Handling large dynamic PMT signals with high precision in ground-based gamma-ray detectors

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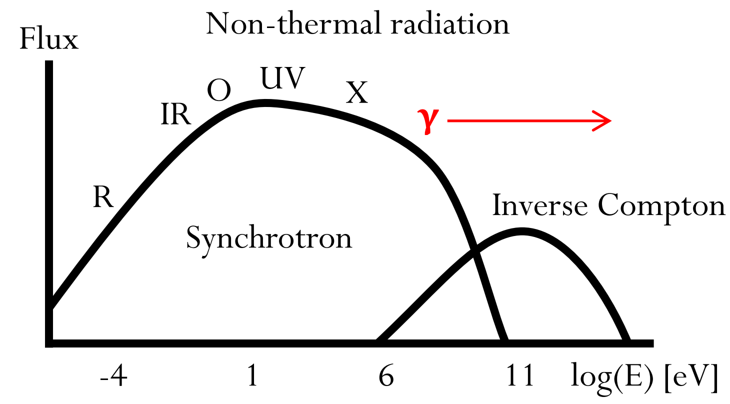
Motivation

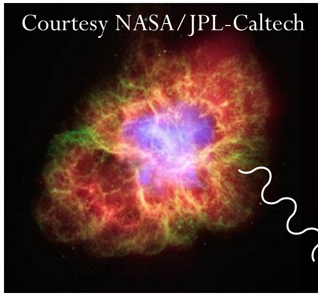
Ground-based high energy gamma-ray astronomy

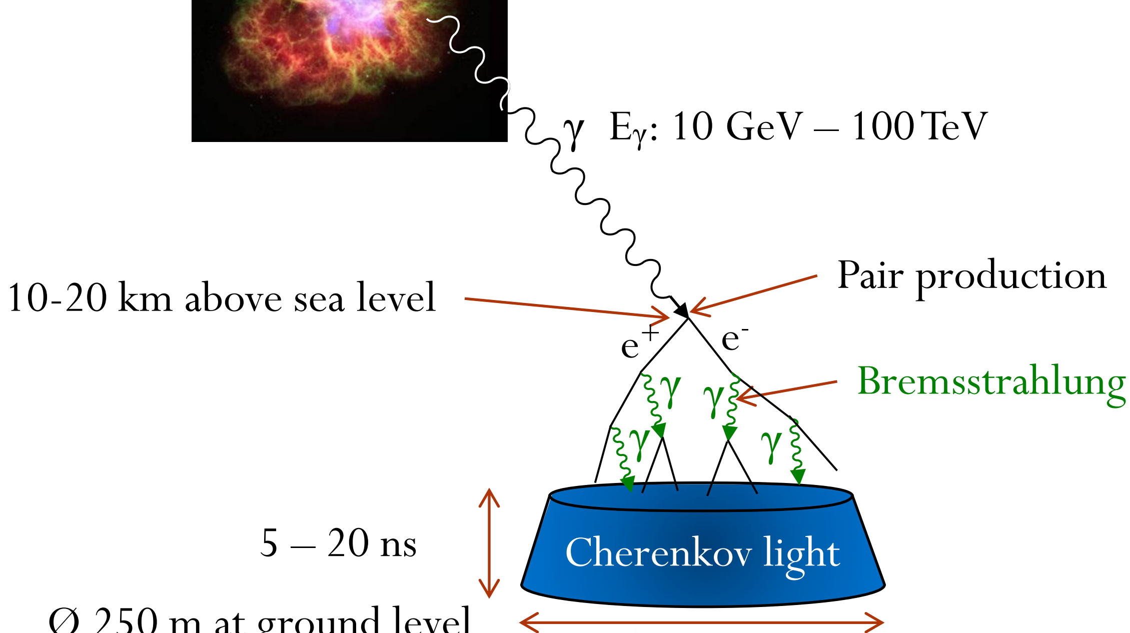


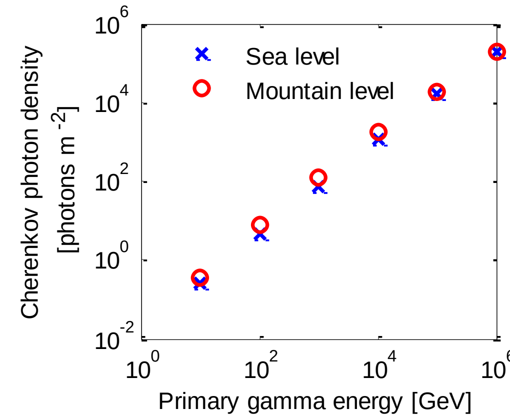
- Non-thermal processes generate high energy gamma-rays (keV – PeV).
- Investigation of galactic and extragalactic objects: SNR, pulsars, x-binaries, Active Galactic Nuclei etc.
- Improve understanding of processes of high energy gamma-ray production.
- Ground-based high energy gamma-ray astronomy uses atmosphere as calorimeter and thus profits of a very large collection area.
- **I**maging **A**tmospheric **C**herenkov **T**elescopes cover energy range of 10 GeV – 100 TeV.

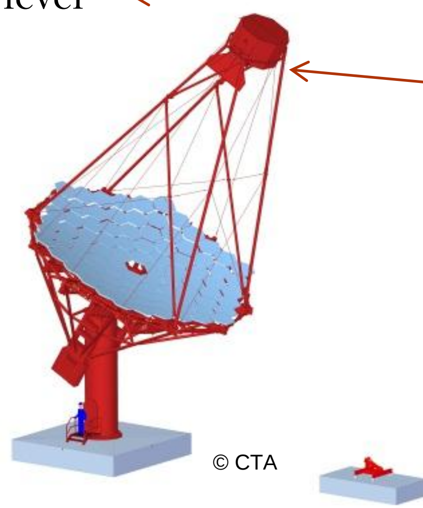
Current and future ground-based telescopes:
MAGIC, H.E.S.S., VERITAS, **C**herenkov **T**elescope **A**rray (under development)

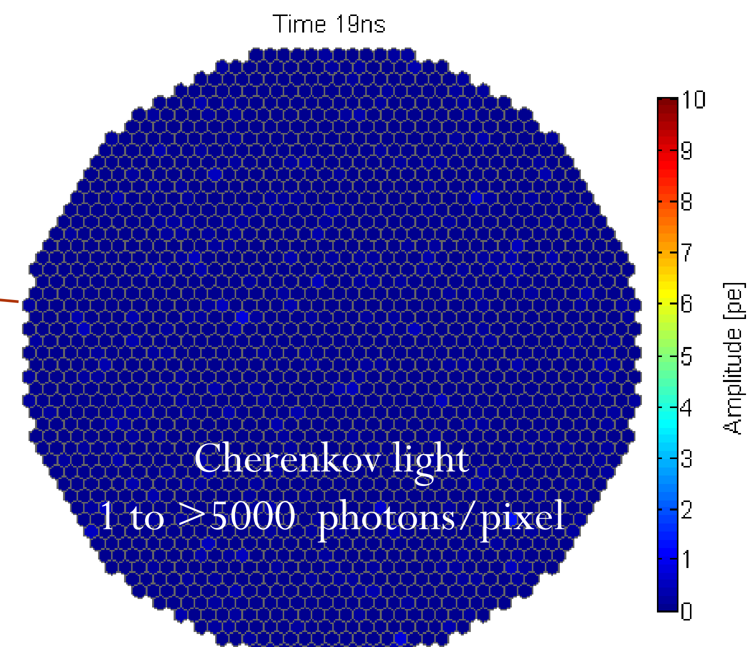
Working principle







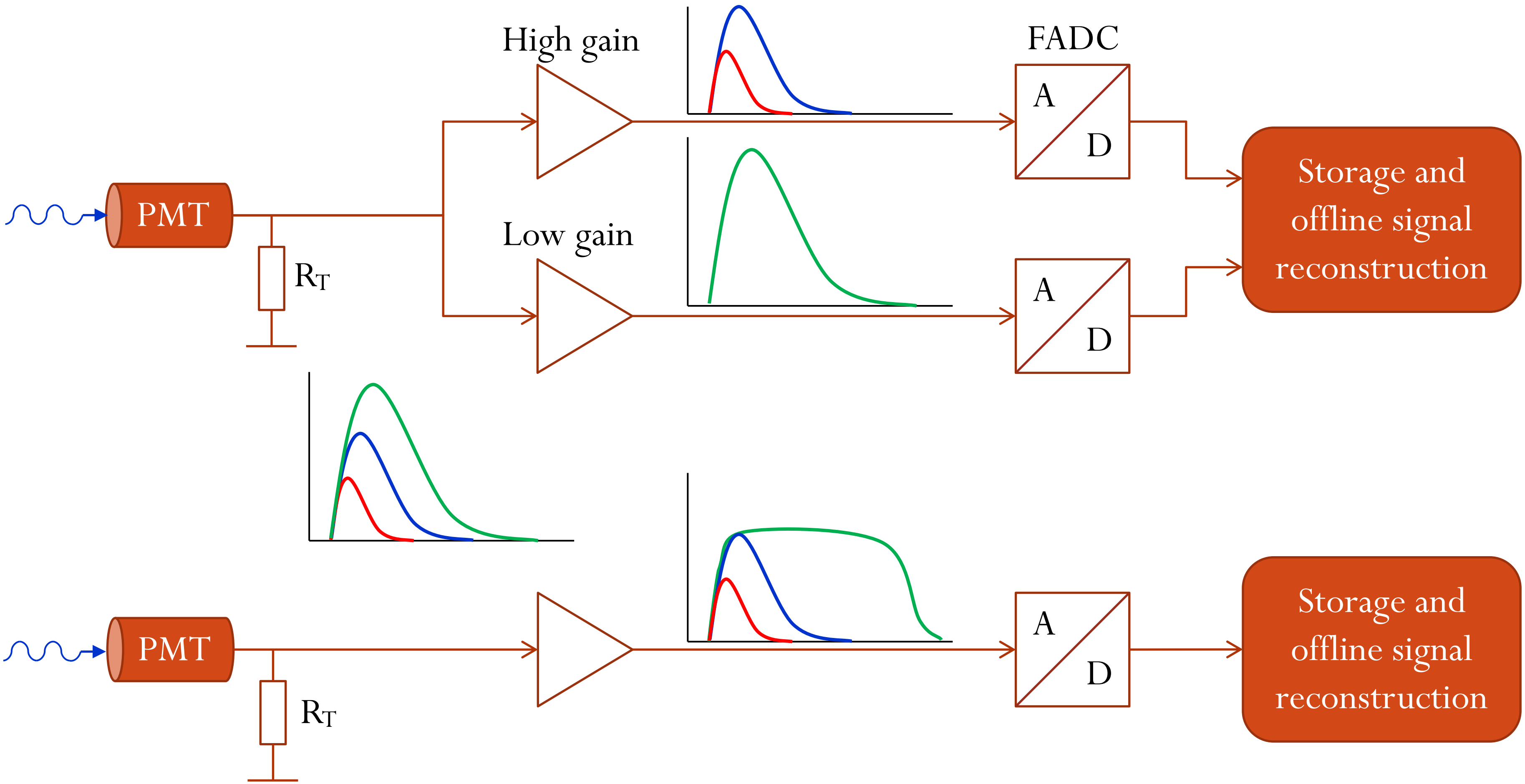




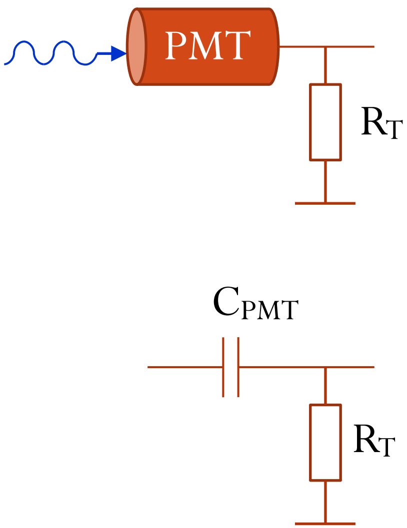
Handling large dynamic signals

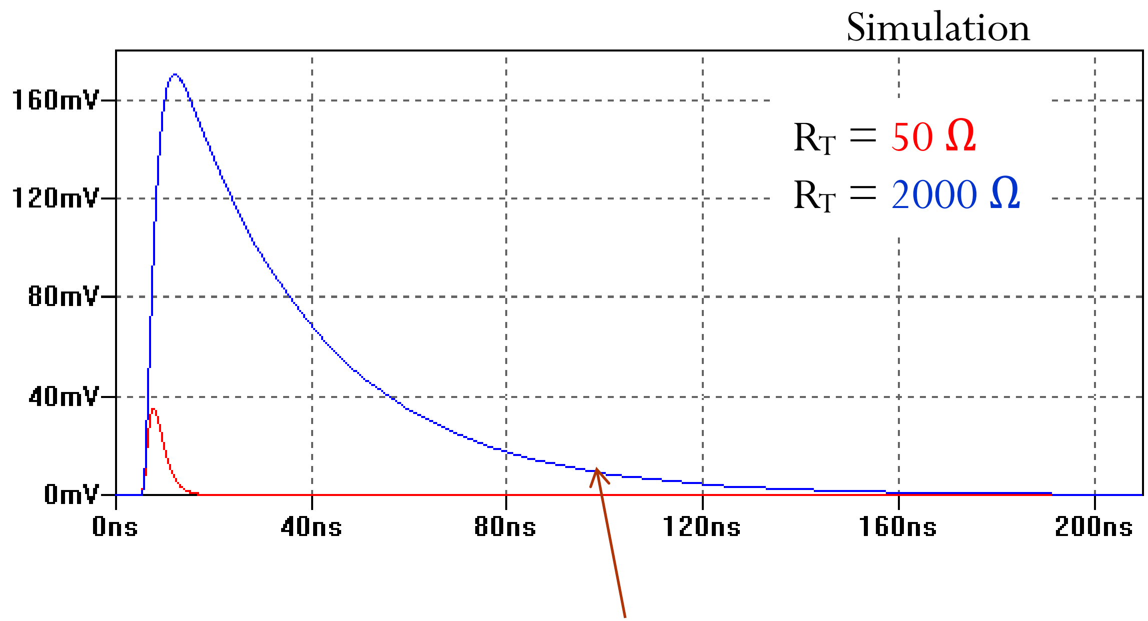
Large dynamic amplitude range can be treated in two ways:

- dual signal path with
  - a high gain covering the low amplitude range (e.g. 0.2 – 200 pe) and
  - a low gain covering the high amplitude range (e.g. 20 – 5000 pe)
- single signal path with non-linear signal treatment



Signal shaping





Signal bandwidth: 3 times lower

Termination resistor R_T influences signal bandwidth:

50 Ω versus 2000 Ω gives 3 times lower bandwidth

⇒ Larger termination resistor allows to digitize signals with a lower sampling rate (~ 3 times)

⇒ Use of reconstruction algorithm on digitized data still produces good timing and amplitude resolution

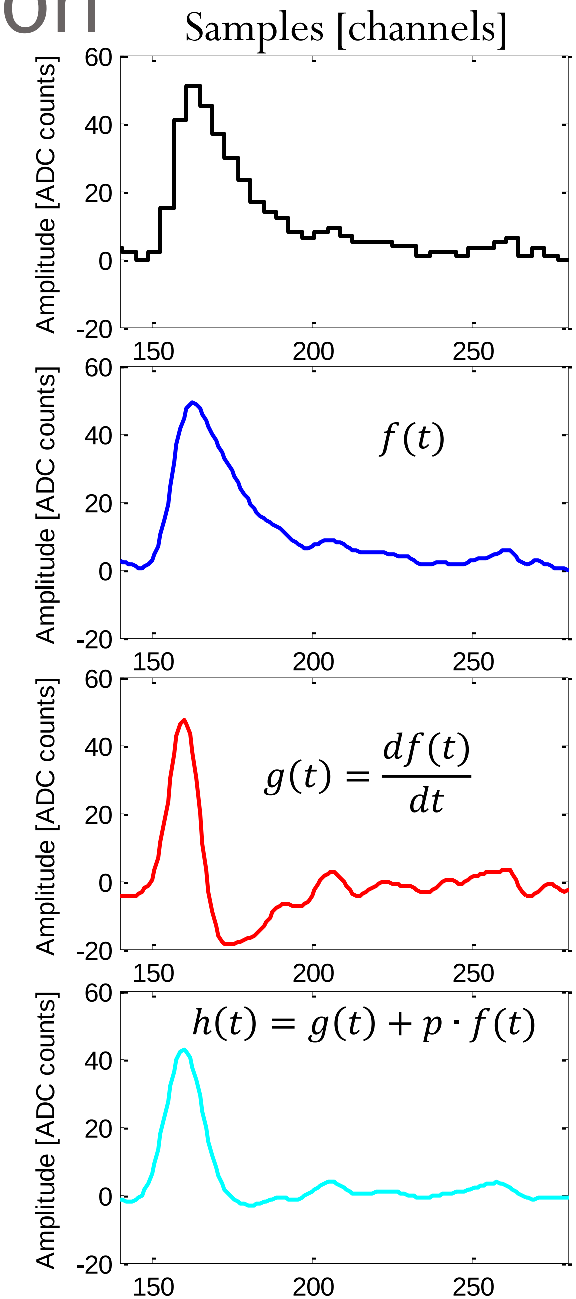
Signal reconstruction

1. Measured and digitized PMT signal (4 channels resolution)

2. Up-sampling: linear interpolation (1 channel resolution) and smoothing (moving average filter)

3. Differentiation and smoothing
   $\Rightarrow$ Center of gravity above zero = photon arrival time

4. Base line restoration: pole-zero cancellation ($0 < p < 1$) and smoothing
   $\Rightarrow$ Peak maximum = pulse amplitude
   $\Rightarrow$ Peak area proportional to pulse amplitude



Signal reconstruction

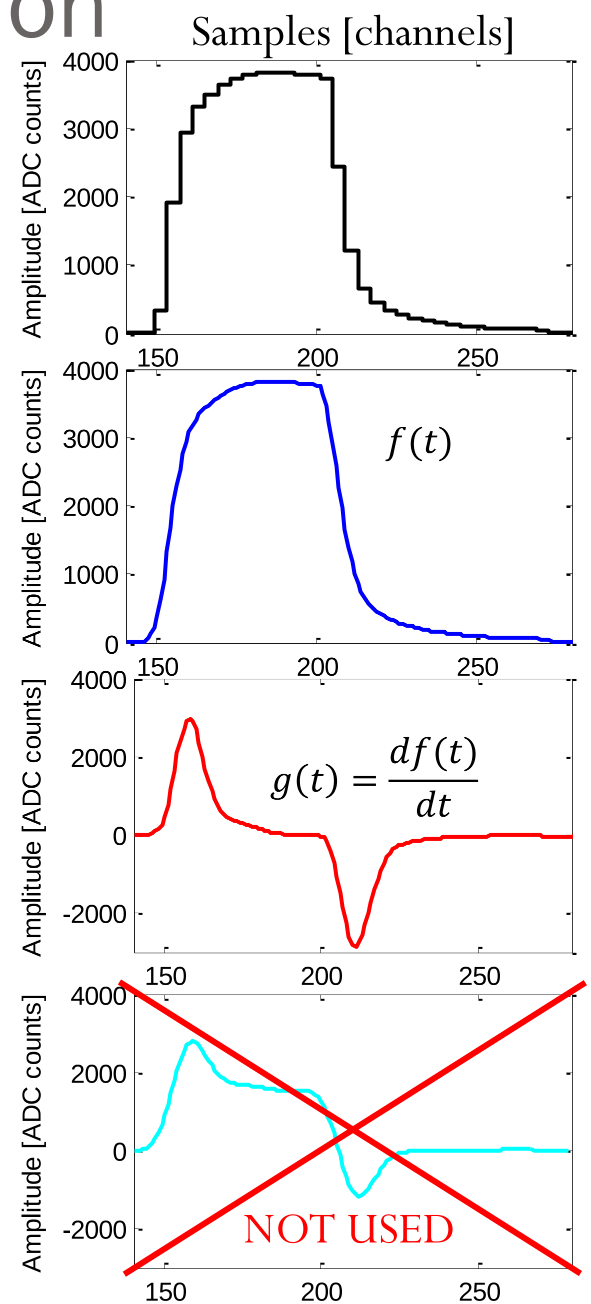
1. Measured and digitized PMT signal (4 channels resolution)

2. Up-sampling: linear interpolation (1 channel resolution) and smoothing (moving average filter)

3. Differentiation and smoothing
   $\Rightarrow$ Center of gravity above zero = photon arrival time

4. Amplitude determined by integration of up-sampled signal over fixed window size (typically 200 channels)

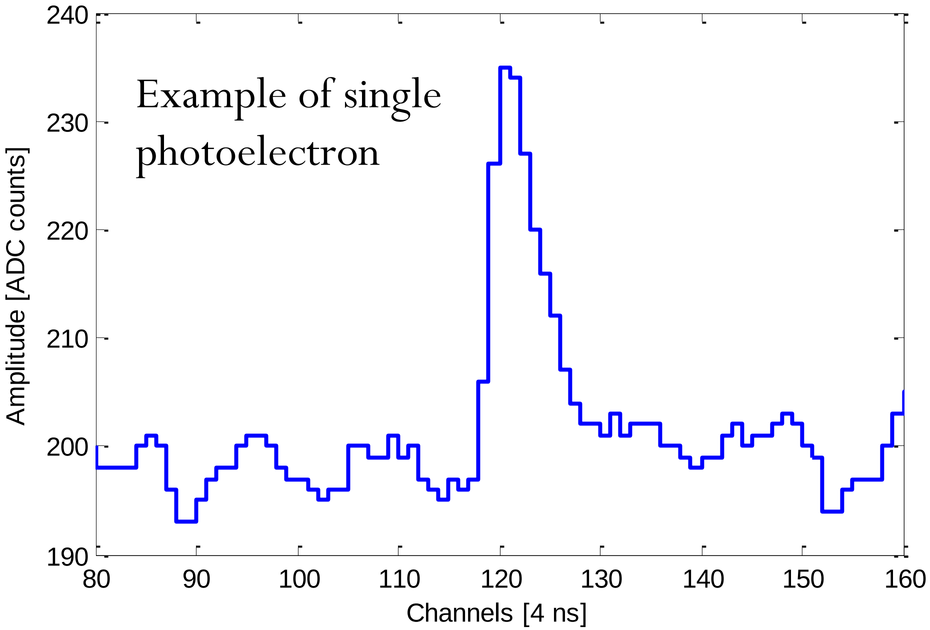
   $\Rightarrow$ Peak area proportional to pulse amplitude: $A = \int_{k=i}^{i+200} f(t)\, dt$

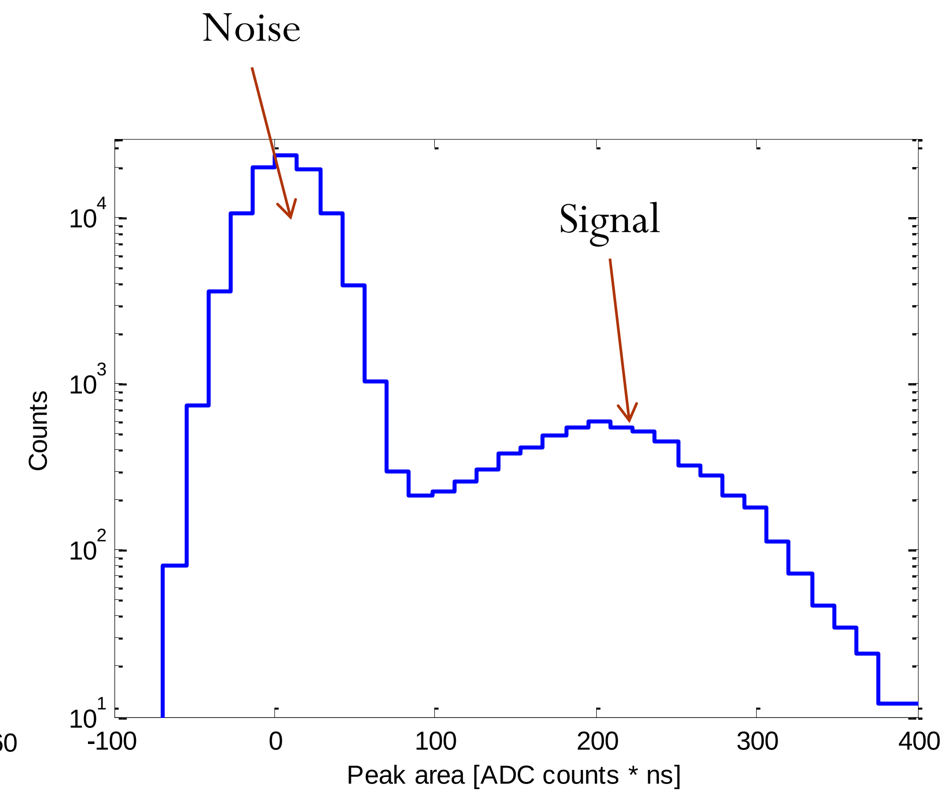


Single photoelectron response

Measured with:

- High voltage of (1000 ± 20) V
- Amplifier gain of 12





Corresponds to a PMT gain of ~48’000 and a PMT SER amplitude of ~700 µV

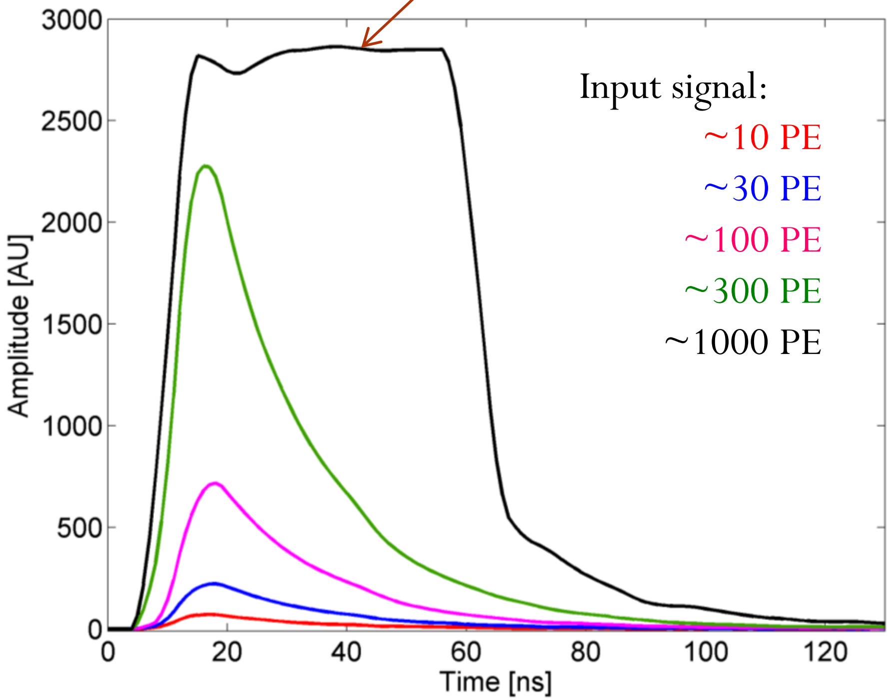
Full range resolution

Measurement of linearity with electric pulser

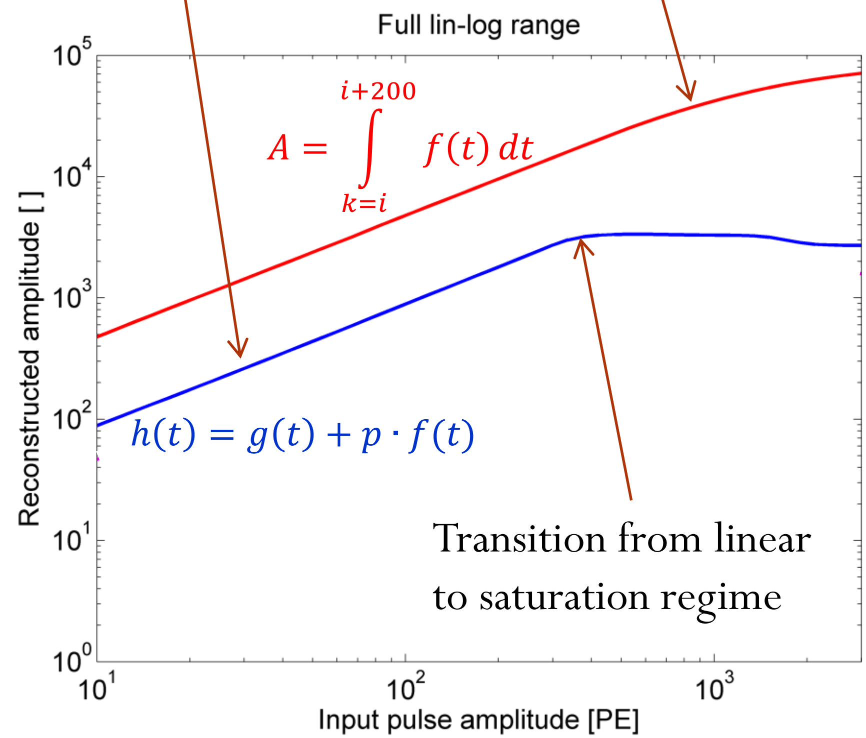
Output of opamp goes in saturation while input * gain is larger than output swing. Eventually, the output recovers as saturation conditions fail.

Pulse amplitude reconstructed by pulse maximum

Pulse amplitude reconstructed by pulse area



Measured signals, resolution 1 ns / sample



Summary

- Investigation of a single signal path concept for large dynamic signals
- Development of signal reconstruction algorithms

- Advantages
  - Lower power consumption
  - Lower costs (everything is needed only once)
  - Digitized signals don't produce huge data streams

- Disadvantages, problems
  - Amplitude and time resolution slightly worse than dual signal path concept
  - Saturation behavior of amplifier may change with a new production batch

- Concept may be installed in first Cherenkov camera for the Cherenkov Telescope Array