高時間分解能Muon実験に必要なエレクトロニクス~~開発~~テスト

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2009-2018 @ KEK物構研+ J-PARC MLF

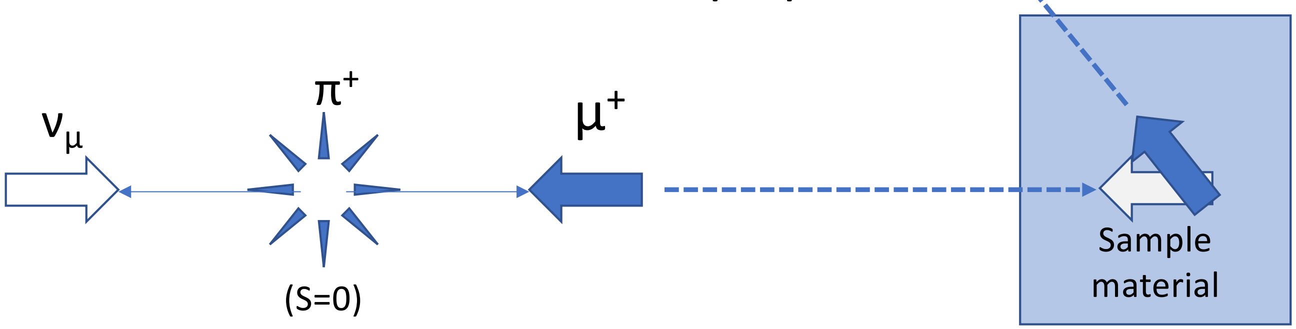
2018- @ TRIUMF

The muon experiment I am talking about

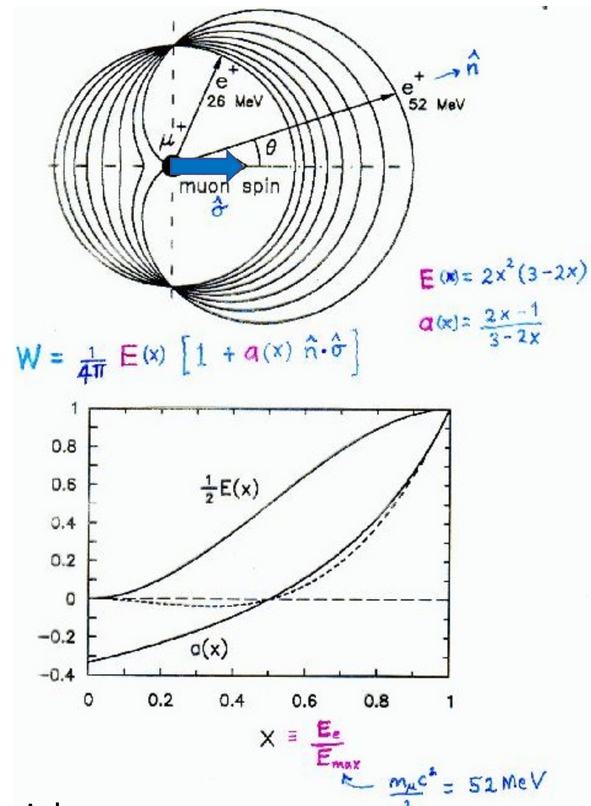
- Muon spin relaxation in Materials Science
- $\pi^+ \rightarrow \mu^+ + \nu_\mu$ $\mu^+ \rightarrow e^+ + \nu_e + \nu_\mu$

100% spin polarized μ^+

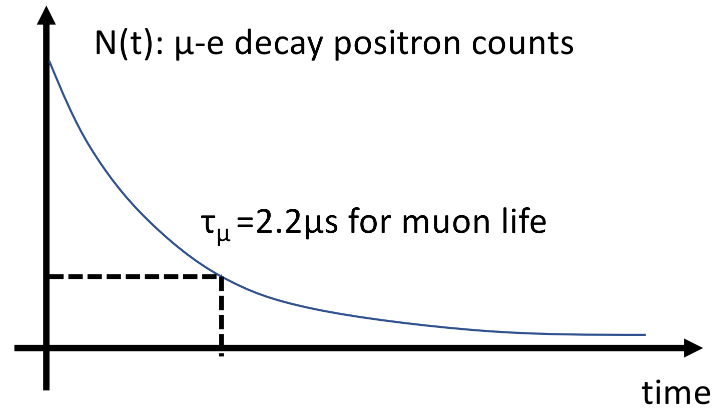
Asymmetric distribution of e^+ emission relative to μ-spin



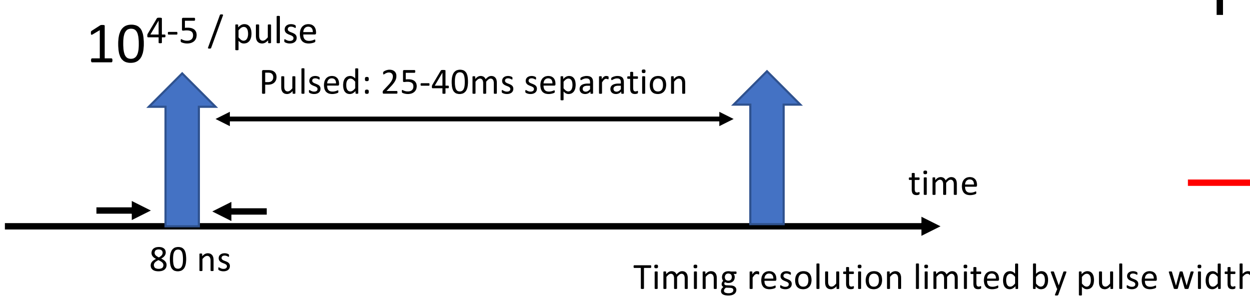
Muon polarization relaxes in materials according to the local environment.

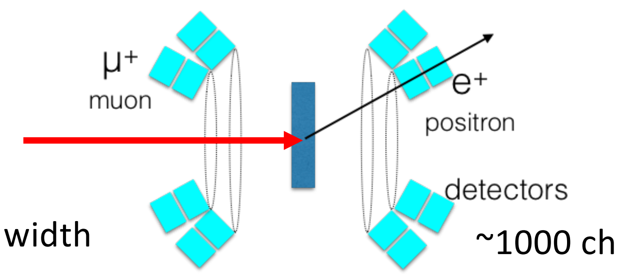


Two types of muon source

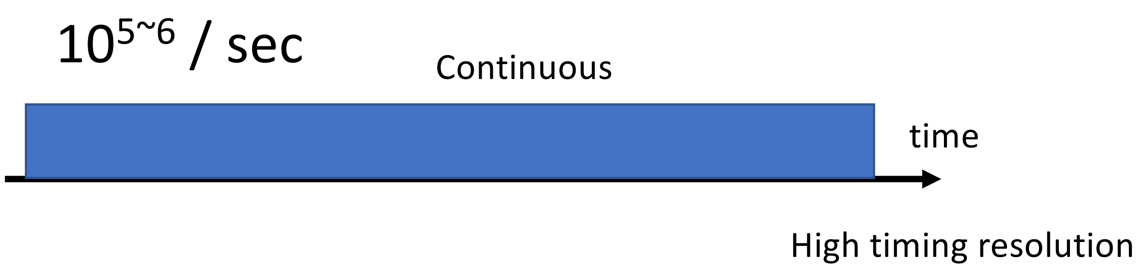


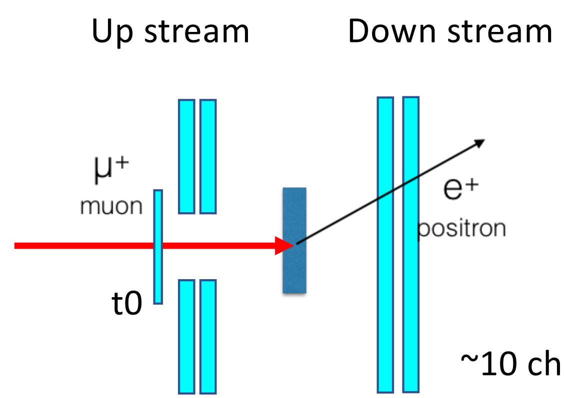
- Synchrotron based (J-PARC, ISIS-RAL)





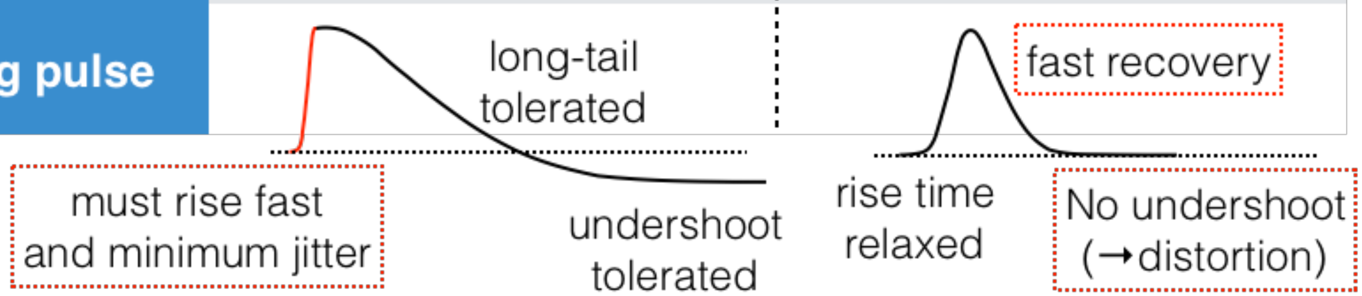
- Cyclotron based (TRIUMF, PSI, MuSIC)





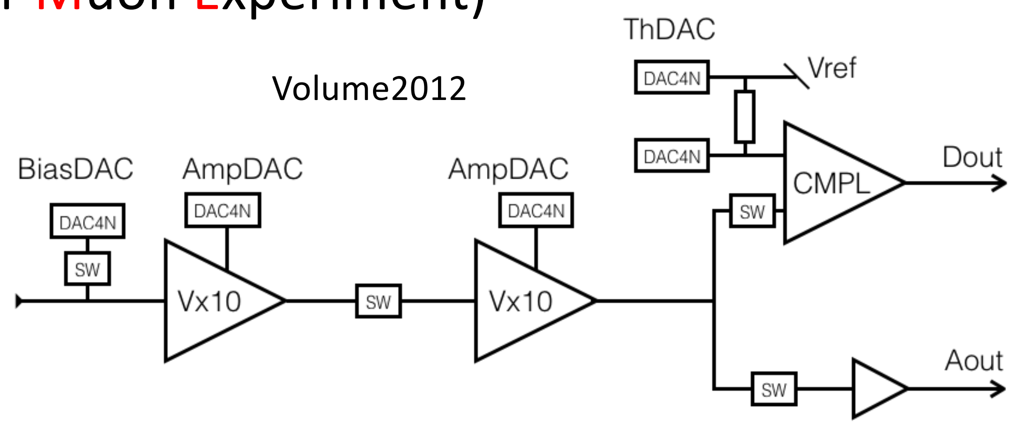
Analog electronics requirement for DC vs. Pulsed muons

Detector specs	DC	Pulsed
Count rate	a few counters ~1e+/10μs 100kcps, continuous	thousands counters ~10e+/pulse 5Mcps,instantaneous
Rise-time resolution	very important	not important
Tail recovery time	any	as short as possible
Base-line stability	any	must be flat, no shift
Desired analog pulse		

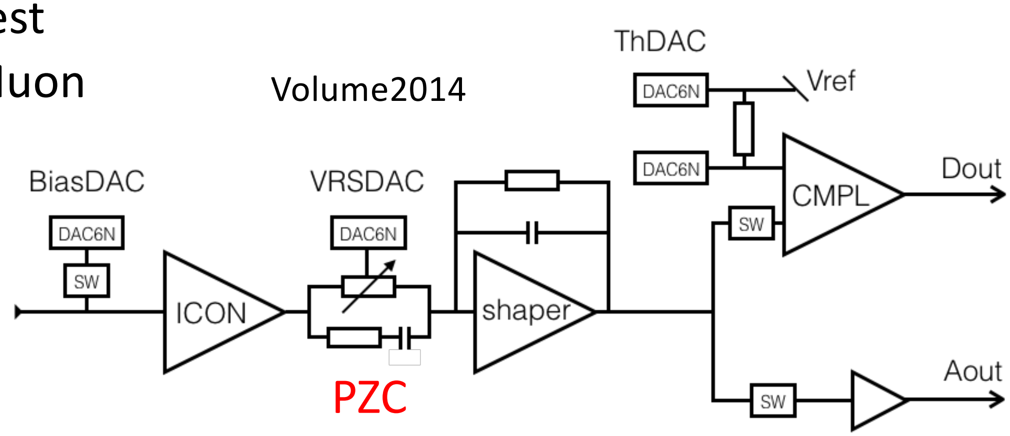


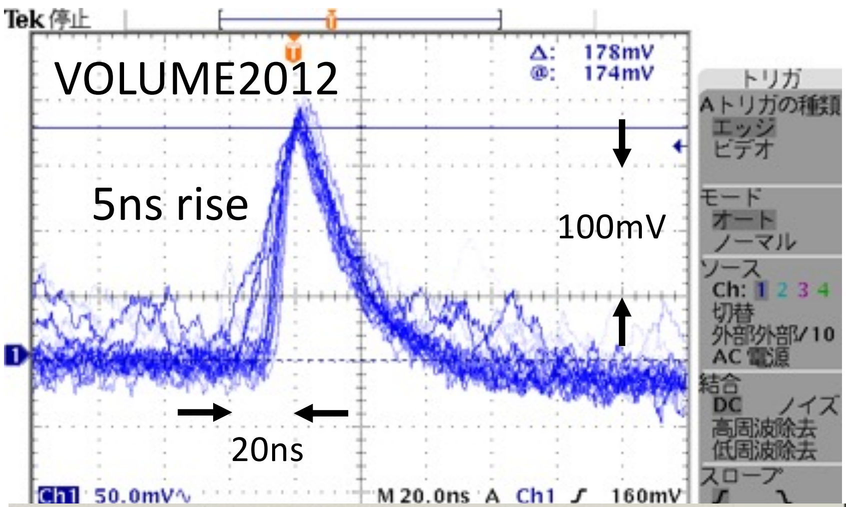
Developments for pulsed facility (J-PARC MLF Muon)

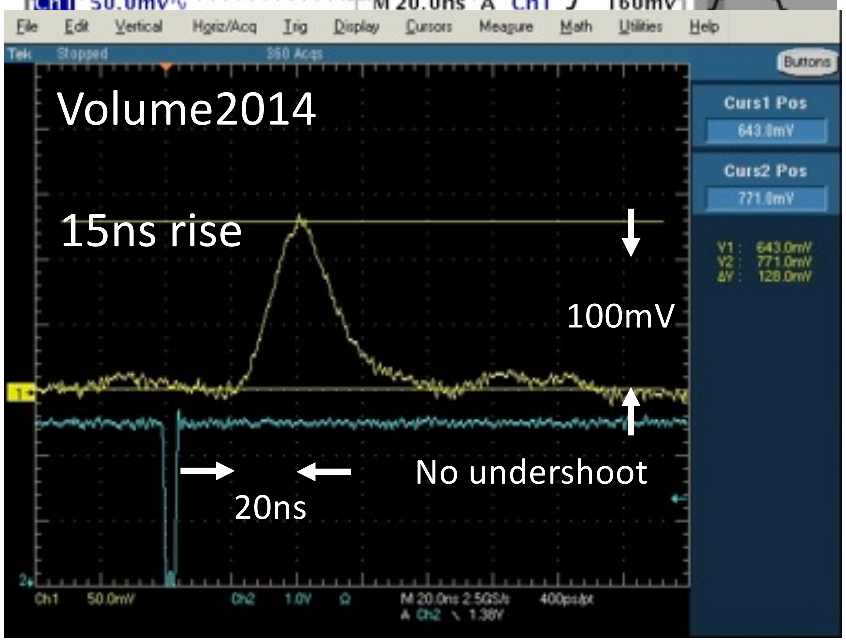
- ASIC: *VOLUME201x* (VOLtage amp for Muon Experiment)
  - Vx10Amp 1ch
  - VOLUME2011 v1, v2
  - VOLUME2012 – first application to spectrometers

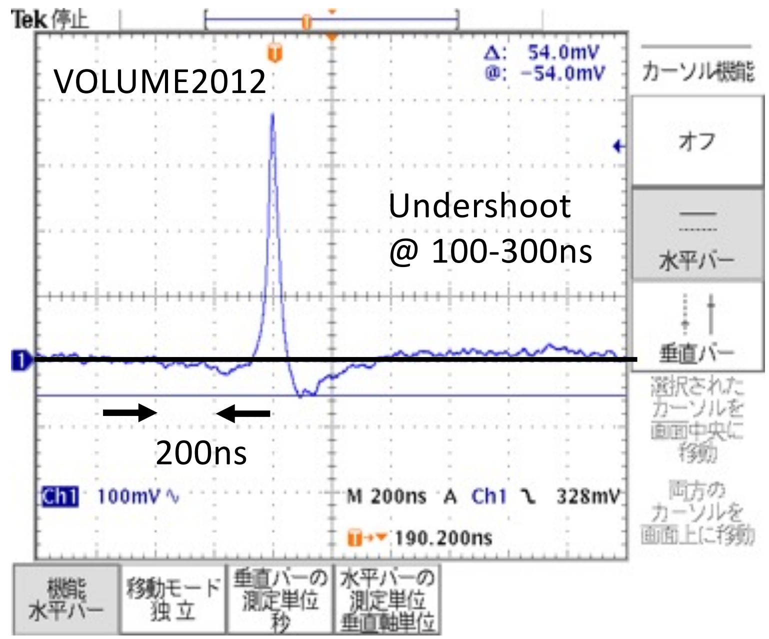


  - VOLUME2013 Pole-Zero Cancellation test
  - VOLUME2014 – final version for MLF Muon







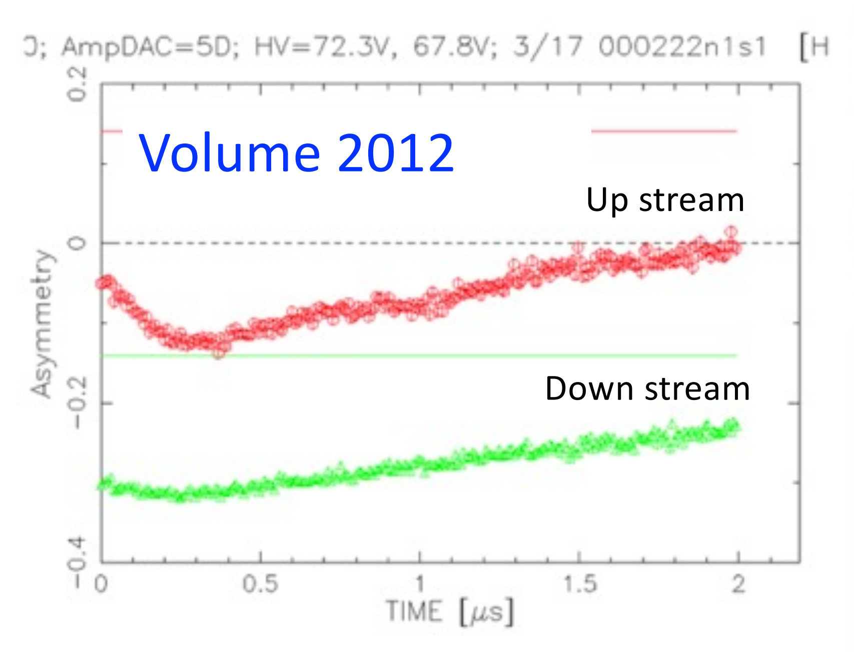


Analog monitor outputs

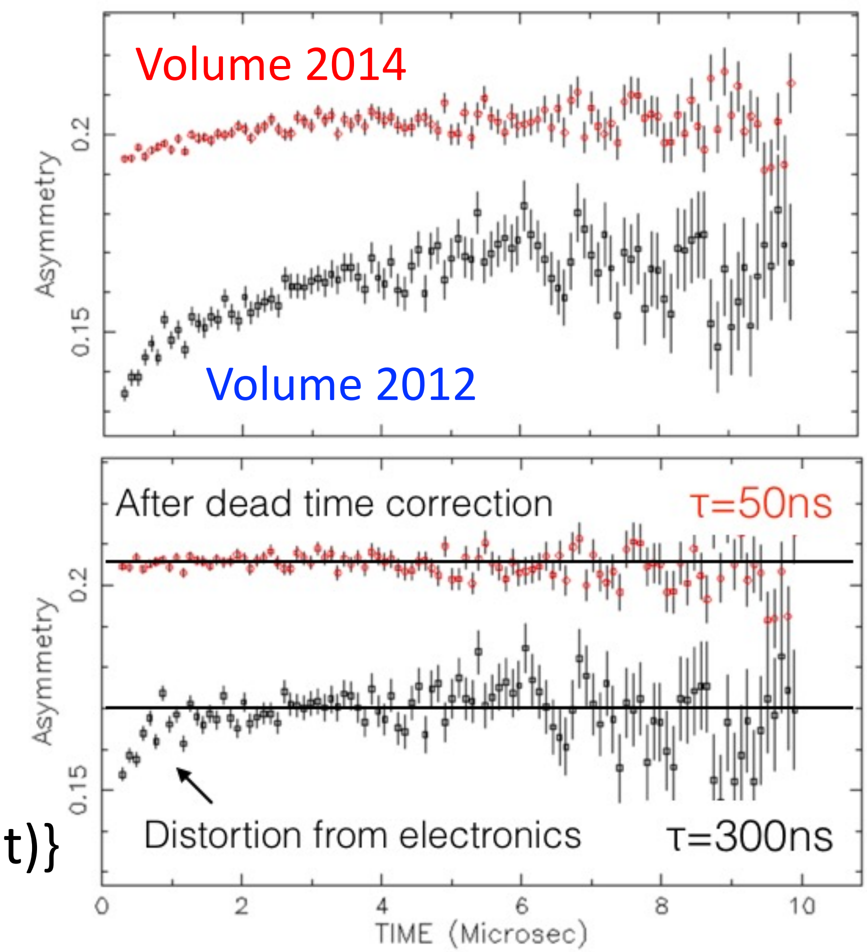
Volume 2012: Fast rise with undershoots at 100-300ns

Volume 2014: slow rise, no undershoots

Spectral distortion in pulsed μ-e decay



In spectrometer: 4−5e⁺/counter/pulse



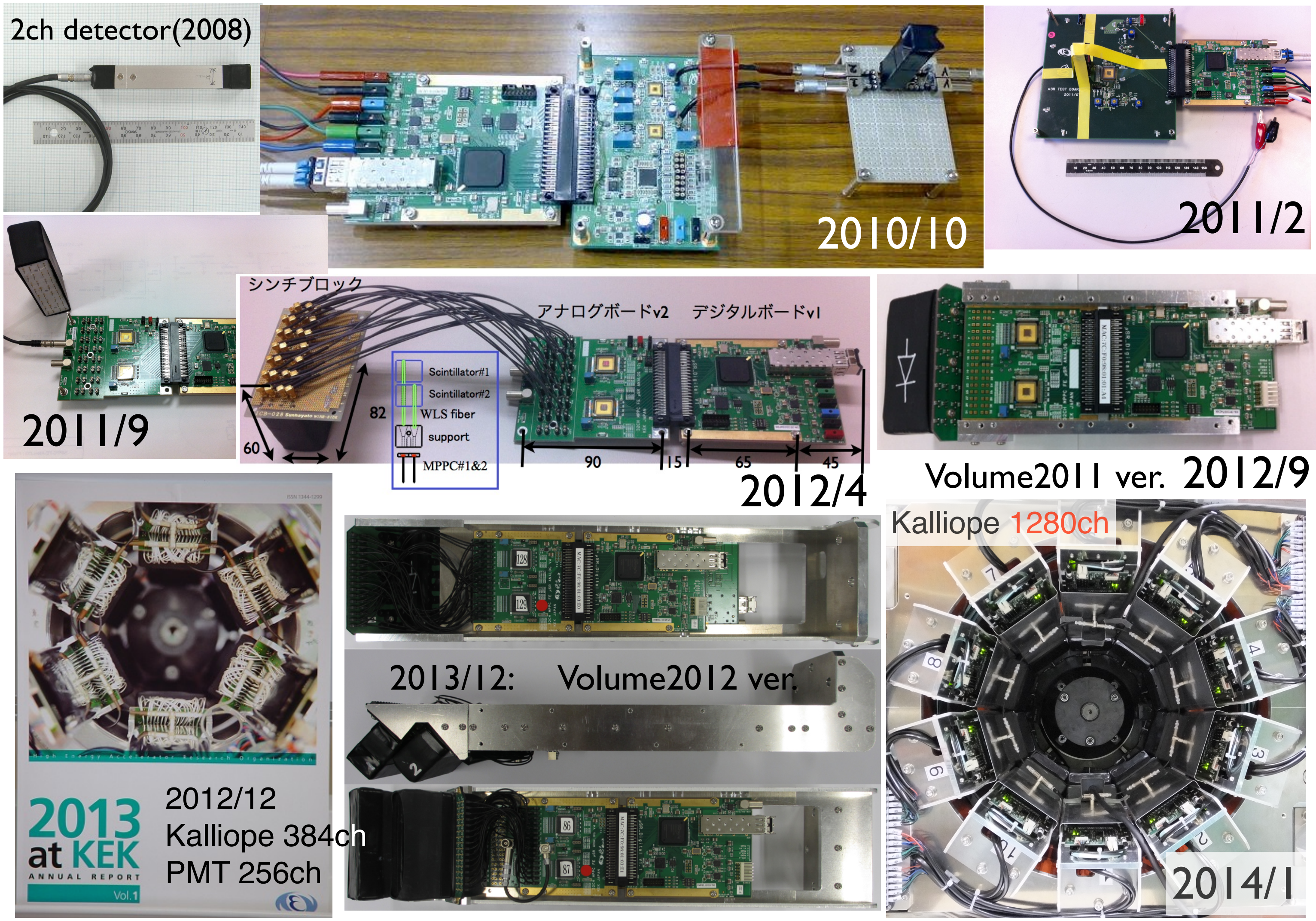
Asymmetry: Positron count, normalized by muon life ↑

$$Asym= N(t) / N_0 exp(-t/\tau_\mu)$$

or count difference, normalized by total →

$$=\{Nup(t) - Ndown(t)\} / \{Nup(t) + Ndown(t)\}$$

Development of Kalliope (2010~2016)



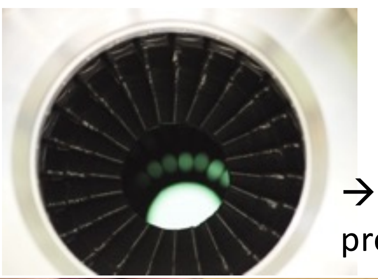
Kalliope units
=KEK Advanced Linear and Logic Integrated boards for Optical detectors in Positron and Electron identifications.

It has
Analog signal shaping and threshold DACs and 1ns resolution, 64μs length TDC

It is compact to install into the spectrometer.
(to avoid wirings)

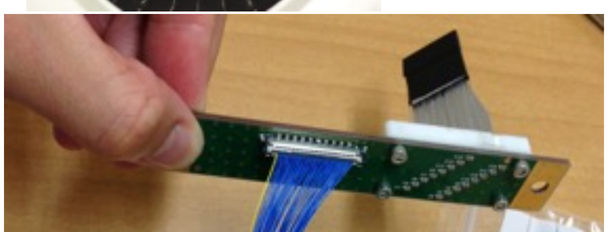
Muon spectrometers at J-PARC MLF muon

Volume2012

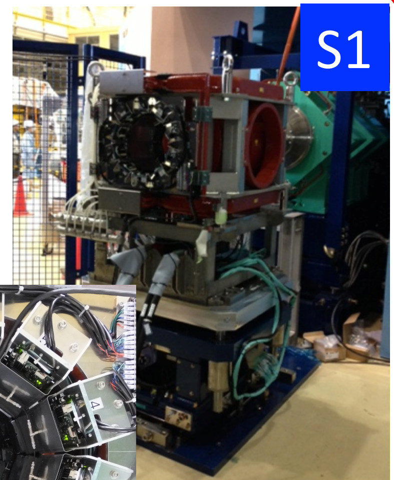


3008 ch

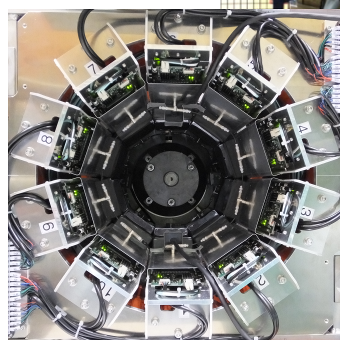
→ Nishimura ‘s presentation?

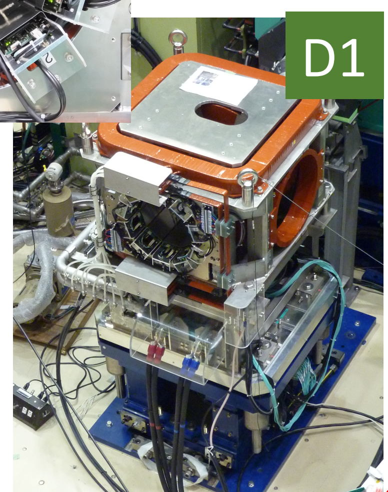


Volume2014



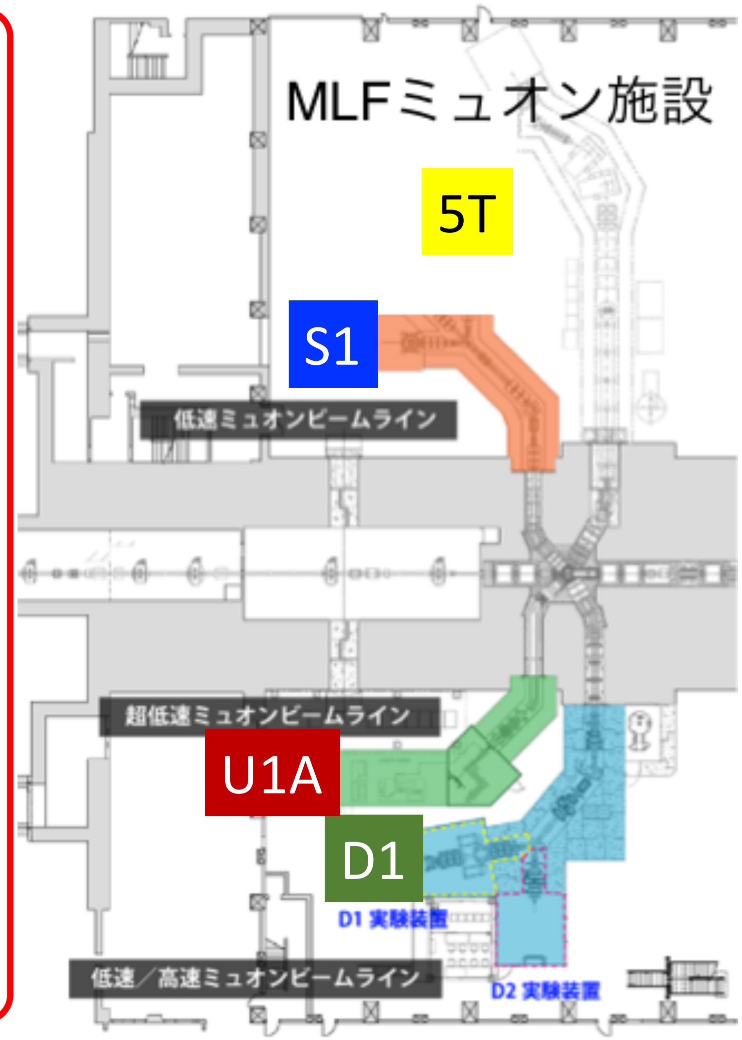
1280 ch





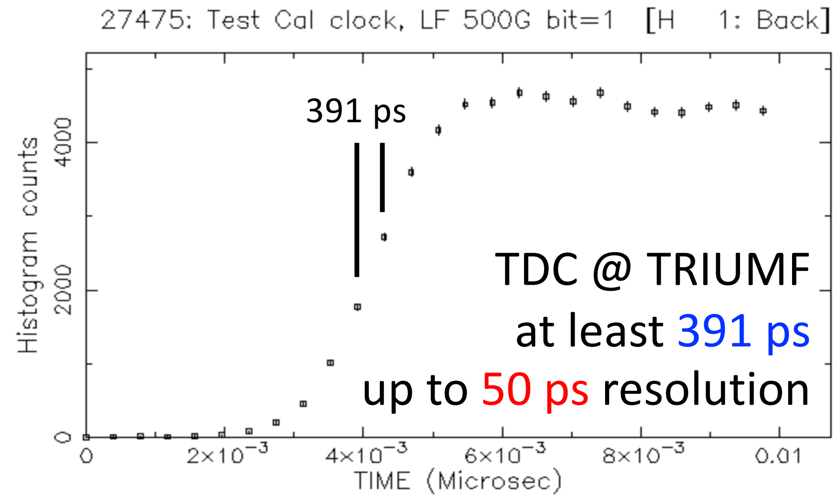
U1A

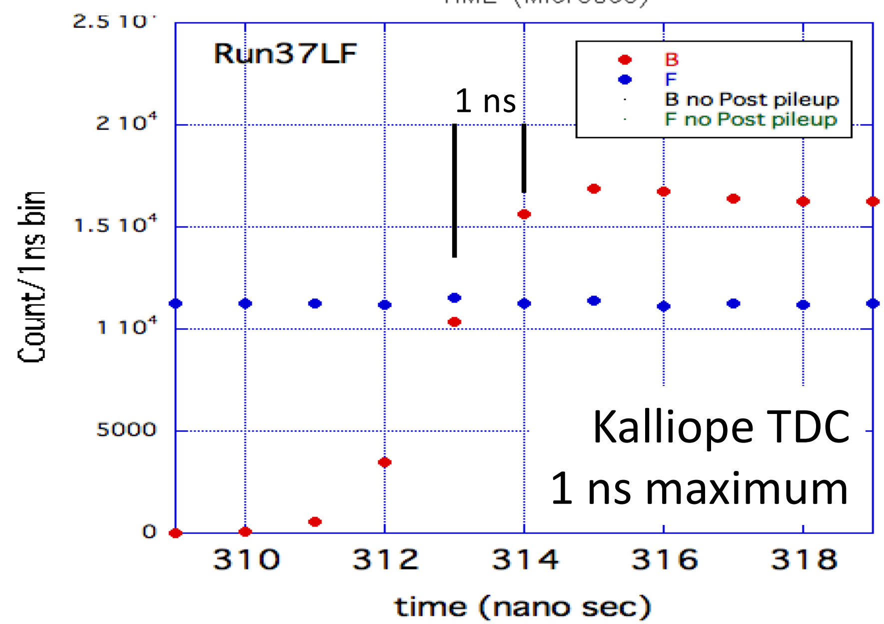
512+512 ch



高時間分解能Muon実験 (TRIUMF)

- Faster rise time (ASIC)
  - *FGATI* (Frontend for GHz Application using Trans Impedance Amplifier)
    - FGATI board v1 – tested at TRIUMF
    - FGATI board v4 – being test by Kanda (KEK)
- Finer TDC resolution
  - 1ns TDC on Kalliope (Spartan-6) is too sparse
  - Honda's HR-TDC (30ps?) would be perfect !
- Different DAQ cycle (for DC)
  - ✓developed for MuSIC (Osaka) on Kalliope
  - → used at neutron imaging (MLF BL10)

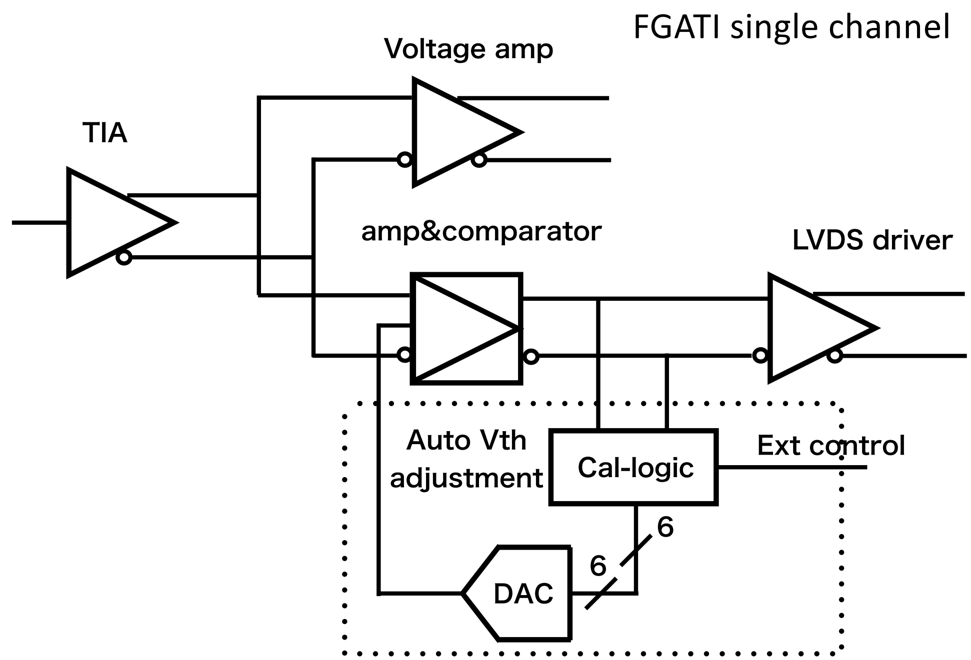




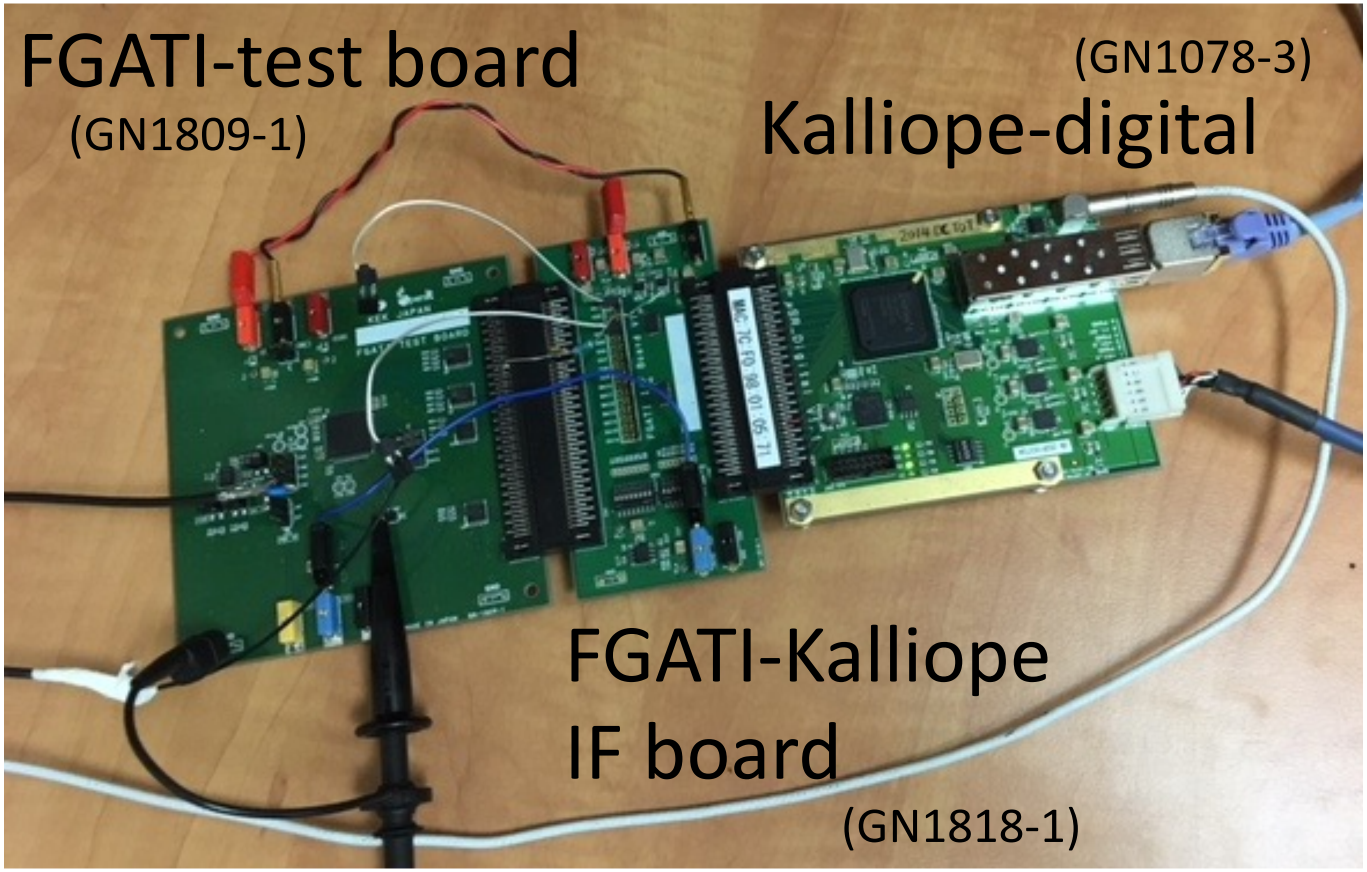
FGATI (Frontend for GHz Application using Trans Impedance Amplifier)

From M. Tanaka: 20170926

	APD	Diamond	MPPC	X-KID
Detector cap	<5pF	<5pF	??	
Qgen in sensor	10^5	10^4~5	10^6	Voltage output
Transient time	<ns	<10ns	~40ns	??
Band width	>GHz	~>GHz	<0.1GHz	??
Conversion gain				
S/N requirement		S~5000~	Don't care	



Testing FGATI board v.1

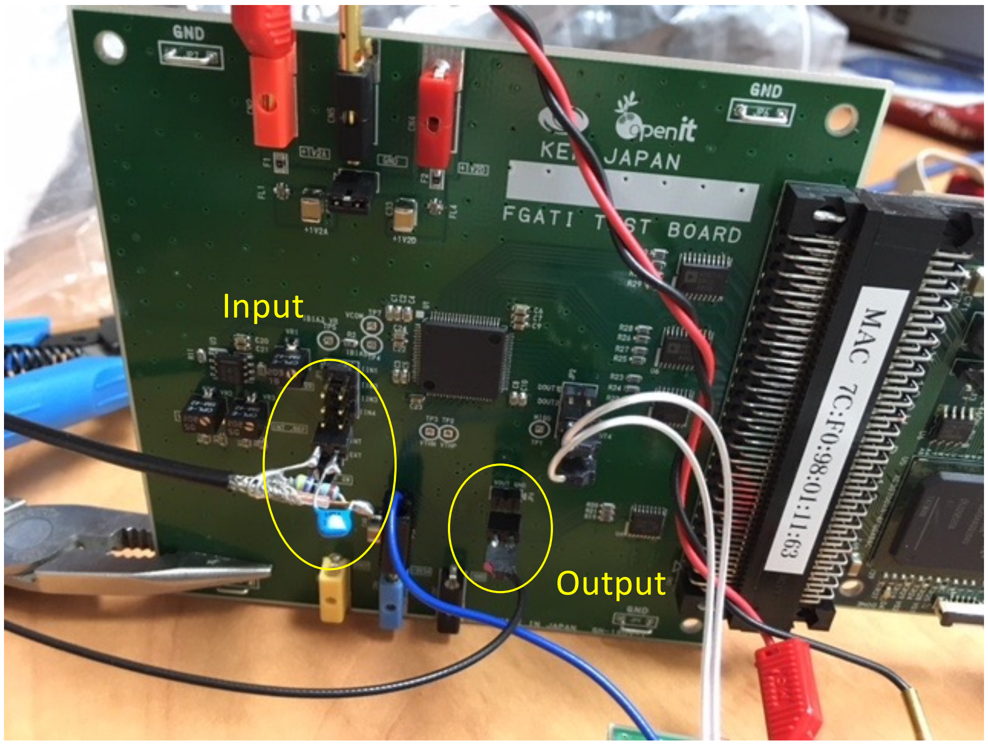


Kalliope provides +5V power for Analog boards for Volume201x

IF board converts powers +5V → +/- 3.3V and +1.2V necessary for FGATI board

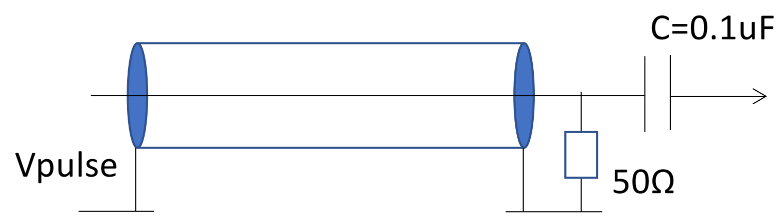
DAC control serial lines (SBB, STRI, CLK, etc) are connected from Kalliope to FGATI board.

Signal inputs / outputs



FGATI is **current** input ASIC, as is Volume2014.
Volume2012 is **voltage** input ASIC.

Voltage pulse from a signal generator is converted to a current pulse by a capacitor. We employ 0.1uF for capacitance.

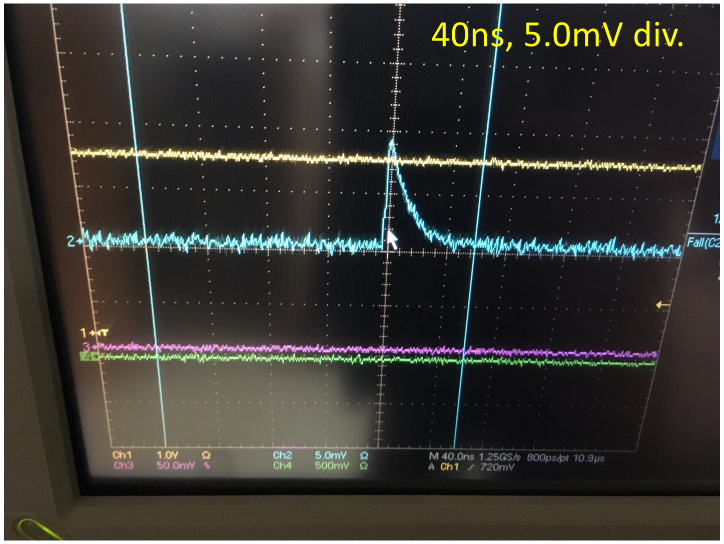


Inputs are taken from the ch1-4 header pins.
Analog output corresponds to ch4 input.
It is a voltage signal, monitored by either 50Ω or 1MΩ scope input termination.

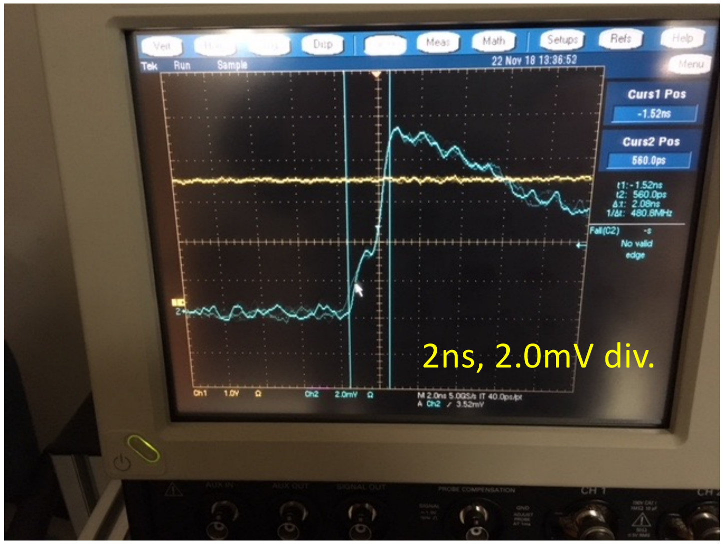
Input signal

10mV height, 40ns tail signal is generated by a pulser. Rise time is ~**2.0ns**

Input charge Q=CV=0.1uF x 10mV /2 =**500pC** (huge !) ~ **2 x 10^9** e's



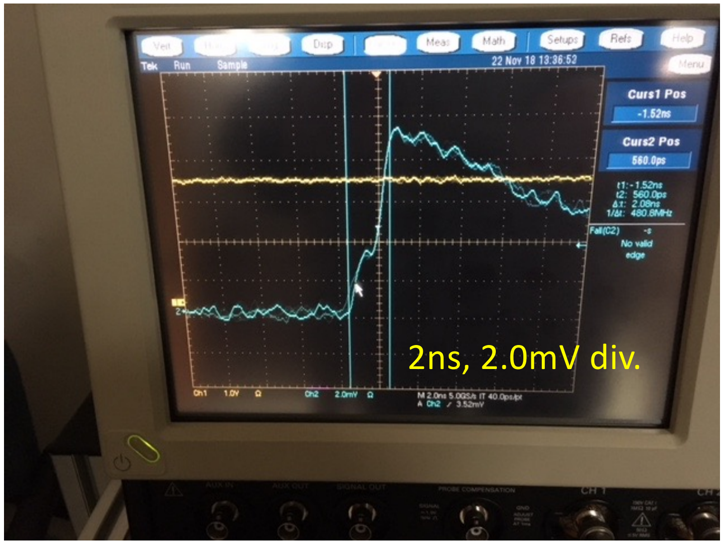
Input pulse: 10mV, 2.0ns rise, 40ns tail



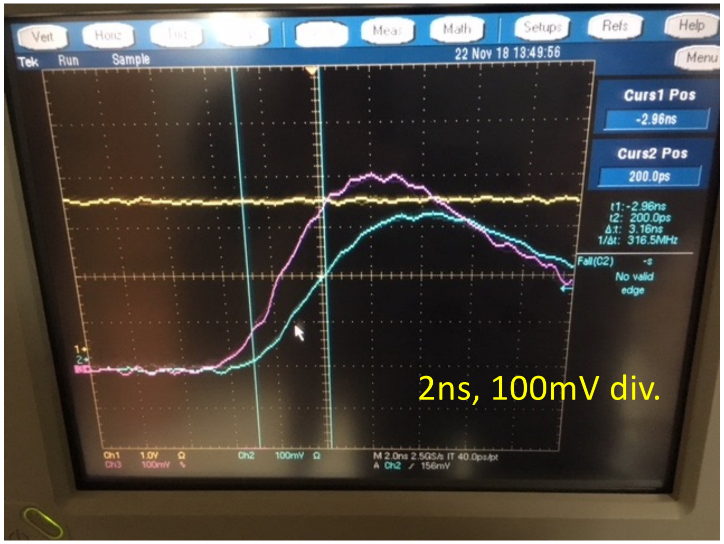
Input pulse: 10mV, 2.0ns rise, 40ns tail

Output signal

400mV height (1MΩ) or 300mV (50Ω) output signal is seen in Vout.
Rise time is ~**3ns** for 1MΩ and ~**5ns** for 50Ω.



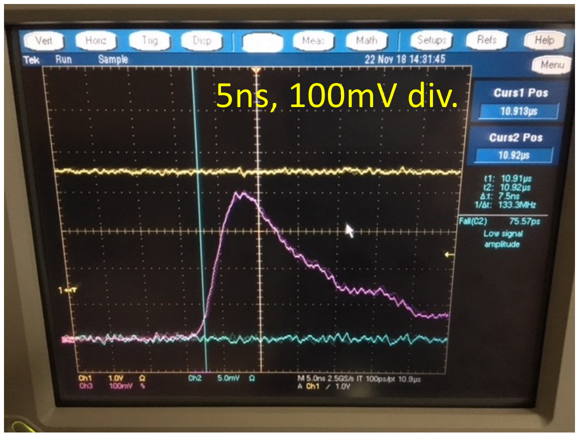
Input pulse: 10mV, 2.0ns rise, 40ns tail



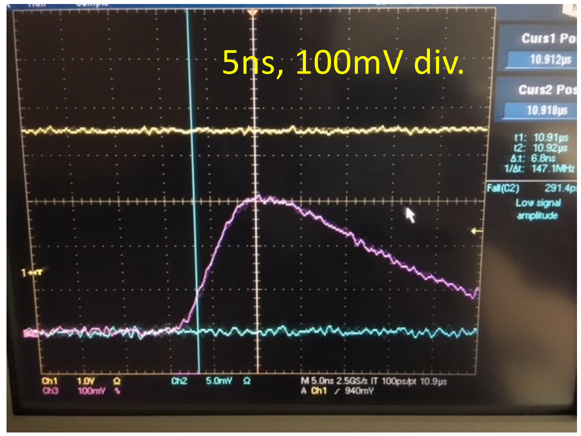
FGATI output signal:
Cyan (50Ω) is 300mV height, 5ns rise
Magenda (1MΩ) is 400mV height, 3ns rise.

Comparison to Volume201x

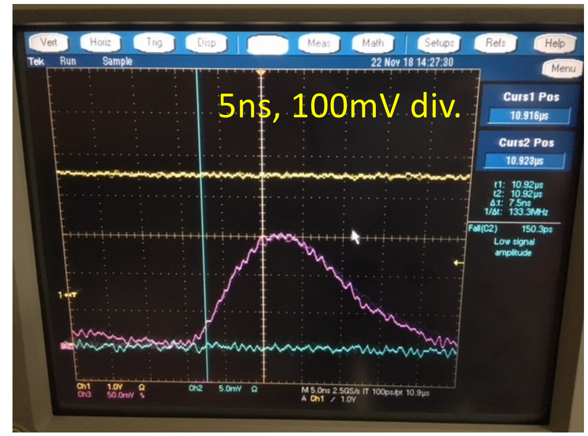
Input pulse: 10mV height, 2ns rise, 40ns tail.



FGATI: 400mV, 3ns rise



Volume2012: 300mV, 5ns rise
(AmpDAC=4C, Gain x100)

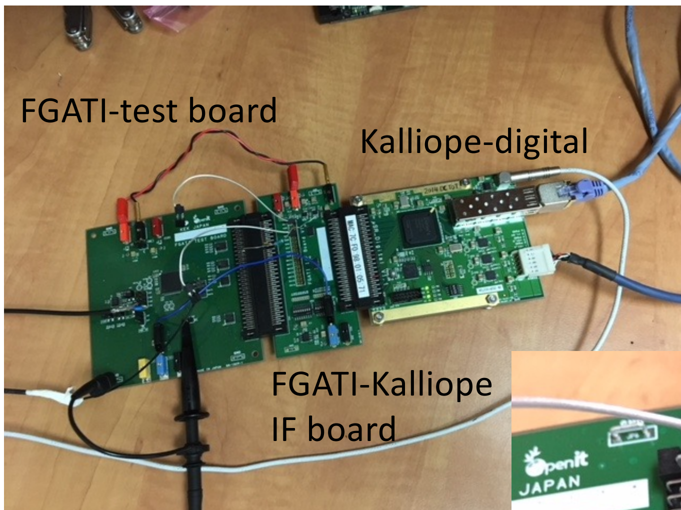


Volume2014: 300mV, 7ns rise
(VRS=0.25 V + DAC=0x24)

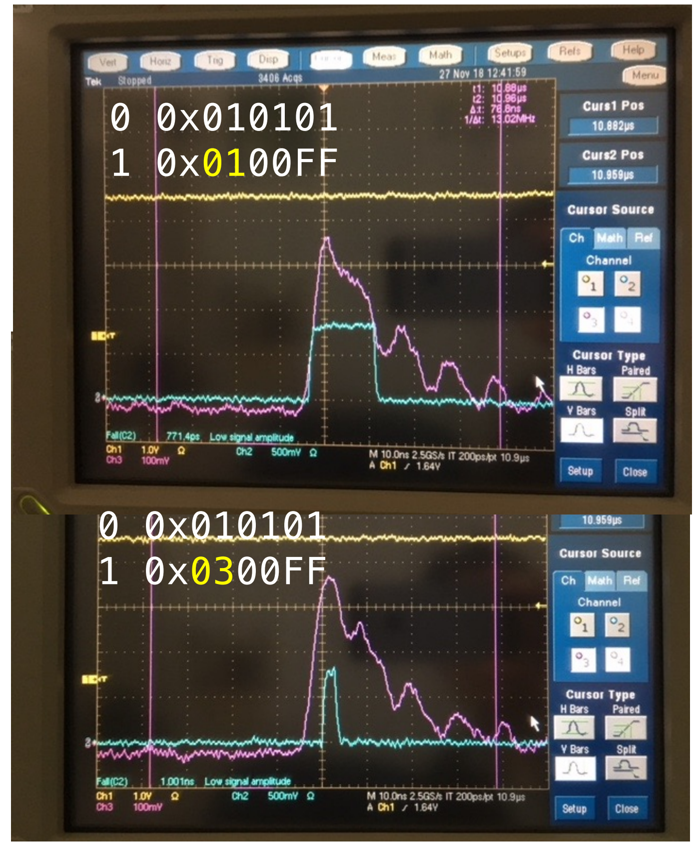
FGATI is a high-gain, fast Amplifier.
According to Kholili's test in FGATI_Analog_Eval_Summary.docx.pdf, the rise time improves in lower gain (1.4 -> 0.7 ns in LG000 -> 111), and smaller charge (70% in 33pC/500pC)

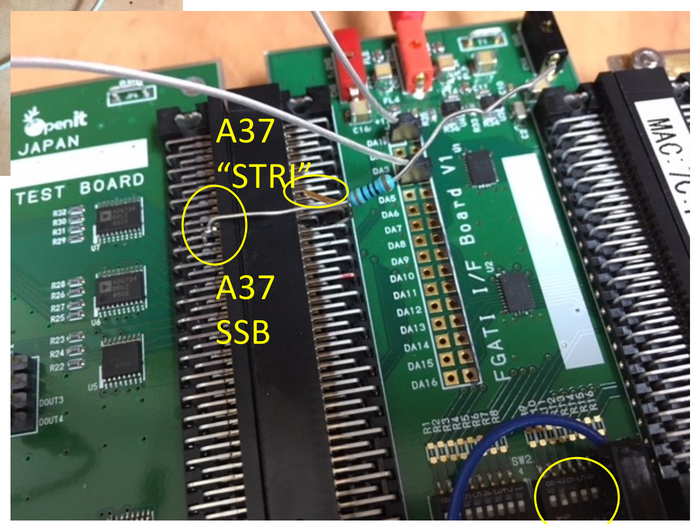
	Input type	Gain @ Vout	Rise time
FGATI	Current (C=0.1u)	400mV/10mV=40	3ns
Volume2014	Current (C=0.1u)	300mV/10mV=30	7ns
Volume2012	Voltage	300mV/10mV=30 (or 12 in low gain)	5ns

Reverse engineering from SOY codes & DAC ctrl
→ Kalliope now controls FGATI



You need a manual"set", but Kalliope now controls FGATI.
→ Later Kalliope firmware is updated for FGATI control (auto SSB)



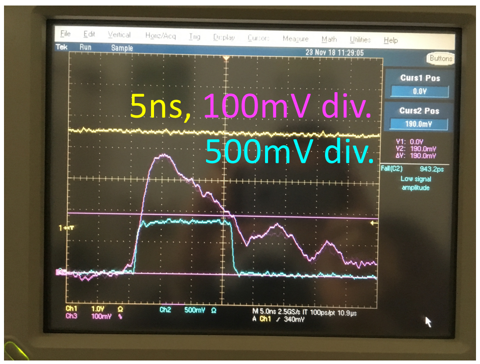


SW1-7 (MSEL=ON)

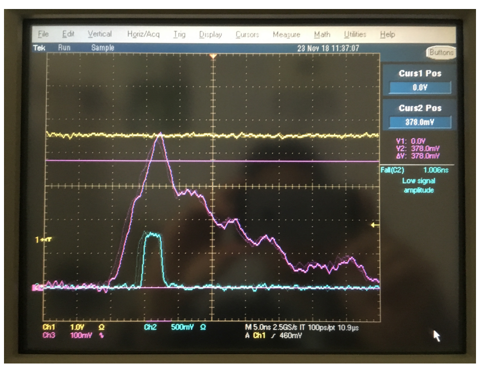
Pulled A37 contact ("STRI") from FGATI-Kalliope IF board, stick it up, and welded a lead to SSB in (A37) of FGATI-test board.
Manually touch the contacts after loading the DACs.
It works!

TDC of Dout (FGATI)

FGATI



ThDAC=0x20
Dout Δt=14ns



ThDAC=0x30
Dout Δt=2ns

```
$ ./offlinedecoder /data/edb/MSE000106_20181127/MSE000106_192.168.10.1.rawdata
```

Time(ns)	ch4-03	ch4-04
...		
10887:	0	0
10888:	0	0
10889:	0	0
10890:	0	1
10891:	0	3
10892:	0	5
10893:	0	8
10894:	0	48
10895:	0	3181
10896:	0	2890
10897:	0	27
10898:	0	1
10899:	0	0
10900:	0	0
10901:	0	0
10902:	0	0
10903:	0	0
10904:	0	0
10905:	0	0
10906:	0	0
10907:	0	0
10908:	0	0
10909:	0	0
10910:	1	0
10911:	28	0
10912:	1098	0
10913:	3519	0
10914:	1205	0
10915:	89	0
10916:	34	0
10917:	33	0
10918:	31	0
10919:	16	0
10920:	21	0
10921:	7	0
10922:	9	0
10923:	8	0
10924:	5	0
10925:	4	0

Run 106, ch4
ThDAC=0x20
TDC Δt=18 ns
10913-10895

```
$ ./offlinedecoder /data/edb/MSE000106_20181127/MSE000106_192.168.10.1.rawdata
```

Time(ns)	ch4-03	ch4-04
...		
10887:	0	0
10888:	0	0
10889:	0	0
10890:	0	0
10891:	0	0
10892:	0	0
10893:	0	0
10894:	0	0
10895:	0	0
10896:	0	0
10897:	0	0
10898:	0	0
10899:	0	13
10900:	0	42
10901:	0	16
10902:	0	10
10903:	0	5
10904:	0	4
10905:	0	0
10906:	0	0
10907:	3	0
10908:	28	0
10909:	22	0
10910:	23	0
10911:	10	0
10912:	4	0
10913:	0	0
10914:	0	0
10915:	0	0
10916:	0	0

Run 111, ch4
ThDAC=0x30
TDC Δt=9 ns
10909-10900

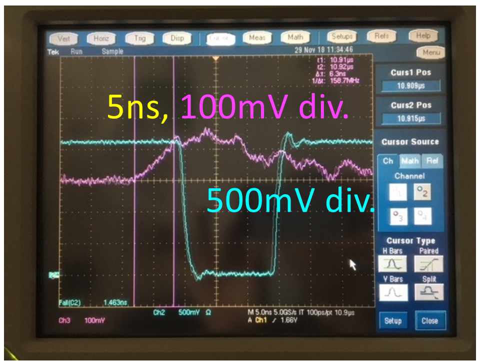
Leading edge timing is +5 ns
10900-10895

Minimum pulse width detectable in TDC is 8ns.

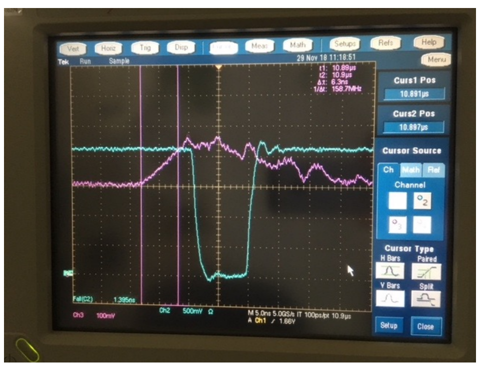
TDC packet is the 04-03 order.
Threshold changes the time over threshold (TOT).
Timing resolution is difficult to determine, because of the jitter of the signals. Laser test bench will do.

TDC of Dout (Volume2014)

Volume2014



ThDAC=0x06
Dout Δt=15ns



DAC=0x20
Dout Δt=10ns

$ ./offlinedecoder /data/edb/MSE000106_20181127/MSE000106_192.168.10.1.rawdata

Time(ns)	ch4-03	ch4-04
...		
10890:	0	0
10891:	0	0
10892:	0	0
10893:	0	0
10894:	0	0
10895:	0	0
10896:	38	0
10897:	4300	0
10898:	9648	0
10899:	407	0
10900:	4	0
10901:	0	0
10902:	0	0
10903:	0	0
10904:	0	0
10905:	0	0
10906:	0	0
10907:	0	0
10908:	0	0
10909:	0	0
10910:	0	11
10911:	0	84
10912:	0	2479
10913:	0	10274
10914:	0	1487
10915:	0	53
10916:	0	9
10917:	0	0
10918:	0	0
10919:	0	0
10920:	0	0
10921:	0	0
10922:	0	0
10923:	0	0
10924:	0	0
10925:	0	0
10926:	0	0
10927:	0	0
10928:	0	0
10929:	0	0
10930:	0	0

Run 120, ch1
DACs=0x06240021
TDC Δt=15 ns
10913-10898

$ ./offlinedecoder /data/edb/MSE000106_20181127/MSE000106_192.168.10.1.rawdata

Time(ns)	ch4-03	ch4-04
...		
10890:	0	0
10891:	0	0
10892:	0	0
10893:	0	0
10894:	0	0
10895:	0	0
10896:	0	0
10897:	0	0
10898:	3	0
10899:	25	0
10900:	4194	0
10901:	8559	0
10902:	281	0
10903:	1	0
10904:	0	0
10905:	0	0
10906:	0	0
10907:	0	2
10908:	0	39
10909:	0	3493
10910:	0	8959
10911:	0	555
10912:	0	13
10913:	0	2
10914:	0	0
10915:	0	0
10916:	0	0
10917:	0	0
10918:	0	0
10919:	0	0
10920:	0	0

Run 121, ch1
ThDAC=0x20240021
TDC Δt=10 ns
10901-10910

Leading edge timing is
+3 ns
10901-10898

TDC packet is the 03-04 order.
Threshold changes the time over threshold (TOT).
Timing resolution is difficult to determine, because of the jitter of the signals. Laser test bench will do.

Instability of DAC control on FGATI board v.1

Summary of FGATI board v.1 (GN1809-1) test

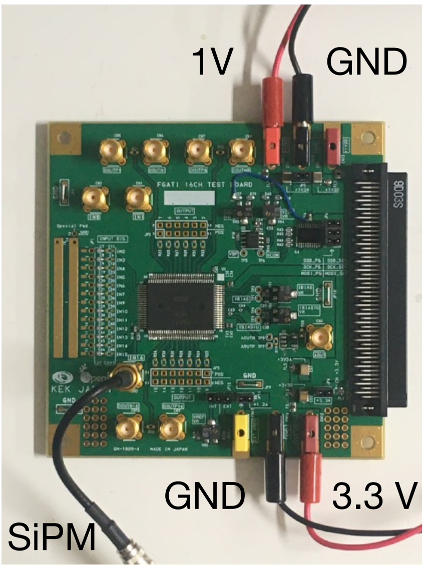
- Faster rise time (ASIC)
  - ✓Kallope controls DAC and take TDC from FGATI.
  - ✓FGATI has faster rise time (3ns) than Volume2012 (5ns) or Volume2014 (7ns).
  - → Instability of DAC setting is an issue to go forward to a beam test.
- Finer TDC resolution needed
  - 1ns TDC on Kalliope (Spartan-6) is too sparse
  - Honda's HR-TDC (30ps?) would be perfect, and we are interested in.

DAQ test at TRIUMF + PMT existing detectors

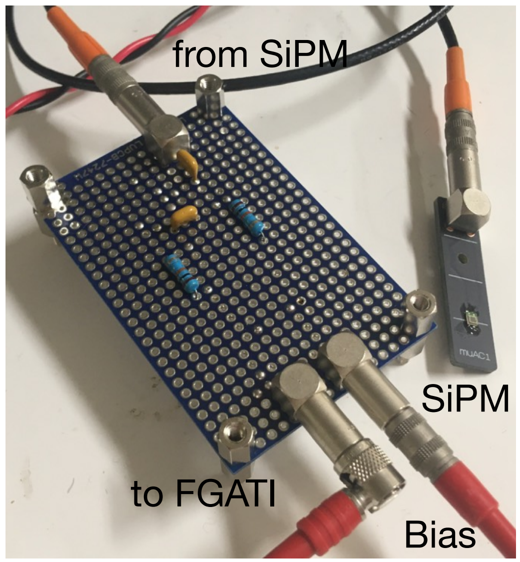
- Different DAQ cycle (for DC)
  - ✓developed on Kalliope for MuSIC (Osaka) and neutron imaging at BL10 (MLF)
  - ✓sitcp_dump (Yamagata's DC-mode program) survived for TRIUMF muon beam intensity (50kcps triggers).

supplement

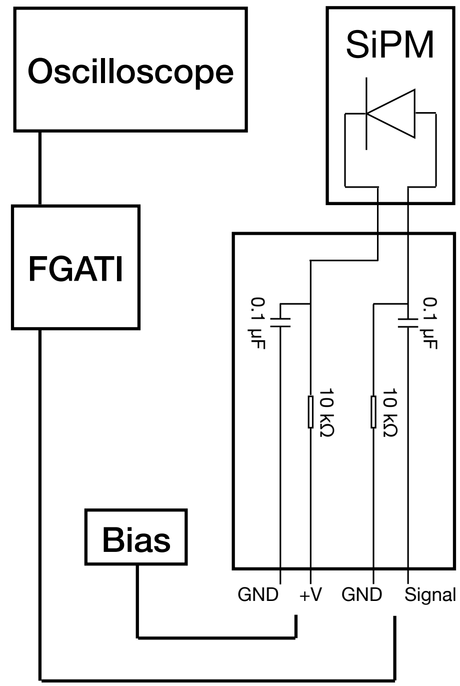
Kanda’s test on FGATI test board v.4 (GN1809-4)



FGATI 16CH TEST BOARD
GN-1809-4

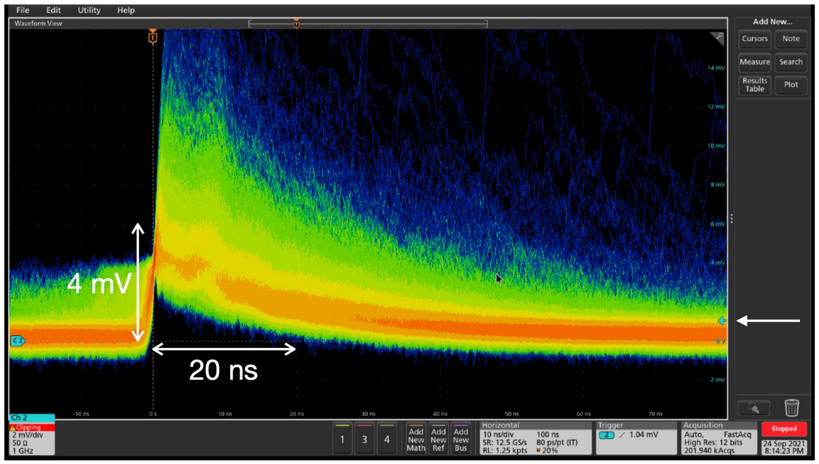


SiPM and FGATI are AC coupled.



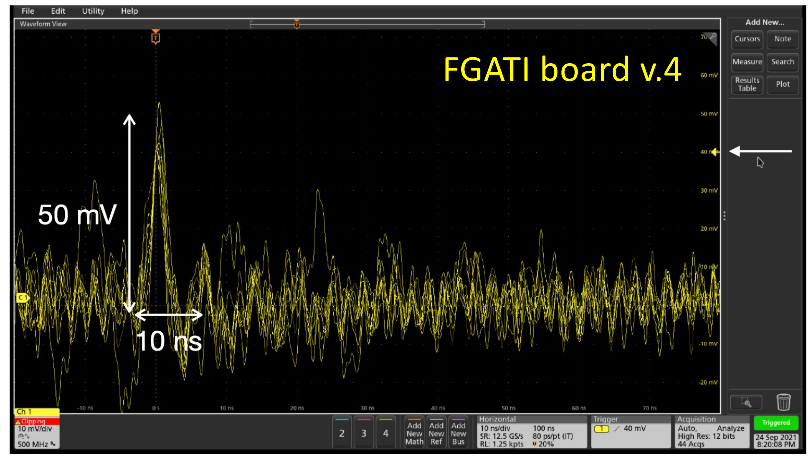
Parameter	Value
Vref	1.2V
Vcom	0.6V
IBIAS1U	1μA
1BIAS	80μA
VBP	2.5V

Input signal and FGATI output: comparison



Charge Q?

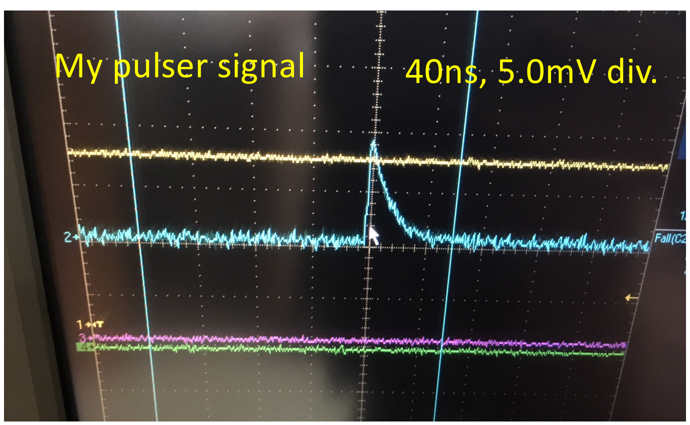
trg.

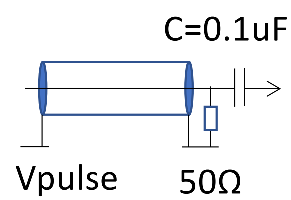


trg. (40 m

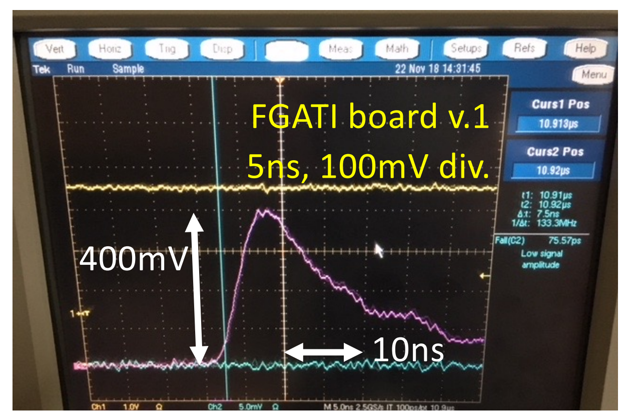
FGATIのIN16への入力信号を直接オシロで見た様子。Vbr.+3 Vで使用。
50 Ohm終端、1 GHz、1 mV self trigger。MPPCのdark 1 p.e.は2 mVくらい。

FGATIの出力信号(TP8)をPassive probeを使ってオシロで見た様子。2秒 persistent。
ノイズが大きくself triggerでいい感じの画を撮るのが難しい。どこでノイズが乗っているのか？回路への電源や周辺機器の影響など簡単に調べたが特定できず。

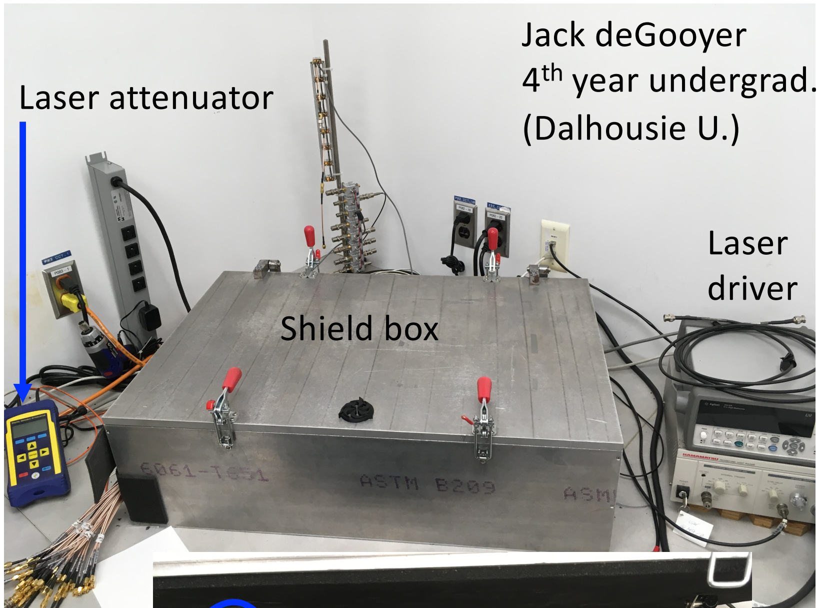


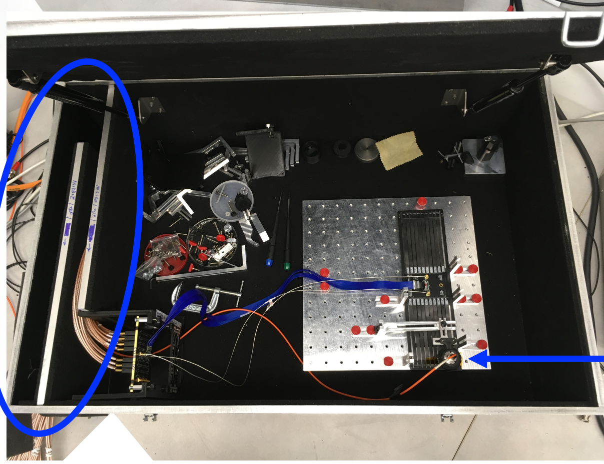


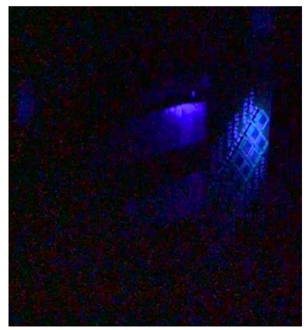
Q=CV=0.1uF x 10mV
=**1000pC**



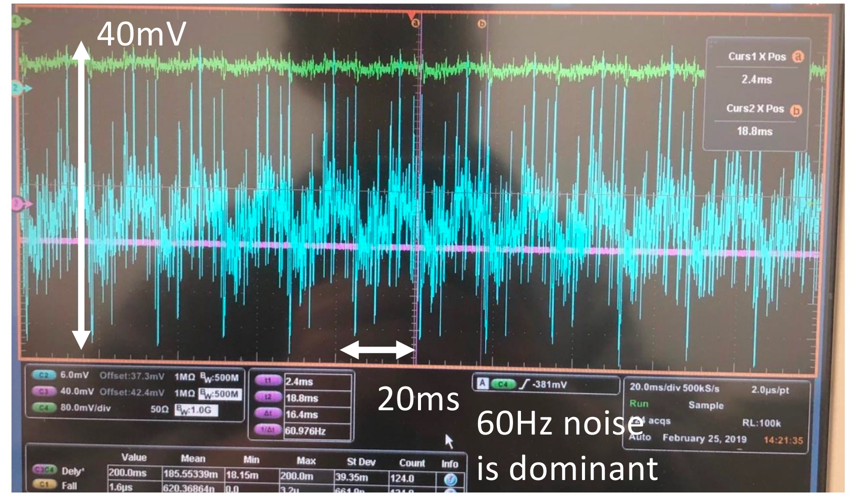
SiPM input test@TRIUMF



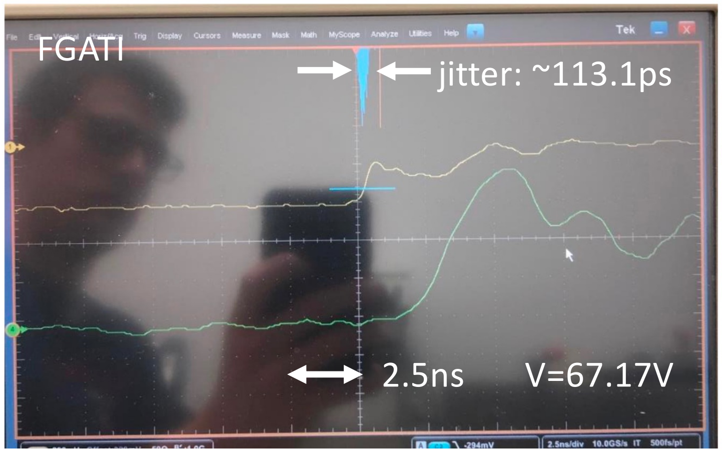




Blue short pulse laser in the dark shield box



SiPM input test@TRIUMF



Volume2014

jitter: ~1.1ns

Summary of (analog) timing resolutions are:

FGATI	113 ps
Volume2012	150 ps
Volume2014	1.1 ns

However, the noise level contributes to the jitter and not conclusive.