Progress in

FDIRC & TOF

J. Va'vra, SLAC

Content

- **FDIRC prototype**
  - Activities related to analysis of the last test beam run

- **TOF detector**
  - Summary of test results

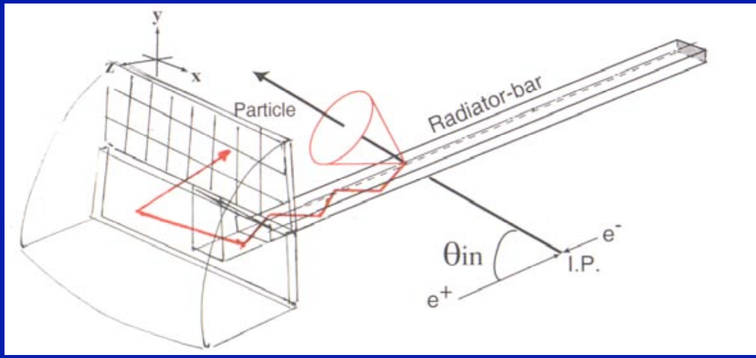
- **Next steps**

- **Appendix**
  - PID electronics summary of parameters, next R&D plans, etc.

Why FDIRC ?

- Super-B will have 100x higher luminosity
- Backgrounds are not yet understood, but they would scale with the luminosity if they are driven by the radiative Bhabhas

⇒ **<u>DIRC may need to be smaller and faster</u>.**

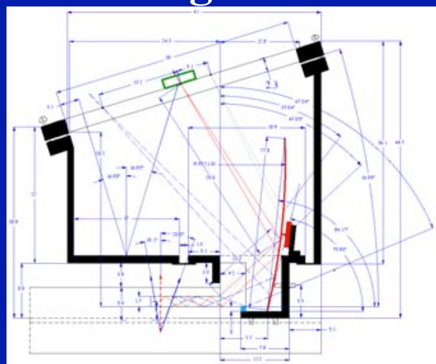


Primary benefit of the upgrade:
- Focusing and smaller pixels can **reduce the expansion volume by a factor of 7-10 !**
- Faster PMTs reduce a sensitivity to background.

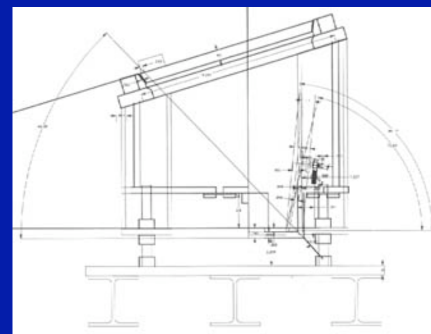
Additional benefit of having the faster photon detectors:
- Timing resolution improvement: **σ ~1.7ns (BaBar DIRC) -> σ ~200ps (~10x better)** which allows the measurement of a **<u>photon color</u>** to correct the chromatic error of θ_c. We do not need to push the timing resolution further as the detector measures the x&y position of each photon.

Comments about the FDIRC design

Optical design:



Mechanical design:



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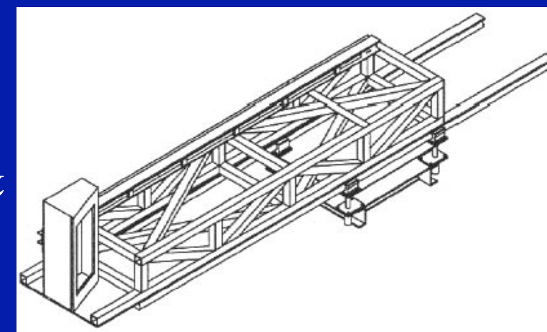
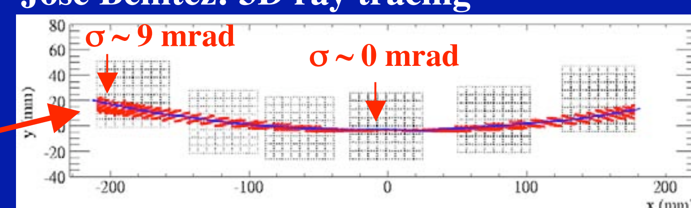


- Use some existing components to keep the cost down (window, CRID mirror, DIRC bars).
- Optical design done by a **ray tracing in 2D** using the Vellum cad program.
- The design was then transferred to our techs Bob & Matt, who know the Vellum program as well, to add nuts and bolts - a very good process to avoid errors.
- The heavy support designed by engineers Scholz & Thurston.
- The alignment checked by a **3D coordinate machine** in situ.

However, we missed one aberration effect:

- Focusing eliminates effect of the bar thickness (contributes $\sigma \sim 4$ mrads in BaBar DIRC)
- However, the spherical mirror introduces an aberration at large ϕ angles (No simple fix found for the prototype)

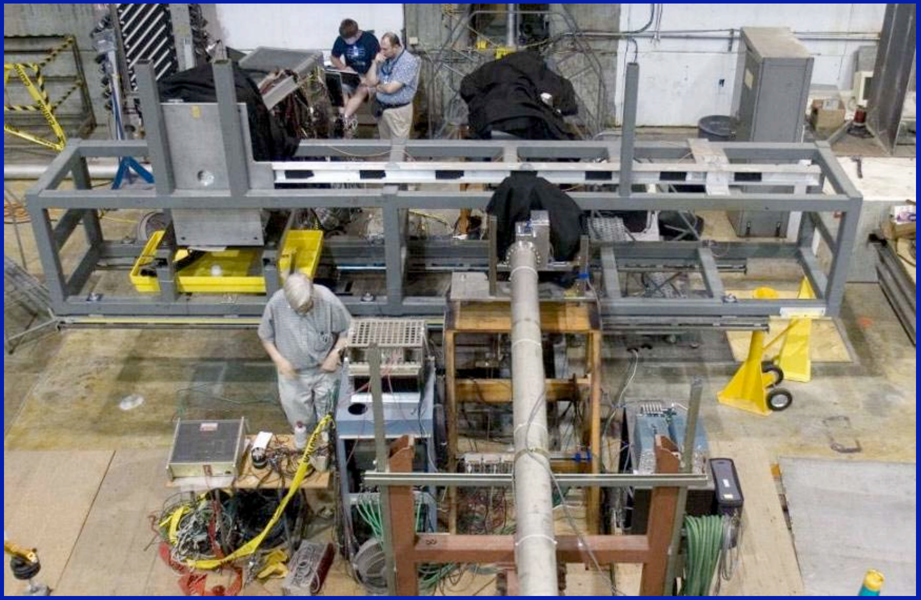
Jose Benitez: 3D ray tracing

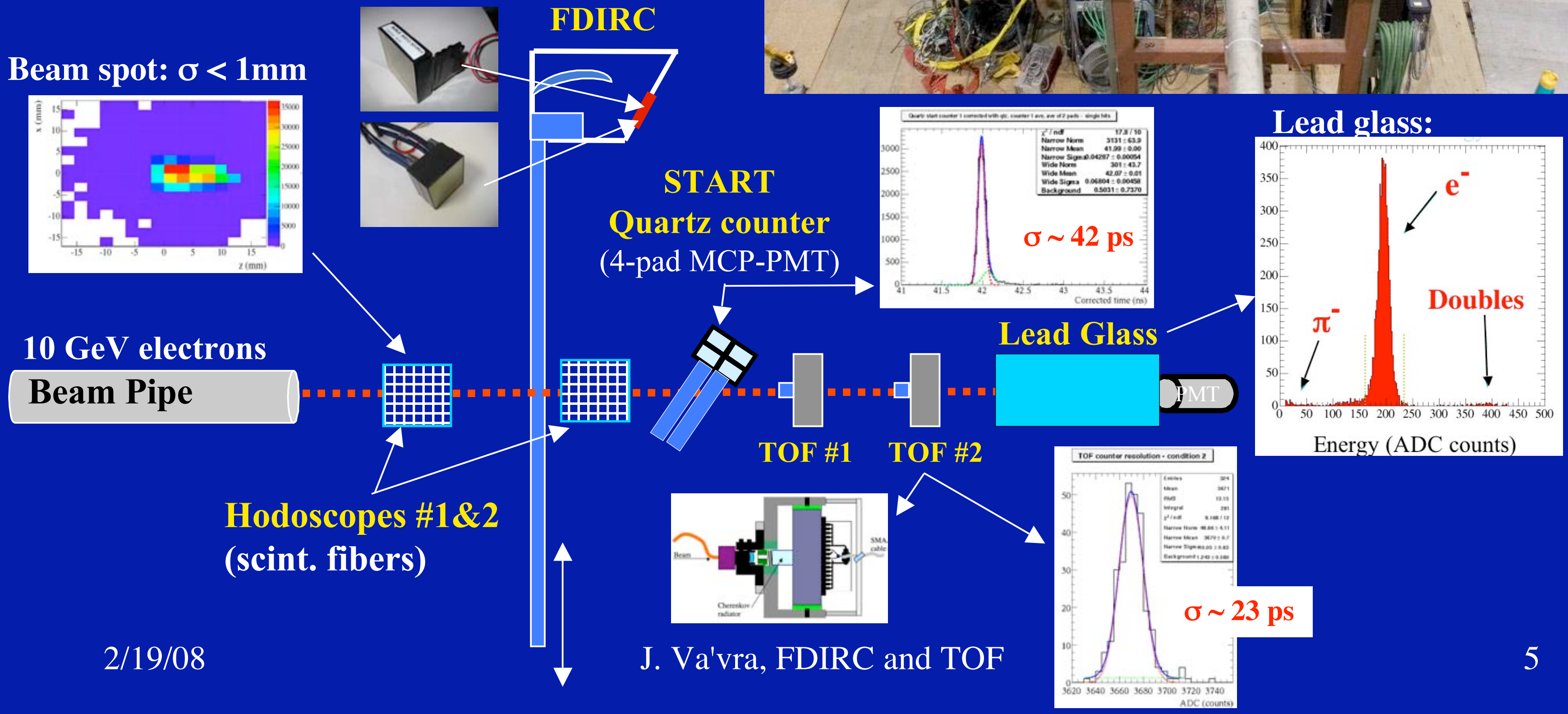


(Geant 4 confirmed it)

Run 4: test beam setup in 2007

- **Instrumentation:**
  - 2 x-y scintillating fiber hodoscopes
  - START Quartz counter to monitor flux
  - Time start from the LINAC RF signal, but correctable with a local START counter
  - Lead glass to monitor beam multiplicity (very important in the SLAC's beam)
  - Two TOF counter prototypes

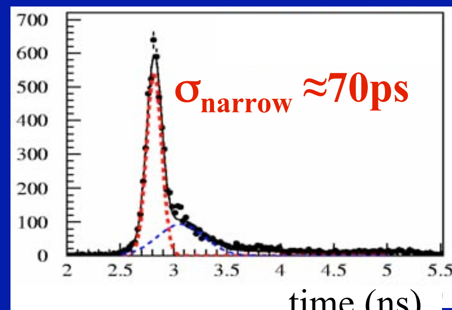


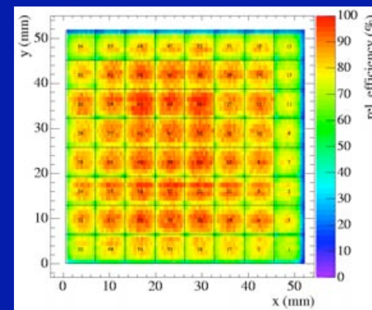


FDIRC prototype photon detectors

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

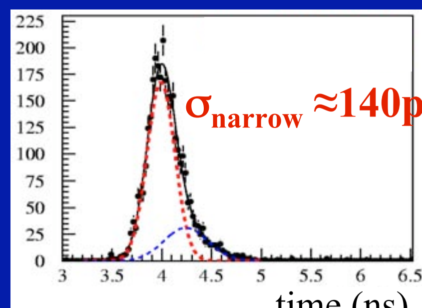
1) Burle 85011-501 MCP-PMT (64 pixels, 6x6mm pad, σ_{TTS} ~50-70ps)

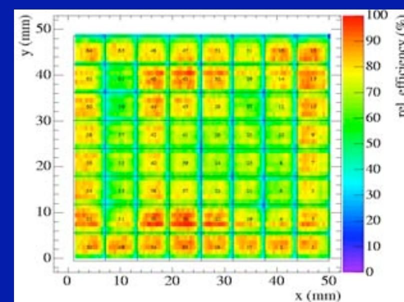




2) Hamamatsu H-8500 MaPMT (64 pixels, 6x6mm pad, σ_{TTS} ~140ps)

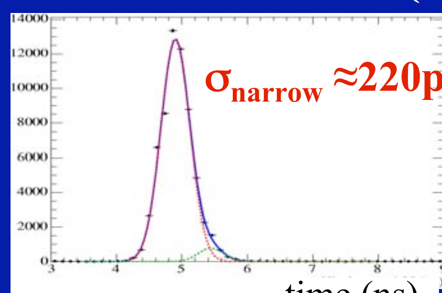
#2

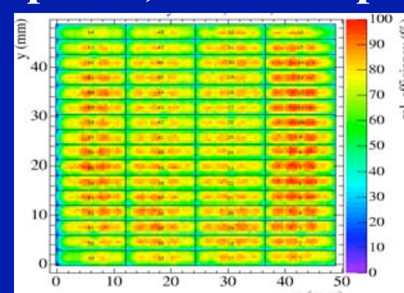




3) Hamamatsu H-9500 Flat Panel MaPMT (256 pixels, 3x12mm pad, σ_{TTS} ~220ps)

#1

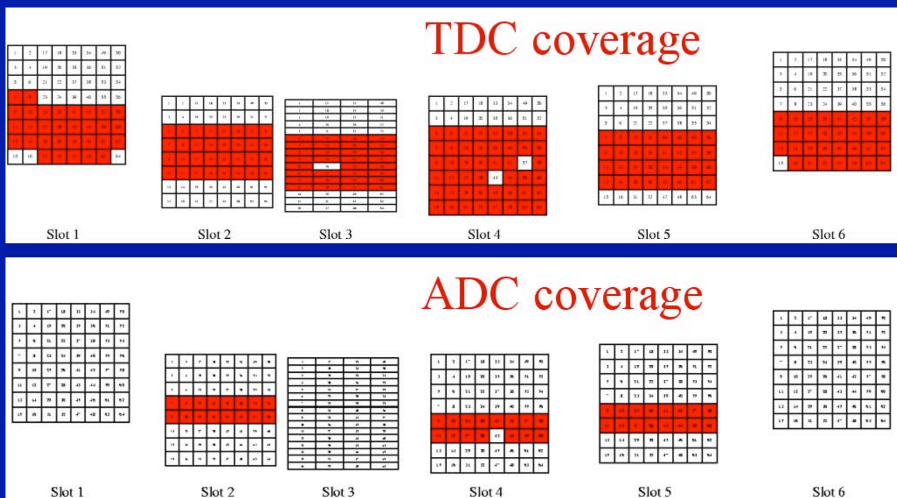




- **Timing resolutions were obtained using a fast laser diode in bench tests with single photons on pad center.**

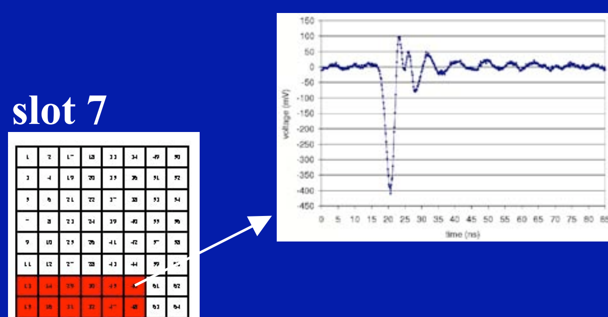
In the FDIRC prototype test we gang four pixels together to be able to use our 64 channel amplifier electronics. In a real device we would use all 256 pixels.

Run 4: FDIRC electronics



- **SLAC electronics in slots 1-6:**
- **SLAC Amplifier**: tandem of two **Elantek** 2075EL chips, net voltage gain: **~130x**, and a rise time: ~1.2ns => **only ~300MHz BW !!!**
- **SLAC constant-fraction-discriminator (CFD)** (32 channels/board).
- **Phillips 7196 TDC** (25ps/count).
- **Phillips 7166 ADC** (0.125pC/count).

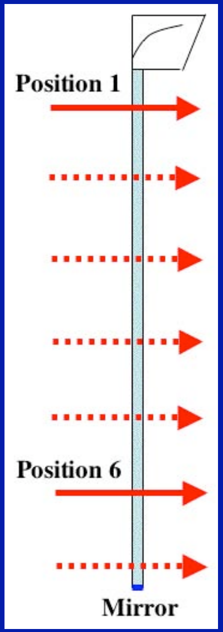
slot 7



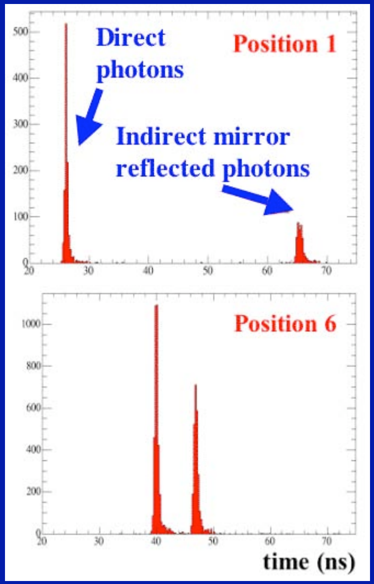
- **Hawaii electronics in slot 7:**
- 16 pixels instrumented.
- **Amplifier:** Minicircuit's **VAM-6**, tandem of three amplifiers + 350 MHz Low Pass filters, net voltage gain: **140x**.
- **ASIC-based waveform digitizing electronics operating with ~ 5.8 GSa/s,** waveform sampling rate: point every **~200ps**.

Run 4: Cherenkov Photons in Time and Pixel domains

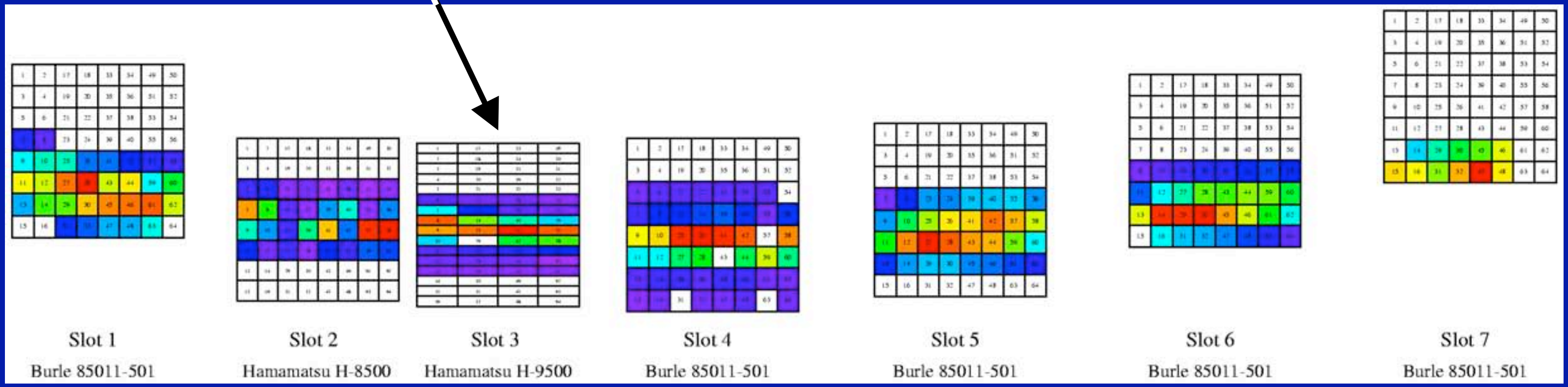
- ~ 200 pixels instrumented with SLAC electronics & 16 with the Hawaii electronics.
- Ring image is most narrow in the 3 x 12 mm pixel detector.



Cherenkov photons in time domain:



Cherenkov ring in pixel domain:



Chromatic correction with three independent analysis programs

- **Jose Benitez**: **Maximum likelihood method**

$$PDF(\lambda,\theta) = \iint_{\lambda_{\min}}^{\lambda_{\max}} N(\lambda',\theta')\varepsilon(\lambda') e^{-\frac{(\theta-\theta')^2}{2\sigma_\theta^2}} e^{-\frac{(\lambda-\lambda')^2}{2\sigma_\lambda^2}} \sin(\theta')\, d\theta' d\lambda'$$

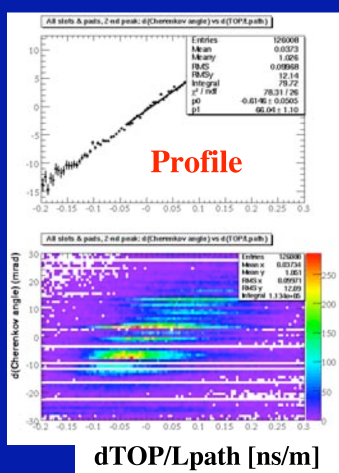
- Use the PDF to determine beta for each photon detected.

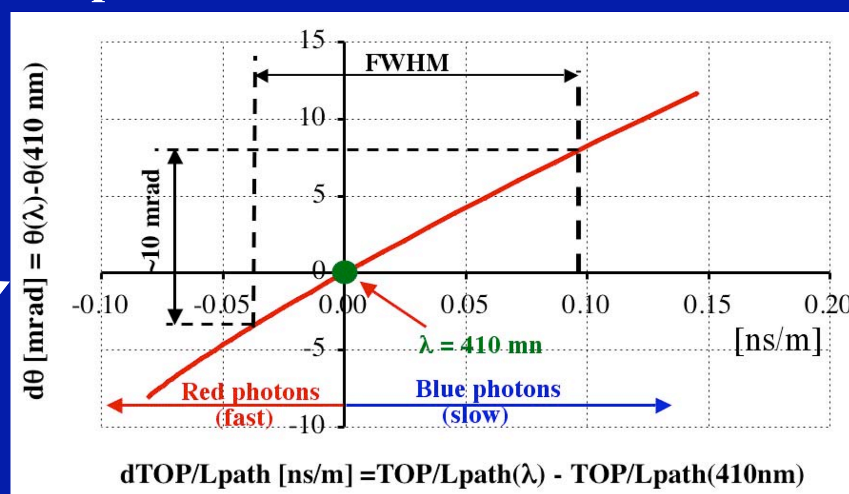
- Fit the beta distribution to determine our resolution.

- **Joe Schwiening**
- **Jerry Va'vra**

Simple method:

Data:





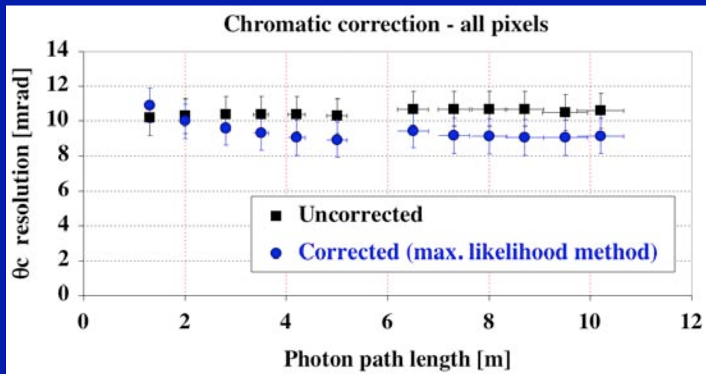
TOP = time of propagation of photon in the bar

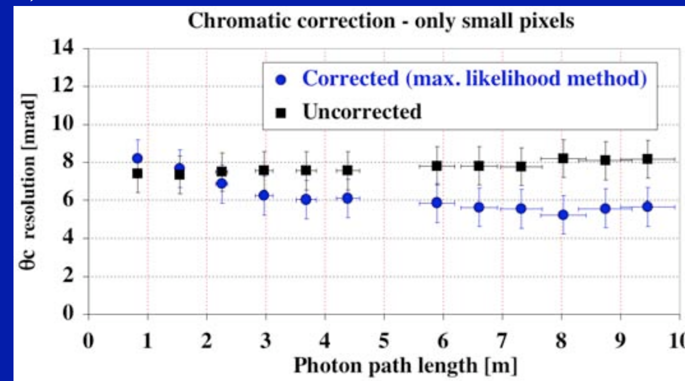
TOP/Lpath = $1/v_{group}(\lambda)$

Run 3: θ_C resolution and Chromatic correction

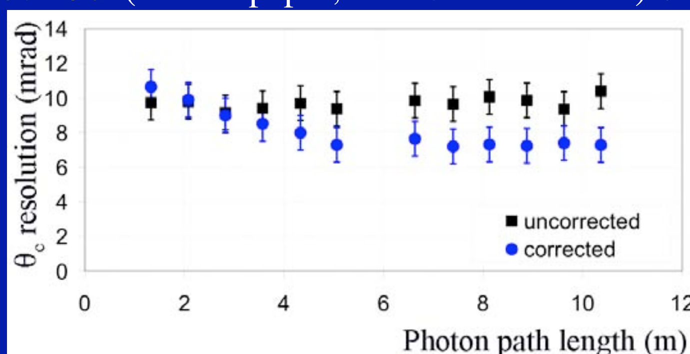
All pixels: | **3mm pixels only:**

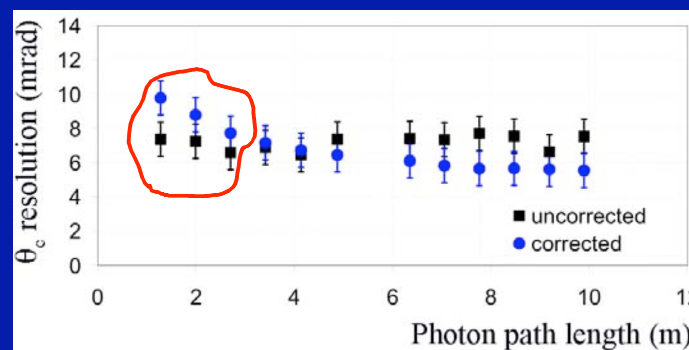
Max. likelihood method (Vienna paper. SLAC-PUB-12803) :





Simple method (Trieste paper, SLAC-PUB-13104) :



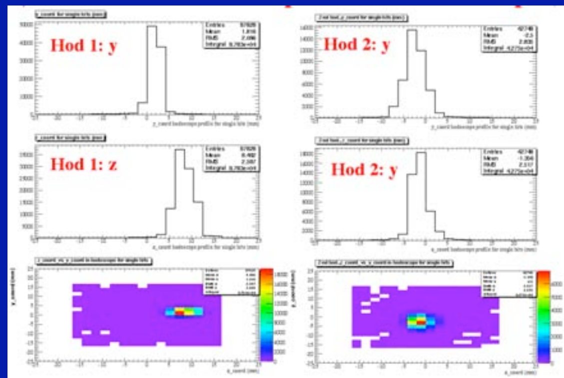


- **The maximum likelihood technique tends to be better for short photon paths.**
- **However, remember that for the BaBar detector geometry: L_{path} > 3 meters.**
- **Smaller pixel size (3mm) helps to improve the Cherenkov angle resolution.**

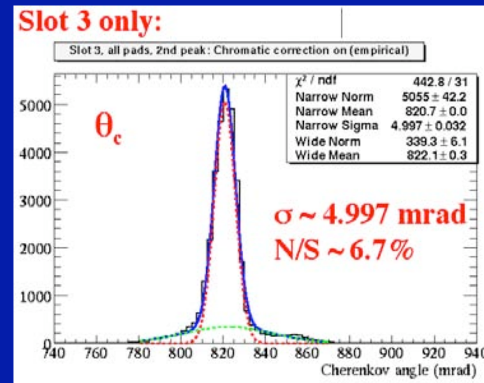
Preliminary look at issues in run 4

Run 4: Would tracking after the DIRC bar help ?

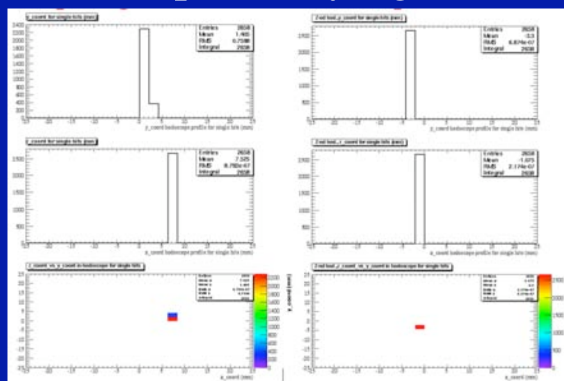
Hodoscopes 1 & 2 (good single hits)**:**

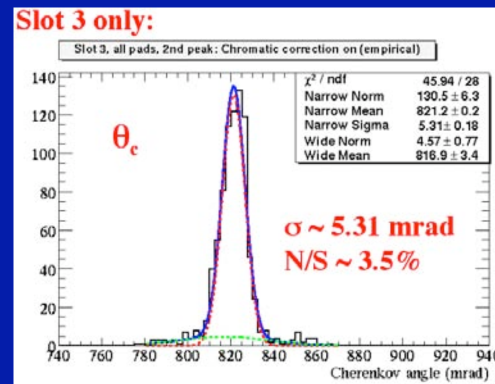


3mm pixels only:



Hodoscopes 1 & 2 (plus very tight cuts on the position)**:**





- **There is a hint that a tight cut on the beam position after the bar helps the S/N ratio.**
- **It would work better if we have more distance between the bar and the 2-nd hodoscope, or a real tracking before & after the bar.**

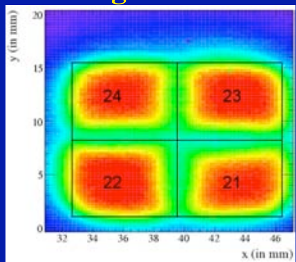
Run 4: Progress report on the pixel interpolation

1) Calibration in the scanning setup (Mathiew)

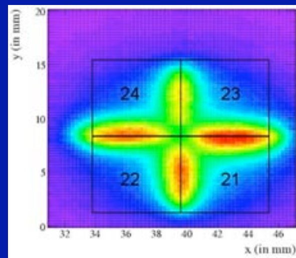
Position of the laser beam in the **scanning setup**:

90% of multiple hits are doubles

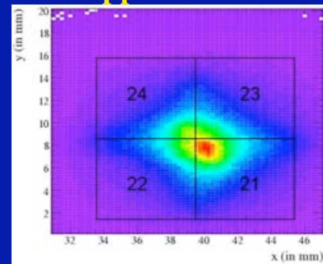
with **single** TDC hits:



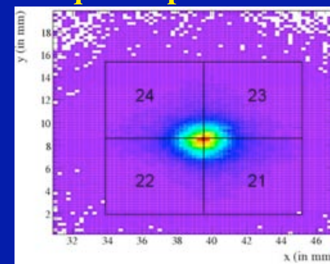
with **double** TDC hits:



with **tripple** TDC hits:



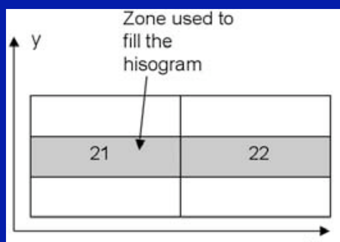
with **quadruple** TDC hits:



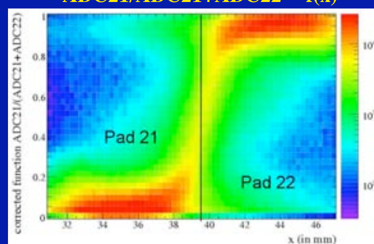
Fractions - TDC:

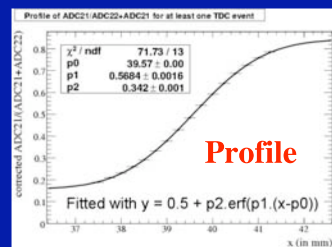
Fractions - ADC:

ADC-based interpolation between two pads - the scanning setup:

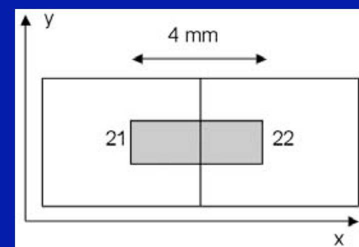


ADC21/ADC21+ADC22 = f(x)

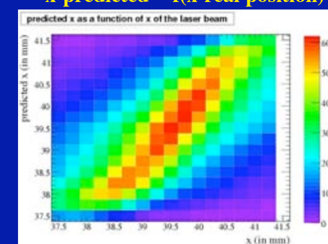




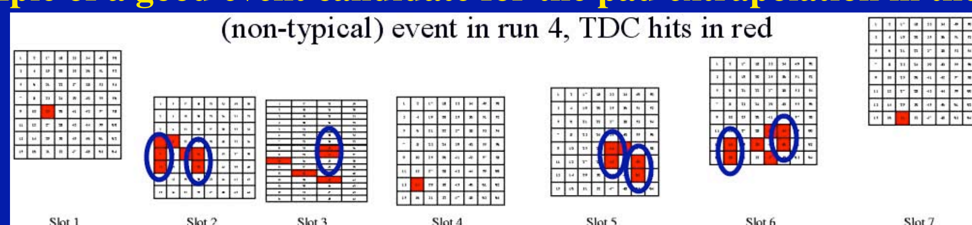
ADC-based interpolation should work over a distance of ±2 mm:



x-predicted = f(x-real position)



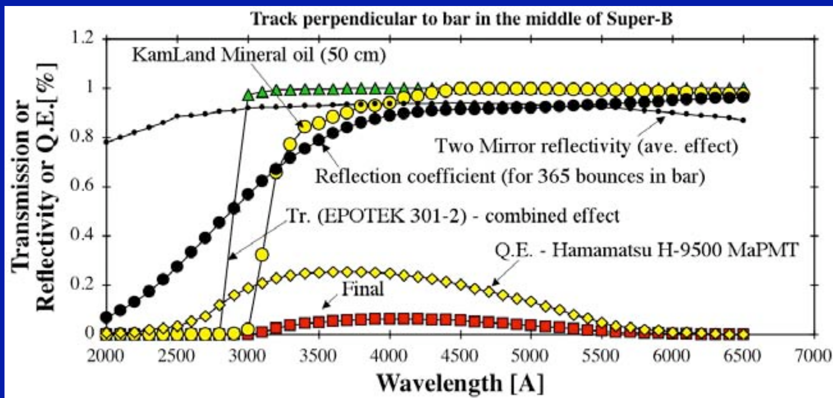
2) Test beam: **An example of a good event candidate for the pad extrapolation in the FDIRC prototype:**



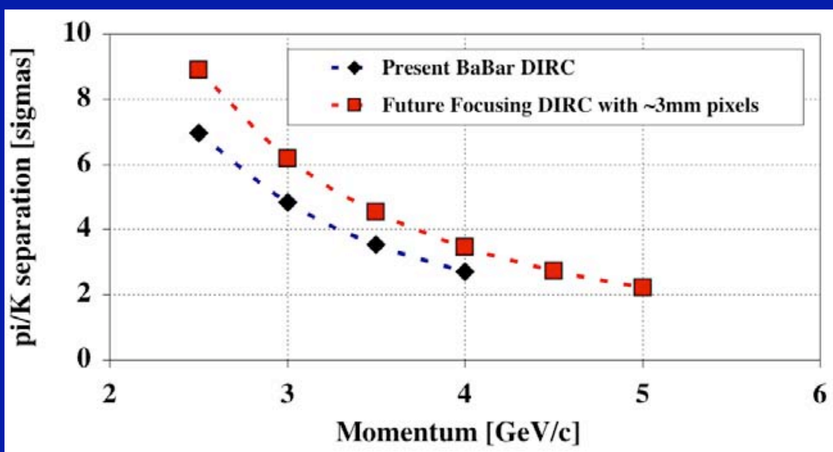
- **Based on the scanning setup results, ADC-based pad sharing should work over a distance of ±2 mm between two pixels.**
- **This is now being studied in the run 4 data from the FDIRC prototype.**

Expected final performance at incidence angle of 90^{o}

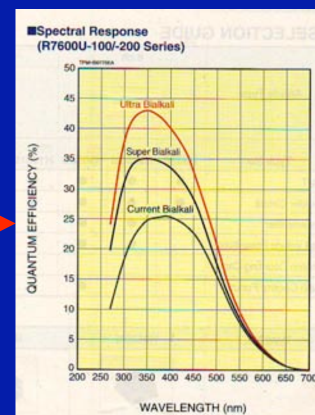
Focusing DIRC prototype bandwidth:



Expected performance of a final device:



- Kamland oil defines the **lower edge** of the wavelength BW. In Babar DIRC, it is the Epotek glue which defines it. **To our knowledge, its transmission did not change in the past ~2 years.**
- Prototype's **Npe_measured** and **Npe_expected** are within **~20%.**
- **Hamamatsu H-9500 MaPMTs**: **No ~ 31 cm^{-1}** & **Npe ~ 28**. (if a higher QE would become available for this MaPMT, this would become really a powerful RICH detector).



- **Burle-Photonis MCP-PMT: No ~ 22 cm^{-1}** & **Npe ~ 20**.
- **BaBar DIRC design**: **No ~ 30 cm^{-1}** & **Npe ~ 27**.

TOF detector

Final goal for the Super-B TOF system:
reach a timing resolution of ~20 ps

However, in the R&D stage we want to see true limits,
so some presented results will be much better.

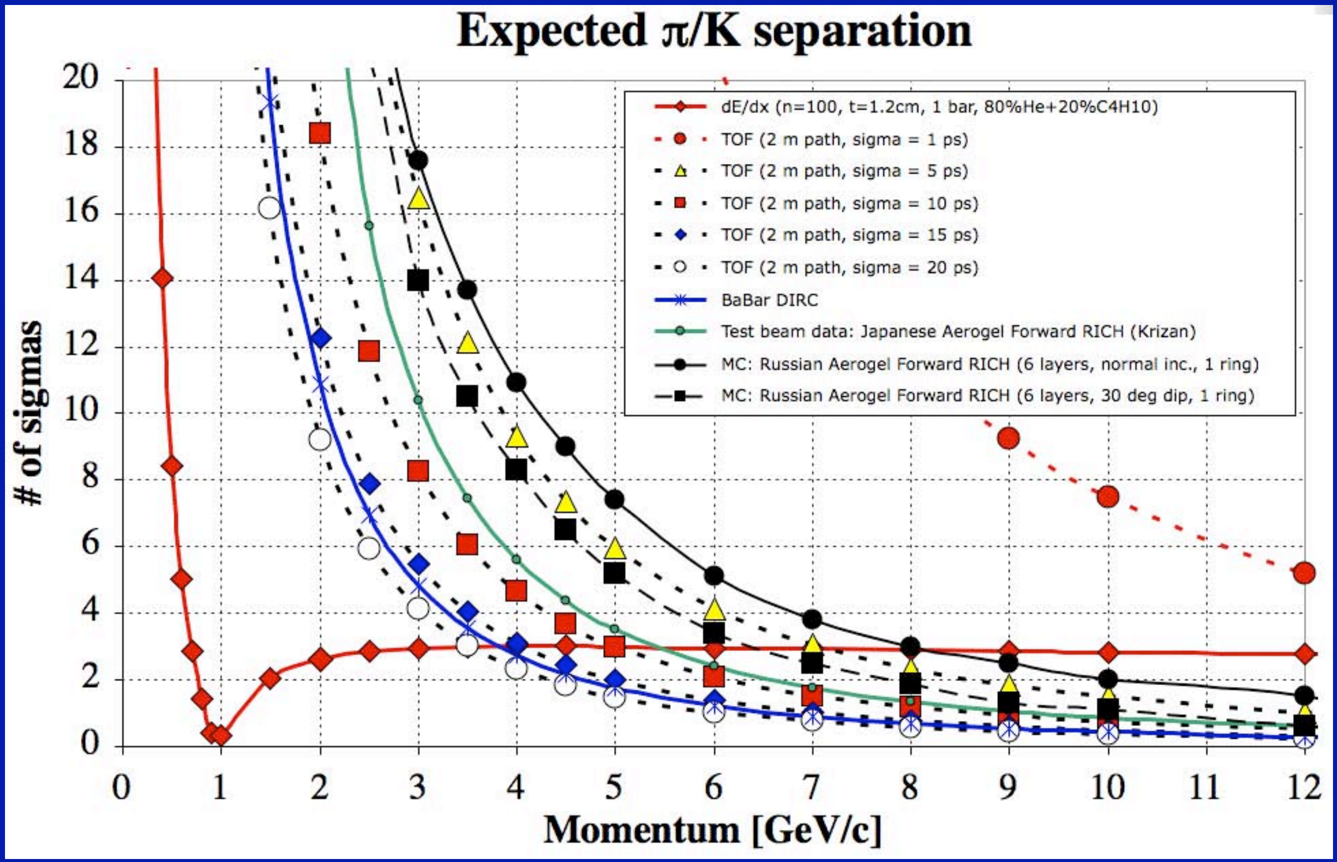
Systematic errors

- **Calibration:**
  - Laser diode start up instability (takes ~30 min before it is stable)
  - Laser diode temperature stability
  - TDC linearity stability
  - Keep track of jumps in t_o
- **Electronics:**
  - CFD & QTNT method vs. Waveform analysis
  - "Sleep-wake up" ADC effect (is ADC sensitive to rate ?)
- **MCP-PMT:**
  - Non-uniform MCP gain response
  - Cross-talk, ringing effects on boundary pads
  - Deflection of the MCP front window
  - Magnetic field effects (lowering of gain, sensitivity to angles, etc.)
  - Aging effects.
- **Tracking:**
  - Vertexing, track length (multiple scattering contribution, etc.)
  - START time (~12 ps contribution due to a bunch length, which is: σ ~4 mm)

Timing at a level of σ ~15-20 ps can start competing with the RICH techniques

Example of various Super-B factory PID designs:

Calculation done for Flight Path Length = 2m



- **A TOF detector with ~20ps resolution will be slightly worse than the Babar DIRC, much better than dE/dx, but worse than the Aerogel RICH.**

Setup with two MCP-PMTs

Control unit

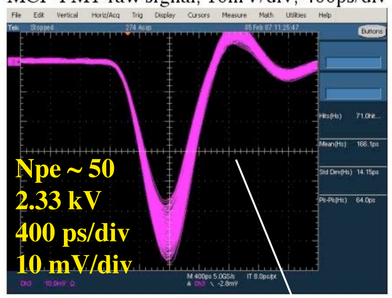
PiLas

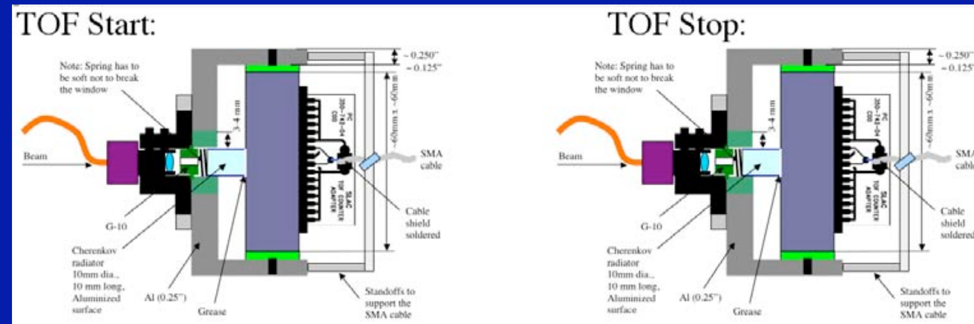
635 nm

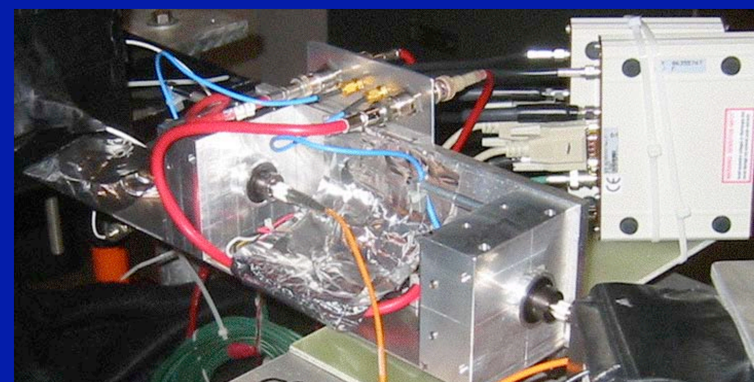
Laser diode

Fiber splitter

MCP-PMT raw signal, 10mV/div, 400ps/div







MCP_start

Ortec 9327 Amp/CFD

MCP_stop

Ortec 9327 Amp/CFD

TAC 566

START

STOP

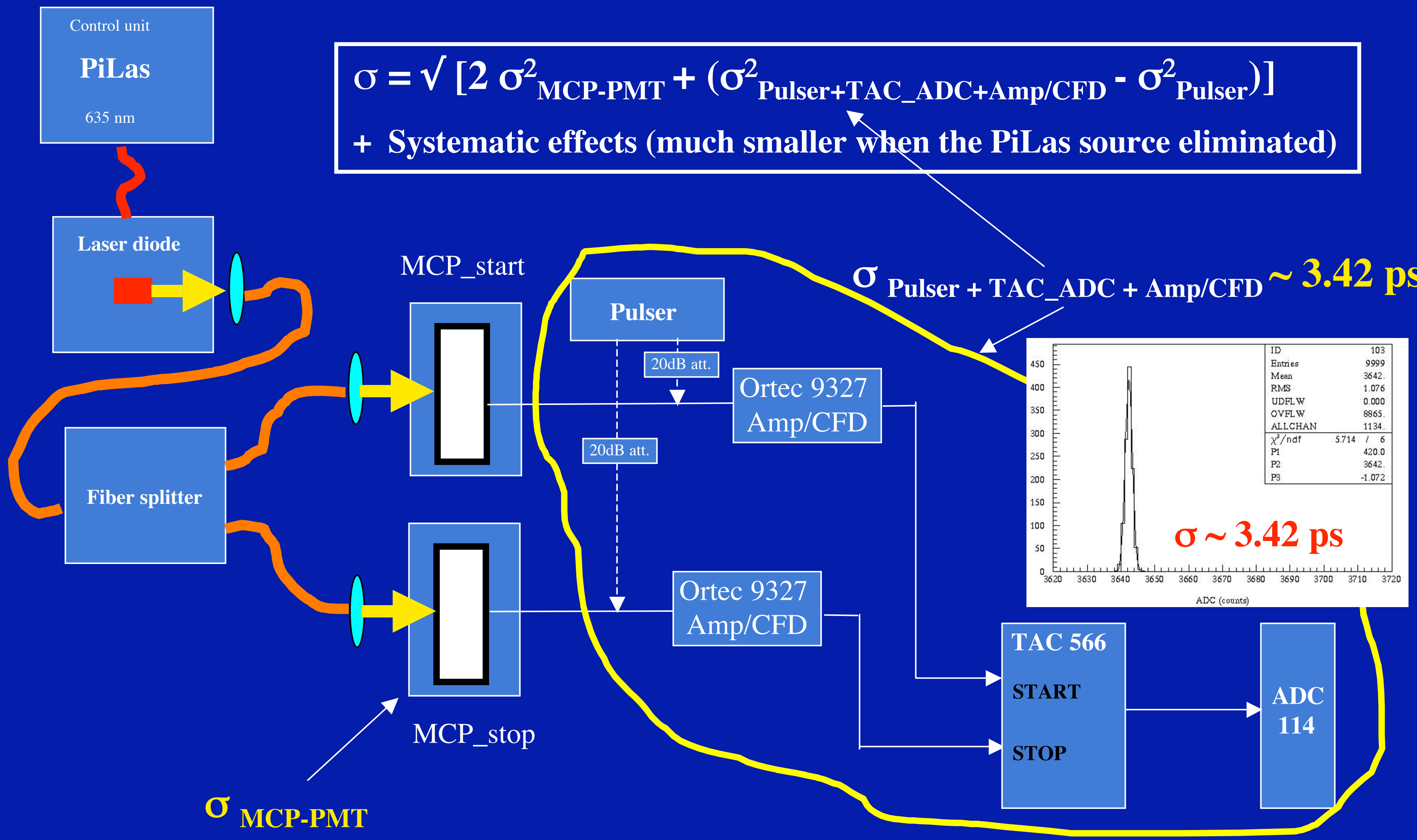
ADC 114

Running conditions:
1) Low MCP gain operation ($<10^5$)
2) Linear operation
3) CFD discriminator
4) No additional ADC correction

Calibration of the electronics

$$\sigma = \sqrt{[2\,\sigma^2_{MCP\text{-}PMT} + (\sigma^2_{Pulser+TAC\_ADC+Amp/CFD} - \sigma^2_{Pulser})]}$$

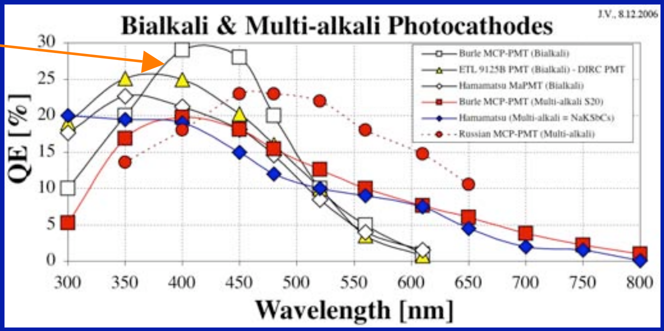
+ Systematic effects (much smaller when the PiLas source eliminated)



The best result in the world !

What resolution do we expect to get ?

- A calculation indicates **N_{pe} ~50** for **1 cm-long** Fused Silica radiator and assuming the Burle/Photonis Bialkali QE of the next graph:



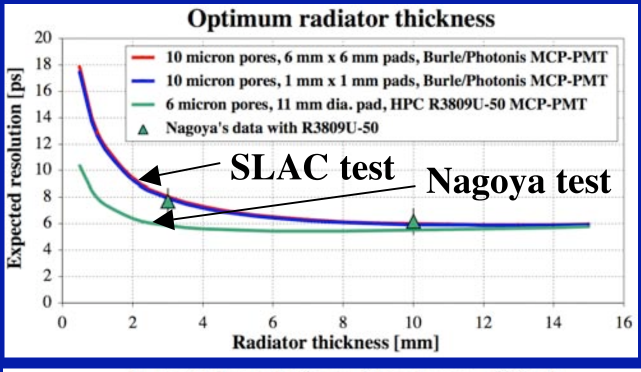
- **Expected resolution:**

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

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

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

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

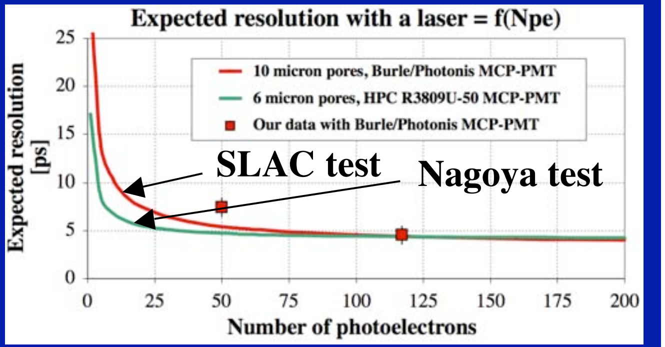


b) Laser (N_{pe} ~ 50 pe$^-$):

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

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

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

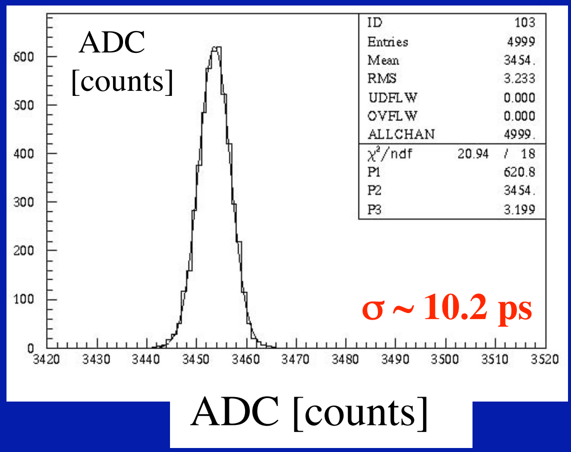


SLAC test: σ_{TTS} (Burle MCP-PMT, 10µm) ~ 27 ps

Nagoya test: σ_{TTS} (HPC R3809U-50, 6µm) ~ 10-11 ps

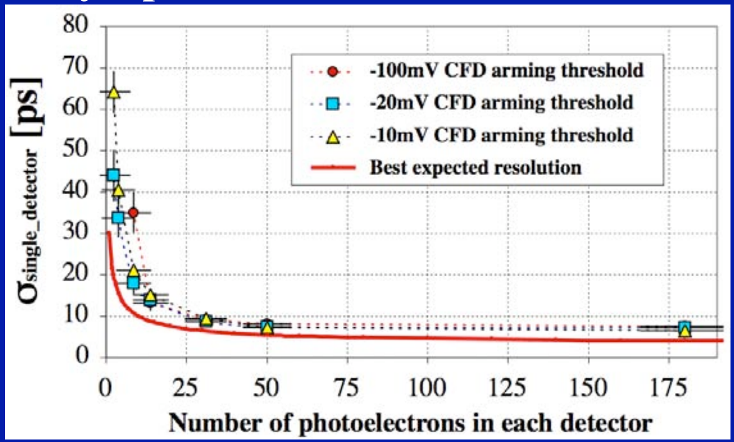
Results with the laser diode

Two detector resolution (Npe ~ 50 pe each):

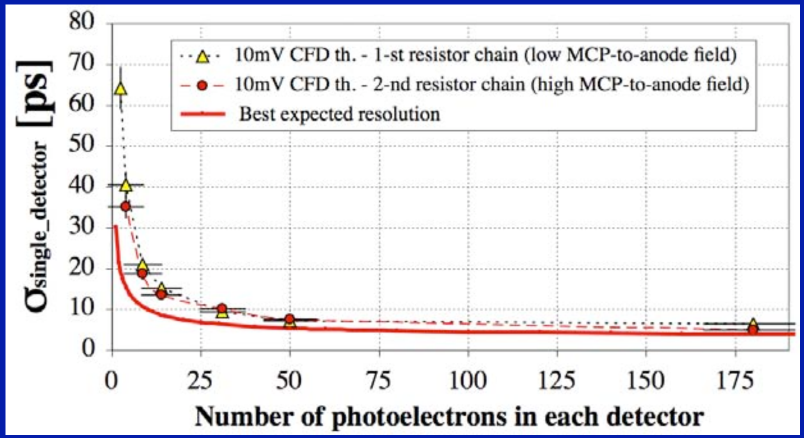


$\sigma_{\text{single detector}} \sim (1/\sqrt{2})\ \sigma_{\text{double detector}}$
~ 7.2 ps

Vary Npe and the CFD threshold:

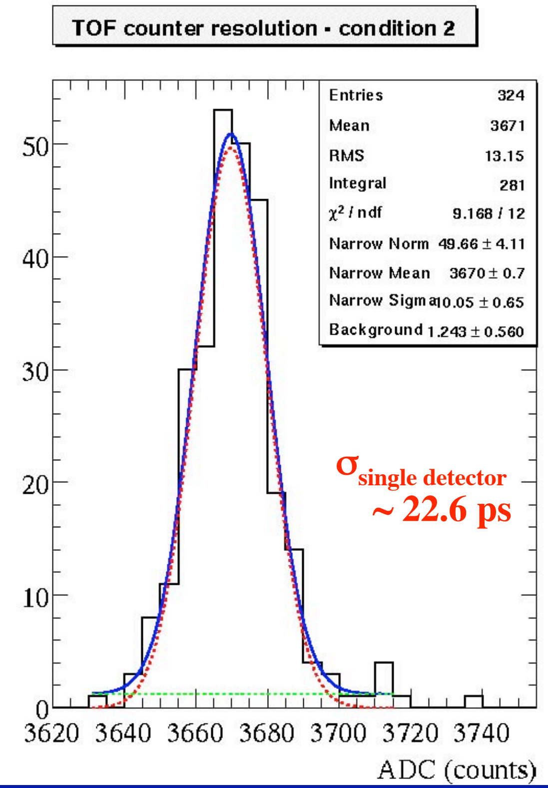


Vary Npe and $E_{\text{MCP-to-Anode}}$:



- Two Burle/Photonis MCP-PMTs with 10 μm MCP holes.
- Ortec 9327Amp/CFD & TAC566 & 14 bit ADC114 (Electronics calibration: $\sigma_{\text{Pulser + TAC\_ADC + Amp/CFD}} \sim 3.42$ ps)

Results in the test beam



Measure:

$\sigma_{\text{single detector}} \sim (1/\sqrt{2})\ \sigma_{\text{double detector}}$
~ 22.6 ps

Expect: a) Npe ~ 50 pe$^-$ in the beam

b) $\sigma \sim 7$ ps for 10 mm radiator

Why the result is worse than expected ? :

- **Poor reflectivity of the radiator's Al coating created a non-uniform number of photoelectrons => This created lower Npe, and the pulse height variation, which the CFD would not correct out.**
- **The CFD timing was not corrected by ADC measurement.**

What next ?

- **Can we have a test beam at SLAC in 2008 ?**
  - John Seeman believes that this year we have a chance, as the LCLS is not yet ready.
  - Therefore, perhaps, with a bit of luck we can try to aim for May & September runs.

- **Plan for the next FDIRC test:**

a) Gary & Larry's next version of the prototype electronics on the MCP in slot 4, and compare it to our present electronics in slots 3 & 5. This could be ready in May.

b) Gary's BLAB2 new electronics with a new ASIC design. This may be ready in August.

- **Plan for the next TOF test:**

a) New quartz radiators (Al coating will be done by Photonis).

b) Add a pulse height correction to the CFD timing:

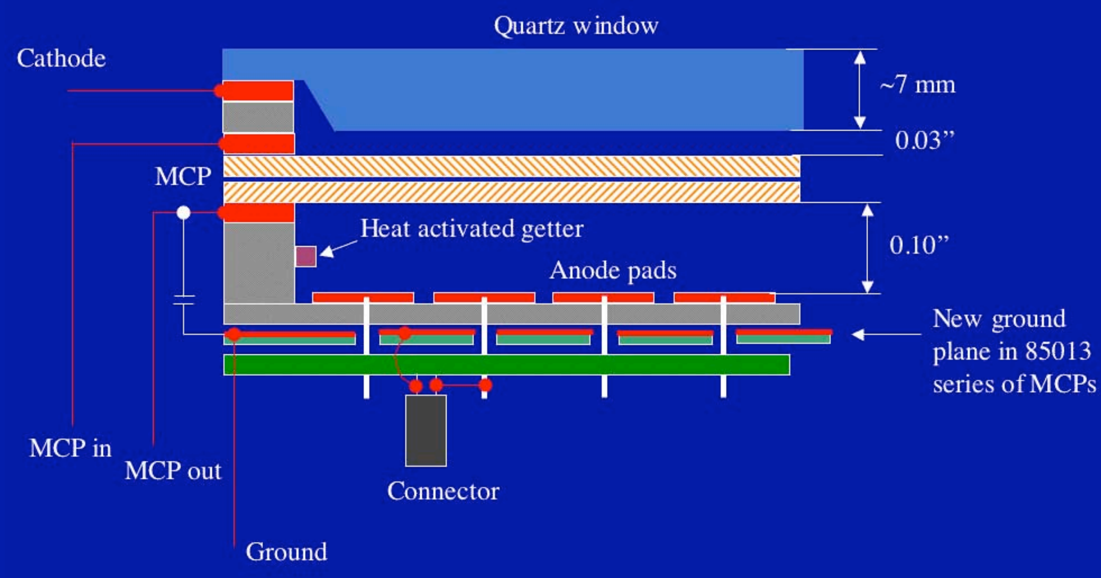
- Modify the existing setup by adding a QTNT module & Hamamatsu amplifier & Phillips ADC.
- Split the MCP signal and send one branch to Larry's new test board with a waveform digitizing electronics. One needs two channels only for this particular test.

c) Two new MCPs, which Burle is willing to deliver for free (an old debt).

- Gary's new BLAB2 electronics. This could be ready for the September run.

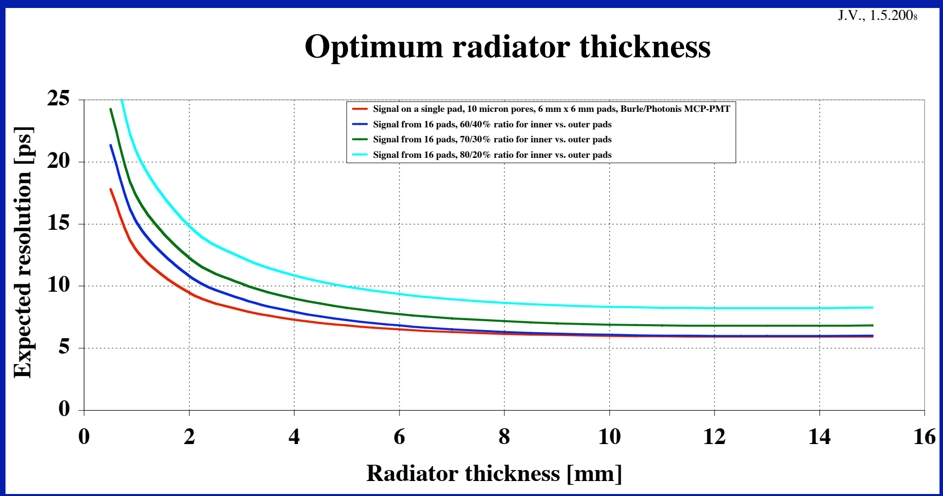
d) If the test is done at SLAC, **may add two small trigger counters**, to help to define the beam spot.

TOF counter detector - next step



- **Two new tubes from Burle, which they are willing to deliver soon (March - May ???).**
- C/pixel ~ 5 pF => cannot gang together 16 pixels as originally thought
- **=> need many more channels**

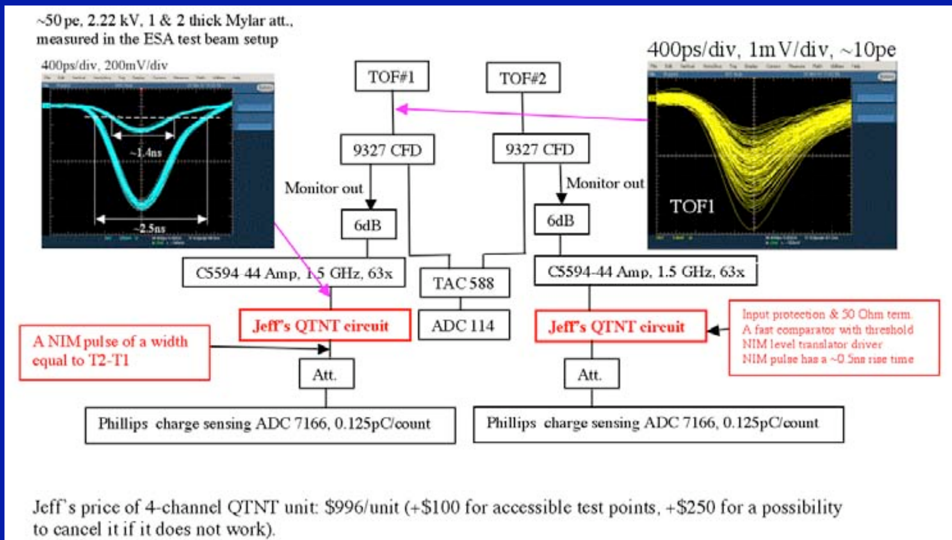
Signal will be distributed on 16 pads:



- **Signal will be spread over 16 pads.**
- **Due to extra noise, the performance slightly worse than a 4-pad detector used so far.**

R&D on FDIRC & TOF electronics

1)



- **CFD & time-over-threshold ADC correction to timing.**
- **QTNT module made by Jeff Peck.**
- One could also send a C5594-44 amplifier signal directly to the Phillips ADC; however, one then integrates the wiggles after the signal, which is not a good idea. One could make a special run to confirm it. However, a long ADC gate is a bad idea in a long run, as one integrates a lot of noise. Using the QTNT method is a clean way to do it.
- **One needs to develop a circuit equivalent to this scheme.**

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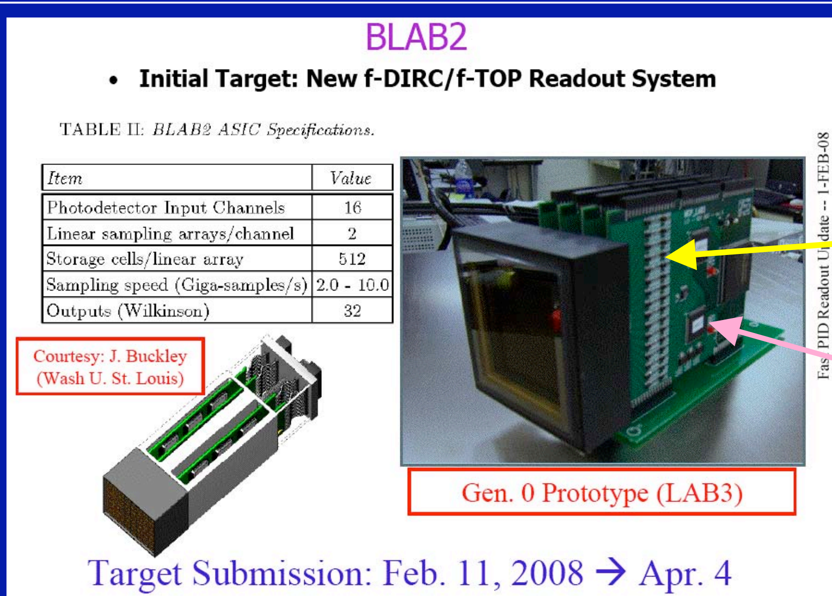
2)



- **Waveform digitizer (Gary Varner)**
- ASIC design almost done. Expect to have a prototype in summer.
- Amplifiers dominate presently the board space (in next version they will be part of the ASIC chip).
- Readout ASIC is tiny (14x14mm/16 ch).
- Signal: ~ 100 mV, noise: ~1 mV.
- **TOF works with 30-50 pe/track.**
- **FDIRC works with 1 pe/photon hit.**

Appendix

DIRC options

	BaBar DIRC	Option 1	Option 2	Option 3	Option 4
PMT type	ETL 9125B	equivalent	upgraded	MaPMT 8500	MaPMT 9500
No of pixels/PMT	1	1	1	8x8 = 64	16x16 = 256
PMT rise time	~1.5 ns	~1.5 ns	0.5 - 1.0 ns	~ 0.5 ns	~ 0.7 ns
PMT σ_{TTS}	1.6 ns	~1.5 ns	0.25 - 0.5 ns	~150 ps	~220 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	~10 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	possibly	possibly
Integration	Custom front end	similar	similar	ASIC for 64 ch.	ASIC for 256 ch.
Latency	12 μs	12 μs	12 μs	12 μs	12 μs
Max. DAQ rate	10 kHz	100 kHz	100 kHz	100 kHz	100kHz
Data link	1.2 Gbit fiber	upgrade	upgrade	upgrade	upgrade
No of channels	12,000	12,000	12,000	64,000	256,000
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 DIRC" with a new SOB - Use flat panel H-8500 MaPMT (with a waveform digitizer a'la Gary Varner)**
4. **"Focusing DIRC" with a new SOB - Use flat panel H-9500 MaPMT (with a waveform digitizer a'la Gary Varner)**

FDIRC photon detector candidates - options 3 & 4

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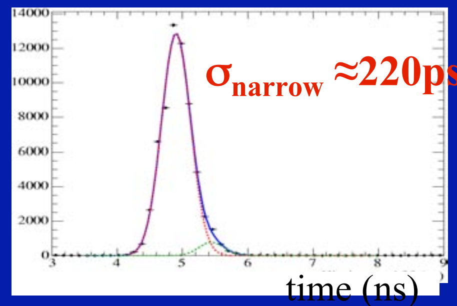
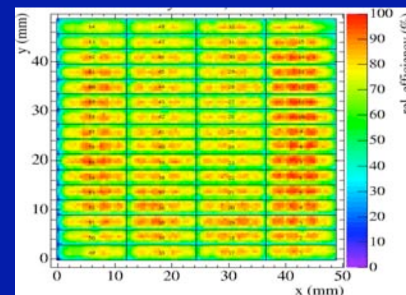
1) Hamamatsu H-9500 Flat Panel MaPMT (256 pixels, 3x12mm pad, σ_{TTS} ~220ps)

#1

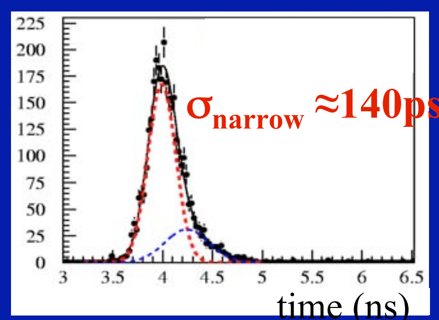


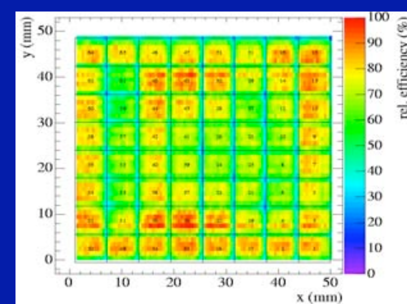


Cost:
Detectors: \$3.6M/1000
Electronics: \$1.3M/1000

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

#2





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

- **Timing resolutions were obtained using a fast laser diode in bench tests with single photons on a pad center.**
- **Note:** **a) Cost of option 1: Detectors:** \$1.44M/120000 (HPK) or \$1.62M/120000 (ETL) , **Electronics:** \$1.1M/12000
  a) Cost of option 2: Detectors: \$2.94M/12000 (HPK) or \$1.68M/12000 (Burle), **Electronics:** \$1.1M/12000

TOF options

	Option 1	Option 2
PMT type	Burle MCP-PMT, 10 μm	Burle MCP-PMT, 10 μm
No of pixels/PMT	8x8 = 64	8x8 = 64
Input capacitance/pix	~ 5 pF	~5 pF
PMT rise time	~ 200-400 ps	~ 200-400 ps
Expected PMT gain	~8x10^4 @0kG, ~4x10^5 @16kG	~8x10^4 @0kG, ~4x10^5 @16kG
PMT σ_{TTS}	~30 ps	~30 ps
No of photoelectrons	~ 50 / 1 cm of radiator	~ 50 / 1 cm of radiator
Raw pulse height/50pe$^-$	~ 50 mV	~ 50 mV
Particle track rate/PMT	A few kHz	A few kHz
TDC/ADC equiv. resol.	5-10 ps/count	5-10 ps/count
Waveform analysis	no	yes
Amplifier gain	~10x	~10x
Effective front end BW	0.7-1 GHz	0.7-1 GHz
Timing scheme	CFD + ADC correction	Waveform digitization (~10 GSa/s)
Latency	12 μs	12 μs
Max. DAQ rate	100 kHz	100 kHz
No of channels	64,000	64,000
No of detectors	1000	1000

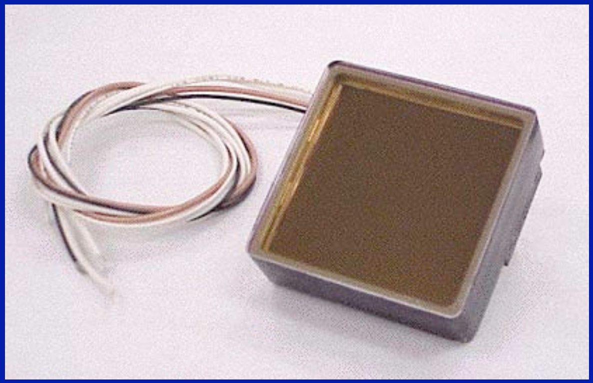
Options:

1. **TOF with CFD & Time-over-threshold ADC correction (a'la Jeff Peck, retired ORTEC engineer)**
2. **TOF with waveform digitization (a'la Gary Varner)**

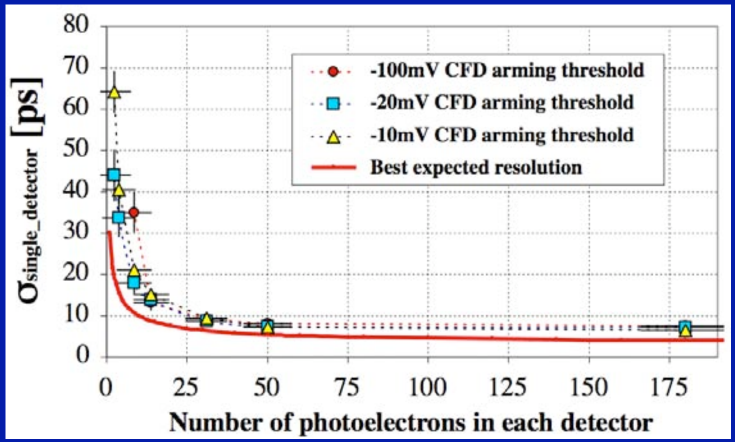
TOF photon detector candidate

SLAC-PUB-13073

Burle/Photonis MCP-PMT (10µm, 64 pixels, 6x6mm pad, σ_{TTS} ~30ps)



Vary Npe and the CFD threshold:



Cost:
Detectors: \$2.25M/1000
Electronics: \$1.4M/1000

- **Timing resolutions were obtained using a fast laser diode.**
- **In the beam, so far, we have reached a resolution of σ ~23 ps (can be improved).**
- **A goal in Super-B is to reach a final resolution of σ ~20ps, with all the corrections.**