Stochastic cooling system for the Collector Ring at FAIR

Update & Progress Report

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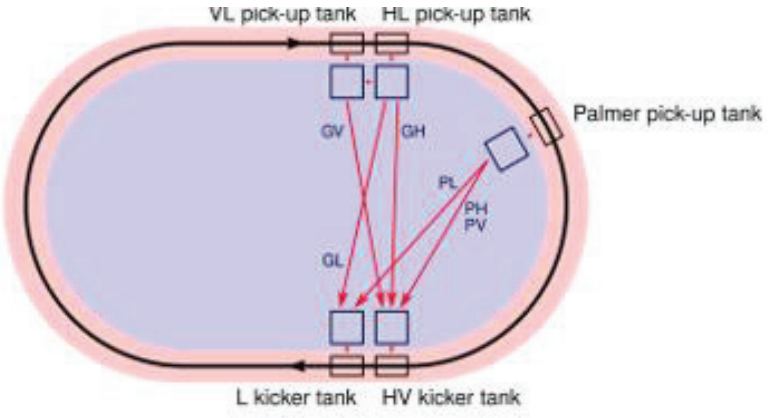
Special acknowledgements to: Lars Thorndahl, Fritz Caspers, Takeshi Katayama

Stochastic Cooling at Collector Ring

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

3D stochastic cooling (band 1-2 GHz) of coasting beams, max. 10^8 ions (antiprotons @ v = 0.97c , rare isotopes/stabe heavy ions @ v = 0.83c)



For antiprotons: increase ratio $\frac{\text{Schottky signal } (\propto Q^2)}{\text{thermal noise}}$

Slot-line PU electrodes cryo 30-40 K + plunging

notch filter for long. cooling
(cooling force + noise suppression around rev. harmonics)

lattice: $|\eta_{pk}|$~0 against undesired mixing;
small $|\eta|\approx 1\%$ for max notch filter momentum acceptance
~1/ $(|2\, x_{pk}\eta_{pk}+\eta|\cdot\Delta p/p)$ for the full initial pbar beam

Cooling branches and their purpose

Slotline Pick-ups HL, VL→ Kickers HV, L
notch filter longitudinal cooling method

- antiproton cooling;
- rare isotopes final-stage cooling;
- stable ions cooling.

Palmer pick-up → Kickers HV, L
Palmer 3D cooling method
rare isotopes 1st-stage cooling (pre-cooling)

For hot RIBs: undesired mixing (from PU to KI)

1st stage: Pre-cooling via Palmer PU, at D=6 m
2nd stage: Cooling stage via slotline pickups and notch filter

CR Stochastic Cooling System 1-2 GHz

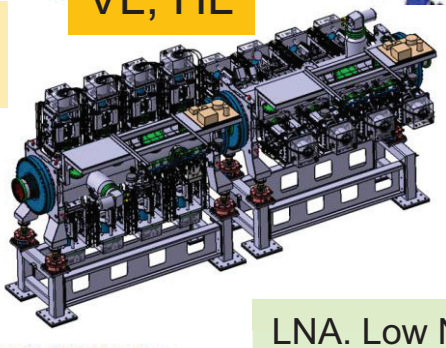
CR UHV aim for requested beam lifetimes of 100 s:
basic static P ≤ 3 ·10^{-9} mbar (N_2 equivalent) at room temperature, **without in situ bakeout**

C=221.45 m
Bρ=13 Tm

Beam

2 cryogenic plunging PUs
(slotline electrodes)

VL, HL



Palmer PU
(Faltin
electrodes)

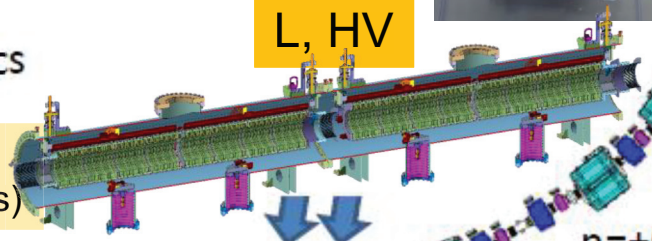
32x 250 W mw
power amps at
kickers
Total=8 kW
to cool in
all planes

Many RF-components
and cables in the building

LNA. Low Noise
preamps at PUs
≤ 43K (≤ 0.6dB)

Microwave damping tubes in all
quad/sextupole chambers in the arcs

L, HV



2 kickers
(slotring electrodes)

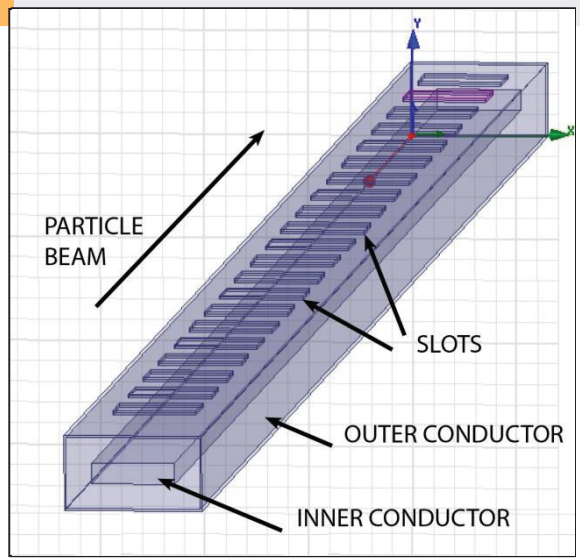
$$\eta = \frac{1}{\gamma^2} - \frac{1}{\gamma_{tr}^2}$$

η=+0.014/-0.011 pbars
η=0.18 RIBs

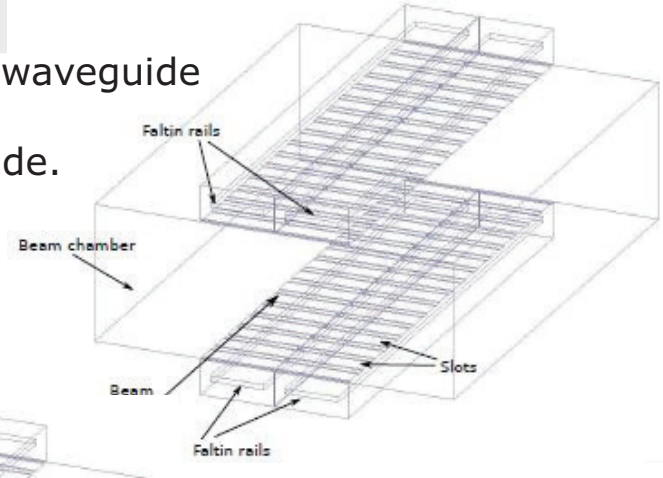
CR optics, lattices, apertures
(frozen since 2016) so as
to serve the stoch. cooling

System bandwidth 1-2 GHz

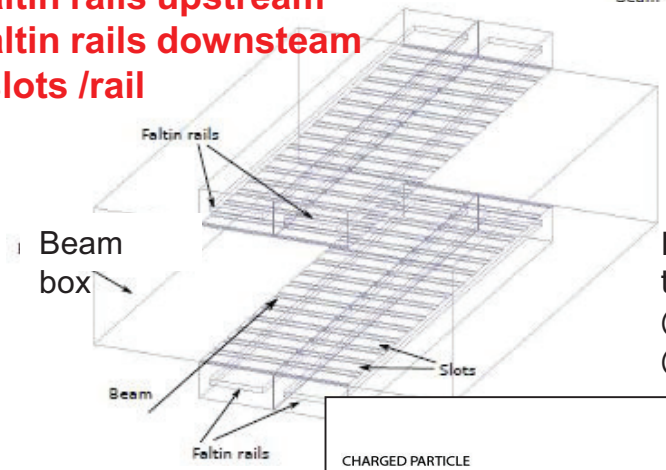
Palmer Pick-Up



A Faltin PU=rectangular coaxial waveguide with slots which couple energy from the beam into the waveguide.
Synchronisation by design
$V_{phase} = V_{particle}$ *RIBs 0.83 c*



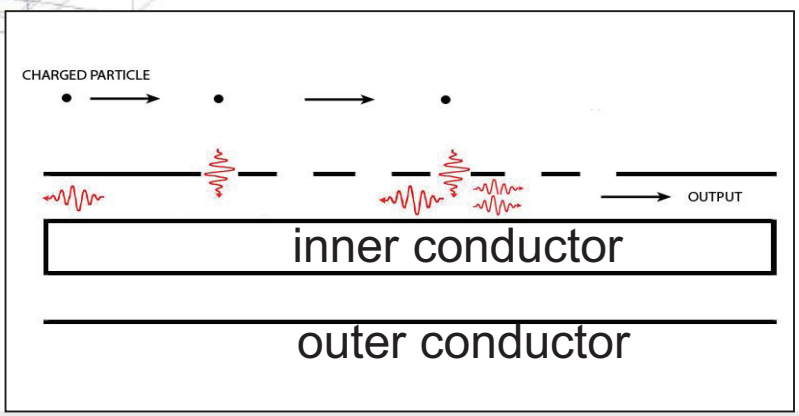
Palmer PU=
4 Faltin rails upstream
4 Faltin rails downsteam
49 slots /rail



Rare isotopes have high Q→ strong signal.

Faltin electrodes:
flat freq. response but large/ insensitive.
compromise high coupling impedance ←→ high phase nonlinearity

Real life: phase slip between travelling wave and particle
@low f : $V_{phase} > V_{particle}$
@high f : $V_{phase} < V_{particle}$

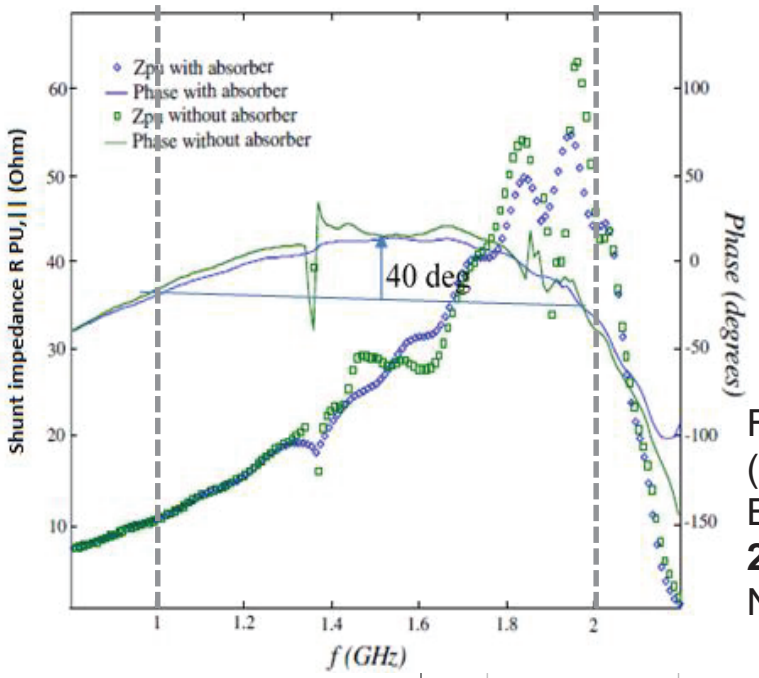


specified fixed electrode apertures :
Horizontal/Vertical = ± 200 mm/ ± 66 mm w.r.t. beam axis

need to fill the beam box with ferrite to damp the unwanted rf modes in 1-2 GHz

L. Faltin, Nucl. Instr. and Meth. 148, p.449-455, (1977).

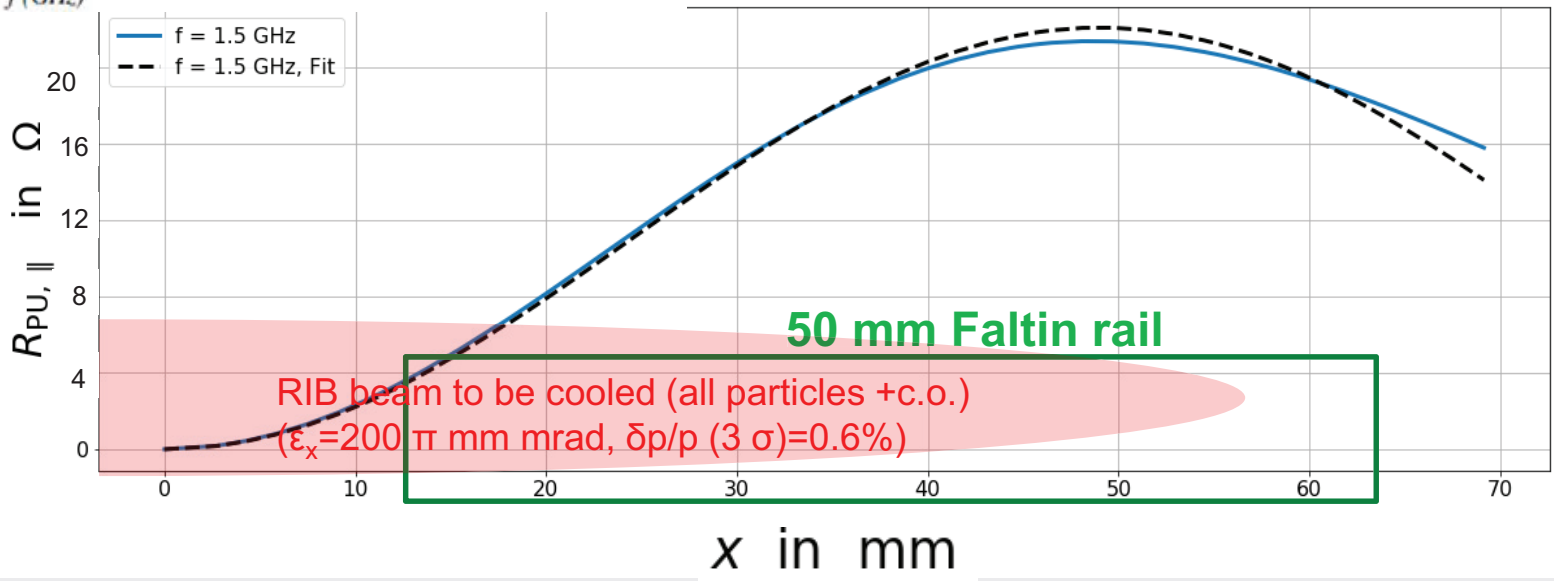
Palmer Pick-Up



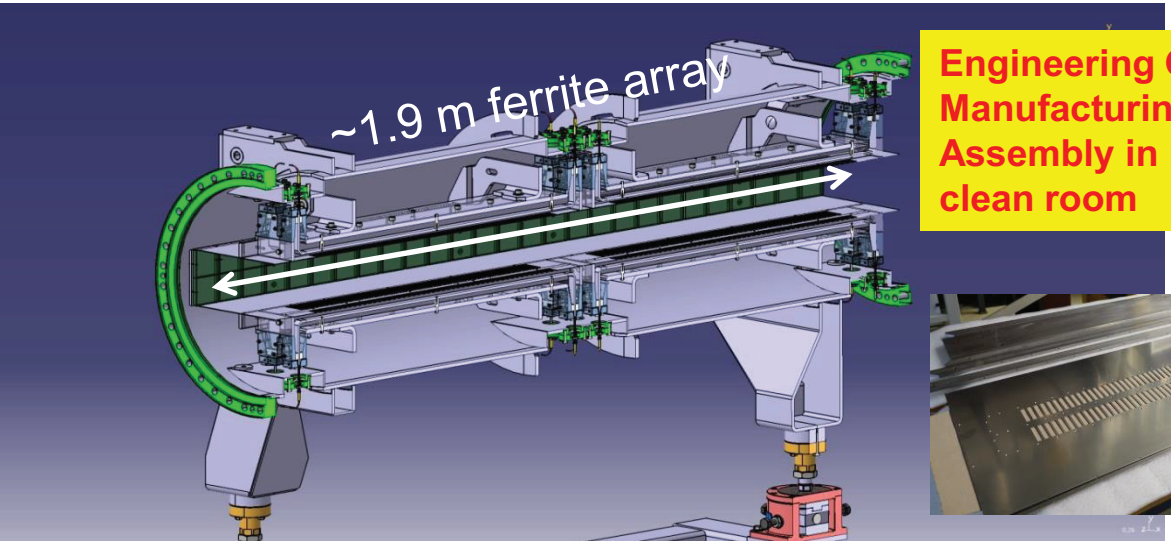
Structure designed & optimised with HFSS code in the band 1-2 GHz
D. Barker, L. Thorndahl et al. COOL'15

Cross-checked, confirmed with CST code
B. Breitkreutz 2020

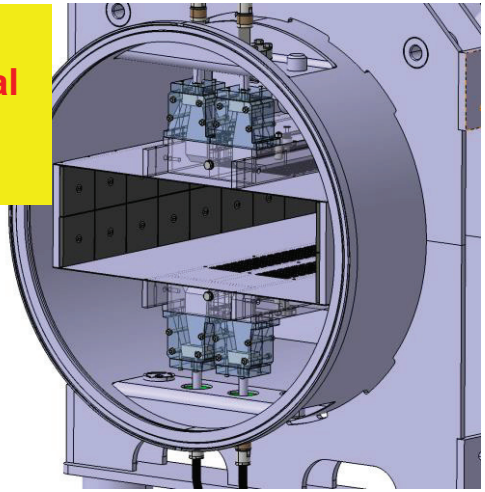
Full shunt impedance Palmer PU tank
(along the beam 2 rails x 49 slots each, whose signals combined)
Beam fixed at y = 0 with horizontal offset x = 40 mm.
24.5 Ω at mid band 1.5 GHz.
Non-linear phase deviation ≤ 40^0 within 1-2 GHz.

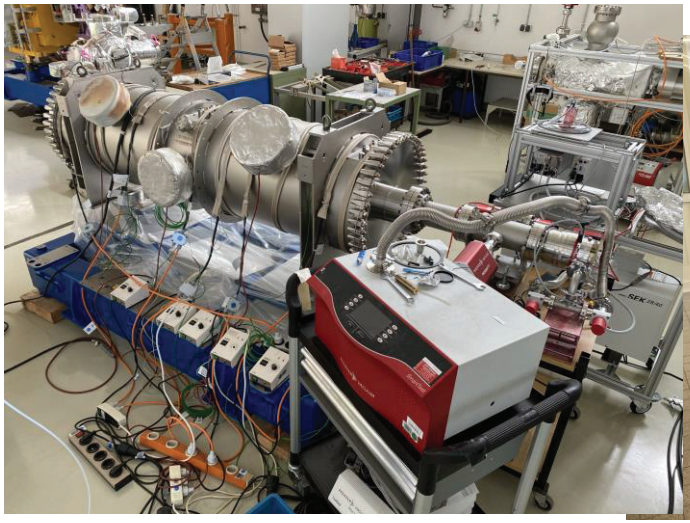


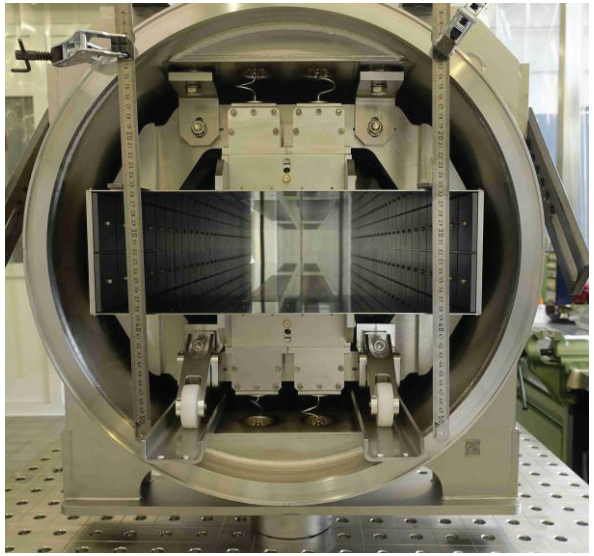
Palmer Pick-Up



Engineering GSI
Manufacturing GSI/external
Assembly in FZJ ZEA-1 clean room

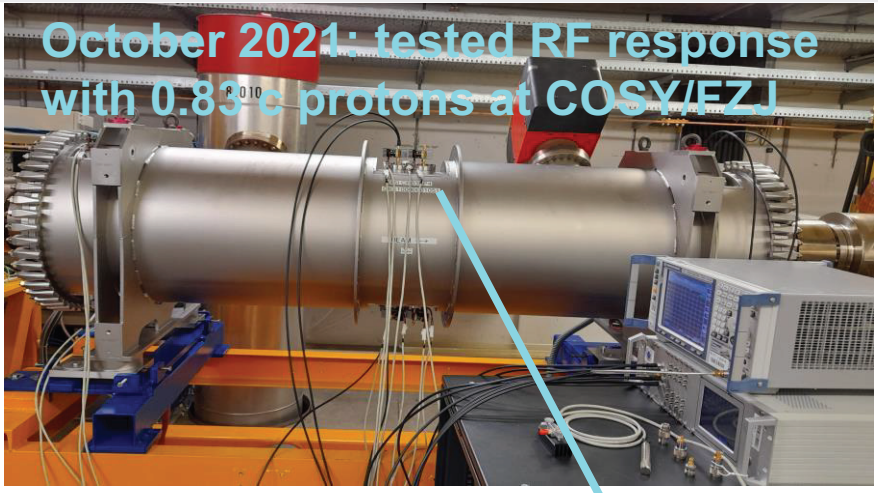




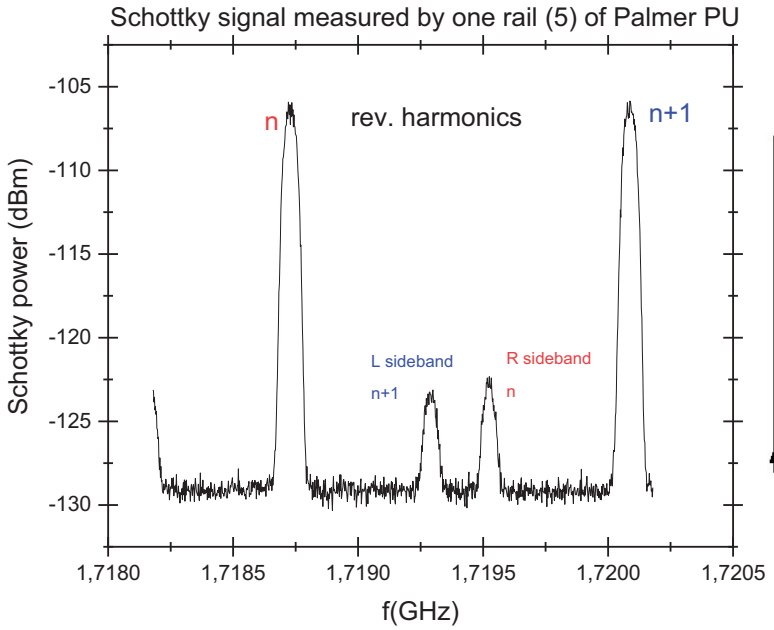


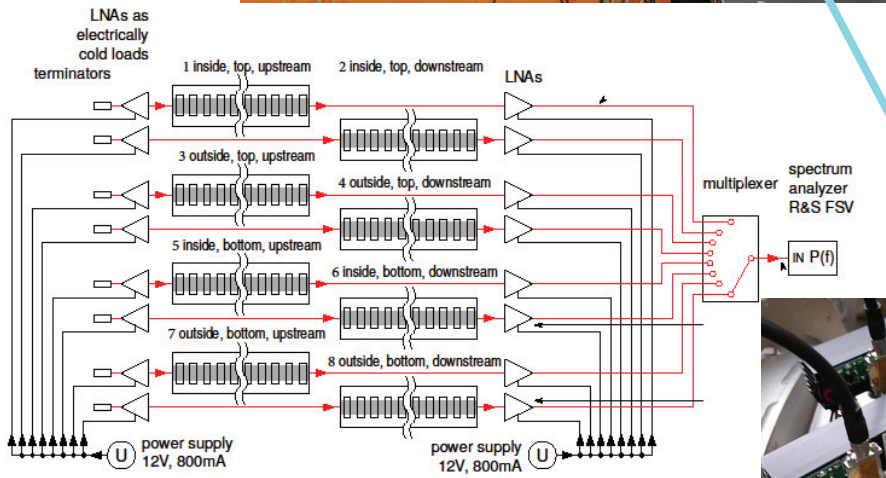
Palmer Pick-Up: Test with beam

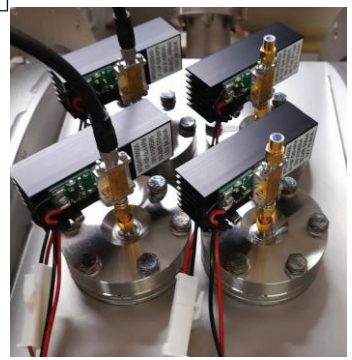
all 8 rails work!!
deliver good signals
at characteristic beam frequencies
(rev. harmonics + vertical betatron)



coasting beam, v=0.83 c
$N=1.8 \cdot 10^{10}$ protons



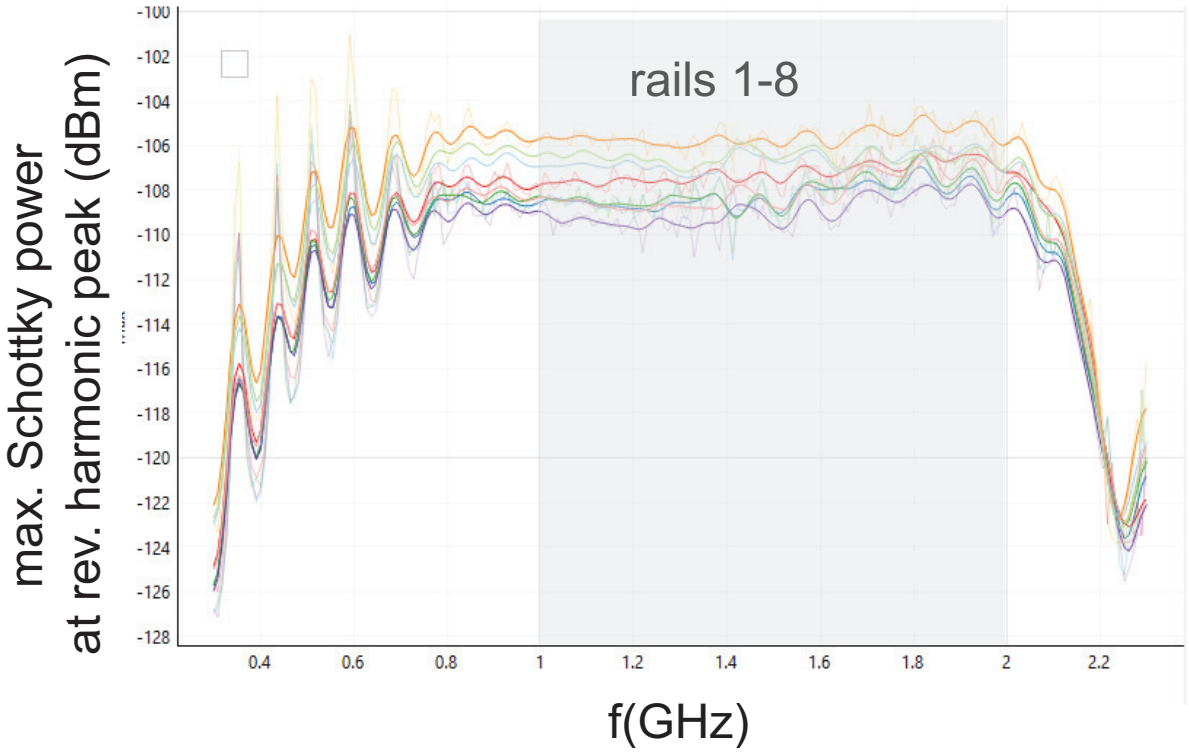




Palmer Pick-Up: Test with beam

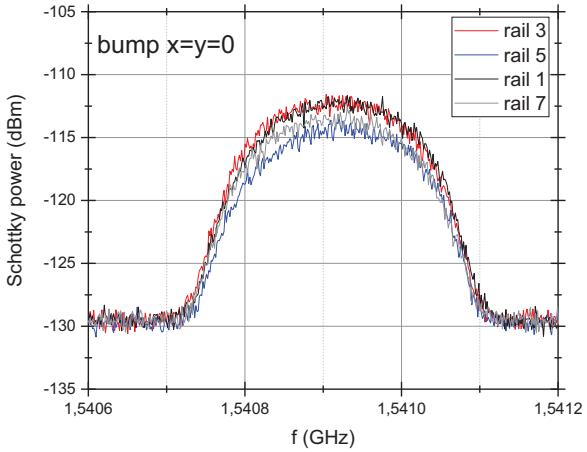
Qualitative raw data control plot showing similar response from all 8 rails

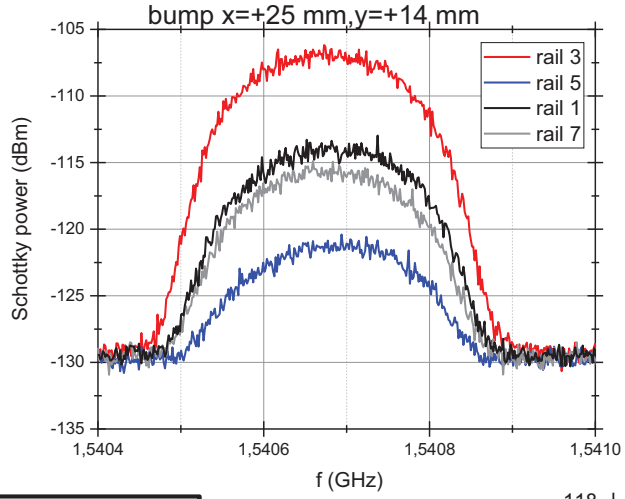
-NOT rail impedance vs f !
-NOT corrected for Schottky noise versus n, beam intensity, LNA/cabling a.o.
-proper analysis underway to extract f-variation of impedance



Palmer Pick-Up: Test with beam

Rail signals for local orbit bumps of the beam in Palmer PU

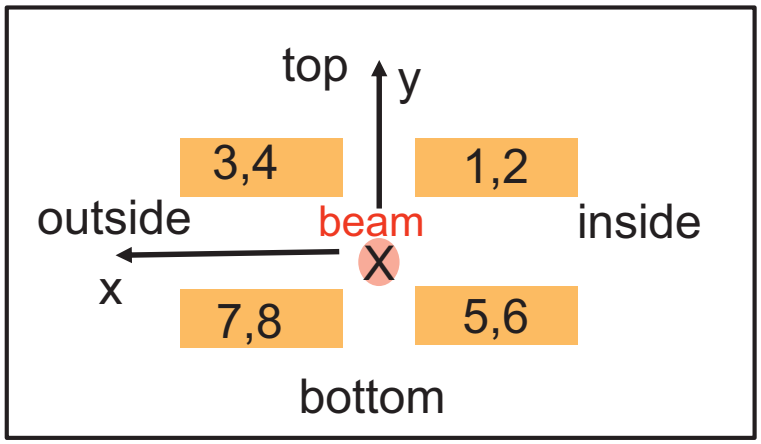


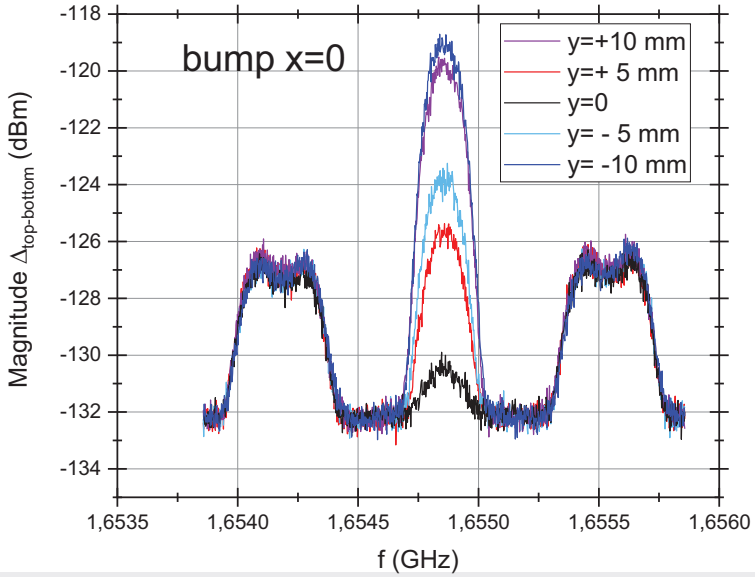


slightly bunched beam,
v=0.83 c
N=1.6 ·10^{10} protons

raw data
from spectrum analyzer

Δ-mode vertical =
Σtop(1,3)-Σbottom(5,7)

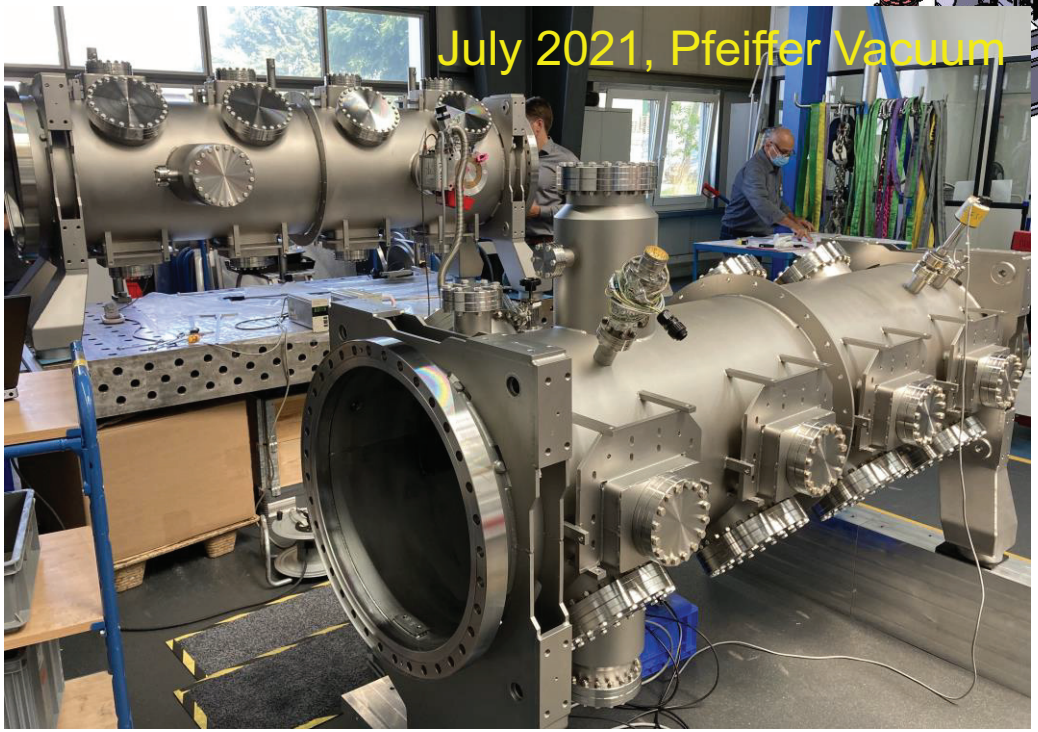


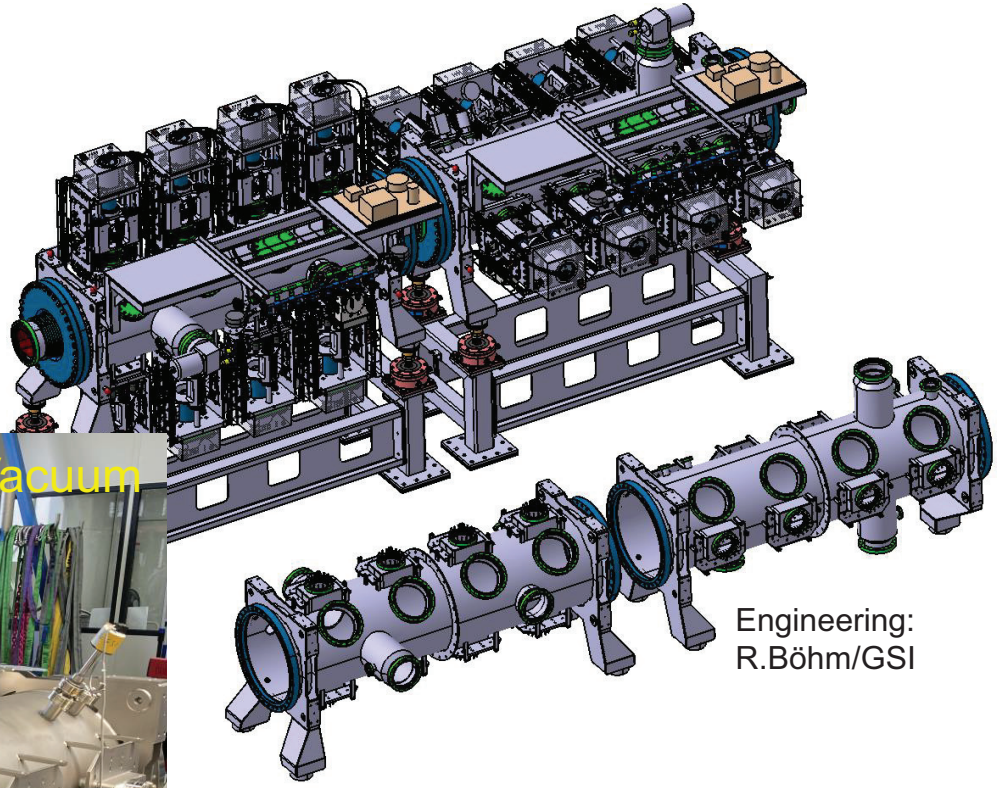


At Palmer PU
D= - 15 m ; rms beam size (x/y)= 4/9 mm

Cryogenic Plunging Pick-Ups

2 vacuum tanks being manufactured according to GSI drawings.
Expect FAT & delivery Q4/2021



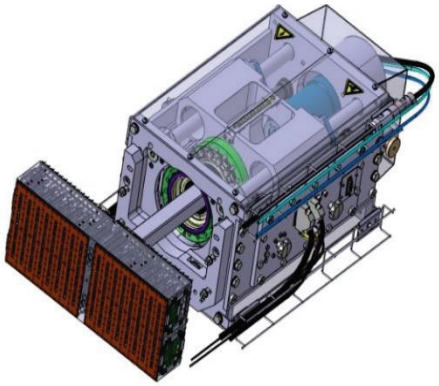


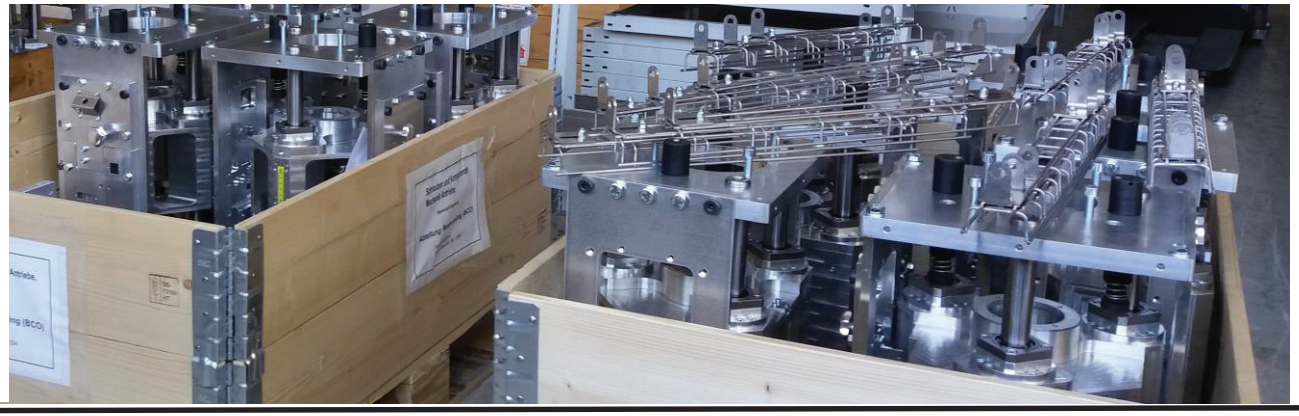
Engineering:
R.Böhm/GSI

Finalizing 3D engineering
& procurement
of inner subsystems

Cryogenic Plunging Pick-Ups

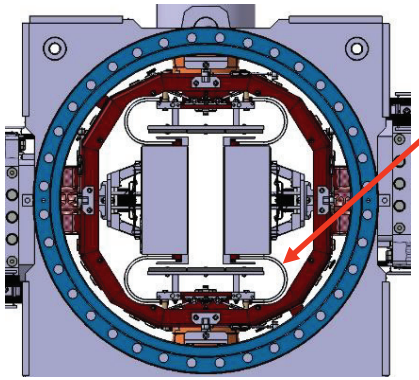
16 Motor Drive Units: ready, pre-assembled in house; stored see Poster PS003



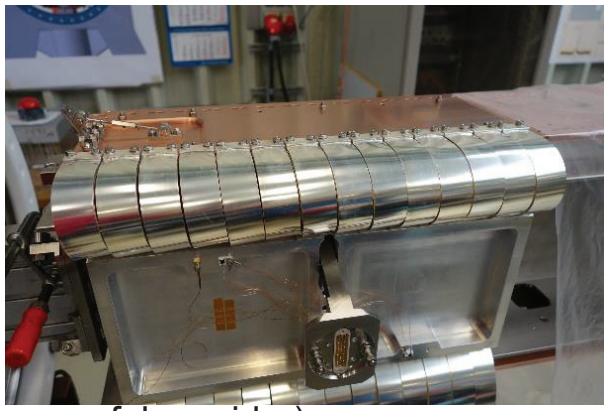


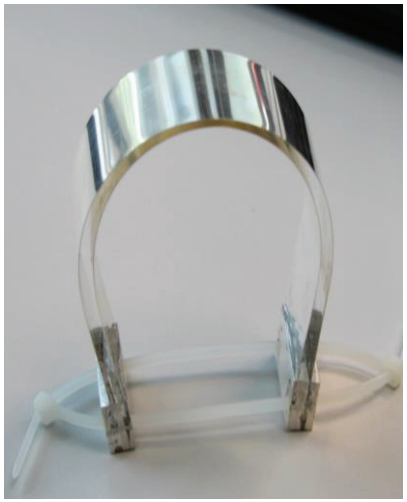
~3500 Ag/CuBe plunging foils and their Ag/Cu holders (incl. spares)

CuBe foils thermally treated in vacuum oven GSI TechLAB
2021-2022: galvanic Ag-plating (1 provider, manually)



Flexible Ag/CuBe foils at 30 K



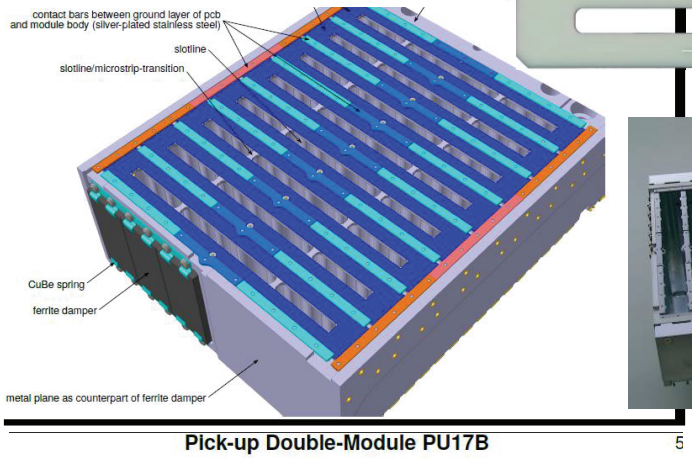


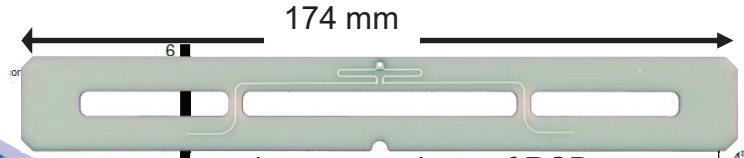
>2022: UHV soldering of foils on holders (1 succesful provider)

Slotline Electrode Module

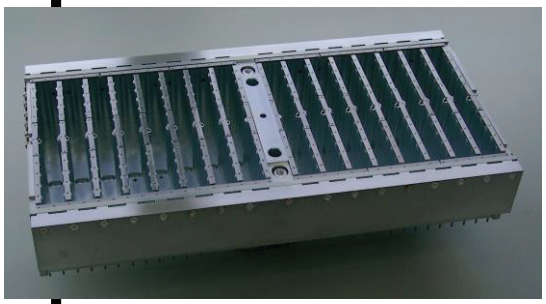
-re-designed for feasibility
-contracted full scope (pre-series, series, spares) metallised ceramic RF boards
-Prototype module: received all pieces & ceramics; full assembly & RF tests Q1/2022

8 single slot PCB
with 1 hole & 3 slots

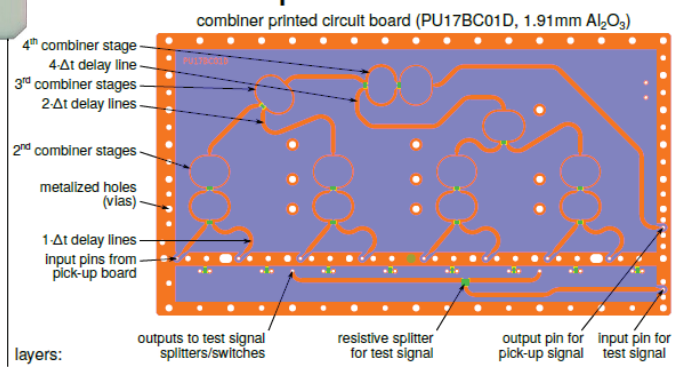




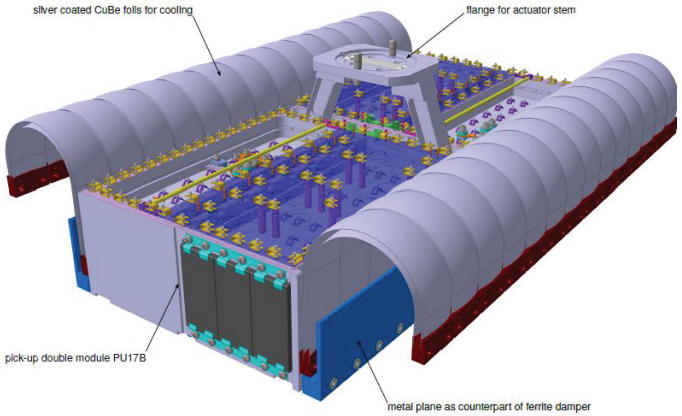
microscope photo of PCB



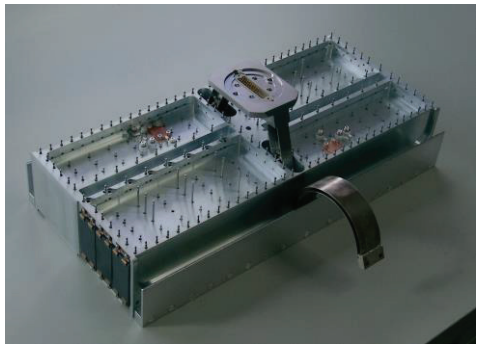
Pick-up Module PU17B Combiner Side

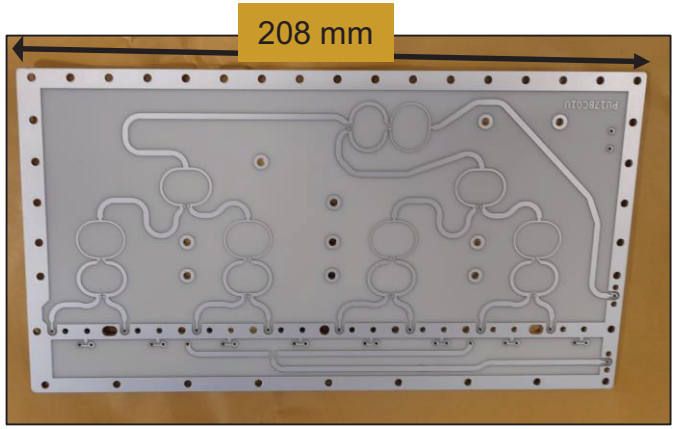


Pick-up Double-Module PU17B



2019 C. Peschke
Engineering: M.Meister/GSI





Slotline Electrodes: RF Design

- **broadband within 1-2 GHz; high coupling impedance to the beam; optimized for antiprotons v = 0.97c**
- **impedance used in all simulations of stoch. cooling performance >2011 (C. Dimopoulou. T. Katayama, H. Stockhorst)**

circuit convention shunt impedance

$R_{PU,||} = P_{PU}/I^2_{b,rms}$

$R_{KI,||} = U^2_{b,rms}/P_{KI}$

$R_{KI,||} = 4 \cdot R_{PU,||}$

$$R_{PU,\parallel} = R_{PU,\parallel}(f_c) \cdot S^2(y) \cdot S^2(f)$$

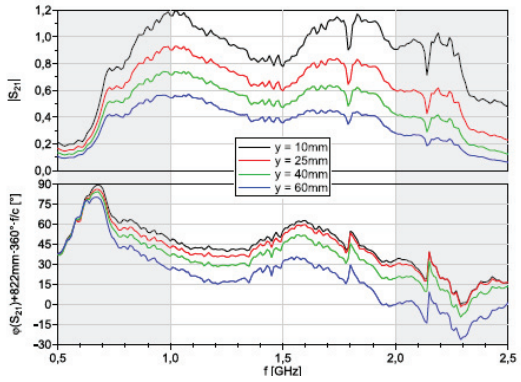
HFSS simulations, absolute values at 1.5 GHz:

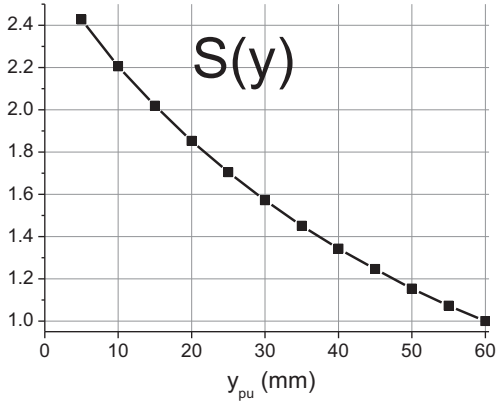
$R_{PU,\parallel}(f_c) = 11.25\ \Omega$ at $y_{PU} = \pm 60$ mm

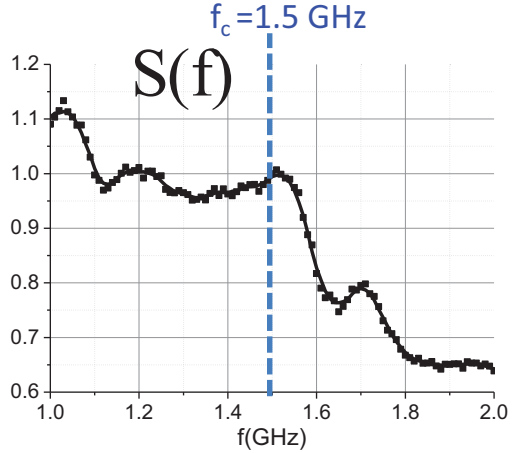
$R_{PU,\parallel}(f_c) = 37.75\ \Omega$ at $y_{PU} = \pm 20$ mm

L. Thorndahl 2005, confirmed C. Peschke 2018

Relative measurements on prototype PU:
C. Peschke 2009







But, thin metallised tracks on the ceramic boards will not withstand high power as kickers!
So, need more robust structure for kickers, with best possible impedance (as above).

see Poster PS002

Kickers

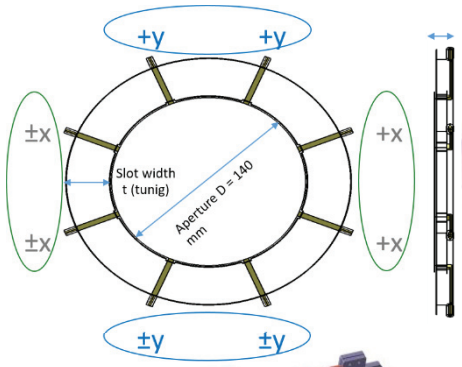
Decision to adapt the well-proven FZJ HESR slot-ring concept to CR case.

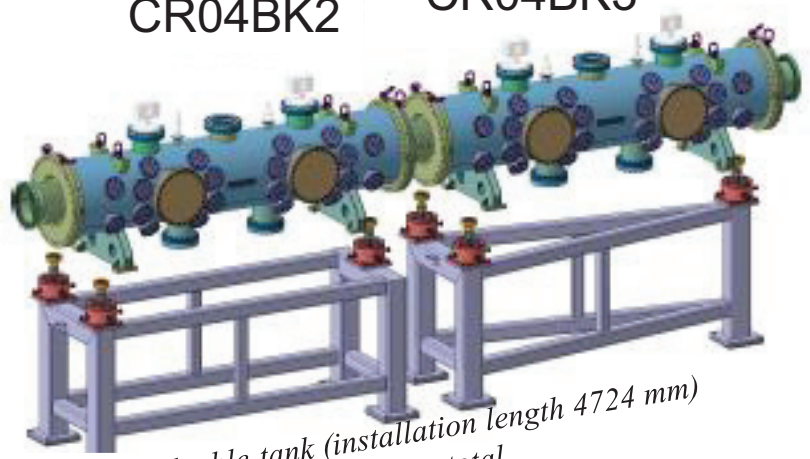
electrodes= slot-rings 1-2 GHz; 140 mm aperture

one tank transverse (HV); one tank longitudinal cooling

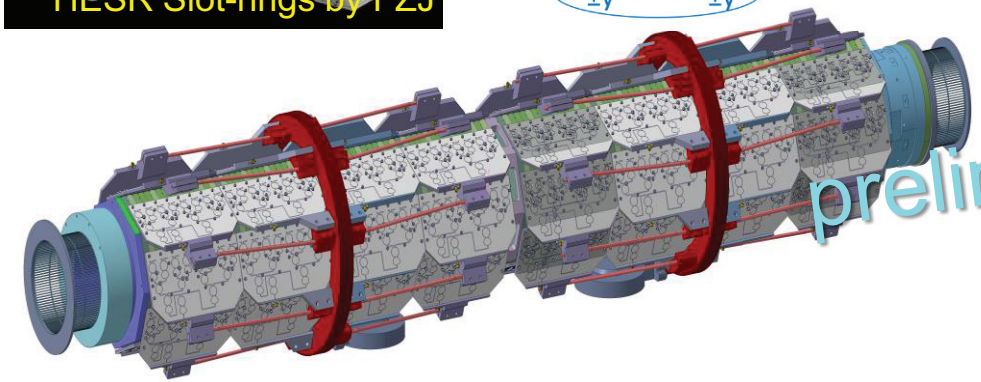
KHV
CR04BK2

KL
CR04BK3





double-tank (installation length 4724 mm) with 256 slot rings in total.



preliminary

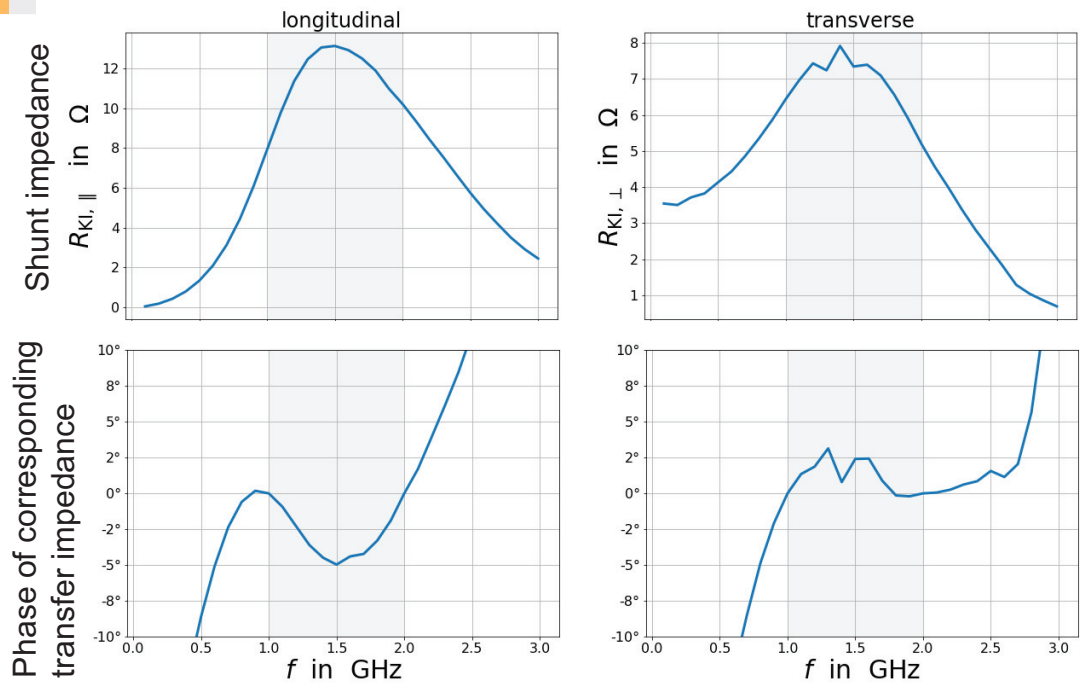
2x64 slot-rings (incl. splitter boards) in each tank

Challenges:

- Space limitations → constrained splitter board size
- Minimization of signal run-time from power amps to kickers
- Heat transfer from splitter boards

Contract for complete CR SC kicker tanks by FZJ team (R.Stassen, B.Breitkreutz, R.Greven): concepts (RF, mechanics, vacuum, cooling water), engineering, production & testing

Kickers : RF Design



For antiprotons v= 0.97 c

Values for one single ring,

with 4 of the 8 electrodes

Phase deviation ≤ *5°*

within 1-2 GHz

Maximum total impedances of kicker tanks		
Antiprotons $v = 0.97\ c$	$R_{KI,\parallel}$=3360 Ω	$R_{KI,\perp}$=1013 Ω
For RIBs $v= 0.83\ c$ ***about ½ the values***	128 rings 8 electrodes each	128 rings 4 electrodes each

Slotring kickers have very similar broadband impedance per unit length as the originally assumed slotline kickers → previous simulations of stoch. cooling performance still valid.

Collector Ring at FAIR Project

Budker Institute for Nuclear Physics (BINP)
Responsibility for the Collector Ring
Machine & System design,
integration of components,
all work packages except

GSI Responsibility (work packages)
RF systems (debuncher)
Stochastic cooling
Some beam diagnostics
Experimental devices (detectors)

The machine
(lattice, vacuum system, magnets, inj.-extr.,
power converters, diagnostics a.o.)

essential for the scope of CR
~40% of its budget

References:
BINP CR Technical Design Report Annex 1, 2016
https://edms.cern.ch/document/1608518/7.6.1
GSI CR Stochastic Cooling WP 2.5.10 Technical Design Report, 2016
https://edms.cern.ch/document/1682639/1
GSI Status reports + stoch. cooling simulations in COOL Proceedings > 2007

Thank you for your attention!