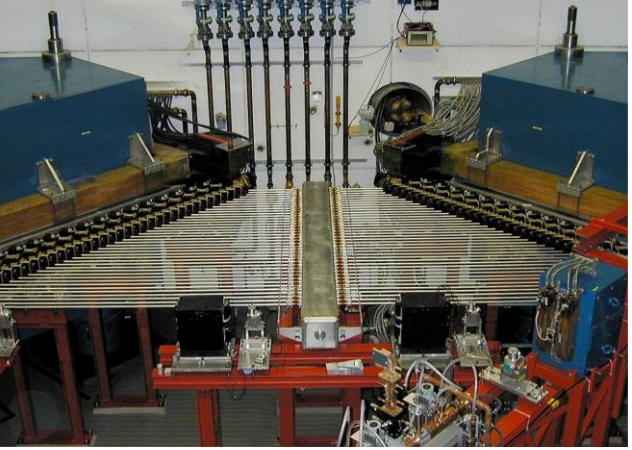

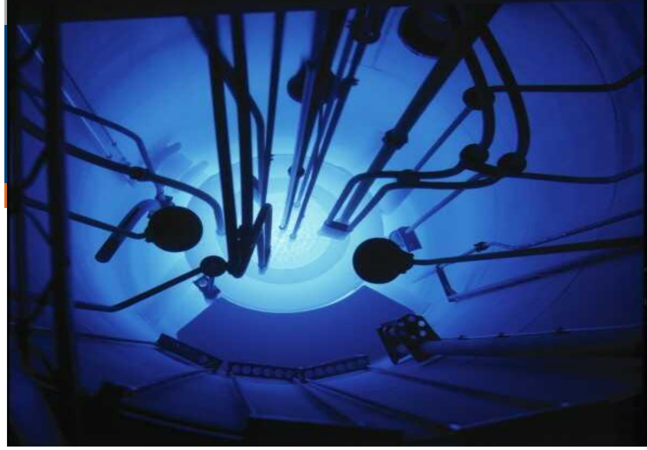

Electron cooler related R&D at Helmholtzinstitut Mainz (HIM)

Kurt Aulenbacher
Cool-13, Mürren-Switzerland
2013, June,11

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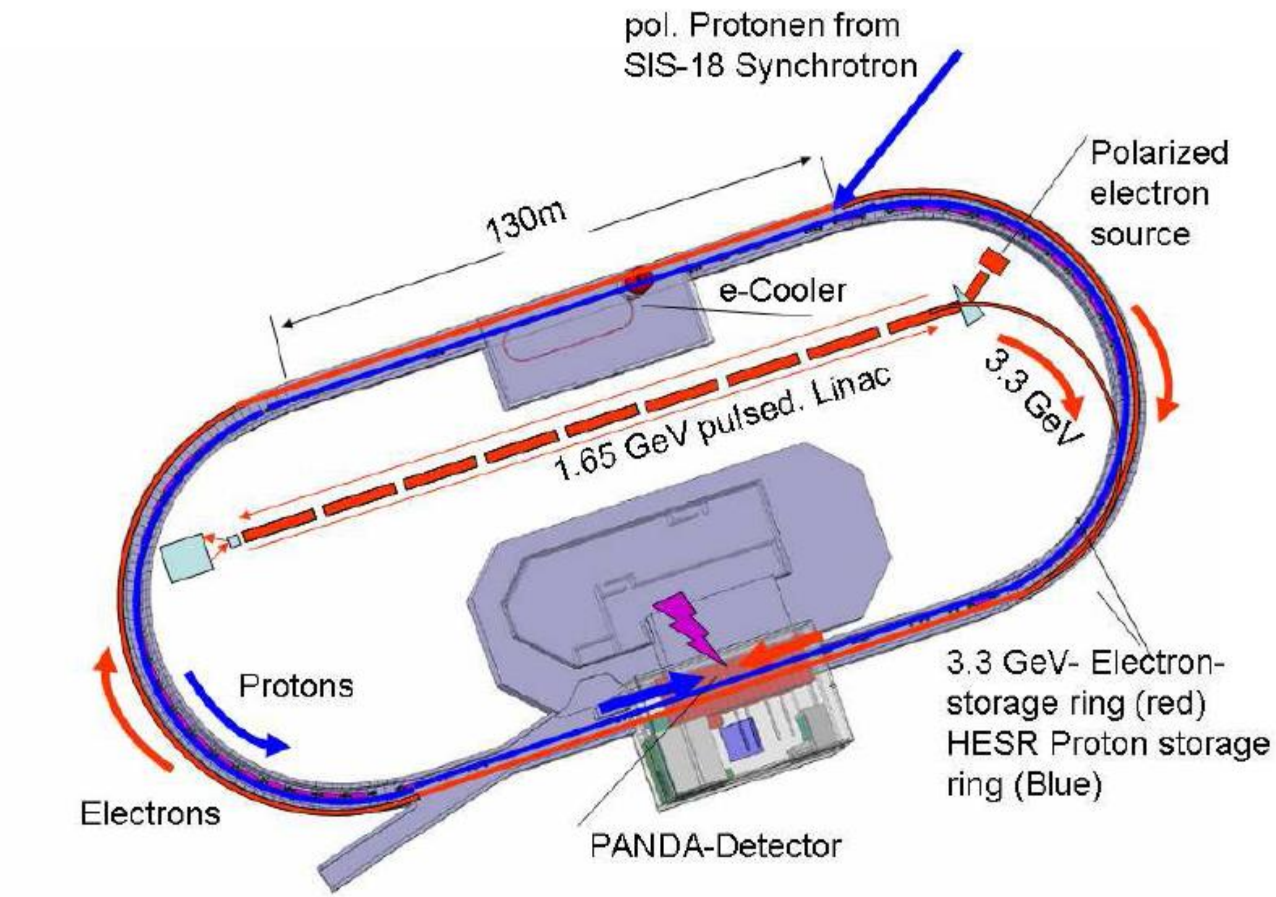
What is HIM ?

- A joint venture between University Mainz & GSI
- Founded 2009…
- Scientific focus: Physics which can be performed at GSI& FAIR
- HIM-Sections: (1) Hadron-spectroscopy, (2)Hadron-structure (PANDA) (3)Theory (e.g. lattice QCD) (4,5)Super-Heavy Elements (two sections: chemistry&physics) (6)Matter & Antimatter
- And last but not least: (7)Accelerators and integrated detectors

Objectives of HIM-section Accelerators and integrated detectors (ACID) (est. 2009)

1. **FAIR: HESR-Cooler support: Beyond 2MV:→4-8MV**
2. **Keeping the ENC (double polarized Electron nucleon collider at FAIR) in perspective!**
3. **Provide accelerator solutions for SHE research by GSI and JGU groups: low beta SRF ion accelerator cavitities**

Double polarized collider ENC:



Cooler device is quite common
to the needs of pbar at HESR/FAIR and (later) ENC!!

ACID- staffing-status (6/2013)

Section head: K. Aulenbacher (since 5/2013)

Name	Position	Project	Task	Started	Contract (or completion)
A. Hofmann	postdoc	Cooler	Solenoid channel	01.01.2012	12/14
M. Bruker	phd	Cooler	collector efficiency	01.08.2011	2015
T.Weilbach	phd	Cooler	cooler diagnostic	01.03.2010	2014
J. Dietrich	Consultant	Cooler	int. coordination	1.4. 2012	12/13
M.Schwarz	Technician (50%)	Cooler	Test-lab support	01.01.2012	6/15
S. Friederich	Master student	Cooler	Collector efficiency	1.10.2012	2013
T. Stengler	Master Student	Cooler	Beam diagnostics	1.3. 2013	2014
V. Gettmann	engineer/FH	cw-Demonstrator	systemintegration	01.12.2010	2
S. Jacke (*).	postdoc	cw-Demonstrator	technical LINAC-layout	01.12.2010	3
M. Amberg.	phd	cw-Demonstrator	cavity layout	01.12.2010	2014
-	postdoc	FAIR/ENC	ENC beam dynamics	in 2012	-
-	phd	FAIR/ENC	Superconducting septum	in 2012	-

HESR-Cooler support

- A cooler device is extremely valuable for the pbar-progamm (2-4.5 MV), even 8MV highly desirable for pbar, **indispensable** for ENC@FAIR

→ Clarify the critical design issues.

→In particular : Beam diagnostics for pbar!

Measures taken:

→ HIM/ACID and FZJ provide for joined cooler activities; HIM/ACID became member of HESR consortium. Service of IKP engineers for FZJ: e.g. BPM calibration for 2MV cooler.

→ KPH at U-MAINZ provides cooler test laboratory for critical components (high effciency recuperator, solenoid channel).

→ KPH at U-Mainz provides additional lab with high density beam to speed up development for advanced cooler diagnostics (Beam induced fluorescence & Thomson scattering).

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Relativistic cooler and POF-III

HIM/ACID tasks in HESR-cooler business: ... provide solutions for unresolved technical questions of relativistic cooling at HESR energies, corresponding to maximum cooler voltage of 8MV:

- More cooling power needed due to stronger beam/target (PANDA) or beam/beam (ENC@FAIR) interactions→ Magnetization of beam required!
- Much Higher beam current: 1A/3A (PANDA/ENC),
- Powering of continuous solenoid channel in d.c. acceleration stage
- Powering of collector: Minimized losses at maximum perveance
- Power requirement 50-150kW for supply floating at U>2MV

???transformer or insulating shaft technological limit???

1. Beam magnetization: How to power solenoid channel & terminal ?→ main issue!
2. Energy recuperation effciency and control
3. Non invasive diagnostic of multi-megawatt beams

HESR cooler: HIM Investments & Timeline 2013-18

<u>HESR cooler: solenoid channel problem & turbine concept</u>

- Solenoids must be powered by floating power supply.
- Turbines for U>2MV → Suggestion of BINP-Novosibirsk: 60kV/Turbogen (400Watt)
- **Not realized** for Jülich 2MV-cooler…
- 2012: ACID contacts German company DEPRAG: Offer for 5kW Turbogens, high reliability
  (V. Parkomchuk: Each 5kW Turbogen may excite ~ 700kV Transformer)

~40cm

Poster by Andre Hofmann,

Two 5kW Turbogenerators have been ordered, delivery 10/2013

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Turbines: „The long run“ & its Timeline 2013-18

- *Request for Helmholtz international research group (HIRG) HIM/FZJ/BINP decision May/June 2013*
- *2 Turbogenerators ordered, delivery to BINP end of 2013*
- *Challenge: Convert Turbogen to SF6 medium/energy efficiency: full scale device requires ~1.5MW of electrical power for compressor.*
- *Negociations with TU-Delft (Prof Colonna) on facing these challenges*

~40cm

<u>Main Projects/Milestones for the mid term future together with potential partners/collaborators:</u>

2016: Operation/Optimization of Turbogenerators using SF6 (TU-Delft)
explore using Organic Rankine Cycle (ORC) instead compressor
→ reduce el. energy consumption by order of magnitude (TU-Delft)
2015: Demonstration of Turbo powered HV generator (BINP, FZJ)
2016: Study/design of full scale SF6 gas handling system (Industry)
2016: Decision on feasibility of concept (BINP,FZJ)
2017: Technical design report for full scale cooler (BINP, FZJ)

Alternatives (*) are being studied in parallel!

(*) e.g. R.f. Cooling for 8MV !

Non-invasive diagnostics for relativistic coolers (PhD T. Weilbach)
Beam induced fluorescence (BIF) & Thomson Laser Scanner (TLS)

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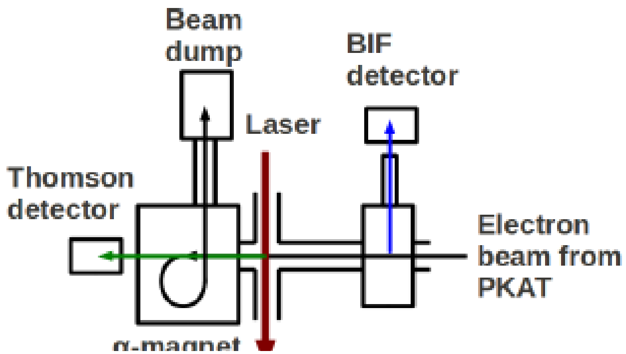
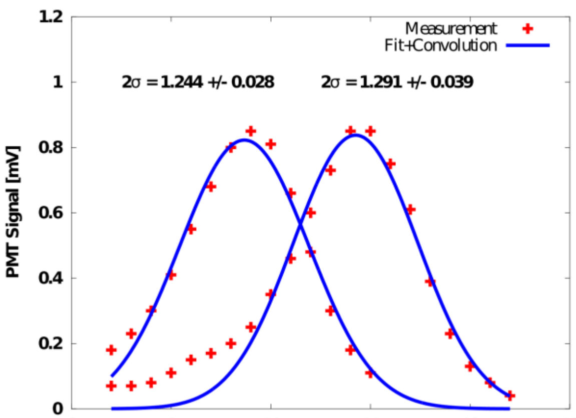
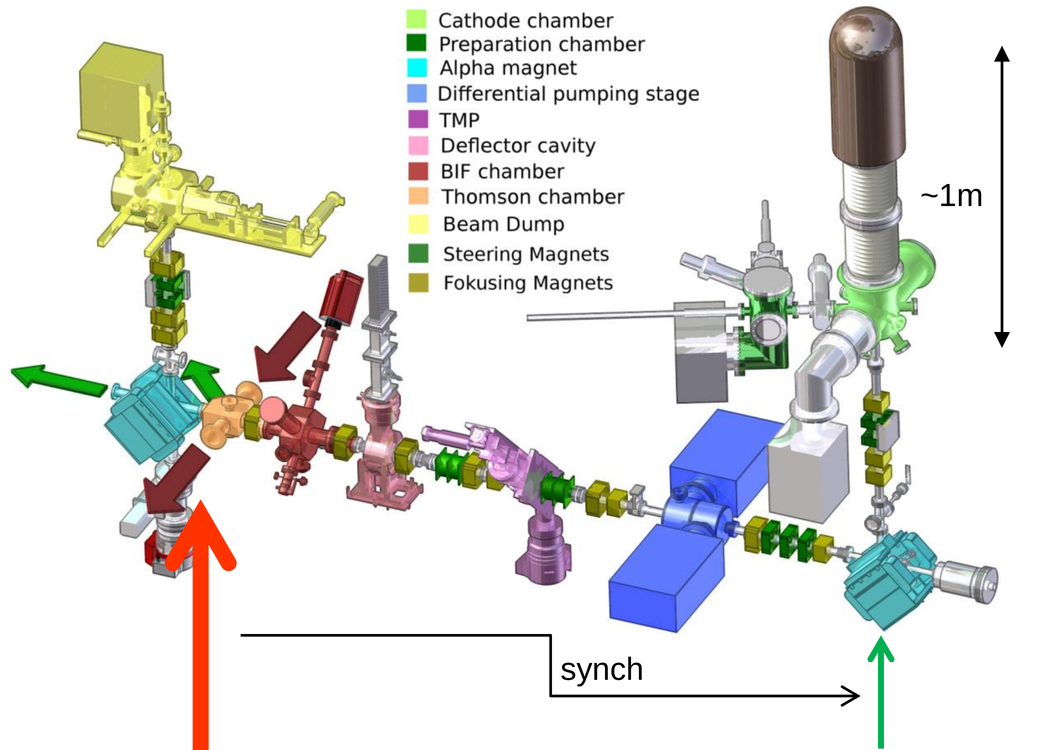




Progress since last meeting:
- non invasive beam profile measurement achieved
- Visible single photon counting mode emasurement: low background!
- Rearrangement of hardware for TLS completed
- Laser acquisition completed, ready for use
- Critical issue: S/N! (5Hz Signal expected)
  Note: count rate *1000 for rel. cooler!

See Poster by Tobias Weilbach !



Thomson Laser 150 Watt c.w.
(150kHz, 20ns),

Laser Wire geometry: $\theta_{laser}=\pi/2$
Scattered photon: $\theta_{sc}=3\pi/2$

Source laser <10W c.w.
150kHz, 20ns
→ I_{peak} ~60mA @100kV

$$\lambda_{SC} = \lambda_{Laser} \frac{1+\beta\cos(\Theta_{Sc})}{1+\beta\cos(\theta_L)}$$

$$\lambda_L = 1.05\mu m \Rightarrow \lambda_{SC} = 0.61\mu m$$

HESR-Cooler-test-laboratory at KPH U- Mainz (PhD M. Bruker)

Progress since last meeting:

- Control system operational (EPICS)
- Hardware operational, (e.g. PS, Solenoids, Gun, HV,)
- Gun parameters (e.g. perveance) measured
- Energy recovering operation demonstrated
- Wien filter design completed
- Simulation of secondaries…
- Extension solenoids delivered 5/2013
- Increased pumping speed possible, NEG modules ordered

Problems:

- Broken control electrode isolator: p>10-9mbar → penning discharge at U>5kV
- Replacement isolator purchased → true UHV operation is now possible

?? Design problem of gun or vacuum issue ??

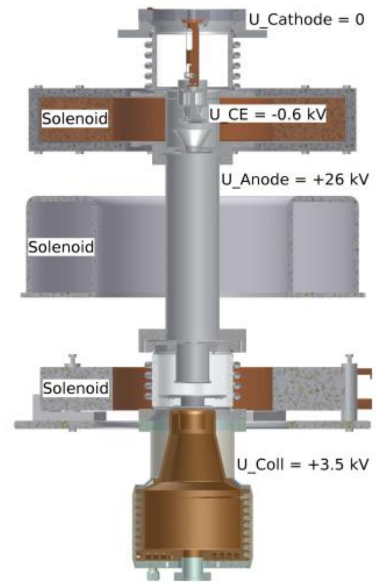
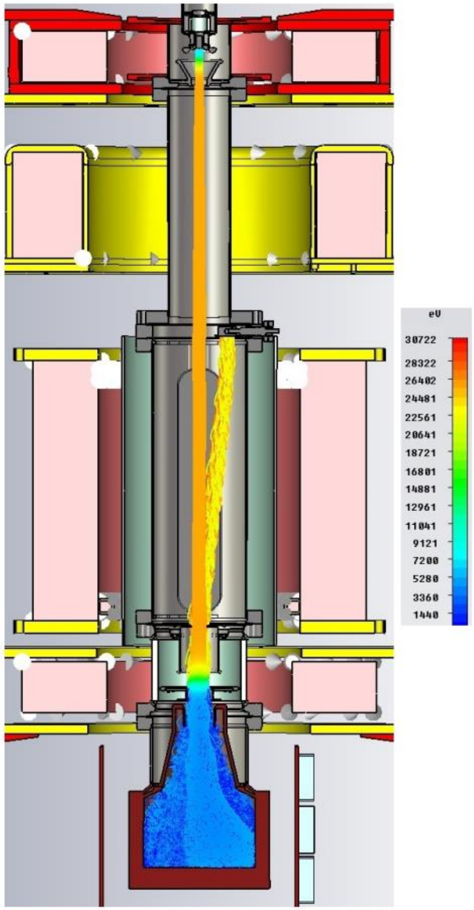


Figure 2: Schematic view of the complete test bench

Operational 9/2012

See poster
By Max Bruker
And Simon Friederich



Computersimulation of extended Set-up with Wien-filter (Master Thesis S. Friederich)

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Summary

- ACID cooler group does R&D on small, well defined aspects related to the design of relativistic magnetized coolers
- Such small scale research is well adapted to the possibilities of HIM (somewhat in between university research and „big science“)
- Ongoing projects: turbines, current/perveance optimization, non invasive beam diagnostics,
- Based on the now established knowledge & networking students from Mainz University may participate in new cooler projects at the big research centers!

Thank you !

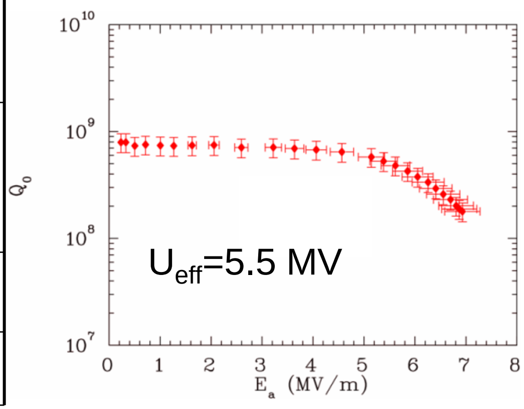
SRF Cavities for heavy ion acceleration

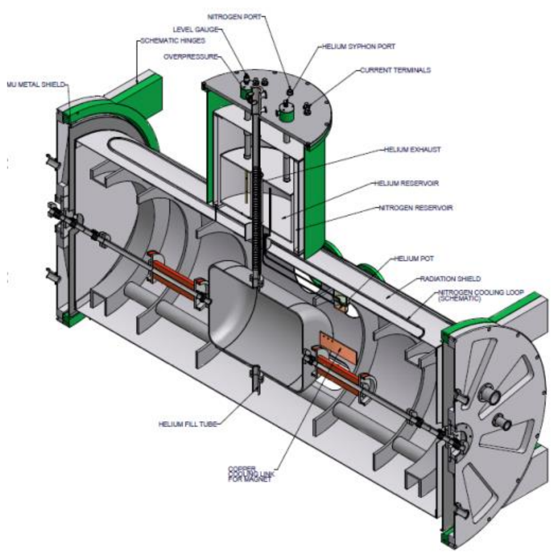
- SHE requires a new powerful c.w. heavy ion accelerator → low beta cavity research
- low β SRF is a competence/component that is of science-strategic importance (e.g. RIB, ESS, Applicatons)
- During the POF-III period ACID will pursue the design/commisioning of an „**advanced cryomudule**“ to be ready to participate as an important player in HI-Linac SRF module design afterwards.
- This is based on our present „demonstrator“ activities

Application for Multicell-Crossbar H-Cavities

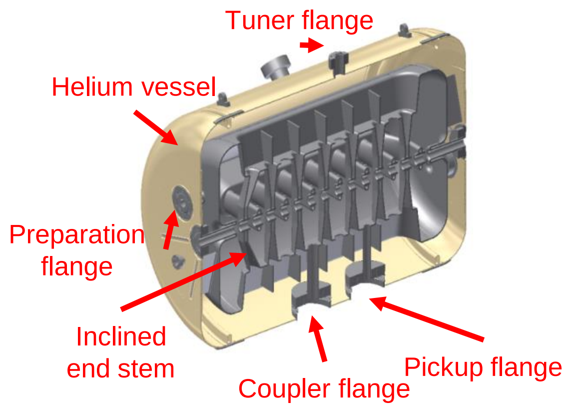
No	Frequency [MHz]	Beta	Status	Application
1	360	0.1	1st prototype Successful rf-tests (warm + cold) @IAP in 2007	Accelerator Driven System (ADS) „EUROTRANS“
2	325	0.16	1st SAT was successful in 2012	Energy Booster LINAC 2nd stage upgrade option for GSI-UNILAC
3	217	0.06	In fabrication Delivery in 2013	Sc cw LINAC @GSI
4	176	0.12-0.18	Under development	MYRRHA , Mol/Belgium

360 MHz Prototype (EUROTRANS)





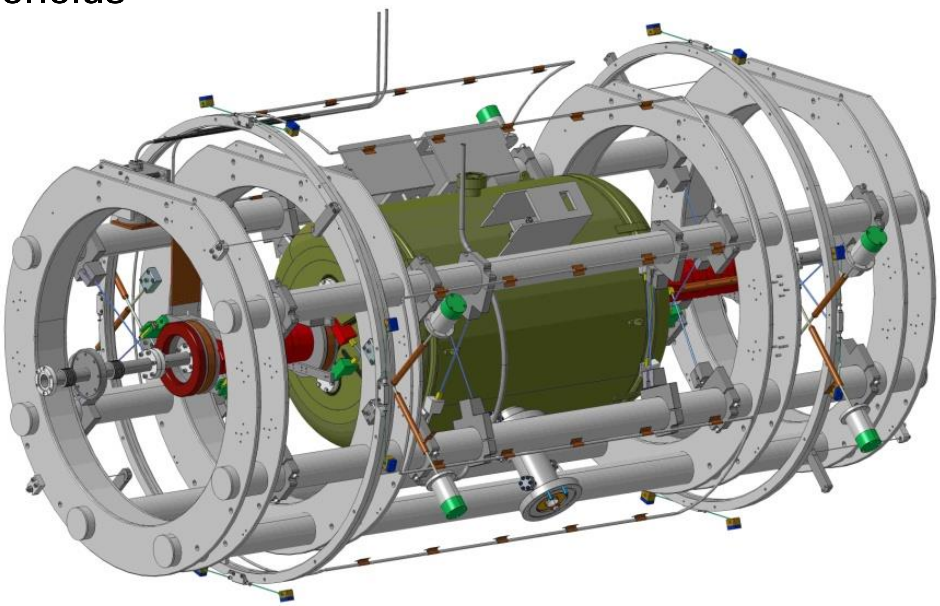
217 MHz sc cw CH cavity (SHE LINAC-Demonstrator)



Developing low-beta cw-structures

Development of CH structures for CW heavy-ion beams (GSI, HIM, GUF)

- Structure design
- Treatment techniques for high-field CW operation
- Development of a full cryomodule with SC solenoids
- Cavity test and preparation facilities at HIM
- Beam tests at GSI injector



Goal:

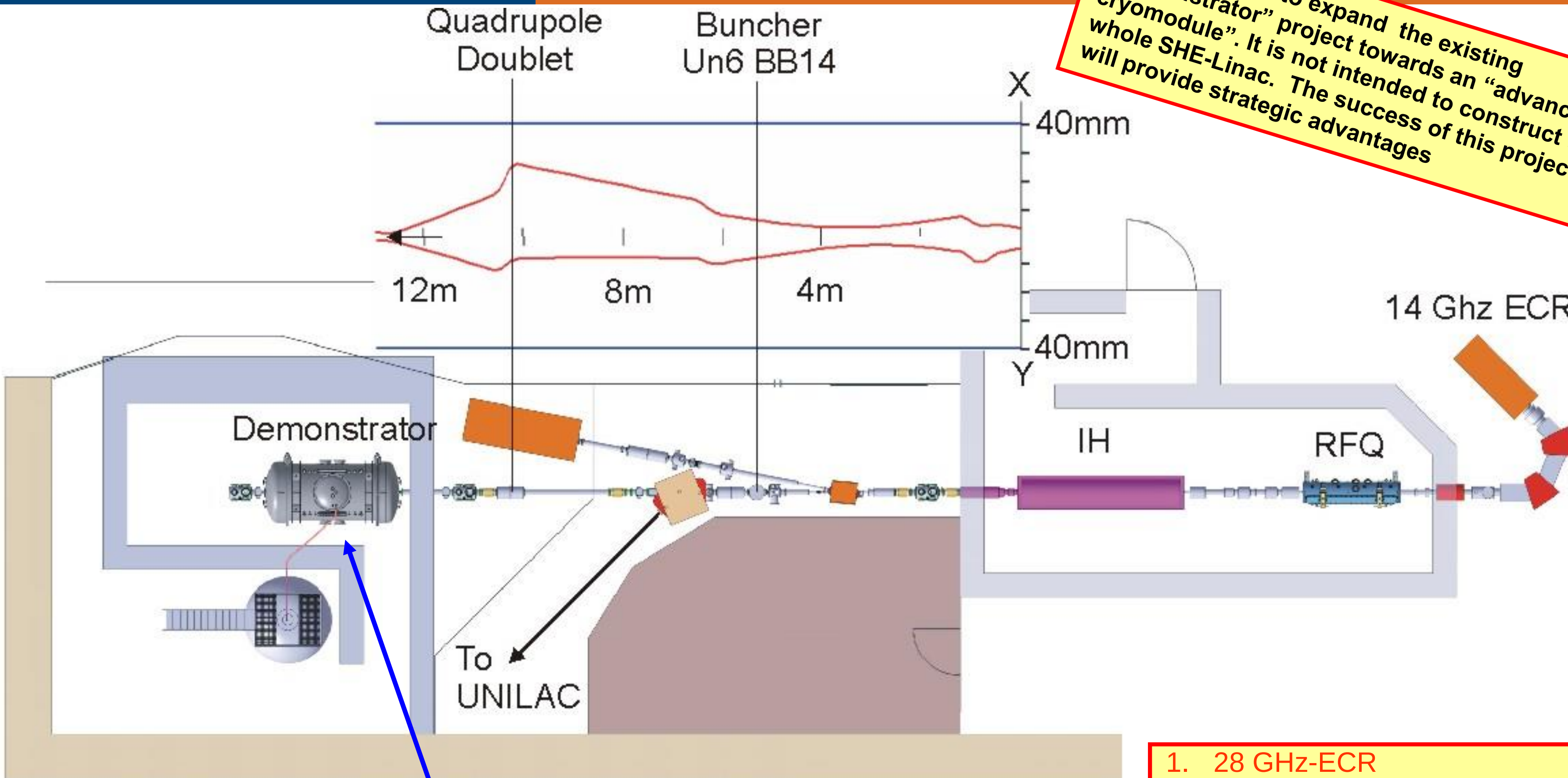
- Taking low-beta cw at high gradients
- Linking to the high-beta world
  (e.g., treatment techniques)

Ongoing R&D:

- CH prototype tested (2007)
- 216 MHz CH cavity to be tested@GUF (2013/14)
- Full performance test of Demonstrator@GSI (2015)
- Beam Dynamics studies for a heavy ion cw-linac
- Feasibility study for an advanced demonstrator

High Charge State Injector Upgrade

ACID proposes to expand the existing "demonstrator" project towards an "advanced cryomodule". It is not intended to construct the whole SHE-Linac. The success of this project will provide strategic advantages



5. Basic cryo module (6.5m)

1. 28 GHz-ECR
2. LEBT (mass spectrometer)
3. cw-RFQ
4. Upgrade of IH-cavity

Parameters of the sc multi-gap accelerating cavities

HIM (<2015)

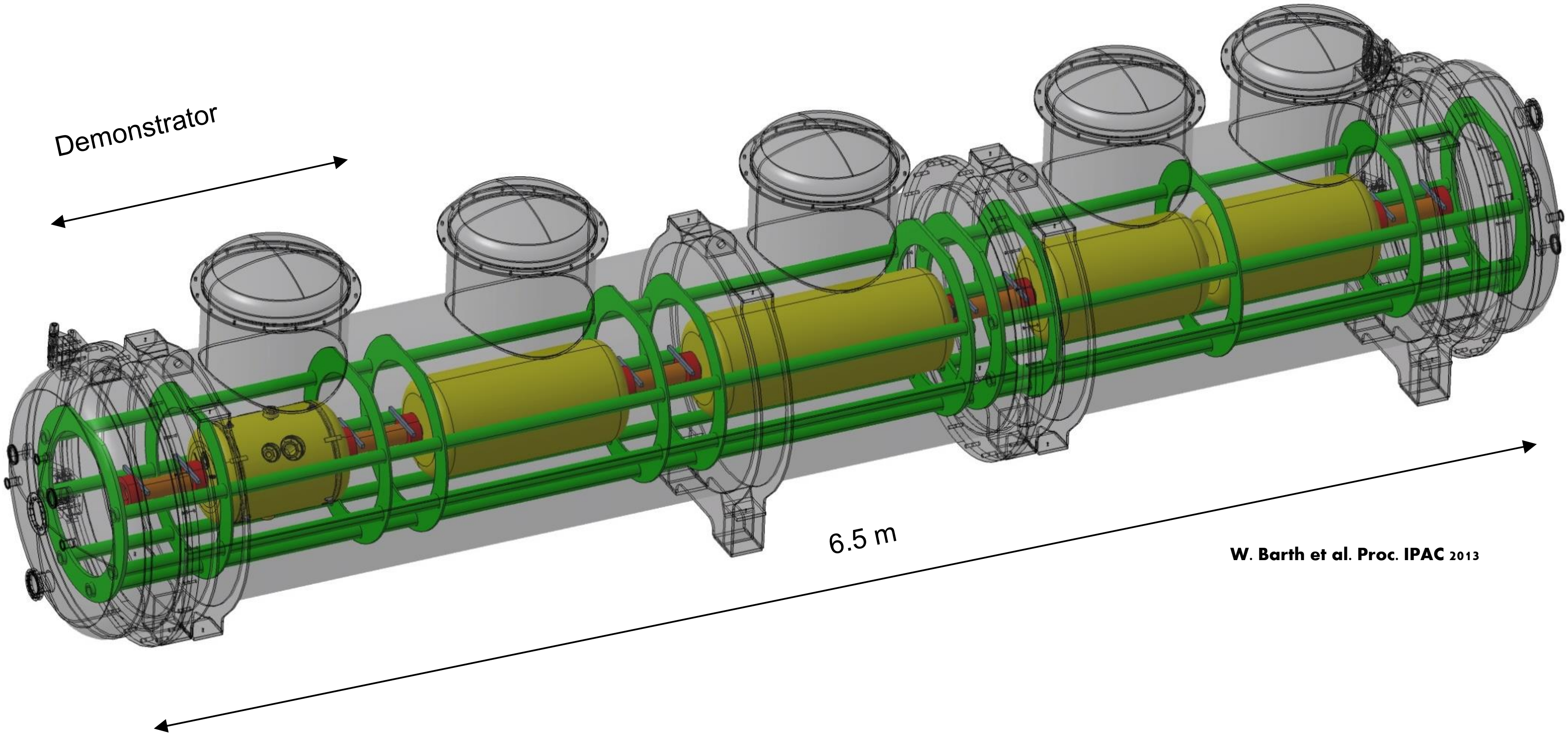
Parameter	*unit*	*C1*	*C2*	*C3*	*C4*	*C5*	*C6*	*C7*	*C8*	*C9*
Gap number		15	17	19	10	10	10	10	10	10
Total length	mm	613	811	1054	636	642	726	726	813	862
Cell length,	mm	40.8	47.7	55.5	63.6	64.2	72.6	72.6	81.3	86.2
Synch. velocity		0.059	0.069	0.080	0.092	0.093	0.105	0.105	0.118	0.125
Aperture diameter	mm	20	22	24	26	28	30	32	34	36
Eff. gap voltage	kV	225	274	317	356	362	408	411	459	538
Voltage gain	MV	3.13	4.14	5.42	3.27	3.30	3.73	3.73	4.18	4.43
Phase Factor*		0.93	0.89	0.90	0.92	0.91	0.92	0.91	0.91	0.82
Accelerating rate	MV/m	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1	5.1

Final Energy [MeV/u]									
	1.9	**2.6**	**3.5**	**4.1**	**4.7**	**5.4**	**6.1**	**6.8**	**7.5**

HIM (2015-2019)

- 1 cryostat
- 4 rf cavities
- 4 sc solenoids

Scetch of Multi cavity cryostat layout



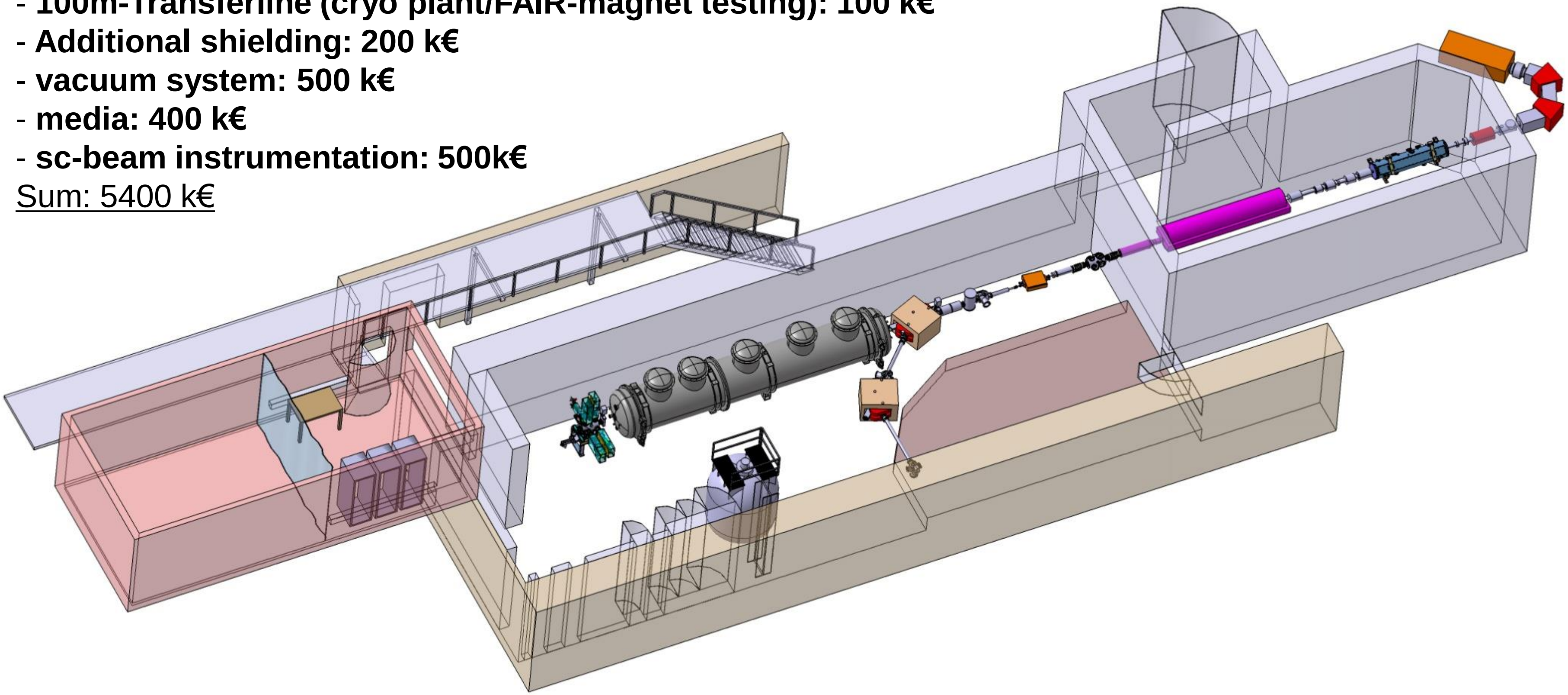
W. Barth et al. Proc. IPAC 2013

Demonstrator Cave@GSI

- Cavities (4): 2000 k€
- cryostat (1): 1000 k€
- sc Solenoids (4): 200 k€
- tuner, coupler, rf-amplifier: 400 k€
- cryo-infrastructure (100l/h): im HIM-Labor (o.k.)
- 100m-Transferline (cryo plant/FAIR-magnet testing): 100 k€
- Additional shielding: 200 k€
- vacuum system: 500 k€
- media: 400 k€
- sc-beam instrumentation: 500k€

Sum: 5400 k€

Advanced cryomodule (HIM)



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SUMMARY & Perspective for POF-III period

- First ACID „main development line“:
  FAIR/ENC Component „Relativistic Magnetized cooler“:
  - Main research project and investment: Beam magnetization.
  - Group established,
  - networking situation (Novosibirsk, Jülich) promising

- Second ACID main development line:
  Low beta SRF: „Advanced Demonstrator project“
  -Task: establishing a sufficiently strong group at HIM/ACID
  - GSI beam testing and HIM laboratory infrastructure can form good basis
  - Networking: GSI/HIM team (again) to be joined by GUF-groups and hopefully others…

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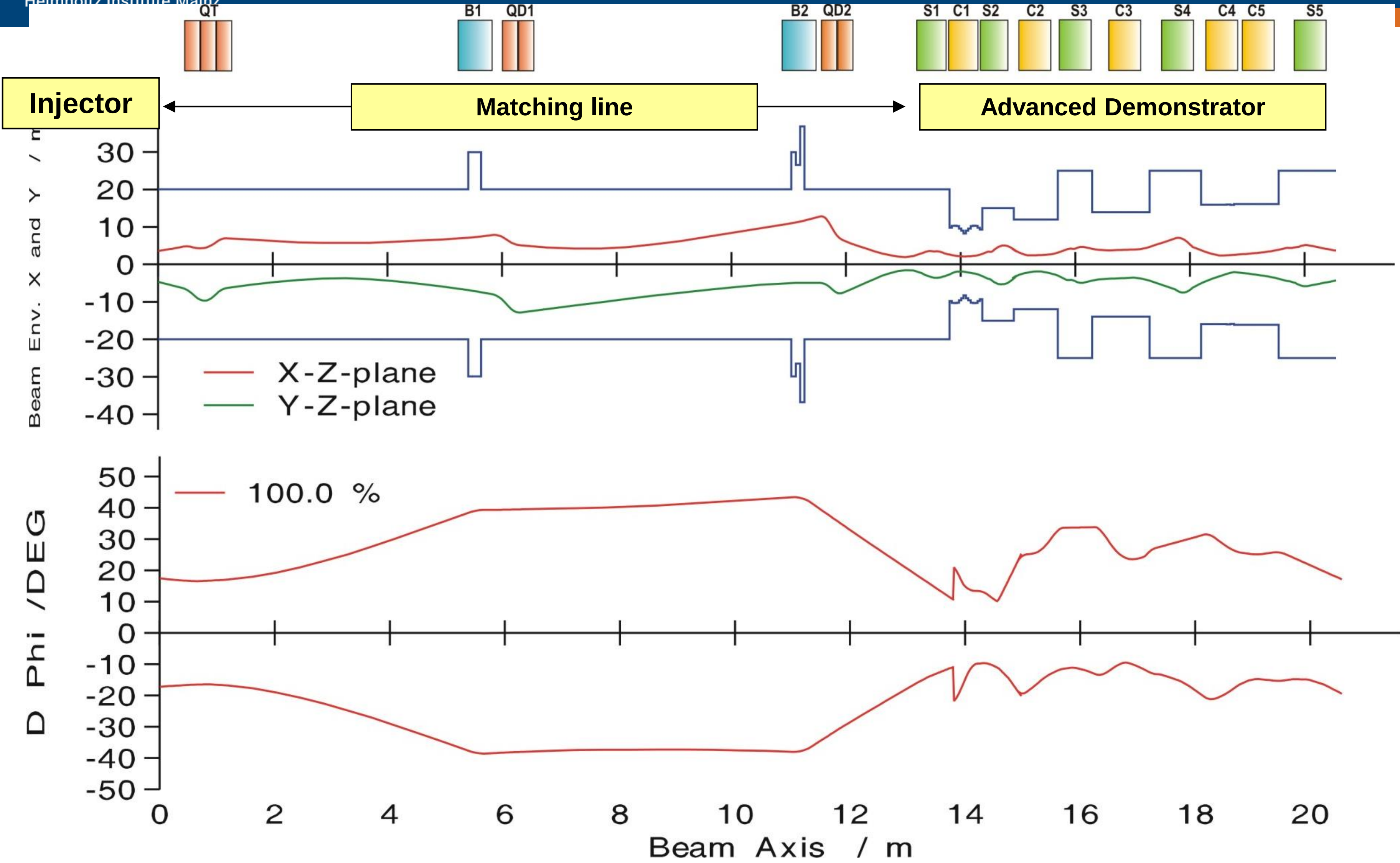
Spare& Support transparencies

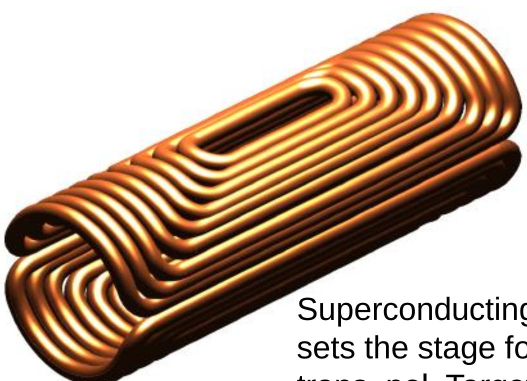
Beam dynamics layout



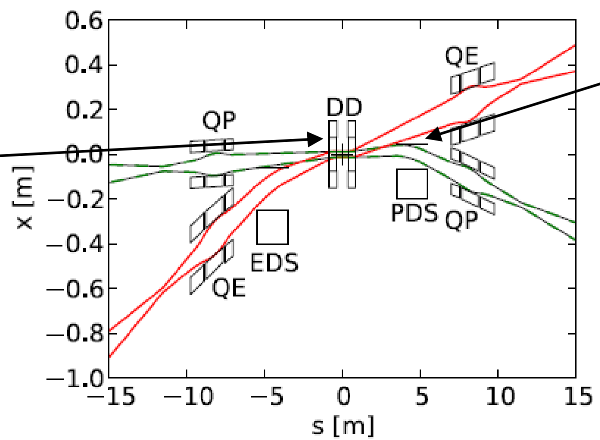
Work package ENC: Interaction region issues in PANDA and ENC@FAIR

- refined three d- Magnet design → P. Schnizer, in proc. IPAC2011
- HTSC-tube procured end 2011
- HTSC tests foreseen 2012: should shield 1Tesla field at 4K with 8mm wall diameter ("Superconducting septum")
- Could allow for other applications within FAIR?

PANDA –Luminosity monitor creates impedance problems for HESR→
HIM/ACID can provide support due to excellent software (CST) and availability of R.f. and and beam dynamics expertise at KPH-U-Mainz!

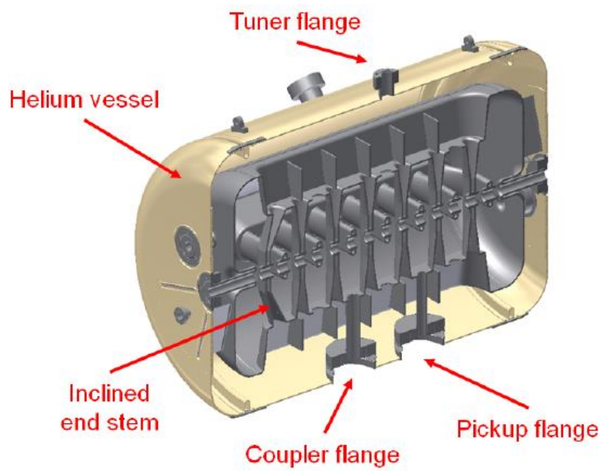


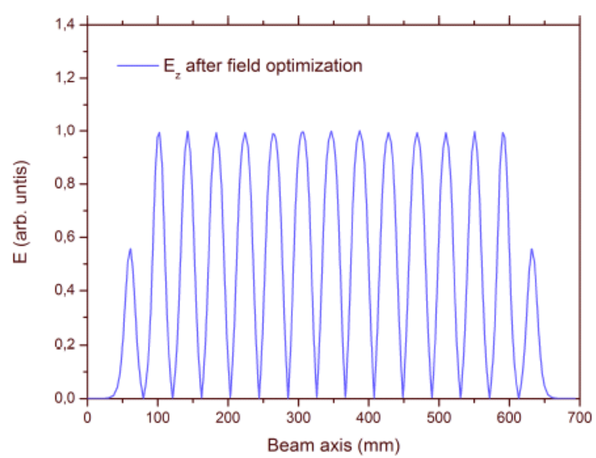
Superconducting Dipole (0.9T) sets the stage for PANDA trans. pol. Target magnets!



Position of HTSC-tube

Layout of the sc CH-cavity (AG Ratzinger, GUF)



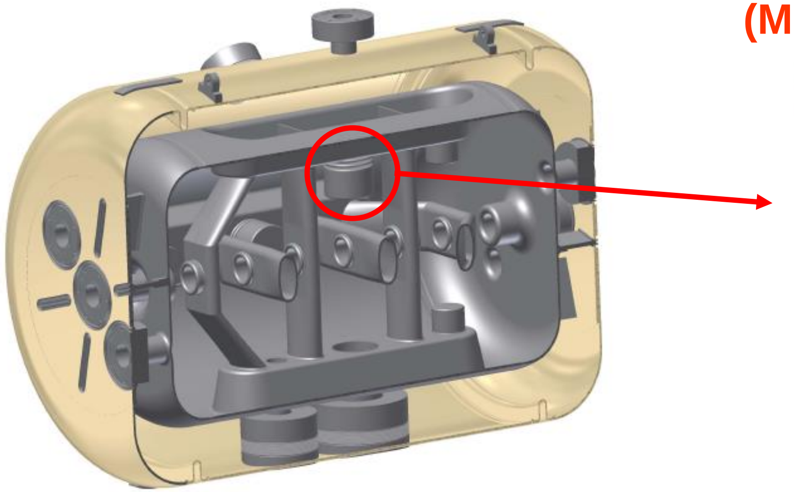


3D-view of the new cavity (top) and E_z along the beam axis after field optimization (bottom)

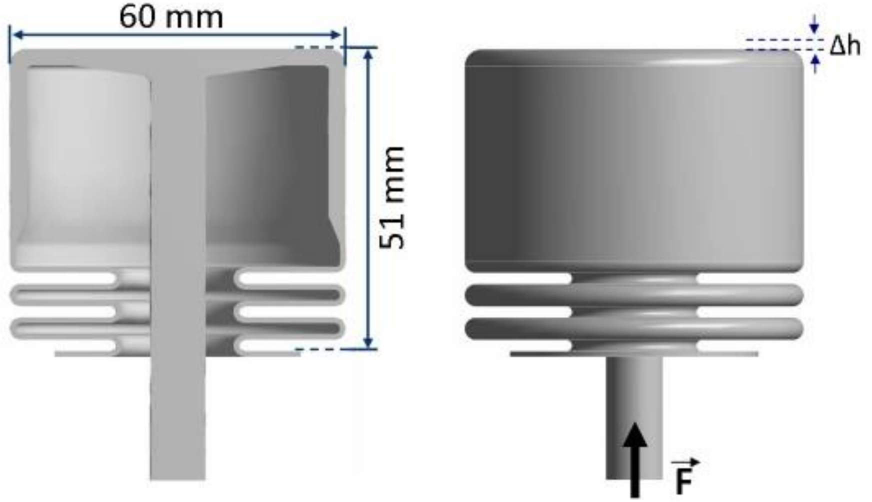
Main parameters of the 217 MHz CH-cavity

Parameter	Unit	CH-1
Beta		0.059
Frequency	MHz	217
Gap number		15
Total length	mm	690
Cavity diameter	mm	420
Cell length	mm	40.82
Aperture	mm	20
Effective gap voltage	kV	225
Voltage gain	MV	3.13
Accelerating gradient	MV/ m	5.1
E_p/ E_a		6.5
B_p/ E_a	mT/ (MV/m)	5.9
R/ Q	Ω	3540
Static tuner		9
Dynamic bellow tuner		3

Novel tuning concept for the s.c. CH-cavity



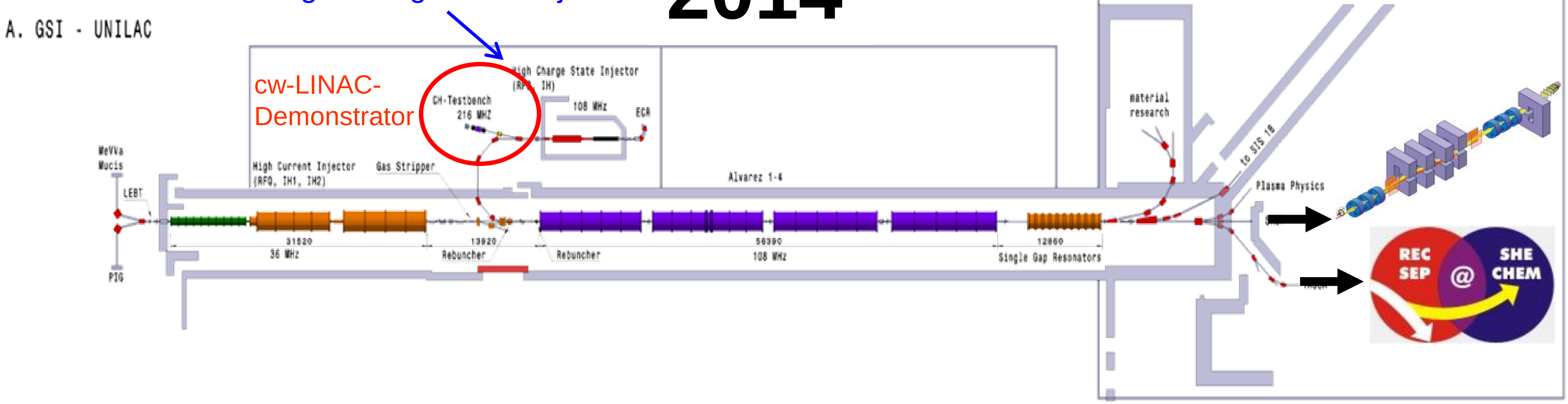
Design of the novel dynamic 3-cell bellow tuner (M. Amberg)



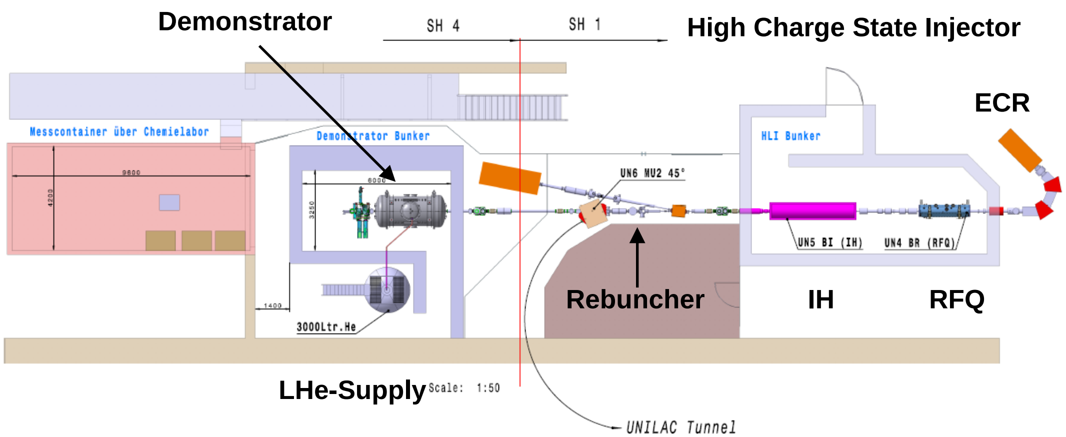
- Additionally to the cylindrical static tuners, several dynamic capacitive **bellow tuners** are welded into the girders to act against slow and fast frequency variations by changing their height
- The goal of the **slow tuners,** driven by stepping motors, is to readjust the frequency changes caused by cavity cool-down to 4.2 K and evacuation effects
- In addition, one of these slow tuners is based on a **fast reacting piezo actuator** to compensate frequency changes due to microphonic excitations and Lorentz Force Detuning
- This tuning device including slow and fast dynamic bellow tuners is sufficient for **frequency tuning during beam operation**

Full performance test at GSI-High Charge State Injector

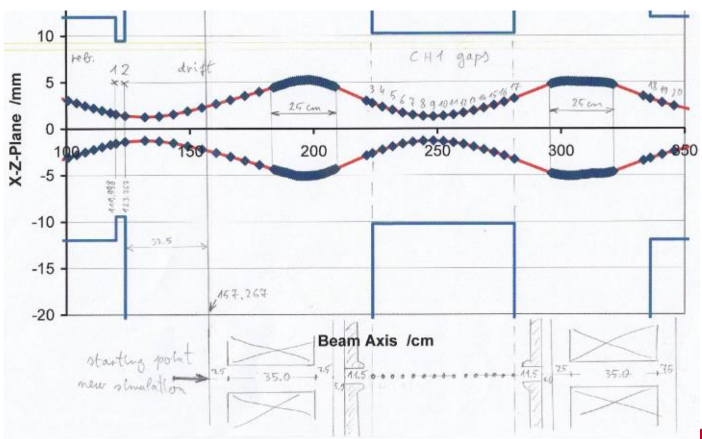
GSI-High Charge State Injector **2014**



Test environment



Beam Matching to the demonstrator



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cw-LINAC-Demonstrator - procurements

Order	ordering	delivery
conceptual study (support system, adjustment concept)	09/2010	11/2010
LHe-supply (He-recovery-ballon, 3000 ltr LHe-reservoir)	11/2010	3/2011
rf-amplifier	09/2010	2. HY/2011
rf-controls	1.HY/2011	1.HY/2012
solenoids & cryostat	1.HY/2012	1.HY/2013
CH-cavity	6/2011	2.HY/2012