CORSIKA, Physics and Technology

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USB stick distributed with virtual machine containing:

- **Codes (work/)**
  - CORSIKA v7.6400
  - CONEX v6.4
  - CRMC v1.7
  - mcEq

- **Utilities (software/)**
  - ROOT
  - Gnuplot
  - RIVET
  - Yoda
  - fastjet
How to open (a) coconut?

Just type it!
How to install CORSIKA?

Dowloading and unpacking the code:

- `ftp corsika-76400.tar.gz`
  from `ftp://ikp-ftp.ikp.kit.edu/corsika-v760`
- use login and password from CORSIKA mailing list
- unpack using: `tar -zxvf corsika-76400.tar.gz`
- enter subdirectory: `cd corsika-76400/`

“Normal” Linux distribution with `gcc` and `gfortran` (or `g77`):

- use directly: `./coconut`
- select options (see following)

Different compiler:

- use the standard `$F77`, `$FFLAGS`, `$CC`, ...
Compatibility Mode

System check the compilation mode of your machine

- Choose between 32 bits or 64 bits compilation
  - choose 2 if you don't know and don't care about compatibility
  - may be important if you compile with CERNLIB, ROOT or FLUKA: should be the same!
Models Selection

First selection is the high energy hadronic interaction model:

- See other talks on models to select the most suitable for your application

  - up-to-date:
    - EPOS LHC, QGSJETII-04 and SIBYLL 2.3c (DPMJETIII to come)

  - references:
    - QGSJET01

  - special use:
    - others

Low energy hadronic interaction model

- GHEISHA only for tests (too old)

- Do not forget to define `FLUPRO` (installation path) to use FLUKA
Geometry Selection

Detector geometry (only change the angular distribution of showers)

- **Horizontal flat detector**
  (KASCADE, Pierre Auger Obs,...)

- **Non-flat (volume) detector**
  (Magic, HESS,...)

- **Vertical String detector**
  (AMANDA, IceCube, Antares, ...)
Geometry Selection

Detector geometry (only change the angular distribution of showers)

- **Horizontal flat detector**
  (KASCADE, Pierre Auger Obs,...)
  \[ I \propto \sin \theta \cdot \cos \theta \]

- **Non-flat (volume) detector**
  (Magic, HESS,...)

- **Vertical String detector**
  (AMANDA, IceCube, Antares, ...)

\[ \theta \]
\[ \sin \theta \]
Geometry Selection

Detector geometry (only change the angular distribution of showers)

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  (Magic, HESS,...)

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\[ I \propto \sin \theta \]
Geometry Selection

Detector geometry (only change the angular distribution of showers)

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  (AMANDA, IceCube, Antares, ...)

\[ I \propto (d/2)^2 \cdot \pi \cdot \sin \theta \cdot (\cos \theta + 4/\pi \cdot l/d \cdot \sin \theta) \]
Cherenkov Light

1a – Cherenkov for rectangular grid
   ➤ cherenkov array at ground

1b – Cherenkov for det. system (IACT)
   ➤ HESS, Magic ...
   ➤ with extension for more informations on particles

1c – atmospheric corrections (CEFFIC)
   ➤ suppression of part of the cherenkov photons (use to speed-up simulations)
   ➤ light absorption in atmosphere
   ➤ mirror reflectivity
   ➤ quantum efficiency
Options ...

1d – Auger Cherenkov long. prof.
   ➤ not full simulation but time consuming

1e – Trajectory
   ➤ follow motion of source on the sky

2 – LPM effect
   ➤ Landau Pomeranchuck-Migdal eff.
   ➤ only if no thinning and high energy showers (incl. with thinning)

2a – THINning
   ➤ faster simulations (next slide)

2b – MULTIPLE THINning
   ➤ unthinned + various thinning level
Thinning

Save computation time by reducing the number of particles: a weight is introduced

- thinning: randomly selected particle carry the weight of all particles produced at the same time to conserve energy

- large spread of weight = large artificial fluctuations!

\[ W_2 = \frac{E_0}{E_2} \]

- Multithinning: simultaneous simulation of unthinned and thinned shower to study thinning properties
3 – PRESHOWER
   ➤ preshowering of gamma primary before atmosphere

4 – Neutrino version
   ➤ add neutrino into list of particle

4a – NUPRIM
   ➤ use HERWIG to have neutrino as primary particle
   ➤ only primary neutrino will interact

4b – ICECUBE1
   ➤ reordering of stack : high E on top

4c – ICECUBE2
   ➤ gzip/pipe output
Options ...

5 – STACKIN
- start shower with a list of particle first interaction given by external program (Neutrino...)

6 – CHARM
- track and decay (using PYTHIA) charmed particles produced by QGSJET01 or DPMJET 2.55

6a – TAULEP
- for Tau lepton propagation and decay (using PYTHIA)

7 – Slant
- longitudinal profile as a function of slant depth and not vertical depth (default)
Options ...

7a – Curved
- use a curved atmosphere instead of flat (default)
- needed for large angles (>70°)

7b – Upward
- track particle going upward
- allows upward going showers

7c – View-cone
- restrict primary angle generation to a cone around a given direction
- to be used for atmospheric Cherenkov detectors.
Options ...

8a – PLOTSH
- only to make a “picture” of the shower

8b – PLOTSH2
- more compact output for PLOTSH (need some special library)

8c – ANAHIST
- plot various particle distributions from air shower in hbook file

8d – Auger-histos
- hbook file but with many layers

8e – MUON-histo
- hbook file for muon production depth and muon distribution
Options ...

8a – PLOTSH
- only to make a “picture” of the shower

8b – PLOTSH2
- more suitable than 8a for PLOTSH (need some special library)

8c – ANAHIST
- plot various particle distributions from air shower in hbook file

8d – Auger-histos
- hbook file but with many layers

8e – MUON-histo
- hbook file for muon production depth and muon distribution
9 – External atmosphere
- Using Bernlohr C-routines

9a – Efield
- Electric field in atmosphere

9b – RIGIDITY
- generate shower direction taking into account magnetic field

10a – DYNamic STACK
- manipulation of secondary particle stack at running time
  - stop if no high energy muon or neutrino

10b – Remote Control
- run CORSIKA from a web page
Which additional CORSIKA program options do you need?

1a - Cherenkov version
1b - Cherenkov version using Bernlohr IACT routines (for telescopes)
1c - apply atm. absorption, mirror reflectivity & quantum eff.
1d - Auger Cherenkov longitudinal distribution
1e - TRACetoRy version to follow motion of source on the sky
2 - LPM-effect without thinning
2a - THINning version (includes LPM)
2b - MULTiple THINning version (includes LPM)
3 - PRESHOWER version for EeV gammas
4 - NEUTRINO version
4a - NUPRIM primary neutrino version with HERWIG
4b - ICECube FIPO version
4c - ICECUBE2 gzip/piper output
5 - STACK input of secondaries, no primary particle
6 - CHARMed particle/tau lepton version with PYTHIA
6a - TAU LEpton version with PYTHIA
7 - SLLN depth instead of vertical depth for longi-distribution
7a - CURVED atmosphere version
7b - UWARD particles version
7c - VIECONE version
8a - shower PLOT version (PLOTSH) (only for single events)
8b - shower PLOT(C) version (PLOTSH2) (only for single events)
8c - ANALysis HESTos & THEN (instead of particle file)
8d - Auger-histo file & THIN
8e - MUON-histo file
9 - external atmosphere functions (table interpolation)
  (using bernlohr C-routines)
9a - EFIELD version for electrical field in atmosphere
9b - RIGIDITY Octy version rejecting low-energy primaries entering Earth-magnetic field
9c - CONEX for high energy MC and cascade equations
10a - Dynamic intermediate particle STACK
10b - Remote Control for CORSIKA

b – PARALLEL

- parallel calculation
  - shell script or MPI

c – CoREAS

- radio signal emission from air shower (see T. Huege)

Options ...

- a – CONEX
  - use cascade equations to reduce simulation time
  - various option for 1D or 3D
Air Shower Simulations

Air shower simulations, 2 main methods

- Full MC simulations
  - realistic
  - flexible
  - fluctuations
  - slow
- Cascade Equations (CE)
  - fast
  - mean behavior
  - no fluctuations
  - limited to analytic formula?

Can we have the best of the 2?
Cascade Equations

- Can be CE as flexible than MC?

$\frac{d \phi_e(E)}{dX} = -\sigma_e \phi_e(E) + \int_E^{E_0} \sigma_e \phi_e(\tilde{E}) P_{e\rightarrow e}(\tilde{E}, E) d \tilde{E}$

$+ \int_E^{E_0} \sigma_\gamma \phi_\gamma(\tilde{E}) P_{\gamma\rightarrow e}(\tilde{E}, E) d \tilde{E} - \alpha \frac{\partial \phi_e(E)}{\partial E}$
Can be CE as flexible than MC?

→ electron cascade equations

\[
\frac{d \phi_e(E)}{dX} = -\sigma_e \phi_e(E) - \int_E^{E_0} \sigma_e \phi_e(\tilde{E}) \ P_{e\rightarrow e}(\tilde{E}, E) \ d \tilde{E} \\
+ \int_E^{E_0} \sigma_\gamma \phi_\gamma(\tilde{E}) \ P_{\gamma\rightarrow e}(\tilde{E}, E) \ d \tilde{E} - \alpha \frac{\partial \phi_e(E)}{\partial E}
\]
Can be CE as flexible than MC?

→ electron cascade equations

\[
\frac{d \phi_e(E)}{dX} = -\sigma_e \phi_e(E) - \int_{E}^{E_0} \sigma_e \phi_e(\tilde{E}) \cdot P_{e\rightarrow e}(\tilde{E}, E) \, d\tilde{E} \\
+ \int_{E}^{E_0} \sigma_\gamma \phi_\gamma(\tilde{E}) \cdot P_{\gamma\rightarrow e}(\tilde{E}, E) \, d\tilde{E} - \alpha \frac{\partial \phi_e(E)}{\partial E}
\]
Cascade Equations

Can be CE as flexible than MC?

electron cascade equations: analytical solution for each X step

\[
\frac{d \phi_e(E)}{dX} = -\sigma_e \phi_e(E) - \int_{E}^{E_0} \sigma_e \phi_e(\tilde{E}) P_{e\rightarrow e}(\tilde{E}, E) d\tilde{E} + \int_{E}^{E_0} \sigma_y \phi_y(\tilde{E}) P_{\gamma\rightarrow e}(\tilde{E}, E) d\tilde{E} - \alpha \frac{\partial \phi_e(E)}{\partial E}
\]

production terms

interaction term

ionization loss term
Cascade Equations

- Can be CE as flexible than MC?
  - electron cascade equations: analytical solution for each X step
    \[
    \frac{d \phi_e(E)}{dX} = -\sigma_e \phi_e(E) + \int_{E_0}^{E} \sigma_e \phi_e(\tilde{E}) P_{e\rightarrow e}(\tilde{E}, E) d\tilde{E} \\
    + \int_{E_0}^{E} \sigma_y \phi_y(\tilde{E}) P_{y\rightarrow e}(\tilde{E}, E) d\tilde{E} - \alpha \frac{\partial \phi_e(E)}{\partial E}
    \]

- analytical solution needs simplified distributions
  - no analytical function for hadronic production
  - numerical solution more flexible

\[
\frac{dl^i_{ai}(X)}{dX} = \sum_d \sum_{j=i}^{i_{\text{max}}} \tilde{W}^{ji}_{d\rightarrow a} l^j_d(X) + S_{a_i}^{e/m}(X)
\]
Hadronic Particle Spectra (W)

- Simulations of all type of possible interactions:
  - $p + \text{Air} \rightarrow \pi^\pm, \rho, K^\pm, K_L, K_s, n, \gamma, e, \mu$
  - $\pi^\pm + \text{Air} \rightarrow \pi, \rho, K^\pm, K_L, K_s, n, \gamma, e, \mu$
  - $K^\pm + \text{Air} \rightarrow \pi, \rho, K^\pm, K_L, K_s, n, \gamma, e, \mu$
  - $K^0 + \text{Air} \rightarrow \pi, \rho, K^\pm, K_L, K_s, n, \gamma, e, \mu$
  - $n + \text{Air} \rightarrow \pi, \rho, K, K_L, K_s, n, \gamma, e, \mu$

- Results stored in tables copied to W
Hadronic Particle Spectra (W)

\[ \pi^{\pm}/p + \text{Air} \rightarrow p \quad E_{\text{kin}}=10^{10} \, \text{GeV} \]

\[ \pi^{\pm}/p + \text{Air} \rightarrow \pi^{\pm} \quad E_{\text{kin}}=10^{10} \, \text{GeV} \]

\[ \pi^{\pm}/p + \text{Air} \rightarrow \pi^{0} \quad E_{\text{kin}}=10^{10} \, \text{GeV} \]

\[ \pi^{\pm}/p + \text{Air} \rightarrow n \quad E_{\text{kin}}=10^{10} \, \text{GeV} \]

... same for decay ...
Cascade Equations

- Can be CE as flexible than MC?
  - electron cascade equations: analytical solution for each X step

\[
\frac{d \phi_e(E)}{dX} = -\sigma_e \phi_e(E) + \int_{E}^{E_0} \sigma_e \phi_e(\tilde{E}) \, P_{e\rightarrow e}(\tilde{E}, E) \, d\tilde{E}
\]

\[
+ \int_{E}^{E_0} \sigma_y \phi_y(\tilde{E}) \, P_{\gamma\rightarrow e}(\tilde{E}, E) \, d\tilde{E} - \alpha \frac{\partial \phi_e(E)}{\partial E}
\]

- analytical solution needs simplified distributions
  - no analytical function for hadronic production
  - numerical solution more flexible
Cascade Equations

- Can be CE as flexible than MC?
  - electron cascade equations: analytical solution for each X step

\[
\frac{d \phi_e(E)}{dX} = -\sigma_e \phi_e(E) + \int_{E}^{E_0} \sigma_e \phi_e(\tilde{E}) P_{e\to e}(\tilde{E}, E) d\tilde{E}
\]

\[
+ \int_{E}^{E_0} \sigma_\gamma \phi_\gamma(\tilde{E}) P_{\gamma\to e}(\tilde{E}, E) d\tilde{E} - \alpha \frac{\partial \phi_e(E)}{\partial E}
\]

- analytical solution needs simplified distributions
  - no analytical function for hadronic production
  - numerical solution more flexible
Cascade Equations

- Can be CE as flexible than MC?
  ➔ electron cascade equations: analytical solution for each X step

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\frac{d \phi_e(E)}{dX} = -\sigma_e \phi_e(E) + \int_E^{E_0} \sigma_e \phi_e(\tilde{E}) \, P_{e\rightarrow e}(\tilde{E}, E) \, d\tilde{E} \\
+ \int_E^{E_0} \sigma_\gamma \phi_\gamma(\tilde{E}) \, P_{\gamma\rightarrow e}(\tilde{E}, E) \, d\tilde{E} - \alpha \frac{\partial \phi_e(E)}{\partial E}
\]

- analytical solution needs simplified distributions
  ➔ no analytical function for hadronic production
  ➔ numerical solution more flexible
Consistent Hybrid Calculation

- Numerical solution of cascade equations
  - same cross-section, atmosphere, models for CE and MC
  - mixing possible: hybrid simulation
  - CE replace MC when number of particles is large ($E < E_{\text{thr}}$)
  - save lot of time
  - keep fluctuations
  - realistic 1D simulations (longitudinal profiles)
  - 3D results by resampling of low energy particles with fixed weight

MC fill the source function of the CE
Properties

- CORSIKA replace part of the CE
  - First interactions in CONEX independent from $E_{\text{low}}$
    - Event-by-event simulations using first 1D only and then 3D with exactly the same shower (Golden Hybrid, radio)

- CE replace part of the thinning in CORSIKA
  - No thinned high energy gammas (stay in CE)
    - No muons from EM particles with very large weight
  - Very narrow weight distributions: less artificial fluctuations
  - No thinning for very inclined shower
    - Only muons and corresponding EM sub-showers in MC

- Mean showers can be simulated directly (no high energy MC)
Weight distribution $R > 100$ m

- Very narrow weight distribution from sampling
- Less artificial fluctuations
Which additional CORSIKA program options do you need?

1a - Cherenkov version
1b - Cherenkov version using Bernlohr IACT routines (for telescopes)
1c - apply atm. absorption, mirror reflectivity & quantum eff.
1d - Auger Cherenkov longitudinal distribution
1e - TRAJECTory version to follow motion of source on the sky
2 - LPM-effect without thinning
2a - THINning version (includes LPM)
2b - MULTiple THINning version (includes LPM)
3 - PRESHOWER version for EeV gammas
4 - NEUTRINO version
4a - NUPRIM primary neutrino version with HERWIG
4b - ICECUBEL FIPO version
4c - ICECUBE2 gzip/pipe output
5 - STACK input of secondaries, no primary particle
6 - CHArm particle/tau lepton version with PYTHIA
6a - TAU LEpton version with PYTHIA
7 - SLANT depth instead of vertical depth for longi-distribution
7a - CURVED atmosphere version
7b - UPWARD particles version
7c - VIEWCONE version
8a - shower FLOT version (FLotsh) (only for single events)
8b - shower FLOT(c) version (FLotsh2) (only for single events)
8c - ANALysis HESTos & THEN (instead of particle file)
8d - Auger-histo file & THIN
8e - MUON-histo file
9 - external atmosphere functions (table interpolation)
  (using bernlohr C-routines)
9a - EFIELD version for electrical field in atmosphere
9b - RIGIDITY Octy version rejecting low-energy primaries entering Earth-magn.

c - DYNAMIC intermediate particle STACK
10b - Remote Control for Corsika
10c - CONEX for high energy MC and cascade equations
b - PARALLEL treatment of subshowers (includes LPM)
c - COREAS Radio Simulations
d - Inclined observation plane
e - ROOT particle output file
d3 - Use an external COAST user library (Corsika data Access Tool)
e - interaction test version (only for 1st interaction)
f - Auger-info file instead of dbase file
f - COMPACT particle output file
h - MUPROD to write decaying muons
h2 - preHISTORY of muons; mother and grandmother
k - annih test cross-section version (obsolete)
l - hit Auger detector (steered by AUGSCT)
 - - - *** Reset selection ***
 2 - *** Finish selection *** [DEFAULT]

Options ...

a – CONEX
- use cascade equations to reduce simulation time
- various option for 1D or 3D

b – PARALLEL
- parallel calculation
- shell script or MPI

c – CoREAS
- radio signal emission from air shower (see T. Huege)
Parallelization of CORSIKA with MPI

- **MPI Master**
  - Input
  - Reproducibility of the shower: results independent of the number of jobs.

- CORSIKA
  - Low energy secondaries down to observation level

Primary particle
High energy secondaries
Intermediate energy secondaries
Parallelization of CORSIKA

• Each shower is simulated on a large number of CPU
  → Simulation time reduction limited by the number of machines
  → Disk space problem solved by saving particles in detectors only

• Solution tested for high energy showers only
  → Electromagnetic shower not really parallelized ...

Parallel version tested on HP XC3000 (2.53 GHz CPUs, InfiniBand 4X QDR)
Options ... 

Which additional CORSIKA program options do you need?

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- apply atm. absorption, mirror reflectivity & quantum eff.
- Auger Cherenkov longitudinal distribution
- TRAJECTory version to follow motion of source on the sky
- LPM-effect without thinning
- THINning version (includes LPM)
- MULTiple THINning version (includes LPM)
- PRESHOWER version for EeV gammas
- NEUTRINO version
- NUPRIM primary neutrino version with HERWIG
- ICECUBE FIPO version
- ICECUBE2 gzip/pipe output
- STACK input of secondaries, no primary particle
- CHArmed particle/tau lepton version with PYTHIA
- SLANT depth instead of vertical depth for longi-distribution
- CURVED atmosphere version
- UPWARD particles version
- CUDONE version
- shower PLOT version (PLOTSH) (only for single events)
- shower PLOT(C) version (PLOTSH2) (only for single events)
- ANALysis HESTos & THEN (instead of particle file)
- Auger-histo file & THIN
- MUON-histo file
- external atmosphere functions (table interpolation)
- (using bernlohr C-routines)
- EFIELD version for electrical field in atmosphere
- RIGIDITY Octy version rejecting low-energy primaries entering Earth-magnetic field
- Dynamic intermediate particle STACK
- Remote Control for Corsika
- CONEX for high energy MC and cascade equations
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- COREAS Radio Simulations
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- preHISTORY of muons; mother and grandmother
- annih test cross section version (obsolete)
- hit Auger detector (steered by AUGSCAT)
- *** Reset selection ***
- *** Finish selection *** [DEFAULT]

- **a – CONEX**
  - use cascade equations to reduce simulation time
  - various option for 1D or 3D

- **b – PARALLEL**
  - parallel calculation
  - shell script or MPI

- **c – CoREAS**
  - radio signal emission from air showers (see T. Huege)
Which additional CORSIKA program options do you need?

1a. Cherenkov version
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1c. apply atm. absorption, mirror reflectivity & quantum eff.
1d. Auger Cherenkov longitudinal distribution
1e. TRAJECTory version to follow motion of source on the sky
2. LPM-effect without thinning
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2b. MULTiple THINning version (includes LPM)
3. PRESHOWER version for EeV gammas
4. NEUTRINO version
4a. NLPRIM primary neutrino version with HERWIG
4b. ICECUBE FIPO version
4c. ICECUBE2 gzip/pipe output
5. STACK input of secondaries, no primary particle
6. CHARMed particle/tau lepton version with PYTHIA
6a. TAU LEpton version with PYTHIA
7. SLANT depth instead of vertical depth for longi-distribution
7a. CURVED atmosphere version
7b. UPWARD particles version
7c. VIEWCONE version
8a. shower PLOT version (PLOTSH) (only for single events)
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8c. ANALysis HISTos & THIN (instead of particle file)
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8e. MUON-histo file
9. external atmosphere functions (table interpolation) (using bernlohr C-routines)
9a. EFIELD version for electrical field in atmosphere
9b. RIGIDITY Octy version rejecting low-energy primaries entering Earth-magnet fields
10a. DYNAMIC intermediate particle STACK
10b. Remote Control for Coreika
a. CONEX for high energy MC and cascade equations
b. PARALLEL treatment of subshowers (includes LPM)
c. COREBS Radio Simulations
dl. Inclined observation plane
d2. ROOT particle OUTPUT file
d3. Use an external COAST user library (Corsika data AccesS Tool)
e. interaction test version (only for 1st interaction)
f. Auger-info file instead of dbase file
g. COMPACT particle output file
h. NUMROD to write decaying muons
h2. pREReSTory of muons; mother and grandmother
k. amntest cross-section version (obsolete)
l. hit Auger detector (steered by AUGSCT)

**y**. *** Reset selection ***
**2.*** Finish selection *** [DEFAULT]

**COAST Options ...**
(see R. Ulrich exercises)

**d2 – Inclined**
- arbitrary direction for obs. level

**d2 – ROOTOUT**
- produce the DAT file in ROOT

**(d3 – COASTUSERLIB)**
- appear only if COAST is installed
- to use COAST as external package for shower analysis
Options ...

Which additional CORSIKA program options do you need?

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1d - Auger Cherenkov longitudinal distribution
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9a - EFIELD version for electrical field in atmosphere
   (using ridigity Ocy version rejecting low-energy primaries entering earth-magnetic
   field)
10a - DYNAMIC intermediate particle STACK
10b - Remote Control for Corsika
11 - CONEX for high energy MC and cascade equations
12 - PARALLEL treatment of subshowers (includes LPM)
13 - CONEX Radio Simulations
14 - Inclined observation plane
15 - ROOT particle output file
16 - Use an external COAST user library (Corsika data AccesS Tool)
17 - interaction test version (only for 1st interaction)
18 - Auger-info file instead of dbase file
19 - COMPACT particle output file
20 - MUPROD to write decaying muons
21 - pREHISTORY of muons, mother and grandmother
22 - annihilation cross section version (obsolete)
23 - hit Auger detector (steered by AUGSCT)
24 - Reset selection *** [DEFAULT]
25 - Finish selection *** [DEFAULT]

- e – Interaction test
  - only first interaction to plot particle distributions (hbook)

- f – Auger info file
  - special output file on generated showers (primary parameters)

- g – COMPACT output
  - compact output file to be used for low energy showers with few particles at ground

- h – MUPROD
  - write in particle list produced muons which do not reach observation level
Which additional CORSIKA program options do you need?

0. Cherenkov 
1. Cherenkov version 
2. Cherenkov version using Barnlohr IACT routine 
3. Apply electron absorption, air shower reflectivity 
4. Auger Cherenkov longitudinal distribution 
5. TRACEnory version to follow motion of sources 
6. LPM effect without thinning 
7. Multiple thinning version (includes APM) 
8. MULTIPLE version for Ee gamma 
9. PRESHOWER version for Ee gamma 
10. NEUTRON version 
11. NUPRIM primary neutrino version with HERWIG 
12. ICECUBER FIRO version 
13. ICECUBE2 gzip/pip output 
14. STACK input of secondaries, no primary particle 
15. CHARME particle/tau lepton version with PYTHIA 
16. TAU LP EP version with PYTHIA 
17. SLANT depth instead of vertical depth for longi-distribution 
18. CURVED atmosphere version 
19. UWARD particles version 
20. VIEWCONE version 
21. shower PLOT version (PLOUT) (only for single events) 
22. shower PLOT(C) version (PLOUT2) (only for single events) 
23. Analysis HISTOS & THEN (instead of particle file) 
25. MUH-isto file 
26. external atmosphere functions (table interpolation) (using barnlohr C-routines) 
27. EFIELD version for electrical field in atmosphere 
28. RIGIDITY Octy version rejecting low-energy primaries entering Earth-magnetic field 
29. Dynamic intermediate particle STACK 
30. Remote Control for Coreika 
31. CONEX for high energy MC and cascade equations 
32. PARALLEL treatment of subshowers (includes LPM) 
33. CORES Radio Simulations 
34. Inclined observation plane 
35. ROOT particle OUTPUT file 
36. Use an external COAST user library (CORSIKA data ACCESS tool) 
37. Interaction test version (only for 1st interaction) 
38. Auger-info file instead of dbase file 
39. COMPACT particle output file 
40. MUPROD to write decayng muons 
41. PROHISTORY of muons; mother and grandmother 
42. annu test cross-section version (obsolete) 
43. Hit Auger detector (steered by AUGSCT) 
44. *** Reset selection *** (default) 
45. *** Finish selection *** (default) 

Options ...

- **e** – Interaction test
  - only first interaction to plot particle distributions (hbook)
- **f** – Auger info file
  - special output file on generated showers (primary parameters)
- **g** – COMPACT output
  - compact output file to be used for low energy showers with few particles at ground
- **h** – MUPROD
  - write in particle list produced muons which do not reach observation level

Obsolete ... CRMC should be used instead!
Options ...

Which additional CORSIKA program options do you need?

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Cherenkov version</td>
</tr>
<tr>
<td>1b</td>
<td>Cherenkov version using Bernlohr JACT routines (for telescopes)</td>
</tr>
<tr>
<td>1c</td>
<td>apply atm. absorption, mirror reflectivity &amp; quantum eff.</td>
</tr>
<tr>
<td>1d</td>
<td>Auger Cherenkov longitudinal distribution</td>
</tr>
<tr>
<td>1e</td>
<td>TRACETOury version to follow motion of source on the sky</td>
</tr>
<tr>
<td>2</td>
<td>LPM-effect without thinning</td>
</tr>
<tr>
<td>2a</td>
<td>THINning version (includes LPM)</td>
</tr>
<tr>
<td>2b</td>
<td>MULTiple THINning version (includes LPM)</td>
</tr>
<tr>
<td>3</td>
<td>PRESHOWER version for EeV gammas</td>
</tr>
<tr>
<td>4</td>
<td>NEUTRINO version</td>
</tr>
<tr>
<td>4a</td>
<td>NUPRIM primary neutrino version with HERWIG</td>
</tr>
<tr>
<td>4b</td>
<td>ICECUBE1 FIPO version</td>
</tr>
<tr>
<td>4c</td>
<td>ICECUBE2 gzip/pipe output</td>
</tr>
<tr>
<td>5</td>
<td>STACK input of secondaries, no primary particle</td>
</tr>
<tr>
<td>6</td>
<td>CHARMed particle/tau lepton version with PYTHIA</td>
</tr>
<tr>
<td>6a</td>
<td>TAU LEpton version with PYTHIA</td>
</tr>
<tr>
<td>7</td>
<td>SLANF depth instead of vertical depth for longi-distribution</td>
</tr>
<tr>
<td>7a</td>
<td>CURVED atmosphere version</td>
</tr>
<tr>
<td>7b</td>
<td>UPWARD particles version</td>
</tr>
<tr>
<td>7c</td>
<td>VIEWCONE version</td>
</tr>
<tr>
<td>8a</td>
<td>shower FLOT version (FLOTSH) (only for single events)</td>
</tr>
<tr>
<td>8b</td>
<td>shower FLOT(C) version (FLOTSH2) (only for single events)</td>
</tr>
<tr>
<td>8c</td>
<td>ANALysis HIStorys &amp; THEN (instead of particle file)</td>
</tr>
<tr>
<td>8d</td>
<td>Auger-histo file &amp; THIN</td>
</tr>
<tr>
<td>8e</td>
<td>MUON-histo file</td>
</tr>
<tr>
<td>9</td>
<td>external atmosphere functions (table interpolation) (using bernlohr C-routines)</td>
</tr>
<tr>
<td>9a</td>
<td>EFIELD version for electrical field in atmosphere</td>
</tr>
<tr>
<td>9b</td>
<td>RIGIDITY Octy version rejecting low-energy primaries entering Earth-magnetic field</td>
</tr>
</tbody>
</table>

Any options can be selected at the same time (separated by space) an option can be deselected using “-” sign

**h2 – preHISTORY**
- to get information about mother and grandmother particles of particles arriving at ground
  - MUADDI: muons
  - EMADDI: electrons and photons

**k – annist test** (nothing)

**l – Auger hit**
- save particles on hexagonal grid
Other Options ...

y – reset selection

z – Finish selection
   ➤ just press “return” key

r – restart
   ➤ from the beginning (model selection)

x – exit make
   ➤ stop installation
If Cherenkov

Che. longitudinal distribution
- differential (prod. per bin)
- integrated (sum in bin)
- none

Che. light emission
- refraction index wavelength independent
- refraction index wavelength dependent
- emission angle change at low energy
By default the program is compiled

- answer “n” (no) only if you know why!

Source file not saved by default

- using “k” source (after precompilation) can be saved if you want to see what is really used in the code
System Check

System check important only if something goes wrong ...

- Please send it with your email if you have unsolved problem during your installation.

- In case of incompatible option or missing declaration (like path variables) an error message appears here and program stops
  - no compilation!

- If you can't solve the problem, please send us screen output and config.status file.
Installation Complete

If no compilation problem

- CORSIKA installed in the run/ subdirectory
- follow instructions and enjoy CORSIKA …
Installation Complete

If no compilation problem

- CORSIKA installed in the `run/` subdirectory
- follow instructions and enjoy CORSIKA …

… using the steering file!
Input (steering) File

CORSIKA to be used via standard input (keyboard) or by a steering text file redirected in CORSIKA

```
./corsika76400Linux_QGSJ ET_gheisha < all-inputs
```

3 Types of controls:
- shower parameters
- options parameters
- output parameters

End steering:
- EXIT
# Shower Parameters (1)

<table>
<thead>
<tr>
<th>Identification</th>
<th>Particle</th>
<th>Identification</th>
<th>Particle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>γ</td>
<td>17</td>
<td>η</td>
</tr>
<tr>
<td>2</td>
<td>e⁺</td>
<td>18</td>
<td>Λ</td>
</tr>
<tr>
<td>3</td>
<td>e⁻</td>
<td>19</td>
<td>Σ⁺</td>
</tr>
<tr>
<td></td>
<td></td>
<td>20</td>
<td>Σ⁻</td>
</tr>
<tr>
<td>5</td>
<td>μ⁺</td>
<td>21</td>
<td>Σ°</td>
</tr>
<tr>
<td>6</td>
<td>μ⁻</td>
<td>22</td>
<td>Ξ°</td>
</tr>
<tr>
<td>7</td>
<td>π⁰</td>
<td>23</td>
<td>Ξ⁻</td>
</tr>
<tr>
<td>8</td>
<td>π⁺</td>
<td>24</td>
<td>Ω⁻</td>
</tr>
<tr>
<td>9</td>
<td>π⁻</td>
<td>25</td>
<td>η</td>
</tr>
<tr>
<td>10</td>
<td>K⁺</td>
<td>26</td>
<td>Λ</td>
</tr>
<tr>
<td>11</td>
<td>K⁻</td>
<td>27</td>
<td>Σ⁻</td>
</tr>
<tr>
<td>12</td>
<td>n</td>
<td>28</td>
<td>Σ°</td>
</tr>
<tr>
<td>13</td>
<td>p</td>
<td>29</td>
<td>Σ⁺</td>
</tr>
<tr>
<td>14</td>
<td>p̄</td>
<td>30</td>
<td>Ξ⁺</td>
</tr>
<tr>
<td>16</td>
<td>K⁺</td>
<td>31</td>
<td>Ξ⁻</td>
</tr>
<tr>
<td>16</td>
<td>K⁰</td>
<td>32</td>
<td>Ω⁺</td>
</tr>
</tbody>
</table>

**EVTNR**
- event number of first shower

**NSHOW**
- Number of showers to simulate

**PRMPAR**
- primary particle

**ERANGE and ESLOPE**
- primary energy (GeV)

**THETAP**
- zenith angle (in °, limits depend on CURVED and UPWARD options)

**PHIP**
- azimuth angle (in °)
Shower Parameters (1)

- **EVTNR**: event number of first shower

- **NSHOW**: Number of showers to simulate

- **PRMPAR**: primary particle
  - primary energy (GeV)

- **ERANGE and ESLOPE**: primary energy (GeV)

- **THETAP**: zenith angle (in °, limits depend on CURVED and UPWARD options)

- **PHIP**: azimuth angle (in °)
Shower Parameters (2)

### SEED

- fix the sequence of random numbers
- each line correspond to a subpart of CORSIKA (min 2)
  - 1 – Hadron
  - 2 – EGS4 (e/m)
  - 3 – Cherenkov
  - 4 – IACT
  - 5 – HERWIG
  - 6 – Parallel seed
  - 7 – CONEX hadronic
  - 8 – CONEX EGS4

### OBSLEV

- observation level in cm
- 1 line / level (up to 10)
Shower Parameters (3)

**FIXCHI (g/cm²)**
- starting point of shower primary
- not used if FIXHEI is used

**MAGNET**
- magnetic field

**HADFLG**
- first 5 numbers related to HDPM (obsolete)
- last fix the nuclear fragmentation
  - 0 – None
  - 1 – Full
  - 2 or more – Realistic
Earth Magnetic Field

Earth Magnetic Field has to be defined according to experiment position on Earth.

Total strength (nT) of Earth magnetic field for year 2000.

Declination (degrees) of Earth magnetic field for year 2000.

Inclination (degrees) of Earth magnetic field for year 2000.
Shower Parameters (3)

**FIXCHI** *(g/cm²)*
- starting point of shower primary
- not used if FIXHEI is used

**MAGNET**
- magnetic field

**HADFLG**
- first 5 numbers related to HDPM (obsolete)
- last fix the nuclear fragmentation
  - 0 – None
  - 1 – Full
  - 2 or more – Realistic
Shower Parameters (4)

**ECUTS**
- lower kinetic energy of particle in GeV
  - hadrons
  - muons
  - electrons/positrons
  - photons

**MUADDI**
- additional informations on muon mother particle

**MUMULT**
- muon multiple scattering type
  - F – Gauss approx.
  - T – Moliere's theory
Shower Parameters (5)

**ELMFLG**
- NKG: approximation for LDF
- EGS: real MC for e/m particles

**STEPFC**
- electron multiple scattering length factor: better not to change

**RADNKG**
- maximum radius for NKG LDF
Options Parameters

All compilation options have their corresponding steering options ... most important ones:

- **THIN**  $F_{\text{Ethr}}$, $W_{\text{max}}$, $R_{\text{max}}$
  - $F_{\text{Ethr}}$: if $E < F_{\text{ethr}} \times E_{\text{prim}}$ thinning is used
  - $W_{\text{max}}$: maximum weight for thinned particles
  - $R_{\text{max}}$: maximum radius for inner radius thinning
    - only to save disk space in DATnnnnnnn file

- **THINH**  $T_{\text{had}}$, $W_{\text{had}}$
  - define $F_{\text{had}} = F_{\text{Ethr}} / T_{\text{had}}$ and $W_{\text{had}} = W_{\text{max}} / W_{\text{had}}$ for hadrons

- **THINEM**  $T_{\text{em}}$, $W_{\text{em}}$
  - define $F_{\text{em}} = F_{\text{Ethr}} \times T_{\text{em}}$ and $W_{\text{em}} = W_{\text{max}} \times W_{\text{em}}$ for e/m particles
Options Parameters

All compilation options have their corresponding steering options ... most important ones :

- **THIN** $F_{Ethr}$ $W_{max}$ $R_{max}$
  - $F_{Ethr}$: if $E < F_{ethr} \times E_{prim}$ thinning is used
  - $W_{max}$: maximum weight for thinned particles
  - $R_{max}$: maximum radius for inner radius thinning

"optimal thinning" for $W_{max}^{em} = F_{Ethr} \times E_{prim}$ and $W_{max}^{h} = 0.01 \times W_{max}^{em}$

with $F_{Ethr} \sim 10^{-6}-10^{-8}$

- **THINEM** $T_{em}$ $W_{em}$
  - define $F_{Ethr}^{em} = F_{Ethr} \times T_{em}$ and $W_{max}^{em} = W_{max} \times W_{em}$ for e/m particles
CORSIKA with CONEX

Parameters:
- $E_{\text{thr}}$: $\text{MC} \rightarrow \text{CE}$ (ha, $\mu$, e/m)
- $E_{\text{low}}$: $\text{CE} \rightarrow \text{MC}$ (ha, $\mu$, e/m)
- $W_{\text{max}}$: weight $\text{CE} \rightarrow \text{MC}$ (ha, $\mu$, e/m)
- $Z_{\text{em}}$: minimum slant depth to ground for $\text{CE} \rightarrow \text{MC}$ (only e/m)
CORSIKA keywords for CONEX (easy)

- When CONEX selected in CORSIKA options
  - at least 3 "SEED" lines and last one used to control hadronic interactions in CONEX
    - same last seed = same first interactions = same shower!
  - nothing new in input file = use CE as thinning (3D results with WMAX as sampling weight).
  - "CASCADE" as easy selection of simulation type
    - CASCADE F F F = only MC (CONEX MC+CORSIKA MC)
      - 3D no approximations
    - CASCADE T F F = hybrid 3D (CONEX MC + CE + CORSIKA MC)
      - 3D faster but some information lost
    - CASCADE T T F = hybrid 3D for muons (hadrons) only
      - very fast but 3D only for muons (only longitudinal profile for EM)
    - CASCADE T T T = hybrid 1D (CONEX MC + CE)
**CORSIKA keywords for CONEX (expert)**

- When CONEX selected in CORSIKA options
  - “CORSIKA” switch CORSIKA on/off:
    - **CORSIKA T** (default) = for all options in “CASCADE” particles in last depth bin always sampled (total number of particle in DAT file correct (and energy distributions) but LDF might be wrong if no low energy MC is active
    - **CORSIKA F** = CORSIKA MC not used at all. Make simulations very fast (like standalone CONEX) since no low energy particles are save: *only the total energy deposit profile is correct!* (no influence of energy threshold)

- “CONEX F_{had}(=10^{-3})\ F_{mu}(=1)\ F_{em}(=10^{-4})” keyword fix high energy threshold ($E_{thr}=F\cdot E_0$) for CONEX MC (below this limit particles go to CE or CORSIKA)

- “CX2COR E_{had}(=300) E_{mu}(=10^{20}) E_{em}(=10) Z_{em}(=400)” keyword fix the low energy threshold ($E_{low}$ in GeV) to start CORSIKA MC and vertical depth above which MC is not needed ($Z_{em}$ in g/cm$^2$)
CORSIKA keywords for CONEX (smart expert !)

When CONEX selected in CORSIKA options

“CXWMX $W_{\text{had}}$(-1) $W_{\text{mu}}$(-1) $W_{\text{em}}$(-1.) S2T(F) T2CX(F)” keyword fix sampling weight (SW=$W\times E_0$) after CE. S2T and T2CX allows you link thinning maximum weight in CONEX (MWCX) and CORSIKA (MWCA) and sampling weight:

- **$W=-1$** means MWCA from THIN (THINEM/THINH) is used for SW and MWCX in CONEX (default)

- **$0<W<1$, S2T=F, T2CX=F** $\Rightarrow$ SW=$W\times E_0$ and MWCX=MWCA from THIN
  Not recommended if SW < MWCA (lost of time and precision)

- **$0<W<1$, S2T=T, T2CX=F** $\Rightarrow$ SW=$W\times E_0$ and MWCA=MWCX=SW
  simplified way of defining thinning level (relative value instead of absolute)

- **$0<W<1$, S2T=T, T2CX=T** $\Rightarrow$ SW=$W\times E_0$ and MWCA=SW but MWCX from THIN needed if you want to study the same shower (same SEED) for different value of SW
Output Types

4 different types of output files:

- Control output (text file)
- Particle list (binary files)
  - DAT file for secondary particles of shower
  - CER file for Cherenkov photons
- Histograms
  - LONGitudinal profile and energy deposit (ASCII)
  - ANAHIST (CERNLIB)
  - AUGERHIST (CERNLIB)
  - MUONHIST (CERNLIB)
  - First Interaction (CERNLIB)
  - COAST (with or withoutROOT)
- Infos on shower production
  - DBASE
  - INFO (Auger)
Control Output

Text appearing on screen during CORSIKA runs

- Can be saved in a text file using the “>” sign
  
  ./corsika76400 < all-inputs > output.txt

- Content all input parameters, how they are used and general informations on simulated showers

  - time
  - number of particles and interactions
  - distributions (longitudinal, energy, ...) per shower and/or averaged

- Should be used to control if all parameters are correct (please sent it in case of problem during simulation)

- Part of the content can be controlled by steering file
Output Parameters : screen

- **ECTMAP**
  - printout option (for check)

- **MAXPRT**
  - detailed printout on screen

- **DEBUG**
  - switch on/off debug output
### Output Parameters: files (1)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUNNR</td>
<td>identification of run number</td>
<td>2</td>
<td>(number in all output file names)</td>
</tr>
<tr>
<td>EVTNR</td>
<td>number of first shower event</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>NSHOW</td>
<td>number of showers to generate</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>PRMPAR</td>
<td>particle type of prim. particle</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>ESOLE</td>
<td>slope of primary energy spectrum</td>
<td>-2.7</td>
<td></td>
</tr>
<tr>
<td>ERANGE</td>
<td>energy range of primary particle</td>
<td>1.E4</td>
<td></td>
</tr>
<tr>
<td>THETAP</td>
<td>range of zenith angle (degree)</td>
<td>20.</td>
<td></td>
</tr>
<tr>
<td>PHP</td>
<td>range of azimuth angle (degree)</td>
<td>-180.</td>
<td></td>
</tr>
<tr>
<td>SEED</td>
<td>seed for 1. random number sequence</td>
<td>1 0</td>
<td></td>
</tr>
<tr>
<td>SEED</td>
<td>seed for 2. random number sequence</td>
<td>2 0</td>
<td></td>
</tr>
<tr>
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<td>observation level (in cm)</td>
<td>110.E2</td>
<td></td>
</tr>
<tr>
<td>FIXCHI</td>
<td>starting altitude (g/cm^4)</td>
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<td></td>
</tr>
<tr>
<td>MAGNET</td>
<td>magnetic field centr. Europe</td>
<td>20.0</td>
<td></td>
</tr>
<tr>
<td>HADFLG</td>
<td>hadr.interact. &amp; fragmentation</td>
<td>0 0</td>
<td></td>
</tr>
<tr>
<td>ECUTS</td>
<td>energy cuts for particles</td>
<td>0.3</td>
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<td>MUADTI</td>
<td>additional info for muons</td>
<td>T</td>
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</tr>
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<td>MUMULT</td>
<td>muon multiple scattering angle</td>
<td>T</td>
<td></td>
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<tr>
<td>ELMFLG</td>
<td>em. interaction flags (NKG,E65)</td>
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</tr>
<tr>
<td>STEPCF</td>
<td>mult. scattering step length fact.</td>
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<td>RADNKG</td>
<td>outer radius for NKG lat.dens.distr.</td>
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<tr>
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<td>lonit.distr. &amp; step size &amp; fit &amp; out</td>
<td>T 10.</td>
<td></td>
</tr>
<tr>
<td>ECTMAP</td>
<td>cut on gamma factor for printout</td>
<td>1.E4</td>
<td></td>
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<tr>
<td>MAXPRT</td>
<td>max. number of printed events</td>
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<tr>
<td>DIRECT</td>
<td>output directory</td>
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<tr>
<td>USER</td>
<td>user</td>
<td>you</td>
<td></td>
</tr>
<tr>
<td>DEBUG</td>
<td>debug flag and logunit for out</td>
<td>F 6</td>
<td></td>
</tr>
<tr>
<td>EXIT</td>
<td>terminates input</td>
<td>F 100000</td>
<td></td>
</tr>
</tbody>
</table>
Output Parameters : files (2)

**LONGI**
- switch on/off longitudinal profile and fit
- last flag for extra .long file

**PAROUT**
- switch on/off DATnnnnnnn file
- switch on/off .tab file

**DATBAS**
- switch on/off .dbase or .info file

**(CERFIL**
- switch on/off CERnnnnnnn file)
Much More Options ...

Please read the user guide for details and particular options ...

For output analysis:

- use the binary DAT file

- convert it to your format (ROOT, ASCII, ...) using COAST:

  - coast/CorsikaOptions/CorsikaRead/README

  (more flexible than the ROOTOUTput and no need to understand the structure of the DAT file)

- Have fun!
Structure of Binary Files

Normal or Cherenkov output files without (with) THIN

- information stored unformatted in a fixed block structure
- block length = 22932(26208) bytes
- 1 block = 5733(6552) words (4 bytes)
  = 21 sub-blocks of 273(312) words

sub-block are
- RUN HEADER (273(312) words)
- EVENT HEADER (273(312) words)
- DATABLOCK (39*7(8) words)
- LONG (13+26*10(+39) words)
- EVENT END (273(312) words)
- RUN END (273(312) words)

- if less than n*21 sub-blocks used, end of block filled with 0

example to read the files: src/corsikaread.f
(src/corsikaread_thin.f)
Content of Binary Files (1)

Different type of info per sub-block:

- **HEADER**
  - general informations (options and primary) on run and events

- **END**
  - end of event (including NKG output) and run

- **DATABLOCK**
  - list of particles at observation level
    - id, generation and observation level
    - momentum
    - position
    - time
    - (weight)
  - only list of Cherenkov photons in CERnnnnnnnn file
**Content of Binary Files (2)**

**Longitudinal profile in binary output file**

- `LONG`
  - only number of particles (no energy deposit)
  - for each depth bin, 10 numbers
    - different particle types
  - 26 depth bins per sub-block
    - for 20 gr/cm² per bin, at least 2 sub-blocks needed per event
  - depth bin = vertical depth
    - use SLANT option to have slant depth

**Alternative for longitudinal profile**

- `.long` file
  - text file
  - include energy deposit and particle number
Time Selection

Date and time :

- Available only in expert mode
- `coconut -e`
- Used only to print date in output file

- default correct in most of the case
- try something different only in case of problem before or after compilation when “date” appears.
Hybrid Codes

- **L.G. Dedenko et al.**, pioneering work in 1968 (3D, transport equations, Monte Carlo)

- **A.A. Lagutin et al.** (1+1D, transport equations)

- **Bartol code**, J. Alvarez-Muniz et al. (1D, pre-simulated shower libraries, muons)

- **SENeca**, H.J. Drescher & G. Farrar (3D, 1D transport eqs. for hadrons, 1D em. shower matrix formalism based on EGS)

- **CONEX**, T. Bergmann, V. Chernatckin, R. Engel, D. Heck, N. Kalmykov, S. Ostapchenko, T. Pierog, K. Werner (1D Transport equations for hadrons and em with realistic cross section and particle distributions)
CONEX

- **e/m MC (EGS)**
- **Hadronic MC**
- **Stack**
- **Proton, nucleus**
- **Stack**
- **Hadron Source**
- **Photonuclear effect, muon pair production**

**Stack**

- **E > E_{e/m}**
- **E > E_{hadr}**

**e/m Source**

- **Electromagnetic Cascade Equations**

**Hadronic Cascade Equations**

- **2 \gamma \leftrightarrow \pi^0**
- **N, \pi, K, \mu**

- **Electron, Gamma**
- **Nucleon, pion, kaon, muons**

- **Proton, nucleus**
**CONEX MC**

- **e/m MC (EGS)**
- **E > E\text{e/m}**
  - Yes: **Stack**
  - No: **e/m Source**

**Stack**

- **E > E\text{had}**
  - Yes: **Hadron Source**
  - No: **Hadronic Cascade Equations**

**Hadronic MC**

- **Proton, nucleus**
- **N, \pi, K, \mu**

**Electromagnetic Cascade Equations**

- **Elec., Gamma**

**Hadronic MC**

- **Stack**
- **2 \gamma \leftrightarrow \pi^0**

**Photonuclear effect, muon pair production**

- **Nucleon, pion, kaon, muons**
CONEX CE

Proton, nucleus

Hadronic MC

Stack

e/m MC (EGS)

E > E_{e/m}

Elec, γ

N, π, K, μ

Yes

No

Hadron Source

E > E_{hadr}

Stack

Yes

No

e/m Source

2 γ ← π^0

Electromagnetic Cascade Equations

Hadronic Cascade Equations

Electron, Gamma

Nucleon, pion, kaon, muons

Photonuclear effect, muon pair production

CONEX CE

Proton, nucleus

Hadronic MC

Stack

e/m MC (EGS)

E > E_{e/m}

Elec, γ

N, π, K, μ

Yes

No

Hadron Source

E > E_{hadr}

Stack

Yes

No

e/m Source

2 γ ← π^0

Electromagnetic Cascade Equations

Hadronic Cascade Equations

Electron, Gamma

Nucleon, pion, kaon, muons

Photonuclear effect, muon pair production
CONEX vs CORSIKA : time

● Calculation time
  ➡ CORSIKA : CPU time ∝ Energy
  ➡ CONEX : CPU time ∝ Log(Energy)
    • ~1mn / shower
    • and no artificial fluctuations due to thinning

● Comparisons :
  ➡ Longitudinal profile for a vertical shower
  ➡ Energy distributions for a given depth
  ➡ Xmax fluctuations for proton and iron
CORSIKA vs CONEX: particles

- Vertical proton induced shower $10^{18}$ eV:
  - Longitudinal distribution
  - Energy distribution
CORSIKA vs CONEX: fluctuations

$X_{\text{max}}$ fluctuations

both mean and RMS reproduced

Flat distribution of proton and iron showers from $10^{17}$ to $10^{20}$ eV
Threshold Effect

- $E = 10^{18}$ eV, Sibyll
- Probability distribution of $X_{\text{max}}$, using SIBYLL model at $10^{18}$ eV ($60^\circ$)
- Almost all fluctuations from the first interaction
Example:
3D View with COAST

- **MC 3D**: no cascade equation
- **CONEX MC** at high energy
- **CORSIKA** at low energy
- **Track connection** at bin boundary

**Legend**:
- **Purple**: CONEX hadrons
- **Dark blue**: CONEX muons
- **Dark**: CORSIKA hadrons
- **Blue**: CORSIKA muons
Example:
3D View with COAST

- Hybrid 3D: Cascade equation only at intermediate energy
  - High energy particle tracks until bin boundaries
  - Low energy particle tracks from bin boundaries

- Purple: CONEX hadrons
- Dark blue: CONEX muons
- Dark: CORSIKA hadrons
- Blue: CORSIKA muons

Bin boundary every 10 gr.cm$^{-2}$
Example:
3D View with COAST

- Hybrid 1D: Cascade equation only at low energy
- Particle track only until bin boundaries
- Interaction of leading particles

- Purple: CONEX hadrons
- Dark blue: CONEX muons

Bin boundary every 10 gr.cm$^{-2}$
Example:
3D View with COAST

- 3D muons: Cascade equation only for hadrons
  - Muon tracks start from bin boundaries
  - Muons generated with realistic angular distribution

Bin boundary every 10 gr.cm$^{-2}$

Blue: CORSIKA muons
Example

- QGSJET01/GHEISHA Iron shower $10^{19}$ eV
  - MC: 49h (max weight = 1000(em)/100(had))
  - Hyb: 10h (max weight = 1000(em)/100(had))
- 1 shower (same seed): $X_{\text{max}} = 670$ (MC) / 673 (Hyb) g/cm$^2$
Example:
1 shower with different thresholds

Proton @ 0.1 EeV EGS4 off

QGSJET + GHEISHA

→ MC : CONEX MC FOR E > 1 TeV
   CORSIKA FOR E < 1 TeV

→ Hybrid hadron : CONEX MC < 1 TeV
   100 GeV < hadronic CE < 1 TeV
   CORSIKA < 100 GeV

→ CE hadron : CONEX MC < 1 TeV
   CORSIKA only for muons (all E)

One shower, same random numbers

Same profile within 3%
Example:
1 shower with different thresholds

Proton @ 0.1 EeV EGS4 off
QGSJET + GHEISHA

Reasonable results for CE but hadronic MC needed for precise results