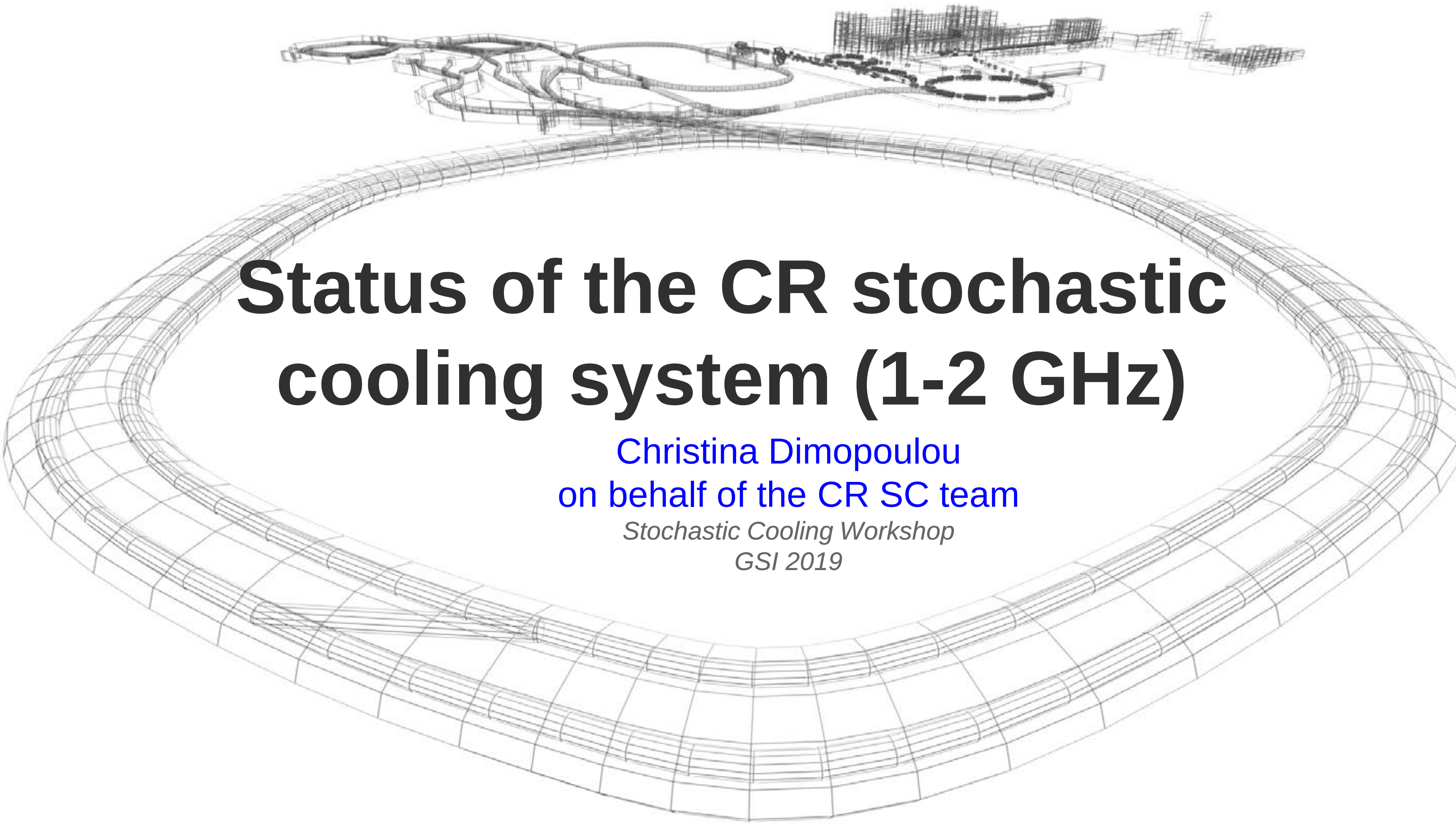


Status of the CR stochastic cooling system (1-2 GHz)

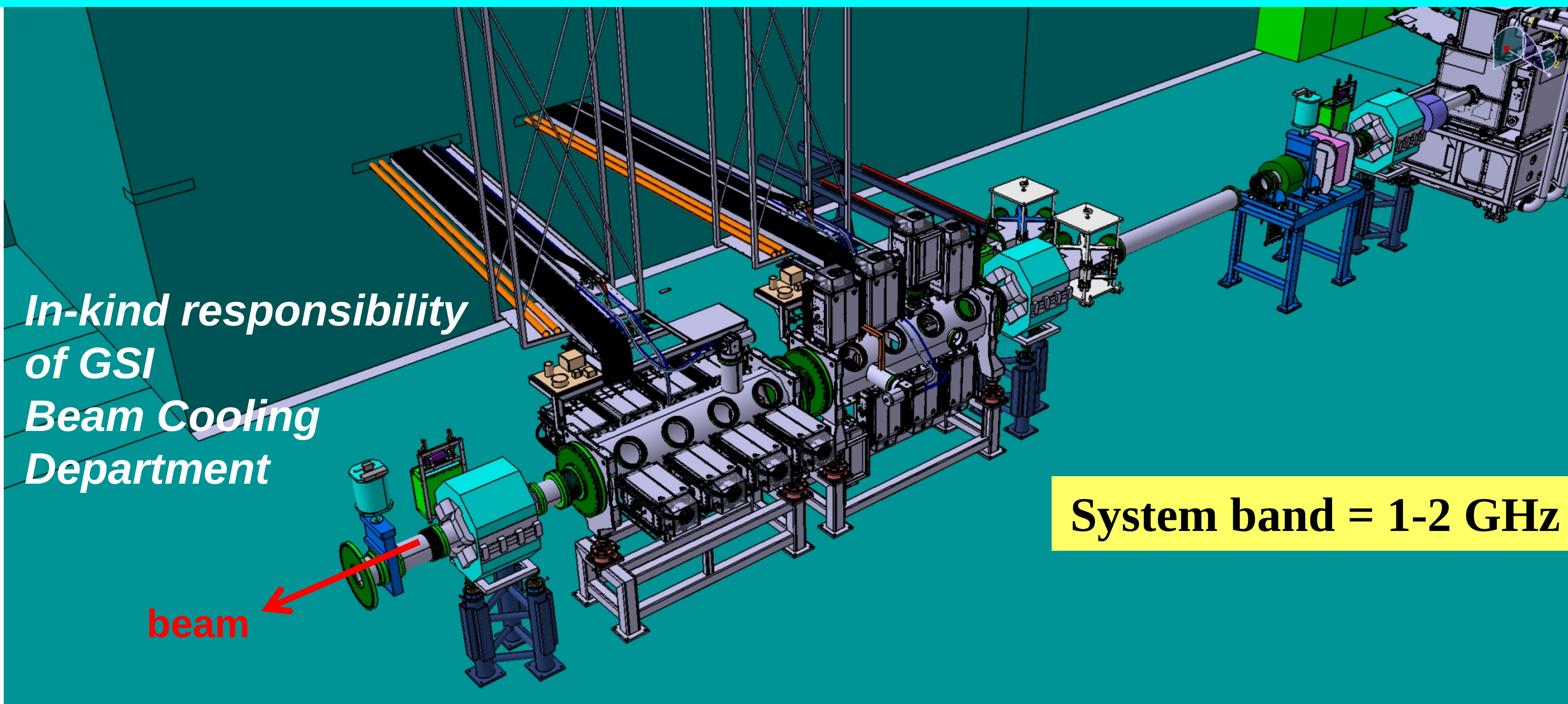
Christina Dimopoulou
on behalf of the CR SC team

Stochastic Cooling Workshop
GSI 2019

Stochastic Cooling System for the Collector Ring @ FAIR

Main task of the CR = efficient collection & fast stochastic cooling of hot secondary beams (antiprotons,rare isotopes) coming from production targets

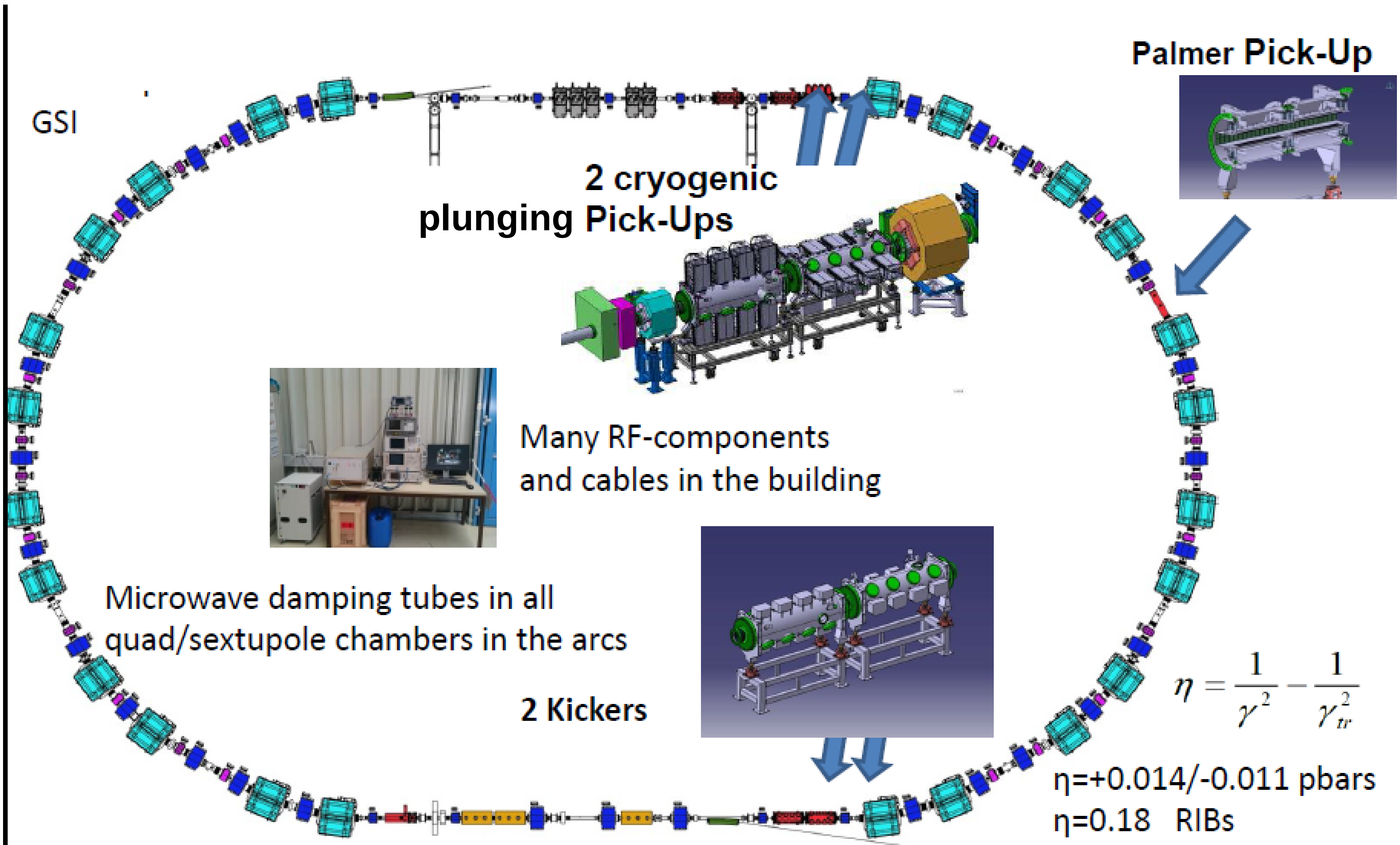
3D stochastic cooling of coasting secondary beams, max. 10^8 ions (antiprotons @ v = 0.97c , rare isotopes @ v = 0.83c)



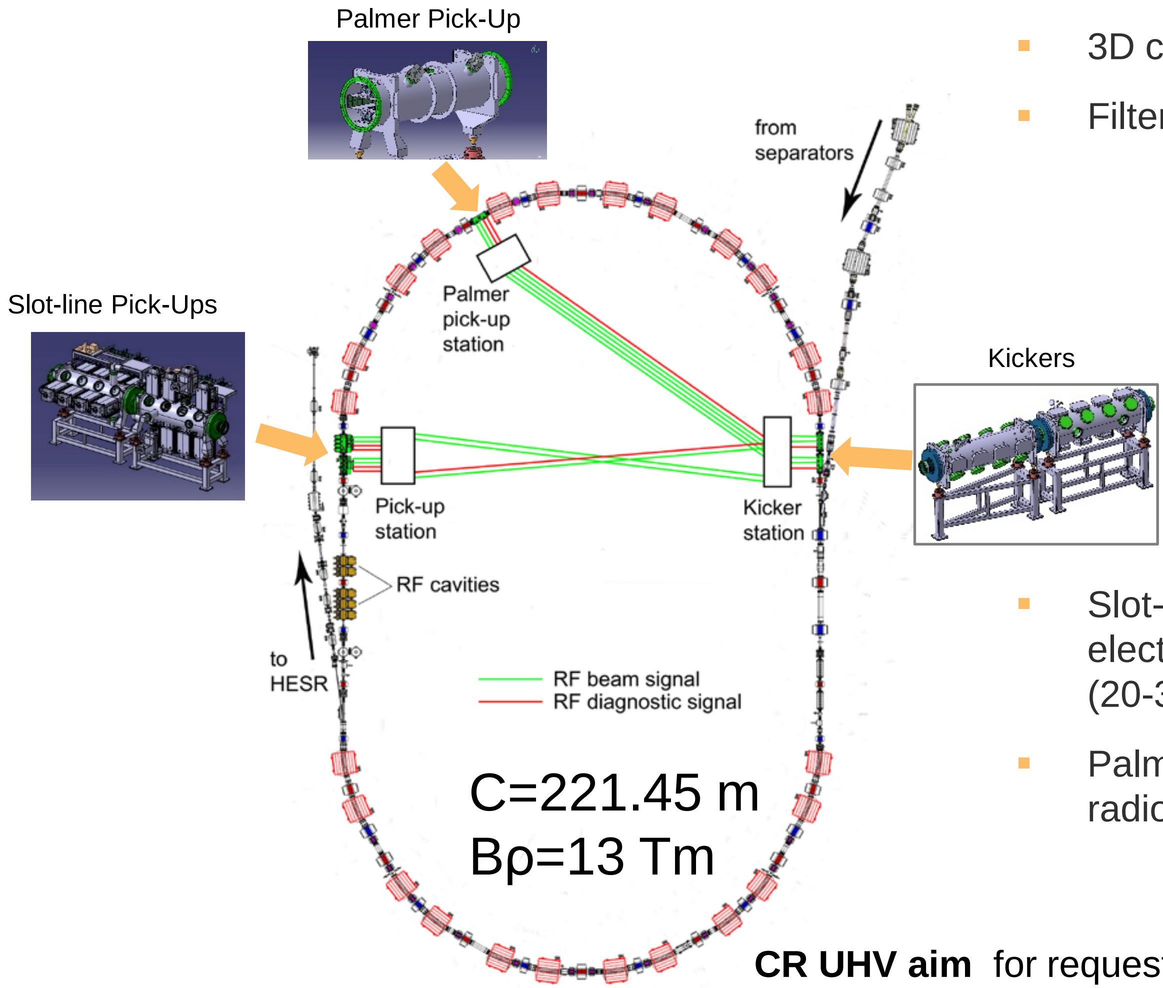
Outline

- Overview CR SC System
- Cryogenic plunging pick-ups
- Palmer pick-up
- RF signal processing 1-2 GHz
- Power amplifiers
- Microwave damping for SC purposes
- CR SC –Building integration
- Required CR SC performance for HESR users downstream

Overview


GSI
Palmer Pick-Up
2 cryogenic
plunging Pick-Ups
Many RF-components
and cables in the building
Microwave damping tubes in all
quad/sextupole chambers in the arcs
2 Kickers
$\eta = \frac{1}{\gamma^2} - \frac{1}{\gamma_{tr}^2}$
η=+0.014/-0.011 pbars
η=0.18 RIBs

Overview



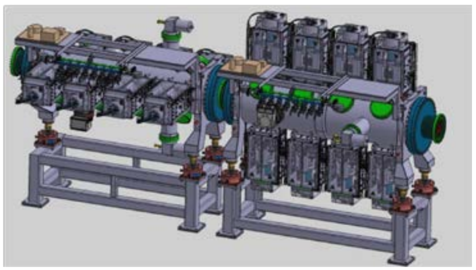
- System bandwidth 1-2 GHz (MSV).
- 3D cooling
- Filter, Palmer or TOF long. cooling methods.

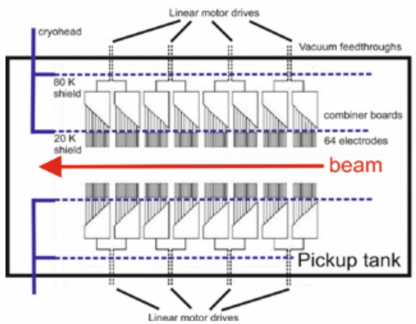
- Slot-line pick-ups with movable (plunging) electrode modules at cryogenic temperature (20-30 K).
- Palmer pick-up for pre-cooling of hot radioactive ion beams.

CR UHV aim for requested beam lifetimes of 100 s: basic static pressure $P \leq 3 \cdot 10^{-9}$ mbar (N_2 equivalent) at room temperature, **without in situ bakeout**

Cryogenic Plunging Pick-Up

Cryogenic slot-line double pick-up.

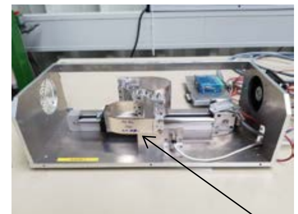


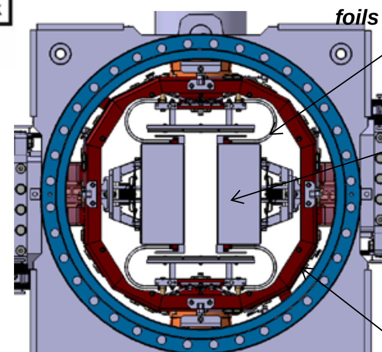


- Towards fixing remaining design issues.
- Testing of the full cryo-plunging concept in the GSI prototype tank ongoing.
- Engineering/mechanics/assembly activities ongoing.
- Long-time mechanical durability tests of the plunging foils ongoing.
- Vacuum-compatibility tests of materials.
- Electrode module re-design, contacts with providers.

see visit GSI SC test bench

Test-bench for testing of the plunging Ag/BeCu foils.

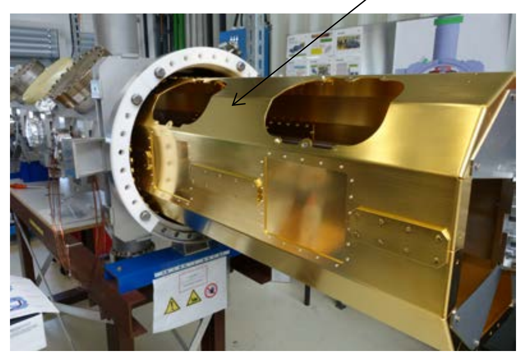




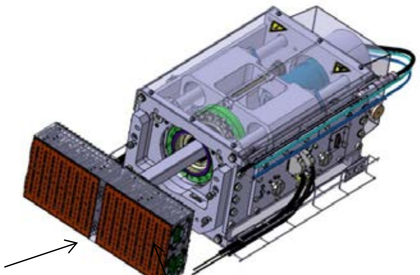
Flexible Ag/BeCu foils at 30 K

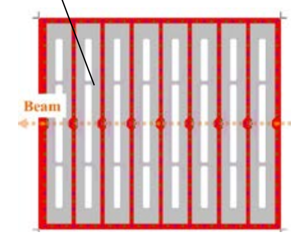
Electrode double-module

Au/Cu cryoshield at 80 K

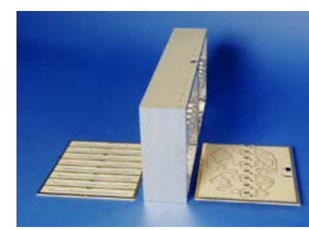


Assembly of the electrode double-module mounted to the linear motor drive unit.





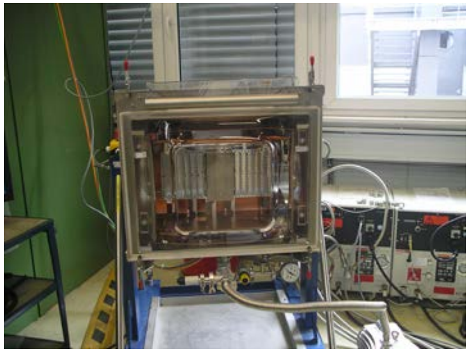
Slot-line electrode module on Al2O3 ceramic substrate.

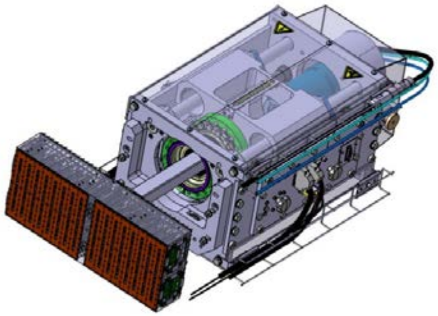


Milled module body with pick-up board & combiner board

Plunging Pick-up – Motor Drive Unit


see visit GSI SC test bench

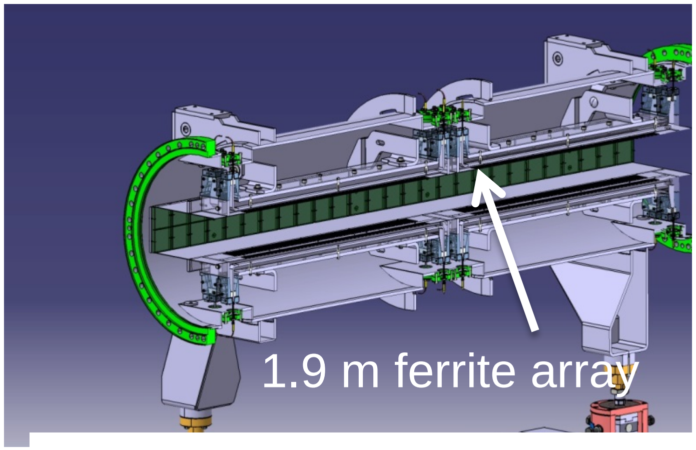


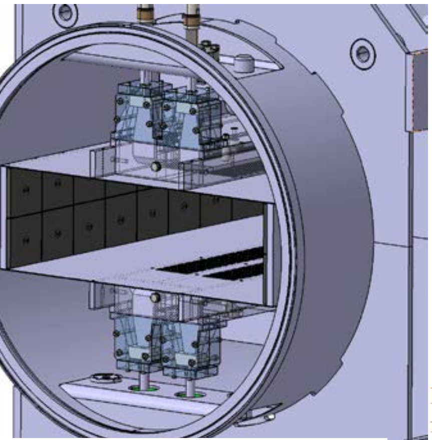


- Linear motor drives designed to synchronously move the electrode modules from ±80 mm to ±10 mm towards beam axis.
- Concept successfully tested at GSI test bench for all required plunging directions (horiz., vert.).
- Purchased the series of motors
- Absolute positioning packages successfully tested with industry
- Manufacture series of drive units

Palmer Pick-up

Palmer pick-up (rail electrodes) for precooling of RIBs





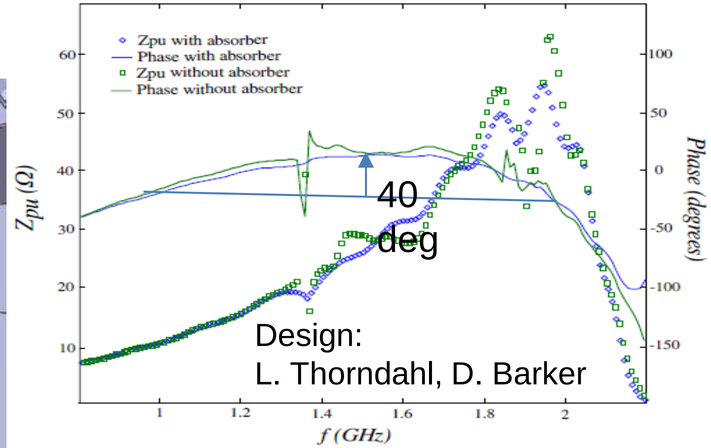
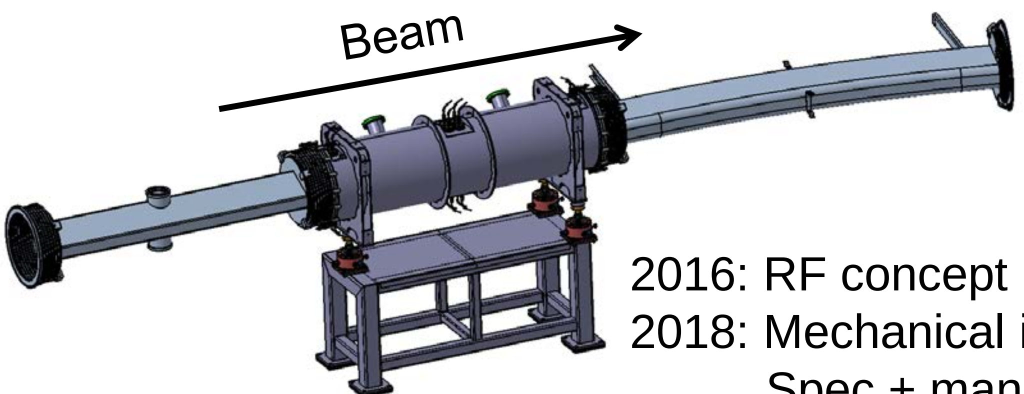


Figure 6: Pickup impedance and nonlinear phase deviation for Faltin rail structure B consisting of two rails of 49 slots each whose signals have been combined. The performance both with and without the presence of ferrite damping material is shown. Simulations are done with a beam centred vertically and with horizontal offset of 40 mm.



2016: RF concept + engineering ready

2018: Mechanical integration with BINP flanges/bellows
Spec + manufacturing drawings ready
for tendering the vacuum tank

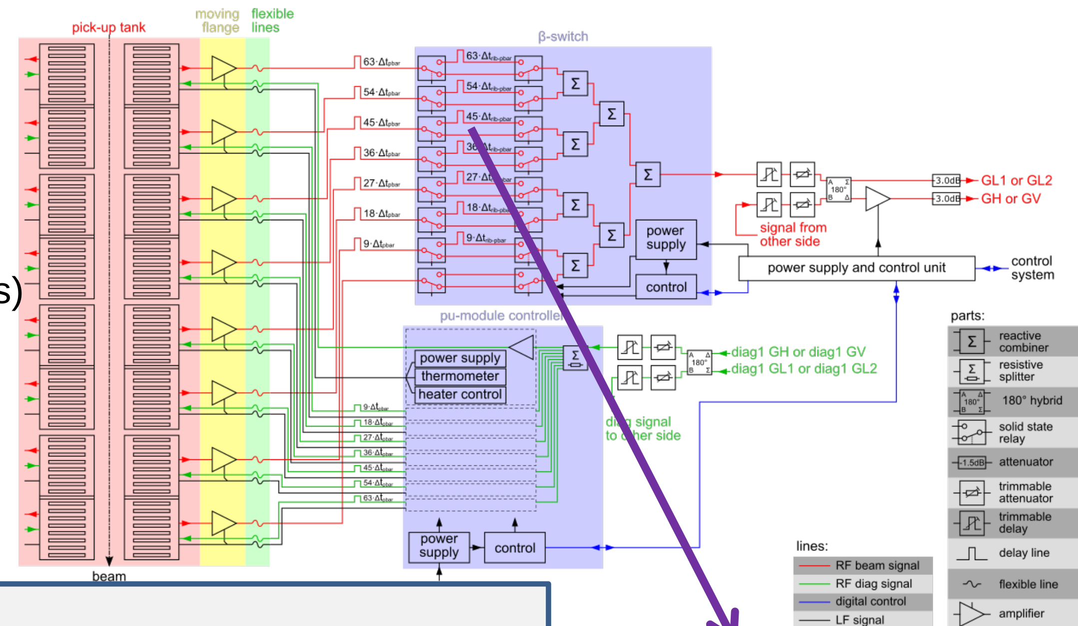
RF Signal Processing (1-2 GHz)

- typically, small series of RF components with stringent requirements for amplitude flatness & phase linearity in the band 1-2 GHz

- Striving for short electrical lengths (components & paths of the suspended RF cables) because signal transit time critically close to particle flight time from PU-Kicker

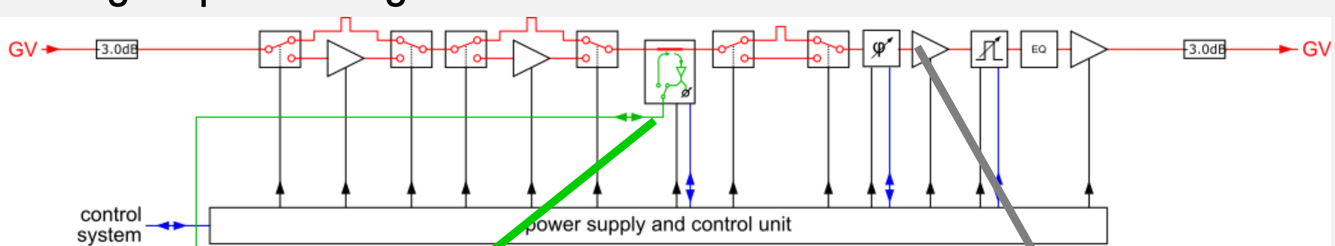
Low-noise (NF ≤ 0.5 dB, T_N ≤ 35 K) preamplifiers at 290 K: procurement

Pick-Up Tank RF (One Side Shown)



Beta switch; variable attenuator: ready

PU signal processing vertical



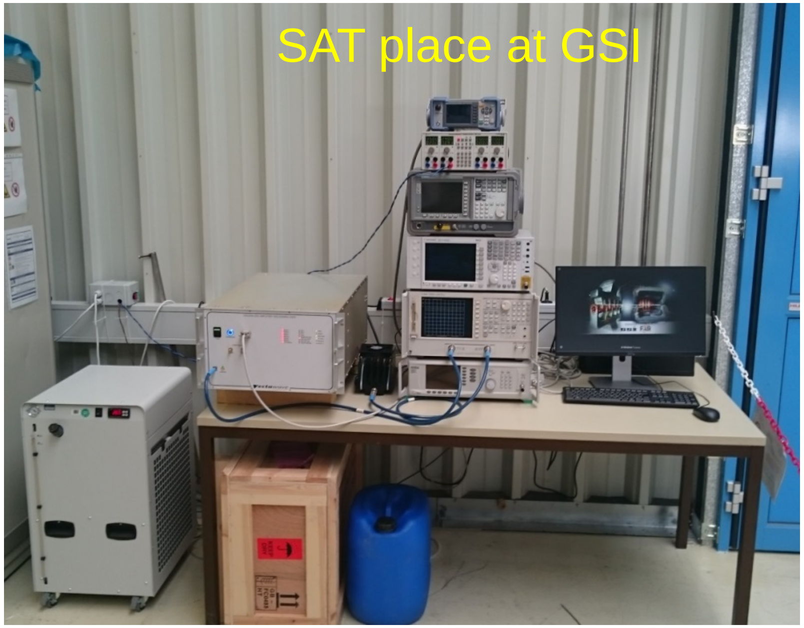
embedded power meter ready

variable phase shifters in-house design ready

see talk by C. Peschke/ S. Wunderlich

Power Amplifiers

8 kW installed microwave CW power at the kickers for cooling
34 Power amplifiers (250 W each) is a large cost factor.
Procurement contract in 2014.

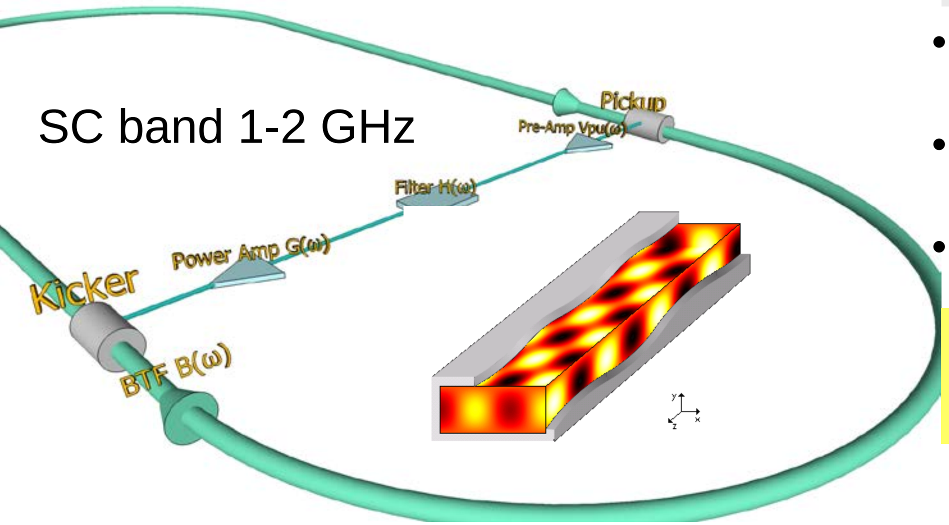


- Improved FoS with re-designed RF-module fulfills specifications at SAT (Q4/2017).

- But, reliability issue: RF-Combiner re-designed, FAT (Q2/2018)
- successful long-time SAT of FoS (Q3/2018)
- launched the series production

see talk by C. Peschke/ S. Wunderlich

Microwave (mw) Damping for SC



- Large aperture machine
  many propagating RF modes; low cut-off freq.
- High gain (>130 dB) in signal paths for fast SC; short beam path Palmer PU-KI
- NO in situ bakeout in the CR

Passive, UHV-compatible, RF-absorbing (@1-2 GHz mw range) materials

E-fields applied at SC kickers excite RF modes:
SC = wanted closed loop (feedback) system
beam vacuum chambers are waveguides = unwanted closed loop system

→must suppress possible amplitude oscillations & phase ripples from unwanted modes

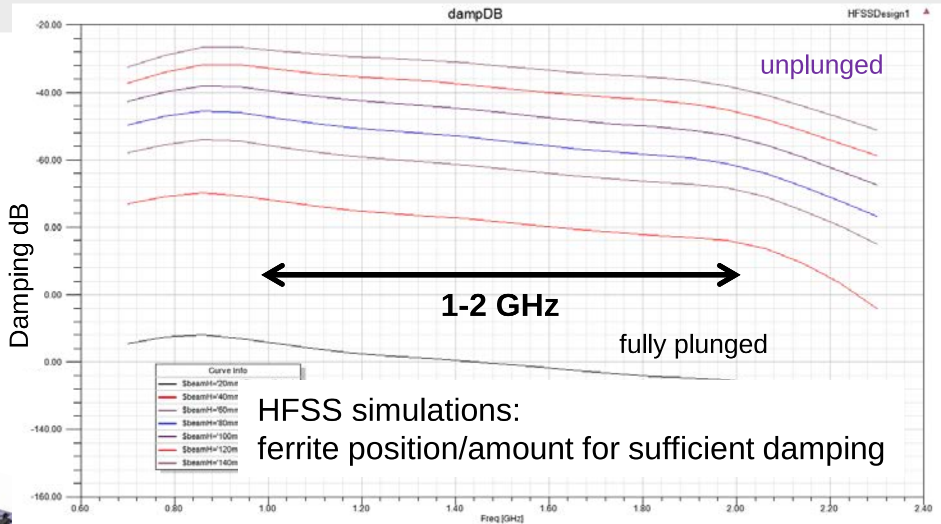
- **Concept ready** using:

-ferrite absorbers inside SC pickups & kickers (magnet free regions)
-resistively coated ceramic tubes inside quad/sext. magnets

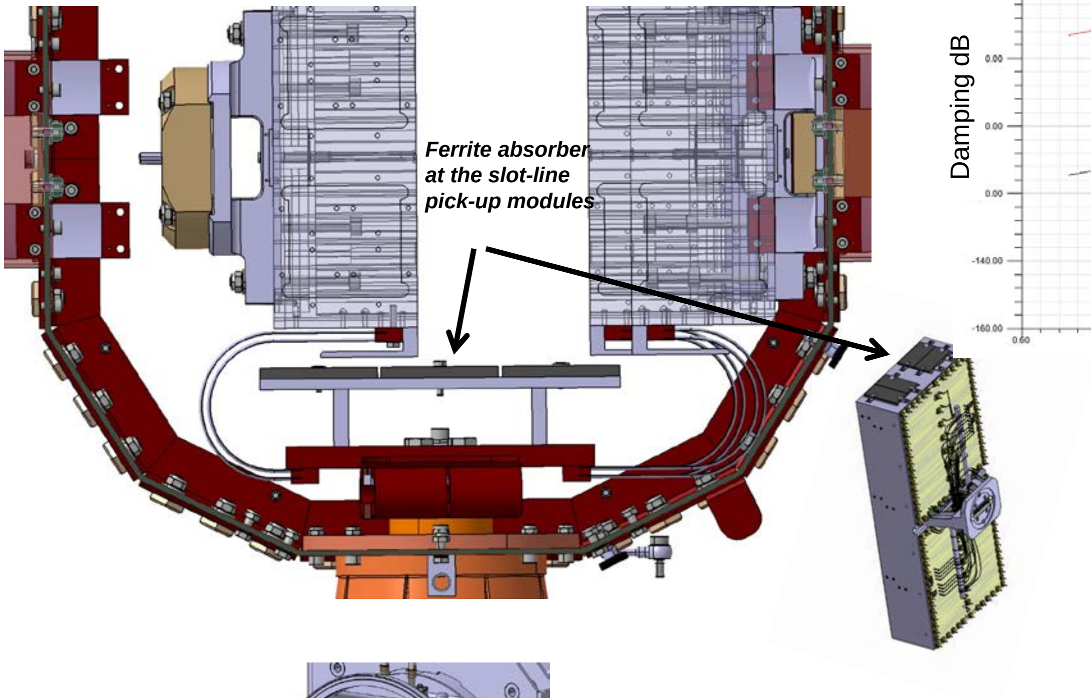
- Close monitoring with industry and CERN pioneers (Fritz Caspers)
  to optimize cost, time and effort.

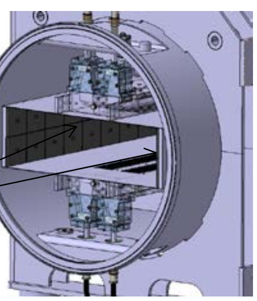
Microwave Damping-Ferrite Absorbers

Ferrite absorbers inside SC pick-ups & kickers (≤ 2 m² per tank)



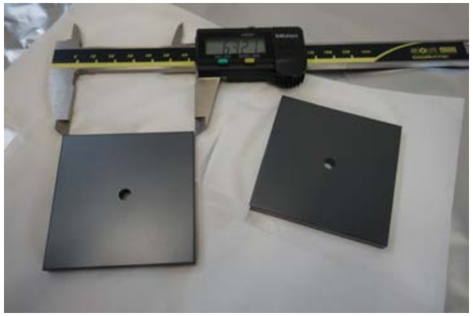
HFSS simulations:
ferrite position/amount for sufficient damping





Ferrite absorber at the Palmer pick-up electrodes

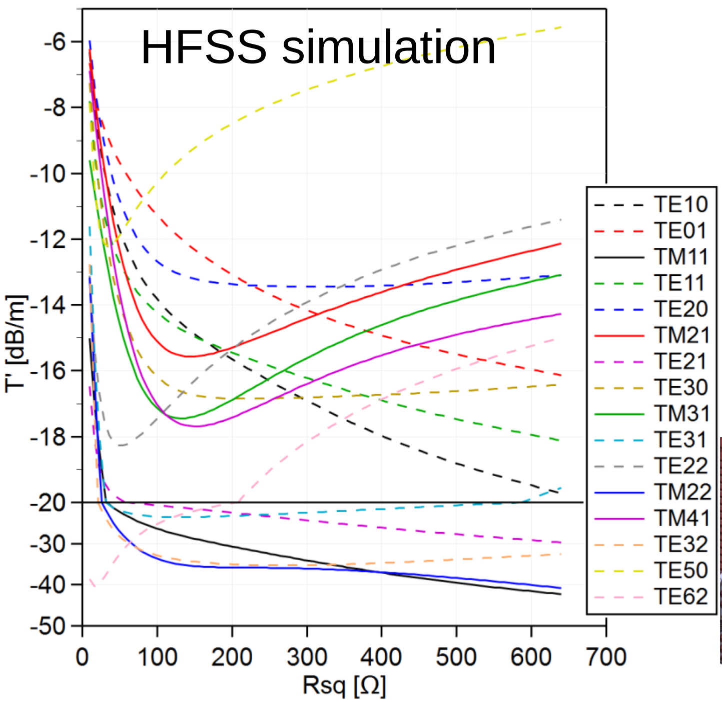
- **Ferrite design ready.**
- **UHV test done (outgassing rate acceptable).**
- **Ferrite tiles purchased for all pick-ups.**

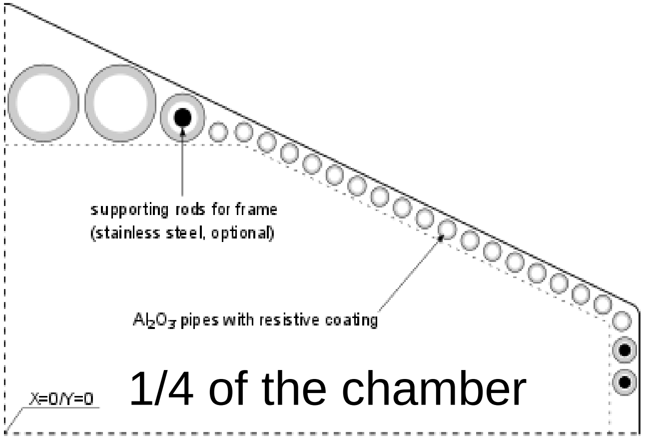


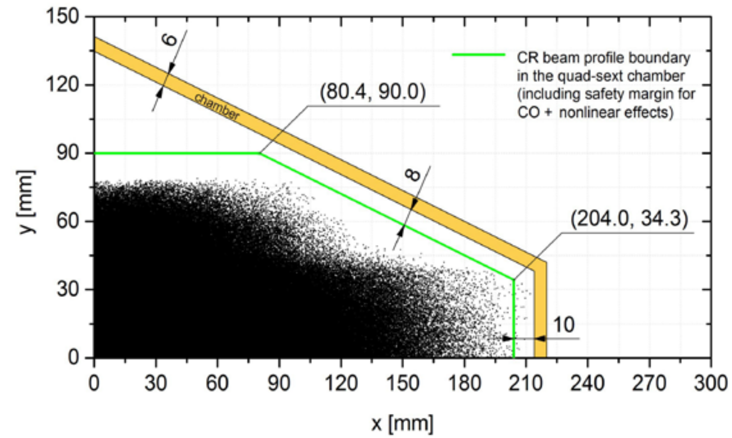
Microwave Damping-
Coated Ceramic Absorbers

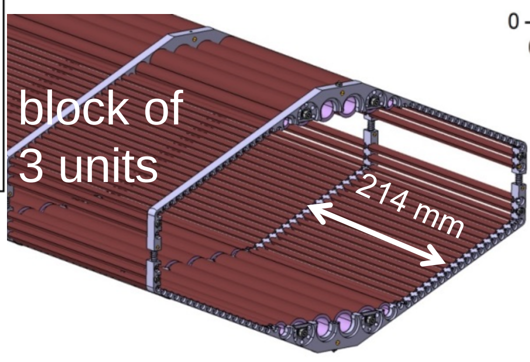
Resistively coated ceramic tube modules inside all hexagonal quadrupole/sextupole vacuum chambers in the CR arcs

- Al_2O_3 tubes (4 standard diameters ⌀6...24 mm), with resistive outside coating Rsq =150 Ω/□ ± 30%
- total module surface < 60 m^2 /arc.





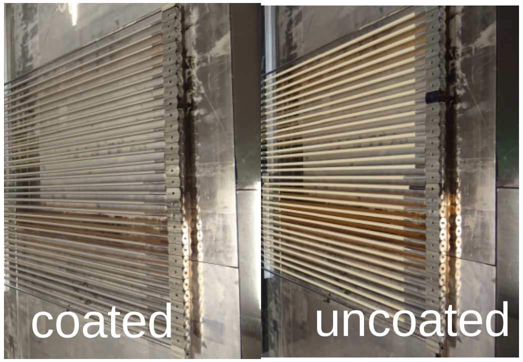


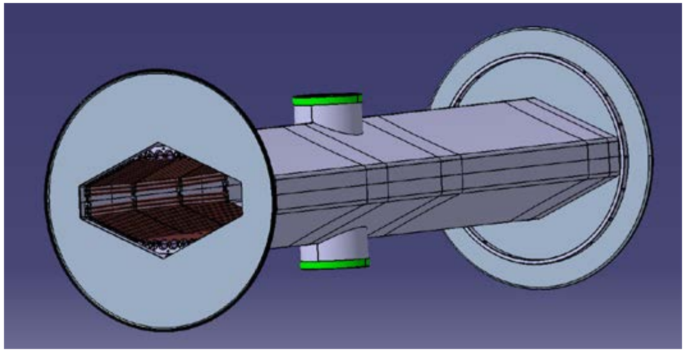


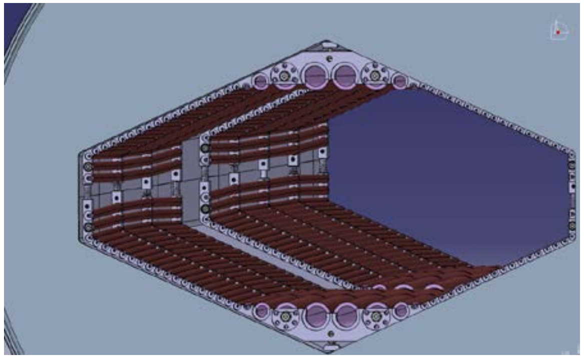
140 units (incl. 5% spares)

Microwave Damping-
Coated Ceramic Absorbers

- Draft engineering concept ready.
- First batch of Al_2O_3 tubes for prototyping coated (by NiCr-sputtering at ISE Freiburg).
- UHV test done (outgassing rate acceptable). RF test planned.
- 2019: Procure and store series of tubes.
- Q2/2019: assembly and full damping tube concept test after delivery of a prototype chamber by BINP.
- Procurement of the series of holders if tested successfully.

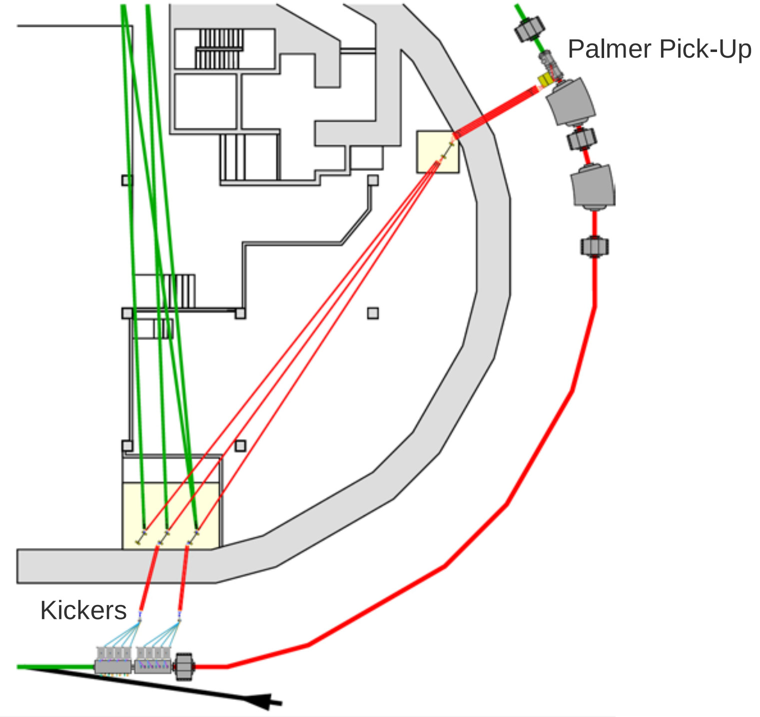


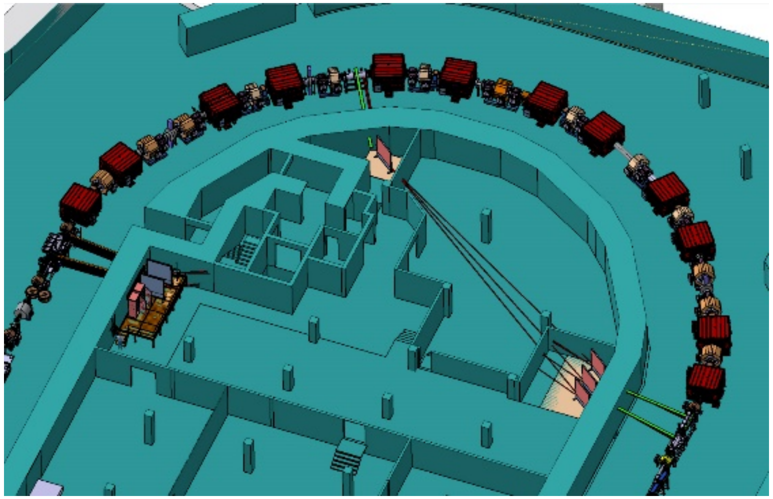




CR SC – Building Integration

- No reserve for signal path time with respect to the ion beam flight time from Palmer pick-up to kickers.
- Optimization of the signal path is ongoing.
- Current solution by changing the position/angle of the holes for the signal path in the inner building wall.
- Corresponding change request will be submitted to FAIR S&B until end of 2018.





Required CR stochastic cooling performance

- **Short bunch of hot secondary beam (pbars/RIBs) from production target into the CR**
- **After bunch rotation & adiabatic debunching, the δp/p of the coasting beam is low enough to cool all particles**
- **Fast 3D stochastic cooling necessary for maximum production rate of secondary beams**
- **The CR delivers to the HESR (i) pre-cooled pbars for accumulation and PANDA experiment and (ii) (pre-cooled) stable ions/ pre-cooled RIBs for in-ring experiments**

For HESR downstream: no safety margin, larger values can be accepted

CR TDR 2016 (Stoch. Cooling part)	**Antiprotons 3 GeV, 10^8 antiprotons**		**Rare isotopes/stable heavy ions 740 MeV/u, cooling of 10^8 ions** (max. 10^9 ions in ring)	
	δp/p (rms)	$\varepsilon_{h,v}$ (rms) [π mm mrad]	δp/p (rms)	$\varepsilon_{h,v}$ (rms) [π mm mrad]
Before/after cooling	0.35 % / 0.05 %	**40 / 1.25**	0.2 % / 0.025 %	**35 / 0.125**
Phase space reduction	7×10^3		6×10^5	
Cooling down/cycle time	$\leq$ 9.7 s / **10 s**		$\leq$ 1.4 s / **1.5 s**	

From the CERN/Fermilab experience→ Cooling of pbars is very demanding!

From the ESR experience→ Very fast cooling of hot RIBs is challenging!

Stable ions come from the synchrotrons with better beam quality than RIBs→ relaxed

Cooled pbars from CR to HESR

see talk by T. Katayama

CR
cooled coasting beam

if possible
$\delta p/p$ (rms) ≤ 1.7 ·10^{-4}
to avoid beam loss
during transfer

CR
rebunching for transfer
$\delta p/p$ increases by x 3.5 (*)

HESR
adiabatic debunching option:
reduce $\delta p/p$ to match acceptance
before notch filter cooling

Simulations of pbar cooling:
most critical case

HESR acceptances
$\delta p/p = 6 \cdot 10^{-4}$ (rms); ± 1.8 ·10^{-3} (±3 σ)
(notch filter stoch. cool system)
transverse x,y= 2.6 π mm mrad (rms)

*T. Katayama, Bunch length, bunch rotation and stochastic cooling of 3 GeV pbar beam in the CR, internal report, February 2016.

Thank you for your attention!