



An μ TCA.4 based BPM electronics system for the CSNS-II RCS

Chunjie Xie, Ruiyang Qiu, Zhihong Xu, Weiwen Chen, Wei Long, Yang Liu, Peng Zhu, Sinong Cheng,
Renjun Yang,
CSNS/IHEP, Dongguan, China

15/09/2026

Beijing, China

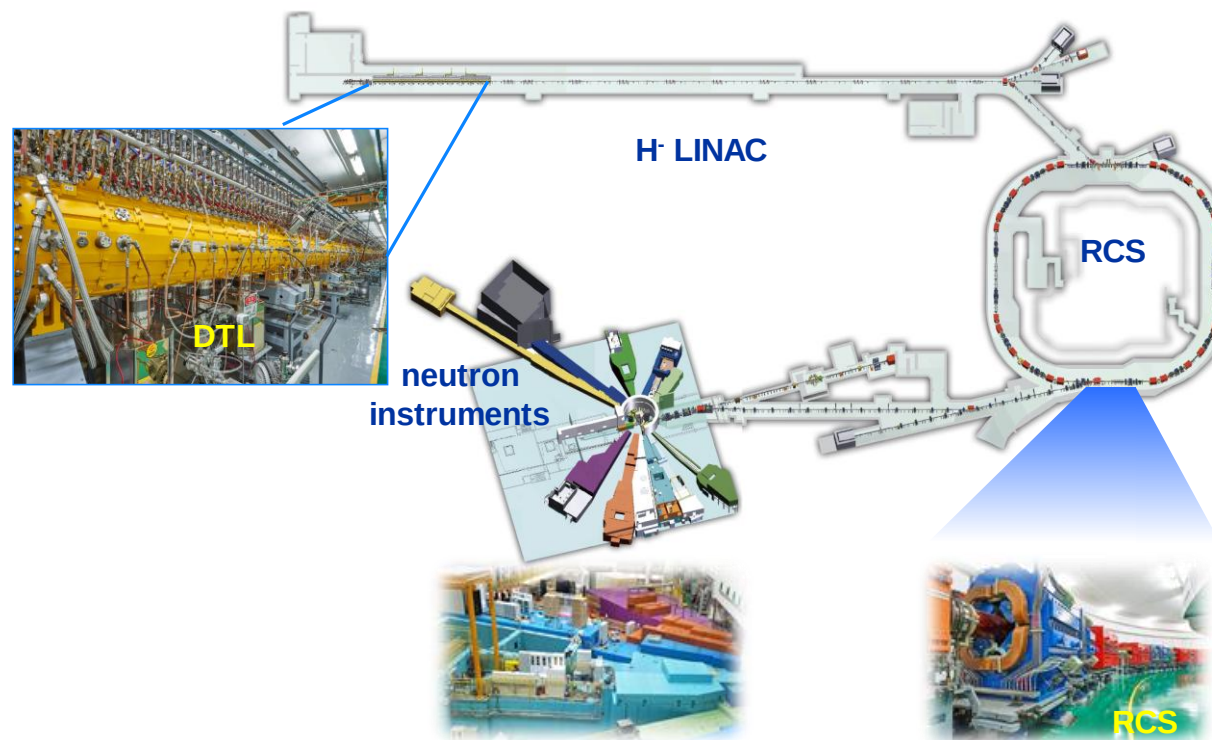
China spallation neutron source



- The 4th pulsed neutron source in the world; user program started since October 2018
- CSNS-II (2024-2030): beam power ramp up to 500 kW
- Beam parameters upgrade in Linac: 300MeV, 575us, 50mA

Major machine parameters

	CSNS	CSNS-II
Beam Power on target [kW]	185	500
Proton energy [GeV]	1.6	1.6
Average beam current [μ A]	62.5	312.5
Pulse repetition rate [Hz]	25	25
Linac energy [MeV]	80	300
Macropulse. ave current [mA]	15	50
Linac bunch frequency [MHz]	324	324



[1] H. Chen et al., NIMA 2025

Requirement of RCS bpm electronics system



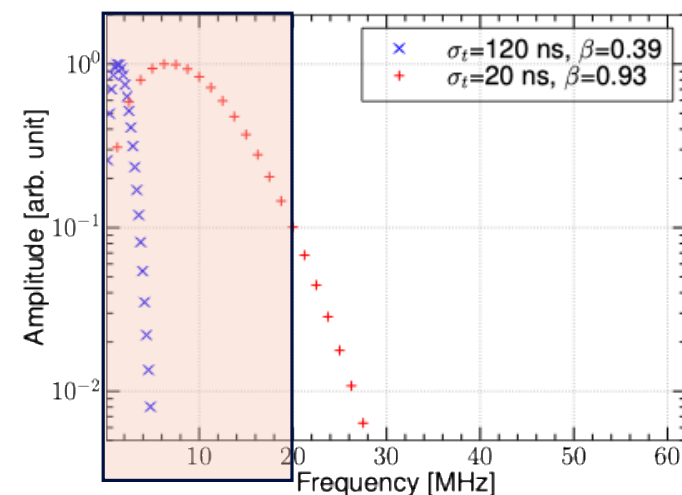
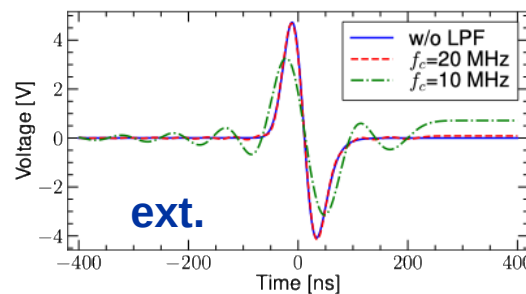
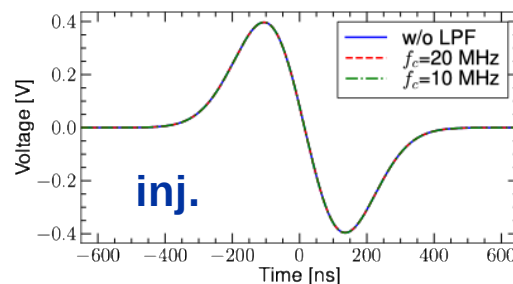
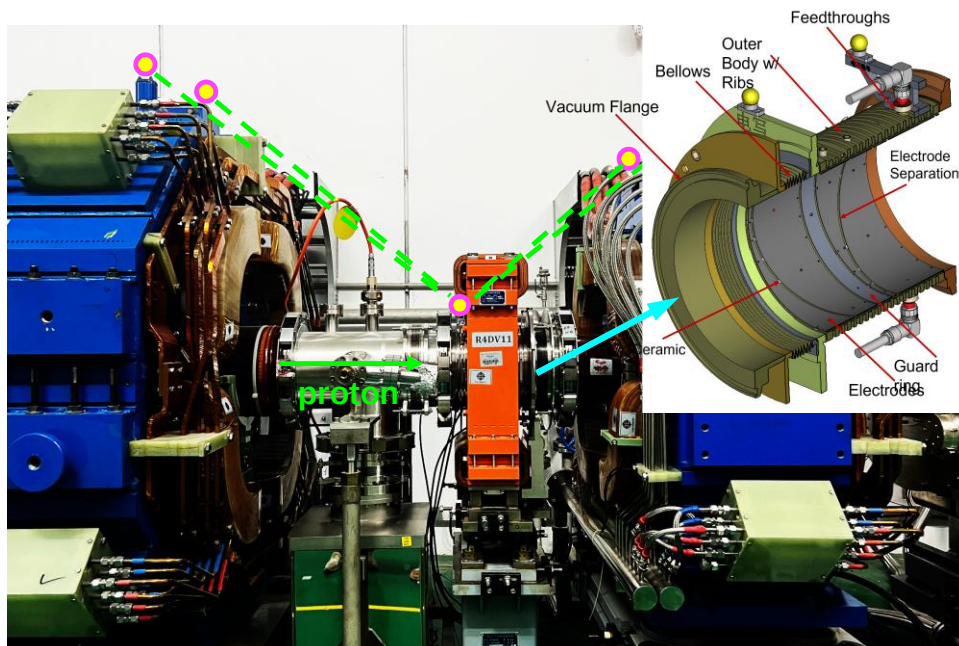
• Machine & beam

- ~40 diagonal-cut plane BPMs around the ring ($r = 110$ mm)
- Bunch length: 120 ns @ injection (80 MeV); 20 ns @ extraction (1.6 GeV)
=> signal amplitude: ~0.1 Vpp @ injection → ~100 Vpp @ extraction
- Revolution frequency: 0.51 – 1.22 MHz
- Acceleration time: ~20 ms, 2 bunches, 25 Hz



• Electronics requirements

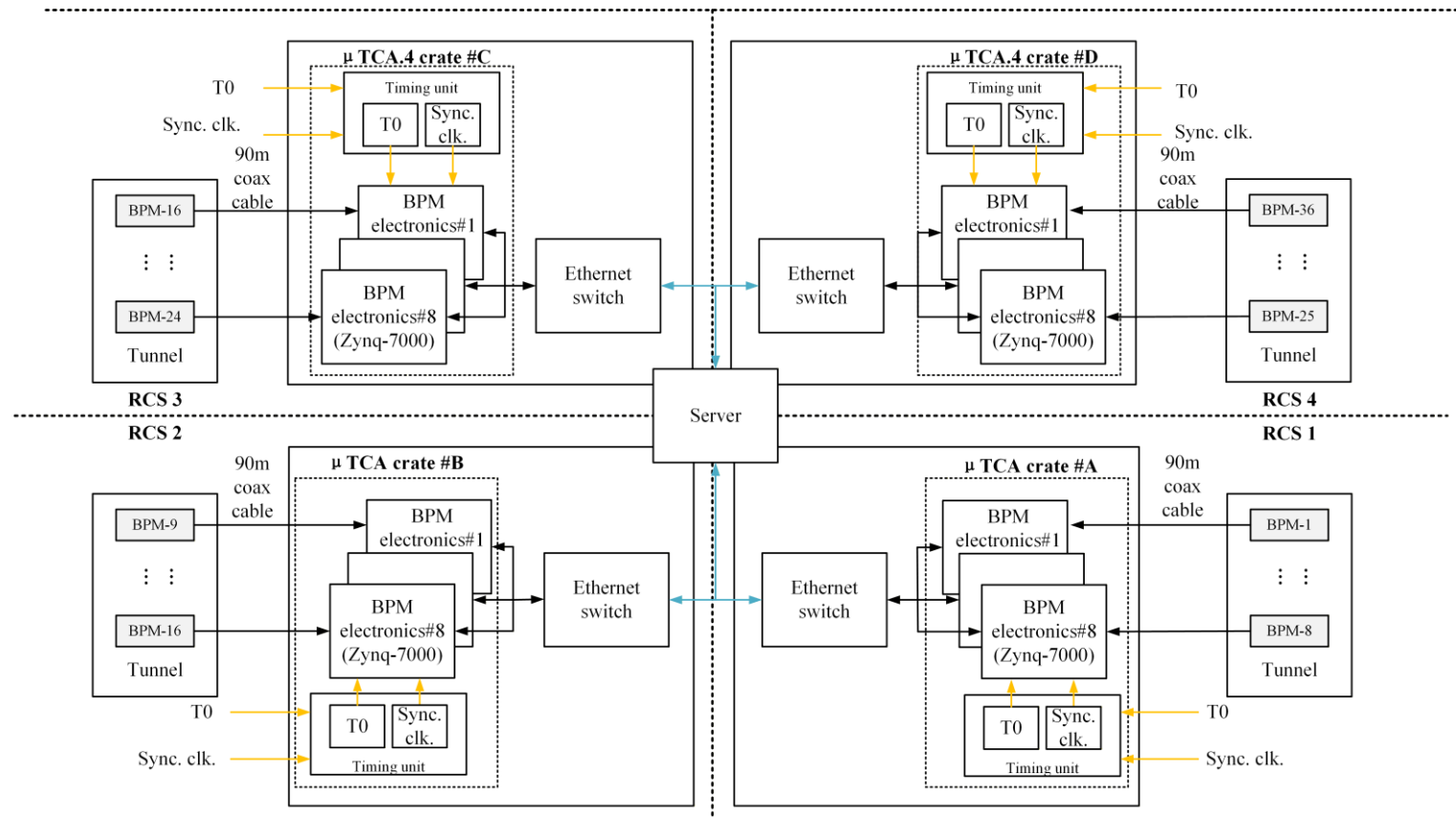
- Dynamic range: > 60 dB (0.1 – 100 Vpp)
- Peak power tolerance: 100 Vpp into 50 Ω
- Bandwidth: 0.1 – 20 MHz
- BxB resolution: < 0.5 mm
- COD resolution: < 0.2 mm
- Position accuracy: R*1%



BPM electronics distribution at CSNS RCS



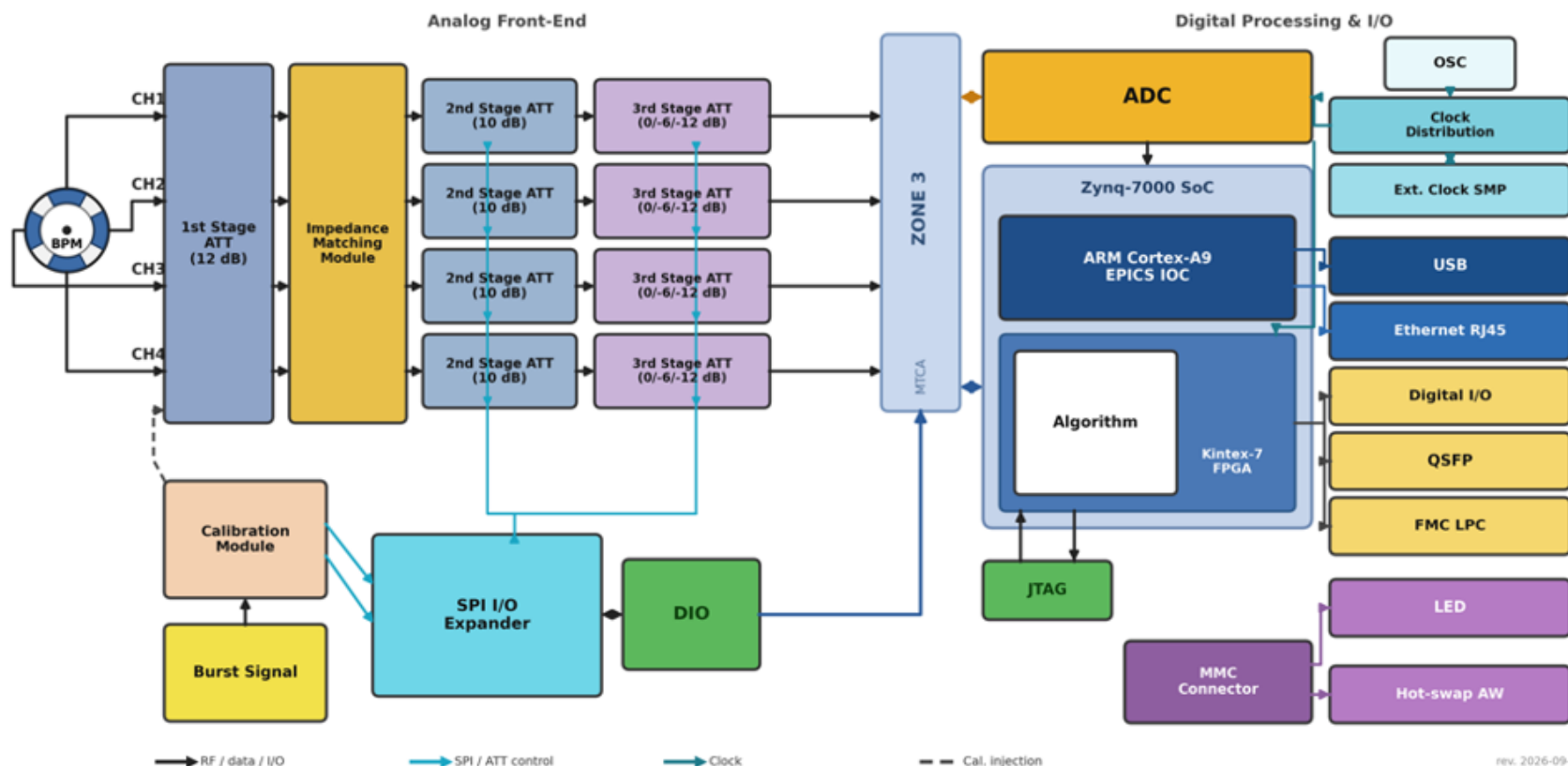
- Four electronics huts around the RCS, 8 BPMs per sector(μ TCA.4 crate: 8 BPM board sets + 1 timing unit)
- BPM electronics process position data $\rightarrow$ control system via network (Ethernet)
- Timing unit: receives T0 trigger + synchronous clock (sync. clk.) $\rightarrow$ all 32 BPMs synchronized to the same machine cycle



μ TCA.4 framework scheme



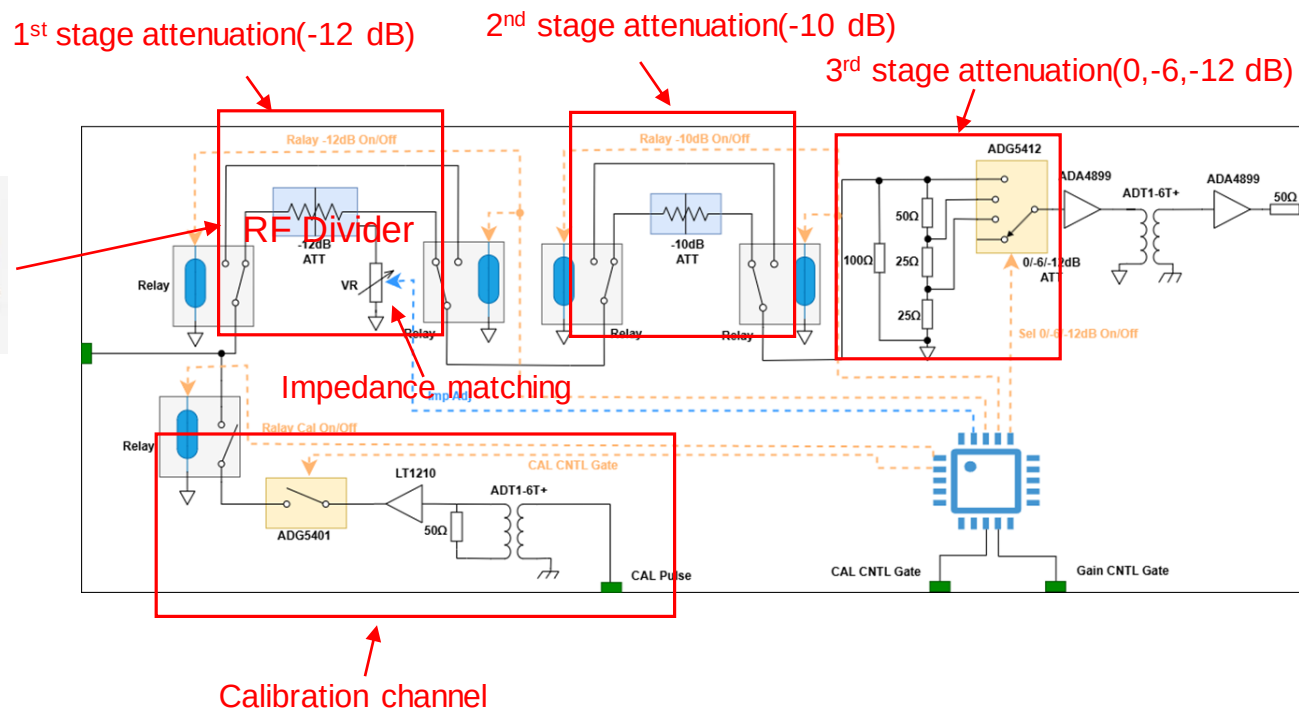
- RTM + DPS-AMC + Timing board
 - RTM (analog front end) 3-stage attenuation, gear switching in μ s; impedance matching $\rightarrow$ 0.3 mm error (ref. J-PARC MR)
 - AMC (digital core) Zynq-7000 SoC; digitization + real-time position calc. (STD algorithm); Data modes: TBT / BXB / RAW



Analog signal processing design



- For all possible beam powers (double-bunch), and the respective signal amplitude ranges from 0.1 V to 50 V for the accelerating beams while the ADC linear range is ± 1 V
 - Tantalum Nitride (TaN) thin-film RF divider (-12 dB atten. + impedance matching, BW=0.03-30 MHz)
 - Three-stage attenuation modules (-12 dB, -10 dB, 0/-6/-12 dB)



Design value of RTM	
Parameter	Design Specification
Attenuation	-12 dB ~ -34 dB (with impedance matching)
Impedance Matching Range	49 ~ 51 Ω (0.1 Ω accuracy)
Input Signal	>50 V (MAX) @ 500 kW
Zero-Input Noise	20 nV / $\sqrt{\text{Hz}}$
Rated input power	>2 W
Bandwidth	30 kHz ~ 25 MHz
Isolation	>50 dB
Nonlinearity	<2%
Channel-to-Channel Consistency	<2%
Switching Time	Slow switching <1 ms; fast switching <1 μs
Signal Output	2 Vpp

RF divider: attenuation & impedance matching

- Hirak RF-20033** — metal-film component developed for the J-PARC MR BPM electronics (high-power handling + impedance matching)
 - Rated input power: 10 W (max)
 - Max. input voltage: ± 100 V
 - Frequency range: DC – 50 MHz
 - Attenuation: 12 dB
 - Impedance: 50 Ω
 - Operating temperature: -55°C to $+150^{\circ}\text{C}$

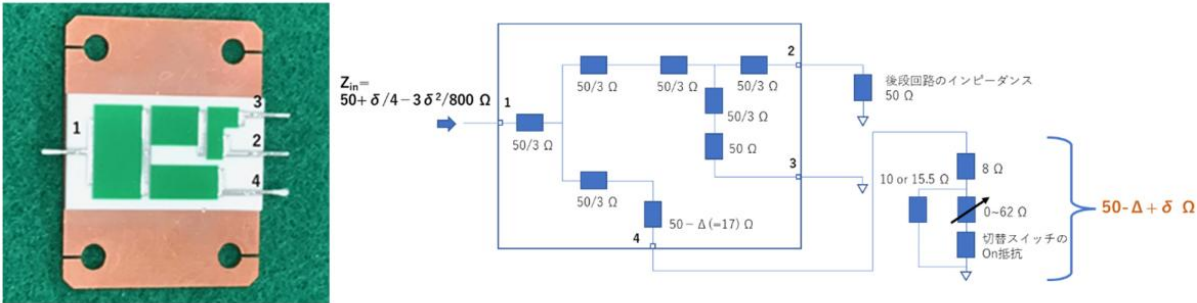


Figure 3: 12 dB 50 Ω power divider RF2033 from HIRAKU Ltd, which has impedance tuning pad labeled as 4 in the figure, here the Δ is 17.

price: 2.5k RMB/pcs

主な仕様	
入力インピーダンス	50 Ω $\pm 0.1\%$ (所定個回路構成で測定)
信号減衰量	12.0dB (Typ.)
最大入力電圧	± 100 V
信号帯域幅	DC～50 MHz
最大電力	10W(MAX)
VSWR	1.001 以下 (5MHZ) (所定個回路構成で測定)
外形寸法	25 mm(W) x 26 mm(L) x 1.9 mm(H)
アクセサリ	
ネットワーク抵抗器ホルダ	



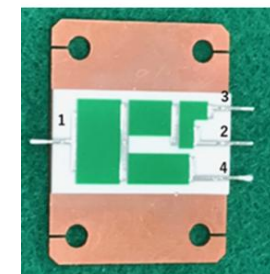
KEK/J-PARC K. Satou private communication/collaboration

RF divider: localization

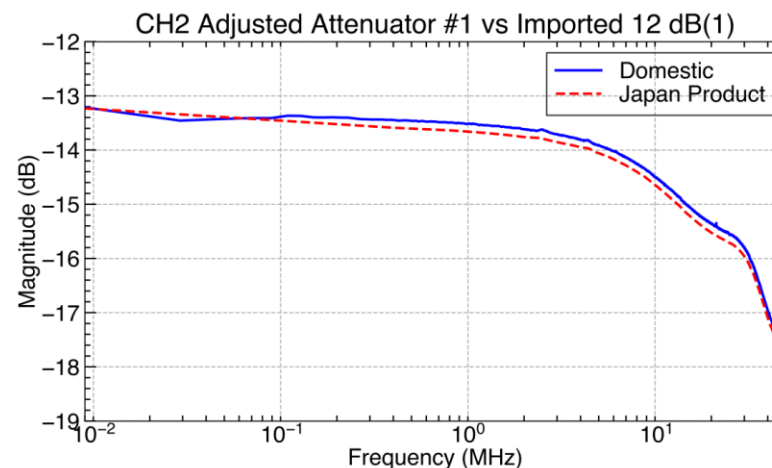
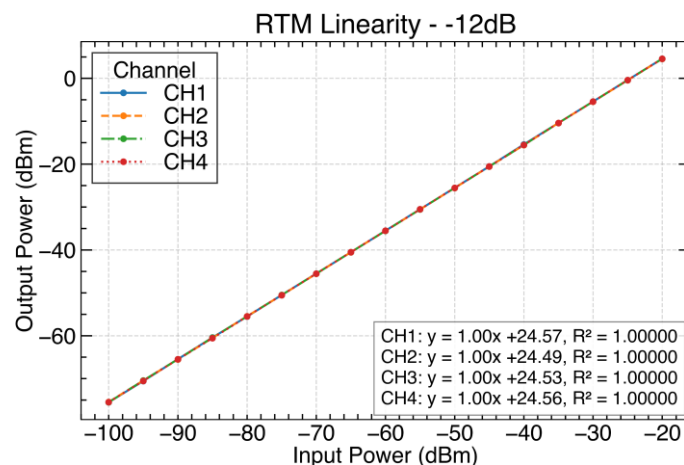
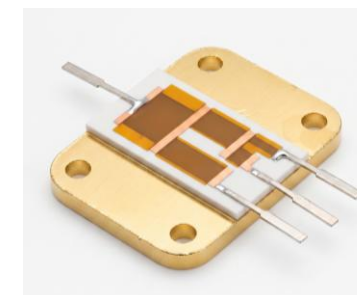


- **Domestic substitution**—Tantalum Nitride (TaN) thin-film resistor technology
 - Rated input power: 10 W
 - Frequency range: DC – 50 MHz
 - Attenuation: 12 dB
 - Impedance: 50 Ω
 - Operating temperature: -55°C to $+150^{\circ}\text{C}$
 - **Same 12 dB / 10 W / 50 Ω rating as the Hirak RF-20033**
-> with better temperature stability

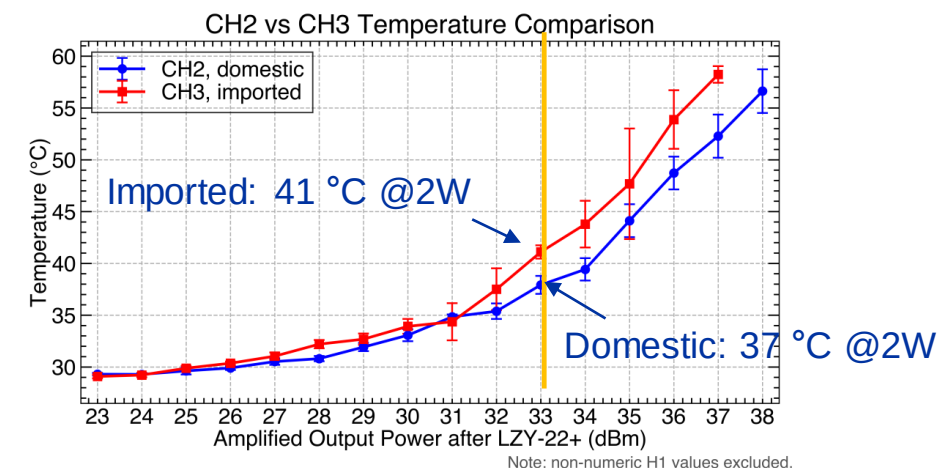
Hirak&J-PARC



IHEP



Consistent amplitude–frequency response



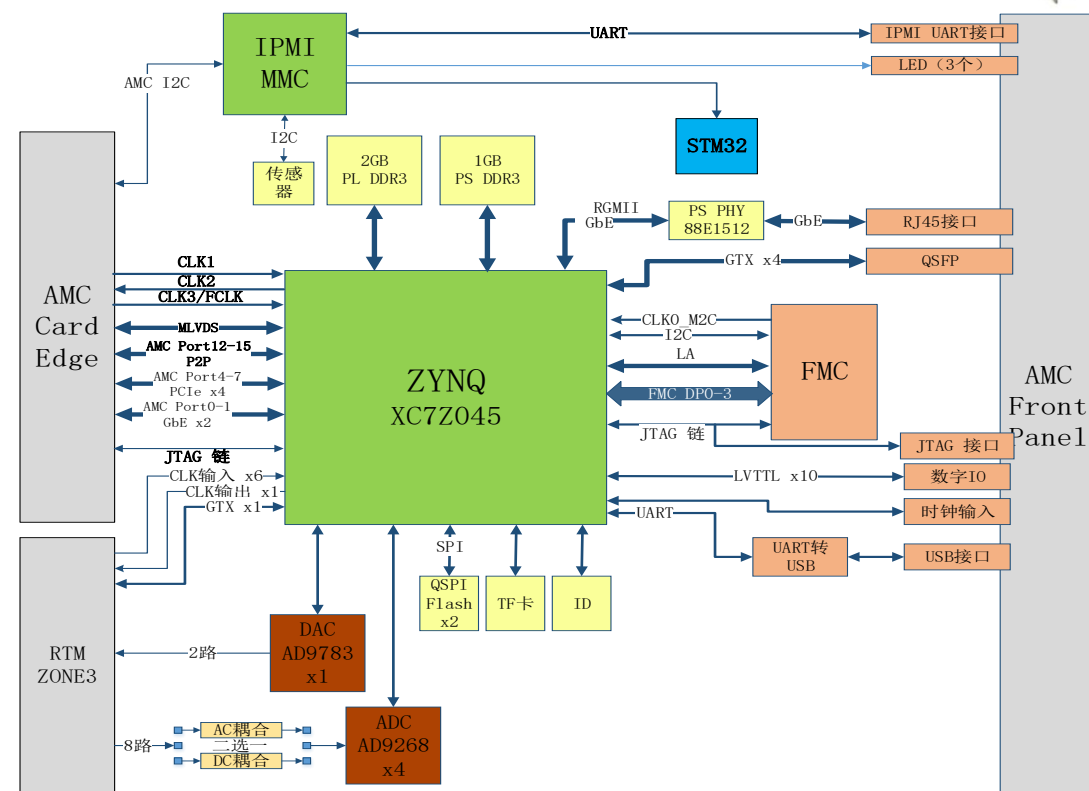
AMC: from LLRF to BPM at CSNS

- Beam position processing + timing trigger/clock receive; same board already employed by the CSNS-II RCS LLRF system
- Zynq-7000 based signal processing
- 8 MLVDS ports for trigger receive, FMC site for sync. clk. receive
- RJ-45 1GbE; 40G QSFP; 10 GPIO



Specifications of AMC

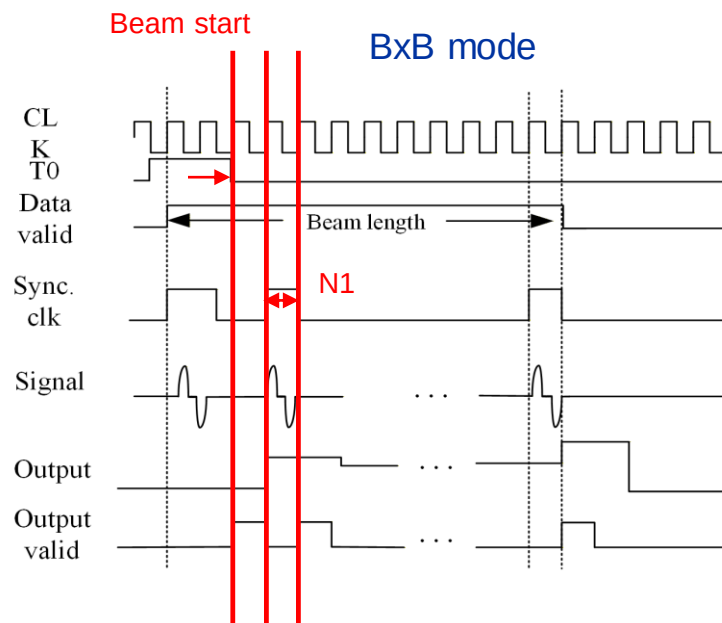
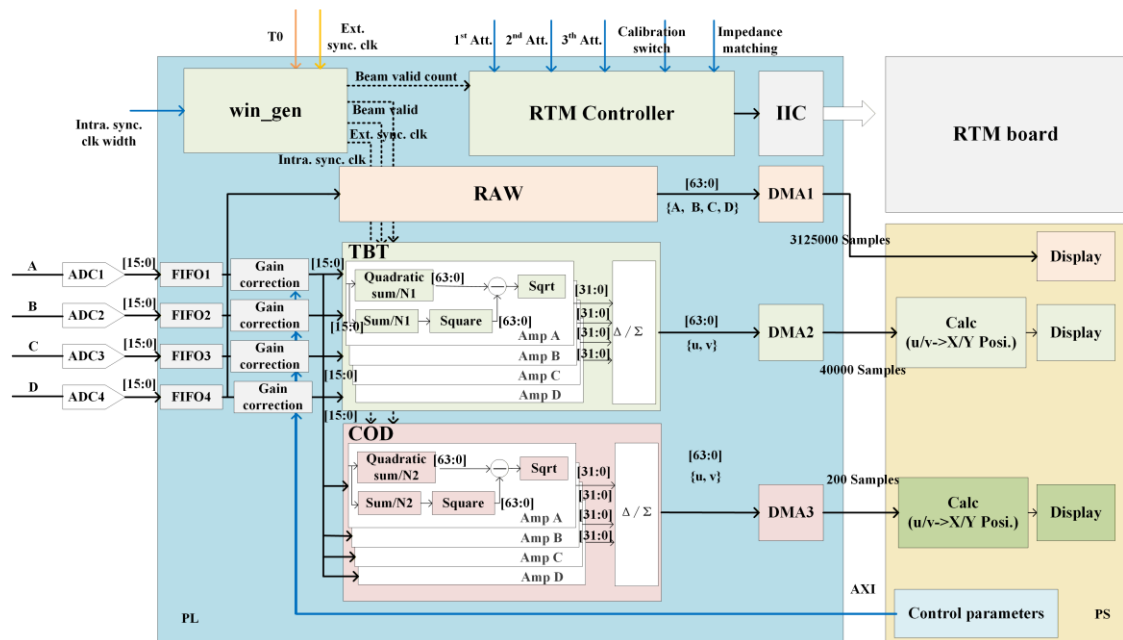
Parameters	New electronics
ADC sampling rate	125 MHz
ADC resolution	16 bit
Zero-input noise	0.01%
SNR	> 70 dB
Isolation	> 75 dB
Signal range	-1 ~1 V
FPGA platform	ZYNQ7000



Digital signal processing



- Three data modes: COD: closed-orbit position (0.1 ms / 20 ms); TBT: turn-by-turn, triggered by the sync. clock in step with the beam; RAW: raw waveforms of the 4 channels
- Position calculation: standard deviation(STD) algorithm(chosen for its superior DC-offset rejection)
- Front-end control: attenuation switching, gain-correction coefficients, impedance-matching control
- EPICS IOC on the ARM core of the Zynq: PV serving, configuration & status monitoring
- DMA engines stream acquired data from the FPGA logic to DDR memory



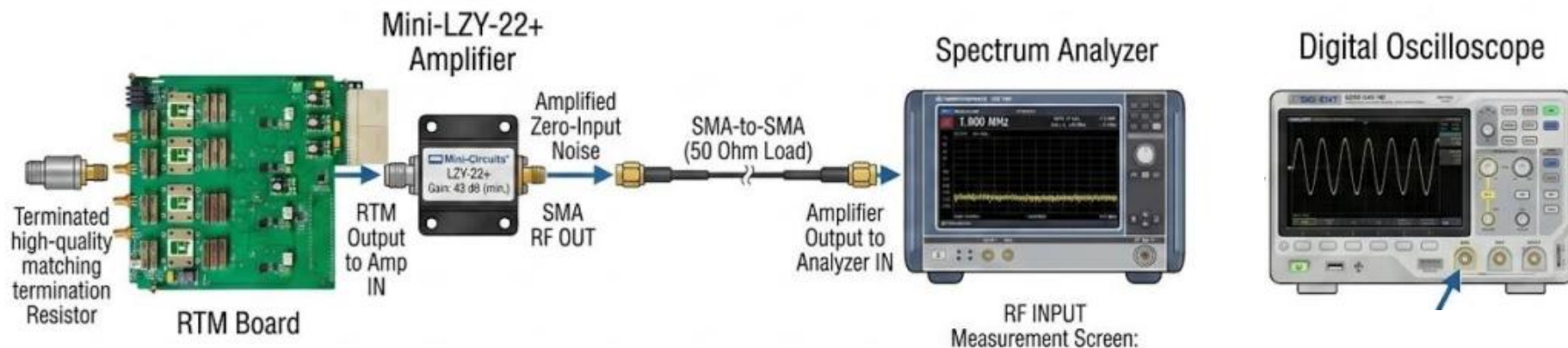
STD algorithm

$$amp = \frac{\sum_{i=1}^{N1} x_i^2}{N1} - (E(x_i))^2$$

- * N1 dependence on the width of sync. clk.,
- * N2 = 12500 samples(0.1 ms)

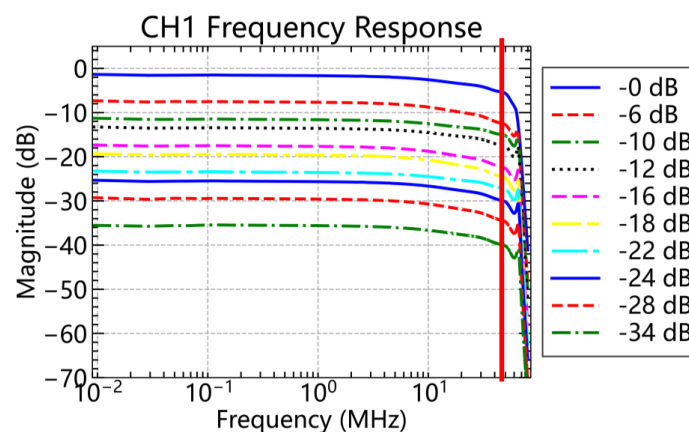
Laboratory test of RTM

- A high-power test bench was built (for the attenuator evaluation)

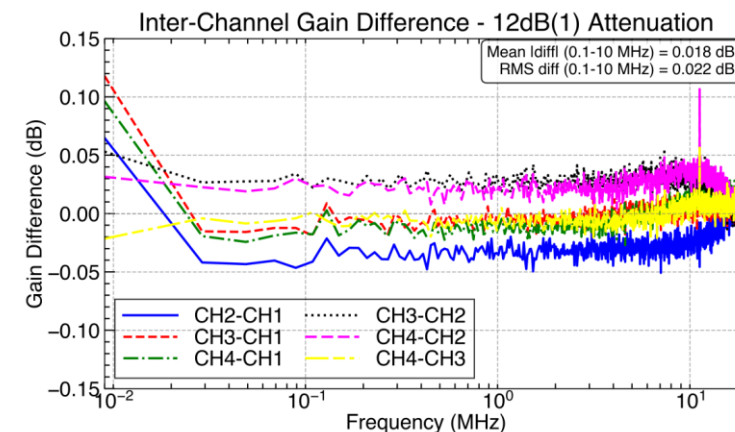


- **Test instruments and equipment**

- Signal source: R&S SMA100B
- Amplifier: mini-LZY-22+
- Oscilloscope: Tektronix TDS3054B
- Spectrum analyzer: R&S N9020A



-3 dB bandwidth = 34.2 MHz



Inter-channel difference
<50 dBm @20 kHz- 20MHz

Laboratory test results: RTM



Performance of the RTM (v1)

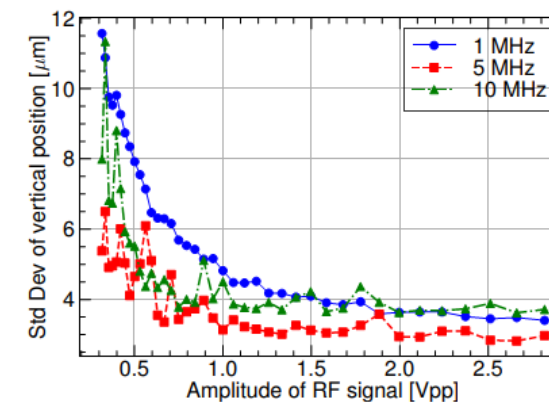
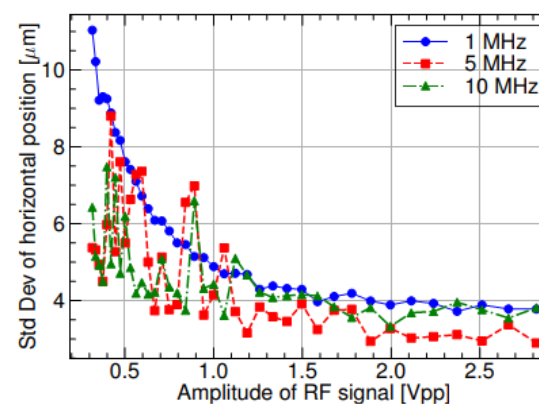
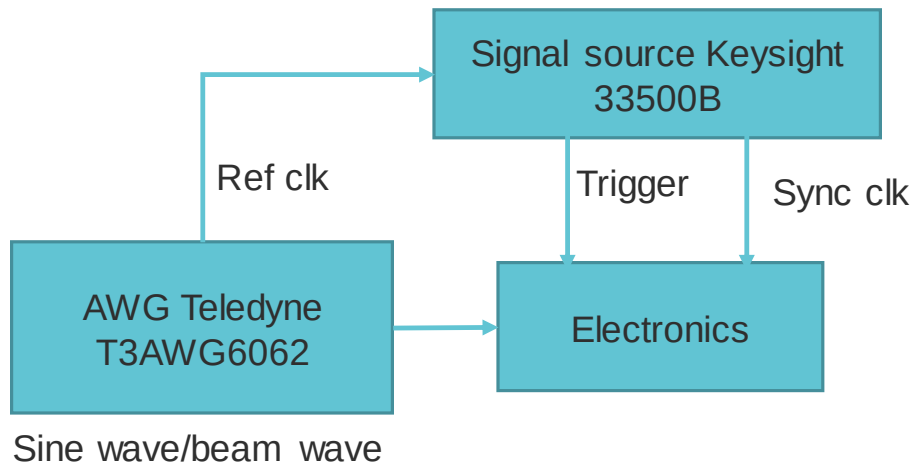
Parameter	Design Specification	Measured Performance
Attenuation	-12 dB ~ -34 dB (with impedance matching)	Compliant
Impedance Matching Range	49 ~ 51 Ω (0.1 Ω accuracy)	Not yet tested
Input Signal	>50 V (MAX) @ 500 kW	Compliant
Zero-Input Noise	20 nV / $\sqrt{\text{Hz}}$	4.14 nV / $\sqrt{\text{Hz}}$
Rated input power	>2 W	Compliant
Bandwidth	30 kHz ~ 25 MHz	30 kHz ~ 34 MHz (-3 dB)
Isolation	>50 dB	>50 dB @ 80 MHz
Nonlinearity	<2%	<1.85%
Channel-to-Channel Consistency	<2%	<0.6%
Switching Time	Slow switching <1 ms; fast switching <1 μs	Compliant
Number of Switching Cycles	10^7	/
Signal Output	2 Vpp	Compliant
Board Power Supply	+12 V (MTCA chassis)	Compliant

Laboratory test of RTM-AMC



Specifications of RTM-AMC

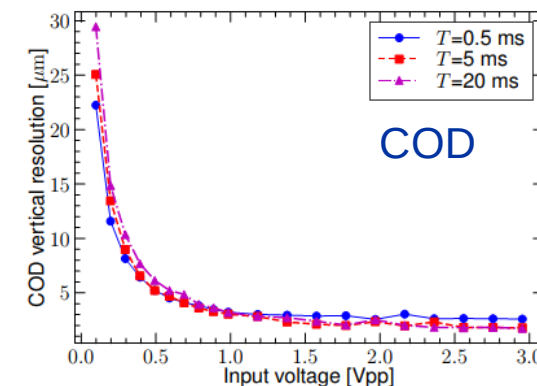
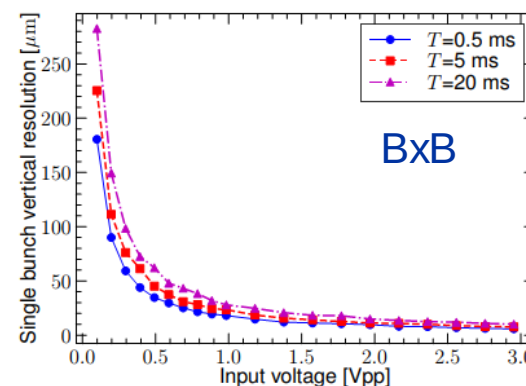
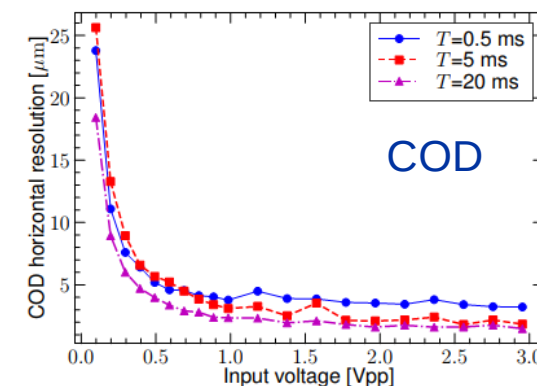
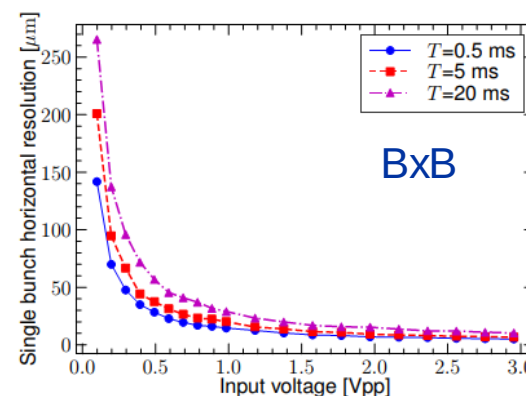
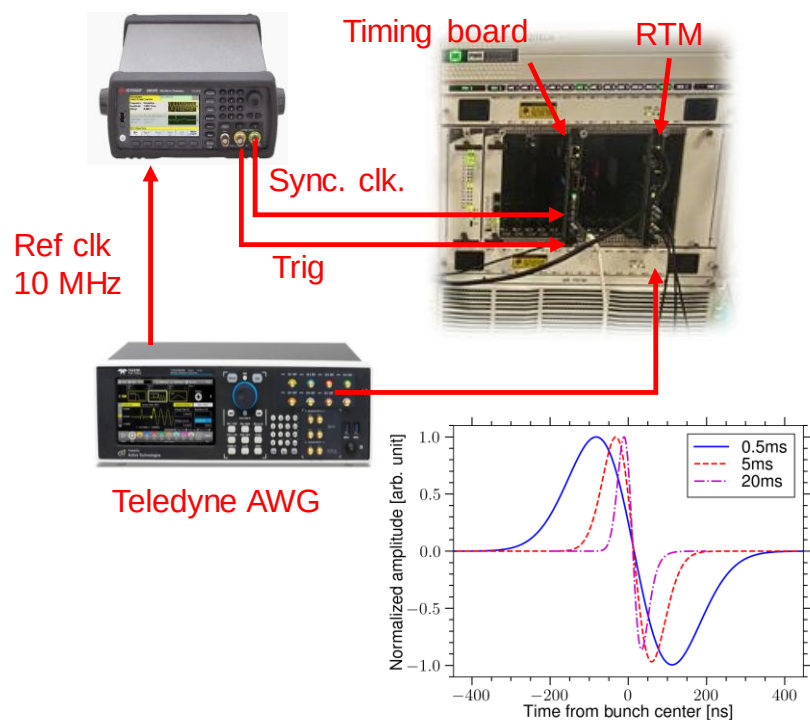
Parameters	Technical specifications
Sampling rate	125 MHz
Bandwidth	25 MHz
SNR	>70 dB
Isolation	>85 dB
Signal range	0.1~80 Vpp (60 dB)
Timing resolution	12.3 ns
Zero-input noise	0.01%
COD resolution(sine waveform)	15 μm @0.3 Vpp
COD resolution(beam waveform)	5 μm @0.6 Vpp
TBT resolution(beam waveform)	50 μm @0.6 Vpp



COD resolution(sine waveform)

Laboratory test of RTM-AMC (cont')

- An arb. waveform generator (16 bits, 12.32 GS/s, 5 Vpp) generates the expected PU output signal with varying amplitudes ((injection extraction, analytical assessment w/ known pickup parameters)
- COD and BxB positions calculated by STD algorithm (sync. window: 0.5-1 μs @BxB; 0.1 ms@COD)
- BxB position resolution: < 50 μm (x & y) @Vpp>0.6 V (0.05% R); COD resolution: <5 μm @Vpp>0.6 V



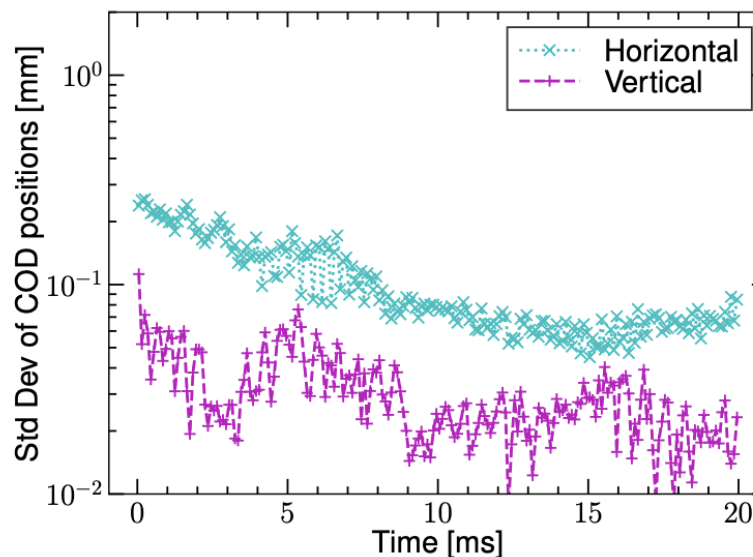
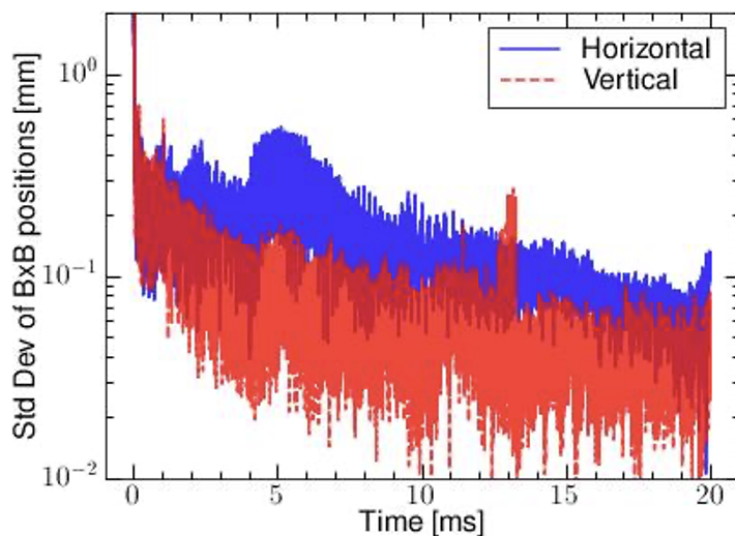
Beam test of electronics



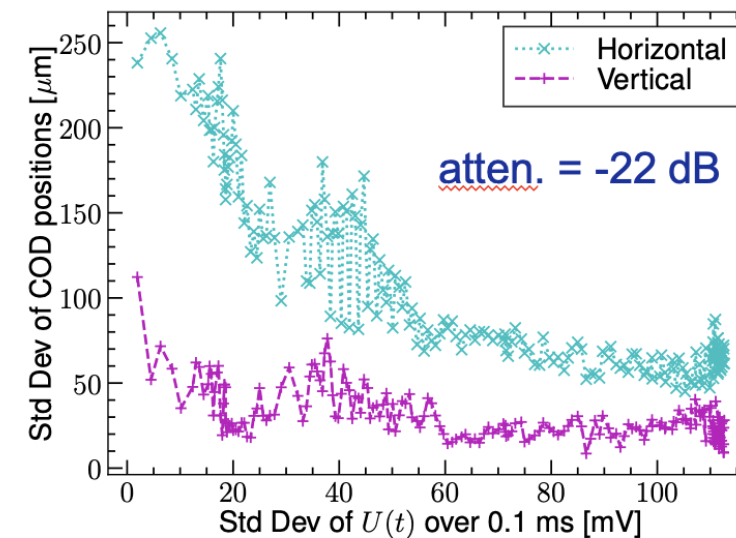
July, 2026

- BxB position resolution: <0.2 mm (x) and <0.1 mm (y) at high input signal amplitude (>2 V, 10-20 ms)
- COD position resolution: <0.1 mm (x) and <0.05 mm (y) at higher input signal amplitude (>2 V, 10-20 ms) assuming $f_b \sim 2$ MHz $\Rightarrow$ 200 beam passives/0.1 ms $\Rightarrow$ res. scales by $1/\sqrt{200} \sim 0.071$
 $\Rightarrow$ obtained COD position resolution is dominated by beam jitter? ($\sim 10\% \sigma_{x,y}$ for BxB, ~ 0.1 mm for COD w/ $N_{\text{aver}} \sim 200$)
- The std. of COD position indicated similar bottom limits

Resolution of the BxB and COD positions: beam, environment & electronics, algorithm, ..



Resolution of COD position vs. signal amplitude (*sampling pts varying)



Summary



- An μ TCA.4-based BPM electronics system for the CSNS-II RCS was developed
- RTM provides a wide dynamic range, fast attenuation switching, impedance matching, and a bandwidth over 25 MHz
- AMC performs real-time beam position processing and supports COD, TBT, and RAW data modes
- Both laboratory tests and beam tests have been carried out. And the measured results show that the system can meet the main requirements for the CSNS-II RCS BPM system
- Integration and commissioning of 8 BPM electronics in this fall.
- Massive production in 2027

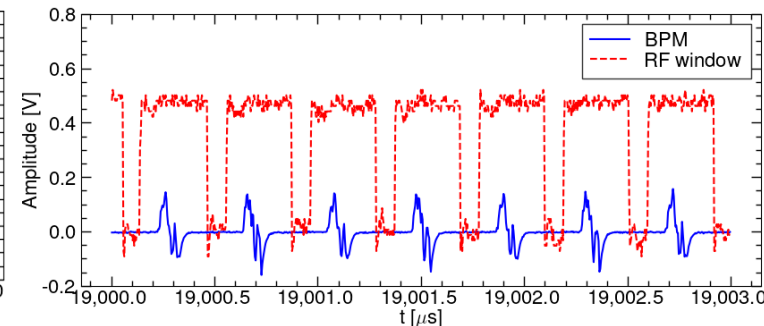
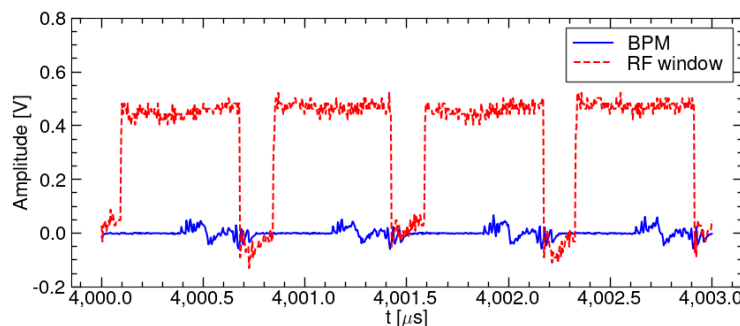
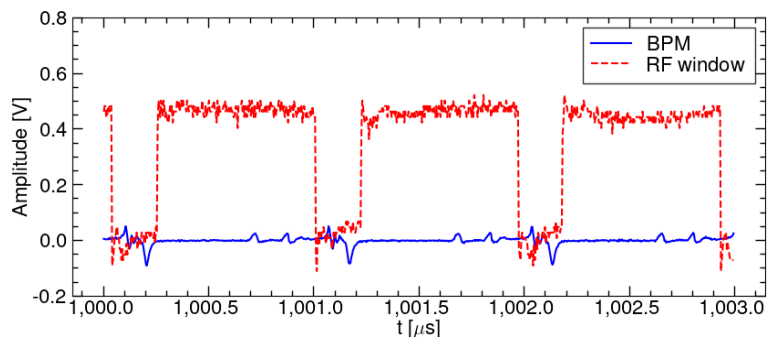
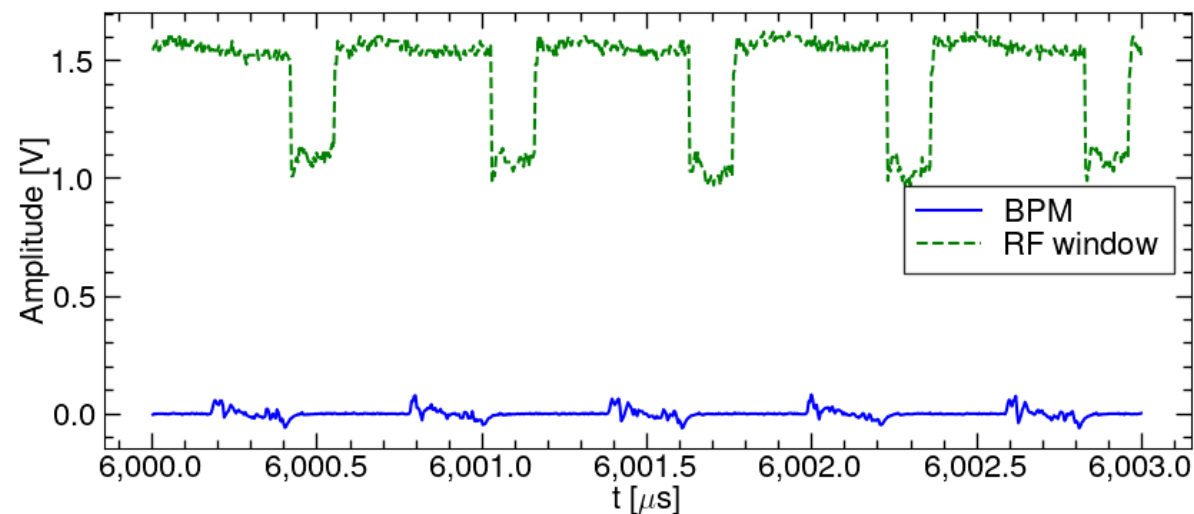
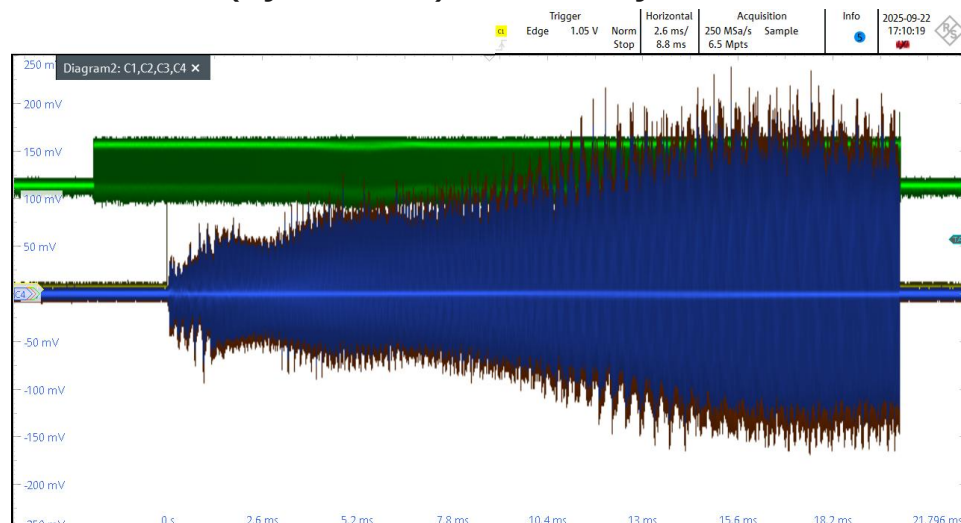


Thank you!
CSNS/IHEP, Dongguan, China

Back up



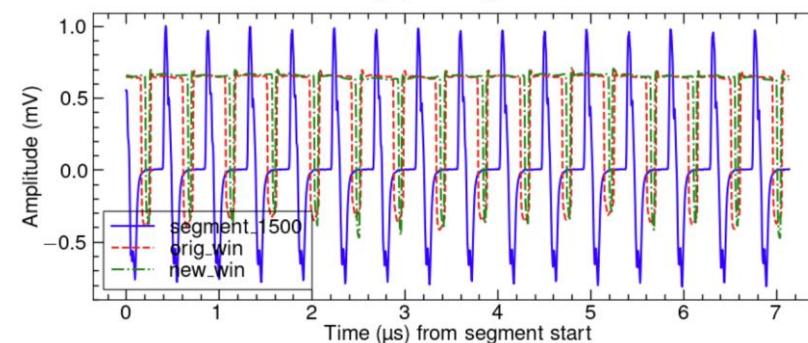
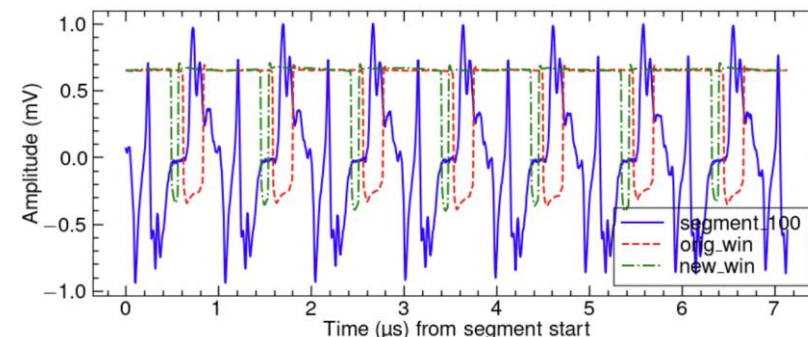
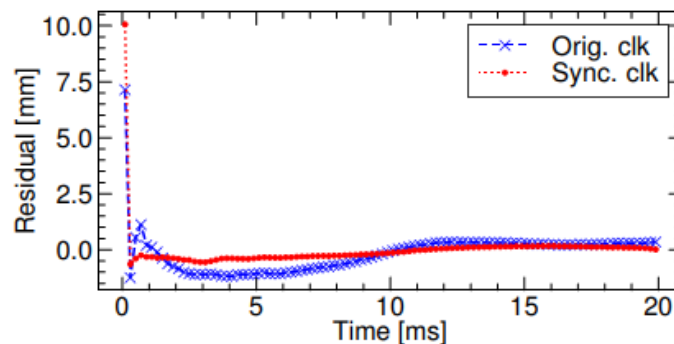
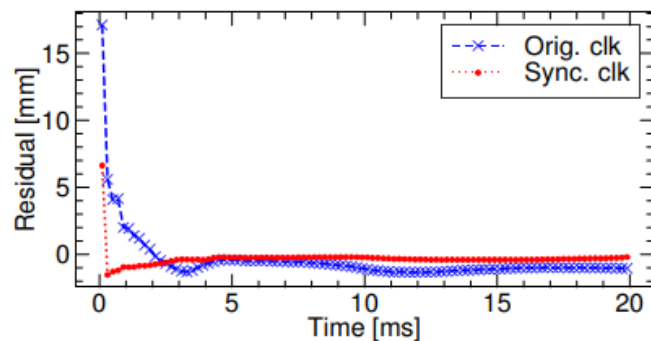
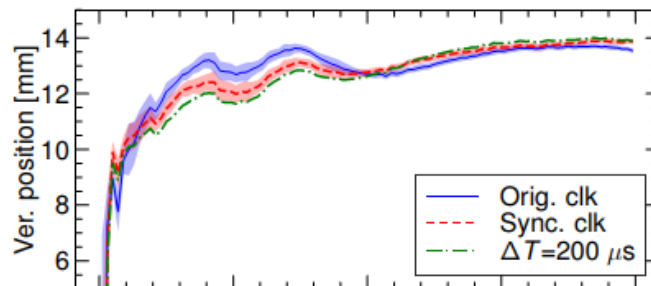
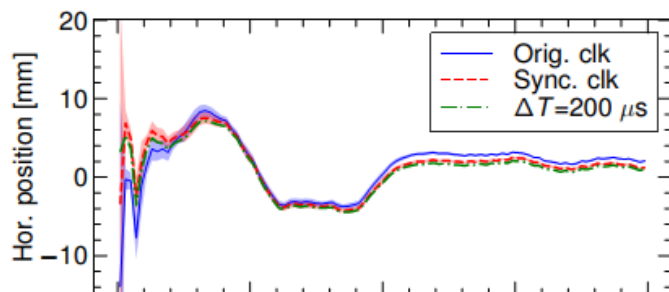
- TBT position calculation relies on the high-frequency window
- RF Window(sync. clk.)–beam synchronization is critical; otherwise information will lost



Sync. Clk in AC mode



- Well synced (Duty = 92%)
- Use orig(blue) & sync.(red) & fix(green, base line) clk to calc. TBT
- Exceeding 5 mm occurs within the first 1 ms(unsync status)



Thanks to CSNS high frequency group.