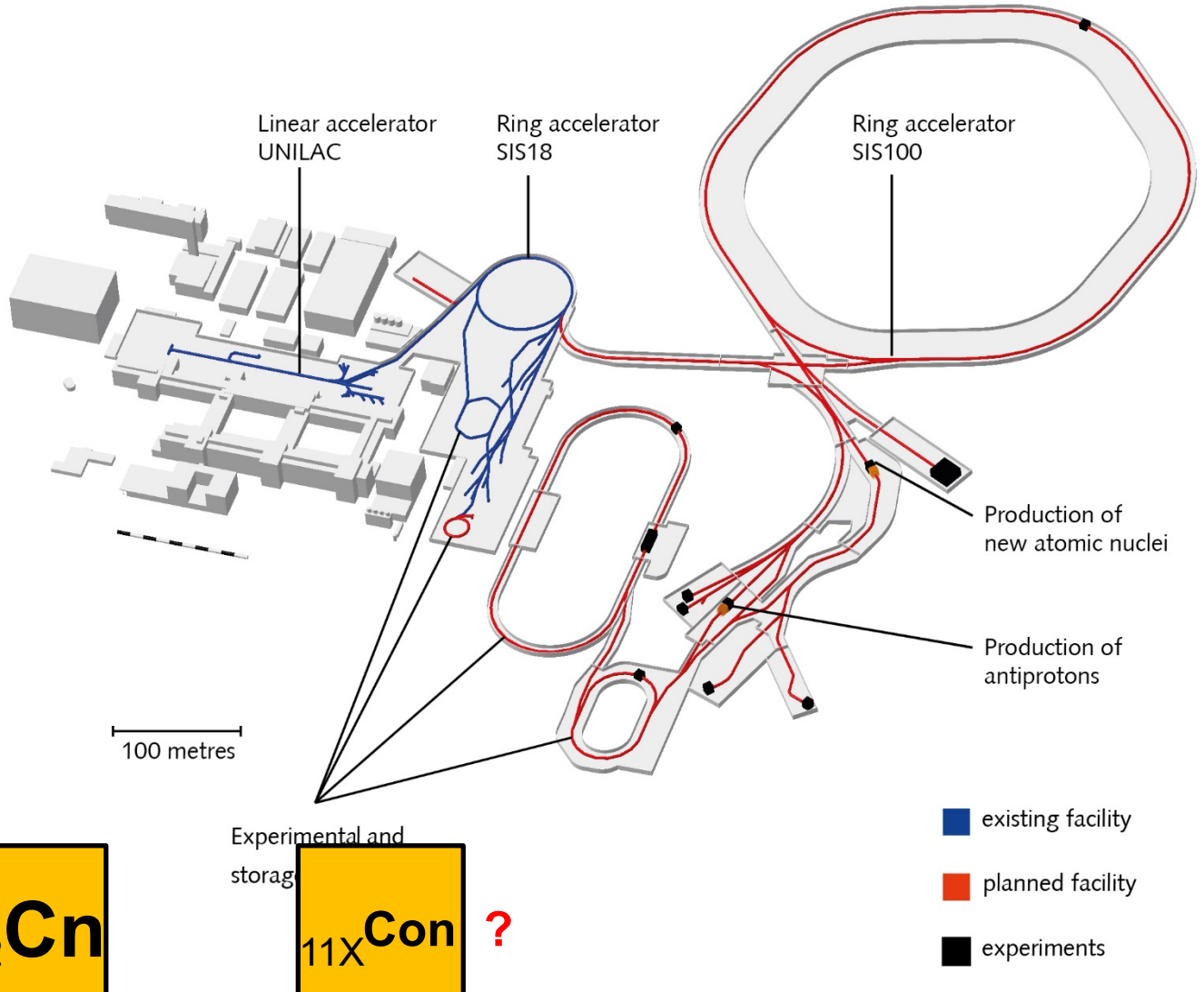




$_{107}$Bh $_{108}$Hs $_{109}$Mt $_{110}$Ds $_{111}$Rg $_{112}$Cn

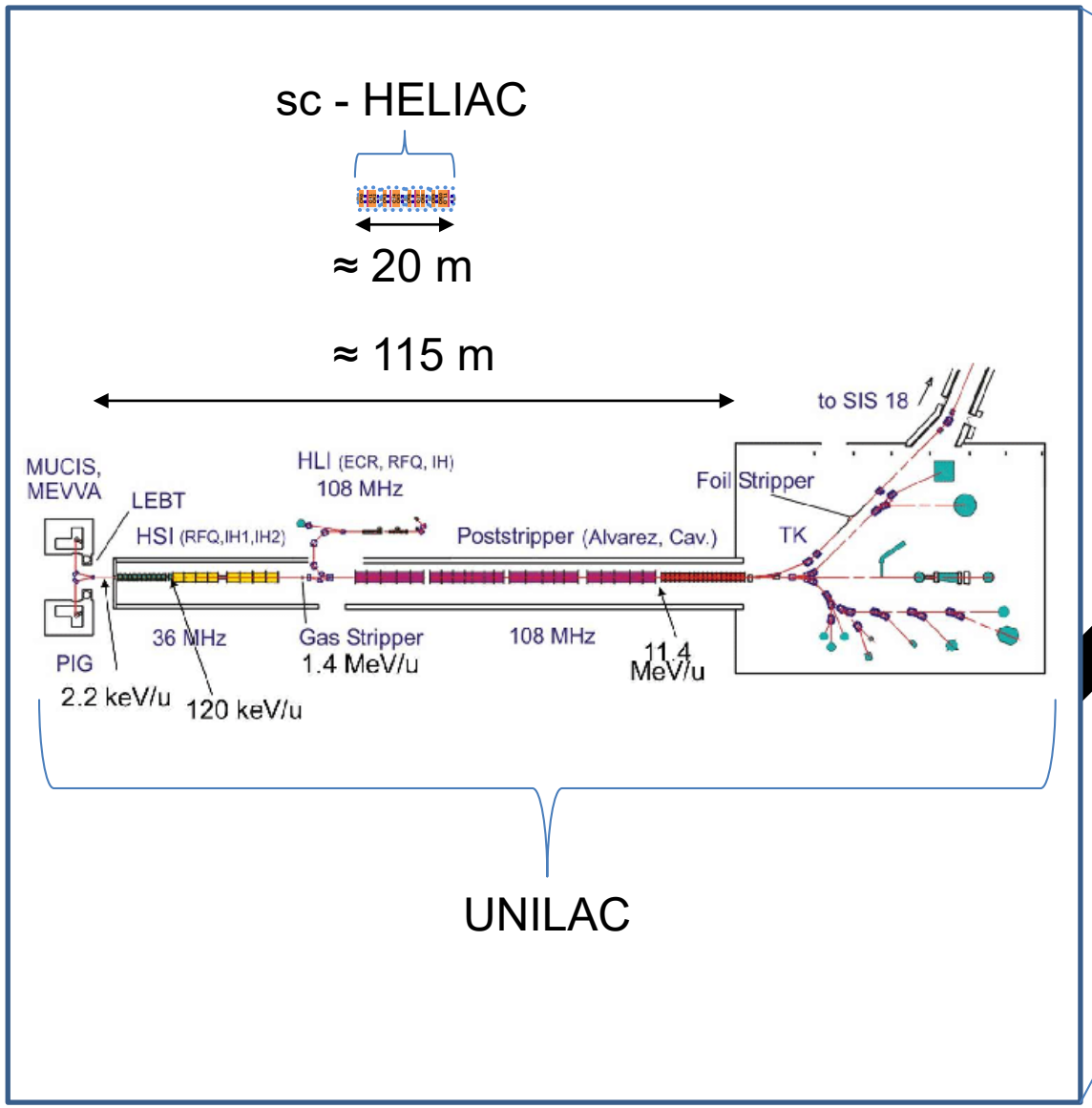
Superheavy Element Synthesis at GSI

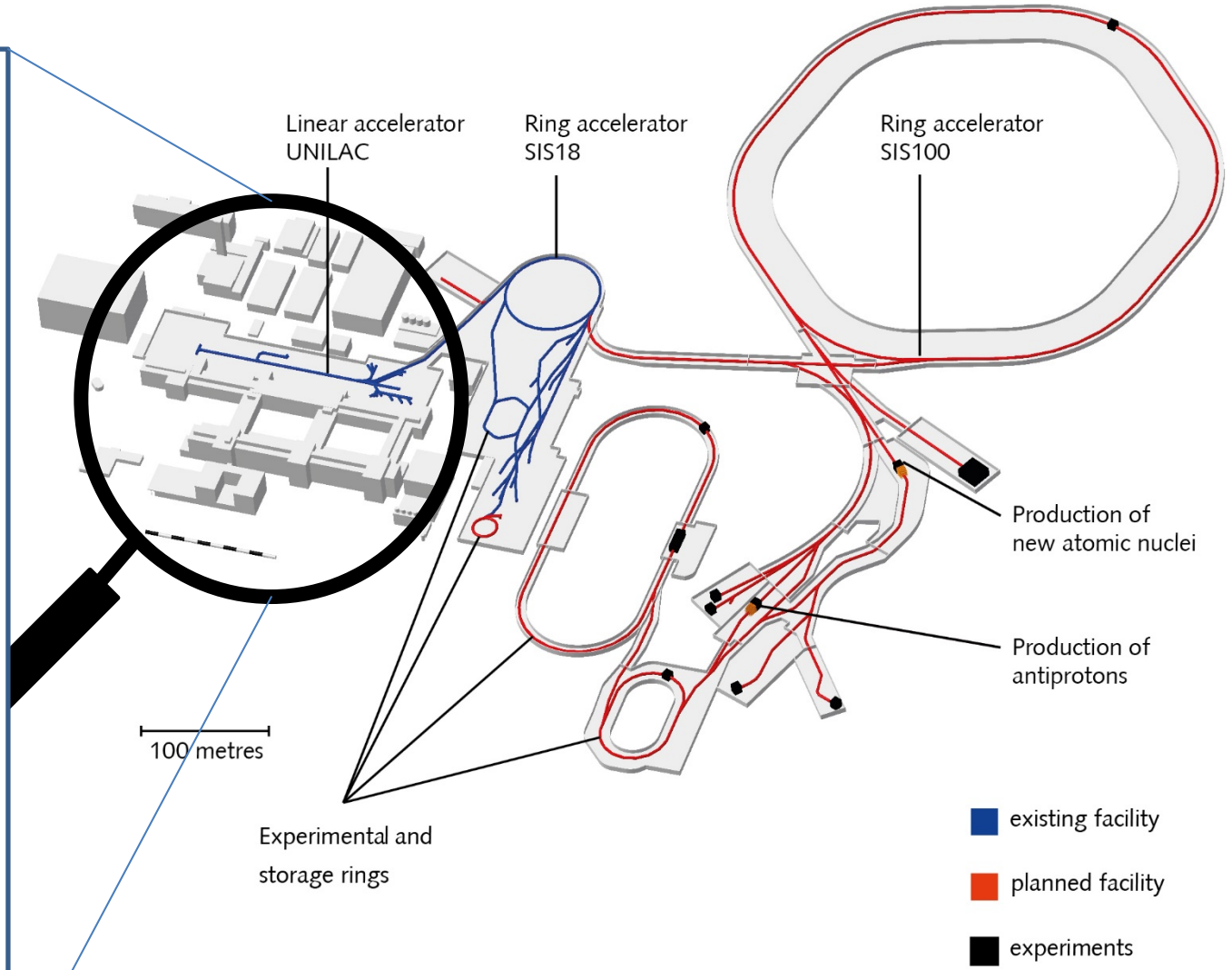




$_{107}$Bh $_{108}$Hs $_{109}$Mt $_{110}$Ds $_{111}$Rg $_{112}$Cn $_{11X}$Con ?

FAIR


sc - HELIAC
≈ 20 m
≈ 115 m
to SIS 18
MUCIS, MEVVA
LEBT
HSI (RFQ,IH1,IH2)
HLI (ECR, RFQ, IH)
108 MHz
Poststripper (Alvarez, Cav.)
Foil Stripper
TK
PIG
2.2 keV/u
36 MHz
120 keV/u
Gas Stripper
1.4 MeV/u
108 MHz
11.4 MeV/u
UNILAC

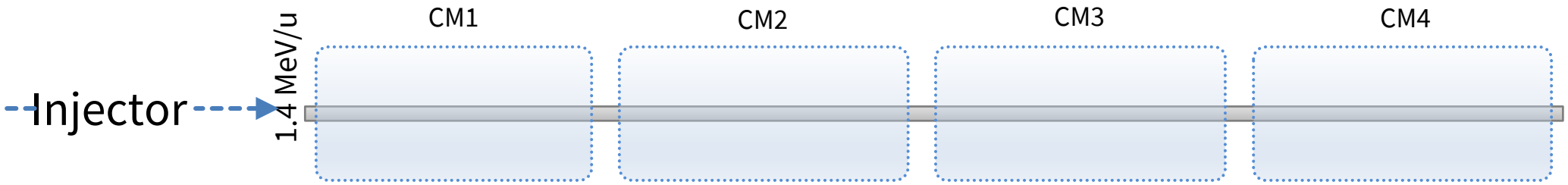

Linear accelerator
UNILAC
Ring accelerator
SIS18
Ring accelerator
SIS100
Production of
new atomic nuclei
Production of
antiprotons
100 metres
Experimental and
storage rings
existing facility
planned facility
experiments

HELIAC Layout

Injector

HELIAC Layout

HELIAC Layout



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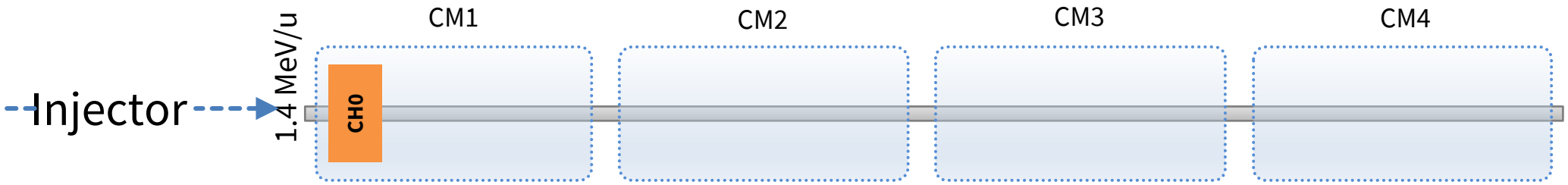

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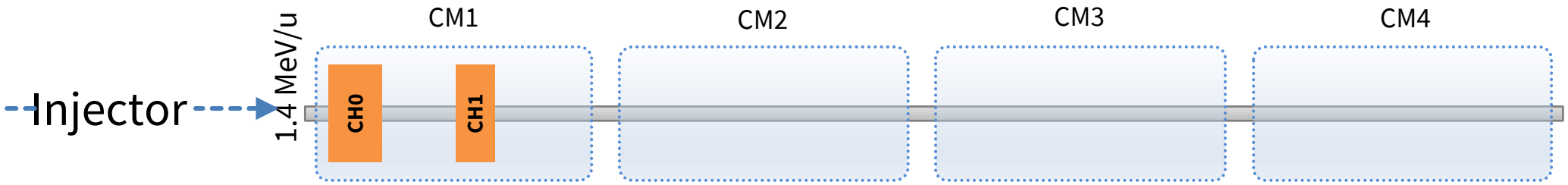

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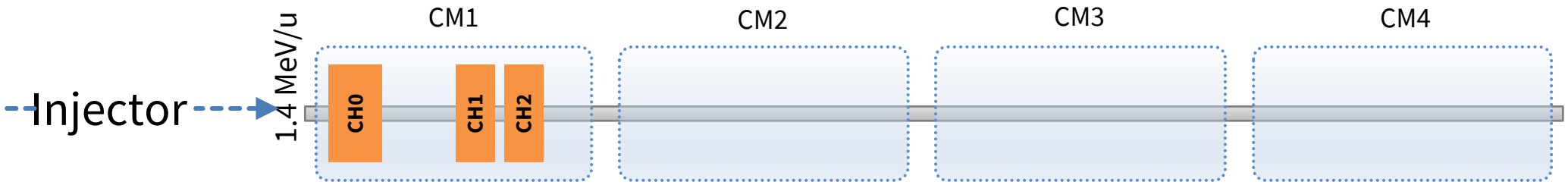

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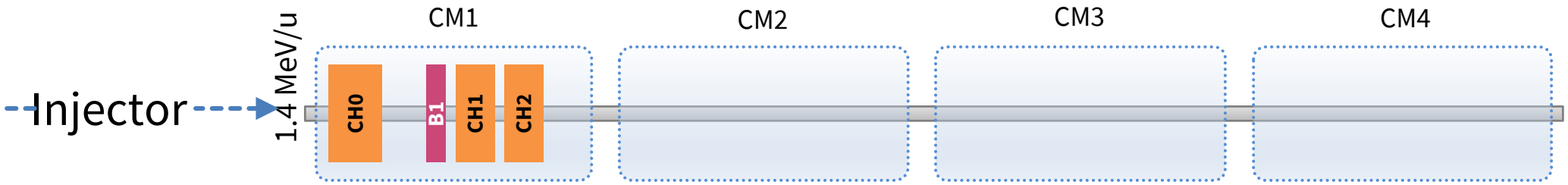

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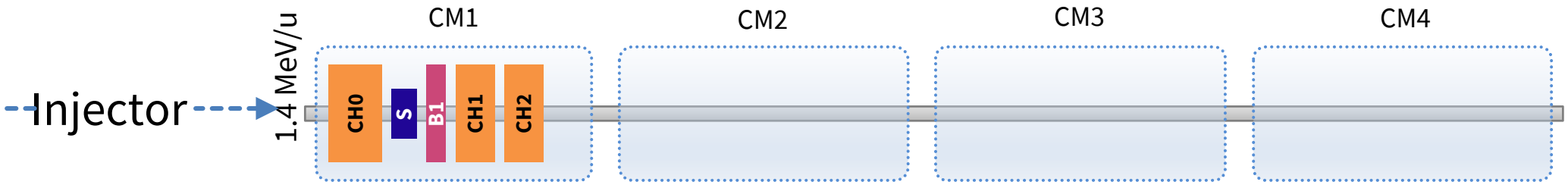

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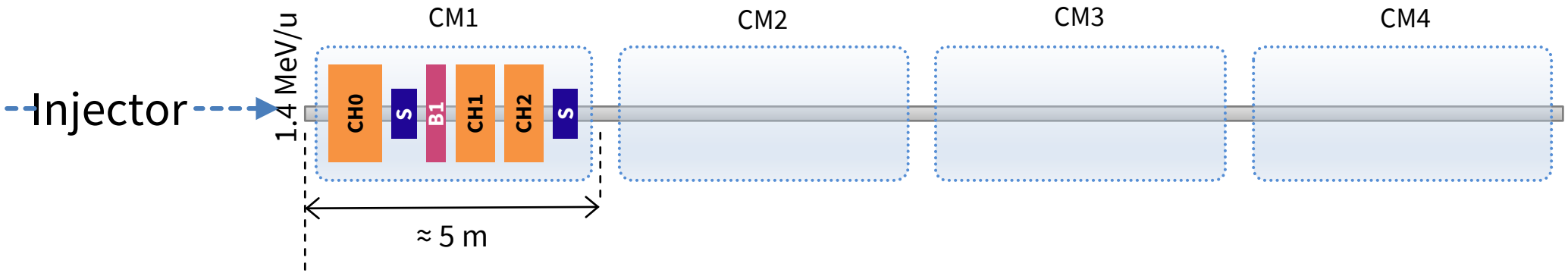

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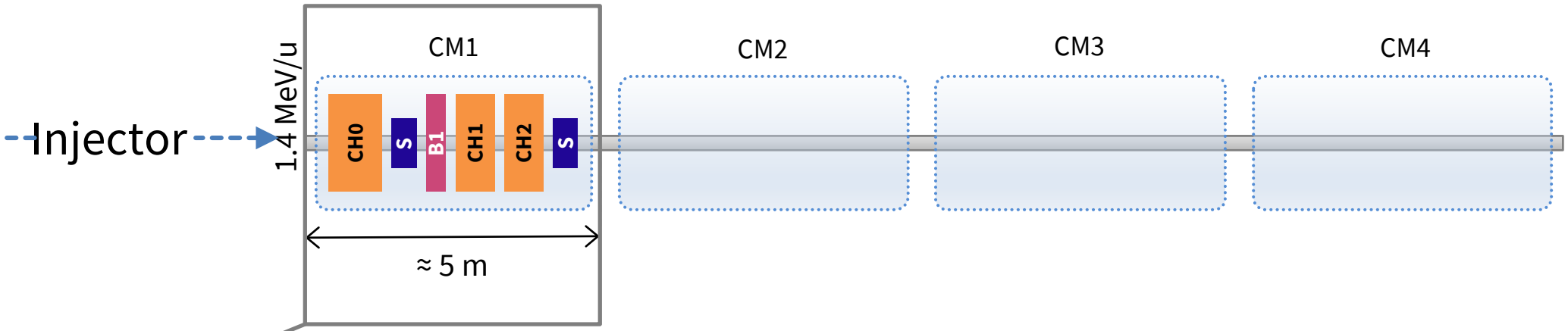

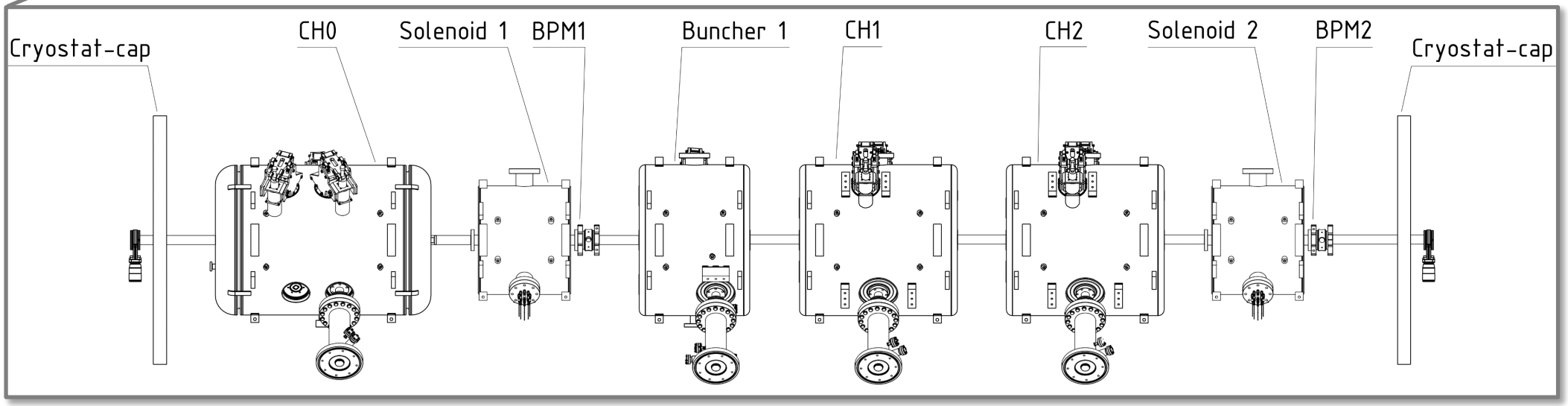

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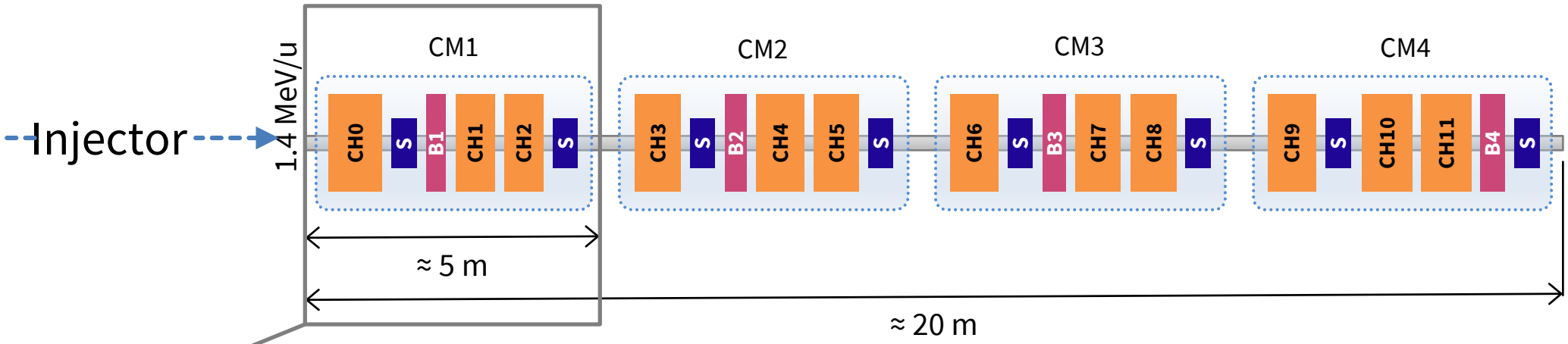

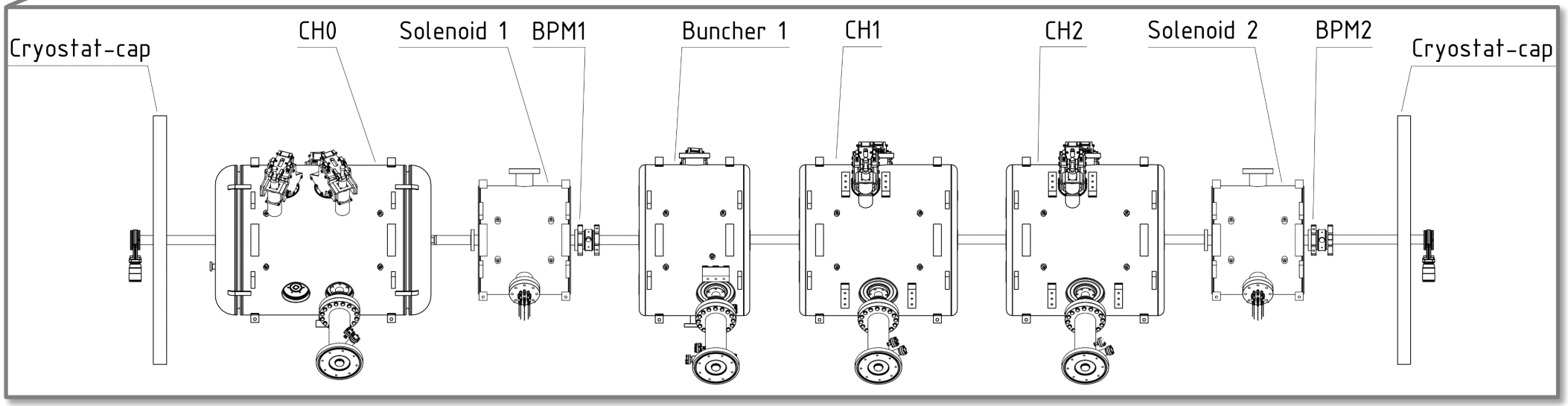

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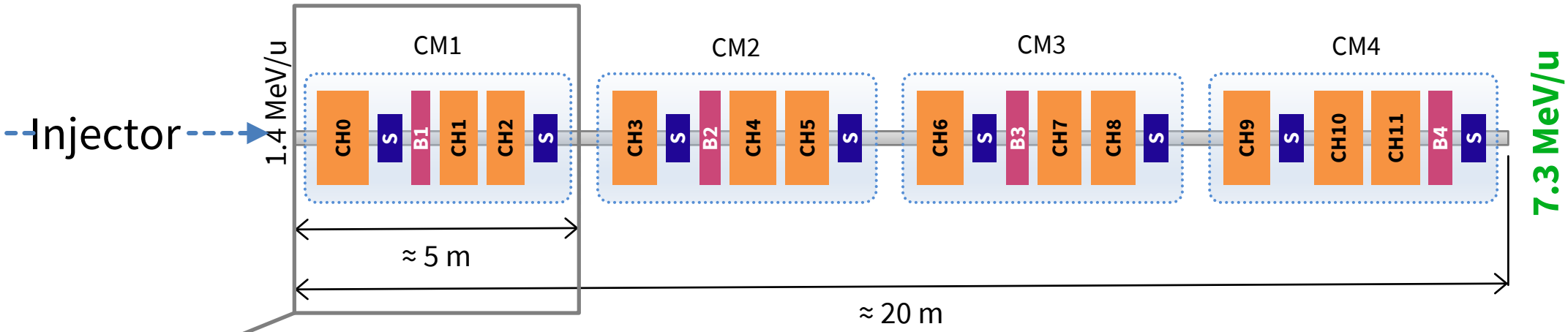

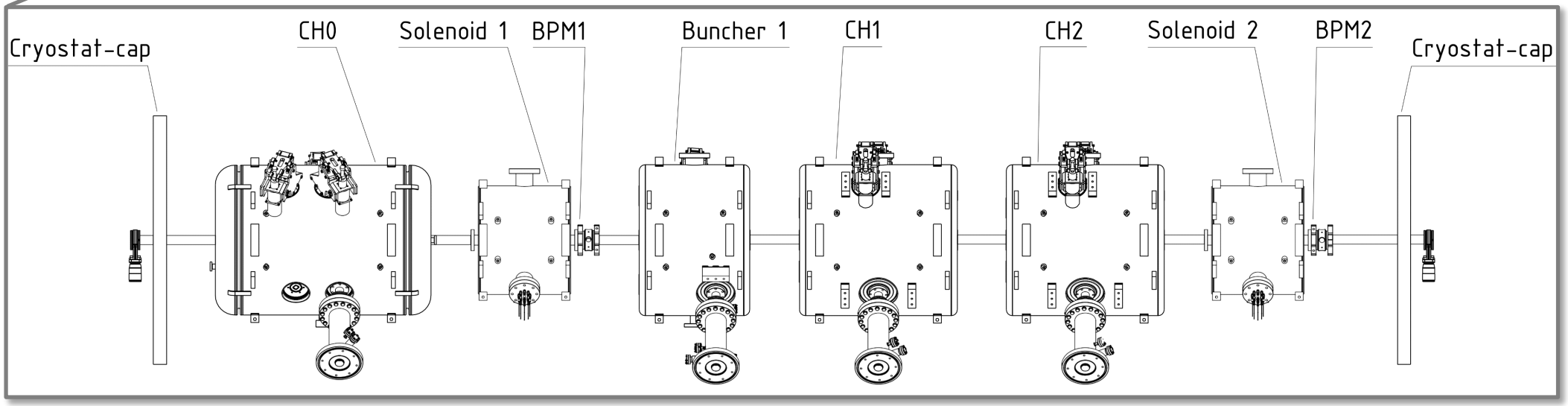

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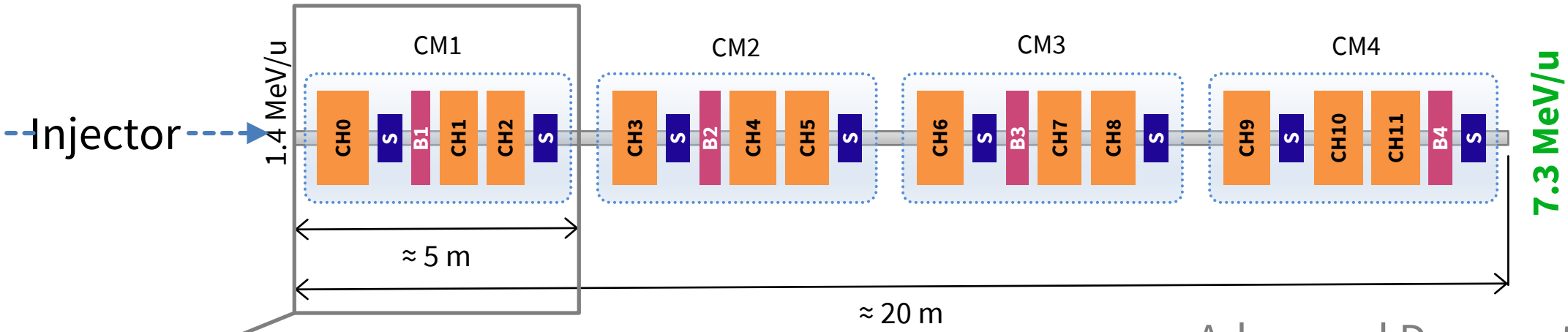
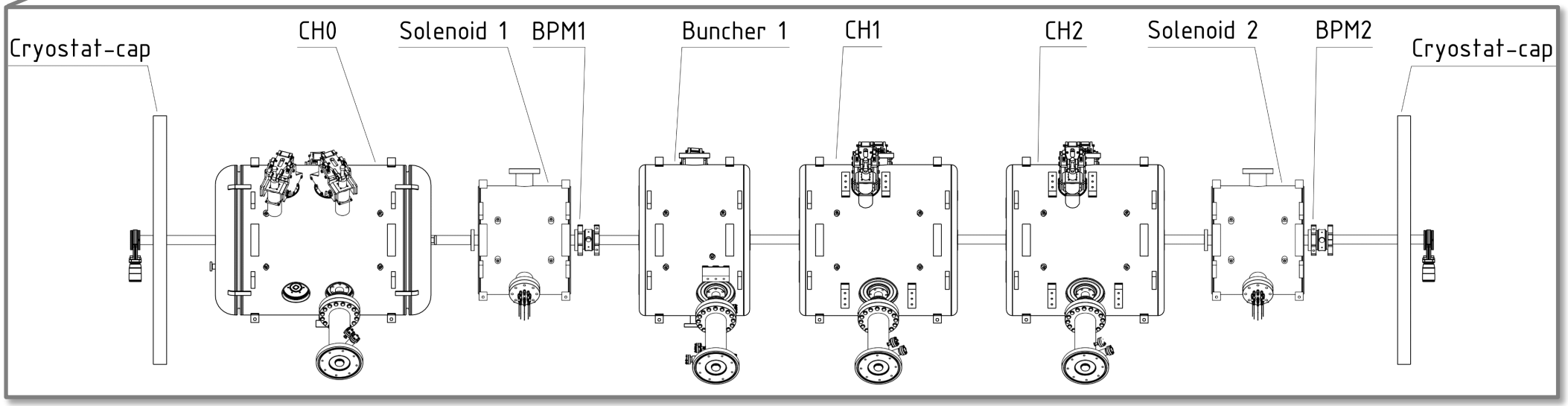


Advanced Demonstrator



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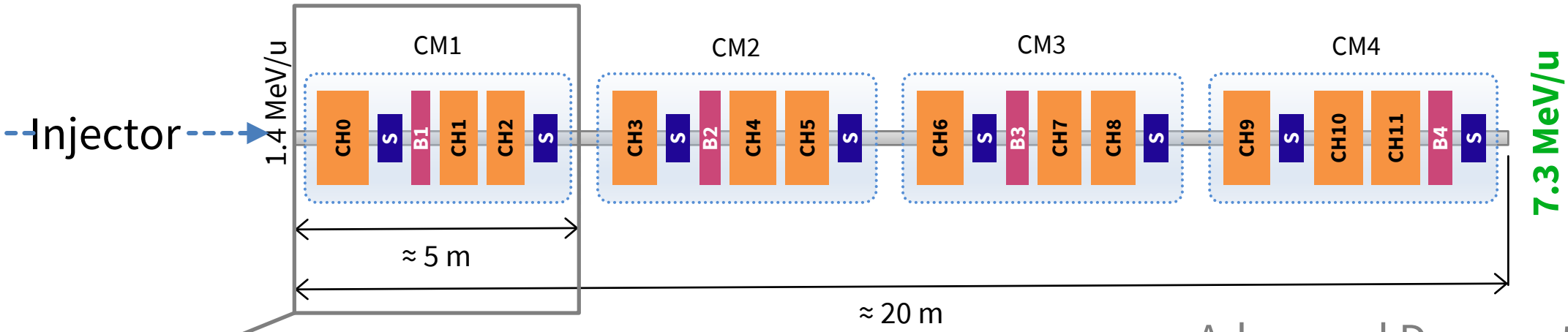
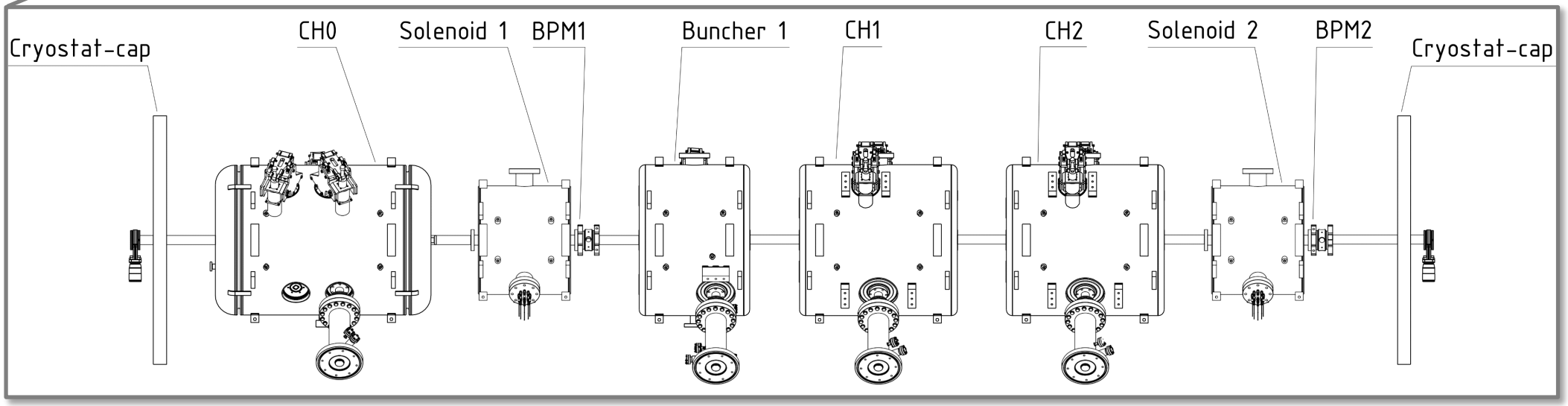


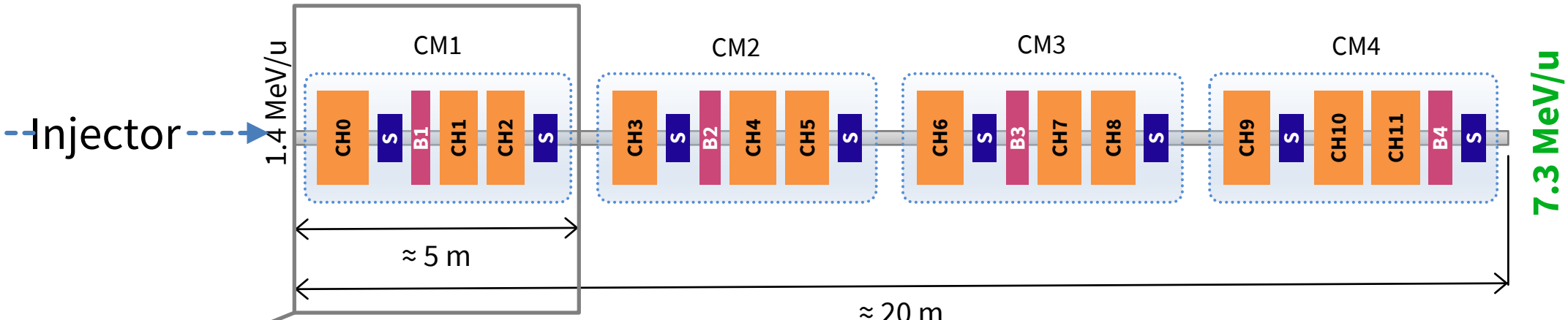
Advanced Demonstrator



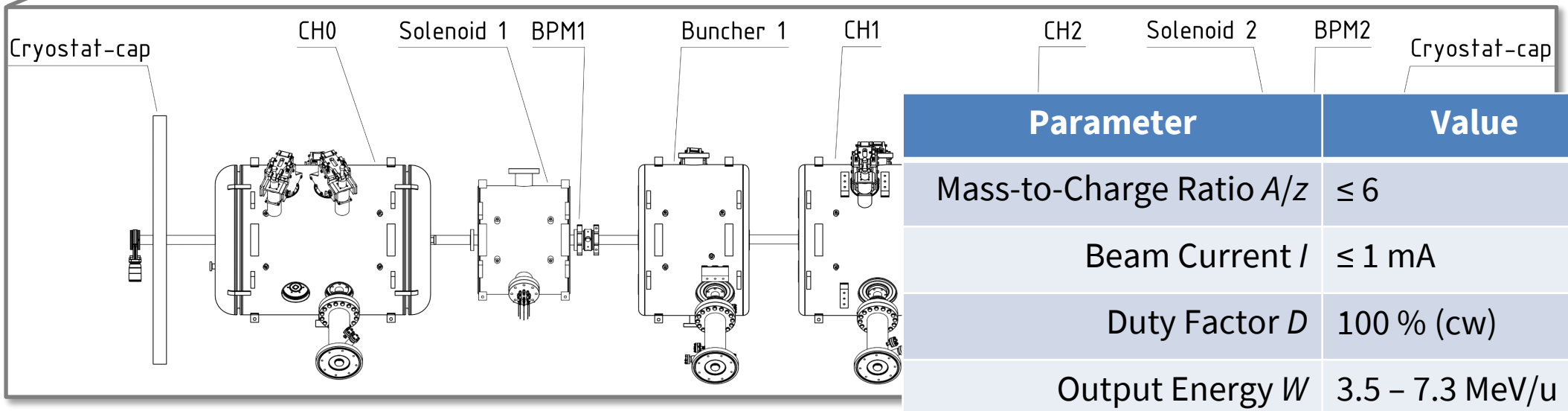
HElmholtz LInear ACcelerator

HELIAC GSI DARMSTADT

HELIAC Layout



Advanced Demonstrator

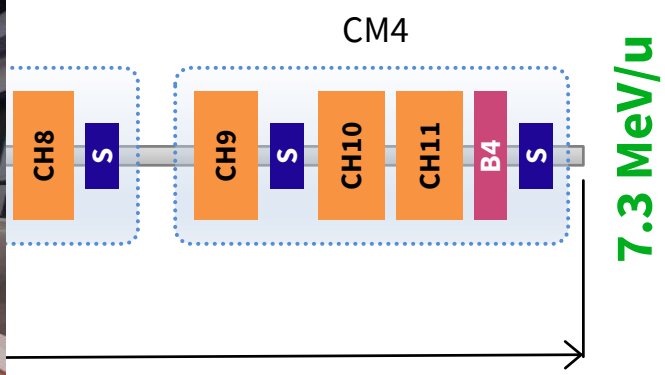


Parameter	Value
Mass-to-Charge Ratio *A*/*z*	≤ 6
Beam Current *I*	≤ 1 mA
Duty Factor *D*	100 % (cw)
Output Energy *W*	3.5 – 7.3 MeV/u
Output Energy Spread Δ*W*	max. ± 3 keV/u

HElmholtz LInear ACcelerator

HELIAC GSI DARMSTADT

HELIAC Layout



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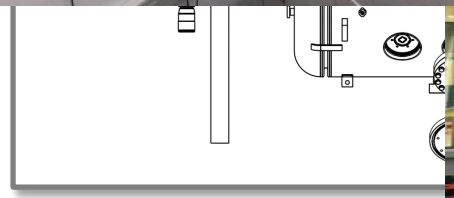


HELIAC
GSI DARMSTADT

HElmholtz

Thorsten Conrad

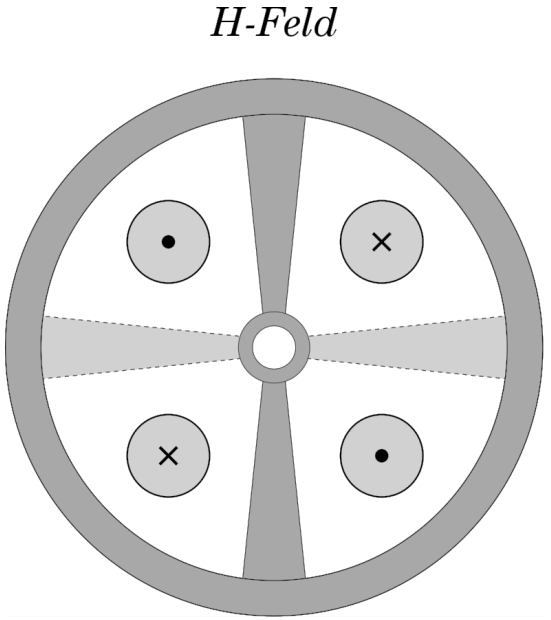
CH - DTL cavities

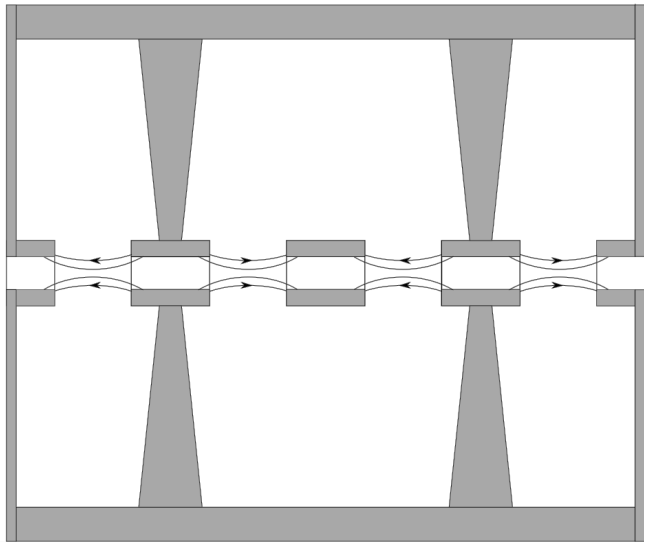
The Crossbar H-mode (CH) structure is a multicell drift tube cavity for the acceleration of protons and ions in the low and intermediate energy range:

- TE_{211}-Mode (H_{211}-Mode)
- Frequency range: 150 – 800 MHz
- Energy range: 1 – 150 MeV/u
- Velocity range β = 0.05 – 0.6
- Cell length $l = \beta\lambda/2$

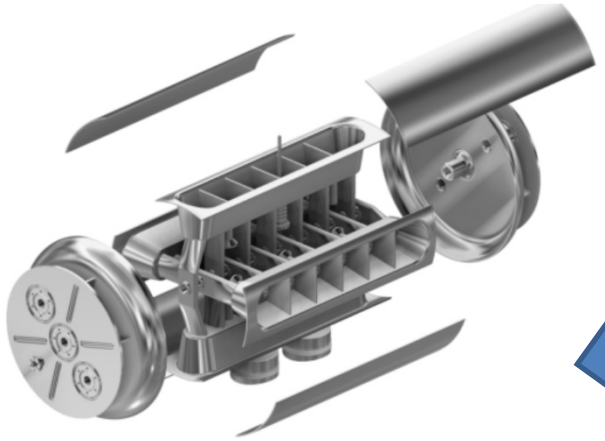
How is the particle beam accelerated?

- Stems are alternately charged to different potential
- Electric fields between the drift tubes along the beam axis lead to an acceleration voltage





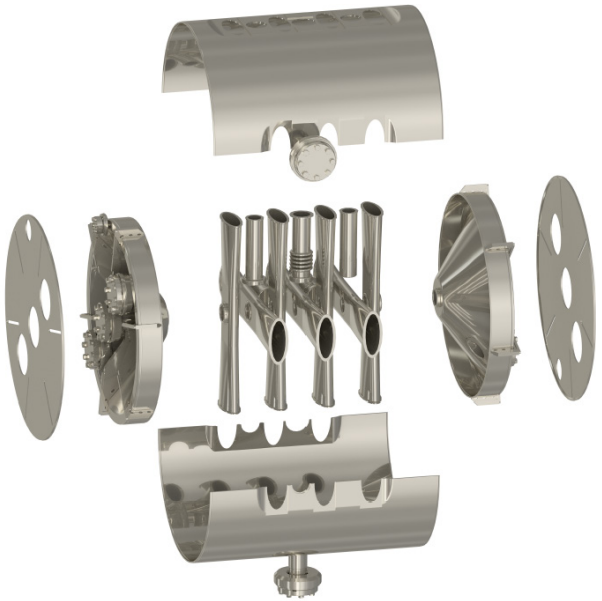
Evolution of SC CH - Cavities



CH0 *F. Dziuba (2016)*

- Straight lids
- Girder
- Bend spokes

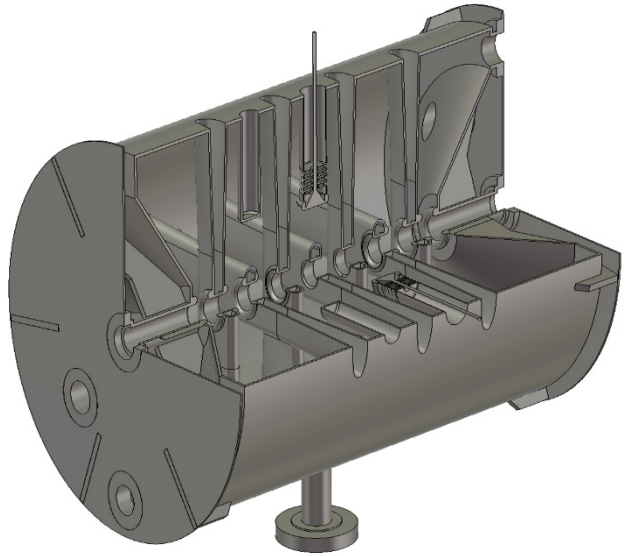
CH1/2 *M. Basten (2019)*



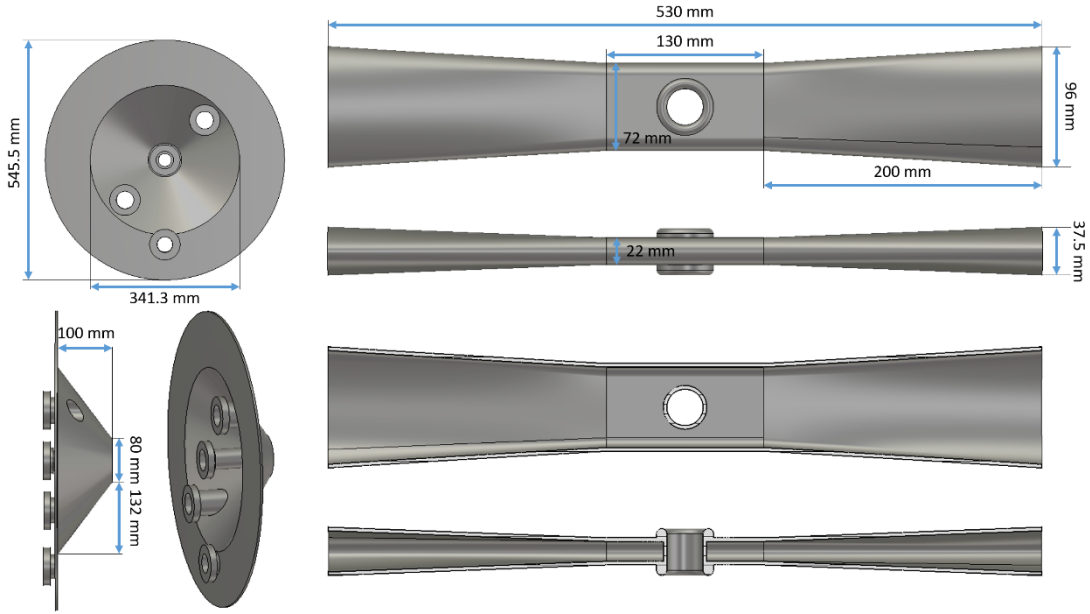
- Conical lids
- No girder
- Straight spokes
- Flushing flanges

- New bellow tuner
- Modular cavity design
- Adapted drift tube geometry

CH3 - 11 *T. Conrad (2022)*

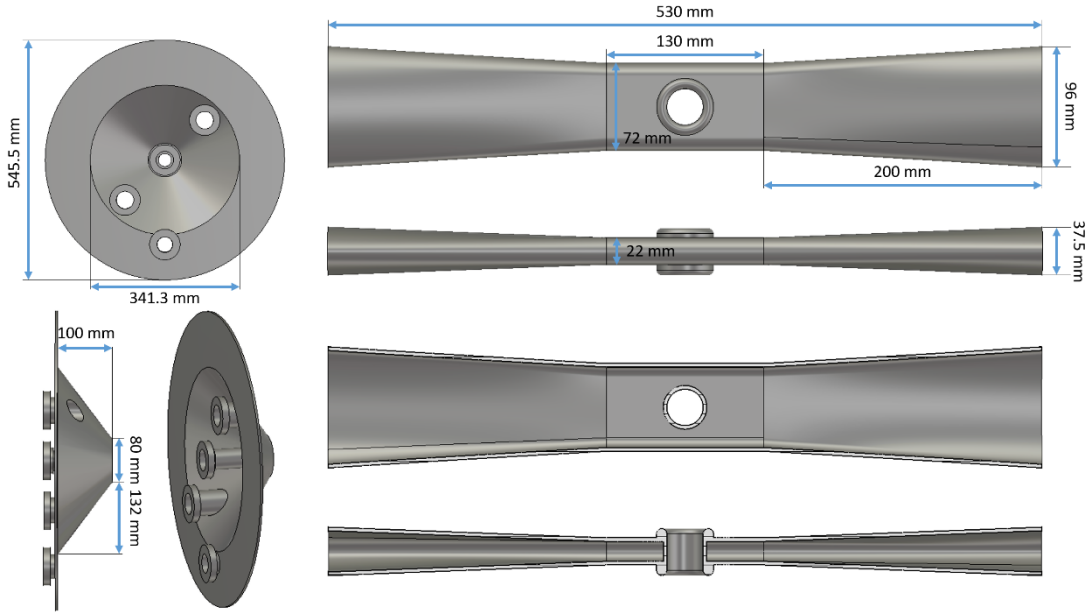


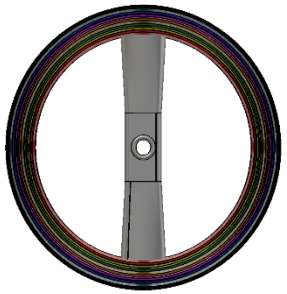
Modular Cavity Design

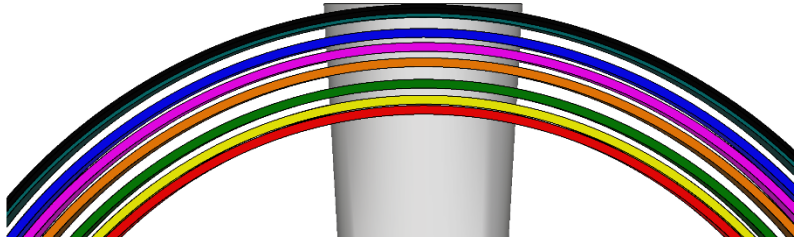


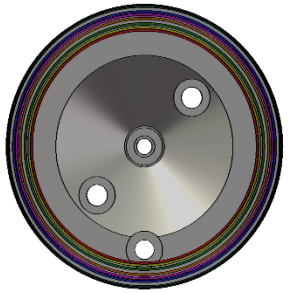
→ **Spokes, lids, flanges, tuners, and helium tanks are identical for all nine cavities**

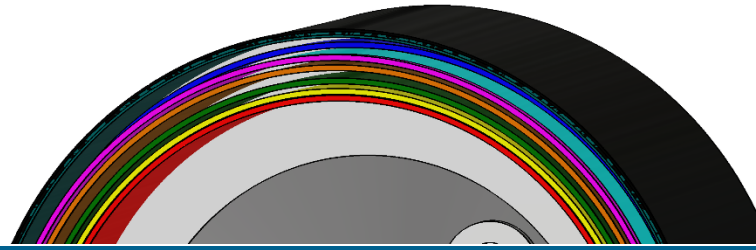
Modular Cavity Design





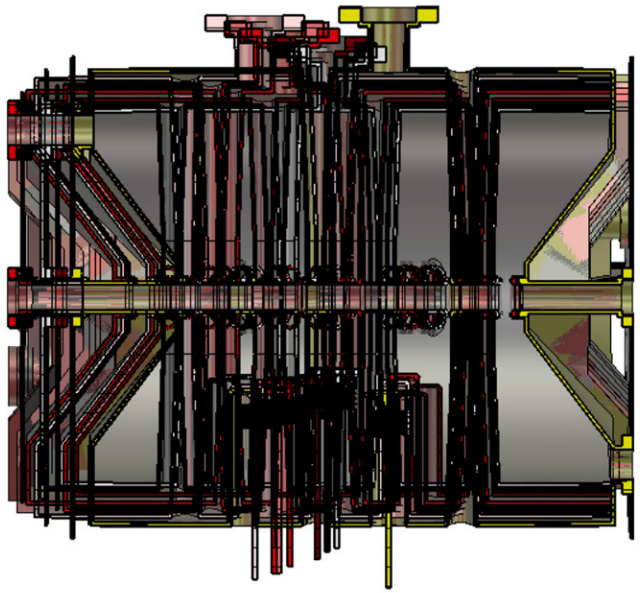


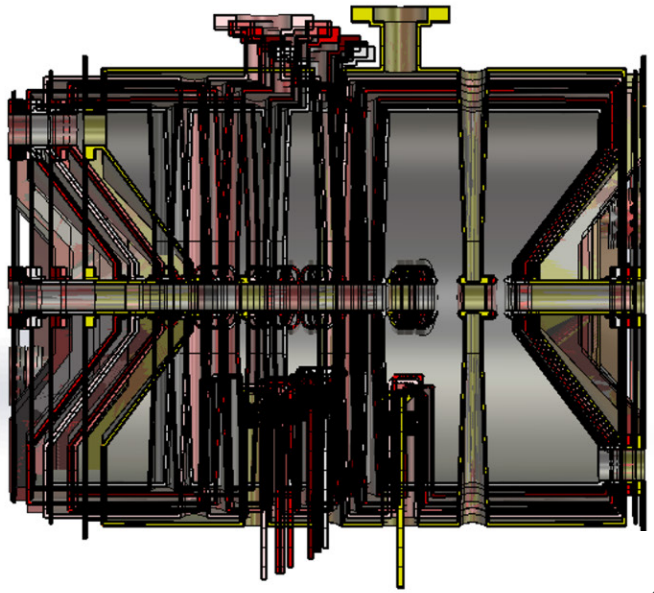




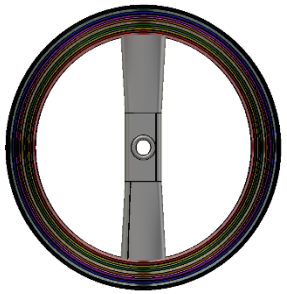
- Spokes, lids, flanges, tuners, and helium tanks are identical for all nine cavities
- They can be mass produced and then adapted to the particular cavity

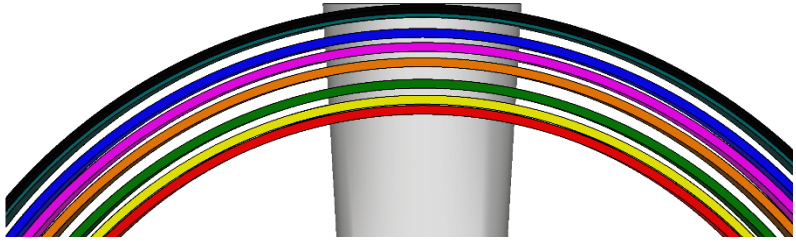
Modular Cavity Design





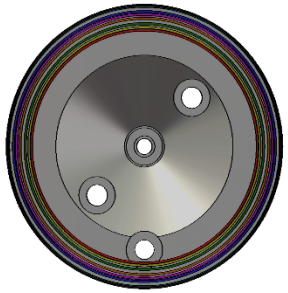
→ This saves both production costs and production time

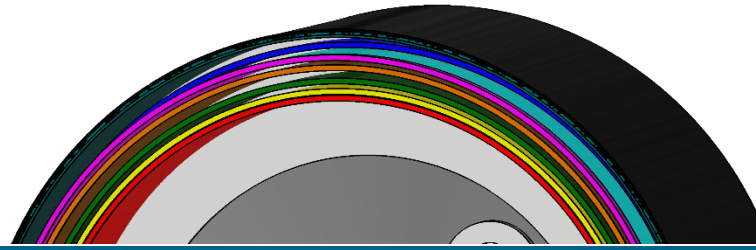




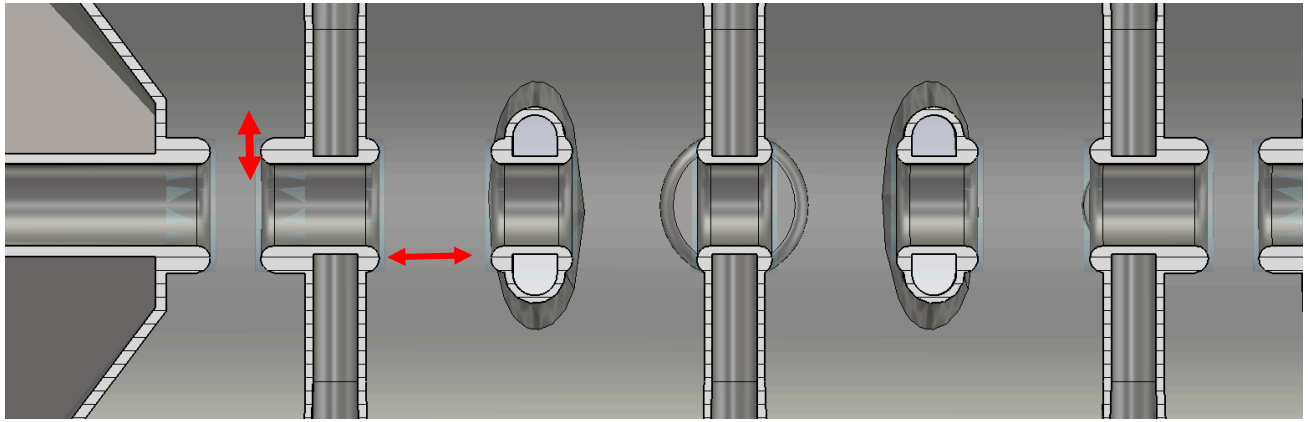
→ Spokes, lids, flanges, tuners, and helium tanks are identical for all nine cavities

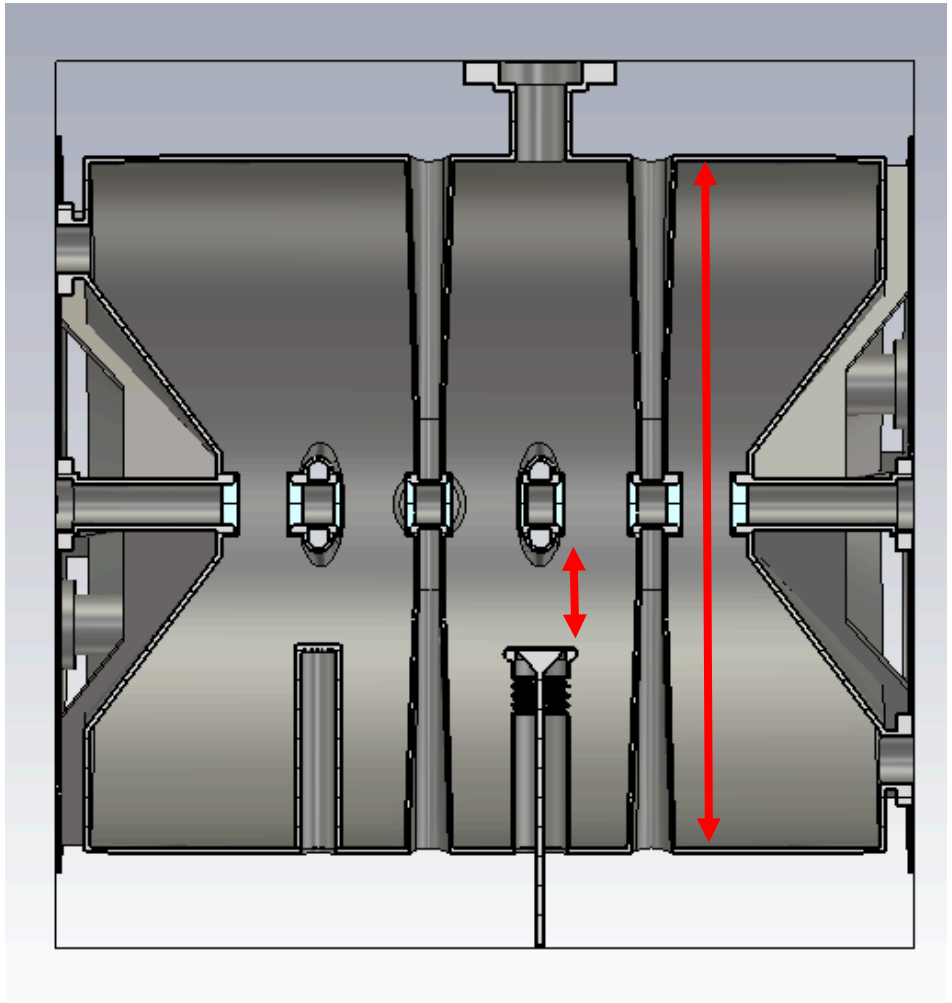
→ They can be mass produced and then adapted to the particular cavity





Optimization





The only remaining adjusting screws

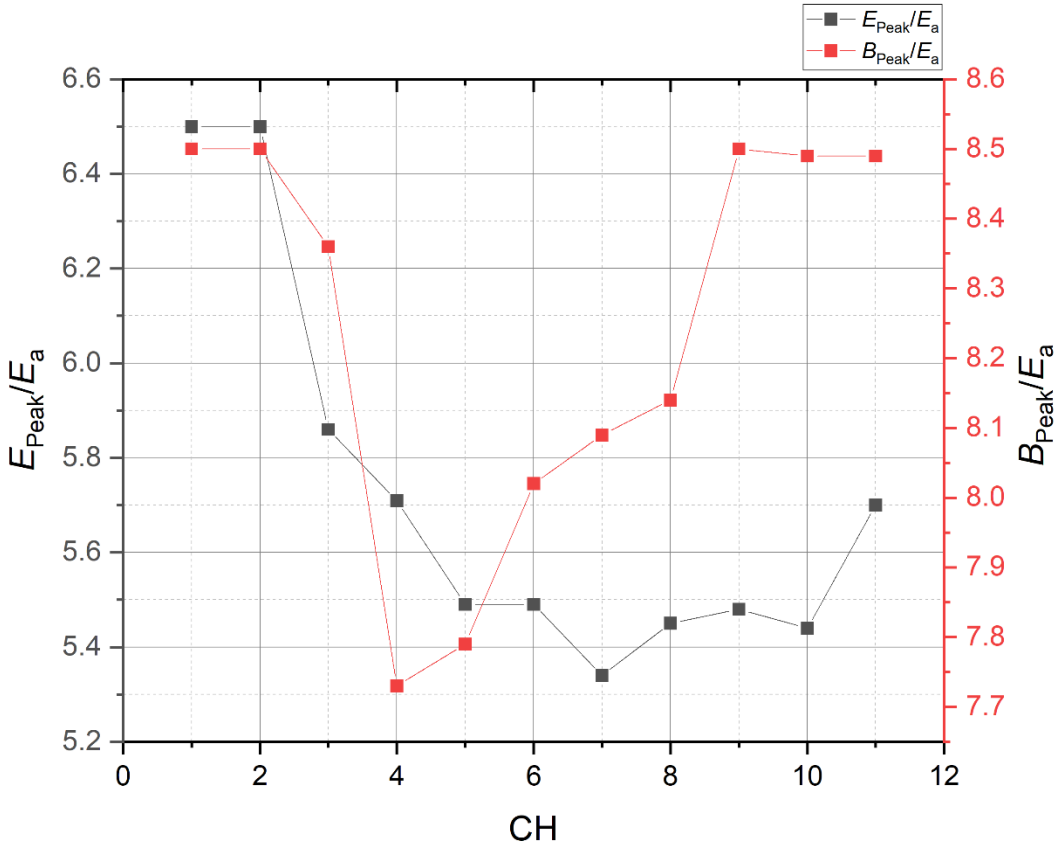
- radius
- dynamic bellow tuner height
- drift tube length
- drift tube width

Optimization

The only remaining adjusting screws

- radius
- dynamic bellow tuner height
- drift tube length
- drift tube width

# CH	E_{Peak} / E_A	B_{Peak} / E_A
CH1	6.5	8.5
CH2	6.5	8.5
CH3	5.86	8.36
CH4	5.71	7.73
CH5	5.49	7.79
CH6	5.49	8.02
CH7	5.34	8.09
CH8	5.45	8.14
CH9	5.48	8.5
CH10	5.44	8.49
CH11	5.7	8.48



- ~ 5 % cost reduction
- ~ 15 % performance improvement electric fields
- ~ 4 % performance improvement magnetic fields

Pressure Sensitivity

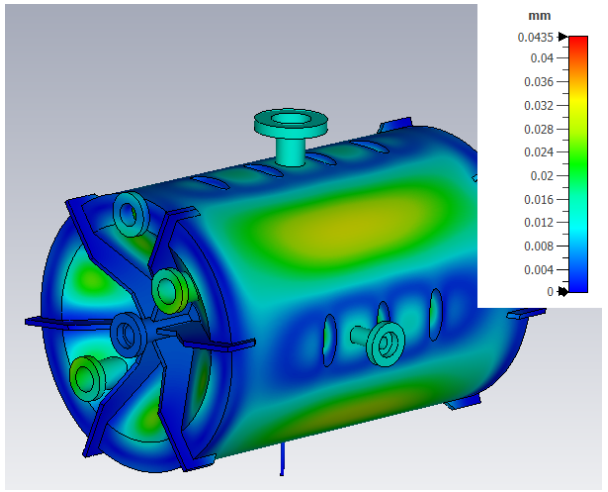
A major problem for superconducting CH cavities is their susceptibility to evacuation due to the very thin wall thickness

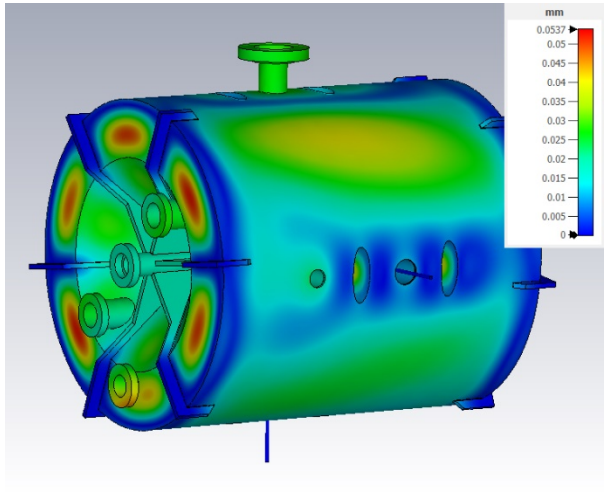
- **Outer wall ≈ 4 mm**
- **Bellow tuner ≈ 1 mm**
- **Spoke wall ≈ 3 mm**

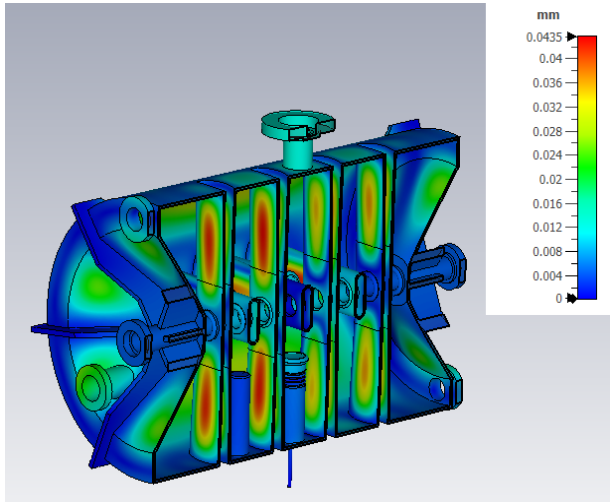
Measures were taken in the design of CH1 and CH2 to counteract this vulnerability

- **Bend lids**
- **Straight spokes**
- **Lid stabilizers**

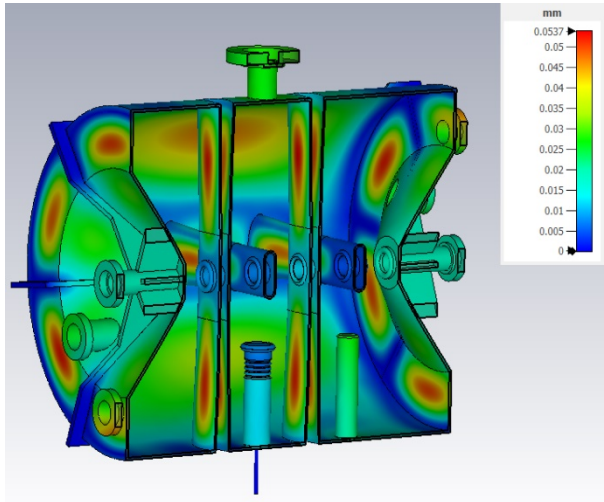
These measures are <u>only</u> fully effective for CH3 now!





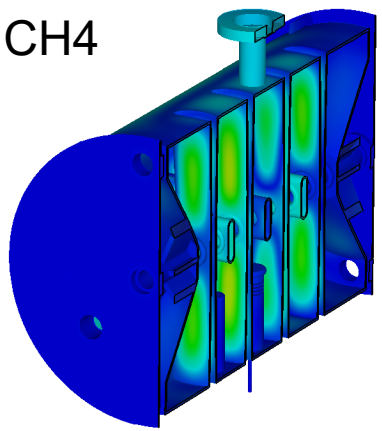


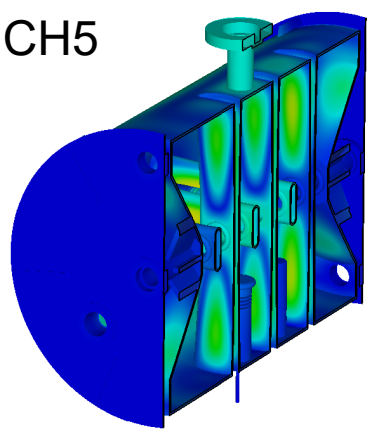
CH3

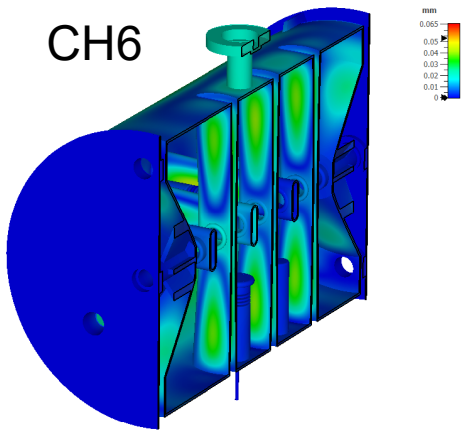


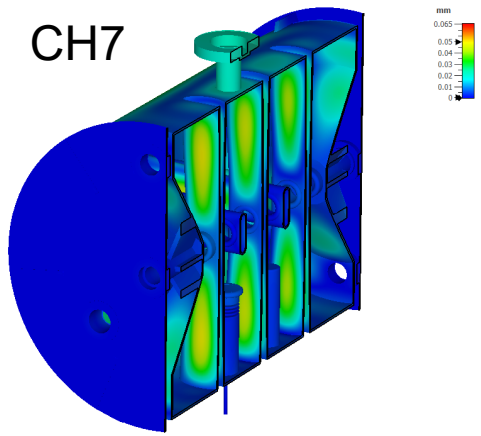
CH11

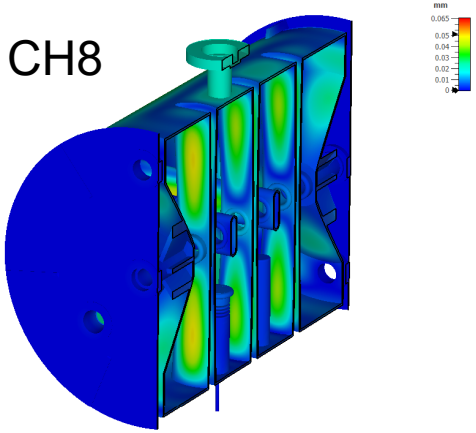
Pressure Sensitivity

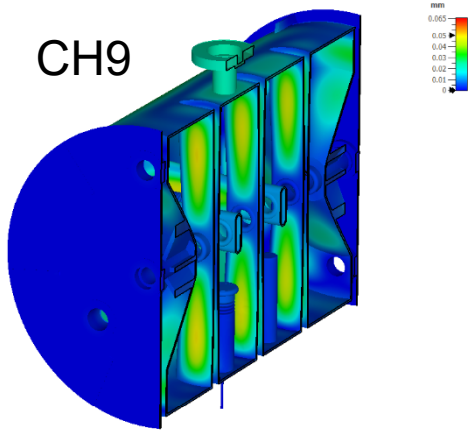


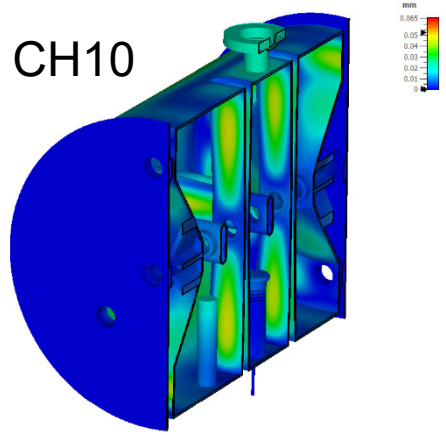


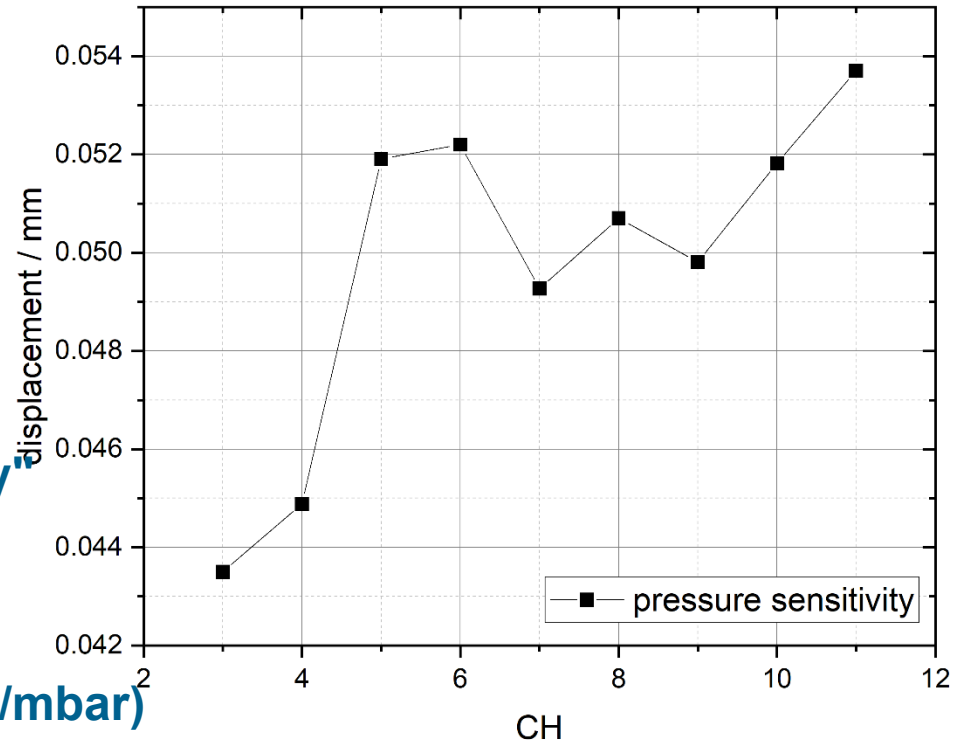








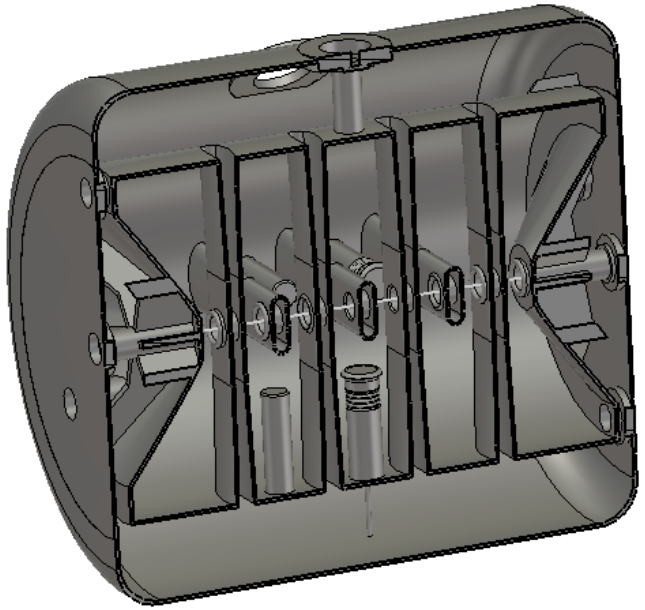




The largest change in frequency when the cavity is "completely" evacuated is ≈ -12 Hz/mbar

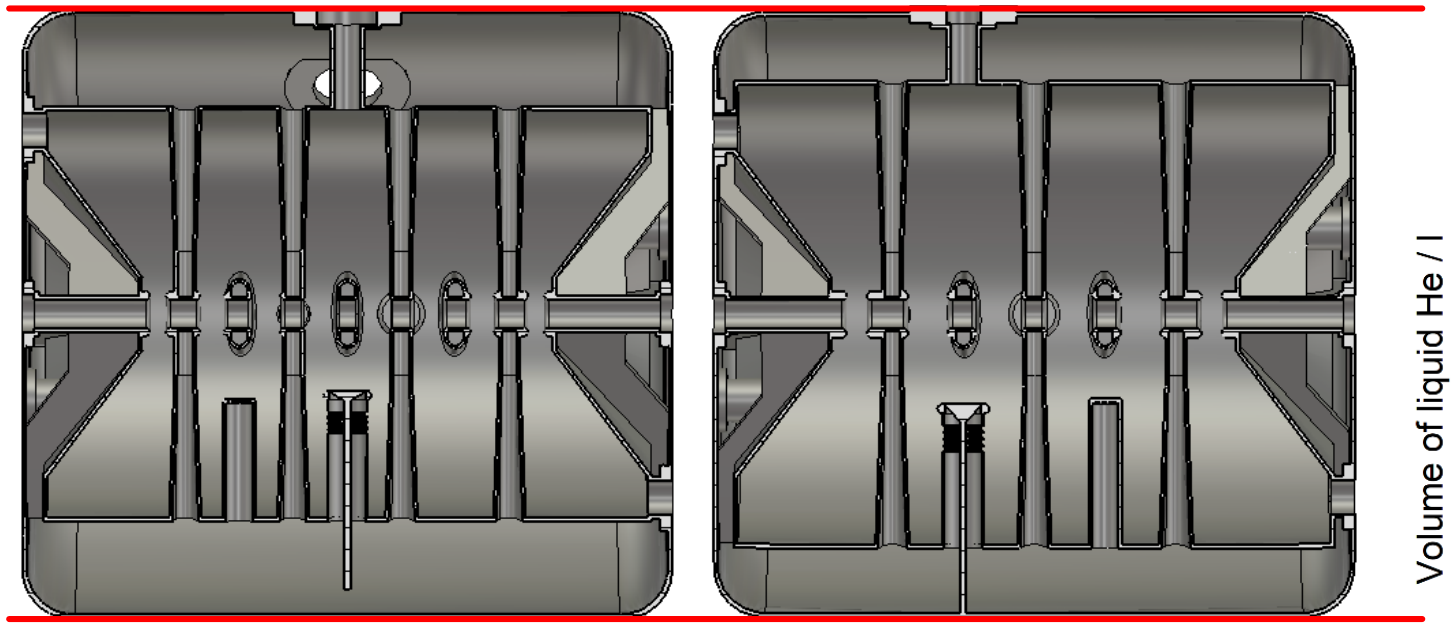
This is within the range o fthe experimentally determined pressure sensitivity of CH1 (≈ -4.5 Hz/mbar) and CH2 (≈ -9.6 Hz/mbar)

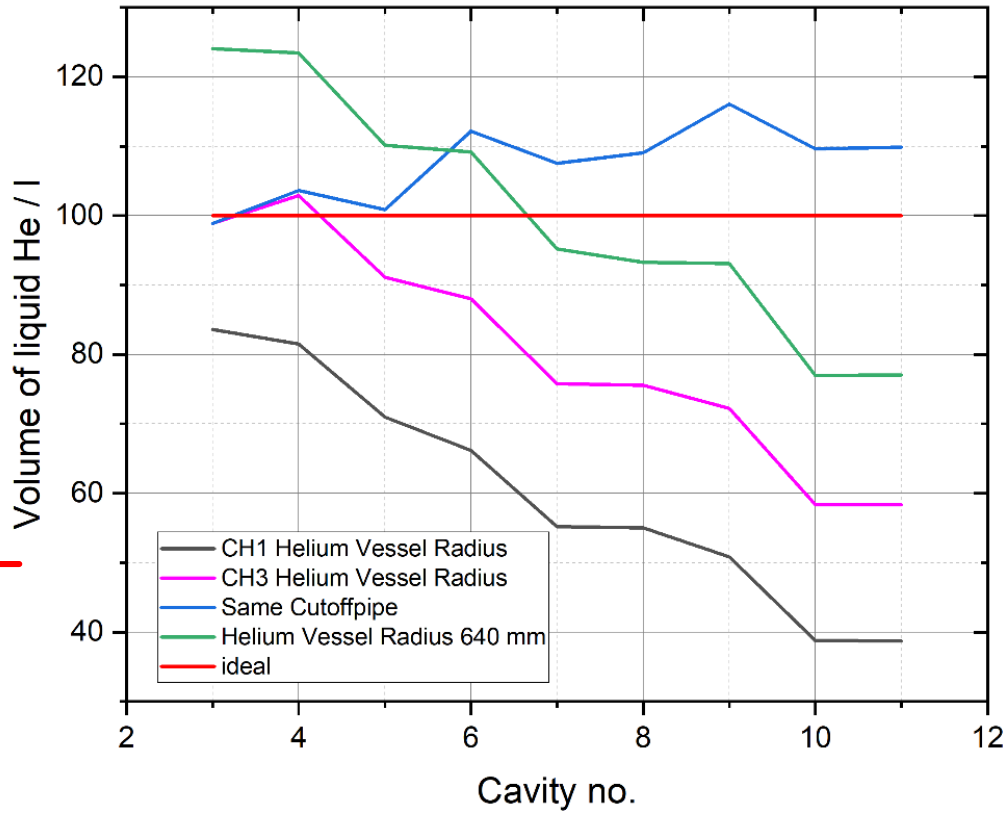
Helium Vessel



As already mentioned, the helium tank is part of the Modular Cavity Design

Helium Vessel

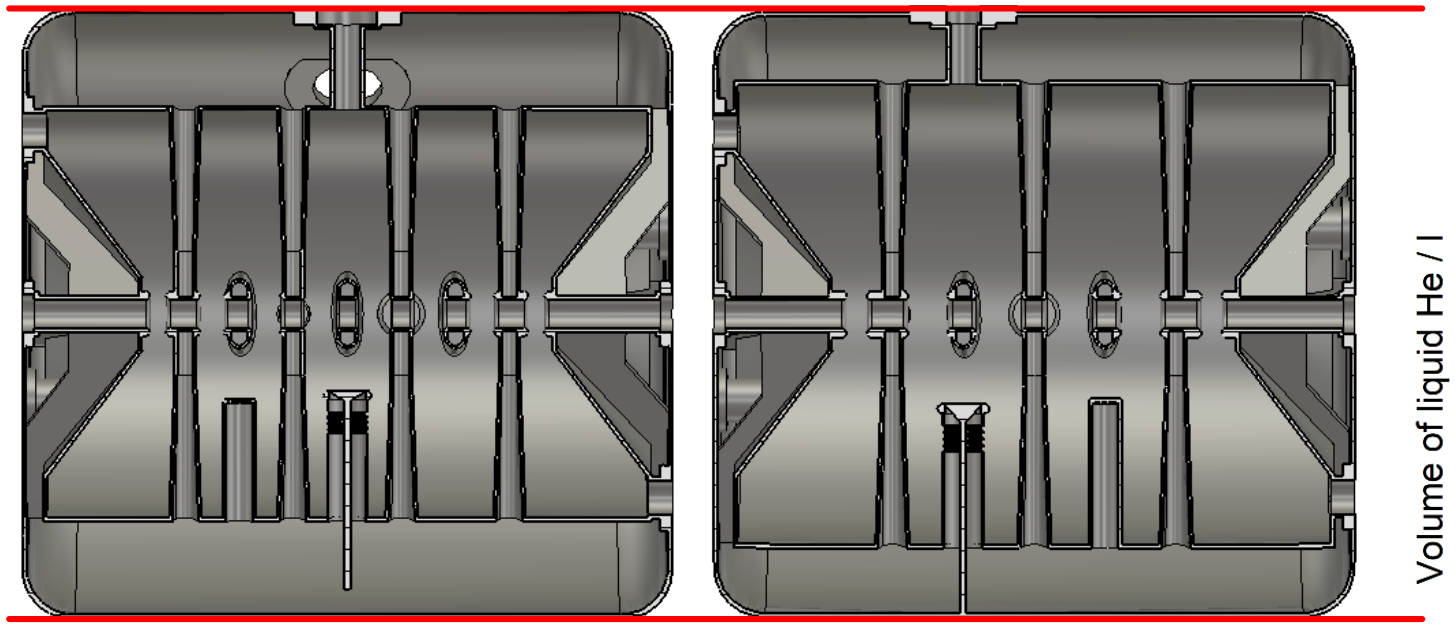


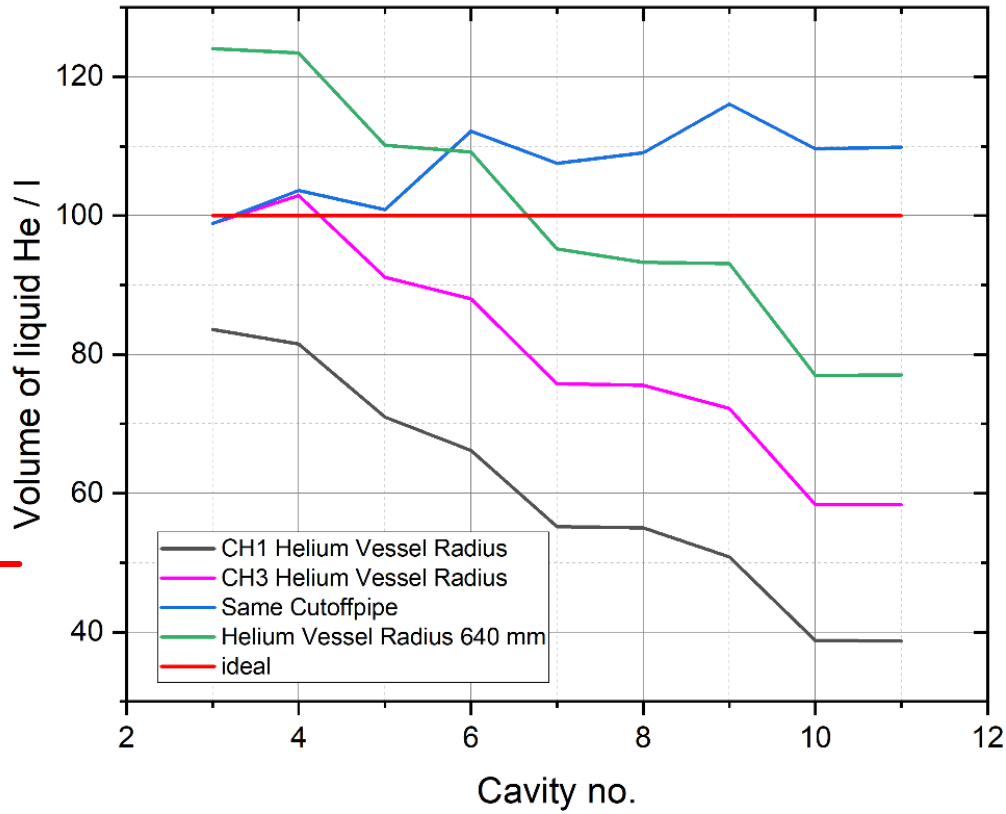


As already mentioned, the helium tank is part of the Modular Cavity Design

Different radii were considered and the resulting helium reservoir was calculated

Helium Vessel





As already mentioned, the helium tank is part of the Modular Cavity Design

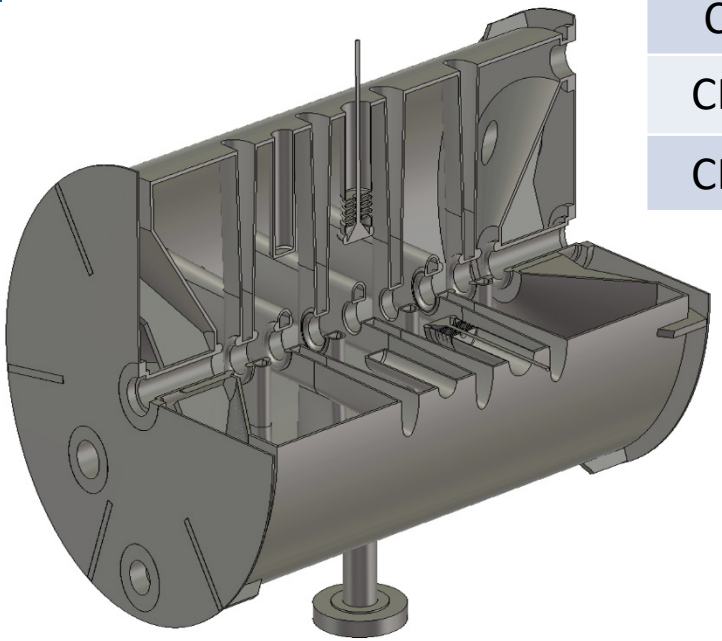
Different radii were considered and the resulting helium reservoir was calculated

The radius was designed for the maximum of the cryostats

The Cavities

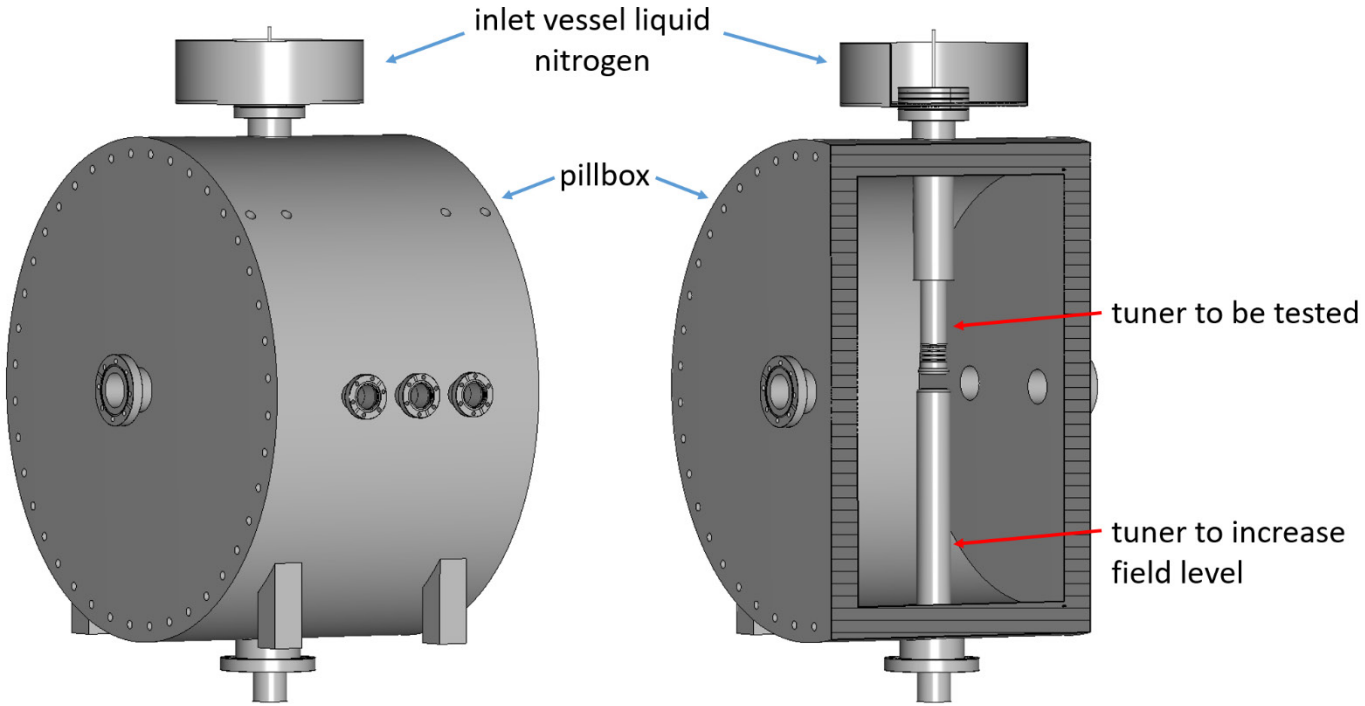
Although the radius of the cavities increases steadily from CH3 to CH11, the length varies

# CH	No. of gaps	r_{Cavity} / mm	l_{Cavity} / cm	l_{Cell} / mm	Bellow Tuner	Static Tuner	β_{in}	β_{out}
CH3	8	221.9	68.12	56.7	2	2	0.076	0.083
CH4	8	226.76	70.44	59.6	2	2	0.083	0.090
CH5	7	233.87	67.44	62.4	2	2	0.090	0.096
CH6	7	243.57	71.97	70.3	2	2	0.096	0.102
CH7	6	250.48	66.92	73.6	2	2	0.102	0.107
CH8	6	251.56	67.3	73.9	2	2	0.107	0.112
CH9	6	257.25	71.00	80.4	2	2	0.112	0.116
CH10	5	266.1	64.56	83.6	2	2	0.116	0.1209
CH11	5	266.1	64.71	83.9	2	2	0.1209	0.1213



Despite the modular cavity design, it was possible to increase the performance, keep the pressure sensitivity sufficiently low and ensure a sufficiently large helium supply.

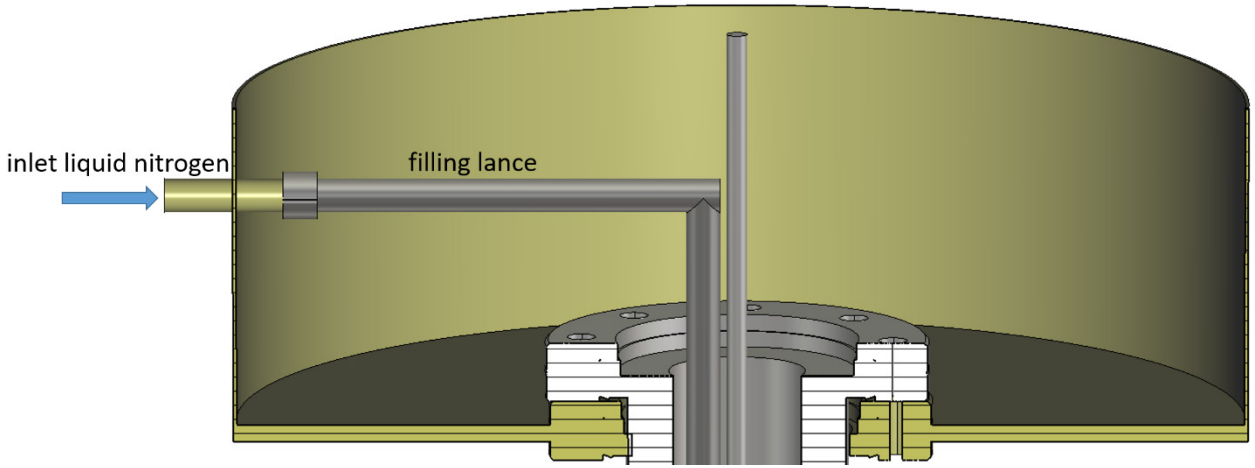
Bellow Tunter Investigation



For this purpose, a pillbox cavity is converted so that the tuners can be cooled safely and the deformation can be measured

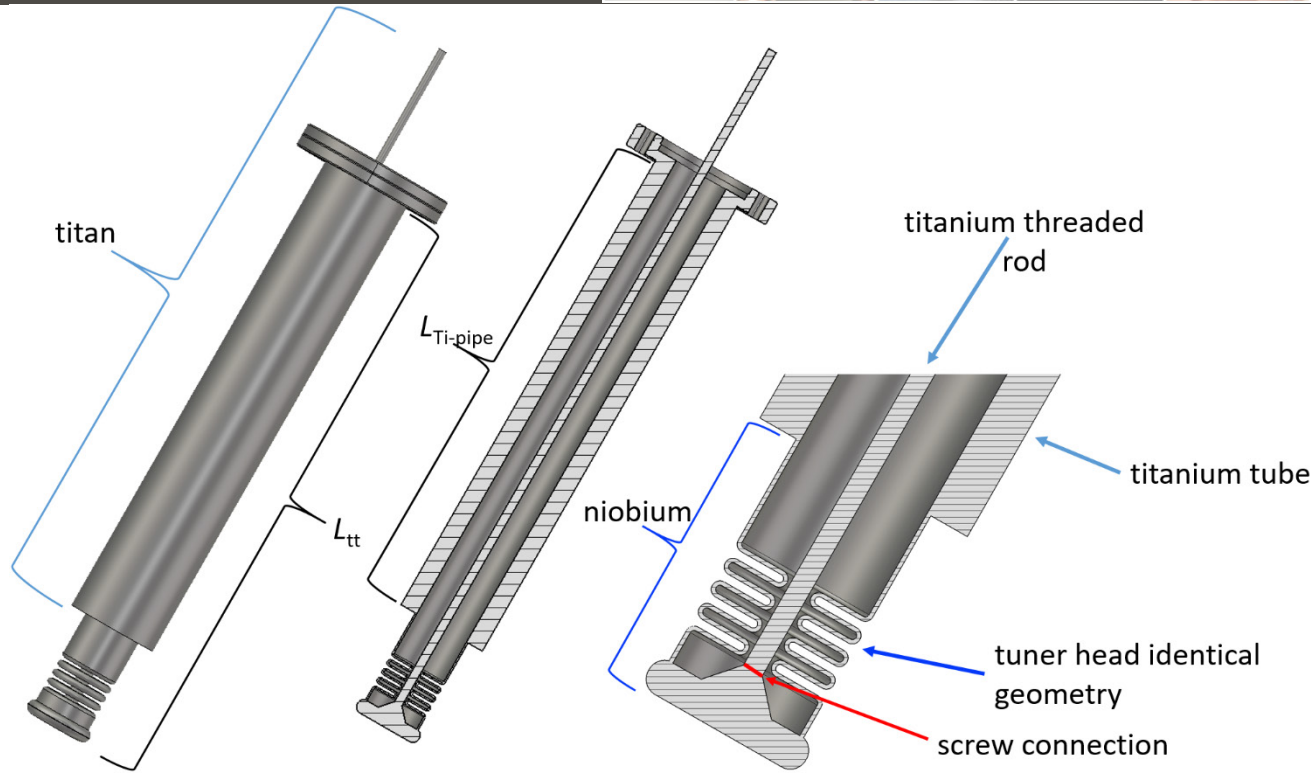
A test stand for the experimental determination of the mechanical properties of the dynamic bellow tuner is to be set up. In the process, the following is to be investigated:

- **The maximum load capacity before a fracture**
- **The service life before material fatigue impairs functionality**



Bellow Tunter Investigation

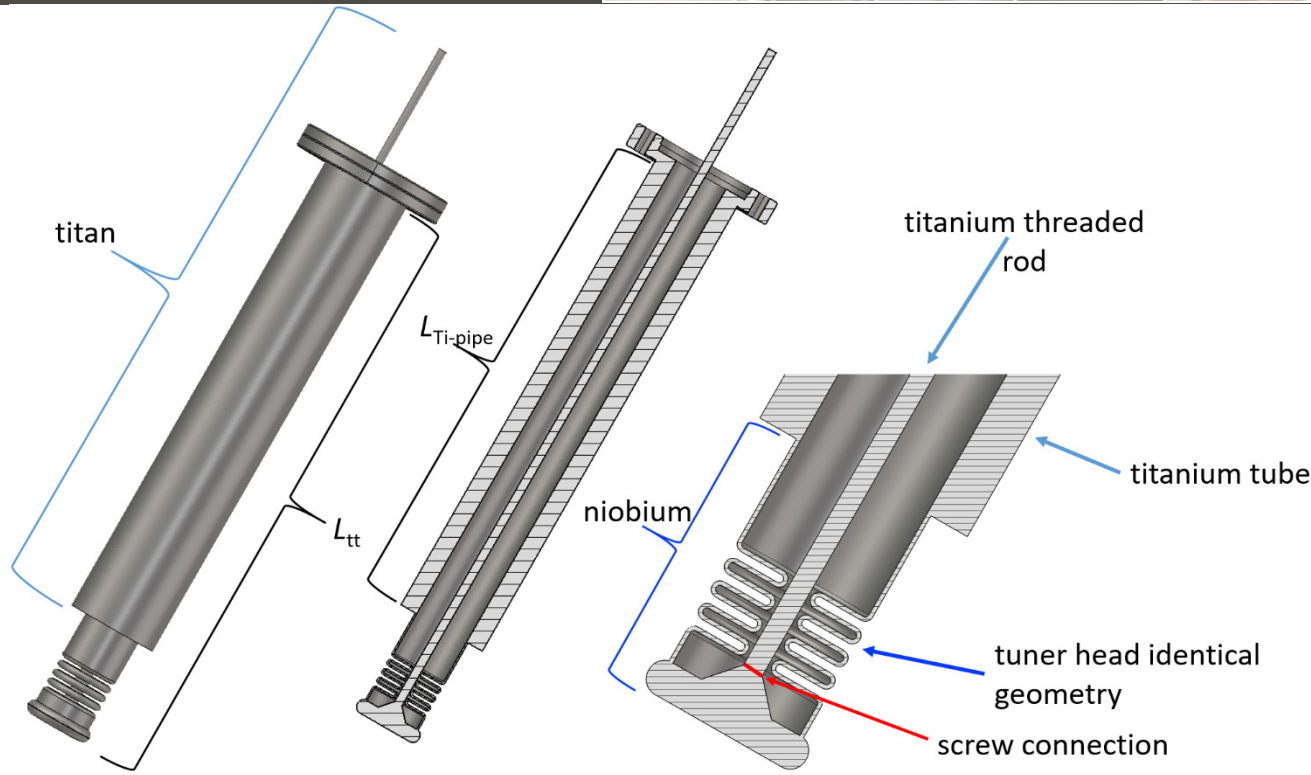
The tuner to be examined must be adapted for the pillbox



Bellow Tunter Investigation

The tuner to be examined must be adapted for the pillbox

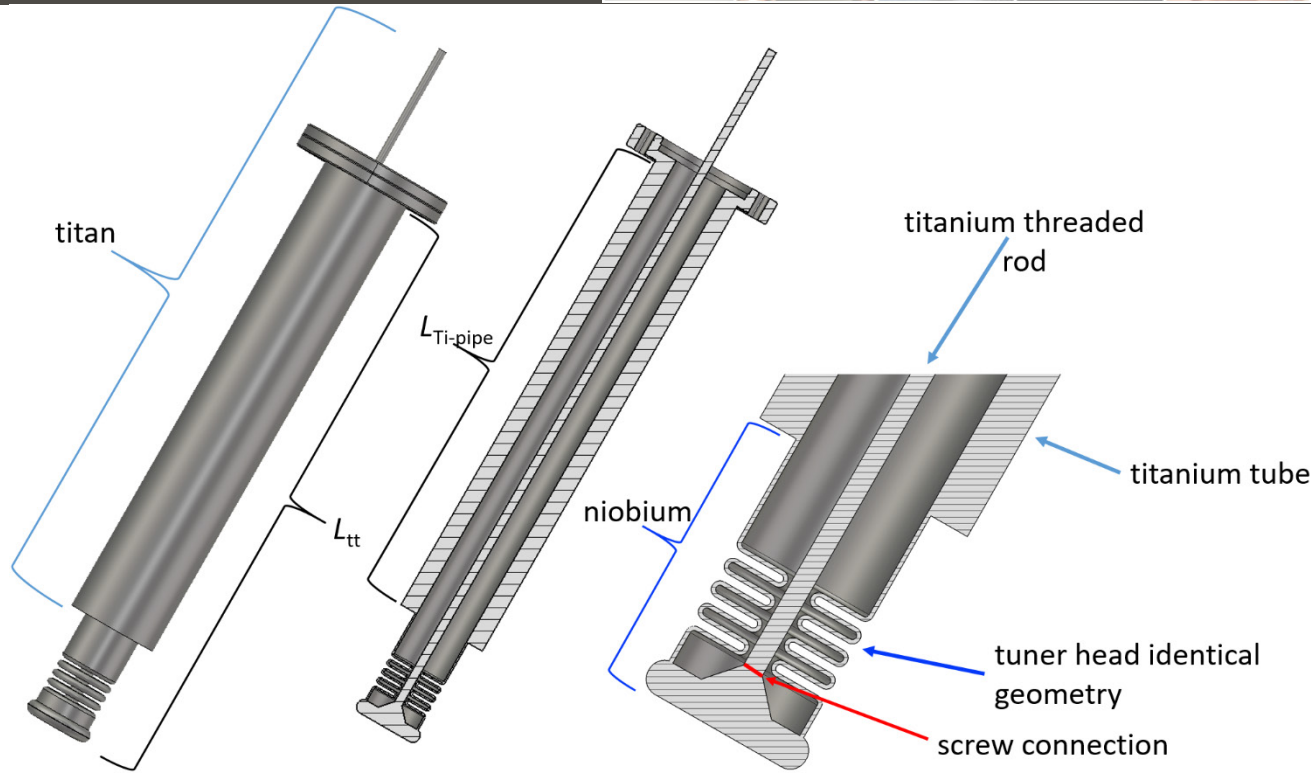
- Extended
- Reinforced



Bellow Tunter Investigation

The tuner to be examined must be adapted for the pillbox

- **Extended**
- **Reinforced**

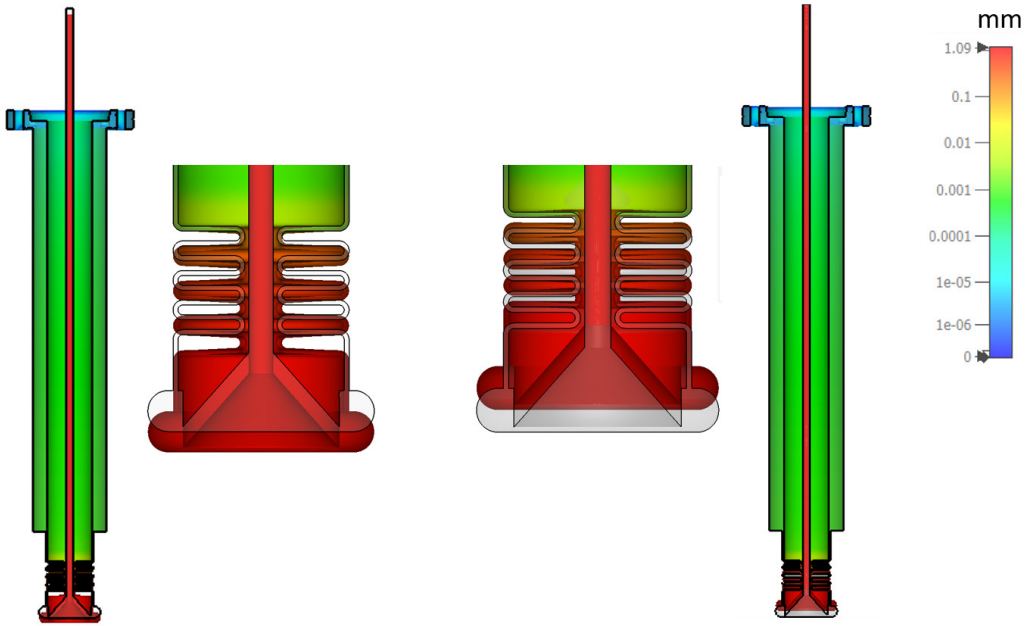


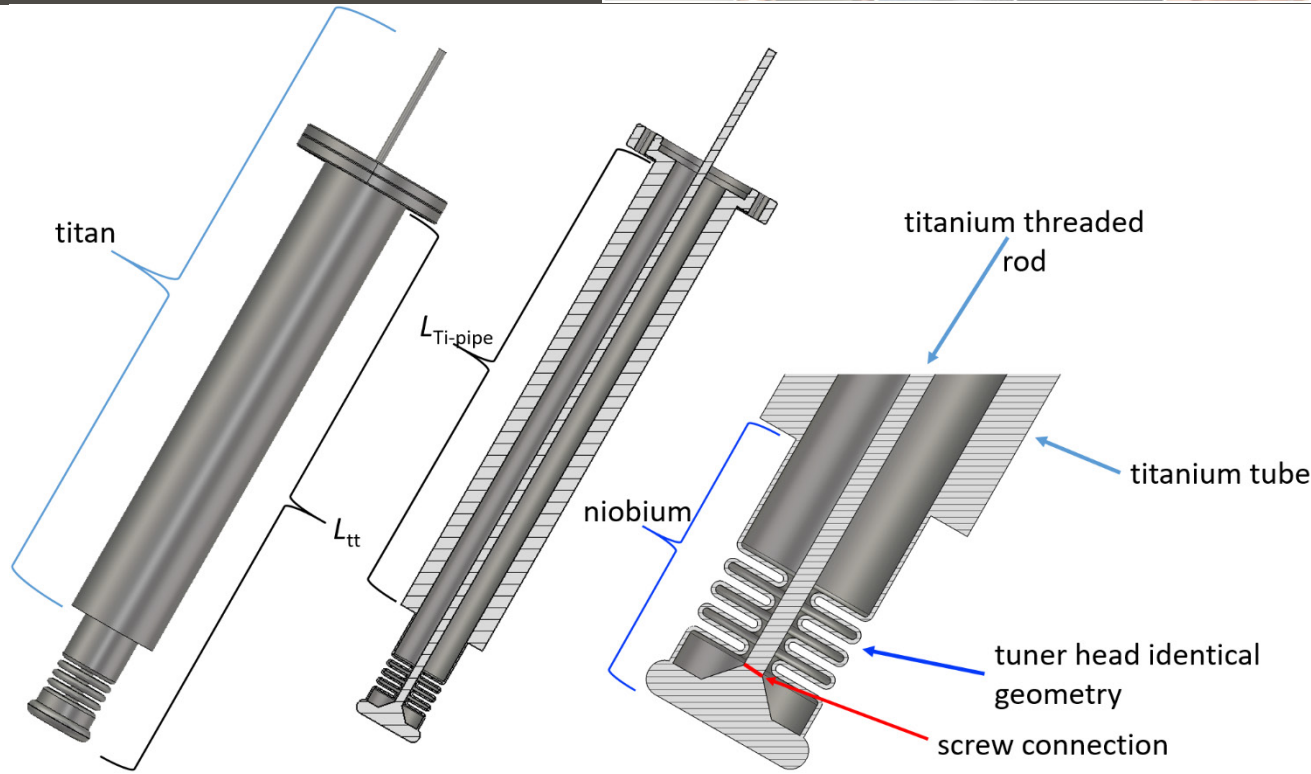
It could be confirmed by simulations that the planned adjustments do not influence the validity of the measurements.

Bellow Tunter Investigation

The tuner to be examined must be adapted for the pillbox

- Extended
- Reinforced





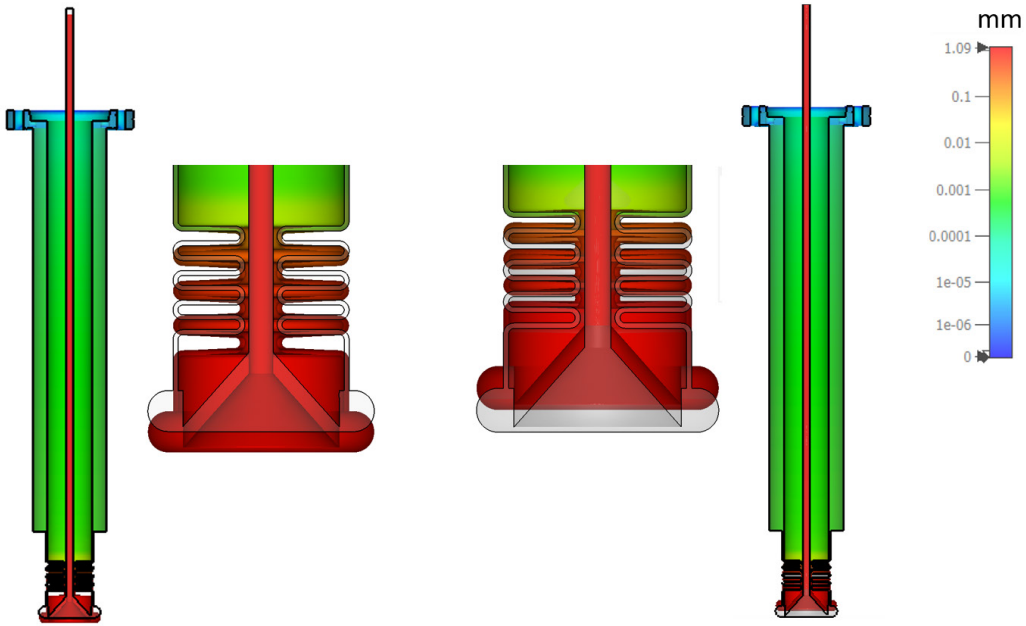
It could be confirmed by simulations that the planned adjustments do not influence the validity of the measurements.

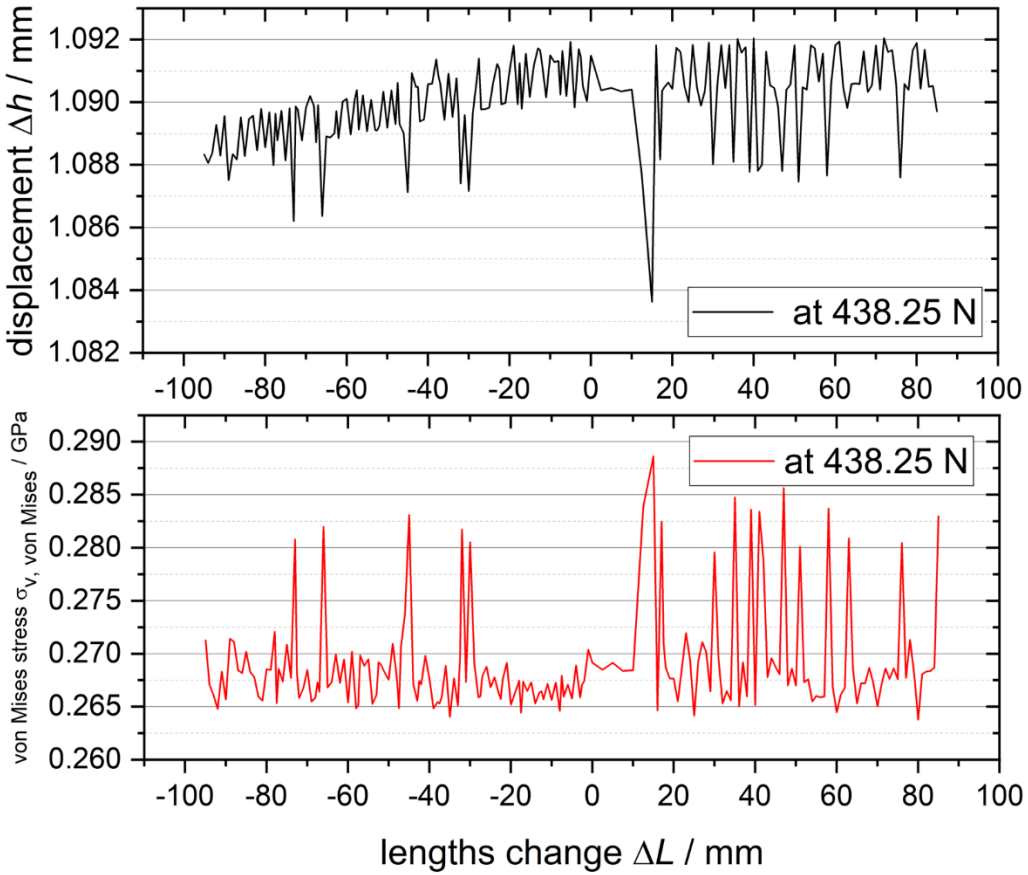
- Expansion exclusively in the bellow

Bellow Tunter Investigation

The tuner to be examined must be adapted for the pillbox

- Extended
- Reinforced





It could be confirmed by simulations that the planned adjustments do not influence the validity of the measurements.

- Expansion exclusively in the bellow
- Mechanical properties almost unaffected

Lets sum this up

- A modular cavity design was developed for the upcoming sc CH-cavities of the HELIAC
- This modular design was examined for its suitability and could be confirmed in a wide variety of simulations
- A concept for a tuner bench was developed, a tuner adapted to the test bench was designed and its suitability was tested by simulations.

- The first three cavities will soon enter the construction phase
- The tuner test bench will be built
- The modular cavity design is fed into an autonomously operating software for the design of cavities (N. Petry LINAC2022)

Thank You!

Special thanks to my colleagues at IAP, GSI and HIM/JGU Mainz for their support and valuable contributions to this research!

M. Busch
H. Podlech
M. Schwarz
K. Aulenbacher
W. Barth
M. Basten
F. Dziuba
V. Gettmann
M. Heilmann
T. Kuerzeder
S. Lauber
J. List
M. Miski-Oglu
A. Rubin
A. Schnase
S. Yaramyshev

Financial Support

GEFÖRDERT VOM Bundesministerium für Bildung und Forschung
Horizon 2020 European Union Funding for Research & Innovation
HIC for FAIR Helmholtz International Center
HELIAC GSI DARMSTADT
HGS-HIRe for FAIR Helmholtz Graduate School for Hadron and Ion Research
HFHF Helmholtz Forschungsakademie Hessen für FAIR
WILHELM UND ELSE HERAEUS-STIFTUNG