Ground-based gamma-ray astronomy at IRFU

J-F. Glicenstein

DSM/IRFU

7th Rencontres de l'IRFU

The Cygnus X-3 controversy (end 1980)

- Evidence was found for periodic signals in high energy gamma-rays (Whipple) and underground muons towards Cygnus X-3 (microquasar).
- Not seen by the Frejus (Saclay-Orsay-Polytechnique-Aachen-Wuppertal) underground detector.

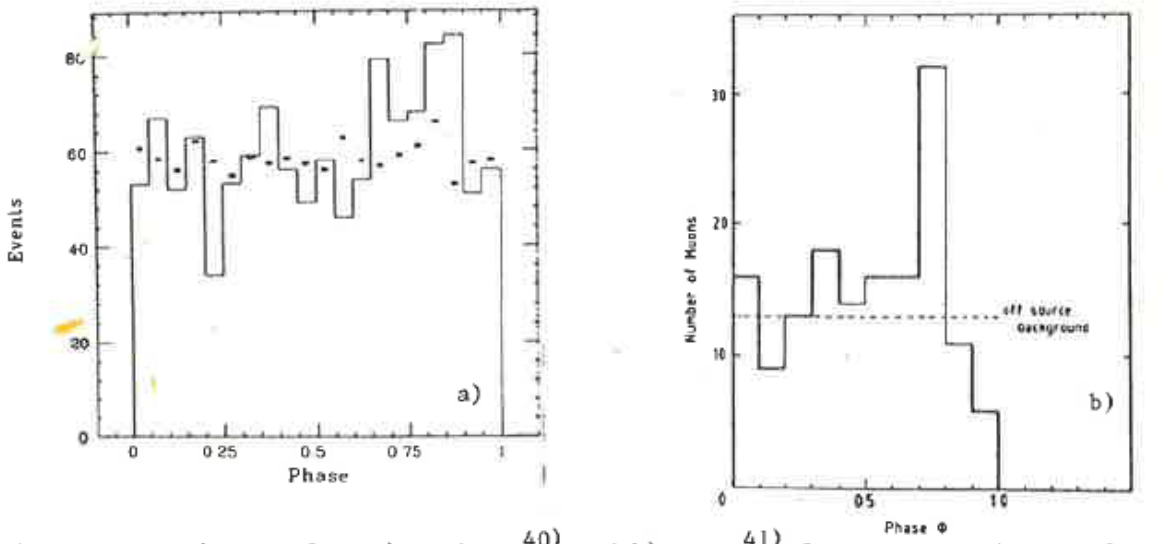
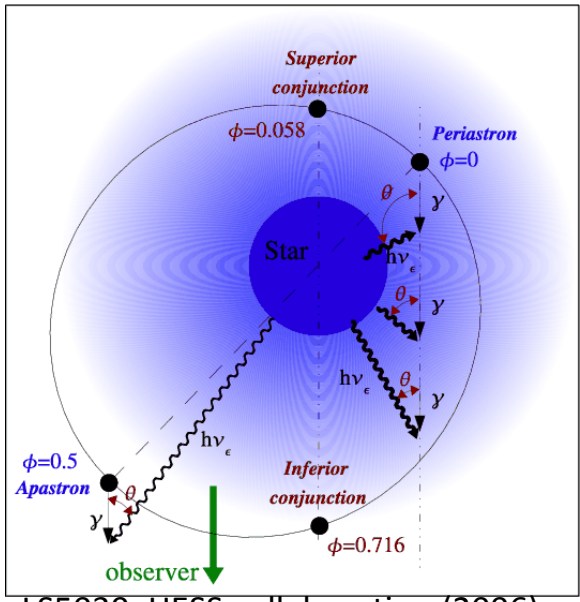


Figure 5. Evidence from a) Soudan I[40] and b) NUSEX[41] for underground muons from Cygnus X-3.

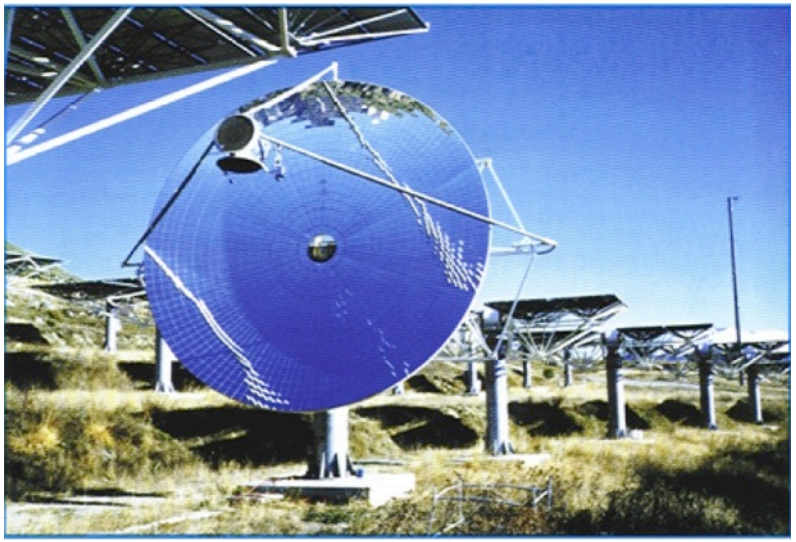


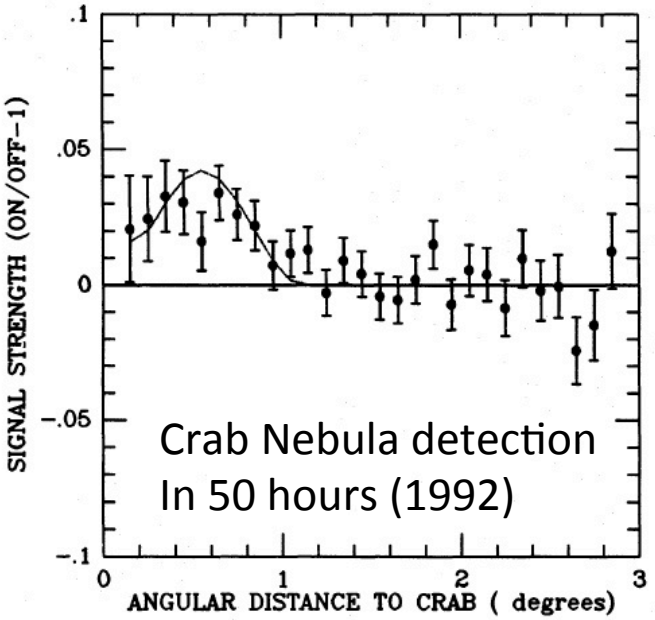
LS5039, HESS collaboration (2006)

- Saclay team starts building a Cherenkov array prototype at Themis.
- Motivation: direct detection of controversial gamma-ray sources (P. Goret et al, NIMPA 1988)

ASGAT (1987-1994)

- 7 7-meter diameter mirrors
- Equipped with 7 photomultipliers in focal plane
- Installed at Themis solar farm
- Installation of an IN2P3 team on site: Themistocle





ASGAT : A FAST TIMING VHE GAMMA-RAY TELESCOPE

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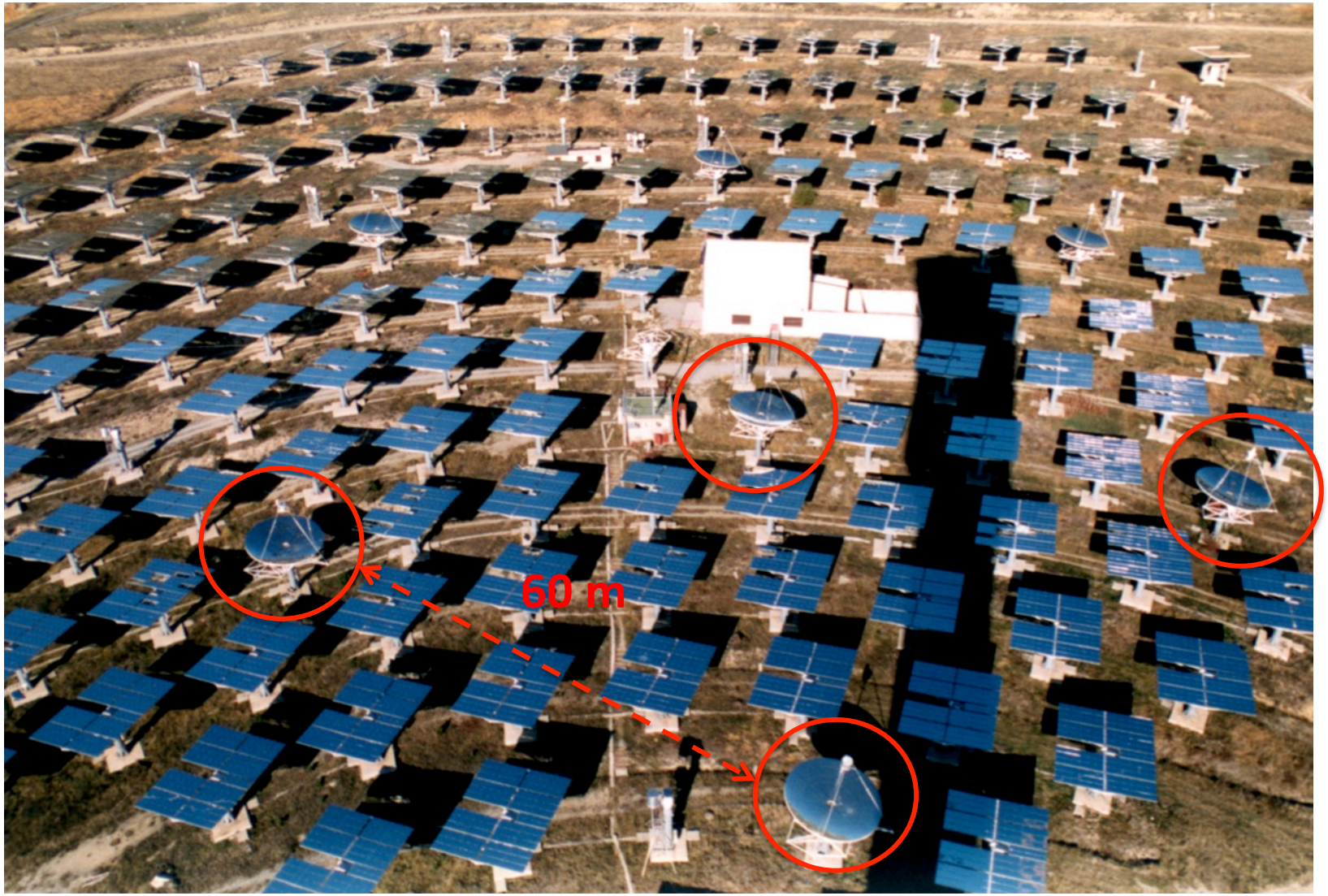
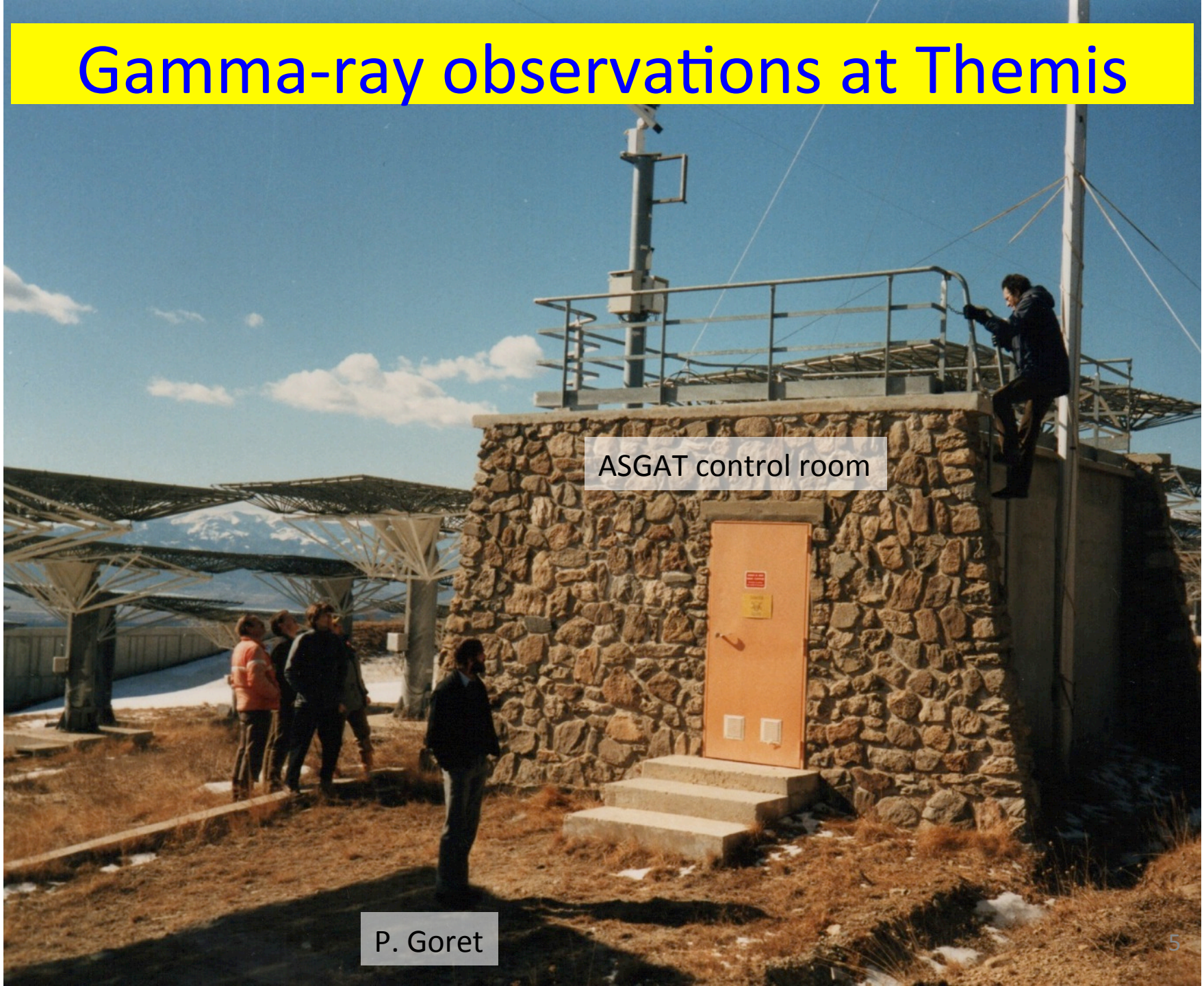
Gamma-ray observations at Themis



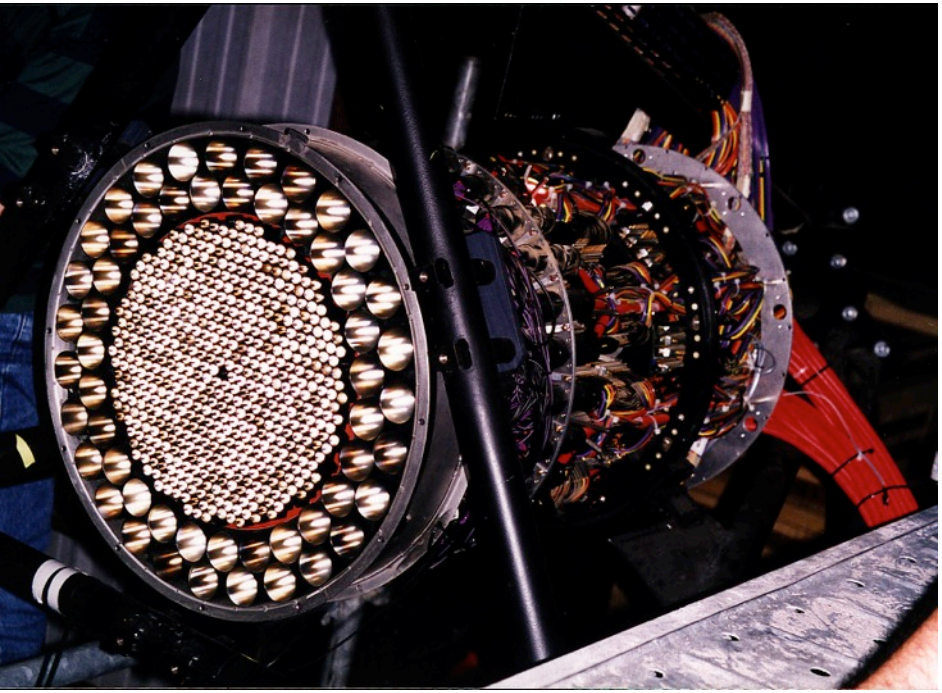
Gamma-ray observations at Themis

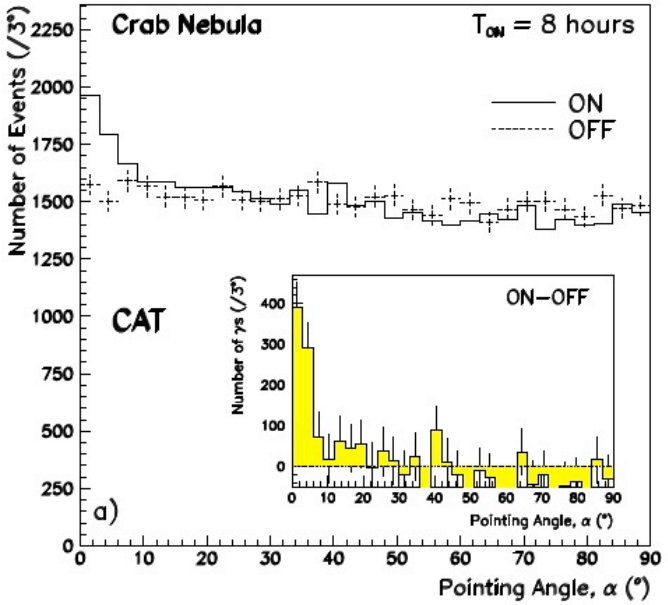


CAT (1993-2001)

The ASGAT and Themistocle teams merge to build CAT at Themis.

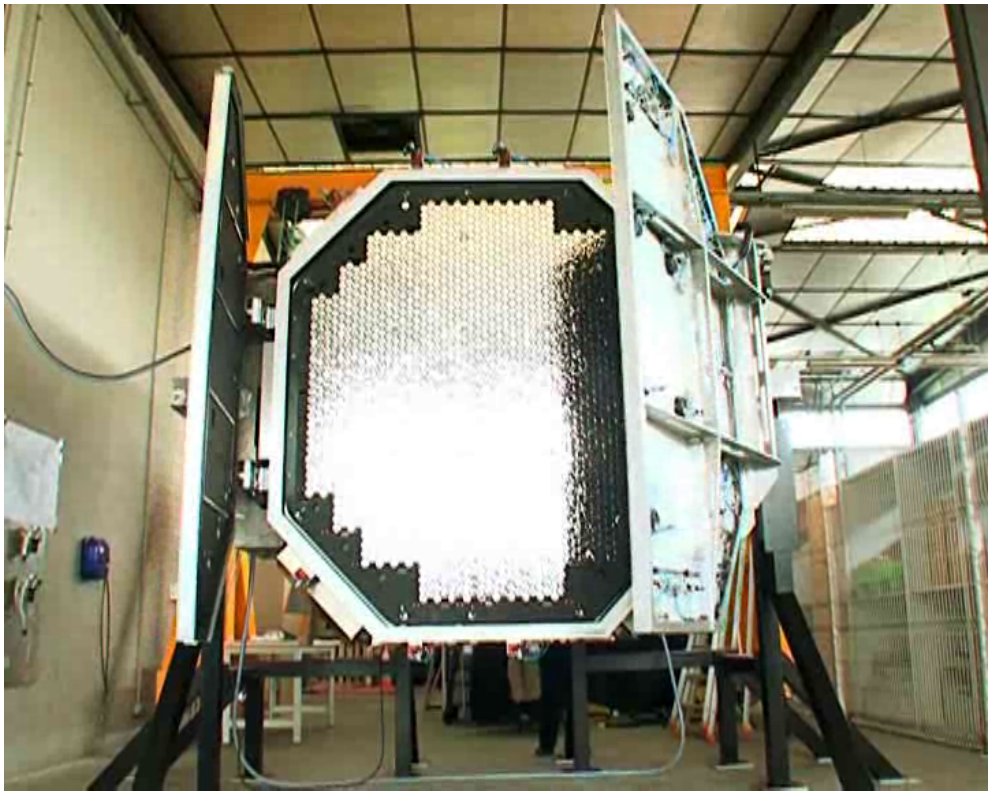
- High definition imaging camera
- 546 PMTs (0.12°/pixel)
- Charge read-out with fast analogue gates+ADC
- Use of light guides to optimize Signal/background light ratio

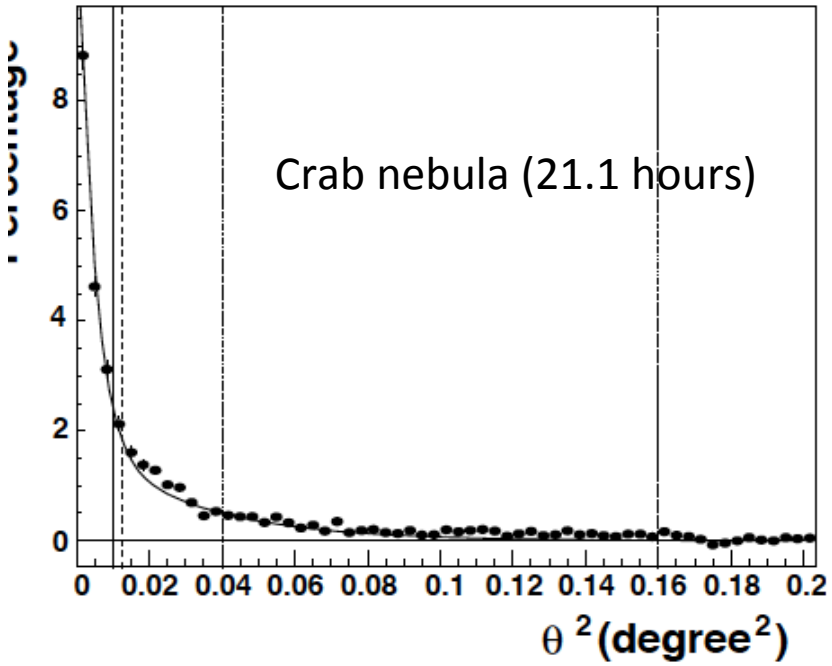




Crab nebula detected in 2 hours (1996)

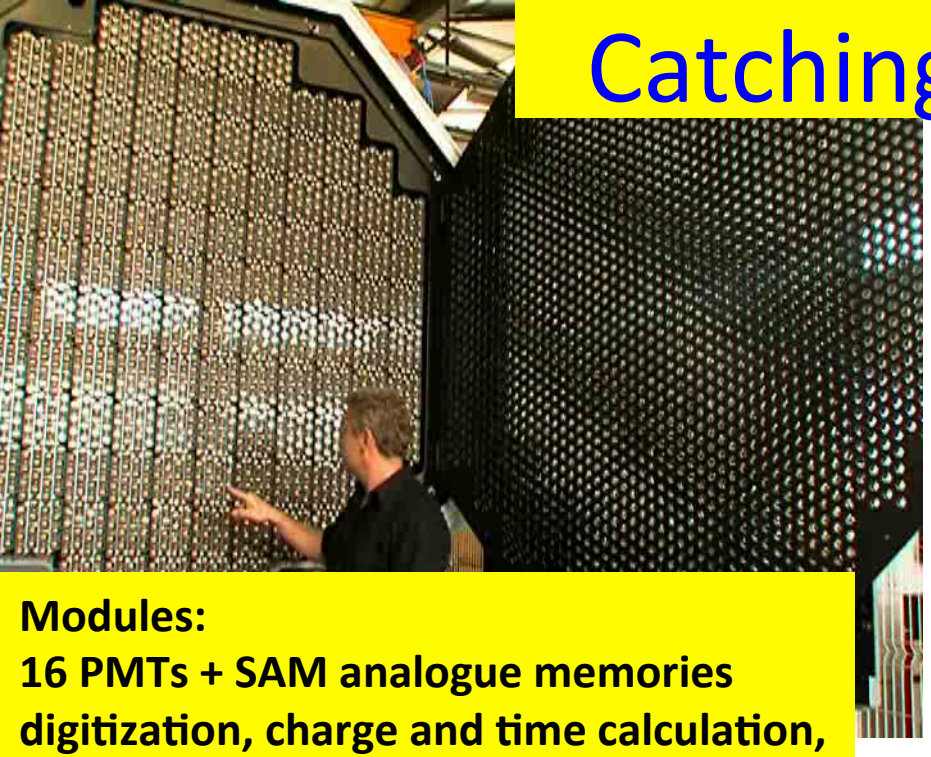
HESS and HESS2 (2002-)



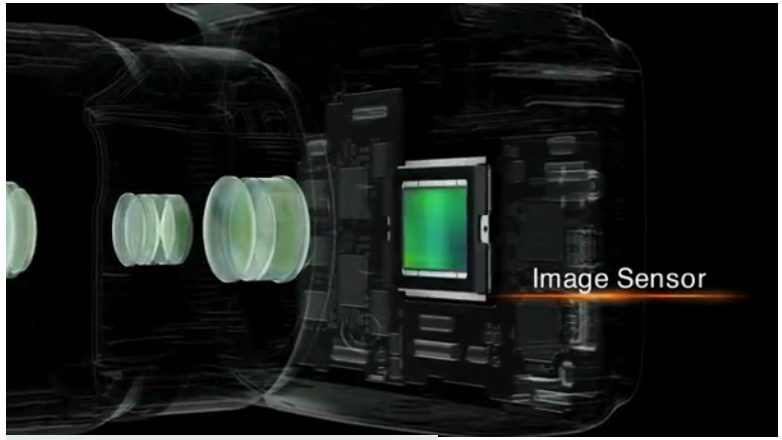


- Installed in Khomas Highlands (Namibia), PI C. Stegmann (Zeuthen), previous PI W. Hofmann
- Four 12 m diameter telescopes CT1..CT4 (2004), with 960-pixel cameras
- Upgrade of CT1-4 cameras in 2015
- One 28 m diameter telescope CT5 (2012), with a 2048-pixel camera
- Crab nebula detectable at 5σ in 30 s.

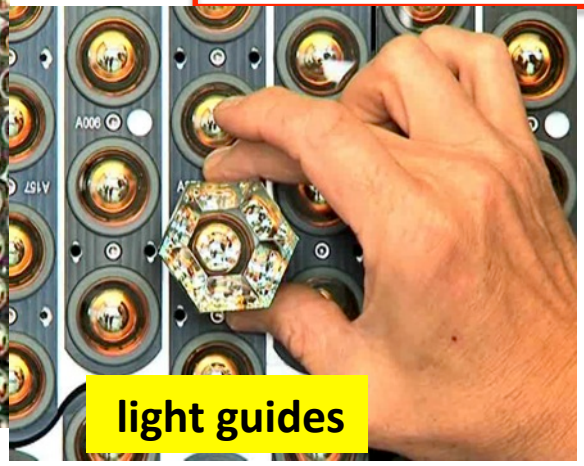
Catching Cherenkov light



Modules:
16 PMTs + SAM analogue memories digitization, charge and time calculation, read-out

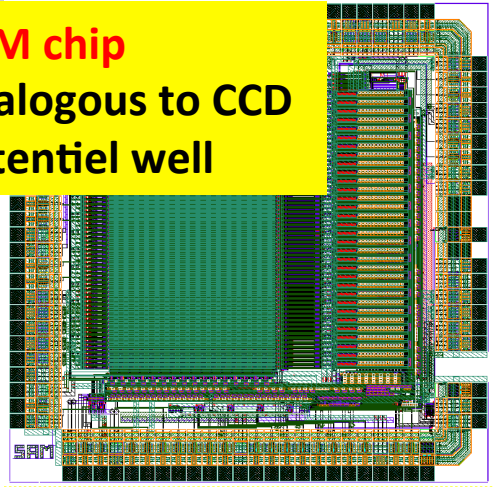


CCD camera analogy

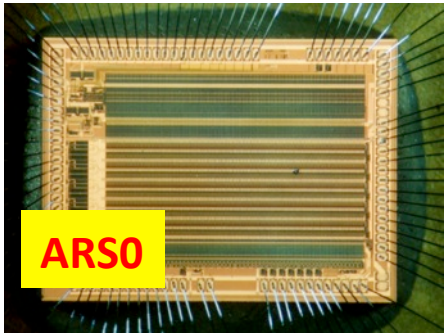


light guides

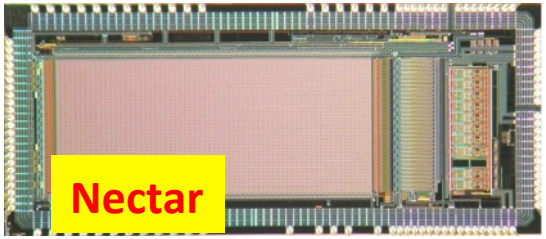
SAM chip
Analogous to CCD
Potentiel well



Analogue memories for gamma-ray astronomy



- ARS0 chip designed for ANTARES neutrino telescope by IRFU
- Data stored at 1 GHz in a circular buffer of 128 slots
- Used in HESS CT1-4
- Readout at lower frequency
- Advantages:
  - allows to build a compact camera (no long wires)
  - low cost
  - low power consumption
- Drawback: large readout dead-time (256 μs for 16 slots)

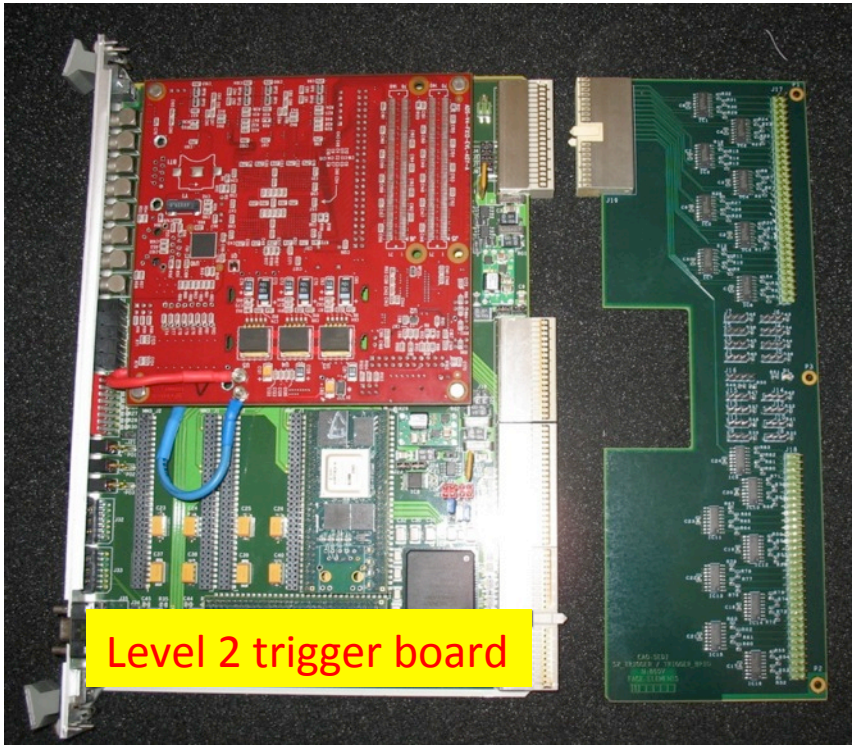


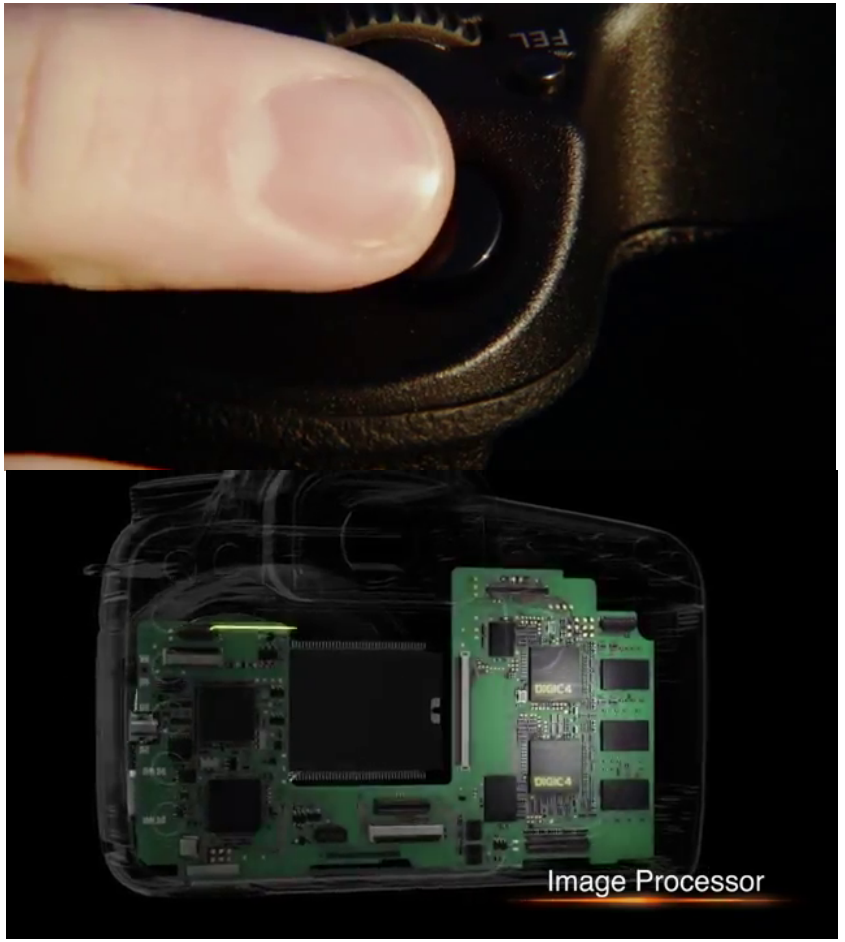
Upgrades

- SAM: HESS CT5
  - Dynamic range increased by a factor of 4, longer memory (256 slots) reduced read-out deadtime (1.5 ms)
- Nectar: HESS upgrade CT1-4 cameras, CTA: NectarCAM
  - longer memory (1024 slots), analogue to digital conversion

Recording events

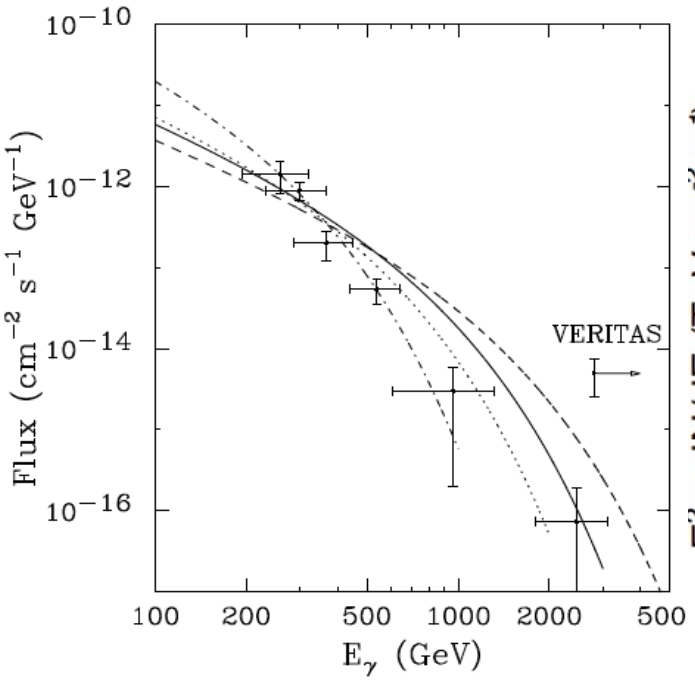
- camera self-triggered by a multi-step process
- The first level is a hardware based logic.
- The second step is a computer based decision based on the topology of the event

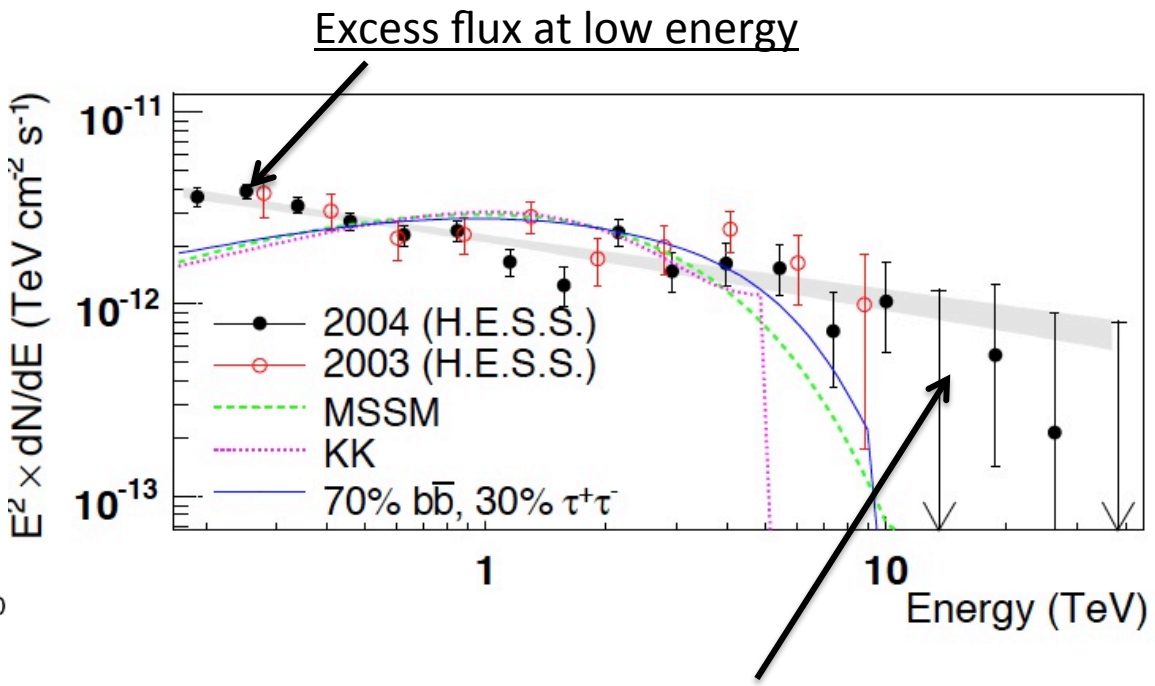




CCD camera analogy

Have atmospheric Cerenkov telescope observed dark matter at the Galactic Center?



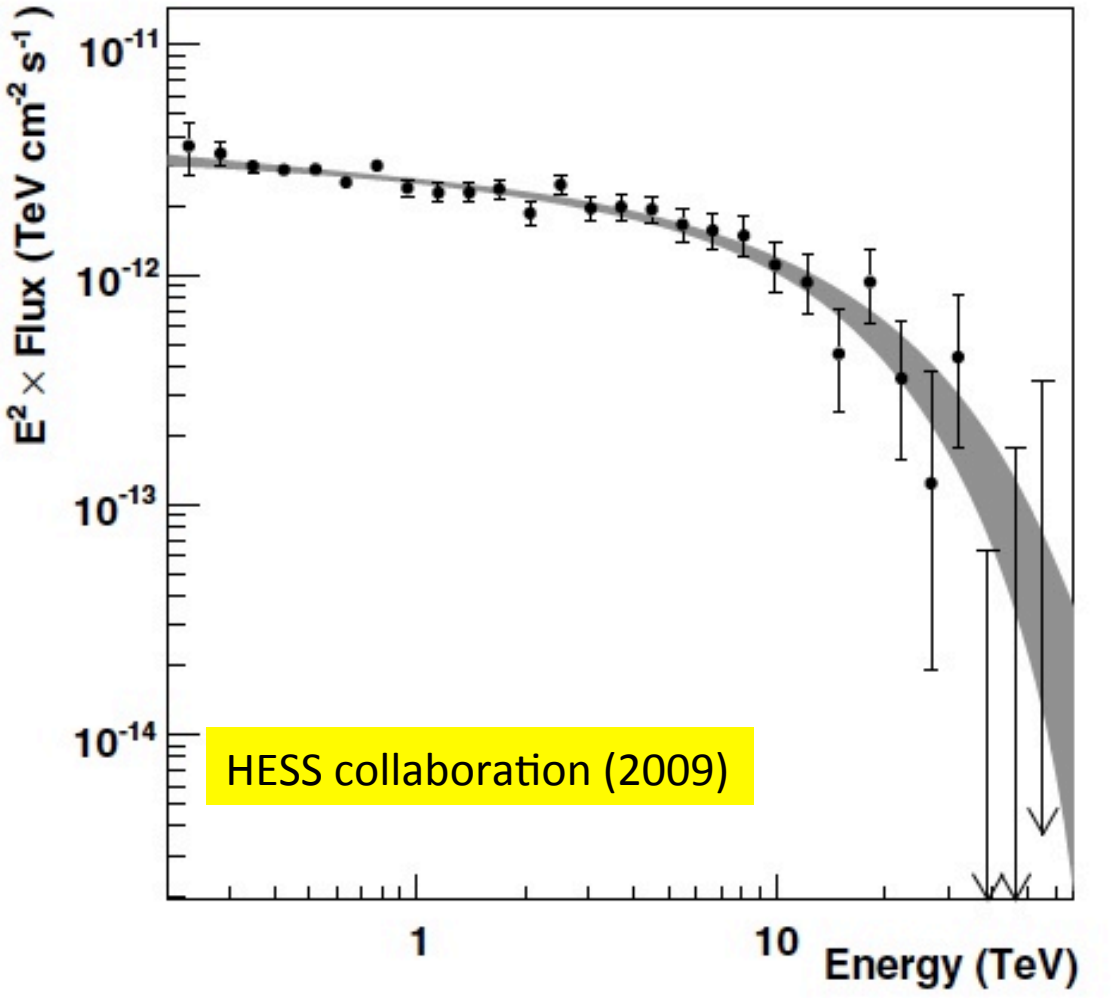


No spectral break at DM particle mass

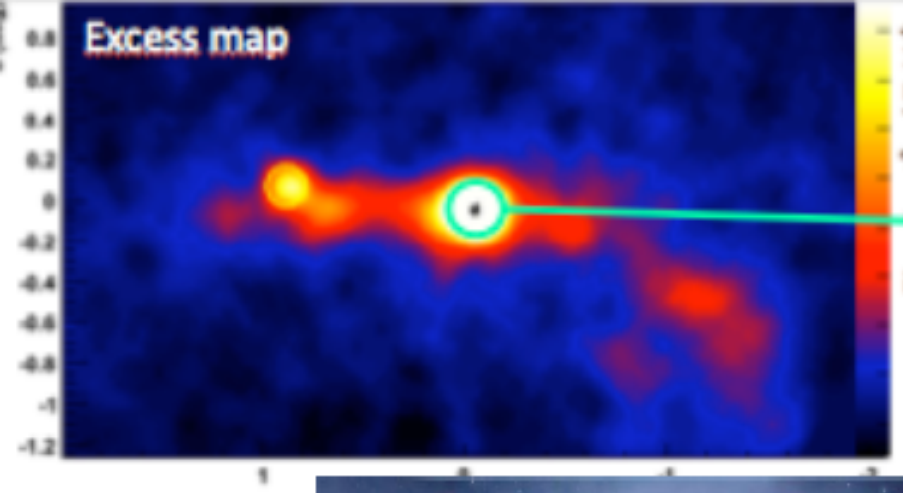
Yes: D. Hooper et al (2005)

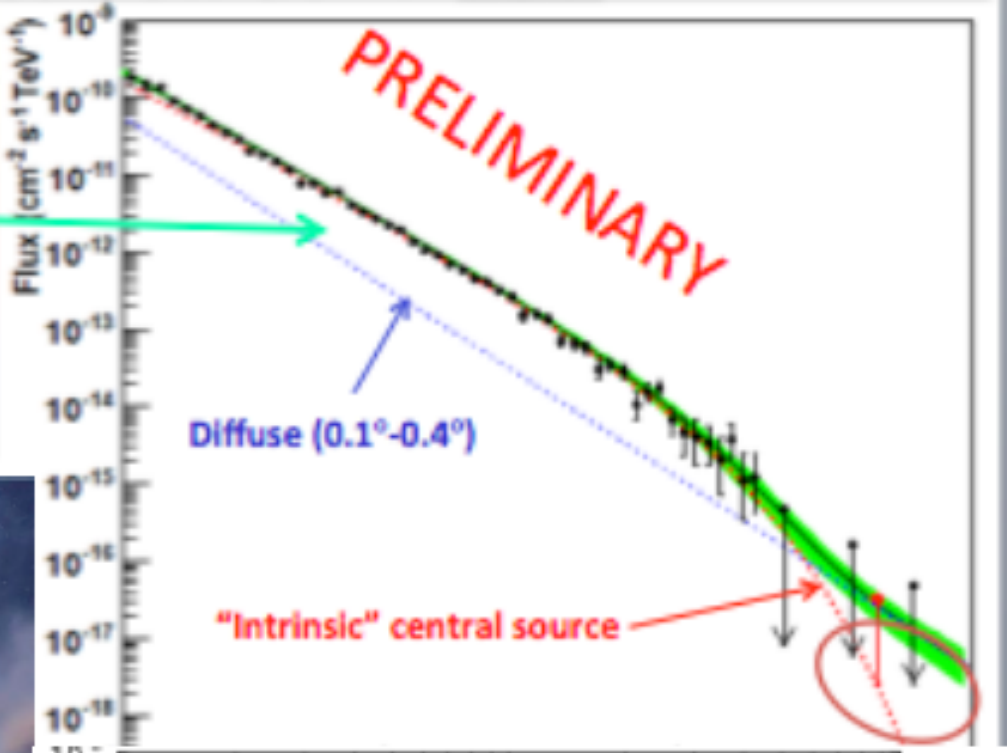
NO: HESS collaboration (2006)

Galactic Center source: improved spectrum

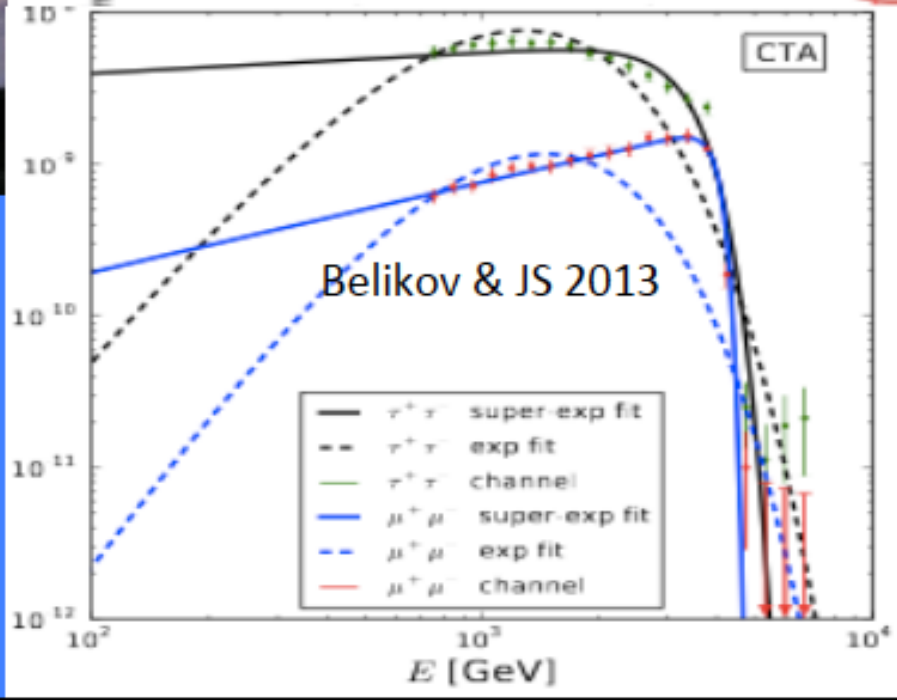


- There is a spectral break after all!
- Contribution of Galactic diffuse background at high energy hard to assess





Vaiana, Moulin 2014

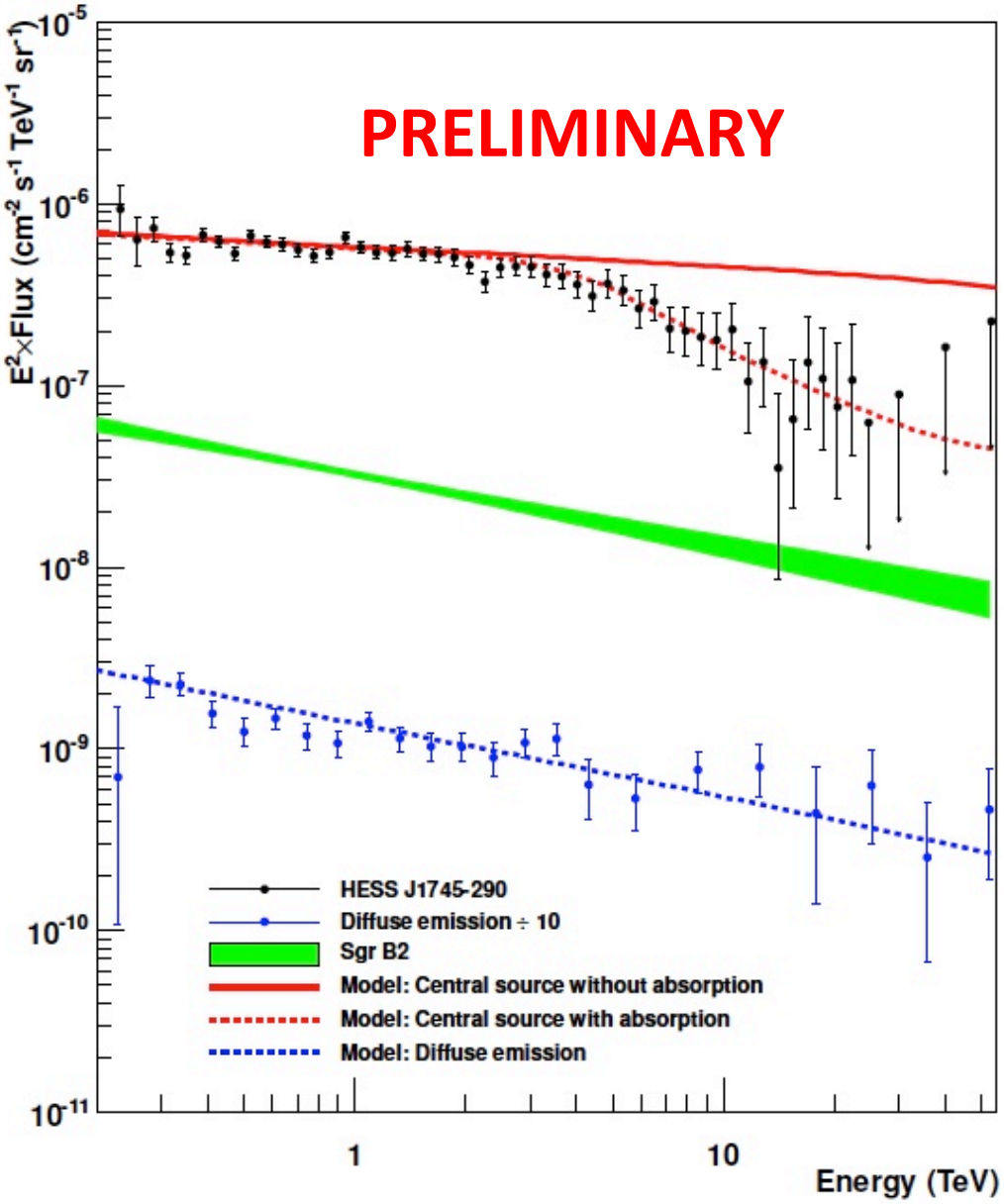


J. Silk
Rencontres de l'IRFU (2014)

A prediction for CTA: superexponential signature of TeV DM annihilations

The Galactic Center source (2015)

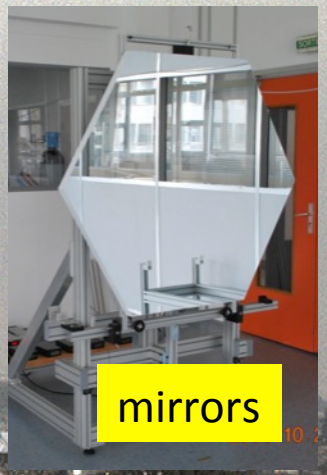
Better data available
Spectral break compatible with absorption by infrared background



CTA at IRFU

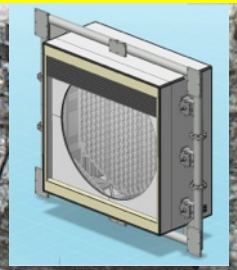
Contribution to « Medium size » telescopes:

- Produce 2000 1.2 m^2 mirrors
- Produce 20 cameras



mirrors

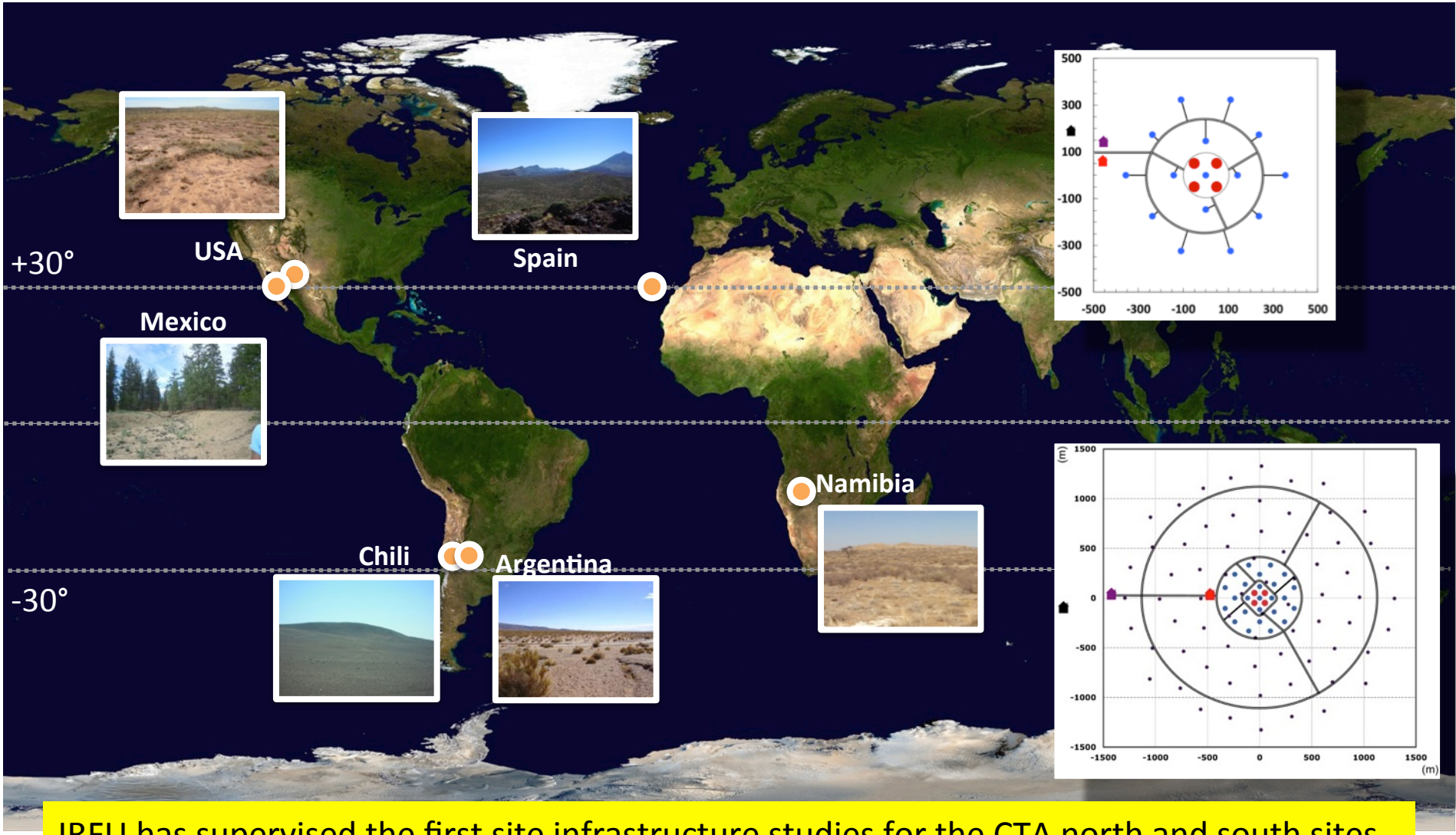
NectarCAM camera



CTA Site infrastructure

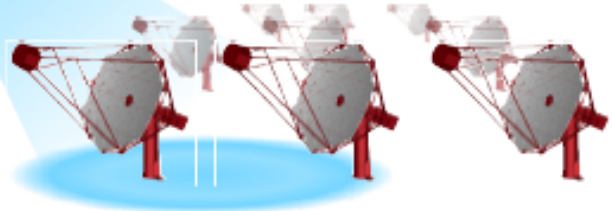
Data acquisition and science tools

CTA Site(s) infrastructure

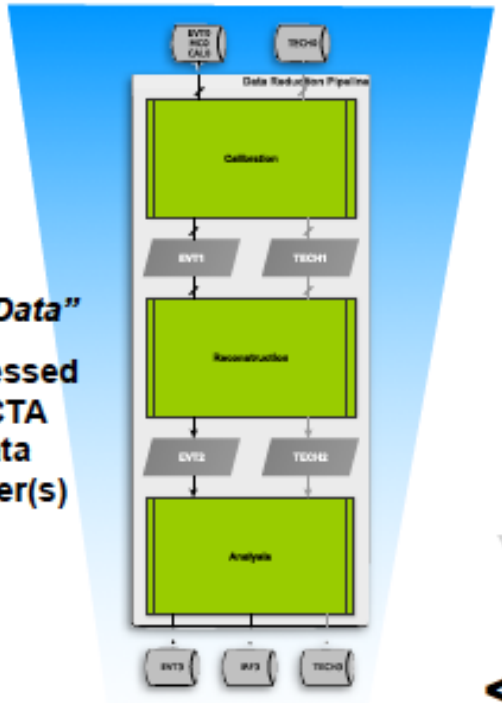


IRFU has supervised the first site infrastructure studies for the CTA north and south sites.

Data reduction and processing



On-Site



"Big Data"

Processed at CTA Data Center(s)

33 TB/day

Data Processing Pipeline

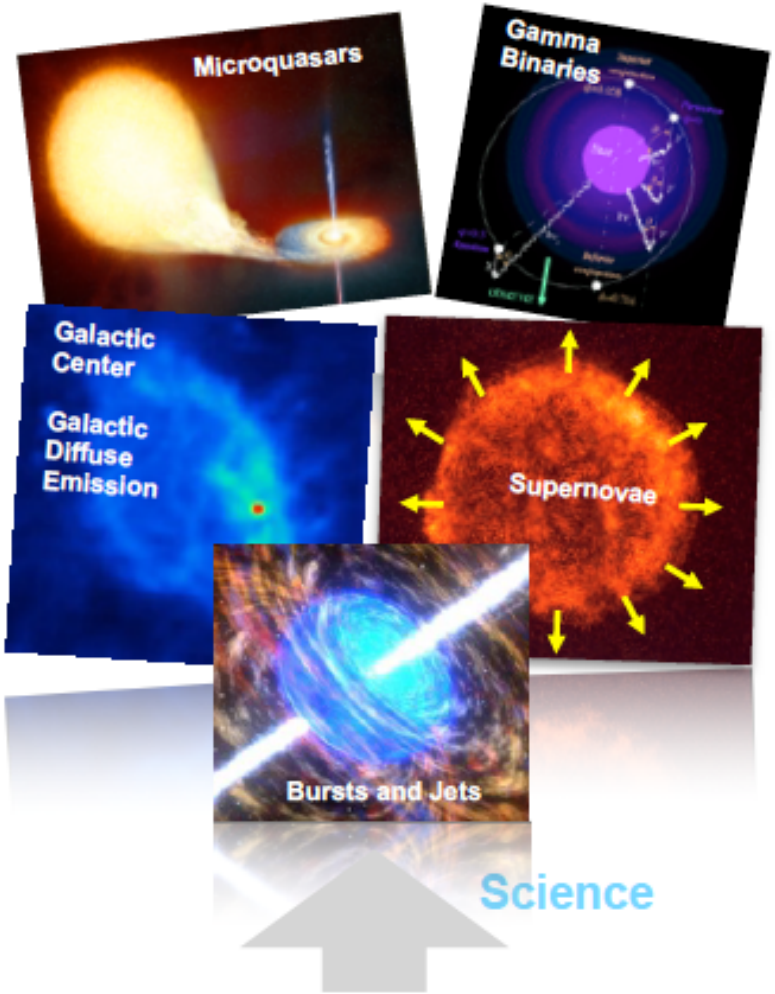
(project lead and algorithm development at IRFU/SAp)

<GB/day

Science Data Processed locally, or at CTA Data Center

Science Tools

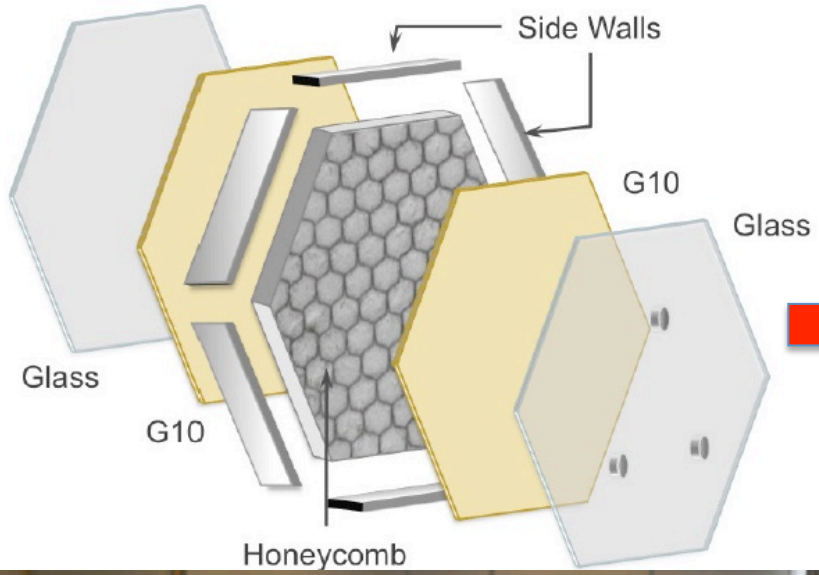
(IRFU contributing)

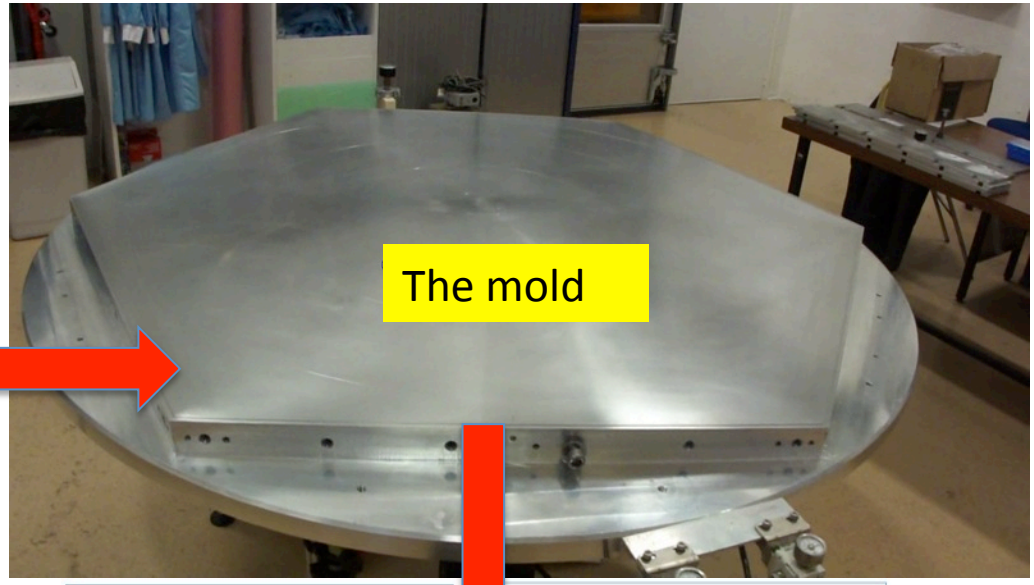


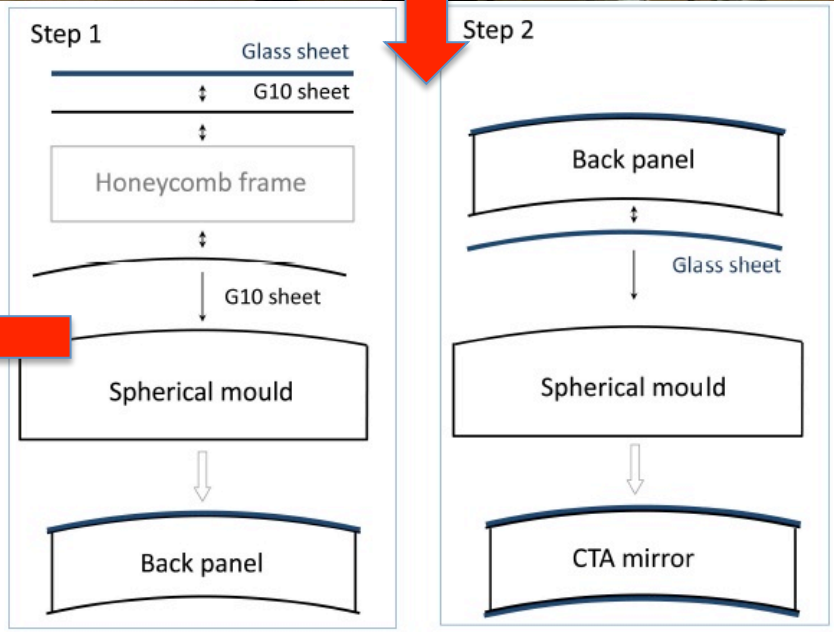
Science

Variability Search
Catalog Generation
Survey Tools
Morphology Analysis

Design of mirrors for Medium Size Telescopes



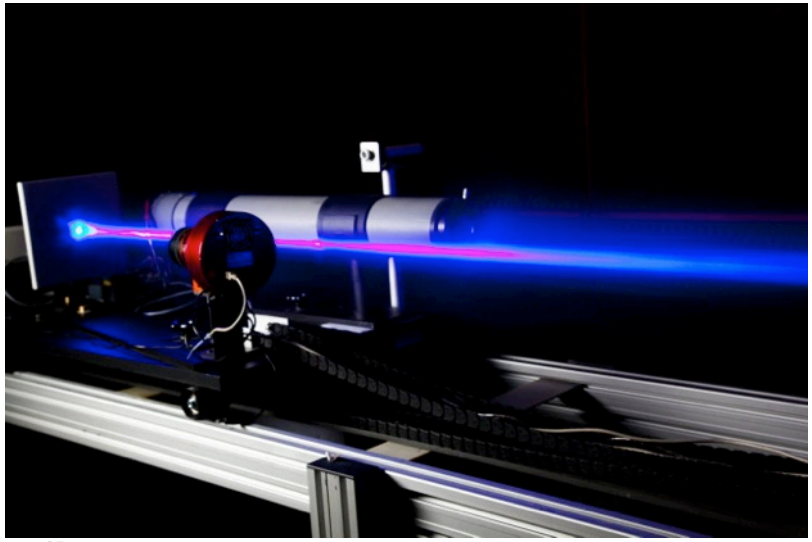


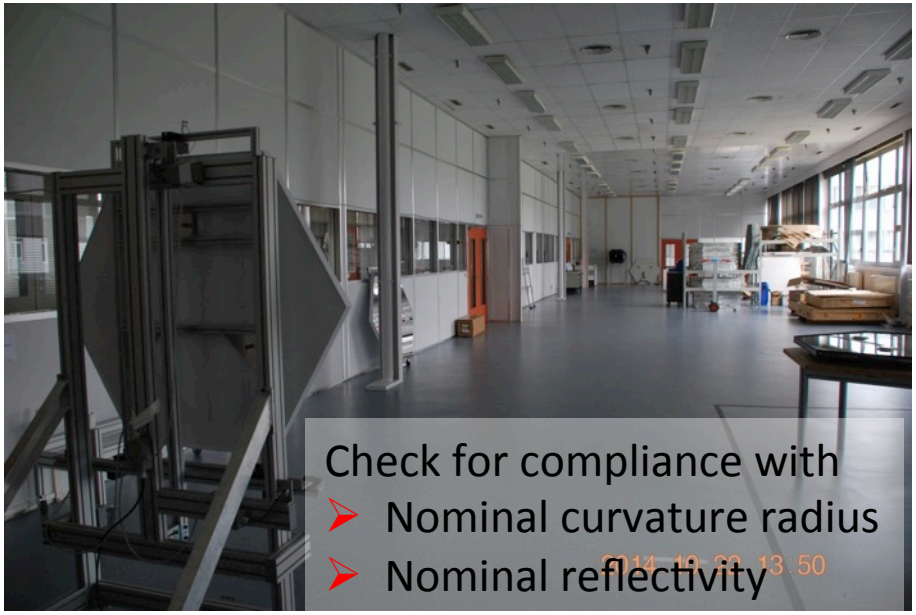


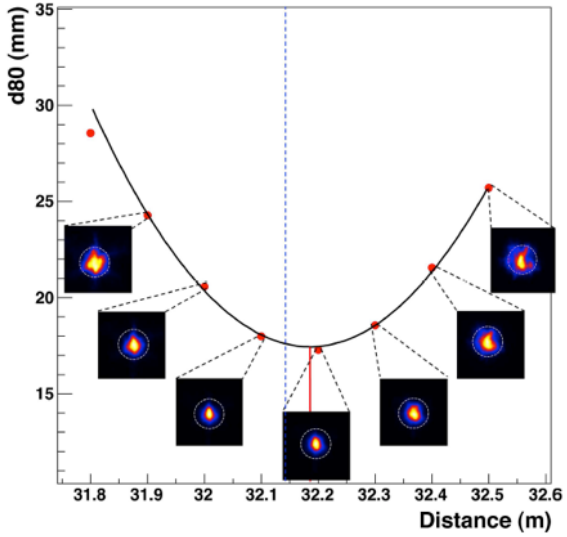
Mirror being removed from vacuum chamber at KERDRY

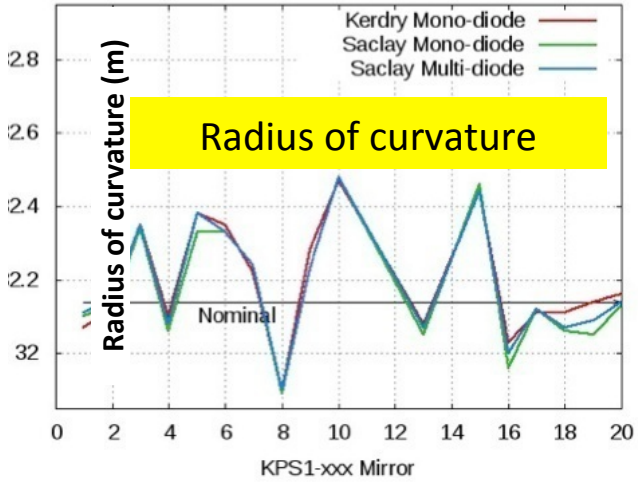
Aluminization of mirrors at Kerdry (Lannion)

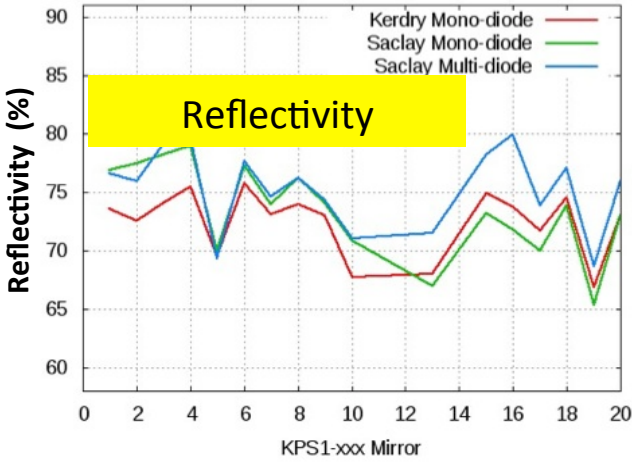
Optical tests at Saclay and Lannion



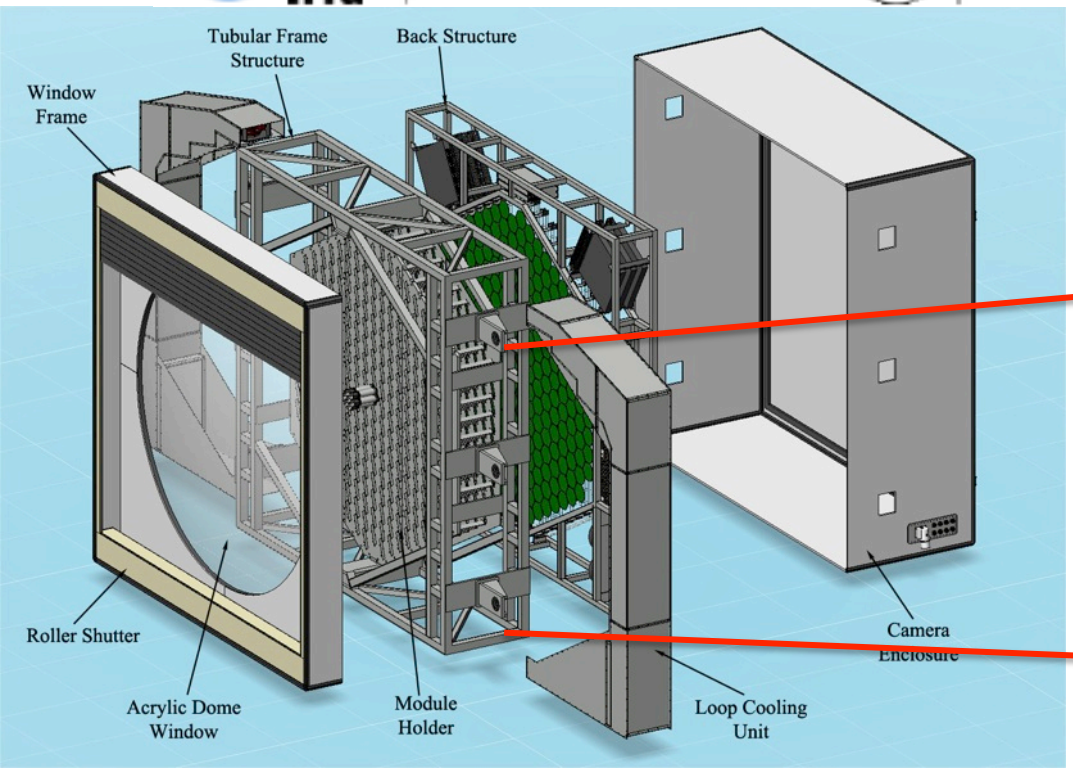


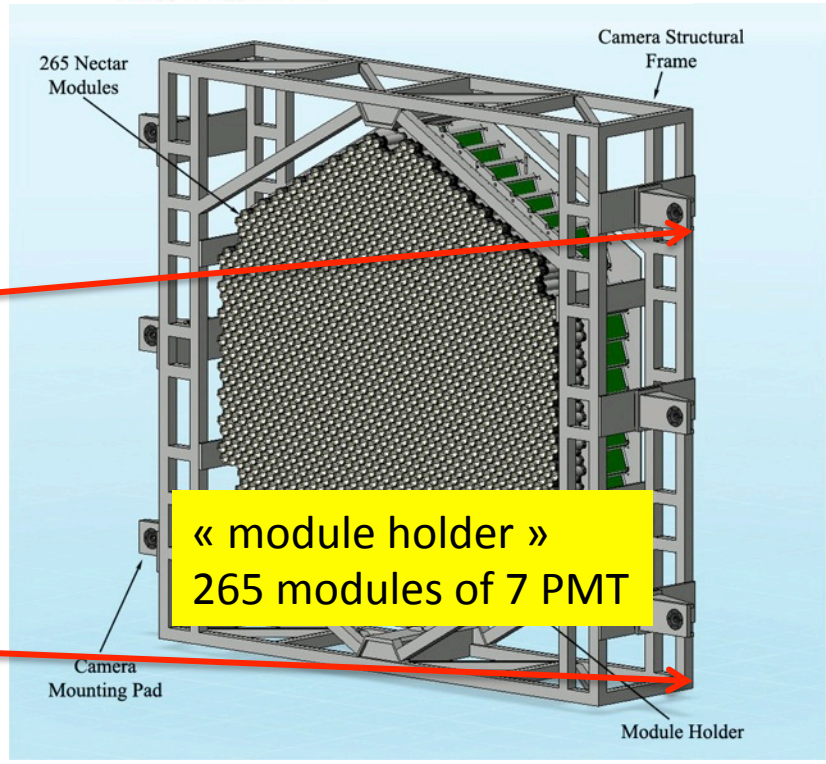






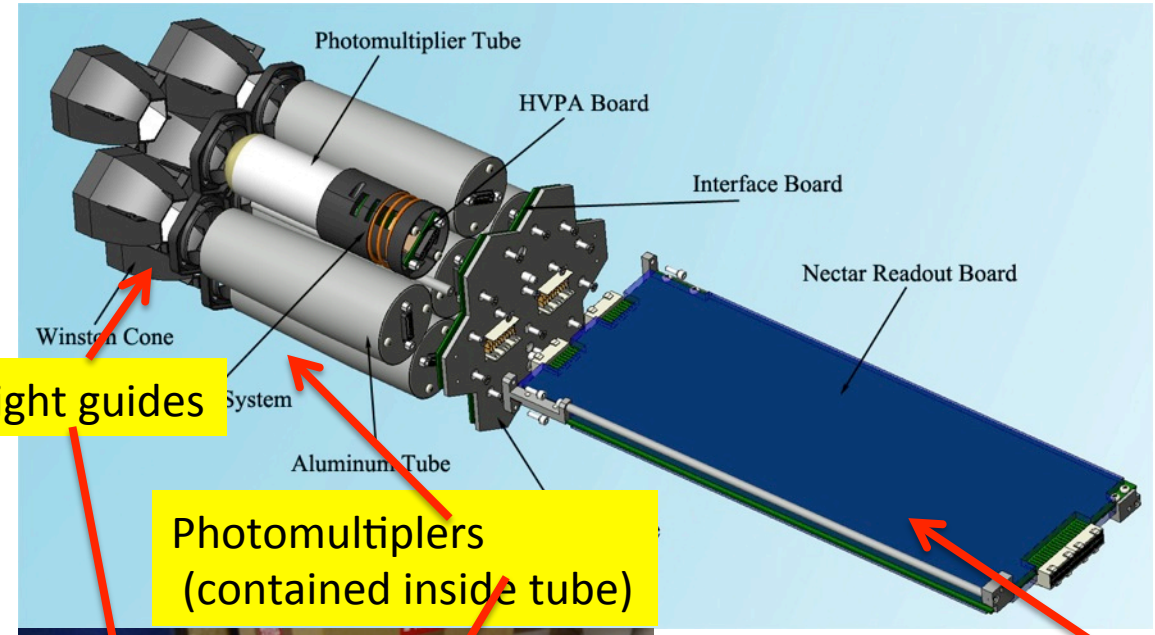
NectarCAM





- 1.9 ton camera, dimensions: 2.8 m x 2.9 m x 1.15 m
- field of view 8^o (compared to CT1-4: 5^o)
- 1865 photomultipliers
- collaboration France (CEA/IRFU, CNRS/IN2P3 and /INSU), Spain and Germany

Nectar modules

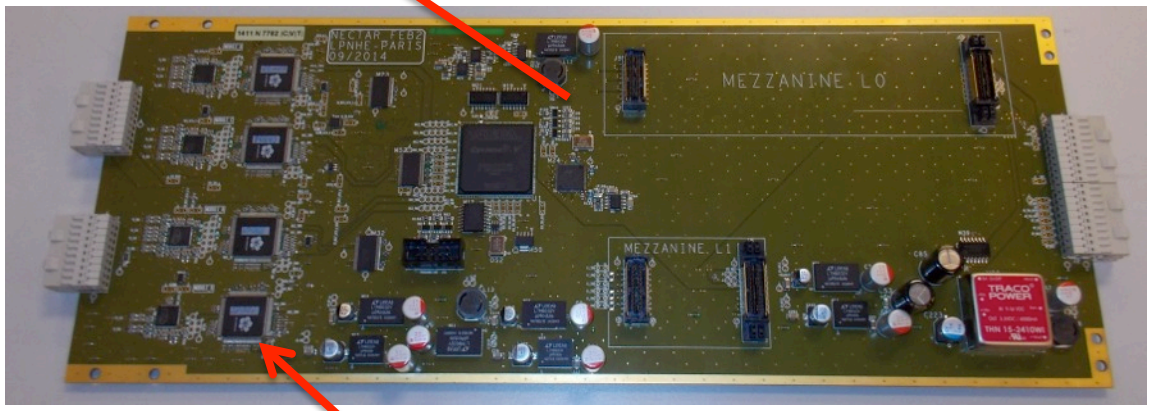


- Basic block of the camera (equivalent of CCD matrix)
- Groups 7 photomultipliers
- Built by collaboration of 9 labs
- Assembly of multiple blocks tested at IRFU.

Light guides

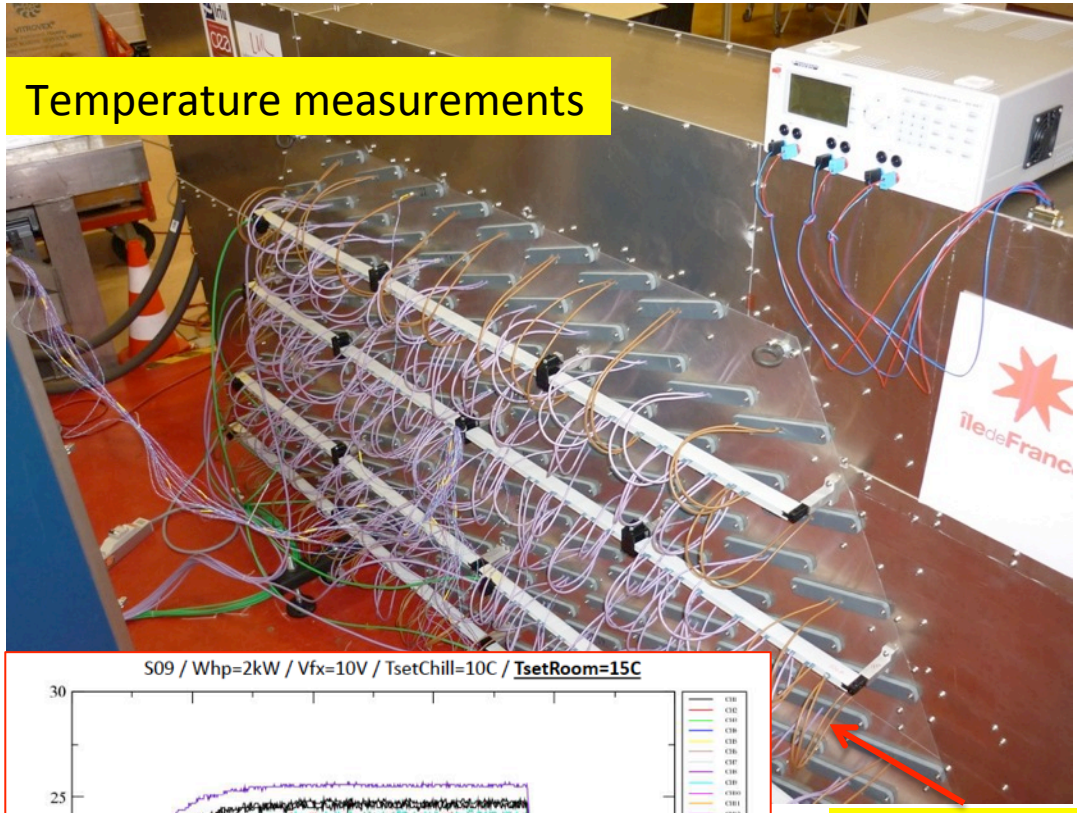
Photomultiplers (contained inside tube)

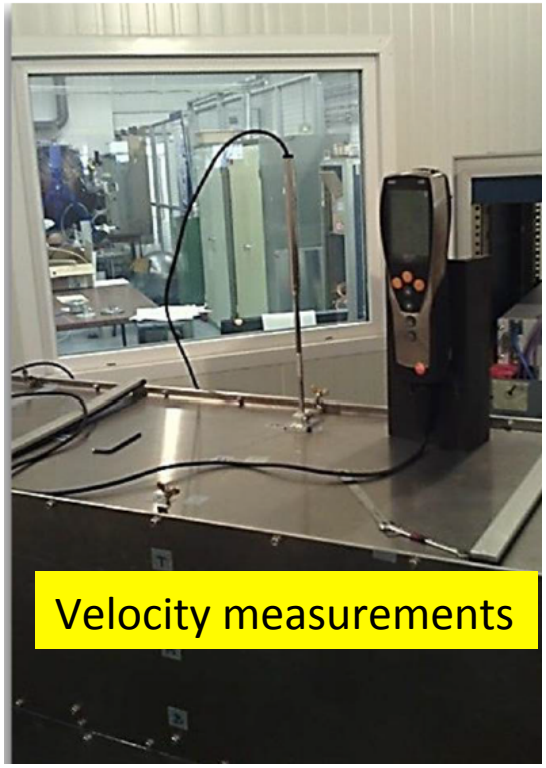
Readout-digitization board

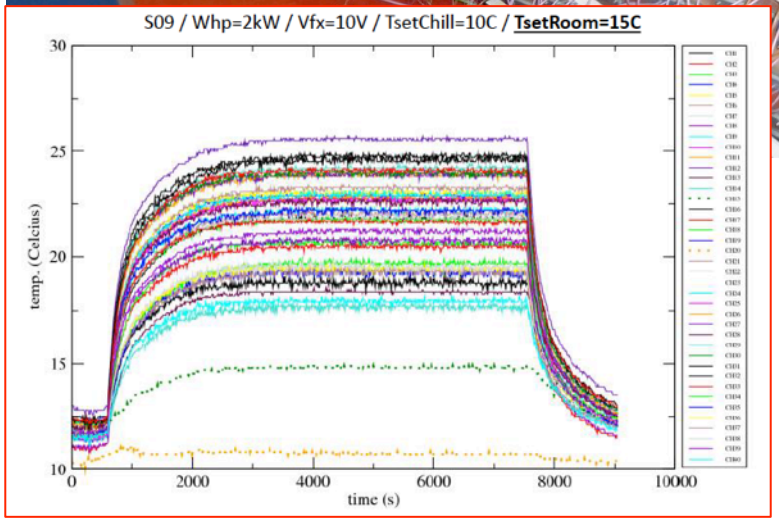


Nectar chips

NectarCAM cooling test bench at IRFU(2014)



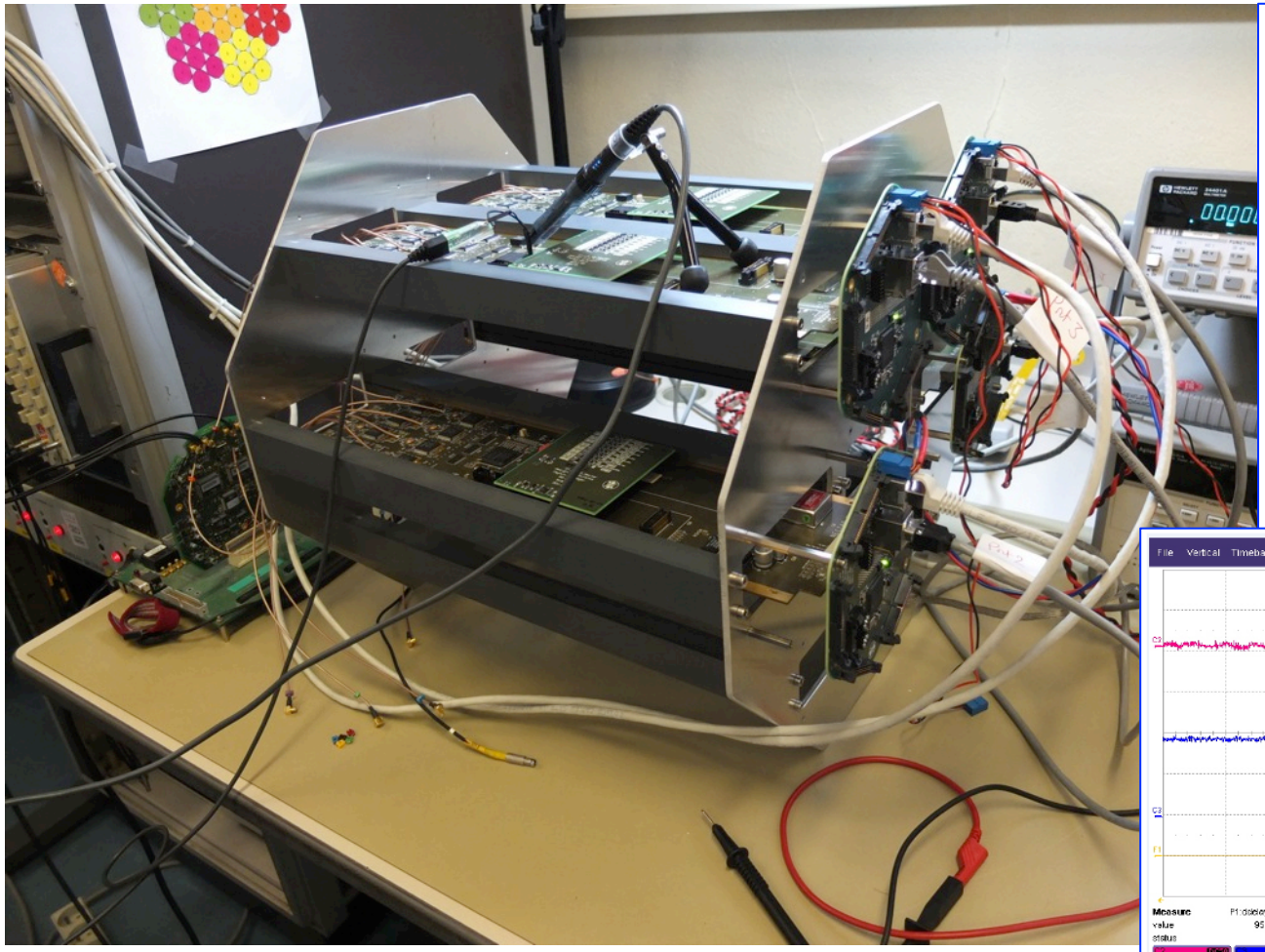


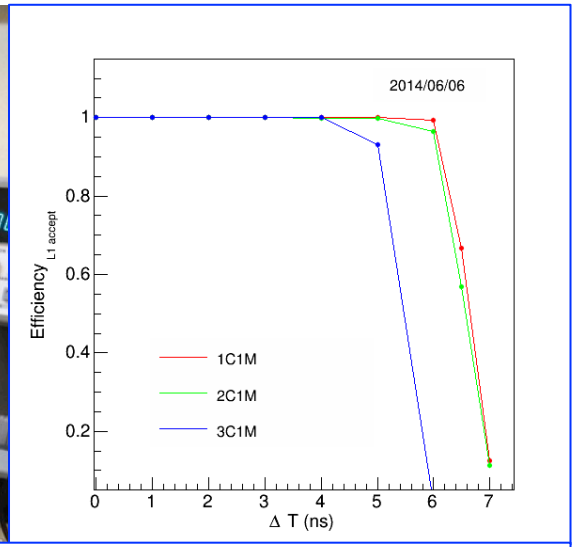


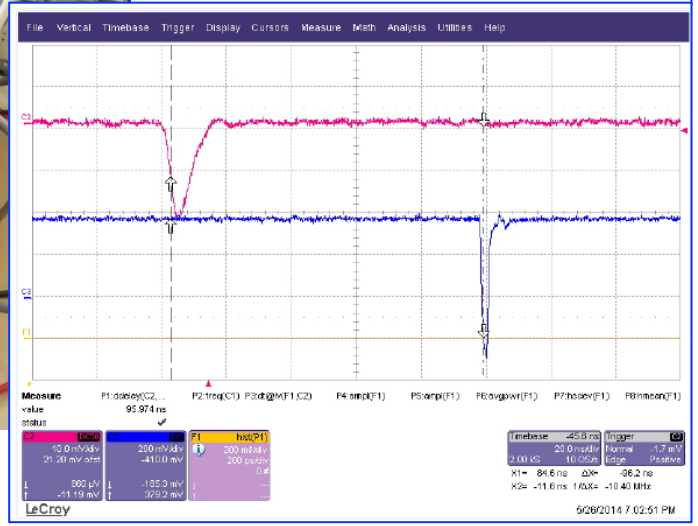
Thermal model of the camera module holder

- NectarCAM produces ~7 kW of heat, which has to be removed.
- Cooling of camera studied with a mechanical / thermal model.

Multi-module test bench at IRFU(2014)







Tests:

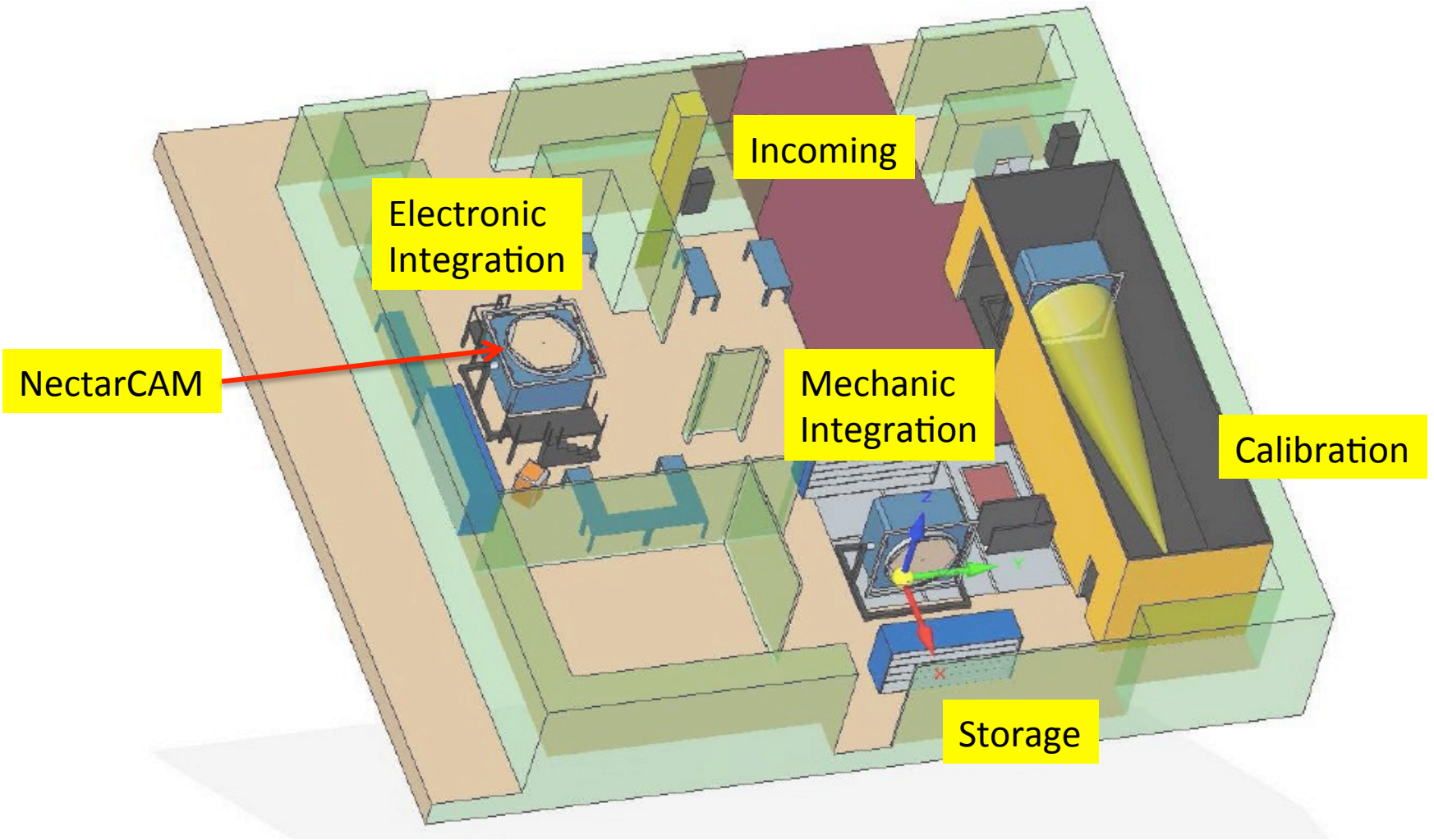
the triggering mechanism of NectarCAM

the delay between the signal arrival and the read-our (¬ 100 ns)

The 19-module mini-camera and beyond

- Installation of a 19-module mini camera at IRFU in 2015
- Production of 20+ cameras starts in 2018 (5 camera/year)

Production of 20+ cameras at IRFU (>2017)



Summary

- Ground-based gamma-ray astronomy is now a well recognized part of astrophysics and astropartice physics with plenty of exciting discoveries (e.g. the nature of high energy emission at the Galactic Center)

- IRFU has been at the forefront of gamma-ray astronomy since the early 90s, thanks notably to the efforts of P. Goret. It has participated in the ASGAT, CAT, HESS collaborations and is now part of the world-wide CTA effort.

- The cooperation between physicists and technical teams was and is a major asset for IRFU.

- On CTA, the IRFU has or had major contributions to site development, data reduction and mirror design. It is a leading lab in the NectarCAM collaboration and may host the production of 20+ cameras in the near future.

HESS and CTA at IRFU, past and present

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Backup

IRFU MST quadropod