### Geosynchrotron radio emission from

### **CORSIKA-simulated air showers**





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### Cosmic ray measurements

different observing techniques yield different observables
 hybrid detection is especially favourable

techniques 10<sup>19</sup> \* PROTON KASCADE (QGSJET 01) Akeno direct **KASCADE H** HiRes I RUNJOB **KASCADE He** 10<sup>18</sup> HiRes II **KASCADE** heavy sec <sup>-1</sup> sr <sup>-1</sup> eV <sup>1.5</sup> measuredirect data AGASA KASCADE (SIBYLL 2.1) **AUGER 2005 KASCADE H** ments **KASCADE He** 10<sup>17</sup> **KASCADE** heavy surface particle 10<sup>16</sup> 2 detectors <sup>2.5</sup> J(E) (m RUNJOE JACEE <sup>---</sup>660 air fluores-ATIC 15 10 MUBEE SOKOL cence **Radio detection**<sup>a</sup> ш KASCADE-single h Flux telescopes proton data 10<sup>14</sup> radio **Pierre Auger Observatory** -Grande KASCADE detection 10<sup>13</sup> . . . . . . . . . . 10<sup>14</sup> 10<sup>17</sup> 10<sup>18</sup> 10<sup>13</sup> 10<sup>15</sup> 10<sup>16</sup> 10<sup>19</sup> 10<sup>20</sup> 10<sup>21</sup> Energy (eV/particle)

# Radio emission mechanism

- historical works
  - geomagnetic mechanism
  - not detailed enough
- new model as part of LOPES: coherent geosynchrotron emission
  - electron-positron pairs gyrate in the Earth's magnetic field: radio pulses
  - coherent emission at low frequencies (tens of MHz)
- first step: analytical calculations
  - second step: Monte Carlo simulations using parametrised air showers
- current stage: Monte Carlo simulations based on CORSIKAsimulated, realistic air showers





### **Parametrised Monte Carlo**

time-domain MC
no far-field approximations
full polarisation info
thoroughly tested
compared with analytics and data
parametrisations for



- particle arrival time distribution (pancacke thickness)
- lateral particle distribution (pancake width)
- particle track length & energy distributions
- shower evolution as a whole (for integration)

### **CORSIKA-based Monte Carlo**



keep established Monte Carlo code

- replace parametrised air shower model with CORSIKA simulated showers
  - 50 detector planes distributed over shower evolution
  - separate information for electrons and positrons
  - 3d-histogram
    - 1. arrival time
    - 2. lateral position
    - 3. particle energy
- 3d-histogram
  - 1. angle to shower axis
  - 2. azimuthal direction
  - 3. particle energy
- new concept eliminates remaining free parameter for particle track length
   charge ratio is taken into account correctly
   important step on the way to direct implementation of radio code in CORSIKA

### Parametrised vs. histogrammed



### take a "reference shower"

- 10<sup>17</sup> eV vertical proton-induced shower
- CORSIKA 6.5 with QGSJET-II and UrQMD
- parametrised and CORSIKA showers have shower max. at 640 g cm<sup>-2</sup>
- compare particle distributions
  - parametrised vs. histogrammed

Compare effect on radio pulses when going from parametrised to histogrammed distributions

- can analyse the distributions individually
- look at pulses close to the shower core (75 m) and far away from the shower core (525 m)



# parametrisation and CORSIKA very similar but: CORSIKA includes shower to shower fluctuations and composition dependence arbitrary time shift unimportant



NKG parametrisation was already very similar to histogrammed distribution
 consequently, no significant changes



high-energy particles dominate in centre



particle pancake is much thinner close to the shower core than in parametrisation

parametrisation was made from all charged particles
 pulses in shower centre get much "spikier"

## Pitch angle distribution



# no systematic correlation with particle position much broader distribution

- strong damping of radio emission, especially near shower core
  - part of the radio emission goes "to the sides"

### **Combined effects from histograms**



### strong damping, mostly from pitch angle distribution



## The track length problem

must convert from "particles passing a detector plane" to "particles injected at a certain height" free parameter: average particle track length • "few long

tracks" or "many short tracks"



 normalisation is unaffected
 but: other characteristics (angular distributions, ...) can change





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### **Overall effect: radio footprint**



### very similar, especially also polarisation





- EAS phases contribute to different parts of overall pulse
  - evolving arrival time distribution
  - geometric delays distant from the shower core
- In principle, information on the air shower evolution is encoded in the pulse shape



strongest contribution from γ ~ 10-1000
 higher-energy particles contribute in centre, lower-energy at larger distances
 as derived already in analytic calculations



# new, CORSIKA-based Monte Carlo of radio from EAS available

- Controlled transition from parametrised EAS Monte Carlo, very well understood
- pulse changes are slight, considering the drastic improvement of the shower model
  - slight damping of about a factor 2-3
  - •flatter spectra in shower centre
- detailed analyses and comparison with LOPES-30 data in the near future