Stochastic Cooling Project at the Experimental Storage Ring, CSRe at IMP

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Purpose of the stochastic cooling

- Pre-cooling of the radio isotope beam
- Beam energy: 300 MeV/u-400 MeV/u
- Number of RI particles: < 5e3
- Mass number: 100-150
- Atomic number: 50-60
- Lifetime of RI ion: about 10~40 s
- Beam parameters: Emittance=50 pi mm mrad, Dp/p=±1%

Electron cooling at CSRe (Without stochastic cooling)

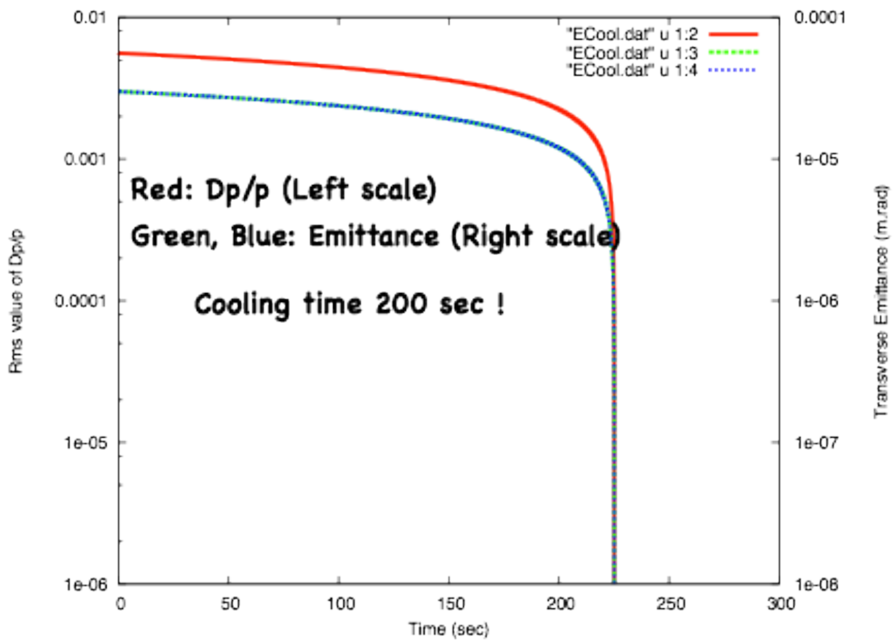
Ion 132Sn50+, 380 MeV/u, Ie=1A

Ion beam initial condition

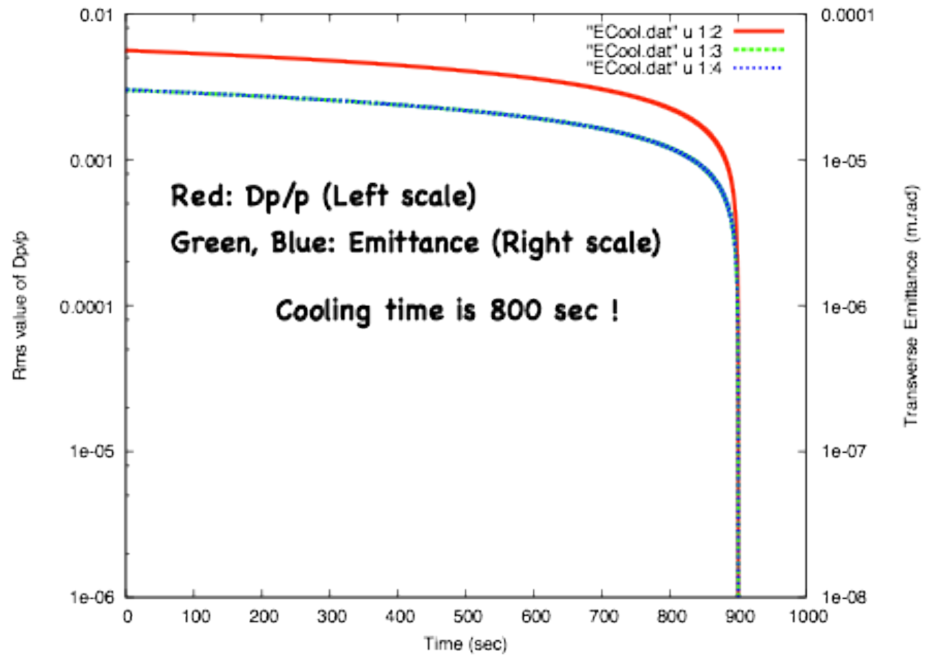
Dp/p=5.6e-3 (rms) (Corresponding to Dp/p=+/- 1.0e-2 uniform),

Emittance=30 Pi mm.mrad

Diameter of Ie=2 cm



Diameter of Ie=4 cm

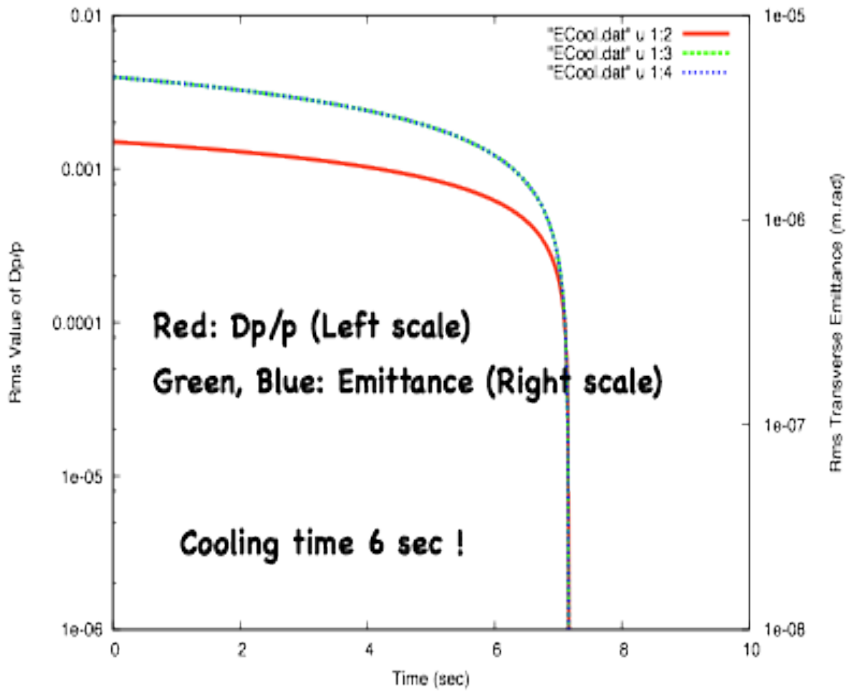


Electron cooling at CSRe after Stochastic Pre-cooling

Ie=1A, Diameter=2.0e-2m

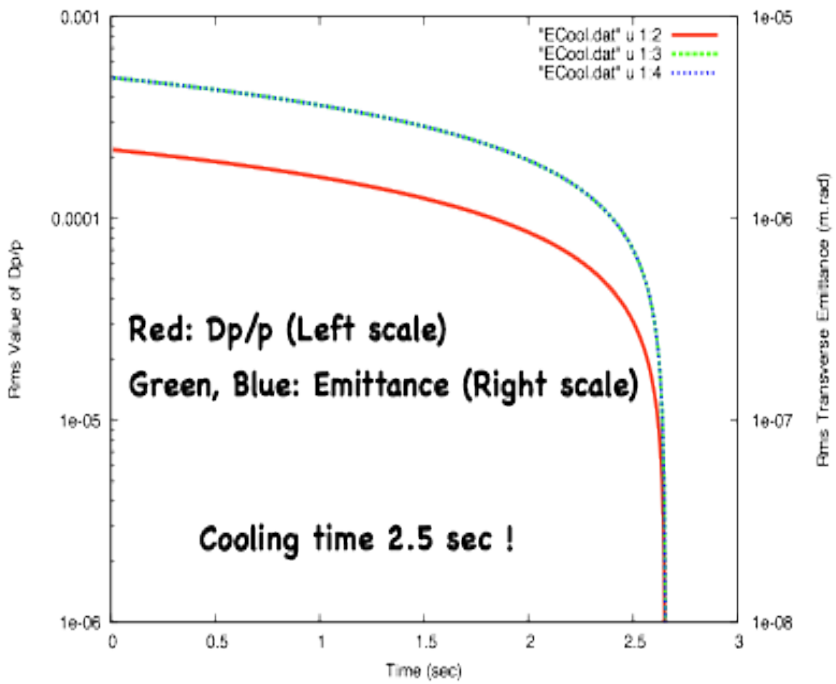
Initial condition

Dp/p=1.5e-3, Emittance=5 Pi mm.mrad

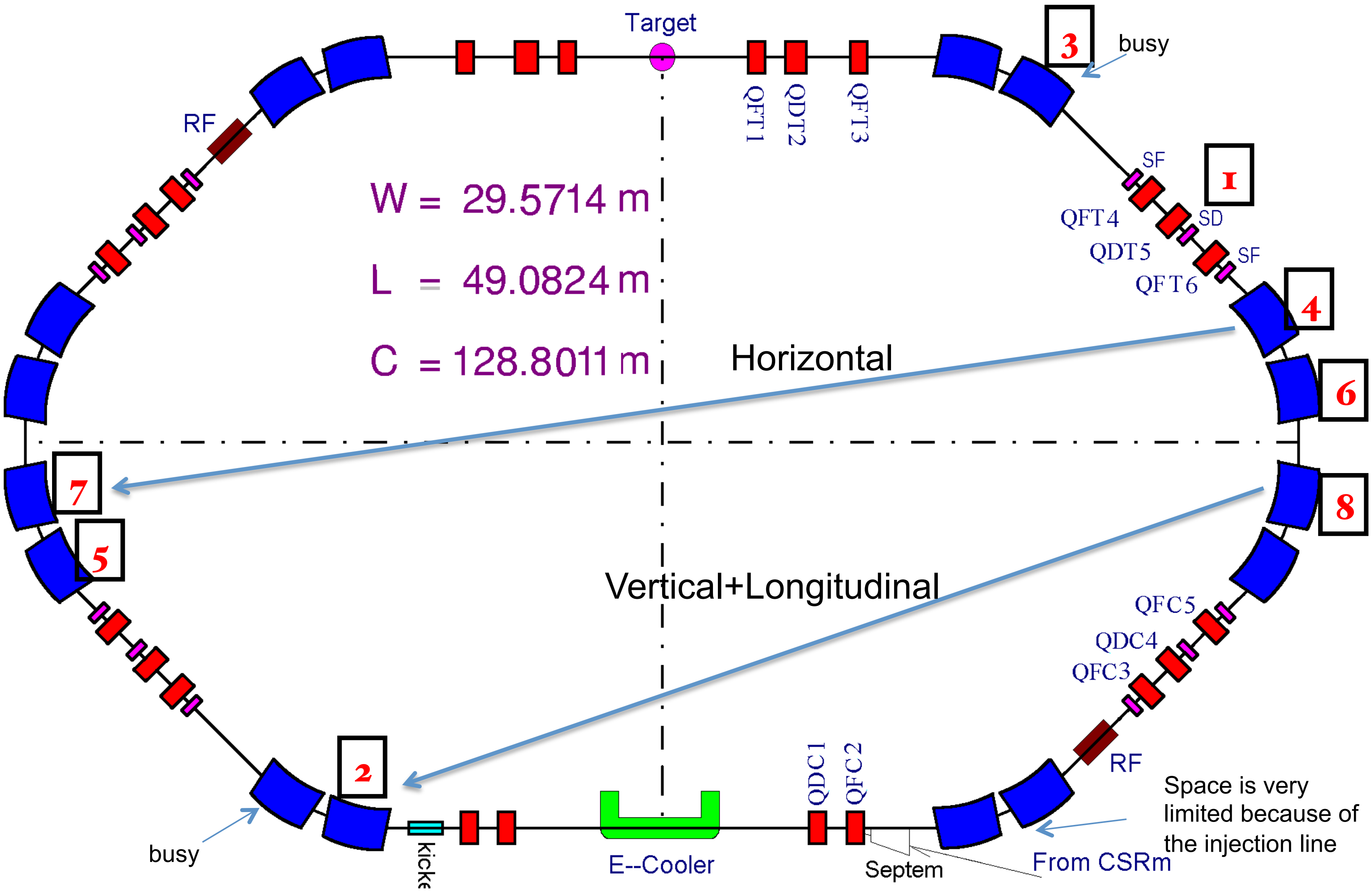


Initial condition

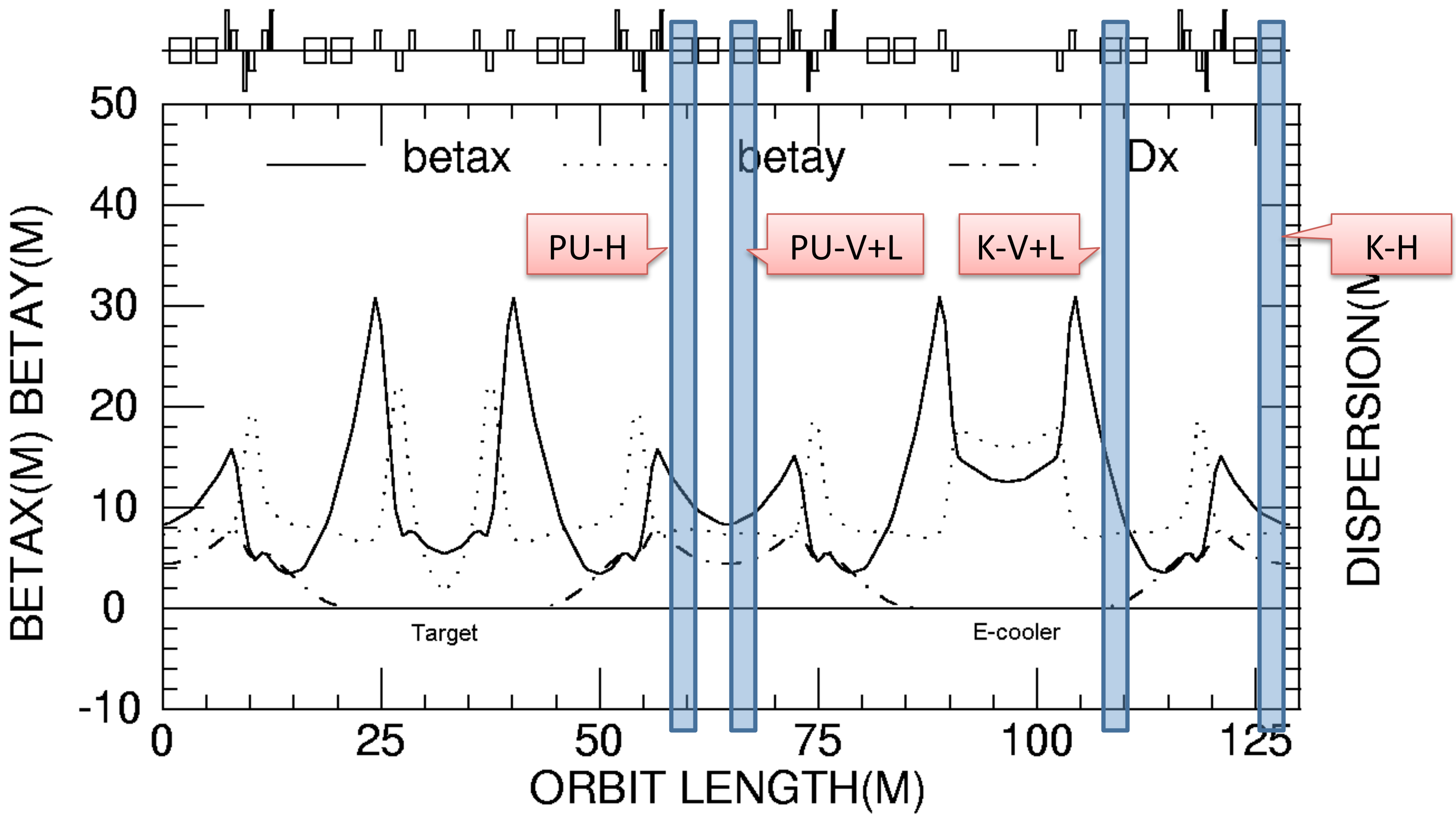
Dp/p=2.2e-4, Emittance=5 Pi mm.mrad



Layout of CSRe



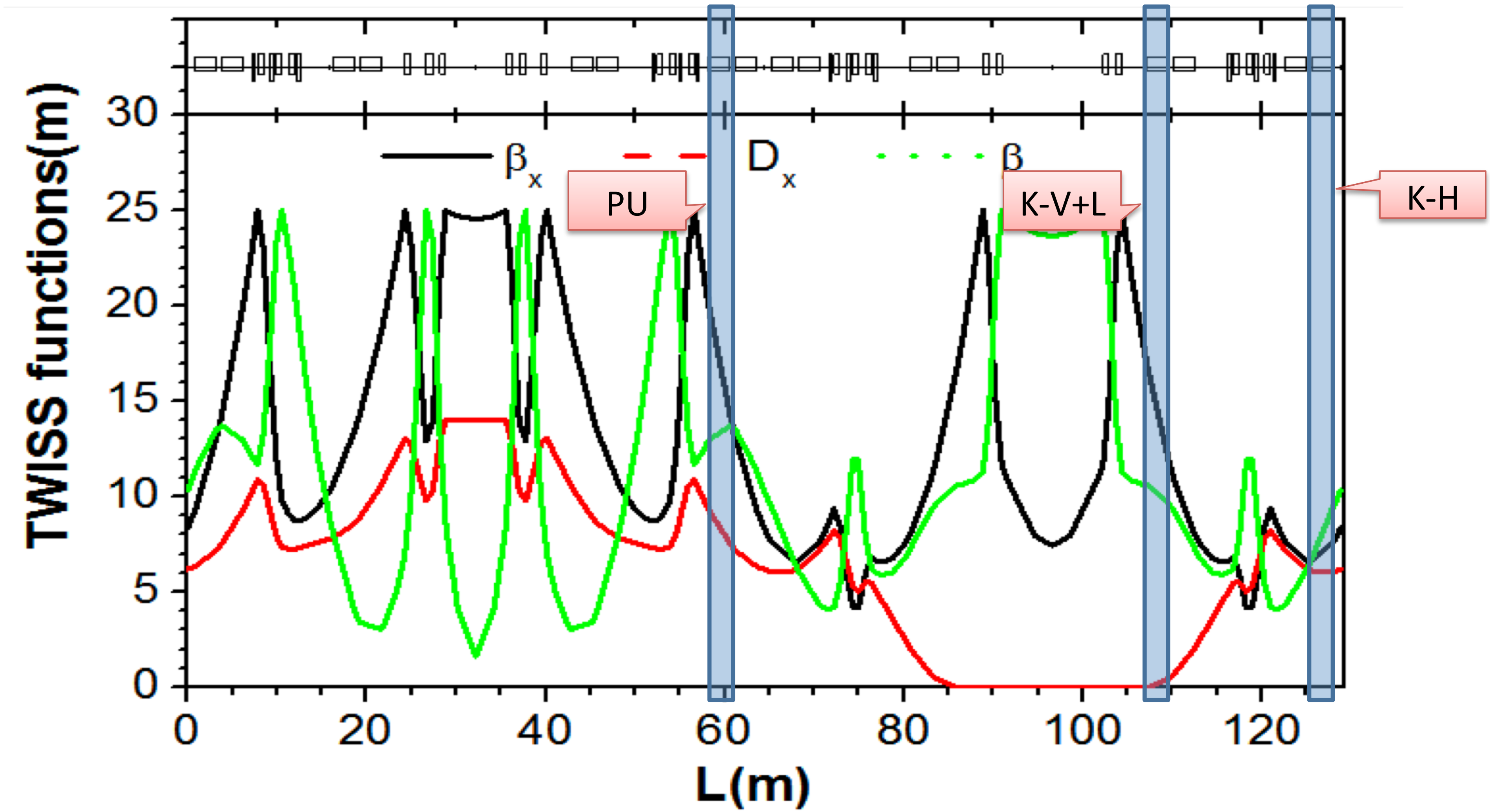
Normal Mode (γt=2.629)



Twiss parameters for PU & Kikcer of stochastic cooling (normal mode, γtr = 2.629)

	Horizontal		Vertical+Momentum	
	Pickup	Kicker	Pickup	Kicker
β_x (m)	12.6-11.6	9.7-9.4	8.6-9.4	17.3-13.6
β_y (m)	8.2-8.0	6.6-6.5	7.4-7.6	7.4-7.6
D_x (m)	6.5-5.8	4.8-4.5	4.4-4.5	0.09-0.19
θ	82^0		80^0	
L(m)	67		42	

New Mode (γt=1.748)



Stochastic cooling Layout of New mode

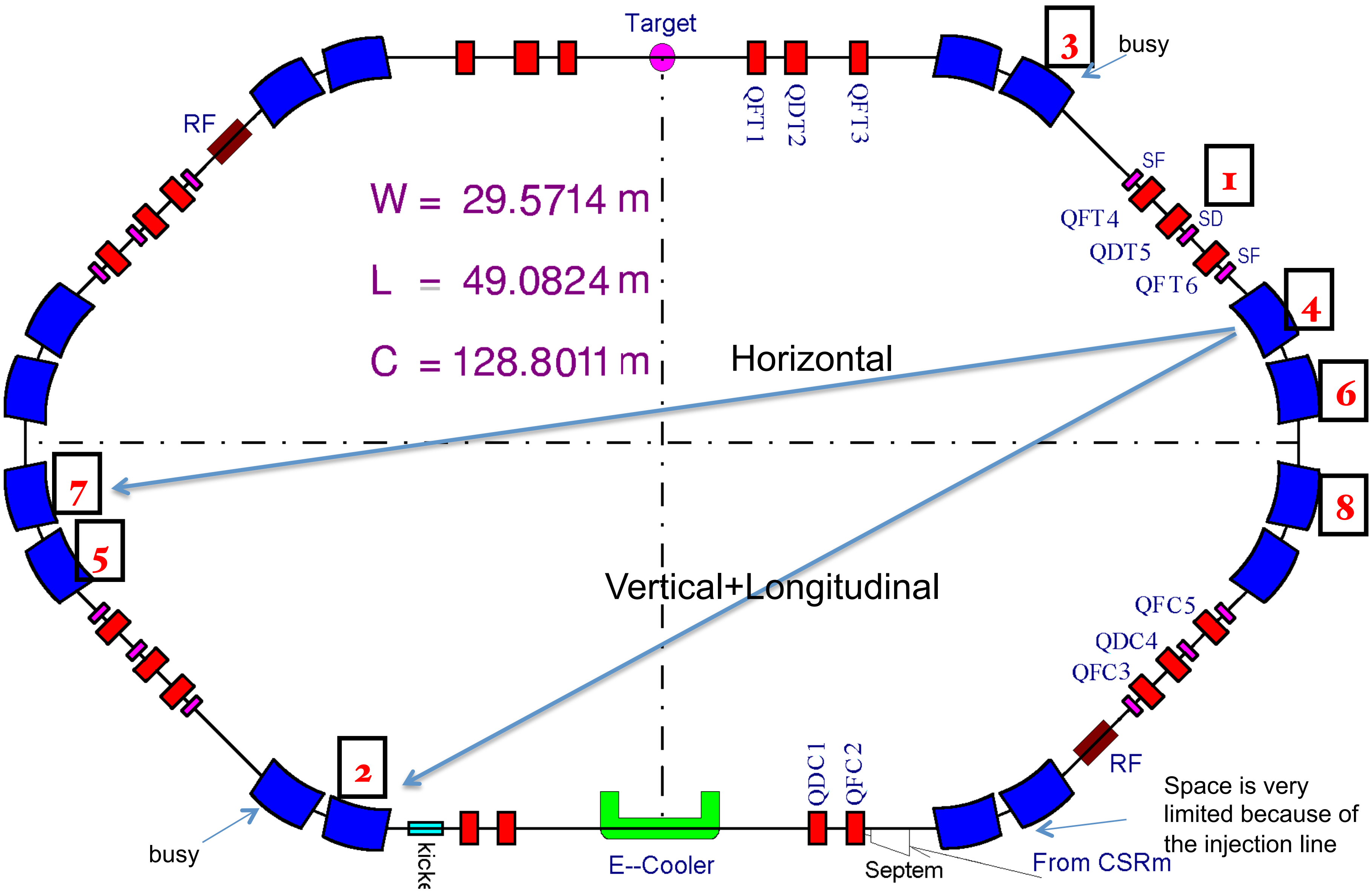


Table 2-2 Twiss parameters for stochastic cooling PU & Kicker (New mode, $\gamma t = 1.748$)

	Horizontal		Vertical+Momentum	
	Pickup	Kicker	Pickup	Kicker
βx (m)	19.9-14.3	6.6-7.6	7.6-6.6	16.8-11.9
βy (m)	12.9-13.7	6.7-9.4	9.4-6.7	10.6-9.6
Dx (m)	9.3-7.5	6.0-6.1	6.0-6.1	0-0.4
θ	76^0		78^0	
L(m)	67		49	

Useful aperture of CSRe

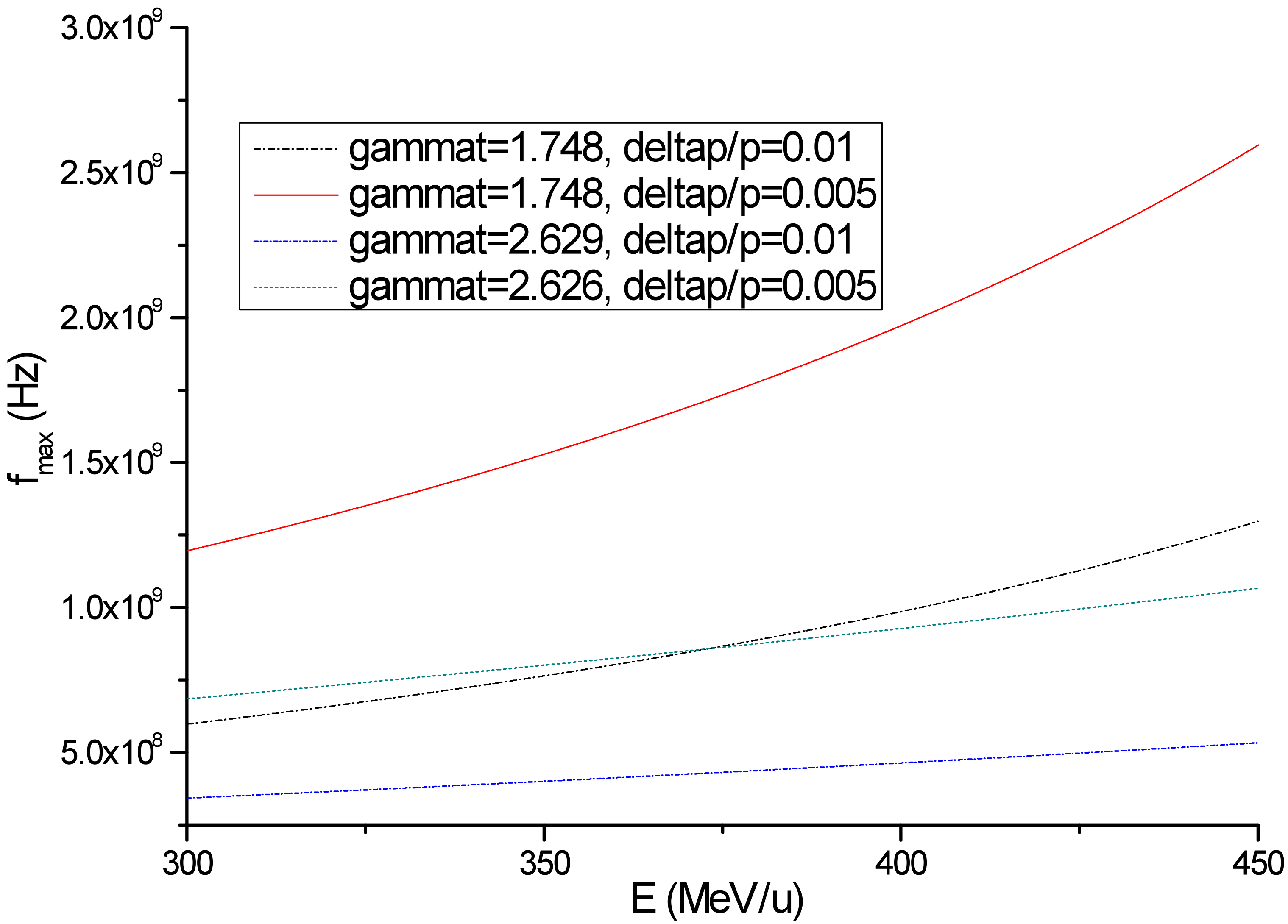
Dipole	Quadruple
$220 \times 70\ mm^2$	$280 \times 140\ mm^2$
$B_{Max.} = 1.6\ T$	$K_{Max.} = 7\ T/m$

Beam Acceptance

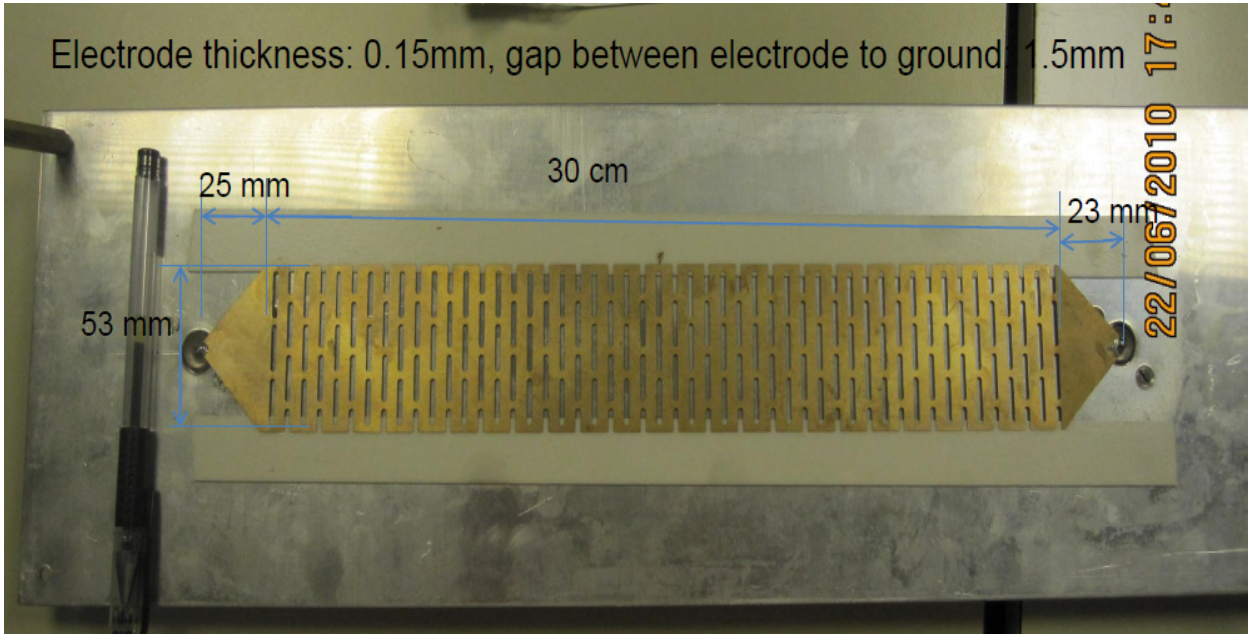
Internal-Target Mode	Normal Mode	New Mode
A_h=150 π mm-mrad (ΔP/P=±0.5%)	A_h=150 π mm-mrad (ΔP/P=±0.5%)	A_h=50 π mm-mrad
A_v=75 π mm-mrad	A_v=80 π mm-mrad	A_v=80 π mm-mrad
ΔP/P=2.0% (ε_h=10 π mm-mrad)	ΔP/P=2.6% (ε_h=10 π mm-mrad)	ΔP/P=0.7%

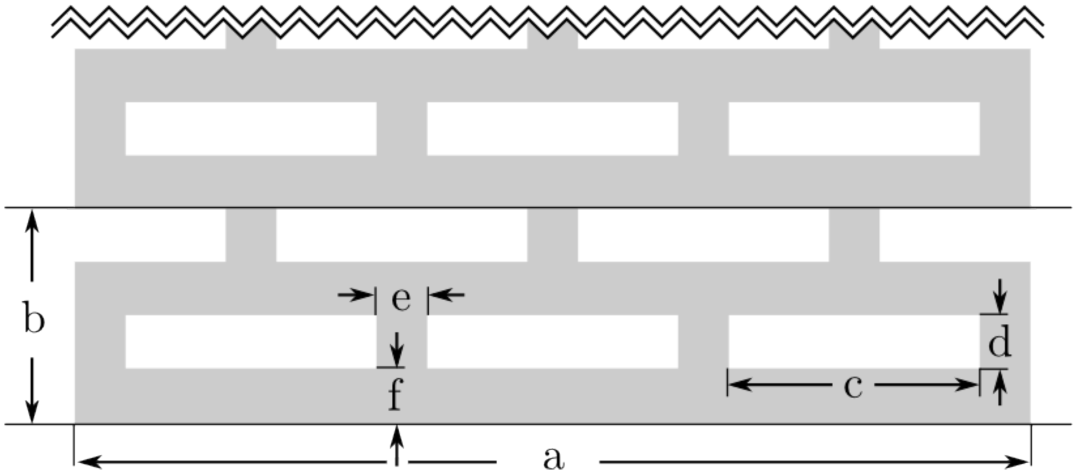
Need to be Measured !!

Maximum frequency limit



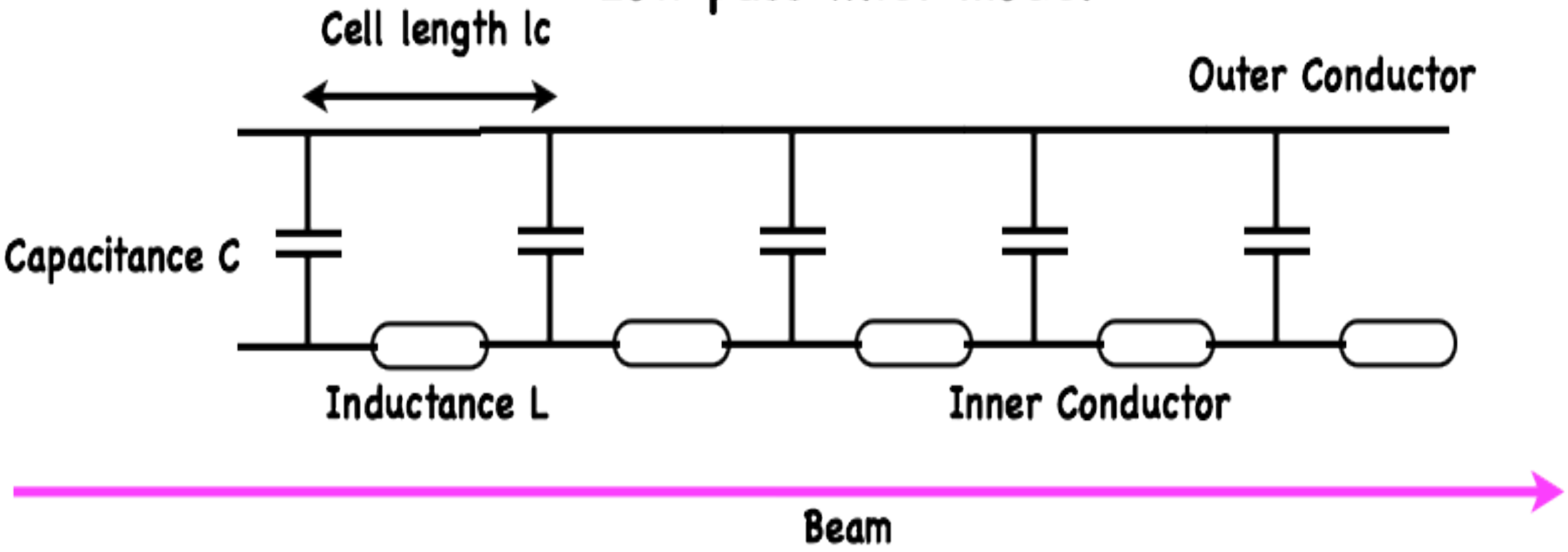
Fritz Caspers's model (proposed in 1998) Travelling Wave, Slotted Line structure





[mm]
a = 53
b = 12
c = 15
d = 02
e = 02
f = 04

Low pass filter model



Beam velocity Beta=0.7

Cutoff Frequency=3.7 GHz

Characteristic impedance=18 Ohm

Cell Length= 1.2 cm

Length of PU=0.48 m

$$Gain\ Function = \frac{V(l)}{i_b} = |G| \cdot \exp(j\phi)$$

$$Cutoff\ Frequency\ f_c = \frac{1}{\pi\sqrt{LC}}$$

$$Abs(GainFunction) = \frac{2\omega}{\beta c}\frac{Z_0 l}{A}\sin(A/2)$$

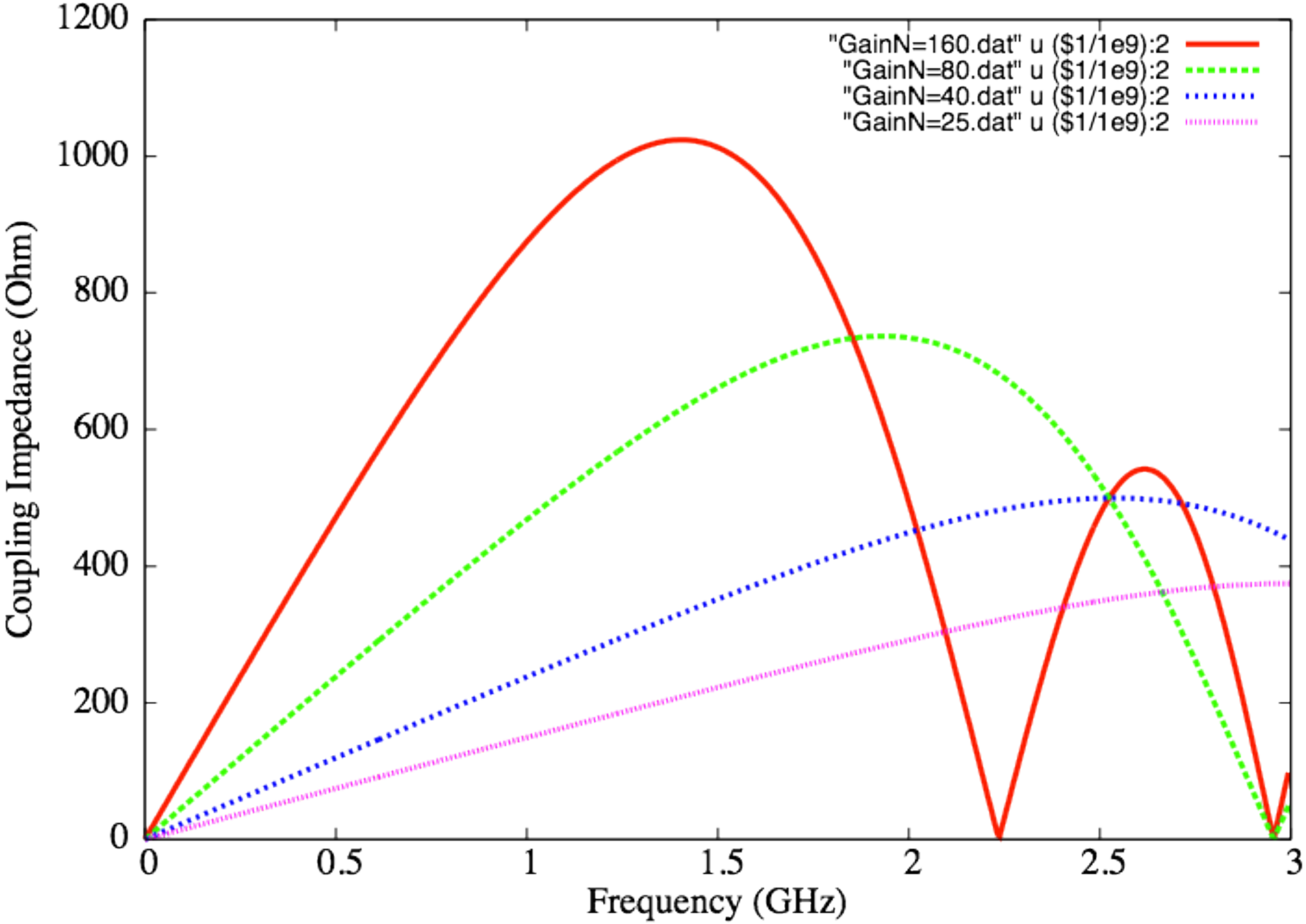
$$Phase\ Velocity\ v_p/c = \frac{l_c}{c\sqrt{LC}}$$

$$Phase(GainFunction) = \frac{A}{2} - \frac{\pi}{2}$$

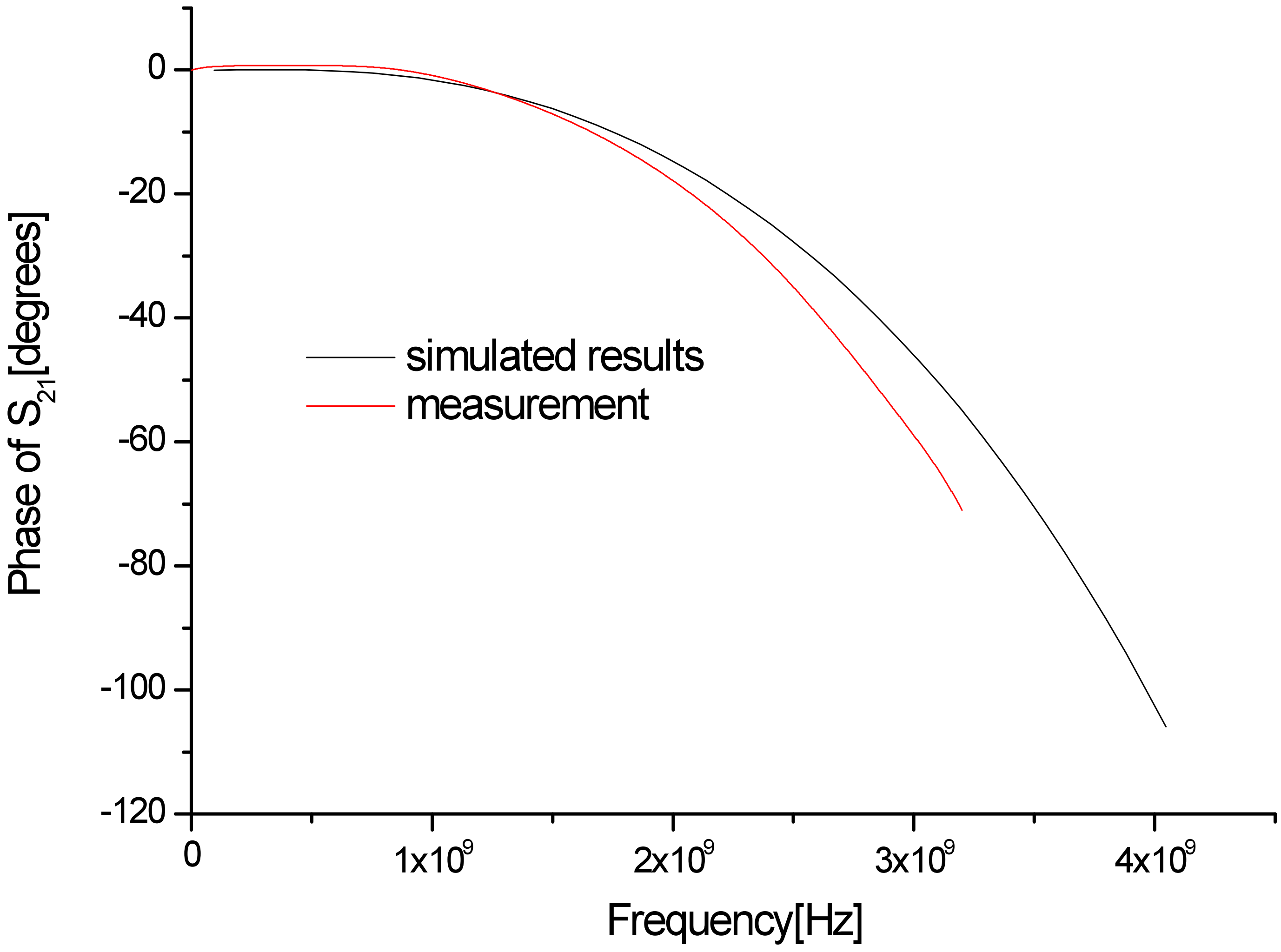
$$Charcteristic\ \mathrm{Im}pedance\ Z_0 = \sqrt{\frac{L}{C}}$$

$$A = \frac{2l}{l_c}\sin^{-1}\left(\frac{\omega}{\omega_c}\right) - \frac{\omega l}{\beta c}$$

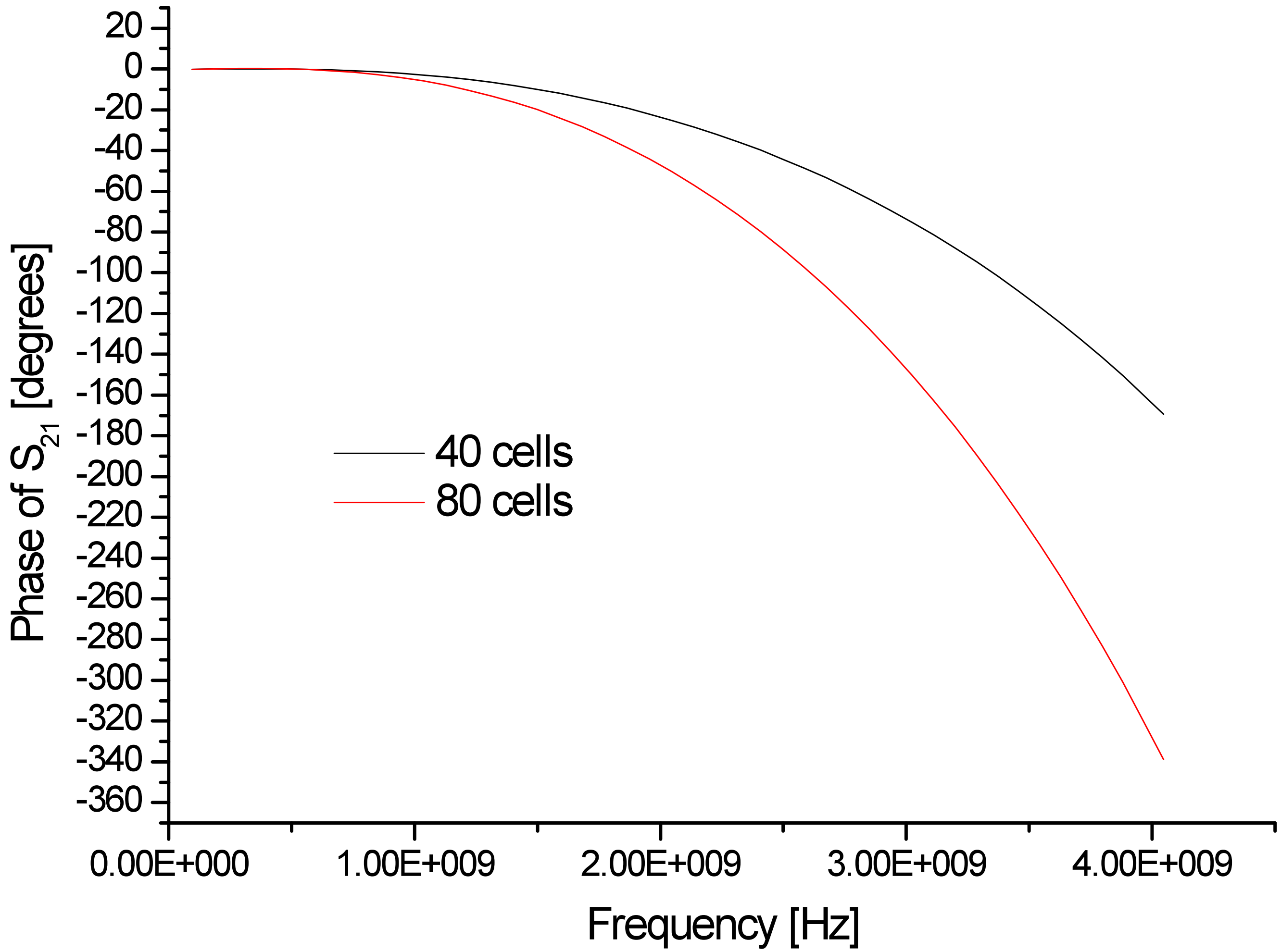
400 MeV/u (Low pass filter model)



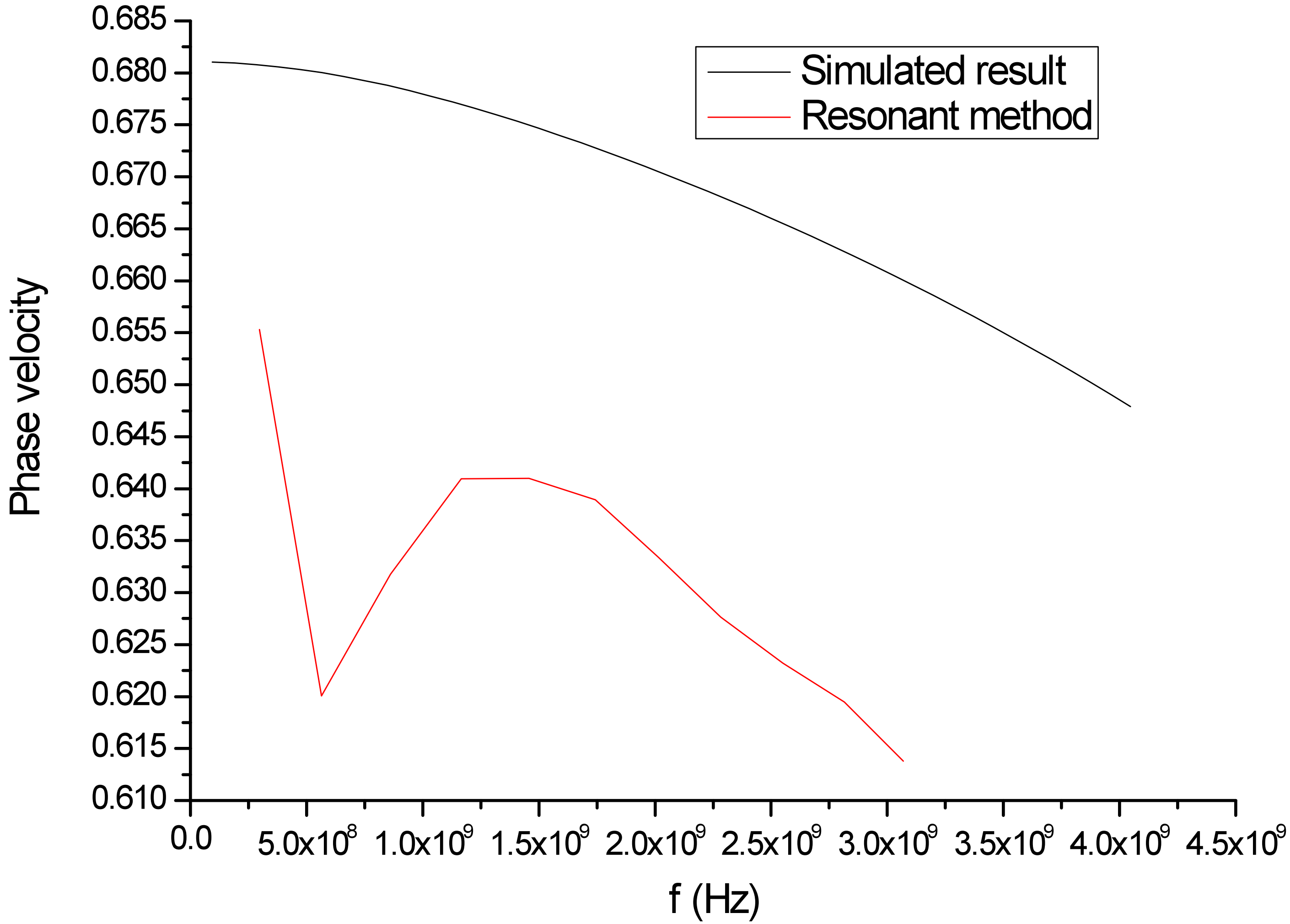
S21 phase with gating on (25 cells) Simulation: Microwave Studio



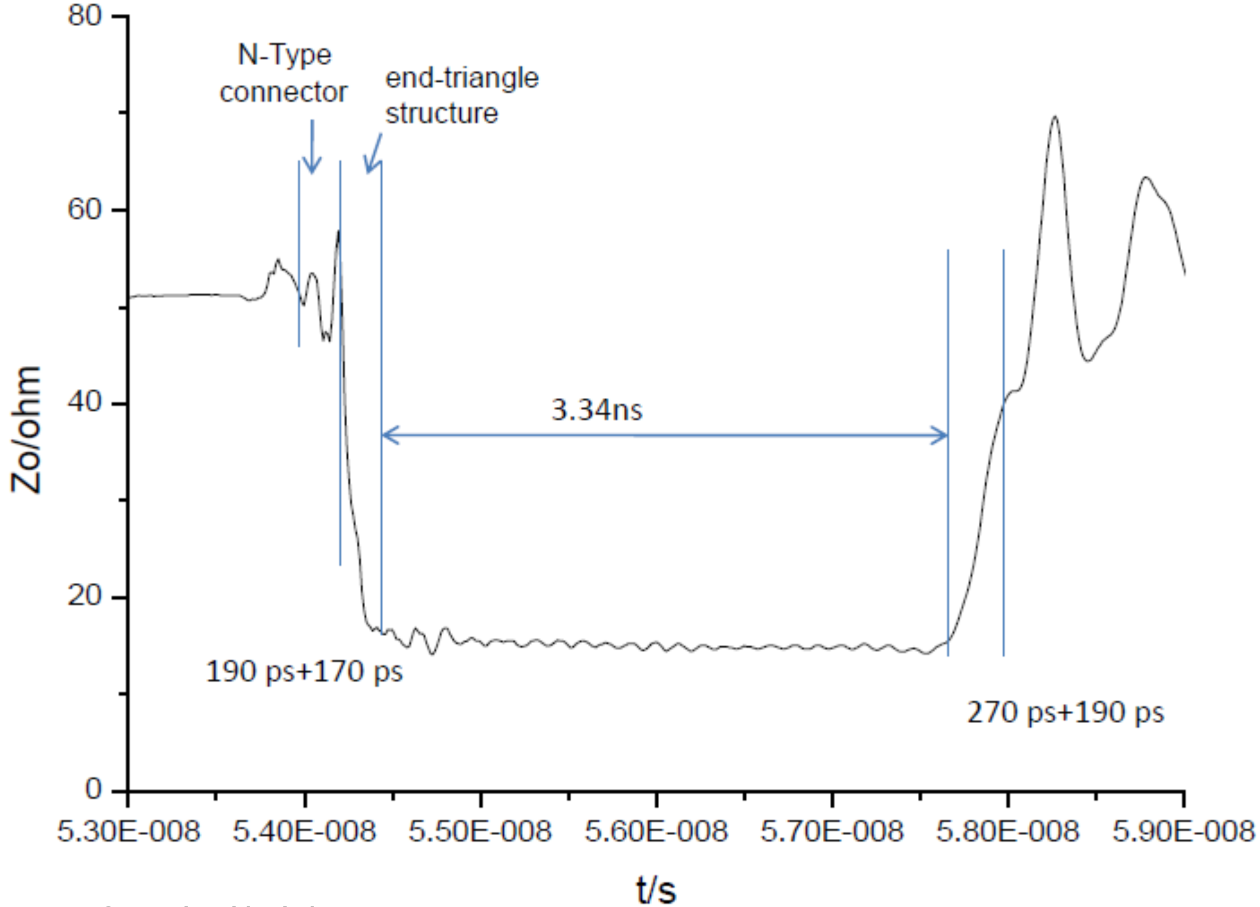
Phase dispersion of 40 cells and 80 cells (simulation)



Phase velocity of Fritz's model

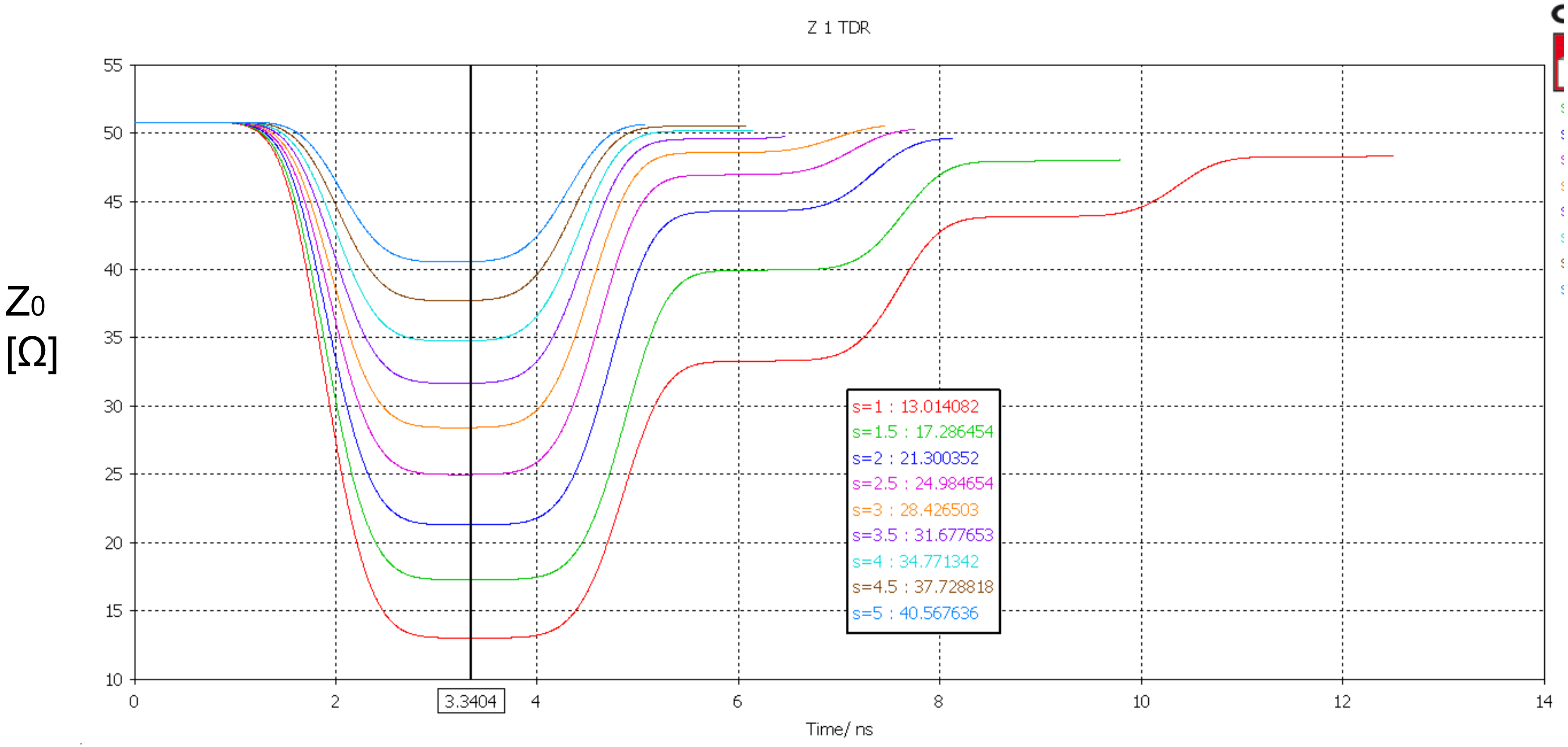


Characteristic impedance measurement by TDR (Lecroy sampling scope)

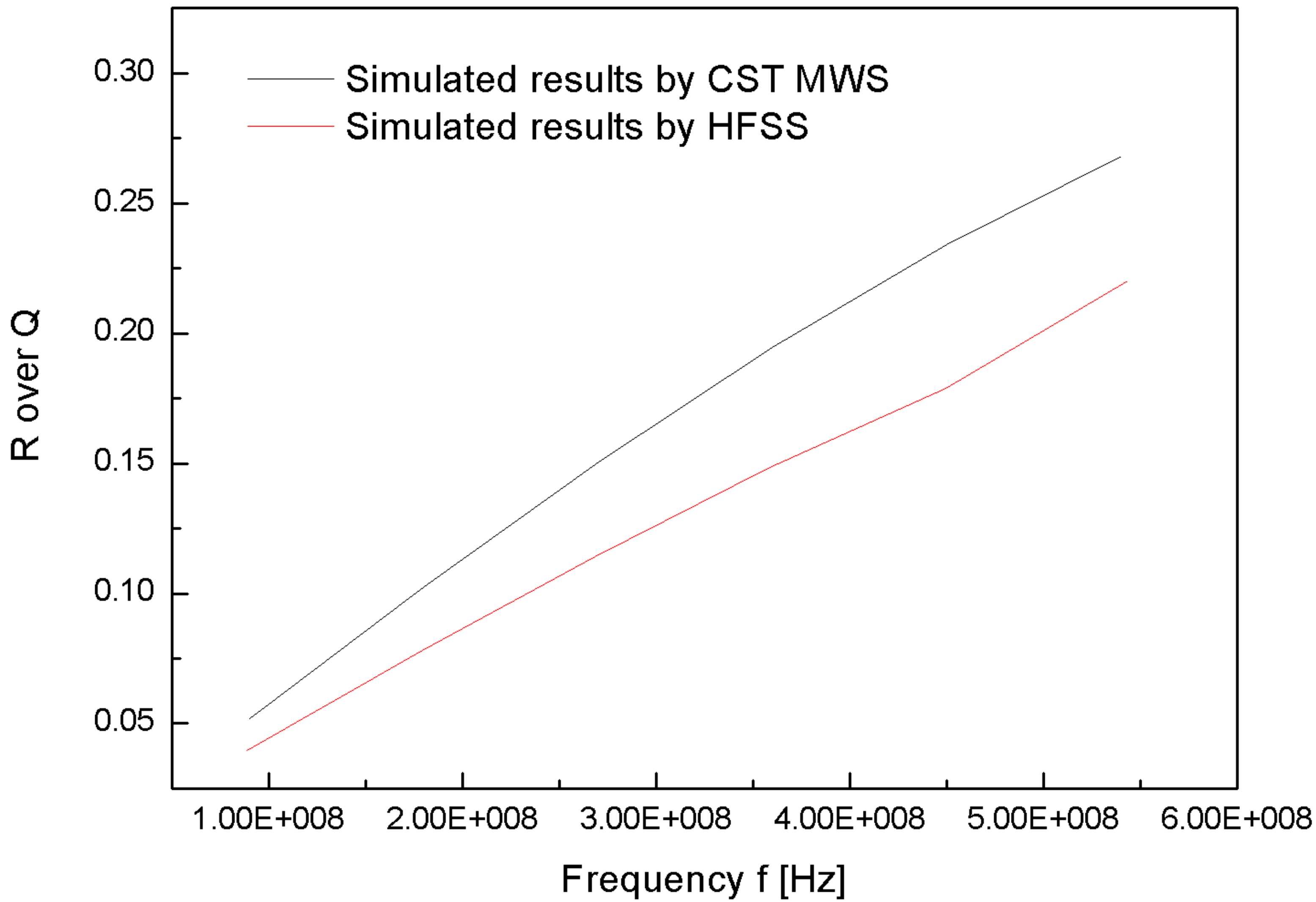


$\beta = 2*L/(c*t) = 0.5988$

Simulated character impedance for different distance between electrode to ground

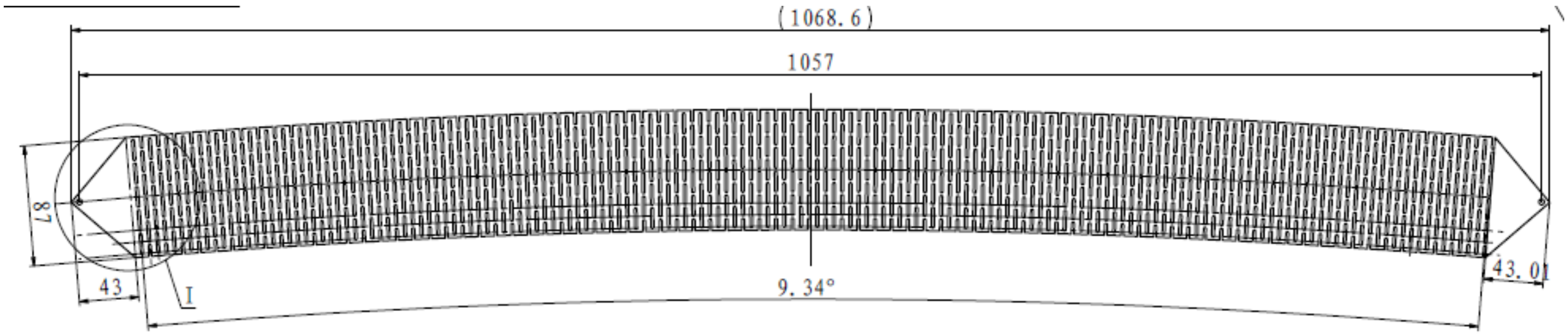


R/Q Value



Simulated results by CST MWS
Simulated results by HFSS
R over Q
0.30
0.25
0.20
0.15
0.10
0.05
1.00E+008
2.00E+008
3.00E+008
4.00E+008
5.00E+008
6.00E+008
Frequency f [Hz]

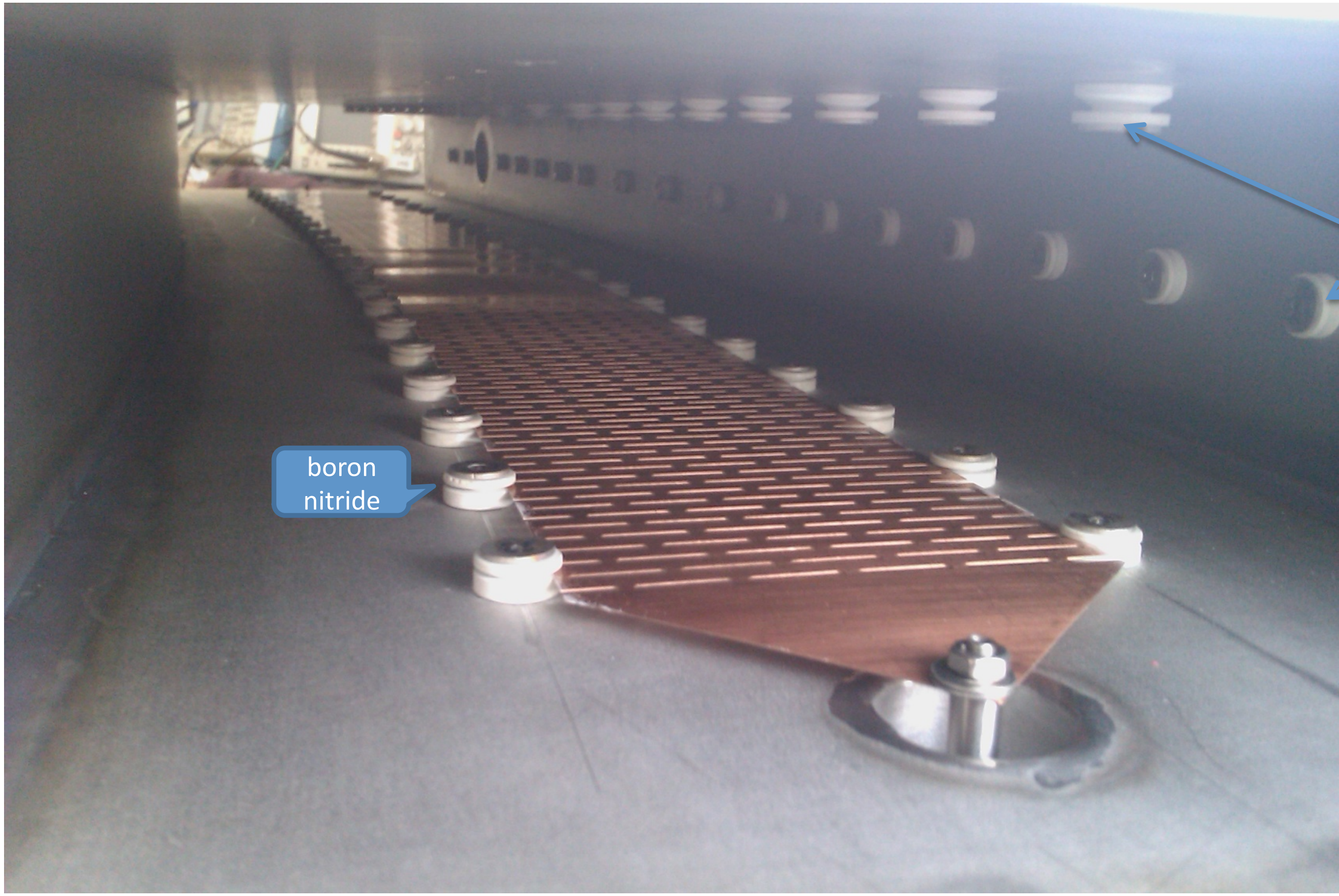
1m long electrode



Laser drilled electrode, not very flat

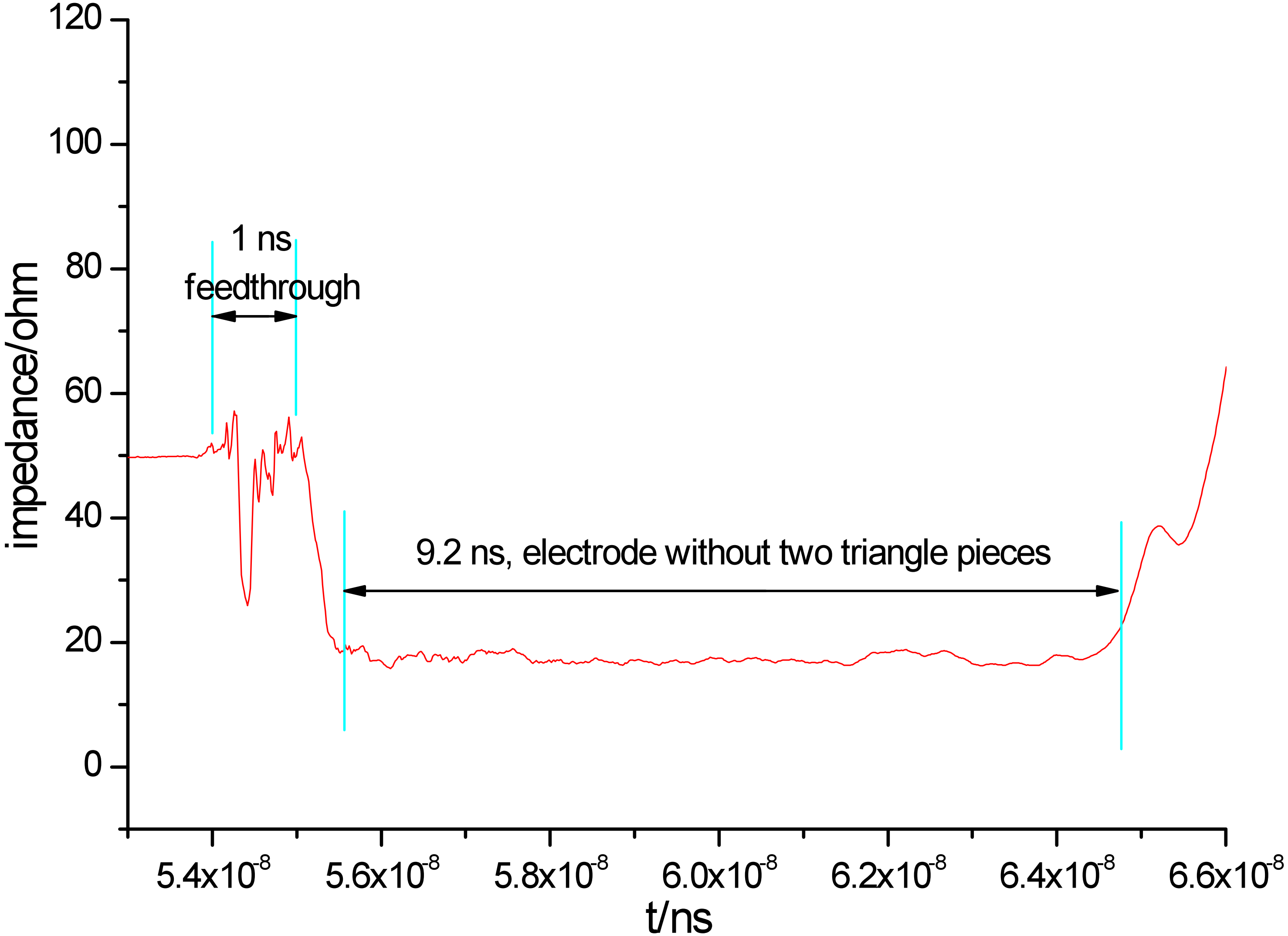
Cutted electrode with mould, better shape

The photo of the electrode installed in the 1.2 m long bending vacuum tube



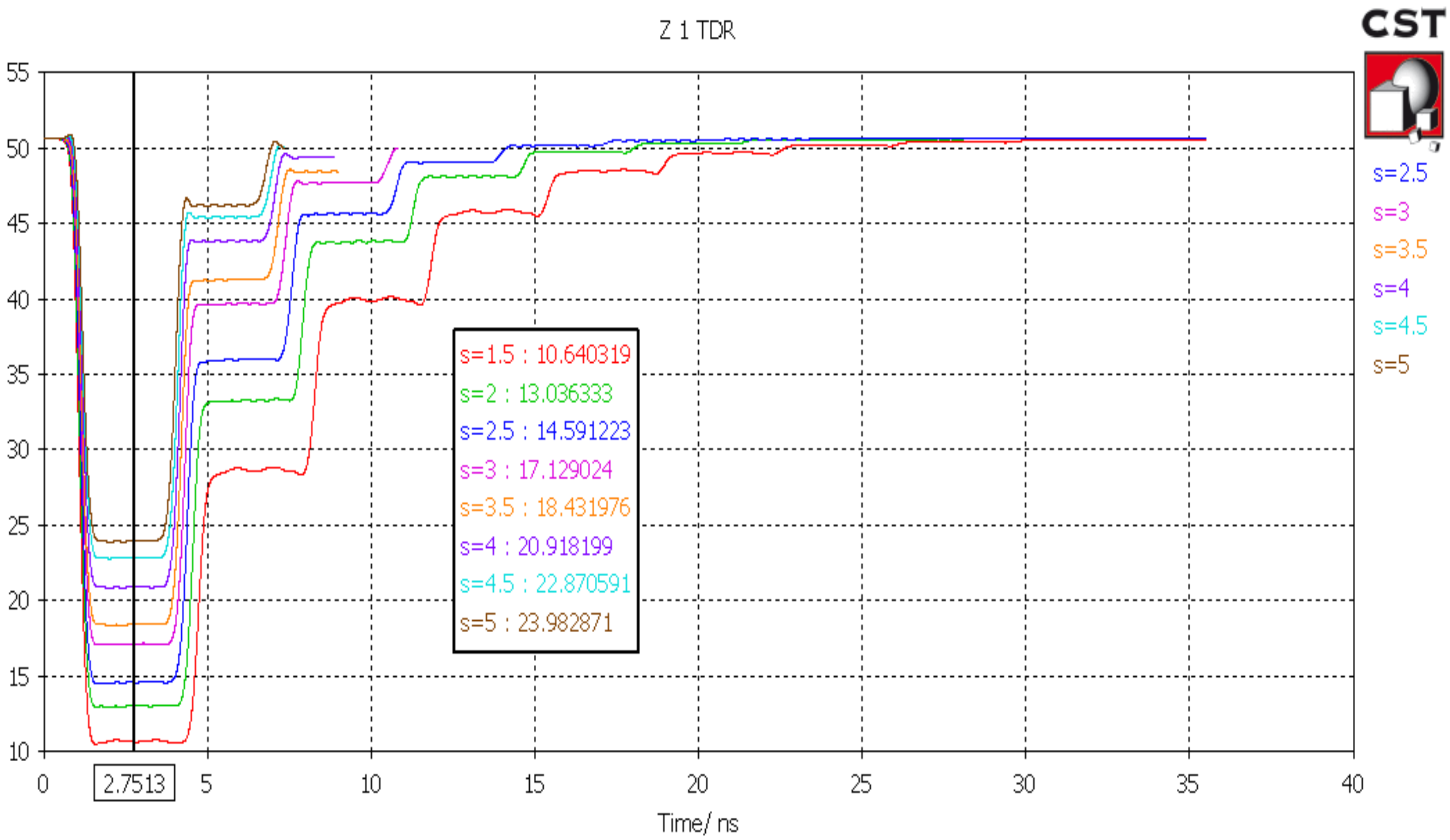
Fixation for the unknown future elliptical electrode.

TDR result with Lecroy sampling oscilloscope

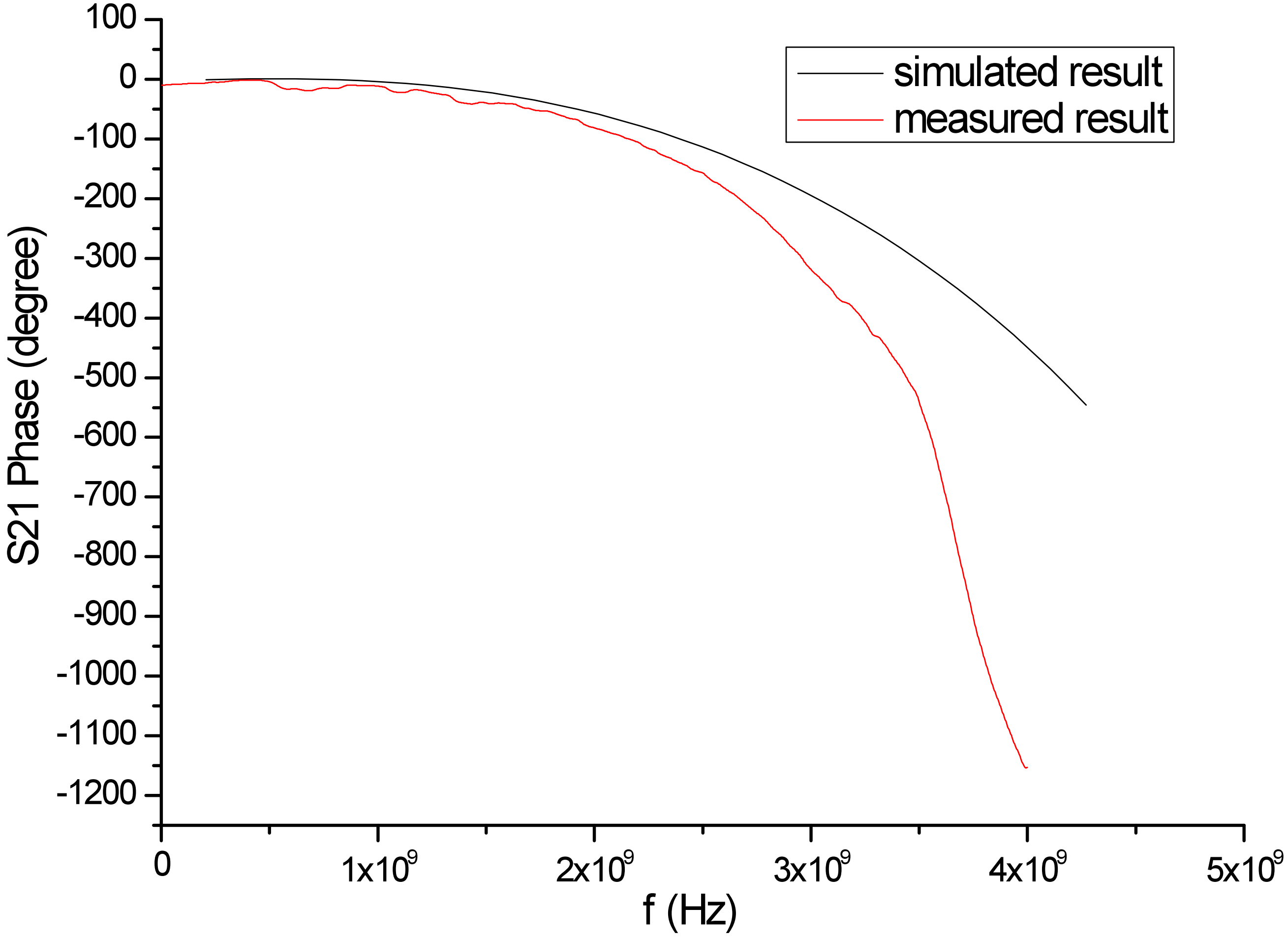


v/c=L/t=82*12 mm/(9.2 ns/2)/3.0e8=0.713

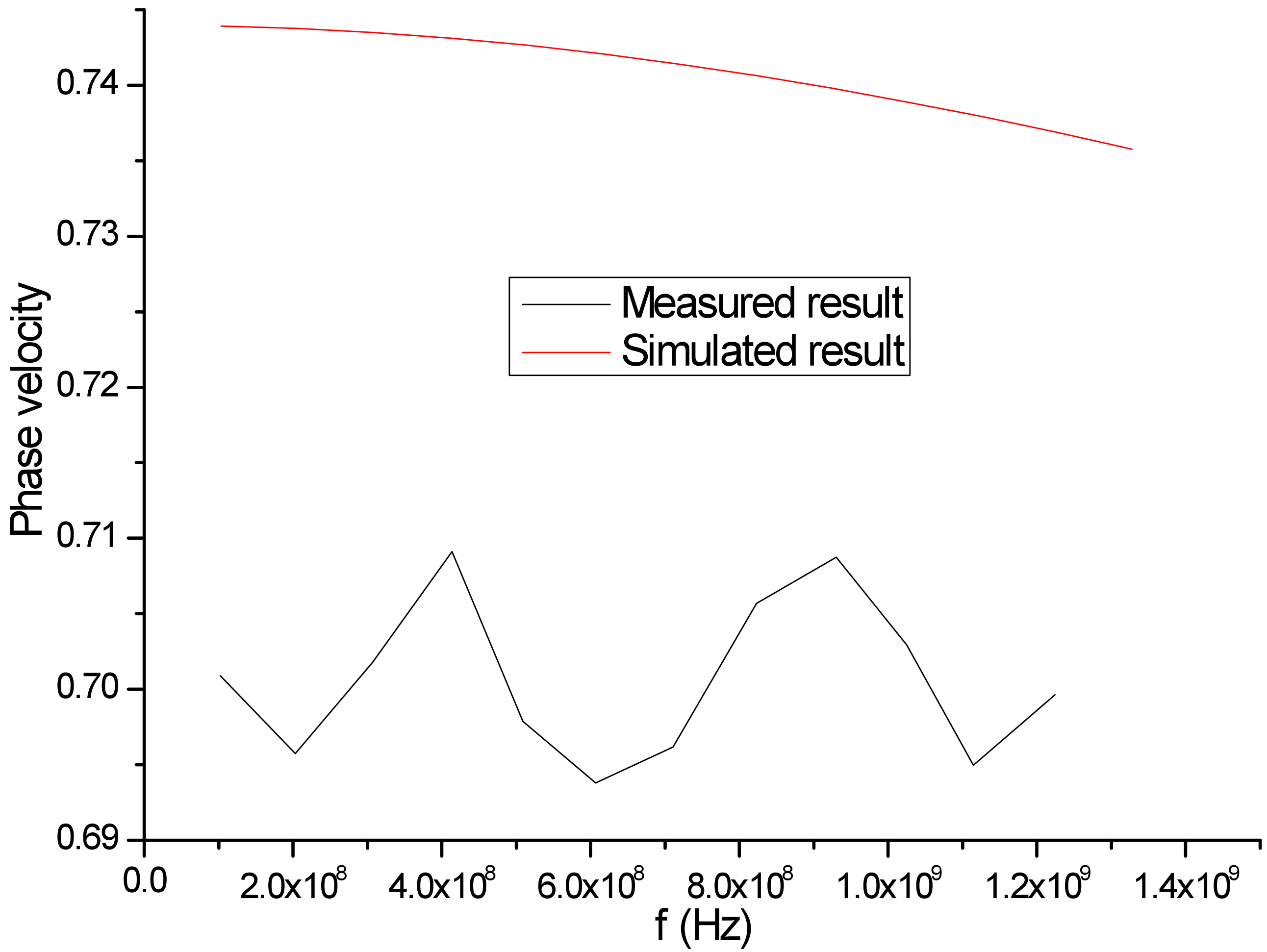
TDR from the simulation with CST



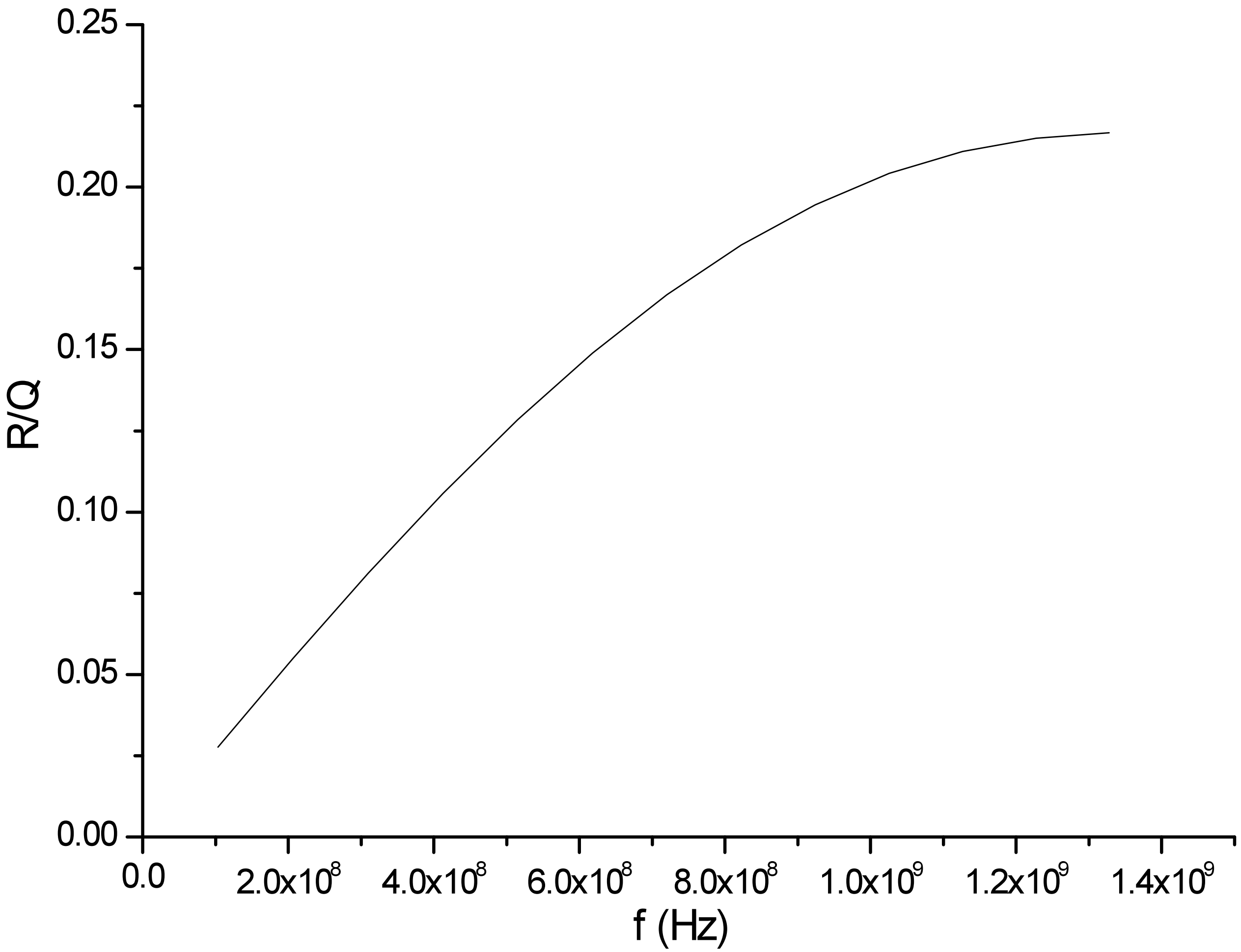
Comparison of phase dispersion between measurement and simulation



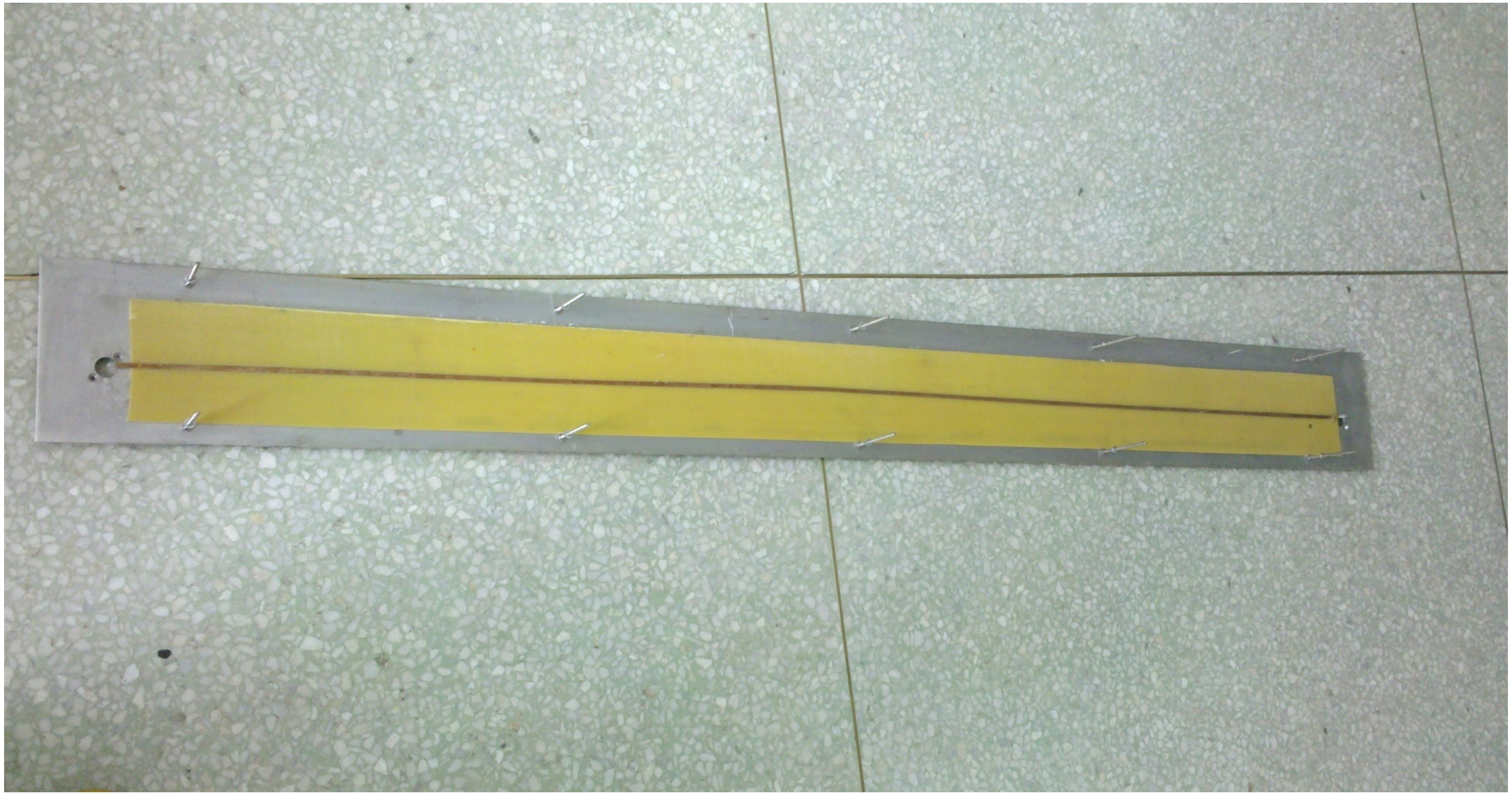
Phase velocity



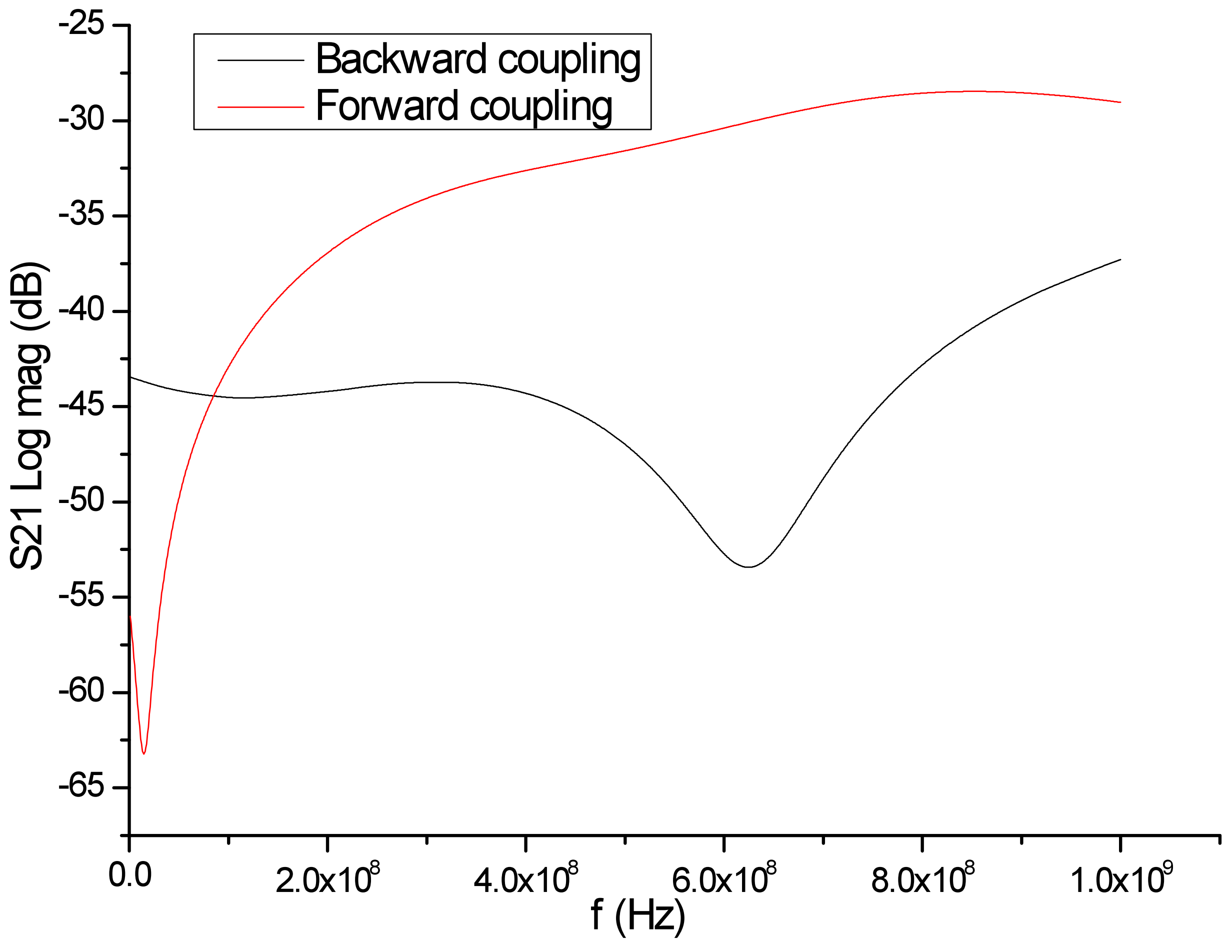
R/Q value of the 87 mm wide structure (Simulation)



Beam simulating wire



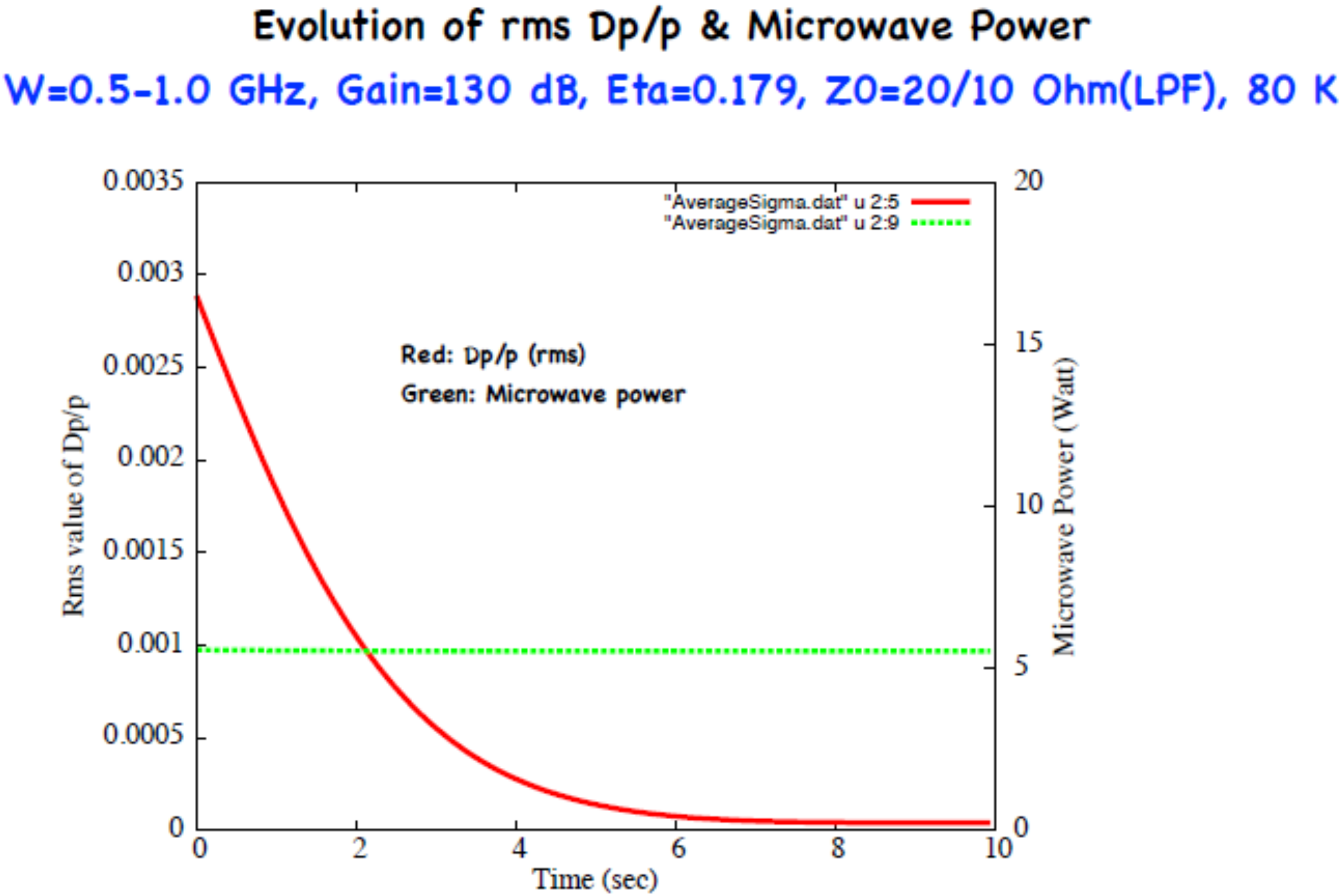
Forward and backward coupling



Example of momentum stochastic cooling parameters

Beam kinetic energy	380 MeV/u, 132Sn50*
Number of particles	5e3
Initial momentum spread	+/- 5e-3 (Uniform distribution)
Ring slipping factor	0.179 (Gammt=1.748)
Slipping factor from PU to K	0.179
Type of Pickup and Kicker	Traveling Wave Slotted Line Coupler
Cooling method	Palmer method
Temperature at PU	80 K
TOF from PU to Kicker	0.27e-6 sec
Dispersion at PU	5.0 m
Distance of Two PU Plates	5.0e-2 m
Dispersion at Kicker	0.0 m
Number of PU and Kicker	1/2
Loop length	1 m
Loop height, width	74e-3 m, 50e-3m (or 83e-3m)
Characteristic impedance	20/Reduction Ohm (Reduction=1,4,10)
Band	0.5-1.0 GHz
Gain	120 ~130 dB

Cooling simulations



Conclusion

- Stochastic cooling is quite effective and useful for RI beams at CSRe.
- The low γ_t lattice mode is preferable to get fast cooling
- RF power is small (less than 10 Watt).
- The slotted line structure fits well the requirement of the CSRe stochastic cooling system, it features
  - a sufficiently broad bandwidth
  - good beam coupling impedance
  - low losses
  - easy mechanical construction and installation
  - low height in vertical direction

Thanks for your attention!!