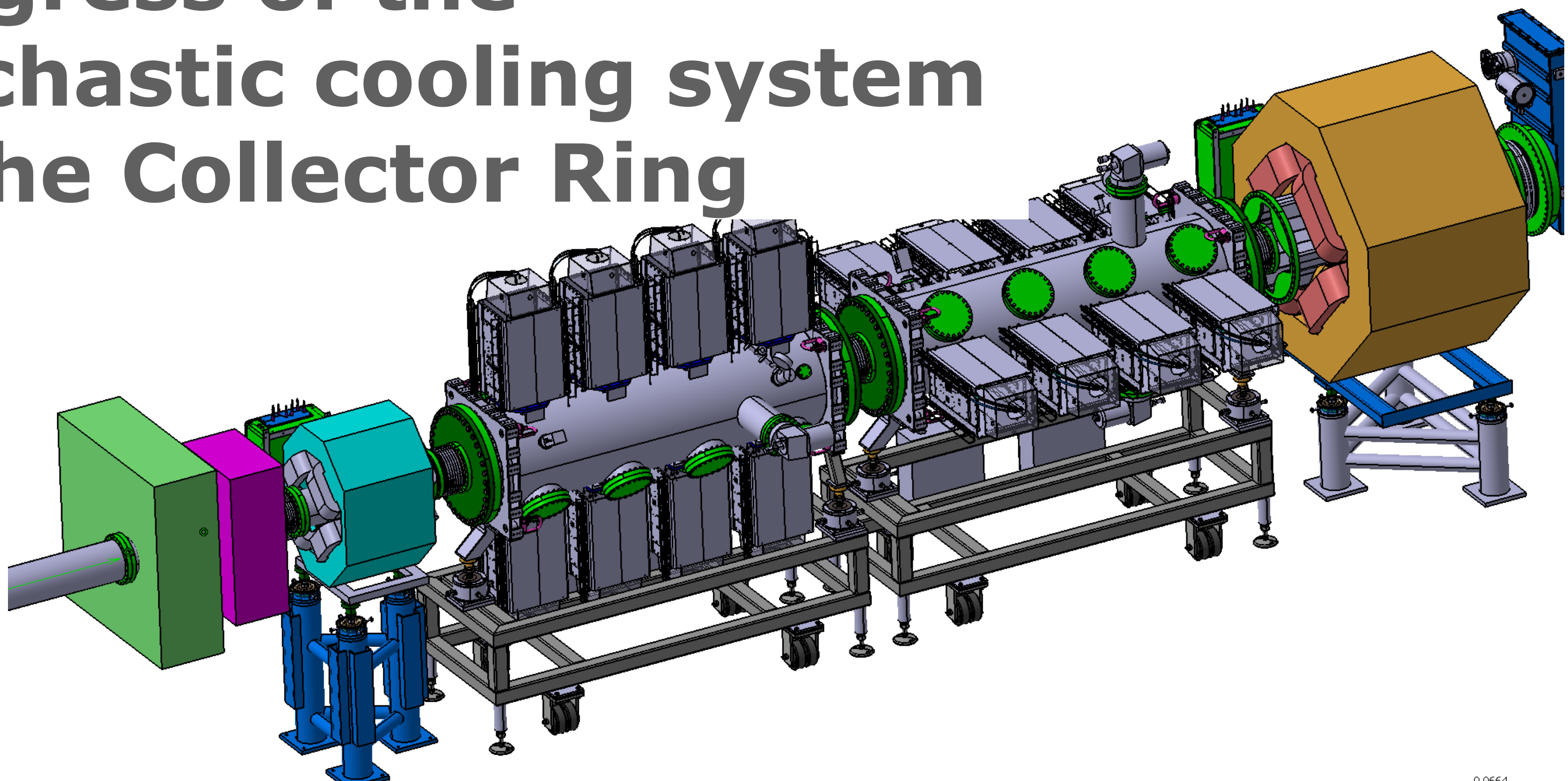
Progress of the stochastic cooling system of the Collector Ring



C. Dimopoulou, D.Barker, R.Böhm, O.Dolinskyy, B.Franzke, R.Hettrich, W.Maier, R.Menges, F.Nolden, C.Peschke, P.Petri, M.Steck, L.Thorndahl

COOL'13, Mürren, Switzerland

Required performance of the CR stochastic cooling

- **Short bunch of hot secondary beam (pbars/rare isotopes) from production target into the CR**
- **After bunch rotation & adiabatic debunching, the δp/p of the coasting beam is low enough for stochastic cooling of all particles**
- **Fast 3D stochastic cooling necessary for maximum production rate of secondary beams**
- **The CR provides the HESR (i) with pre-cooled pbars for accumulation as planned in the first FAIR phase and (ii) with (pre-cooled) stable ions/rare isotopes for in-ring experiments**

	Antiprotons **3 GeV, 10^8 ions**		**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 %	45 / 1.25	0.2 % / 0.025 %	45 / 0.125
Phase space reduction	9×10^3		1×10^6	
Cooling down/cycle time	≤ 9 s / **10 s**		≤ 1 s / **1.5 s**	

Challenges and design criteria

Main issue for antiprotons: increase ratio

$$\frac{\text{Schottky signal } (\propto Q^2)}{\text{thermal noise}}$$

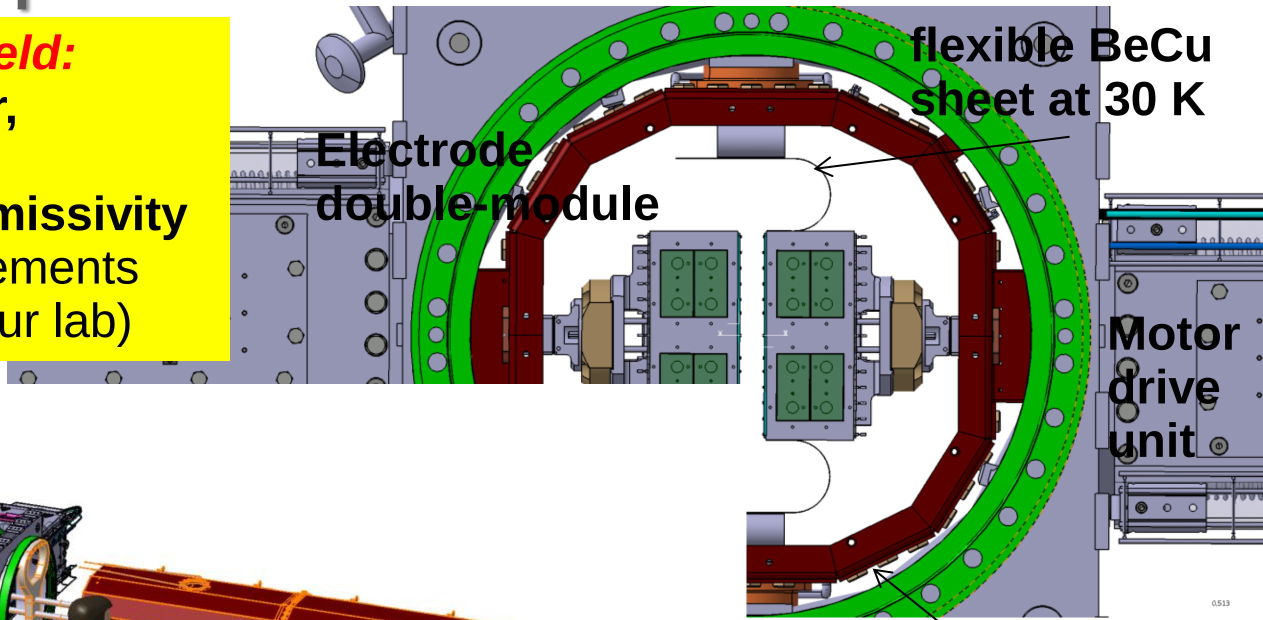
- **Pick-up electrodes cooled at 20-30K**
- **Plungeable pick-up electrodes i.e. moving closer to the beam during cooling**
- **Notch filter momentum cooling for noise suppression around revolution harmonics**

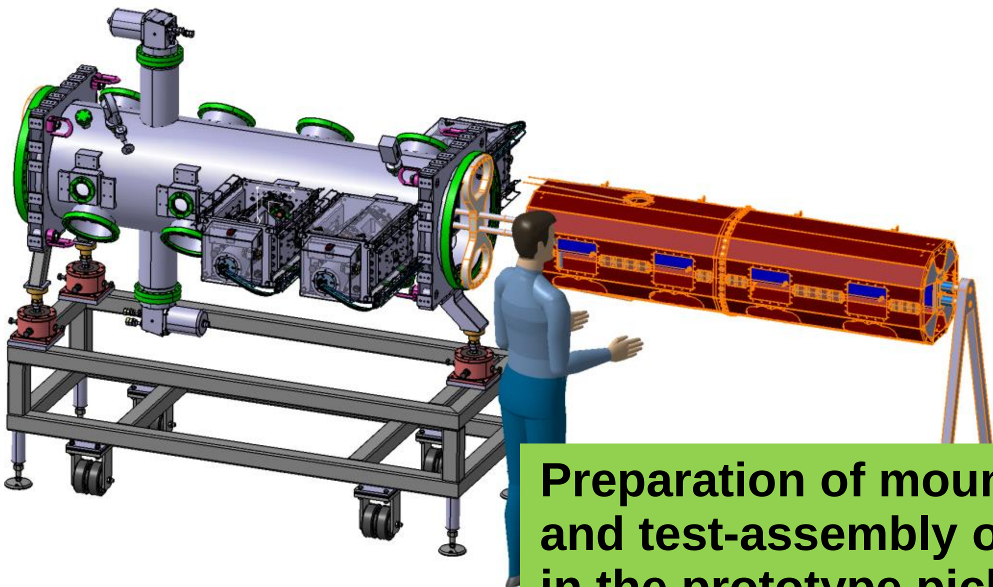
Main issue for rare isotopes: undesired mixing (from PU to K)

- **Pre-cooling (1st stage) with Palmer method**
- **Cooling (2nd stage) with the notch filter**

Prototype PU tank at GSI

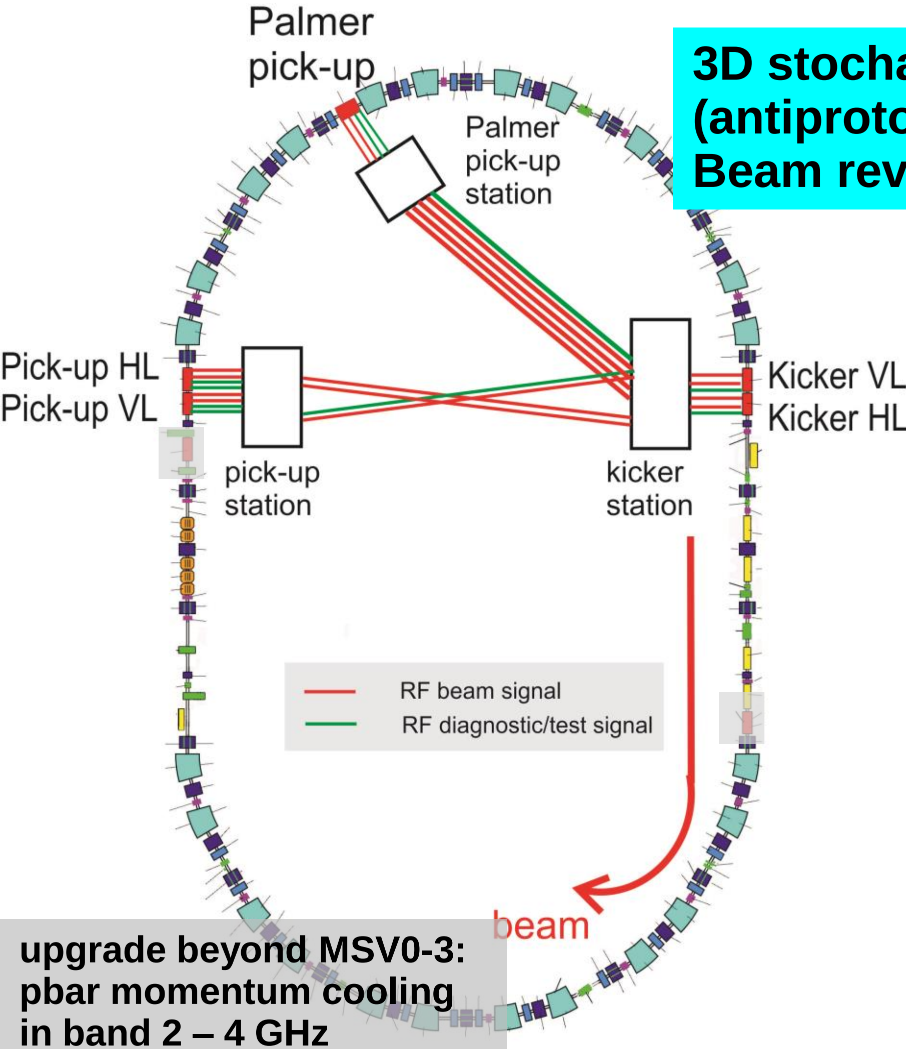
technical challenge cryoshield:
made of oxygen-free copper,
gilded galvanically
to reach very low thermal emissivity
(expected < 2% from measurements performed on speciments in our lab)





Preparation of mounting pieces
and test-assembly of the Cu-cryoshield
in the prototype pick-up tank
July 2013: gilding of the cryoshield by contractor

CR Stochastic Cooling System 1-2 GHz



3D stochastic cooling of coasting secondary beams (antiprotons @ v = 0.97c , rare isotopes @ v = 0.83c)
Beam revolution frequency (period)~ 1 MHz (1μs)

System bandwidth = 1-2 GHz

3D cooling branches and their purpose

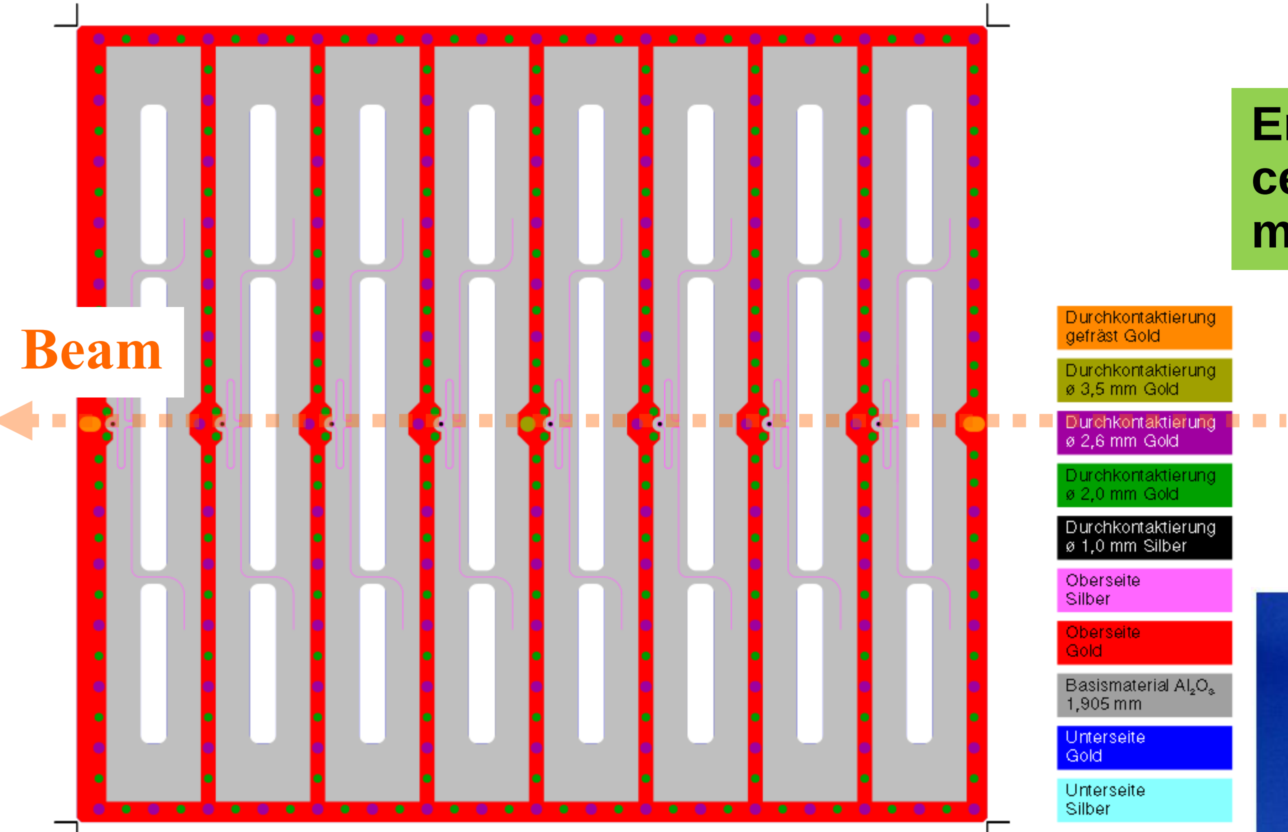
Pick-ups HL, VL→ Kickers HL, VL
notch filter longitudinal cooling method

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

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

upgrade beyond MSV0-3: pbar momentum cooling in band 2 – 4 GHz

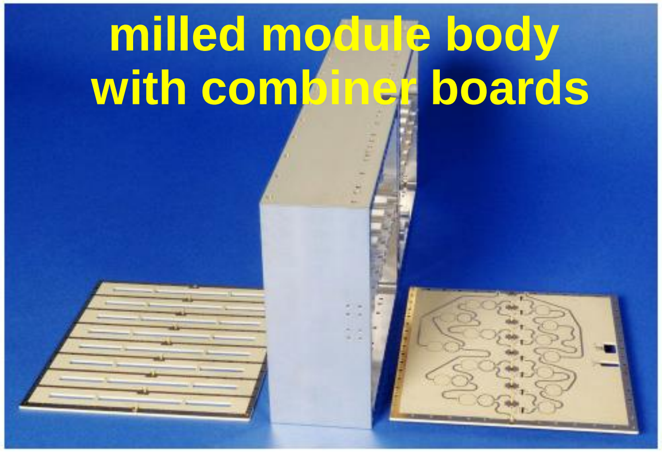
Slotline electrodes for PUs (HL/VL)



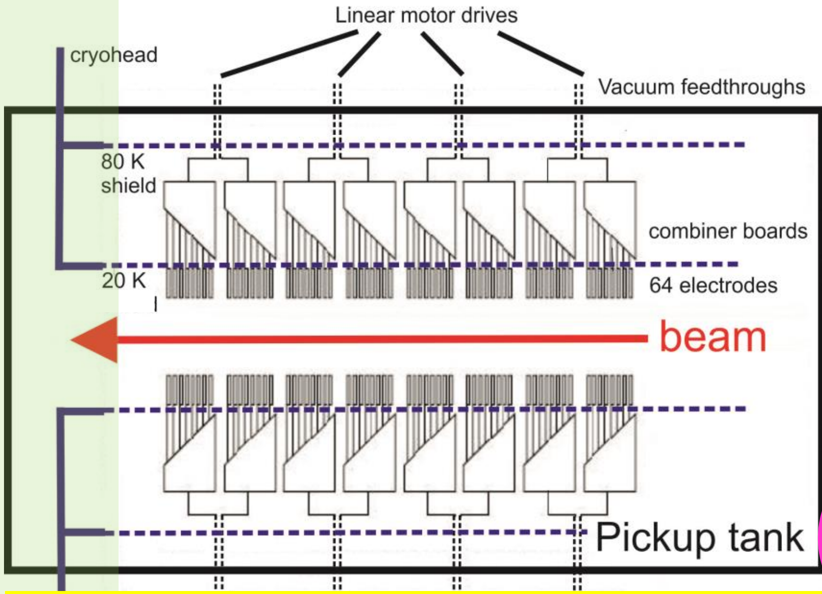
End 2012: first electrode ceramic plates delivered; metallisation pending

→ Poster WEPPO20

- **UHV-compatible**
- **broadband within 1-2 GHz**
- **high coupling impedance to the beam**
- **mechanically robust for plunging**



Challenging PU vacuum tanks

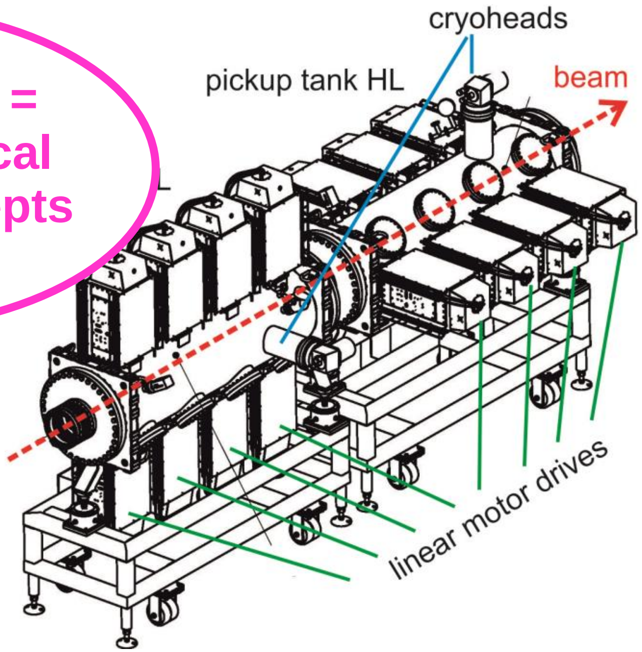


Cryo-cooling reduces considerably the thermal noise originating from the pick-up structures.
Examples: CERN AC, FNAL

Plunging is a very effective way to increase the transverse sensitivity (AC, AD) and can be used together with cryo-cooling (but its a mechanical challenge)

F. Caspers: Design Aspects for Stochastic Cooling.System Components
Hirschegg Workshop Feb2002

Highest priority = testing the critical technical concepts



robust, programmable, water-cooled linear motor drive units for synchronous movement of the electrode double-modules

electrode modules sliding along flexible BeCu sheets cooled by cryoheads at 20-30 K

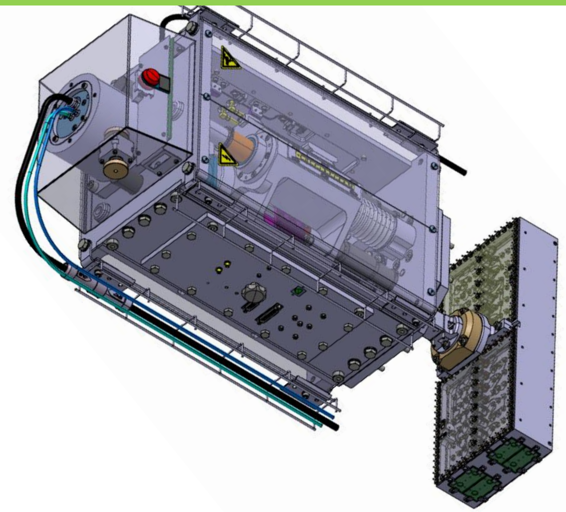
intermediate cryoshield at 80 K

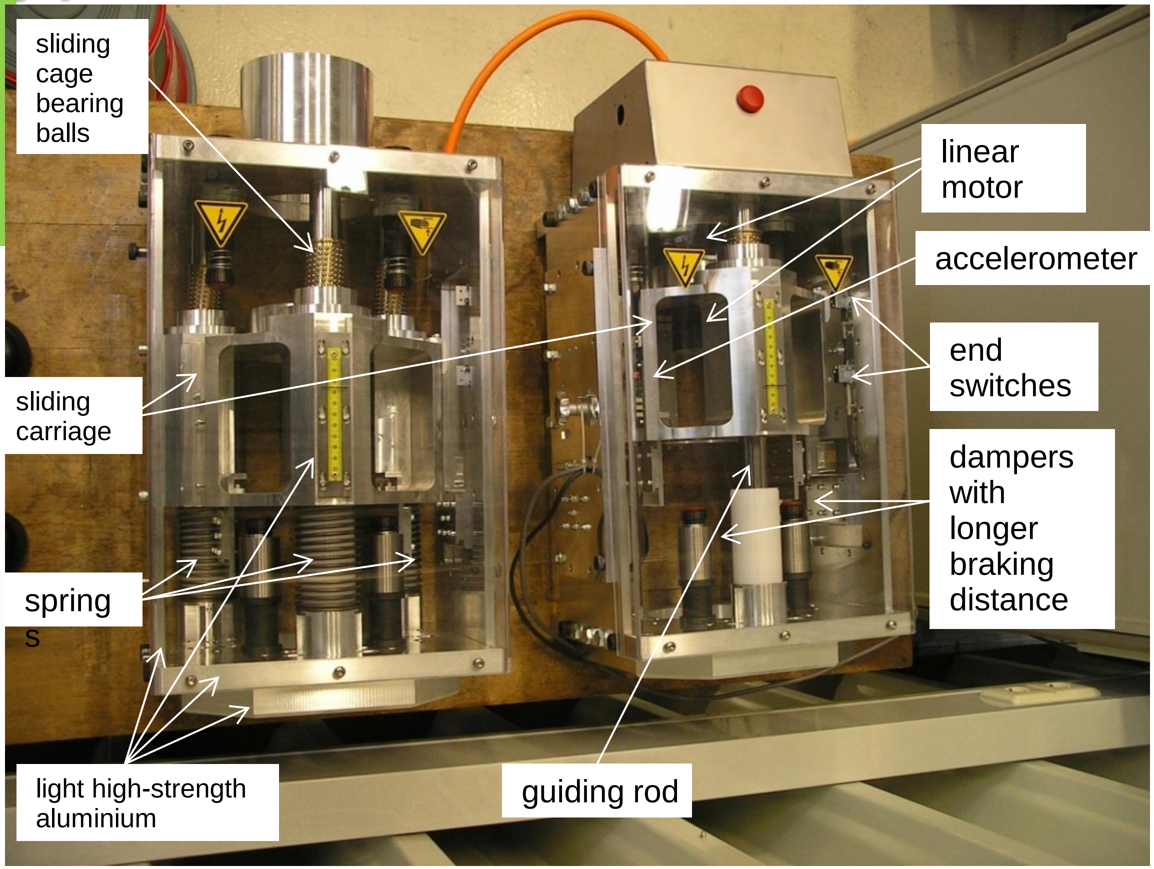
Prototype PU tank at GSI

2 m long vacuum tank

Prototype PU tank at GSI

2 new linear motor drive units (designed & manufactured in 2012)

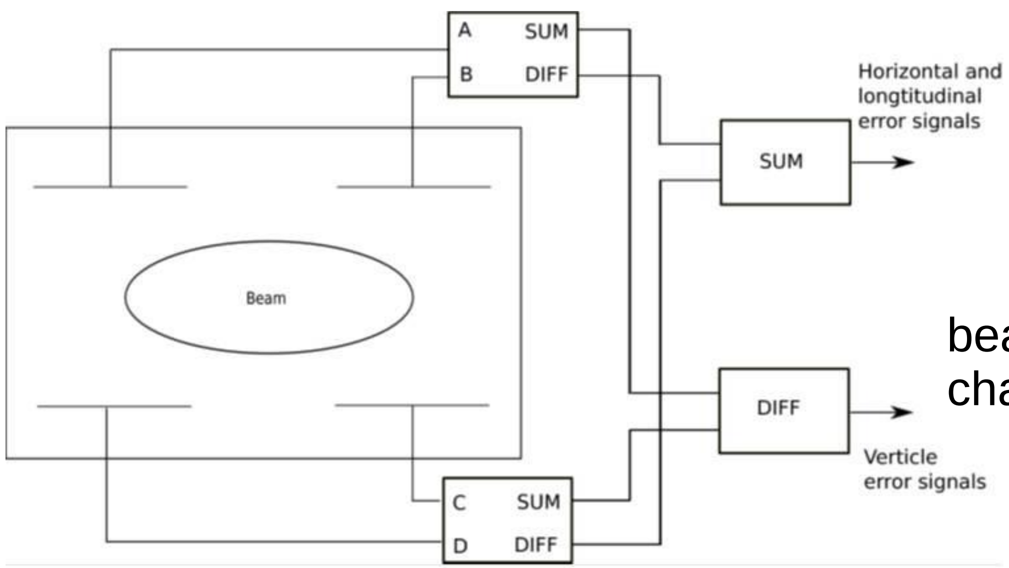




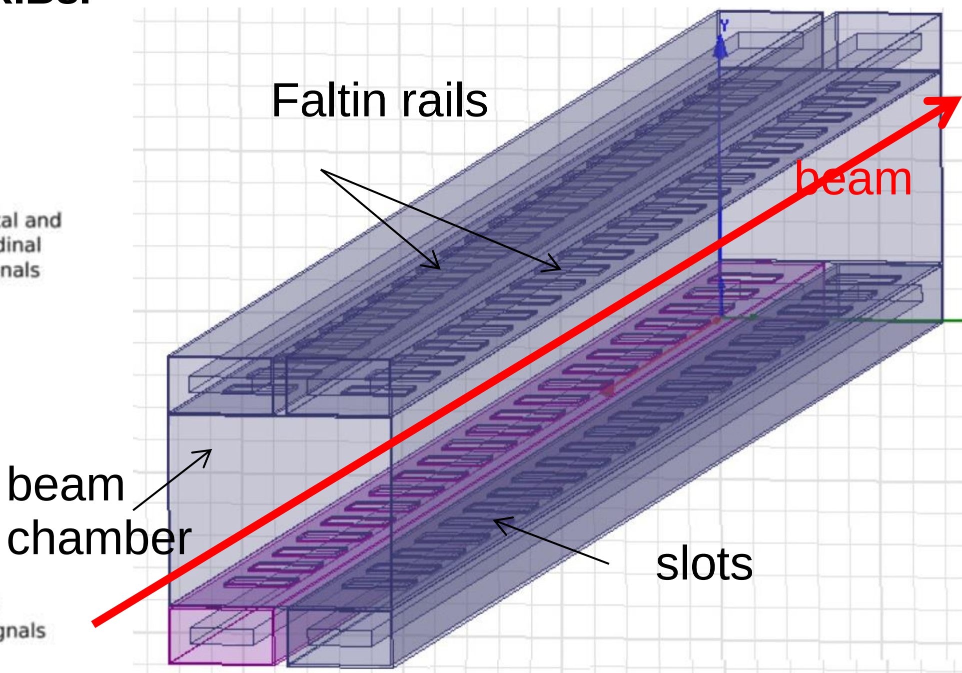
2013: re-assembly in the tank & synchronous tests at room temperature planned

Design of the Palmer pick-up for pre-cooling of RIBs

Rare isotopes have high Q, hence offer strong signal.
Faltin electrodes have flat frequency response but are large and insensitive.
Faltin pick-ups are suitable for pre-cooling of RIBs.
Plunging is not necessary.



Palmer cooling signal combination for vertical
and simultaneous horizontal and longtitudinal cooling.



4 Faltin rail pick-ups in 1 tank.

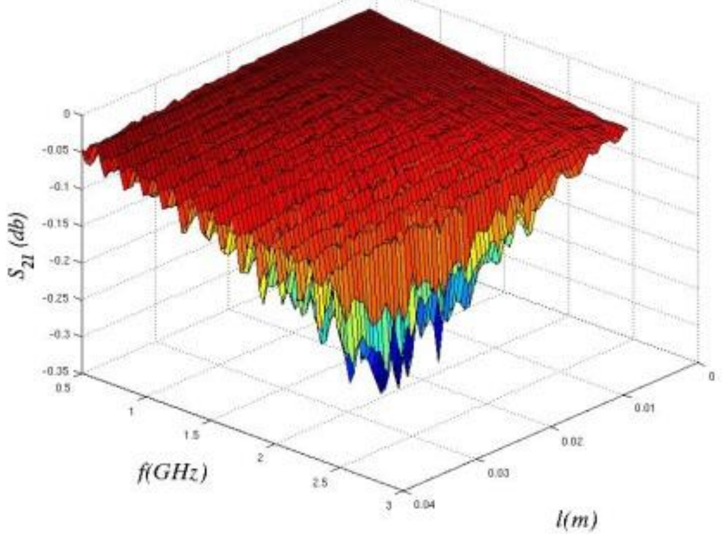
→ Poster WEPPO21

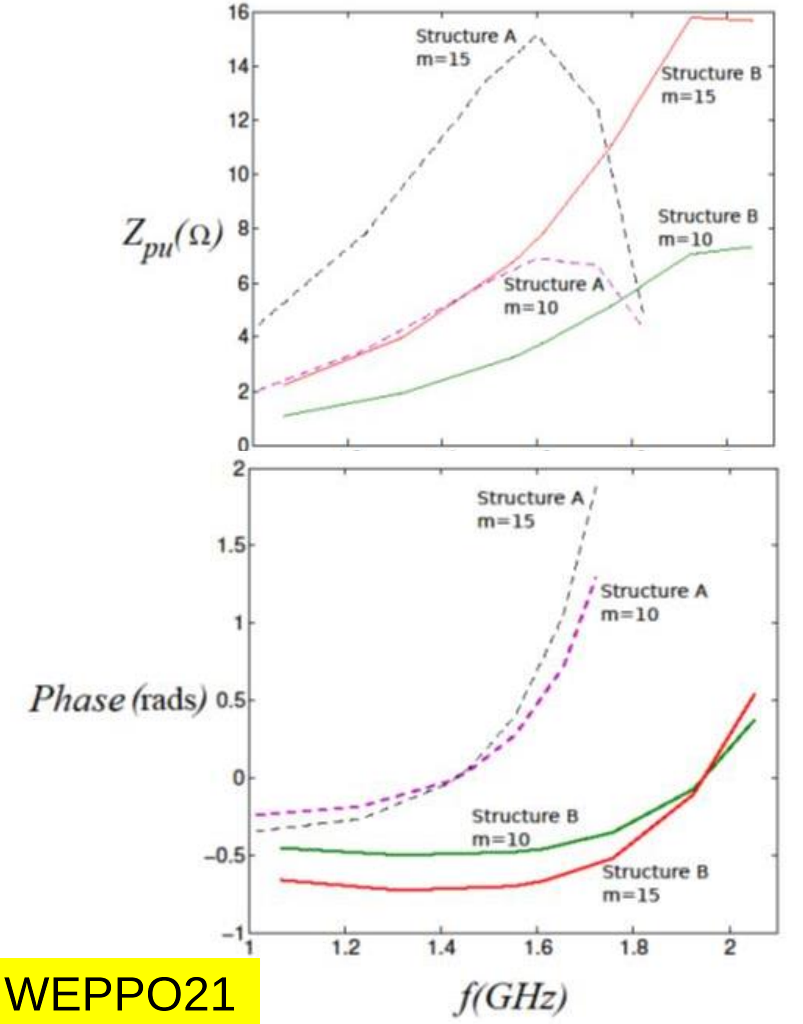
Design of the Palmer pick-up for pre-cooling of RIBs

The Faltin rail is divided into cells
and simulated with the HFSS code.

The structure is optimised in the band 1-2 GHz

- for maximum PU and kicker impedance
- small and flat output signal phase w.r.t. the particle pulse

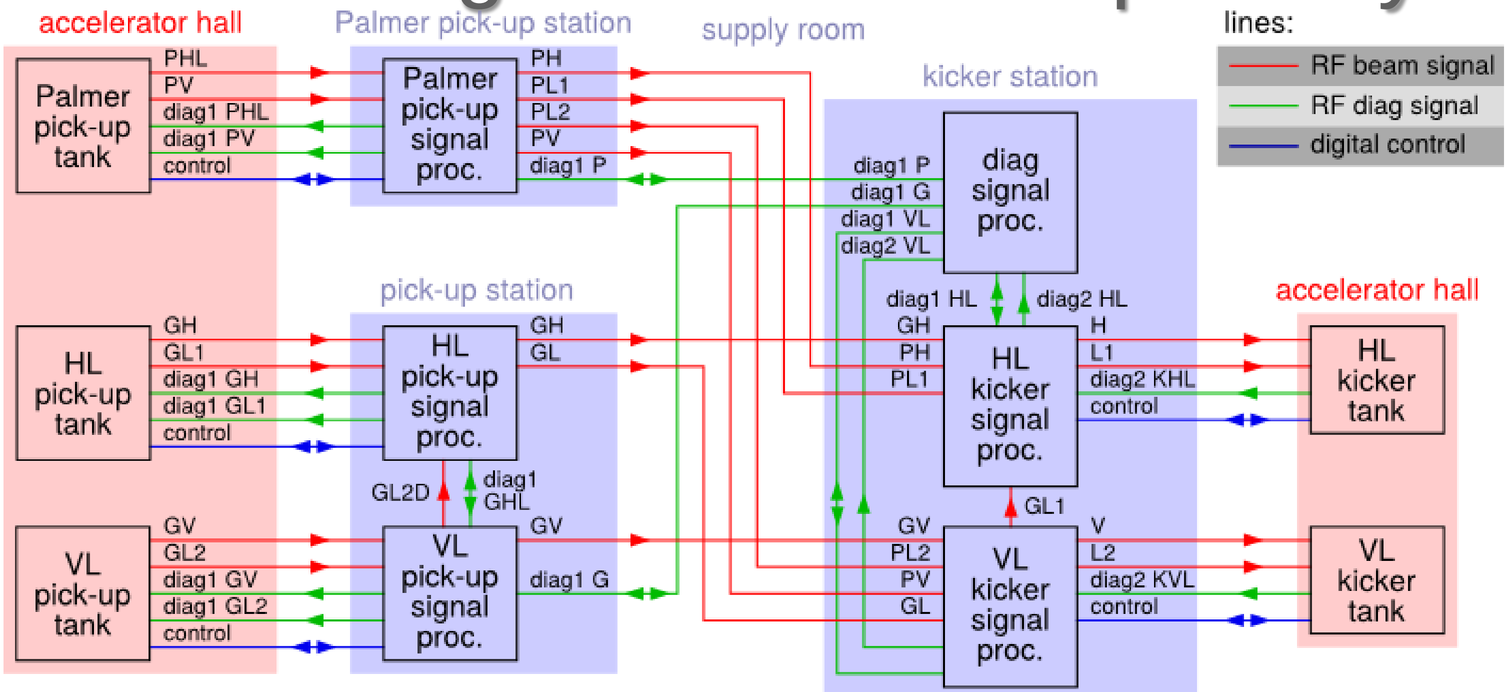




- The transmission coefficient S_{21} is also calculated at each frequency to ensure thereare minimal reflections.

→ Poster WEPPO21

RF Block diagram of the complete system

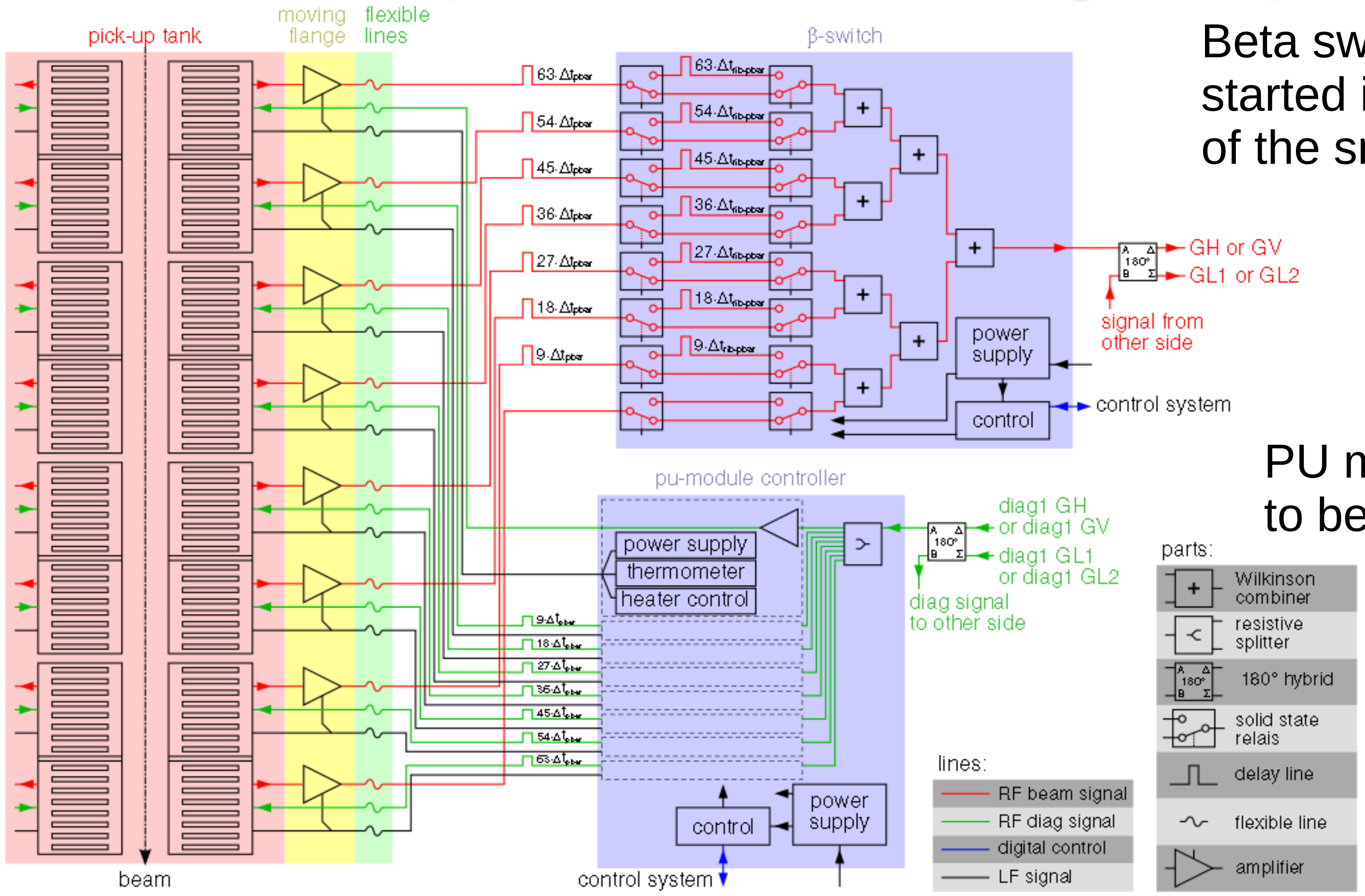


- ***2012: First layout of HF signal processing components for all cooling branches***
  typically, small series of HF components with stringent requirements for amplitude flatness & phase linearity in the band 1-2 GHz

- Ongoing refinements in interplay with lattice/building and physics requirements
- Example: specification of the dynamic range for the medium power level amplifiers to cover all foreseen operation modes with beam

→ Poster WEPPO20

Example: PU tank signal processing



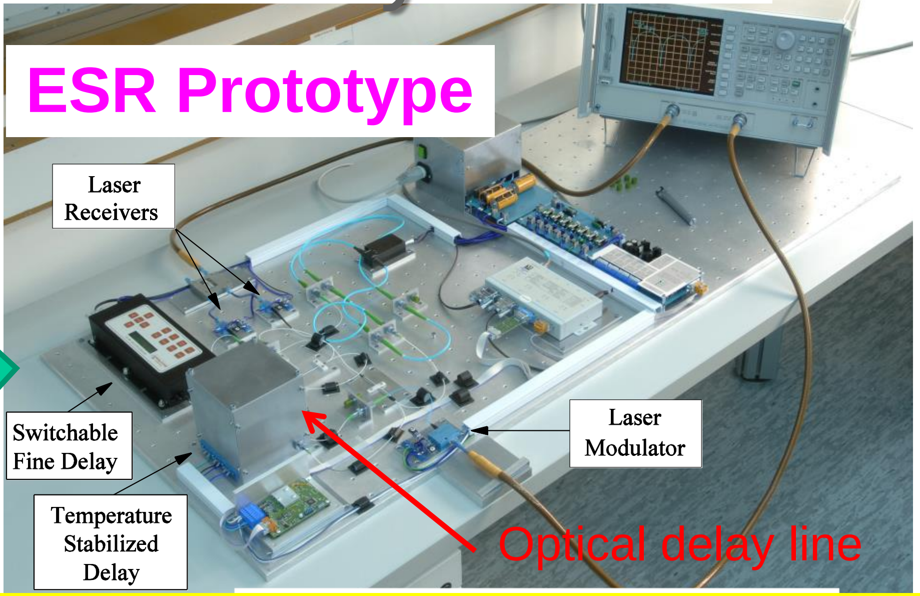
Beta switch: design ready, started in-house assembly of the small series

PU module controller: to be designed

Low-noise (NF ≤ 0.5 dB, T_N ≤ 35 K) preamplifiers at room temperature (290 K): procurement in 2017

Notch filter with optical delay line

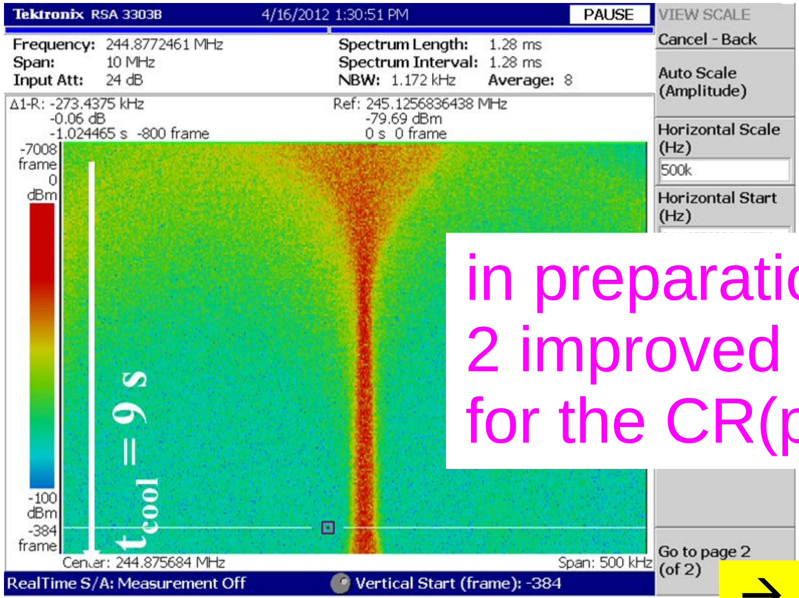
Notch filter (Thorndahl's method): pushes particles towards the correct revolution frequency



< -24 dB deep notches within 1-2 GHz !

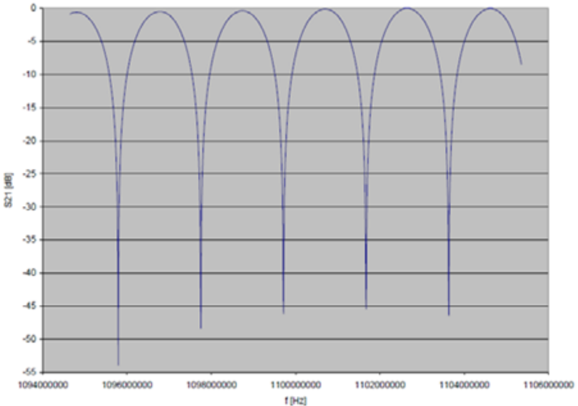
Machine Beamtime 2012

4x10^6 Au^{79+} ions @ 400 MeV/u



in preparation:
2 improved notch filters
for the CR(pbars/RIBs)

→ Poster WEPPO19



Power amplifiers at the kickers

→ 8 kW installed microwave cw power
(32 power amplifiers, 250 W each)

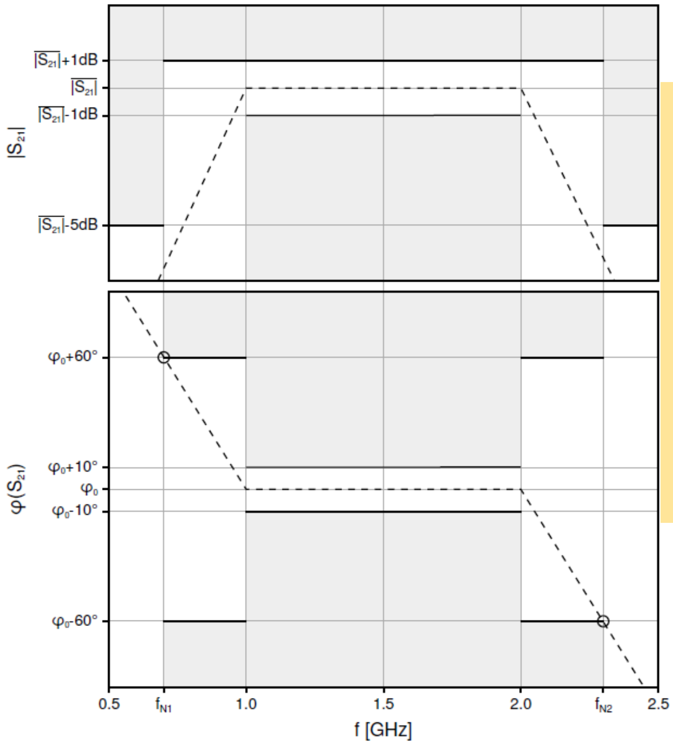


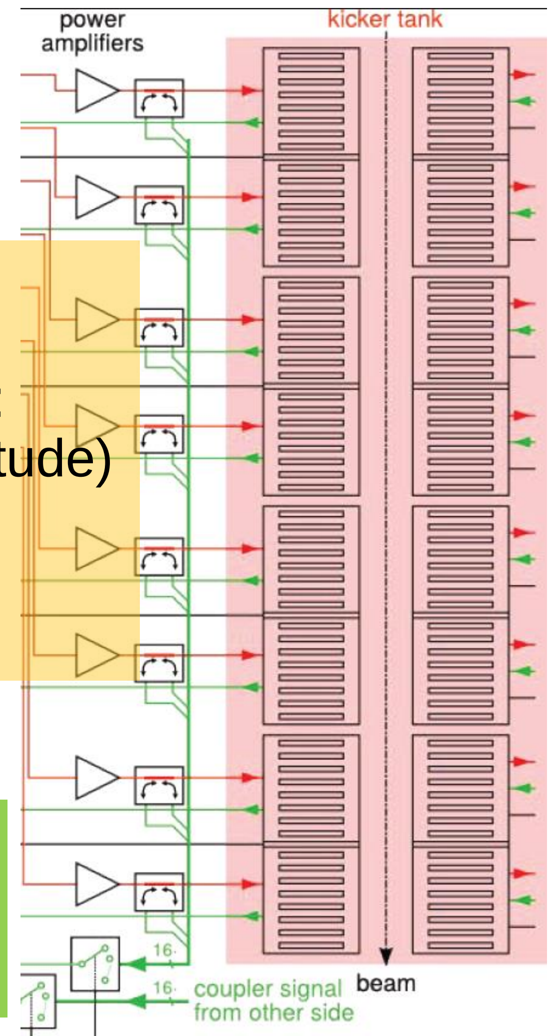
Figure 1.1: Tolerance bands for amplitude and phase of the transmission within and beyond the specified frequency range of 1...2 GHz. The gray areas are forbidden. The frequencies f_{N1} and f_{N2} are those (if any) where $\Delta\varphi = \pm 60°$.

→stringent requirements within tight tolerances inside the 1-2 GHz band:

- constant gain (flat amplitude)
- high phase linearity

→ short electrical length

Call for tender started
Large cost factor
for the SC system



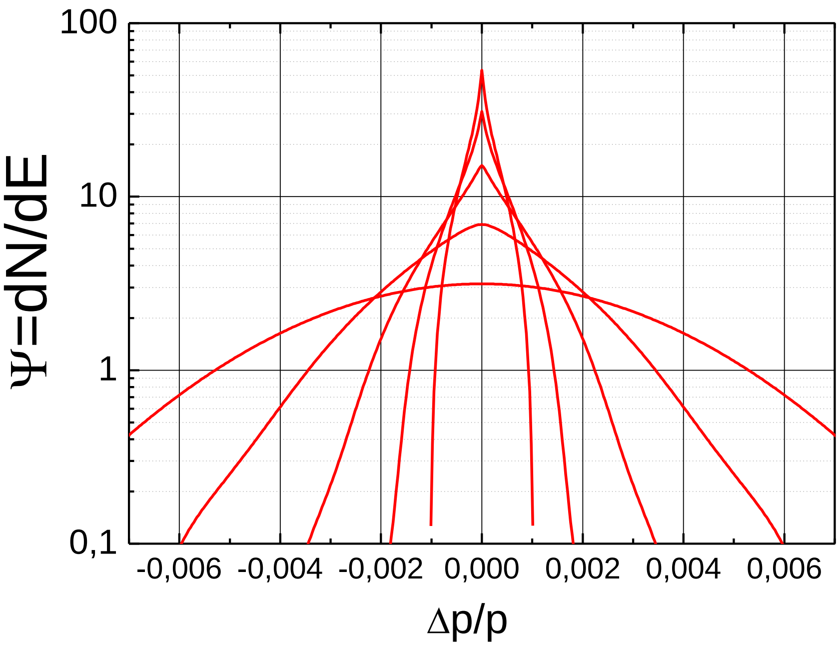
Simulations of cooling of antiprotons

Longitudinal cooling of 10^8 antiprotons with notch filter in band 1 – 2 GHz

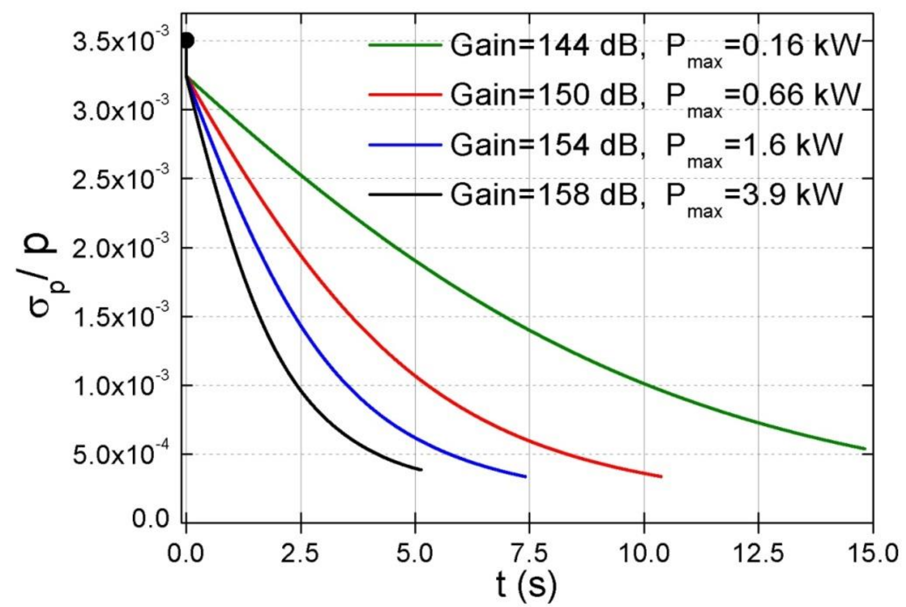
using the CERN code
cross-checked with
T. Katayama/H.Stockhorst

main goal: 10 s cycle time

t=0, 2.5, 5, 7.5 and 10 s



g=150 dB; t=10 s



Simulations of cooling of heavy ions

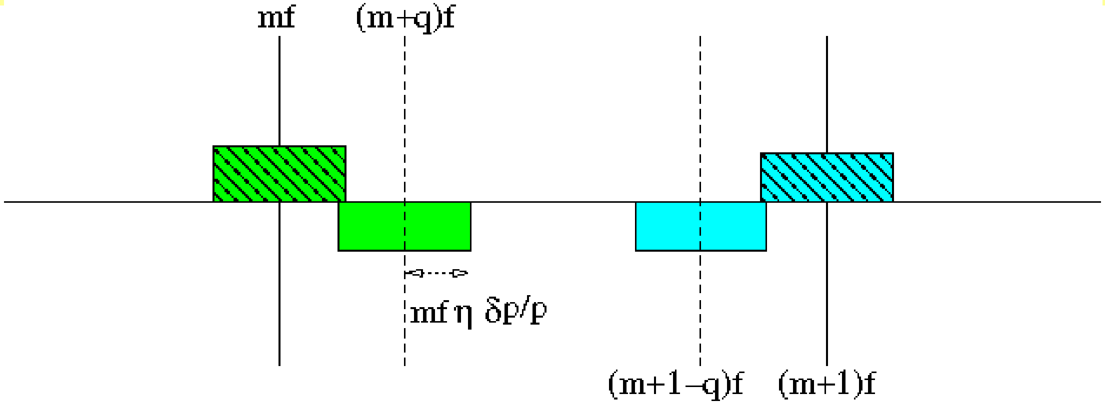
Longitudinal cooling (notch filter/TOF) of *stable* ions with the pickups HL/VL

- RIB lattice CR68: η=0.176 ; η_{pk}=0.128; x=0.369 (PU-K/circumference)
- response of the designed slotline electrodes; no plunging assumed.

Reference ions (coasting beam) @ 740 MeV/u: U^{92+} and ion with Q=50

Initial rms momentum spread $\delta p/p$:

- within notch filter/TOF acceptance
- small so as to avoid band overlap (not in the FP)



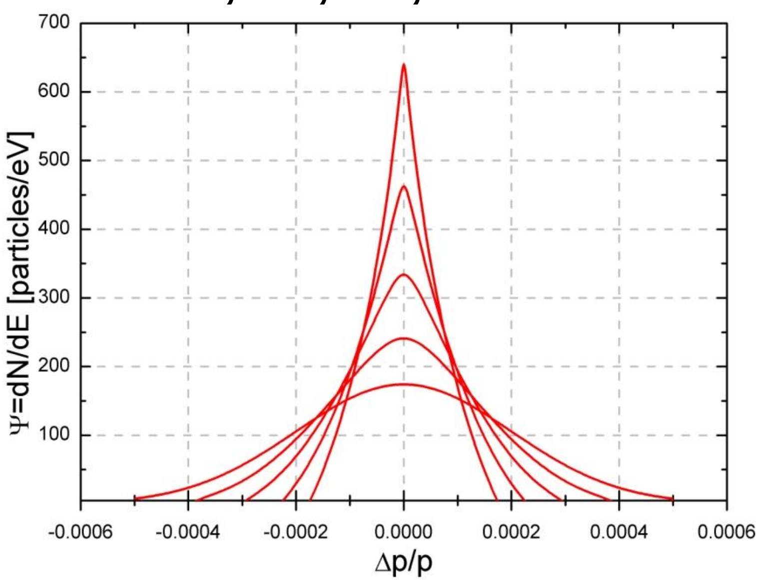
η	f0	Qx (Qy)	Overlap @ 1 GHz	Overlap @ 2 GHz
0.176	1.124 MHz	3.17 (3.67)	$\delta p/p$ (rms)= 5.4 10^{-4}	**$\delta p/p$ (rms)= 2.7 10^{-4}**

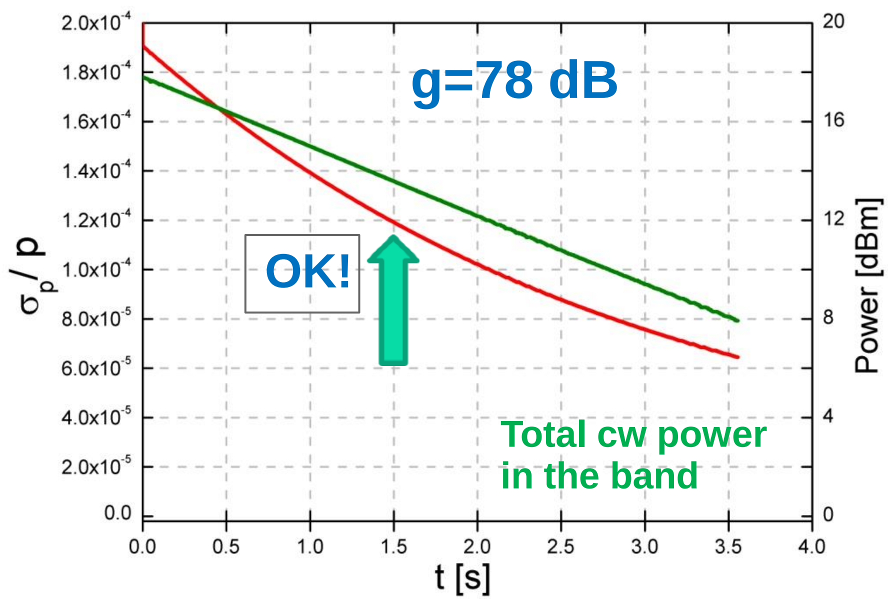
Simulations of cooling of heavy ions

Longitudinal cooling of 10^8 U^{92+} ions with notch filter in band 1 – 2 GHz

using the CERN code, preliminary

t=0, 0.9, 1.8, 2.6 and 3.5 s



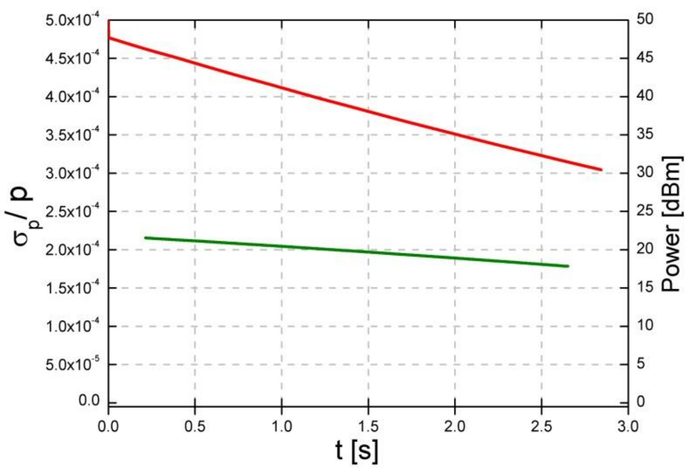


Particle noise scales with Q^2, thermal noise negligible
→same results for ions with $Q=50^+$ and +6 dB more gain

But, main goal: 1.5 s cycle time for hot rare isotopes (Palmer pre-cooling followed by notch filter cooling)

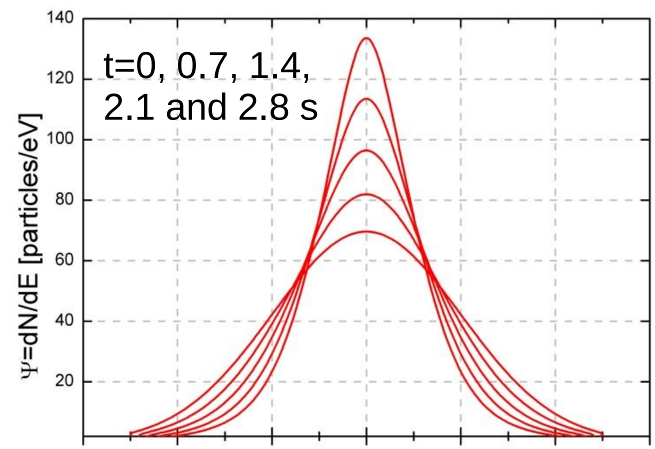
→ Talk TUAM1HA04

Simulations of cooling of heavy ions



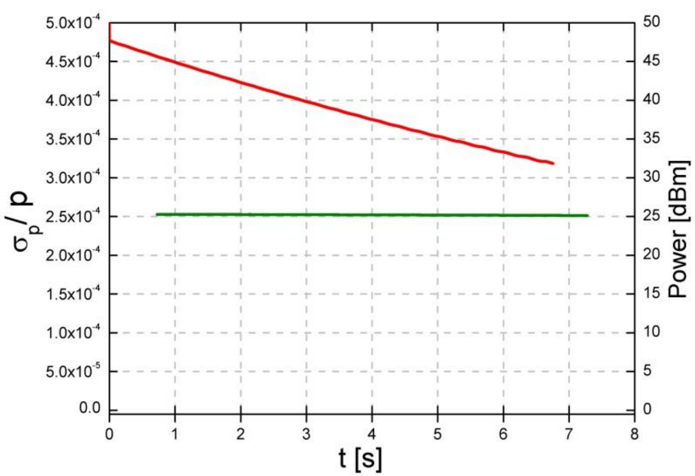
10^8 U^{92+} ions

g=74 dB



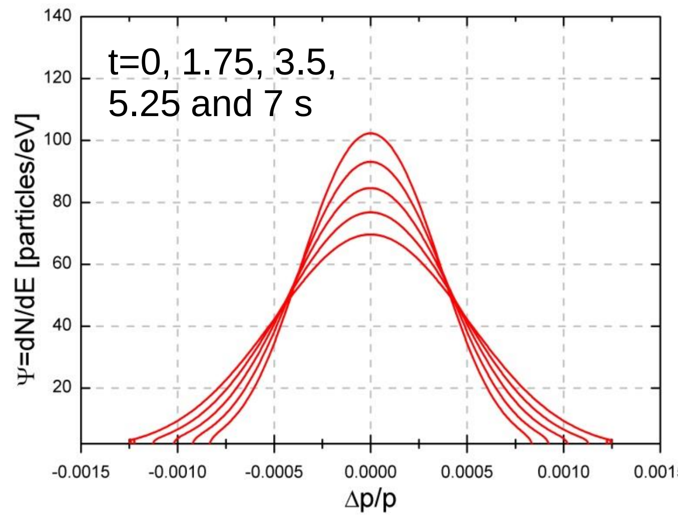
Notch filter

$\sigma_p/p = 5 \rightarrow 3 \cdot 10^{-4}$
in 2.8 s



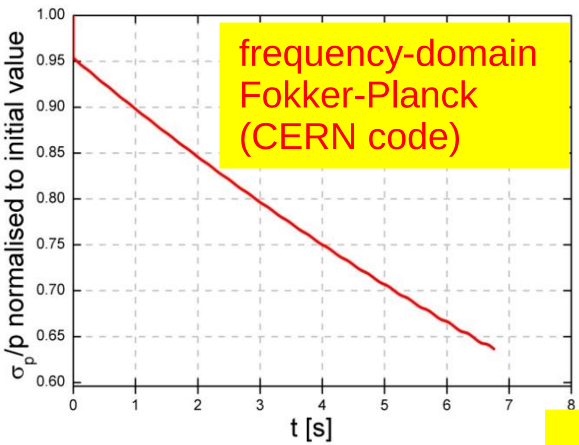
TOF

$\sigma_p/p = 5 \rightarrow 3 \cdot 10^{-4}$
in 7 s



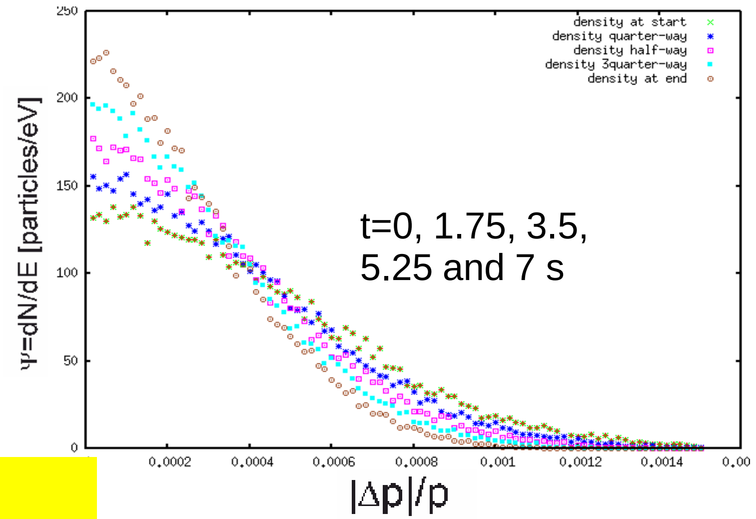
C. Dimopoulou, TUAM1HA01, COOL13

Cooling simulations in the time domain



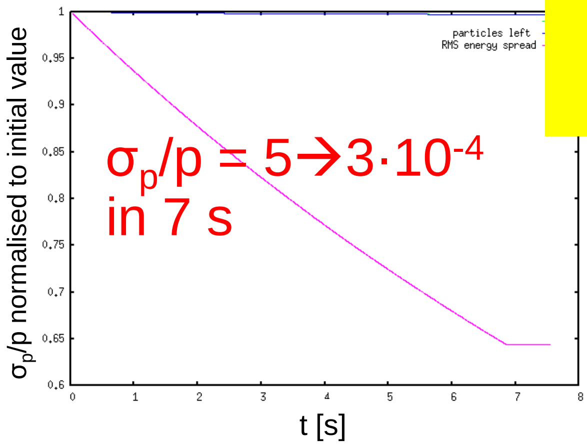
TOF cooling
10^8 U^{92+} ions

g=74 dB

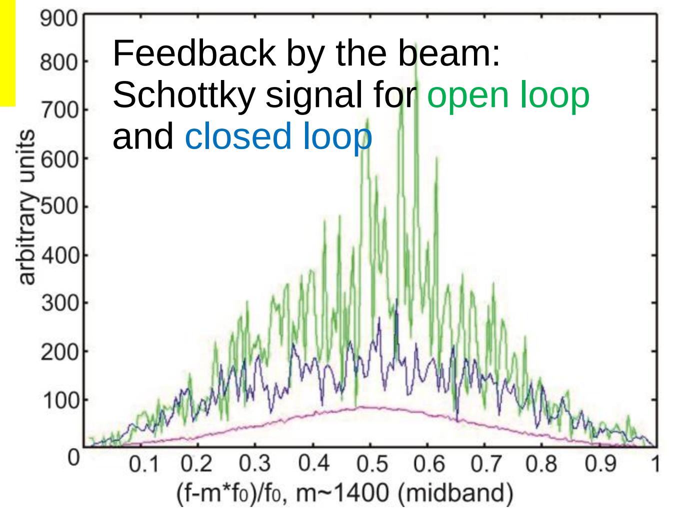


time-domain simulation by Lars Thorndahl

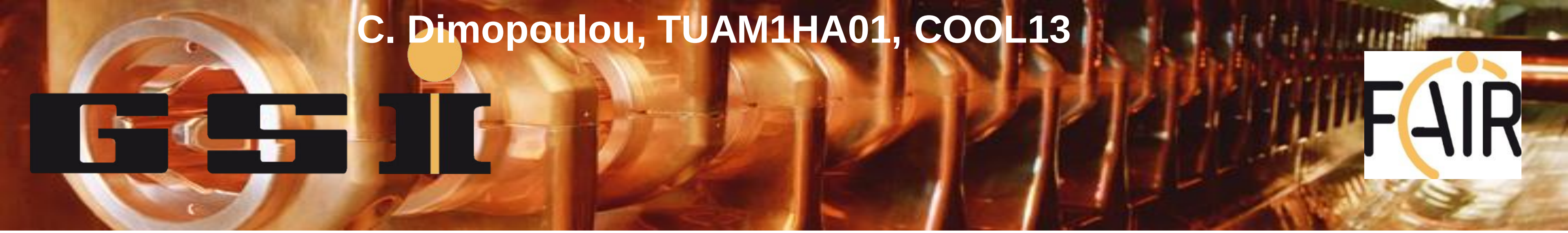
→ Talk TUAM1HA03



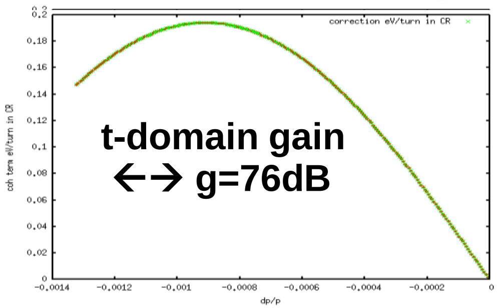
t-domain gain is matched to the pure coherent effect (without undesired mixing) for the electronic gain g in the f-domain

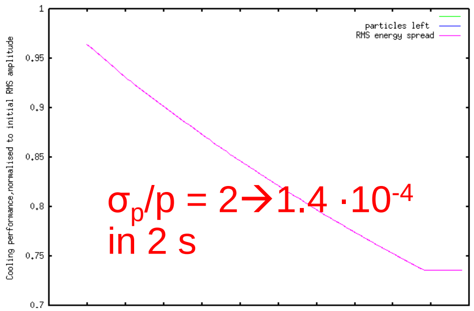


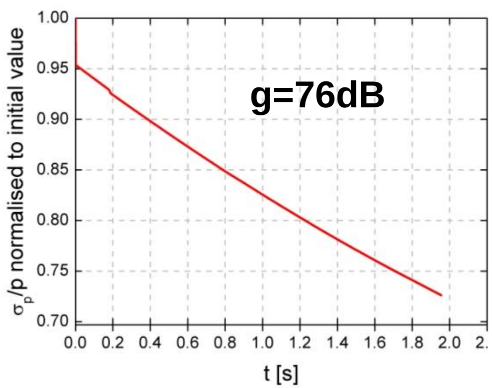
Agreement within a few %, also for notch filter cooling!

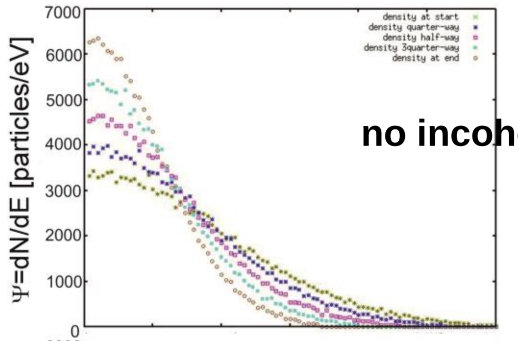


Cooling simulations in the time domain

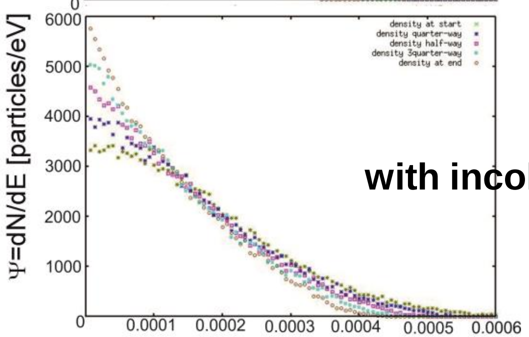




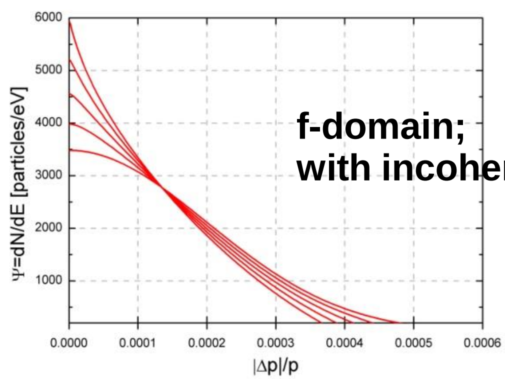




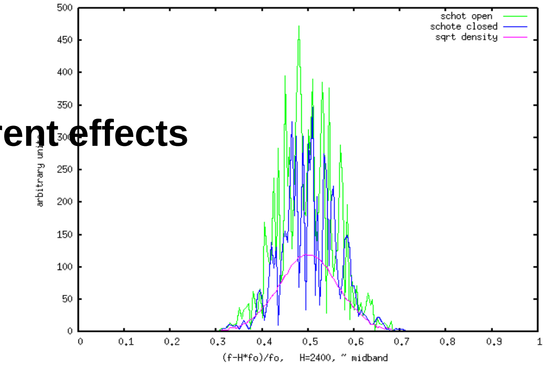
no incoherent effects

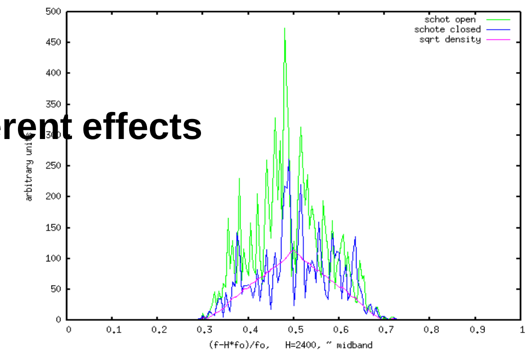


with incoherent effects



f-domain;
with incoherent effects





notch filter cooling
10^9 U^{92+} ions

Next goals

- Procurement contract for the power amplifiers

- Prototype pick-up tank:
  -Intensive tests of the challenging mechanical concepts at room temperature
  -First cryogenic test with cryoheads, cryoshield and movable electrode dummies
  -Commissioning of the testing chamber for linear motor drive units

- Ongoing specification and in-house developments/production of the Palmer pick-up, the notch filters and other HF components

- testing of new operation programs at the ESR stochastic cooling system

- simulations of the system performance have to proceed at low priority and mainly with support from external experts

Thank you for your attention!