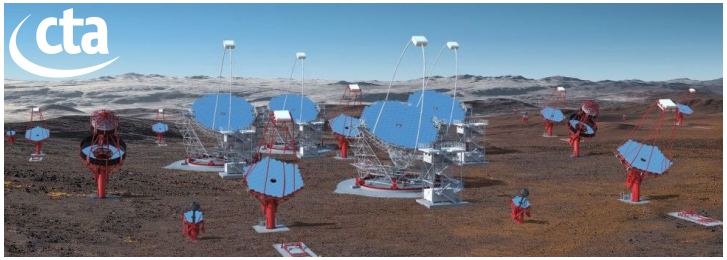
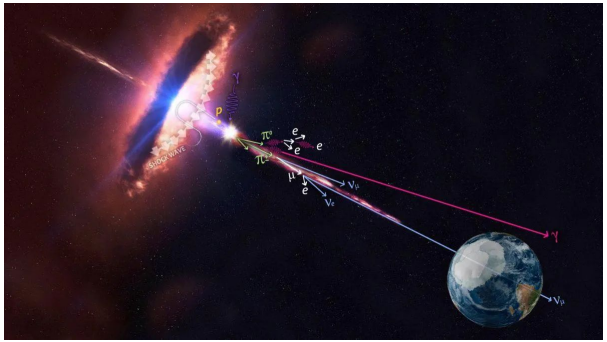
Equipe RCMN - Rayonnement Cosmique

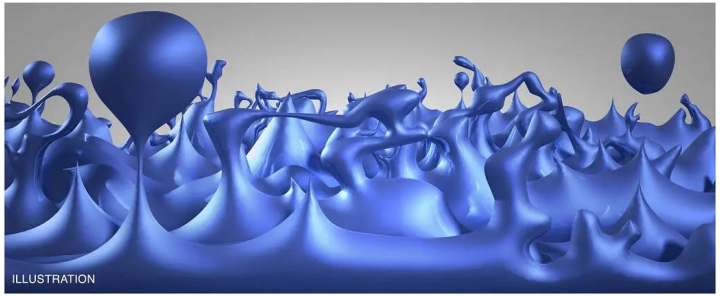
H.E.S.S., CTA, GRAND



Science drivers

- **Origin of cosmic rays**
  - Study of secondaries (gamma rays, neutrinos, electrons)
  - Nature of accelerated particles in astrophysical compact objects
  - Variability and time delays in blazar jets
- **Tests of fundamental physics**
  - Time delays due to Lorentz invariance violation
  - In the past: indirect dark matter searches





Current team composition




- 3 permanent staffs + 1
  - **J. Bolmont** (MdC HDR, research: 70% CTA/30% H.E.S.S.)
  - **J.-P. Lenain** (CR HDR, 90% CTA/10% H.E.S.S.)
  - **O. Martineau** (MdC HDR, research: 100% GRAND)
  - **D. Kerszberg,** will arrive on 01/01/2024 (CRCN, 90% CTA/10% H.E.S.S.)

- But 3 departures: **J.-P. Tavernet** (2016), **A. Jacholkowska** (†2018), **P. Vincent** (2019)


- 2 post-docs:
  - **A. Rosales de Leon** (50% CTA/50% modelling, postdoc IPI SU, feb. 2023 - jan. 2025) *Modelling of intrinsic temporal effects in AGN and confrontation to data*.
  - **P. Correa** (100% GRAND, postdoc ANR GRAND, nov. 2022-nov. 2024) *Development of an analytical trigger for the next phases of GRAND. Implementation and tests in real conditions (on GRAND@Nançay prototype)*.

Current team composition (cont'd)

- 4 PhD students
  -  **G. Grolleron** (90% CTA/10% H.E.S.S., 2021–2024), supervision : J.-P. Lenain
    Transient extragalactic phenomena at very high energies and preparations for the future CTA observatory.
  -  **M. Guelfand** (100% GRAND, 2022–2025), co-supervision : O. Martineau, K. Kotera (IAP) & S. Prunet (OCA)
    Modelling and analysis of radio signals detected with GRAND.
  -  **U. Pensec** (40% CTA/40% H.E.S.S./20% modelling, 2022–2025), co-supervision : J. Bolmont & H. Sol (LUTh)
    Discriminating Lorentz invariance violation effects and source-induced temporal effects in high-energy gamma astronomy.
  -  **A. Ferriere** (100% GRAND, 2023–2026), co-supervision: O. Martineau (20%) et A. Benoit-Levy (CEA-LIST, 80%)
    GRAND data analysis with Machine Learning techniques.

For the RC team

Reply to the recommendations of the previous HCERES report

Recommandations du rapport HCERES précédent:

A – Recommendations on scientific production and activities (criterion 1)

After the initial “exploration” period, the direct DM detection research should get focused on a main project (given the limited resources of the team). The DAMIC project appears as a good project-of-opportunity building on the expertise of the unit in the low-noise CCD readout technology, but perhaps only on short term. On longer time scale, a clear choice between XENON and DARKSIDE projects has to be done, preferentially based on the fair judgement of the scientific reach of the projects (assessment of advantages / drawbacks of xenon vs. argon).

Projects support from the unit should take into account availability of a “critical mass” of permanent researchers with scientific expertise relevant to the project and willing to contribute.

The high-energy astrophysics group still has strong position in the HESS project, but strengthening of the CTA team and transfer of manpower and expertise to the CTA should be planned to preserve the high visibility of the unit in ground-based gamma-ray astronomy field.

B – Recommendations on the team’s organization and life (criterion 2)

The committee recommends to develop an internal team communication to help building a common strategy to define the priority between projects.

C – Recommendations on scientific strategy and projects (criterion 3)

Better planning of the team involvement in long-term projects is needed, taking into account the scientific profiles of permanent researchers and availability of the technical personnel and workshops. Concentration of resources around “flagship” activities, rather than a range of “auxiliary” contributions in many projects, would provide higher impact and better visibility for the team.

For the RC team

Reply to the recommendations of the previous HCERES report

The high-energy astrophysics group still has strong position in the HESS project, but strengthening of the CTA team and transfer of manpower and expertise to the CTA should be planned to preserve the high visibility of the unit in ground-based gamma-ray astronomy field.

- The three departures from the group were not compensated by new hirings until this year (D. Kerszberg will arrive in january 2024), still resulting in a net loss of -2.
- A steady flow of excellent PhD students and postdocs helped mitigating the impact a little.
- As a result, more FTEs in CTA mathematically result in less FTEs in HESS.
- Nonetheless, the visibility of the team in HESS remains high with
  - important responsibilities on simulations and calibration
  - important contributions to extragalactic science and physics beyond standard model working groups
- In parallel, the visibility of the team in CTA is already very good thanks to its important contributions in NectarCAM (calibration, software) & in EGAL Science Working Group (analysis pipelines & AGN expertise).
- This visibility will grow even further with the contribution to the analysis pipeline for energy dependent time delays which is ongoing.

For the RC team

Reply to the recommendations of the previous HCERES report

The committee recommends to develop an internal team communication to help building a common strategy to define the priority between projects.

- The HESS and CTA teams are one team, with all members contributing to both projects.
- Strong links between HESS/CTA and GRAND teams.
- For the RCMN team as a whole, the “Rayonnement Cosmique” part of the team is not involved anymore in dark matter searches, and it was only in *indirect* search for DM.

For the RC team

Reply to the recommendations of the previous HCERES report

Better planning of the team involvement in long-term projects is needed, taking into account the scientific profiles of permanent researchers and availability of the technical personnel and workshops. Concentration of resources around “flagship” activities, rather than a range of “auxiliary” contributions in many projects, would provide higher impact and better visibility for the team.

- The gamma-ray astrophysics group has narrowed its topics of research in the past few years:
  - Physics of transient or variable extragalactic objects
  - Searches related to time-delays, either intrinsic or due to Lorentz Invariance Violation

  ⇒ No more indirect DM search, studies of diffuse emission, or Galactic science

- Technical activities have stopped in H.E.S.S., while GRAND technical activities have ramped up.
- No “auxiliary contribution”...

For the RC team

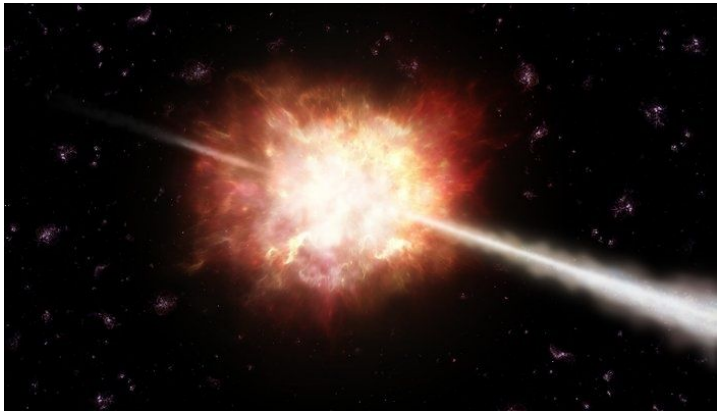
Reply to the recommendations of the previous HCERES report

Experience of development of radio detection techniques of ultra-high-energy cosmic rays with R&D for PAO upgrade and TREND/GRAND projects has been unsuccessful.

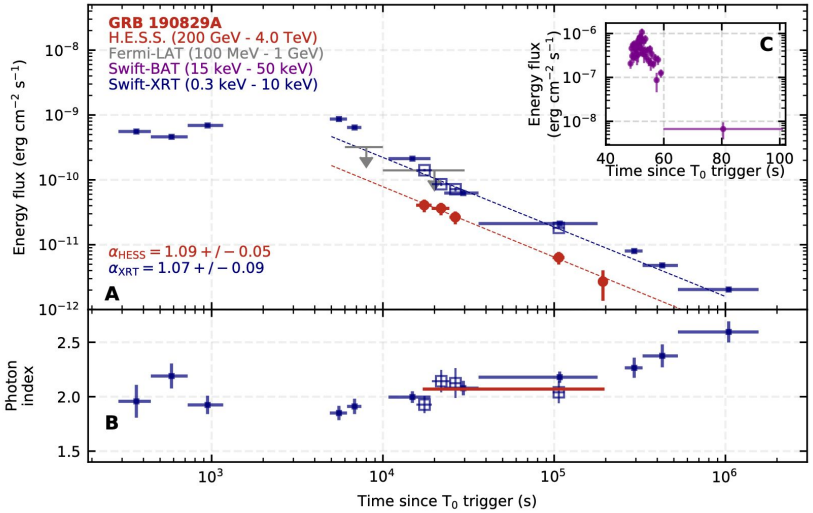
- GRAND/TREND was not evaluated by previous HCERES committee.
- GRAND/TREND was not evaluated by the LPNHE Scientific Council until 2021.
- TREND was successful (i.e. achieved autonomous detection of air showers).
- GRAND was only a proposal in 2017.
- Progress over the past years proved the community considers the GRAND project seriously.

Highlights: the discovery of GRBs at VHE

- Involvement in the analysis of GRB 190829A data
  - Detection of a significant signal in the afterglow phase, 56 h after the prompt phase
  - Measurement of the power law decay of the emission
  - Observation of a clear correlation between gamma and X-ray decay rates



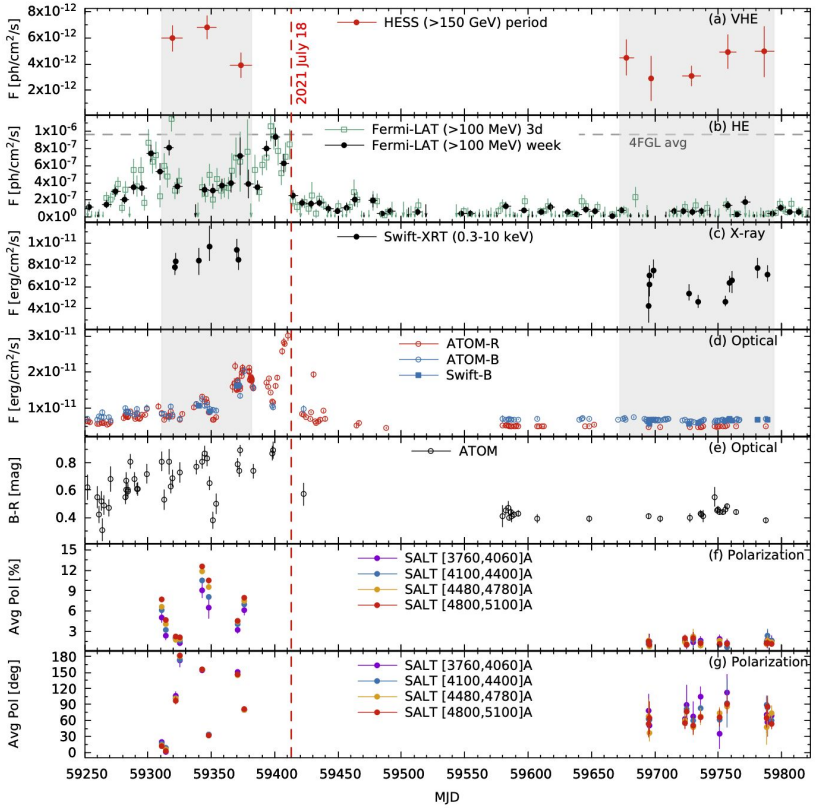
H.E.S.S. collaboration (2019, *Nature*)
H.E.S.S. collaboration (2021, *Science*)



Highlights: a quiescent state of PKS 1510-089

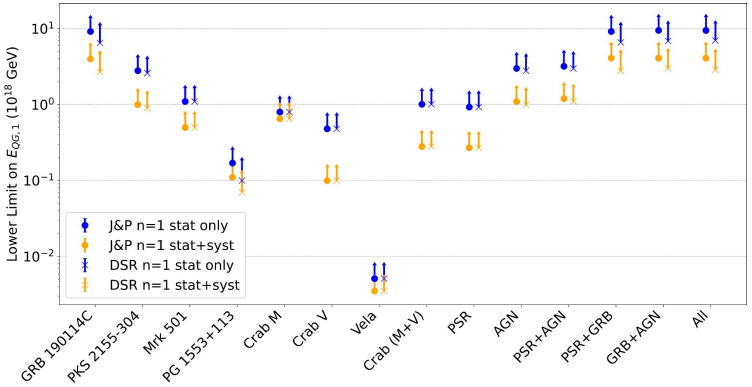
- Involvement in the analysis of PKS 1510-089 low state of 2021
  - Sudden drop in flux in July: /10 in gamma and /5 in optical
  - Signal in X and VHE reappears in October, but not in HE and optical
  - Points towards different emission zones
  - A result of a weakening inner jet ?
  - A result of jet axis shifting?

H.E.S.S. collaboration (2023, *ApJ*)

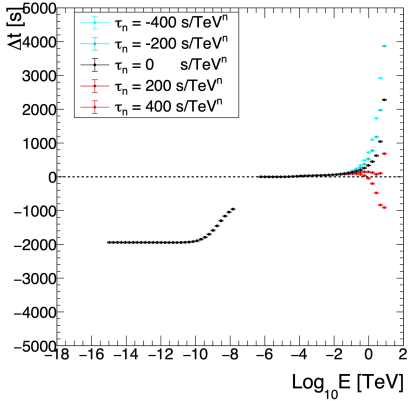


Highlights: energy-dependent time delays

- Energy-dependent time delays could be due to:
  - a propagation effect : quantum nature of space-time, inducing a violation of Lorentz Invariance
  - a source intrinsic effect : emission and acceleration mechanisms at the source
- LIV: the team initiated the creation (2016) of a common working group with H.E.S.S., MAGIC and VERITAS (+ LST-1 in 2023). The goal: prepare population studies (combination) and CTA era.
- Intrinsic effects: the team initiated (2015) a common effort (LPNHE+LUTh) dedicated to the study of time delays in blazar jet leptonic models. The goal: design strategies for LIV & intrinsic effect separation.



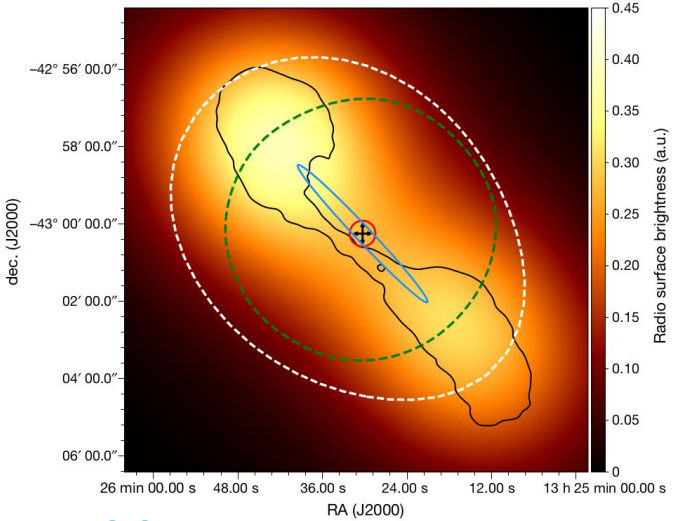
Bolmont et al. (2022, *ApJ*)



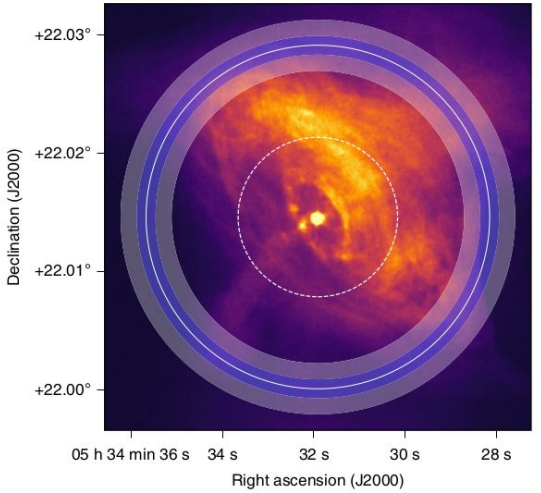
Perennes et al. (2020, *A&A*), Levy et al. (in prep)

Highlights: other important contributions

- Involvement in numerous refinements for Monte Carlo simulations
  - In particular, participation in the implementation of Run-Wise Simulations (RWS) used for several high-impact results



H.E.S.S. collaboration (2020a, *Nature*)

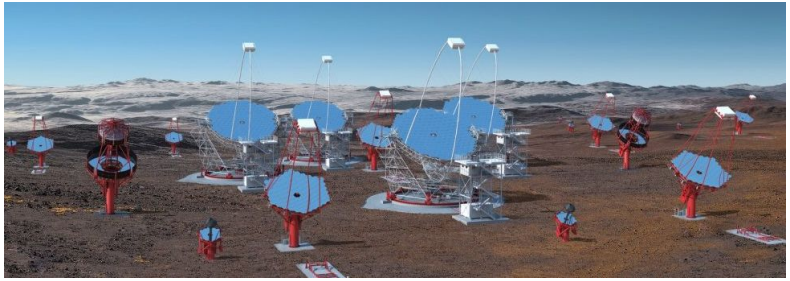


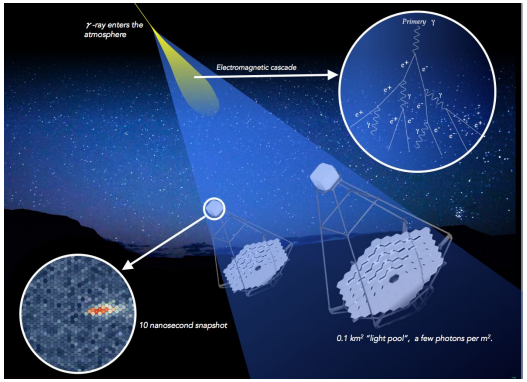
H.E.S.S. collaboration (2020b, *Nature*)

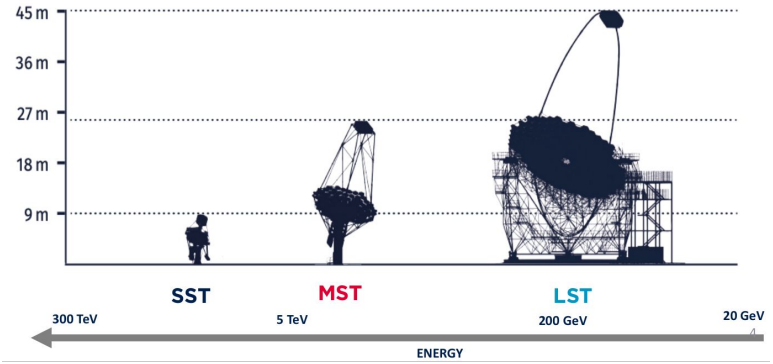
CTA: Cherenkov Telescope Array

La Palma, Spain:
9 MSTs + 4 LSTs

Paranal, Chile:
14 MSTs + 37 SSTs

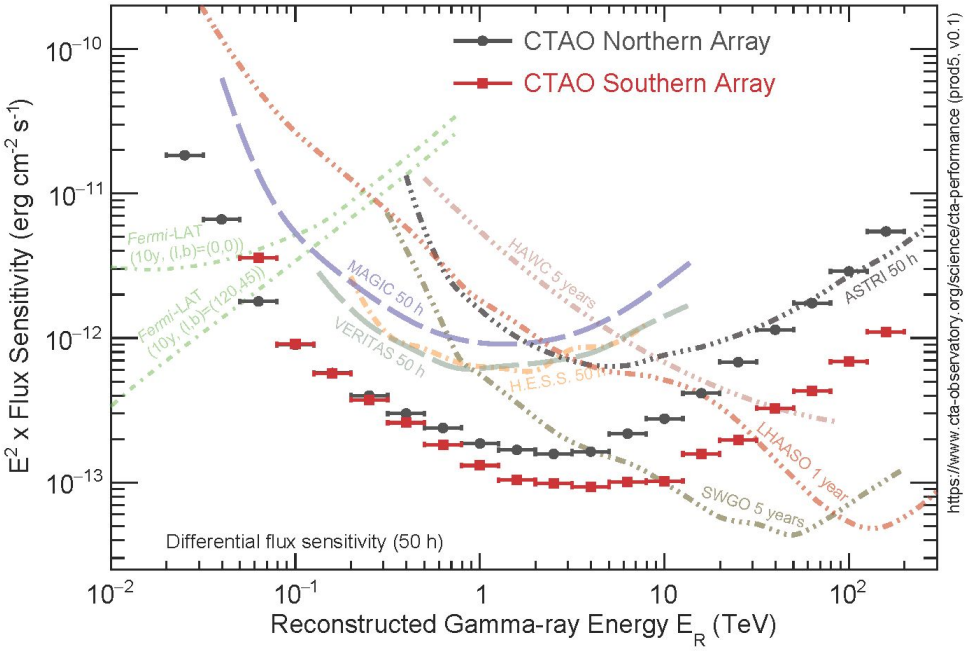


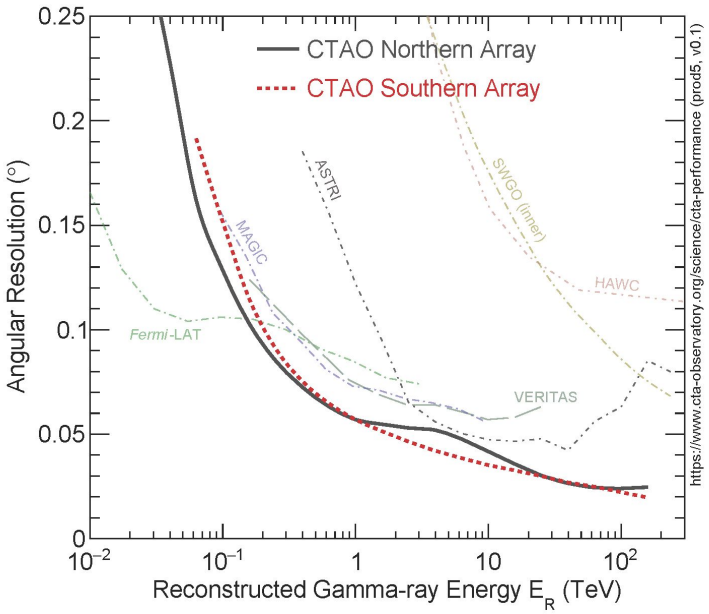




CTA: Cherenkov Telescope Array

CTAO performances





https://www.cta-observatory.org/science/ctao-performance/ (alpha configuration)

LPNHE scientific involvements within CTA

Document "CTA Science Prospectives at IN2P3",
prospectives IN2P3 2020–2021, GT04

	APC	CENBG	CPPM	IPNO	LAPP	LLR	LPNHE	LUPM
Galactic centre								
Gal. plane survey								
LMC survey								
Ex.Gal. survey								
γ-ray cosmology								
Transients								
PeVatron								
Magnetospheres								
Star form. region								
AGN								
Galaxy clusters								
DM & Exotic								

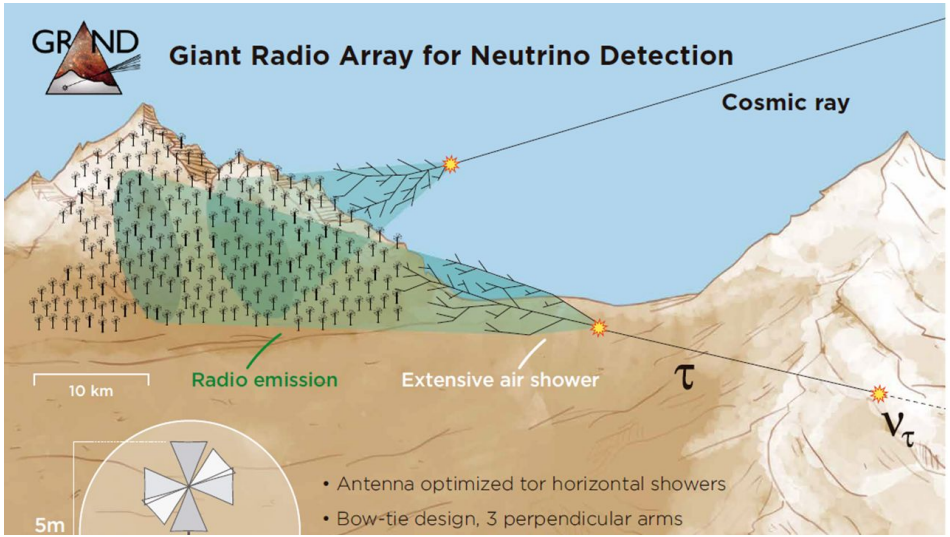
Primary interest
Secondary interest

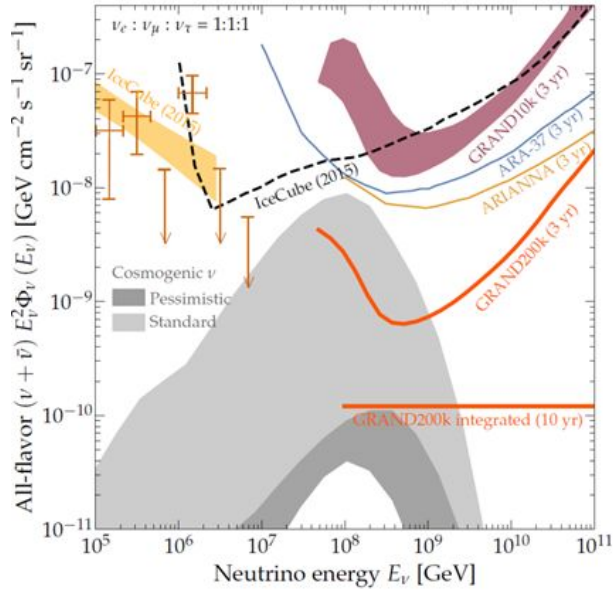
See also:
CTA consortium (2019)

The Giant Radio Array for Neutrino Detection

Proposal (born @ LPNHE in 2015) to build a giant network of radio antenna arrays aiming at the study of UHE cosmic particle (total targeted area: 200,000km²).

Today: 106 members from 41 institutes in 12 countries. Co-spokespersons: K. Kotera (IAP), OM (LPNHE), X. Wu (NAOC).



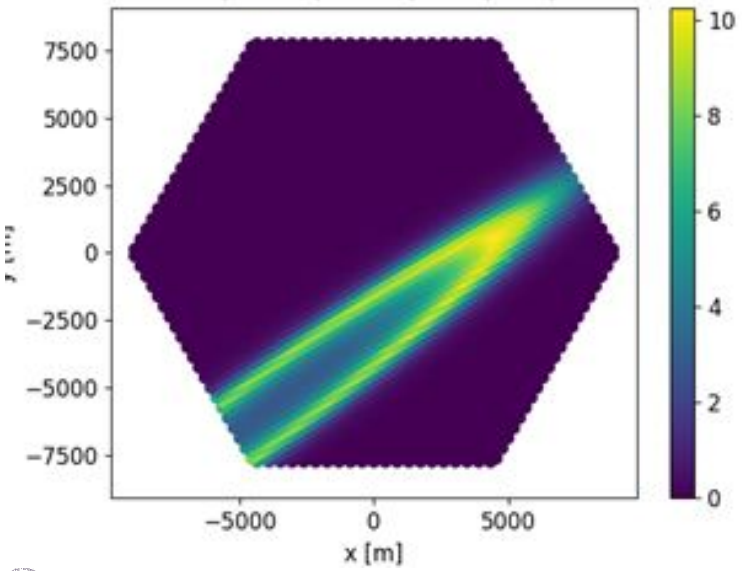


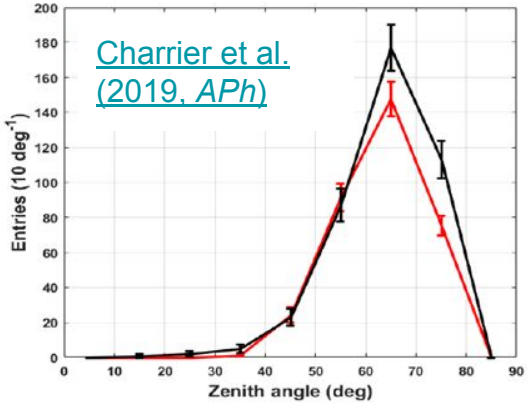
Álvarez-Muñiz et al. (2020)

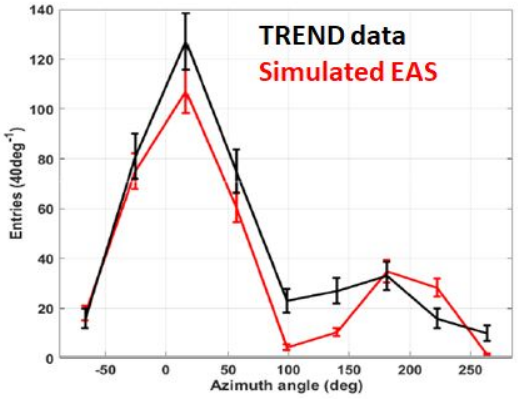
TREND (2009-19): the seed of GRAND

Project led by OM. 50 self-triggered antennas in Tianshan mountains. Showed that distinct radio signatures allow for **autonomous radio detection of air showers**.

Simulated radio footprint for an air shower







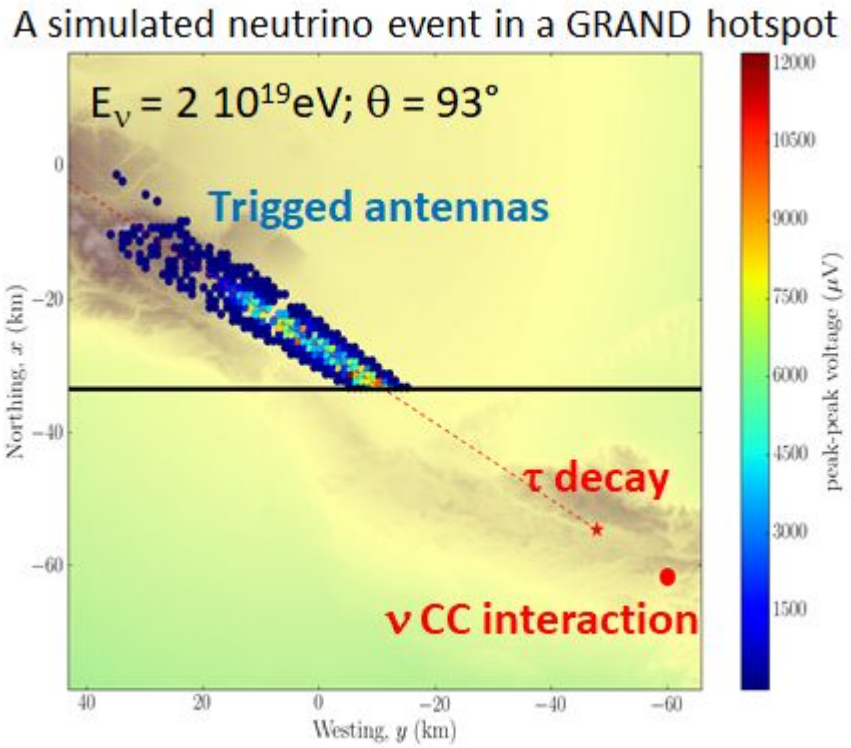
GRAND: sensitivity computation for complete phase

Effort coordinated by LPNHE (with LPC Clermont & IAP) for end-to-end neutrino simulation over realistic topography for 10^4 antennas, leading to detector layout proposal & sensitivity estimate.

Niess & Martineau-Huynh, arXiv:1810.01978

Niess et al. (2019, *Comput.Phys.Commun.*)

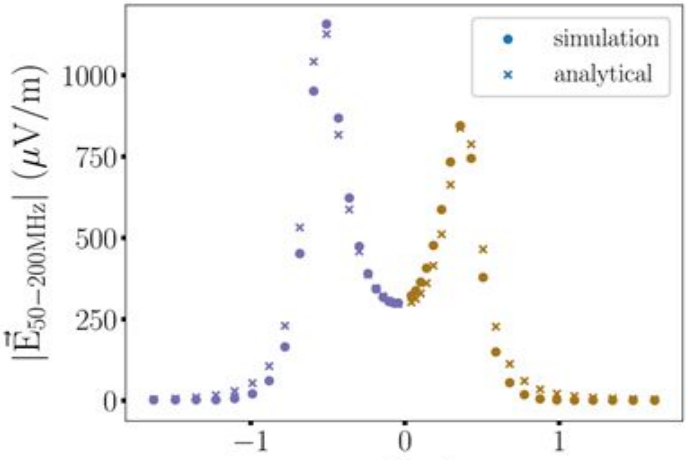
Zilles et al. (2020, *APh*)



GRAND:
preparation for prototype phase

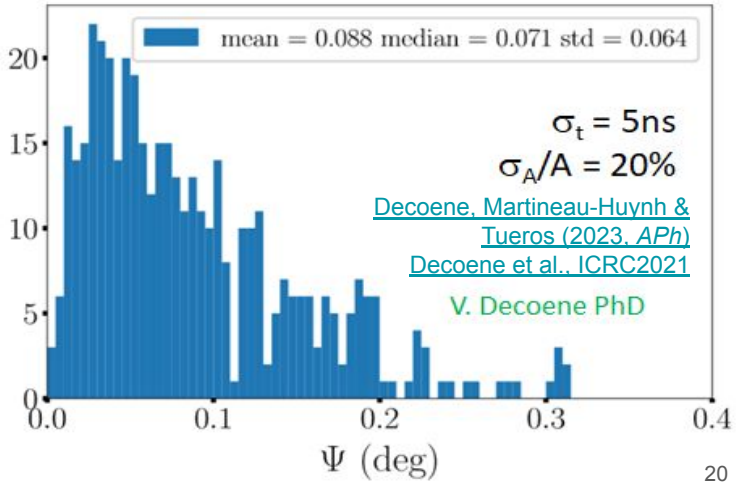
Angular reconstruction: Effort led within collab by LPNHE (with IAP). Provide analytical description of radio wavefront and amplitude pattern at ground. Fit yields **direction of origin with resolution better than 0.1° for very inclined showers.**

Data management: effort led within collaboration by LPNHE to setup & manage data format, DB and data flow (CC-IN2P3 main repository for data).



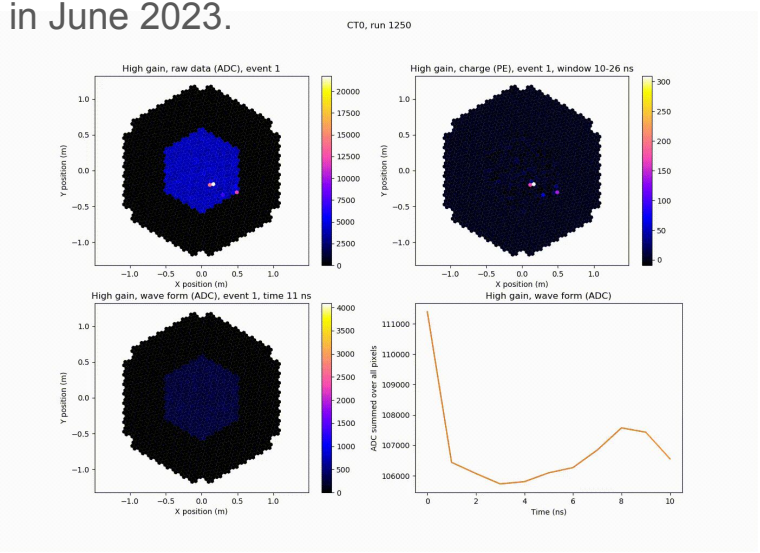
Angular distance to shower axis (deg)

GP300 simulations



Highlights: Hardware developments

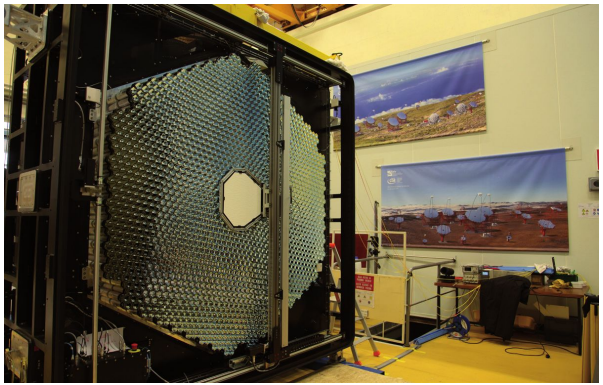
- NectarCAM:
  - FEB design, tests & production.
  - NectarCAM first light in 2019 on MST structure prototype next to Berlin.
  - NectarCAM CDMR (Critical Design & Manufacturing Readiness) review started in February 2021 and declared passed & closed by CTAO in June 2023.

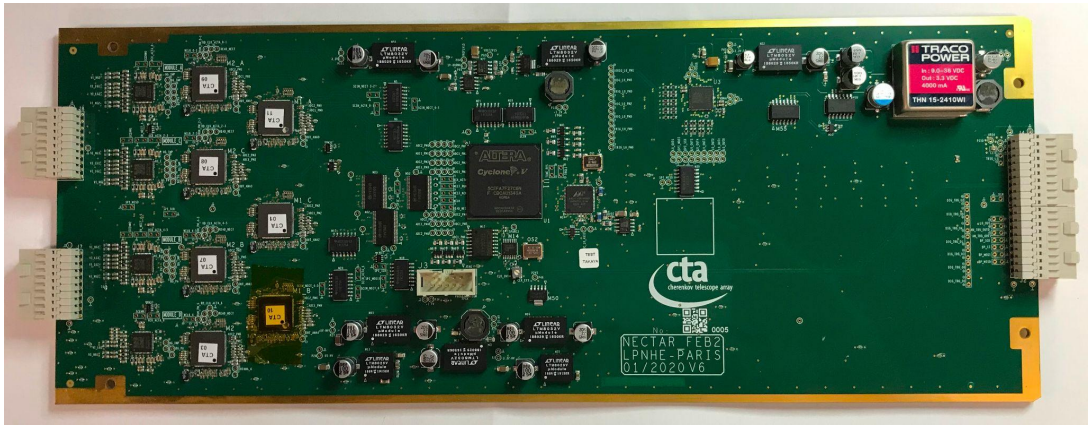


Highlights: Hardware developments

- Front-end board (FEB) for NectarCAM:
  - NectarCAM: 265 modules, with 7 PMT each
  - 60 ns-long “movies” of air shower events, sampled at 1 GHz.
  - FEB card: 12 layers, designed, prototyped & tested at LPNHE, ongoing production with Ouestronic (Rennes): ~3000 cards for 9 cameras.
  - v6: “ping-pong” mode → reduced dead-time (7.2 µs → 400 ns)

See poster

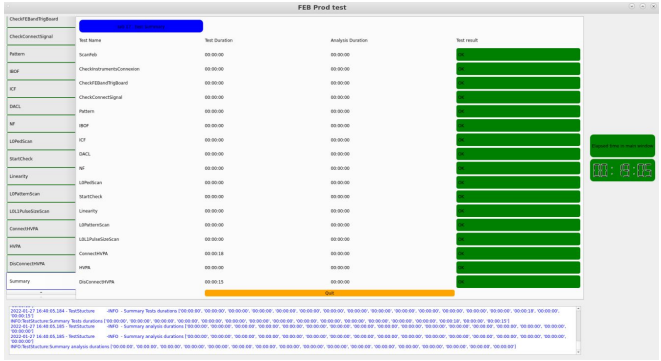


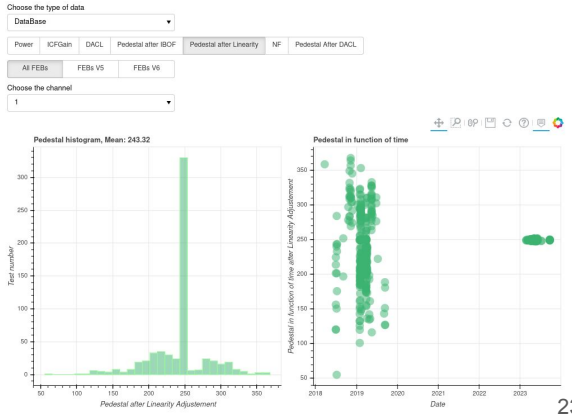


Highlights: Hardware developments

- Front-end board (FEB) for NectarCAM:
  - Test benches designed by LPNHE and deployed at Ouestronic
  - Software & web application to validate the FEBs and monitor the production quality
- Calibration & characterization of NectarCAM & FEB

Caroff et al. (2019), Grolleron et al. (2023), Patel et al. (2023), Bradascio et al. (2023a), Bradascio et al. (2023b)

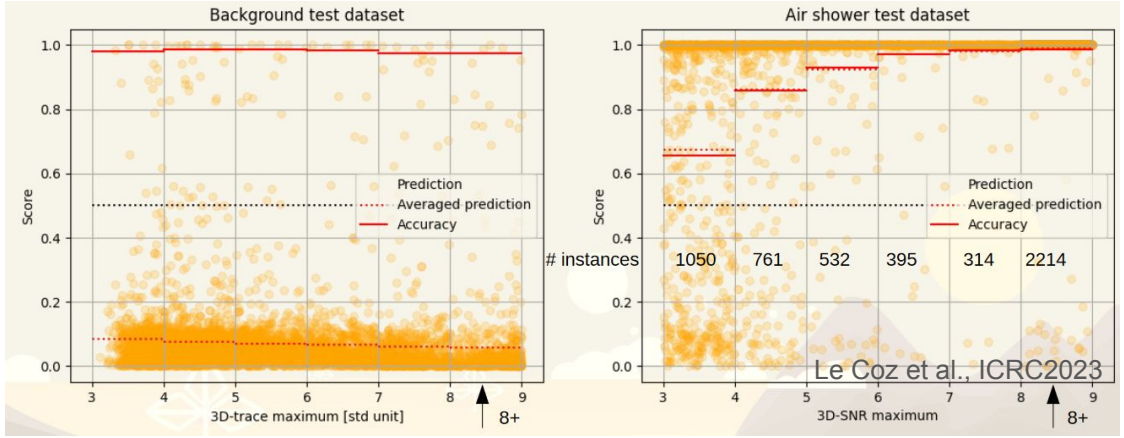


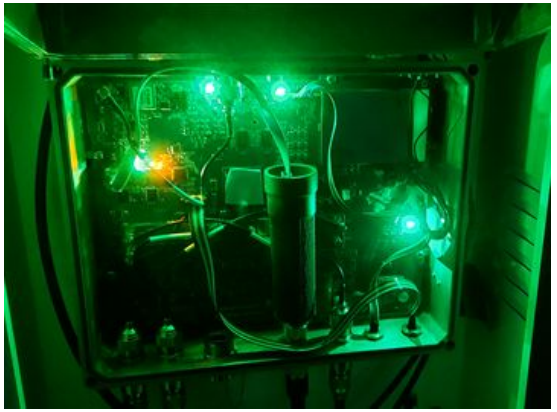


Highlights: Hardware developments

- GRAND: the **NUTRIG proposal** (ANR-DFG 09/2022-09/2025) to develop next generation triggers (efficient, pure and scalable to giant arrays).
- Principle: fully exploit air shower info online to optimise background rejection at single unit level (eg pulse shape) or central DAQ (eg amplitude pattern).
- ML trigger at antenna level: developed & implemented on Front End CPU.

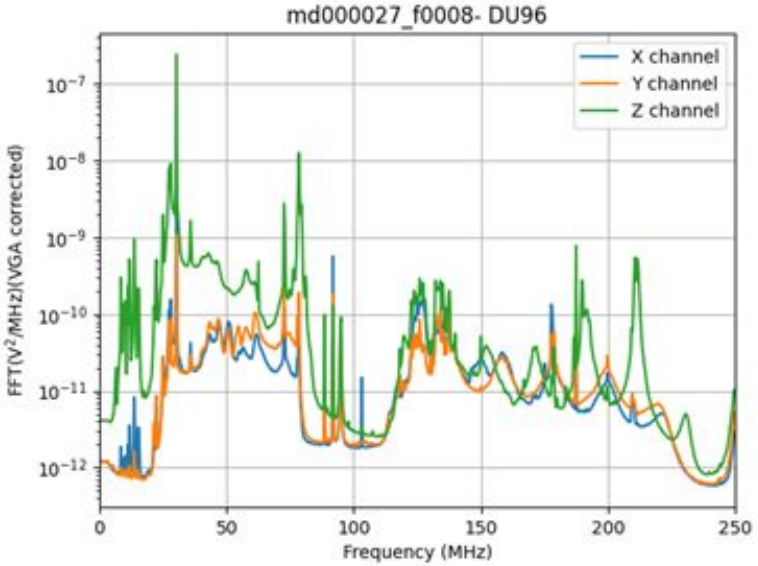
See poster





Highlights: Hardware developments

- GRAND @ Nançay (LPNHE): 4 GRAND units deployed @ Nançay radio
- Functional, ready for NUTRIG tests in spring.



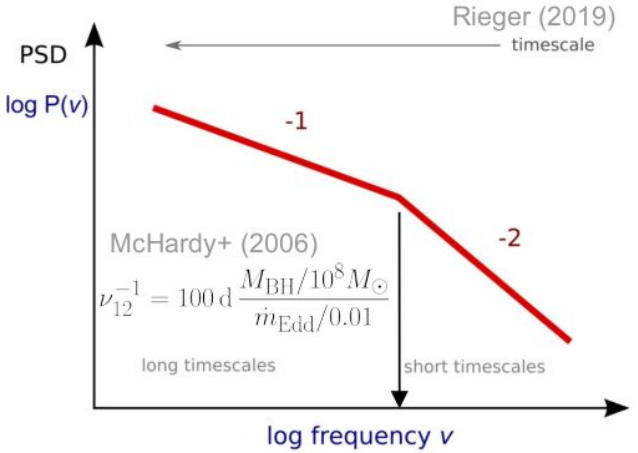
CTA AGN KSP: Long-term monitoring of VHE AGN

$$\phi_z(E,t) = \phi_0(t)\left(\frac{E}{E_0}\right)^{-\Gamma(t)-\beta\ln\frac{E}{E_0}} \mathrm{e}^{-\frac{E}{E_{\mathrm{cut}}}} \mathrm{e}^{-\tau_{\gamma\gamma}(E,z)} = \phi_z^{\mathrm{med}}(E)\left(\mathcal{LN}_t(\mu,\sigma)\right)^{1+b_\Gamma \ln\frac{E}{E_0}}$$

Spectral Model | Temporal Model

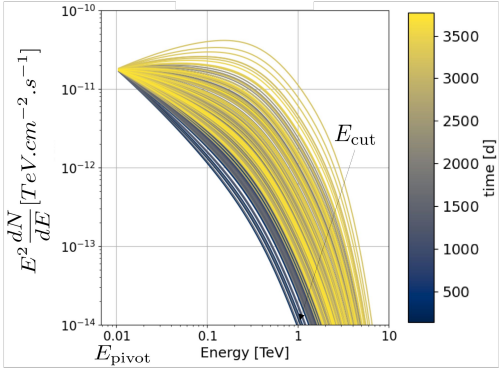
- Variable flux normalization $\phi_0(t)$
  - Log-normal colored noise (Emmanoulopoulos+ 13)
  - Broken power-law from pink to red noise
- Variable index: $\Gamma(t) = \Gamma_0 - b_\Gamma \ln \frac{\phi_0(t)}{\phi_{\mathrm{ref}}}$

  where $b_\Gamma^{-1} = \ln \frac{E_0}{E_{\mathrm{pivot}}}$ and $E_{\mathrm{pivot}} = 10\ \mathrm{GeV}$
  - Harder when brighter based on PKS 2155-304 (H.E.S.S. collaboration, 2010)

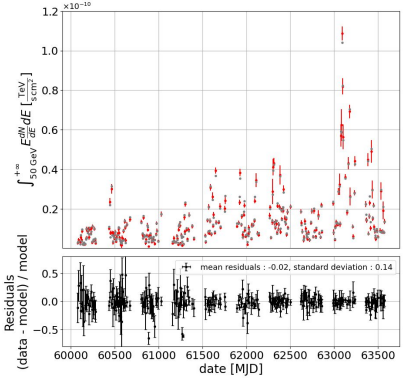


Highlights: CTA AGN KSP

- AGN populations with CTA
- `ctaagnvar`, a versatile pipeline for the AGN variability:
  - from *Fermi*-LAT data, extrapolated to VHE
  - from MWL phenomenological models
  - from generic assumptions on AGN variability: log-normal flux distribution, harder-when-brighter behavior, PSD transitioning from pink to red noise.
- On both aspects, LPNHE in charge of simulation productions.



Spectra generated for BL Lac,
for an evolution over 10 years.



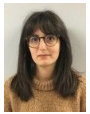
10 yrs of simulated observations of BL Lac.
Injected light curve in gray, reconstructed one is in red.

Grolleron et al. (2023)

Scientific responsibilities, visibility and attractiveness

- Responsibilities in collaborations:
  - O. Martineau: GRAND co-spokesperson, since 2015.
  - J.-P. Lenain:
    - Several convenerships within H.E.S.S. (Extragalactic WG, Simulations WG) from 2012 to 2021.
    - 2021–2022: Convener of the CTA Extragalactic WG
  - J. Bolmont:
    - 2018–2022: convener of H.E.S.S./MAGIC/VERITAS common working group on LIV searches
  - F. Cangemi:
    - 2020–2021: NectarCAM software co-coordinator
- Other responsibilities:
  - J. Bolmont:
    - 2019–2023: member of the management committee of COST Action “Quantum Gravity in the Multi-Messenger Era”
    - 2022–2023: co-convener of a scientific committee in DIM ORIGINES (Région Ile de France)
    - 2017–2021: member of the scientific council of DIM ACAV^{+} (Région Ile de France)
    - 2016–now: radioprotection advisor at LPNHE
- Distinctions:
  - J.-P. Lenain: H.E.S.S. prize (2018)
- H.E.S.S./CTA: 36 participations in conferences.

Scientific responsibilities, visibility and attractiveness (cont'd)





- Former group members hired in academia: **3**/4 post-docs, **2**/6 PhD
  - F. Cangemi (post-doc 2020-2022): MdC, SVOM at UPC (APC), 2022
  - V. Decoene (PhD 2017-2020): MdC, KM3Net at Nantes Université (Subatech), 2022
  - S. Caroff (post-doc 2018-2020): CR, CTA at LAPP, 2020
  - M. Cerruti (post-doc 2015-2018): MdC, H.E.S.S./CTA at UPC (APC), 2020
  - D. Kerszberg (PhD 2014-2017): CR, CTA at **LPNHE**, 2023 → starting on 02/01/2024
- External funding:
  - ANR NuTrig
  - IPI x 2 (post-doc fellowships)
  - DIM-ACAV^{+} (EGI resources on GRIF for H.E.S.S. & CTA)

Trajectory

- Complete the initiated transition from H.E.S.S. to CTA
  - H.E.S.S.: ongoing 2nd extension until late 2025, collaboration wishes to pursue until 2028.
  - LIV codes currently being prepared for future CTA data
  - Codes for AGN variability ready, will be fully tested on CTAO *Science Data Challenge* (release by Q2 2025)
  - Commissioning & early science with NectarCAM from mid-2025
  - Full exploitation of CTA starting ~2028

- GRAND: maintain leadership within collaboration
  - GP300 (2023-2025-2028): leading role in data analysis, building on methods built over last years
  - Next experimental stages:
    - ≤ 2025: complete NUTRIG (ie validate new trigger methods on GP300)
    - ≥ 2025: take lead on development of communication system in GRAND10k

- Proposal:
  RCMN → AM3N (Astrophysique Multi-Messager & Matière Noire)

BACKUP

For the RC team

SWOT analysis

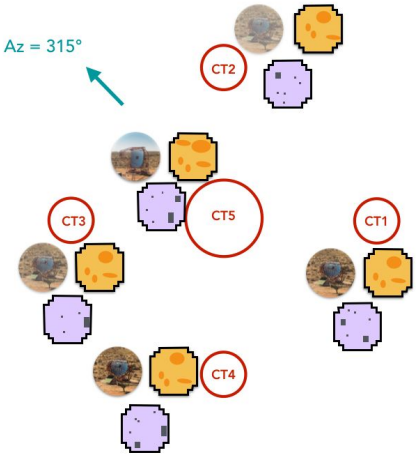
Strengths:
- High visibility within our collaborations and beyond.
- Recognized scientific expertise on LIV & AGN.
- Recognized expertise in analyses (data, MC).
- Recognized expertise in electronic developments.
- High potential of GRAND.
- Training through research, attractive group.

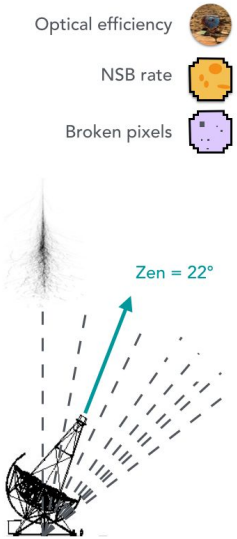
Weaknesses:
- Manpower (small group, several departures), partially alleviated by CRCN arriving on 01/01/2024
- Delays on GRAND (started in 2015)

Opportunities:
- Procurements for CTA under control (CNRS admin., Ouestronic, Intel).
- CTAO project: highly international, very high priority in several roadmaps; CTAC led by European researchers, key role to play on KSPs.
- Part of european network COST CA18108 “QG in the Multi Messenger Era”
- GRAND@Auger prototype & deployment of GRANDProto300 (started in Feb. 2023), NuTrig ANR, increasing involvement of international teams within collab.

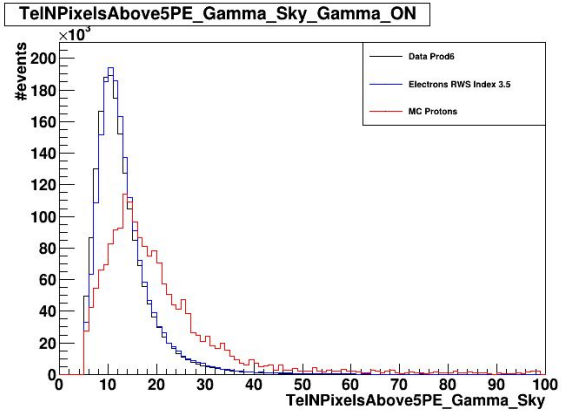
Threats:
- Involvement in H.E.S.S. beyond 2024 and smooth transition to CTA.
  → H.E.S.S. SC extended until end-2025, collab. willing to pursue until 2028.
- International context (COVID, war in Ukraine → tension on semiconductors), now alleviated.
- Local context: Modelling of time delays: collab. with LUTh (H. Sol, retiring soon) → solution in sight with A. Zech.
- Geopolitical context (GRAND deployment in China).

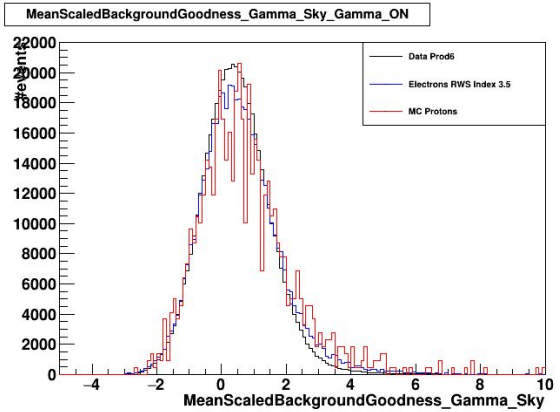
Run-wise Monte Carlo simulations for IACTs



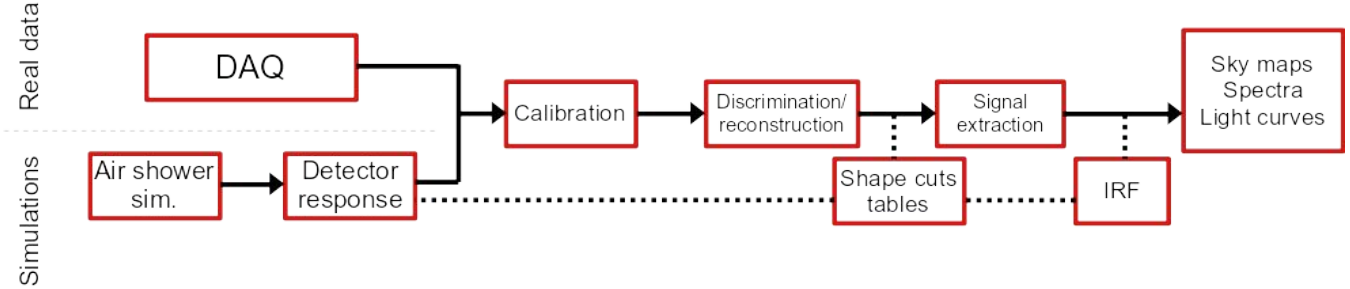


Holler et al. (2020)

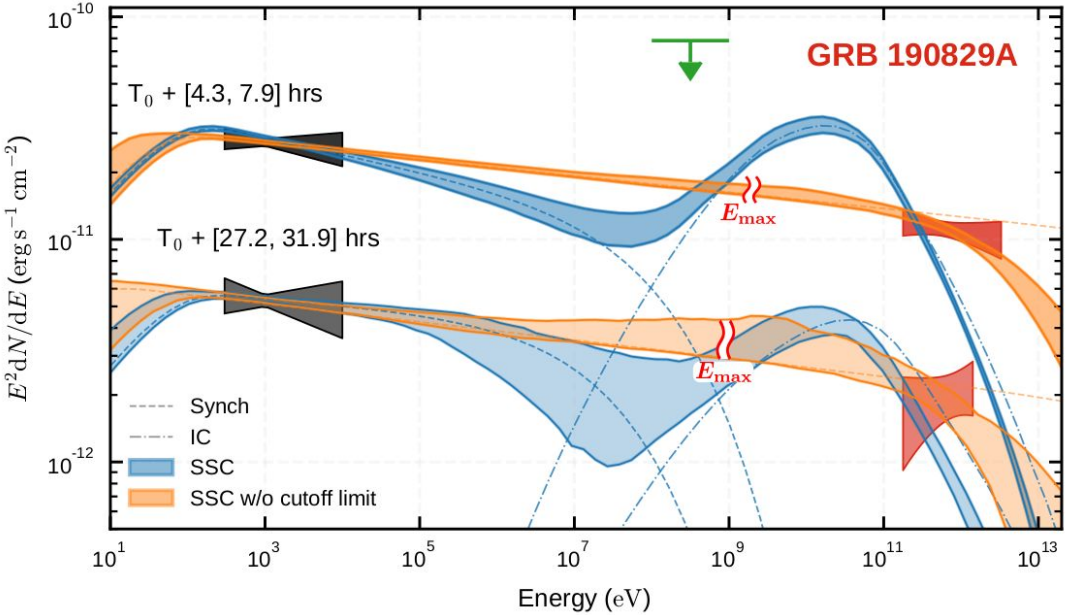




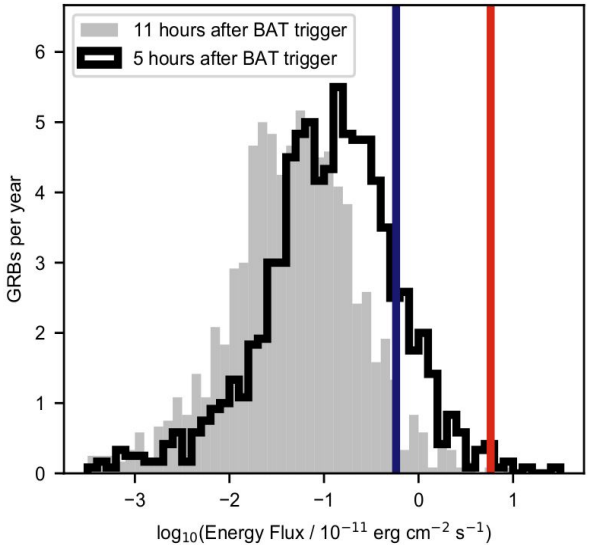
Analysis pipeline & data workflow



Discovery of GRBs at VHE



H.E.S.S. collaboration (2019, *Nature*)
H.E.S.S. collaboration (2021, *Science*)



GRB 180720B

GRANDProto300 in Xiao Dushan

- 13 antennas deployed in Feb 2023 for design validation (Xidian U. & Purple Mountain Observatory)
  - Thermal regulation ➔ OK
  - Control of radio self-emission ➔ OK
  - Trigger / transient pulse detection ➔ in progress