Dark Matter Workshop in UAB - 17th-19th January 2019

Pointing optimization for IACTs

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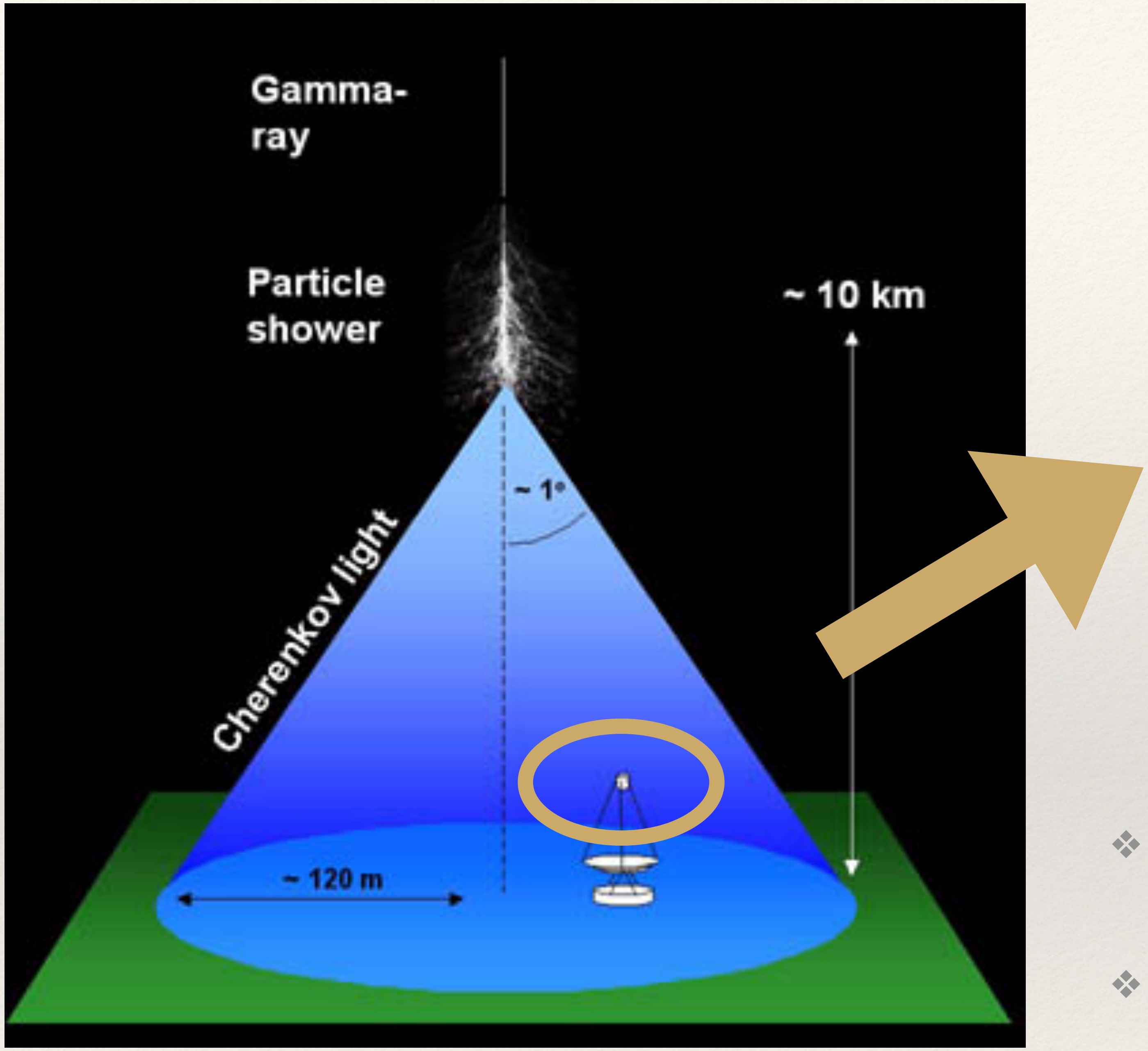
(on behalf of J. Rico and D. Navarro-Gironés)

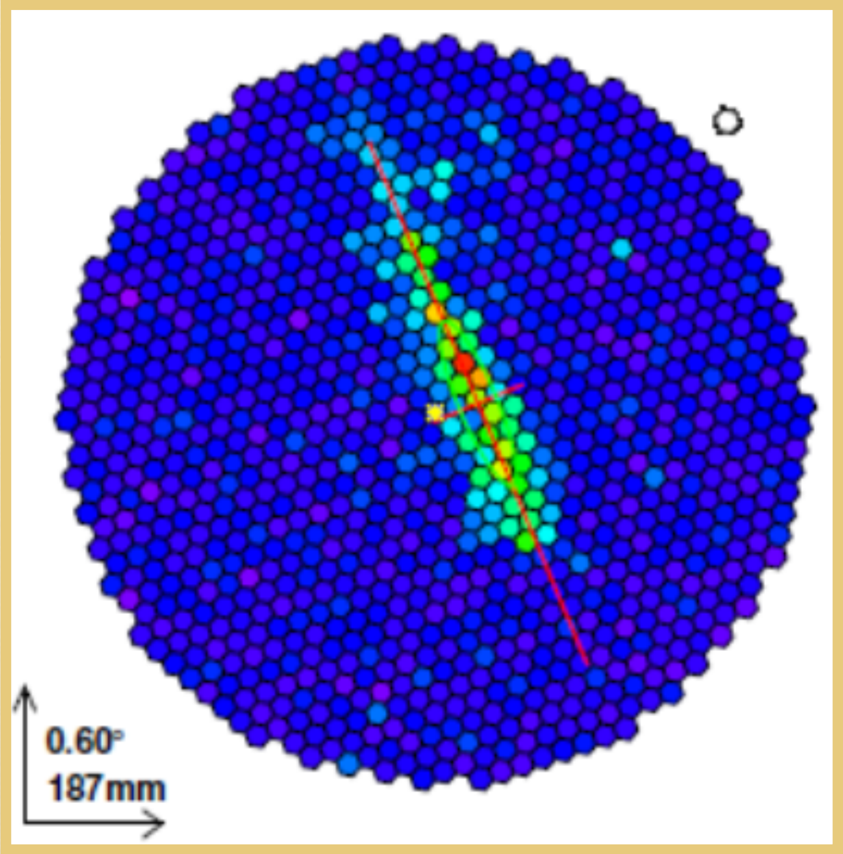
M. Doro was the first one to express (repetitively) his interest in this idea

Outline

- Introduction to IACTs
- Off-axis performance: MAGIC & CTA
- Pointing optimization (PO)
  - Off-axis
  - Leakage
  - Angular resolution
- PO for indirect dark matter searches
- Open-source tool

Imaging Atmospheric Cherenkov Telescopes

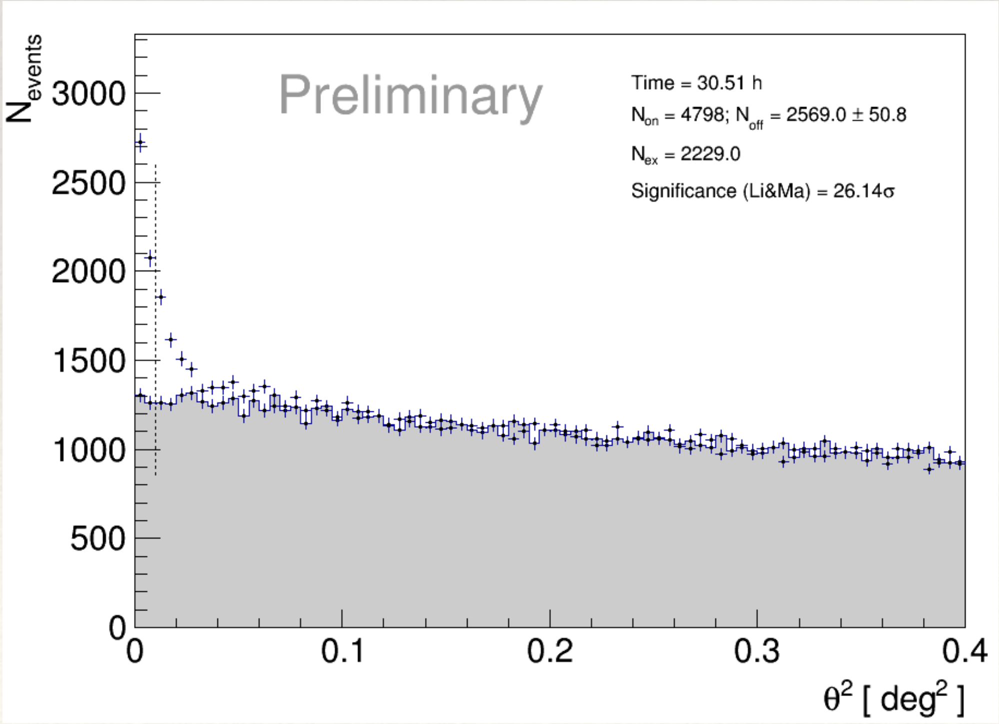


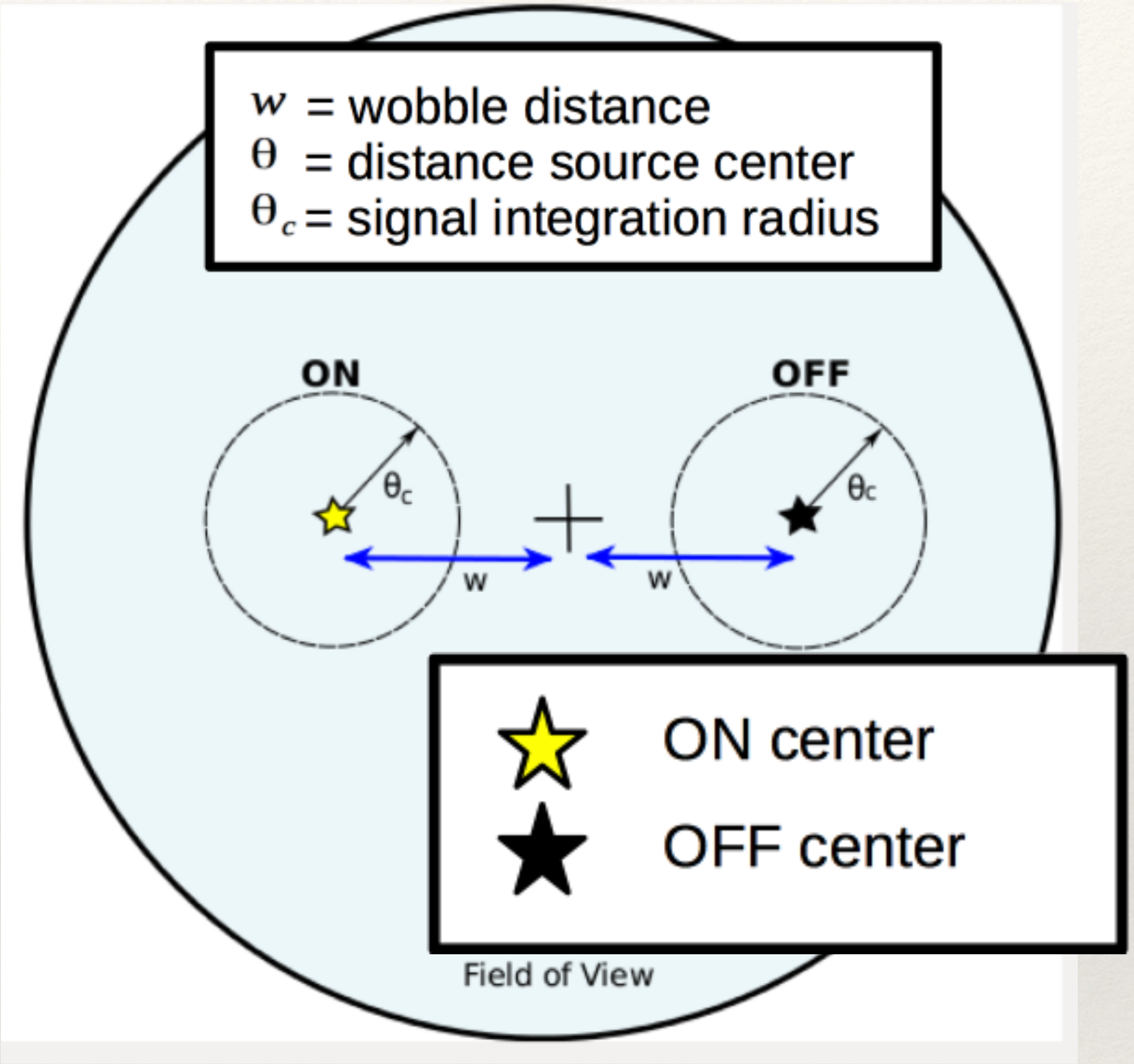


- Large reflection areas
- Fast response photo-sensors
- Cherenkov light density

IACTs pointing mode & analysis

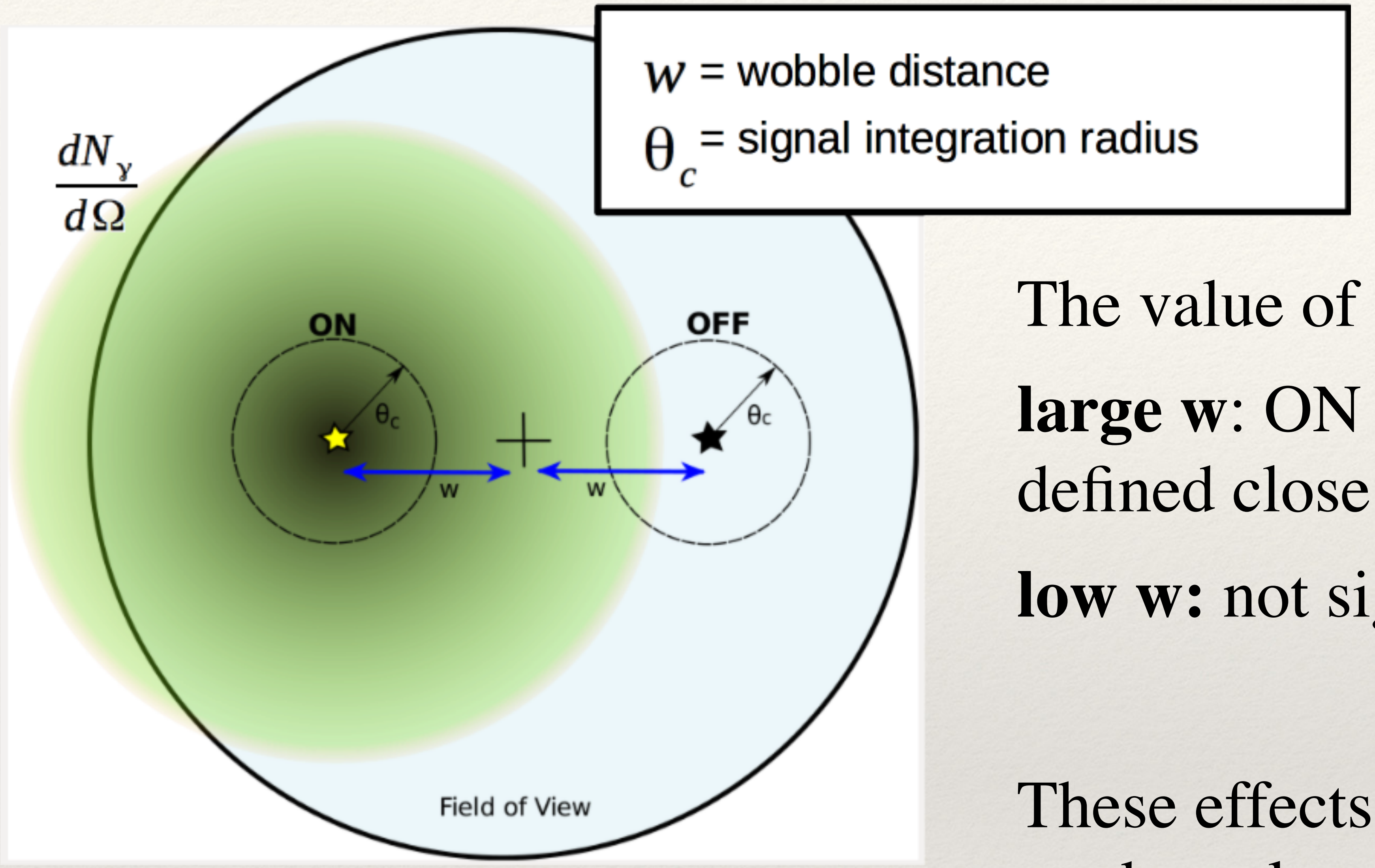
- Observations are in **wobble mode**
- Signal region
  - Quality cuts (atmosphere, hardware, …)
  - Spatial cuts (θ_c)
  - Hadronness (h_c)
- **ON/OFF** comparison





Unlike θc that is used in the analysis, w is fixed during data taking

Wobble pointing for moderately extended sources



The value of w can be optimized:

large w: ON and OFF regions are defined close to the edge of the FoV

low w: not signal-free OFF region

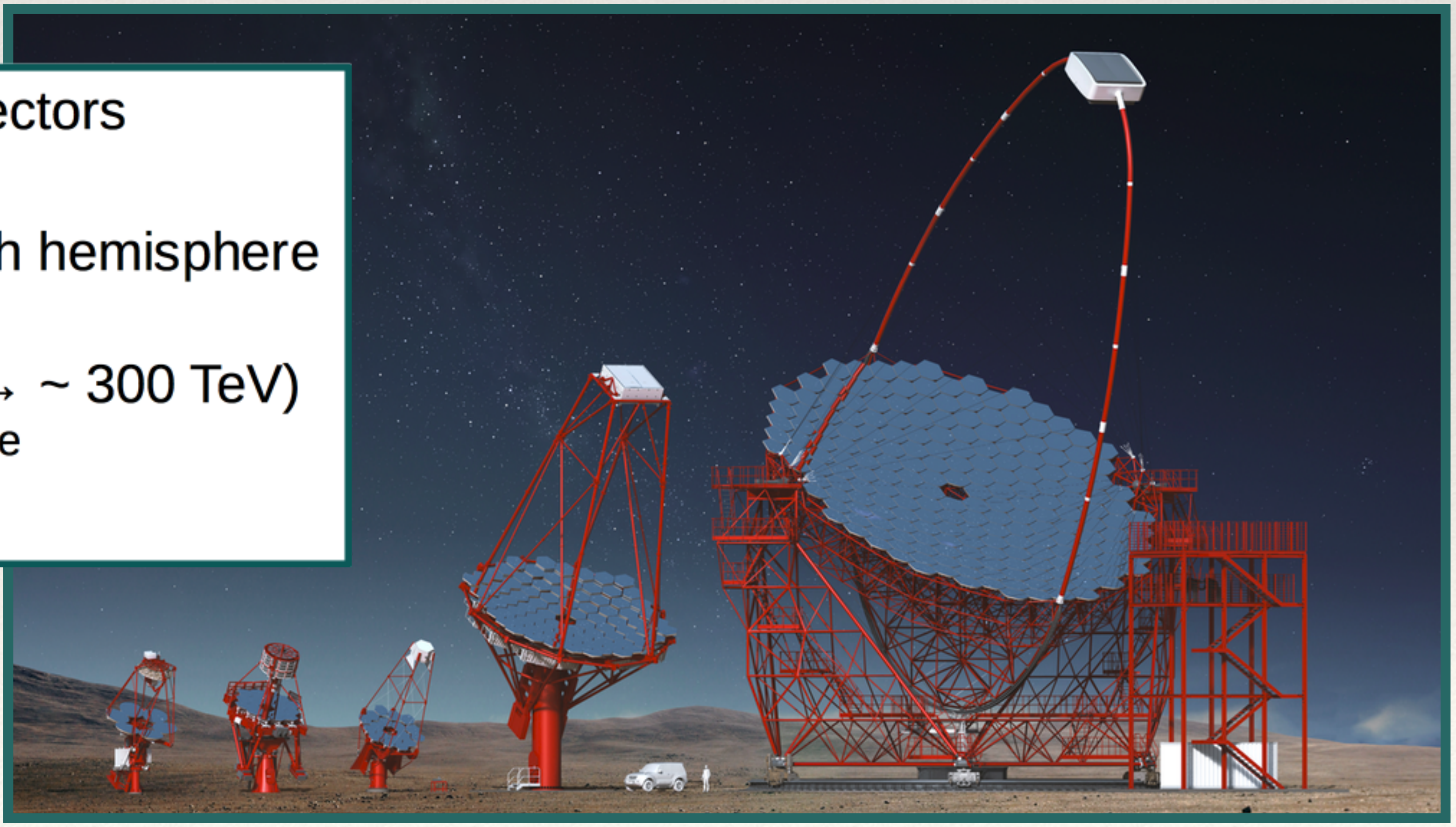
These effects become critical for moderately extended sources…

Procedure to optimize the wobble distance w and signal integration radius θ_C, taking into account the **off-axis performance** of the instrument

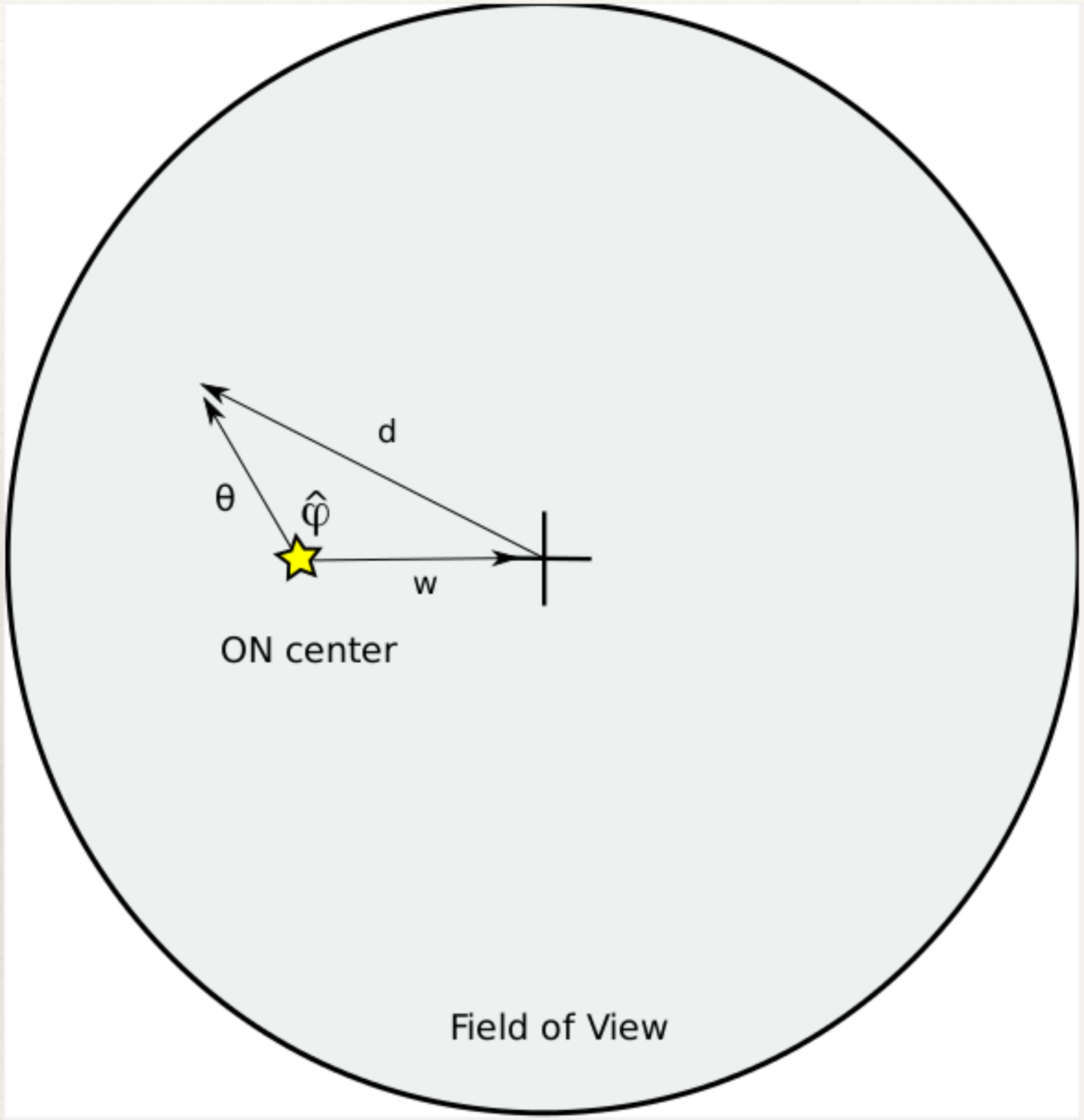
MAGIC & CTA

- Collaboration of **~160 scientists**
- **2-telescopes** (MAGIC-I 2004, MAGIC-II 2009)
  - Stereoscopic system
  - 17m diameter reflector each
- Angular resolution 0.1°, Energy resolution 15-25%
- **~50 GeV energy threshold** (with standard trigger)
  - Sensitivity (E>220 GeV) 0.66% Crab Nebula flux
- **Pointed observations** (**fov ~3 deg**)

- Next generation of VHE gamma-ray detectors
- Full sky coverage: two sites, one in each hemisphere
- **4 decades** of energy range (~20 GeV → ~ 300 TeV)
  → **Large, Medium** and **Small** Sized Telescope



IACTs Relative Acceptance

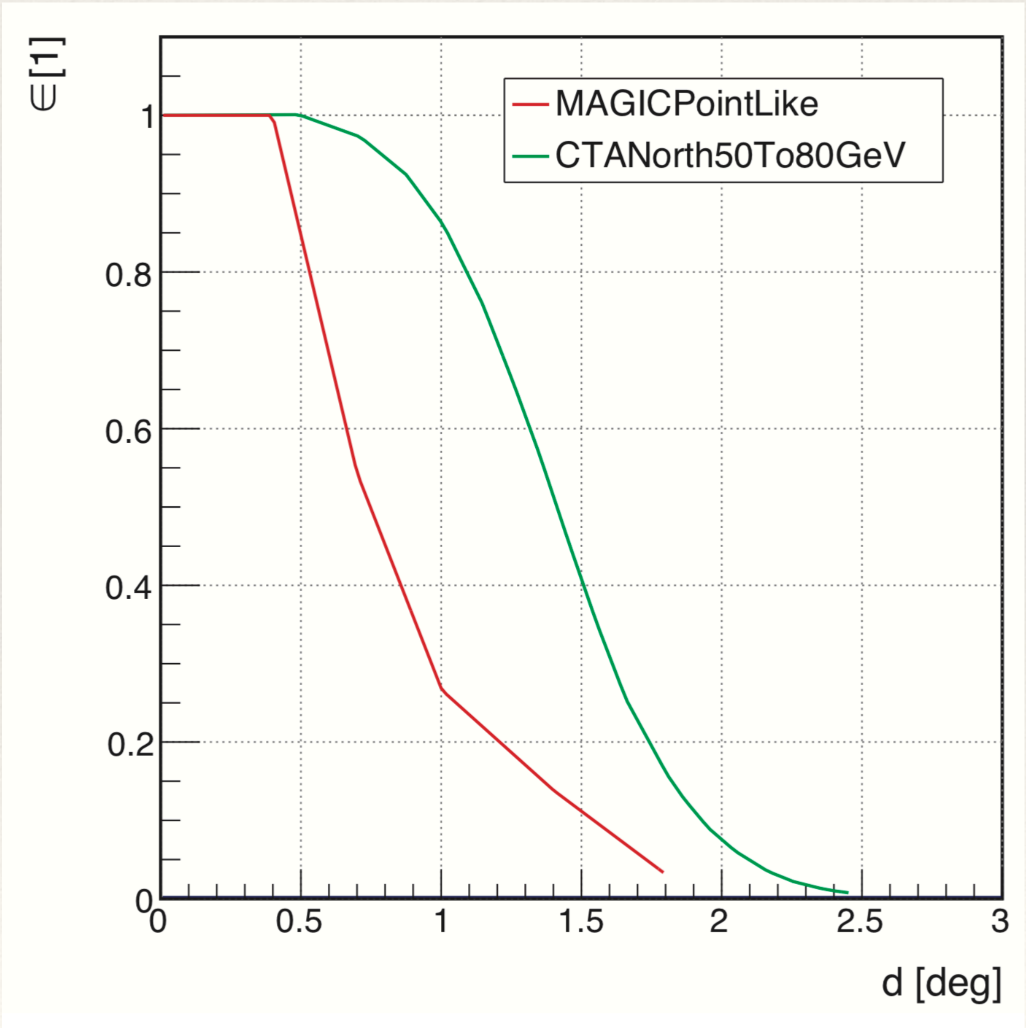


Define *Relative Acceptance* as:

$$\epsilon(d) = \frac{R_\gamma(d)}{R_\gamma(d=0)}$$

$R_\gamma =$ Gamma-ray rate

(assuming θ_C to be much smaller than the scale of the FoV)

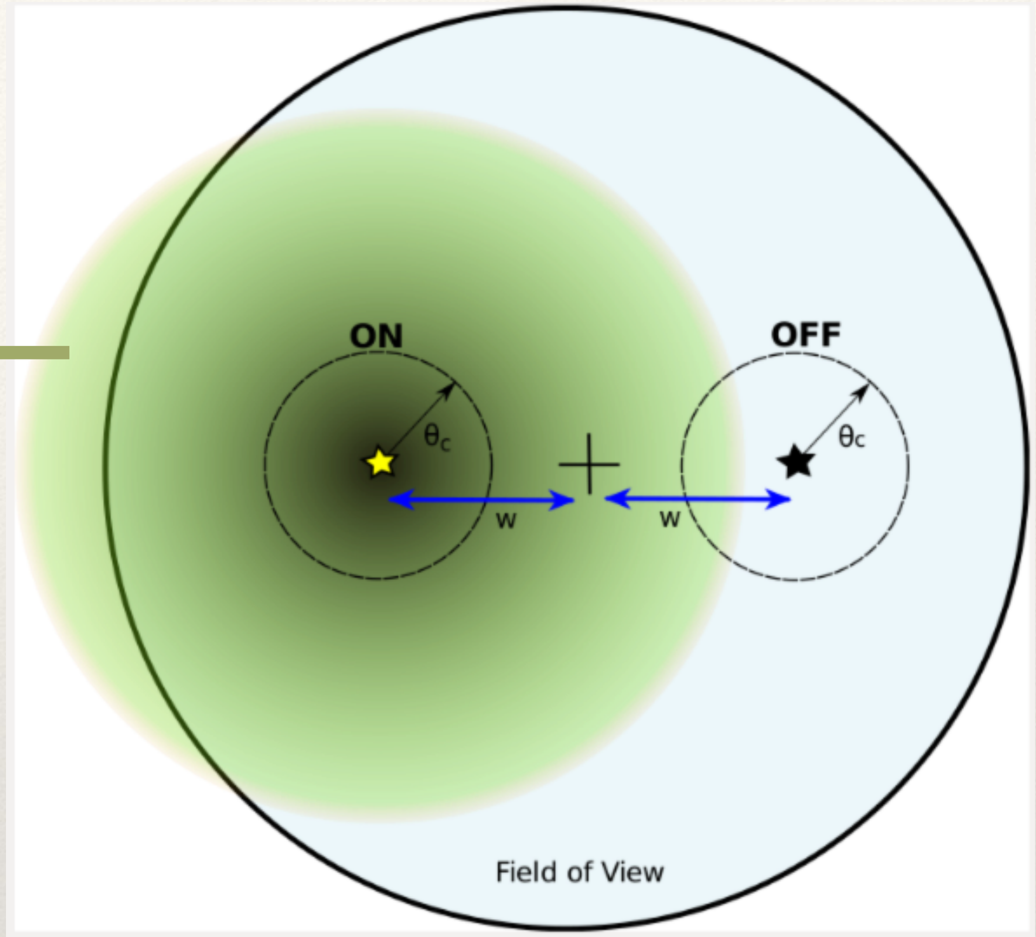


Quality factor

Optimize a quality factor

$$Q(w, \theta_c) = \frac{N_\gamma}{\sqrt{N_{bkg}}}$$

Uniform

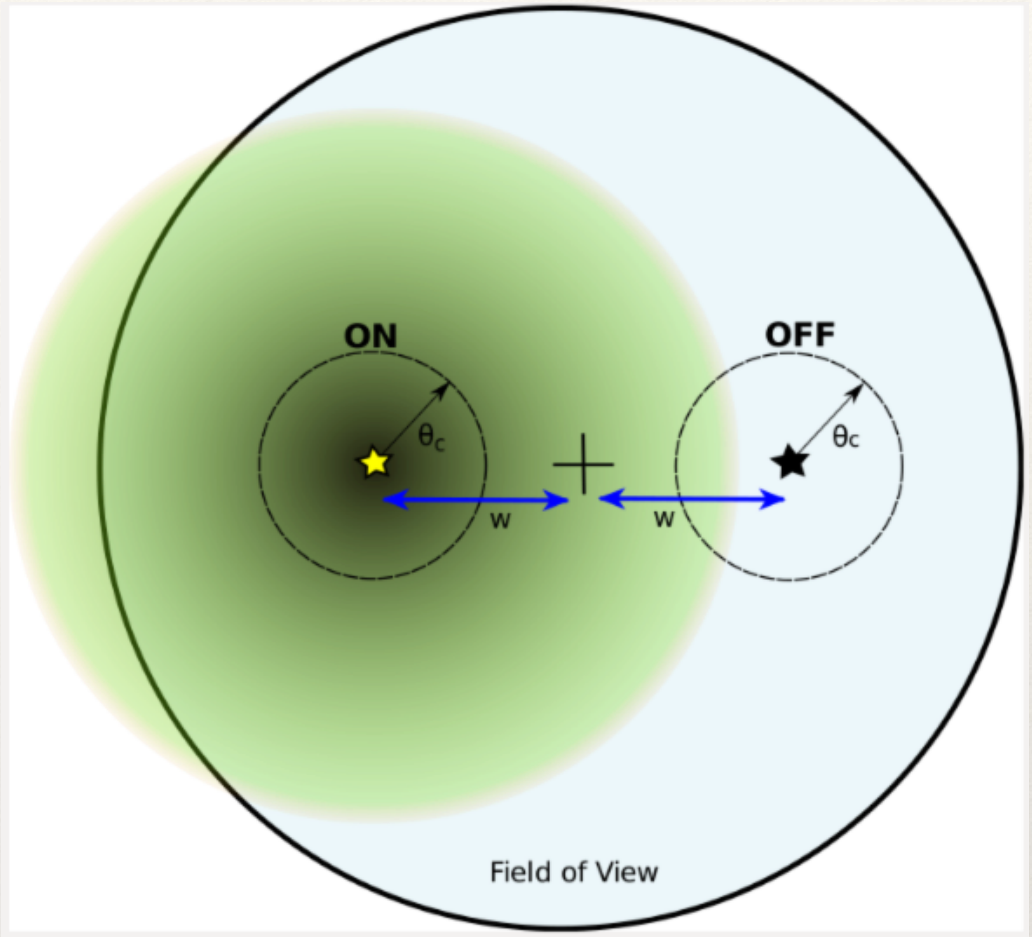


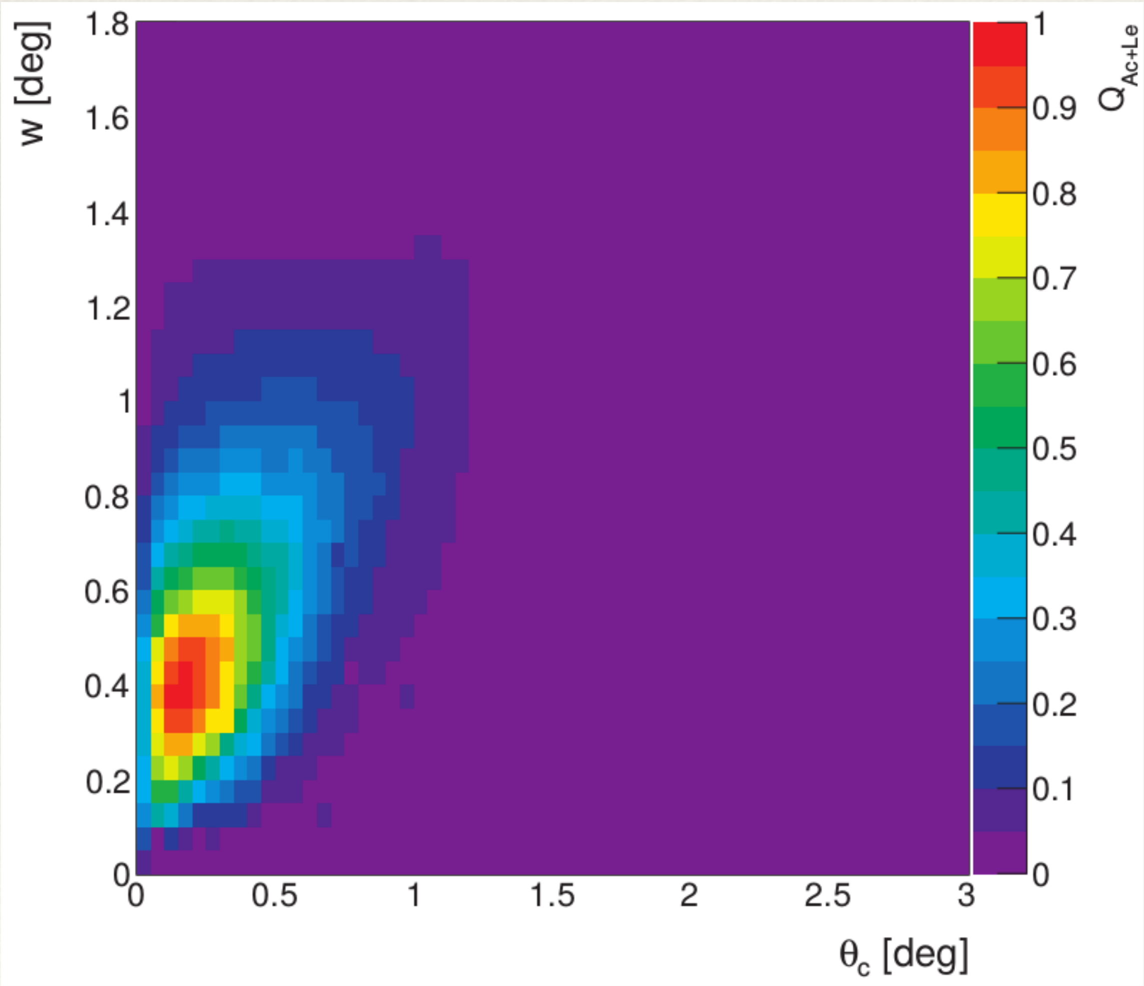
Taking into account:

- Source morphology (+ angular resolution)
- Finite off-axis performance
- Signal contamination into OFF

Quality factor

$$Q(w,\theta_c) \propto \frac{\int_{ON} dN_\gamma/d\Omega \;\; \epsilon(d)\,d\Omega - \int_{OFF} dN_\gamma/d\Omega \;\; \epsilon(d')\,d\Omega'}{\sqrt{\int_{ON} \epsilon(d)\,d\Omega}}$$

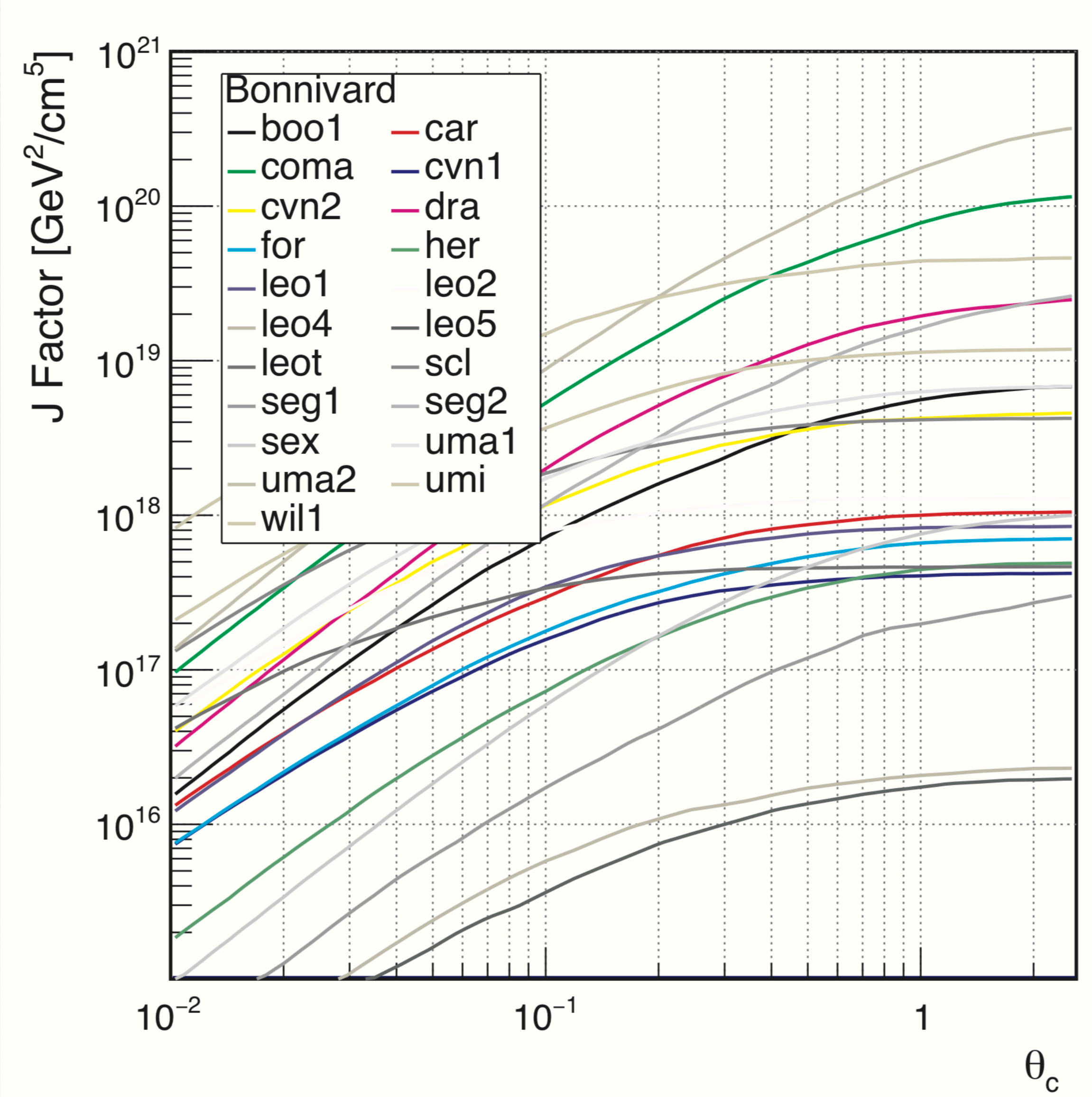


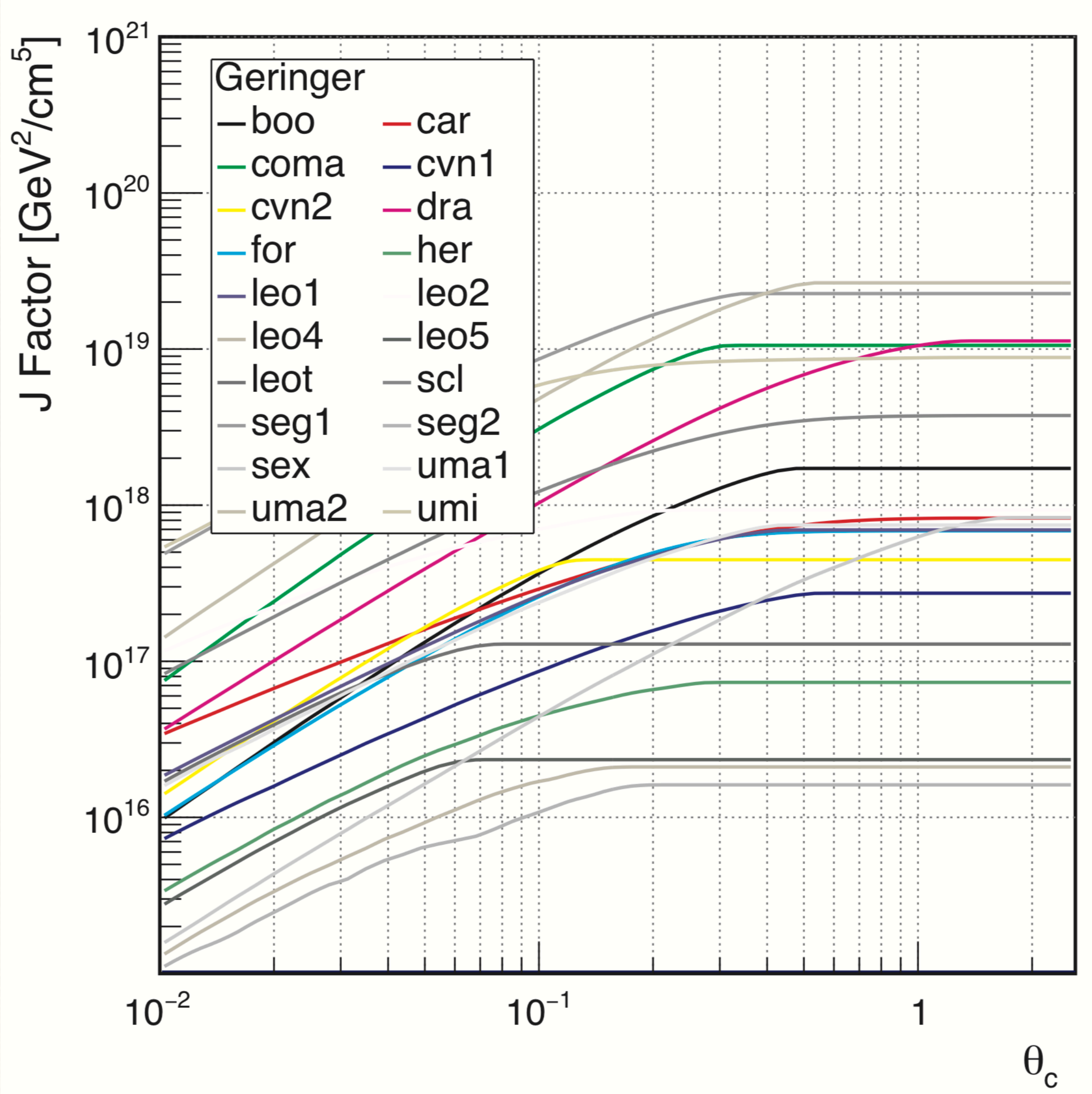


Indirect dark matter searches in dwarf spheroidal galaxies

Based on a set of JFactors from dwarf spheroidal galaxies (both for Annihilation and Decay)

$$\frac{dN}{d\Omega} \propto \frac{dJ}{d\Omega}$$





Indirect dark matter searches in dwarf spheroidal galaxies

Optimized pointing configurations for MAGIC and CTA:

source	MAGIC θ_{opt}		MAGIC w_{opt}		CTA θ_{opt}		CTA w_{opt}	
boo1	0.1	(0.05, 0.2)	0.30	(0.15, 0.50)	0.15	(0.05, 0.45)	0.60	(0.25, 1.06)
car	0.05	(0, 0.2)	0.30	(0.10, 0.45)	0.05	(0, 0.25)	0.45	(0.10, 1.01)
coma	0.15	(0.05, 0.3)	0.35	(0.25, 0.50)	0.3	(0.1, 0.45)	0.60	(0.40, 1.06)
cvn1	0.05	(0, 0.15)	0.30	(0.10, 0.45)	0.05	(0, 0.2)	0.45	(0.10, 1.01)
cvn2	0.1	(0.05, 0.2)	0.30	(0.15, 0.45)	0.1	(0.05, 0.25)	0.45	(0.20, 1.01)
dra	0.15	(0.05, 0.25)	0.35	(0.20, 0.50)	0.2	(0.1, 0.45)	0.65	(0.30, 1.06)
for	0.05	(0, 0.15)	0.30	(0.10, 0.45)	0.05	(0, 0.25)	0.45	(0.10, 1.01)
her	0.1	(0.05, 0.2)	0.35	(0.20, 0.50)	0.15	(0.05, 0.4)	0.55	(0.25, 1.01)
leo1	0.05	(0.05, 0.15)	0.30	(0.10, 0.45)	0.05	(0.05, 0.2)	0.45	(0.10, 1.01)
leo2	0.05	(0, 0.1)	0.30	(0.10, 0.45)	0.05	(0, 0.1)	0.40	(0.10, 1.01)
leo4	0.05	(0.05, 0.2)	0.30	(0.15, 0.45)	0.1	(0.05, 0.25)	0.50	(0.15, 1.01)
leo5	0.1	(0, 0.2)	0.30	(0.15, 0.50)	0.1	(0.05, 0.3)	0.50	(0.20, 1.01)
leot	0	(0, 0.05)	0.35	(0.05, 0.45)	0	(0, 0.05)	0.45	(0.05, 1.01)
scl	0.05	(0, 0.15)	0.30	(0.10, 0.45)	0.05	(0, 0.15)	0.45	(0.10, 1.01)
seg1	0.1	(0.05, 0.25)	0.35	(0.20, 0.50)	0.3	(0.05, 0.55)	0.70	(0.40, 1.06)
seg 2	0.15	(0.05, 0.25)	0.35	(0.20, 0.50)	0.25	(0.1, 0.55)	0.70	(0.35, 1.06)
sex	0.15	(0.05, 0.3)	0.35	(0.25, 0.50)	0.25	(0.1, 0.55)	0.70	(0.35, 1.06)
uma1	0.05	(0.05, 0.2)	0.30	(0.10, 0.45)	0.1	(0.05, 0.25)	0.45	(0.15, 1.01)
uma2	0.15	(0.05, 0.3)	0.35	(0.25, 0.50)	0.25	(0.1, 0.6)	0.75	(0.40, 1.11)
umi	0.05	(0, 0.15)	0.30	(0.10, 0.45)	0.05	(0, 0.2)	0.45	(0.10, 1.01)
wil1	0.05	(0, 0.15)	0.30	(0.10, 0.45)	0.05	(0, 0.2)	0.45	(0.10, 1.01)

Open-source tool

https://github.com/IndirectDarkMatterSearchesIFAE/

git clone https://github.com/IndirectDarkMatterSearchesIFAE/ObservationOptimization.git

(a released version)
git checkout V1.0

…see hands-on slides from J. Palacio

Conclusions

Method to optimize the pointing strategy:

- Useful to schedule observations
- General for ALL sources and/or IACTs
- Freely distributed Github
- Implementation on indirect dark matter searches

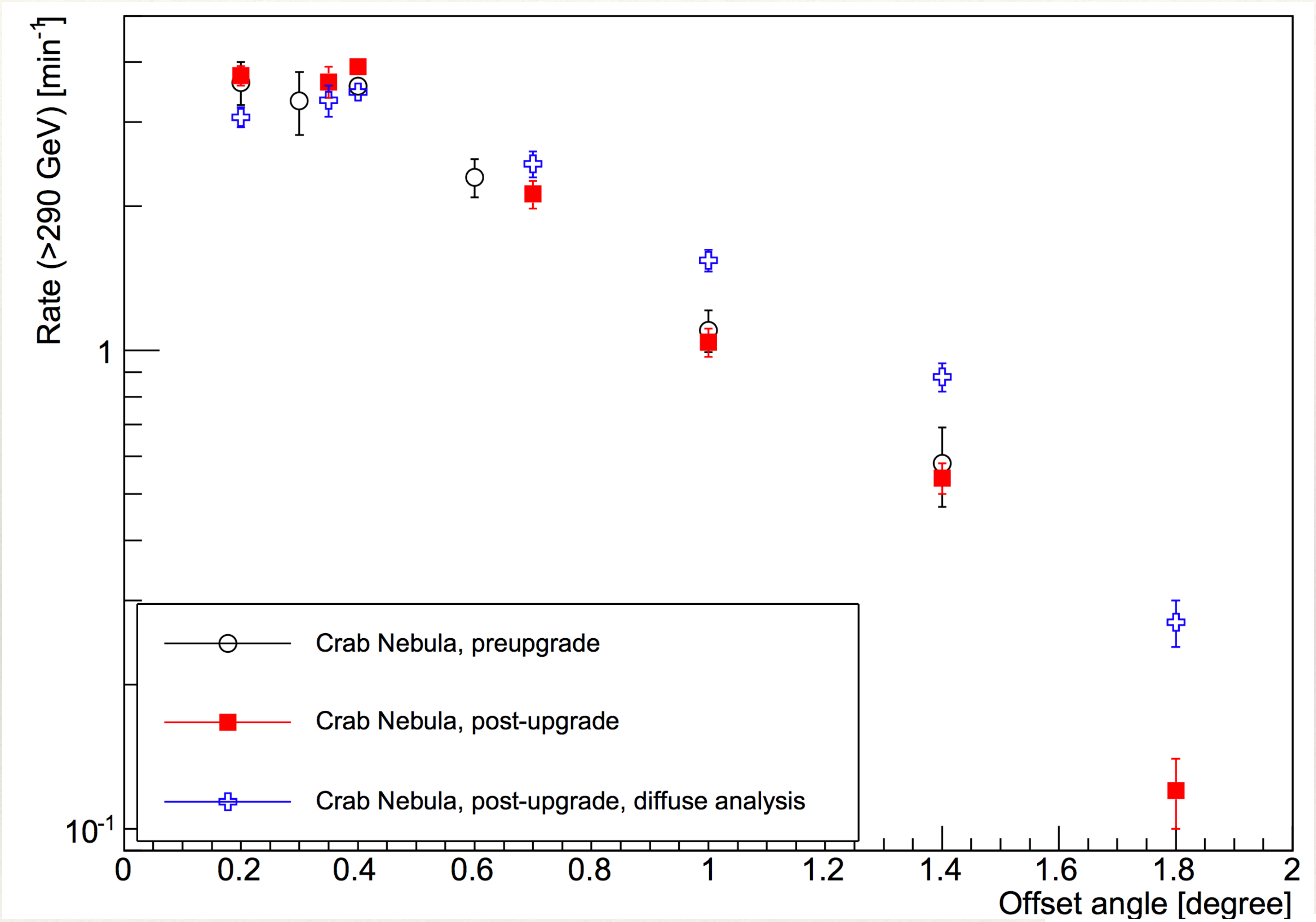
For more info:

D. Navarro-Gironés, Pointing optimisation for IACTs on indirect dark matter searches, **bachelor thesis UAB (2018)**

J. Palacio, D. Navarro-Gironés and **J. Rico**, Pointing optimisation for IACTs on indirect dark matter searches, Astroparticle Physics, **104 (2019) 84-90**

Back Up slides

Off-axis performance: The MAGIC Telescopes

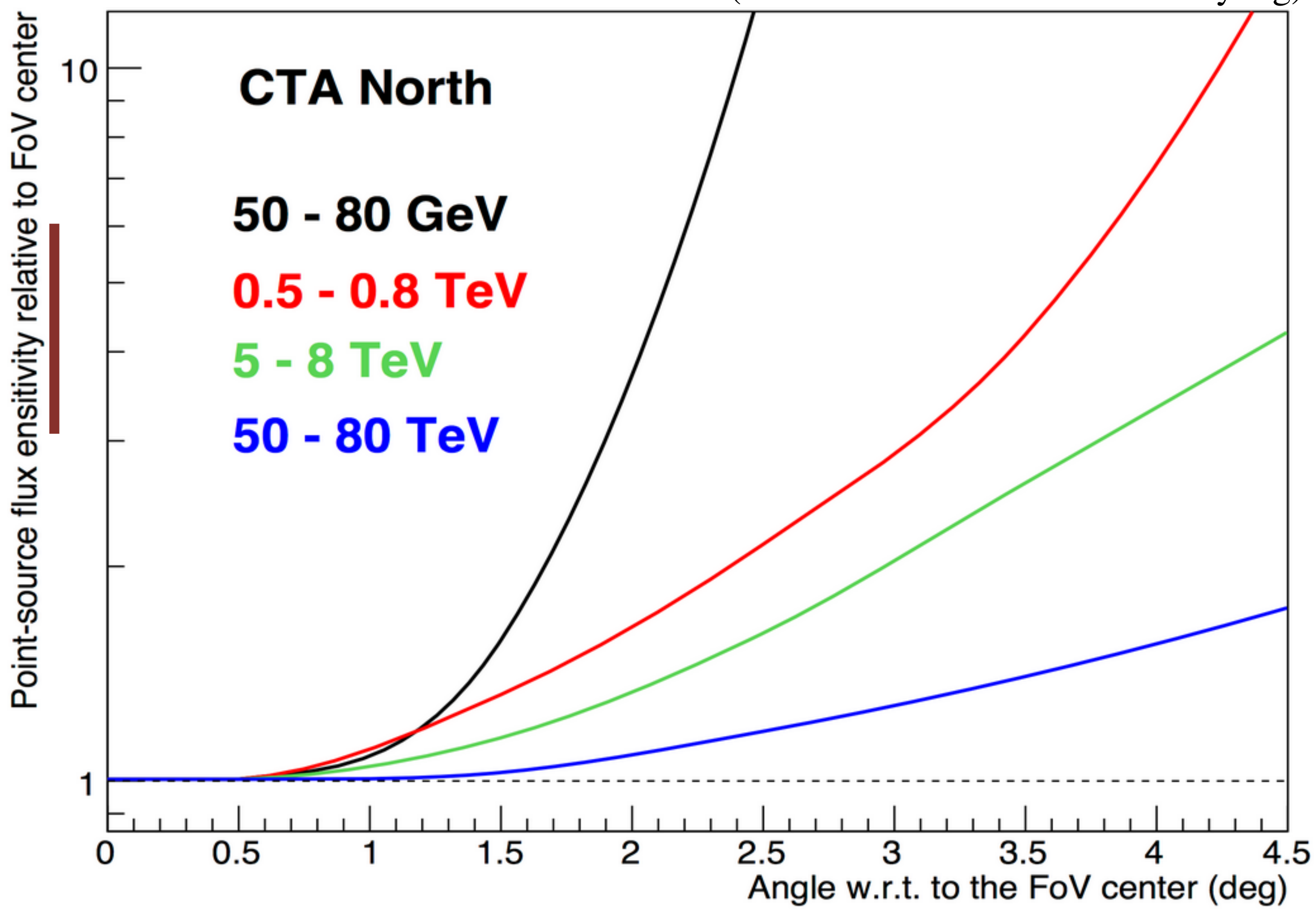


$(= d)$

Off-axis performance: The Cherenkov Telescope Array

$(=\delta)$

(taken from www.cta-observatory.org)



$(=d)$

$$\delta(d) = \frac{\mathcal{S}(d)}{\mathcal{S}(d=0)}$$

$$\mathcal{S}(d) \propto \left(\frac{N_{\mathrm{ON}}(d)}{\sqrt{N_{\mathrm{OFF}}(d)}}\right)^{-1}$$

$$\epsilon_{\mathrm{CTA}}(d) = \frac{1}{\delta^2(d)}$$