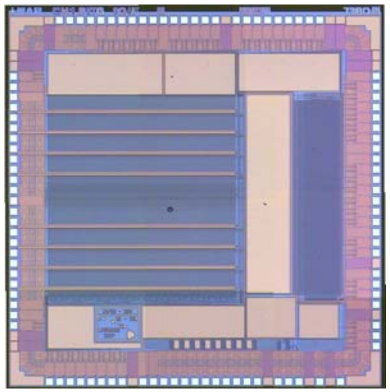
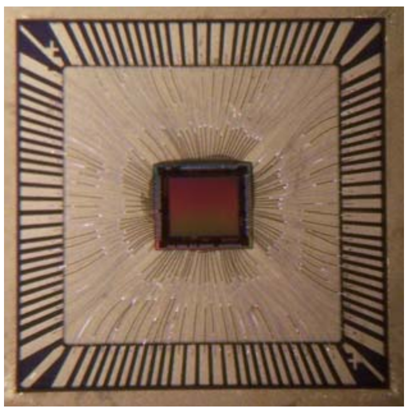
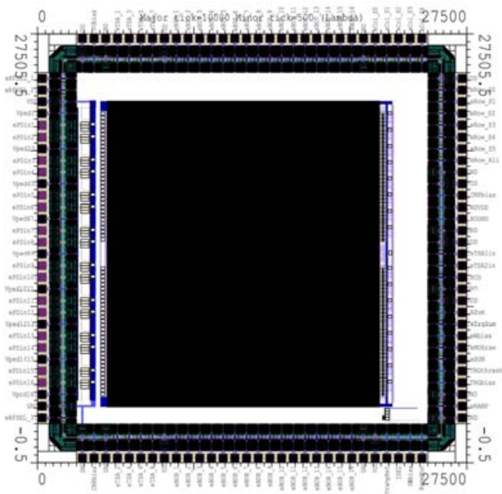
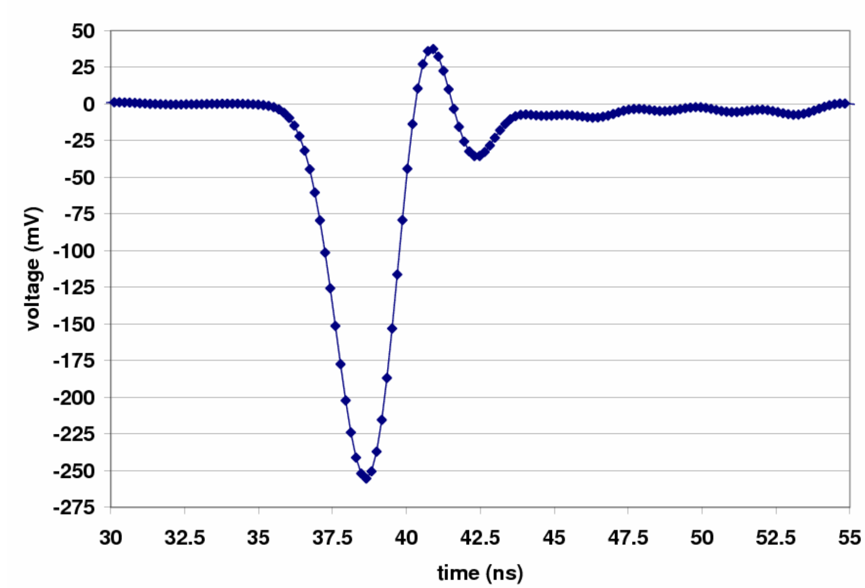
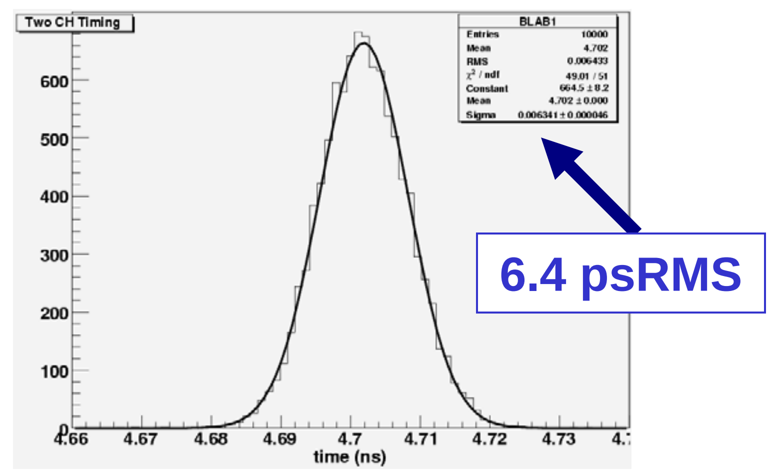
Status and Plans of the Buffered LABRADOR (BLAB) ASICs











Gary S. Varner

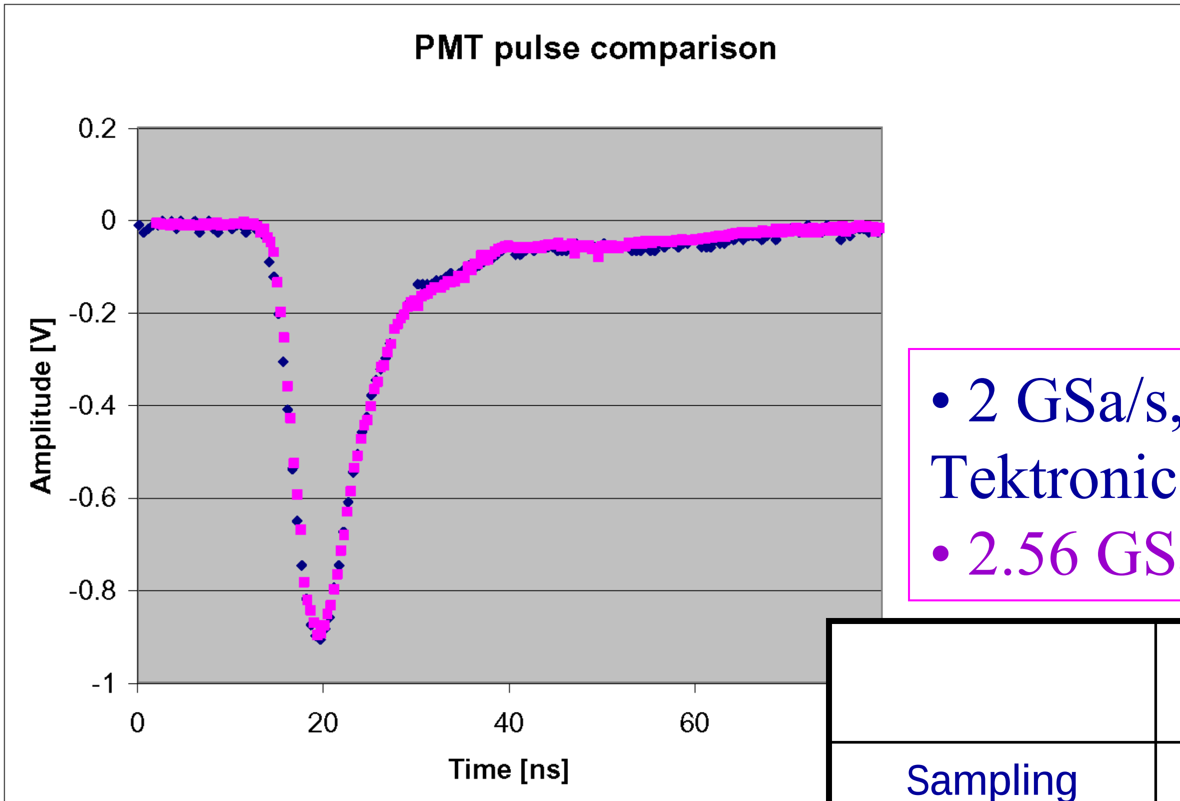
University of Hawaii

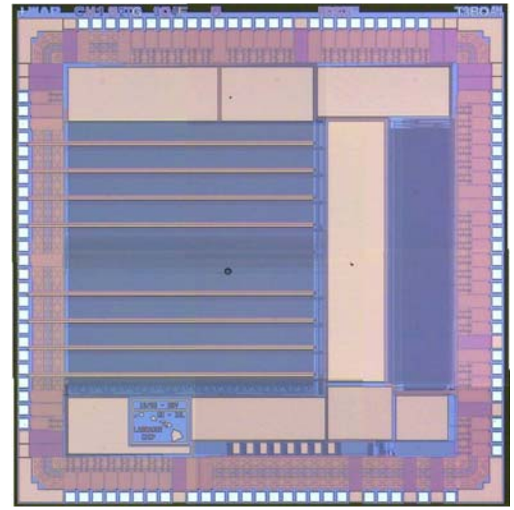
ps Timing Workshop,
Lyon October 2008

Agenda

- High speed waveform sampling
  - BLAB1 pathfinding results
  - Power, form-factor and cost advantages over conventional (CF)D + MTDC
- BLAB2 prototype results
  - Initial test results
  - Understanding limits → BLAB3
- Applications – medium sized DAQ systems
  - Fast focusing DIRC prototype
  - Imaging TOP (iTOP) test bench
- Lessons from B-factory timing

Affordable High Speed sampling





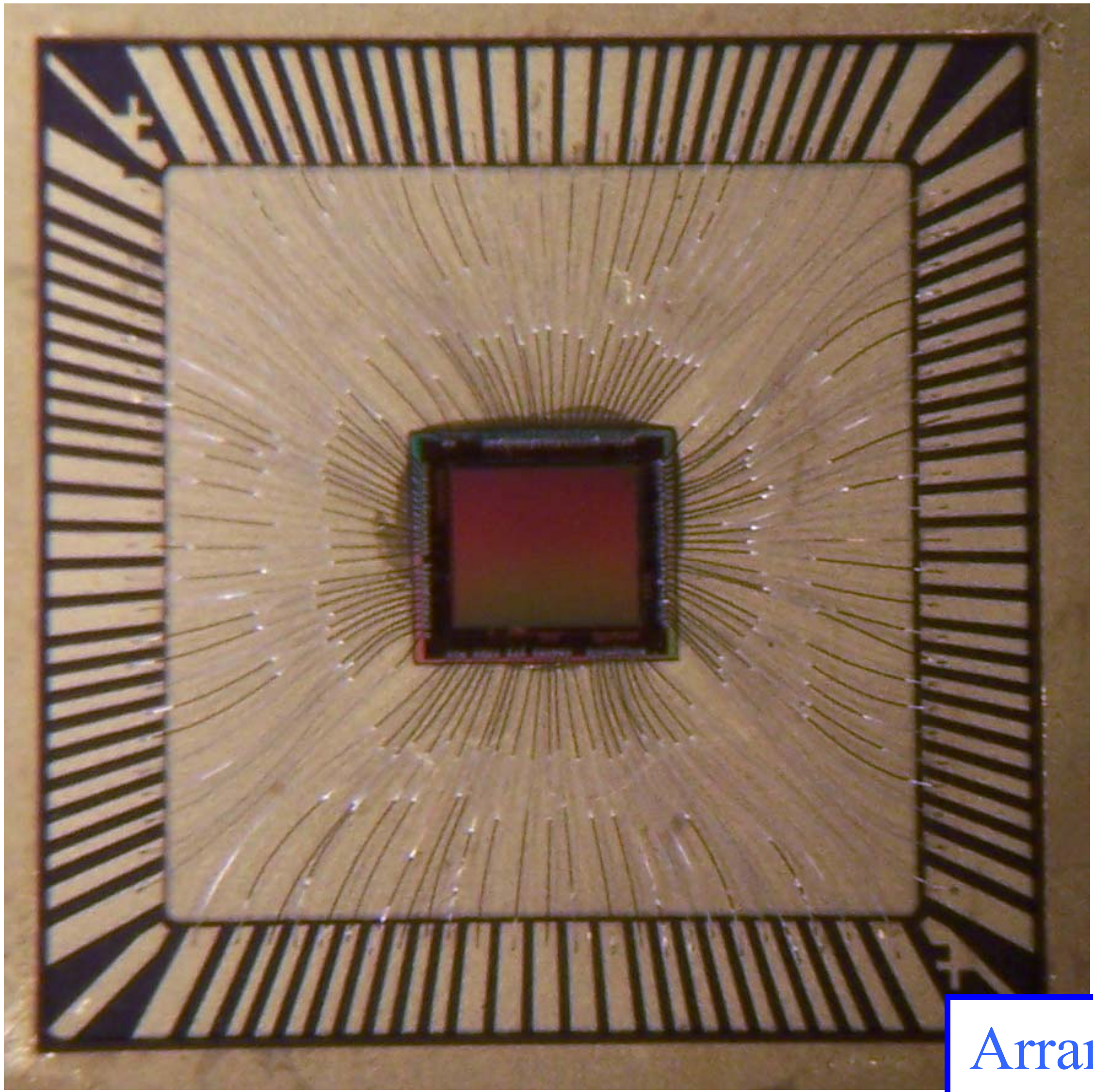
- 2 GSa/s, 1GHz ABW Tektronics Scope
- 2.56 GSa/s LAB

	LABRADOR	Commercial
Sampling speed	1-3.7 GSa/s	2 GSa/s
Bits/ENOBs	12/9-10	8/7.4
Power/Chan.	<= 0.05W	5-10W
Cost/Ch.	$10 (vol)	~> 1k$

"oscilloscope on a chip"

ATWD, DRS, …

Design Basis: Buffered LABRADOR (BLAB1) ASIC

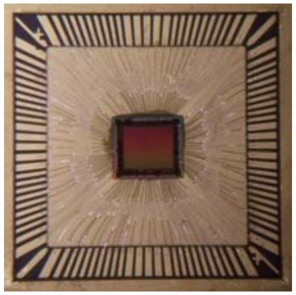


3mm x 2.8mm, TSMC 0.25um

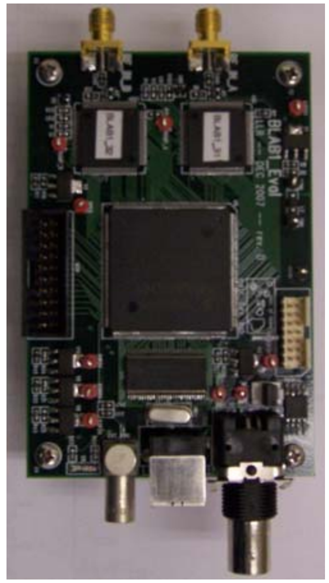
- Single channel
- 64k samples deep, same SCA technique as LAB, no ripple pointer
- Multi-MSa/s to Multi-GSa/s
- 12-64us to form Global trigger

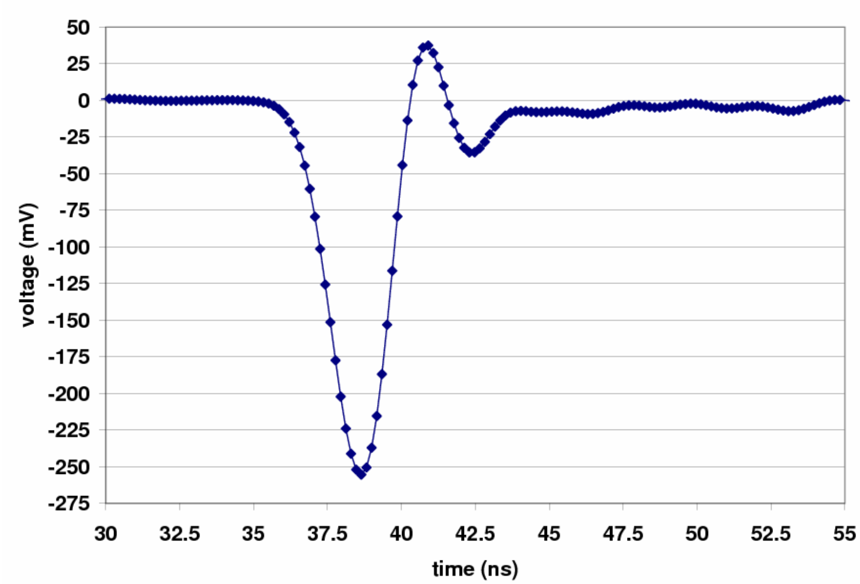
Arranged as 128 x 512 samples
Simultaneous Write/Read

BLAB1 further studies

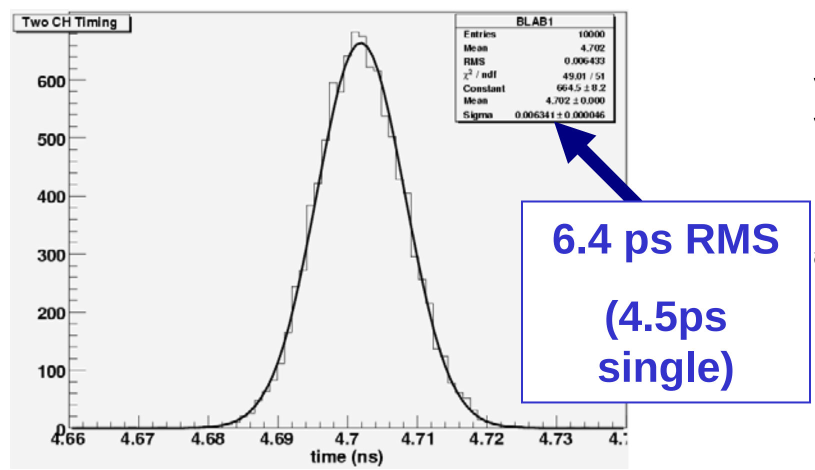


BLAB1 -- NIM **A591** (2008) 534





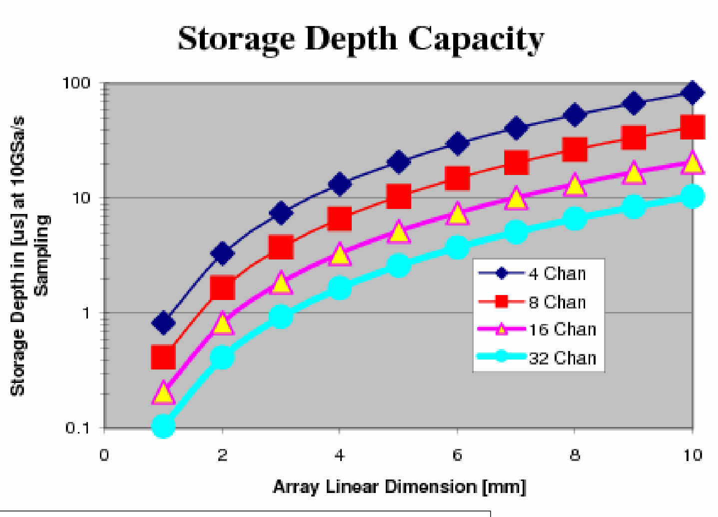
- Comparable performance to best CFD + HPTDC
- MUCH lower power, no need for huge cable plant!
- Using full samples significantly reduces the impact of noise
- Photodetector limited

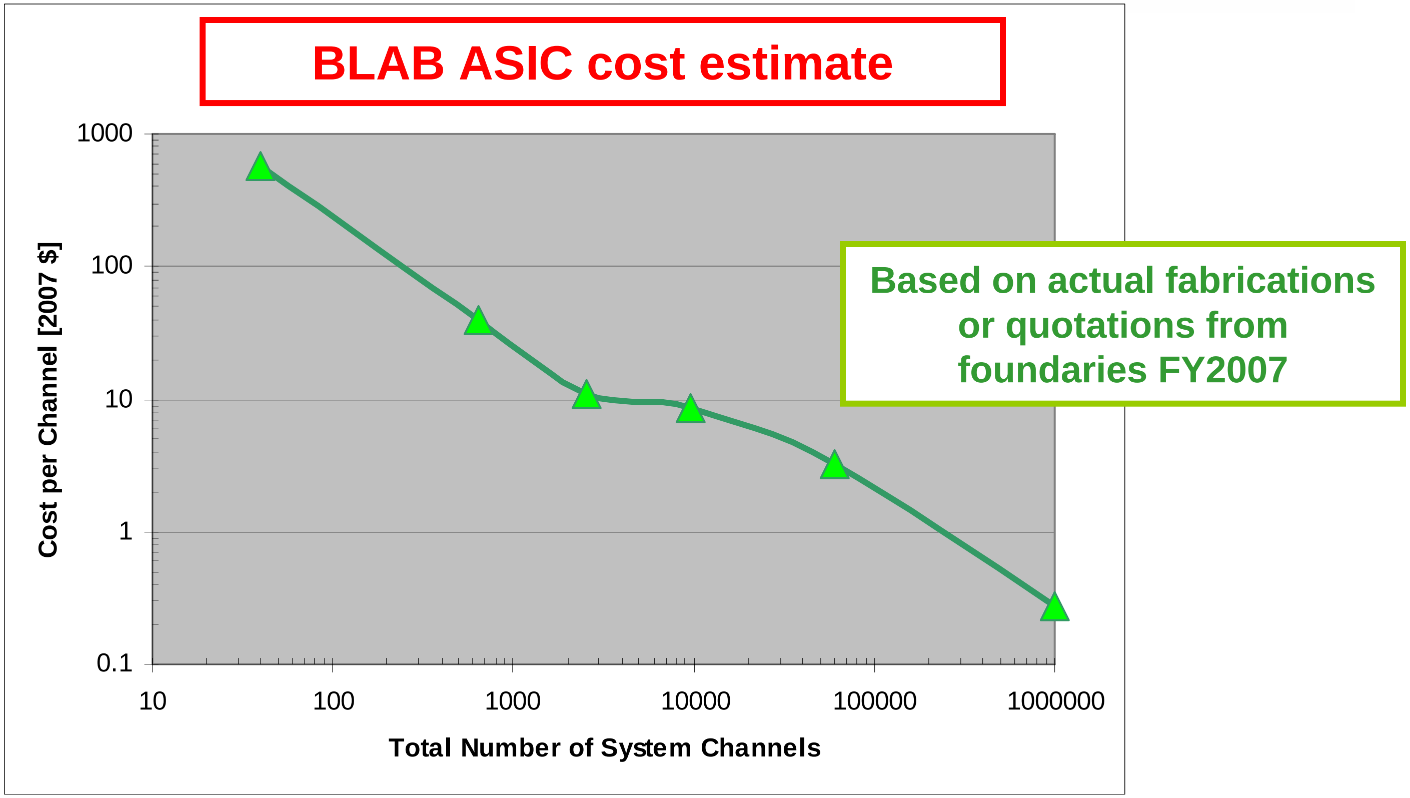


Submitted NIM, arXiv:0805.2225

BLAB Density and Cost

- 16 input channels
- For large-scale systems, cost very competetive





BLAB2 – places to improve

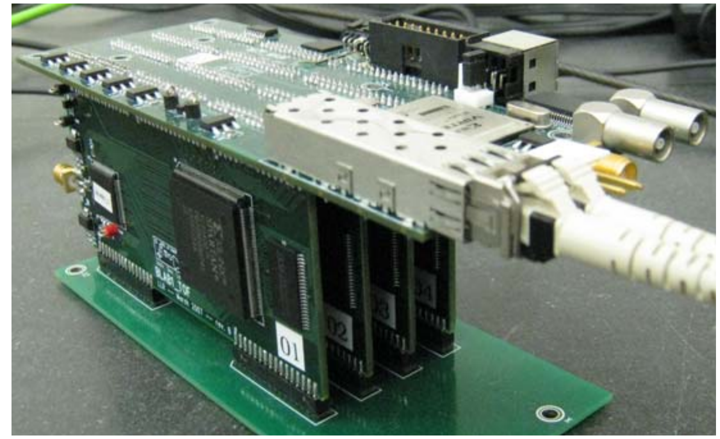
- Addition of gain (lower PD gain)
  - Increase sampling depth over LABRADOR
  - Improvement on BLAB1 bandwidth
- Faster, more stable sampling
  - 2x BLAB1 sampling rate
  - Explicit (continuous) delay-lock
- Reference channel
  - Translate timing between devices
  - Decouple various contributing effects
- Trigger Functionality
  - Basic Discriminator Logic
  - Local zero suppression

Highly Integrated Readout

- **Buffered LABRADOR**

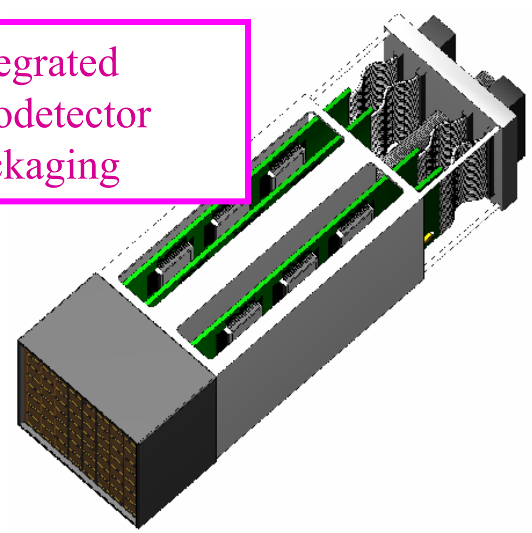
TABLE II: *BLAB2 ASIC Specifications.*

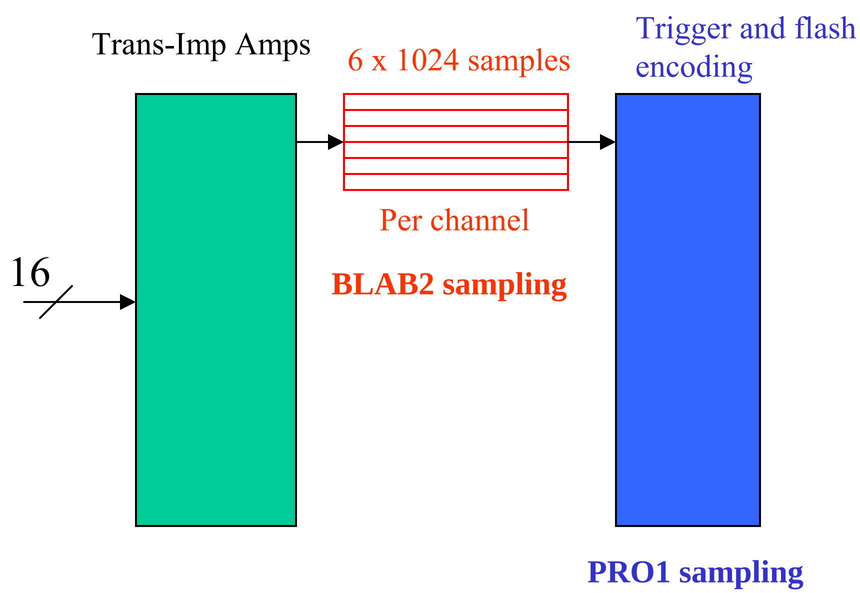
Item	*Value*
Photodetector Input Channels	16
Linear sampling arrays/channel	~~2~~ 6
Storage cells/linear array	~~512~~ 1024
Sampling speed (Giga-samples/s)	2.0 - 10.0
Outputs (Wilkinson)	32



BLAB2 ASIC

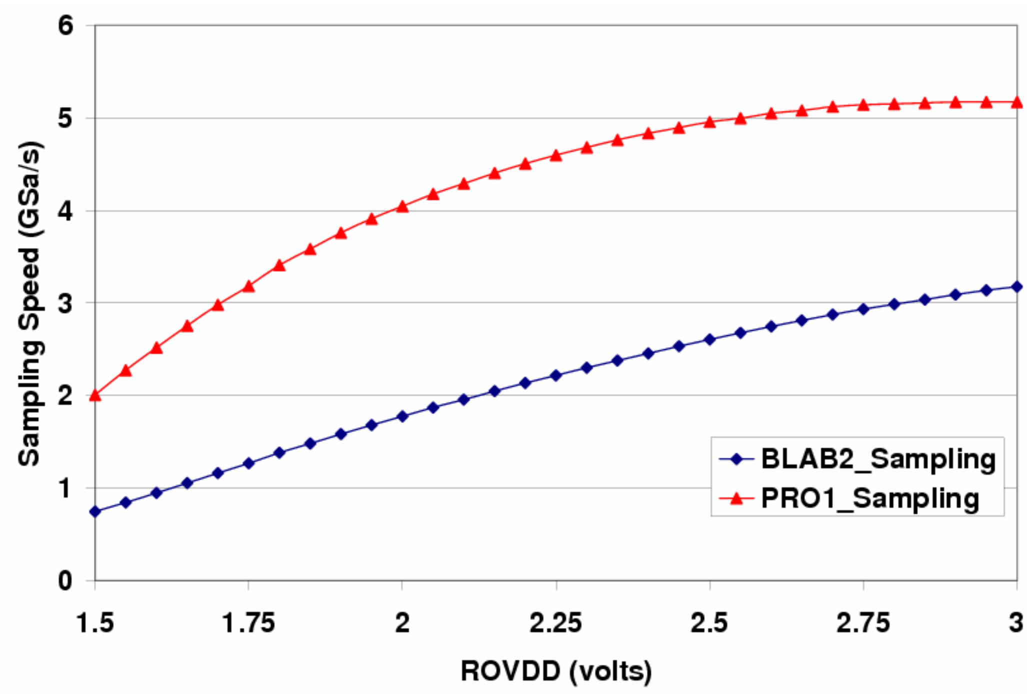
Integrated Photodetector packaging

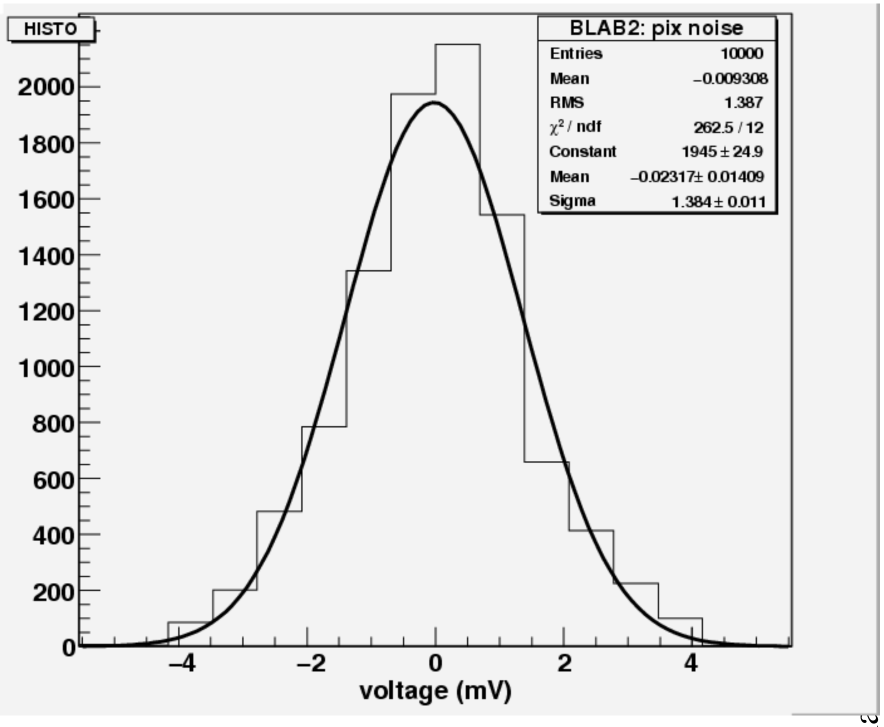


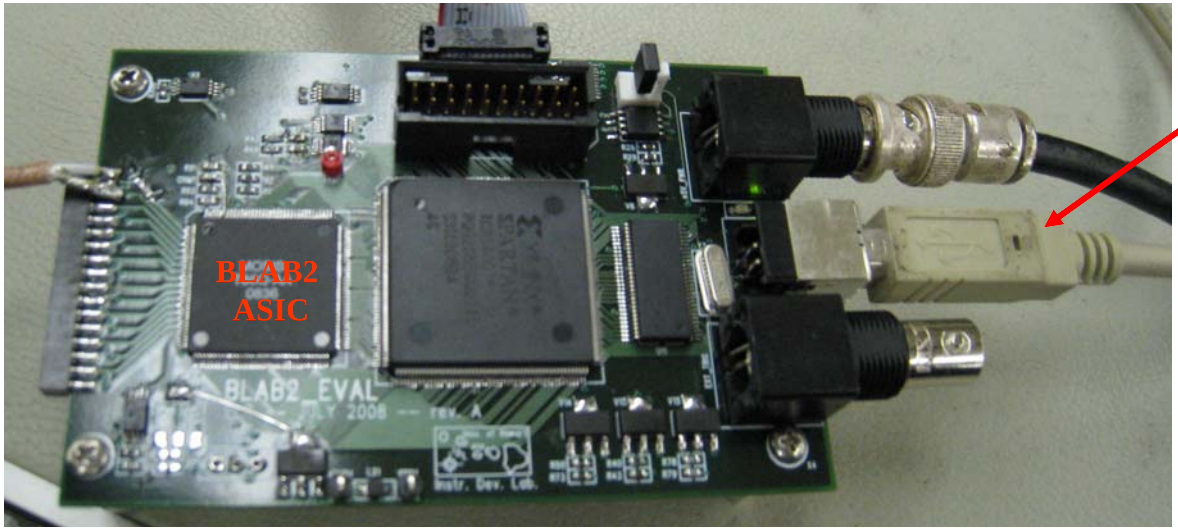


BLAB2 ASICs received September

Sampling Speed and noise







Eval board USB2

-Win XP

- Linux

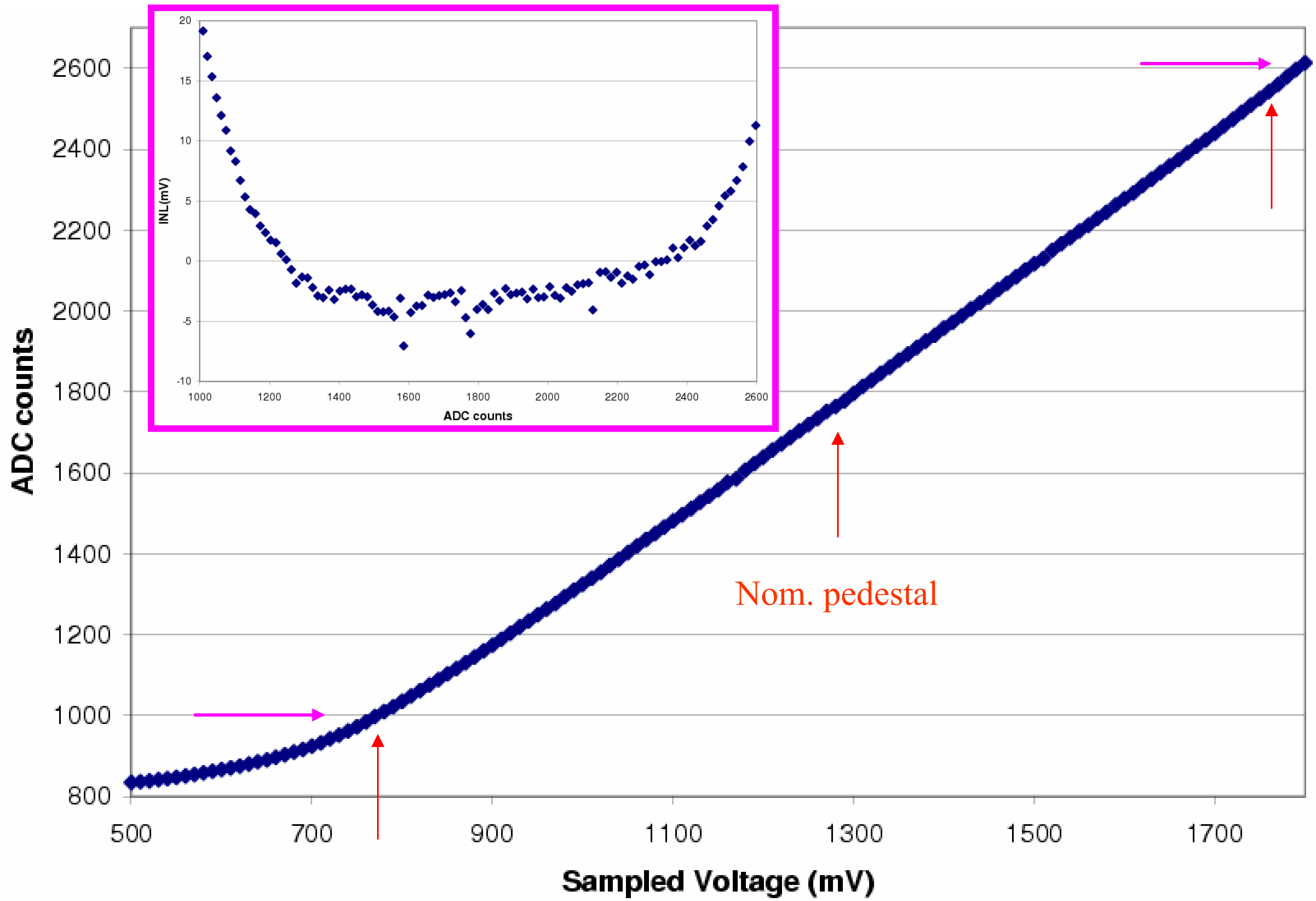
- Mac OS-X

80 ASICs total
(1280 channels)
[448 needed f-fDIRC]

Status and Pla

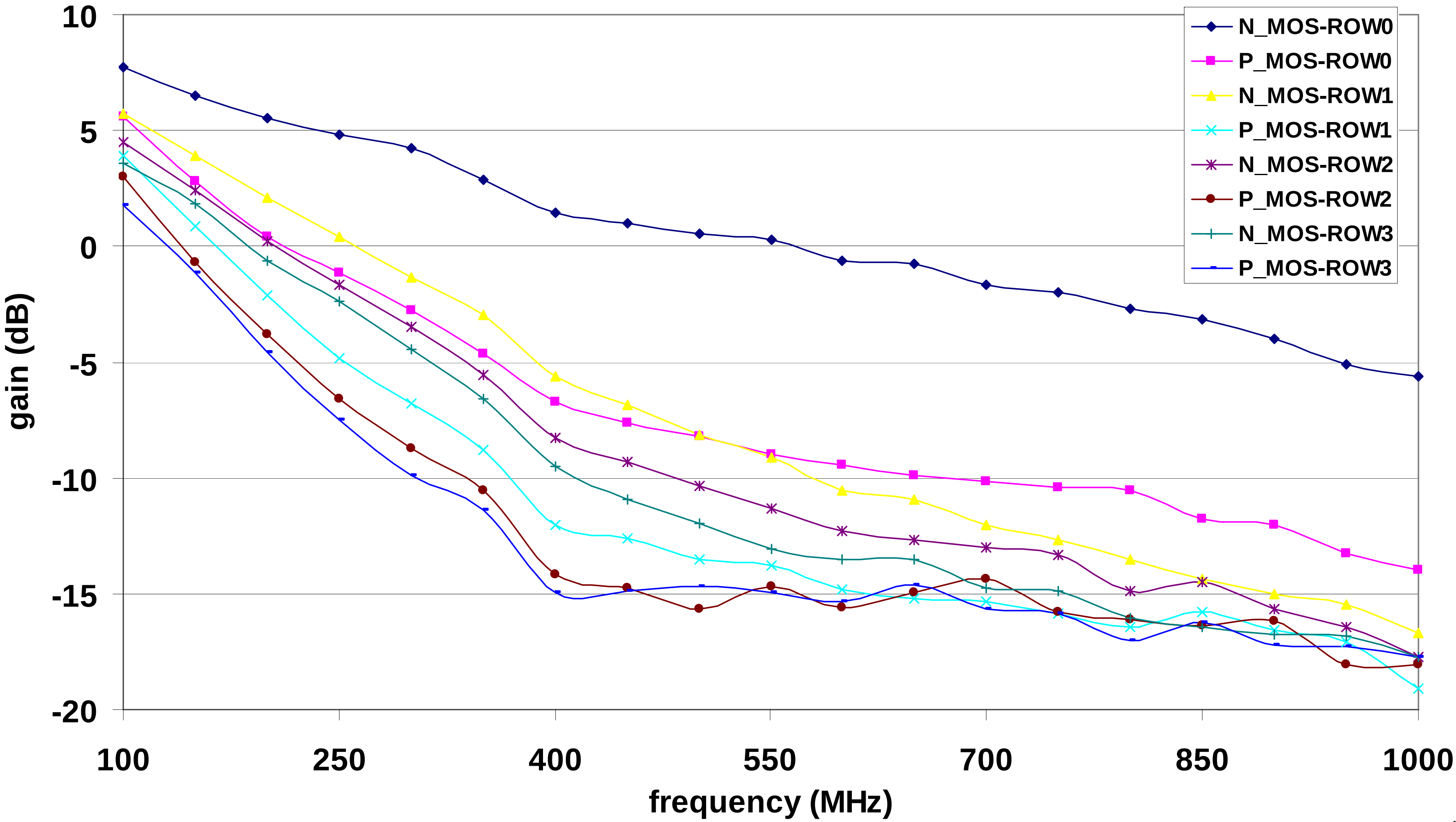
Linearity

In practice, correct with LUT so INL ~1-2 mV

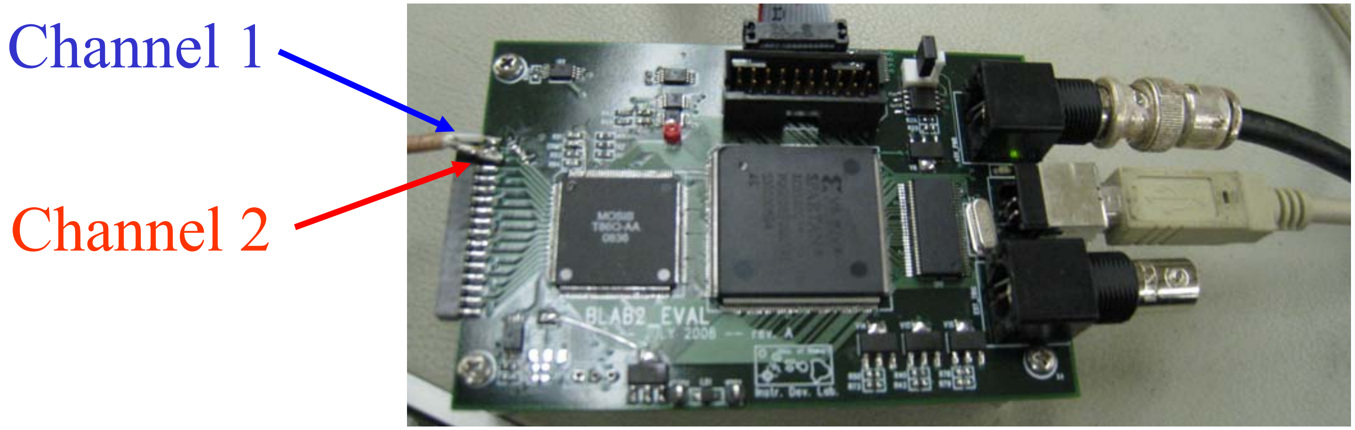


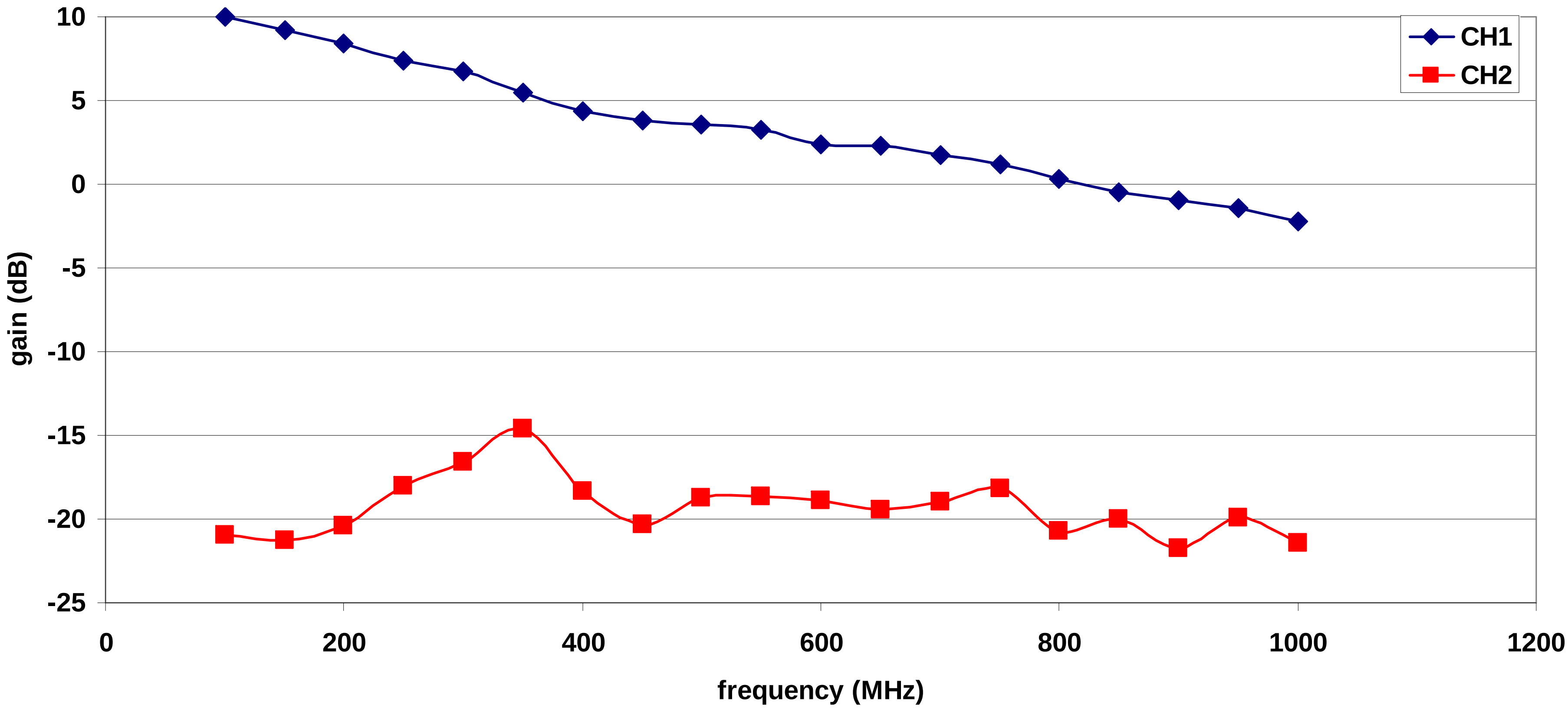
Frequency Response (with TIA)

Each channel has 6 storage rows of 1024 samples
(512 NMOS and 512 PMOS interleaved)

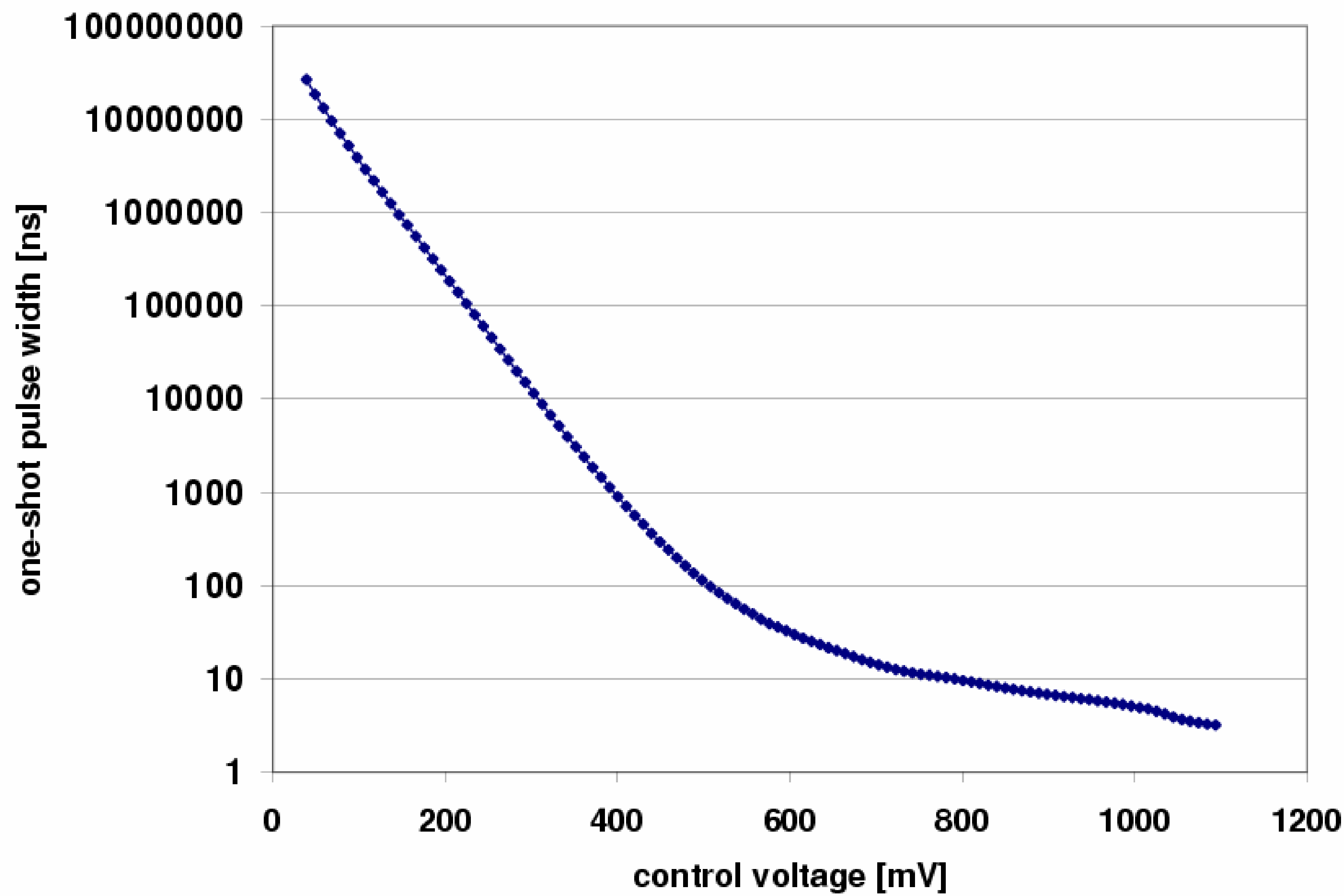


Measured cross-talk

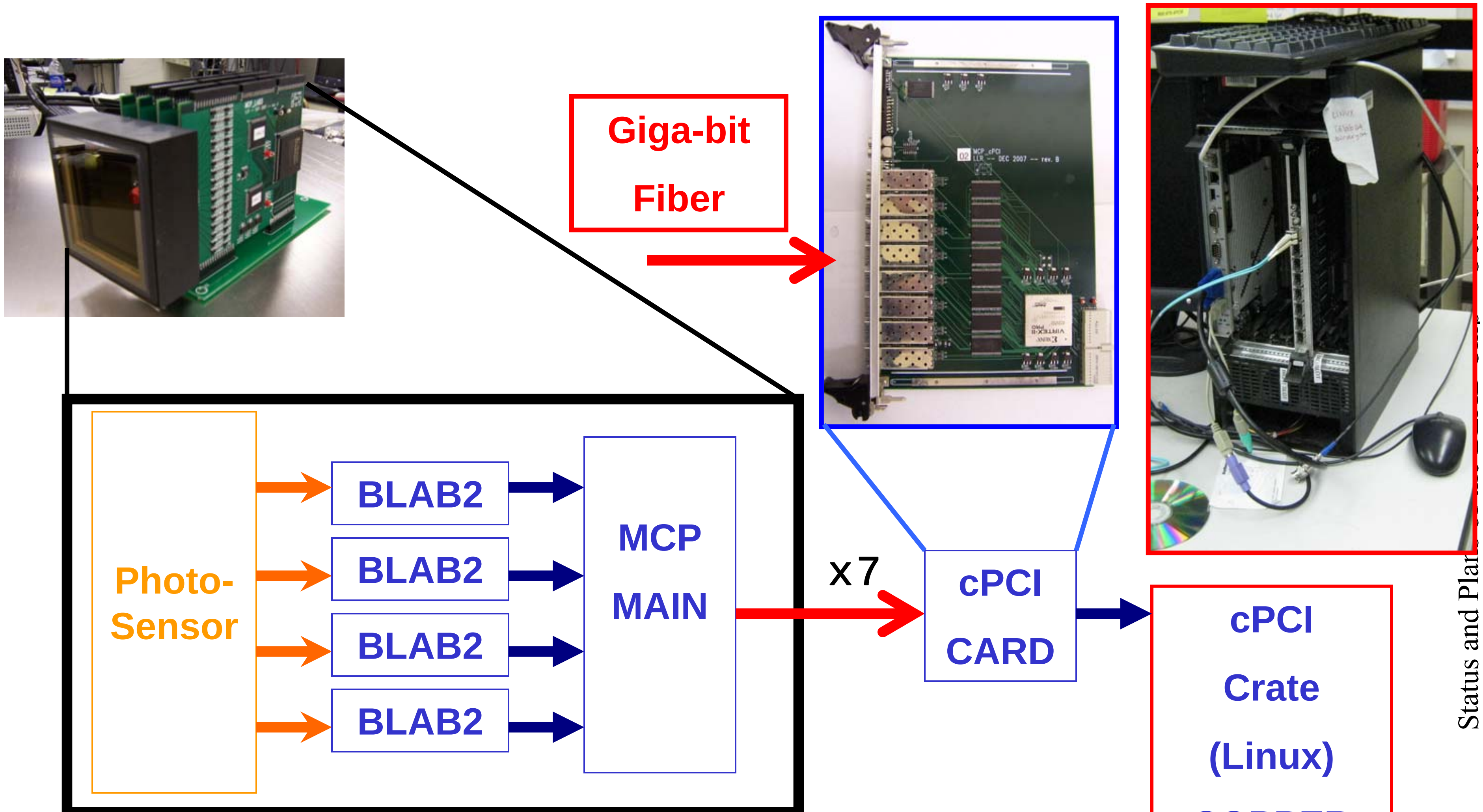




BLAB2 Trigger Performance



High Density Readout

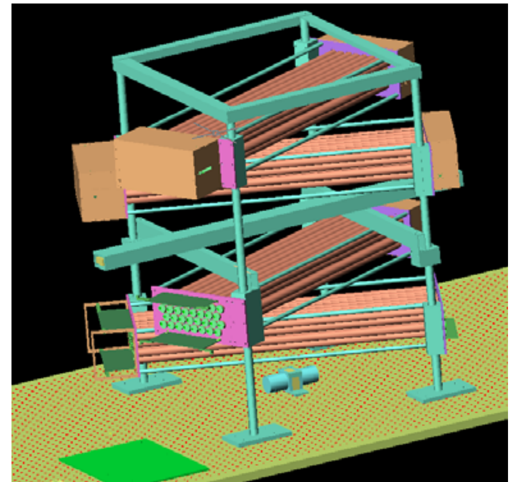


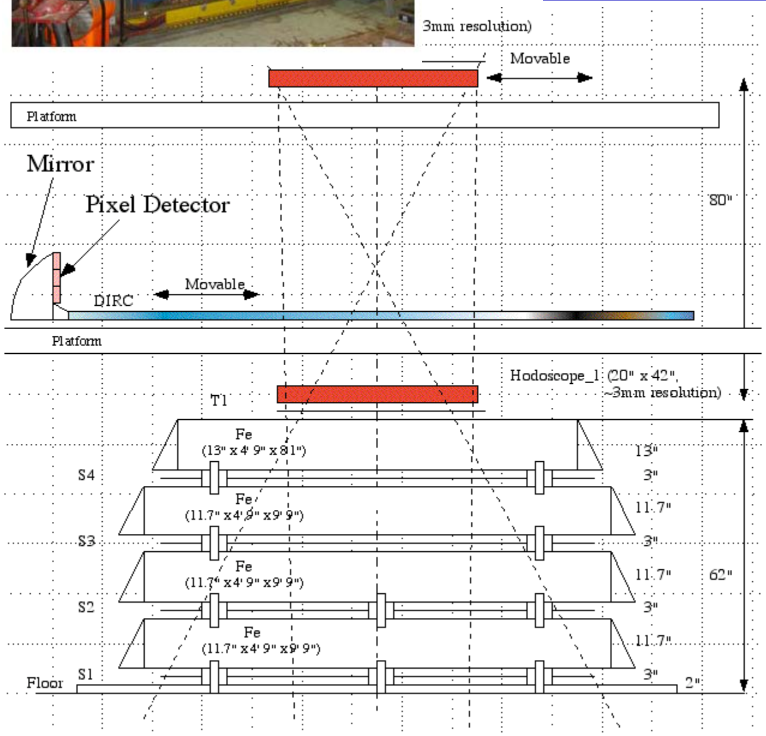
- Up to 7x64 channels per cPCI card
- Very portable DAQ
- Up to 32,256 channels/cPCI crate

Very cost effective, board hardware already exists, firmware/software dev.

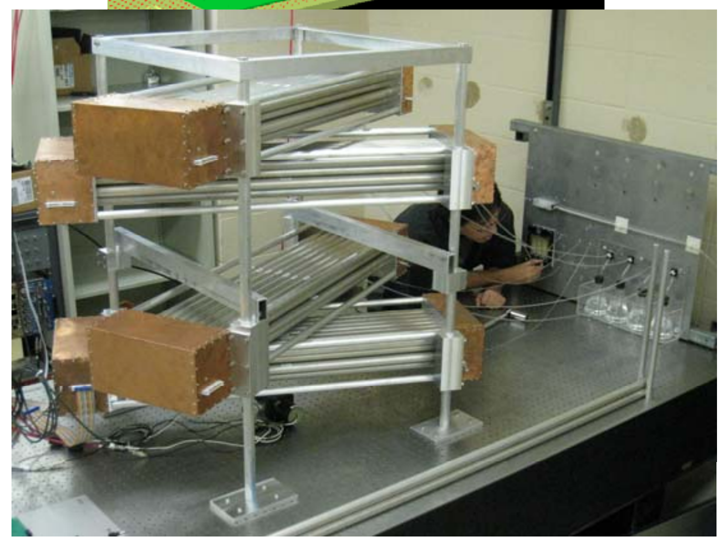
Cosmic Test Stand Deployments

AGIS proto: ~1k chan TARGET





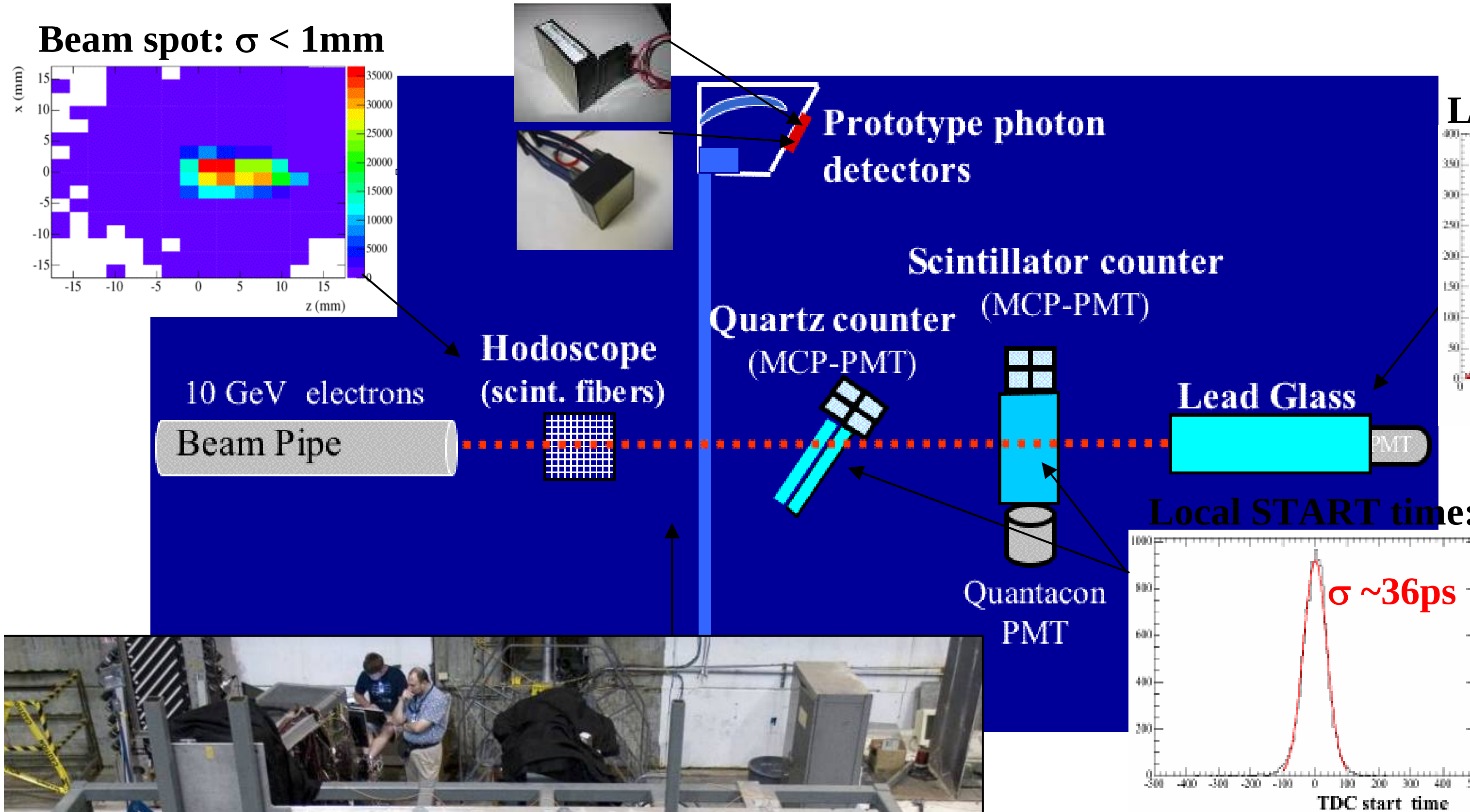
SLAC: f-DIRC test stand
7 x 64chan H8500



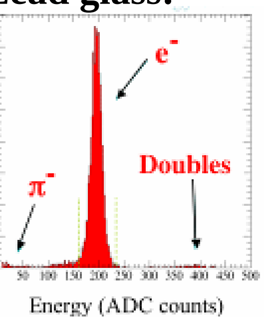
UH: phase 1 – 192 BLAB2 chan.
phase 2 – 2k BLAB2/3 chan.

Focusing DIRC Prototype (T-492)

Beam spot: σ < 1mm



Lead glass:



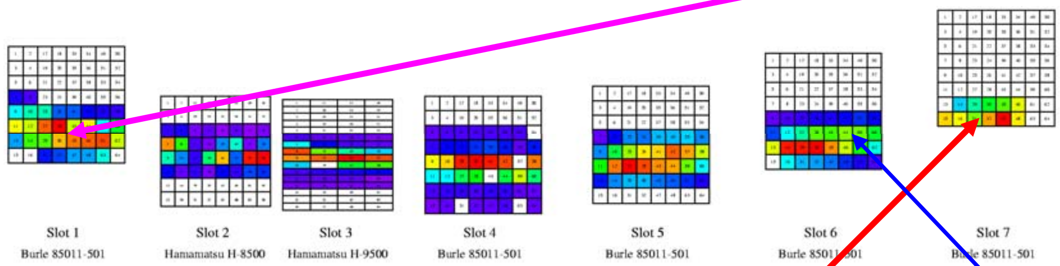
SLAC-PUB-13104 (RICH 2007)

Focusing DIRC R&D effort at SLAC:

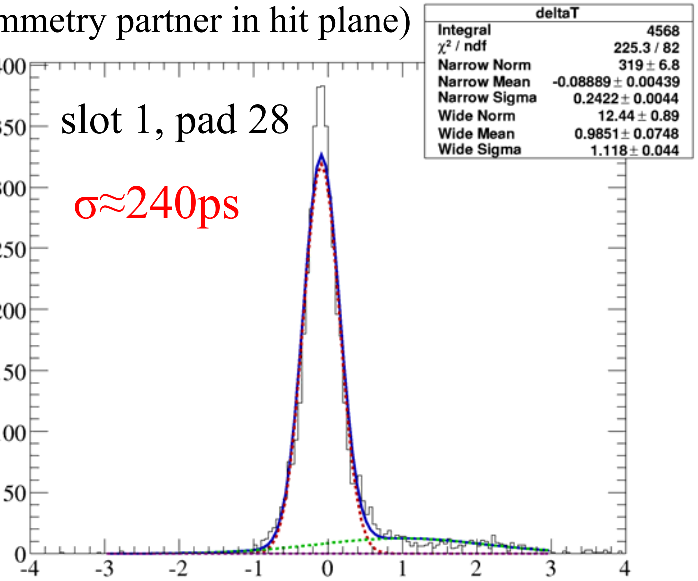
Jose Benitez [#] David W.G.S. Leith [#]
Gholam Mazaheri [#] Blair N. Ratcliff [#]
Larry L. Ruckman [+] Jochen Schwiening [#]
Gary S. Varner [+] Jerry Va'vra [#]

[#] SLAC [+] University of Hawaii

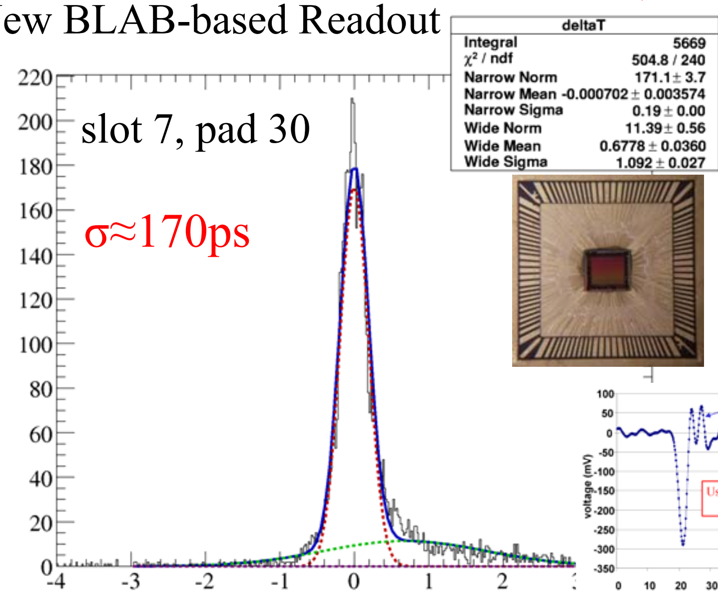
Test results: timing slot 7, pad 15
to Philips slot 1&6
for run 27, pos 1, direct photons

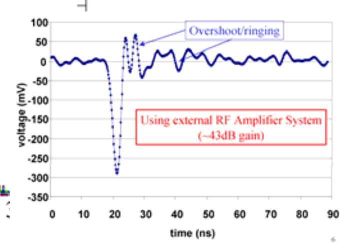


(symmetry partner in hit plane)

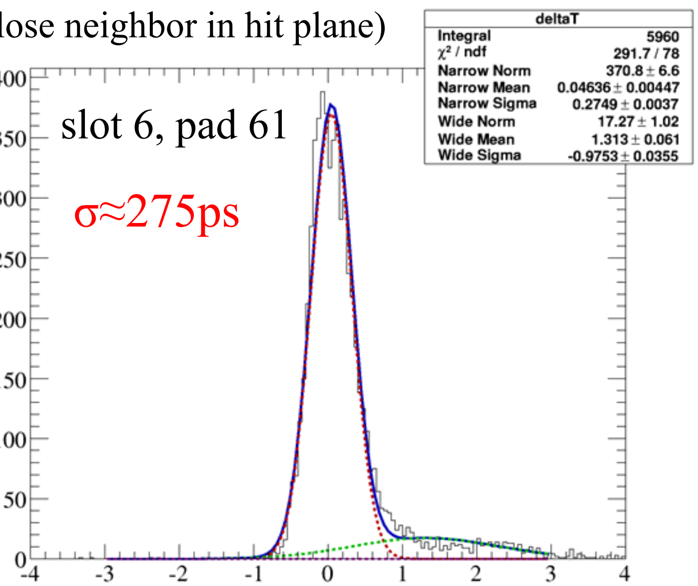


New BLAB-based Readout





(close neighbor in hit plane)

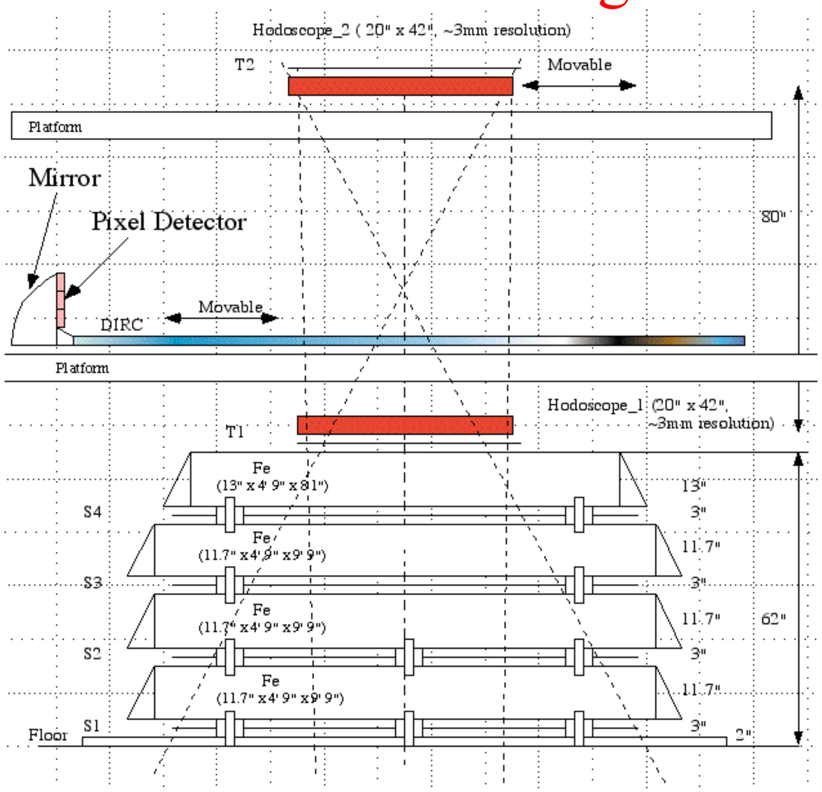


delta(time) (ns)

Decided to upgrade all channels to new BLAB electronics

Continuing SLAC Tests

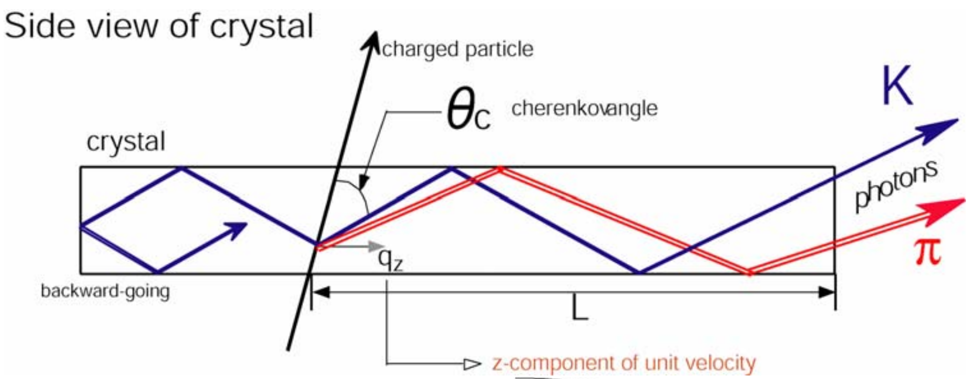
- LCLS Operations
  - Parasitic running possible, but
  - Rad safety system in ESA
- Moved to nice cosmic stand
  - 1 mrad resolution
  - Precision timing and further studies w/ new electronics



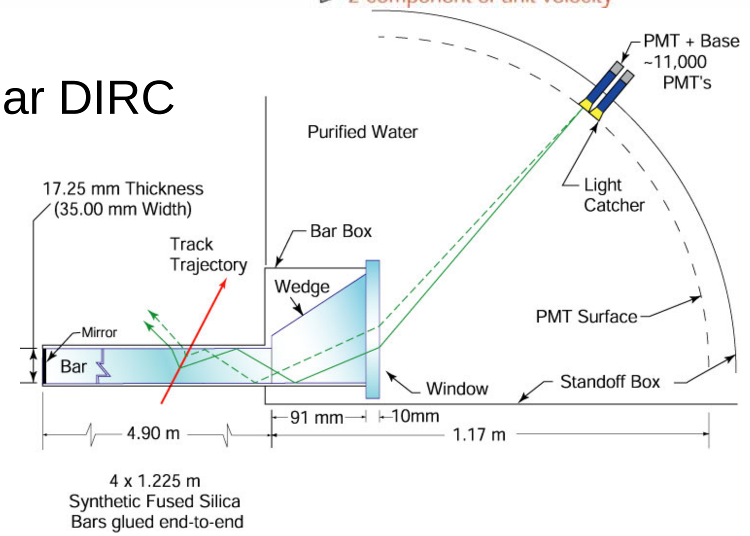
1.6GeV/c P_min through range stack

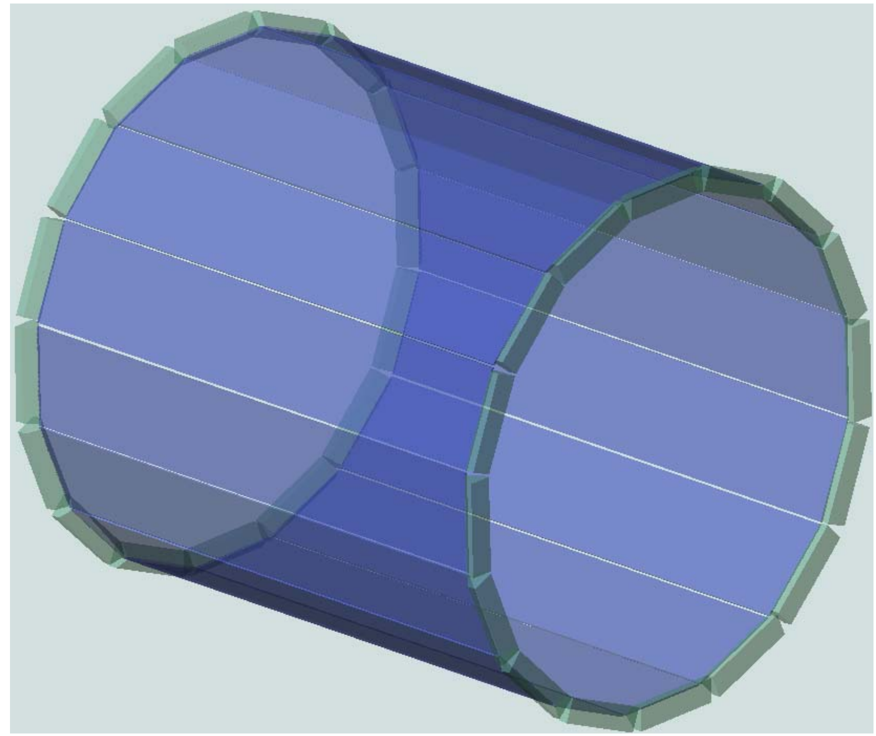
imaging TOP (iTOP)

Concept: Use best of both TOP (timing) and DIRC and fit in Belle PID envelope



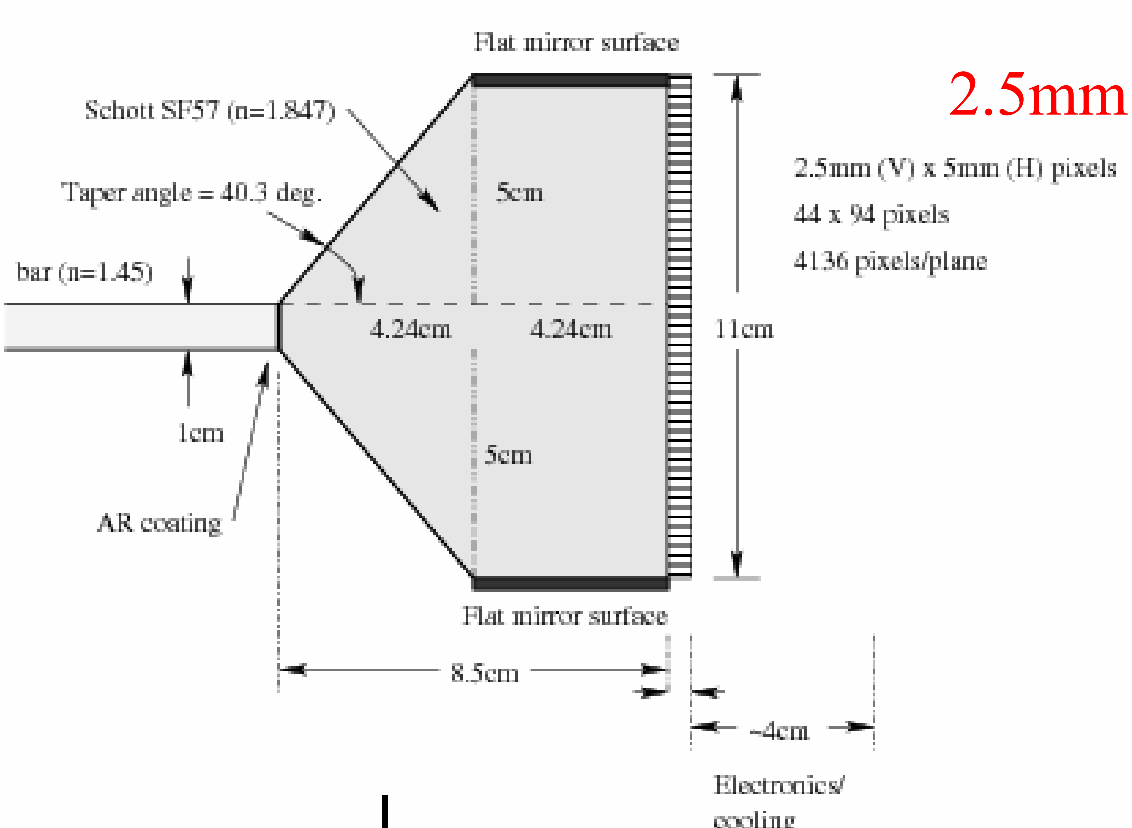
BaBar DIRC

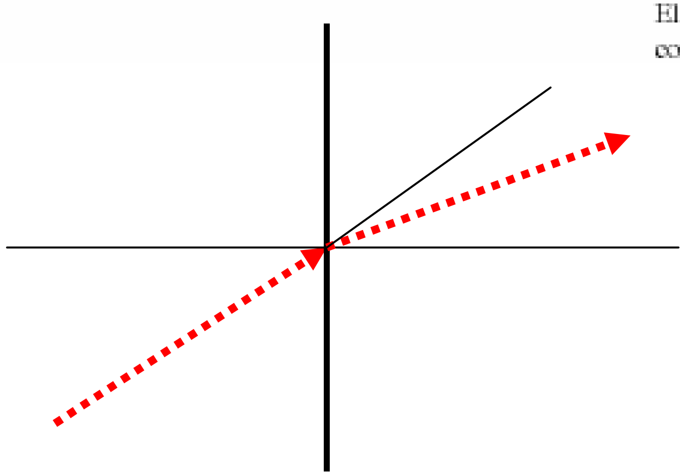




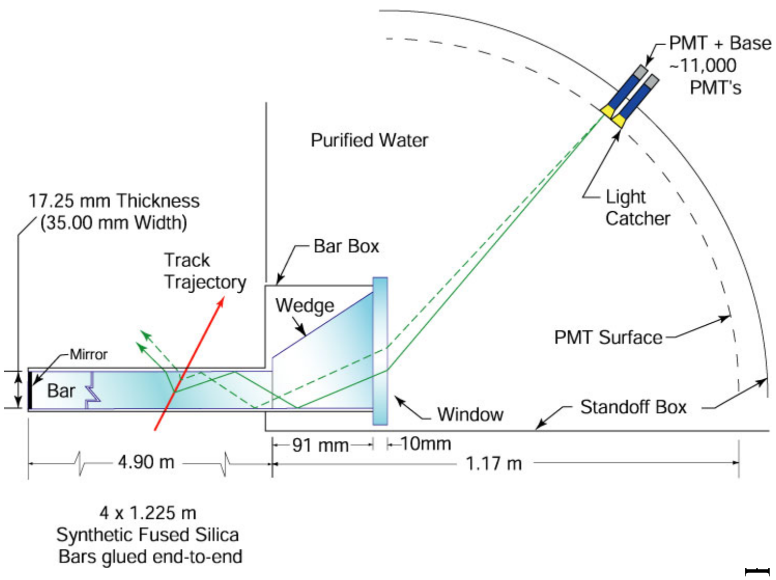
- Use new, compact solid-state photon detectors, new high-density electronics
- Use simultaneous T, θc [measured-predicted] for maximum K/π separation
- Keep pixel size comparable to DIRC

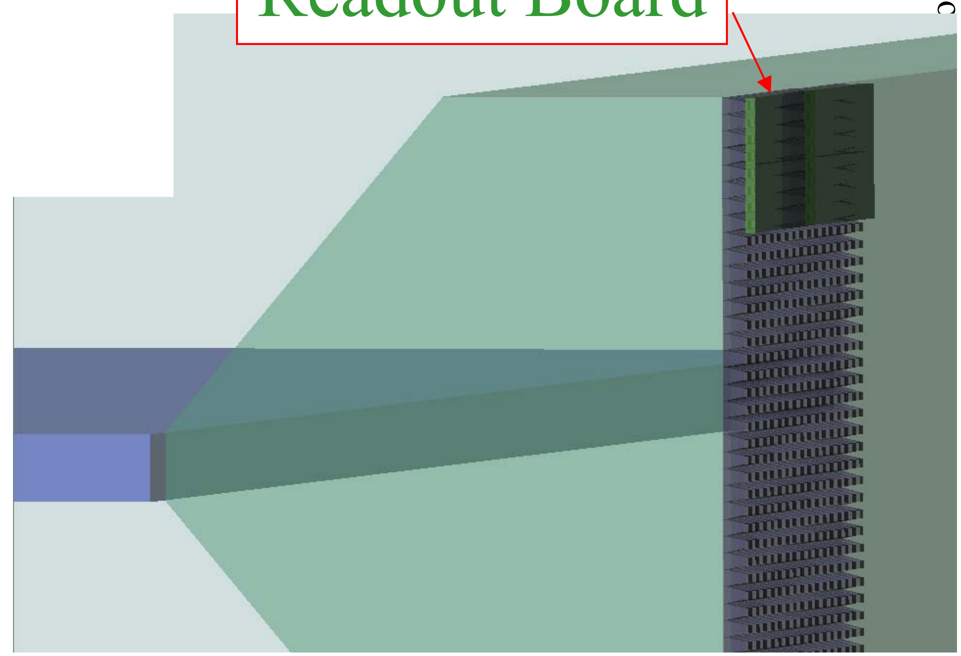
(too) Simple initial idea



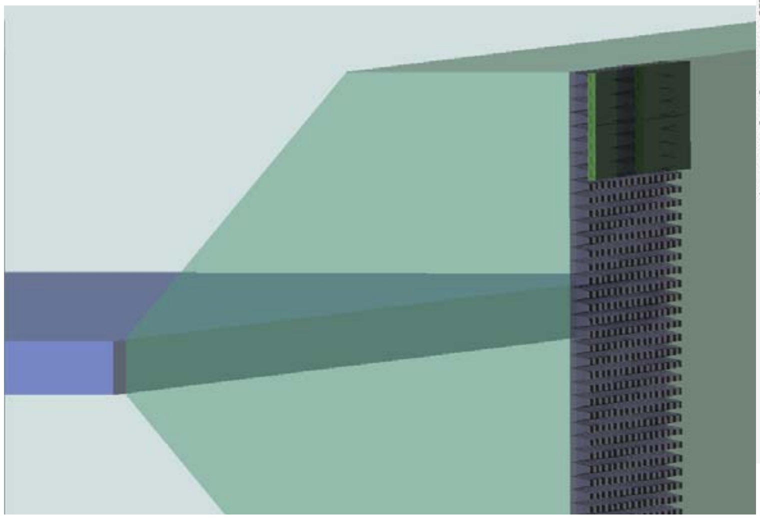


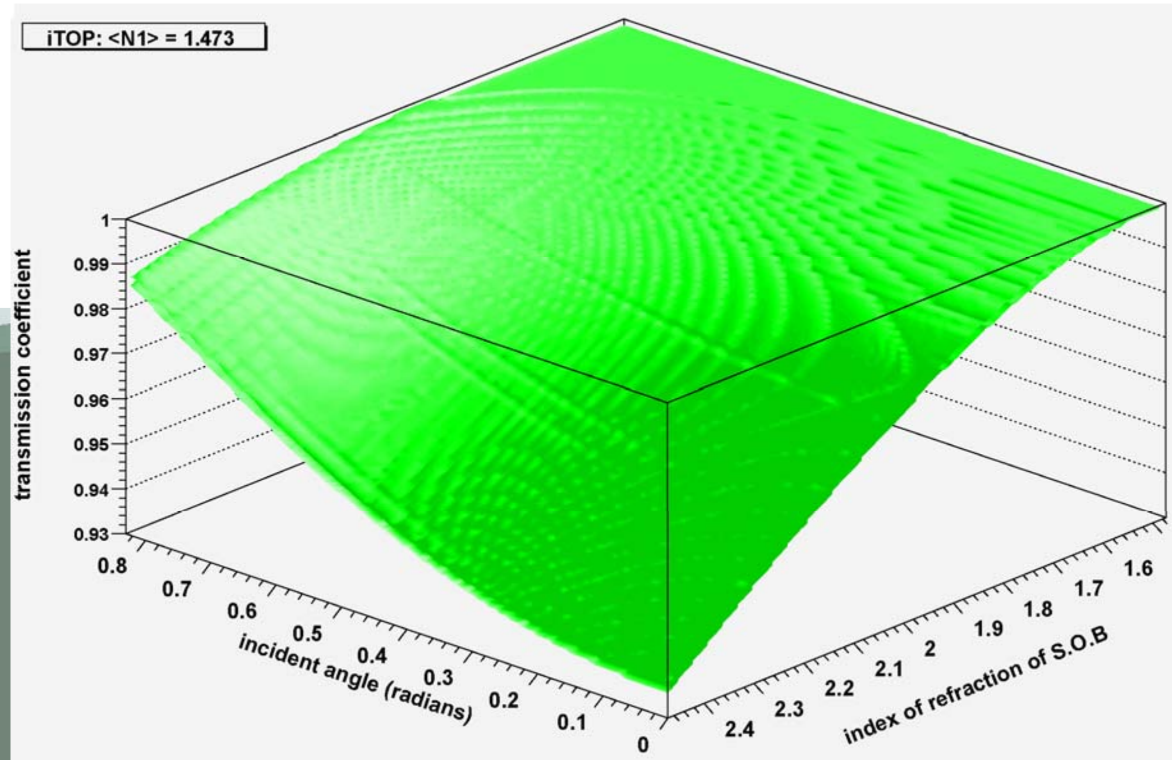
29mm





Stand-Off Block (SOB) Coupling



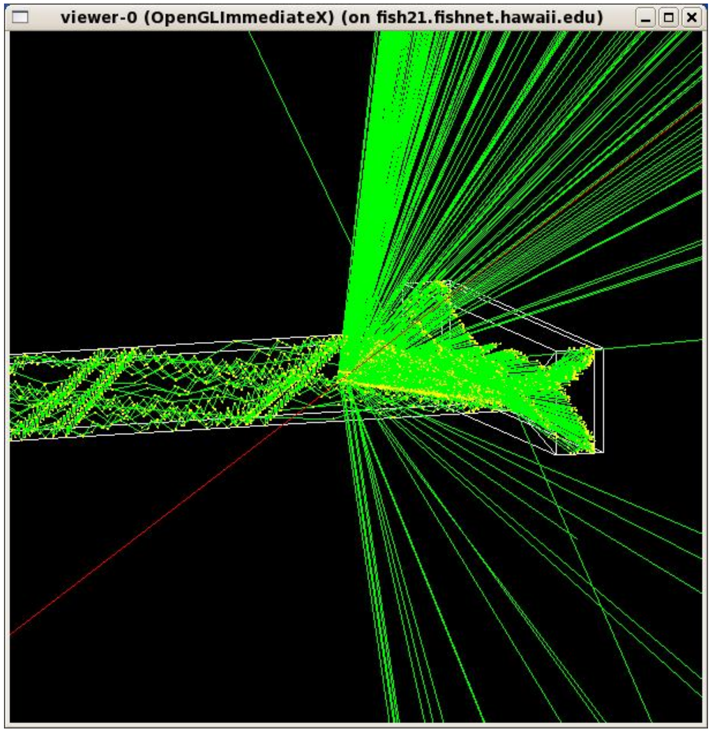


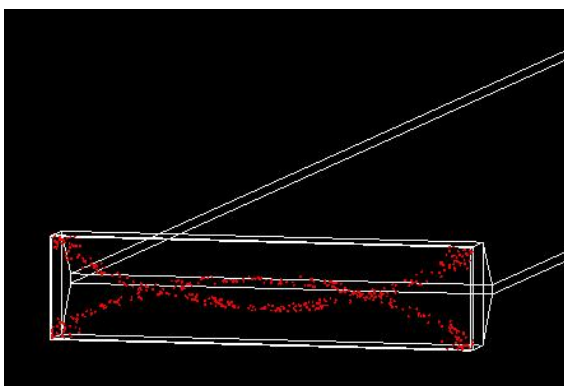
44 x 92 pix/plane = 4048 channels
16 bars x 2 ends x 4048 = ~130k channels

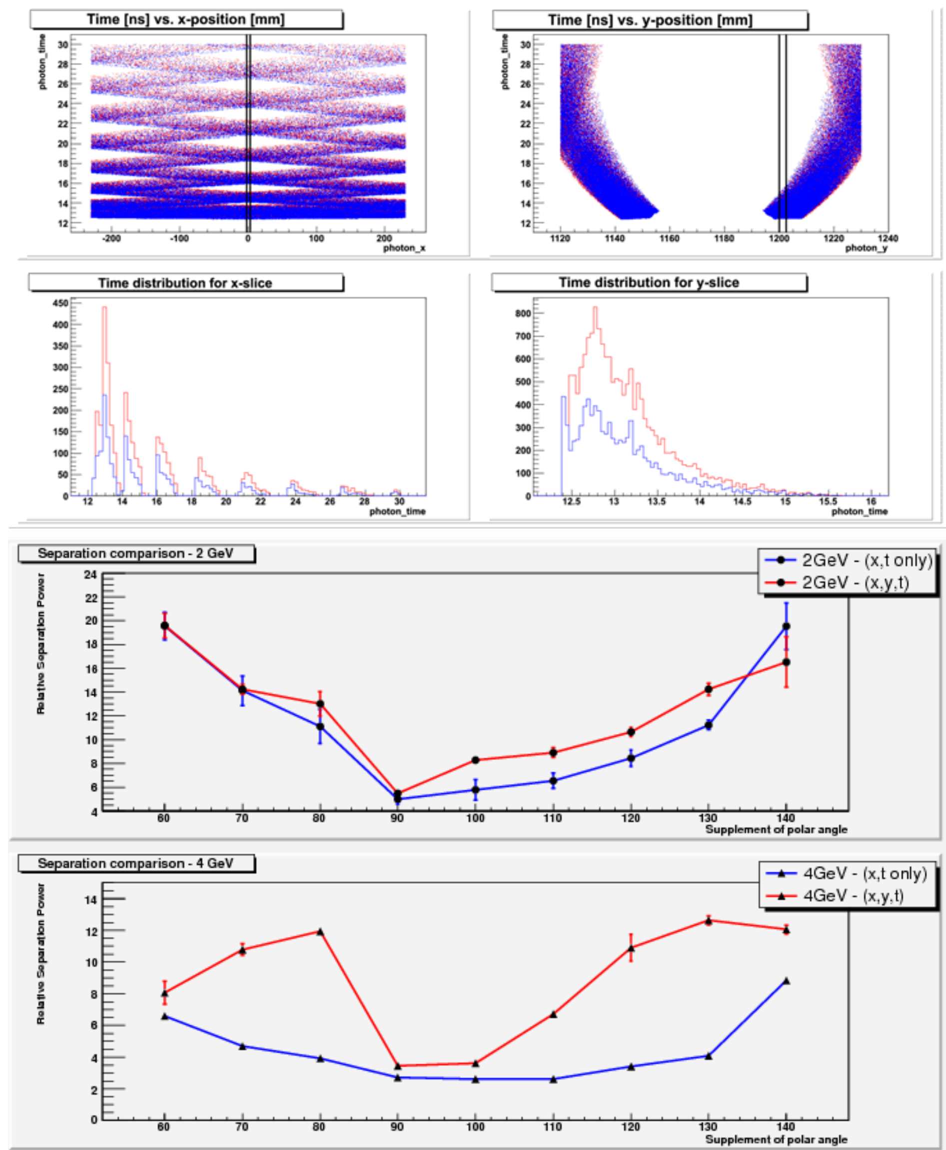
Problem is, once get in, hard to get out…
Exploring a number of concepts

GEANT4 Simulation

Kurtis Nishimura/Larry Ruckman



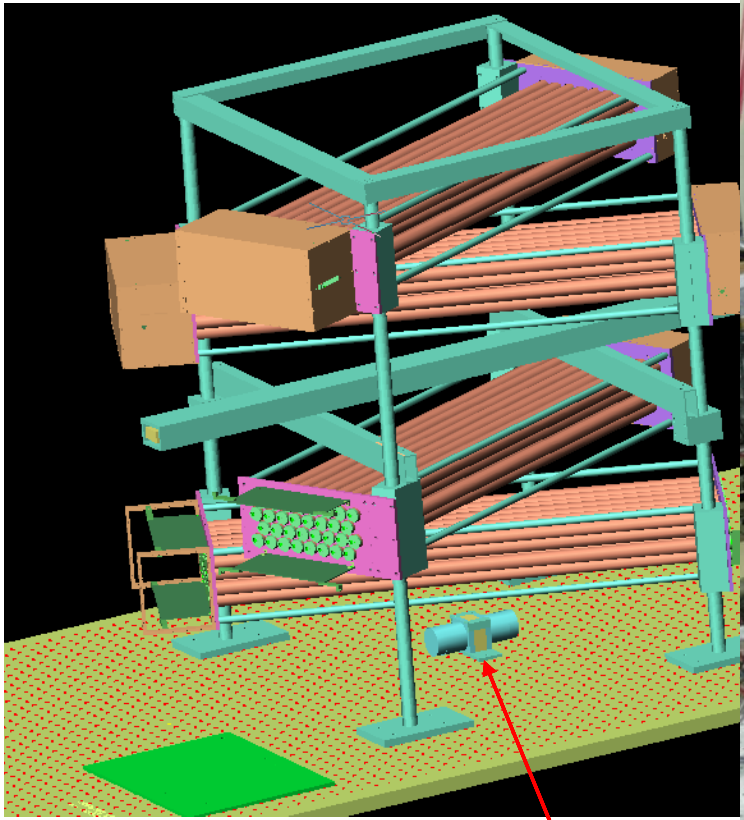


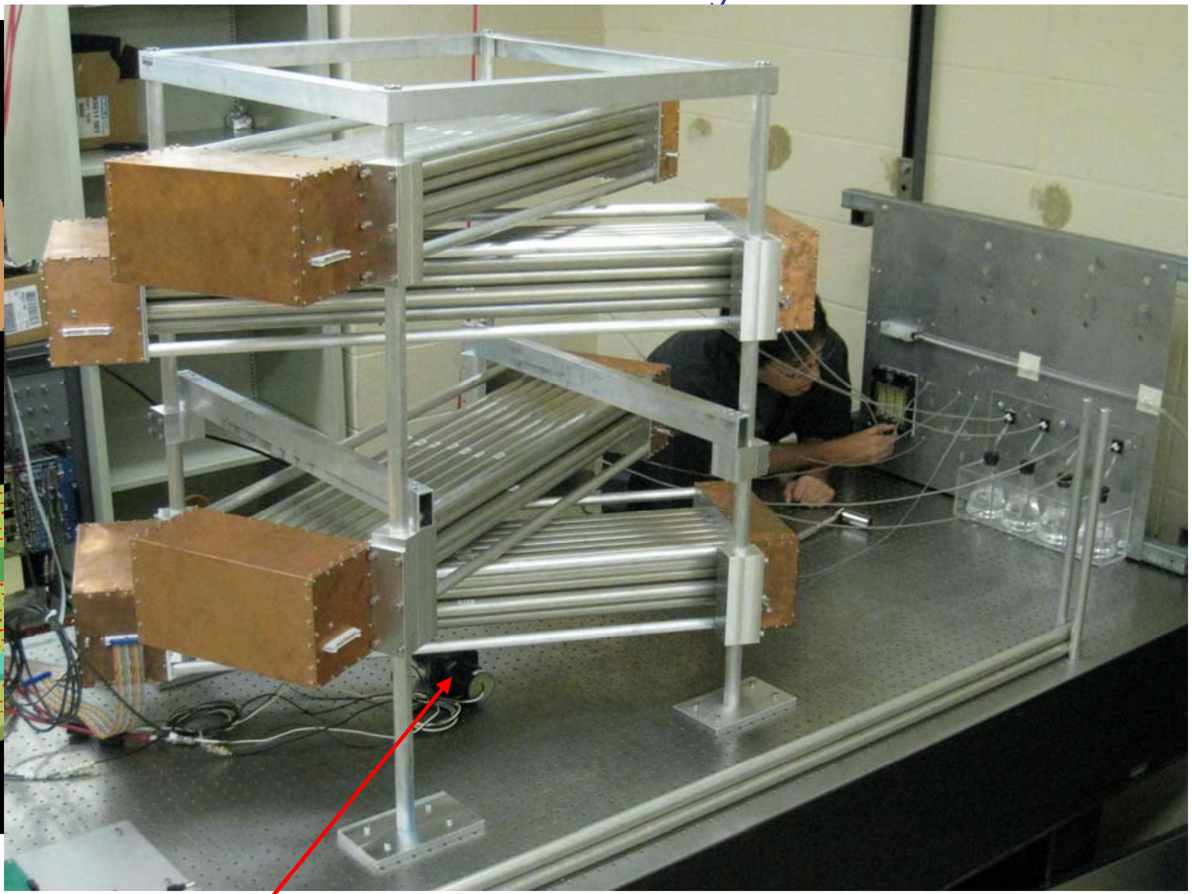


Looks promising, need to test

Cosmic Test Bench

- Quartz bar test bed – 128 drift tube array

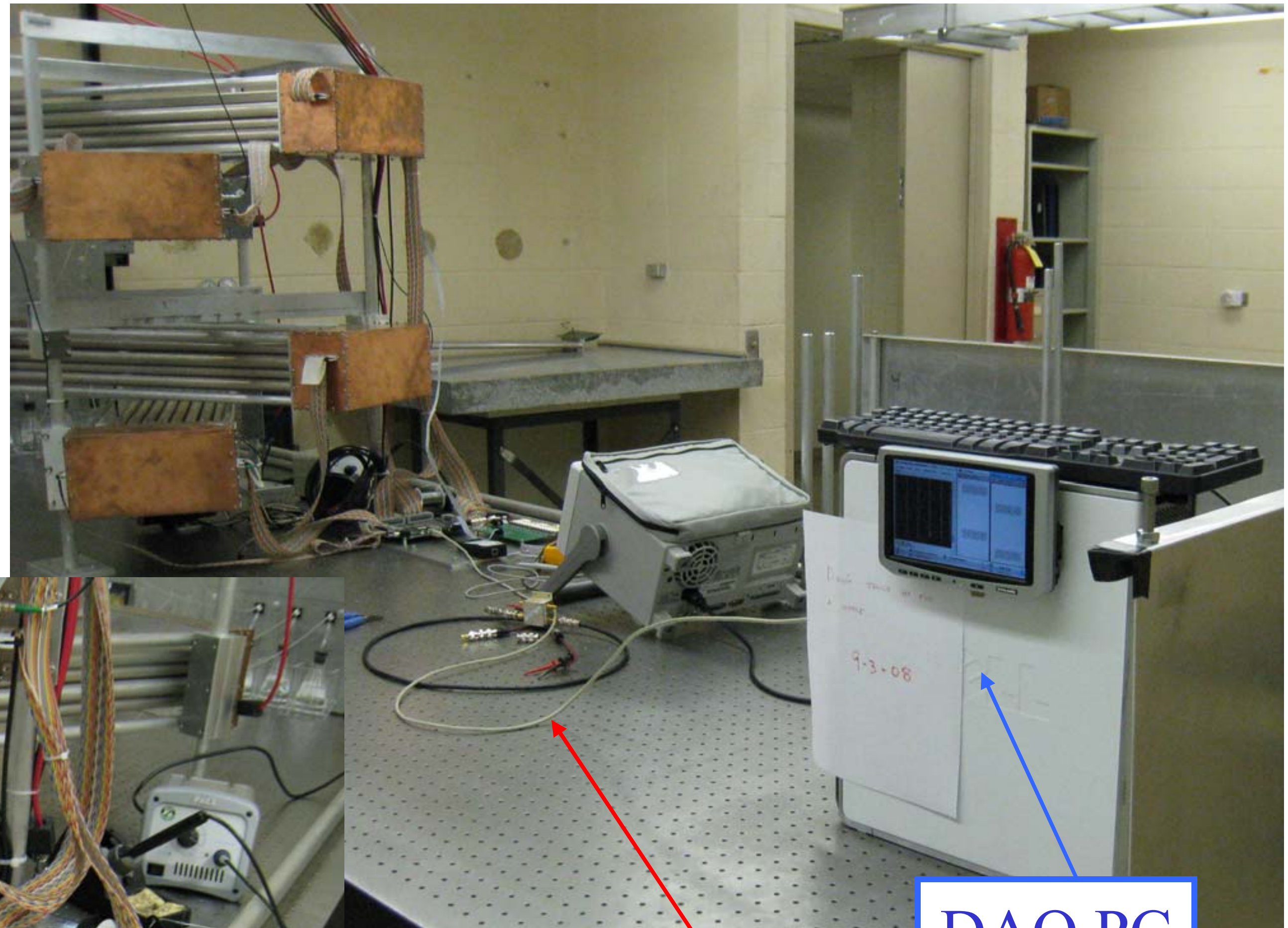


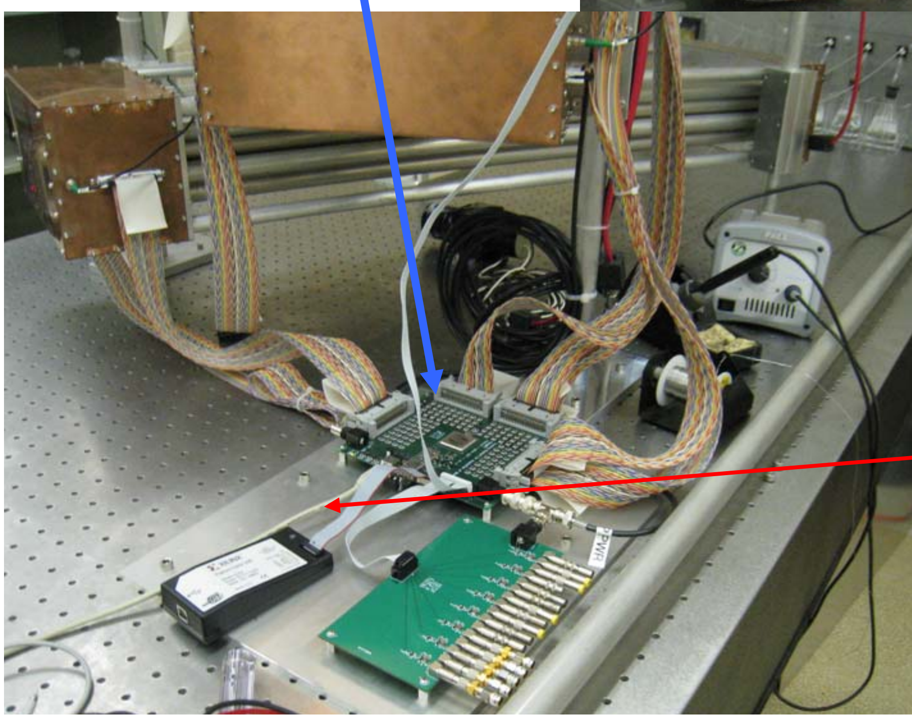


Precision Timing Block (T=0)
Radiator viewed by 2x (4x) fine-mesh PMTs

Cosmic Test Bench - Infrastructure

- 128 channel Discriminator and TDC board (TRAMP)

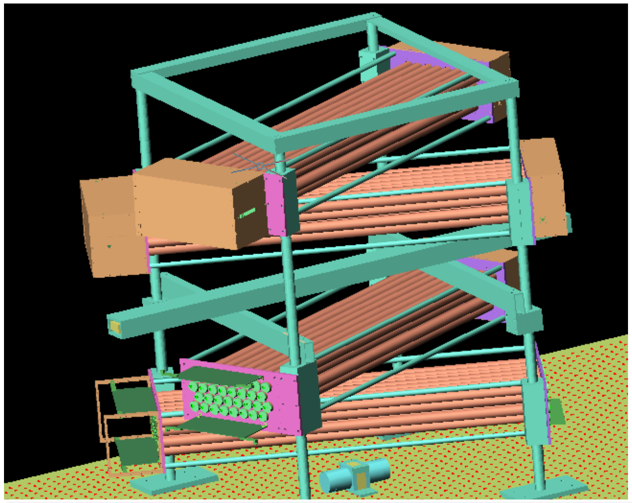


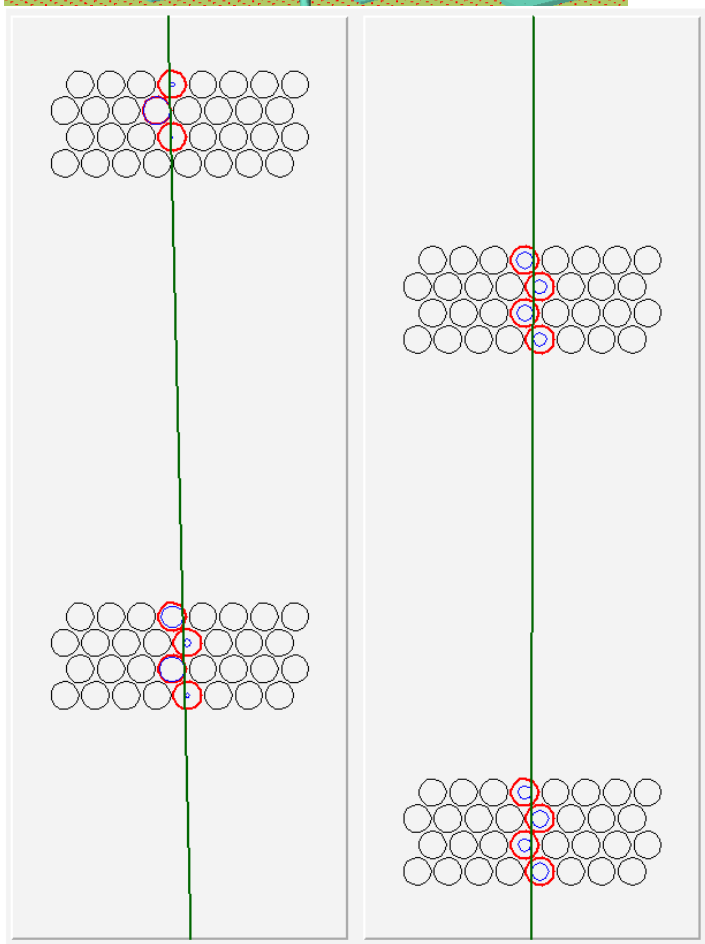


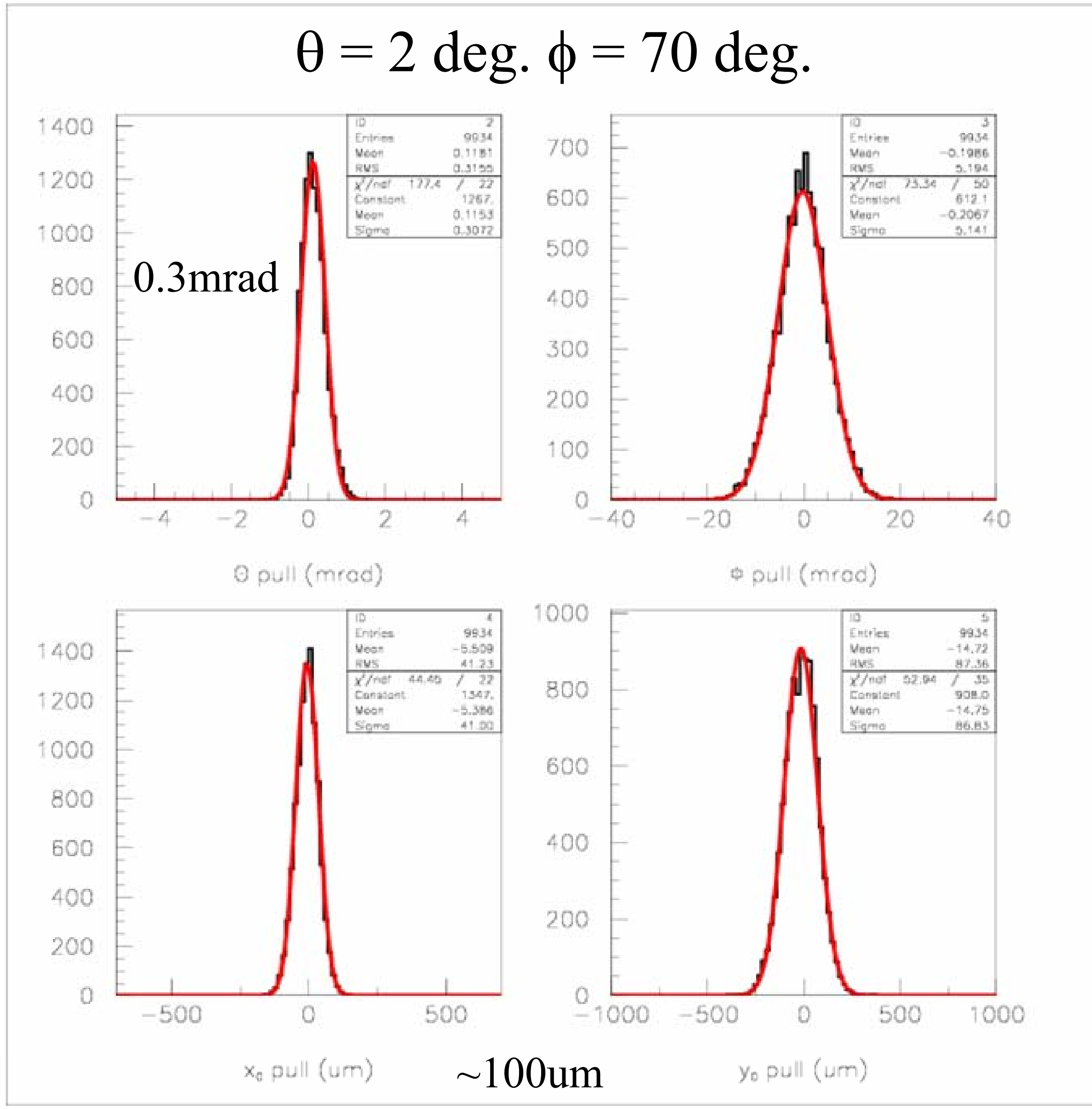
USB2 link (drift-tubes)

DAQ PC

Tracking Resolution Sims.

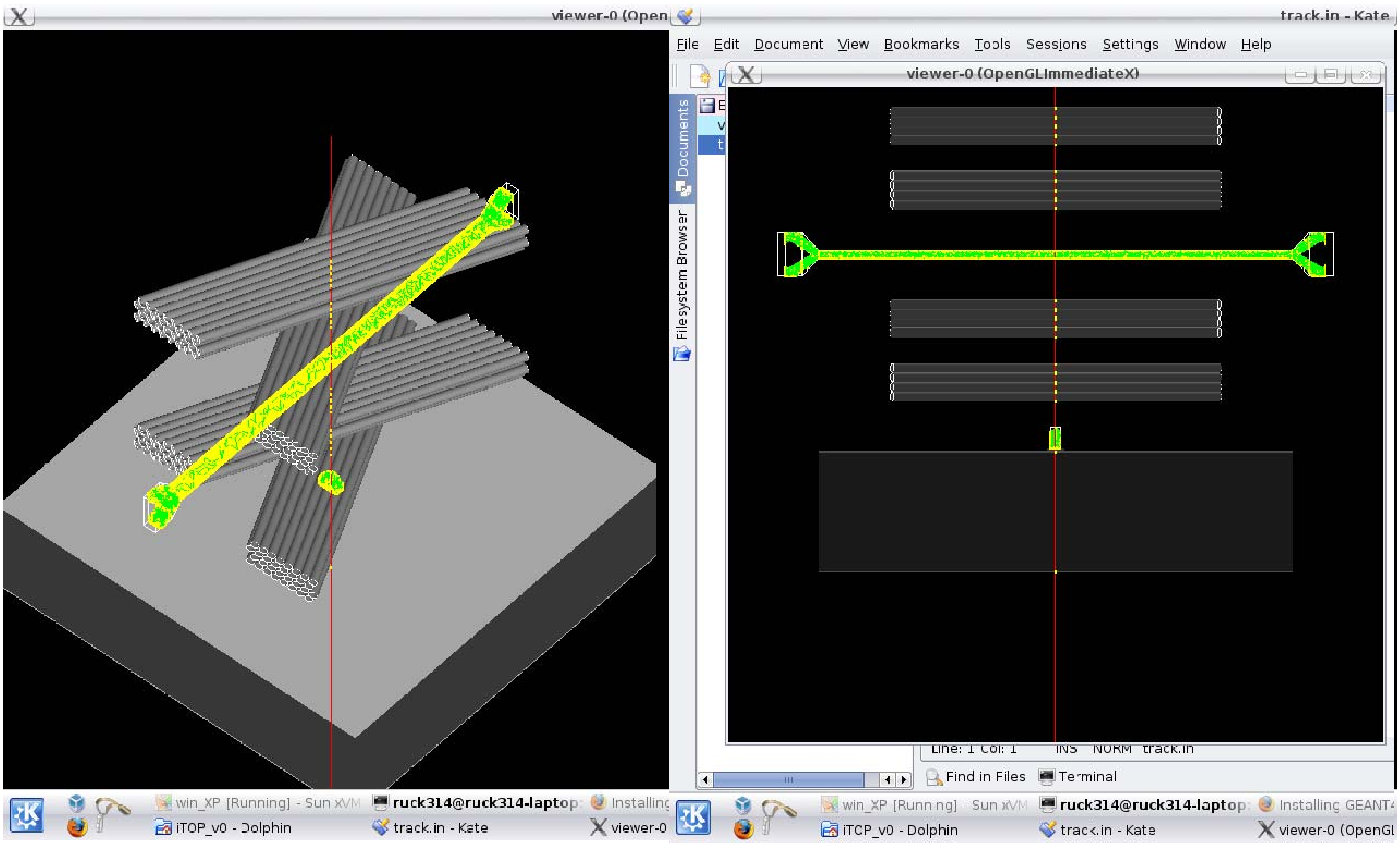






G4 Simulation

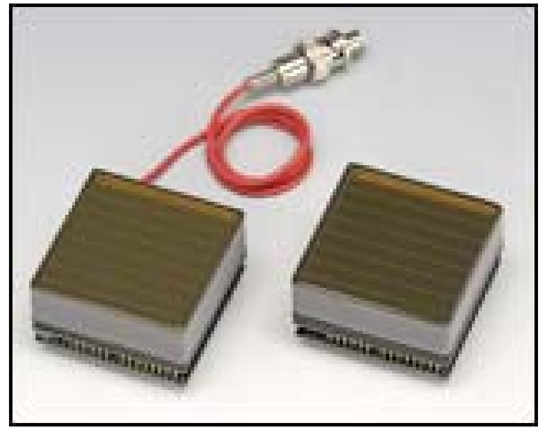
- Studying optimizations for image planes



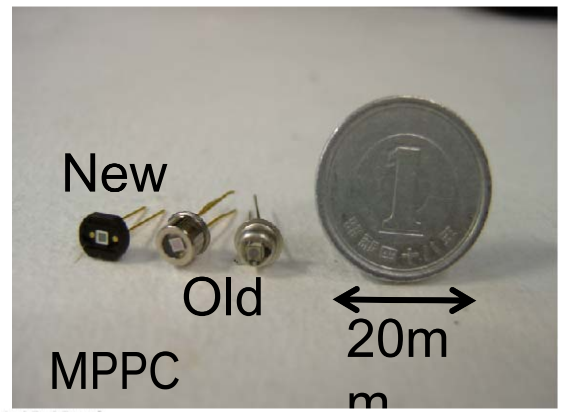
- 100% avail. beam, test different concepts – GEANT confirm

Photon detector options

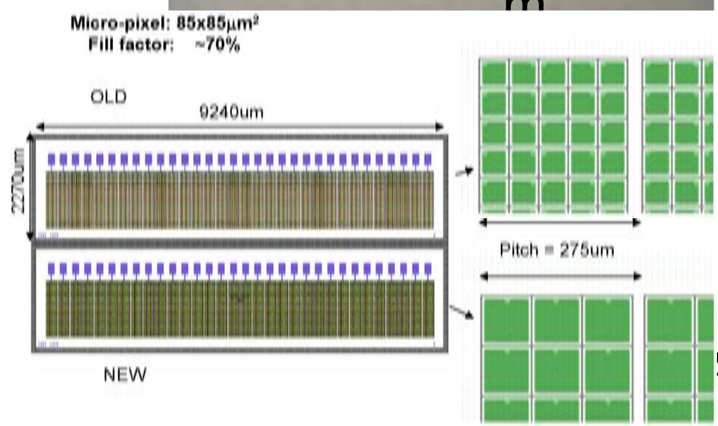
- MCP-PMT (H-8500)
  - Will use for initial testing
    - Study realistic time resolution
    - Use BLAB gain to extend lifetime
  - Demonstrate timing at lower gain



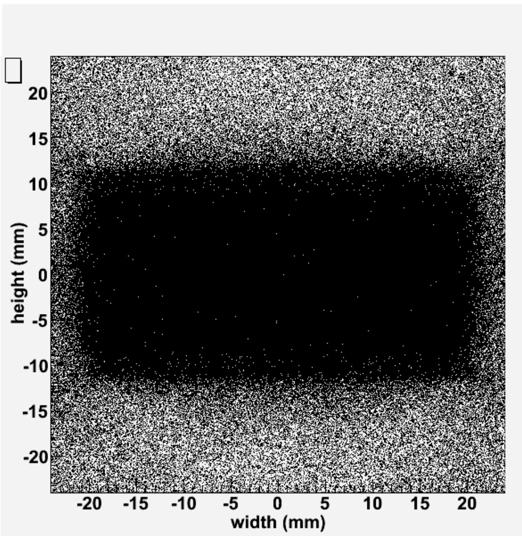
- SiPM/MPPC
  - Good stability, 100ps TTS (N=100 p.e. → 10ps)
  - Need light guide to make
  - Radiation hardness?

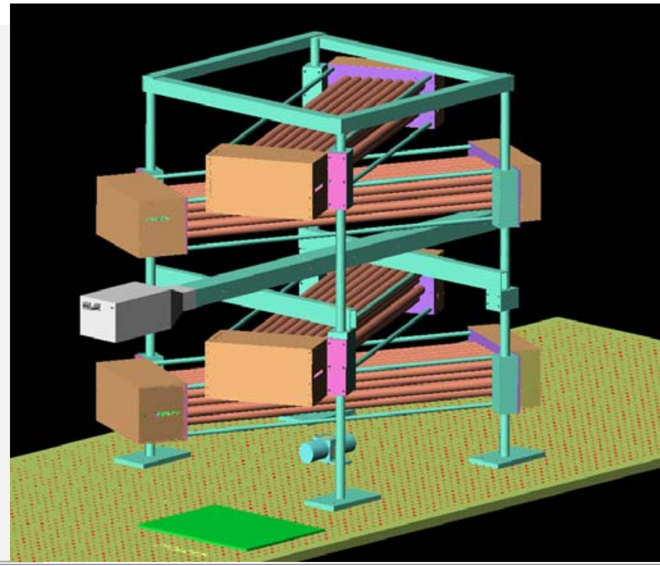


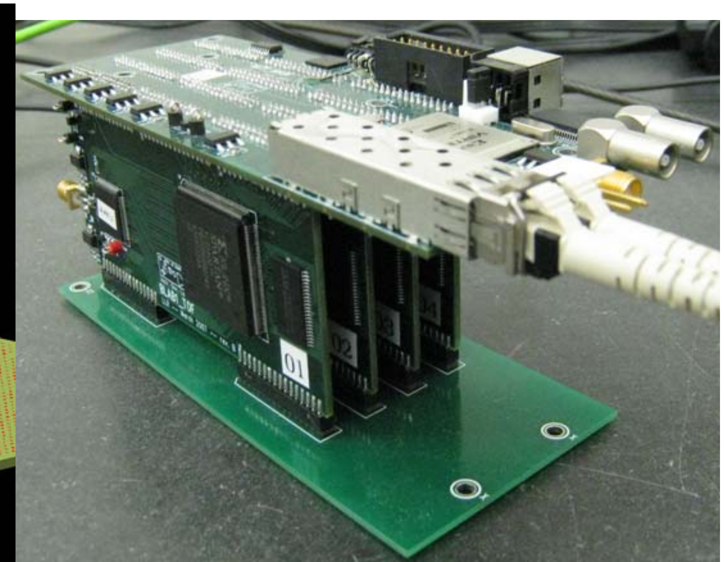
- Linear arrays
  - Started evaluating (good vertical resolution)
  - Packaging considerations



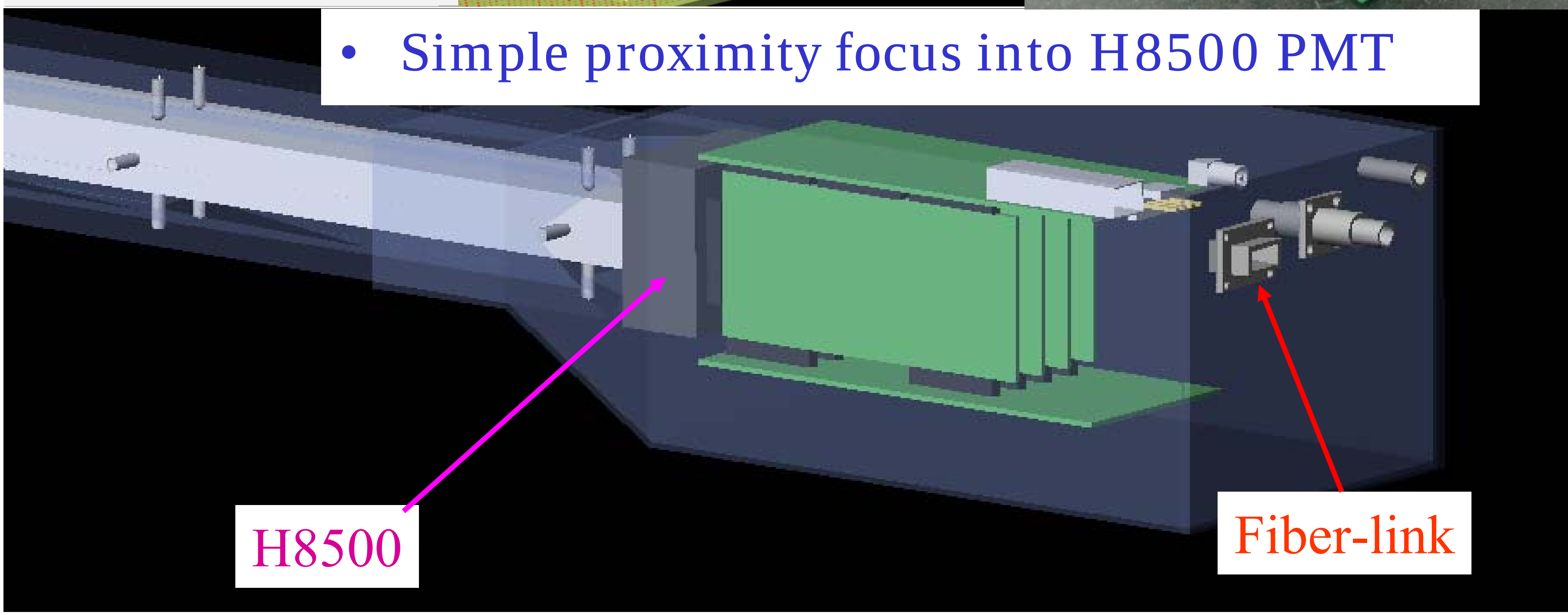
Initial Quartz bar test





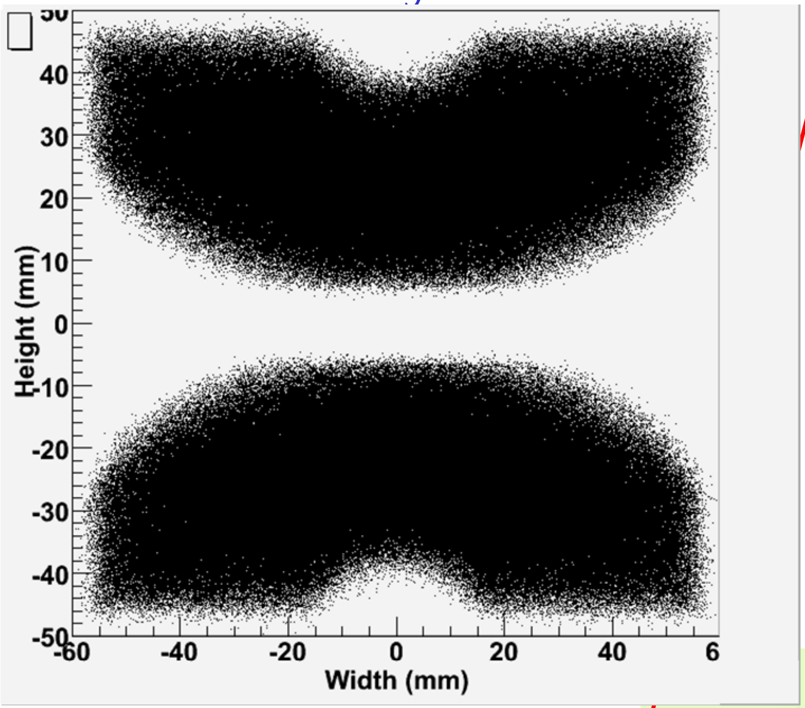


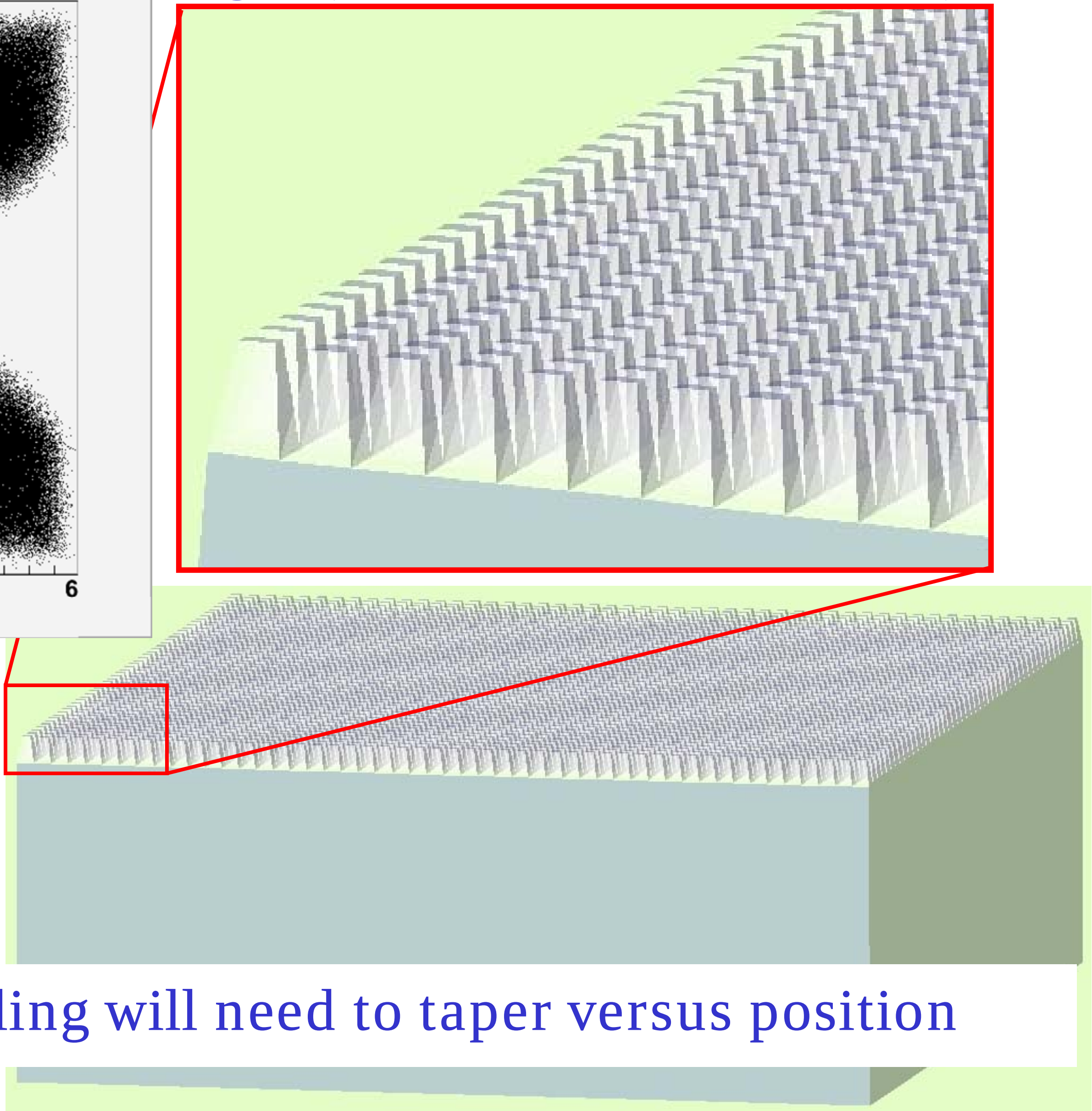
- Simple proximity focus into H8500 PMT



Full Image plane test (40mm SOB)

- Proximity focus initial target (100mm iTOP thickness)



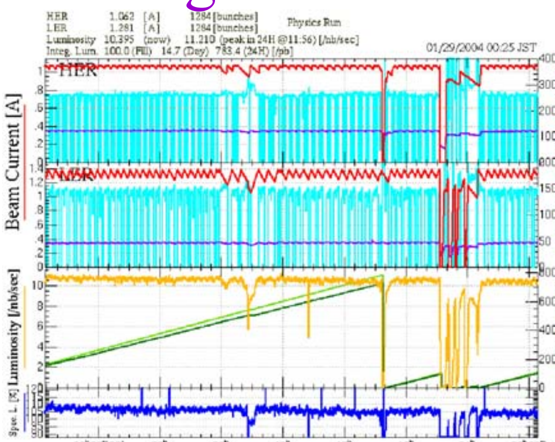


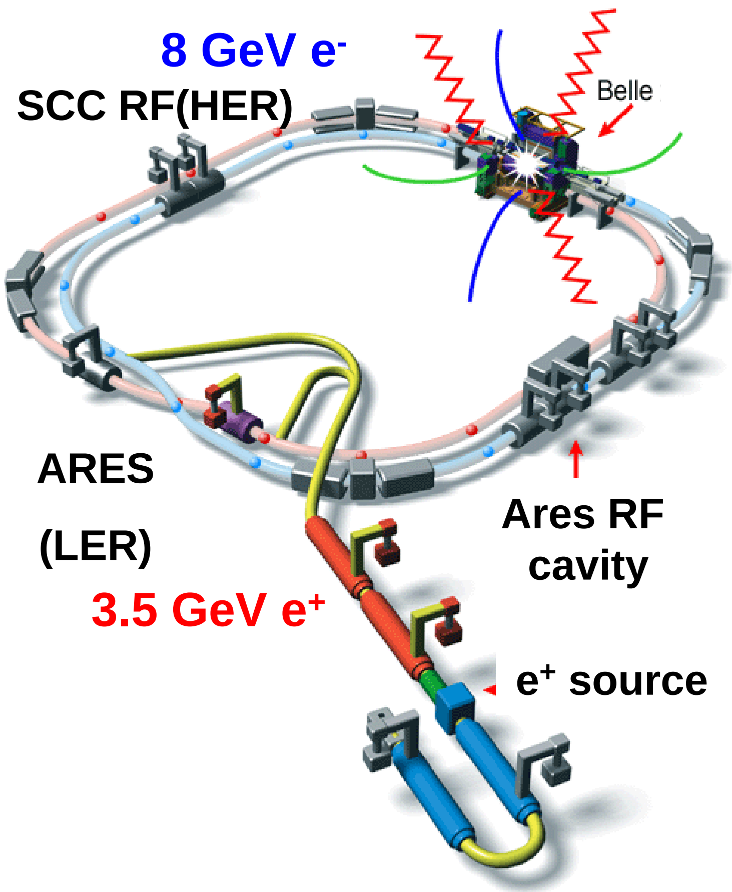
120mm (W)
x 100mm (H)
x 40mm (T)
2.4k pixels shown

- For good coupling will need to taper versus position

Lessons from KEKB Timing (I)

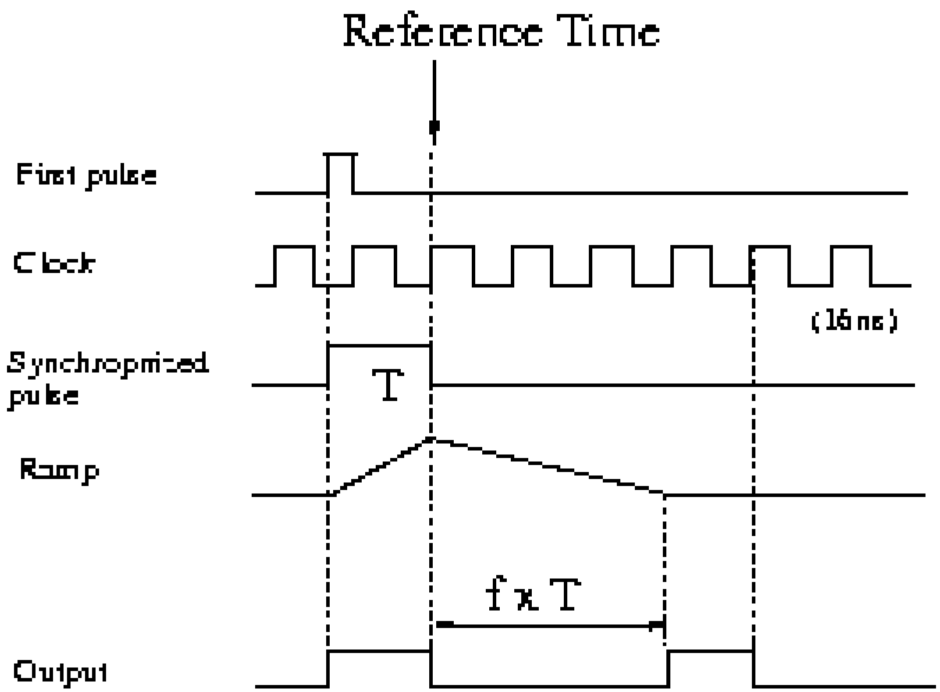
World's highest Luminosity collider

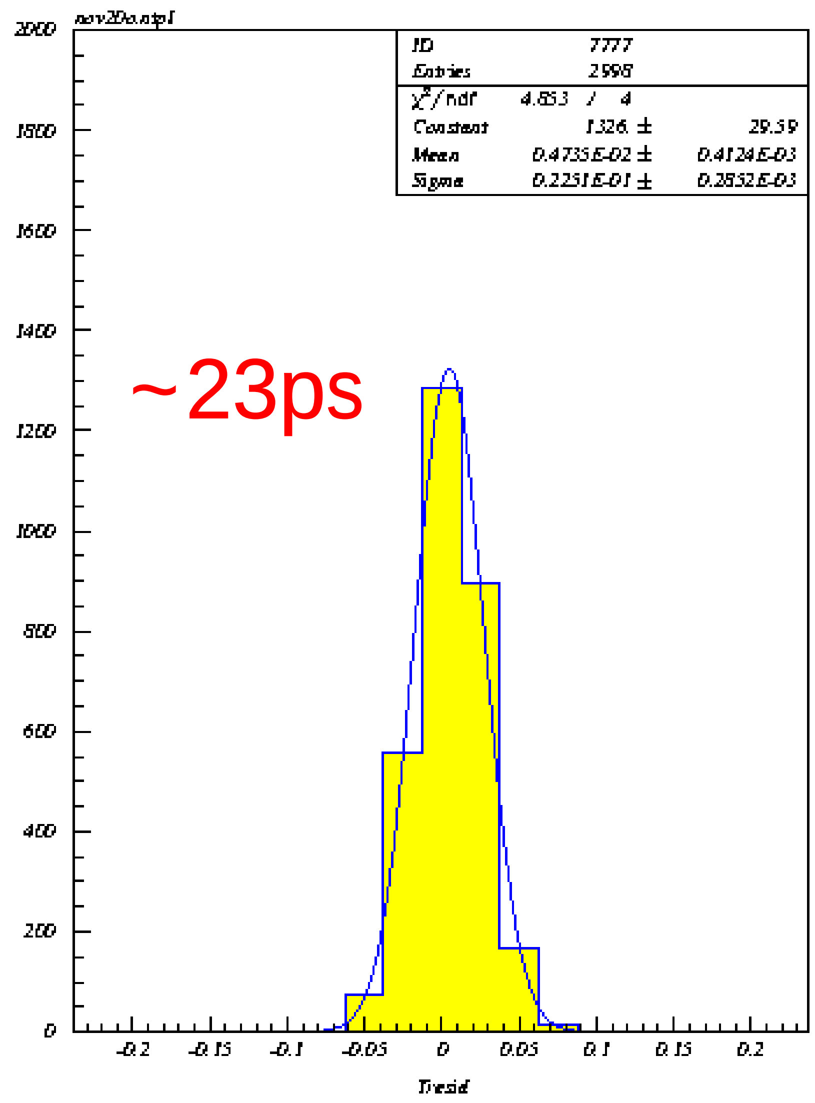




Fiber-optic distribution RF clock

Continuous hit recording



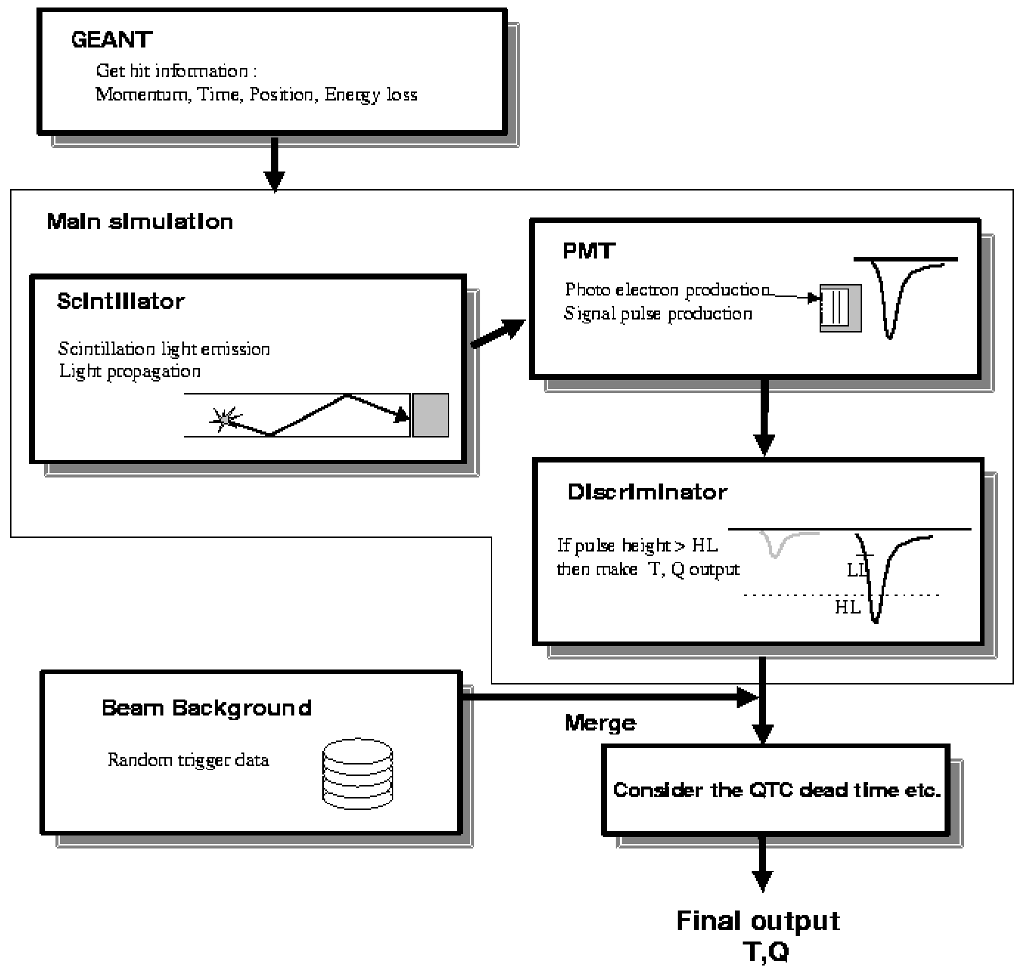


~23ps

500ps LSB → 25ps LSB

Trying to understand performance

- While basic Belle TOF performance good:
  - Wanted to understand limitations
  - Acceptance and Trigger efficiency
  - Nuclear/hadronic interactions
  - Higher Luminosity prediction



- Full GEANT simulation:
  - Full simulator [NIM **A479** (2002) 117].
  - Accurate modeling of secondaries
  - Detector response and readout chain
  - Adjust parameters where required
  - Include beam background

Estimating performance

- Q: what does this mean for BESIII TOF?

	Belle		BESIII		
	Spec.	guess?	Spec.		
RF/BCO	<35 ps	35 ps	<35 ps		
uncorrected t=0		?	?	within run	
Discrim. Overdrive		?	?	could be calibrated	
Beam bunch length	2.5 mm	8.3 ps	50 ps	15 mm	
Time Encoding	<20ps	22 ps	?		
		(~42 ps)			
TOTAL	< 40 ps	**~45 ps**	< 45 ps ?	looks difficult	

- GEANT/full simulator contribution:

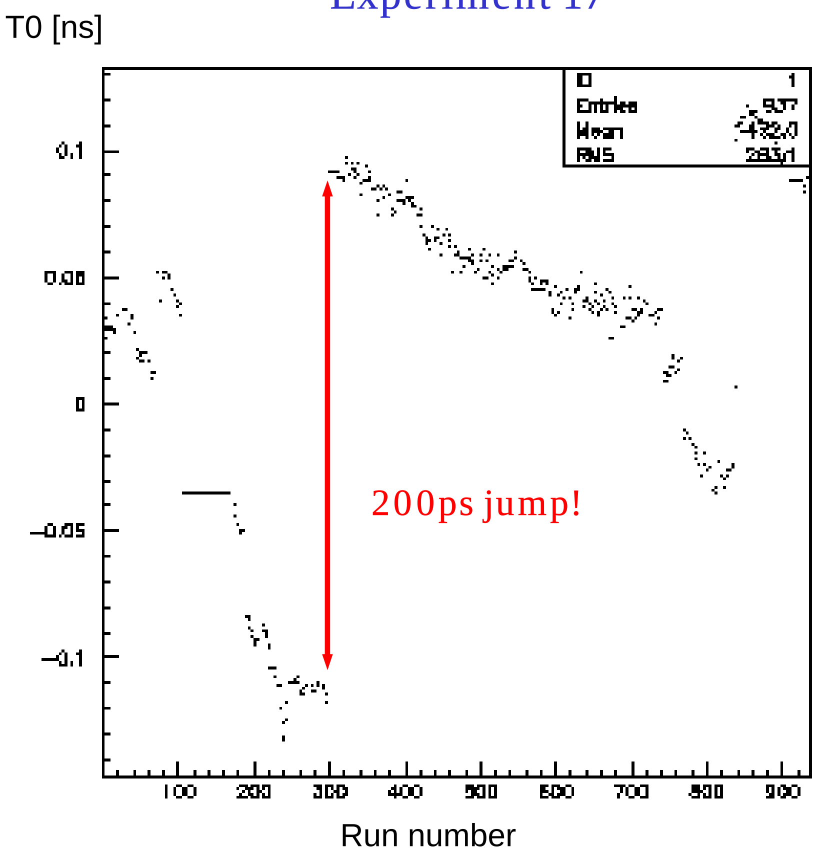
σ^2_{fin} → 100ps – "known" ~ "physics" → 40ps

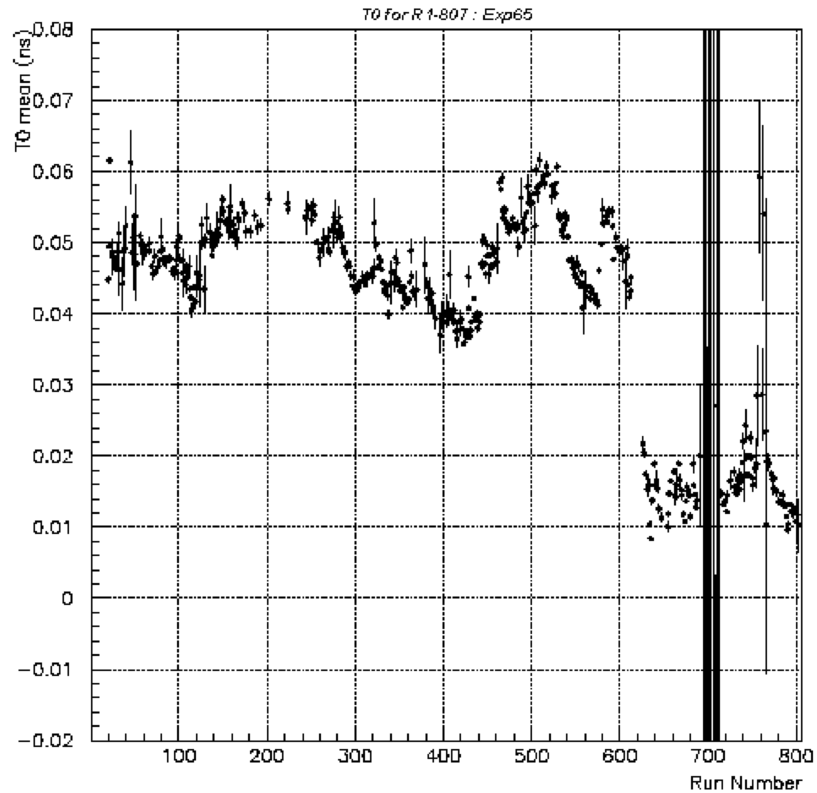
(Belle detector/KEKB environment dependent)

- In summary, can parameterize:

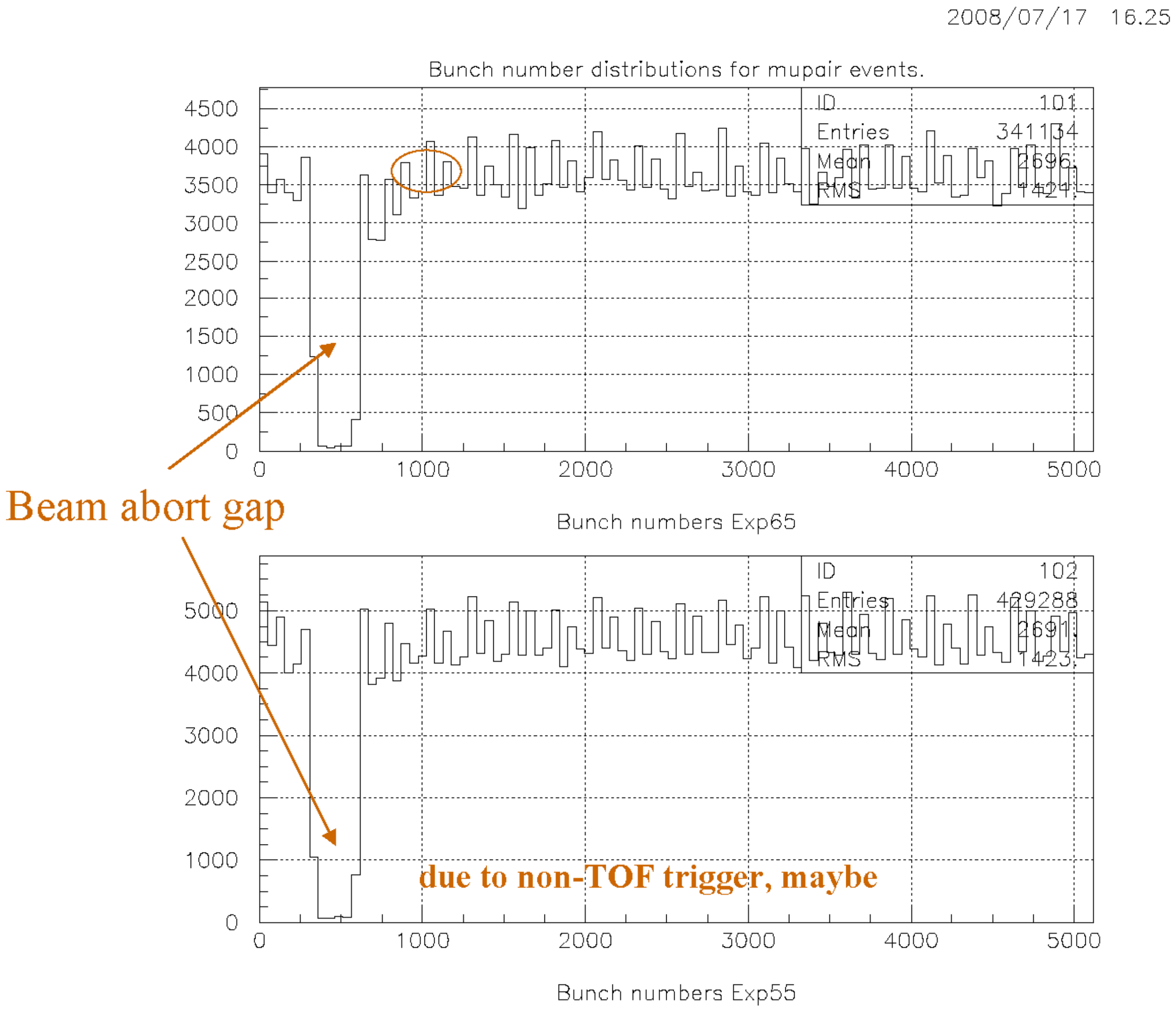
Sudden shifts, no obvious KEKB correlation

Experiment 17





Bunch number distribution for μ-pair skim events



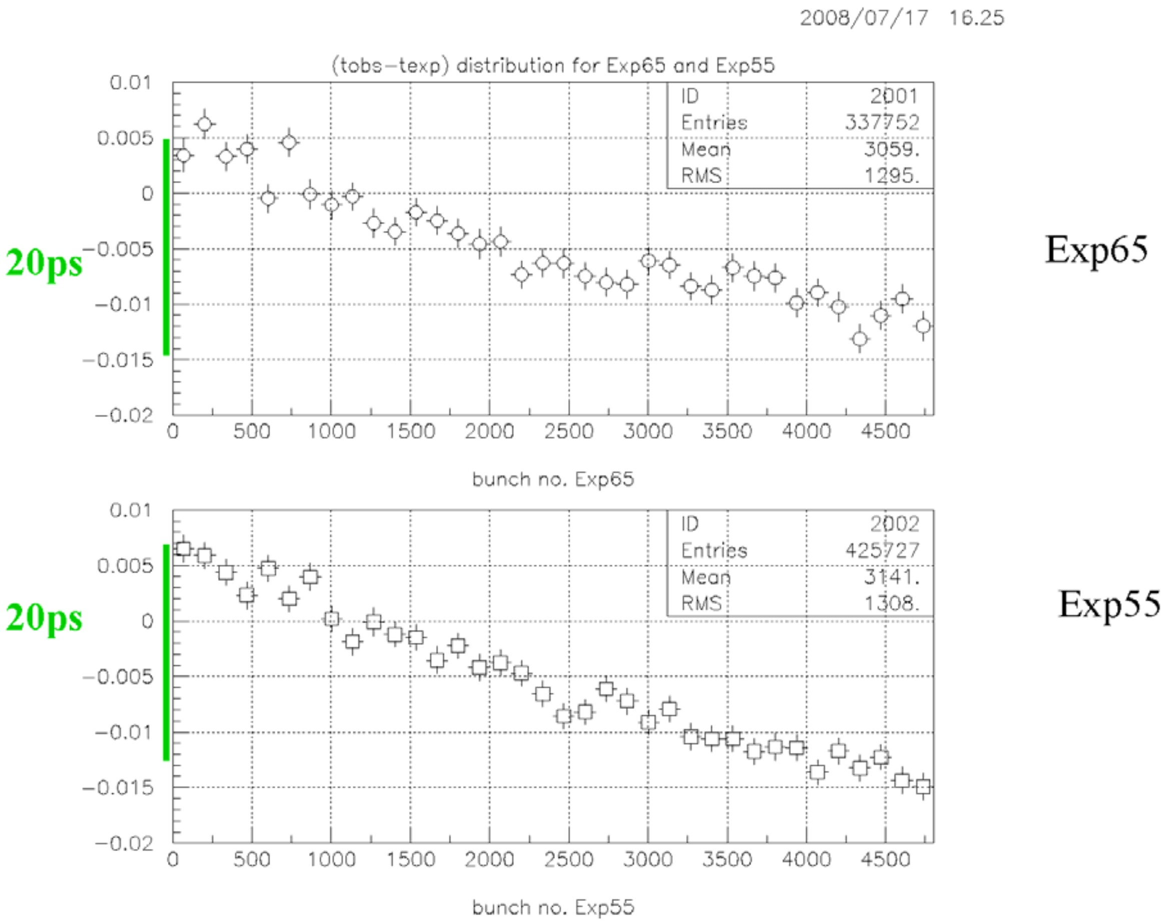
Exp65

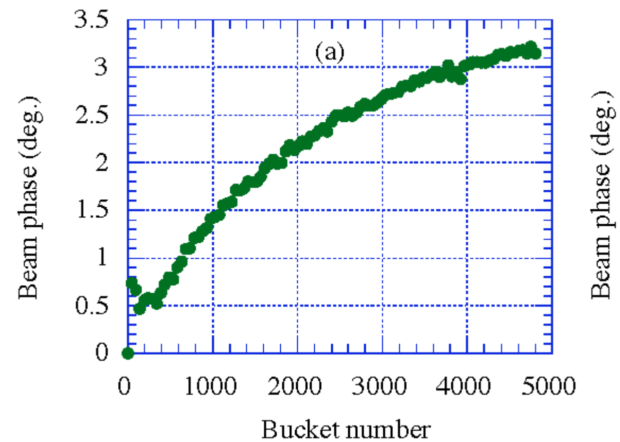
Exp55

Fine structures
due to Beam Fill Pattern

Lessons from KEKB Timing (II)

dT= (T_{obs} – T_{exp}) distribution in ns

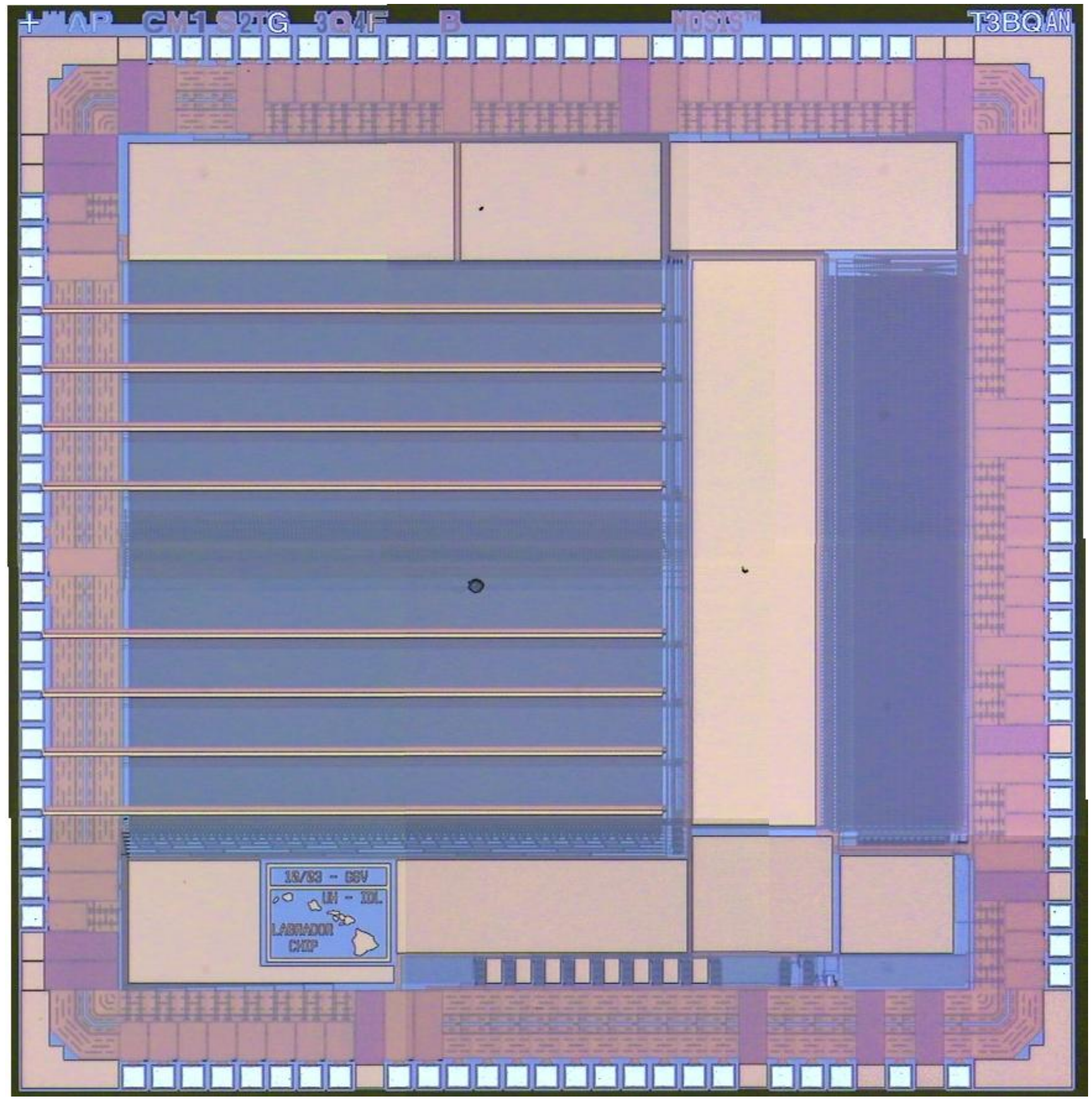




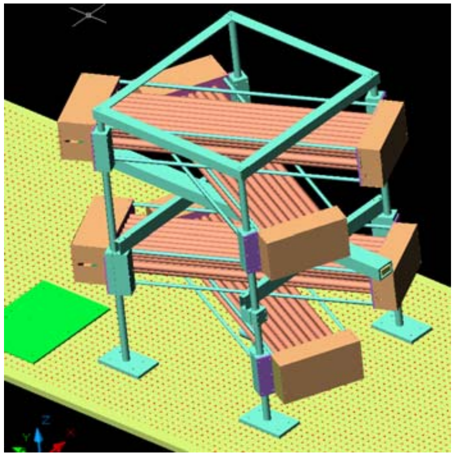
BLAB Summary

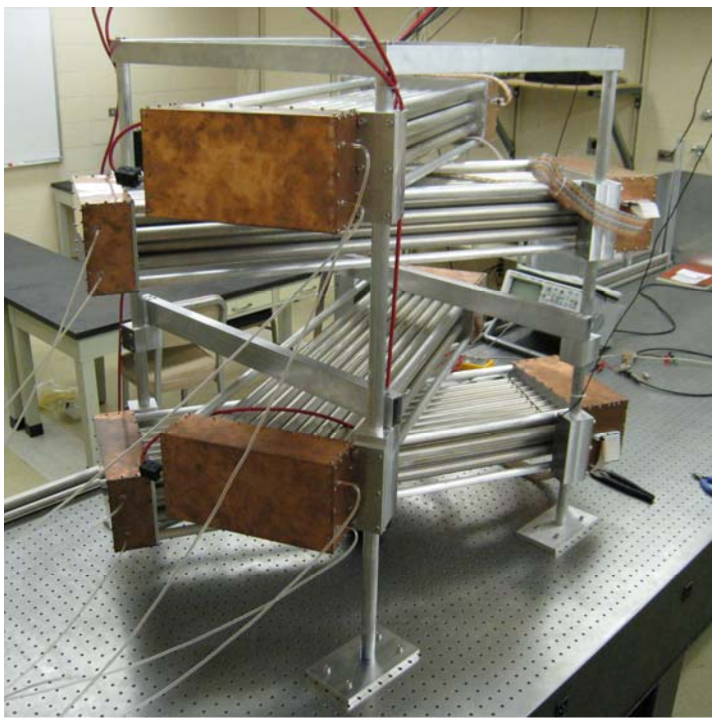
- BLAB2 readout of MCP-PMT signals
  - Photo-detector limited
  - Impact of systematics, reference timing distribution important
- BLAB3 in works
  - Lessons learned from TIA experience
  - Explore higher bandwidth, participation in 40GSa/s ASIC
- Compact, integrated photodetector readout
  - Commission 2x 500 ch. systems in ~Dec. (BLAB2 based)
  - Demonstrate windowing, online T, Q extraction
  - Results from these systems next time

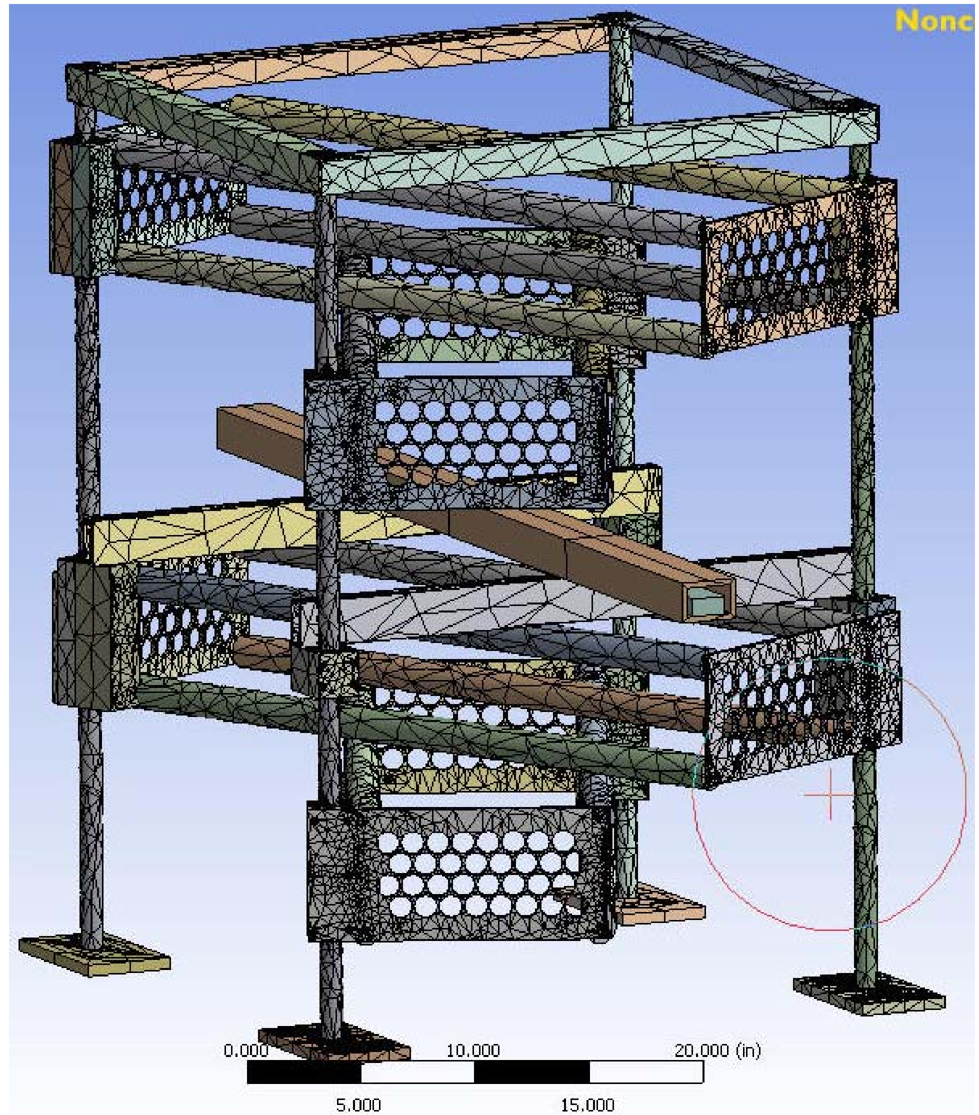
Back-up slides



Cosmic Test Bench – mech. Stability

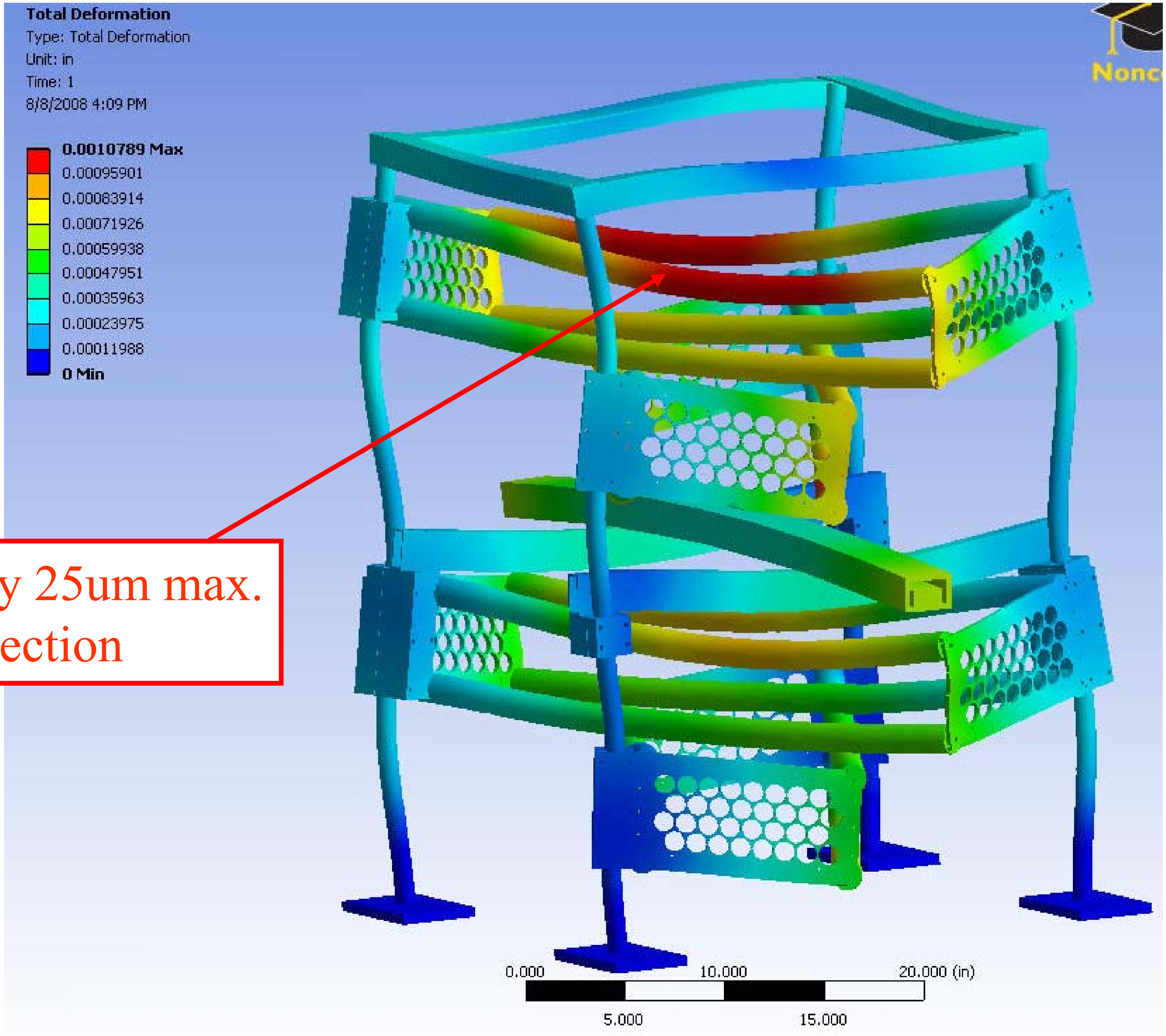






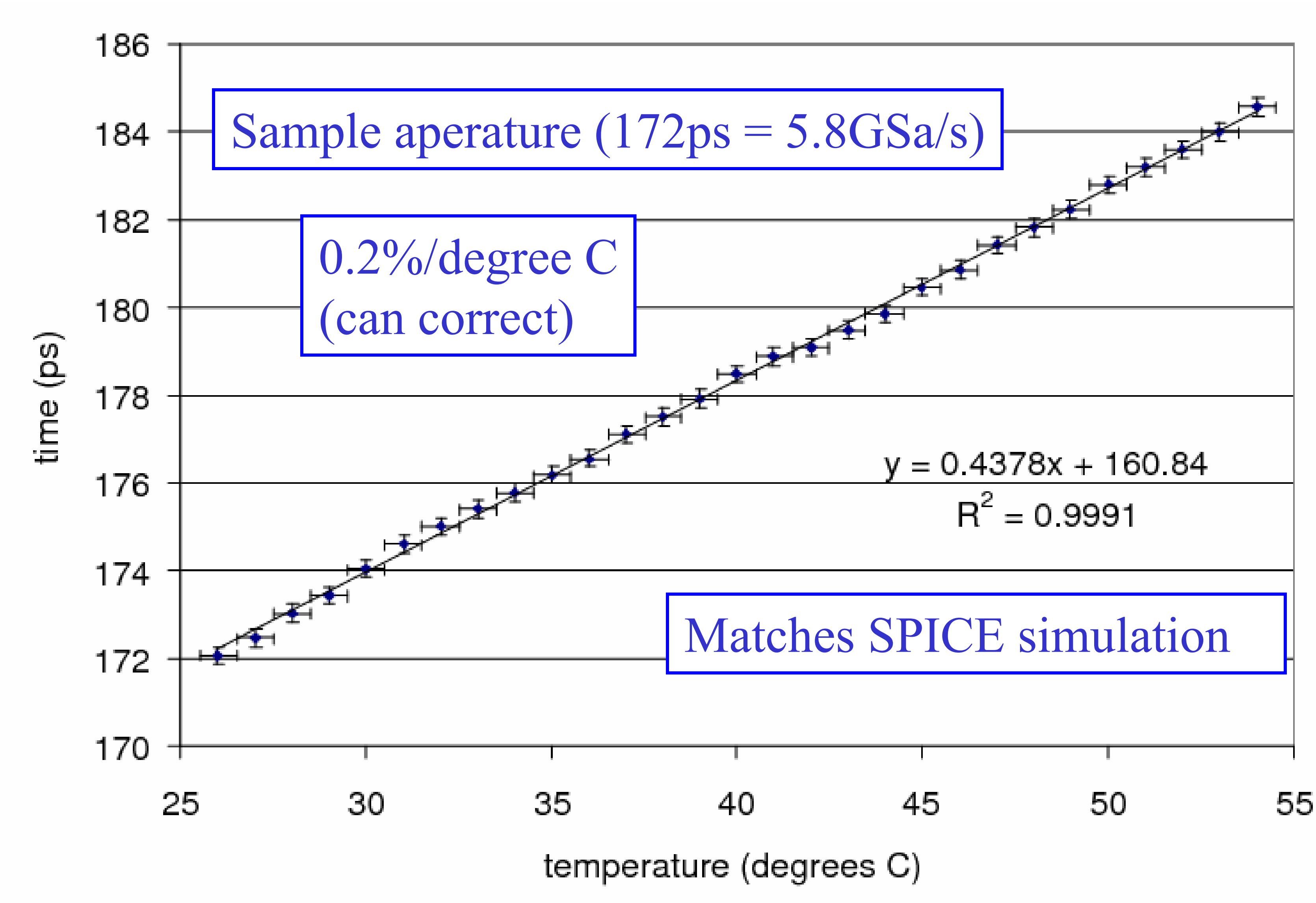
Rigidity and stability are excellent

Cosmic Test Bench – Sag analysis



Only 25um max. deflection

Temperature Dependence

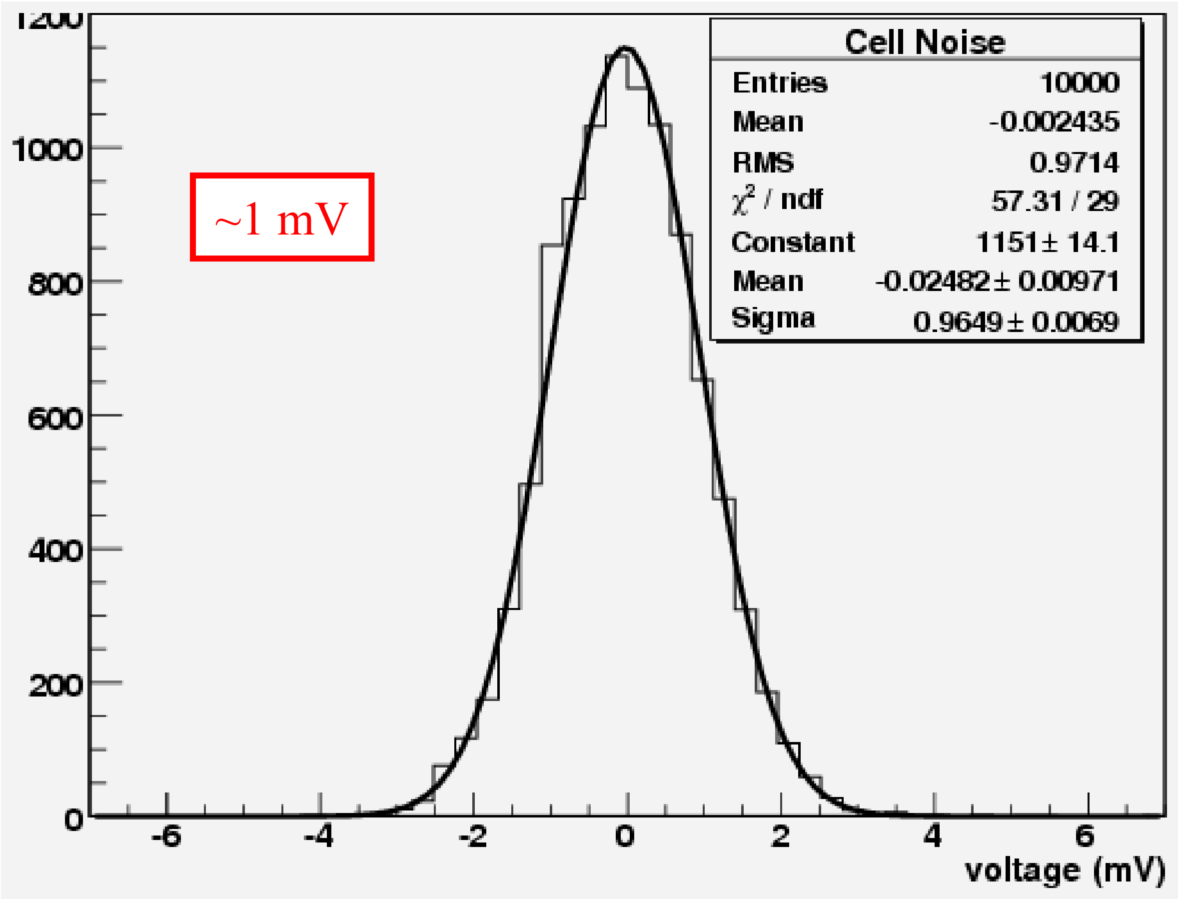


Buffered LABRADOR (BLAB1) ASIC

- 10 real bits of dynamic range, single-shot

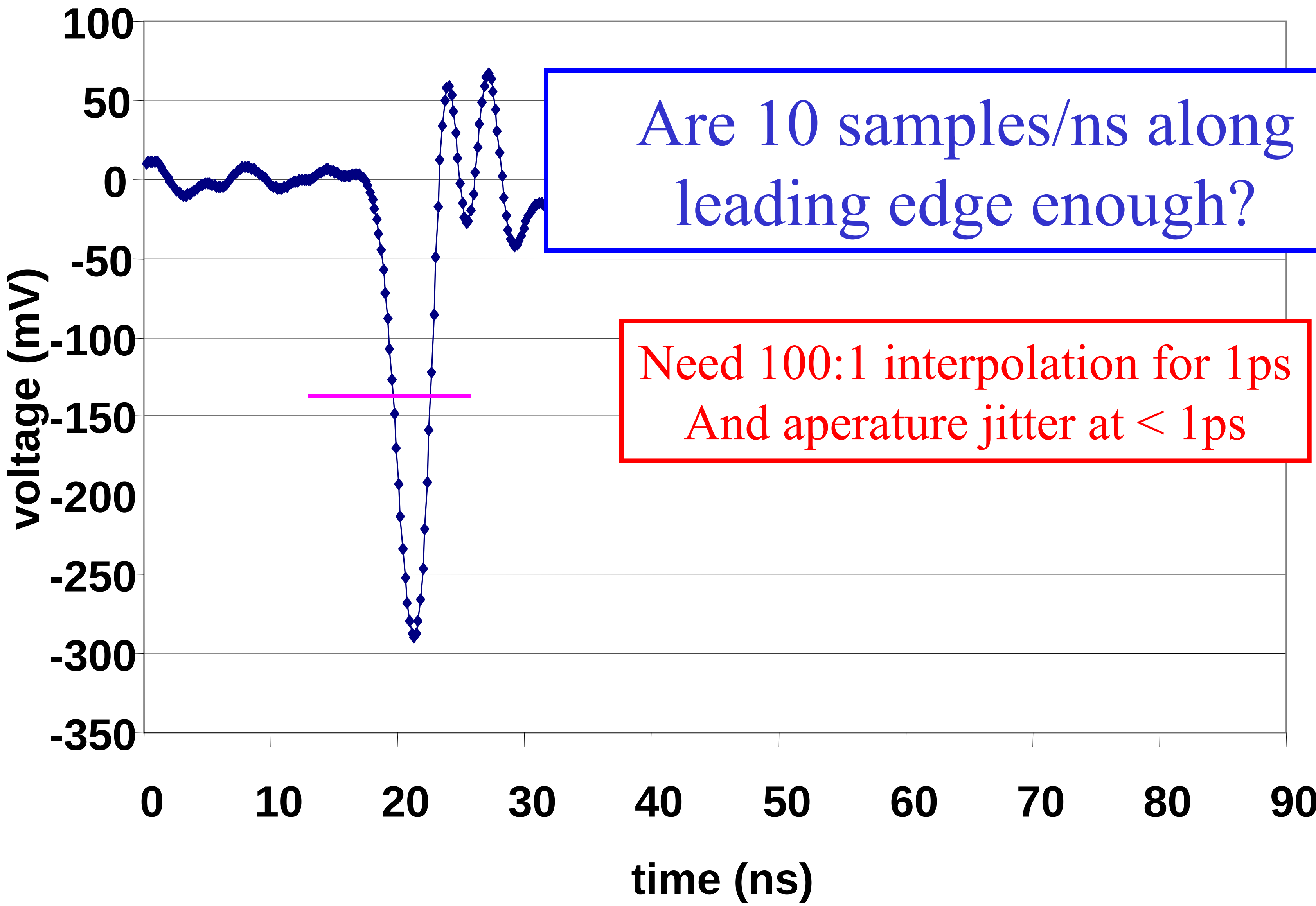
1.6V dynamic range

Measured Noise



Limitations 2a: Interpolation Error

Tied to Bandwidth Issue

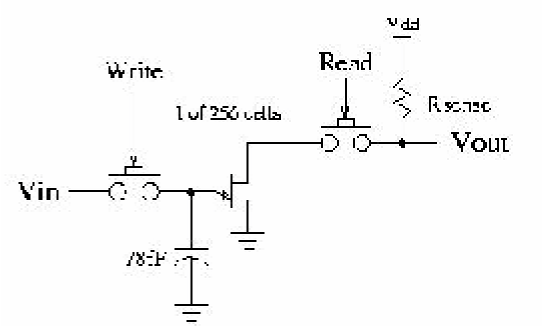


Are 10 samples/ns along leading edge enough?

Need 100:1 interpolation for 1ps
And aperature jitter at < 1ps

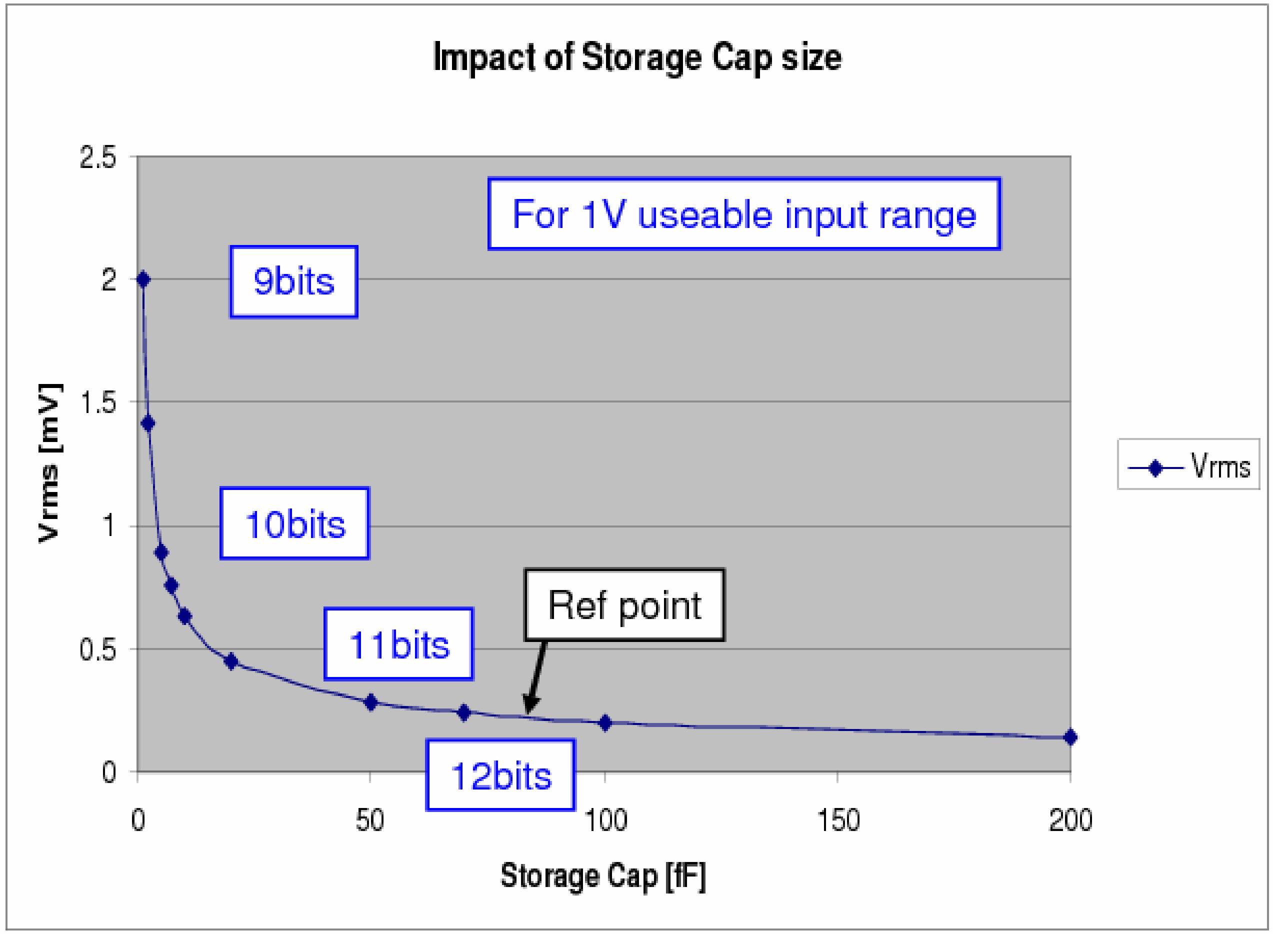
Constraint: kTC Noise

Desire small C for better Input Coupling, cell size



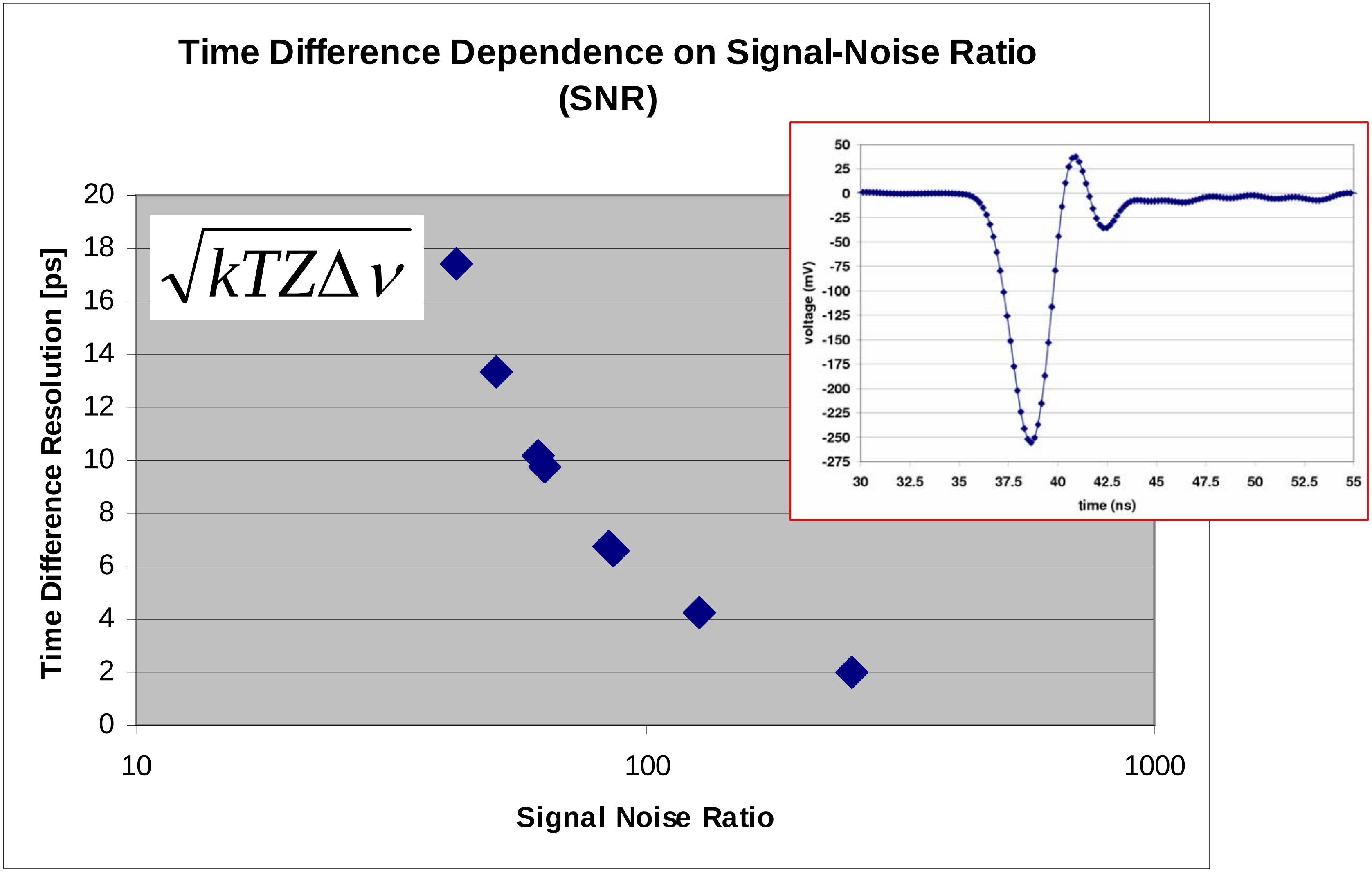
$$v_{rms} = \sqrt{\frac{kT}{C_{store}}} = 0.23mV$$ For 78fF

$C_{store} \sim 14fF$



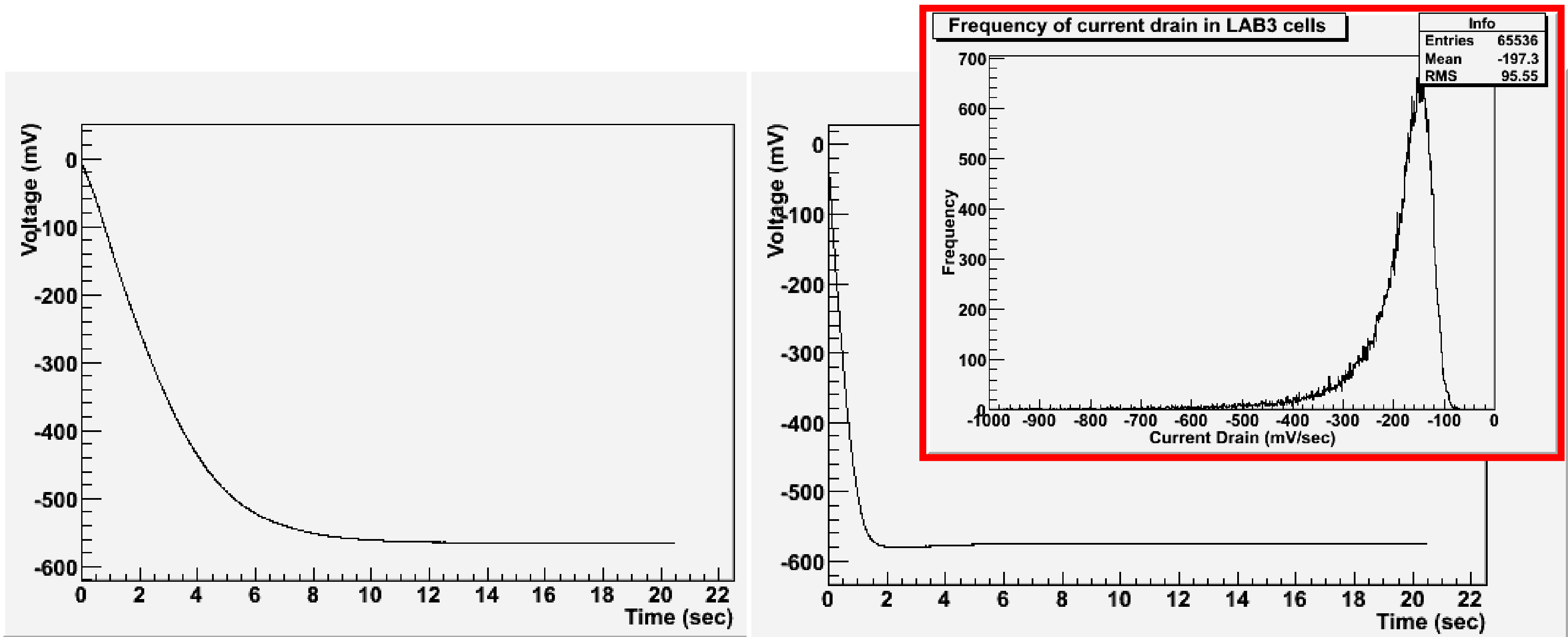
Simulated Performance vs. SNR

300MHz ABW, 5.9GSa/s



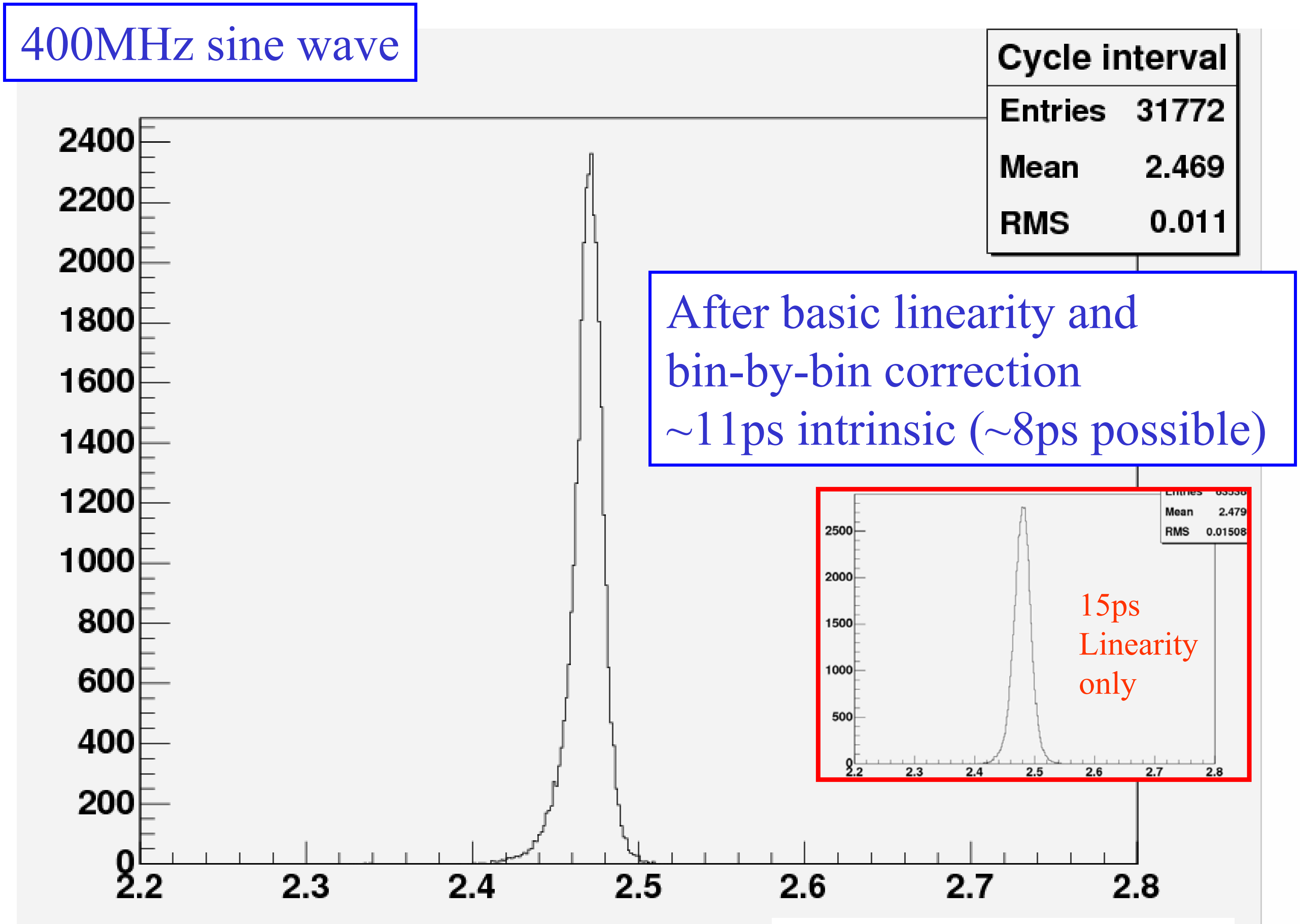
Another Constraint: Leakage Current

Less of an issue for BLAB2;
Smaller window (readout faster) << 1mV

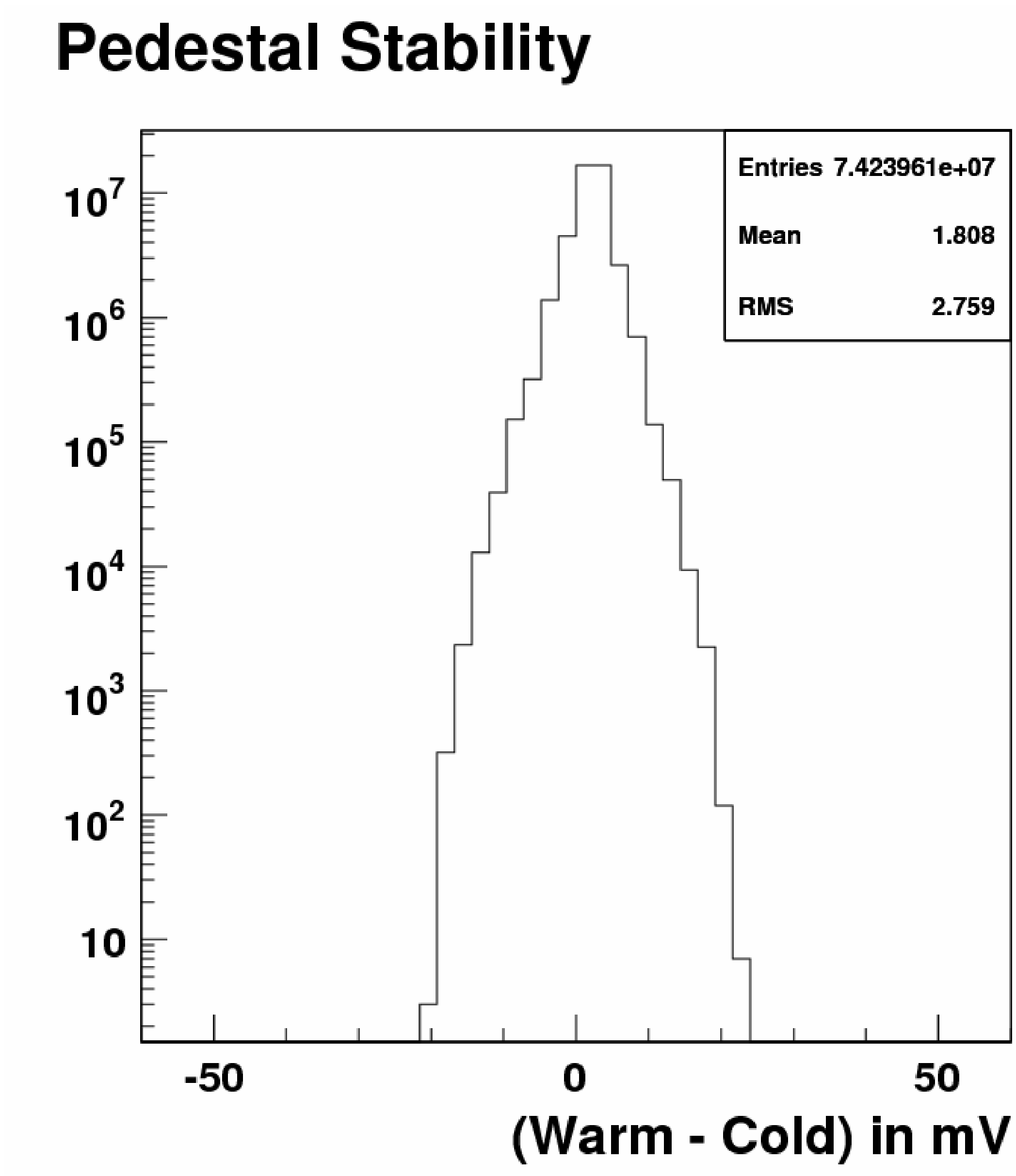


Sample channel-channel variation
~ fA leakage typically

Sine fit zero-crossing residuals



Extracted Period [ns]



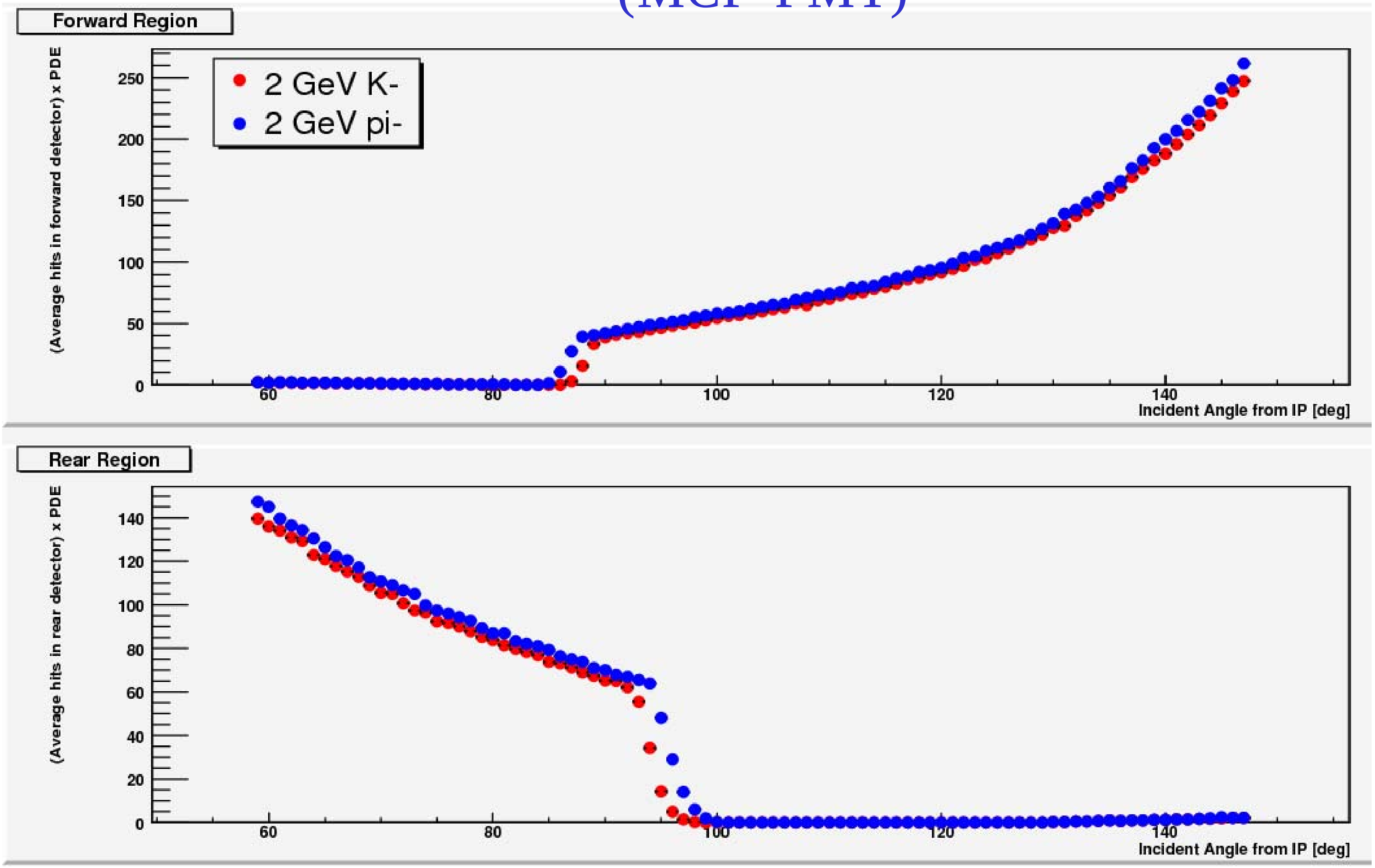
ΔT = 17C (δt ~ 24hours)

~0.052mV/C

Trigger Simulations

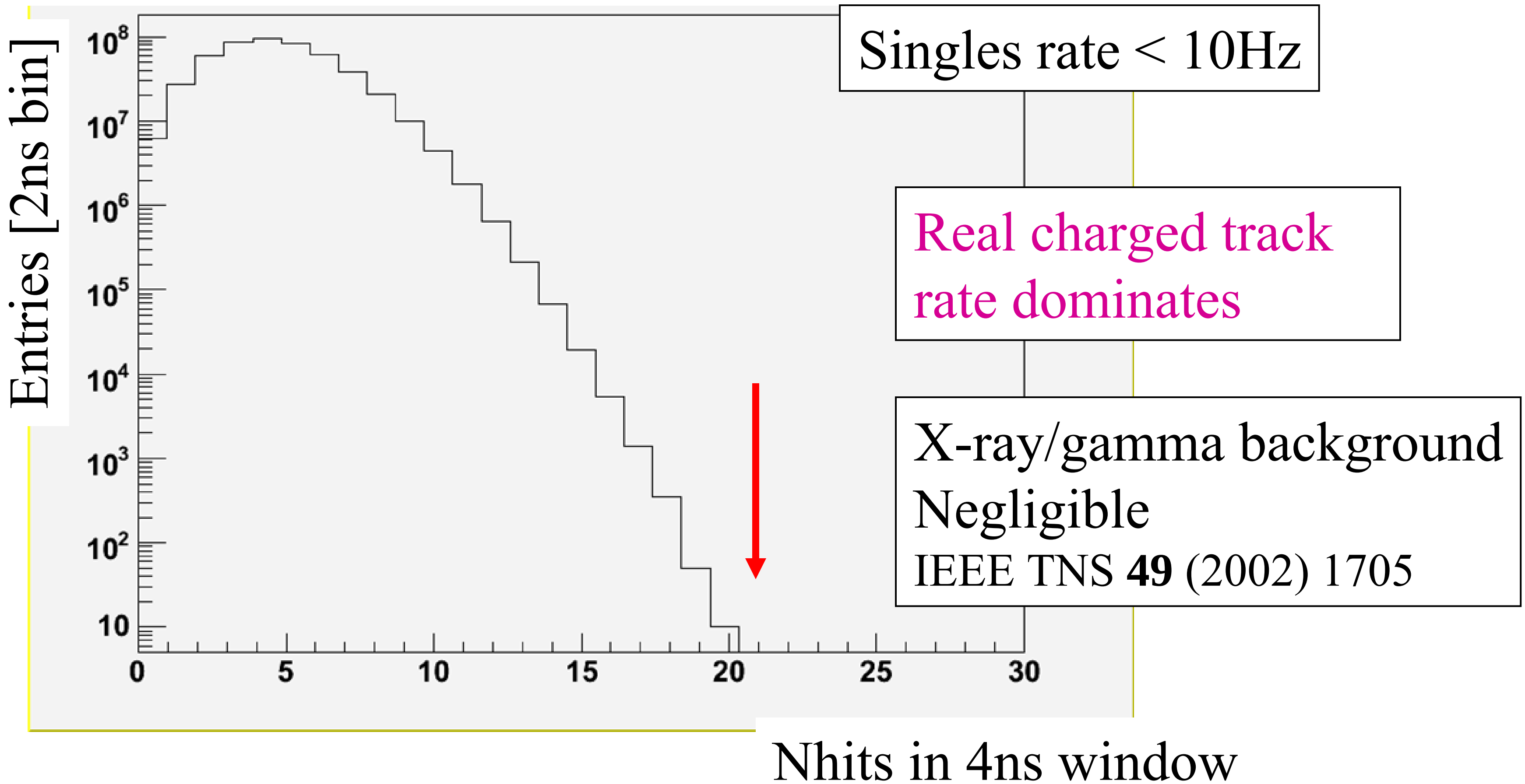
- 50% PDE
  - 350nm UV cutoff
  - Perfect bar

- To be conservative, use much lower threshold in estimates (MCP-PMT)



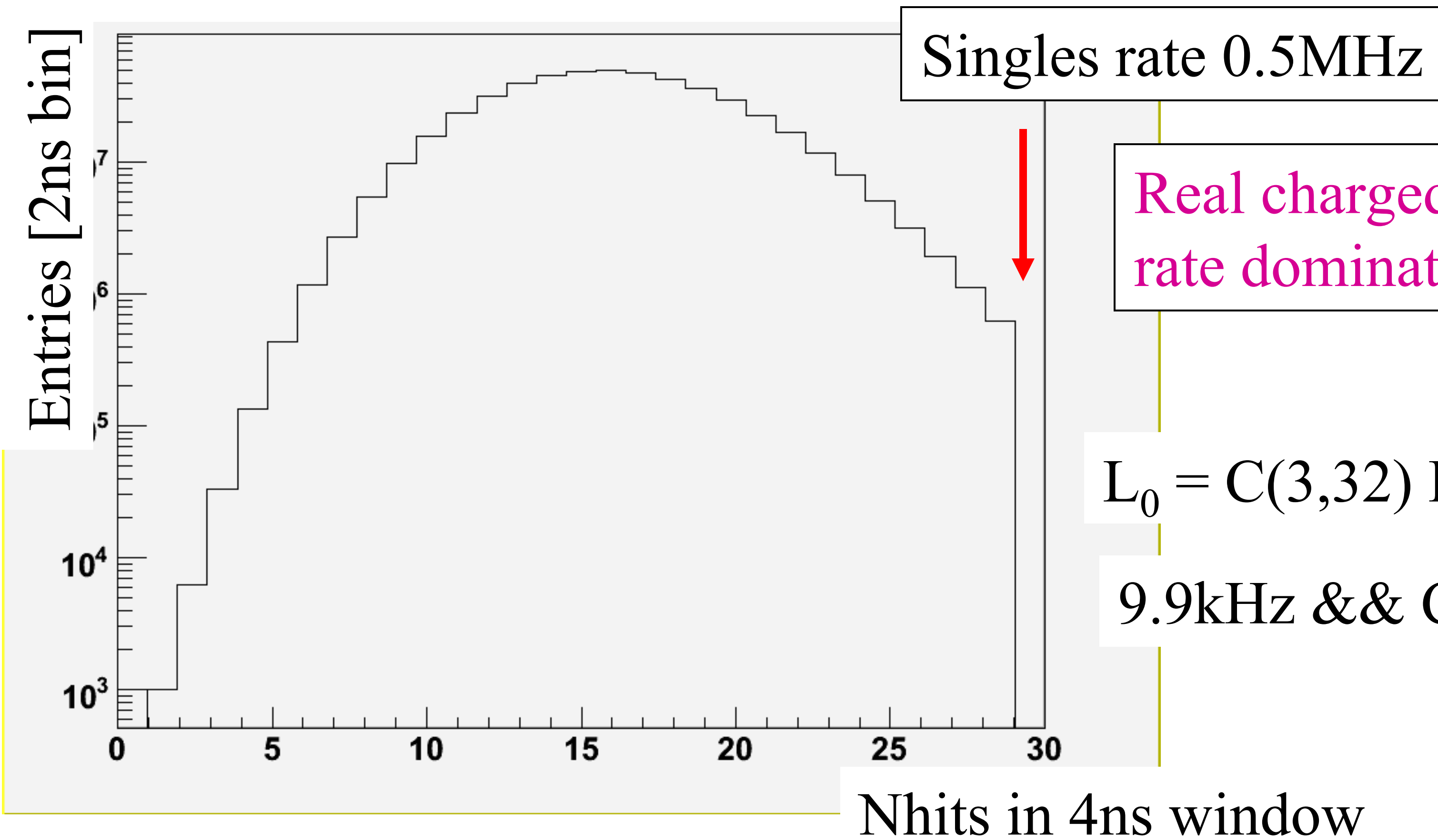
Trigger Simulations

- Assume 50um pixel (MPPC) as reference
  - 270kHz dark count rate
  - 44 x 92 = 4048 pixels/plane (2 planes/bar)
  - If require Nhits >20 (in 4ns window), 2ns pipeline



Trigger Simulations (better TTS)

- Rate can increase
  - 1MHz dark count rate
  - 44 x 92 = 4048 pixels/plane (2 planes/bar)
  - If require Nhits >30 (in 4ns window), 2ns pipeline



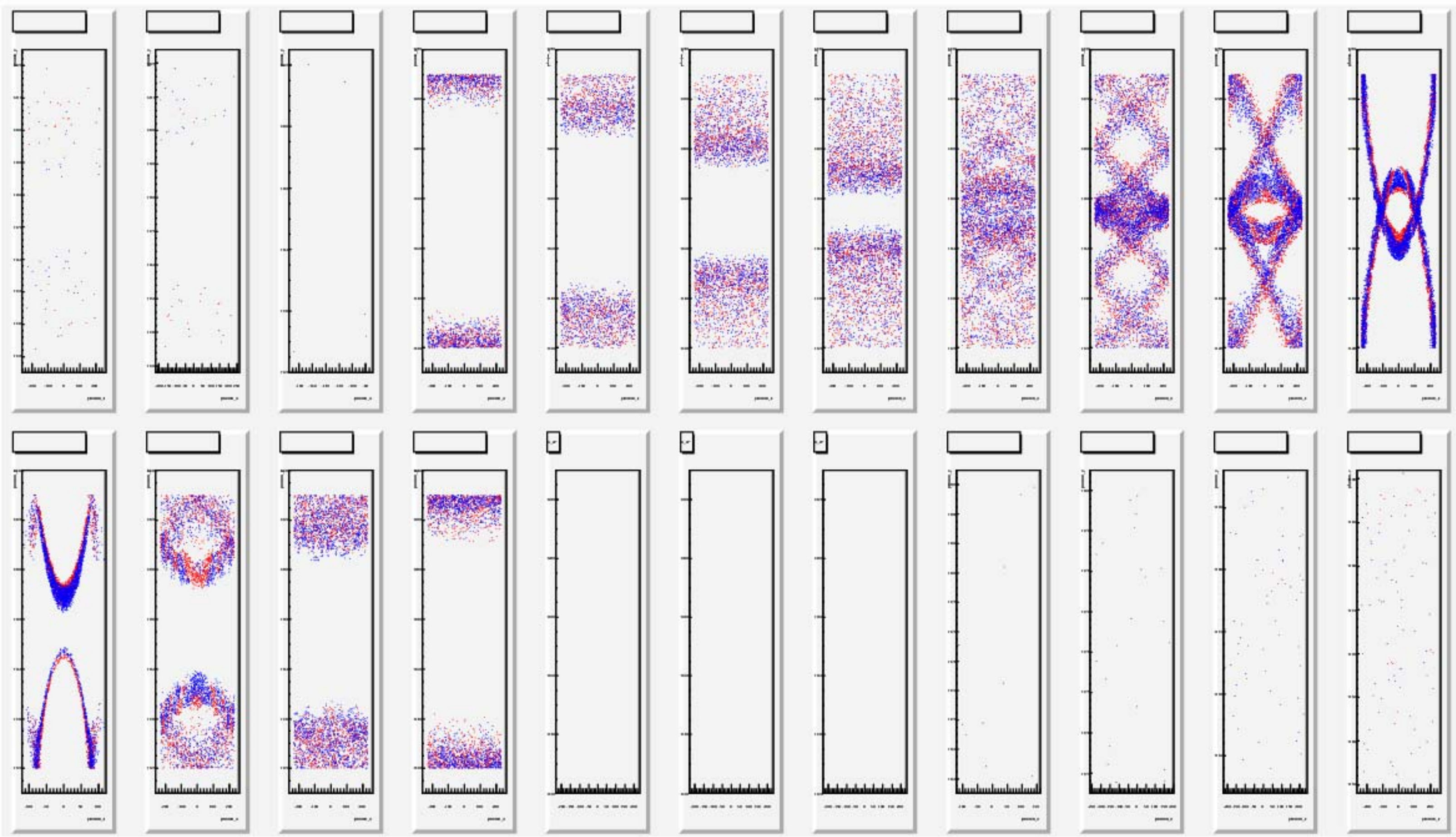
Real charged track rate dominates

$L_0 = C(3,32)\ L_s^3\ \tau^2$

9.9kHz && CDC

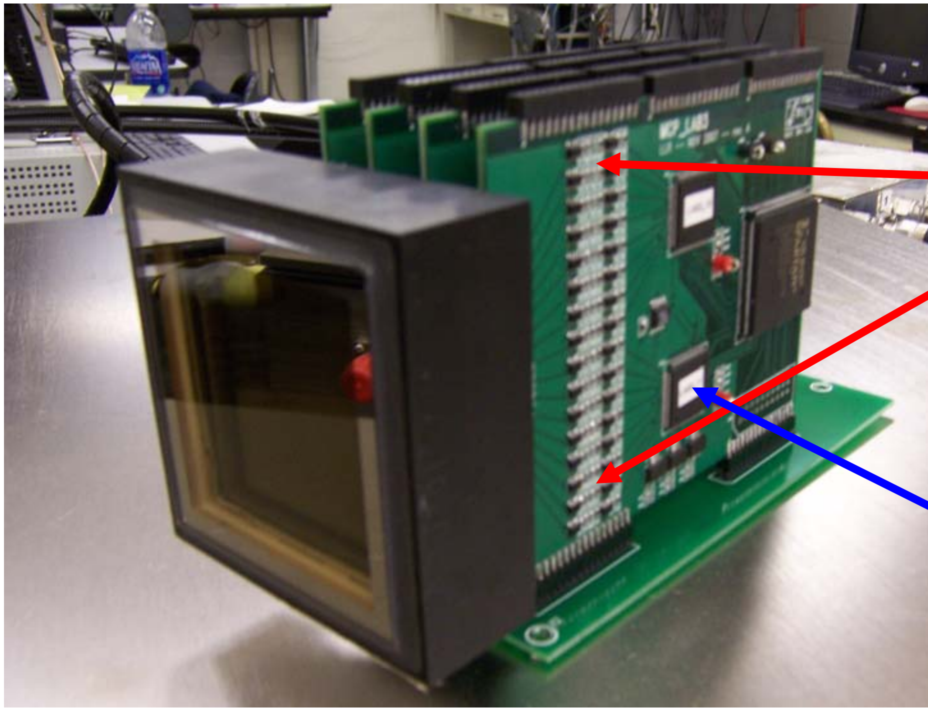
Trigger Timing?

- Use FPGA (simple) pattern recognition to improve



- 25cm segments ~ 2ns trigger timing, within 200ns

Gain Needed ?



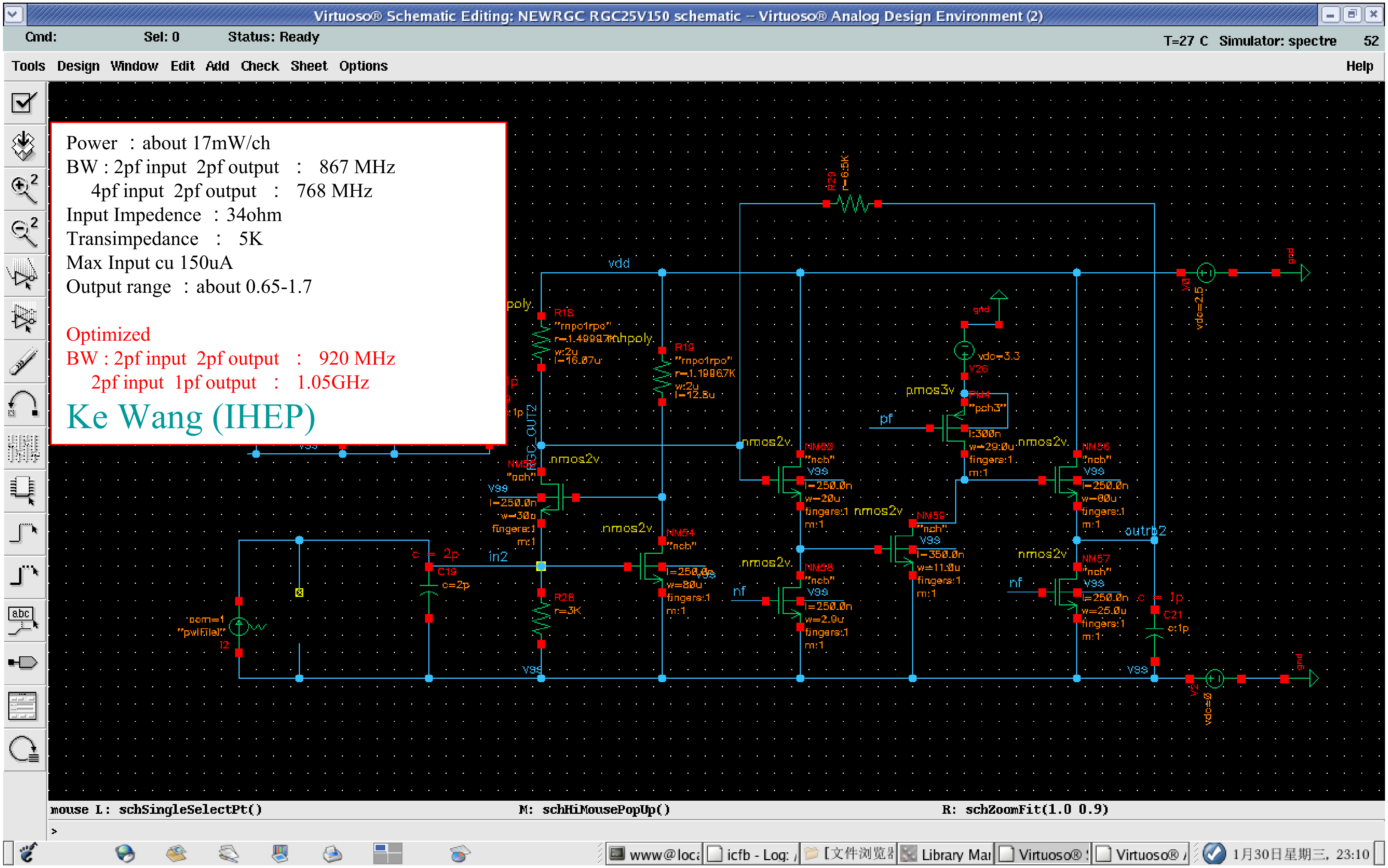
Amplifiers dominate board space

Readout ASIC tiny (14x14mm for 16 channels)

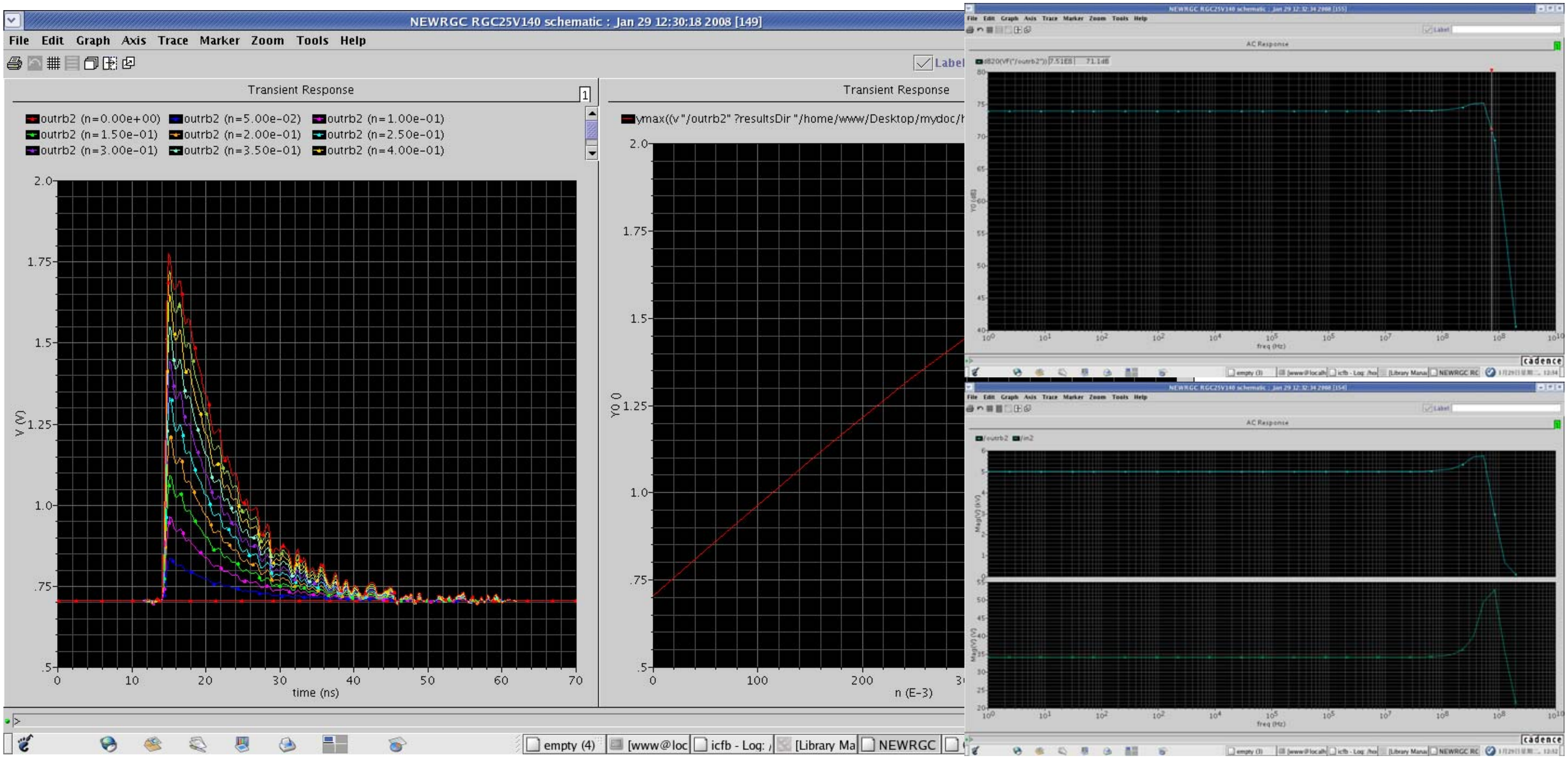
- What gain needed?
  - At 10^6 gain, each p.e. = 160 fC
  - At $2\text{x}10^5$ gain (better for aging), each p.e. = 32 fC
  - In typical ~5ns pulse, Vpeak = dQ/dt * R = 32uA * R = 32mV * R [kΩ] (6.4mV)

Gain Estimate	
Rterm	**1 p.e. peak**
50	1mV
1k	20mV
20k	400mV

RGC_TIA Circuit

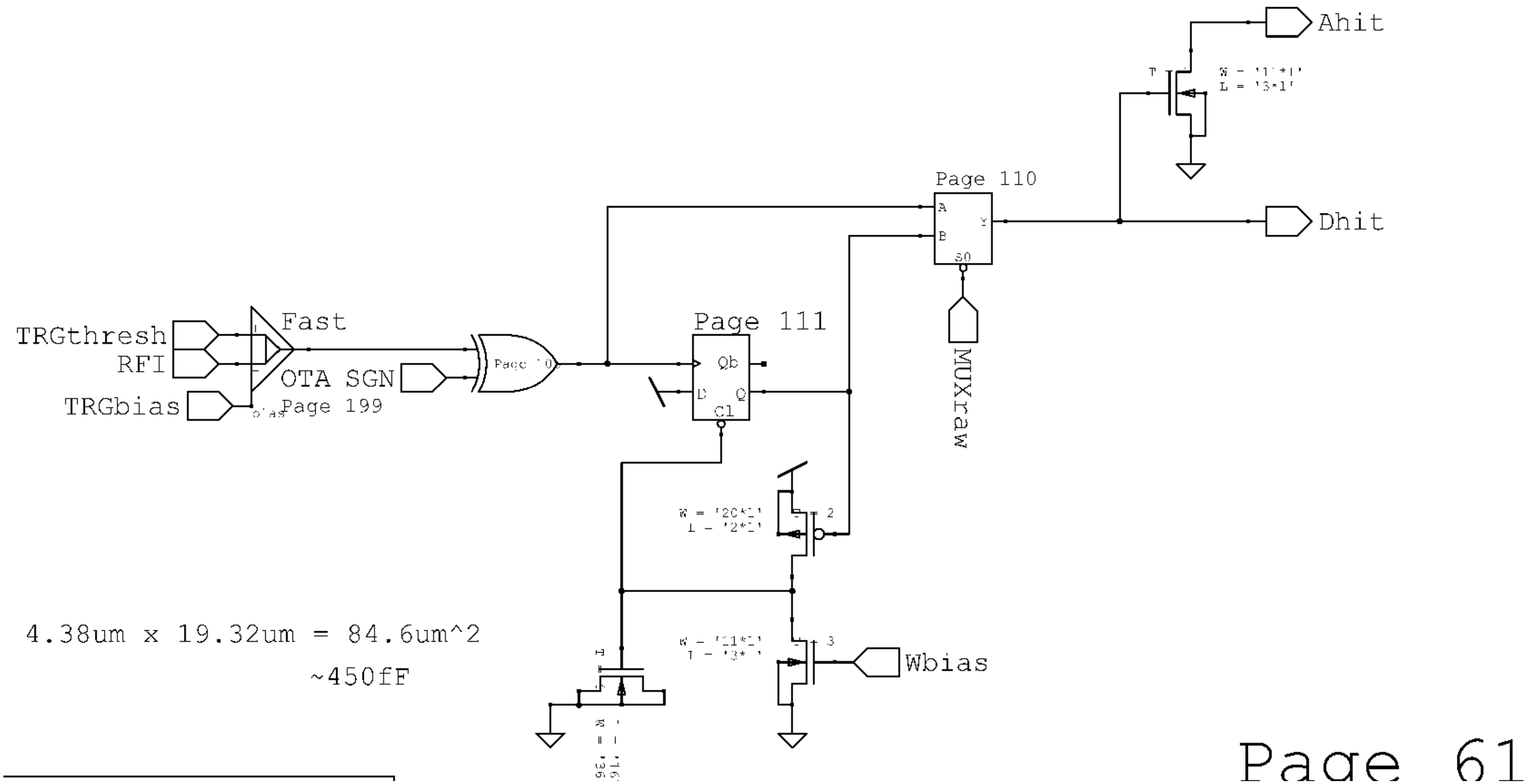


Simulated Performance



- Meets specs on previous slide
- 5k → ~100mV
- Sample noise ~2mV, if match input noise: 13pA/sqrt(Hz)
- SNR is then ~50:1

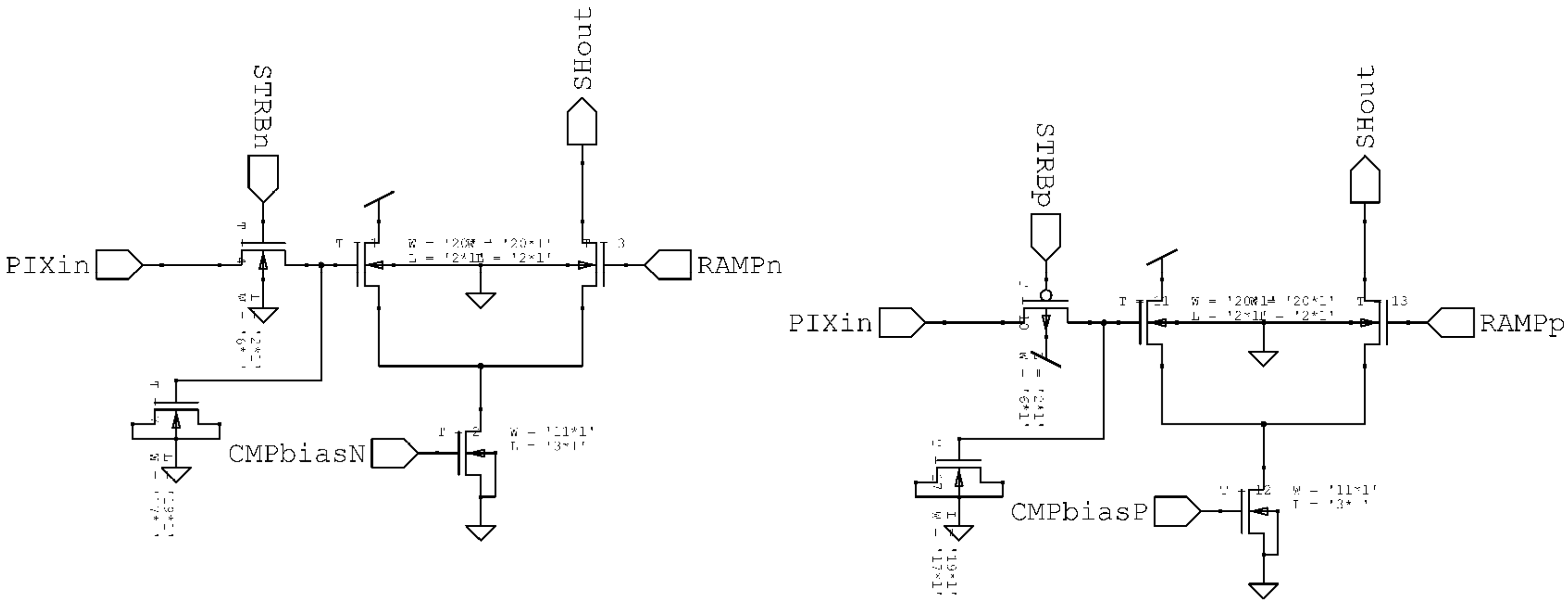
Trigger Logic



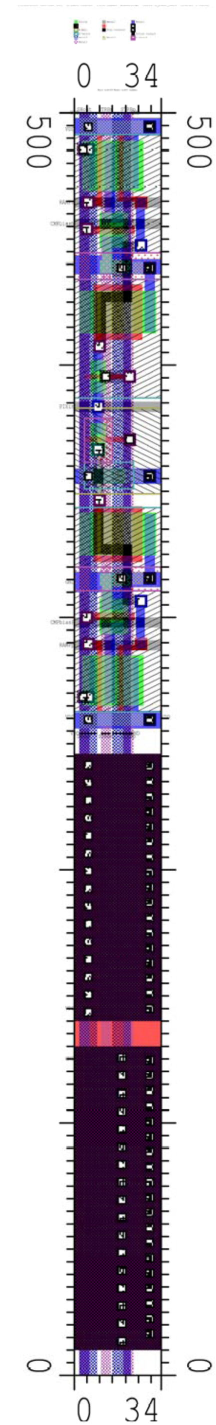
- Analog (Sum of # Ch. ON) & Digital OR output
- 1-Shot or Raw comparator output

Storage Cell

BLAB2 Storage Base Cell (B2_sample_cell)



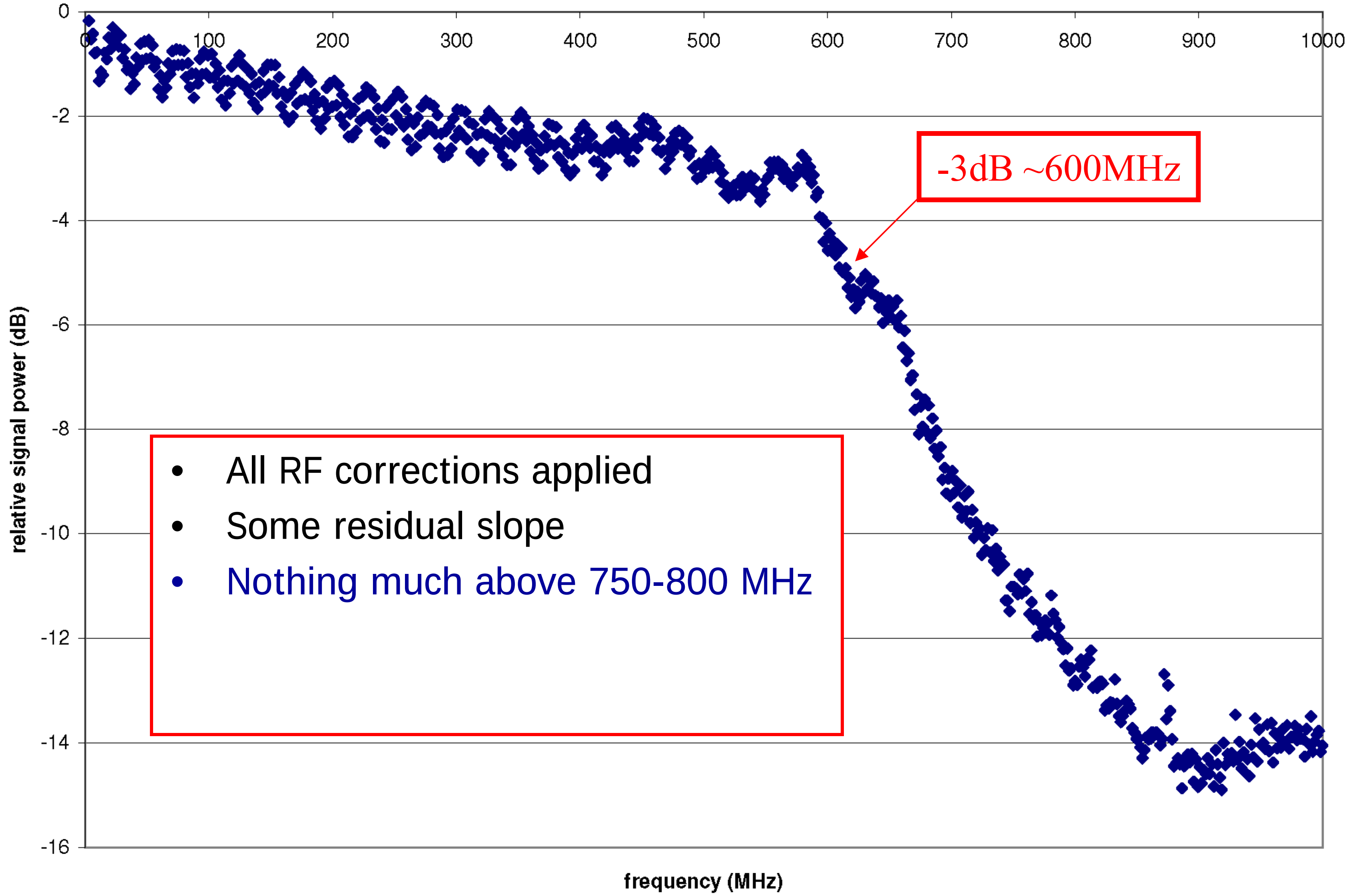
Capacitance = 201 * 21 ~ 5.18 um^2 * ~4.8fF/um^2 =~24.9fF



- Storage Pair configuration
  - n/p sample strobes

60.0μm x 4.1μm

TDS Scope (>1GHz ABW) Measure

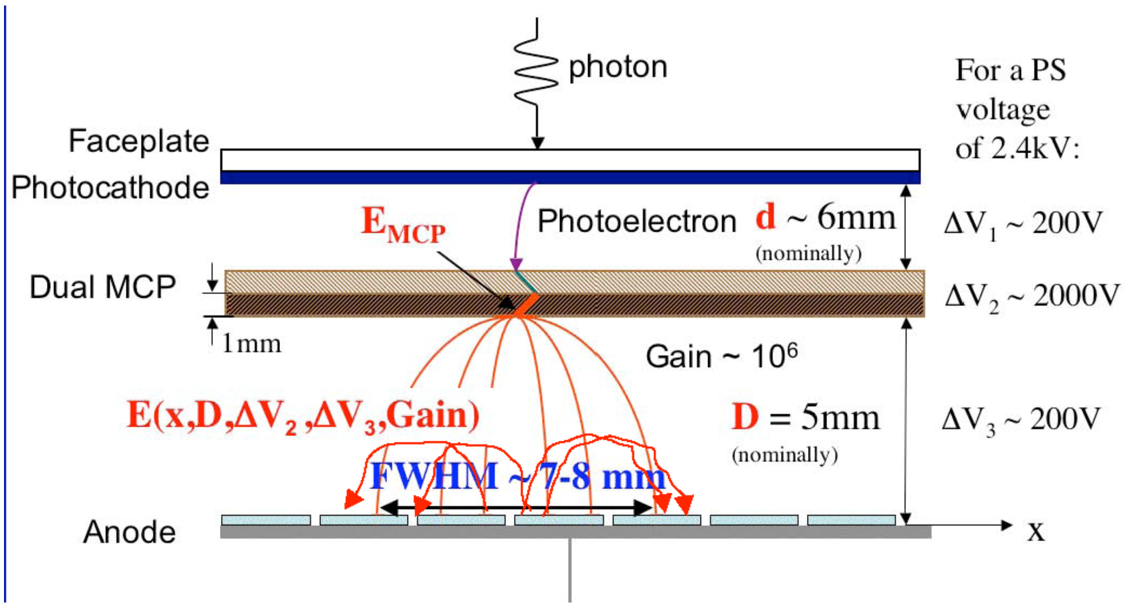


- All RF corrections applied
- Some residual slope
- Nothing much above 750-800 MHz

Limitations 1: Analog Bandwidth

Difficult to couple in Large BW (C is deadly)

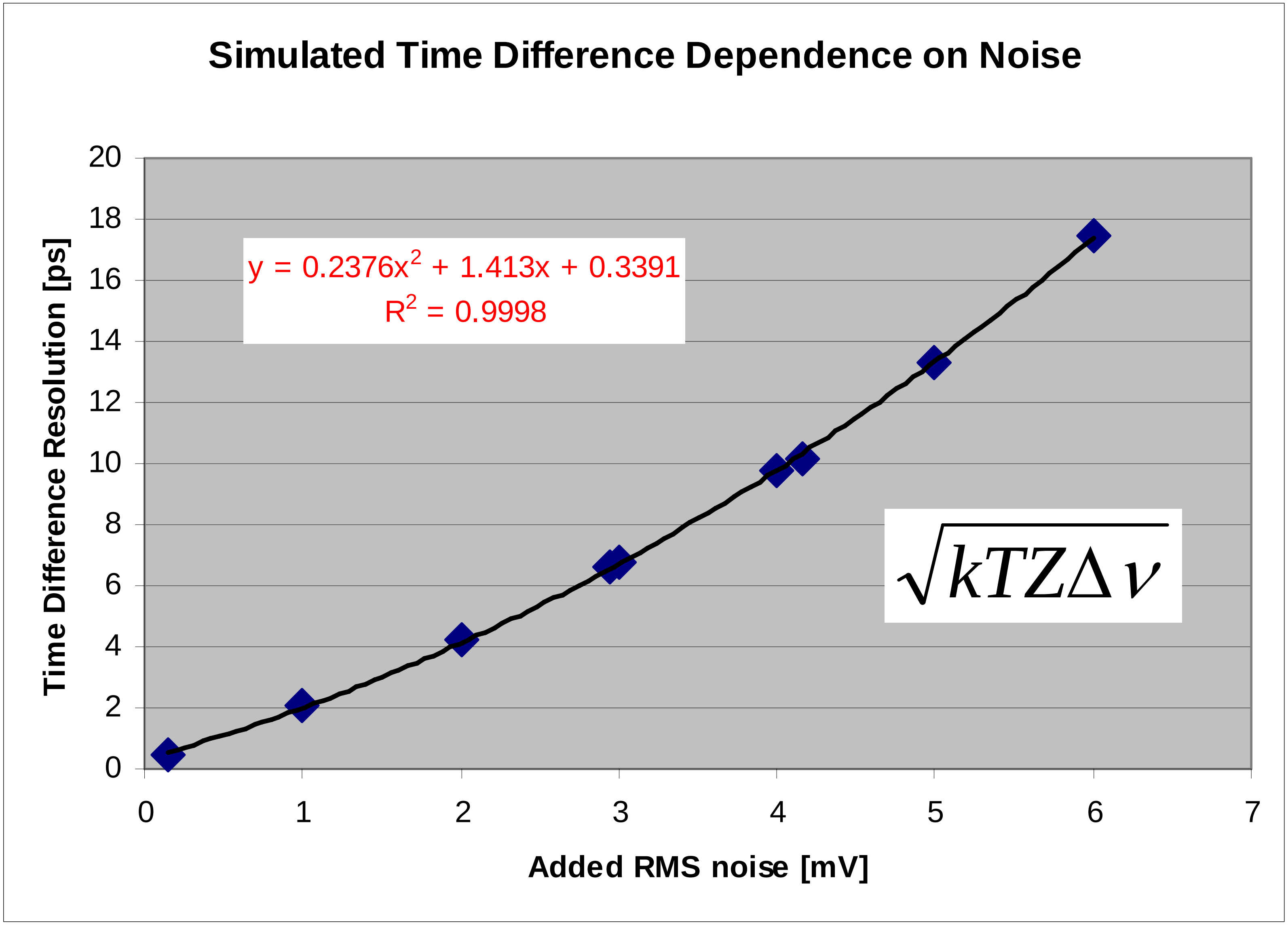
At what point stop getting useful information?



For resolving time << 10ps, Ramo's Theorem important

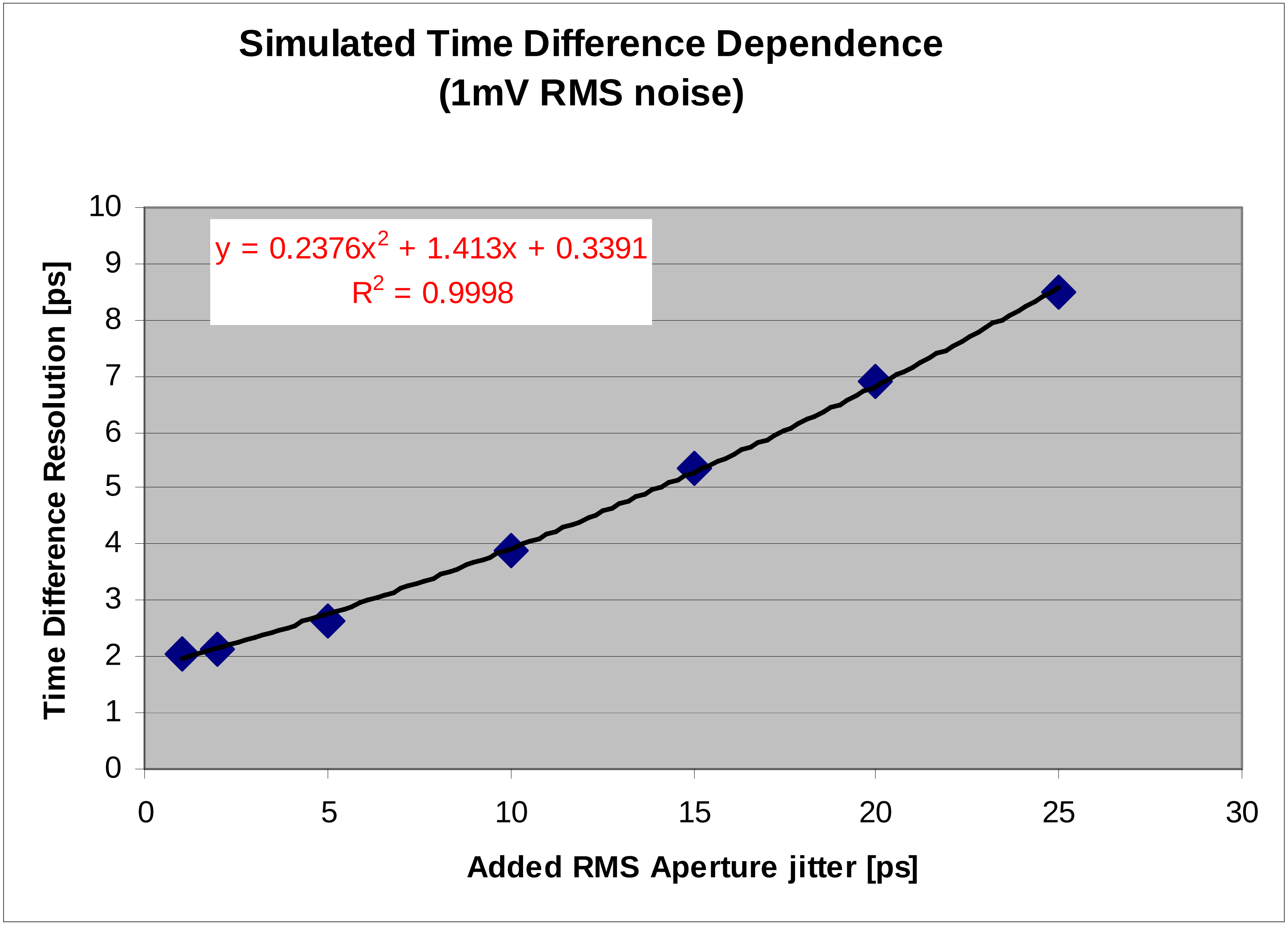
$$f_{3dB} = 1/2\pi ZC$$

Performance versus Random Noise



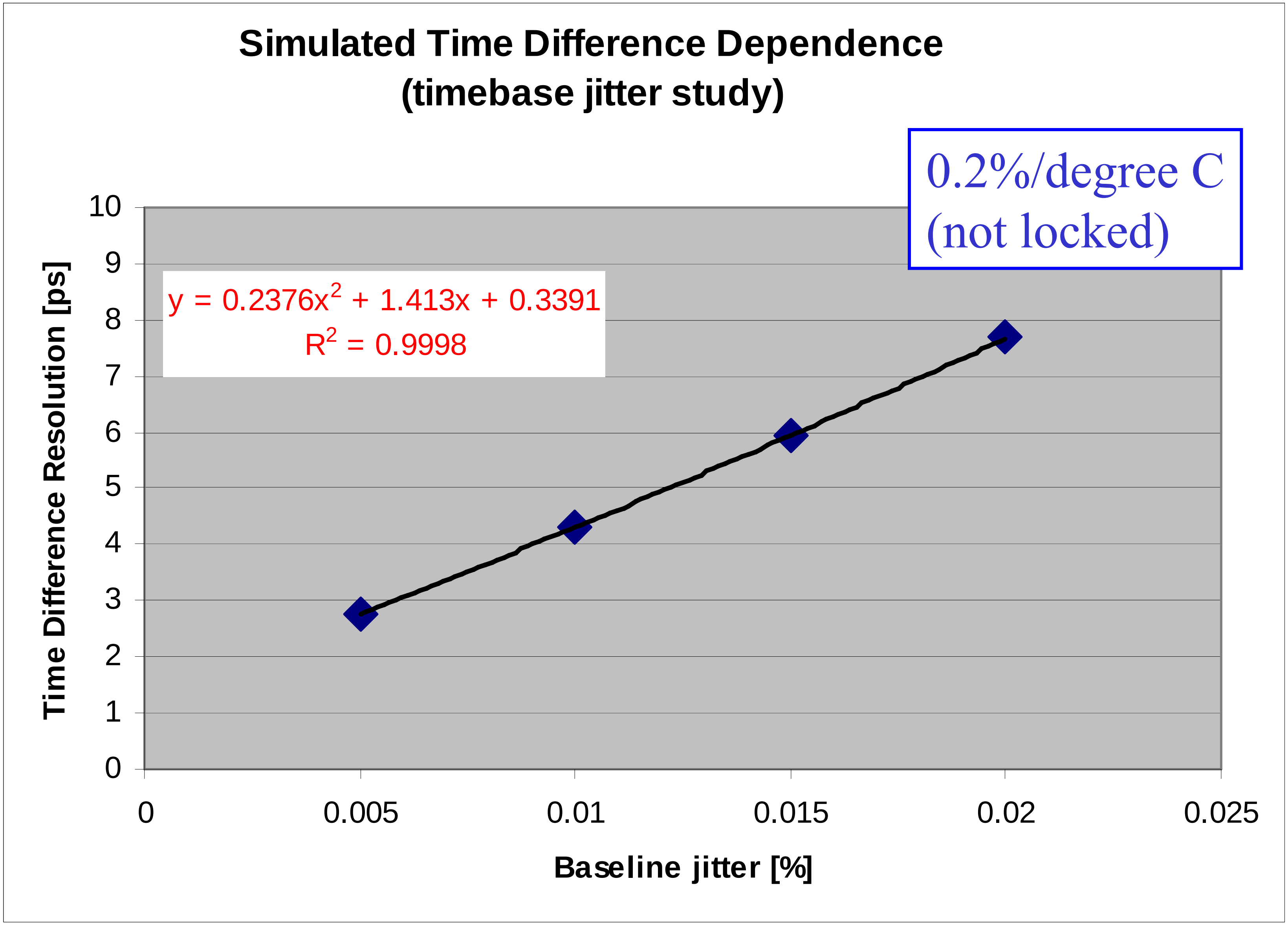
Performance versus Aperture jitter

5.9GSa/s



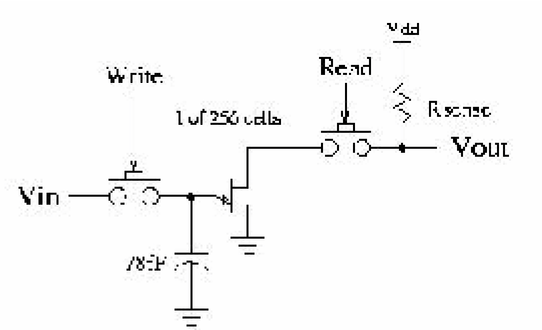
Performance versus Baseline jitter

5.9GSa/s



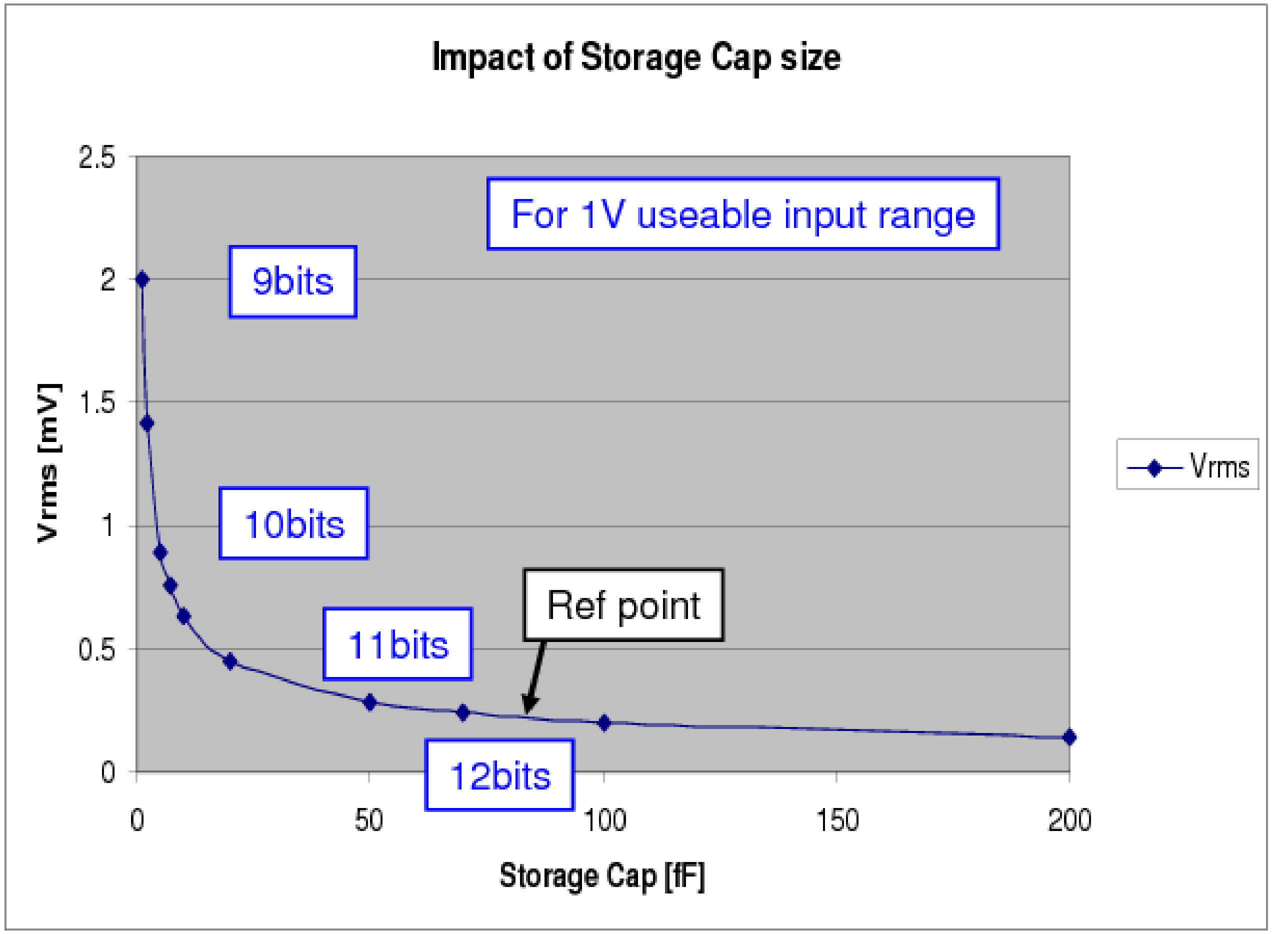
Limitations 2b: kTC Noise

Need small C for Input Coupling



$$v_{rms} = \sqrt{\frac{kT}{C_{store}}} = 0.23mV$$

>25pF ?

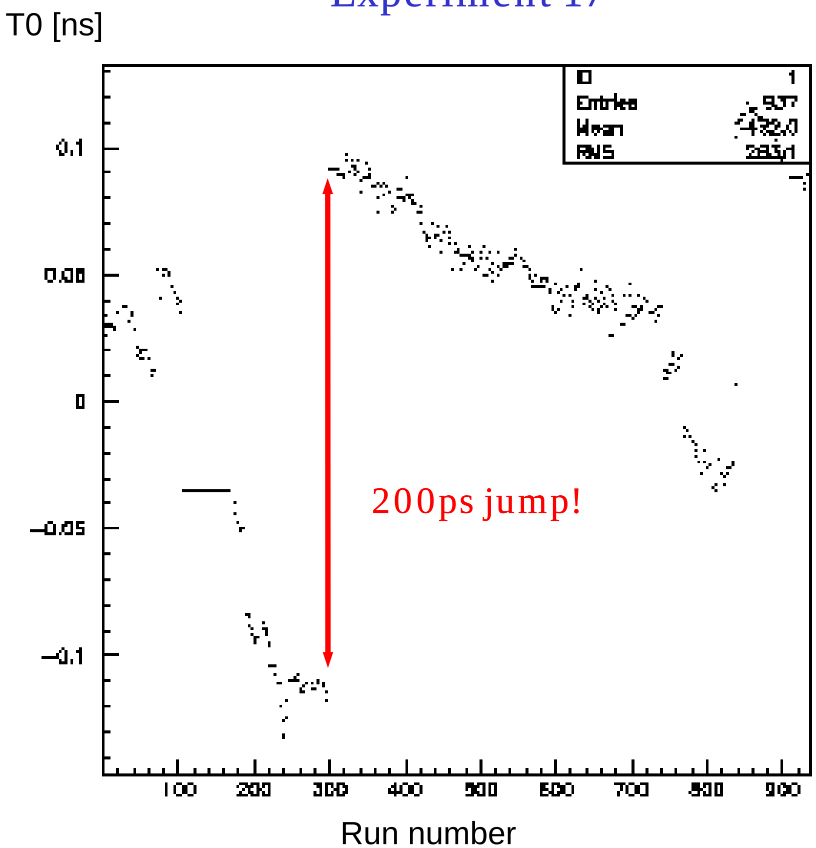


Limitations 3: Systematic Errors

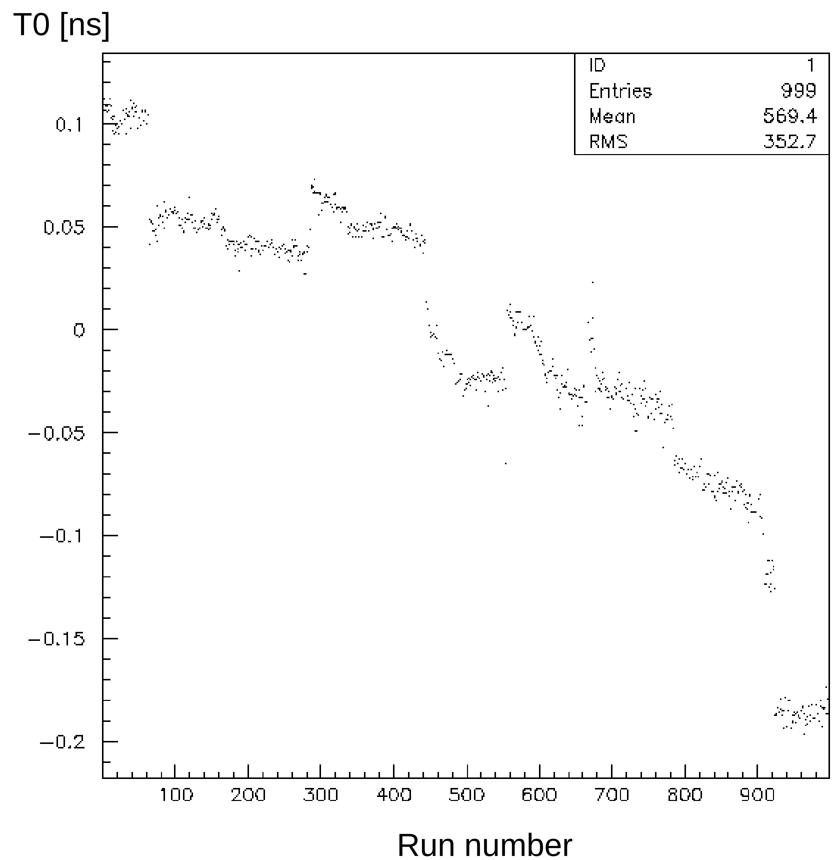
Experience with running Belle TOF System for ~ a decade

Any jitter/shift/jump in reference time is fatal? (differential measurements)

Experiment 17



Experiment 19



- Run-by-run T_0

Limitations 4: Leakage Current

Need small C for Input Coupling

Shouldn't forget about, especially after radiation damage