Digitization of PMT signals with FADCs:

comparison of simulation and measurement

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Outline

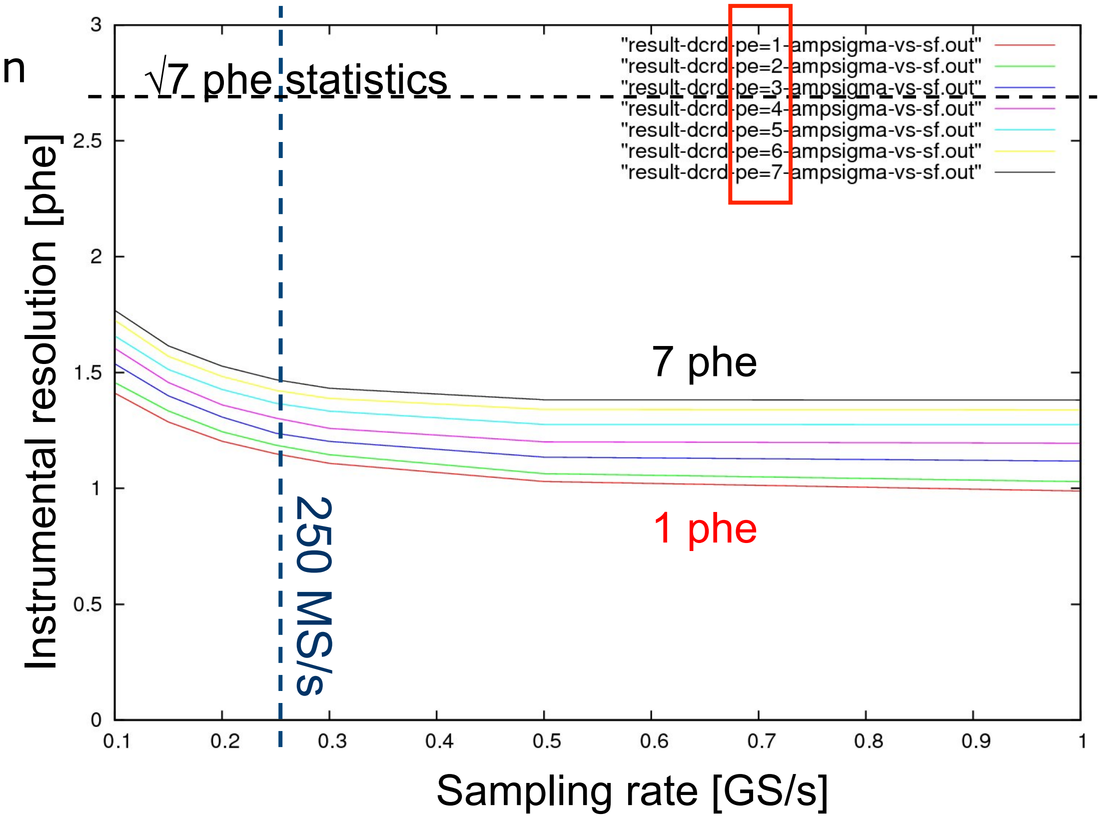
- Summary of previous presentations
  - Impact of sampling rate
- Verification of simulation by real measurements
  - Parameters
  - Production of measured data
  - Generation of simulated data
- Data analysis and comparison of results
- Conclusion

What has already been shown?

From earlier presentations (German Hermann, Thomas Kihm)…
(see: http://www.cta-observatory.org/ctawpcwiki/images/a/a3/FlashCam_for_CTA_Zurich_meeting_www.ppt)

Instrumental resolution depends on

- Digitization rate
- Analogue shaping
- Intrinsic signal width & amplitude
- Night sky background level
- Photon detector time jitter
- Intrinsic resolution of PMT
- Electronics noise level
- Analysis method



Conclusions from simulations

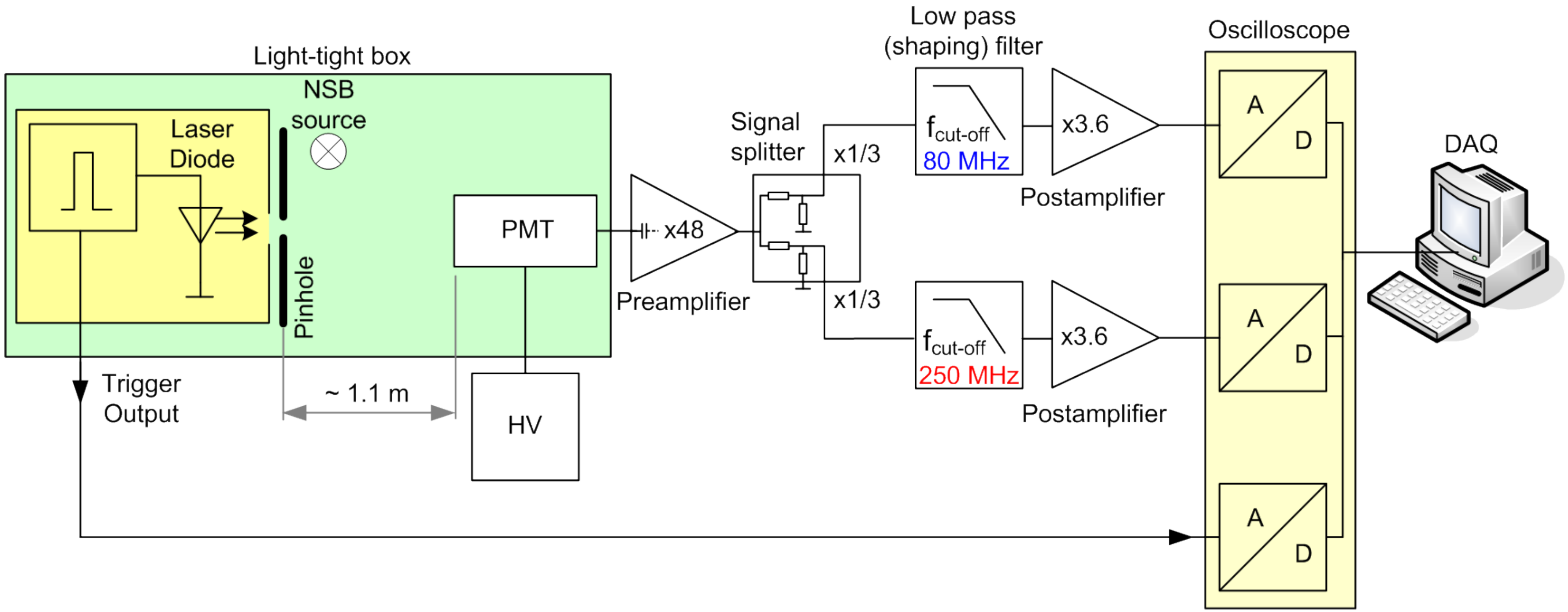
- The simulation shows that varying the sampling rate between 250 MS/s and 1 GS/s has only a small effect on the instrumental resolution: instrumental resolution ±5 % (Davis Cotton)

- Lowering the sampling rate would save costs, lower power consumption on the camera electronics, reduce data band width, and allow for a fully digital trigger.

BUT: it is only a simulation! How does that look in the real world?

➔ Verification of the simulation by replacing the signal production (light source, PMT, shaping) with hardware and comparing both outcomes!

Test setup


Light-tight box
NSB
source
Laser
Diode
Pinhole
PMT
HV
Trigger
Output
~ 1.1 m
x48
Preamplifier
Signal
splitter
x1/3
x1/3
Low pass
(shaping) filter
f cut-off
80 MHz
f cut-off
250 MHz
x3.6
x3.6
Postamplifier
Postamplifier
Oscilloscope
A
D
A
D
A
D
DAQ

Processing the signal(s)

Processing steps	Test setup (hardware)	Modeling, parameters
Cherenkov pulse	Laser head λ = 370nm, t_{FWHM} = 0.6ns	Pulse amplitude, width, jitter
NSB	Light bulb	NSB frequency
PMT	Photonis XP2960 (HESS) @ 950 V (1.4 kV typ.)	Bandwidth, time distribution, amplification (1 phe amplitude)
Preamplification	ZFL1000, MMIC, NIM	Multiplication factor
Shaping	Bessel LP, n = 5 $f_{cut-off}$ = **80 MHz** $f_{cut-off}$ = **250 MHz**	Bessel LP, n = 5 $f_{cut-off}$ = **80 MHz** $f_{cut-off}$ = **250 MHz**
Digitisation	Oscilloscope LeCroy bw = 1 GHz, f_S = 2 GS/s	
RAW data	0.5 ns resolution (2 GS/s)	0.02 ns resolution (50 GS/s)
Downsampling	f_S = **250 MS/s** and **2000 MS/s**	
Signal reconstruction	Peak search for signal and for noise (window width ±4 ns)	

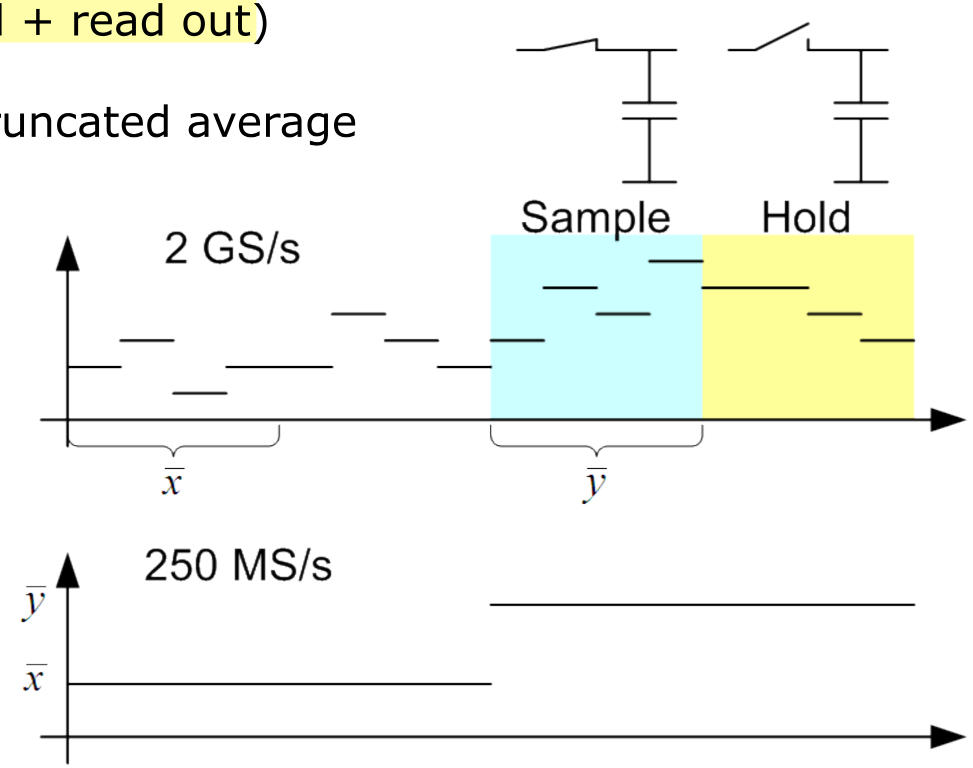
Downsampling

Modelling of a Sample & Hold of an ADC

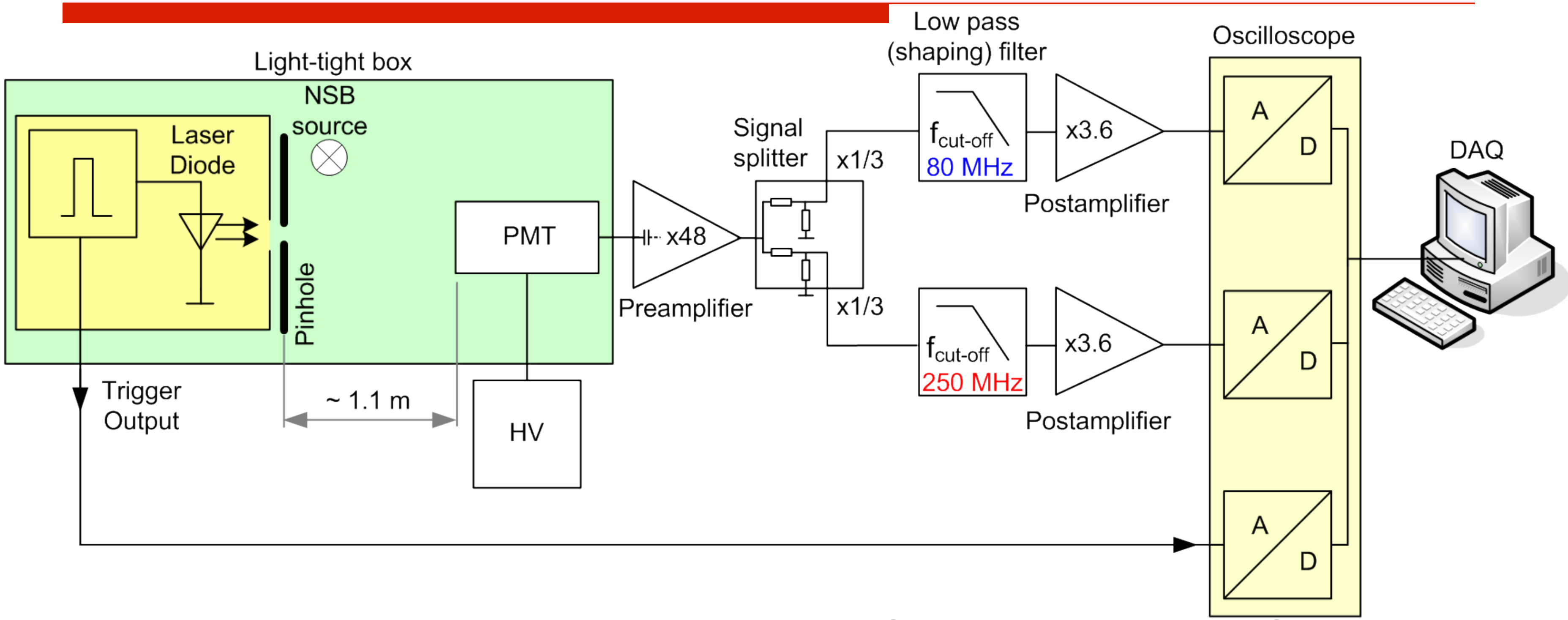
1. Taking average of 4 samples (sample)

2. Round average to integer (hold + read out)

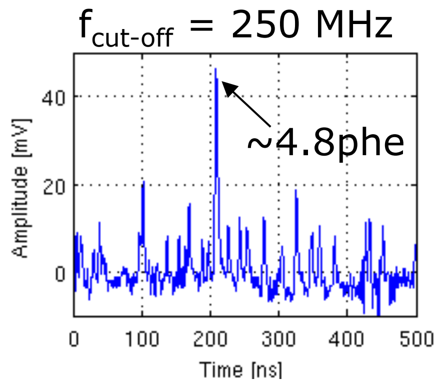
3. Filling up 8 samples with the truncated average

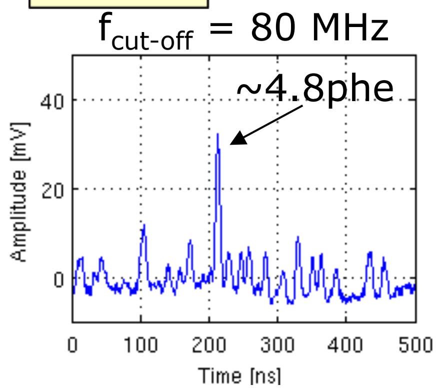


Test setup



- ☑ Laser pulse stability (mean 4.8 phe)
- ☑ NSB frequency -> DC value
- ☑ 1 phe amplitude determination
- ☑ Statistics: 200’000 events per setting (variation of NSB frequency)
- ☑ Determination of uncertainties





Simulation parameters

Parameter	Value from measurements	Determination
PMT bandwidth	70 MHz	**Determined** from measured PMT pulse rise time (~2 ns @ 950V)
Mean photon pulse amplitude	4.8 phe	**Determined** by histograms of 1 and 5 phe measurements
Electronics noise	0.05 phe/$\sqrt{}$ns for f_S = 250 MS/s and 2 GS/s	**Determined** by the comparison of the width of the noise peak distribution of the simulated and measured data.
NSB frequency	f_{NSB} = 0 - 455 MHz (± 5-8% uncertainty)	**Determined** by subtracting the baseline from the low NSB measurements (f_S = 250 and 2000 MS/s) and comparing with the measured DC values.
Time jitter of laser pulse photons	σ_L = 0.5 ns	**Estimated!** Assuming a Gaussian distribution.
PMT transit time difference	$\sigma_{PMT} = 3\text{ns}/\sqrt{12} \approx 870$ ps (datasheet: 800 ps) $\sigma^2_{total} = \sigma^2_L + \sigma^2_{PMT} = 1\ \text{ns}^2$	**Estimated!** Assuming box distribution with 3 ns width. σ_{PMT} = difference between centre of cathode and 18 mm from it

Generating simulated data

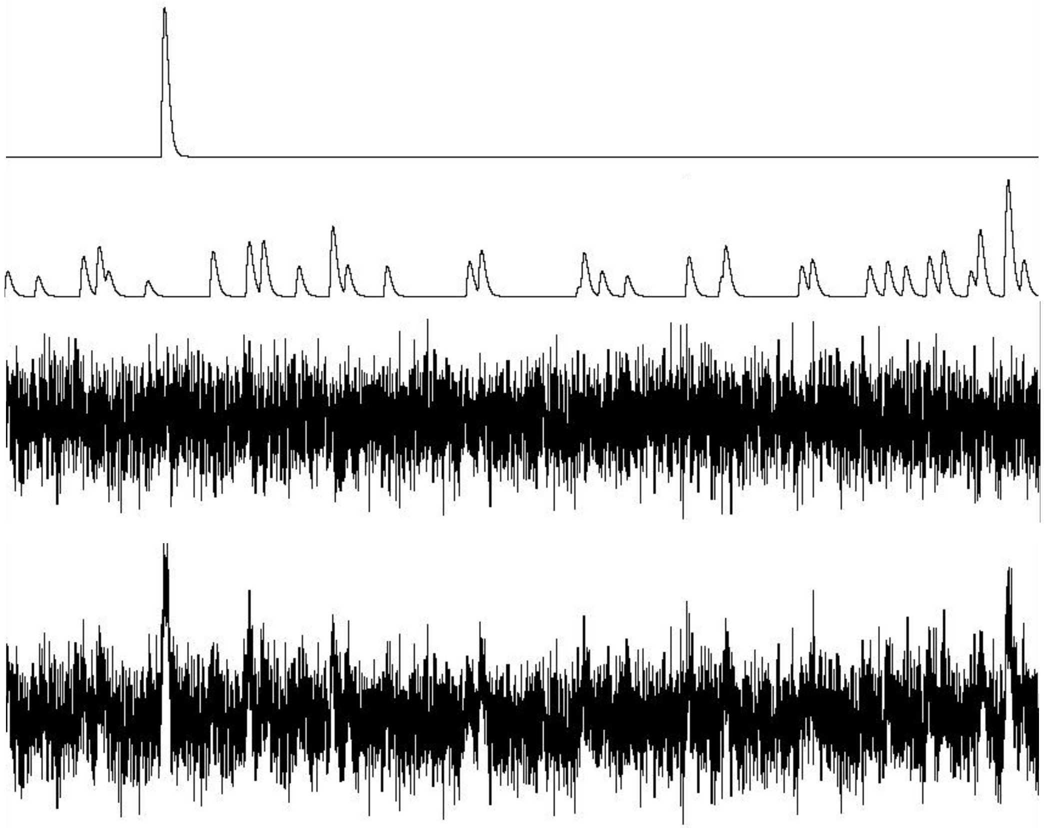
Simulation resolution = 20 ps

Cherenkov pulse: 5 phe

NSB

White noise

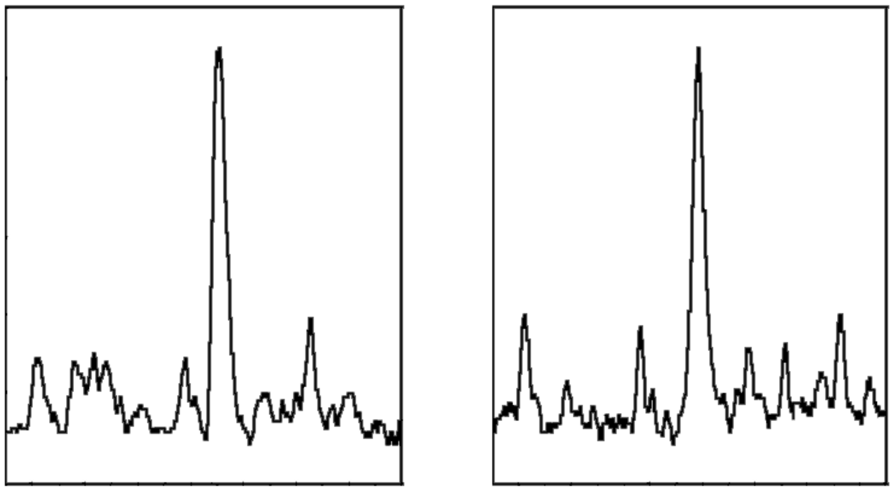
Sum of the three components



PMT has <100 MHz bandwidth ⇨ cut-off of white noise at high frequencies

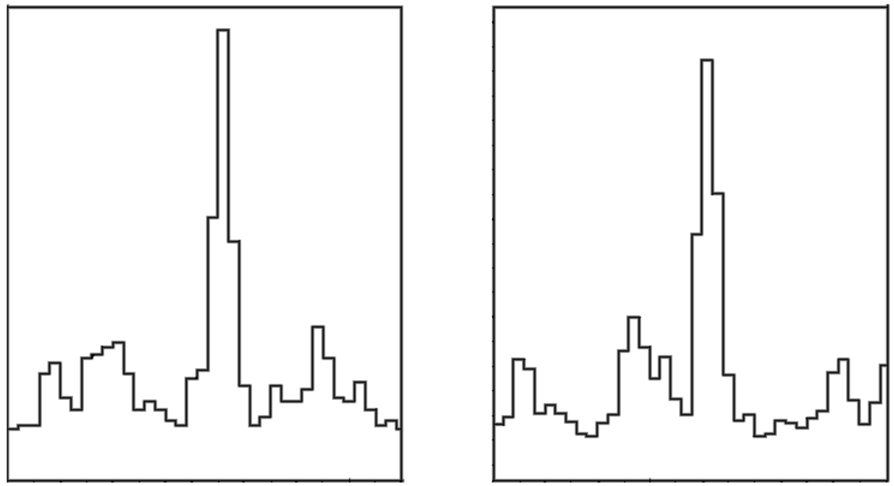
Digitized signals

Examples of a simulated and a measured event at f_{NSB} = 115 MHz with a 4.8 phe Cherenkov pulse.



Simulated event Measured event

2 GS/s sampling



Simulated event Measured event

250 MS/s sampling

Plots for the simulated and measured events show different events!

Signal analysis

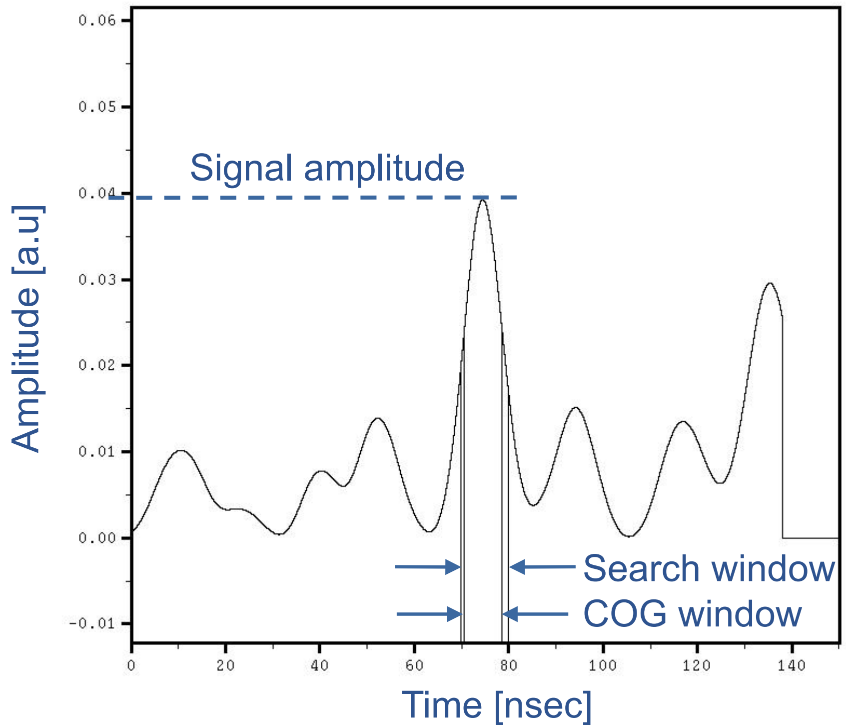
Determination of

- **amplitude (noise)**
  Maximum in a search window with a width of ±4 ns in a region on the left hand side of the signal peak.

- **amplitude (signal)**
  Same as described above in the signal region. Position of the signal peak needs to be known with good precision.

- **time information (signal)**
  COG (centre of gravity) of the area of the signal peak above the FWHM.

Peak search

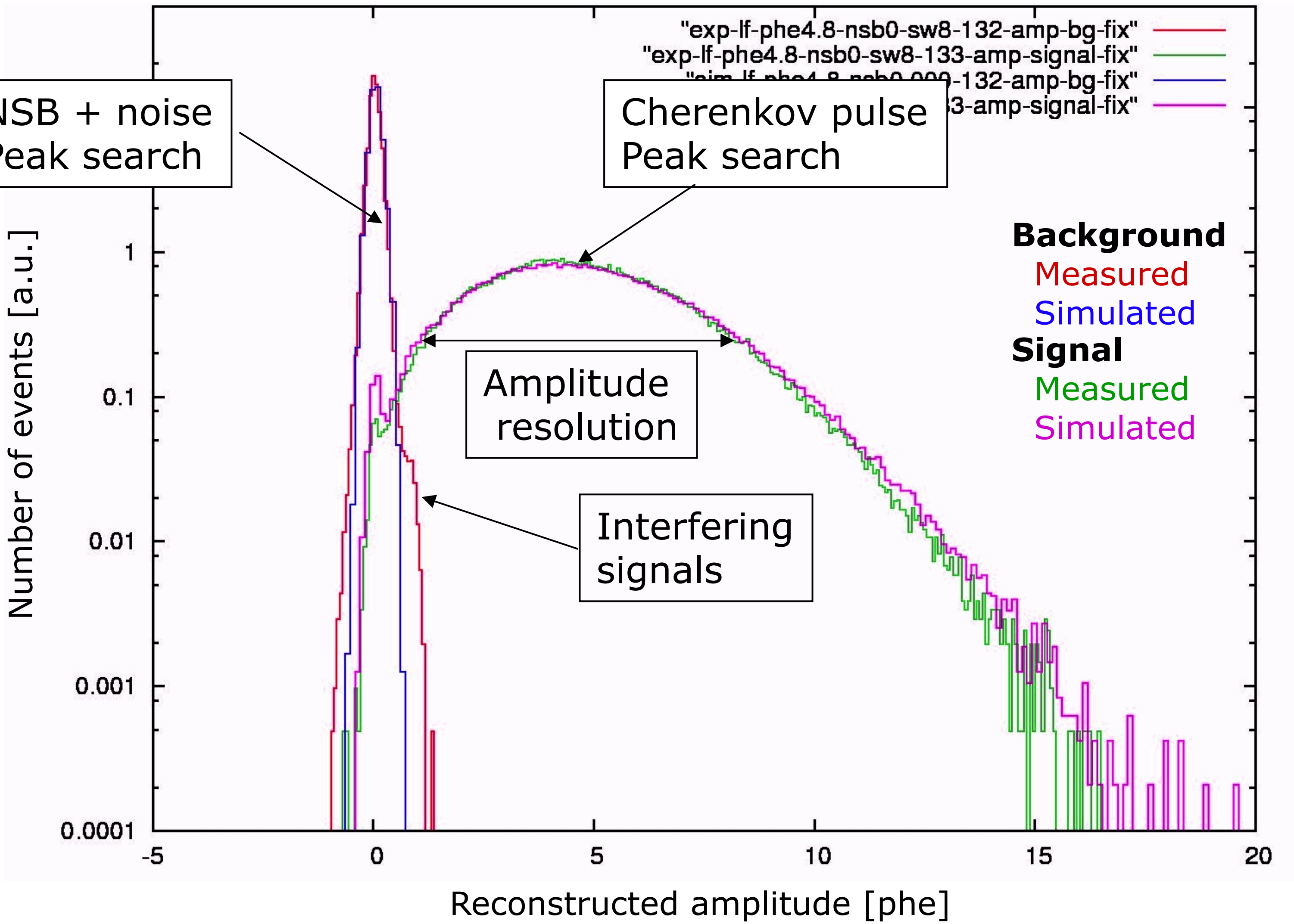


Results: Consistency check

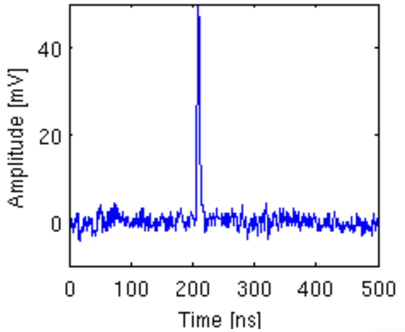
Comparison of:

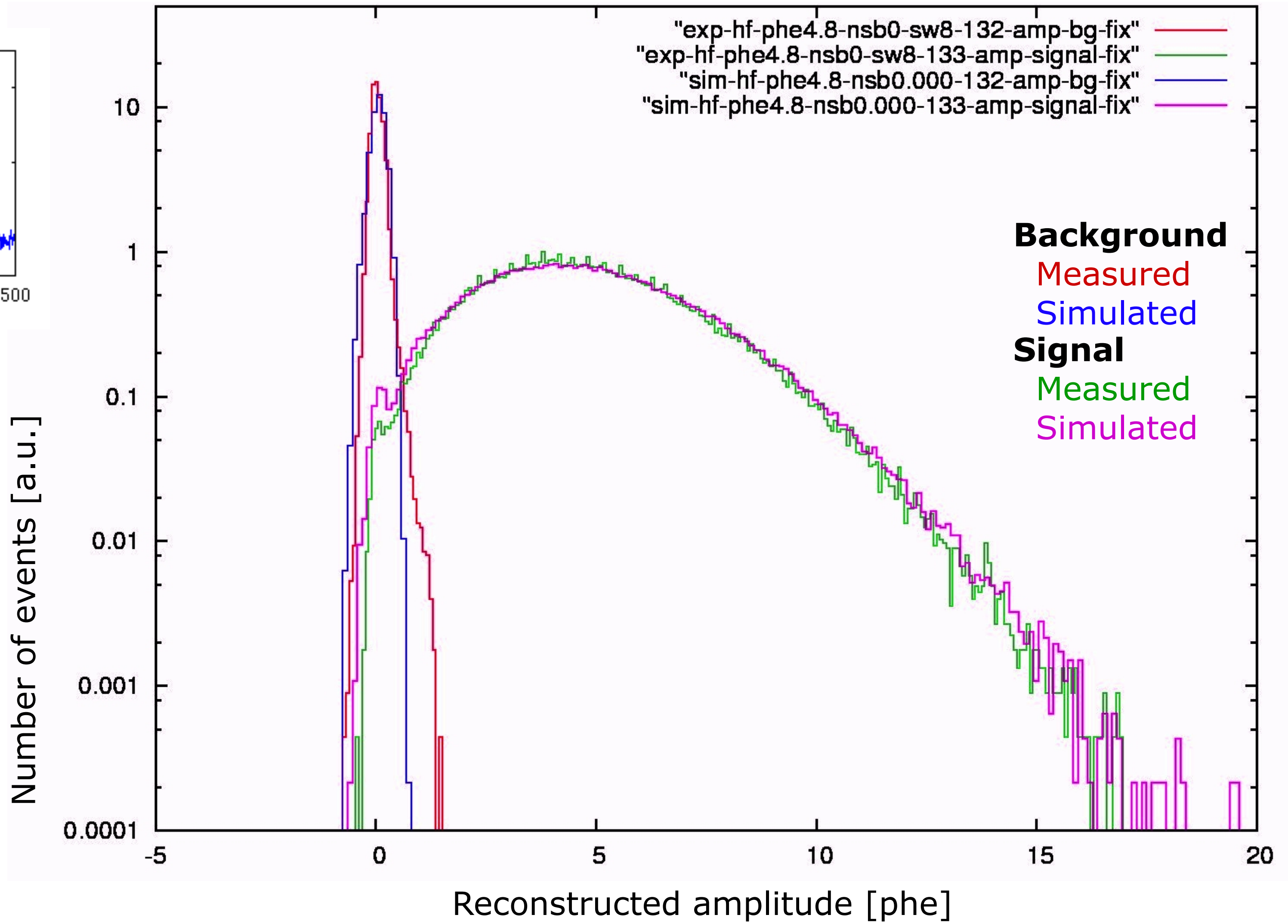
- Measured signal sampled with 250 MS/s and 2 GS/s
- Simulated signal sampled with 250 MS/s and 2 GS/s
- Parameters:
  - Cherenkov pulse: 4.8 phe (mean)
  - NSB frequency: 0 MHz, 10 MHz, 50 MHz, 115 MHz, 455 MHz
  - Search window width ±4 ns
- COG of each spectrum is centered at 0 phe for the noise and at 4.8 phe for the signal (normalized spectra)

NSB = 0 MHz, fs = 250 MS/s

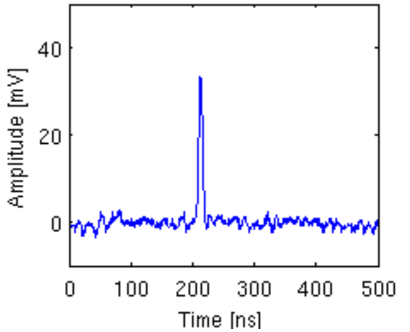


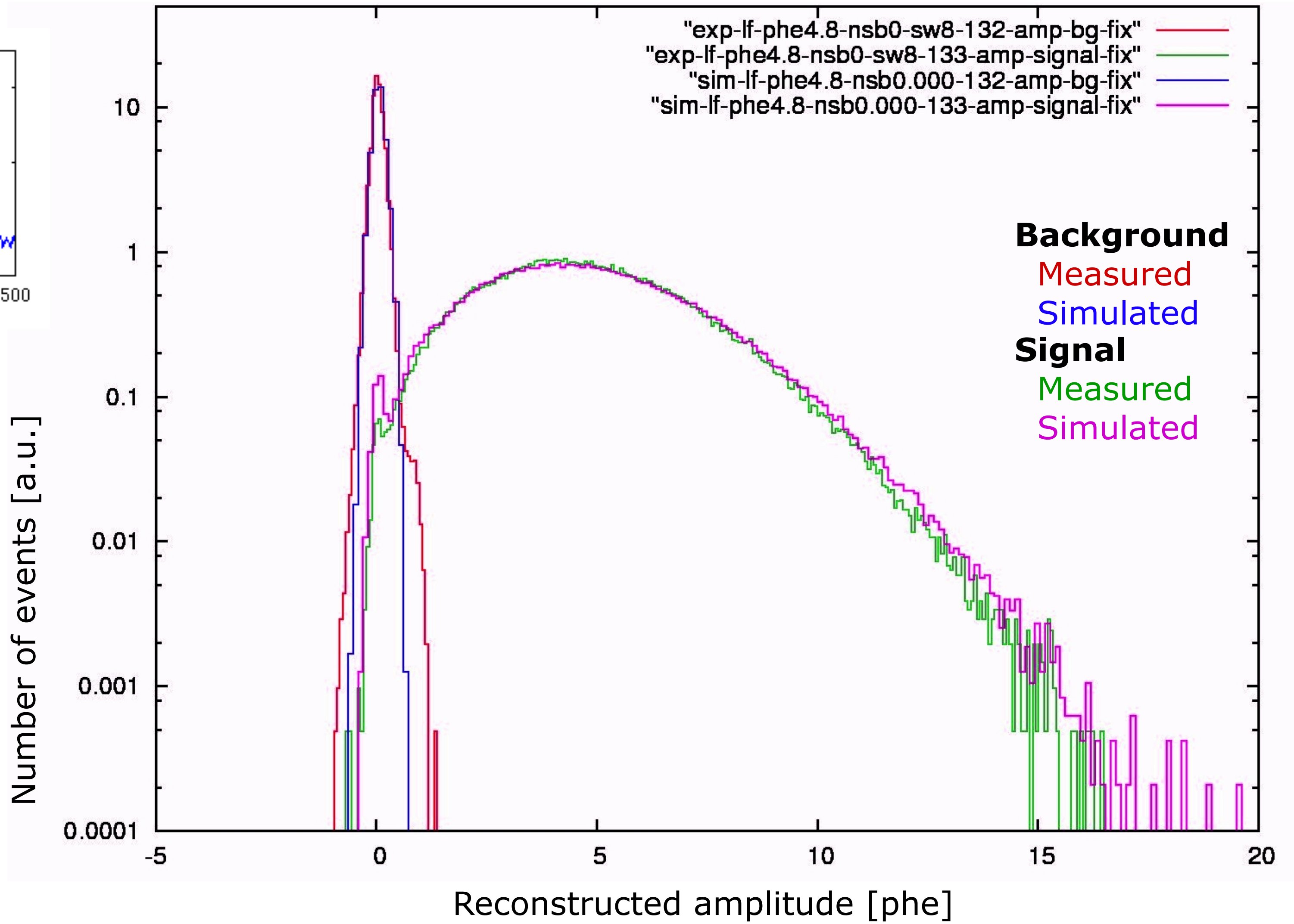
NSB = 0 MHz, fs = 2 GS/s



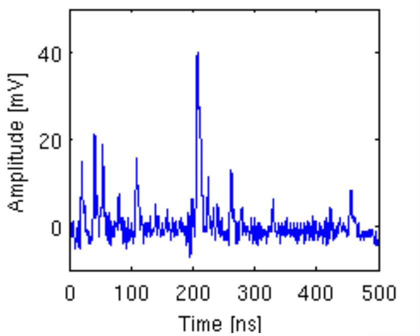


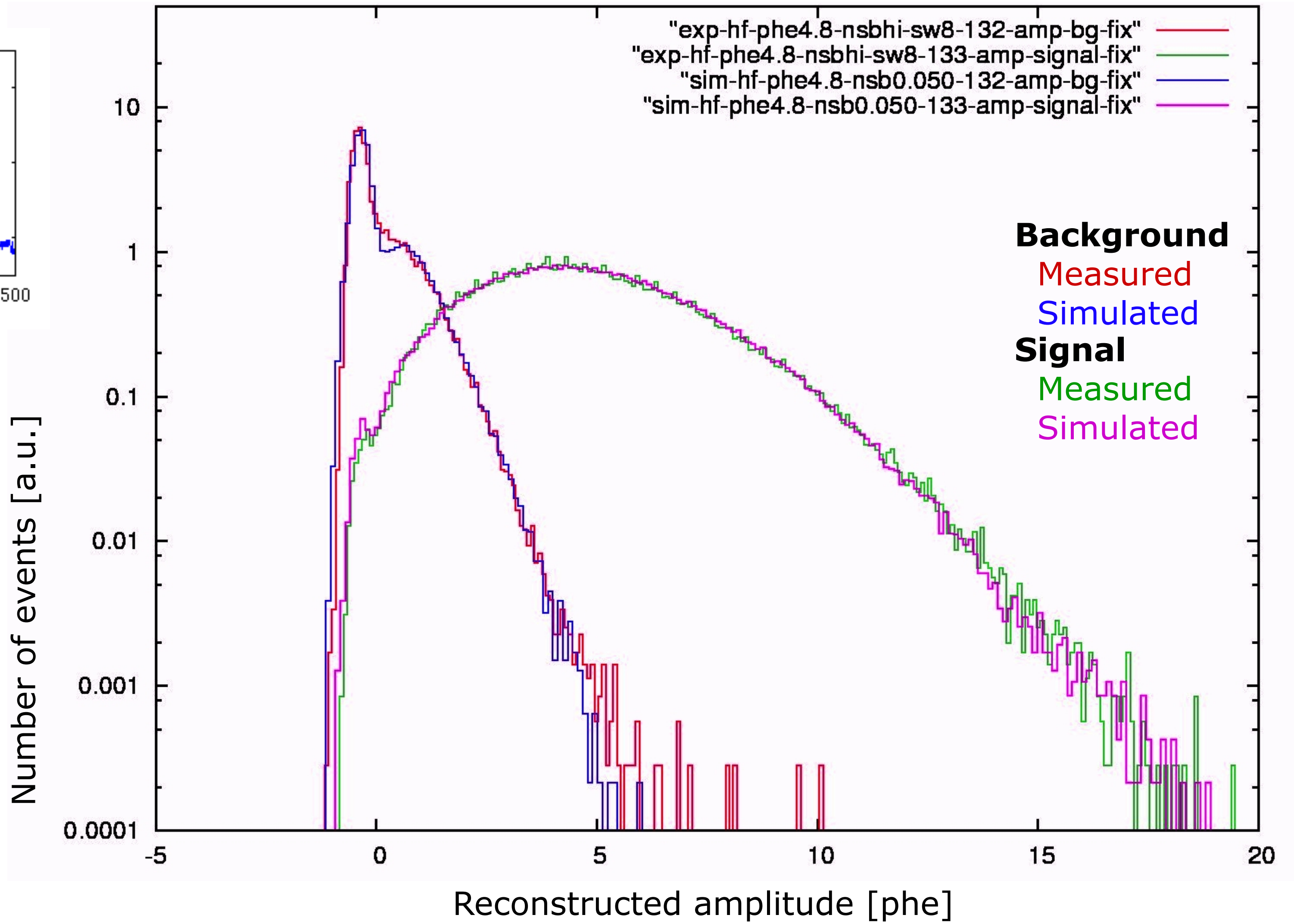
NSB = 0 MHz, fs = 250 MS/s



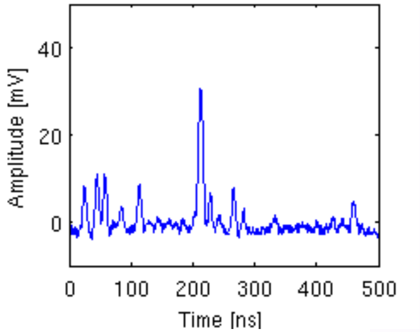


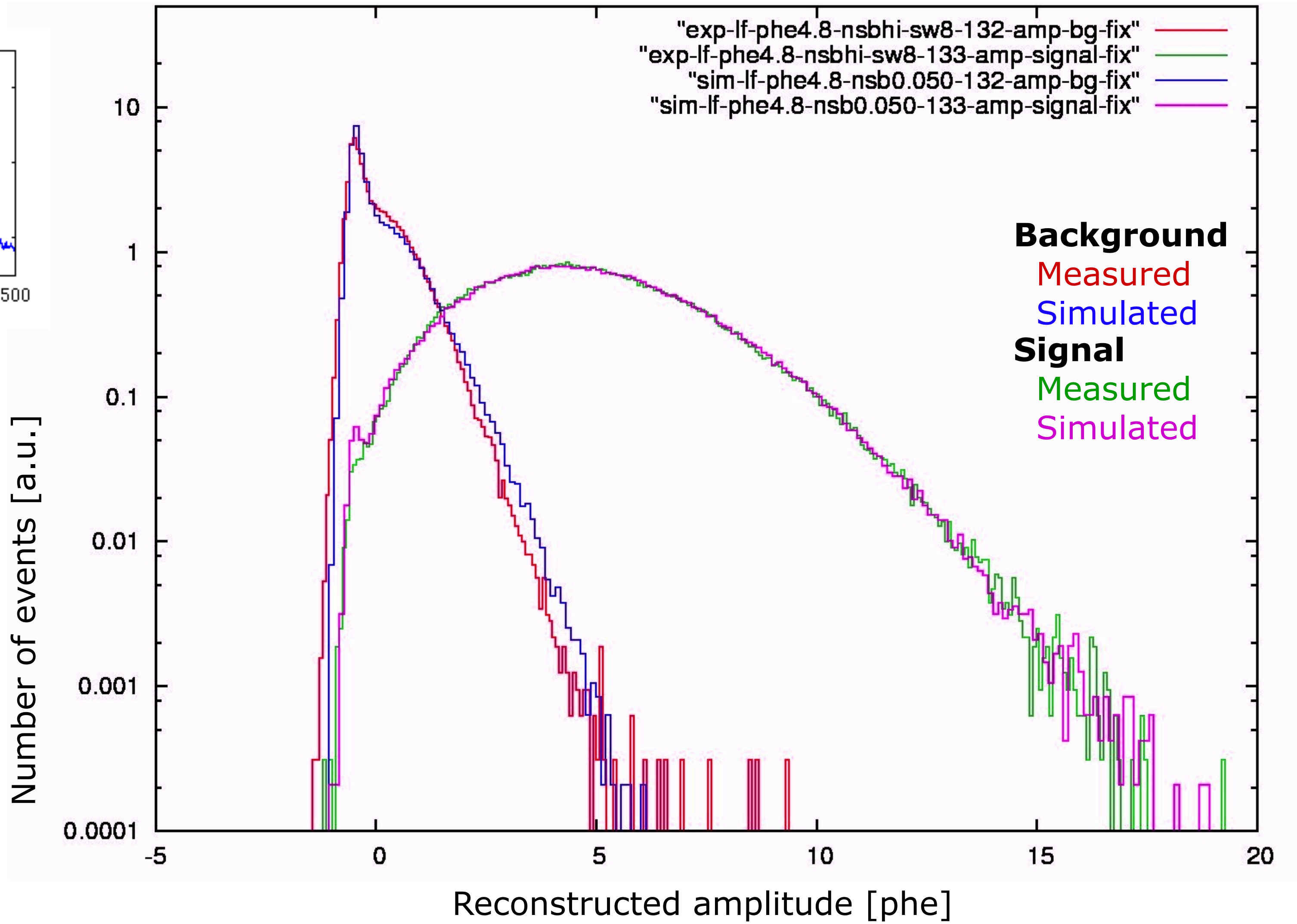
NSB = 50 MHz, fs = 2 GS/s



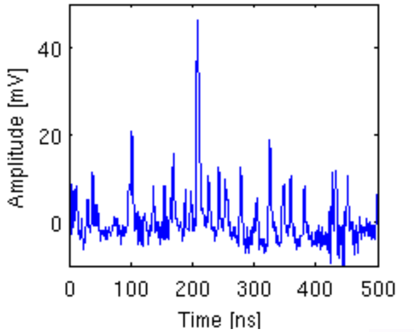


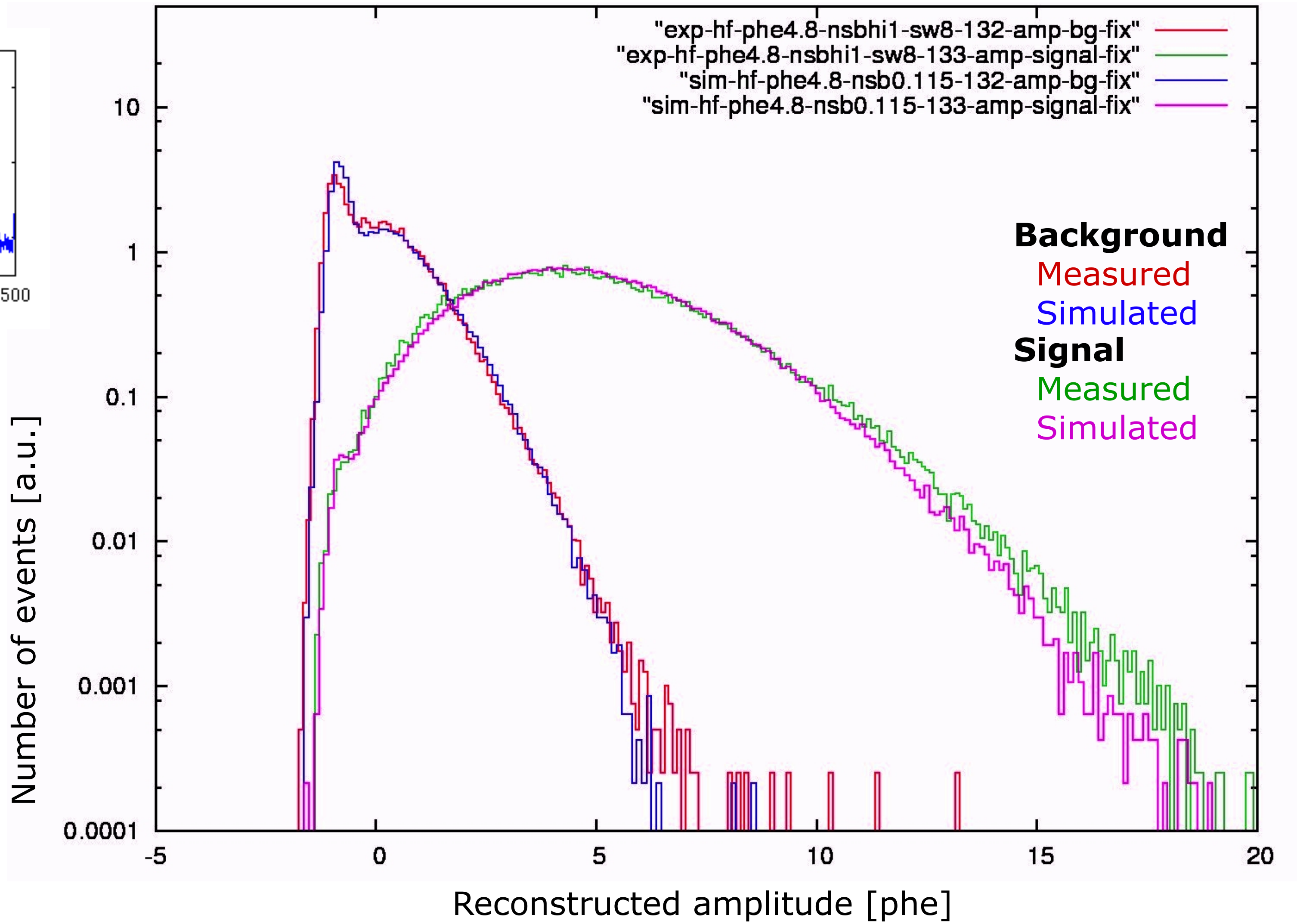
NSB = 50 MHz, fs = 250 MS/s



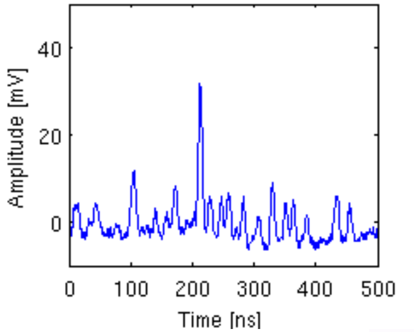


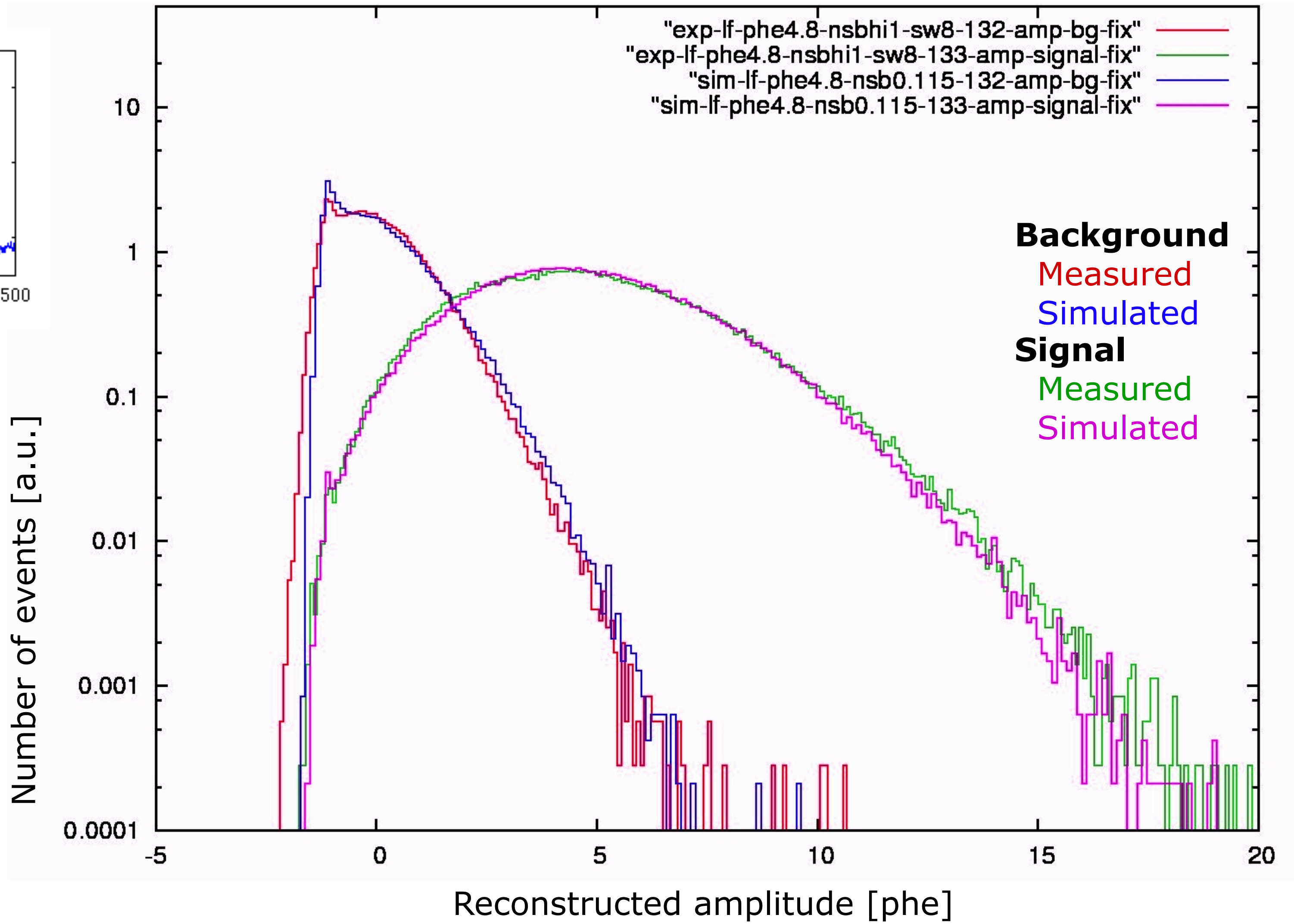
NSB = 115 MHz, fs = 2 GS/s



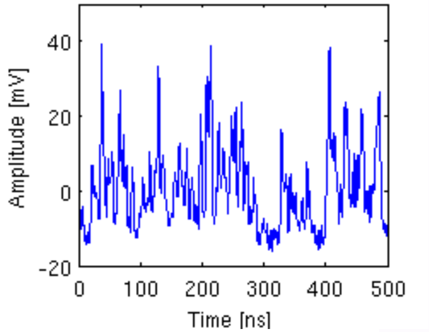


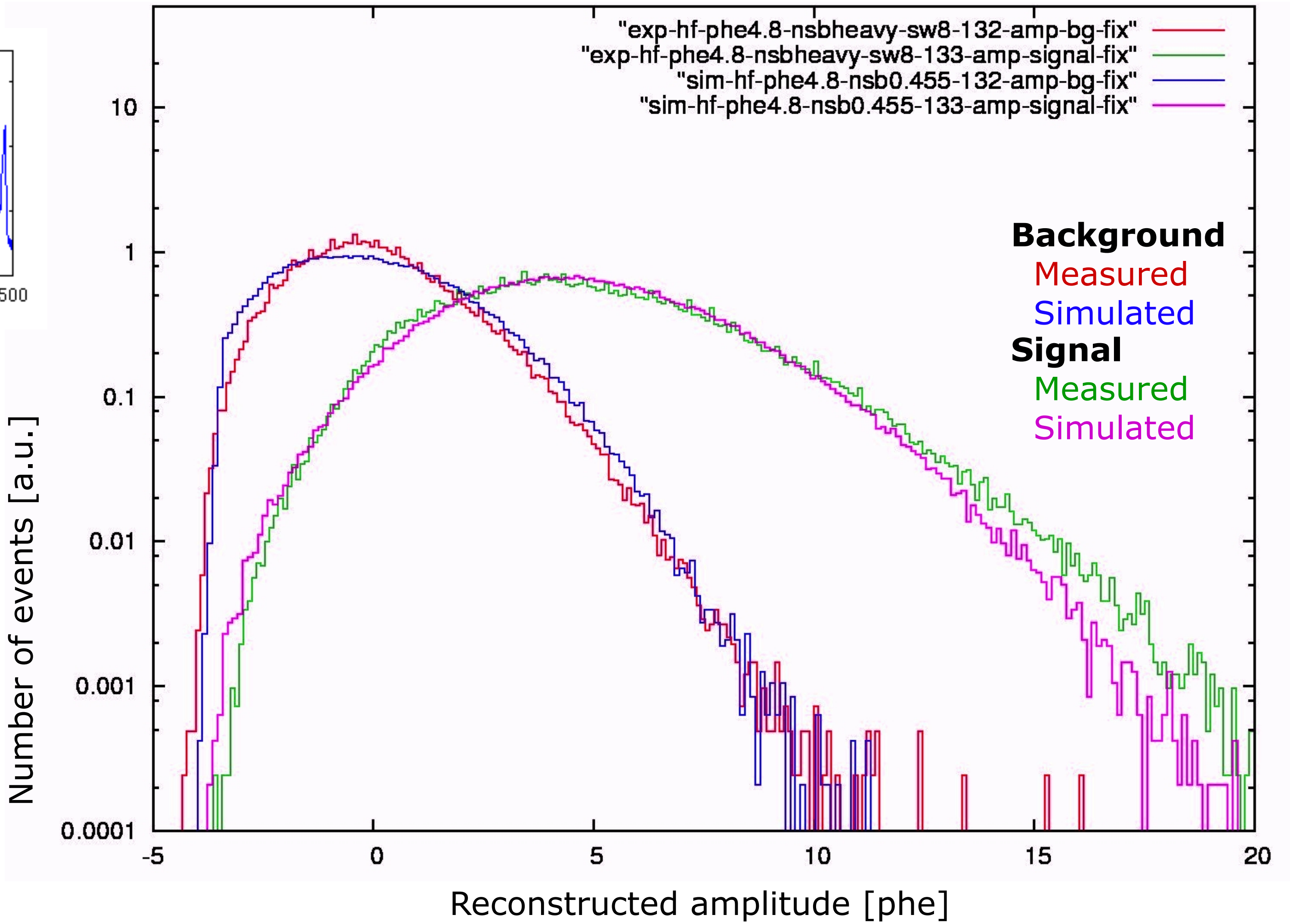
NSB = 115 MHz, fs = 250 MS/s



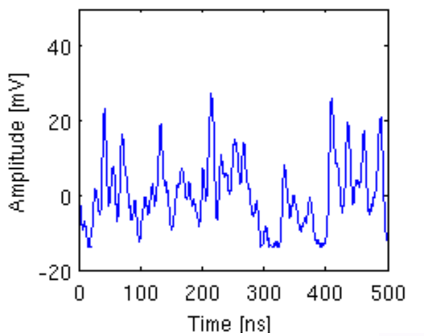


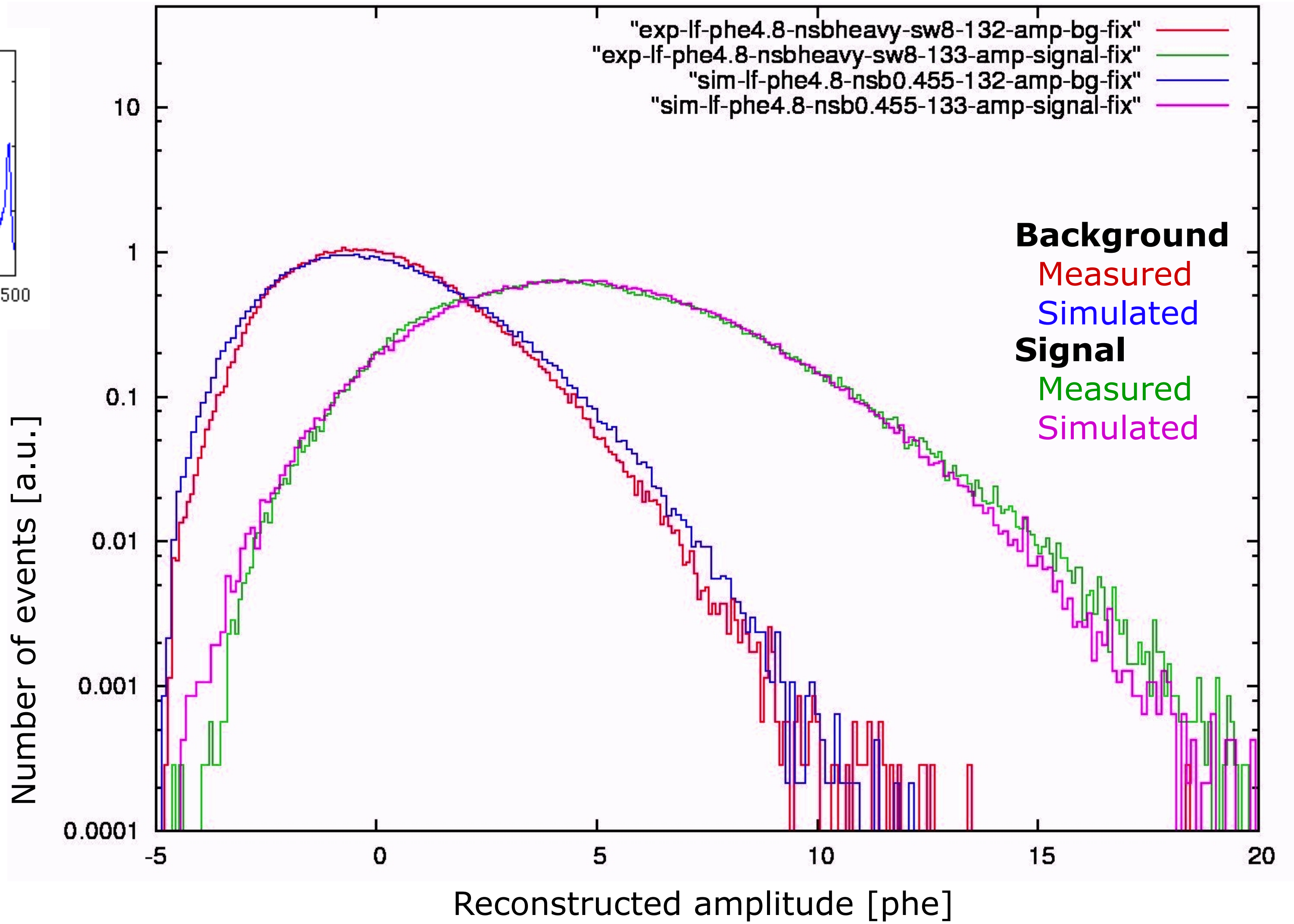
NSB = 455 MHz, fs = 2 GS/s





NSB = 455 MHz, fs = 250 MS/s



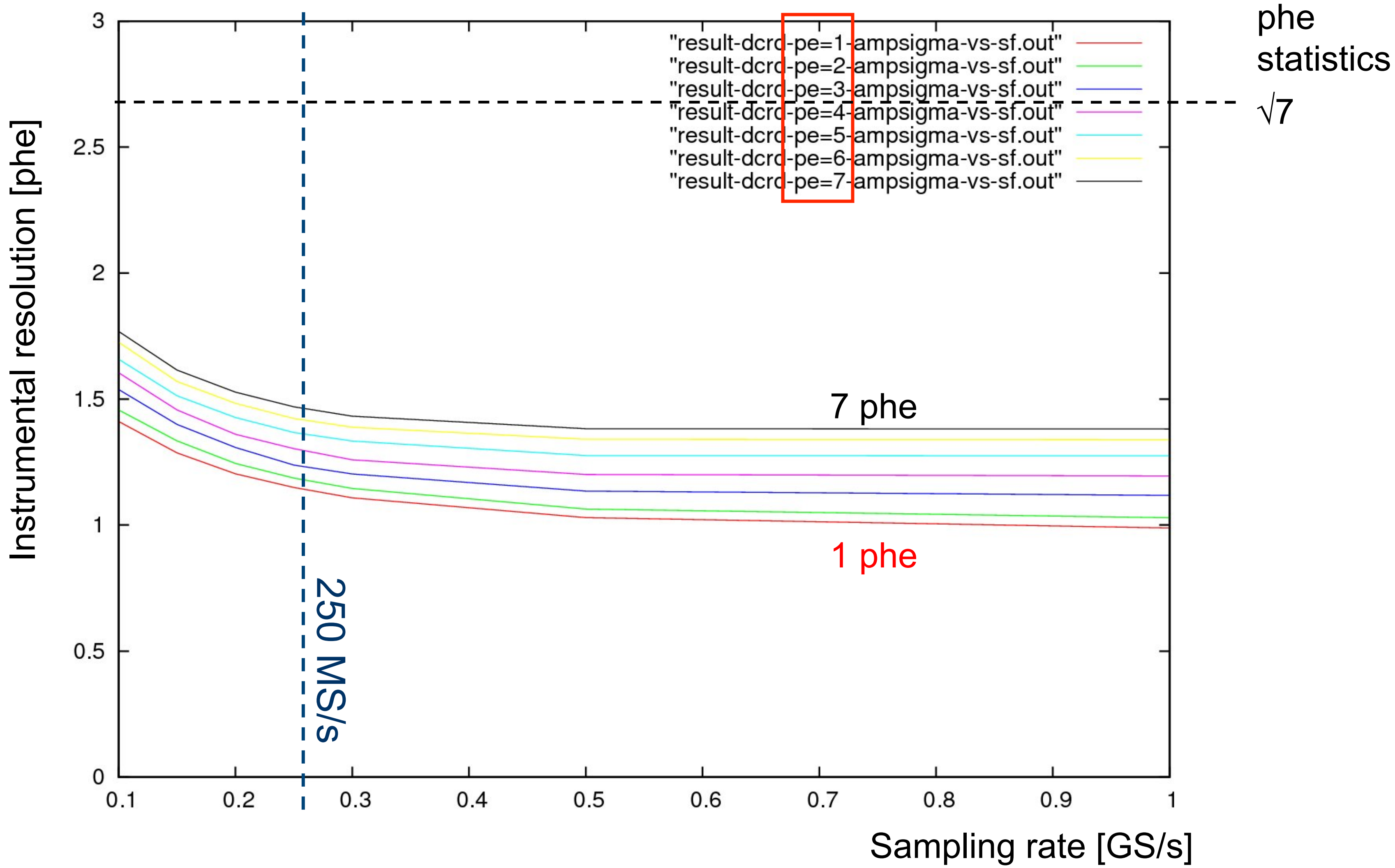


Conclusion

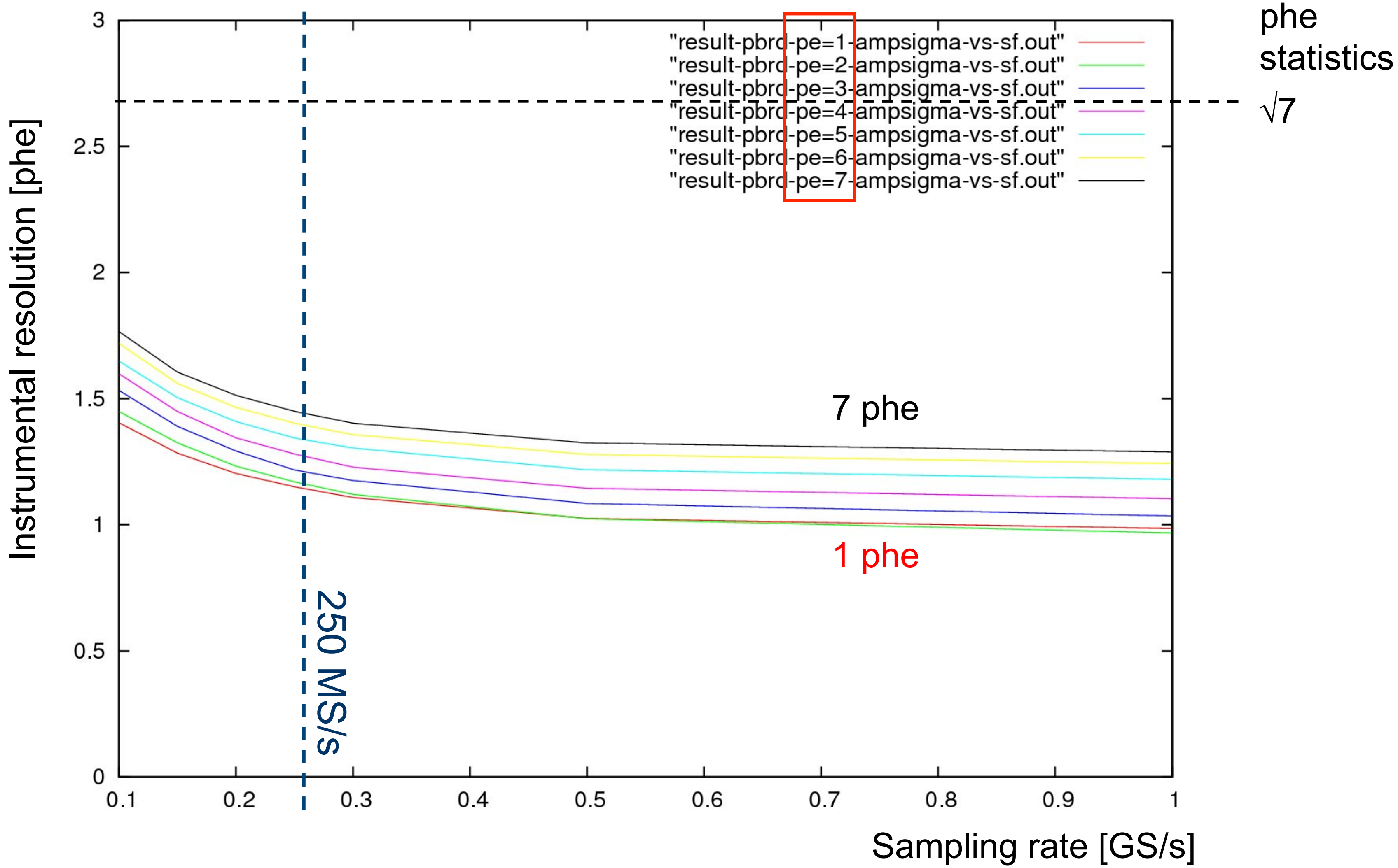
- Previous simulations have shown that using sampling rates down to 250 MS/s for the signal digitization would have little effect on the reconstructed signal quality and accuracy.
- The comparison of amplitude spectra of measured and simulated data shows no significant difference as seen in the preceding plots.
- That means that we have understood the simulation and its parameters at a very good level and therefore believe the validity of the simulation and its results.
- A digitization at 250 MS/s should therefore be a real option for the CTA camera.

Backup slides

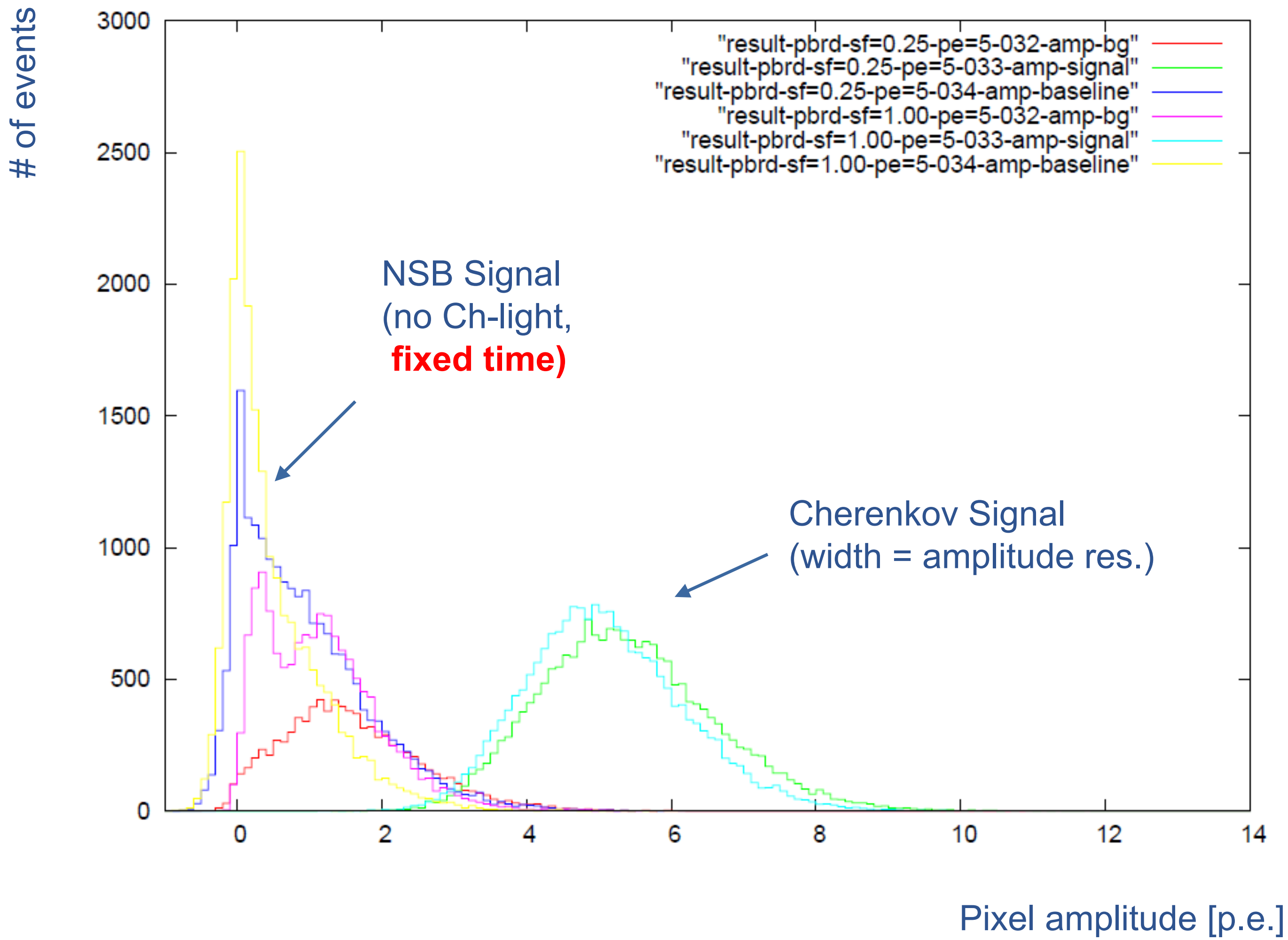
Instrumental resolution vs. sampling rate
"**Davis Cotton**"; 1 … 7 phe signals



Instrumental resolution vs. sampling rate
"**Parabolic**"; 1 … 7 phe signals

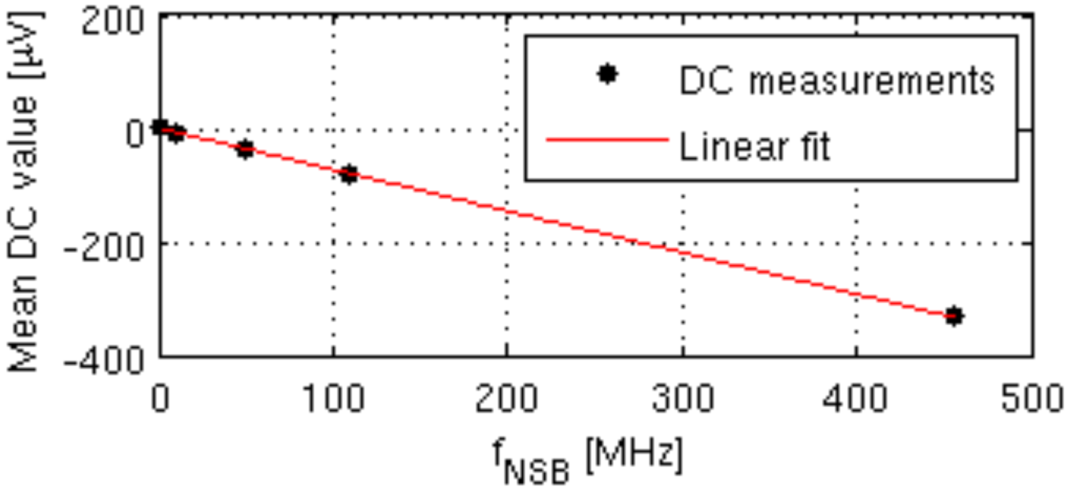


Ex: amplitude distribution @ 250 MS/s and 1000 MS/s sampling

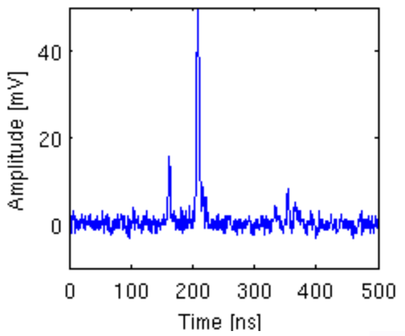


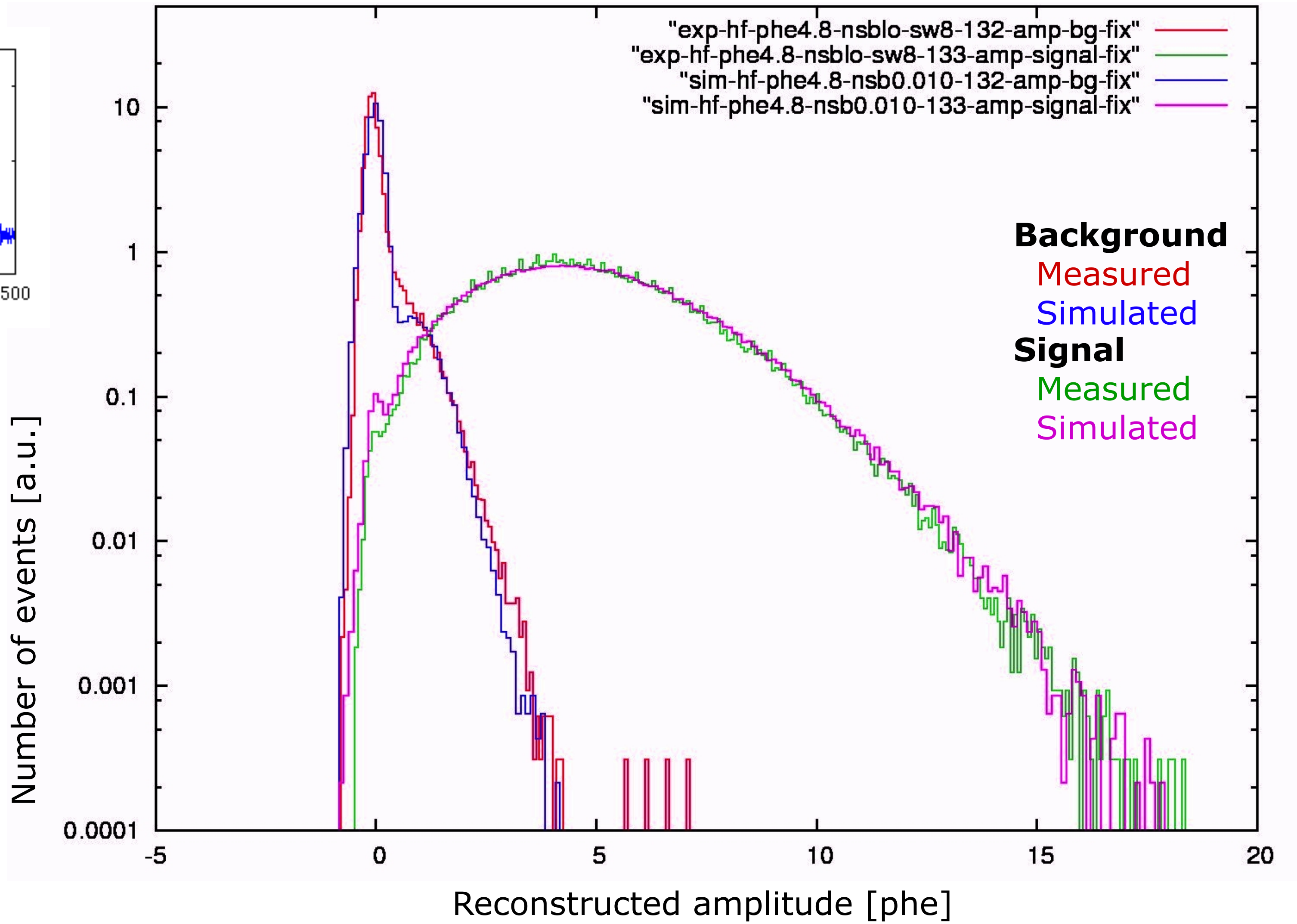
Test setup: NSB determination

- Determination of f_{NSB} for the low NSB measurements (10MHz and 50 MHz)
- Fitting f_{NSB} linearly to DC measurements
- Determination of DC value for f_{NSB} = 115 MHz
- ☑ Compare measurements and simulations for all f_{NSB} => ± 5-8% uncertainty



NSB = 10 MHz, fs = 2 GS/s





NSB = 10 MHz, fs = 250 MS/s