Influence of Site Characteristics on Instrument Sensitivity & Multiwavelength Environment

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Site Selection Committee Meeting - April 2013

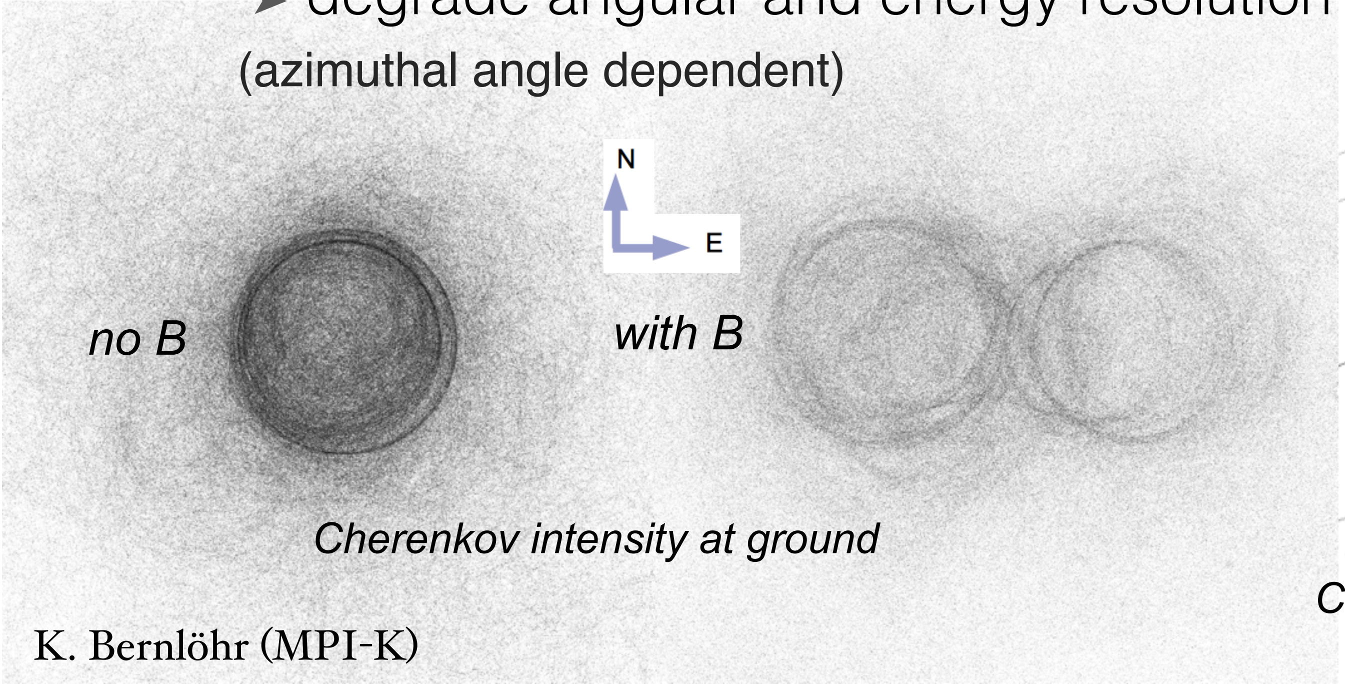
Instrument Sensitivity

3 Instrument Sensitivity

- Many site-dependent impacts on overall instrument performance
    - ➤ Atmospheric clarity
    - ➤ Number of clear nights / year
    - ➤ Light pollution
    - ➤ Cost ➔ number of telescopes at fixed cost
    - ➤ …
- All considered already as part of site selection – additional considerations addressed here:
    - ➤ Altitude
    - ➤ Geomagnetic field
    - ➤ (Atmospheric density profile)

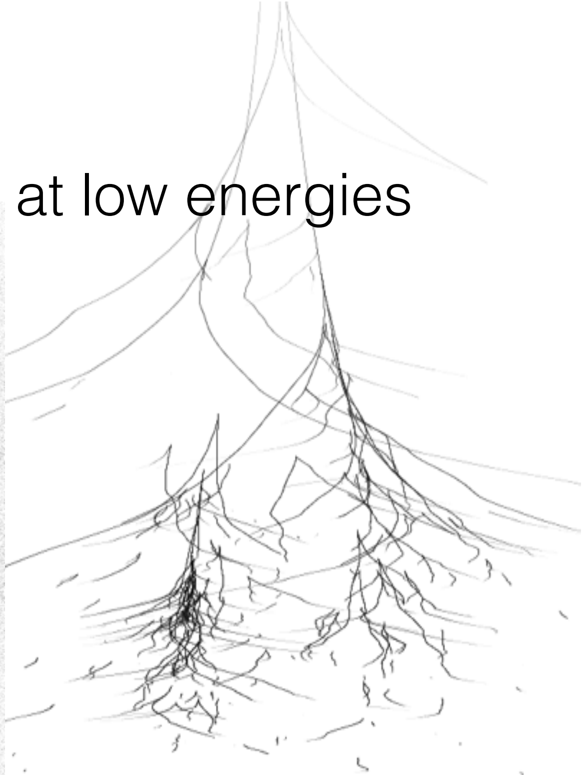
Geomagnetic Effects

- Separation of e^+ and e^- in air-showers
  - distortion of the Cherenkov light pool on the ground
  - distortion of Cherenkov image shapes
- In general higher B-fields will
  - increase energy thresholds slightly and
  - degrade angular and energy resolution at low energies (azimuthal angle dependent)



Cherenkov intensity at ground

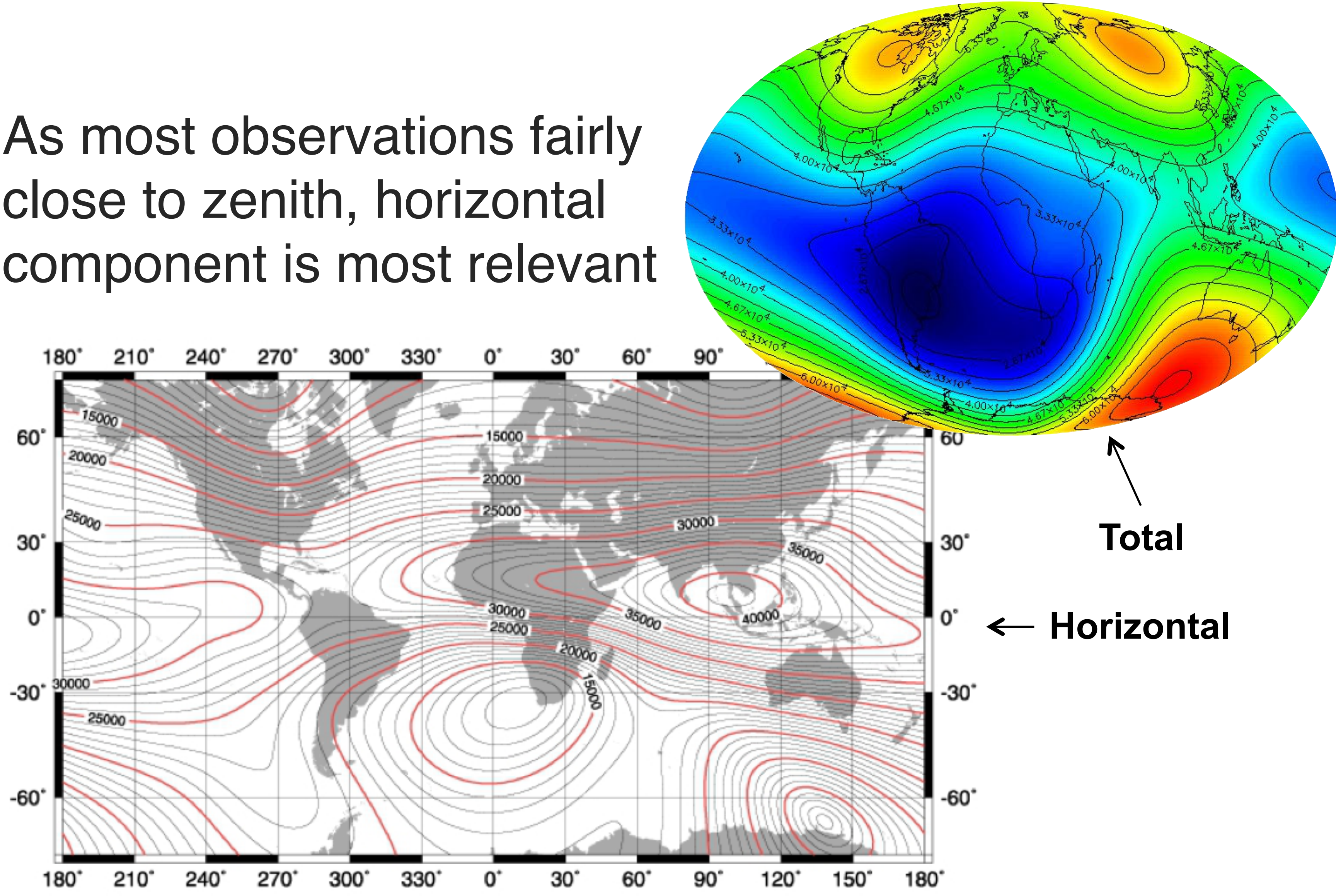
K. Bernlöhr (MPI-K)



Cherenkov-emitting particles

Geomagnetic Field

- As most observations fairly close to zenith, horizontal component is most relevant

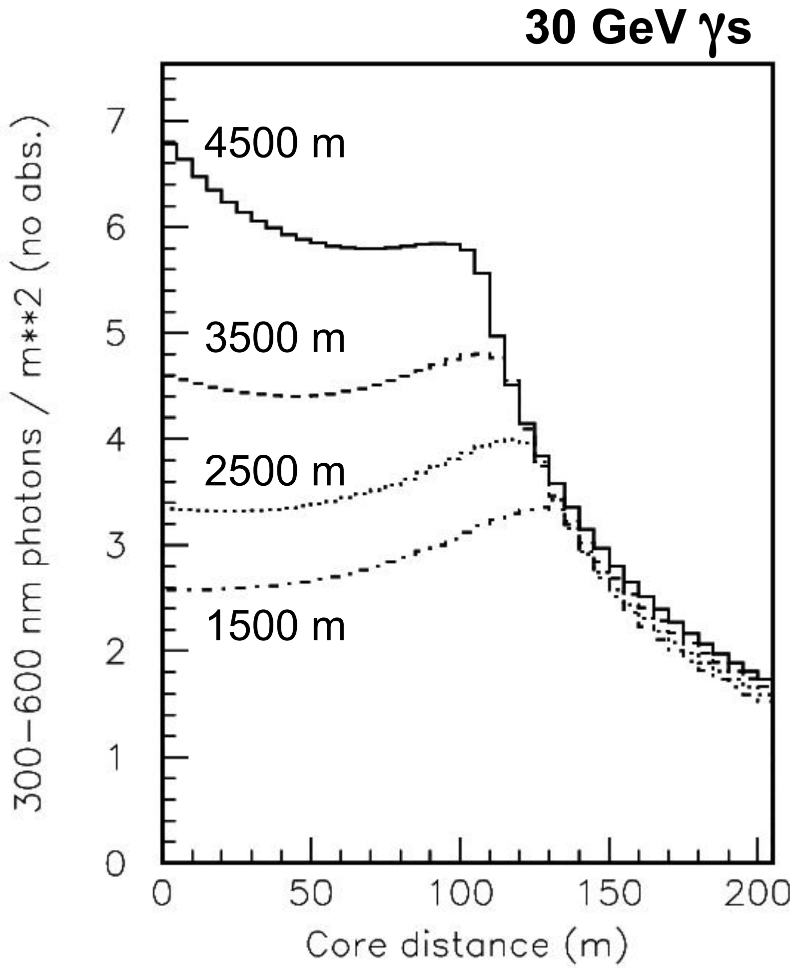


Total

Horizontal

6 Altitude Effects

- For a higher altitude site
    - Less atmosphere between emission site and observer
        - *Less absorption*
        - *(higher NSB)*
    - Smaller distance to emission site
        - *Peak Cherenkov density higher*
        - *Smaller pool of light*
        - *Larger angular offset of peak Cherenkov emission*
    - More light from ground-level particles



K. Bernlöhr
(MPI-K)

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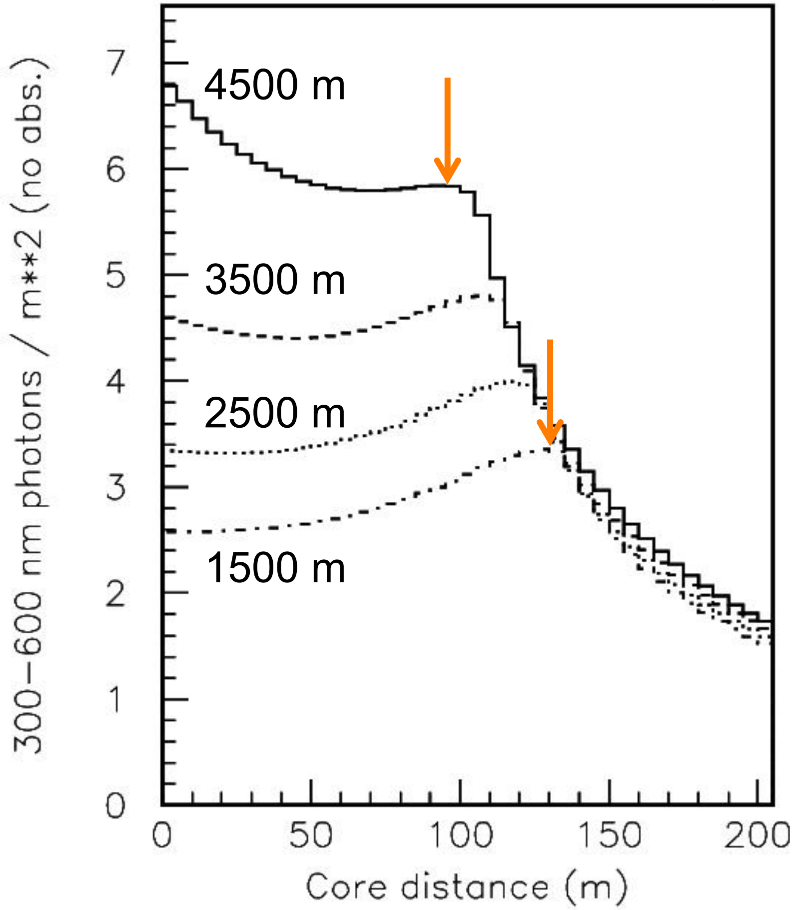
30 GeV γs



8 Altitude Effects

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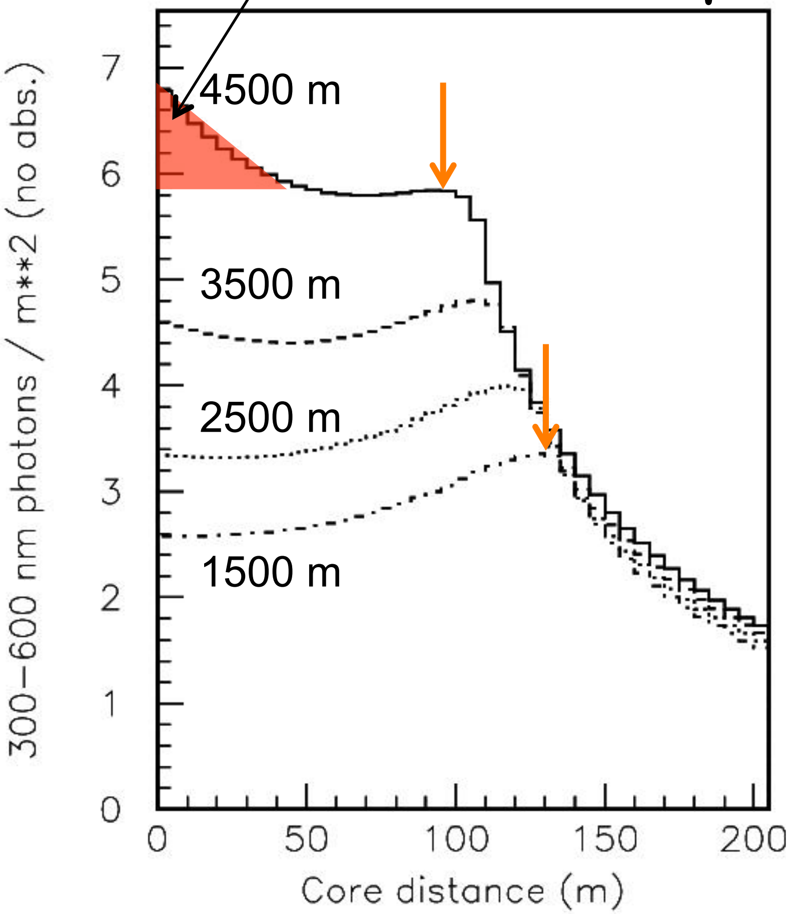
Ground-level particles - large fluctuations

30 GeV γs



K. Bernlöhr
(MPI-K)

9 Altitude Effects

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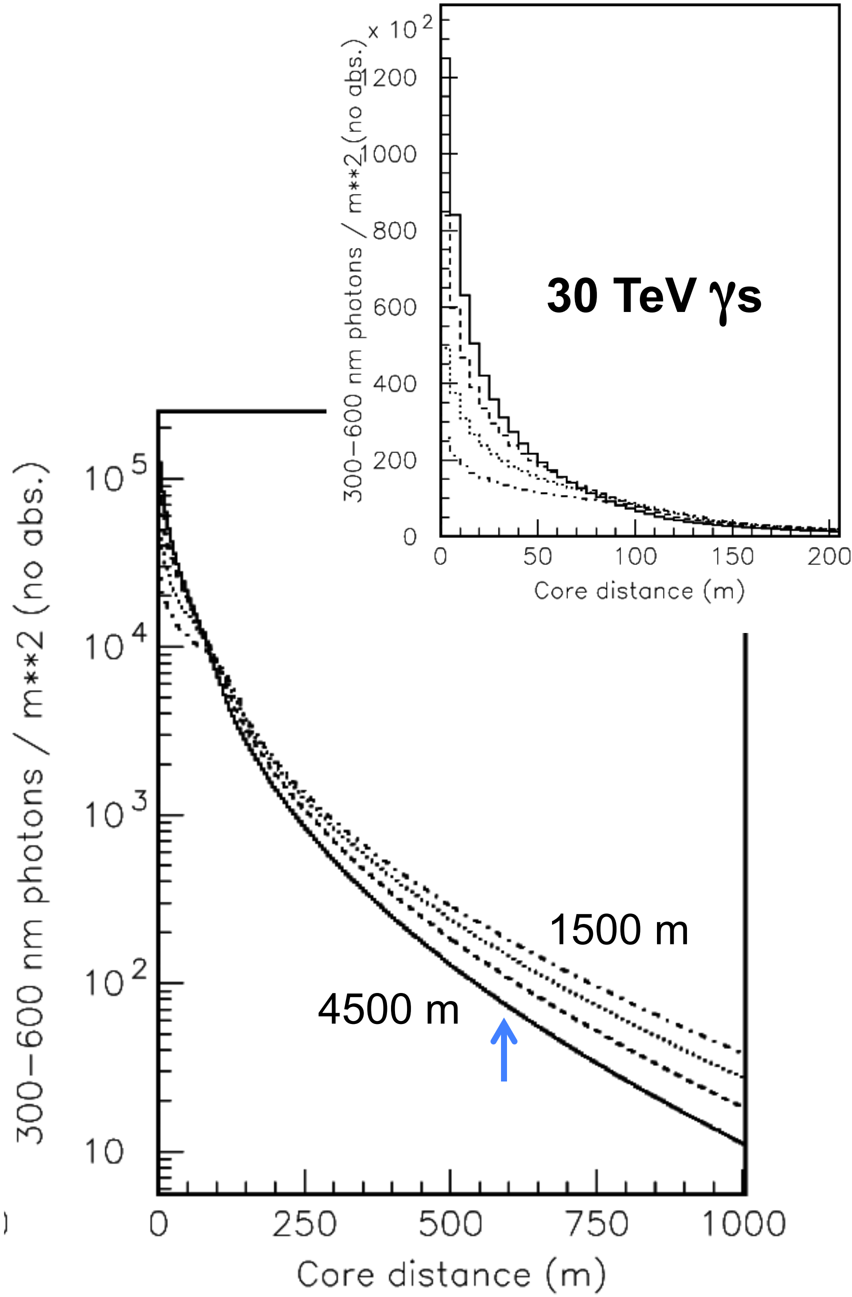

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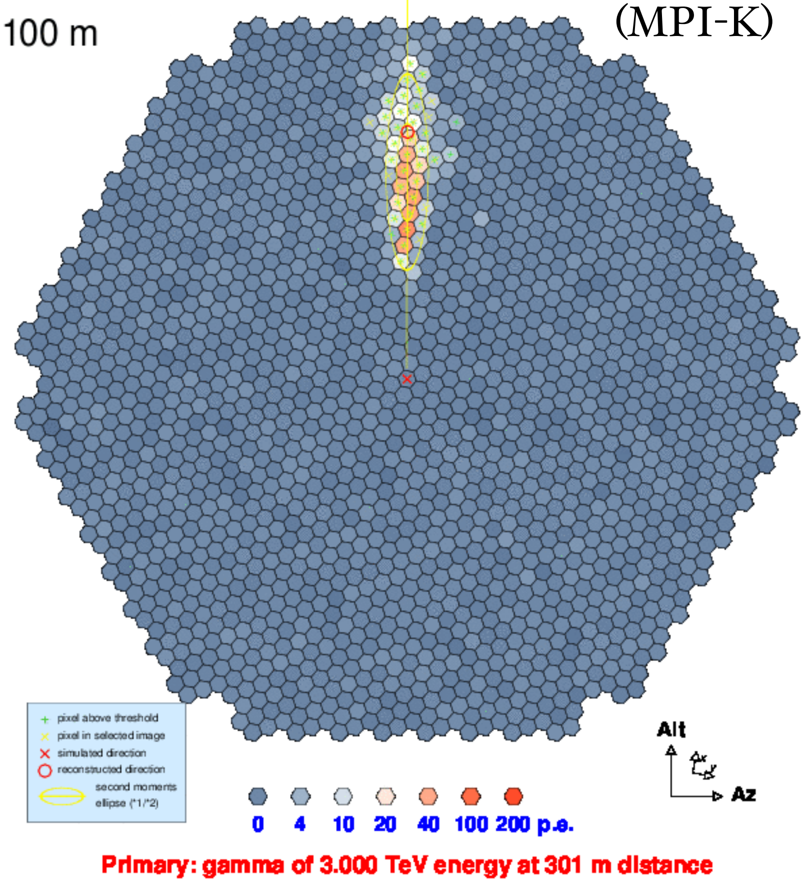
(MPI-K)

Altitude Effects

- Low energies
  - Higher altitude better
    - *As long as not too high (shower tail particles) - <4 km*
- High energies
  - Lower altitude better
    - *Larger Cherenkov footprint*
    - *Smaller angular offsets in FoV*
- Intermediate energies
  - Trade-off between more light at small impact distance and reduced multiplicity + ground-level particles

(movie)

K. Bernlöhr
(MPI-K)



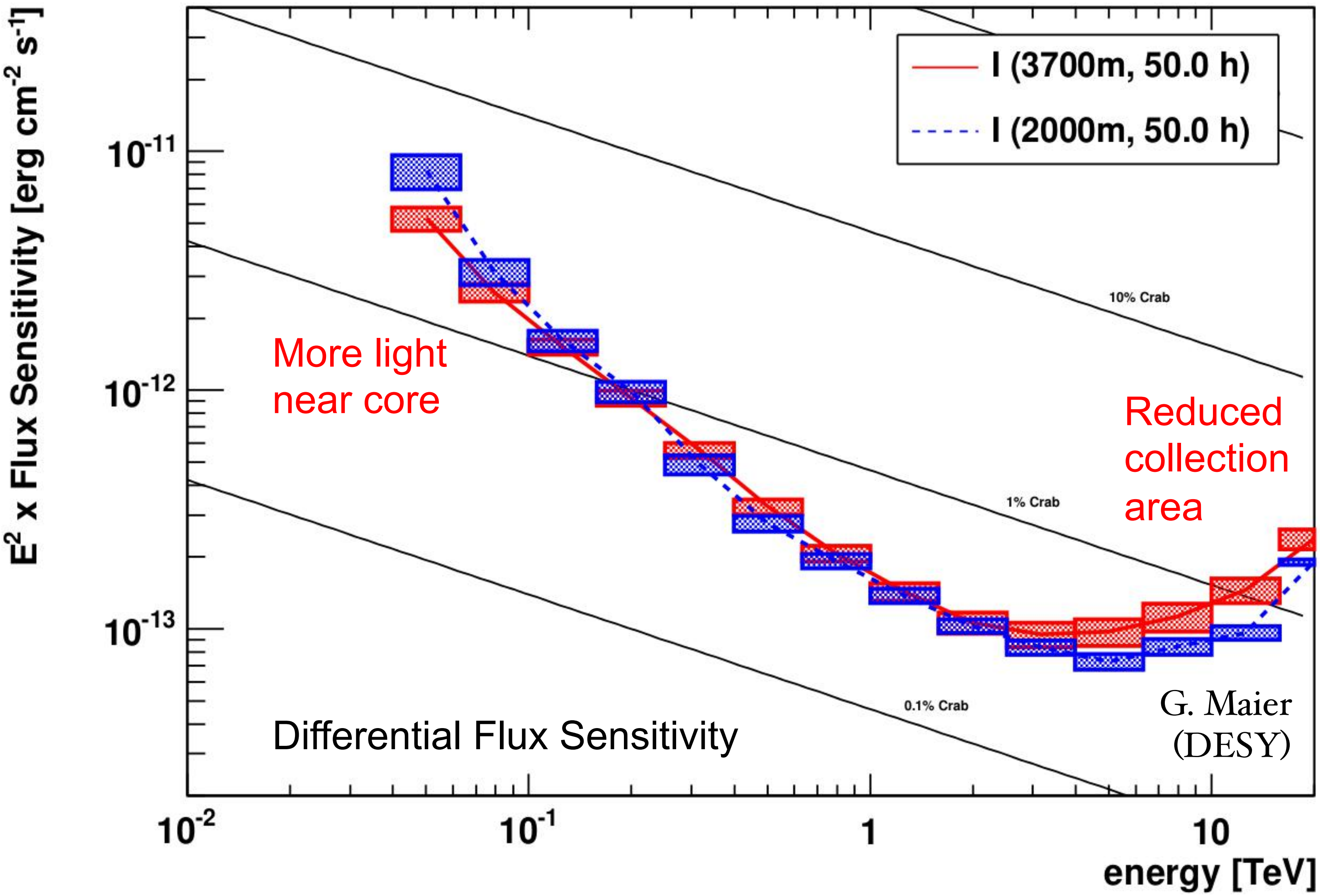
Threshold for LSTs

- *LSTs are targeted at low energy performance*
  - *20 GeV to 1 TeV*
  - *Work effectively alone below 50 GeV*
  - *This is where most geomagnetic effects are felt*
  - *Dedicated study with just LSTs:* ***arXiv:1302.6387***

	Site		Altitude	H (μT)	Et (GeV)
MEX	**San Pedro Martir**	**N**	2434	25.3	20.0
ESP	**Izana**	**N**	2290	30.6	21.1
USA	**Meteor Crater**	**N**	1680	23.6	*25.6*
USA	**Yavapai 9**	**N**	1630	23.6	*25.6*
ARG	**San Anotonio**	**S**	3610	21.1	14.4
ARG	**Leoncito**	**S**	2640	20.1	17.6
CHIL	**Armazones**	**S**	2500	21.5	*19.8*
NAM	**HESS**	**S**	1810	12.1	21.0
NAM	**Aar**	**S**	1650	11.0	21.4

Italics=based on parameterisation

CTA Sensitivity



More light near core

Reduced collection area

Differential Flux Sensitivity

G. Maier (DESY)

Array "I" Prod-1

Next Steps

- Production-2 Configuration
  - Refined layout, updated telescope parameters
- Simulations tuned to (ideal) sites (altitude, density profile, extinction, NSB, geomagnetic field)
  - 2600 m – Leoncito
  - 1600 m – Aar
  - 3600 m – Salta

Should be complete by late June

- Can also be considered as representative of other sites at similar altitudes
  - Except close to threshold – geomag. – separate study
- Optimisation
  - Well tune telescope spacing based on smaller studies

Multi-wavelength Environment

Multi-wavelength Needs

- Non-thermal continuum emission
  - need simultaneous observations for variable objects - and/or use other wavebands for alerts/triggers
- Information on the nature of TeV emitter
  - Class, environment, distance, …
  - No need for simultaneous obs. - except for need to observe transients whilst possible, e.g. GRB afterglows
- Key MWL considerations for CTA (site):
  - GRB: alerts/positions (hard/soft X-ray)
  - AGN: radio→gamma-ray time-dep. SED, optical++ alerts, follow-up (redshifts, host-galaxies, …),
  - Galactic binaries, Galactic Centre: X-ray, NIR, radio…

MWL: Ground-based

- Local Facilities
    - Same objects at same zenith angles at the same time
    - Same weather
    - Usually important only for optical and NIR instruments
- Regional Facilities
    - Same sources observable at a given time (given good weather in both places)

MWL: Ground-based

	Site					Local MWL	Regional MWL	Comments
MEX	**San Pedro Martir**	N	31.014	W	115.480	SPM (2m optical)	LBT, Kitt Peak, VLA+GBT, +	Very good optical and radio
USA	**Meteor Crater**	N	35.043	W	111.037	Lowell Obs (4m optical)	LBT, Kitt Peak, VLA+GBT, +	Very good optical and radio
USA	**Yavapai 9**	N	35.139	W	112.874	-	LBT, Kitt Peak, VLA+GBT, +	Very good optical and radio
ESP	**Izana**	N	28.277	W	16.536	~1m optical telescopes	ORM LOFAR, +	Very good optical and radio
ARG	**San Anotonio**	S	24.045	W	66.235	-	La Silla, Panchon, Paranal, ALMA	Excellent optical, mm
ARG	**Leoncito**	S	31.722	W	69.265	CASLEO (2m optical+)	La Silla, Panchon, Paranal, ALMA	Excellent optical, mm
CHIL	**Armazones**	S	24.567	W	70.200	(E-ELT), Paranal	La Silla, Panchon, ALMA	Excellent optical, mm
NAM	**HESS**	S	23.272	E	16.500	ATOM (0.8m optical)	SAAO, Meerkat, (SKA)	Excellent radio
NAM	**Aar**	S	26.692	E	16.441	-	SAAO, Meerkat, (SKA)	Excellent radio

ORM	GTC, WHT, LT
Kitt Peak	4m, 3.5m, 2.1m
La Silla	NTT, 3.6m, 2.2m
Paranal	VLT, VISTA
Armazones	(E-ELT)
Pachón	Gemini, (LSST)
SAAO	SALT, 1.9m, 1.0m

See also CTA "Scientific Requirements" (SCI-LINK/121120) Appendix C

Notes:

- Availability as well as performance is a key consideration for value to CTA of a facility
- Optical/NIR instrumentation is key, but evolving on the CTA timescale
- A wide altitude range is covered by radio facilities (very large region covered)
- A dedicated local optical (and/or NIR) facility could be built for CTA

Satellites

- Some longitude effects due to SAA for current instruments such as Swift and Fermi
  - GRB alerts as primary consideration - less impact on longer term variability studies
    - *Future missions such as SVOM likely to have similar orbits*
- Look for an effect in number of previous alerts visible at each site
  - Marginally significant Africa – America effect (~15%)

Site	**Swift**	**GBM**	**Total**	**%**	**Error**
Izana	88	130	218	103	7
Yavapai/MC	84	126	210	100	7
San Pedro	78	126	204	97	7
SAC/Arm.	80	121	201	95	7
Leoncito	79	120	199	94	7
Aar/HESS	93	140	233	111	7
Mean	83.7	127.2	210.8		

Swift and GBM alerts which would have been observable at night at altitude>30 degrees at a given site (from 719+1095 bursts)
Credit: Phil Evans (Swift Team)

Multi-messenger Facilities

- VHE neutrinos as indicator of proton acceleration, wide-field → alerts/transients (GRB, AGN)
  - IceCube: similar latitudes of site candidates = equal coverage
  - KM3NeT (planned): South America favoured
    - ~60° separation from southern Africa - transient within 30° of zenith is above horizon for KM3NeT *(bad)*, ~100° separation from South American sites - most overhead transients below horizon for KM3NeT
- UHECR clusters/sources *(if found/proved)*
  - Many possibilities for associated TeV emission
  - Pierre Auger Observatory: no time-critical obs → no site sensitivity (in given hemisphere)
- GWs as indicators of merger/collapse of compact objects → jet formation → particle acceleration?
  - Larger error boxes over South America for current instruments

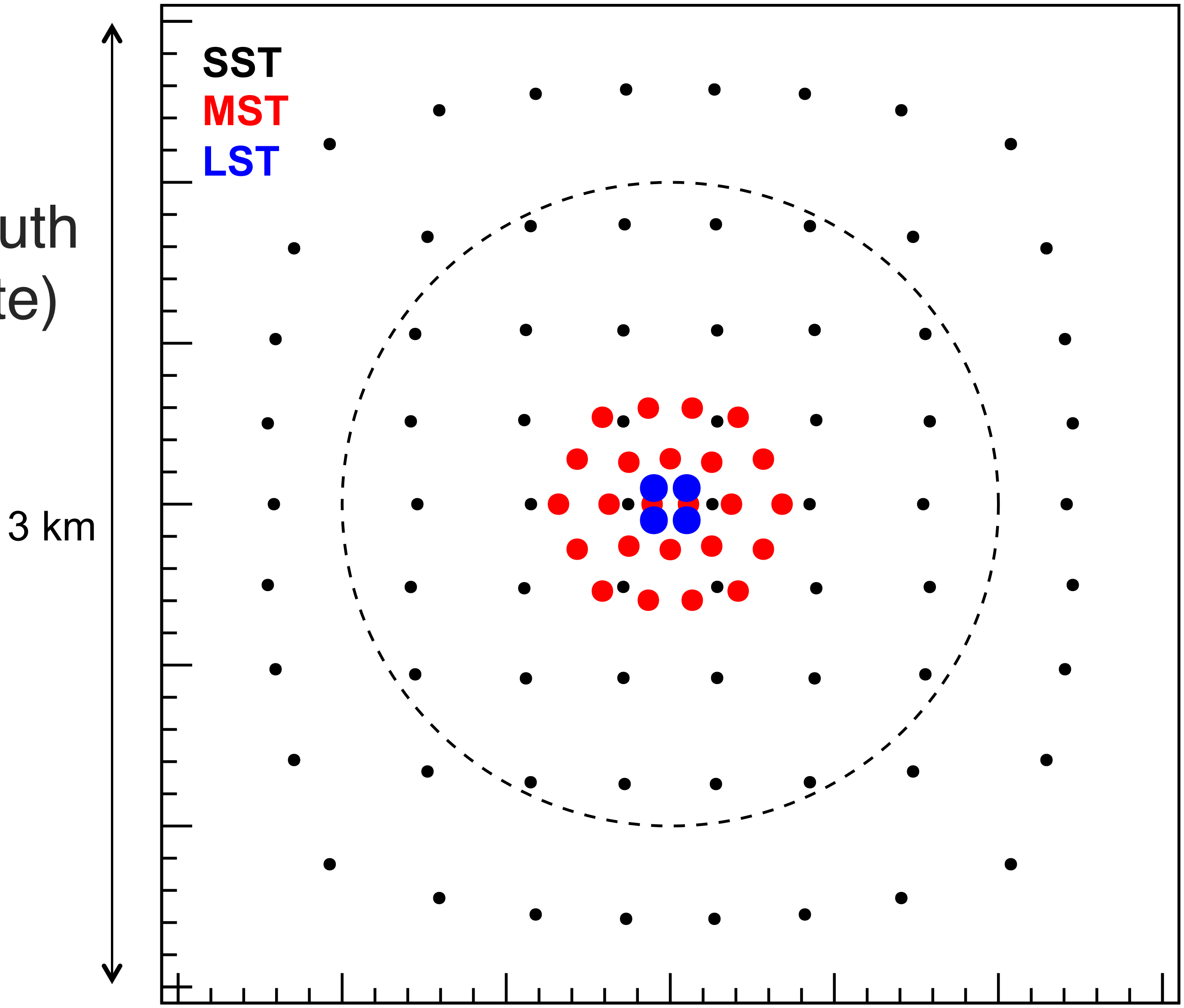
Summary

- Significant impact on instrument sensitivity and MWL/MM environment from site choice
  - But – it is clear that no site should be excluded from consideration on these grounds – all can meet required performance and have high quality MWL coverage
- Weighting of the many factors a difficult process
  - Good luck!
- Additional input will be provided in a few months
  - Performance details from new sims.
  - More complete MWL assessment

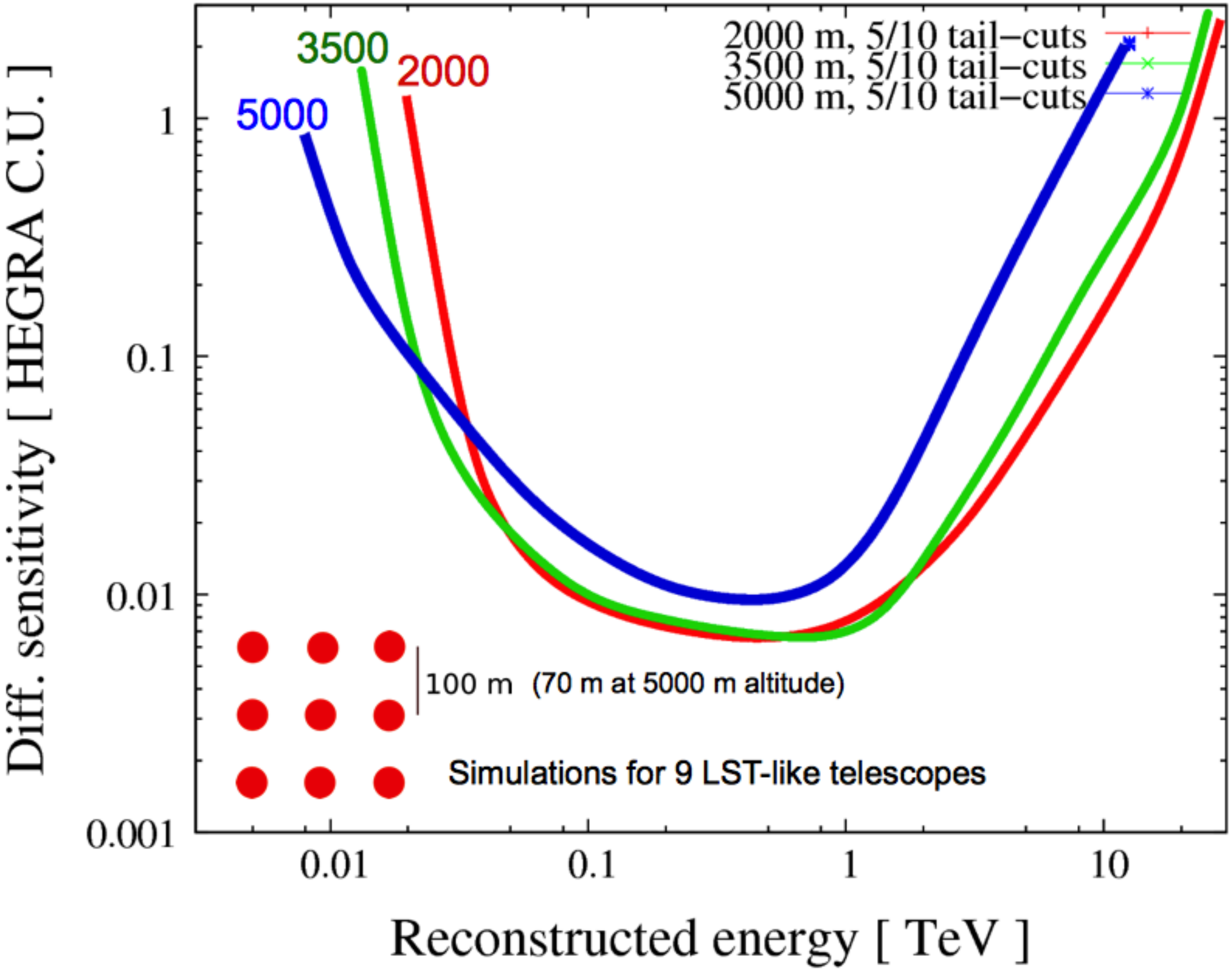
Additional Information

Example Layout/Subset

- Prod-2 Subset (CTA South Candidate)



Very high altitudes



Older simulation for a system of 9 telescopes of 24 m diameter.

Trend low → high: lower energy threshold but less effective area.

Very high altitudes have the problem that extend down to the telescopes and then are more difficult to distinguish from hadron showers.

Angular Resolution

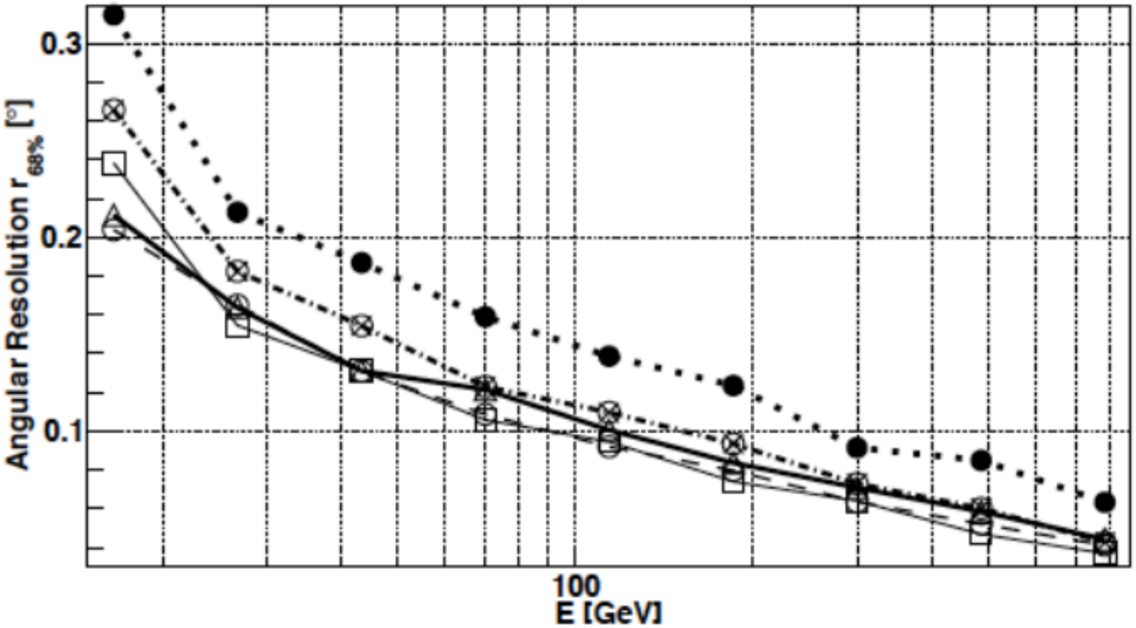
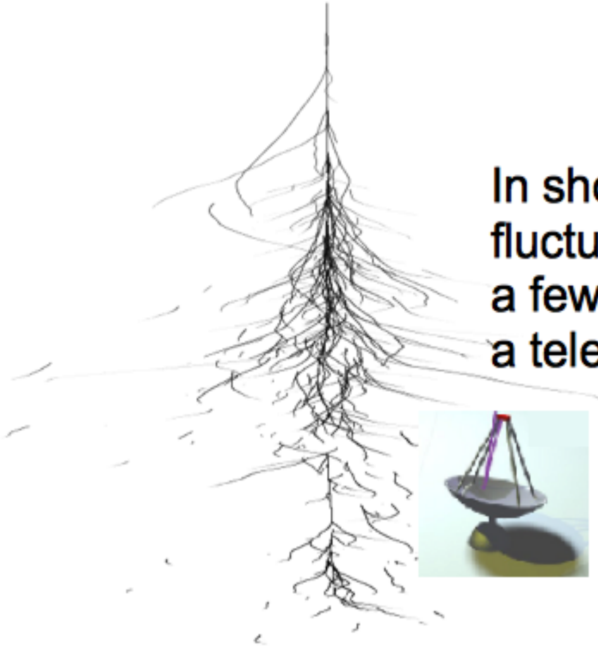


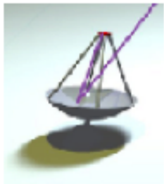
Figure 12: Angular resolution as a function of energy for the 68% containment radius. Three sites are presented: Argentina-Salta without GF (thick-solid line with triangles), Namibia without GF (thinner solid line with boxes), Tenerife without GF (dashed line with empty circles), Tenerife with GF at $\phi = 0°$ (dot-dashed line with starred circles) and Tenerife with GF at $\phi = 180°$ (dotted line with filled circles). The energy-dependent cuts in *Size* are used (e.g. 85, 300 and 2000 pe (per telescope) for 20, 300 and 500 GeV, respectively).

Examples of shower development

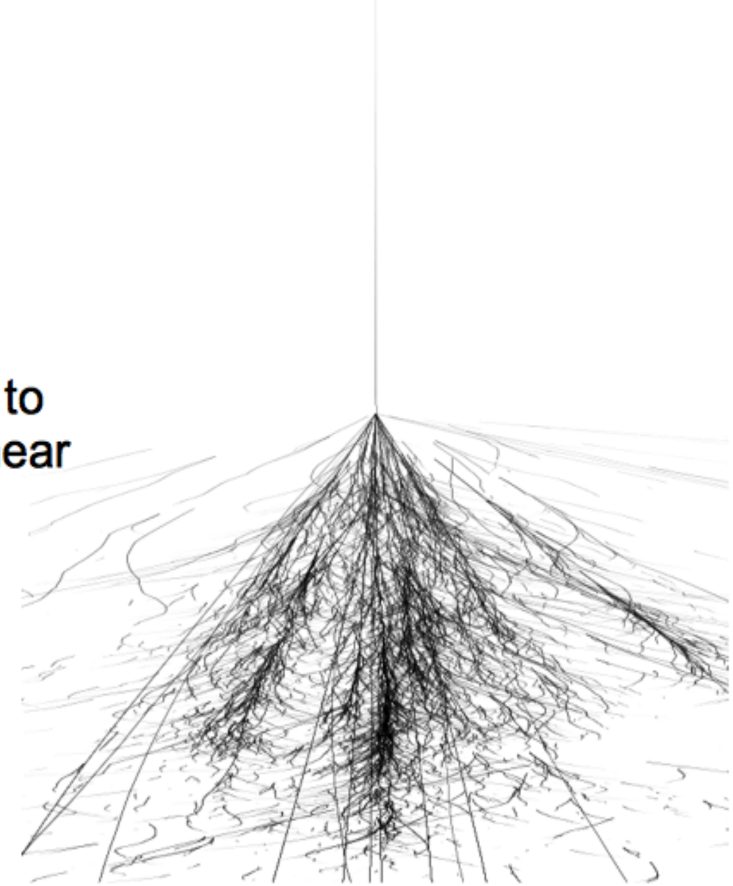
Image of a shower depends not only on the type of particle initiating a shower but also on how close to the shower your telescope is located.



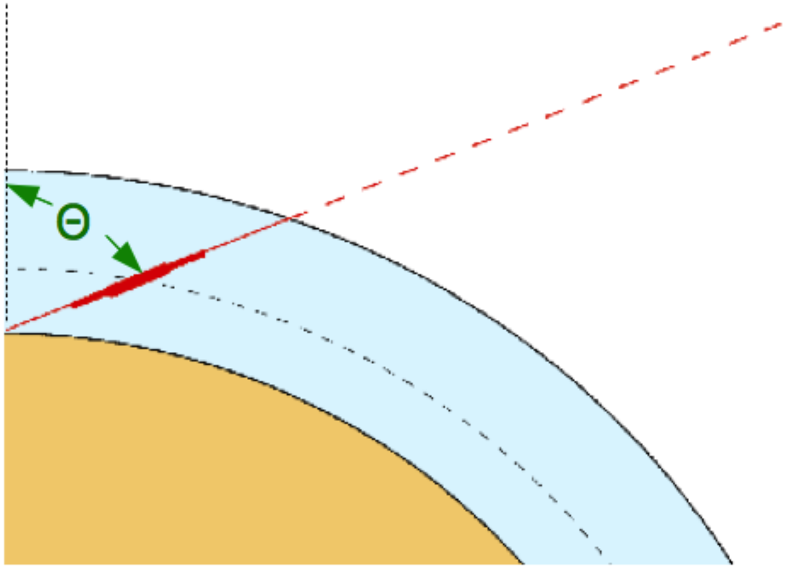
In shower: large fluctuations due to a few particles near a telescope.

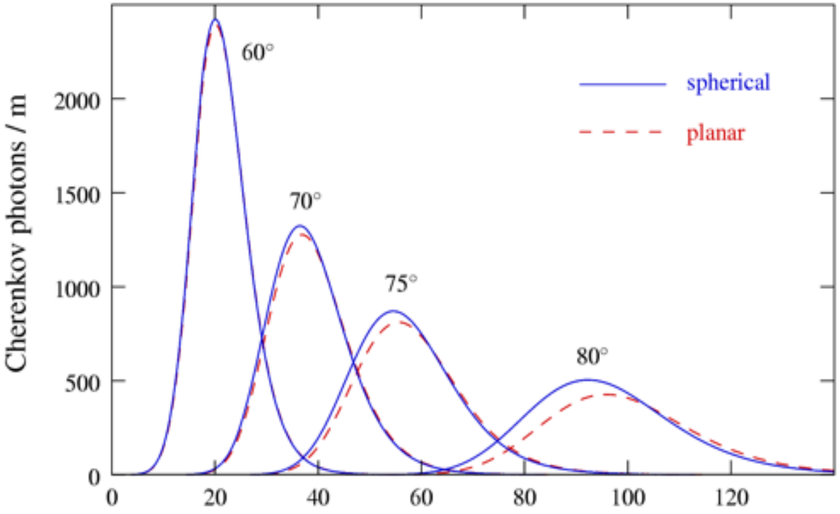


Behind/outside shower: Cherenkov light is more diluted at low altitude.



Altitude impact at large zenith angles





At large zenith angles, the shower maximum is always far from the telescopes.
→ The altitude dependence of this distance is much weaker than for small zenith angles.

The impact of extinction is somewhat stronger at large zenith angles.

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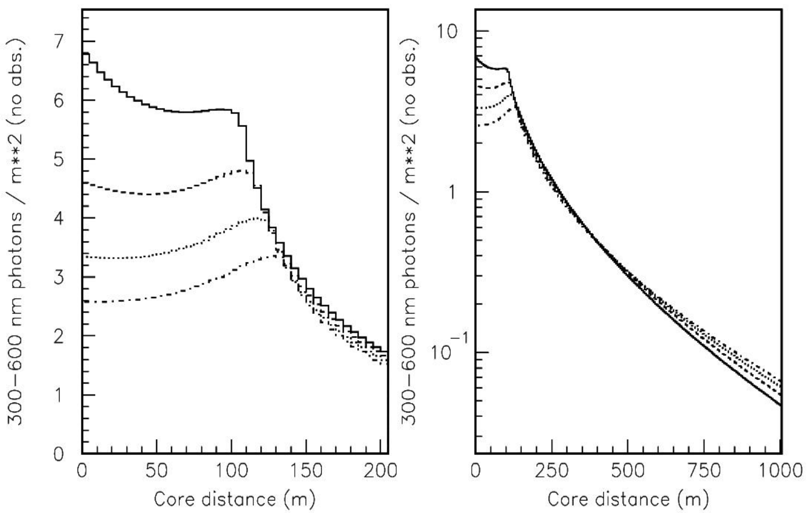
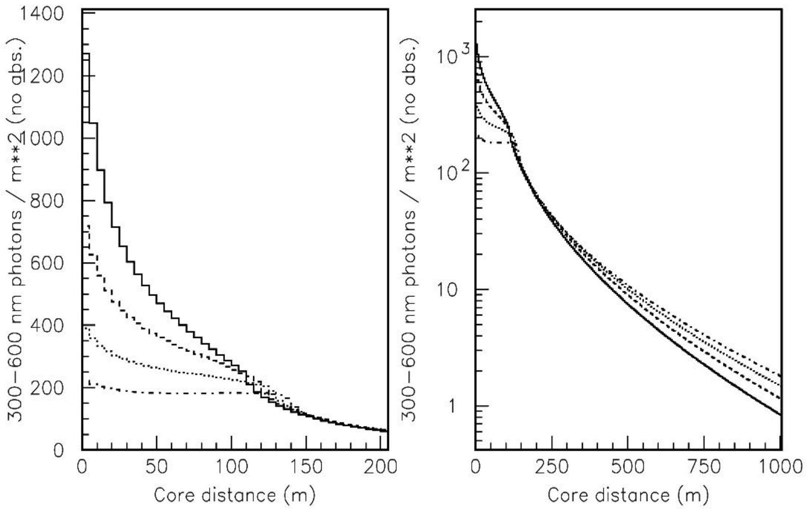


Lateral distributions for E = 30 GeV at h = 1500, 2500, 3500, and 4500 m



Lateral distributions for E = 1 TeV at h = 1500, 2500, 3500, and 4500 m

Ground-based:wavebands

- Radio
  - Major synergy CTA/SKA for steady sources
  - Variability timescales typically rather long (e.g. GRB, AGN), but radio transients explored by LOFAR -> SKA
- mm-FIR
  - Synchrotron dominated SEDs rare at these wavelengths, excellent resolution helps, synergies with CTA on time-variable objects need to be explored – ALMA is the major ground-based facility
- NIR-optical
  - Non-thermal continuum emission and polarisation – TeV IC emitting electrons typically produce optical/UV synchrotron emission, variability can be fast