Monte Carlo simulations of air showers with CORSIKA

Cosmic Neutrino Observations at Ultra High Energy

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Introduction to CORSIKA

- Due to the limitting flux of high energy primaries, the indirect measurement of Extensive Air Showers (EAS) is only detection technique.
- The EAS is measured to identify the properties of primary,
  - Direction: relative arrival time
  - Energy: shower size
  - Type: particle contents / shower shape
- Analyzing the experimental data on EAS requires a detailed modelling of the cascade which can only be achieved by detailed Monte Carlo calculations taking into account all knowledge of high energy strong and electromagnetic interactions.
- CORSIKA (COsmic Ray SImulations for KAscade) is a detailed Monte Carlo program of the development of EAS in the atmosphere.
- Photons, protons, nuclei, or any other particle can be treated as the primary.

Introduction to CORSIKA

- Along with tracking and decay in atmosphere, CORSIKA code is developed on the basis of three well program systems.

1. High Energy hadadronic interaction model (> 80GeV):
   - QGSJET
   - SIBYLL
   - EPOS-LHC, ...

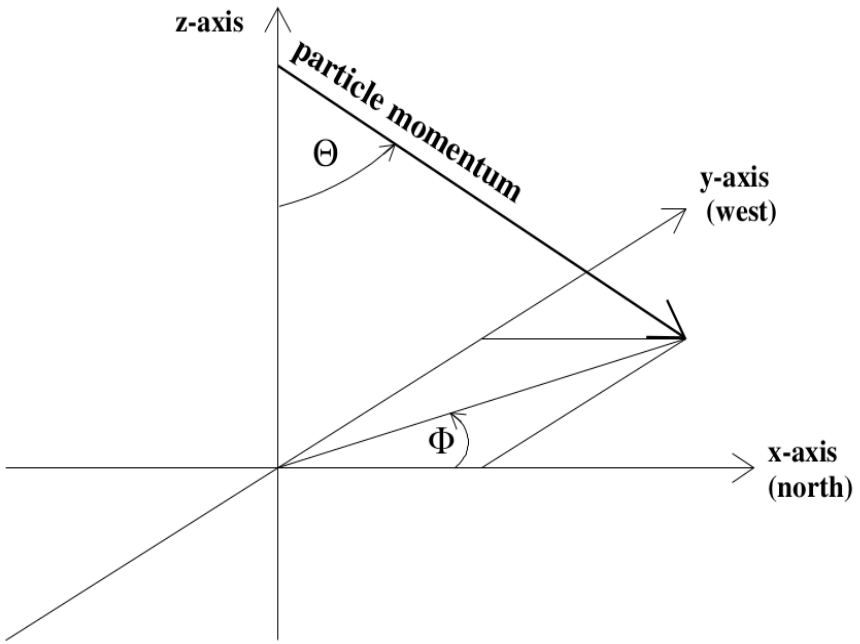
2. Low Energy hadadronic interaction model (< 80GeV):
   - FLUKA
   - GHEISHA, ...

3. Electromagetic Interaction:
   - EGS4
   - NKG

- 1 and 2 are the source of systematic uncertainty.
- Tuned at collider energies, extrapolated to 10^{20} eV

Co-ordinate system in CORSIKA

- Defined with respect to a Cartesian coordinate system with the positive X-axis pointing to the magnetic North, the positive Y-axis to the West, and the Z-axis upwards.
- Origin is located at sea level.
- Zenith angle θ is measured between the particle momentum vector and the negative Z-axis.
- Azimuthal angle φ between the positive X-axis and the horizontal component of the particle momentum vector (i.e. with respect to North) proceeding counter-clockwise.



Particles in CORSIKA

Identification	Particle	Identification	Particle
1	γ	50	ω
2	e^+	51	ρ°
3	e^-	52	ρ^+
		53	ρ^-
5	μ^+	54	Δ^{++}
6	μ^-	55	Δ^+
7	π°	56	Δ°
8	π^+	57	Δ^-
9	π^-	58	$\overline{\Delta}^{--}$
10	K_L°	59	$\overline{\Delta}^-$
11	K^+	60	$\overline{\Delta}^\circ$
12	K^-	61	$\overline{\Delta}^+$
13	n	62	$K^{*\circ}$
14	p	63	K^{*+}
15	$\overline{p}$	64	$\overline{K^*}^-$
16	K_S°	65	$\overline{K^*}^\circ$
17	η	66	ν_e
18	Λ	67	$\overline{\nu}_e$
19	Σ^+	68	ν_μ
20	Σ°	69	$\overline{\nu}_\mu$
21	Σ^-		
22	Ξ°	71	$\eta \to \gamma\gamma$
23	Ξ^-	72	$\eta \to 3\pi^\circ$
24	Ω^-	73	$\eta \to \pi^+\pi^-\pi^\circ$
25	$\overline{n}$	74	$\eta \to \pi^+\pi^-\gamma$
26	$\overline{\Lambda}$	75	μ^+ add. info.
27	$\overline{\Sigma}^-$	76	μ^- add. info.
28	$\overline{\Sigma}^\circ$		
29	$\overline{\Sigma}^+$	85	decaying μ^+ at start[89]
30	$\overline{\Xi}^\circ$	86	decaying μ^- at start[89]
31	$\overline{\Xi}^+$		
32	$\overline{\Omega}^+$	95	decaying μ^+ at end[89]
48	η'	96	decaying μ^- at end[89]
49	Φ		

Identification	Particle	Identification	Particle
116	D°	155	$\overline{\Xi_c'}^-$
117	D^+	156	$\overline{\Xi_c'}^\circ$
118	$\overline{D}^-$	157	$\overline{\Omega_c}^\circ$
119	$\overline{D}^\circ$		
120	D_s^+	161	Σ_c^{*+++}
121	$\overline{D_s}^-$	162	Σ_c^{*++}
122	η_c	163	$\Sigma_c^{*+\circ}$
123	$D^{*\circ}$		
124	D^{*+}	171	$\overline{\Sigma_c^*}^{--}$
125	$\overline{D^*}^-$	172	$\overline{\Sigma_c^*}^-$
126	$\overline{D^*}^\circ$	173	$\overline{\Sigma_c^*}^\circ$
127	D_s^{*+}		
128	$\overline{D_s^*}^-$	176	B°
		177	B^+
130	J/ψ	178	$\overline{B}^-$
131	τ^+	179	$\overline{B}^\circ$
132	τ^-	180	B_s°
133	ν_τ	181	$\overline{B_s}^\circ$
134	$\overline{\nu}_\tau$	182	B_c^+
		183	$\overline{B_c}^-$
137	Λ_c^+	184	Λ_b°
138	Ξ_c^+	185	Σ_b^-
139	Ξ_c°	186	Σ_b^+
140	Σ_c^{++}	187	Ξ_b°
141	Σ_c^+	188	Ξ_b^-
142	Σ_c°	189	Ω_b^-
143	$\Xi_c'^+$	190	$\overline{\Lambda_b}^\circ$
144	$\Xi_c'^\circ$	191	$\overline{\Sigma_b}^+$
145	Ω_c°	192	$\overline{\Sigma_b}^-$
		193	$\overline{\Xi_b}^\circ$
149	$\overline{\Lambda_c}^-$	194	$\overline{\Xi_b}^+$
150	$\overline{\Xi_c}^-$	195	$\overline{\Omega_b}^+$
151	$\overline{\Xi_c}^\circ$		
152	$\overline{\Sigma_c^*}^{--}$		
153	$\overline{\Sigma_c}^-$		
154	$\overline{\Sigma_c}^\circ$		

$A \times 100 + Z$	nucleus of Z protons and $A - Z$ neutrons ($2 \le A \le 56$)
$8888jjj$	weights of preceding particle (MULTITHIN option)
9900	Cherenkov photons on particle output file

- For Nuclei

  A * 100 + Z,

  $2 \le A \le 56$

- Particles with code from 116 to 173 are only available in CHARM or TAULEP option.
- Cherenkov photons can not be a primary particle for an air shower simulation.

CORSIKA Installation

```
[fahim.varsi@cchpcm1 corsika-76900]$ ./coconut


|========================================================================|
|                        Welcome to COCONUT (v3.1)                       |
|                  -- the CORSIKA CONfiguration UTility --               |
|========================================================================|
|                                                                        |
|                                                                        |
|           create an executable of a specific CORSIKA version           |
|                                                                        |
|                                                                        |
|        Please read the documentation for a detailed description        |
|                   of the options and how to use it.                    |
|                                                                        |
|             Try './coconut -h' to get some help about COCONUT          |
|    Use './coconut --expert' to enable additional configuration steps.  |
|                                                                        |
| (press 'Enter' to select an option followed by "[DEFAULT]" or "[CACHED]") |
|                                                                        |
|========================================================================|




************************************************************************
*  INFO:                                                               *
*        You are using the cached configuration from "include/config.h". *
*        To turn off this you may use the --no-cache option.           *
************************************************************************

------------------------------------------------------------------------
 Compile in 32 or 64bit mode ?
    1 - Force 32bit mode
    2 - Use compiler default ('-m64' on a 64bit machine) [CACHED]

    r - restart (reset all options to cached values)
    x - exit make

    (only one choice possible): 2
    SELECTED         : NOM32
```

- The Code corsika-76900.tar.gz can be obtained from the URL: ftp://ikp-ftp.ikp.kit.edu/corsika-v760 using login and password (which you get by e-mail).
- Decompress the download and go to directory corsika-76900.
- Prerequisite compiler: gcc and gfortran (or g77).
- Type the command ./coconut to start installation and select the following,

1. Select compilation mode
   - Select option 2 if you do not know the compilation mode of your machine, the system will detect compilation mode of your machine.

Hadronic interaction models selection

```
------------------------------------------------------------------------
 Which high energy hadronic interaction model do you want to use ?
    1 - DPMJET-III (2017.1) with PHOJET 1.20.0
    2 - EPOS LHC
    3 - NEXUS 3.97
    4 - QGSJET 01C (enlarged commons)
    5 - QGSJETII-04
    6 - SIBYLL 2.3c [CACHED]
    7 - VENUS 4.12

    r - restart (reset all options to cached values)
    x - exit make

    (only one choice possible): 6

    ADDING CHARM

    SELECTED         : SIBYLL


------------------------------------------------------------------------
 Which low energy hadronic interaction model do you want to use ?
    1 - GHEISHA 2002d (double precision)
    2 - FLUKA  [CACHED]

    r - restart (reset all options to cached values)
    x - exit make

    (only one choice possible): 2

  WARNING : FLUKA might not be compatible with 64bit architecture.
          If you use FLUKA gfor64bit, also all other programs have
          to be compiled with gfortran. To do so you may give the
          command 'export F77 = gfortran' before using coconut.
          In case of incompatibility you will get the following
          error message :
          - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
          configure: Missing required packages:  FLUKA
          - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
          If it happens please compile in 32bit mode
          or change to another low energy interaction model...
          (with ./coconut -e)

    SELECTED path to installation: "/home/fahim.varsi/FLUKA"
    SELECTED         : FLUKA
    NOT COMPATIBLE TO: DPMJET INTTEST
```

2. Select high energy hadronic interaction model,
   - QGSJET-II-04
     SIBYLL 2.3c

3. Select low energy hadronic interaction model,
   - FLUKA code is distributed seperately. Install FLUKA prior to install CORSIKA.
   - Use following command to set path to the FLUKA:
     export $FLUPRO=flukadir

Detector geometry and additional options

```
------------------------------------------------------------------------
 Which detector geometry do you have ?
    1 - horizontal flat detector array [CACHED]
    2 - non-flat (volume) detector geometry
    3 - vertical string detector geometry

    r - restart (reset all options to cached values)
    x - exit make

    (only one choice possible): 1
    SELECTED         : HORIZONTAL
    ADDING CACHED OPTIONS :  CHARM CHARM

Use program PYTHIA for linking
    SELECTED path to installation: "/home/fahim.varsi/CORSIKA/corsika-76900/pythia"
    SELECTED         : CHARM
    NOT COMPATIBLE TO: TAULEP EPOS NEXUS QGSJETII VENUS

Use program PYTHIA for linking
    SELECTED path to installation: "/home/fahim.varsi/CORSIKA/corsika-76900/pythia"
    SELECTED         : CHARM
    NOT COMPATIBLE TO: TAULEP EPOS NEXUS QGSJETII VENUS
------------------------------------------------------------------------
  options:   FLUKA FLUKADIR HORIZONTAL SIBYLL TIMEAUTO
  selection: PYTHIADIR CHARM

 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 - ICECUBE1 FIFO 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
```

4. Select detector geometry
   - Horizontal flat detectors (GRAPES-3, KASCADE, ...)
   - Non-flat (volume) detector (MAGIC, HESS, ...)
   - Vertical string detector (IceCube, ...)

- Select additional options
  - Cherenkov, Thinning, PreShowers, Neutrino, Stack Input, Charmed particles / Tau lepton, ...

Additional options

```
  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)
  8b - shower PLOT(C) version (PLOTSH2) (only for single events)
  8c - ANAlysis HISTos & THIN (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 Ooty version rejecting low-energy primaries entering Earth-magnetic field
  10a - DYNamic intermediate particle STACK
  10b - Remote Control for Corsika
  a - CONEX for high energy MC and cascade equations
  b - PARALLEL treatment of subshowers (includes LPM)
  c - CoREAS Radio Simulations
  d1 - Inclined observation plane
  d2 - ROOT particle OUTput file
  e - interaction test version (only for 1st interaction)
  f - Auger-info file instead of dbase file
  g - COMPACT particle output file
  h - MUPROD to write decaying muons
  h2 - prEHISTORY of muons: mother and grandmother
  k - annitest cross-section version (obsolete)
  l - hit Auger detector (steered by AUGSCT)
    - ----------------------------------------
  y - *** Reset selection ***
  z - *** Finish selection *** [DEFAULT]

  r - restart (reset all options to cached values)
  x - exit make

  (multiple selections accepted, leading '-' removes option):
```

```
make[1]: Leaving directory '/home/fahim/ANALYSIS/Software/corsika-76900/pythia'
Making install in src
make[1]: Entering directory '/home/fahim/ANALYSIS/Software/corsika-76900/src'
/bin/bash ../libtool  --tag=F77   --mode=link gfortran -O0 -I../pythia -I/home/fahim/ANALYSIS/Software/corsika-76900/herwig  -g -std=legacy  -D_
FILE_OFFSET_BITS=64 -o corsika corsika-corsikacompilefile.o tobuf.o    corsika-sibyll2.3c.o  corsika-gheisha_2002d.o   timerc.o -L/home/fahim/AN
ALYSIS/Software/corsika-76900/lib/unknown -lpythia -lherwig
libtool: link: gfortran -O0 -I../pythia -I/home/fahim/ANALYSIS/Software/corsika-76900/herwig -g -std=legacy -D_FILE_OFFSET_BITS=64 -o corsika co
rsika-corsikacompilefile.o tobuf.o corsika-sibyll2.3c.o corsika-gheisha_2002d.o timerc.o  -L/home/fahim/ANALYSIS/Software/corsika-76900/lib/unkn
own -lpythia -lherwig
make[2]: Entering directory '/home/fahim/ANALYSIS/Software/corsika-76900/src'
 /bin/mkdir -p '/home/fahim/ANALYSIS/Software/corsika-76900/run'
  /bin/bash ../libtool   --mode=install /usr/bin/install -c plottracks corsika '/home/fahim/ANALYSIS/Software/corsika-76900/run'
libtool: install: /usr/bin/install -c plottracks /home/fahim/ANALYSIS/Software/corsika-76900/run/plottracks
libtool: install: /usr/bin/install -c corsika /home/fahim/ANALYSIS/Software/corsika-76900/run/corsika
make[2]: Nothing to be done for 'install-data-am'.
make[2]: Leaving directory '/home/fahim/ANALYSIS/Software/corsika-76900/src'
make[1]: Leaving directory '/home/fahim/ANALYSIS/Software/corsika-76900/src'
Making install in .
make[1]: Entering directory '/home/fahim/ANALYSIS/Software/corsika-76900'
make[2]: Entering directory '/home/fahim/ANALYSIS/Software/corsika-76900'
make  install-exec-hook
make[3]: Entering directory '/home/fahim/ANALYSIS/Software/corsika-76900'



--> "corsika76900Linux_SIBYLL_gheisha" successfully installed in :
    /home/fahim/ANALYSIS/Software/corsika-76900/run/

--> You can run CORSIKA in /home/fahim/ANALYSIS/Software/corsika-76900/run/ using for instance :
    ./corsika76900Linux_SIBYLL_gheisha < all-inputs > output.txt



make[3]: Leaving directory '/home/fahim/ANALYSIS/Software/corsika-76900'
make[2]: Nothing to be done for 'install-data-am'.
make[2]: Leaving directory '/home/fahim/ANALYSIS/Software/corsika-76900'
make[1]: Leaving directory '/home/fahim/ANALYSIS/Software/corsika-76900'
fahim@iitk:~/ANALYSIS/Software/corsika-76900$
```

- On successful installation, ./corsika76900Linux_SIBYLL_fluka is created in run subdirectory.

Input (steering) files

```
 1 RUNNR   1                              run number
 2 EVTNR   1                              number of first shower event
 3 NSHOW   50000                          number of showers to generate
 4 PRMPAR  14                             particle type of prim. particle
 5 ESLOPE  -2.7                           slope of primary energy spectrum
 6 ERANGE  1E+3  1.58E+3                  energy range of primary particle
 7 THETAP  0.  45.                        range of zenith angle (degree)
 8 PHIP    -180.  180.                    range of azimuth angle (degree)
 9 SEED    1000001   0   0                seed for 1. random number sequence
10 SEED    2000001   0   0                seed for 2. random number sequence
11 OBSLEV  2.2E5                          observation level (in cm)
12 FIXCHI  0.                             starting altitude (g/cm**2)
13 ATMOD   5                              atmospheric model selection
14 MAGNET  39.96  16.16                   magnetic field at Ooty (GRAPES-3)
15 HADFLG  0  0  0  0  0  2               flags hadr.interact.&fragmentation
16 ECUTS   0.05  0.01  0.001  0.001       energy cuts for particles
17 MUADDI  T                              additional info for muons
18 MUMULT  T                              muon multiple scattering angle
19 ELMFLG  T   T                          em. interaction flags (NKG,EGS)
20 STEPFC  1.0                            mult. scattering step length fact.
21 RADNKG  200.E2                         outer radius for NKG lat.dens.distr.
22 ARRANG  0                              rotation of array to north
23 LONGI   F  20.  F  F                   longit.distr. & step size & fit & out
24 ECTMAP  1.E3                           cut on gamma factor for printout
25 MAXPRT  10                             max. number of printed events
26 DIRECT  ./scratch/fahim.varsi/binary/  output directory
27 DATBAS  F                              write .dbase file
28 PAROUT  T   F                          suppress DAT file
29 USER    Fahim                          user
30 DEBUG   F  6  F  1000000               debug flag and log.unit for out
31 PLOTSH  T                              craete track map
32 EXIT                                   terminates input
```

- Contains
  - shower parameters
  - options parameters
  - output parameters

- RUNNR: Run number of this simulation.
  $0 \leq NRRUN \leq 999999$

- EVTNR: Event number of 1st shower. Next, EVTNR + 1.
  $1 \leq EVTNR \leq 999999$

- NSHOW: Number of showers to be generated in a run.
  $NSHOW \geq 1$

- ESLOPE: Slope of the differential primary energy spectrum.

- PRMPAR: Particle type of the primary particle. See table for particle code. Primary neutrinos can only be used in the NUPRIM option.

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- OBSLEV: Observation level above sea level (in cm). 10 observation levels can define.

- ERANGE: Lower and Upper limit of the primary particle energy range (in GeV).
  1.0E11 ≤ ERANGE ≤ 1.0E20.

- THETAP: Zenith angle range.
  0 ≤ THETAP ≤ 70.
  For θ > 70, you should use the CURVED option.
  For the UPWARD option, 110 ≤ THETPR(i) ≤ 180.

- PHIP: Azimuth angle range
  -180 ≤ PHIP ≤ 180

- SEED: Fix the sequence of random numbers. At most 7 seeds are used, at minimum 2 seeds should be activated.
  1: Hadron
  2: EGS4 (e/m)
  3: Cherenkov. For other options, see CORSIKA_GUIDE7.6900.pdf

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```

- FIXCHI: starting point of shower primary in g/cm^2.
- MAGNET: horizontal and vertical component of the Earth magnetic field (in μT).
- HADFLG: first 5 numbers related to HDPM (obsolete). Last fix the nuclear fragmentation
  - 0 – None
  - 1 – Full
  - 2 or more – Realistic
- ECUTS: KE of particle in GeV. (Had, Muon, Ele, Photon).
- MUADDI: additional information on muons at their origin is written in output file.
- MUMULT: muon multiple scattering type
  - F – Gauss approx
  - T – Moliere's theory

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21 RADNKG  200.E2                         outer radius for NKG lat.dens.distr.
22 ARRANG  0                              rotation of array to north
23 LONGI   F  20.  F  F                   longit.distr. & step size & fit & out
24 ECTMAP  1.E3                           cut on gamma factor for printout
25 MAXPRT  10                             max. number of printed events
26 DIRECT  ./scratch/fahim.varsi/binary/  output directory
27 DATBAS  F                              write .dbase file
28 PAROUT  T   F                          suppress DAT file
29 USER    Fahim                          user
30 DEBUG   F  6  F  1000000               debug flag and log.unit for out
31 PLOTSH  T                              craete track map
32 EXIT                                   terminates input
```

- ELMFLG:
  - NKG: approximation for LDF
  - EGS: real MC for e/m particles
- STEPFC: electron multiple scattering length factor.
- RADNKG: maximum radius for NKG lateral distribution function.
- LONGI: switch on/off longitudinal profile and fit.
- DIRECT: Path for output directory.
- DATBAS: switch on/off .dbase.
- PAROUT: switch on/off binary DATnnnnnn file, switch on/off tabular output .tab file

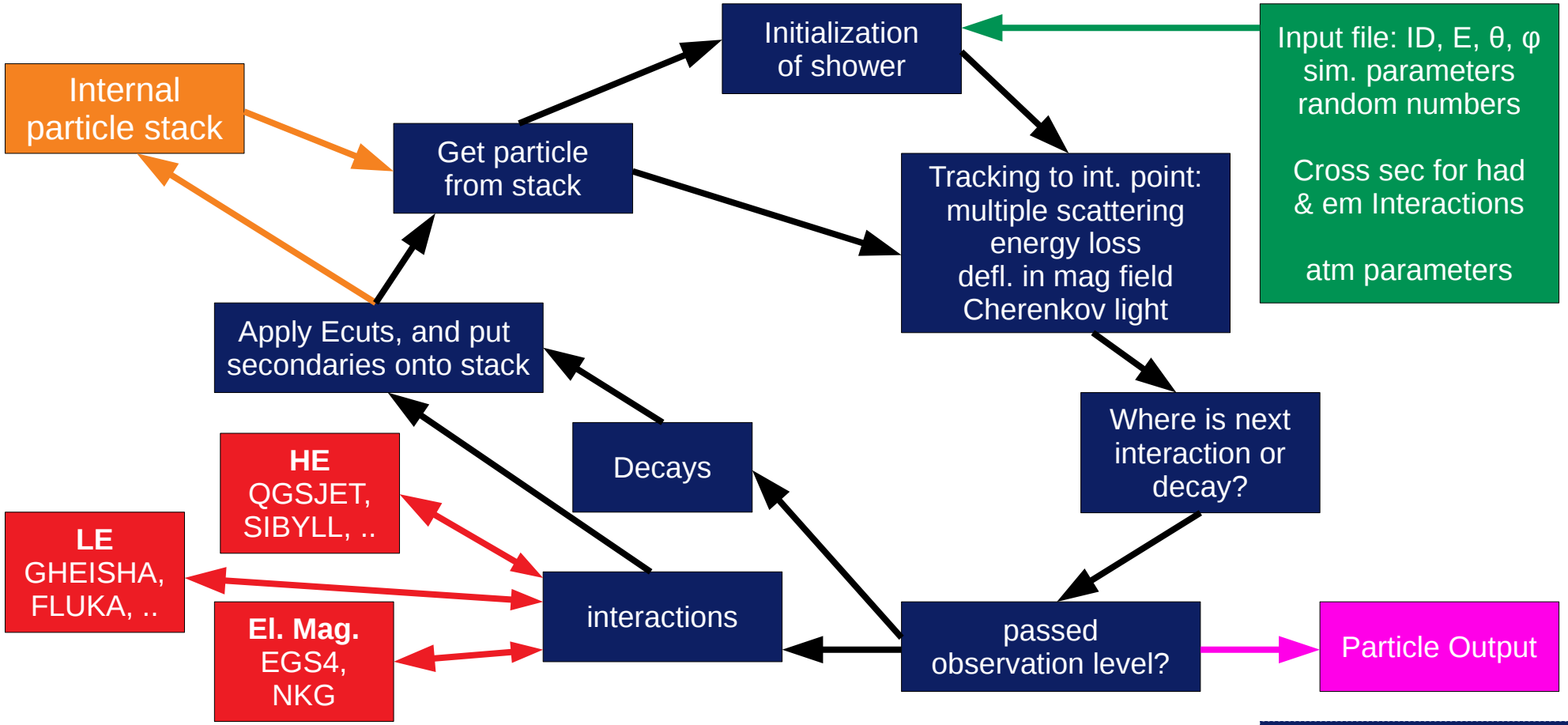
- Please read the CORSIKA_GUIDE7.6900.pd for details and particular options...

RUN1, Vertical proton

```
 1 RUNNR   1                              run number
 2 EVTNR   1                              number of first shower event
 3 NSHOW   1                              number of showers to generate
 4 PRMPAR  14                             particle type of prim. particle
 5 ESLOPE  -2.7                           slope of primary energy spectrum
 6 ERANGE  1.E3  1.E3                     energy range of primary particle
 7 THETAP  0.  0.                         range of zenith angle (degree)
 8 PHIP    -180.  180.                    range of azimuth angle (degree)
 9 SEED    1   0   0                      seed for 1. random number sequence
10 SEED    2   0   0                      seed for 2. random number sequence
11 OBSLEV  2.2E5                          observation level (in cm)
12 FIXCHI  0.                             starting altitude (g/cm**2)
13 MAGNET  39.96   16.16                  magnetic field centr. Europe
14 HADFLG  0  0  0  0  0  2               flags hadr.interact.&fragmentation
15 ECUTS   0.05  0.01  0.001  0.001       energy cuts for particles
16 MUADDI  T                              additional info for muons
17 MUMULT  T                              muon multiple scattering angle
18 ELMFLG  T   T                          em. interaction flags (NKG,EGS)
19 STEPFC  1.0                            mult. scattering step length fact.
20 RADNKG  200.E2                         outer radius for NKG lat.dens.distr.
21 LONGI   F  20.  F  F                   longit.distr. & step size & fit & out
22 ECTMAP  1.E3                           cut on gamma factor for printout
23 MAXPRT  10                             max. number of printed events
24 DIRECT  ./                             output directory
25 USER    you                            user
26 DEBUG   F  6  F  1000000               debug flag and log.unit for out
27 PLOTSH  T
28 PLAXES  -5E5 5E5 -5E5 5E5 1E5 5E6
29 EXIT                                   terminates input
```

CORSIKA flow diagram

- CORSIKA can run by following command: ./corsika76900Linux_SIBYLL_fluka < all-inputs > out.txt.



Output files

- Several types of output files. The important ones are listed below

1. **Control output (text file)**: contains control information about the simulation run, the program version with interaction model, steering keywords, physical constants, atmospheric model, and the primary particle.

2. **Particle list (binary files)**: cannot be read directly using text editors, must be processed to convert into ROOT format.
   - DATnnnnnn: contains the secondary particles data of shower.
   - CERnnnnn: contains data for Cherenkov photons.

3. **Histograms (.lhbook File Output)**: contains histograms produced by the LONGitudinal profile and energy deposit, ANAHIST, AUGERHIST and MUONHIST.

4. **DATnnnnnn.long**: contains a table of the longitudinal distribution of particles numbers and energy deposit.

5. **DATnnnnnn.dbase**: consists of parameter words enclosed within # marks, followed by information on the corresponding parameter. In the AUGERINFO version this file is named as DATnnnnnn.info.

Output plot

- Type ./map2png [options] <CORSIKA DATnnnnnn file> <output PNG file>
  - ./map2png -log DAT000001 Proton_Ver.png
- Type eog Proton_Ver.png

RUN2, Vertical iron

```
 1 RUNNR   2                          run number
 2 EVTNR   1                          number of first shower event
 3 NSHOW   1                          number of showers to generate
 4 PRMPAR  5626                         particle type of prim. particle
 5 ESLOPE  -2.7                       slope of primary energy spectrum
 6 ERANGE  1.E3  1.E3                 energy range of primary particle
 7 THETAP  0.  0.                     range of zenith angle (degree)
 8 PHIP    -180.  180.                range of azimuth angle (degree)
 9 SEED    1   0   0                  seed for 1. random number sequence
10 SEED    2   0   0                  seed for 2. random number sequence
11 OBSLEV  2.2E5                      observation level (in cm)
12 FIXCHI  0.                         starting altitude (g/cm**2)
13 MAGNET  39.96   16.16              magnetic field centr. Europe
14 HADFLG  0  0  0  0  0  2           flags hadr.interact.&fragmentation
15 ECUTS   0.05  0.01  0.001  0.001   energy cuts for particles
16 MUADDI  T                          additional info for muons
17 MUMULT  T                          muon multiple scattering angle
18 ELMFLG  T   T                      em. interaction flags (NKG,EGS)
19 STEPFC  1.0                        mult. scattering step length fact.
20 RADNKG  200.E2                     outer radius for NKG lat.dens.distr.
21 LONGI   F  20.  F  F               longit.distr. & step size & fit & out
22 ECTMAP  1.E3                       cut on gamma factor for printout
23 MAXPRT  10                         max. number of printed events
24 DIRECT  ./                         output directory
25 USER    you                        user
26 DEBUG   F  6  F  1000000           debug flag and log.unit for out
27 PLOTSH  T
28 PLAXES  -5E5 5E5 -5E5 5E5 1E5 5E6
29 EXIT                               terminates input
```

RUN3, Inclined proton

```
 1 RUNNR   1                              run number
 2 EVTNR   1                              number of first shower event
 3 NSHOW   1                              number of showers to generate
 4 PRMPAR  14                             particle type of prim. particle
 5 ESLOPE  -2.7                           slope of primary energy spectrum
 6 ERANGE  1.E3  1.E3                     energy range of primary particle
 7 THETAP  20.  20.                         range of zenith angle (degree)
 8 PHIP    -180.  180.                    range of azimuth angle (degree)
 9 SEED    1   0   0                      seed for 1. random number sequence
10 SEED    2   0   0                      seed for 2. random number sequence
11 OBSLEV  2.2E5                          observation level (in cm)
12 FIXCHI  0.                             starting altitude (g/cm**2)
13 MAGNET  39.96   16.16                  magnetic field centr. Europe
14 HADFLG  0  0  0  0  0  2               flags hadr.interact.&fragmentation
15 ECUTS   0.05  0.01  0.001  0.001       energy cuts for particles
16 MUADDI  T                              additional info for muons
17 MUMULT  T                              muon multiple scattering angle
18 ELMFLG  T   T                          em. interaction flags (NKG,EGS)
19 STEPFC  1.0                            mult. scattering step length fact.
20 RADNKG  200.E2                         outer radius for NKG lat.dens.distr.
21 LONGI   F  20.  F  F                   longit.distr. & step size & fit & out
22 ECTMAP  1.E3                           cut on gamma factor for printout
23 MAXPRT  10                             max. number of printed events
24 DIRECT  ./                             output directory
25 USER    you                            user
26 DEBUG   F  6  F  1000000               debug flag and log.unit for out
27 PLOTSH  T
28 PLAXES  -1E6 1E6 -1E6 1E6 1E5 5E6
29 EXIT                                   terminates input
```

RUN4, Vertical neutrino

```
 1 RUNNR   1                                  run number
 2 EVTNR   1                                  number of first shower event
 3 NSHOW   1                                  number of showers to generate
 4 PRMPAR  68                                 particle type of prim. particle
 5 ESLOPE  -2.7                               slope of primary energy spectrum
 6 ERANGE  1.E3  1.E3                         energy range of primary particle
 7 THETAP  0.  0.                             range of zenith angle (degree)
 8 PHIP    -180.  180.                        range of azimuth angle (degree)
 9 SEED    1   0   0                          seed for 1. random number sequence
10 SEED    2   0   0                          seed for 2. random number sequence
11 SEED    3   0   0                          seed for 2. random number sequence
12 SEED    4   0   0                          seed for 2. random number sequence
13 SEED    5   0   0                          seed for 2. random number sequence
14 OBSLEV  2.2E5                             observation level (in cm)
15 FIXCHI  0.                                starting altitude (g/cm**2)
16 FIXHEI  1E6 1
17 MAGNET  39.96   16.16                     magnetic field centr. Europe
18 HADFLG  0  0  0  0  0  2                  flags hadr.interact.&fragmentation
19 ECUTS   0.05  0.01  0.001  0.001          energy cuts for particles
20 MUADDI  T                                 additional info for muons
21 MUMULT  T                                 muon multiple scattering angle
22 ELMFLG  T   T                             em. interaction flags (NKG,EGS)
23 STEPFC  1.0                               mult. scattering step length fact.
24 RADNKG  200.E2                            outer radius for NKG lat.dens.distr.
25 LONGI   F  20.  F  F                      longit.distr. & step size & fit & out
26 ECTMAP  1.E3                              cut on gamma factor for printout
27 MAXPRT  10                                max. number of printed events
28 DIRECT  ./                                output directory
29 USER    you                               user
30 DEBUG   F  6  F  1000000                 debug flag and log.unit for out
31 PLOTSH  T
32 PLAXES  -1E6 1E6 -1E6 1E6 1E5 5E6
33 EXIT                                      terminates input
```