FlashCam Signal Reconstruction

Speaker: Aaron Manalaysay, Universität Zürich
For the FlashCam group
14 May 2012
CTA Consortium Meeting, Amsterdam, The Netherlands

UNIWERSYTET JAGIELLOŃSKI W KRAKOWIE

MPIK - Heidelberg

AGH University of Science and Technology

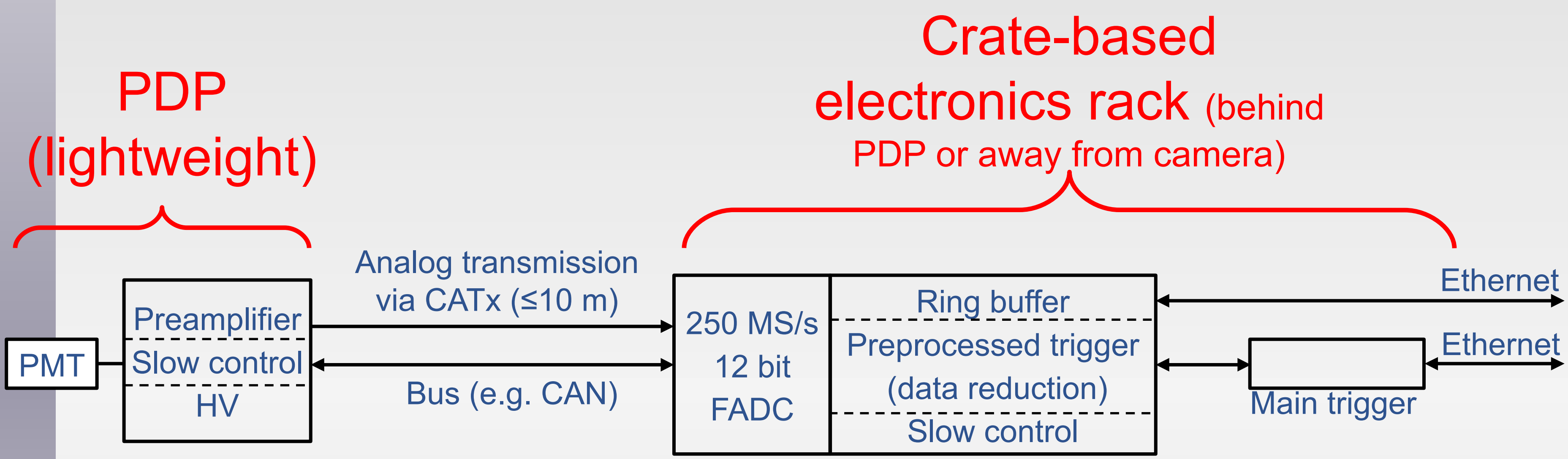
Universität Tübingen

Universität Zürich[UZH]

ETH Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

cta
cherenkov telescope array

FlashCam Architecture



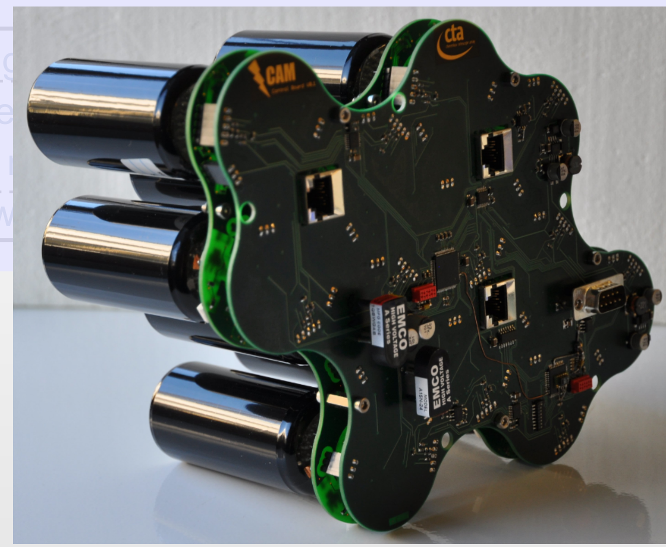
FlashCam PDP

PDP
(lightweight)

PMT

Preamplifier
Slow control
HV

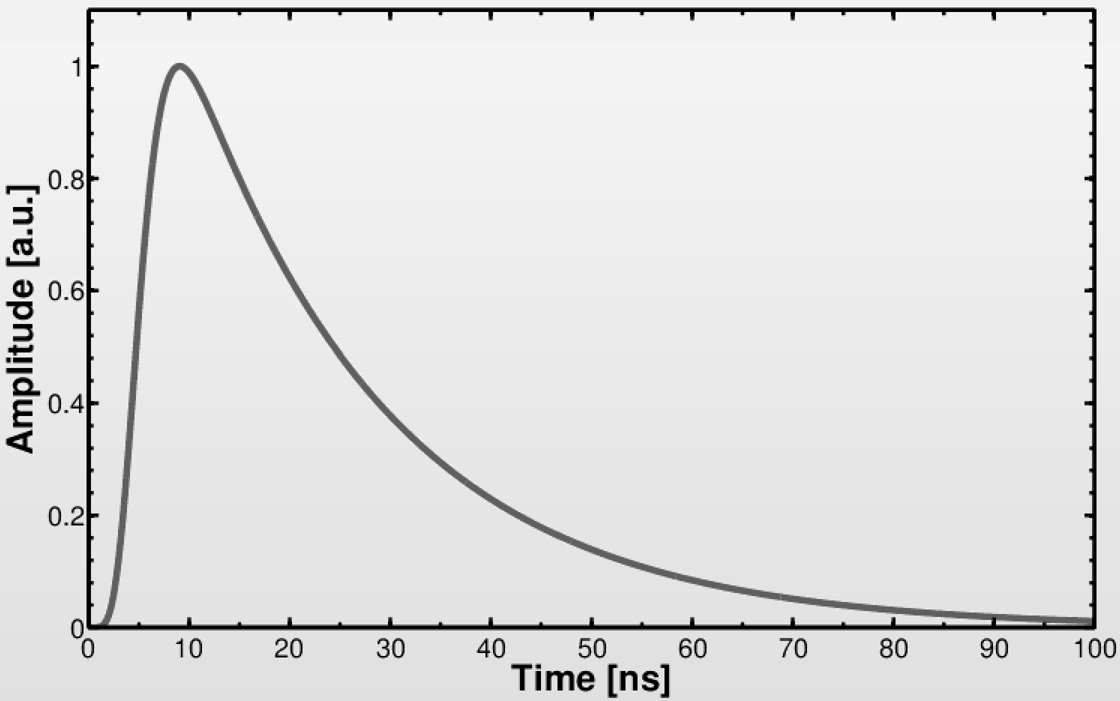
Crate-based
electronics rack (behind
PDP or away from camera)



Analog signal

250 MHz op-amp (20 ns tail from the input coupling, formally translating into 8 MHz)

~80 MHz

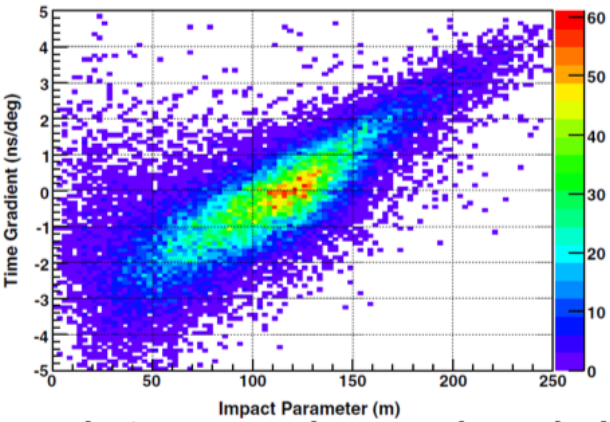


Our electronics introduce a long exponential tail to our pulses, which must be removed in software by the signal reconstruction algorithm.

Signal processing

- A sampling of the order 1 GHz to digitize the pulse saving enough information for pulse reconstruction (time position of the maximum of the amplitude or width of the signal).

FlashCam	250 MHz
DRAGON	0,7 - 5 GHz
NECTAr	0,4 - 3,2 GHz
TARGET	0,4 - 1,2 GHz



☹ A sampling slower than 1 GHz need to use lower bandwidth amplifier to reconstruct the signal shape

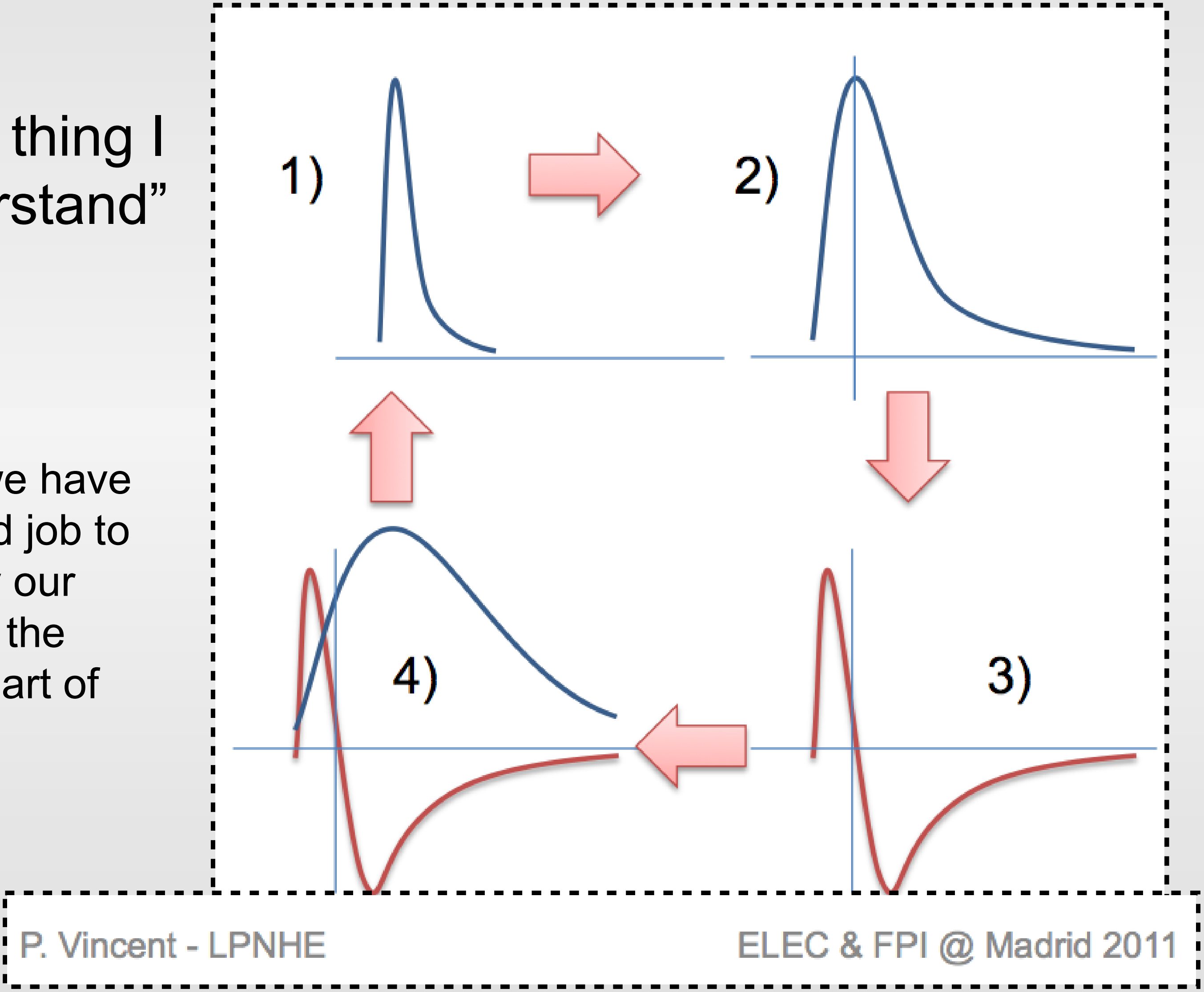
😐 or to involve sophisticate reconstruction method.

P. Vincent ELEC @ Munich, May 2012 5

Signal processing

"This derivative thing I don't fully understand"

It seems clear that we have not done a very good job to communicate clearly our techniques, which is the purpose of the first part of these slides.

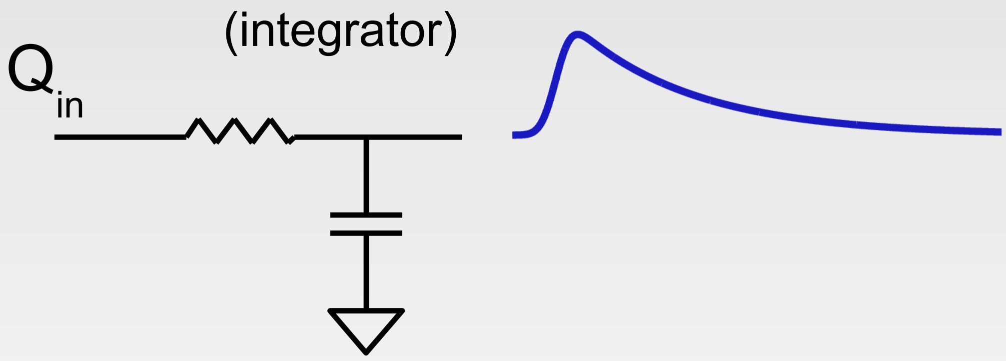


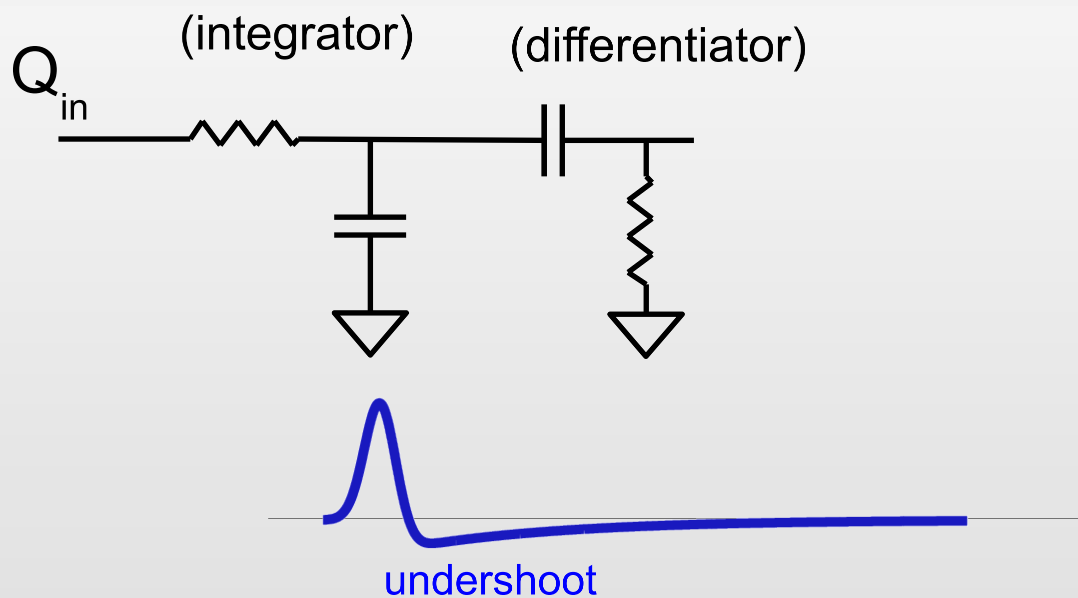
Amplifying a charge signal

- Long pulse tails are a problem common in other fields (i.e. calorimetry/spectroscopy)

- Differentiating the signal gives well-defined peak, but also an undershoot

- Undershoot is the result of a divergence in the filter's transfer function. This divergence is called a “pole”.



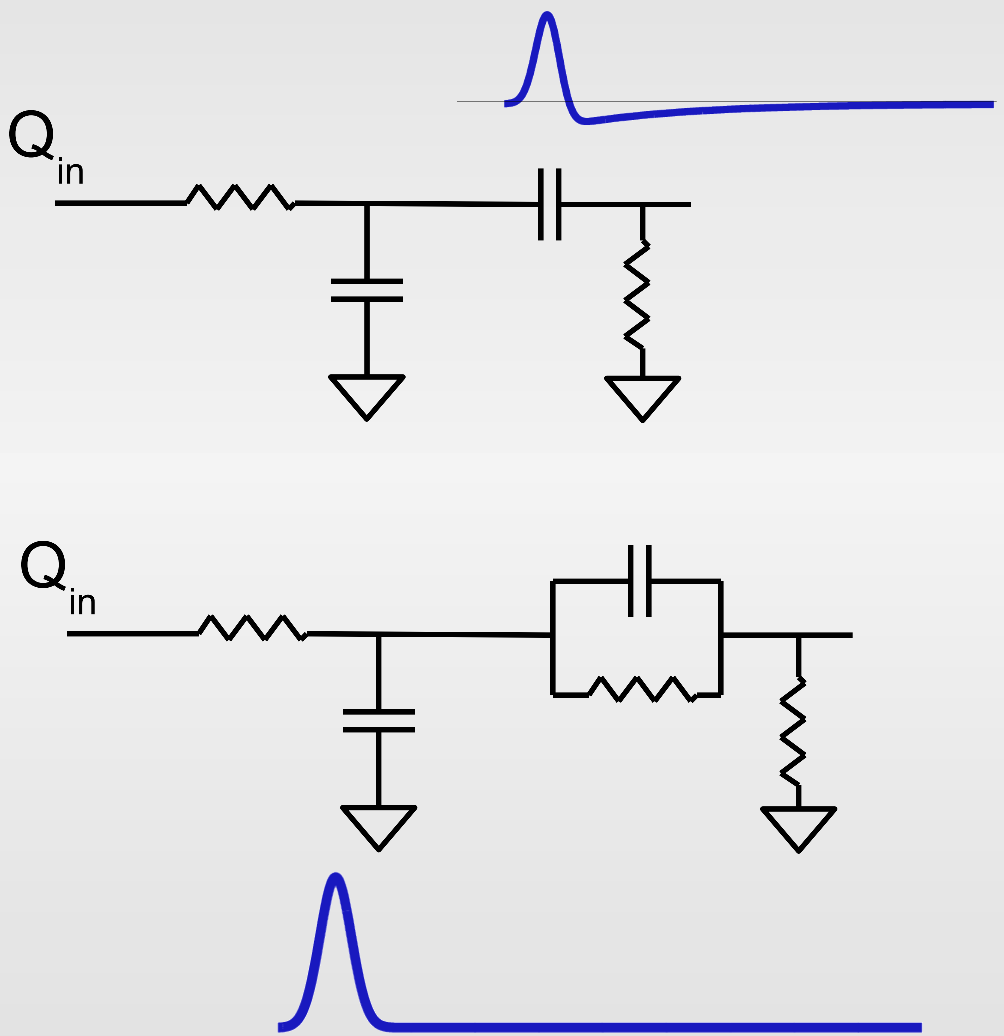


Amplifying a charge signal

- Solution: modify the circuit so that the transfer function has an additional “zero” that overlaps the pole.

- When the pole is cancelled by the added zero, the undershoot disappears.

- Not surprisingly, this technique is called “pole-zero cancellation”



Pole-zero cancellation is old

III. POLE-ZERO CANCELLATION

The solution to the problem of undershoot is straightforward, provided one uses the pole-zero concepts of network theory[5] rather than the simpler concepts of "integration" and "differentiation." A study of Eq. (7) shows that the undershoot occurs because the pole at $S=-b$ is unable to cancel the zero at $S=0$. This observation is reinforced by noting that, in the idealized transfer function of Eq. (1), the zero at $S=0$ is exactly cancelled by the pole at $S=0$, i.e., as produced by the perfect charge sensitive preamplifier. The problem must be solved by

[5] There are many excellent treatments of modern network theory. One of these is E. A. Guillemin, *Synthesis of Passive Networks* (John Wiley & Sons, Inc., New York, 1957).

- Used in the context of undershoot removal for almost 50 years

DECEMBER 1965

THE REVIEW OF SCIENTIFIC INSTRUMENTS VOLUME 36, NUMBER 12 DECEMBER 1965

Elimination of Undesirable Undershoot in the Operation and Testing of Nuclear Pulse Amplifiers*

C. H. Nowlin and J. L. Blankenship
Oak Ridge National Laboratory, Oak Ridge, Tennessee

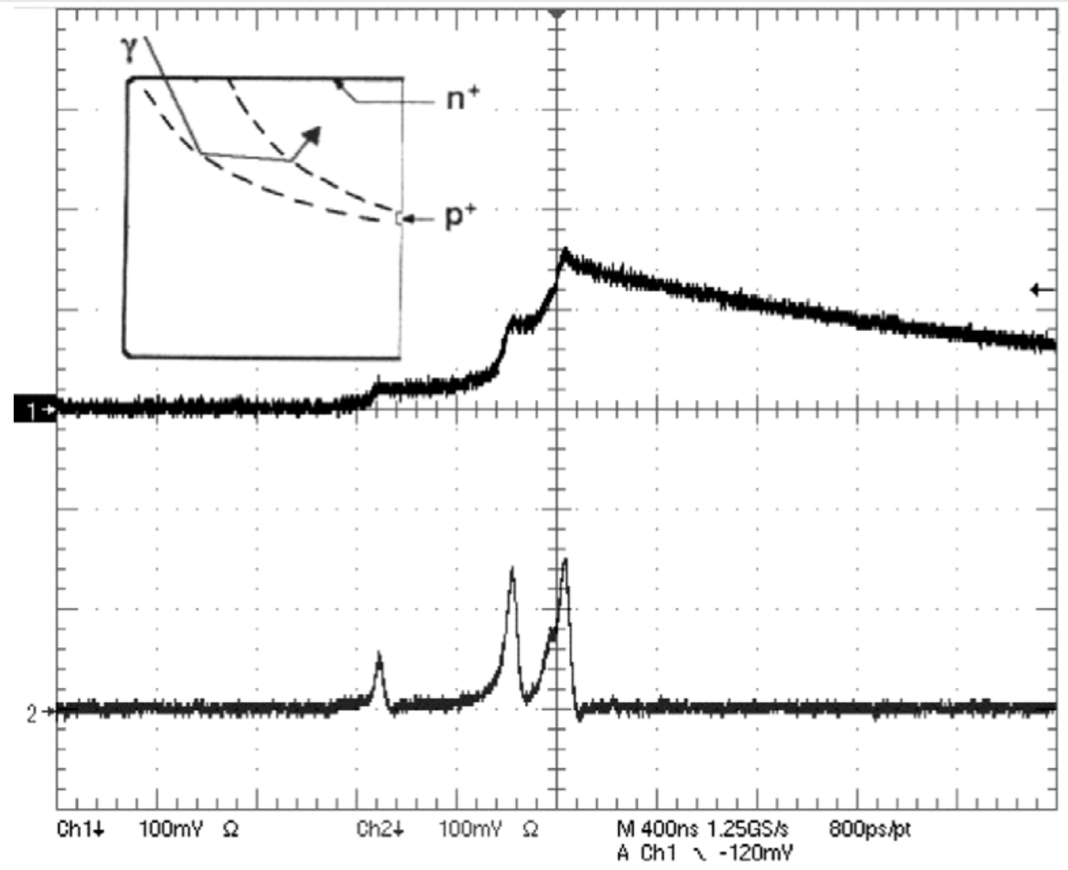
(Received 1 September 1965)

The techniques of modern network theory have been applied to some of the problems of pulse shaping in nuclear pulse amplifiers. A technique referred to as pole-zero cancellation has been evolved which permits a system designer to specify the pulse decay time at the amplitude limiting section of the system and the pulse shape at the final out

Examples of pole-zero in hardware

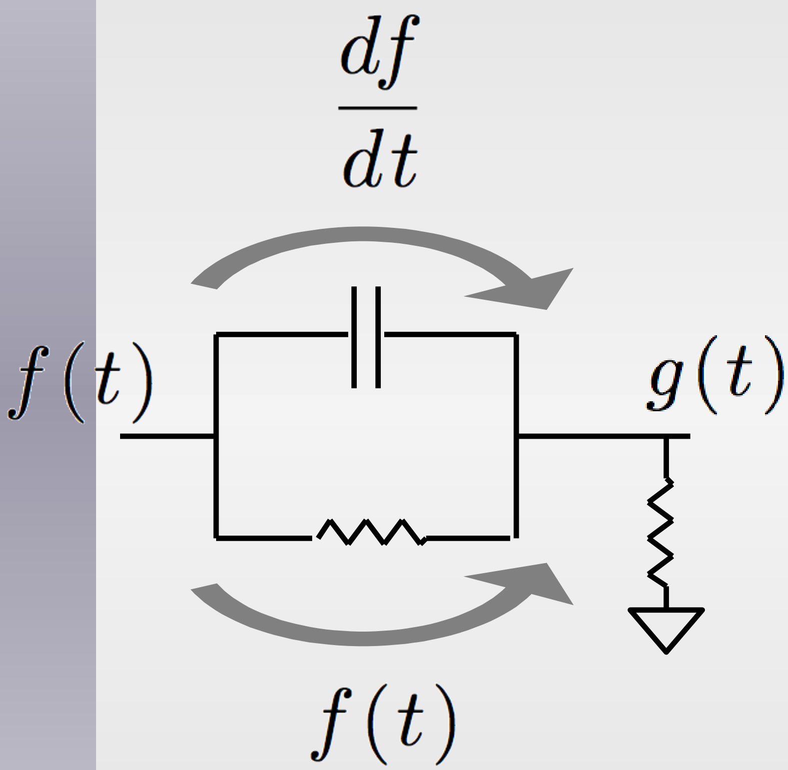
- Many devices now have “PZ ADJ” (pole-zero adjust)

Examples of pole-zero in hardware



P.S.Barbeau *et al.*, JCAP**09** (2007) 009

Mathematical form



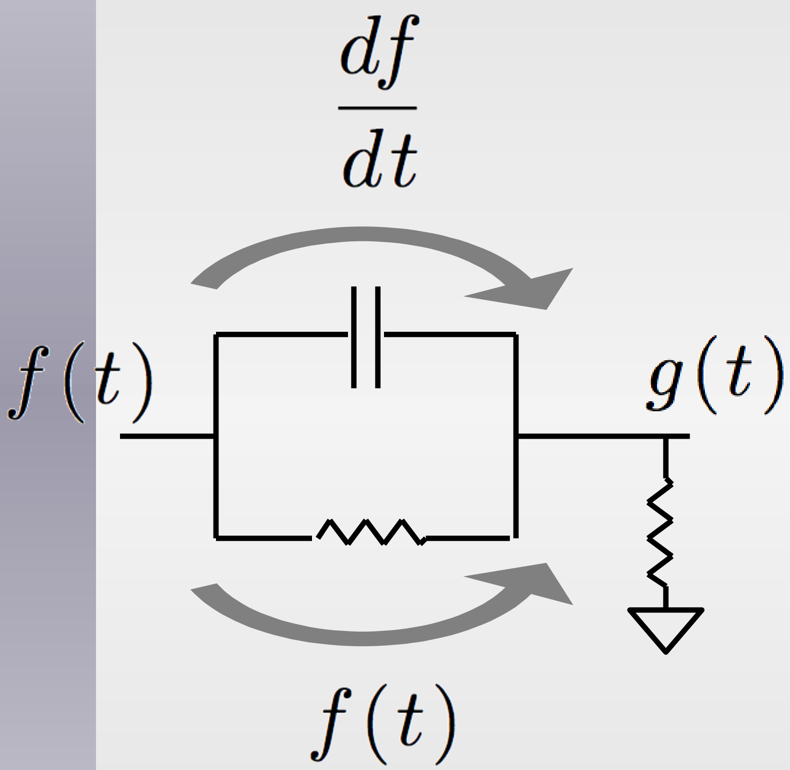
Analytic form of the filtered signal:

$$g(t) = f(t) + a\dot{f}(t)$$

$$f(t) = f_1(t)\, e^{-t/\tau}$$

$$\dot{f}(t) = \dot{f}_1(t)\, e^{-t/\tau} - \frac{1}{\tau} f_1(t)\, e^{-t/\tau}$$

Mathematical form



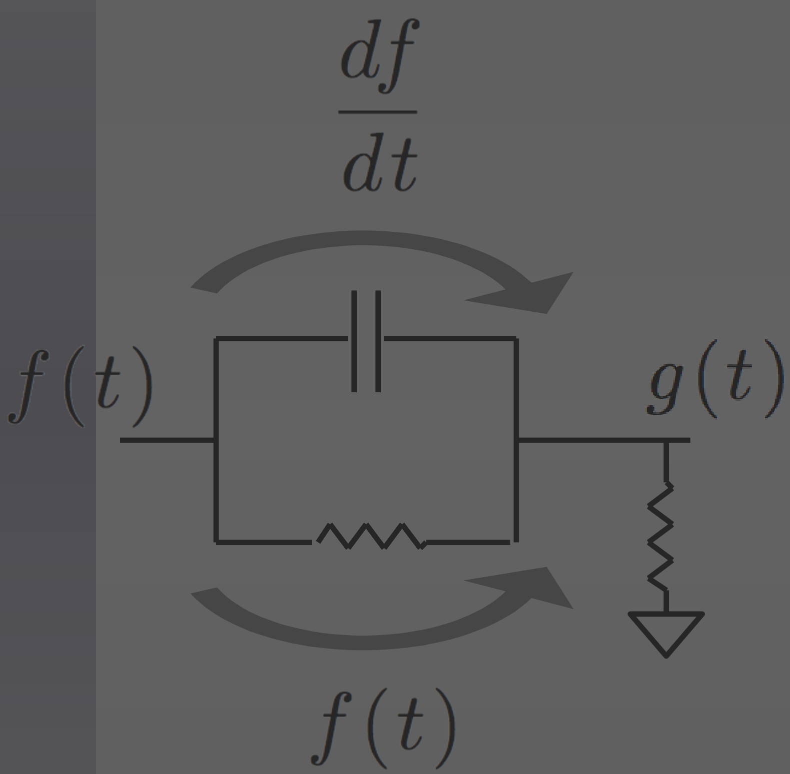
Analytic form of the filtered signal:

$$g(t) = f(t) + a\dot{f}(t)$$

$$f(t) = \boxed{f_1(t)\, e^{-t/\tau}}$$

$$\dot{f}(t) = \dot{f}_1(t)\, e^{-t/\tau} - \boxed{\frac{1}{\tau} f_1(t)\, e^{-t/\tau}}$$

Mathematical form



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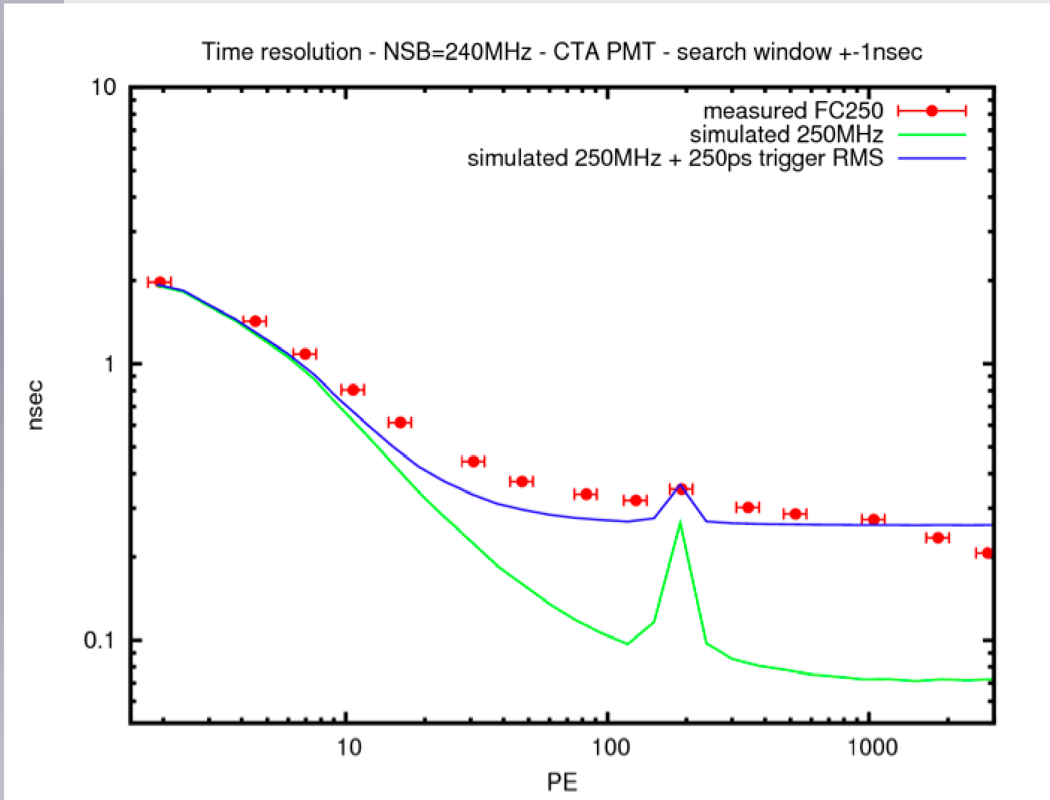
Discrete form:

$$g[i] = f[i+1] - b f[i]$$

(extremely simple form, computationally fast... everyone should be doing this!)

Timing results

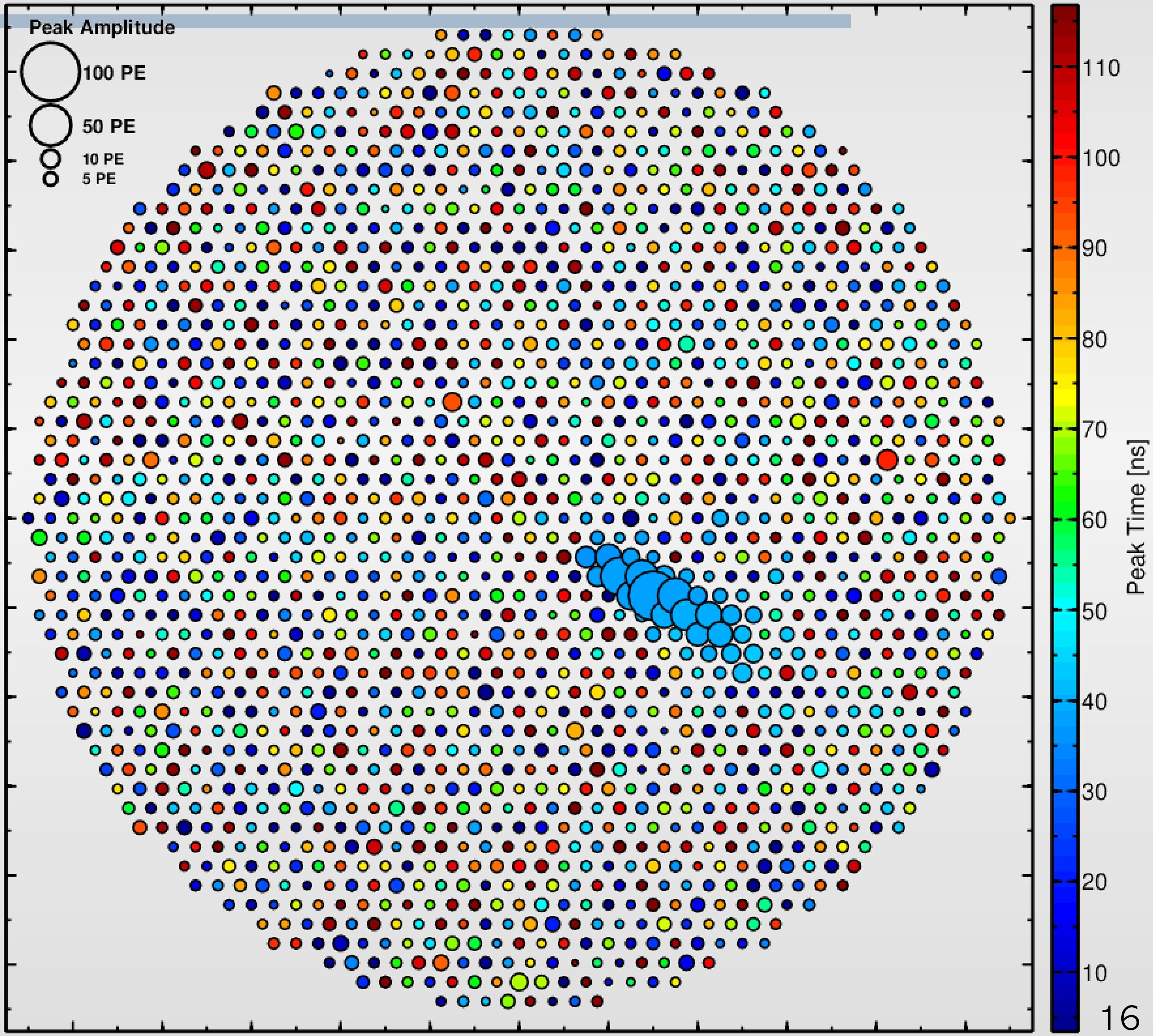


This is a plot you have seen before, but hopefully now with a bit more context. Bottom line: ~500 ps resolution above 20 PE.

Timing results

Now applying this to simulated 1 TeV showers:

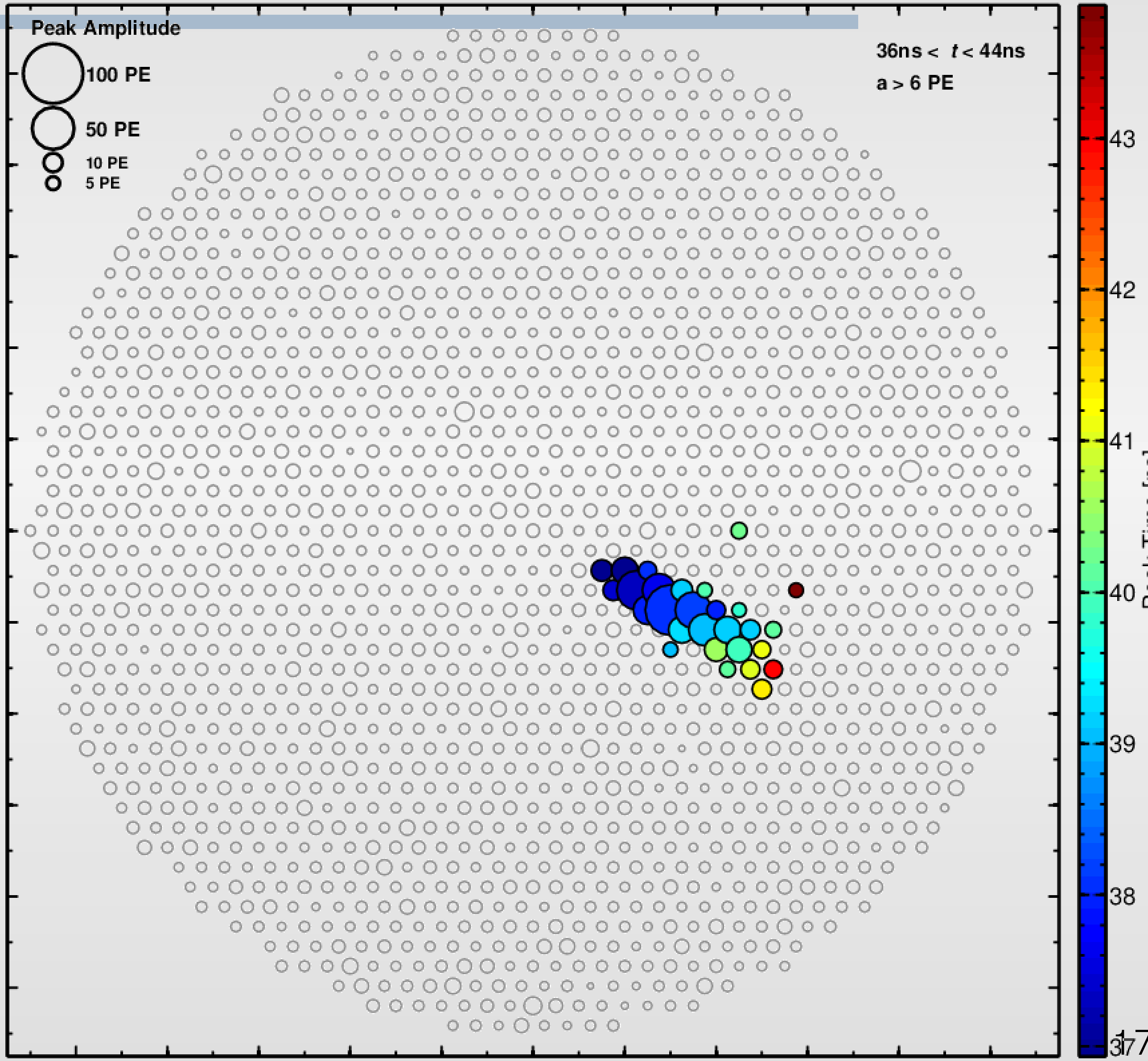
- NSB included (125 MHz)
- Afterpulsing included (1e-4 above 4 PE)
- Baseline noise included (0.1 PE rms)
- Photon time jitter included (1 ns)
- Sampling rate (250 MS/s)
- Dot size gives pixel amplitude
- Dot color gives pixel time



Timing results

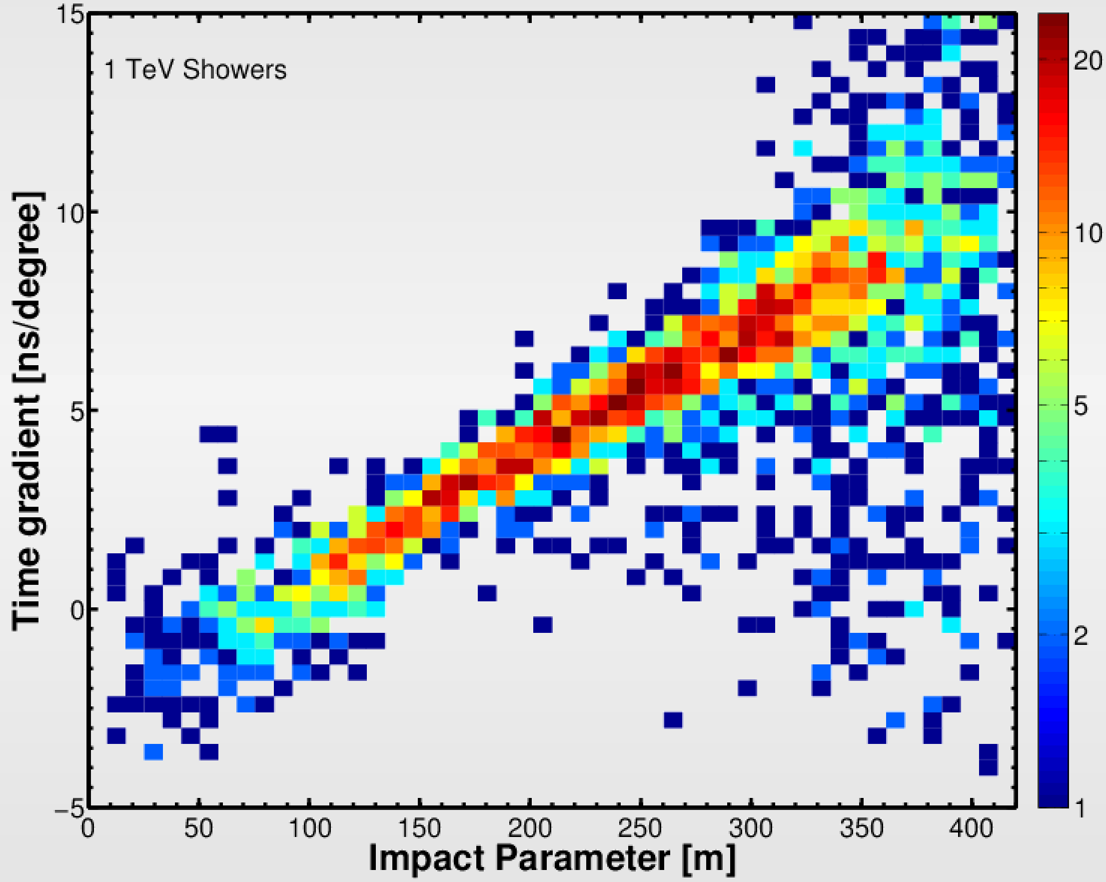
The shower pixels from the previous image are easy to identify. Isolating the signals in amplitude and time allows a “zoom-in” of the shower image.

- A clear time gradient visible, over a range of less than 8 ns (2 ADC samples)



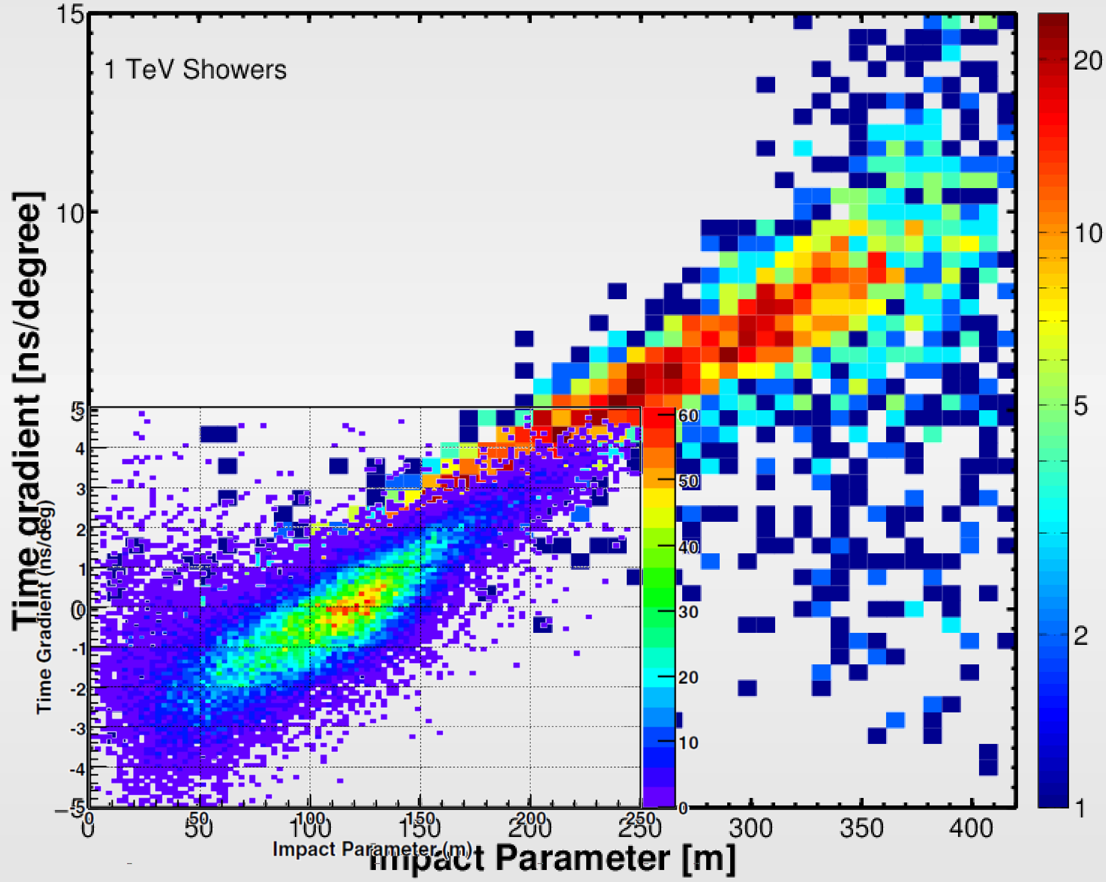
Timing results

- Using very simple and naïve image processing methods, the time gradient versus impact parameter can be easily observed.



Timing results

- Using very simple and naïve image processing methods, the time gradient versus impact parameter can be easily observed.
- I superimpose the similar plot from Pascal's talk at Munich as a comparison (scaled for equal axes).



Summary

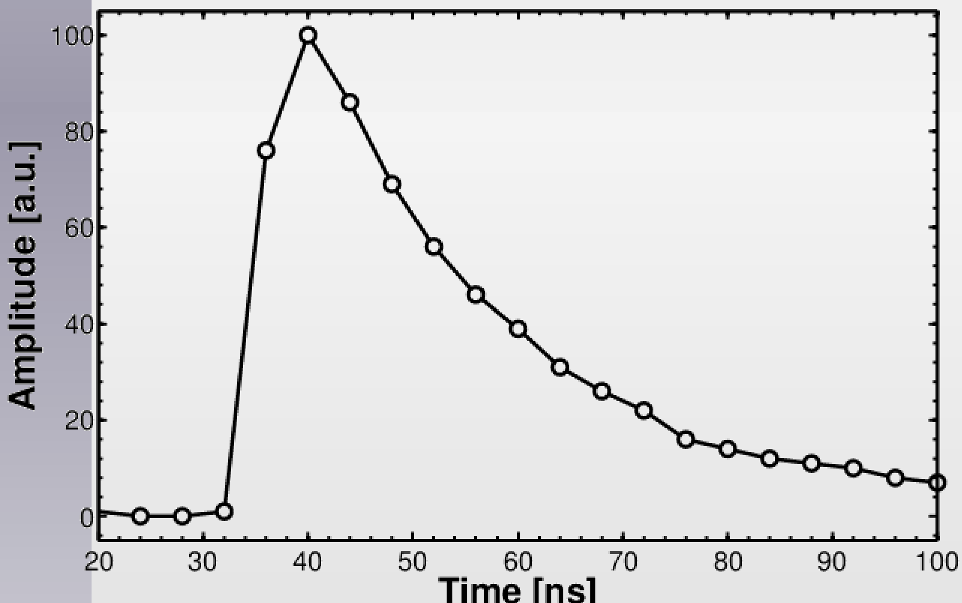
- FlashCam signal processing uses pole-zero cancellation, an old and well-established technique.
- The technique is extremely simple.
- Impulse timing resolution is better than 200 ps above 10 PE.
- Clear time gradients are visible in shower images when applying this technique.

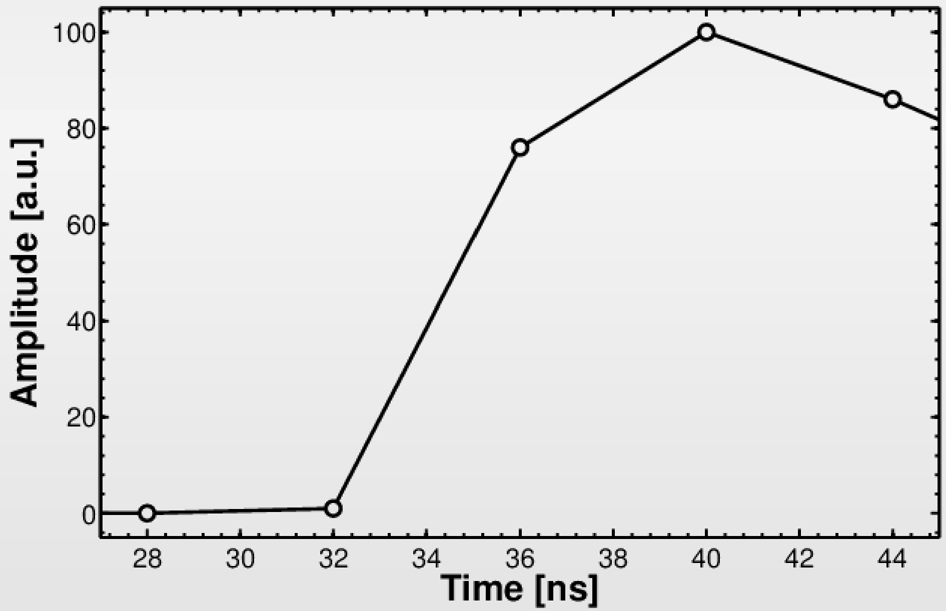
Thanks to Pascal for finding time for these slides in an already tight schedule!

Extra slides

Up-sampling

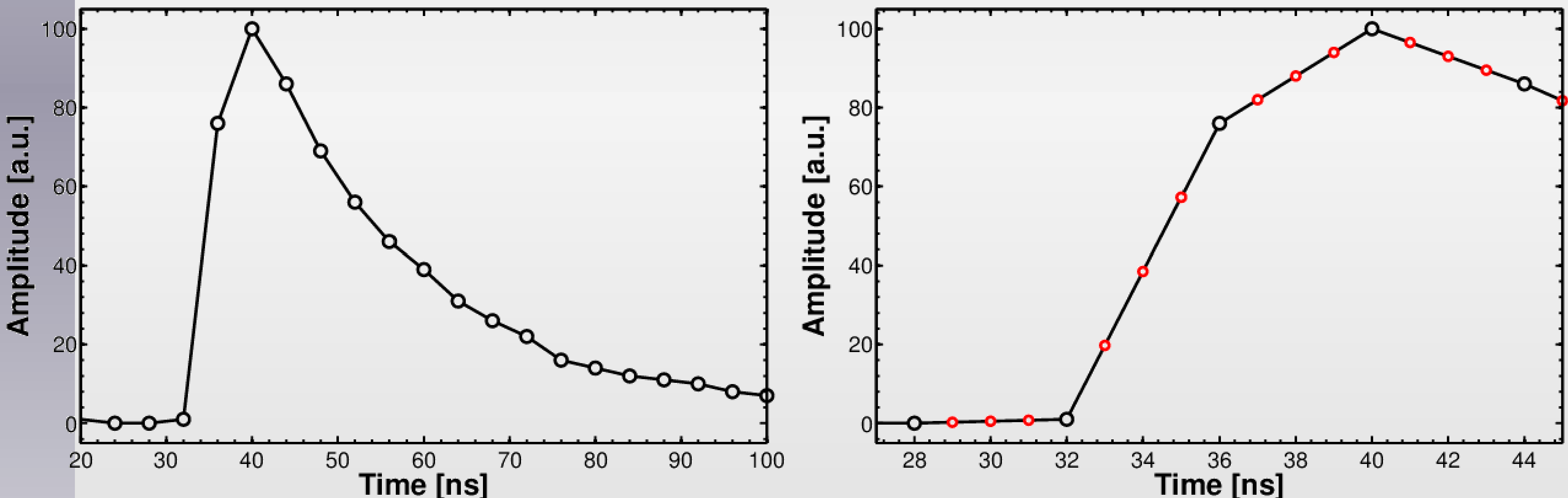
Digitized signal: one sample every 4 ns





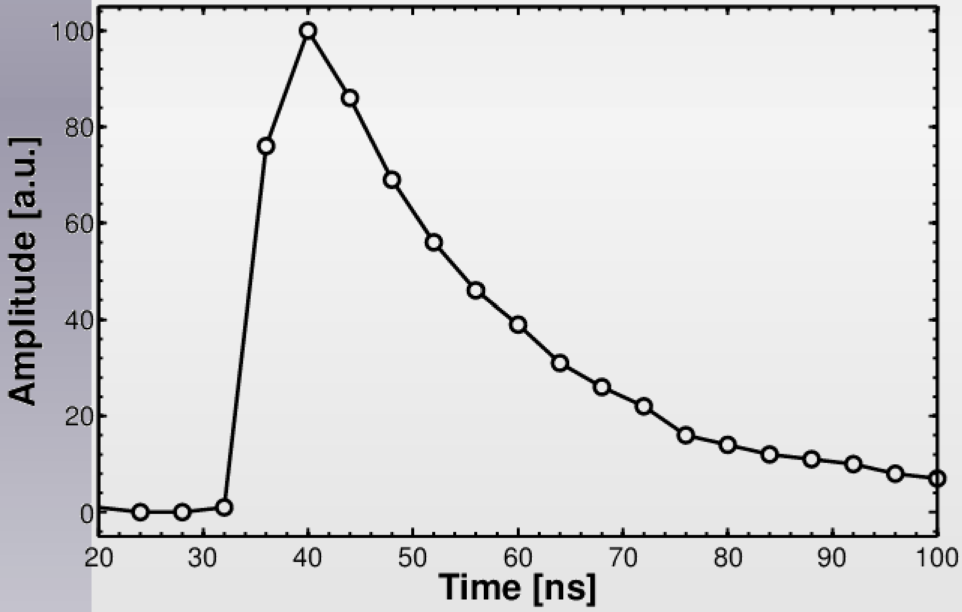
Up-sampling

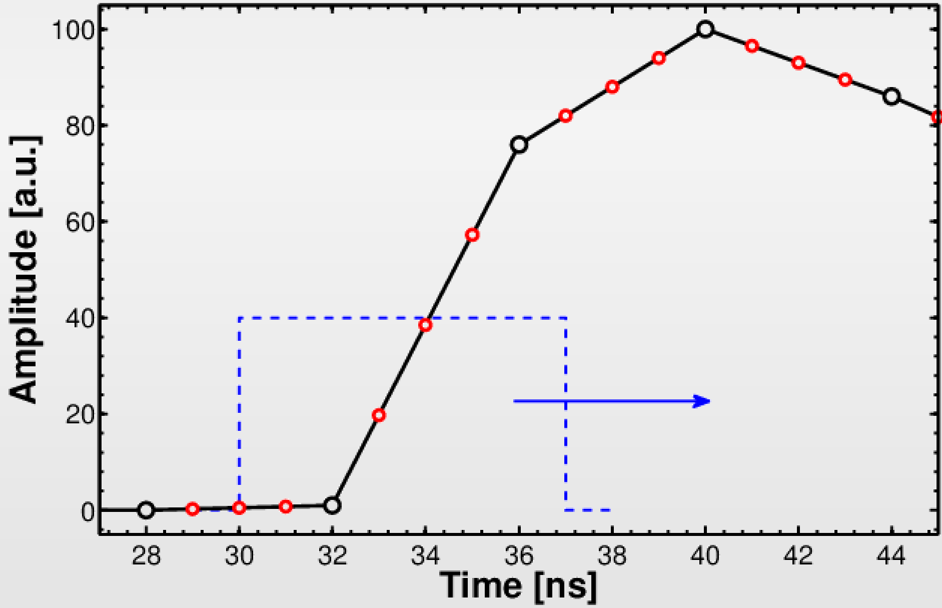
Linear interpolation every 1 ns between ADC samples



Up-sampling

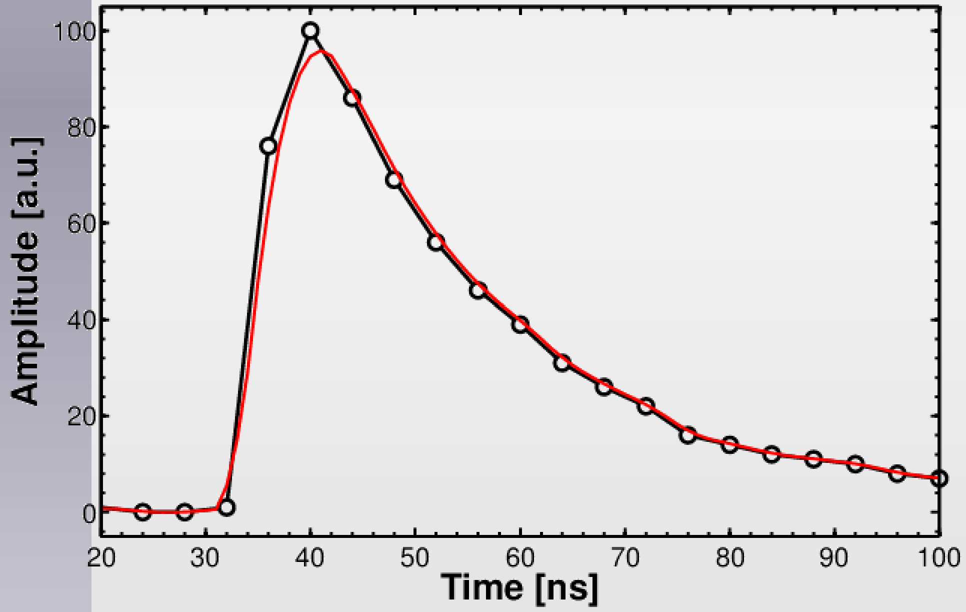
8 ns rolling box average over the interpolated signal

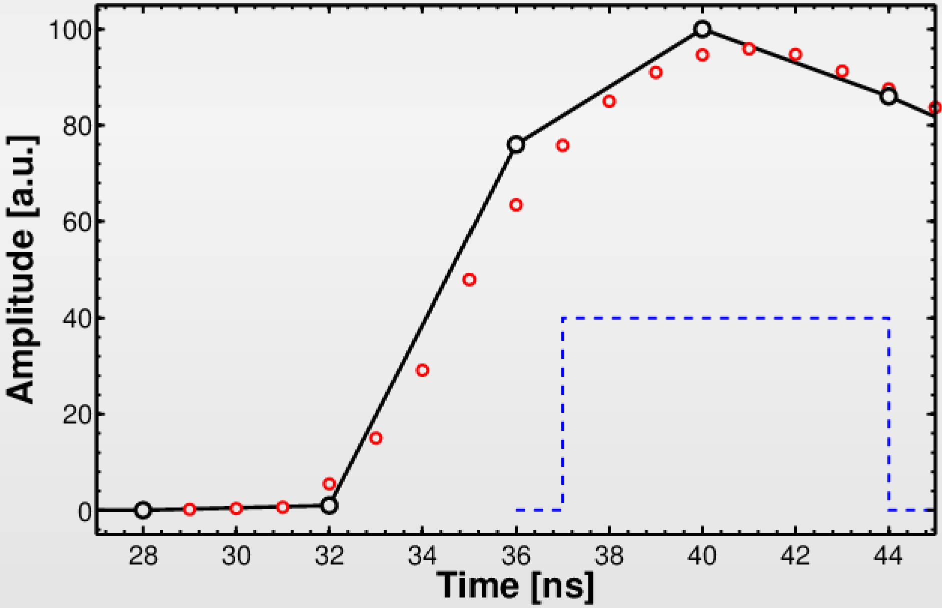




Up-sampling

8 ns rolling box average over the interpolated signal





⟶ and from here, use the pole-zero filter