



Active galactic nuclei and leptonic cosmic rays

From H.E.S.S. to CTA

Jean-Philippe Lenain

Habilitation à diriger des recherches

19/02/2018

High energy astrophysics



- Basically, study of astrophysical objects emitting X rays and beyond + neutrinos, cosmic rays, gravitational waves
- Non-thermal sources
 - Highly energetic particles → acceleration processes
 - Violent environment (shocks, relativistic sources, ...)

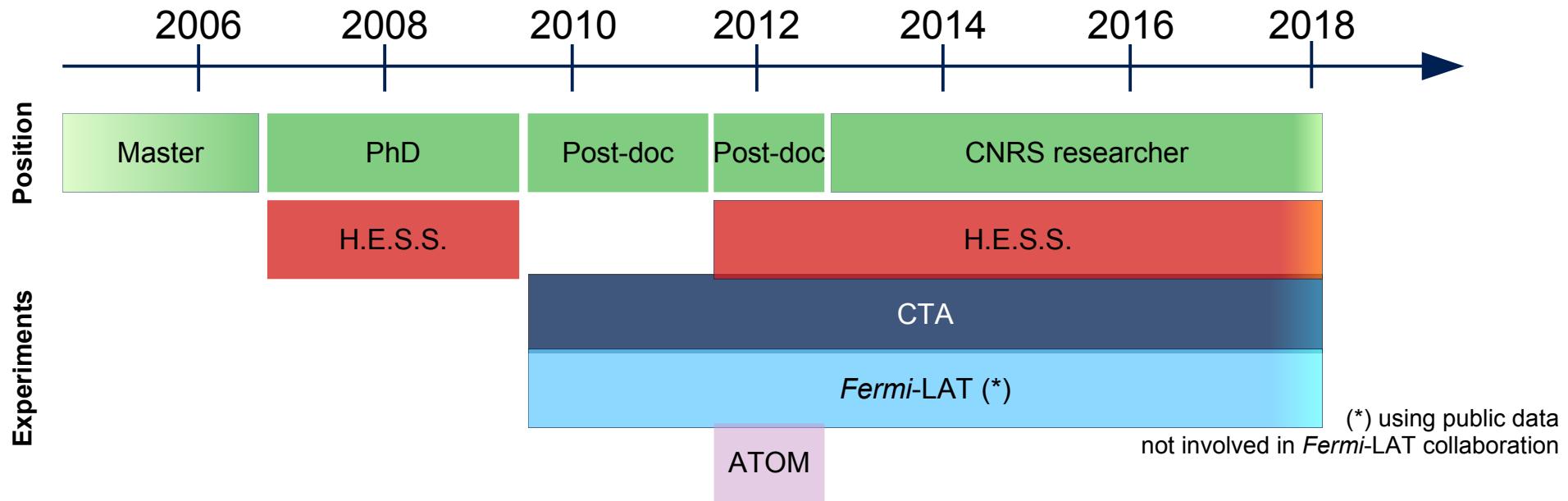
Outline

- **Brief CV**
- **Study of high energy emission from AGN**
- **Characterising the instrument performances**
- **Cosmic e-/e+ spectrum**
- **Conclusions & prospects**

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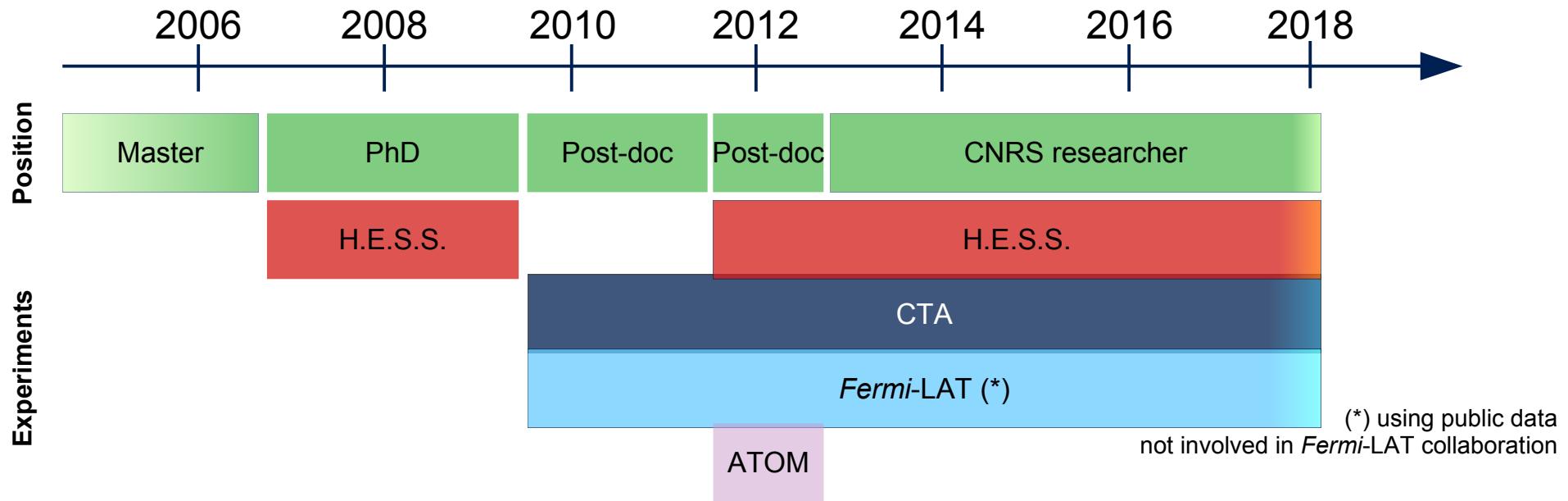
Brief CV



Phenomenology → data analysis & simulations

Since 2006, research on high-energy emitting galaxies

Brief CV



Within collaboration:

- H.E.S.S. extragalactic WG (deputy-)convener
- EGI implementation in H.E.S.S.
- MC responsible in H.E.S.S.-France

Locally:

- CTA group leader
- Council of laboratory

Supervision:

- Work with C. Couturier during his PhD thesis (2011–2014)
- Co-supervision of D. Kerszberg's PhD thesis (2014–2017), with P. Vincent
- Co-supervision of G. Emery's PhD thesis (2017–), with J. Bolmont
- 2 L3, 3 M1, 2 M2 internships

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The active galactic nuclei (AGN) zoo

Seyfert galaxies

Ultra-Luminous InfraRed Galaxies

Fanaroff-Riley radio galaxies

Quasi Stellar Objects

Steep spectrum radio quasars

BL Lacertae objects

Blazars

Type I AGN
Type II AGN

Optically Violent Variables

Flat spectrum radio quasars

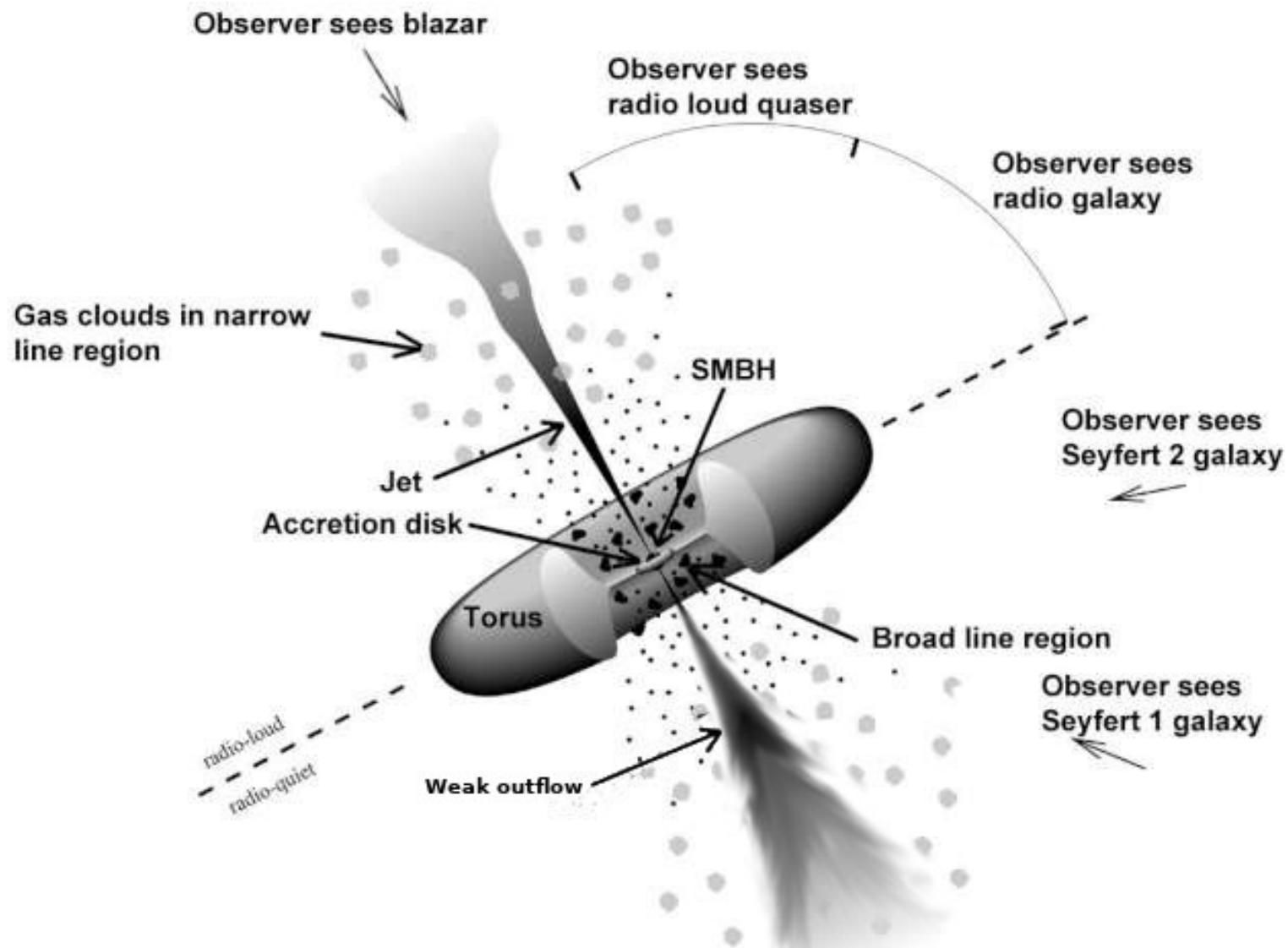
LINER galaxies

Broad Line Regions

AGN

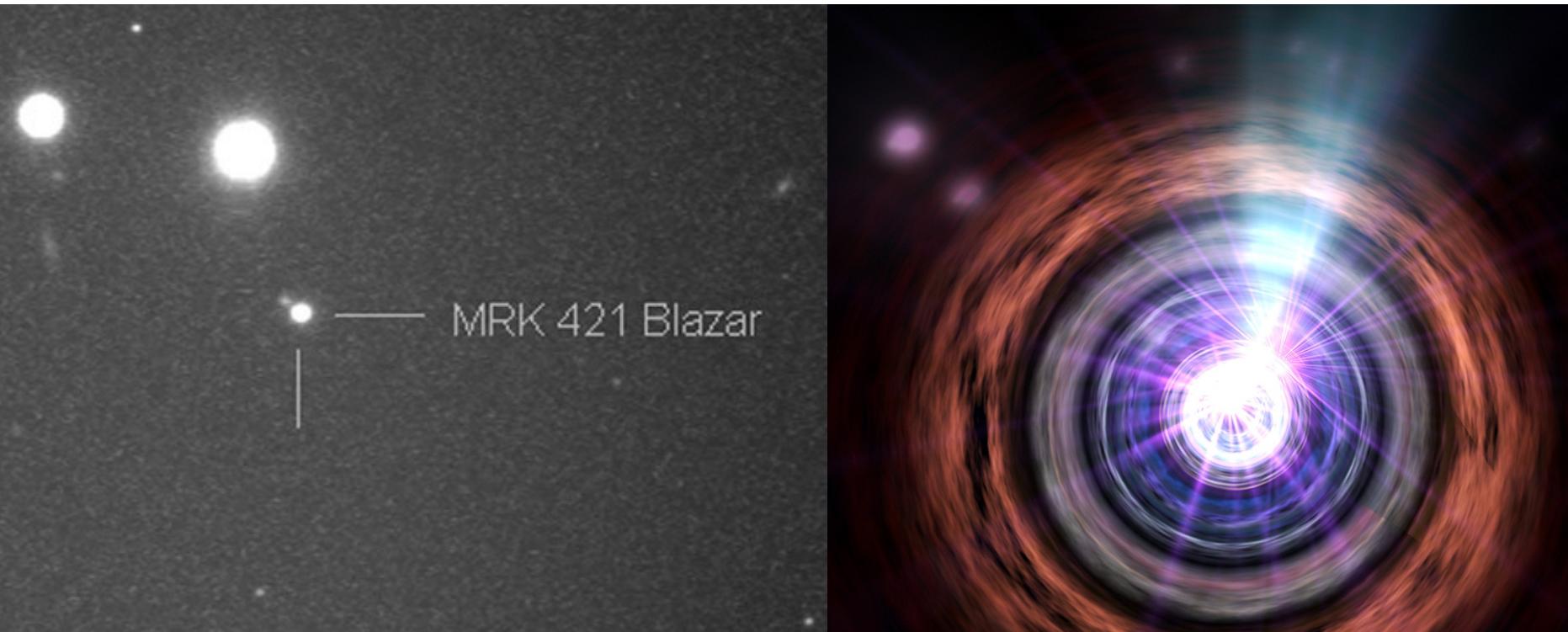


AGN: a unified scheme to rule them all



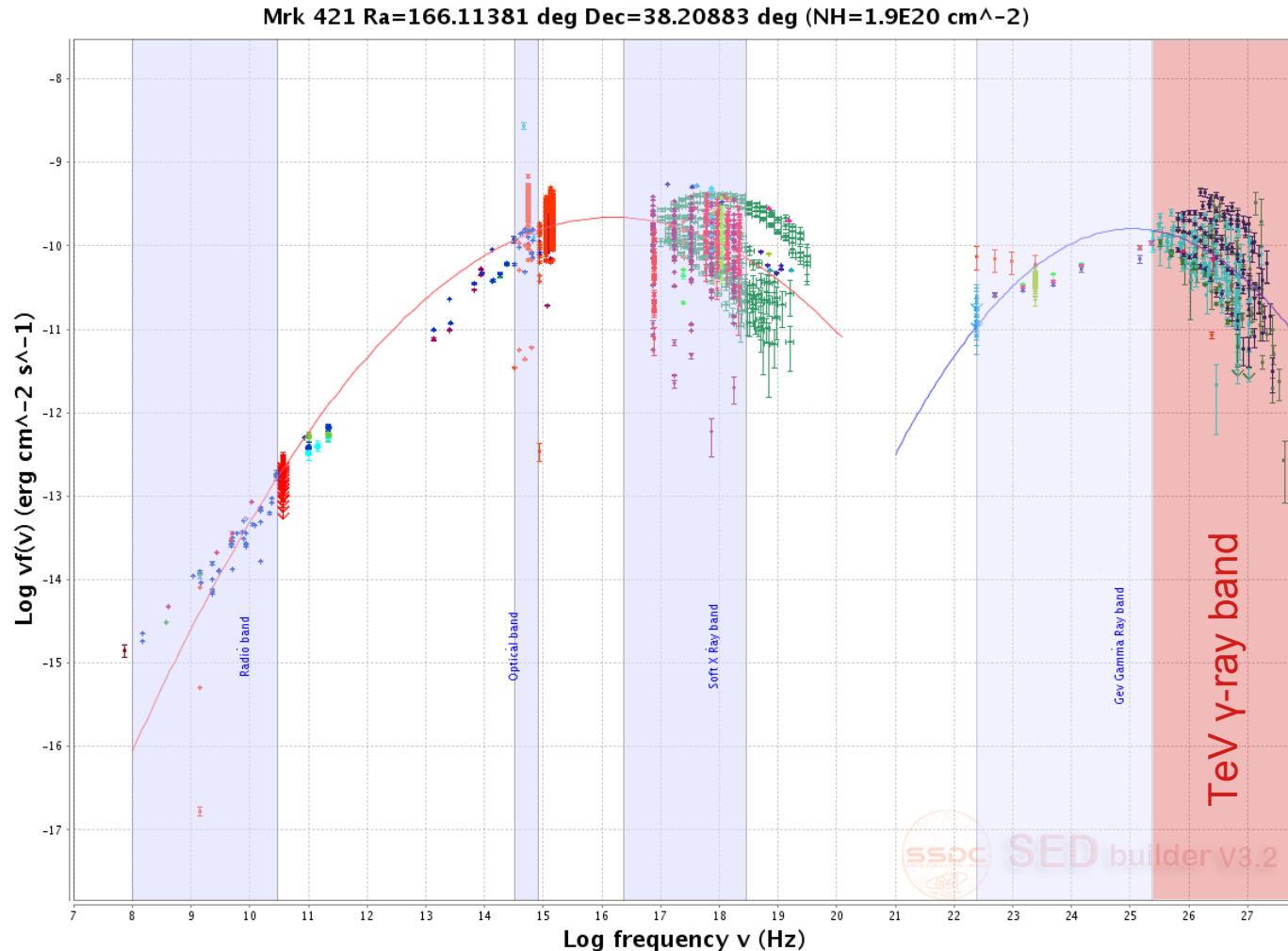
Antonucci, *ARA&A* (1993)
Urry & Padovani, *PASP* (1995)

Blazar



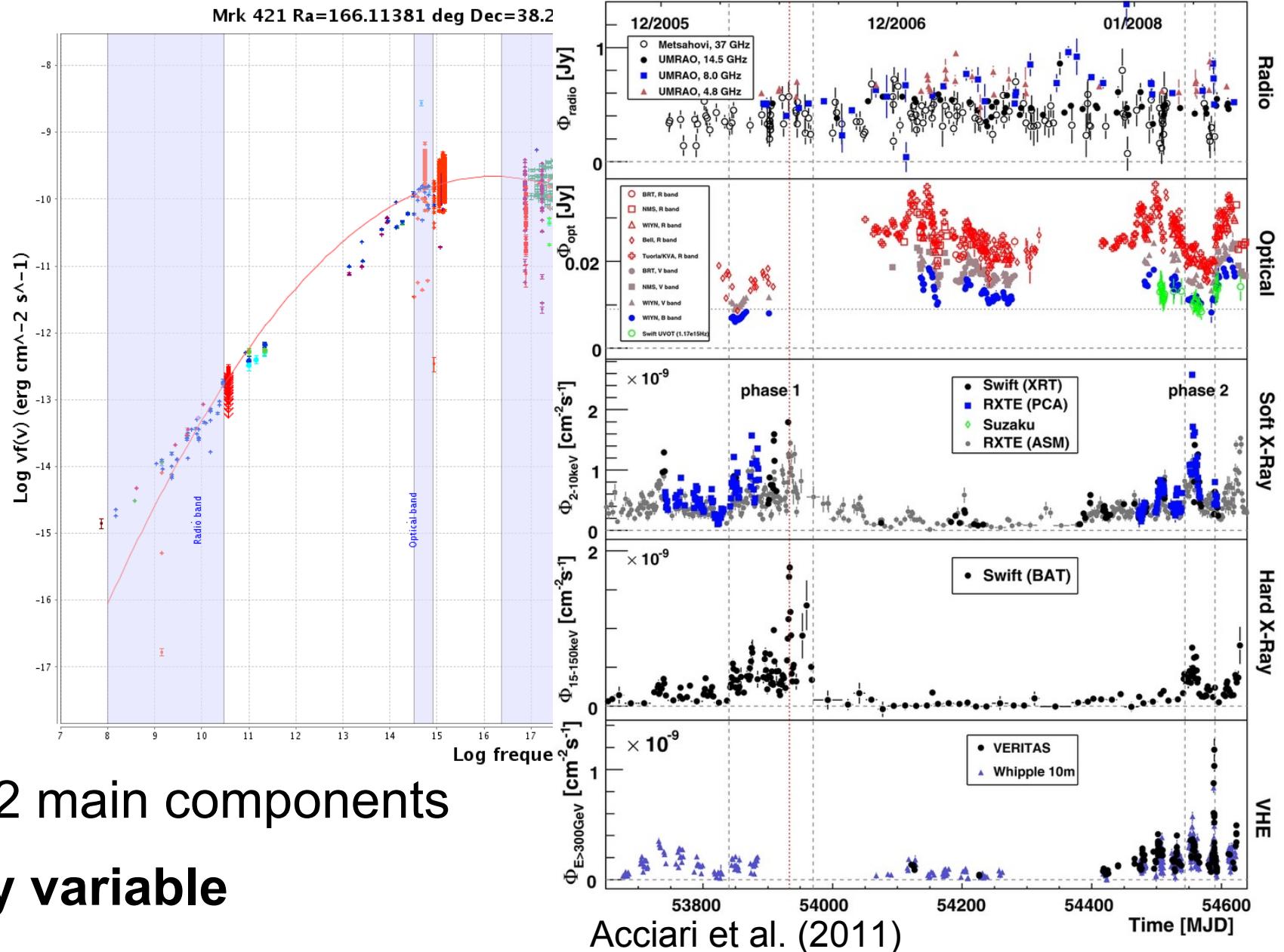
- Central enging outshines other components
- Highly relativistic jet (aparent superluminal motion)

Blazar



- SED: 2 main components
- Highly variable

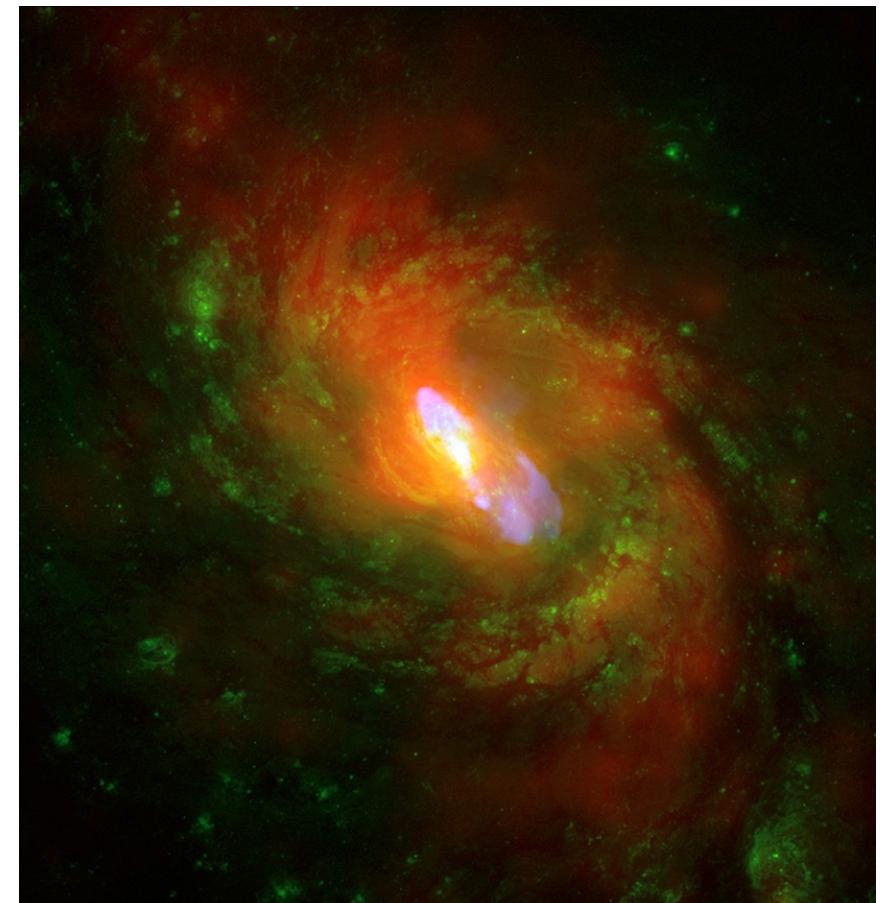
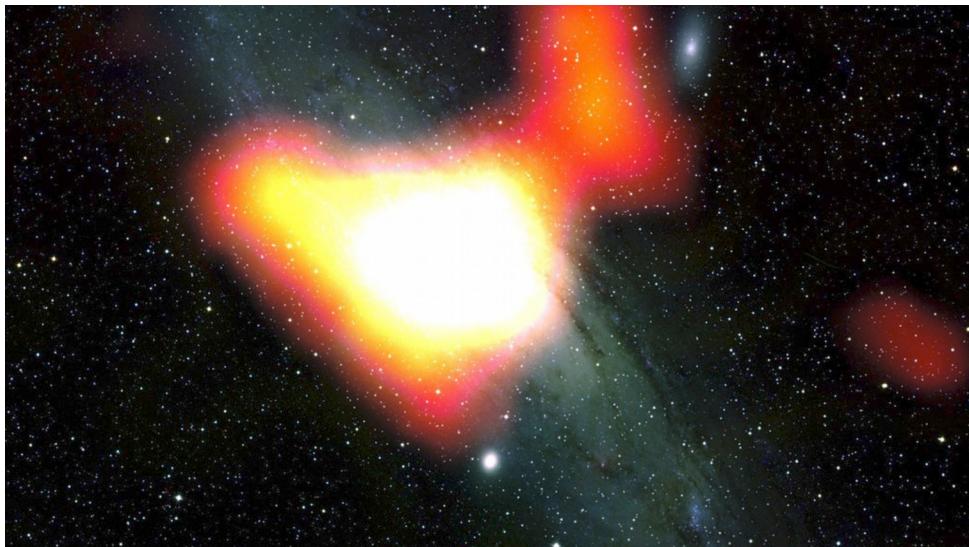
Blazar



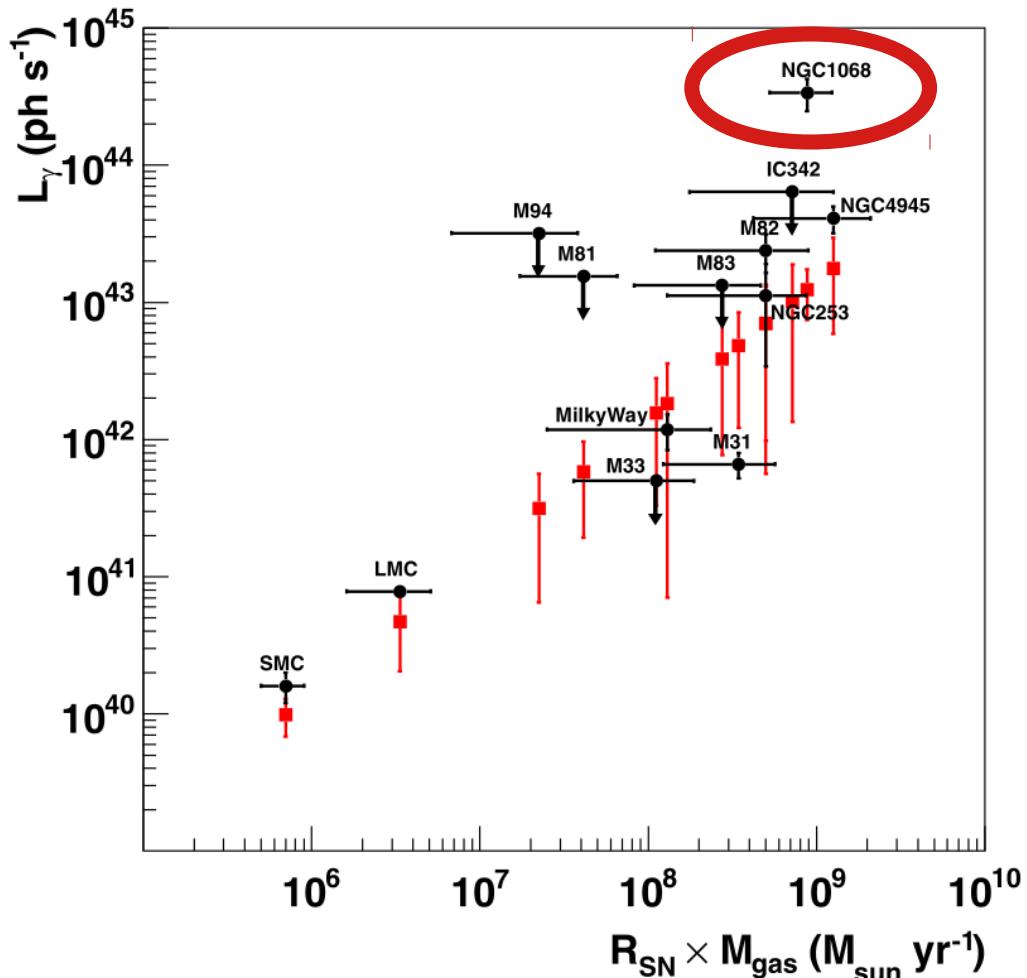
- SED: 2 main components
- Highly variable

HE emission from radio-quiet objects

- 2009: discovery of γ -ray emission from starburst galaxies:
 - M 82 (VERITAS)
 - NGC 253 (H.E.S.S.)
- 2010: discovery of γ -ray emission from M 31 (*Fermi*-LAT)
- → Can “intermediate” objects such as Sy 2 radiate at HE ?



HE emission from radio-quiet objects



- Detection of NGC 4945 and NGC 1068 with *Fermi*-LAT
- $p_{\text{CR}} p_{\text{ISM}} \dashrightarrow \pi^0, \eta \dashrightarrow \gamma$

$$L_{\gamma} \propto R_{\text{SN}} M_{\text{gas}}$$

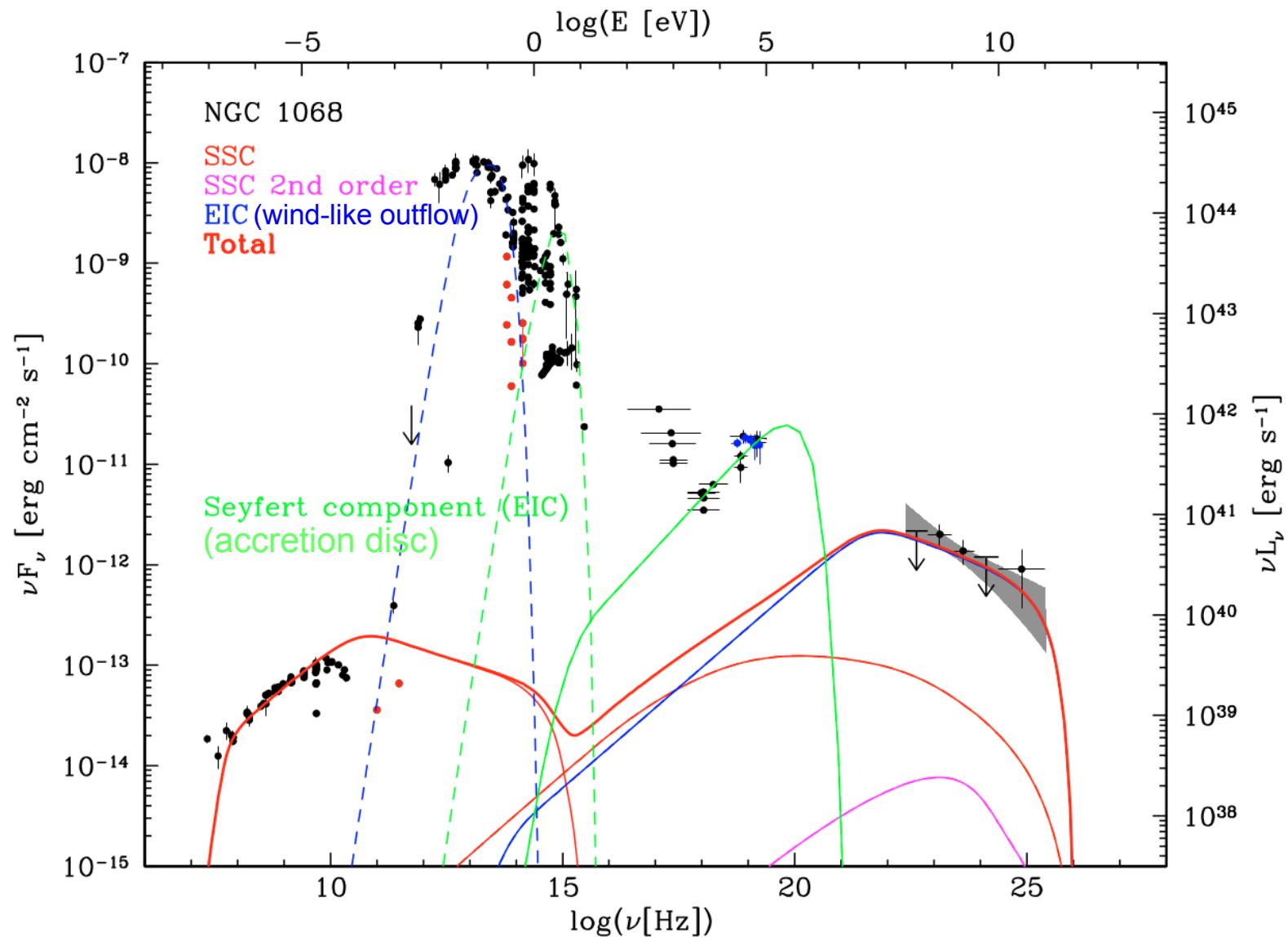
Pavlidou & Fields (2001)

- γ -ray emission in NGC 1068 seems too bright to be accounted for by starburst activity alone.

Lenain et al., A&A (2010)

Lenain & Walter, A&A (2011)

HE emission from radio-quiet objects



Lenain et al., A&A (2010)

The H.E.S.S. experiment



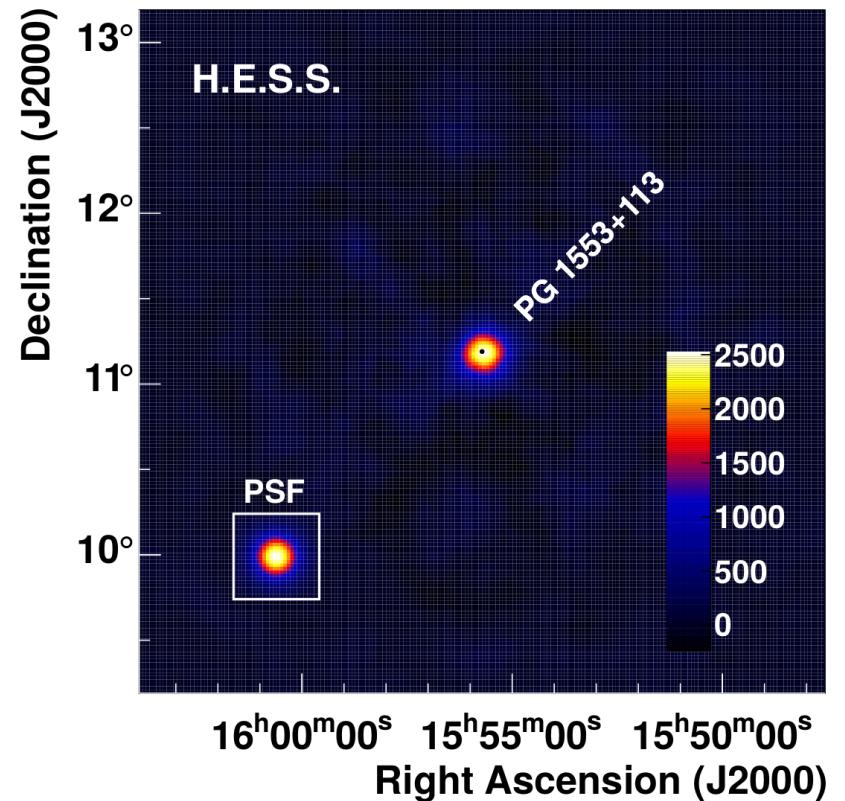
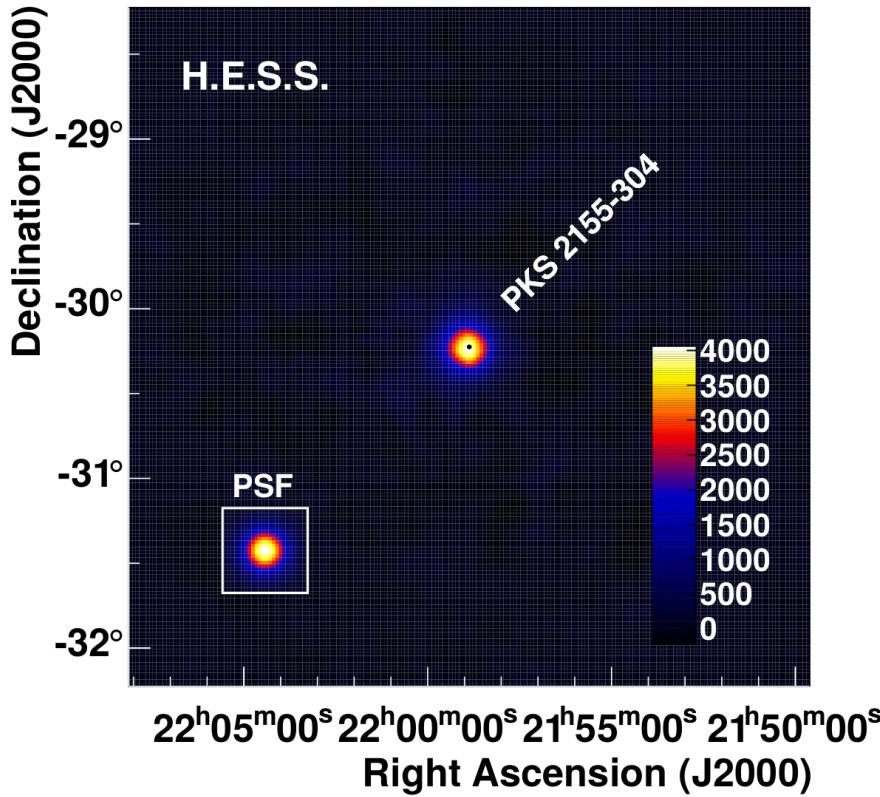
- Phase I

- Since 2003–2004,
4 telescopes (12m Ø)
- 960 PMT/camera
- 5° FoV
- Stereo trigger

- Phase II

- Addition of 5th telescope in 2012
(28m Ø)
- 2048 PMT
- 3.5° FoV
- Dual trigger:
mono (CT5) & stereo (≥ 2 tel.)

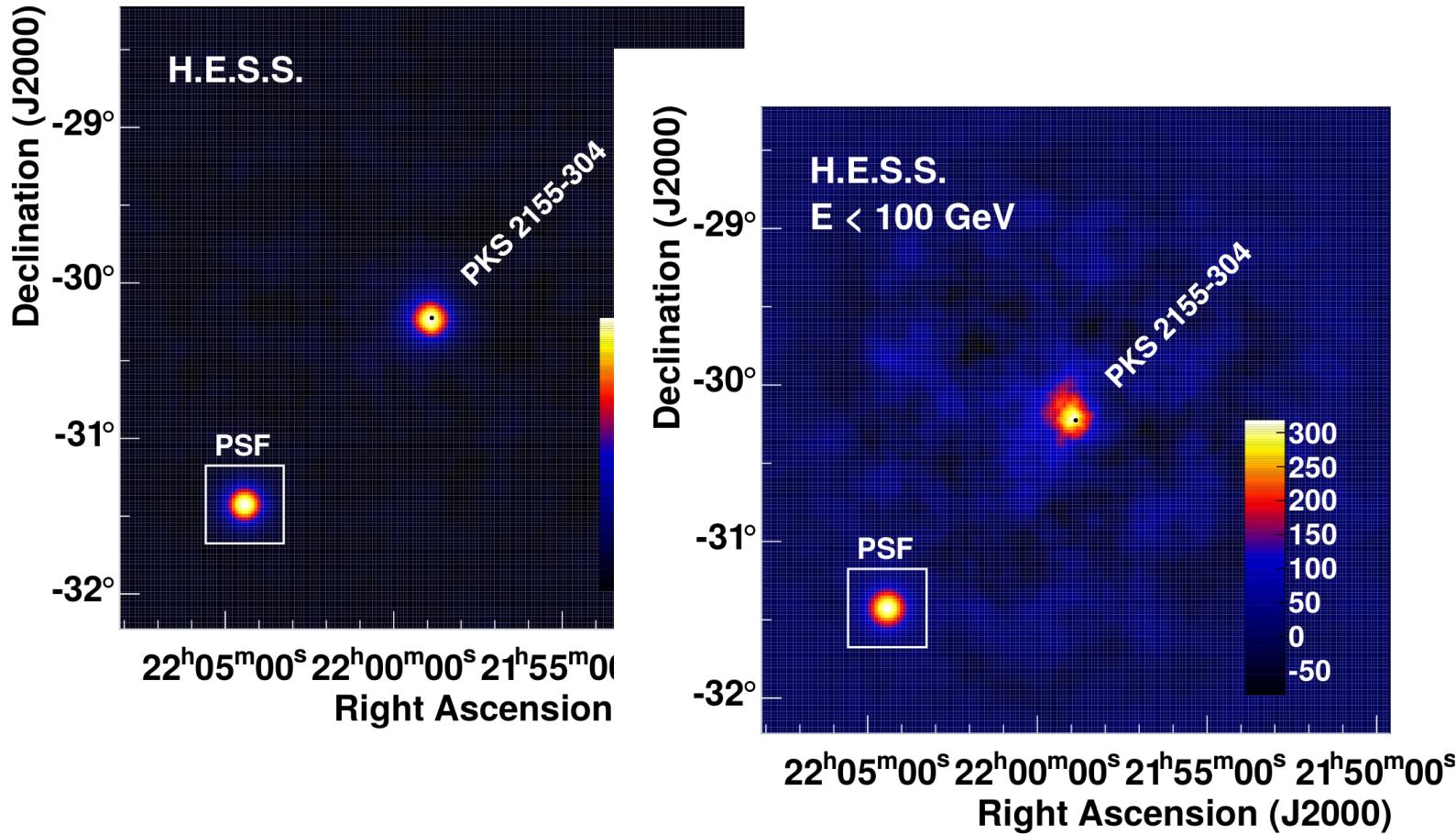
First results on AGN with H.E.S.S. II



- CT5 commissioning observations: **PKS 2155-304, PG 1553+113**
- Monoscopic reconstruction

H.E.S.S. & *Fermi*-LAT collaborations, *A&A* (2017)

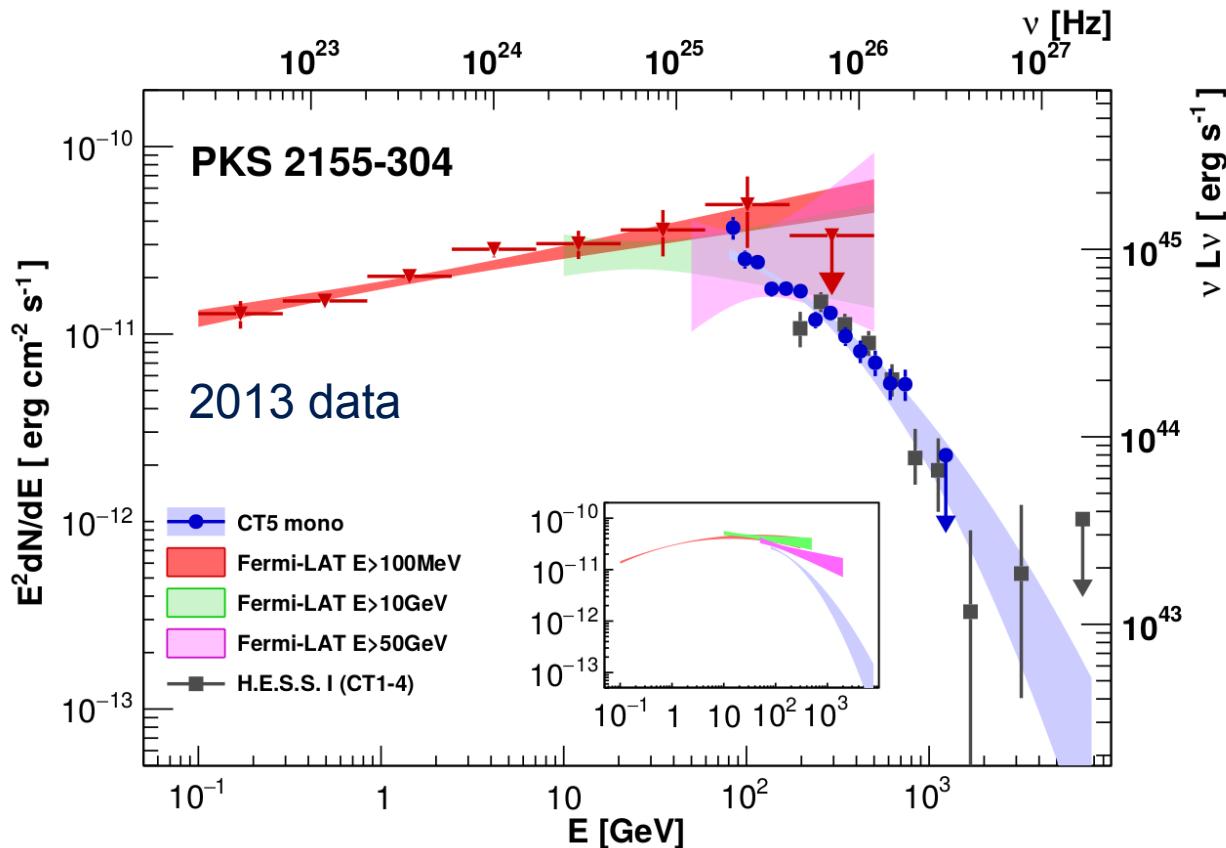
First results on AGN with H.E.S.S. II



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H.E.S.S. & *Fermi*-LAT collaborations, *A&A* (2017)

First results on AGN with H.E.S.S. II



- CT5 monoscopic vs H.E.S.S. I (CT1–4):
 - Simultaneous observations

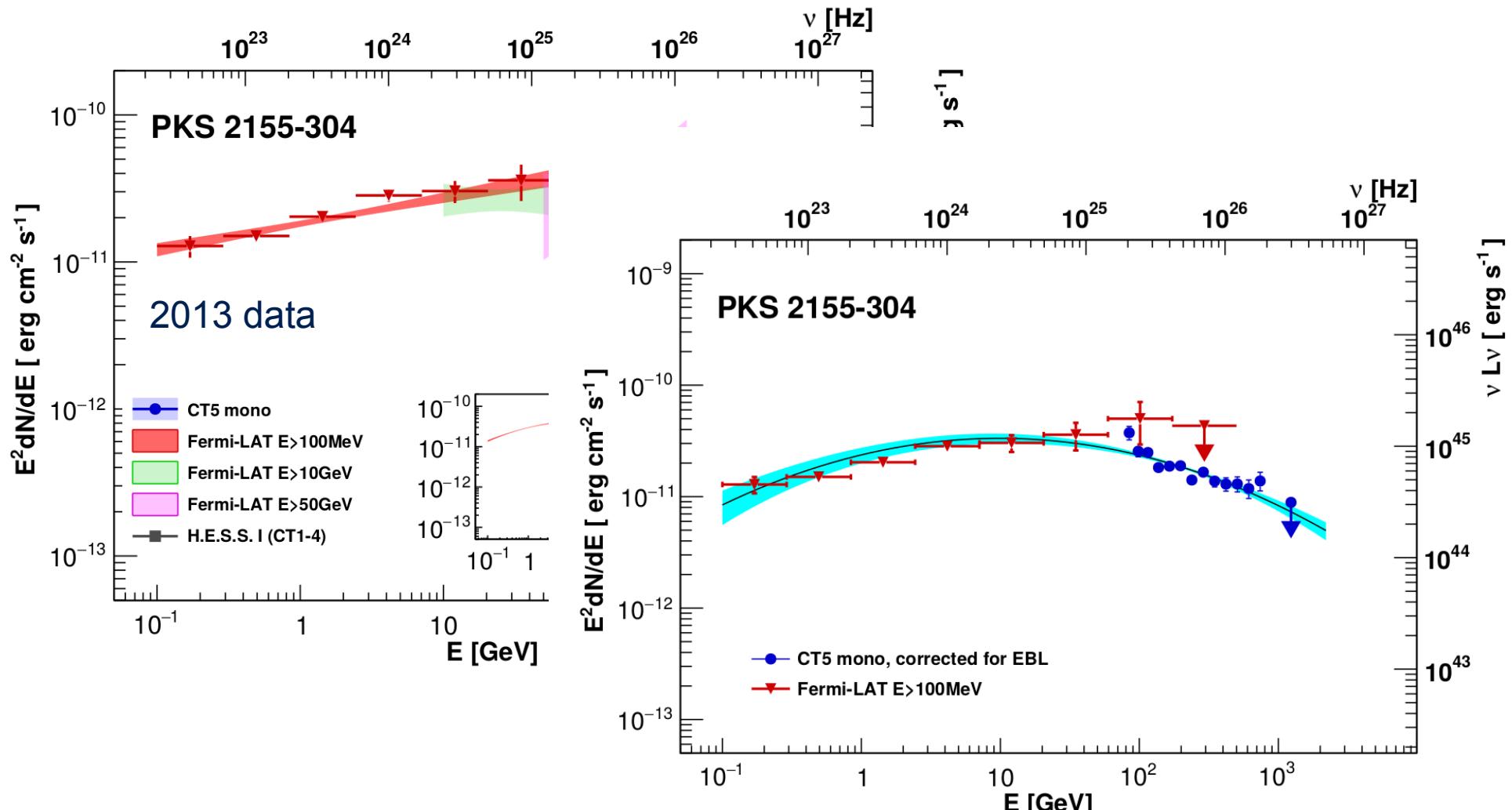
- 2013+2014 data:
 - ~ 36σ excess, $E_{\text{th}} = 80 \text{ GeV}$

$$\frac{dN}{dE} = \Phi_0 (E/E_0)^{-(\Gamma + \beta \log(E/E_0))}$$

$$\Gamma = 2.63 \pm 0.07_{\text{stat.}}$$

$$\beta = 0.24 \pm 0.06_{\text{stat.}}$$

First results on AGN with H.E.S.S. II



Intrinsic peak around 10 GeV

H.E.S.S. & *Fermi*-LAT collaborations, A&A (2017)

First results on AGN with H.E.S.S. II

	Energy scale	Flux	Spectral index	Curvature
MC shower interactions	–	1%	–	–
MC atmospheric simulation	7%		–	–
Instrument simulation/calibration	10%	10%	–	–
“Broken” pixels	–	5%	–	–
Live time	–	<5%		
Reconstruction & selection cuts	15%	15%	0.1	0.01
Background subtraction	–	6%	0.14	0.12
Total	19%	20%	0.17	0.12

- Systematics dominated by:

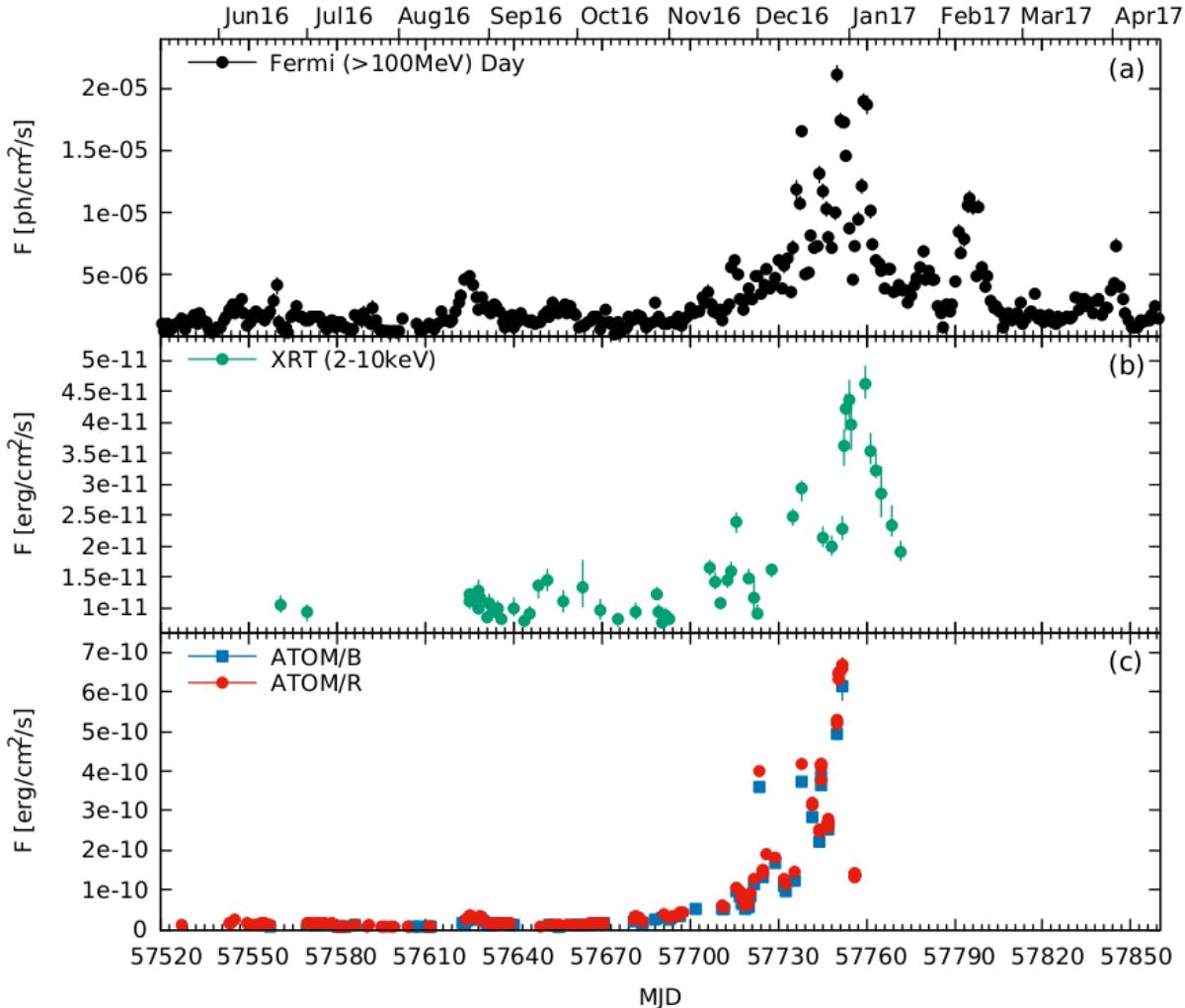
for PKS 2155-304

- mono reconstruction and selection cuts for flux and energy scale
- background subtraction for spectral index and curvature

H.E.S.S. & *Fermi*-LAT collaborations, A&A (2017)

The high energy regime of FSRQs CTA 102

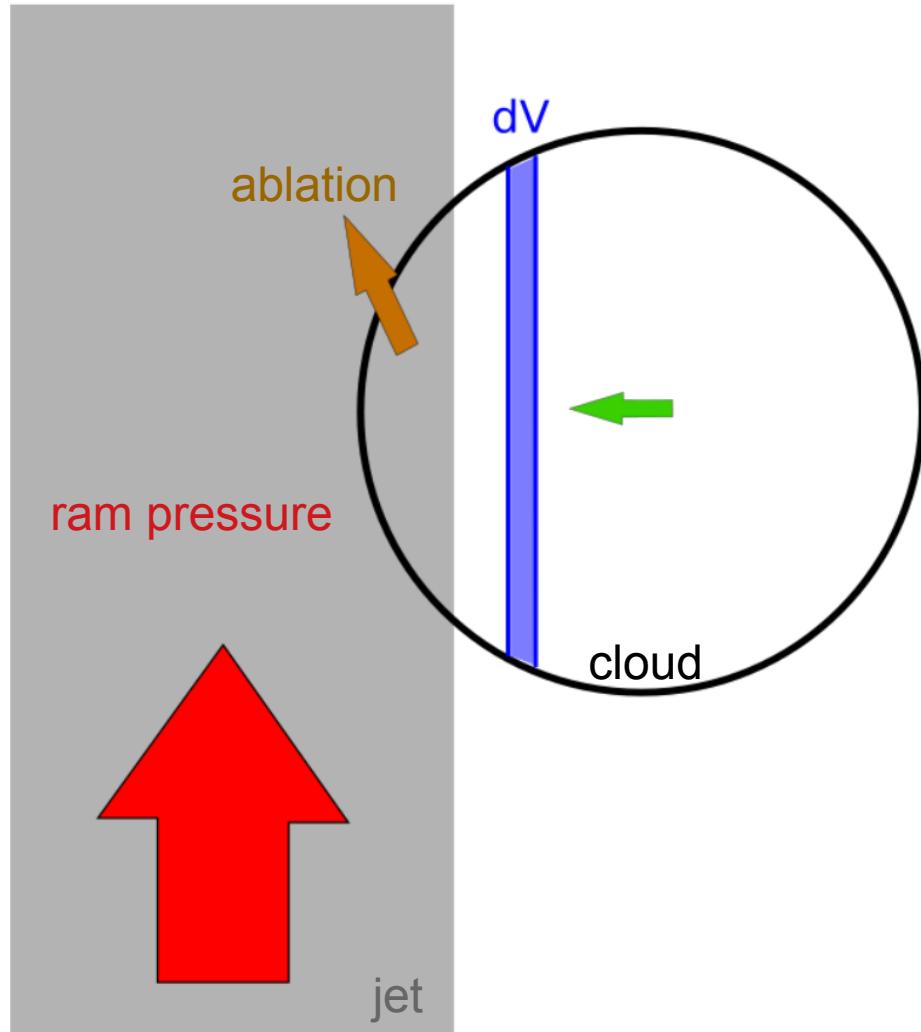
In collaboration with M. Zacharias, M. Böttcher, F. Jankowsky, S. Wagner, A. Wierzcholska
Non H.E.S.S.-related project



- FSRQ @ $z=1.037$
- 2016–2017:
 - ~4 months-long flare + short-term spikes
- Very large variations in HE (x50) and optical (x100)
- What can cause such a long lasting flare ?

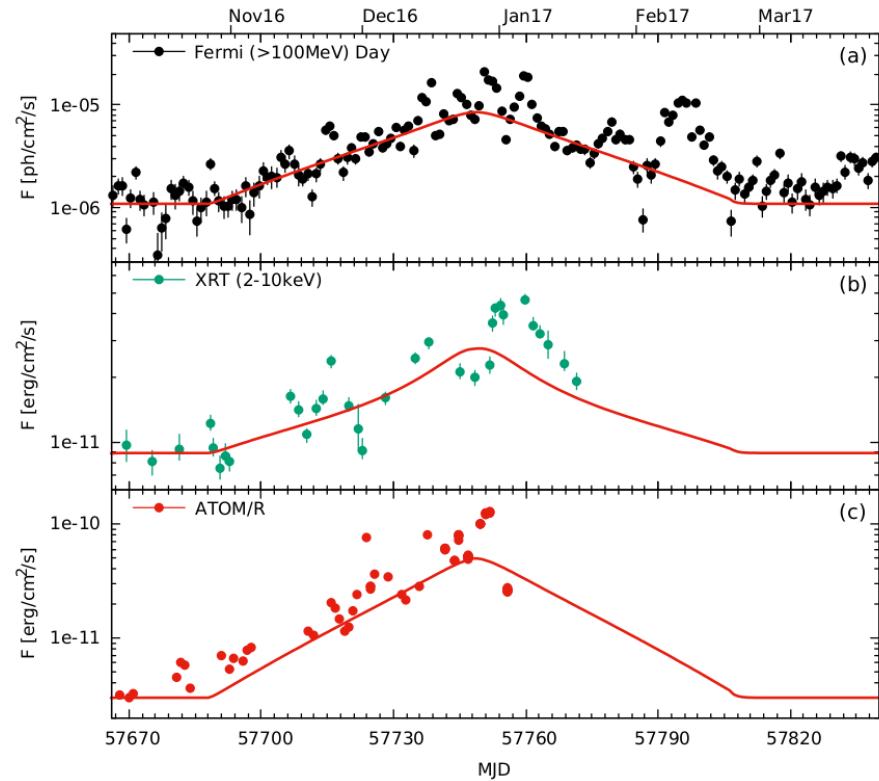
Zacharias et al., *ApJ* (2017)

The high energy regime of FSRQs CTA 102



Ablation of a gas cloud

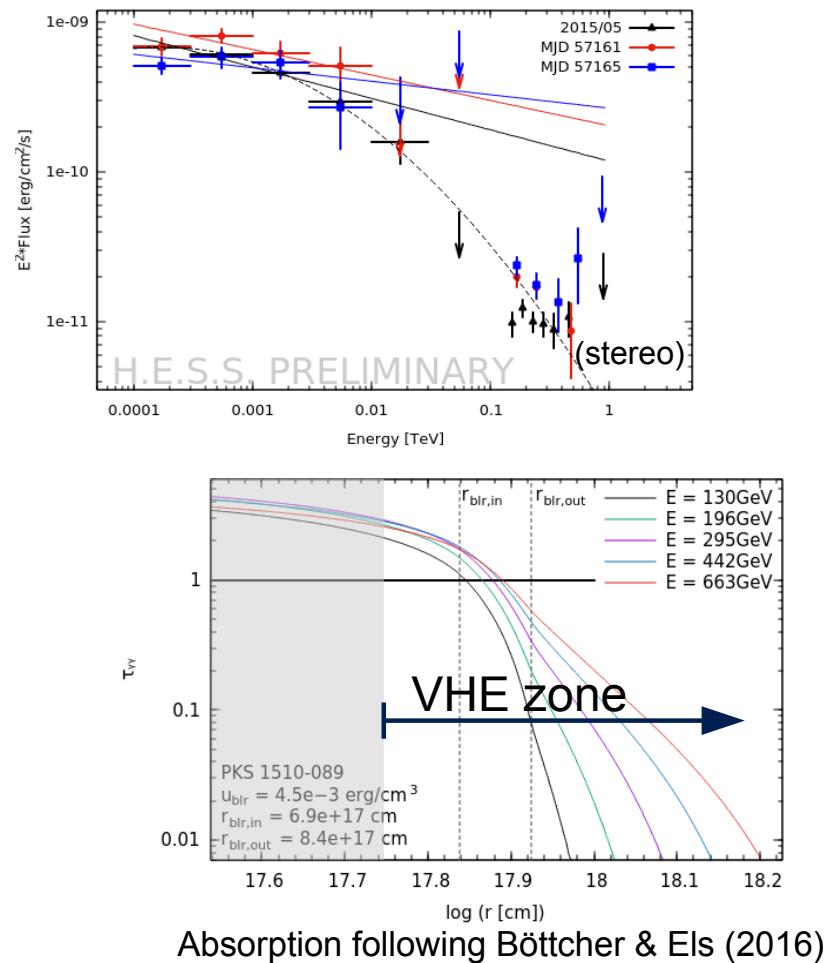
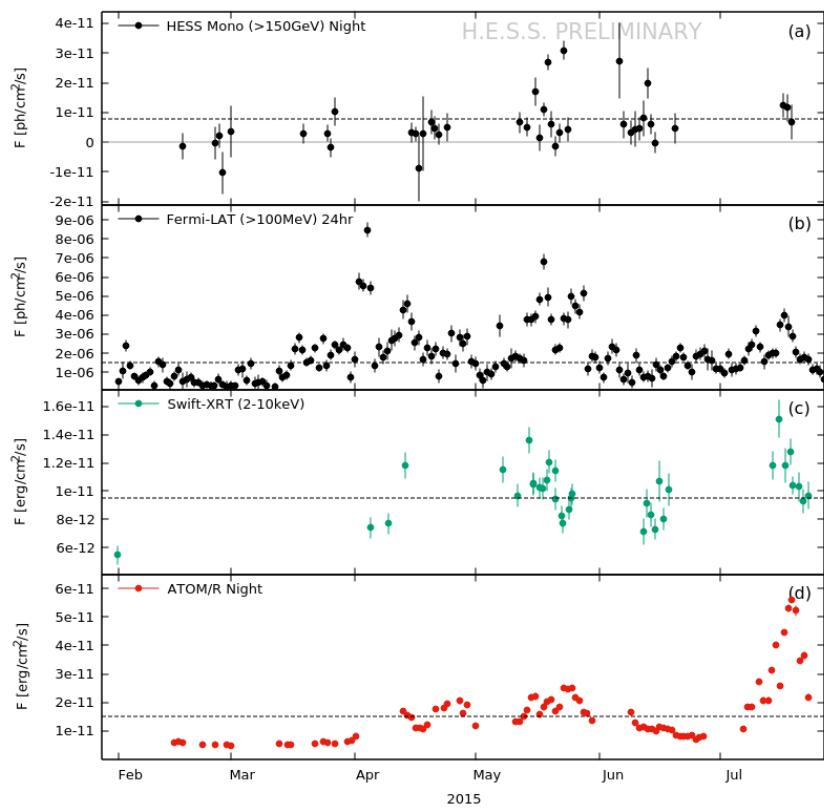
- Radiation model:
1-zone leptonic with IC/BLR
- Emitting zone at outer edge of BLR



Zacharias et al., *ApJ* (2017)

The high energy regime of FSRQs

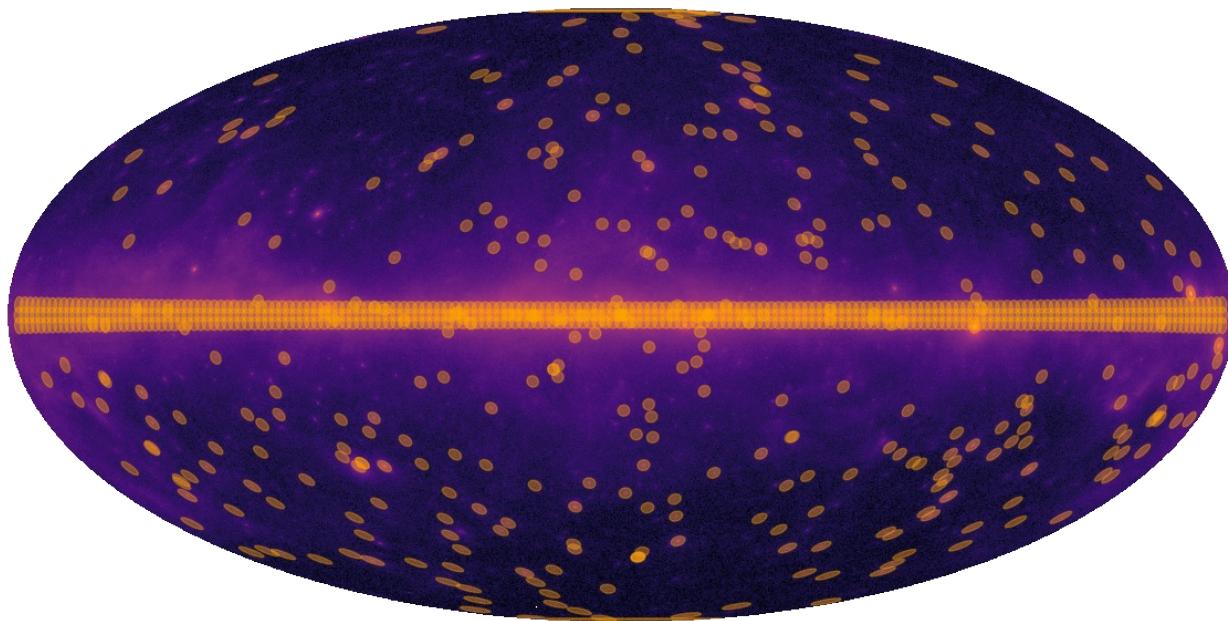
PKS 1510-089



- 7 currently known FRSQs @ VHE
- Emerging picture:
 - VHE zone within (in quiescence ?) or beyond BLR (during flares ?)

Zacharias et al. (for the H.E.S.S. collaboration), AIP Conf. Proc. (2017)
 Zacharias et al. (for the H.E.S.S. collaboration), ICRC (2017)

FLaapLUC: generation of alerts from *Fermi*-LAT transients



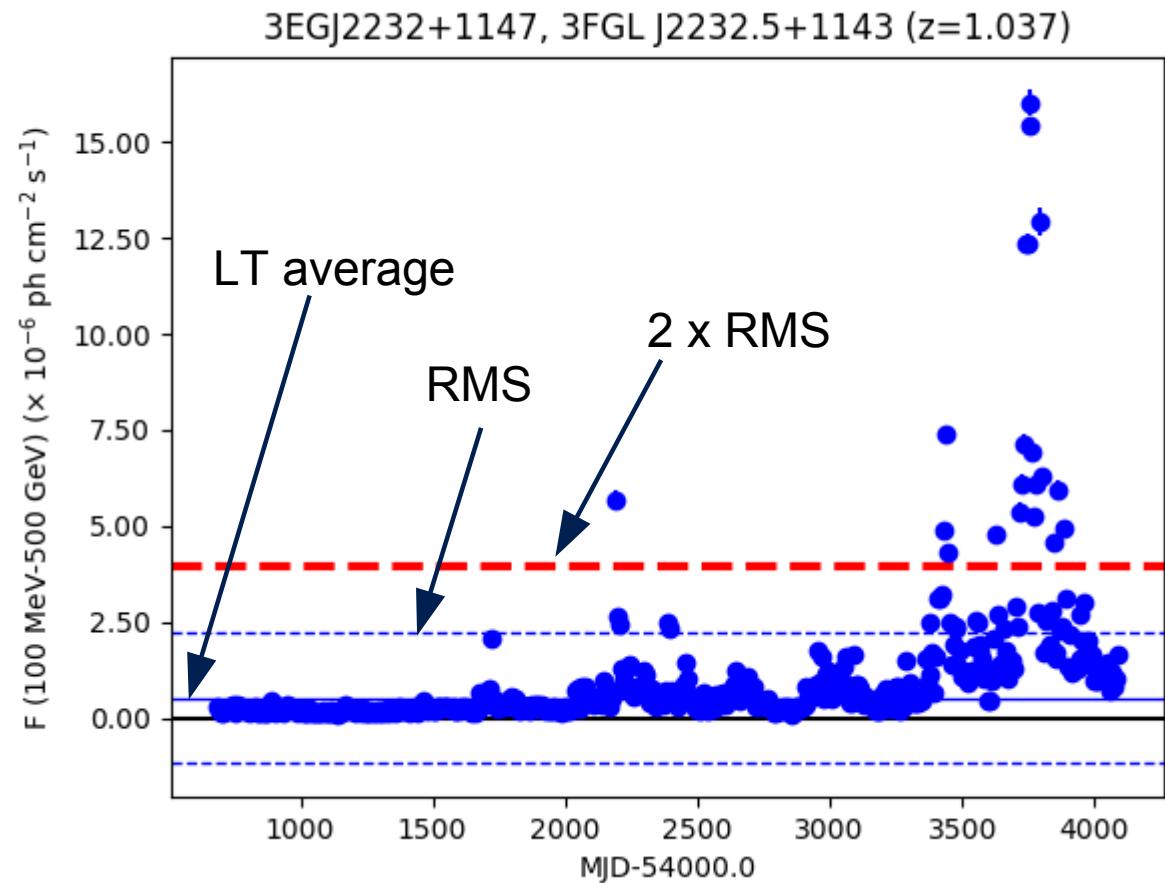
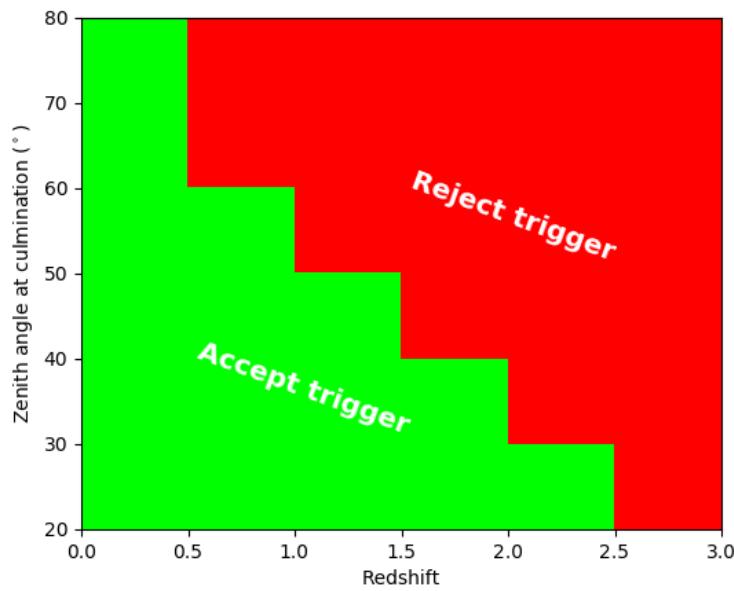
- Search for active sources at high energies
 - ~900 fields of view monitored every morning
 - ~320 AGN
 - ~60 γ -ray binaries/binary candidates
 - Galactic plane survey

Lenain, *Astronomy & Computing* (2018)

FLaapLUC: generation of alerts from *Fermi*-LAT transients

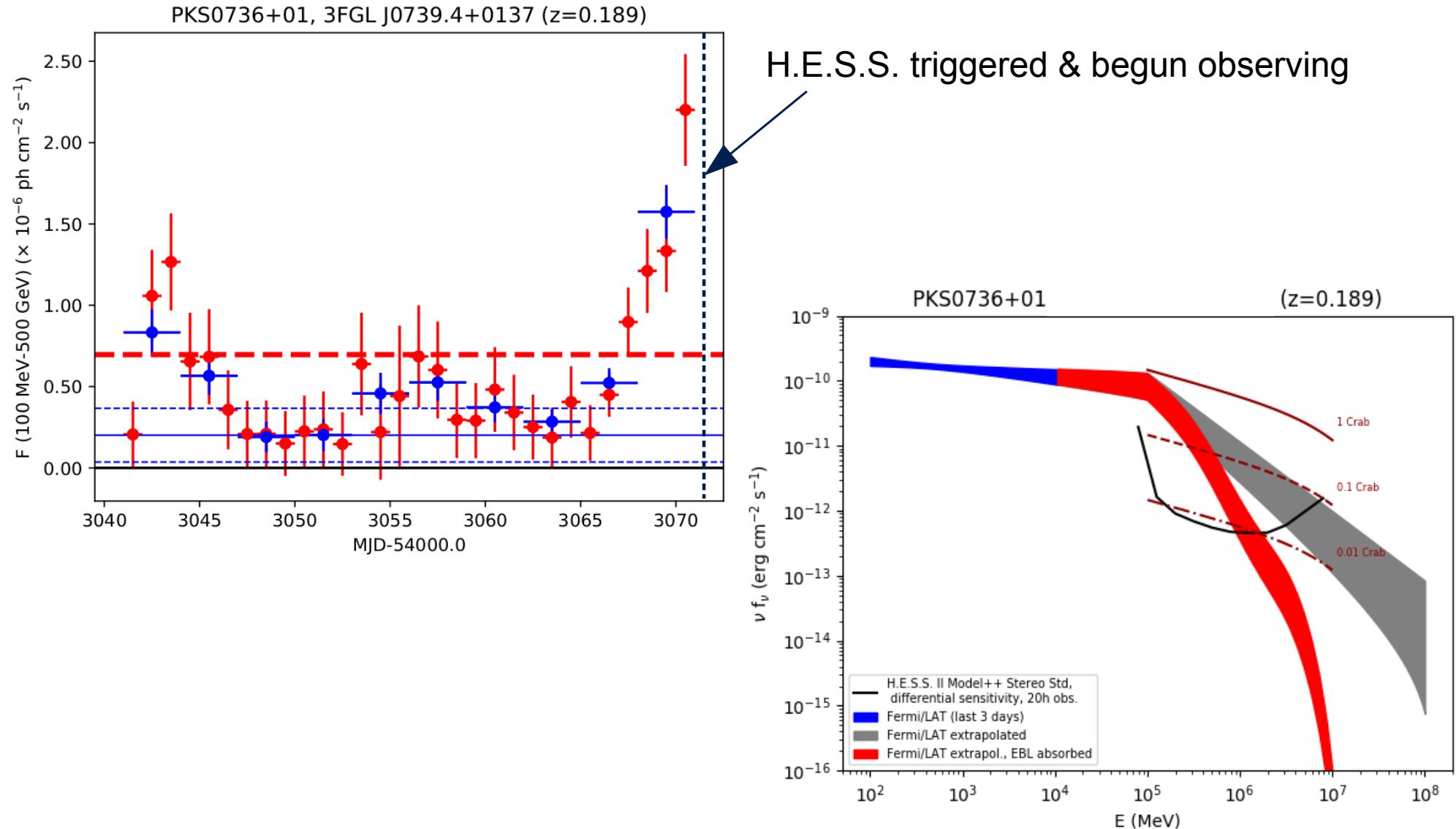
- 2-step process: N_1 - & N_2 -binned light curves
 - 1) $F_{N_1} - \delta F_{N_1} > \overline{F_{LT}} + \alpha_{N_1} \text{ RMS}(F_{LT})$
 - 2) $F_{N_2} - \delta F_{N_2} > \overline{F_{LT}} + \alpha_{N_2} \text{ RMS}(F_{LT})$
- If 1), then computes N_2 -binned LC and assess 2)
- E.g. for AGN, $N_1=3$ days, $N_2=1$ day,
 $\alpha_{N_1} = 2$, $\alpha_{N_2} = 3$

FLaapLUC: generation of alerts from *Fermi*-LAT transients

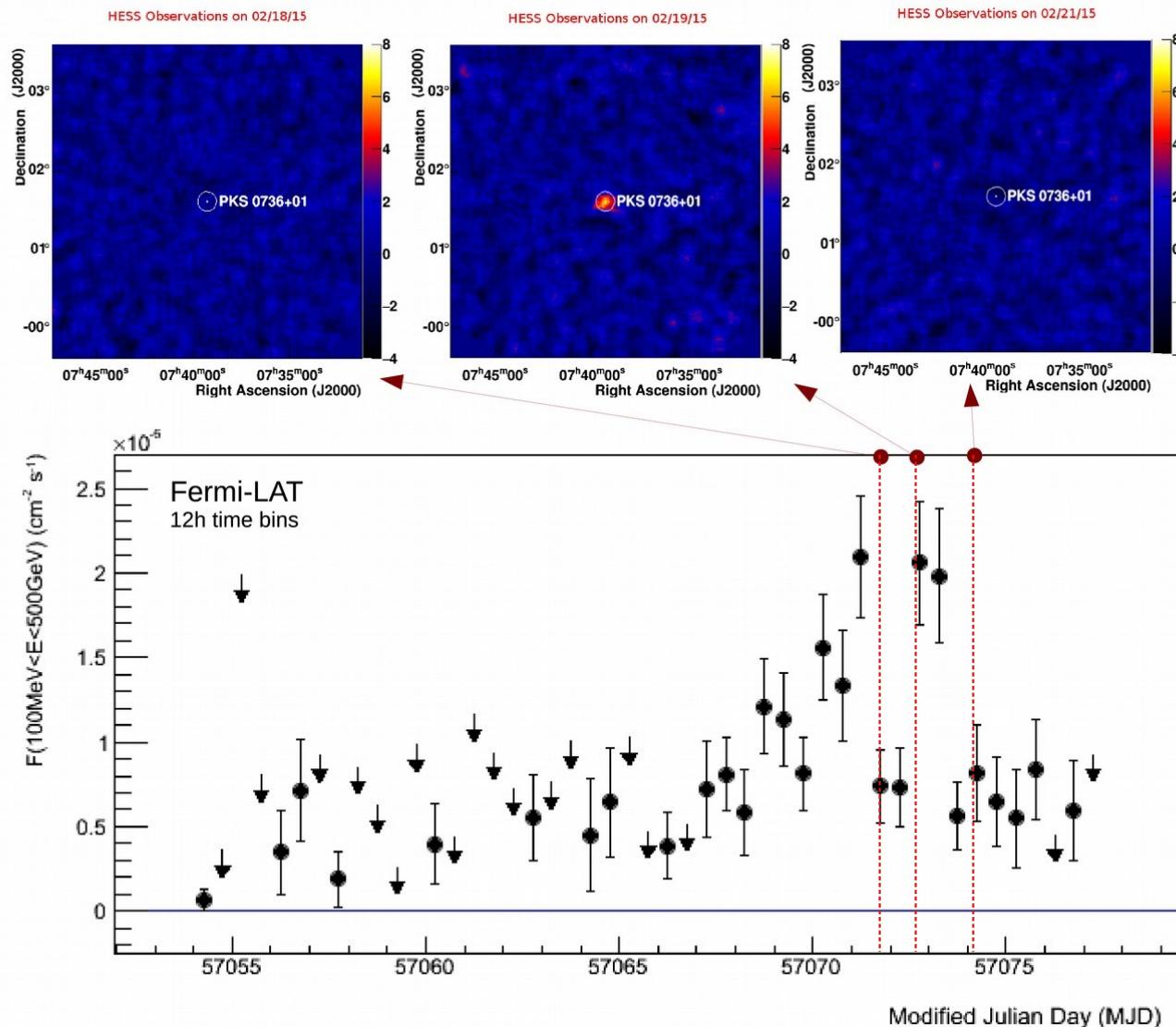


Use long-term flux average as baseline

FLaapLUC: triggering VHE observations



FLaapLUC: triggering VHE observations

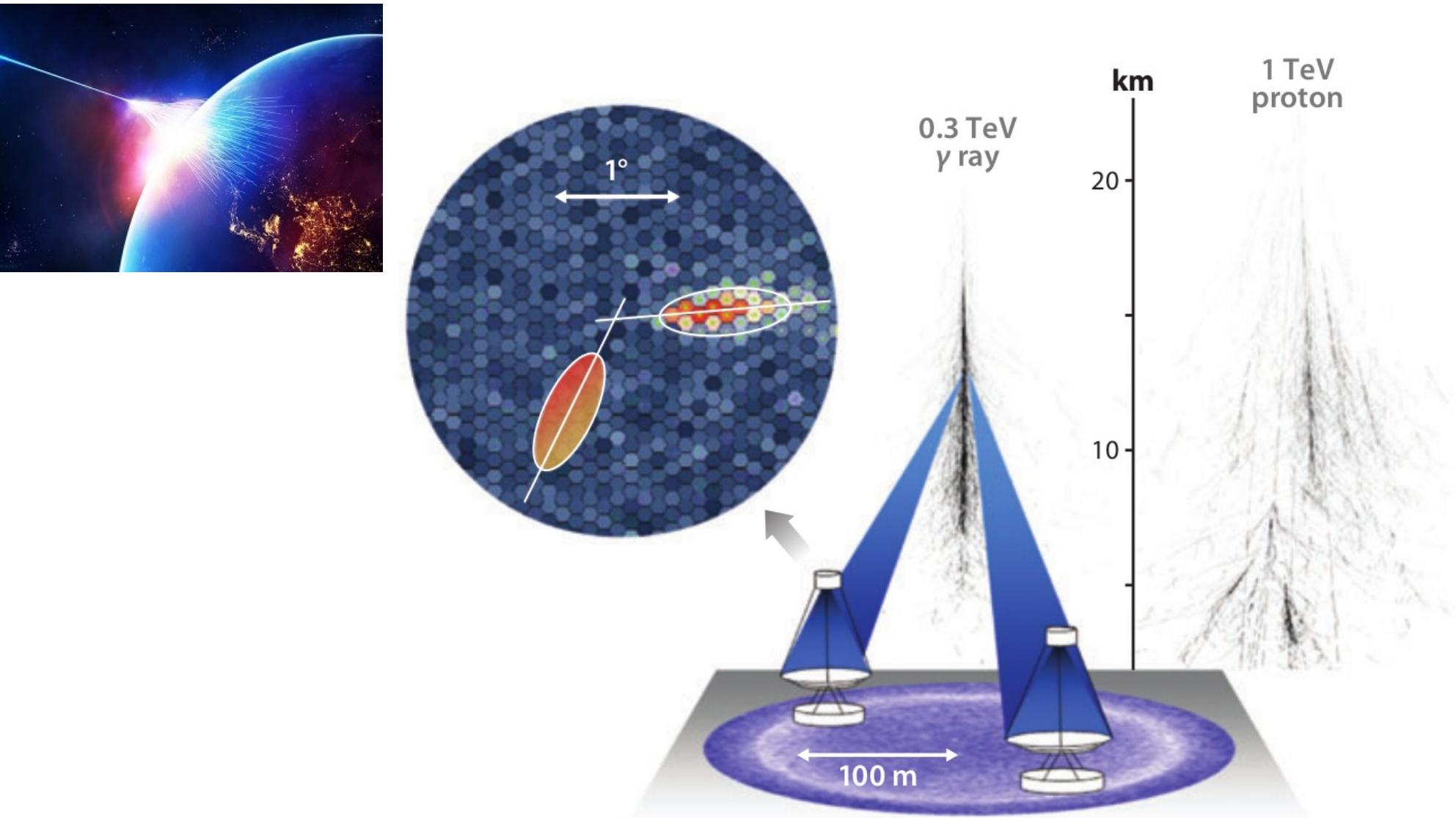


Cerruti et al. (for the H.E.S.S. collaboration), ICRC (2017)

Outline

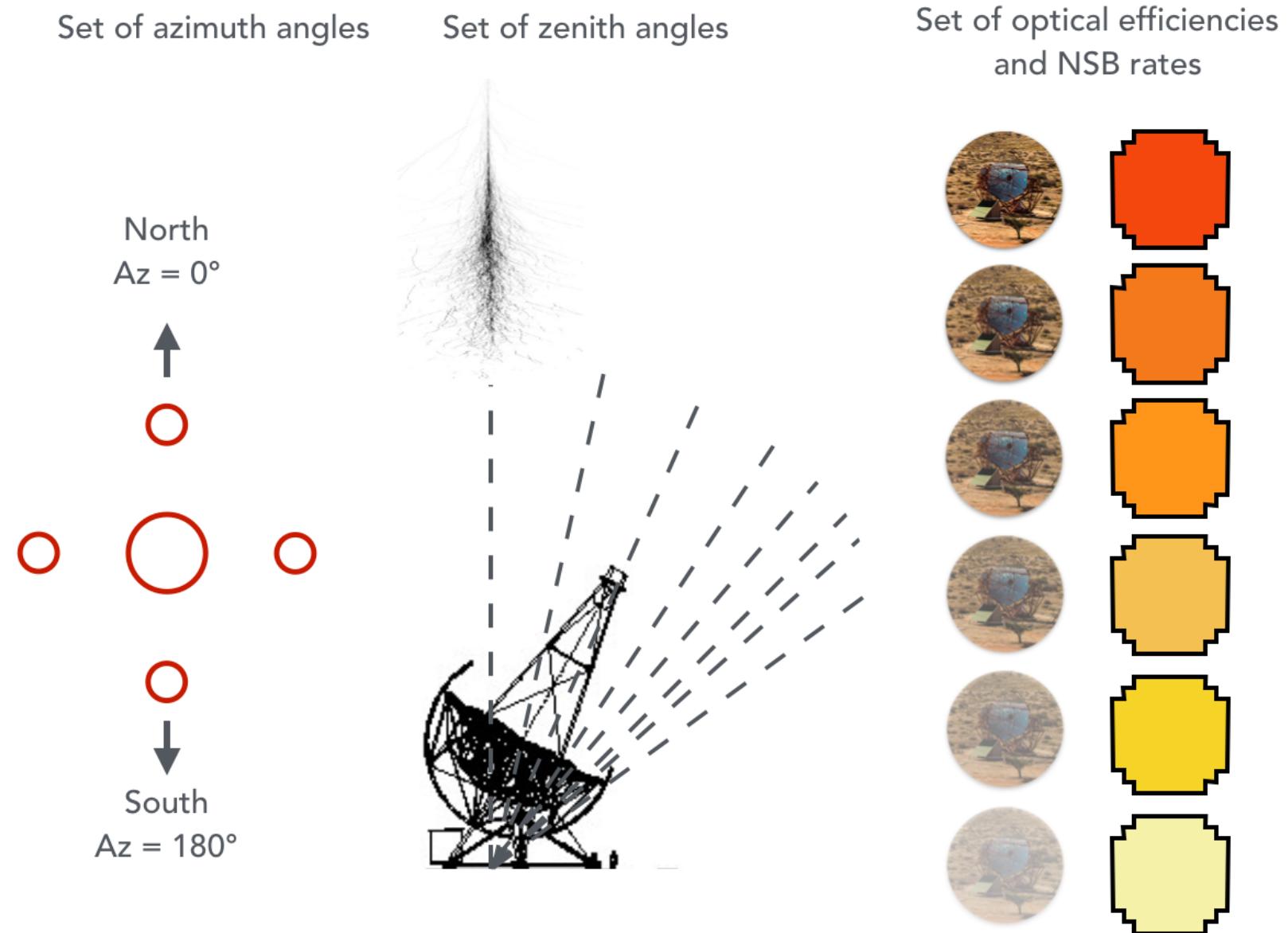
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Detecting VHE γ rays from the ground

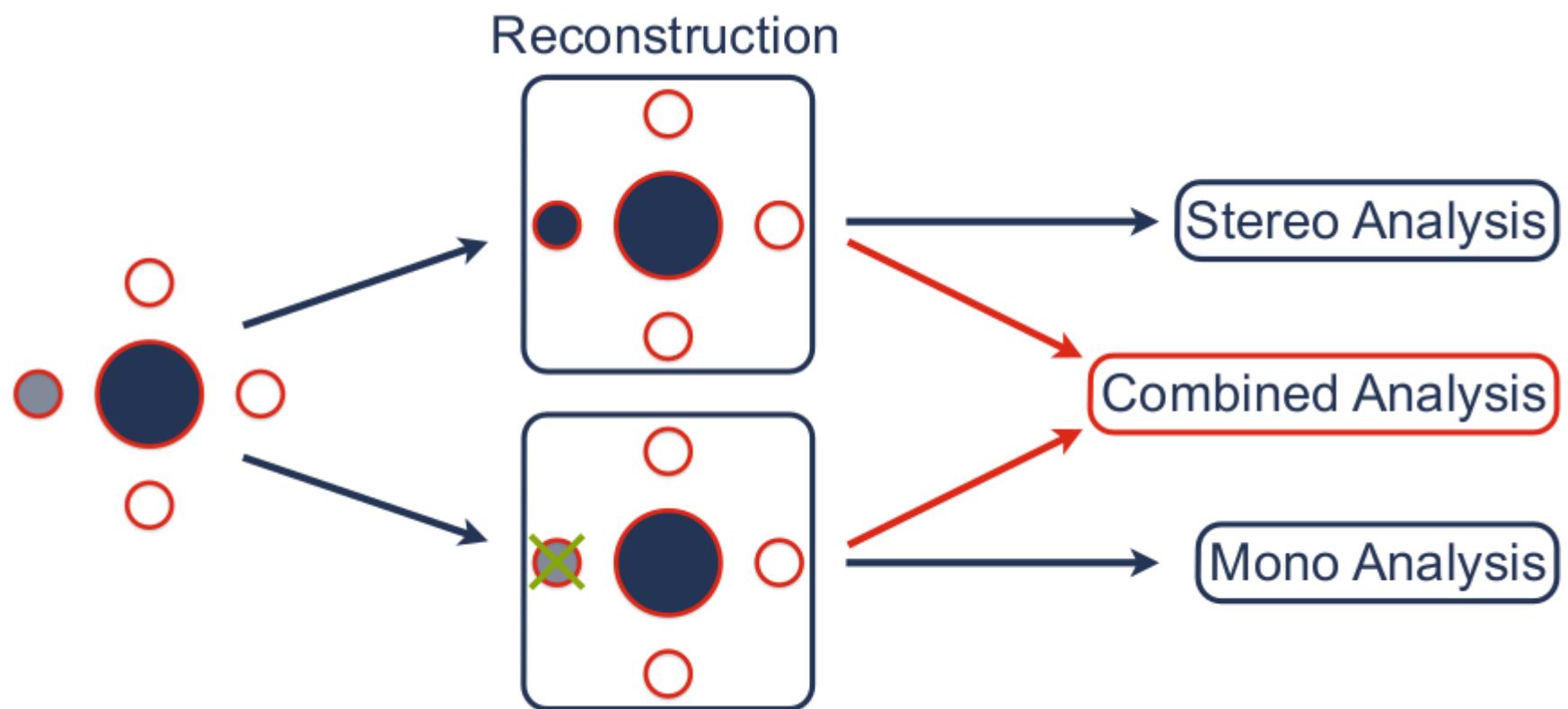


Hinton & Hofmann (2009)

Monte Carlo simulations



H.E.S.S. II analysis modes



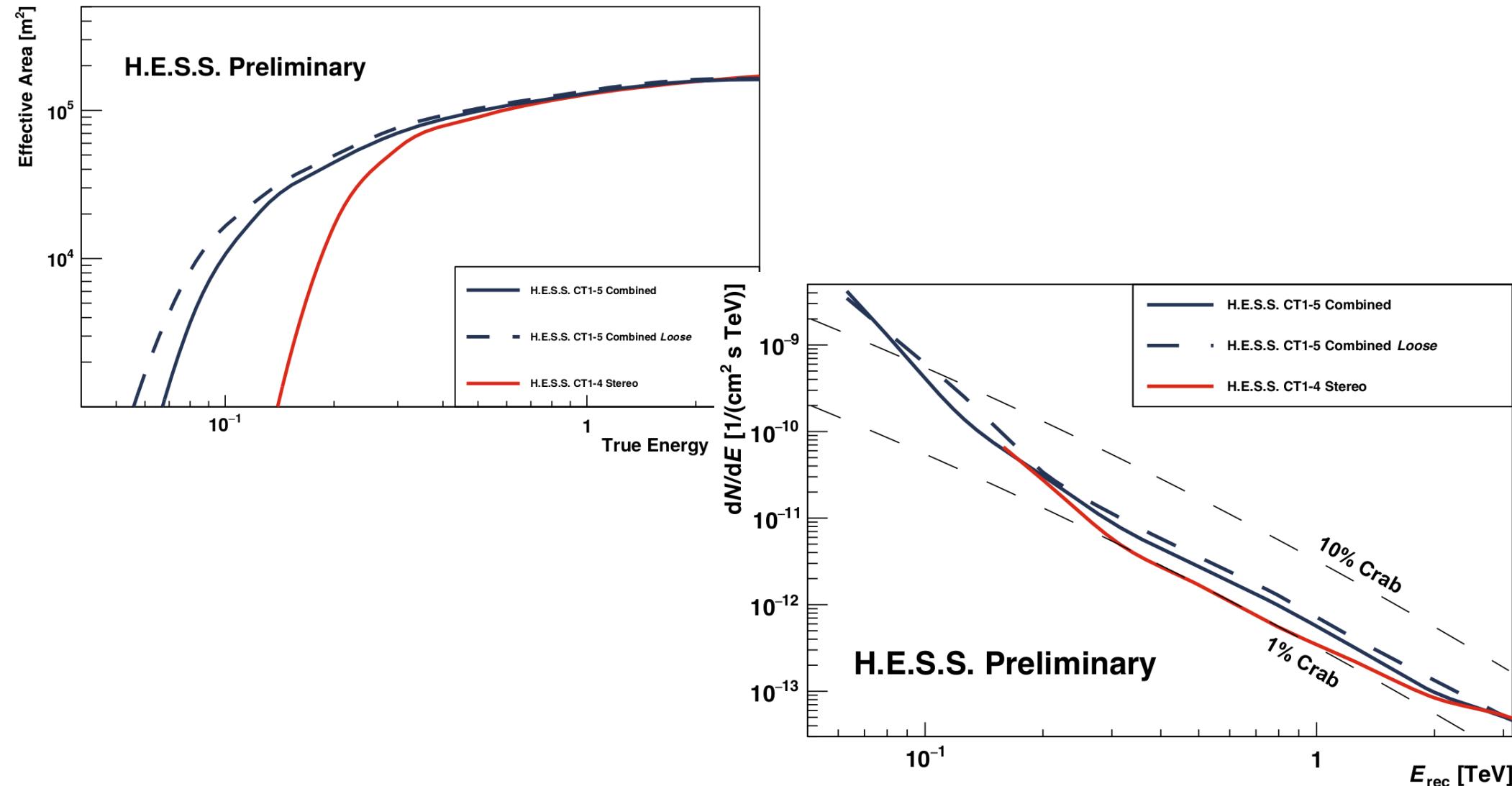
Side note:integration of EGI in H.E.S.S. software

ParisAnalysis Interface (on cca002)

[Web page](#)

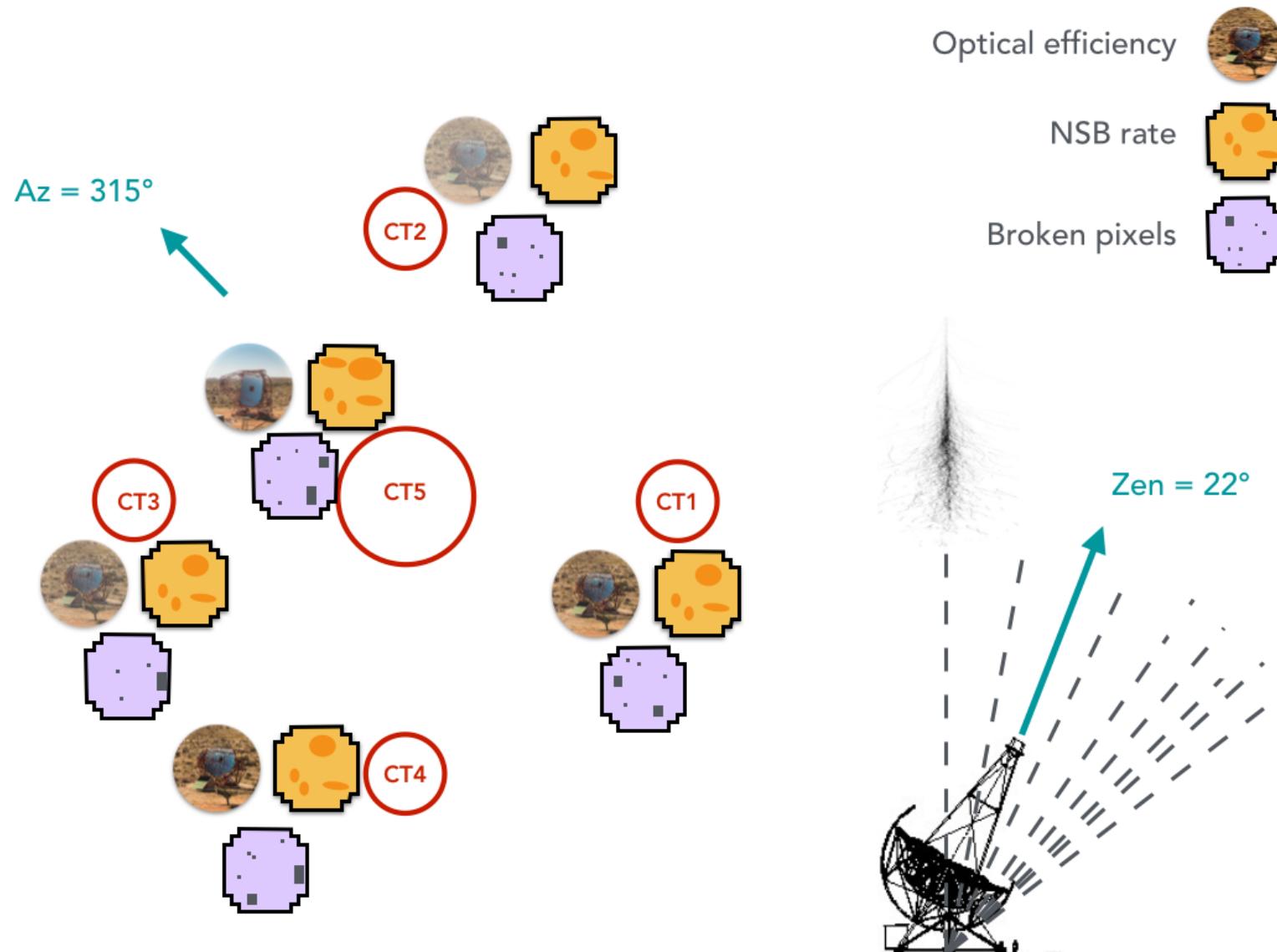
Target and Run List	Batch System Type	
	Batch System	EGI
	Input/Output Directories	
	Working	DISK
	Calibration	DISK
	DST	LFC STORAGE
	Tables	LFC STORAGE
	Output Tables	DISABLED
	Results	LFC STORAGE
	General Batch System Settings	
	<input checked="" type="checkbox"/> Automatic Resources	<input type="checkbox"/> Software built using Scons
	<input type="radio"/> Use TMPDIR	<input type="radio"/> Use WORKINGDIR
	<input type="checkbox"/> Open in Terminal	<input type="checkbox"/> Clear XROOTD
	<input type="checkbox"/> Use XROOTD	LCG Root Directory
	<input type="checkbox"/> Use LCG	LFC Root Directory
	<input checked="" type="checkbox"/> Use LFC	/grid/vo.hess-experiment.eu
	Specific Batch System Settings	
	ROOT Directory	/opt/exp_soft/vo.hess-experiment.eu/LLR.Local/root-5.34.32
	HESS Soft version	HESS_Soft_0-8-32
	List of Computing Elements	List of Storage Elements
	<input type="checkbox"/> Use WMS	<input type="checkbox"/> Use proxy delegation
	<input type="checkbox"/> Use myproxy	<input type="checkbox"/> Use SandBox GFTP server
	<input checked="" type="checkbox"/> Use DIRAC	<input checked="" type="checkbox"/> JDL requirements
	JDL sites reqs.	
	JDL banned sites	
Additional JDL reqs.	(other.GlueCEStateFreeCPUs>1)	
ParisAnalysis Settings		
<input checked="" type="checkbox"/> Verbose Analysis	<input checked="" type="checkbox"/> Generate stack trace	
<input type="checkbox"/> Produce Run Files		
<input type="checkbox"/> Use sliced analysis	Runs per Slice: 20	

H.E.S.S. II performances



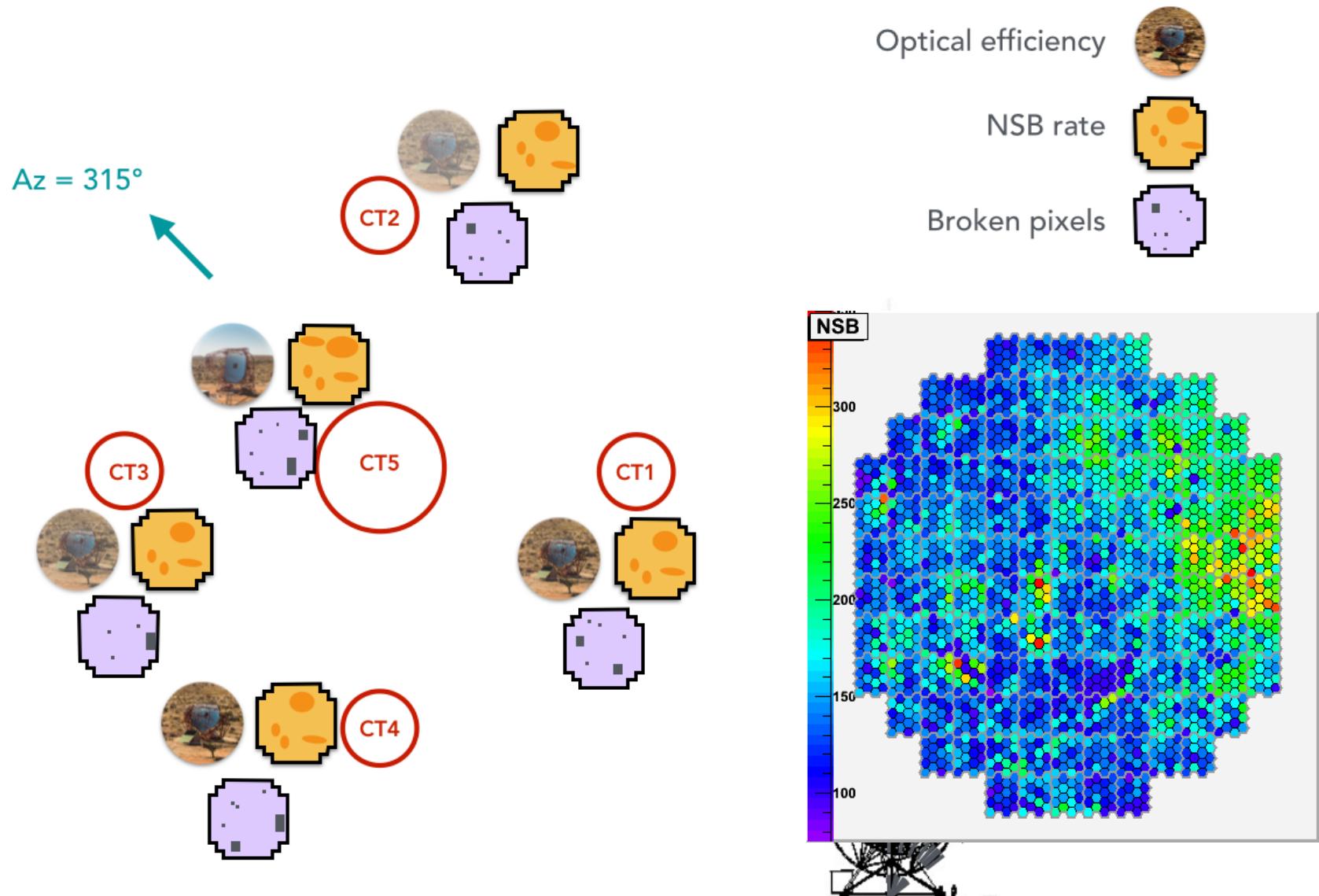
Holler et al. (for the H.E.S.S. collaboration), ICRC (2015)

An alternative: run-wise simulations



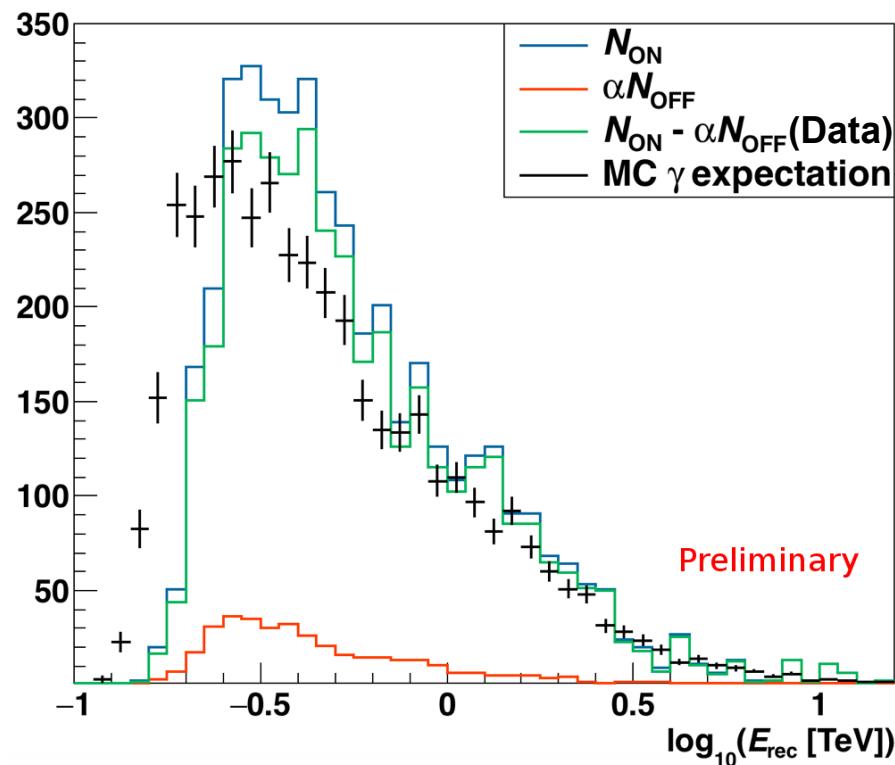
In collaboration with M. Holler, M. de Naurois, J. Chevalier, D. Sanchez

An alternative: run-wise simulations

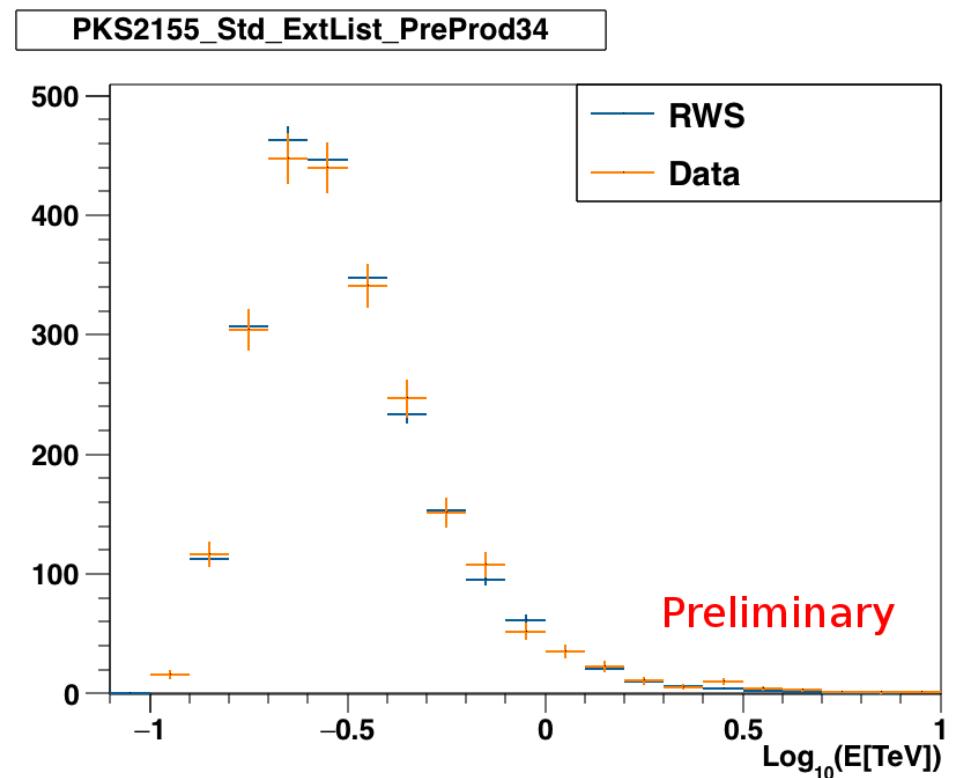


In collaboration with M. Holler, M. de Naurois, J. Chevalier, D. Sanchez

An alternative: run-wise simulations

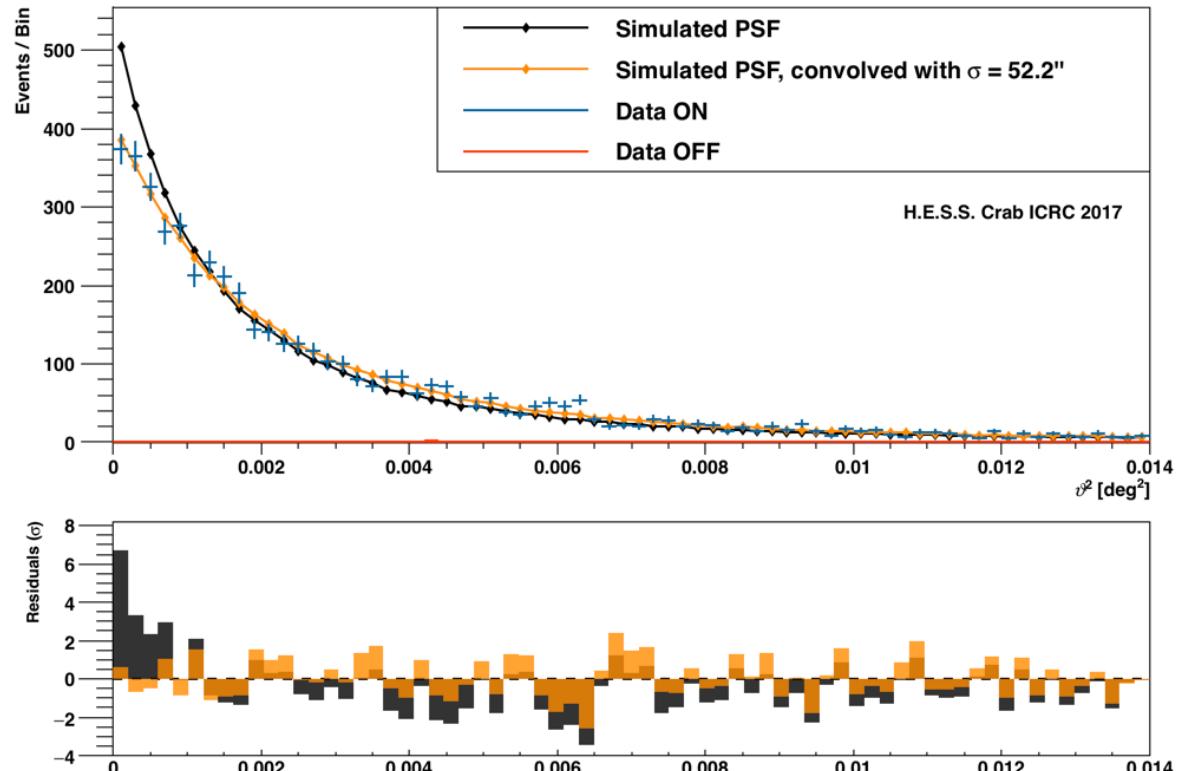
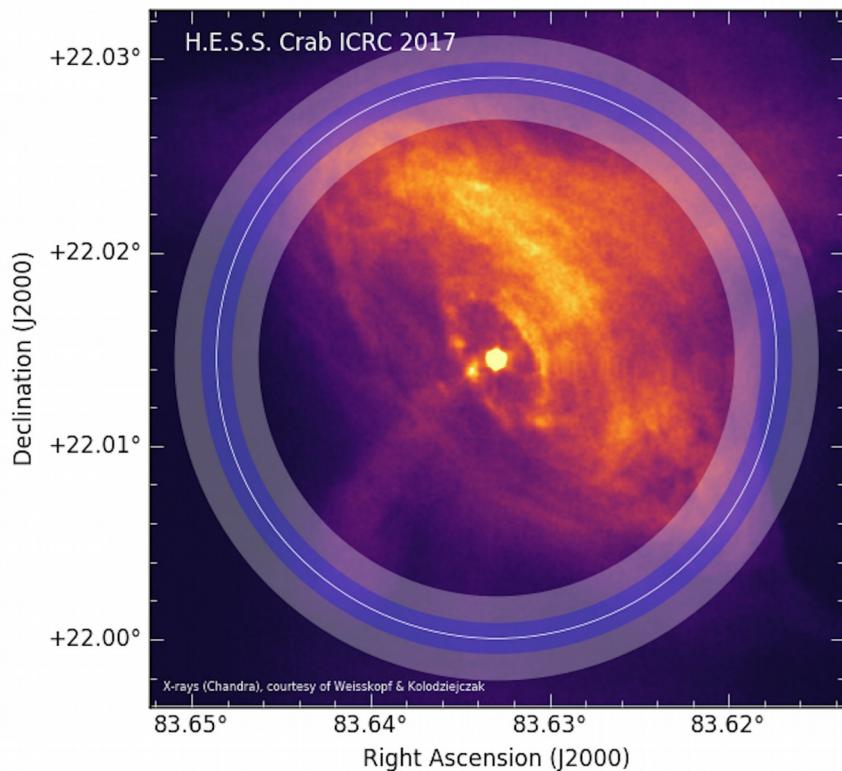


Classic Monte Carlo simulations



Run-wise simulations

An alternative: run-wise simulations

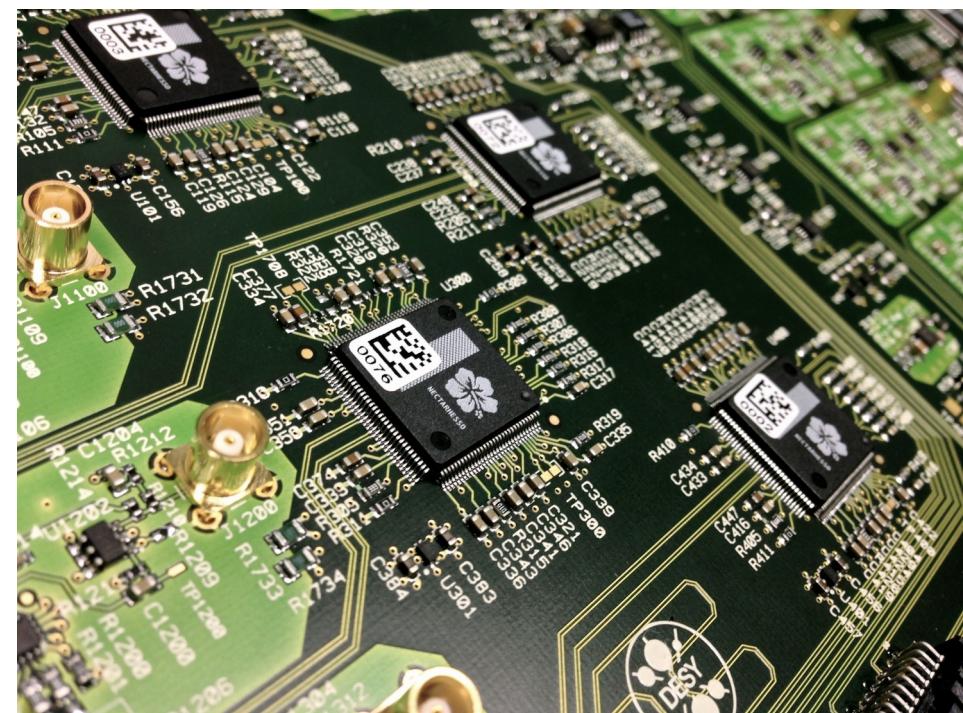
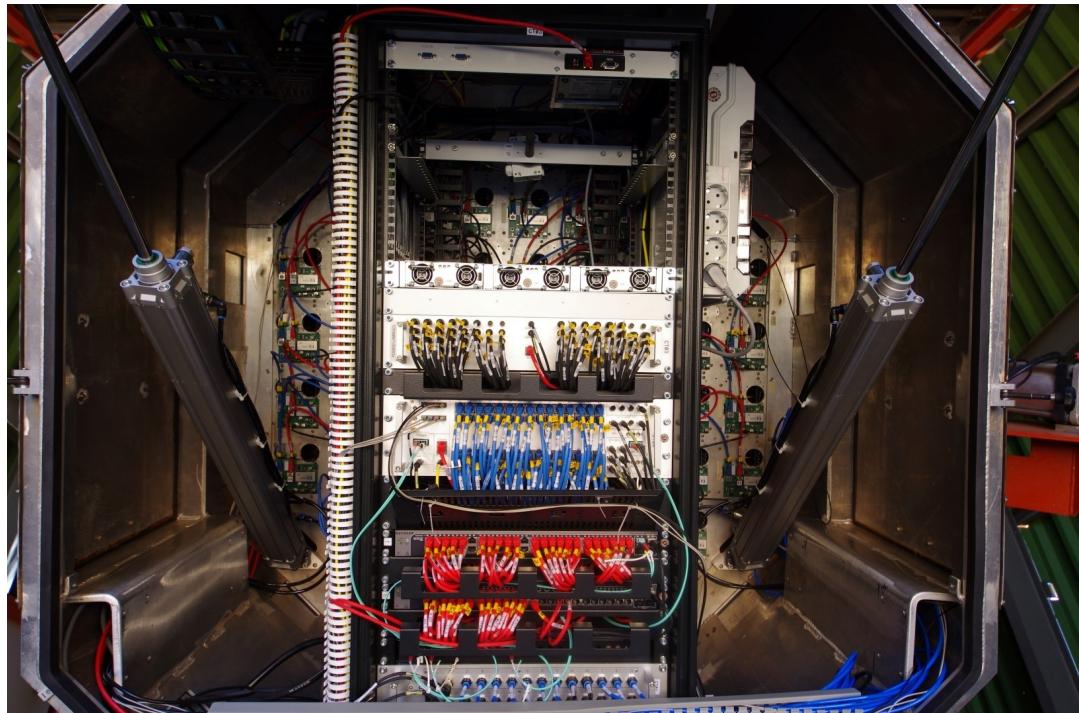


- PSF: from $\sim 3'$ to $\sim 25'' \rightarrow \sim 6 \times$ improvement
- Crab nebula is extended at VHE:
 $\sigma \sim 52''$ (assuming a Gaussian shape)

Holler et al. (for the H.E.S.S. collaboration), ICRC (2017)

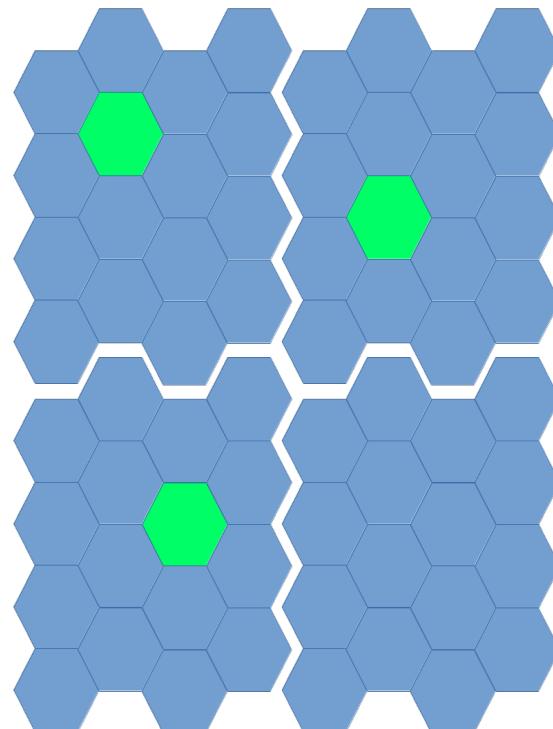
H.E.S.S. IU

- Upgrade of H.E.S.S. I cameras → reduced dead-time, increased stereo trigger overlap with CT5



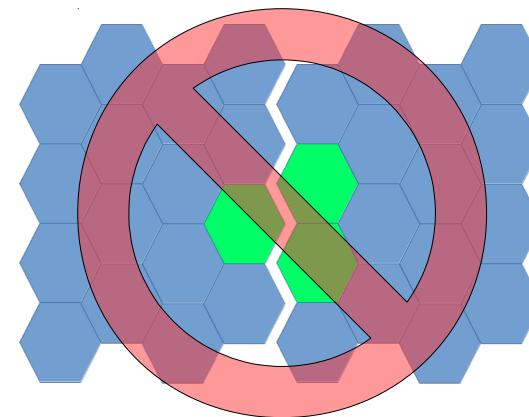
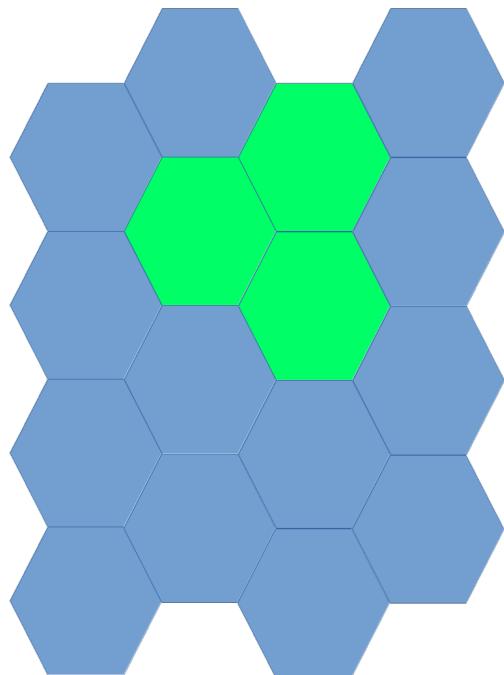
H.E.S.S. IU: effect of topological trigger

- H.E.S.S. I: Standard N-majority trigger
 - Fire a trigger if M pixels $\geq N$ p.e. within a sector (= group of 64 PMTs)
 - Operation point: 3 pixels ≥ 4 p.e.



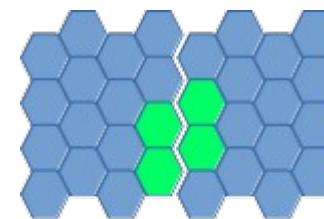
H.E.S.S. IU: effect of topological trigger

- H.E.S.S. IU: additional supported trigger schemes
 - Next-neighbour (NN): cluster of M pixels $\geq N$ p.e. in drawer

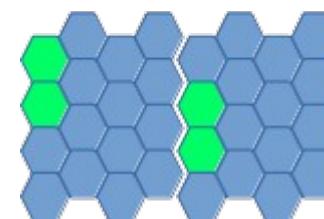


H.E.S.S. IU: effect of topological trigger

- Different NN implementation in MC simulations:
 - “True” NN: ideal case where drawer boundaries do not matter
 - “HESS1U” NN: only look for clusters fully enclosed in a drawer
 - “Hybrid” NN: compromise, implementable with small change in firmware:
 - For “3NN Hybrid”:
 - Score of 2 for 3NN within drawer
 - Score of 1 for 2NN at edge of drawer
 - **Trigger if $\text{sum(score within sector)} \geq 2$**
 - For “4NN Hybrid”:
 - Score of 4 for 4NN within drawer
 - Score of 3 for 3NN within drawer
 - Score of 1 for 2NN at edge of drawer
 - **Trigger if $\text{sum(score within sector)} \geq 4$**

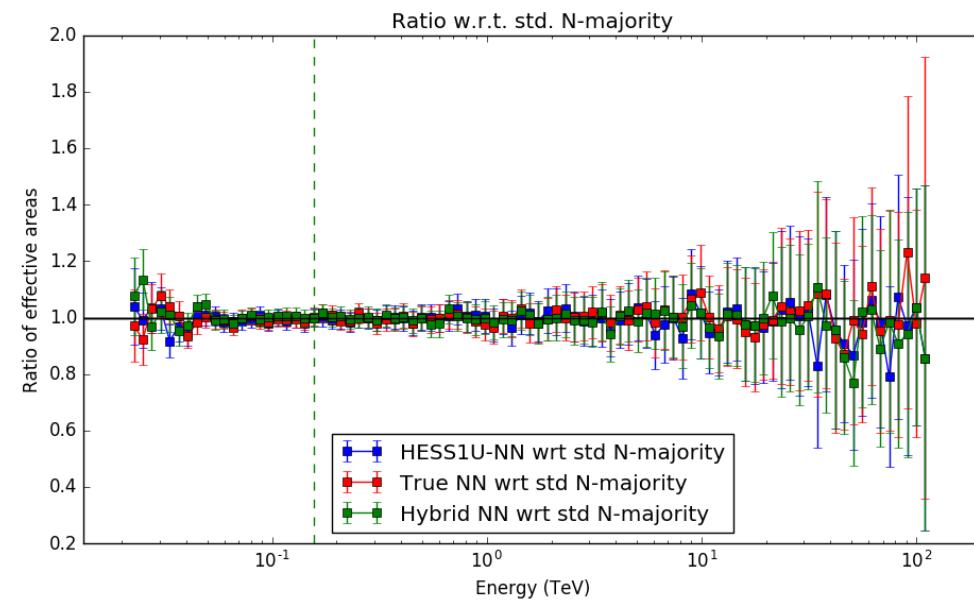
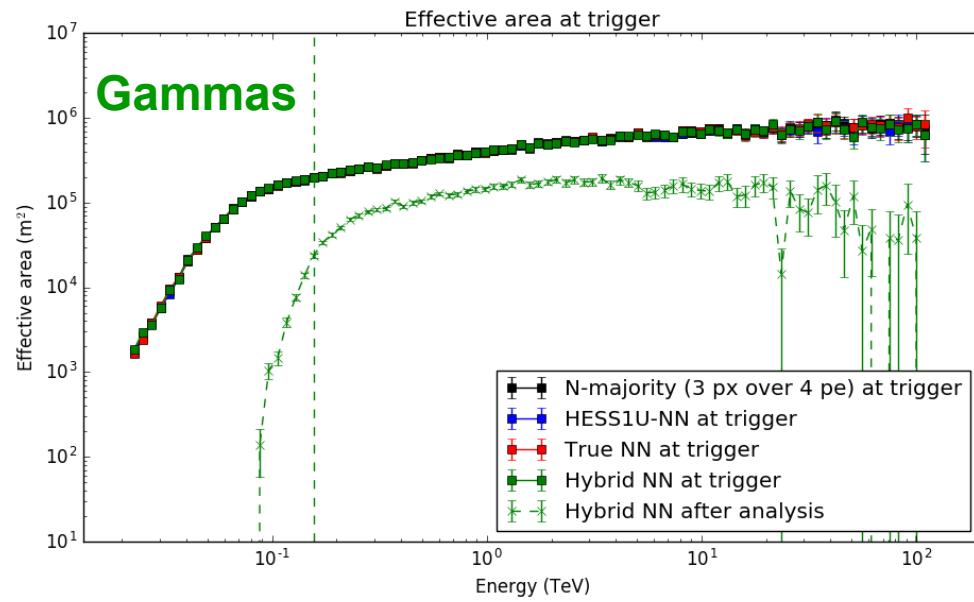


Accepted as
3NN Hybrid
:-)



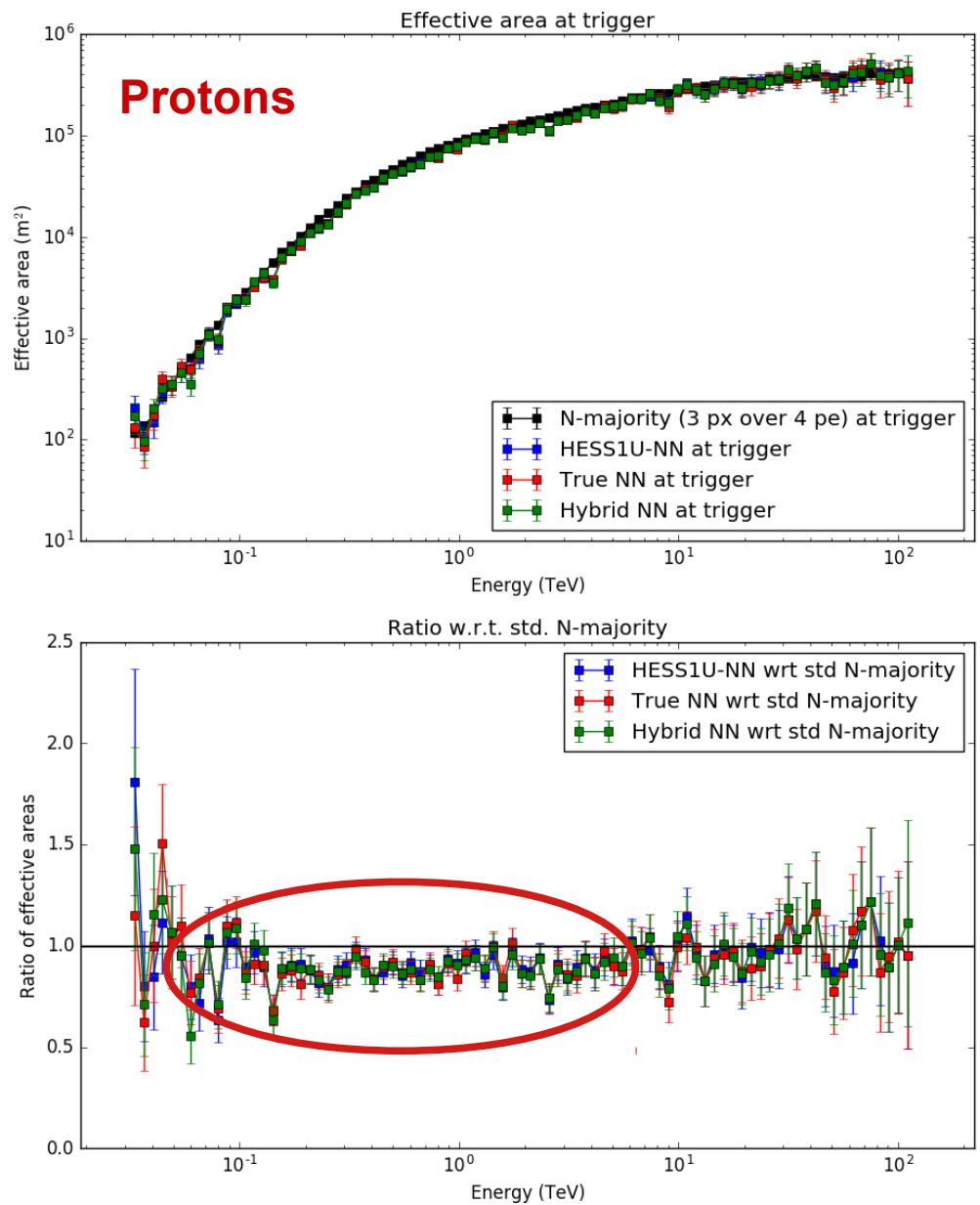
Also accepted as
3NN Hybrid
:-)

H.E.S.S. IU: effect of topological trigger

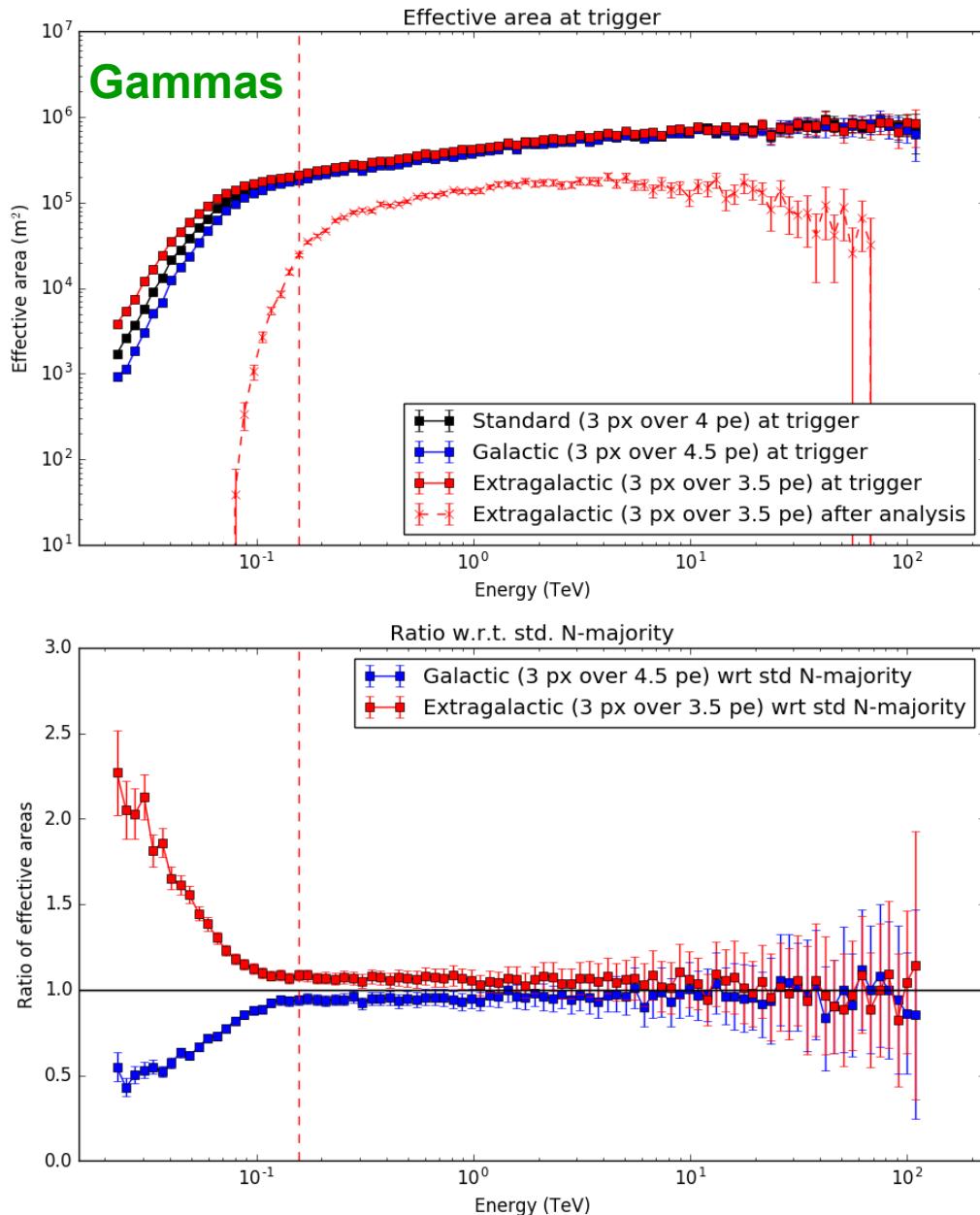


H.E.S.S. IU: effect of topological trigger

Could gain ~10% in purity
between 100 GeV and 1 TeV



H.E.S.S. IU: N-majority trigger



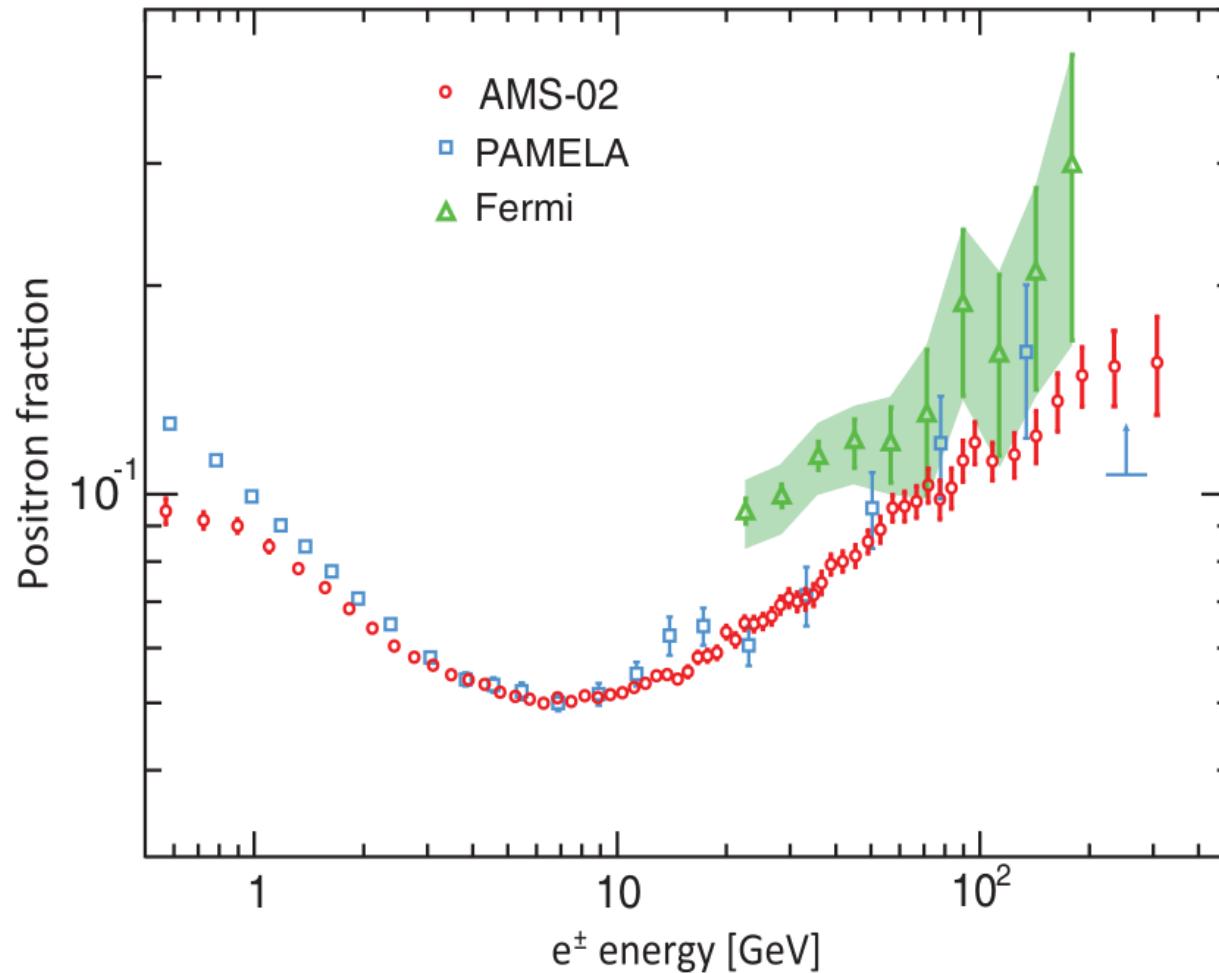
Different amplitude thresholds depending on NSB rate:

- Extragalactic (>3.5 p.e.)
NSB \sim 75 MHz
- Galactic (>4.5 p.e.)
NSB \sim 100 MHz
- Galactic “high NSB” (>5.5 p.e.)
NSB \sim 300 MHz

Outline

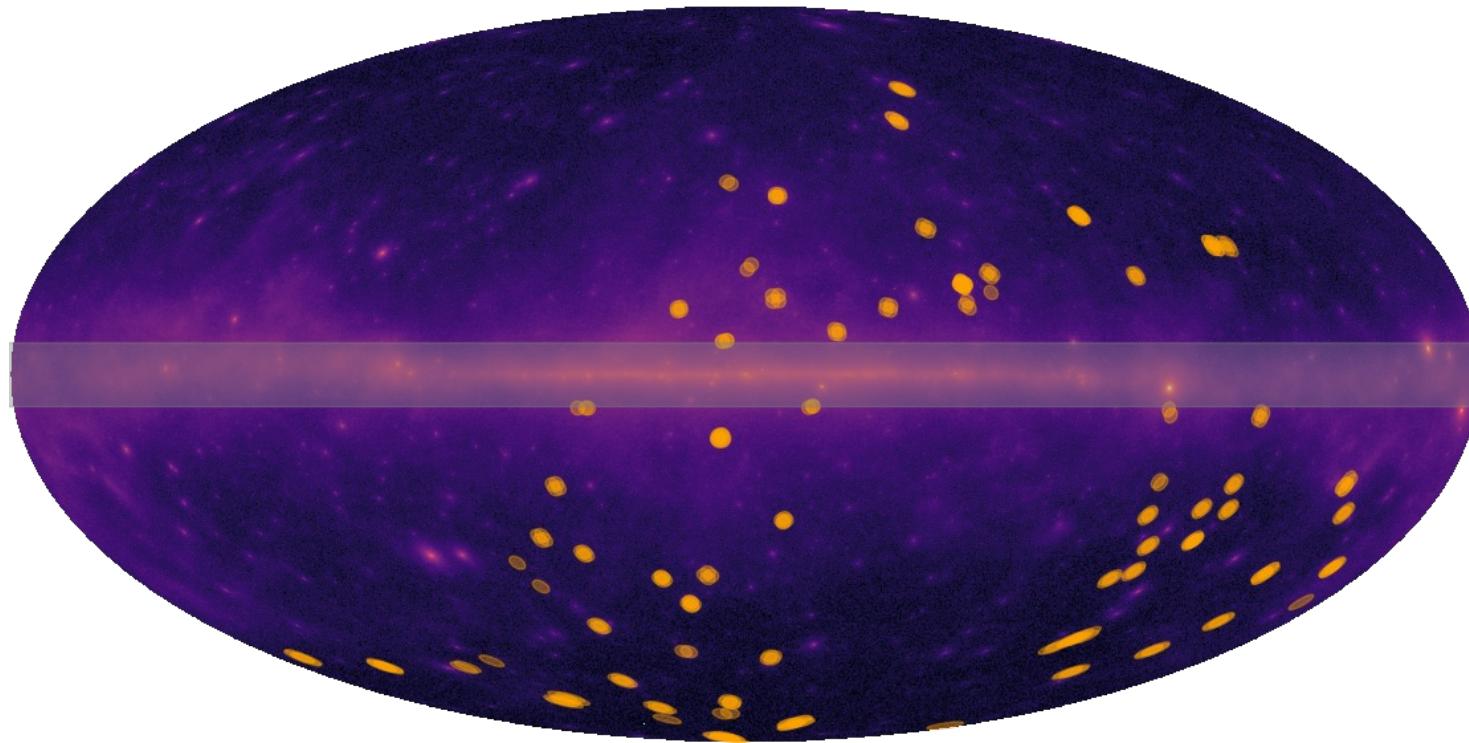
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Positron fraction



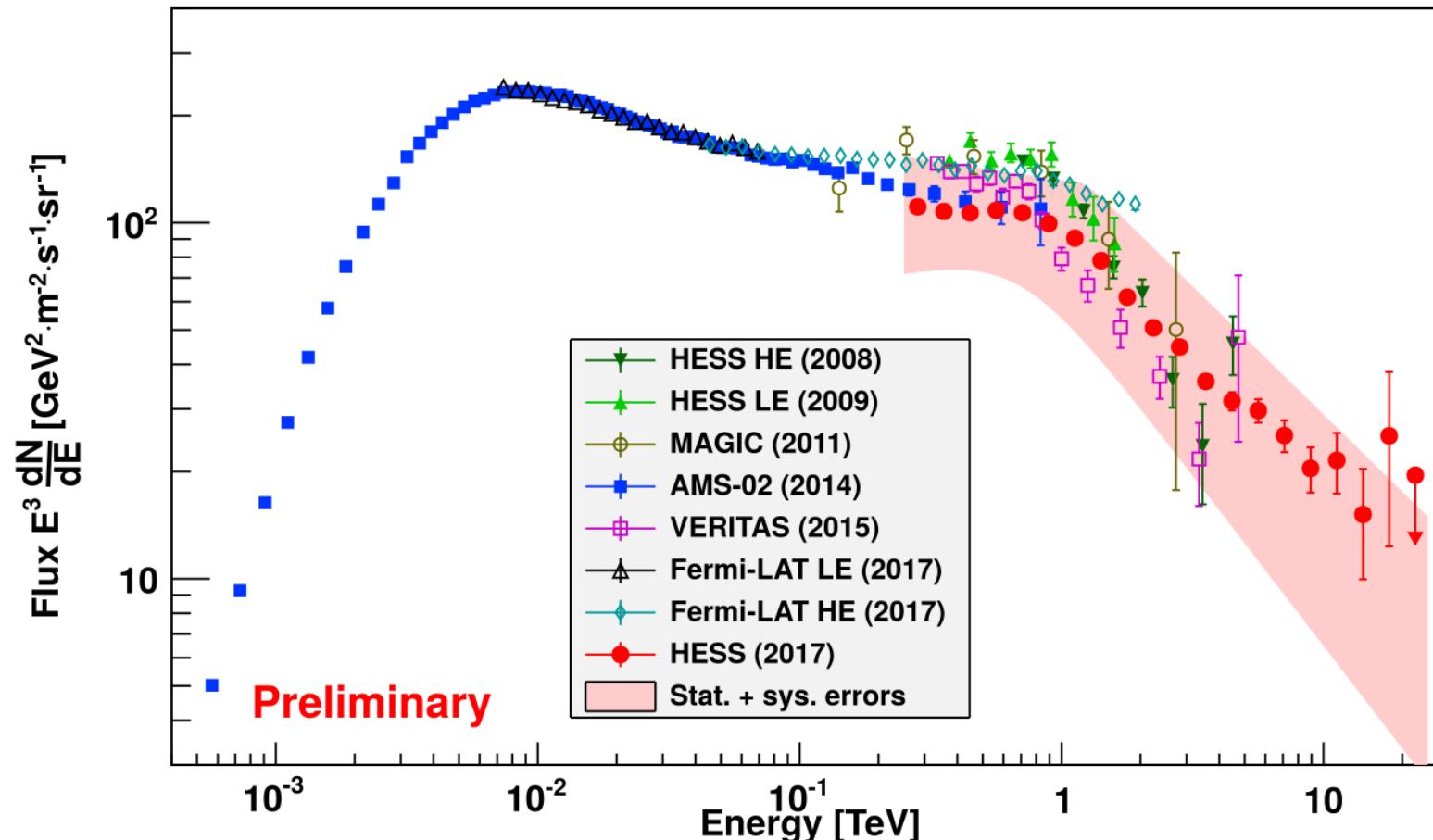
- Dark matter ?
- Primaries from pulsars ?
- Secondaries from supernova remnants ?

Data selection



- Observations at high Galactic latitude
- Extruded known astrophysical sources (AGN, ...)
- “Simply” apply *Model* reconstruction (de Naurois & Rolland, 2009)

Updated H.E.S.S. electron spectrum

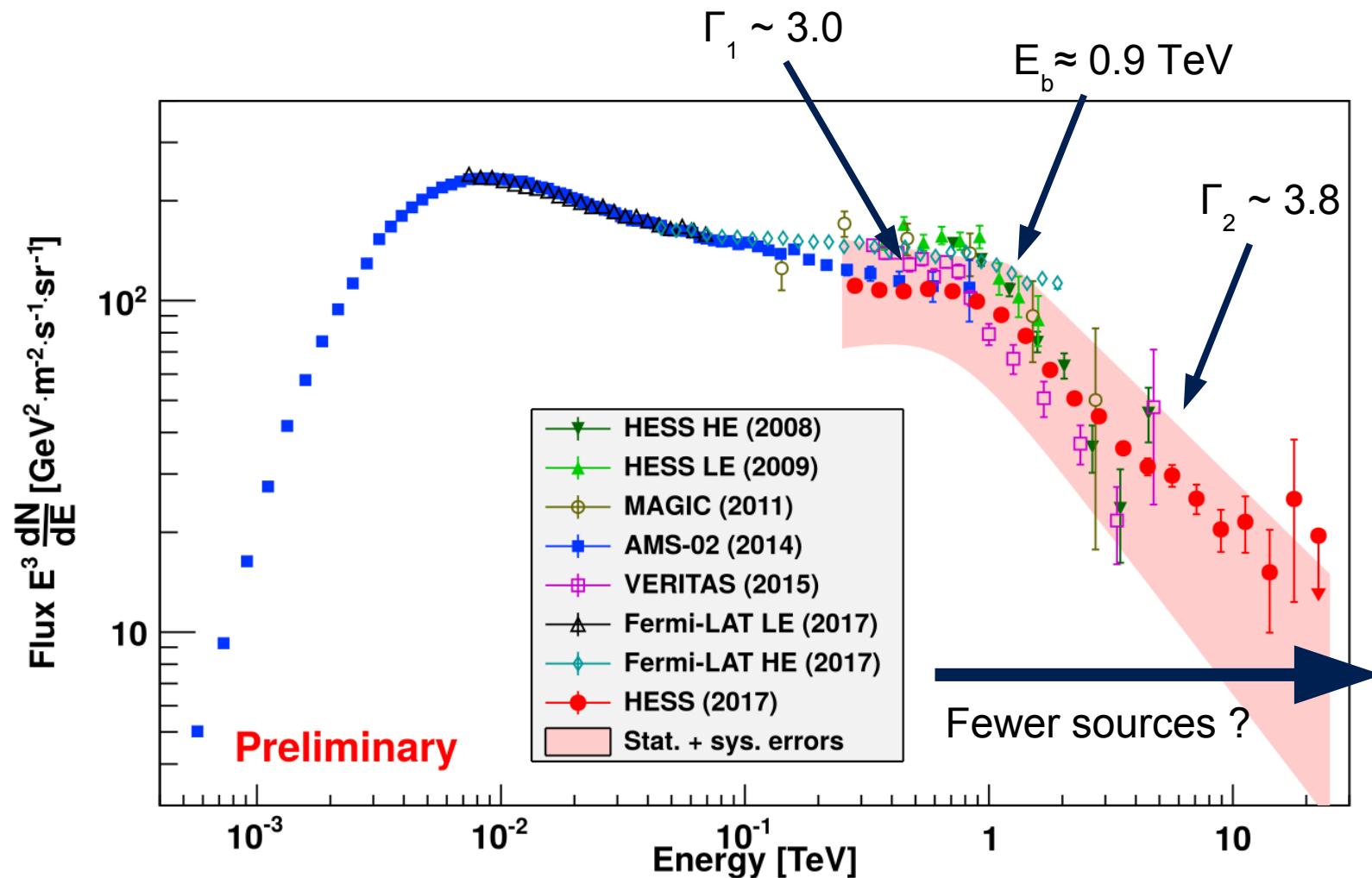


- Proton contamination evaluated to be $\sim 15\%$ @ 1 TeV

460,346,321 events (before cuts)
480,739 events (after cuts)

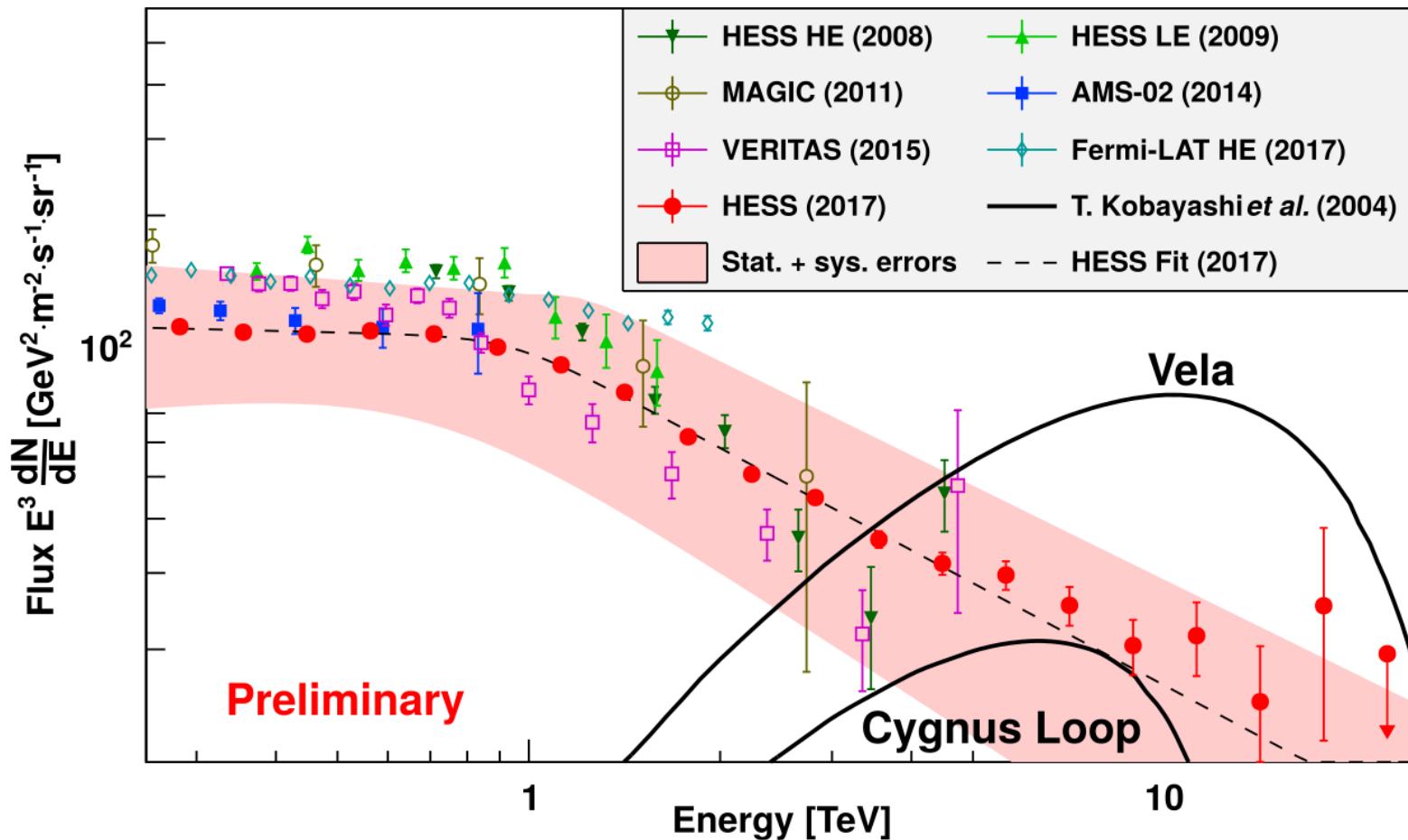
Kerszberg et al., ICRC 2017

Updated H.E.S.S. electron spectrum



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Updated H.E.S.S. electron spectrum



Kerszberg et al., ICRC 2017

Outline

- Brief CV
- Study of high energy emission from AGN
- Characterising the instrument performances
- Cosmic e-/e⁺ spectrum
- **Conclusions & prospects**

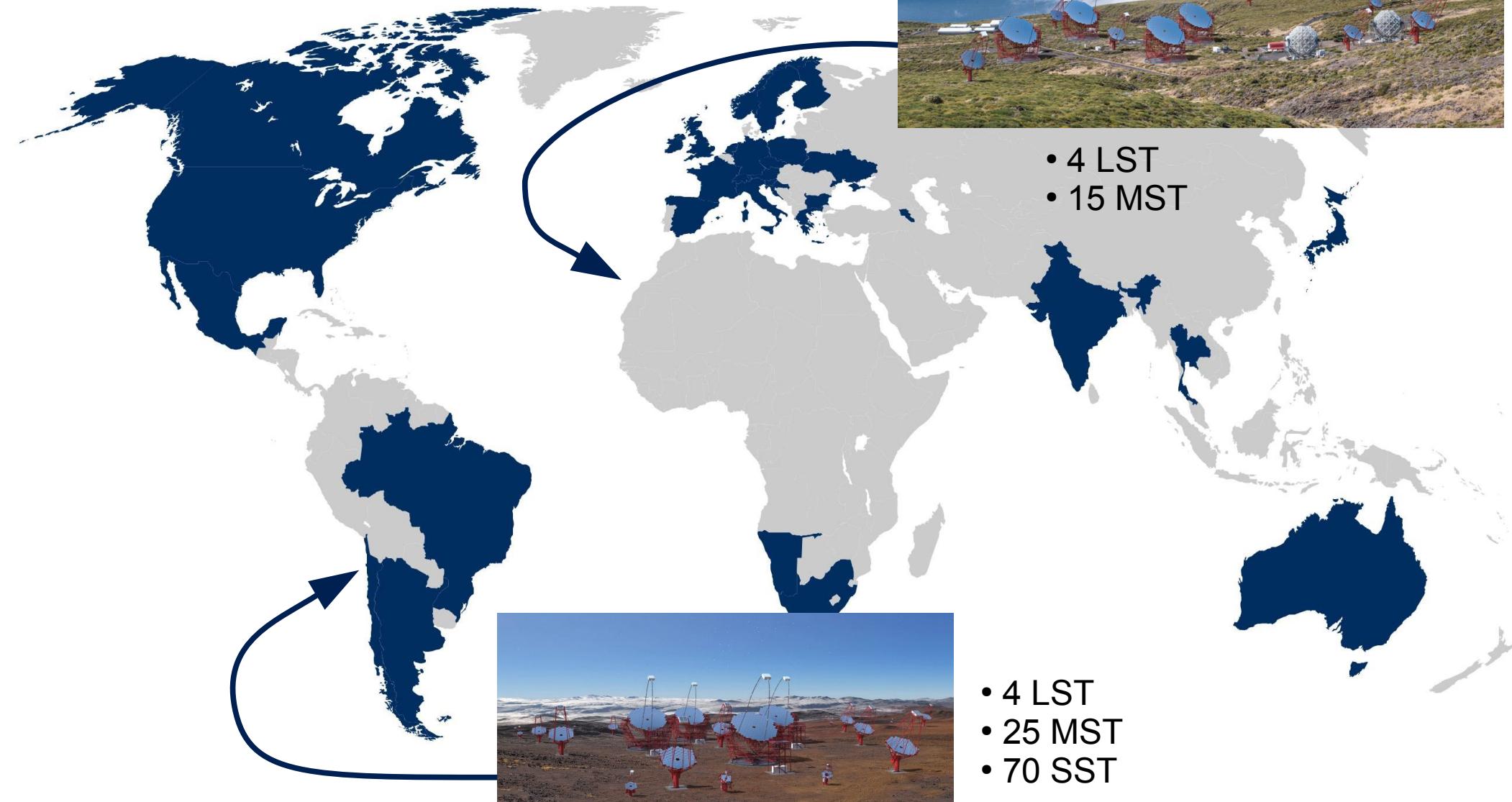
Conclusions & prospects

- High-energy astrophysics
 - Fascinating domain (of course !)
 - At the boundary between particle physics & astronomy
- What next ?
 - Where in the source does the VHE emission come from ?
 - How are particles accelerated to such high energies ?
 - What is the nature of HE emission ?
- Need more data !

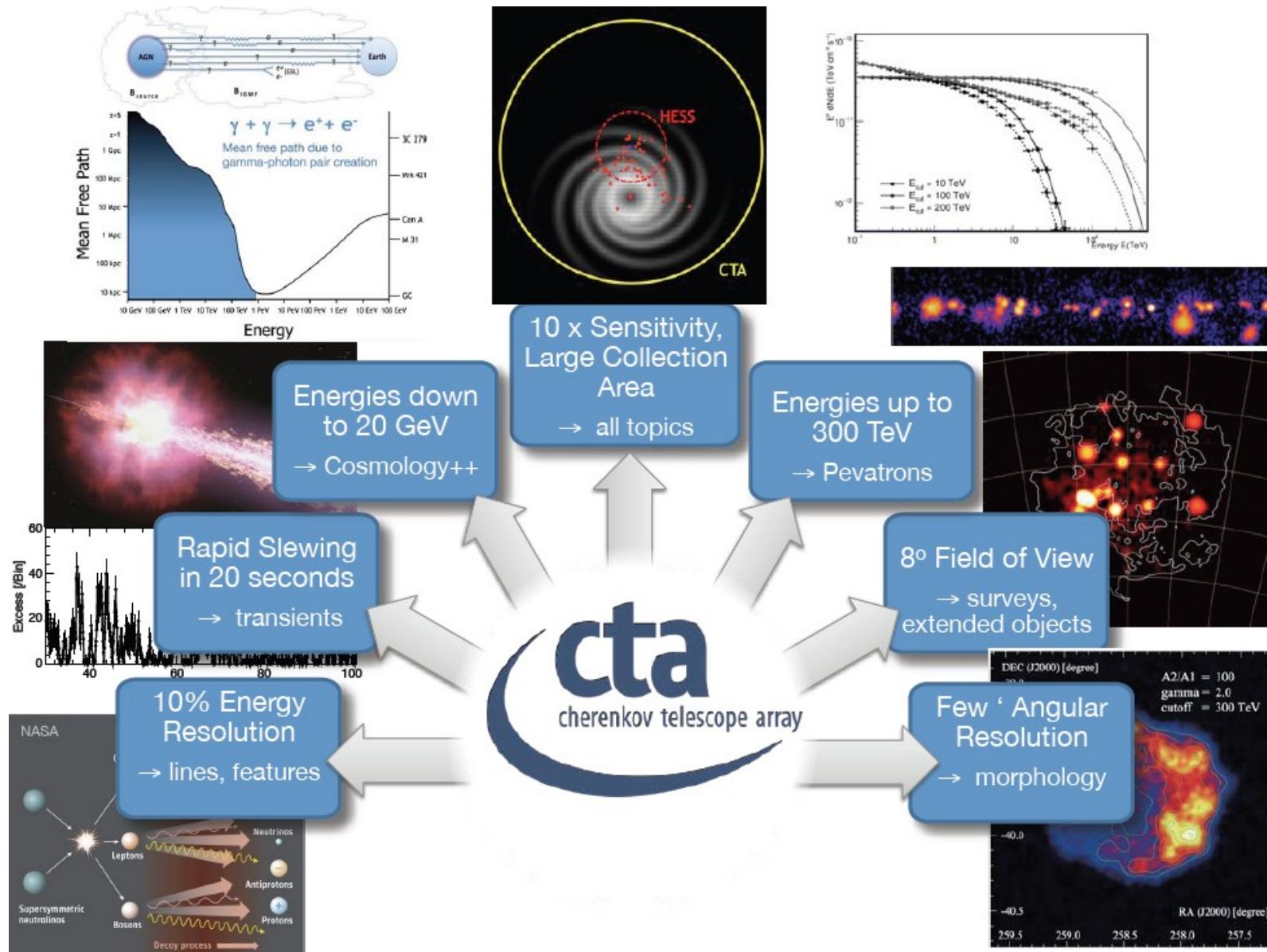
Conclusions & prospects

- High-energy astrophysics
 - Fascinating domain (of course !)
 - At the boundary between particle physics & astronomy
- What next ?
 - Where in the source does the VHE emission come from ? → **Population studies !**
 - How are particles accelerated to such high energies ? → **Progress on theory !**
 - What is the nature of HE emission ? → **Multi-messenger connection, transient studies !**
- Need more data !
→ **Next generation of instruments**

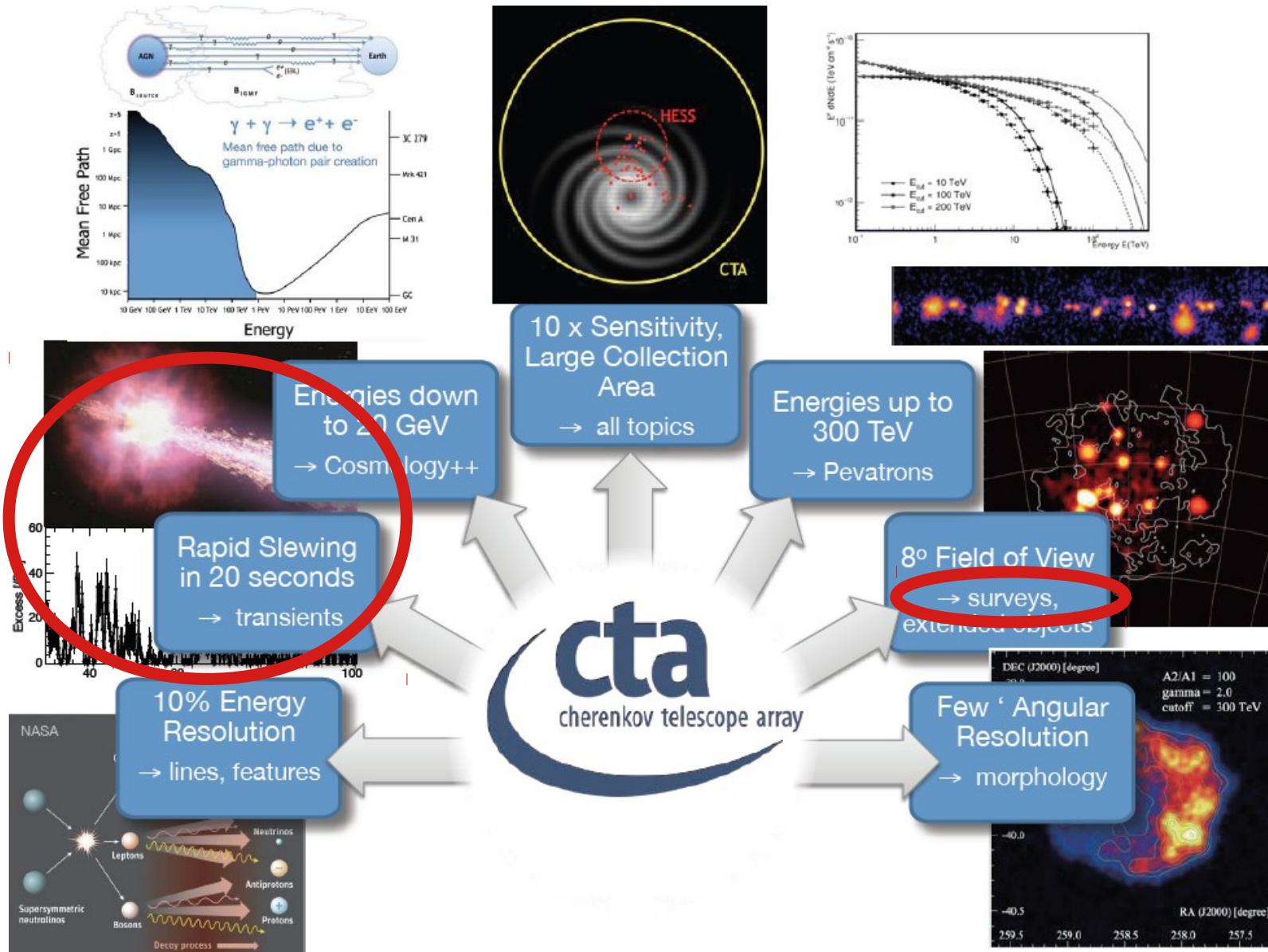
Cherenkov Telescope Array



Cherenkov Telescope Array

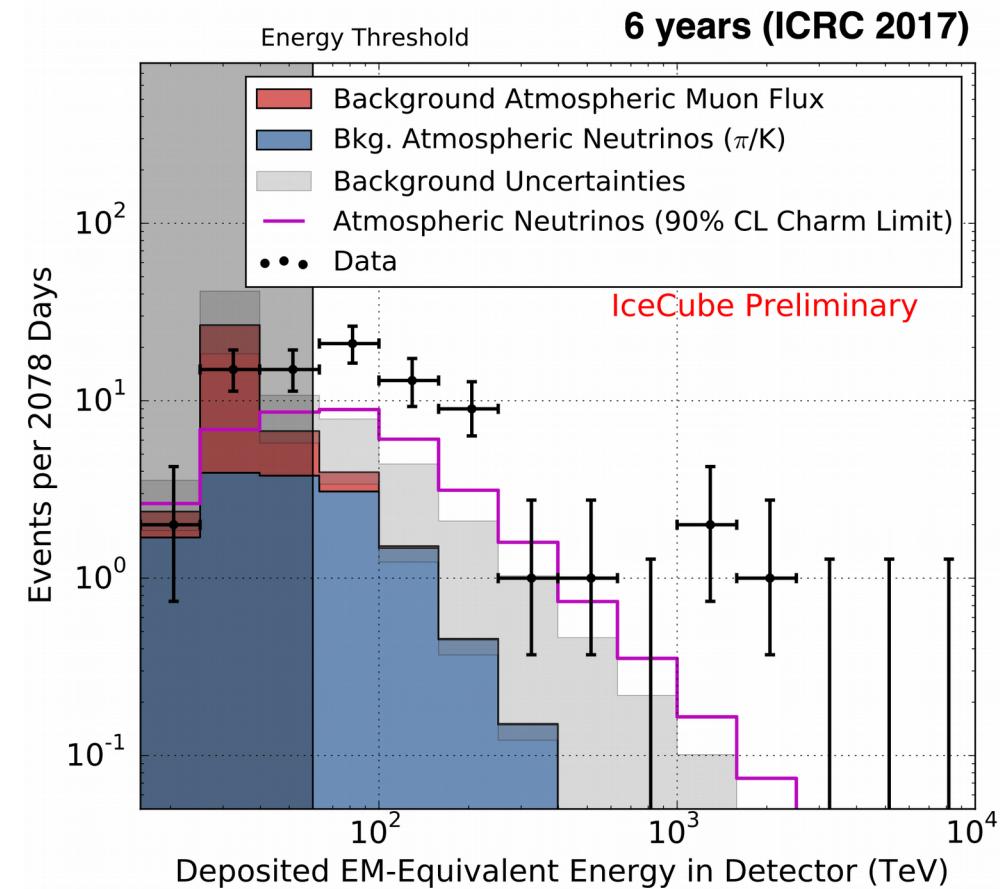
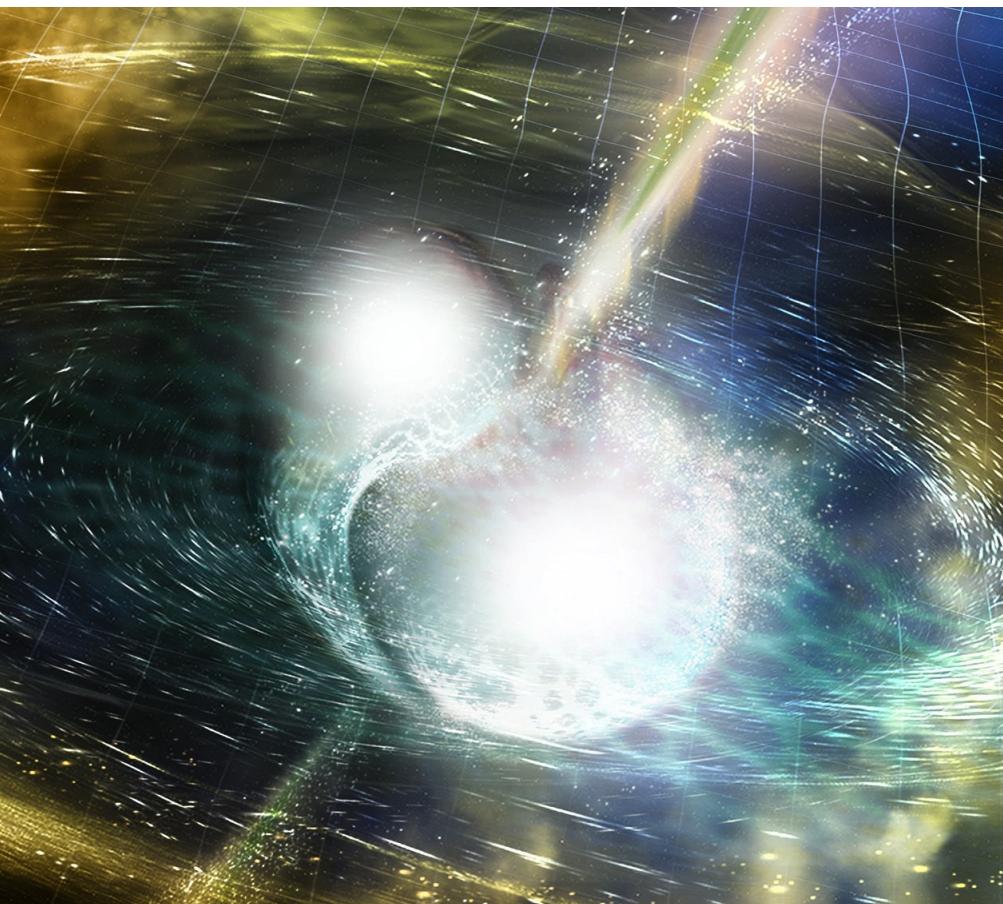


Cherenkov Telescope Array



The multi-messenger era

- Recent openings
 - Towards a global picture ? Photons, neutrinos, gravitational waves, cosmic rays
 - (Near-)real time alerts



Abbott et al., *ApJ* (2017)



Thanks !

Merci !