NECTAr: New Electronics for the Cherenkov Telescope Array

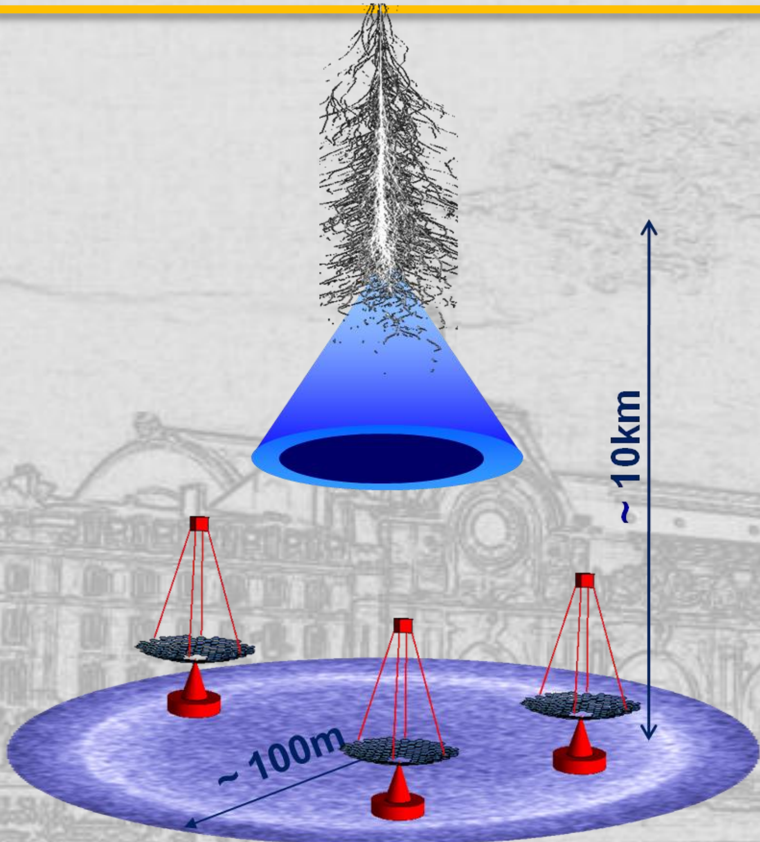
PHOTODET 2012, Orsay

Christopher Lindsay Naumann

LPNHE Paris

on behalf of the CTA consortium

Motivation: FE electronics for CTA



Imaging Cherenkov Telescopes:

indirect detection of TeV gamma rays: Cherenkov light from e.-m. showers

cameras with O(10^3) PMTs → shower shape

signal in each pixel: pulse few ns long, amplitude 1 to > 10^3 photons per pixel

optical noise: ~100 MHz per pixel

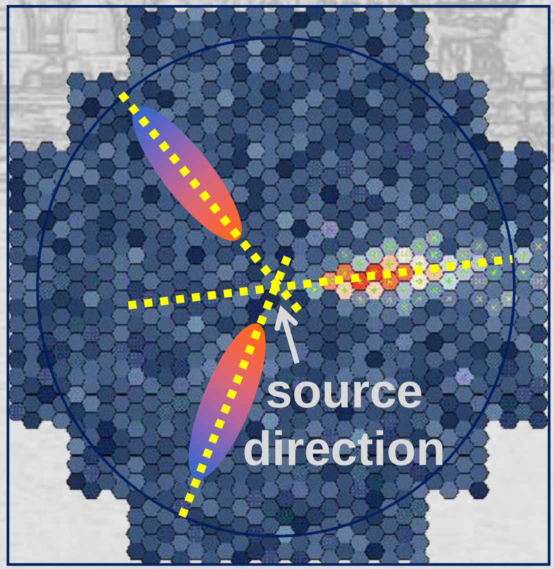
→ fast and low-noise FE electronics

CTA (2014+): ~100 telescopes, O(10^5) channels

→low cost, compactness, high reliability

→several camera projects

*here: **NECTAr project for MST***



The NECTAr Project

NECTAr: 3-year programme (2009+), financed by ANR

development of highly-integrated front-end electronics for the CTA Cherenkov telescope array (focus: medium-size telescope)

aims:

- improved version of existing hardware (HESS, MAGIC)
- high degree of integration (ASIC) but also flexibility (clusters)

- **requirements**:
  - charge and time of Cherenkov signal → high analogue bandwidth
  - several GS/s sampling, few μs readout dead-time
  - flexible window, full or partial readout

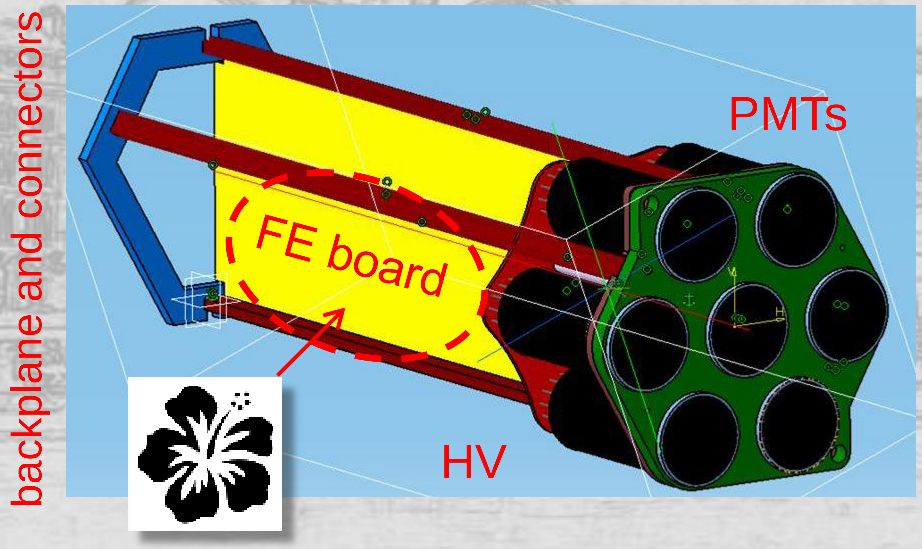
participants:

LPNHE, IN2P3/CNRS Universités Paris VI
IRFU/CEA/DSM, Saclay, Gif-sur-Yvette
LUPM, Université Montpellier II
ICC-UB, Universitat Barcelona, Barcelona, Spain (associated)

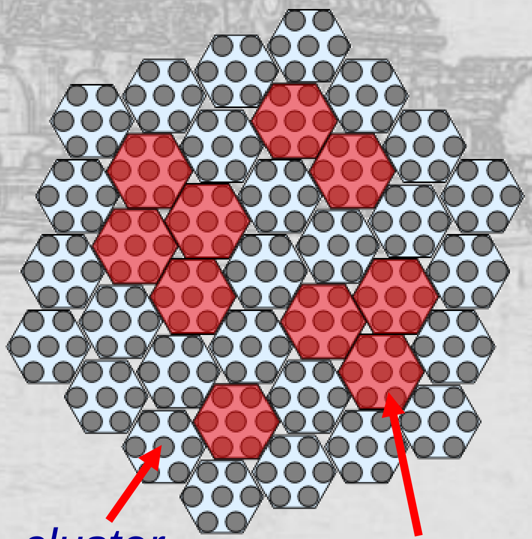
Modular cameras

CTA camera separated into clusters of 7 pixels each → flexibility

- PMTs, HV board, front-end board, backplane
- shared readout and communication
- limited inter-cluster communication (trigger)
- semi-autonomous triggering and readout



schematic of mechanical structure (MST: 1987 pixels total)



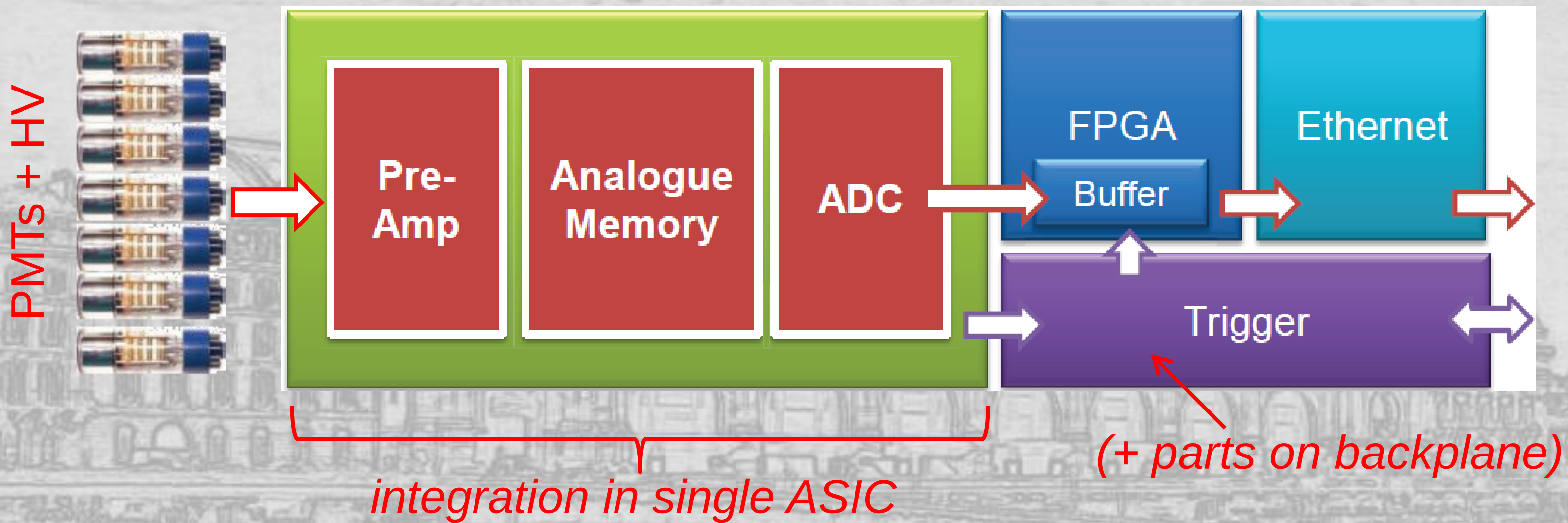
-triggering: groups of adjacent cluster

-support for partial readout

The NECTAr board

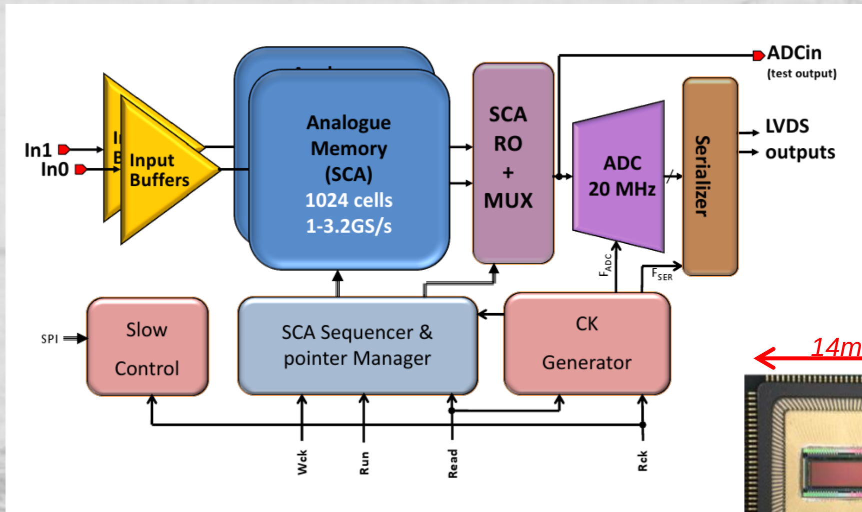
combination of amplifiers, memory, ADC, trigger, readout and communication on single board → ***1 board per cluster (7 pixels)***

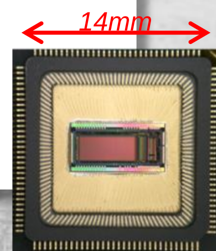
autonomous readout: on-board FPGA (signal treatment and processing)



- two-level trigger system: pixels in each cluster (L0), adjacent clusters (L1) options: *analogue* (IFAE, UCM, CIEMAT) or *digital* (DESY)
- multiple gains per pixel possible → large dynamic range
- pre-amplifiers, analogue memory and ADC combined into single ASIC (→ "NECTAr chip")

The NECTAr chip





single ASIC containing memory, ADC and amplifiers

multiple channels per chip, up to 8 chips per board

→***prototype NECTAr0***

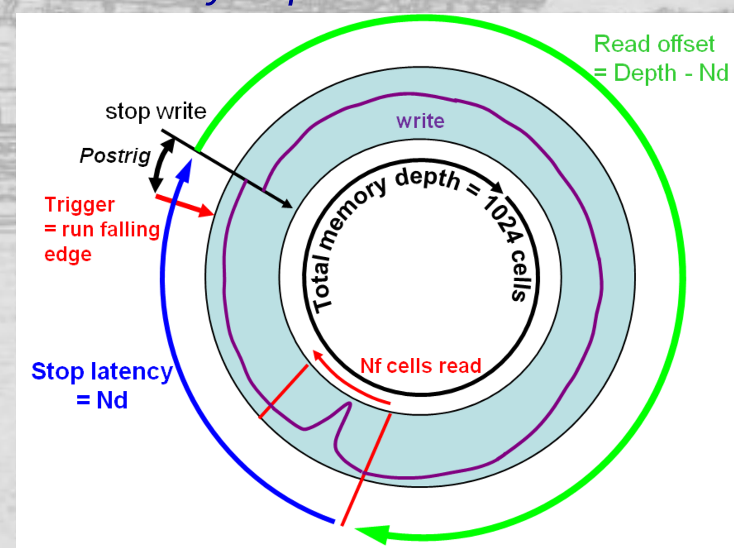
CMOS AMS 0.35µm, 3.3 V

analogue ring memory (SCA), 1024 bins

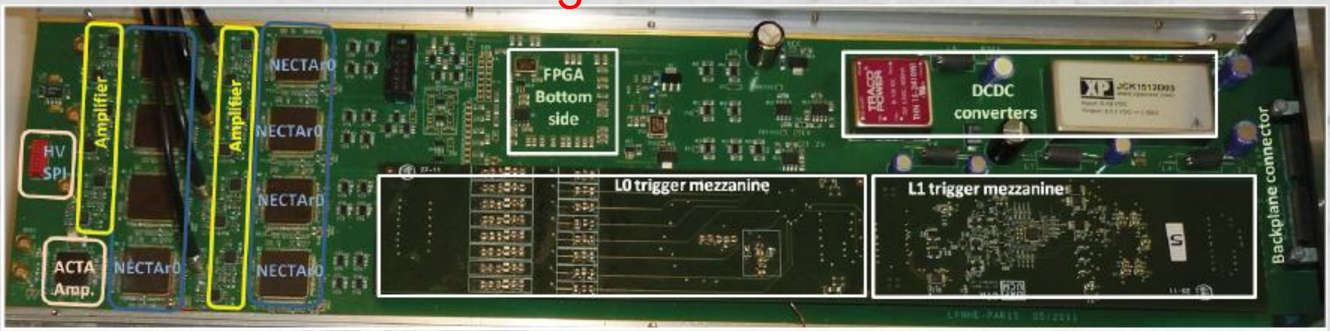
- based on SAM chip (used in HESS-II)
- sampled at 0.4 – 3.2 GS/s
- 2 channels each → 2 gains per PMT
- when triggered, read with *programmable latency (N_d), region of interest possible*

readout: 20MHz ADC controlled by FPGA
→2µs-3.2µs (16-32 samples)

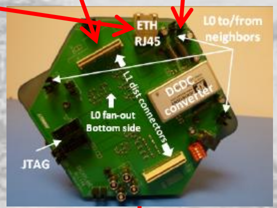
memory depth: 1024ns at 1GS/s



Development: The NECTAr module



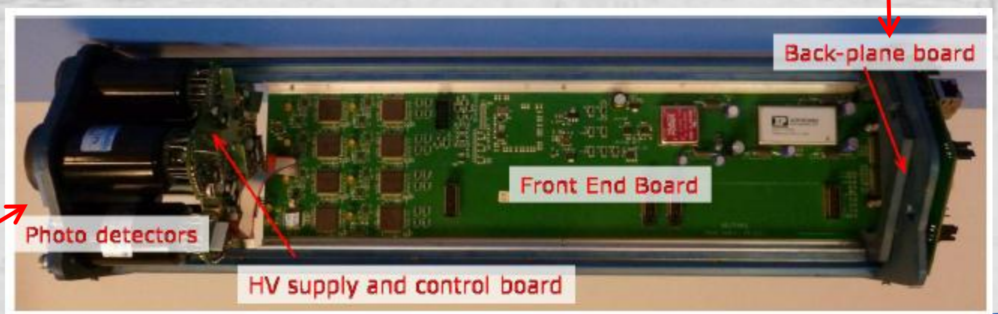
ACTA amplifiers (1), 8x NECTAr0 chips (2), ALTERA FPGA (3), DC/DC converters (4), L0 (5) and L1 (6) trigger mezzanines



integrated **in full cluster prototype** (+ 7 PMTs + HV + backplane)

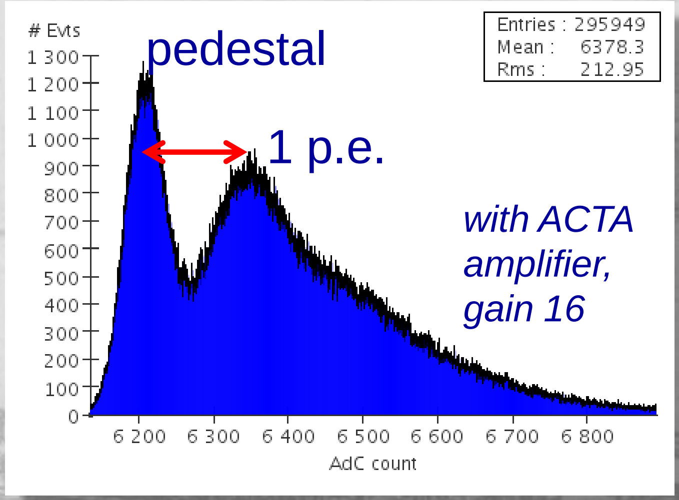
→*semi-autonomous "mini camera"*

measurement of chips alone and in full cluster setup



HAMAMATSU R11920-100-01 (1.5")

Performance



single-photoelectron spectrum measured at (low!) PMT gain of 5x10^4

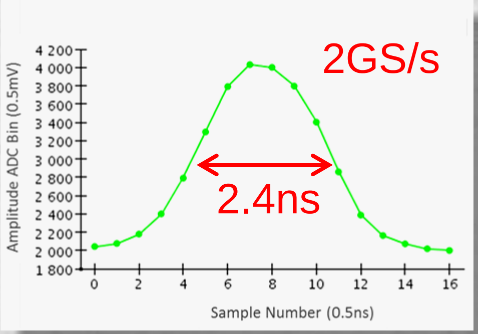
→ clear separation pedestal / single p.e.

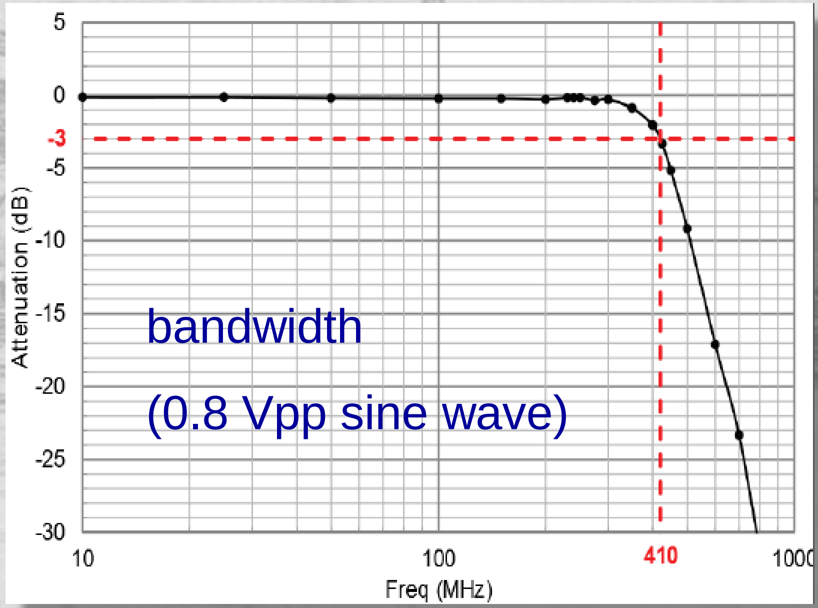
→ **calibrate system at nominal gain at run-time**

analogue bandwidth measured with test board = **410MHz** (-3dB)

requirement 300MHz

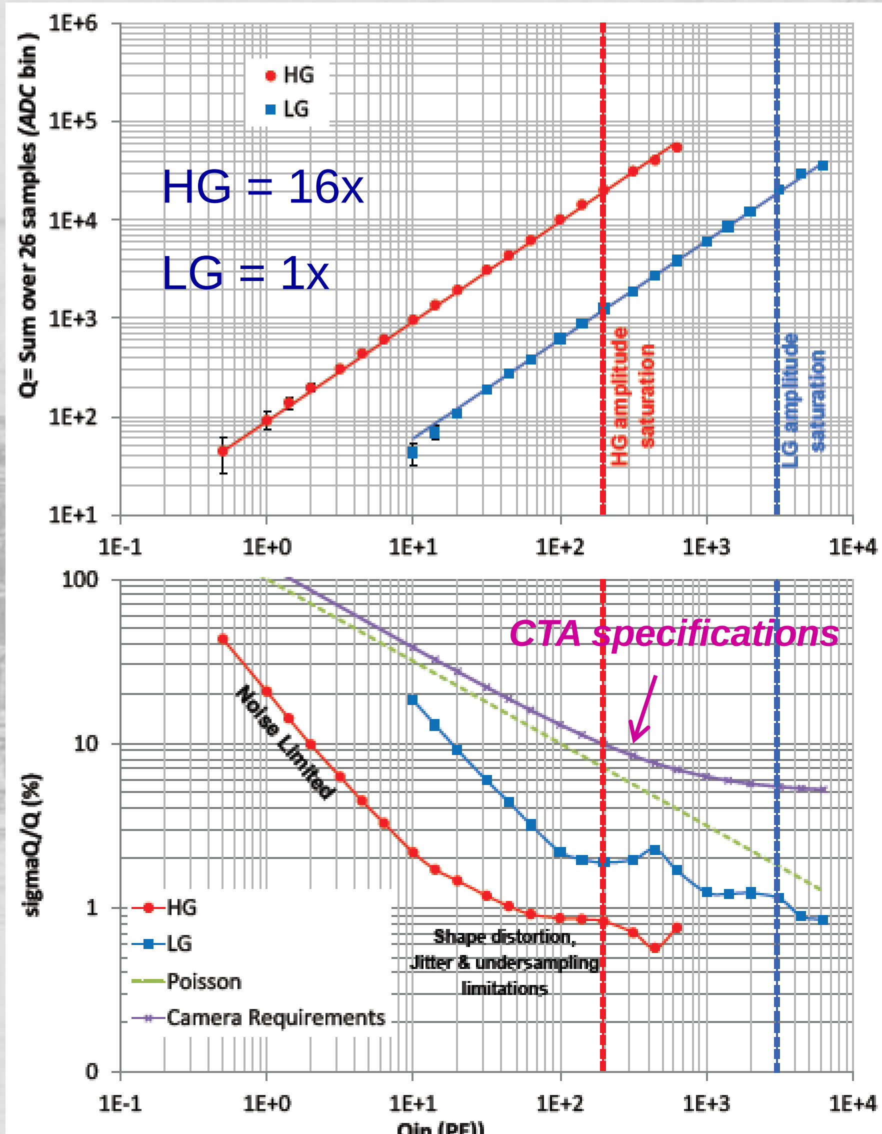
→ good **pulse resolution**





readout deadtime < 2.5µs
for 16ns readout at 1GHz (measured)

Charge resolution and dynamic range



dual gain system:

HG saturation 200pe → **high precision**

LG saturation 3000pe → **high range**

→ ***>11 bit dynamic range***

good linearity over whole dyn. range (NL < 2% over 4 orders of magnitude)

charge resolution

→ 20% for single pe (limited by noise)

→down to 1-2% for high charge

low cross-talk between channels < 0.4% on single chip

Performance summary

	Feature or Performances	Initial Requirement	Unit
Nb of Channels	2		Differential Channels
Memory Depth	1024		Cells
Input impedance	4		pF
Power Consumption	210	$\leq$ 300	mW
Analog Bandwidth	410	$\geq$ 300	MHz
Sampling Frequency	0.4 to 3.2	0.5 to 2	GSPS
Deadtime/event (16 samples)	2	5	μs
ADC LSB	0.5	0.5	mV
Total Noise	$\leq$ 0.8	$\leq$ 0.8	mV RMS
Maximum signal	2	2	V
Dynamic Range	11.3	$\geq$ 11	Bit RMS
Crosstalk	0.4		%
Relative NonLinearity	$\leq$ 3	$\leq$ 3	%
Sampling Jitter	$\leq$ 40	$\leq$50	ps RMS

fast!

sensitive

current design offers **required high bandwidth** (> 400Mhz) and **dynamic range** (>11 bits) with **low cross-talk**, noise and **non-linearity**

all **design goals met** or in very close reach

→ready for **development of multi-cluster prototype!**

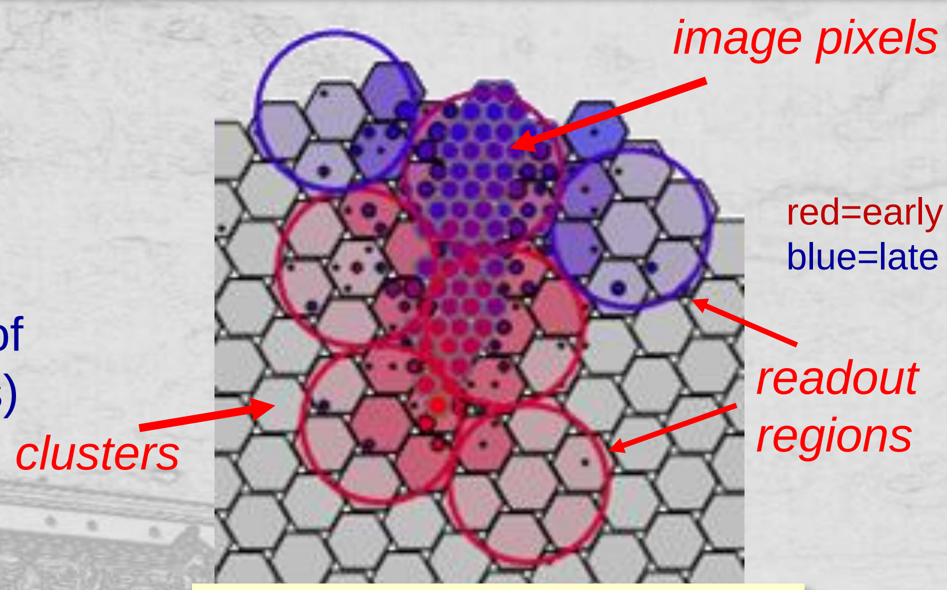
additional option: flexible readout

Flexible readout ("Colibri")

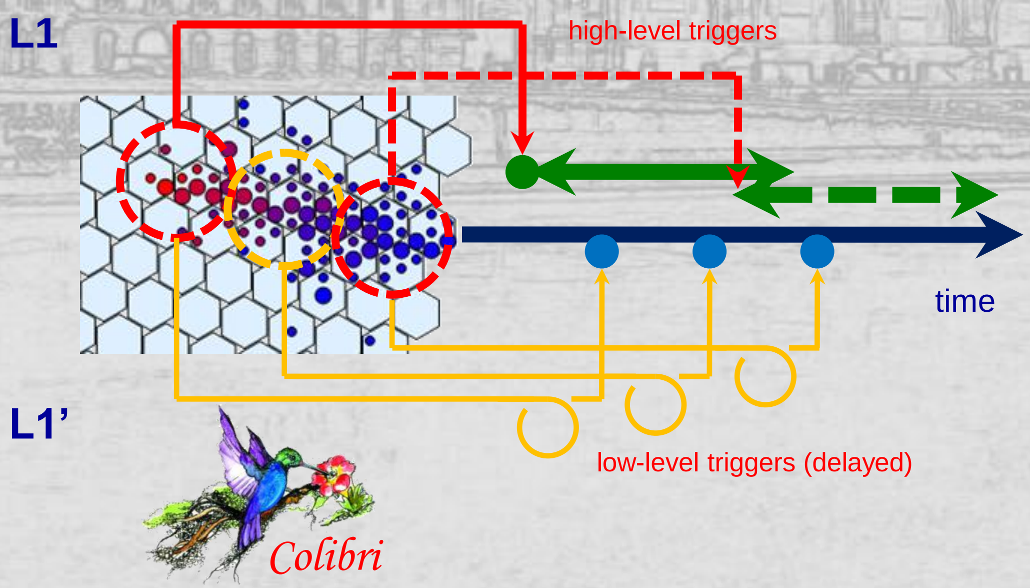
two-threshold trigger system for **local definition** of **regions of interest** and **readout windows**

→ reduction of **data rates** (×5 - ×10),
→ follow **slow image development** of high-energy showers (10^2 ns)

→**gain in image quality,** confirmed by MC studies



gamma 15 TeV, duration 55ns



- **fully analogue** solution, no dead-time outside r.o.i.
- integrated in trigger hardware, usable with NECTAr
- *proposed design option for CTA*

Summary and Outlook

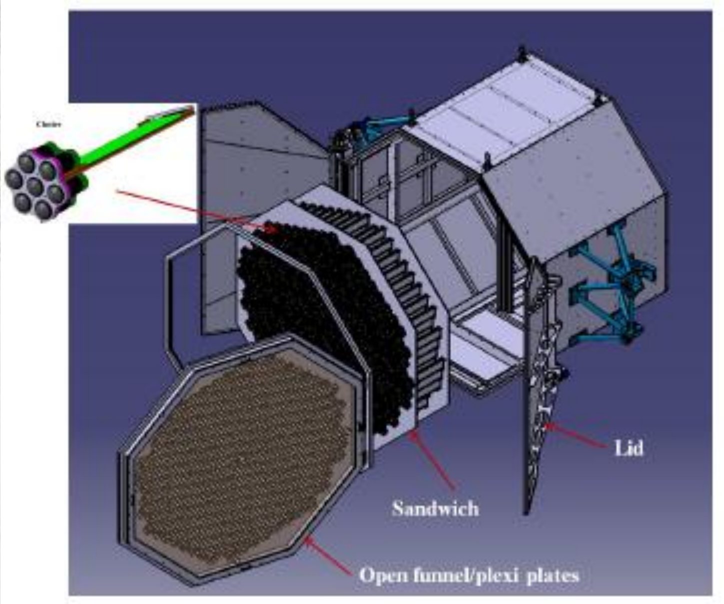
development of new, powerful front-end electronics for next-generation Cherenkov telescopes

- **highly integrated: analogue memory + ADC + amplifiers on single ASIC**
- **Prototypes: based on HESS-II hardware, several revisions**
- **GHz sampling and high-bandwidth digitisation, low dead-time (<5 µs)**
  → high readout rates possible (several kHz)
- **good signal fidelity, good separation of single-photoelectron signal, high dynamic range (1 to > 5000 with 2 channels)**

Next steps: NECTArCam

= concept for a NECTAr-based CTA camera

- **final demonstrator (19-37 modules): 2013**
- **first camera 2014**
- **integration in CTA 2015 ?**



contributors:

C.L. Naumann[a,*], E. Delagnes[b], J. Bolmont[a], P. Corona[a], D. Dzahini[c], F. Feinstein[d], D. Gascón[e], J.-F. Glicenstein[b], F. Guilloux[b], P. Nayman[a], F. Rarbi[c], A. Sanuy[e], J.-P. Tavernet[a], F. Toussenel[a], P. Vincent[a], S. Vorobiov[f]

a LPNHE, IN2P3/CNRS Université Paris VI & IN2P3/CNRS, Paris, France.

b IRFU, CEA/DSM, Saclay, Gif-sur-Yvette, France.

c LPSC, Université Joseph Fourier, INPG & IN2P3/CNRS, Grenoble, France.

d LUPM, Université Montpellier II & IN2P3/CNRS, Montpellier, France.

e ICC-UB, Universitat Barcelona, Spain.

f now at DESY-Zeuthen, Platanenallee 6, 15738 Zeuthen, Germany