Development of the Focusing DIRC prototype

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Collaborators:

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Technicians who built it: M. McCulloch, B. Reif

Content

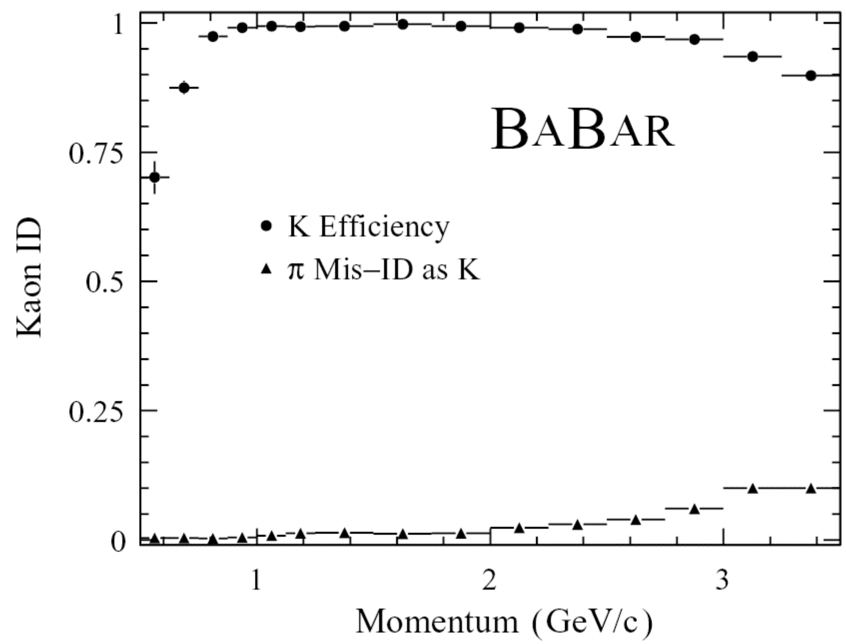
- **Motivation**
- **Design of the prototype**
- **Status of the analysis of the test beam data**
- **Next steps**

Test beam runs with 10GeV e^-

- **Run 1** - finished a few months ago
- **Run 2** - just finished with “improved” beam optics
- **Run 3** - will take more data sometime in spring next year with better photon detectors, as well as and all improvements we get from the present data analysis

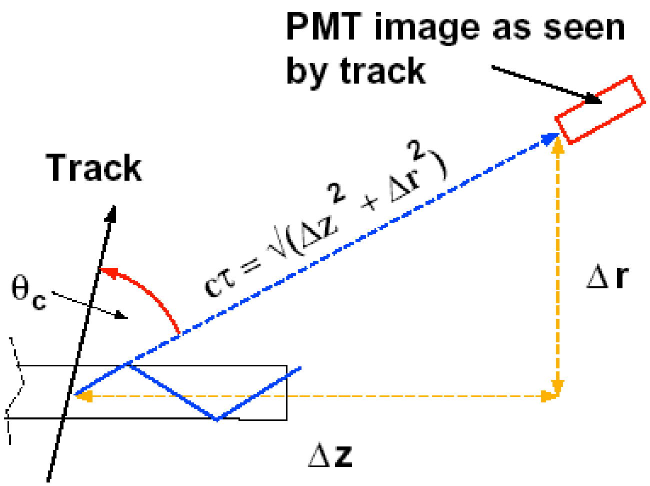
- **All results from the data analysis presented in this talk are preliminary based on Runs 1 & 2.**

Motivation



- **BaBar DIRC is a very successful detector as this plot proves.**
- We thought that we should be in a position to propose a DIRC upgrade for the Super B-factory, which sould have a comparable or better performance, be less sensitive to background, and, perhaps, be able to correct the chromatic error contribution to the Cherenkov angle.

DIRC principle



- A concept invented by B. Ratcliff
- **TOP(Φ,θ_c) = [L/v_g(λ)] k_z(Φ,θ_c)**

  θ_c - Cherenkov angle,

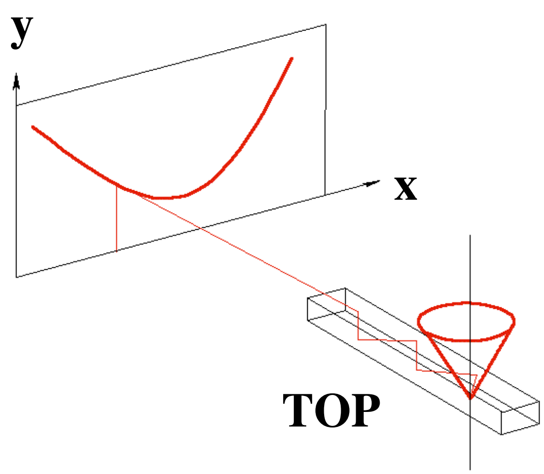
  L - distance of light travels in the bar,

  $v_g(\lambda)$ - group velocity of light,

  λ - wavelength , and

  $k_z(\Phi,\theta_c)$ - z-comp. of the unit velocity vector.
- To determine the Cherenkov angle θ_c, one measures (a) a track position, (b) Δz and Δr ($\equiv \Delta y$), and (c) a photon time-of-propagation (TOP). This over-determines the triangle.
- In the present BaBar DIRC, the time measurement is not good enough to determine the Cherenkov angle θ_c or even correct the chromatic error. The time is, however, used to reduce the background.

Various approaches to imaging methods



BaBar DIRC: x & y & TOP

- x & y is used to determine the Cherenkov angle
- TOP iw used to reduce background only

Focusing DIRC prototype: x & y & TOP

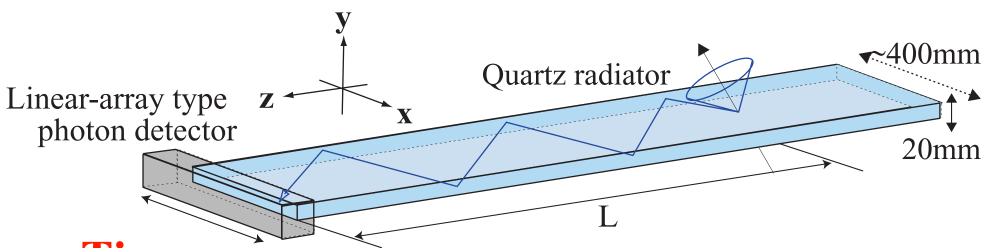
- x & y is used as in BaBar DIRC
- TOP can be used to determine the Cherenkov angle for longer photon paths (gives a better result)
- Requires large number of pixels

TOP counter: x & TOP

- x & TOP is used to determine the Cherenkov angle
- TOP could be used for an ordinary TOF
- In principle, more simple, however, one must prove that it will work in a high background environment

Examples of two "DIRC-like" detectors

TOP counter (Nagoya):



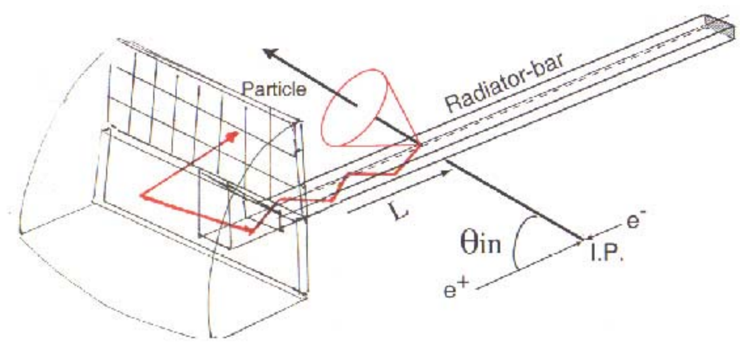
x, Time

- **2D imaging:**

  a) x-coordinate

  b) TOP ($\sigma < 100ps$).

Focusing DIRC prototype (SLAC):



x, y, Time

- **3D imaging:**

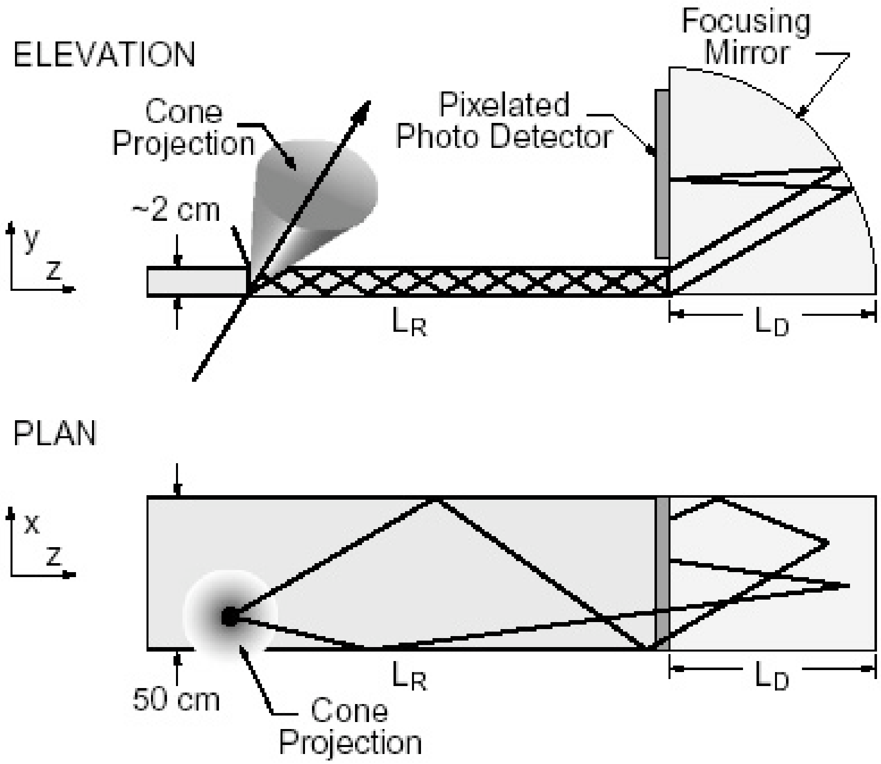
  a) x-coordinate

  b) y-coordinate

  c) TOP ($\sigma < 130ps$).

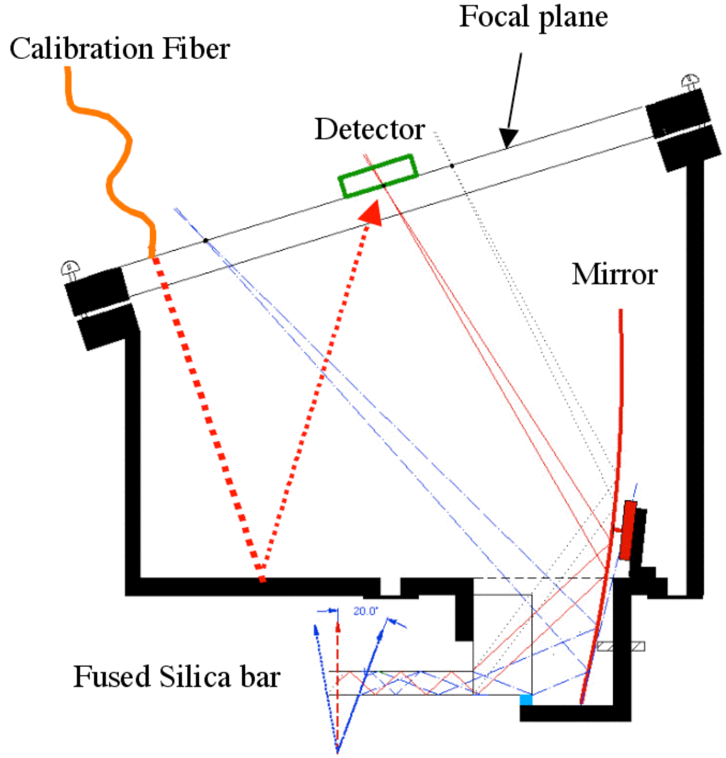
Focusing DIRC detector - "ultimate" design

B. Ratcliff, Nucl.Instr.&Meth., A502(2003)211



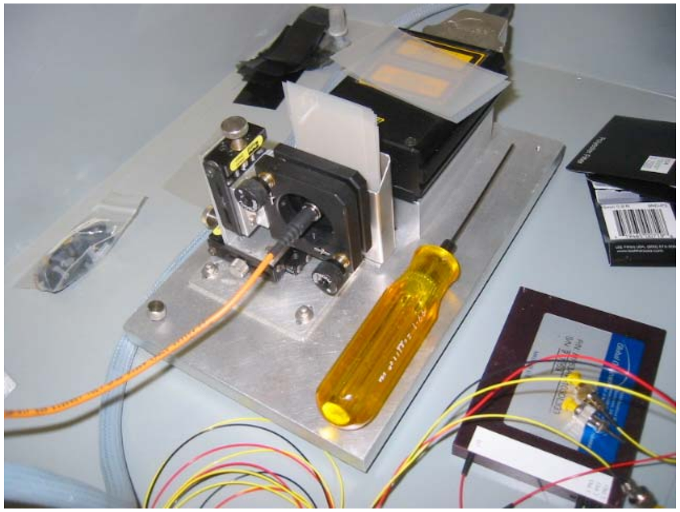
- **Goal: 3D imaging using x,y and TOP, and wide bars.**
- **The detector is located in the magnetic field of 15 kG.**

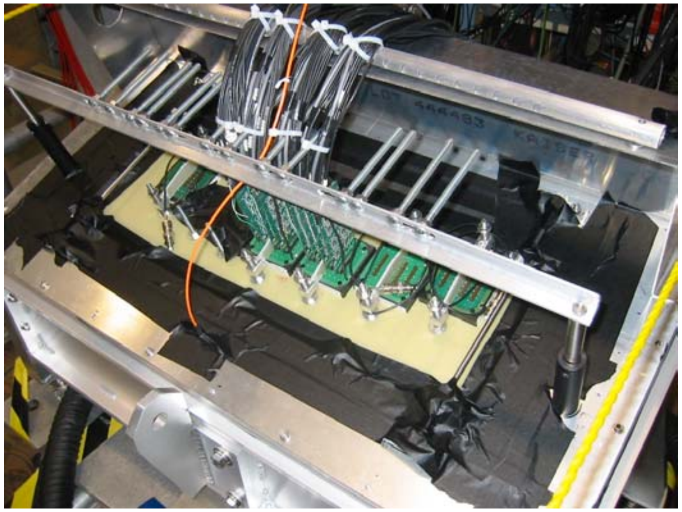
Focusing DIRC prototype



- Detectors sit in the focal plane
- Spherical mirror corrects quartz bar thickness. Used spherical mirror from CRID
- KamLand oil makes it very affordable. Its refraction index matches that if fused silica very well.
- The focused fiber light from the PiLas pulser enters through the window and reflects from the etched Al surface to all detectors. This is extremely good way to calibrate the system, to find cable offsets, and verify that all is well. I am 100% sure that without the PiLas laser diode we would not succeed.

PiLas laser diode and fiber optics

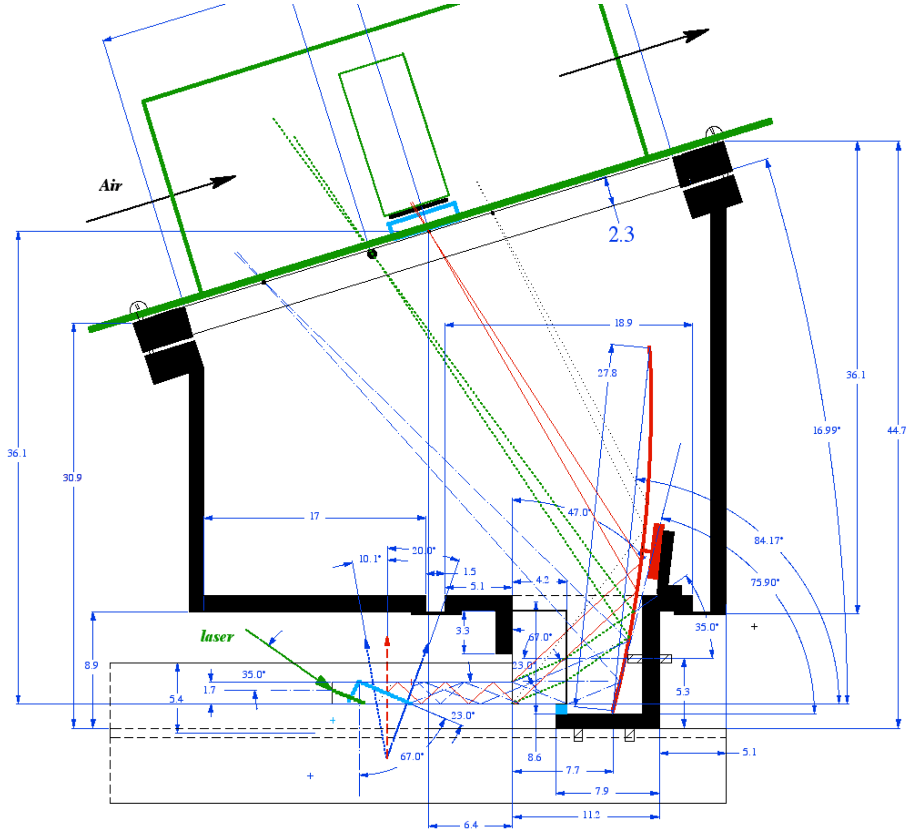




- **Achieved 40-70ps resolutions with:**
  - 635 and 407nm wavelengths
  - 63μm multi-mode fiber diameter
  - 5 & 10 m fiber lengths
  - Fiber 1-to-3 splitter
  - “Home-made” alignment with x&y small stage
  - Mylar attenuators to get single photons
  - CFD discriminator or TDC/ADC electronics

Optical design

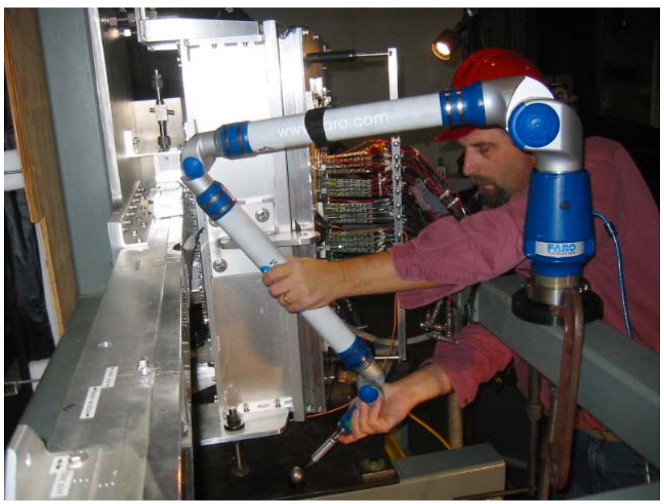
Design by ray tracing:



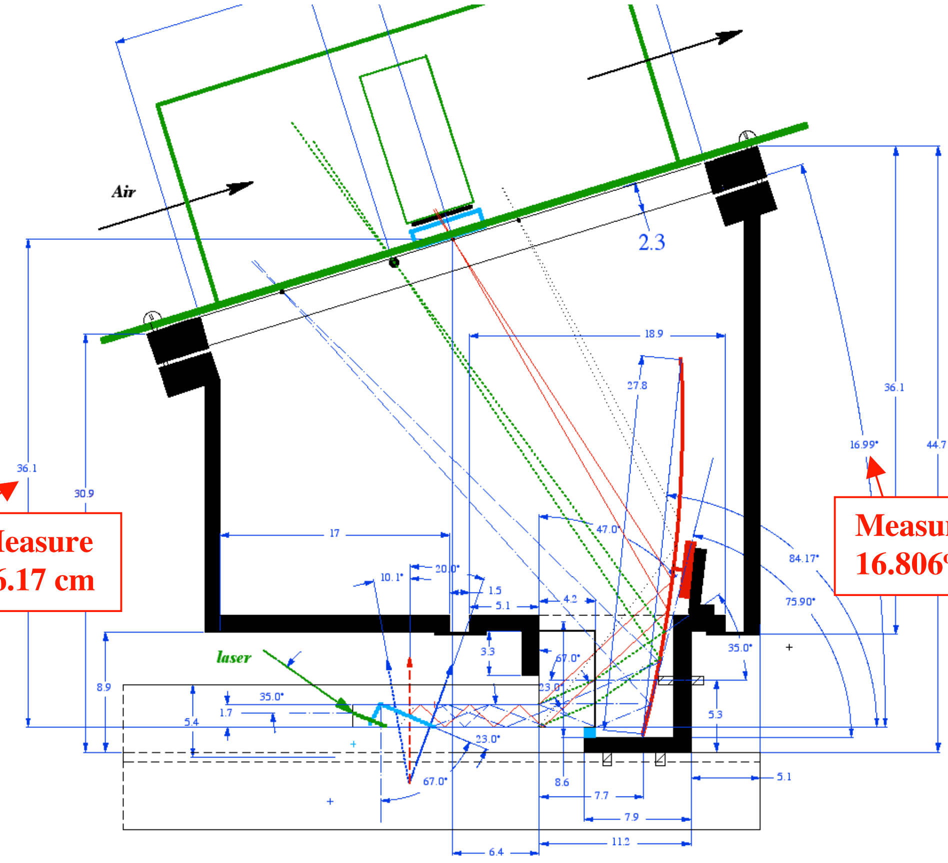
- We send the beam perpendicularly to the bar, and position detectors along the contour of the Cherenkov ring.
- **Red line** (with oil) - running in the beam
- **Green line** (no oil) - laser check in the clean room with

Checking dimensions with the coodinate machine

Portable coordinate measuring machine:



Geometry of the detector:



Measure
36.17 cm

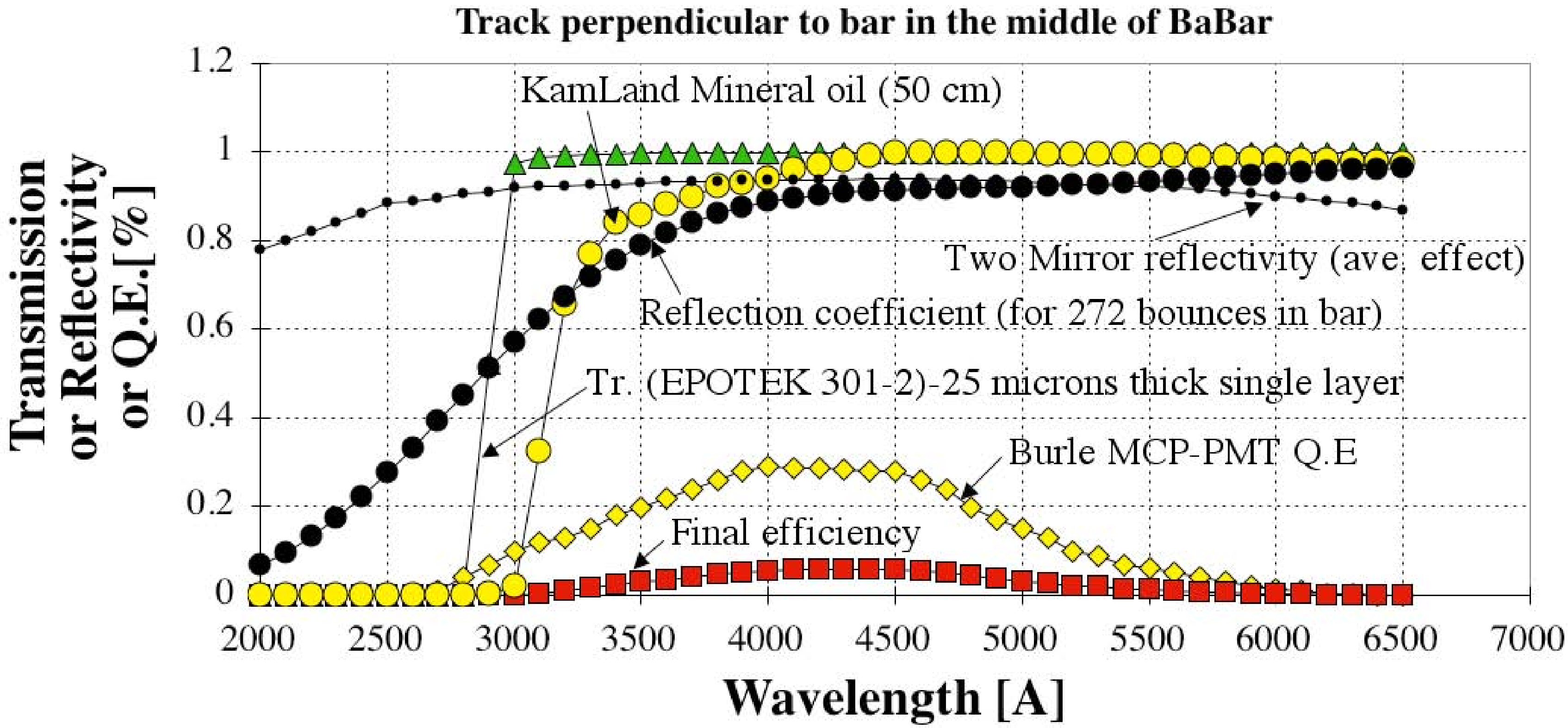
Measure
16.806°

Measure
5.93 cm

- Fixed a few mistakes…

Various efficiencies in the Focusing DIRC

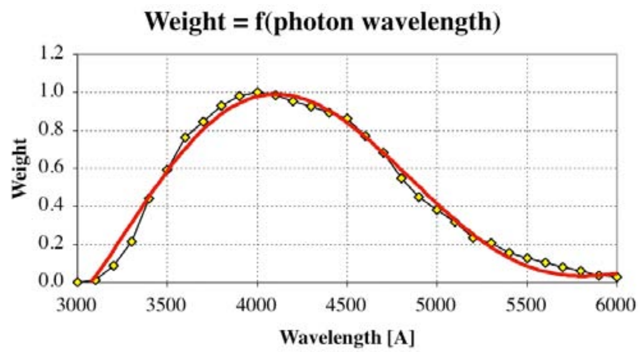
Spreadsheet calculation:

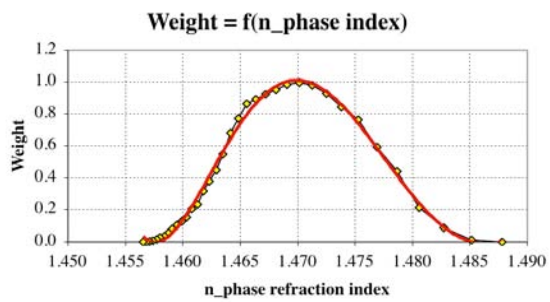


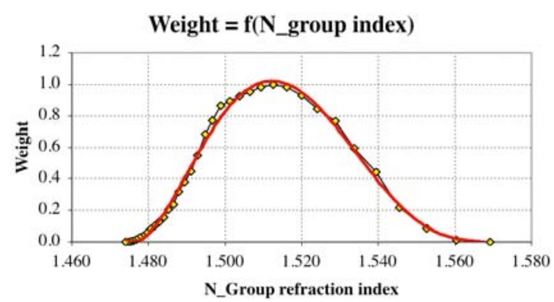
- **Assume: "Focusing DIRC prototype-like" DIRC is in the present BaBar.**
- **Burle QE peaks at higher wavelength than the Hamamatsu MaPMT or ETL PMT.**

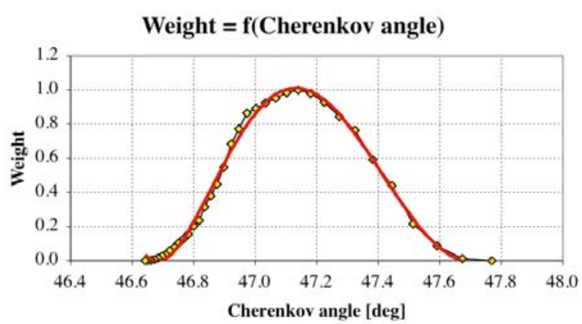
Weight functions in the Focusing DIRC

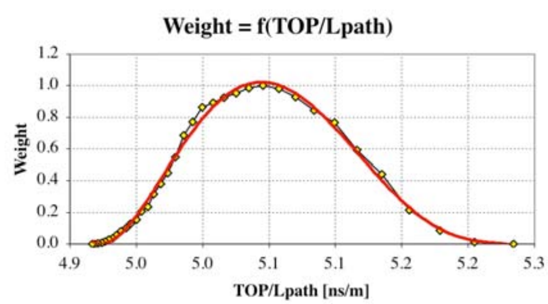
Spreadsheet calculation:





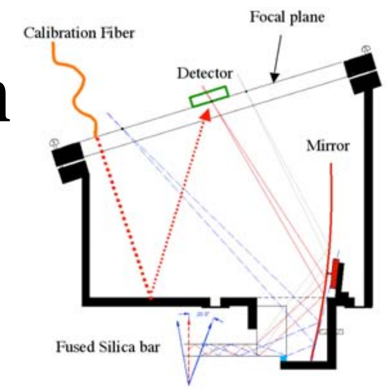




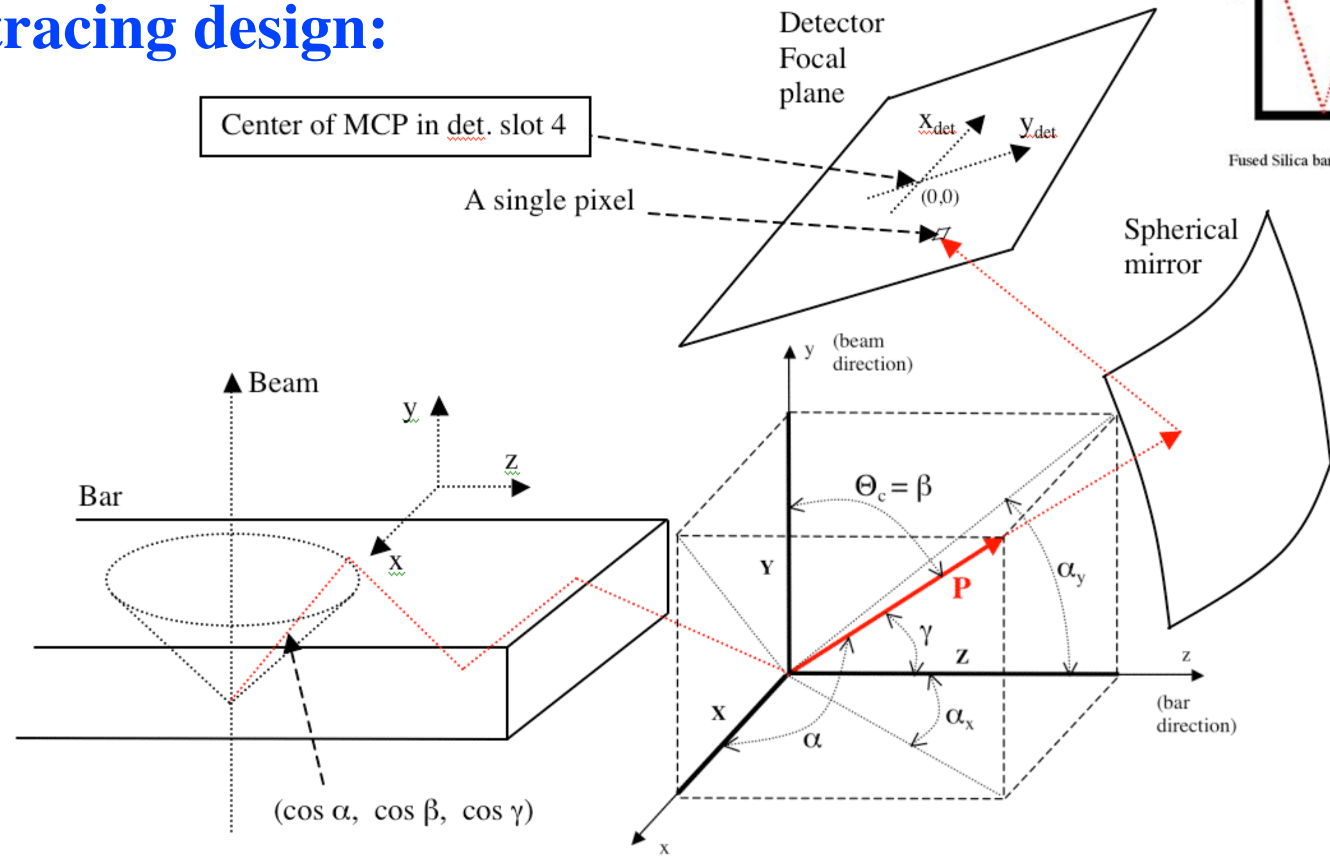


- **Focusing DIRC prototype**
- **Fold in the photon production yield of the Cherenkov photons, as well as all known efficiencies and transparencies.**
- **The most probable λ ~400nm, average 410-420nm.**

Photon path reconstruction



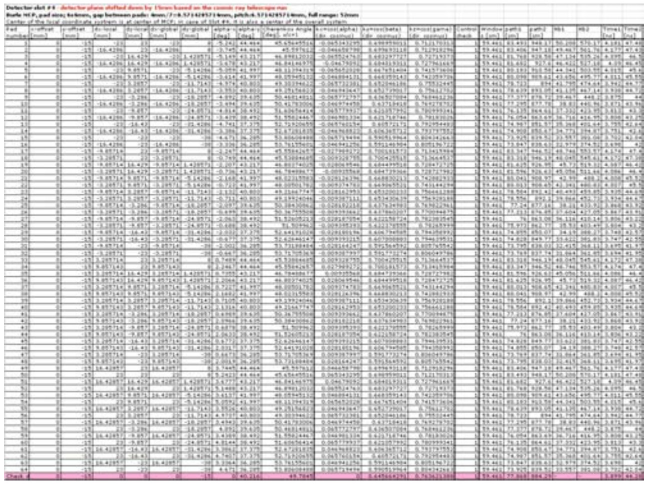
Ray tracing design:



- **Each detector pixel determines these photon parameters:**
  θ_c, α_x, α_y, cos α, cos β, cos γ, L_{path}, $t_{propagation}$, $n_{bounces}$ – for average λ.

A beautiful aspect of DIRC - predictivity of the photon propagation in the bar, if everything is right…

Spreadsheet calculation:



- **Each pad predicts the photon propagation history for average λ of ~ 410nm.**
- **Example - detector slot #4, pad #26, beam in position #1:**

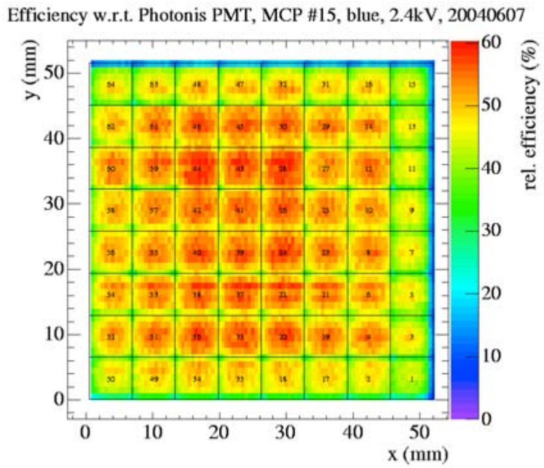
  $\theta_c = 47.662^o$, $L_{path\ 1} = 80.447$ cm, $n_{bounces\ 1} = 43$, $t_{path\ 1} = 4.028$ ns, $L_{path\ 2} = 913.58$ cm, $n_{bounces\ 2} = 489$, $t_{path\ 2} = 45.75$ ns, dT(|Peak2 - Peak1|) = 41.722 ns
- **Error in detector plane of 1mm in y-direction will cause this systematic shift:**

  $\Delta\theta_c$ ~3mrad, $\Delta L_{path\ 1}$ ~2.2mm, $\Delta t_{path\ 1}$ ~11ps, $\Delta L_{path\ 2}$ ~24.5mm, $\Delta t_{path\ 2}$ ~123ps, ΔT (|Peak2-Peak1|) ~112ps

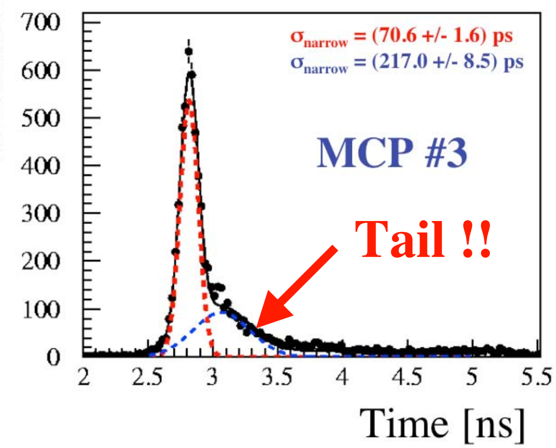
Photon detectors in the prototype (σ~70-140ps)

Burle MCP PMT (64 pixels):

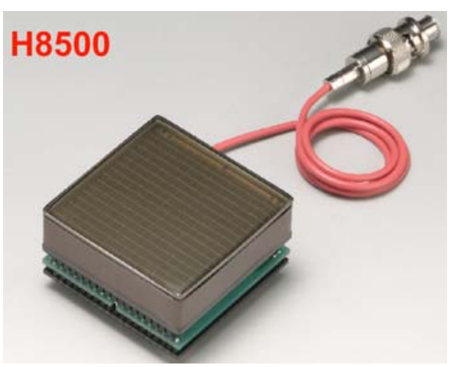
PiLas single pe calibration:

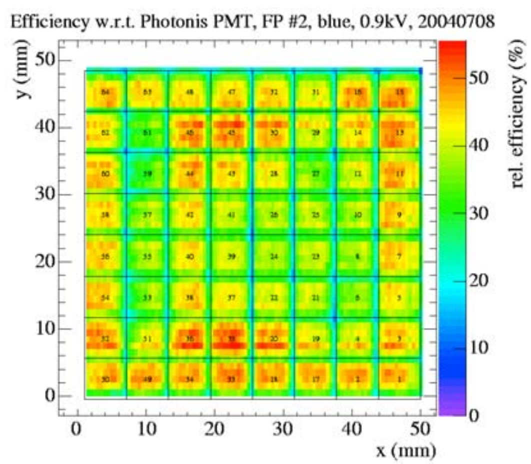


Burle 85011-501 MCP-PMT:

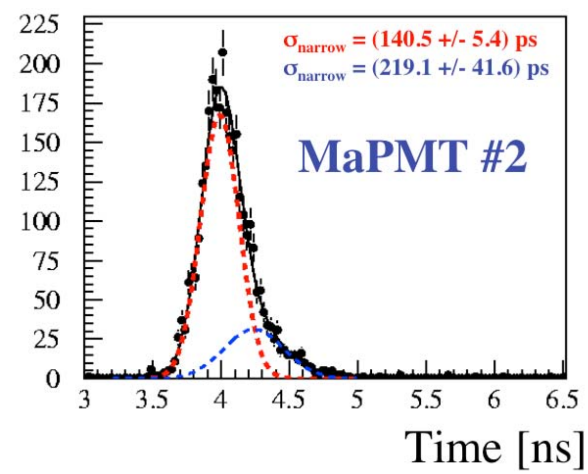


Hamamatsu MaPMT (64 pixels):

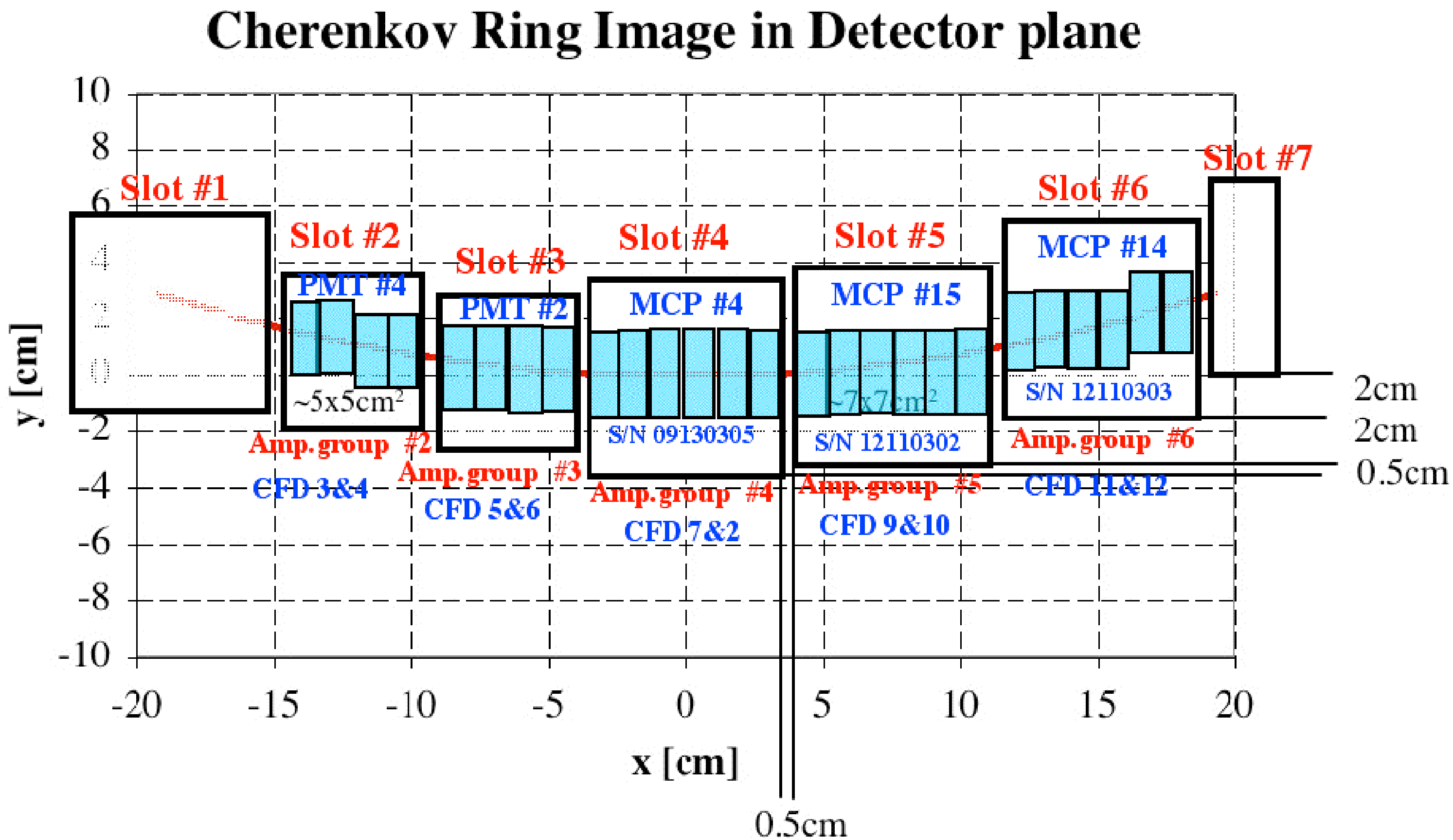




Hamamatsu Flat Panel H8500 PMT:



Distribution of detectors on the prototype

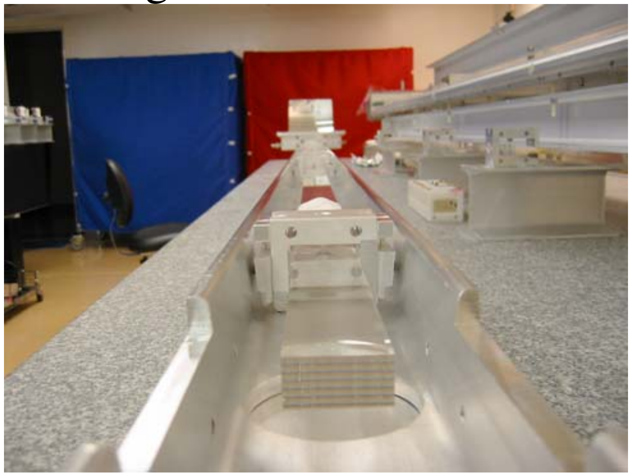


- **3 Burle MCP-PMT and 2 Hamamatsu MaPMT detectors (~320 pixels active).**
- **Only pads around the Cherenkov ring are instrumented (~200 channels).**

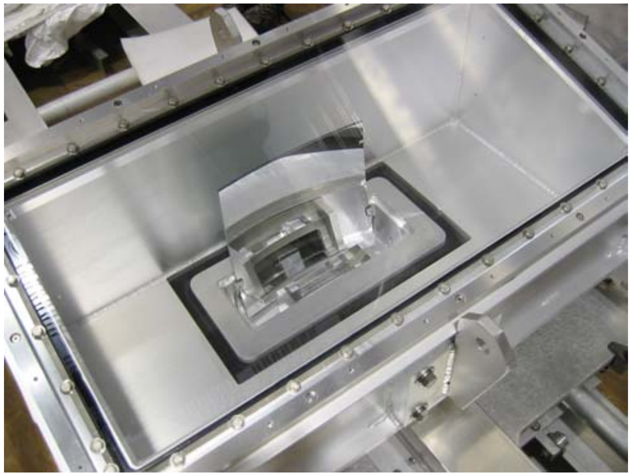
Construction of the Focusing DIRC prototype

Spherical mirror:

4m-long fused silica DIRC bar:



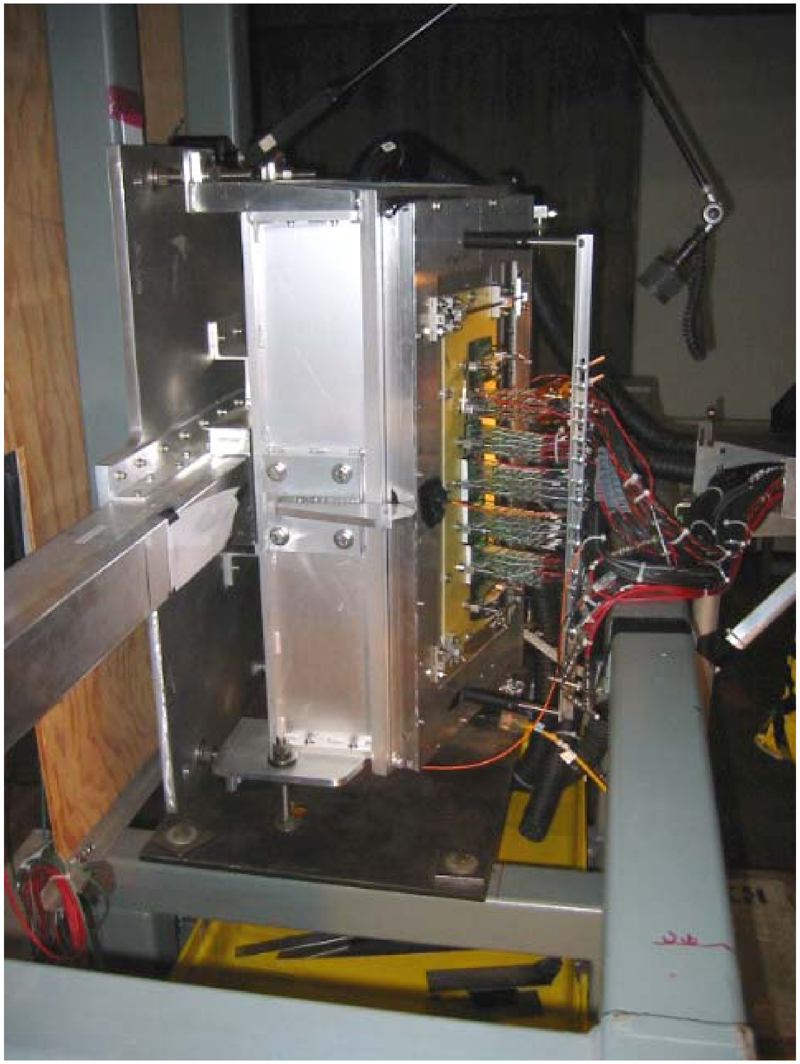
Detector filled with KamLand oil:



End block and mirror adjustement:

The Focusing DIRC prototype test beam

Electronics & cables:

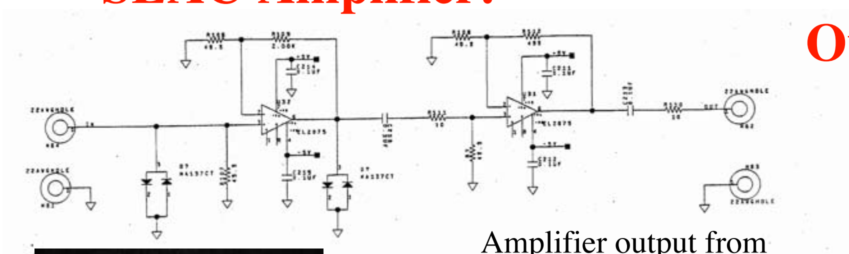


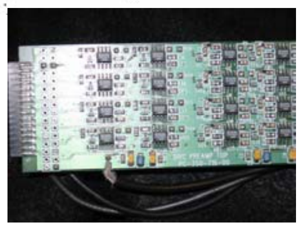
Start counters 1 &2, lead glass:

Bar can be moved transversly:

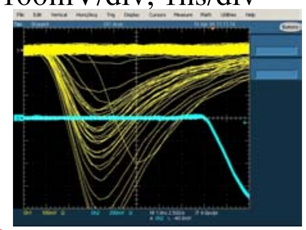
Focusing DIRC electronics

SLAC Amplifier:





Amplifier output from MCP-PMT (trigger on PiLas), 100mV/div, 1ns/div



Overall chain:

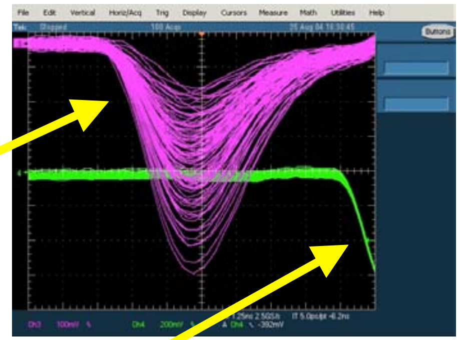
Detector

Amplifier

CFD & TAC

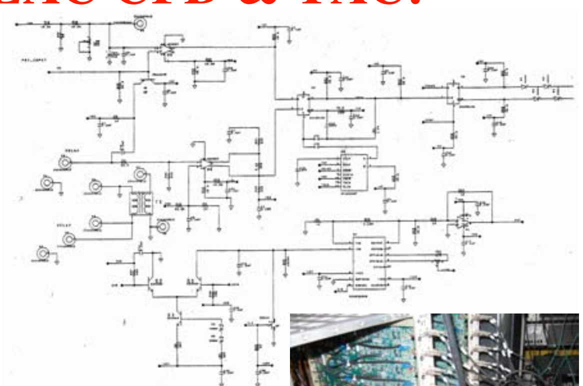
12 bit ADC

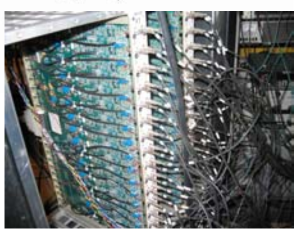
Amplifier outputs from MCP-PMT (trigger scope on CFD analog output), 100mV/div, 1ns/div



CFD analog pulse out

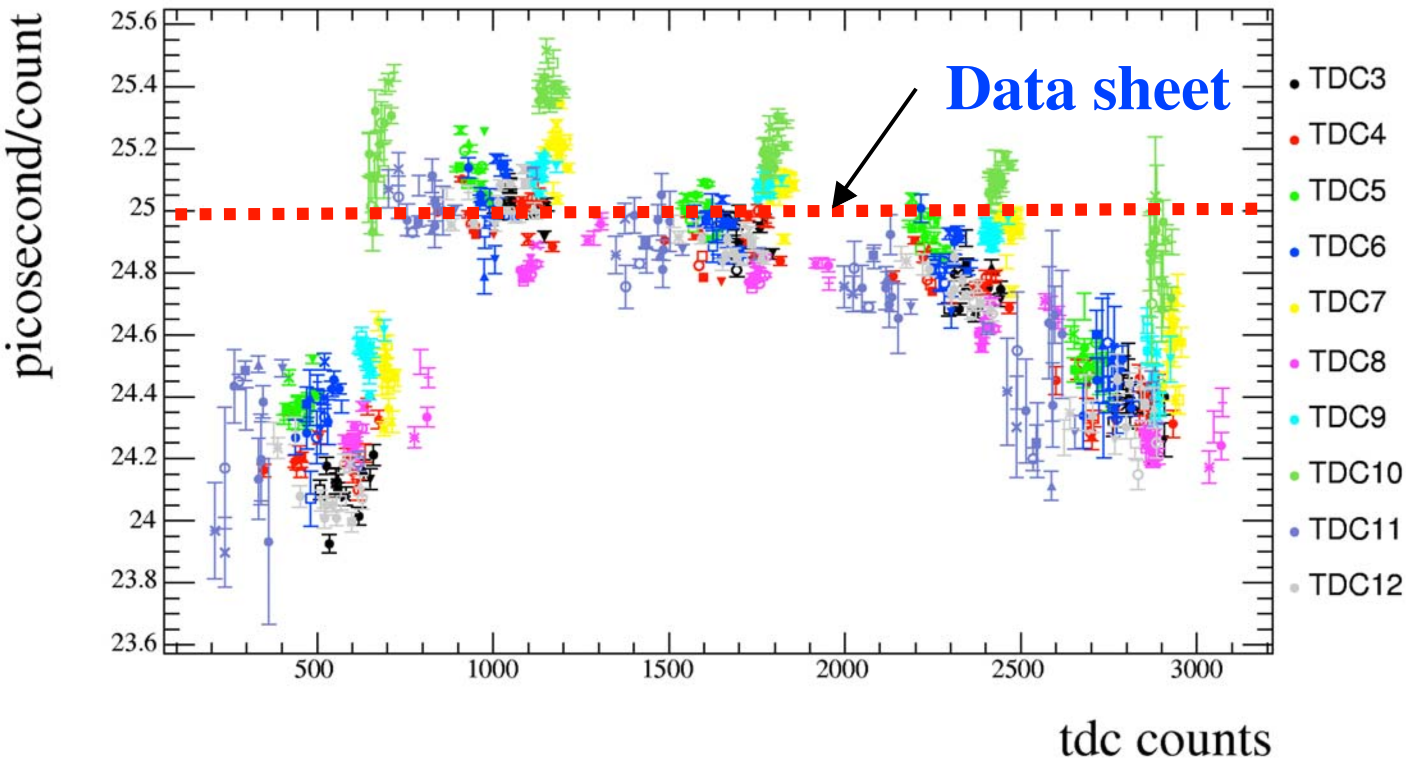
SLAC CFD & TAC:





- Signals from Burle MCP-PMT #16, P/N 85011-430. PiLas laser diode is used as a light source, and as a TDC start/stop.
- Amplifier is based on two Elantek 2075EL chips with the overall voltage gain: ~130x, and a rise time of ~1.5ns.
- Constant-fraction-discriminator (CFD) analog output is available for each channel (32 channels/board), and can be used with any TDC for testing purposes (proved to be the essential feature for our R&D effort).
- TAC circuit is based on Burr-Brown Sample/Hold SHC5320 chip.
- 32-channel/board, VME-based, 12 bit ADC, controlled by FPGA logical array. TAC/ADC system gives 25ps/count.

Phillips TDC calibration



- **Is it stable in time ? How often we have to measure this ?**
- The differential linearity measured with the calibrated cables. May have to automatize process with a precision digital delay generator if we get convinced.

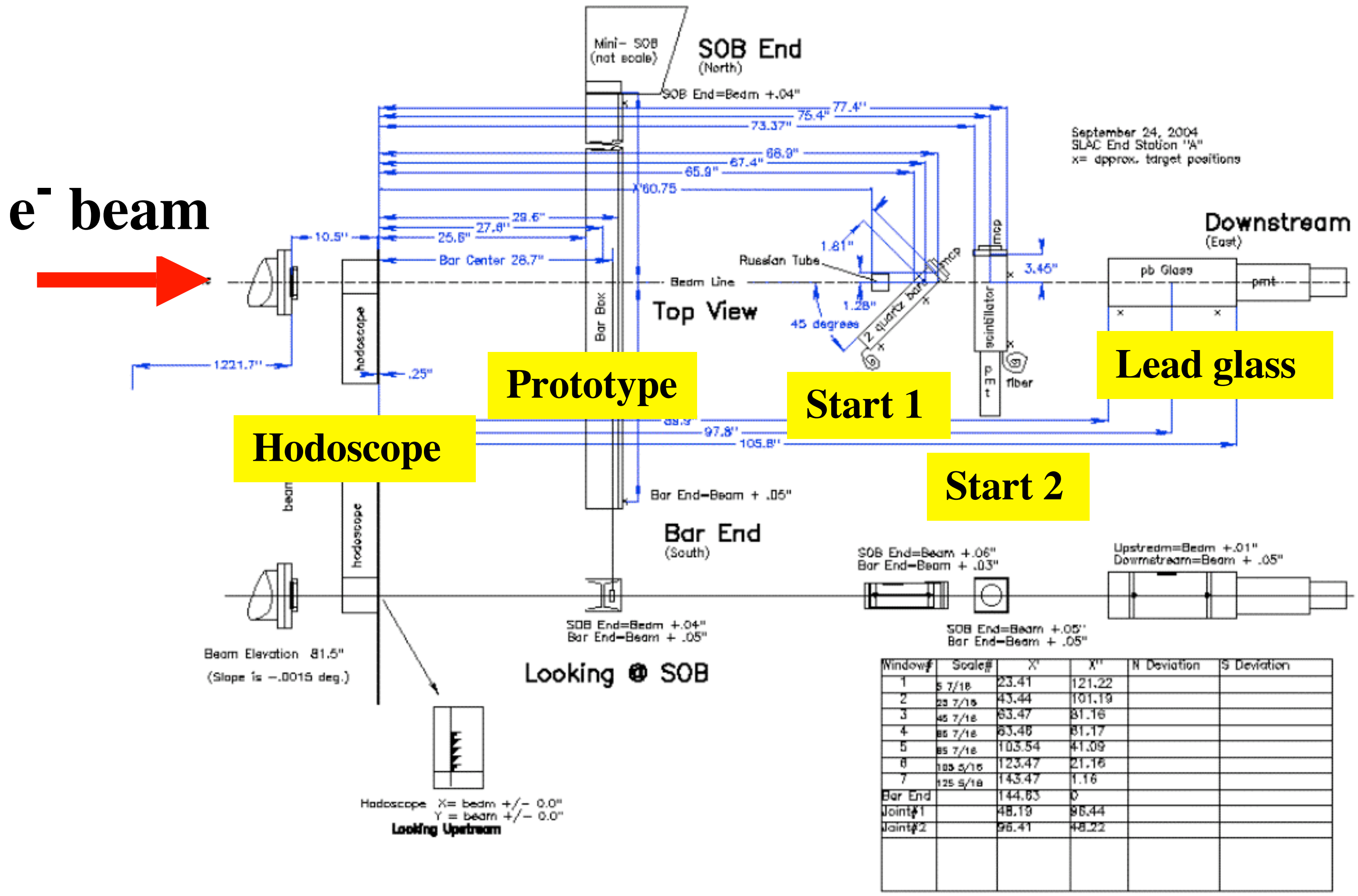
Results from the test beam

(preliminary)

Need a good start signal

- We start TDCs with a pulse derived from the LINAC RF. However, this pulse travels on a cable several hundred feet long, and therefore it is a subject to thermal effects.
- By making rolling averages on our local start counter we can correct out the thermal drifts to **<20ps**, even though that our Start counter has a single beam resolution of σ ~42ps "only."

Test beam setup



Window#	Scale#	X'	X''	N Deviation	S Deviation
1	5 7/16	23.41	121.22		
2	25 7/16	43.44	101.19		
3	45 7/16	63.47	81.16		
4	65 7/16	83.46	61.17		
5	85 7/16	103.54	41.09		
6	105 5/16	123.47	21.16		
7	125 5/16	143.47	1.16		
Bar End		144.63	0		
Joint#1		48.19	96.44		
Joint#2		96.41	48.22		

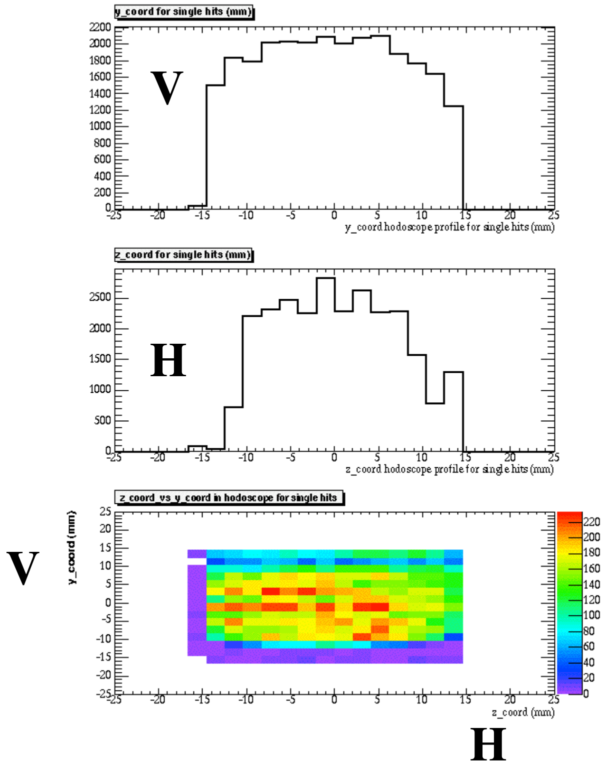
- **Beam enters bar at 90 degrees.**
- **Bar can be moved along the bar axis**

- **Trigger and time ref: accelerator pulse**
- **Hodoscope measures beam's 2D profile**

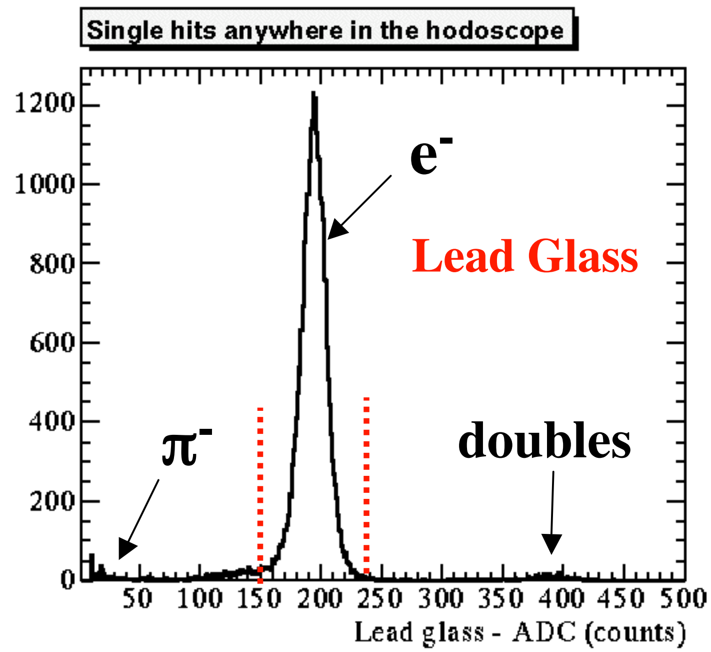
Definition of a good beam trigger

Run 1

Single hodoscope hits only:



Lead glass for single hodoscope hits:

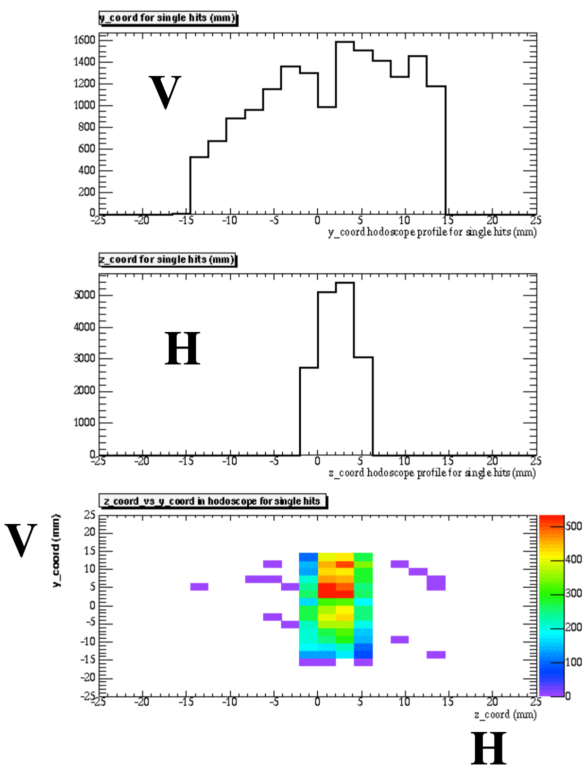


- **A definition of "good" event: single hit in hodoscope & tight cut on lead glass.**
- Beam are 10 GeV/c electrons (very few pions).
- Hodoscope is a x&y matrix made of square 2mm wide scintillating fibers.

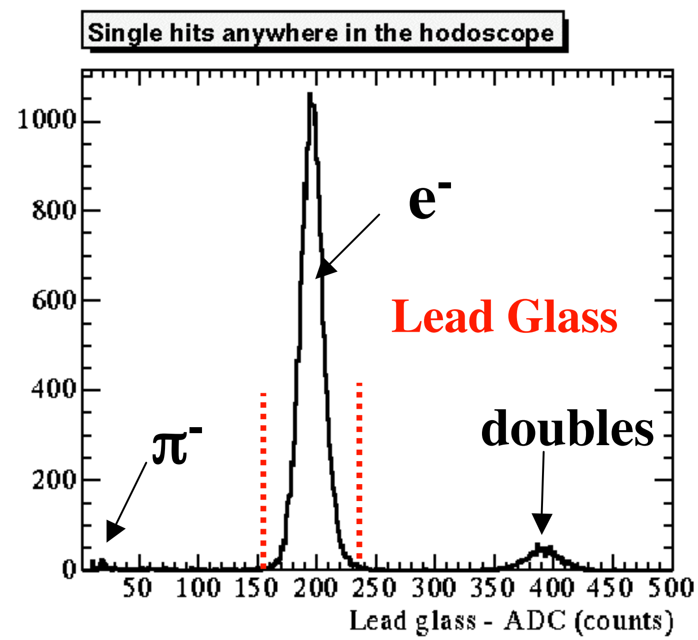
Definition of a good beam trigger

Run 2

Single hodoscope hits only:



Lead glass for single hodoscope hits:

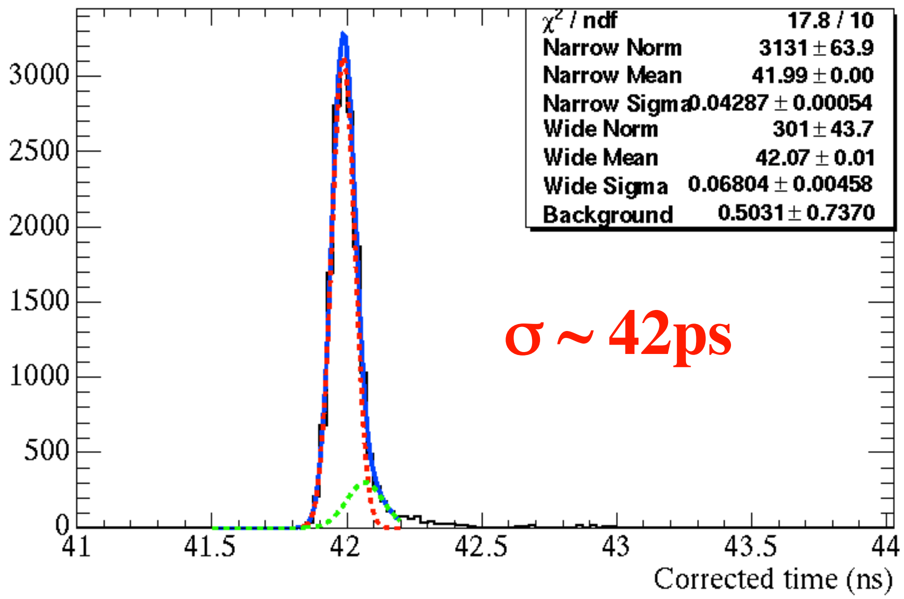


- **Much smaller beam size in horizontal direction, which is a direction along the bar, and also along TOP. All timing distribution became better.**

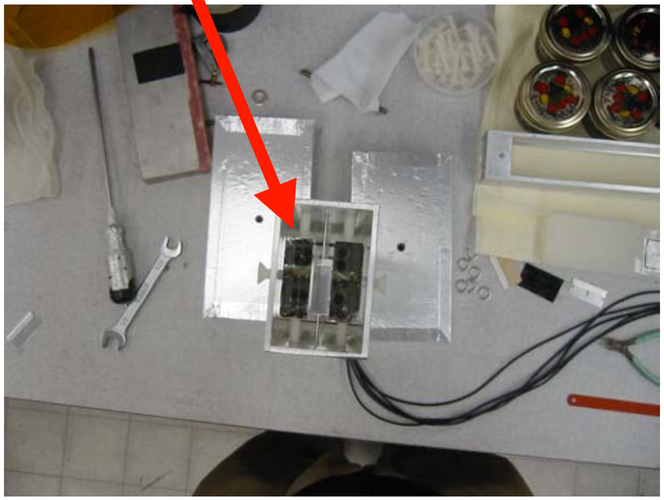
Start counter 1 - Double-quartz counter

Run 2:

Average of 2 pads:



Two quartz bars coupled to 4-pad Burle MCP-PMT



- **Corrections: ADC, hodoscope position and timing drifts.**

Start counter 1 - ADC & z-position corrections

Run 1

ADC correction: Before: After:

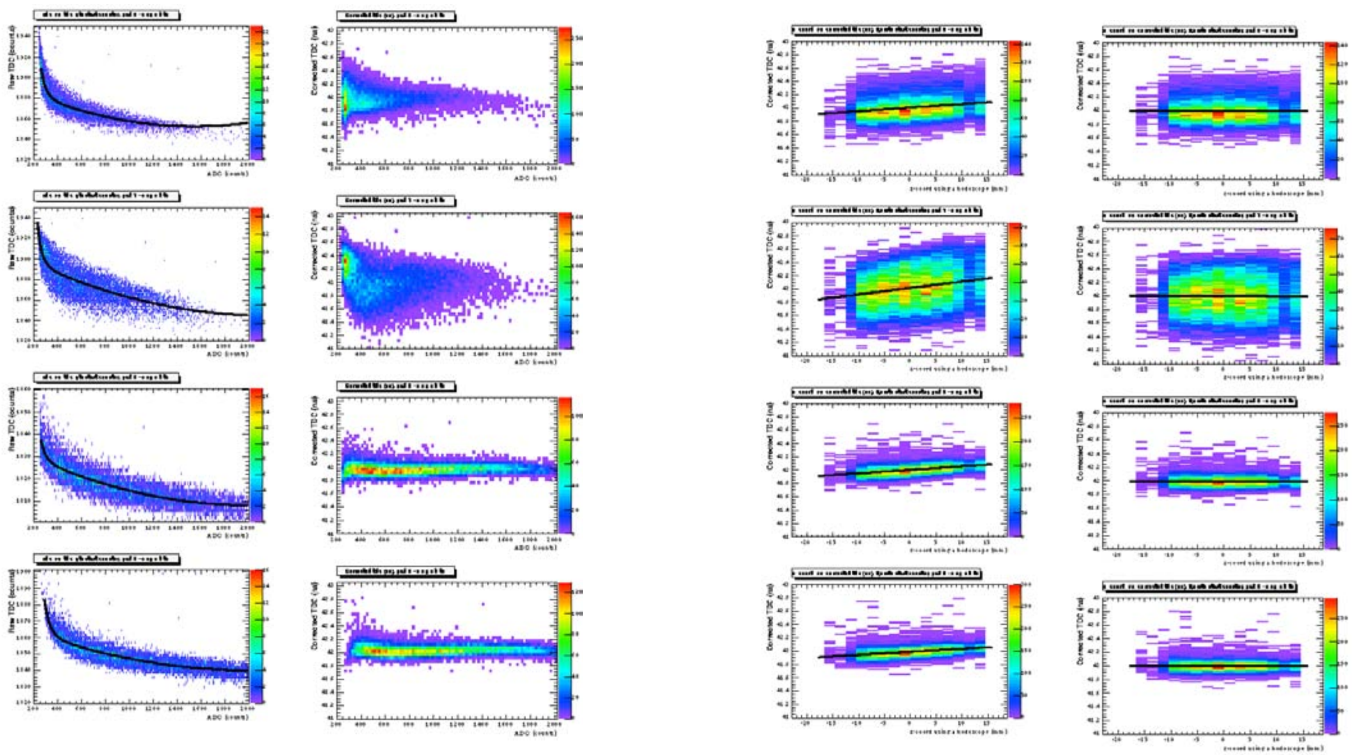
Z- position correction: Before: After:

Pad 0:

Pad 1:

Pad 2:

Pad 3:

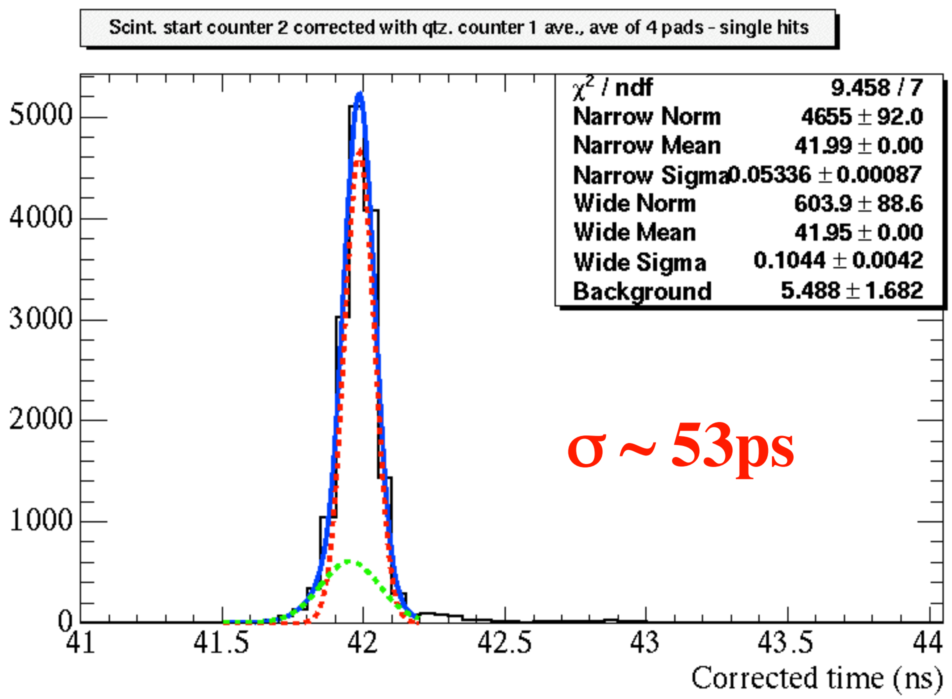


- **MCP pads 3 & 4 see more light. Use only those in the average time.**

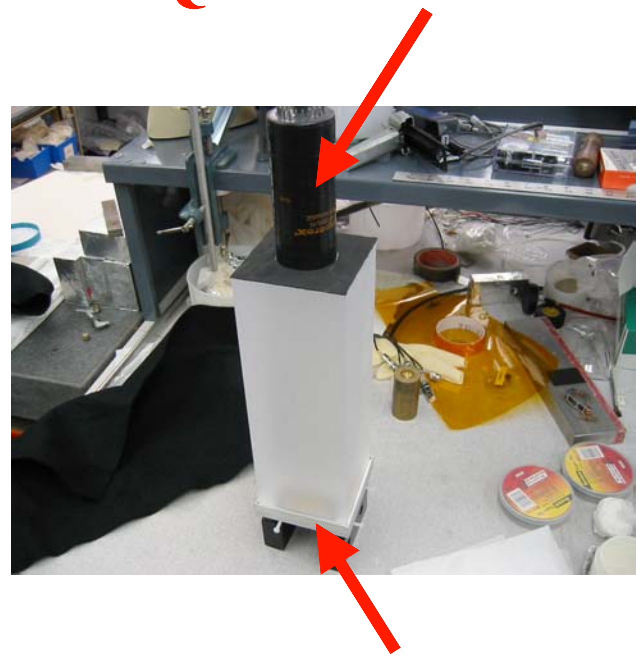
Start counter 2 - Scintillator counter

Run 2:

Average of four MCP-PMT pads:



Quantacon PMT



4-pad Burle MCP-PMT

- **Corrections: ADC, hodoscope position and timing drifts.**

Start counter 2 - ADC & z-position corrections

Run 1

ADC correction: Before: After:

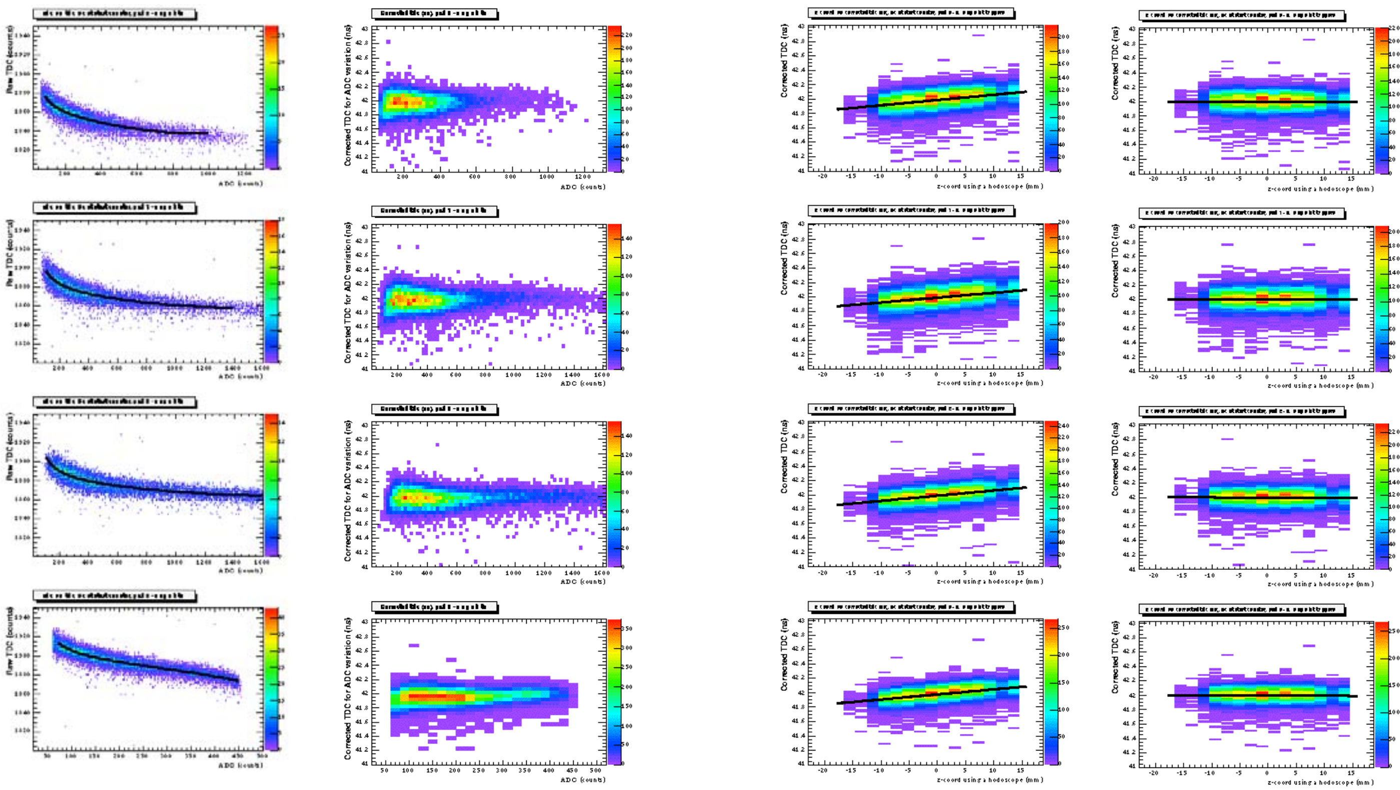
Z- position correction: Before: After:

Pad 0:

Pad 1:

Pad 2:

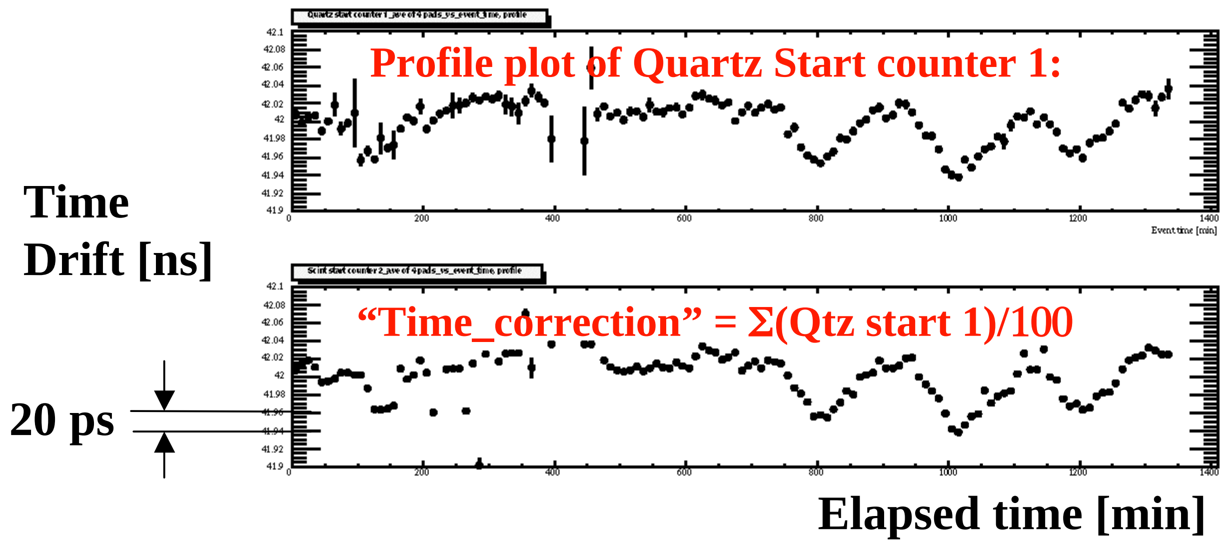
Pad 3:



- **Use all four pads to define the average time.**

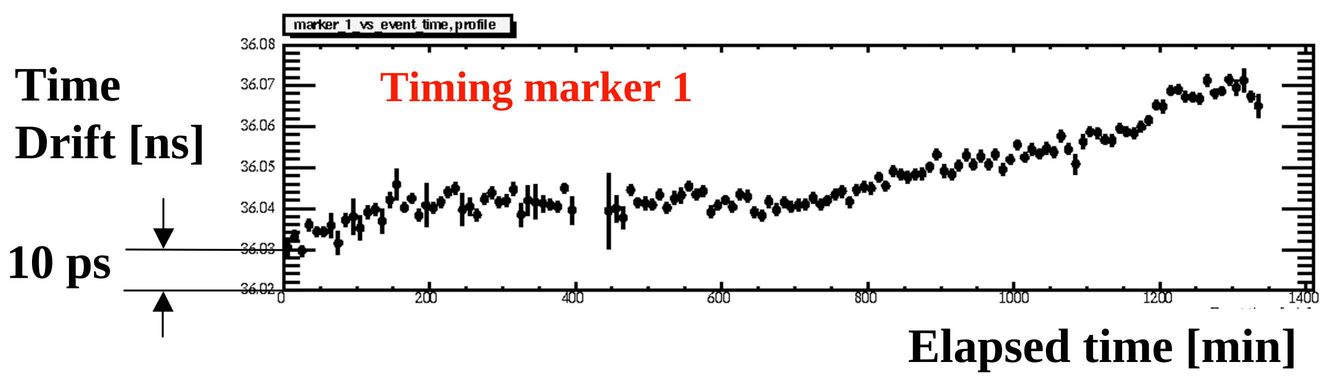
Run 1 Timing stability corrections

1) Stability of the MCC START is monitored by rolling averages:



Can see instability at a level of: 10-20ps

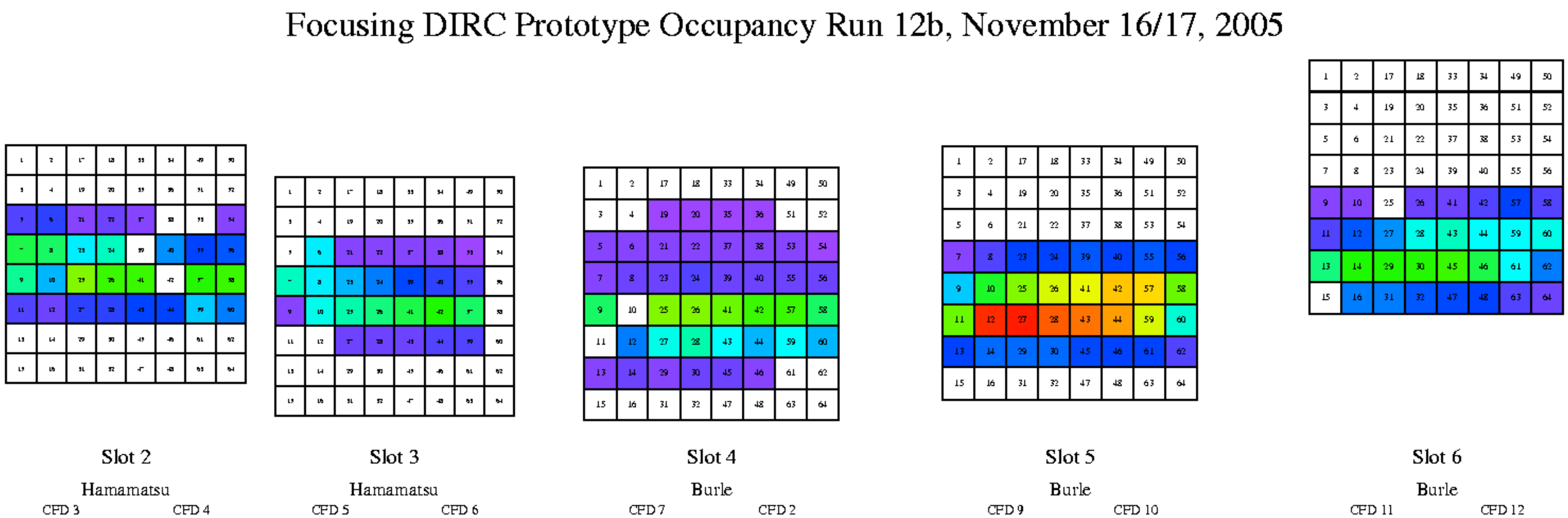
2) Stability within our electronics system monitored by 7 timing markers:



Can see instability at a level of: 10-20ps

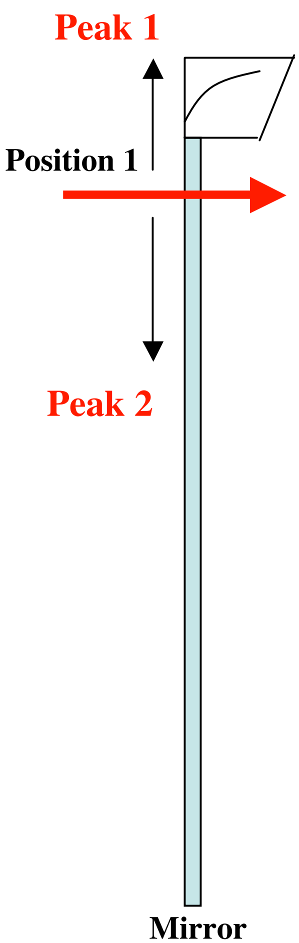
Cherenkov ring in x & y pixel plane

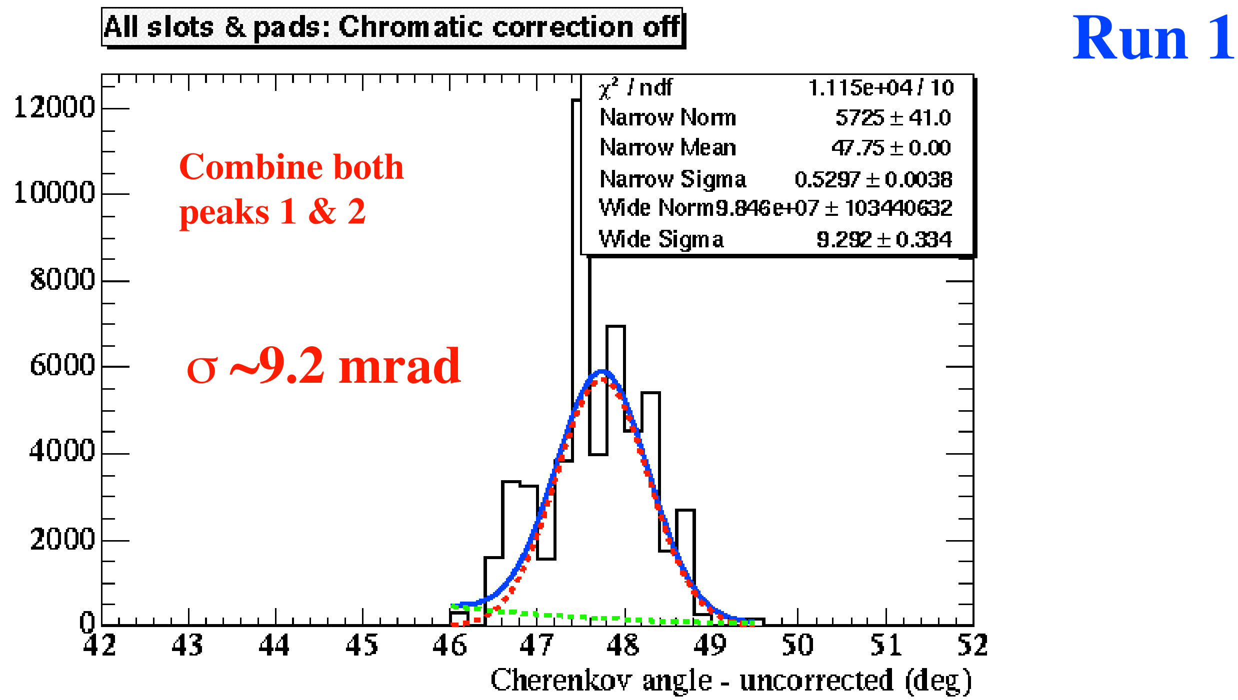
Run 2



- **Only pixels around the ring instrumented with TDCs.**
- **Each pixel defines the expected Cherenkov angle and Lpath, assuming $\lambda_{average}$ ~410nm.**
- **Each pixel measures time to 80-130ps.**

Ring resolution from x & y pixels

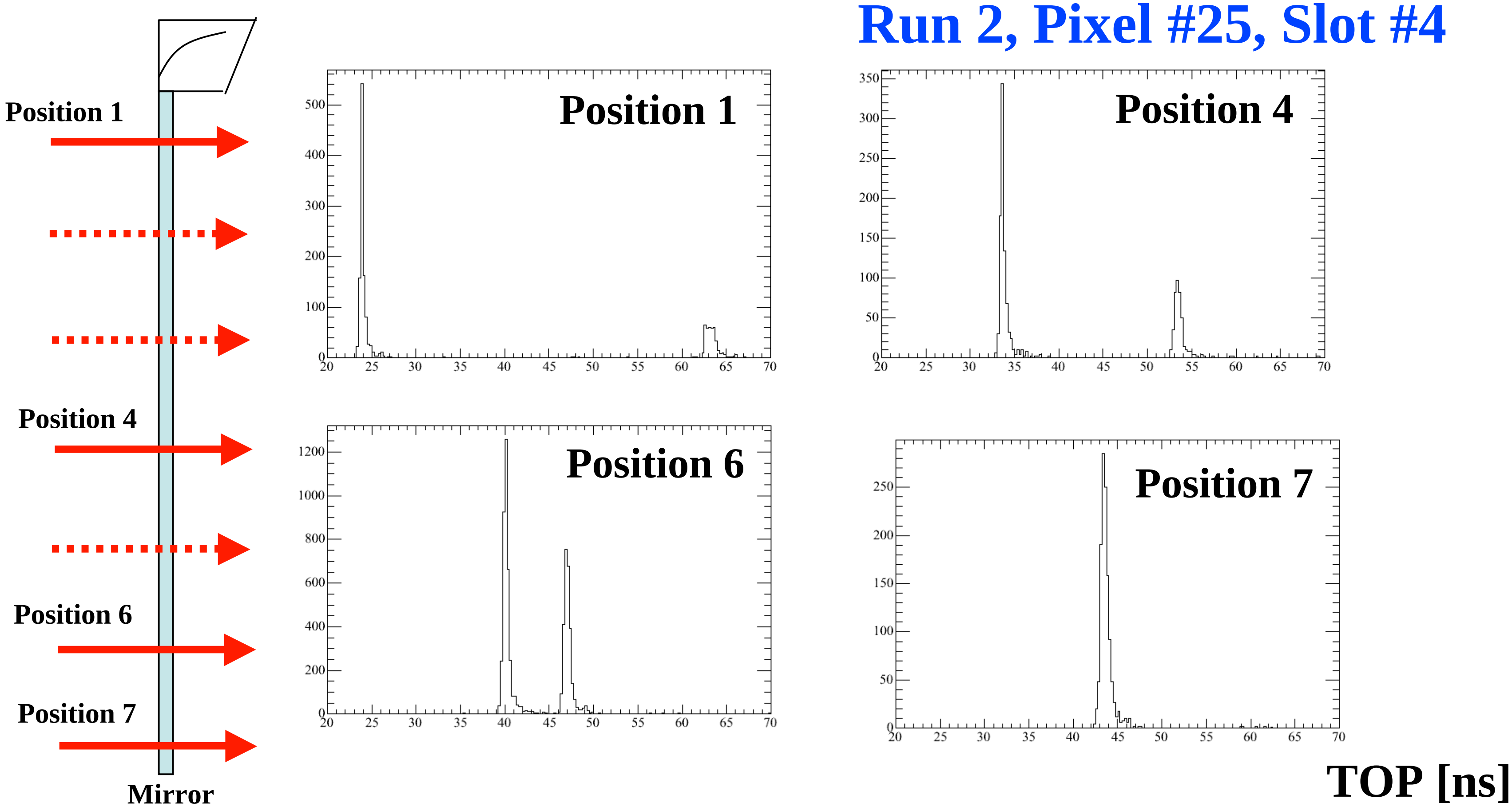




- **Preliminary** - must still include the geometry tweaks, etc.
- **See a clear pixelization effect.**
- Already better resolution than BaBar DIRC (~9.6 mrad).

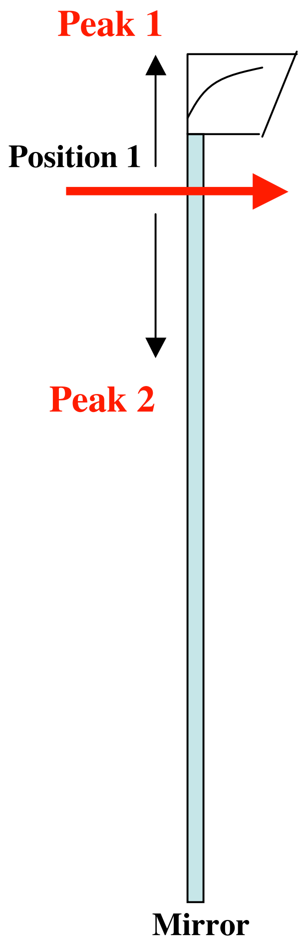
Cherenkov ring in the time domain

Run 2, Pixel #25, Slot #4

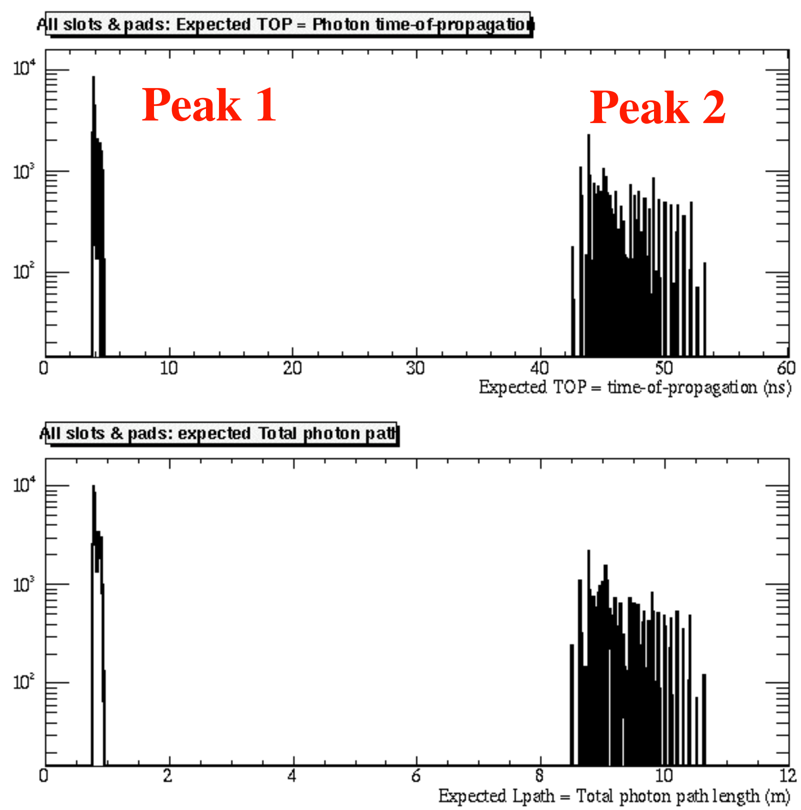


- **Two peaks correspond to forward and backward going part of the Cherenkov ring (the backward part is reflected by a mirror back).**

Expected TOP and Lpath



Run 1



TOP [ns]

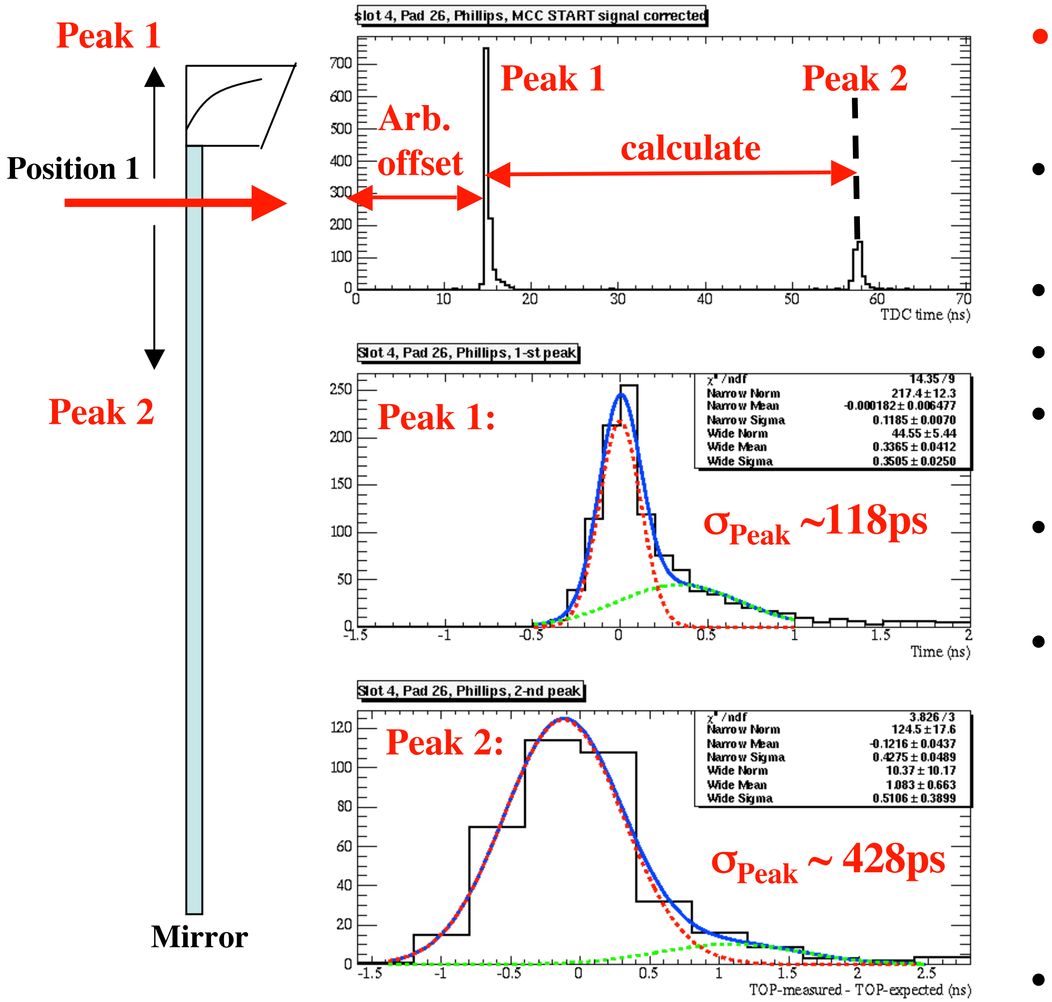
Lpath [m]

- **Integrate over all pixels**
- **Bar length:**
  - (Peak 1): beam pos (window 1) to bar beginning
  - (Peak 2): beam position to the mirror and back to the bar beginning

Run 2

Example of the analysis

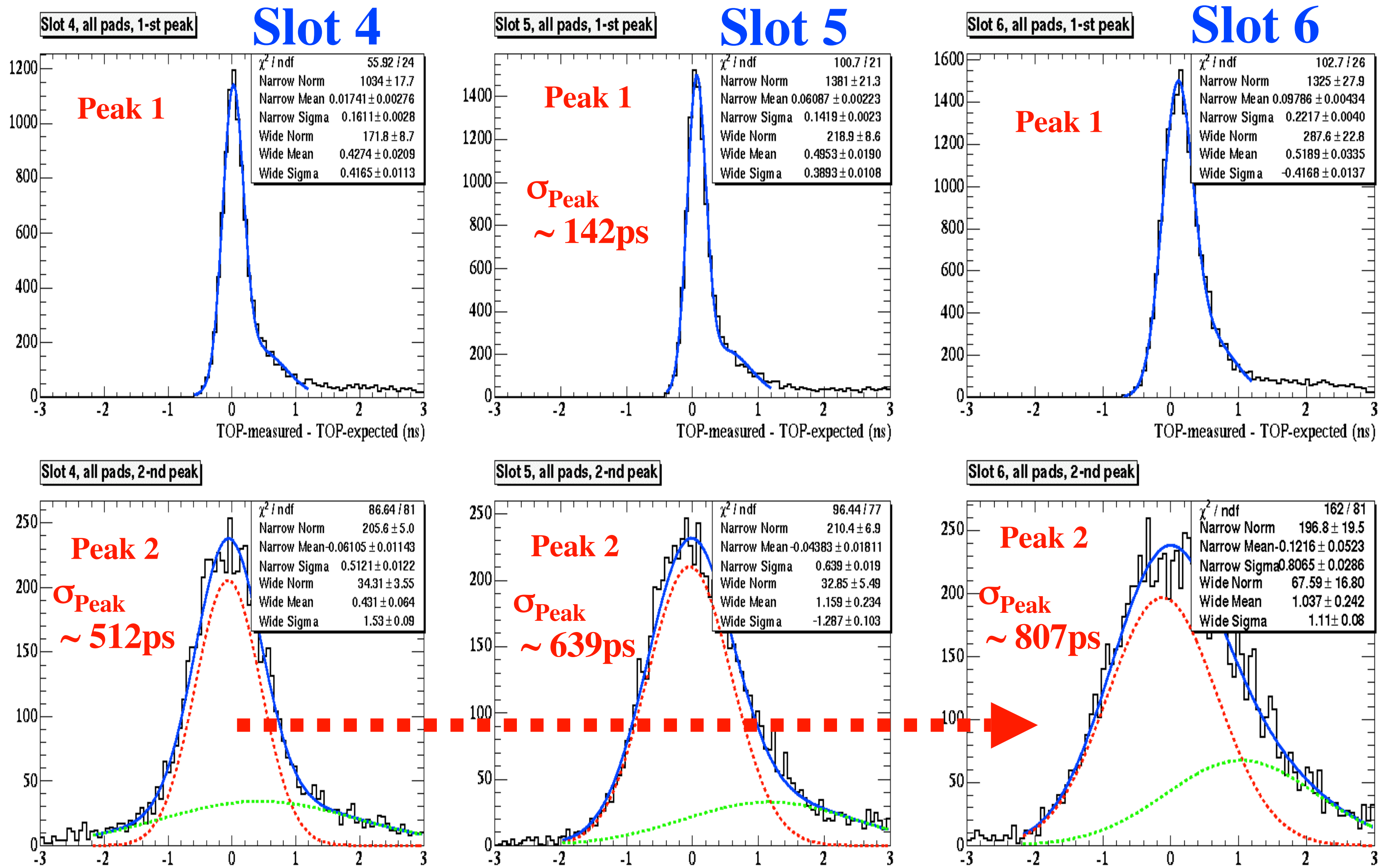
Slot 4, single pixel #26, Burle MCP-PMT



ΔTOP = TOP_measured - TOP_expected [ns]

- **The largest chromatic effect is in the position 1**
- Peak 1: ~75cm photon path length
  Peak 2: ~870cm photon path length
- Calculate TOP using average λ.
- Plot $\Delta TOP = TOP_{measured} - TOP_{expected}$
- ΔTOP (Peak 1) was tweaked arbitrarily to zero.
- $\Delta TOP\ (\text{Peak 2 - Peak 1})_{calc}$ was calculated.
- **Many corrections needed:**
  - MCP cross-talk
  - thermal time drifts
  - cable offsets (PiLas)
  - TDC calibration(PiLas)
  - geometry tweaks
- **Observe a clear broadening of the timing peak for the mirror-reflected photons.**

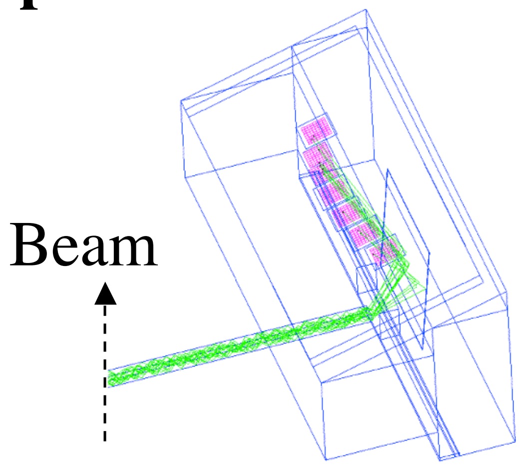
Run 1 Chromatic growth (include all pads/slot)



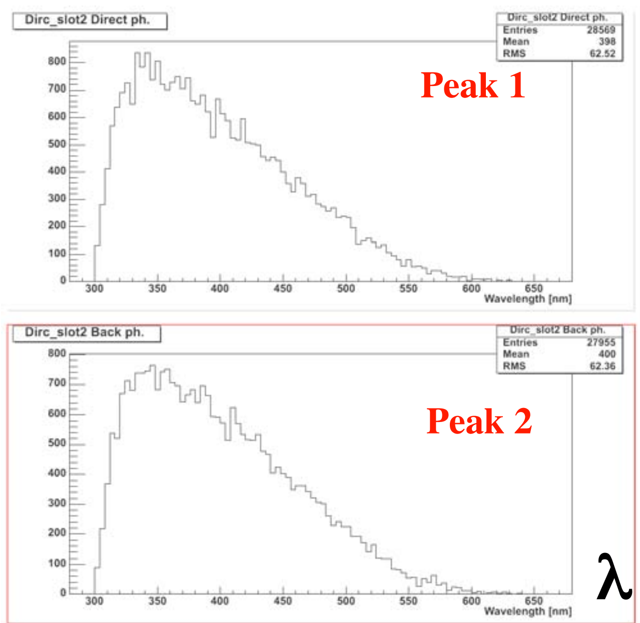
ΔTOP = TOP_measured - TOP_expected [ns]

Monte Carlo prediction of the chromatic behavior

Position 1

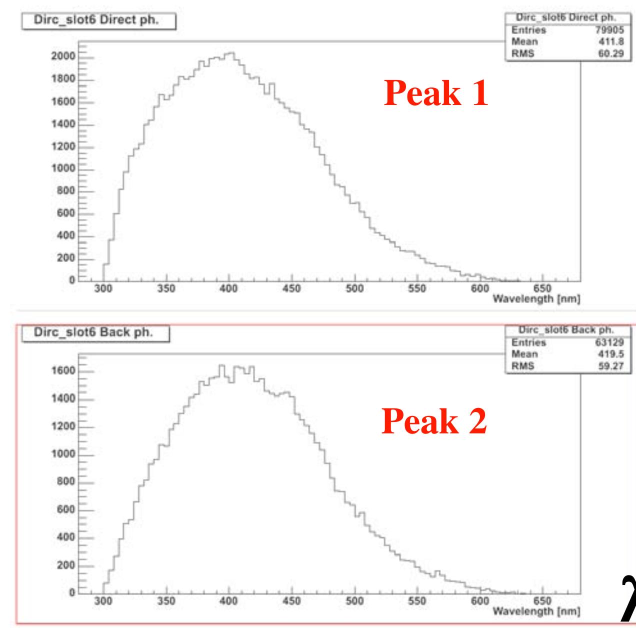


Hamamatsu MaPMT - slot 2



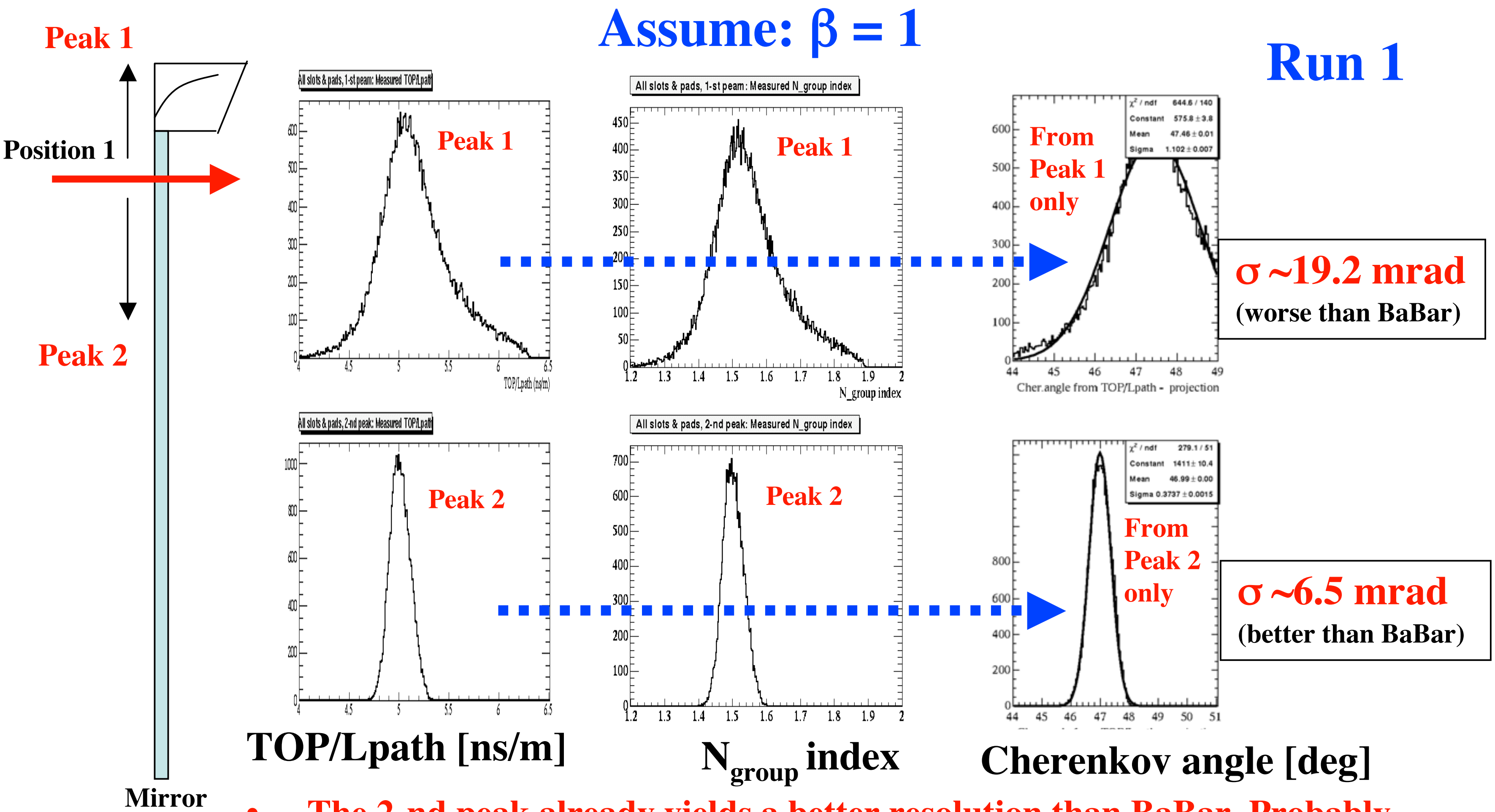
λ [nm]

Burle MCP-PMT - slot 6



λ [nm]

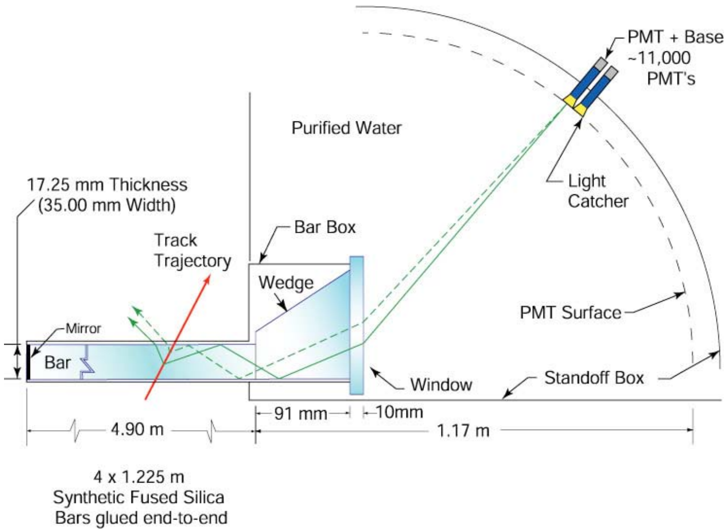
Ring resolution from TOP measurement

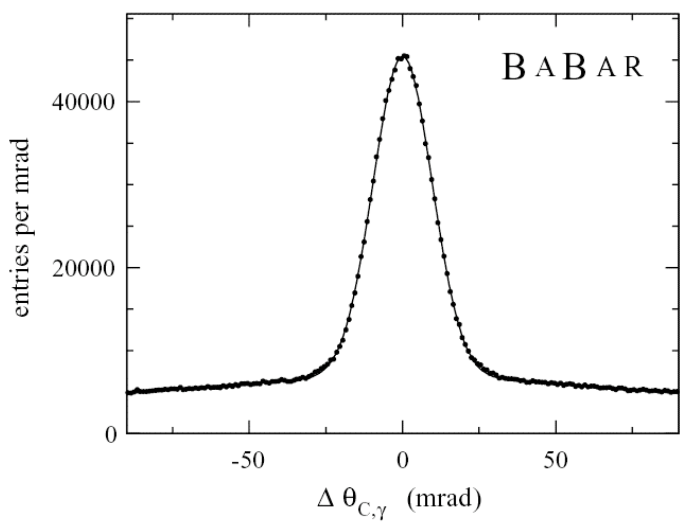


- **The 2-nd peak already yields a better resolution than BaBar. Probably because the Burle MCP-PMTs are effectively making a chromatic cut.**
- Use a pixel to determine the photon path length Lpath
- TOP will compete with a x&y method probably for Lpath > 3-4m

Present BaBar DIRC : Error in θ_c

J. Schwiening et al., Nucl.Instr.&Meth., A502(2003)67





- **Per photon:**

- $\Delta\theta_{track}$ ~1 mrad
- $\Delta\theta_{chromatic}$ ~5.4 mrad
- $\Delta\theta_{transport\ along\ the\ bar}$ ~2-3 mrad
- $\Delta\theta_{bar\ thickness}$ ~4.1 mrad
- $\Delta\theta_{PMT\ pixel\ size}$ ~5.5 mrad, etc.

- Total: $\Delta\theta_c^{photon}$ ~ 9.6 mrad

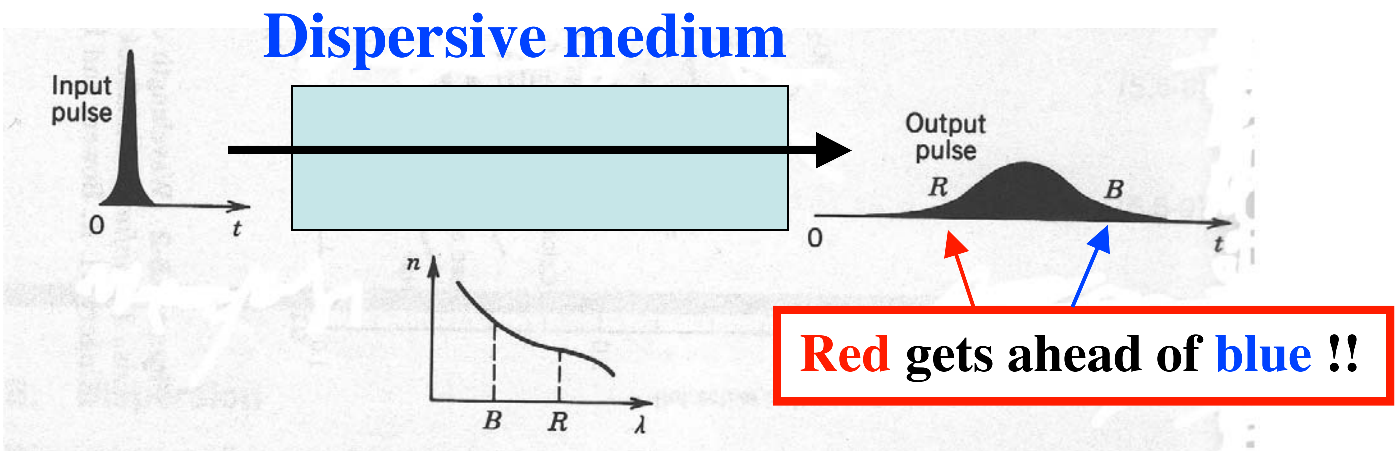
- **Per track (N_{photon}~18-60/track):**

$$\Delta\theta_c^{track} = \Delta\theta_c^{photon}/\sqrt{N_{photon}} \otimes \Delta\theta_{track}$$

~ 2.4 mrad on average

Can we correct the chromatic error ?

Chromatic broadening of a light impulse



$$dt = L \ \lambda \ d\lambda / c_0 * | - d^2n/d\lambda^2 |$$

dt is pulse dispersion**,** fiber length **L,** wavelength bandwidth **dλ,** refraction index **n(λ)**

- **Well known effect in the fiber industry**

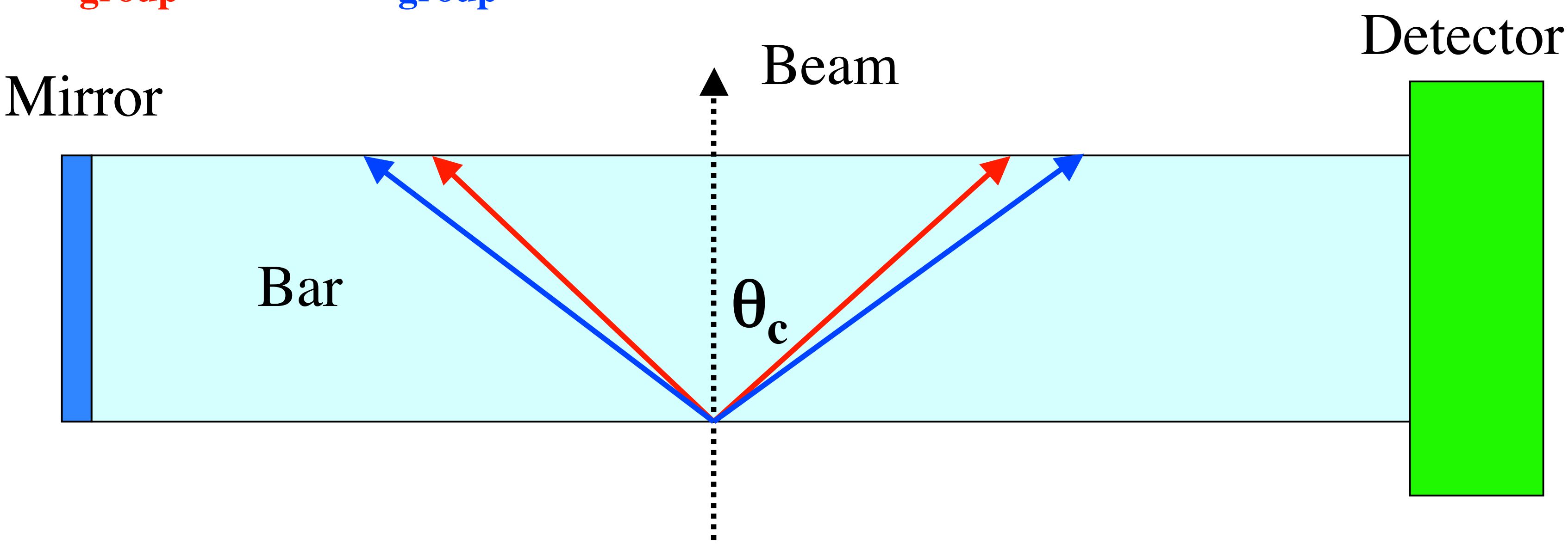
Chromatic effect of the Cherenkov light

$\cos\theta_c = 1 / (n_{phase}\,\beta)$

$v_{group} = c_0 / n_{group} = c_0 / [n_{phase} - \lambda * dn_{phase}/d\lambda]$

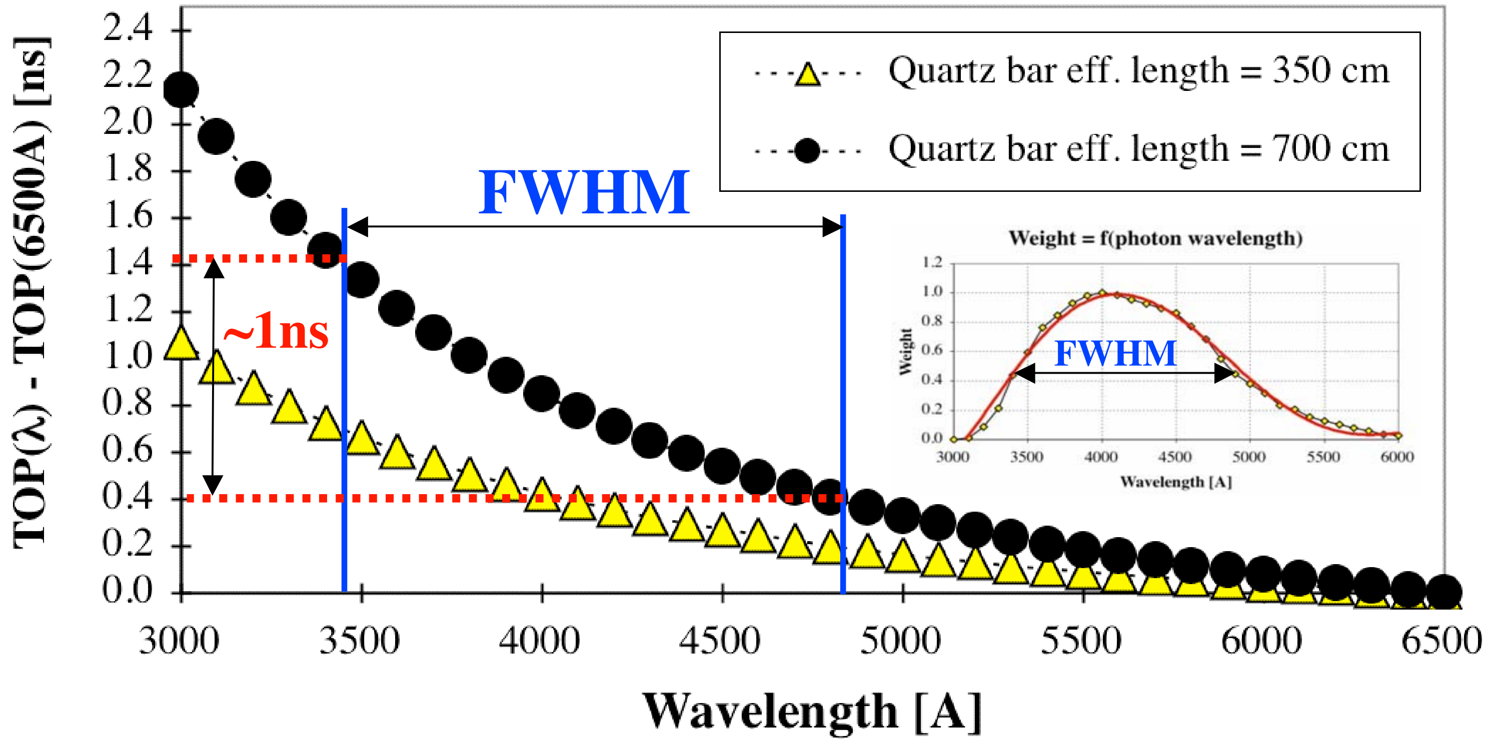
$n_{phase}(red) < n_{phase}(blue)$

$v_{group}(red) > v_{group}(blue)$



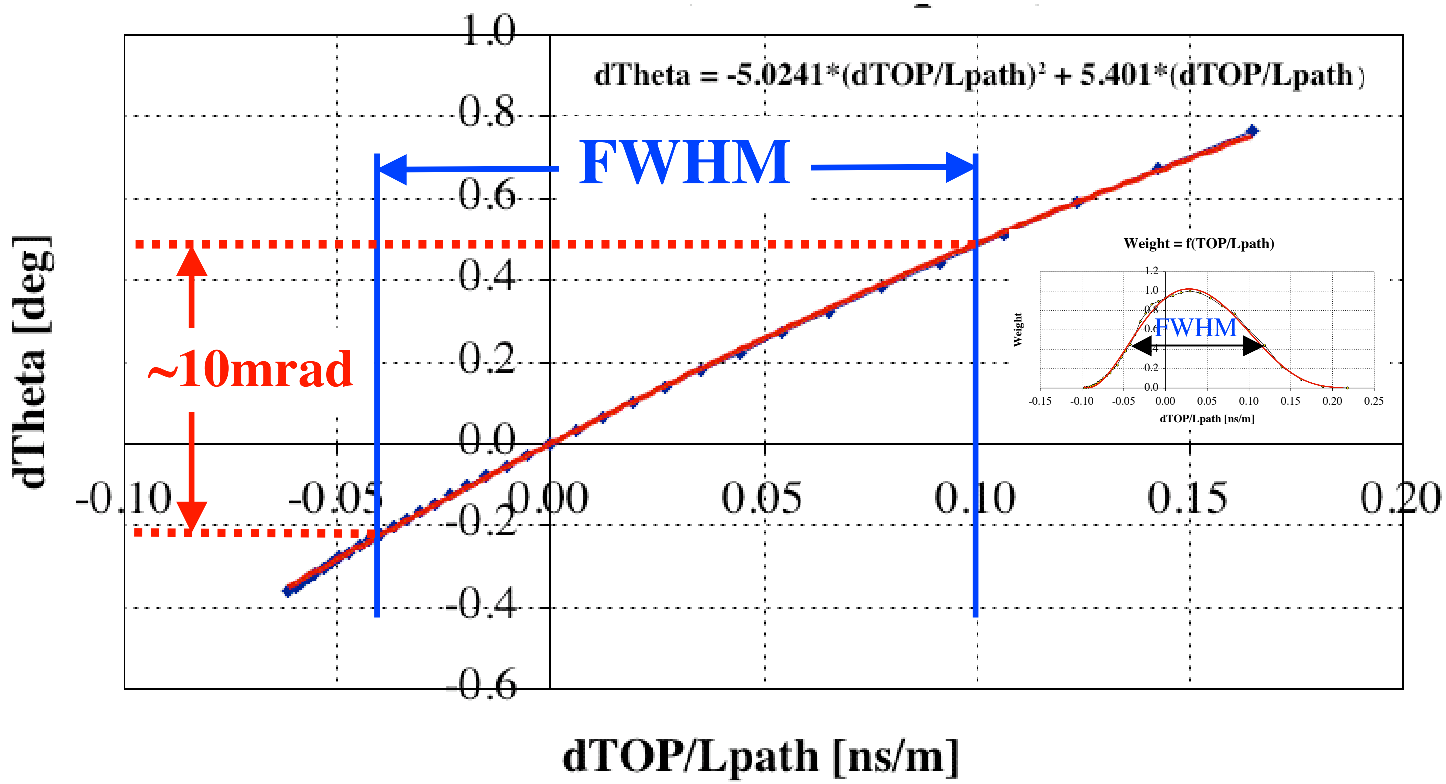
- $\Theta_{track} = 90^o$ **(perpendicular to bar).**
- **Red goes faster than blue - this tends to minimize the timing difference**

TOP(λ)-TOP(6500A) = f(wavelength, bar length)



- **Θ_{track} = 90° (perpendicular to bar).**
- Photons propagate in y-z plane only in these calculations.
- **1-2 ns overall range. Need 100-150ps timing resolution to parameterize it.**
- **Because of the weighting function, it will be a small effect**

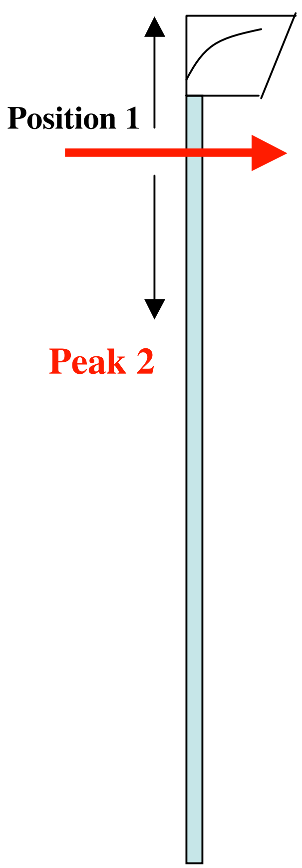
Expected chromatic correction



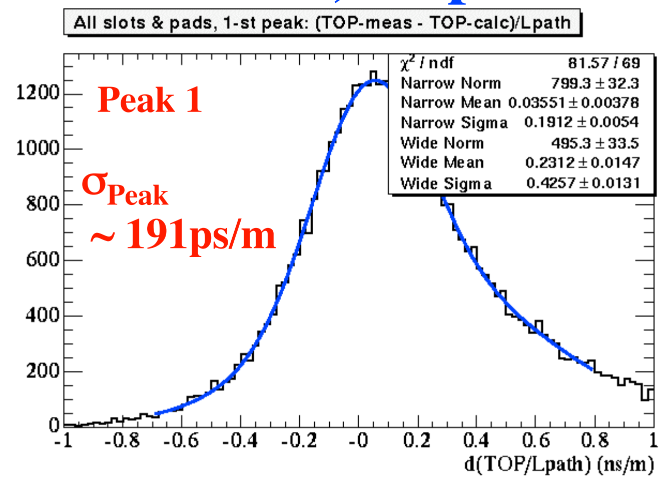
- An average photon with a color of ~410nm arrives at 0 ns offset. A photon of different color, arrives either early or late.
- The overall effect is small, only ~10mrad, i.e., everything has to be right to be able to see it in the data.

d(TOP/Lpath) - variable to use for the chromatic correction

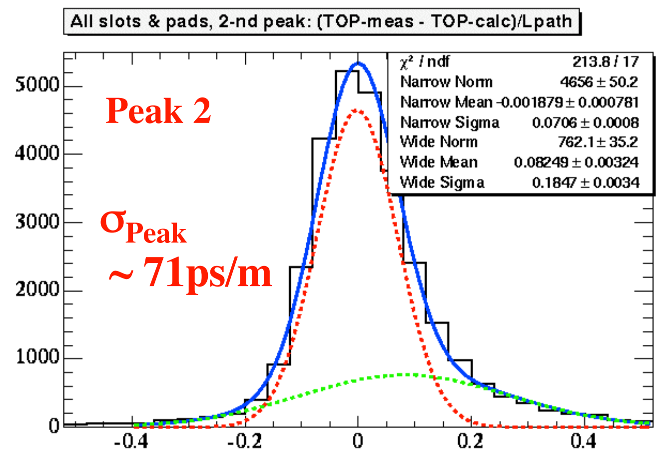
Run 1



All slots, all pads



Peak 1 is hopeless for determining of the chromatic correction

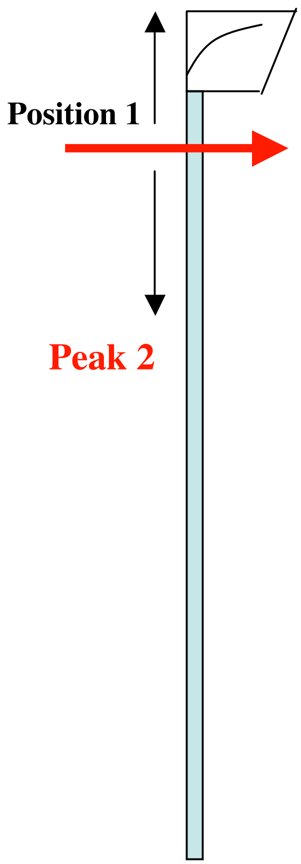


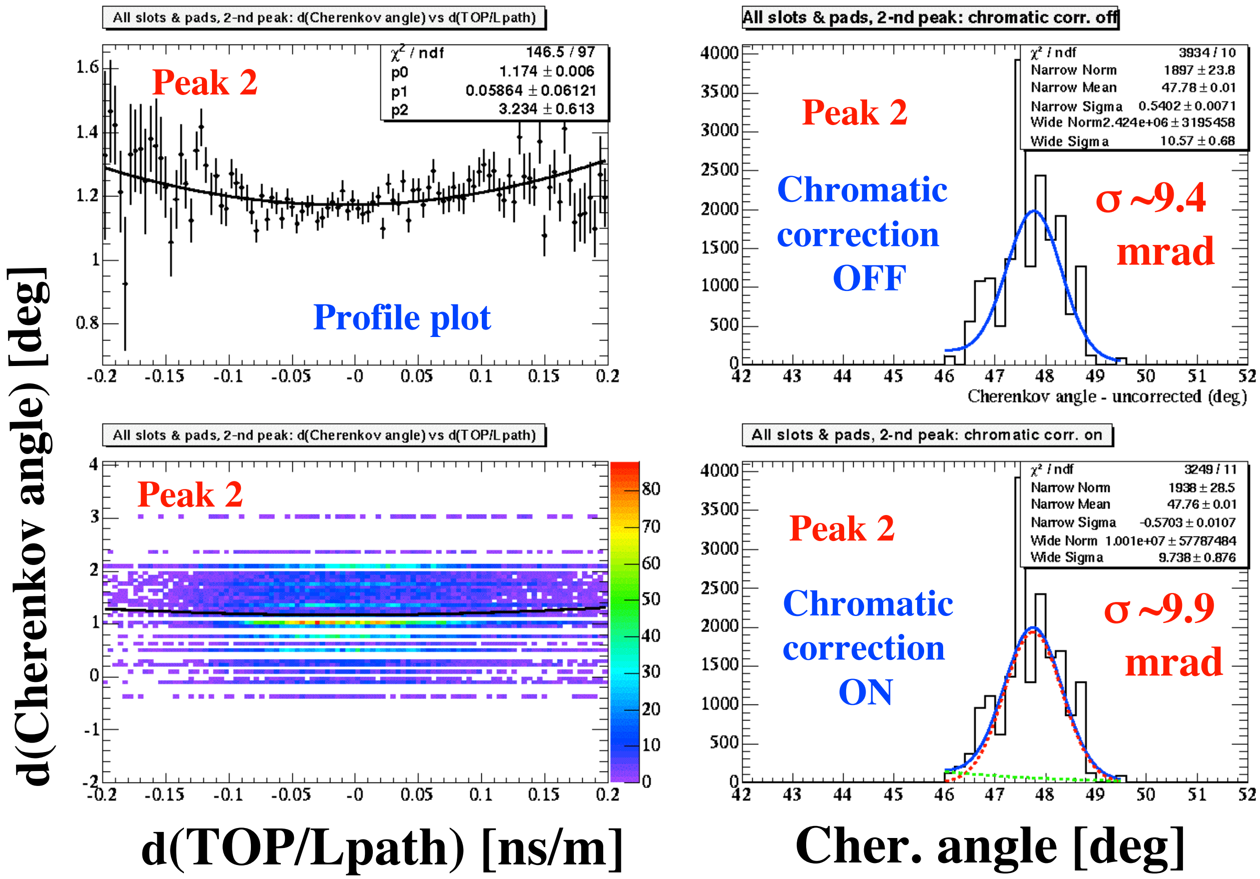
Peak 2 has a good precision to determine the chromatic correction (Lpath > 8-9 meters)

d(TOP/Lpath) =
(TOP/Lpath)_measured - (TOP/Lpath)_expected [ns/m]

A method to determine the chromatic correction in the data

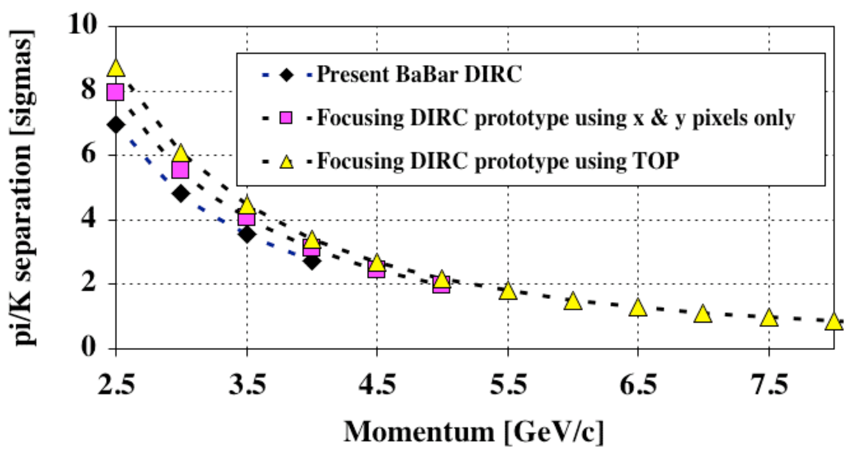
Run 2 All slots, all pads, Peak 2 only:





- **Still needs a very precise TDC calibration, tweaks in geometry, etc.**

Performance of Focusing DIRC vs BaBar DIRC



Contribution to Cherenkov angle resolution [mrad]	BaBar DIRC (using x&y pixels)	Focusing DIRC prototype (using x&y pixels or TOP)
$\Delta\theta_{track}$	~1	~1
$\Delta\theta_{chromatic}$	~5.4	~5.4
$\Delta\theta_{transport\ along\ the\ bar}$	~3	~3
$\Delta\theta_{bar\ thickness}$	~4.1	~1
$\Delta\theta_{PMT\ pixel\ size}$	~5.5	~5.1
Total $\Delta\theta_c^{photon}$	~9.3	~8.1 -> 6.5
Measure	~9.6	~9.2 (preliminary)

- **Focusing DIRC assumptions:**
  - optics to remove the bar thickness
  - similar efficiency as BaBar DIRC
  - improvements in the tracking accuracy
  - x&y pixels are used for Lpath <3-4 m.
  - TOP is used for Lpath > 3-4m.
  - The chromatic error is not improved by timing.
  - Pixel size 6x6mm^2.

- **One can improve the Cherenkov angle determination using the x&y pixel method, if the pads are made rectangular, say 2x8mm^2**
- **Further improvements are possible if one succeeds with the chromatic correction.**

Plan for the 3-rd run in the beam

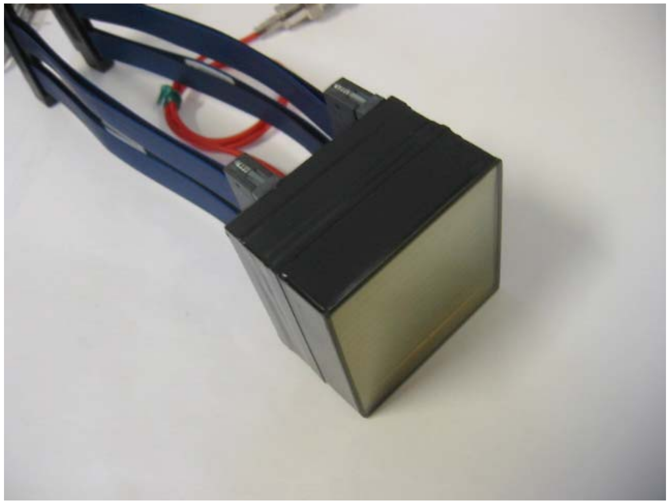
(Spring 2006)

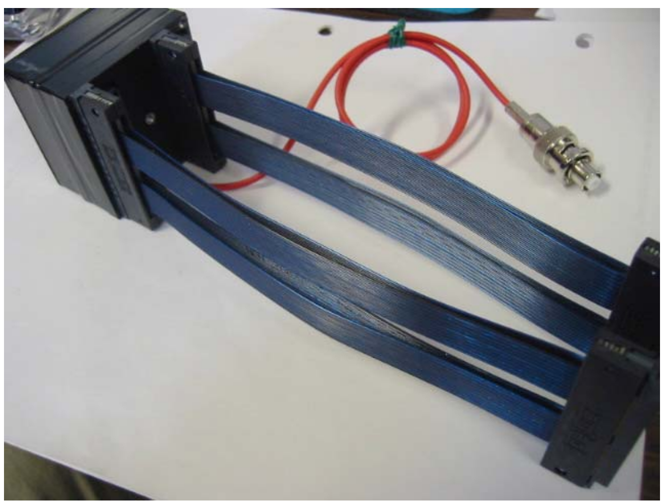
- **We will have four new photon detectors in the prototype with rectangular pads:**

  - "Open area" 1024-pixel Burle MCP (25 μm MCP holes),
  - "Open area" 64-pixel Burle MCPs (25 μm MCP holes),
  - "Small cathode-to-MCP gap" 64-pixel Burle MCPs (25 μm MCP holes),
  - 256-pixel Hamamatsu Flat Panel MaPMT.

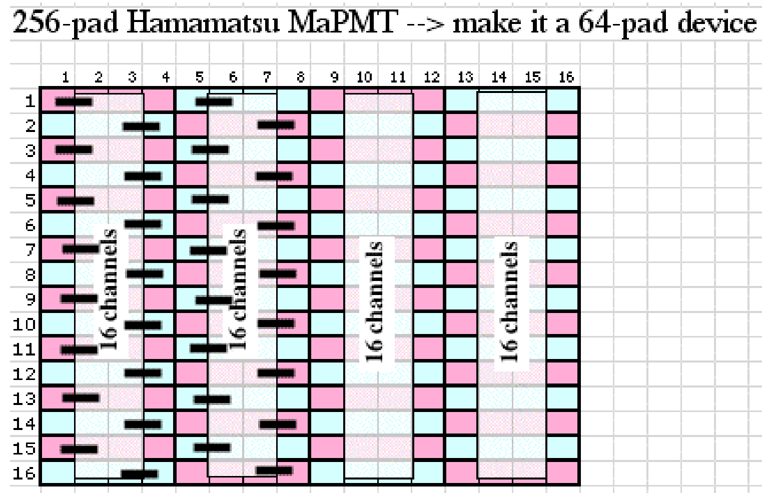
- **We will create the rectangular pads to provide finer sampling along the y-direction, which will reduce the pixelization effect in the Cherenkov angle space**
- **One slot should have a MCP-PMT with suppressed tail (a small cathode-to-MCP distance of 0.75mm).**

New 256-pixel Hamamatsu MaPMT H-9500



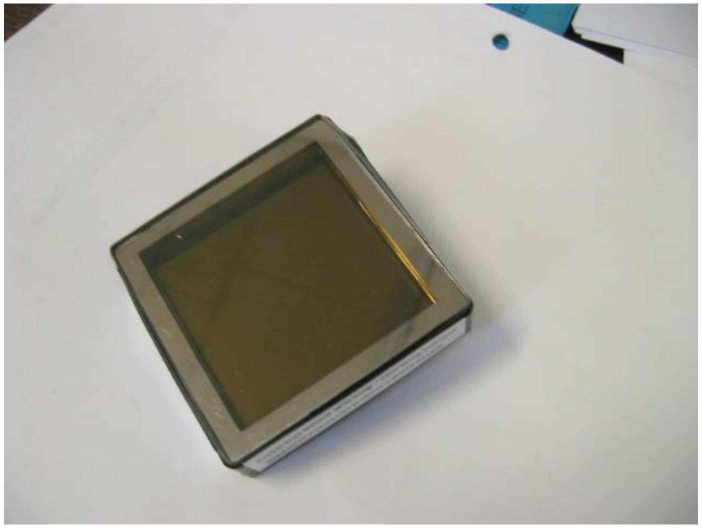


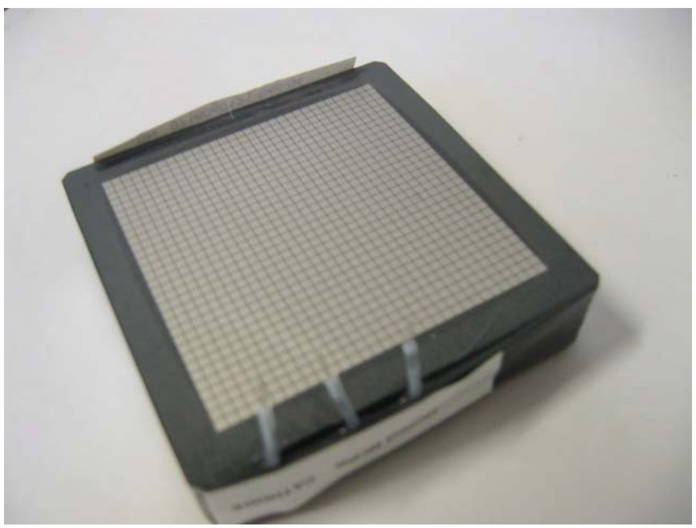
A proposal how to connect pads:



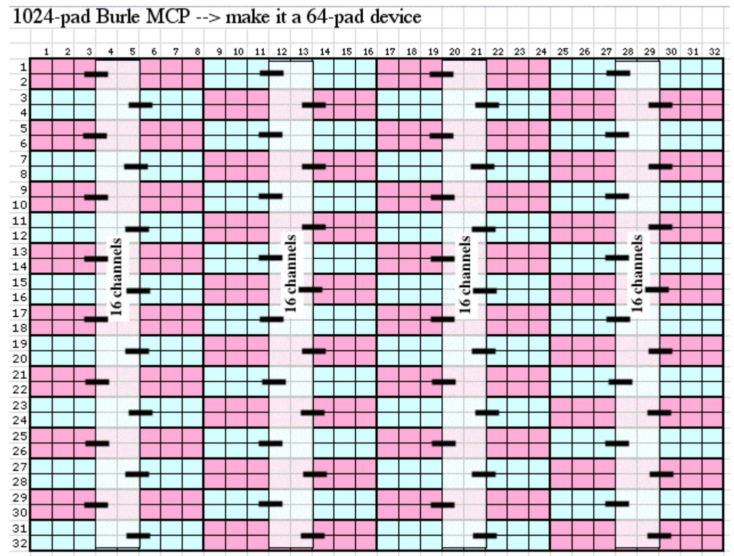
- **Large rectangular pad: 1x4 little ones**
- 256 pixels (16 x 16 pattern).
- Pixel size: 2.8 mm x 2.8 mm
- Pitch of 3.04 mm.
- Very neat connections

“Open area” 1024-pixel Burle MCP 85021-600



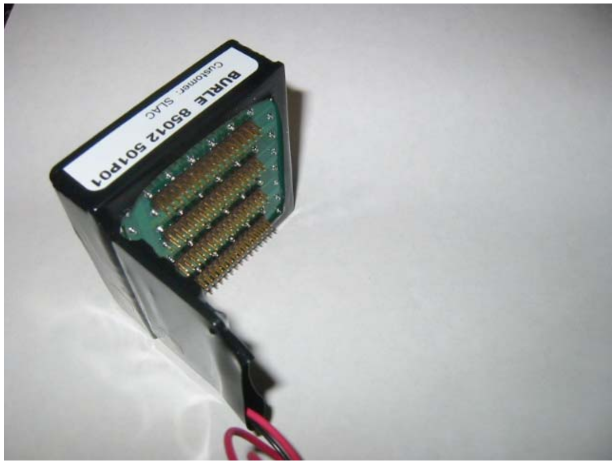


A proposal how to connect pads:



- **Large rectangular pad: 2x8 little ones**
- Small margin around boundary
- 1024 pixels (32 x 32 pattern)
- Small pixel size: ~1.4mm x 1.4mm
- Pitch: 1.6 mm

“Open area” Burle MCP 85012-501



- Small margin around the boundary
- 10 & 25 μm MCP hole diameter
- Pad size: 6 mm x 6 mm.
- The MCP-PMT still has 6-7mm cathode-to-MCP distance, thus making a long tail in the timing distribution
- Can change the resistor chain. Will study if the tail can be supressed by a choice of the MCP operating voltages

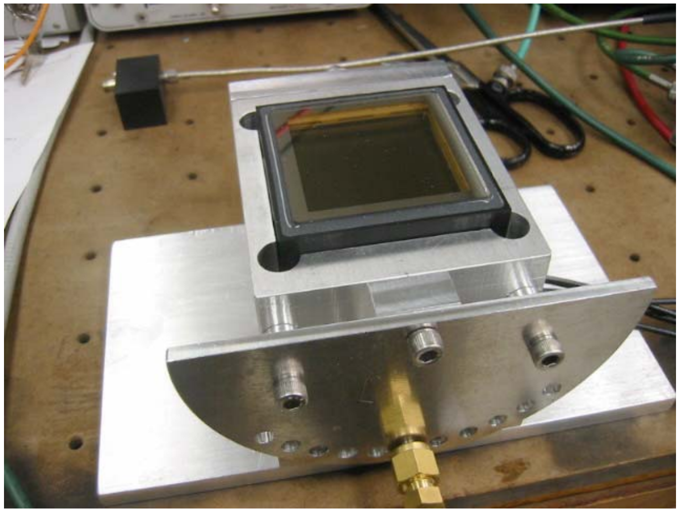
Conclusions

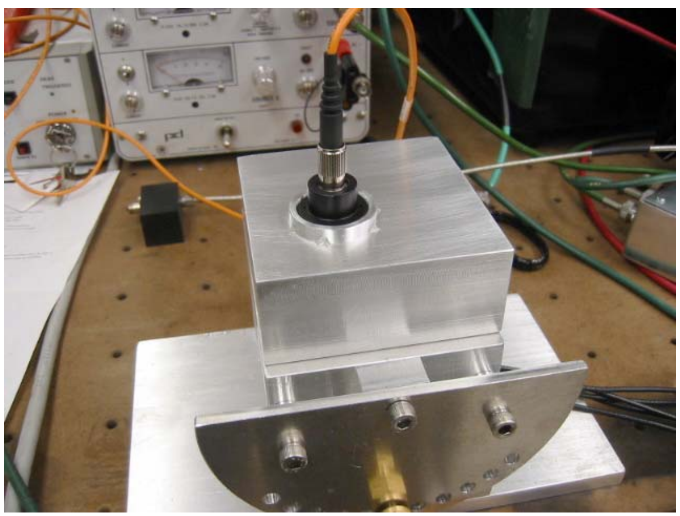
- **We are just at the beginning of a long road.**
- **Clearly, a challenging detector, requiring new approaches to the calibration, software design, etc.**
- **Many detector questions: geometry of MCP-PMT, aging, rate capability, efficiency, reliability, electronics, timing method, etc.**
- **The Focusing DIRC can operate as the BaBar DIRC for photons of shorter Lpath, or, as a TOP counter for photons with longer Lpath, or even as an ordinary TOF counter in a certain region of the phase space.**
- **Cherenkov angle resolution of the prototype already surpassed that of BaBar DIRC when used as the TOP counter, even in this early stages of the analysis.**
- **Nagoya TOP counter is more sinple. If the background will be small, such detector may be sufficient. However, at this stage of the game, it is good to have more general device, which allows a measurement of all three variables: x, y and TOP.**
- **A lot of fun; intelectually very satisfying detector; but, hard work….**

Additional slides

Single photoelectron timing resolution at B = 15 kG

Burle MCP-PMT with 10μm holes

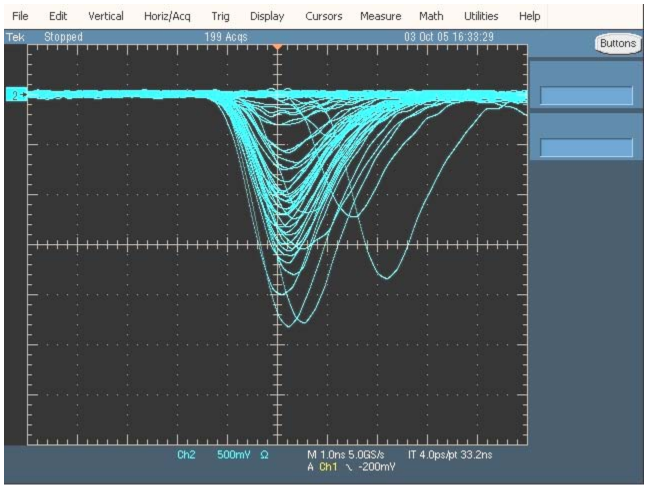


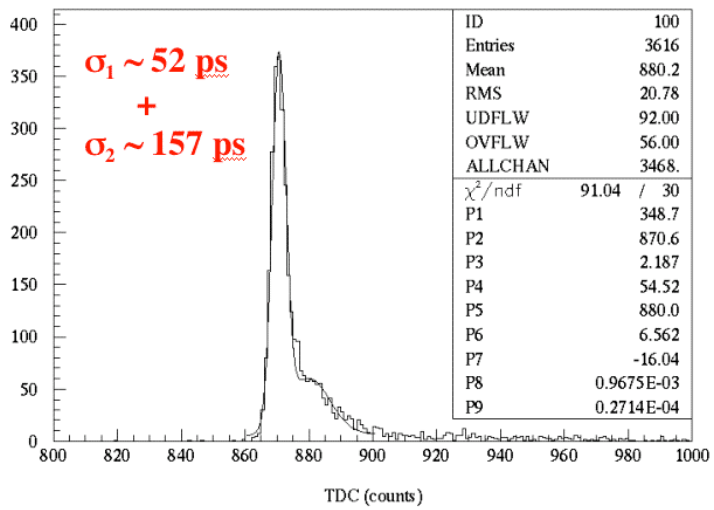


- 4-pixel MCP-PMT 85001-501 P01 tube for the initial tests.
- PMT has two MCPs with 10 μm dia. holes
- Cathode-to-MCP distance ~6mm
- According to Burle, this particular 10μm MCP should produce a gain of $\sim 10^6$ at –2.2kV.
- Setup had a capability to measure sensitivity to angles in 5^o steps between the magnetic field and axis perpendicular to the face plate.

Choice of amplifier and timing results at B = 0 kG

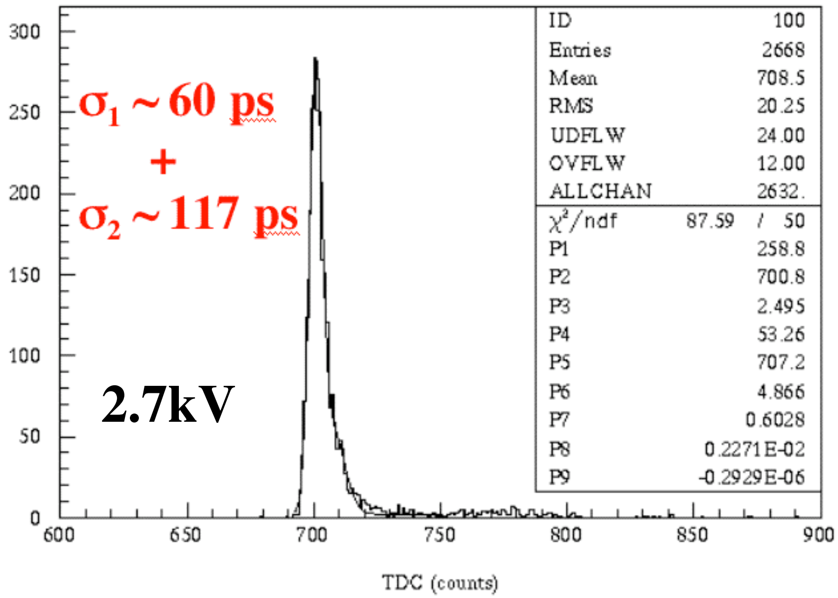
500mV/div, 1ns/div, 2.2kV:

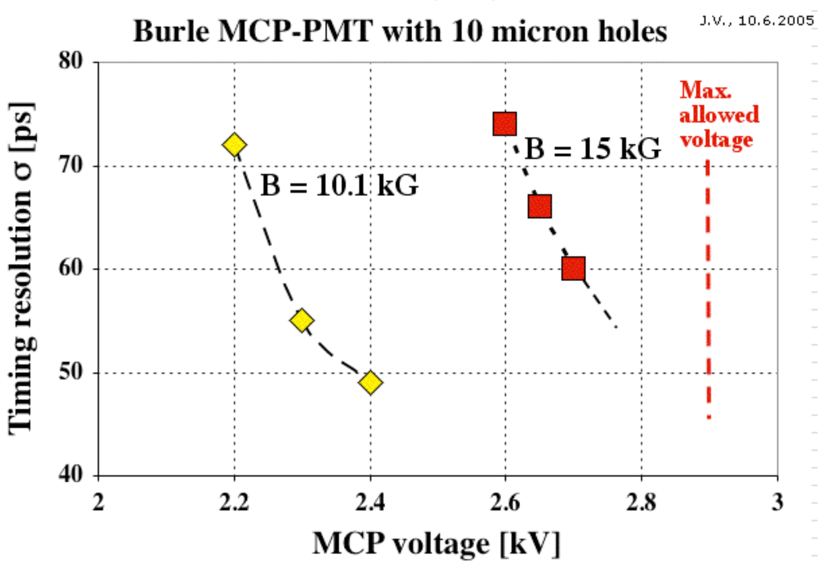




- **Ortec** VT-120A amplifier, gain of 200x, $(ds_o/dt)_{t=0} \sim 1.2V/1ns$
- **Elantek** 130x amplifier gives a smaller pulse height than the MCP with a 25µm hole diameter for the same operating voltage. The Elantek for this gain has a rise time of ~1.5ns. At 2.2kV, the Elantek produces barely ~100mV pulses, much less than the 25µm MCP at –2.4kV with a gain of ~$5x10^5$.
- **Explanation**: Elantek amp is too slow for this particular MCP.
- **The detector controls the choice of amplifier:** If the amplifier is too slow compared to the detector, one reduces the maximum peak amplitude for a given gain. On the other hand, if the amplifier is much faster than the detector, one increases the noise.

Timing results at B = 15 kG



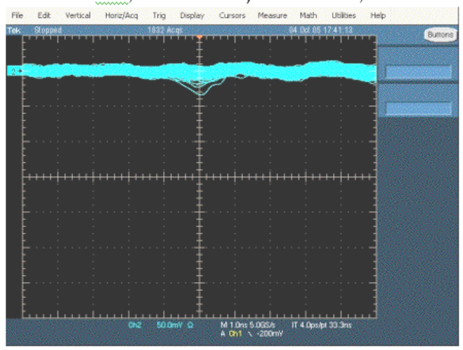


- **Ortec VT-120A amp**
- **Initially, there was some confusion what the maximum allowed voltage. Burle initially thought that it is -2.4kV. After I have "overvoltaged" the tube to -2.7kV to get a decent timing result at 15kG, Burle corrected the max voltage value to -2.85kV. I could have gone higher. This means that it is possible to reach a resolution of σ ~50ps at 15kG.**

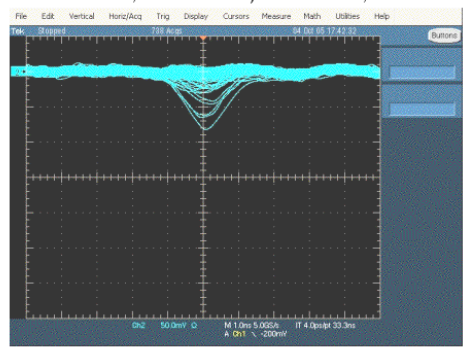
Sensitivity to volatge at B = 15kG

Ortec VT-120A amp, -2.65kV, 50mV/div, 1ns/div:

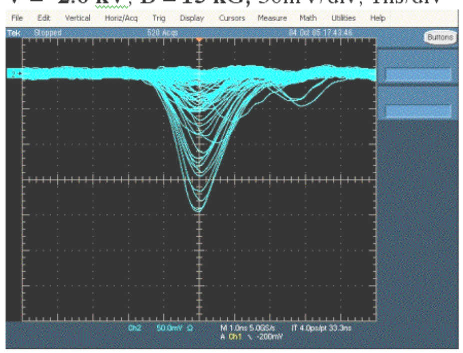
V = -2.4 kV, B = 15 kG, 50mV/div, 1ns/div



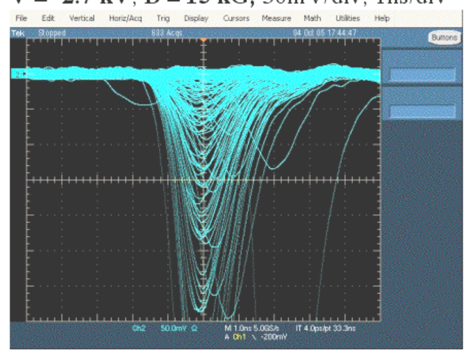
V = -2.5 kV, B = 15 kG, 50mV/div, 1ns/div



V = -2.6 kV, B = 15 kG, 50mV/div, 1ns/div



V = -2.7 kV, B = 15 kG, 50mV/div, 1ns/div

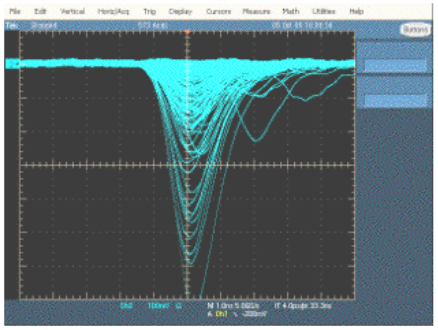


- **The necessary voltage to get a good timing resolution is 2.7-2.8kV.**

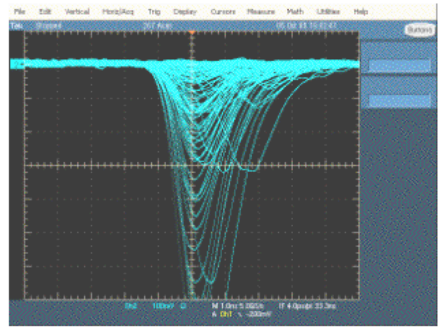
Sensitivity to angular rotation at B = 15kG

Ortec VT-120A amp, -2.65kV, 100mV/div, 1ns/div:

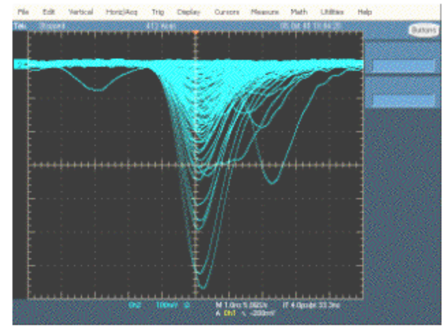
Θ = 0° (face perp. to field)



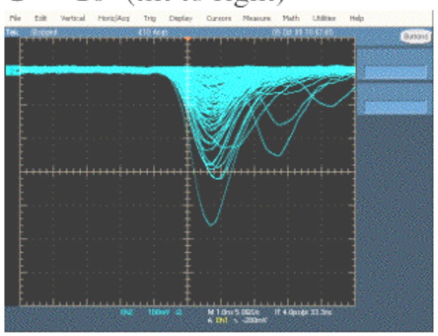
Θ = +3° (tilt to left)



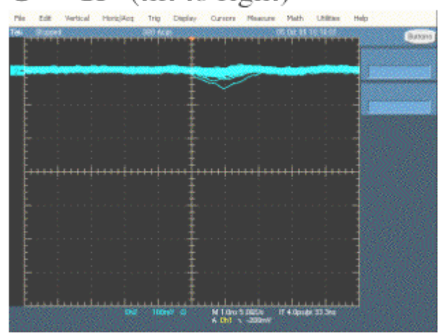
Θ = -3° (tilt to right)



Θ = -10° (tilt to right)



Θ = -15° (tilt to right)



Θ = -20° (tilt to right)

- **The MCP can be tilted by 3-5° before pulse height is affected. At 10°, one sees a clear reduction of the pulse height, but the tube can still be used. At 15° and above, the response is killed entirely.**

Aging of MCP-PMT

Aging of MCP-PMT

- **Aging due to damage of the photocathode by ion bombardment.**
- **Burle claims a ~50% loss after of ~10 C/25cm^2 area of MCP-PMT.**
- **Example:** DIRC single photon background rate is: ~200 kHz per 1" dia PMT at a luminosity of **~10^{34}cm^{-2}sec^{-1}**. If I assume that ~1/3 comes from the bar, we run ~6 months/year, then after 10 years, I get about **~10^{13} pe$^-$/cm^2. This translates to ~ 1-2 C/25cm^2, if we would have the MCP-PMTs in the present DIRC.** It is dominated by the LUMI-term, caused by the radiative Bhabhas striking beam components.
- **Nobody knows how to scale things for a Super B factory with a luminosity of > 10^{35} cm^{-2}sec^{-1}, however, it is clear that one has to pay attention to this problem.**