# Studying the Stability of the Electronic Chain in the Beam Aerogel Data

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General Task

Construct an algorithm for **KaonLT experiment data fitting** based on the findings in E.H. Bellamy paper https://doi.org/10.1016/0168-9002(94)90183-X. Validate the algorithm. Apply the algorithm to Beam data and ensure the stability of the electronics.
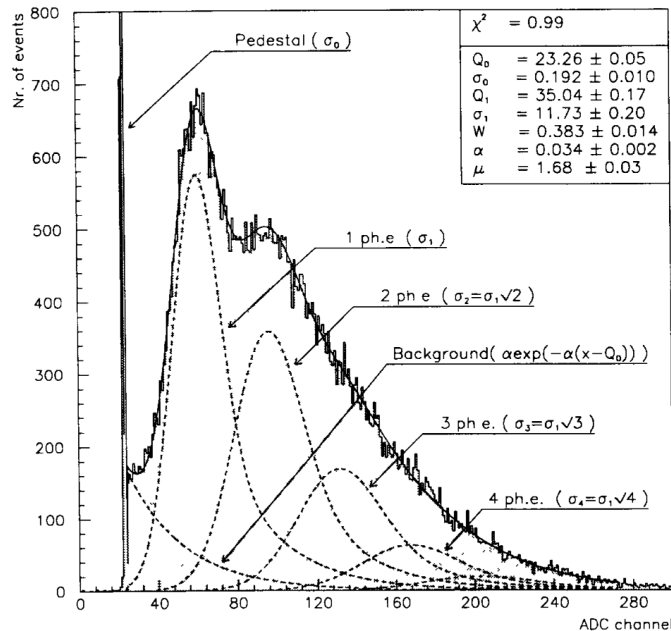
Apply same fitting to KaonLT spectra

Parameter μ corresponds to the number of photo-electrons
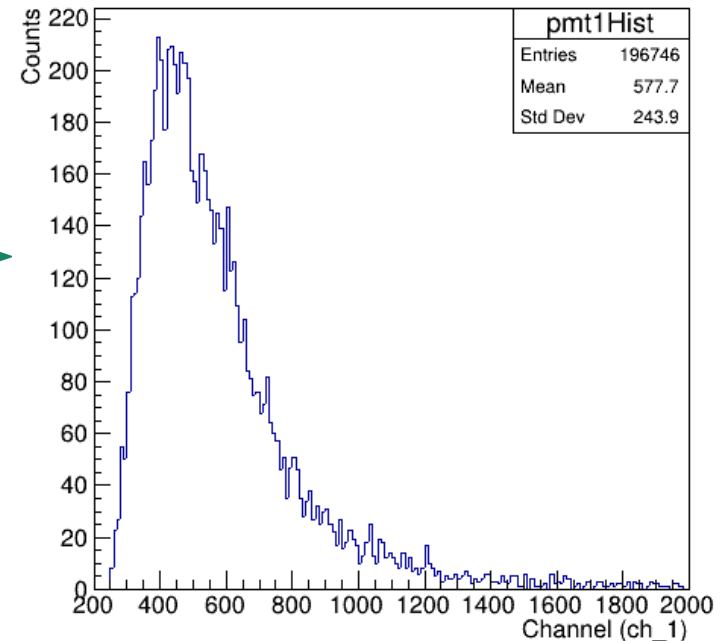
MILESTONES:

1. Extract PMT spectra from the ROOT file. Make 1D projections at certain Tile #.
2. Construct and validate fitting algorithms.
3. Account on absence of the Pedestal and exponential background.
4. Support iteration of the Beam runs an export of the fit parameters to a file.
5. Ensure the stability of the fit parameters (position and width of the 1PE peak).

Mathematics behind the fit

Theoretical shape of the spectrum:

$$S_{\text{ideal}}(x) = \sum_{n=0}^{\infty} \frac{\mu^n e^{-\mu}}{n!} \frac{1}{\sigma_1 \sqrt{2\pi n}} \exp\left(-\frac{(x - nQ_1)^2}{2n\sigma_1^2}\right)$$

Normalized Gaussian (PDF)

Background contribution:

$$B(x) = \frac{(1 - w)}{\sigma_0 \sqrt{2\pi}} \exp\left(-\frac{x^2}{2\sigma_0^2}\right) + w\theta(x)\alpha \exp(-\alpha x)$$

step function

Normalized Gaussian + Exponential function

Real spectrum:

$$S_{\text{real}}(x) = S_{\text{ideal}}(x) * B(x)$$

$$= \sum_{n=0}^{\infty} \frac{\mu^n e^{-\mu}}{n!} \cdot S_{\text{real}_N}(x, n)$$

=1

Fig. 2. Typical deconvoluted LED spectrum (EMI-9814B photomultiplier).

Components $S_{\text{real N}}$ should normalized.

Because convolution of any function with a normalized function does not change the definite integral $(-\infty, \infty)$.

Q_0 − pedestal position.

σ_0 − standard deviation of the type I background process (pedestal).

Q_1 − average charge at the PM output.

σ_1 − corresponding standard deviation of the charge distribution.

w − probability that signal is accompanied by type II background process.

α − coefficient of the exponential decrease of the type II background.

μ − number of photo-electrons. ← we are interested in this parameter

3
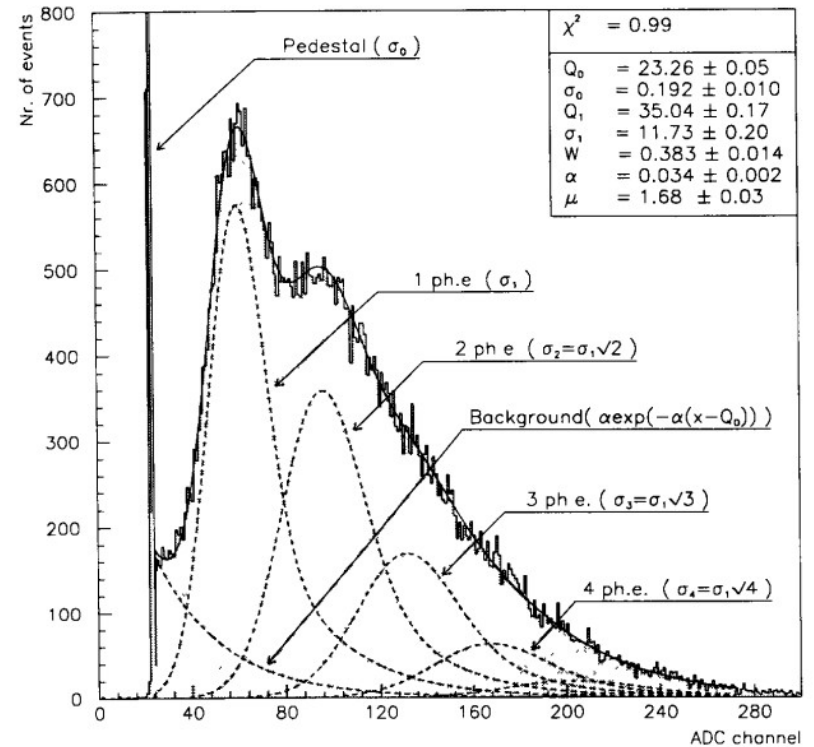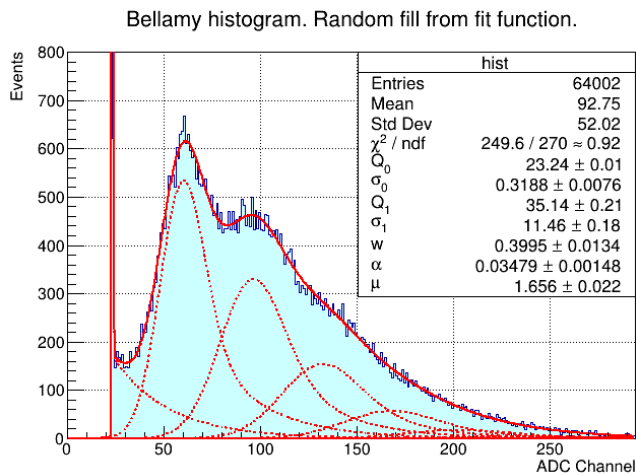
Validation of the KaonLT fitting techniques

Three fitting techniques are developed and applied to fit the original Bellamy histogram from paper. Fitting parameter values compared to the parameter values in the paper.
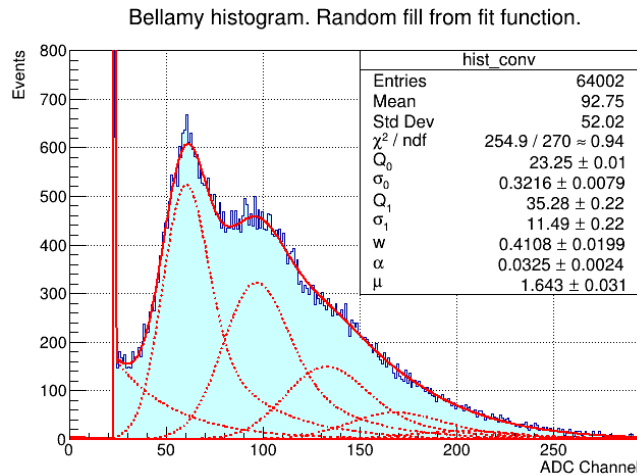
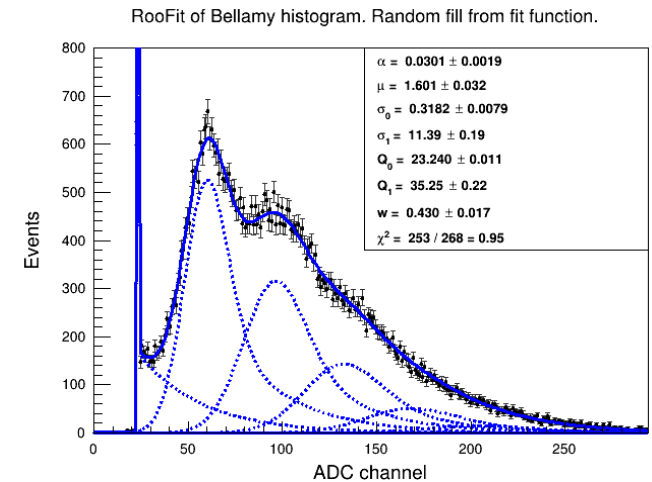**A** ROOT fit with analytical convolution

B ROOT fit with FFT convolution

C RooFit with FFT convolution

Parameter	Bellamy Value	**A** Analytical conv.	**B** FFT Conv.	**C** RooFit
χ^2 – goodness of fit	0.99	258/270 ≈ 0.96	265/270 ≈ 0.98	253/268 ≈ 0.95
μ – number of photo-e$^-$	1.68 ± 0.03	1.66 ± 0.02	1.64 ± 0.03	1.60 ± 0.03

Additionally, the fitting algorithm were validated on the Prototype Aerogel spectra acquired by V. Berdnikov.

How to account on the absence of the Term0?

Pure mathematical approach. Not sure about the instrumentation behind it.
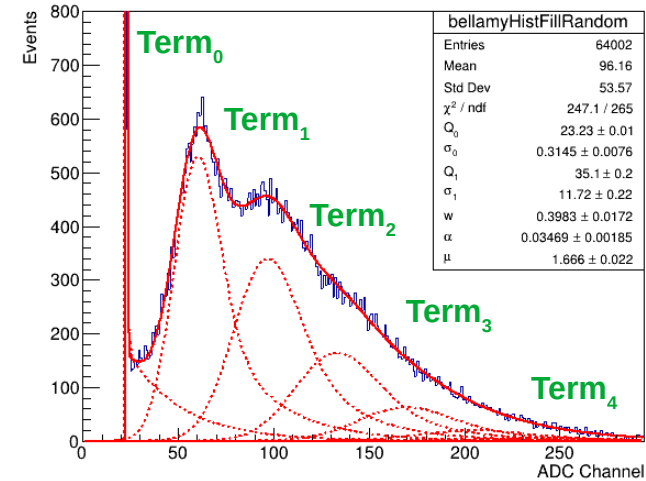
Originally sum of the term coefficients is normalized (equals to 1):

$$S_{real}(x) = \sum_{n=0}^{\infty} \frac{\mu^n e^{-\mu}}{n!} \cdot S_{real_N}(x, n)$$

where

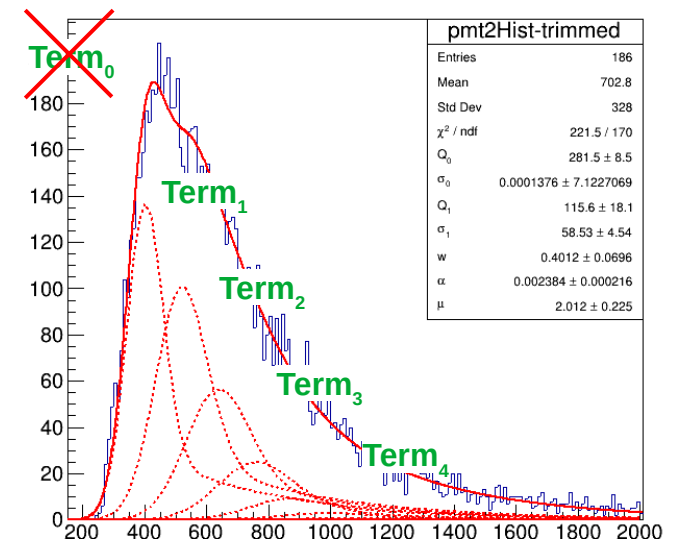$$\sum_{n=0}^{\infty} \frac{\mu^n e^{-\mu}}{n!} = 1$$

In Prototype spectra the zero term (pedestal + exp background) is missing. Therefore we have to re-normalize the PDF coefficients:

$$\sum_{n=1}^{\infty} \frac{\mu^n e^{-\mu}}{n!} = 1 - e^{-\mu}$$

$$S_{real}(x) = \sum_{n=0}^{\infty} \frac{\mu^n e^{-\mu}}{n!(1 - e^{-\mu})} \cdot PDF_n$$
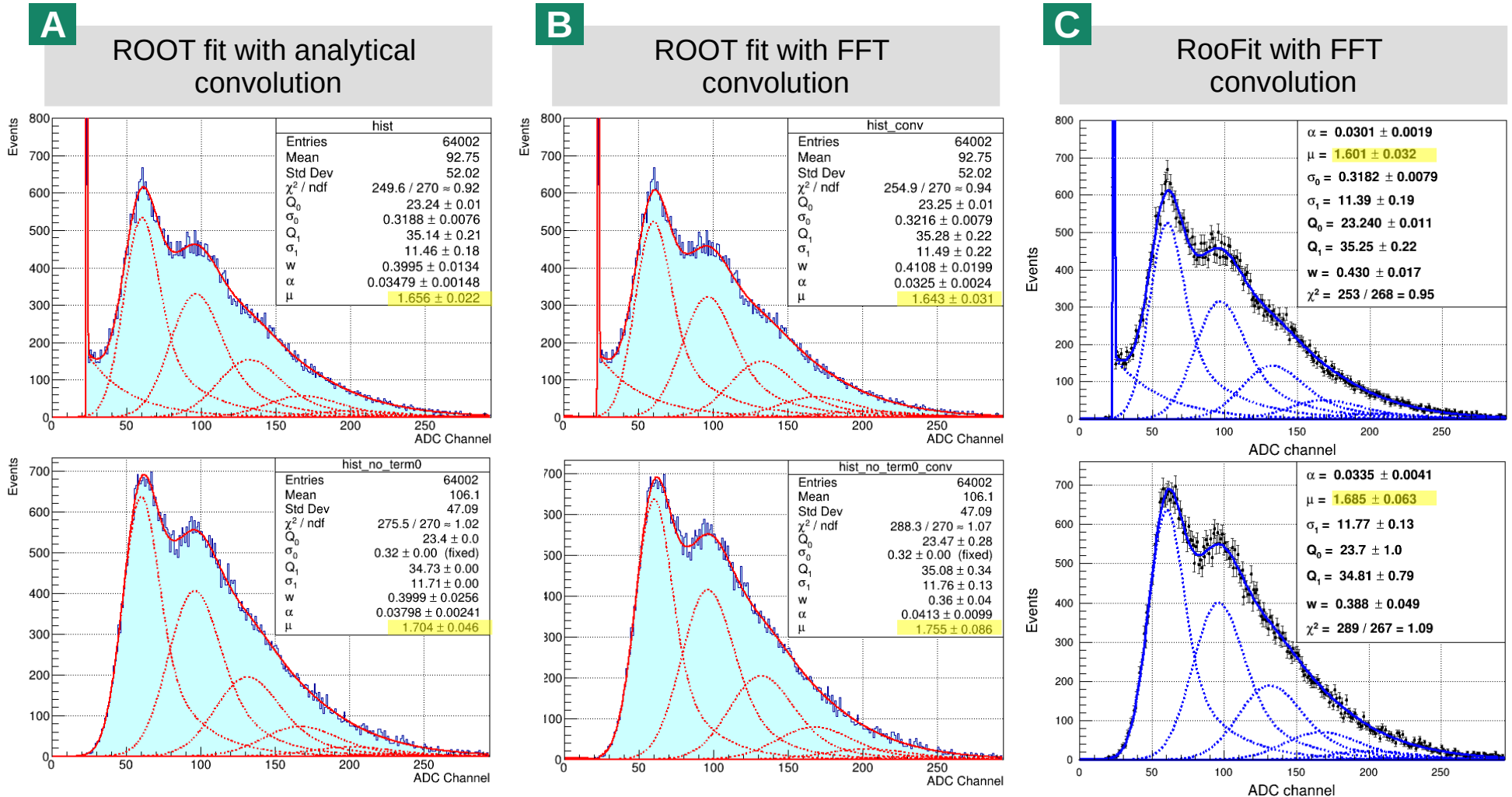
new coefficients

Bellamy histogram. Random fill from fit function.

bellamyHistFillRandom	
Entries	64002
Mean	96.16
Std Dev	53.57
χ^2 / ndf	247.1 / 265
Q_0	23.23 ± 0.01
σ_0	0.3145 ± 0.0076
Q_1	35.1 ± 0.2
σ_1	11.72 ± 0.22
w	0.3983 ± 0.0172
α	0.03469 ± 0.00185
μ	1.666 ± 0.022

PMT2 profile at tiler=55

pmt2Hist-trimmed	
Entries	186
Mean	702.8
Std Dev	328
χ^2 / ndf	221.5 / 170
Q_0	281.5 ± 8.5
σ_0	0.0001376 ± 7.1227069
Q_1	115.6 ± 18.1
σ_1	58.53 ± 4.54
w	0.4012 ± 0.0696
α	0.002384 ± 0.000216
μ	2.012 ± 0.225

Does absence of Term0 change fitting parameters?

Our fitting function is missing the pedestal and exponential background.

Before fitting the Prototype spectra we need to make sure that absence of the Term0 does not terribly affect the fitting results.

A ROOT fit with analytical convolution

hist	
Entries	64002
Mean	92.75
Std Dev	52.02
χ^2 / ndf	249.6 / 270 ≈ 0.92
Q_0	23.24 ± 0.01
σ_0	0.3188 ± 0.0076
Q_1	35.14 ± 0.21
σ_1	11.46 ± 0.18
w	0.3995 ± 0.0134
α	0.03479 ± 0.00148
μ	1.656 ± 0.022

hist_no_term0	
Entries	64002
Mean	106.1
Std Dev	47.09
χ^2 / ndf	275.5 / 270 ≈ 1.02
Q_0	23.4 ± 0.0
σ_0	0.32 ± 0.00 (fixed)
Q_1	34.73 ± 0.00
σ_1	11.71 ± 0.00
w	0.3999 ± 0.0256
α	0.03798 ± 0.00241
μ	1.704 ± 0.046

B ROOT fit with FFT convolution

hist_conv	
Entries	64002
Mean	92.75
Std Dev	52.02
χ^2 / ndf	254.9 / 270 ≈ 0.94
Q_0	23.25 ± 0.01
σ_0	0.3216 ± 0.0079
Q_1	35.28 ± 0.22
σ_1	11.49 ± 0.22
w	0.4108 ± 0.0199
α	0.0325 ± 0.0024
μ	1.643 ± 0.031

hist_no_term0_conv	
Entries	64002
Mean	106.1
Std Dev	47.09
χ^2 / ndf	288.3 / 270 ≈ 1.07
Q_0	23.47 ± 0.28
σ_0	0.32 ± 0.00 (fixed)
Q_1	35.08 ± 0.34
σ_1	11.76 ± 0.13
w	0.36 ± 0.04
α	0.0413 ± 0.0099
μ	1.755 ± 0.086

C RooFit with FFT convolution

$\alpha = 0.0301 \pm 0.0019$
$\mu = 1.601 \pm 0.032$
$\sigma_0 = 0.3182 \pm 0.0079$
$\sigma_1 = 11.39 \pm 0.19$
$Q_0 = 23.240 \pm 0.011$
$Q_1 = 35.25 \pm 0.22$
$w = 0.430 \pm 0.017$
$\chi^2 = 253 / 268 = 0.95$

$\alpha = 0.0335 \pm 0.0041$
$\mu = 1.685 \pm 0.063$
$\sigma_1 = 11.77 \pm 0.13$
$Q_0 = 23.7 \pm 1.0$
$Q_1 = 34.81 \pm 0.79$
$w = 0.388 \pm 0.049$
$\chi^2 = 289 / 267 = 1.09$

Without the background (pedestal and exponential tail) parameter μ resides **within its error value** (<7%). Therefore we **can attempt fitting** the Kaon LT spectra with above mechanism.

How to compile and run the program on the Farm?

Login to the Computing Farm and source the Environment:

```
ssh -Y <user>@login.jlab.org
ssh -Y <user>@ifarm
source /site/12gev_phys/softenv.csh 2.4
```

Check out the code from Git, compile, move the executable to ~/bin:

```
mkdir -p ~/Downloads && cd Downloads/ && rm -rf kaonlt-fit/
git clone https://github.com/petrstepanov/kaonlt-fit && cd ./kaonlt-fit
make release

mkdir -p ~/bin && cp ~/Downloads/kaonlt-fit/dist/* ~/bin/
```

Navigate to a temporary folder and create "fit-parameters.txt" file

```
mkdir -p /work/hallc/kaon/petrs/SHMS_Stability/ && cd
/work/hallc/kaon/petrs/SHMS_Stability/

cp ~/Downloads/kaonlt-fit/resources/beam-params.txt ./
```

Start spectrum analysis

```
kaonlt-fit-local /work/hallc/kaon/petrs/SHMS_Aerogel_replay/result_*.root \
--params-filename=beam-params.txt --plot-profiles=kFALSE --terms-number=20 --tile-
profile=55 --fit=root --ch-fit-min=0.1 --ch-fit-max=10 --ch-fit-range-min=0.5
```

Beam Spectra Fits

Fitting performed in the full spectrum range.
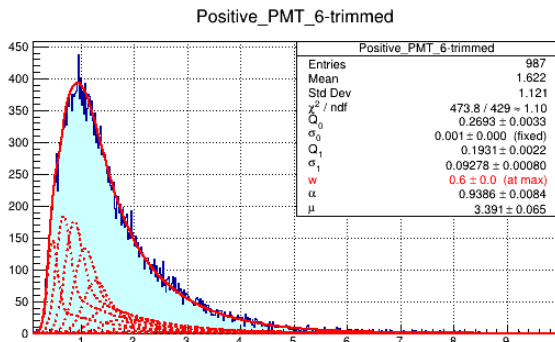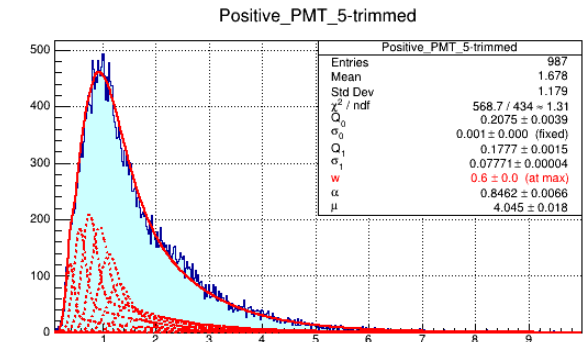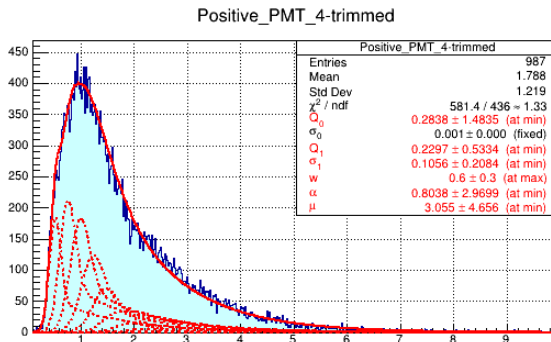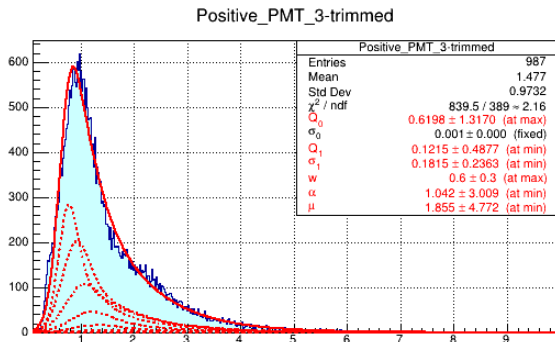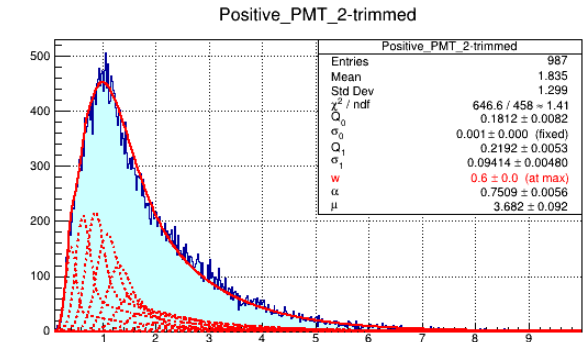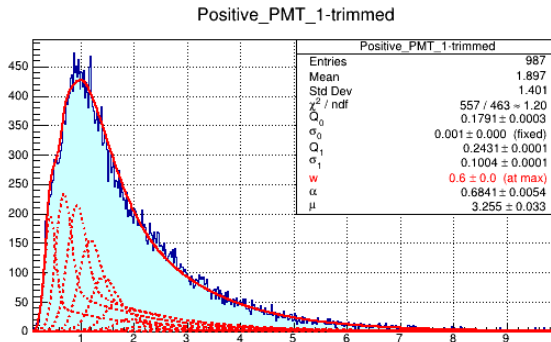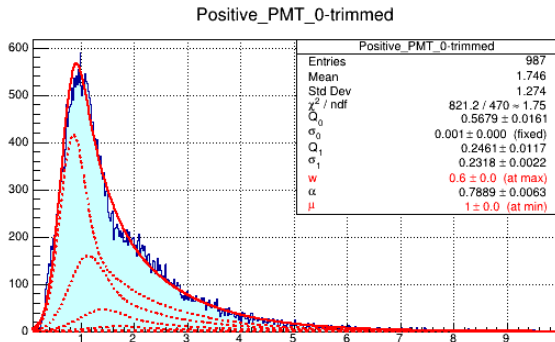
PROBLEM:

Spectrum rise shape is not Gaussian. Components are packed on left to account on the "rise hump" (could be noise?). Therefore, the "fall" of the spectrum is fitted by the exponential contribution; ratio of the Exponent to Gauss background contribution reaches its limit ($w \rightarrow 1$).

Beam Spectra Fits

Fitting interval is limited to exclude the rise hump
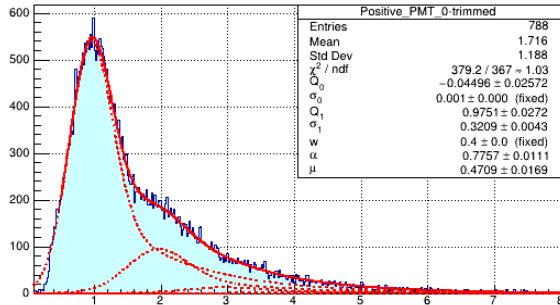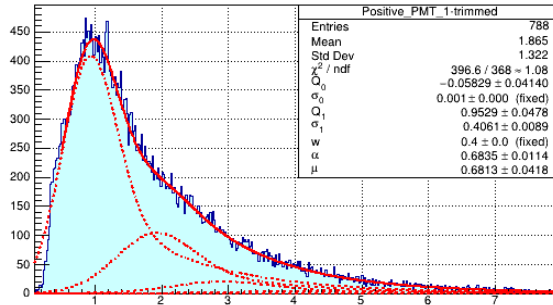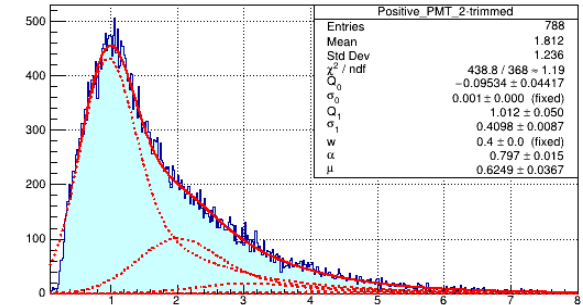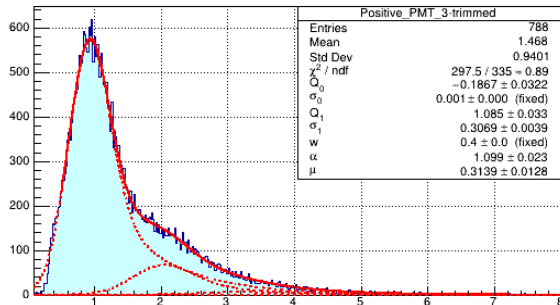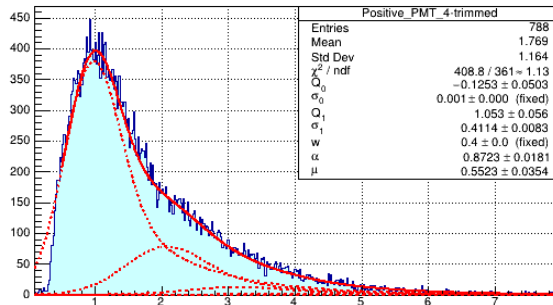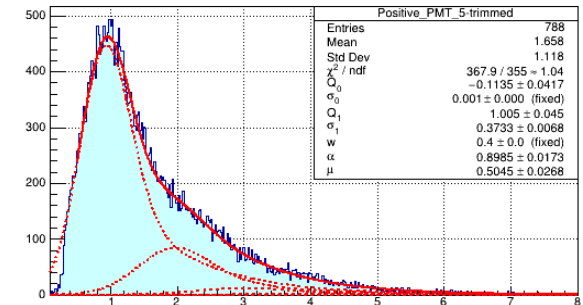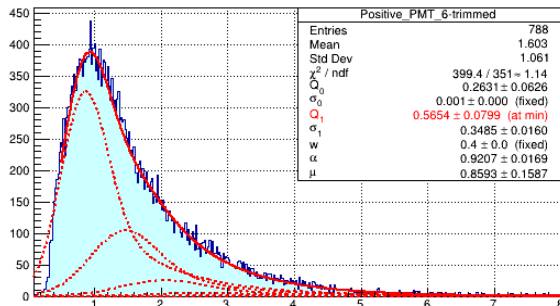
FITTING APPROACH:

1. The ADC threshold set the lower region provides the hump on the rise of the spectra. Hump was excluded from the fit range.

2. Ratio of the gauss to exponential background (w = 0.4) as well as the pedestal width (σ_0=1E-3) are fixed due to the absence of the pedestal.

Extracting the Stability of the Beam Run Parameters

KaonLt Fit program code was updated to support iterating multiple input spectra. Fit parameters and their values for all 14 PMTs are exported to an ASCII file for every run.

Fit parameter values and errors are exported to ASCII file for every run.
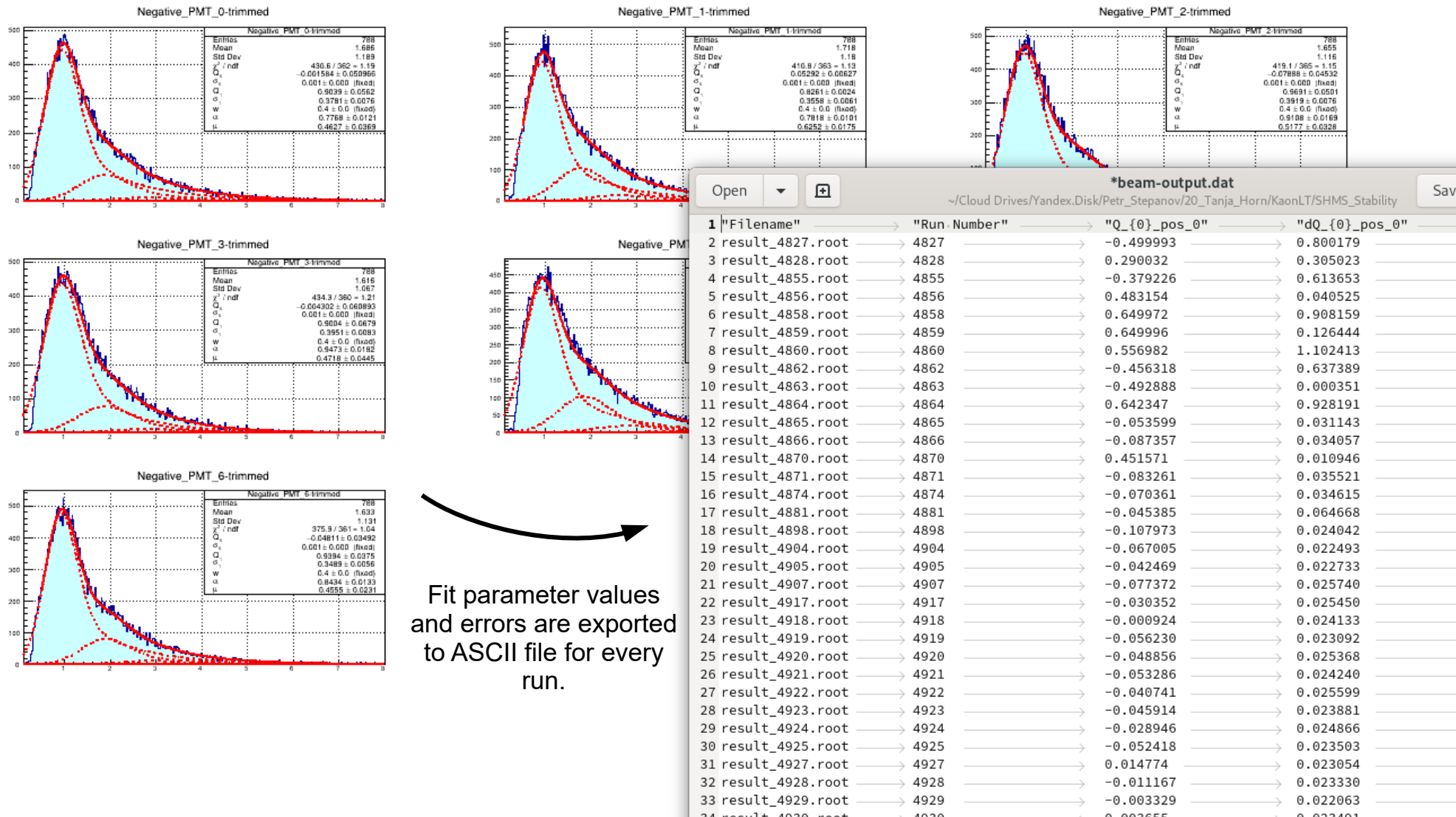
Plotting the Beam stability data

Command-line plotting interface Gnuplot was selected as a tool for plotting the stability graphs.
It is convenient to use plain text Gnuplot scripts on the Computing Farm environment.


```
# Input ASCII delimeter
set datafile separator "\t"

plot1height = 0.6

# Start multiplot
set multiplot layout 2,1 rowsfirst

# Top plot Q_0 + Q_1
set title "Stability of the Aerogel fit for PMT0+"
set lmargin at screen 0.12
set size 1,plot1height
set origin 0,1-plot1height

# Turn on grid
set grid

# X axis
set xrange[4500:8500]

# Remove x axis labels
set format x ''

# Y axis for Q_0+Q_1
set ylabel "First term mean Q_0 + Q_1"

plot './SHMS_Stability/beam-output-exclude.dat' using 2:($3+$7):($4+$8) title 'Q_0 + Q_1' with yerrorbars

# Bottom residuals plot
set title ""
set lmargin at screen 0.12
set size 1,1-plot1height

# X axis
set xlabel "Run Number"
set xrange[4500:8500]
set format x

# Second y axis for chi^2
set ylabel "Goodness of fit chi^2"

plot './SHMS_Stability/beam-output-exclude.dat' using 2:17          title 'chi^2'
```
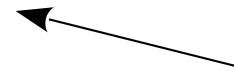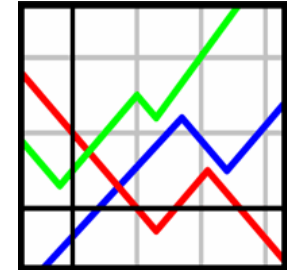
Gnuplot allows plotting sum of ASCII data columns (Q_0+Q_1).

This value corresponds to the position of the first PE peak
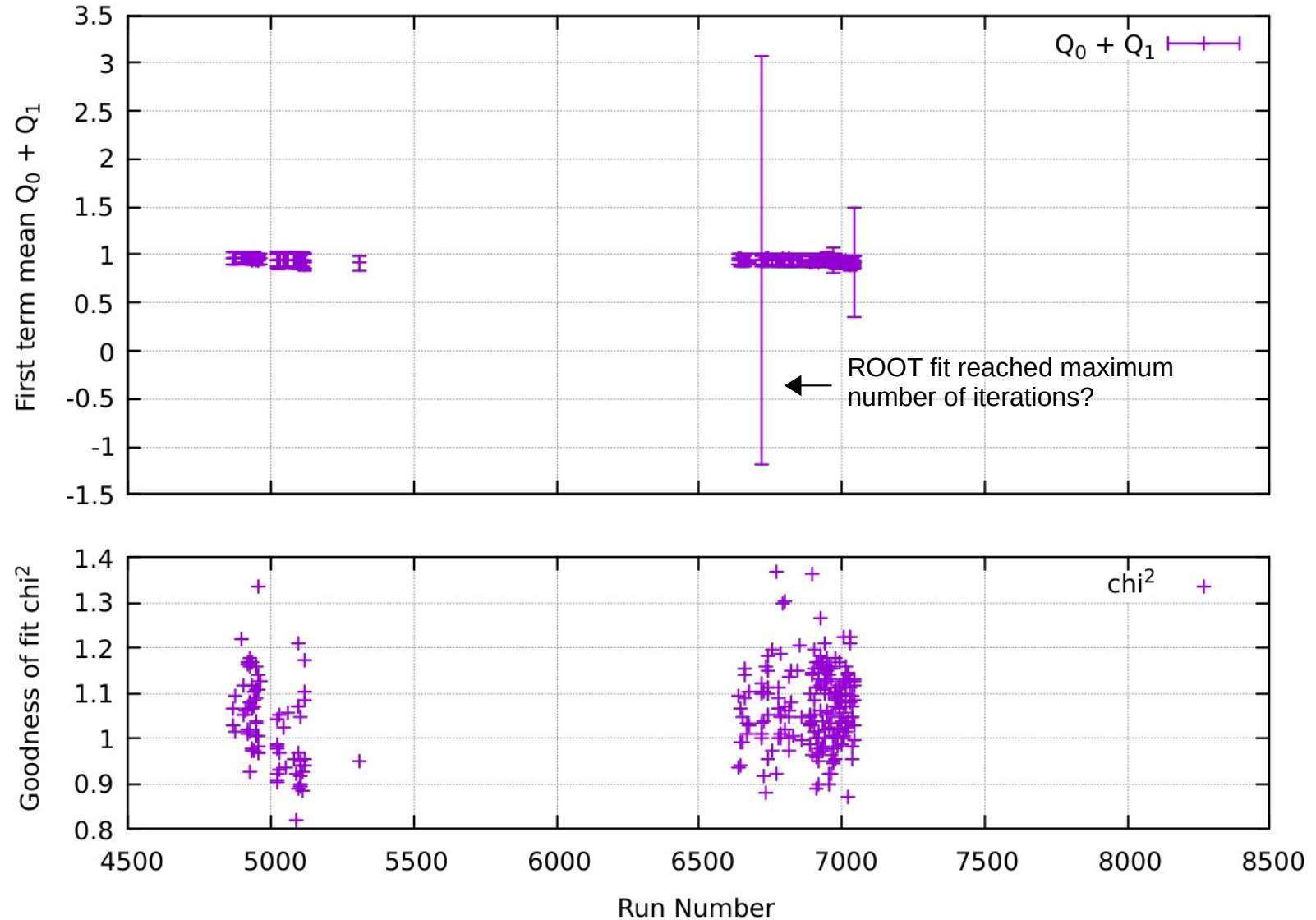
Stability of the Beam runs for PMT0+

Plots of all non-corrupted ROOT files from the last year.
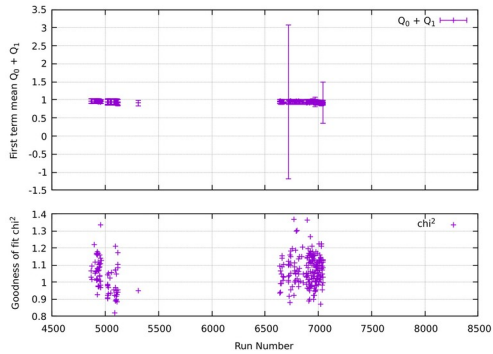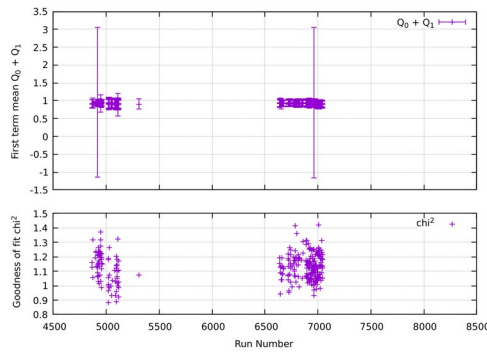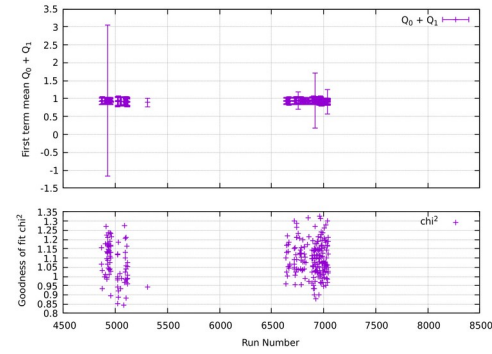Spectra with poor statistics (< 60kB) are excluded: `find . -type f -size -60000c | sort -n`

Stability of the Aerogel fit for PMT0+

Stability of the Beam runs for PMT0+ to PMT6+

Plots of all non-corrupted ROOT files **from the last year**.
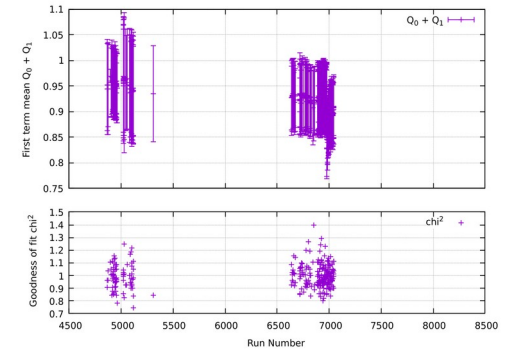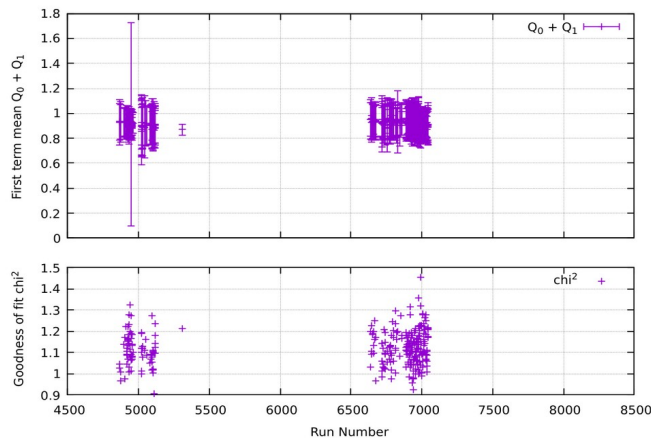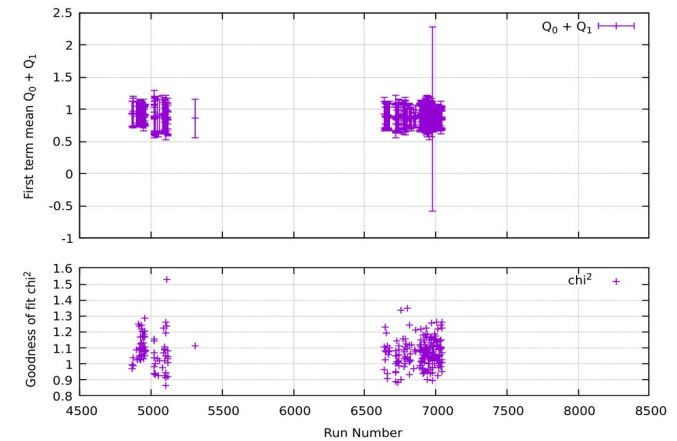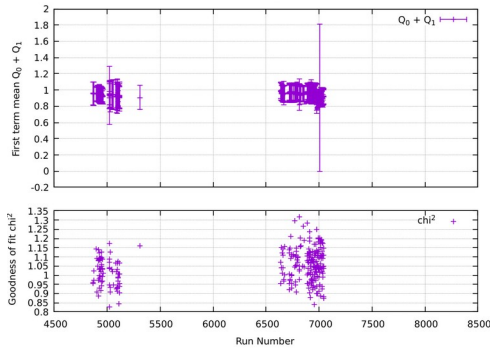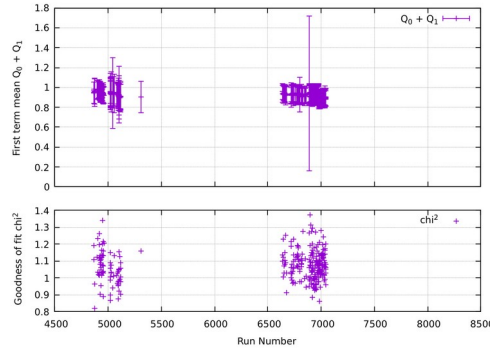Spectra with poor statistics (< 60kB) are excluded.
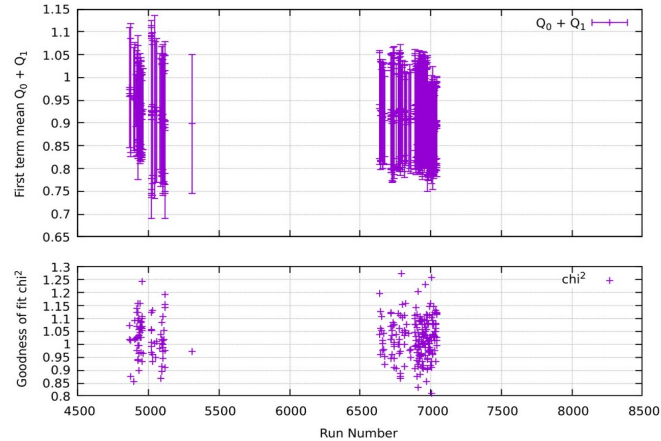
Stability of the Beam runs for PMT0− to PMT6−

Plots of all non-corrupted ROOT files **from the last year**.
Spectra with poor statistics (< 60kB) are excluded.
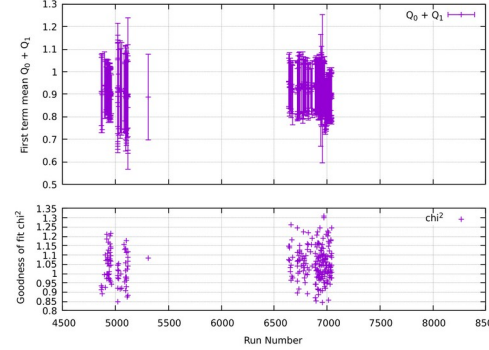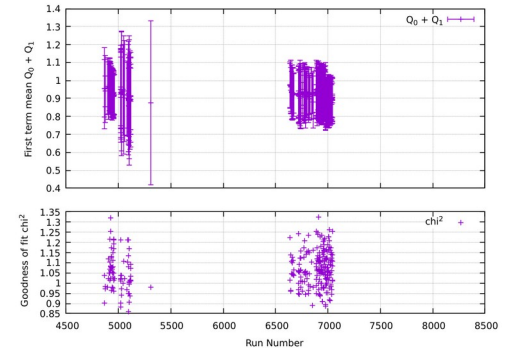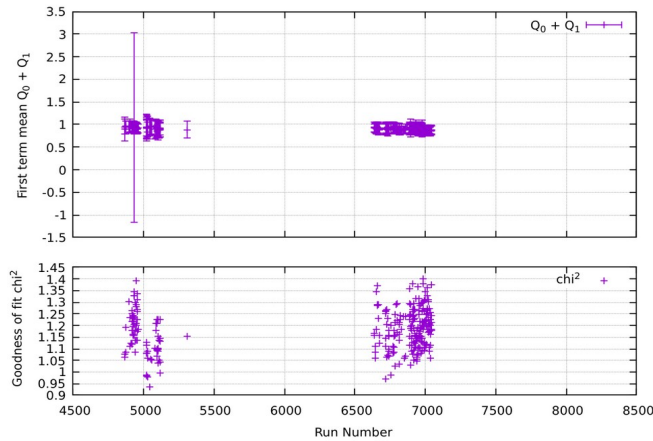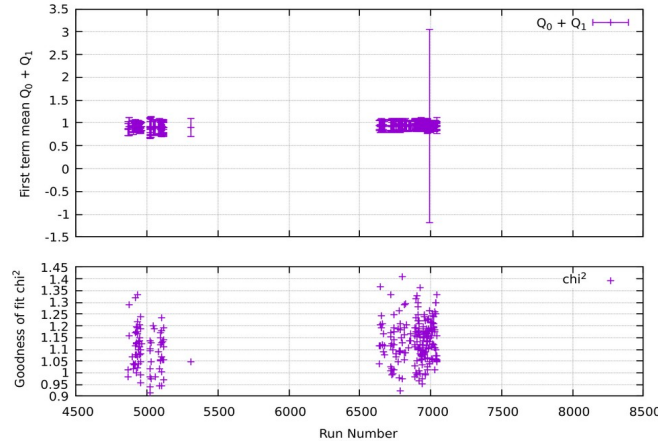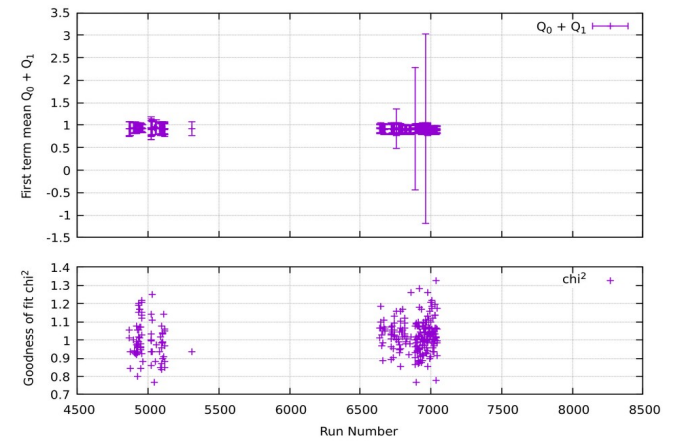
Processing the Recent Replay Beam Data

Sept 2020 Replay beam data has **improved Analyzer code** and includes more stability information (more runs).
Aerogel Replay program code for processing the Replay data **is developed** and [available on GitHub](#).
Many raw ROOT files turned out to be **corrupted** therefore error handling mechanisms are implemented.

README.md

Aerogel Replay

A ROOT script that extracts data from the beam raw data and exports series of corresponding PMT histograms. Every output ROOT file contains seven Positive and seven negative PMT histograms. There are two ROOT scripts in the repository. Script `replay.c` uses the TTreeReader interface to iterate the ROOT trees. It works quick but will more likely crash if the input ROOT files are corrupt. A better ROOT TFile error handling is implemented in the script `replayConv.c` which uses a conventional TTRee::GetEntry() mechanism for reading the tree. The downside of this mechanism is the speed which is about 10 times more slow compared to the TTreeReader.

How to use

1. Checkout the repository to the folder where the output data will be located.

```
git clone https://github.com/petrstepanov/aerogel-replay/ && cd aerogel-replay
```

2. Tweak the RegExp input filename pattern on the line 14 of the script to match the desired name of the input files.
3. Limit the the output spectra statistics by setting the maximum number of the reads from thetree on the line 77.
4. Run either `replay.c` or `replayConv.c` script specifying the path to the directory containing the raw spectra:

```
root 'replayConv.c("/path/to/the/root/replay/files")'
```

5. Script will automatically scan the directory for the input files and start processing them.

If the script crashes during the run you can restart the script from the desired input filename index. In order to do so specify the starting input filename index on line 13 of the script.

Stability of the Beam Replay Runs (Sept 2020)

Graphs represent the position of the 1st photo-electron peak Q_0+Q_1. Every 10th file with **full statistics** is processed. Corrupted ROOT data files are skipped.
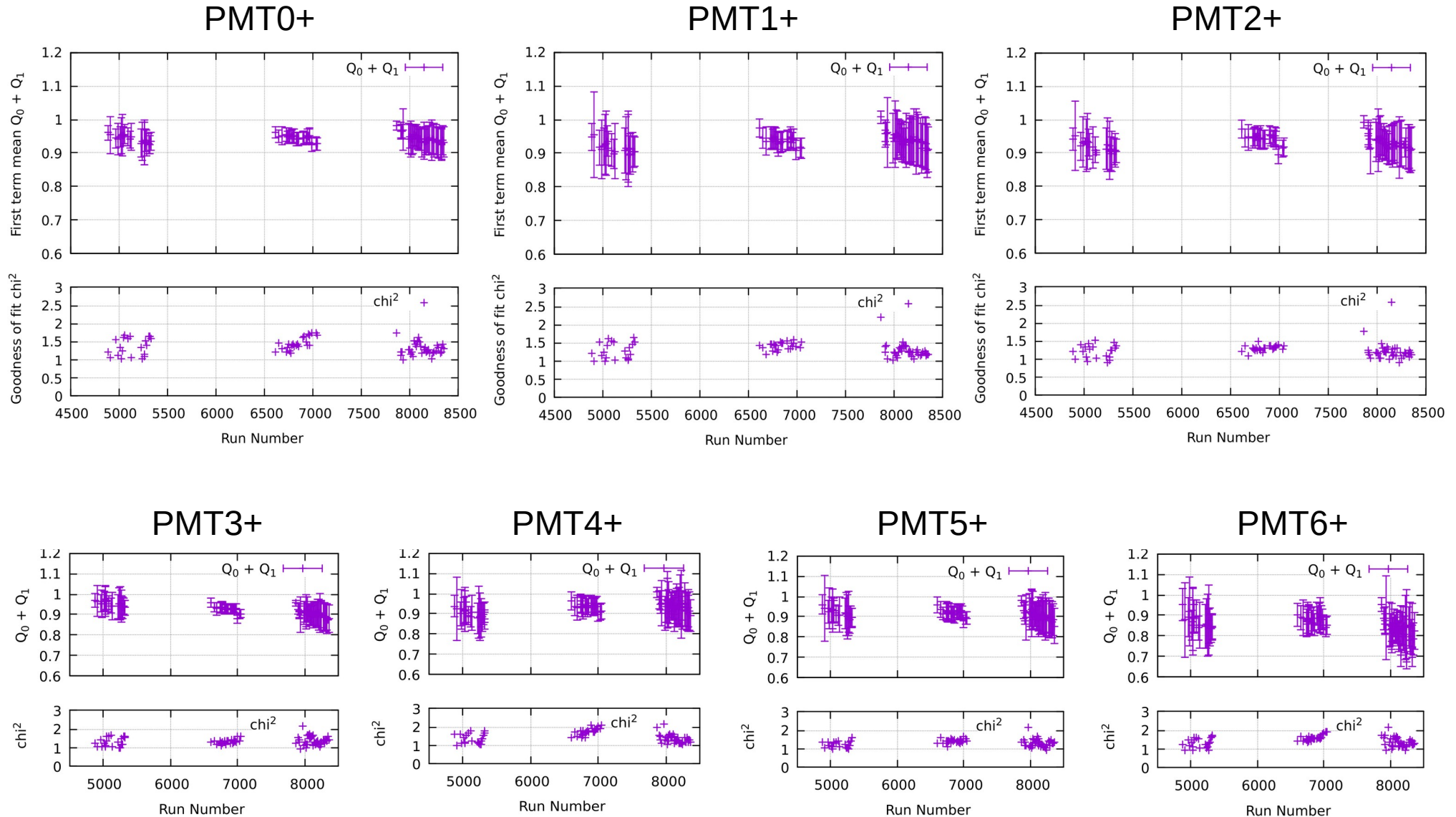
Stability of the Beam Replay Runs (Sept 2020)

Graphs represent the position of the 1st photo-electron peak Q_0+Q_1. Every 10th file with **full statistics** is processed. Corrupted ROOT data files are skipped.
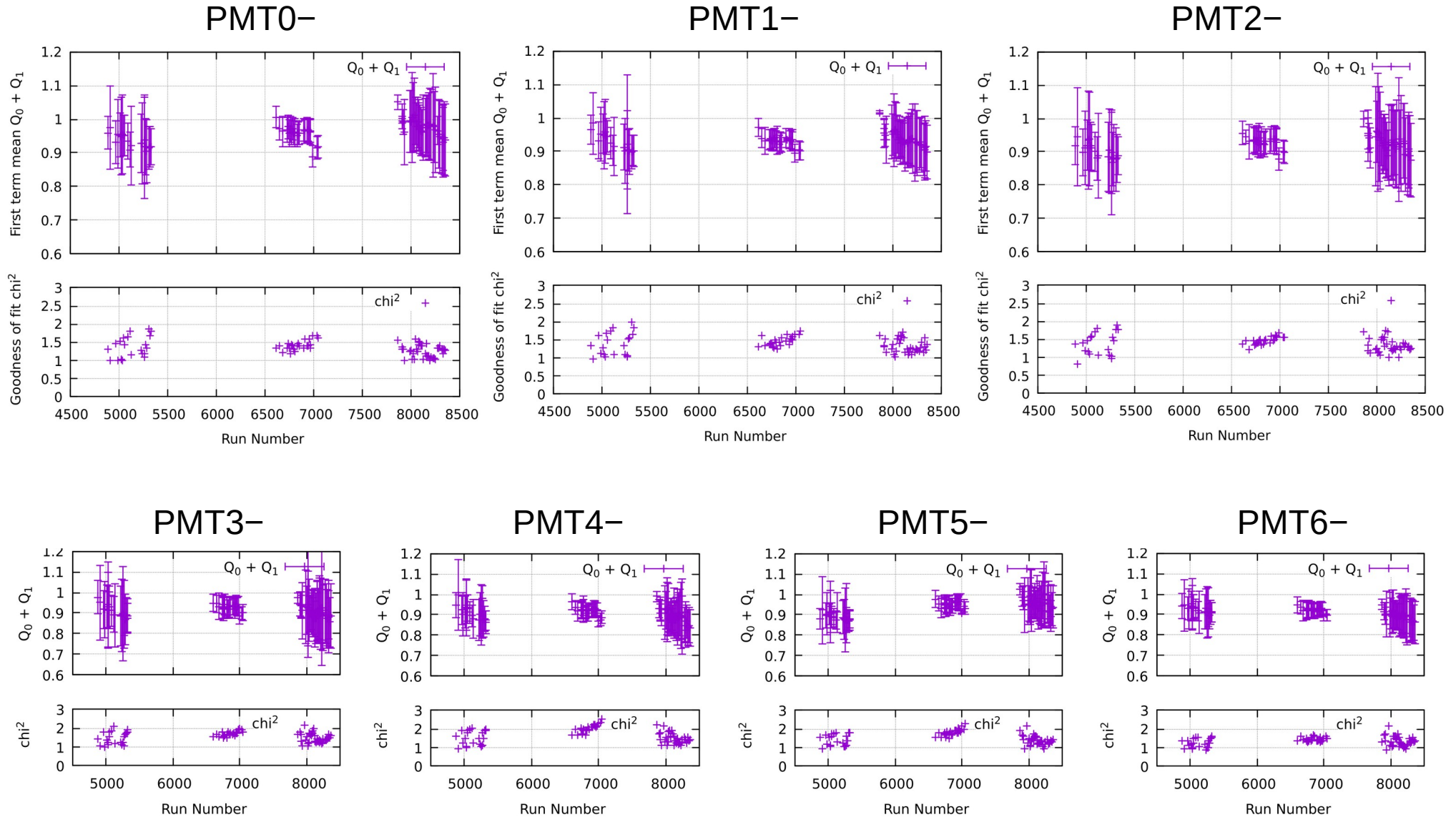
Summary of the past two weeks

- `KaonLT Fit` program for fitting the Aerogel PMT data is developed:
  https://github.com/petrstepanov/kaonlt-fit

- `KaonLT Fit` fitting results are validated on the spectra from the E.H. Bellamy paper as well as series of Prototype Aerogel spectra (V. Berdnikov).

- KaonLt Fit. Added ability to iterate and fit multiple beam spectra and export the fitting parameters in order to inspect their stability.

- `Aerogel Replay` program for extracting the PMT histograms from the raw replay data is developed: https://github.com/petrstepanov/aerogel-replay

- Stability of the fitting parameters of the "old" and "new" Replay PMT spectra is plotted in Gnuplot.

- Aerogel Replay data shows good stability of the sum of Q0+Q1 parameters. This corresponds to the position of the 1st photo-electron peak.