Focusing DIRC prototype

(T-469 test)

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Special thanks to:

Engineering help: T. Thurston and A. Scholz

EFD help to setup the beam line: C. Hast, J. Weisand, and their techs

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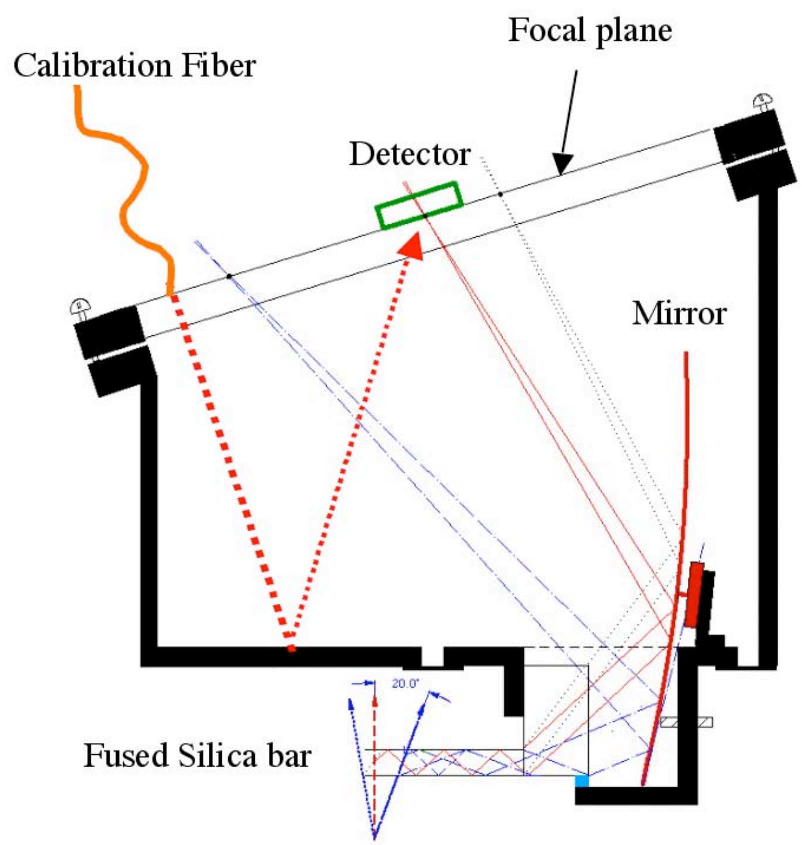
MCC help: M. Stanek, R. Erickson, and MCC operators running our beam

Advice about running in ESA: R. Arnold, P. Bosted

Motivation

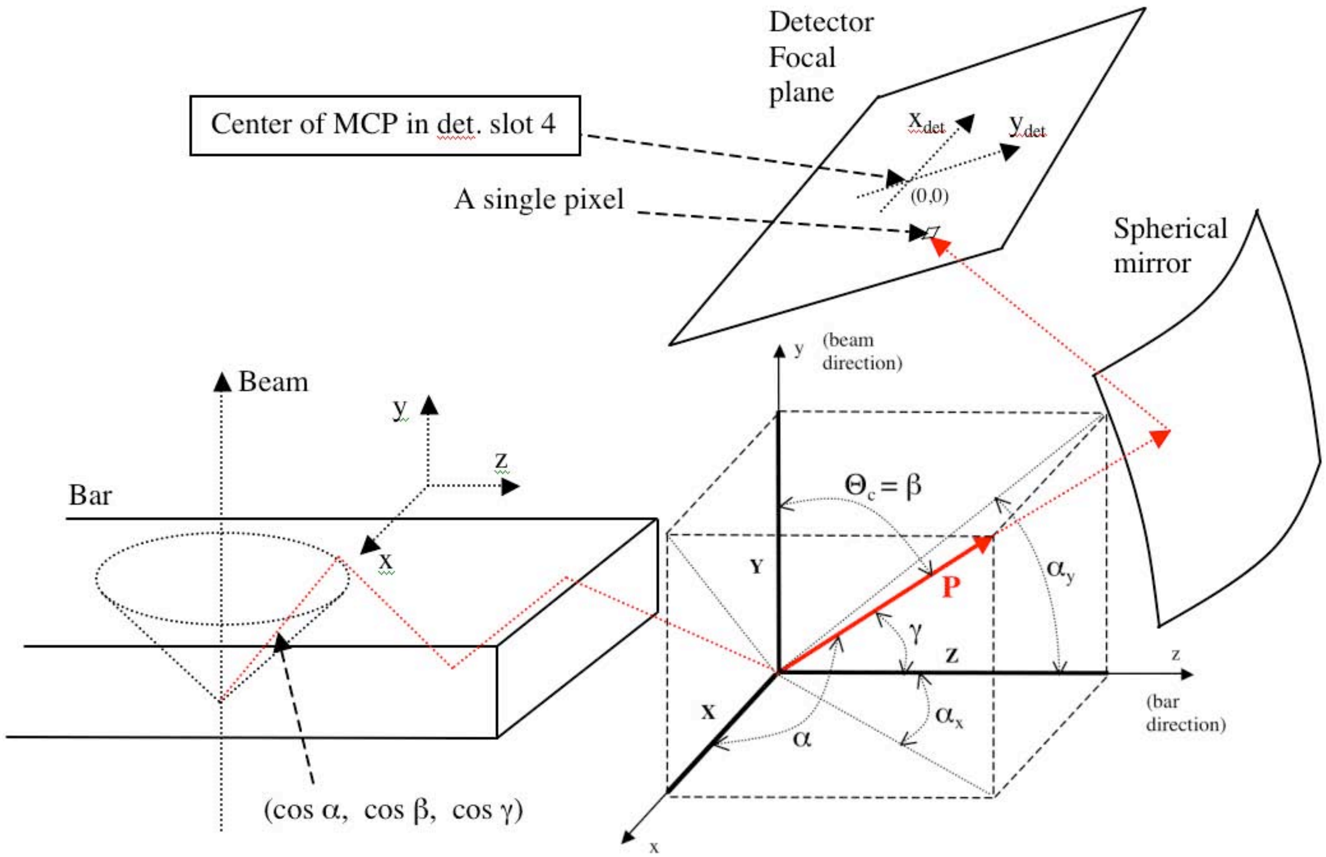
- DIRC is a very successful particle identifying detector.
- One can measure its success by a fact that the Japanese are trying to come up with it also for their Super B-factory. They are choosing to measure **x & Time-of-Propagation (TOP time)** for each Cherenkov photon.
- We thought that we should be in a position to propose DIRC upgrade for Super B-factory, which would be capable of taking higher rates, be less sensitive to background and be able to correct the chromatic error contribution to the Cherenkov angle. We are choosing to measure **x, y and the TOP time** for each photon. We believe that this a better way to do it in a high background.

Optics of the prototype



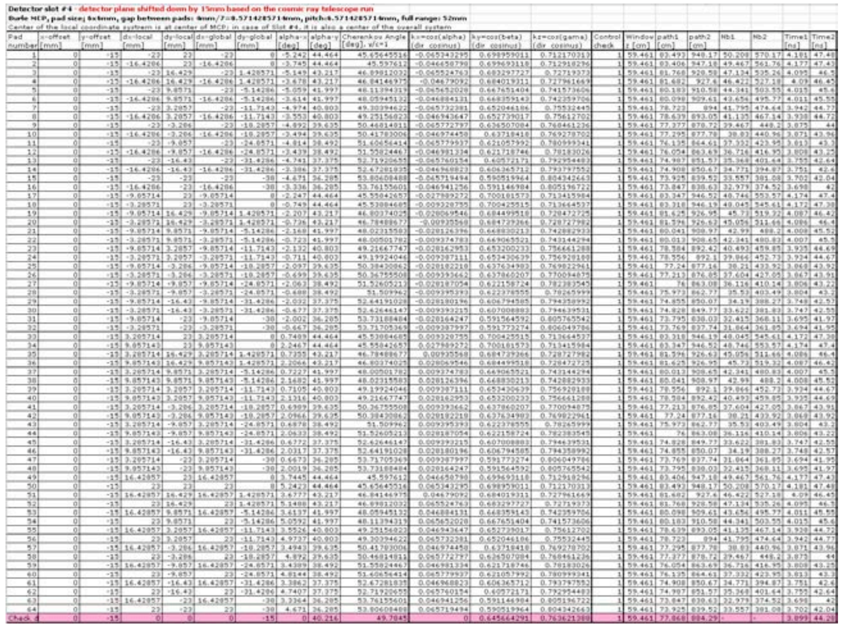
- Spherical mirror corrects quartz bar thickness
- Oil filling makes it affordable; a final device would be made out of solid quartz.

Focusing DIRC principle



- **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…



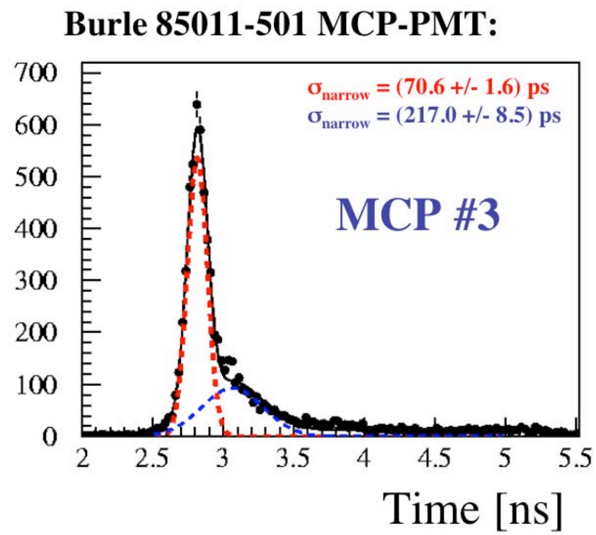
- **Each pad predicts the photon's time and path history, and you can work it out using a spreadsheet…**
- **Pad 26, position 1**:

  a) <u>The initial design:</u> $\theta_c = 47.662^o$, $L_{path\ 1} = 80.447$ 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, **<u>dT (Peak1 - Peak2) = 41.722 ns</u>**

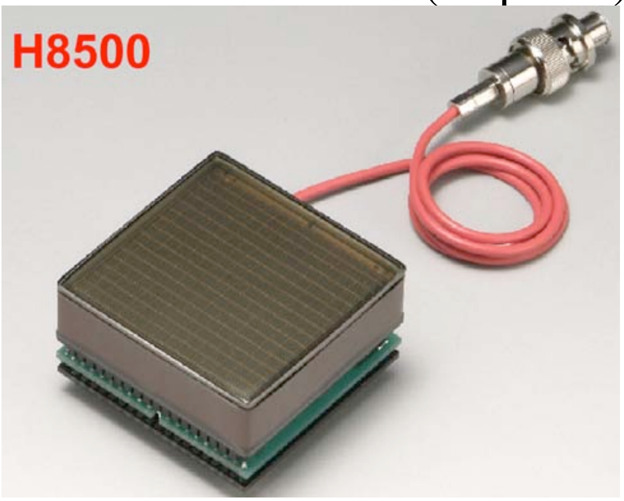
  b) <u>With 1.5 cm shift:</u> $\theta_c = 50.367^o$, $L_{path\ 1} = 77.213$ cm, $n_{bounces\ 1} = 37$, $t_{path\ 1} = 3.867$ ns, $L_{path\ 2} = 876.85$ cm, $n_{bounces\ 2} = 427$, $t_{path\ 2} = 43.91$ ns, **<u>dT (Peak1 - Peak2) = 40.043 ns</u>**

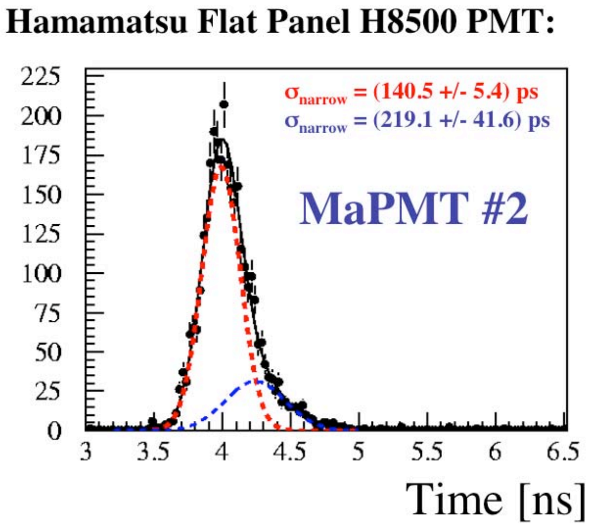
Photon detectors in this test: σ~70-140ps

Burle MCP PMT (64 pixels):

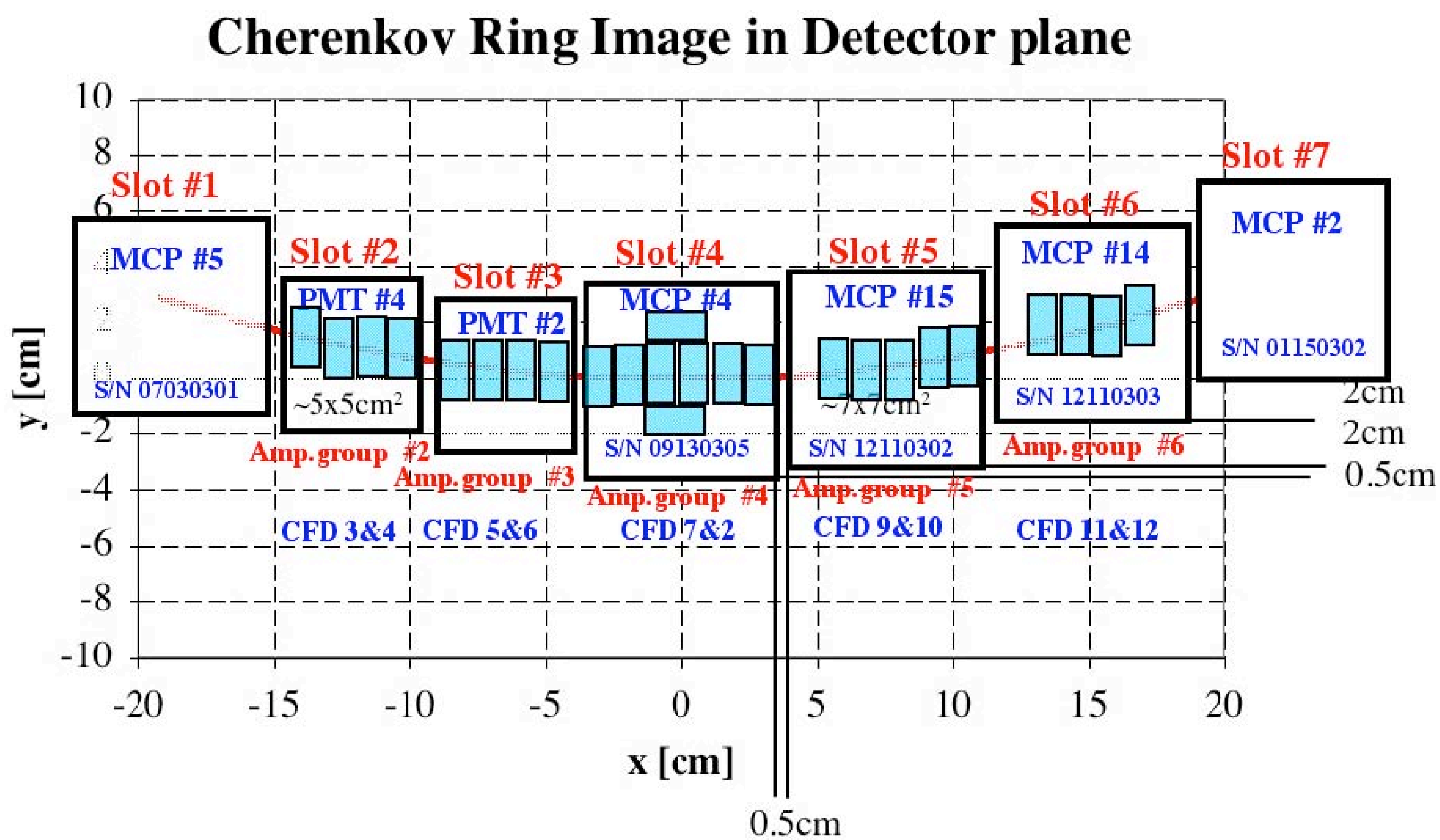


Hamamatsu MaPMT (64 pixels):





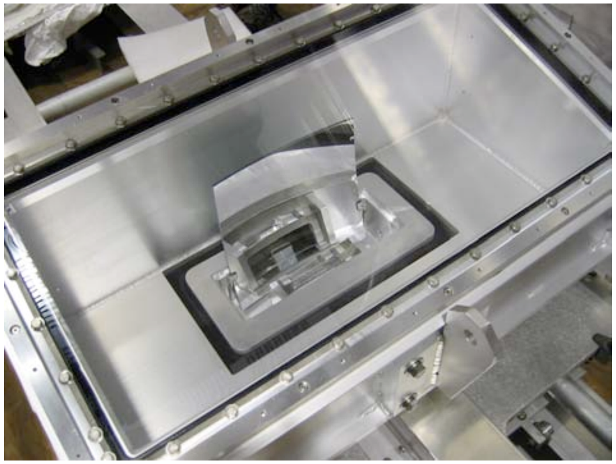
Distribution of detectors on the prototype



- 2 Hamamatsu MaPMTs
- 3 Burle MCPs

Detector setup in ESA

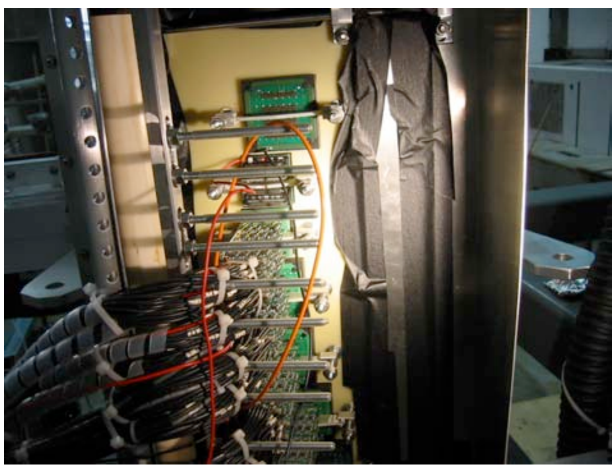
Mirror and oil-filled detector box:



Start counters, lead glass:

Orient the MCPs to minimize the timing dependency on the beam position

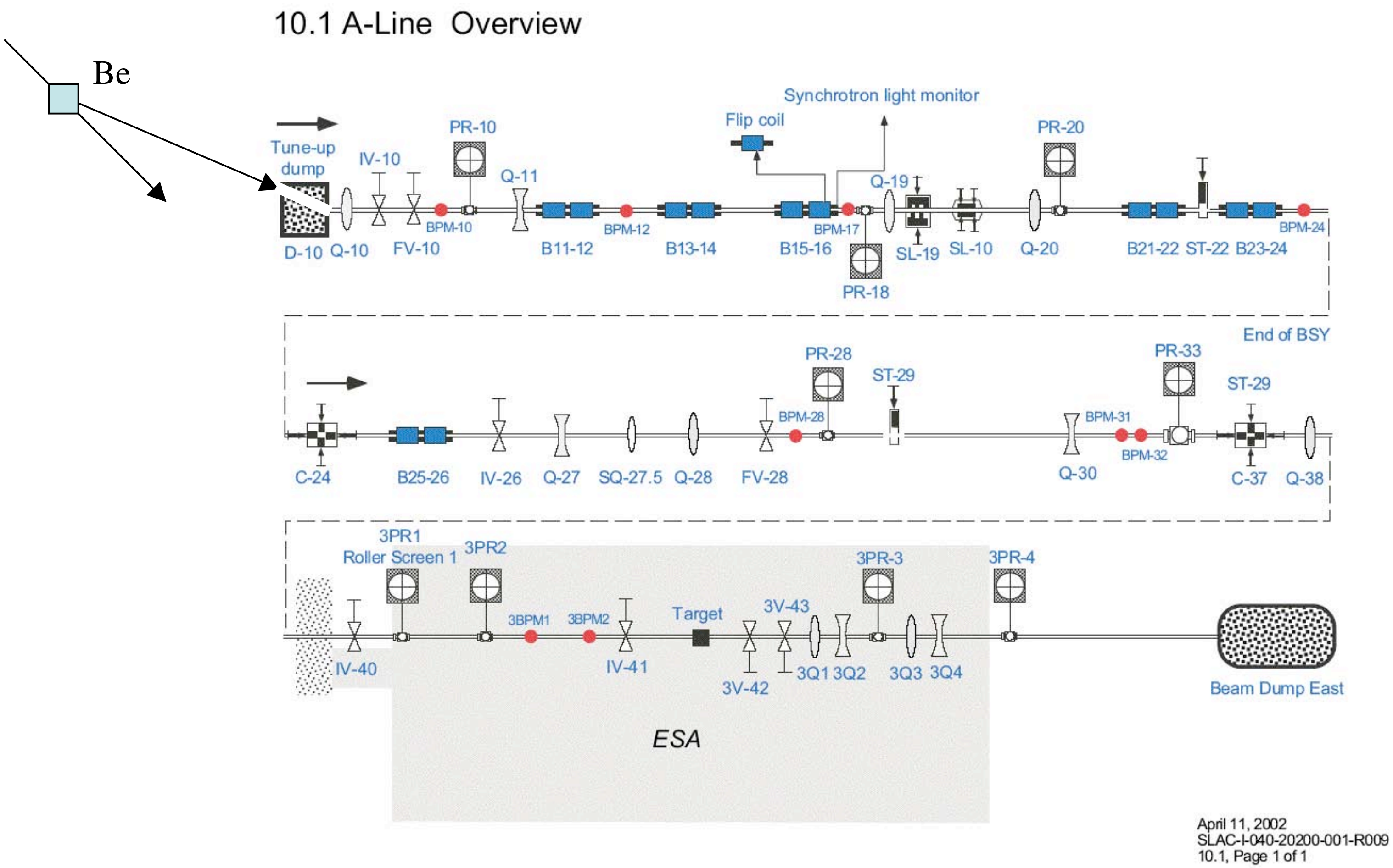
Electronics:



Movable bar support, hodoscope:

Moving the bar worked very well

Beam line A



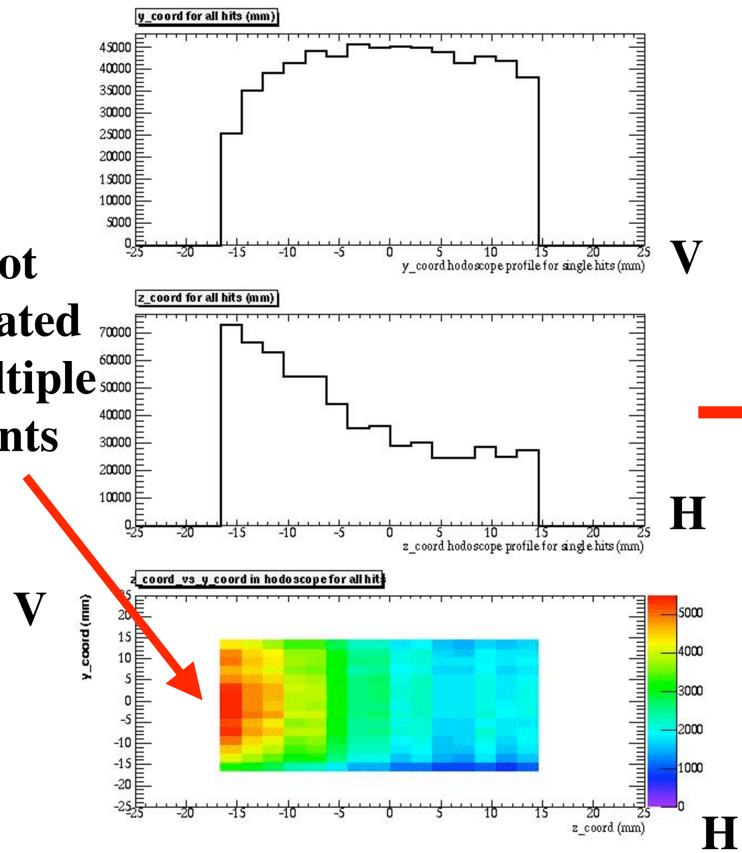
- Q10 & Q11 had to run at a very low current, otherwise we would get nothing. Mike Stanek found a solution to "detune" all other quads compared to nominal values. As a result, we had a "beam pipe filler" beam entering the collimator.

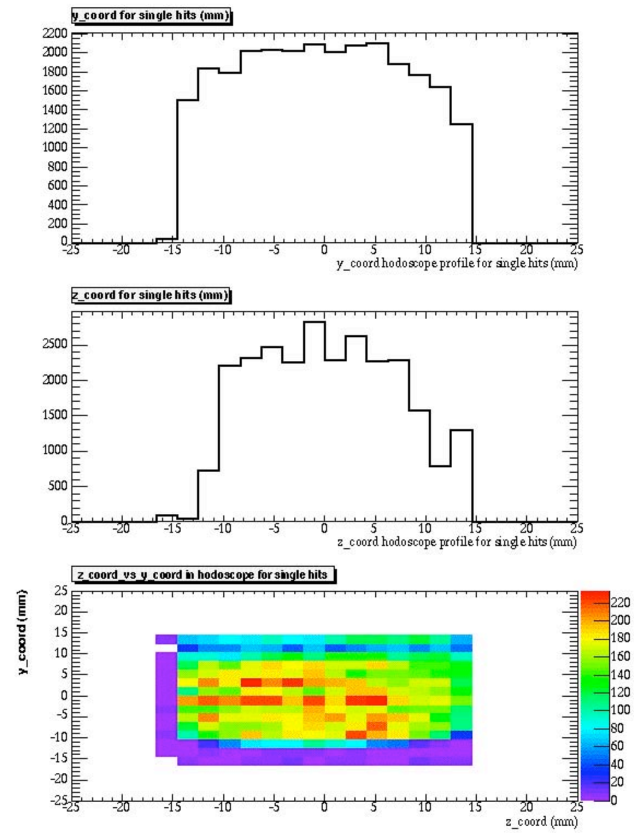
Beam profile in the fiber hodoscope

All triggers:

Single hodoscope hits only:

Hot spot dominated by multiple hit events

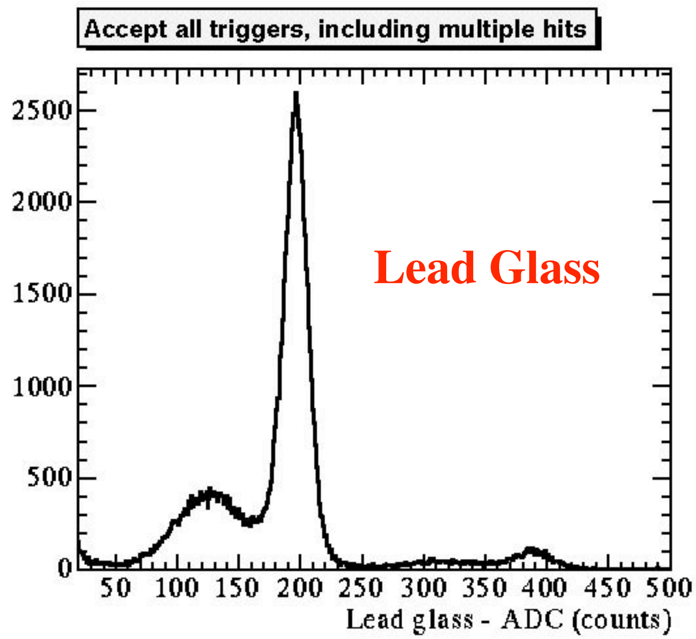




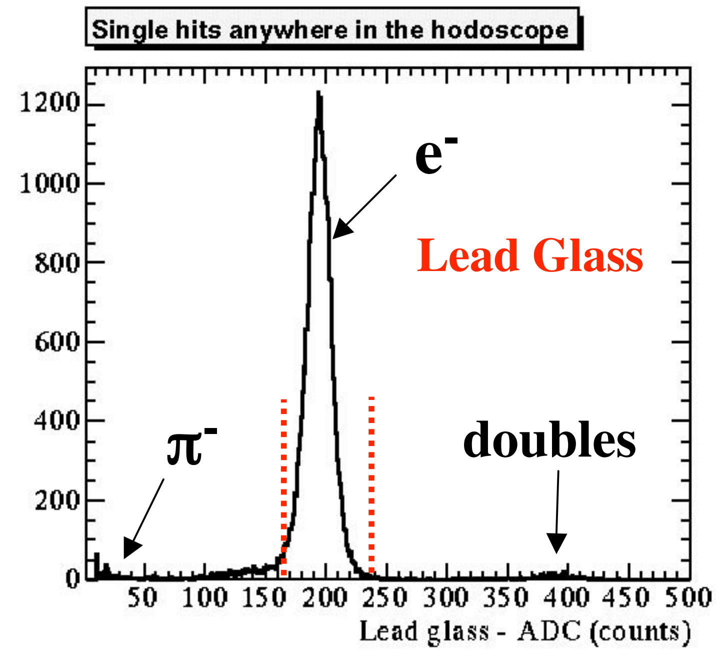
- The big blob on left side dominated by multiple hits (showers). Demanding the single hits in the hodoscope cleaned up the distribution.

For the negative polarity: mostly electrons

All triggers:



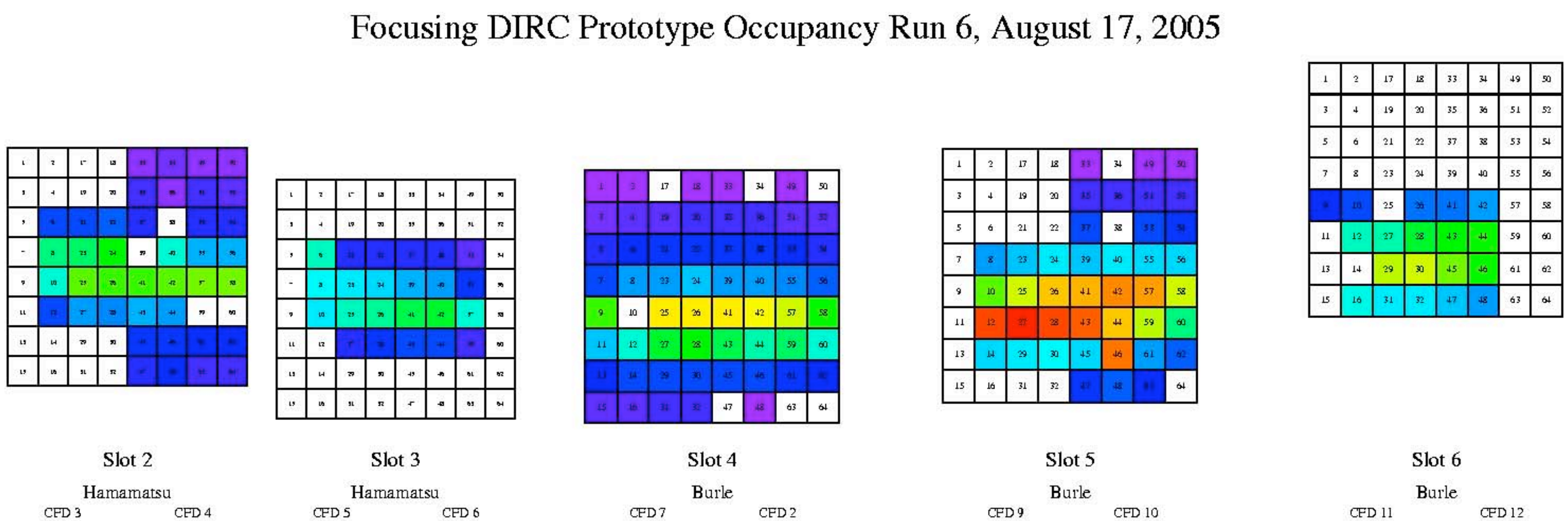
Single hodoscope hits only:



- P. Bosted guess: should get mostly electrons when selecting the negative polarity in beam line A with a Be target. We confirm that.
- A definition of a "good" event: **single hit in hodoscope and tight correct energy in the lead glass (160<ADC<240)** - this cleans up our events nicely.

Cherenkov ring in x & y plane

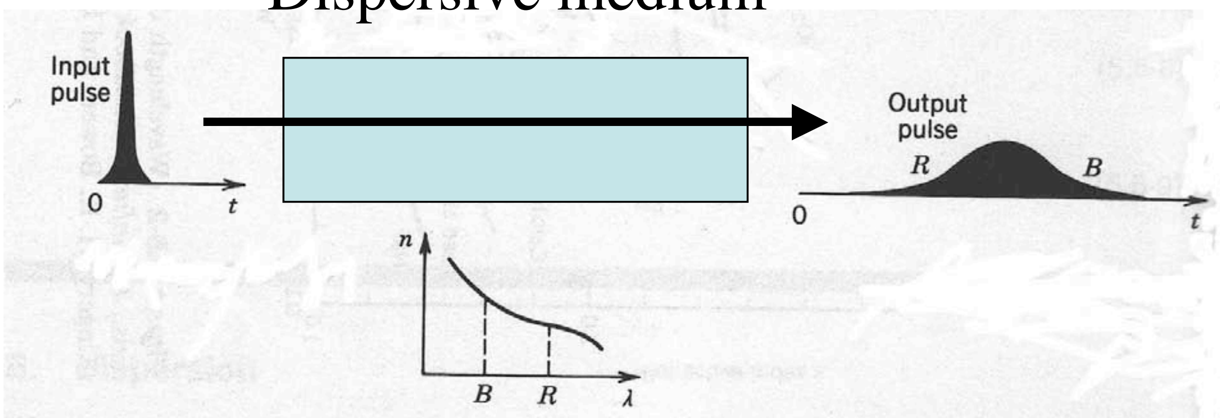
Joe’s picture:



- A clear image, but that is not what we are after. In this test, we are mainly interested in the time domain.
- Not all pixels instrumented, only those around the ring.

Chromatic broadening of a light impulse

Dispersive medium

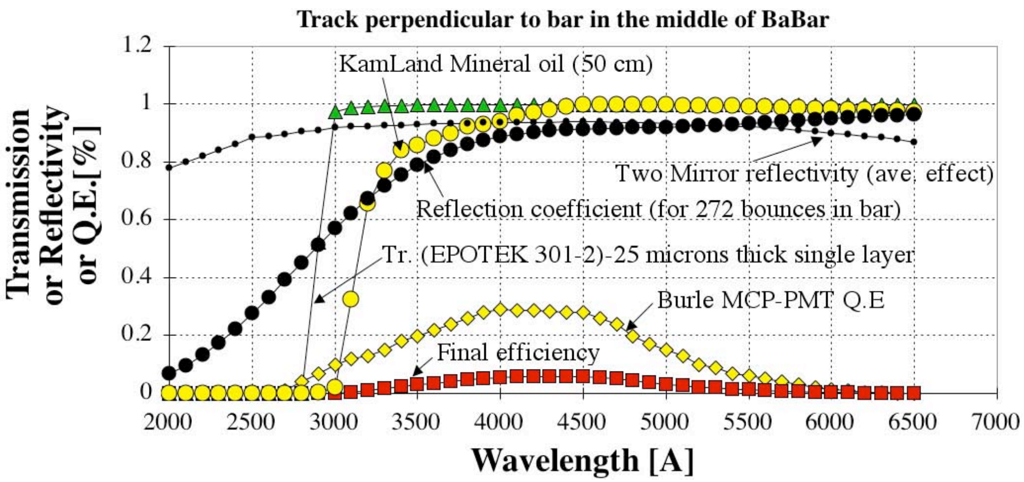


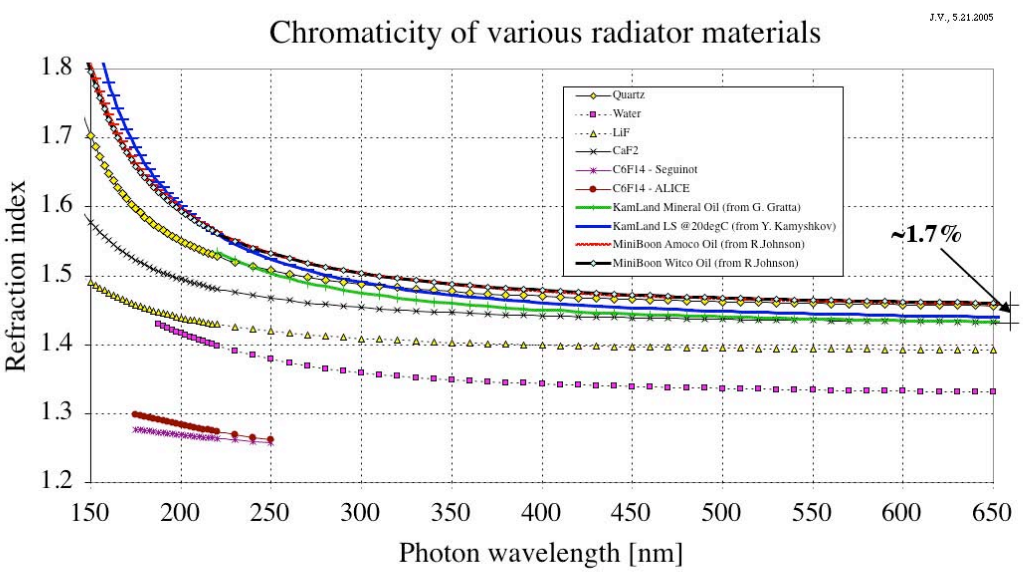
$$dt = -L\ \lambda\ d\lambda / c_0 * d^2n/d\lambda^2$$

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

- **Well known effect in the fiber industry**
- **DIRC behaves the same way.**

Focusing DIRC chromaticity

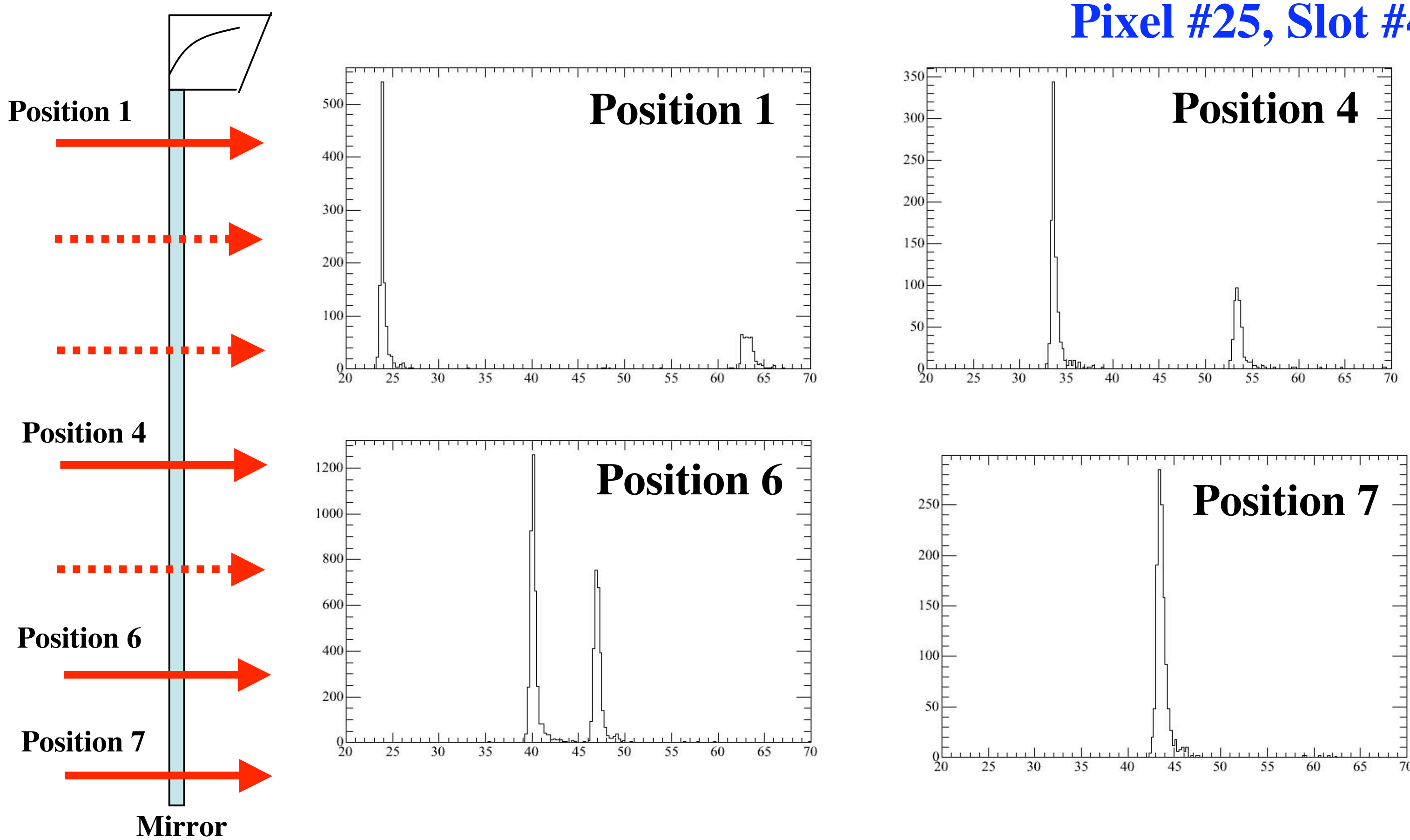




- **Burle QE curve has a peak a bit higher than that of the DIRC PMT.**
- **dλ ~ 300 nm**
- **Assume an average wavelength of ~430nm**
- **Some uncertainty in the oil refraction index (<1.7%).**

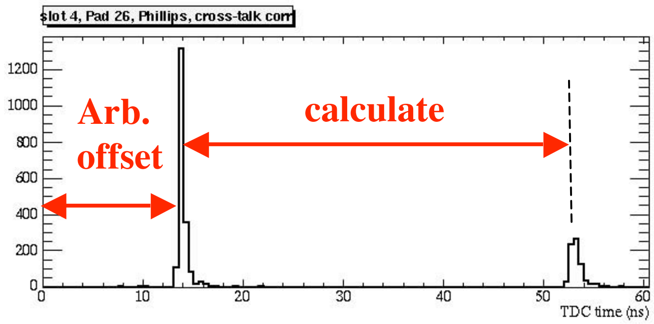
The Cherenkov ring in the time domain

Pixel #25, Slot #4

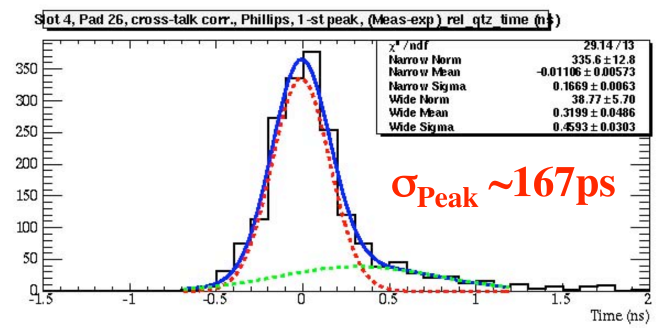


- **Two peaks correspond to forward and backward going part of the Cherenkov ring (the backward part is reflected by a mirror back)**

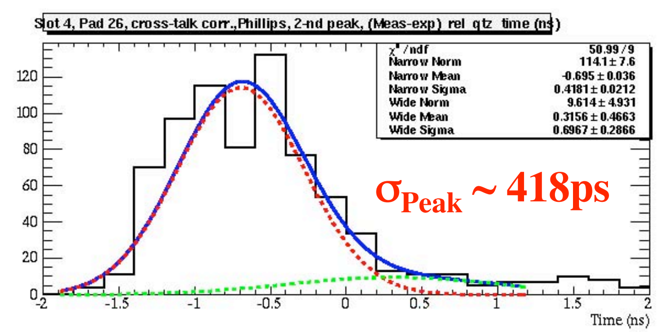
Chromatic growth in pixel #26, slot 4, Run7, position 1 (Burle MCP)



1-st peak:

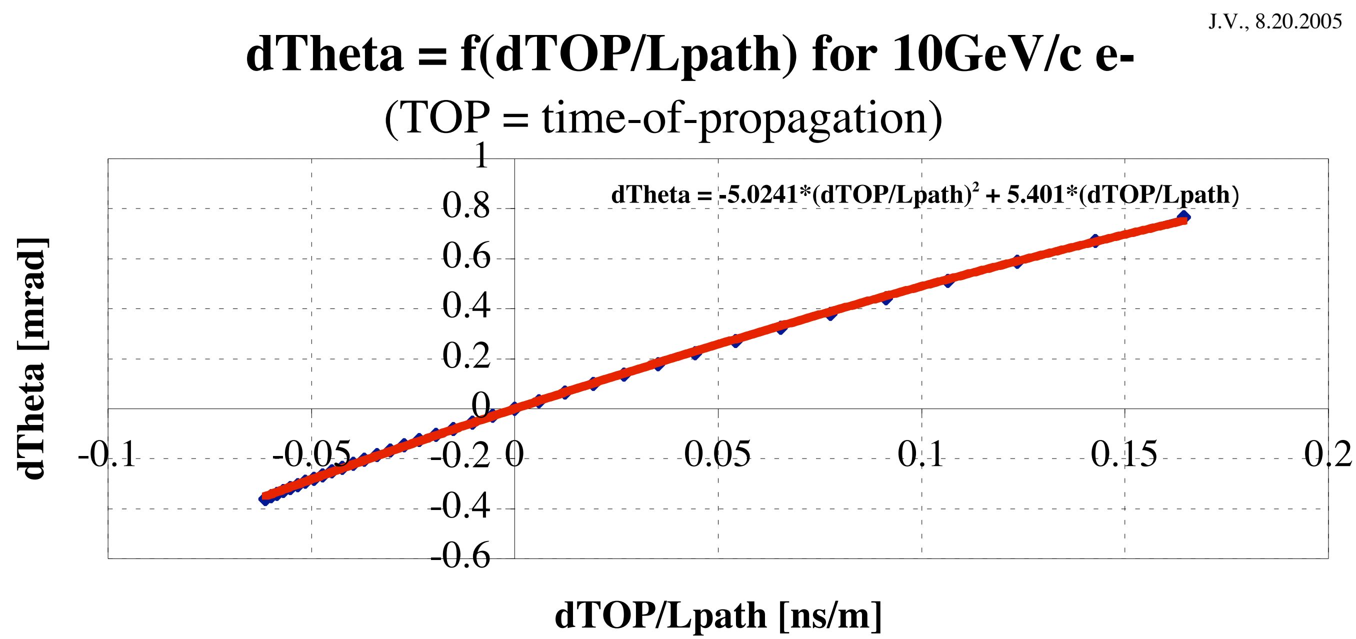


2-nd peak:



- The largest chromatic effect is in the position 1
- Peak 1 was was first adjusted with Joe's constants based on the PiLas calibration. Then it was adjusted arbitrarily adjusted to zero by a constant $C_{pad26,slot4,run7}$.
- Peak 2 was adjusted using the calculated offse using my spreadsheett, and assuming a TDC calibration of 23 ps/count.
- The 2-nd peak does not come to zero. It is off by ~.65ns at present.
- Corrected for the MCP cross-talk and for time drift using the Start counter 1.
- Assume that the detector plane is shifted down by 1.5cm in this analysis.

Chromatic correction



- An average photon with a color of ~430nm arrives at 0 ns offset, and the Cherenkov angle is not corrected.
- A photon of different color, arrives either early or late. We can calculate its total photon path length, measure dTOP, and then determine $d\theta_c$ according to the above graph (one way to do it).
- **Doing this correction, and doing several other upgrades in future, the future Focusing DIRC could reach the π/K PID limit of 5-6 GeV/c.**

Start counter 1 - Quartz counter MCP

ADC correction: | **Z- position correction:**

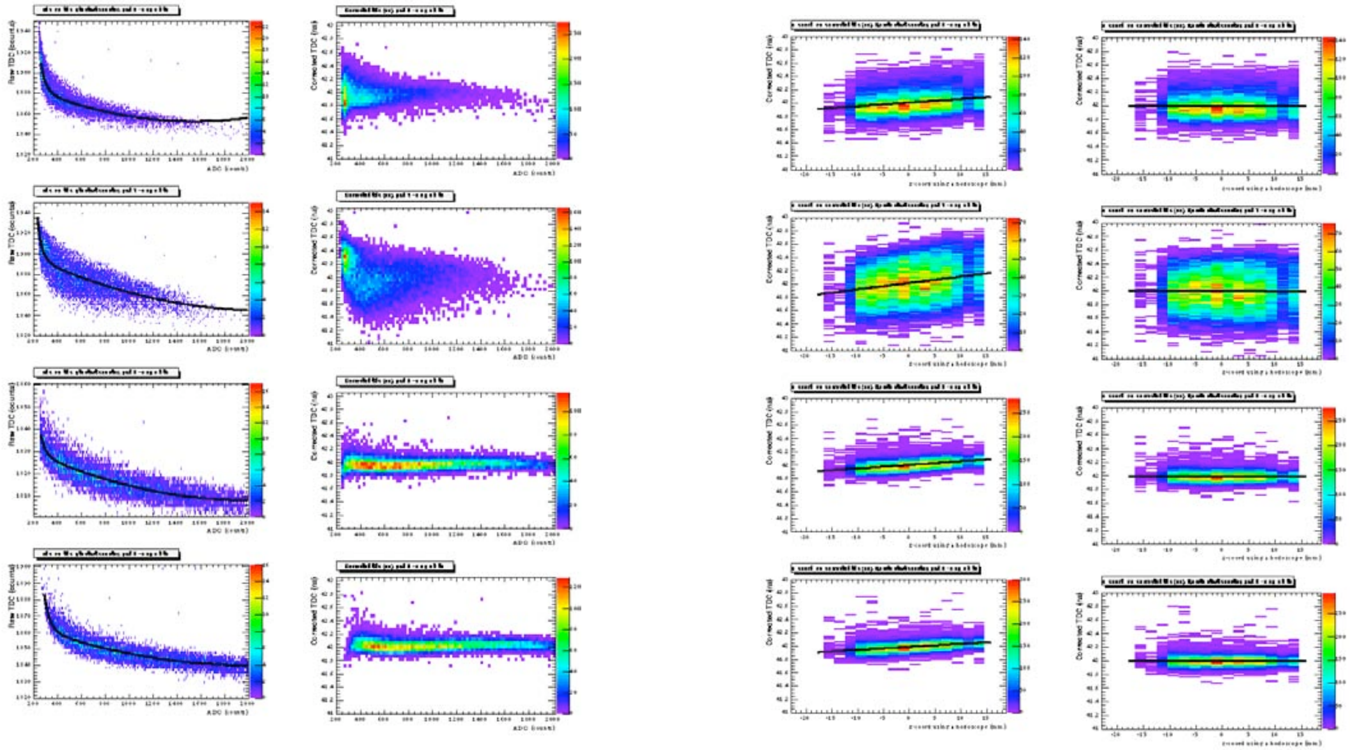
Before: After: | Before: After:

Pad 0:

Pad 1:

Pad 2:

Pad 3:

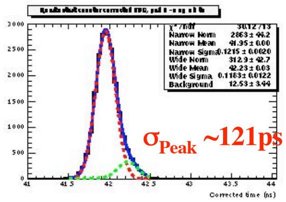


- MCP pads 3 & 4 see much more light. Will use only those for the time definition.

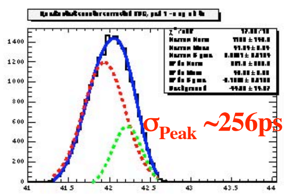
Start counter 1 - Quartz counter MCP

Individual pads:

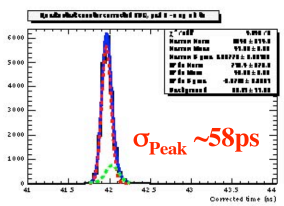
Pad 0:



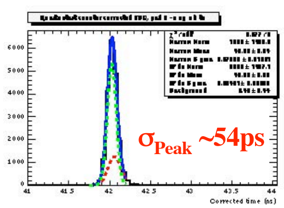
Pad 1:



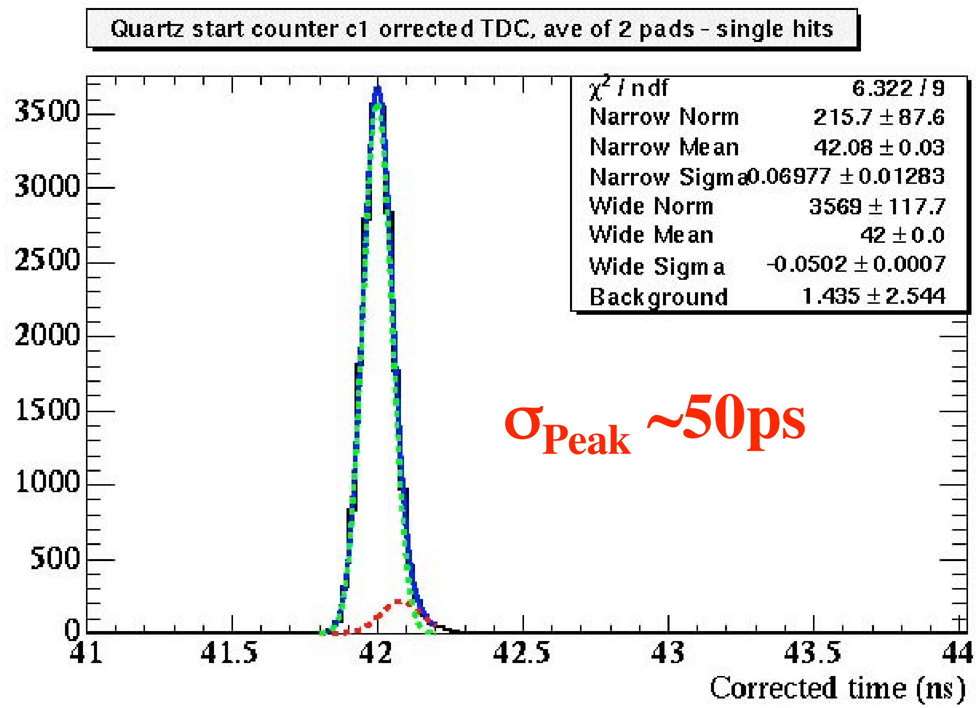
Pad 2:



Pad 3:



Average of 2 pads (3 & 4):



- Excellent resolution. Time drifts due to temperature effects are not yet corrected out, so further improvements possible.

Start counter 2 - Scintillator counter MCP

ADC correction:

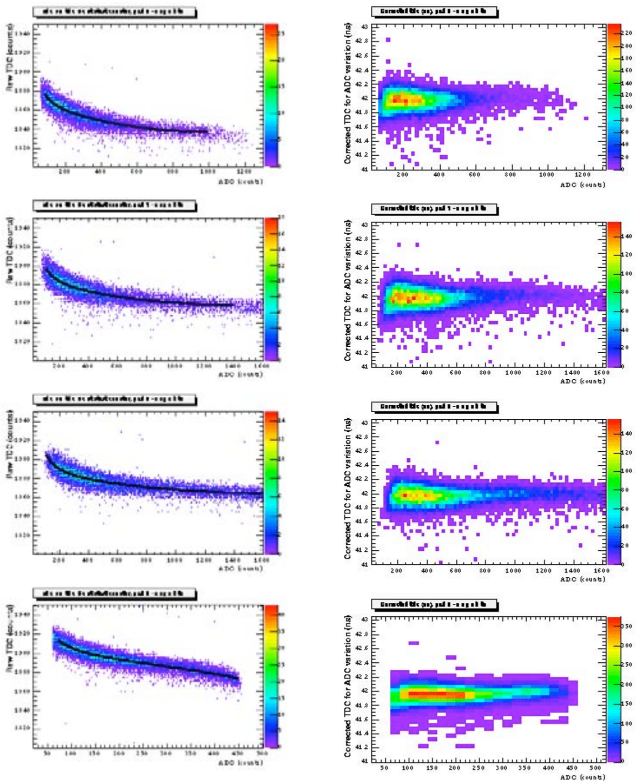
Before: **After:**

Pad 0:

Pad 1:

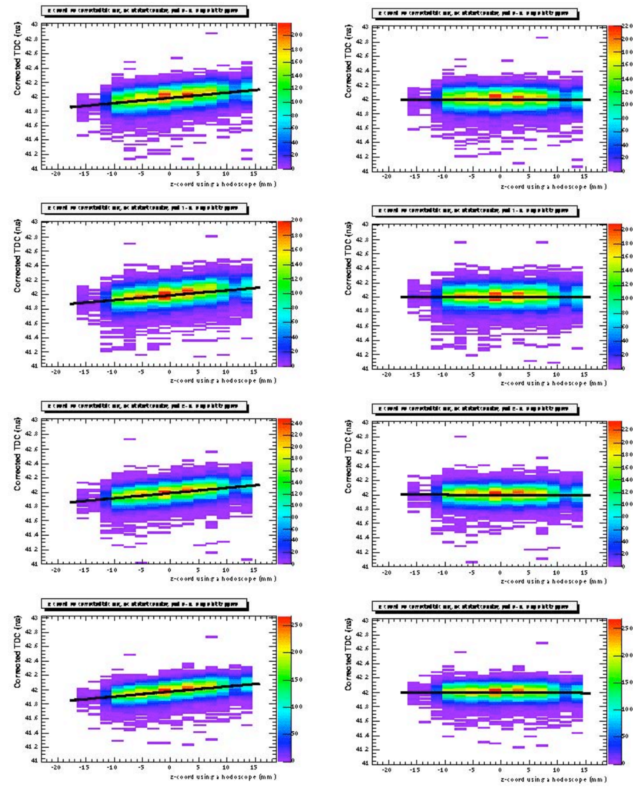
Pad 2:

Pad 3:



Z- position correction:

Before: **After:**

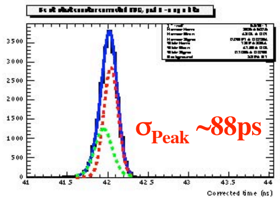


- All MCP pads are OK.

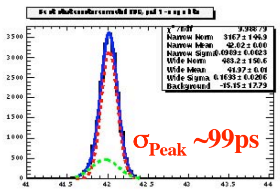
Start counter 2 - Scintillator counter MCP

Individual pads:

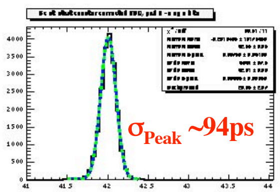
Pad 0:



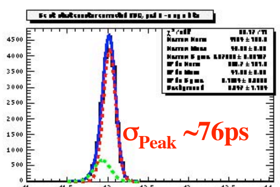
Pad 1:



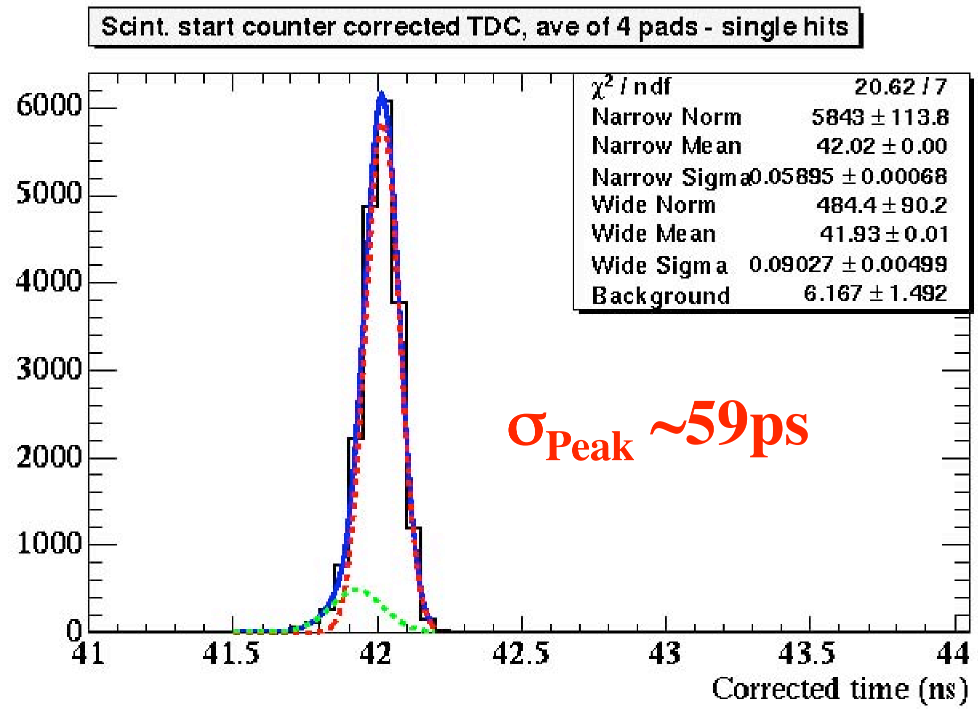
Pad 2:



Pad 3:



Average of all pads:

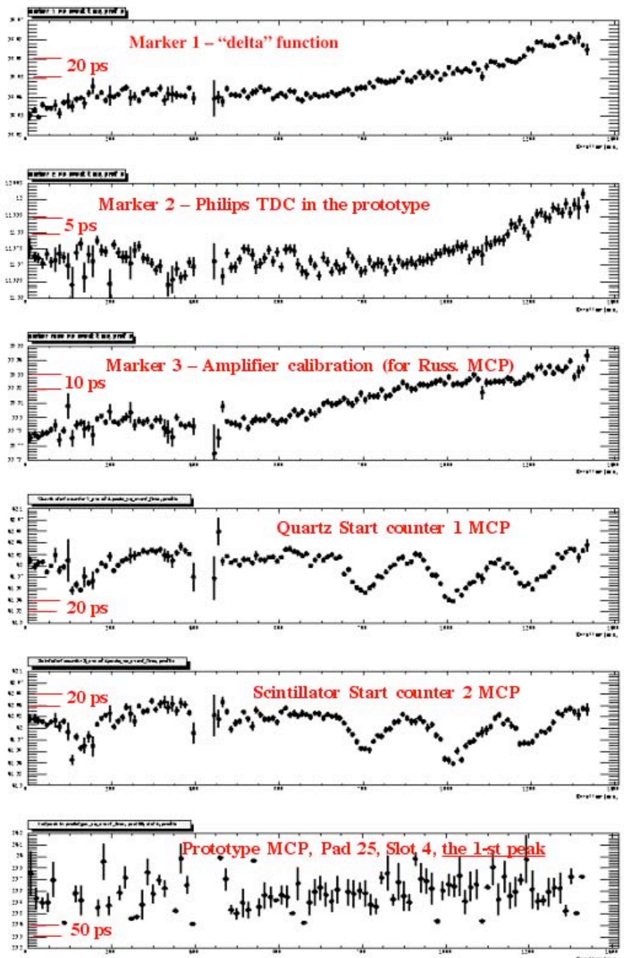


- Excellent resolution. Time drifts due to temperature effects are not yet corrected out, so further improvements possible.

The timing stability and TDC calibration is very critical for this type of detector

Run 7, Position 1 – Stability as a function of time over ~22 hours:

Time Drift [ns]



Elapsed time [min]

- To keep track of the timing drifts between the MCC start signal and the beam, we have two precise beam start counters

  (can probably achieve better then **σ < 50ps**).
- To keep track of timing drifts within the electronics system, we have altogether 7 timing markers, which can be used to correct the system drifts

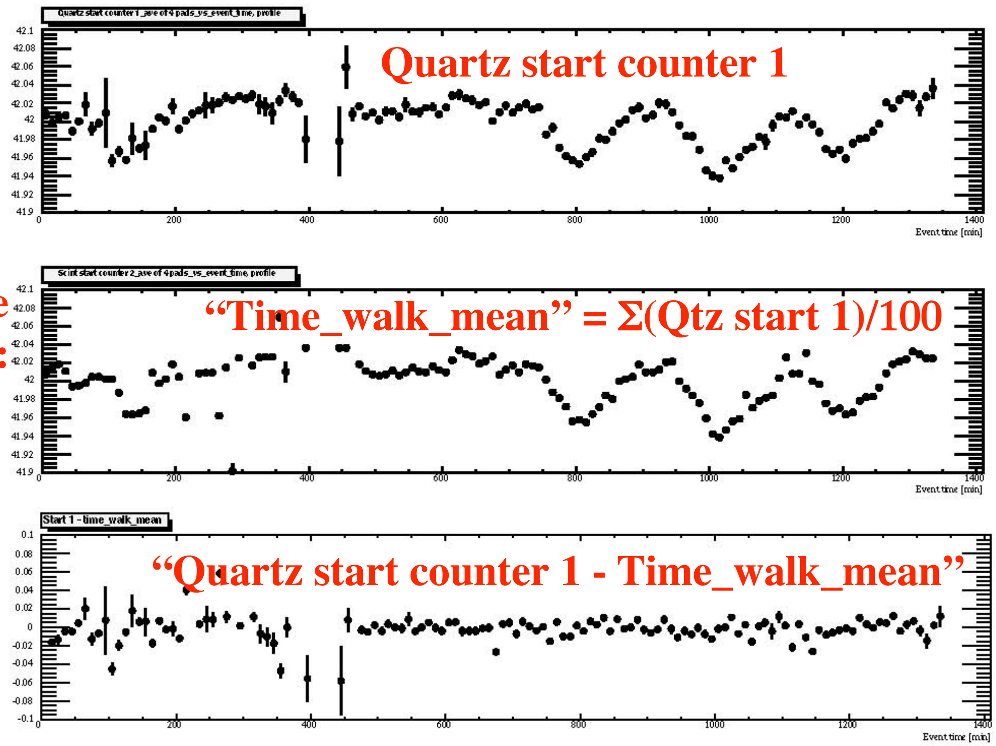
  (can easily achieve **σ < 5-10ps**).
- Understanding of the TDC calibration and its stability using a PiLas laser diode is very important.

Correction using the Start counter 1

Profile of Quartz Start counter 1:

Correction reference “Time_walk_mean”:

Difference:



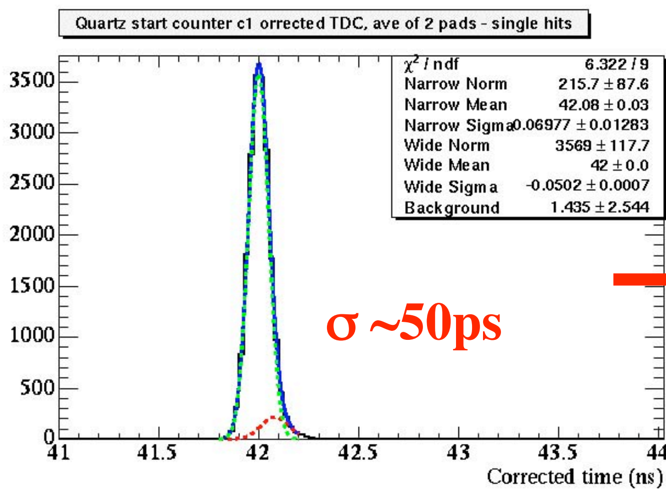
Elapsed time [min]

- The correction reference “Time_walk_mean” is doing the same thing as the profile of the Quartz start counter 1. It is created by averaging over the previous 100 measuements of “good hits” in the Quartz start counter 1.

Scintillator Start counter 1 corrected by the Quartz Start counter 1 (averages over 100 events).

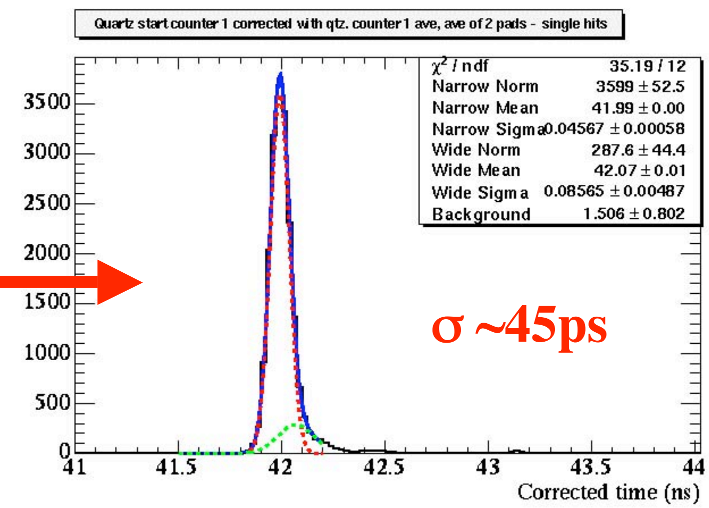
Start 1, average of all pads:

(Start TDC with the MCC signal, which is derived from the Linac RF)



Start 1, average of all pads:

(Correct the MCC signal with the Quartz Start 1 counter; averages over 100 events)



- **It helps a bit.**

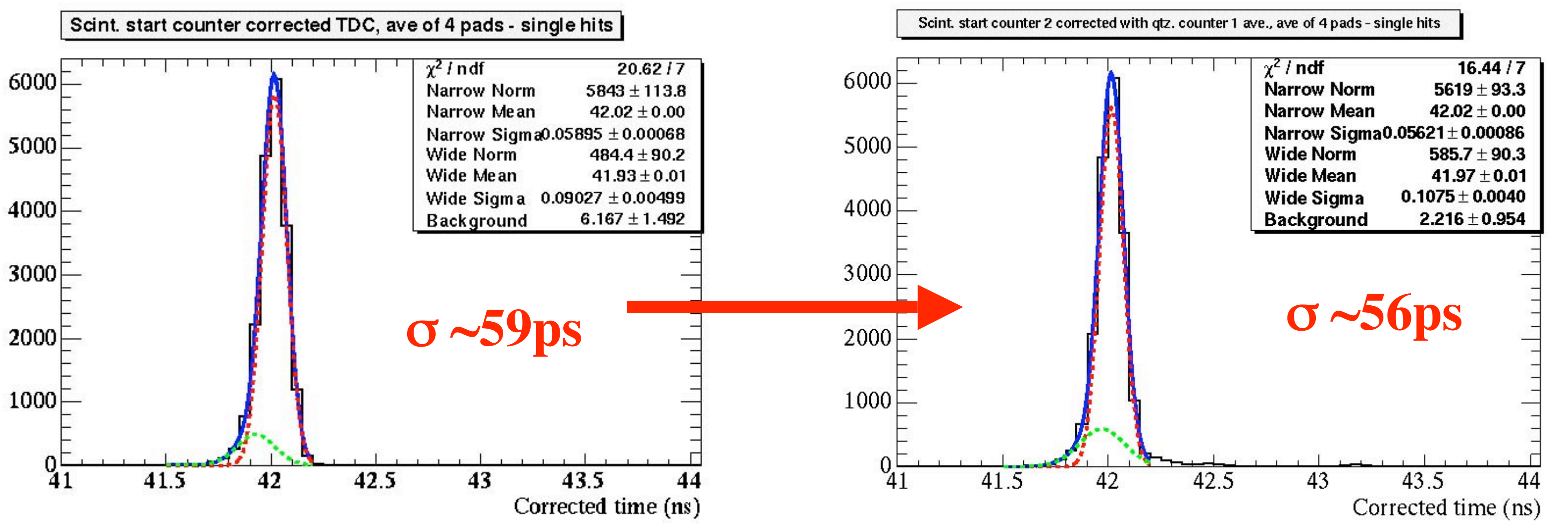
Scintillator Start counter 2 corrected by the Quartz Start counter 1 (averages over 100 events).

Start 2, average of all pads:

(Start TDC with the MCC signal, which is derived from the Linac RF)

Start 2, average of all pads:

(Correct the MCC signal with the Quartz Start 1 counter; averages over 100 events)

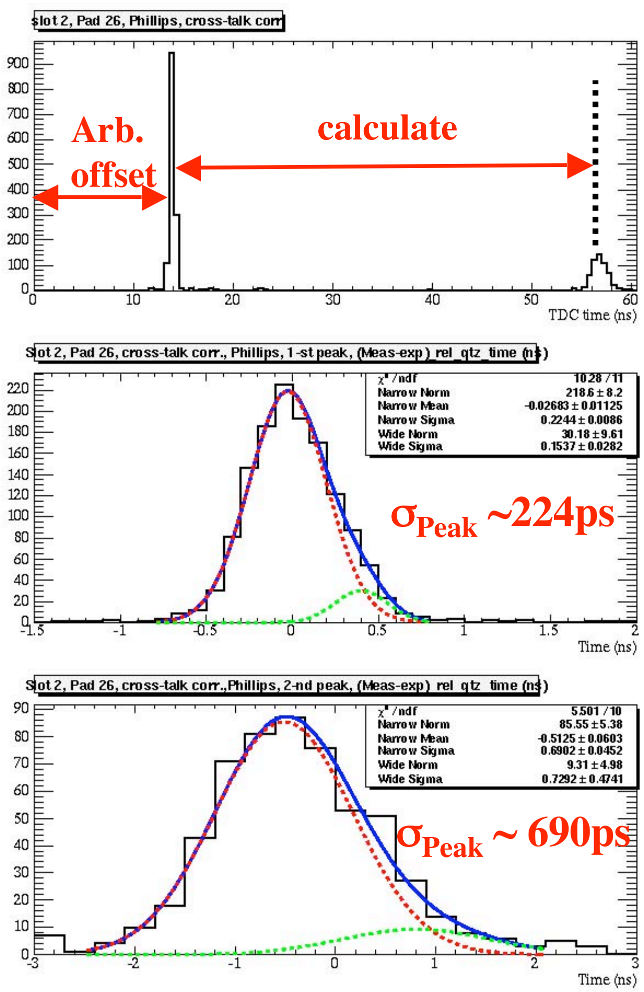


- **It helps only a little bit. This may mean that the resolution of the counter is comparable to a size of the correction.**

Chromatic growth in pixel #26, slot 2, Run7, position 1 (Hamamatsu MaPMT)

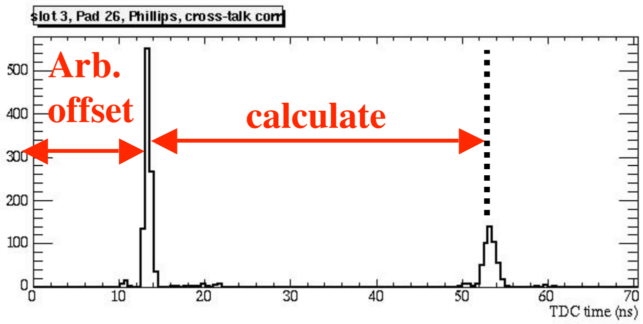
1-st peak:

2-nd peak:

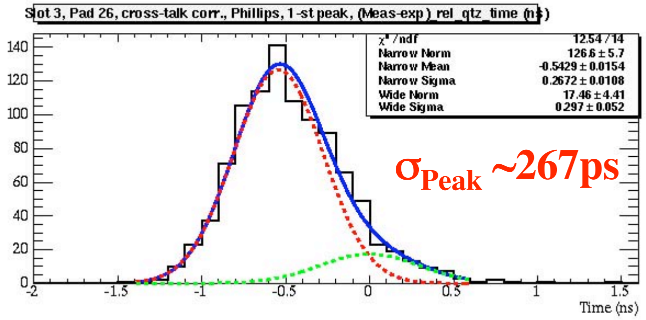


- Hamamatsu MaPMT does not have as large tail as the Burle MCP, but it is good enough to correct the chromatic error
- Peak 1 was was first adjusted with Joe's constants based on the PiLas calibration. Then it was adjusted arbitrarily adjusted to zero by a constant $C_{pad26,slot4,run7}$.
- Peak 2 was adjusted using the calculated offset, and assuming a TDC calibration of 23 ps/count.
- The 2-nd peak does not come to zero. It is off by ~.51ns at present.
- Corrected for the MCP cross-talk and for time drift using the Start counter 1.
- Assume that the detector plane is shifted down by 1.5cm in this analysis.

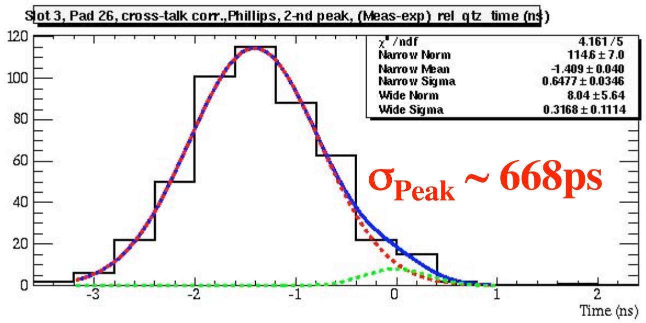
Chromatic growth in pixel #26, slot 3, Run7, position 1 (Hamamatsu MaPMT)



1-st peak:

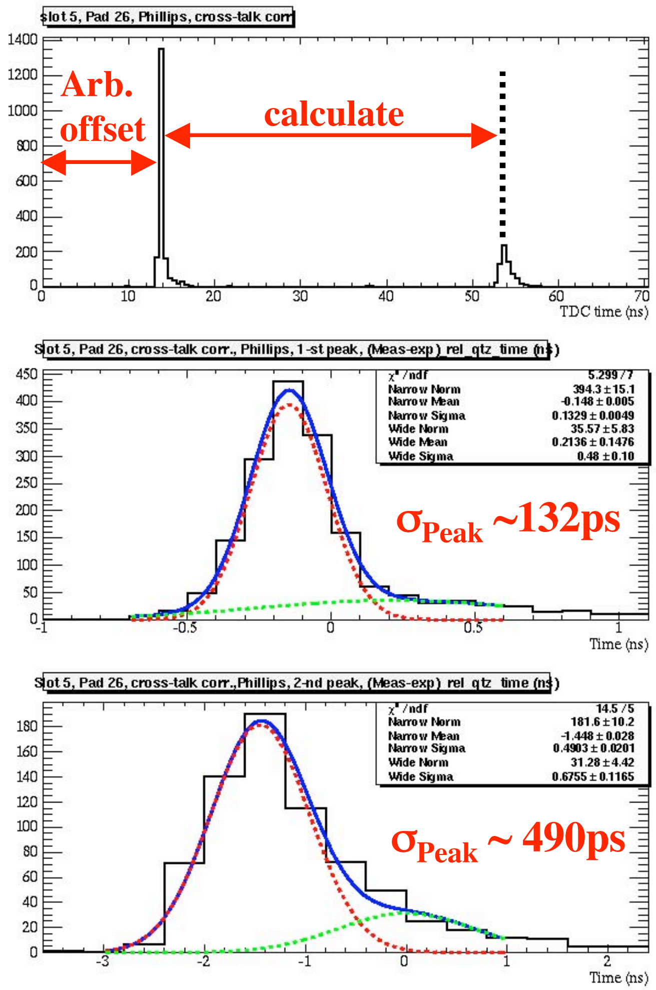


2-nd peak:



- Hamamatsu MaPMT does not have as large tail as the Burle MCP, but it is good enough to correct the chromatic error
- Peak 1 was was first adjusted with Joe's constants based on the PiLas calibration. Then it was adjusted arbitrarily adjusted to zero by a constant $C_{pad26,slot4,run7}$.
- Peak 2 was adjusted using the calculated offset, and assuming a TDC calibration of 23 ps/count.
- The 1-st peak does not come to zero. It is off by ~.54ns at present. The 2-nd peak is off by 1.4ns.
- Corrected for the MCP cross-talk and for time drift using the Start counter 1.
- Assume that the detector plane is shifted down by 1.5cm in this analysis.

Chromatic growth in pixel #26, slot 5, Run7, position 1 (Burle MCP)



1-st peak:

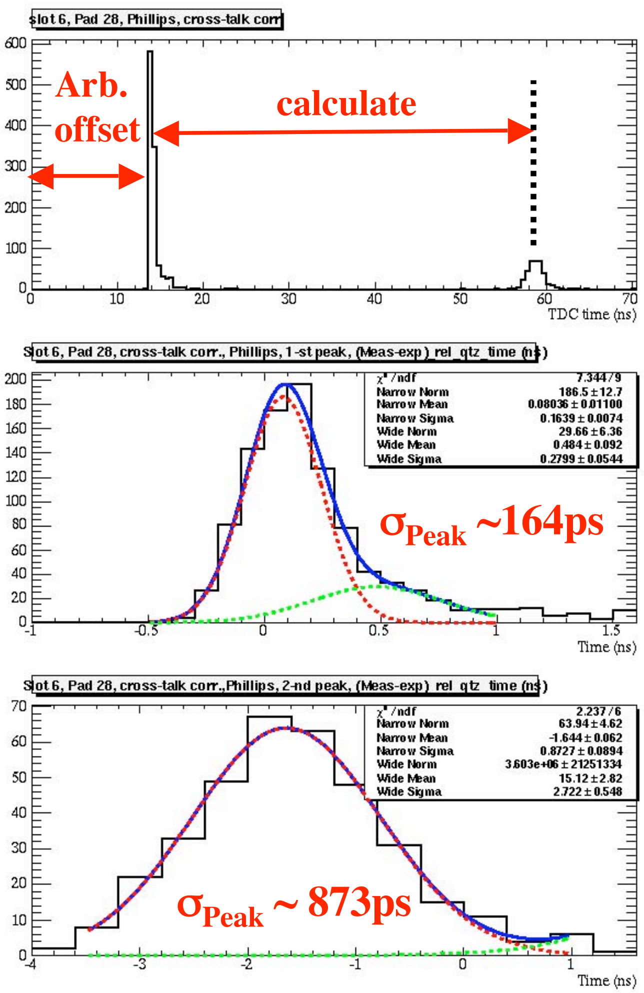
2-nd peak:

- Hamamatsu MaPMT does not have as large tail as the Burle MCP, but it is good enough to correct the chromatic error
- Peak 1 was was first adjusted with Joe's constants based on the PiLas calibration. Then it was adjusted arbitrarily adjusted to zero by a constant $C_{pad26,slot4,run7}$.
- Peak 2 was adjusted using the calculated offset, and assuming a TDC calibration of 23 ps/count.
- The 1-st peak does not come to zero. It is off by ~.15ns at present. The 2-nd peak is off by 1.5ns.
- Corrected for the MCP cross-talk and for time drift using the Start counter 1.
- Assume that the detector plane is shifted down by 1.5cm in this analysis.

Chromatic growth in pixel #28, slot 6, Run7, position 1 (Burle MCP)

1-st peak:

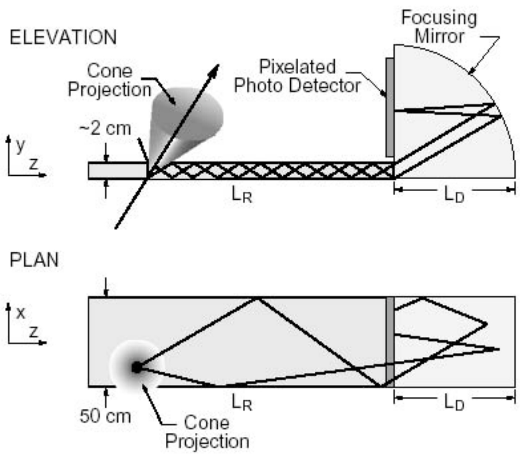
2-nd peak:



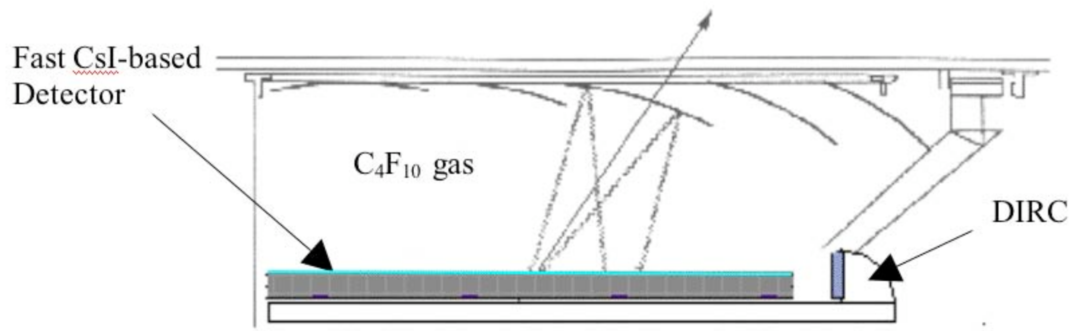
- Hamamatsu MaPMT does not have as large tail as the Burle MCP, but it is good enough to correct the chromatic error
- Peak 1 was was first adjusted with Joe's constants based on the PiLas calibration. Then it was adjusted arbitrarily adjusted to zero by a constant $C_{pad26,slot4,run7}$.
- Peak 2 was adjusted using the calculated offset, and assuming a TDC calibration of 23 ps/count.
- The 1-st peak does not come to zero. It is off by ~.08ns at present. The 2-nd peak is off by 1.6ns.
- Corrected for the MCP cross-talk and for time drift using the Start counter 1.
- Assume that the detector plane is shifted down by 1.5cm in this analysis.

What are possible applications ?

Super B-factory (?):



ILC (?):



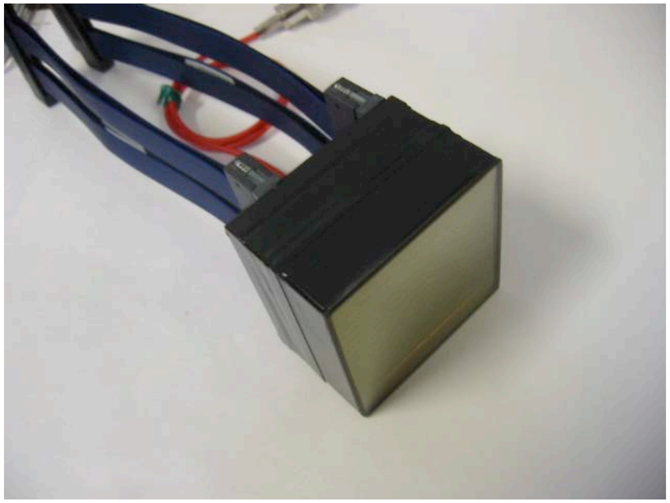
- Or, just simply publish it.

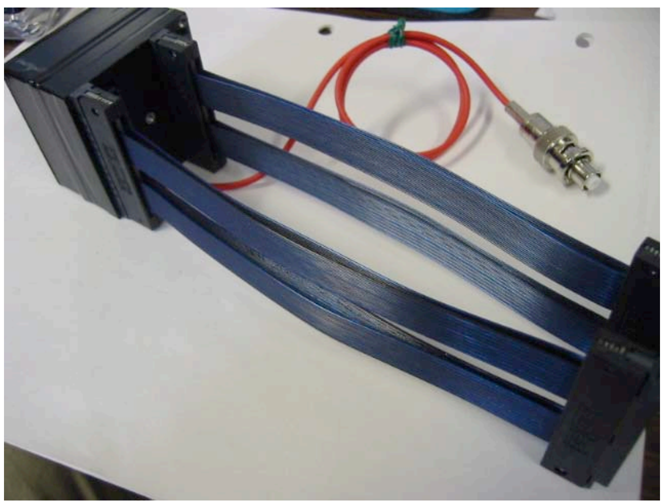
- **This is the first time ever that a Cherenkov ring imaging detector attempts to correct the chromatic error.**

Plan for the next 6 months

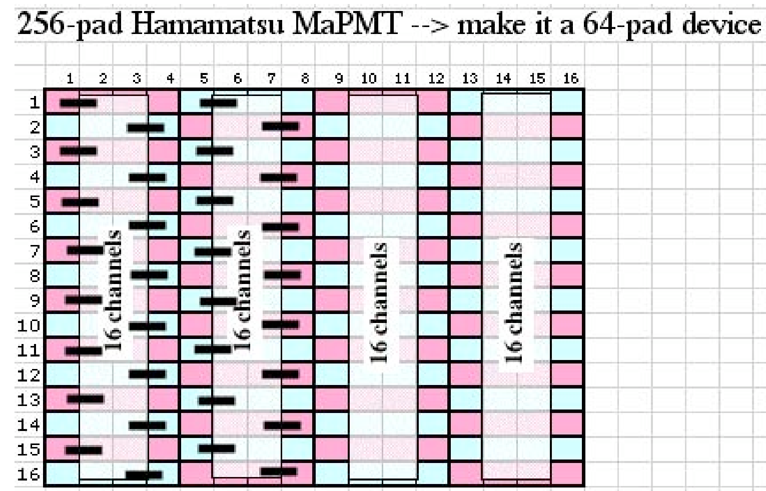
- Mike Woods is planning to run in November and we have to move the hodoscope, beam telescope and the prototype (not the table though).
- We will have three new devices, one is a 1024-pixel Burle MCP, two are small margin 64-pixel Burle MCPs, and one 256-pixel Hamamatsu MaPMT.
- We have one 4-pixel Burle MCP with 10 micron holes, which will be used in tests in the magnetic field. This tube is only on a loan and have to return it by the end of the year.

New 256-pixel Hamamatsu MaPMT H-9500



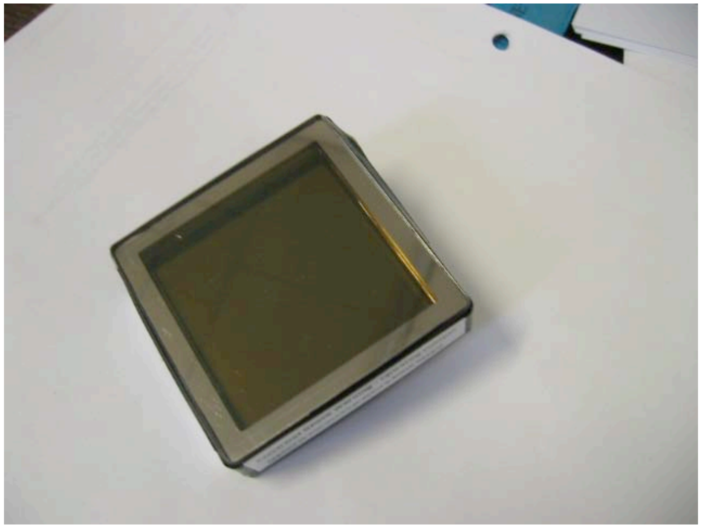


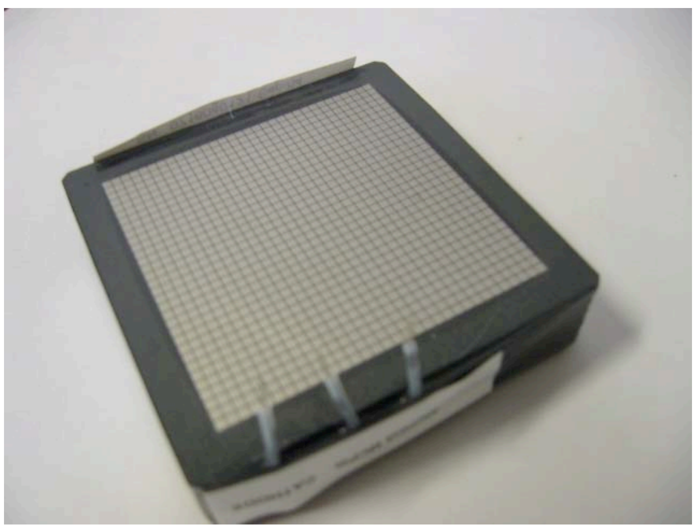
A proposal how to connect pads:



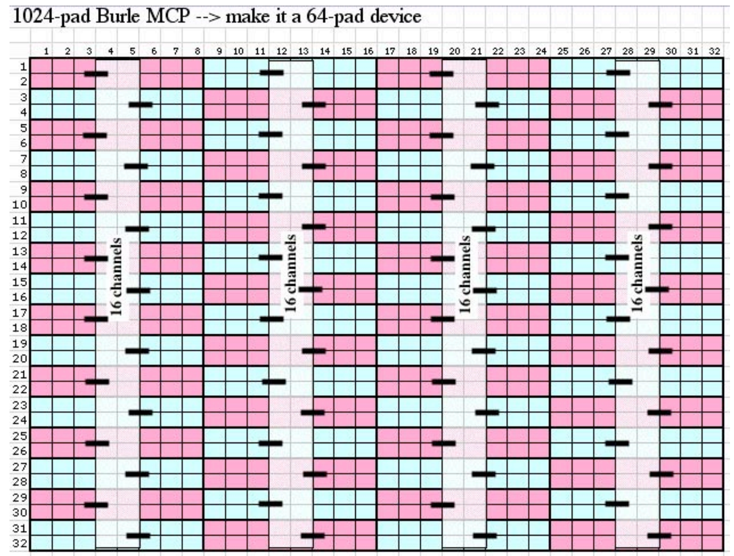
- 256 pixels (16 x 16 pattern).
- Pixel size: 2.8 mm x 2.8 mm, with a pitch of 3.04 mm.
- Very neat connections

New 1024-pixel Burle MCP 85021-600





A proposal how to connect pads:



- 1024 pixels (32 x 32 pattern)
- Pixel size: it looks to like ~1/16” x ~1/16”, which is ~1.59mm x 1.59mm (need to verify with Burle).