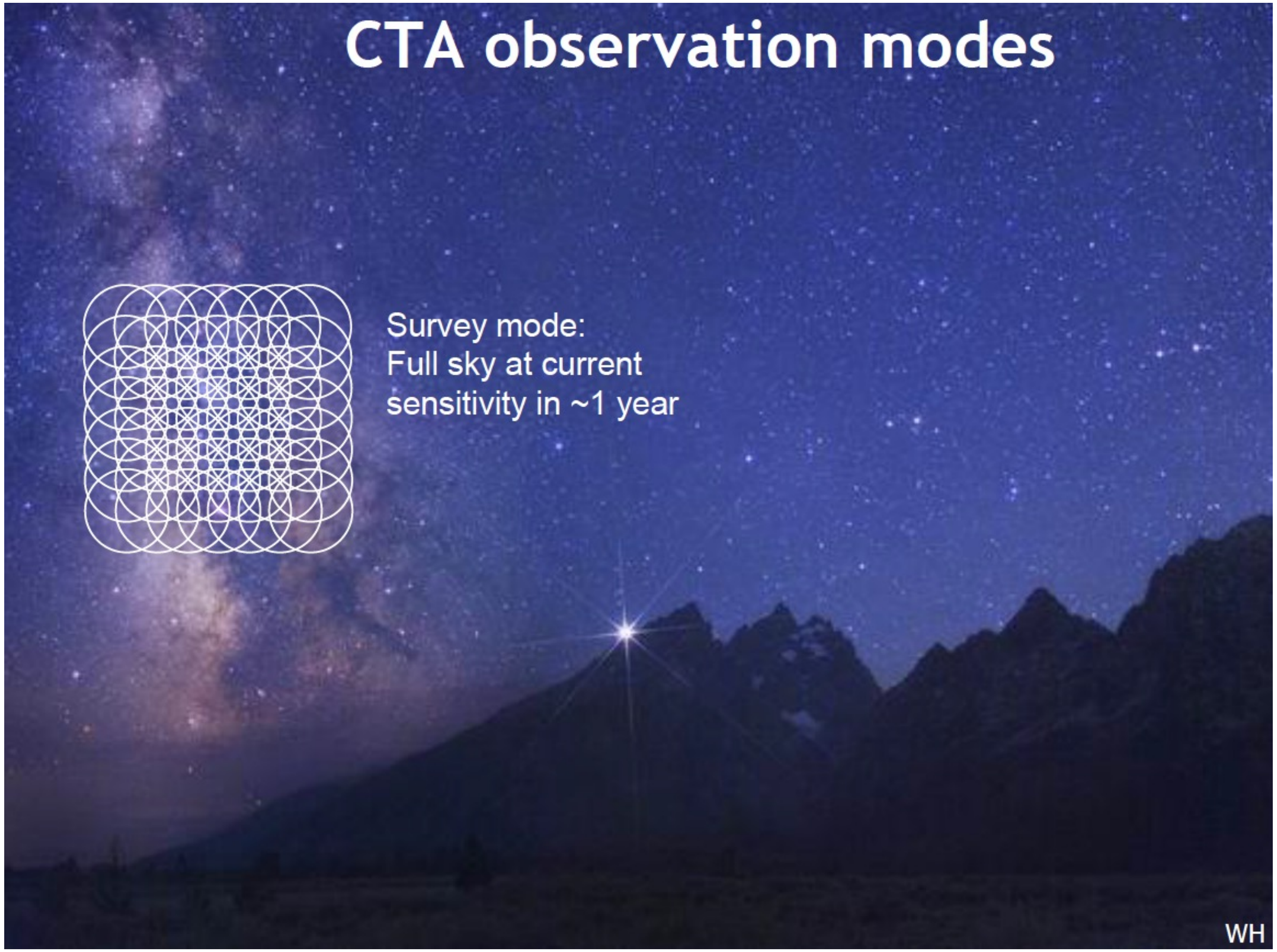
Science with the Divergent Pointing

Work in progress!!

Francesco Longo (Trieste) on behalf of many … within the CTAO simulation team

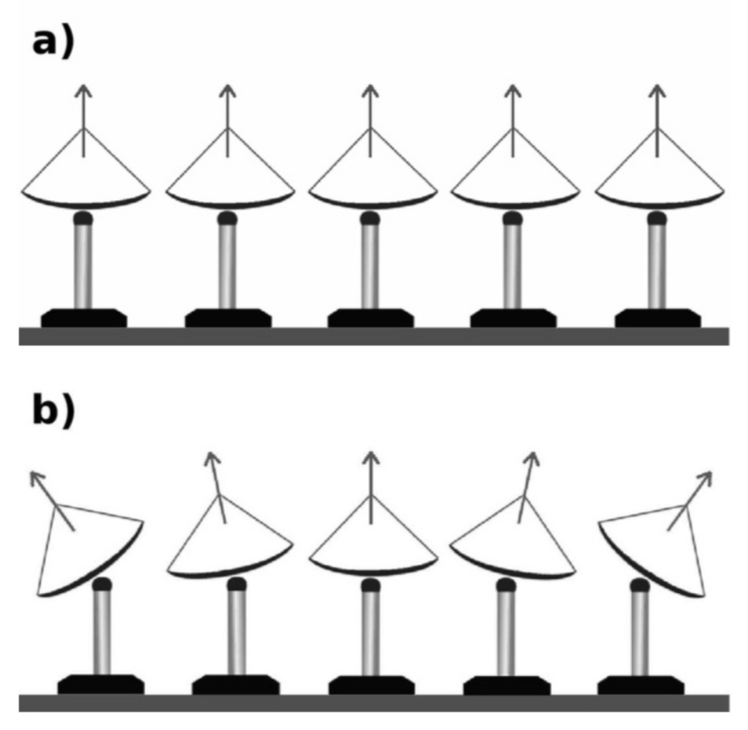
T.Vuillame, T.Gasparetto, A.Donini, I.Burelli, A.Iuliano, C.Aramo, Jahanvi, H.Luciani, D.Ambrosino et al.

What is the Divergent Pointing?



J.Hinton (2010)

What is the Divergent Pointing?



- Non-parallel pointing mode
  - Telescopes are inclined into the outward direction by an angle increasing with the telescope distance from the array center
- Pro:
  - Wider FoV
  - Reduce of observation time needed
- Cons:
  - Worse angular and energy resolution
- Why?
  - KSP: Extragalactic and Galactic Survey
  - Search for transient phenomena

What was done already?

CTAO

Divergent pointing with the Cherenkov Telescope Array for surveys and beyond

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The galactic and extragalactic surveys are two of the main proposed legacy projects of the Cherenkov Telescope Array (CTA), providing an unbiased view of the Universe at energies above tens of GeV. Considering Cherenkov telescopes' limited field of view ($< 10^\circ$), the time needed for those projects is large. The many telescopes of CTA will allow taking full advantage of new pointing modes in which telescopes point slightly offset from one another. This divergent pointing mode leads to an increase of the array field of view ($\sim 14^\circ$ or larger) with competitive performance compared to normal pointing. We present here a study of the performance of the divergent pointing for different array configurations and number of telescopes. We briefly discuss the prospect of using divergent pointing for surveys.

Gerard et al 2013-2015

What was done already?

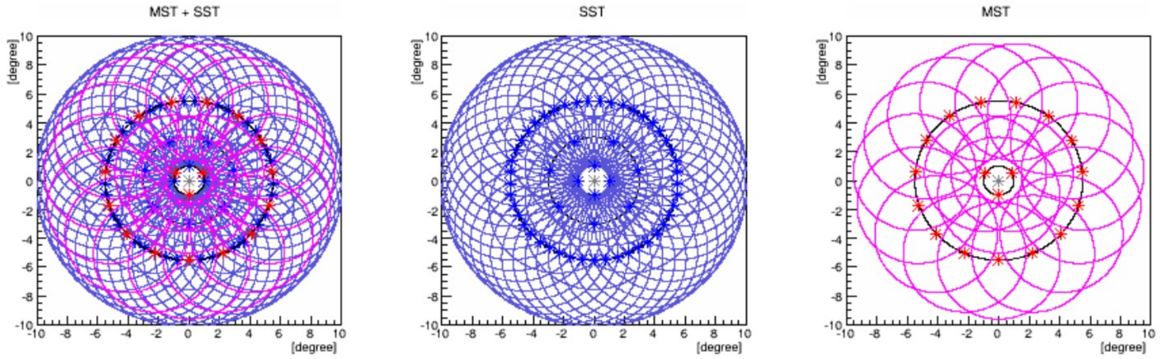

Figure 2: Pointing direction of the telescopes for the divergent mode, the circles represent the size of the telescopes field of view: 8° for MST and 9° for SST; the stars are the pointing directions.

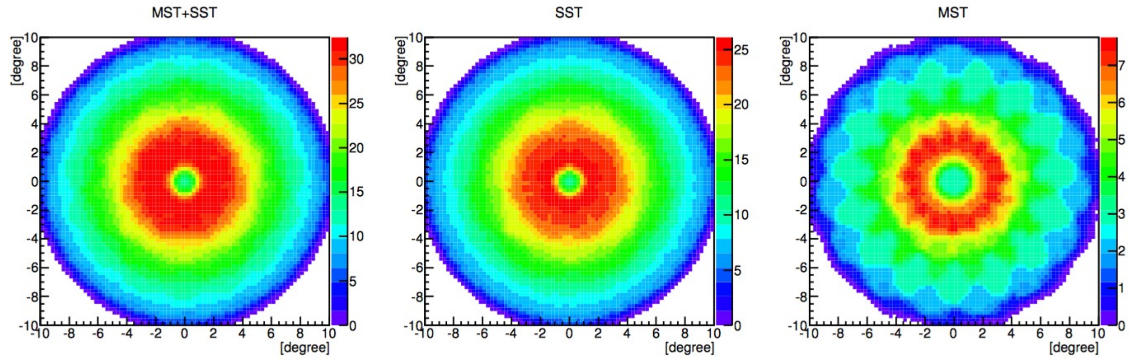

Figure 3: Divergent pointing field of view characteristics. The color scales represent the pointing mulitplic-ity.

Gerard et al 2013-2015

What was done already?

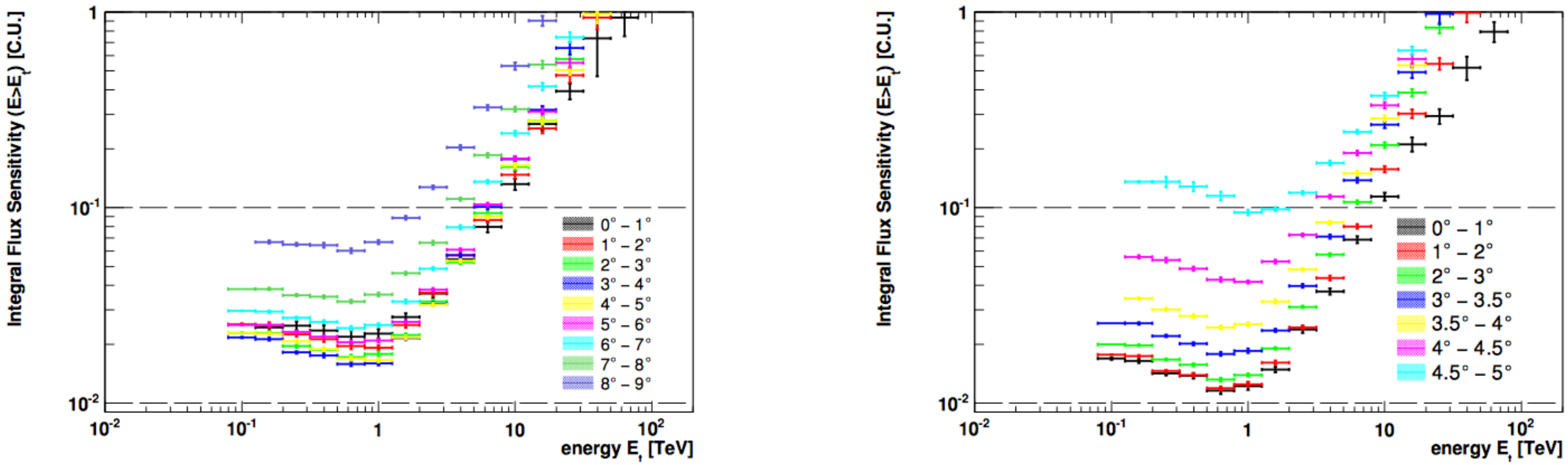

Figure 5: Integrated sensitivities at different distances to the center of the field of view. **Left:** 8 hours of observations with the divergent mode. **Right:** 2 hours of observations with the normal mode.

Gerard et al 2013-2015

What was done already?

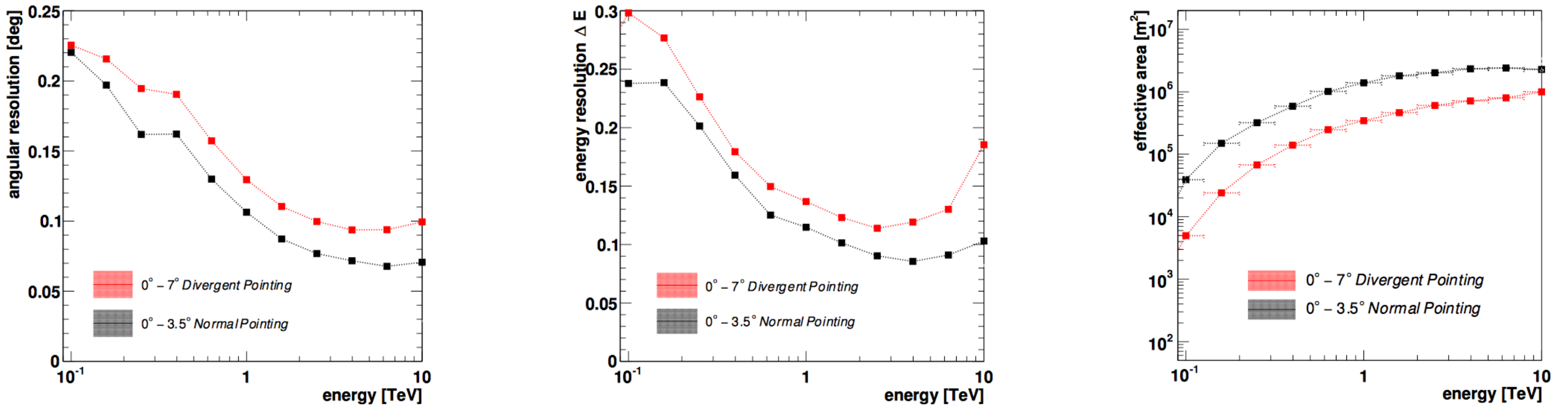

Figure 6: Performance within the divergent and normal pointing effective fields of view. From left to right, the angular resolution defined as the angle containing 68% of the reconstructed gammas, the energy resolution defined so that 68% of the gamma have their true energy within ΔE of their reconstructed energy and the effective area, after cuts and gamma hadron separation.

Gerard et al 2013-2015

What was done already?

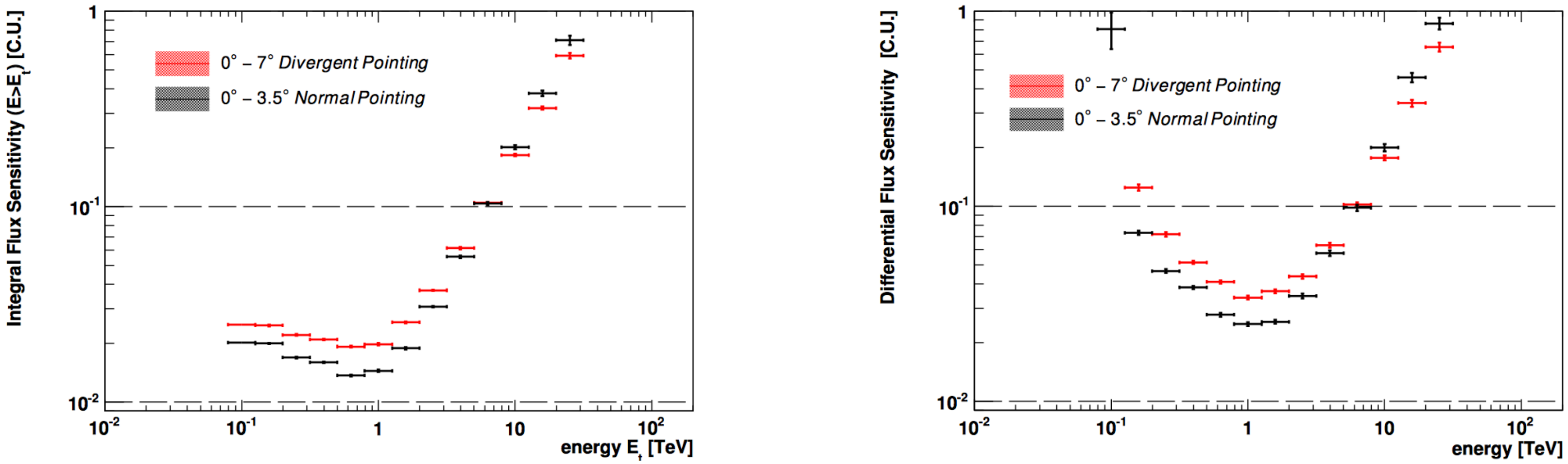

Figure 7: Left: Integrated sensitivities above the E_t. **Right** Differential sensitivities, within the energy range (5 bins per energy decade). The sensitivities are calculated within each mode effective fields of views, for 8 hours for the divergent mode and 2 hours for the normal mode, the ratio of the observation times corresponds to the ratio of the effective field of view areas.

Gerard et al 2013-2015

What was done already?

Monte Carlo simulations of alternative sky observation modes with the Cherenkov Telescope Array

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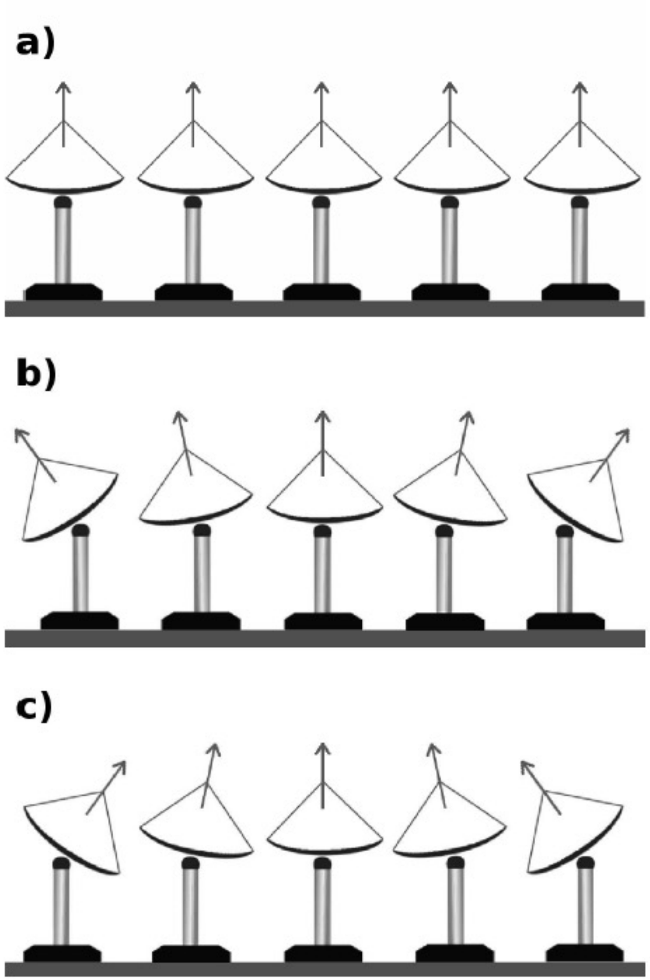
Abstract

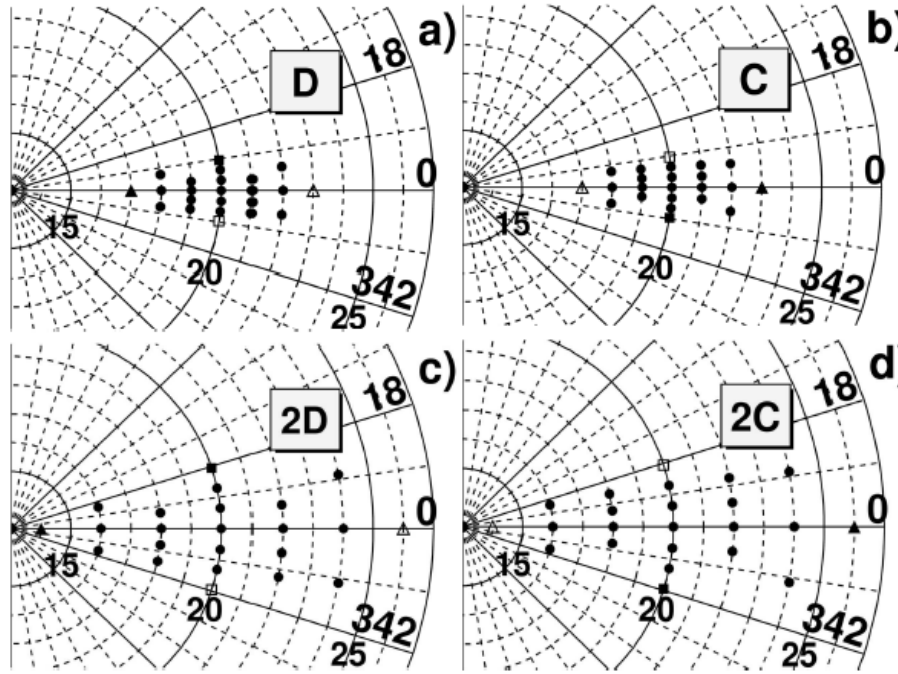
We investigate possible sky survey modes with the Middle Sized Telescopes (MST, aimed at covering the energy range from ~100 GeV to 10 TeV) subsystem of the Cherenkov Telescope Array (CTA). We use the standard CTA tools, `CORSIKA` and `sim_telarray`, to simulate the development of gamma-ray showers, proton background and the telescope response. We perform simulations for the H.E.S.S.-site in Namibia, which is one of the candidate sites for the CTA experiment. We study two previously considered modes, parallel and divergent, and we propose a new, convergent mode with telescopes tilted toward the array center. For each mode we provide performance parameters crucial for choosing the most efficient survey strategy. For the non-parallel modes we study the dependence on the telescope offset angle. We show that use of both the divergent and convergent modes results in potential advantages in comparison with use of the parallel mode. The fastest source detection can be achieved in the divergent mode with larger offset angles (~ 6° from the Field of View centre for the outermost telescopes), for which the time needed to perform a scan at a given sensitivity level is shorter by a factor of ~2.3 than for the parallel mode. We note, however, the direction and energy reconstruction accuracy for the divergent mode is even by a factor of ~ 2 worse than for other modes. Furthermore, we find that at high energies and for observation directions close to the center of the array field of view, the best performance parameters are achieved with the convergent mode, which favors this mode for deep observations of sources with hard energy spectra.

Keywords: Extensive Air Shower, Cherenkov light, Cherenkov detectors, Imaging Air Cherenkov Technique, CTA observatory project, Monte Carlo simulations

Szanescki et al 2015

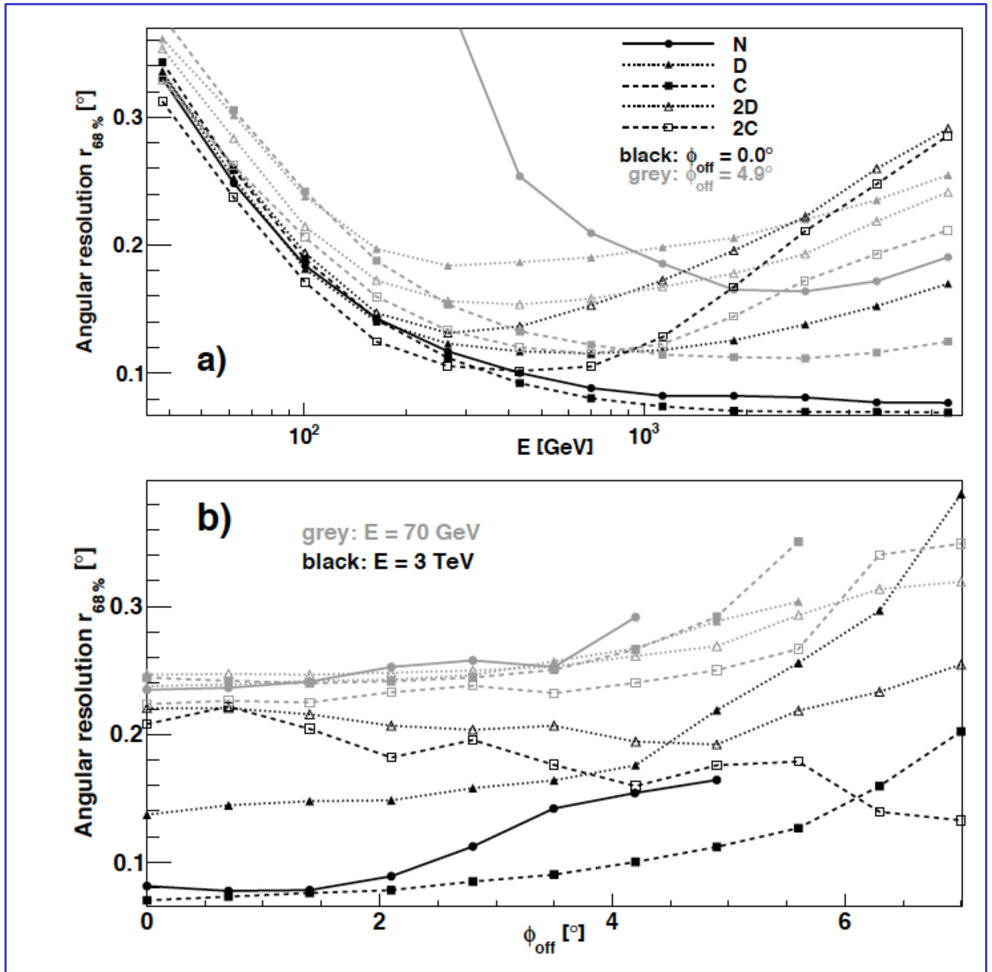
What was done already?

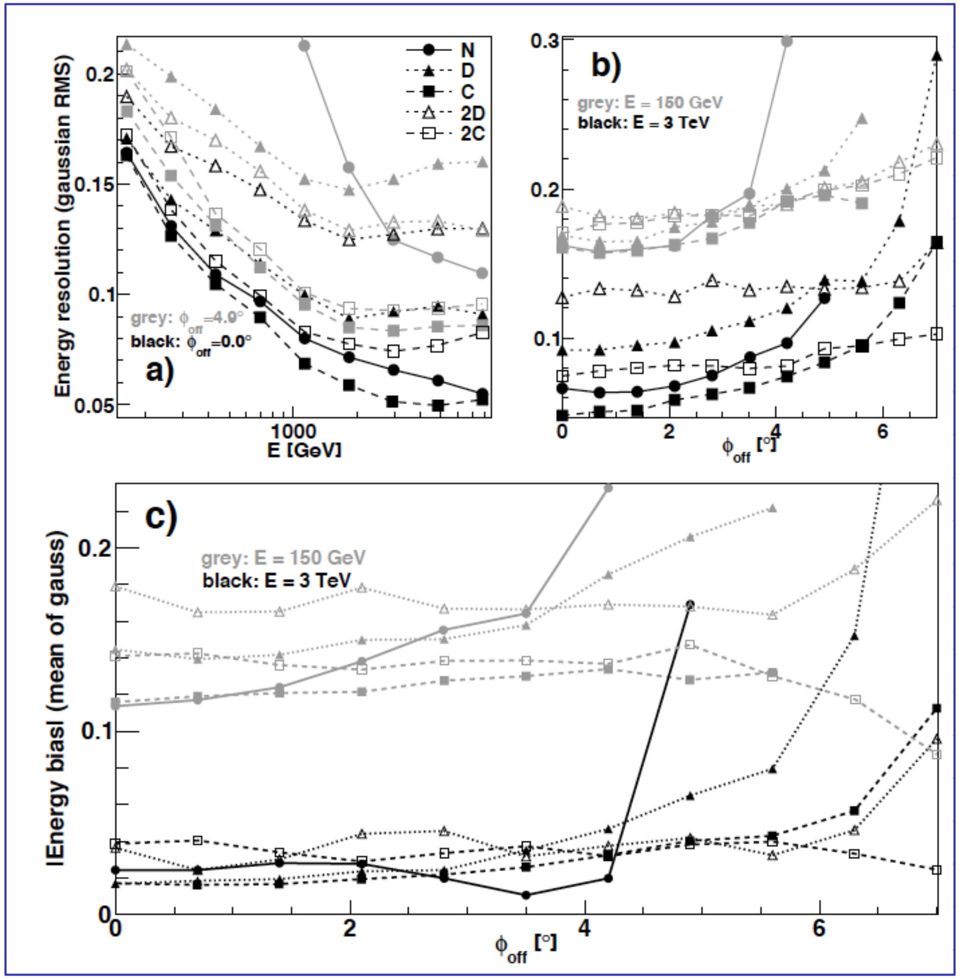




Szanescki et al 2015

What was done already?





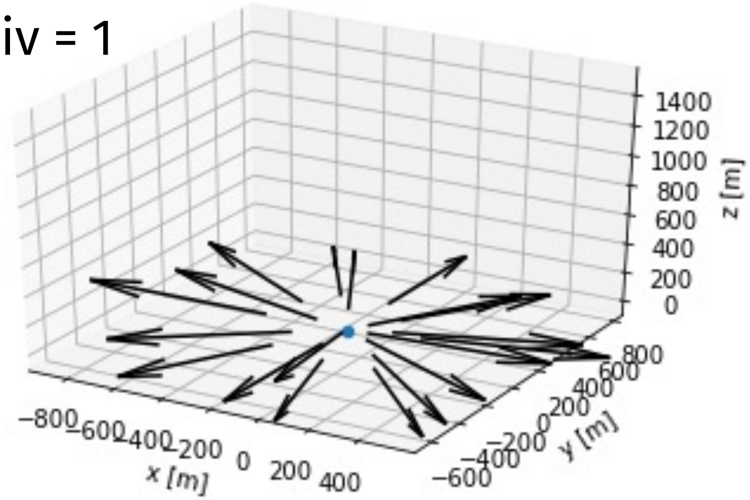
Szanescki et al 2015

What was done already?

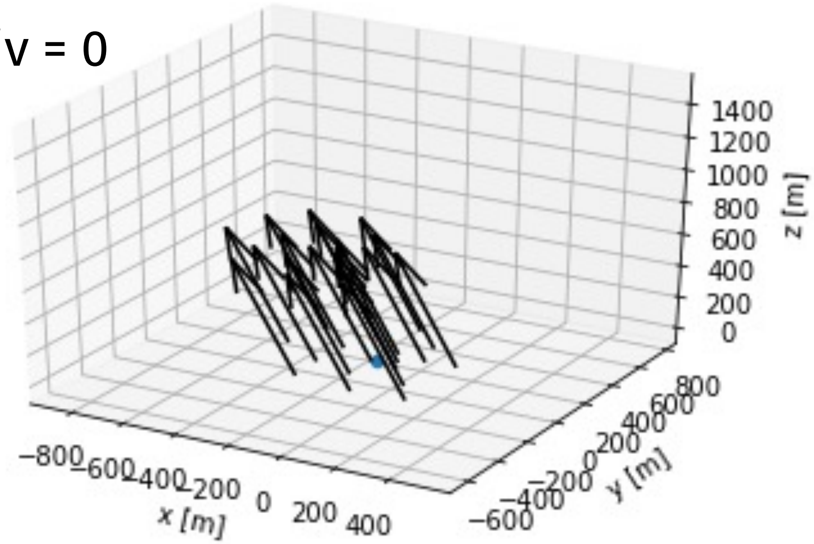
Pointing tool

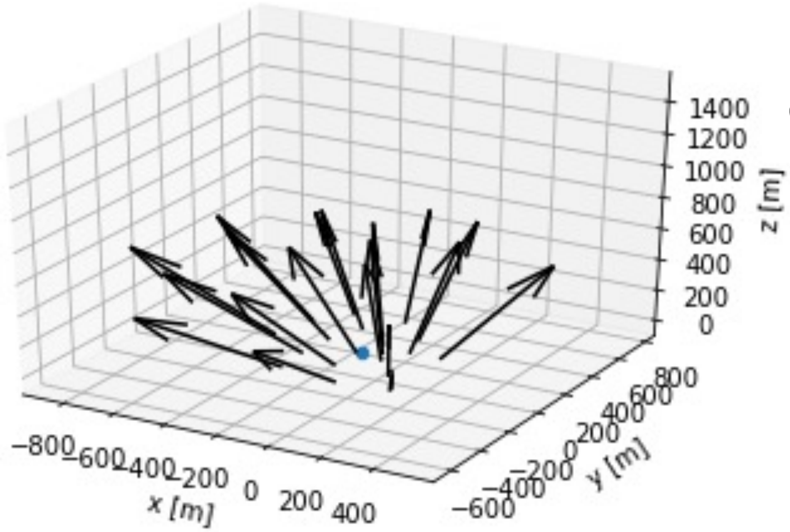
The “umbrella” mode
= 1 parameter to parametrize the divergent pointing

div = 1



div = 0





div = 0.5

Donini et al. 2021

What was done already?

HFoV

	parallel	cfg1.5	cfg2	cfg3	cfg4	cfg5
HFoV (deg^2)	46.5	69.62	93.70	140.3	186.37	233
Overall average multiplicity	16.25	10.85	8.06	5.38	4.05	3.24
MSTs average multiplicity	15	10.02	7.44	4.97	3.74	3
LSTs average multiplicity	4	3.41	2.98	2.41	2.05	1.8
LSTs HFoV (deg^2)	14.5	17	19.47	24.04	28.32	32.38

TABLE 6.2: Comparison of the values for the hyper field of view and telescope's multiplicity between the parallel pointing and the five divergent configurations simulated.

PRELIMINARY

Donini et al. 2021

What was done already?

Determine the array response

- Define the array configuration
  - Array footprint and camera types (agreed with CTAO)
- Define the suitable divergent configurations
  - The divtel code allows to study the geometrical properties of the hFoV
- Simulate the shower development and the detection by the array
  - Run corsika in "standard" conditions for the chosen configuration
  - Run sim_telarray with customised input files
- Analyse the simulations
  - DL0 to DL2 with ctapipe
  - IRFs with pyirf

Irene Burelli - ASWG call - June 5th 2024

Burelli et al. 2024

What was done already?

Details on the divergent configurations

cfg name	div	hFoV deg^2	$hFoV_{eff}$ deg^2	m_ave
parallel	0.0	62.21	62.21	53.38
cfg1.5	0.0022	99.0	89.6	33.5
cfg2	0.0043	141.5	118.3	23.5
cfg3	0.008	232.1	174.7	14.3
cfg4	0.01135	331.5	230.1	10.0
cfg5	0.01453	439.3	285.4	7.6

Irene Burelli - ASWG call - June 5th 2024

PRELIMINARY

Burelli et al. 2024

Science with Divergent Pointing

Surveys with the Cherenkov Telescope Array

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Abstract

Surveys open up unbiased discovery space and generate legacy datasets of long-lasting value. One of the goals of imaging arrays of Cherenkov telescopes like CTA is to survey areas of the sky for faint very high energy gamma-ray (VHE) sources, sources that would not have drawn attention were it not for their VHE emission (*e.g.* the Galactic "dark accelerators"). The Galactic Plane concentrates more than half the currently known VHE sources. Using standard techniques, CTA can carry out a survey of the region $|\ell| \leq 60°$, $|b| \leq 2°$ in 250 hr (1/4th the available time per year) down to a uniform sensitivity of 3 mCrab ("Galactic Plane survey"). CTA could also survey 1/4th of the sky in 370 hr down to a sensitivity of 20 mCrab ("all-sky survey"), which complements well surveys by the *Fermi*/LAT (at lower energies) and extended air shower arrays (at higher energies). Observations in (non-standard) divergent pointing mode may shorten the "all-sky survey" time to about 100 hr with no loss in survey sensitivity. We present the scientific rationale for these surveys, their place in the multi-wavelength context, their possible impact and their feasibility. We find that the Galactic Plane survey has the potential to detect hundreds of sources based on known source populations. Implementing such a survey should be a major goal of CTA. About a dozen blazars or counterparts to *Fermi*/LAT sources are expected to be detected by the all-sky survey, whose prime motivation is the search for extragalactic "dark accelerators".

Keywords: survey, gamma ray

Dubus et al 2013

Science with Divergent Pointing

Divergent mode also appears promising in the search for transient phenomena. The successive visits required to build up sensitivity in a targeted patch of extragalactic sky provide chances to detect sources flaring at $\geqslant 60$ mCrab, based on the sensitivity for detection of a point source in a single visit. The visits can be spread out to probe various timescales. For example, four visits can be divided into two visits per night on consecutive nights to probe hour to day timescales. Two additional visits can be scheduled the following week and another two the following month, allowing for detection of variability on longer timescales while ensuring the total number of visits (8) is sufficient to reach the survey sensitivity goal for steady sources. Such a program is observationally feasible in principle, although we have not studied in detail its practical implementation.

Divergent pointing offers clear advantages in terms of variability studies and investment in observing time. However, divergent modes require non-standard analysis with possible complications to *e.g.* background estimation since each telescope observes a slightly different direction on the sky. Further studies are being carried out to assess precisely the potential of this observing mode.

Dubus et al 2013

Science with Divergent Pointing

Gamma-Ray Burst Science in the Era of the Cherenkov Telescope Array

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Inoue et al 2013

CTA Follow-up Observations. For GBM alerts, the trigger threshold in peak photon flux is taken to be 1.5 ph cm^{-2} s^{-1} in the 8 – 10^3 keV band, which is satisfied by 90% of actual GBM bursts. Follow-up with CTA will be feasible for only a fraction of them that is sufficiently well localized so that they can be reasonably covered by the FoV of the LSTs. Here we choose the criterion for initiating follow-up to be when the GBM error radius is < 5 deg (note the current condition of < 4 deg for MAGIC; Section 3.1). Compared with the ~ 4.6 deg diameter currently foreseen for the LST FoV, this implies that a considerable fraction of the bursts can be missed by falling outside the FoV. Although the actual situation would vary somewhat from burst to burst, we approximate the probability that such GBM bursts are still caught within the LST FoV with a constant value of ~ 0.1 (see [226] for more details), which is incorporated in all calculations below. Nontrivial LST follow-up strategies such as divergent initial pointing (currently under study by the CTA Monte Carlo simulation group) or scanning of the GBM error circle [71], as well as future improvements in the GBM localization algorithm can significantly increase this probability, the quantitative effects of which will be discussed in subsequent studies. We also evaluate the probability that a given GBM localization accuracy is realized as a function of the fluence by making use of actually measured values as reported in the GCN. The delay time $T_{\rm delay}$ between the burst trigger and the start of CTA observations is assumed to obey a log-normal distribution, with a fiducial peak at $\tau_{delay} = 100$ s, dispersion $\sigma_{\rm delay} = 0.4$ dex, and a lower bound of $T_{\rm delay} > 20$ s. This accounts for a plausible degree of improvement from the delay times actually realized during MAGIC-I observations in 2005-2008, which can be fit by a similar distribution but with $\tau_{delay} = 160$ s and $\sigma_{\rm delay} = 0.5$ dex, and for which the average telescope slewing time was ~ 90 s (c.f. [66, 228]).

What is going on now?

- Use of Divergent Pointing Reconstruction
  - Reconstruction and IRF production
- Optimisation of Divergent
  - Increase the Field of View (GRB, Transients, GW counterparts)
  - Sensitivity vs Parallel pointing → Time dedicated to the Survey
  - What about the sensitivity of the EGAL survey?
  - Other usages?
- Creation of Divergent IRFs
  - A few Science cases …
- Implementation of Divergent Pointing
  - Usage of Divergent Pointing in operations …