Stochastic Cooling Plan and Experiments for HIAF and CSRe

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Outlines

- Stochastic cooling on HIRFL-CSRe

  (Heavy Ion Research Facility in Lanzhou-experimental Cooler Storage Ring)

  – Hardware

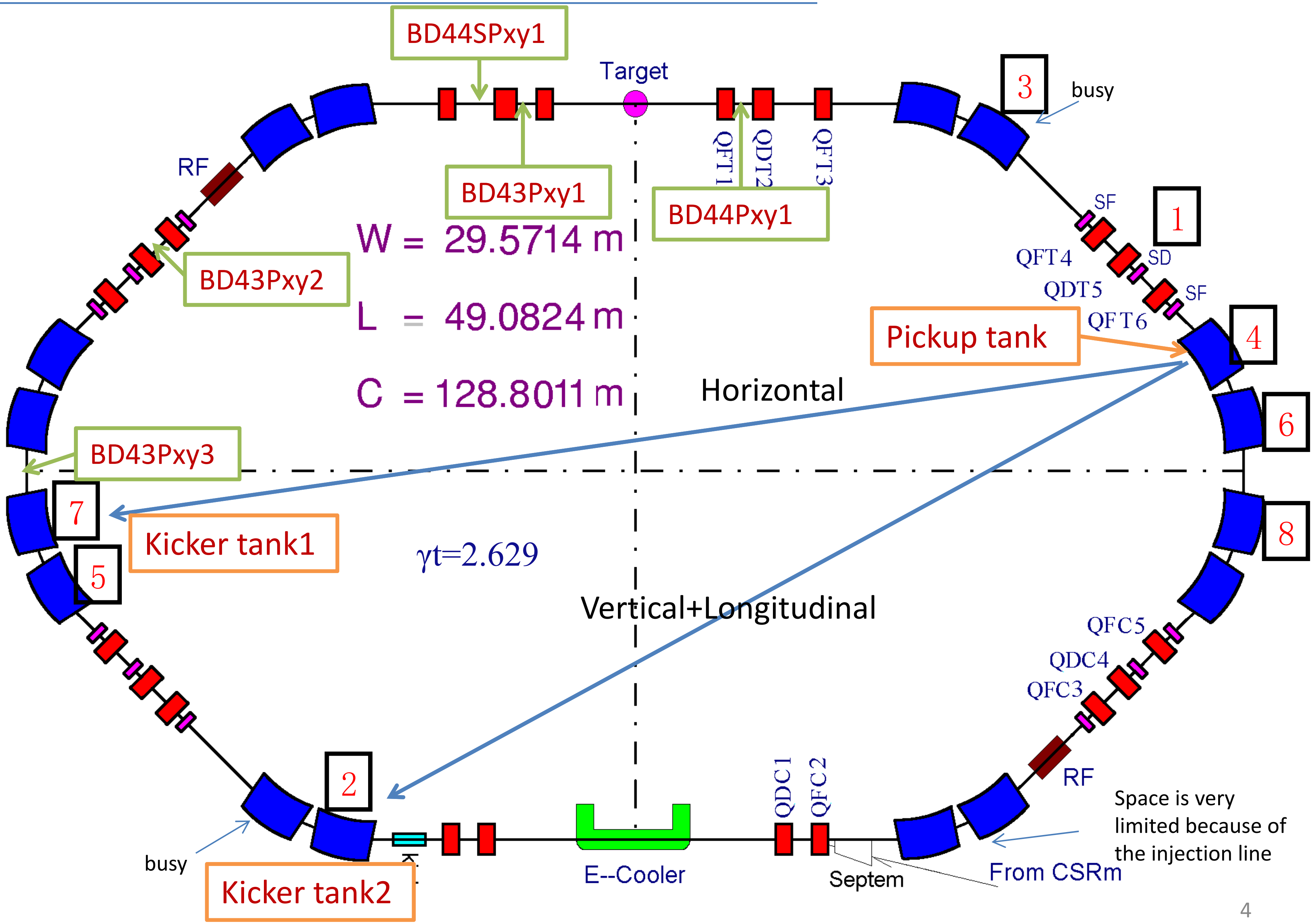
  – Experimental result

- Progress of stochastic cooling on Sring (Spectrometer Ring) of HIAF (High Intensity heavy-ion Accelerator Facility)

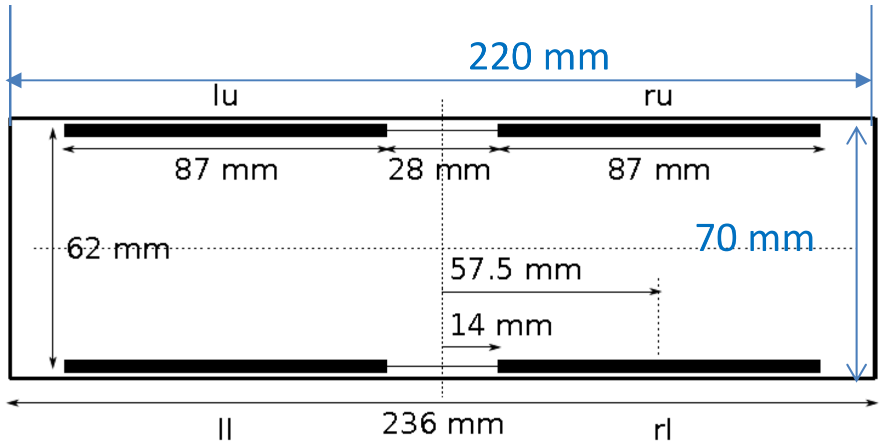
Purpose and parameters of the CSRe stochastic cooling

- Pre-cooling of the rare isotope beam
- Beam energy 350 MeV/u-400 MeV/u (beta: 0.68-0.71)
- Number of RI particles <5e3
- Mass number 100-150
- Atomic number 50-60
- Before cooling ε=50 π mm mrad, $\Delta p/p$=+-1%
- After cooling ε =5 π mm mrad, $\Delta p/p$=5e-4
- Bandwidth 100 MHz – 600 MHz

Stochastic cooling on the CSRe ring



PU/Kicker structure-Fritz Caspers's structure



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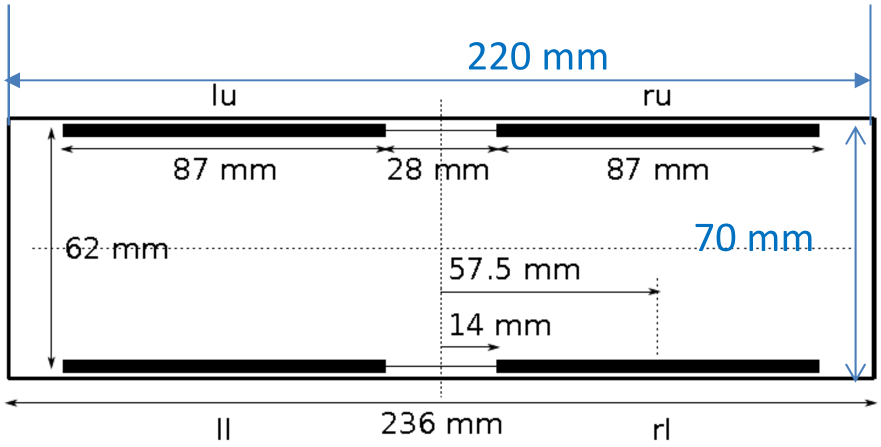

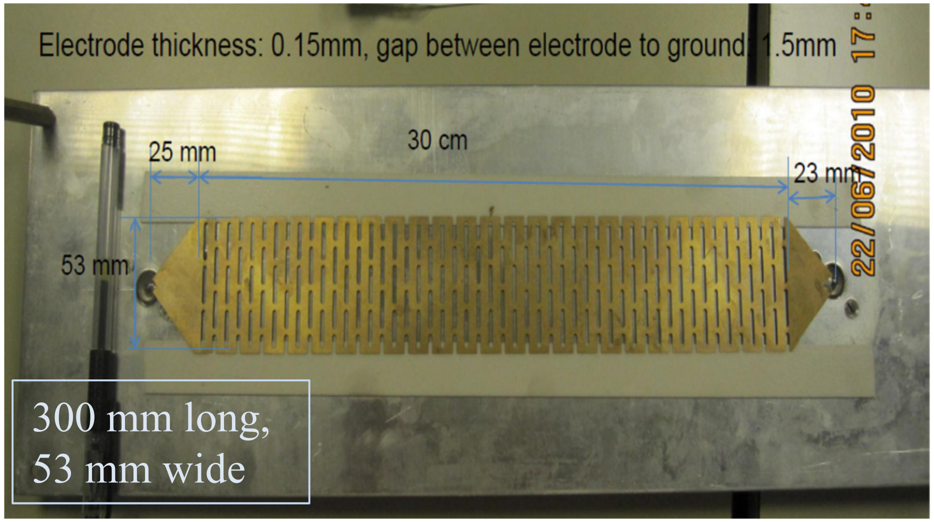

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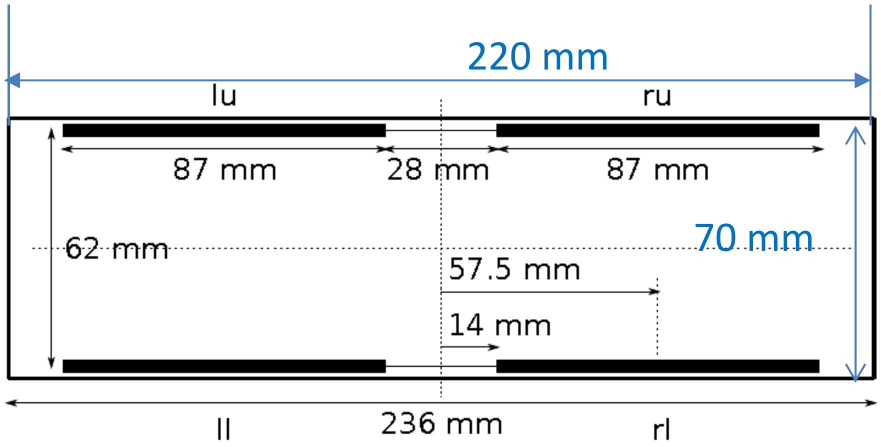

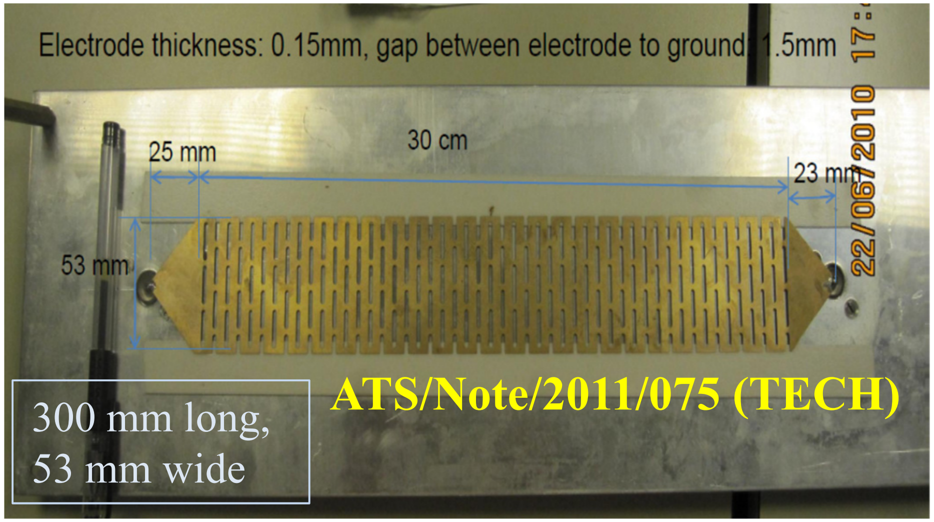

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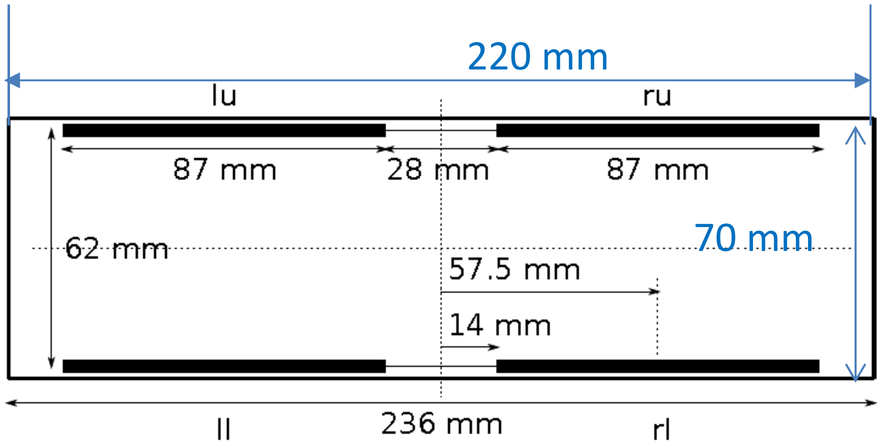

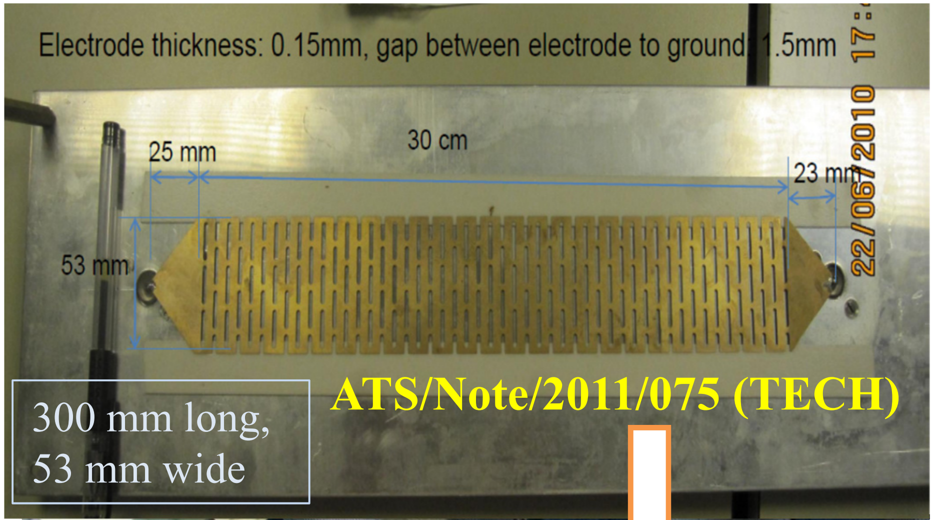

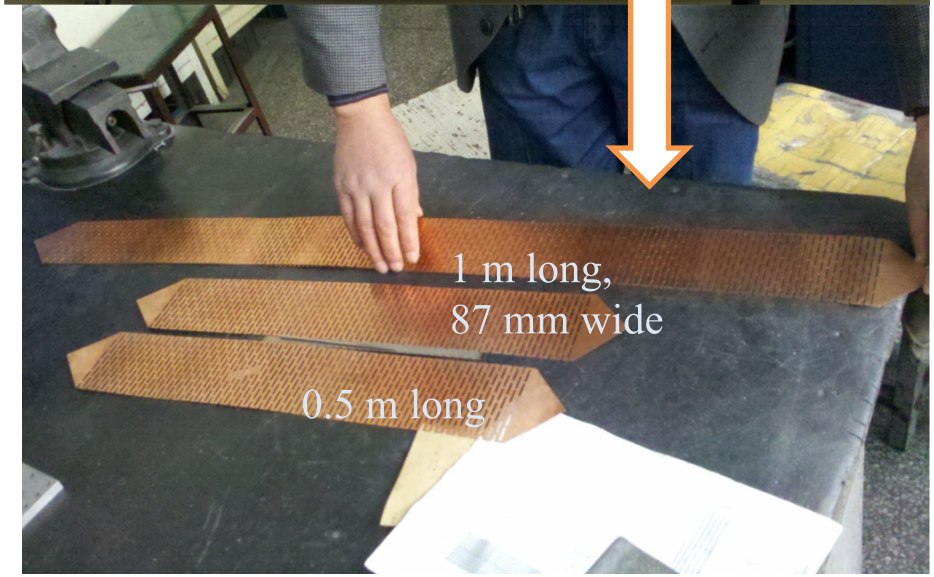

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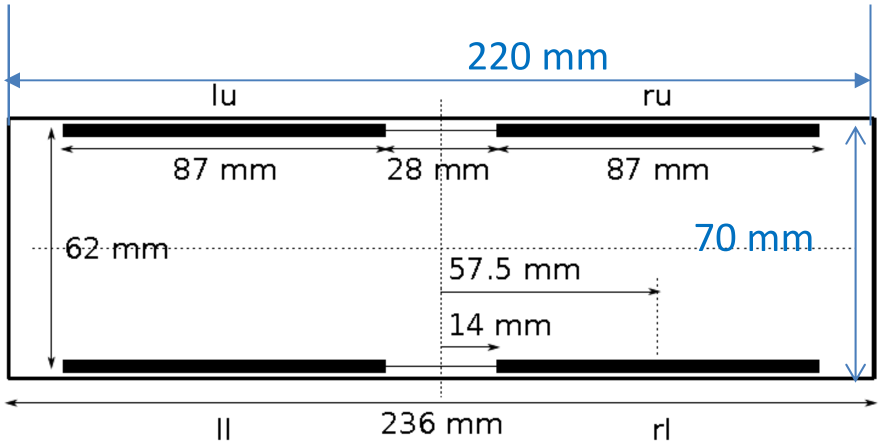
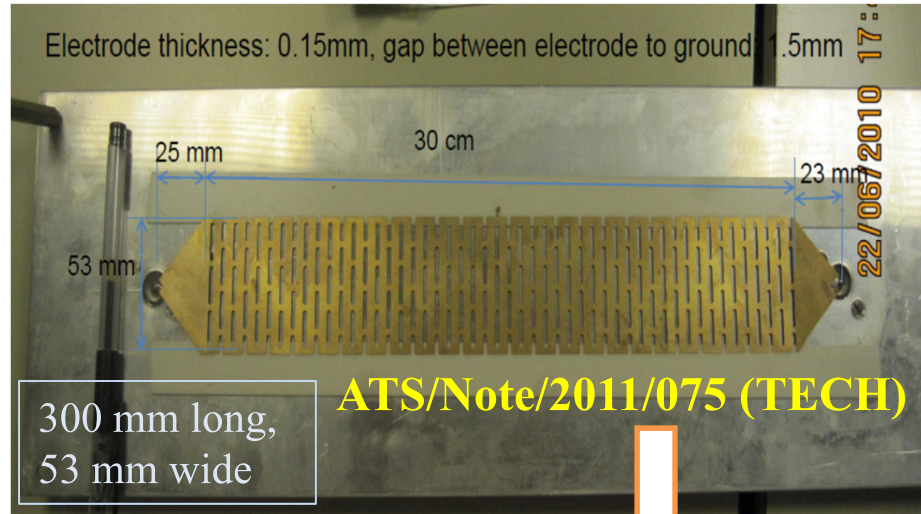
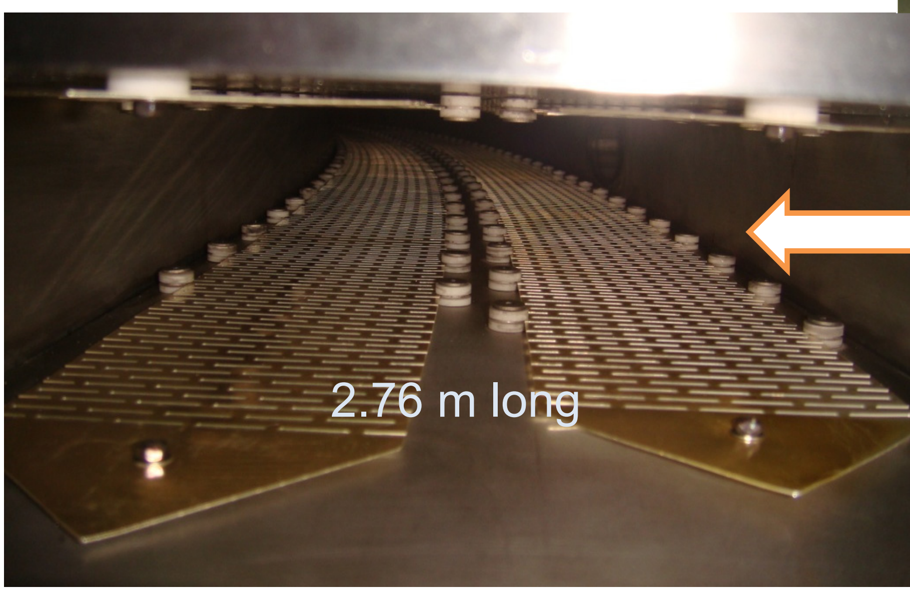
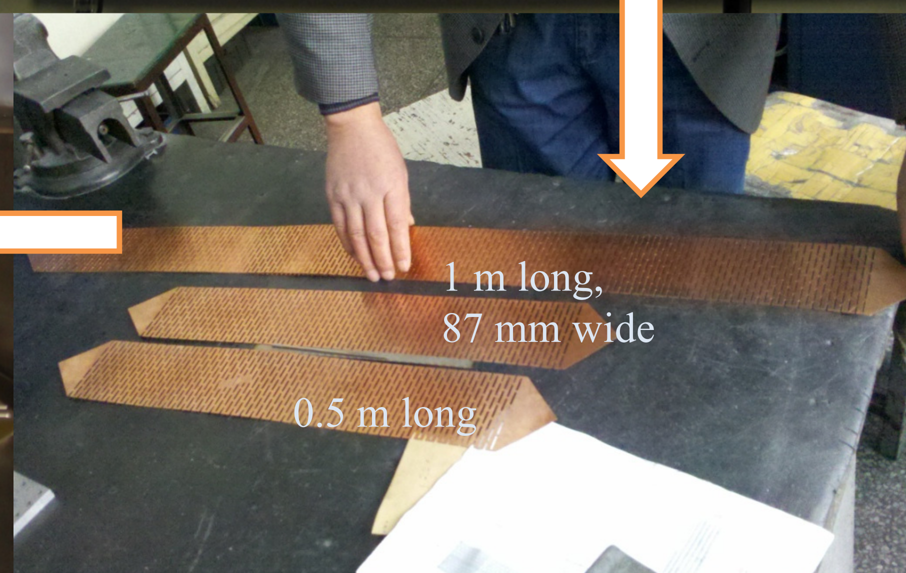
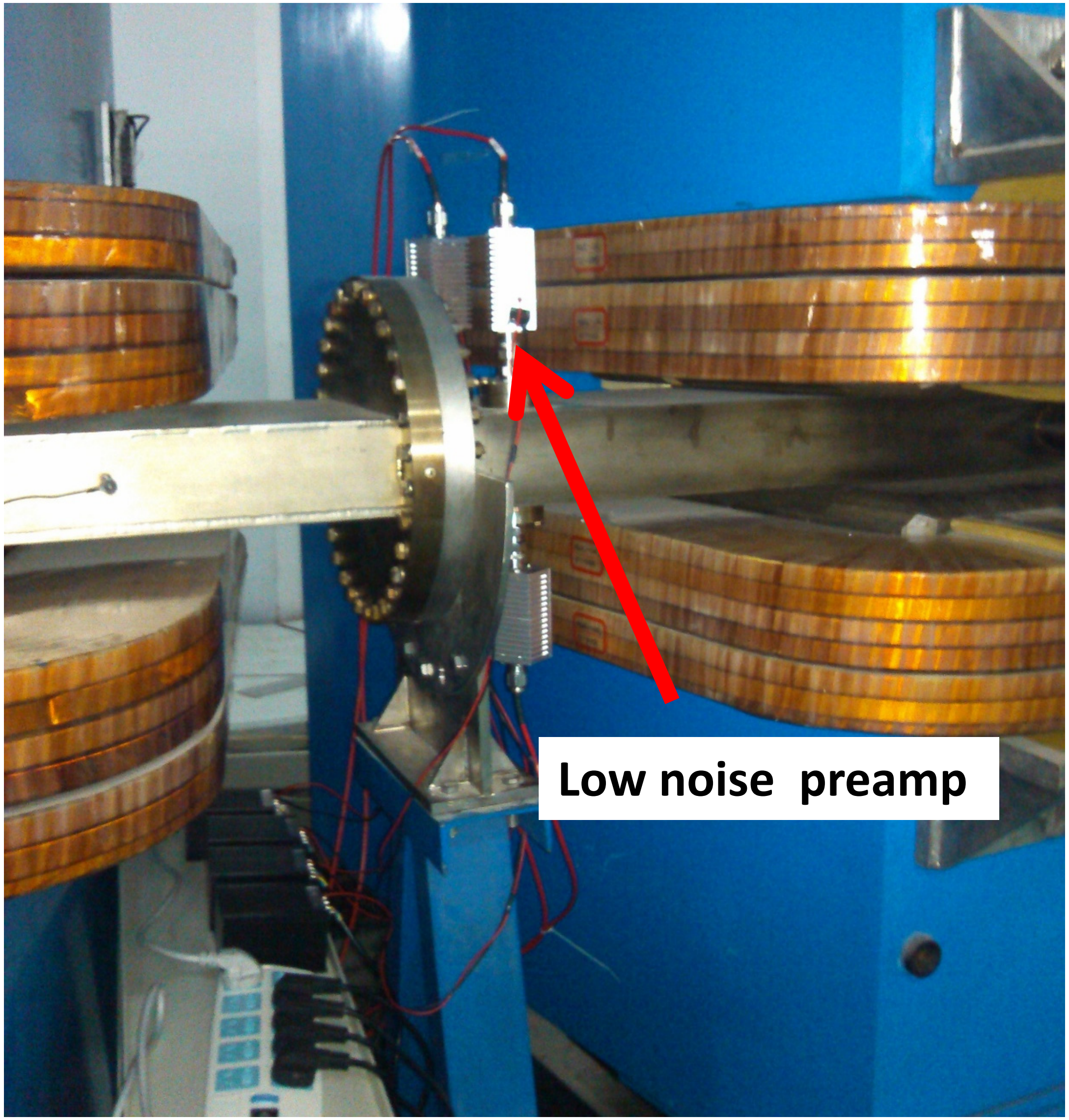




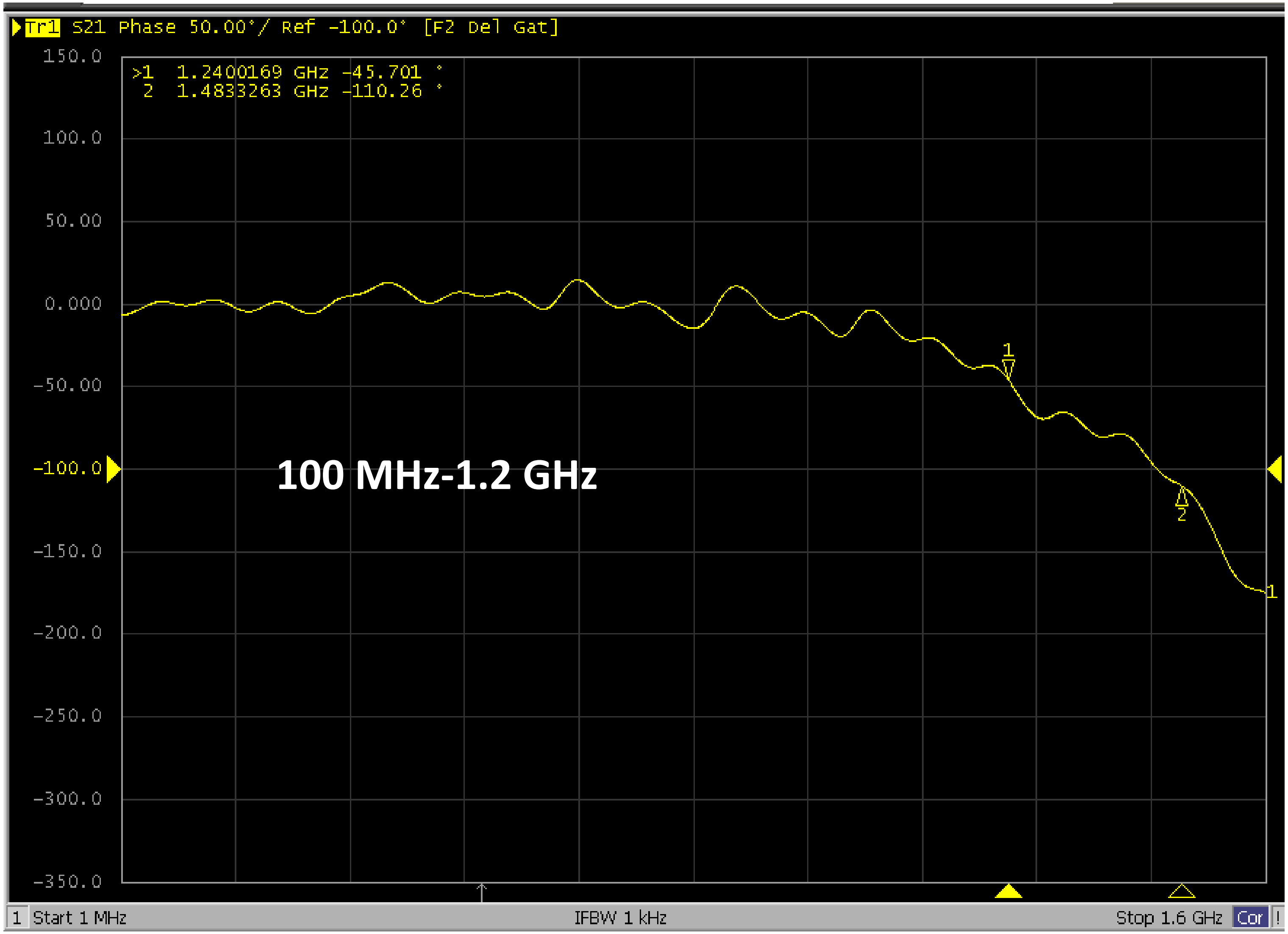




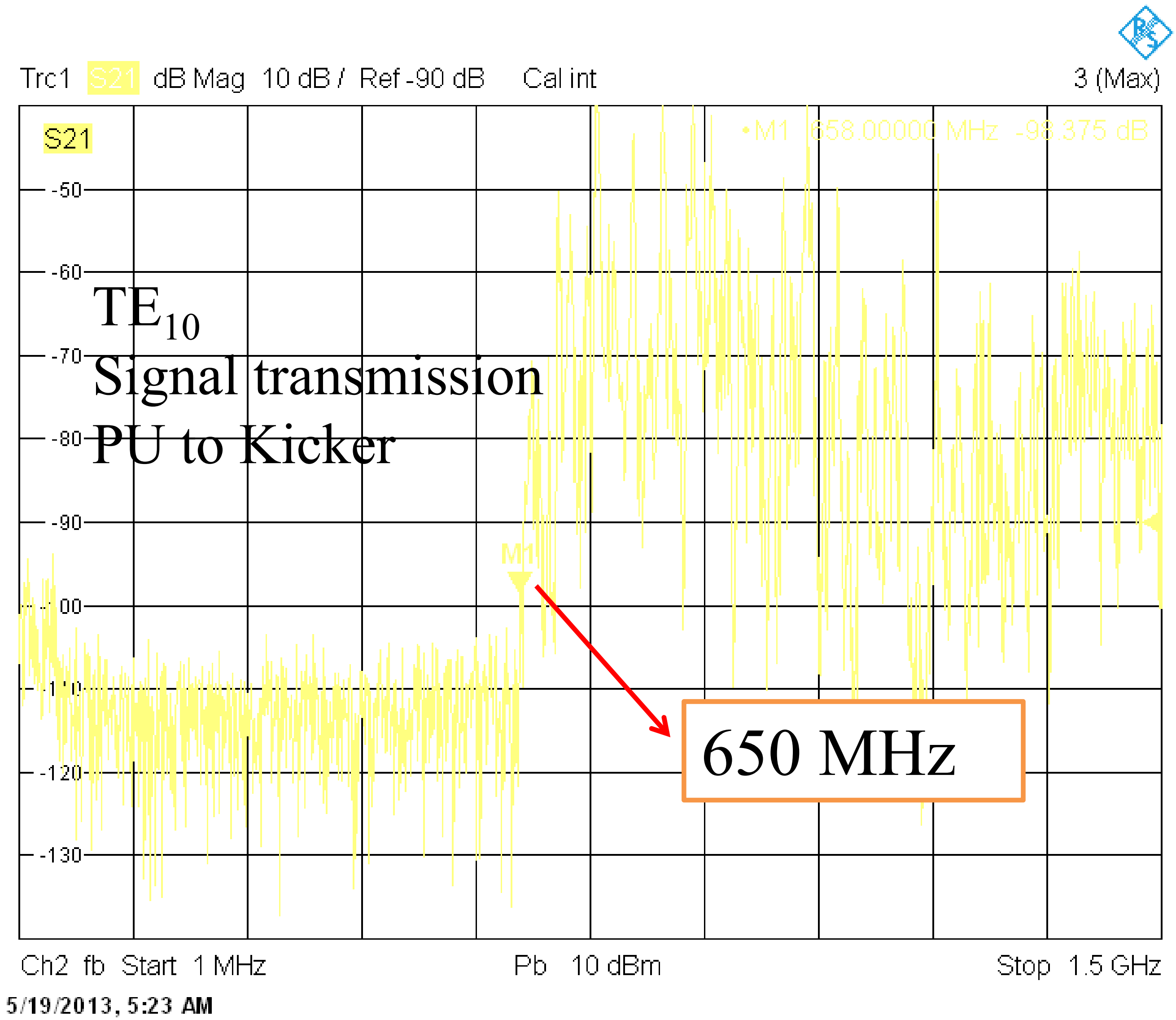
PU/Kicker feedthroughs for Fritz C structure



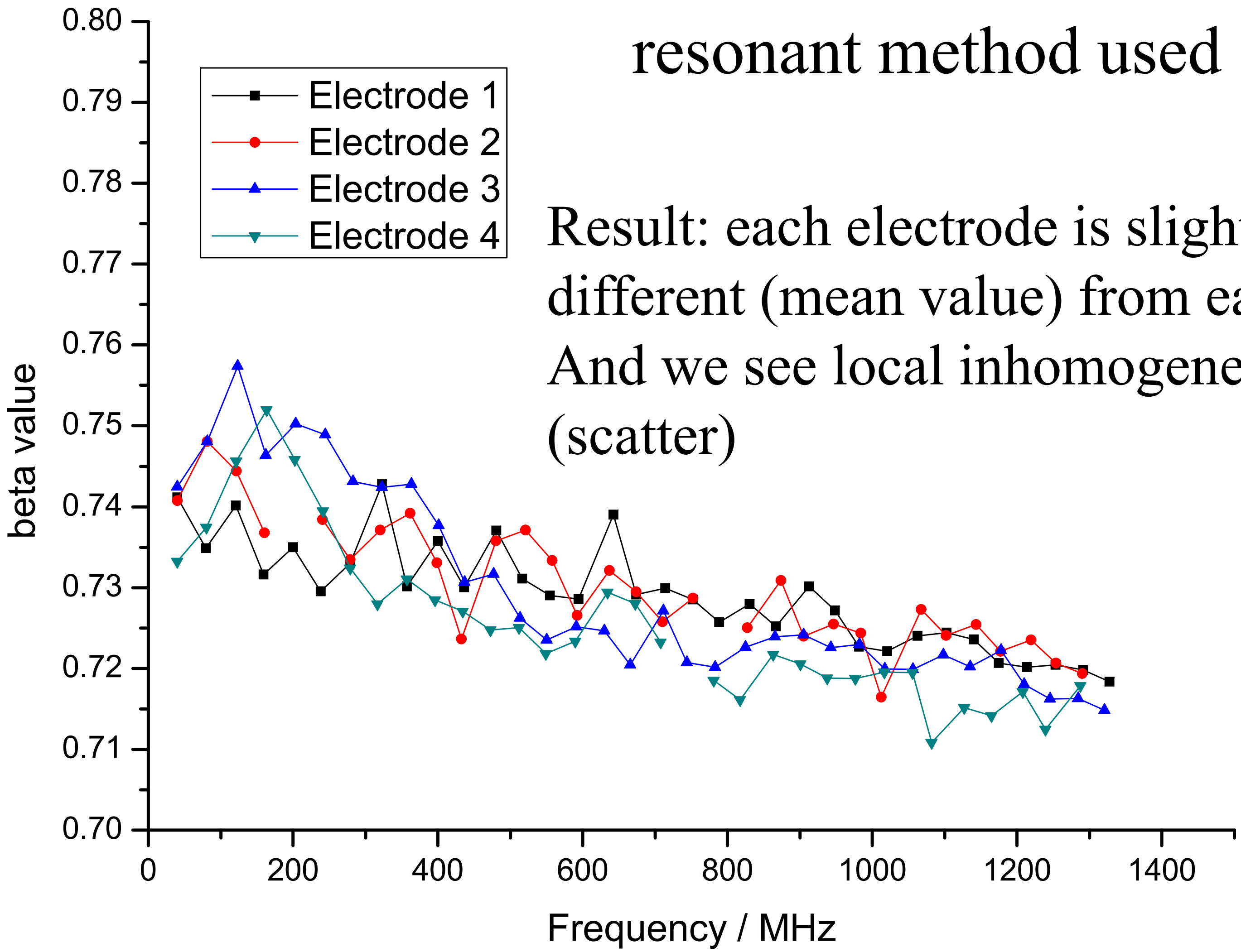
S_{21} transmission measurement-2.76 m long perforated electrode in vacuum chamber with 4 striplines



Cutoff frequency measurement of CSRe vacuum tube



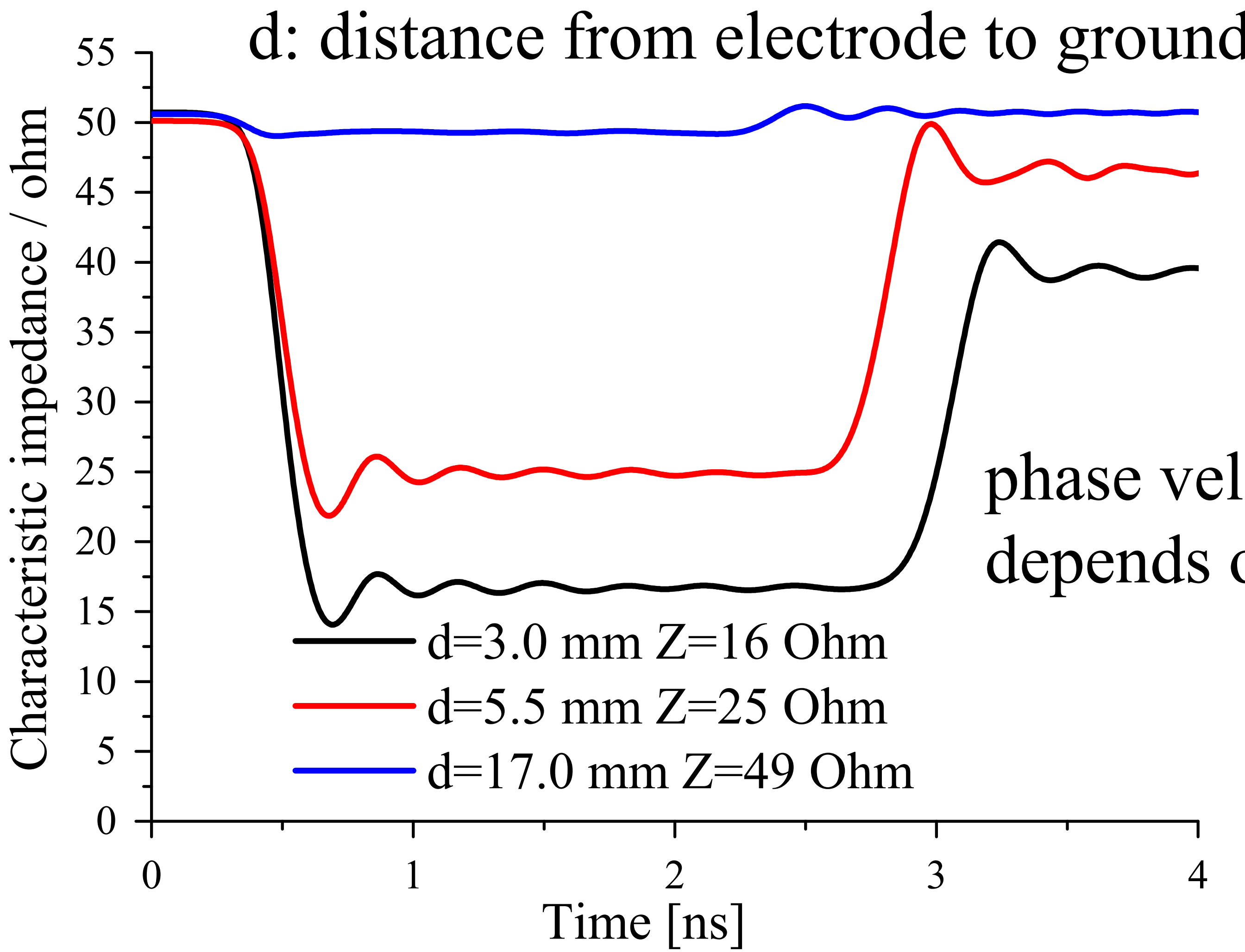
Phase velocity measurement result



resonant method used

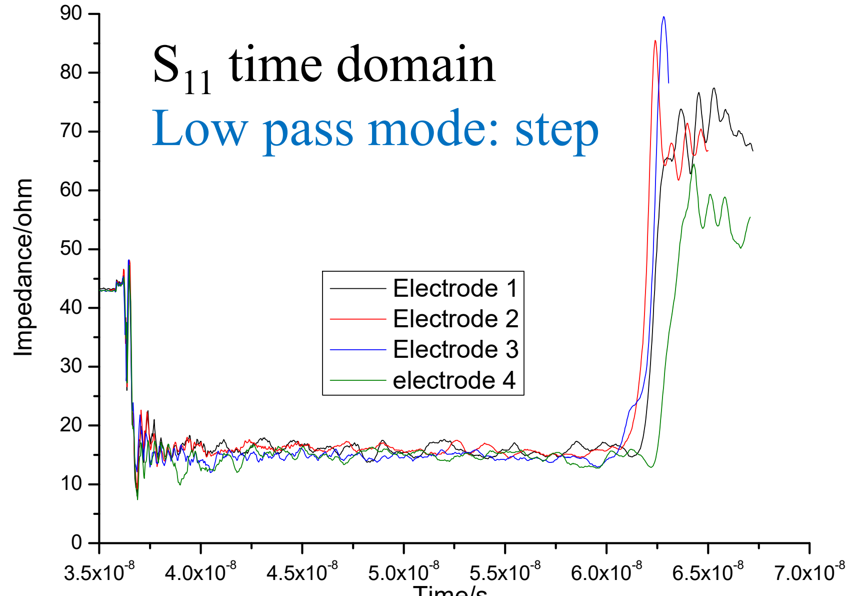
Result: each electrode is slightly different (mean value) from each other
And we see local inhomogeneities (scatter)

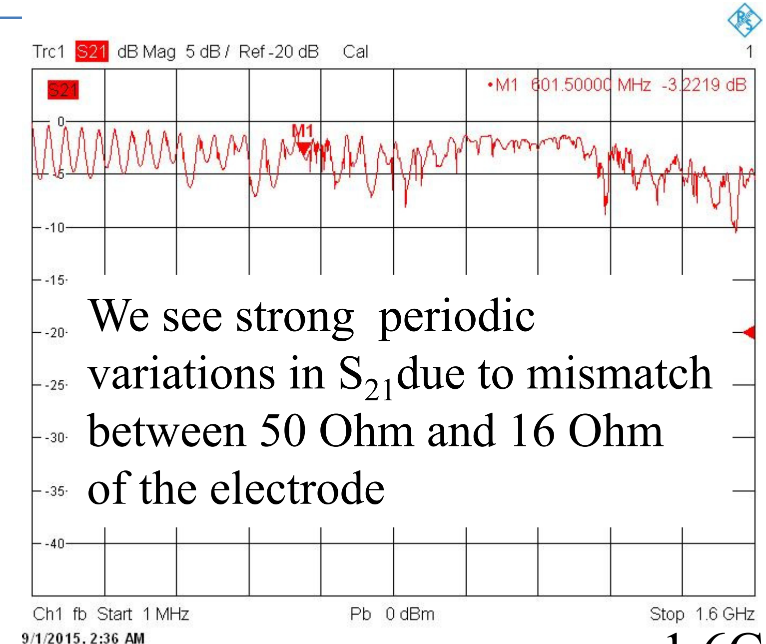
Characteristic impedance simulation via S_{11} in time domain



phase velocity also depends on: d

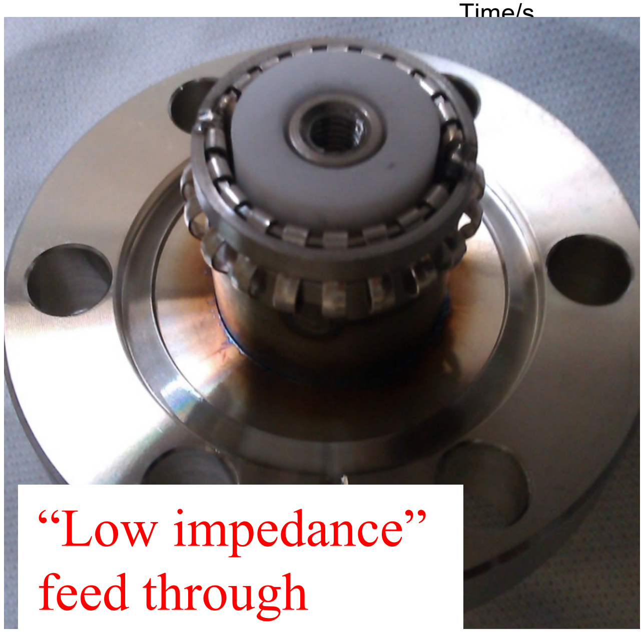
Characteristic impedance measurement





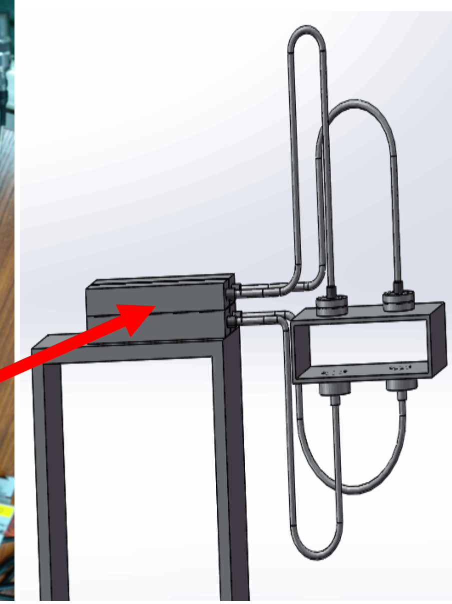
We see strong periodic variations in S_{21} due to mismatch between 50 Ohm and 16 Ohm of the electrode

1.6GHz



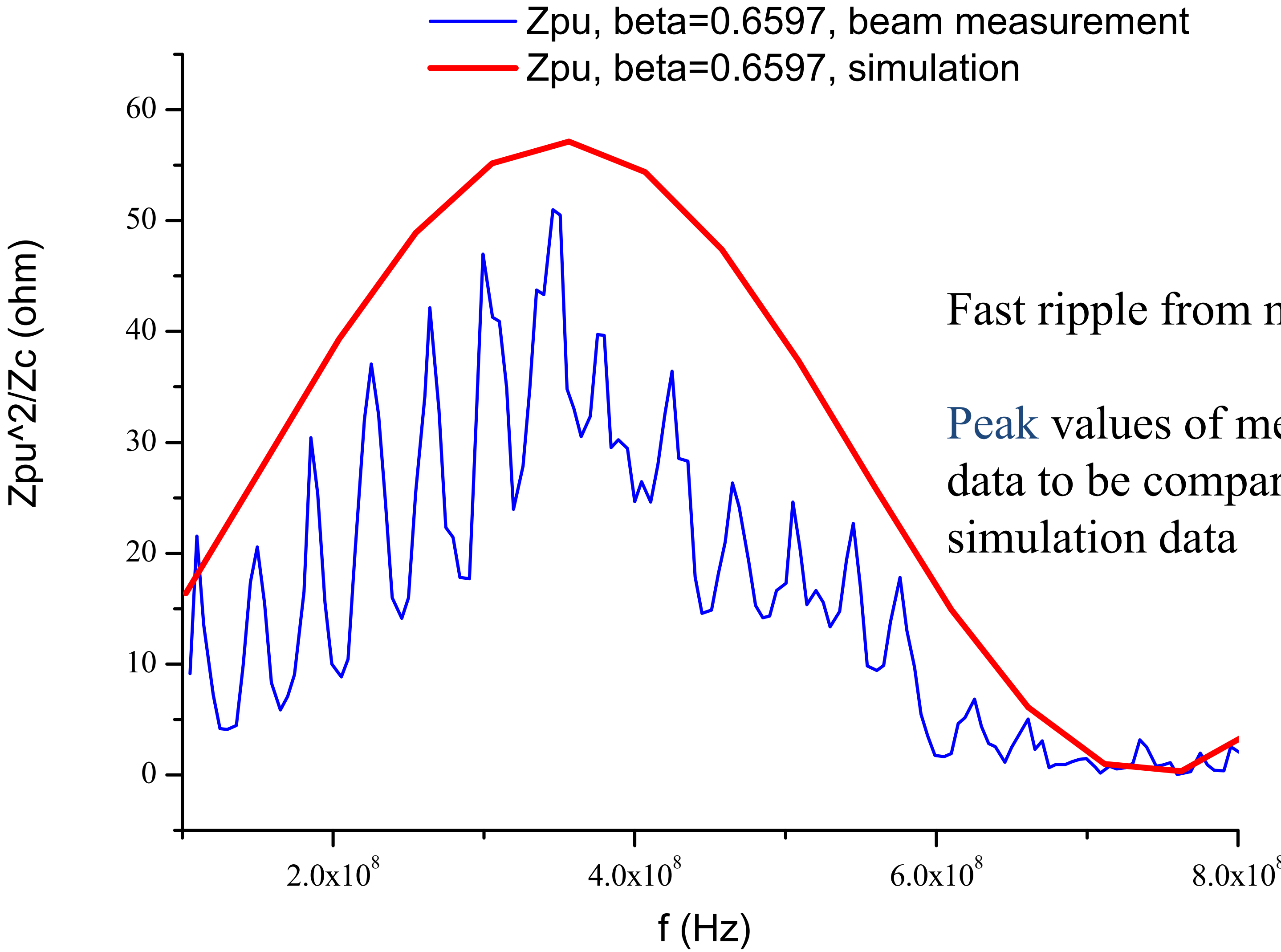
"Low impedance" feed through

Impedance transformer



Comparison of Z^2_{pu}/Z_c with simulation and beam measurement-2.76 m long

Jan. 6, 2014, 78Kr36+, E=308 MeV/u, beta=0.6597, f=1.5373 MHz



Fast ripple from mismatch

Peak values of measured data to be compared with simulation data

Methods to get coupling impedance

- Beam measurement: Signal power from the SC electrode arriving on spectrum analyzer
  Psc=Zpu*Ipu^2*Gsc
- Simulation formula from Lars Thorndahl:

Gsc: electronic gain
Q: quality factor
rovq: R / Q per cell
vg: group velocity
Lcell: cell length

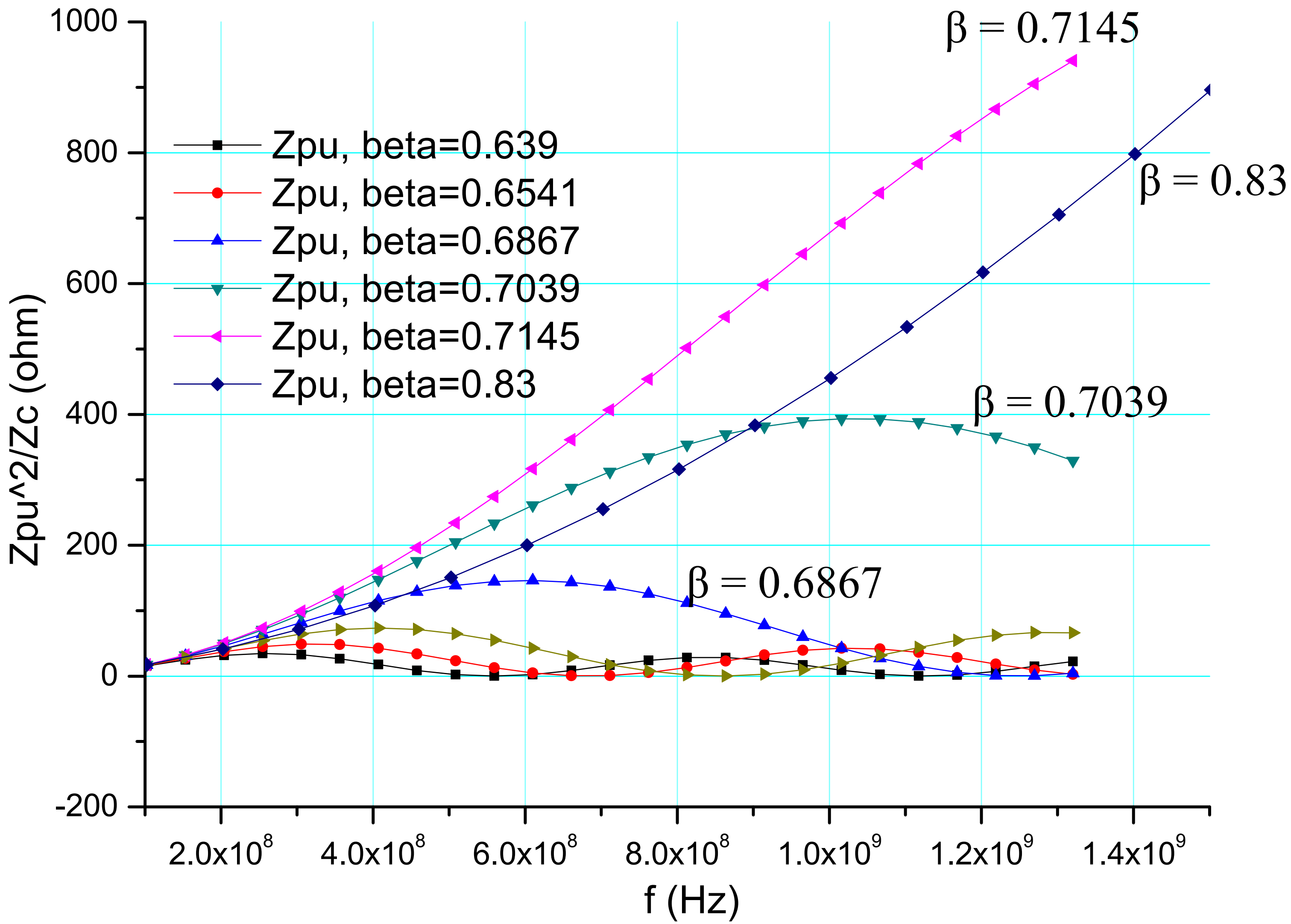
$$Zpu_{n,mm} := m \cdot rovq_{n,mm} \cdot 2 \cdot \pi \cdot f_{n,0} \cdot \frac{Tfill_{n,mm}}{4} \cdot \left(\left| Fphaslip_{n,0} \right| \right)^2$$

$$Qexp_{n,0} := \frac{Lcell \cdot 2\pi \cdot f_{n,0}}{Q_{n,0} \cdot 2 \cdot vg_{n,0}}$$

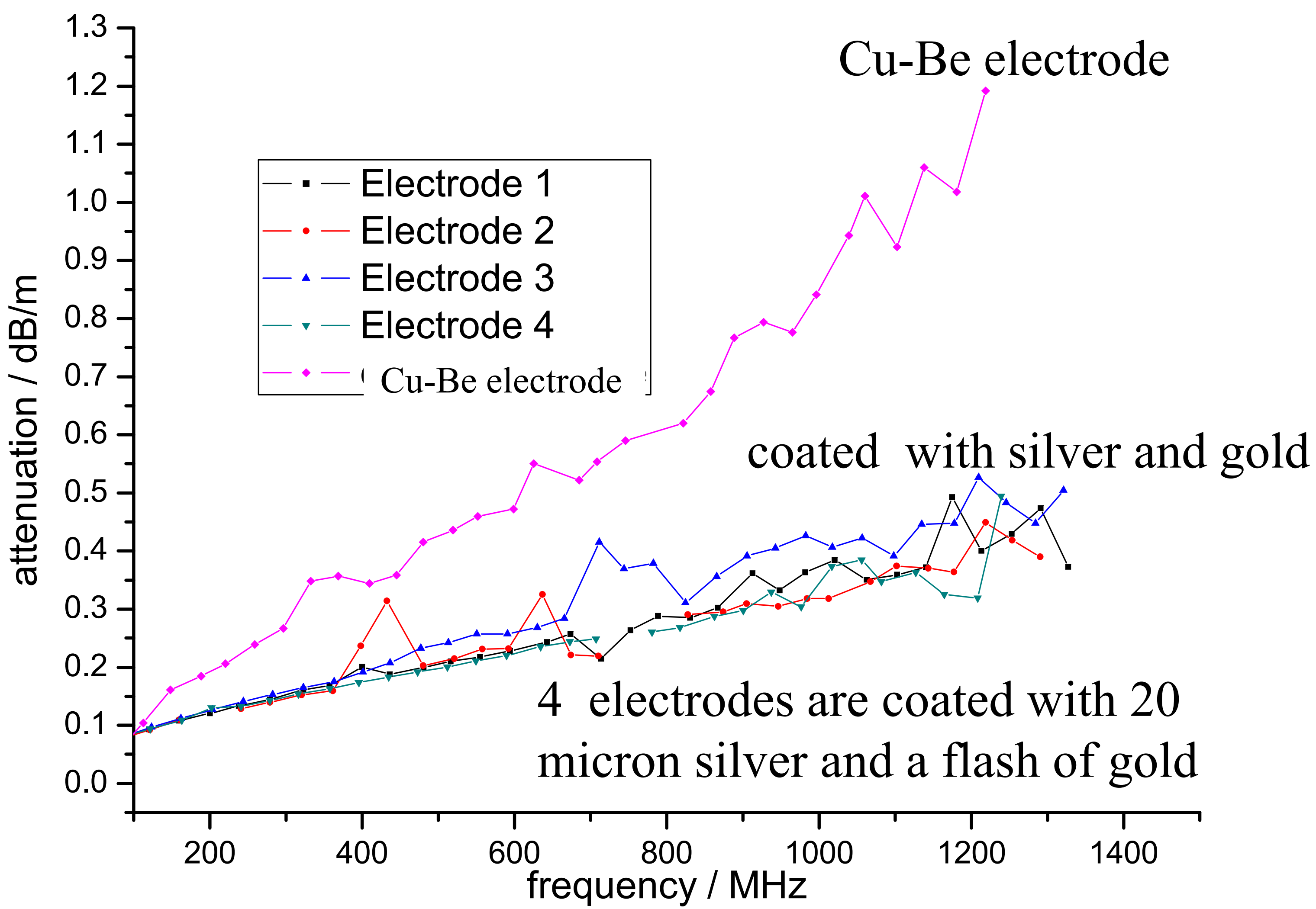
to include wall losses amplitudewise

$$Fphaslip_{n,0} := \sum_{k=1}^{m} \frac{e^{-i \cdot \left[k \cdot \left(ph_{n,0} \cdot \frac{\pi}{180} - 2 \cdot \pi \cdot f_{n,0} \cdot \frac{Lcell}{\beta part_{75} \cdot c} \right) \right]} \cdot e^{-k \cdot Qexp_{n,0}}}{m}$$

Simulated Z_{pu} for different beam energy for 225 cells



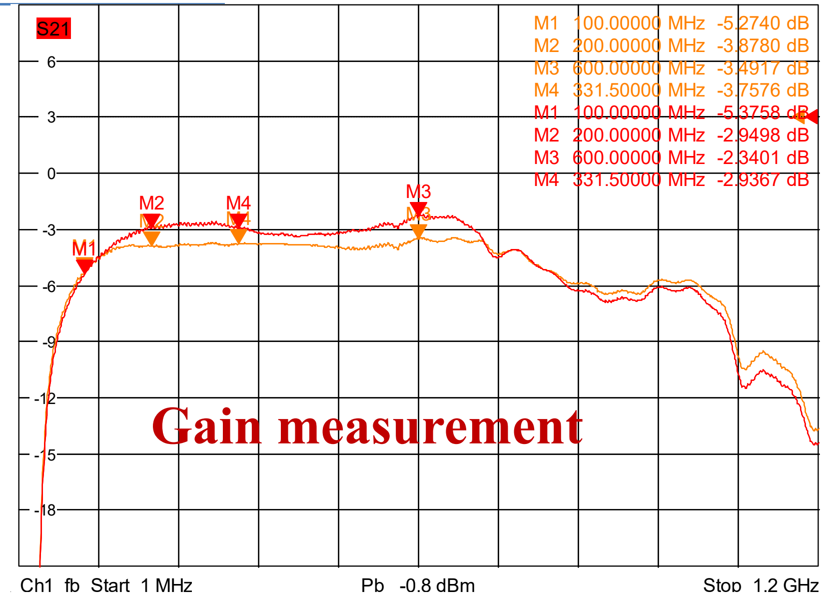
Attenuation measurement result

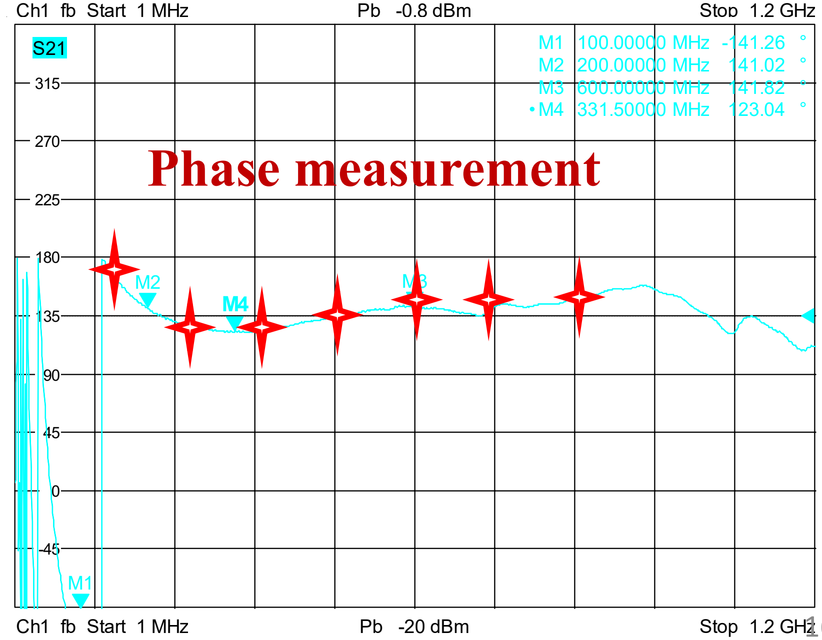


Power amplifier

R&S

frequency band, lower limit / MHz	100
frequency band, upper limit /MHz	600
Output power at P1dB / W	150
minimum amplification / dB	30
maximum amplification / dB	50
Gain flatness, 10 dB below 1 dB compression / dB	±2
Phase variation,10 dB below 1 dB compression / degrees	±10
total electric length / ns	<15

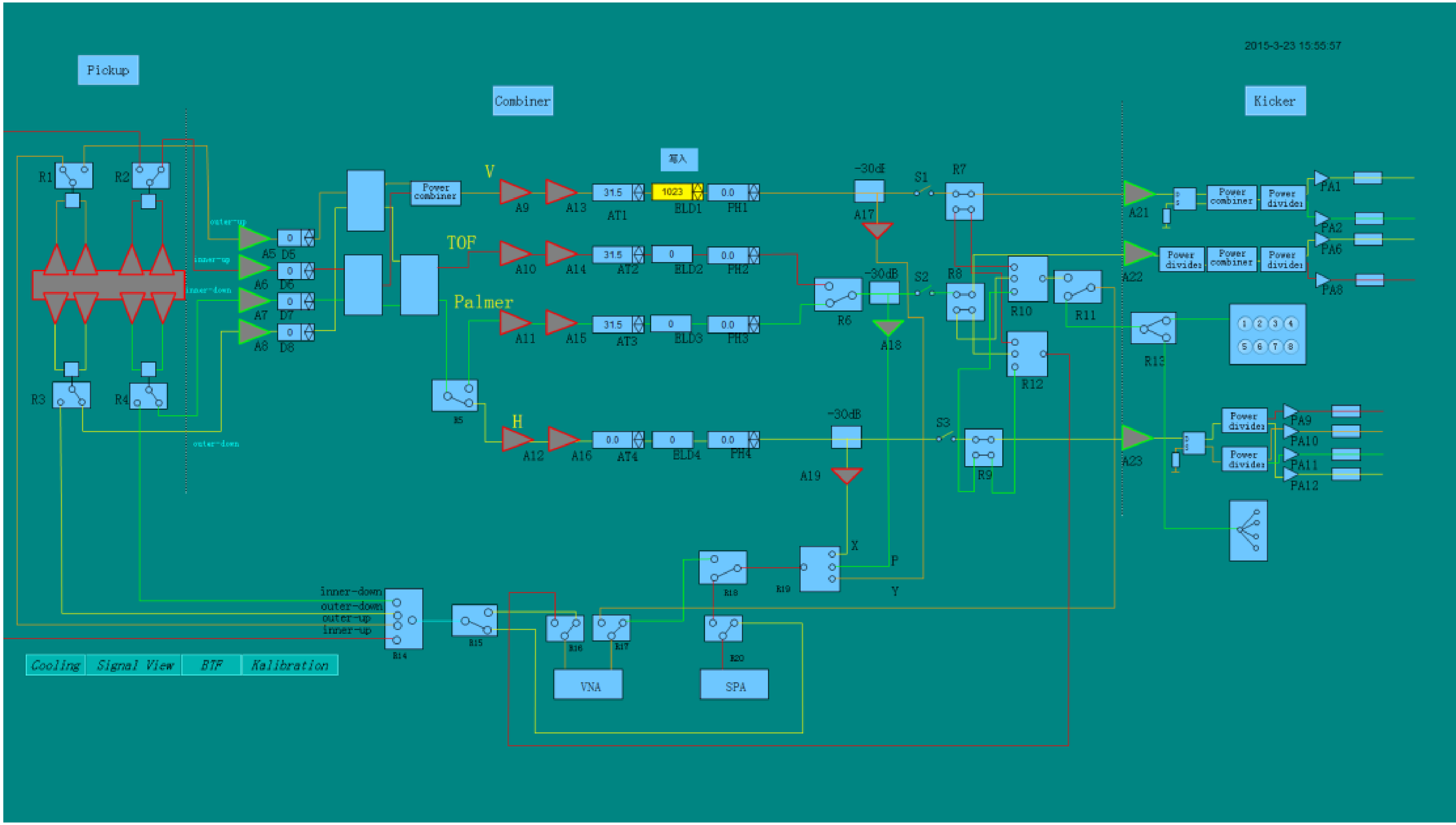




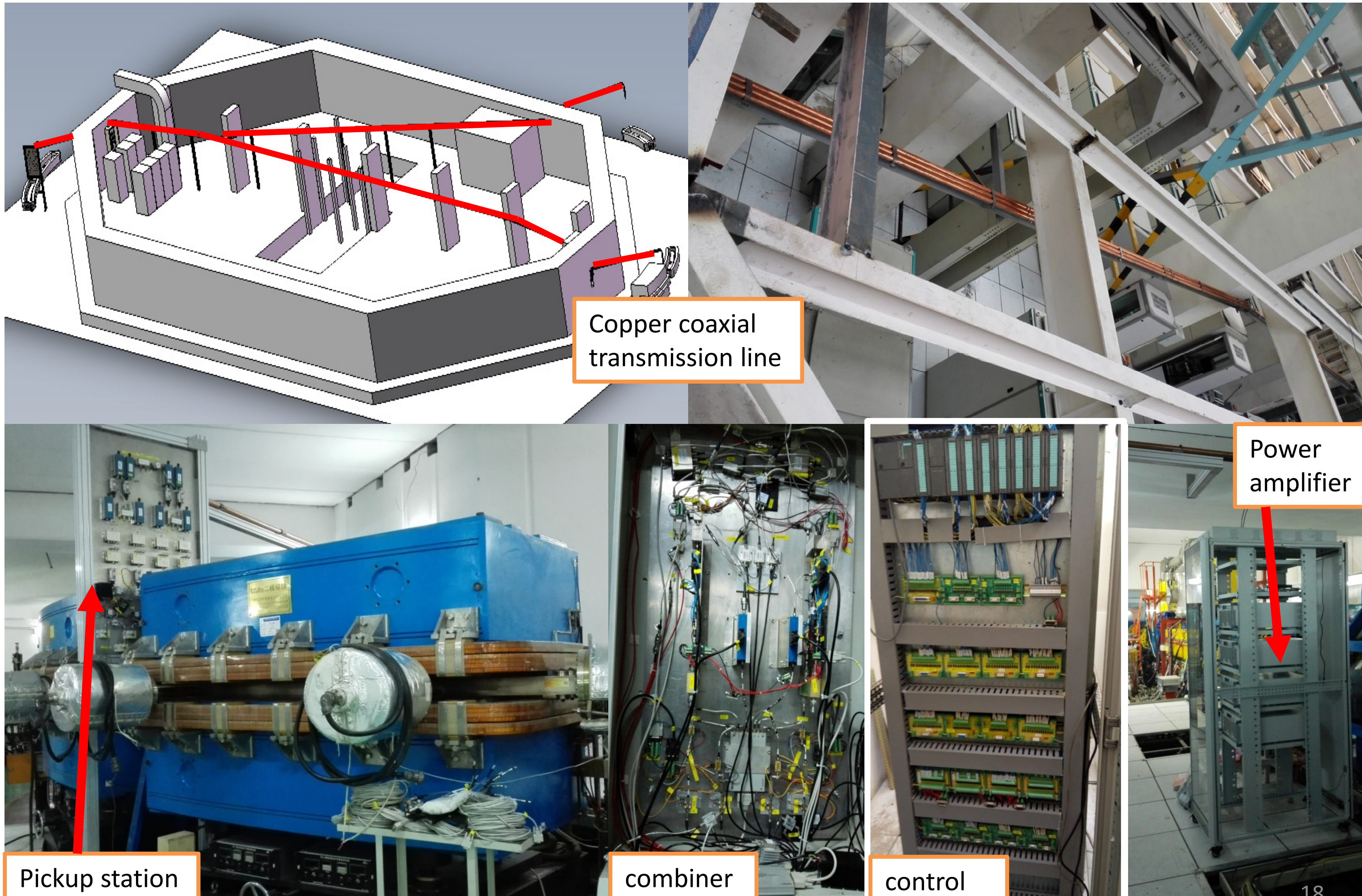
0.001GHz

1.2GHz

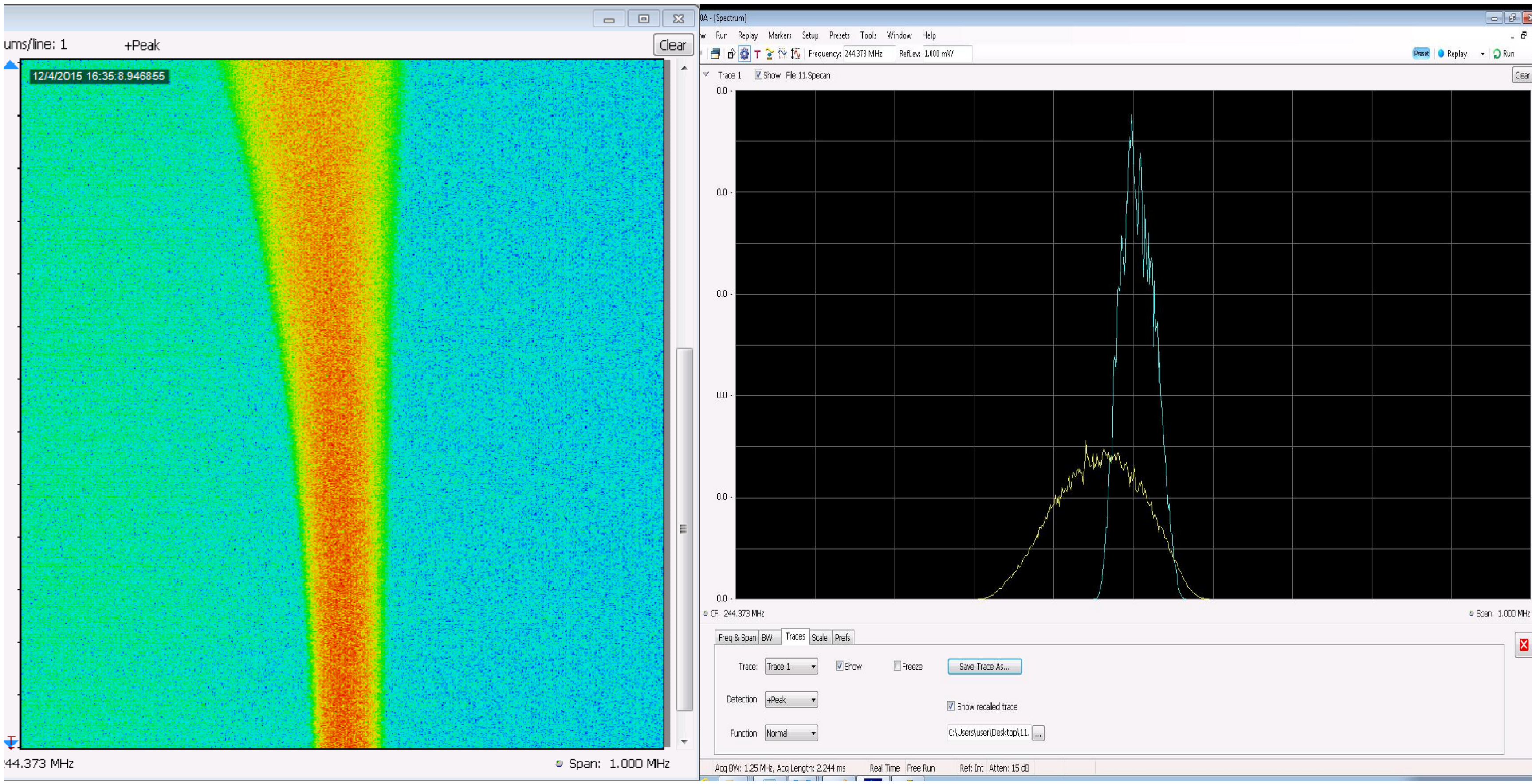
Control interface with block diagram



Hardware of the CSRe stochastic cooling



First beam experiment result – longitudinal cooling



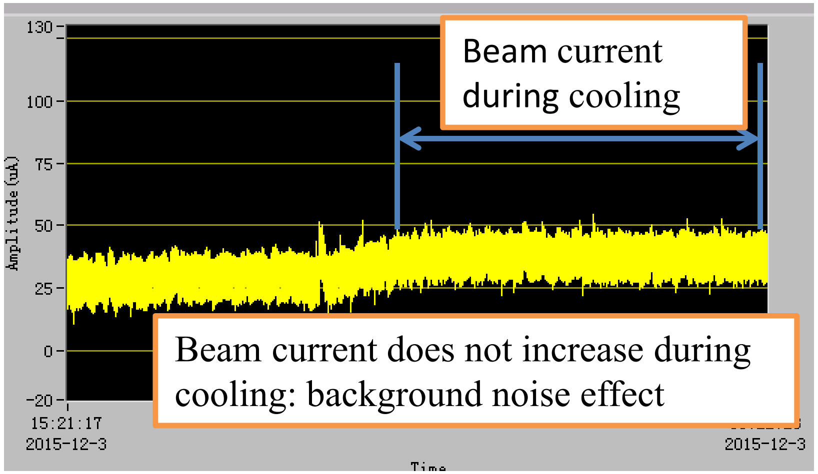
Beam: C6+ Energy: 380MeV/u

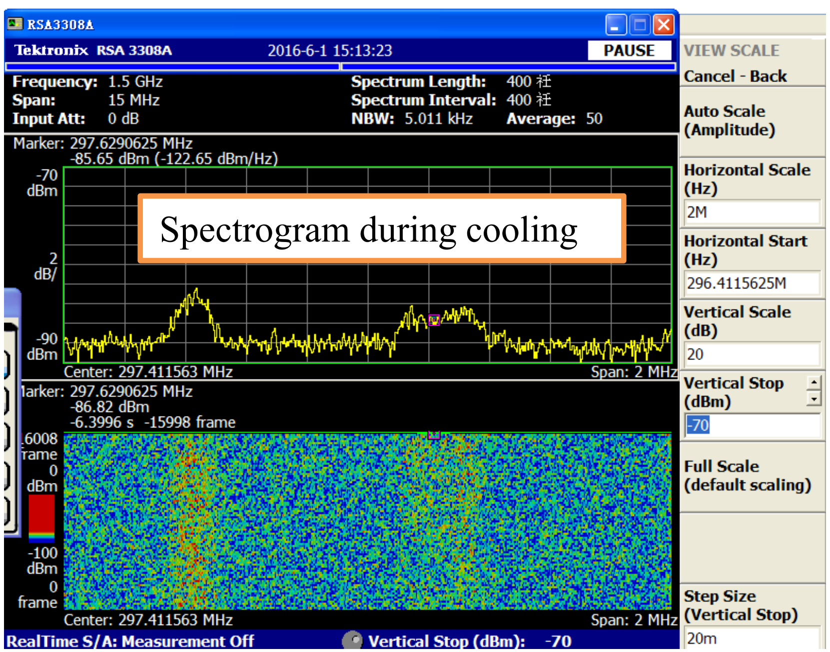
Particle number: 7.0e7 Cooling time: 160 s

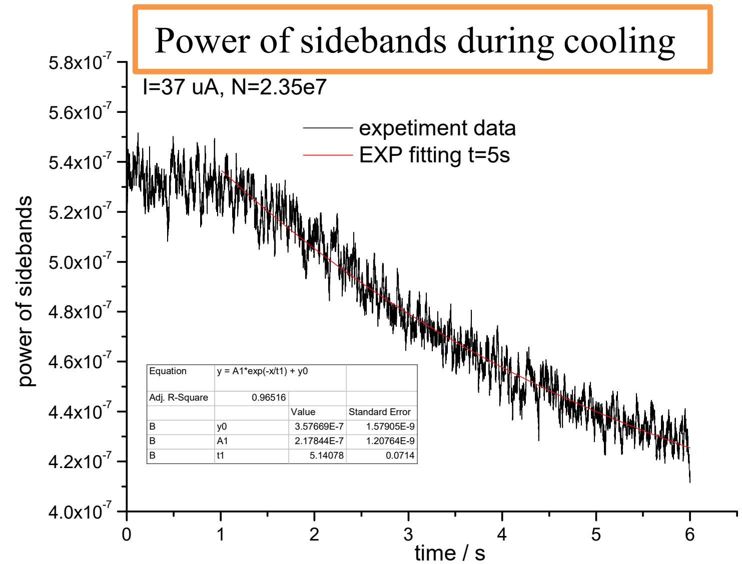
Before cooling（rms）: Δp/p=± 8.0e-4

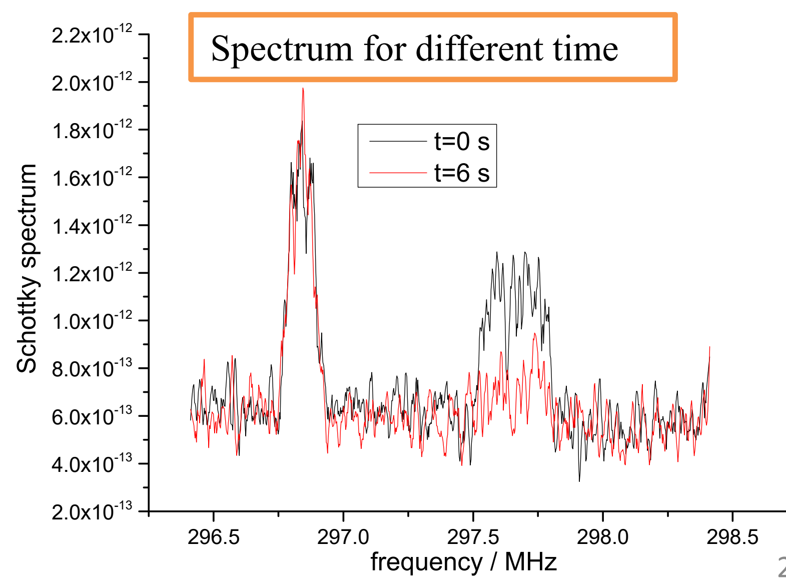
After cooling（rms）: Δp/p=± 3.0e-4

Beam experiment result – transverse cooling

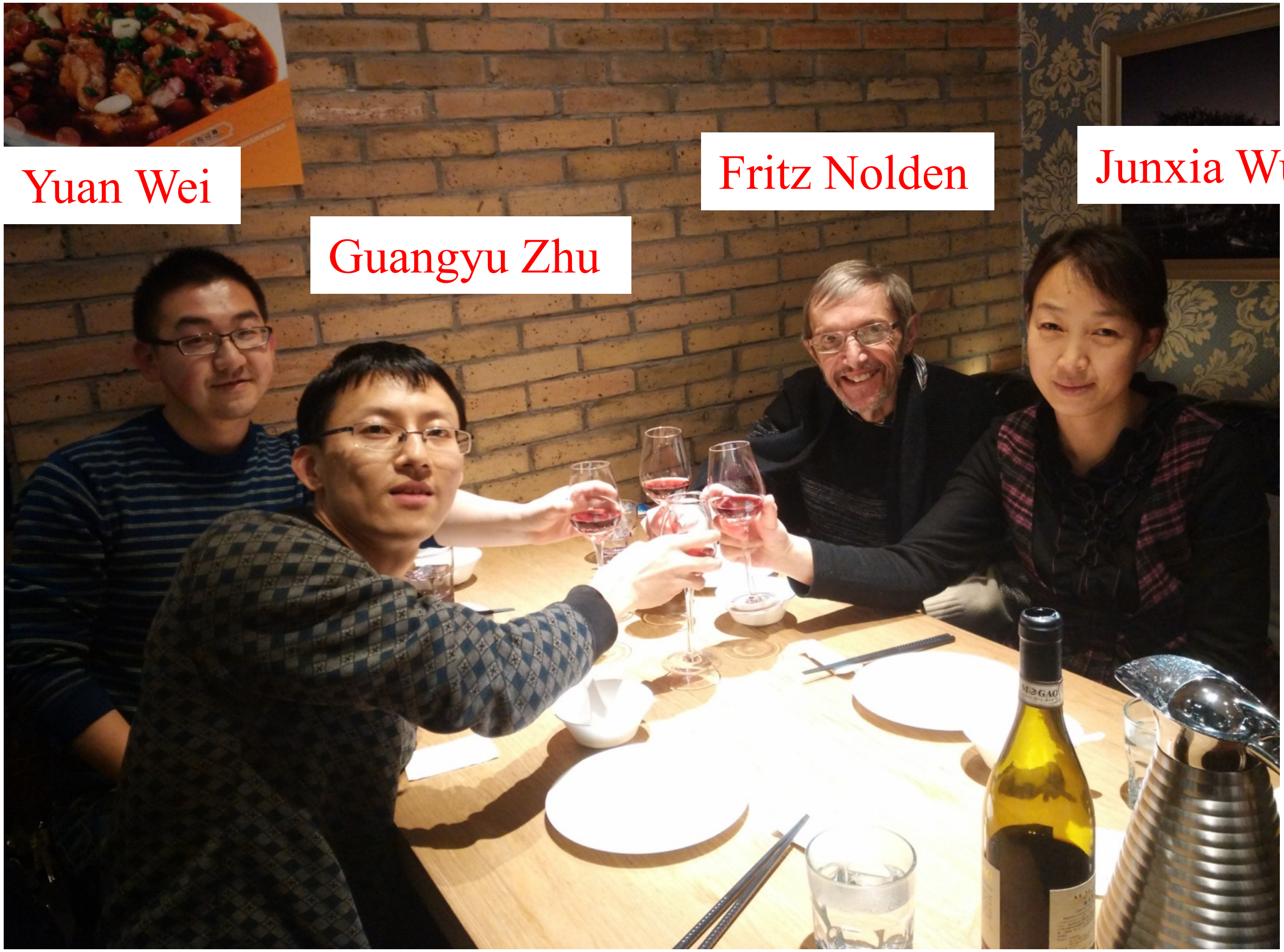








Cheers for CSRe stochastic cooling experiment

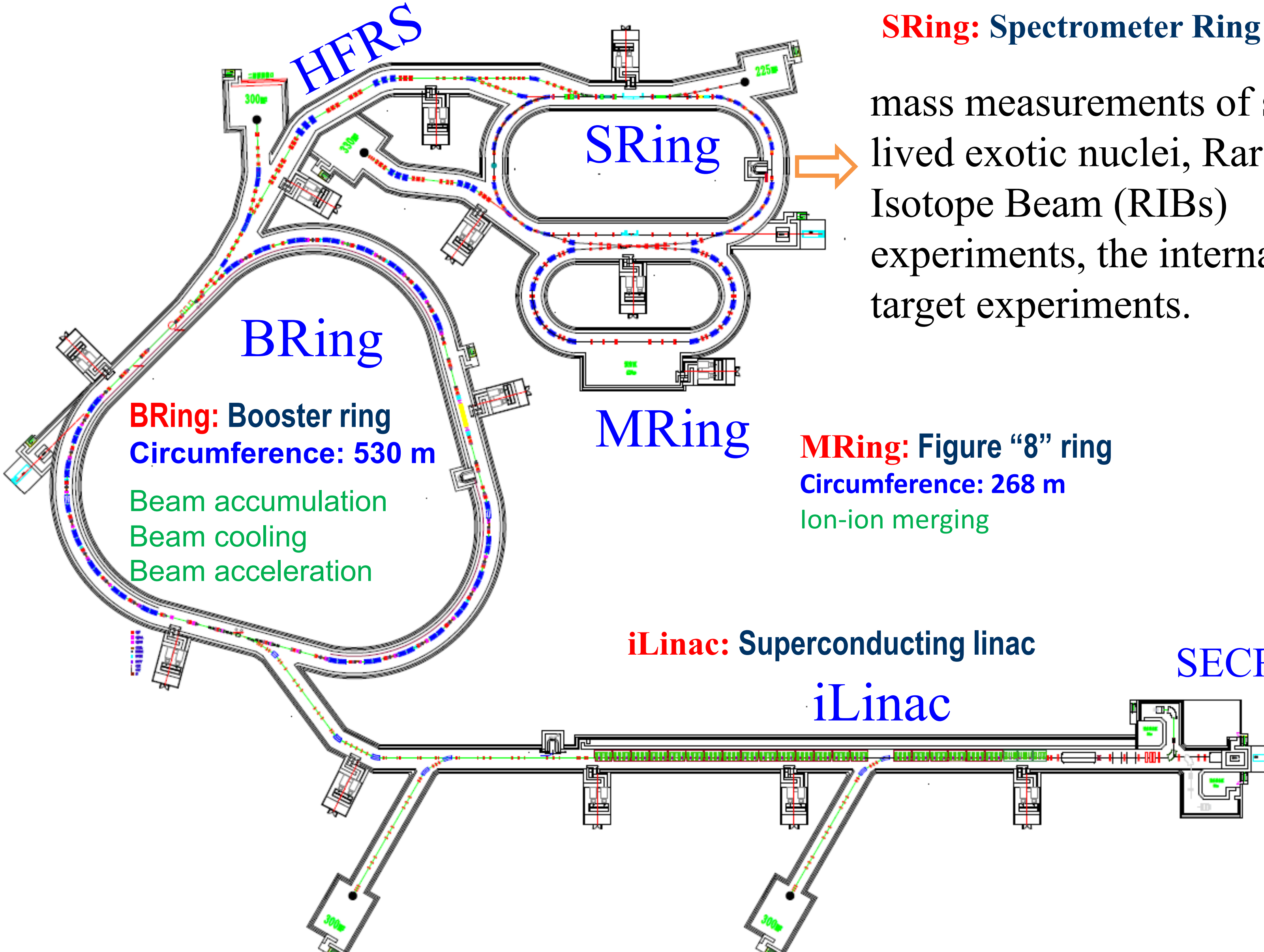


Outlines

- HIRFL-CSRe stochastic cooling
  - Hardware
  - Experimental result

- **Progress of the stochastic cooling on Sring (Spectrometer Ring) of HIAF (High Intensity heavy ion Accelerator Facility)**

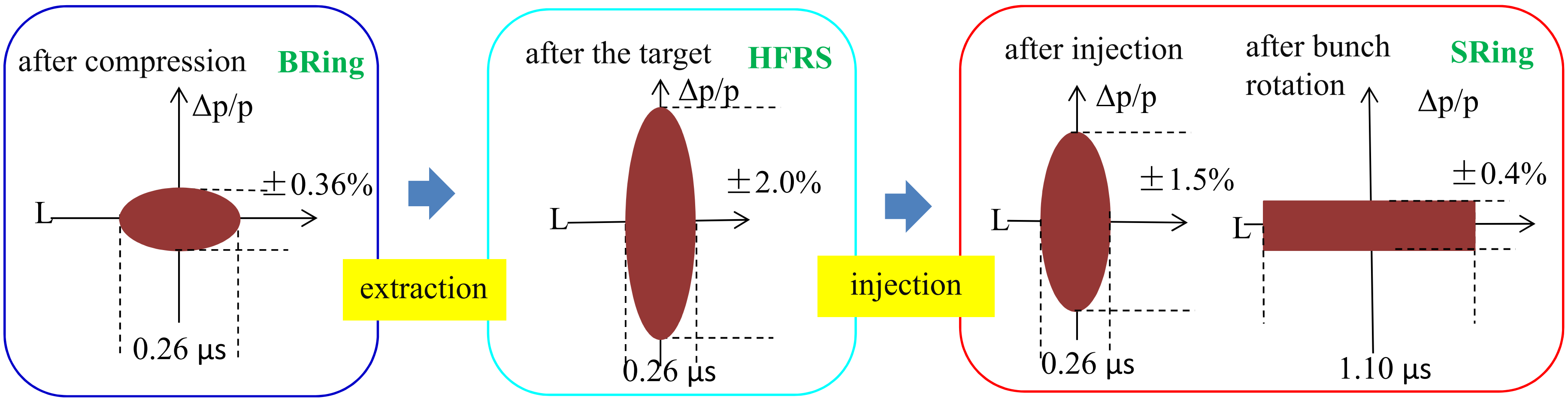
Layout of HIAF



SRing: Spectrometer Ring

mass measurements of short-lived exotic nuclei, Rare Isotope Beam (RIBs) experiments, the internal target experiments.

Normal stochastic cooling operation mode on SRing



$\Delta p/p$ $\varepsilon_x/\varepsilon_y$ 3σ

total cooling time<2.3 s

precooling

Stochastic Cooling **SRing**

$\Delta p/p$: $\pm 0.40\%$ $\rightarrow$ $\pm 0.025\%$

ε_x: 120 π mm·mrad → 5 π mm·mrad

ε_y: 40 π mm·mrad → 5 π mm·mrad

cooling time<1.2 s

electron cooling

Electron-Cooling **SRing**

$\Delta p/p$: $\pm 0.025\%$ $\rightarrow$ $\pm 0.001\%$

$\varepsilon_x/\varepsilon_y$: 5 π mm·mrad → 0.1 π mm·mrad

cooling time<1.0 s

Purpose and requirements of the stochastic cooling on the SRing – Nuclear physics

- Precooling of the radio isotope beams
- Beam energy: $\boxed{\text{625 MeV/u-840 MeV/u } (\beta\text{: 0.8-0.85})}$
- Number of particles: <1.0e5
- Mass number: 100-200
- Atomic number: 40-80
- Lifetime: seconds
- Before cooling: ε_H=200 π mm mrad, ε_V=40 π mm mrad,
  $\Delta p/p=\pm 4.0\text{e-}3$ ($\pm 3\sigma$)
- After cooling: $\varepsilon_{H,V}$=6.25 π mm mrad, $\Delta p/p=\pm 3.6\text{e-}4$ ($\pm 3\sigma$)
  $\varepsilon_{H,V}$=1.25 π mm mrad, $\Delta p/p=\pm 6.0\text{e-}5$ (1 σ)
- Cooling time < 1s

$\boxed{\text{Below 400 MeV/u } (\beta\text{: 0.71})}$

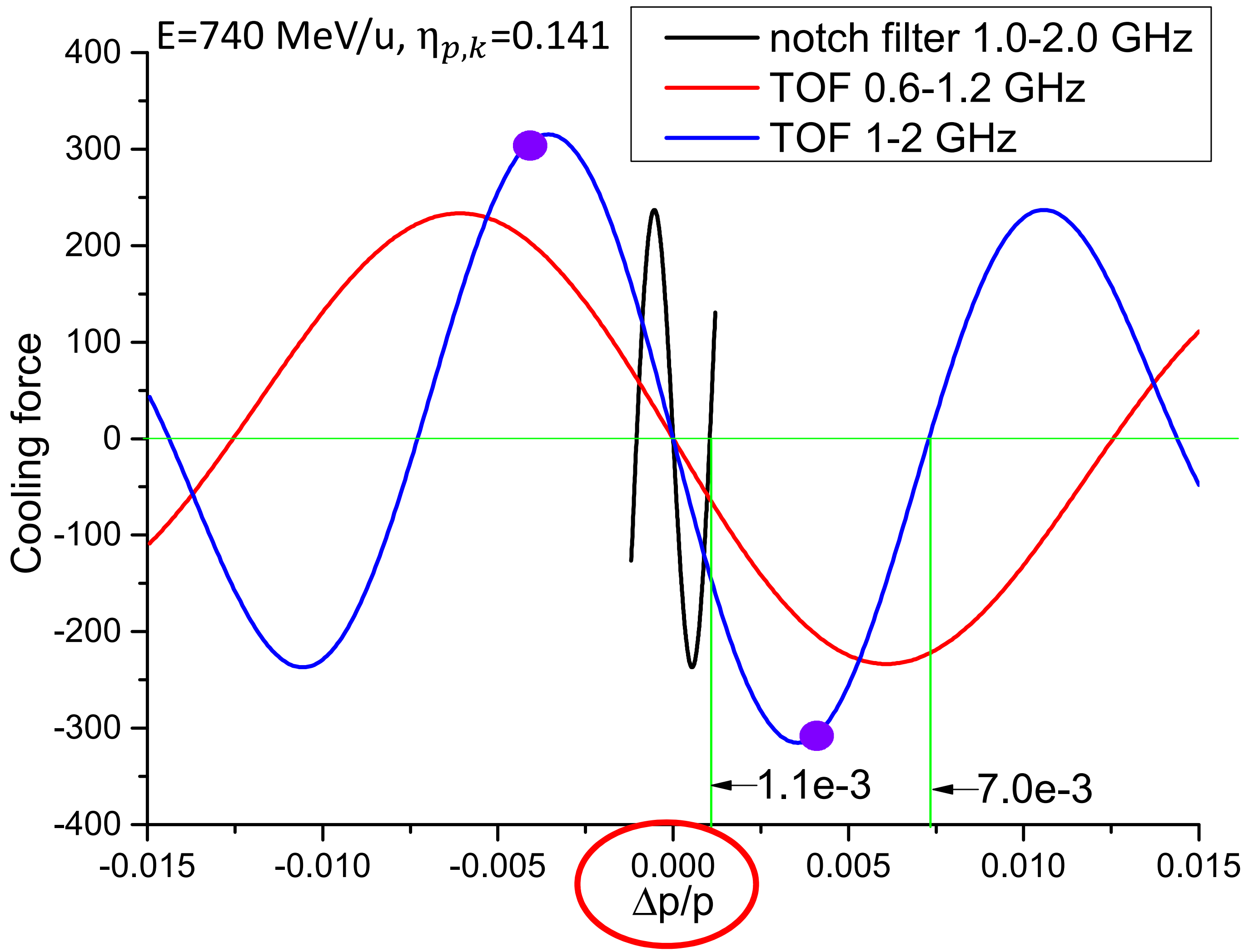
Purpose and requirements of the stochastic cooling on the SRing – atomics physics

DR pilot experiment with the radioisotopes

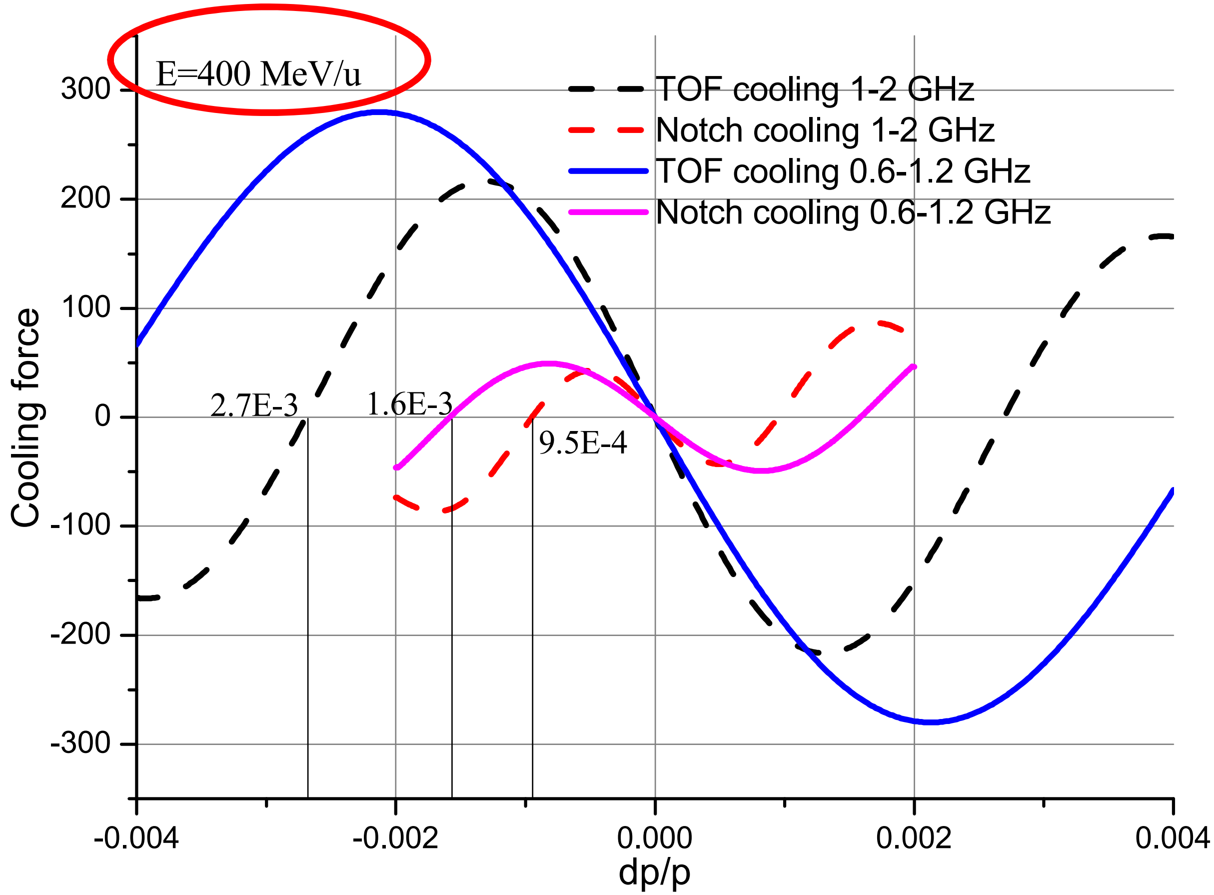
$6.25\times10^9\ {}^{238}U^{34+} \rightarrow$ C-target $\rightarrow {}^{235,237}U^{91+,89+}$

Initial energy (MeV/u)	Thickness of the target	^{235}U			^{237}U		
		Output energy (MeV/u)	Ion production rate(pps)		Output energy (MeV/u)	Ion production rate(pps)	
			H-like	Li-like		H-like	Li-like
500	$3g/cm^2$	171	2.34e6	1.61e6	173	2.25e6	1.45e6
600		311	5.53e6	5.08e5	313	5.19e6	4.56e5
700		433	6.87e6	2.05e5	434	6.39e6	1.89e5
800		546.5	7.18e6	9.69e4	548.5	6.67e6	8.95e4
900		656.5	6.96e6	4.92e4	658	6.47e6	4.55e4
1000		764	6.51e6	2.7e4	765	6.03e6	2.46e4
1100		869	5.96e6	1.52e4	870	5.53e6	1.39e4
600	$4g/cm^2$	187	3.02e6	1.57e6	190	3.06e6	1.37e6
700		330	6.48e6	4.94e5	333	6.07e6	4.41e5
800		454.5	7.82e6	1.98e5	456.5	7.24e6	1.84e5
900		570	7.99e6	9.54e4	572	7.42e6	8.6e4
1000		681	7.64e6	4.64e4	683	7.09e6	4.16e4
1100		789.5	7.13e6	2.58e4	791.5	6.61e6	2.38e4

Momentum acceptance for TOF and notch filter cooling
TOF= time of flight method



Momentum acceptance for TOF and notch filter cooling 400 MeV/u



So for the beam energy below 400 MeV/u, 1-2 GHz can not be used, the cooling frequency should be below 1.2 GHz.

Longitudinal cooling methods choice

$$\left(\frac{\Delta p}{p_s}\right)_{\text{limit}} = \begin{cases} \left[2m_c\, x\eta_{pk}\right]^{-1} & \text{for time of flight (TOF) cooling} \\ \left[4m_c\, x\eta_{pk}\right]^{-1} & \text{for Palmer and transverse cooling} \\ \left[2m_c\,(2x\eta_{pk} + \eta)\right]^{-1} & \text{for notch filter cooling} \end{cases}$$

Longitudinal cooling methods choice

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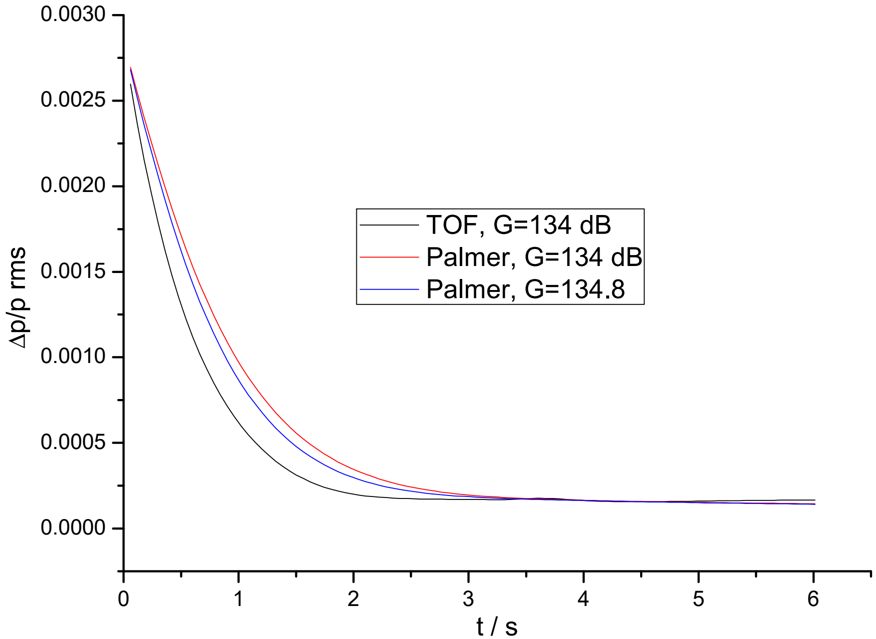

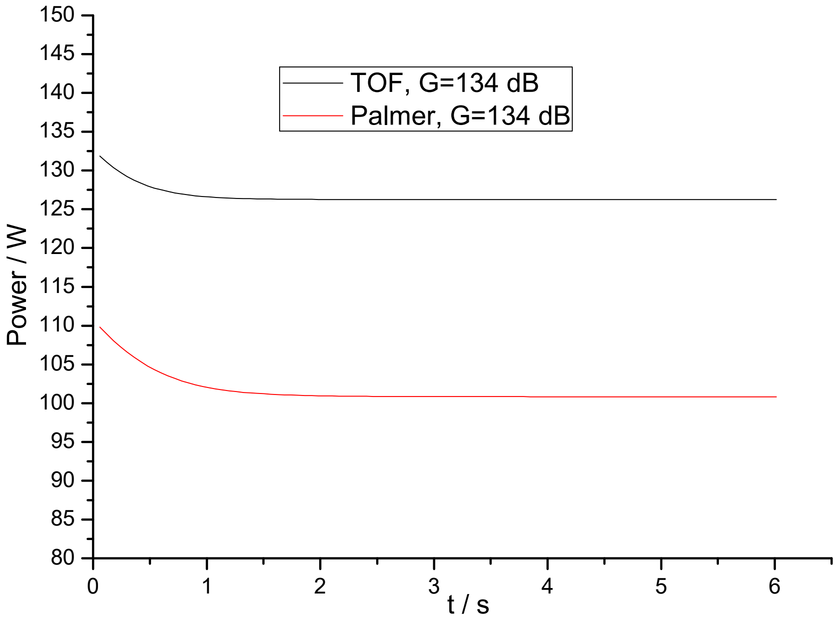

Longitudinal cooling methods choice

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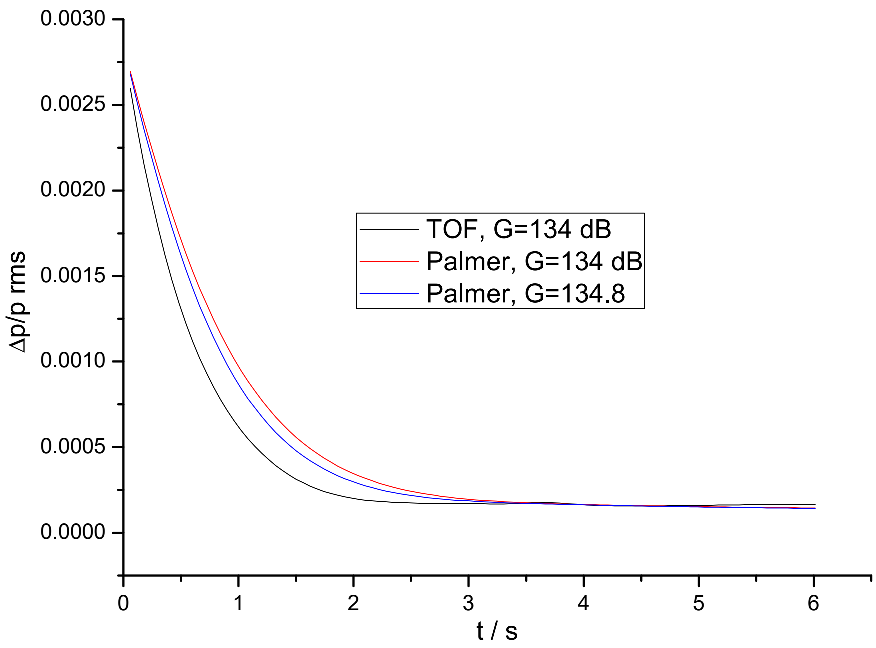
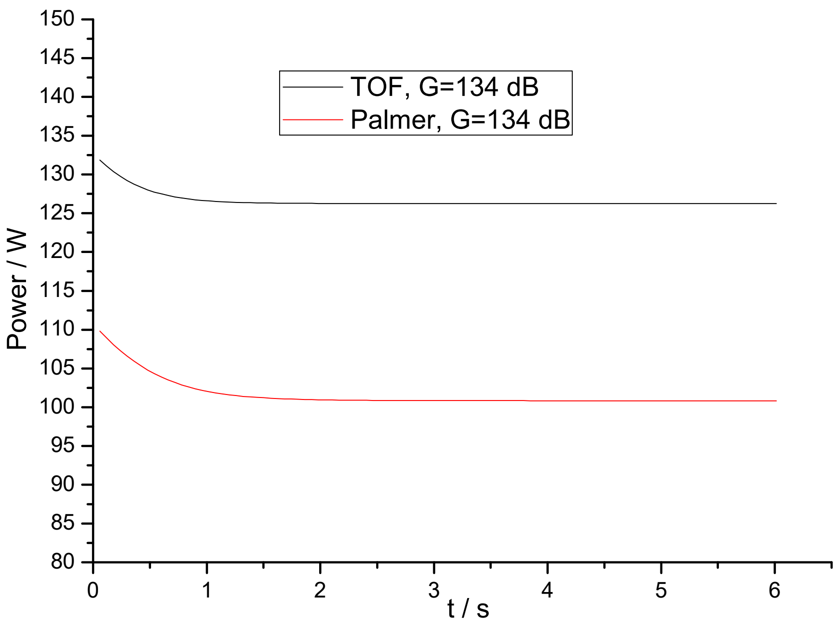
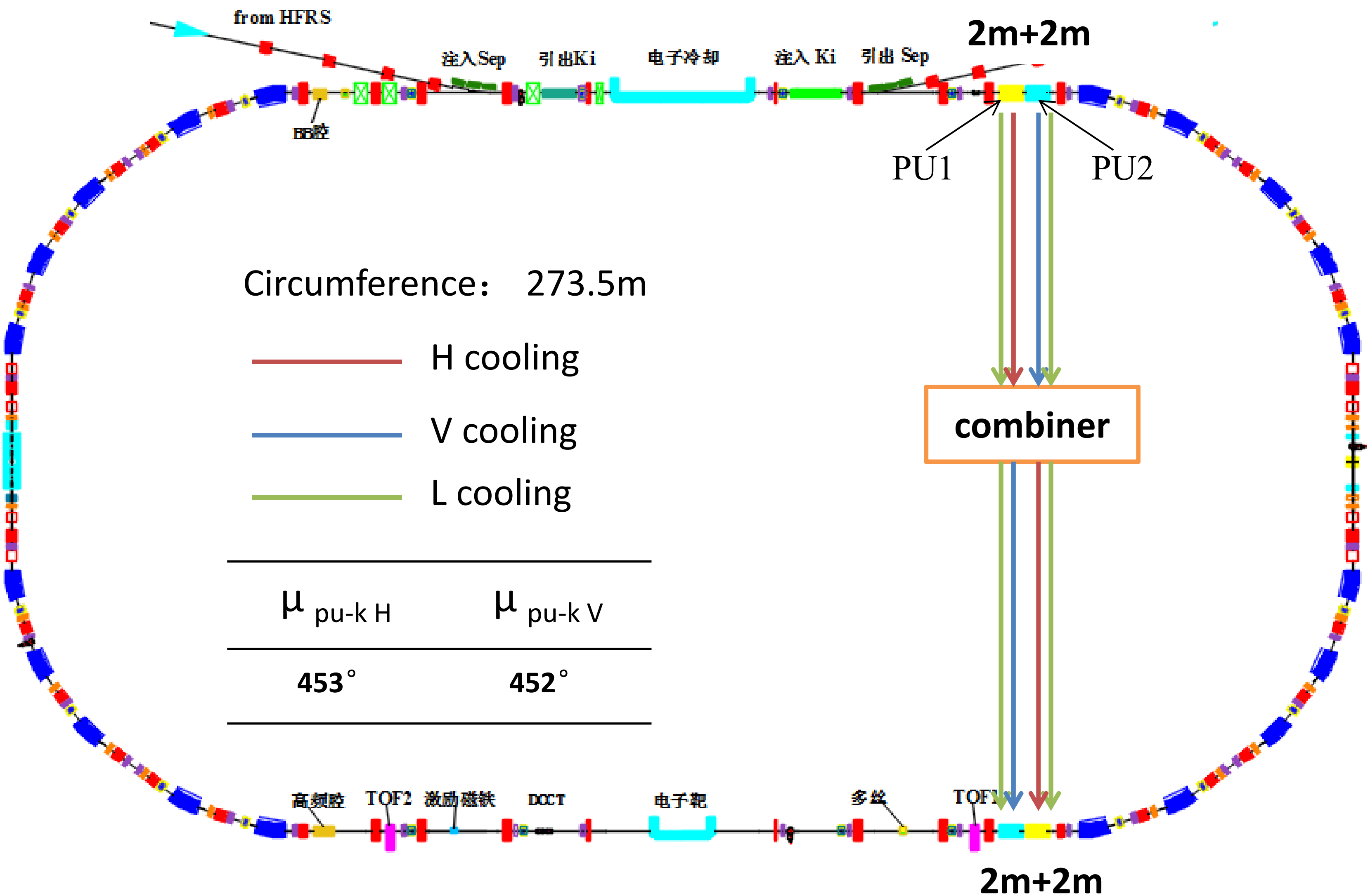


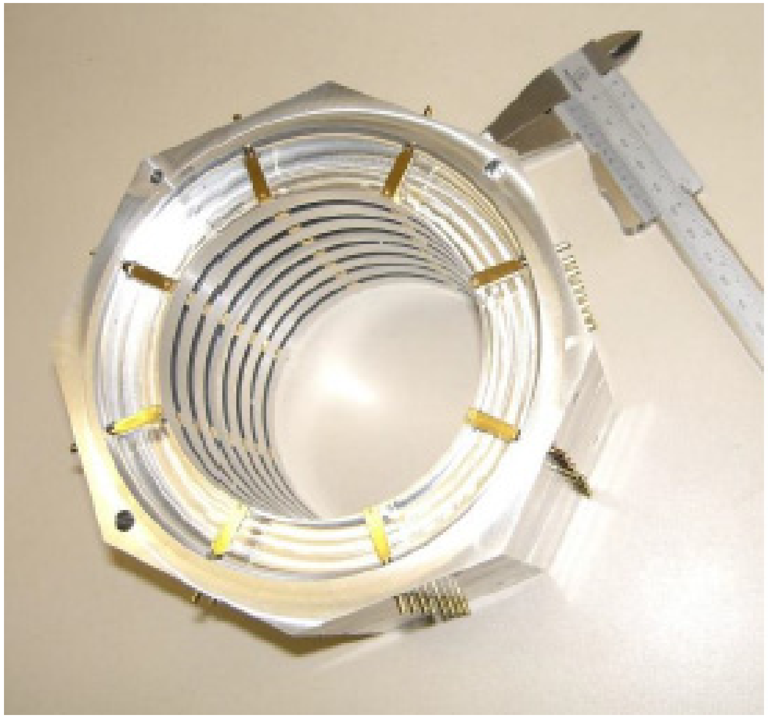


Layout of the PU and kicker of SRing stochastic cooling

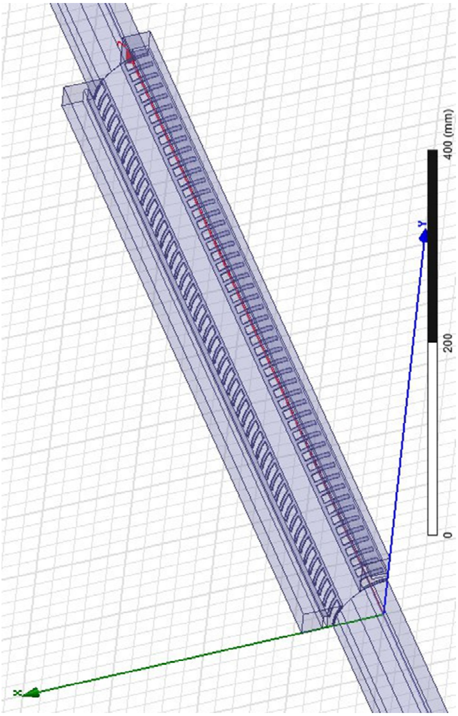


Pickup/kicker structure considered

Slot-ring structure
Used in HESR stochastic cooling



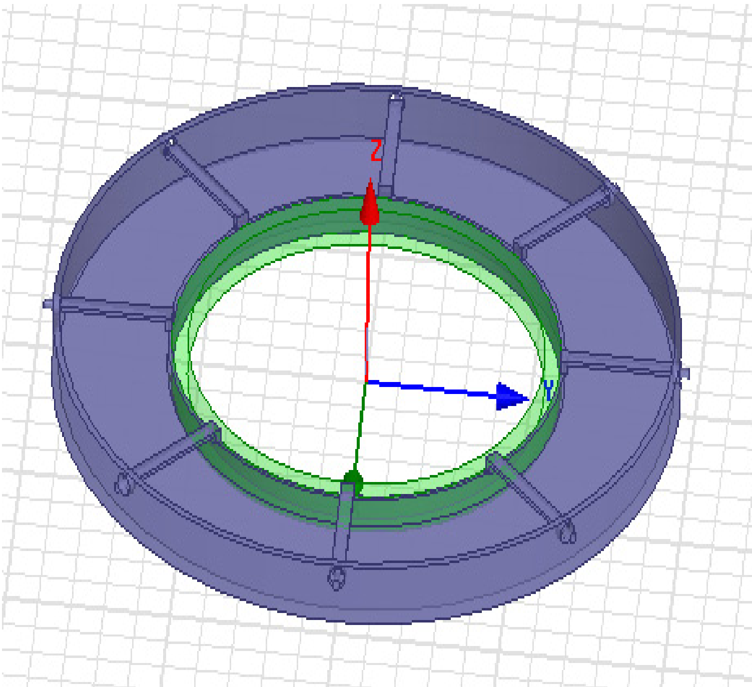
Faltin structure

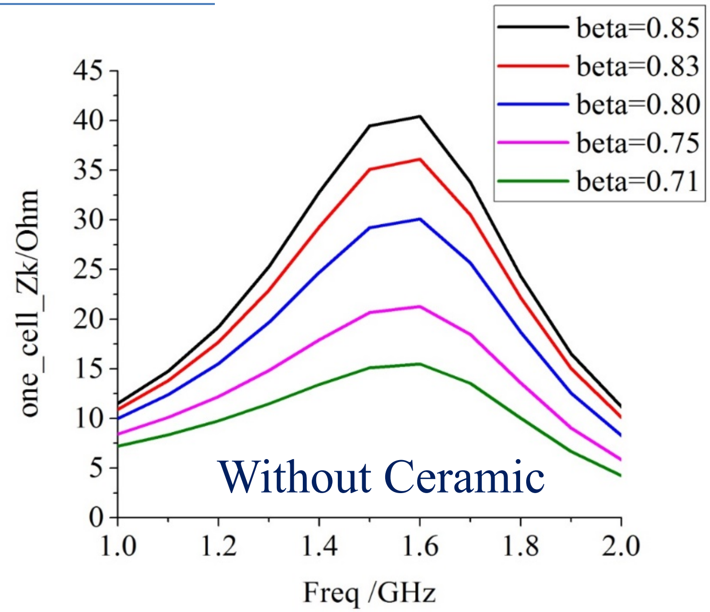


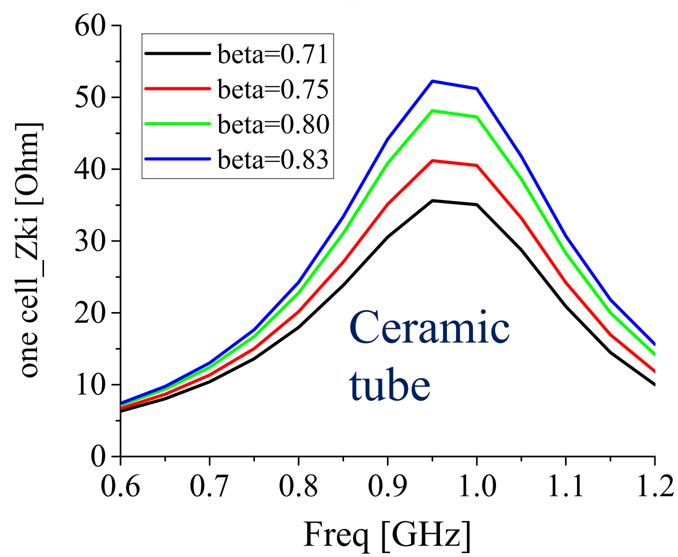
Detailed simulation about these two structures: Poster, Guangyu Zhu

Pickup/kicker structure considered

Slot-ring structure with the ceramic tube as the vacuum barrier, put the slot ring outside the vacuum

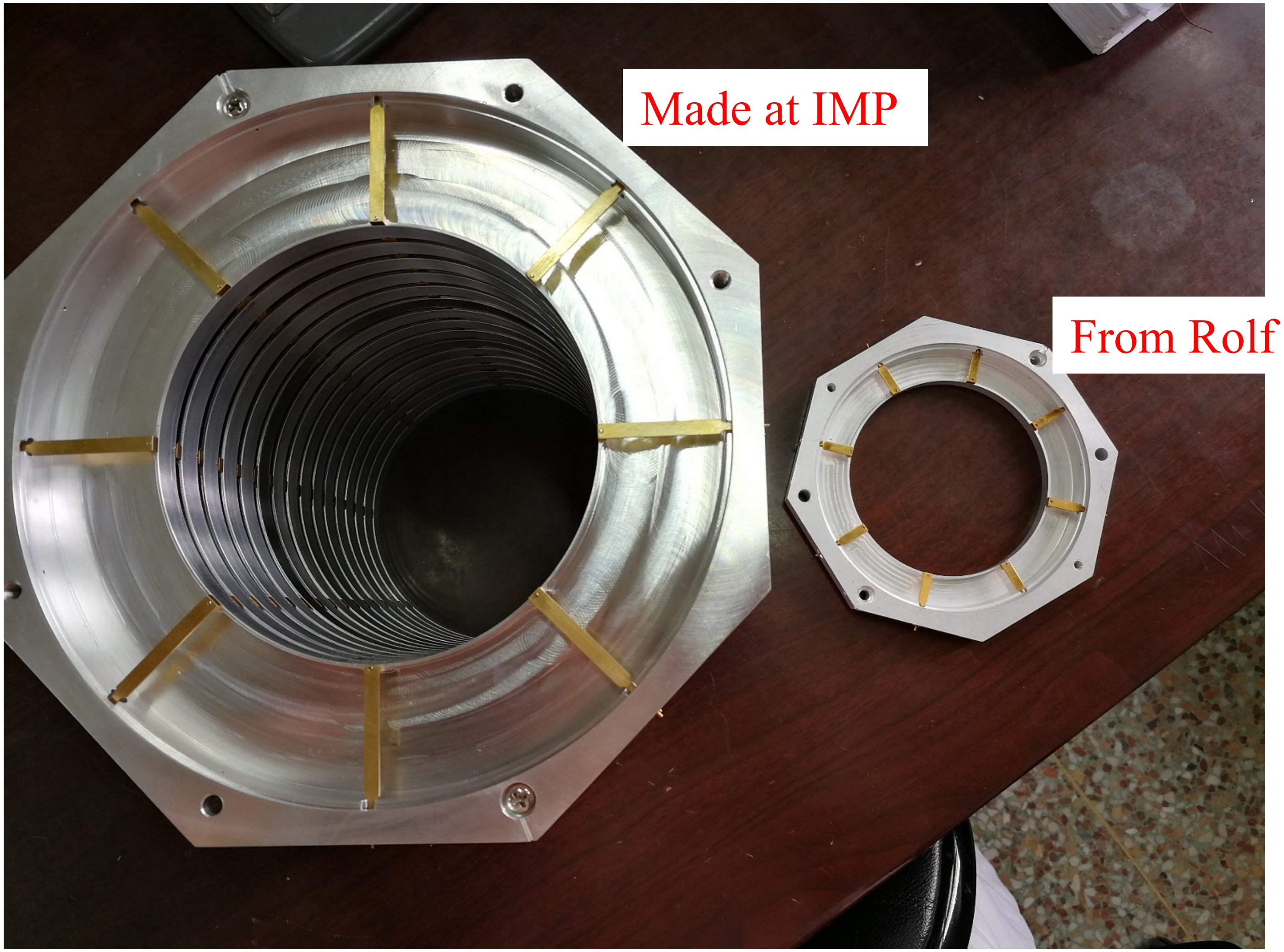






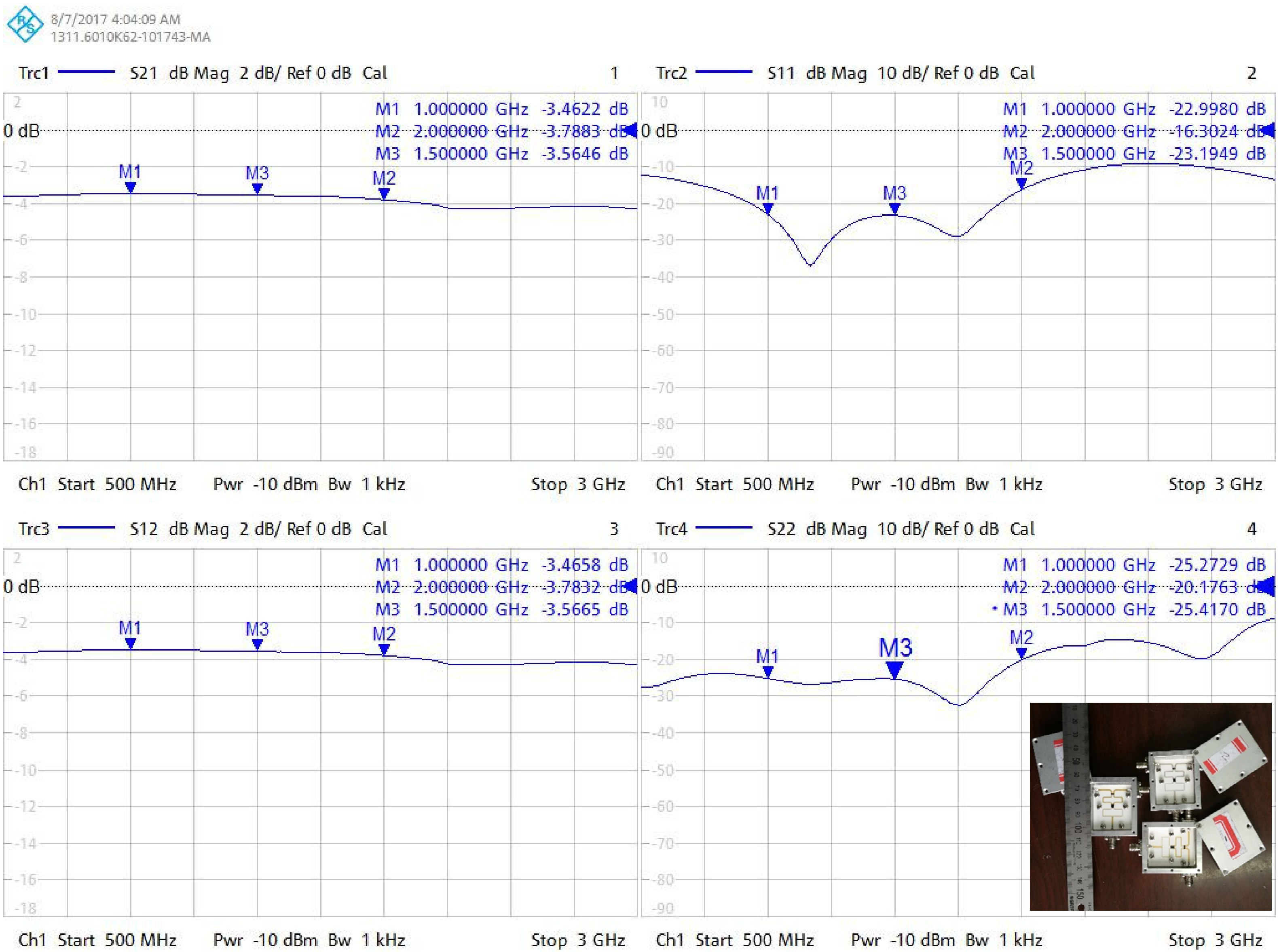
Detailed simulation about these two structures: Poster, Guangyu Zhu

Slot ring structure-lab test model



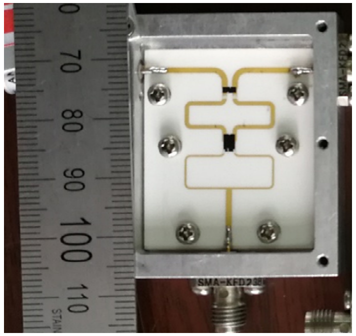
2 way Wilkinson microstrip type combiner/splitter

2 way combiner-transmission measurement

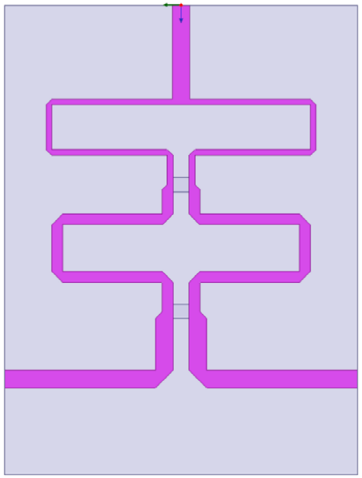


2 way combiner – improvement using thicker ceramic

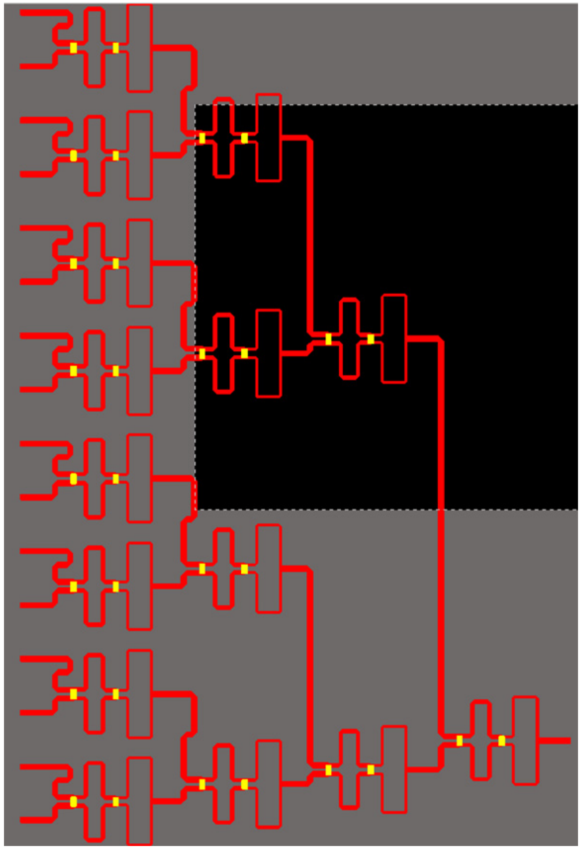
Attenuation: 0.6 dB
Ceramic thickness: 1 mm
The purity is 96%

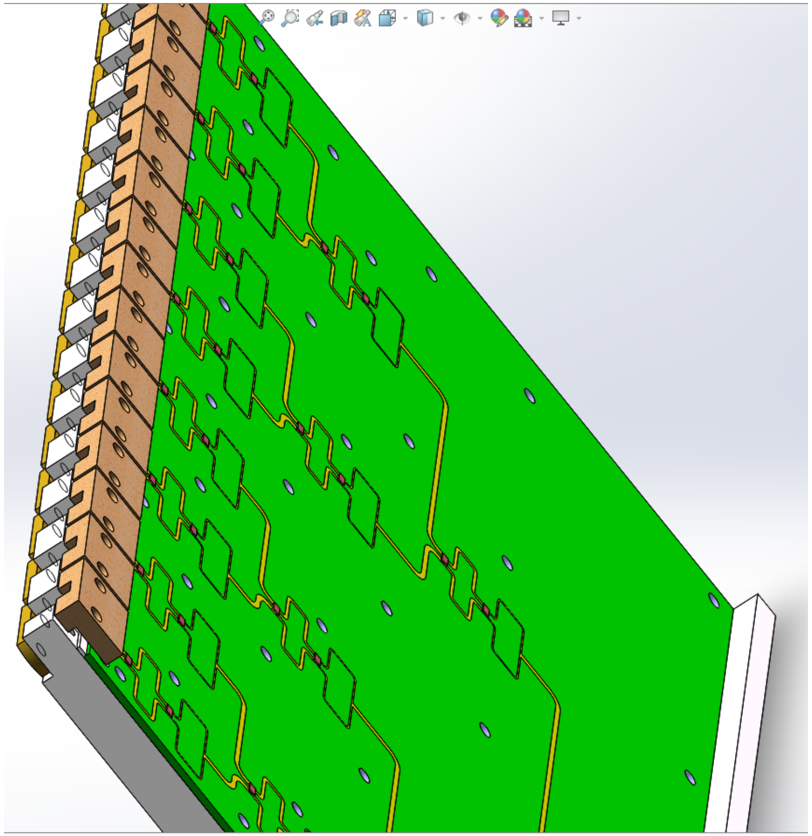


Waiting for manufacture
2 mm thick ceramic
Purity: 99.5%

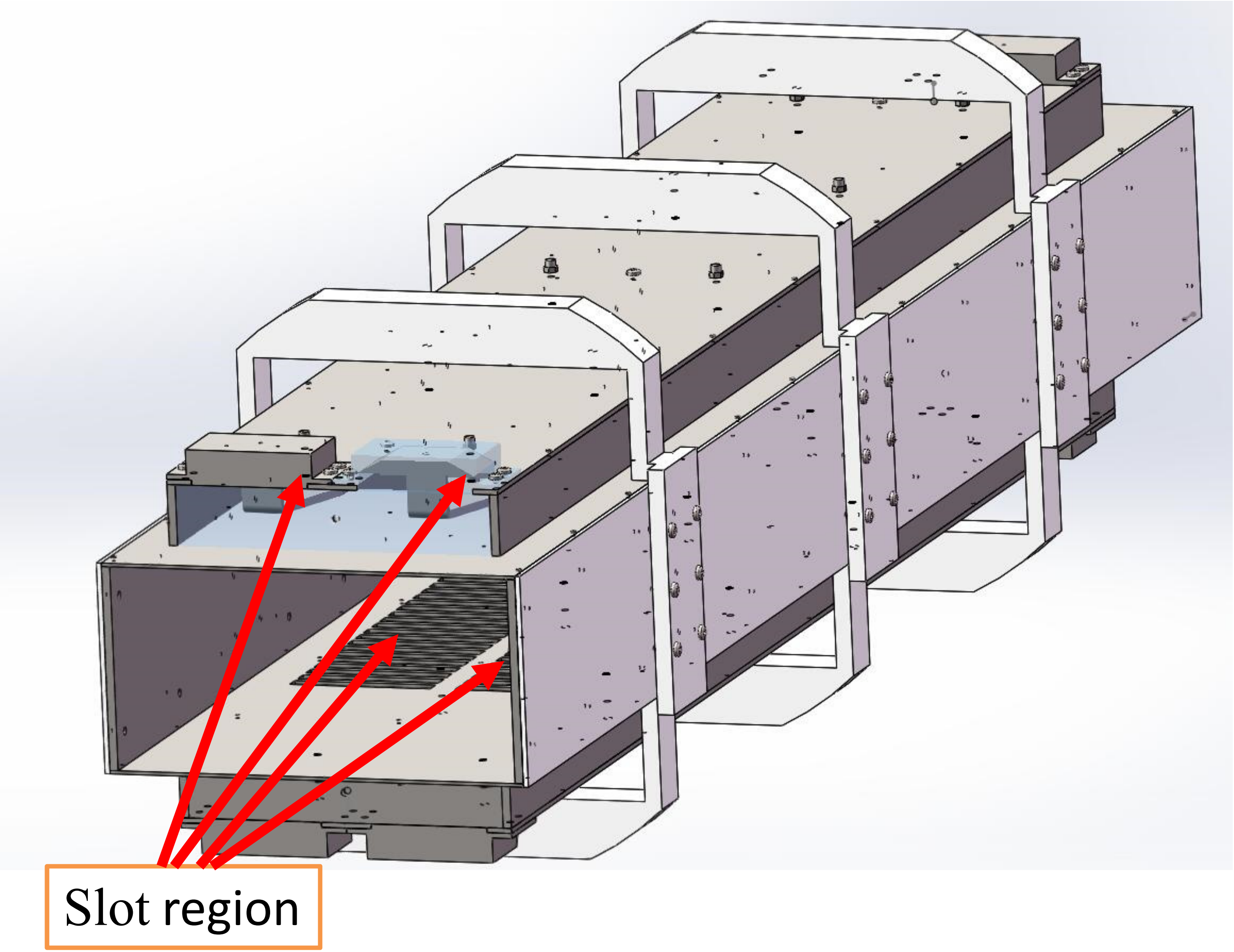


16 way combiner





Faltin structure- mechanical layout

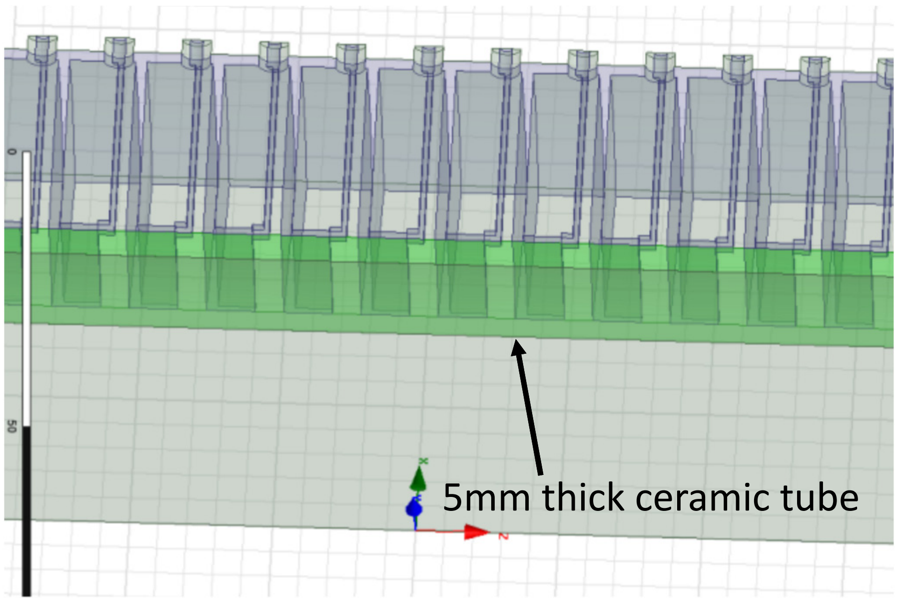


Simulation parameters for SRing stochastic cooling

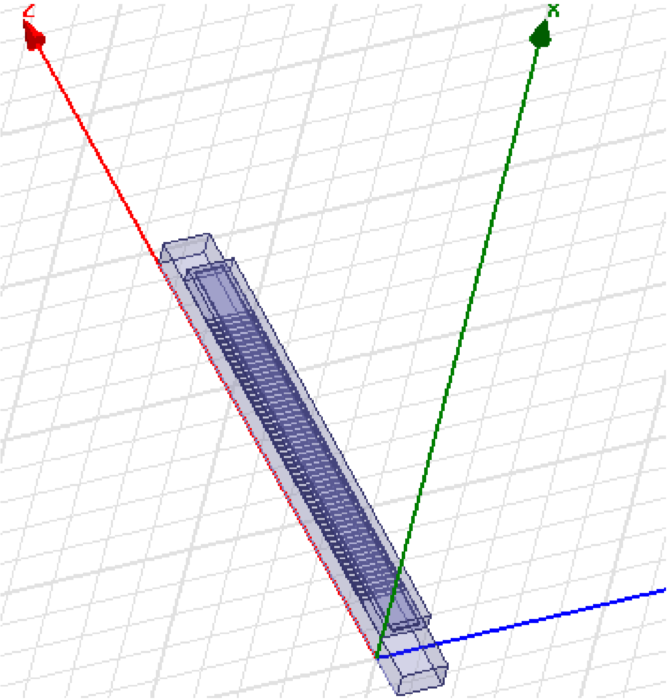
• Ion	132Sn50+
• Kinetic energy	740 MeV/u, 400 MeV/u
• Total number of RI	1.0e5, 1.0e8
• γ_t	3.317
• Local γ_t	2.568
• Bandwidth	0.6-1.2 GHz
• Number of slot rings for Pickup	64
• Number of slot rings for kicker	128
• Number of Faltin pickup (0.75 m)	2
• Number of Faltin kicker (0.75 m)	4
• Temperature (physical)	300 K
• Distance from pickup to kicker	75.25 m
• Dispersion at pickup/kicker	0.0 m

Pickup/kicker– slot ring and Faltin

Slot ring with ceramic tube inside
Circular pipe, diameter=200 mm

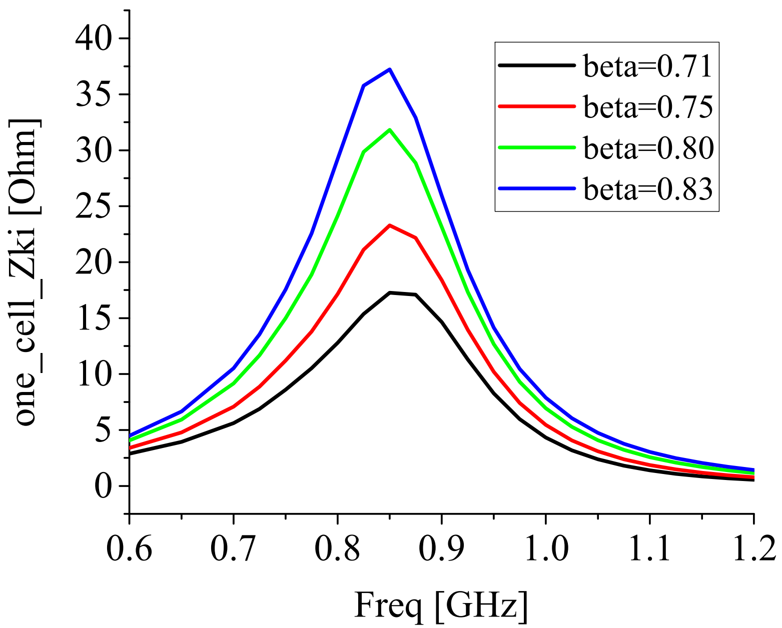


Faltin, rectangular shape,
dimension: 200 mm * 120 mm

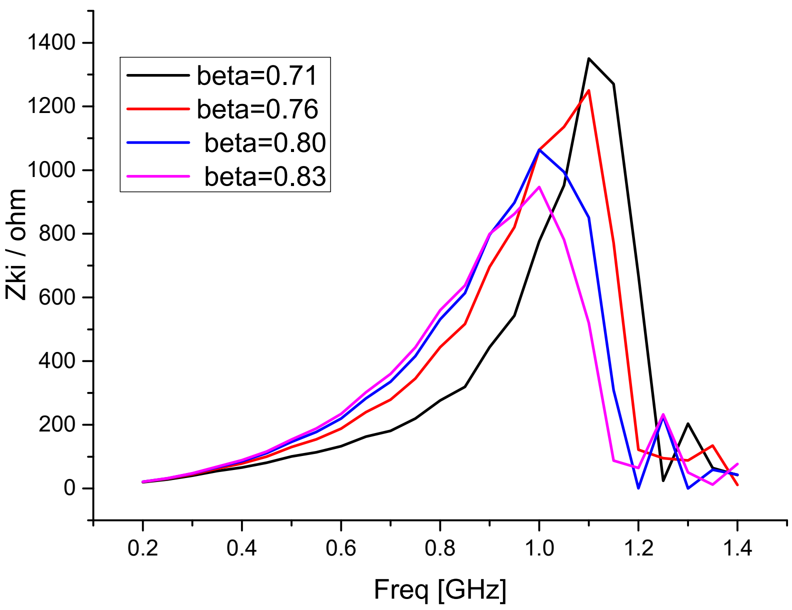


Shunt impedance – slot ring and Faltin

Slot ring with ceramic tube inside
Circular pipe, diameter=200 mm

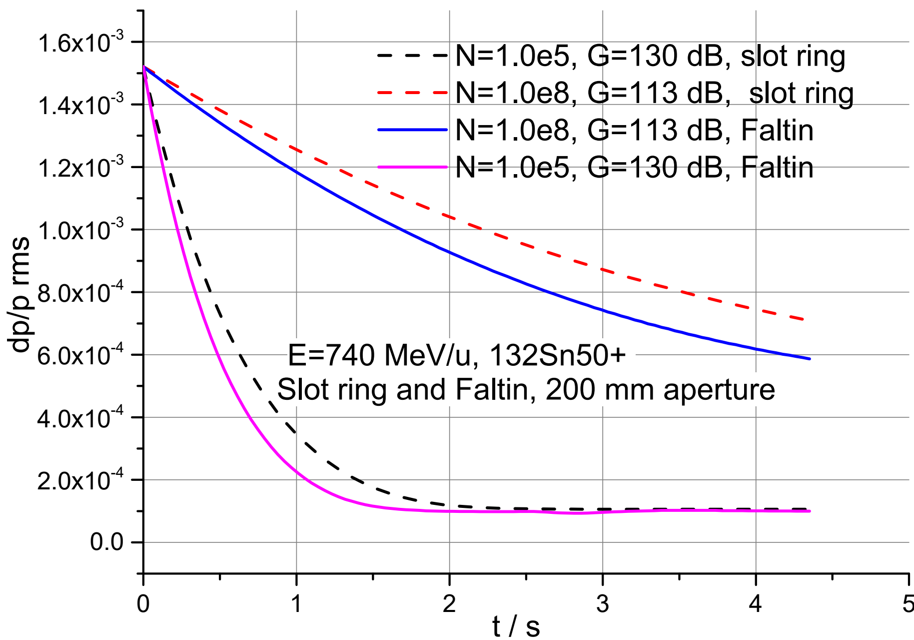


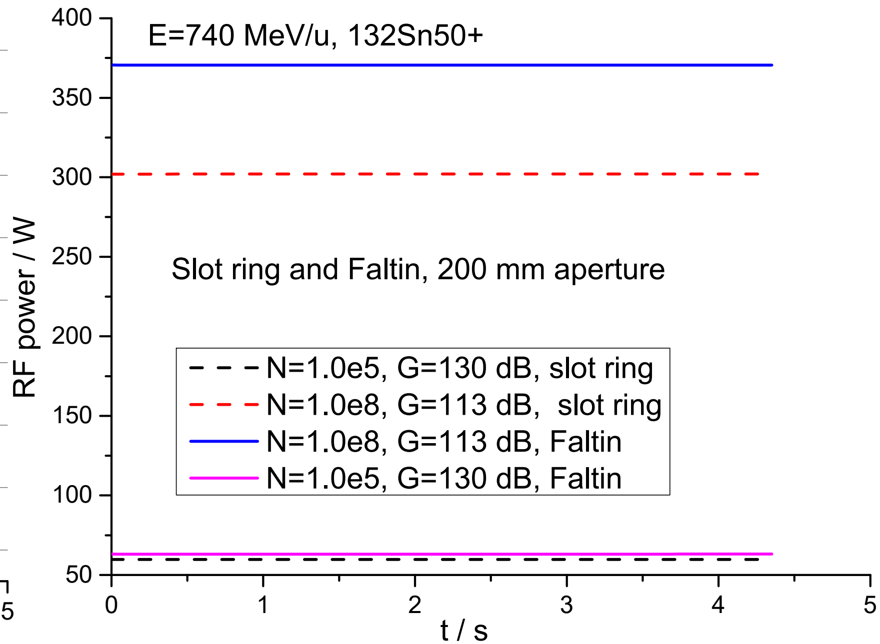
Faltin, rectangular shape,
dimension: 200 mm * 120 mm



SRing TOF cooling simulation

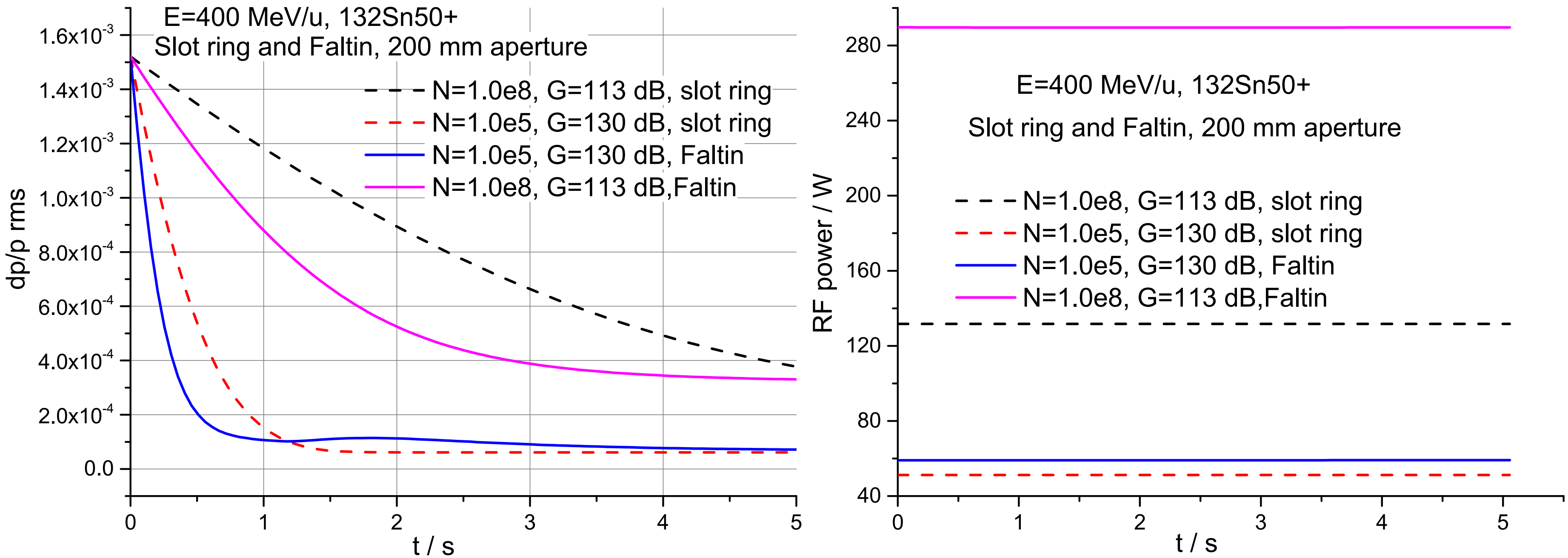
740 MeV/u, 132Sn50+ , 0.6-1.2 GHz





SRing TOF cooling simulation

400 MeV/u, 132Sn50+ , 0.6-1.2 GHz

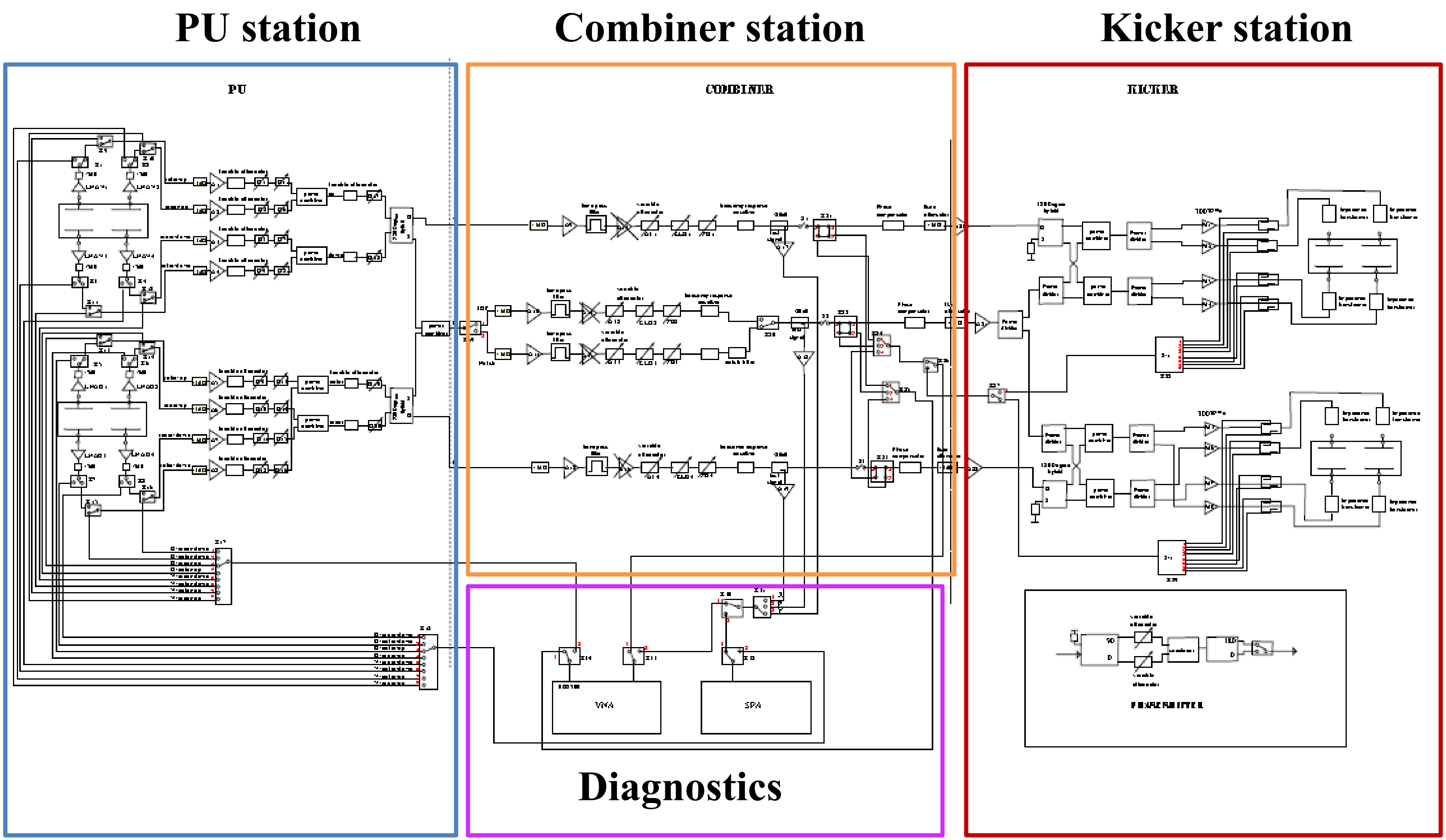


If the beam aperture is increased to 200 mm, Faltin structure is better than slot ring structure.

Summary of SRing longitudinal cooling

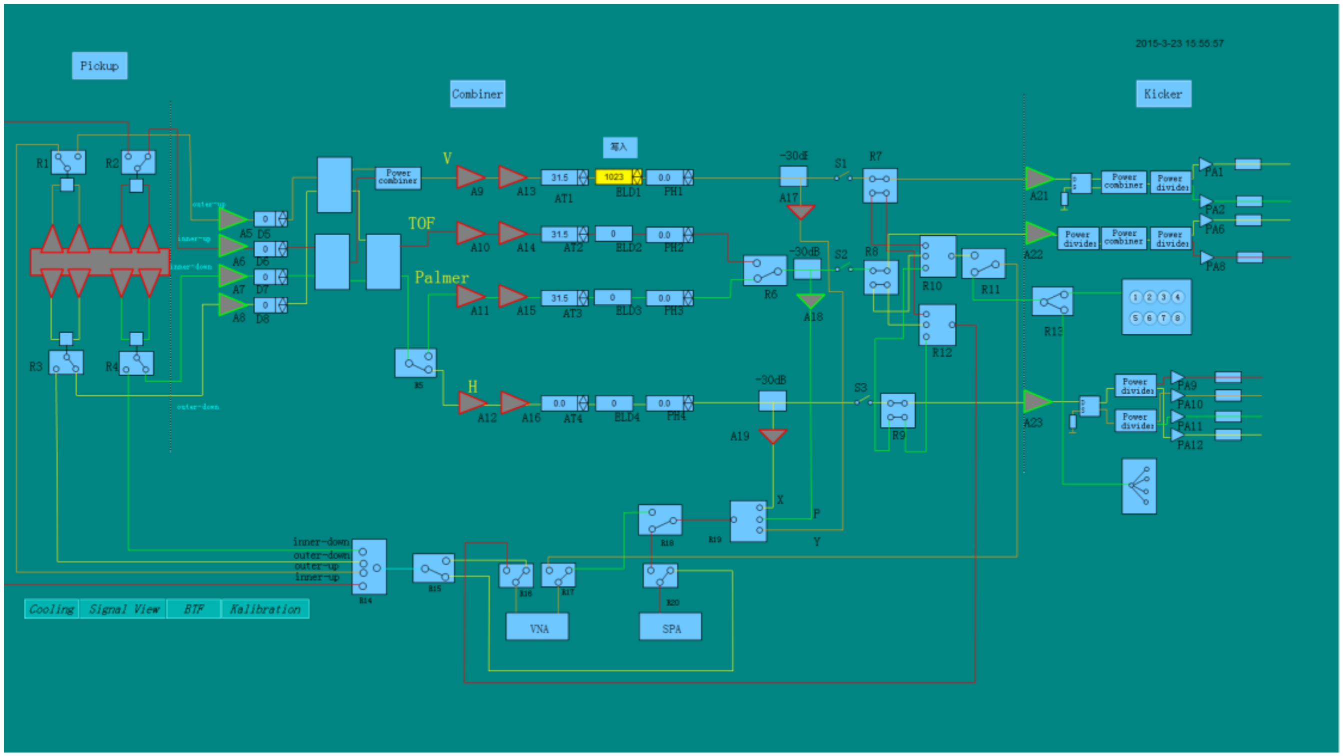
	Rare isotope 740 MeV/u, 1.0e5 ions	Rare isotope 740 MeV/u, 1.0e8 ions
Before cooling	$\Delta p/p$: $\pm$4.0e-3 εx/ εy: 40 π mm·mrad	$\Delta p/p$: $\pm$4.0e-3 εx/ εy: 40 π mm·mrad
After cooling	$\Delta p/p$: $\pm$2.5e-4 εx/ εy: 5 π mm·mrad	$\Delta p/p$: $\pm$3.0e-4
Cooing time	1.0 s	10 s

Signal transmission



Control - PLC

Interface



PLC

acknowledgements

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Fritz Nolden
Takeshi Katayama
Lars Thorndahl
Rolf Stassen
……

- ***Thank you for your attention!***

- ***Any comments welcomed!***