Projet Emblématique P2IO
CAmera NEctarcam
VAlidation at Paris-Saclay

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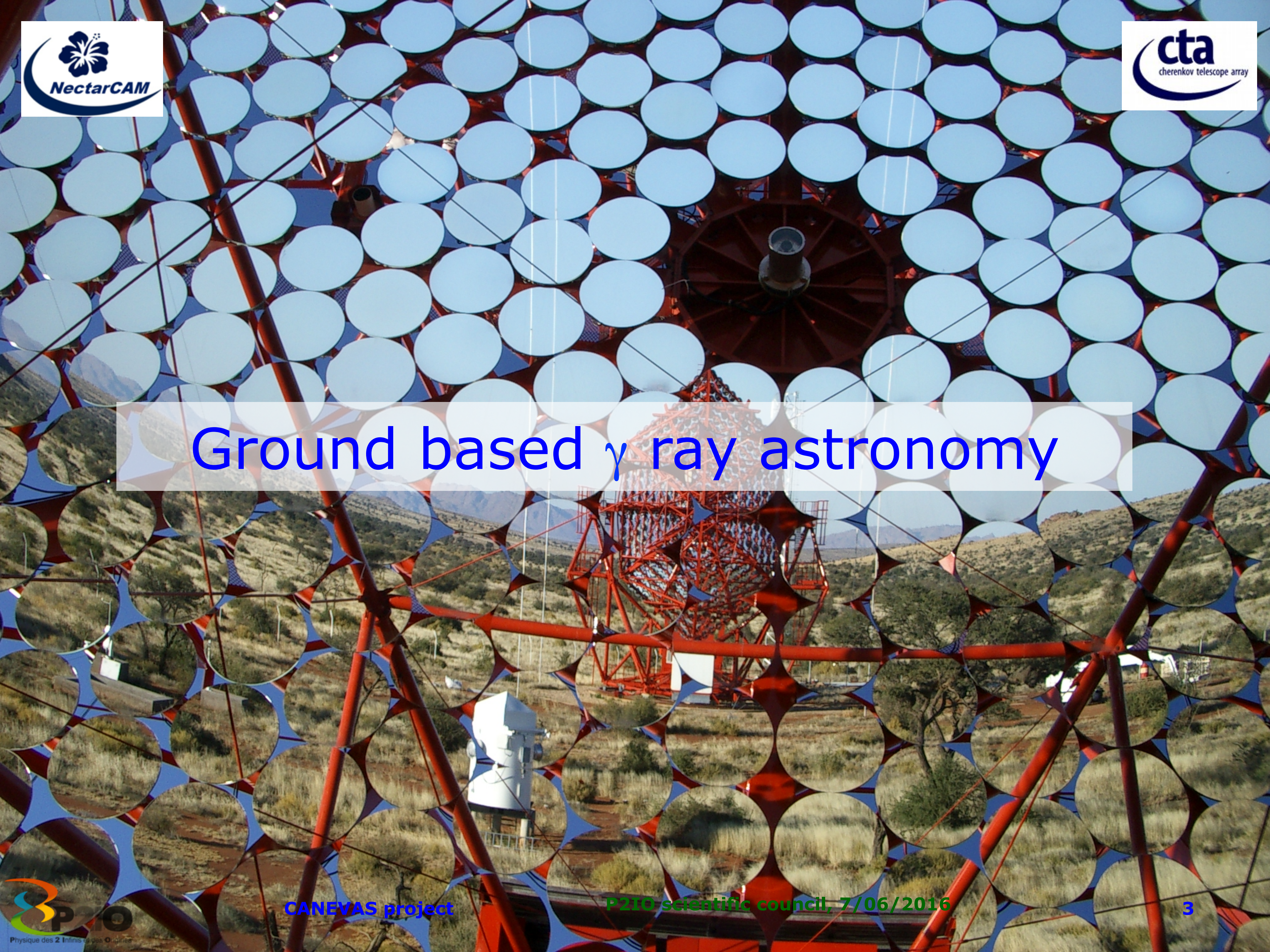
for Canevas n and NectarCAM

Outline

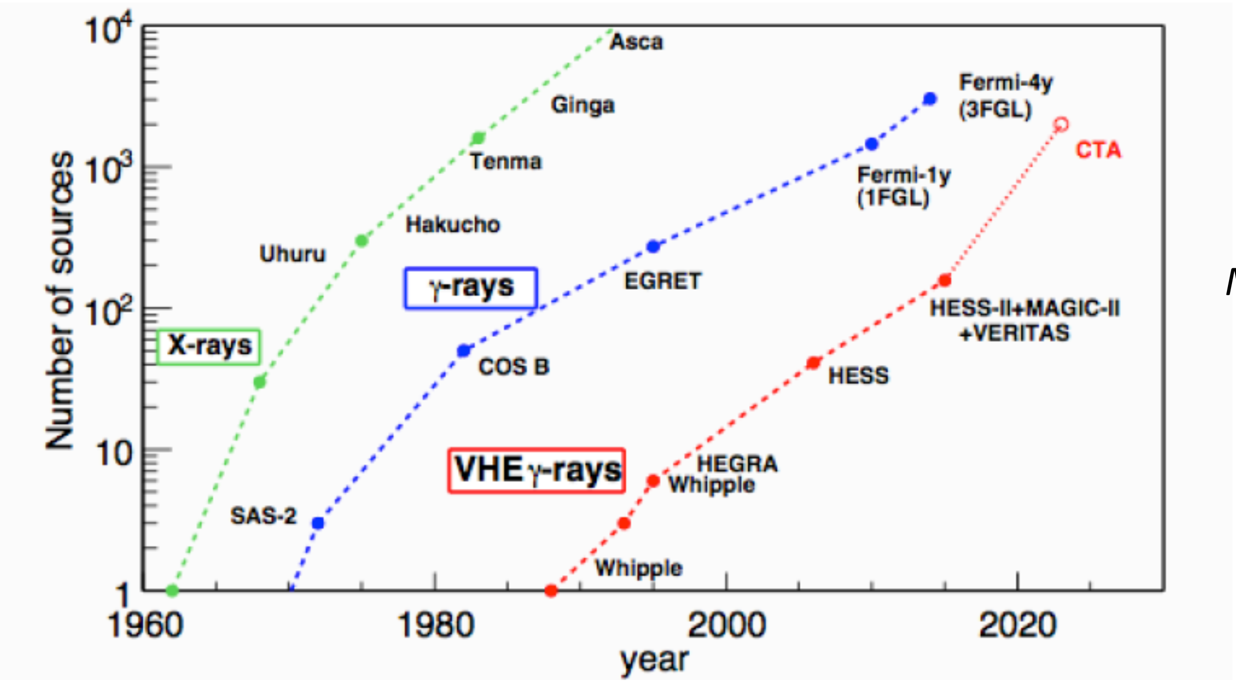
- Ground based gamma ray astronomy
- The Imaging Cherenkov Telescope Array technique
- Improving the performances of present arrays with CTA
- MST telescopes and NectarCAM
- The CANEVAS project: prototyping NectarCAM cameras

Ground based γ ray astronomy



Ground-based gamma ray astronomy: a brief history

- First results in the late 1980's: discovery of the Crab nebula by Whipple.
- In the 1990's: several telescopes/arrays (Themistocle, CAT, CELESTE) operated at Font-Romeu by Paris-Saclay teams (IRFU-Sap, LLR, LAL). Other notable teams: HEGRA, Whipple.
- After 2000: strong involvement of french teams on H.E.S.S. The (initial) H.E.S.S. cameras are designed and built by LPNHE (Paris 6), LLR, APC, in collaboration with IRFU, LAPP and LUPM.
- With H.E.S.S. and its competitors (MAGIC, VERITAS), the field reaches maturity. H.E.S.S. is awarded the Descartes (2006) and Rossi (2010) prizes.



M.Lemoine-Goumard ICRC 2015

Very High Energy γ ray Astronomy

- Detect the photons produced by interactions of very high energy cosmic rays (> 100 GeV)

⇒ Finding and mapping the sources of VHE charged cosmic rays in the Universe

⇒ Discover or test the acceleration mechanisms

Standard photon production mechanisms:

Bremsstrahlung

Synchrotron radiation

Inverse Compton Scattering

Non Standard production:

Wimp and other DM particle annihilation

Primordial Black Hole evaporation

- Propagation effects:

Standard:

intra/extragalactic magnetic field (cascades)

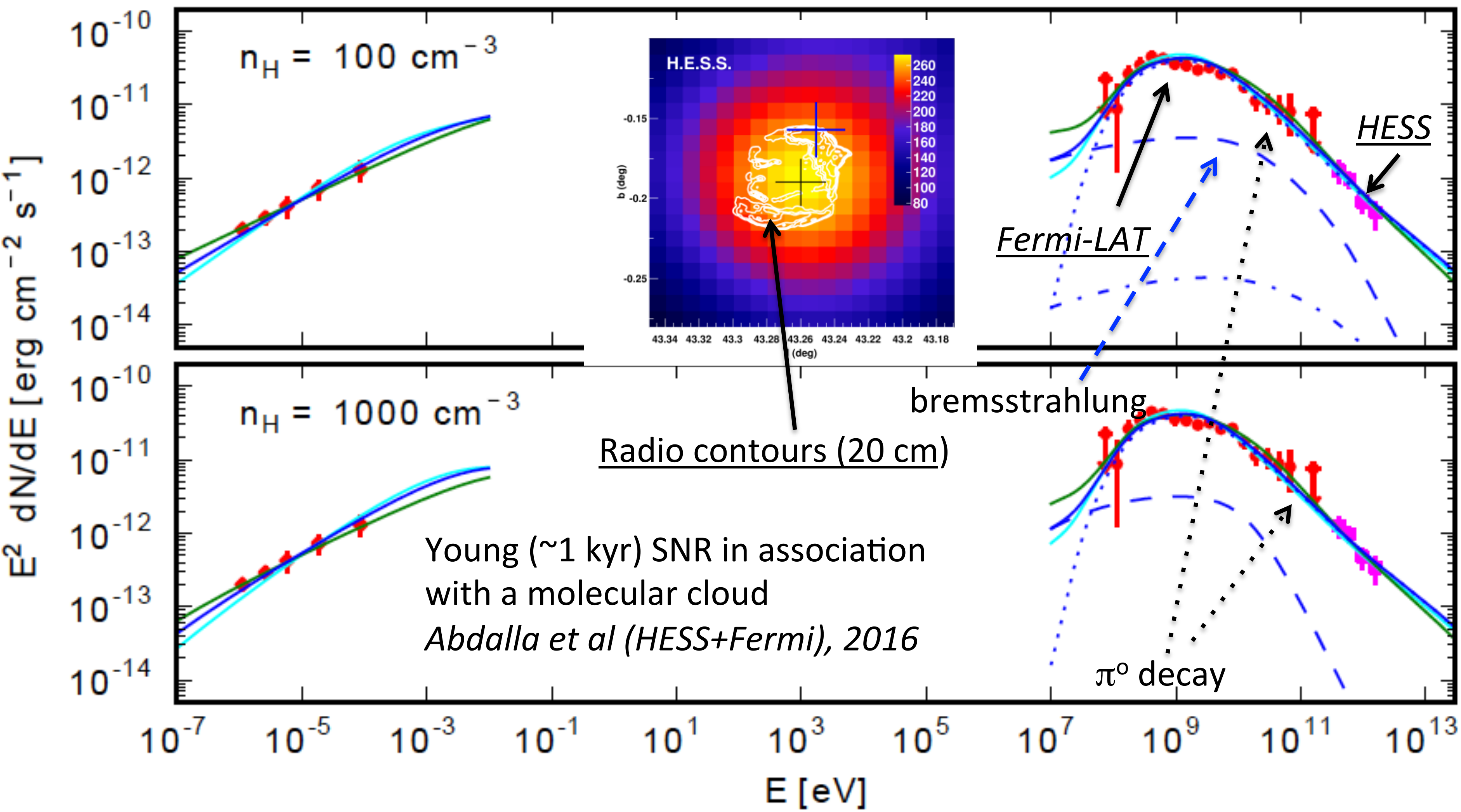
Photon background

Non-standard:

Oscillations

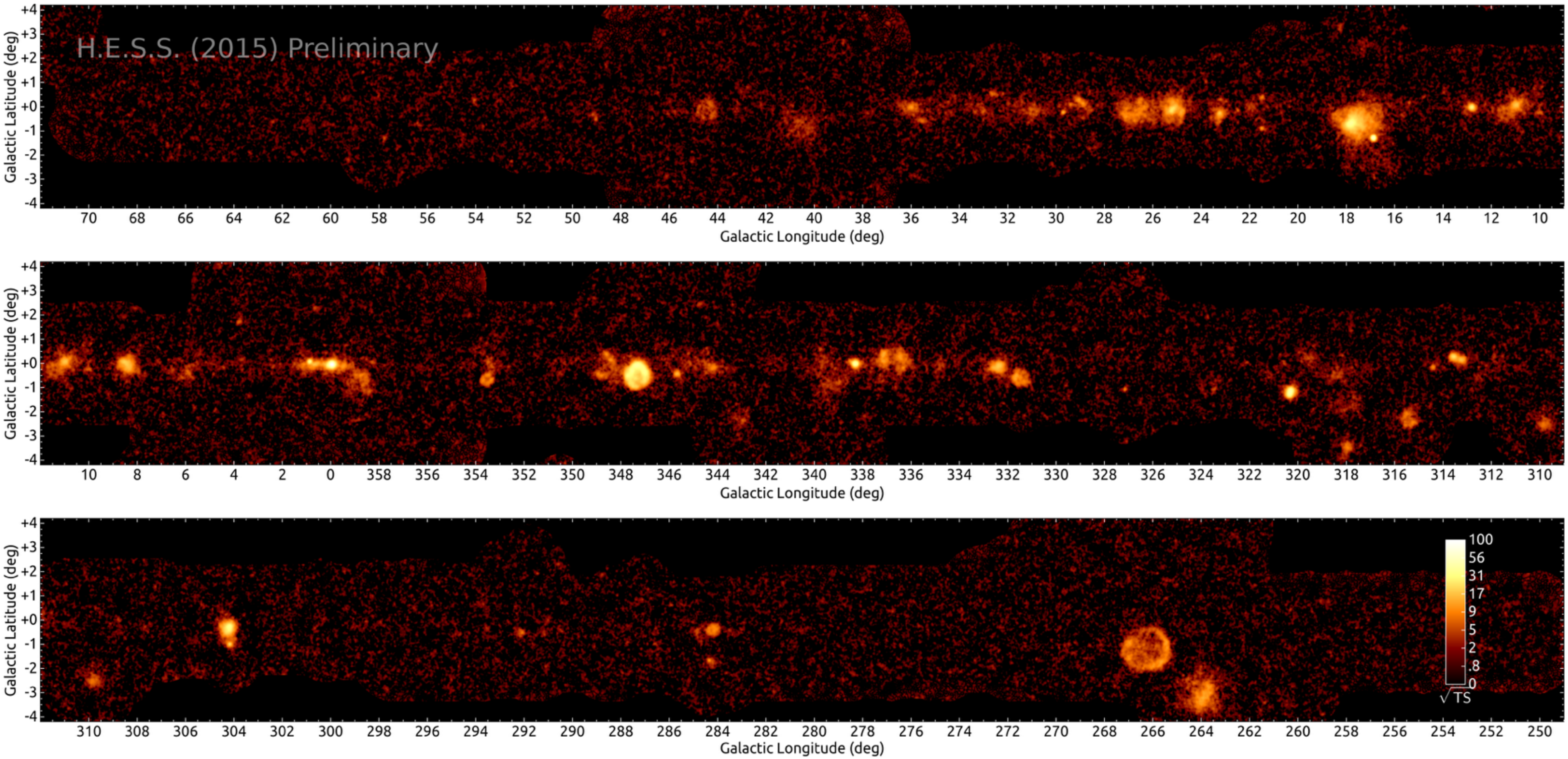
Measurements/ discoveries

A conventional source:SNR W49B



(Astro)physicist wish list: better low energy threshold

From single sources to population studies

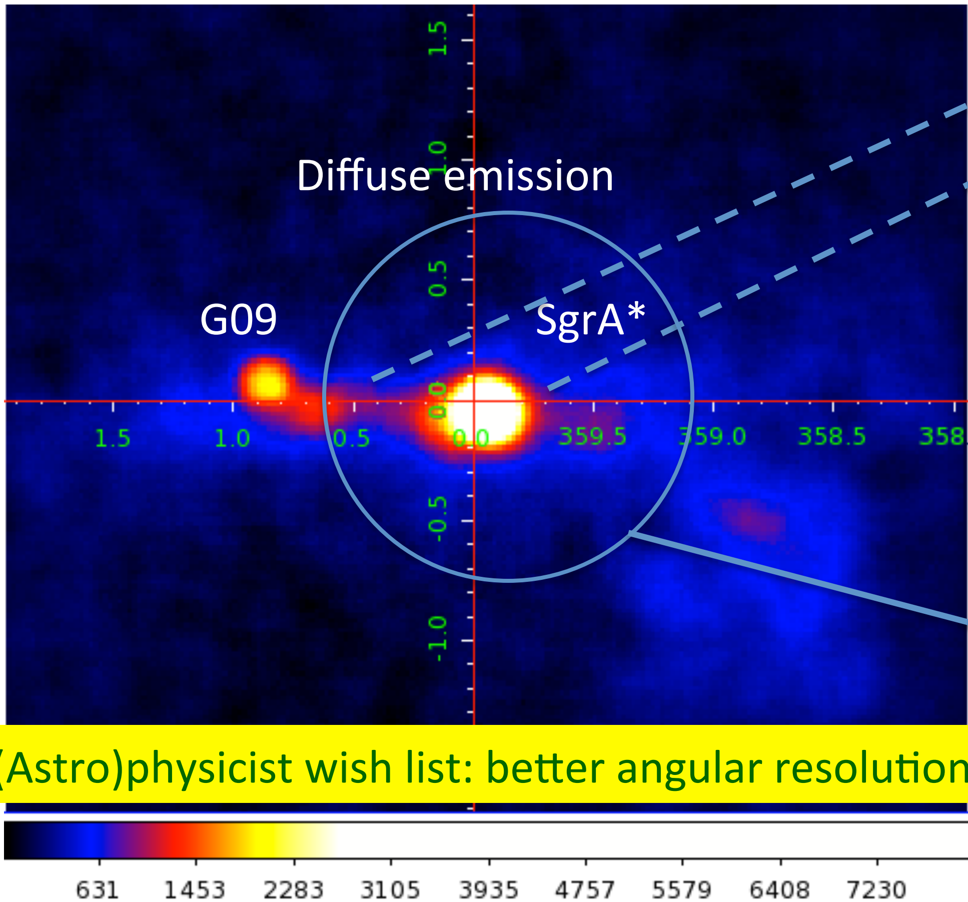


- *HESS (2016), submitted to Astronomy and Astrophysics*
- First surveys with H.E.S.S. => source population studies (e.g. pulsar wind nebulae)

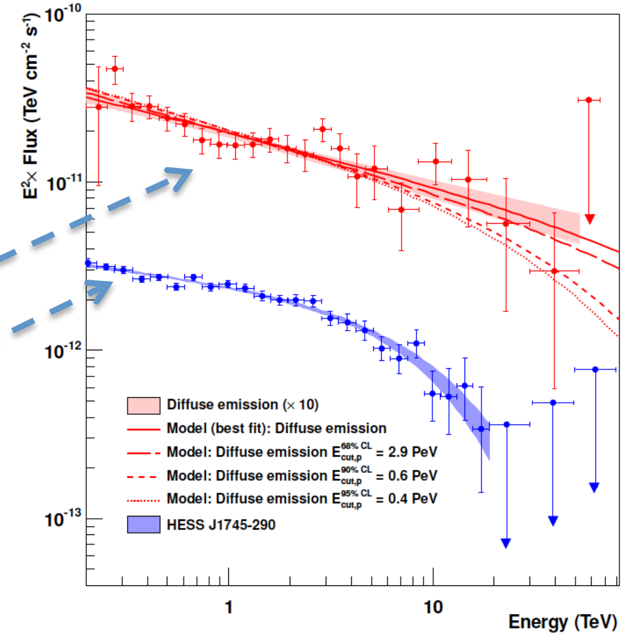
(Astro)physicist wish list: complete survey (magnitude limited), large size (>1°) objects

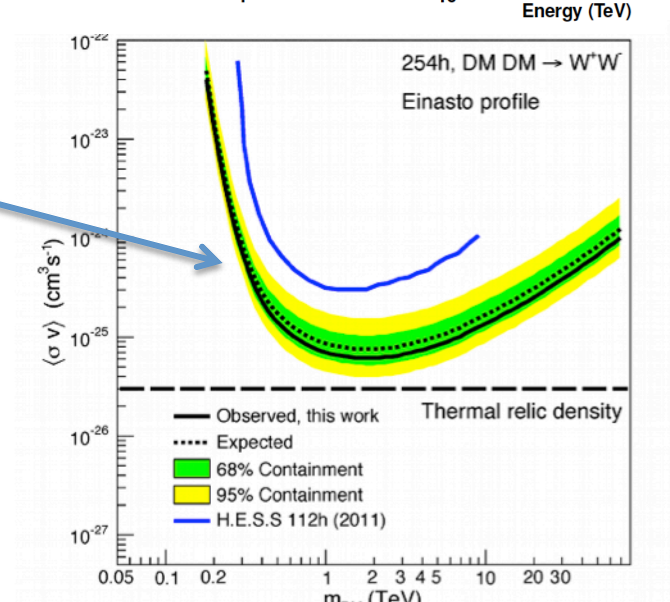
A less conventional source: SgrA*

Pevatron in central H.E.S.S. source
Nature (2016)



(Astro)physicist wish list: better angular resolution

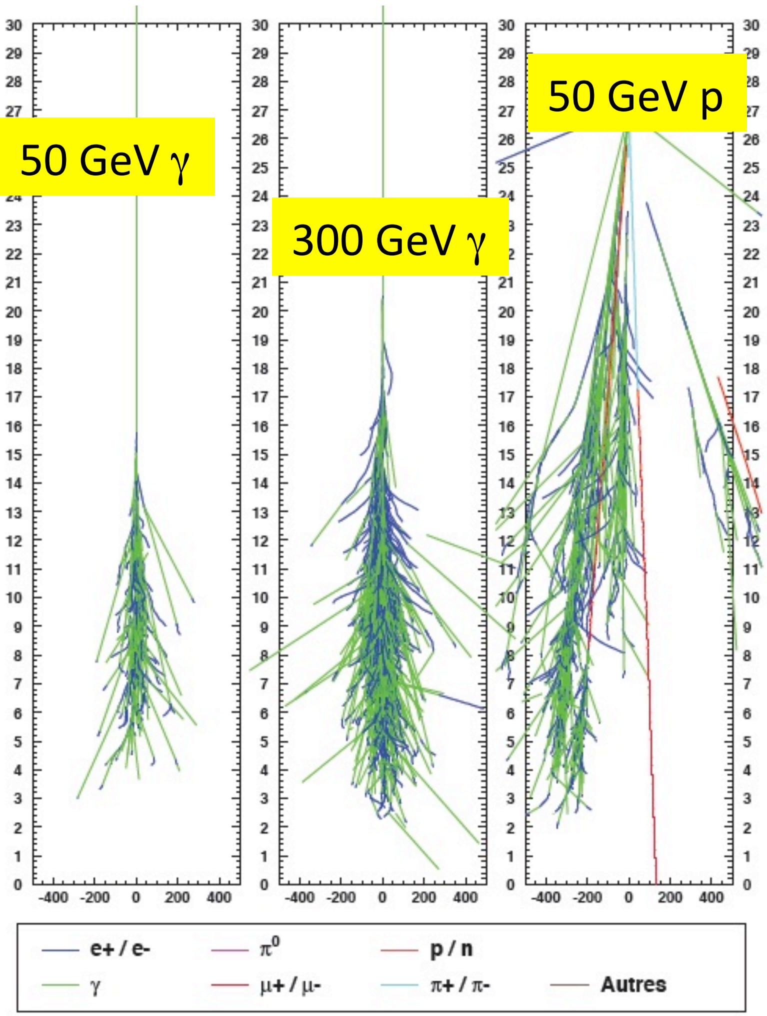




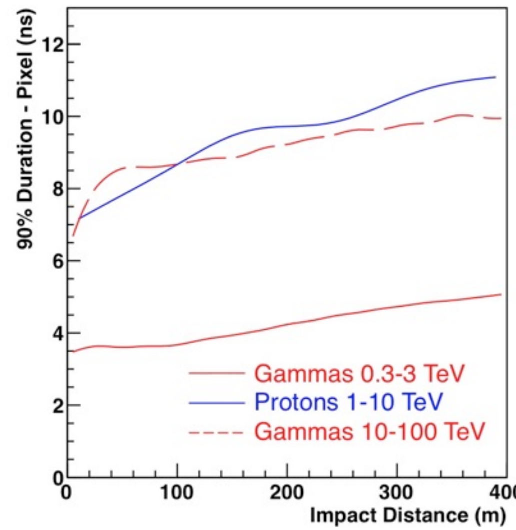
Dark matter bounds from the Galactic Halo
(Lefranc ICRC 2015)

The Imaging Cherenkov Telescope Array technique

Ground based γ ray astronomy in a nutshell

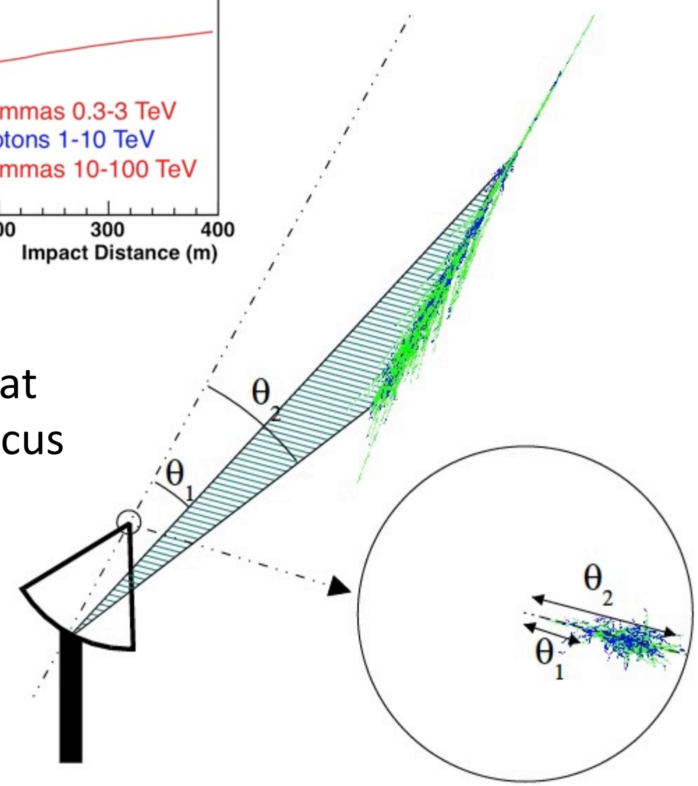


Courtesy M.de Naurois

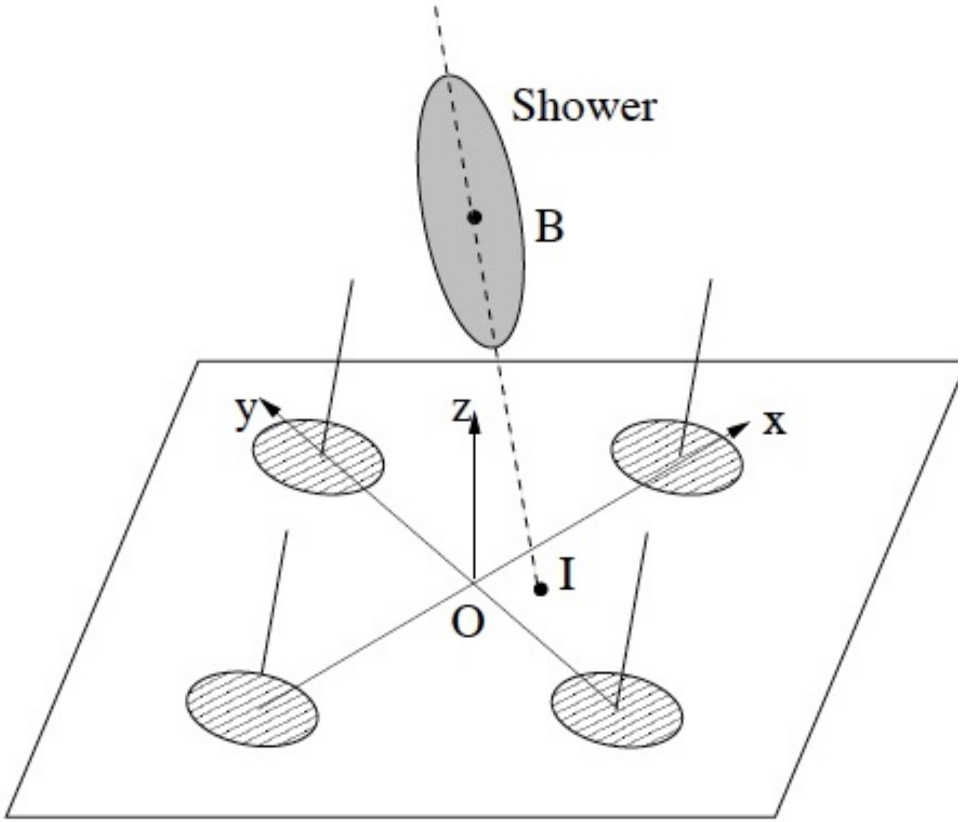


Shower duration inside a pixel ~ 4 ns

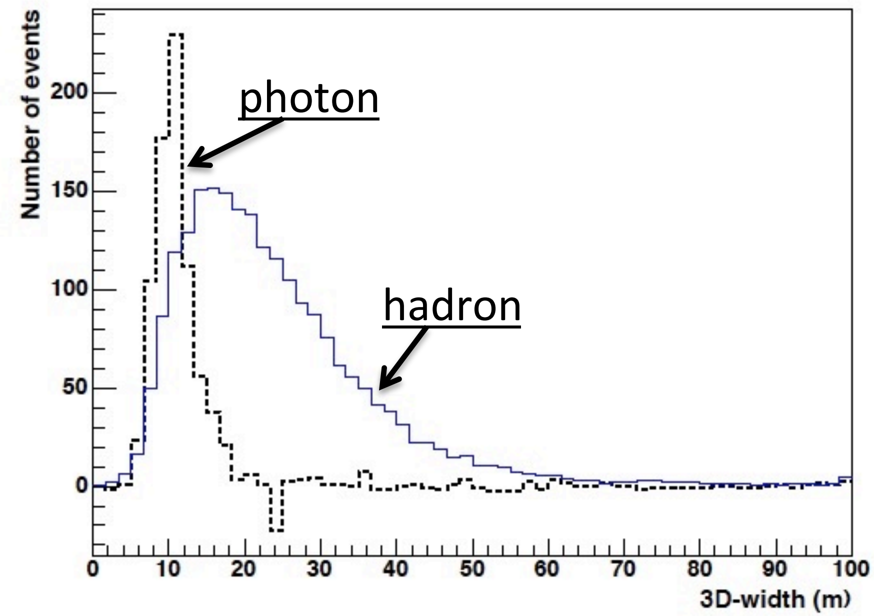
Shower imaged at the telescope focus



Ground based γ ray astronomy in a nutshell (2)

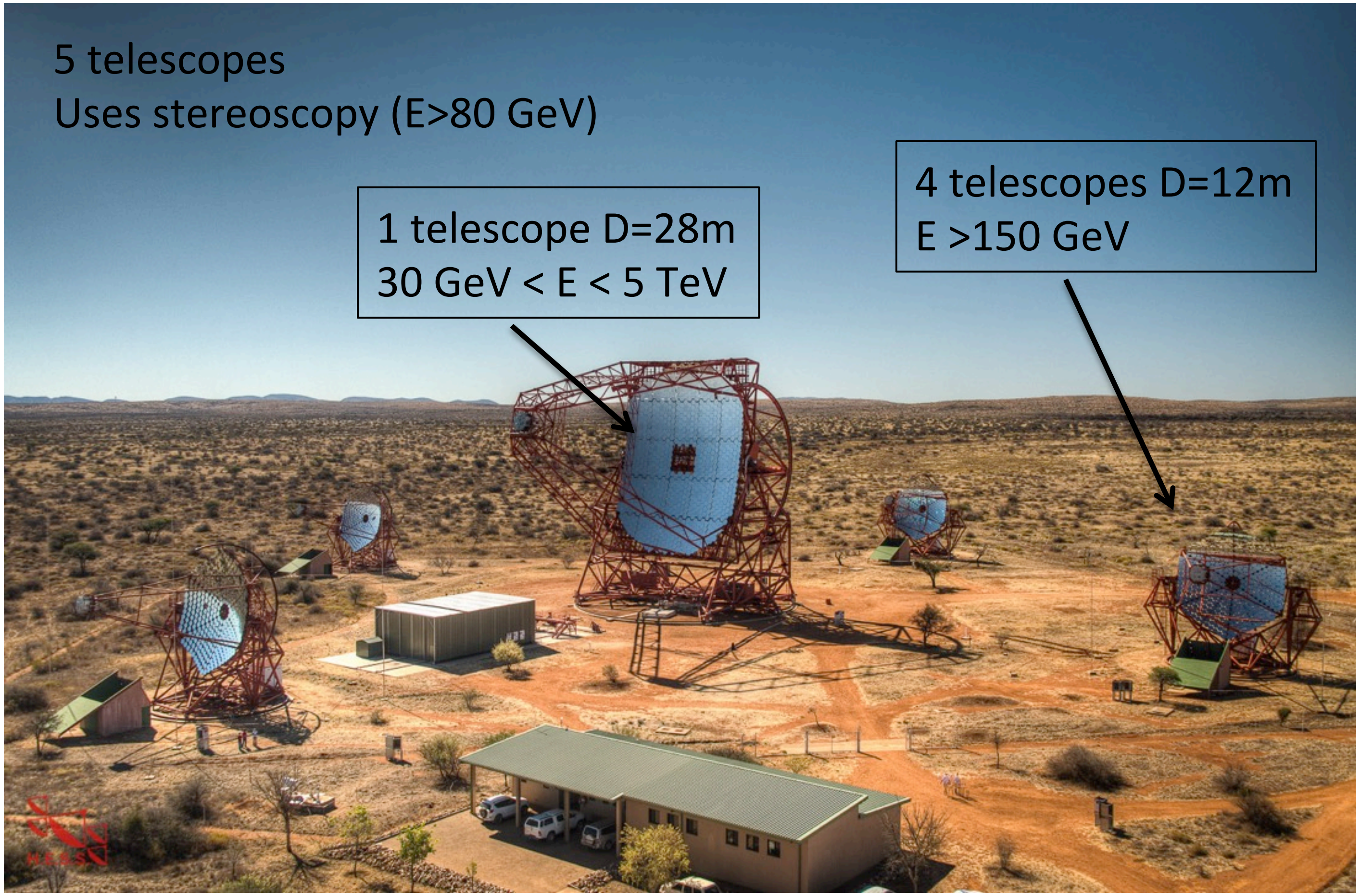


- Energy obtained from photon count once the impact parameter and the zenith angle of shower are known.
- Gamma-hadron separation from shower width

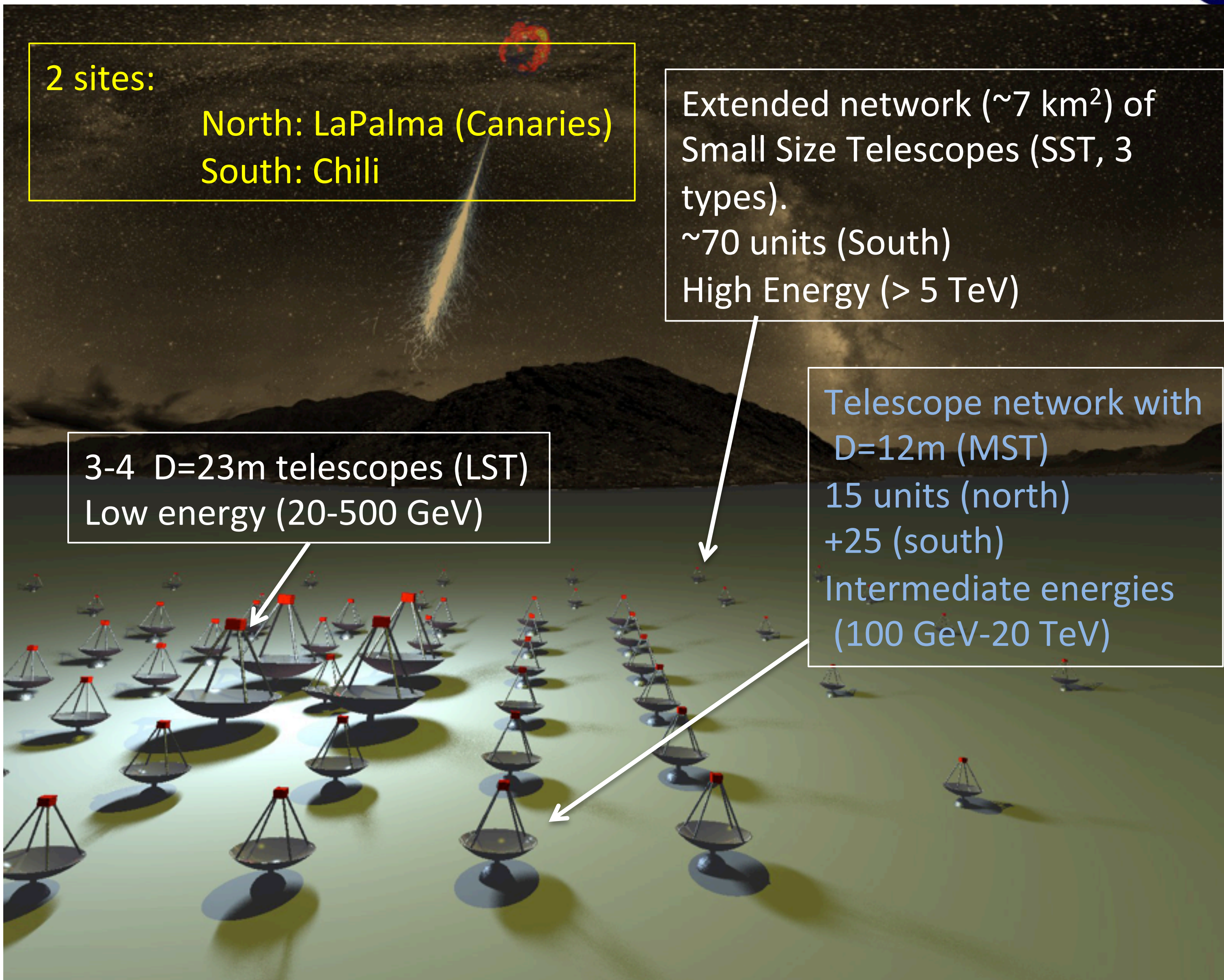


- Use stereoscopy to constrain the impact parameter (2 parameters) and 3-D direction (2 parameters)
- Other mesurables:
  - width and length of shower image
  - center of gravity of image
  - total number of photons

Present generation of IACT: H.E.S.S.



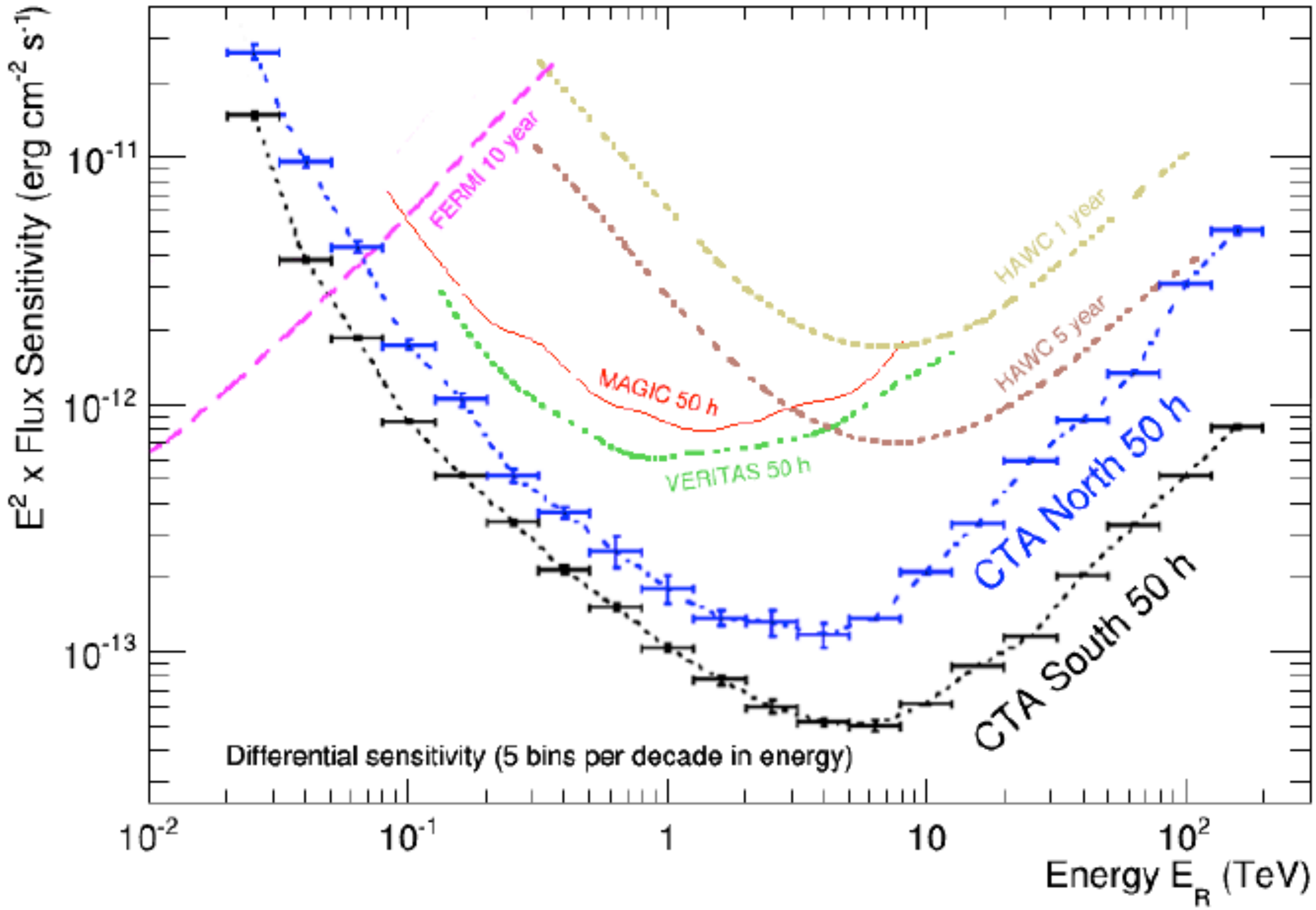
The near future: CTA



Improving the performances of present arrays with CTA

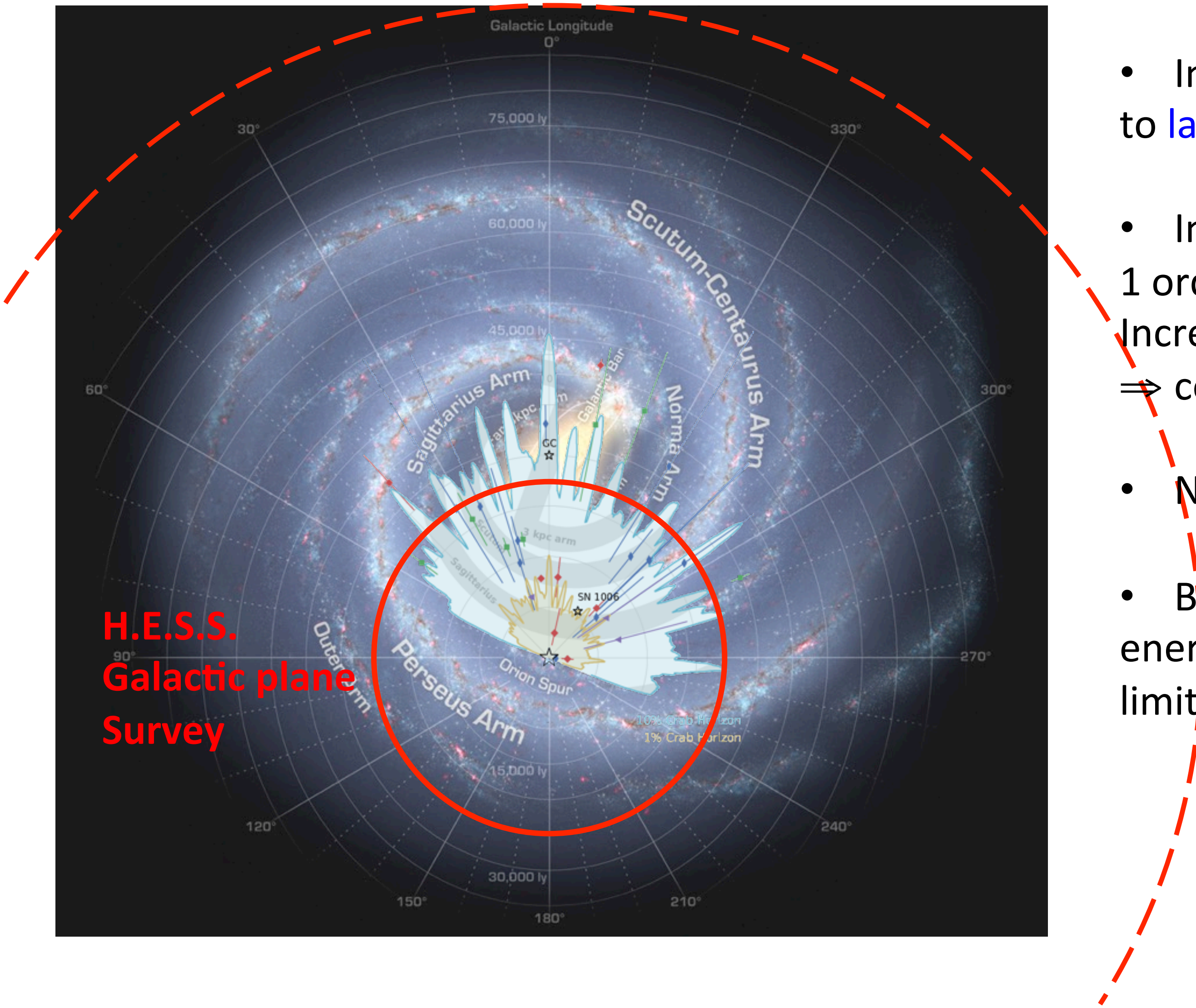
- Performances are improved thanks to
  - A larger collection area
  - Improved stereoscopy
  - Better instruments

Sensitivity of the CTA array



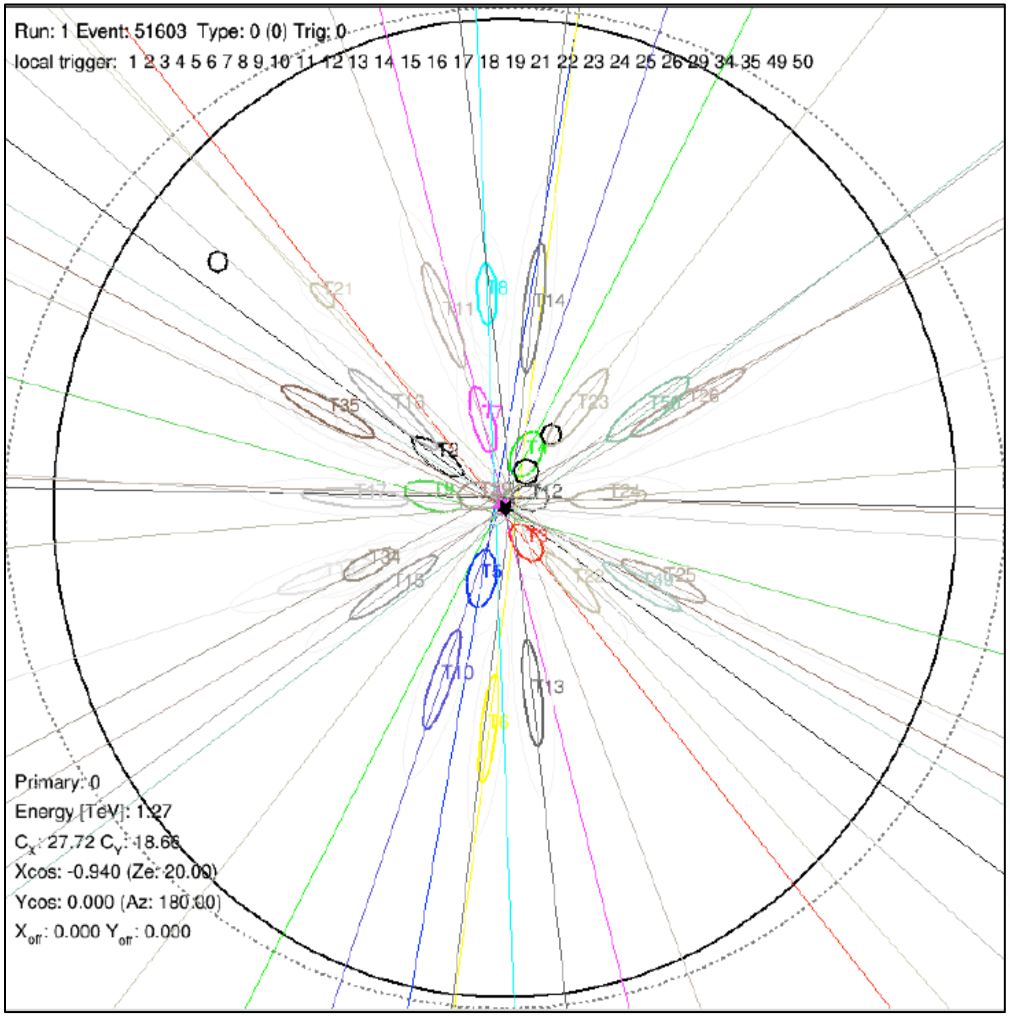
- Improvement of ~1 order of magnitude compared to H.E.S.S. in the 100 GeV – 10 TeV range
- Extended range towards low and high energy

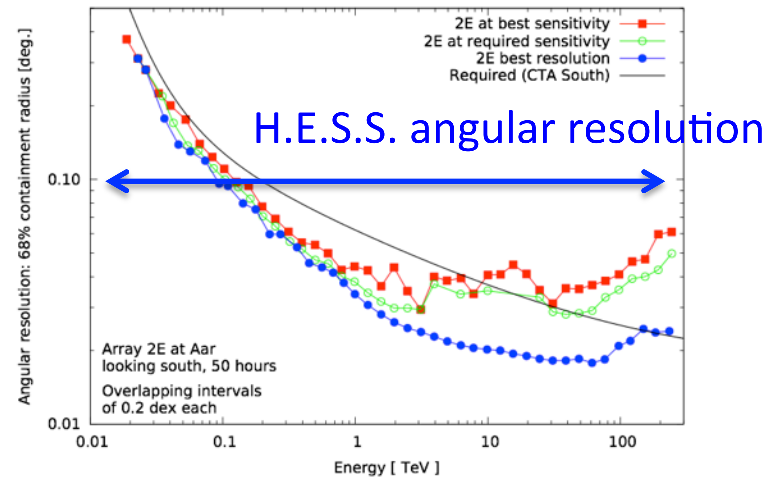
Another look to H.E.S.S. galactic plane survey

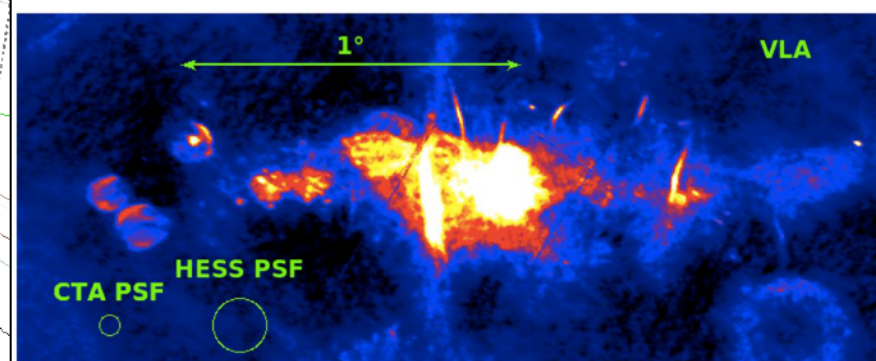


- Increase in sensitivity due to larger collection area.
- Increase in sensitivity by 1 order of magnitude => Increase in distance by 3 => complete galactic survey
- Number of objects x 10
- Better sensitivity at high energy =>study the high E limit of galactic accelerators

Improving the angular resolution with stereoscopy

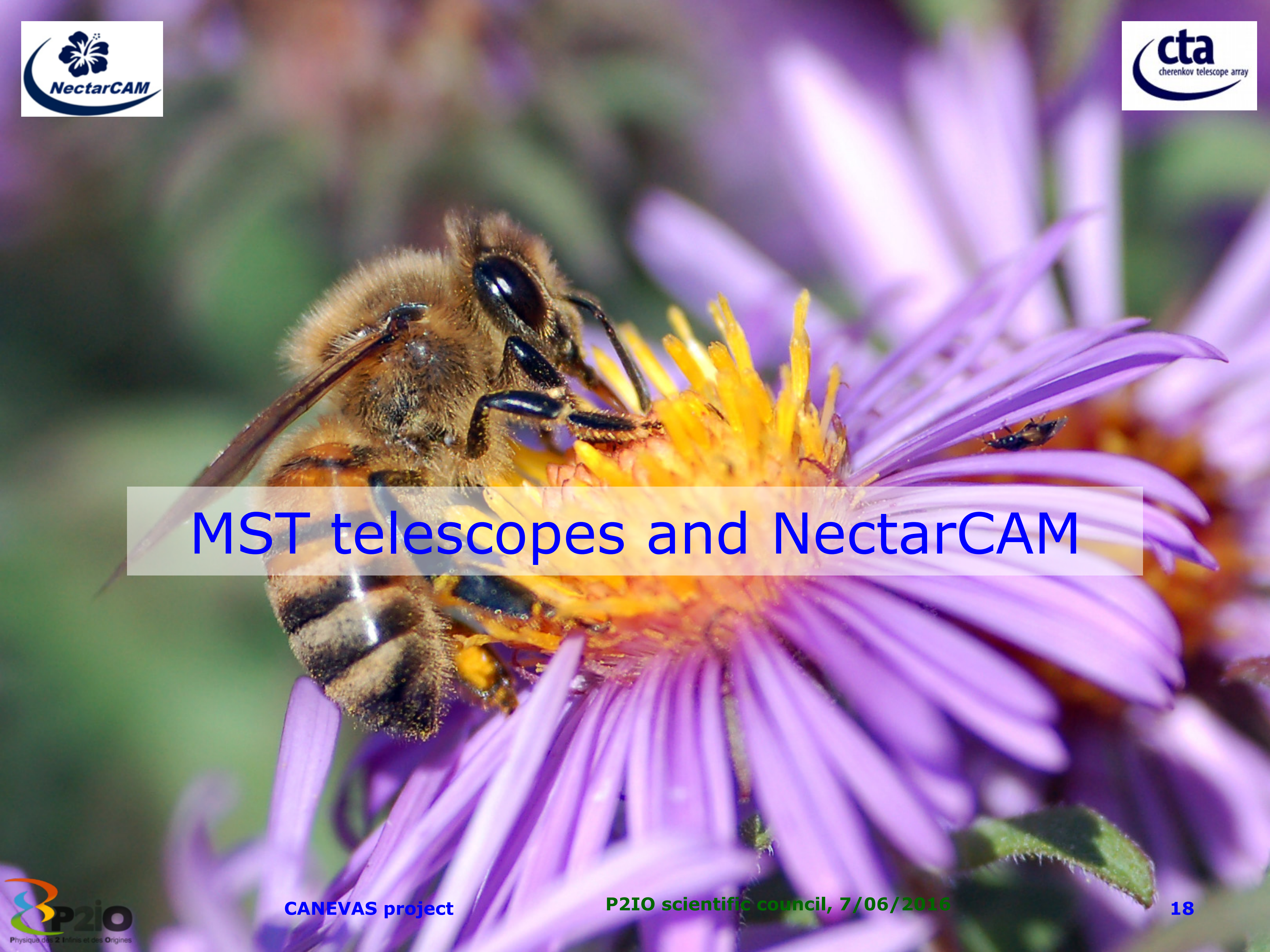






Galactic Centre

~6 telescopes hit in average, much larger than H.E.S.S. (~2 – 2.5)

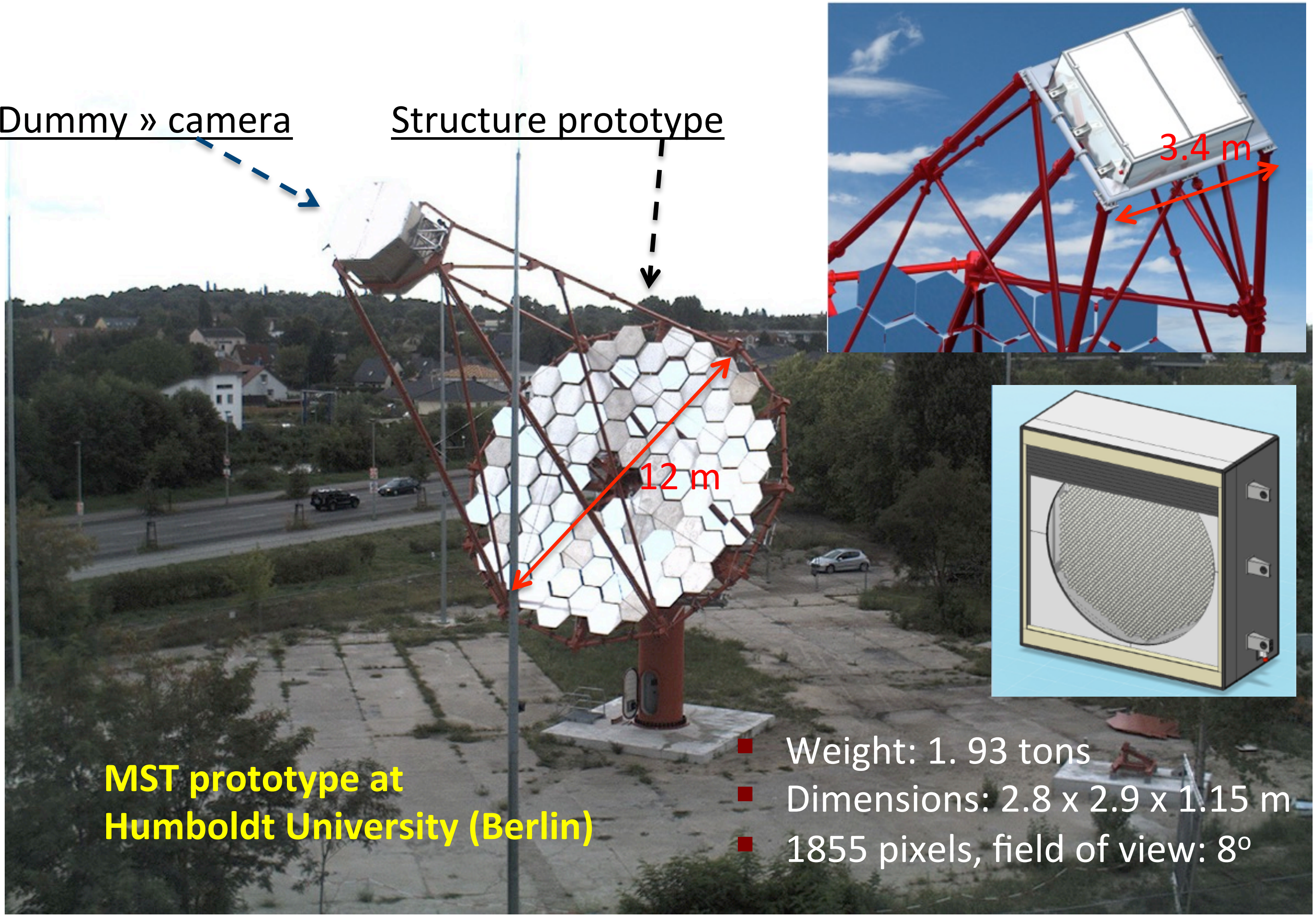


MST telescopes and NectarCAM

NectarCAM and Medium Size Telescopes

« Dummy » camera

Structure prototype

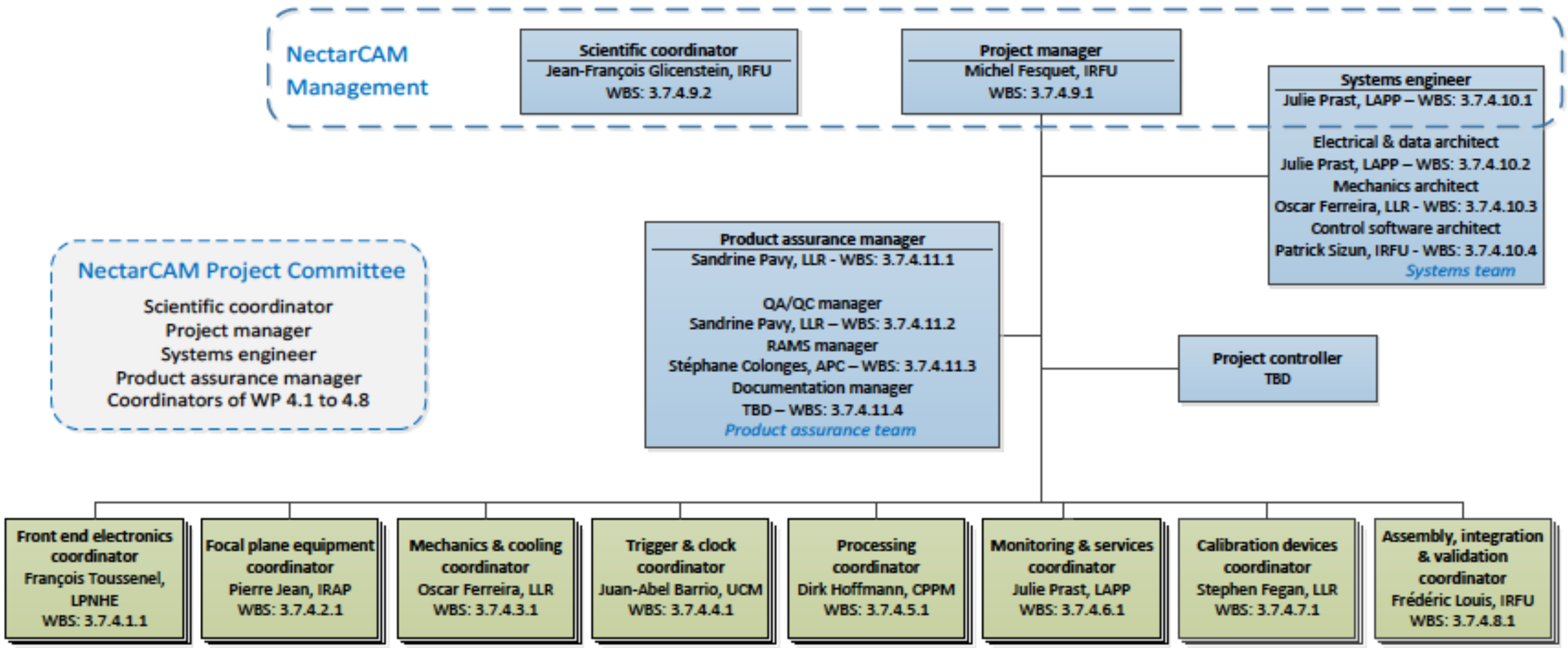


MST prototype at Humboldt University (Berlin)

- Weight: 1. 93 tons
- Dimensions: 2.8 x 2.9 x 1.15 m
- 1855 pixels, field of view: 8°

The NectarCAM consortium

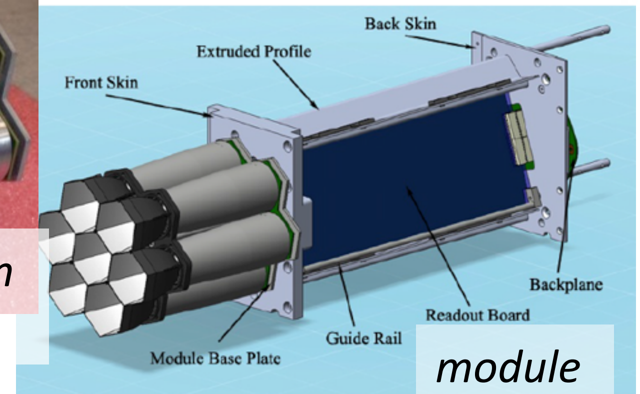
Aim: build cameras for the MST telescopes of CTA
15 institutes from 3 countries (France, Espagne, Germany)
~50 engineers et physicists

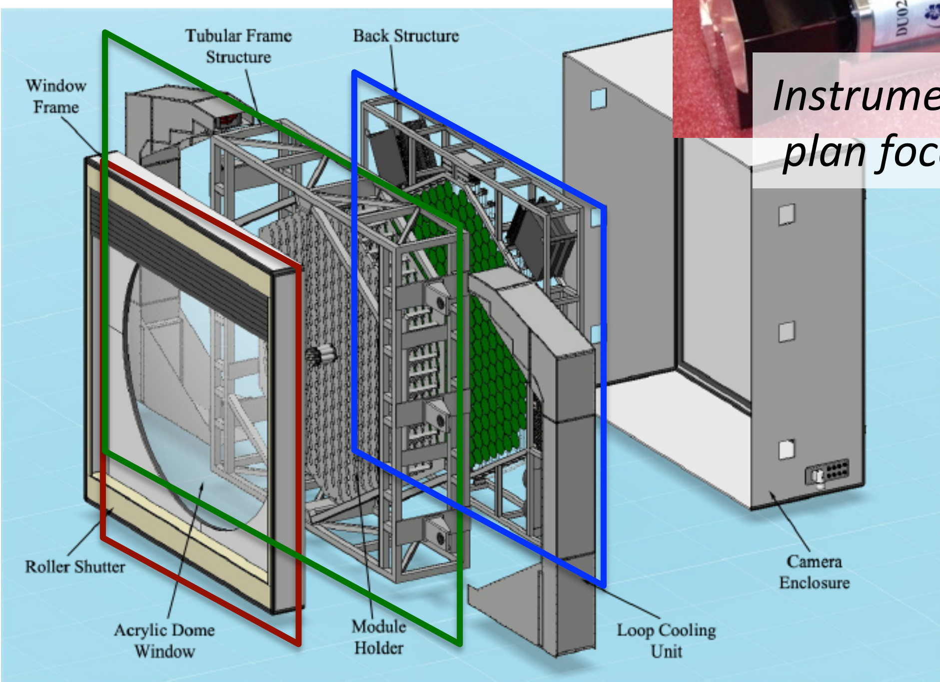


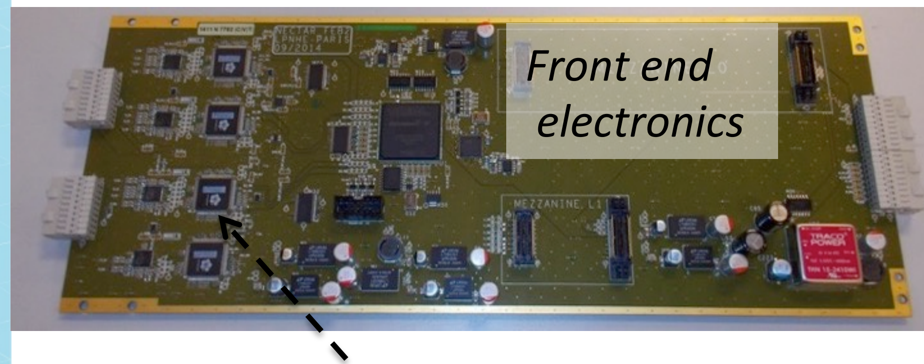
LUPM Laboratoire Univers & Particules Montpellier — LPNHE Paris — LLR — lapp — Irfu — irap astrophysique & planétologie

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas — Centre de Physique des Particules de Marseille CPPM — DESY — GAE — IFAE — ICCUB Institut de Ciències del Cosmos — IPAG — IPN Institut de Physique Nucléaire Orsay

NectarCAM







Nectar chips

Modular camera (265 7-photomultipliers modules)

Camera front: roller shutter, acrylic window (protection from dust)

Central part: active part, photon capture and data digitization, first level trigger

Rear part: trigger management, data switches, power and clock distribution, slow control

Camera performances

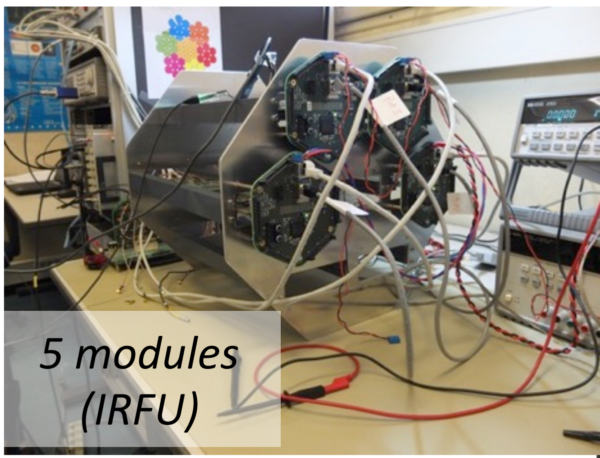
Most of the CTA gain in performance comes from the array size effect
However, NectarCAM is expected to perform significantly better and more reliably than H.E.S.S. cameras.

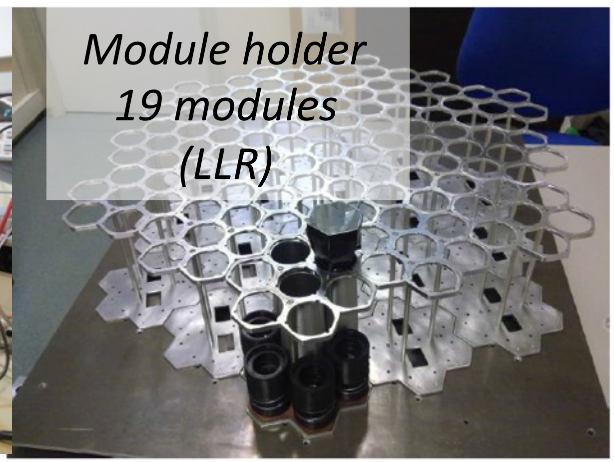
	H.E.S.S. cameras	NectarCAM (CTA)	
Field of view	5 deg. (H.E.S.S.1)	8 deg.	*Study of extended objects*
Output	Integrated charge	Integrated charge	
	Time of arrival	Time of arrival	
		Waveform (16-60 samples)	*Time/charge resolution*
Dead-time	15 μs (H.E.S.S.2)	<7 μs	*Energy threshold*
Trigger rate	3 kHz (H.E.S.S.2)	12 kHZ	*Energy threshold*
Trigger	Sector based	Sector or pixel	
	Fixed time window	Allows for signal propagation in camera	*High energy shower reconstruction*
Weight	3.3 tons (H.E.S.S.2)	2 tons	
Cooling	air (fans)	forced convection	*signal systematics*

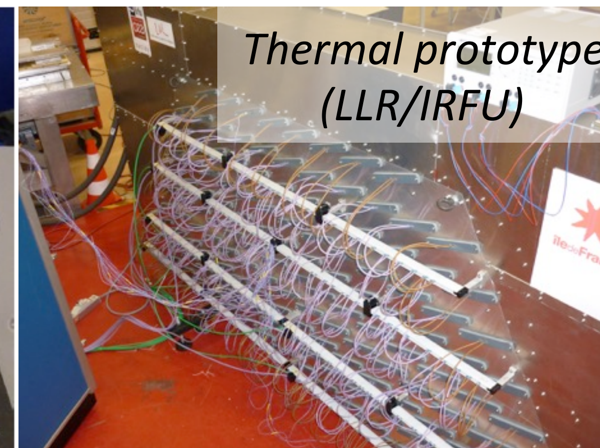
NectarCAM prototyping strategy

- Sub-component prototyping (2011-2015)
- Full module assembly (2012-2014)
- 5-module cluster (2013-2015): interface between front-end and backplane validated, first trigger tests
- Thermal prototype, temperature control (2014)
- 19-module mini-camera (2015-2016): validation and choice of camera trigger

R & D





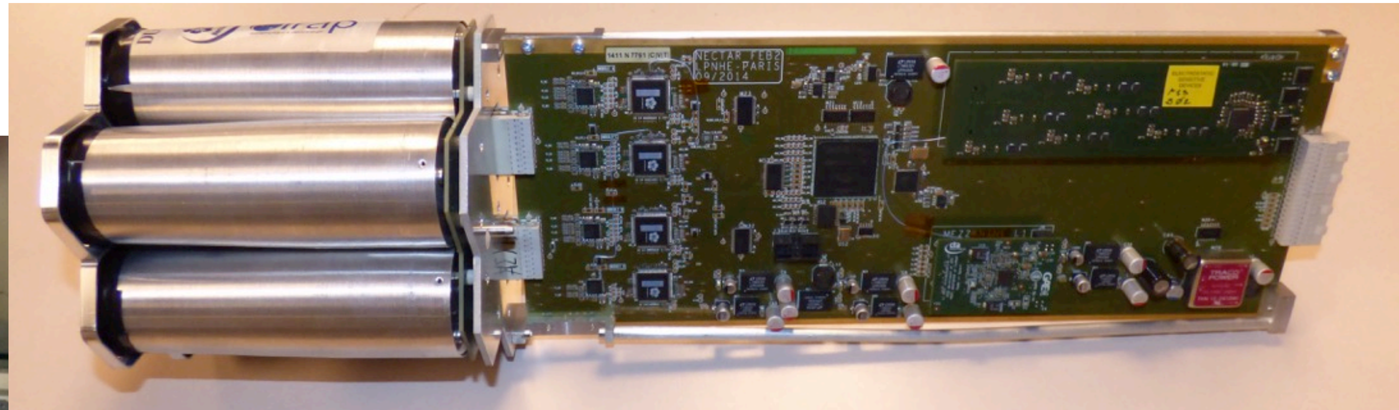


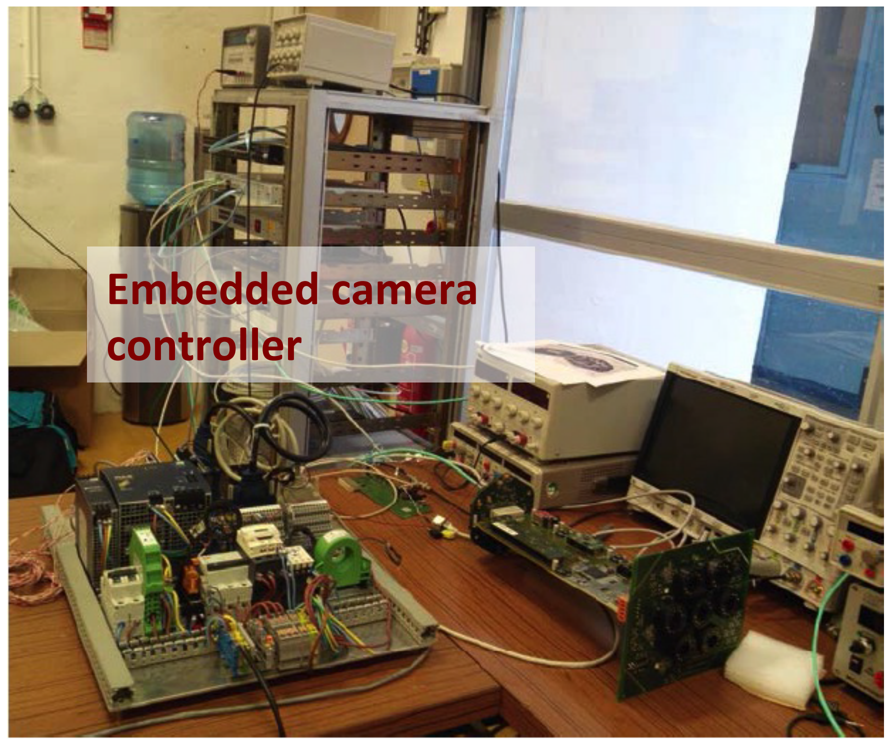
- CANEVAS camera (2016-2019), scale 1, partially->fully equipped

Full validation and installation on a telescope structure, on site

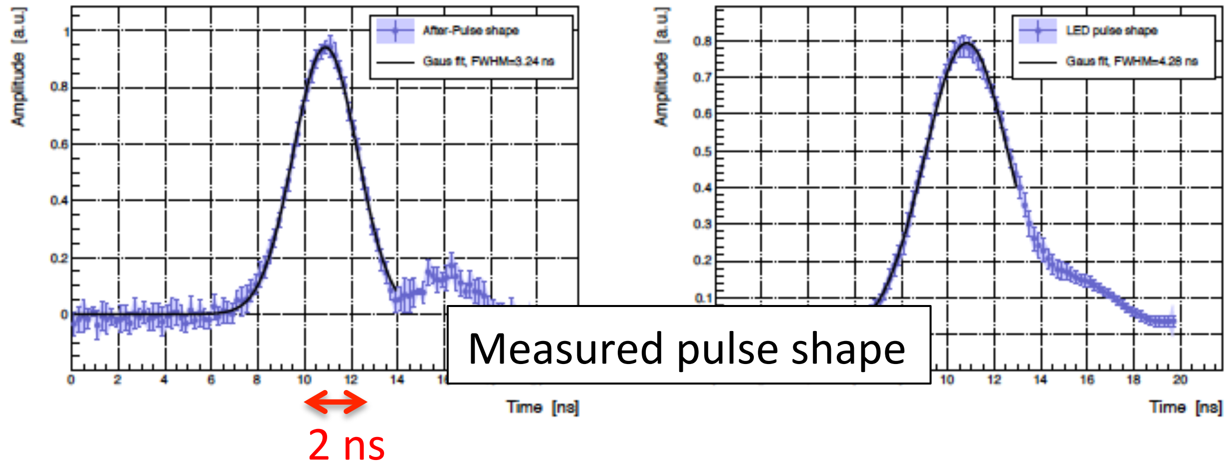
Pre-industrialization

Subcomponent prototyping

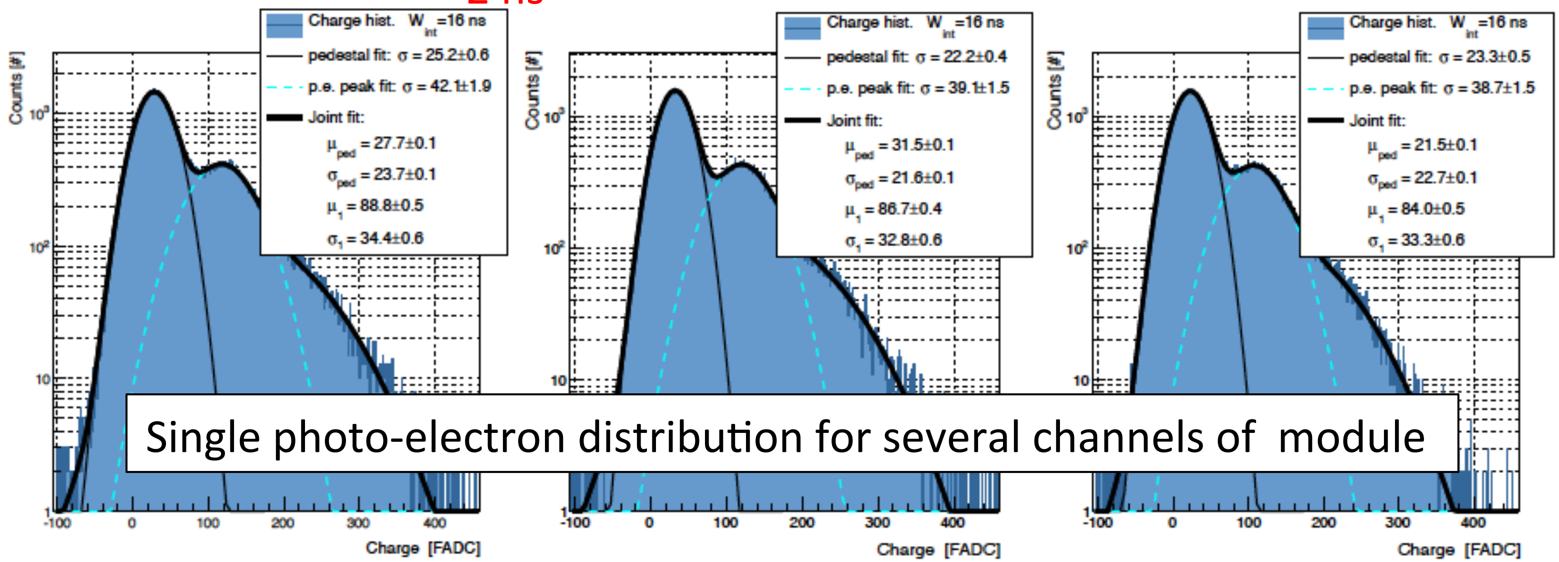




NECTAr module results (light source)



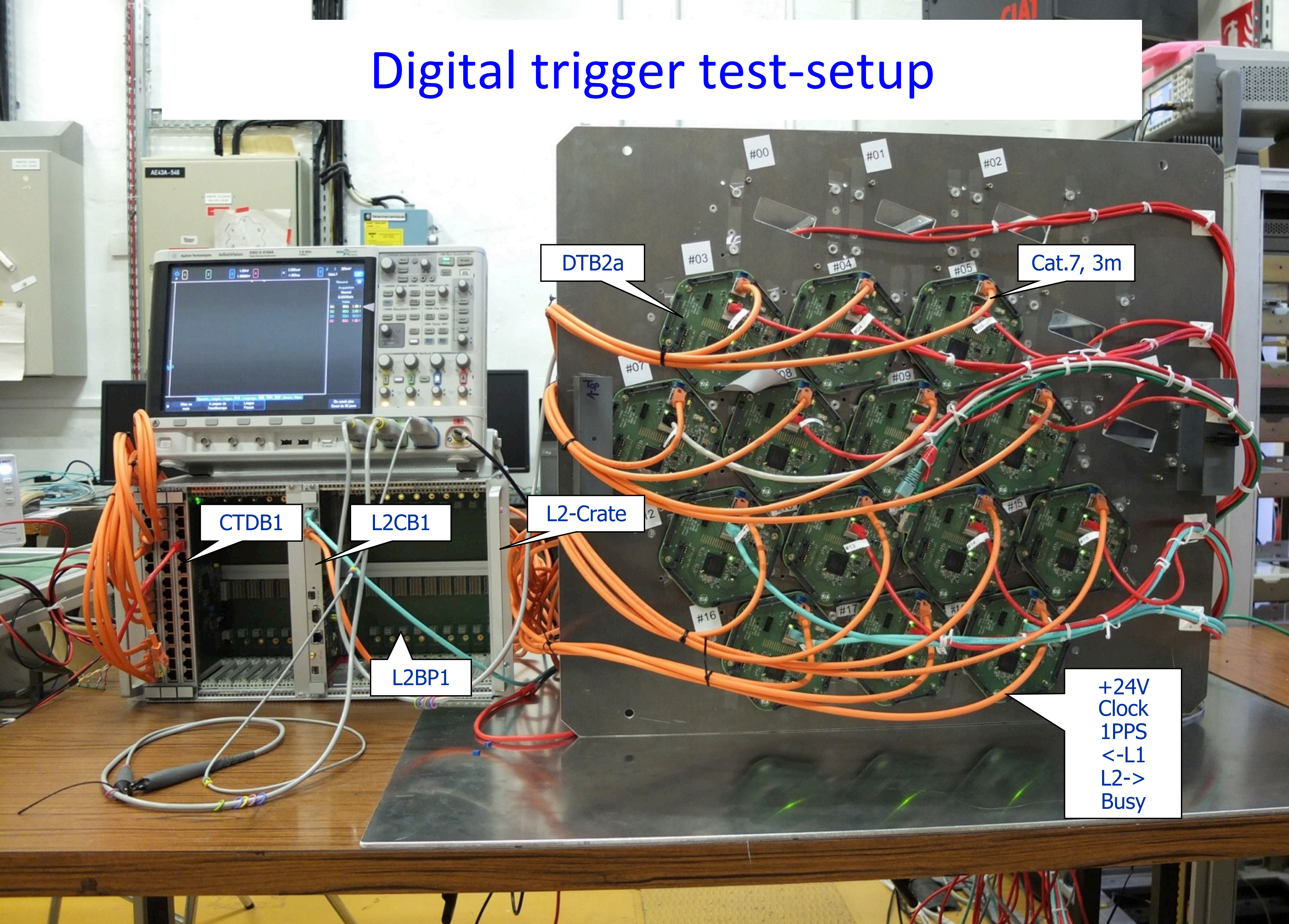
Measured pulse shape



Single photo-electron distribution for several channels of module

Courtesy: F.Louis, E.Moulin, M.Shayduk (IRFU)

Digital trigger test-setup



The CANEVAS project

The CANEVAS project

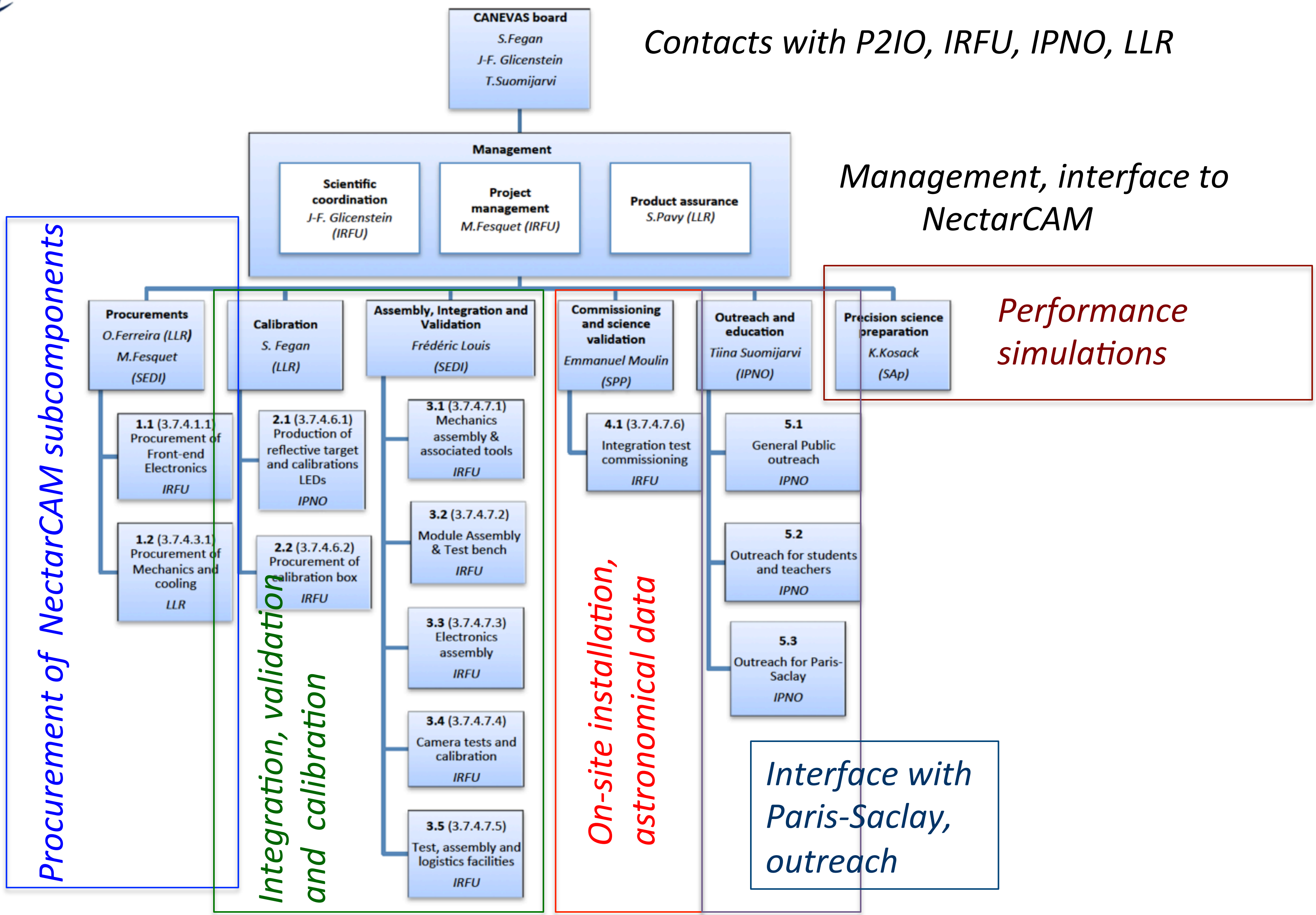
- Selected as P2IO « Projet emblématique »

- Total grant from P2IO Labex: 459 k€ hardware+250 k€ personnel
- 120 k€ additional grants from OCEVU, OSUG2020 Labexs
- Contributions from IRFU, IN2P3

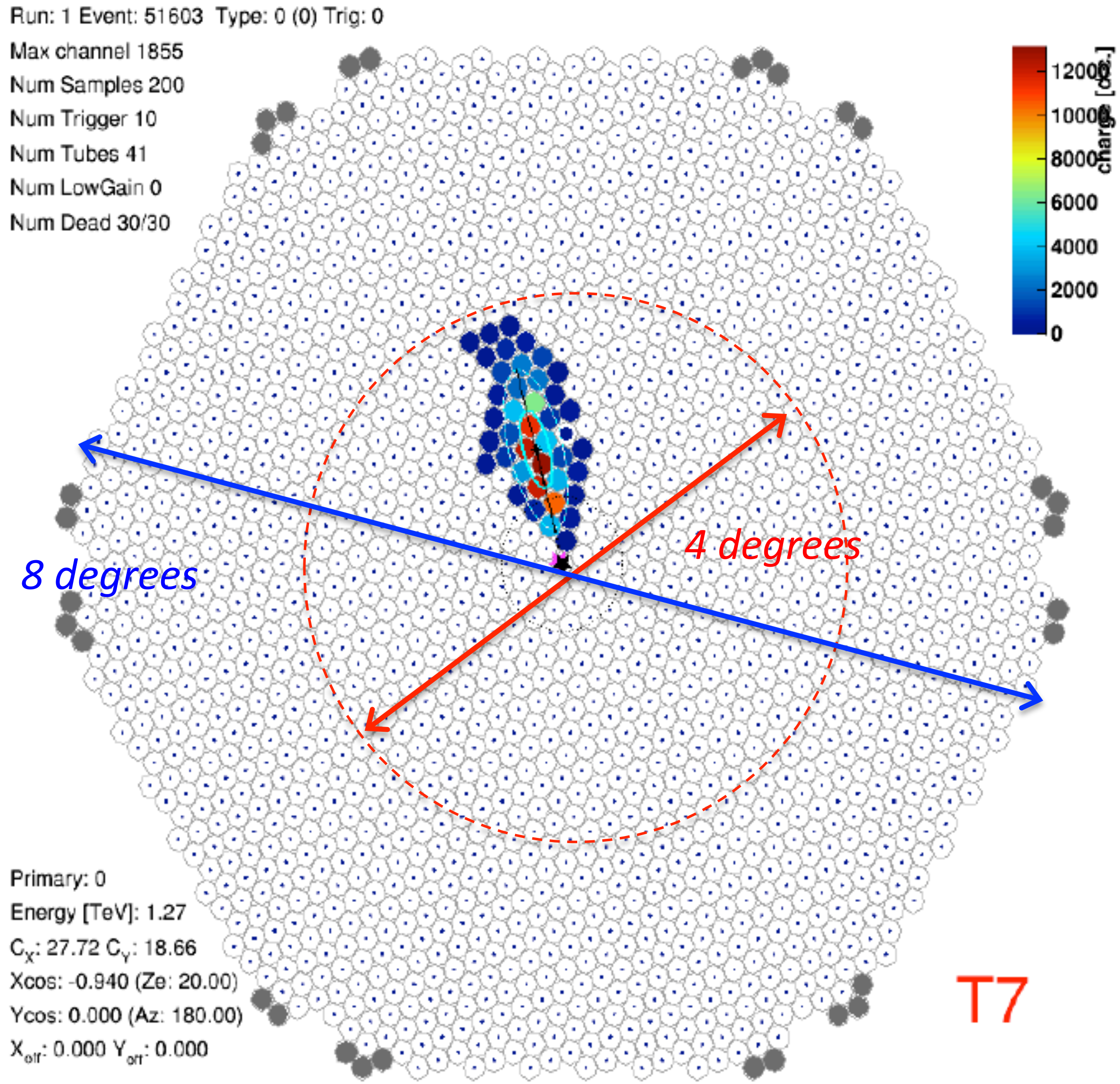
- Research and innovation component:
  - Construction of a camera aimed at validating NectarCAM with astronomical data
  - Installation on a site such as Roque de los Muchachos (Canaries)
  - The camera is a NectarCAM with a scale 1 mechanics, cooling system, data acquisition, slow control, power, trigger and clock, ¼ of detector units and readout module.
  - Field of view ~ 4^o

- Teaching and outreach component:
  - 3 post-doctoral positions (2 yrs+2 yrs+1 yr) at LLR, IRFU and IPNO
  - Outreach for students, engineer and general public.

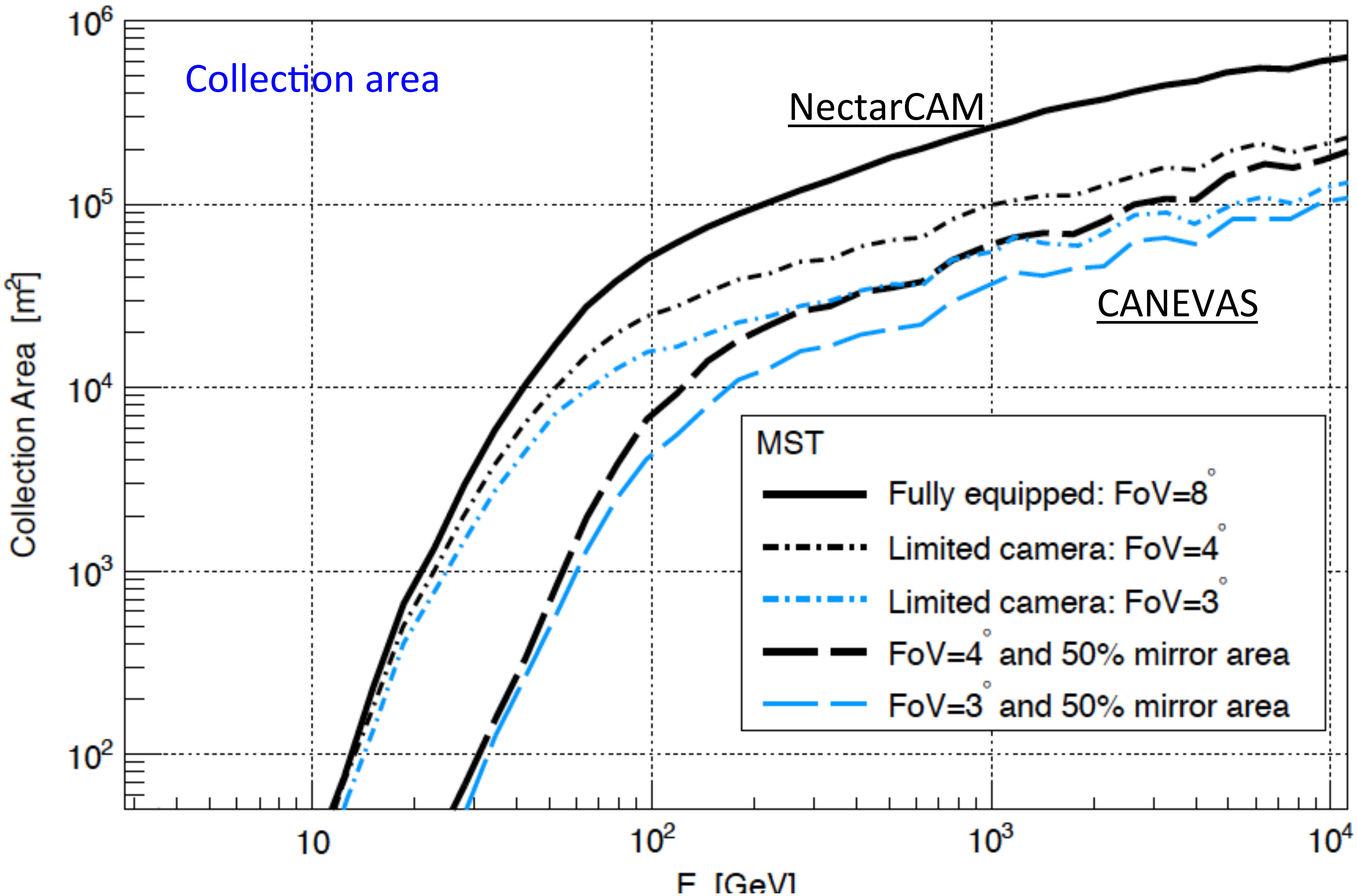
CANEVAS organisation



CANEVAS project: partially equipped NectarCAM



CANEVAS: collection area



Observations with the CANEVAS camera

- CANEVAS will be first tested in mono-telescope mode.

- Improved version of CAT (18 m^2 reflector, 600 pixels, FOV 4.8°) and Whipple (75m^2 reflector, 379 pixels, FOV 3°) camera => should be sensitive to sources such as the Crab nebula, Mkn 421 and Mkn501, the Galactic Center.

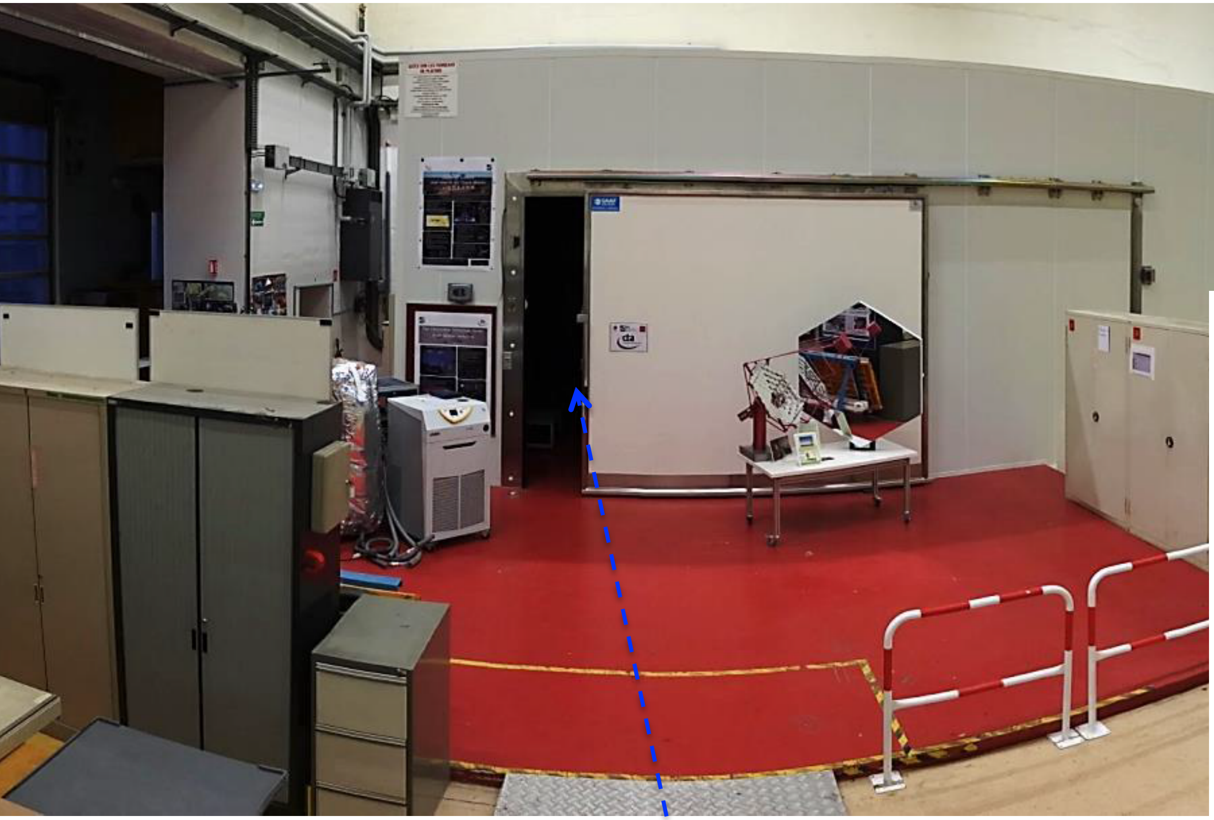
- CANEVAS should be installed on the top of a telescope structure end 2017-early 2018. Most likely site is the Roque de los Muchachos observatory.

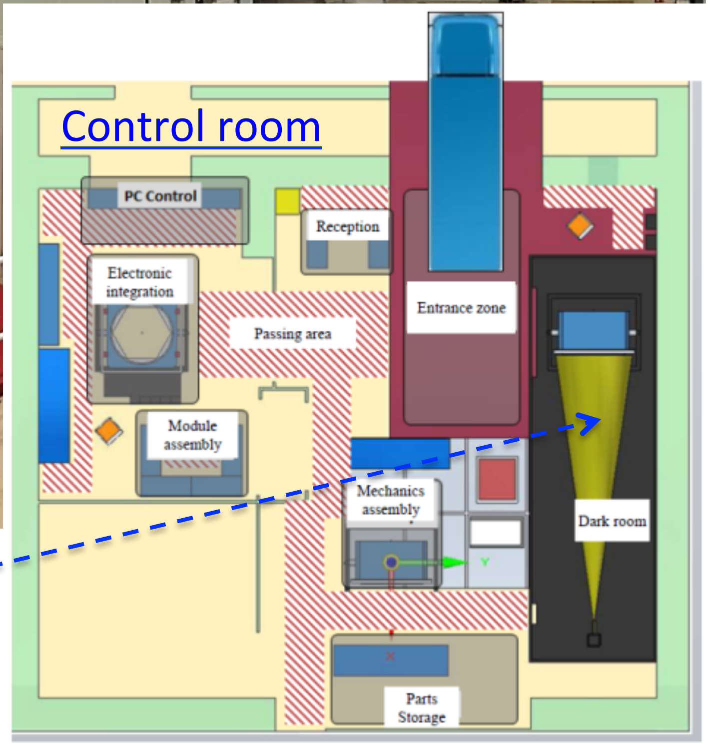
- Goals of CANEVAS on-site data taking:
  - Check the interfaces to structure and data acquisition.
  - On-site calibration procedures.
  - Tests dismounting, transport et re-mounting on site of the camera.
  - Astronomical observations on a few bright targets: Crab nebula, Mkn421 and 501, Galactic Centre.

Goals reached = Success of CANEVAS

- Possible stereo runs with the LST prototypes being installed at la Palma.

CANEVAS camera integration facility

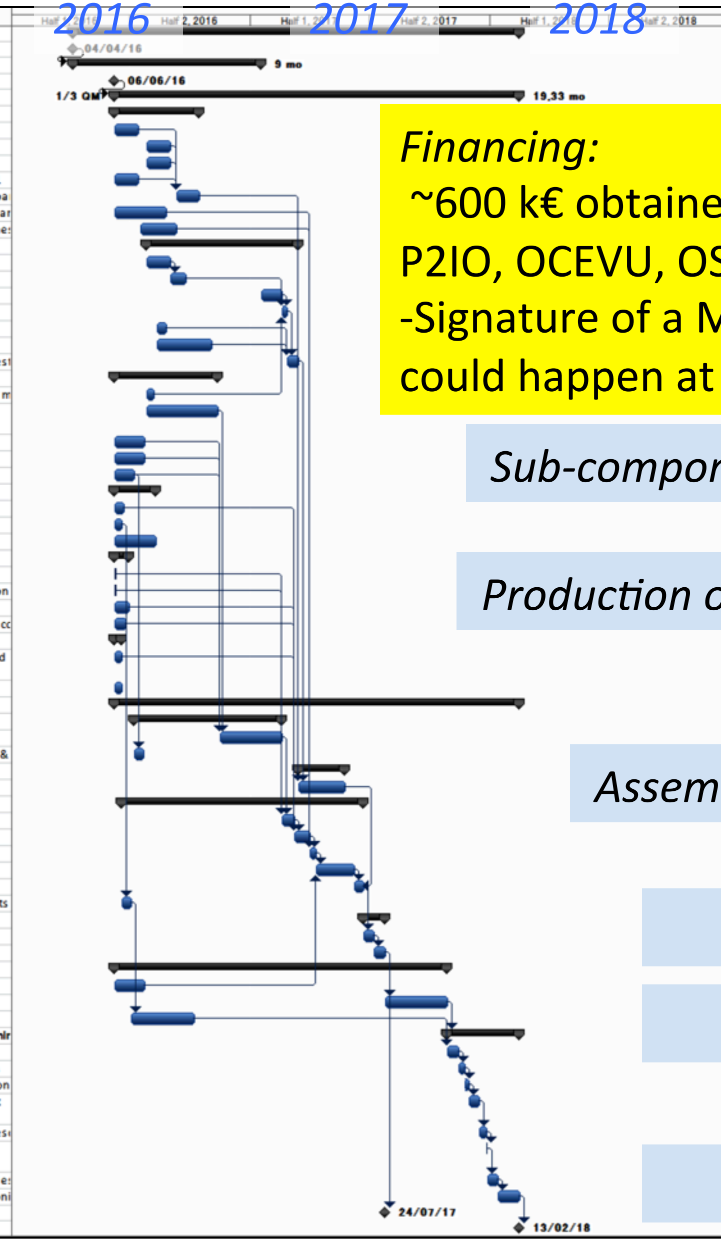




- 500 m^2 equipped Dark room
- Located at IRFU (Saclay)
- Camera first assembled, then tested in dark room

Detailed development plan of CANEVAS

ID	WBS	Nom de la tâche
61		**CANEVAS**
62	M T-PP	Start Tenders process
63		**Tender process**
96	M Fund-1/3QM	Start production of Canevas Prototype
97		**Procurement and AIV**
98	**3.7.4.1**	**Front-end electronics**
99	2.3.4.1.1	Pre-Production of Nectar ASIC
100	2.3.4.1.2	Pre-Production of ACTA ASIC
101	2.3.4.1.3	Pre-Production of L0 trigger ASIC
102	2.3.4.1.4	Pre-Production of L1 trigger ASIC opt 1
103	2.3.4.1.5	Pre-Production of Nectar front-end boa
104	2.3.4.1.6	Pre-Production of trigger interface boar
105	2.3.4.1.7	Pre-Production of analogue backplane:
106	**3.7.4.2**	**Focal plane equipment**
107	2.3.4.2.1	Pre-Production of PACTA ASIC
108	2.3.4.2.2	Pre-Production of HVPA
109	2.3.4.2.3	Pre-Production of PMTs
110	2.3.4.2.4	Detector unit assembly and test
111	2.3.4.2.5	Pre-Production of interface board
112	2.3.4.2.6	Pre-Production of light concentrator
113	2.3.4.2.7	Focal plane module assembly and test
114	**3.7.4.3**	**Camera mechanics & cooling**
115	2.3.4.3.1	Pre-Production of mechanics parts of m
116	2.3.4.3.2	Pre-Production of module holder, camera body and cooling mechanics
117	2.3.4.3.3	Pre-Production of camera shutter
118	2.3.4.3.4	Pre-Production of entrance window
119	2.3.4.3.5	Purchasing of cooling system parts
120	**3.7.4.4**	**Clock & processing**
121	2.3.4.4.1	Purchasing of switches
122	2.3.4.4.2	Pre-Production of camera server
123	2.3.4.4.3	Pre-Production of UCTS
124	**3.7.4.5**	**Monitoring and services**
125	2.3.4.5.1	Purchasing of power supplies
126	2.3.4.5.2	Purchasing of main power distribution
127	2.3.4.5.3	Pre-Production of sensor boards
128	2.3.4.5.4	Pre-Production of embedded camera cc
129	**3.7.4.6**	**Calibration devices**
130	2.3.4.6.1	Pre-Production of reflective target and calibrations LEDs
131	2.3.4.6.2	Pre-Production of calibration box
132	**3.7.4.7**	**Assembly, integration and validation**
133	**3.7.4.7.1**	**Mechanics assembly & associated tools**
134	3.7.4.7.1.1	Structure and cooling assembly
135	3.7.4.7.1.2	Ground cooling parts preparation &
136	**3.7.4.7.2**	**Module assembly & test bench**
137	3.7.4.7.2.1	Module assembly and tests
138	**3.7.4.7.3**	**Electronics assembly**
139	3.7.4.7.3.1	Power system integration
140	3.7.4.7.3.2	Auxiliary system integration
141	3.7.4.7.3.3	Backplane integration
142	3.7.4.7.3.4	Connections integration
143	3.7.4.7.3.5	Modules integration
144	3.7.4.7.3.6	Camera server configuration & tests
145	**3.7.4.7.4**	**Camera tests and calibration**
146	3.7.4.7.4.1	Functional tests
147	3.7.4.7.4.2	Camera calibration
148	**3.7.4.7.5**	**Test, assembly and logistics facilities**
149	3.7.4.7.5.1	Purchase of internal cabling
150	3.7.4.7.5.2	Camera delivery
151	3.7.4.7.5.3	External parts delivery
152	**3.7.4.7.6**	**Camera integration, test and commissionir**
153	3.7.4.7.6.1	On site Incoming process
154	3.7.4.7.6.3	On site Cooler preparation & tests
155	3.7.4.7.6.4	On site Camera server configuration
156	3.7.4.7.6.5	On site Camera preparation & test in dark room
157	3.7.4.7.6.6	On site Cooler installation on teles
158	3.7.4.7.6.7	On site Data camera server installation in data center
159	3.7.4.7.6.8	On site Camera installation on tele:
160	3.7.4.7.6.9	On site Camera system commissioni
161	M Valid 1/3 QM	Validation of Canevas Prototype in lab
162	M Valid 1/3 QM	Validation of Canevas Prototype on site



Financing:
~600 k€ obtained from french LABEX P2IO, OCEVU, OSUG2020
-Signature of a MoU with IAC (Spain) could happen at fall 2016

Sub-component production

Production of calibration tools

Assembly and validation

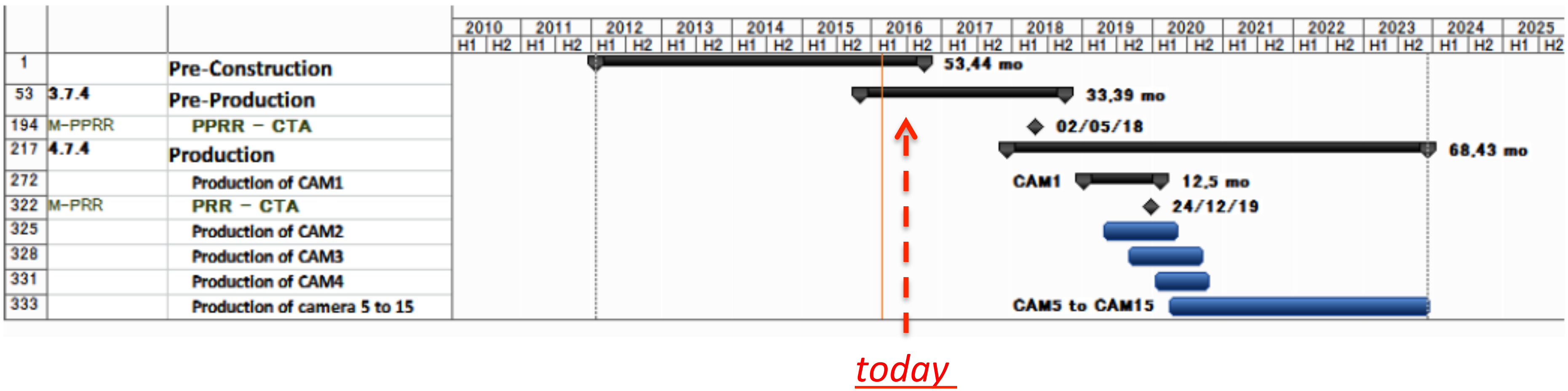
Calibration

Installation on-site

Engineering runs

Beyond the CANEVAS project

- Pre-construction (design validation): ends 2016
- Pre-production: build the CANEVAS camera and upgrade to the first NectarCAM
  2015-1018
- Production of 15+1 cameras (French EoI): 2018-2023
  Financing by french TGIR (decision in 2017)



	Pre-Production	Production			
	2016	2019	2020	2021	2022
# of cameras	1 (QM)	3	4	4	4

Table 4.3 – Production flow

Conclusion

- The CANEVAS project is a joint project of (IRFU(SPP/SEDI/SIS/SAp)-LLR-IPNO).
- It aims at building and operating a 4° Cherenkov camera to validate the NectarCAM design with astronomical data.
- CANEVAS will be upgraded to the first NectarCAM camera when funding will become available (e.g. from Spain or the french TGIR).
- It was selected as a « Projet emblèmatique » with a grant of 709 k€.
- It received additional financial contributions from labex OCEVU and OSUG2020.