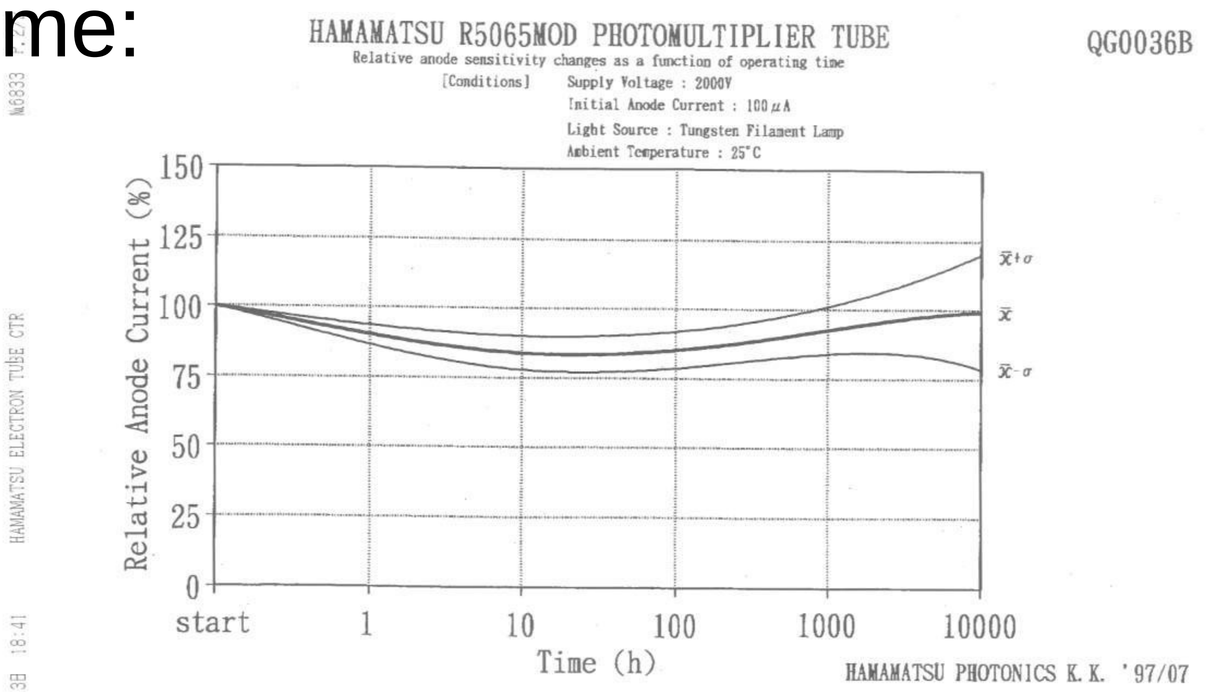
TOF Aging Issues

- Pre-history
- Operating history
- Observations related to gain loss
- Impact on timing resolution
- Possible courses of action

Pre-history – Before installation

- We knew that PMT response degrades with time:



- Belle’s experience suggested this might be worse in a magnetic field.

Pre-history – Before installation

- CDF Note 5358 – Estimated maximum anode current expected in Run-IIa:

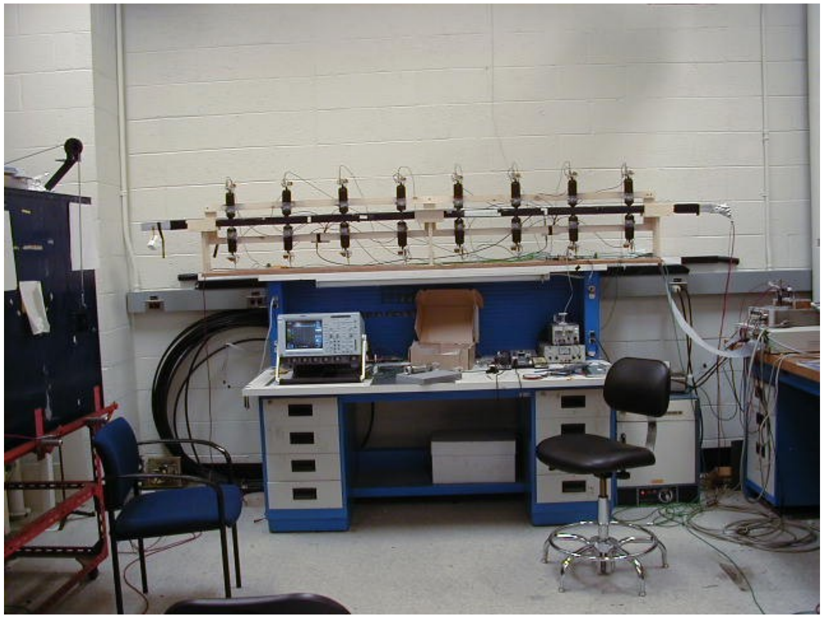
$$
\begin{aligned}
Q_{anode} &= \epsilon x \frac{dE}{dx} e^{-d/\Lambda} S_k G(V) \\
\overline{I}_{anode}[\mu\text{A}] &= \epsilon[\text{lm} \cdot \mu s/\text{MeV}] R[\text{MHz}] \overline{E}[\text{MeV}] S_k [\mu\text{A}/\text{lm}] G(V)
\end{aligned}
$$

The light acceptance parameter, ε, was measured in a cosmic ray experiment...

Also assumed:

$\sigma_{min\text{-}bias}$=68 mbarn

L = 2×10^{32} $cm^{-2}s^{-1}$



Pre-history – Before installation

Wide range of S_k and G(V).

We were always conservative:

Most PMT's would operate at less than 10 μA with $G=5x10^4$.

Found we could operate at $3x10^4$.

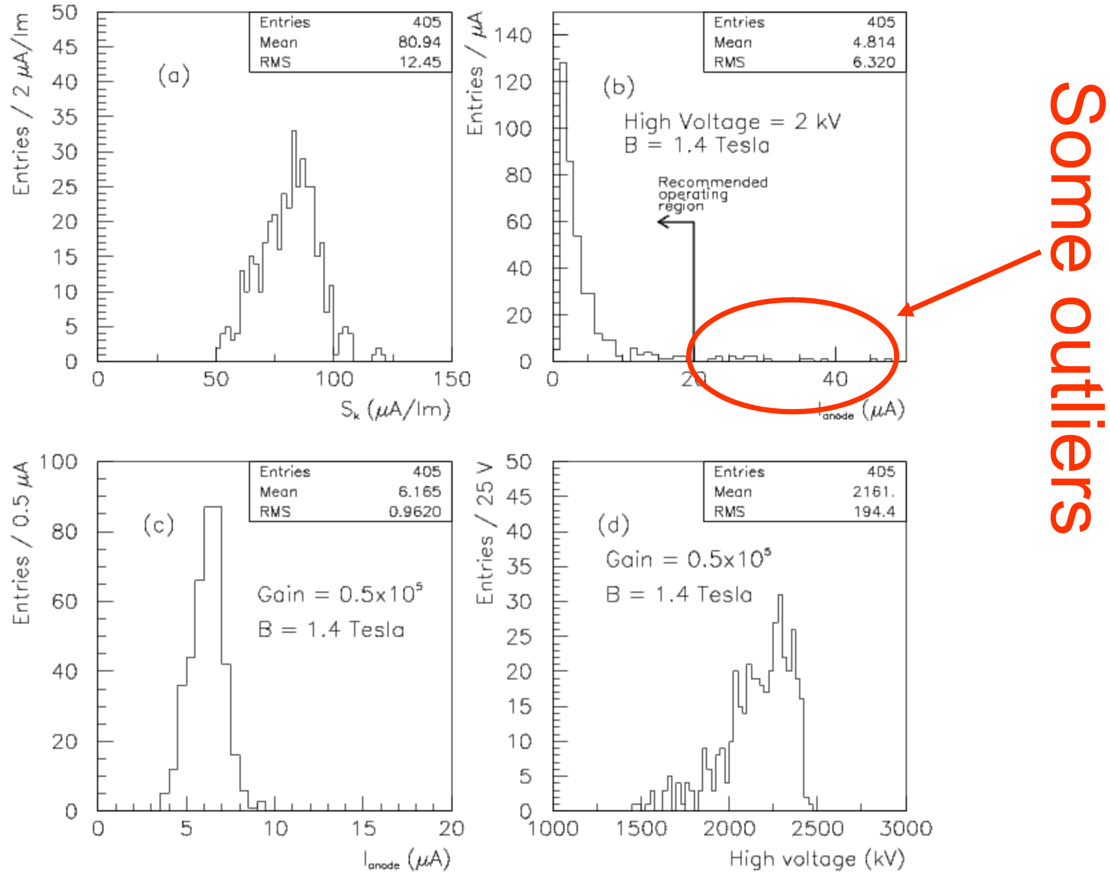


Figure 13: (a) Cathode luminous sensitivity of the 405 R7761 PMT's studied. (b) Average anode current with all tubes operated at 2.0 kV. (c) Average anode current with all tubes operated at a gain of 0.5×10^5. (d) Voltage required to give a gain of 0.5×10^5. All gains are calculated using parameters determined from measurements made in a 1.4 Tesla magnetic field.

Pre-history – before installation

- An observed loss of gain is not necessarily associated with the PMT’s themselves...
- Scintillator aging:
  - CLEO and CMP scintillator went yellow.
  - Expect this to happen eventually.
  - Does not appear to be related to radiation damage.
- Other optical components:
  - OPAL had to replaced their cookies because they went opaque (Sn vs Pt catalyst?)

Operating Parameters

- High Voltage: COULD INFLUENCE AGING
  - Specified in file on the TOF HV PC
  - Downloaded to CAEN SY527 modules
- Discriminator thresholds:
  - Set by 8-bit DAC's on TOMAIN board
  - Configurable by hardware database
- ADC gate width:
  - ADC integrates charge while a gate is asserted following discriminator firing
  - Configurable by hardware database

DON'T INFLUENCE AGING

Operating History

- Run 124022 – one of the first with TOF
  - HV set to give "nominal" gain of $5x10^4$
  - Gain equalization studies by Koji and Gerry
- Sept 2, 2001 – Nominal gain set to $3x10^4$
- Sept 6, 2001 – Disc. threshold scans
  - Set to 15 mV for all subsequent running
- March, 2002 – Gate width scans
  - ran with 21 ns until Sept 2003
  - subsequently ran with 13 ns
- Dec, 2004 – Increased HV on 2 channels
  - These frequently showed up in the tails of distributions associated with calibrations

ADC response history

- First studied by Koji/Fumi/Gerry (CDF Note 6003)
- Gain degradation effects were subtle
  - Only studied by averaging over all channels
  - Difficult to rule out luminosity dependence
- Possibly observed a decrease in ADC response as a function of time
  - Can't find the plots that demonstrate this

History Plots

- Model for ADC response:

$$Q(z) = Q_0 \left(\frac{d}{4\ \text{cm}}\right) e^{-(L/2 \mp z)/\Lambda + az^2}$$

- Determine parameters for each channel using un-binned likelihood fit
- Values depend on how well the model describes the data:
  - Not simple exponential attenuation
  - Q_0 is Landau distributed
  - Need to know (or account for) path length in the scintillator

ADC Response

- Note 6948 – ADC response fit:

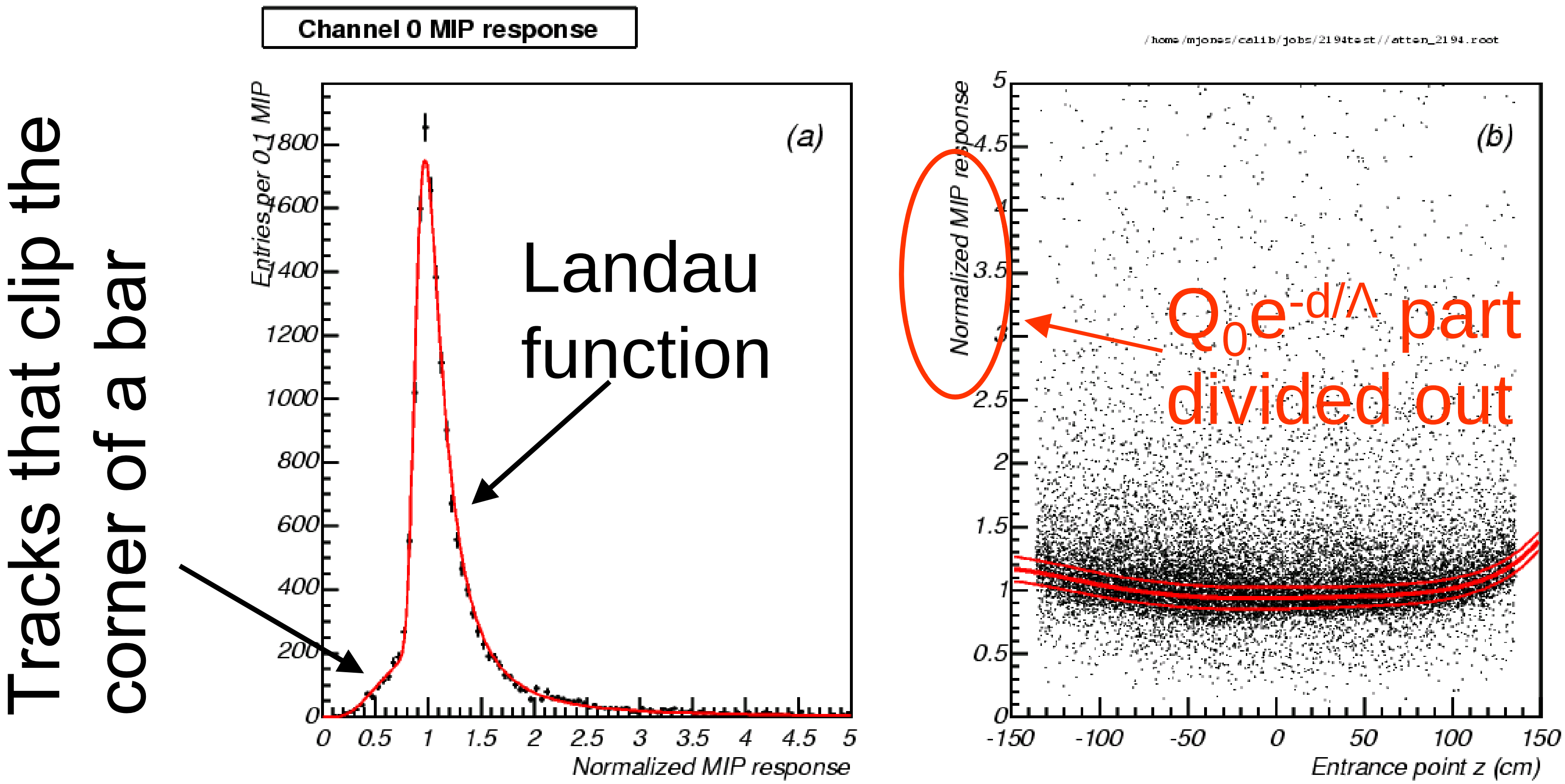
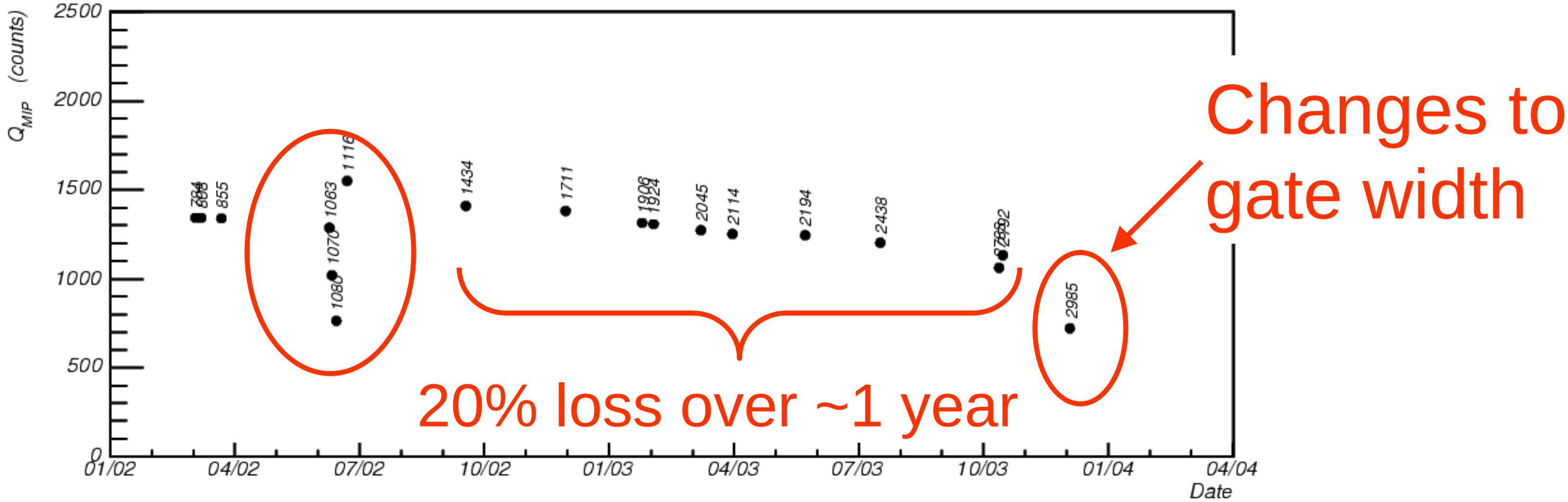
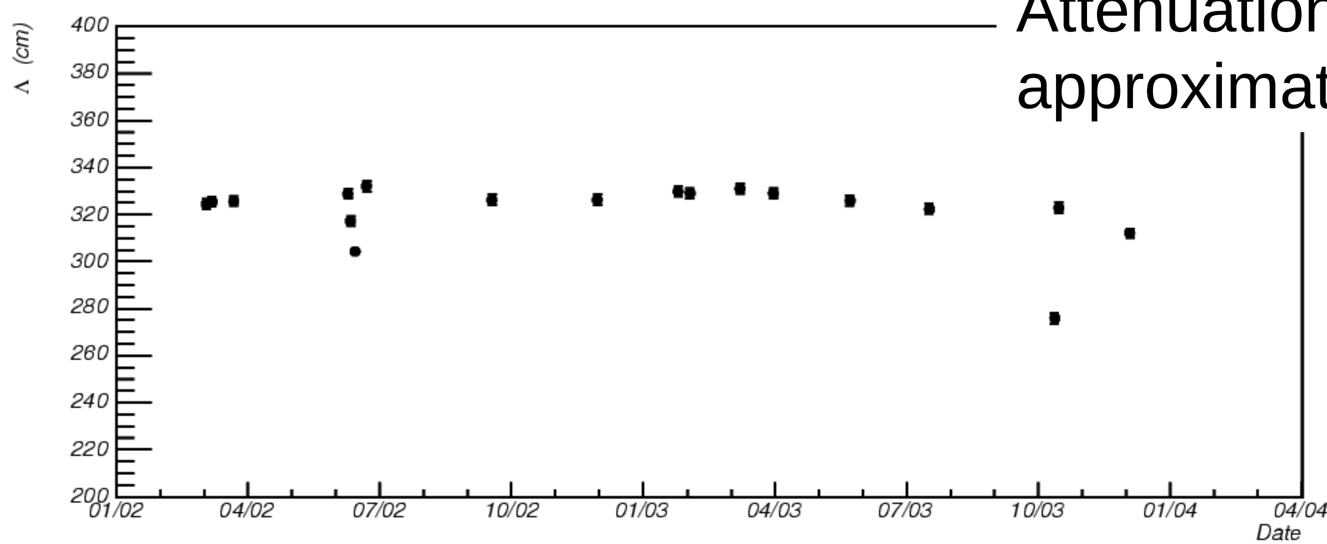


Figure 8: (a) Normalized MIP response for channel 0 with the fitted probability density superimposed. (b) Deviations from the naive linear attenuation model with the fitted parameterization of the residuals superimposed.

Mean of ADC response distribution





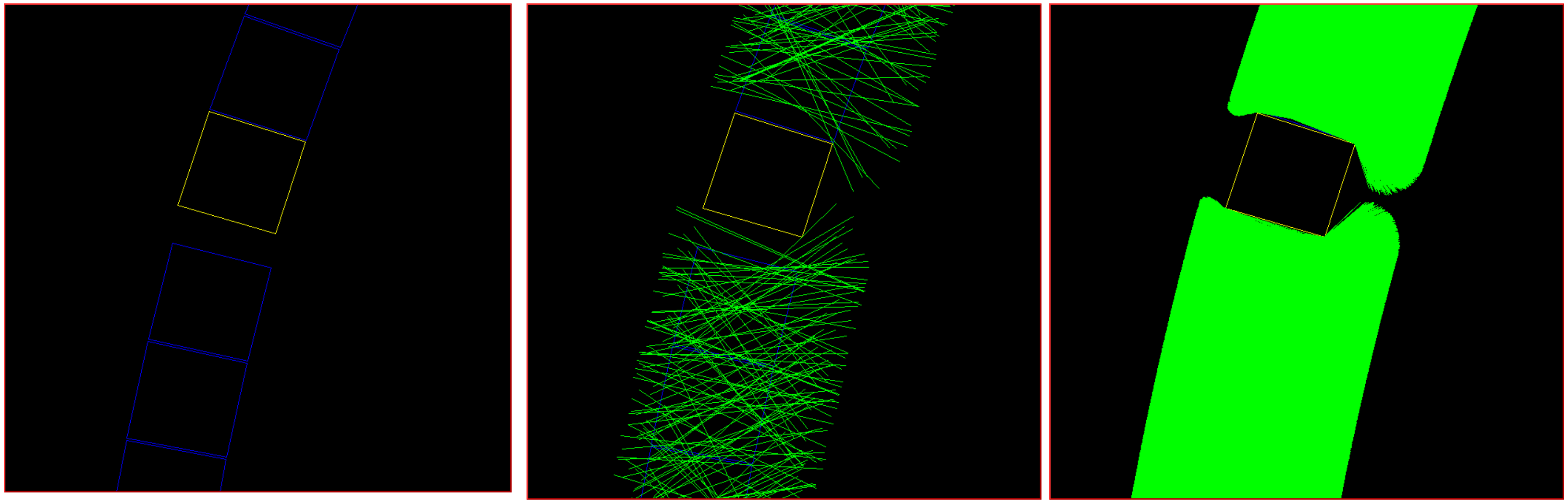
Attenuation length approximately constant?

More recent studies (June 2005)

- Not obvious how to relate ADC response to performance
- We don’t even sample the ADC if the discriminator doesn’t fire (introduces bias)
- Difficult to relate this to a loss of efficiency
- Also related: alignment of TOF scintillator
  - Did it ever move after the initial survey?
- These issues addressed in CDF Note 7693.

Model for Hit Bars

- First studied in late 2002:
  - Plot the track segments when bar is not hit:



  - This analysis finds where the corners are.

Model for Hit Bars

- Construct the likelihood function:

$$\begin{aligned}
\ell &= \text{calculated 3d path length} \\
\mathcal{P}_{\text{track}} &= 1 - \Phi\left(\frac{\ell_{\text{min}} - \ell}{\sigma\ell}\right) \quad \longleftarrow \text{Landau distribution} \\
\mathcal{P}_{\text{random}} &= \text{Probability of random hit} \\
\mathcal{P}_{\text{crazy}} &= \text{Probability that track has crazy track parameters.} \\
\mathcal{P}_{\text{nothit}} &= (1 - \mathcal{P}_{\text{random}})(1 - \mathcal{P}_{\text{track}}) \\
\mathcal{P}_{\text{hit}} &= \mathcal{P}_{\text{random}}\mathcal{P}_{\text{crazy}} + (1 - \mathcal{P}_{\text{crazy}})(1 - \mathcal{P}_{\text{nothit}})
\end{aligned}$$

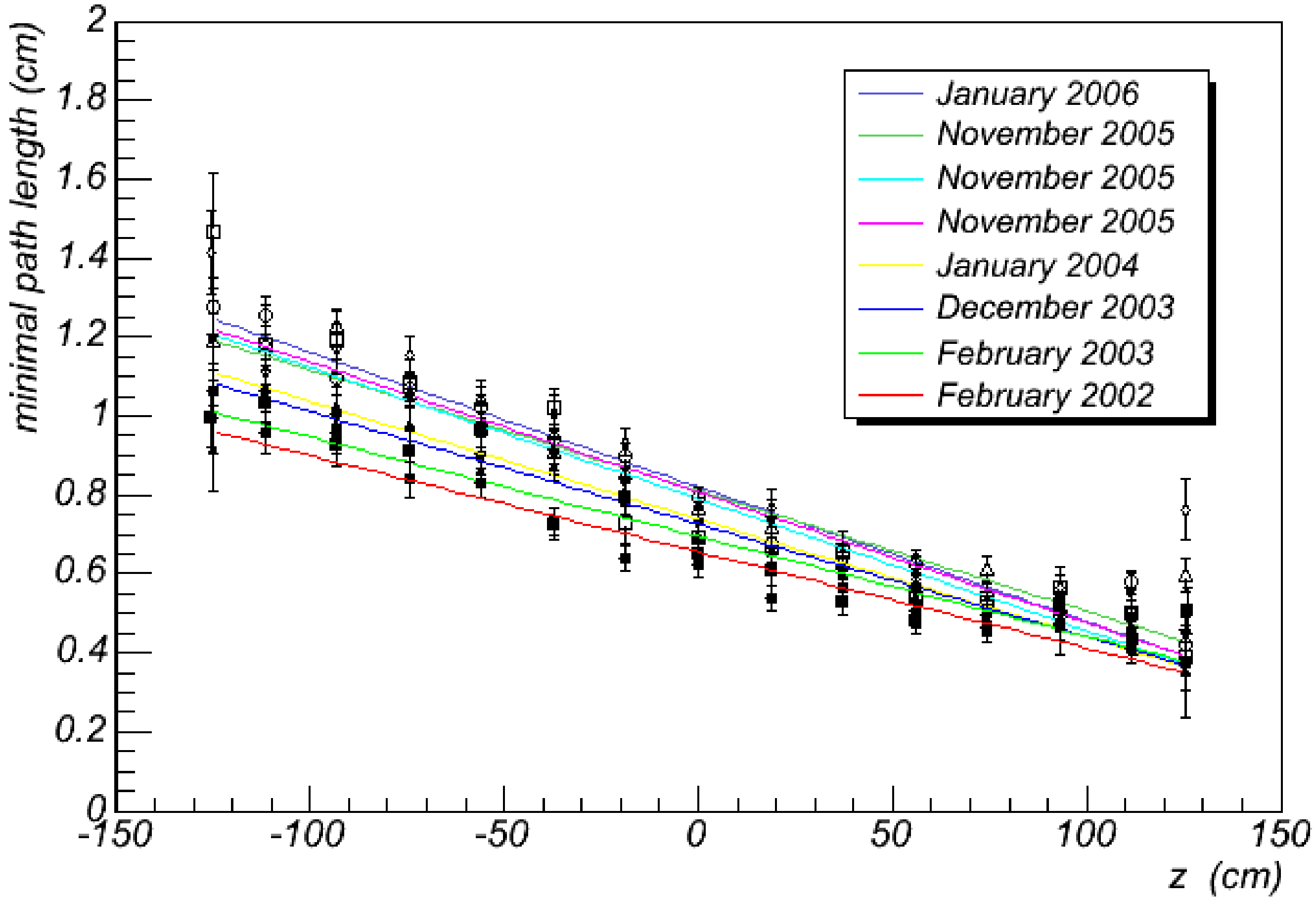
$$\mathcal{L} = \prod_{\text{bar hit}} (\mathcal{P}^{(i)}_{\text{hit}}) \prod_{\text{bar not hit}} (1 - \mathcal{P}^{(i)}_{\text{hit}})$$

Hit bar analysis

- Results of the fit:
  - Alignment parameters (useful, but not necessarily for this study)
  - Minimum path length in scintillator needed to fire the discriminator
  - Path length resolution (might tell us something useful)
- All are determined as a function of z
- Directly relates minimum path length to the discriminator threshold (15 mV)
- Quantifies loss of efficiency

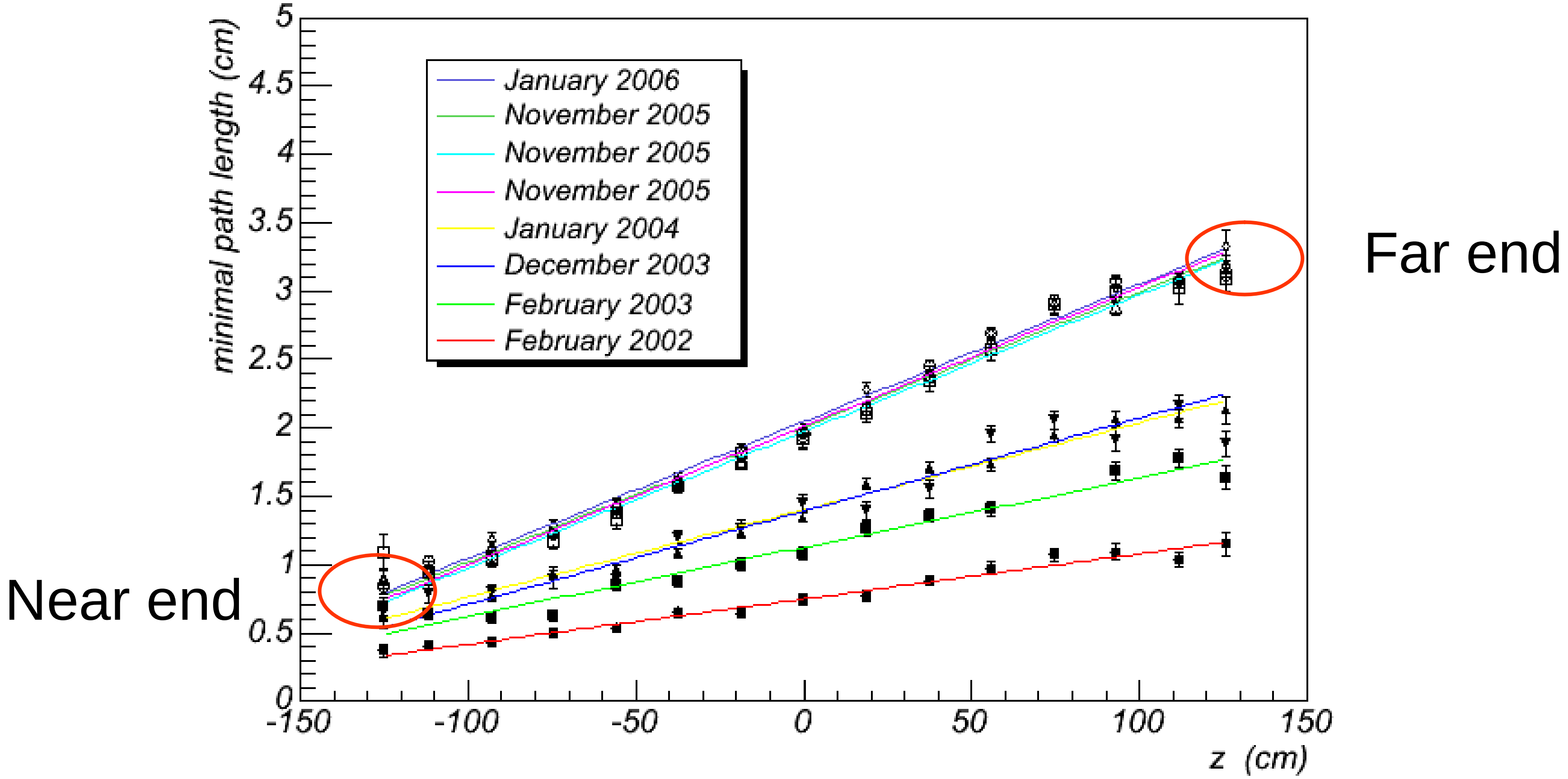
Minimal path length study

- Channel 5: one that ages gracefully.

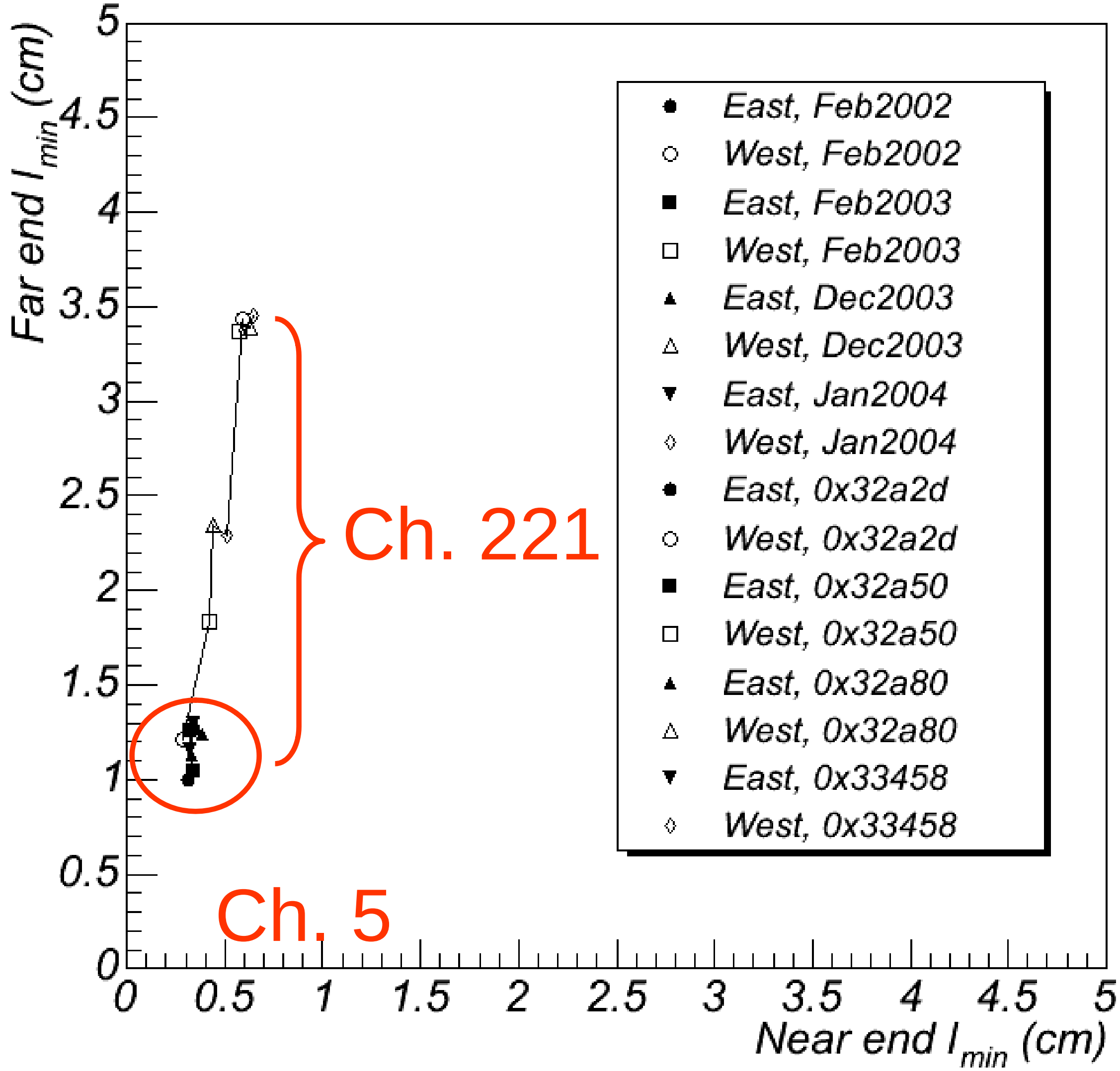


Minimal path length study

- Channel 221: one that does not.

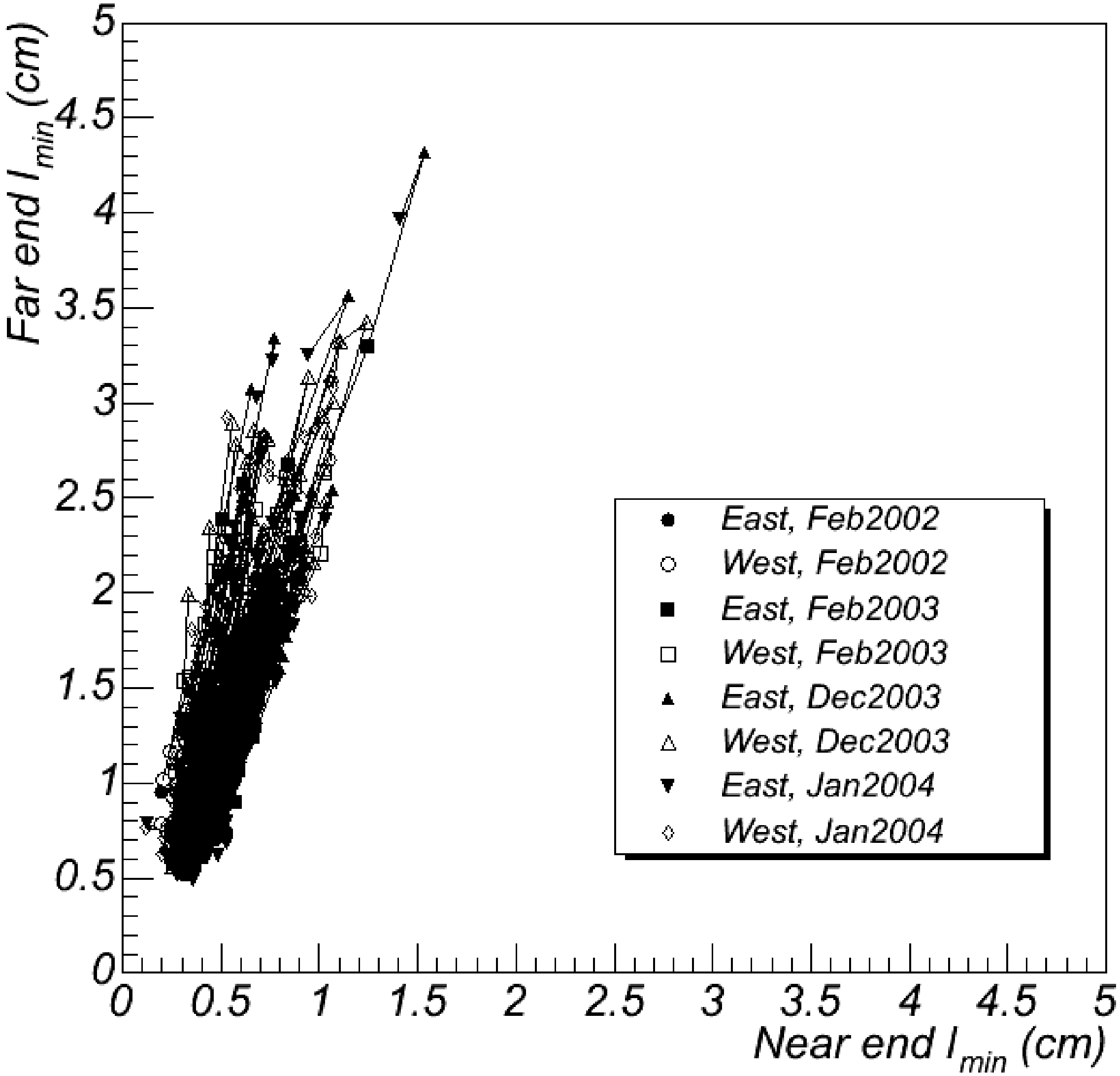


Evolution of l_{min} for PMT's on Bar 5



Constant slope would suggest no change in the "attenuation length"...

Evolution of l_{min} (all channels)

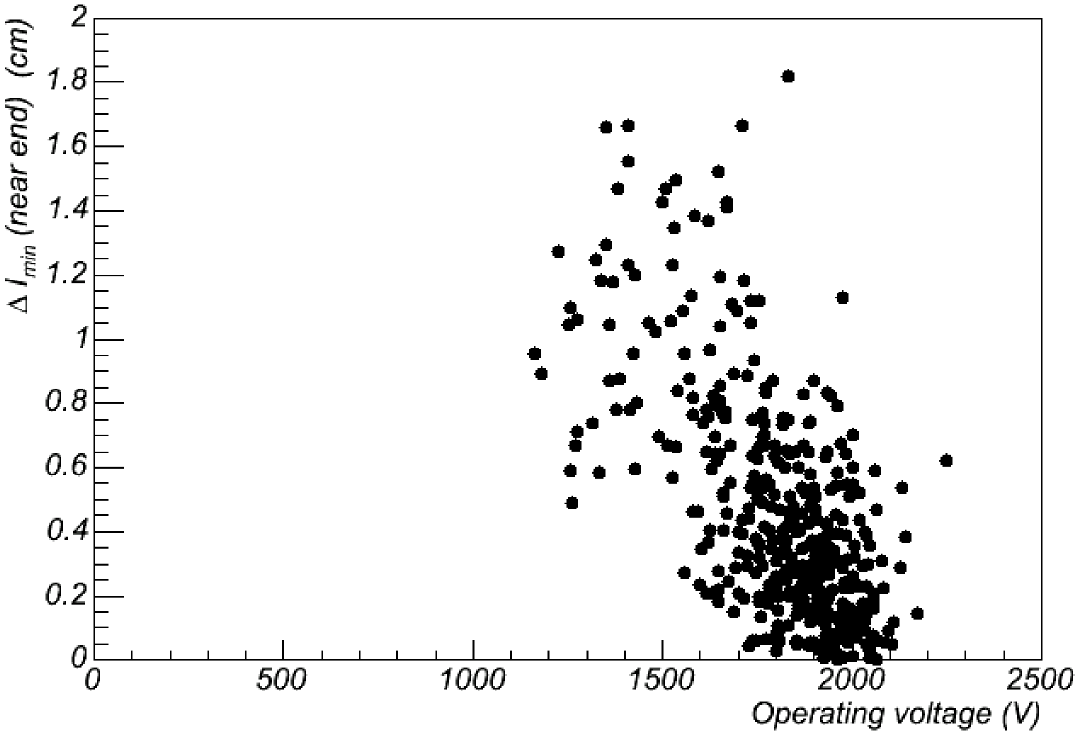


Not dominated by changes in attenuation length.

In more recent data, l_{min} exceeds thickness of the scintillator for some channels.

What Property of the PMT's Causes This?

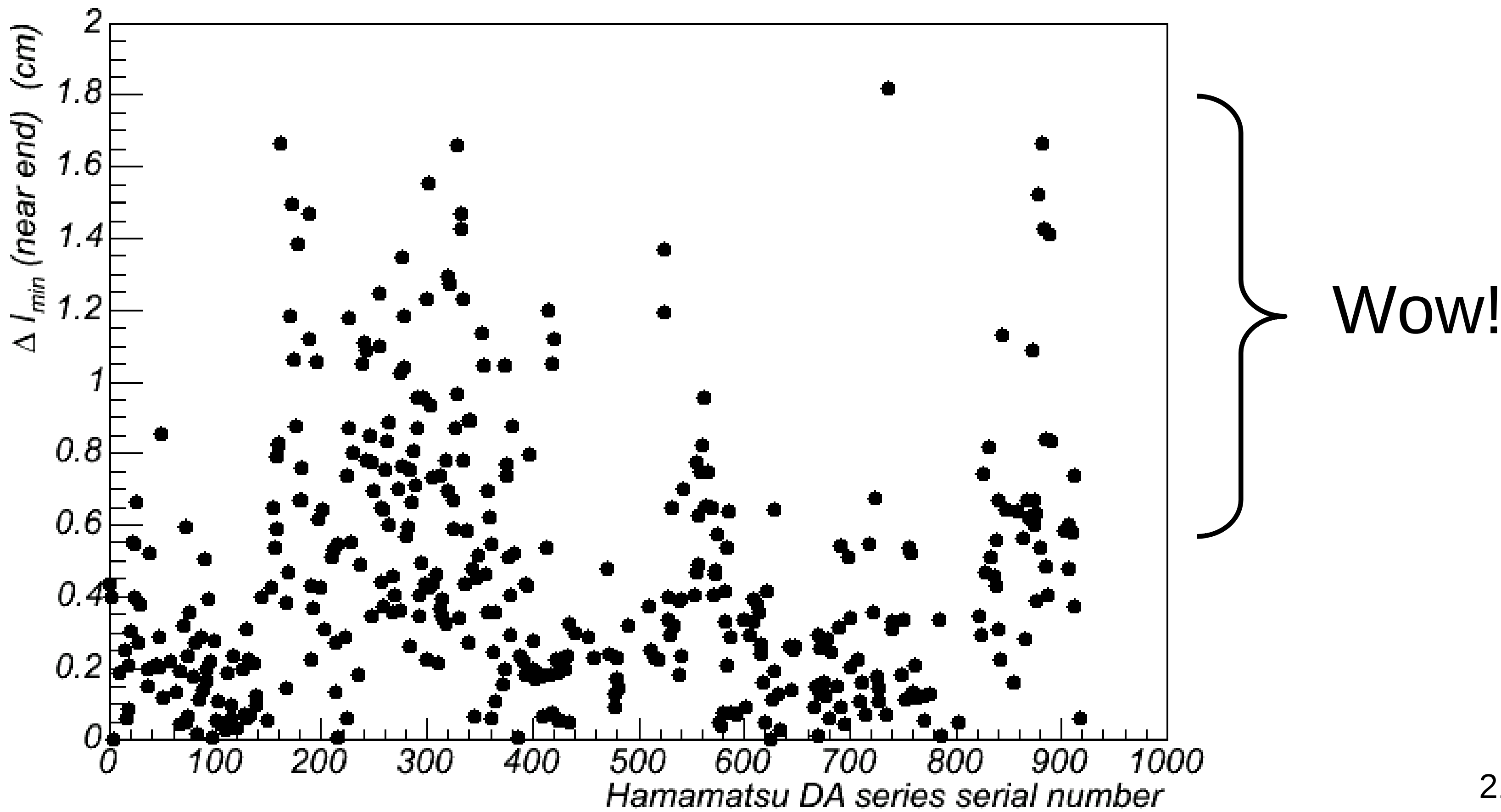
- Several parameters are somewhat correlated... They can change dramatically and unpredictably in a magnetic field.
- Strongest correlation seems to be with HV:



Interesting... But this does not imply causality.

Gain loss vs PMT serial number

- Assumes that serial numbers correlate to manufacturing date (probably reasonable).

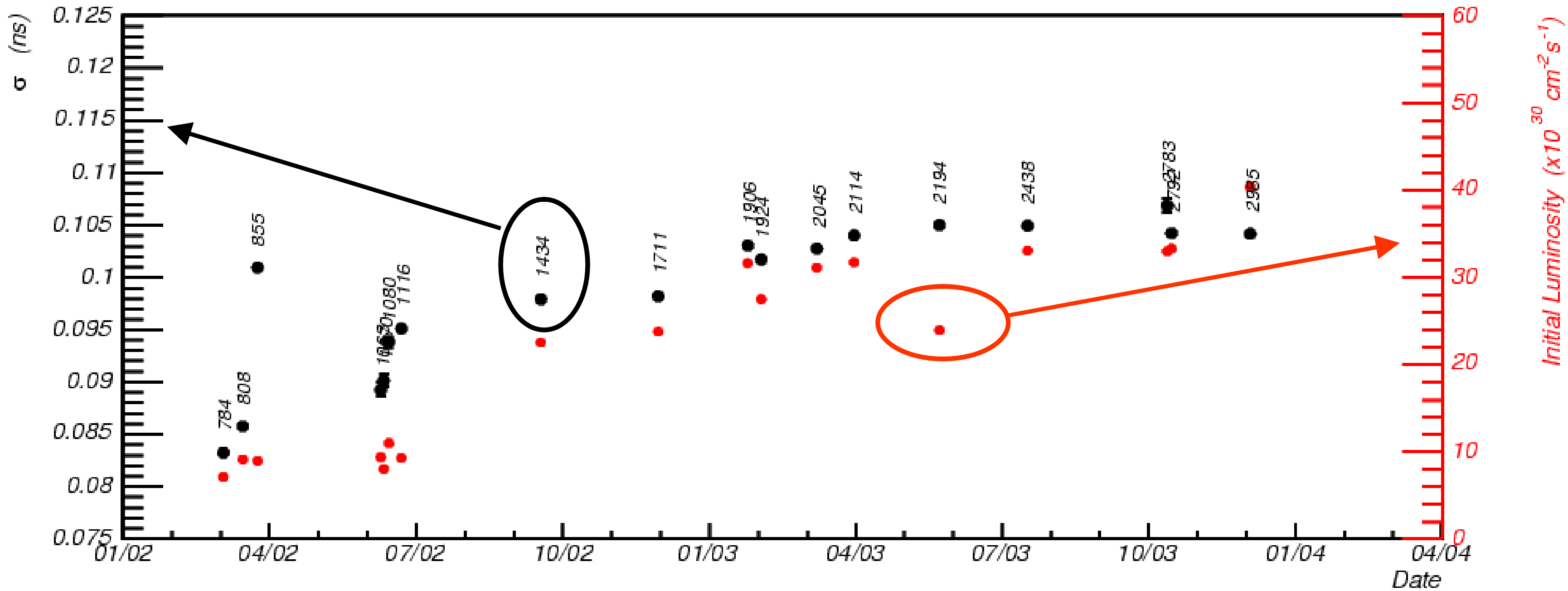


What about timing resolution?

- "Timing resolution" has been defined in several ways:
  - Using $J/\psi \rightarrow \mu^+ \mu^-$ or $K^0_S \rightarrow \pi^+ \pi^-$ events
  - Using $D^{*+} \rightarrow D^0 \pi^+$: low statistics but still useful
  - Low momentum particles: needs ad-hoc corrections at low momentum
- All are useful "indicators" of timing resolution performance
- All distributions have two components and non-Gaussian tails, some are worse than others.
- Careful: using a single parameter to quantify timing resolution might not necessarily tell the whole story...

Timing resolution history

- Fit all particle components using double Gaussian
- Time evolution of narrow Gaussian width:



Effect on timing resolution

- Presumably affects time slewing correction
  – At threshold, corrections are very large
  – Shape of pulse depends strongly on z
  – Parameterization needs to describe shape of pulse over a very large range of amplitudes
- Significant z-dependence could affect the performance of the calibration procedure

Possible Courses of Action

- Do nothing and suffer efficiency loss and degraded timing resolution
- Turn up the HV: might accelerate the aging? Or maybe it wouldn't...
- Replace PMT's? Probably too many need to be replaced to make an impact.
- Attach amplifiers between ends of cable and front end electronics?
- Others?

Conclusions

- The PMT's in the TOF system are losing gain as the run progresses
  - Presumably depends on integrated luminosity but still need to check this explicitly
- Mechanism still a bit unclear
  - Degradation in later dynode stages
  - Related to PMT manufacturing
- Obvious loss of efficiency in many channels
  - Changes particle dependent efficiencies?
- Effect on timing resolution
  - Can we calibrate out some of this?
- What can we do about it? Probably something...