Timing and Low Level RF Control System of New Injector Linac for New-SUBARU

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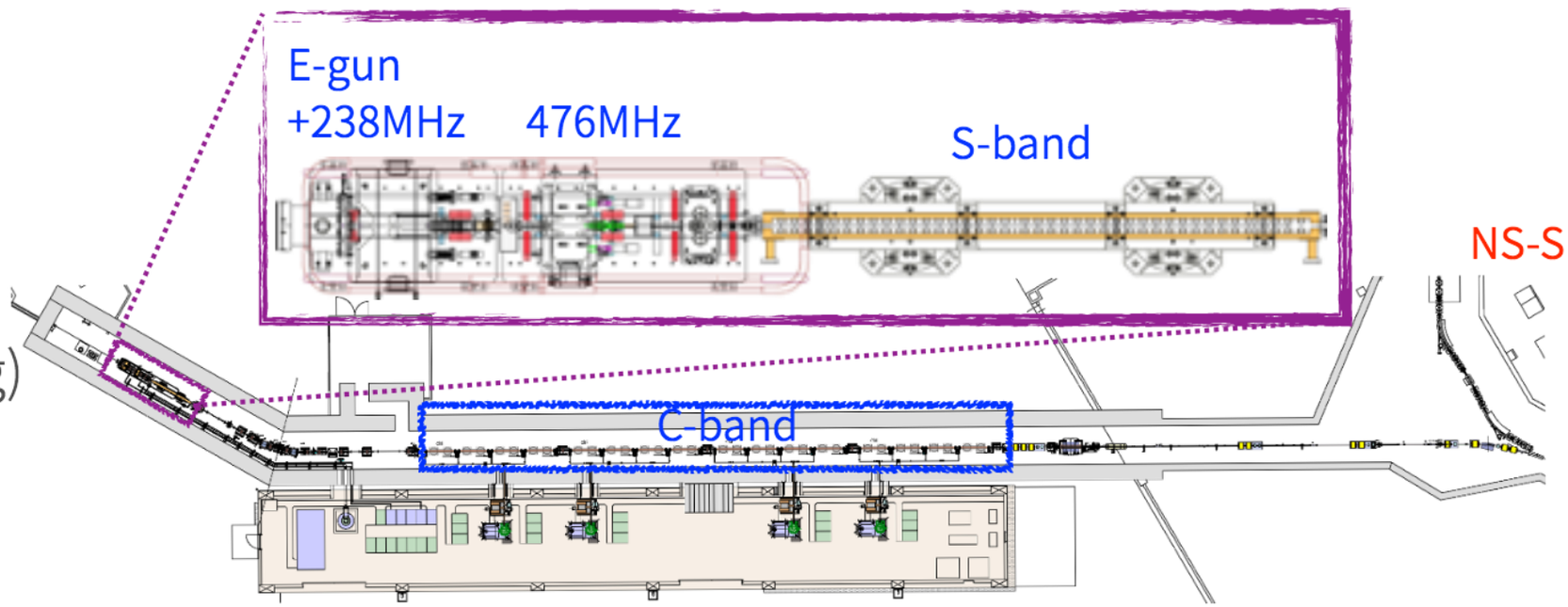
Introduction: NewSUBARU

- New SUBARU (NS)
  - Synchrotron radiation facility hosted by Laboratory of Advanced Science and Technology for industry (LASTI)
  - 118m dia. SR with 9 beamlines
  - 1 GeV, 350 mA Top-up operation
  - 1.5 GeV, 400 mA Decay operation

- Injector Linac
  - had shared 1 GeV Linac with SPring-8 SR
  - beam injection from SACLA to SPring-8 (2020/02~, for SP8-II upgrade)
    1GeV Linac and 8 GeV Sy were terminated

  ➡ A new dedicated injector linac for NS
  (prototype of a new linac for 3 GeV synchrotron radiation facility in Tohoku)

new NS Linac and LLRF/timing system



- NS new Linac
  - 1GeV, 0.3nC, 1pps (up to 60pps for conditioning)
  - RF: 238, 476, SB, CB x4

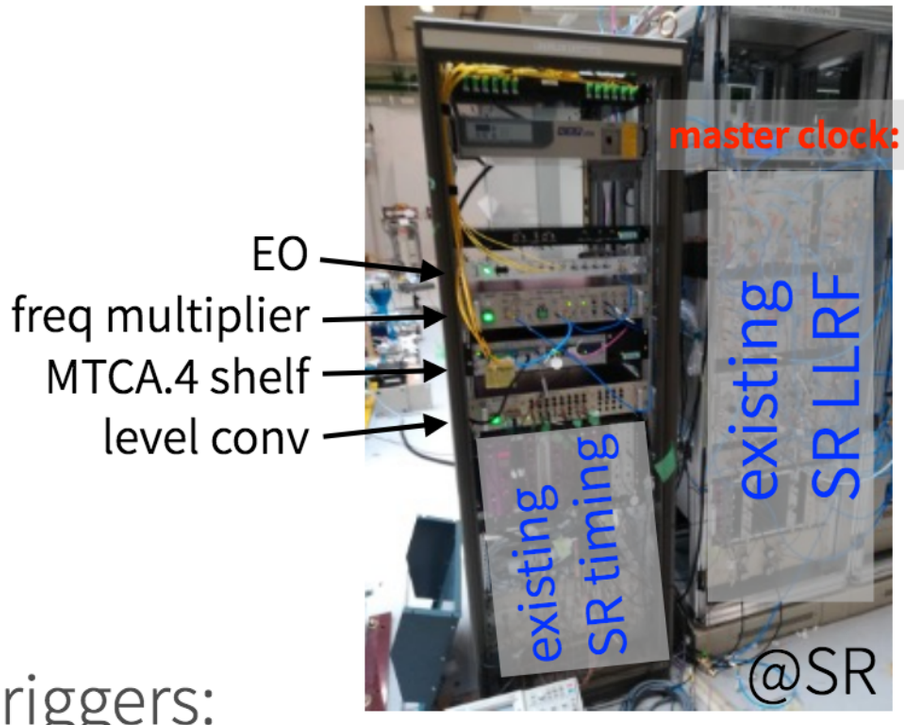
- Timing-sync with SR
  - base frequencies: rational number relationship

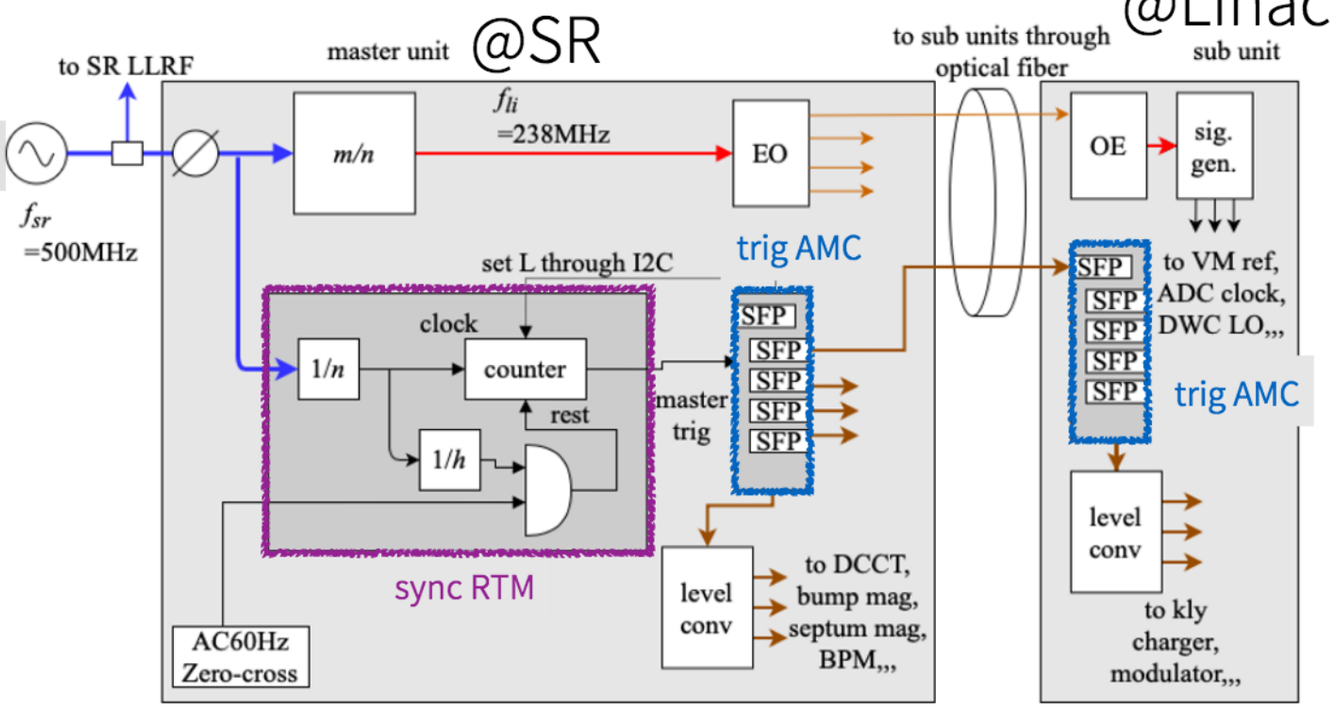
- Requirements
  - stable to keep >90% injection efficiency almost without daily machine-tunings
  - high reliability
  - low cost
- MTCA.4 based system
  - High-integration, High-throughput, Less-wiring, module-management
  - COTS: digitizer AMC, RF-frontend RTM, MCH, CPU, PS, shelf …
  - developing items: digitizer firmware, trigger AMC, timing-sync RTM …

timing sync with SR

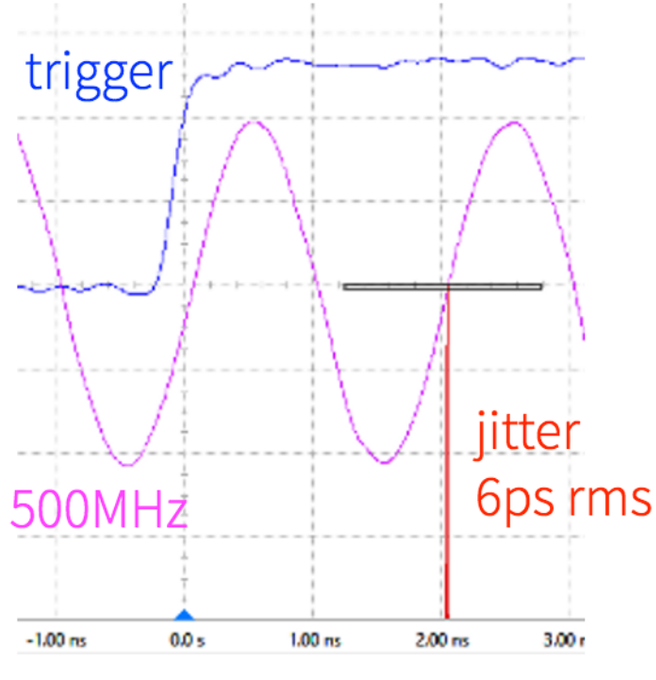
- base clock of Linac: 238MHz, generated from base clock of SR, 500MHz

$$f_{li} = \frac{m}{n} \times f_{sr} = \frac{308}{647} \times 499.9555\ \mathrm{MHz} \cong 238\ \mathrm{MHz} \times (1 + 1.2 \times 10^{-6})$$

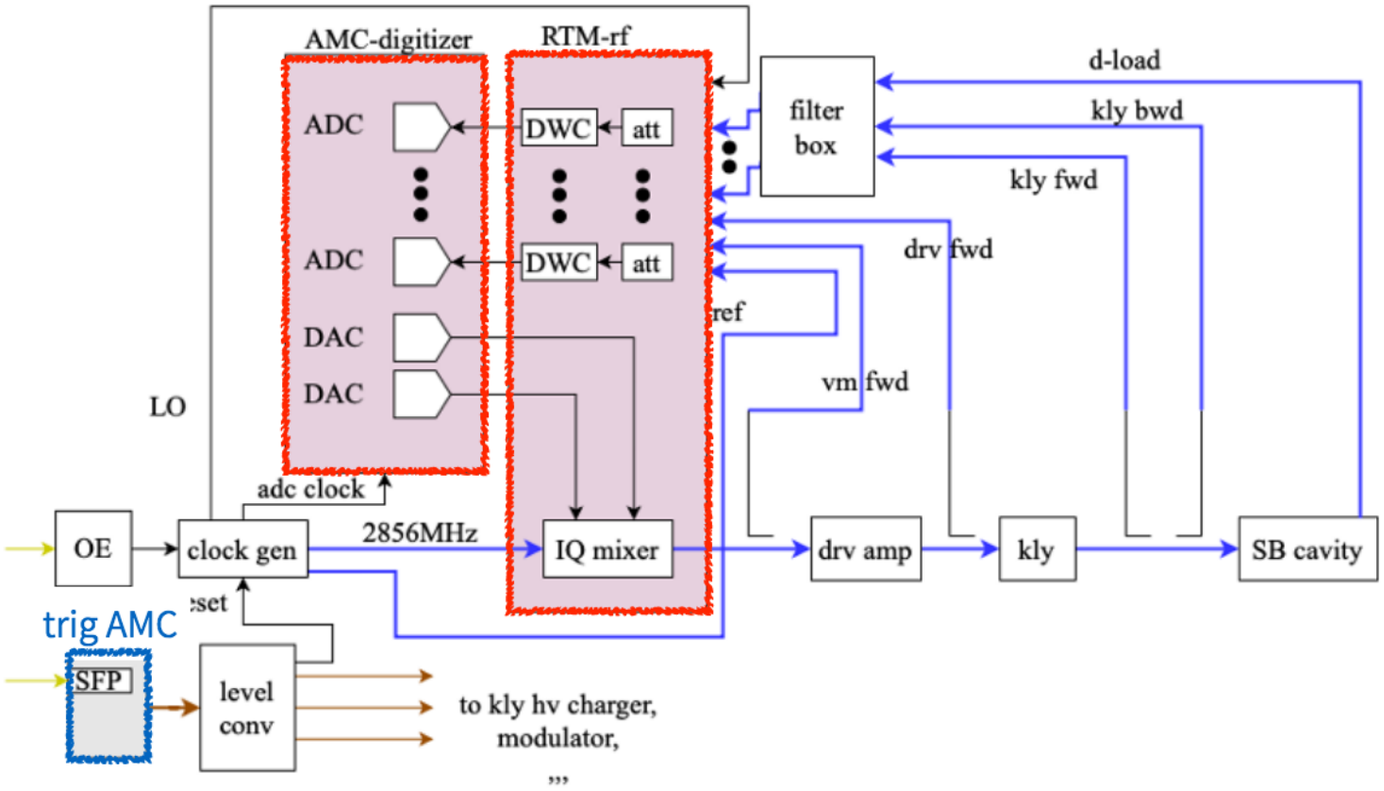




- triggers:
  - wait for followings to sync
    - AC 60Hz
    - target bucket in SR
    - 238MHz
  - coincidence between the two base-freqs: every ~1.3μs
    → wait certain times to the target bucket



LLRF for new NS Linac



@SB

(※ including non-LLRF stuff)

unit	type	ADC/DAC clock [MHz]	Pulse width [μs]	LO clock [MHz]	requirement	
					δA/A [%]	δφ [deg]
238	under sampling	238 x 4/5	100	—	0.08	0.5
476	down conversion	238	40	476 - 238/4	0.15	0.2
SB			1	2856 - 238/4	0.3	0.5
CB-N			3 (PSK)	5712 - 238/4	0.3	2.5

- AMC/RTM
  - 238MHz: MME-ADC01B (Mitsubishi Elec. Tokki System) + 72DSR238A (Candox Systems)
  - else: SIS8325 + DWC8VM1 (Struck innovative systeme) w/ custom firmware (Mitsui E&S Systems Research)

Check & Calibrations

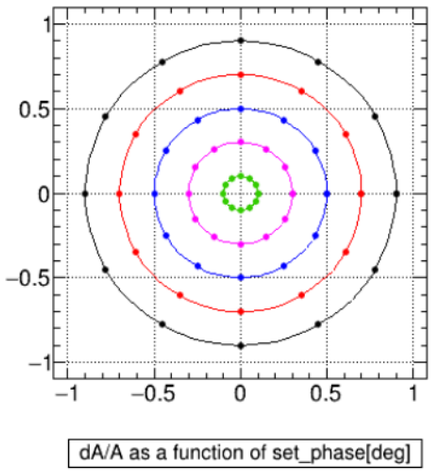
- Output characteristics of DAC/VM
  → use ADC for (self-)calibration
- Amplitude dependence (~linearity)
- Phase dependence (phase-slipping measurement)
  → To guarantee the VM calibration above
- Crosstalk
- Step attenuator
- llrf trigger timing

DAC/VM

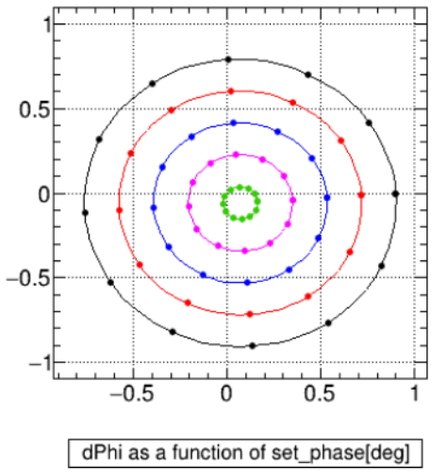
@CB

- using ADC for (self-)calibration for Struck modules
  - much better even without correction for 238MHz one

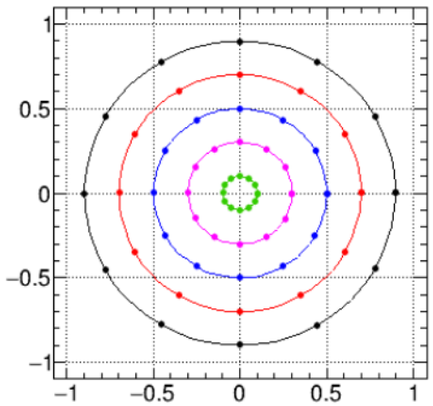
DAC input



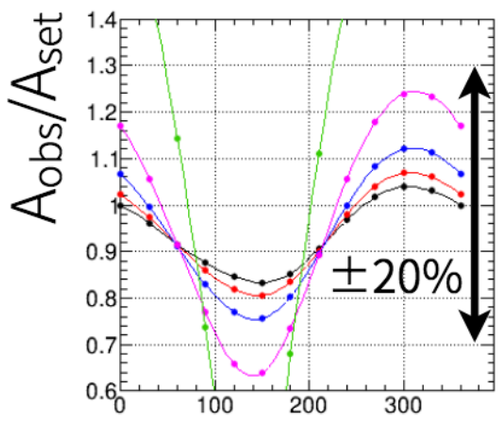
VM output

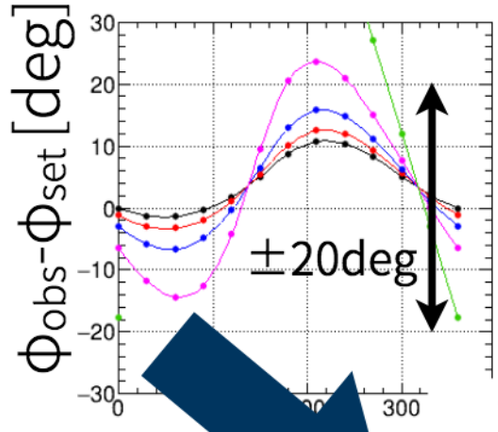


VM output w/ cor-matrix



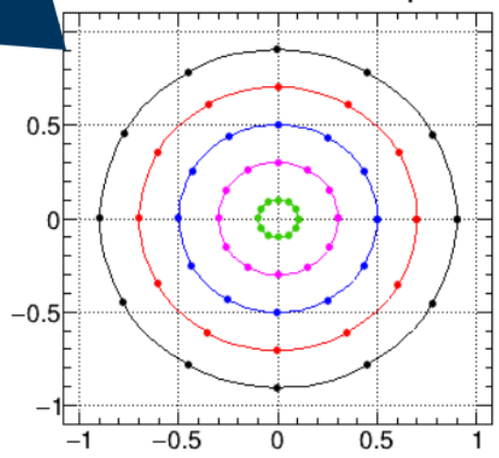
← Parameterize correction matrix
- DAC offset
- distortion (I/Q scale, angle)
- rotation

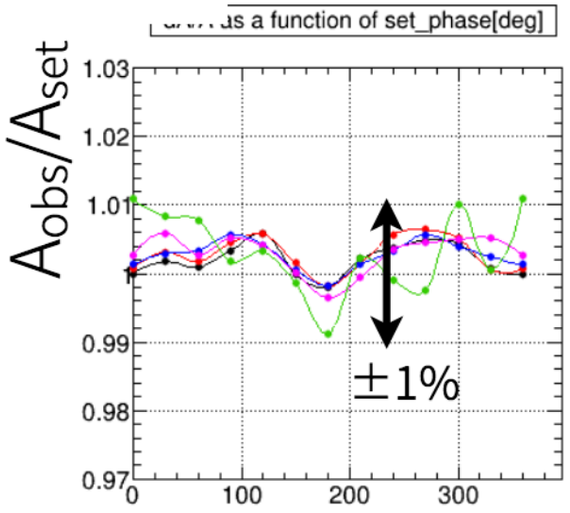


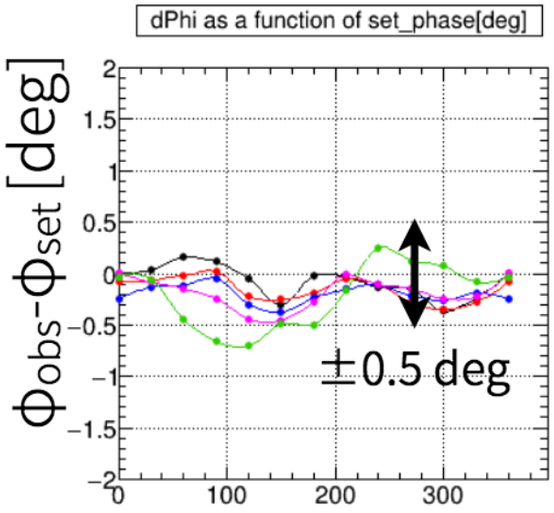


0.9
0.7
0.5
0.3
0.1

VM output w/ corrected DAC inputs

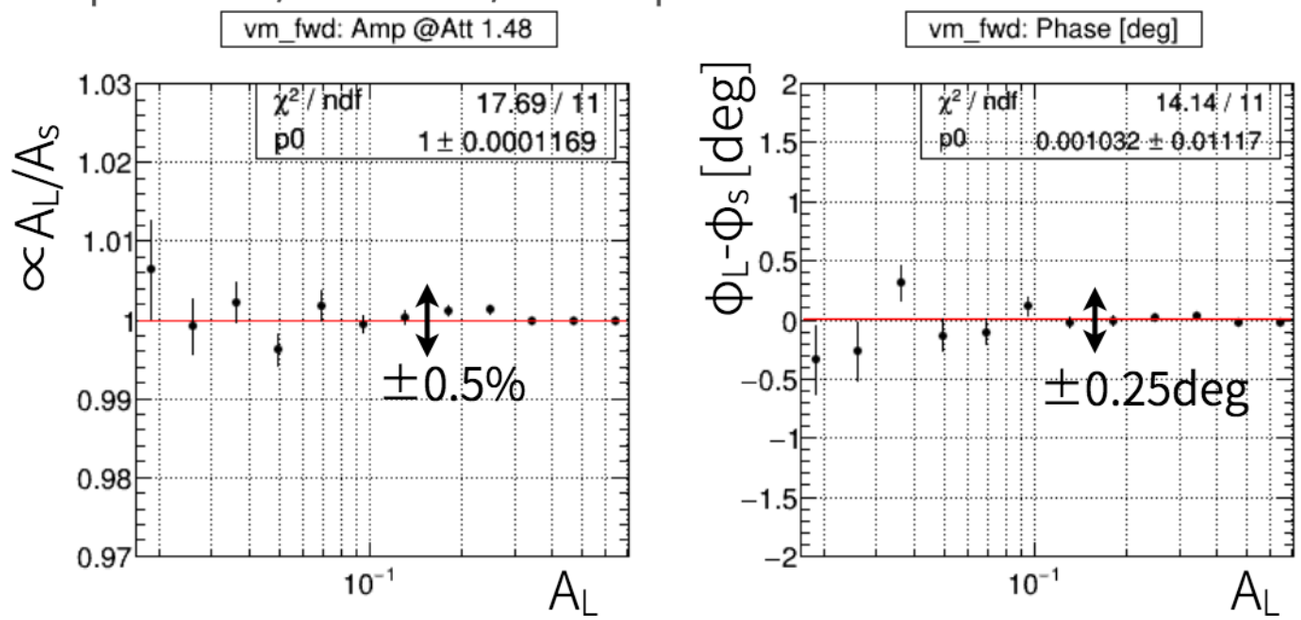




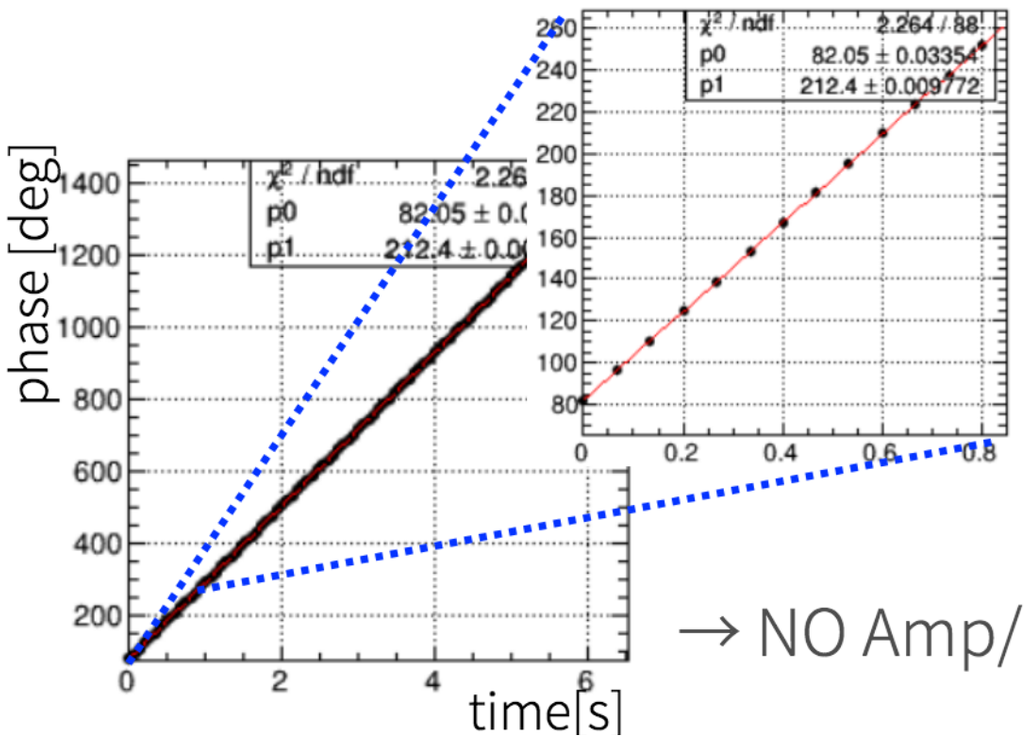


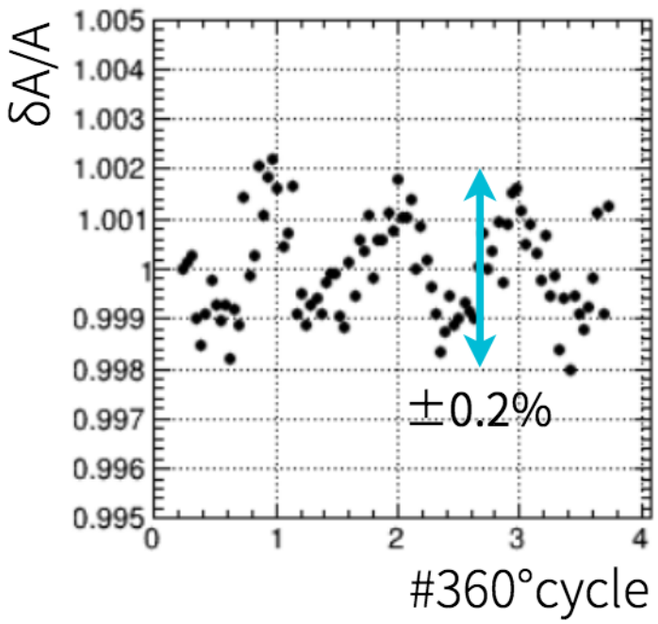
Amp/Phase dependence of ADC @CB

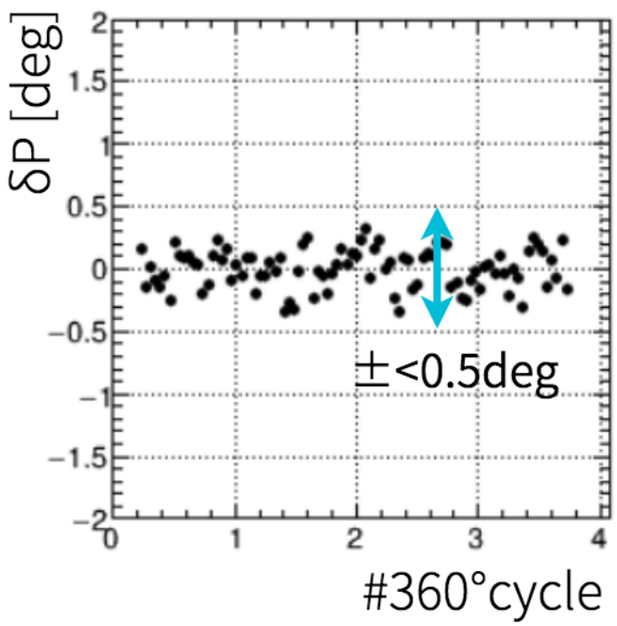
- Amplitude dep (~linearity) : compare outputs w/ and w/o step attenuator while changing the input amplitude



- Phase dep: Giving inputs w/ slightly different frequency and measure phase slipping over several cycles



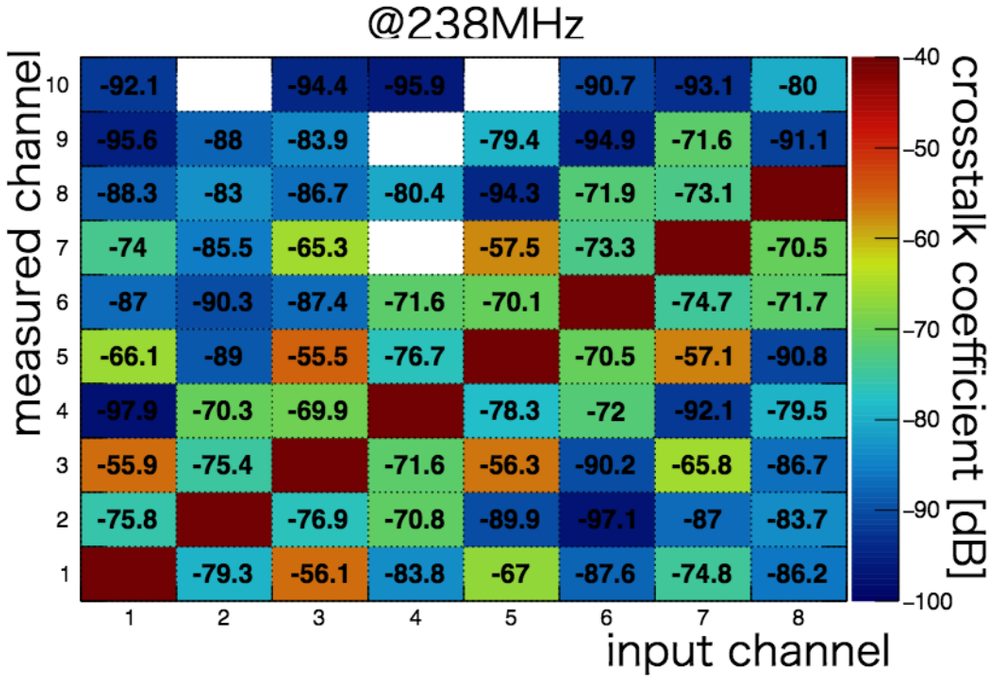




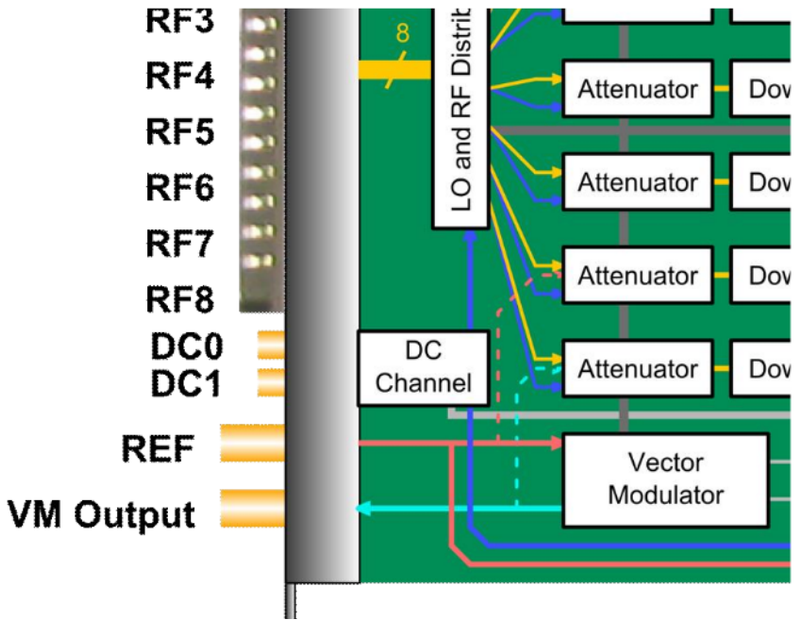
→ NO Amp/Phase dep observed, VM correction should be OK

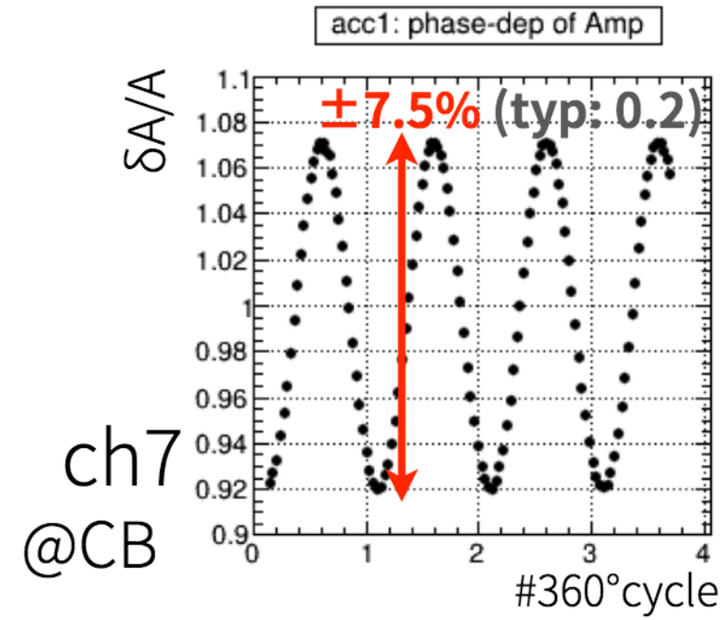
Crosstalk

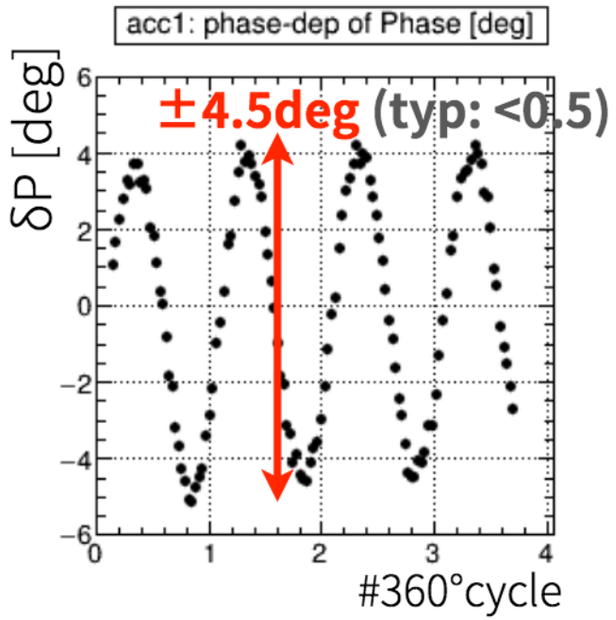
- Under sampling: MME-ADC01B + 72DSR238A
  - limitation from Zone3 Class A1
  - < -70dB by disabling ch3 & ch5



- Down conversion: SIS8325 + DWC8VM1
  - ch-assign options for ch7&8: external or REF/VMout
  - isolation seems to be not good even selecting “external” option
  - If not wiring REF&VMout (ex: monitor), isolation is good enough
  - <-70dBm assigning ch7, 8 to REF, VMout respectively

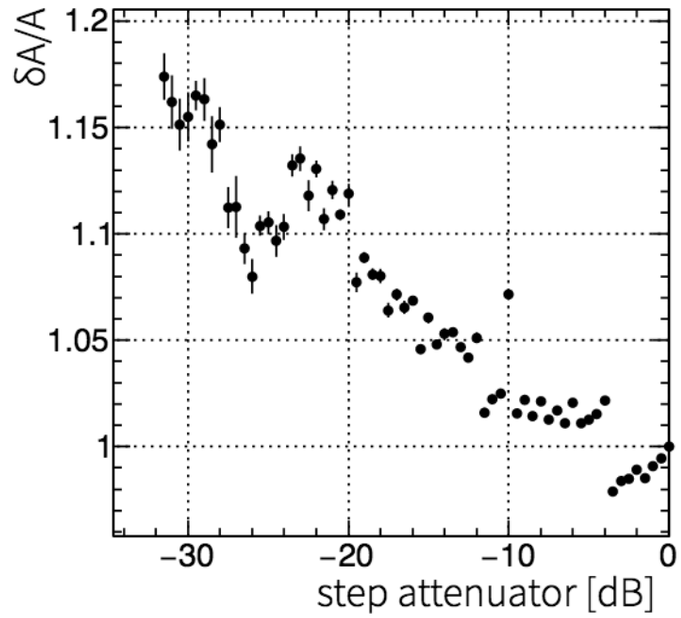


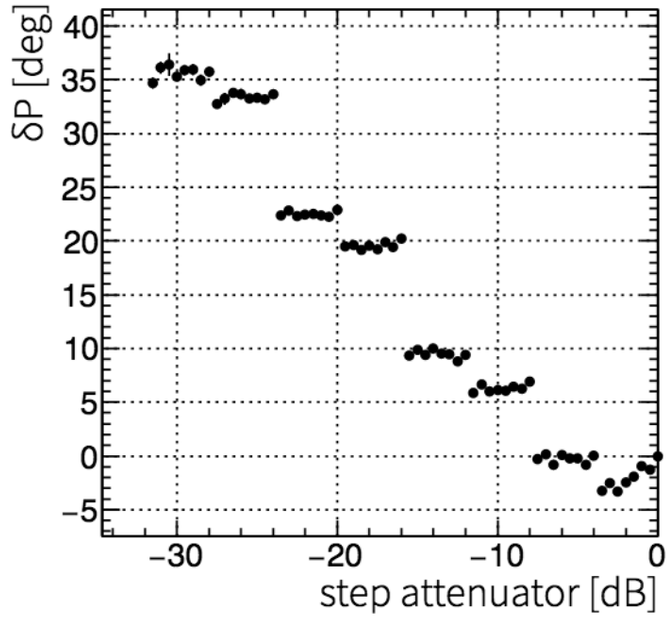




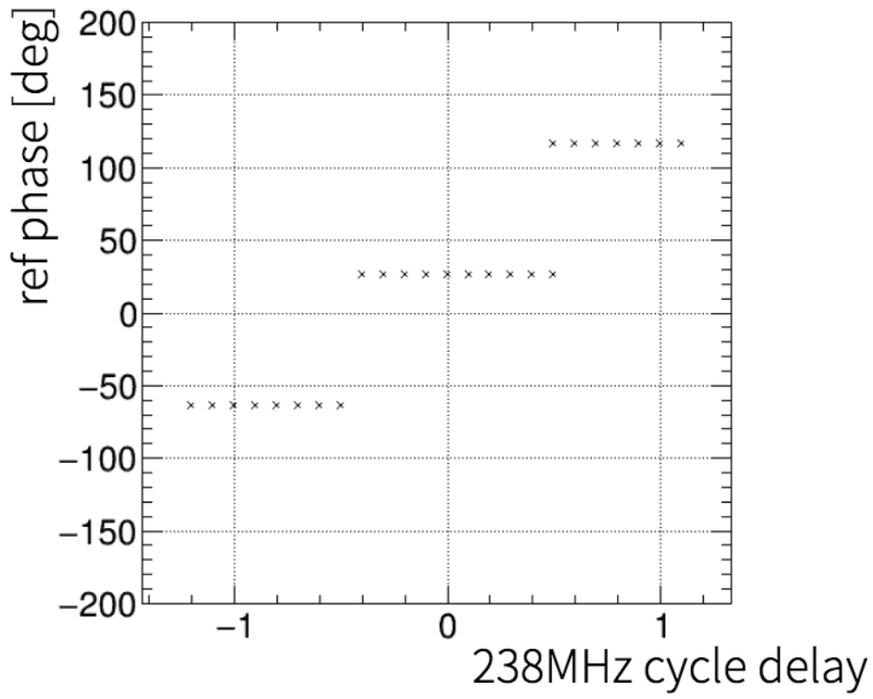
step attenuator, trigger-timing

- step attenuator calibration
  - difference from the specified attenuation
  - important especially to observe beam induced signal





- trigger timing:
  - IQ sampling w/ 4 sampling points
  - observed phase jumps 90 degree every 238MHz-cycle
  - llrf trigger timing should be set to the middle of flattop

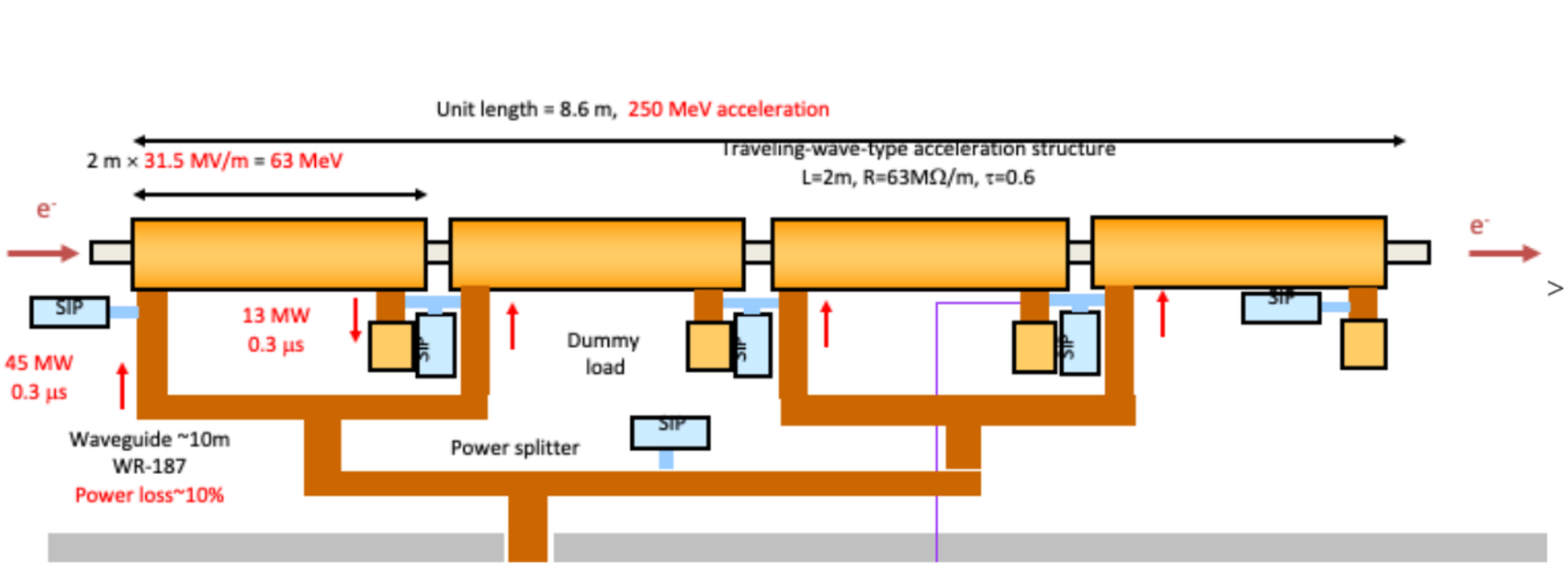


beam induced signal

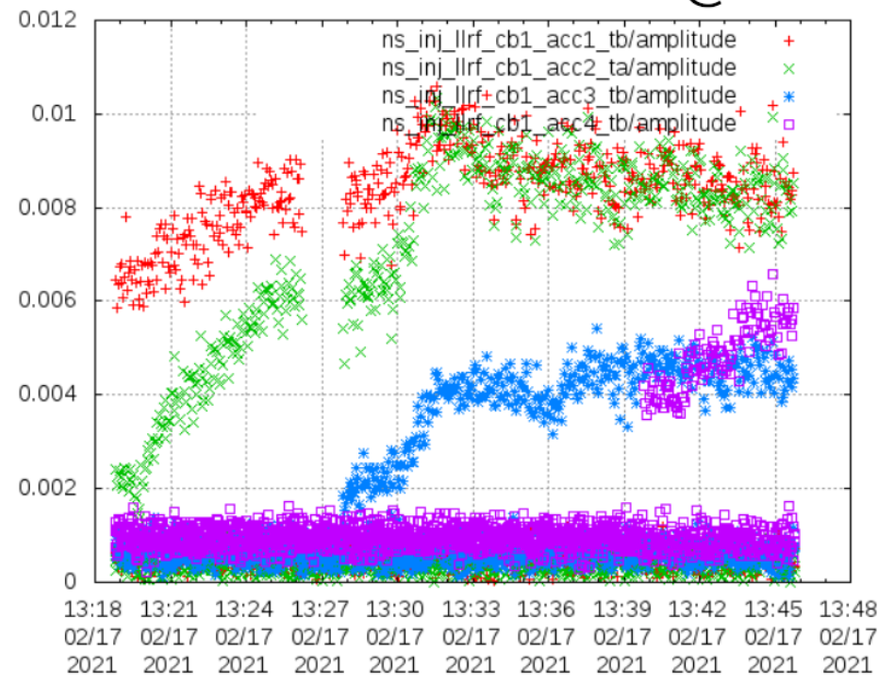
- Limited number of beam monitors to reduce cost

➡ Adjust beam so that the induced signal strength from accelerating tube from upstream during the beam commissioning

  - S/N was good enough to see the induced signal
  - Remotely controllable step attenuator

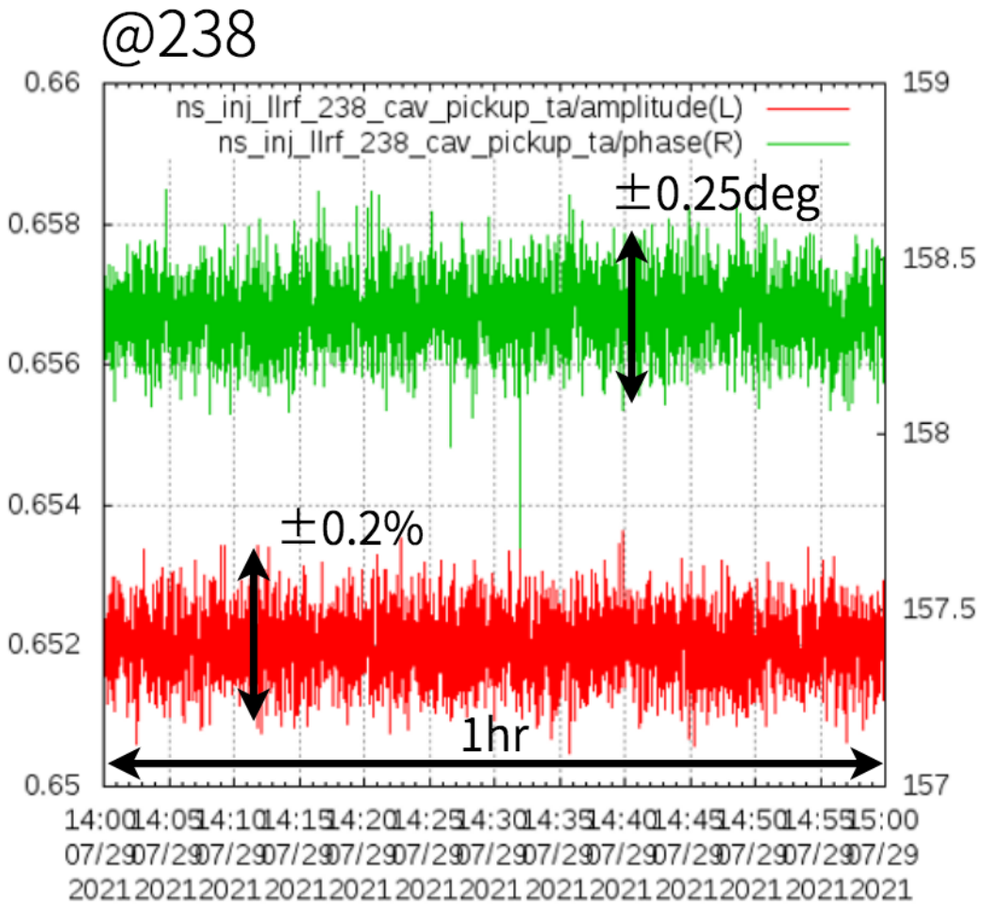


@CB1



- calibration of step attenuator was crucial, especially for phases to apply on-crest RF because it had non-negligible offsets as shown in the previous

stability



(※ including non-LLRF stuff)

unit	δ A/A [%]		δ ϕ [deg]	
	required	achieved	required	achieved
238	0.08	0.07	0.5	0.10
476	0.15	0.03	0.2	0.17
SB	0.3	0.06	0.5	0.06
CB	0.3	0.07	2.5	0.08

- stability within 1hr in rms
  → stable enough to satisfy requirements
- Almost NO daily tuning required

✓ Demonstrate good performance as a prototype of “3GeV”

Summary

- LLRF/timing system for a new Linac of NewSUBARU
  - based on MTCA.4 modules
    - digitizer AMC + RF-frontend RTM (238, 476MHz, SB, CB)
    - trigger AMC
    - timing-sync RTM
    - …
  - beam commissioning: 2021/02~, user operation: 2021/04~

✓ NO serious troubles so far

✓ successfully fulfilled required performance

✓ achieved stable beam operation, almost NO daily tuning

➡ A similar system will be installed in the next generation 3GeV synchrotron radiation facility in Sendai (under construction)