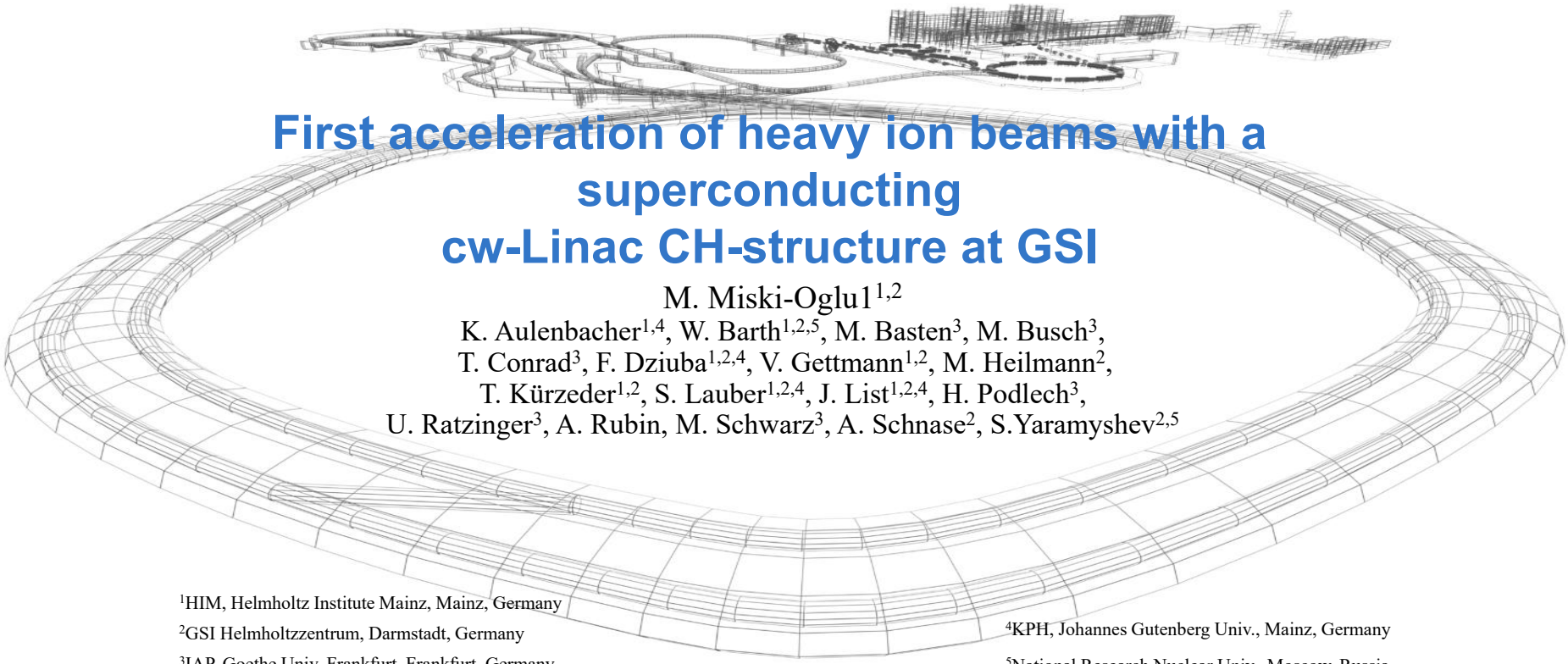


First acceleration of heavy ion beams with a superconducting cw-Linac CH-structure at GSI

M. Miski-Oglu1[1,2]

K. Aulenbacher[1,4], W. Barth[1,2,5], M. Basten[3], M. Busch[3], T. Conrad[3], F. Dziuba[1,2,4], V. Gettmann[1,2], M. Heilmann[2], T. Kürzeder[1,2], S. Lauber[1,2,4], J. List[1,2,4], H. Podlech[3], U. Ratzinger[3], A. Rubin, M. Schwarz[3], A. Schnase[2], S.Yaramyshev[2,5]

[1]HIM, Helmholtz Institute Mainz, Mainz, Germany

[2]GSI Helmholtzzentrum, Darmstadt, Germany

[3]IAP, Goethe Univ. Frankfurt, Frankfurt, Germany

[4]KPH, Johannes Gutenberg Univ., Mainz, Germany

[5]National Research Nuclear Univ., Moscow, Russia

Requirements for FAIR and the SHE-Program

FAIR requirements:

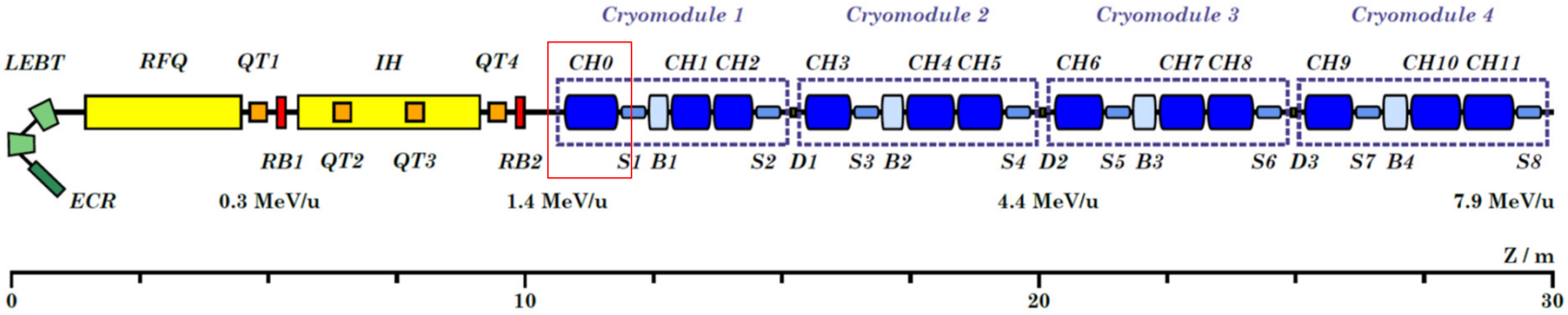
- high beam currents
- low repetition rate (max. 3 Hz)
- low duty factor (0.1 %, pulse length for SIS18 only 100 µs)

“Super Heavy Element” requirements:

- relatively low beam currents
- high repetition rate (50 Hz)
- high duty factor (100 %, pulse length up to 20 ms)

- **Material Science at GSI-experimental hall**
- Heavy Ions (m > 200)
- High Beam Energy (up to 10 MeV/u)
- Continuous Beam Energy Variation (1.5 – 10 MeV/u)

Recent layout of the future superconducting cw HELIAC*



Design parameters sc cw-LINAC		
A/q		≤ 6
Frequency	MHz	216.816
Beam current	mA	≤ 1
Injection energy	MeV/u	1.4
Output energy	MeV/u	3.5–7.9
Length	m	20
CH cavities	#	12
Rebuncher	#	4
Solenoids	#	8

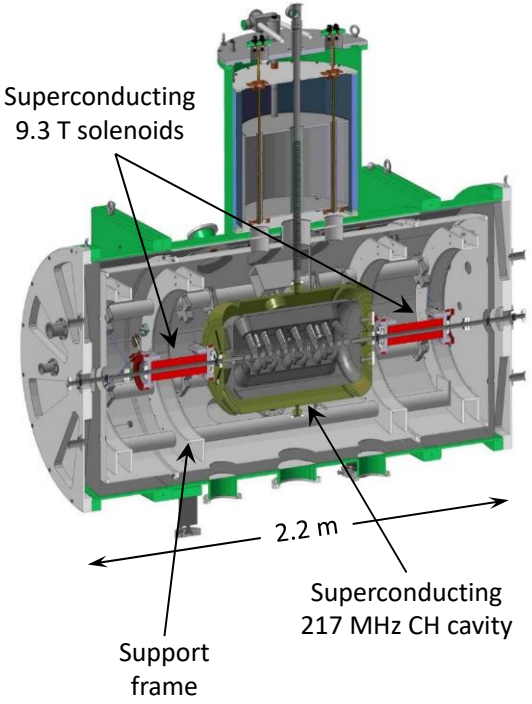
Layout properties

- Multigap CH cavities
- Cavities with short lengths (<1 m) and small transverse dimensions (<0.5 m)
- Modular construction with 4 cryomodules
- Each containing 3 CH cavities, 1 buncher, 2 solenoids
- E_a = 7.1 MV/m enables compact linac design
- First step → Demonstrator project

* HElmholz LInear ACcelerator

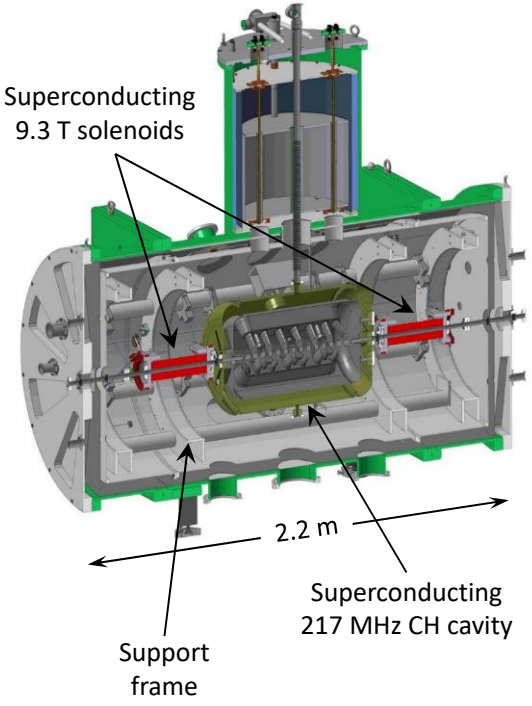
Experimental setup of the demonstrator at GSI

Layout of demonstrator cryomodule

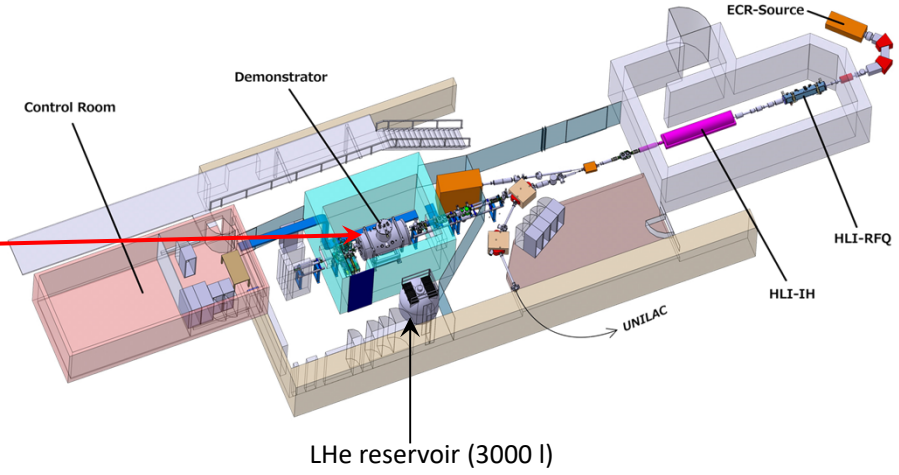


Experimental setup of the demonstrator at GSI

Layout of demonstrator cryomodule

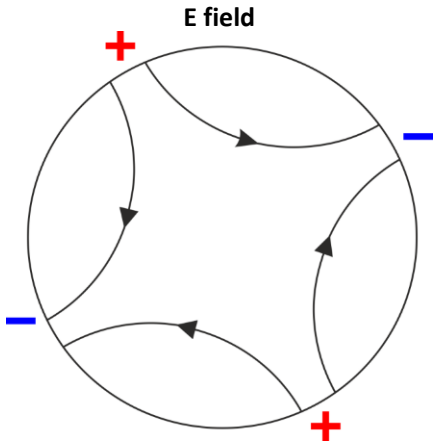


Demonstrator at GSI-High Charge State Injector (HLI)



Field Profiles of CH-Cavity

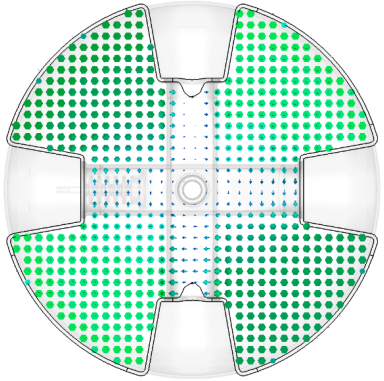
H_{211} mode of ”pillbox“ cavity



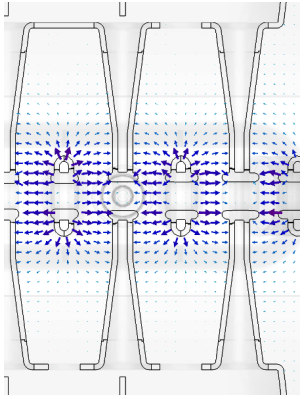
- Drift tubes are alternating connected to “+” and “-” potential
- **C**ross-bar-**H**-mode cavity → CH cavity

Field Profiles of CH-Cavity

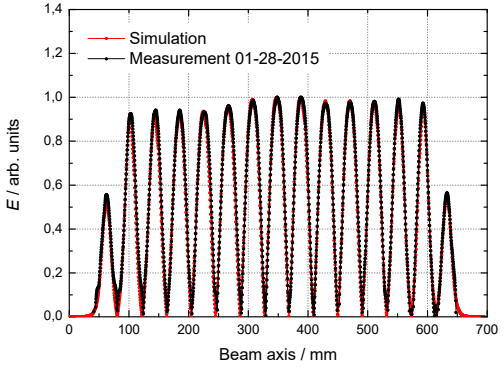
H field



E field



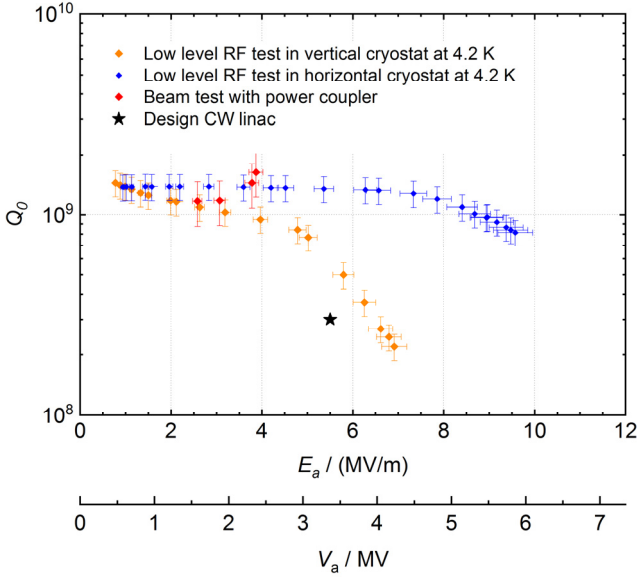
E field along beam axis

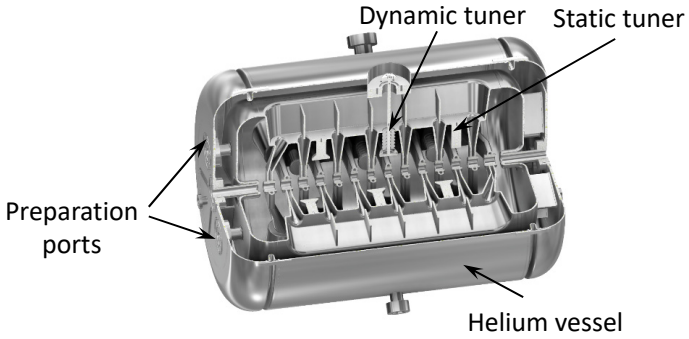


- Drift tubes are alternating connected to "+" and "-" potential
- **C**ross-bar-**H**-mode cavity → CH cavity
- Multigap drift tube cavity for the acceleration of protons and ions in the low and medium energy range ($0.05<\beta<0.6$)
- Accelerating voltage up to 6 MV
- Equidistant gaps provide for flexible beam dynamics

RF Tests of the Cavity at IAP and GSI

(more information on **poster** WEPRB014, WEPRB012)

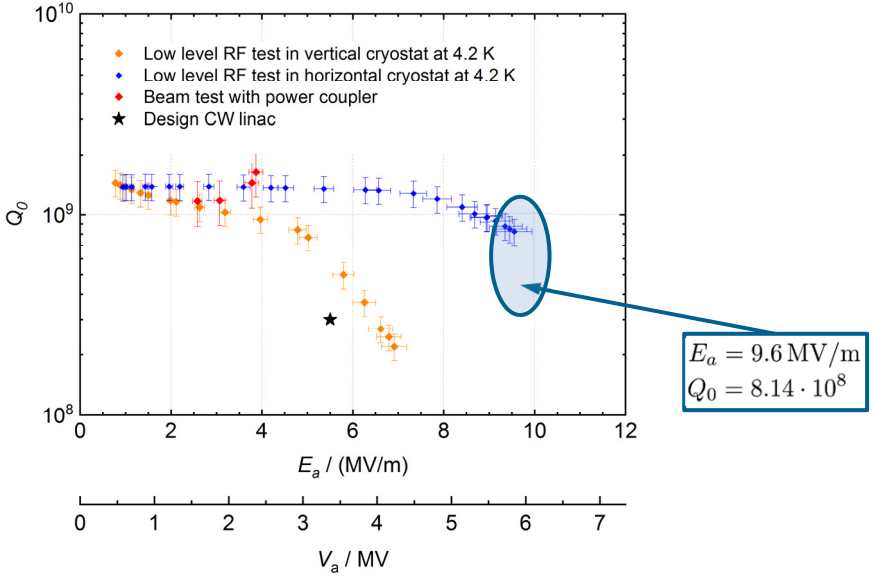


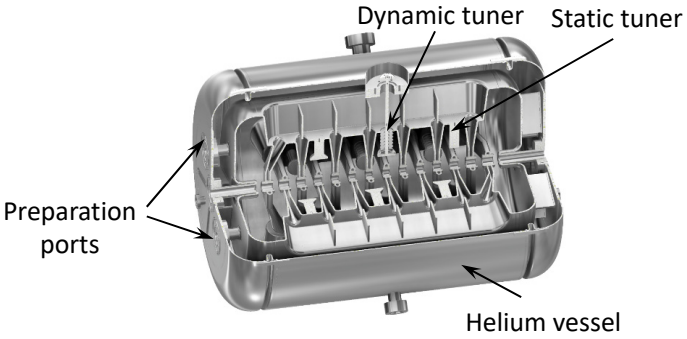


- Improved performance due to an additional HPR
- Low field emission activity

RF Tests of the Cavity at IAP and GSI

(more information on **poster** WEPRB014, WEPRB012)

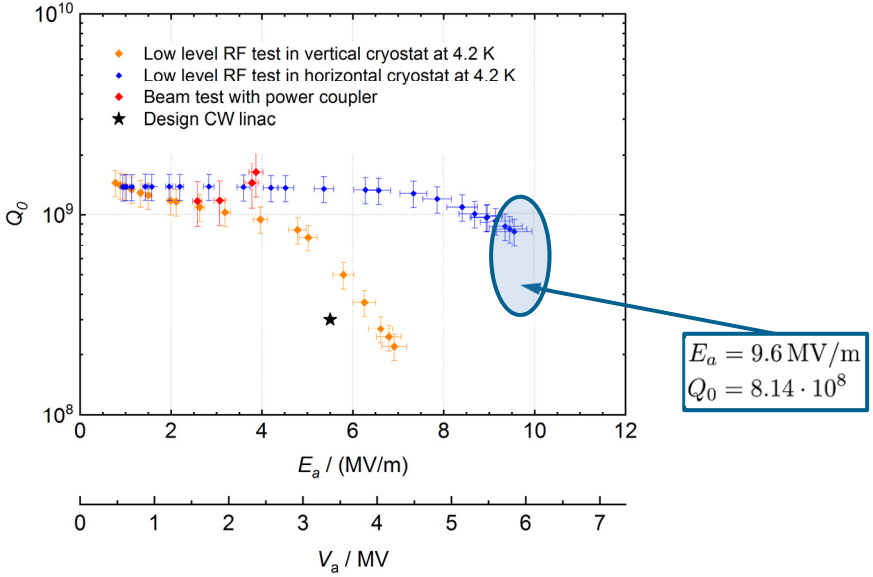


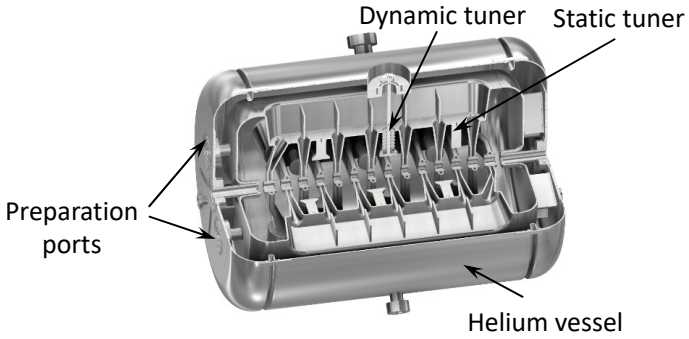


- Improved performance due to an additional HPR
- Low field emission activity
- High accelerating gradient
- Acceleration of ions over design up to A/q = 12

RF Tests of the Cavity at IAP and GSI

(more information on **poster** WEPRB014, WEPRB012)

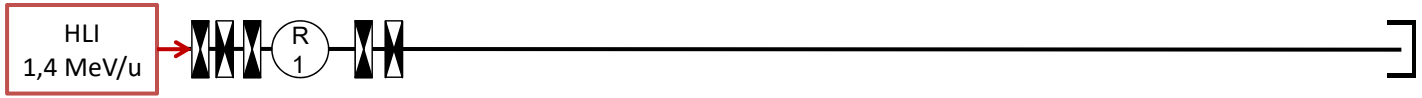




		Vertical test w/o He vessel	Horizontal test with He vessel
Q_0^{low}		$1.44 \cdot 10^9$	$1.37 \cdot 10^9$
R_S	nΩ	36	38
R_{BCS}	nΩ	15	15
R_{mag}	nΩ	9	12
R_0	nΩ	12	11
E_a	MV/m	6.9	9.6
Q_0		$2.19 \cdot 10^8$	$8.14 \cdot 10^8$
V_a	MV	4.2	5.9
E_p	MV/m	43	60
B_p	mT	39	55

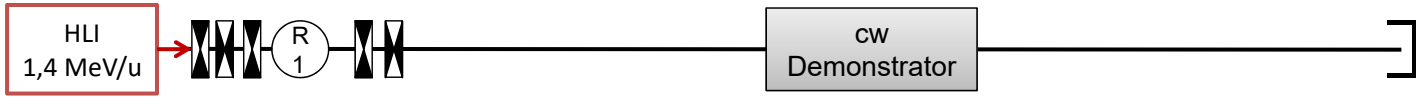
- Improved performance due to an additional HPR
- Low field emission activity
- High accelerating gradient
- Acceleration of ions over design up to A/q = 12
- R&D for further improvement of rf-performance

Matching Line for the Beam Test



- HLI provides Ar^{11+}, Ar^{9+}, Ar^{6+}, He^{2+} @ 1,4 MeV/u

Matching Line for the Beam Test



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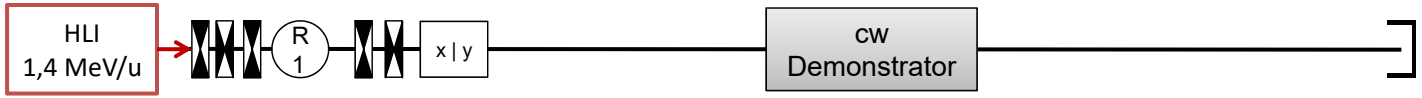
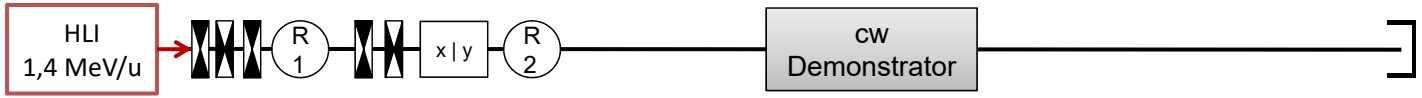


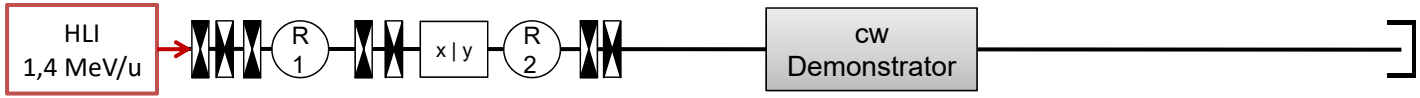
- HLI provides Ar^{11+}, Ar^{9+}, Ar^{6+}, He^{2+} @ 1,4 MeV/u
- Steering magnets

Matching Line for the Beam Test



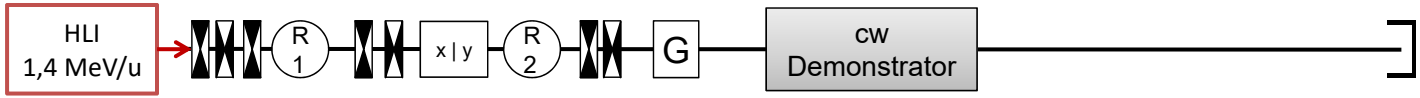
- HLI provides Ar^{11+}, Ar^{9+}, Ar^{6+}, He^{2+} @ 1,4 MeV/u
- Steering magnets
- Additional Re-Buncher

Matching Line for the Beam Test



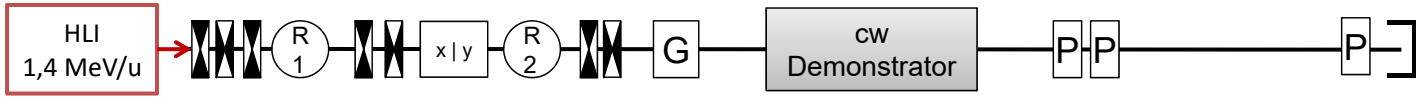
- HLI provides Ar^{11+}, Ar^{9+}, Ar^{6+}, He^{2+} @ 1,4 MeV/u
- Steering magnets
- Additional Re-Buncher
- Quadrupole doublet

Matching Line for the Beam Test



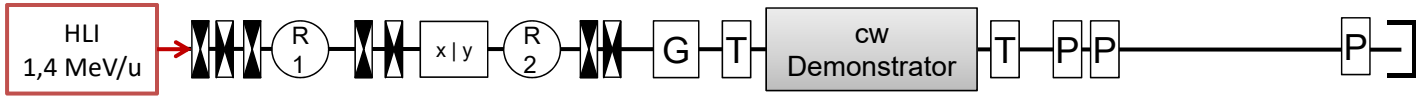
- HLI provides Ar^{11+}, Ar^{9+}, Ar^{6+}, He^{2+} @ 1,4 MeV/u
- Steering magnets
- Additional Re-Buncher
- Quadrupole doublet
- Profile Grid

Matching Line for the Beam Test



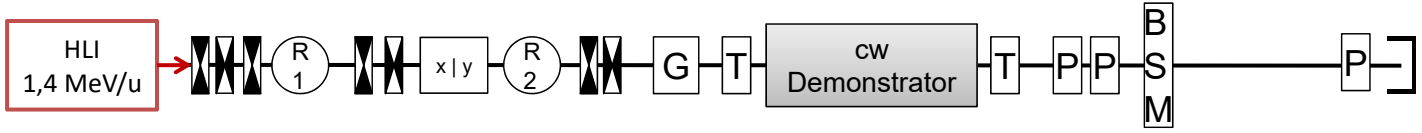
- HLI provides Ar^{11+}, Ar^{9+}, Ar^{6+}, He^{2+} @ 1,4 MeV/u
- Steering magnets
- Additional Re-Buncher
- Quadrupole doublet
- Profile Grid
- Phase probes for TOF measurement of beam energy (also as BPM)

Matching Line for the Beam Test



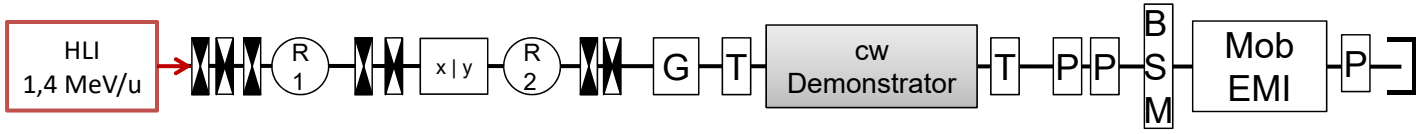
- HLI provides Ar^{11+}, Ar^{9+}, Ar^{6+}, He^{2+} @ 1,4 MeV/u
- Steering magnets
- Additional Re-Buncher
- Quadrupole doublet
- Profile Grid
- Phase probes for TOF measurement of beam energy (also as BPM)
- Beam current transformers for transmission measurement

Matching Line for the Beam Test



- HLI provides Ar^{11+}, Ar^{9+}, Ar^{6+}, He^{2+} @ 1,4 MeV/u
- Steering magnets
- Additional Re-Buncher
- Quadrupole doublet
- Profile Grid
- Phase probes for TOF measurement of beam energy (also as BPM)
- Beam current transformers for transmission measurement
- Bunch shape monitor (Feschenko monitor)

Matching Line for the Beam Test



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- Steering magnets
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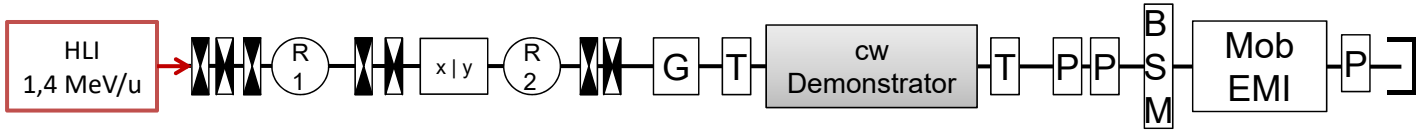
- Quadrupole doublet
- Profile Grid
- Phase probes for TOF measurement of beam energy (also as BPM)
- Beam current transformers for transmission measurement
- Bunch shape monitor (Feschenko monitor)
- Slit-Grid emittance measurement device

Matching Line for the Beam Test



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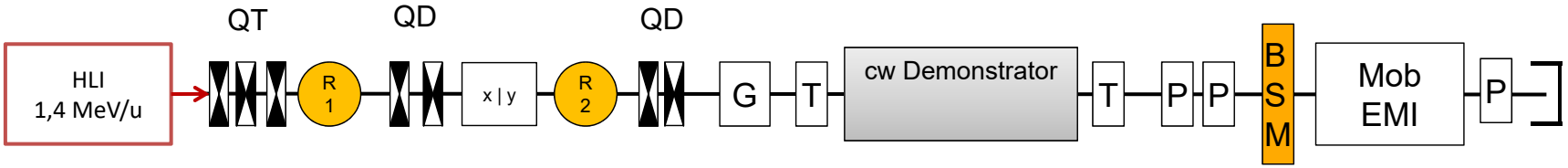
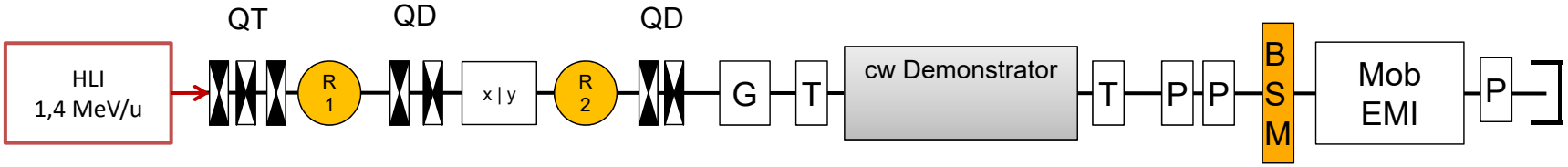
- Steering magnets
- Additional Re-Buncher
- Quadrupole doublet
- Profile Grid
- Phase probes for TOF measurement of beam energy (also as BPM)
- Beam current transformers for transmission measurement
- Bunch shape monitor (Feschenko monitor)
- Slit-Grid emittance measurement device
- 6d characterization of the beam
- Test Bench of components and procedures for future HELIAC

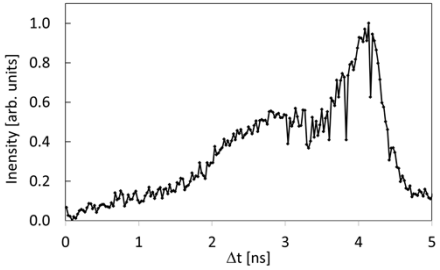
Longitudinal Matching



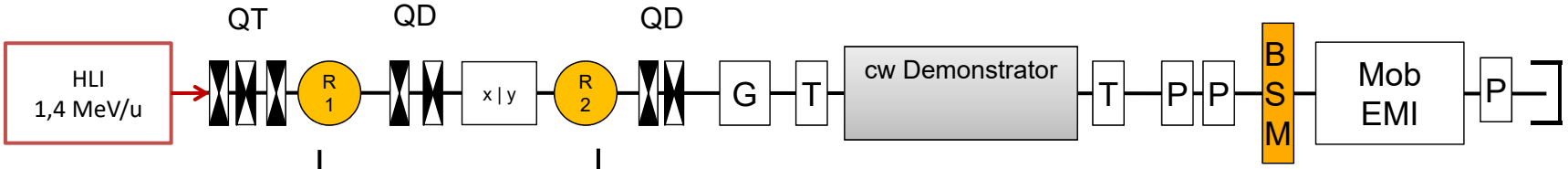
Longitudinal Matching

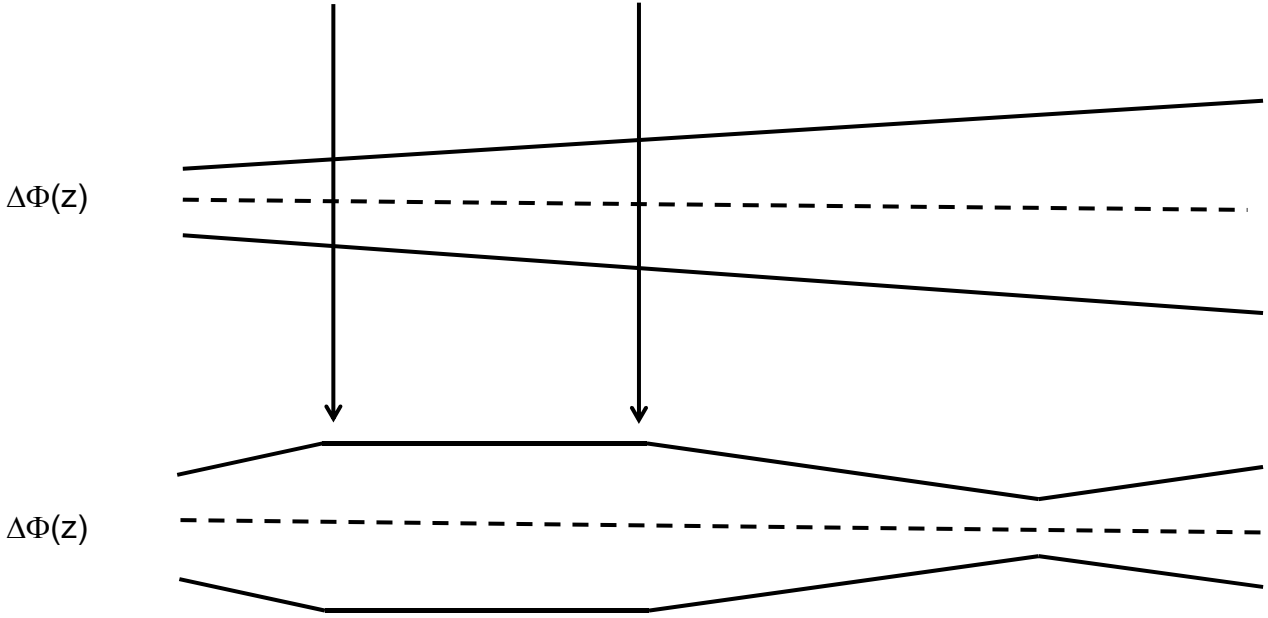


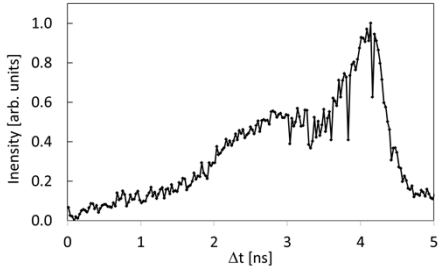
$\Delta\Phi(z)$

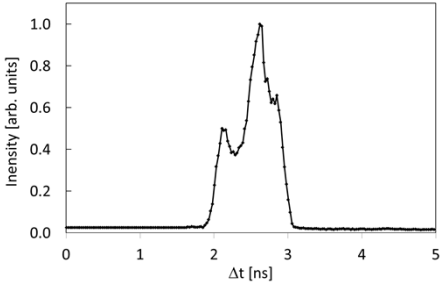


Longitudinal Matching



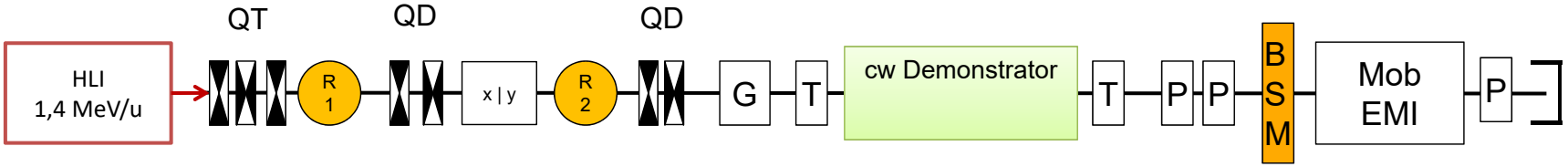


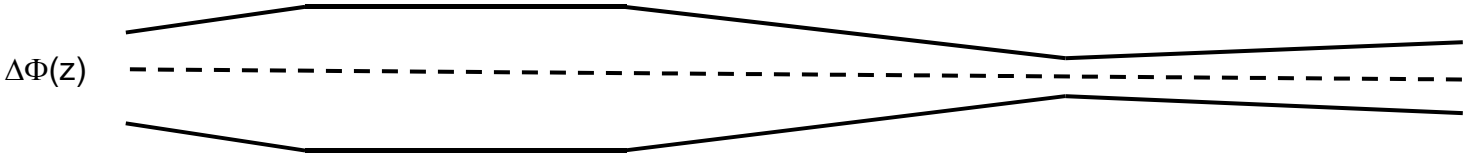




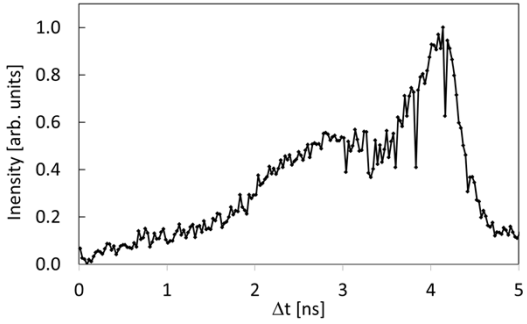
Bunch Length of Accelerated Beam

(more information on **poster MOPTS024**)

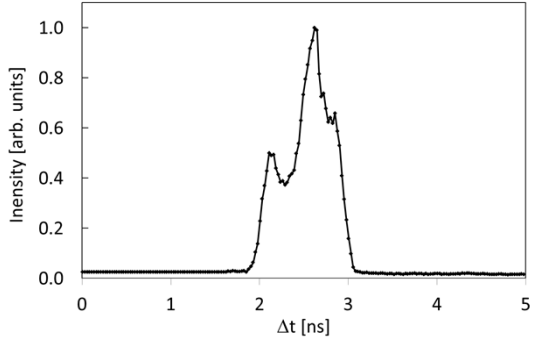




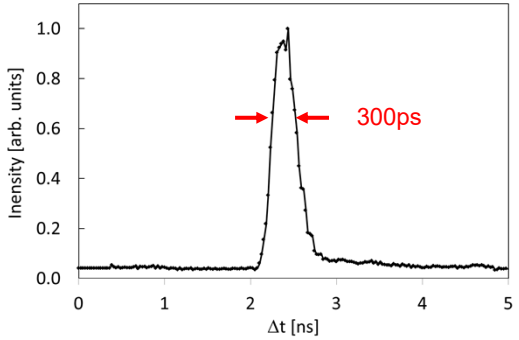
cavities off



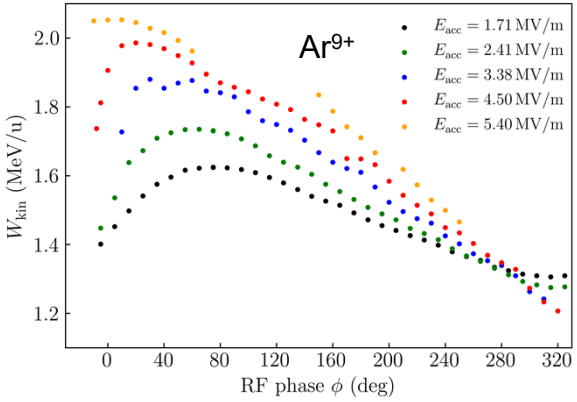
R1 + R2



R1 + R2 + CH0

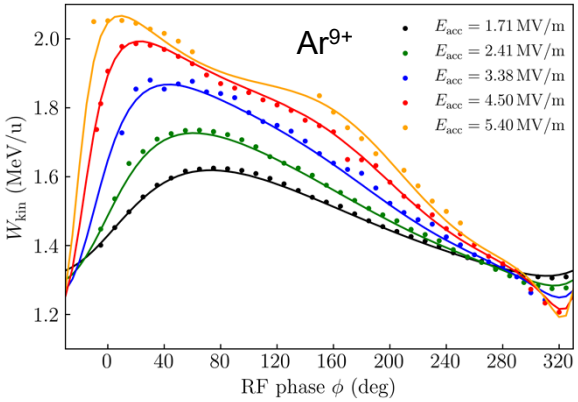


Beam Energy vs. RF-Phase and -Amplitude



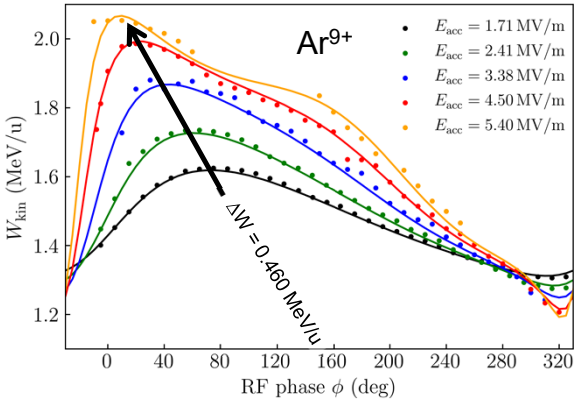
- Beam energy measured by TOF
- Independent rf-calibration of pick-up
- Accelerating field calculated by CST
- Amplitude of the field scaled according rf-calibration

Beam Energy vs. RF-Phase and -Amplitude



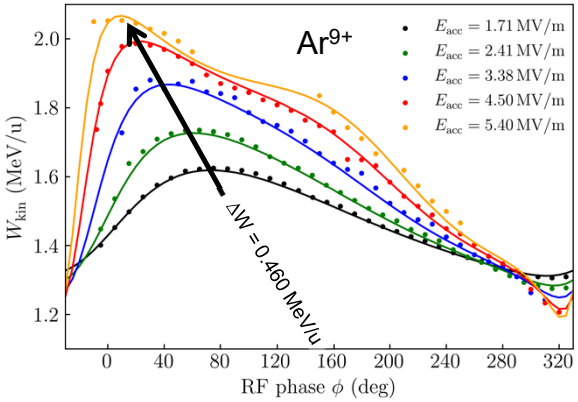
- Beam energy measured by TOF
- Independent rf-calibration of pick-up
- Accelerating field calculated by CST
- Amplitude of the field scaled according rf-calibration
- Energy gain calculated by tracking of particles in E-field
- Agreement between measurement and calculation

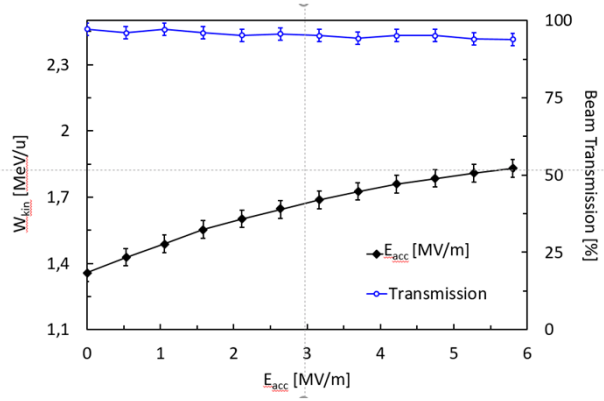
Beam Energy vs. RF-Phase and -Amplitude



- Beam energy measured by TOF
- Independent rf-calibration of pick-up
- Accelerating field calculated by CST
- Amplitude of the field scaled according rf-calibration
- Energy gain calculated by tracking of particles in E-field
- Agreement between measurement and calculation
- Smooth energy variation

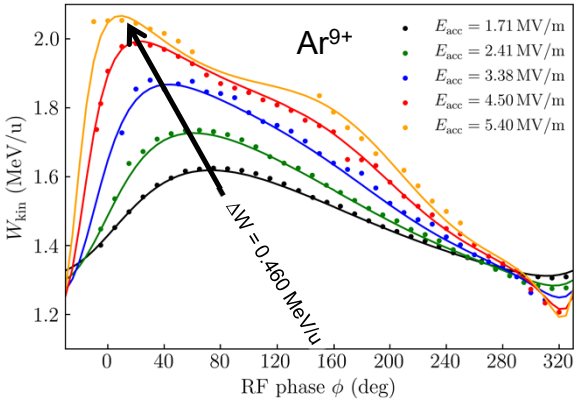
Beam Energy vs. RF-Phase and -Amplitude

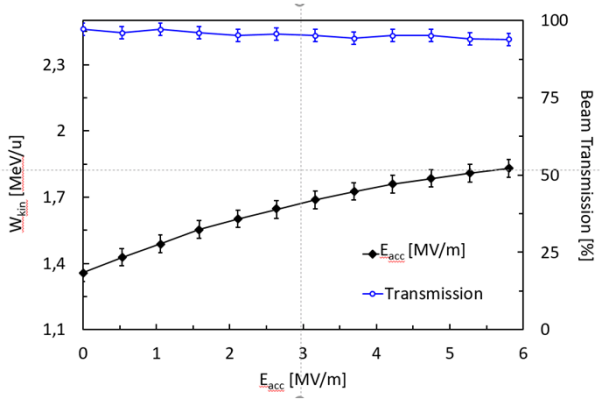




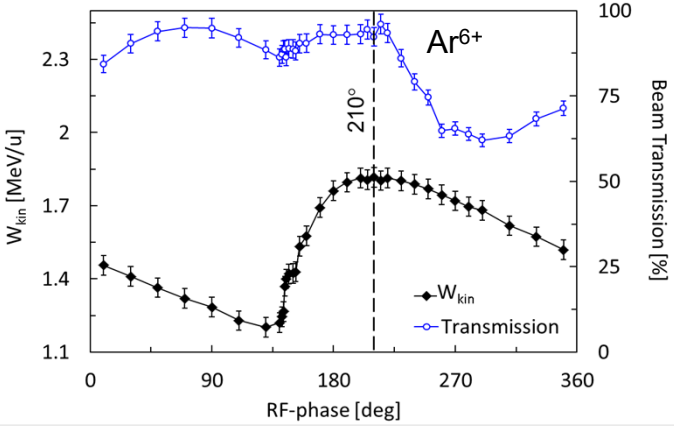
- Beam energy measured by TOF
- Independent rf-calibration of pick-up
- Accelerating field calculated by CST
- Amplitude of the field scaled according rf-calibration
- Energy gain calculated by tracking of particles in E-field
- Agreement between measurement and calculation
- Smooth energy variation
- High beam transmission

Beam Energy vs. RF-Phase and -Amplitude

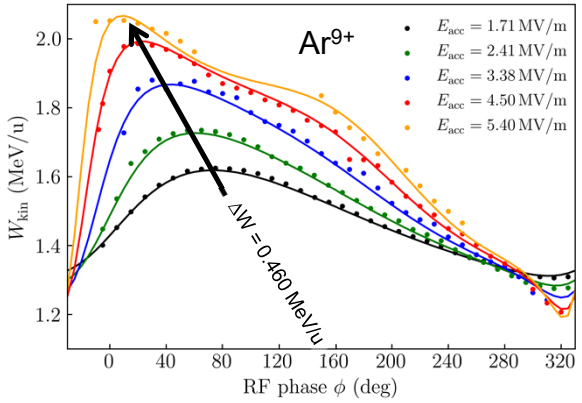


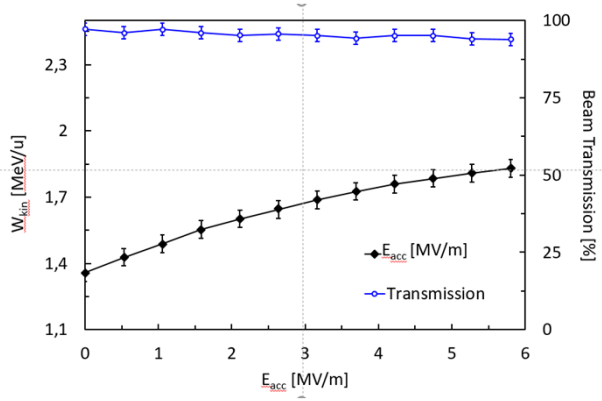


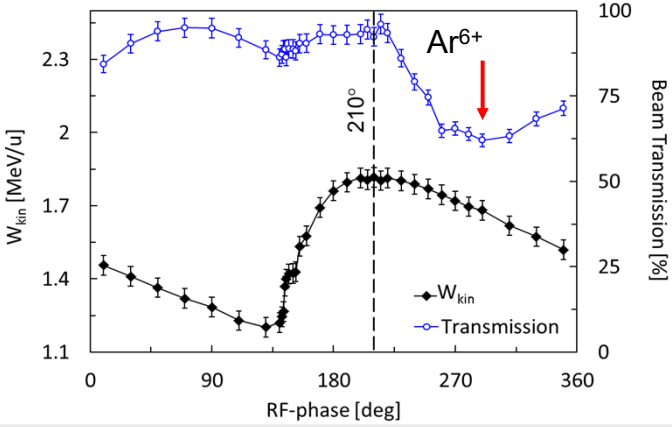
- Beam energy measured by TOF
- Independent rf-calibration of pick-up
- Accelerating field calculated by CST
- Amplitude of the field scaled according rf-calibration
- Energy gain calculated by tracking of particles in E-field
- Agreement between measurement and calculation
- Smooth energy variation
- High beam transmission



Beam Energy vs. RF-Phase and -Amplitude







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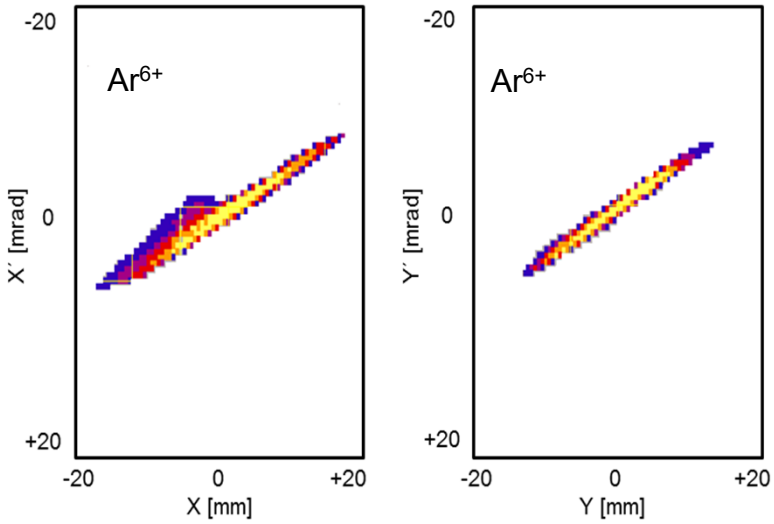
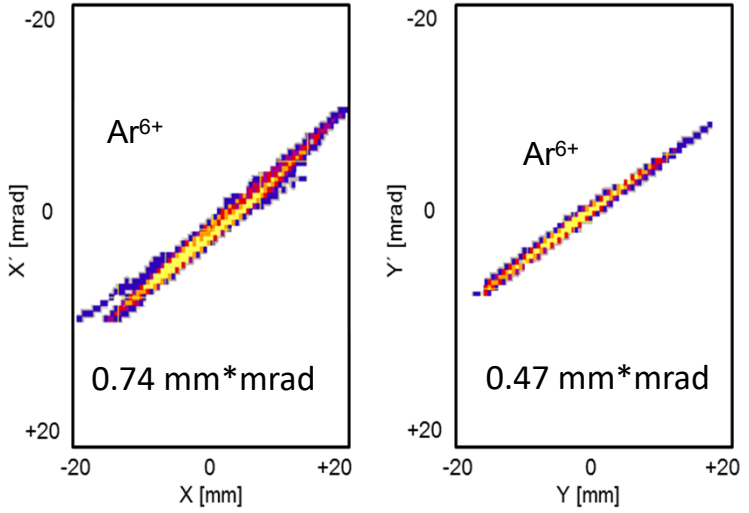
- Transmission break-in du to strong rf-defocusing

Transversal emittance

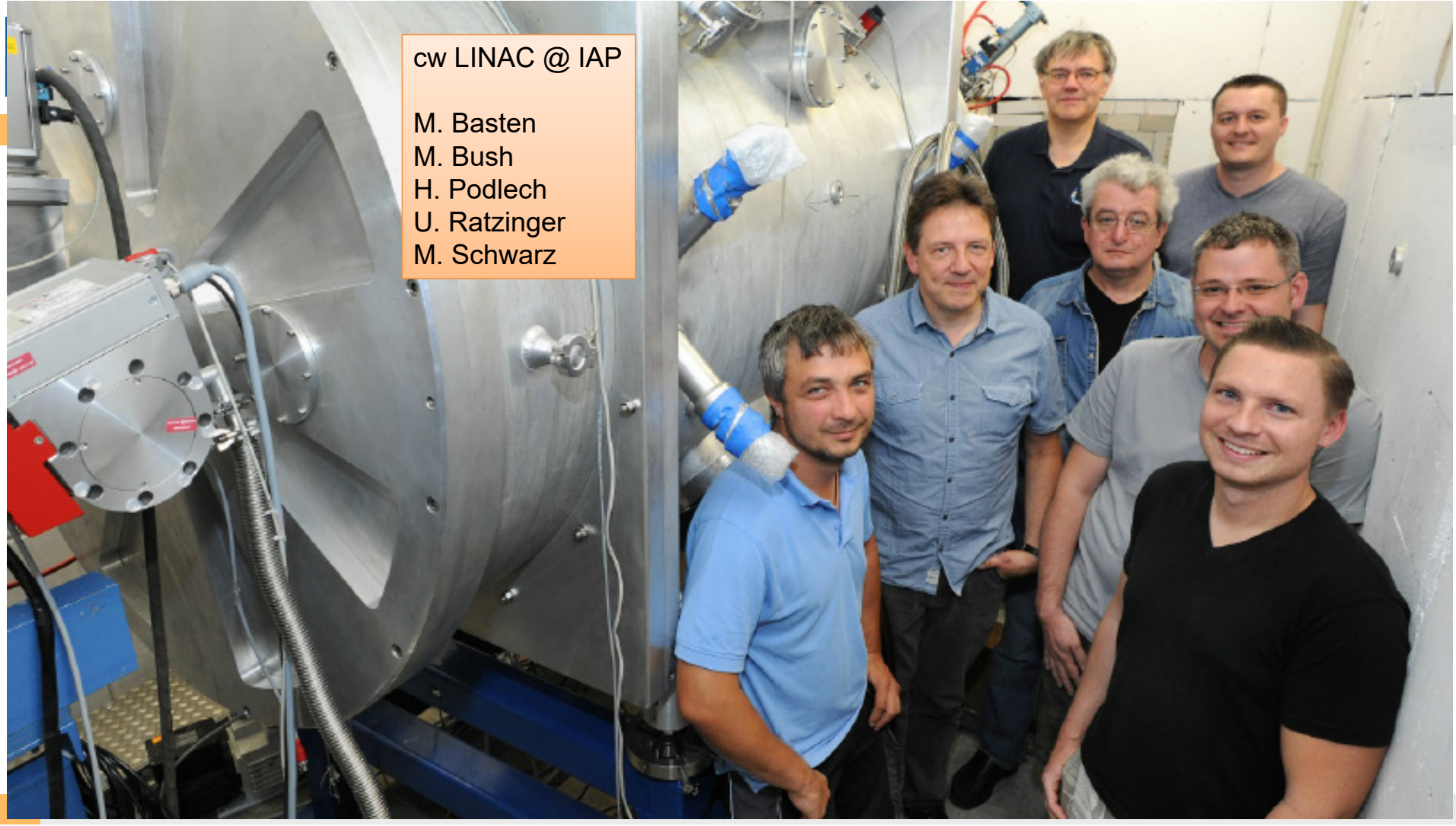
Injection (1.4MeV/u)



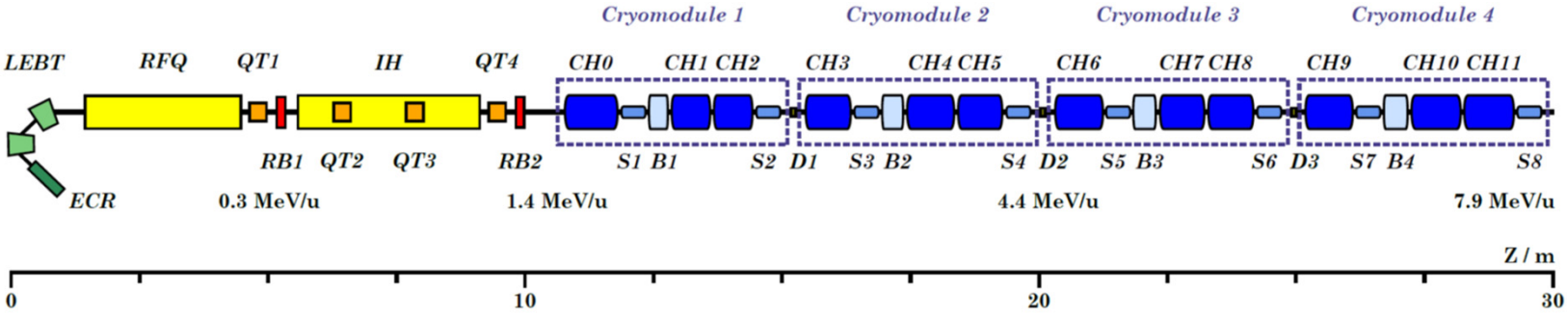
Acceleration (1.86 MeV/u)



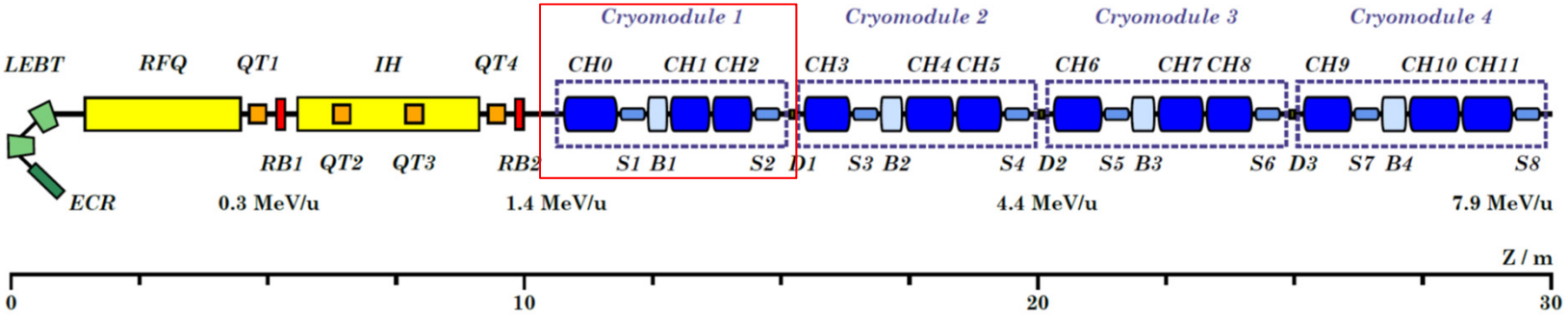
- Transversal emittance have been measured by slit-grid device exemplarily for Ar6+
- Reference emittance measured with cavity off
- Beam transmission above 90%
- Normalized emittance growth is about 15%


cw LINAC @ IAP
M. Basten
M. Bush
H. Podlech
U. Ratzinger
M. Schwarz

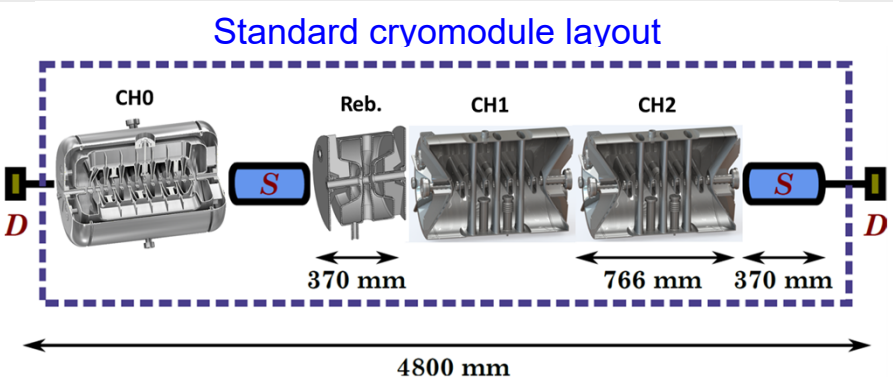
Next Phase: Advanced Demonstartor



Next Phase: Advanced Demonstartor



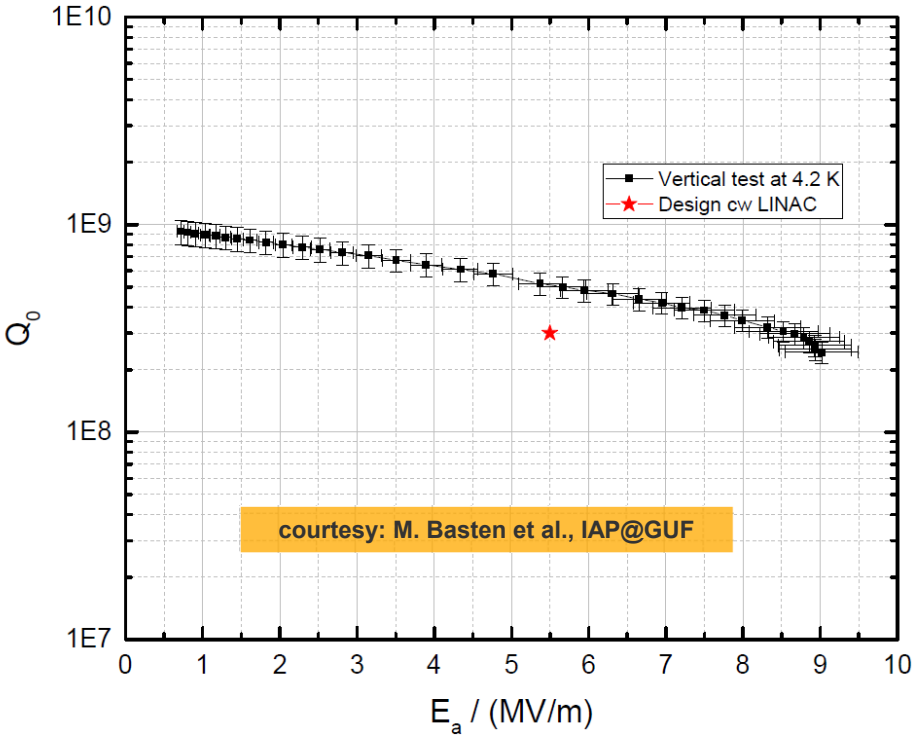
Next Phase: Advanced Demonstartor



- New cryo module layout containing demonstrator CH cavity, 2 short CH cavities, 1 re-buncher and 2 solenoids
- Simplified cavity design (easier manufacturing & surface processing)
- CH1 & CH2 are already in testing (delivery at 4th quarter of 2019)
- Re-buncher cavity is designed and Nb material is ordered
- Cryostat is ordered, expected delivery Q2 2020
- Solenoids are tendered

- R&D on single aux. components is in advanced stadium
  - Rf-power couplers
  - Tuner mechanics
  - cold BPM
- New radiation protection shelter
- Connection to cryoplant

First RF-measurement for CH1 in a vertical cryostat (more information on poster WEPRB012)



- Rf-test @ IAP
- Accelerating gradient is twice of design value
- Low field emission
- Assembly of He-vessel
- Expected delivery of CH1/CH2 in Q4/2019

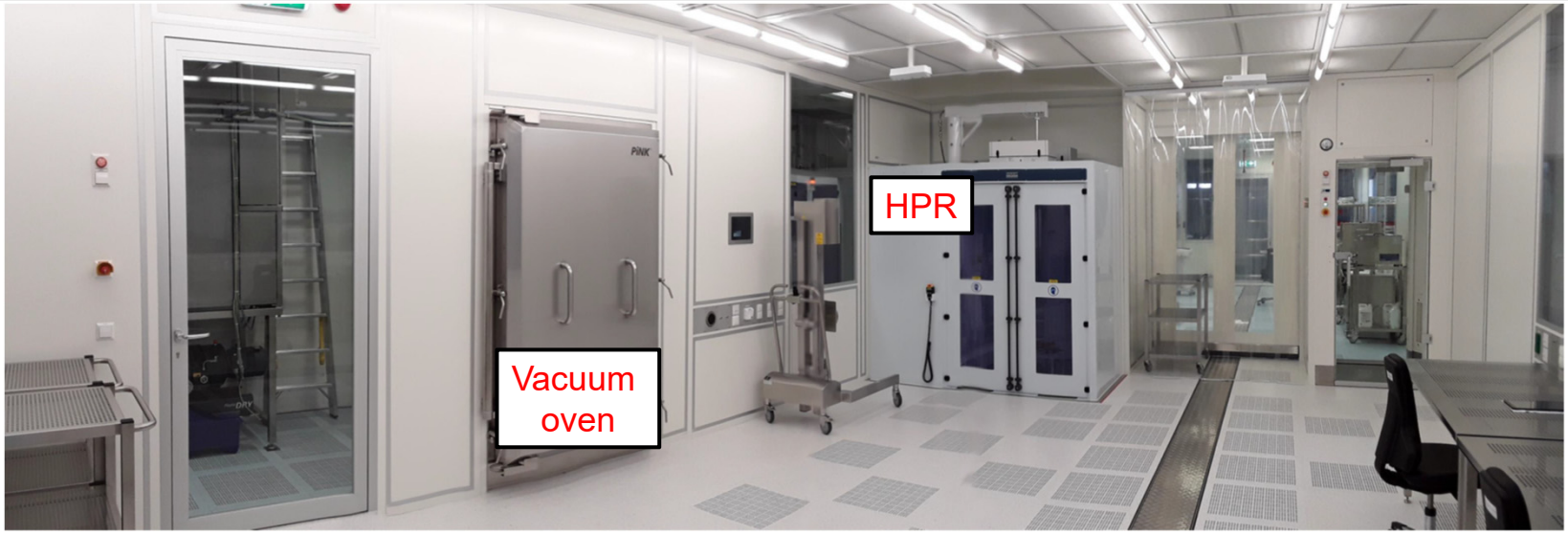
Infrastructure @ HIM
(more information on poster WEPRB015)

- Clean room complex
  - ISO6 for cleaning and preparation
  - ISO4 for final preparation and assembly

Infrastructure @ HIM
(more information on poster WEPRB015)

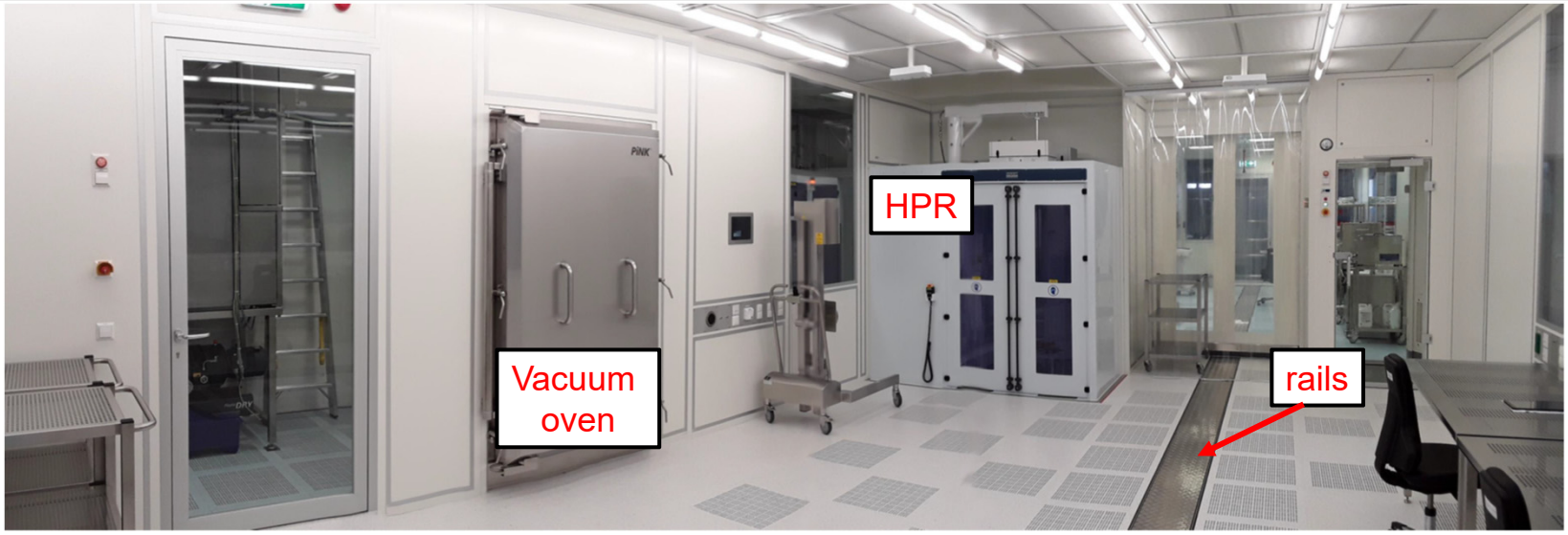
- Clean room complex
  - ISO6 for cleaning and preparation
  - ISO4 for final preparation and assembly
- HPR

Infrastructure @ HIM
(more information on poster WEPRB015)



- Clean room complex
  - ISO6 for cleaning and preparation
  - ISO4 for final preparation and assembly
- HPR
- Vacuum oven

Infrastructure @ HIM
(more information on poster WEPRB015)



- Clean room complex
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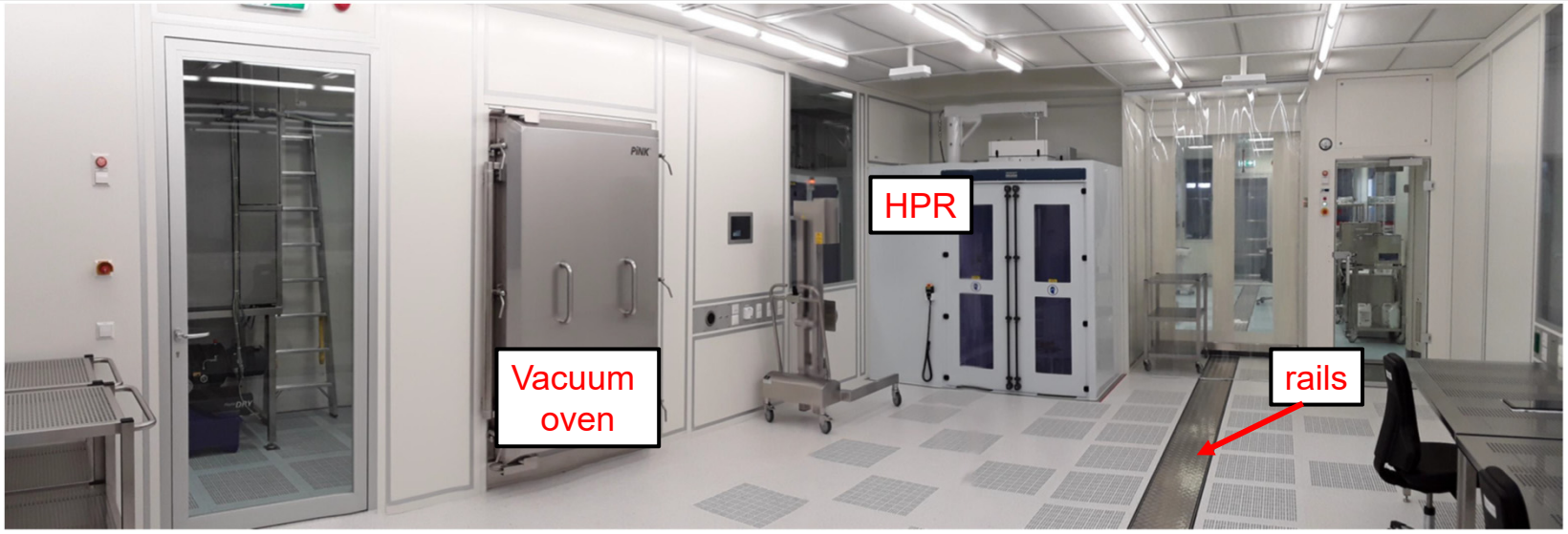
  - ISO4 for final preparation and assembly
- HPR
- Vacuum oven
- Rail system for string assembly

Infrastructure @ HIM
(more information on poster WEPRB015)



- Clean room complex
  - ISO6 for cleaning and preparation
  - ISO4 for final preparation and assembly
- HPR
- Vacuum oven
- Rail system for string assembly
- RF-Bunker for testing
- He-infrastructure
- Sub atmospheric compressor for 2K tests

Timeline of Advanced Demonstrator Project

02/2015	Funding of the Advanced Demonstrator within POF3
09/2016	Ordering of two short CH-cavities
11/2018	Tendering of cryostat
05/2019	Modification of radiation protection shelter @GSI
10/2019	Delivery of short cavities
12/2019	Link of testing area to STF cryoplant
04/2020	Delivery of cryostat
04/2021	Assembly of cryomodule @ HIM
10/2021	Beamtest @ GSI

Acknowledgments

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GA: *G. Gruber*

LRF: *E. Plechov, A.Schnase*

TRI: *T. Lüding*