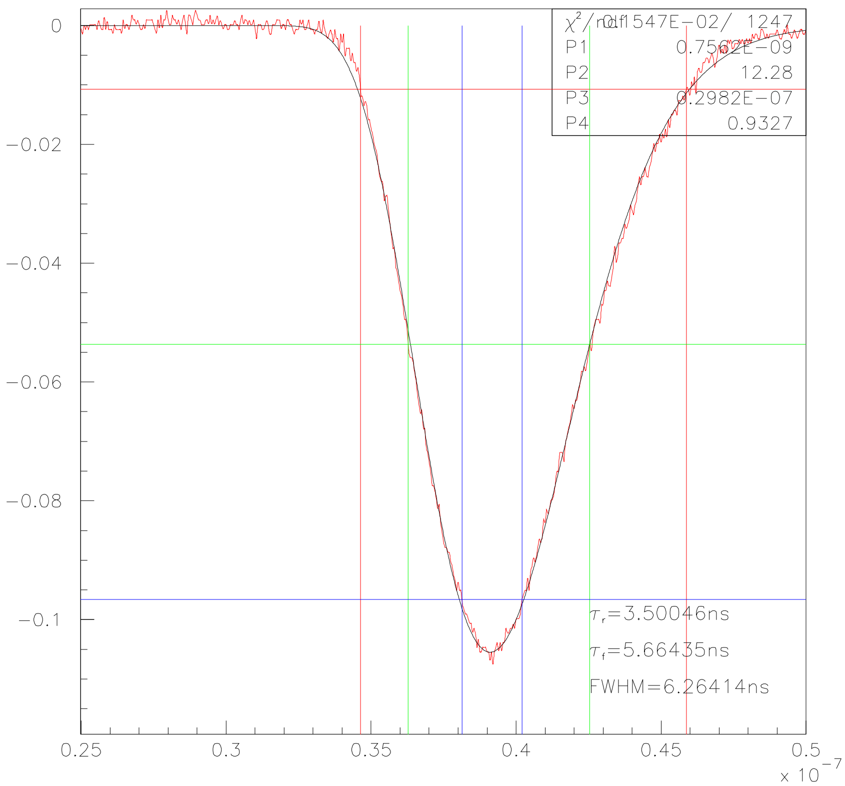
Result from June Frascati test beam

Data taken with a narrow ($\sigma \approx 0.5cm$) electron beam.
In each run the beam impinged at fixed z along a single bar.
Data read with a digital oscilloscope at sampling time $\Delta t = 400ps$.

Pos.(cm)	-36	-26	-16	-6	4	14	24
14d	●	●	●	●	●	●	●
15d	●	●	●	●	●	●	●
16d	●	●	●	●	●	●	●
17d	●		●		●	●	●
17dnew	●	●	●	●	●	●	●
18d					●	●	●
19d	●	●	●		●	●	●
20d		●	●	●	●	●	●
2d	●	●	●	●		●	
8dnuda					●	●	

Analysis topics

- PMT transfert function (laboratory measurement)
- Attenuation length measurements
- Position measurements with $\ln(Q_1/Q_2)$
- Effective velocity v_{eff} measurement



PMT transfert function

A preliminary measurement is the PMT transfert function.
In laboratory PMT output response to a δ pulses (500ps) are sampled with a digital oscilloscope.
The easiest approach is to measure the rise time τ_r, the τ_f and the $fwhm$.
A careful analysis leads to a two parameters functions for the PMT transfert function.

$$f(t;\tau_{RC},n_{RC}) = \frac{1}{\Gamma(n_{RC}+1)}\left(\frac{t}{\tau_{RC}}\right)^{n}_{RC} e^{-\frac{t}{\tau_{RC}}}$$

This function gives a good fit the PMT transfert function for different HV.

Attenuation length measurements

The effective bar attenuation length λ_{eff} can be estimated using the log of the charge ratio between opposite side PMT. Defining z as the longitudinal coordinate, L the bar length and G_n the gain factor

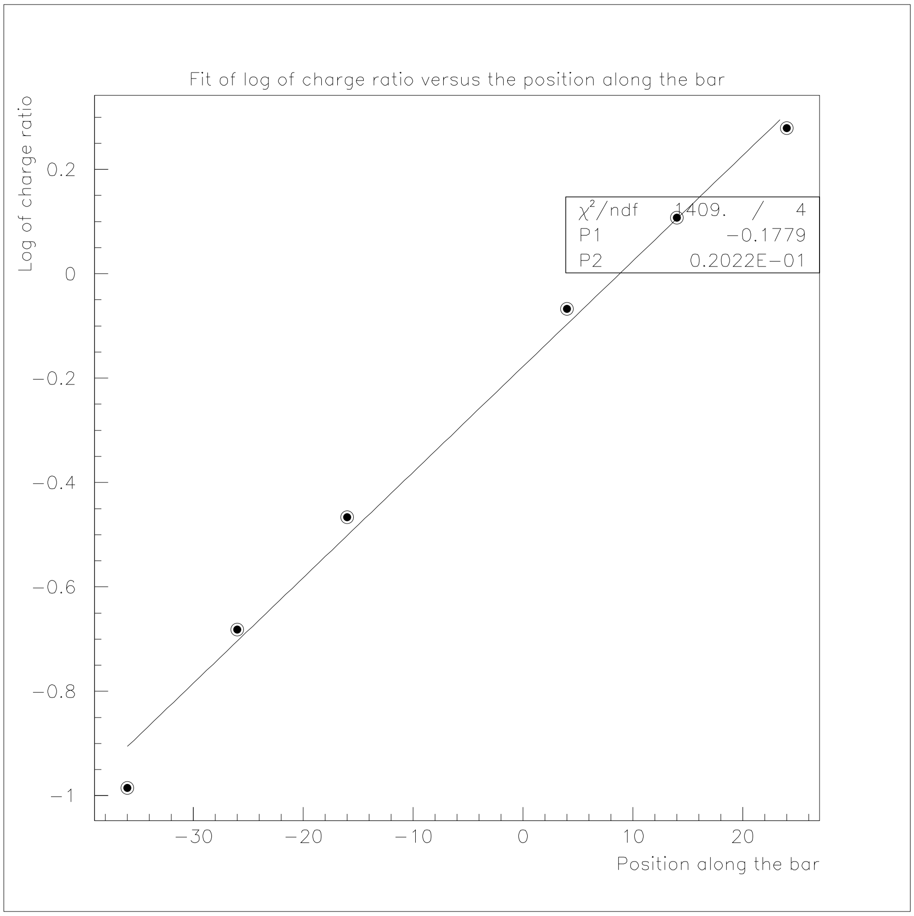
$$
\begin{aligned}
Q_1 &= G_1 E_0 \exp(-(L/2 - z)/\lambda_{eff}) \\
Q_2 &= G_2 E_0 \exp(-(L/2 + z)/\lambda_{eff}) \\
\ln(Q_1/Q_2) &= \ln(G_1/G_2) + z\frac{2}{\lambda_{eff}}
\end{aligned}
$$

The linear fit is generally as good or better as for bar 19d.

Bar	λ_{eff}(cm)	Bar	λ_{eff}(cm)
15d	93.96±0.25	16d	79.95±0.17
17d	72.38±0.13	19d	98.91±0.20
20	73.57±0.23	2d	100.02±0.31
8d	70.32±0.80	Ave	84.24±12.0

λ_{eff} is not the bulk attenuation length $\lambda = 140\,cm$ reported in the data sheets. They are related by

$$
\lambda = \frac{\lambda_{eff}}{< cos\Theta >}
$$



where $< cos\Theta >= (1 + 1/n_{sc})/2 = 0.81$ is averaged over the incident angles.

That gives an average

$$\overline{\lambda} = \frac{\overline{\lambda}_{eff}}{< cos\Theta >} = 103.49 \pm 14.74cm$$

There is a significant different from the expected value and there is a spread difficult to understand.

Influence of reflection loss on λ

An effect not yet included neither in MC nor in analysis is the reflecion loss at the surface.
Defining R_2 the reflection efficiency below the critical angle and a the bar thickness, the number of reflections for photons travelling at angle Θ for a distance x is

$$N_R = \frac{x}{a} \tan\Theta$$

This effect gives a reflection absorption length as

$$\lambda_R = \frac{a}{< \tan\Theta >} \frac{1}{\ln\frac{1}{R_2}}$$

Therefore λ_{eff} can be defined as

$$\frac{1}{\lambda_{eff}} = \frac{1}{\lambda < \cos\Theta >} + \frac{1}{\lambda_R}$$

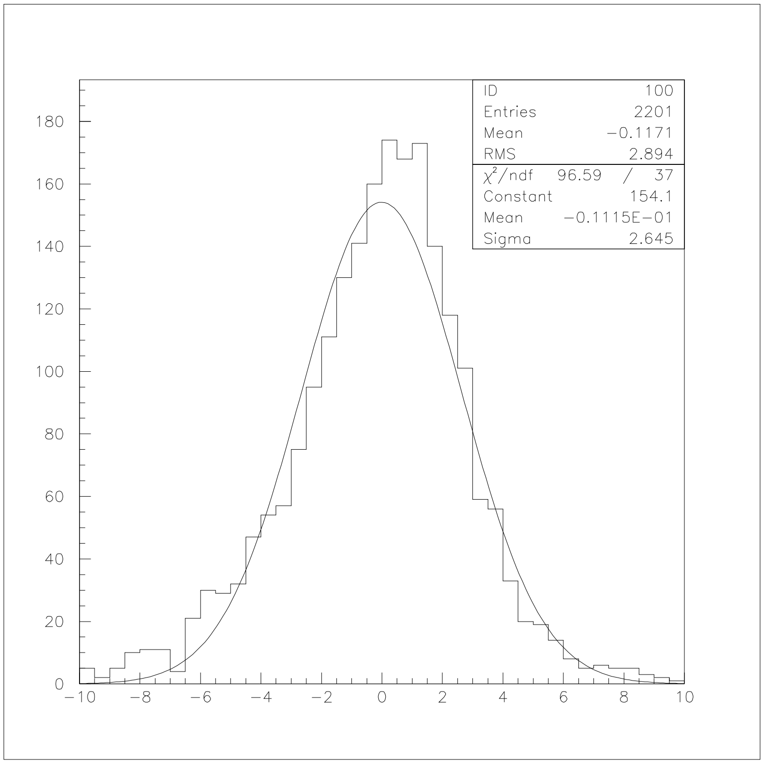
If $R_2 = 1 - \epsilon$ for $\epsilon << 1$

$$\lambda_R = \frac{a}{< \tan\Theta >} \frac{1}{\epsilon}$$

Estimating R_2 from λ_{eff} measurements

Bar	15d	16d	19d	20	2d	8d	Ave
0.60	1.21	1.63	0.43	1.56	0.40	1.76	1.00

If the difference between λ_{eff} and the bulk value is due to reflection losses, ϵ can be obtained for each bars. A spread in ϵ that depends on the surface quality is more credible that the same spread in bulk property.



Position measurements

Using λ_{eff} we can obtain a position measurement from

$$\ln(Q_1/Q_2) = \ln(G_1/G_2)_{fit} + z\frac{2}{\lambda_{eff,fit}}$$

Averaging all measurements on a bar, the position resolution is $\sigma(z) = 2.6cm$.
This error does not depend on the hit position except when its distance is comparable to PMT diameter.
In this case the linear relation between $\ln(Q_1/Q_2)$ and z breaks down because photons at $|\cos\Theta| < \frac{1}{n_{sc}}$ can reach the PMT without reflection.

Effective velocity v_{eff} measurements

The formulae for the timing are

$$t_1 = t_0 + (\frac{L}{2} - z)\frac{1}{v_{eff}}$$
$$t_2 = t_0 + (\frac{L}{2} + z)\frac{1}{v_{eff}}$$
$$t_2 - t_1 = \frac{2}{v_{eff}}z$$

Important: the timing t_1 t_2 depends on the algorithm.
We used amplitude normalized threshold, the timing fires when the signal cross $\alpha\%$ of the maximum amplitude: 10%,50%,90%.
The time profile of the signal is due to different components:

- Transfer function of the PMT
- Photon time distribution due to the scintillation process
- Photon propagation in the bar

The last contribution depends on hit position, that implies that v_{eff} depends on the fraction of photons ϵ contributing to the timing.
Different ϵ corresponds approximately to different α.
Different ϵ correspond to different $\cos(\Theta_\epsilon)$, where $\cos(\Theta_\epsilon)$ is the angle within which the fraction ϵ is emitted.

$$(1-\cos(\Theta_\epsilon)) = (1-\frac{1}{n_{sc}})\epsilon$$

v_{eff} is established by the formulae

$$\begin{aligned} t(x,\cos(\Theta)) &= \frac{z}{\cos(\Theta)}\frac{n_{sc}}{c} \\ t_\epsilon(x) &= t(x,\cos(\Theta_\epsilon)) = \frac{z}{\cos(\Theta_\epsilon)}\frac{n_{sc}}{c} \\ v_{eff,\epsilon} &= \frac{x}{t_\epsilon(x)} = \frac{c}{n_{sc}}\cos(\Theta_\epsilon) = \frac{c}{n_{sc}}(1-(1-\frac{1}{n_{sc}})\epsilon) \end{aligned}$$

Therefore for $\epsilon \to 0$ ($\alpha \to 0$) $v_{eff,0} \to \frac{c}{n_{sc}} = 18.87\frac{cm}{ns}$.
For $\epsilon \to 1$ ($\alpha \to 1$??) $v_{eff,0} \to \frac{c}{n_{sc}^2} = 11.87\frac{cm}{ns}$.
These two values constrain the range of values of v_{eff}.
In the test beam the relation between z and $t_2 - t_1$ is measured for several bars and it is very linear.

Bar	$v_{eff,0.1}(\frac{cm}{ns})$	$v_{eff,0.5}(\frac{cm}{ns})$	$v_{eff,0.9}(\frac{cm}{ns})$
15d	14.81±0.05	14.17 ±0.02	13.76±0.05
16d	15.03±0.04	14.31 ±0.02	13.85±0.03
17d	15.42±0.02	14.62 ±0.02	14.31±0.02
19d	14.98±0.02	14.24±0.01	13.82±0.02
20	15.26±0.03	14.38±0.02	13.62±0.04
2d	15.13±0.04	14.33±0.03	14.06±0.05
8d	15.06±0.33	14.33±0.25	13.82±0.21

The trend of increasing $v_{eff,\alpha}$ with decreasing α is confirmed.