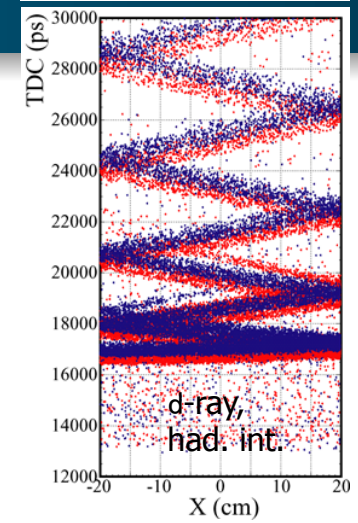
Status of Belle II TOP

KEKB Steering Committee Meeting
(2013.8.21)

Toru Iijima (Nagoya University)

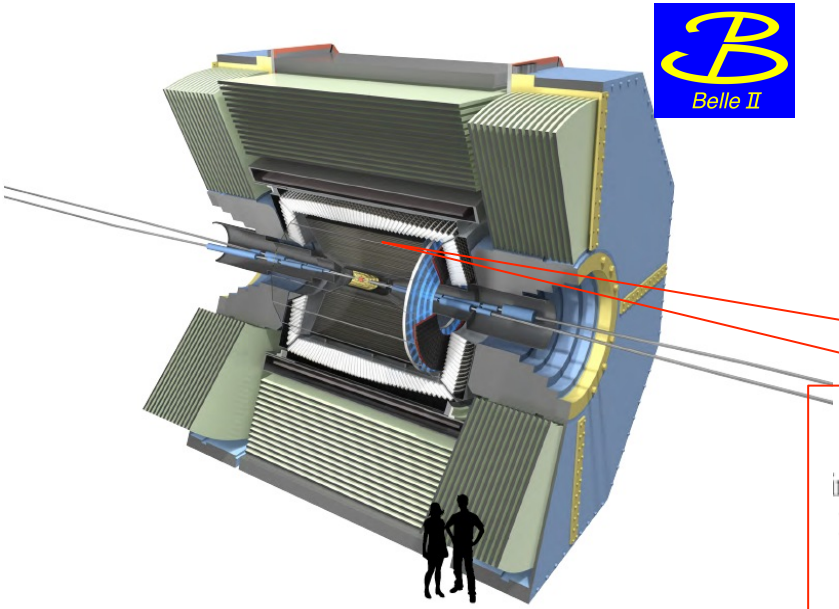
Belle II TOP counter

Simulation
2GeV/c, q=90 deg.

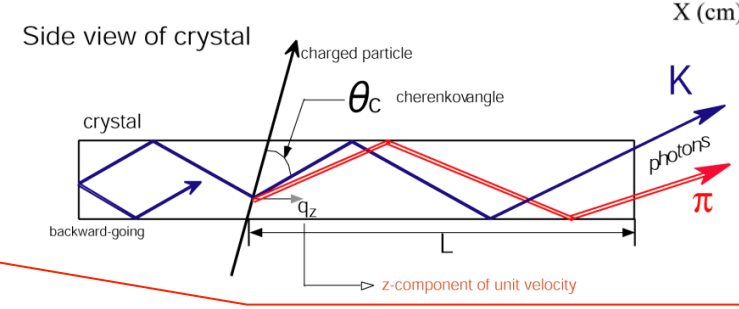


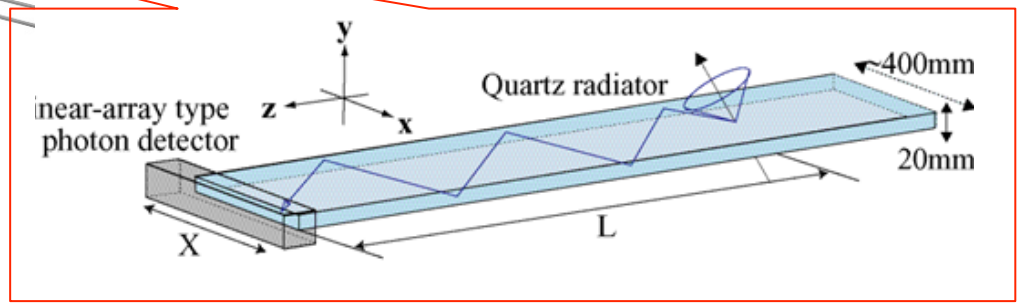
Time-Of-Propagation counter

- Cherenkov ring imaging using precise timing information.
- Idea developed by Nagoya group.
- Very compact, suitable for collider geometry.



$$cos\theta_c = \frac{1}{n(\lambda)\beta}$$

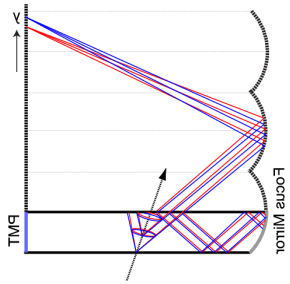




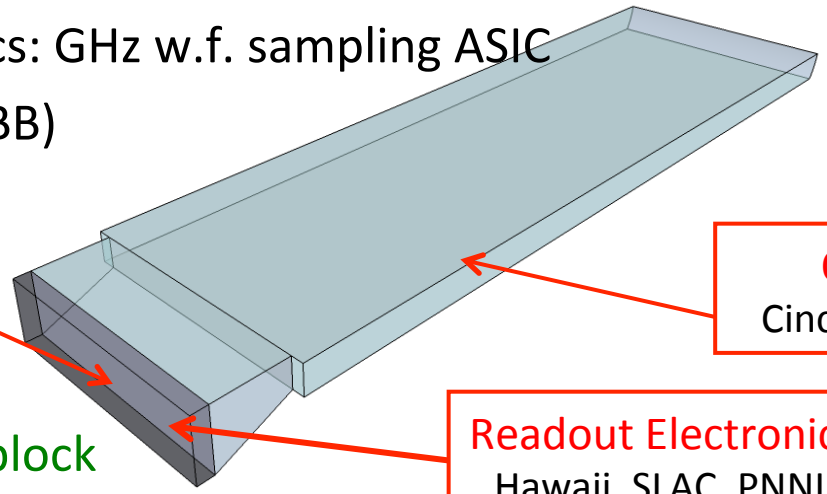
- Key technologies:
  - Photodetection w/ precision timing: ~50ps/photon
  - Accurately polished quartz bar: ~5Å

Belle II TOP: Components/Collaboration

- Module components
  - Quartz optics: radiator bars x 2, focusing mirror, expansion block)
  - MCP-PMT: 4ch × 4ch × 16 PMT's x 2 layers
  - Readout electronics: GHz w.f. sampling ASIC
  - Quartz bar box (QBB)
- 16 modules



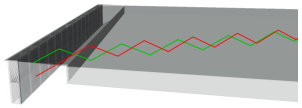
Focusing mirror
(chromatic dispersion correction)



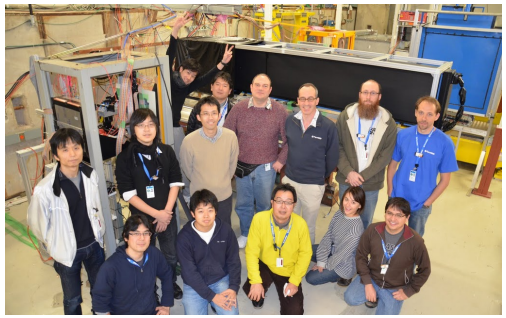
MCP-PMT
Nagoya

Quartz radiators
Cincinnati, Nagoya, PNNL

Readout Electronics
Hawaii, SLAC, PNNL



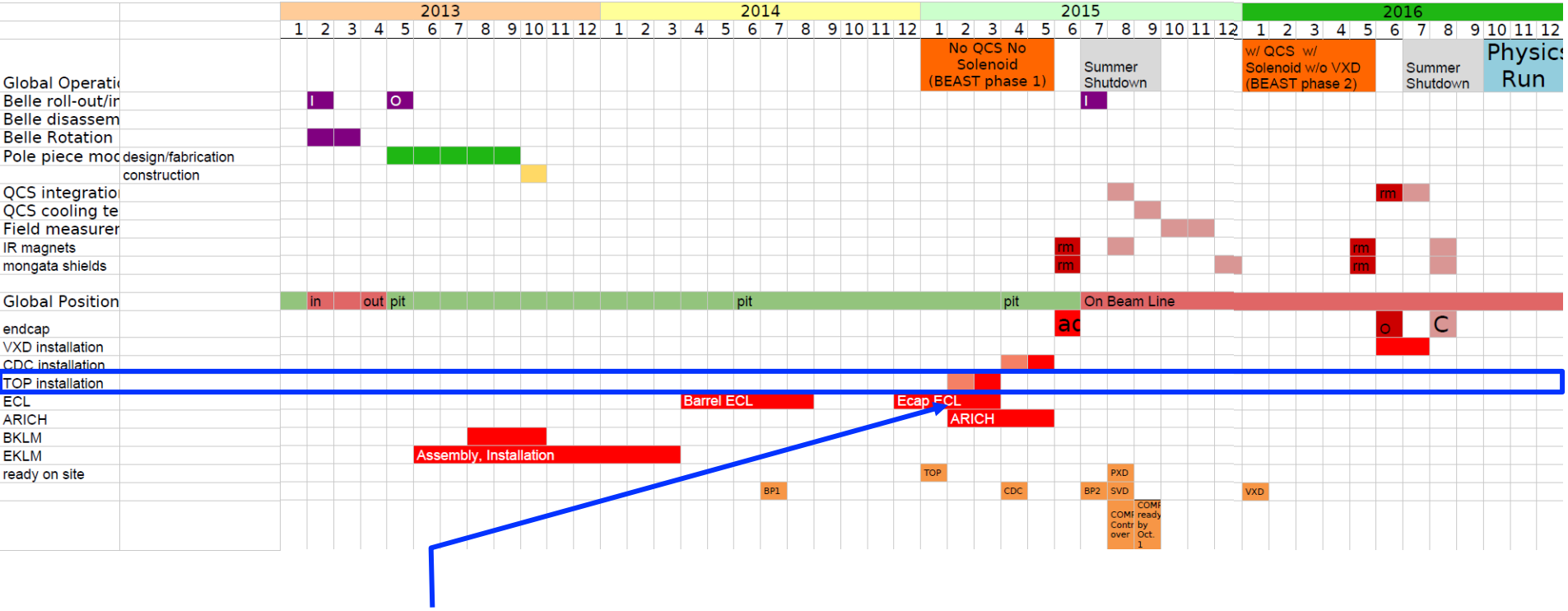
Expansion block
+ MCP-PMT array



Collaborators;
- Japan (Nagoya, KEK)
- US (Hawaii, Cincinnati, PNNL, …)
- Slovenia (IJS)
- Italy (Torino, Padova)

Money source;
- KEK detector money
- KAKENHI (Nagoya)
- DOE project
- US-Japan
- INFN

Belle II Construction Schedule



- TOP must be ready by March 2015.
  - Module assembly need be completed by Dec. 2014 (16 modules in total).

Overall Schedule (as of Mar.2013)

	CY2013						CY2014						CY2015					
	1	3	5	7	9	11	1	3	5	7	9	11	1	3	5	7	9	11
MCP-PMT	Mass production						The last 200 pcs with ALD coating											
Quartz bar	Mod. #1	#2	#3,4	#5			#6					#16	Rate (CY2014) =1mod (2bars)/mo.					
Module Assembly	Mod#1					#4	#5					#16	Rate (CY2014) =1mod/mo.					
Electronics	Prototype 1/16		3/16		ASIC/PCBs Mass production			Assembly/Installation										
Test/install	CRT													Installation to Belle II				
			Beam test		LEPS													
DOE				CD2/3			DOE money flow											

Overall Schedule (as of Aug.2013)

	CY2013						CY2014						CY2015					
	1	3	5	7	9	11	1	3	5	7	9	11	1	3	5	7	9	11
MCP-PMT	Mass production												The last 200 pcs with ALD coating					
Quartz bar				Mod. #1	#2	#3	#4					#16	Rate (CY2014) >1mod (2bars)/mo. Need 3rd vendor ?					
Module Assembly		Mod#1					#2					#16	Rate (CY2014) =1.3 mod/mo. Need 2nd prod. line					
Electronics		Prototype 1/16					Mass production → Installation						Plan B option ?					
Test/install		CRT												Installation to Belle II				
		Beam test LEPS																
DOE						CD2/3	DOE money flow ?											

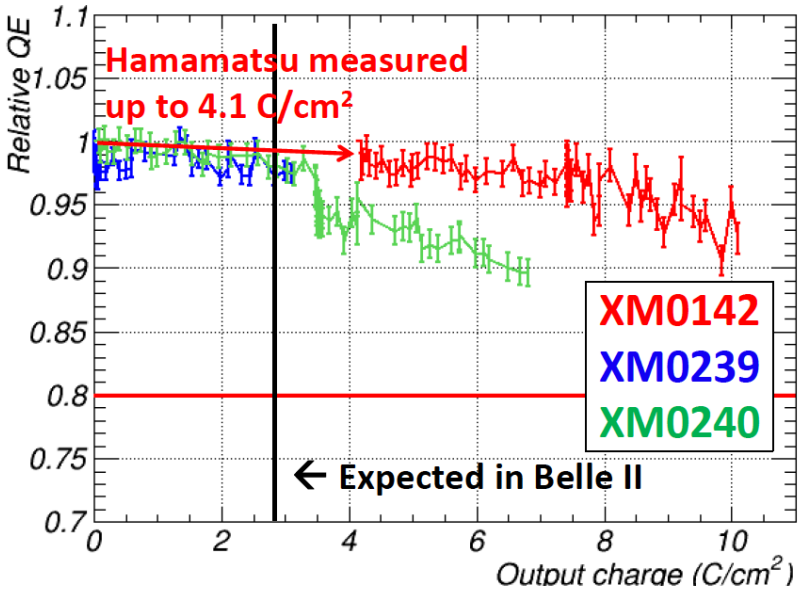
MCP-PMT Status

- 550 pcs. (512+38spare) will be produced by April 2014.
- 318 pcs. have been delivered by now and tested.
  - 313 pcs. are normal type.
  - 5pcs. are new type w/ ALD coating on MCP to improve lifetime.
- The remaining PMTs will be produced w/ ALD technology.
- Performance check in B-field is underway at KEK.

Result of acceptance test for MCP-PMT's

Test items	done	Passed	Status
Delivered	318	-	
QE measurement (>24%)	311 (98%)	299	Almost completed
HV test (No HV discharge)	271 (89%)	265	Almost completed
Gain/TTS check (TTS <50 ps)	111 (35%)	111	Delayed
Measurement in 1.5T	(10 (3%))	-	trial measurement
All passed (except measurement in 1.5T)	111	111	18 failed 189 not measured

Lifetime test for MCP-PMT's w/ ALD coating



Quartz Procurement

Overview of Quartz Optics for iTOP

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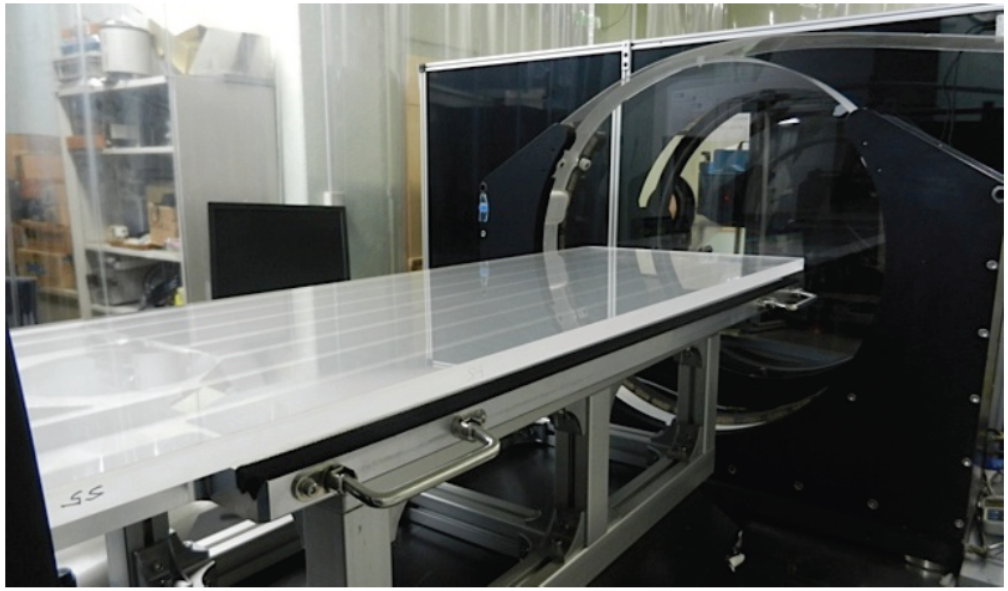
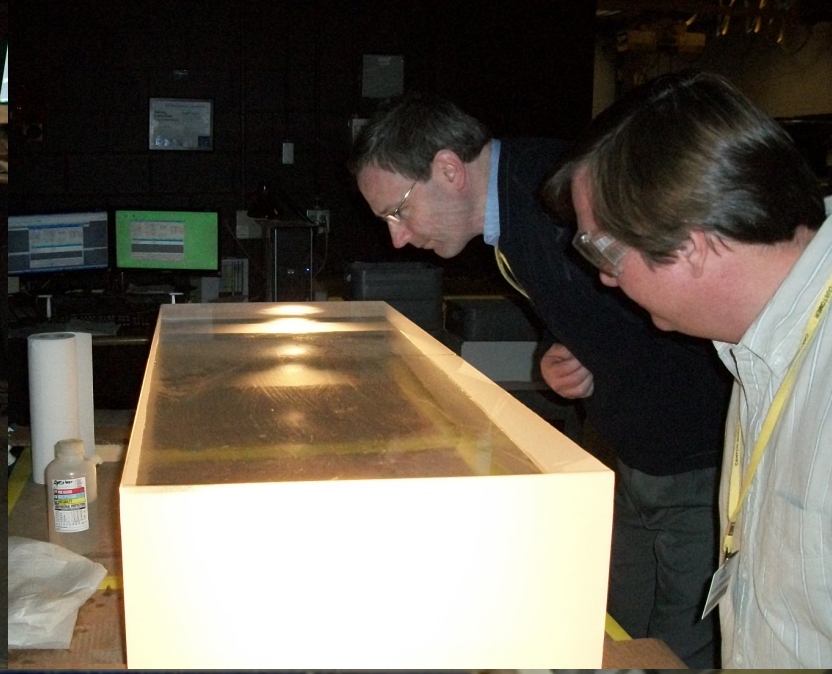
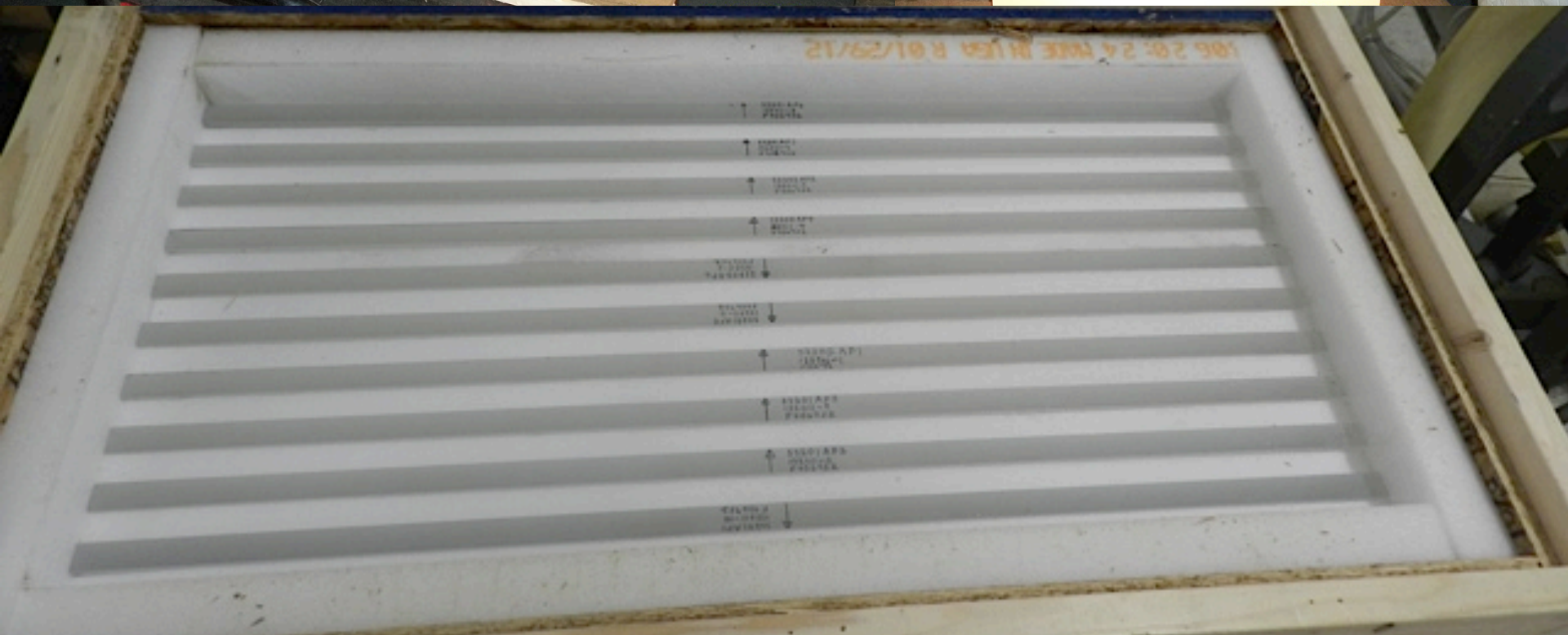
- Each module has 2 bars, 1 mirror and 1 prism
- Project plan includes optics for 16 installed + 4 additional modules
- Vendor evaluation prior to DOE CD-2/3 includes 4 full modules



First AOS/OOW bar undergoing metrology to evaluate material quality (homogeneity).

Cf. Report by D. Asner @ B2GM (July 6)





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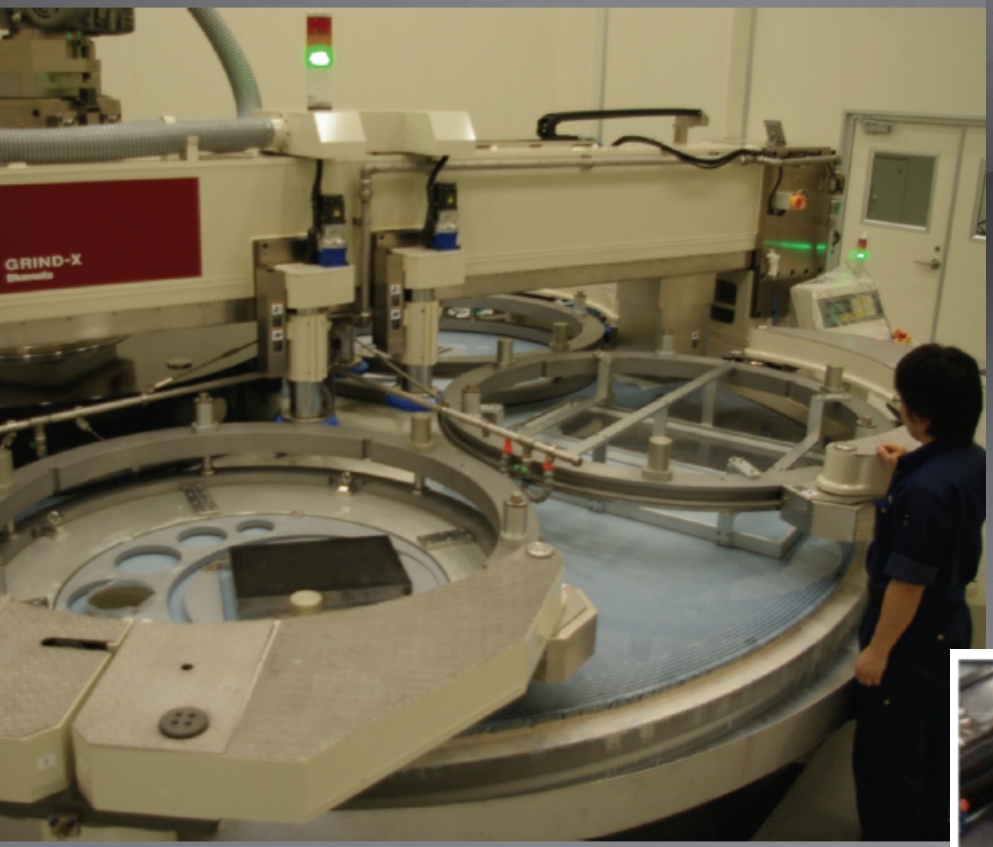
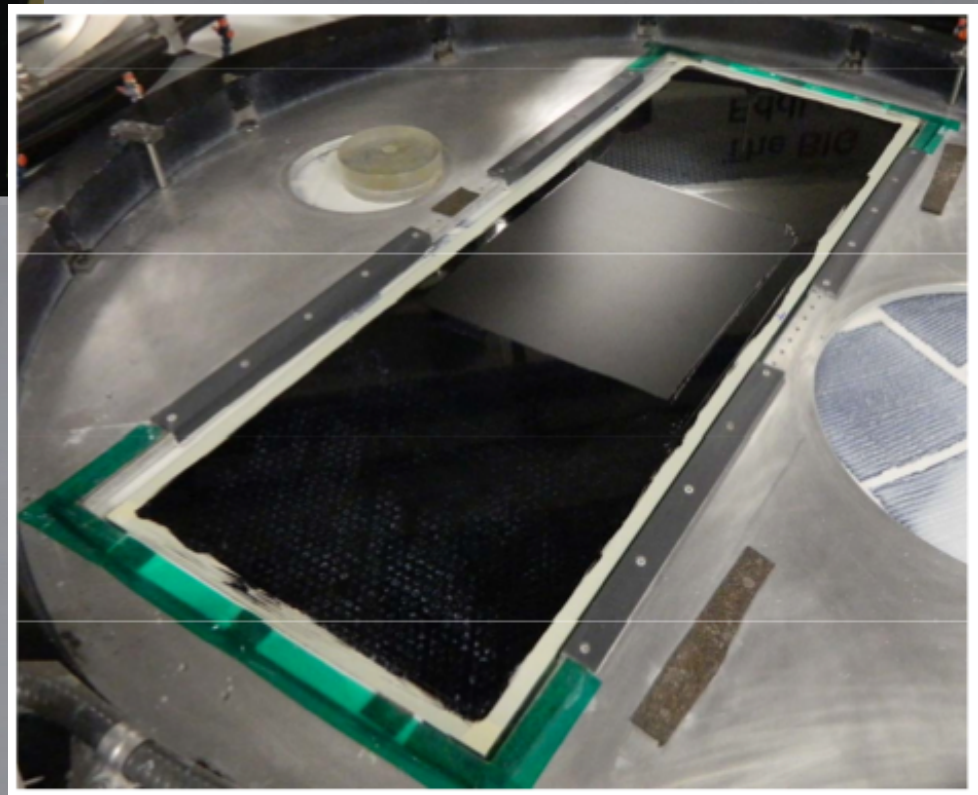


Aperture/Okamoto



Zygo

Cosmo Optics Prism

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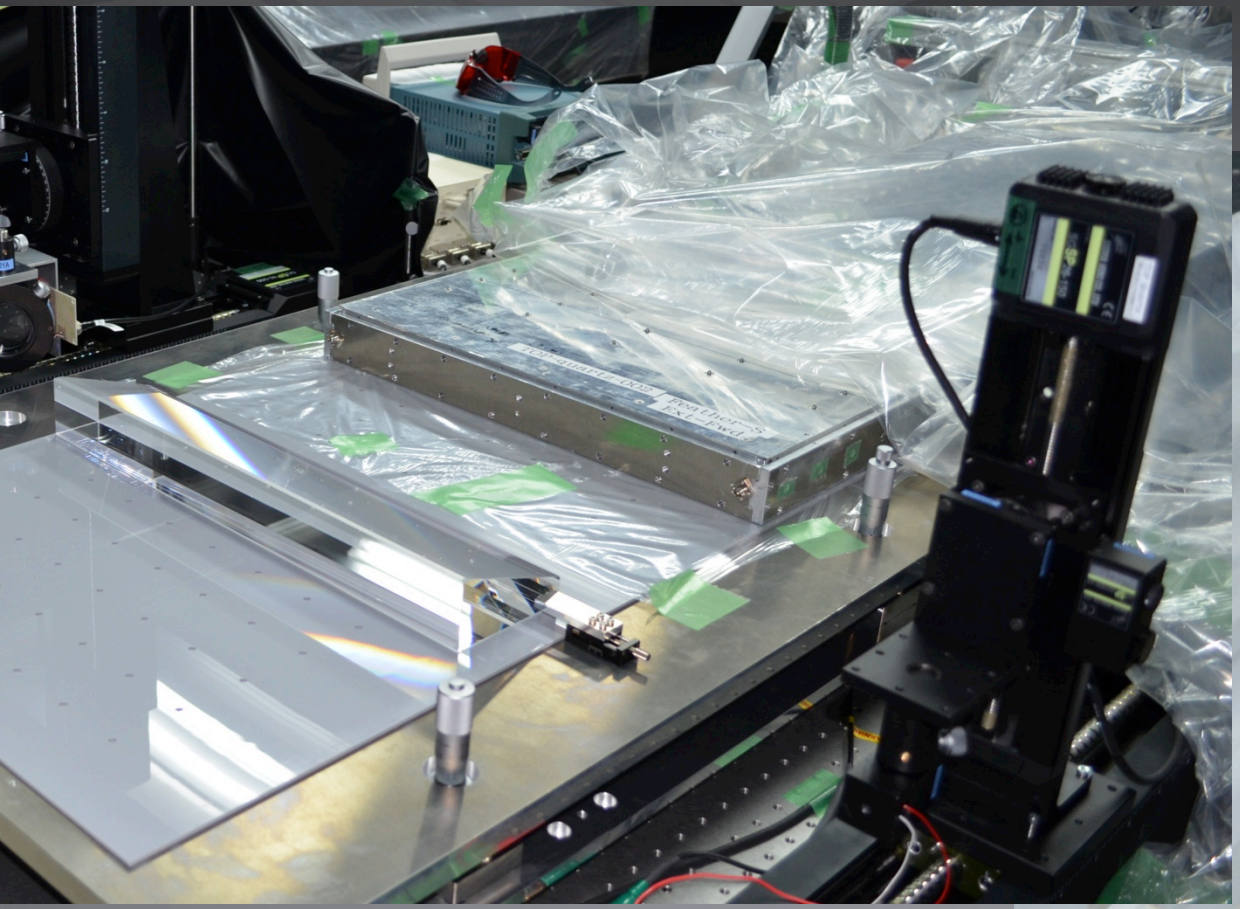

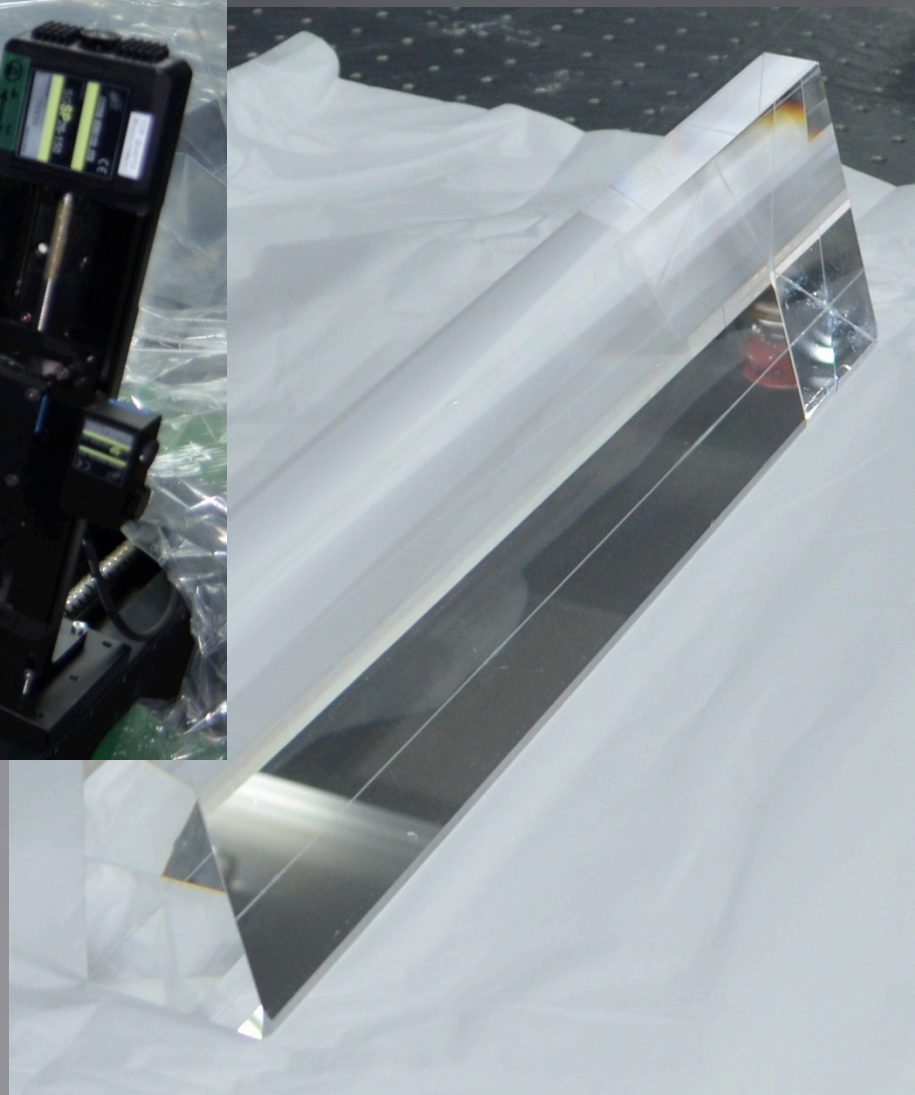

2013年 8月 23日

Quartz Order Status

- Bars
  - 14 bar saw-cut blanks have been produced (10 are in Japan, 4 in US)
  - Aperture (subcontractor Okamoto) under contract to produce 4 bars
    - Significant schedule slippage has occurred due primarily to poor grinding
    - First bar, due in December, still being worked at OOW
  - Zygo is under contract for 5 bars now
    - First bar is due in September
    - Pairs of bars due end of December and end of February
  - Considering adding third vendor (ITT Exelis) given AOS/OOW experience
- Mirrors
  - ITT Exelis under contract for 1 prototype
    - Completed 8/15; will be delivered to Cincinnati on 8/20
  - Under contract for 4 more – **STOP WORK** delayed 2 months while mirror radius was settled within iTOP group; delivery now February 2014.
- Prisms
  - Cosmo Optics has delivered a prototype meeting all but 1 specification
    - 2nd copy available to collaboration – Italians will be purchasing it
  - Zygo under contract to produce 4 prisms
    - Pairs due at end of September and end of October

Latest NOTIONAL quartz schedule

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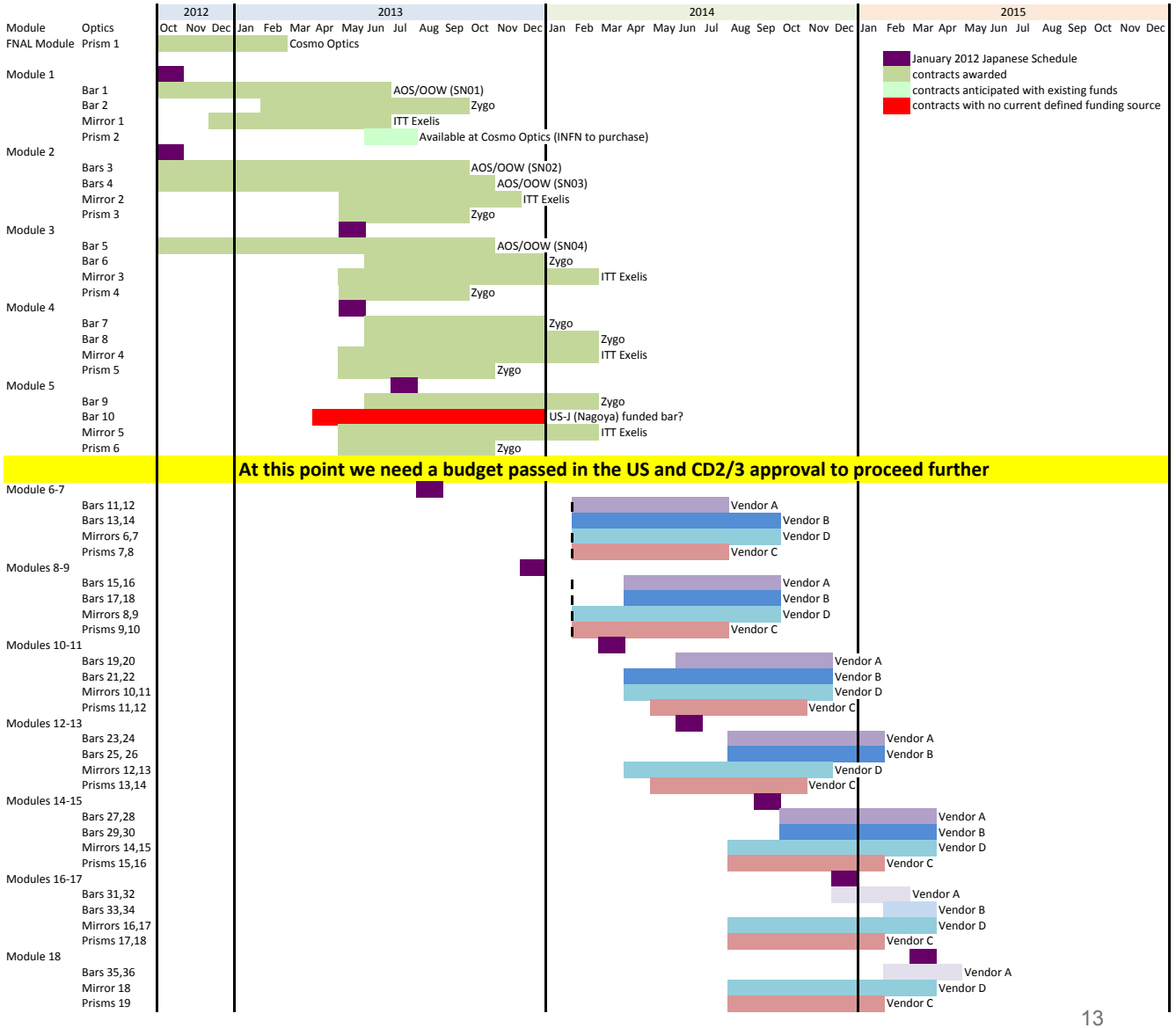
Schedule is a moving target as we gain experience with vendors (some good, some bad)

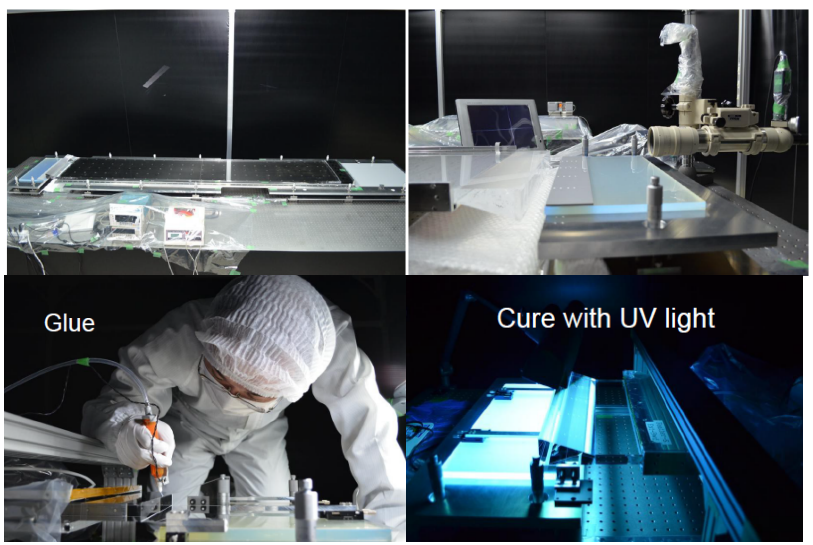
FY14 funding is tenuous at best and is likely to be delayed, moving schedule further to the right

No easy solutions remain after the lengths taken in FY13 (recall we were only supposed to have 2 modules as prototypes and have nearly 5 now thanks to DOE/PNNL)



Module Assembly

- The module assembly requires;
  - Class 1000 clean room, equipped w/ large flat tables for optical measurements, gluing of quartz and assembly into a bar box.
  - Well skilled scientists, technicians, workers.
- The expected assembly rate is ~ 1module/month, if only one production line.



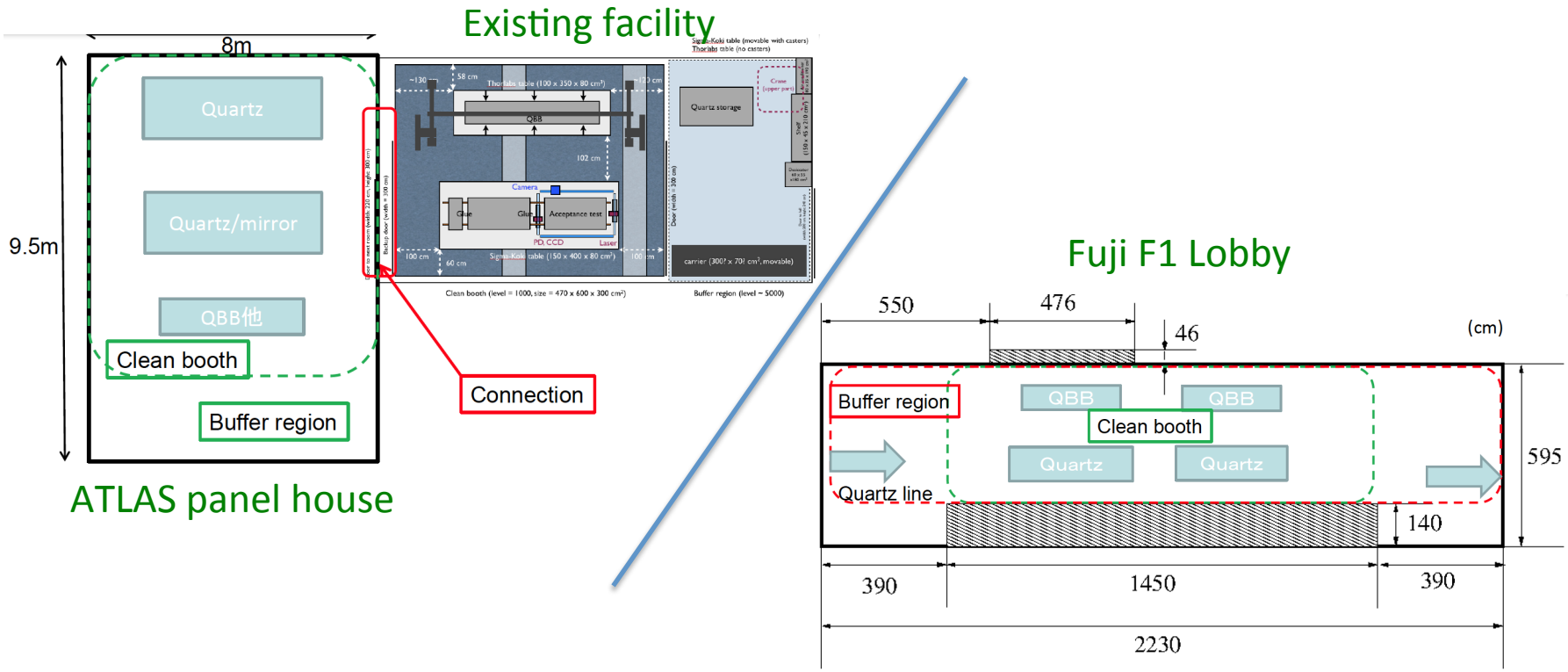
Horii's personal estimate on timeline (from 2nd module) in case of production delay

	Contents	Time [days]	Resource [persons]
Acc. test (10 days)	put bar on the stage	0.5	2
	chip measurement	1.5	2
	bulk transmittance measurement	1	1–2
	surface reflectance measurement	1.5	1–2
	put bar on the stage	0.5	2
	chip measurement	1.5	2
	bulk transmittance measurement	1	1–2
	surface reflectance measurement	1.5	1–2
	chip measurement for mirror and prism	1	1
Assembly (10 days)	align bar and mirror	1	2
	glue bar and mirror	1	2
	check of alignment and laser measurement	1	2
	align bar and prism	1	2
	glue bar and prism	1	2
	check of alignment and laser measurement	1	2
	align (bar+mirror) and (bar+prism)	1	2
	glue (bar+mirror) and (bar+prism)	1	2
	check of alignment and laser measurement	1	2
	move the glued bar to another optical table	0.5	3
	bar box assembly	0.5	2
	total	20 (1 month)	1–3

Expect 1 month per module. 3 months for the 1st module.

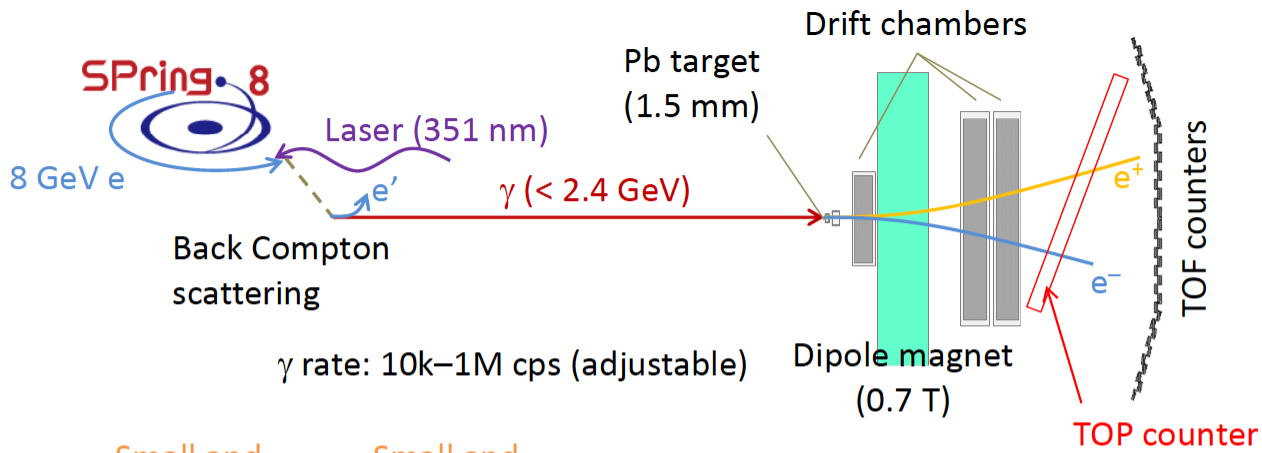
2nd production line

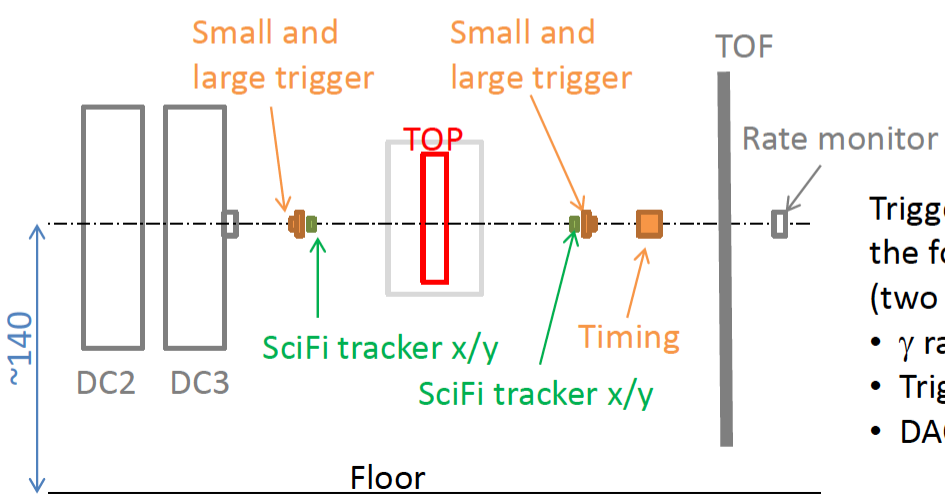
- The assembly facility at Fuji Hall B4 can accommodate only one production line.
- We need the 2nd production line to boost the assembly rate.
- Two candidates; ATLAS panel house @ B4 or the lobby @ F1.



Beam Test at Spring-8/LEPS

- June 4-14 + June 17-20
- Great help from the LEPS collaboration



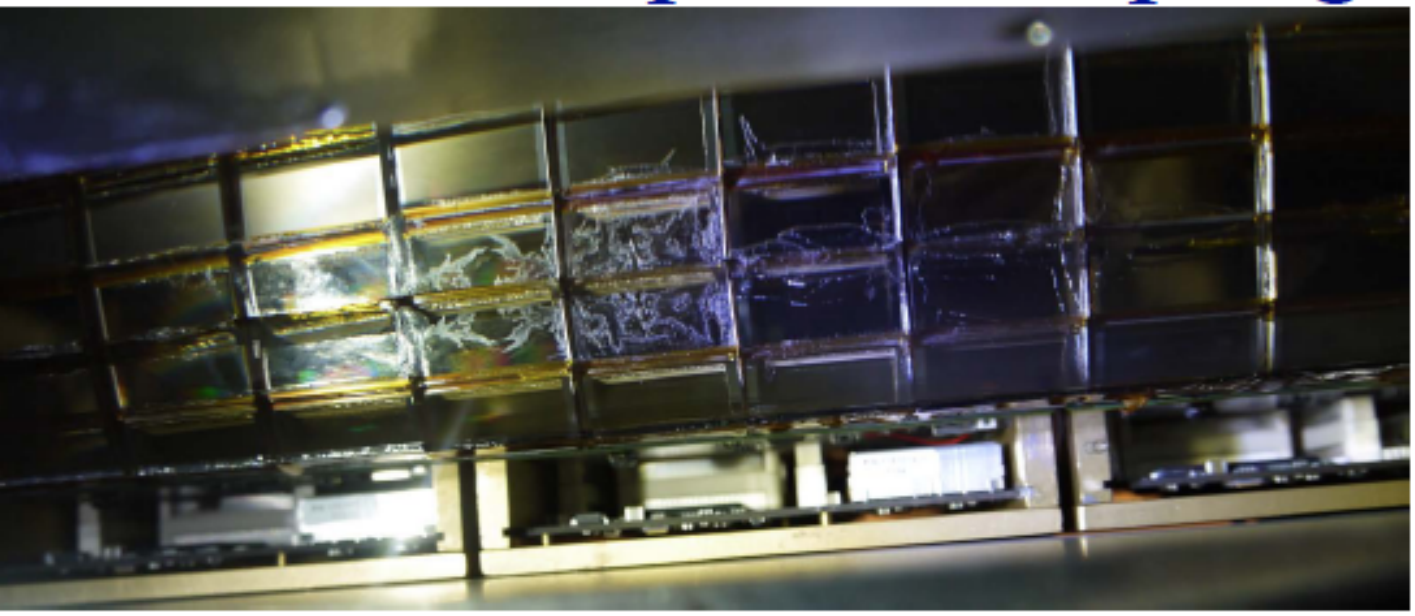


Triggered the 2 GeV/c e^+ beam with the four trigger counters (two 40 x 40 mm^2 and two 5 x 5 mm^2)

- γ rate: ~30 kHz
- Trigger rate: ~10 Hz
- DAQ rate: ~5 Hz (IRS3B)
  ~10 Hz (CFD)

Setup for IRS3B Experiment 3 (cosq = 0.43)

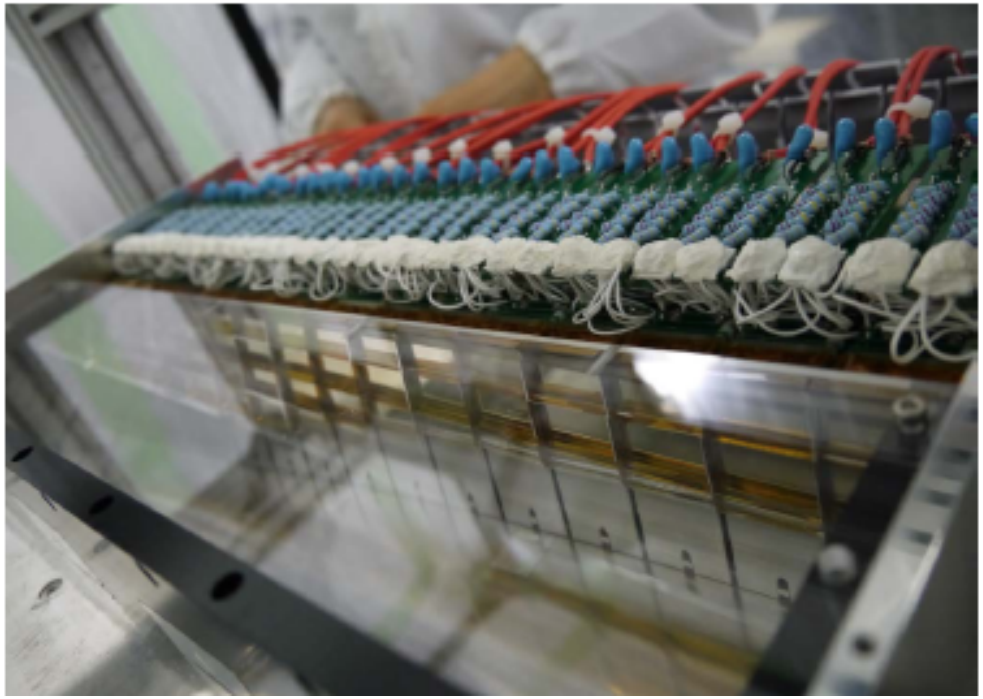
Optical Coupling



IRS3B

Despite heroic efforts, including custom push-rods, some bad spots

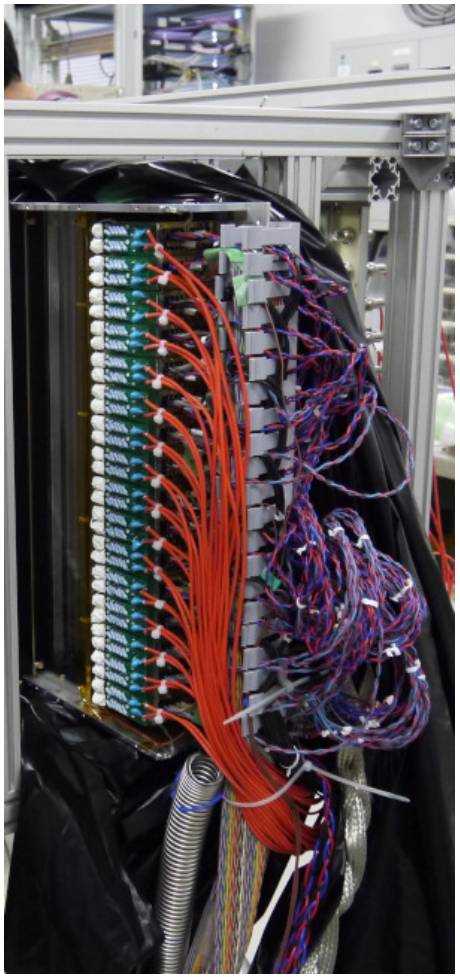
CFD

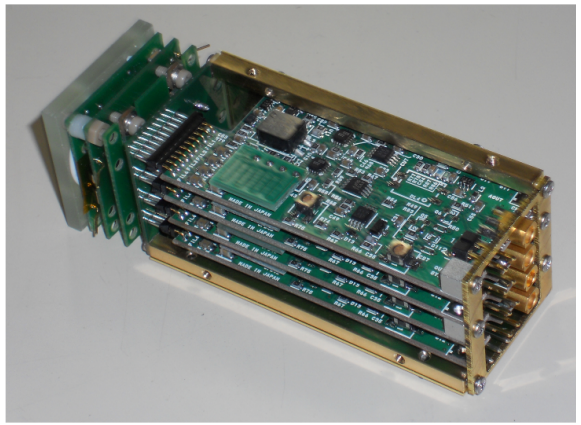


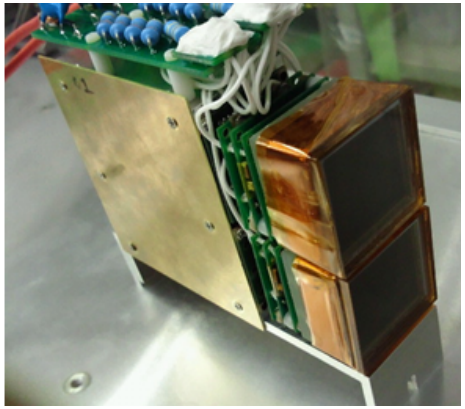
Coupling good both before and after data taking

Plan B electronics

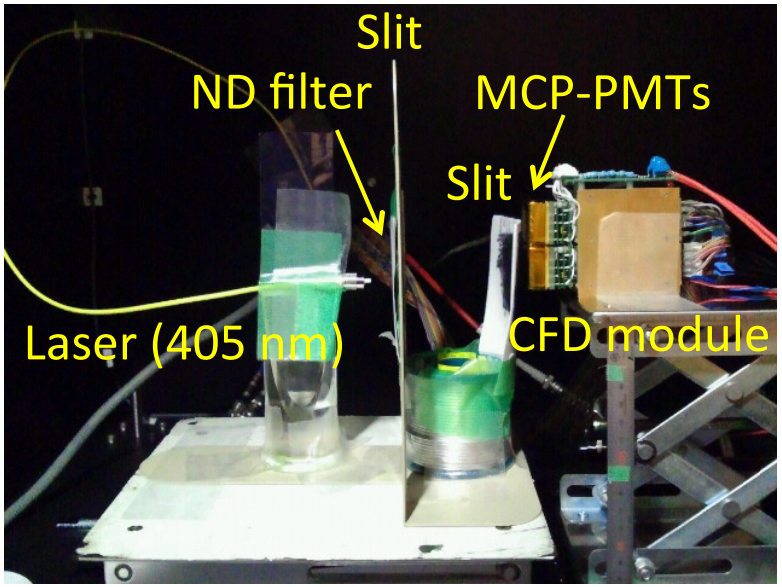
- CFD readout (Nagoya)
  - Used already at CERN beam test in 2010.
  - Successfully used also at LEPS beam test in June 2013.
  - 1x4 readout. 4-channels are combined (128 ch/module).
  - Fit in the same readout chassis + 8 flat cables for LVDS outputs to back-ends outside Belle II.
- Suitable back-up for beam tests.
  - with CAEN VME TDC as back-end.
- Need back-end electronics, compatible with the Belle II DAQ framework.

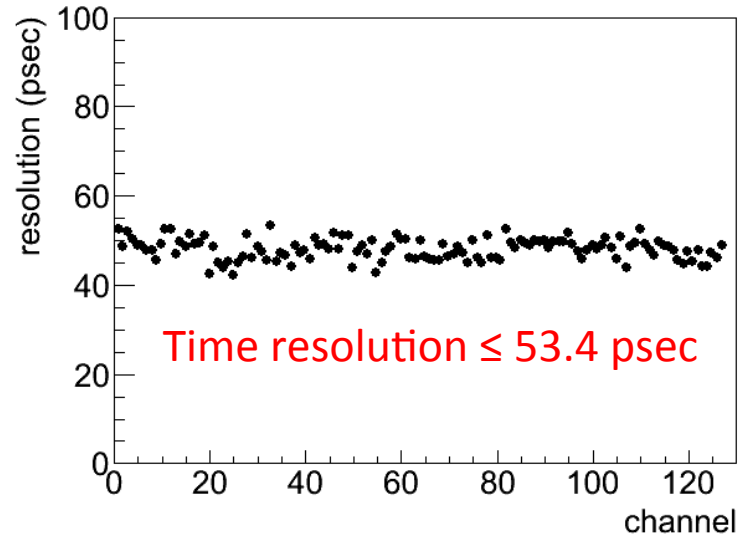




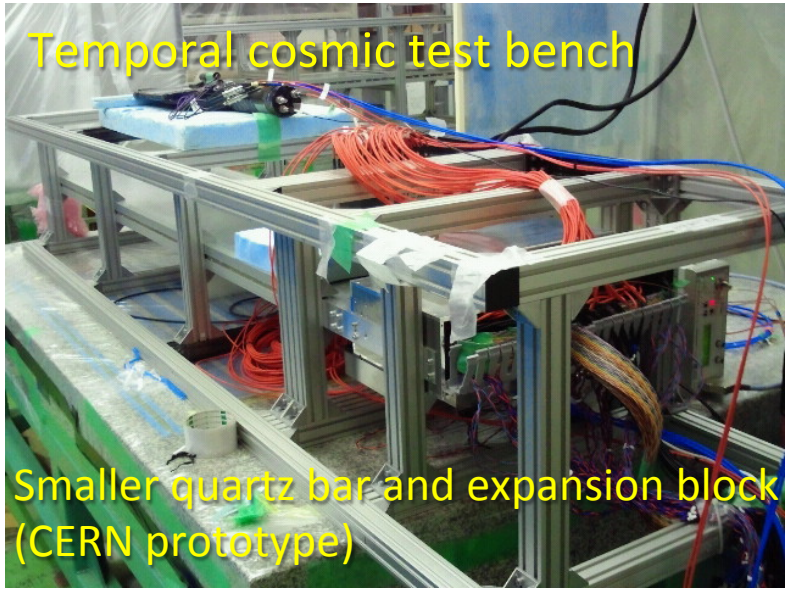


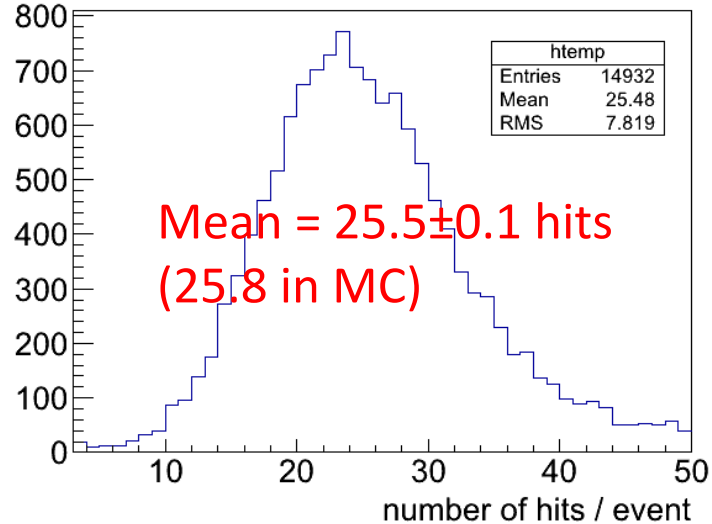
Tests at KEK





Laser on bar → Hit detection efficiency = 90.5% (av.)
Cross talk rate = 2.1% (av.)

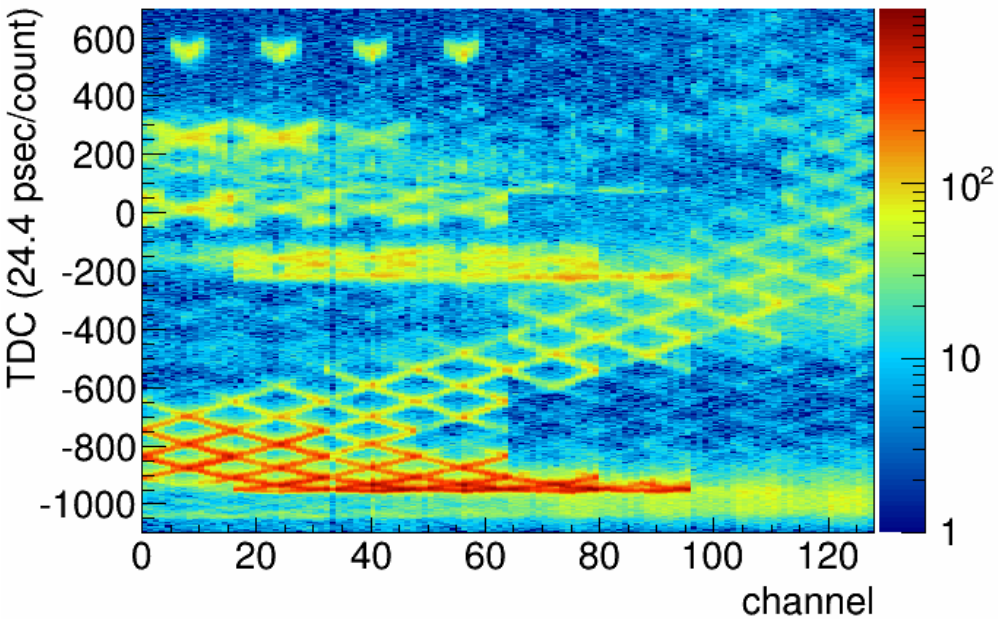




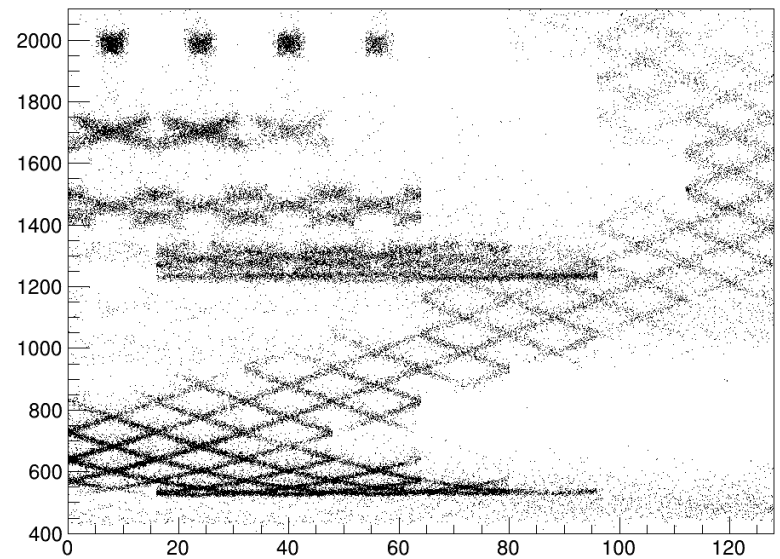
CFD TOP ring image

- Channel-by-channel t_0 alignment done with the laser data.
- Global t_0 obtained from RF.
- No event selection applied yet.

cosq = 0.009, x = 0.0 cm



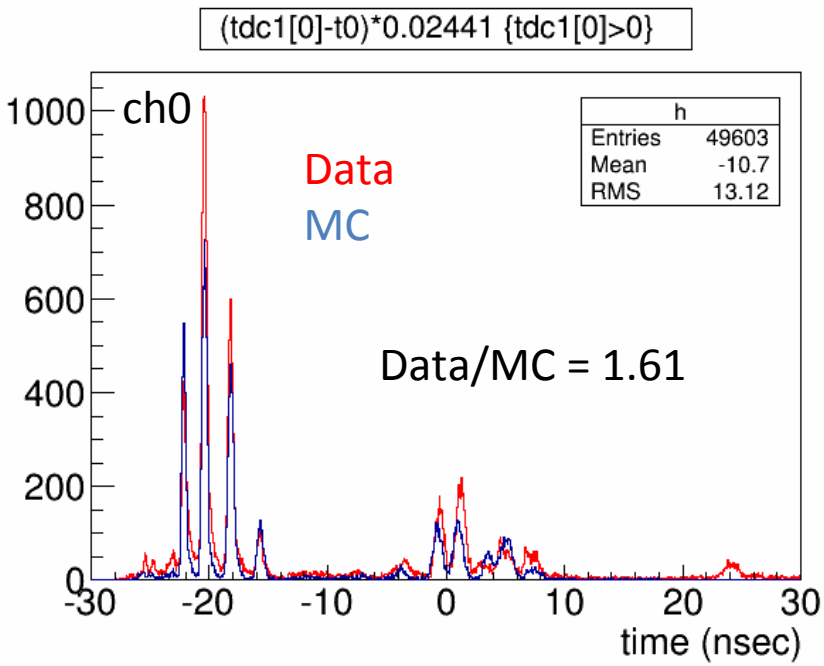
MC (by Marko-san)

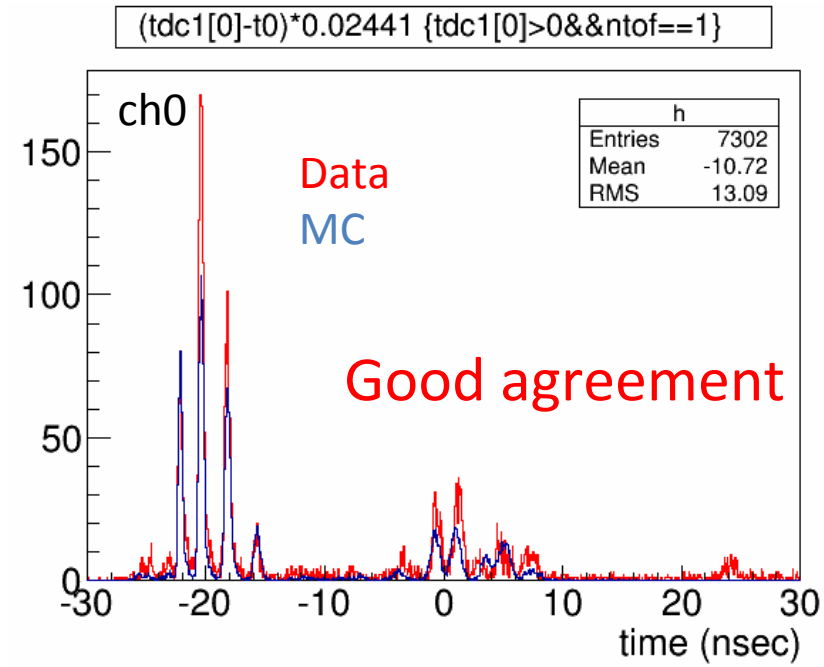


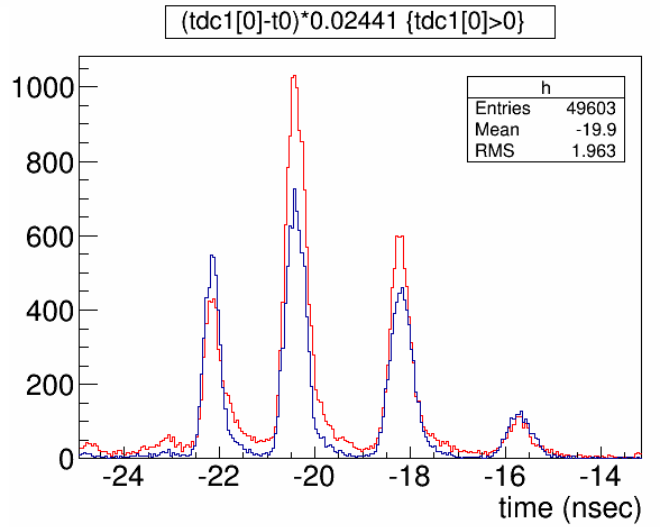
Clear TOP ring image. Good agreement with the MC.

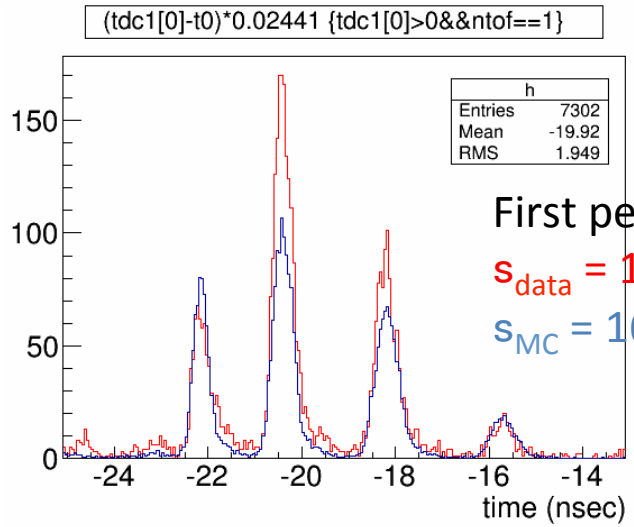
exp001

Time distribution





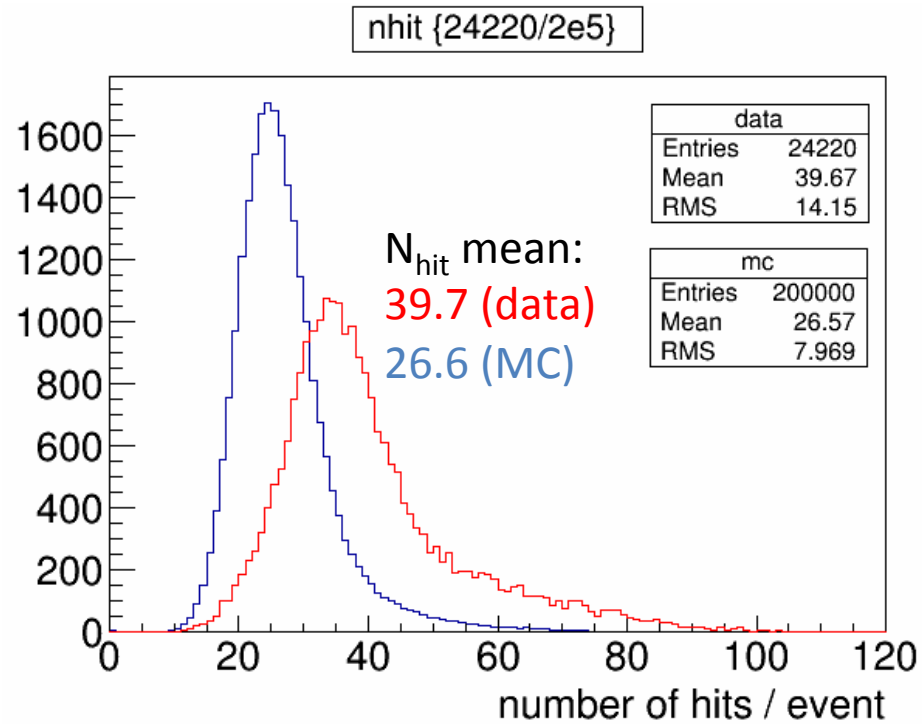




Comparison with MC

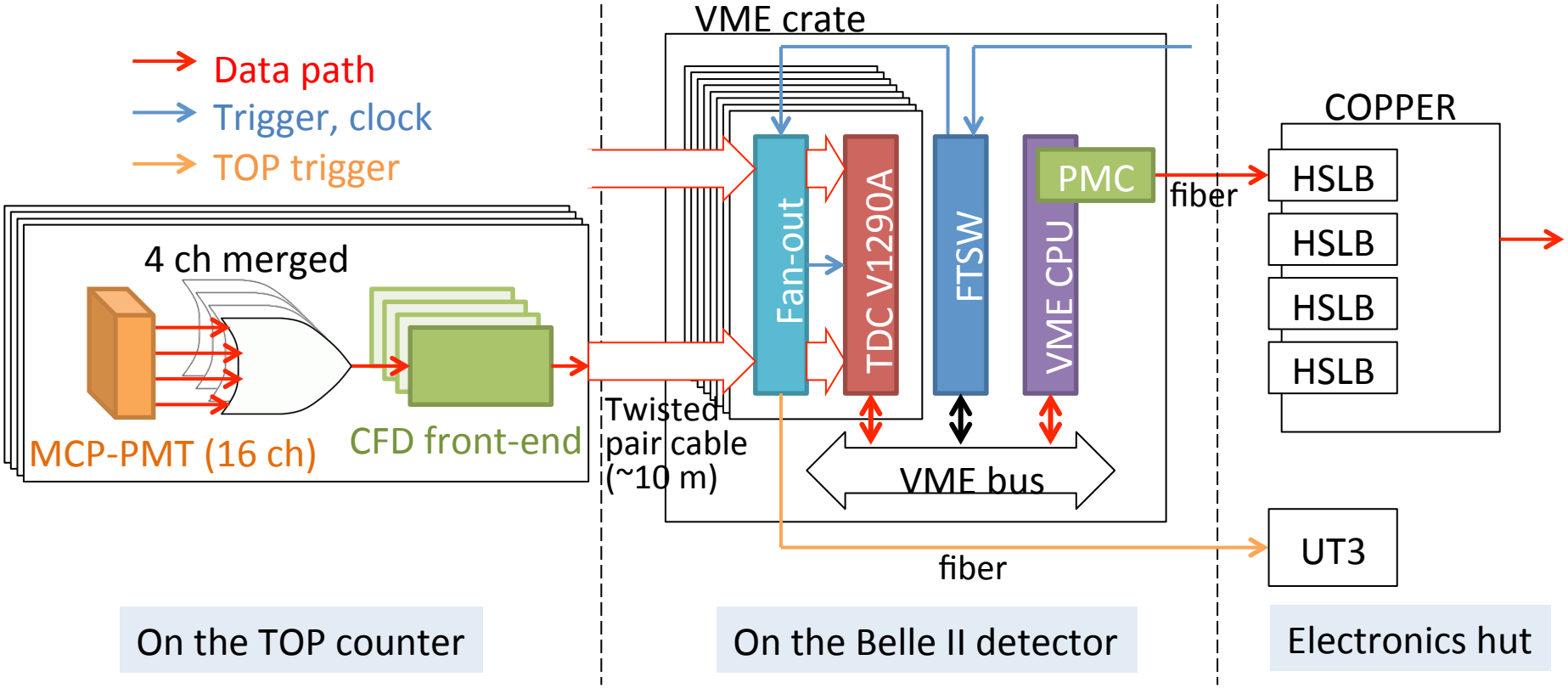
- Nagoya MC by Inami-san
  - 2 mm and 2 mrad beam fluctuation
  - 28% QE
  - Before beam position alignment
  - No polarization effect
- Data
  - Count only the first hits
  - Select N_{TOF} = 1 events

Probably the discrepancy comes from the MCP-PMT QE dependence on the photon incident angle and polarization. Need further study.



Data/MC = 1.49

Plan B of the TOP readout

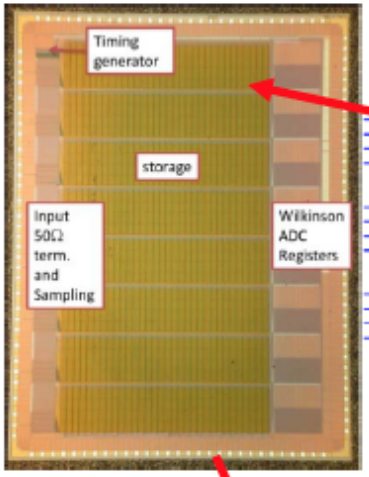


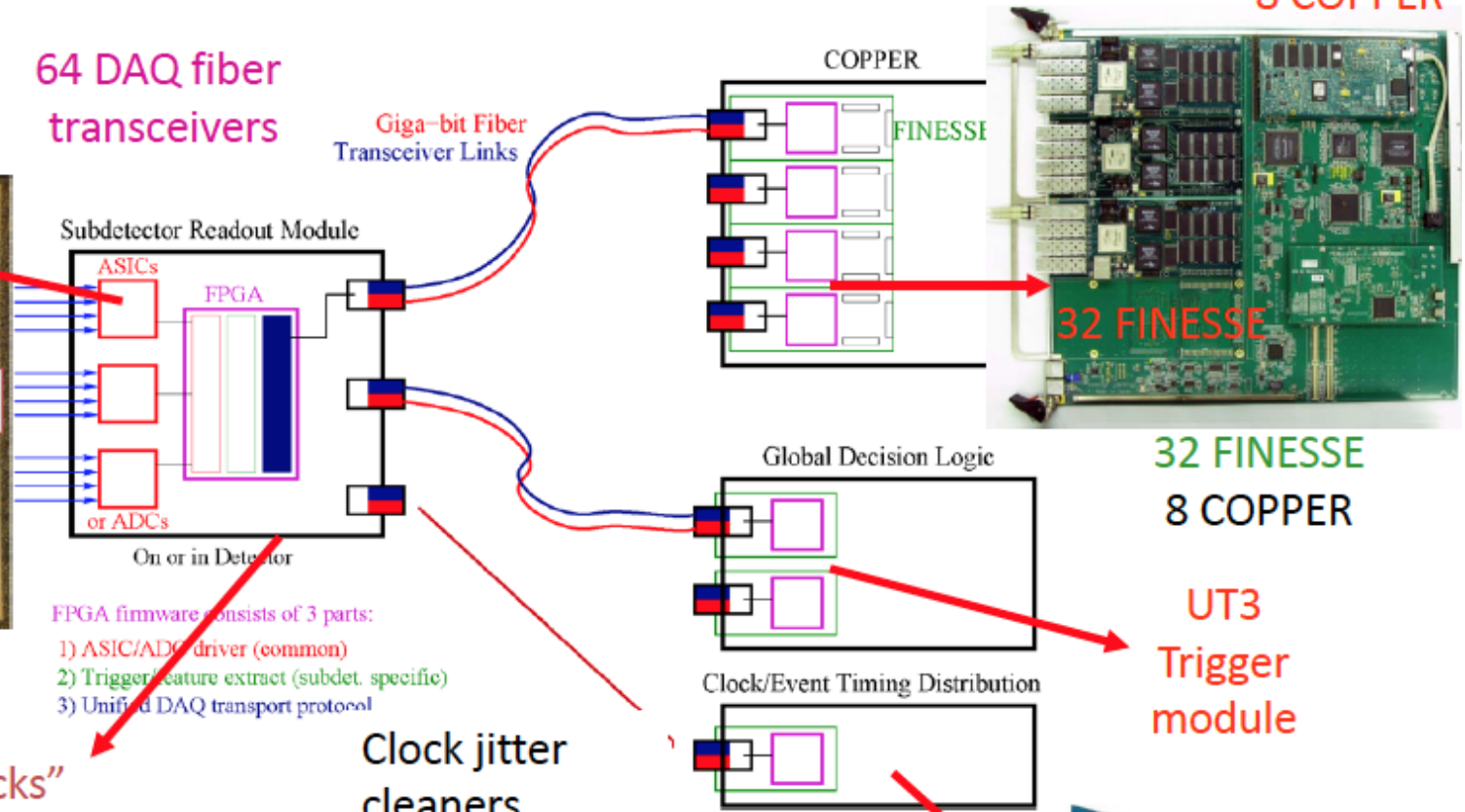
- Use established technologies (CFD for the front-end and CAEN TDC for the back-end).
- 4 channels of the MCP-PMT are merged to reduce the number of readout channels.
- Compatible with the Belle II DAQ/trigger system.
- Limitation: TDC V1290A does not work when the background hit rate exceeds 16.4 MHz/PMT (5.6 times higher than the current estimation).

IRS3B-based Readout Overview

Waveform sampling ASIC

64 DAQ fiber transceivers





8 COPPER

32 FINESSE

8 COPPER

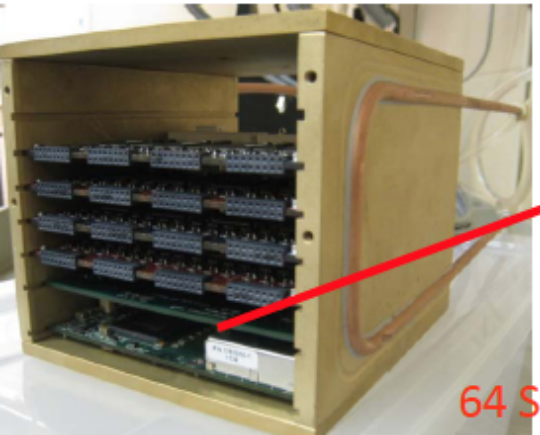
UT3 Trigger module

8k channels

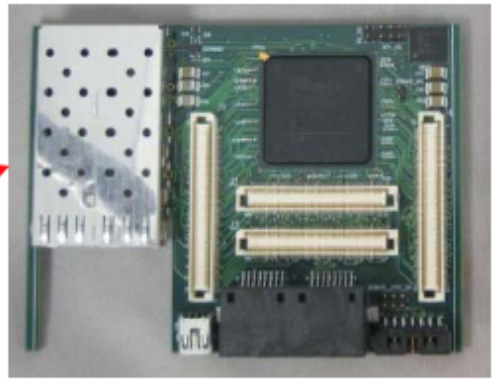
1k 8-ch. ASICs

64 SRM "board stacks"

Clock jitter cleaners



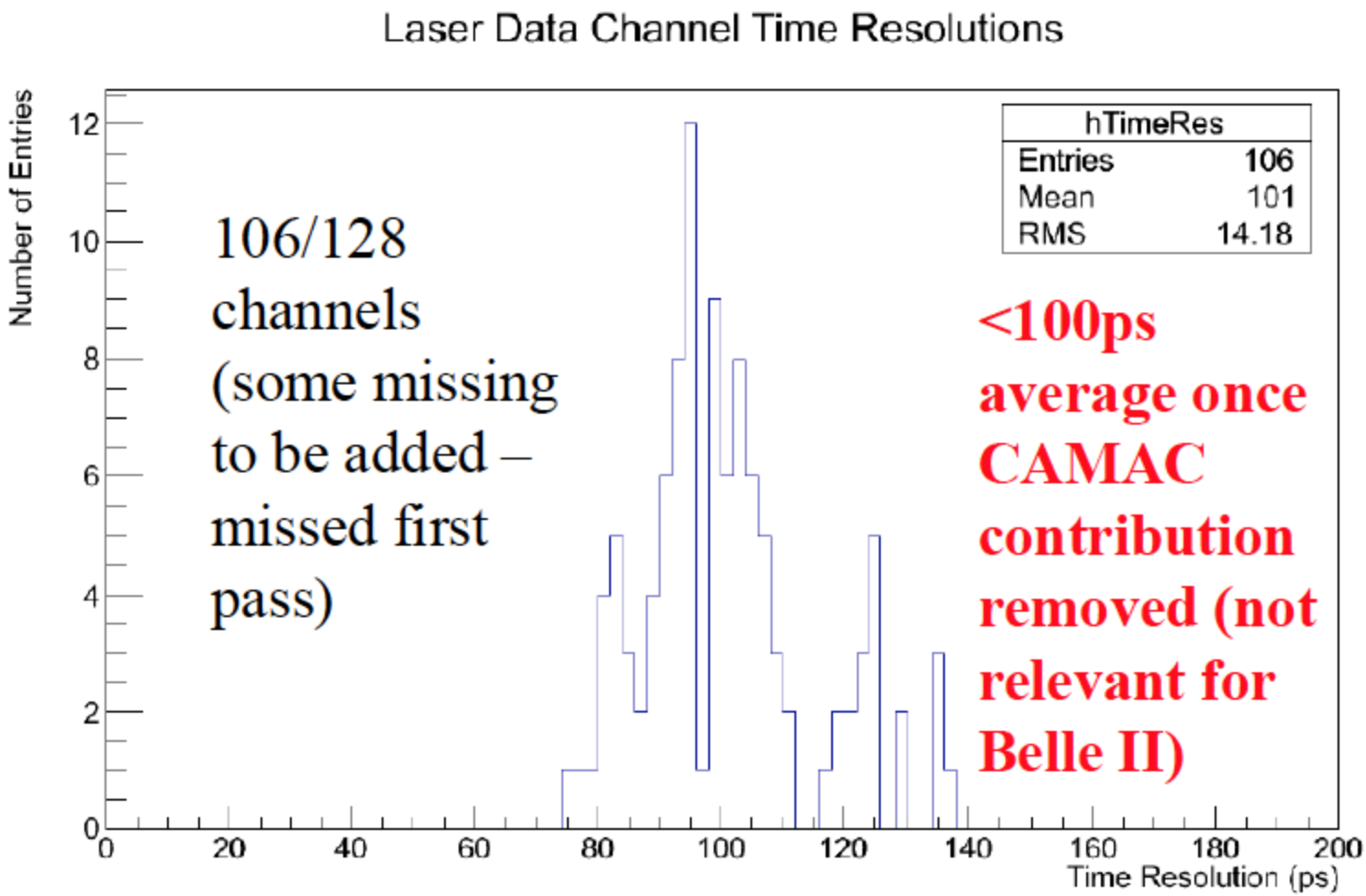
64 SRM



FTSW clock, trigger, programming

16 FTSW

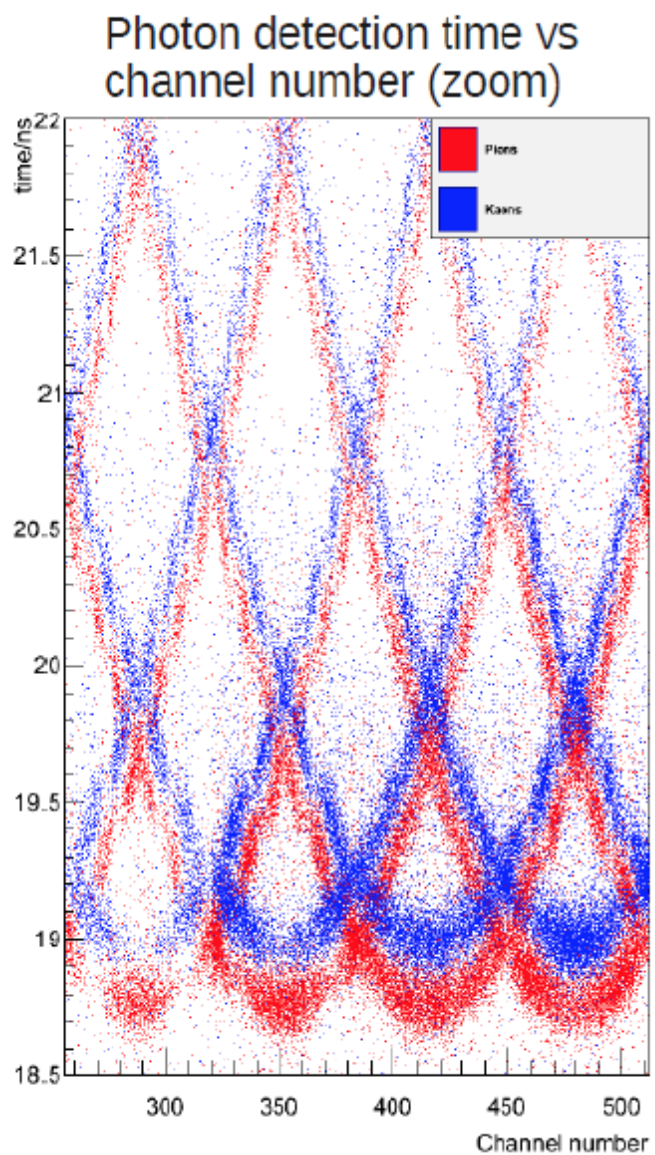
Board Stack #37 single photon timing, no ADC cuts, no modifications from LEPS configuration



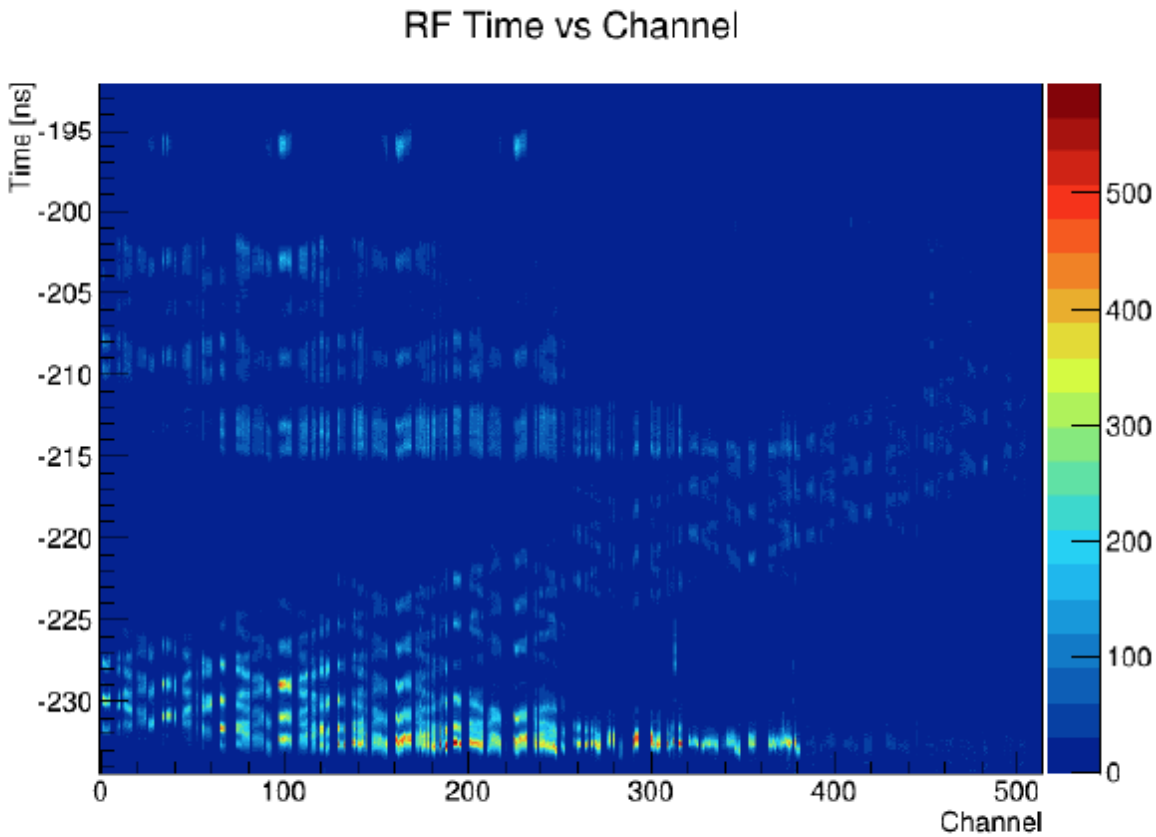
- Overall average time resolution is 101 +/- 14 ps
- Need to understand large variation in time resolution across channels

Pedagogical slides about timing…

- Space-time correlations

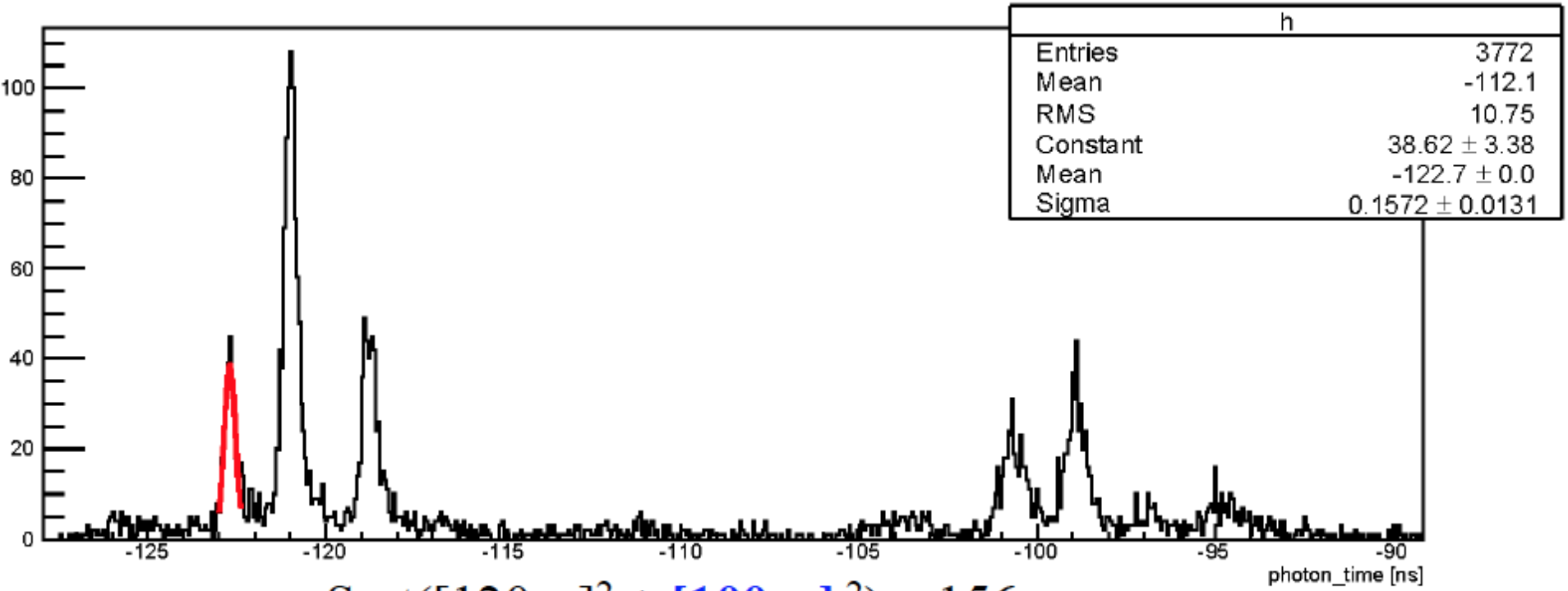


Beam Test Data



About LEPS timing current status… (work in progress)

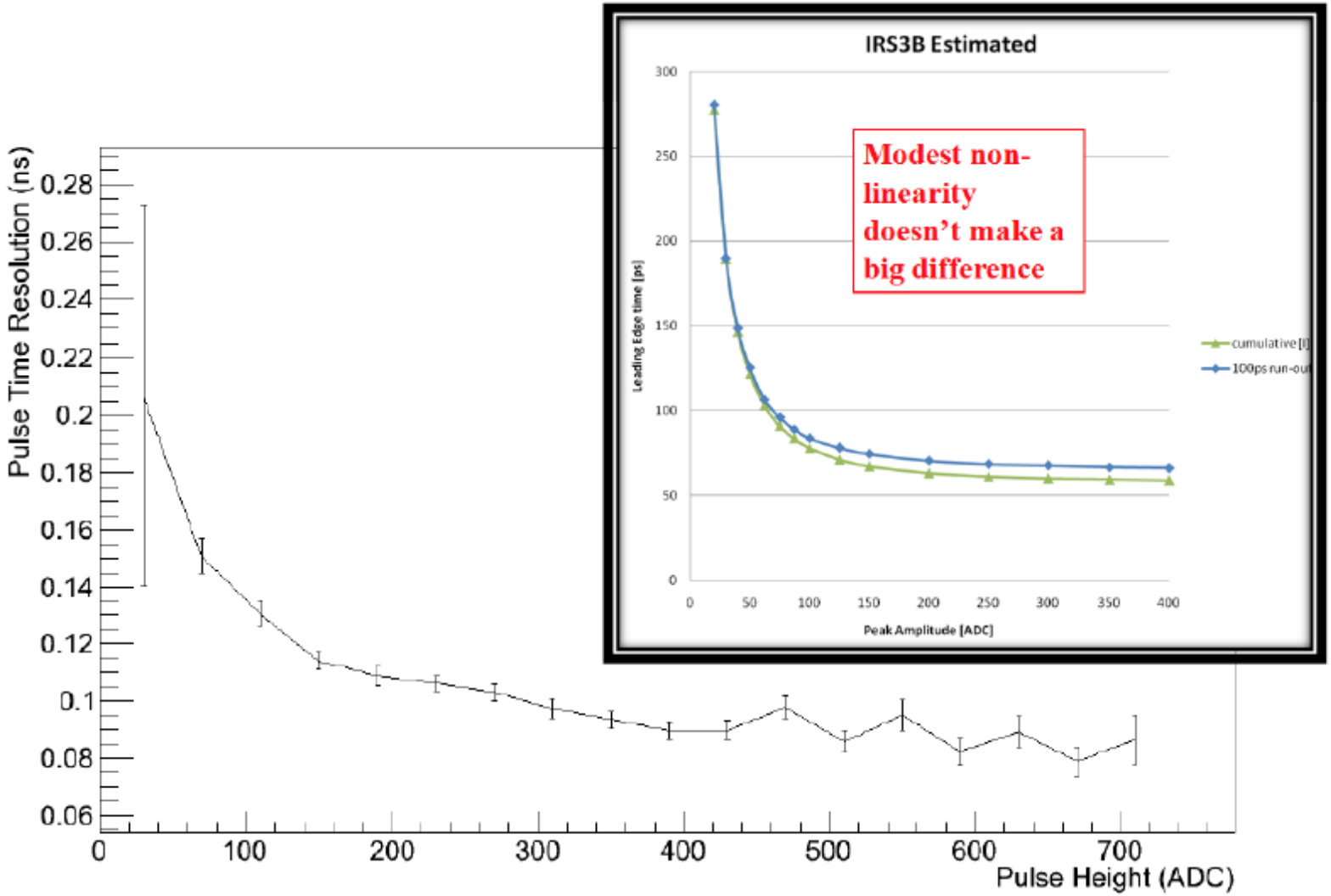
- For large amplitude, corresponding to the tight cuts applied, and assuming ("120ps" width)…



Sqrt([120ps]^2 + **[100ps]** ^{2}) ~ 156 ps

Electronics contribution

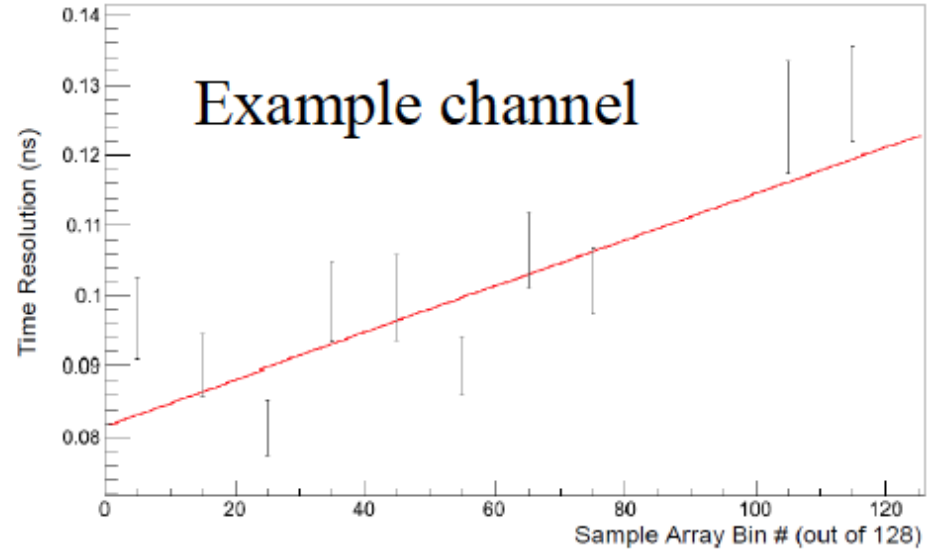
As understood from simulation

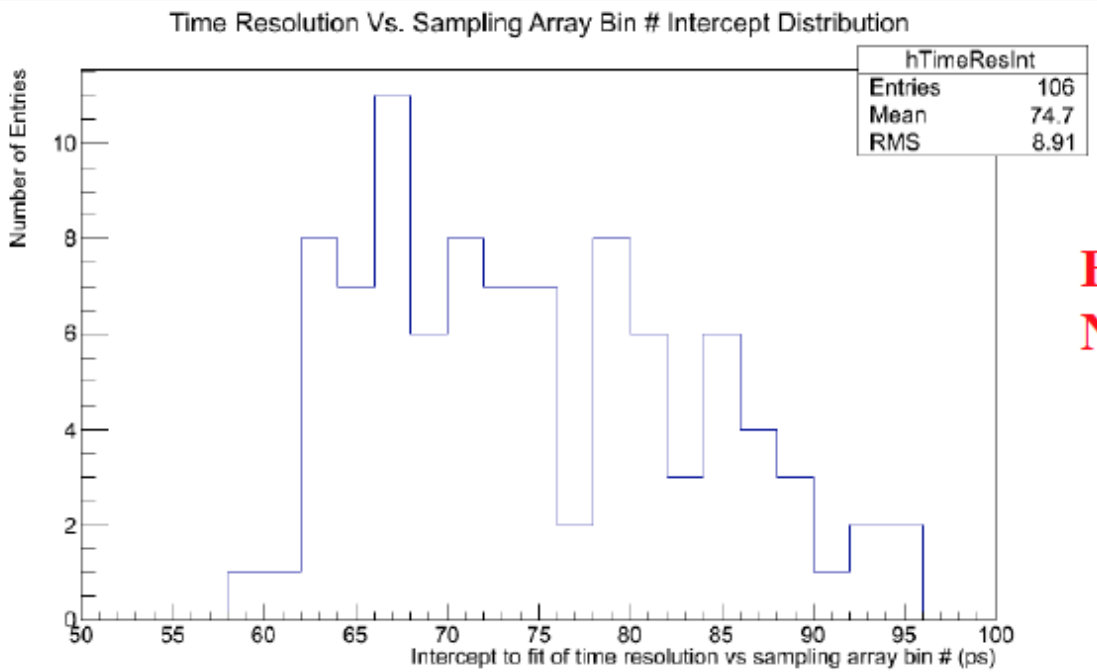


- Time resolution clearly depends on pulse height
- To a large extent, channel time resolution will depend on pulse height distribution

And it is clearly observed

Probably a combination of jitter (noise on VadjN) and coarseness of DAC [under study]





Ensemble distribution, No ADC cuts

- Plot distribution of intercepts from linear fit to time resolution vs. sampling array bin # plot
- Represents time resolution if there was no degradation along sampling array

Executive Summary

- After commissioning/learning period, now obtaining electronics resolutions commensurate with stated minimum requirements (<100ps timing)
- Still room to improve:
  - Processing: timebase cal, leading edge timing extraction
  - Board improvements: sampling timebase, gain, risetime
- Rev. C Carrier boards [improved mechanics, amplifiers, signal coupling] being assembled, testing soon
- IRS3C [extended dynamic range] due this week
- **Details in subsequent slides**

Quartz Production Outlook

- Remaining procurements are dependent on “construction” funding from DOE which requires CD-2/3 approval and “new start” approval
  - New starts can not occur under a continuing resolution without specific Congressional approval; DOE has put Belle II forward for approval, but the probability of success is not high (Office of Science is a small part of DOE)
- We are working very hard to see if other solutions can be found
  - e.g. forward funding from US Universities (already done for KLM modules)
  - High level discussions underway (Jim Siegrist and Yamauchi-san)
- Problem is ~$2.5M in first 6 months of USFY14; $6M for the year
- We also need technical success to pass DOE reviews
  - September BPAC is an initial “dry run” that will be informative
  - Not clear yet if June beam test data are adequate for review
  - New DOE Federal Program Manager, Helmut Marsiske, is much more engaged than predecessors – this is good for us
    - Visited PNNL in July to go over US Belle II and beam test in detail

DOE Review

David Asner @ B2GM (July.6)

Path to DOE CD-2/3 Approval – Notional Schedule

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- April/May: iTOP module with prism and IRS3B operating in CRT stand
- June: Beam test
- June/July: Beam test analysis
- July: DOE visit to PNNL
- **End of July: Beam test data verified "good"**
  - **Trigger to schedule PNNL Director's Review of project**
- Mid-August: Complete TDR/presentation materials for Directors Review
  - Materials must be posted 2 weeks prior to review
- Early September: BPAC – Dry run for PNNL Directors Review
- Mid-to-late September: Directors Review
  - Triggers request for DOE Independent Project Review (CD-2/3 review)
  - Assuming no action items from DR, can schedule 6-8 weeks out
- October: Materials posted for IPR
- November: Independent Project Review ("Lehman" review)
  - Assuming success, recommended to present to ESAAB following US budget

To path CD2/3 review

- It is requested to demonstrate performance with
  - Readout system to be installed in Belle II.
  - Near final optics (must have prism)
  - Near final electromechanical assembly (gas seal, close to final board stack package, thermal management under control etc.)
  - At several conditions of incidence
    - Beam test + cosmic ray test for very steep angle
    - Understanding data by comparing to MC.
- Vendor capability to produce quartz optics

Summary

- It is possible to make the Belle II ready in time.
- But, the schedule is very tight.
- The major issues are;
  - Readiness of readout electronics
    - Demonstrate Plan A (IRSX) or Plan B (CFD)
  - Quartz Procurement
    - Vendor capability
  - DOE funding situation
    - Technical readiness to pass CD2/3 review
    - US congress situation (continuing resolution, anomaly list)
  - Module assembly
    - Need 2nd production line (location, cost).

Will make it clearer at Belle II focused review in Sep. 9-10

Backup

Man Power

- "This group is just too small !" (comment by Blair Ratcliff).
  - For instance, having a beam test stops almost all other activities, while we expect more beam tests in CY2013, 2014.
  - Will be limited by assembly capacity soon.
  - Need more engineers, technicians.

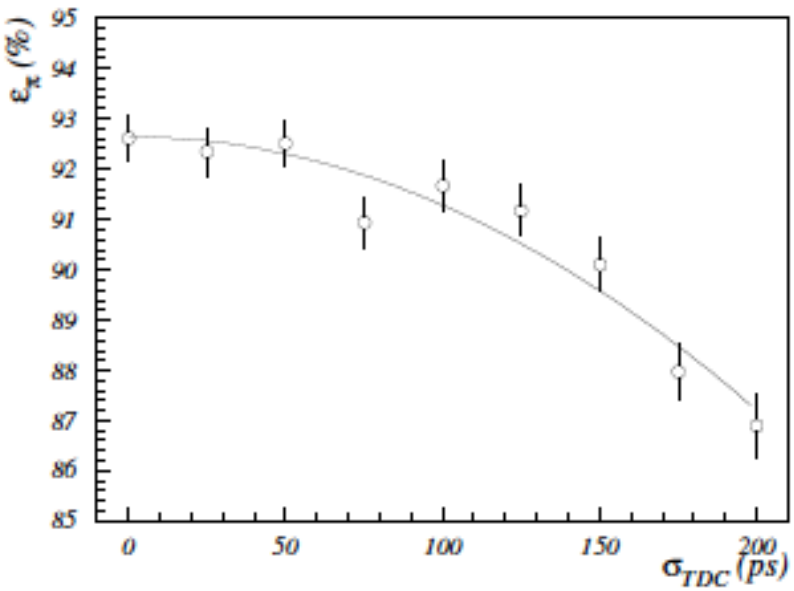
- Reinforcing mechanics experts from existing groups;
  - Ljubljana
  - PNNL
  - Nagoya

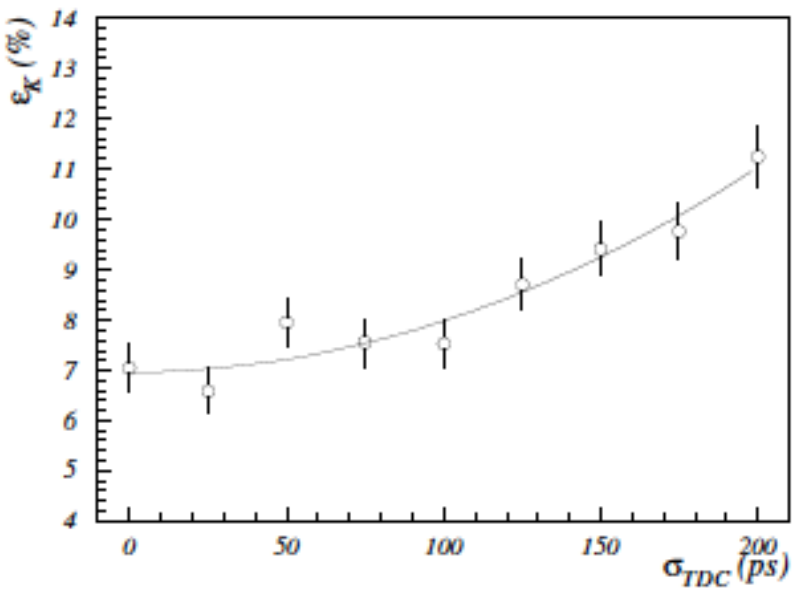
- New comers from Italy (R. Mussa et al.)
  - Including 1 optomechanical engineer/designer, 2 skilled technicians.
  - Possible contribution (under discussion)
    - TOP fiber calibration system,
    - Environment monitor,
    - Software works
    - Power supply
    - Cooling system,
    - Testing MCP-PMT (ALD version)
    - Module assembly

Impact of electronics jitter

$B \to K\pi$ signal MC

- Additional Gaussian smearing of photon arrival times (up to 200 ps)
- For each data point different MC sample used

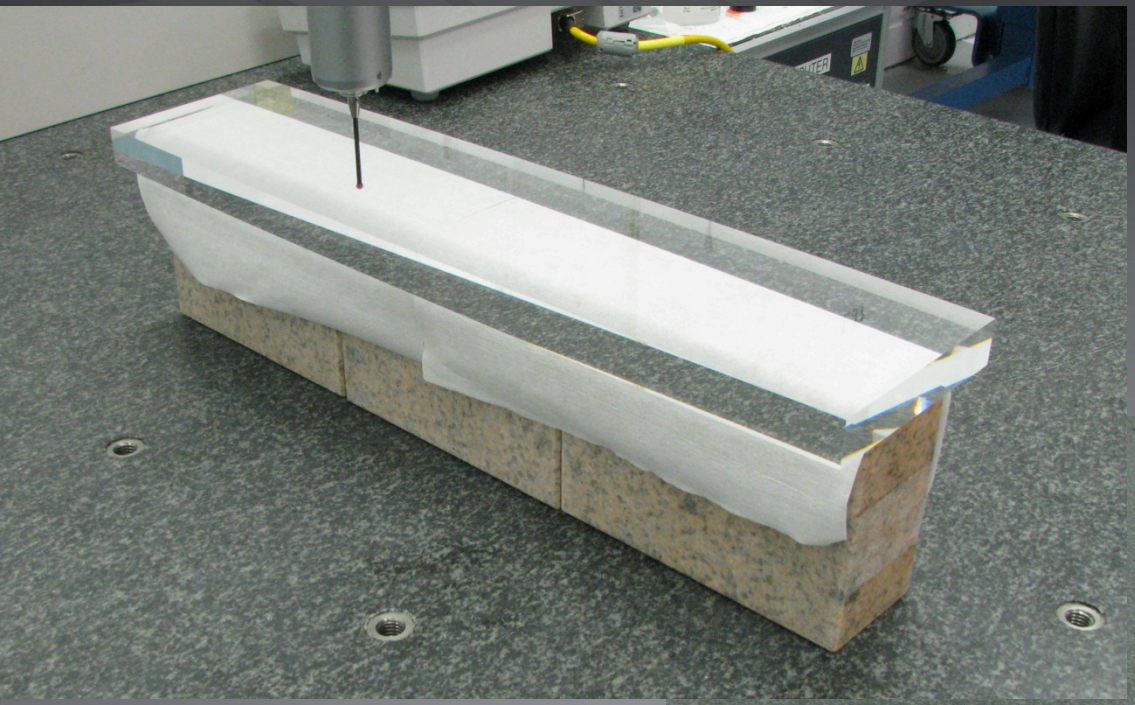




- Quadratic dependence
- Negligible up to 50 ps
- Small performance degradation observed for 100 ps ($\sim$1%)

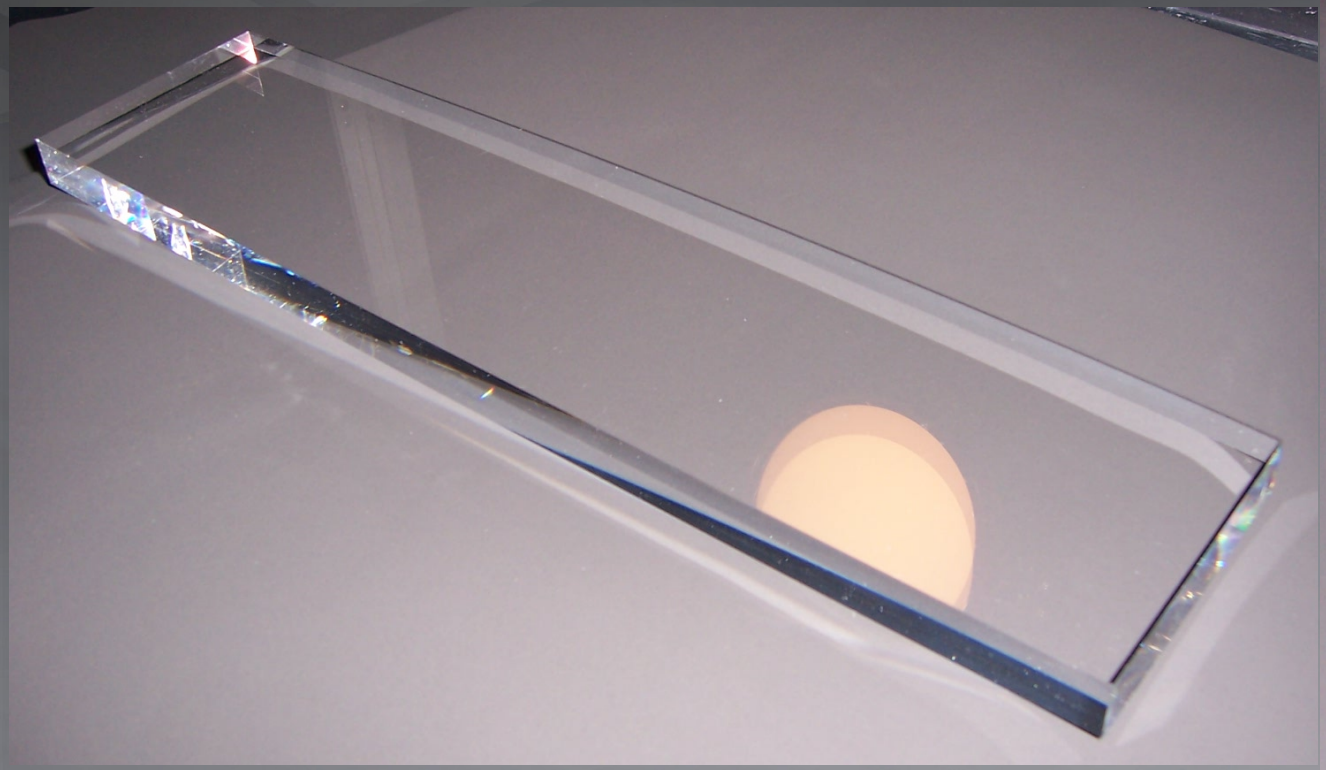
Mirror undergoing final metrology at ITT

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

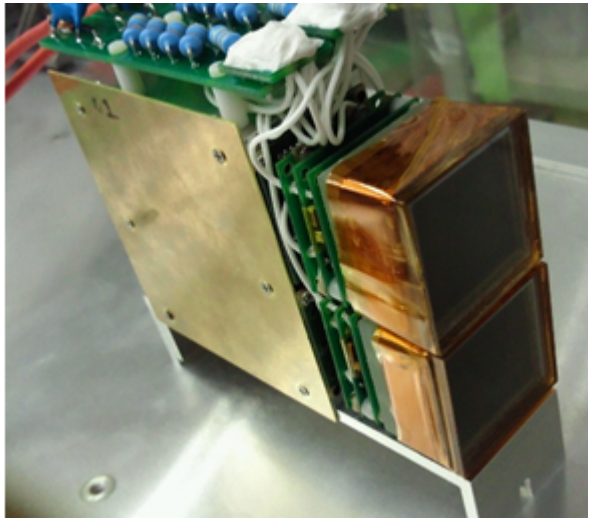


First mirror at ITT after coating

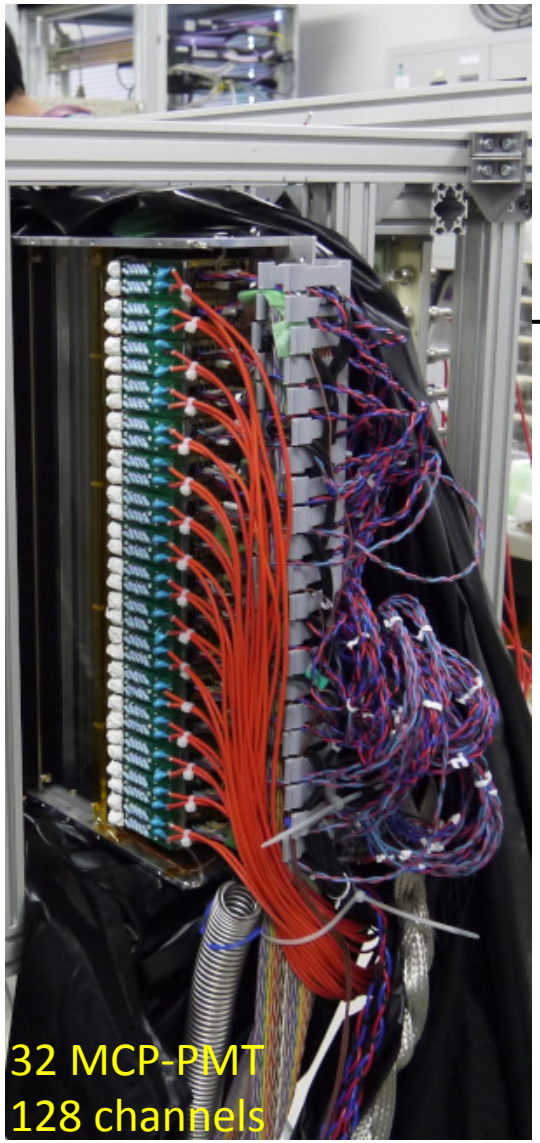
Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

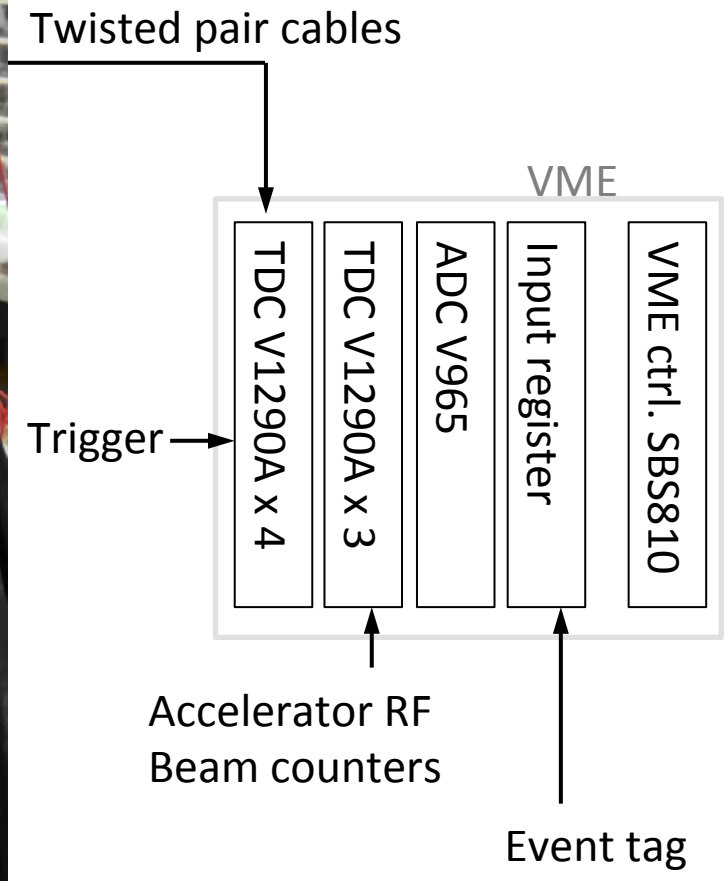


CFD readout system



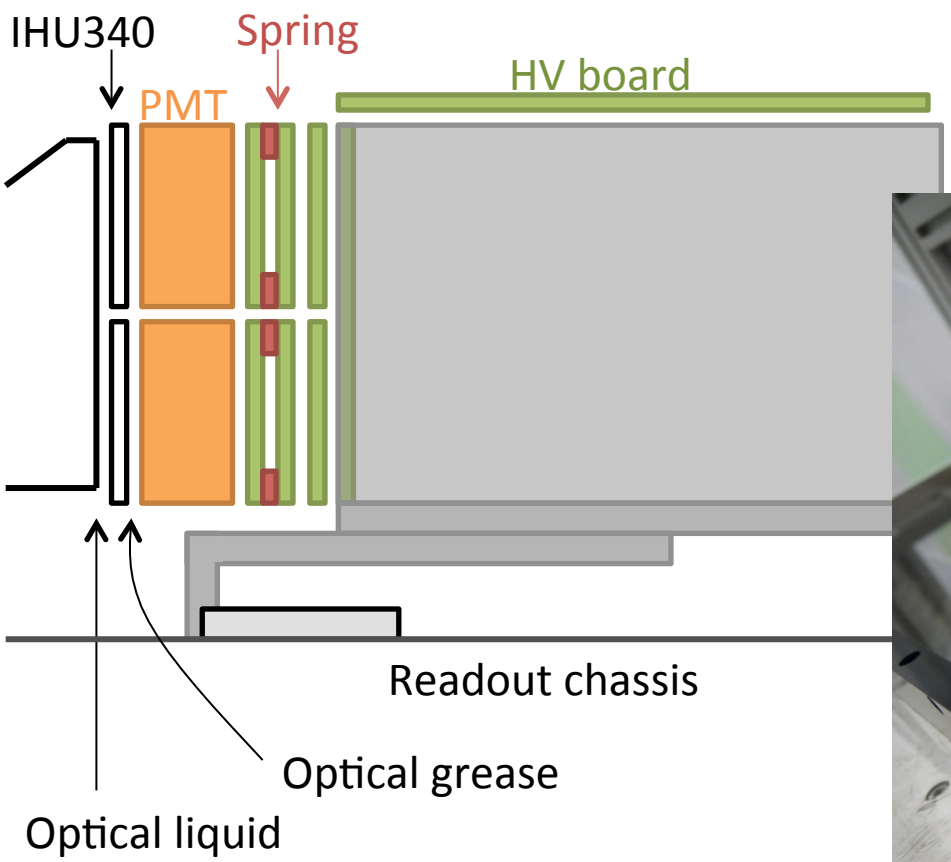
MCP-PMT 16 channels are merged into 4 at the MCP-PMT socket.





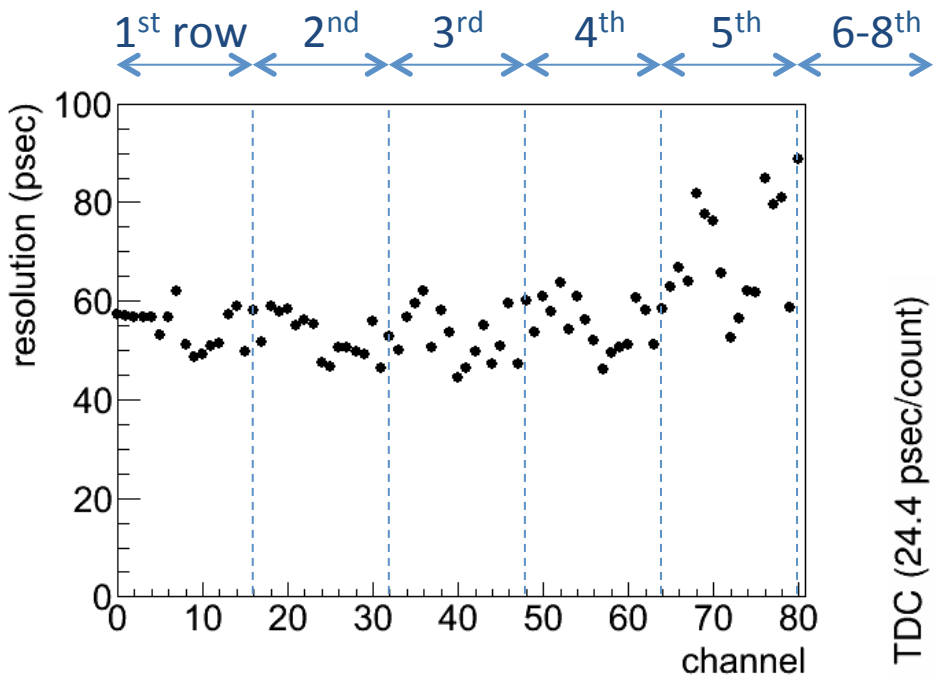
MCP-PMT optical coupling to the prism

- Each MCP-PMT can move separately and does not need to be aligned.
- Misalignment of the mechanical structure can be compensated by the spring on the socket.



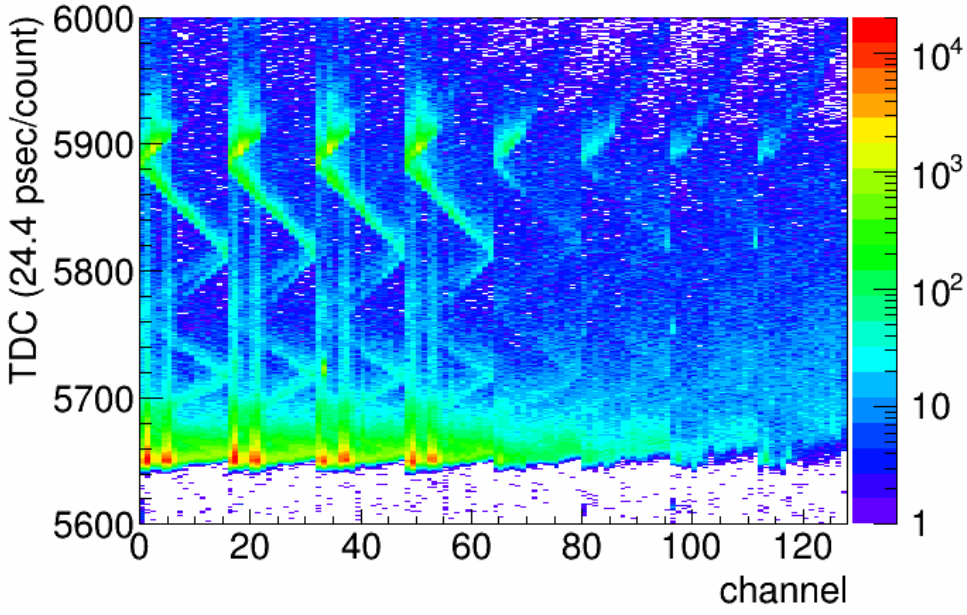
Laser data (cont'd)

Laser photons hardly reach these PMTs



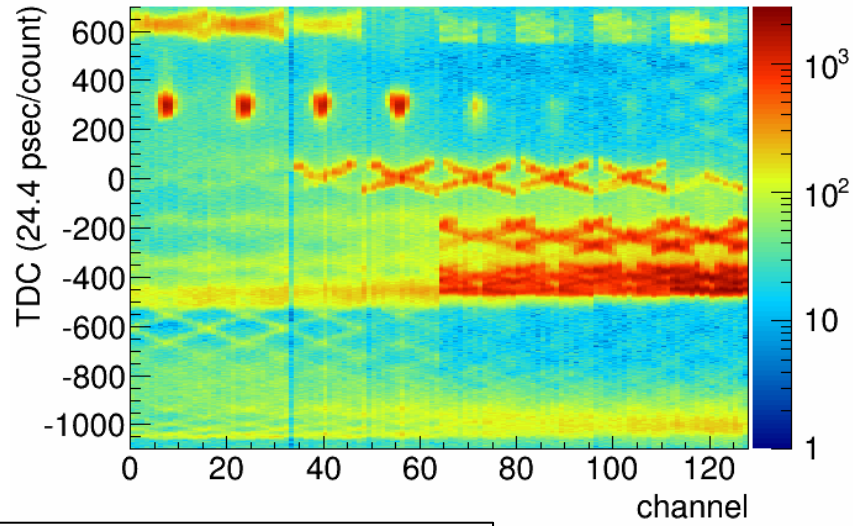
Good time resolution was confirmed at SPring-8, too.

Laser image after the t_0 alignment

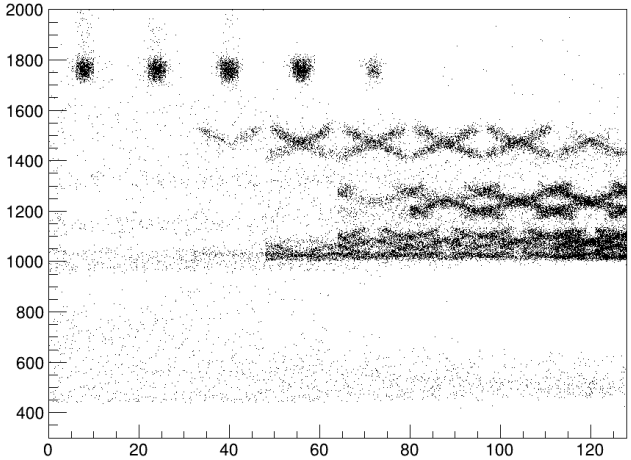


CFD TOP ring image

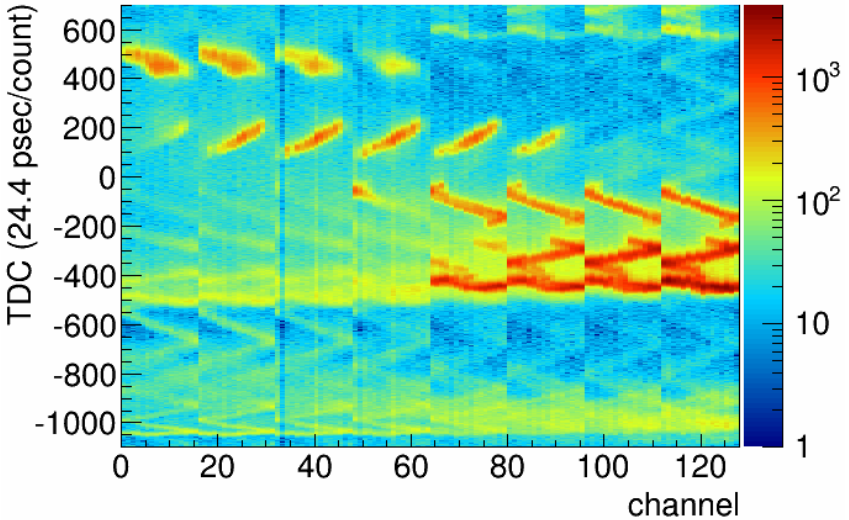
cosq = 0.392, x = –1.0 cm



MC (by Marko-san)



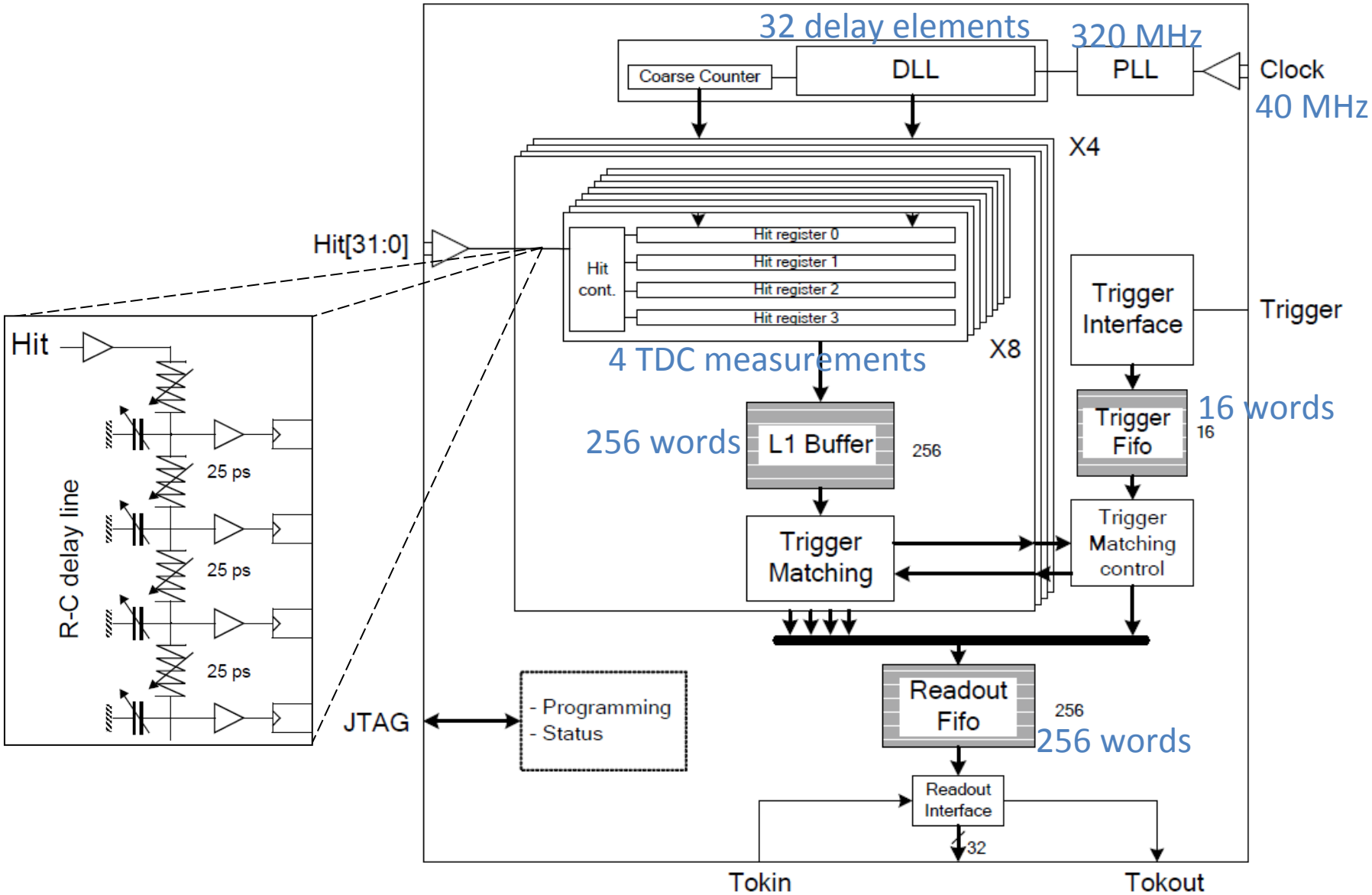
cosq = 0.376, x = 20.0 cm



Advantage/disadvantage

- Advantage
  - The performance has been proved, confirmed in the beam test.
  - Easy to use, stable, only pre-calibration (or performance check) is necessary.
  - No technical problem in terms of the trigger and DAQ.
  - Even with the 1/4 number of channels, the PID performance changes little.
    - e.g. pp efficiency with 4/16 and 16/16 number of channels is 94.0% and 95.1%, respectively, with the expected background rate.
- Disadvantage
  - Need extra budget (approximately \80,000,000).
  - Less robust against the occupancy due to 1/4 number of channels.
    - e.g. pp efficiency becomes 91.0% at 10 times larger background than expected, while it becomes 93.0% with the full number of channels.
  - No waveform information (but the analog output can be read out for some or all channels).
  - Due to buffer overflow, TDC V1290A does not work when the background hit rate exceeds 16.4 MHz/PMT (x 5.6 higher than the current estimation).

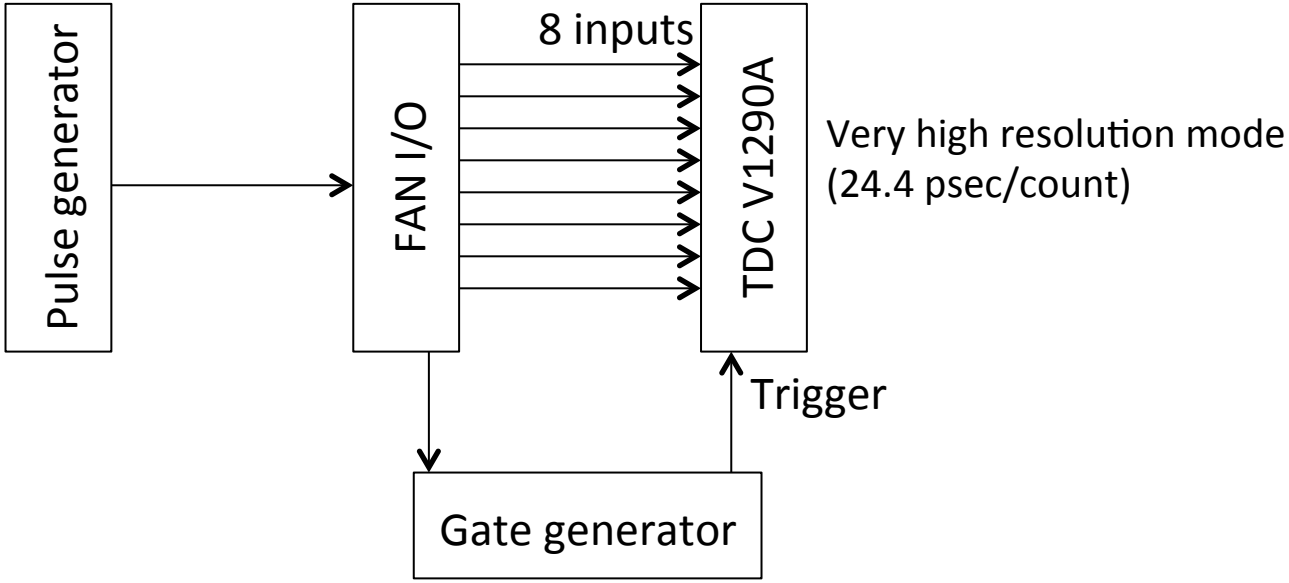
HPTDC


32 delay elements
320 MHz
Coarse Counter
DLL
PLL
Clock
40 MHz
X4
Hit[31:0]
Hit cont.
Hit register 0
Hit register 1
Hit register 2
Hit register 3
Trigger Interface
Trigger
X8
4 TDC measurements
16 words
256 words
L1 Buffer
256
Trigger Fifo
16
Trigger Matching
Trigger Matching control
Hit
R-C delay line
25 ps
25 ps
25 ps
JTAG
- Programming
- Status
Readout Fifo
256
256 words
Readout Interface
32
Tokin
Tokout

Check the hit loss rate

- Input periodic pulses into 8 channels (all the channels of one HPTDC chip) with 100% correlation, which is the worst case in terms of the hit loss.
- The number of input hits can easily calculated as

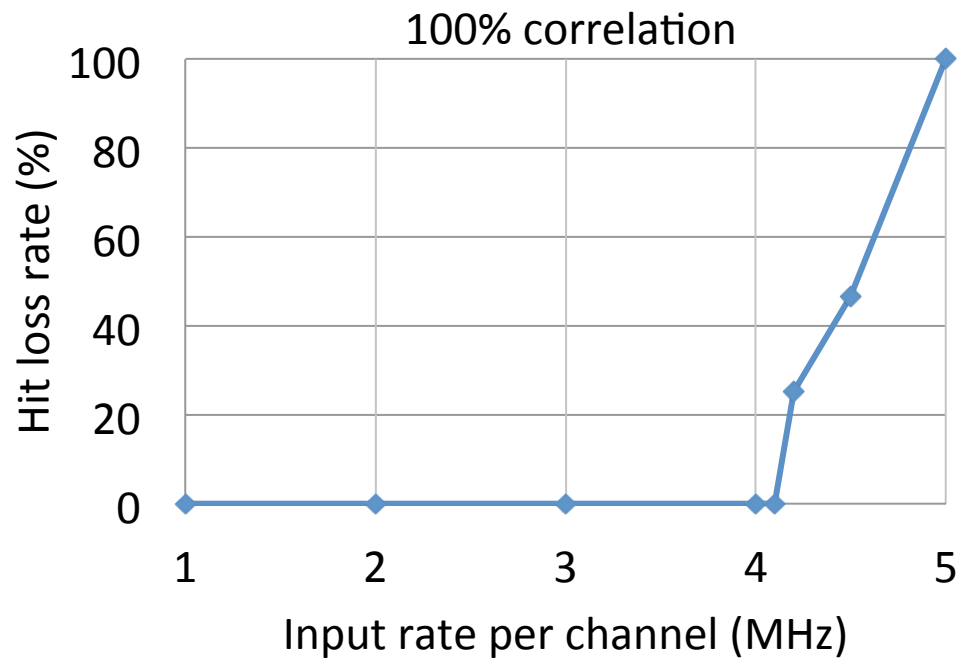
  [input rate] x [TDC window width]
- Count the number of hits actually read out from V1290A.



Result of the test

- Counted the number of events where the number of hits read out was smaller than the expected (some hits were lost).

Input rate (MHz)	Hit lost event (%)
1.0	0.00
2.0	0.00
3.0	0.00
4.0	0.00
4.1	0.00
4.2	25.19
4.5	46.66
5	100

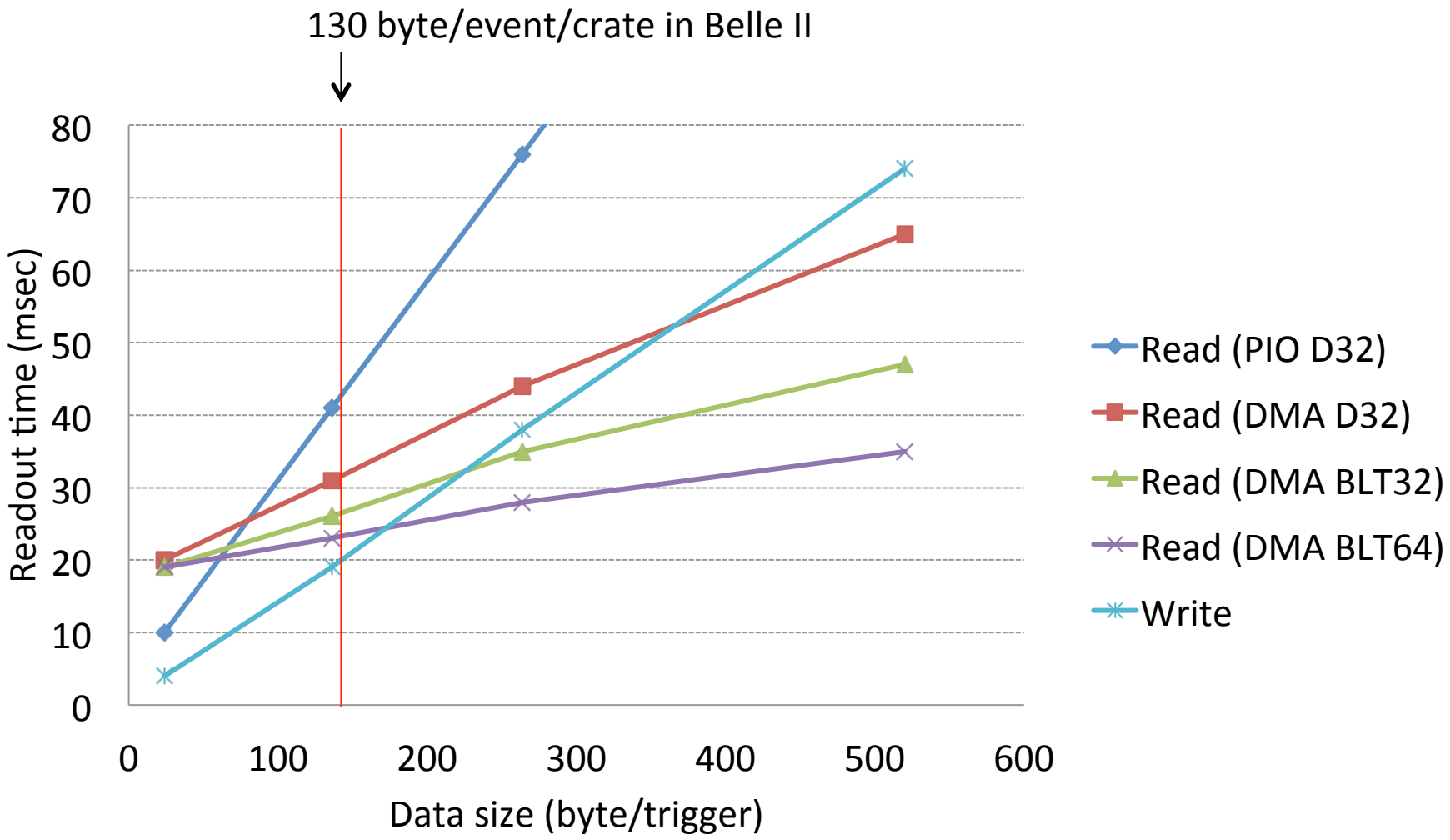


Note: There was no event where the L1 buffer overflowed.

Due to the 100% correlation, the result is worse than the one shown in the data sheet.

The maximum tolerable input rate is 4.1 MHz/ch.

Data transfer rate

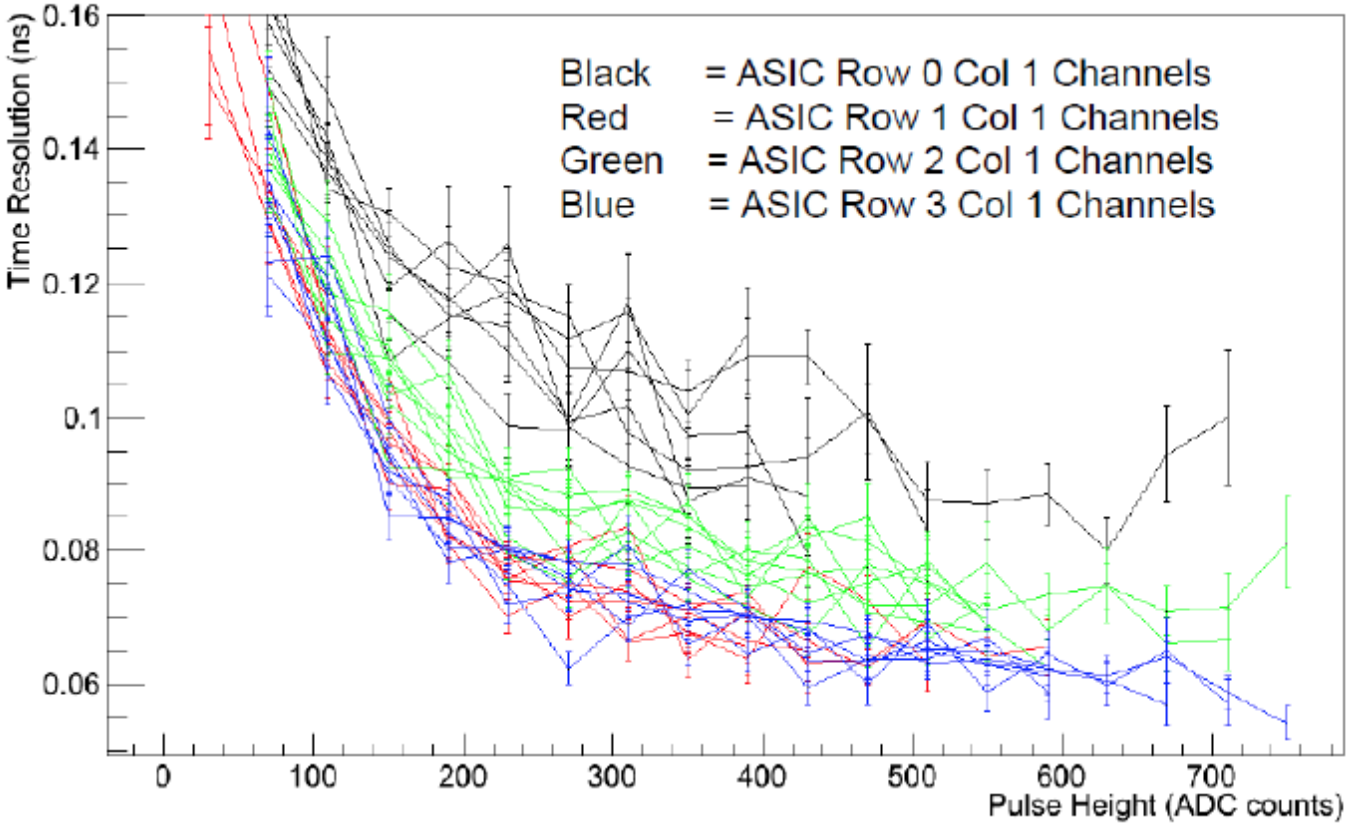


Status of the plan B

- Components to be developed (just a combination of existing modules)
  - PMC which converts the data to the Belle2Link format.
  - VME module to fan-out the TOP data and the trigger-data.

  → Board design is ongoing.
- All the other components were tested and no problem was found.

Channels within same ASIC similar – common timing/timebase issue

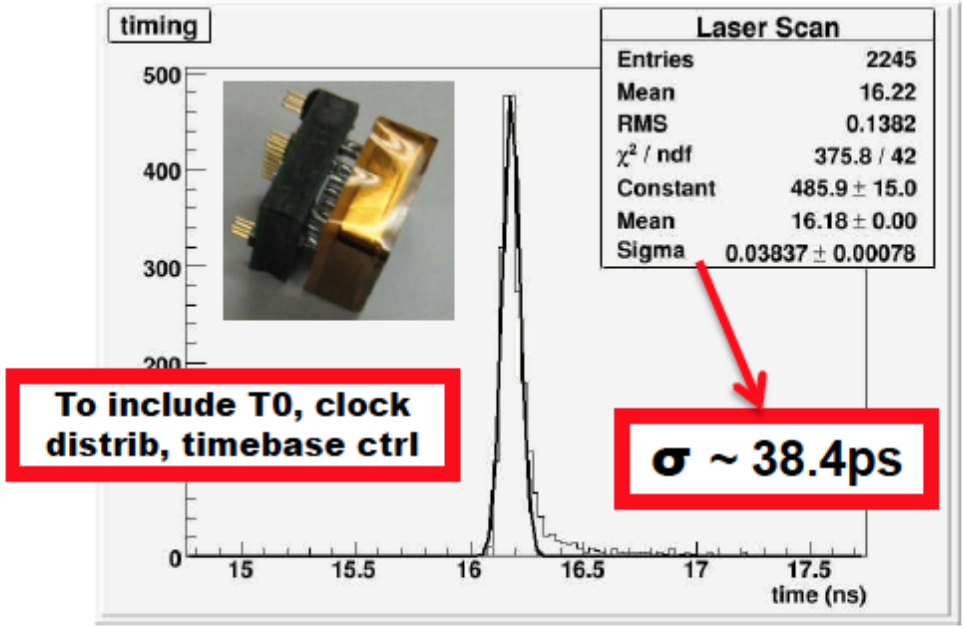


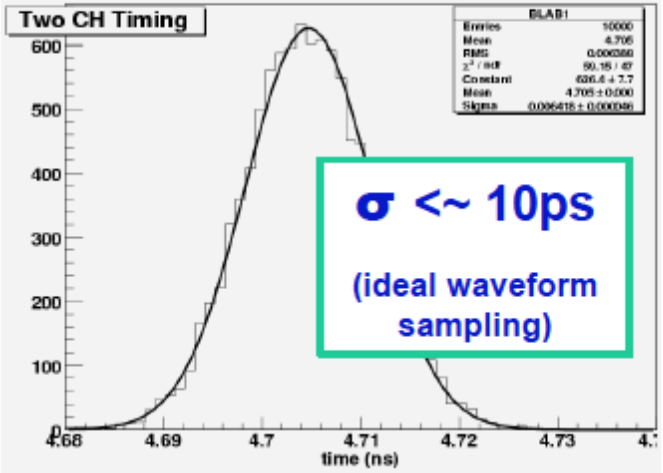
- Channels on same ASIC share have similar pulse height dependence for time resolution

If dominated by DAC/VadjN jitter, should see clear dependence…

Performance Requirements (TOP)

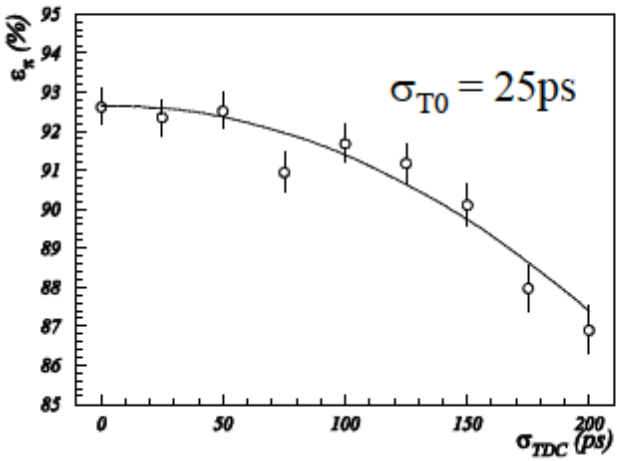
- Single photon timing for MCP-PMTs

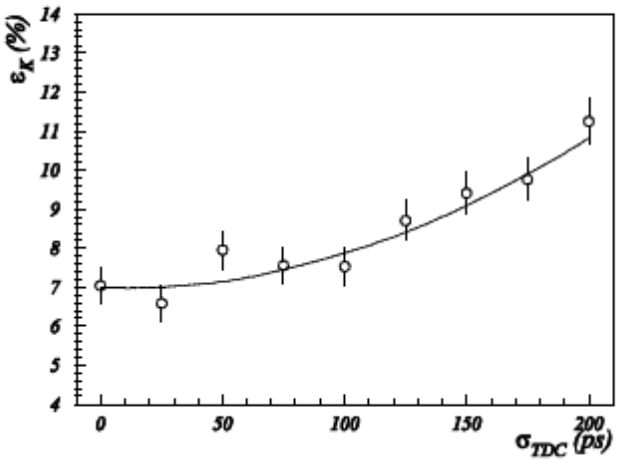




NIM **A602** (2009) 438

σ <= 100ps ➔ 1% impact



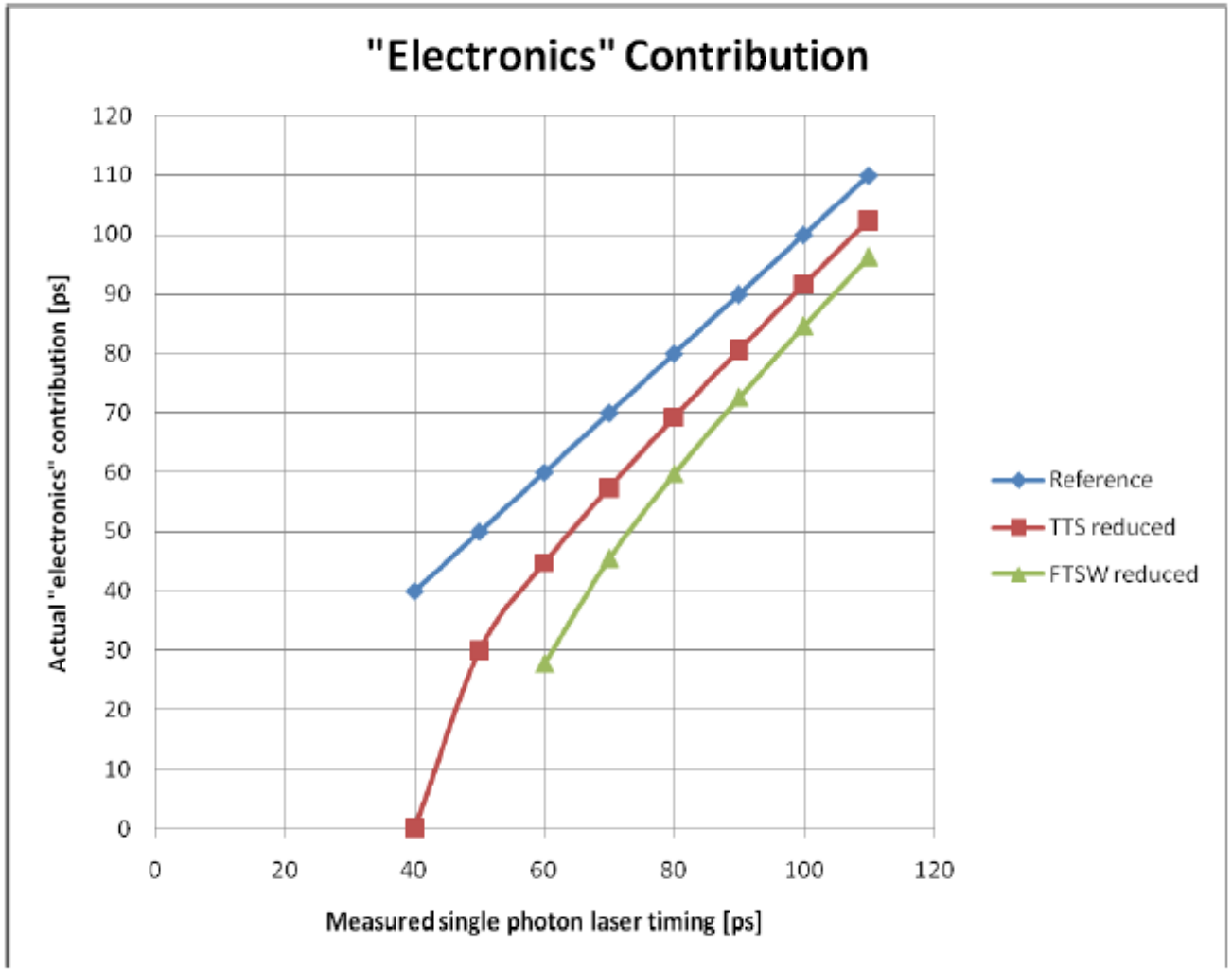


σ <~ 50ps target

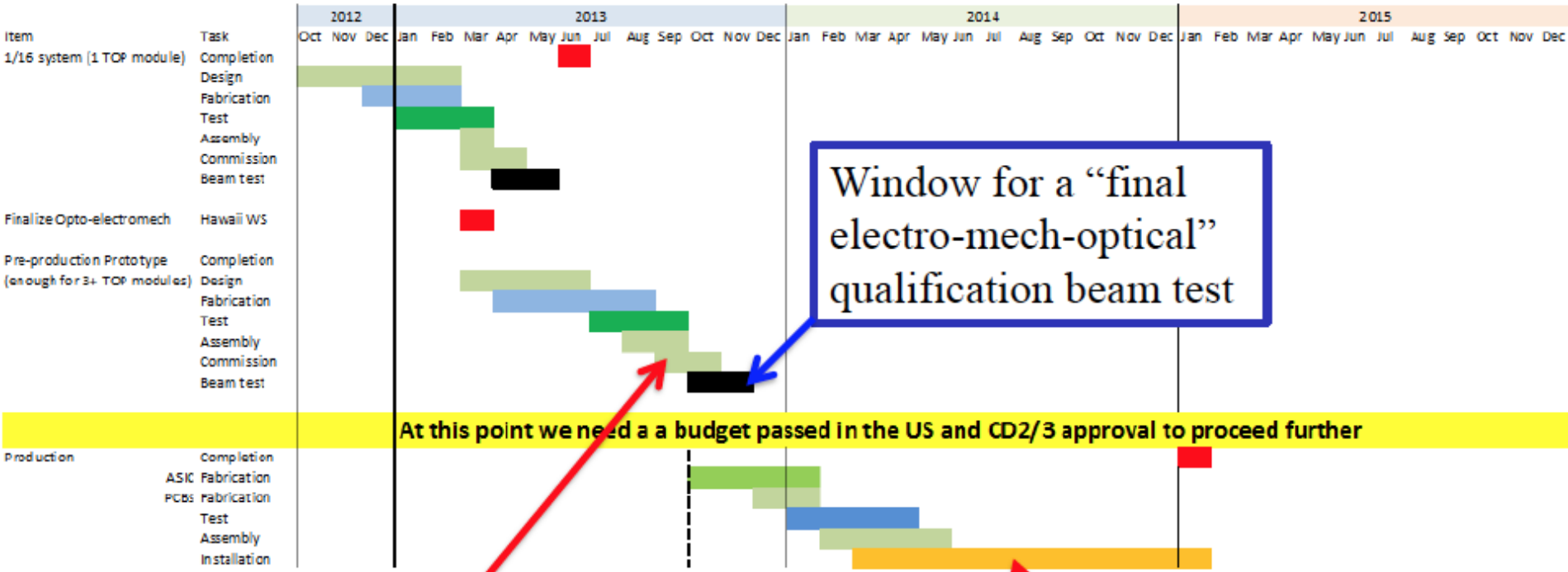
NOTE: this is single-photon timing, **not** event start-time "T_0"

Electronics contribution

- 100ps is min. required for Key Performance Parameters (50ps target)



TOP Electronics Production Schedule



Window for a "final electro-mech-optical" qualification beam test

3+ TOP modules of readout possible (when actual modules ready?)

Install and operate completed modules in Fuji CRT

Enough ASICs, Rev. C or D (final, dual-stage amp), SCROD Rev. C (?)

Status and Prospects

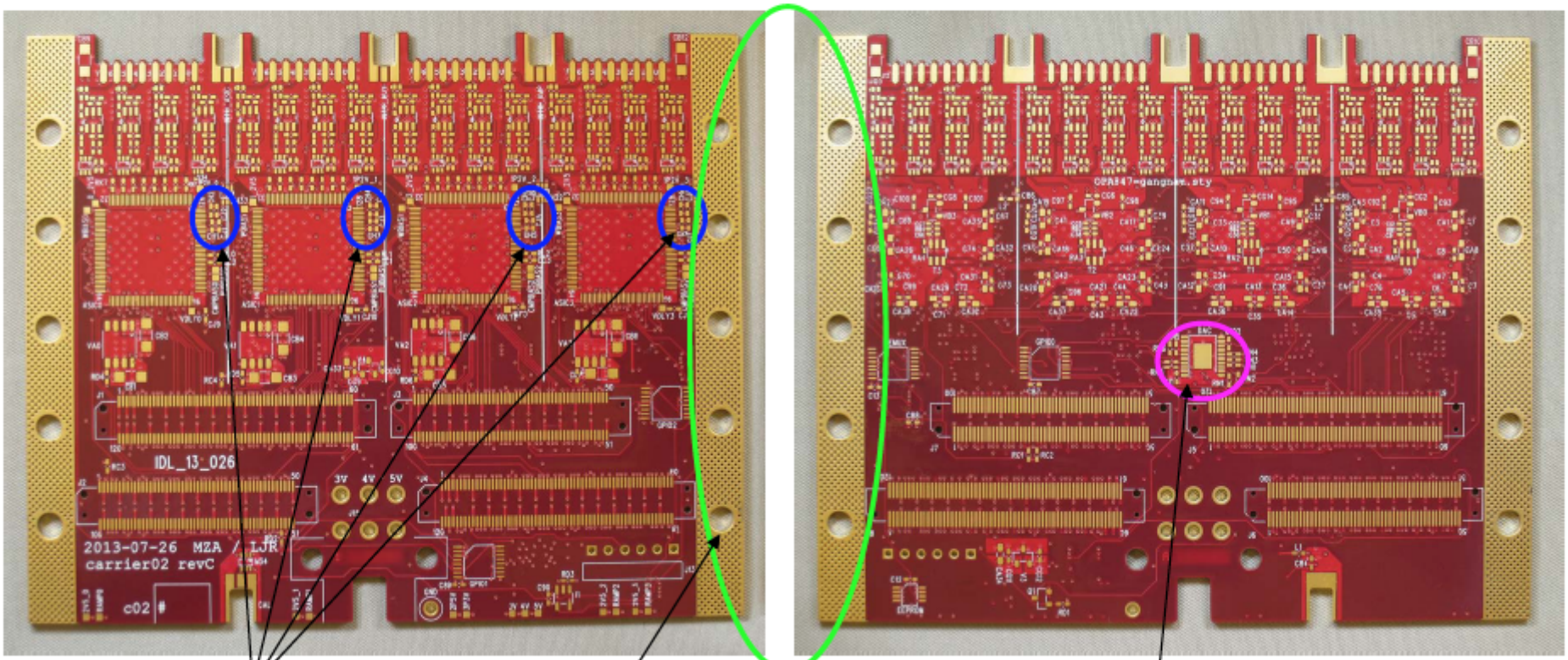
- Have achieved Key Performance Parameters over entire IRS3B-based readout module used in beam test; this is only minimum, <=50ps looks achievable

- Will fabricate/populate Carrier02 [IRS3B limited] so can have spares and distribute for testing elsewhere – improved thermo-mechanics

- IRS3C drop-in for IRS3B [extended dynamic range]

- Demonstrate true timing limits

carrier02 revC improvements



new VadjN/P filtering

new thermal wall connections

new 16 bit DAC with series resistance

- received PCBs last week
- assembly to begin imminently
- will have assembled boards by end of August