A PMT test stand for the Pierre Auger Observatory

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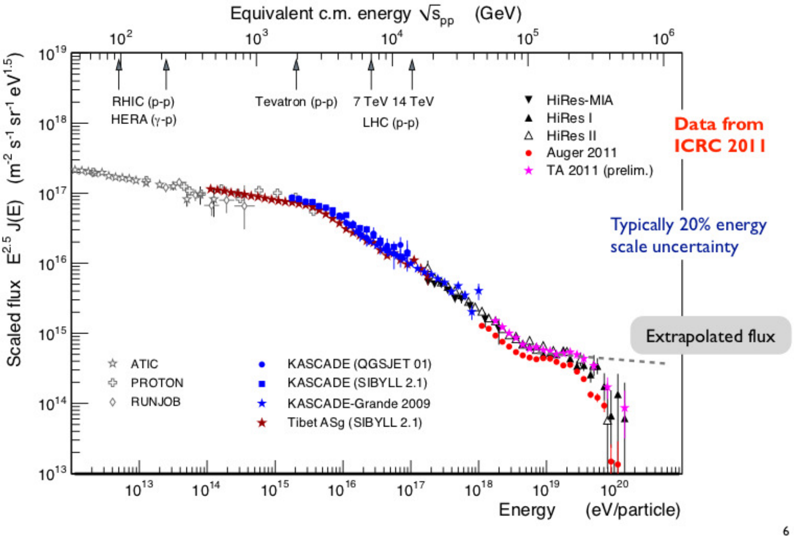
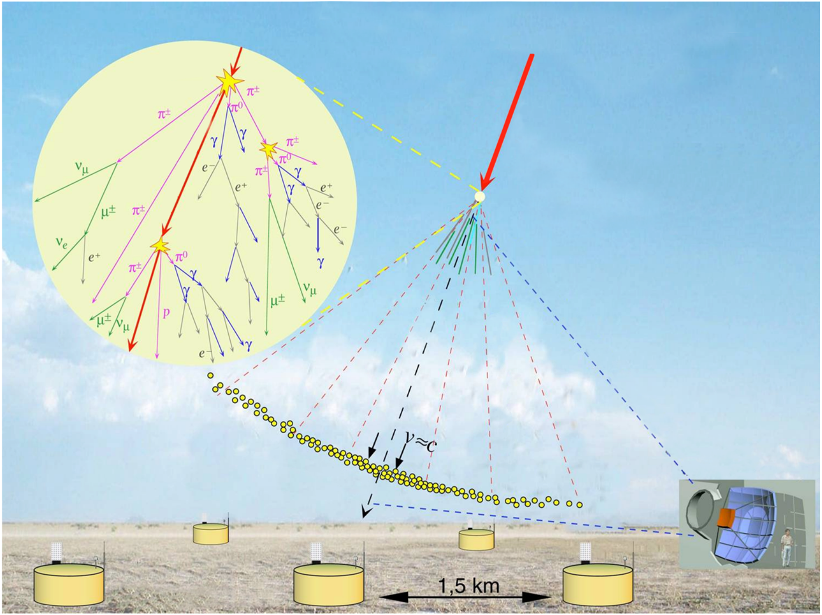
Cosmic Rays



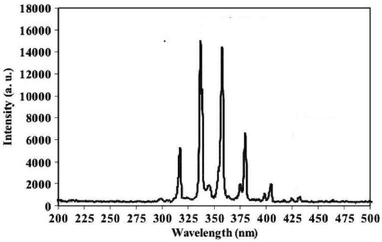
Open questions: Features of the spectrum, e.g. what happens at 10^{20} eV?

Extensive air showers and fluorescence light



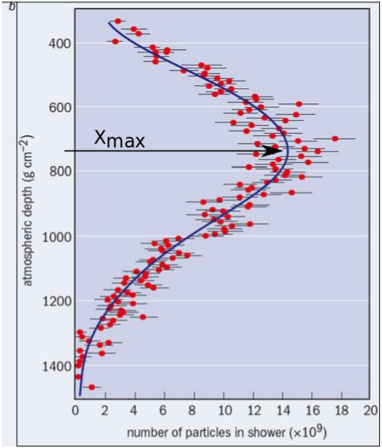
Fluorescence light and shower profile

Fluorescence light from the excitation of N_2-molecules

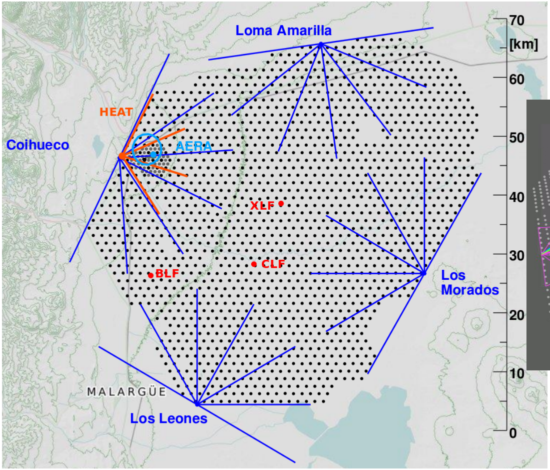


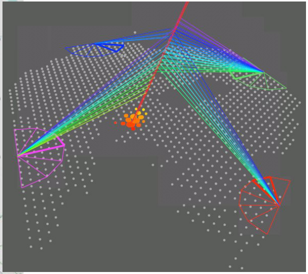
- isotropic emission,
- in the UV-range
  $\hookrightarrow$ PMT acceptance

Fluorescence light
$\propto$ number of particles,
$\propto$ energy of primary particle.



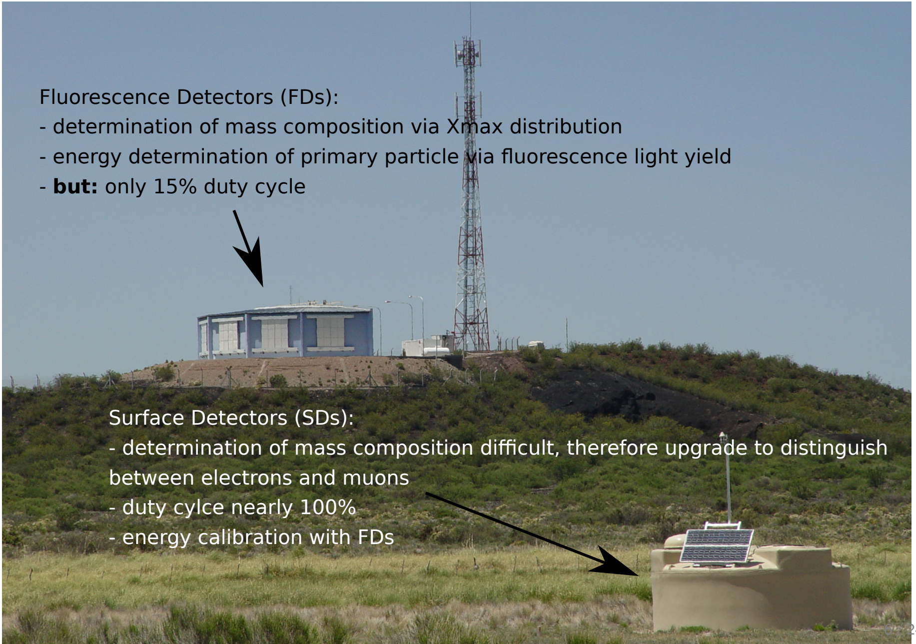
Pierre Auger Observatory - a hybrid experiment





- near Malargüe (Mendoza, Argentina)
- ca. 1600 water tanks (surface detectors, SD) on a 3000 km^2 array
- 27 fluorescence telescopes at 4 sides (fluorescence detectors, FD)

A hybrid detection method



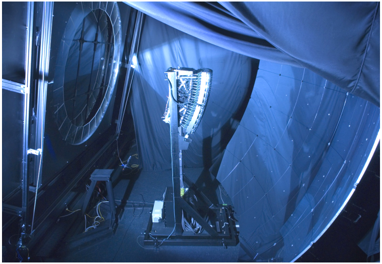
Fluorescence Detectors (FDs):
- determination of mass composition via Xmax distribution
- energy determination of primary particle via fluorescence light yield
- **but:** only 15% duty cycle

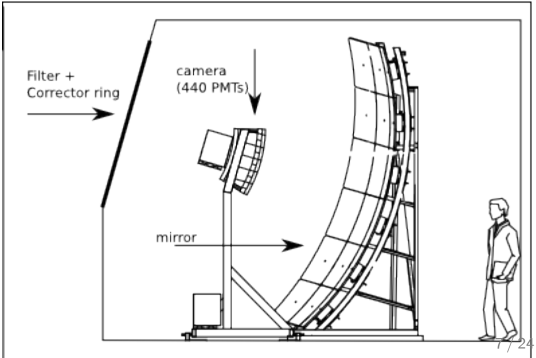
Surface Detectors (SDs):
- determination of mass composition difficult, therefore upgrade to distinguish between electrons and muons
- duty cylce nearly 100%
- energy calibration with FDs

Fluorescence telescopes

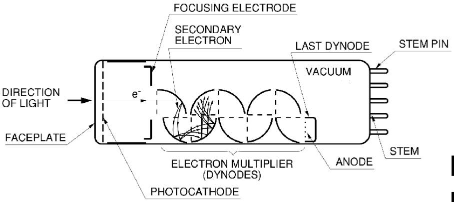
Telescopes consist of

- filter and aperture with corrector ring,
- mirror and
- camera with 440 Photonis PMTs.





FD-Photomultiplier Tube (PMT)



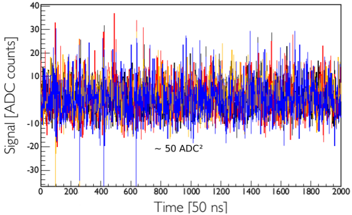
PMT + electronics:

1. Amplification stage with gain g,
2. ac coupling network,
3. low-pass filter.

Poisson statistics:
Fluctuations (σ^2)
$\Rightarrow$ info background light

different background light conditions (for a gain of 10^5):

condition	I_A (μA)	σ^2 (ADC^2)
no moon	0.5	25
1/4 moon	5	250
full moon	50	2500



Actual status and goals

Actual gain of PMTs:
$G = 10^5$

data sheet Photonis

Gain shift when the anode current varies from dark current to 10 µA and back	max.	10	n.s.	%

(for a gain G=10^5)

n.s.: no standard specification

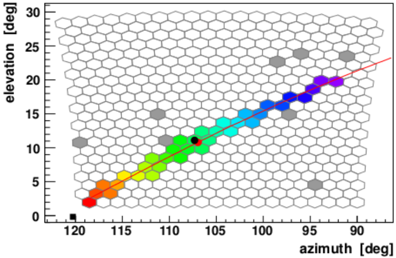
$\hookrightarrow$ no operation at higher background light possible (quick aging of PMTs)

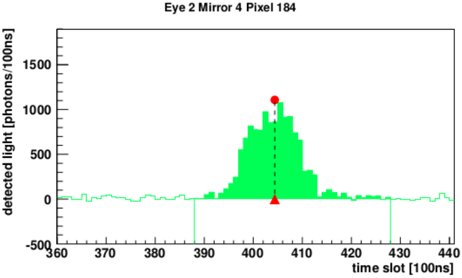
Superior goal:

- Operate PMTs at lower HV (i.e. lower gain) & higher background.
- But: Performance of PMTs at low HVs (400-600 V) and higher background light unknown.
- Test stand to simulate new conditions and determine aging of PMTs

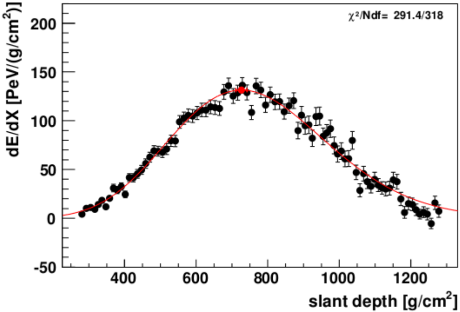
But: Is the shower reconstruction for the high energy events ($> 10^{18}$ eV) still possible at higher background light conditions?

FD measurements at nominal conditions (Los Morados)

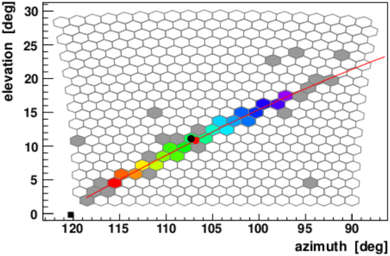


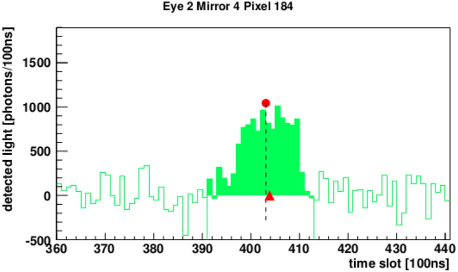


[M. Unger]



Simulation with an added Gaussian noise (1000 ADC^2)





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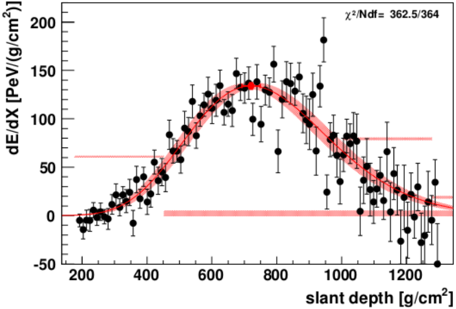
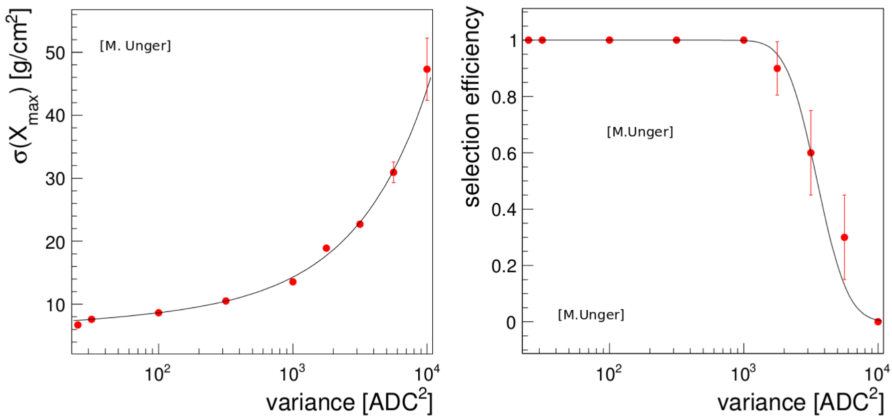
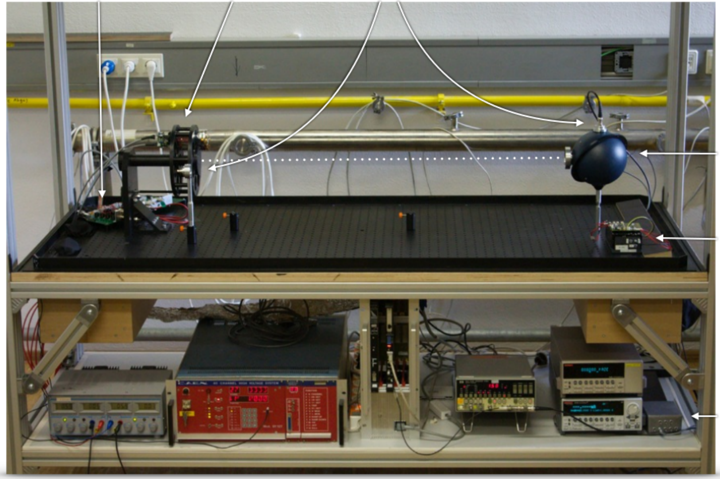


Reconstruction at higher background light

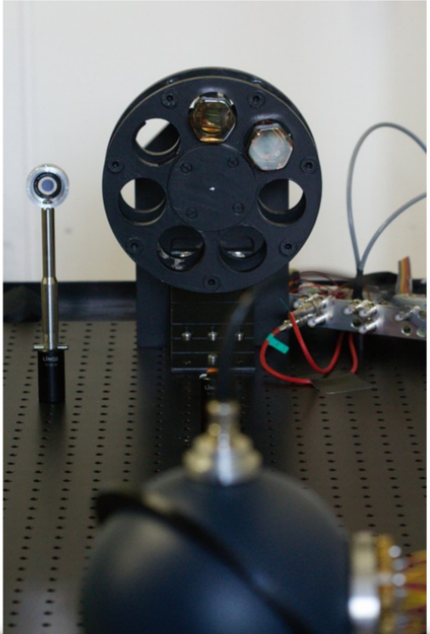


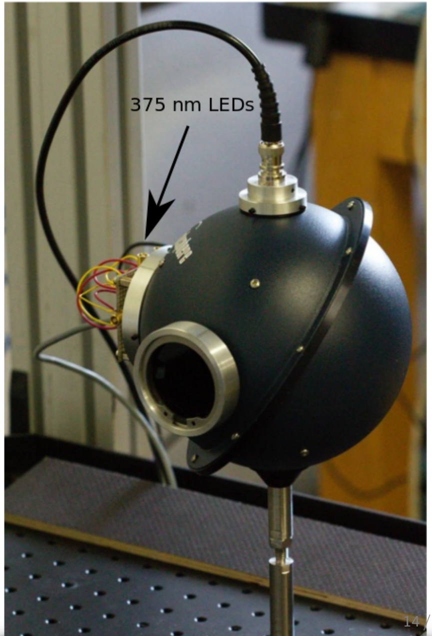
- Error on the Xmax reconstruction still small and
- shower selection efficiency still equal to 1 for $\sigma^2 \leq 1000\ \mathrm{ADC}^2$.

Experimental setup



Experimental setup





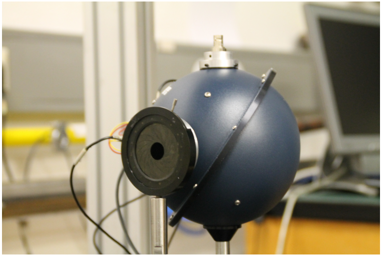
PMT characterization - Electronic gain calculation

Electronic gain
(ADC counts/(phel/50 ns)):

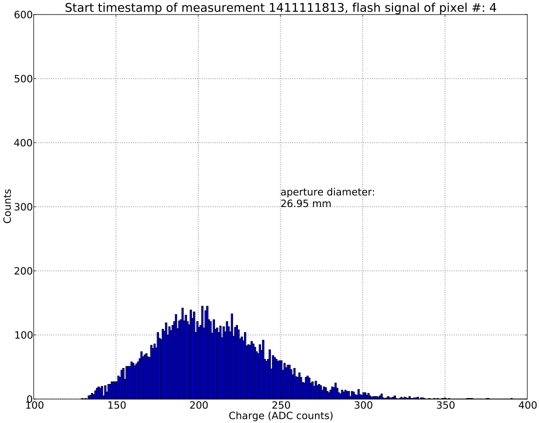
$G_\mathrm{e} = \frac{D}{M} \cdot \frac{5}{(1+v_g) \cdot F}$

- v_g: relative variance of the PMT gain
- $(1 + v_g)$: single photoelectron resolution
- D: variance of flasher pulse signal (in ADC^2)
- M: mean value of flasher pulse signal (in ADC)
- $F = 3.3\ \mathrm{MHz}$: noise equivalent bandwith

- Measure single photoelectron peak for v_g-determination,
- use optical filters and aperture to reduce light flux.



Searching single photoelectron peak - example PMT 41249



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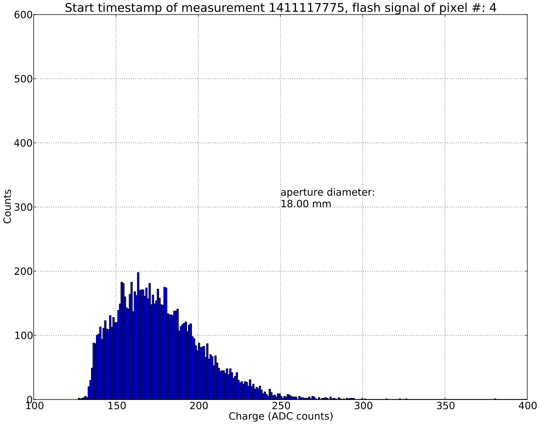

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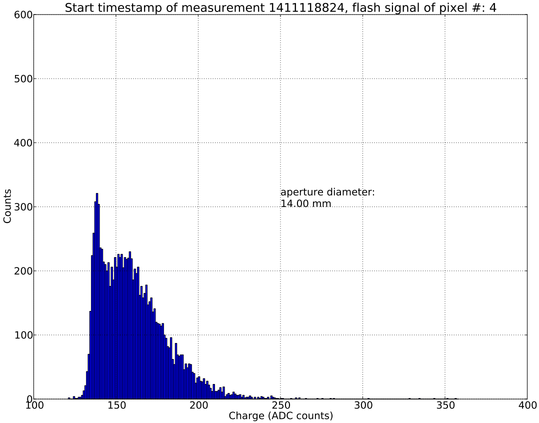

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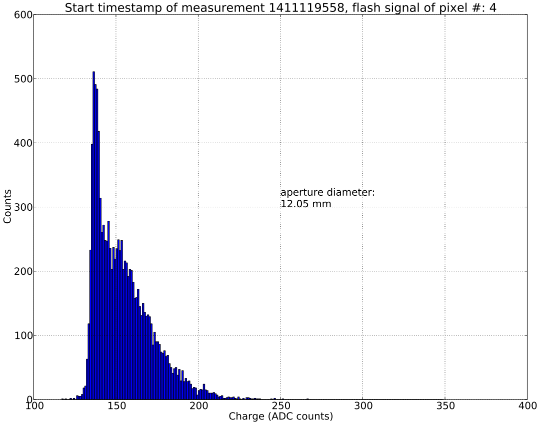
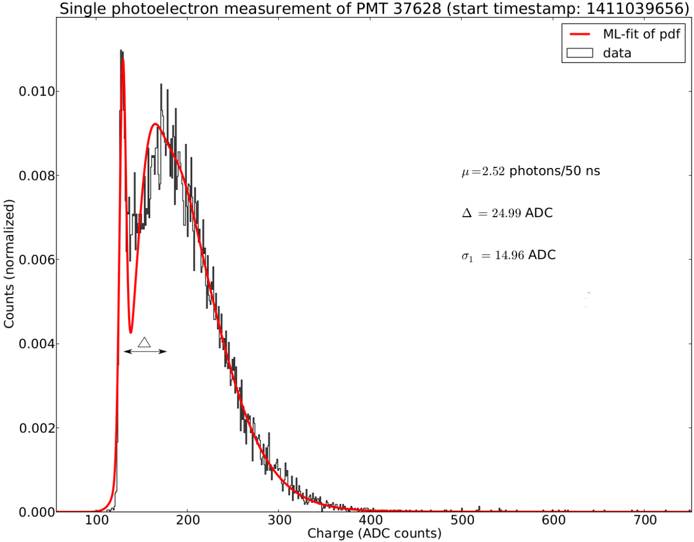


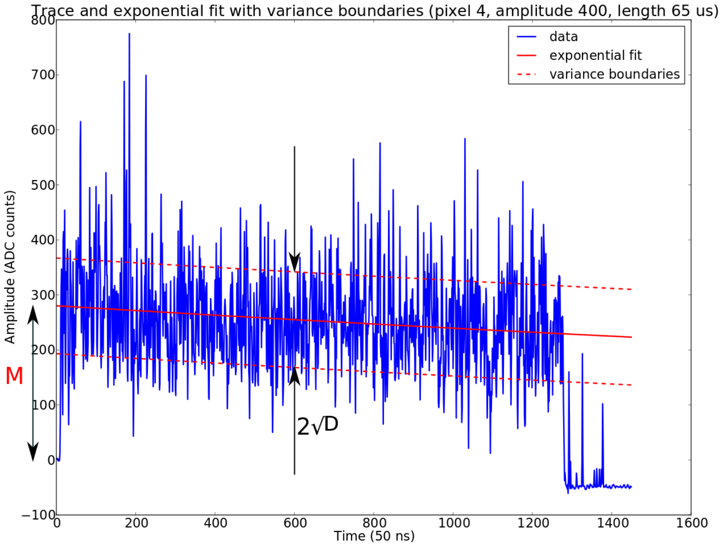
Fitting single photoelectron peak to calculate SER

$$G_{\mathrm{e}} = \frac{D}{M} \cdot \frac{5}{(1+v_g)\cdot F}, \qquad \text{relative variance: } v_g = \left(\frac{\sigma_1}{\Delta}\right)^2 = 0.36$$

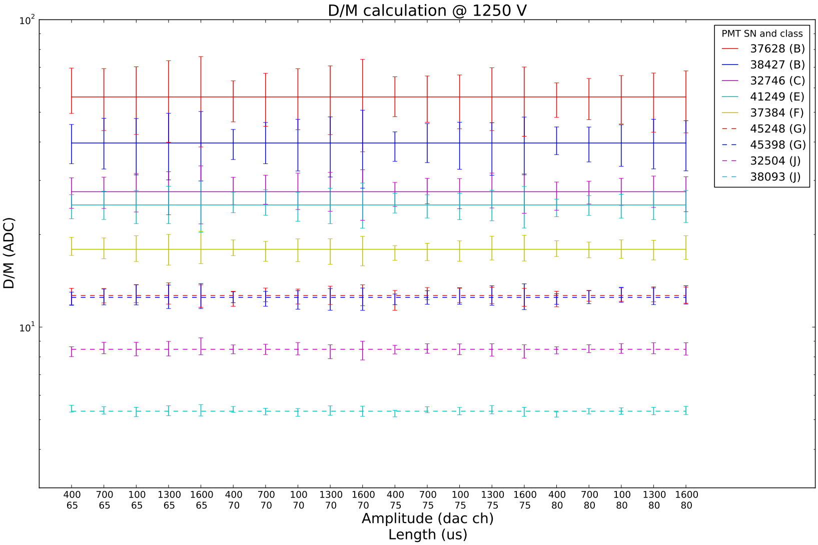


D/M calculation with long flasher pulses

$G_e = \frac{D}{M} \cdot \frac{5}{(1+v_g) \cdot F}$ $M(t) \approx M \cdot \exp(-\frac{t}{\tau})$ → fit function



D/M calculation for all PMTs



Summary & Outlook

Summary:

- Mounting of PMT test stand completed,
- systematics mostly understood, excepting external noise signal,
- single photoelectron peaks can be seen and
- characterization of used PMTs is possible.

Outlook:

- Finish characterization measurements of used PMTs, i.e.
  - gain determination for all PMTs and
  - check linearity of PMTs for different AC & DC light conditions.
- Start aging measurements at nominal and lower HV.
- Find lower HV for higher background conditions and impliment results directly at the Observatory in Argentina.

Backup

- 20 γ's per 1 MeV energy deposit (e^-: 2.2 $\frac{\mathrm{MeV}}{\mathrm{g/cm^2}}$),
- $X_{\mathrm{max}} \propto D_{\mathrm{e}} \cdot \ln(E_0/A) = D_{\mathrm{e}} \cdot (\ln E_0 - \ln A)$,
- $N_\mu^A = A \cdot \left(\frac{E_0/A}{E_{\mathrm{dec}}}\right)^\alpha = A^{1-\alpha} \cdot N_\mu$