Stochastic Cooling of Heavy Ions in the HESR

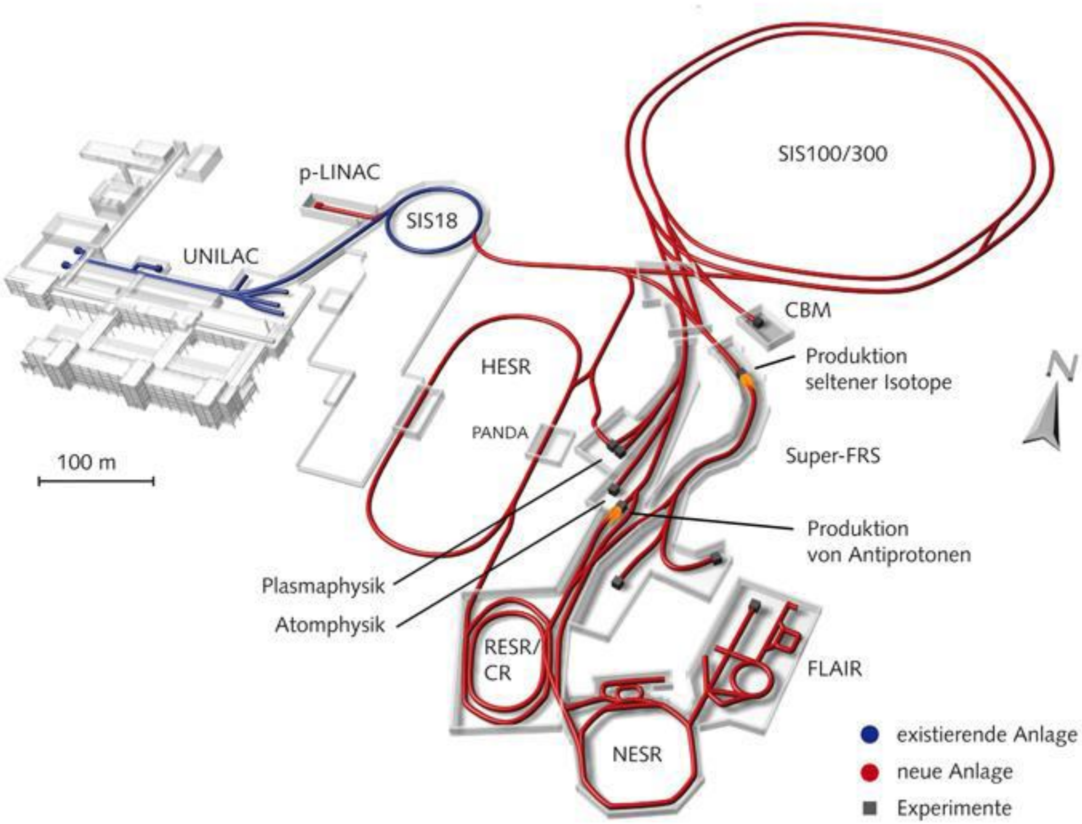
COOL'15

Sept. 28 – Oct. 2, 2015 | Rolf Stassen

outline

- Introduction
- Basic system
- Limitations for heavy ions
- High power amplifiers
- Status of fabrication

The FAIR Facility



Modularized Start Version (MSV):

- No SIS300
- No RESR
- No NESR
- No FLAIR

MSV and HESR:

- No e-cooler
- Accumulation of pbars in the HESR
- HESR attractive for heavy ions physics

Design criteria

- Cooling of pbars in the momentum range from 1.5 GeV/c to 15 GeV/c in two different modes (HR: 10^{10}pbars, $\Delta p/p \leq 5*10^{-5}$ + HL: 10^{11}pbars, $\Delta p/p \leq 10^{-4}$, but no HL in MSV)
- Due to MSV: accumulation in HESR with moving barrier buckets and stochastic cooling
- Particle numbers $10^{8} - 10^{11}$

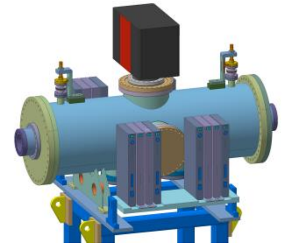
System Parameters

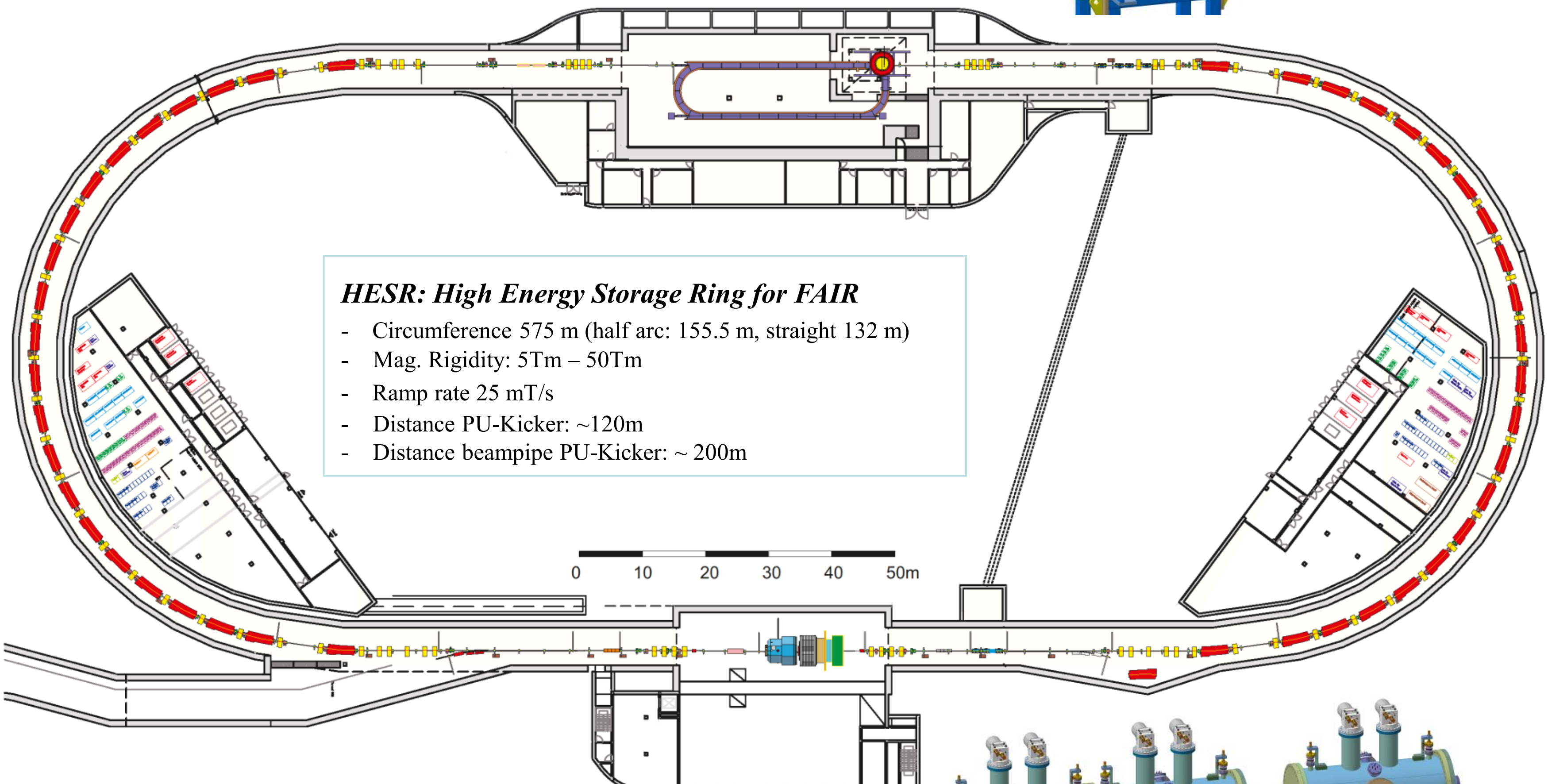
Main System	Based on slot-ring couplers	
Bandwidth	2 – 4	GHz
Cooling methods	Transversal, longitudinal Filter cooling, longitudinal ToF cooling	-> see next talk
β-range	0.83-0.99	
Pickup:	2	Tanks
Number of rings/tank	64	
Shunt impedance / ring	9	Ω
Total shunt impedance	1152	Ω
Structures temperature	30	K
Kicker:	3	Tanks
	2 tanks for transversal **or** longitudinal, 1 tank longitudinal	
Number of rings/tank	64	
Shunt impedance / ring	36	Ω
Shunt impedance / tank	2304	Ω
Installed power / tank	640	W (longitudinal)
	320	W (transversal)

System Parameters

additional System	Still in design phase	
Bandwidth	4 – 6	GHz
Cooling methods	longitudinal Filter cooling	
Pickup:	1	Tank
Number of rings/tank	88	
Shunt impedance / ring	4	Ω
Total shunt impedance	352	Ω
Structures temperature	30	K
Kicker:	1	Tank
Number of rings/tank	88	
Shunt impedance / ring	16	Ω
Shunt impedance / tank	1408	Ω
Installed power / tank	700 (not jet fixed)	W

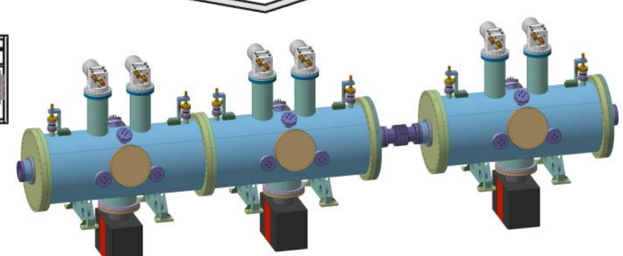
Layout of HESR



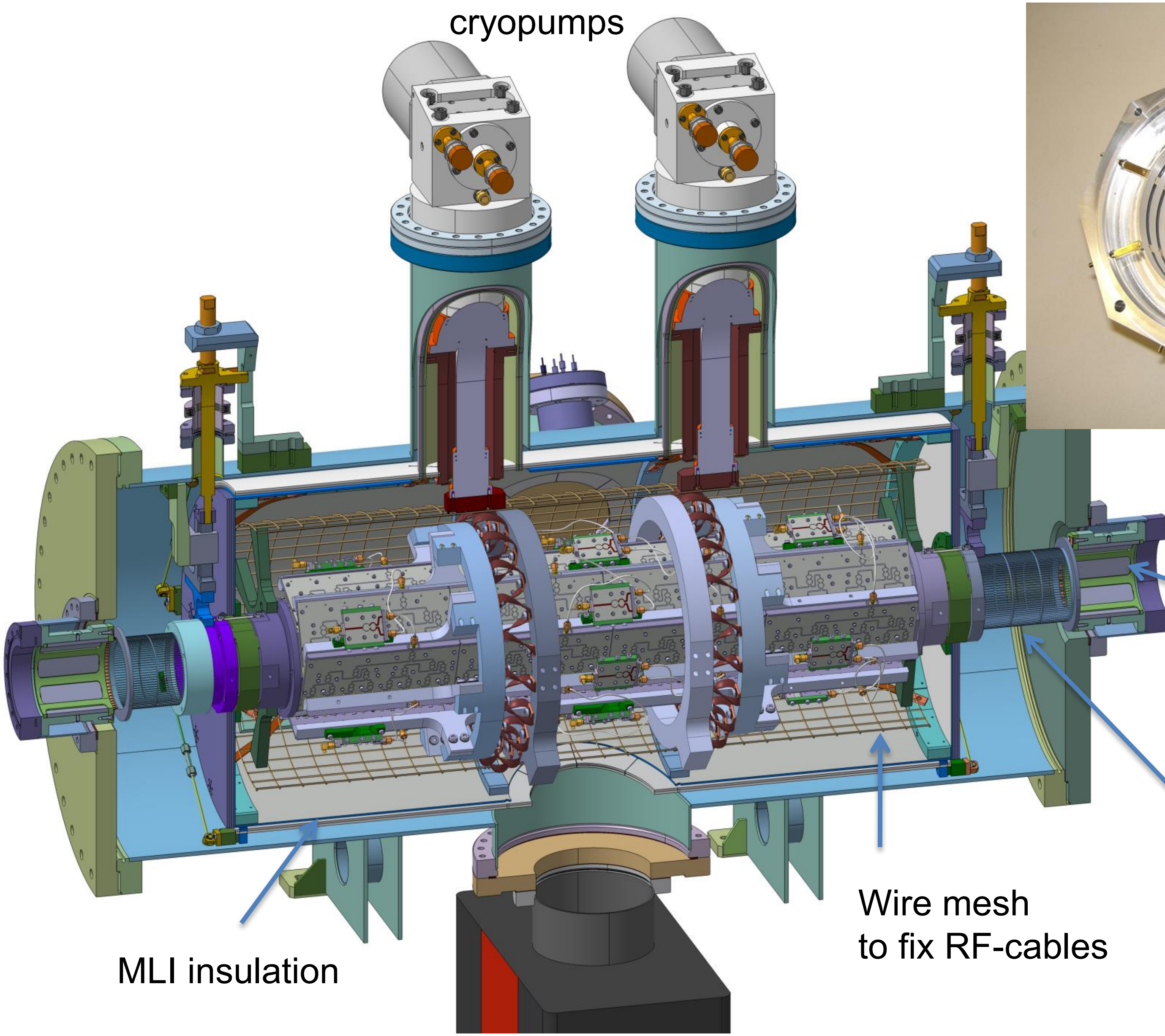


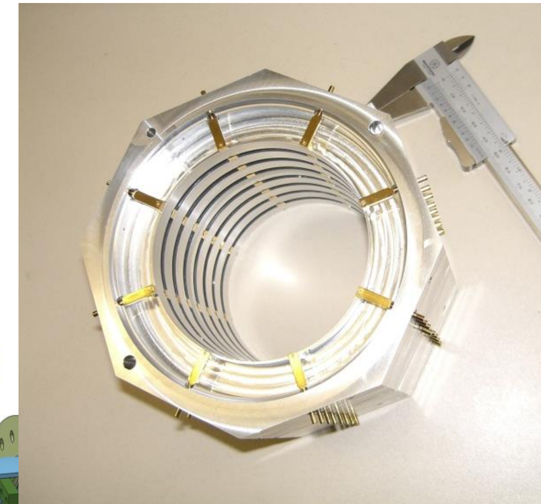
HESR: High Energy Storage Ring for FAIR

- Circumference 575 m (half arc: 155.5 m, straight 132 m)
- Mag. Rigidity: 5Tm – 50Tm
- Ramp rate 25 mT/s
- Distance PU-Kicker: ~120m
- Distance beampipe PU-Kicker: ~ 200m

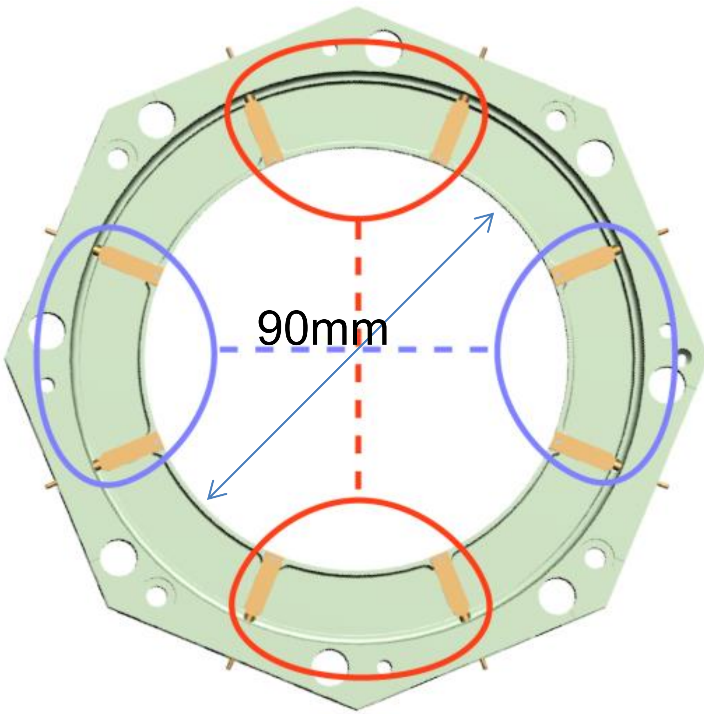


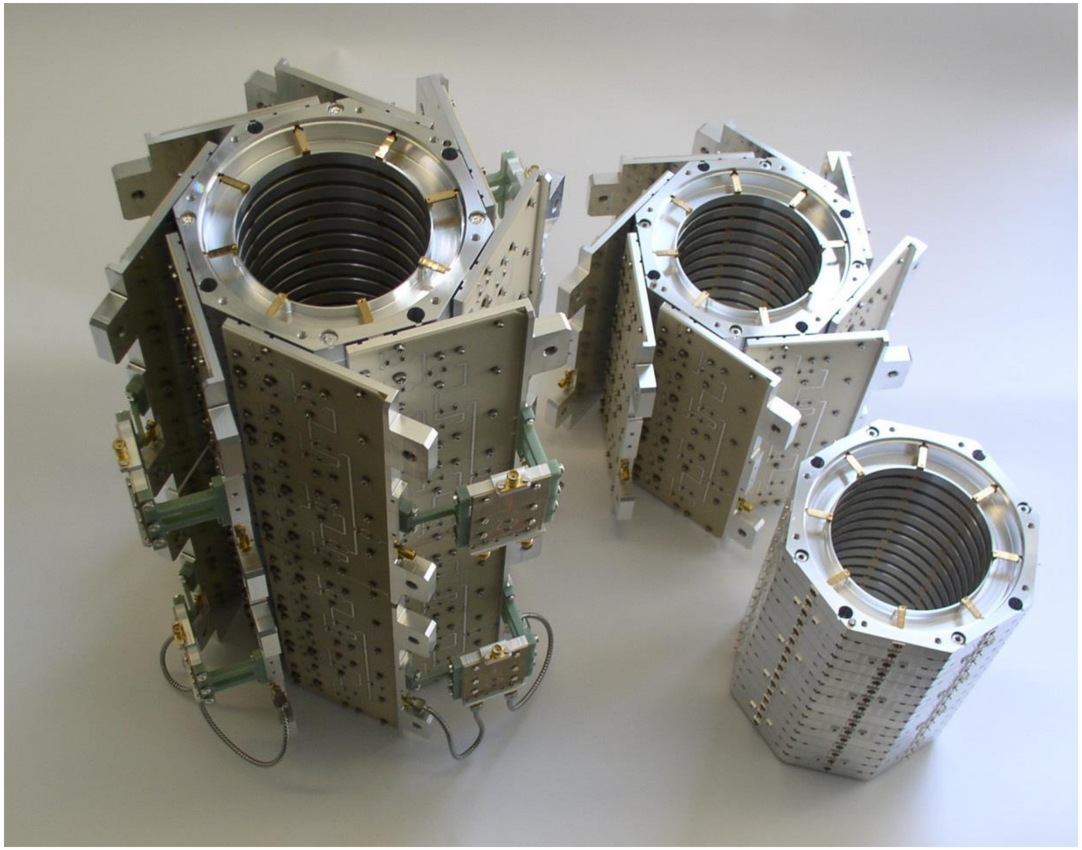
2-4 GHz Pickup





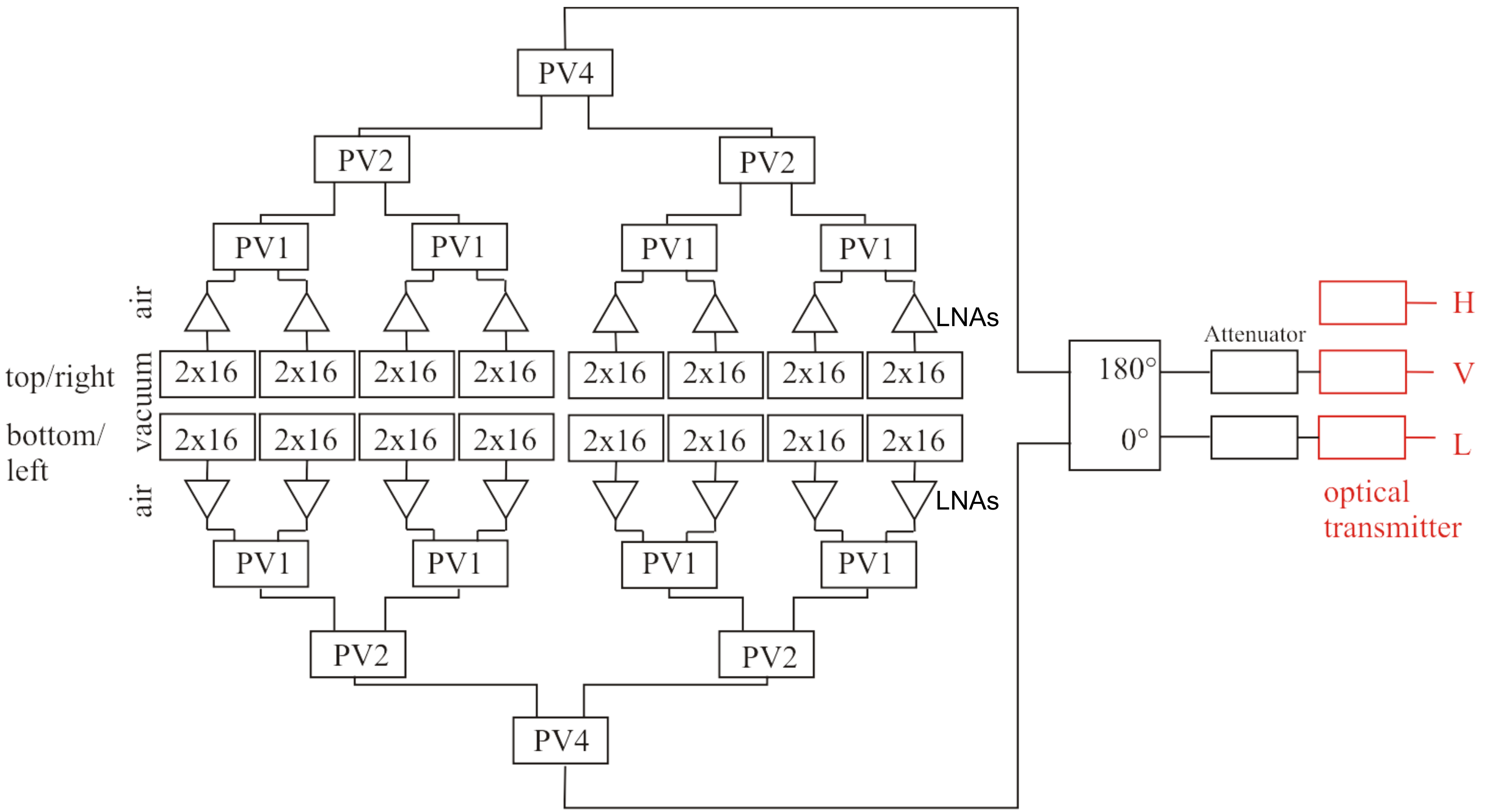
Slot ring couplers (thanks to Lars Thorndahl)





- Self-supporting structure
- No plunging
- All three cooling planes with same structures
- No aperture reduction
- 8x50Ω electrodes for broadband operation

System layout pick-up (2-4GHz)



PV1,2,4: programmable delay lines

JÜLICH
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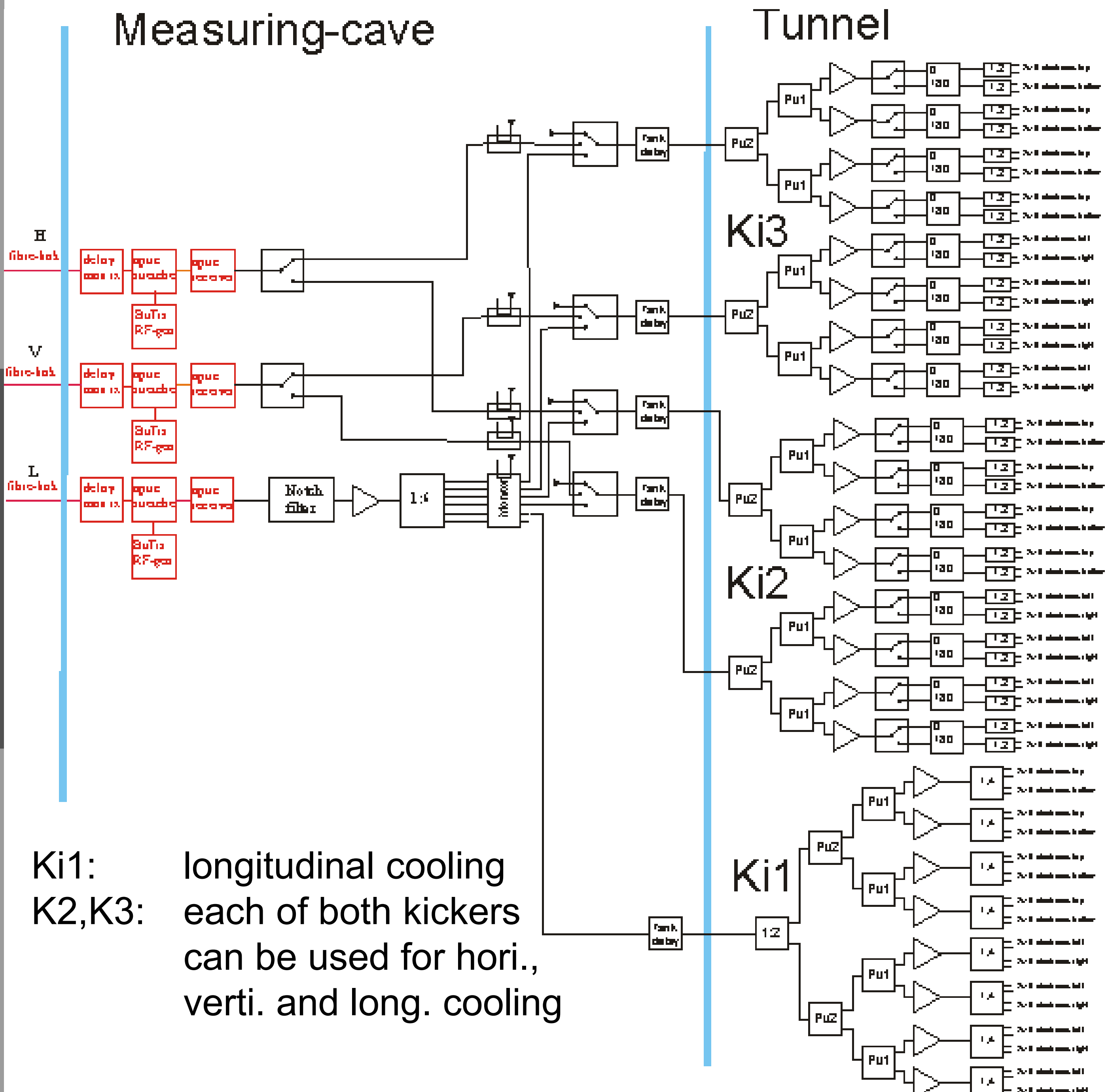


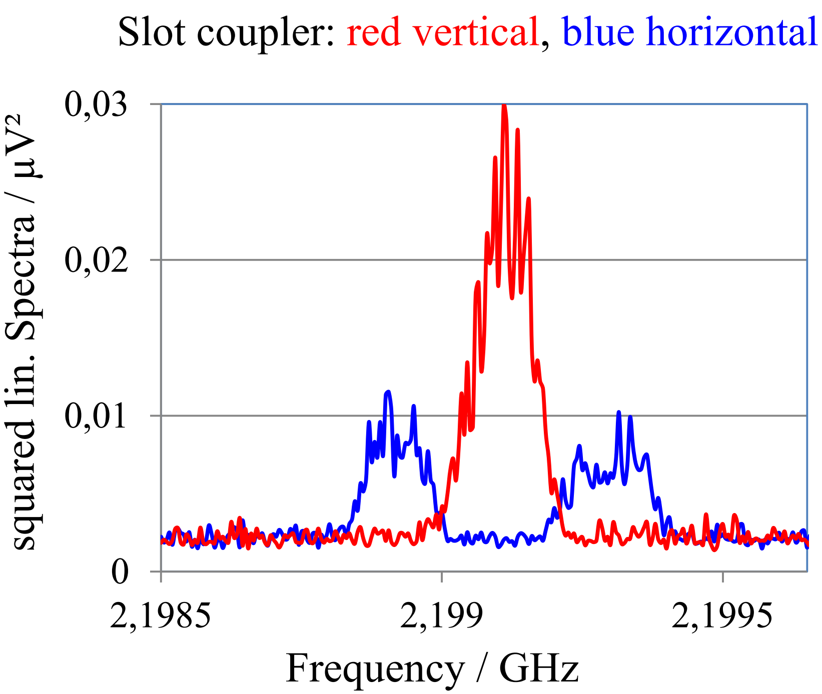
Ki1: longitudinal cooling

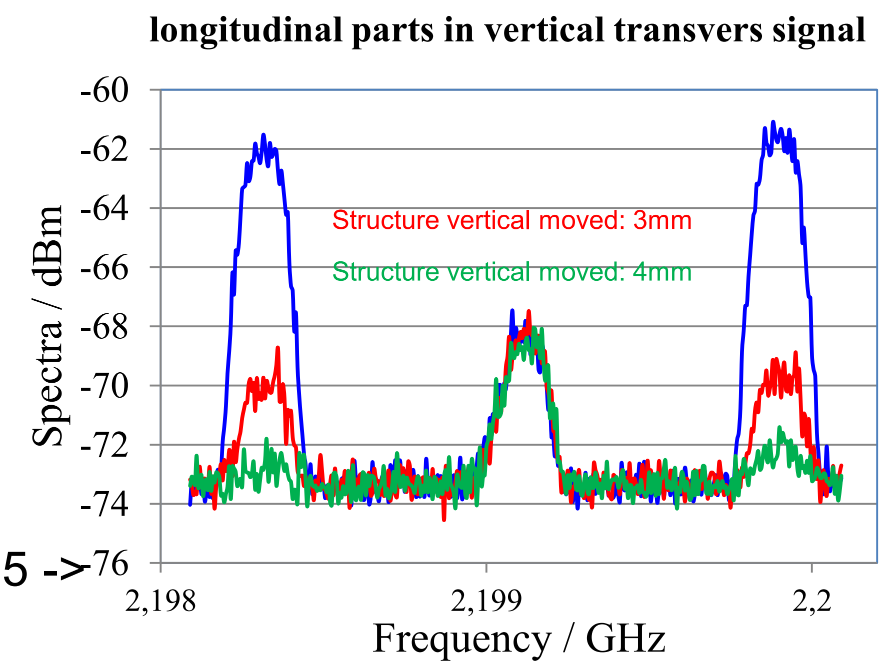
K2,K3: each of both kickers can be used for hori., verti. and long. cooling

Pickup tests at COSY

16 rings in test-tank cooled down to 30K:

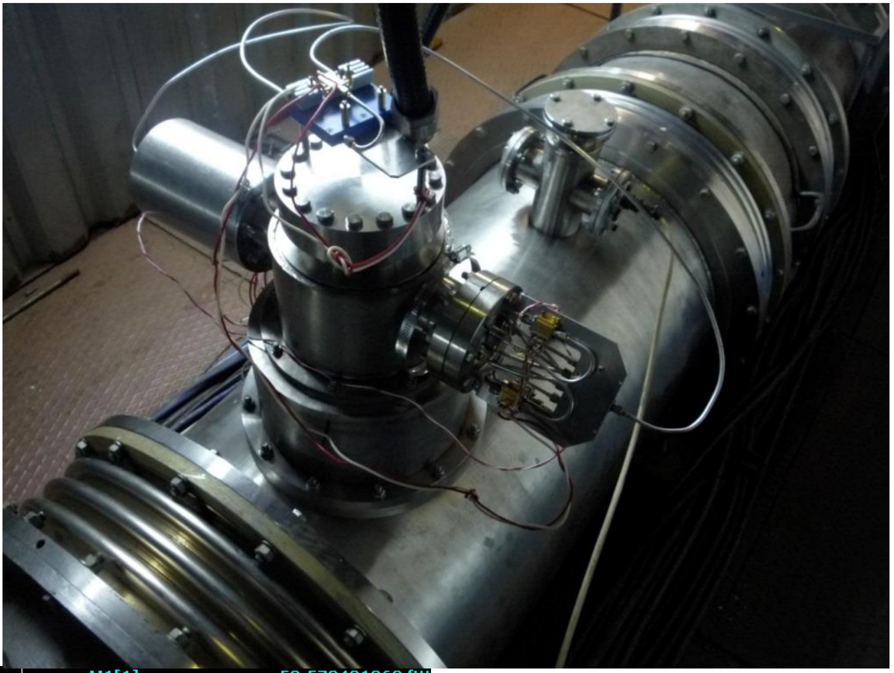
Betafunktions at TP1: Horizontal 5.2 m
Vertical 14 m

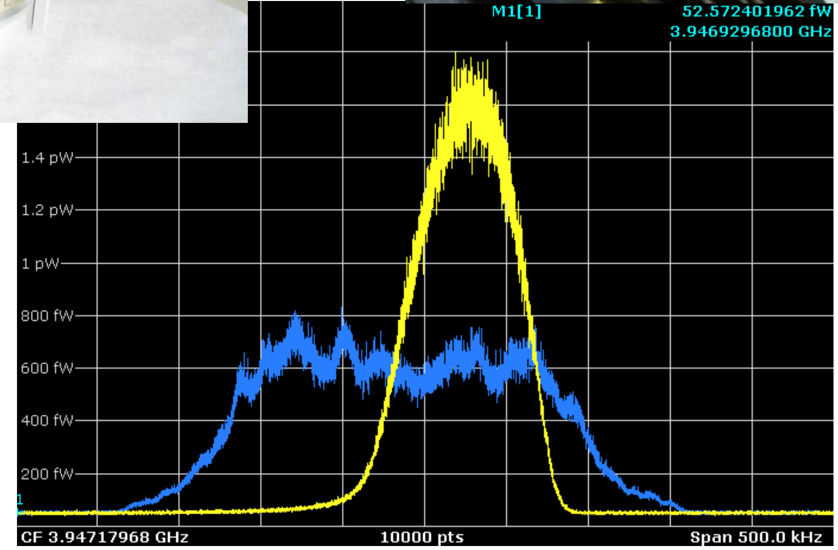




Betatron sidebands measured with the same structure (vertical tune close to 3.5 -> bandoverlap)

Cooling at nuclotron Dubna





-> talk on Friday by N.Shurkhno

Pickup:	16 rings
Kicker:	16 rings
Filter cooling with optical Notch-Filter	
Ions:	D+
Intensity:	2E9
Cooling time:	480s
Initial dp/p:	0.55x10-3
Final dp/p:	0.25x10-3

Data for Heavy Ions ($^{238}U^{92+}$)

Injection: $B^*\rho$=12 Tm (740 MeV/u)

$\beta = 0.83$

Maximum magn. Rigidity: $B^*\rho$=50 Tm (5 GeV/u)

$\beta = 0.98$

Minimum magn. rigidity $B^*\rho$= 5 Tm (165 MeV/u)

$\beta = 0.53$

Power/gain demands according the simulations by H.Stockhorst and T.Katayama (1)

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- Accumulation pbars:
  $P \leq 70W$, $G_a = 130dB$, $N=10^{10}$
- Longitudinal cooling @ 3 GeV pbars, (Hydrogen-Target $N_T = 1*10^{15}$ /cm²)
  $P \leq 5W$, $G_a = 110dB$, $N=10^{10}$
- Transversal cooling @ 3GeV pbars
  $P \leq 35W$, $G_a = 130dB$, $N=10^{10}$

regarding safety margin, cable attenuation and noise peaks, installed power is sufficient (rule of thumb: factor 10 between P and P_{1db})!

Power/gain demands according the simulations by H.Stockhorst and T.Katayama (2)

- Longitudinal ToF cooling @ 740 MeV/u, $^{283}U^{92+}$ (Hydrogen-Target $N_T = 1*10^{15}$ /cm²)
  $P \leq 13W$, G_a = 85dB, $N=10^8$ (limited due to radiation safety)
- Longitudinal Filter cooling @ 2 GeV/u, $^{283}U^{92+}$
  $P \leq 60W$, G_a = 108dB, $N=10^8$

Cooling of heavy ions: No limitation by installed power and gain settings

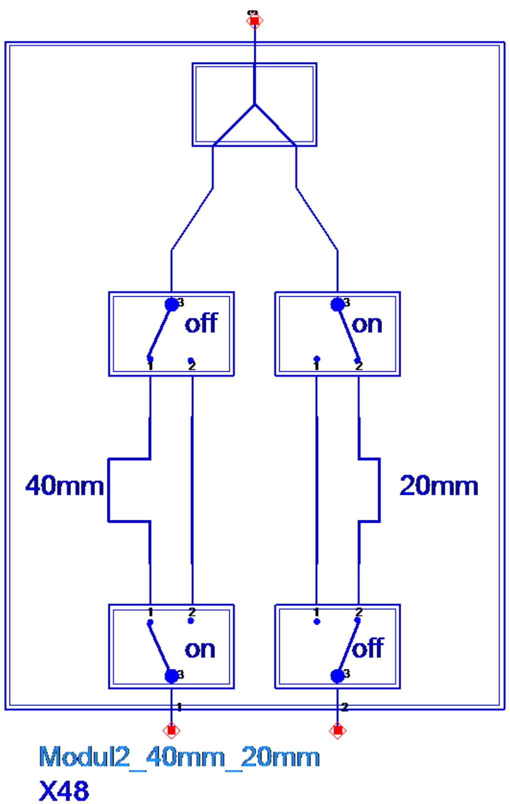
Limitation to lower energies

- Number of prog. delay lines outside the tanks to combine the groups of each tank and the two PU-tanks
- Smallest group within tank: 16 rings combined by 16:1 combiner
- Sensitivity of structures

Programmable delay lines

to cover the whole pbar energy range (0.76-14 GeV)

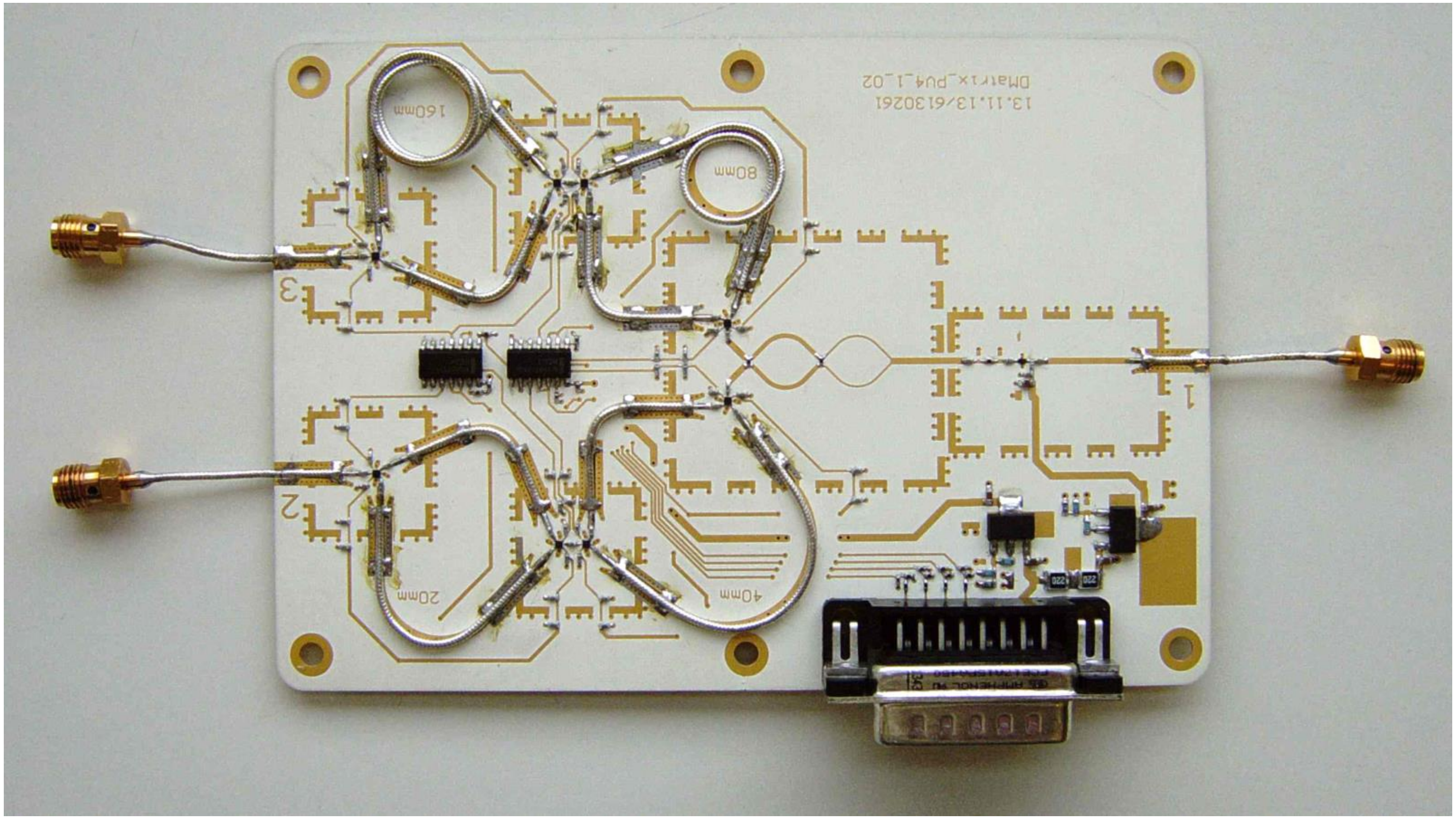
Concept: Switches optimized with changing reference-plane, advantage: equal number of switches, minimized numbers of switches



3 different modules:

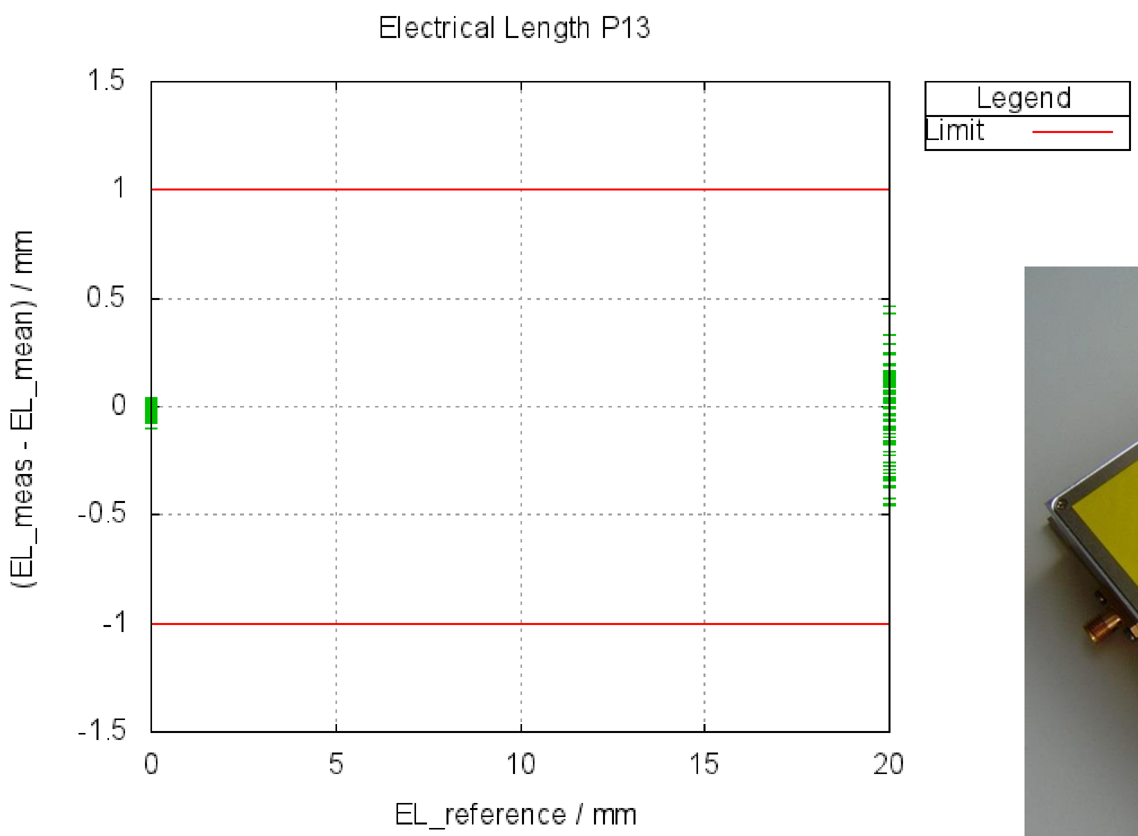
- Module 1: 10mm, 20mm
- Module 2: 20mm, 40mm
- Module 3: 20mm, 40mm, 80mm, 160mm
- equalizer to compensate frequency response of all modules
- All modules delivered and tested

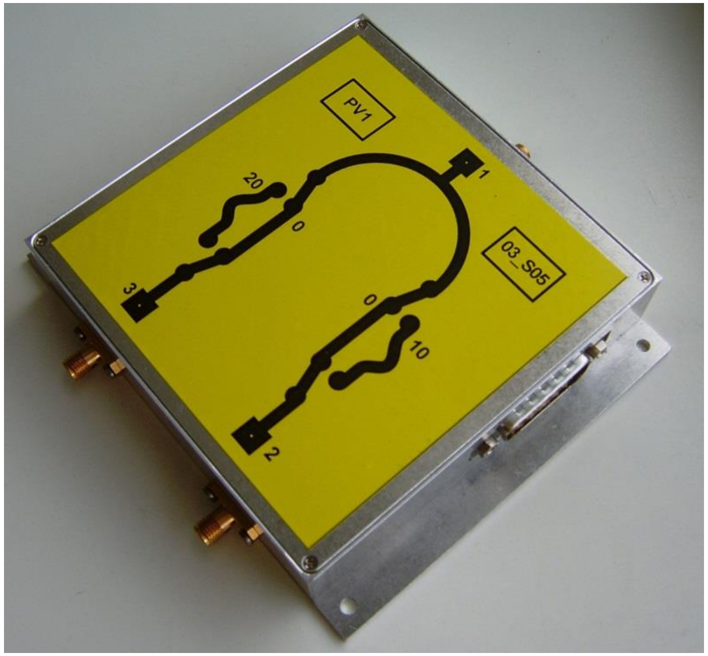
Layout PV4 (20,40,80,160mm)



Mitglied der Helmholtz-Gemeinschaft

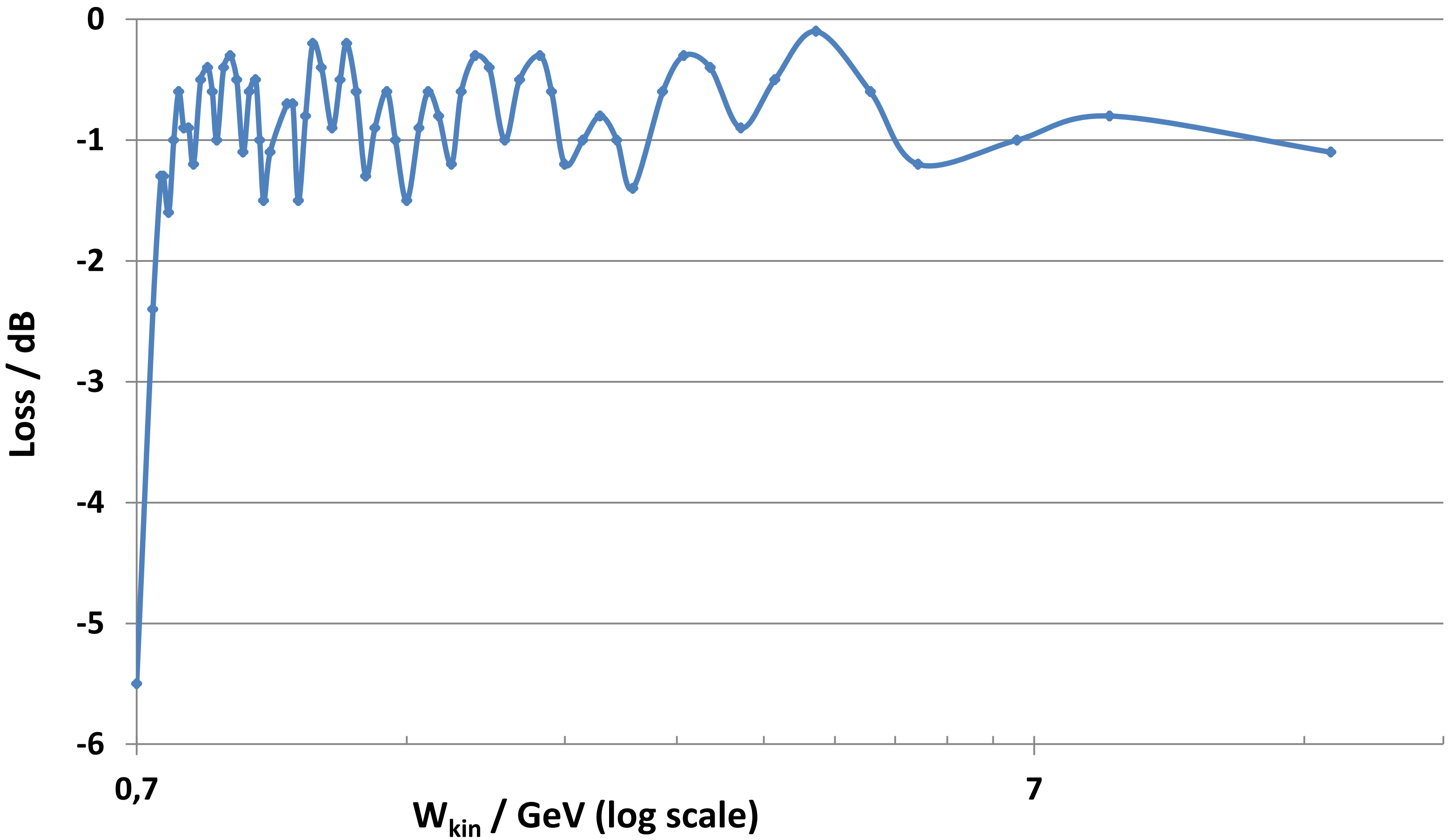
Tolerances between all PV1, second path



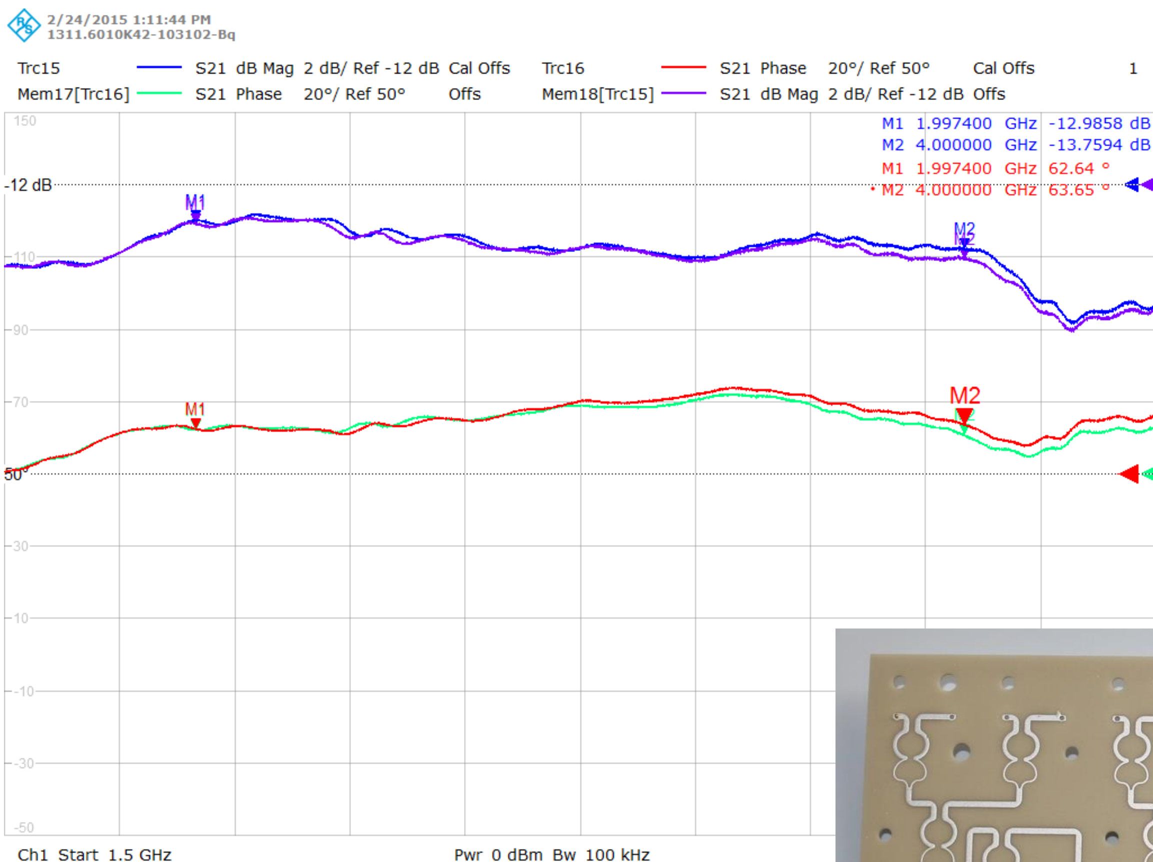


Very good tolerances reached over all PV's
But of course still switching steps and no continuous change of lengths

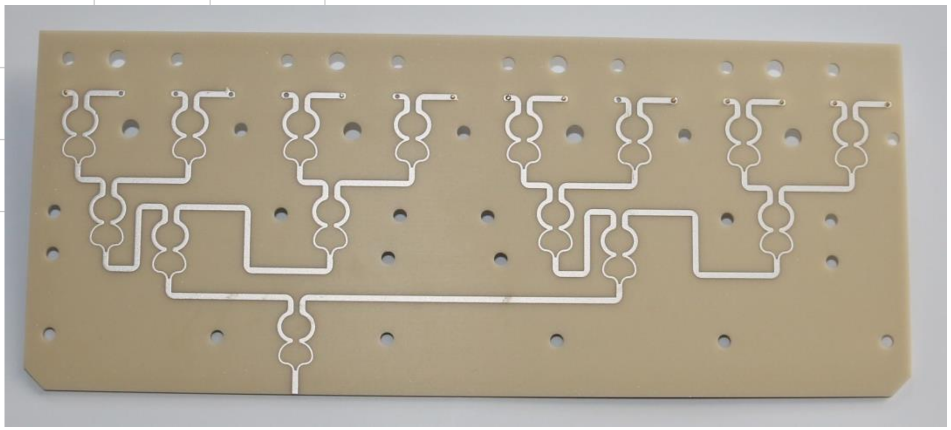
Combiner-losses outside the tanks



16:1 combiner-board (Al_2O_3)

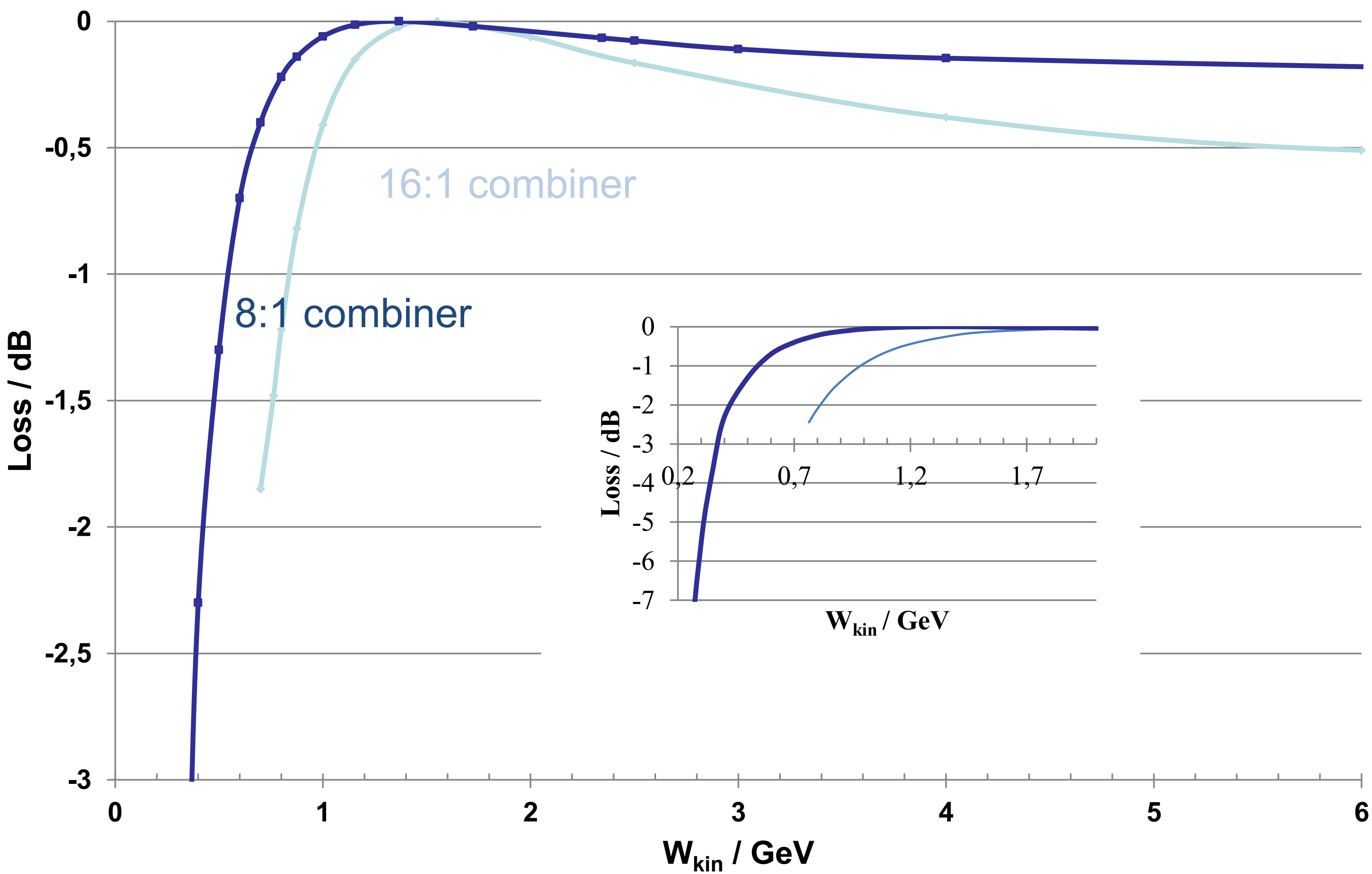


- Very low losses
- Good matching to design energy (β=0.92)



All Al_2O_3 combiner-boards for main-system fabricated

16:1 Combiner losses compared to 8:1 combiner losses (optimum energy shifted from 1.55 GeV to 1.36 GeV

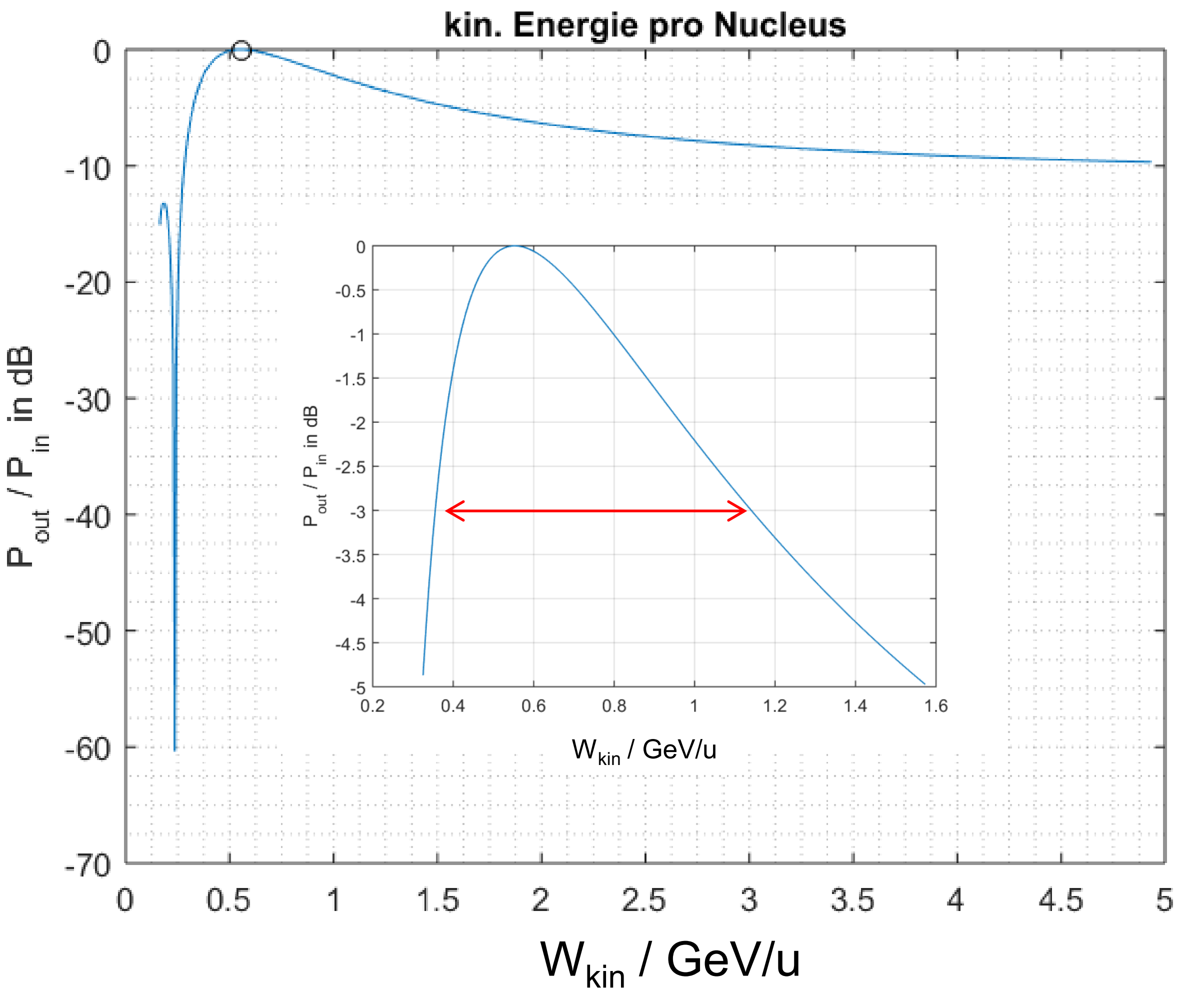


Consequences of changing to 8:1 combiner

- Doubling the feed-throughs for PU and Kicker
- Increased heat load (additional cryo-pump needed, change of mechanical layout)
- Doubling pre-amplifiers
- New combiner-boards
- More complicate signal combination with additional programmable delay lines outside the tanks
- Higher number of power amplifiers but less power

-> Redesign of whole system layout……

Possible Solution: one stack of 16 rings with optimized combiner-board to 10Tm ($^{283}U^{92+}$)



S/N ~ Z^2 : that helps to operate with reduced numbers of rings

useful range of combiner-board: 0.35 GeV/u – 1.1 GeV/u, (β: 0.68 – 0.89)

Additional reduction of range, due to sensitivity change in the structures. (still under investigation)

Conclusion (1)

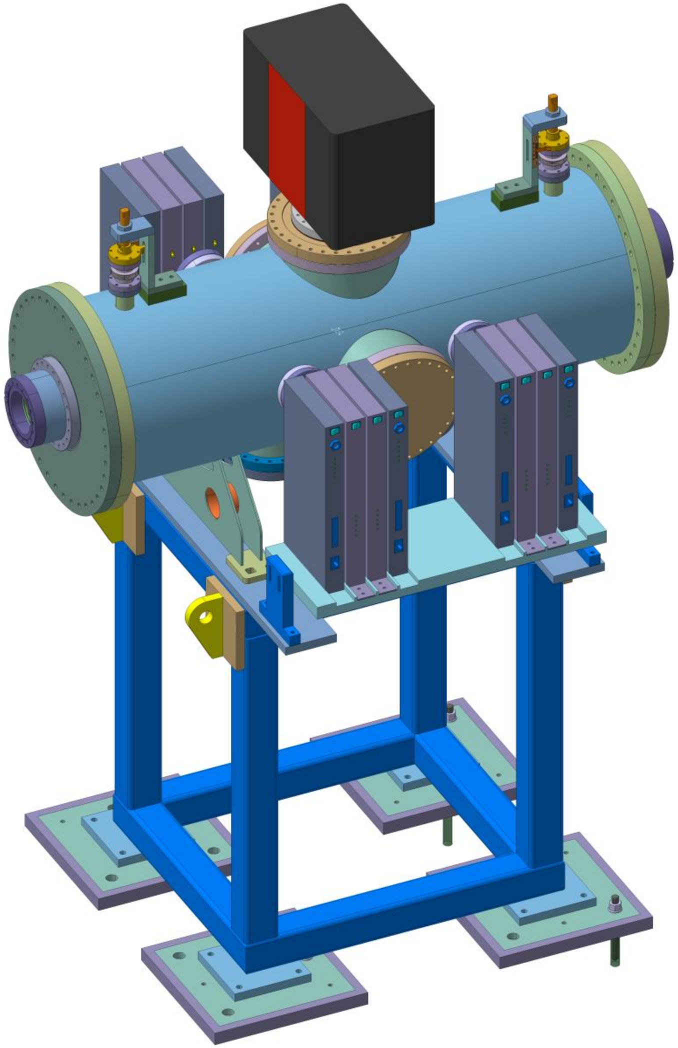
- The main stochastic cool system is well prepared to cool pbars in the whole energy range
- Heavy ions with particle velocities higher than $\beta=0.83$ can be cooled directly with the same system.
- Cooling down to $\beta=0.68$ possible with one short additional system

High power amplifier

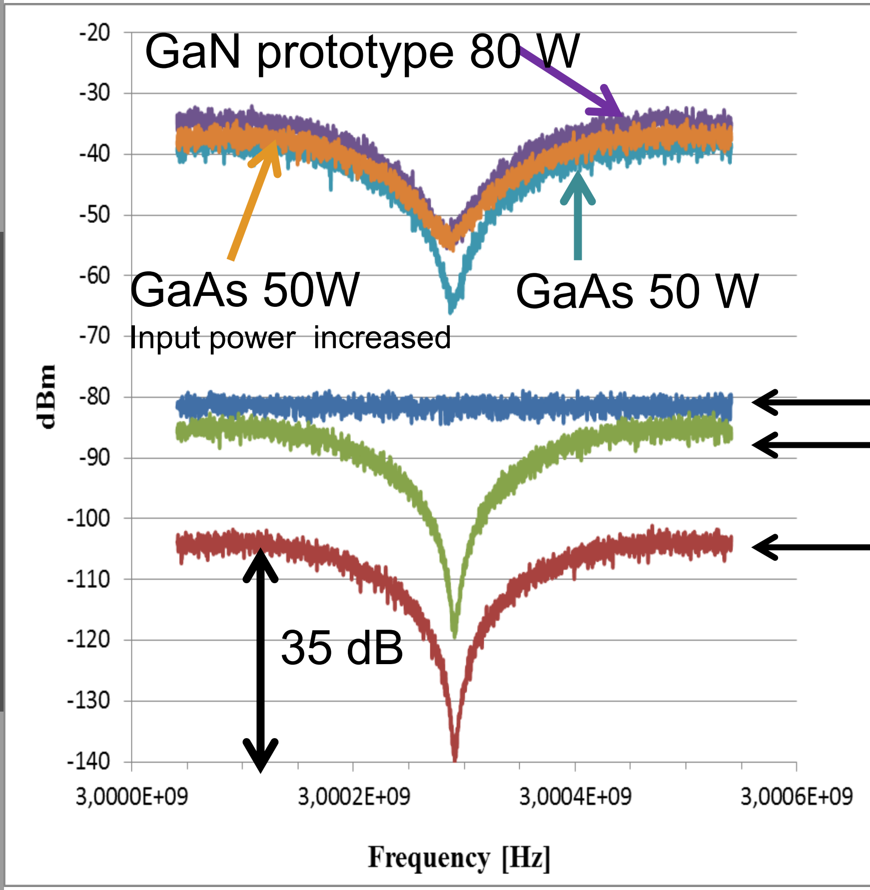
most critical device in active chain

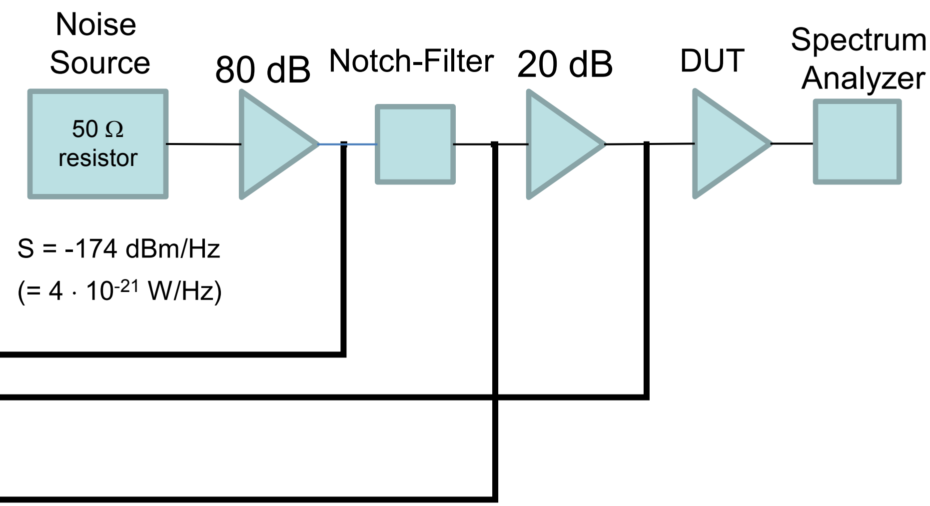
- GaN based solid state amplifier
- Optimized in amplitude, phase and group delay (good experience at COSY)
- Different technics analyzed (housed transistors or dies bonded direct into the structure, separate modules, LTCC (Low Temperature Co-fired Ceramics))

2nd prototype



Filling up the notches due to IMD (thanks to Fritz Caspers)





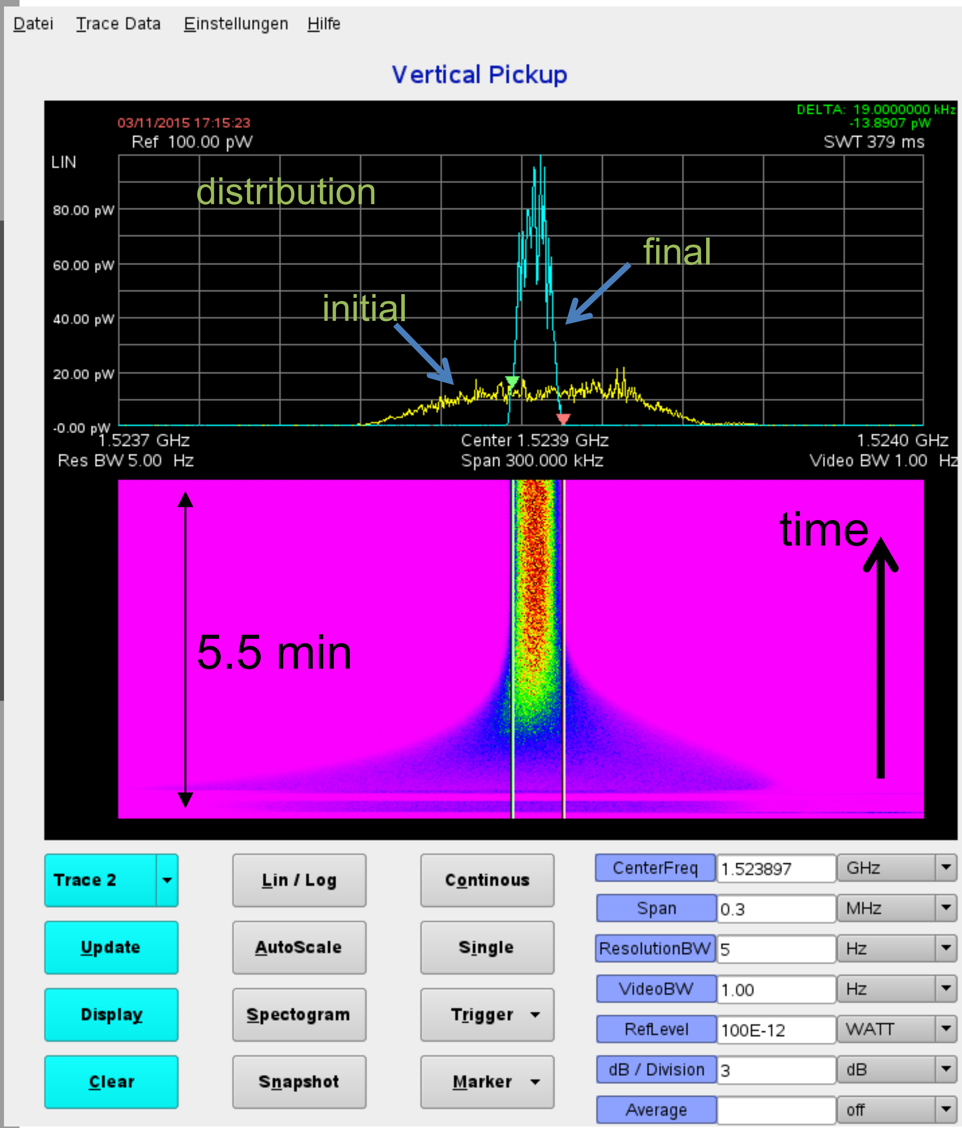
- Notch depth at the output of power amplifier reduced to - 20 dB
- Creates additional heating of beam particles
- Cooling down time increases
- Equilibrium momentum spread increases

Taking into account the kicker-tank setup (4 groups) this is already the highest needed gain

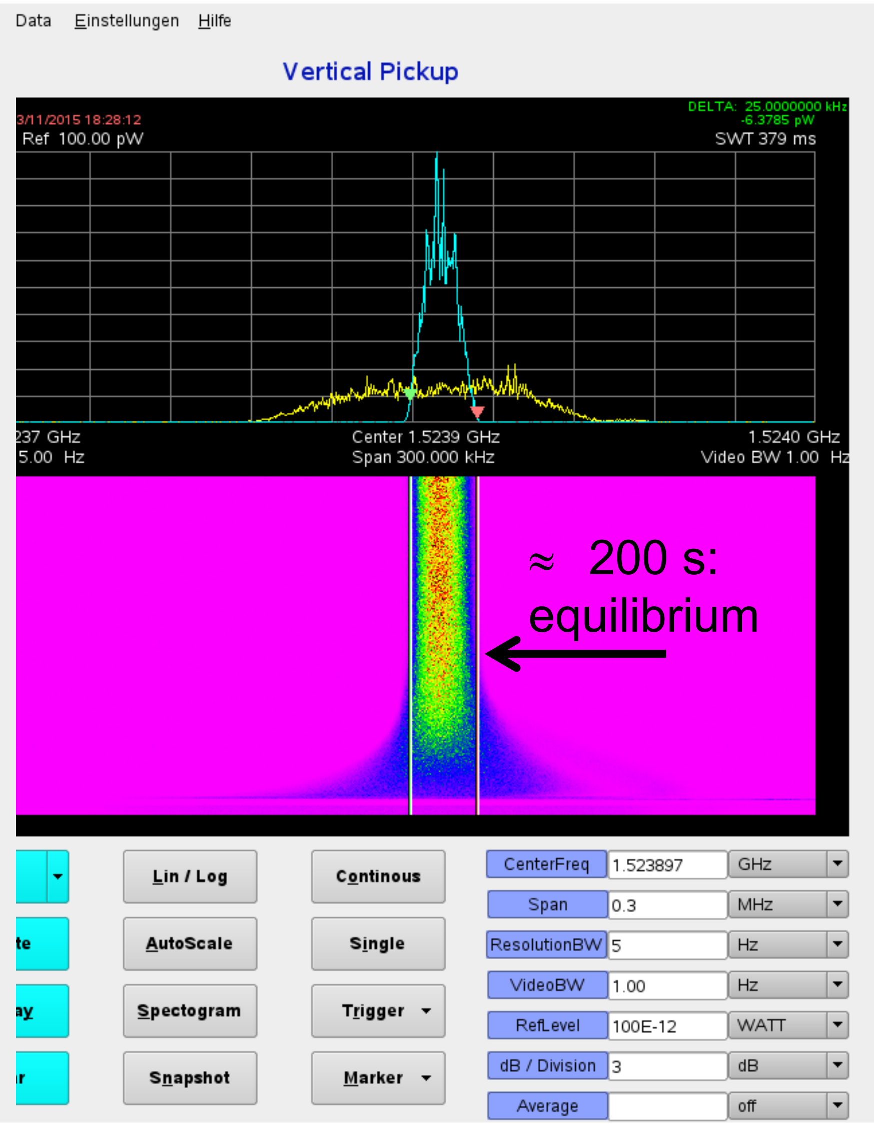
-> Solution with GaN based amplifier possible

Different Notch Depth

Notch Depth > 30dB

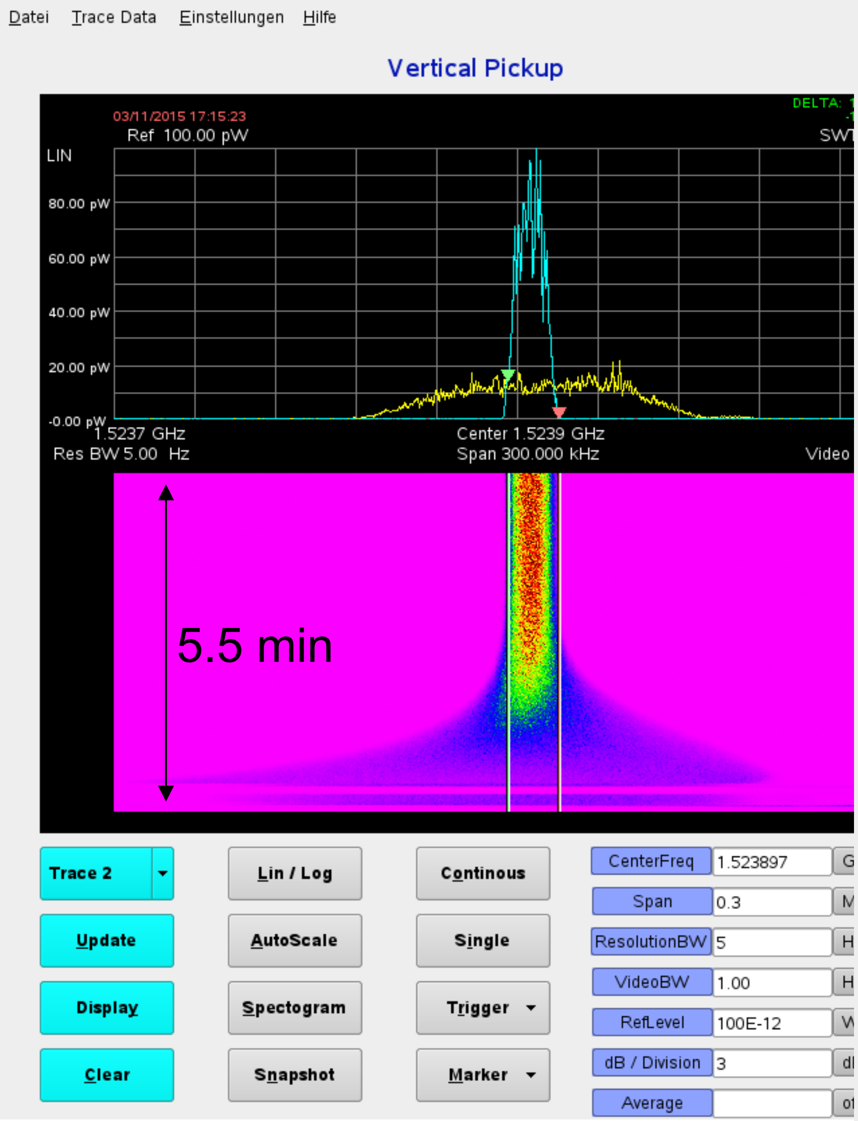


Notch Depth ~ 20dB

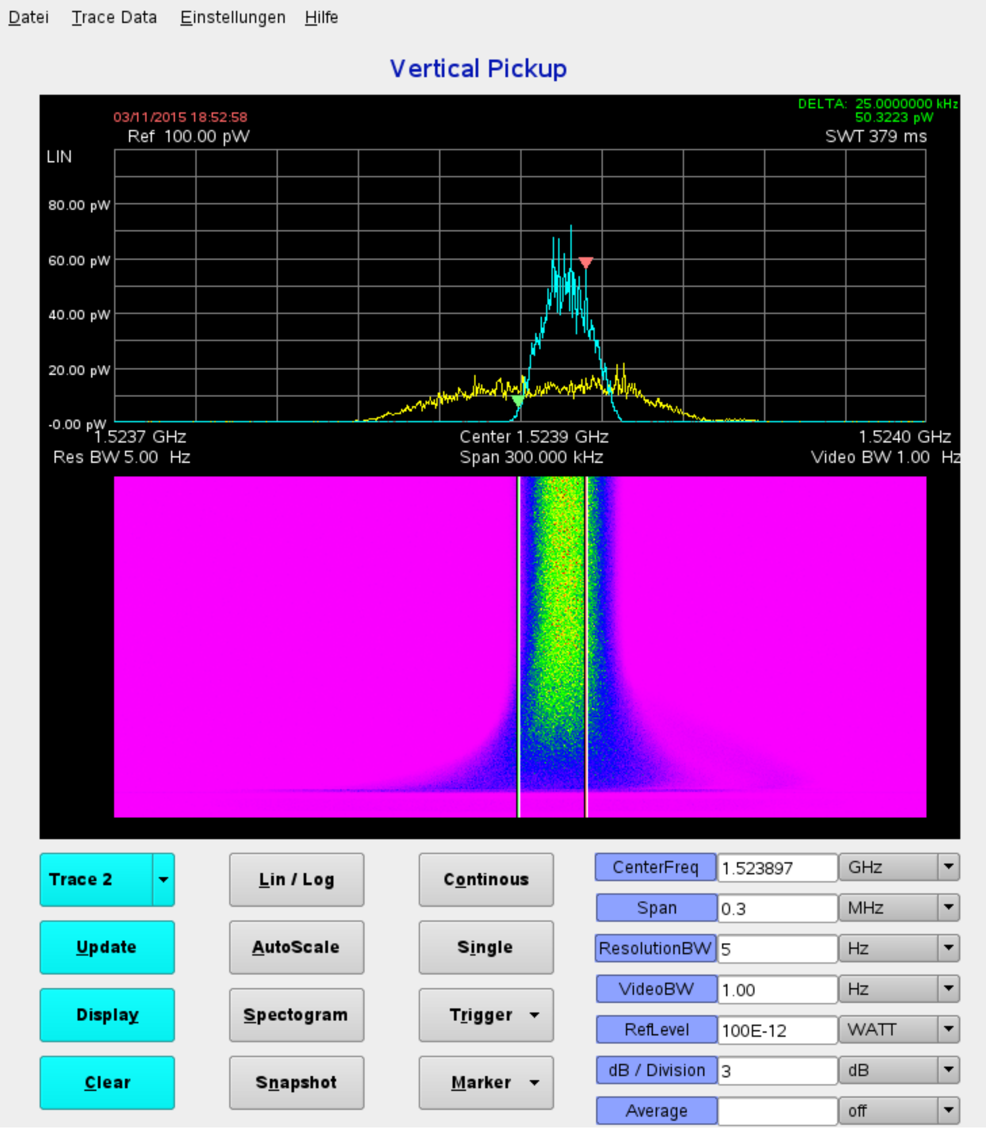


Different Notch Depth

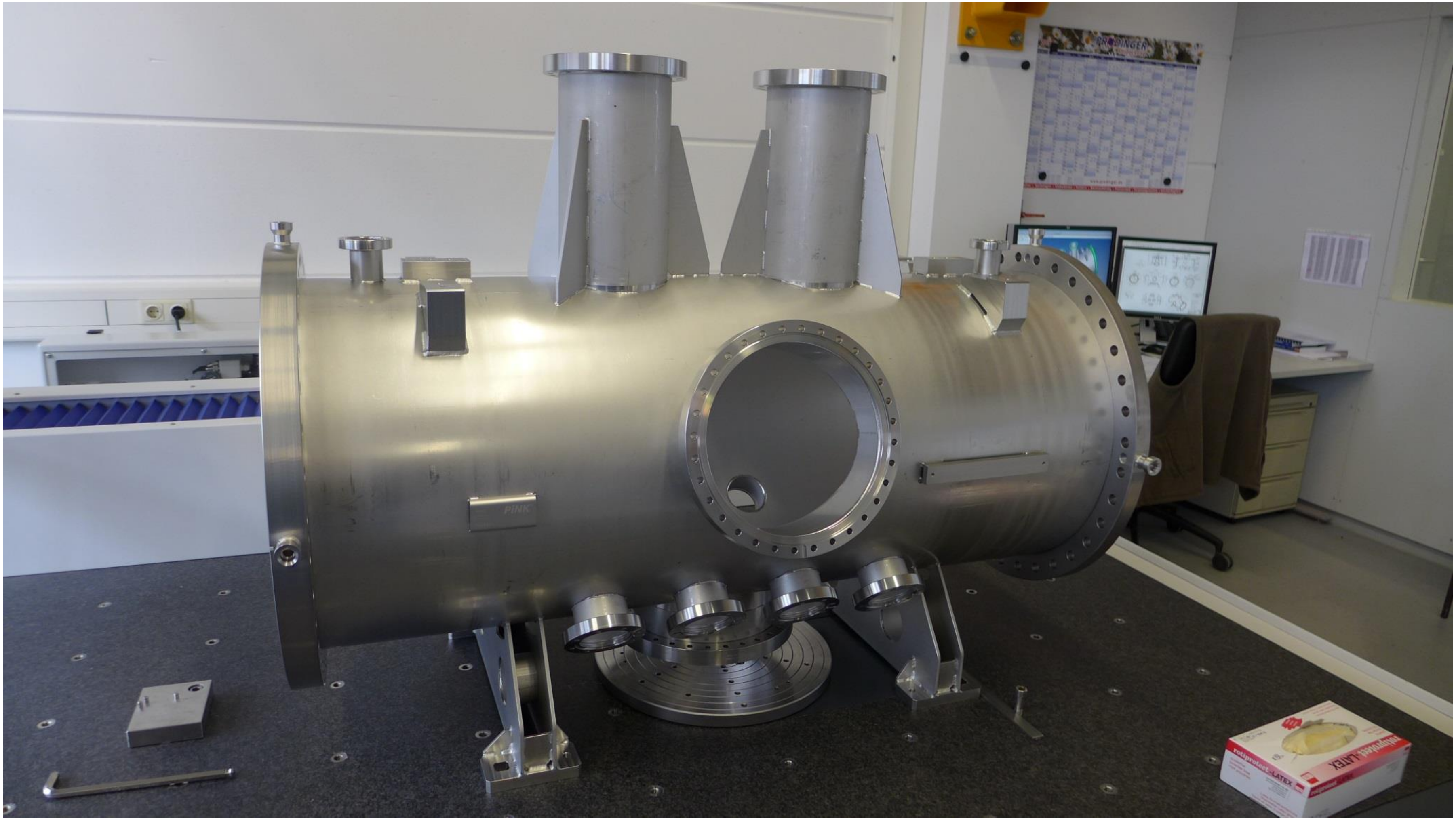
Notch Depth > 30dB

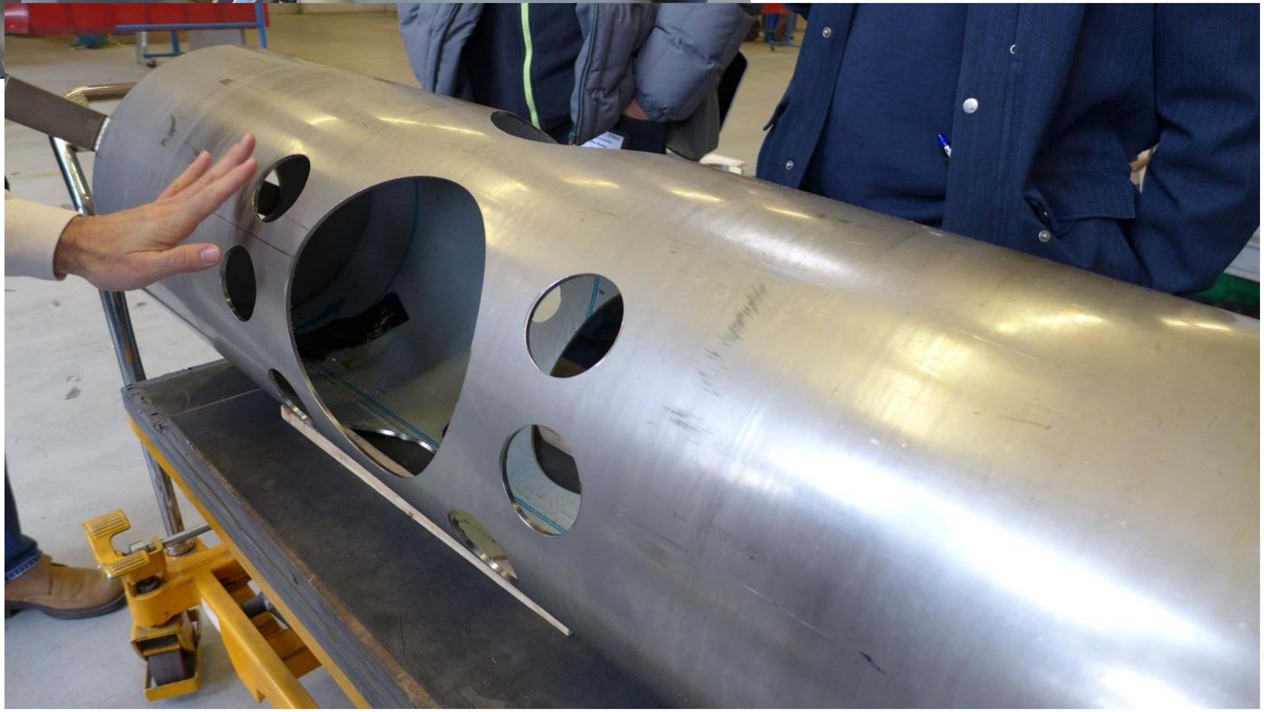


Notch Depth ~ 15dB

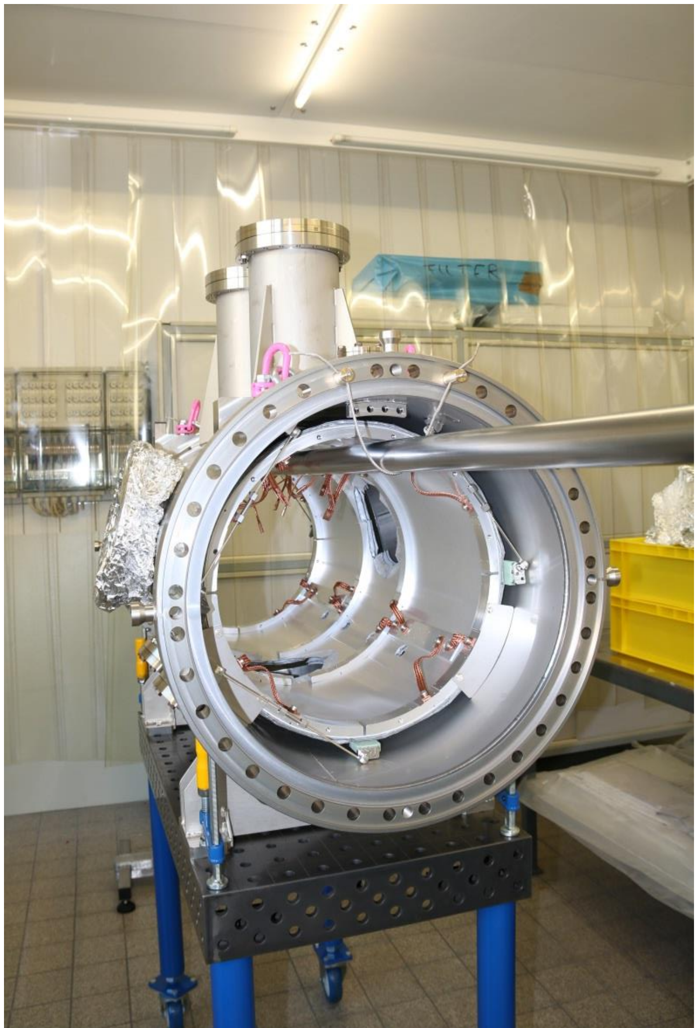


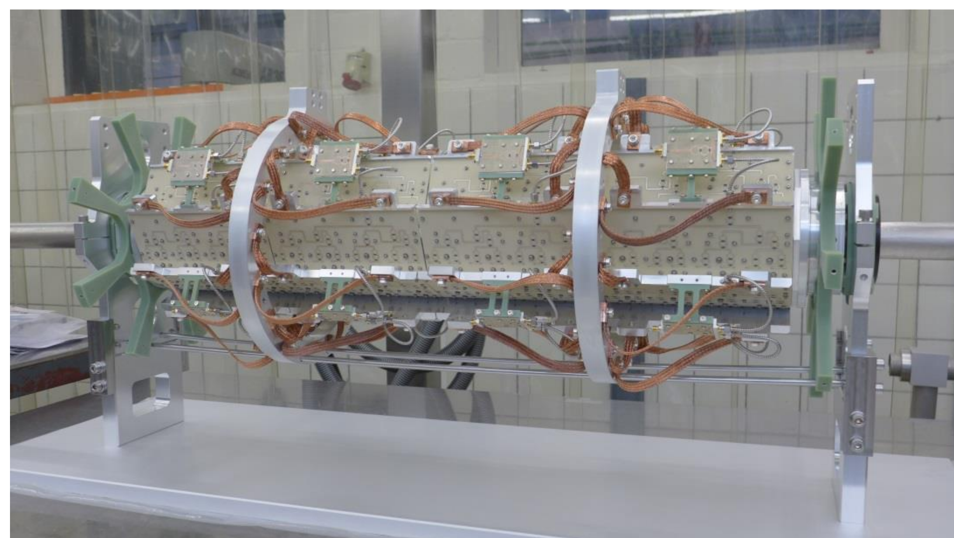
First tank: 20.01.2015





In the clean-room of ZEA1





Thank you for your attention