PID electronics

J. Va'vra, SLAC

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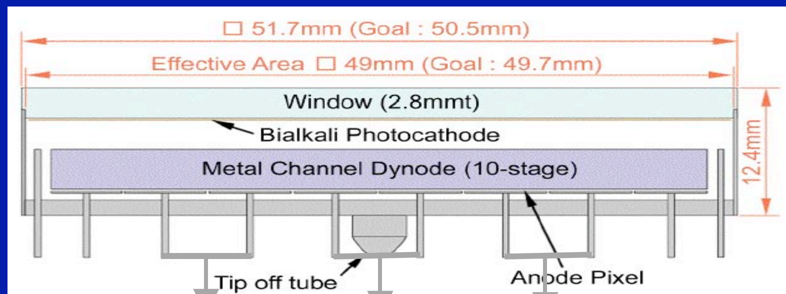
- **Expected DIRC electronics**
  - Detector choice
  - Possible electronics design concept
  - Test results
- **Forward PID electronics**
  - Detector choices: TOF or FARRICH
  - Possible electronics design concept
  - Test results (from TOF tests only)
- **Expected DIRC pixel rates at Super-B**
- **Expected DAQ performance**

DIRC electronics

Proposed DIRC electronics chain

H-8500

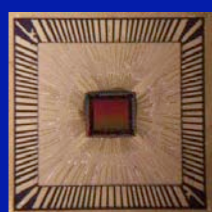
MaPMT:

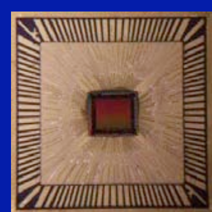


Tube has 64 pixels, but plan to **<u>short 2 pads together</u>** => 32 macro-pixe

32 Amplifiers/MaPMT,
Amp. gain ~50 -100x, BW < 0.5 GHz

BLAB ASIC





Waveform sampling electronics:
2 BLAB2 chips / MaPMT,
2000 BLAB2 chips / system
Wafeform sampling rate: ~ 2-5 GSa/s
Timing resolution goal:

$\sigma_{electronics}$ **~ 50-100 ps**

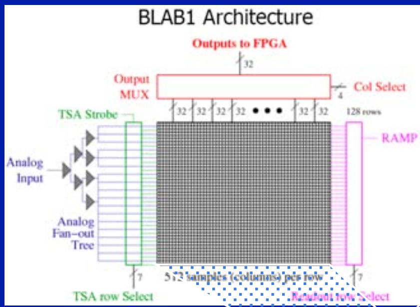
σ_{final} **~ 150-200 ps**

FPGA array

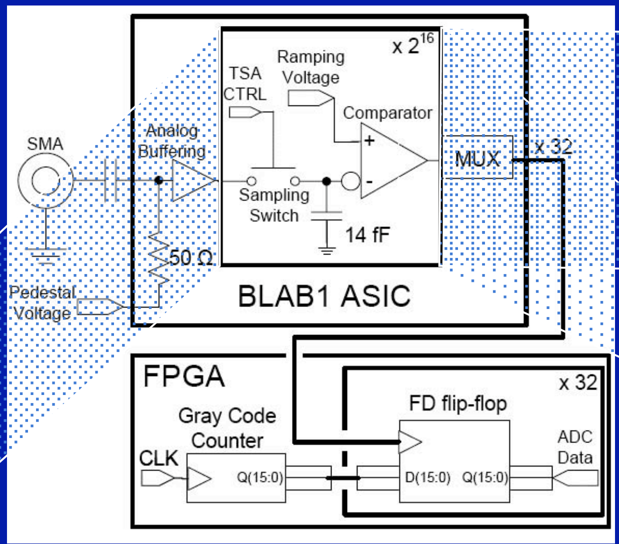
Sensitive to a neutron background

Waveform sampling principle: Switched Capacitor Array

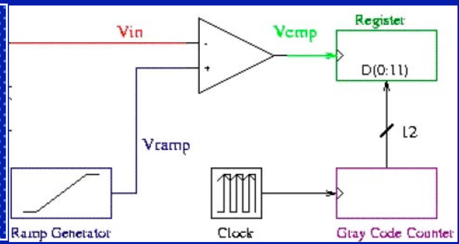
G. Varner, Larry Ruckmann and A. Wong, arXiv:0802.2278v1 [physics.ins-det], submitted to NIM, 2008



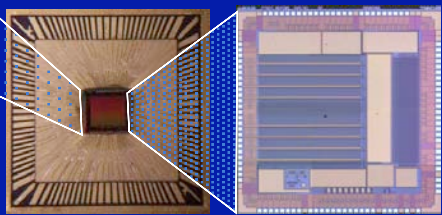
Capacitor array:



Wilkinson ADC:



BLAB1/BLAB2 ASIC:



Principle of wafeform sampling in BLAB chip:

- Fast signal waveform is terminated in 50 Ω on the chip
- BLAB1: 1ch & 128 rows & 512 samples (64k storage cells); BLAB2: 17ch & 6 rows & 1024 samples (102k storage cells)
- Each row can be independently addressed to initiate a storage cycle
- When analog switch is closed the instantaneous signal is stored on a 14 fF capacitor
- ADC conversion is done via the Wilkinson method:
  Comparators done inside BLAB chip & high speed encoding done in FPGA
  32 samples are converted in parallel
- 10-bits corresponds to a conversion time of 1 μs in the current scheme.
- Up to 10 GSa/s (100ps sampling interval <=> ~5 samples on the leading edge).
- 12 μs latency: (a) TOF: self-trigger and digital temporary storage
  (b) FDIRC: analog storage

Both BLAB chips are still prototypes, no final storage configuration implemented yet !

Notes:
1. BLAB2 chip will be submitted to foundry by June 2.
2. Improvemnts over BLAB1:
   a) a larger sampling depth
   b) 2x sampling rate
   c) improved BW
   d) triggering, etc.

Summary of BLAB2 ASIC parameters

G. Varner

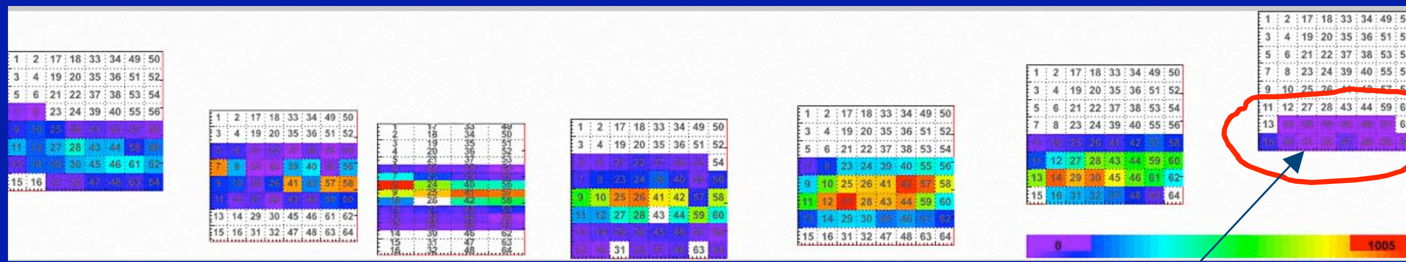
Parameter	Value
Samples	6 rows & 1024 samples
Triggering mode	Trigger on individual pixel
Analog BW	~ 0.85 GHz
BLAB2 chip input impedance	30-80 Ω (adjustable)
Number of MaPMT pixels / BLAB2 ASIC	16
Number of BLAB2 ASICS / MaPMT (final vs. prototype)	2 - 4
Dynamic range	1mV / 1V
Cross-talk	< 0.1%
BLAB2 wafeform sampling speed	1 - 10 GSa/sec
On chip ADC	1 GHz Wilkinson
Number of Wilkinson conversions in parallel	32
ADC resolution	10 bits
ADC conversion time for 10 bits	1 μs
Number of words / event	32 - 512
Read time for 16 channels (1 BLAB2 chip) / event	16 μs
Sustained readout speed	50 kHz
12 μs latency accomplished by	Self-trigger & analog or digital storage
Cost per chanel	< $10 in volume

Test results

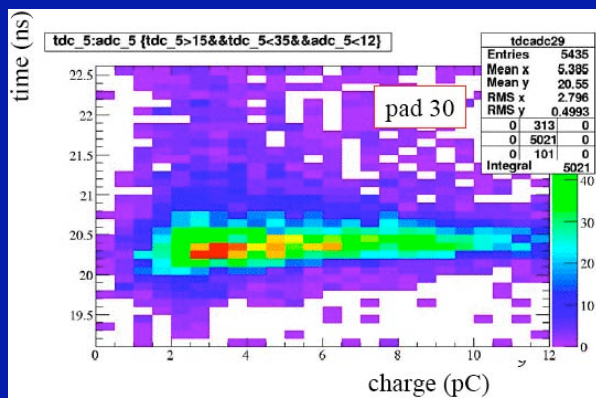
BLAB1 electronics in the FDIRC prototype beam test at SLAC

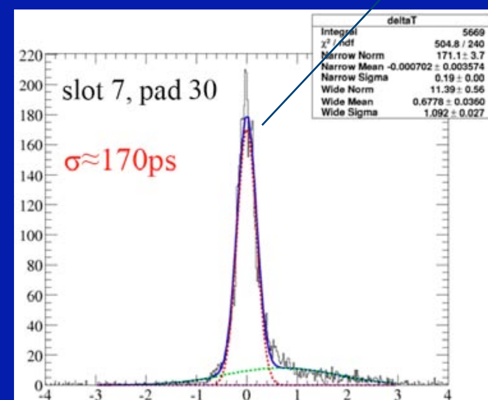
Electronics by Gary Varner & Larry Ruckman & data analysis by Joe Schwiening

FDIRC prototype Cherenkov ring:



Waveform sampling performance:



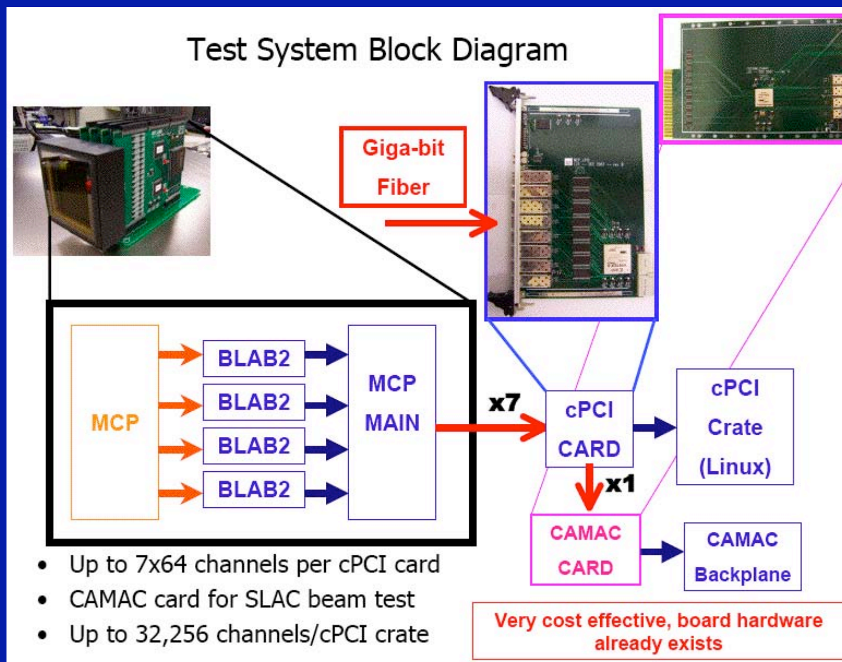


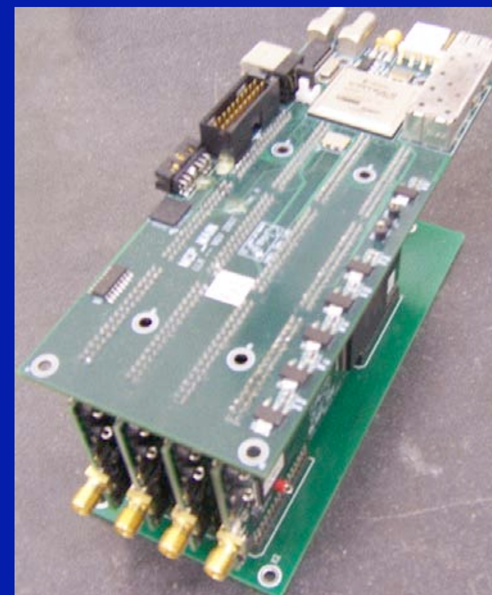
$\Delta t = \text{time}_{\text{measured}} - \text{time}_{\text{expected}}$ [ns]

- Use Minicircuit VAM-6 preamplifier with a 43dB gain, ~6 GSa/s waveform sampling
- 16 channels instrumented (one BLAB1 chip) on one Burle/Photonis MCP-PMT.
- The new electronics performed very well; better than our CFD-based electronics
- Very small time dependence on pulse height observed.

BLAB2 lectronics for the next beam or cosmic ray tests at SLAC

Gary Varner & Larry Ruckman





- Prototype boards with BLAB1 chip now exists; BLAB2 chip is almost ready and will be sumbitted to a foundry on June 2.
- To instrument all 64 pixels one needs 4 BLAB chips. That is what we want to have in the prototype in the fall. However, the final DIRC will very likely use 2 chips per MaPMT (2 pads ganged together, 32 pixels/MaPMT).
- Worry about a minituarization later.

Forward PID electronics

Various timing schemes for TOF

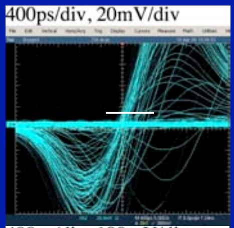
Timing strategies for TOF detector

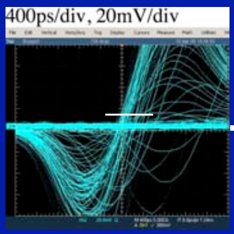
1) High detector gain operation:

- **Either <u>no</u> amplifier, or a small amplification only:**
  - One would expect much worse aging effects due to a high gain operation.
- **Single pe- sensitivity (with an amplifier):**
  - In addition to the above comment, a very poor pulse recovery

2) Low detector gain, linear operation:

- **Constant-fraction-discriminator (CFD).**
- **CFD + additional pulse height correction.**
  - A slight time-walk as number of photoelectrons corrected by the QTNT + ADC
- **Waveform sampling (a'la Gary Varner's design from U. of Hawaii).**
  - The most powerful timing method.
- **Double-threshold timing on both leading and trailing edges.**
- **Single threshold on both leading and trailing edges.**
  - The most simple.





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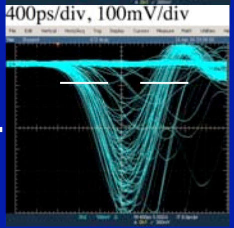
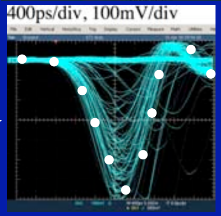
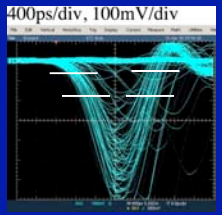
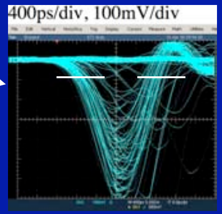


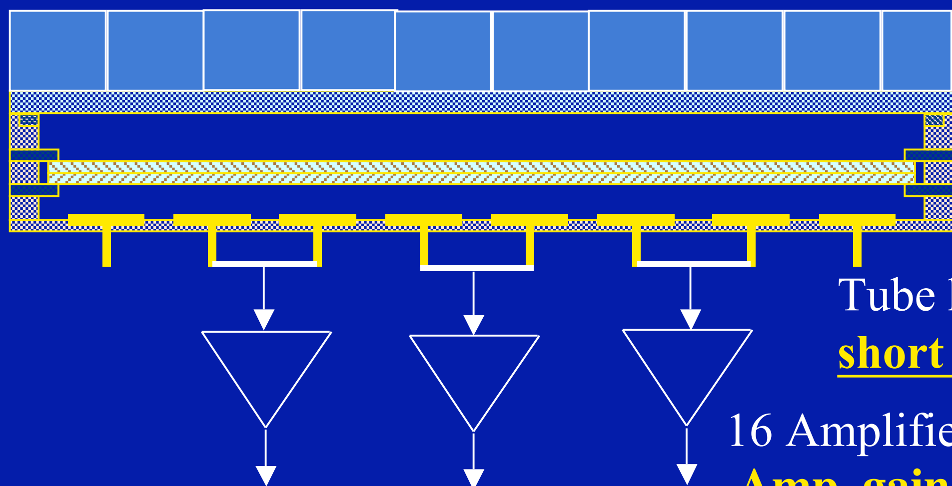


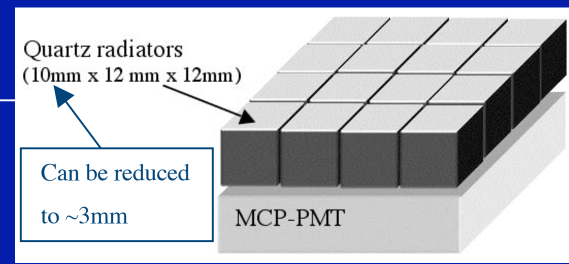




Example of TOF electronics for MCP-PMT

Photonis MCP-PMT:





Tube has 64 pixels, but we plan to **short 4 pads together** => 16 macro-pixels

16 Amplifiers/MCP-PMT , Amp. in ASIC, **Amp. gain ~10x**, BW ~ 1 GHz

BLAB ASIC

FPGA array

Waveform sampling electronics:

Single BLAB2 chip / MCP-PMT,

1000 chips / system

Wafeform sampling rate: ~ 5-10 GSa/s

Timing resolution goal:

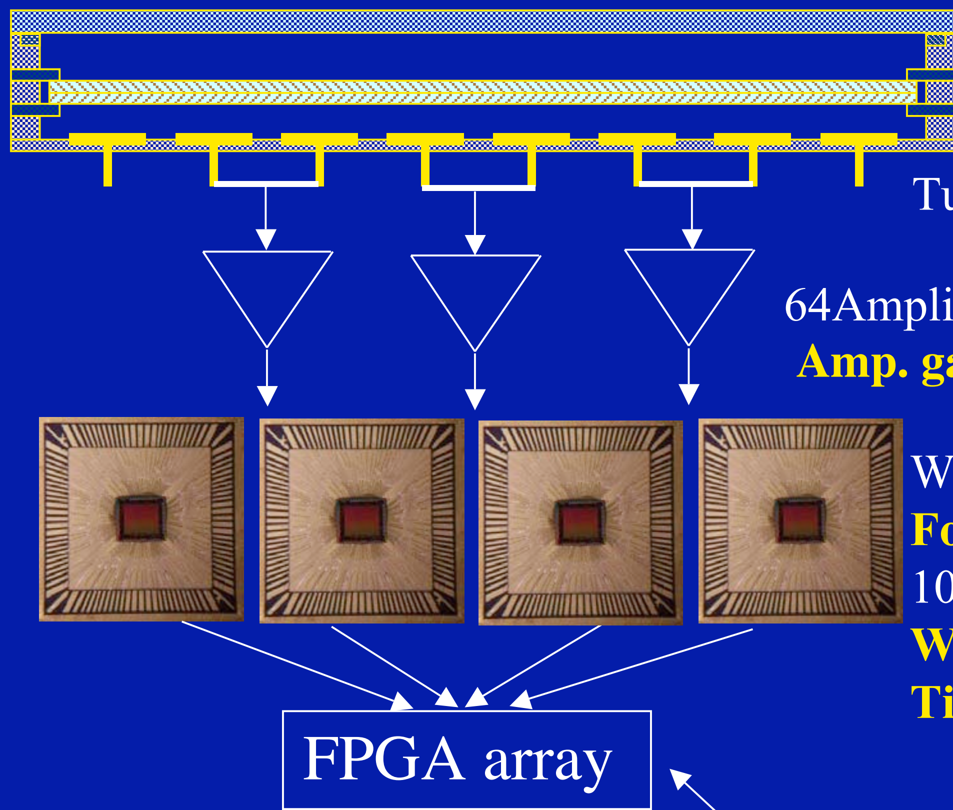
$\sigma_{electronics}$ **~ 5-10 ps**

σ_{final} **~ 20 ps**

Sensitive to a neutron background

Example of FARRICH electronics for MCP-PMT

Photonis
MCP-PMT:



Tube has 64 pixels

64Amplifiers/MCP-PMT ,
Amp. gain ~100x, BW ~ 0.5 GHz

BLAB
ASIC

Waveform sampling electronics:
Four BLAB2 chips / MCP-PMT,
1000 chips / system
Wafeform sampling rate: ~ 2-5 GSa/s
Timing resolution goal:
$\sigma_{electronics}$ ~ 50-100 ps
σ_{final} ~ 200 ps

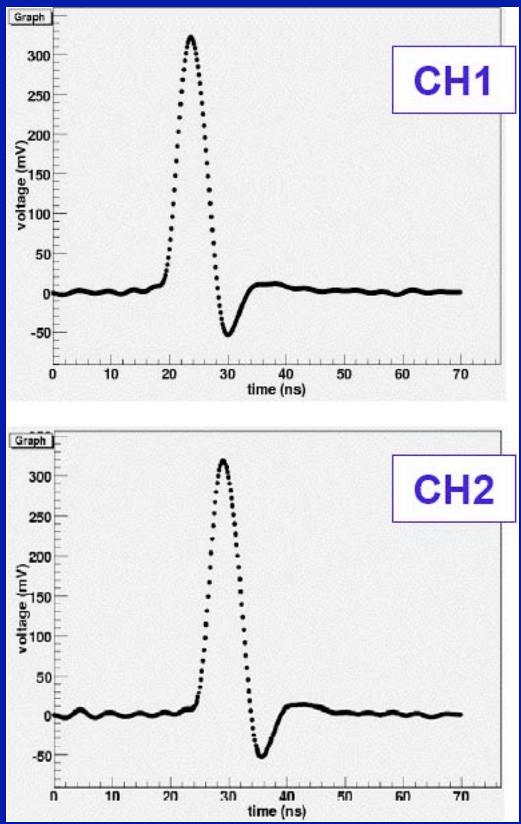
Sensitive to a neutron background

Test results

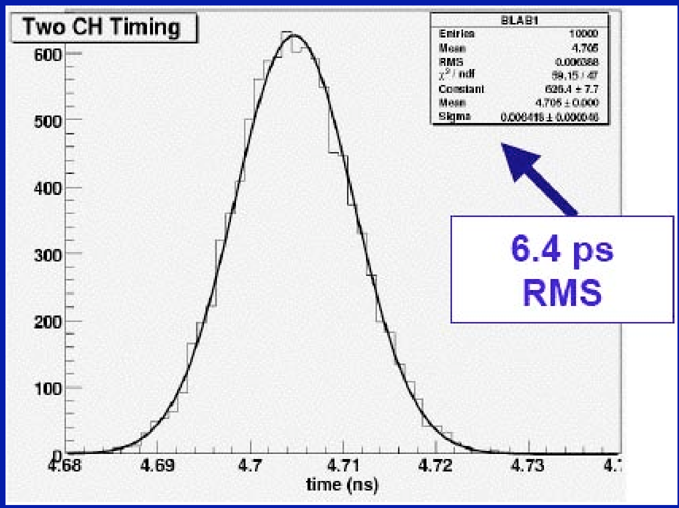
Calibration of BLAB1-based electronics resolution

Gary Varner and Larry Ruckmann

Two identical pulser pulses:



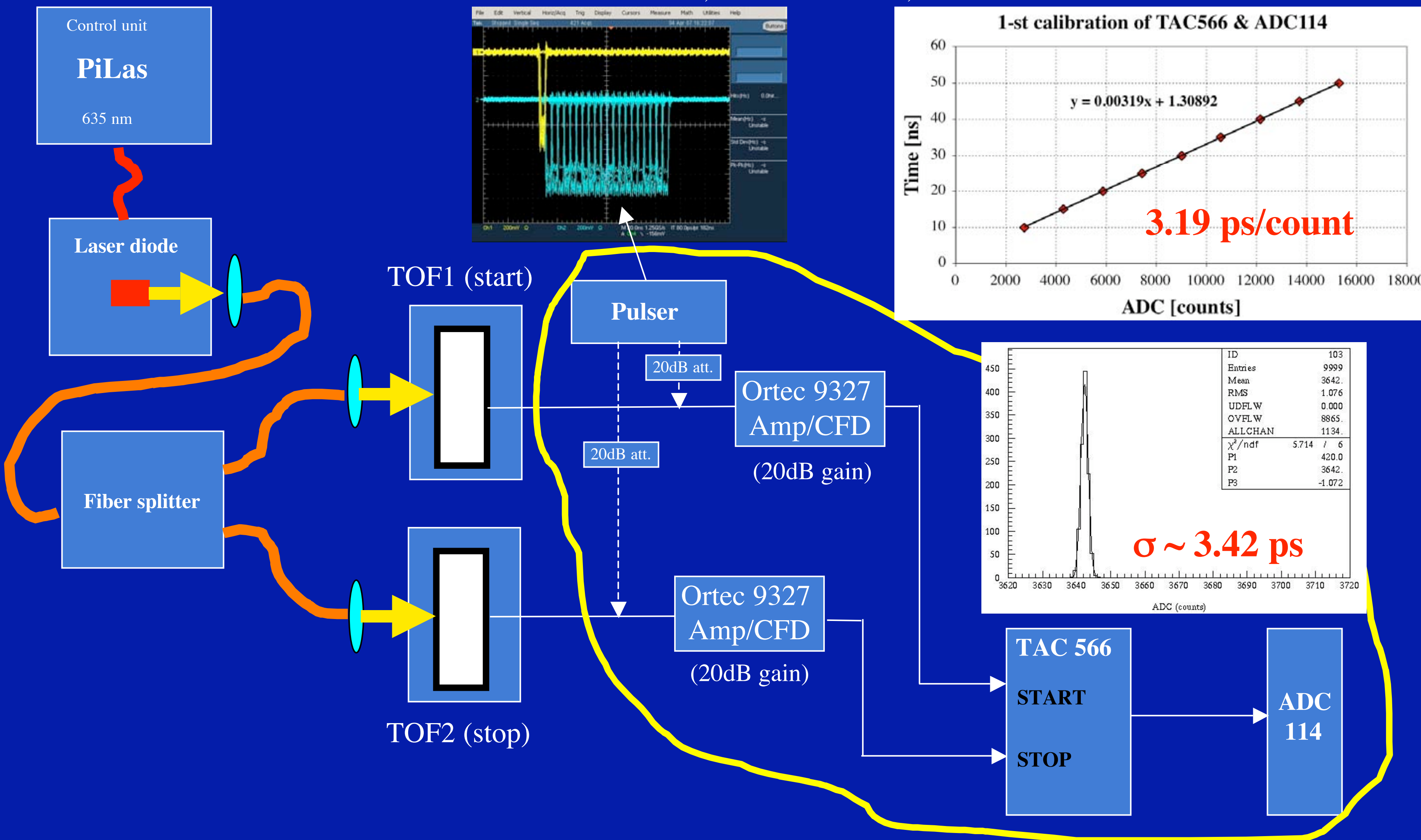
BLAB1 chip:



This resolution would be sufficient for the Super-B TOF, and too good for FARRICH

TOF: Calibration of CFD/TAC-based electronics

J. Va'vra et al., SLAC-PUB-13073, Jan. 2008

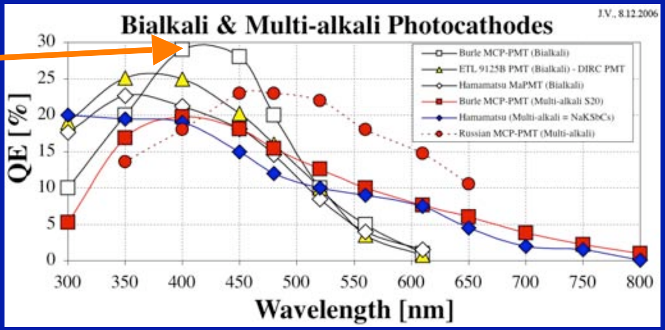


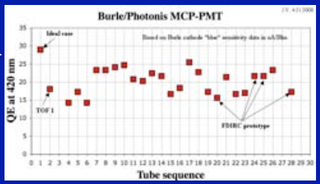
- <u>**This is the best electronics performance, to my knowledge.**</u>

TOF: A simple model for tuning parameters

J. Va'vra et al., SLAC-PUB-13073, Jan. 2008

- A calculation indicates **N_{pe} ~50** for **1 cm-long** Fused Silica radiator & Burle/Photonis Bialkali photocathode (in reality, a typical QE peak is ~20% on average rather than 30%):





- **Expected resolution for Npe = 50**

a) Beam (Radiator length = 10 mm + window):

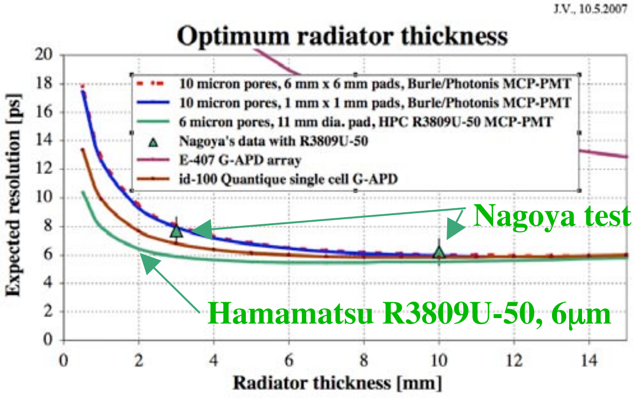
$$\sigma \sim \sqrt{[\sigma^2_{\mathrm{MCP\text{-}PMT}} + \sigma^2_{\mathrm{Radiator}} + \sigma^2_{\mathrm{Pad\ broadenibng}} + \sigma^2_{\mathrm{Electronics}} + \ldots]} =$$

$$= \sqrt{[(\sigma_{TTS}/\sqrt{N_{pe}})^2 + (((12000\mu m/\cos\Theta_C)/(300\mu m/ps)/n_{group})/\sqrt{(12Npe)})^2 + ((6000\mu m/300\mu m/ps)/\sqrt{(12Npe)})^2 + (3.42\ ps)^2]} \sim$$

$$\sim \sqrt{[3.8^2 + 3.3^2 + 0.75^2 + 3.42^2]} \sim \mathbf{6.1\ ps}$$

13.2 for $L_{radiator}$ = 3 mm

4.9 for N_{pe} = 30

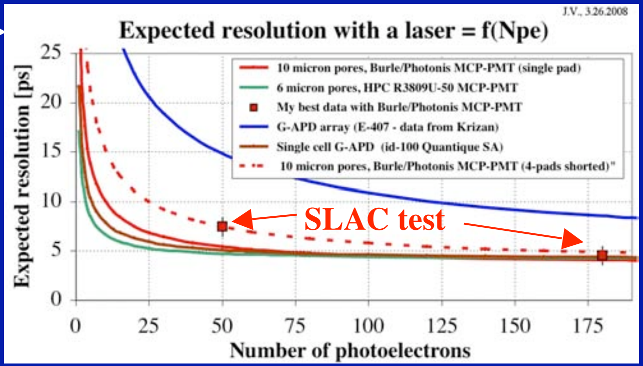


b) Laser (635nm):

$$\sigma \sim \sqrt{[\sigma^2_{\mathrm{MCP\text{-}PMT}} + \sigma^2_{\mathrm{Laser}} + \sigma^2_{\mathrm{Electronics}} + \ldots]} =$$

$$= \sqrt{[\sigma_{TTS}/\sqrt{N_{pe}})^2 + \sqrt{((FWHM/2.35)/\sqrt{N_{pe}})^2} + (3.42\ ps)^2]} \sim$$

$$\sim \sqrt{[3.8^2 + 1.8^2 + 3.42^2]} \sim \mathbf{5.4\ ps}$$



SLAC test with Burle MCP-PMT, 10μm : σ_{TTS} (1 pad)~ **27 ps** (my data)
SLAC test with Burle MCP-PMT, 10μm : σ_{TTS} (4 pads shorted)~ **40-50 ps** (my data)
Nagoya test with HPK R3809U-50, 6μm: σ_{TTS} ~ **10-11 ps** (Hamamatsu data)
E-407 G-APD array: σ_{TTS} ~ **100 ps** (Krizan's data for blue wavelength)
id-100 Quantique single cell G-APD : σ_{TTS} ~ **17 ps** (company's data)

Expected rates and DAQ performance

DIRC expected rates at Super-B

J. Va'vra and B. Ratcliff

- **BaBar empirical scaling law for DIRC PMT rate:**

  Sector 3: PMT rate/kHz ~ 5.3 I_{LER} / A + 19.2 I_{HER} / A + 22.2 LUMI / 10^{33}

  => PMT Rate (LUMI contribution) ~200 kHz at L ~ 10^{34}, which agrees what we observe when things are good !!!

  => If we blindly use this formula we get a PMT Rate > 20 MHz at L ~ 10^{36}.

- **We know that our Belle friends do not have a LUMI term.**

- **We will assume that Super-B LUMI term is 10% of the BaBar LUMI term.**

- **Simple method to estimate the pixel rate for the option 3 (H8500 MaPMT):**

  a. BaBar DIRC 1" dia. PMT rate at L ~ 10^{34}: Measured rate ~200 kHz/PMT

  b. Scale pixel sizes using a total pixel count => Factor ~ 60000/10000 ~6

  c. Non-focusing DIRC SOB is smaller for at Super-B => Factor ~ 7

  => Expected pixel rate ~ 200 kHz * 100 / (10 * 7 * 6) ~ 50 kHz / pixel

  BaBar PMT Scaling to 10^{36} LUMI term SOB volume Total pixel count

  Double pixel confl: ~100kHz
  FDIRC: ~200kHz/(2 pixel)

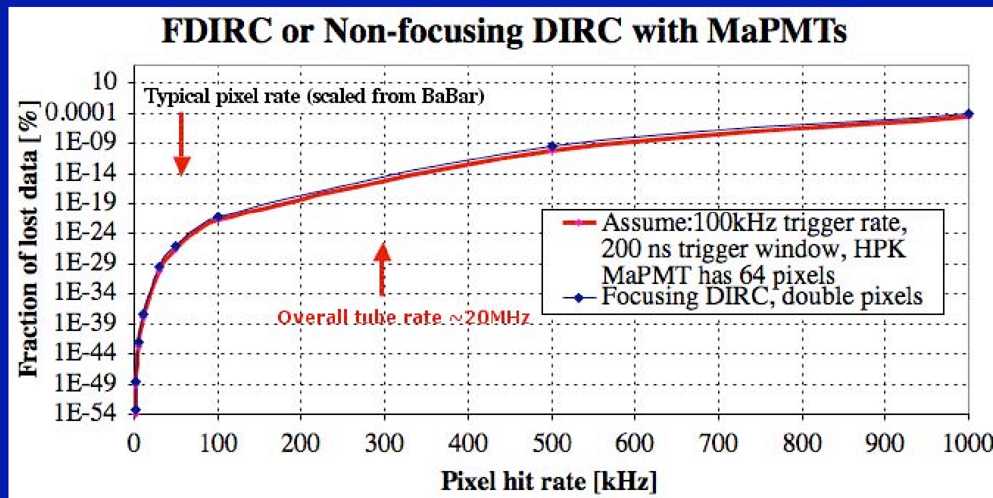
Expected DAQ performance for DIRC

G. Varner & J. Va'vra

DIRC has

a single pe$^-$

sensitivity:



We will reach a maximum possible rate on the PMT before we hit troubles with the dead time.

Gregory:
Assumes uncorrelated bursts of backgrounds.In reality, there may be some correlation. Babar will have to develop a common model for all subsystems.

Note: 1) BLAB2 chip performance comes from Gary Varner
2) Pixel rates from scaling of BaBar PMTs (J. Vavra & B. Ratcliff)
FDIRC or Non-focusing DIRC with MaPMT detectors:
(assume that we use 64 pixel HPK MaPMT tubes)

Hit Rate/pixel [Hz]	Hit Rate/pixel [kHz]	Trigger window [ns]	Occupancy Singels/pixel [fraction]	Occupancy Doubles/pixel [fraction]	Total Occupancy per pixel [fraction]	Ave. number of BLAB2 chip reads/trigger {16 pixels/chip} [pixels]	Ave. dead time per BLAB2 chip [1us/16 pixels] {16 pixels/chip} [us]	Ave. dead time per tigger [1us/16 pixels] {16 pixels/chip} [fraction]	Max Super-B trigger rate [Hz]	Fraction of time that data start to be "delayed" (Not yet lost !!) [Fraction]	Fraction of time that data start to be "delayed" (Not yet lost !!) [%]	Fraction of time data is lost due to overflowing the buffer (assuming 16x deep analog bufering) [%]
1000	1	200	0.0002	0.00000004	0.00020004	0.00320064	0.00320064	3.20064E-09	100000	0.000320064	0.0320064	1.2128E-54
2000	2	200	0.0004	0.00000016	0.00040016	0.00640256	0.00640256	6.40256E-09	100000	0.000640256	0.0640256	7.97367E-50
5000	5	200	0.001	0.000001	0.001001	0.016016	0.016016	1.6016E-08	100000	0.0016016	0.16016	1.87441E-43
10000	10	200	0.002	0.000004	0.002004	0.032064	0.032064	3.2064E-08	100000	0.0032064	0.32064	1.2482E-38
30000	30	200	0.006	0.000036	0.006036	0.096576	0.096576	9.6576E-08	100000	0.0096576	0.96576	5.72674E-31
50000	50	200	0.01	0.0001	0.0101	0.1616	0.1616	1.616E-07	100000	0.01616	1.616	2.16303E-27
100000	100	200	0.02	0.0004	0.0204	0.3264	0.3264	3.264E-07	100000	0.03264	3.264	1.6596E-22
500000	500	200	0.1	0.01	0.11	1.76	1.76	0.00000176	100000	0.176	17.6	8.47623E-11
1000000	1000	200	0.2	0.04	0.24	3.84	3.84	0.00000384	100000	0.384	38.4	2.23511E-05

Trigger window*Hit rate

(Trigger window*Hit rate)^2

Total occupancy*16

Convert to µs

Convert to fraction

Max.trigger rate*Ave.dead time

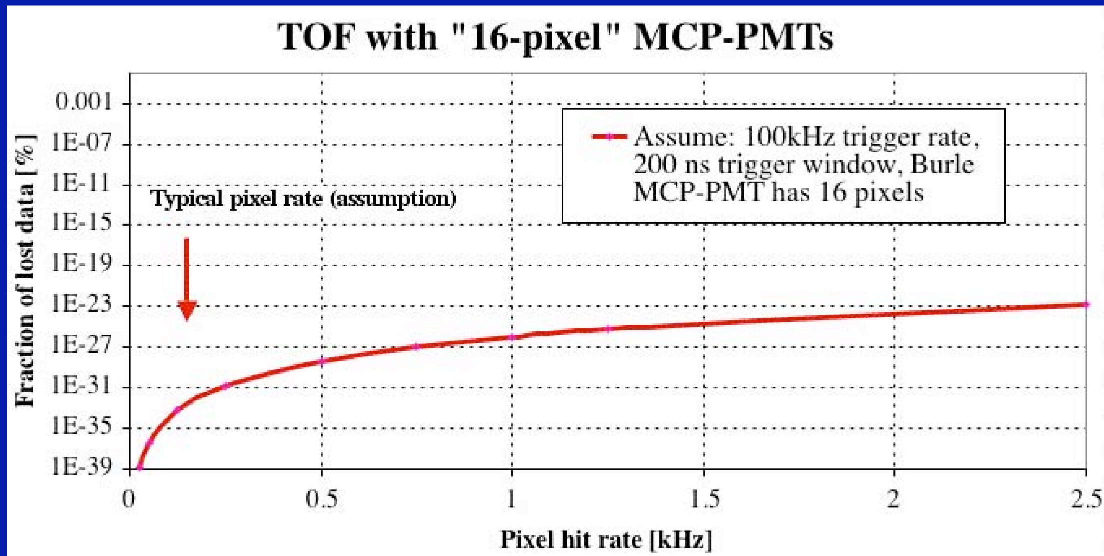
Convert to %

Fraction of lost data:
(100*Max.trigger rate*Ave.dead time)^{16}

Expected DAQ performance for TOF

G. Varner & J. Va'vra

TOF is sensitive to tracks only:



Lower rates because the TOF detectors are not sensitive to single pe$^-$ rate (threhold: 3-5pe$^-$).

Gregory:
Assumes uncorrelated bursts of backgrounds.In reality, there may be some correlation. Babar will have to develop a common model for all subsystems.

Assume: 1. Short 4 pads together
2. Run with a threshold of 5-10 pe- => DAQ does not see the Cherenkov photons
3. Typical expected track rate per PMT is ~2kHz. => 125 Hz/pixel

Track Rate/PMT [Hz]	Track Rate/PMT [kHz]	Hit Rate/pixel {assume: 16 pixels/track} [Hz]	Hit Rate/pixel {assume: 16 pixels/track} [kHz]	Trigger window [ns]	Occupancy Singels/pixel [fraction]	Occupancy Doubles/pixel [fraction]	Total Occupancy per pixel [fraction]	Ave. number of BLAB2 chip reads/trigger {16 pixels/chip} [pixels]	Ave. dead time per BLAB2 chip [1us/16 pixels] {16 pixels/chip} [us]	Ave. dead time per tigger [1us/16 pixels] {16 pixels/chip} [fraction]	Max. Super-B trigger rate [Hz]	Fraction of tim that data start to be "delayed (Not yet lost ! [Fraction]	Fraction of time that data start to be "delayed" (Not yet lost !!) [%]	Fraction of time data is lost due to overflowing the buffer (assuming 8x deep analog bufering) [%]
100	0.1	6.25	0.00625	200	0.00000125	1.5625E-12	1.25E-06	2E-05	2E-05	2E-11	100000	2E-06	0.0002	2.56003E-44
200	0.2	12.5	0.0125	200	0.0000025	6.25E-12	2.50001E-06	4.00001E-05	4.00001E-05	4.00001E-11	100000	4E-06	0.000400001	6.55373E-42
500	0.5	31.25	0.03125	200	0.00000625	3.90625E-11	6.25004E-06	0.000100001	0.000100001	1.00001E-10	100000	1E-05	0.001000006	1.00005E-38
1000	1	62.5	0.0625	200	0.0000125	1.5625E-10	1.25002E-05	0.000200003	0.000200003	2.00003E-10	100000	2E-05	0.002000025	2.56026E-36
2000	2	125	0.125	200	0.000025	6.25E-10	2.50006E-05	0.00040001	0.00040001	4.0001E-10	100000	4.0001E-05	0.0040001	6.55491E-34
3000	3	187.5	0.1875	200	0.0000375	1.40625E-09	3.75014E-05	0.000600023	0.000600023	6.00023E-10	100000	6.0002E-05	0.006000225	1.68012E-32
4000	4	250	0.25	200	0.00005	2.5E-09	5.00025E-05	0.00080004	0.00080004	8.0004E-10	100000	8.0004E-05	0.0080004	1.67839E-31
5000	5	312.5	0.3125	200	0.0000625	3.90625E-09	6.25039E-05	0.001000063	0.001000063	1.00006E-09	100000	0.00010001	0.010000625	1.0005E-30
10000	10	625	0.625	200	0.000125	1.5625E-08	0.000125016	0.00200025	0.00200025	2.00025E-09	100000	0.00020003	0.0200025	2.56256E-28

Trigger window*Hit rate

(Trigger window*Hit rate)^2

Total occupancy*16

Convert to µs

Convert to fraction

Max.trigger rate*Ave.dead time

Convert to %

Fraction of lost data:
(100*Max.trigger rate*Ave.dead time)^8

Appendix

DIRC options

Favored

	BaBar DIRC	Option 1	Option 2	Option 3	Option 4
PMT type	ETL 9125B	equivalent	upgraded	MaPMT 8500	MaPMT 8500
No of pixels/PMT	1	1	1	8x8 = 64	4x8 = 32
PMT rise time	~1.5 ns	~1.5 ns	0.5 - 1.0 ns	~ 0.5 ns	**~ 0.5 ns**
PMT σ_{TTS}	1.6 ns	~1.5 ns	0.25 - 0.5 ns	~150 ps	~150 ps
Expected PMT gain	~3x10^6	similar	similar	~10^6	**~10^6**
Amplifier voltage gain	~10	~10	~10	40-60x	**40-60x**
Typ. pulse height	~40 mV	equivalent	equivalent	A few hundred mV	**A few hundred mV**
Typ. expected rate/PMT	~200 kHz	1 MHz	1 MHz	**~50 kHz/pixel**	**~100 kHz/pixel**
TDC/ADC equiv. resol.	500 ps/count	500 ps/count	~100 ps/count	~50 ps/count	**~50 ps/count**
Waveform analysis	no	no	no	yes	yes
Integration	Custom front end	similar	similar	ASIC for 64 ch.	ASIC for 32 ch.
Latency	12 μs	12 μs	12 μs	12 μs	12 μs
Max. DAQ rate	10 kHz	100 kHz	100 kHz	100 kHz	100 kHz
Data link	1.2 Gbit fiber	upgrade	upgrade	upgrade	upgrade
No of channels	12,000	12,000	12,000	64,000	**32,000**
No of detectors	12,000	12,000	12,000	1000	1000

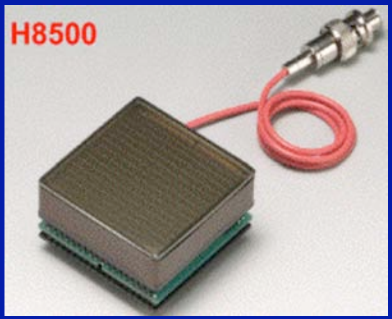
Options:

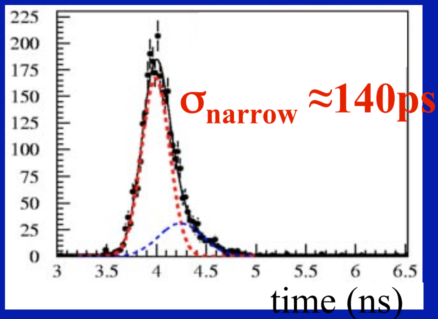
1. **DIRC detector as it is now, but replace PMTs to types with similar specs (σ_{TTS} ~ 1.5 ns)**
2. **DIRC detector as it is now, but upgrade PMTs to types with faster transit time spread (σ_{TTS} ~ 250 - 500 ps)**
3. **"Non-focusing or Focusing DIRC" with a new SOB - Use flat panel H-8500 MaPMT (Gary Varner's waveform digitizer)**
4. **"Non-focusing or Focusing DIRC" with a new SOB - Use flat panel H-8500 MaPMT (two pixels shorted together)**

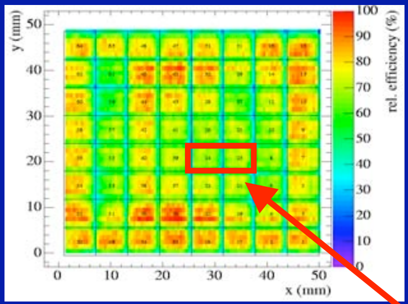
FDIRC photon detector candidates - options 3&4

Nucl.Inst.&Meth., A 553 (2005) 96

Hamamatsu H-8500 MaPMT (64 pixels, 6x6mm pad, σ_{TTS} ~140ps)







Cost:
Detectors: $1.6M/1000
Electronics: $1.1M/1000

- **64-pixel nominally; however, we may short 2 pixels together in x-direction.**
- **Total overall MaPMT tube rate: ~ 3.2 MHz**
- **What is a max useful rate the tube can take ? ~30 MHz ? Need tests !**
- **HERA-B had up to ~20 MHz/16 pixel MaPMT (P. Krizan).**

TOF options

Favored

	Option 1	Option 2	Option 3
PMT type	Burle MCP-PMT, 10 μm	Burle MCP-PMT, 10 μm	Burle MCP-PMT, 10 μm
No of pixels/PMT	8x8 = 64	8x8 = 64	4x4 = 16
Input capacitance/pix	~ 5 pF	~5 pF	~20 pF
PMT rise time	~ 200-400 ps	~ 200-400 ps	~ 300-500 ps
Expected PMT gain	~8x10^4 @0kG, ~4x10^5 @16kG	~8x10^4 @0kG, ~4x10^5 @16kG	~8x10^4 @0kG, ~4x10^5 @16kG
PMT σ_{TTS}	~30 ps	~30 ps	~30 ps
No of photoelectrons	~ 50 / 1 cm of radiator	~ 50 / 1 cm of radiator	~ 50 / 1 cm of radiator
Raw pulse height/50pe^-	~ 50 mV	~ 50 mV	~ 40 mV
Particle track rate/PMT	A few kHz	A few kHz	A few kHz
Pixel rate	~ 500 Hz	~ 500 Hz	~ 125 Hz
TDC/ADC equiv. resol.	5-10 ps/count	5-10 ps/count	5-10 ps/count
Amplifier gain	~10x	~10x	~10x
Effective front end BW	0.7-1 GHz	0.7-1 GHz	0.7-1 GHz
Timing scheme	CFD + ADC correction	Waveform digitization (~10 GSa/s)	Waveform digitization (~10 GSa/s)
Latency	12 μs	12 μs	12 μs
Total number of pixels	64,000	64,000	16,000
No. of detectors	1000	1000	1000

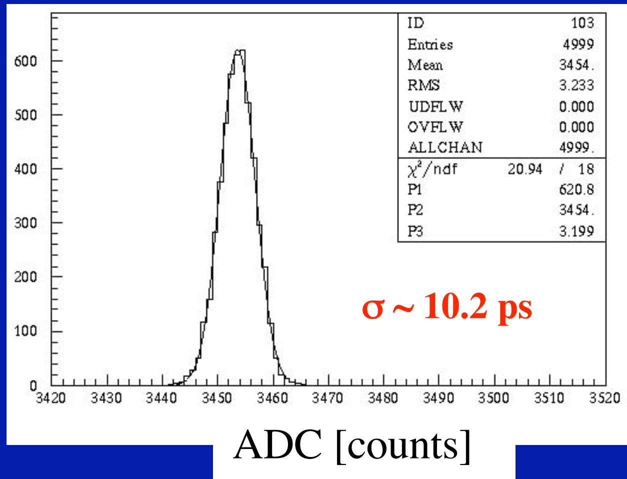
Options:

1. TOF with CFD/TAC/ADC & Time-over-threshold ADC correction (a'la Jeff Peck, retired ORTEC engineer)
2. TOF with waveform digitization (a'la Gary Varner)
3. The same as option 2, but short 4 pixels together (live with a larger capacitance)

A laser-based result with two TOF counters

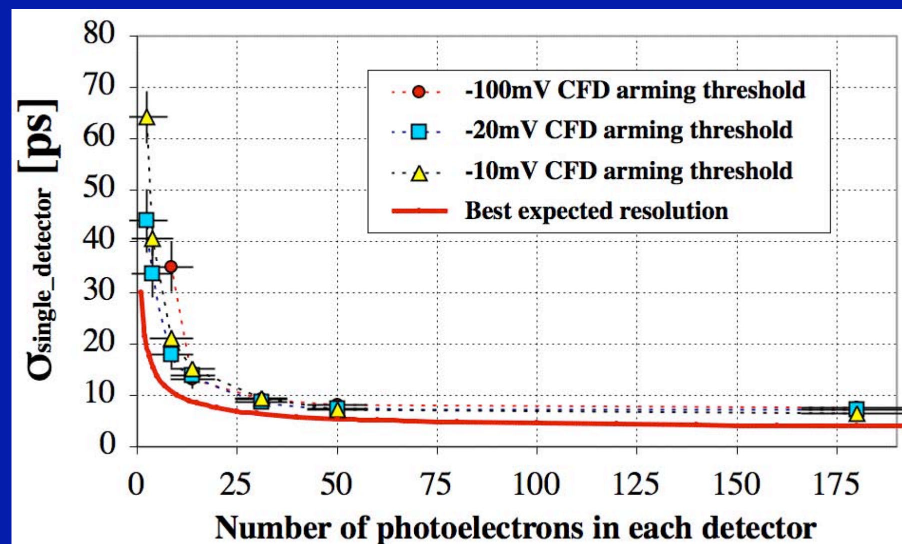
J. Va'vra et al., SLAC-PUB-13073, Jan. 2008

Two detector resolution (Npe ~50 pe ea.):



Each detector has Npe ~ 50 pe$^-$:

$\sigma_{\text{single detector}} \sim (1/\sqrt{2})\ \sigma_{\text{double detector}}$
~ 7.2 ps



Running conditions:

1) Low MCP gain operation (~1.4x10^5)
2) Linear operation
3) CFD discriminator
4) No additional ADC correction
5) 4 pixels connected
6) Radiator illuminates 4 pixels only

- Two Burle/Photonis MCP-PMTs with 10 μm MCP holes operating at 2.27 & 1.88 kV.
- Ortec 9327Amp/CFD (two) with a -10mV threshold and a walk threshold of +5mV & TAC566 & 14 bit ADC114

Burle/Photonis MCP-PMT 85012

J.V., log book #3

MCP-PMT 85012-501:

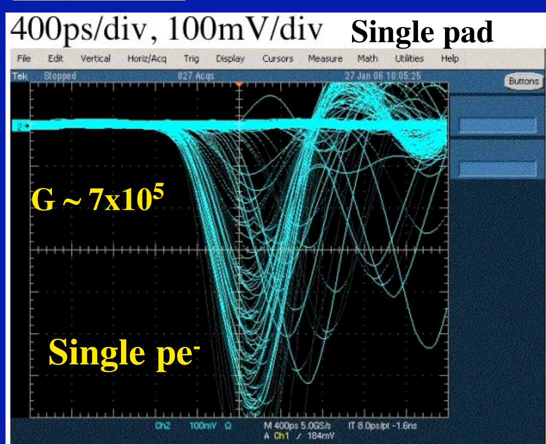
- **10 µm MCP hole diameter**
- 64 pixel devices (use a single pad, ground the rest)
- $C_{Anode\text{-}to\text{-}ground} \sim 5.5$ pF
- 1 GHz BW scope limits the rise time
- **MCP-PMT rise time:** $\sqrt{500^2-350^2-230^2}$ **~ 270 ps**
  => $BW_{MCP\text{-}PMT} \sim 0.35/270\text{ps}$ ~**1.3 GHz**
- **With the PiLas red laser diode (635 nm):**

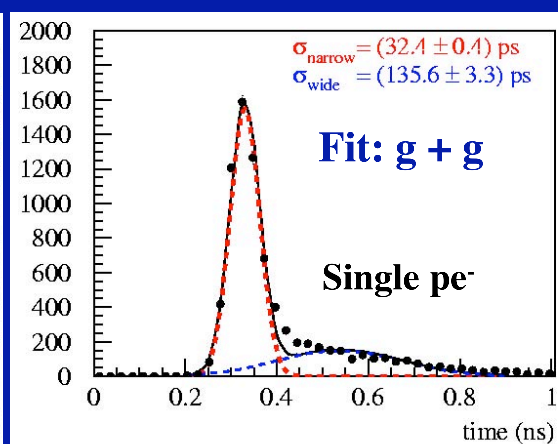
$$\sigma_{TTS} \sim \sqrt{(32^2-13^2-11^2)} = 27 \text{ ps}$$

PiLas laser diode   Electronics (TDC mainly)

Hamamatsu C5594-44 amplifier

1.5 GHz BW, 63x gain





S/N MCP-PMT 85012

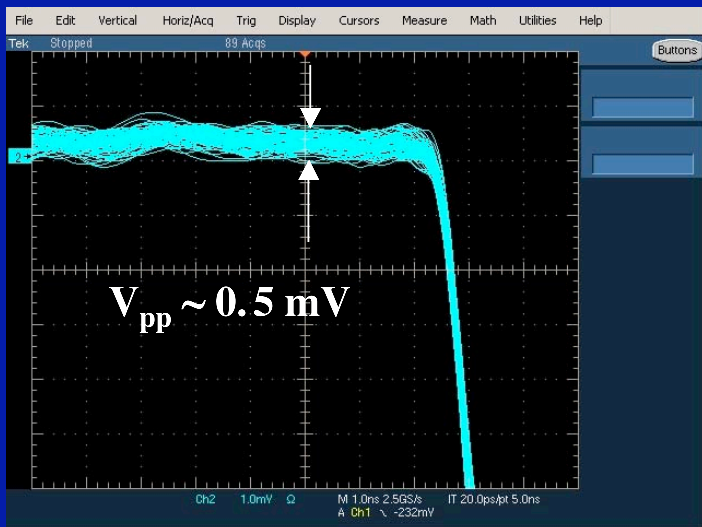
J.V., log book #5

!

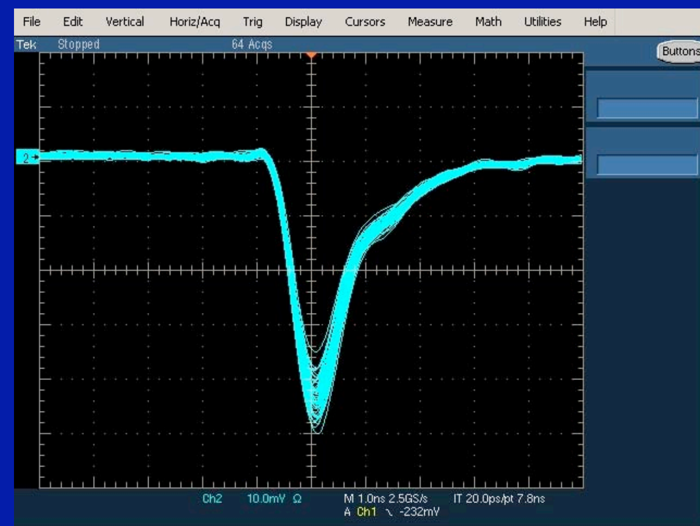
With a 1 GHz BW scope:

Laser pulse, ~50 pe$^-$, no amplifier, Gain ~ 1.4 x10^5

1mV/div, 1ns/div



10mV/div, 1ns/div, 2.22kV, 4 pads connected



$$\boxed{(S/N)_{pp} \sim 43mV/0.5mV \sim 80}$$