Observing the VHE sky in divergent mode

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Extragalactic Survey at VHE

Air shower arrays have been historically used to perform surveys:

- ➔ wide FoV
- ➔ high duty cycle
- ➔ moderate angular resolution
- ➔ high energy threshold
- ➔ background rejecting ability

IACTs on the other hand have

- ➔ excellent angular and energy resolution → better suited for transients
- ➔ strong background- rejection
- ➔ Small FoV
- ➔ Reduced duty cycle

There is not much we can do for duty cycle but we can try to improve the FoV

Preliminary studies on divergent pointing

M. Szaneck et al.

An independent study on the prospects of the divergent pointing mode was made by [253] using early simulations of an array of 23 MSTs. The authors showed that the divergent mode will be significantly superior to the normal pointing mode for source detections, i.e. it will have a superior flux sensitivity. They calculated that by separating the telescope pointings by up to 6° (from the pointing of the inner telescopes to the outermost ones), the needed time for a given flux sensitivity can be reduced by a factor of 2.3, which confirmed the gain in sensitivity seen in the study discussed earlier. As expected, however, the angular and energy reconstruction accuracy for the divergent pointing mode is up to a factor of about two worse than for the normal pointing. Still, such an increase in flux sensitivity is very attractive for the survey, especially because of the increased chances of observing GRBs that occur within the field of view.

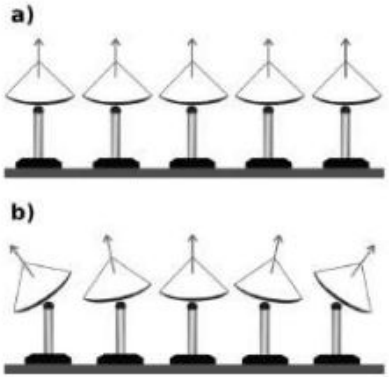
The studies of the divergent pointing mode are very promising and will be continued with the latest simulations using the final array layout for the northern and southern arrays in order to reach a robust conclusion on the use of this mode.

Divergent pointing strategy

Parallel (standard) pointing:
all telescopes point together at the same direction

Divergent pointing:
telescopes are inclined into the outward direction by an angle increasing with the telescope distance from the array center

- **Pros**: Increased FoV
- **Cons**: Reduced sensitivity of the array

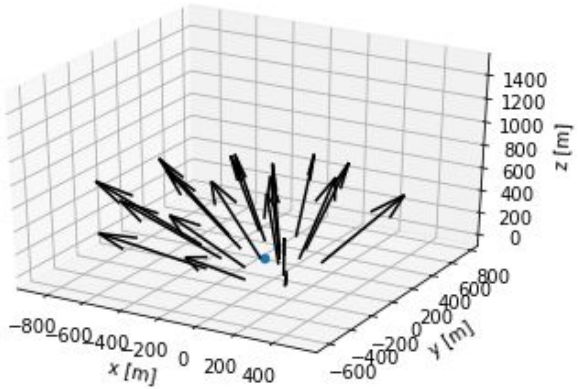


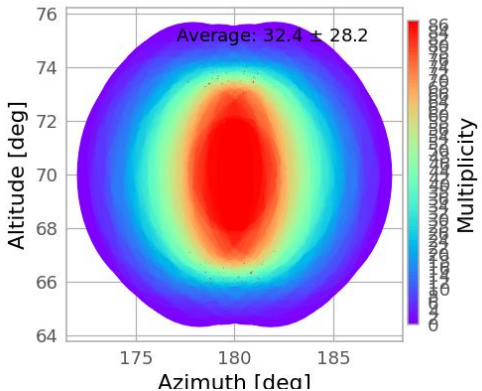
Divergent pointing implementation

simple code hosted on cta-observatory github repo

➔ one parameter (div) to compute single telescope poitnings divergent or convergent

➔ notebooks to check geometrical HFoV and telescope multiplicity

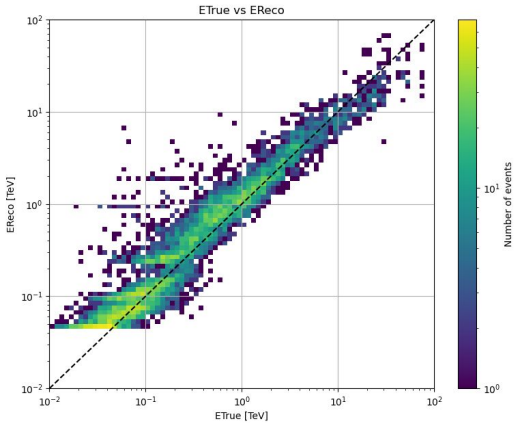


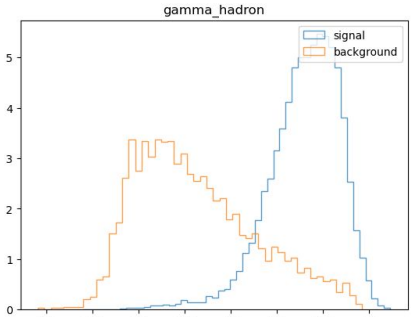


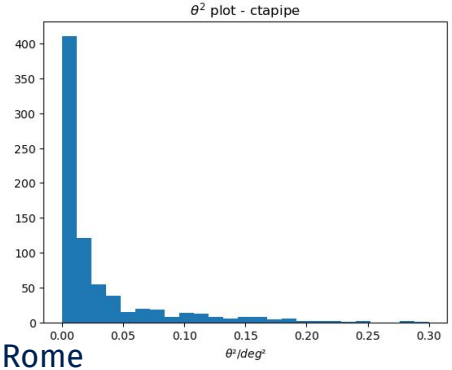
Data analysis of divergent simulations

Divergent pointing reconstruction implemented in ctapipe

- ➔ every pipeline based on ctapipe can be used to analyse divergent data (protopipe, magic-cta-pipe, lstchain...)
- ➔ currently testing the new pipeline
- ➔ Preliminary IRFs (North) are consistent with parallel pointing





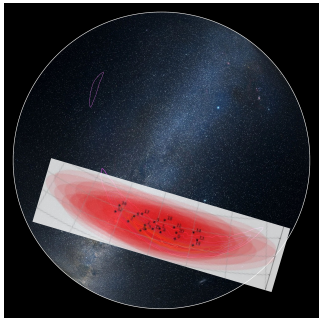


Science with divergent pointing

- EGAL Survey KSP
  - Divergent pointing is listed as a possible mode for this KSP in the science requirements
  - Larger FoV, reduced angular and energy resolution
  - Larger angular separation among neighbouring pointings

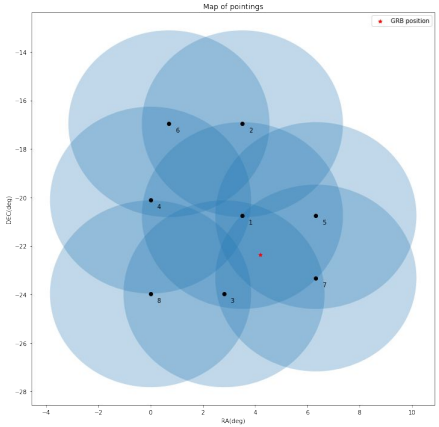
The divergent pointing mode will be used for egal KSP if it can be shown that the required flux sensitivity can be achieved within the same time (even if this results in a moderate worsening of the spectral and angular resolutions)

Science with divergent pointing



- Search of GW electromagnetic counterparts
  - GW error-boxes are large (~100-1000deg^2), this task will benefit from enlarged FoV
  - Less pointings to cover the ‘error box’

	Observation_Time_UTC	RA[deg]	DEC[deg]	Observatory	PGW	ZenIni[deg]	ZenEnd[deg]	Duration[s]	Delay[s]
0	2016-09-13T08:11:00	3.5156	-20.7424	South	0.5759	38.4663	40.4022	510	79735
1	2016-09-13T08:19:50	3.5156	-16.9578	South	0.1589	41.5248	43.4631	510	80265
2	2016-09-13T08:28:40	2.8125	-23.9695	South	0.1009	42.4251	44.3374	510	80795
3	2016-09-13T08:37:30	0.0000	-20.1055	South	0.0333	47.8438	49.8107	520	81325
4	2016-09-13T08:46:30	6.3281	-20.7424	South	0.0322	43.9935	45.9999	530	81865
5	2016-09-13T08:55:40	0.7031	-16.9578	South	0.0109	52.2533	54.3028	540	82415
6	2016-09-13T09:05:00	6.3281	-23.3180	South	0.0098	47.5789	49.6373	550	82975
7	2016-09-13T09:14:30	0.0000	-23.9695	South	0.0066	55.1921	56.4876	350	83545



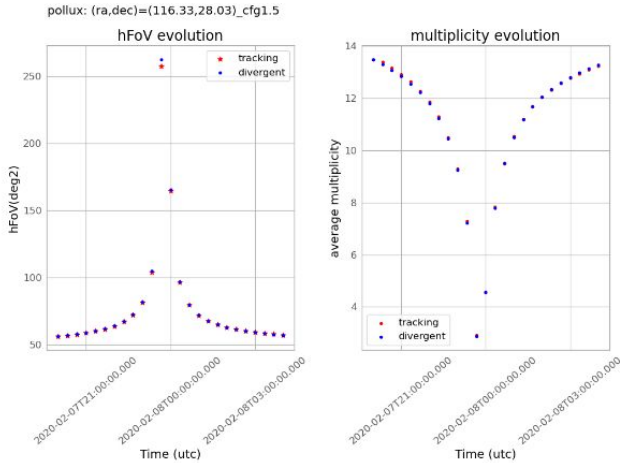
Science with divergent pointing

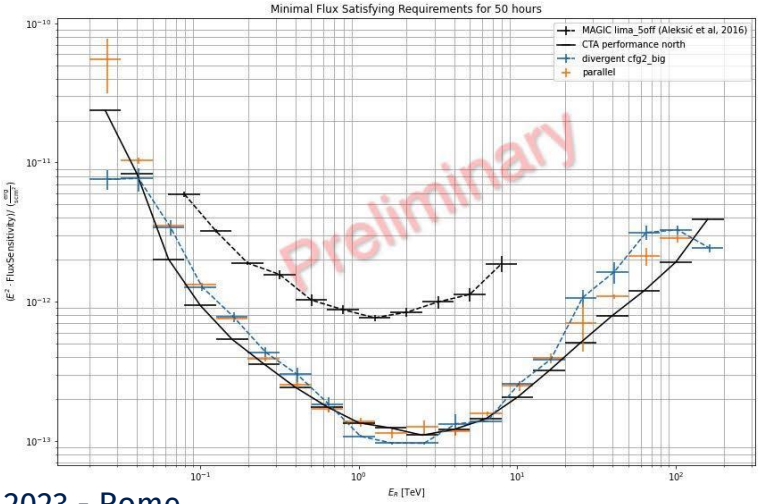
- Serendipitous transient discovery (Transient survey)
  - Enhanced probability of serendipitously detecting transients inside the field of view while the array is operating in survey mode.
  - utilizing divergent pointing and in conjunction with the CTA Extragalactic Survey KSP
    - GRBs from their onset and consequently
    - improved tests of Lorentz invariance violation (LIV),
    - searches for new classes of VHE transients,
    - simultaneous multiwavelength (MWL) and/or multi-messenger (MM) studies with other wide FoV facilities of short-duration transients such as SSBs and FRBs.

Where are we?

- Development of Divergent Pointing Reconstruction
- High statistics MC simulations for both sites
- Pipeline validation (ongoing)
- Preliminary IRFs available (ongoing)
- Preliminary analysis of tracking

→ by now our work is not ‘science-case’ driven!!





Potential issues

Pointing

- Low zd observations (pictures in backup-slides)
- How do we combine pointings? Which is the appropriate spacing?

Performance

- Should we include LSTs?
- Time needed to achieve desired sensitivity?
- performance around hFoV (energy th and angular resolution!!!!)

Analysis

- Background estimation and NSB variations → e.g. clouds around hFoV
- Software trigger

Future prospects

Optimize pointings seeking symmetry

➔ Modulate divergence ?

➔ Diverge only subarrays (e.g. LSTs) to match a certain shape uniformly covered?

Performance estimates independent from CORSIKA

➔ skip CORSIKA simulations in the performance estimation process (AI methods)

‘Real world’ implementation

➔ Possible technical tests (4LSTs in LP)

➔ Setting up the drive system to handle divergent pointing

Optimizations must be implemented with a scientific target in mind!

Conclusions

- Divergent pointing is a promising mode to enhance the detection of extragalactic sources
- Better suited for non steady/transient sources
- Both sites have been simulated
- Analysis is possible with ctapipe
- Optimization still needed (possibly based on science cases)
- Real world issues need to be pointed out and solved
- Tests with real arrays needed

BACKUP

Observing the sky at VHE

Characteristic	IACT	SA/WCD
Energy threshold	$\sim$ tens of GeV (for a few hundred m^2 mirror dish)	$\sim$TeV
Duty cycle	$\sim$ 10%	$\lesssim$ 100%
Field of view	$\sim$ a few millisr	$\sim$ sr
Energy resolution	$\sim$ 15%	$\sim$ 40%
Angular resolution	$\sim 0.1^\circ$	$\sim 0.2^\circ$
Sensitivity	$\sim$ 1% Crab Nebula flux in 25 h	a few % Crab Nebula flux in 5 yr
Main present instruments	H.E.S.S., MAGIC, VERITAS	Tibet AS-γ, HAWC, LHAASO-WCDA, LHAASO-KM2A
Future instruments	CTA	SWGO, ALPACA

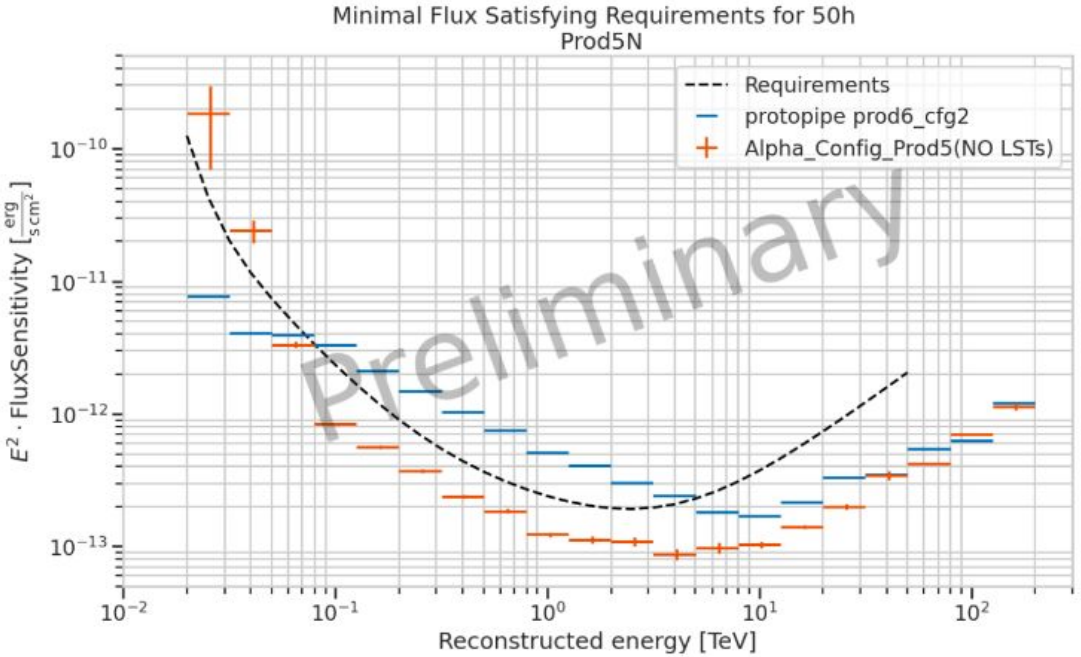
Where are we now?

- Development of Divergent Pointing Reconstruction ✓
  - T.Gasparetto's thesis
- Development of simple FigureOfMerit calculations (eg. HFOV vs Sensitivity) ✓
  - A.Donini's thesis
- Generation of few MC samples and related analysis
  - A.Donini's thesis → Prod3b, site North, baseline config ✓
  - I.Burelli's thesis → Prod5, both sites, alpha config ONGOING
- First production of Divergent IRFs
  - Preliminary IRFs produced – A.Donini's thesis
  - Ongoing work on the GRID – I.Burelli's thesis
- Organisation of code development (T.Vuillame) ✓
- Work under the responsibility of CTAO simulation team
- Work with ACADA team ONGOING

Site South - pointing configurations

cfg name	div	hfov deg^2	$hfov_{eff}$ deg^2	m_ave
cfg1.5	0.0022	145.1	132.1	32.4
cfg2	0.0043	248.2	212.6	18.9
cfg3	0.008	485.0	372.2	9.7
cfg4	0.01135	758.0	523.6	6.2
cfg5	0.01453	1064.4	650.2	4.4

Preliminary analysis with protopipe (South)



Preliminary analysis with protopipe (South)