Development of proton beam position and profile interlock module at J-PARC,T2K experiment

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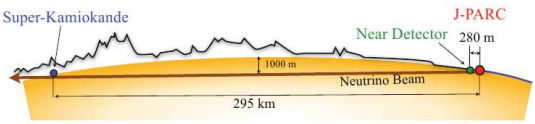
1.T2K experiment

<About T2K experiment>



T2K(Tokai to Kamioka) is a long baseline neutrino oscillation experiment in Japan.T2K has observed $\nu_\mu \rightarrow \nu_e$ or $\overline{\nu_\mu} \rightarrow \overline{\nu_e}$ oscillation. ν_μ or $\overline{\nu_\mu}$ beam is generated in J-PARC (Japan Proton Accelerator Research Complex) and go to SK(Super-Kamiokande). Neutrino beam is observed in J-PARC and SK , and check $\nu_\mu \rightarrow \nu_e$ or $\overline{\nu_\mu} \rightarrow \overline{\nu_e}$ oscillation to compare these observations.

T2K is planning to increase the number of the $\nu_\mu \rightarrow \nu_e$ and $\overline{\nu_\mu} \rightarrow \overline{\nu_e}$ oscillation statistics to search for CP violation in neutrino more than 3σ C.L.

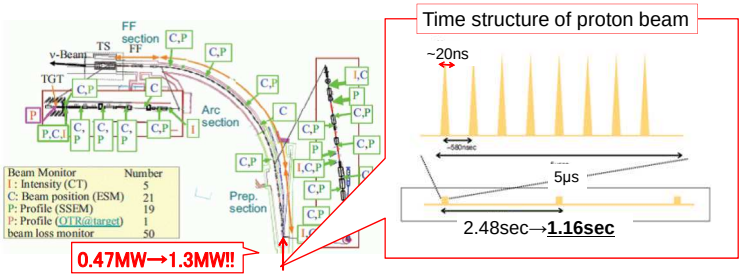
⇒T2K needs higher beam power.

⇒Beam repetition time will become shorter.

	Now	future
Bean power[MW]	0.47	1.3
Proton per pulse	2.4 $\times 10^{14}$	3.2 $\times 10^{14}$
Rep.time[sec]	2.48	1.16

<Proton beam line in J-PARC>

Various beam monitors are located on the proton beam line of the J-PARC T2K experiment and observe beam strength and position, profile, beam loss and check a beam not to be out of the track of the beam.



Time structure of proton beam

2.Motivation

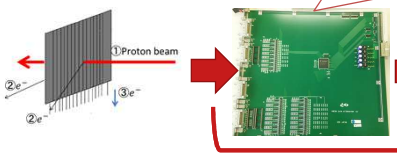
<SSEM (Segmented Secondary Emission Monitor)>

Material	Ti
Thickness	5μm
Strip width	3.5mm~5.0mm
Strip interval	1mm

24 belts called “strip” form a line

Attenuate signal from SSEM

Calculate beam position and profile



This latency is long! (~1s)

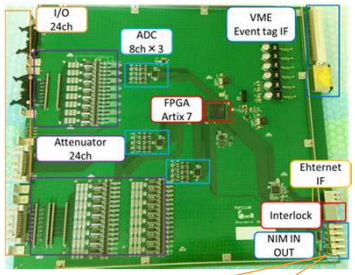
Toward high beam power (short repetition), in T2K future, we need to develop new interlock module to reduce the latency .

Add some function and remake this module

<About new module>

- Board size：KEK VME 9U
- Board’s name：”PAPILLON”
  →beam **P**osition **A**nd **Prof**I**L**e inter**L**ock m**O**dule for **N**eutrino experiment

1. Input trigger signal(※) and start to get beam signal from SSEM
2. Attenuate beam signal
3. Convert the analog signal to the digital signal(FADC)
4. Calculate beam position in FPGA
5. If the beam is bigger than threshold level, stop proton beam

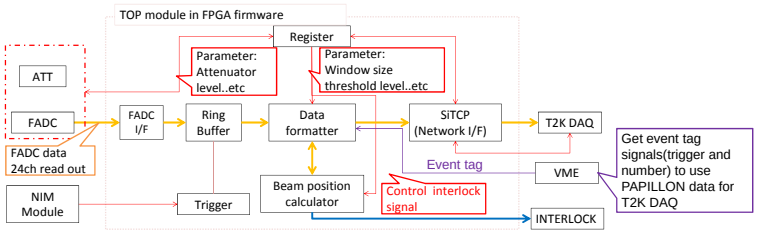


(※)Trigger signal is input before beam signal.

3.FPGA firmware development

<FPGA firmware function>

1. Beam position calculation
2. Read out beam signal per strip, beam position, interlock status.
3. Control board to use T2K DAQ (threshold level, interlock, strip position…)



<The beam position calculation method=papillon calculation method>

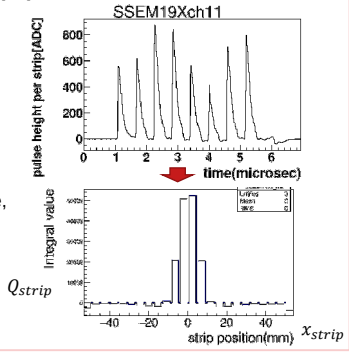
1. Get each strip signal waveform per spill ($p(t)$) from FADC
2. Integrate signal waveform ($p(t)$) over spill

※Strip=strip number(0~23) i=sampling number

$$Q_{strip} = \int_0^{spill} p_{strip}(t)dt \cong \sum_{i=1}^{640} p^i{}_{strip}$$

3. Gather 24 Q_{strip} values and make beam profile, calculate beam position $X(mm)$

$$X(mm) = \frac{\sum_{strip=0}^{23} Q_{strip} \times x_{strip}}{\sum_{strip=0}^{23} Q_{strip}}$$

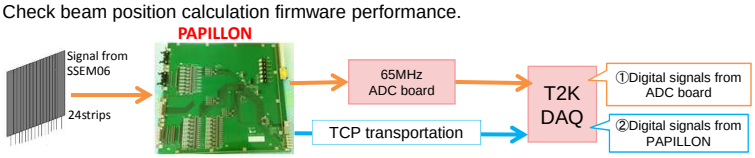


⇒Measured the latency to calculate beam position and shot interlock is 9.04μs

4.Operation test with beam

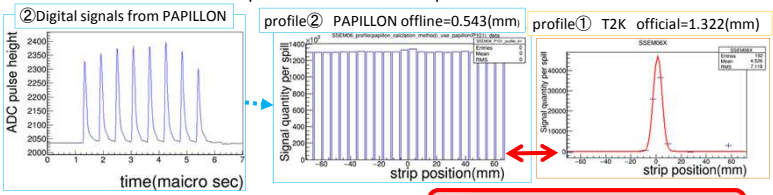
<Motivation>

- Check waveform readout with PAPILLON (80MHz sampling rate)
- Check beam position calculation firmware performance.



<The result of the first test>

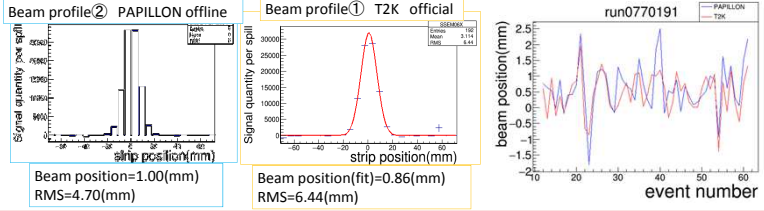
I did the first operational test in November 20th to use 40kw 8 bunch proton beam. It was clear that PAPILLON could read signal from SSEM06 well. But it was clear that PAPILLON calculation method couldn’t reproduce correct beam profile.



Improved calculation method to take into account pedestal

<The result of the second test>

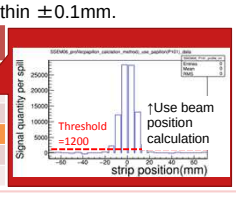
I did the second operational test in December 12th to use 450kw 8 bunch proton beam. It was clear that PAPILLON calculation method could reproduce correct beam profile to take into account pedestal. I checked beam position vs event and it was clear that there were some correlation between T2K official beam position and PAPILLON calculated beam position.



5.Future prospect

I found some problems in the second beam test. PAPILLON received trigger and calculated beam position though there were no proton beam hit in SSEM. So I improved calculation method to set threshold level of Q_{strip} value. I checked this improved firmware using simulation and it is confirmed that the interlock error is recovered and the improved firmware calculation is consistent with T2K official calculation within ±0.1mm.

Event number	2017/12/12 T2K official(mm)	Improved firmware simulation Using 2017/12/12 data(mm)	2017/12/12 Firmware calculation (mm)
5(no beam)	No analyzation	-1	9.71 (shot interlock)
20	0.86	0.92	0.42
30	0.07	0.01	-0.16
40	1.20	1.30	1.83 (shot interlock)
50	0.62	0.68	0.17
60	0.77	0.79	0.07



6.Conclutsion

Toward high beam power (short repetition) in T2K future, I developed the proton beam position and profile interlock module , PAPILLON. I did operation test and checked firmware performance. I improved the firmware based on the beam test results. The improved firmware calculation is consistent with T2K official calculation within ±0.1mm.

I will install PAPILLON to T2K experiment in this March.