Summary of Beam Test Data Analysis Approach

Dec 15, 2005 JS

Beam Test data set (Jul-Nov):
- 14 runs
- 4M triggers
- ~200k good single-track events

included in that (Nov 16-18):
- 2.5 runs with narrow beam spot
- 1.1M triggers
- 82k good single-track events

Web page summarizes available runs.

DAQ files converted to ROOT ntuples, available on linux cluster, backed up to EB NFS disks.

data set	position	date	run	triggers	comments
July 2005: first run period					
run 1	4	Jul 22, 2005	20050722_1917	64,094	beam starts after ~44,000 triggers
			20050722_2136	100,000	smooth running
		Jul 23, 2005	20050723_0053	8,284	Note that all of run 1 has fake data in SLAC ADC slot 5.
run 2	4	Jul 25, 2005	20050725_2330	100,000	smooth running
		Jul 26, 2005	20050726_0605	17,807	
			20050726_0649	39,600	
run 3	1	Jul 26, 2005	20050726_0940	100,000	
			20050726_1246	83,034	
			20050726_1505	100,000	Tuning of beam spot
			20050726_1842	29,043	
run 4	7	Jul 26, 2005	20050726_1949	42,830	very brief beam, ends after 4100 triggers; 24 tracks in start counter.
August 2005: second run period					
run 5	7	Aug 15, 2005	20050815_1414	34,775	beam starts after ~25,000 triggers; beam tuning.
			20050815_1657	100,000	still beam tuning
			20050815_1949	4,834	still beam tuning, beam ends after ~4000 triggers
run 6	6	Aug 17, 2005	20050817_1215	30,642	
			20050817_1735	100,000	
			20050817_1609	43,288	beam scan but some useful events
			20050817_2022	78,610	
			20050817_2309	100,000	
		Aug 18, 2005	20050818_0211	100,000	
			20050818_0458	59.984	
run 7	1	Aug 19, 2005	20050819_1009	100,000	
			20050819_1440	53,672	
			20050819_1737	100,000	
			20050819_2055	100,000	
			20050819_2341	100,000	
		Aug 20, 2005	20050820_0228	100,000	
			20050820_0527	97,386	
run 8	2	Aug 20, 2005	20050820_0905	100,000	
			20050820_1154	19,203	
run 9	3	Aug 20, 2005	20050820_1256	100,000	
run 10	5	Aug 20, 2005	20050820_1649	94,473	
run 11	4	Aug 20, 2005	20050820_1953	100,000	
			20050820_2252	100,000	
		Aug 21, 2005	20050821_0200	100,000	
			20050821_0503	97,558	
November 2005: third run period					
run 12(a)	1	Nov 15, 2005	20051115_1829	42,478	beam starts after ~5000 triggers. Note that the SLAC ADCs were mirroring during most of run 12.
			20050115_2055	94,072	beam ends after ~9000 triggers
		Nov 16, 2005	20051116_1634	100,000	beam tuning
			20051116_1923	31,369	beam tuning towards narrow beamspot (end of run 12(a))
run 12(b)			20051116_2016	100,000	Start of run 12(b), new narrow beamspot in Z
			20051116_2307	100,000	
		Nov 17, 2005	20051117_0155	47,088	beam ends after 42,300 triggers
			20051117_1400	100,000	some tuning in X early on, then stable running
			20051117_1735	53,666	ended to move to next bar position
run 13	3	Nov 17, 2005	20051117_1939	100,000	
			20051117_2226	100,000	
		Nov 18, 2005	20051118_0113	100,000	
			20051118_0405	100,000	
			20051118_0652	61,727	
run 14	5	Nov 18, 2005	20051118_0907	14,814	beam starts after 6,500 triggers
			20051118_0932	65,829	
			20051118_1122	94,738	
			20051118_1406	17,443	
			20051118_1518	23,528	low intensity and rate during recovery from klystron failure

Goals of the measurement

- demonstrate and utilize chromatic time dispersion in fused silica bar
- improve thetaC resolution of device by correcting for chromatic production term

For BABAR-DIRC the average thetaC resolution per photon is about 9.6mr

• size of DIRC PMT for chosen standoff distance:	~5.5mr
• size of bar image:	~4.1mr
• bar imperfections:	~3mr
• chromatic production:	~5.4mr

The timing resolution of BABAR-DIRC PMT is ~1.7ns.

Some benchmark numbers

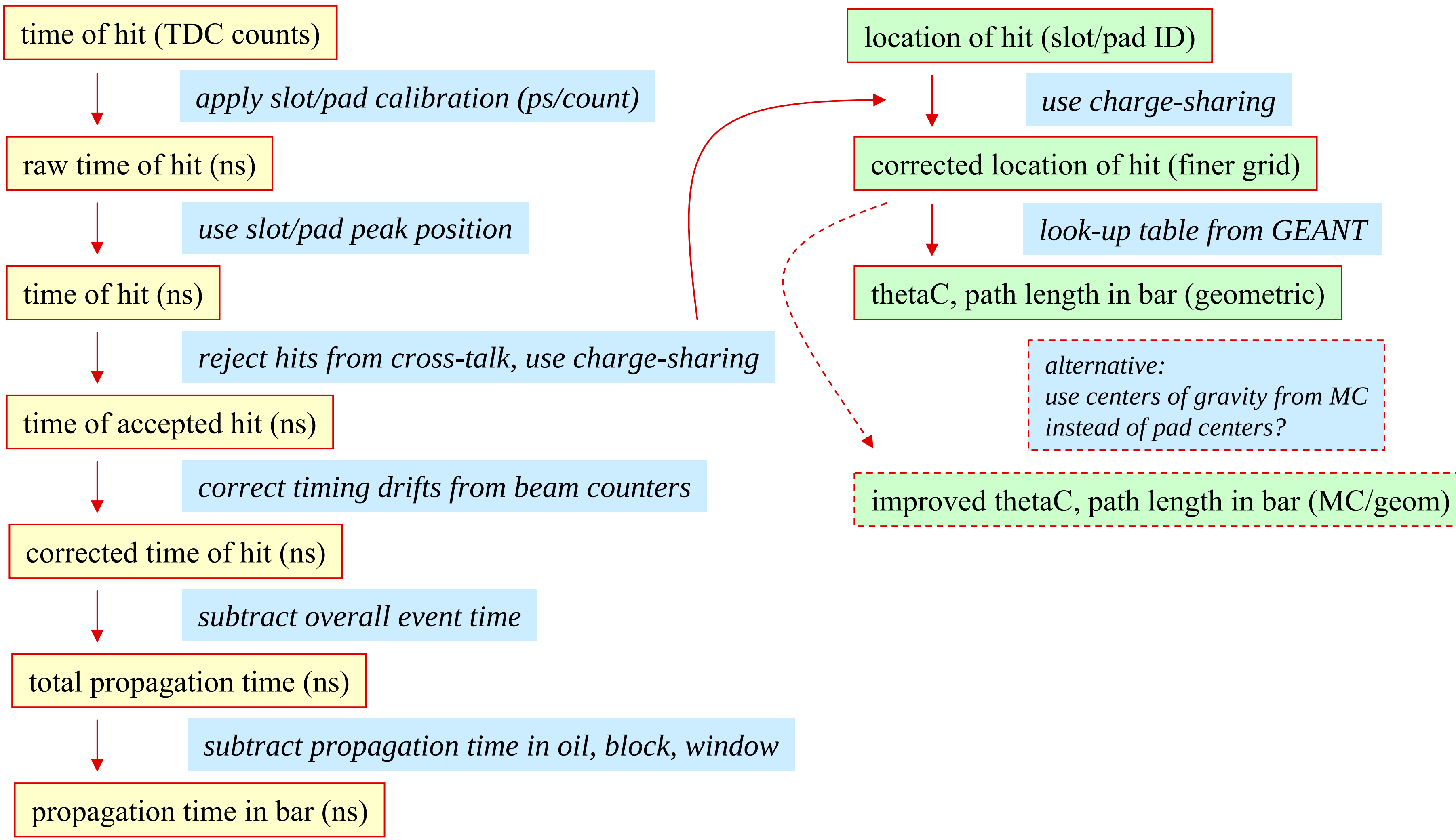
average wavelength of a detected photon in DIRC	~400 nm
average wavelength of a detected photon in prototype	~410 nm
Cherenkov angle of 410nm photon	822.07 mr
range of photon wavelength detected	300…650 nm
Cherenkov angle corresponding to that range	834…814 mr
phase index corresponding to range	1.488…1.457
group index corresponding to range	1.572…1.474
size of PMT pixel	~20 mr
prototype expected thetaC resolution per photon	~8-9 mr *(before correction)*

Measured quantities:

time of hit (TDC counts)
location of hit (slot/pad ID)

Want to know:

thetaC of photon at production



$n_{group} = c_0 \cdot top(\lambda) / path(\lambda)$ $n_{group} \rightarrow \lambda$, $n_{phase} \rightarrow \theta_C^{prod}(\lambda)$

Current approach:

assume that path length in bar(λ) $\approx$ path length in bar (geometric)

path length in bar (geometric) is determined from pad centers

propagation time in bar (ns) = top(λ)
path length in bar (geometric) $\approx$ path(λ)

$\rightarrow n_{group} = c_0 \cdot top(\lambda) / path(\lambda)$ = propagation time in bar (ns) / path length in bar (geometric)

Use look-up table to determine corresponding $\lambda \rightarrow n_{phase} \rightarrow \theta_C^{prod}(\lambda)$

Correct "geometric" thetaC from slot/pad θ_C^{geom}

$\Delta\theta_C = \theta_C^{prod}(\lambda) - \theta_C^{prod}(\lambda{=}410\text{nm})$

$\theta_C^{corrected} = \theta_C^{geom} - \Delta\theta_C$

Data analysis starts with ROOT file from DAQ.
“Raw” data contains for each “event” = “trigger” response from all TDCs and ADCs (values, look-at-me, number if channels of board) as well as time stamp of event.

(time stamp is initially UNIX time in ASCII file; for ROOT file we subtract Dec 31, 2001, 19:00, to keep data in Float_t range)

As of November there are currently 415 numbers that describe each event. The files are stored on `kifaru`, backed up to NFS disks.

Example of one event:

```
1132305206 1 12 42 42 62 83 53 71 61 1 15 116 102 229 1 12 48 1 1 1 1 1 1 1 1 1 1 1 12 21 14 29 28 1 12
20 18 20 9 17 17 1 12 198 219 168 254 5 11 1 1 1 1 80 2 1 16 4095 0 0 0 0 0 0 0 0 0 0 1841 1962 0 0 1625
0 8 4058 4058 4058 4058 4058 4058 4058 4058 1 12 76 186 62 39 76 69 76 87 63 69 69 70 1 16 4095 0 0 0 537
0 0  0 0 0 0 0 0 0 0 0 0 16 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 16 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 16 0 0
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 16 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 16 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 16
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 16 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 16 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0 16 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 32 102 168 167 173 168 152 170 165 167 163 171 169 159 162 156 159
2794 167 172 165 187 170 169 177 184 173 184 187 163 167 16 4 171 1 32 834 840 849 857 701 277 297 313 278
277 266 318 840 684 715 729 338 3 167 299 301 826 815 798 830 303 358 290 285 731 464 697 710 1 32 170 177
153 168 167 2823 162 162 181 177 158 161 154 161 149 162 163 163 165 167 164 161 166 16 6 158 152 87 44 156
146 168 154 1 32 164 2628 160 166 176 0 163 154 165 163 153 176 156 154 137 165 161 148 161 170 161 173
4095 163 172 172 162 177 175 161 172 0
```

Event in formatted output:

```
******************************* NEXT EVENT *******************************
Event time=1132305206
ADC 1: lam=1 chnls=12 dta: 42 42 62 83 53 71 61 1 15 116 102 229
ADC 2: lam=1 chnls=12 dta: 48 1 1 1 1 1 1 1 1 1 1 1
ADC 3: lam=1 chnls=12 dta: 21 14 29 28 1 12 20 18 20 9 17 17
ADC 4: lam=1 chnls=12 dta: 198 219 168 254 5 11 1 1 1 1 80 2
TDC 1: lam=1 chnls=16 dta: 4095 0 0 0 0 0 0 0 0 0 0 1841 1962 0 0 1625
TDC 2: lam=0 chnls=8 dta: 4058 4058 4058 4058 4058 4058 4058 4058
ADC 5: lam=1 chnls=12 dta: 76 186 62 39 76 69 76 87 63 69 69 70
TDC 3: lam=1 chnls=16 dta: 4095 0 0 0 537 0 0 0 0 0 0 0 0 0 0 0
TDC 4: lam=0 chnls=16 dta: 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
TDC 5: lam=0 chnls=16 dta: 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
TDC 6: lam=0 chnls=16 dta: 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
TDC 7: lam=0 chnls=16 dta: 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
TDC 8: lam=0 chnls=16 dta: 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
TDC 9: lam=0 chnls=16 dta: 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
TDC 10: lam=0 chnls=16 dta: 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
TDC 11: lam=0 chnls=16 dta: 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
TDC 12: lam=0 chnls=16 dta: 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
TDC 13: lam=1 chnls=32 dta: 102 168 167 173 168 152 170 165 167 163 171 169 159 162 156 159 2794 167 172 165 187 170 169 177 184 173 184 187 163 167 164 171
TDC 14: lam=1 chnls=32 dta: 834 840 849 857 701 277 297 313 278 277 266 318 840 684 715 729 338 3167 299 301 826 815 798 830 303 358 290 285 731 464 697 710
TDC 15: lam=1 chnls=32 dta: 170 177 153 168 167 2823 162 162 181 177 158 161 154 161 149 162 163 163 165 167 164 161 166 166 158 152 87 44 156 146 168 154
TDC 16: lam=1 chnls=32 dta: 164 2628 160 166 176 0 163 154 165 163 153 176 156 154 137 165 161 148 161 170 161 17 3 4095 163 172 172 162 177 175 161 172 0
```

Conversion is done with `readTDCADCfile_create_rootfile_noNumOfChannels.C` called by `slacAdcDat2root.sh`

The DAQ/ROOT information has to be related to physical detectors in a look-up table.
This job is done using an xml file that comes from Josef's online monitoring package.
A version of this "connection table" is linked from the R&D page.
I manually edit the connection table file and create an array of associations between detector elements and ROOT leafs.

The TDC/ADC info then has to be translated into physical numbers.
For ADCs we have to subtract pedestals, for TDCs we need to know the ps/count calibration.
That information should eventually come from a common method, essentially a simple text database coupled to a C function, that allows retrieval of pedestals and calibrations.
Initially this information was manually stored in slot/pad arrays in my code.

For now I decided to ignore the SLAC ADC information due to the "mirroring" and the poor resolution and coverage.

The prototype TDCs then need to be "aligned."
This is because the pads have all very different delays due to both the internal wiring of the PMT pads and amplifiers and the daisy-chain setup of our Phillips TDCs.
That delay information should be stored in the text database but initially was manually stored in my code.

We need to know which detector elements are useful/connected to readout in any given run.
Again, a job for a database but stored in my code for now.

The delay information and ps/count measurements come from the PiLas calibration runs, analyzed by Jose.

We don't need to consider propagation time differences of PiLas photons in the SOB to different pads for determination of delays.

Jose calculated the time differences between center of slot 4 and the wings of slot 2/6 to be less than 20ps.

Pads have to be aligned in time, not in TDC counts.

Jose created a set of functions that allow retrieve both the delay and the picosecond per count measurement.
Due to differential variation of ps/count calibration the time in ps has to be calculated by integrating the calibration curve, assuming a linear varation between measurement points.

Just how large that differential variation of the calibration is needs to be determined in the future.

Different configurations and calibrations in our runs are currently handled via C preprocessor statements.

Cherenkov angles and photon directional cosines come from either Jerry's spreadsheet or Ivan's GEANT simulation.
As of Dec 2005 those are not a good match, we will need to check each against the data.

Photon path in quartz block, quartz windows, and in KamLand oil come from Ivan's simulation.

Wavelength vs. group/phase refractive index comes from Melles Griot, lookup table from Excel spreadsheet.

Data analysis steps:

- compare detector response in different runs
- compare spreadsheet/GEANT to real data, improve, create thetaC and kBar
- event/track selection to select clean sample of 10GeV/c electrons – can we use the SOB veto counter?
- transform TDC values to meaningful time measurements for all detectors
- align all prototype pads
- correct drifts in detector timing using start counters
- use hodoscope to correct for measured track Z position
- calculate thetaC and expected pathlength in bar of hit from pad geometry
- add path in quartz block and windows and in oil from lookup table
- calculate phase refractive index
- calculate photon wavelength from time-of-propagation (using lookup table)
- correct raw thetaC measurement of hit using time information, obtain corrected thetaC
- combine runs with different detector geometry and calibrations (and different bar positions)

A couple of open puzzles:

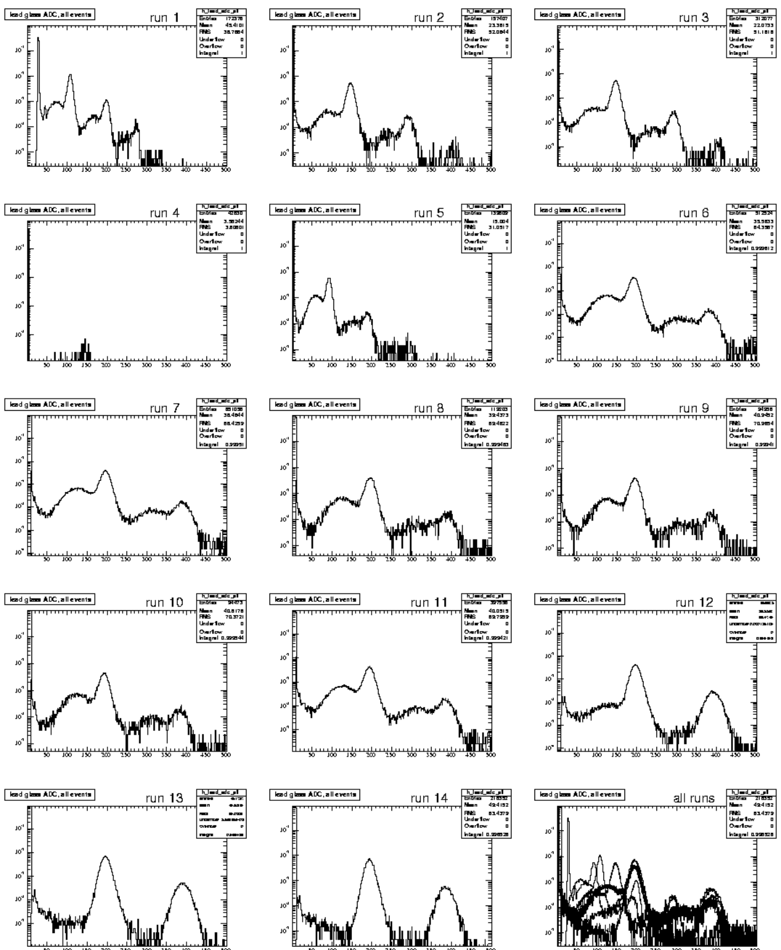
- why do Jerry, Jose, and Ivan disagree on the kBar and thetaC angles?
- what causes the time shift in beam counter TDC values when we have an electron in the lead glass?
- are all the pads correctly assigned? (there was still a question about slot 2, channel 41/42)
- do we have to "sacrifice" one or two bar positions for alignment of the first peak and use that calibration for all other bar positions?
- how stable are alignment and calibration over time? -> Min's study
- how do we treat charge sharing and reject cross-talk? How much cross-talk do we see?
- how useful is a start-counter based (rolling) correction of the prototype times? does it help or hurt?
- how useful are the veto counters close to the hodoscope and at the SOB?
- to determine the thetaC correction and photon wavelength: do we keep the raw measurements and assume a global average refractive index or do we align pads with "epsilons" and use mean pad refractive index from simulation?
- how do we correct the geometric thetaC using the wavelength measurement?
- we need to verify that we are using correct kBar vectors by comparing data to simulation. Which distributions are the best to compare data to ray-tracing (Jose) or GEANT (Ivan)?

Lead glass ADC in all runs

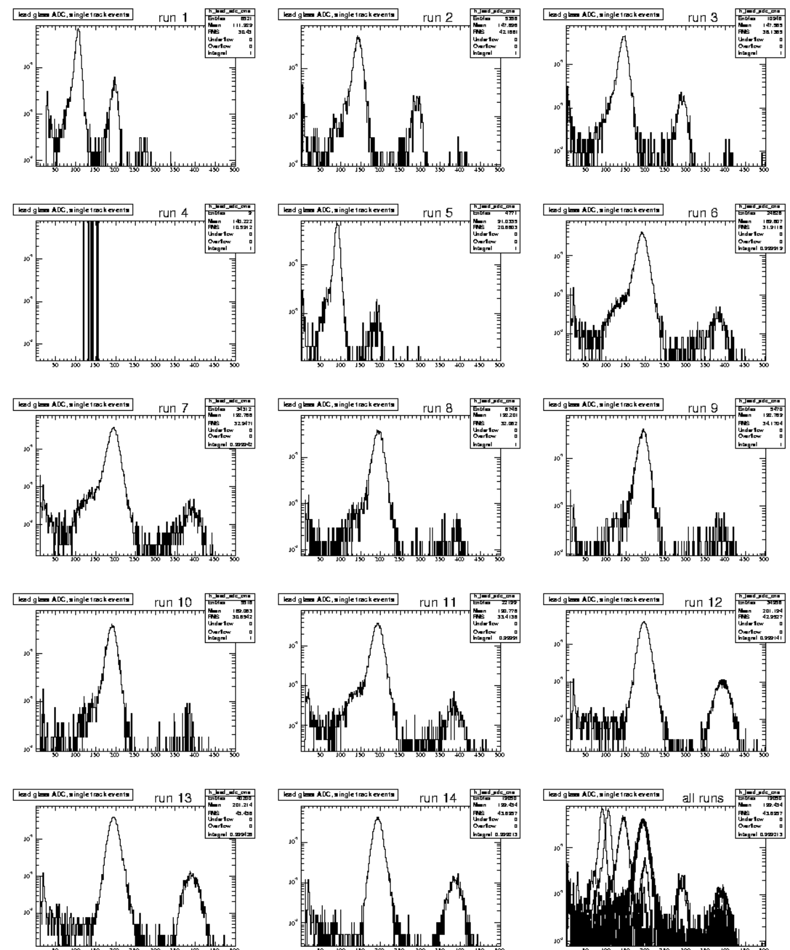
We changed the amplification of the lead glass signal after the first run period to minimize the effect of the large charge in the lead glass on the timing measurements of the beam counters.

Beam tuning changed the beam composition.

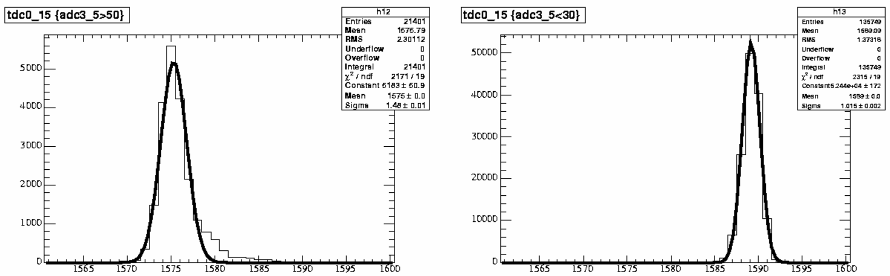
all tracks

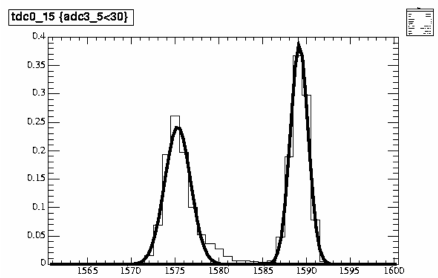


single tracks in hodoscope



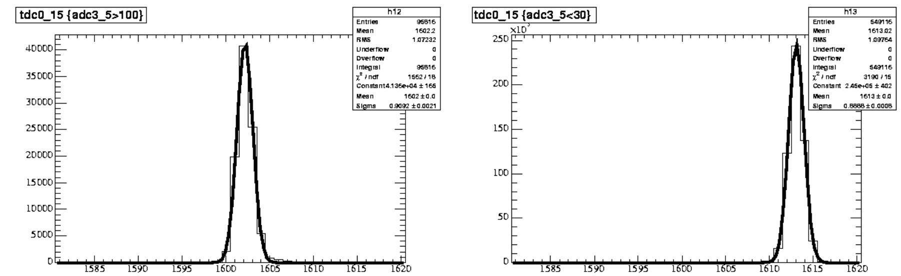
Maker slot 2, pad 38 in events with and without large charge in lead glass.

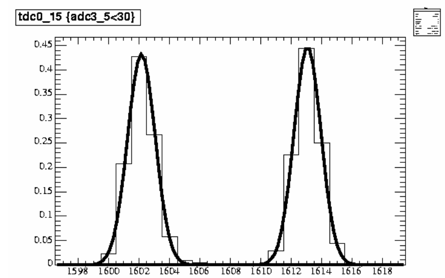




run 2

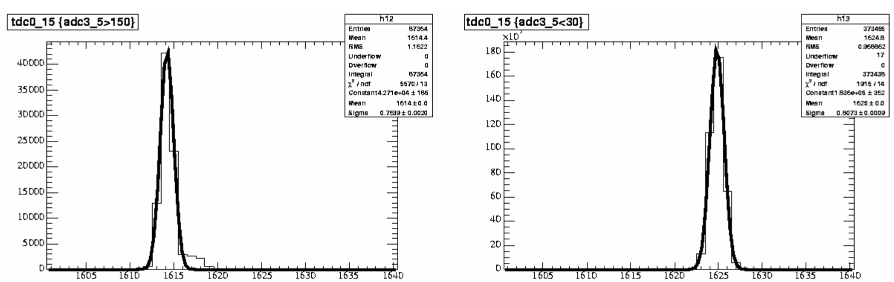
14 counts shift

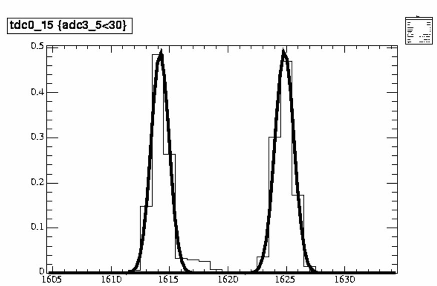




run 7

11 counts shift





run 13

11 counts shift

Not sure what causes this timing shift.

Since we only analyze events with electron charge in the lead glass ADC, this is probably not a problem

In the latest runs (for instance in run 13) we seem to see a tail in the marker timing for electron charges. That could be a problem.

Beam tuning: lead glass

single tracks required in hodoscope and Cherenkov counter, use lead glass to select single electrons

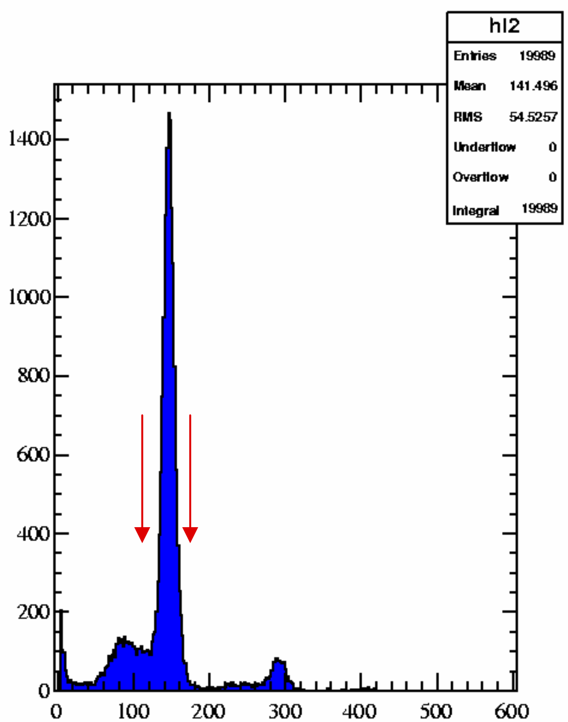
Run 2, July

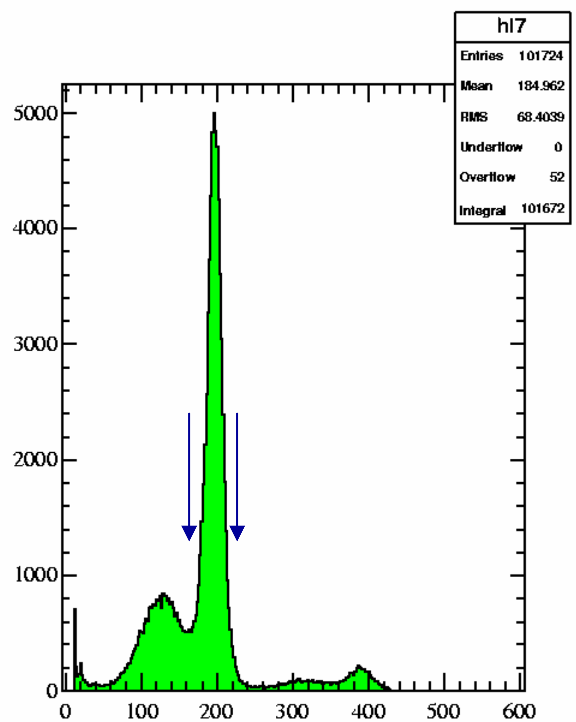
Run 7, August

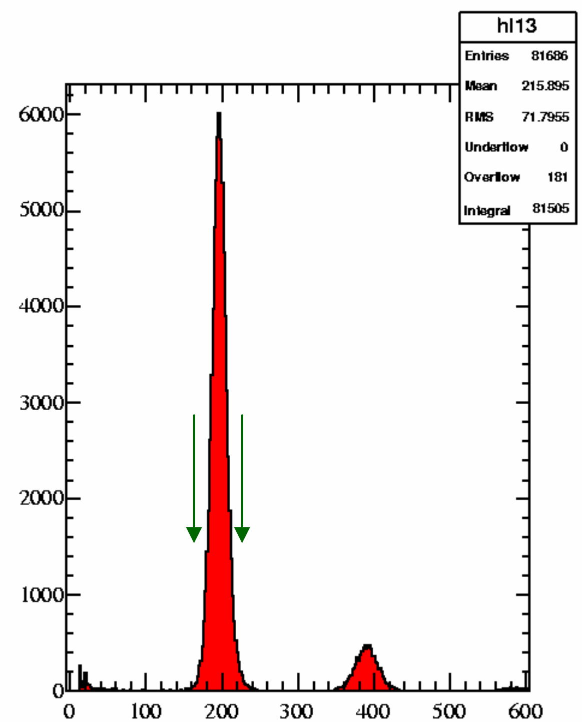
Run 13, November

secondary tracks, scattered particles, pions in “hump”
~2-3% of triggers are good single-track events

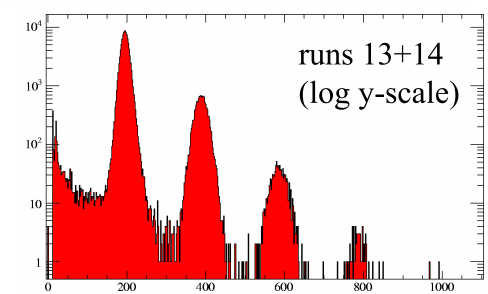
much cleaner electron beam, 2e, 3e, 4e peaks
~8% of triggers are good single-track events





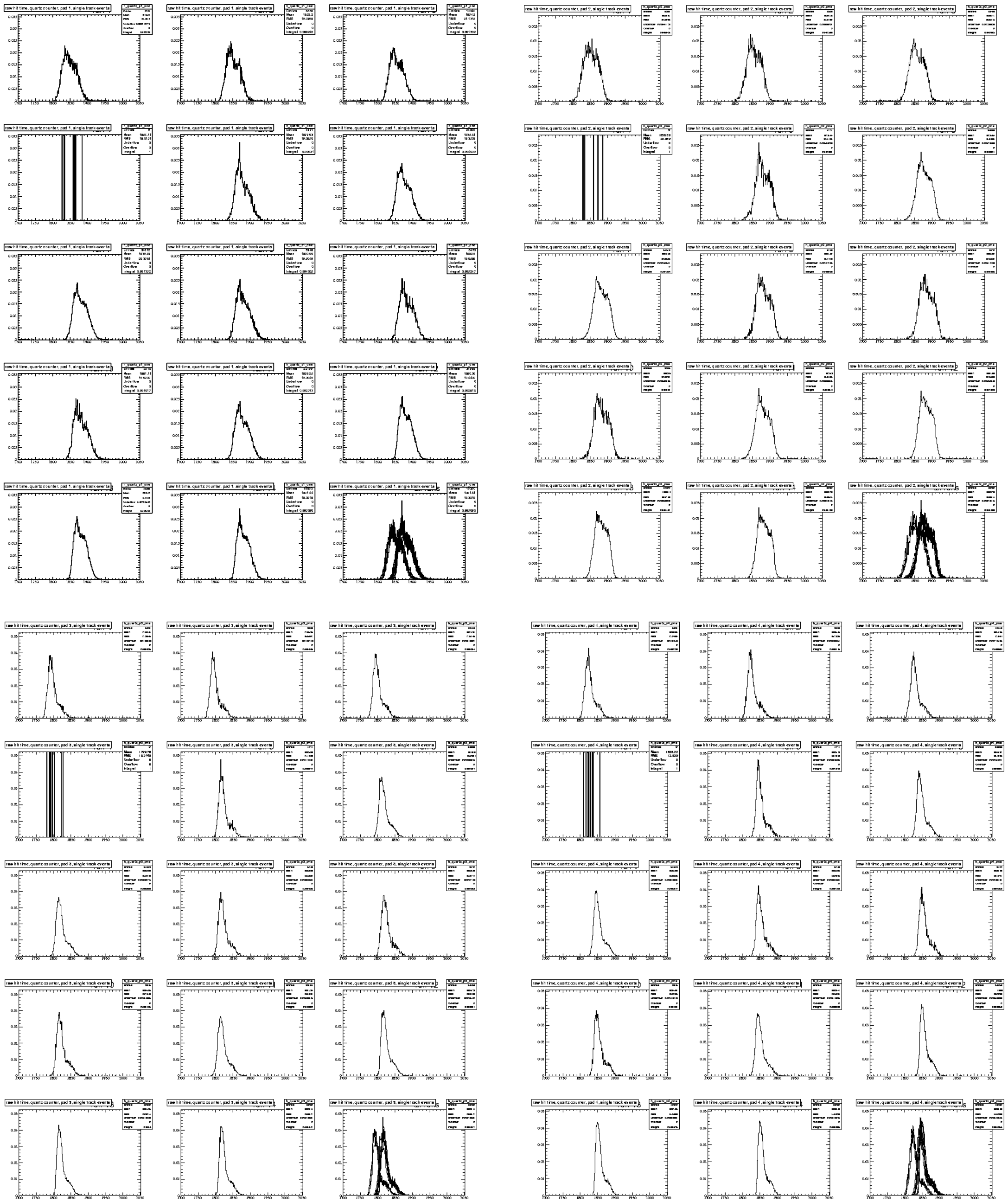


Charge in lead glass ADC [counts]

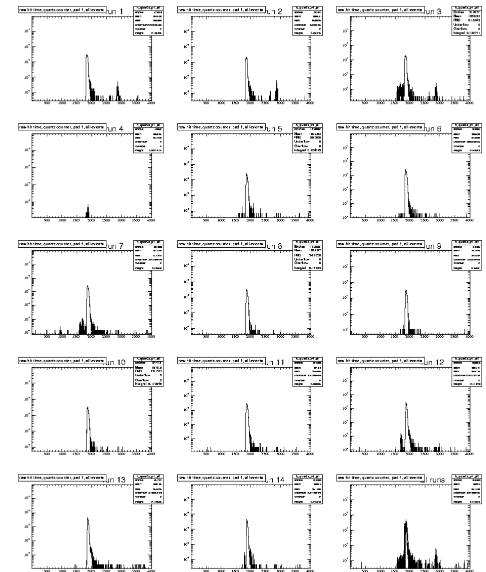


Cherenkov start counter spectra

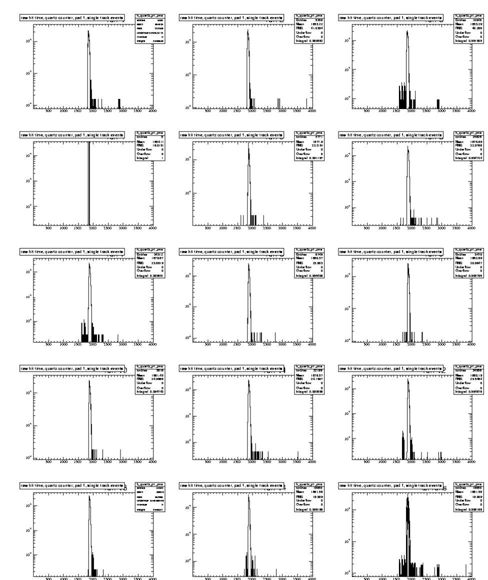
Single track pads 1 (upper left), 2 (ur), 3 (ll) 4 (lr)



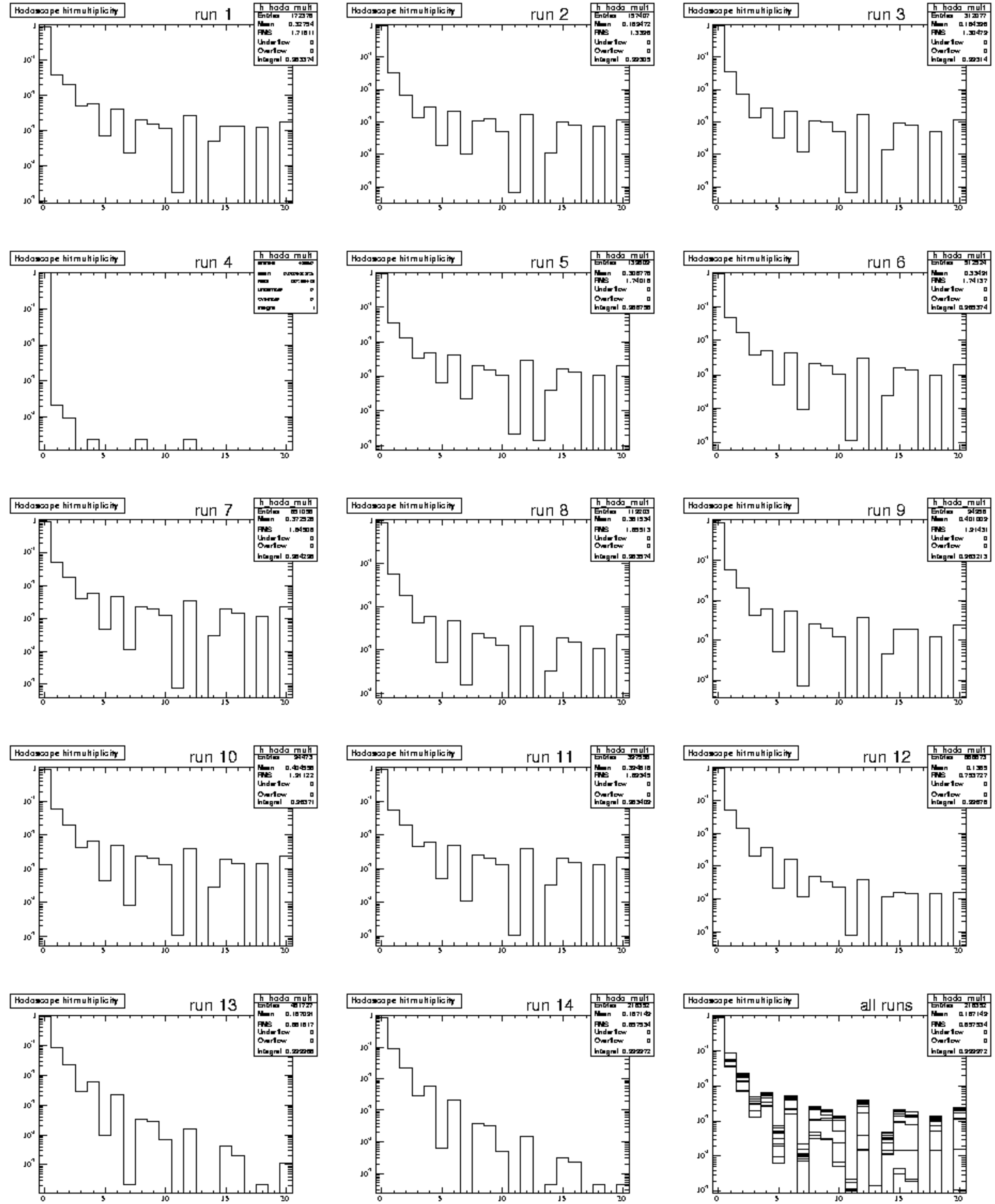
pad 1, all events, log scale



pad 1, single tracks, log scale



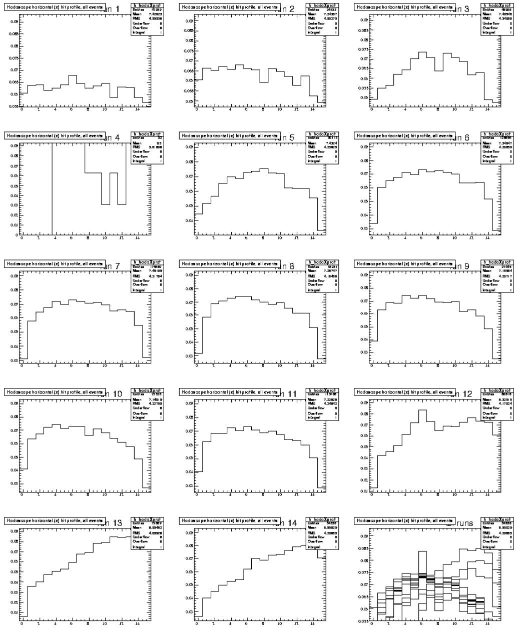
Hodoscope multiplicity



mean covers range of 0.13 … 0.40

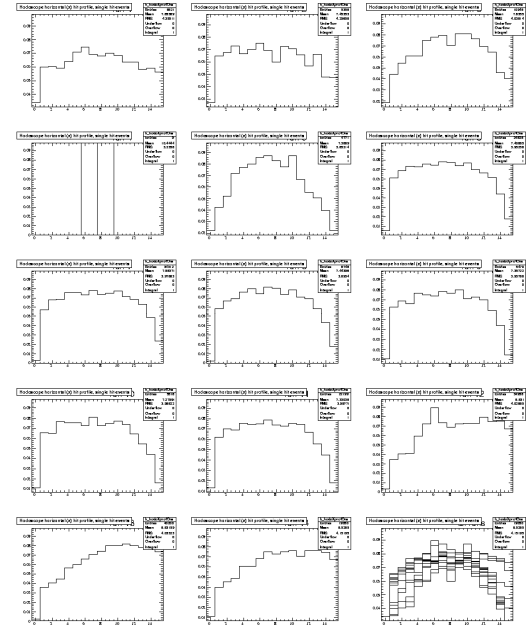
RMS covers range of 0.7 … 1.7

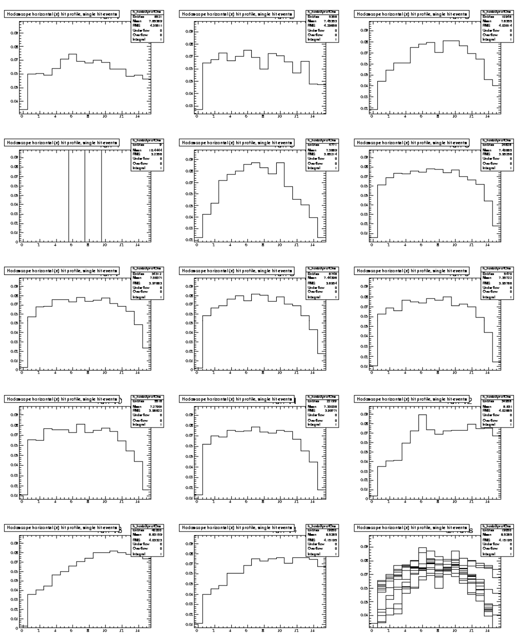
Hodoscope hit profiles – effect of beam tuning

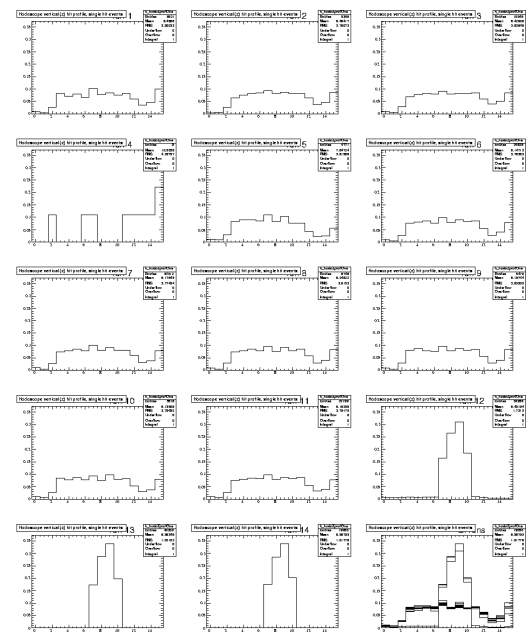


profile in X (left) and Z (right)

for all events (top) and
single-track events (bottom)







Beam tuning: hodoscope hit map

- all triggers (top)
- single hodoscope hits (bottom)

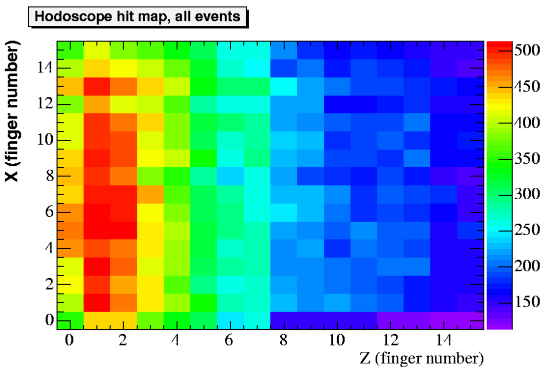
Run 2, July

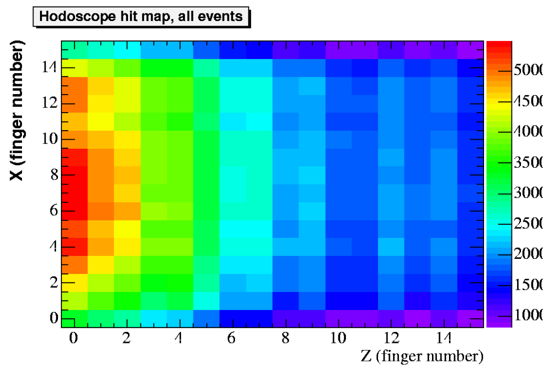
Run 7, August

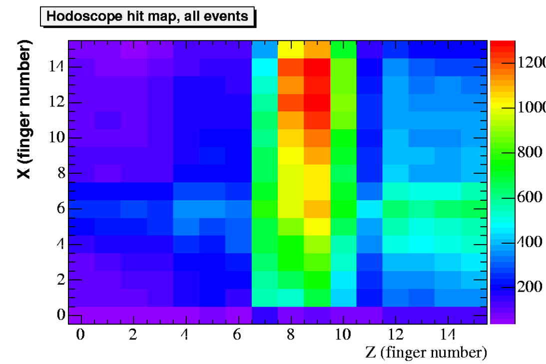
Run 13, November

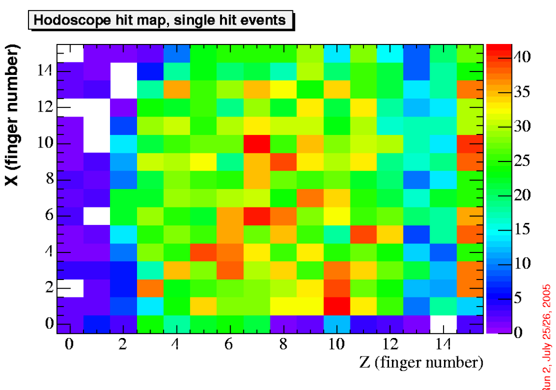
"pipe-filling" beam, lots of secondary tracks, high multiplicity,

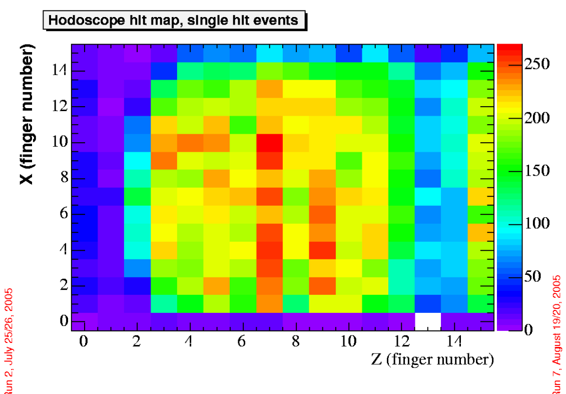
much effort to focus beam, success with Q38
narrow beam in Z, still wide in X

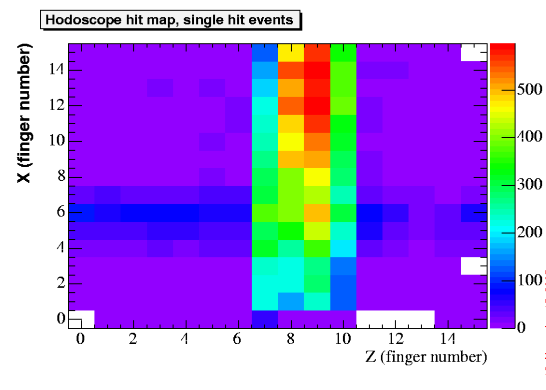






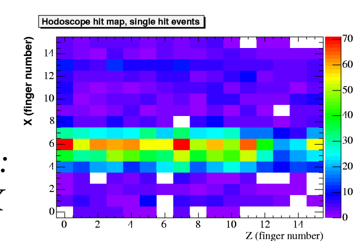




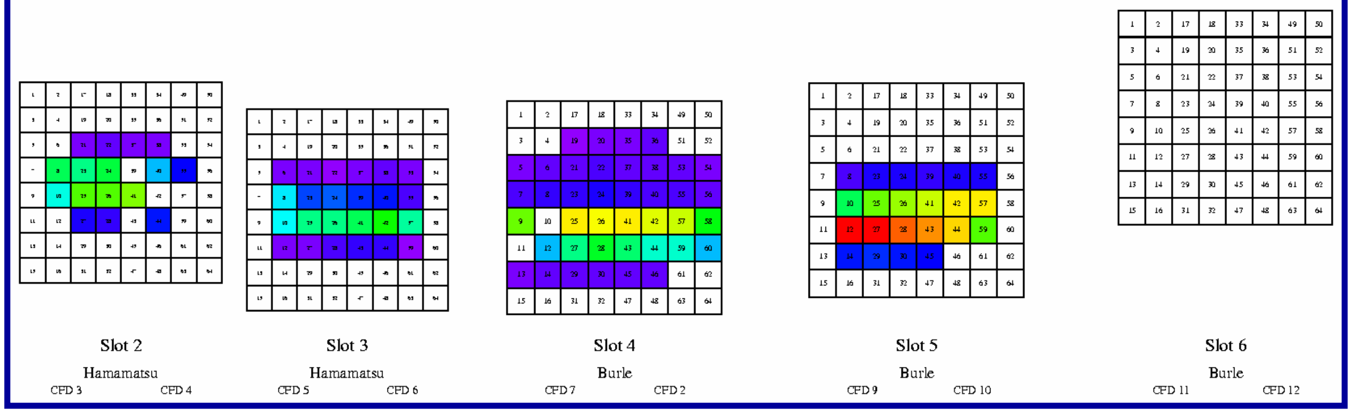


One finger covers
- *in Z: 2.2mm*
- *in X: 2.1mm*

Tune in run 12a:
better focus in X



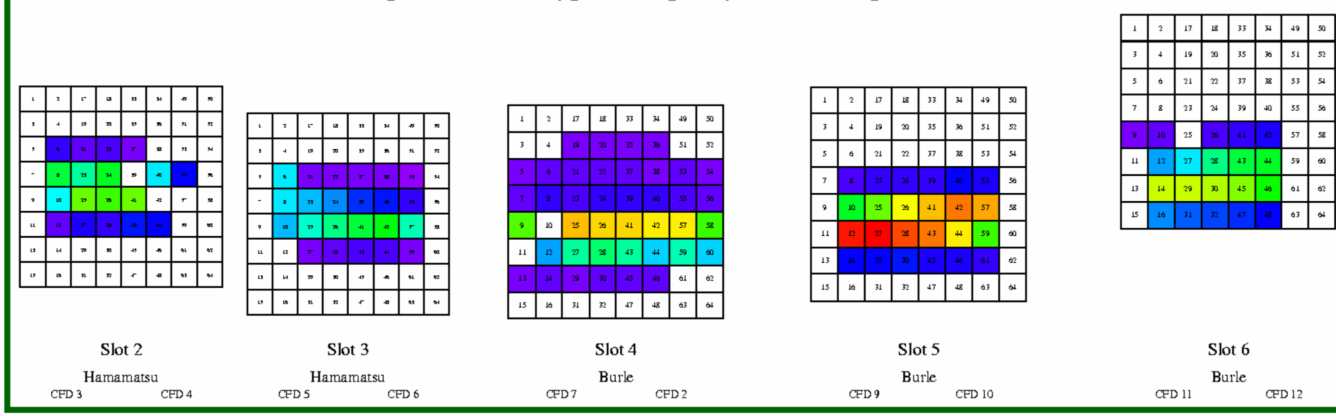
Focusing DIRC Prototype Occupancy Run 2, July 25/26, 2005



Run 2

104 good Phillips TDC channels

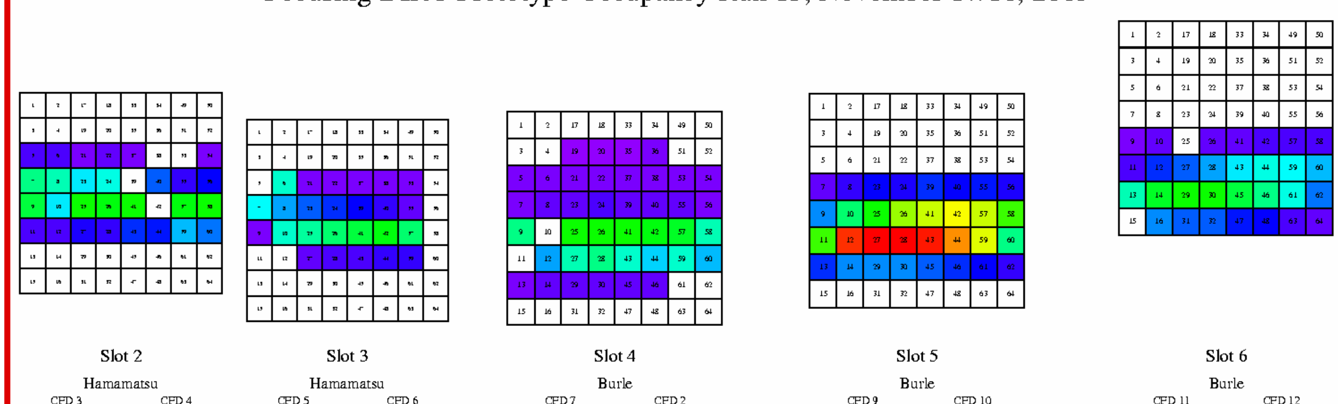
Focusing DIRC Prototype Occupancy Run 7, August 19/20, 2005



Run 7

125 good Phillips TDC channels

Focusing DIRC Prototype Occupancy Run 13, November 17/18, 2005

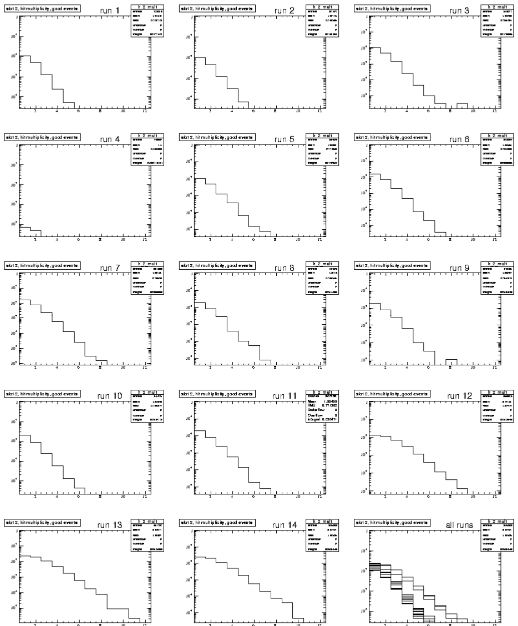


Run 13

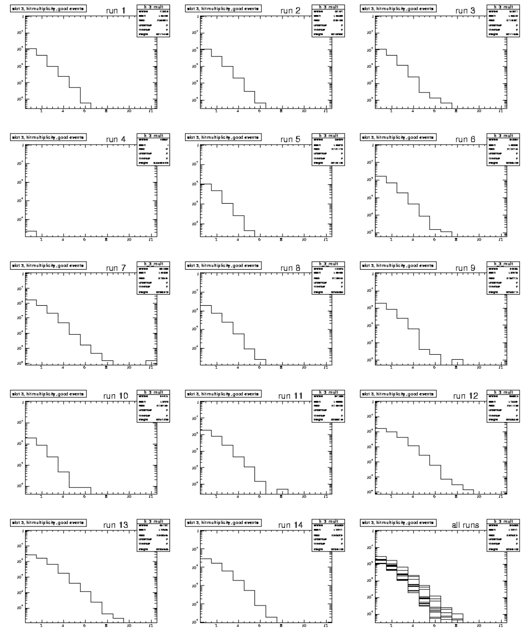
155 good Phillips TDC channels

Prototype hit multiplicity by slot – we added TDC channels for the “wings” over time

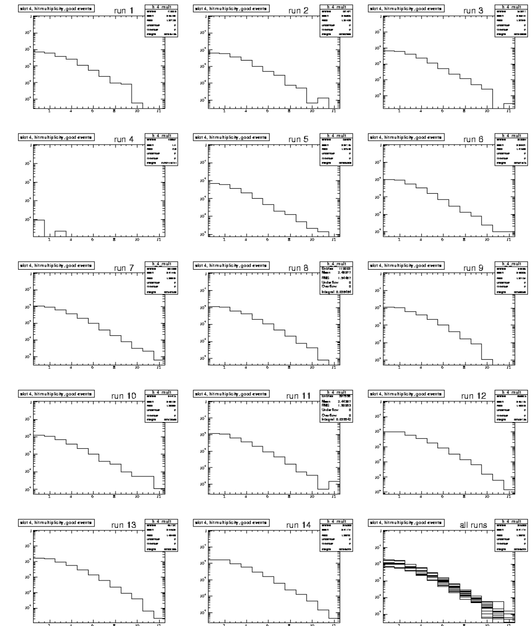
slot 2: 1.5 → 2.1



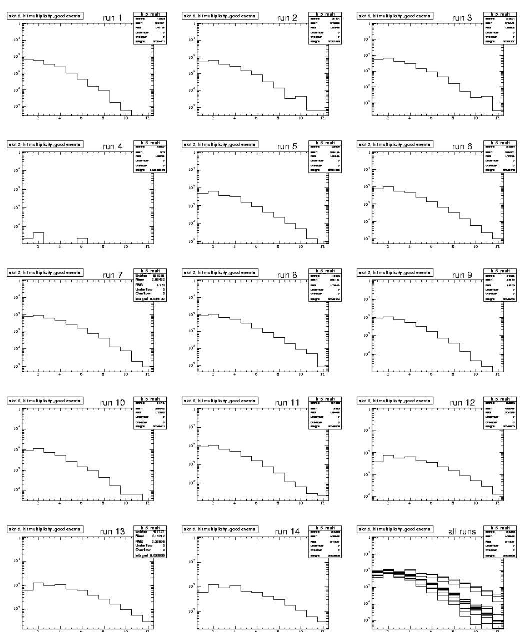
slot 3: 1.4 → 1.7



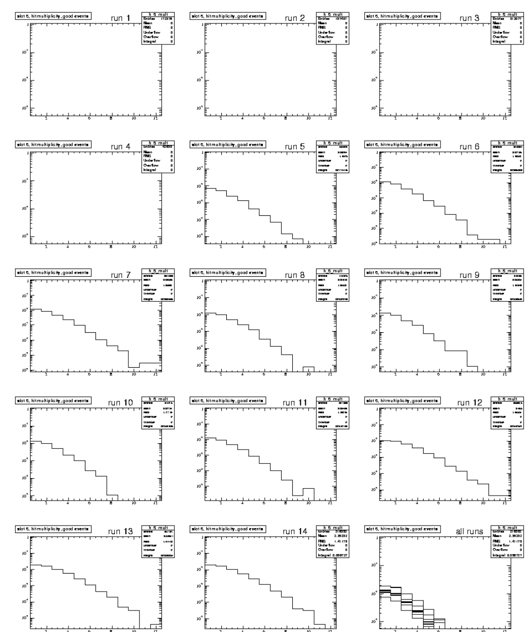
slot 4: ~2.5



slot 5: 2.4 → 4.2

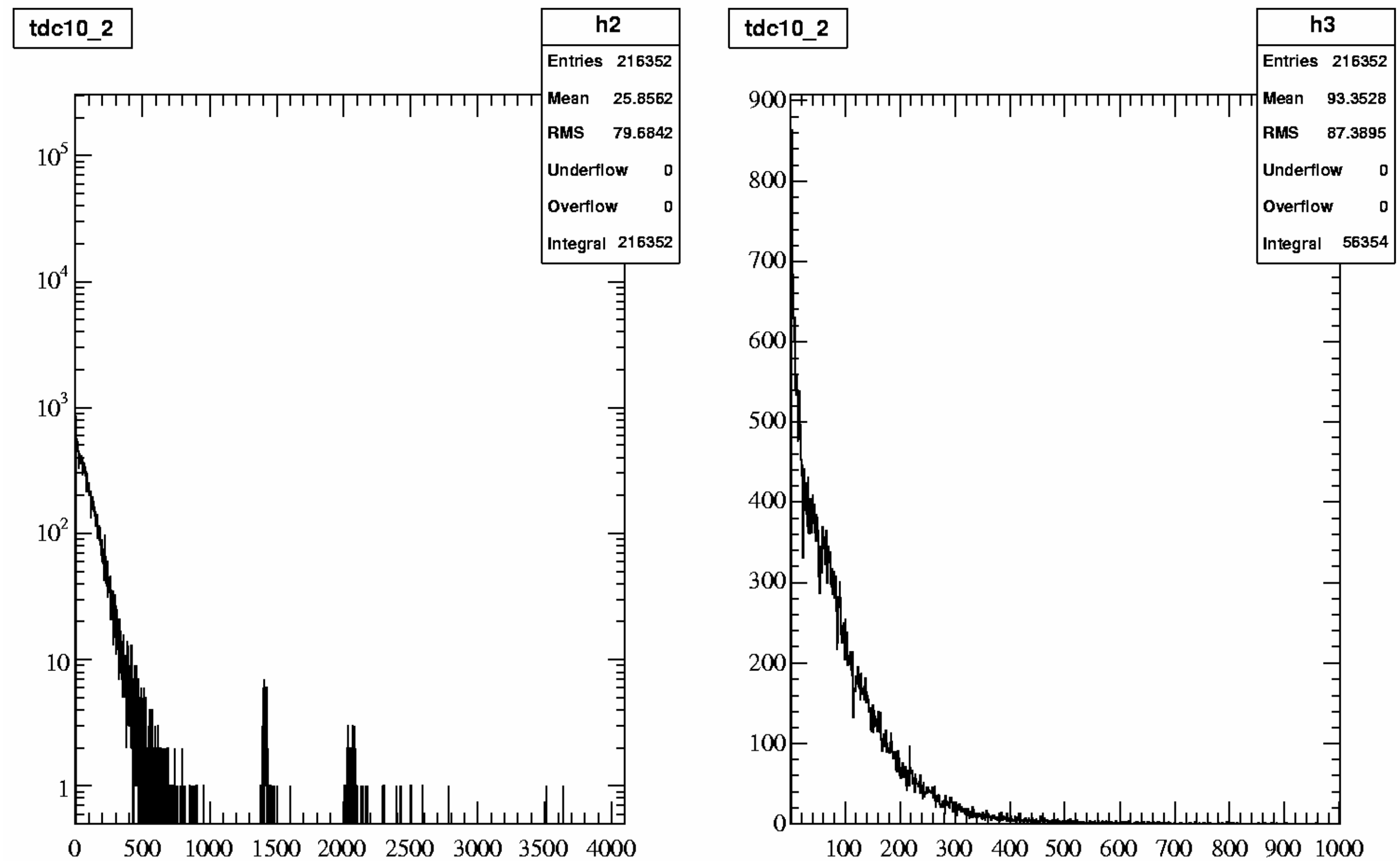


slot 6: 0 → 2.4



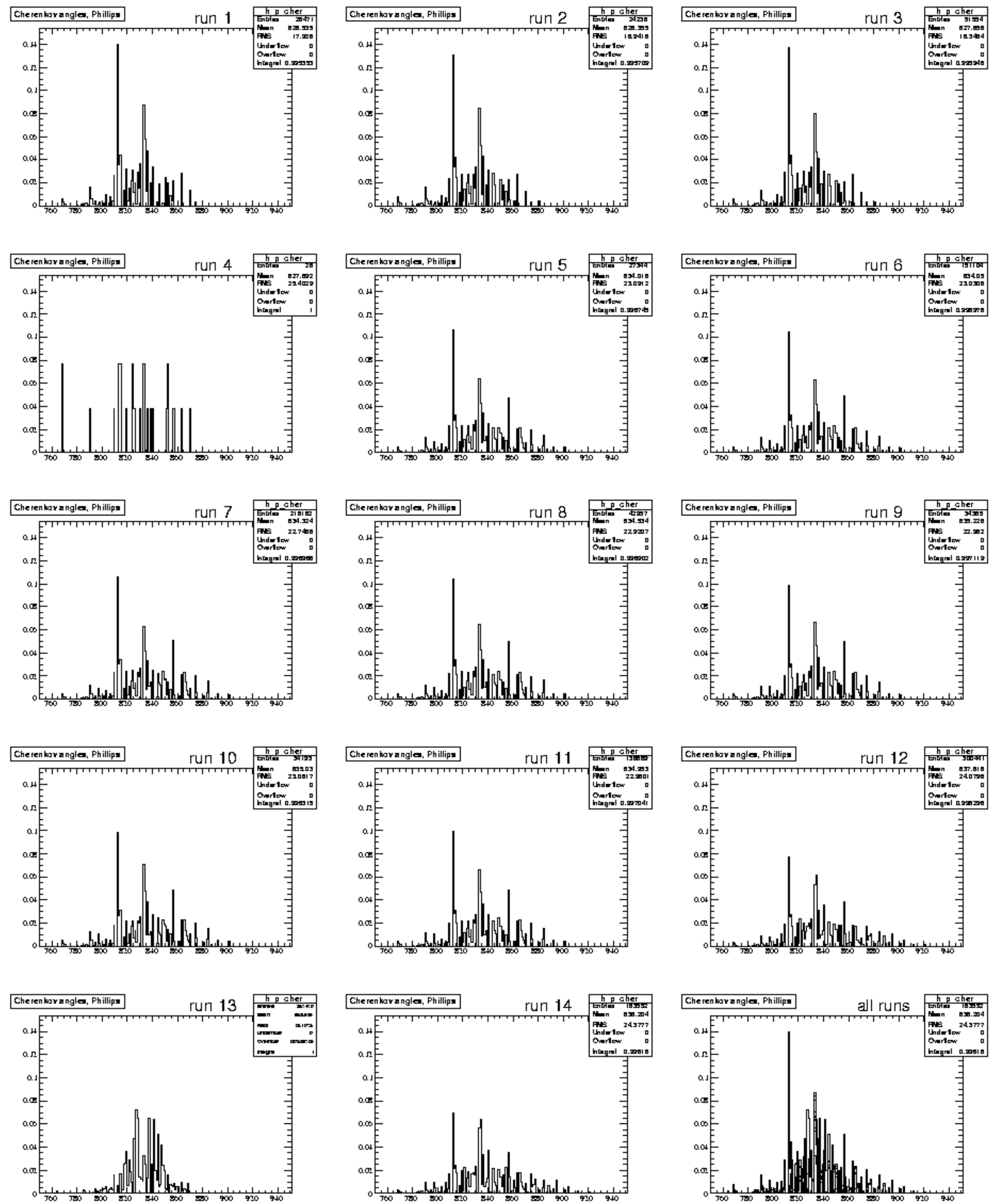
Bad channels?

In addition to marker in slot 2, pad 38, only found one channel so far with
data that we cannot use: slot 6, pad 15 (tdc10_2) has strange hits at small TDC counts.|
Very little evidence of a Cherenkov signal.



Cherenkov angle from geometry

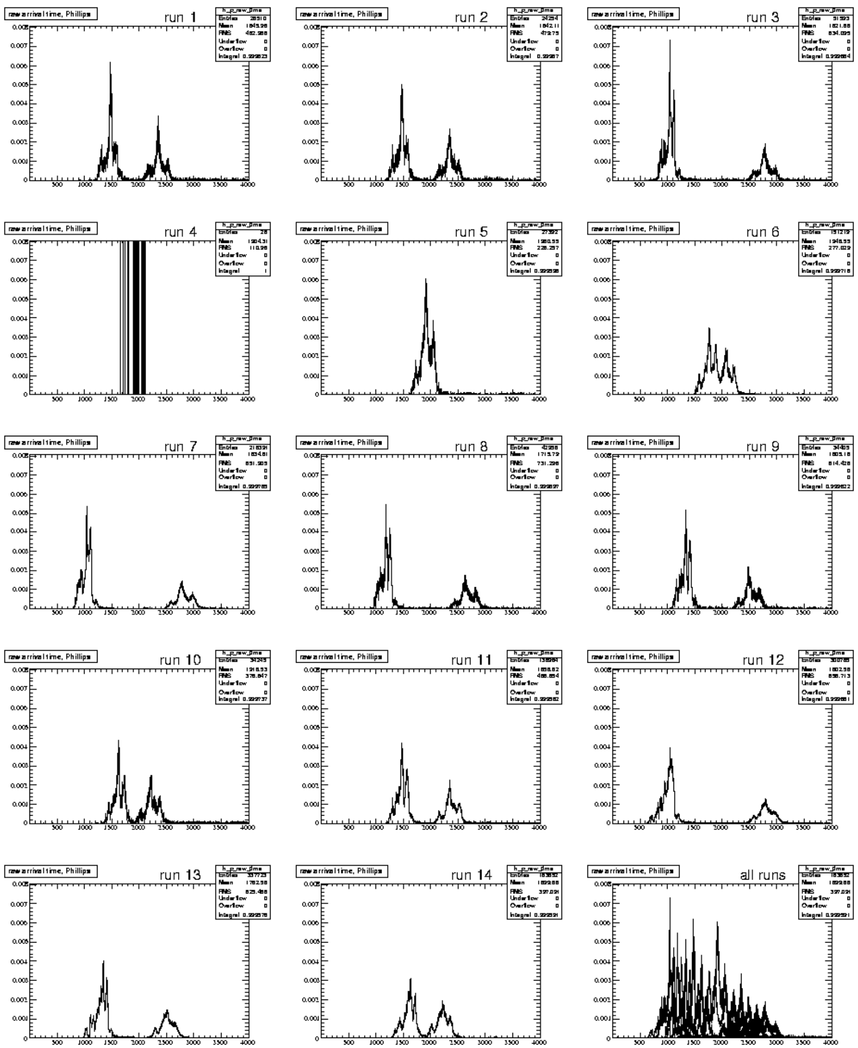
Still odd structures visible. There is not one single clean Gaussian. Using Ivan's thetaC and kBar.



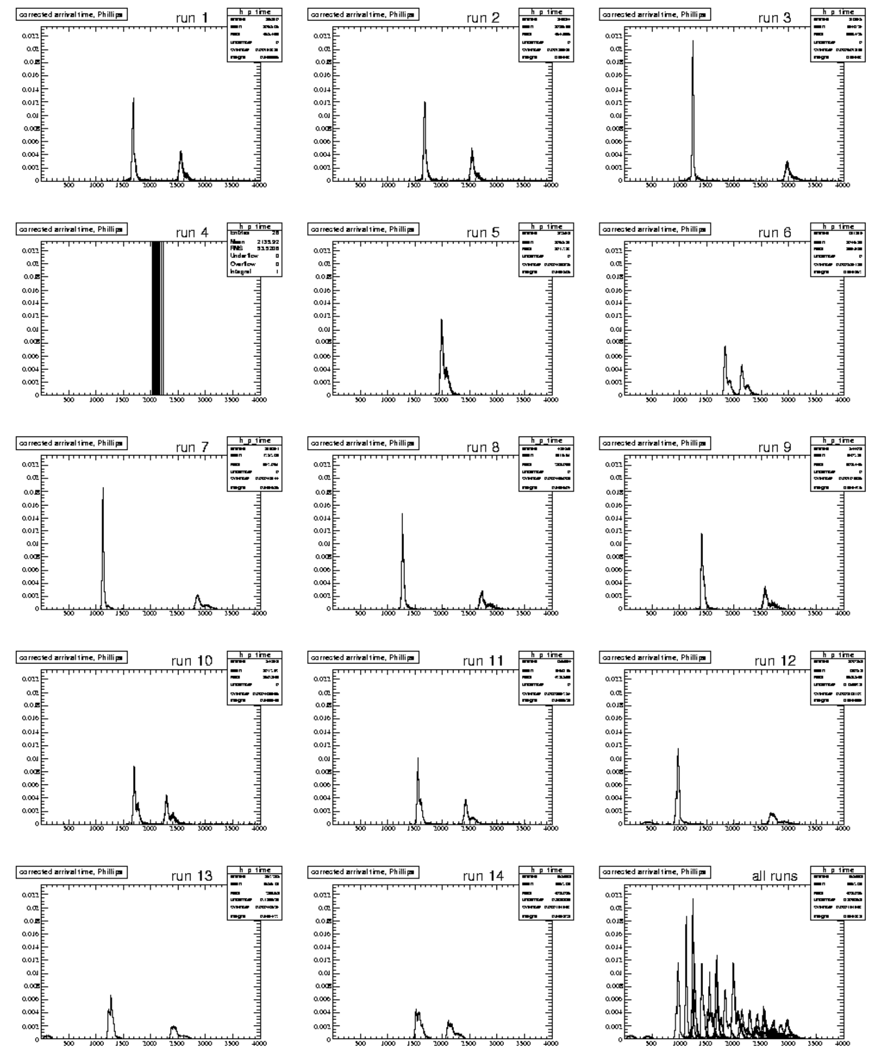
Phillips time spectra

Old method – pre-Jose functions.

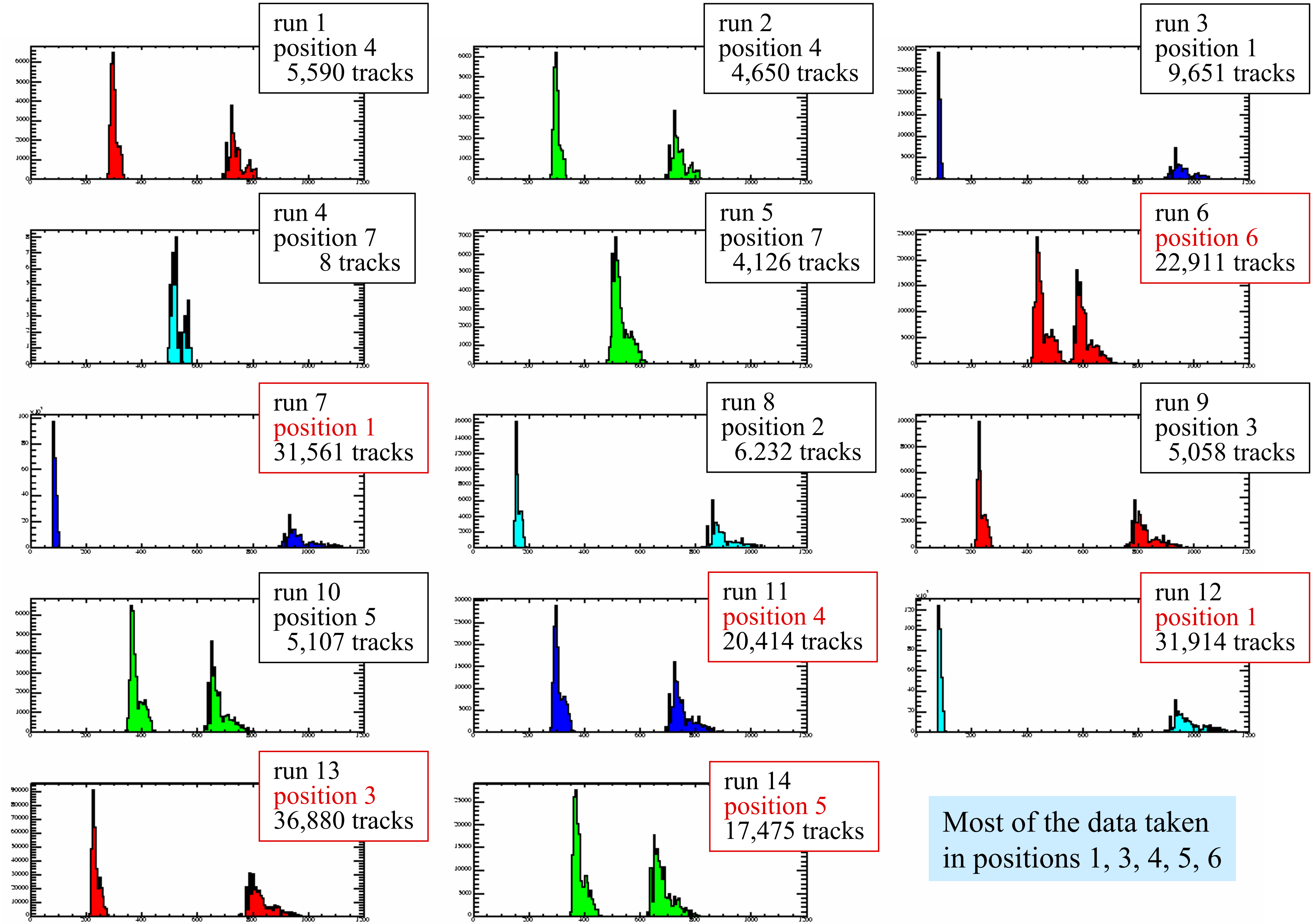
Raw times of all pads, no special alignment



Raw time after pad alignment

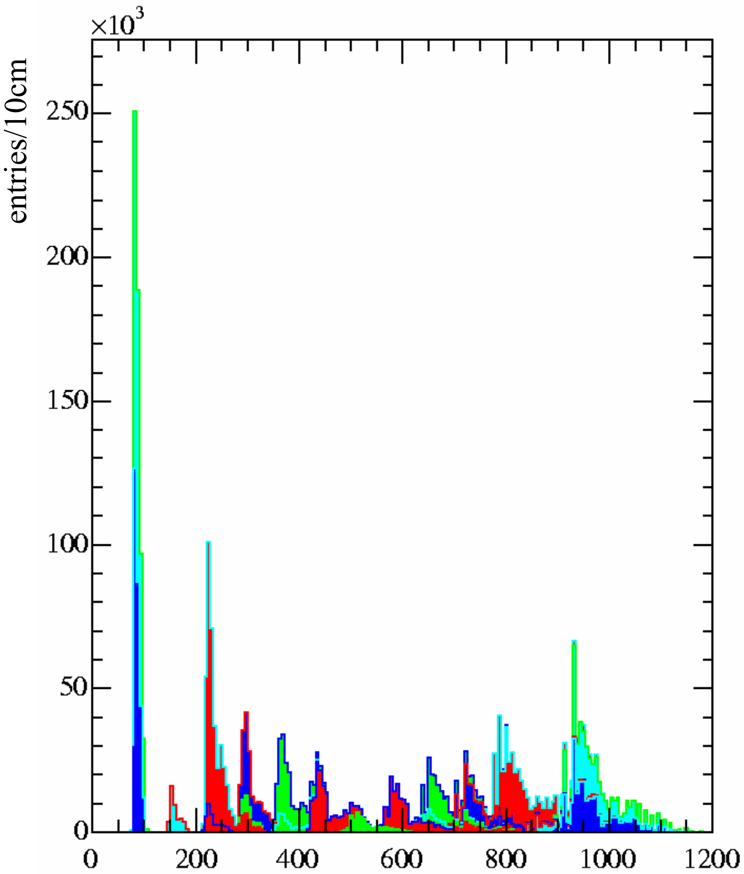


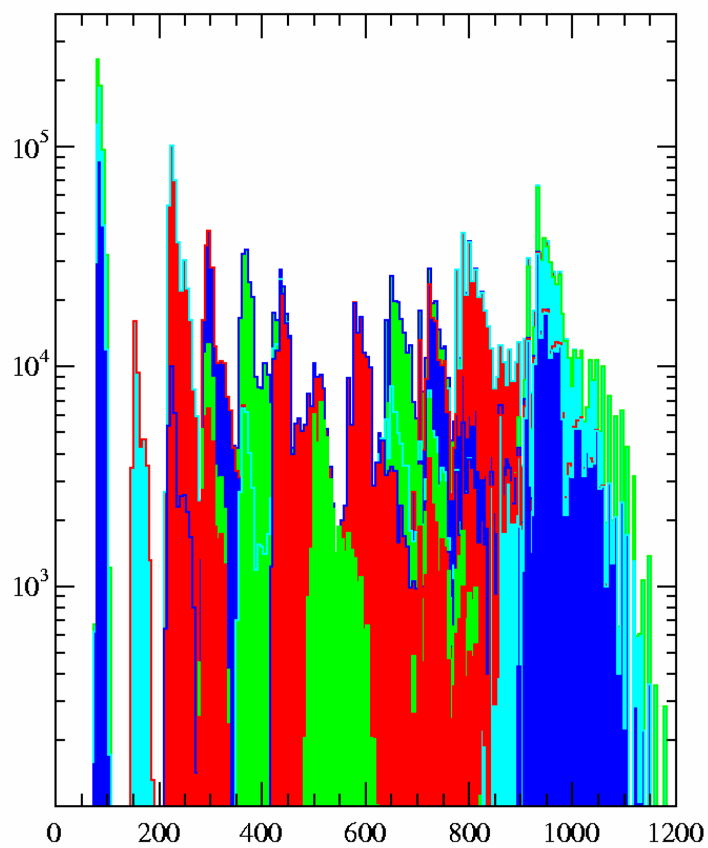
Photon Pathlength in bar [cm]



Most of the data taken in positions 1, 3, 4, 5, 6

Photon pathlength coverage for all runs combined

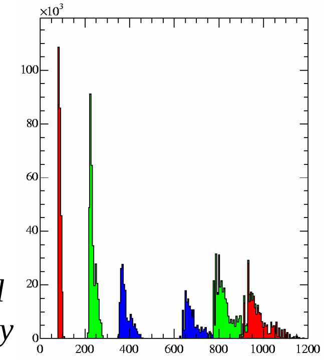


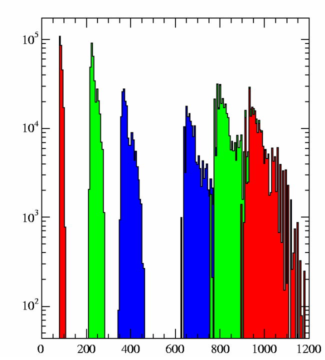


Photon Pathlength in bar [cm]

Good continuous coverage from 250-1100cm.

Same plot for small beam spot data only

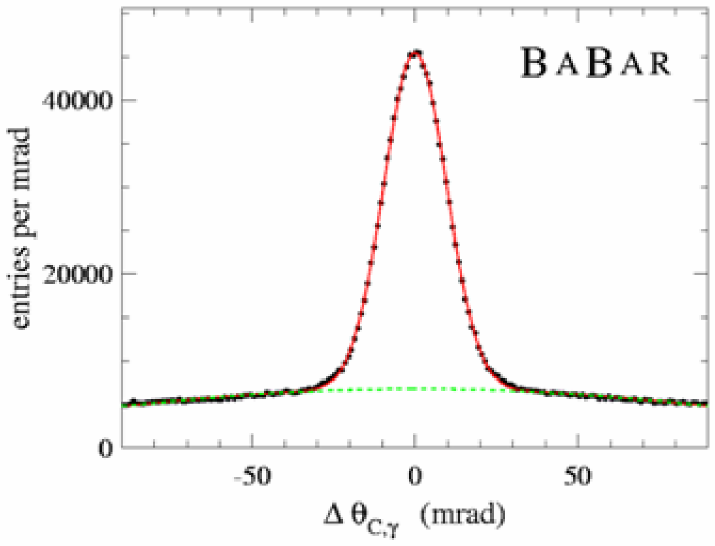




BABAR-DIRC PERFORMANCE

BABAR-DIRC successful, essential to most BABAR physics analyses§.

Resolution, PID performance close to design.



Timing resolution: 1.7ns per photon

Cherenkov angle resolution: 9.6mrad per photon → 2.4mrad per track

Limited currently by:			Could be improved by:		
▪ size of bar image	~4.1mrad	----→	▪ focusing optics		
▪ size of PMT pixel	~5.5mrad	----→	▪ smaller pixel size	→	multi-anode PMTs
▪ chromaticity ($n=n(\lambda)$)	~5.4mrad	----→	▪ better time resolution	→	multi-anode PMTs
	9.6mrad	----→	4-5mrad per photon → 1.5mrad per track		
	2.7σ	----→	4.3σ π/K sep. at 4GeV/c		

Better time resolution also essential for background suppression at higher luminosities.

§ *J. Schwiening, RICH02, SLAC-PUB-9473 (Aug. 2002)*

Measured minus expected propagation time

Not the final calibrations yet.

(In these plots I do not use time to make a decision if a hit was reflected off the mirror or not, which causes the triple-peak structure.
In the future I will assign the nz solution based on time.)

Old method – pre-Jose functions.