CCF Face-to-face meeting

# Muons & LST

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# LST muon issues

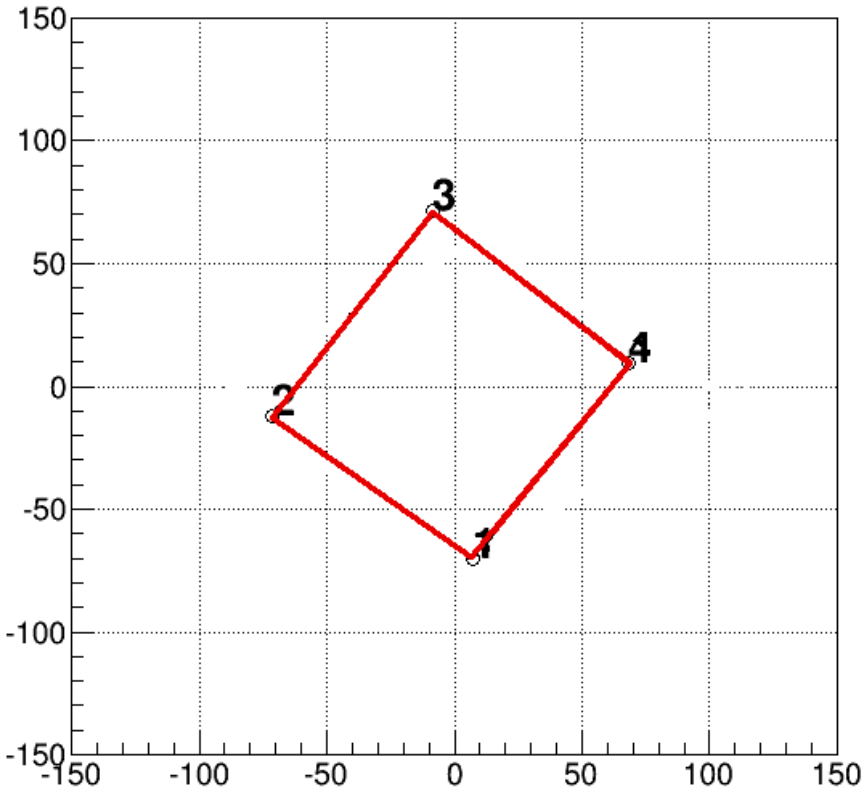
- Muon rings are mostly observed as single-telescope events
- LST has HW-trigger $\Rightarrow$ single-telescope LST events need special HW conditions (mono-runs). Essential for us to check the stereo-LST muons
- Probably necessary to flag muons efficiently at level of the camera server, from un-calibrated images, so ensuring that all 'usable' estimated muon rings are written on disc.

# Muon simulations

- Corsika (provided by K. Bernlöhr) - Input card definition
- sim_telarray (provided by K. Bernlöhr) - Input card definition
- Data interpretation and analysis:
  - Counting of triggered events
  - More advanced event handling:
    - CHIMP + MARS

# Corsika Input: Telescopes

- Site: La Palma
- Telescopes: LST id 1,2,3,4 (Altitude site: 2147 m, orography considered)



# Corsika Input: Other Parameters

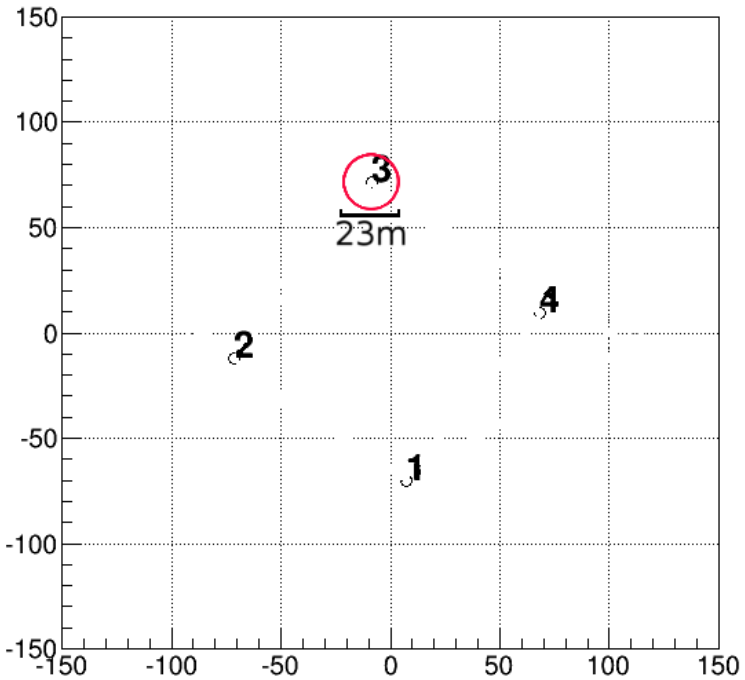
- Atmosphere and magnetic field from Prod3:
  - Atmosphere: 36 Y
  - Magnetic field: 30.541 23.814
- Energy: 4 GeV - 1 TeV

# Corsika Input: Other Parameters

- Injection height:
  $h_{inj} = h_{tel} + 2R/tan(\theta_c) = 2147\text{m} + 2 \cdot 11.5 \cdot 115\text{m} = 4792\text{m}$
- FIXCHI (starting altitude [g/cm$^2$]): atmospheric depth at ground level: 811.455 g/cm$^2$ $\Rightarrow$ FIXCHI= 594g/cm$^2$
- All other parameters taken from Prod3 La Palma simulations

# Corsika Input: Stereo analysis

- Injection height optimized for mono analysis (full ring in a single telescope)
- $h_{inj} = h_{tel} + 2R/tan(\theta_c) \Rightarrow h_{inj} = h_{tel} + (2R + Dist)/tan(\theta_c) = 16281\text{m} \Rightarrow \text{FIXCHI}= 155\text{g/cm}^2$



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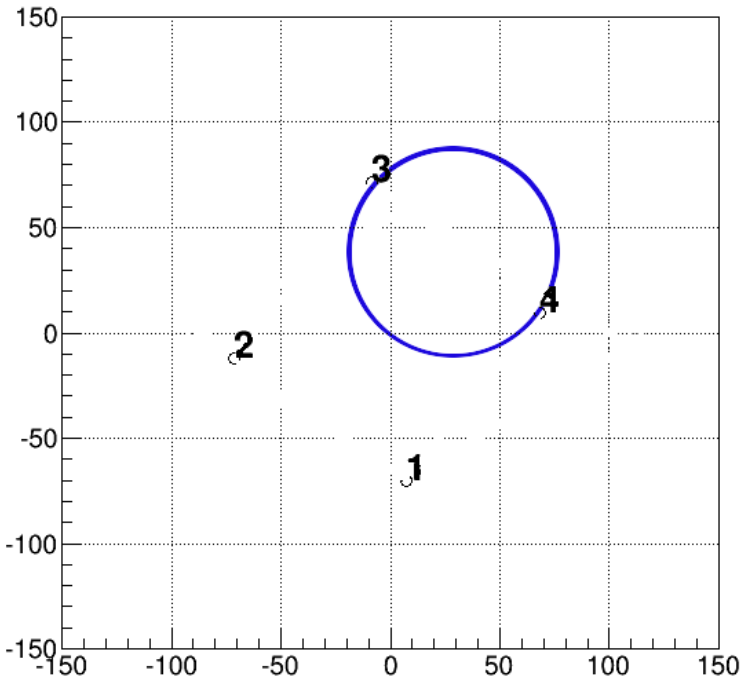

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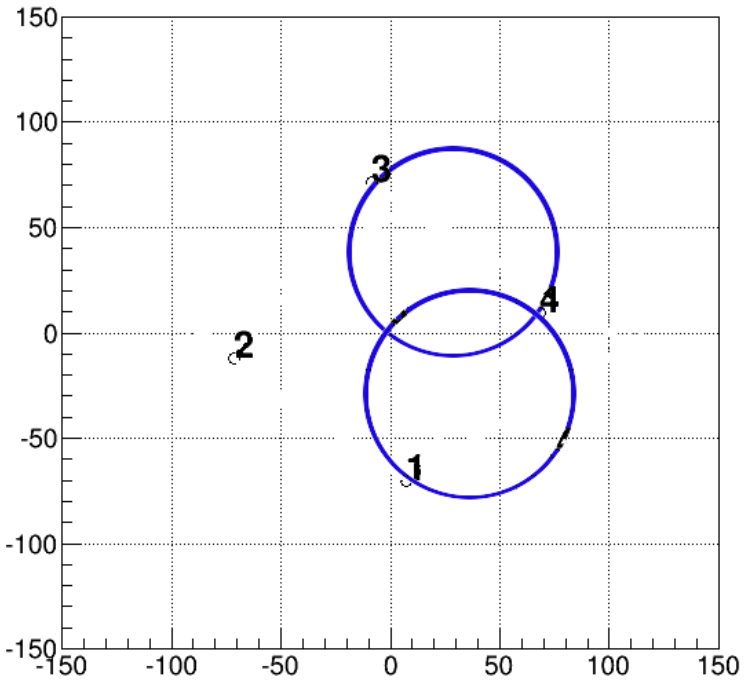

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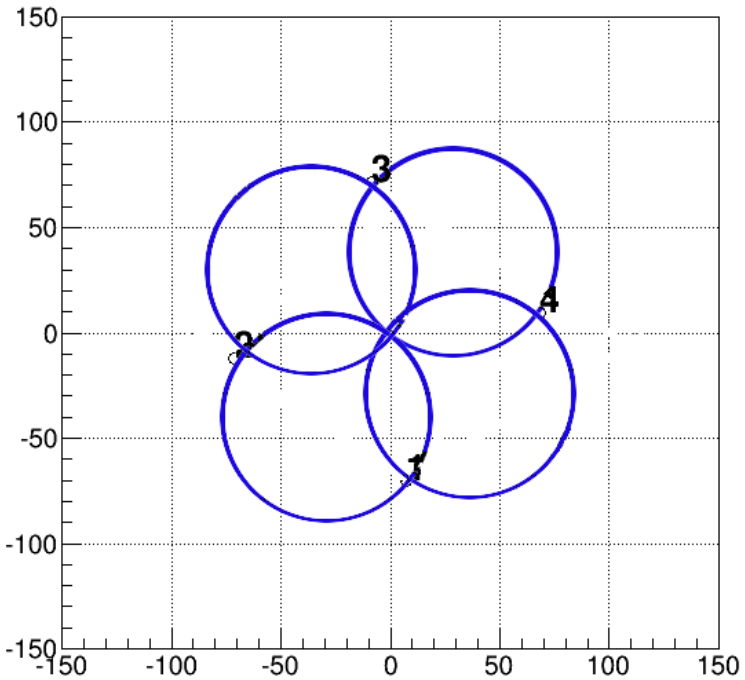


# Simtel

Starting point: standard Prod3 LST card

- Mono: only events that triggered LST 1
- Stereo: events that triggered an LST pair

No other changes!

All observations are on axis

# Simtel: Triggered events

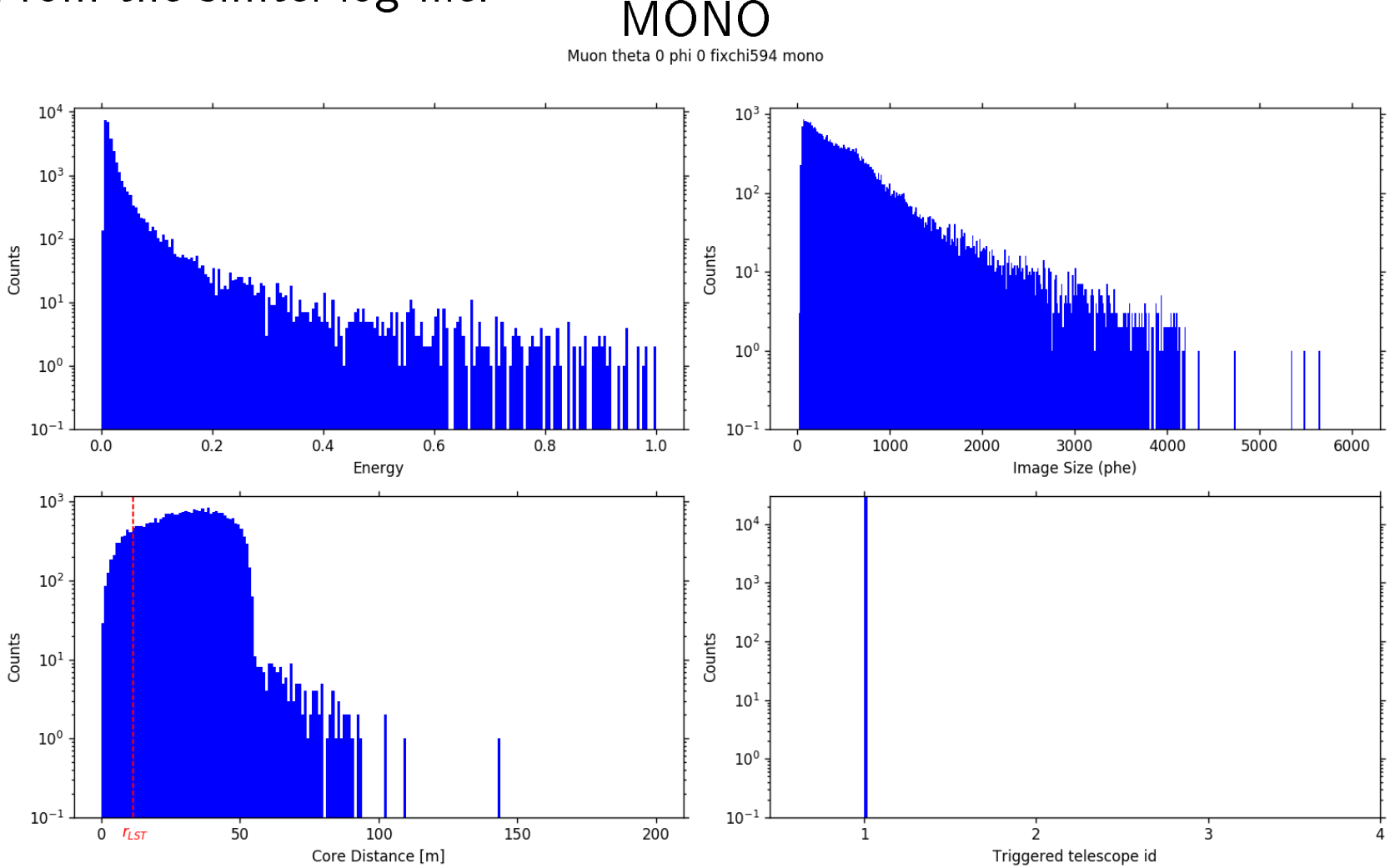
Percentage of events that triggers from the simtel log file:

| | | $\theta$ | |
|---|---|---|---|
| | FIXCHI | 0. | 20. |
| Mono (only LST 1) | 155 | 6.3% | 8.8% |
| | 594 | 3.0% | 2.5% |
| Stereo | 155 | 12.4% | 12.8% |
| | 594 | 0.03% | 0.17% |

Before applying any cut!

# Simtel: Triggered events

From the simtel log file:



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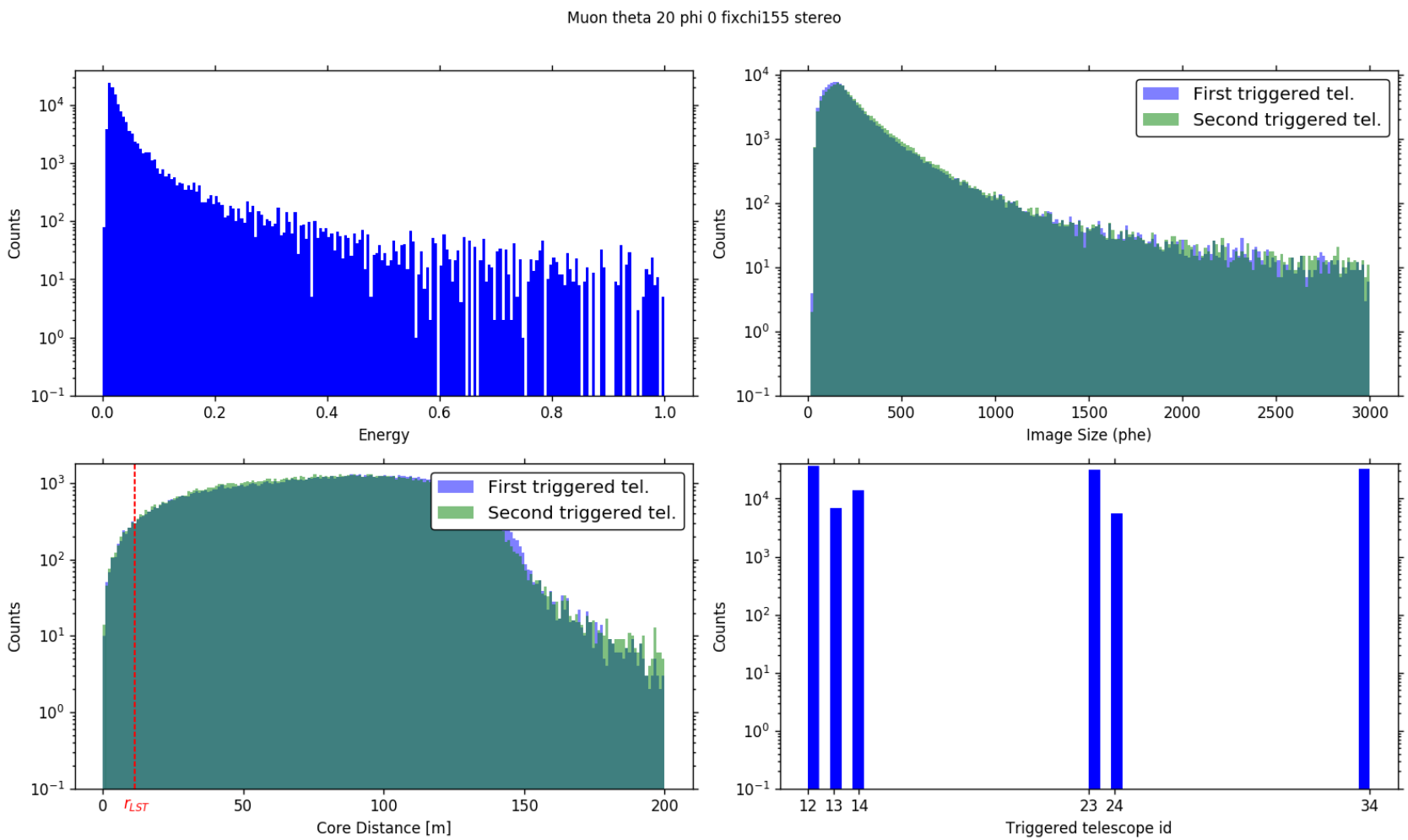
From the simtel log file:



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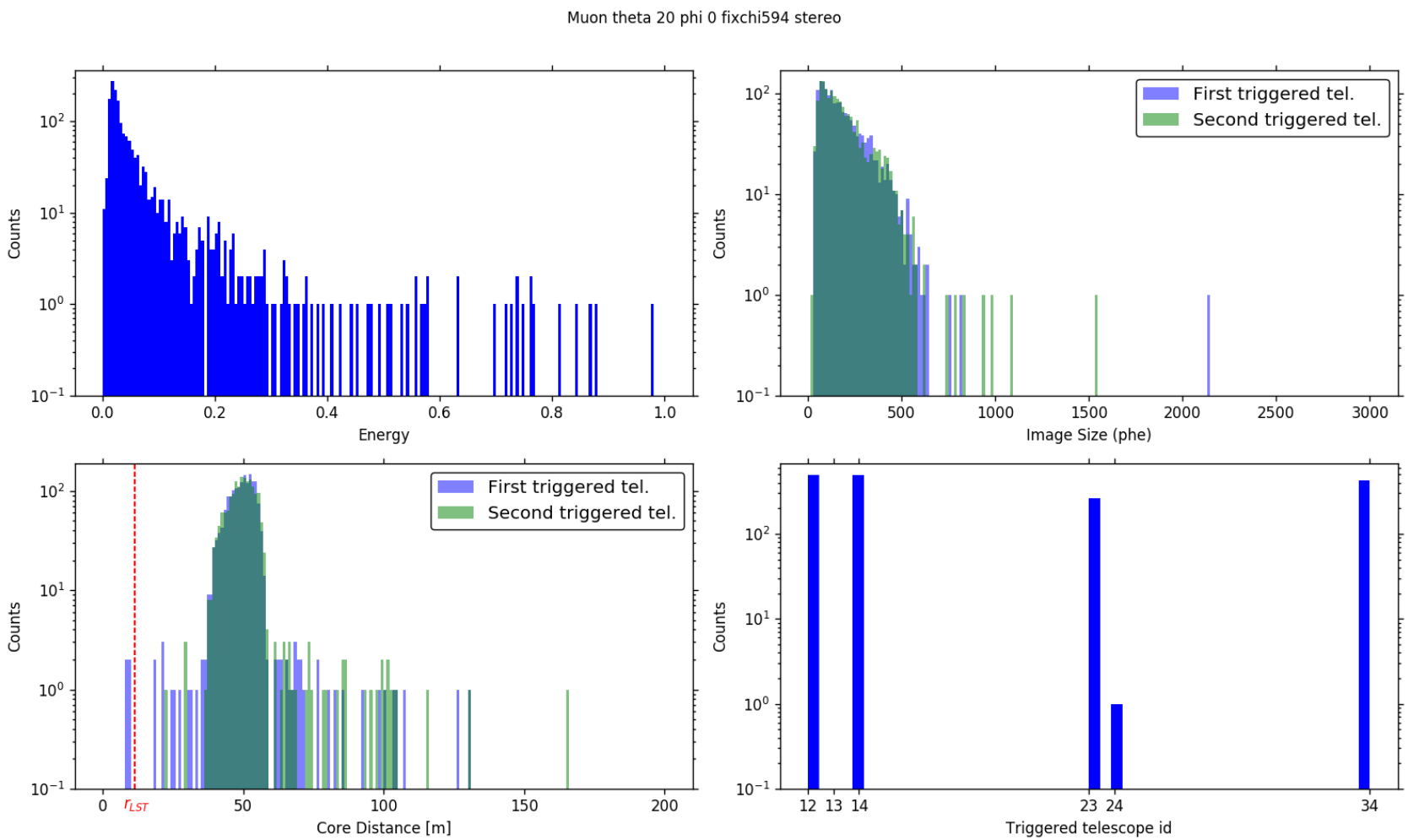
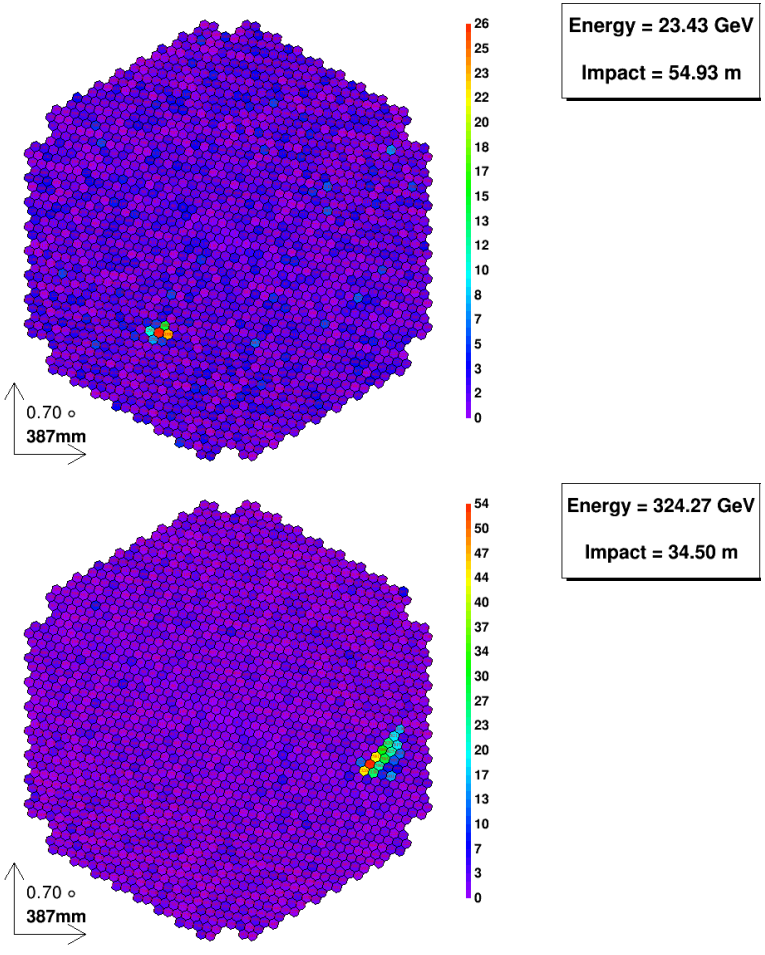
From the simtel log file:



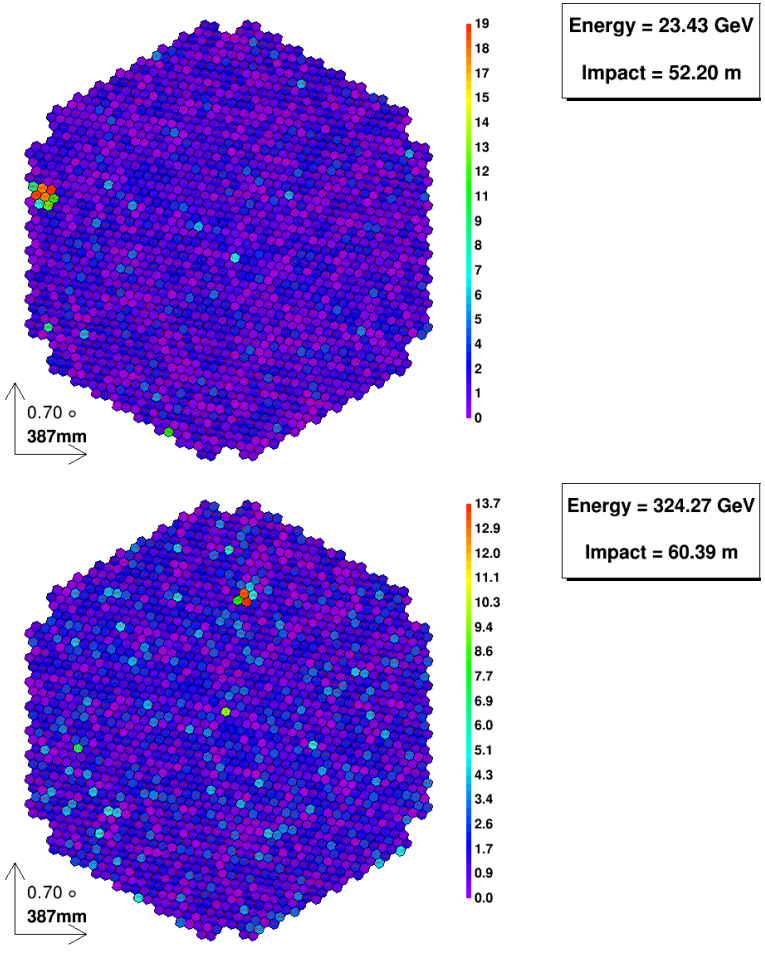
# Simtel: Triggered events

## STEREO

### LST 1




### LST 3






macro by T. Hassan

# CHIMP: Convert Hessio Into Mars inPut

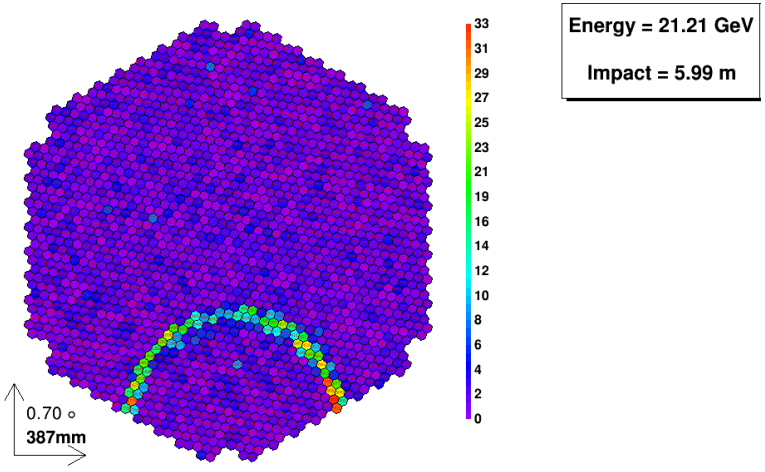
Transforms CTA MC files into calibrated files for analysis with MARS

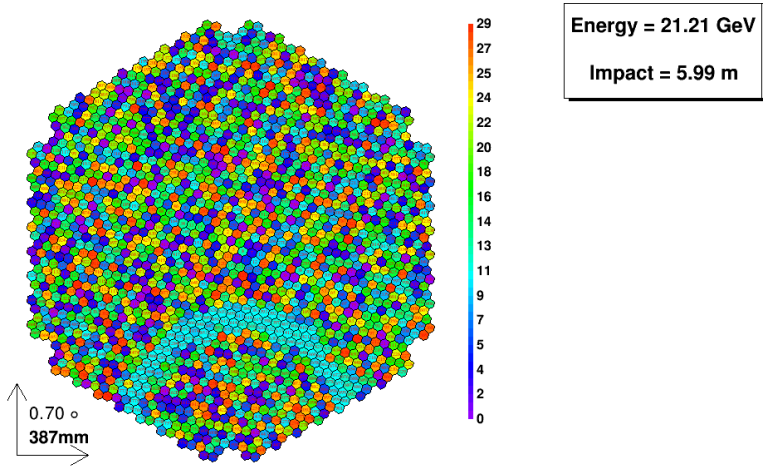
Differently from the "usual" analysis:

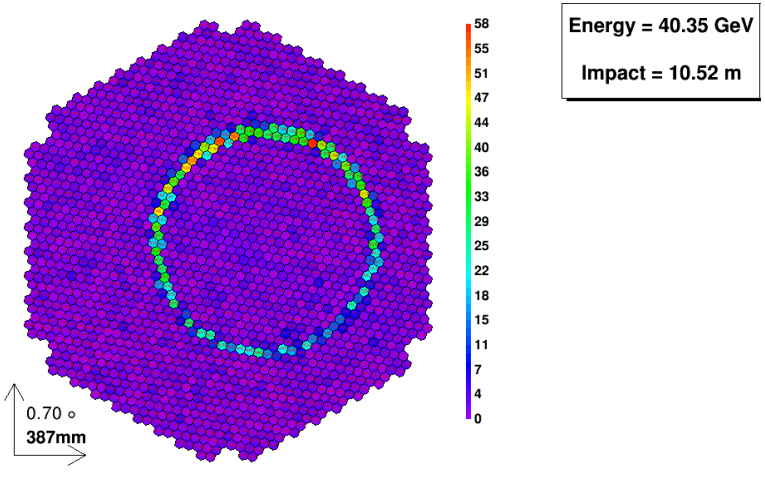
- No minimum number phe$^-$ to store
- No time fit is applied during the trace extraction process

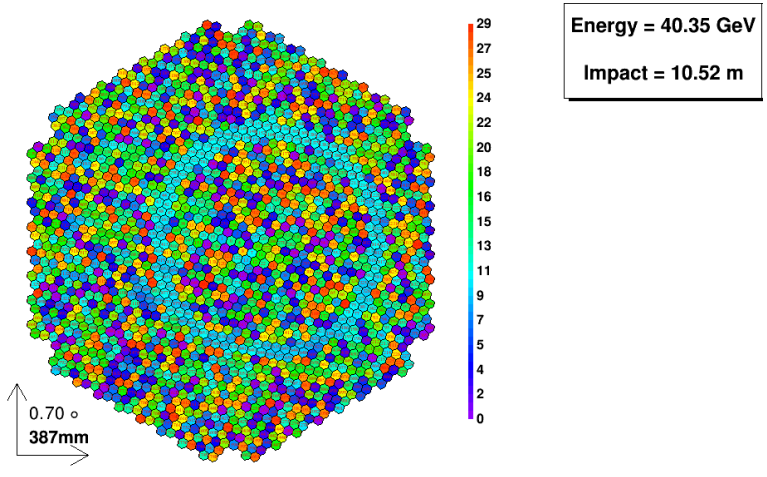
# CHIMP

## MONO




macro by T. Hassan

# Muon search & fit: Mono Cuts

1. Image Cleaning
2. Pre-cut: Size$>$ 150
3. Calculation of the search parameters
4. Search cut
5. Calculation of the calibration parameters
6. Final cut

# Muon search & fit: Mono Cuts

1. Image Cleaning
2. Pre-cut: Size$>$ 150
3. Calculation of the search parameters:
   - Radius
   - Standard deviation from the estimated ring
   - Center position
   - Charge outside the ring
   - Mean arrival time of core pixels
   - RMS of arrival time of core pixels
4. Search cut
5. Calculation of the calibration parameters
6. Final cut

# Muon search & fit: Mono Cuts

1. Image Cleaning
2. Pre-cut: Size$>$ 150
3. Calculation of the search parameters
4. Search cut:
   - $1^\circ <$Radius$< 1.5^\circ$
   - $\sigma_r < 0.14^\circ$
5. Calculation of the calibration parameters
6. Final cut

Cuts NOT optimized!

# Muon search & fit: Mono Cuts

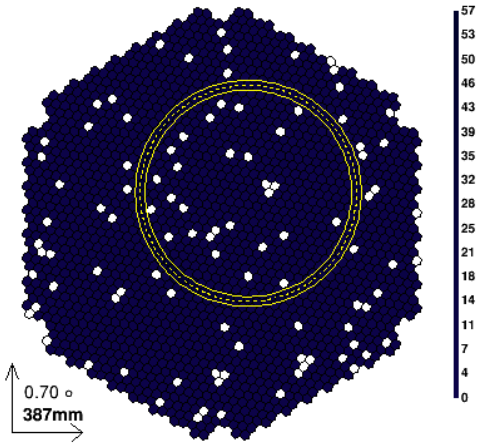
1. Image Cleaning
2. Pre-cut: Size$>$ 150
3. Calculation of the search parameters
4. Search cut
5. Calculation of the calibration parameters:
   - Opening angle
   - Width
   - Brightness
   - Gaussian fit to time profile
6. Final cut

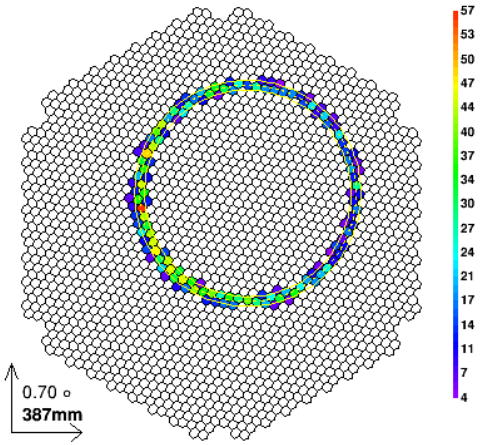
# Muon search & fit: Mono Cuts

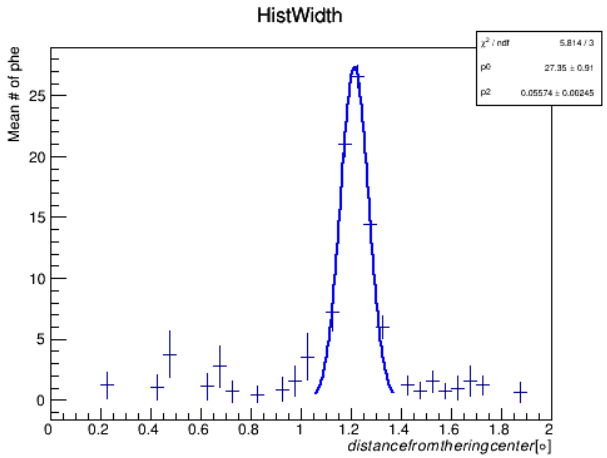
1. Image Cleaning
2. Pre-cut: Size$>$ 150
3. Calculation of the search parameters
4. Search cut
5. Calculation of the calibration parameters
6. Final cut:
   - $0.02^\circ <$Width$< 1^\circ$
   - $180^\circ < \phi < 360^\circ$: at least a half ring
   - $\sigma_{radius} < 0.08^\circ$
   - $\sigma_{time} <$ 1ns

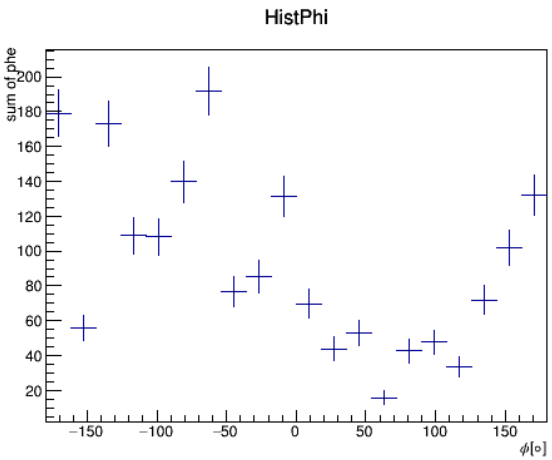
Cuts NOT optimized!

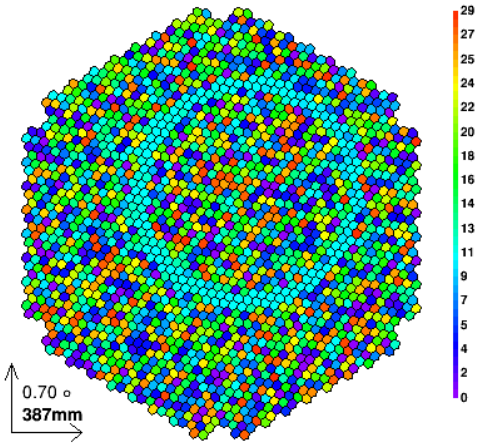
# Muon search & fit: Mono Results

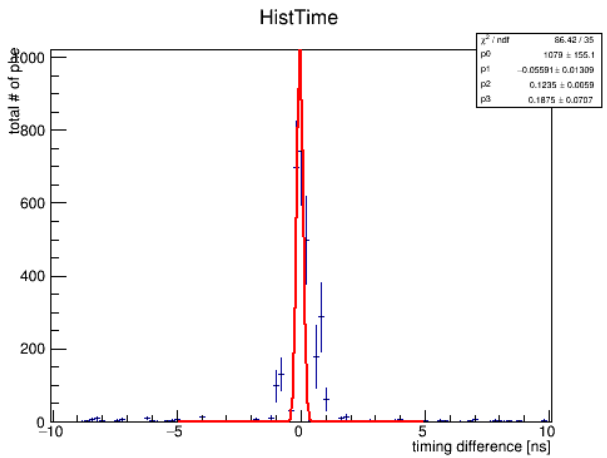


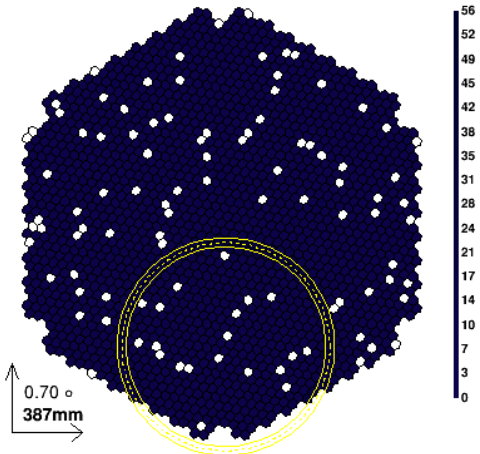



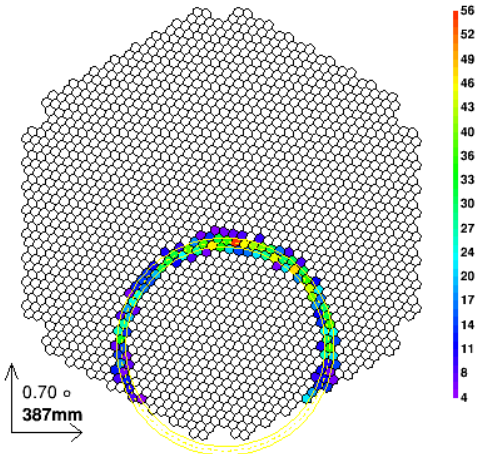



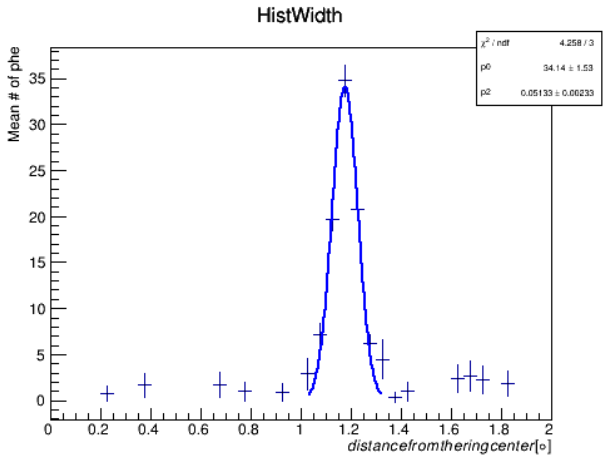



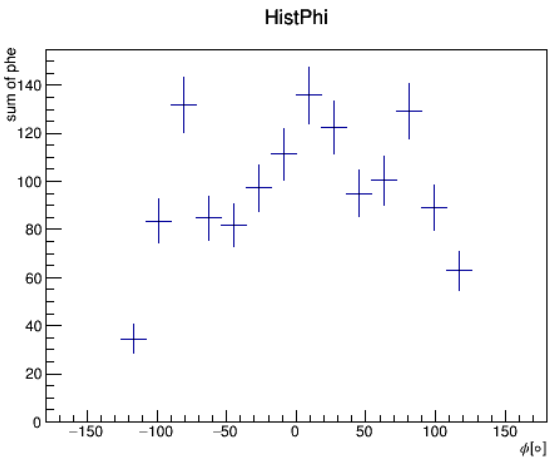

Size: 1862 phe$^-$

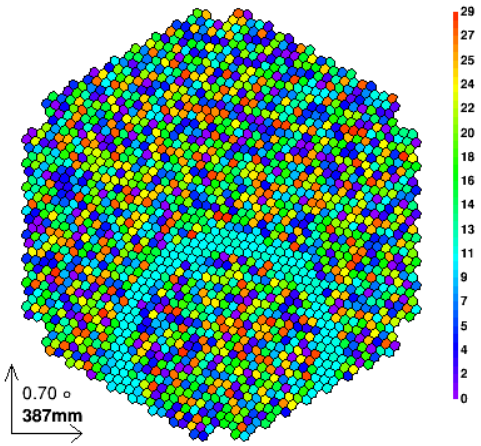
# Muon search & fit: Mono Results

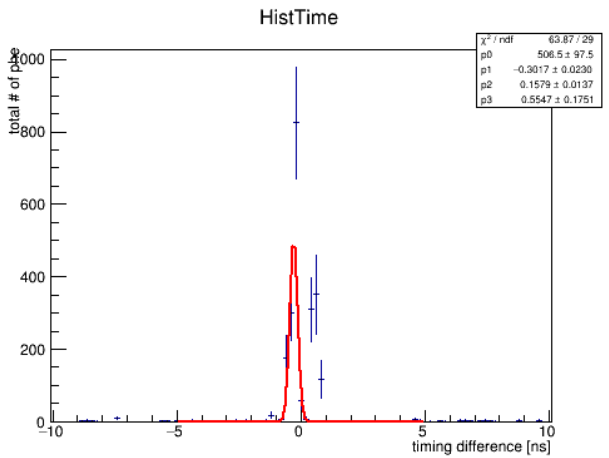



Size: 1395 phe$^-$

# Muon search & fit: Mono Results

Cuts NOT optimized!

| | | Survival Percentage | | | |
|---|---|---|---|---|---|
| | | Cleaning | Pre-cut | Search | Final |
| $\theta$ | 0° | 98 | 68.3 | 10.4 | 0.6 |
| | 20° | 98 | 67.9 | 9.1 | 0.6 |

# Conclusions

LST muon analysis just starting:

- Mono analysis a little more advanced
- Stereo analysis is at a very early stage
- Not completely sure about corsika/simtel configurations

# Future Prospects

- Reconstruction:
  - CHIMP is not optimal
  - Tune CHIMP+MARS to get preliminary results and move to ctapipe
- To totally assess muon calibration:
  - Different atmospheric conditions
  - Different NSB conditions
  - Mirror defocussing
  - Coma effects
  - Etc. . .

# Corsika input card

```
EVTNR   1                          NUMBER OF FIRST SHOWER EVENT (USUALLY 1)
NSHOW   100000                      NUMBER OF SHOWERS TO GENERATE
PRMPAR  5                          PARTICLE TYPE OF PRIM. PARTICLE (5: MU+)
*PRMPAR  6                         PARTICLE TYPE OF PRIM. PARTICLE (6: MU-)
ESLOPE  -2.                        SLOPE OF PRIMARY ENERGY SPECTRUM (-2.0 IS EQUAL CPU TIME PER DECADE)
THETAP  0.  0.                    RANGE OF ZENITH ANGLES (DEGREE)
PHIP    0. 0.                      RANGE OF AZIMUTH ANGLES (DEGREE): PRIMARIES COMING FROM SOUTH
ATMOSPHERE 36 Y                    Should be slightly better for La Palma than profiles 1 (tropical)
OBSLEV  2147.E2                    OBSERVATION LEVEL (IN CM)
MAGNET 30.541 23.814               Magnetic field at assumed site [H, Z] (muT) (for La Palma site)
ARRANG  -6.                        ROTATION OF ARRAY TO NORTH [D] (DEGREE); USE ZERO HERE FOR ANY SITE FOR NOW
FIXHEI  0.  0                      FIRST INTERACTION HEIGHT & TARGET (0. 0 FOR RANDOM)
FIXCHI  594.                       STARTING ALTITUDE (G/CM**2). 0. IS AT BOUNDARY TO SPACE.
TSTART  T                          NEEDED FOR EMISSION AND SCATTERING OF PRIMARY
ECUTS   0.3  0.1  0.020  0.020     ENERGY CUTS FOR PARTICLES
MUADDI  F                          ADDITIONAL INFO FOR MUONS NOT NEEDED
MUMULT  T                          MUON MULTIPLE SCATTERING ANGLE
LONGI   T  20.  F  F               LONGIT.DISTR. & STEP SIZE & FIT
MAXPRT  0                          MAX. NUMBER OF PRINTED EVENTS
ECTMAP  1.E6                       CUT ON GAMMA FACTOR FOR PRINTOUT
STEPFC  1.0                        MULT. SCATTERING STEP LENGTH FACTOR
CERSIZ  5.                         NOT ABOVE 10 FOR SUPER/ULTRA-BIALKALI QE; 7 IS FAIRLY OK; 5 SHOULD BE SAFE.
CERFIL  F                          NO OLD-STYLE CHERENKOV OUTPUT TO EXTRA FILE
CWAVLG  250.  700.                 CHERENKOV WAVELENGTH BAND
DEBUG   F  6  F  1000000           DEBUG FLAG AND LOGICAL UNIT FOR OUTPUT
DATBAS YES                         WRITE A FILE WITH PARAMETERS USED
DIRECT  /dev/null                  means no normal CORSIKA data written
TELFIL /nfs/cta-ifae/pcumani/Muons/Data/Corsika/Muon_t20_phi0_fixchi500.corsika.gz:100:100:1       If telescope simulation not done
IACT SPLIT_AUTO 8M                 Split data with more than 15 million bunches
IACT IO_BUFFER 800MB               At 32 bytes per bunch this could be up to 500 MB
IACT MAX_BUNCHES 1000000           Let photon bunch thinning set in earlier.
ERANGE  4.0 1E3                    Energy range of primary particle (in GeV): protons
VIEWCONE 0. 3.5                    Such that at half of maximum Cherenkov angle the ring still fits into FoV. (LST: FoV-diam=4.6 deg)
CSCAT  10  150E2  0.               USE SHOWER SEVERAL TIMES (PROTONS+ELECTRONS+..., LARGER AREA FOR DIFFUSE ORIGIN)
TELESCOPE    -70.05E2       -7.23E2    56.00E2    12.50E2   # Telescope 1:   Alt=2187.00  "LST1 (A)"
TELESCOPE    -12.30E2       71.29E2    47.00E2    12.50E2   # Telescope 2:   Alt=2178.00  "LST2"
TELESCOPE     71.82E2        8.20E2    43.00E2    12.50E2   # Telescope 3:   Alt=2174.00  "LST3"
TELESCOPE      9.31E2      -68.07E2    50.00E2    12.50E2   # Telescope 4:   Alt=2181.00  "LST4"
SEED   385928125   401   0        Seed for 1st random number sequence, to be re-generated
SEED   827619802   859   0        Seed for 2nd random number sequence, to be re-generated
SEED   195989238   390   0        Seed for 3rd random number sequence, to be re-generated
SEED   539053819   323   0        Seed for 4th random number sequence, to be re-generated
```

# Simtel input card

Starting point: CTA-ULTRA6-LST.cfg

Mono

```
190 array_trigger = array_trigger_1_of_1to1.dat
191 maximum_telescopes = 1
192 trigger_telescopes = 1
193 only_triggered_telescopes = 1
```

Stereo

```
191 array_trigger = array_trigger_2_of_1to4.dat
192 maximum_telescopes = 4
193 trigger_telescopes = 2
194 only_triggered_telescopes = 1
```