Cherenkov Transparency Coefficient Part 1: Atmospheric calibration

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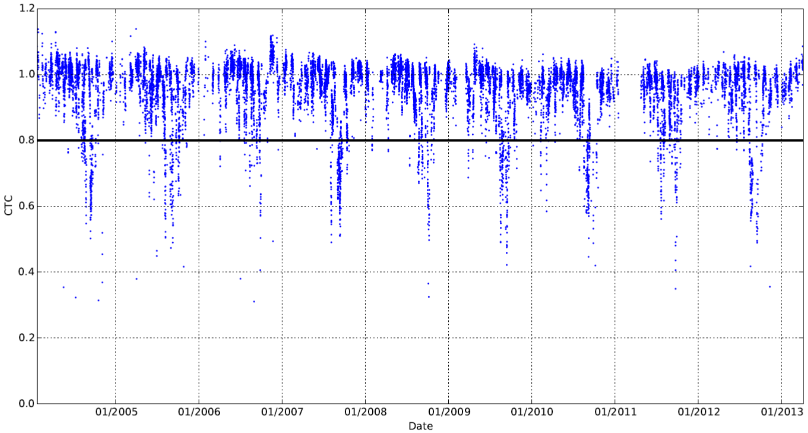
Cherenkov Transparency Coefficient
(H.E.S.S.)

$$CTC = \frac{1}{N_{tel}} \sum_{i}^{N_{tel}} t_i$$

$$= \frac{1}{N_{tel}} \sum_{i}^{N_{tel}} \frac{\left[\frac{1}{\mathcal{N}} \frac{1}{M} R_i(\theta_{zen} = 0°)\right]^{\frac{1}{1.7}}}{\mu_i . g_i}$$

- N_{tel} … number of telescopes
- R … trigger rate
- μ … muon efficiency
- g … gain
- $\mathcal{N}$ … normalization
- M … multiplicity correction

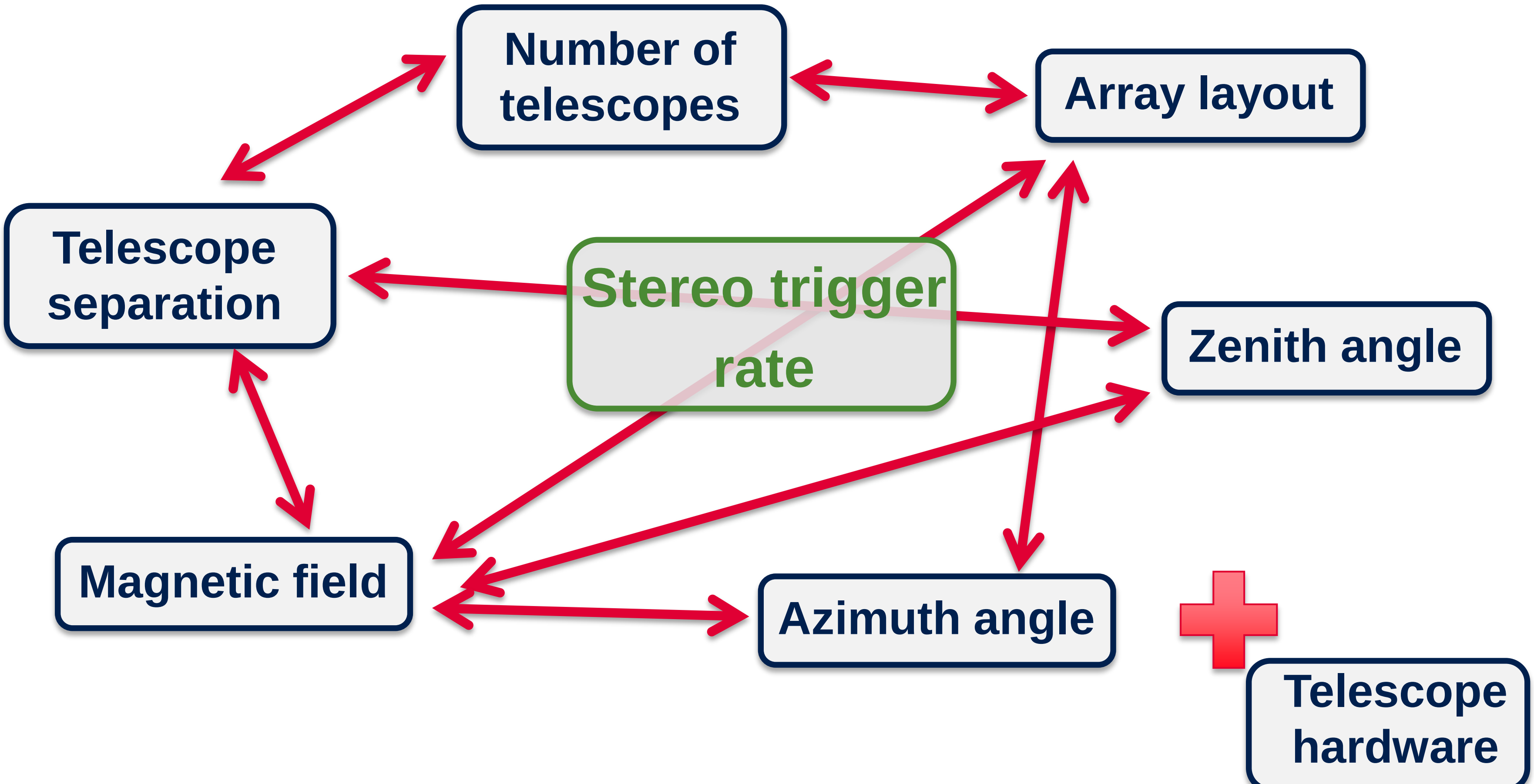
- hardware independent for H.E.S.S.-I
- sensitive to atmosphere only
- atmospheric monitoring using CTC:
  - contemporaneous with the data taking
  - performed in the same direction and FoV as the actual observation



Hahn et al., Astropart. Phys. 54, 25, 2014

CTC in CTA

- CTC uses **stereo** trigger rates: complex dependencies



CTC in CTA (current state)

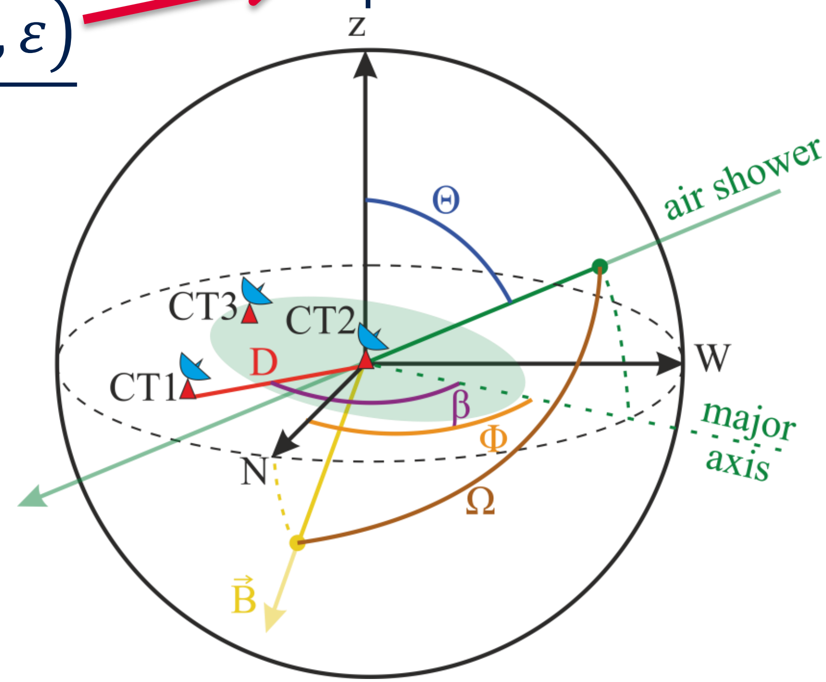
- final decision (at least for now :-):
  - calibrate only within pairs of telescopes
  - apply for many pairs and constrain the calibration quantities

- transparency estimates for telescope pairs *(i, j)*:

experiment

$$\tau_{ij}(AOD) = \frac{R_{ij}\left(AOD, D, \theta, \beta, \vec{B}, \varepsilon\right)}{F\left(D, \theta, \beta, \vec{B}, \varepsilon\right)}$$

simulations



- atmospheric calibration:

$$CTC(AOD) = \overline{\tau_{ij}}$$

Monte Carlo simulations

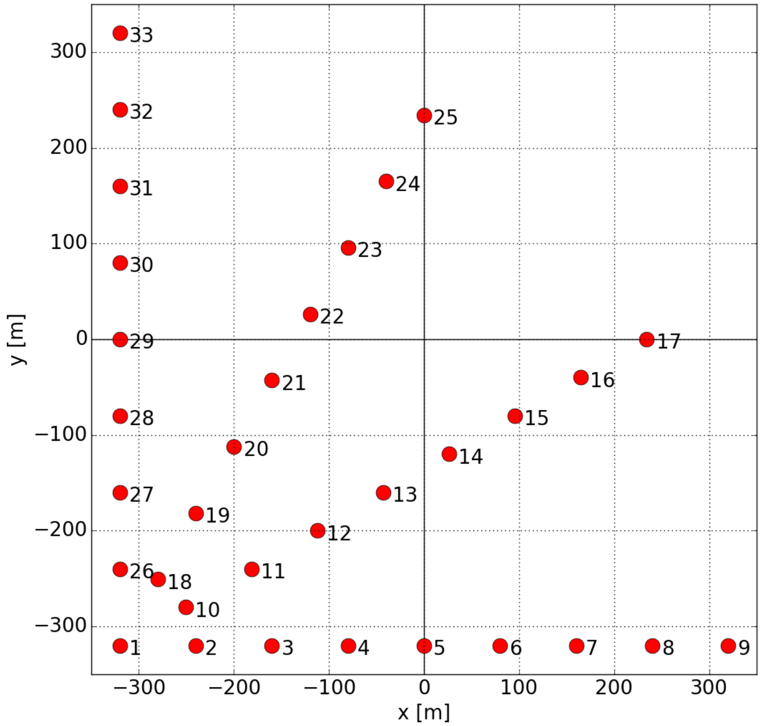
- CORSIKA (v. 6990) + sim_telarray (21/12/2016)
- primary particles: **protons**
- energy range: **4 GeV – 100 TeV**
- site: **La Palma**
- atmospheric profile: **atm. 36**
- aerosols: **atm_trans_2147_1_3_0_0_0**
- number of showers: **250000**
- core re-scattering: **20**
- telescopes: **MST-F**, **LST**
- array layout: **3AL4M15-5-F + some “testing” layouts**
- jobs: **> 50**

Monte Carlo simulations

Decouple zenith & azimuth angle dependence from other issues:

- fixed azimuth $\boldsymbol{\Phi = 0^o}$ (i.e. along the x-axis)
- zenith angle $\boldsymbol{\theta \in [0^o, 60^o]}$
- fixed magnetic field $\boldsymbol{B \approx 0}$
- telescope separation $\boldsymbol{D \in [1\ \mathrm{m}, 640\ \mathrm{m}]}$
- telescope alignment w.r.t.

  the shower direction $\boldsymbol{\beta \in [0^o, 90^o]}$
- fixed telescope efficiencies $\boldsymbol{\varepsilon = 1.0}$
- **fixed atmosphere**

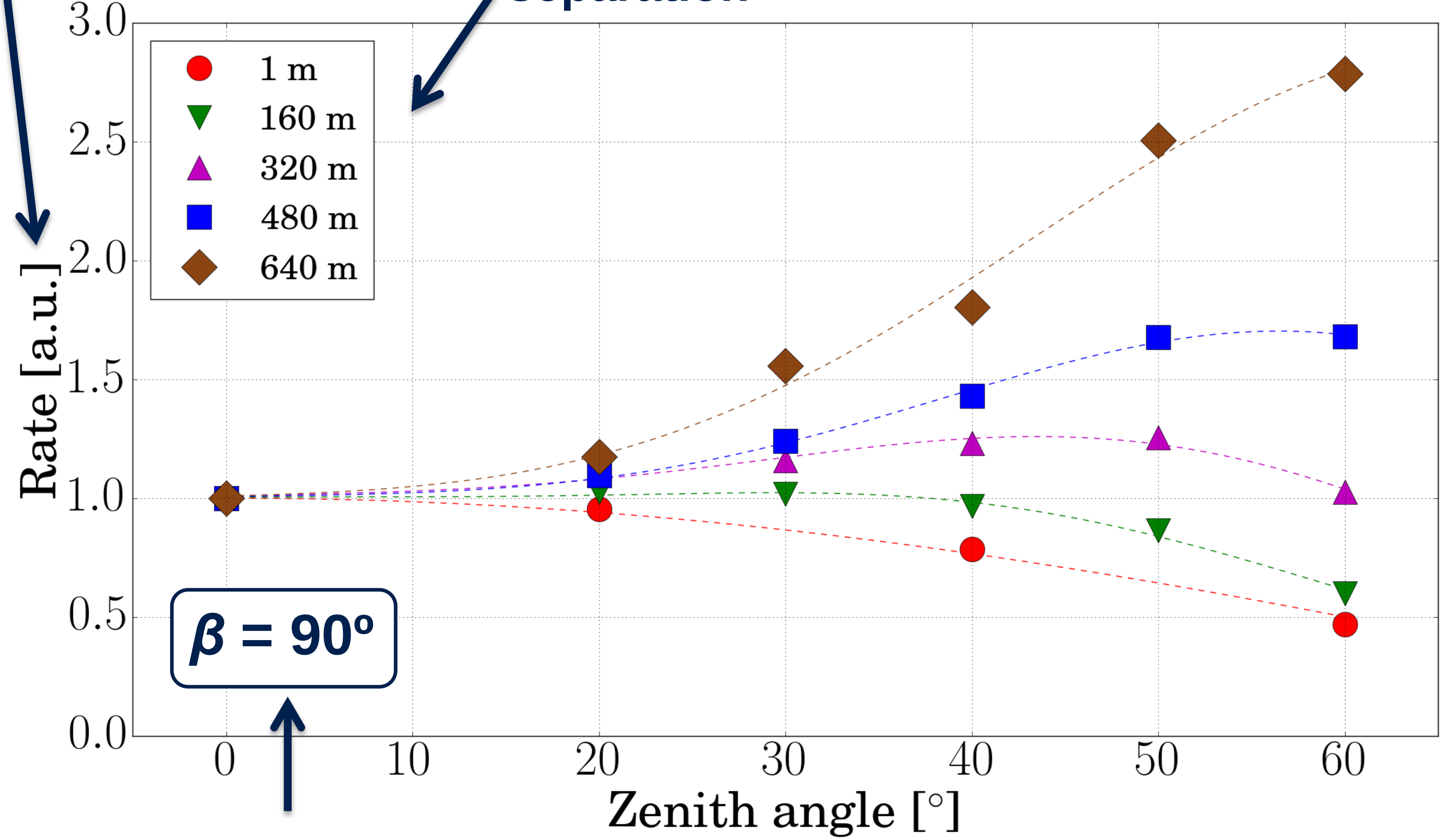


Zenith angle

B ≈ 0

2 – MST trigger rate

telescope separation



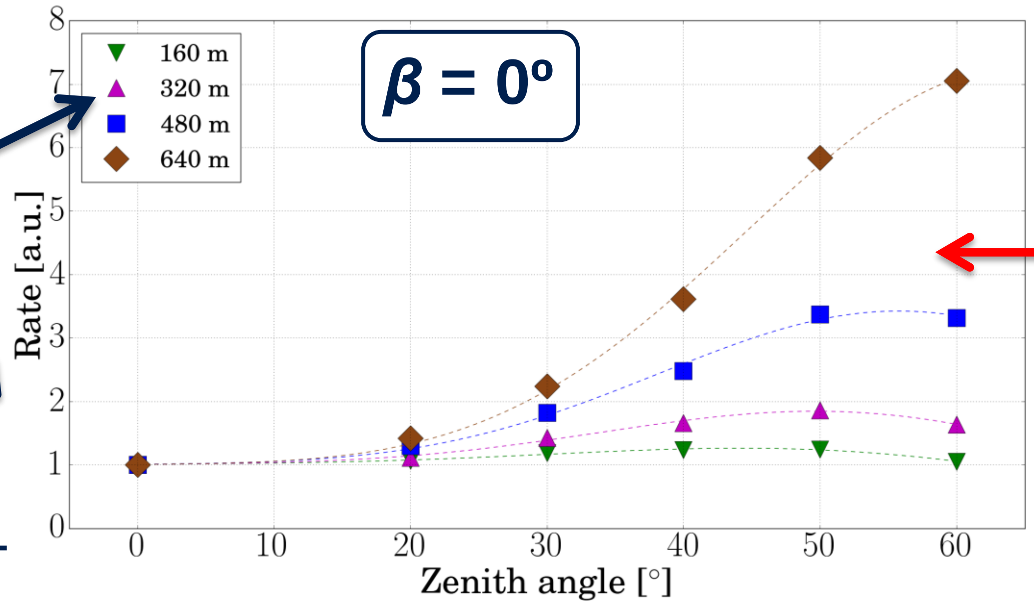
angle between the shower direction (azimuth) and the line connecting telescopes

Telescope alignment

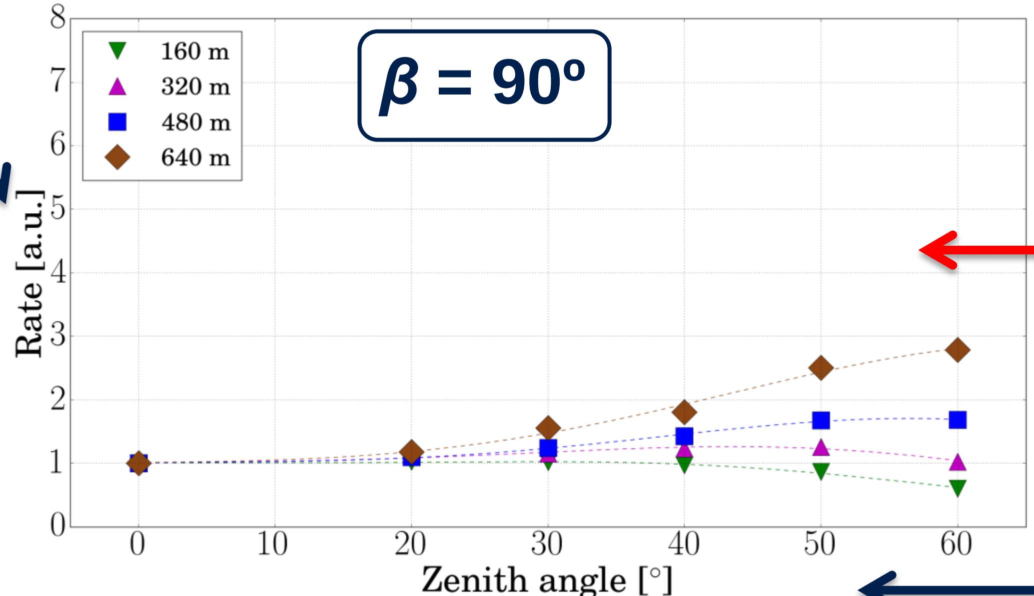
B ≈ 0

telescope separation

2 – MST rate



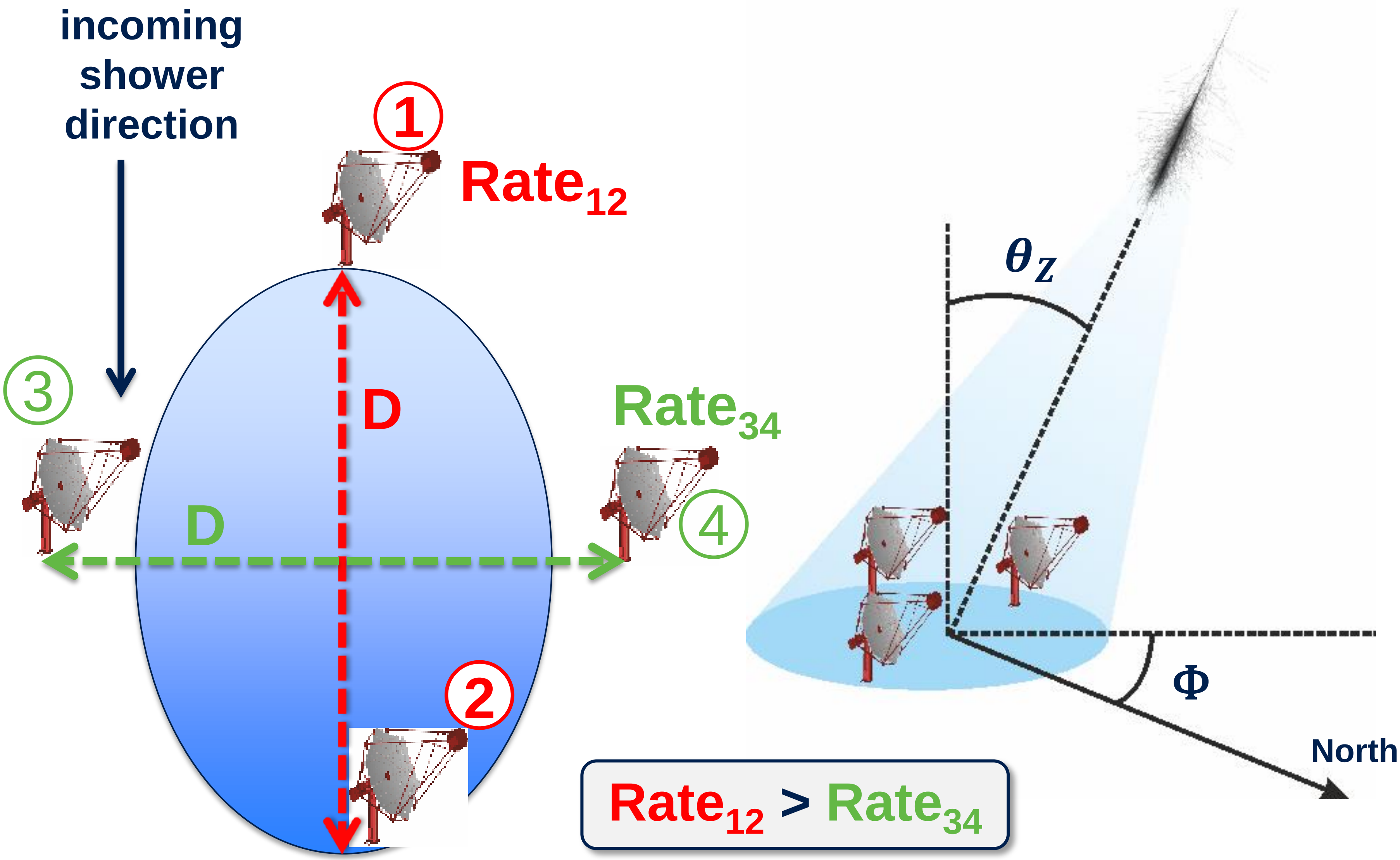
Line between telescopes parallel to the shower direction



Line between telescopes perpendicular to the shower direction

zenith angle

Telescope alignment

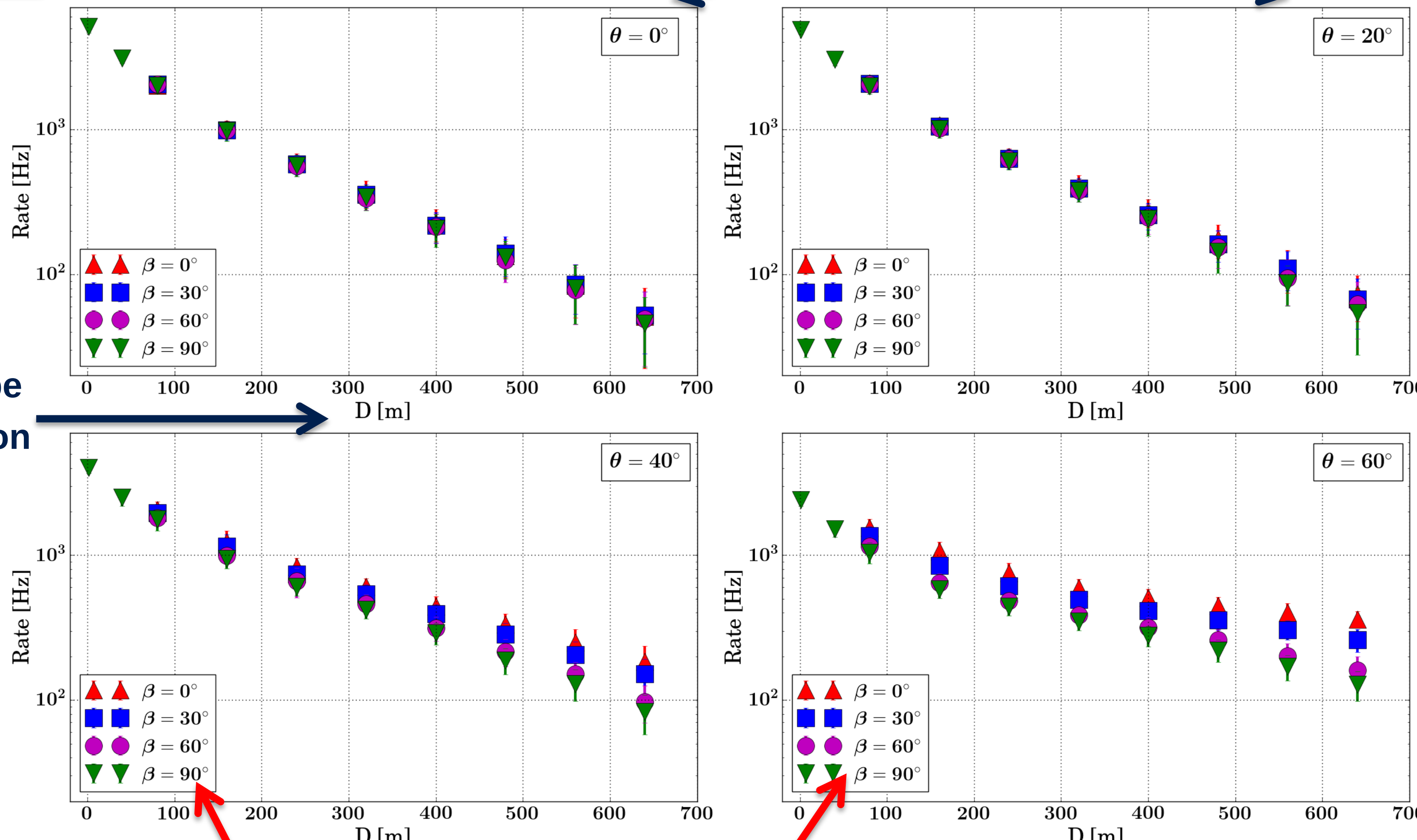


Telescope separation

B ≈ 0

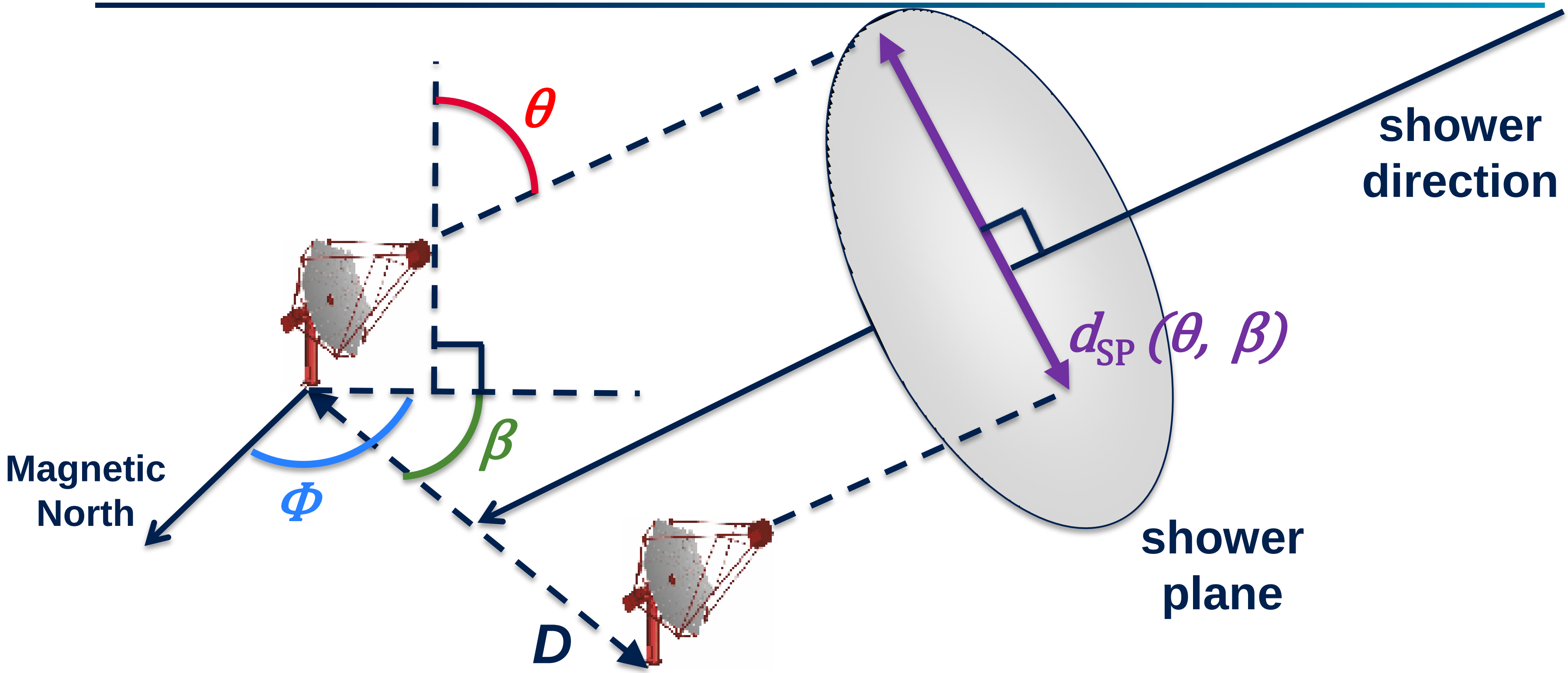
Zenith angle

Telescope separation



Angle between shower direction & line connecting telescopes

Separation in the shower plane



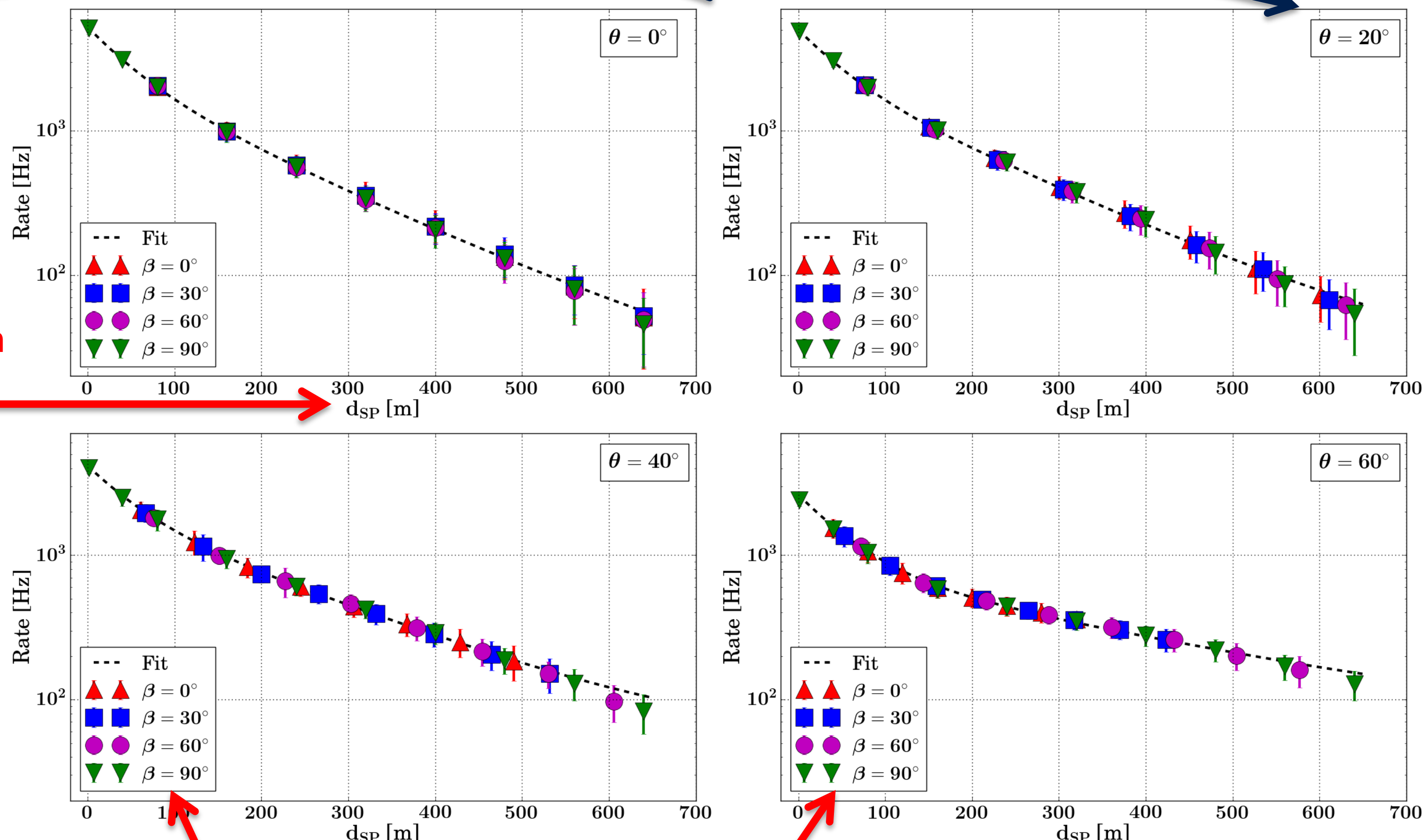
- θ … zenith angle of the air shower
- Φ … azimuth angle of the shower w.r.t. the magnetic North
- β … angle between the telescope line and the shower direction
- $d_{SP} = D\,.\sqrt{1 - \sin^2\theta\,.\cos^2\beta}$

Separation in the shower plane

B ≈ 0

Zenith angle

Telescope separation in the shower plane



Angle between shower direction & line connecting telescopes

Other issues

- **Hardware dependence:**
  - rates proportional to the product of telescope efficiencies
  - for the purpose of atmospheric calibration, the values of telescope optical efficiencies can be taken from previous night

- **Magnetic field dependence:**
  - non-negligible influence of the Earth's magnetic field
  - depends on the zenith (θ) & azimuth (Φ) angles and telescope pair alignment (β)

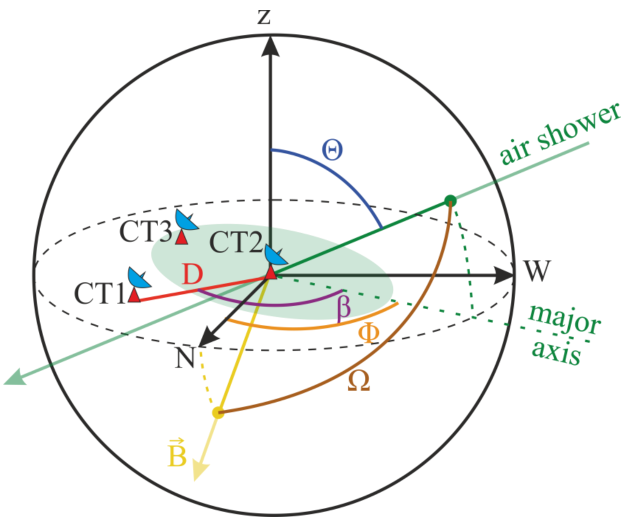
I will cover this in more detail in the array calibration talk on **Wednesday.**

Atmospheric calibration

ICRC '17 contribution:

- layout 3AL4M15-5-F (La Palma)
- no change in atmospheric conditions
- 3 different configurations (θ, Φ)
- transparency estimates for telescope pairs *(i, j)*:

$$\tau_{ij}(AOD) = \frac{R_{ij}\left(AOD, D, \theta, \beta, \vec{B}, \varepsilon\right)}{F\left(D, \theta, \beta, \vec{B}, \varepsilon\right)}$$



- fits of the stereo trigger rate vs. $\boldsymbol{d_{SP}}$ and $\boldsymbol{\theta}$
- ***B***-field contribution neglected
- $\boldsymbol{\varepsilon}$ taken as results of the telescope inter-calibration (Wednesday talk)

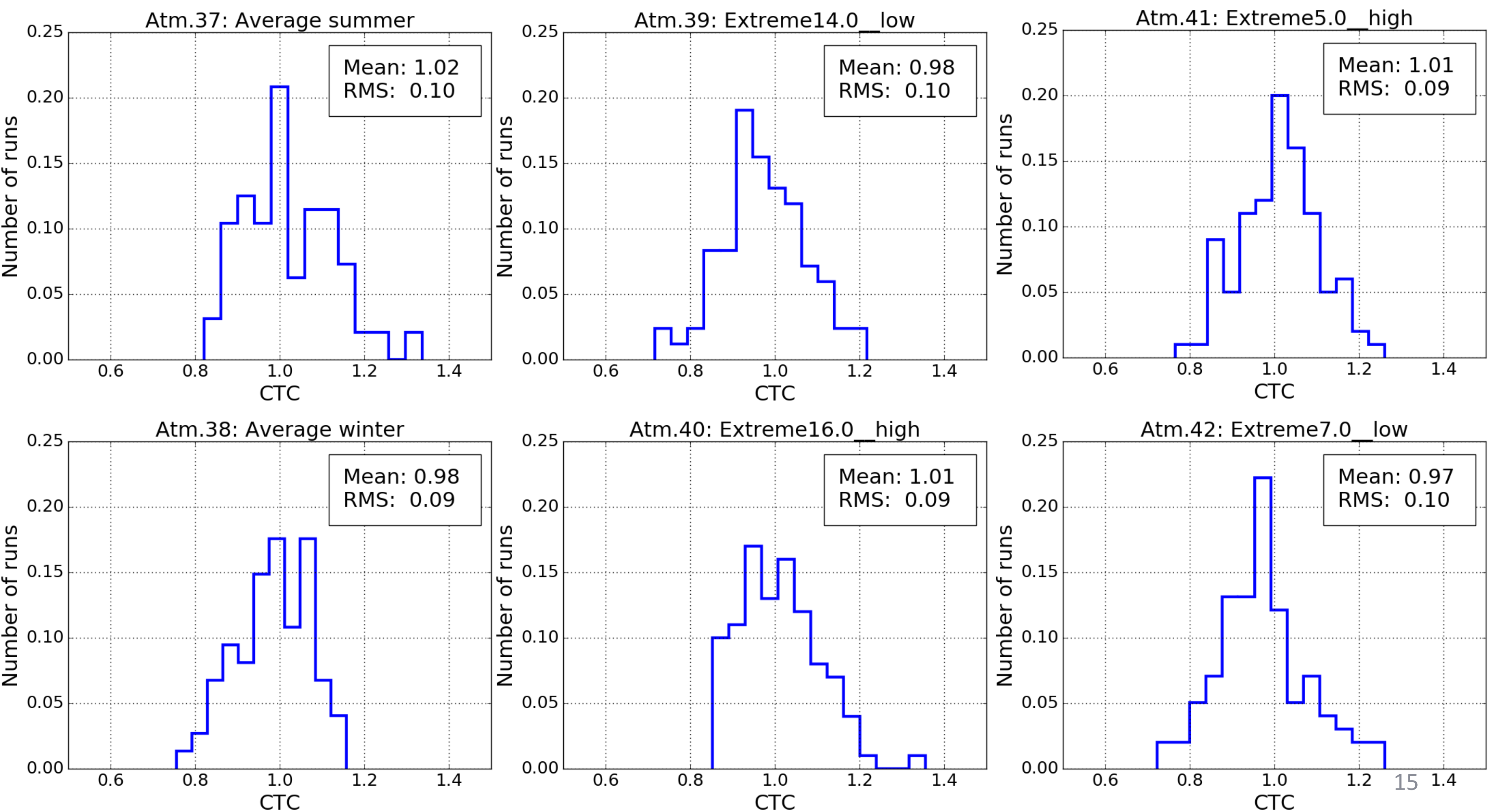
$$CTC(AOD) = \overline{\tau_{ij}} = 1.02 \pm 0.04$$

arXiv:1709.01117

A very preliminary result:
precision might worsen for different orientations w.r.t. the B-field

Atmospheric profiles

- March (CCF-board) results:



To-do list

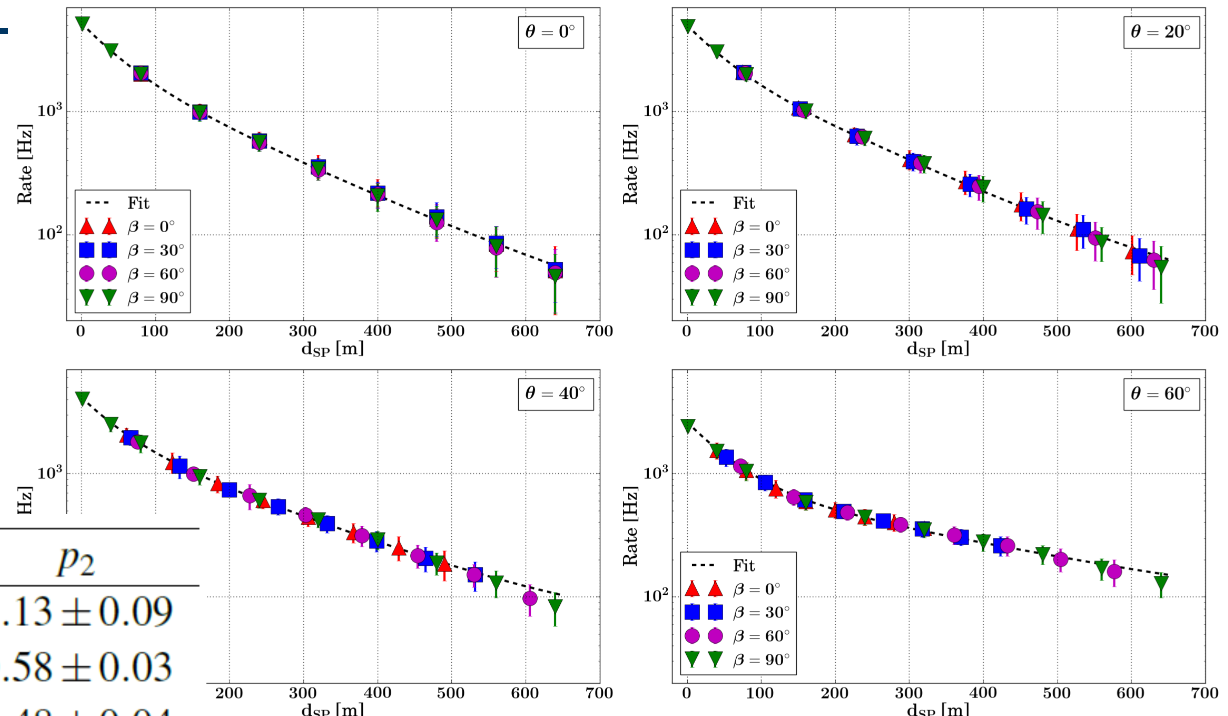
- solve the magnetic field issue
- parametrize the stereo trigger rate for SSTs
- once the final CTC scheme is settled, verify with the simulations of different atmospheric conditions
  - full array simulations
  - 2-3 aerosol concentrations at ~3 altitudes should be sufficient
  - clouds ?
  - need for the transmission input files: I lack the expertise for that and would greatly appreciate any help

Summary

Feasibility study of the CTC for atmospheric calibration:

- quantification of the influence of the zenith & azimuth angles, telescope alignment
- ongoing study of the Earth’s magnetic field influence (Wednesday)
- CTC seems to be independent of the molecular profiles
- CTC consistent with the expectation for the B ≈ 0 case (but only 1 atmosphere tested)
- preliminary results presented at ICRC ’17 (poster)
- aerosol simulations necessary

Back-up



P	p_0	p_1	p_2
A_0	934 ± 14	15.9 ± 9.9	1.13 ± 0.09
A_2	$(7.4 \pm 0.4)\mathrm{e}^{-3}$	-3.7 ± 0.4	0.58 ± 0.03
A_3	184 ± 9	-6.5 ± 2.2	0.48 ± 0.04

Table 1: Fit results of the parameters of the Eq.(2.2) to the relation $P = p_0 \cdot [1 + \exp(p_1 \cdot (\cos\theta - p_2))]^{-1}$. A_1 can be described by the expression $p_0 \cdot [\cos(p_1 \cdot \theta - p_2)] + p_3$, where $p_0 = (5.9 \pm 0.5)\mathrm{e}^{-4}$, $p_1 = 6.2 \pm 0.3$, $p_2 = 53.9 \pm 7.4$, $p_3 = (8.63 \pm 0.03)\mathrm{e}^{-3}$ and θ is given in degrees.

$$R_{\mathrm{Fit}}(d_{\mathrm{SP}}) = \begin{cases} A_0 \cdot e^{A_1 \cdot (d_{\mathrm{SP}} - A_3)}, & \text{if } d_{\mathrm{SP}} < A_3 \\ A_0 \cdot e^{A_2 \cdot (d_{\mathrm{SP}} - A_3)}, & \text{if } d_{\mathrm{SP}} > A_3 . \end{cases}$$