Fast luminosity measurements by ZDLM of the counter type

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For meetings at IPHC, Strasbourg

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Luminosity measurement by ZDLM

Zero **D**egree **L**uminosity **M**onitor

detects the very-forward Radiative Bhabha events

$e^+ e^- \rightarrow e^+ e^- \gamma$

Each of the final-state particles goes to

0-degree for either of incident beams

(The photon is collinear with either of the incident e^+ or e^-,

even in lab. with the finite-angle crossing).

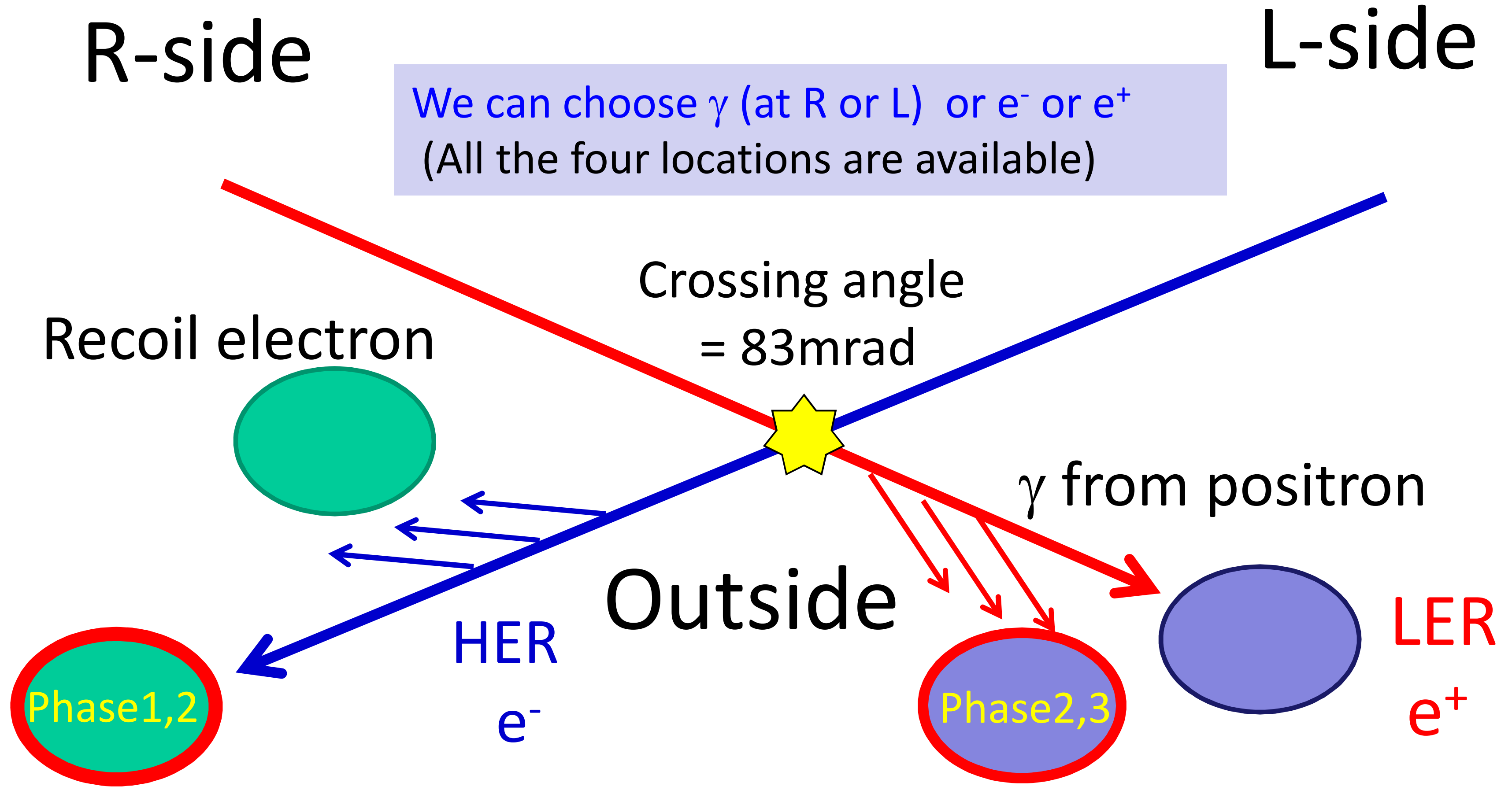
Cross section at $\sqrt{s}$ = M(Υ(4S))

σ = ~10^{-25} cm^2 for E_γ>10MeV

very high (sometimes too high) rate for L~$10^{35}/cm^2/s$

rate ~10 GHz > bunch-collision rate (max. 0.509 GHz)

Where are the signals?



γ from electron @ ~15m

High rate
Sensitive to background from the single beam's bremsstrahlung with beam gas

Recoil positron @ ~12 m

Moderate rate
The best location for high-purity measurement

ZDLM@SuperKEKB/Belle II

(1) Analog integration or discrimination by threshold for Real-time measurement of luminosity for automatic feedback

High-rate (multiple-event) problem for simple counting against the intersecting rate

Integrate pulse size/shape (Capable to the higher rate)

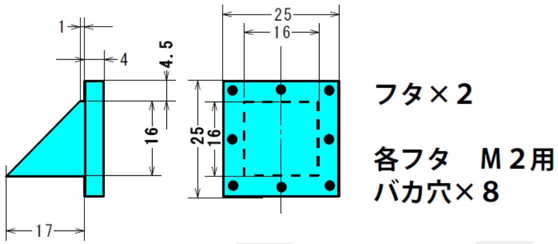
(2) High-precision timing measurement for

- bunch-by-bunch (every ~1s, with Δt < 2ns separation)
  high-freq. vibration (every ~ 1ms) measurements
  as performed at Belle

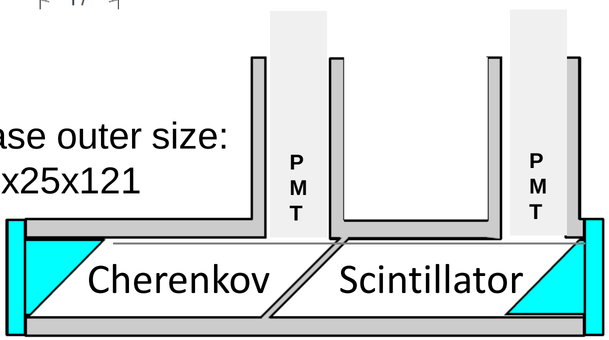
Aiming a 100% duty factor and a quick online analysis

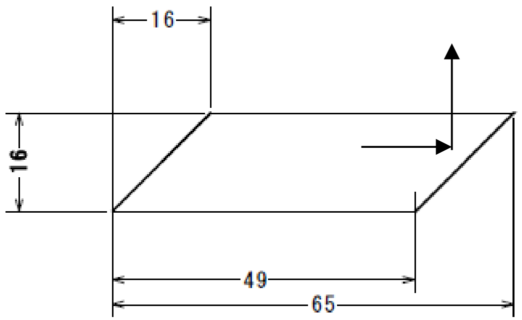
Detector

ZDLM for SuperKEKB of the counter type



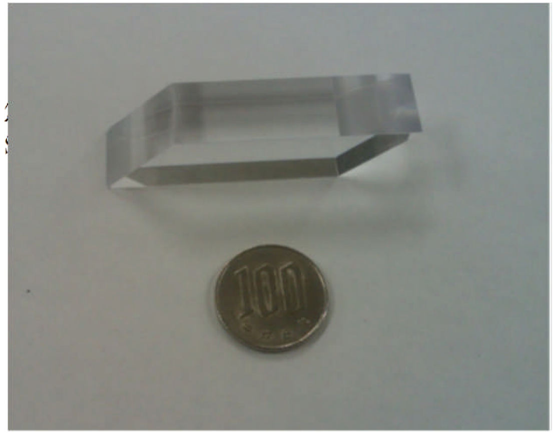
Case outer size:
25x25x121





15x15x64(full length) cut with 45 deg at the two ends
Scintillator is covered by an Al-foil

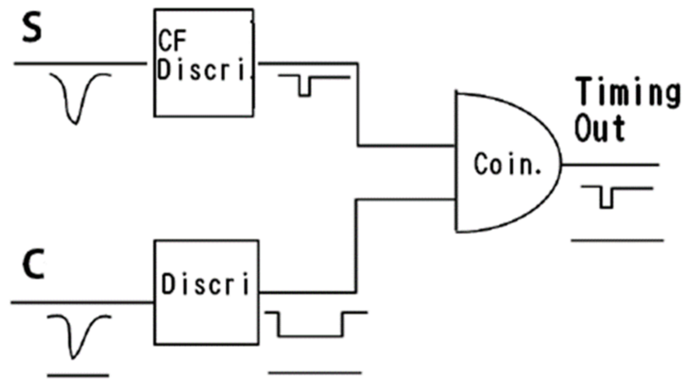
Hamamatsu PMT H3165-11 (1/2”)
for each



LGSO non-organic scintillator
and ES-crystal (quartz)
Both no-color and fully transparent

Scintillator vs Cherenkov

Cf. Diamond sensor type (LAL)



Scintillator:

Larger pulse size

better photon-quanta statistics

safer even in a weak magnetic field degrading PMT

Cherenkov:

Not sensitive to low-energy photon backgrounds

rejection with the coincidence

Time resolution

Better at Cherenkov when its pulse size is large enough

Better at Scintillator when Cherenkov's pulse size is small

LGSO Crystal Scintillator

- LGSO (similar to LSO) -- ($Lu_xCe_yGd_{2-x-y}SiO_2$) produced by Hitachi Chemical

- High density, high Z
- Large light yield
- Radiation hardness expected
- Not-bad timing response (decay is a little slow)
- Self radiation of Luthetium176

(2.59%, β-decay, <1.2MeV, HL 37.8Gyr)

■ Characteristics

Crystal scintillators	GSO	GSOZ	LGSO (Lu:20%)	LGSO	BGO	LSO	$LaBr_3$:Ce	NaI:Tl
Density (g/cm 3)	6.71	6.71	6.5	7.3	7.13	7.4	5.29	3.67
Effective Z	58	58	59	63	72	65	47	50
Absorption Coeffi. at 511 kev	0.7	0.7	0.7	0.85	0.96	0.86	0.47	0.35
Decay constant (ns)	30 - 60	30 - 60	50,115	41	300	42	26	230
Light output (relative)	20	24	42	85 - 90	7 - 12	40 - 90	120-160	100
Energy Resolution (%)	9	9	8.5	8	10	8 - 10	3	7
Peak emission λ_{em} (nm)	430	430	430,500	420	480	420	380	415
Index of refraction at λ_{em}	1.85	1.85	1.85	1.83	2.15	1.82	1.88	1.85
Hygroscopicity	no	no	no	no	no	no	Strong	Strong
Melting point (deg.C)	1950	1950	1950	2050	1050	2100	783	651

※Data in this sheet are typical values, are not guaranteed value.

From "Hitachi single crystal scintillators", Hitachi Chemical

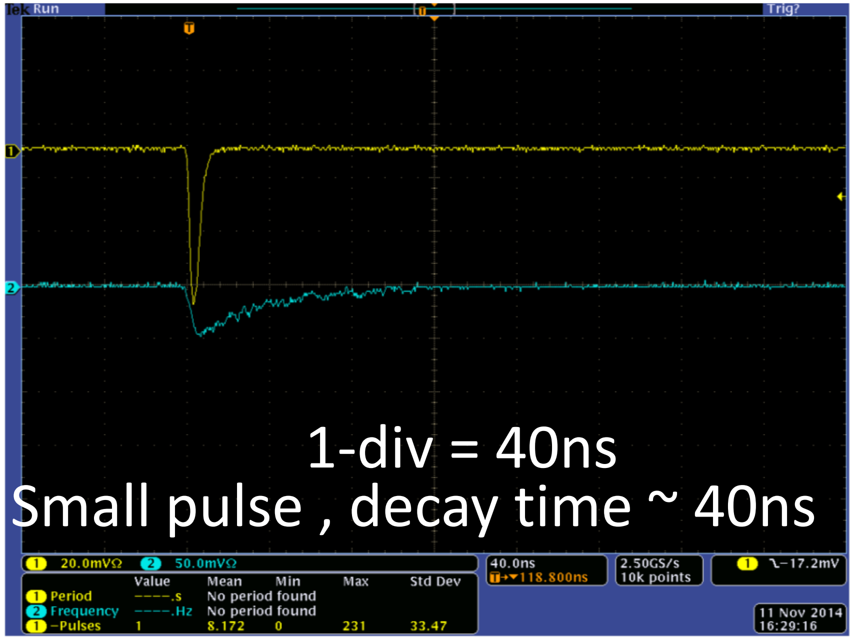
Signals from LGSO

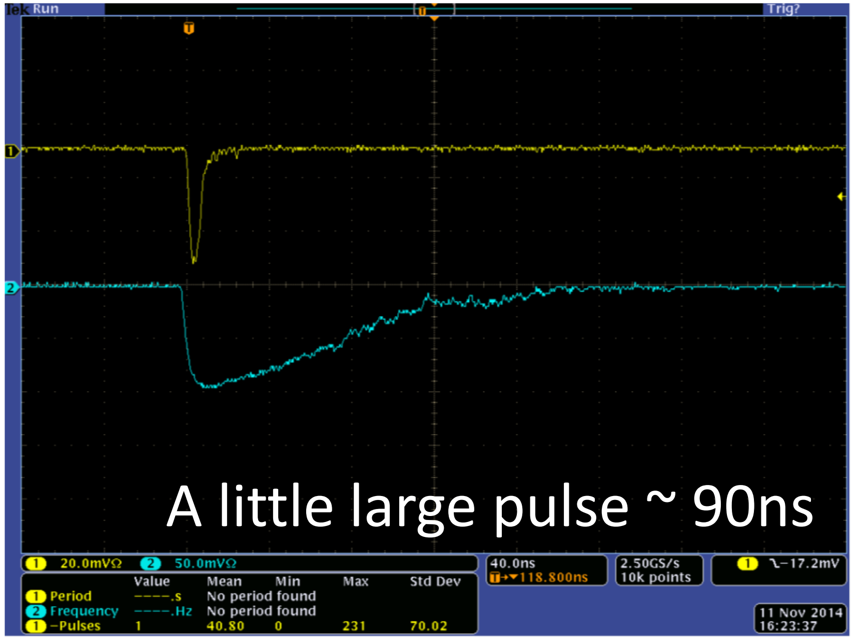
Slow decay time (variable in 40ns – 200 ns) observed

Seems to be dependent of the pulse size, perhaps due to the saturation of the PMT looking at strange pulse shape

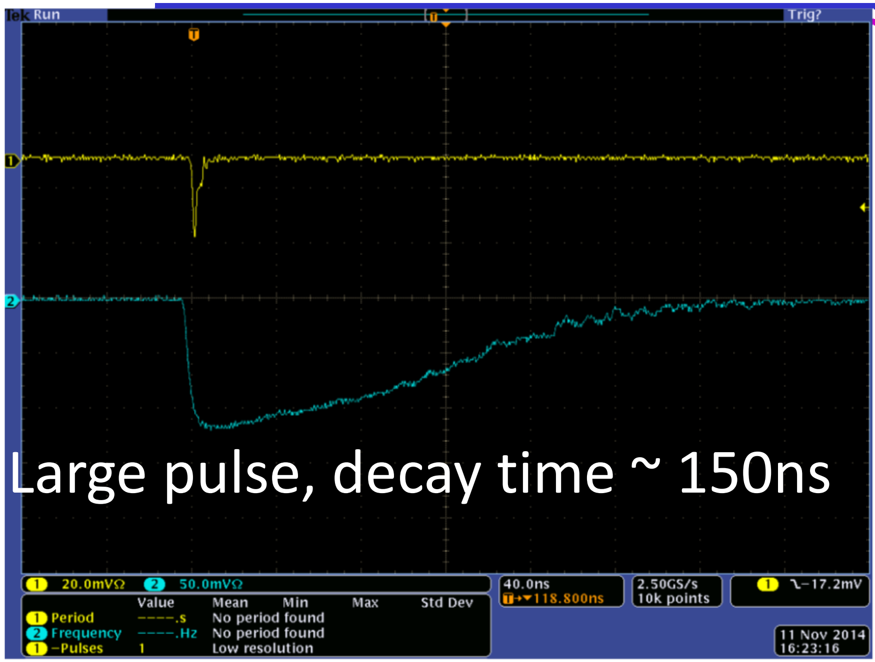
Look cosmic rays with coincidence with Cherenkov

(Upper yellow: Cherenkov, Lower cyan: LGSO)





Signals/backgrounds from LGSO



Large pulse, decay time ~ 150ns

Timing measurement under a high rate (>1MHz) is impossible

The rising speed is reasonably good

Self irradiated by radio-Lutetium's beta rays --- decay time ~ 40ns

Pulse size safely smaller than 0.5 penetrating mip

No problem for separation Provides a calibration

Our piece including 55g Lu -- 4.5kBq in calculation

about 2 kHz in measurement (with the lowest threshold setting)

Analog Electronics for Integration amplifier

Signal-to-noise ratio

$$S/N = \frac{S}{\sqrt{N+S}}$$ for counting measurement

$$S/N = \frac{S}{\sqrt{(\Delta N)^2 + (1+\sigma^2)S}}$$ for analog sum

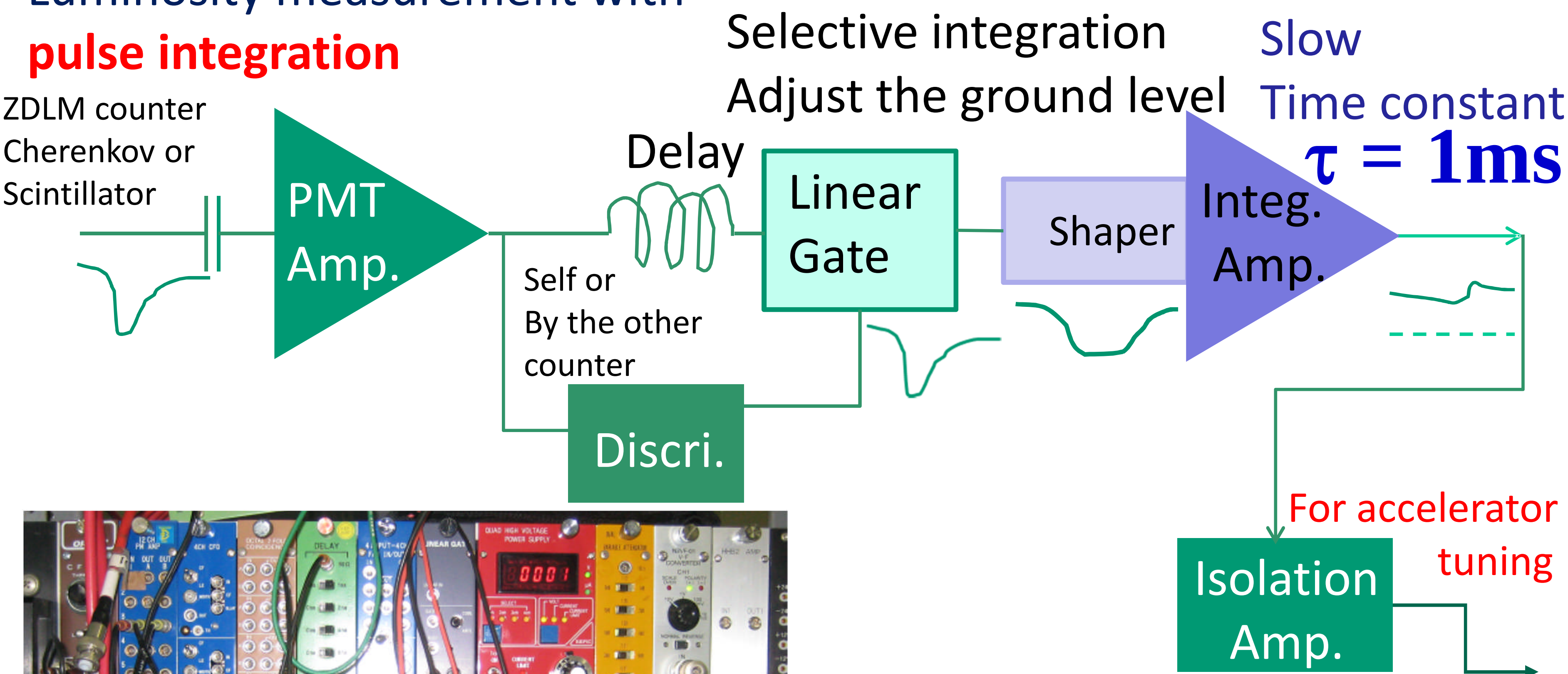
S: total signal count, N: total noise count,

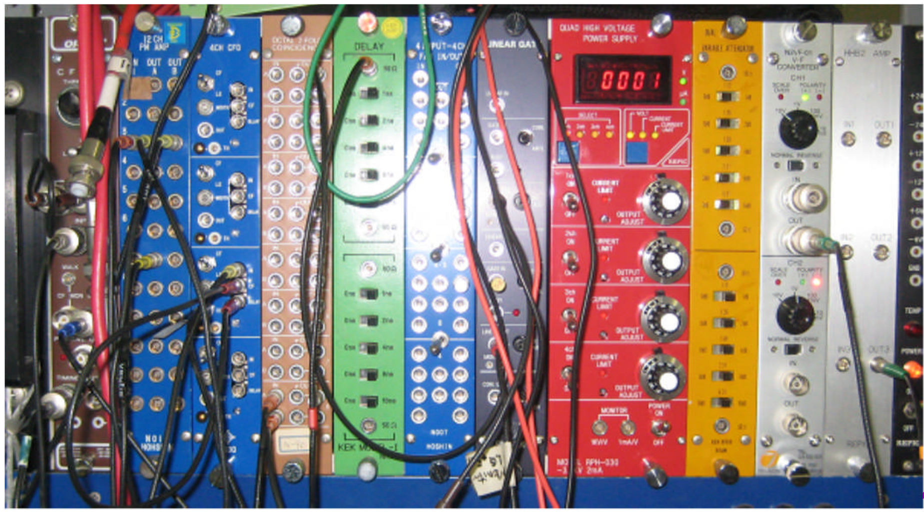
ΔN: fluctuation of the noise size relative to the averaged single signal size

σ^2 : variance of the single signal size relative to the averaged single signal size

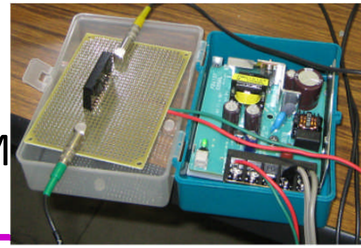
Measurement scheme

Luminosity measurement with
pulse integration

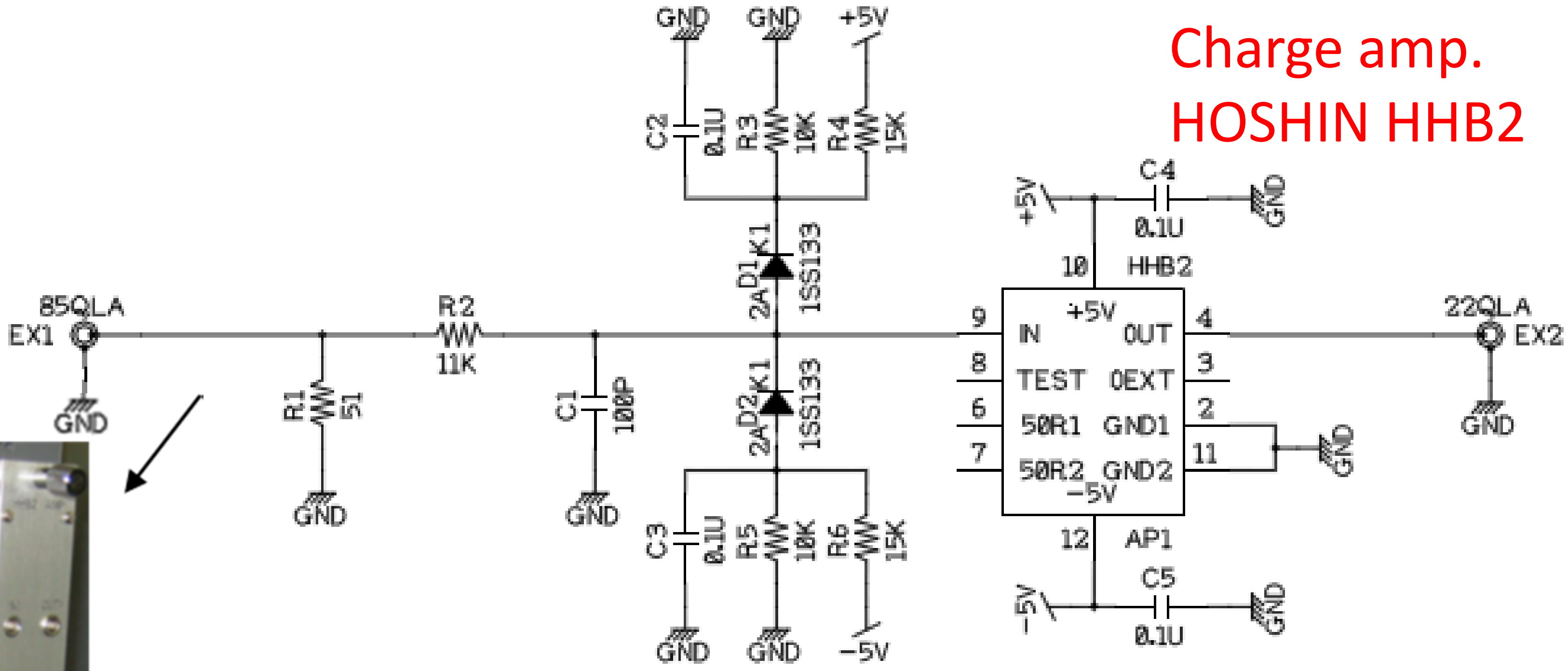




M-SYSTEM
20VS3-U



Circuit of the Shaper + Integration amp.



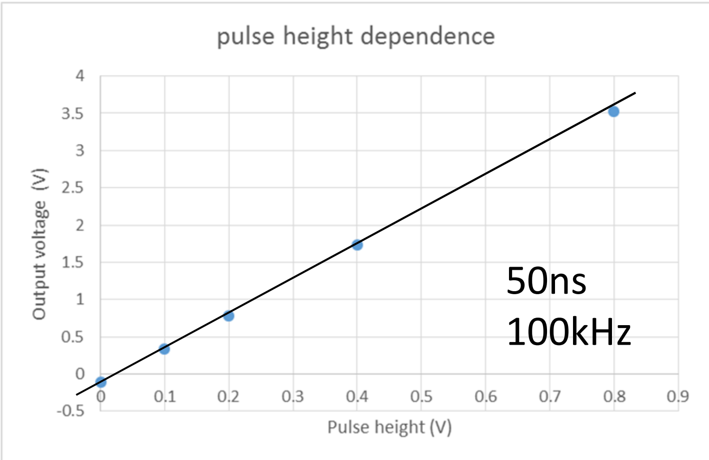
Three channels
in a NIM module

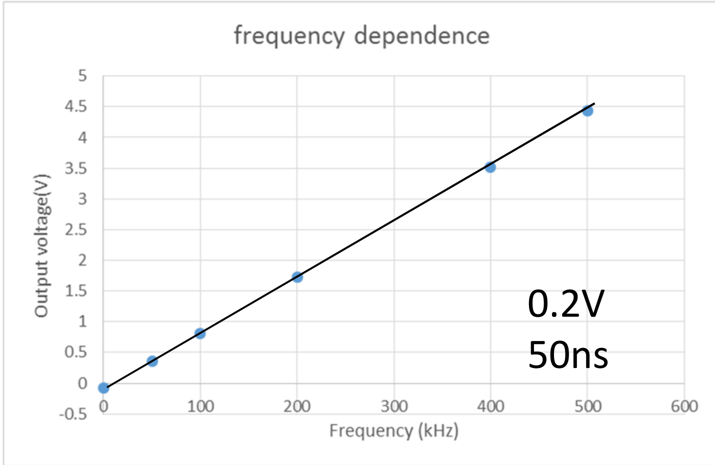
Functional test of the integration amp.

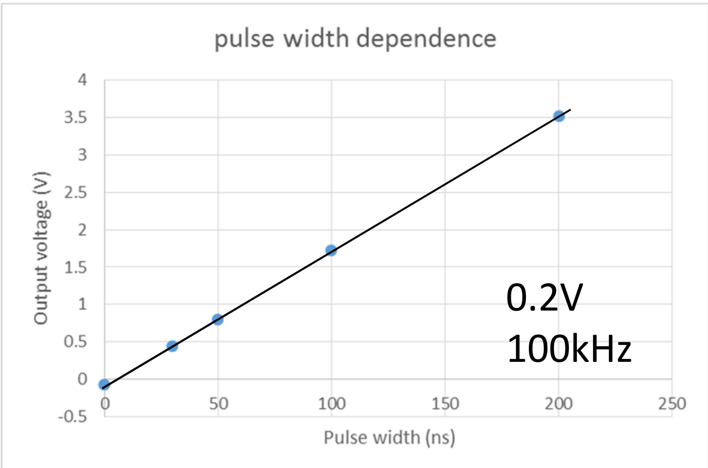
Should have **a linearity for pulse-size integration** with τ = 1ms. That is,

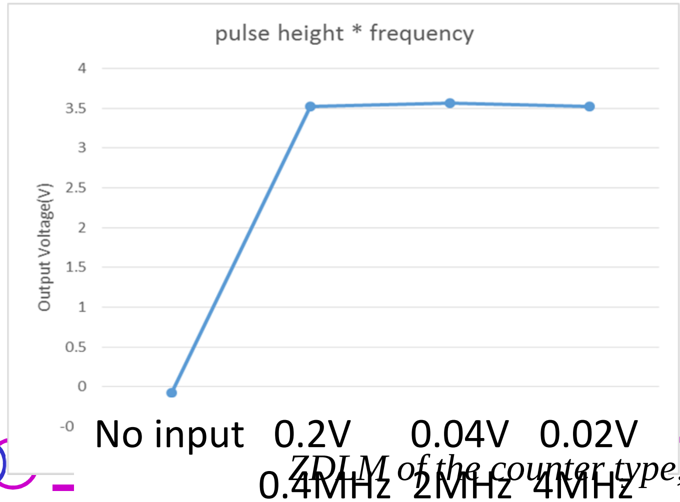
be proportional to **each** of pulse height, pulse width and frequency.

Test Results (measured by an oscilloscope via an isolation amp.)









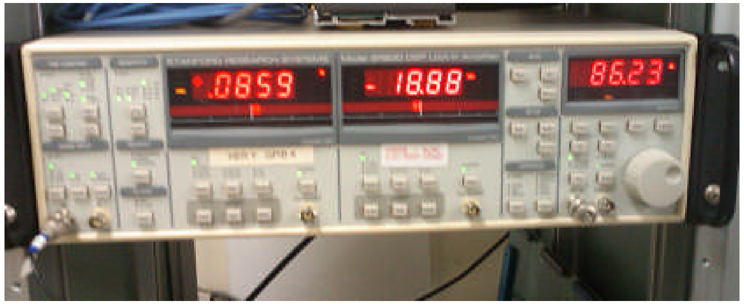
The lines are guide for eyes (not fit)

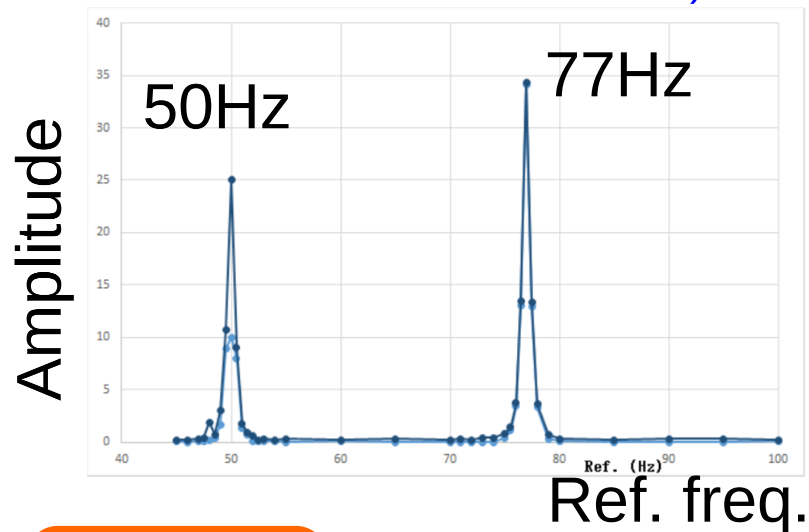
Connection test to Lock-in Amp.

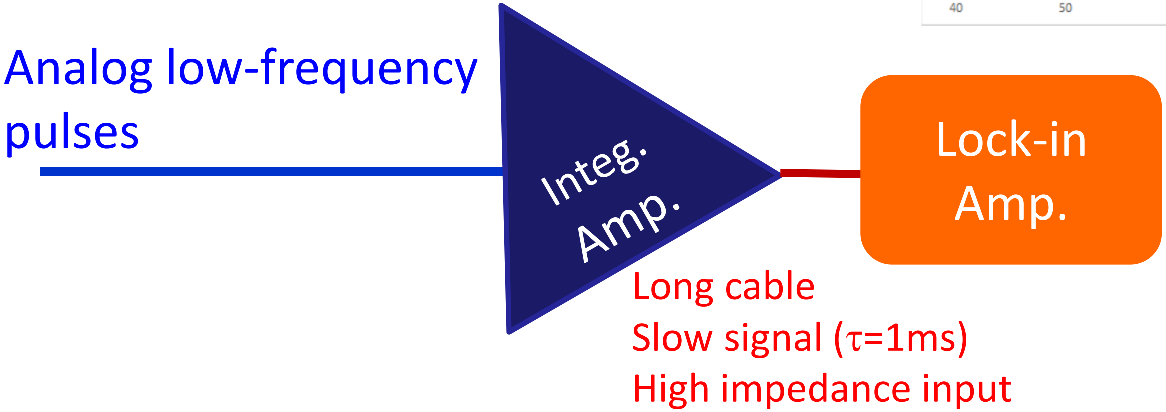
For dithering tuning (Tested by T.Kawamoto, M.Masuzawa, S.Uehara)

- Time constant tentatively tuned at (300ms, 18dB)
- Access via EPICS developed

Response to Emulated signals (50Hz, 77Hz sine-waves admixture)







A model of Lock-in Amp.

- Modulated Amplification

  Output(t) ~ Input(t)*$\cos(2\pi f_0 t + \phi)$

  Two phases $\cos 2\pi f_0 t$ and $\sin 2\pi f_0 t$

Measuring signal size

$C = \Sigma \cos 2\pi f_0 t_i$ t_i : time of each event

$S = \Sigma \sin 2\pi f_0 t_i$ Σ: summation for one measurement

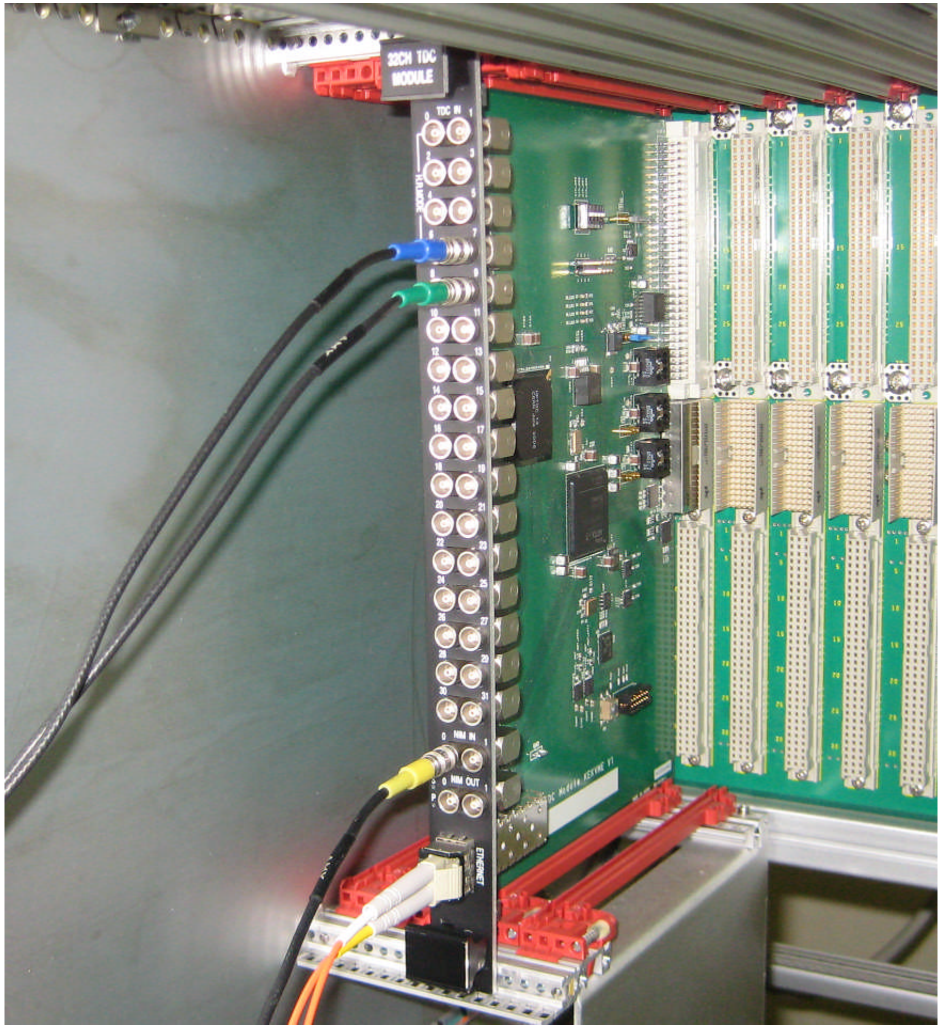
Size: $\sqrt{C^2 + S^2}$, Phase = arctan(S/C)

Dithering frequency: f_0=77Hz

doubled: f_0=154Hz

TDC system for bunch-by-bunch luminosity measurement

VMETDC module for precise timing measurement



A VME module (6U)

A HP-TDC chip

Ethernet (Optical Gbit) Communication

without use of VME bus

Developed by KEK-IPNS Electronics Group

The sides about TDC are prepared by the KEK Electronics group (M.Shoji, M.Ikeno, T.Uchida, M. Tanaka, Translated by S.U).

HP-TDC

- Specifications of TDC
  - **HP-TDC** chip

    developed at CERN

Required performance for ZDLM

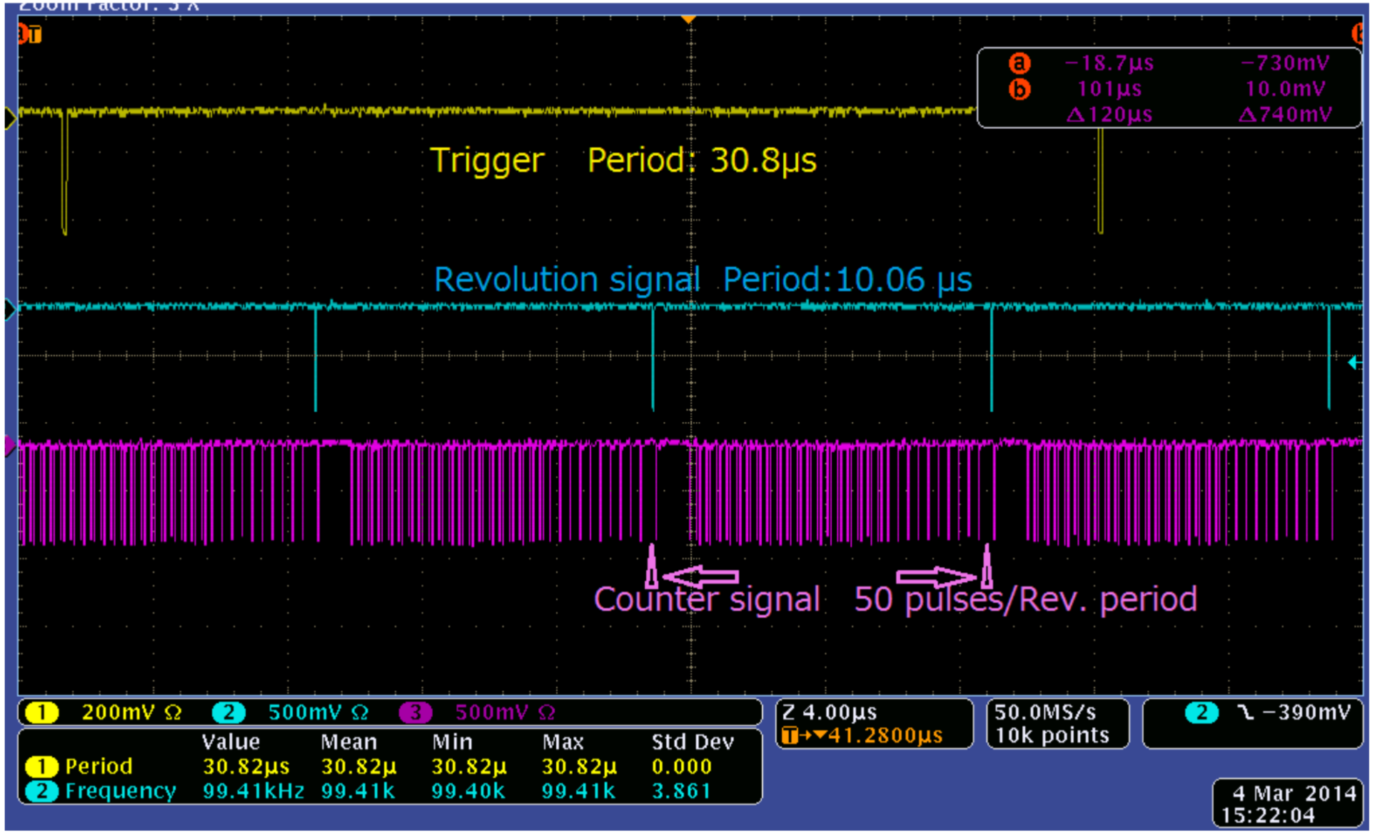
Time resolution	500ps
I/O I/F	9ch or more
Average rate	Max. 5MHz

External clock	40MHz
Readout methods	parallel, serial or JTAG
Signal Input	**Max 32ch**
Signal level	LVDS or LVTTL
Power consumption	450～2000mW
Resolution	781, **195, 98, 25 ps**
Input Rate	**Max 8MHz**

Very High Resolution mode(Resolution : 25ps)
Use 8/32ch(ch# 0,4,8,12,16,20,24,28

Operation test of VMETDC

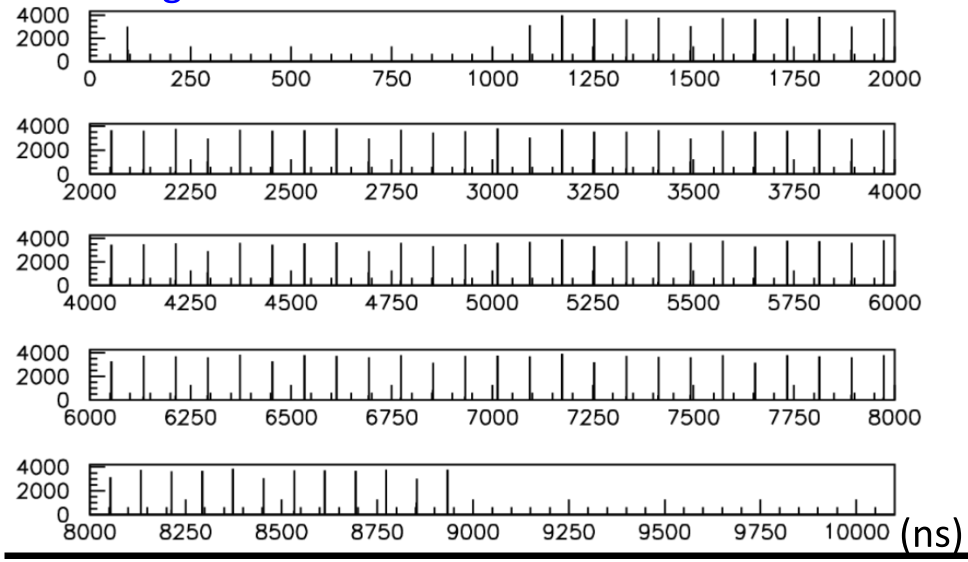
Test patterns of collision-bunch signals and the revolution signal are generated by pulse generators of DAC type controlled by PC



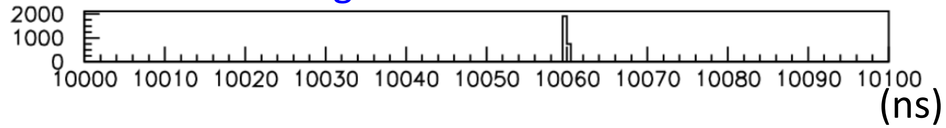
ELMOS AWG-100

10MHz – DAQ -- Online-histogramming achieved

Hit timing from VMETDC



Revolution timing

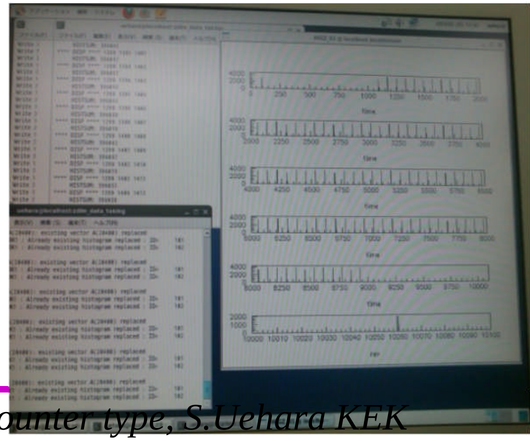


Test pattern from the pulser ---
100 pulses every 1 beam-turn
period (=10.061ms)
→ 10MHz hits @VMETDC

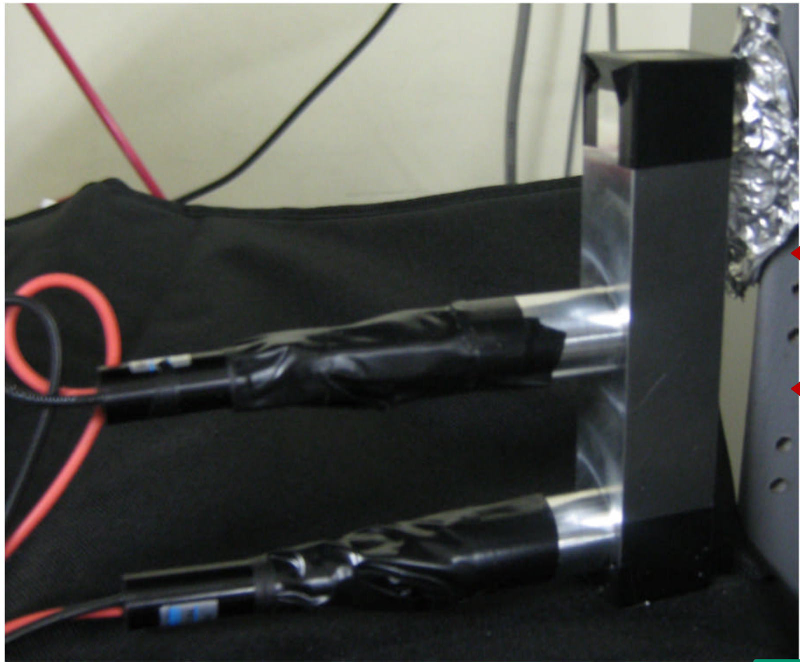
←

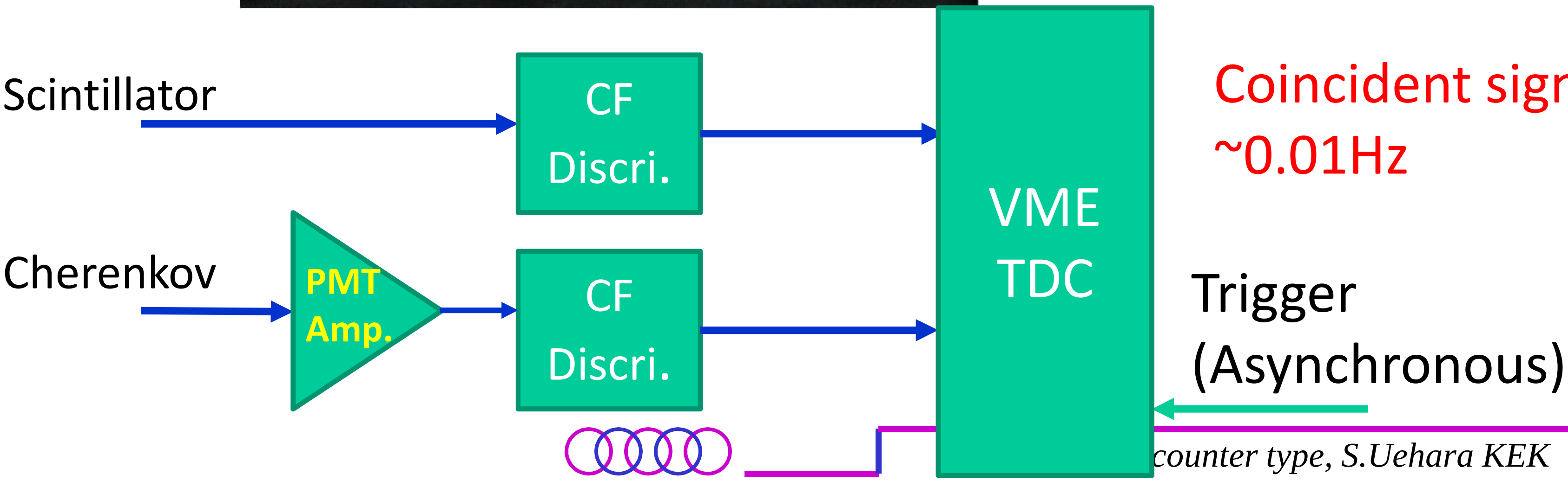
Histogramming --- every 0.4M hit
Such a histogram is produced
every 40ms (25 histograms/sec)
Counting number of hits,100% duty-factor is confirmed

DAQ PC (Linux)
Multi-task
Dual shared-memory buffer
1. DAQ → 2. Histogramming (100%)
→ 3. Display (sampling)



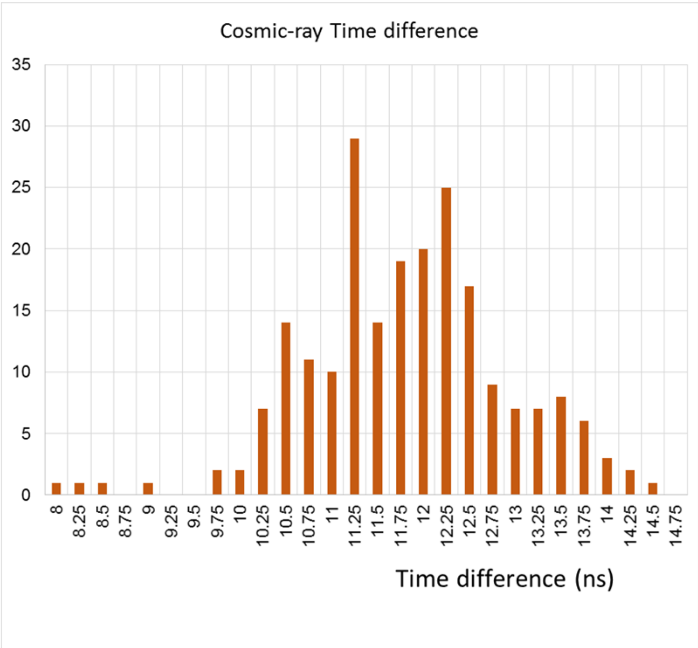
Cosmic-ray test for using CF discriminators





Coincident signals:
~0.01Hz

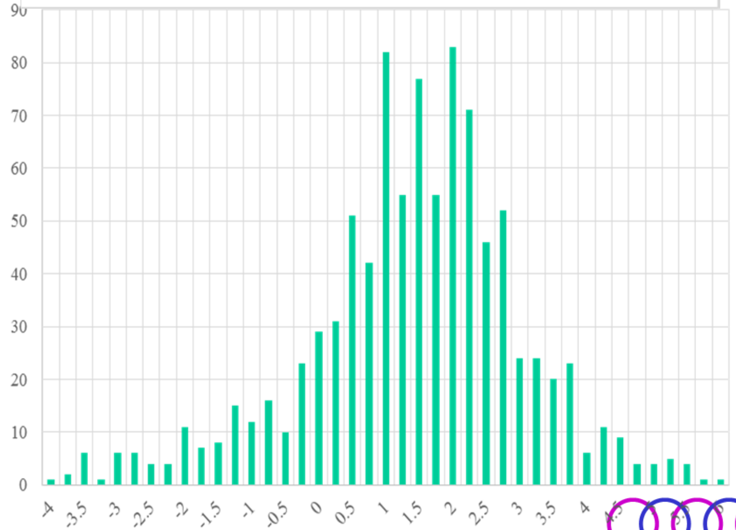
Timing Measurement by VMETDC in Cosmic-ray test



Time difference between two counters ZDLMs,

Cherenkov and **Plastic** scintillator

σ = 0.98 ns for 2 counters



Cherenkov and **LGSO** scintillator

σ = 1.31 ns for 2 counters

Time resolution < 1 ns is achieved for one counter.

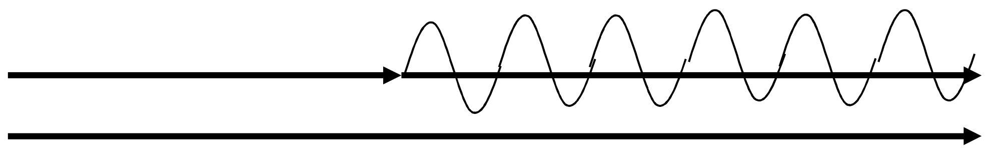
LGSO is worse than plastic, perhaps due to saturation of PMT

Operation at Phase I

Detects beam-nucleus Bremsstrahlung at the gamma position (HER) – Provide a calibration

$e + A \rightarrow e + \gamma + A'$ (A: beam gas nucleus)

- The energy spectrum is the same as in the e^+e^- collision signal.
- The timing structure directly corresponds to the bunch-by-bunch structure of the beam (because the beam electrons and radiated photons propagates the same distance in the same time, independently of the scattering point).



Commissioning Plan

~2015 Summer-fall --

Setup a ZDLM outside Belle II/BEAST II

2015 Phase I --

Background (mainly beam-gass brems)

with ZDLM + BEAST II

2016 –

Fast luminosity monitoring → Accelerator tunings

Summary

Machine – detector interface through luminosity measurement at a luminosity-frontier machine

Instantaneous luminosity measurement and feedback using
ZDLM scintillator and Cherenkov counters via an integration amplifier
The basic function of the circuit confirmed.

Bunch-by-bunch luminosity measurement using high-precision TDC and constant-fraction discriminator
~1.0ns time resolution (per counter) is achieved for m.i.p. (cosmic-ray muon) is achieved.

Studies using Nuclear bremsstrahlung (under single-beam condition) is aimed

Backup

Full Story

- Feedback on the accelerator with a fast luminosity measurement

  Radiative Bhabha process

  Zero-degree luminosity monitor

  Dithering

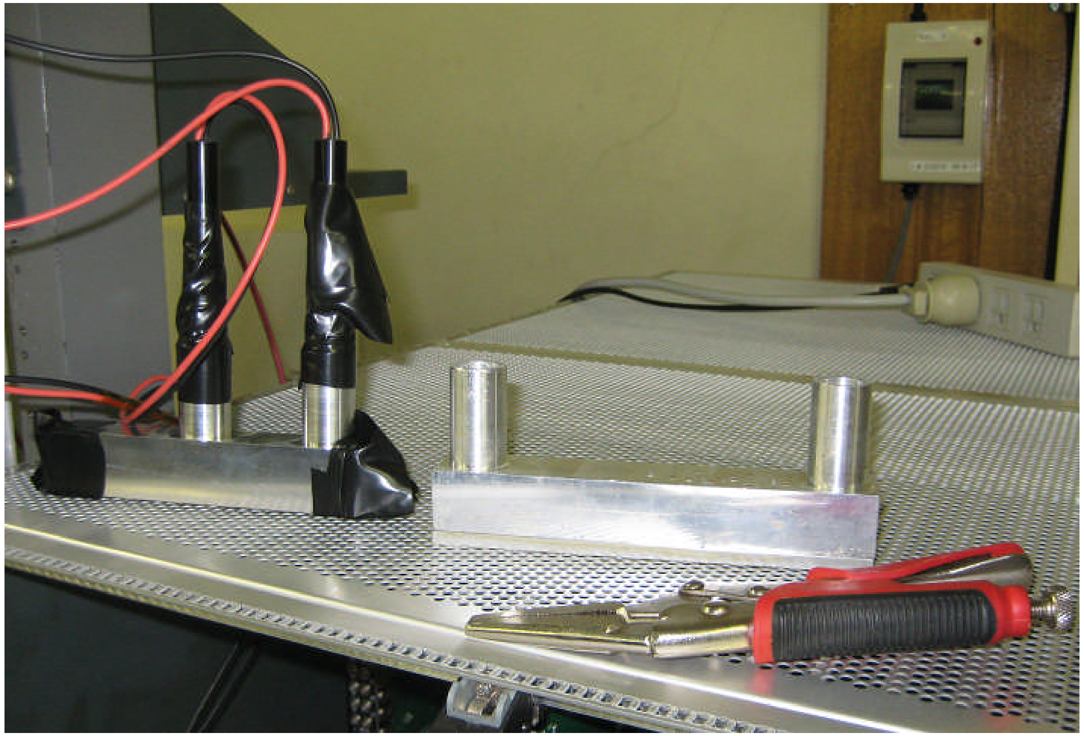
  Simulations

  Detector R&D

  Collaboration

  (Belle II + ZDLM + BEAST II) + SuperKEKB + SLAC + LAL

with the Belle type



↑New and ↑Old

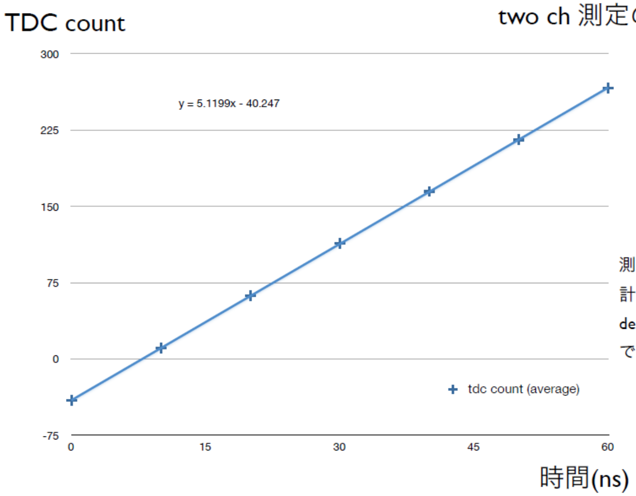
with two 13mmϕ PMTs (Hamamatsu H3165-11)

Coincident signals of cosmic rays have been observed on oscilloscope

Test and data analyses

Linearity測定

The data are read-out from VMETDC. (analyzed by M.Shoji)



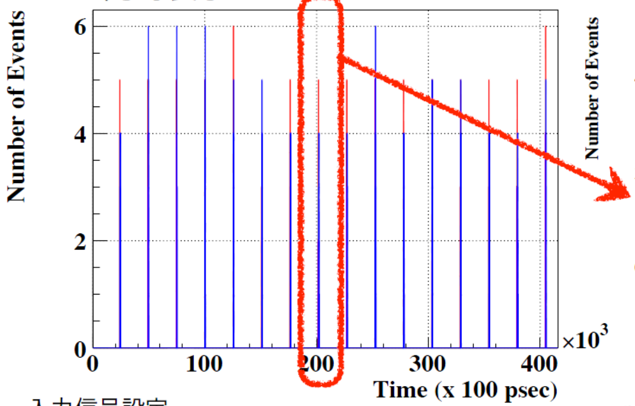
two ch 測定の結果(tdc countは2chの差です)

delay	tdc count (average)	sigma	差分
0	-40.66	0.789	51.708
10	11.048	0.579	51.212
20	62.26	0.453	51.51
30	113.77	52.37	51.02
40	164.79	0.824	50.77
50	215.56	0.784	51.12
60	266.68	0.591	

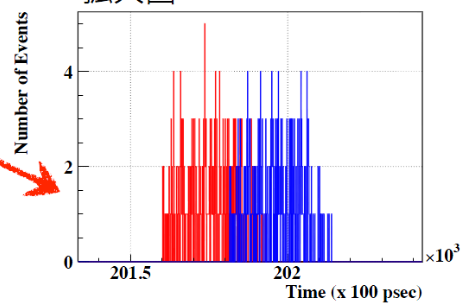
σ = 50 – 80 ps

測定
計算
delay
であ

2ch同時表示



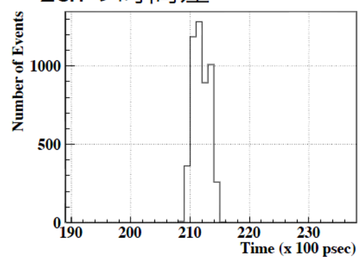
拡大図



入力信号設定

- トリガー間隔 : 40μs
- 信号間隔 : 2.5μs
- 2chの時間差 : 20ns

2chの時間差



約21.1ns

1 TDC count=100psで測定できていることを確認
トリガー信号or入力信号が揺らいでいるように見える
2chの時間差は21.1nsだったので、設定とあっている

Readout Circuit at KEK

Counting rate -- proportional to Luminosity

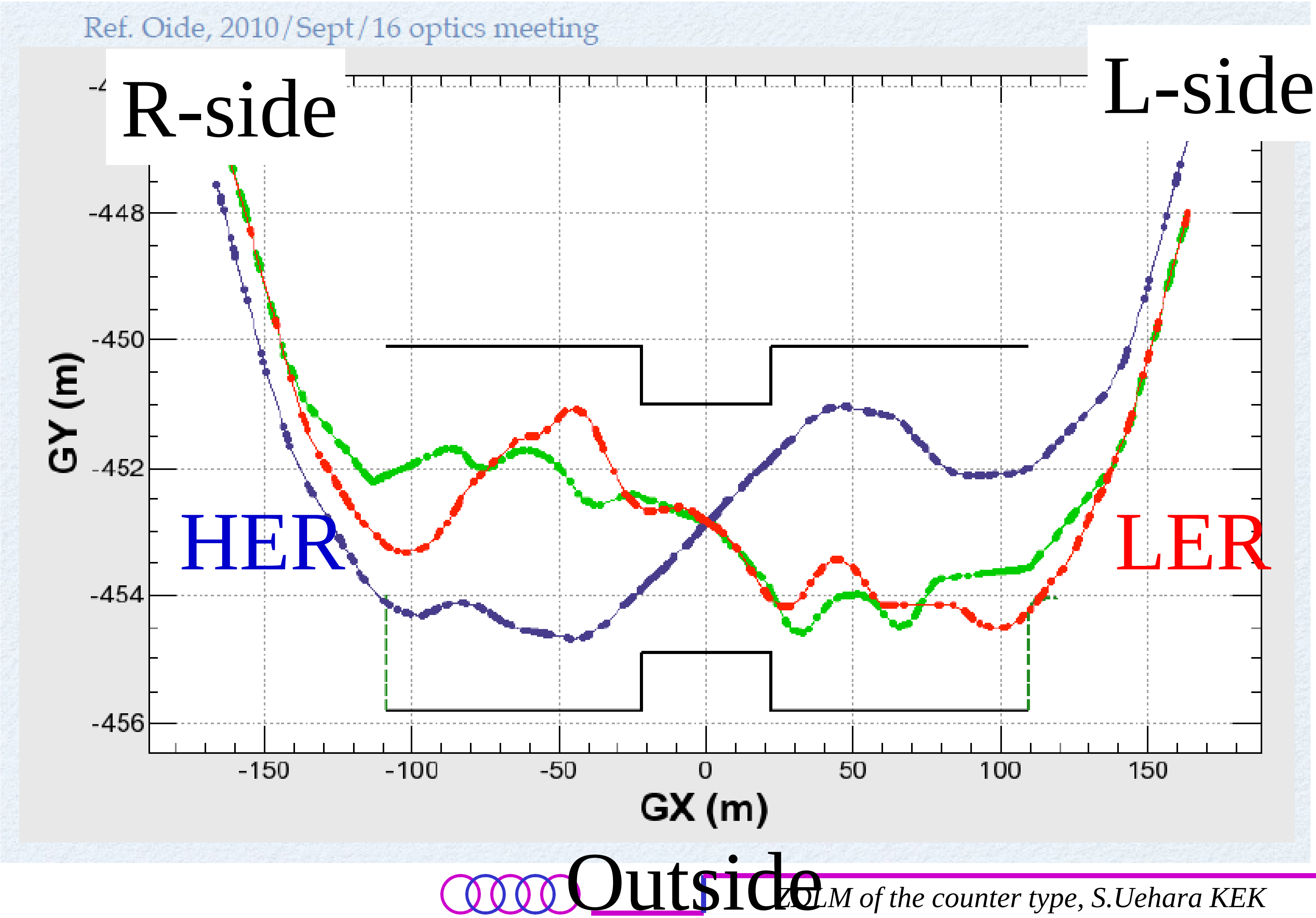
$\sim 10^{35}$ >O(1MHz) --- 1% stat. accuracy in 100Hz readout
$\sim 10^{34}$ >O(100kHz) --- 3% stat. accuracy in 100Hz readout
Tune depends on Luminosity

Cf. Collision rate (2-bucket spacing) 250MHz

Charge amp (Makes slow change) → V/F conversion (1MHz max)
for Feedback @ SuperKEKB

Analog input (with pulse overlaps) is also OK in this scheme
Capable for >=2 events per bunch collision
when we use analog sum

Central Orbits near IR



Expected ZDLM rate

- Funakoshi-san's simulation for the Recoil e- or e+

0.1mA/s -> 6.2GHz

- The rate should be proportional to luminosity
  10^{35} luminosity --- ~ O(1GHz/m/s)

- Effective detector length --- ~ 0.1m
- Efficiency --- 10% (conservative, may be more)
  (angular coverage and shower loss)

Expected Rate --- 0.1mA/s → 10 MHz

LER 4 m point (upstream BLC1LP) ~ 2MHz @10^{35}

9 m point (downstream BLC1LP) ~ 8MHz @10^{35}

13 m point (downstream QKBLP) ~ 30MHz @10^{35}

HER 11 m point (downstream BLC1RE) ~ 2MHz @10^{35}

Expected ZDLM acceptance

- Spread from HER ~±30deg

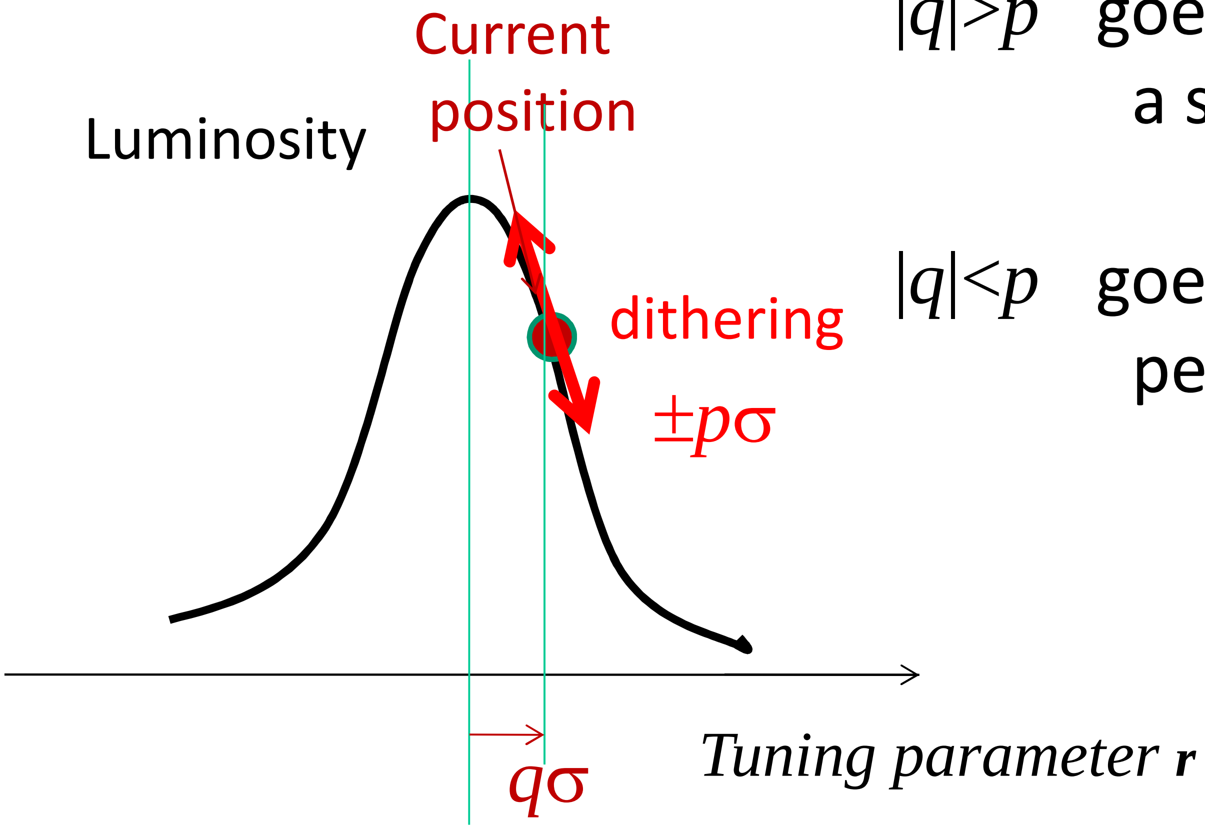
  There may be efficiency loss

Larger counter:

robust for an orbit change

worse time resolution

Illustrating the dithering quantities



$|q|>p$ goes up and down on a side of slope

$|q|<p$ goes over across the peak

Assumption of simulation

. Measure the rate of ZDLM during 1 sec (1 second for 1 measurement)

- Sampling rate = 1024 Hz (Counting rate every 0.977 ms)
- Dithering frequency at accelerator

f = 77Hz Vibrate a certain tuning parameter r

$$r \sim \sin 2\pi f t$$

We assume the luminosity depends of this parameter with a Gaussian function:

$$L(t) \sim \mathrm{Exp}[-(q+p \sin 2\pi f t)^2/2]$$

q : Shift of the operation point from the luminosity peak

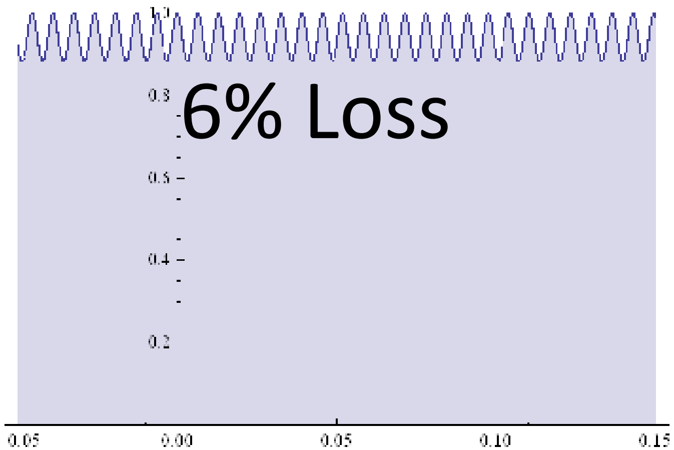
p : Amplitude of the dithering

f : Dithering frequency (taken to be 77Hz, here)

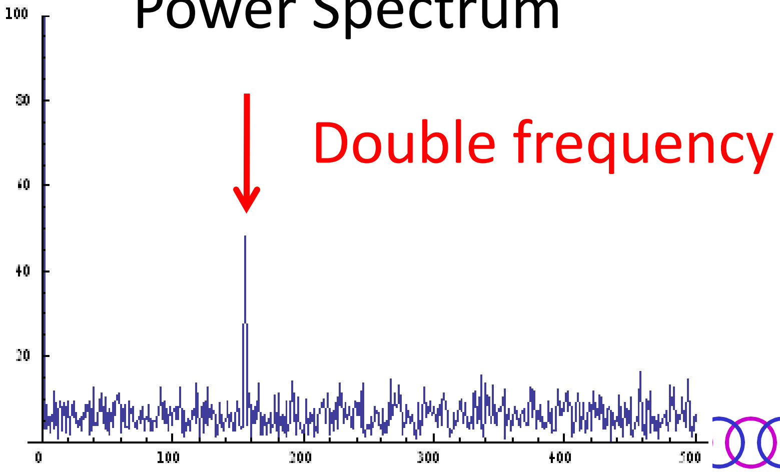
Artificial vibration of luminosity

Simulations for p =0.5, q=0, 50kHz

Luminosity



Power Spectrum



Lock-in Amplifier

$C = \Sigma \cos 2\pi f_0 t_i$

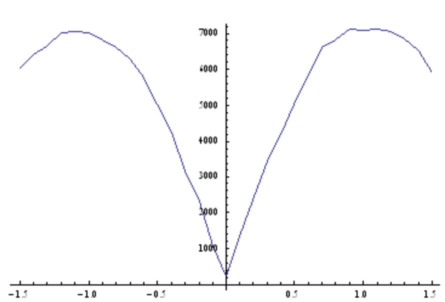
$S = \Sigma \sin 2p f_0 t_i$

t_i : time of each event

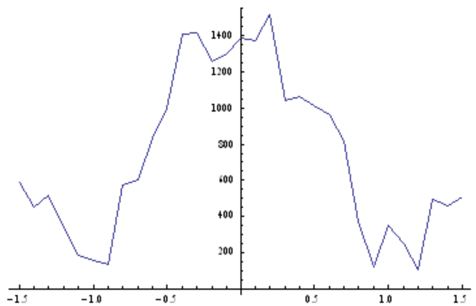
S: summation for one measurement

f_0 : Same as the dithering frequency and twice the frequency

Base freq.



Double freq.



Simulation

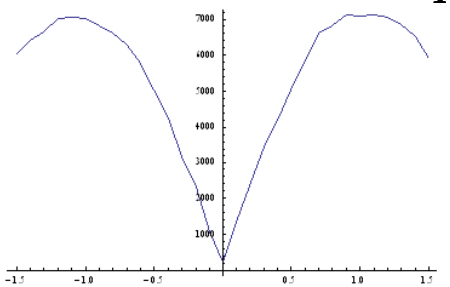
Dithering with a lock-in amp.

p= 0.5, Rate=50kHz, Measurement in 1 sec

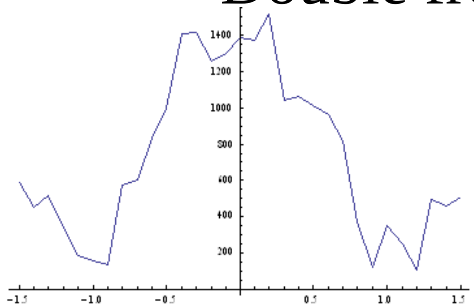
Horizontal axis: q = -1.5 ∼ +1.5,

Vertical axis: Size (arbitrary)

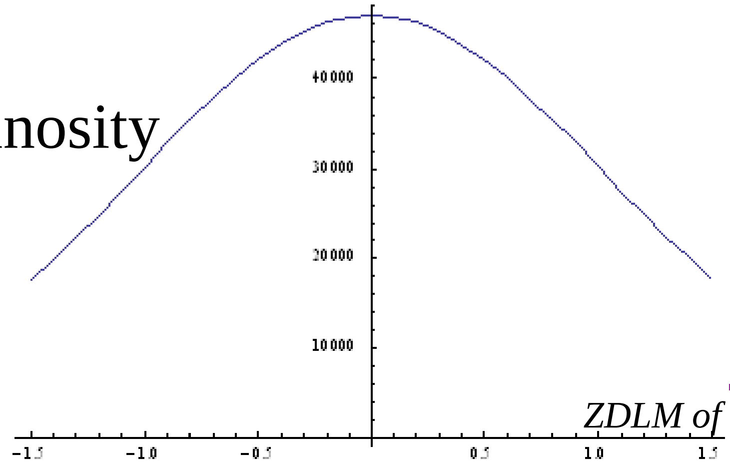
Base freq.



Double freq.



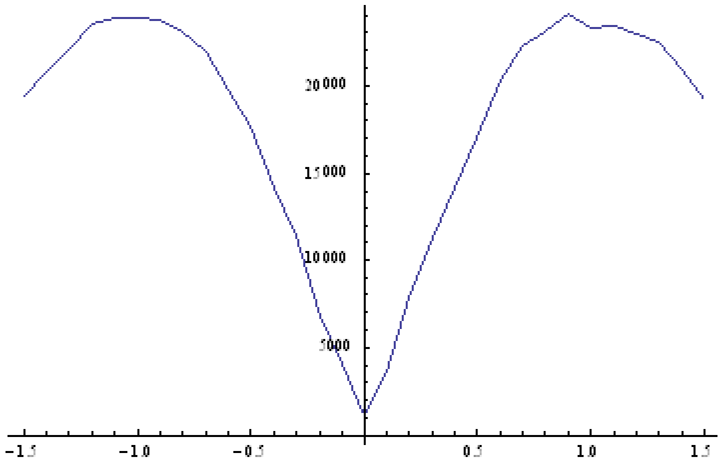
Luminosity



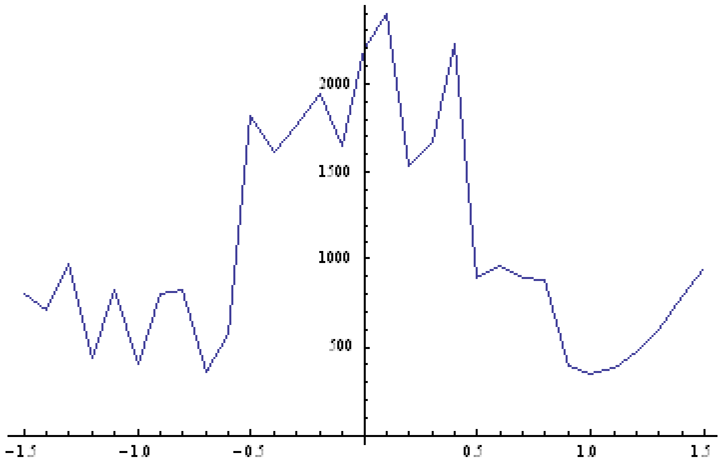
Simulation

p= 0.2, Rate=400kHz

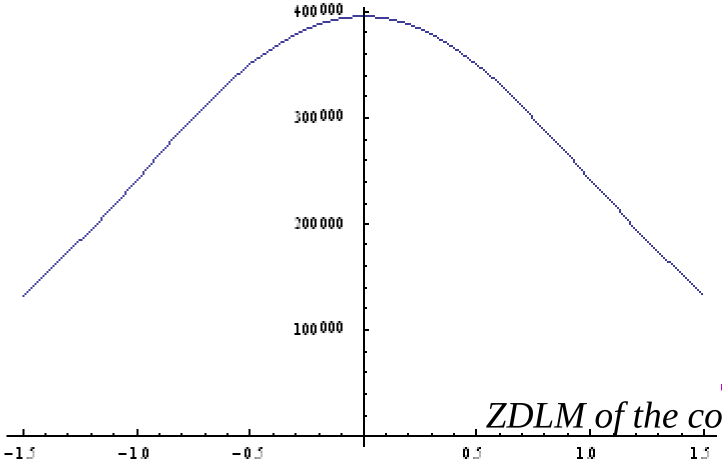
Base Freq.



Double Freq.



Luminosity



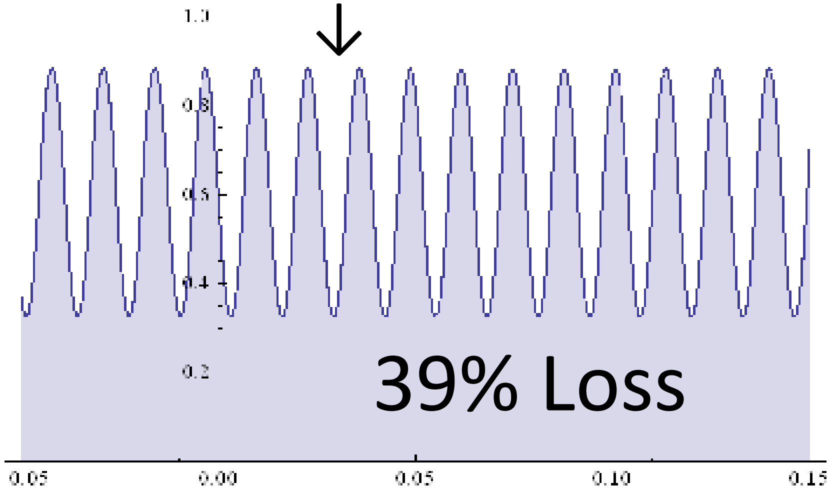
Not good

Observation with the base frequency is the most sharp.

Simulation on the slope

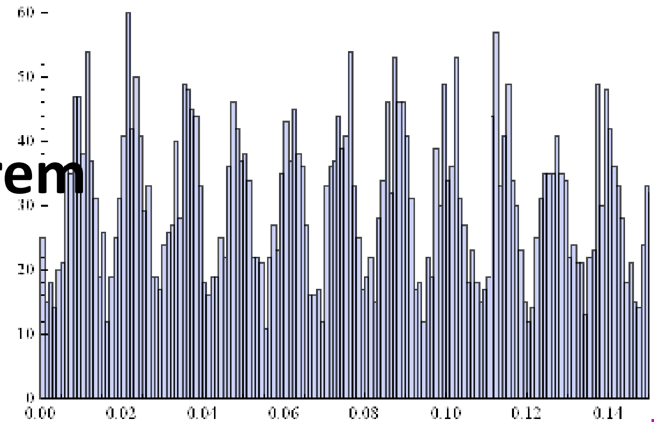
p =0.5, q=1.0, 10kHz

Luminosity (input)



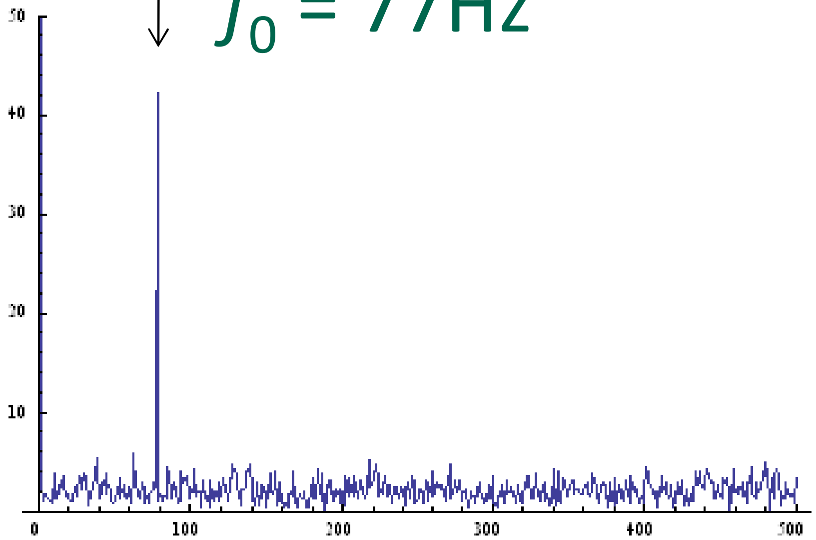
39% Loss

Measurement (MC)



Sqrt of the
Power Spectrum
Absolute value of the Fourier coefficient

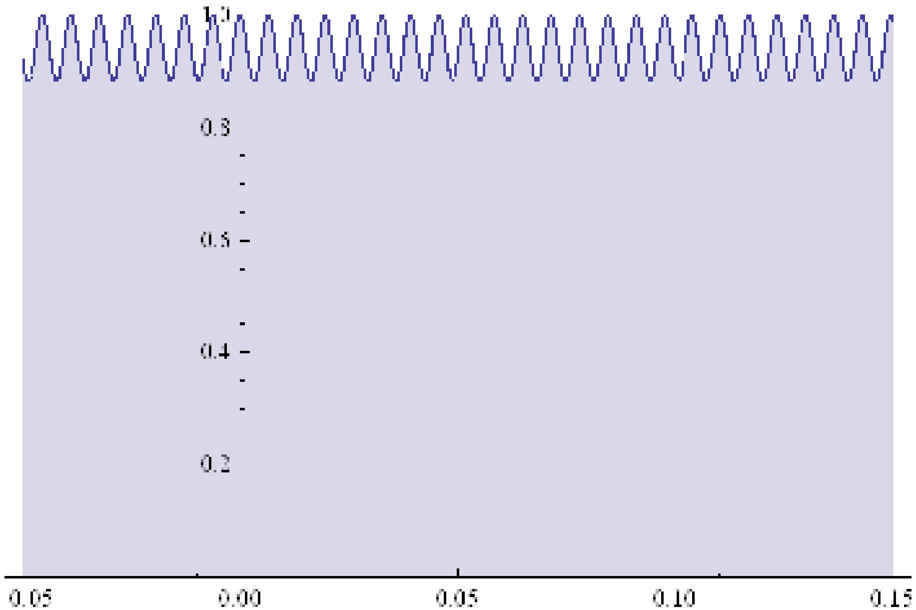
f_0 = 77Hz



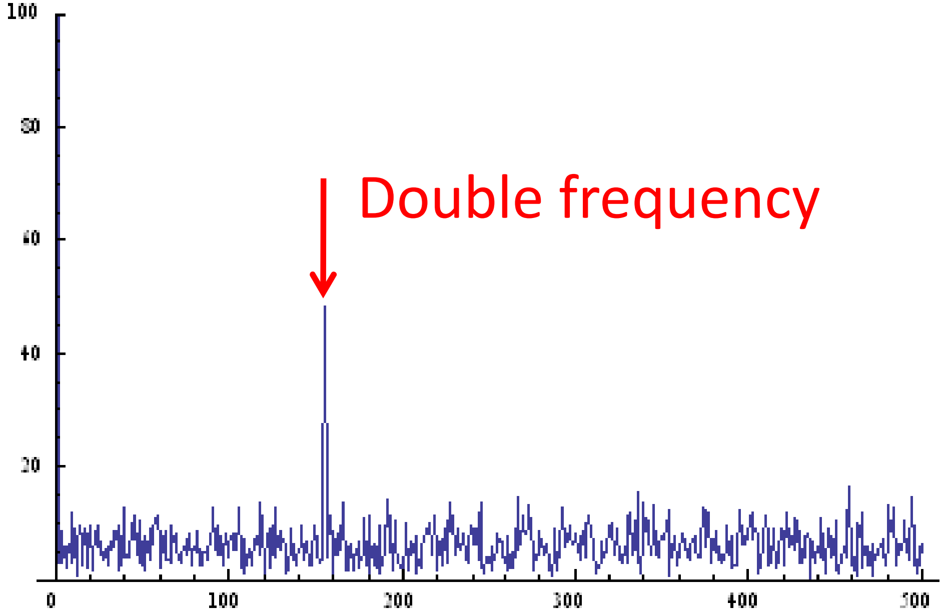
Simulation on the peak

p =0.5, *q*=0, 50kHz

Luminosity



Power Spectrum



6% Loss

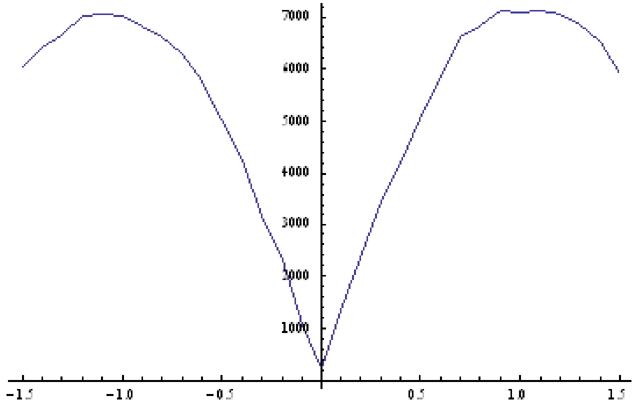
Simulation

p= 0.5, Rate=50kHz, Measurement in 1 sec

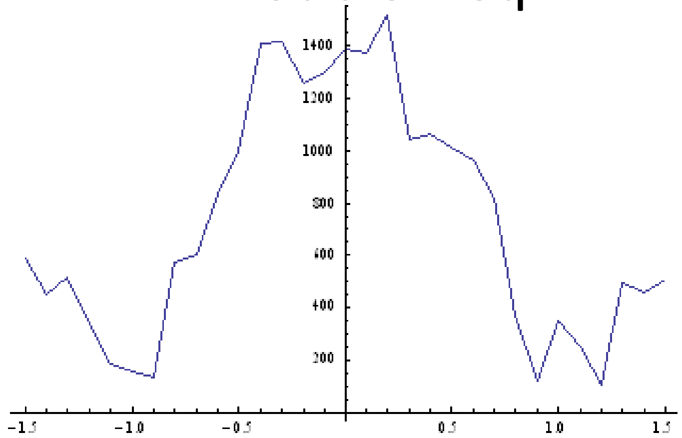
Horizontal axis: *q* = -1.5 〜 +1.5,

Vertical axis: Size (arbitrary)

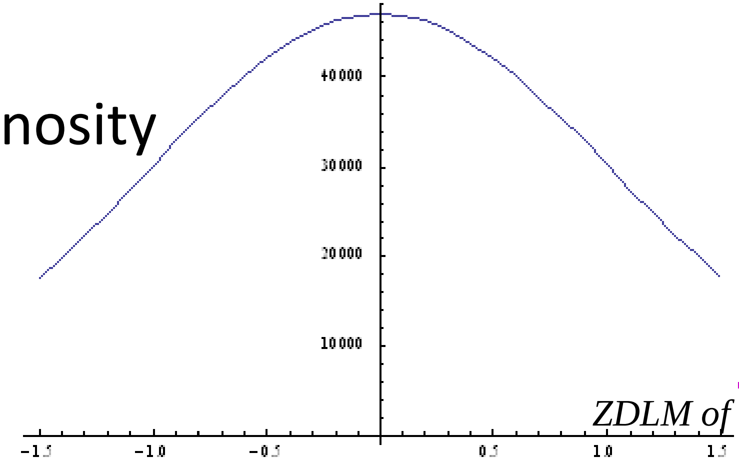
Base freq.



Double freq.



Luminosity



Integrated to a NIM module

HV PS – attenuator-

VF converter –
Integration amplifier

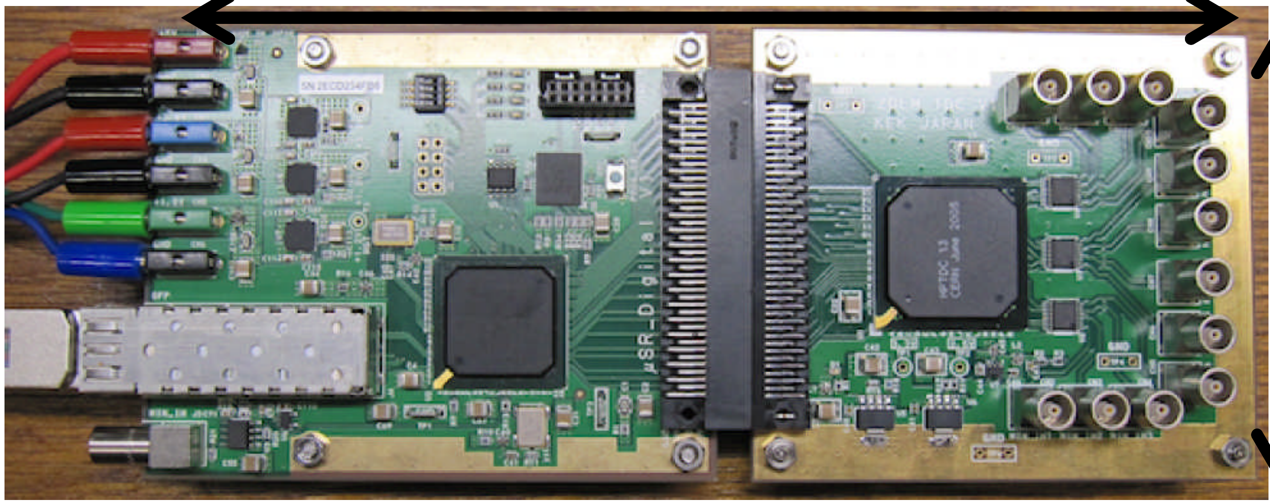
(left to right)

Basic operations are
Confirmed.

TDC Module for precise timing measurement

SFP optical module

20cm × 9cm

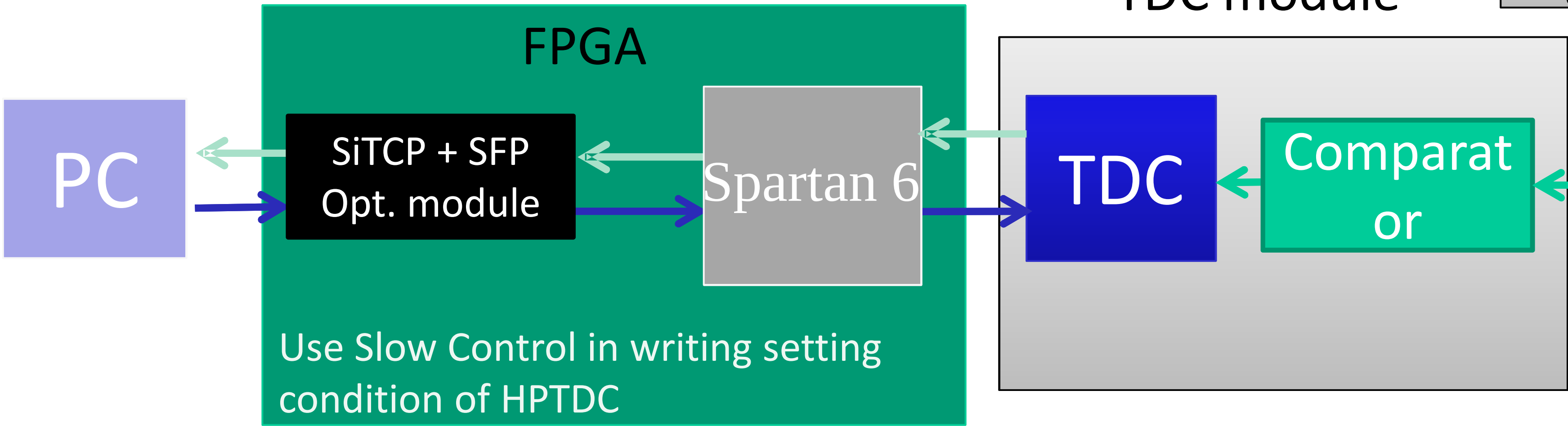


Communicate with 1Gbps

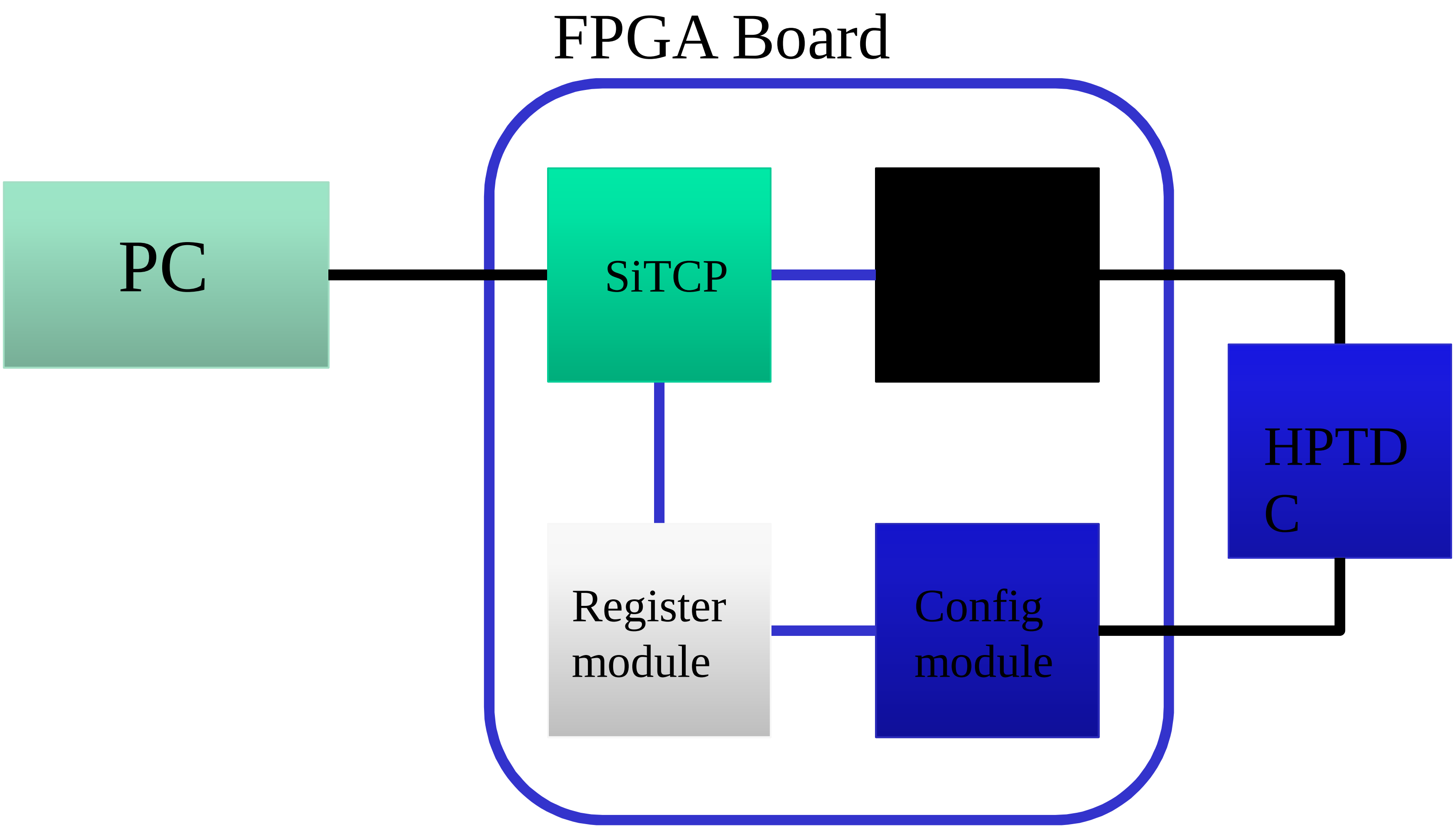
FPGA board

TDC module

ZDLM signal



FPGA



Writing a setting with about 700 bits on HPTDC in a serial mode