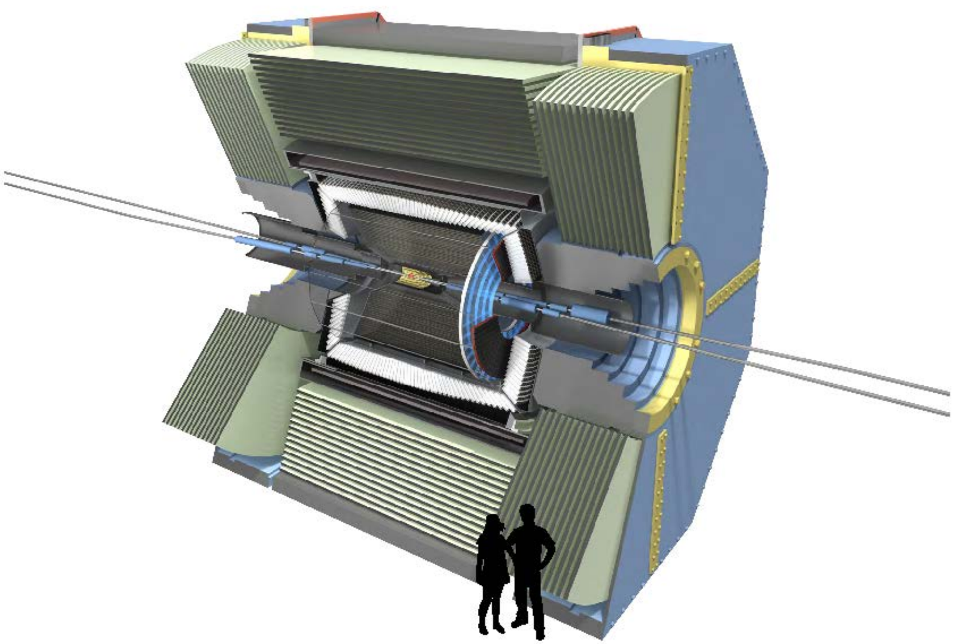
Electronic Readout System for Belle II Imaging Time of Propagation Detector



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March 3, 2017

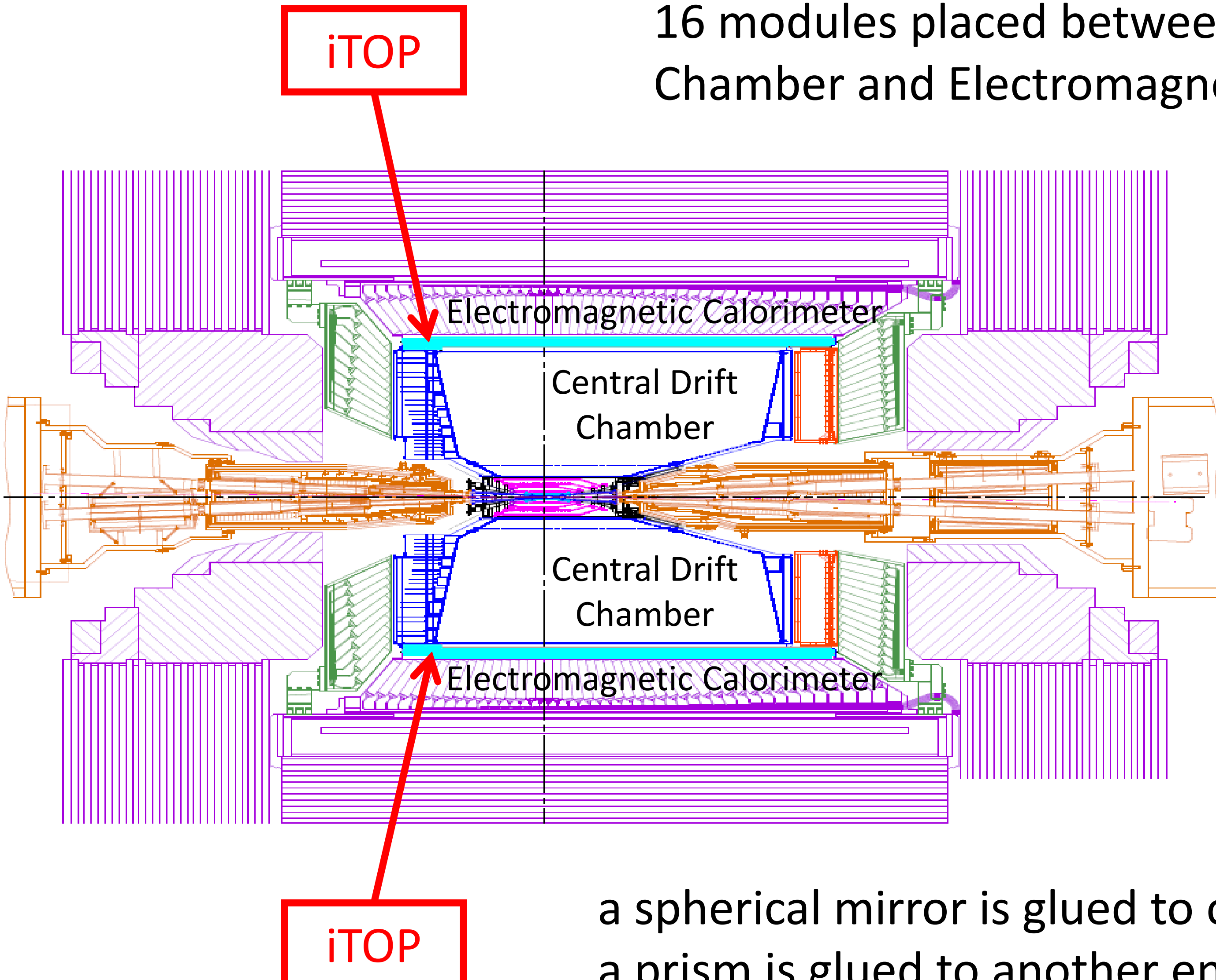
Barrel Particle Identification at Belle II

Belle II experiment at SuperKEKB electron-positron collider
(KEK, Tsukuba, Japan):

- asymmetric collisions of 7 GeV electron beam with 4 GeV positron beam (program's total integrated luminosity = 50 ab^{-1})
- studies of CP-violating physics processes from decays of Υ(4S) resonances
- need for improved barrel particle identification to detect rare and previously unobserved phenomena and to mitigate beam backgrounds
- in the p_T range from 1 GeV/c to 4 GeV/c pions have to be separated from kaons with the efficiency of 85-90%, while the misidentification efficiency has to be less than 5%
- new 8192-channel Cherenkov radiation imaging Time of Propagation Detector (iTOP)

Imaging Time of Propagation Detector

16 modules placed between Central Drift Chamber and Electromagnetic Calorimeter

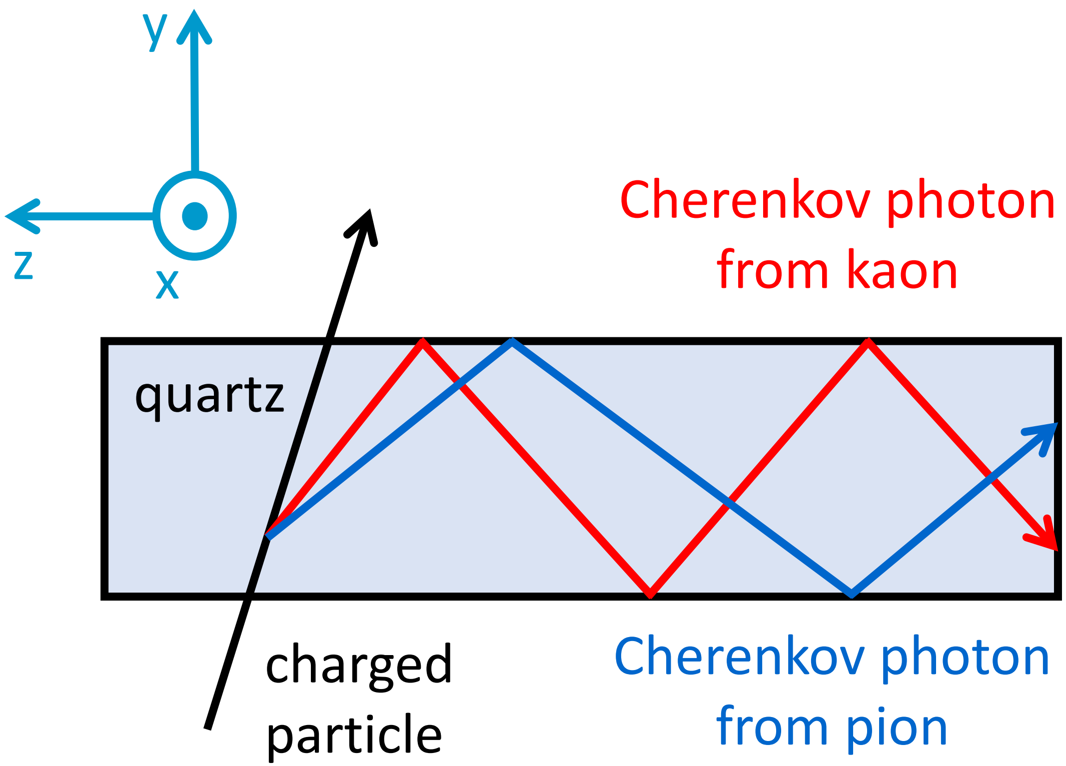


<u>in each module:</u>

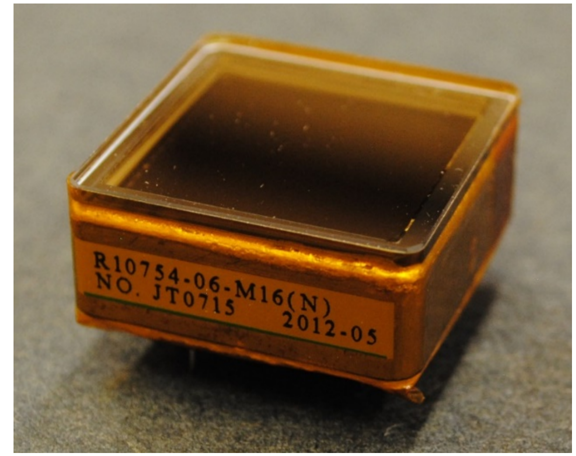
2.5 m long quartz bar glued from two 125 x 44 x 2 cm^2 pieces

a spherical mirror is glued to one end and
a prism is glued to another end of the bar

Cherenkov Radiation in Quartz



measurement of Cherenkov photon x-y position at the prism surface (MCP-PMT pixel coordinate) and in-quartz propagation time

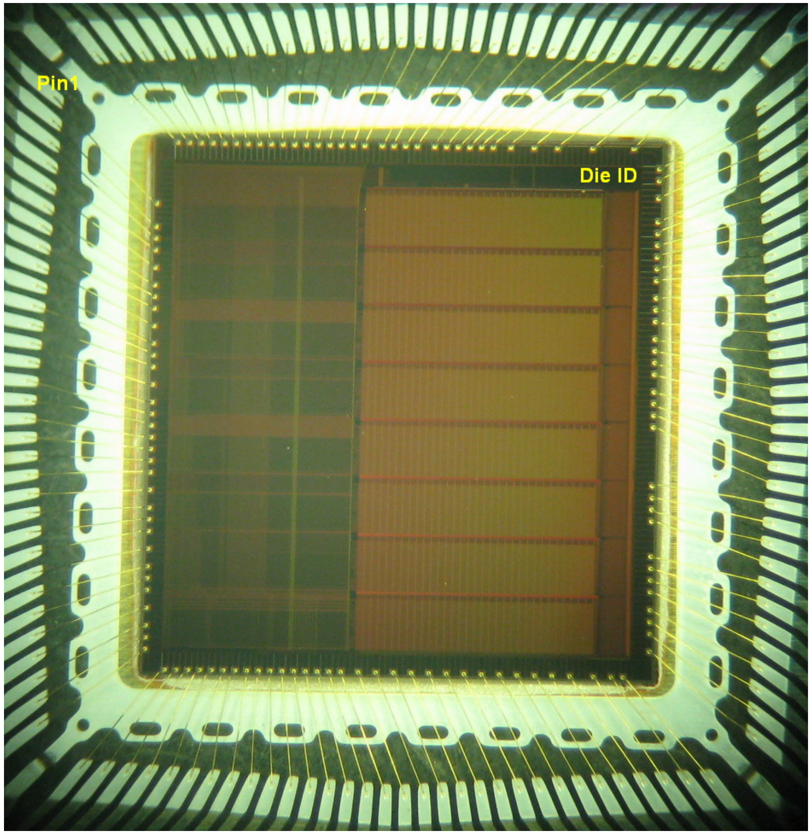


Hamamatsu microchannel plate photomultiplier tube (MCP-PMT) R10754-07-M16(N)

16-channels (4 x 4 pixel matrix)

32 MCP-PMTs are attached to each prism

Ice Radio Sampler



Ice Radio Sampler version X (IRSX) ASIC

adaptation from designs for neutrino experiments in Antarctica

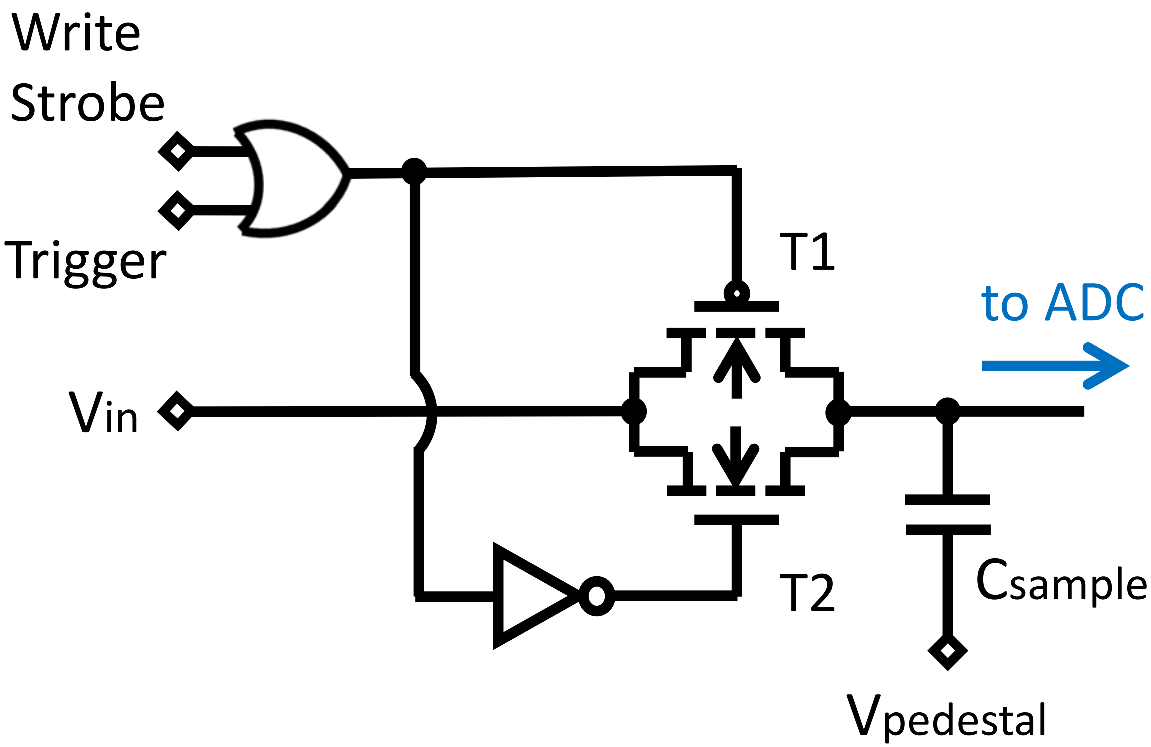
0.25 μm TMSC CMOS process

8 channels

switched capacitor array with 32,768 storage cells for each channel sampling buffer

operational sampling speed is 2.714 gigasamples per second

Sample and Hold Cell

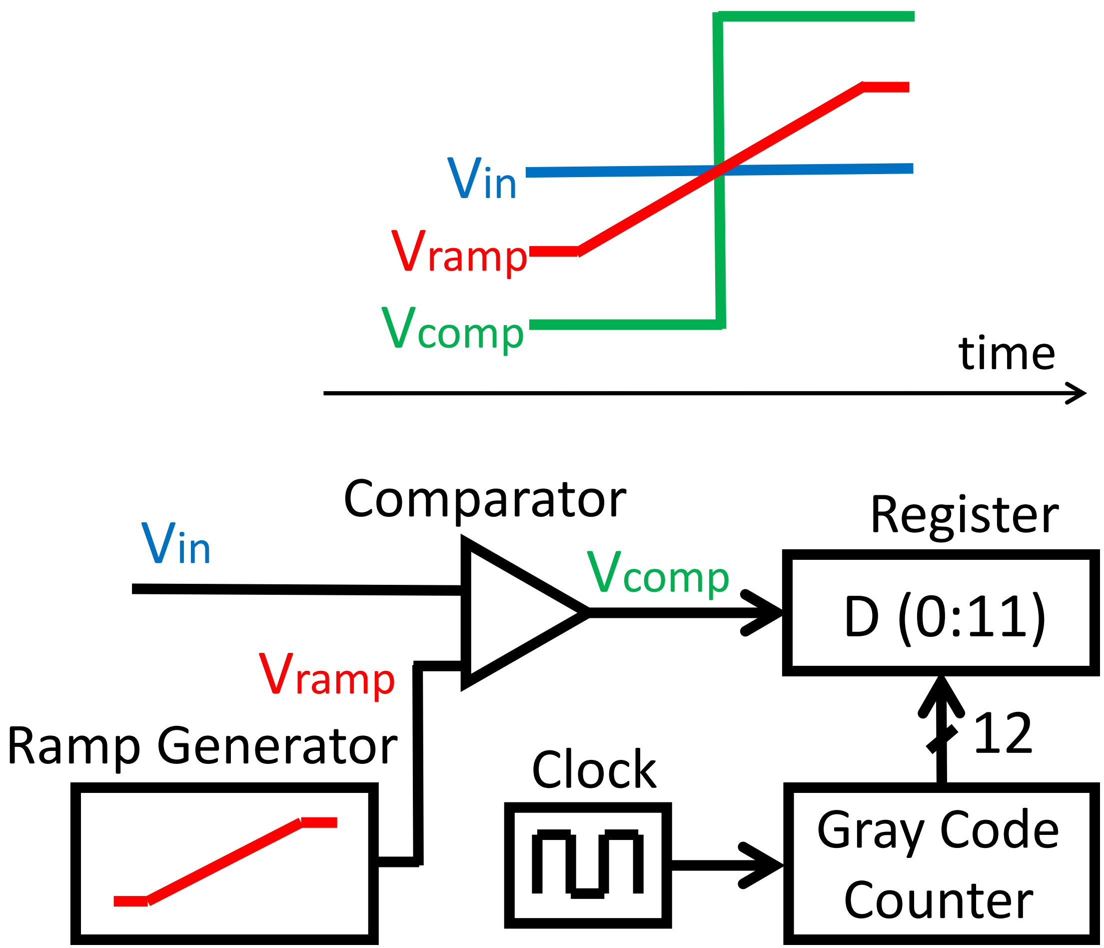


basic unit or Switched Capacitor Array

trigger or write strobe closes an analog switch and an input signal gets stored in 14 fF capacitor

charge remains held in the capacitor until it is overwritten or until discharge occurs through leakage

Wilkinson Analog-to-Digital Conversion



stored voltage → time interval → ADC value

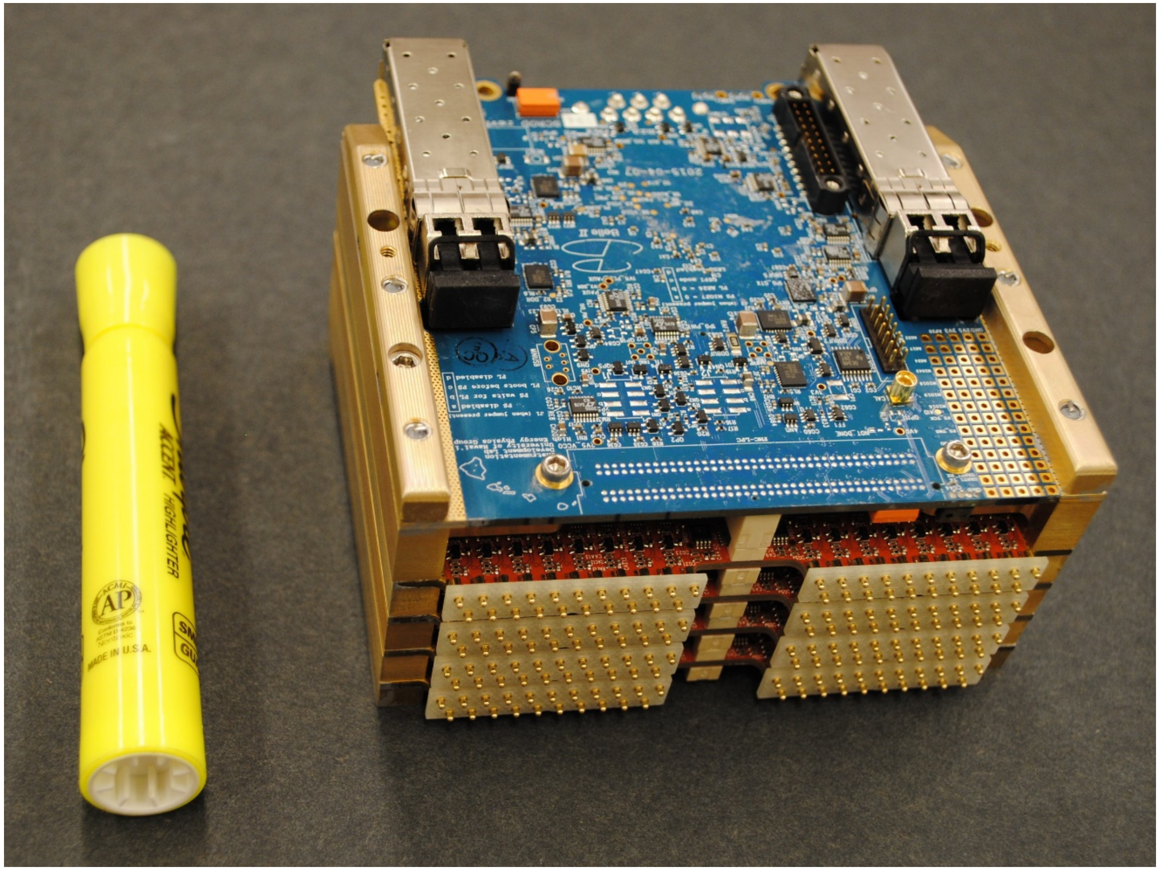
common voltage ramp connected to a positive input of a comparator

11-bit Gray code counter increments while the ramp voltage increases

when the voltage ramp level exceeds the stored sample voltage, the comparator latches the Gray code value

12th bit is for the phase

Subdetector Readout Module

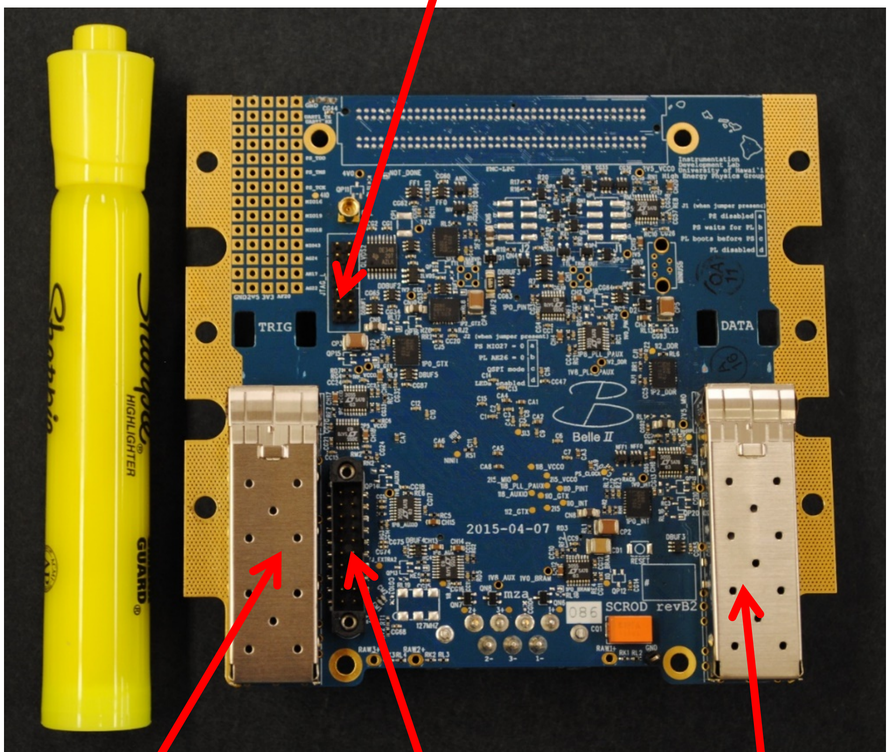


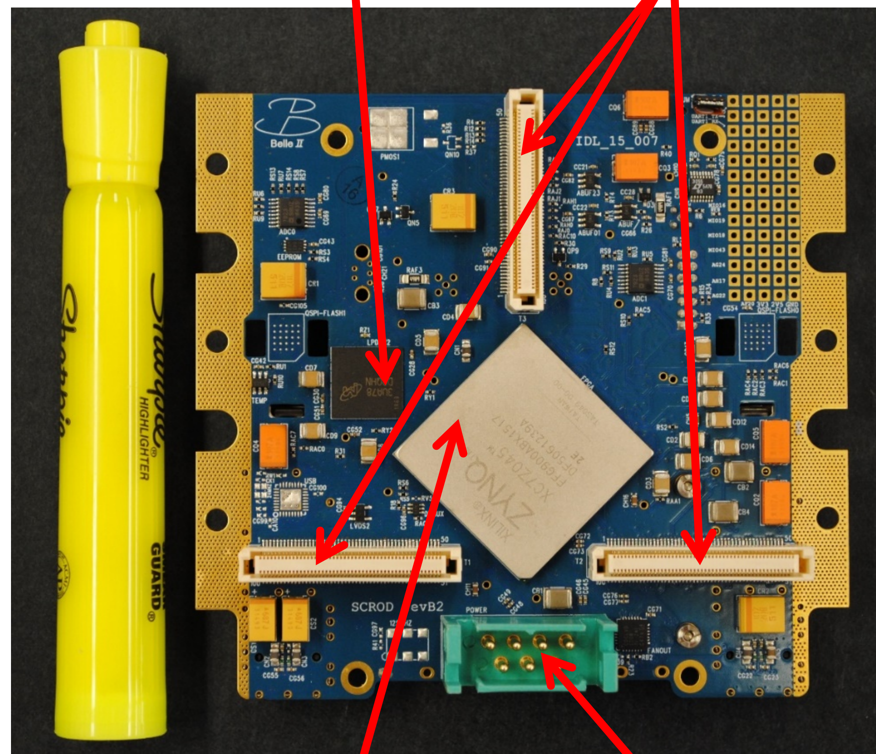
128-channel standalone front-end electronic readout unit

assembly of four ASIC carrier Boards and one Standard Control Read-Out Data (SCROD) board

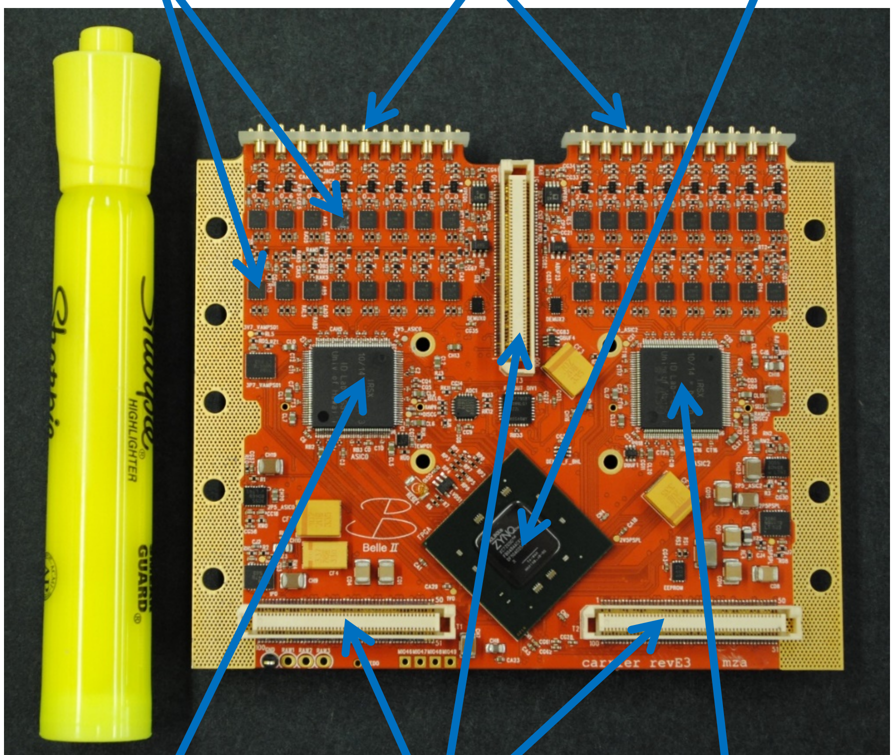
<u>ASIC carrier board:</u>
four 8-channel IRSX ASICs and one Xilinx Zynq Z-7030 System on a Chip
<u>SCROD board:</u>
one Xilinx Zynq Z-7045 System on a Chip

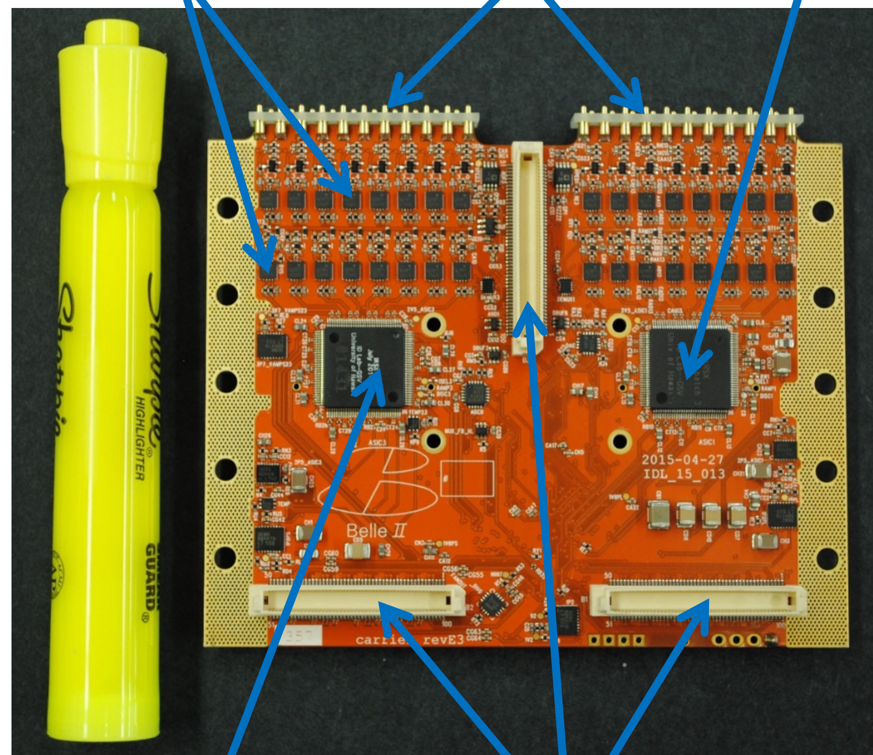
SCROD


debugging
TRIG
DATA
2015-04-07
SCROD revB2
trigger link
programming and clock
data link

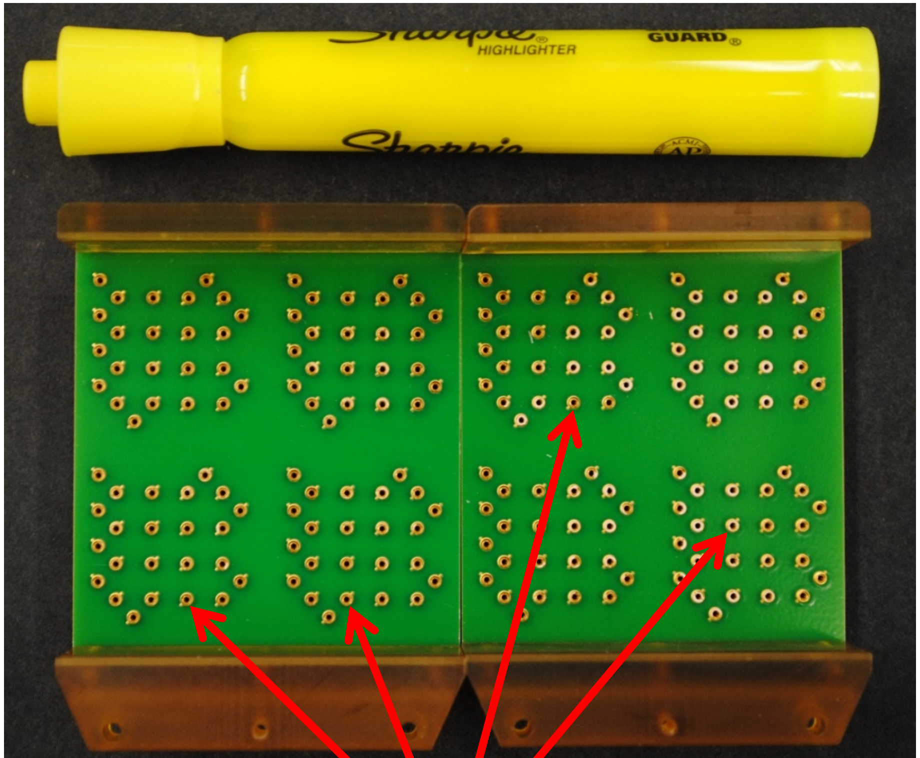

RAM
connectors to ASIC carrier
SCROD revB2
Zynq Z-7045
low voltage power

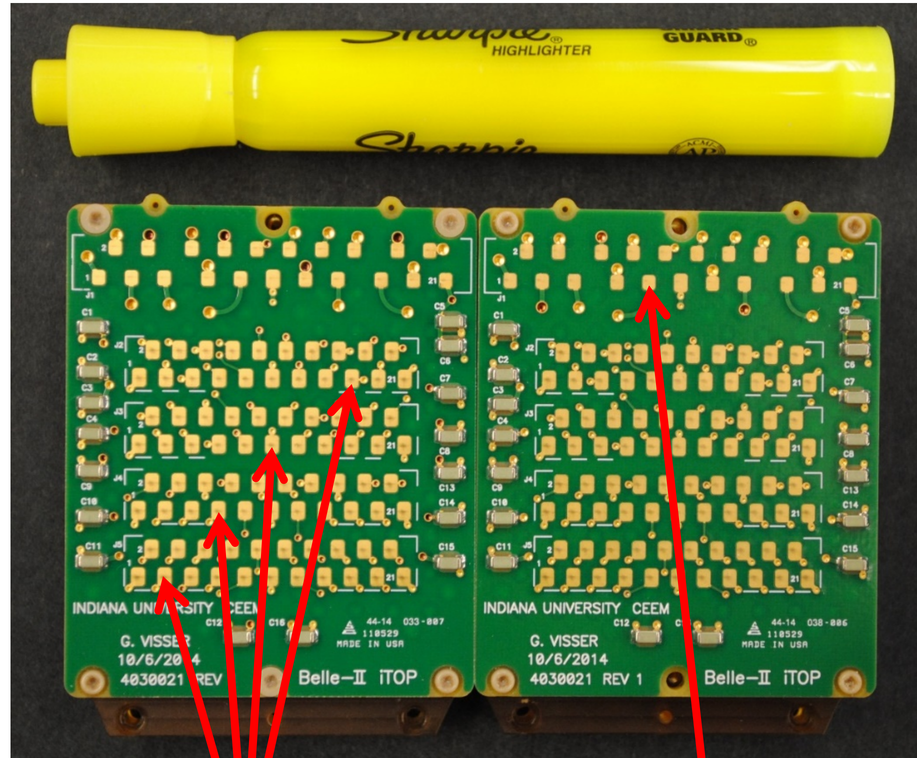
ASIC Carrier Board





Front Boards



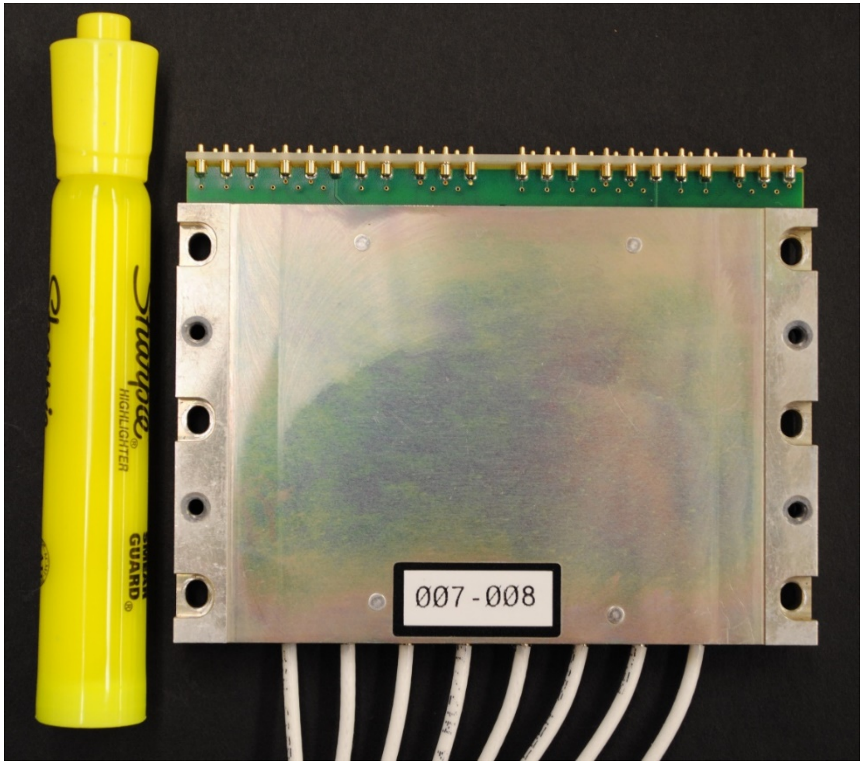


sockets for MCP-PMT anode and HV contacts (one board per four MCP-PMTs)

contact pads for ASIC carrier pogo pins

contact pads for HV divider board

High Voltage Board



8 channels (one channel per one MCP-PMT)

each channel: 400 MOhm resistive divider coupled with high voltage transistors

aluminum enclosure

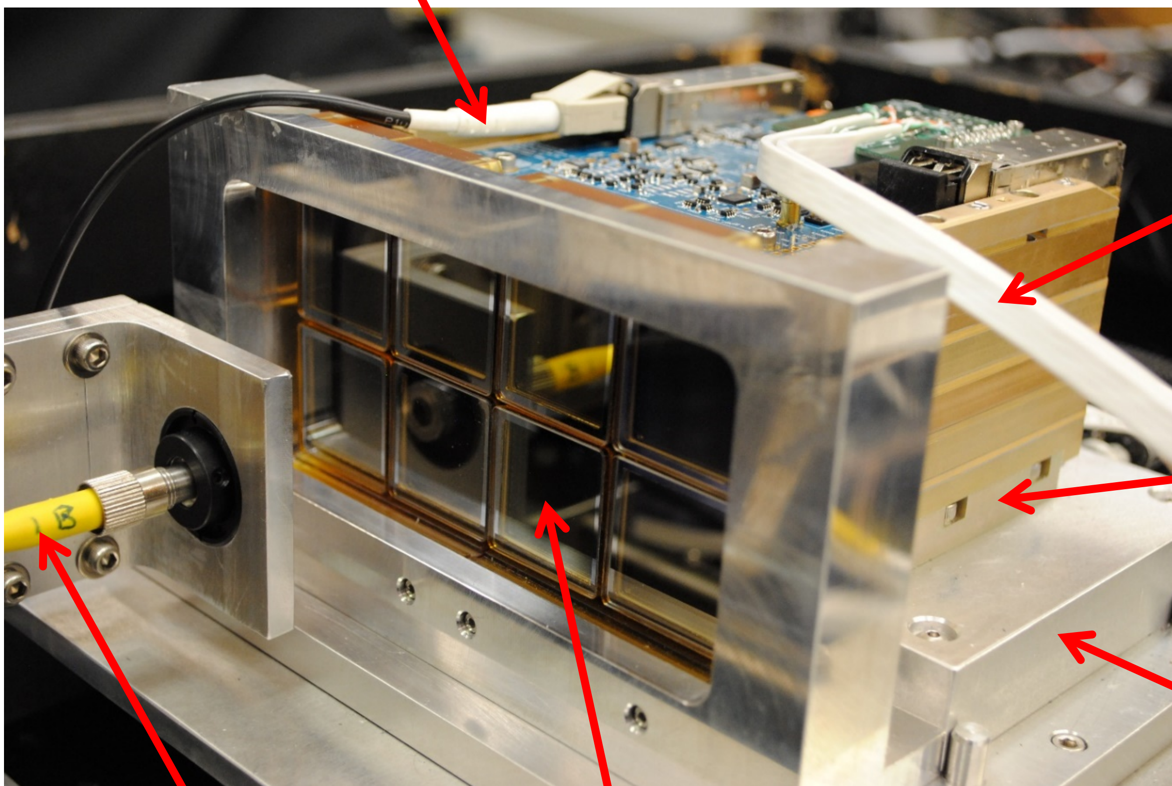
attached to Subdetector Readout Module and to an aluminum water cooling reservoir

pogo pins are pressed against the HV contact pads on two front boards

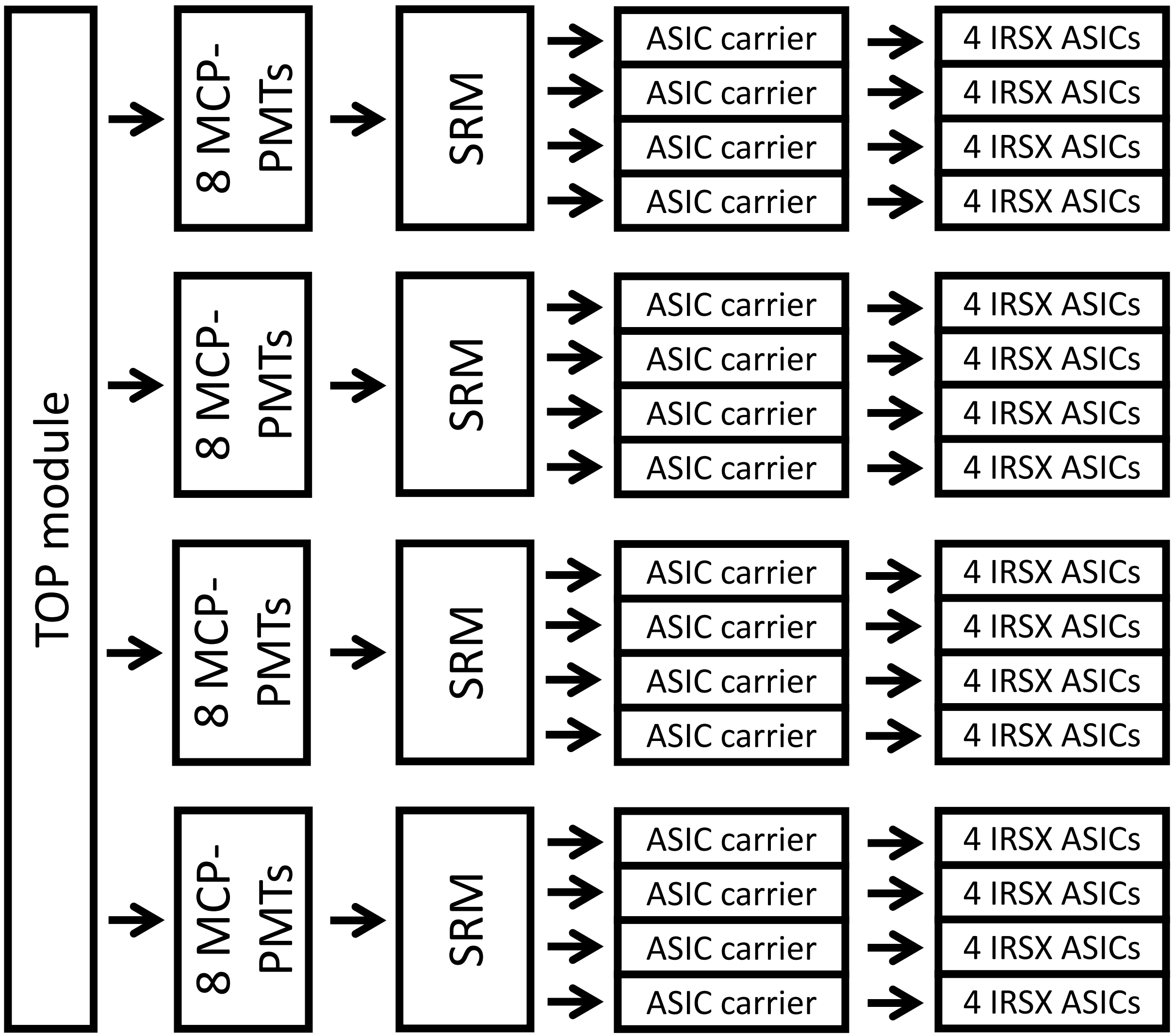
<u>MCP-PMTs:</u>

operational voltage:	from 2100 V to 3100 V
charge gain:	from 2 x 10^5 to 3 x 10^5

Single-Photon Laser Signal Data Taking



iTOP Readout Scheme



<u>one iTOP module:</u>

32 MCP-PMTs

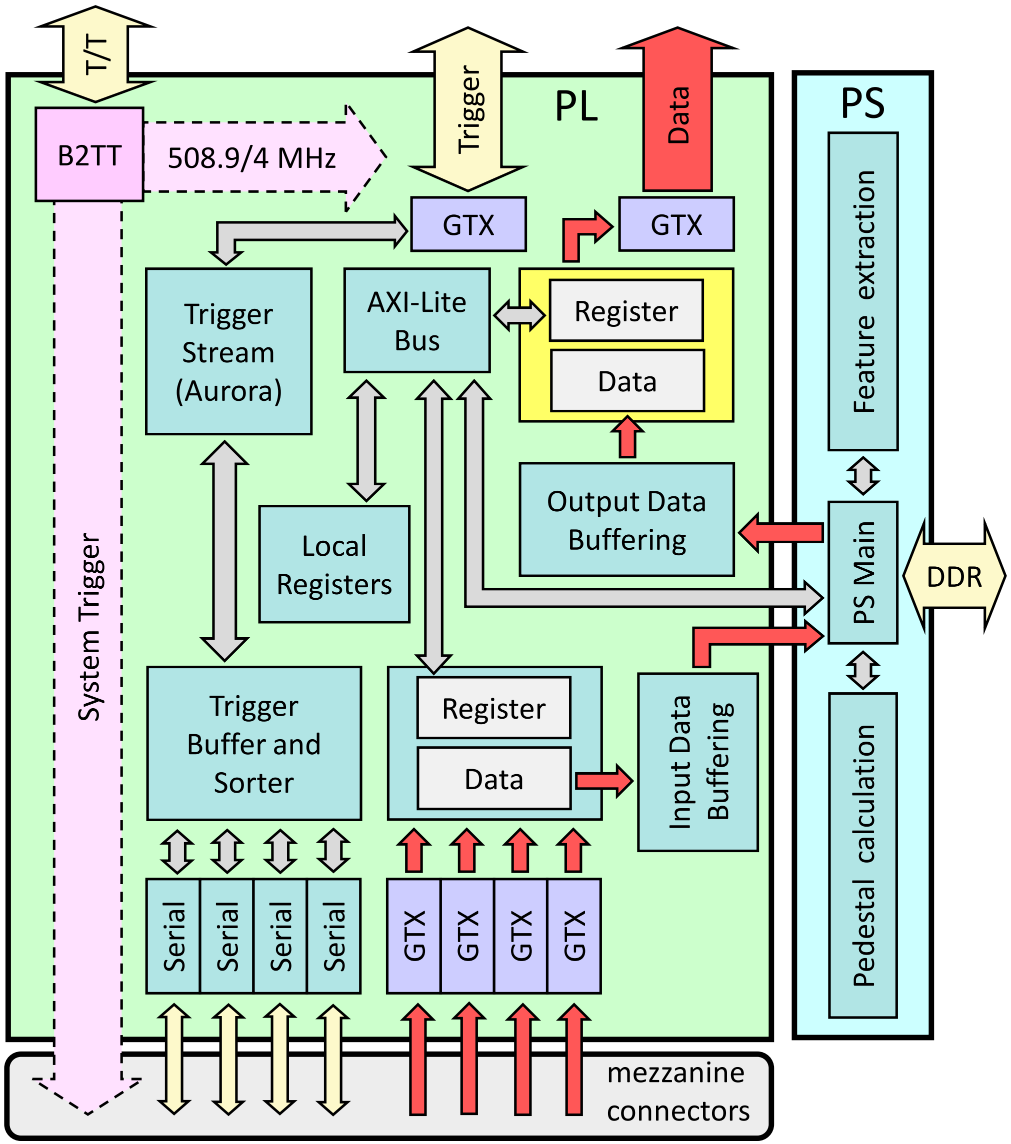
4 Subdetector Readout Modules (SRMs)

16 ASIC carrier boards

64 IRSX ASICs

512 channels

SCROD Firmware



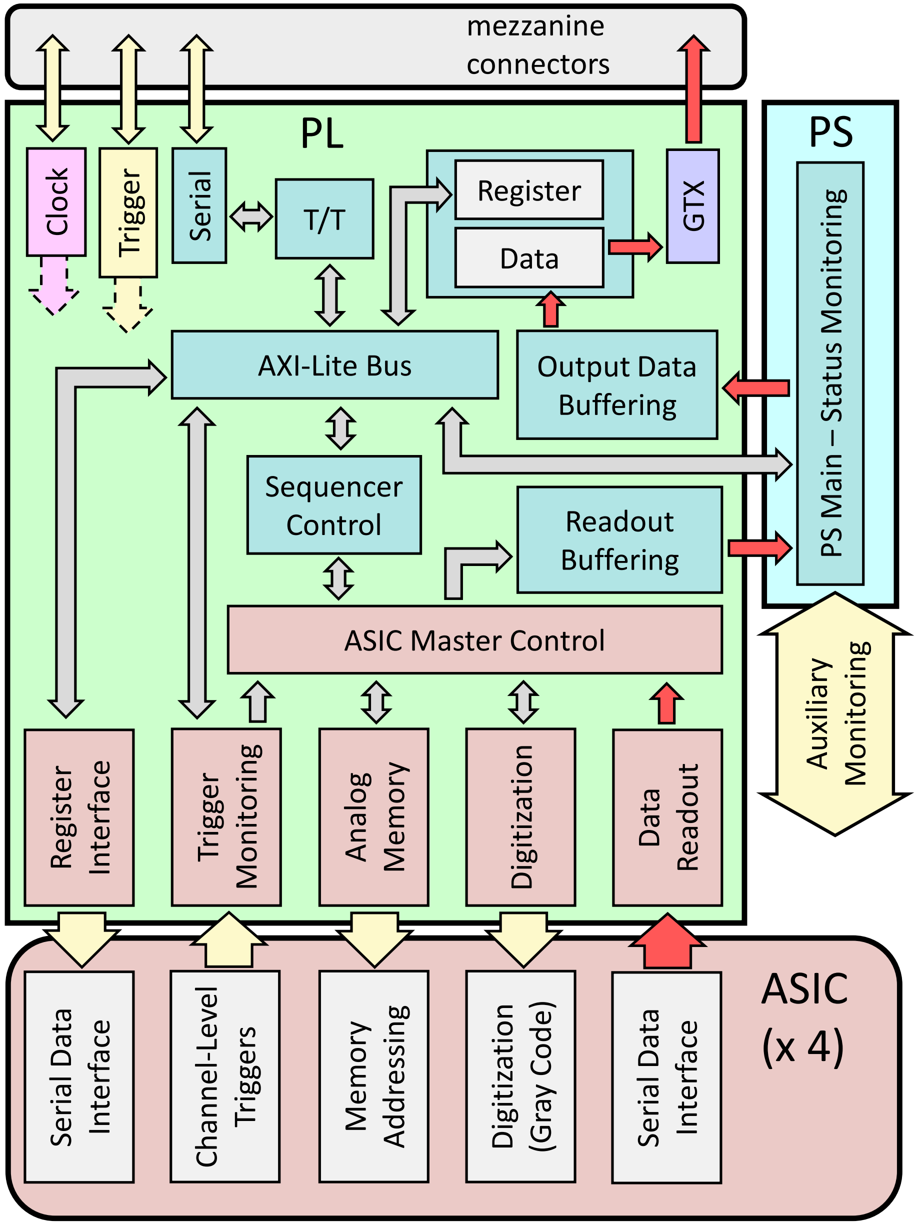
Device: Xilinx Zynq Z-7045

PL: Programmable Logic
Kintex-7 FPGA
350,000 cells
218,600 Luck-Up Tables

PS: Processing System
Dual-core ARM Cortex-9
1 GHz

T/T: Trigger and Timing
GTX: Gigabit Transceiver

ASIC Carrier Board Firmware



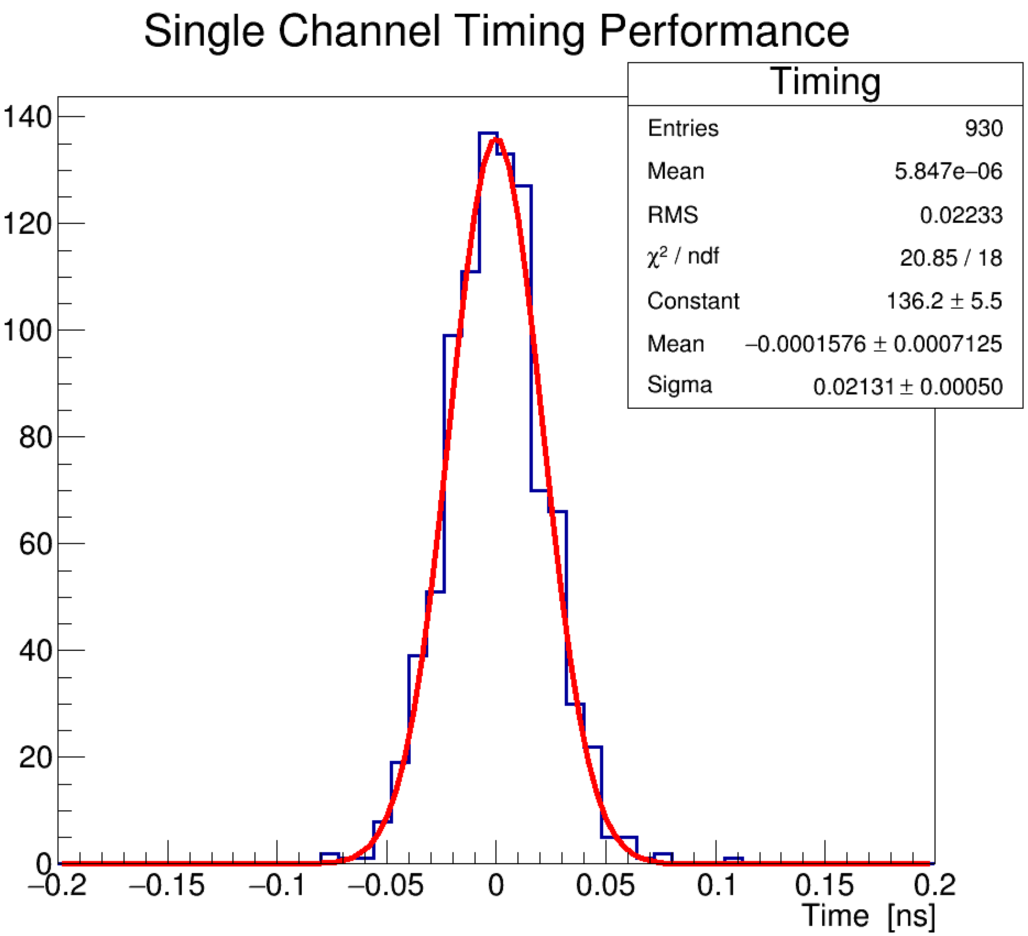
Device: Xilinx Zynq Z-7030

PL: Programmable Logic
Kintex-7 FPGA
125,000 cells
78,600 Luck-Up Tables

PS: Processing System
Dual-core ARM Cortex-9
800 MHz

T/T: Trigger and Timing
GTX: Gigabit Transceiver

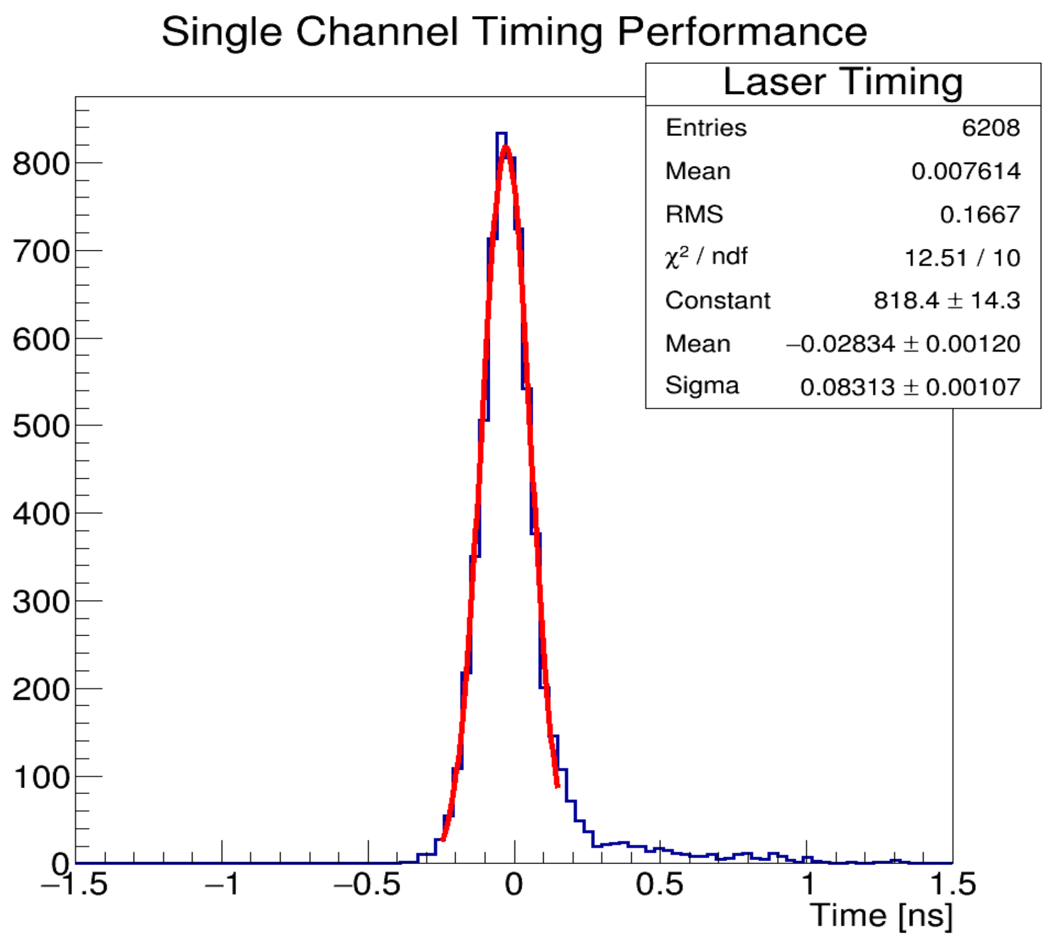
ASIC Carrier Timing Performance



measurement of 20 ns time delay between leading edges of a reconstructed 1.5 V pulse of 7 ns width and its delayed copy

overall time resolution is 20 - 30 ps

Timing Performance with MCP-PMTs



(MCP-PMT transit time spread = 30 ps;
laser bench TDC time resolution = 25 ps)

measurement of a time between leading edges of a reconstructed pulse from MCP-PMT signal and a reconstructed calibration reference pulse

single photon laser signal

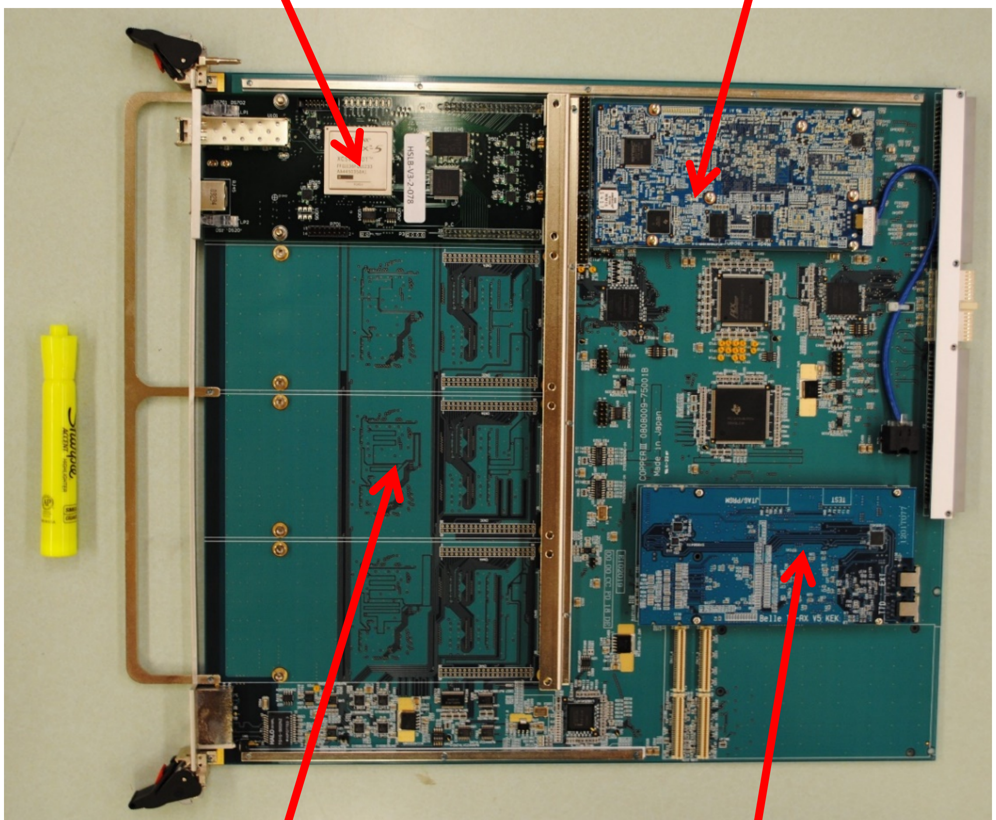
laser trigger is independent from the calibration pulse

overall time resolution at the laser test bench is from 60 ps to 80 ps

Back-End DAQ System

High Speed Link Board

1.6 GHz Intel Atom Z530 CPU



COPPER-III board

global clock and trigger

Common Pipelined Platform for Electronic Readout (COPPER) version III

9U VME format

one High Speed Link Board collects data from one SRM

one COPPER-III board serves one iTOP module

16 COPPER-III boards serve the iTOP detector

Integration at the iTOP

Assembled Subdetector Readout Modules:	78
Installed at iTOP (8192 channels):	64
Installed at a spare iTOP module:	4
Uninstalled spare SRMs:	10

In-situ data taking from calibration laser and cosmic muon ray events without magnetic field demonstrated performance comparable to or surpassing the in-lab performance

DAQ tests with 1.5 T magnetic field have started and will be continued through several campaigns

Calibration software that allows reconstruction of laser, cosmic ray muon, and electron-positron collision data with resolution of less than 50 ps have been developed