cherenkov telescope array

CTA's perspectives on AGN studies and the EBL

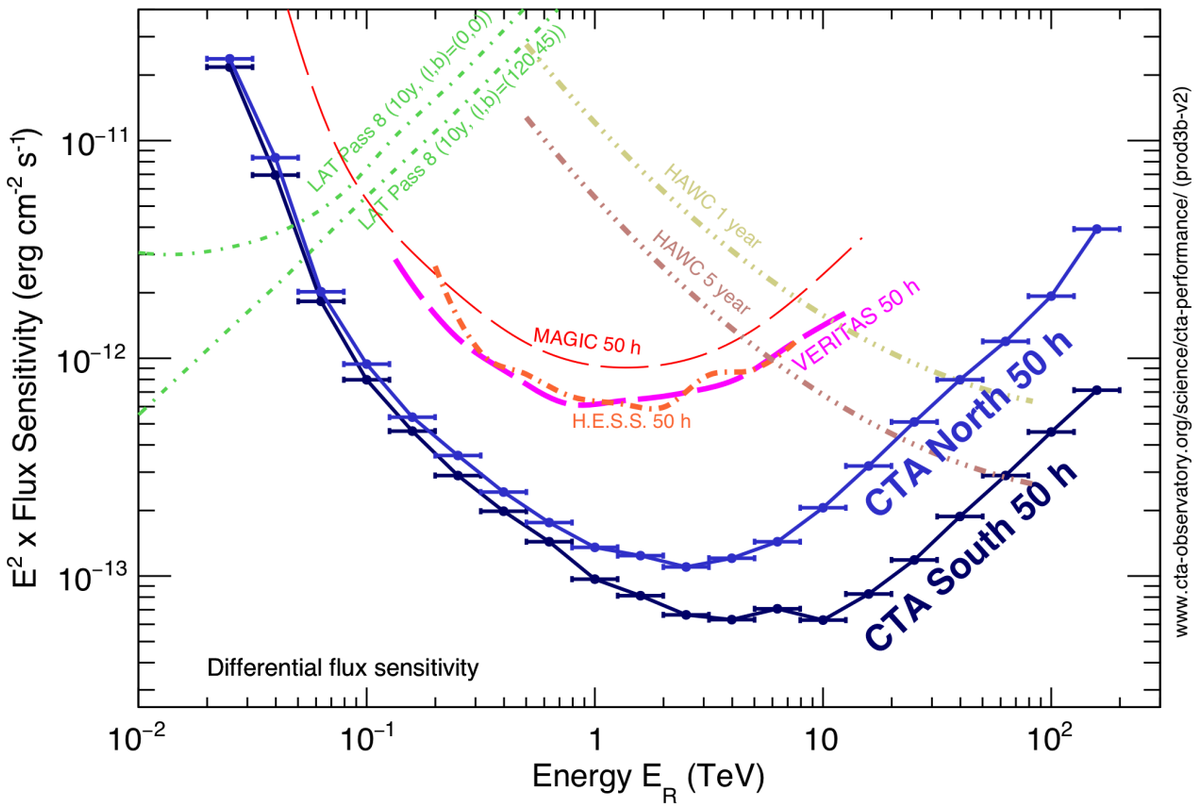
Daniel Mazin, ICRR University of Tokyo and MPP Munich

for the CTA consortium

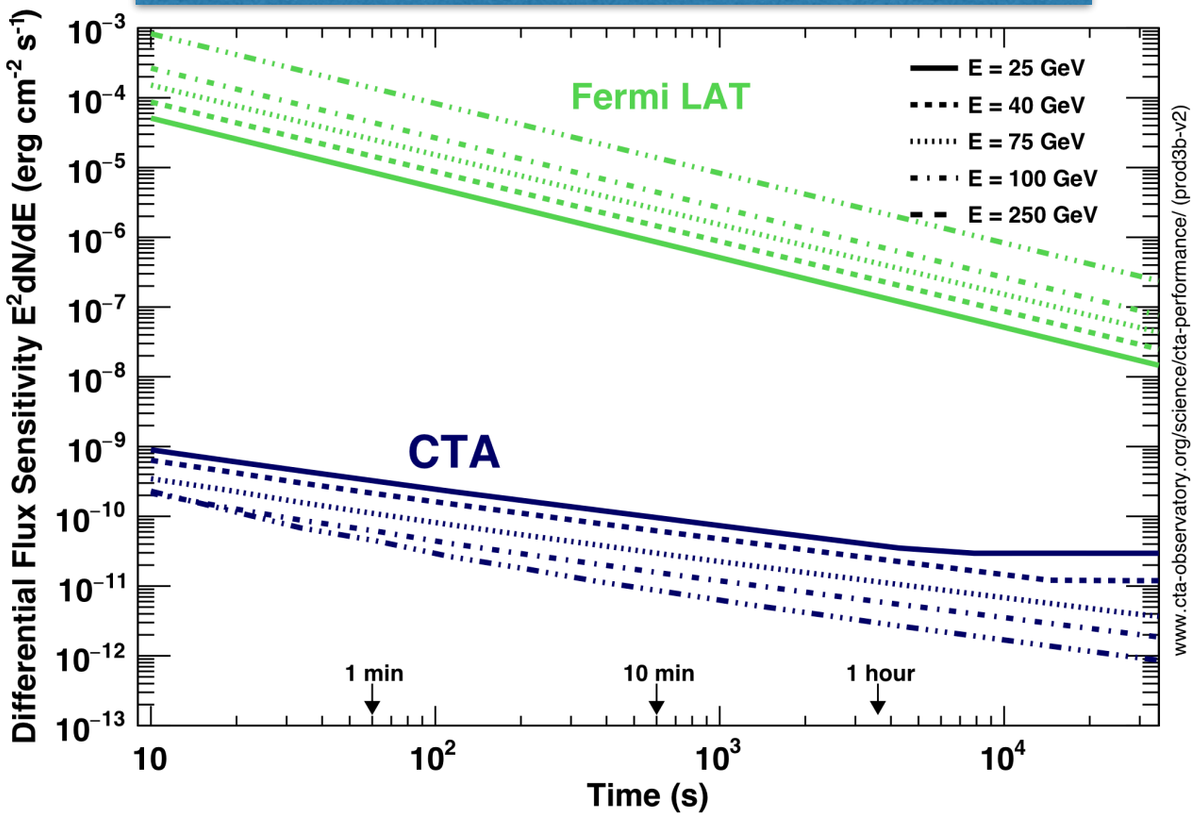
CTA performance

cherenkov telescope array

flux sensitivity for 50h exposure



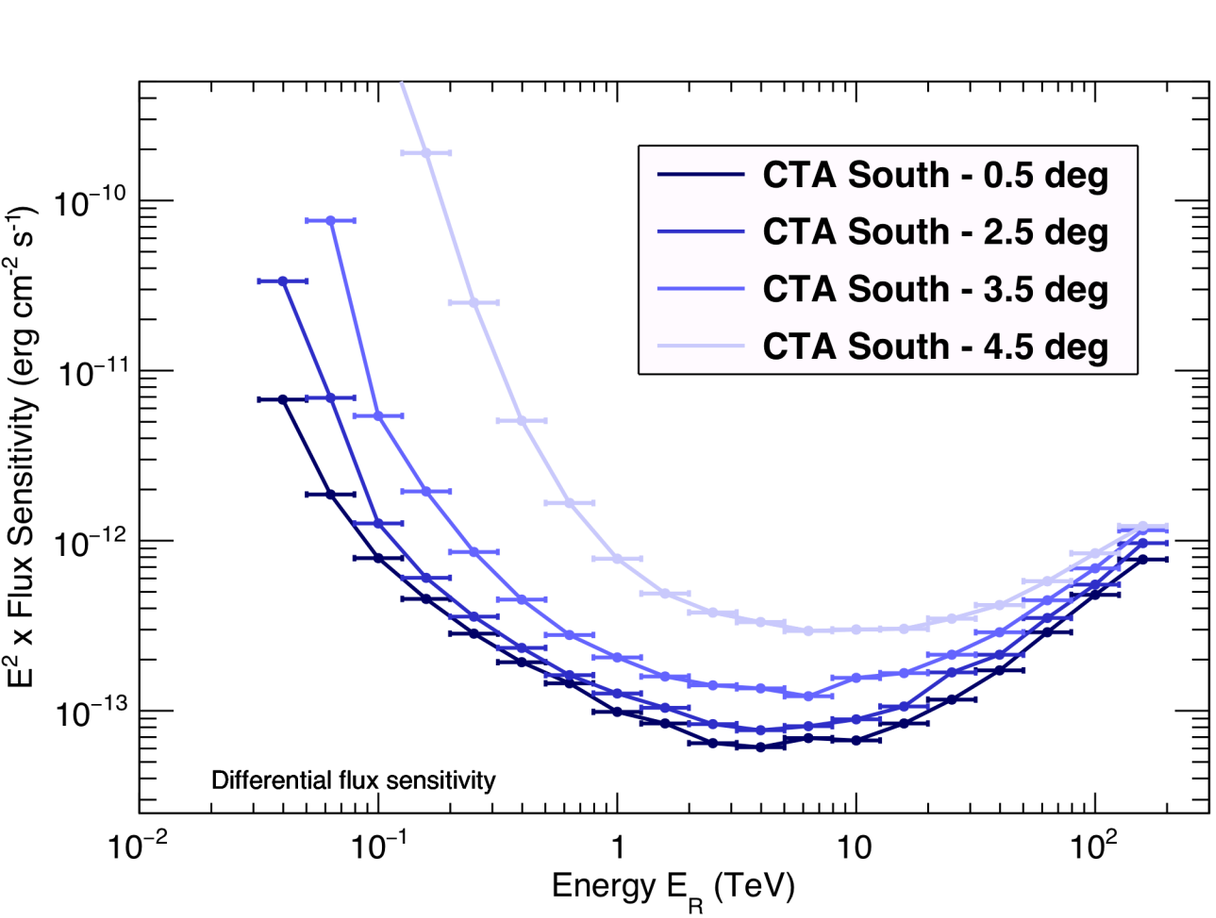
sensitivity versus exposure time



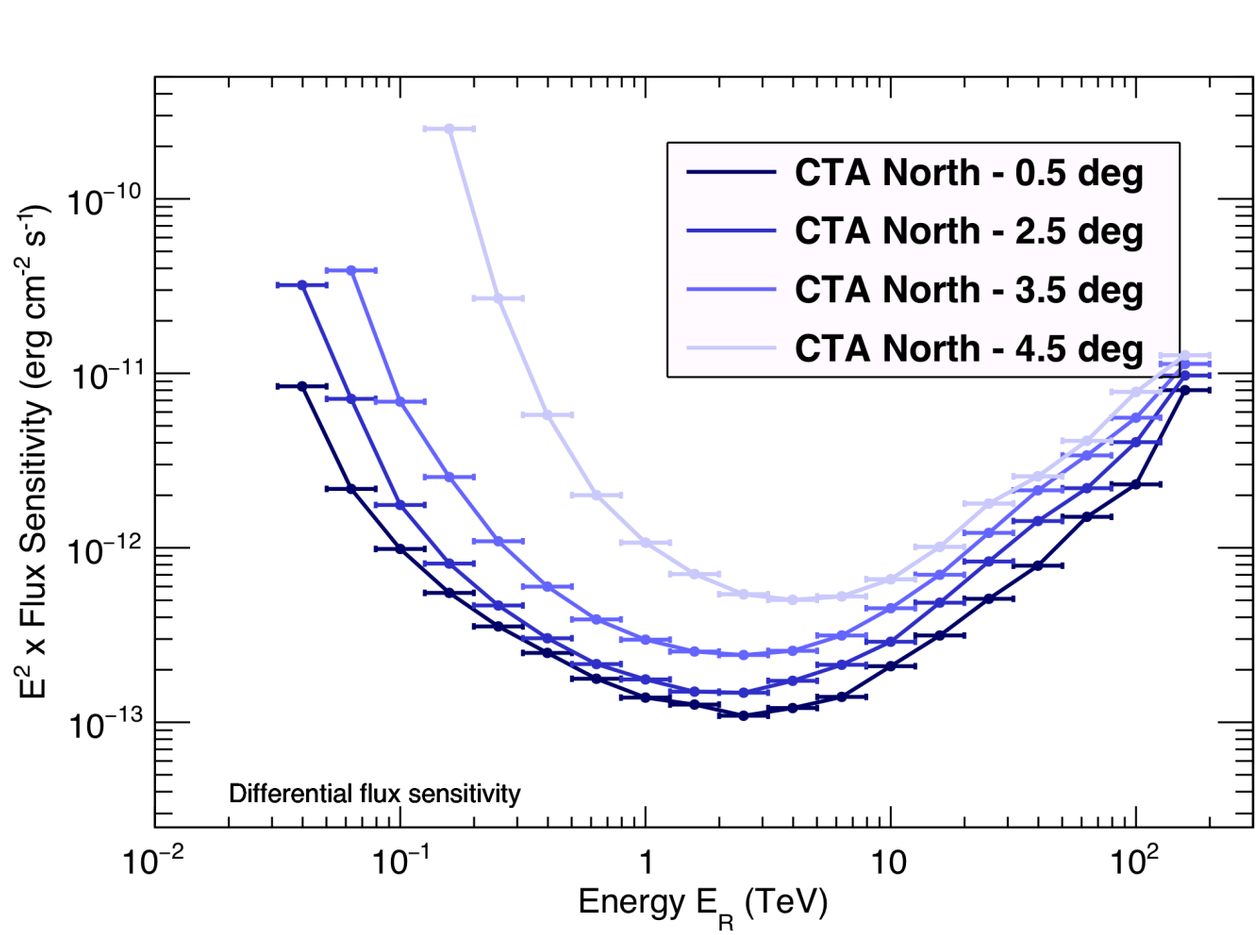
CTA has a survey capability

cherenkov telescope array

Off-axis performance: CTA South

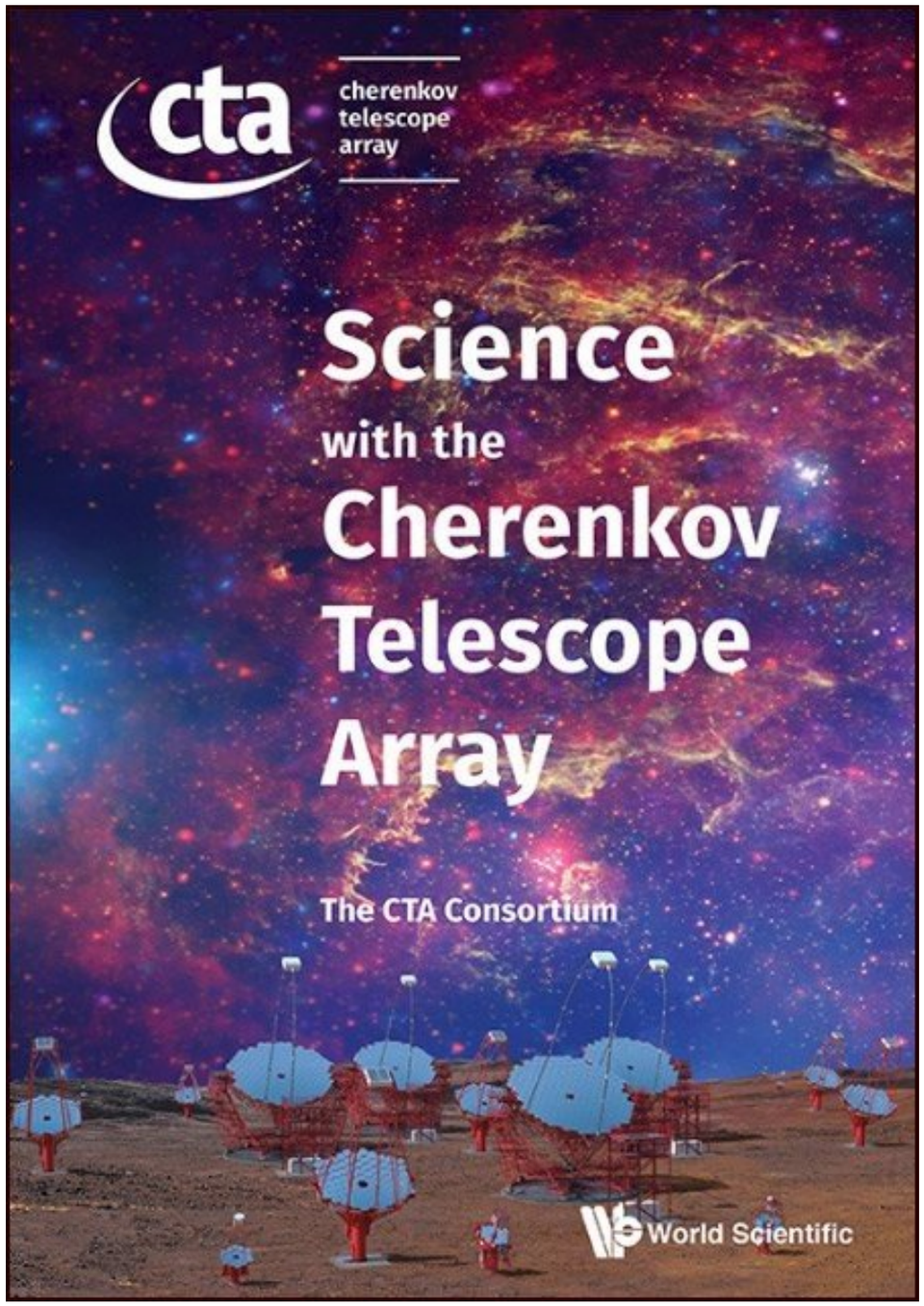


Off-axis performance: CTA North



Key Science Projects

- Submitted to Project Management on May 1, 2015.
- Published: World Scientific open-access Book (213 pages), https://doi.org/10.1142/10986 arXiv:1709.07997
- Include the following KSPs:
  - **AGN Survey (Zech++)**
  - **Transients (Inoue++)**
  - **Extragalactic Survey (Mazin++)**
  - Star forming Galaxies (shared with the fundamental group, Zandanel++)
  - Cluster of Galaxies (shared with Galactic group, Ohm++)



Key Science Questions

- What is the Gamma-Ray Luminosity Function?
- Does the blazar sequence (the synchrotron and inverse Compton (IC) peak photon energies decrease as the bolometric luminosity increases) hold?
- Is there a strong population of hard spectra extreme blazars?
- Are there VHE source classes other than blazars and radio galaxies?
- Are there dark accelerators?
- Is there a correlation with UHECR and HE neutrino events maps?
- What is the origin and strength of the diffuse γ-ray background?
- Large scale anisotropies (related to dark matter distribution?)

Key Science Projects

cherenkov telescope array

Full-array observations proposed in extragalactic KSPs

. Extragalactic survey: ¼ of the sky	~400h (S) + ~600h (N)
. AGN – high-quality spectra: ~40 targets	~150h (S) + ~200h (N)
– high-quality morphology: Cen A and M 87	~150h (S) + ~100h (N)
. AGN – long-term monitoring: ~15 targets with 30' per week when observable	~400h (S) + ~1100h (N)
. AGN – flares: full array follow-up observing time	~500h (S) + ~700h (N)

→ exploiting **MWL**, **MM**, and **internal** triggers *#internal = sub-array snapshots*

Which targets, which fields, what science return?

. Extrapolations to CTA of current populations probed in the GeV, X-ray, and radio bands

. Development of MWL observing programs, particularly relevant for long-term monitoring and flares, and to measure the distances of best extragalactic TeV candidates

. Development of Consortium analysis tools, in particular to measure:
- intrinsic spectra and intervening absorption features → micro jet-physics and gamma-ray cosmology
- flux and spectral variations as a function of time → macro and micro jet-physics

slide from J Biteau

Population Study

4LAC blazars

. Preliminary release of the 4LAC: AGN in 4FGL, including redshifts and SED-based classification

. Used shortly to redo the work done with the 3FHL

. Note: to fully account for EBL absorption, final analysis for Consortium publication will be based on 4FGL spectral points

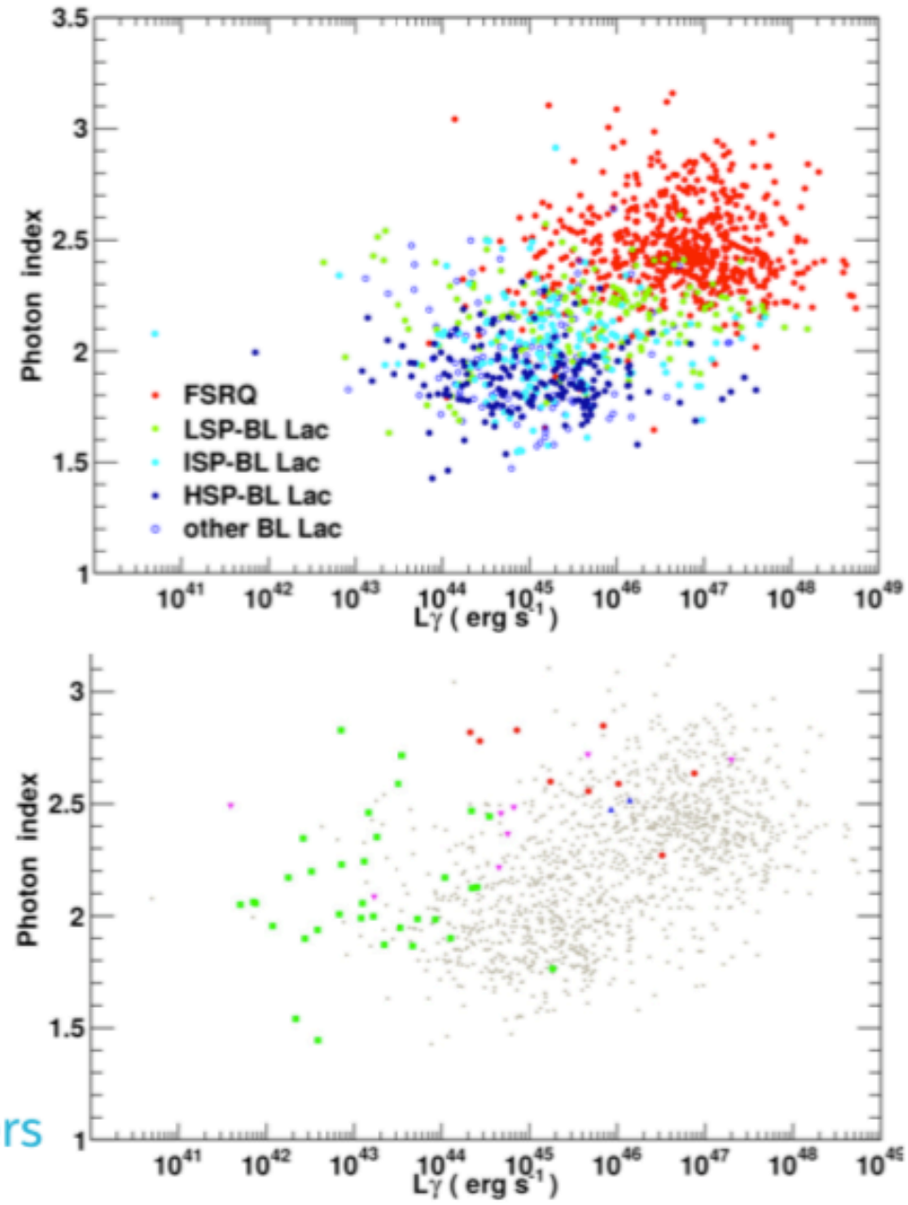
Other AGN and Blazars

. Efforts on populations behind the curtain (cf. CTA symposium):
  . B. Balmaverde et al.: HBLs from the Te-REX radio/X-ray sample
  . G. Chiaro et al. (Fermi-LAT): TeV candidates among LAT unclassified blazars
  . E. Torresi et al.: spectrum and variability of TeV radio-galaxies
  . P. Romano et al.: Modeling of narrow-line Seyfert 1 galaxies

. More efforts welcome in coordination with task force

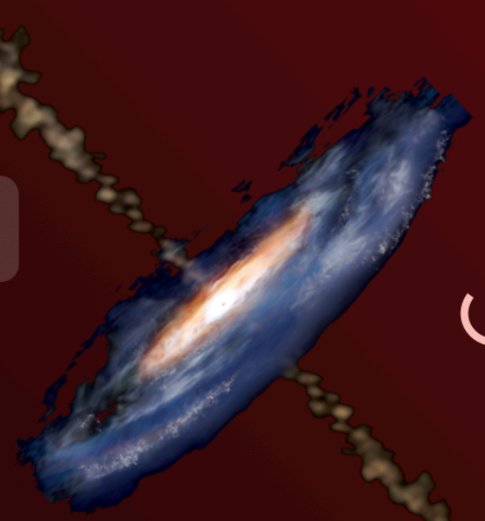
Towards TeV AGN luminosity functions

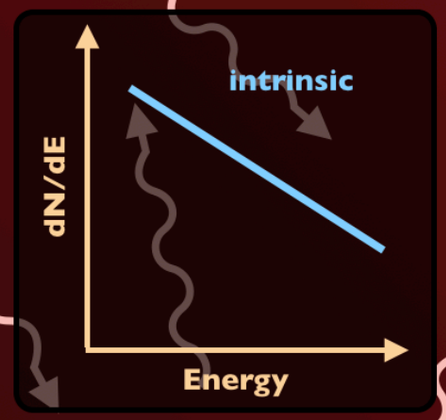
. Unbiased measurement with variability: observation strategy matters



slide from J Biteau

AGN



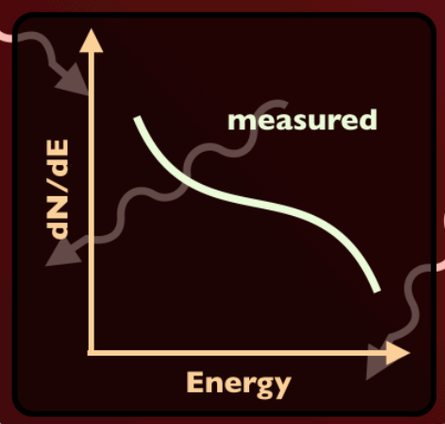


Stars and **Dust**
in Galaxies

HE/VHE ϒ-Rays

UV/O/IR
Photons

e-
e+



$$E_\gamma E_{\mathrm{EBL}} \approx 4(m_e c^2)^2 \approx 1\,\mathrm{MeV}^2$$
$$E_{\mathrm{EBL}} \sim \mathrm{eV} \rightarrow E_\gamma \sim \mathrm{TeV}$$

Nikishov (1962), Jelley (1966), Gould & Schreder (1966)

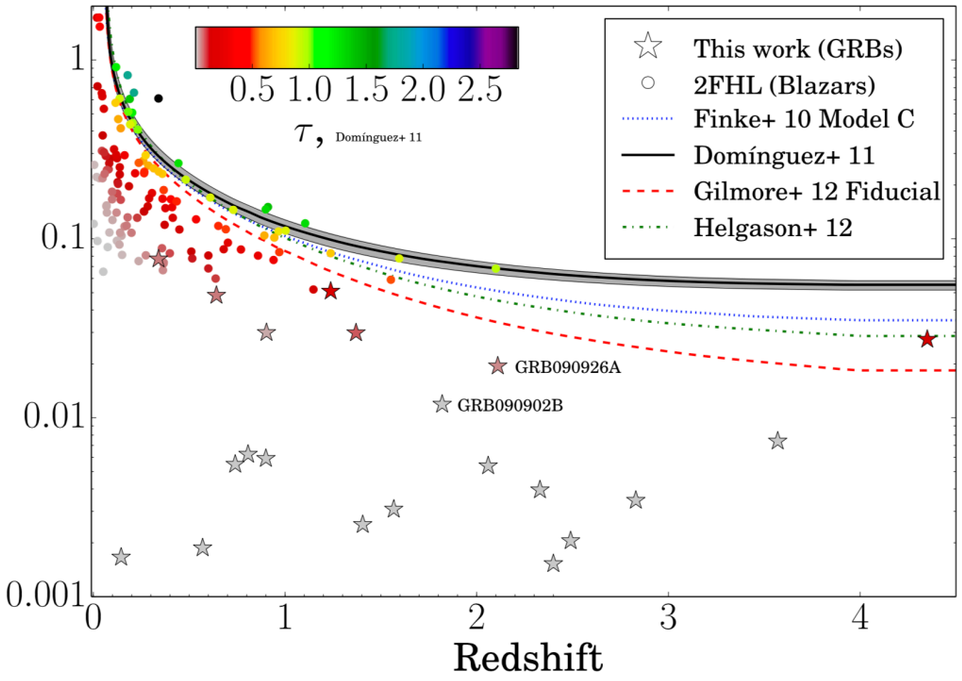
slide from M Raue

Extragalactic Background Light

cherenkov telescope array

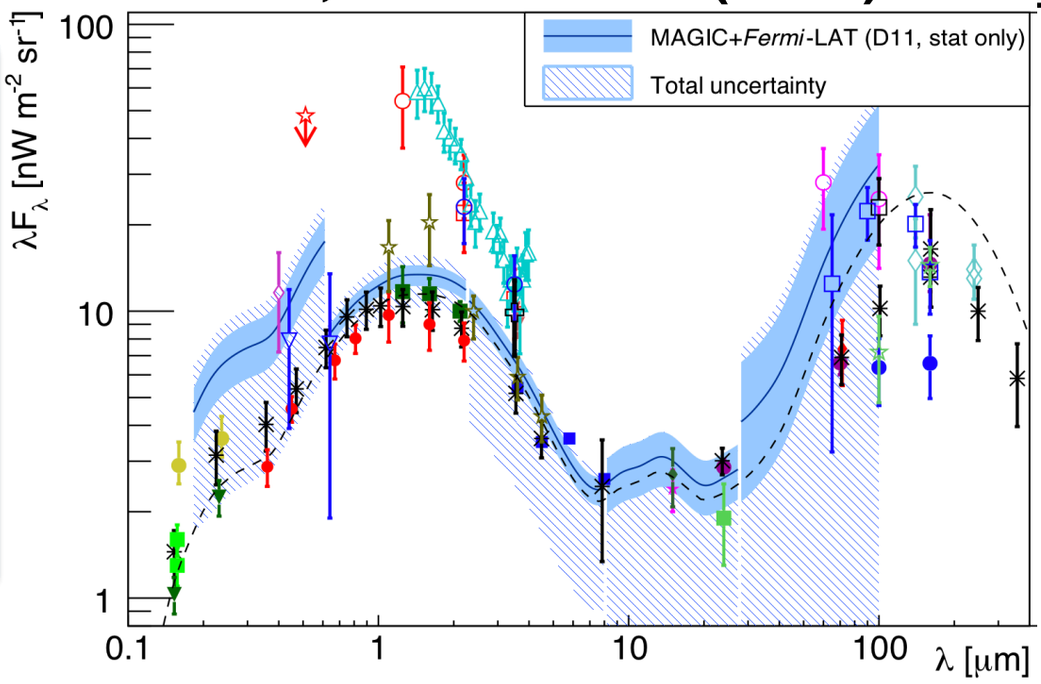
γ-ray horizon

Desai et al., ApJ 850 (2017) 73



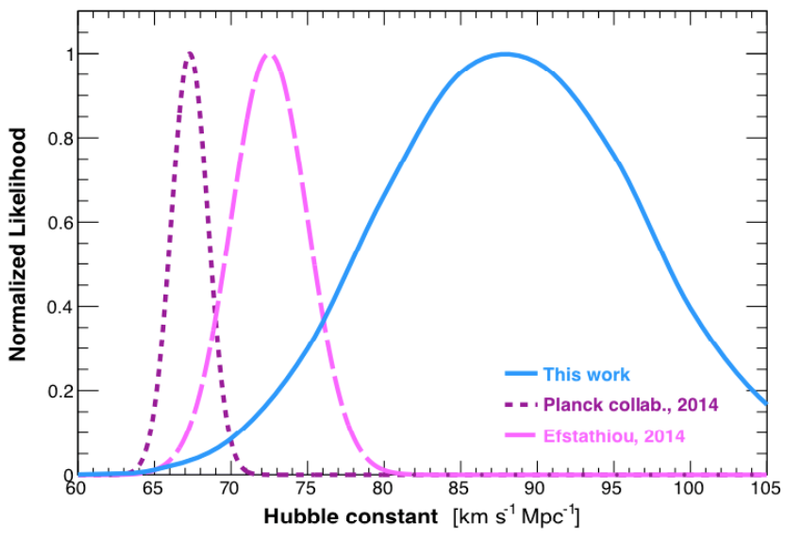
EBL density at z=0

MAGIC, MNRAS 486 (2019) 4233

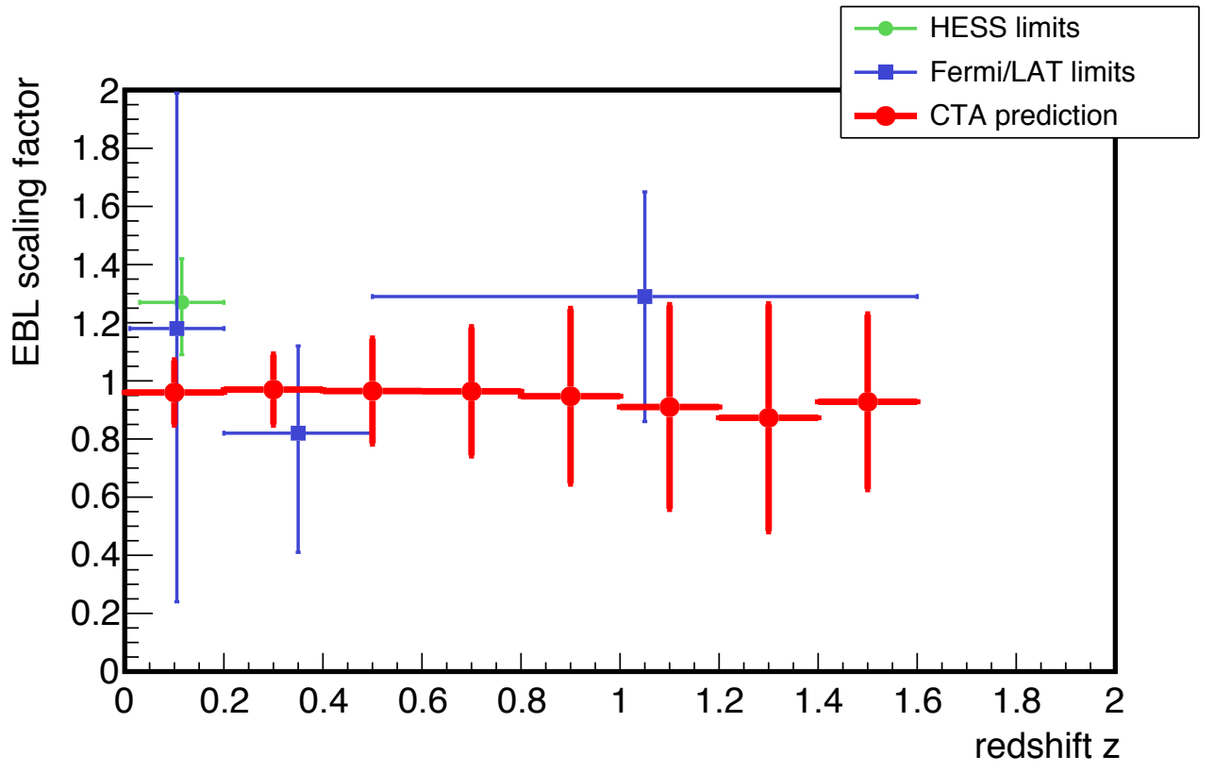


Hubble constant

Biteau & Williams 2015



EBL evolution

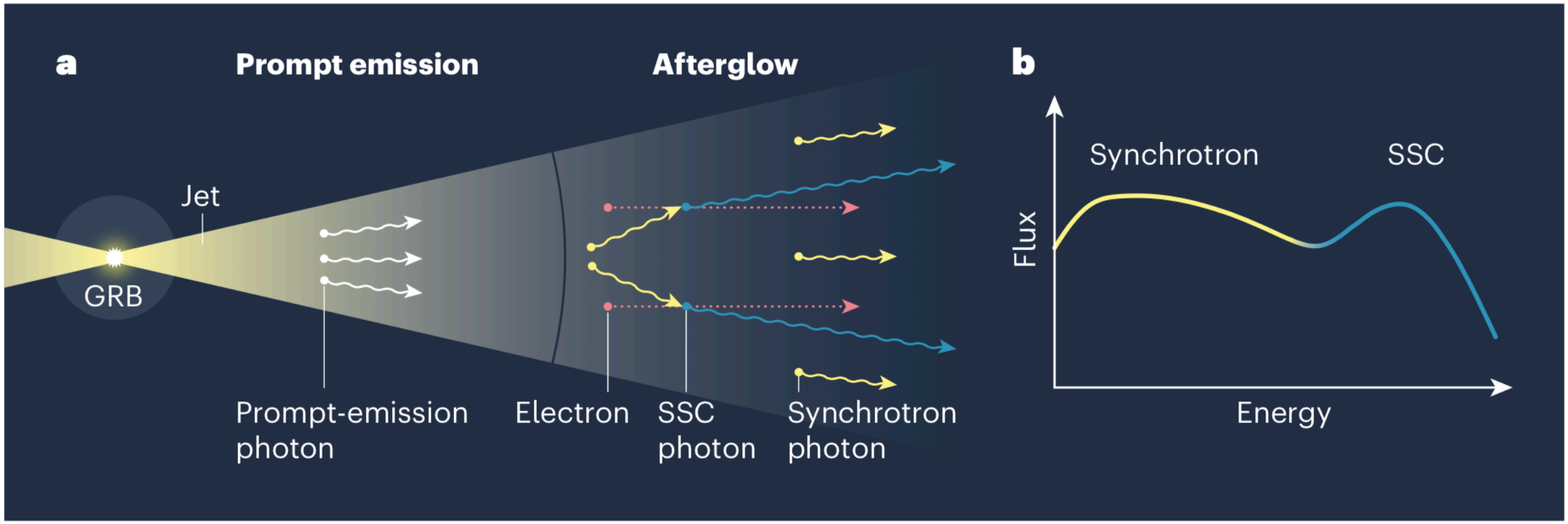


Transients. Finally GRBs!

cherenkov telescope array

- 2017: First hint of GRB detection with MAGIC, short GRB160821B, z=0.16 (T0+24, Inoue et al, 35th ICRC in Busan, proper publication in preparation)
- Jan 2019: MAGIC reports strong signal from long GRB190114C, z=0.42 (ATel#12390, Nature 575 (2019) 455ff and 459ff)
- May 2019: HESS reports detection from long GRB180720B, z=0.653 (CTA symposium, Nature 575 (2019) 464ff)
- August 2019: HESS reports detection of long GRB190829A, z=0.0785 (GCN25566, publication in preparation)

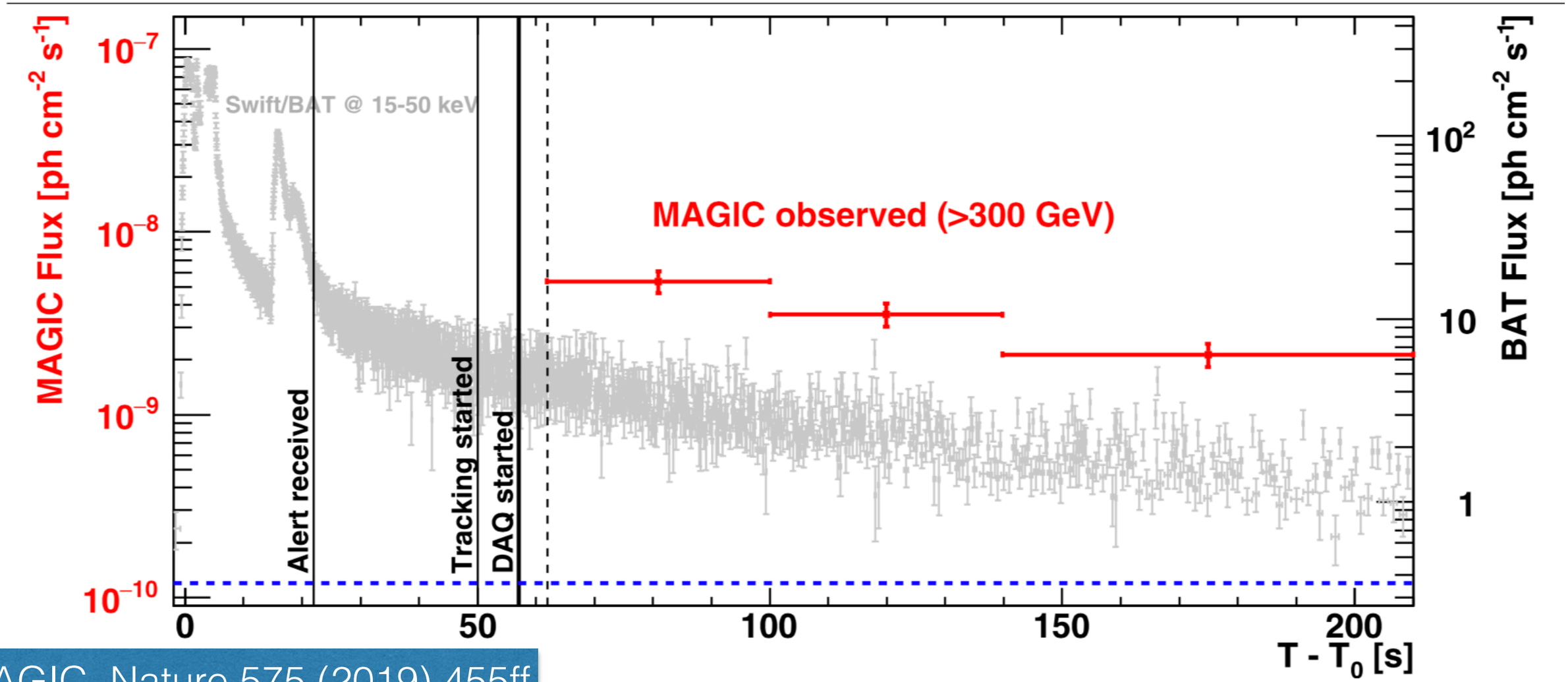
GRBs



- Bing Zhang, Nature 575 (2019) 448ff: MAGIC and HESS show that SSC component exists!

GRBs

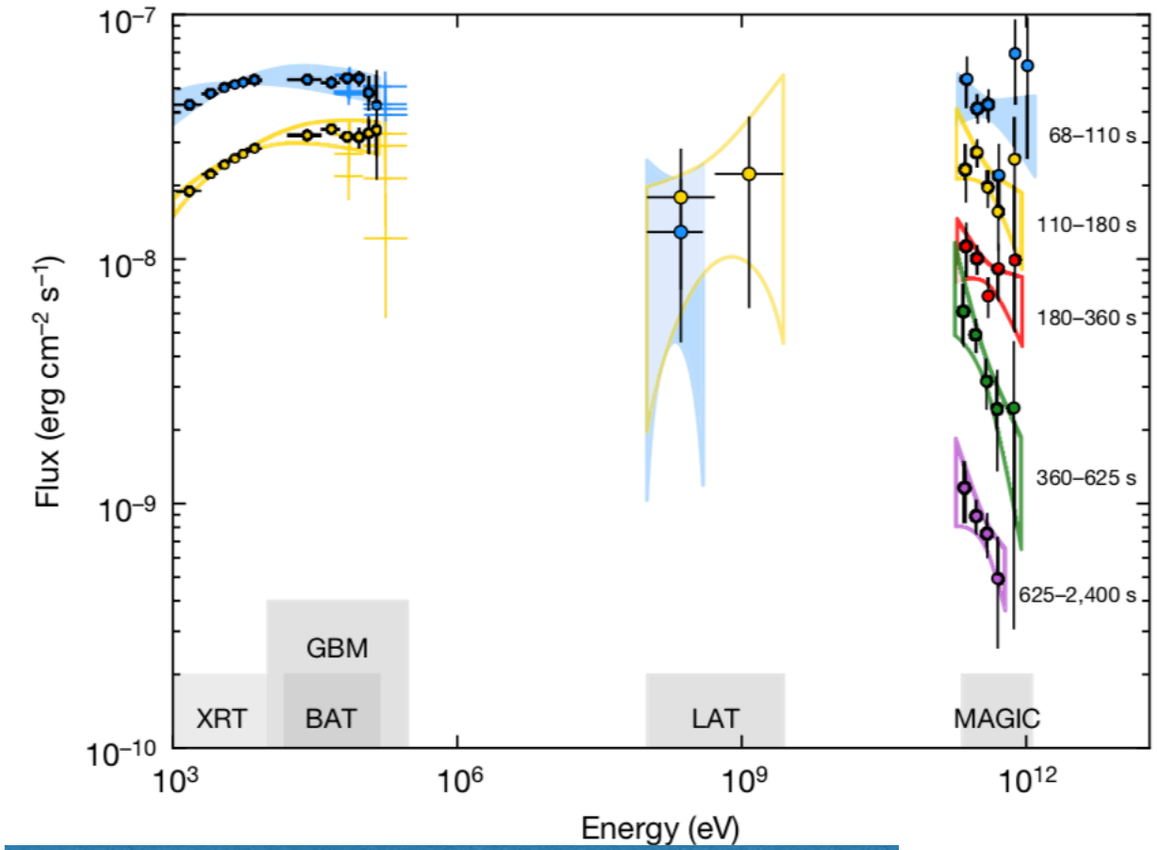
- MAGIC: plenty of signal seconds after alert received



MAGIC, Nature 575 (2019) 455ff

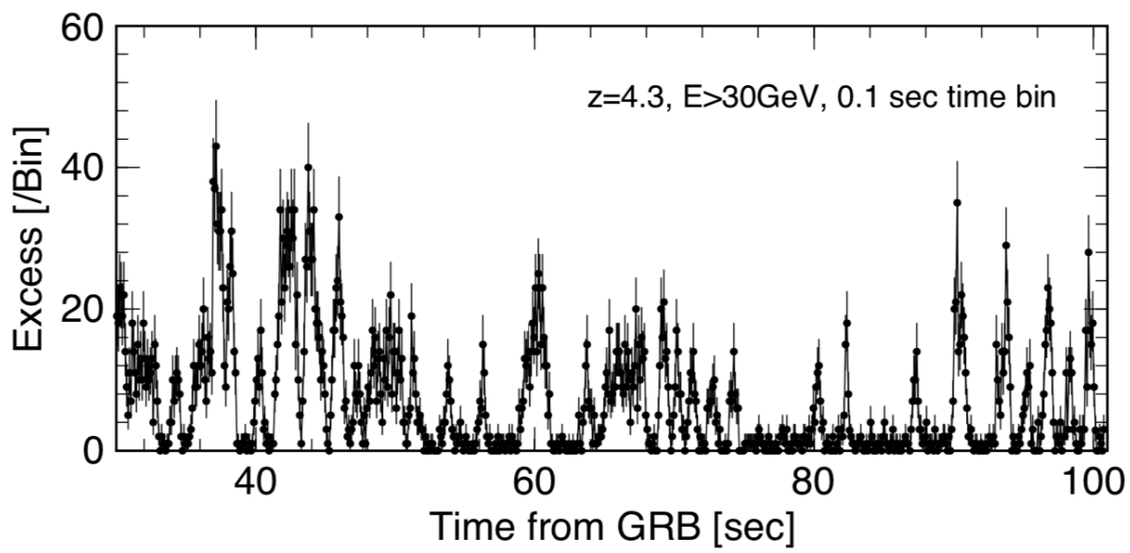
GRBs

- MAGIC: time resolved energy spectra



MAGIC, Nature 575 (2019) 459ff

- CTA: much larger collection area (x4-10) + faster repositioning
- Expect ~1 GRB detection per year per site



CTA consortium, arXiv:1709.07997

Extragalactic Survey: Strategy

see later discussion on the number

- 1/4 of the sky: Quest for the unknown!
- Unbiased and uniform survey of the extragalactic sky
- Serendipitous discovery of fast flaring sources
- + Added value. Preferred region should include e.g. Virgo cluster or/and Fermi Bubbles

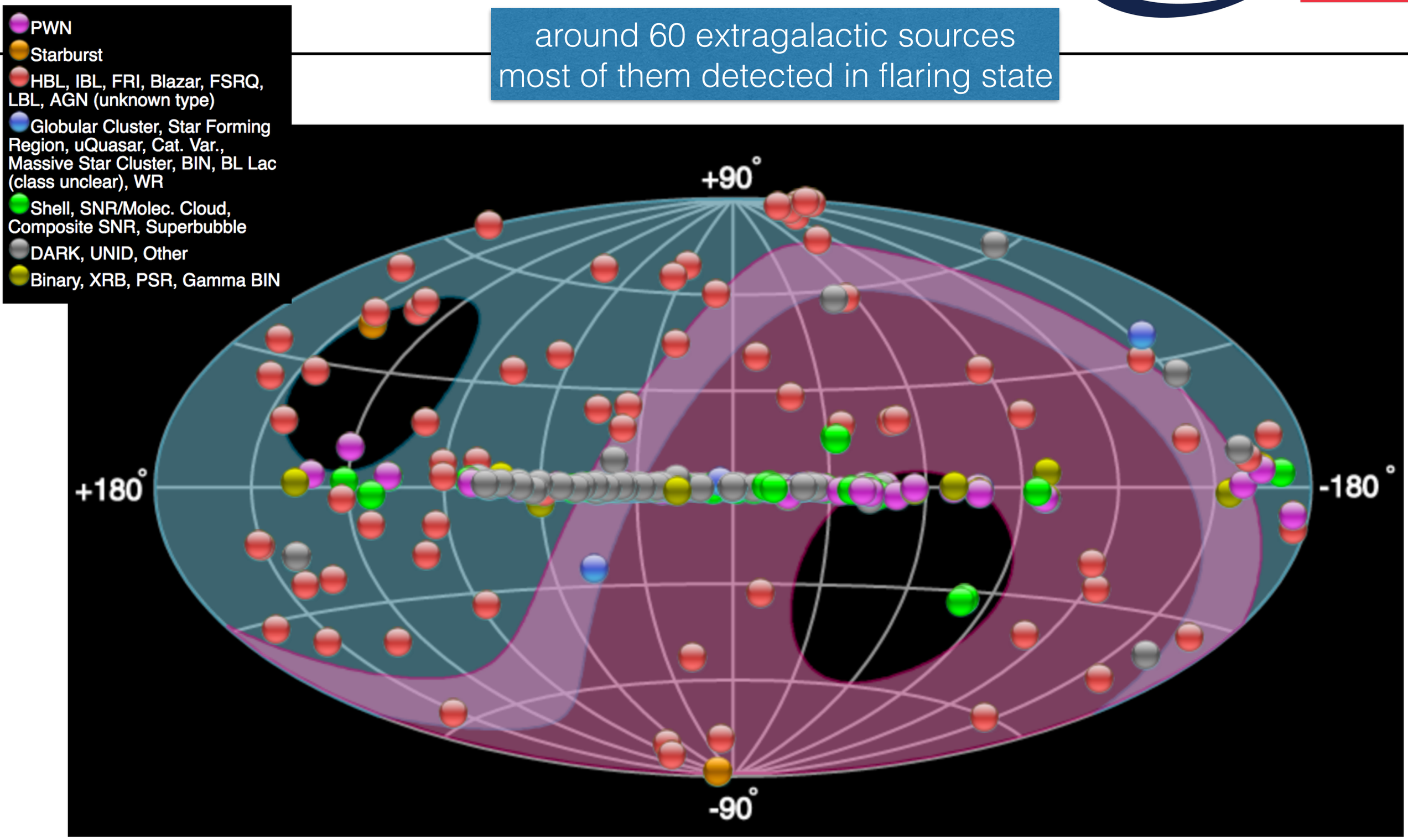
Variability issue

- Blazars are variable sources, especially at >100 GeV
  - flux increases by >1 order of magnitude
  - all time scales
- However, most of the time (90-95%?), blazars do not vary their VHE flux by more than a factor of 2
- <1% of the time blazars spend in flux states 5-10 times higher than the quiescent one
- Therefore, the survey will detect sources mostly (90-95%?) in quiescent or close to quiescent states

Preliminary numbers from Elina and Jonathan (Fermi/LAT data)

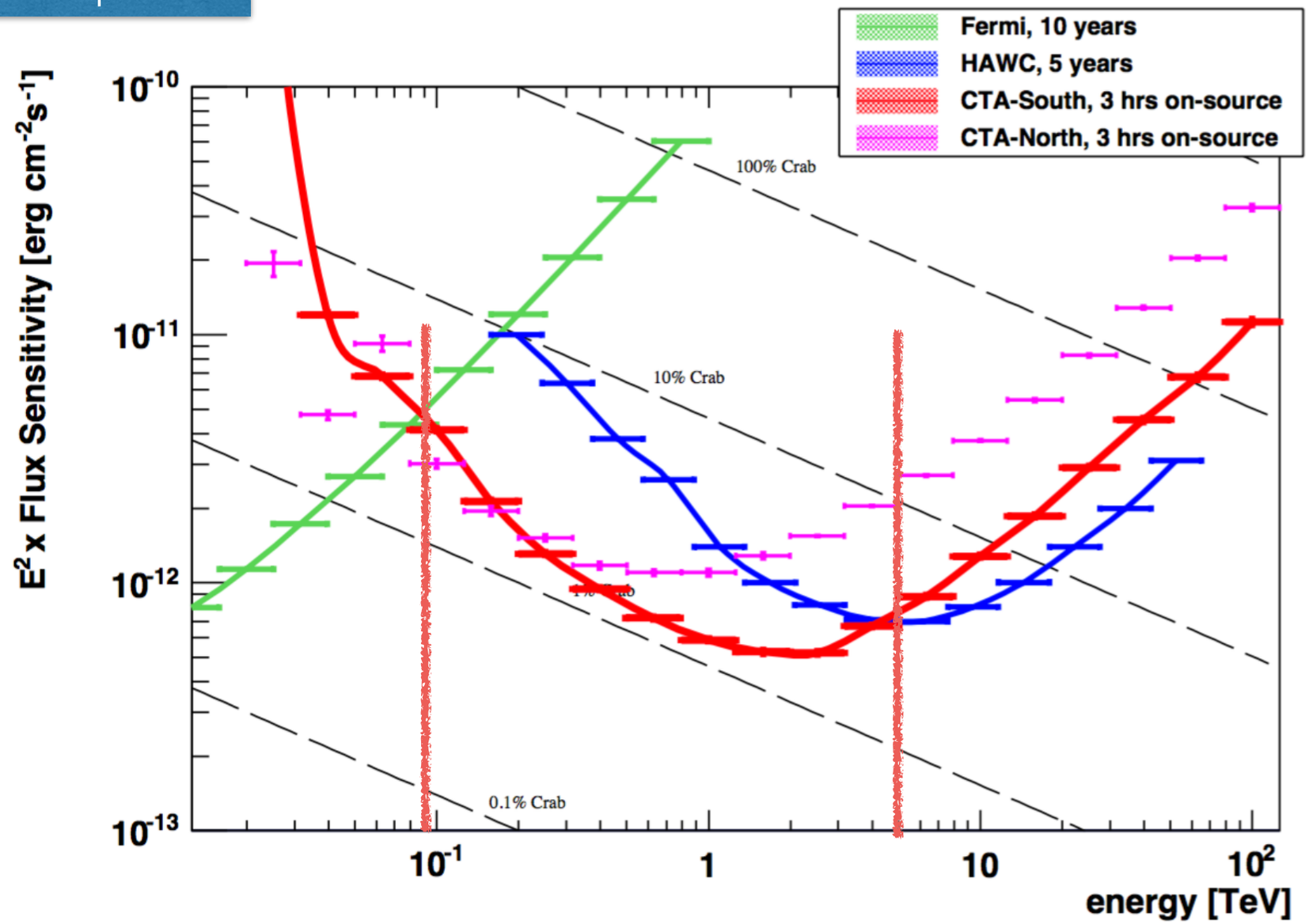
Current TeV catalog

around 60 extragalactic sources
most of them detected in flaring state



Sensitivities

3h exposure



- If we aim for 1/4 sky, effective exposures of 2-3 hrs are feasible. Sensitivities for 3h exposure close to the center of the field of view are shown above

Why 25%?

- We estimate that so far some 150 extragalactic FoV have been observed with HESS+MAGIC+VERITAS:
  - using radius of r=2° we obtain 5% of the sky (of course very non uniform)
- We estimate that with CTA we'll have some 70 extragalactic FoV in first few years
  - using radius of r=3° we obtain 5% of the sky (of course very non uniform)
- Seems that anything above 10% of the sky and above is a big step forward
- Obvious: Exposure vs Area: 2 times less area gives 1.4 better sensitivity for the same survey time

Expectations from known source classes

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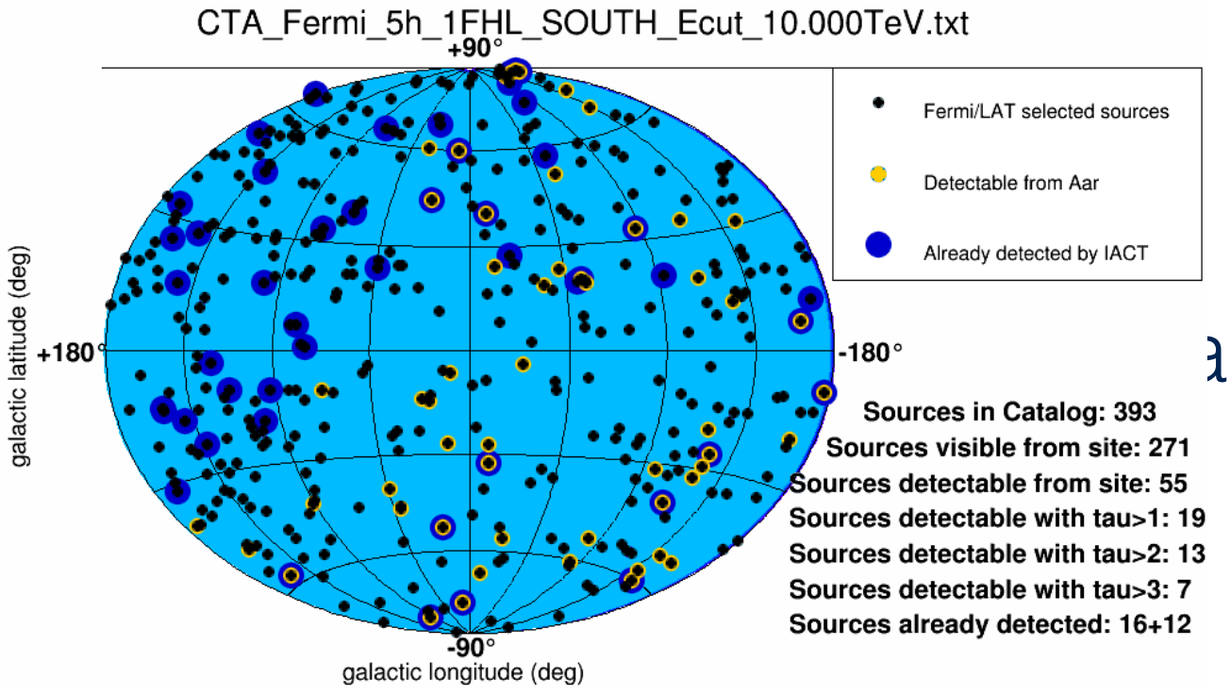
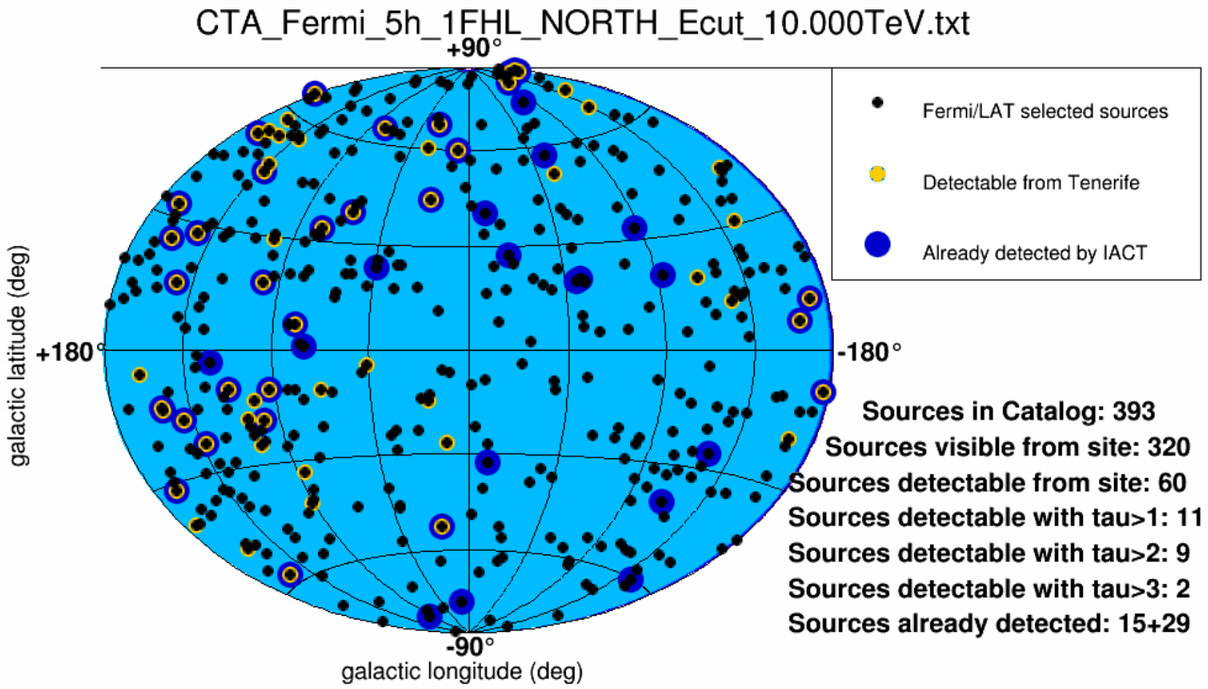
5h exposure

South: 55 sources



North: 60 sources



using CTA macros

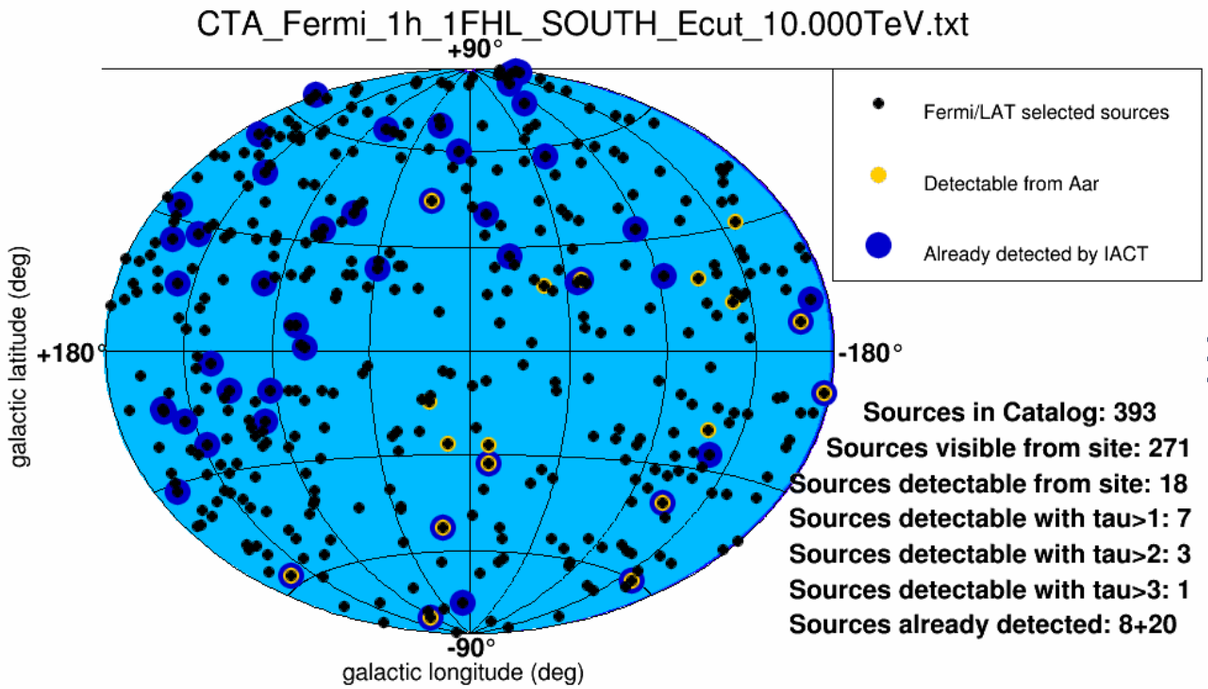
differences in site configurations are taken into account

For 1/4 of the sky this means around 25-35 sources

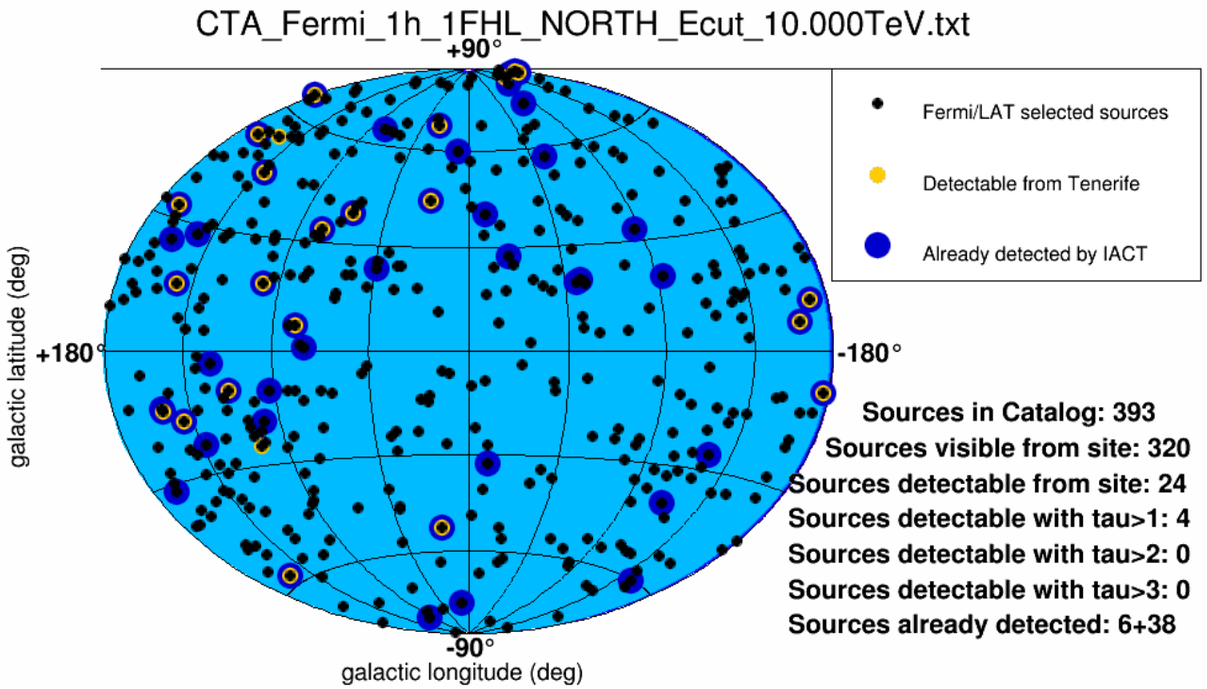
Expectations from known source classes

1h exposure

South: 18 sources



North: 24 sources

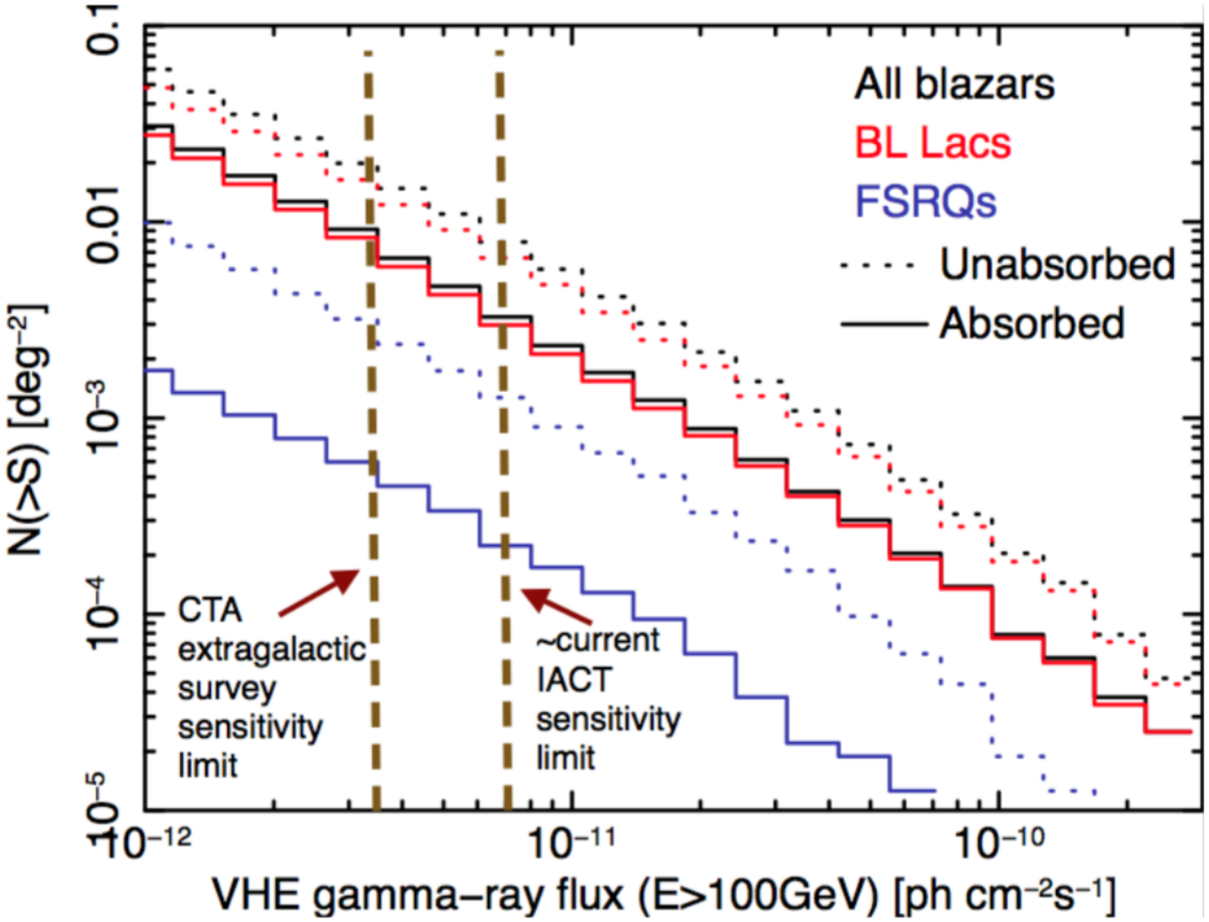


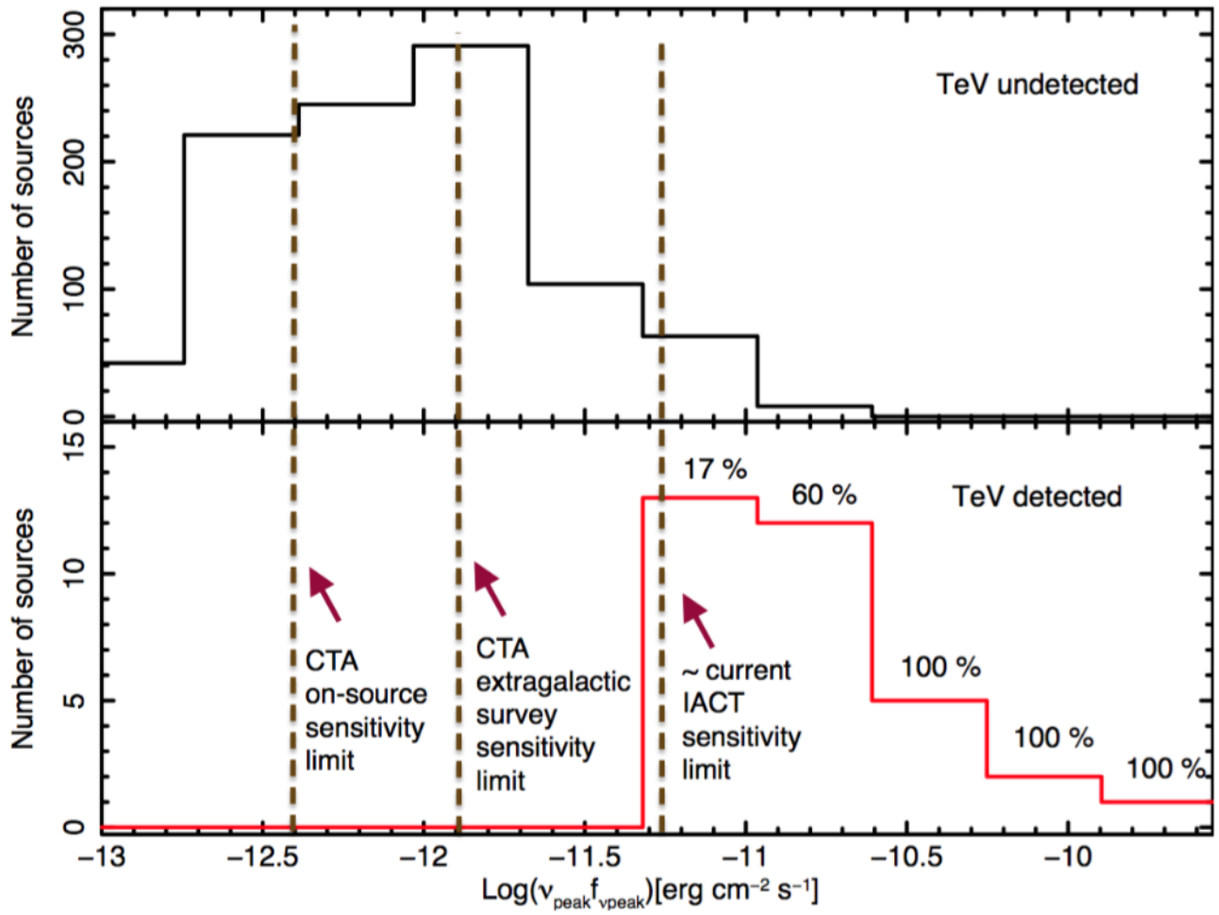
using CTA macros

differences in site configurations are taken into account

For 1/4 of the sky this means around 8-12 sources

Source number predictions





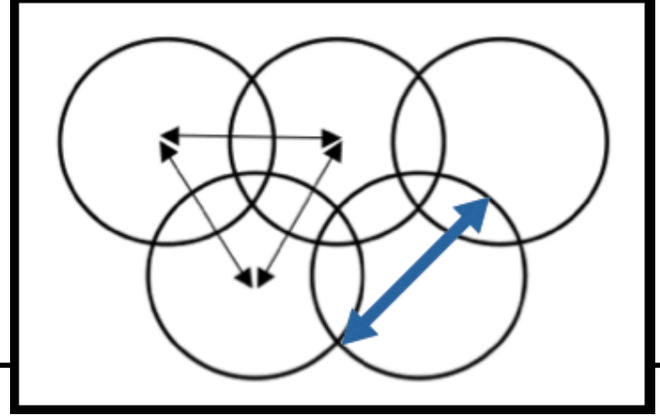
- Arsioli B., Fraga B., Giommi P. Padovani P., & Marrese, P.M., A&A 579 (2017) 34
- Expected source counts as a function of the integral gamma-ray flux above 100 GeV in 27,000 deg2
- scaled down to 1/4 of the sky: 77 source
- Incompleteness of the survey (conservative criteria), factor 2 larger: ~150

- Padovani P. & Giommi P. (2015). A simplified view of blazars: the very high energy γ-ray vision. MNRAS, 446, L41
- Simulated log N - log S distribution. The dashed (solid) lines represent the expected distributions without (with) taking into account the absorption by the EBL. According to this study, with the 6 mCrab sensitivity during the proposed survey CTA should detect around 100 sources in 10,000 deg^2.

Survey strategy

- preliminary result of the optimization:
  - time spent: ~1000h
  - depth (in sensitivity) of the survey: ~6mCrab above 125 GeV = 3e-12 ph/cm2/s
  - area of the survey: 1/4 of the sky
  - no divergent pointing considered at this stage (no MC with divergent pointing yet). However, with 400deg^2 (8 times larger than pointed observation FoV) it would be1-2 GRB in the FoV. And more transients of course

Sensitivities (Lucie Gerard)



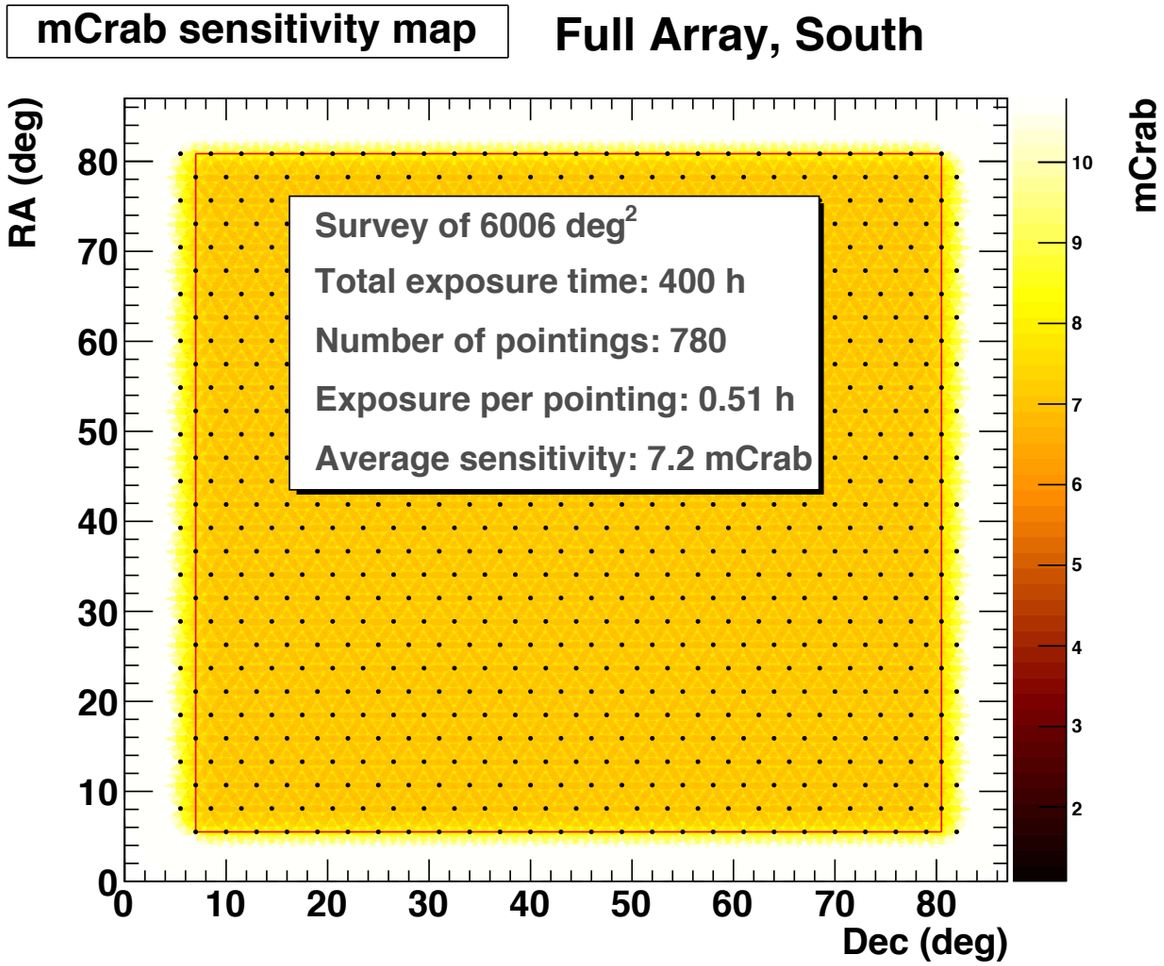
ARRAY / IRF		Spacing between the observations					
		4 degree 0.83h / obs.		3 degree 0.46h / obs.		2 degree 0.21h / obs.	
		S	ΔS	S	ΔS	S	ΔS
South	2a-noLST	5.4	0.9	4.8	0.4	5.0	0.5
North	2NN	8.61	1.2	8.0	0.8	8.1	0.8

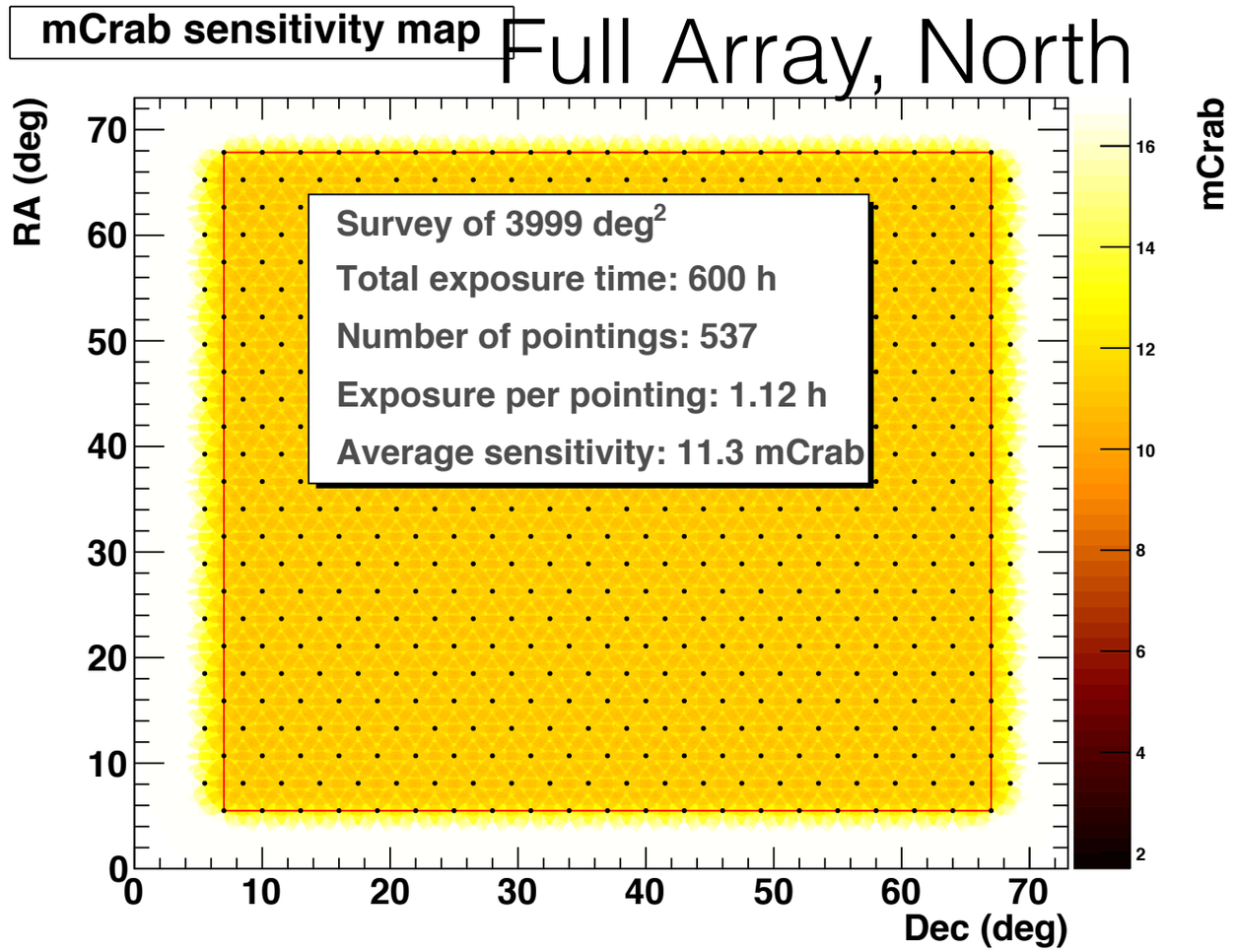
Table 8.1 – Estimation of the survey sensitivity for a total of 600 h of observations and a coverage of 25% of the sky, for the south and north arrays and for various grid spacings (in degrees). The sensitivity, S, in milli-Crab units (mCU), is the average integrated sensitivity above 125 GeV assuming a Crab-like spectra [187]. ΔS represents the survey sensitivity fluctuation; this is the standard deviation of the sensitivity distribution over the sampled survey field-of-view. The instrument response function (IRF) refers to the particular array layout simulated; see text for details.

Northern array needs ~2-3 longer to reach the same sensitivity due to less MSTs and no SSTs

Sensitivities (JohnE Ward)

cherenkov telescope array



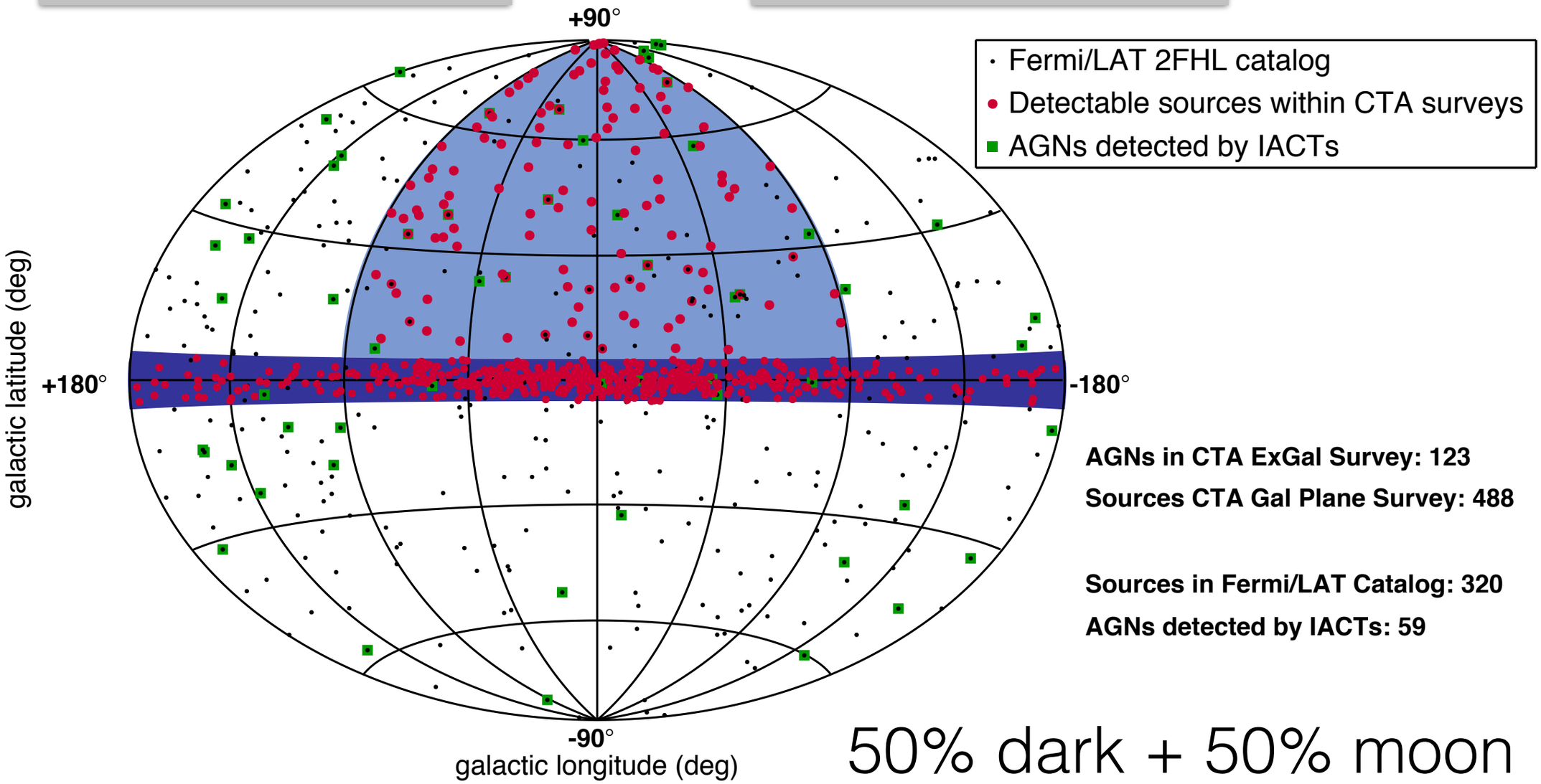


build up excess / background maps as the survey goes and calculate sensitivities using 5sigma/10events/5%background

Which region?

North: 60% of the time, 40% of the area

South: 40% of the time, 60% of the area



50% dark + 50% moon

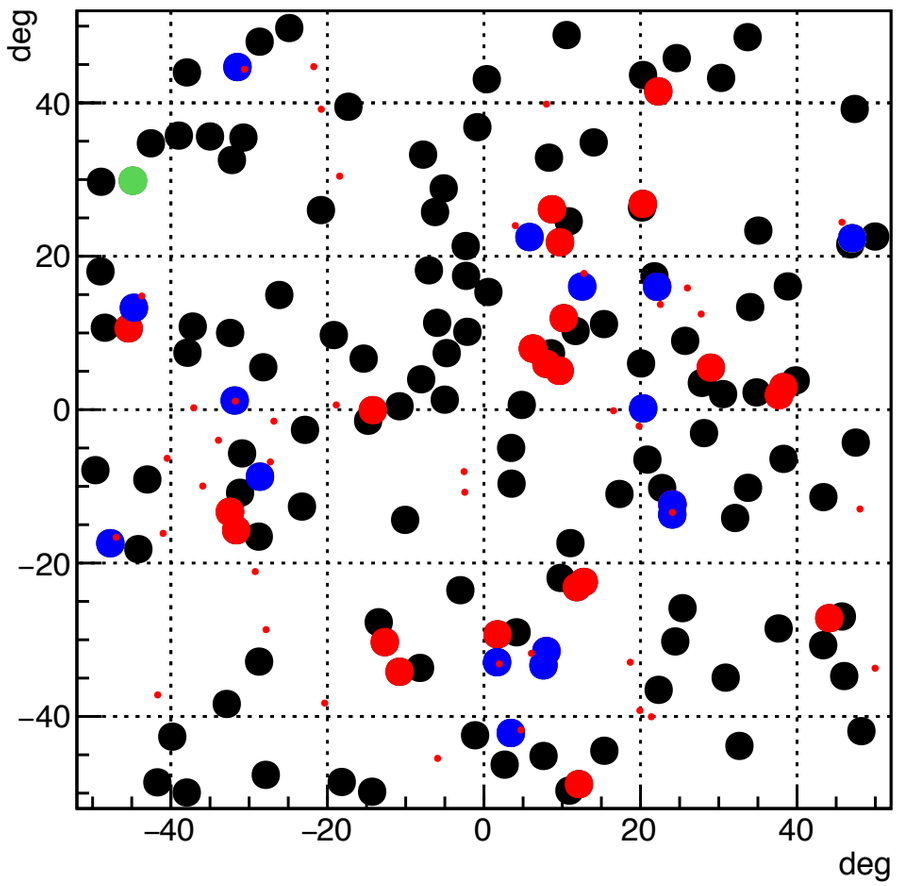
- Such scan would include Fermi Bubble (North), Virgo and Perseus clusters. It can be performed in part from the South and in part from the North

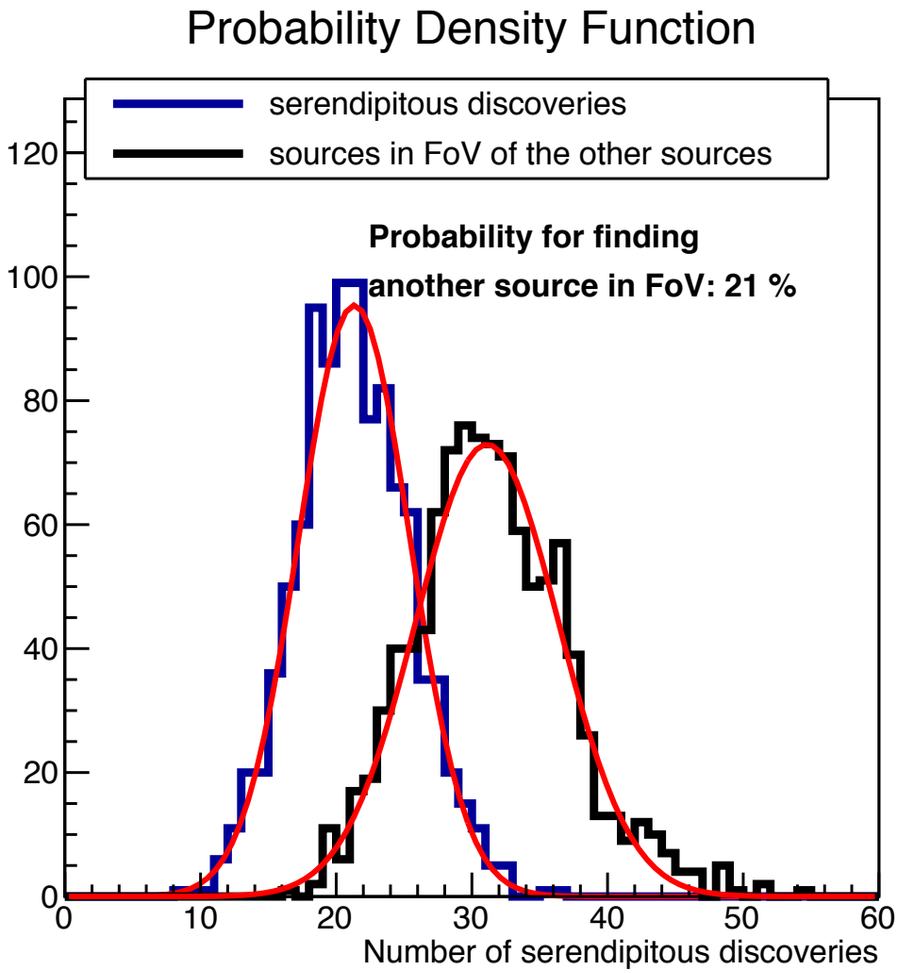
Serendipitous discoveries

- what is the probability to detect sources serendipitously?
  because we foresee some 50 observations of extragalactic objects for about 20h each before CTA is completed

Optimistic case: 150 sources in 10.000 deg2

Toy Monte Carlo





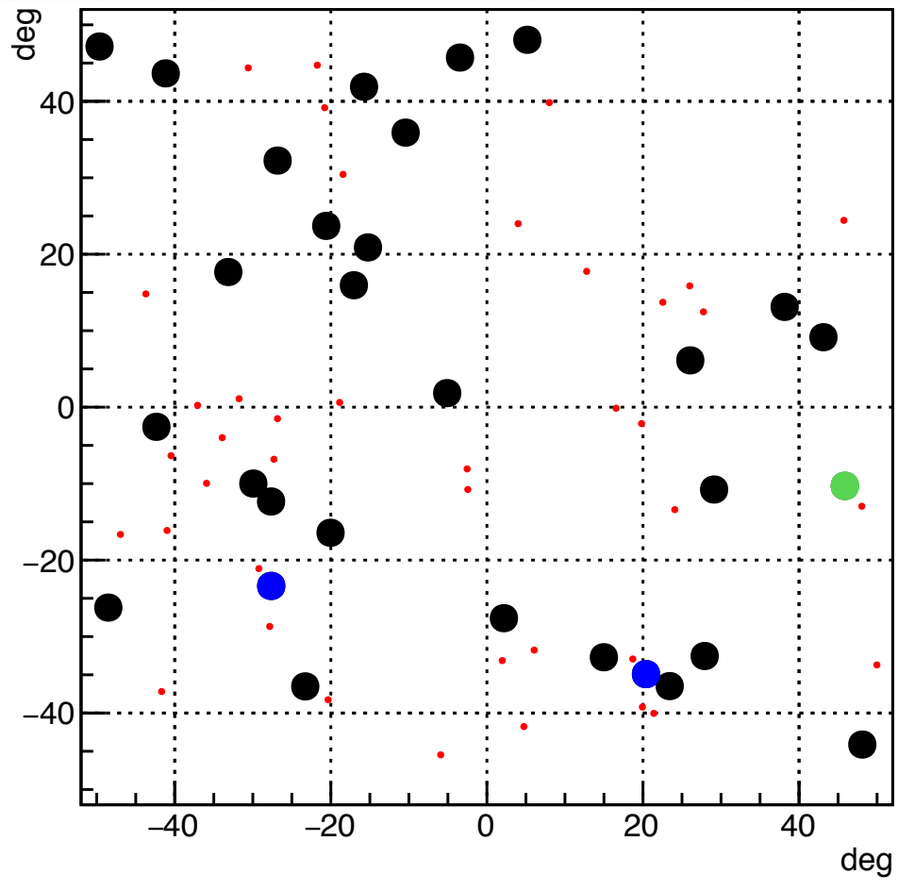
- black dots: sources; large **red** dots: sources in FoV of other sources; **green** dots: in FoV of known sources; **blue** dots: in FoV of random pointings
- Result: 20-30 serendipitous discoveries depending on the assumptions

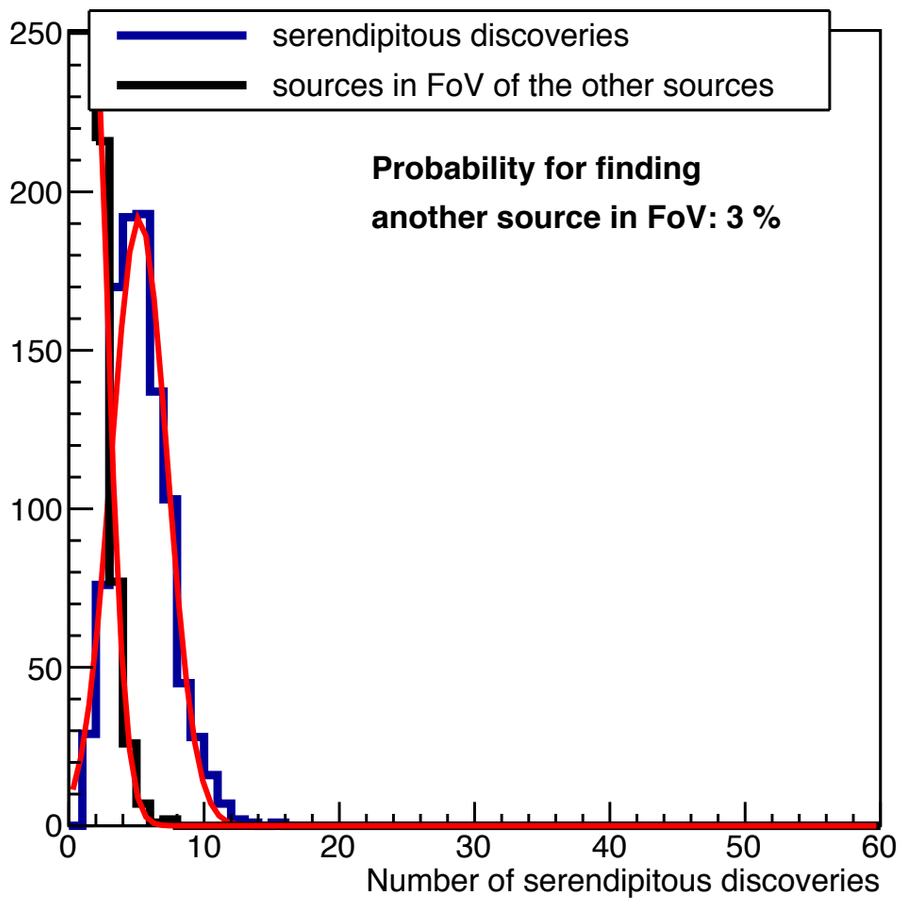
Serendipitous discoveries

- what is the probability to detect sources serendipitously?
  because we foresee some 50 observations of extragalactic objects for about 20h each before CTA is completed

Pessimistic case: 30 sources in 10.000 deg²

Toy Monte Carlo





- black dots: sources; large **red** dots: sources in FoV of other sources; **green** dots: in FoV of known sources; **blue** dots: in FoV of random pointings
- Result: 2-5 serendipitous discoveries depending on the assumptions

Summary / Outlook

- CTA has an ambitious program for AGNs
- CTA will have several Key Science Programs for extragalactic science
- For the first time, extragalactic surveys in the energy range 50 GeV - 1 TeV will have meaningful results
- Great prospects for AGN population studies and EBL / cosmology
- Just need to build CTA …

Backup

Population Study

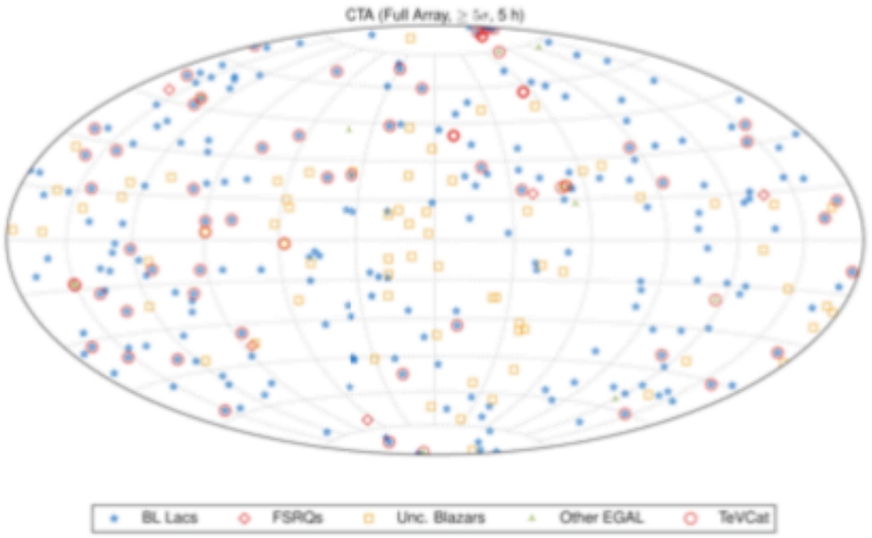
cherenkov telescope array

Assess CTA's reach on the population of AGN

. Including, but not limited too, the extragalactic survey

→ useful both to the Consortium (survey KSP) and to the Community (dedicated proposals)

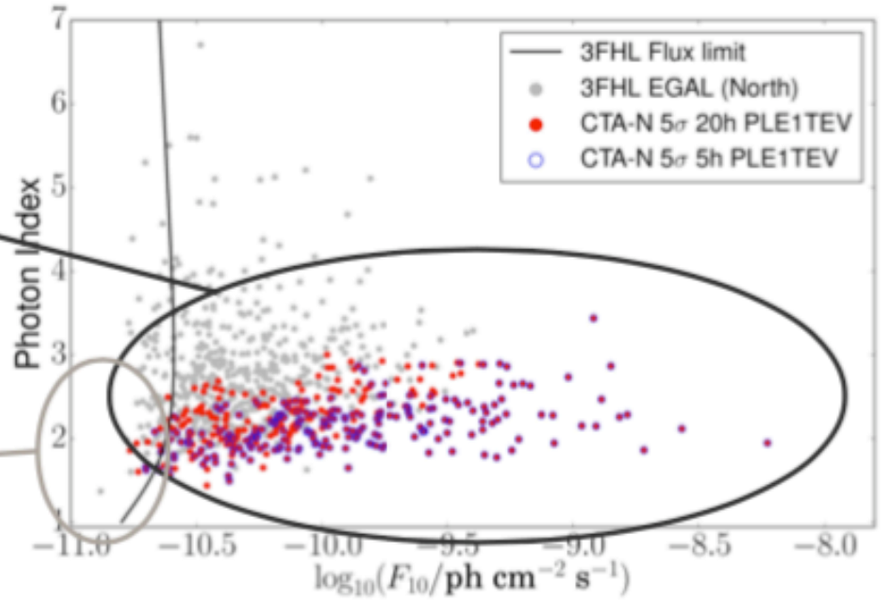
. Aim: full-sky simulation of the AGN population, based on unbiased observations at lower energies (in particular *Fermi*-LAT)
→ quantify the detection livetime for each field



Extrapolating on *Fermi*-LAT

. Preliminary work done both for North and South based on 3FHL

. Limited E-range of 3FHL
→ uncertainty on extrapolation



Beyond *Fermi*-LAT

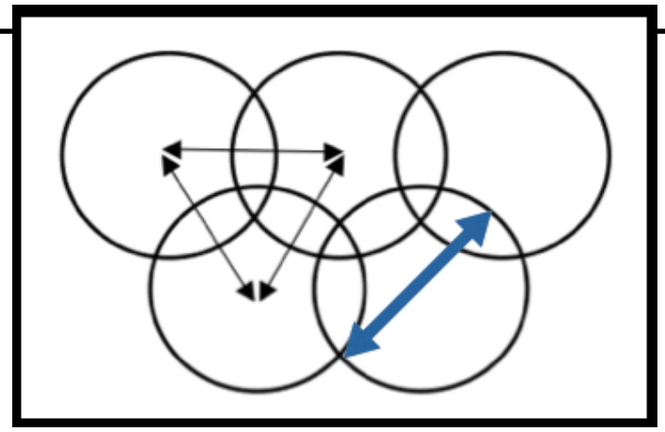
discovery potential for faint/hard sources?

slide from J Biteau

Why a KSP?

- Will answer some key questions (e.g. logN/logS)
- Legacy project for the community
- Needs long exposure (600h-1000h)
- Analysis will be more complicated than for the individual sources
- May profit from a special pointing mode: divergent mode

Feasibility



- Work by Lucie Gerard (DESY)
- Optimized spacing between 2, 3, and 4 deg
- Assumed 600h for 10.000 deg^2
- Used DESY performance files and software dubbed ctools
- Simulated sources in 0.25deg grid
- No systematic limits but we checked that for integral results above 100 GeV there is no problem
- Cross-check by John E Ward (IFAE) using the same performance files and a simple macro (including systematic limits)