Development of a prototype of an improved Sum-Trigger for the MAGIC telescopes

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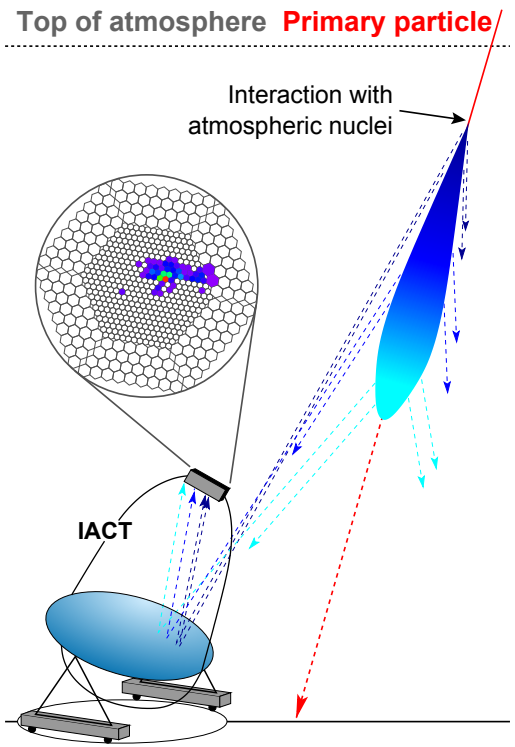
The MAGIC telescopes

- Located on the Canary Island La Palma at 2230m a.s.l.
- Largest IACTs worldwide with two 17m reflectors
- High-resolution PMT cameras (577 and 1039 pixels)
- Advantage: low detection energy threshold ($\geq$ 55 GeV)
- Analog Sum-Trigger (since 2008) reduced threshold to 25 GeV

  $\rightarrow$ detection of pulsed γ-rays from Crab pulsar (SCIENCE publication)



Motivation for lower energy observation with Sum-trigger

Observation in the γ-ray regime provides new hints for physical mechanisms in cosmic objects

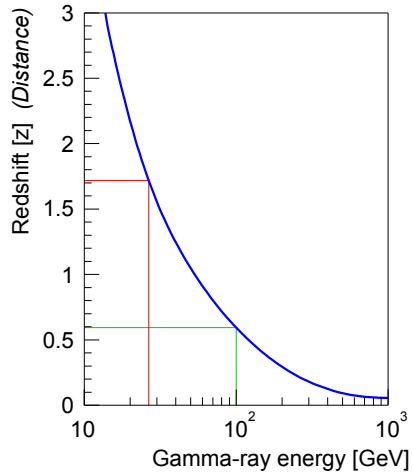
Some classes of γ-ray sources can only be observed below 100 GeV

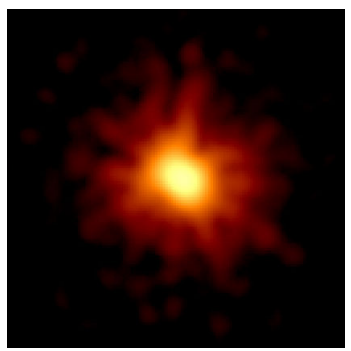
due to the γ-ray production process

- **Pulsars**

due to their distance (EBL absorption)

- high-redshift **AGNs**
- **GRBs**





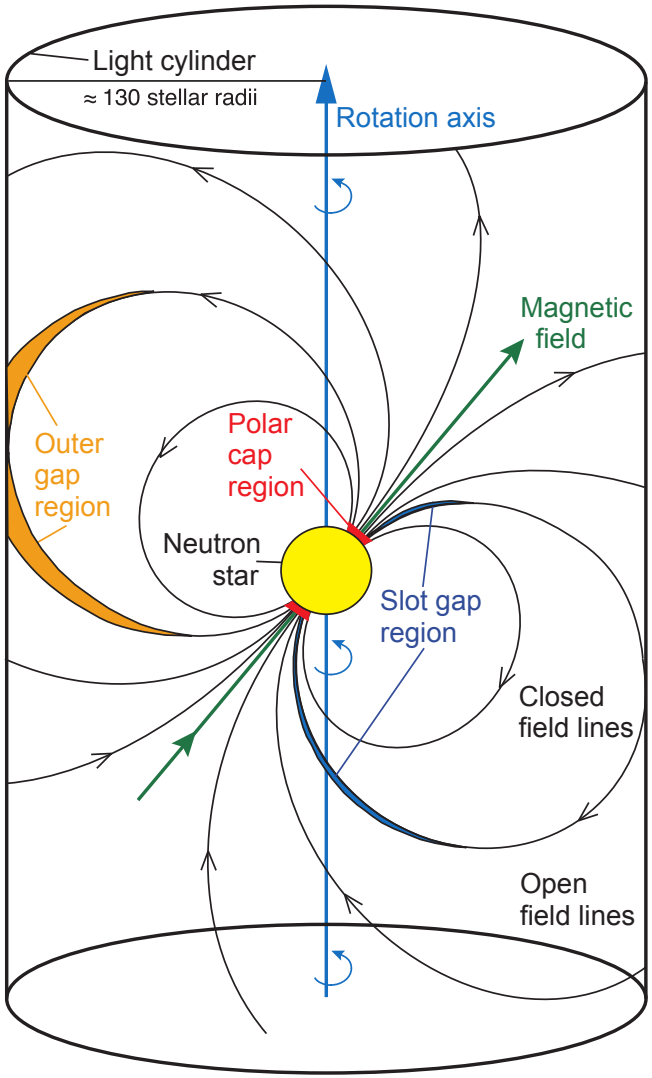
Satellite instruments cover up to 300 GeV, with low efficiency

IACTs with standard setup can only observe *above* 50 GeV

To cover the full range of sources, a trigger with very low energy threshold (< 50 GeV) is indispensable

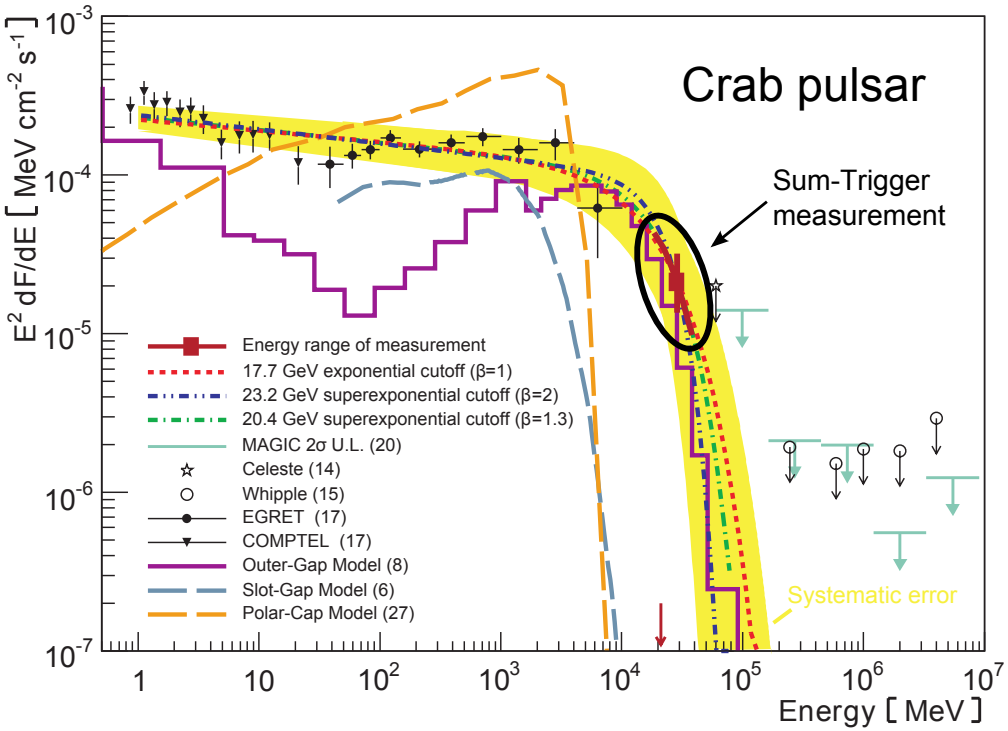
$\rightarrow$ Sum-Trigger is a simple and well proven solution

γ-ray production processes in pulsars



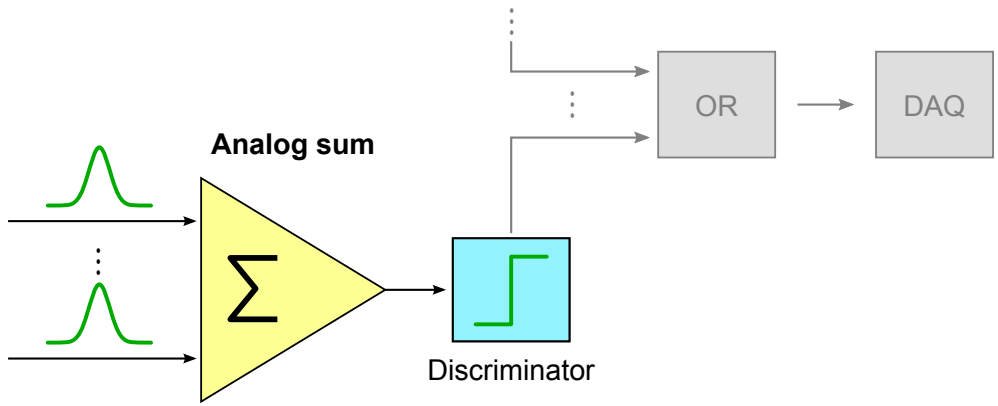
Three concurrent models:

- Polar-Cap model $\rightarrow$ steep cutoff (absorption in magnetosphere)
- Slot-Gap model $\rightarrow$ shallower cutoff
- Outer-Gap model $\rightarrow$ shallow cutoff at higher energies



Principle of the analog Sum-Trigger

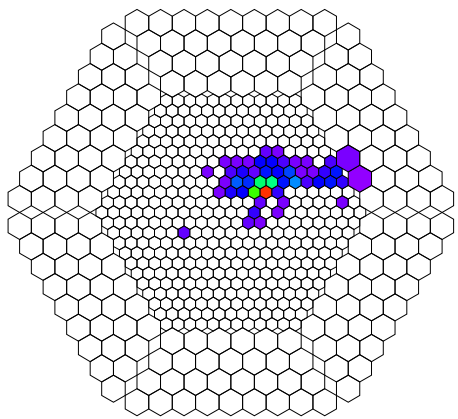
- Analog sum of the signals from adjacent pixels (patch) is produced
- Discriminator is applied to the summed analog signal



→ **Topological** and **timing** constraints:
- Cherenkov light cones produce **extended** images
- Duration of such a Cherenkov flash: **2 - 6 ns**

→ Takes into account **small signals** below the *single channel discriminator* threshold (standard trigger)

→ Charge integration of larger area (> 4NN) increases "signal to noise ratio" compared to standard trigger

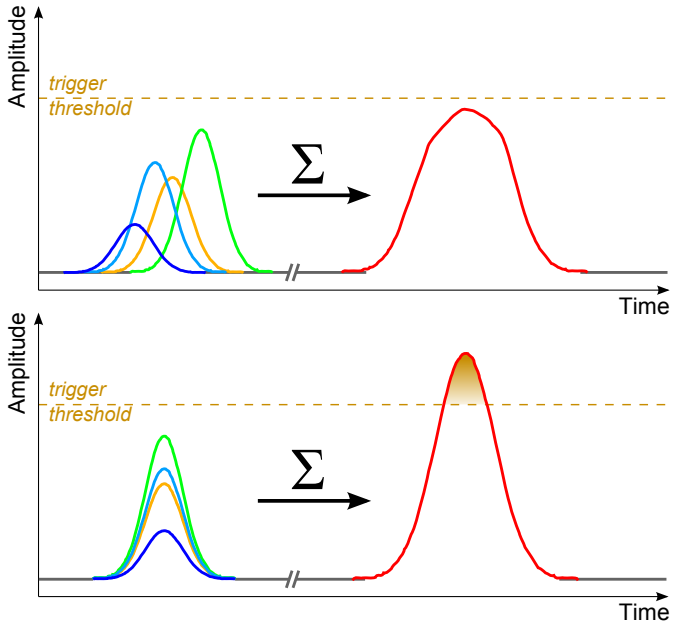


New analog Sum-Trigger II

Main problem:

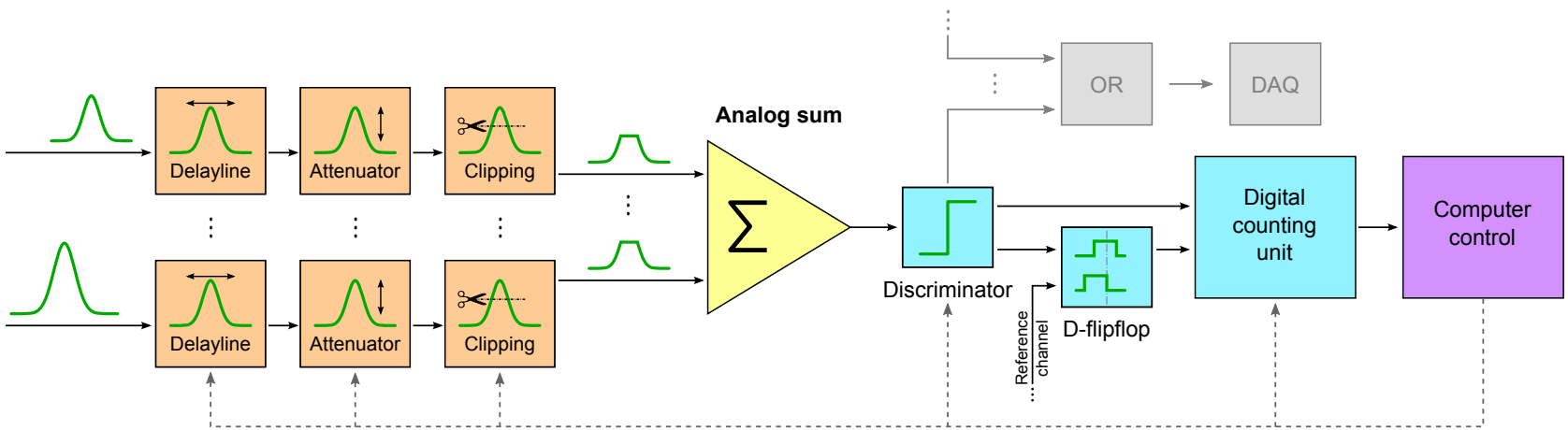
- PMTs introduce differing delays and gains which can **change with time**
- For a correct "pile up" of signals in sum, **precise timing** is required

Current Sum-Trigger only manually adjustable
$\rightarrow$ intensive maintenance required



$\Longrightarrow$ Prototype of a ***new*** **Sum-Trigger** was developed with completely **automated equalization** of **delay** and **gain** per channel

Basic principle:

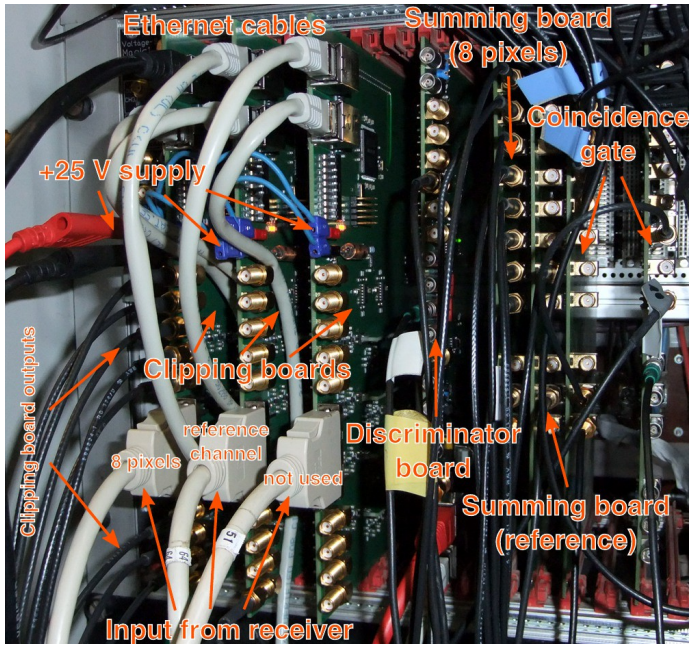


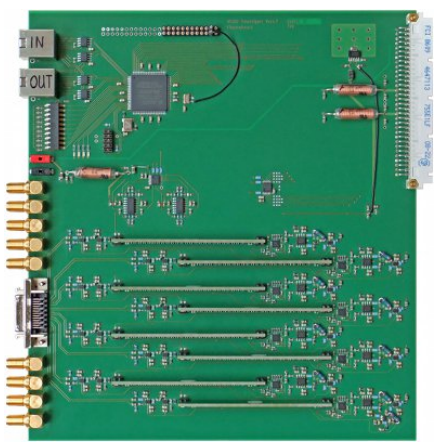
Sum-Trigger II prototype

- **Fully functional prototype** has been designed and built in 2010
- Prototype was tested in August 2010, temporarily installed in MAGIC I

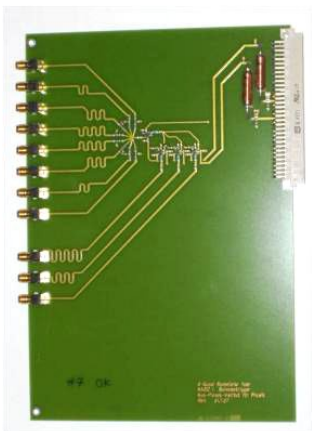
→ New concept of automatic calibration **works satisfactorily**

→ Roughly estimated trigger performance agrees with current Sum-Trigger

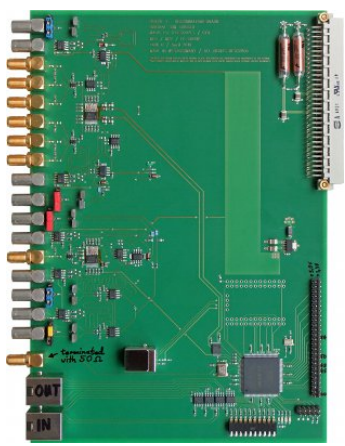




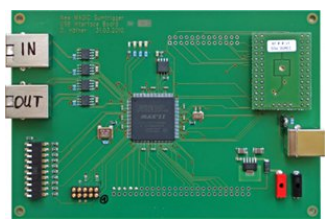
Clip-board



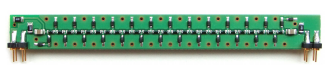
Sum-board
(from old system)



Discriminator-board

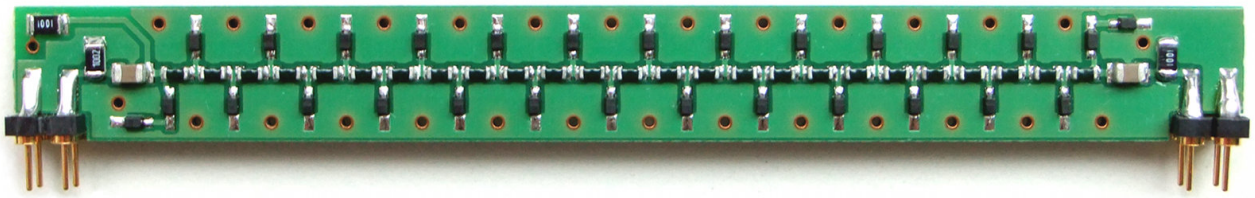


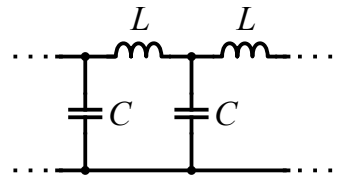
Computer-control-board

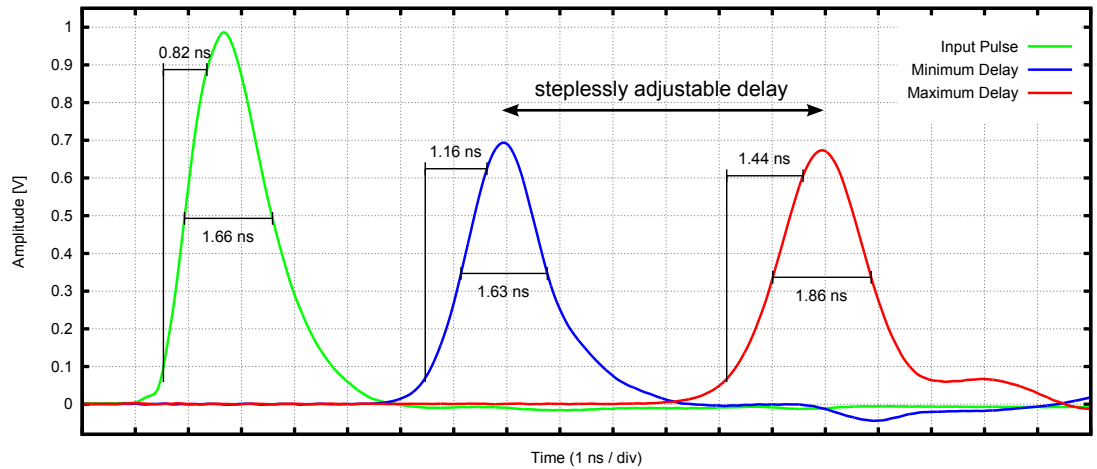


Delay line

Adjustable analog delay line prototype







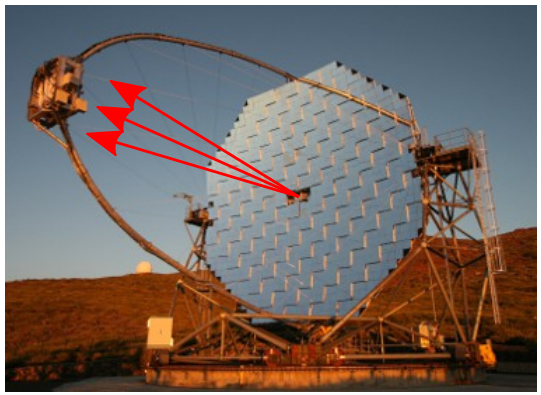
This first prototype module features:

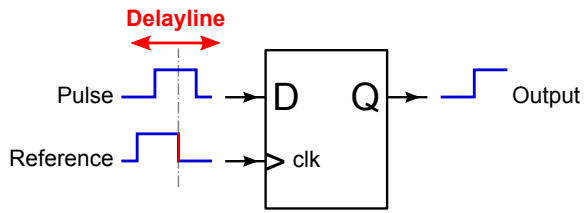
- **Cutoff frequency:** $>$ **420 MHz** @ min. delay, **300 MHz** @ max. delay
- **Total span of delay: 6 ns**. If less required $\rightarrow$ higher bandwidth
- **Temperature stability:** $\ll$ 10 ps between 5°C and 30°C
- **Precision:** $\ll$ 10 ps, no hysteresis, depends solely on applied voltage
- **Tolerance:** no differences in delay or attenuation among modules

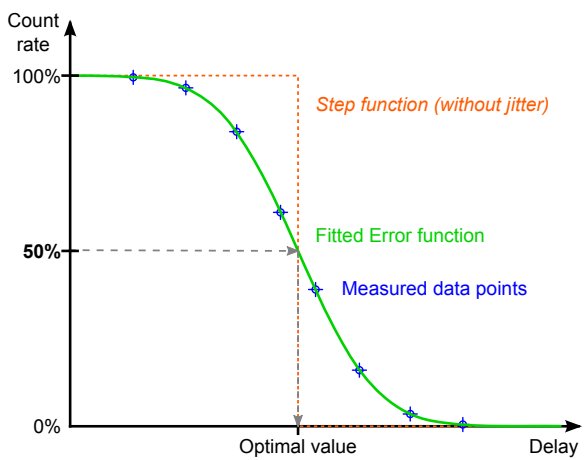
Calibration process: Delay adjustment

- Calibration pulses illuminate all camera pixels
- One single channel is **time reference**
- Measuring channel by channel
- Ultra-fast **ECL D-flipflop** reveals if pulse is *earlier* than reference
- **Rate** of output signals of D-flipflop is recorded for various delay settings
  - Ideal case: no jitter $\rightarrow$ step function
  - Real case: **delay jitter**
  - Step function "smoothes out" $\rightarrow$ shape of **Error function**
- **Inflection point** (50% Rate) represents optimal value

$\rightarrow$ Equal delays (rising edges coincide)



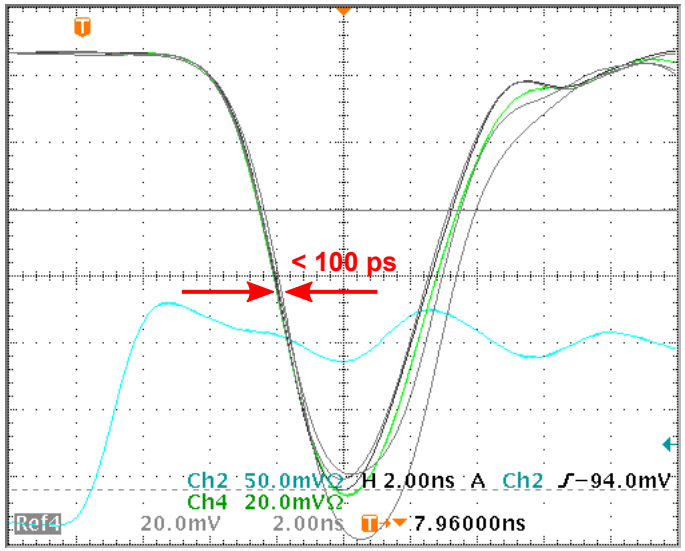


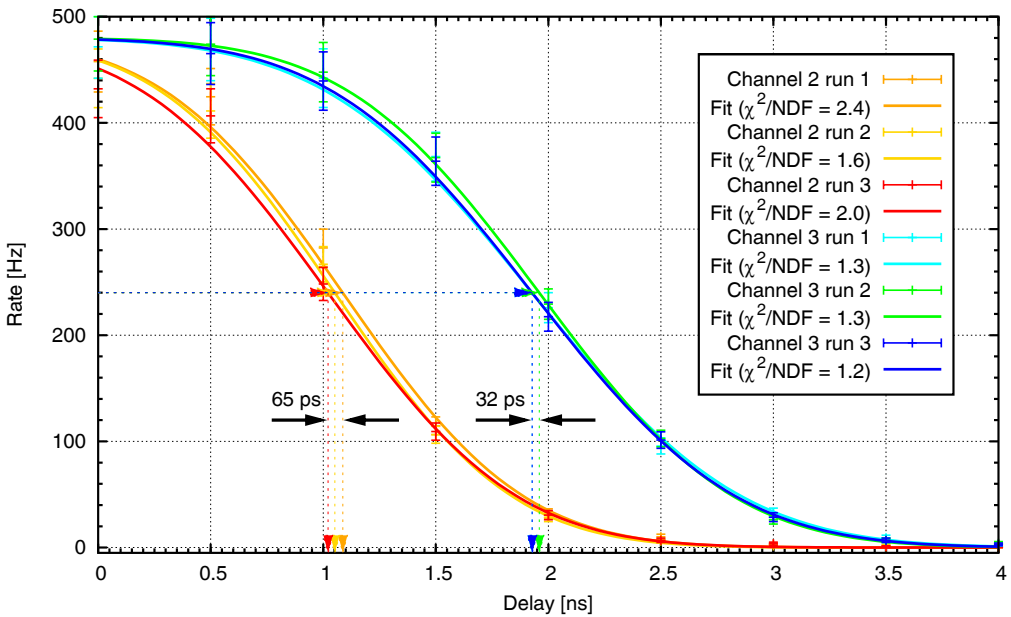


Calibration process: Delay adjustment

Precision of delay adjustment:

- Variance of "optimal" values of repeated calibration runs on **same** channel:
  $< \mathbf{70\ ps}$
- Largest difference in delay (rising edges) among **all 8** prototype channels:
  $< \mathbf{100\ ps}$





→ Sufficient precise:
Required precision only ≈ **250 ps**

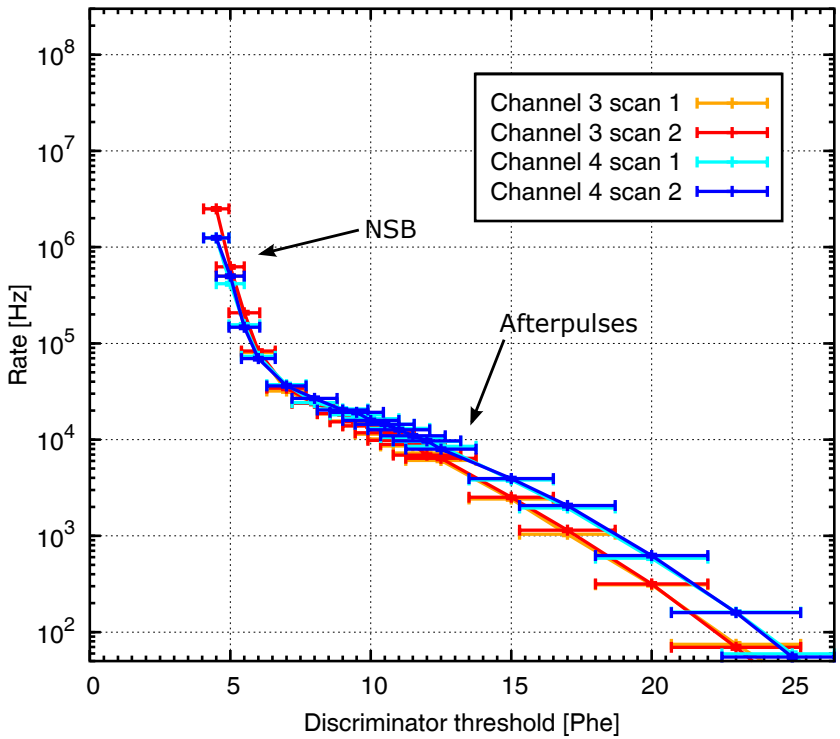
→ Width of measurement steps can be increased

→ Less counting processes required

→ Calibration procedure can be speeded up

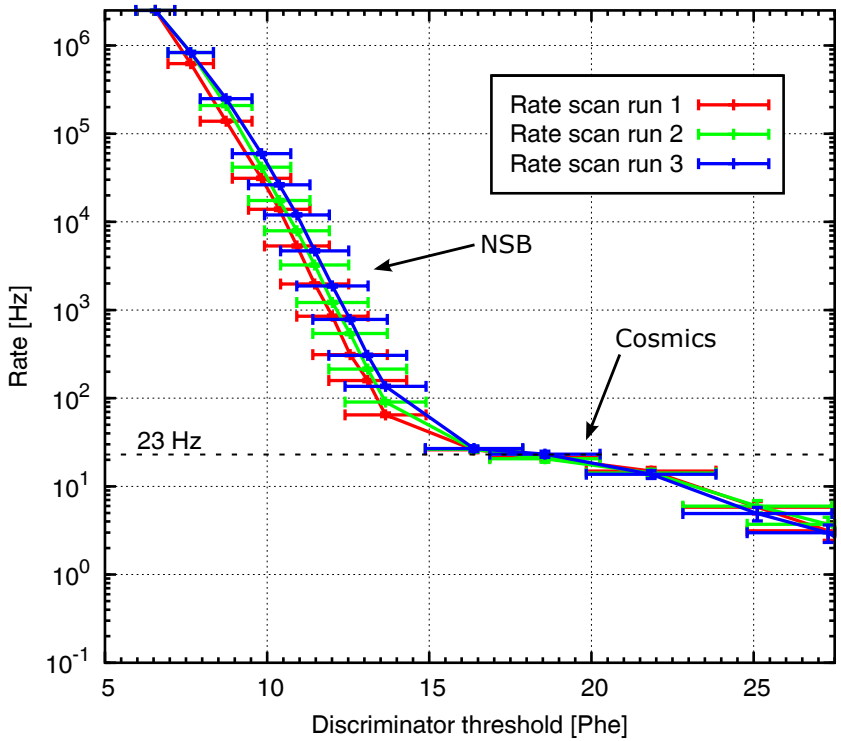
Sum-Trigger II prototype measurements

Individual pixel rate:



→ Kink at 6 - 6.5 Phe
→ correct conversion factor from pulse amplitude (mV) to Phe was derived

Sum of 8 pixels (clipped @ 6 Phe):



Assumption: cosmic rate scales linear with patch area
→ rate (23Hz) in accordance with current Sum-Trigger (50Hz)

Conclusion

- Current analog Sum-Trigger: Great success in detecting pulsed γ-rays from Crab pulsar
- Efficient tool for observation of pulsars and distant GRBs (EBL absorption)
- New Sum-Trigger
  - facilitates setup, calibration and maintenance
  - can further reduce energy threshold below 25 GeV when used in stereo mode (MAGIC I + II at once)
- Adjustable analog delay line
  - adjustment of delays in many fields of application
  - cost-effective design
- Outlook for next generation Cherenkov Telescope Array (CTA)
  - lowest trigger threshold possible
  - Sum-Trigger can reduce total cost
  - low power consumption and low heat emission