# Performance of the prototype of an improved Sum-Trigger for the MAGIC telescopes

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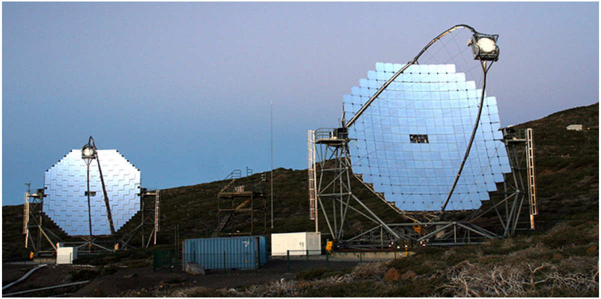
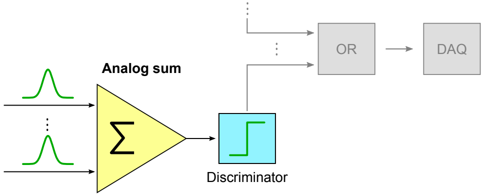
## The MAGIC telescopes

- Located on the Canary Island La Palma at 2230m above sea level
- Detect faint Cherenkov flashes induced by cosmic particles
- Two telescopes, largest IACTs worldwide with two 17m reflectors
- Highly sensitive 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 $\gamma$-rays from Crab pulsar (SCIENCE publication)



# Principle of the 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 are applied to the signals:

- Cherenkov light cones produce **extended** images on camera
- 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 ($> 4$NN) increases "signal to noise ratio" compared to standard trigger

$$U_{NoiseSum} = \sqrt{U^2_{NoiseSrc1} + U^2_{NoiseSrc2} + \cdots + U^2_{NoiseSrcN}}$$

# New analog Sum-Trigger II

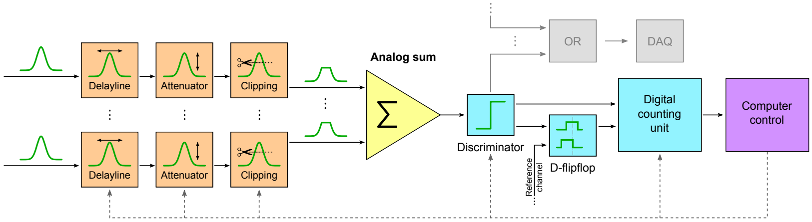
Main problem:

- Camera (PMTs), electronics, and optical fibers introduce differing delays and gains among channels, which can **change with time**
- For a correct "pile up" of signals in sum, precise timing is required

Gains and delays of current Sum-Trigger are only manually adjustable
→ intensive maintenance from experts is required

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

Basic principle:

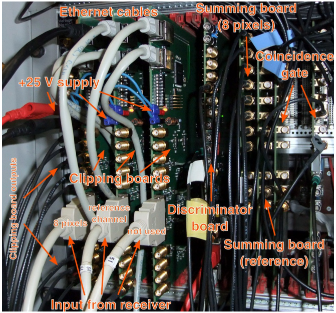


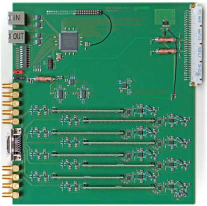
# Sum-Trigger II prototype

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

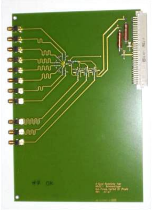
→ New concept of automatic calibration works satisfactorily

→ Roughly estimated trigger performance agrees with current Sum-Trigger

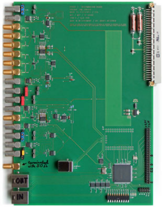


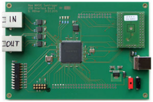
Clip-board



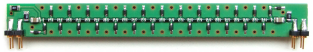
Sum-board
(from old system)



Discriminator-board

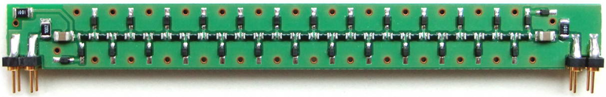


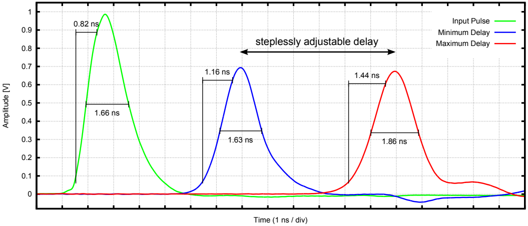
Computer-control-board



Delay line

# Adjustable analog delay line prototype





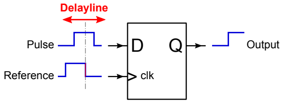

This first prototype module features:

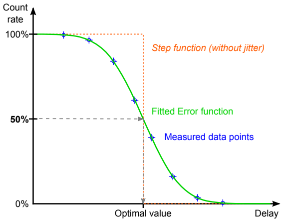
- **Cutoff frequency: > 420 MHz** @ min. delay, **300 MHz** @ max. delay
- **Total span of delay: 6 ns**. If less required → higher bandwidth
- **Temperature stability:** ≪ 10 ps between 5°C and 30°C
- **Precision:** ≪ 10 ps, no hysteresis, depends solely on applied voltage
- **Tolerance:** no differences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

# Calibration process: Delay adjustment

- Calibration pulses synchronously illuminate all camera pixels
- One single channel is **time reference** to which ALL other channels are aligned
- Only the channel which is to be measured is ON, all others are **disabled** (OpAmps OFF)
- Ultra-fast **ECL D-flipflop** is used to tell whether pulse is *earlier* than reference pulse
- **Rate** of HIGH output signals of D-flipflop is recorded for various delay settings
  - Ideal case: no jitter → step function
  - Real case: **delay jitter**
  - Step function "smoothes out" → shape of **Error function**
- **Inflection point** (50% Rate) represents optimal value

→ Equal delays (rising edges coincide)

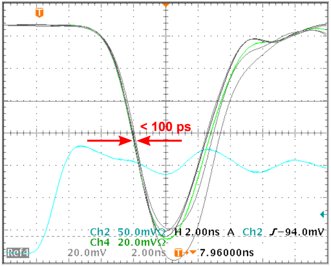


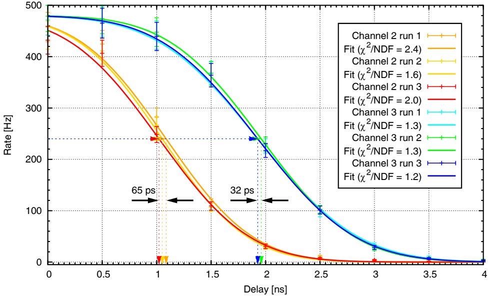



# Calibration process: Delay adjustment

Precision of delay adjustment:

- Variance of “optimal” values of repeated calibration runs on **same** channel: **< 70 ps**
- Largest difference in delay (rising edges) among **all 8** prototype channels: **< 100 ps**




→ Too precise: Required precision only ≈ 250 ps

→ Width of measurement steps can be increased

→ Less counting processes required

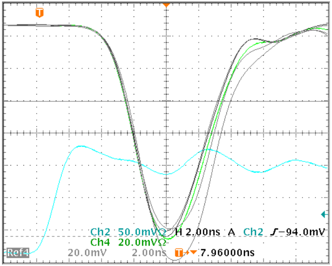
→ Calibration procedure can be speeded up

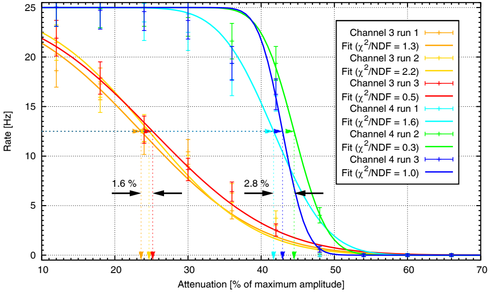
# Calibration process: Gain adjustment

Gain flat-fielding identical, except:

- Instead of D-flipflop a **discriminator** compares signal *amplitude* with reference *voltage*
- Rate of discriminator output is recorded for various **attenuation** levels

→ Amplitude jitter → Error function




→ Too precise: < 5% possible, but only ≈10% required

→ Width of measurement steps can be increased

→ Calibration procedure can be speeded up

# Conclusion

- Current analog Sum-Trigger: Great success in detecting pulsed $\gamma$-rays from Crab pulsar
- Indispensable for observation of pulsars and distant AGNs and GRBs (EBL absorption)
- New Sum-Trigger will
  - facilitate setup, calibration and maintenance
  - further reduce energy threshold below 25 GeV (more precise "stacking" of pulses in sum)
- Using rate scans for calibration enables
  - simple, robust, and cost-effective circuits
  - high precision in adjustment
- Adjustable analog delay line allows
  - adjustment of delays in many fields of application
  - cost-effective designs
- Outlook for next generation Cherenkov Telescope Array (CTA)
  - Sum-Trigger can help to reduce total cost
  - meets requirements for low power consumption and low heat emission