CORSIKA, Physics and Technology

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For CORSIKA School

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 ?

How to install CORSIKA ?

Dowloading and unpacking the code :

- ftp `corsika-76400.tar.gz`

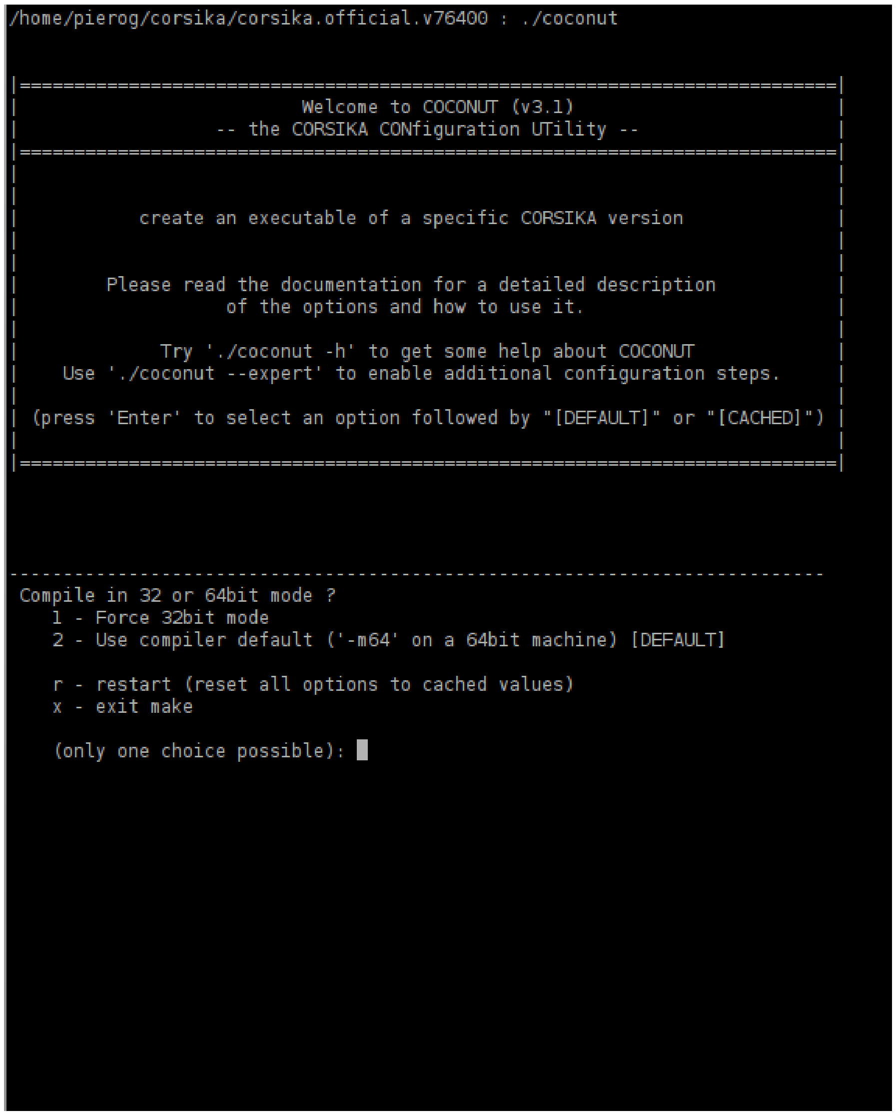
  from `ftp://ikp-ftp.ikp.kit.edu/corsika-v760`
- use login and password from CORSIKA mailing list
- unpack using : `tar -zxvf corsika-76400.tar.gz`
- enter subdirectory : `cd corsika-76400/`

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

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

Different compiler :

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



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

```
--------------------------------------------------------------------------
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) [DEFAULT]
   5 - QGSJETII-04
   6 - SIBYLL 2.3c
   7 - VENUS 4.12

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

   (only one choice possible):
   SELECTED          : QGSJET01


--------------------------------------------------------------------------
Which low energy hadronic interaction model do you want to use ?
   1 - GHEISHA 2002d (double precision) [DEFAULT]
   2 - FLUKA
   3 - URQMD 1.3cr

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

   (only one choice possible):
   SELECTED          : GHEISHA


--------------------------------------------------------------------------
Which detector geometry do you have ?
   1 - horizontal flat detector array [DEFAULT]
   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):
   SELECTED          : HORIZONTAL


--------------------------------------------------------------------------
 options:   GHEISHA TIMEAUTO HORIZONTAL QGSJET01
```

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

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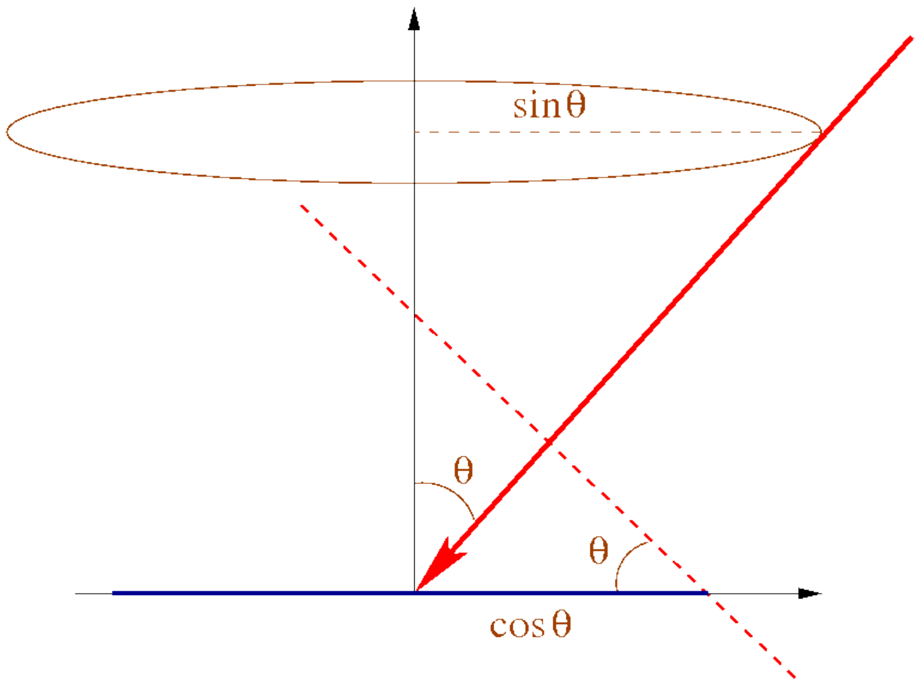
Detector geometry (only change the angular distribution of showers)

- 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,...)
  - $I \propto sin\theta \cdot cos\theta$
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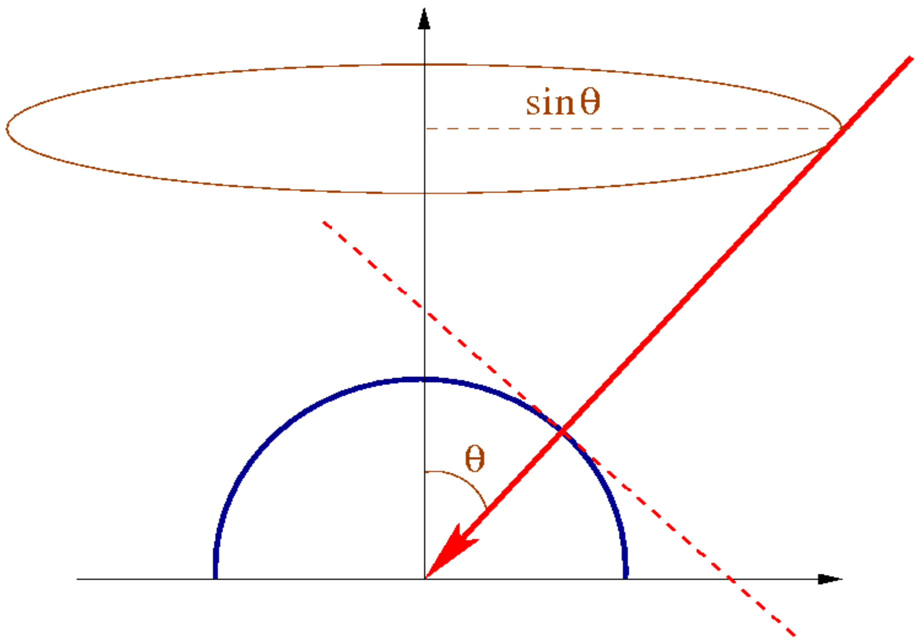

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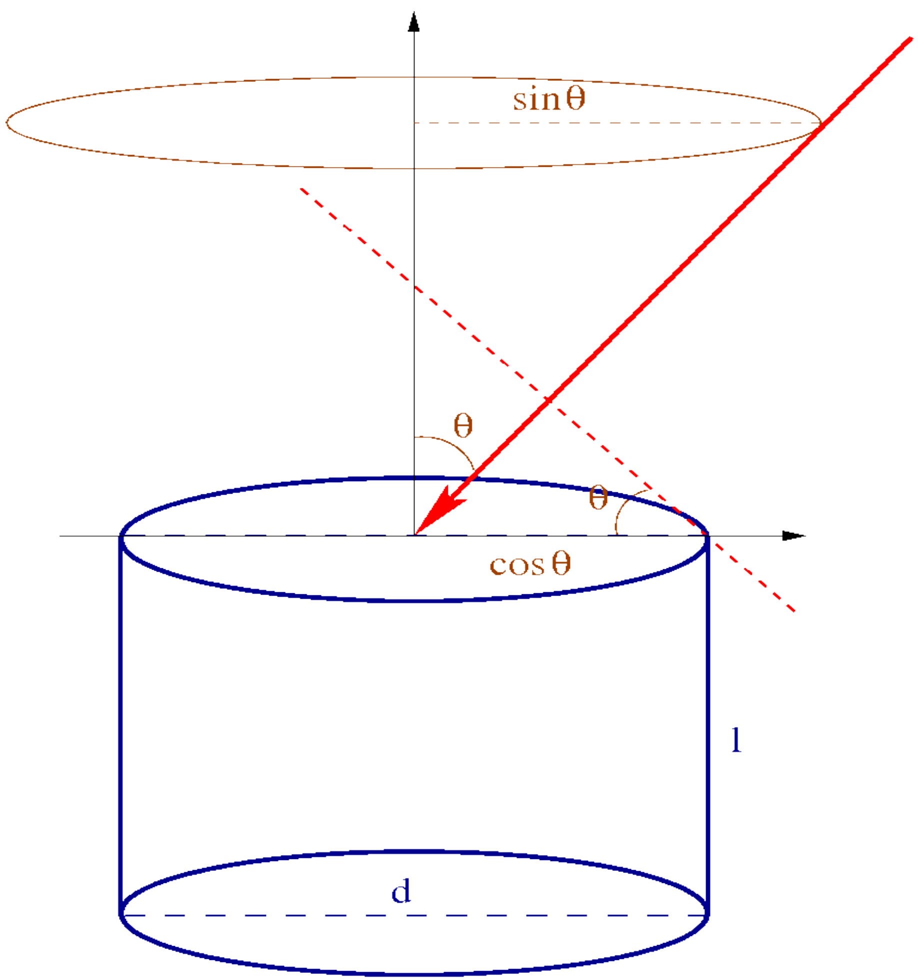

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$$I \propto (d/2)^2 \cdot \pi \cdot sin\theta \cdot (cos\theta + 4/\pi \cdot l/d \cdot sin\theta)$$

Cherenkov Light

```
Which additional CORSIKA program options do you need ?
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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
   2a - THINning version (includes LPM)
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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 ...

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```

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)

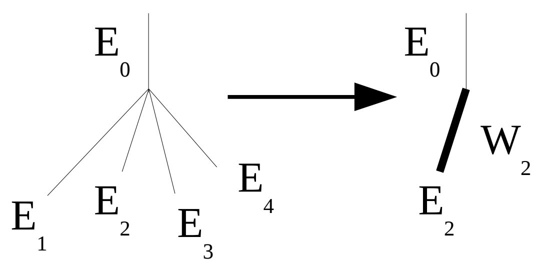
2b – MULTIple THINning

- unthinned + various thinning level

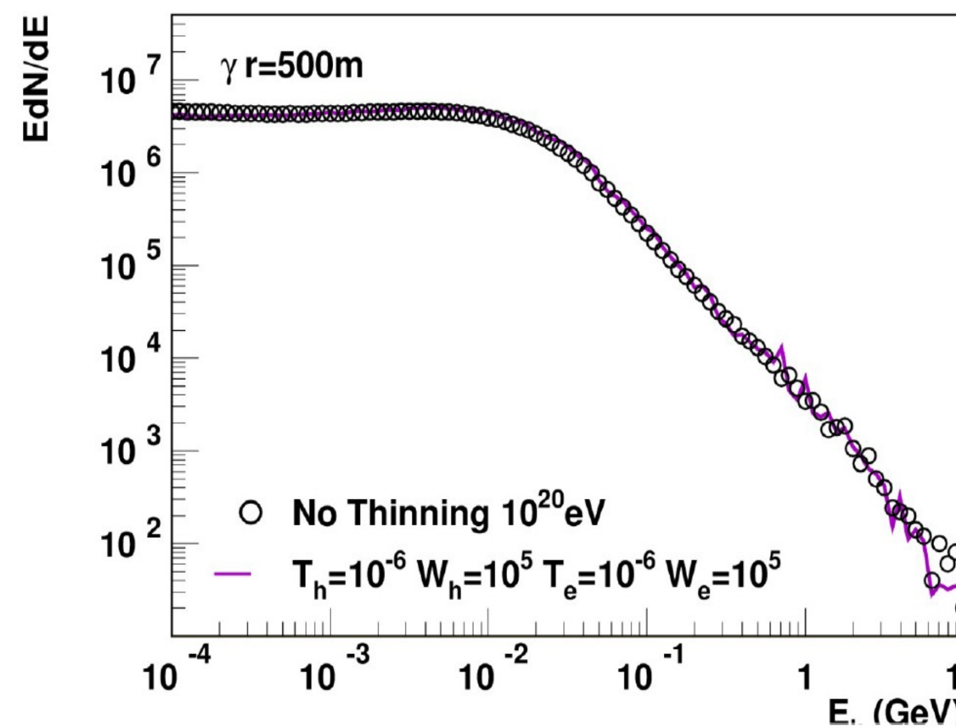
Thinning

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

Options ...

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```

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

- reodering of stack : high E on top

4c – ICECUBE2

- gzip/pipe output

Options ...

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```

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)

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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.

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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

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```

Obsolete ... COAST should be used instead !

8a – PLOTSH

- only to make a “picture” of the shower

8b – PLOTSH2

- more c... for ... special library)

8c – ...ST

- 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 ...

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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

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a – CONEX

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

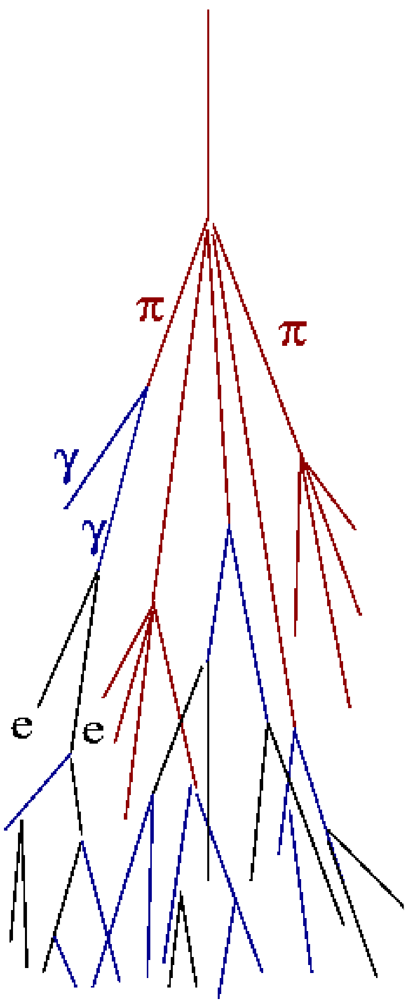
b – PARALLEL

- parallel calculation
  - shell script or MPI

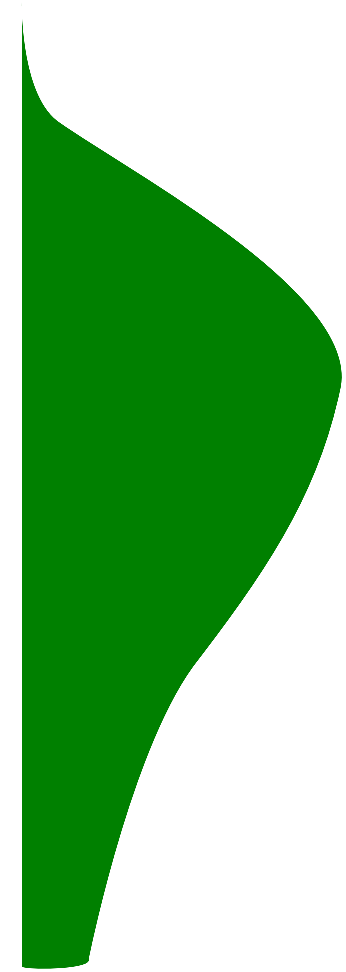
c – CoREAS

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

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 ?**
  - ➜ electron cascade equations

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

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interaction term

Cascade Equations

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production terms

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- **Can be CE as flexible than MC ?**
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interaction term

ionization loss term

Cascade Equations

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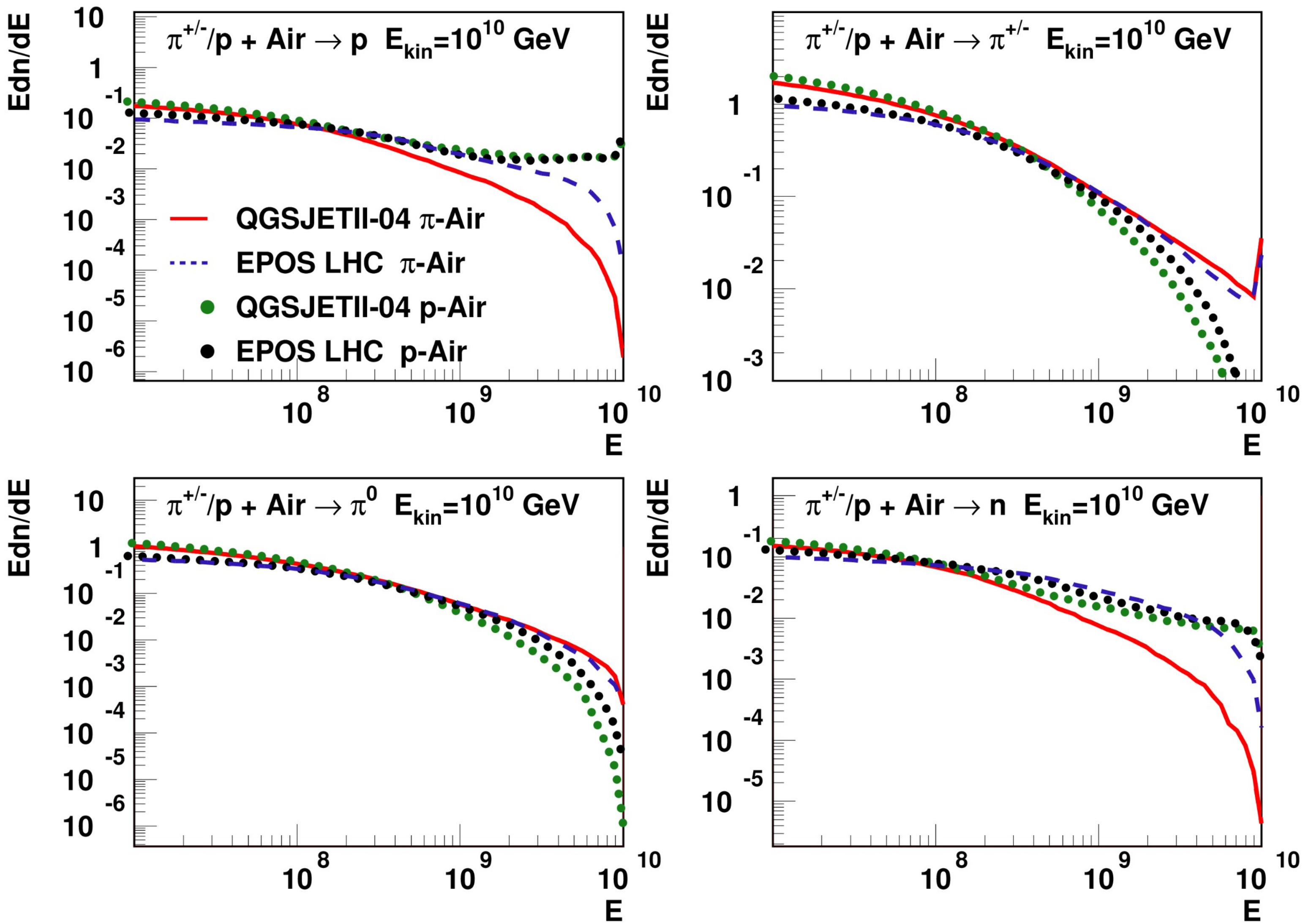
- **analytical solution needs simplified distributions**
  - ➡ no analytical function for hadronic production
  - ➡ numerical solution more flexible

$$\frac{dl_a^i(X)}{dX} = \sum_d \sum_{j=i}^{i_{\max}} \bar{W}_{d\to a}^{ji}\; l_d^j(X) + S_{ai}^{\mathrm{e/m}}(X)$$

Hadronic Particle Spectra (W)

- **Simulations of all type of possible interactions :**
  - $p+Air \rightarrow \pi^{\pm},p,K^{\pm},K_L,K_s,n,\gamma,e,\mu$
  - $\pi^{\pm}+Air \rightarrow \pi,p,K^{\pm},K_L,K_s,n,\gamma,e,\mu$
  - $K^{\pm}+Air \rightarrow \pi,p,K^{\pm},K_L,K_s,n,\gamma,e,\mu$
  - $K^0+Air \rightarrow \pi,p,K^{\pm},K_L,K_s,n,\gamma,e,\mu$
  - $n+Air \rightarrow \pi,p,K,K_L,K_s,n,\gamma,e,\mu$
- **Results stored in tables copied to W**

Hadronic Particle Spectra (W)



- same for decay …

Cascade Equations

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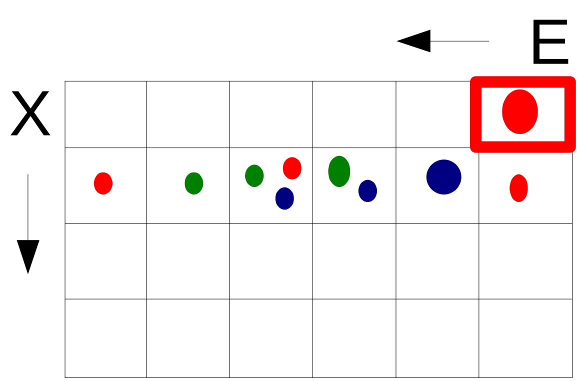

Cascade Equations

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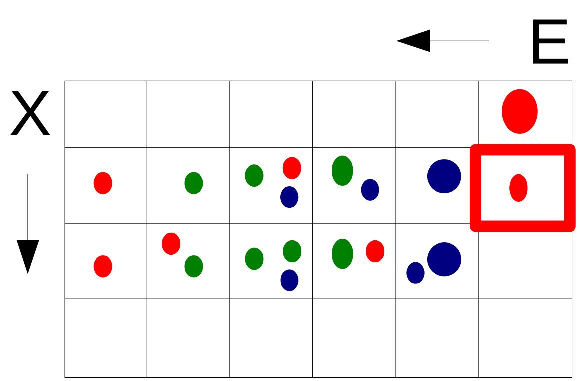

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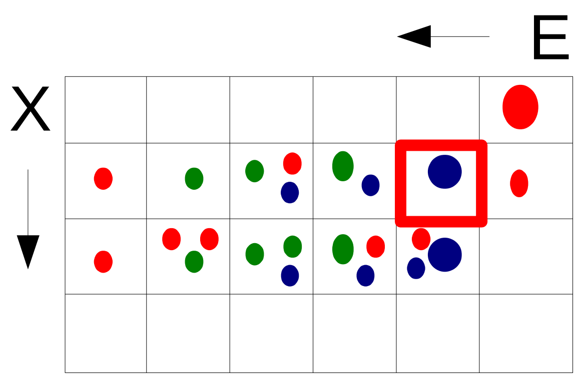
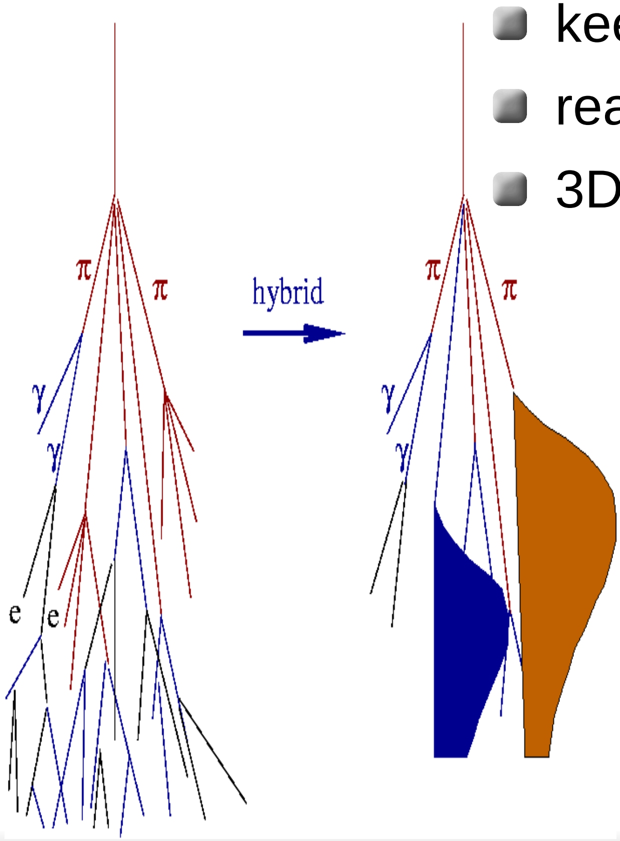
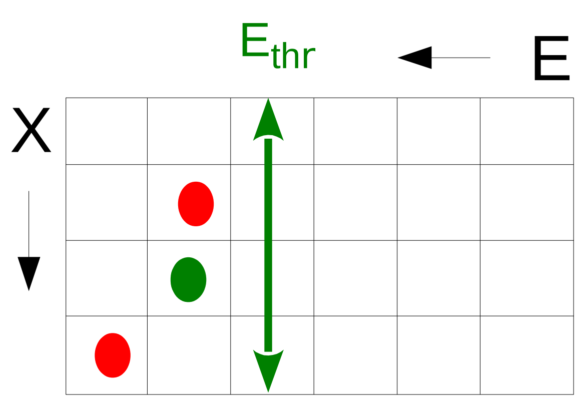


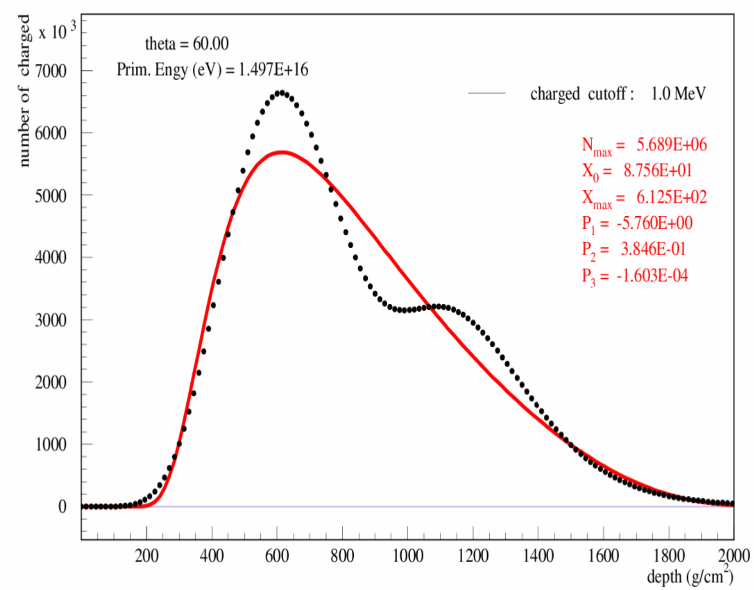
Consistent Hybrid Calculation

- **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 ($E<E_{thr}$)
    - 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



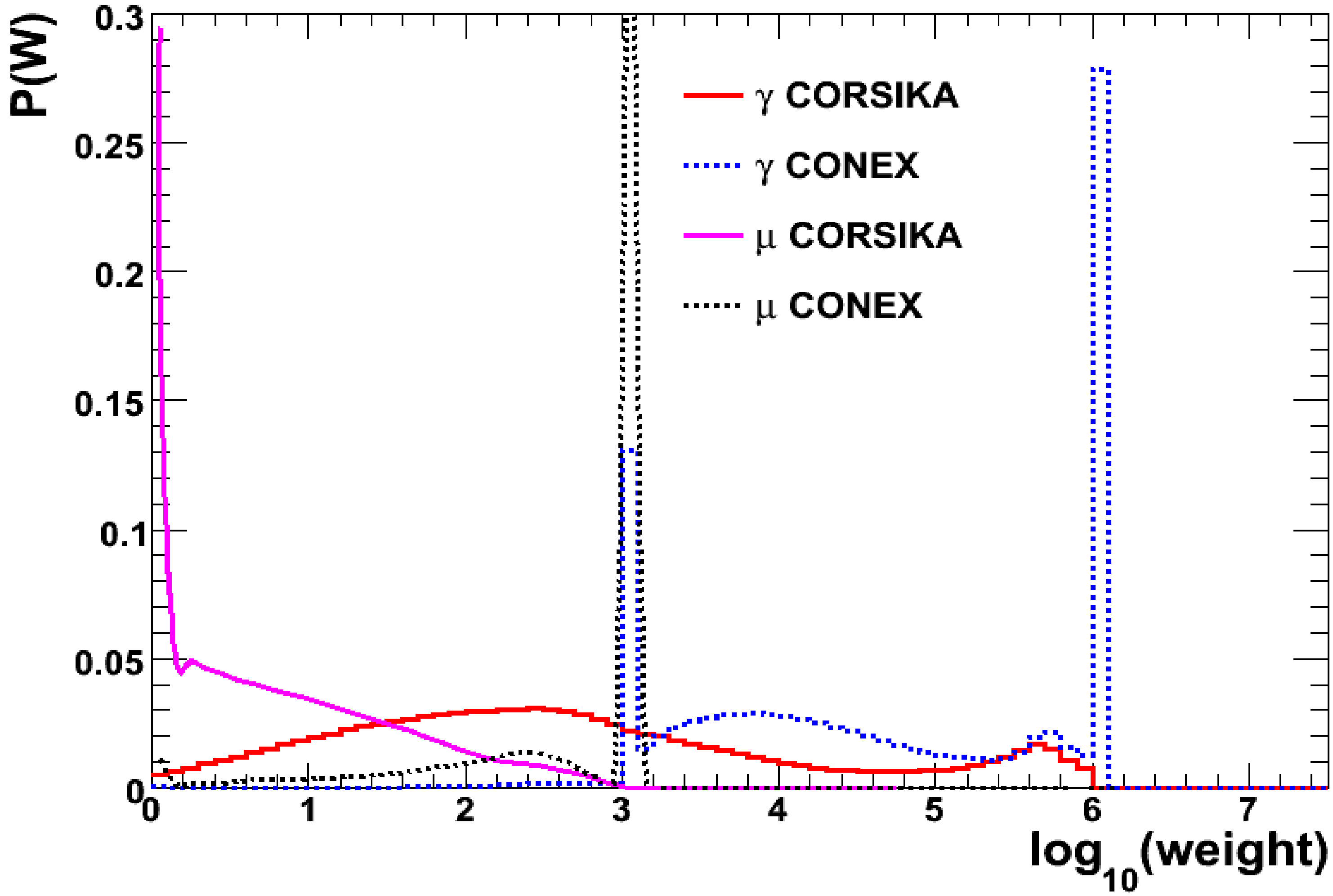


Properties

- **CORSIKA replace part of the CE**
  - ➜ First interactions in CONEX independent from E_{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



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a – CONEX

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

b – PARALLEL

- parallel calculation
  - shell script or MPI

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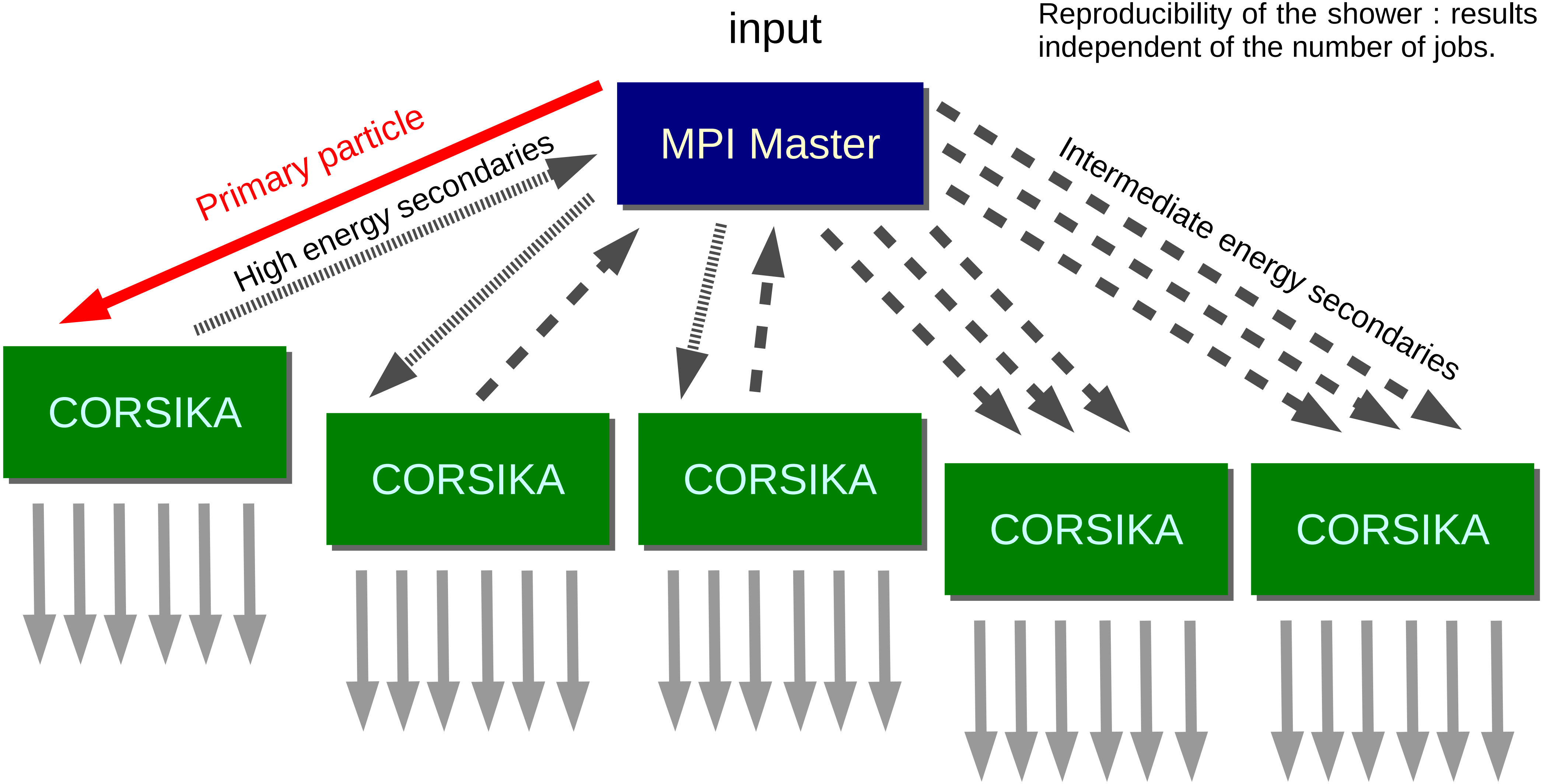
Parallelization of CORSIKA with MPI

Reproducibility of the shower : results independent of the number of jobs.

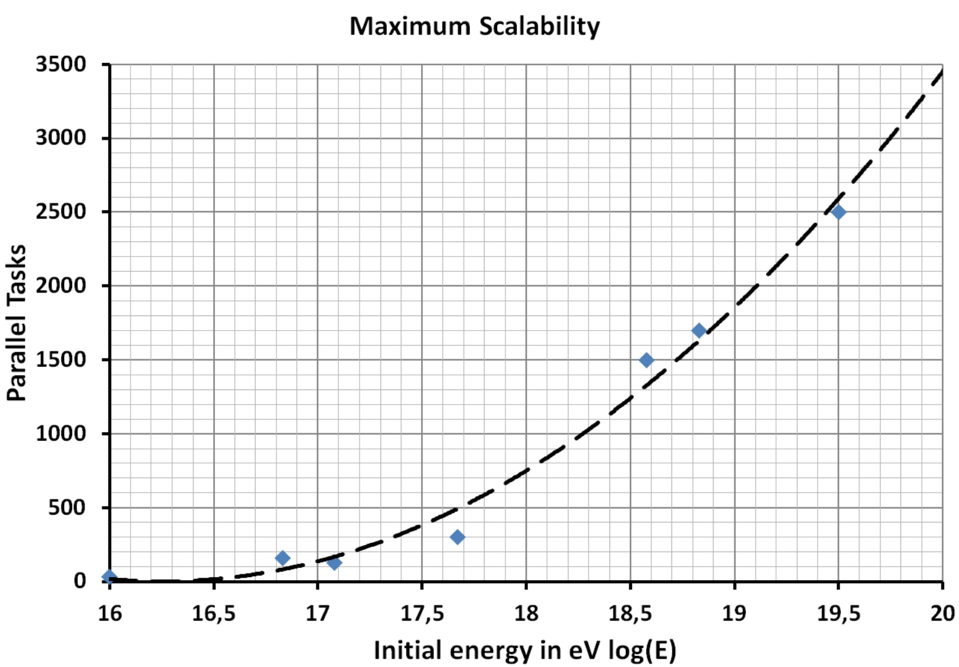


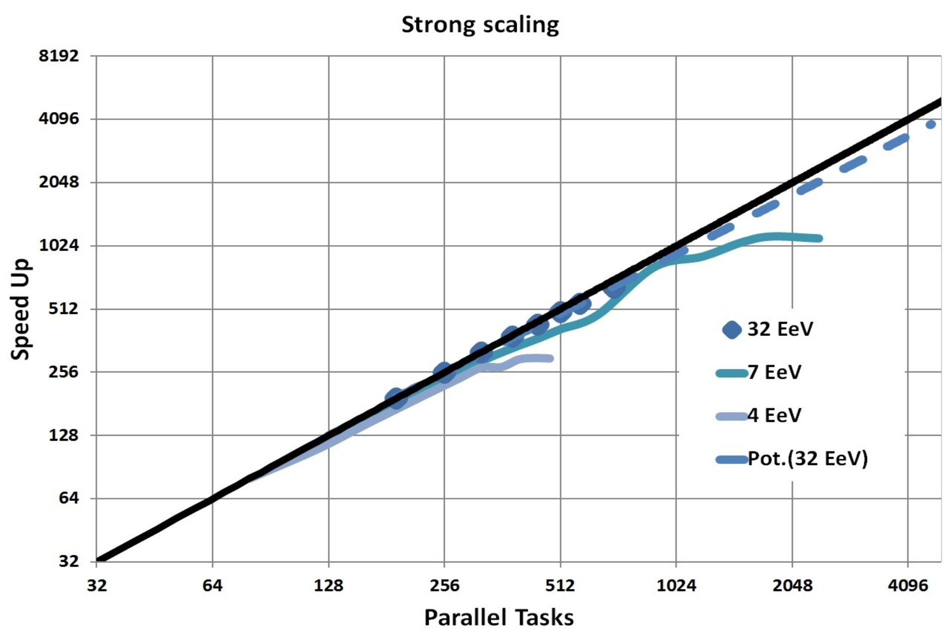
Low energy secondaries down to observation level

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)

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COAST Options ...
(see R. Ulrich exercices)

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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

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   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-magn
etic 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
   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 - 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]
```

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

Options ...

```
Which additional CORSIKA program options do you need ?
   1a - Cherenkov version
   1b - Cherenkov version using Bernlohr IACT rout
   1c - apply atm. absorption, mirror reflectivity
   1d - Auger Cherenkov longitudinal distribution
   1e - TRAJECTory version to follow motion of sou
   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
   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-magn
etic field
   10a - DYNamic intermediate particle STACK
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   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
   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 - 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]
```

e – Interaction test

Obsolete … CRMC should be used instead !

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

Options ...

```
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
   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-magn
etic 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
   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 - 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]
```

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

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

Other Options ...

```
    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
    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-magn
etic 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
    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 - 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):
```

y – reset selection

z – Finish selection

- just press “return” key

r – restart

- from the beginning (model selection)

x – exit make

- stop installation

If Cherenkov

```
-------------------------------------------------------------------------------
 Cherenkov light vertical (longitudinal) distribution option ?
    1 - Photons counted only in the step where emitted [DEFAULT]
    2 - Photons counted in every step down to the observation level
        (compatible with old versions but inefficient)
    3 - No Cherenkov light distribution at all

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

    (only one choice possible):
    SELECTED         : INTCLONGSTD


-------------------------------------------------------------------------------
 Do you want Cherenkov light emission angle wavelength dependence ?
    1 - Emission angle is wavelength independent [DEFAULT]
    2 - Emission angle depending on wavelength

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

    (only one choice possible):
    SELECTED         : CERWLENOFF
    SELECTED         : CERENKOV
    NOT COMPATIBLE TO: COMPACT VOLUMECORR INTTEST ANAHIST AUGERHIST MUONHIST AUGCE
RLONG
```

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

Source and Compilation

```
---------------------------------------------------------------------------
 Configuration is finished. How do you want to proceed ?
    f - Compiling and remove temporary files [DEFAULT]
    k - Compile and keep extracted CORSIKA source code
    n - Just extract source code. Do not compile!

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

    (only one choice possible):
    SELECTED         : COMPILE
checking whether to enable maintainer-specific portions of Makefiles... no
checking build system type... x86_64-unknown-linux-gnu
checking host system type... x86_64-unknown-linux-gnu
checking for a BSD-compatible install... /usr/bin/install -c
checking whether build environment is sane... yes
checking for a thread-safe mkdir -p... /bin/mkdir -p
checking for gawk... gawk
checking whether make sets $(MAKE)... yes
checking whether make supports nested variables... yes
checking to compile without optimisation and system flags... (cached) no
checking whether to generate debug... (cached) yes
checking for pgf77... no
checking for ifc... no
checking for ifort... no
checking for gfortran... gfortran
checking whether the Fortran 77 compiler works... yes
checking for Fortran 77 compiler default output file name... a.out
checking for suffix of executables...
checking whether we are cross compiling... no
checking for suffix of object files... o
checking whether we are using the GNU Fortran 77 compiler... yes
checking whether gfortran accepts -g... yes
checking for cc... cc
checking whether we are using the GNU C compiler... yes
checking whether cc accepts -g... yes
checking for cc option to accept ISO C89... none needed
checking whether cc understands -c and -o together... yes
checking for style of include used by make... GNU
checking dependency style of cc... gcc3
checking for g++... g++
checking whether we are using the GNU C++ compiler... yes
checking whether g++ accepts -g... yes
checking dependency style of g++... gcc3
checking for cpp... cpp
checking how to run the C preprocessor... cpp
checking how to get verbose linking output from gfortran... -v
checking for Fortran 77 libraries of gfortran...  -L/usr/lib/gcc/x86_64-linux-gnu
/4.8 -L/usr/lib/gcc/x86_64-linux-gnu/4.8/../../../x86_64-linux-gnu -L/usr/lib/gcc
```

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

```
checking for root... no
checking particle output in root file... (cached) no
checking machine independent output... (cached) no
checking for COASTUSERLIB... no
checking External COAST user library... (cached) no
checking CoREAS radio simulations... (cached) no
checking Inclined observation level... (cached) no
checking for conex... no
checking CONEX cascade equation (CONEX)... (cached) no
checking produce analysis histograms... (cached) no
checking augerinfo... (cached) no
checking augerhist... (cached) no
checking muonhist... (cached) no
checking parallel computation... (cached) no
checking for mpirunner_lib... no
checking parallel computation with MPI... (cached) no
checking do not compile binaries, just extract CORSIKA compilefile... (cached) no
checking to keep the CORSIKA compilefile... (cached) no
checking that generated files are newer than configure... done
configure: creating ./config.status
config.status: creating Makefile
config.status: creating baack/Makefile
config.status: creating bernlohr/Makefile
config.status: creating conex/Makefile
config.status: creating dpmjet/Makefile
config.status: creating epos/Makefile
config.status: creating pythia/Makefile
config.status: creating herwig/Makefile
config.status: creating nexus/Makefile
config.status: creating urqmd/Makefile
config.status: creating src/Makefile
config.status: creating run/Makefile
config.status: creating doc/Makefile
config.status: creating lib/Makefile
config.status: creating coast/Makefile
config.status: creating coast/Documentation/Makefile
config.status: creating coast/CorsikaOptions/rootout/Makefile
config.status: creating coast/CorsikaOptions/CoREAS/Makefile
config.status: creating coast/CorsikaOptions/Makefile
config.status: creating coast/CorsikaOptions/InclinedPlane/Makefile
config.status: creating coast/CorsikaFileIO/Makefile
config.status: creating coast/CorsikaInterface/Makefile
config.status: creating coast/CorsikaToROOT/Makefile
config.status: creating coast/CorsikaROOT/Makefile
config.status: creating coast/CorsikaIntern/Makefile
config.status: creating include/config.h
config.status: executing depfiles commands
config.status: executing libtool commands
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
```

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.

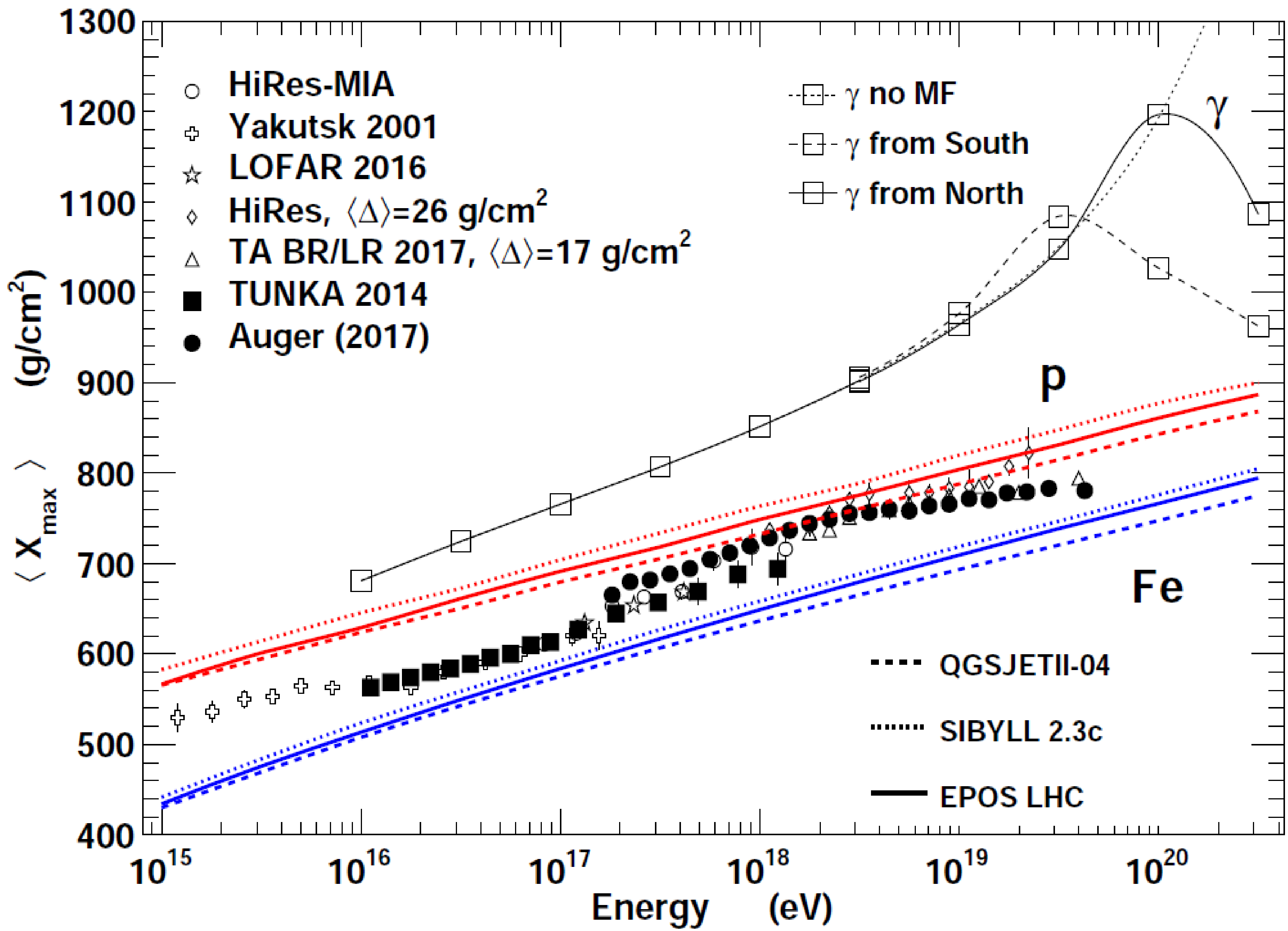
Installation Complete

```
depbase=`echo tobuf.o | sed 's|[^/]*$|.deps/&|;s|\.o$||'`;\
        cc -DHAVE_CONFIG_H -I. -I../include        -g -D_FILE_OFFSET_BITS=64 -MT
tobuf.o -MD -MP -MF $depbase.Tpo -c -o tobuf.o tobuf.c &&\
        mv -f $depbase.Tpo $depbase.Po
gfortran -O0  -g -std=legacy -Wtabs -c -o corsika-qgsjet01d.o `test -f 'qgsjet01d
.f' || echo './'`qgsjet01d.f
gfortran -O0  -g -std=legacy -Wtabs -c -o corsika-gheisha_2002d.o `test -f 'gheis
ha_2002d.f' || echo './'`gheisha_2002d.f
depbase=`echo timerc.o | sed 's|[^/]*$|.deps/&|;s|\.o$||'`;\
        cc -DHAVE_CONFIG_H -I. -I../include        -g -D_FILE_OFFSET_BITS=64 -MT
timerc.o -MD -MP -MF $depbase.Tpo -c -o timerc.o timerc.c &&\
        mv -f $depbase.Tpo $depbase.Po
/bin/bash ../libtool  --tag=F77   --mode=link gfortran -O0  -g -std=legacy -Wtabs
  -D_FILE_OFFSET_BITS=64 -Xlinker --no-as-needed -o corsika corsika-corsikacompil
efile.o tobuf.o  corsika-qgsjet01d.o    corsika-gheisha_2002d.o    timerc.o -L/hom
e/pierog/corsika/corsika.official.v76400/lib/unknown
libtool: link: gfortran -O0 -g -std=legacy -Wtabs -D_FILE_OFFSET_BITS=64 -Wl,--no
-as-needed -o corsika corsika-corsikacompilefile.o tobuf.o corsika-qgsjet01d.o co
rsika-gheisha_2002d.o timerc.o  -L/home/pierog/corsika/corsika.official.v76400/li
b/unknown
make[2]: Entering directory `/home/pierog/corsika/corsika.official.v76400/src'
 /bin/mkdir -p '/home/pierog/corsika/corsika.official.v76400/run'
  /bin/bash ../libtool   --mode=install /usr/bin/install -c corsika '/home/pierog
/corsika/corsika.official.v76400/run'
libtool: install: /usr/bin/install -c corsika /home/pierog/corsika/corsika.offici
al.v76400/run/corsika
make[2]: Nothing to be done for `install-data-am'.
make[2]: Leaving directory `/home/pierog/corsika/corsika.official.v76400/src'
make[1]: Leaving directory `/home/pierog/corsika/corsika.official.v76400/src'
Making install in .
make[1]: Entering directory `/home/pierog/corsika/corsika.official.v76400'
make[2]: Entering directory `/home/pierog/corsika/corsika.official.v76400'
make  install-exec-hook
make[3]: Entering directory `/home/pierog/corsika/corsika.official.v76400'


--> "corsika76400Linux_QGSJET_gheisha" successfully installed in :
    /home/pierog/corsika/corsika.official.v76400/run/

--> You can run CORSIKA in /home/pierog/corsika/corsika.official.v76400/run/ usin
g for instance :
    ./corsika76400Linux_QGSJET_gheisha < all-inputs > output.txt


make[3]: Leaving directory `/home/pierog/corsika/corsika.official.v76400'
make[2]: Nothing to be done for `install-data-am'.
make[2]: Leaving directory `/home/pierog/corsika/corsika.official.v76400'
make[1]: Leaving directory `/home/pierog/corsika/corsika.official.v76400'
```

If no compilation problem

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

Example



HiRes-MIA
Yakutsk 2001
LOFAR 2016
HiRes, ⟨Δ⟩=26 g/cm²
TA BR/LR 2017, ⟨Δ⟩=17 g/cm²
TUNKA 2014
Auger (2017)
γ no MF
γ from South
γ from North
γ
p
Fe
QGSJETII-04
SIBYLL 2.3c
EPOS LHC
⟨X_max⟩ (g/cm²)
Energy (eV)

Installation Complete

```
depbase=`echo tobuf.o | sed 's|[^/]*$|.deps/&|;s|\.o$||'`;\
        cc -DHAVE_CONFIG_H -I. -I../include        -g -D_FILE_OFFSET_BITS=64 -MT
tobuf.o -MD -MP -MF $depbase.Tpo -c -o tobuf.o tobuf.c &&\
        mv -f $depbase.Tpo $depbase.Po
gfortran -O0  -g -std=legacy -Wtabs -c -o corsika-qgsjet01d.o `test -f 'qgsjet01d
.f' || echo './'`qgsjet01d.f
gfortran -O0  -g -std=legacy -Wtabs -c -o corsika-gheisha_2002d.o `test -f 'gheis
ha_2002d.f' || echo './'`gheisha_2002d.f
depbase=`echo timerc.o | sed 's|[^/]*$|.deps/&|;s|\.o$||'`;\
        cc -DHAVE_CONFIG_H -I. -I../include        -g -D_FILE_OFFSET_BITS=64 -MT
timerc.o -MD -MP -MF $depbase.Tpo -c -o timerc.o timerc.c &&\
        mv -f $depbase.Tpo $depbase.Po
/bin/bash ../libtool  --tag=F77   --mode=link gfortran -O0  -g -std=legacy -Wtabs
  -D_FILE_OFFSET_BITS=64 -Xlinker --no-as-needed -o corsika corsika-corsikacompil
efile.o tobuf.o  corsika-qgsjet01d.o    corsika-gheisha_2002d.o    timerc.o -L/hom
e/pierog/corsika/corsika.official.v76400/lib/unknown
libtool: link: gfortran -O0 -g -std=legacy -Wtabs -D_FILE_OFFSET_BITS=64 -Wl,--no
-as-needed -o corsika corsika-corsikacompilefile.o tobuf.o corsika-qgsjet01d.o co
rsika-gheisha_2002d.o timerc.o  -L/home/pierog/corsika/corsika.official.v76400/li
b/unknown
make[2]: Entering directory `/home/pierog/corsika/corsika.official.v76400/src'
 /bin/mkdir -p '/home/pierog/corsika/corsika.official.v76400/run'
  /bin/bash ../libtool   --mode=install /usr/bin/install -c corsika '/home/pierog
/corsika/corsika.official.v76400/run'
libtool: install: /usr/bin/install -c corsika /home/pierog/corsika/corsika.offici
al.v76400/run/corsika
make[2]: Nothing to be done for `install-data-am'.
make[2]: Leaving directory `/home/pierog/corsika/corsika.official.v76400/src'
make[1]: Leaving directory `/home/pierog/corsika/corsika.official.v76400/src'
Making install in .
make[1]: Entering directory `/home/pierog/corsika/corsika.official.v76400'
make[2]: Entering directory `/home/pierog/corsika/corsika.official.v76400'
make  install-exec-hook
make[3]: Entering directory `/home/pierog/corsika/corsika.official.v76400'


--> "corsika76400Linux_QGSJET_gheisha" successfully installed in :
    /home/pierog/corsika/corsika.official.v76400/run/

--> You can run CORSIKA in /home/pierog/corsika/corsika.official.v76400/run/ usin
g for instance :
    ./corsika76400Linux_QGSJET_gheisha < all-inputs > output.txt


make[3]: Leaving directory `/home/pierog/corsika/corsika.official.v76400'
make[2]: Nothing to be done for `install-data-am'.
make[2]: Leaving directory `/home/pierog/corsika/corsika.official.v76400'
make[1]: Leaving directory `/home/pierog/corsika/corsika.official.v76400'
```

If no compilation problem

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

- … using the steering file !

Input (steering) File

```
RUNNR   2                       run number
EVTNR   1                       number of first shower event
NSHOW   1                       number of showers to generate
PRMPAR  14                      particle type of prim. particle
ESLOPE  -2.7                    slope of primary energy spectrum
ERANGE  1.E4  1.E4              energy range of primary particle
THETAP  20.   20.               range of zenith angle (degree)
PHIP    -180.  180.             range of azimuth angle (degree)
SEED    1   0   0               seed for 1. random number sequence
SEED    2   0   0               seed for 2. random number sequence
OBSLEV  110.E2                  observation level (in cm)
FIXCHI  0.                      starting altitude (g/cm**2)
MAGNET  20.0  42.8              magnetic field centr. Europe
HADFLG  0  0  0  0  0  2        flags hadr.interact.&fragmentation
ECUTS   0.3  0.3  0.003  0.003  energy cuts for particles
MUADDI  T                       additional info for muons
MUMULT  T                       muon multiple scattering angle
ELMFLG  T   T                   em. interaction flags (NKG,EGS)
STEPFC  1.0                     mult. scattering step length fact.
RADNKG  200.E2                  outer radius for NKG lat.dens.distr.
LONGI   T  10.  T  T            longit.distr. & step size & fit & out
ECTMAP  1.E4                    cut on gamma factor for printout
MAXPRT  1                       max. number of printed events
DIRECT  ./                      output directory
USER    you                     user
DEBUG   F  6  F  1000000        debug flag and log.unit for out
EXIT                            terminates input
```

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

- ./corsika76400Linux_QGSJET_gheisha < all-inputs

3 Types of controls :

- shower parameters
- options parameters
- output parameters

End steering :

- EXIT

Shower Parameters (1)

Identification	Particle	Identification	Particle
1	γ	17	η
2	e^+	18	Λ
3	e^-	19	Σ^+
		20	Σ°
5	μ^+	21	Σ^-
6	μ^-	22	Ξ°
7	π°	23	Ξ^-
8	π^+	24	Ω^-
9	π^-	25	$\overline{n}$
10	K_L°	26	$\overline{\Lambda}$
11	K^+	27	$\overline{\Sigma}^-$
12	K^-	28	$\overline{\Sigma}^\circ$
13	n	29	$\overline{\Sigma}^+$
14	p	30	$\overline{\Xi}^\circ$
15	$\overline{p}$	31	$\overline{\Xi}^+$
16	K_S°	32	$\overline{\Omega}^+$

EVTNR

- event number of first shower

NSHOW

- Number of showers to simulate

PRMPAR

- primary particle

ERANGE and ESLOPE

- primary energy (GeV)

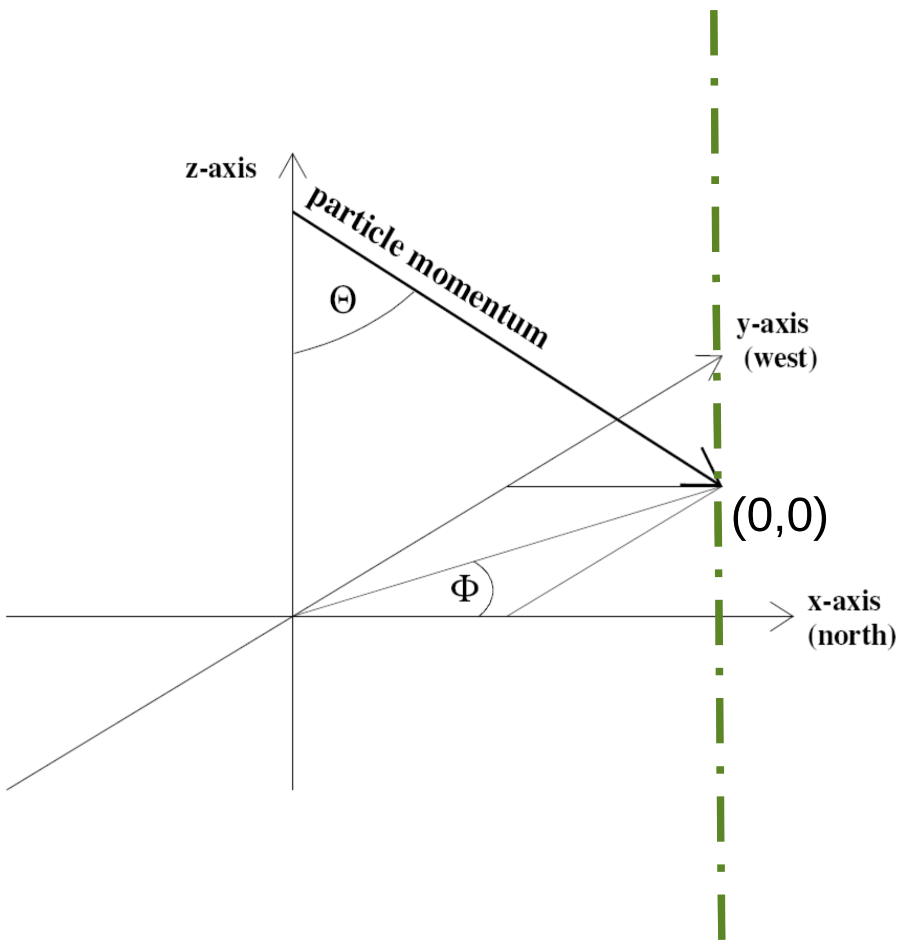
THETAP

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

PHIP

- azimuth angle (in °)

Shower Parameters (1)



reference axis used in many experiments

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 (2)

```
RUNNR   2                            run number
EVTNR   1                            number of first shower event
NSHOW   1                            number of showers to generate
PRMPAR  14                           particle type of prim. particle
ESLOPE  -2.7                         slope of primary energy spectrum
ERANGE  1.E4  1.E4                   energy range of primary particle
THETAP  20.   20.                    range of zenith angle (degree)
PHIP    -180.  180.                  range of azimuth angle (degree)
SEED    1   0   0                    seed for 1. random number sequence
SEED    2   0   0                    seed for 2. random number sequence
OBSLEV  110.E2                       observation level (in cm)
FIXCHI  0.                           starting altitude (g/cm**2)
MAGNET  20.0  42.8                   magnetic field centr. Europe
HADFLG  0  0  0  0  0  2             flags hadr.interact.&fragmentation
ECUTS   0.3  0.3  0.003  0.003       energy cuts for particles
MUADDI  T                            additional info for muons
MUMULT  T                            muon multiple scattering angle
ELMFLG  T   T                        em. interaction flags (NKG,EGS)
STEPFC  1.0                          mult. scattering step length fact.
RADNKG  200.E2                       outer radius for NKG lat.dens.distr.
LONGI   T  10.  T  T                 longit.distr. & step size & fit & out
ECTMAP  1.E4                         cut on gamma factor for printout
MAXPRT  1                            max. number of printed events
DIRECT  ./                           output directory
USER    you                          user
DEBUG   F  6  F  1000000             debug flag and log.unit for out
EXIT                                 terminates input
```

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)

```
RUNNR   2                            run number
EVTNR   1                            number of first shower event
NSHOW   1                            number of showers to generate
PRMPAR  14                           particle type of prim. particle
ESLOPE  -2.7                         slope of primary energy spectrum
ERANGE  1.E4  1.E4                   energy range of primary particle
THETAP  20.  20.                     range of zenith angle (degree)
PHIP    -180.  180.                  range of azimuth angle (degree)
SEED    1   0   0                    seed for 1. random number sequence
SEED    2   0   0                    seed for 2. random number sequence
OBSLEV  110.E2                       observation level (in cm)
FIXCHI  0.                           starting altitude (g/cm**2)
MAGNET  20.0  42.8                   magnetic field centr. Europe
HADFLG  0  0  0  0  0  2             flags hadr.interact.&fragmentation
ECUTS   0.3  0.3  0.003  0.003       energy cuts for particles
MUADDI  T                            additional info for muons
MUMULT  T                            muon multiple scattering angle
ELMFLG  T   T                        em. interaction flags (NKG,EGS)
STEPFC  1.0                          mult. scattering step length fact.
RADNKG  200.E2                       outer radius for NKG lat.dens.distr.
LONGI   T  10.  T  T                 longit.distr. & step size & fit & out
ECTMAP  1.E4                         cut on gamma factor for printout
MAXPRT  1                            max. number of printed events
DIRECT  ./                           output directory
USER    you                          user
DEBUG   F  6  F  1000000             debug flag and log.unit for out
EXIT                                 terminates input
```

FIXCHI (g/cm^2)

- starting point of shower primary
- not used if FIXHEI is used

MAGNET

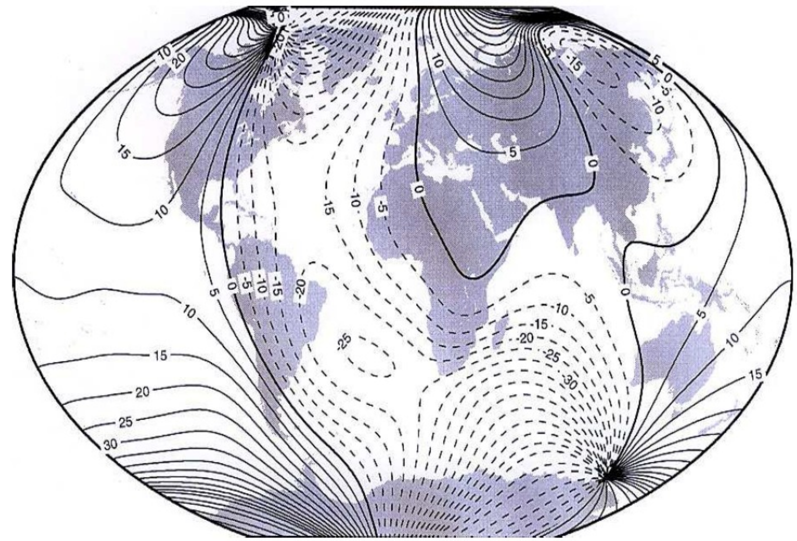
- magnetic field

HADFLG

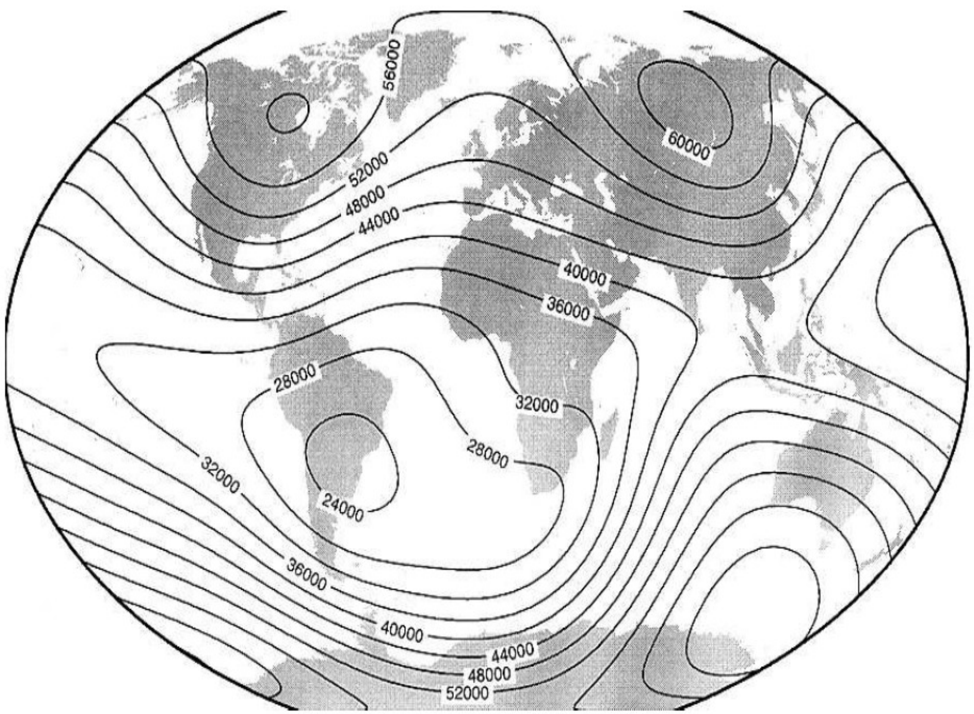
- first 5 numbers related to HDPM (obsolete)
- last fix the nuclear fragmentation
  - 0 – None
  - 1 – Full
  - 2 or more – Realistic

Earth Magnetic Field

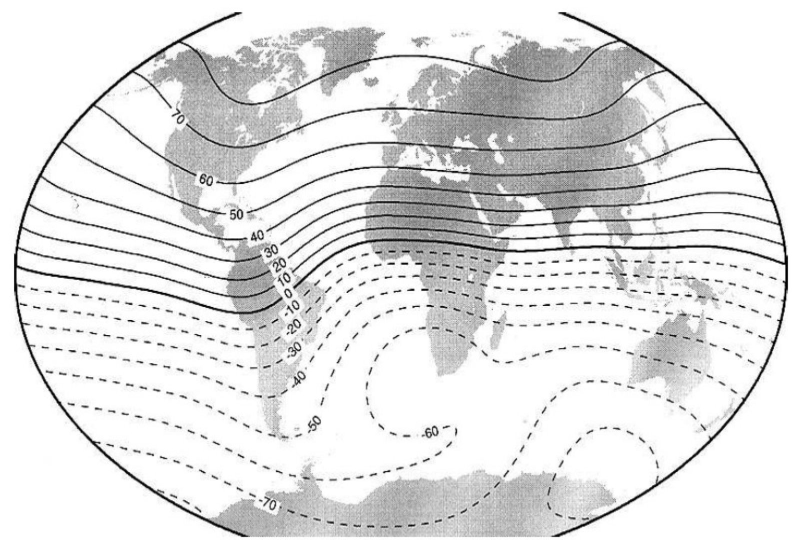
- Earth Magnetic Field has to be defined according to experiment position on Earth



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



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



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

Shower Parameters (3)

```
RUNNR   2                   run number
EVTNR   1                   number of first shower event
NSHOW   1                   number of showers to generate
PRMPAR  14                  particle type of prim. particle
ESLOPE  -2.7                slope of primary energy spectrum
ERANGE  1.E4  1.E4          energy range of primary particle
THETAP  20.  20.            range of zenith angle (degree)
PHIP    -180.  180.         range of azimuth angle (degree)
SEED    1   0   0           seed for 1. random number sequence
SEED    2   0   0           seed for 2. random number sequence
OBSLEV  110.E2              observation level (in cm)
FIXCHI  0.                  starting altitude (g/cm**2)
MAGNET  20.0  42.8          magnetic field centr. Europe
HADFLG  0  0  0  0  0  2    flags hadr.interact.&fragmentation
ECUTS   0.3  0.3  0.003  0.003   energy cuts for particles
MUADDI  T                   additional info for muons
MUMULT  T                   muon multiple scattering angle
ELMFLG  T   T               em. interaction flags (NKG,EGS)
STEPFC  1.0                 mult. scattering step length fact.
RADNKG  200.E2              outer radius for NKG lat.dens.distr.
LONGI   T  10.  T  T        longit.distr. & step size & fit & out
ECTMAP  1.E4                cut on gamma factor for printout
MAXPRT  1                   max. number of printed events
DIRECT  ./                  output directory
USER    you                 user
DEBUG   F  6  F  1000000    debug flag and log.unit for out
EXIT                        terminates input
```

FIXCHI (g/cm^2)

- 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)

```
RUNNR   2                            run number
EVTNR   1                            number of first shower event
NSHOW   1                            number of showers to generate
PRMPAR  14                           particle type of prim. particle
ESLOPE  -2.7                         slope of primary energy spectrum
ERANGE  1.E4  1.E4                   energy range of primary particle
THETAP  20.   20.                    range of zenith angle (degree)
PHIP    -180.  180.                  range of azimuth angle (degree)
SEED    1   0   0                    seed for 1. random number sequence
SEED    2   0   0                    seed for 2. random number sequence
OBSLEV  110.E2                       observation level (in cm)
FIXCHI  0.                           starting altitude (g/cm**2)
MAGNET  20.0  42.8                   magnetic field centr. Europe
HADFLG  0  0  0  0  0  2             flags hadr.interact.&fragmentation
ECUTS   0.3  0.3  0.003  0.003       energy cuts for particles
MUADDI  T                            additional info for muons
MUMULT  T                            muon multiple scattering angle
ELMFLG  T   T                        em. interaction flags (NKG,EGS)
STEPFC  1.0                          mult. scattering step length fact.
RADNKG  200.E2                       outer radius for NKG lat.dens.distr.
LONGI   T  10.   T  T                longit.distr. & step size & fit & out
ECTMAP  1.E4                         cut on gamma factor for printout
MAXPRT  1                            max. number of printed events
DIRECT  ./                           output directory
USER    you                          user
DEBUG   F  6  F  1000000             debug flag and log.unit for out
EXIT                                 terminates input
```

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)

```
RUNNR   2                           run number
EVTNR   1                           number of first shower event
NSHOW   1                           number of showers to generate
PRMPAR  14                          particle type of prim. particle
ESLOPE  -2.7                        slope of primary energy spectrum
ERANGE  1.E4  1.E4                  energy range of primary particle
THETAP  20.   20.                   range of zenith angle (degree)
PHIP    -180.  180.                 range of azimuth angle (degree)
SEED    1   0   0                   seed for 1. random number sequence
SEED    2   0   0                   seed for 2. random number sequence
OBSLEV  110.E2                      observation level (in cm)
FIXCHI  0.                          starting altitude (g/cm**2)
MAGNET  20.0  42.8                  magnetic field centr. Europe
HADFLG  0  0  0  0  0  2            flags hadr.interact.&fragmentation
ECUTS   0.3  0.3  0.003  0.003      energy cuts for particles
MUADDI  T                           additional info for muons
MUMULT  T                           muon multiple scattering angle
ELMFLG  T   T                       em. interaction flags (NKG,EGS)
STEPFC  1.0                         mult. scattering step length fact.
RADNKG  200.E2                      outer radius for NKG lat.dens.distr.
LONGI   T  10.  T  T                longit.distr. & step size & fit & out
ECTMAP  1.E4                        cut on gamma factor for printout
MAXPRT  1                           max. number of printed events
DIRECT  ./                          output directory
USER    you                         user
DEBUG   F  6  F  1000000            debug flag and log.unit for out
EXIT                                terminates input
```

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 $\mathbf{F}_{\mathbf{Ethr}}$ $\mathbf{W}_{\mathbf{max}}$ $\mathbf{R}_{\mathbf{max}}$
  - $\mathbf{F}_{\mathbf{Ethr}}$: if $\mathbf{E} < \mathbf{F}_{\mathbf{ethr}} \mathbf{x}\, \mathbf{E}_{\mathbf{prim}}$ thinning is used
  - $\mathbf{W}_{\mathbf{max}}$: maximum weight for thinned particles
  - $\mathbf{R}_{\mathbf{max}}$: maximum radius for inner radius thinning
    - only to save disk space in `DATnnnnnn` file

or

- THINH $\mathbf{T}_{\mathbf{had}}$ $\mathbf{W}_{\mathbf{had}}$
  - define $\mathbf{F}^{\mathbf{h}}_{\mathbf{Ethr}} = \mathbf{F}_{\mathbf{Ethr}} / \mathbf{T}_{\mathbf{had}}$ and $\mathbf{W}^{\mathbf{h}}_{\mathbf{max}} = \mathbf{W}_{\mathbf{max}} / \mathbf{W}_{\mathbf{had}}$ for hadrons
- THINEM $\mathbf{T}_{\mathbf{em}}$ $\mathbf{W}_{\mathbf{em}}$
  - define $\mathbf{F}^{\mathbf{em}}_{\mathbf{Ethr}} = \mathbf{F}_{\mathbf{Ethr}} \mathbf{x}\, \mathbf{T}_{\mathbf{em}}$ and $\mathbf{W}^{\mathbf{em}}_{\mathbf{max}} = \mathbf{W}_{\mathbf{max}} \mathbf{x}\, \mathbf{W}_{\mathbf{em}}$ for e/m particles

Options Parameters

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

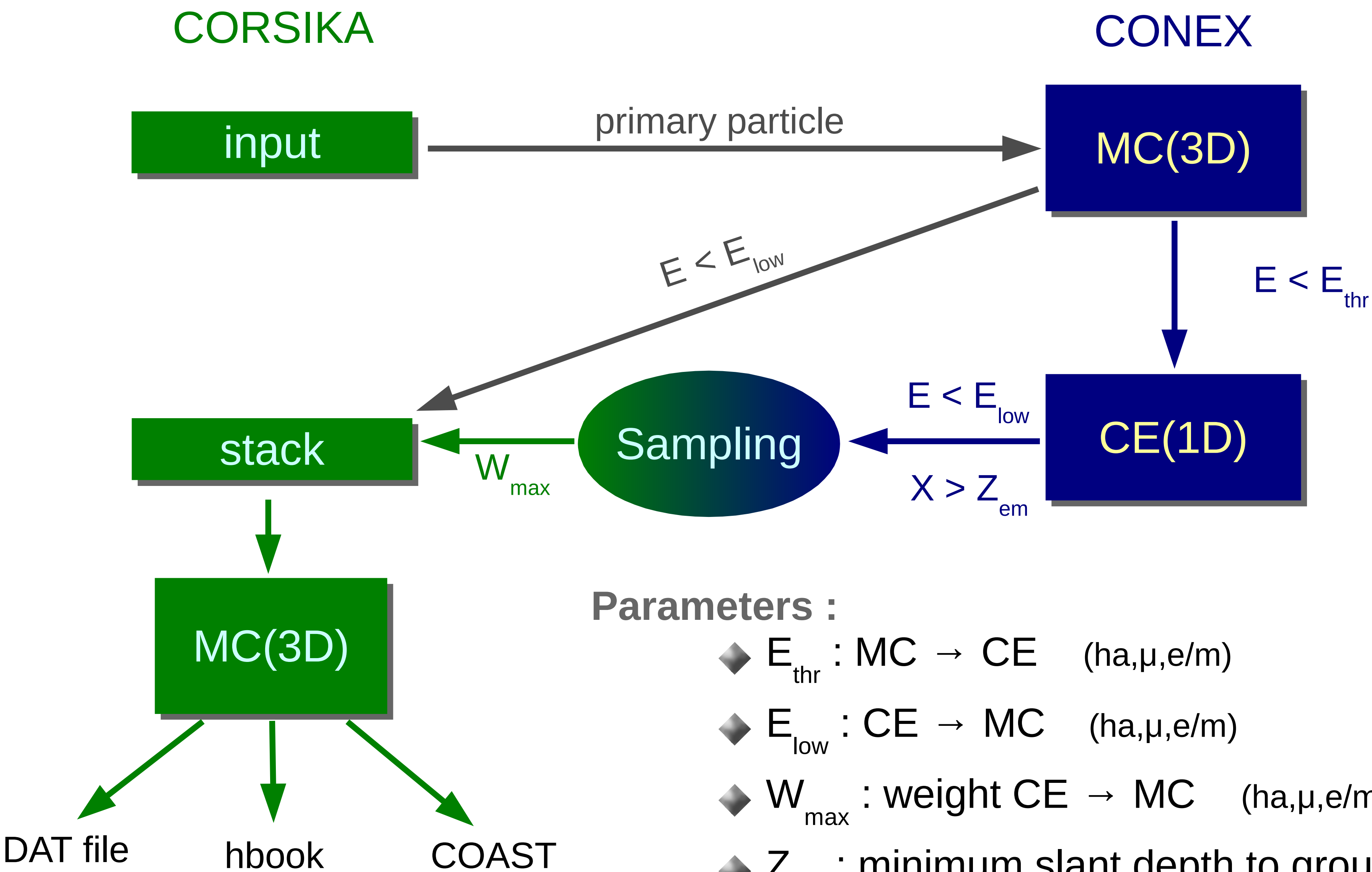
- THIN $\mathbf{F}_{\mathbf{Ethr}}$ $\mathbf{W}_{\mathbf{max}}$ $\mathbf{R}_{\mathbf{max}}$
  - $\mathbf{F}_{\mathbf{Ethr}}$: if $\mathbf{E} < \mathbf{F}_{\mathbf{ethr}} \mathbf{x} \mathbf{E}_{\mathbf{prim}}$ thinning is used
  - $\mathbf{W}_{\mathbf{max}}$: maximum weight for thinned particles
  - $\mathbf{R}_{\mathbf{max}}$: maximum radius for inner radius thinning

“optimal thinning” for $\mathbf{W}^{\mathbf{em}}_{\mathbf{max}} = \mathbf{F}_{\mathbf{Ethr}} \mathbf{x} \mathbf{E}_{\mathbf{prim}}$ and $\mathbf{W}^{\mathbf{h}}_{\mathbf{max}} = 0.01 \mathbf{x} \mathbf{W}^{\mathbf{em}}_{\mathbf{max}}$

with $\mathbf{F}_{\mathbf{Ethr}}$ $\mathbf{\sim 10^{-6}\text{-}10^{-8}}$

- THINEM $\mathbf{T}_{\mathbf{em}}$ $\mathbf{W}_{\mathbf{em}}$
  - define $\mathbf{F}^{\mathbf{em}}_{\mathbf{Ethr}} = \mathbf{F}_{\mathbf{Ethr}} \mathbf{x} \mathbf{T}_{\mathbf{em}}$ and $\mathbf{W}^{\mathbf{em}}_{\mathbf{max}} = \mathbf{W}_{\mathbf{max}} \mathbf{x} \mathbf{W}_{\mathbf{em}}$ for e/m particles

CORSIKA with CONEX



Parameters :

- E_{thr} : MC → CE (ha,μ,e/m)
- E_{low} : CE → MC (ha,μ,e/m)
- W_{max} : weight CE → MC (ha,μ,e/m)
- Z_{em} : minimum slant depth to ground for CE → 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**$_{\mathbf{had}}$(=10^{-3}) **F**$_{\mathbf{mu}}$(=1) **F**$_{\mathbf{em}}$(=10^{-4})” keyword fix high energy threshold (E_{thr}=F*E_0) for CONEX MC (below this limit particles go to CE or CORSIKA)
  - “**CX2COR E**$_{\mathbf{had}}$(=300) **E**$_{\mathbf{mu}}$(=10^{20}) **E**$_{\mathbf{em}}$(=10) **Z**$_{\mathbf{em}}$(=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** $\mathbf{W_{had}}$(=-1) $\mathbf{W_{mu}}$(=-1) $\mathbf{W_{em}}$(=-1.) **S2T**(F) **T2CX**(F)” keyword fix sampling weight (SW=W*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** ⇒ SW=W*E_0 and MWCX=MWCA from THIN

      Not recommended if SW < MWCA (lost of time and precision)
    - **0<W<1, S2T=T, T2CX=F** ⇒ SW=W*E_0 and MWCA=MWCX=SW

      simplified way of defining thinning level (relative value instead of absolute)
    - **0<W<1, S2T=T, T2CX=T** ⇒ SW=W*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

```
RUNNR   2                           run number
EVTNR   1                           number of first shower event
NSHOW   1                           number of showers to generate
PRMPAR  14                          particle type of prim. particle
ESLOPE  -2.7                        slope of primary energy spectrum
ERANGE  1.E4  1.E4                  energy range of primary particle
THETAP  20.   20.                   range of zenith angle (degree)
PHIP    -180.  180.                 range of azimuth angle (degree)
SEED    1   0   0                   seed for 1. random number sequence
SEED    2   0   0                   seed for 2. random number sequence
OBSLEV  110.E2                      observation level (in cm)
FIXCHI  0.                          starting altitude (g/cm**2)
MAGNET  20.0  42.8                  magnetic field centr. Europe
HADFLG  0  0  0  0  0  2            flags hadr.interact.&fragmentation
ECUTS   0.3  0.3  0.003  0.003      energy cuts for particles
MUADDI  T                           additional info for muons
MUMULT  T                           muon multiple scattering angle
ELMFLG  T   T                       em. interaction flags (NKG,EGS)
STEPFC  1.0                         mult. scattering step length fact.
RADNKG  200.E2                      outer radius for NKG lat.dens.distr.
LONGI   T  10.  T  T                longit.distr. & step size & fit & out
ECTMAP  1.E4                        cut on gamma factor for printout
MAXPRT  1                           max. number of printed events
DIRECT  ./                          output directory
USER    you                         user
DEBUG   F  6  F  1000000            debug flag and log.unit for out
EXIT                                terminates input
```

ECTMAP

- printout option (for check)

MAXPRT

- detailed printout on screen

DEBUG

- switch on/off debug output

Output Parameters : files (1)

```
RUNNR   2                               run number
EVTNR   1                               number of first shower event
NSHOW   1                               number of showers to generate
PRMPAR  14                              particle type of prim. particle
ESLOPE  -2.7                            slope of primary energy spectrum
ERANGE  1.E4  1.E4                      energy range of primary particle
THETAP  20.   20.                       range of zenith angle (degree)
PHIP    -180.  180.                     range of azimuth angle (degree)
SEED    1   0   0                       seed for 1. random number sequence
SEED    2   0   0                       seed for 2. random number sequence
OBSLEV  110.E2                          observation level (in cm)
FIXCHI  0.                              starting altitude (g/cm**2)
MAGNET  20.0  42.8                      magnetic field centr. Europe
HADFLG  0  0  0  0  0  2                flags hadr.interact.&fragmentation
ECUTS   0.3  0.3  0.003  0.003          energy cuts for particles
MUADDI  T                               additional info for muons
MUMULT  T                               muon multiple scattering angle
ELMFLG  T   T                           em. interaction flags (NKG,EGS)
STEPFC  1.0                             mult. scattering step length fact.
RADNKG  200.E2                          outer radius for NKG lat.dens.distr.
LONGI   T  10.   T  T                   longit.distr. & step size & fit & out
ECTMAP  1.E4                            cut on gamma factor for printout
MAXPRT  1                               max. number of printed events
DIRECT  ./                              output directory
USER    you                             user
DEBUG   F  6  F  1000000                debug flag and log.unit for out
EXIT                                    terminates input
```

RUNNR

- identification of run number (number in all output file names)

DIRECT

- path for output files
  - `/dev/null` suppress output

USER / HOST

- user and host name for identification in `.log` or `.dbase` files

Output Parameters : files (2)

```
RUNNR   2                          run number
EVTNR   1                          number of first shower event
NSHOW   1                          number of showers to generate
PRMPAR  14                         particle type of prim. particle
ESLOPE  -2.7                       slope of primary energy spectrum
ERANGE  1.E4  1.E4                 energy range of primary particle
THETAP  20.   20.                  range of zenith angle (degree)
PHIP    -180.  180.                range of azimuth angle (degree)
SEED    1   0   0                  seed for 1. random number sequence
SEED    2   0   0                  seed for 2. random number sequence
OBSLEV  110.E2                     observation level (in cm)
FIXCHI  0.                         starting altitude (g/cm**2)
MAGNET  20.0  42.8                 magnetic field centr. Europe
HADFLG  0  0  0  0  0  2           flags hadr.interact.&fragmentation
ECUTS   0.3  0.3  0.003  0.003     energy cuts for particles
MUADDI  T                          additional info for muons
MUMULT  T                          muon multiple scattering angle
ELMFLG  T   T                      em. interaction flags (NKG,EGS)
STEPFC  1.0                        mult. scattering step length fact.
RADNKG  200.E2                     outer radius for NKG lat.dens.distr.
LONGI   T  10.  T  T               longit.distr. & step size & fit & out
ECTMAP  1.E4                       cut on gamma factor for printout
MAXPRT  1                          max. number of printed events
DIRECT  ./                         output directory
USER    you                        user
DEBUG   F  6  F  1000000           debug flag and log.unit for out
EXIT                               terminates input
```

LONGI

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

PAROUT

- switch on/off `DATnnnnnn` file
- switch on/off `.tab` file

DATBAS

- switch on/off `.dbase` or `.info` file

(CERFIL

- switch on/off `CERnnnnnn` 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

Block structure
RUN HEADER nrun
EVENT HEADER 1
DATABLOCK
DATABLOCK
...
...
(LONG 1:1)
...
(LONG 1:n)
EVENT END 1
EVENT HEADER 2
DATABLOCK
DATABLOCK
...
...
(LONG 2:1)
...
(LONG 2:n)
EVENT END 2
...
...
EVENT HEADER nevt
DATABLOCK
DATABLOCK
...
...
(LONG nevt:1)
...
(LONG nevt:n)
EVENT END nevt
RUN END nrun

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)

Particle data sub-block : (up to 39 particles, 7 words each)	
No. of word	Contents of word (as real numbers R*4)
$7\times(n-1)+1$	particle description encoded as: part. id$\times$1000 + hadr. generation[76] $\times$ 10 + no. of obs. level
$7\times(n-1)+2$	px, momentum in x direction in GeV/c
$7\times(n-1)+3$	py, momentum in y direction in GeV/c
$7\times(n-1)+4$	pz, momentum in -z direction in GeV/c
$7\times(n-1)+5$	x position coordinate in cm
$7\times(n-1)+6$	y position coordinate in cm
$7\times(n-1)+7$	t time since first interaction (or since entrance into atmosphere)[77] in nsec [for additional muon information: z coordinate in cm]
	for $n=1\ldots39$ if last block is not completely filled, trailing zeros are added

Table 9: Structure of particle data sub-block.

Cherenkov photon data sub-block : (up to 39 bunches, 7 words each)	
No. of words	Contents of word (as real numbers R*4)
$7\times(n-1)+1$	number of Cherenkov photons in bunch [in case of output on the particle output file: $99.E5+10\times$NINT(number of Cherenkov photons in bunch) + 1]
$7\times(n-1)+2$	x position coordinate in cm
$7\times(n-1)+3$	y position coordinate in cm
$7\times(n-1)+4$	u direction cosine to x axis
$7\times(n-1)+5$	v direction cosine to y axis
$7\times(n-1)+6$	t time since first interaction (or since entrance into atmosphere)[77] in nsec
$7\times(n-1)+7$	height of production of bunch in cm
	for $n=1\ldots39$ if last block is not completely filled, trailing zeros are added

Table 10: Structure of Cherenkov photon data sub-block.

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 `CERnnnnnn` file

Content of Binary Files (2)

'Longitudinal' sub-block: (up to 26 depth steps/block)	
No. of word	Contents of word (as real numbers R*4)
1	'LONG'
2	event number
3	particle id (particle code or $A \times 100 + Z$ for nuclei)
4	total energy in GeV
5	(total number of longitudinal steps)$\times 100 +$ number of longitudinal blocks/shower
6	current number m of longitudinal block
7	altitude of first interaction in g/cm^2
8	zenith angle θ in radian
9	azimuth angle ϕ in radian
10	cutoff for hadron kinetic energy in GeV
11	cutoff for muon kinetic energy in GeV
12	cutoff for electron kinetic energy in GeV
13	cutoff for photon energy in GeV
$10 \times n + 4$	vertical (resp. slant) depth of step j in g/cm^2
$10 \times n + 5$	number of γ-rays at step j
$10 \times n + 6$	number of e$^+$ particles at step j
$10 \times n + 7$	number of e$^-$ particles at step j
$10 \times n + 8$	number of μ^+ particles at step j
$10 \times n + 9$	number of μ^- particles at step j
$10 \times n + 10$	number of hadronic particles at step j
$10 \times n + 11$	number of all charged particles at step j
$10 \times n + 12$	number of nuclei[78] at step j
$10 \times n + 13$	number of Cherenkov photons at step j
	for $n = 1, 26$ and for j longitudinal steps for 1^{st} 'LONG' block: 1 ... j ... 26 for 2^{nd} 'LONG' block: 27 ... j ... 52 ...... for m^{th} 'LONG' block: $(m-1) \cdot 26 + 1$ ... j ... $m \cdot 26$ if last block is not completely filled, trailing zeros are added

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/cm^2 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

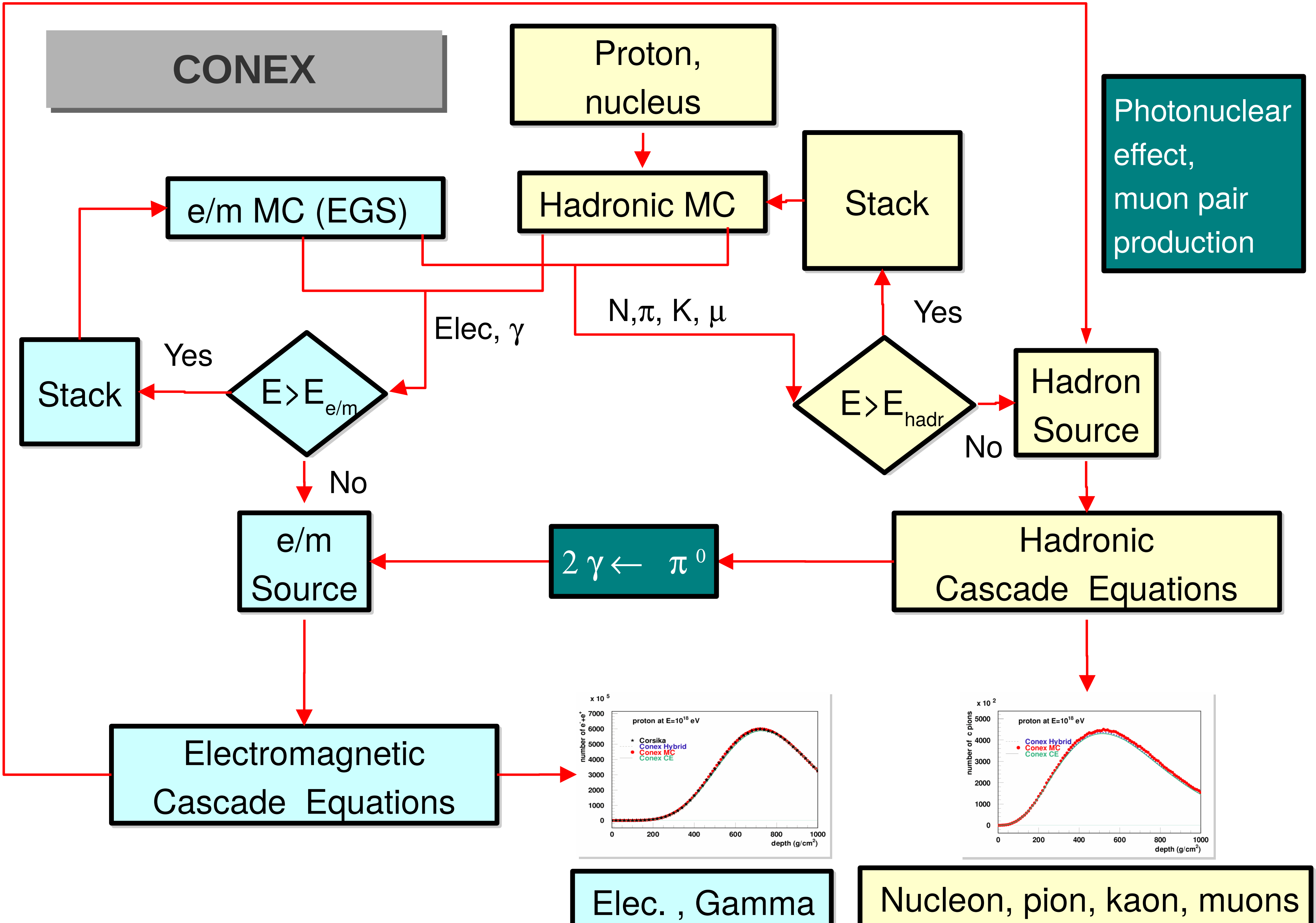
```
   x - exit make

   (only one choice possible):
   SELECTED         : NOM32


--------------------------------------------------------------------------
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) [CACHED]
   5 - QGSJETII-04
   6 - SIBYLL 2.3c
   7 - VENUS 4.12

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

   (only one choice possible):
   SELECTED         : QGSJET01


--------------------------------------------------------------------------
Which low energy hadronic interaction model do you want to use ?
   1 - GHEISHA 2002d (double precision) [CACHED]
   2 - FLUKA
   3 - URQMD 1.3cr

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

   (only one choice possible):
   SELECTED         : GHEISHA


--------------------------------------------------------------------------
Which routine for date and time ?
   1 - automatic detection by configure
     (only use other choices if this one fails) [DEFAULT]
   2 - new date_and_time routine
   3 - old date routine
   4 - timerc routine
   5 - date and time for IBM risc
   6 - old date routine for pgf77

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

   (only one choice possible):
```

Date and time :

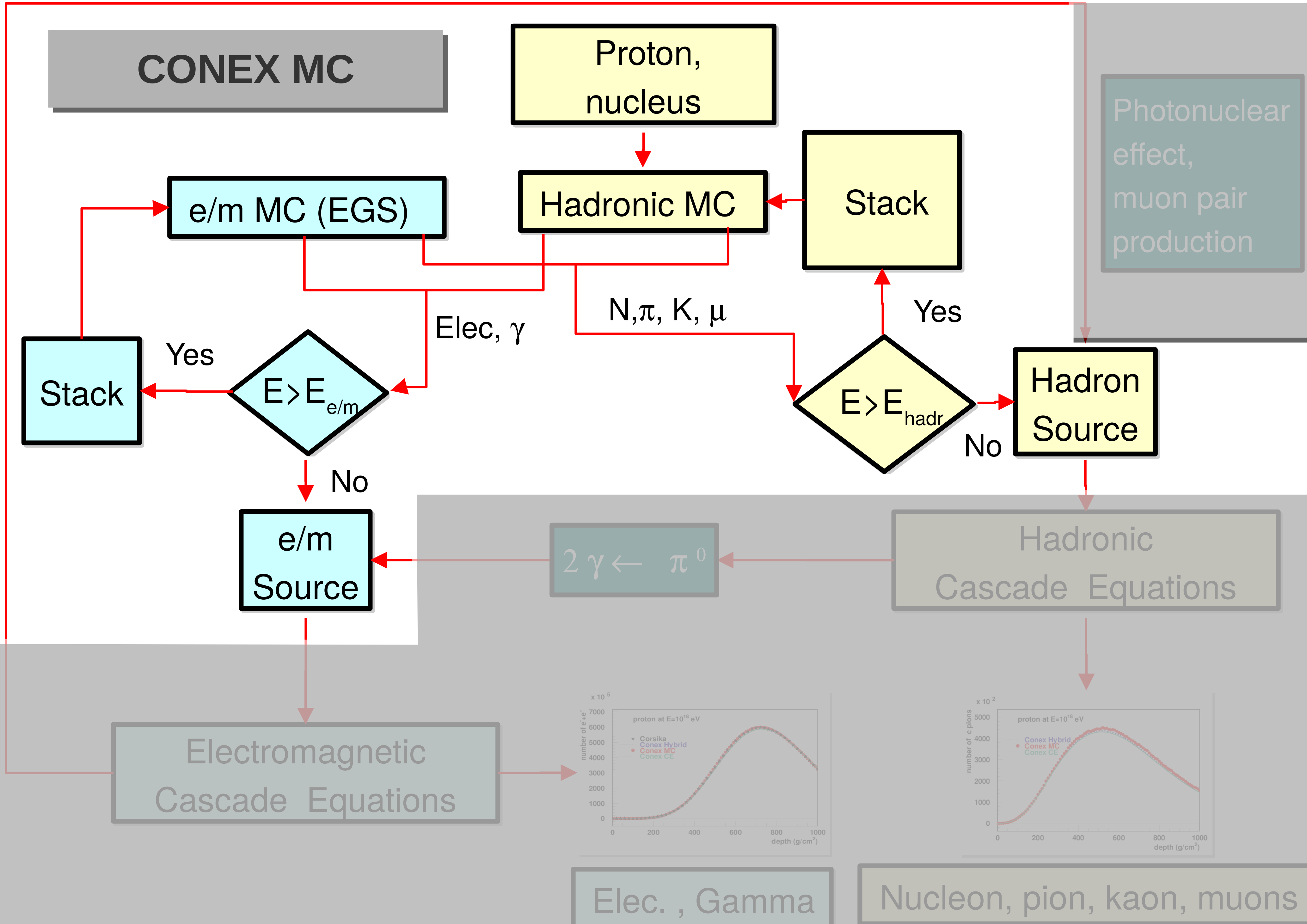
- Available only in expert mode
  - `coconut -e`
- Used only to print date in output file
  - default correct in most of the case
  - try something different only in case of problem before or after compilation when "date" appears.

Hybrid Codes

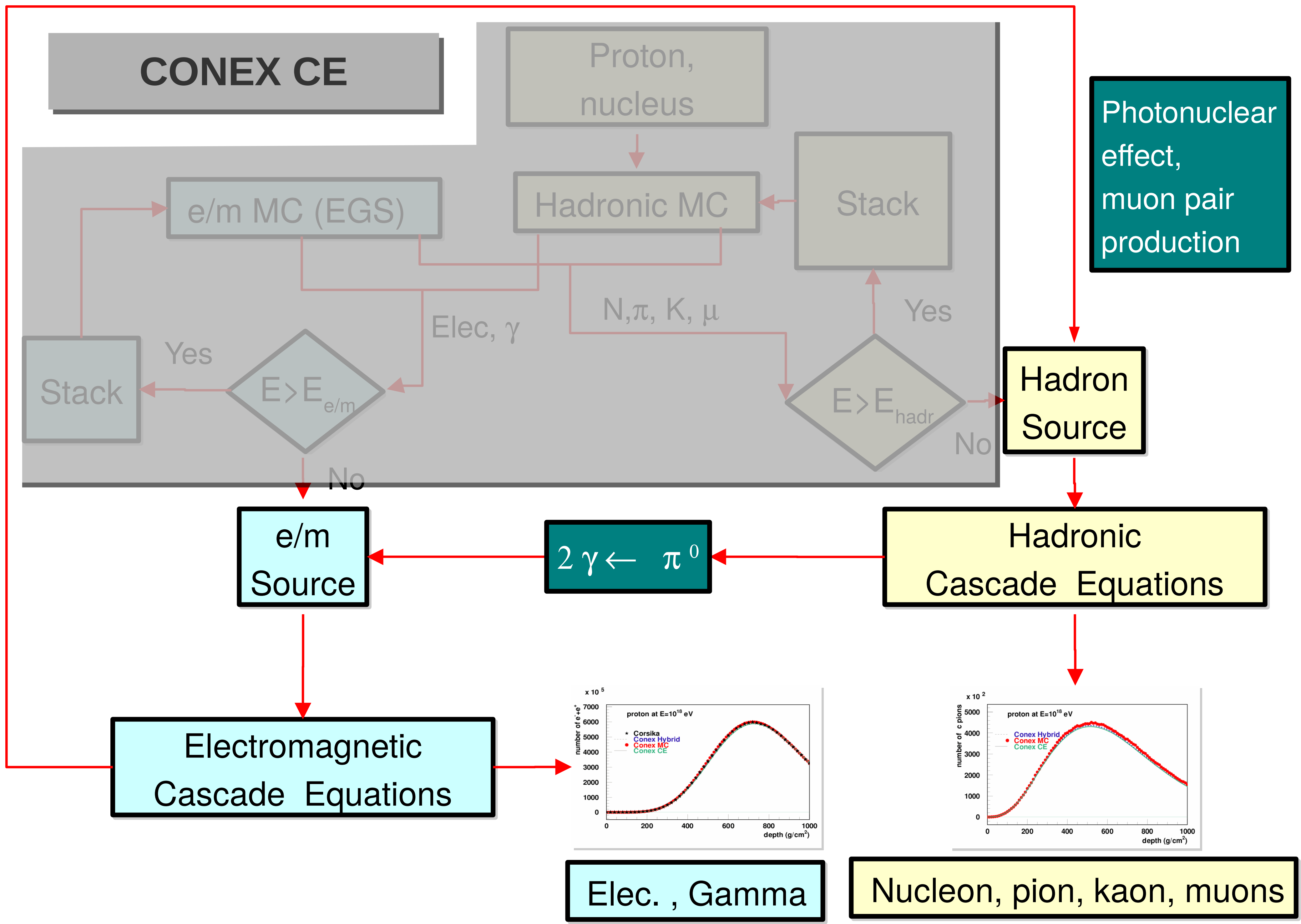
- *L.G. Dedenko et al.*, pioneering work in 1968 (3D, transport equations, Monte Carlo)
- *A.A. Lagutin et al.* (1+1D, transport equations)
- **Bartol code**, *J. Alvarez-Muniz et al.* (1D, pre-simulated shower libraries, muons)
- **SENECA**, *H.J. Drescher & G. Farrar* (3D, 1D transport eqs. for hadrons, 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
Proton, nucleus
Hadronic MC
Stack
Photonuclear effect, muon pair production
e/m MC (EGS)
Elec, γ
N,π, K, μ
Yes
Stack
Yes
E>E e/m
E>E hadr
No
Hadron Source
No
e/m Source
2 γ ← π 0
Hadronic Cascade Equations
Electromagnetic Cascade Equations
proton at E=10^18 eV
Corsika
Conex Hybrid
Conex MC
Conex CE
depth (g/cm²)
Elec. , Gamma
Nucleon, pion, kaon, muons

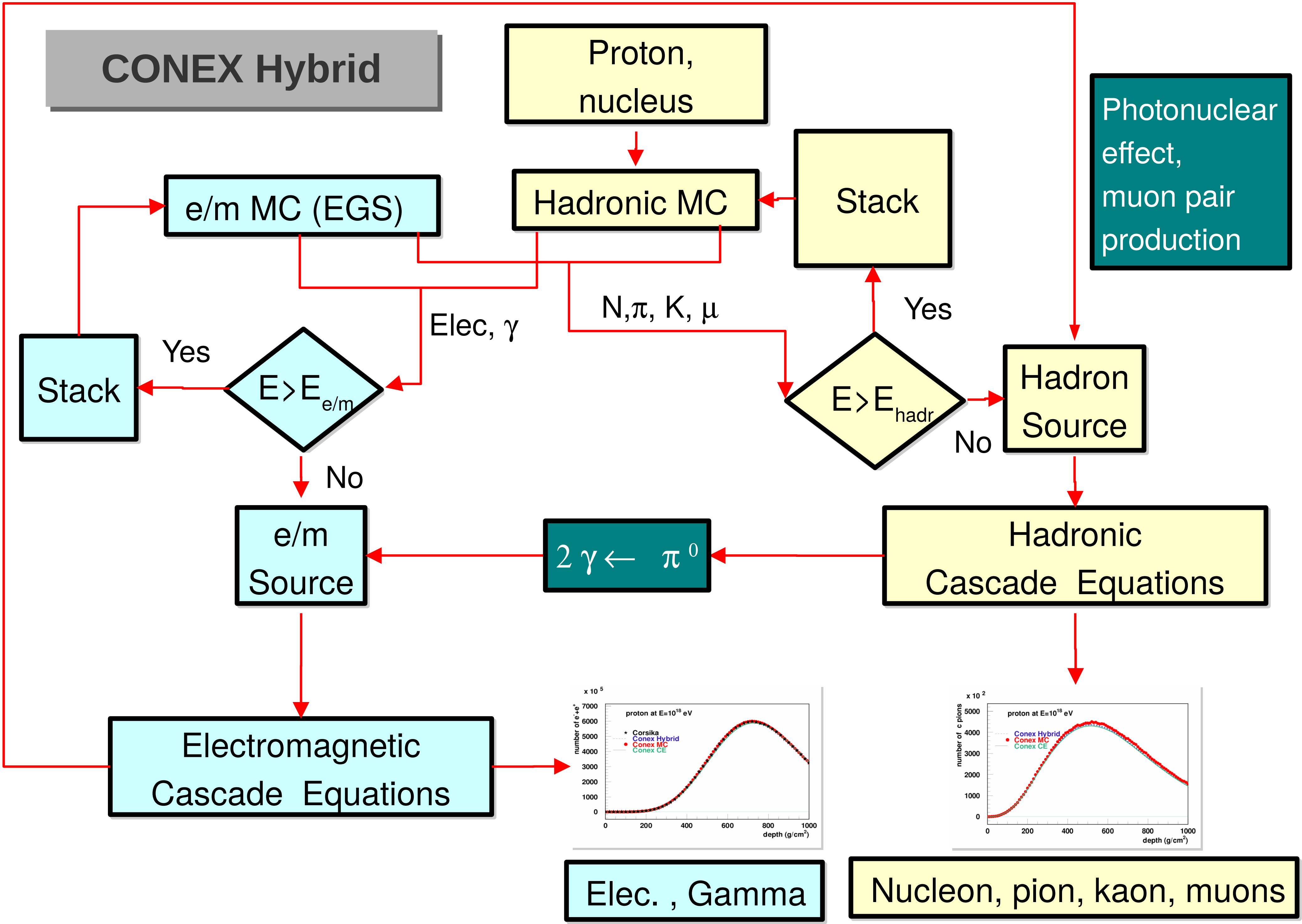
CONEX MC



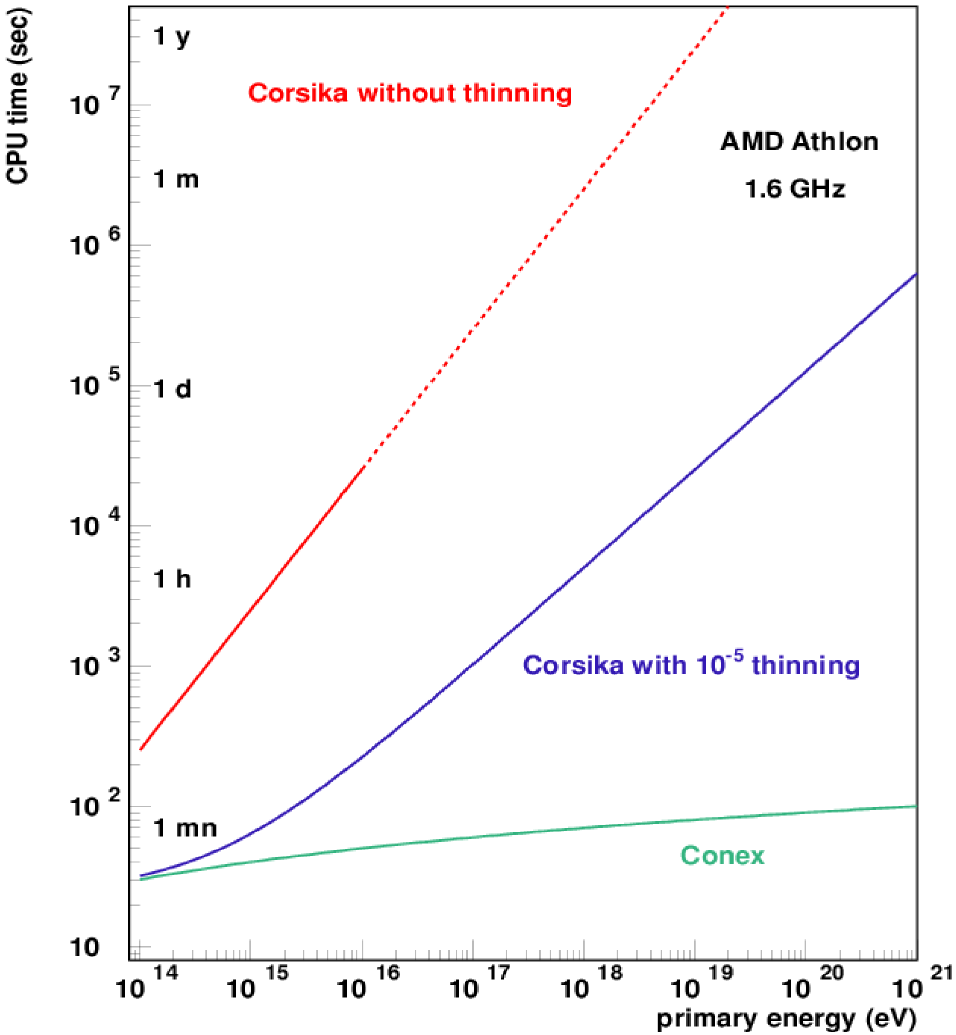
Proton, nucleus
Hadronic MC
Stack
e/m MC (EGS)
N,π, K, μ
Elec, γ
Yes
Stack
Yes
E>E$_{e/m}$
E>E$_{hadr}$
No
Hadron Source
No
e/m Source
Photonuclear effect, muon pair production
$2\gamma \leftarrow \pi^0$
Hadronic Cascade Equations
Electromagnetic Cascade Equations
Elec. , Gamma
Nucleon, pion, kaon, muons


CONEX CE
Proton, nucleus
Hadronic MC
Stack
e/m MC (EGS)
Elec, γ
N,π, K, μ
Yes
Stack
E>E_e/m
E>E_hadr
No
No
Photonuclear effect, muon pair production
Hadron Source
e/m Source
2 γ ← π 0
Hadronic Cascade Equations
Electromagnetic Cascade Equations
proton at E=10^18 eV
Corsika
Conex Hybrid
Conex MC
Conex CE
depth (g/cm^2)
Elec. , Gamma
Nucleon, pion, kaon, muons

CONEX Hybrid



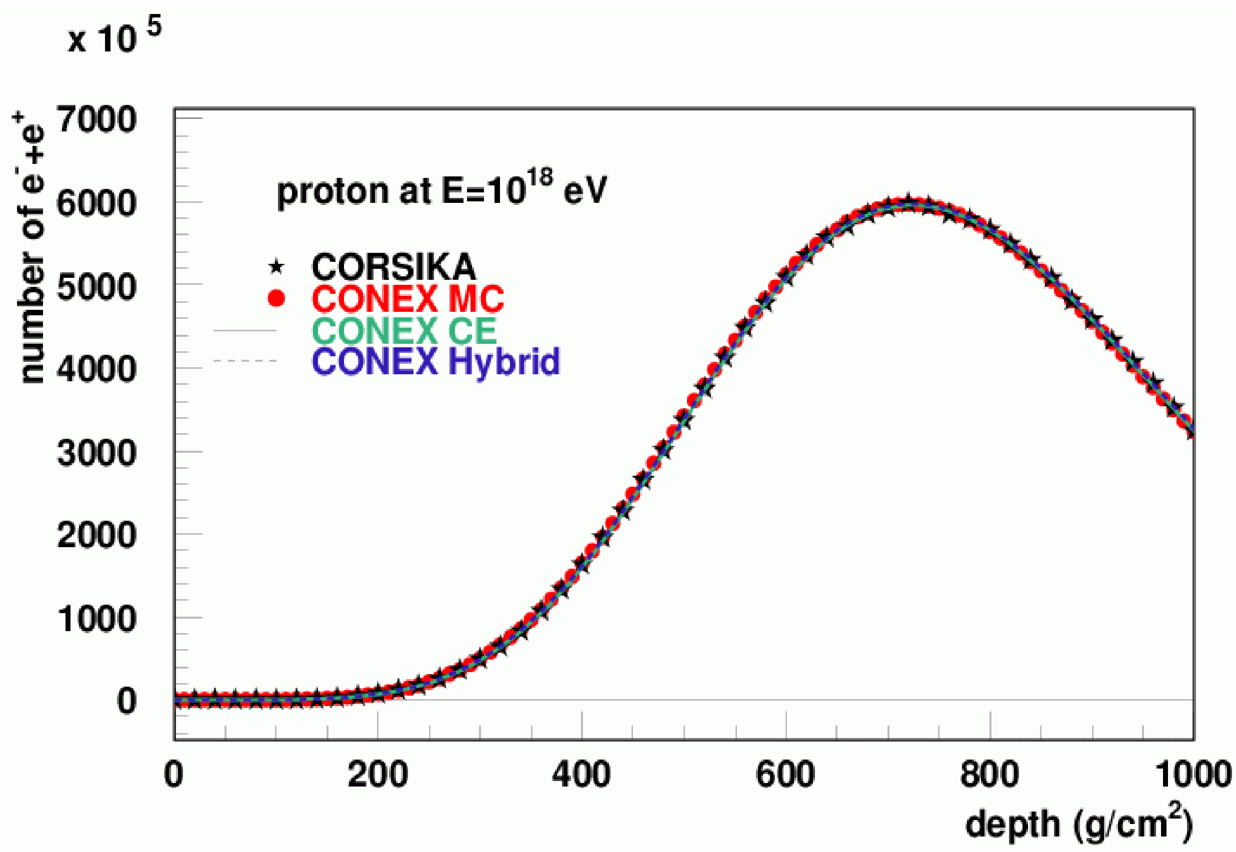
CONEX vs CORSIKA : time

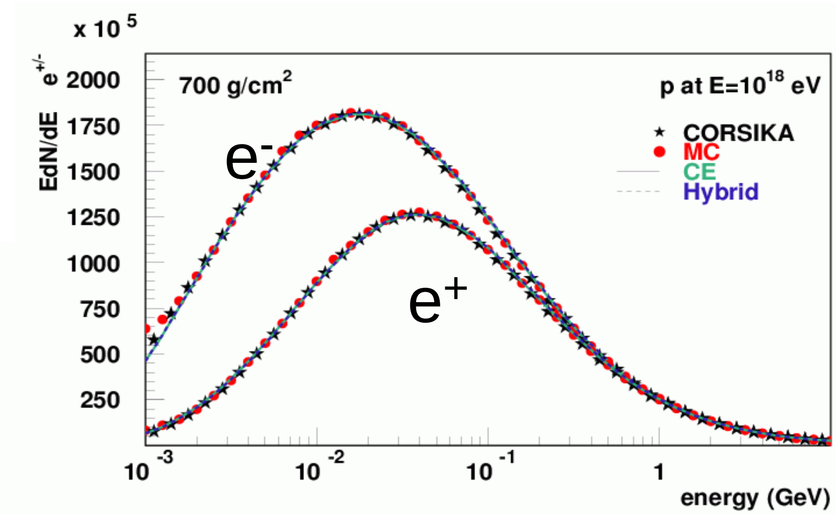


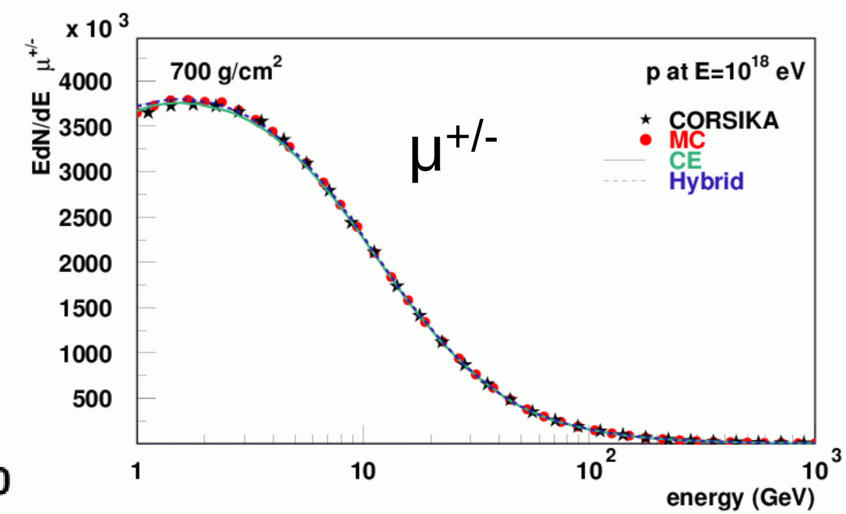
- **Calculation time**
  - ➔ CORSIKA : CPU time ∝ Energy
  - ➔ CONEX : CPU time ∝ Log(Energy)
    - ~1mn / shower
    - and no artificial fluctuations due to thinning
- **Comparisons :**
  - ➔ Longitudinal profile for a vertical shower
  - ➔ Energy distributions for a given depth
  - ➔ Xmax fluctuations for proton and iron

CORSIKA vs CONEX : particles

- **Vertical proton induced shower 10^{18}eV :**
  - Longitudinal distribution
  - Energy distribution

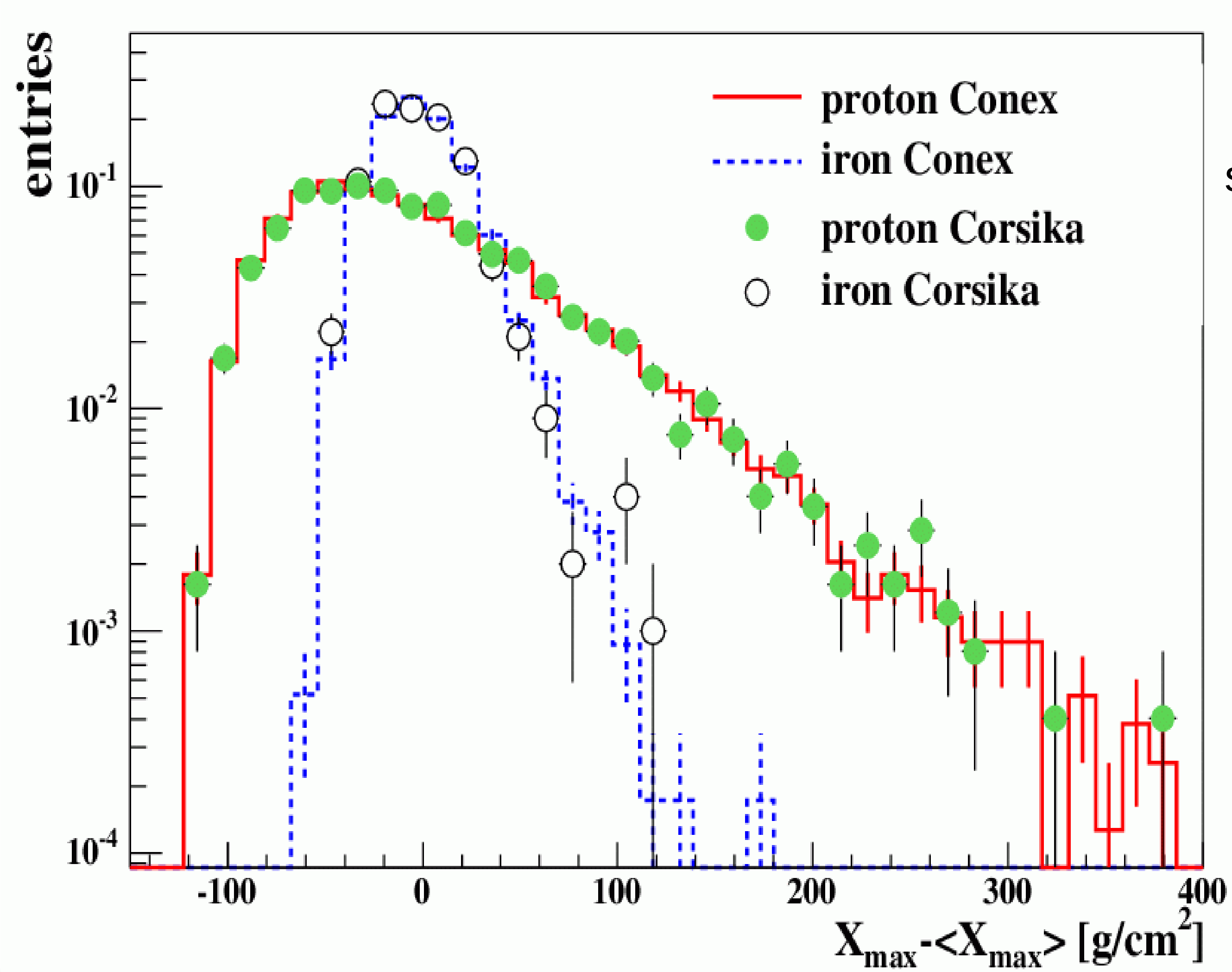






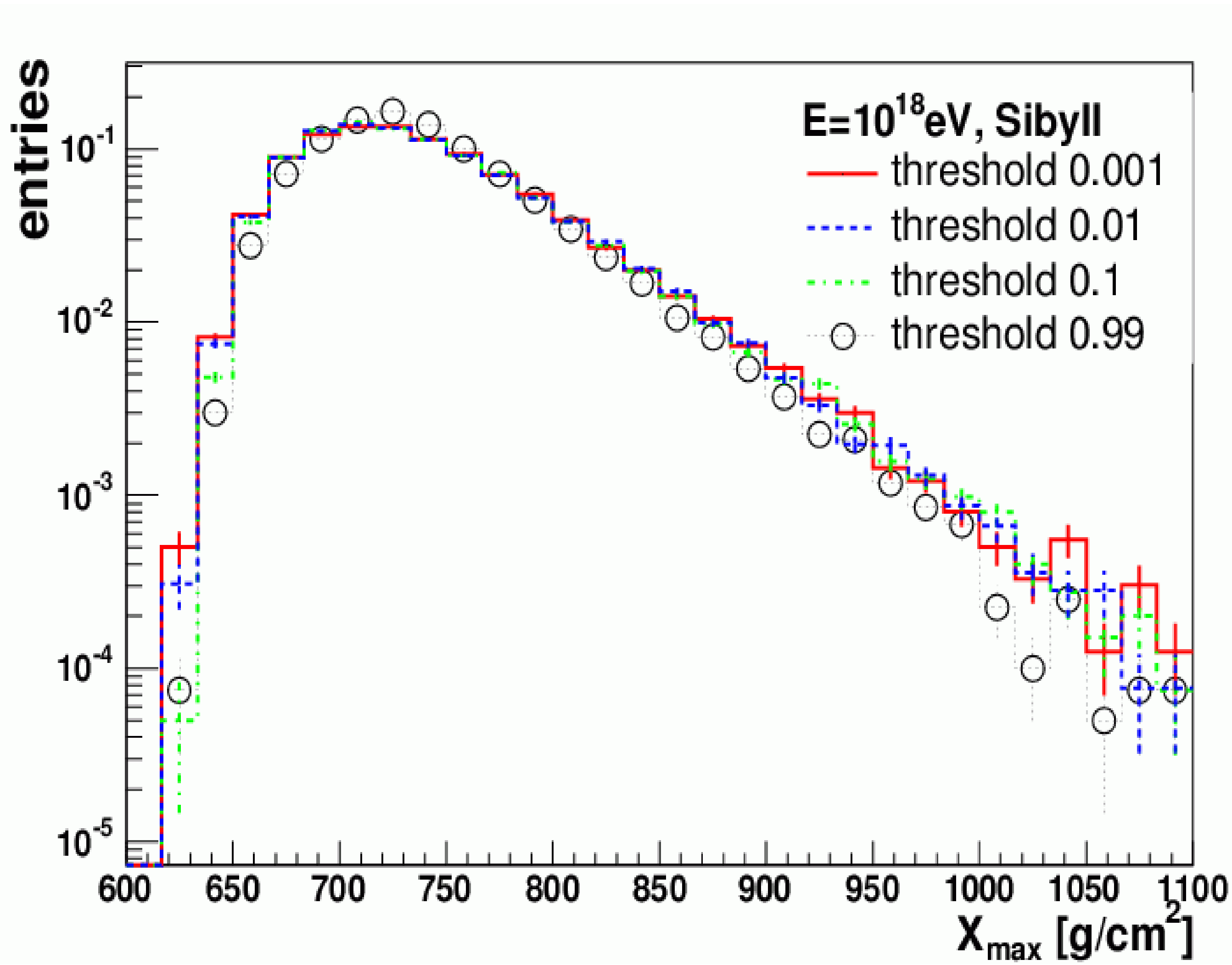
CORSIKA vs CONEX : fluctuations

- X_{max} fluctuations
  - ➜ both mean and RMS reproduced



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

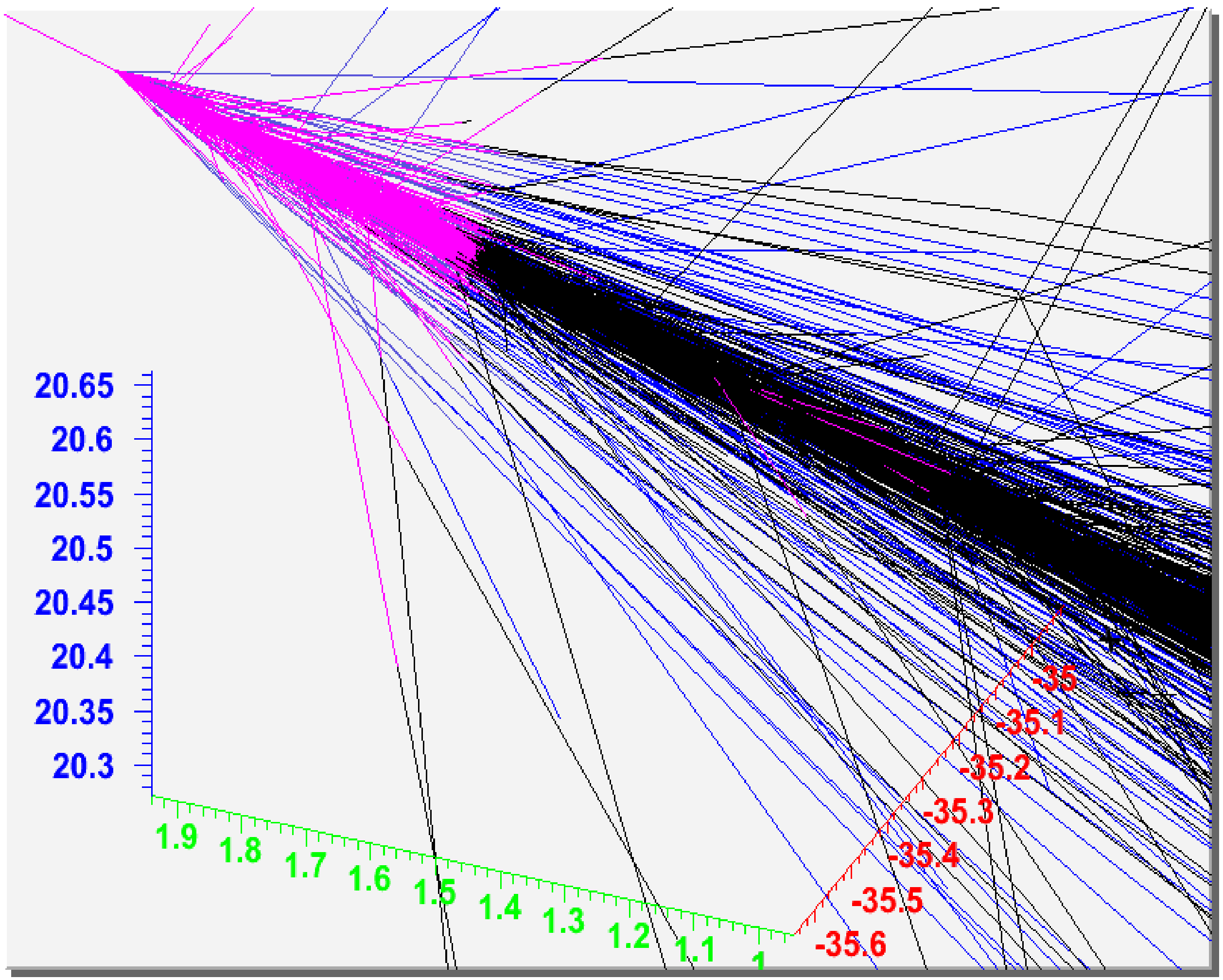
Threshold Effect



- **Xmax fluctuations :**
  - Probability distribution of Xmax, using SIBYLL model at 10^{18} eV (60°)
  - almost all fluctuations from the first interaction

Example :

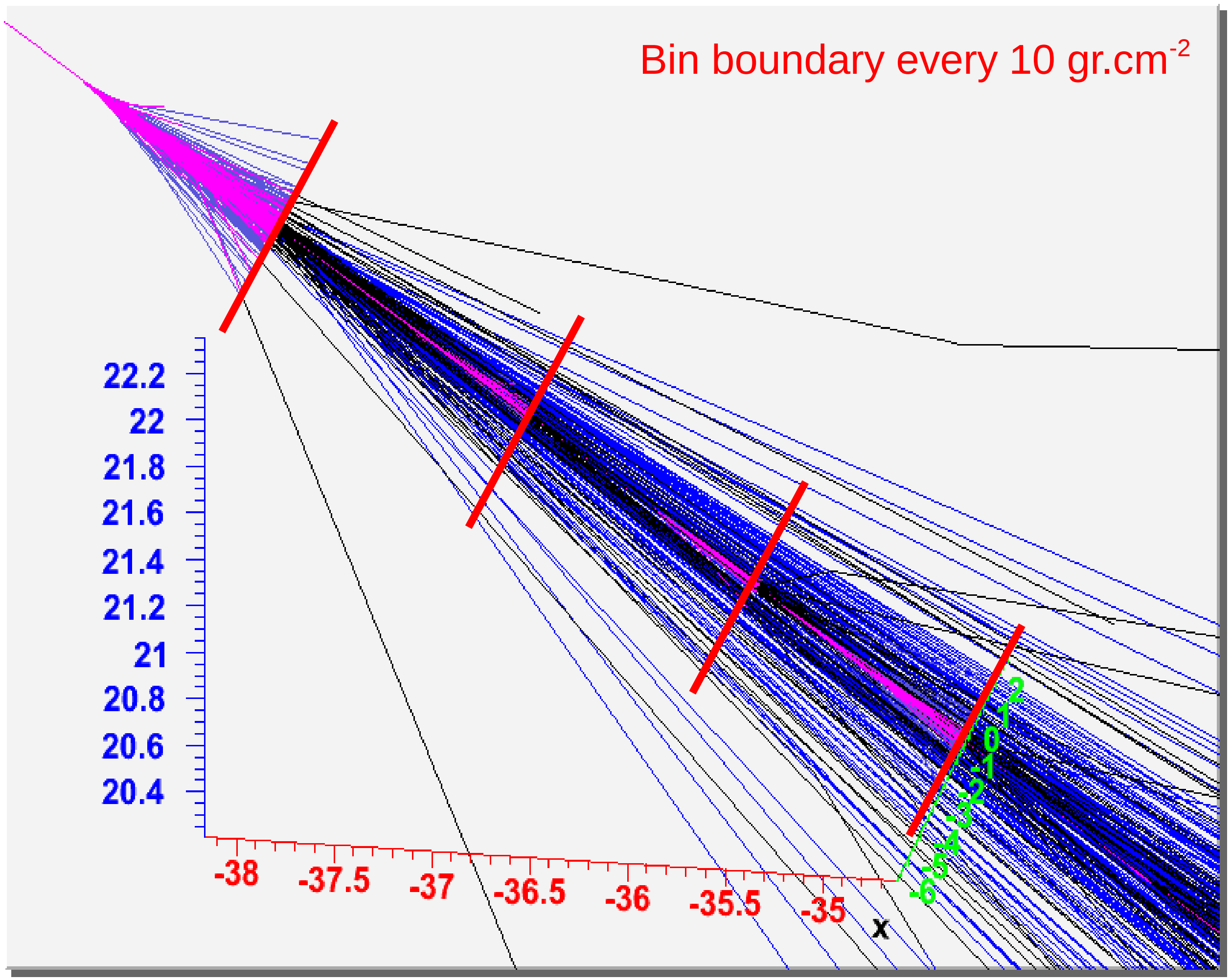
3D View with COAST



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

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

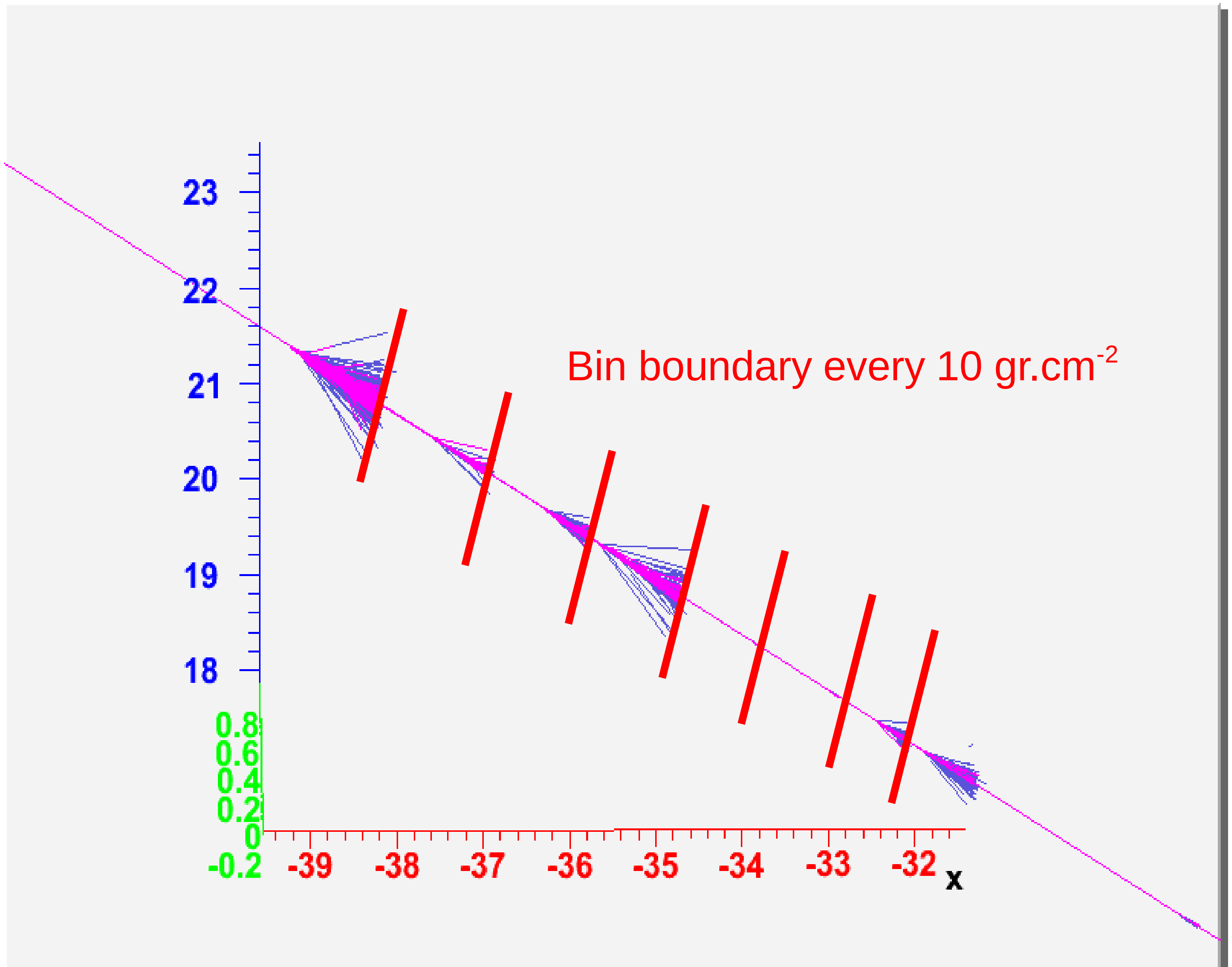
Example :
3D View with COAST



- **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

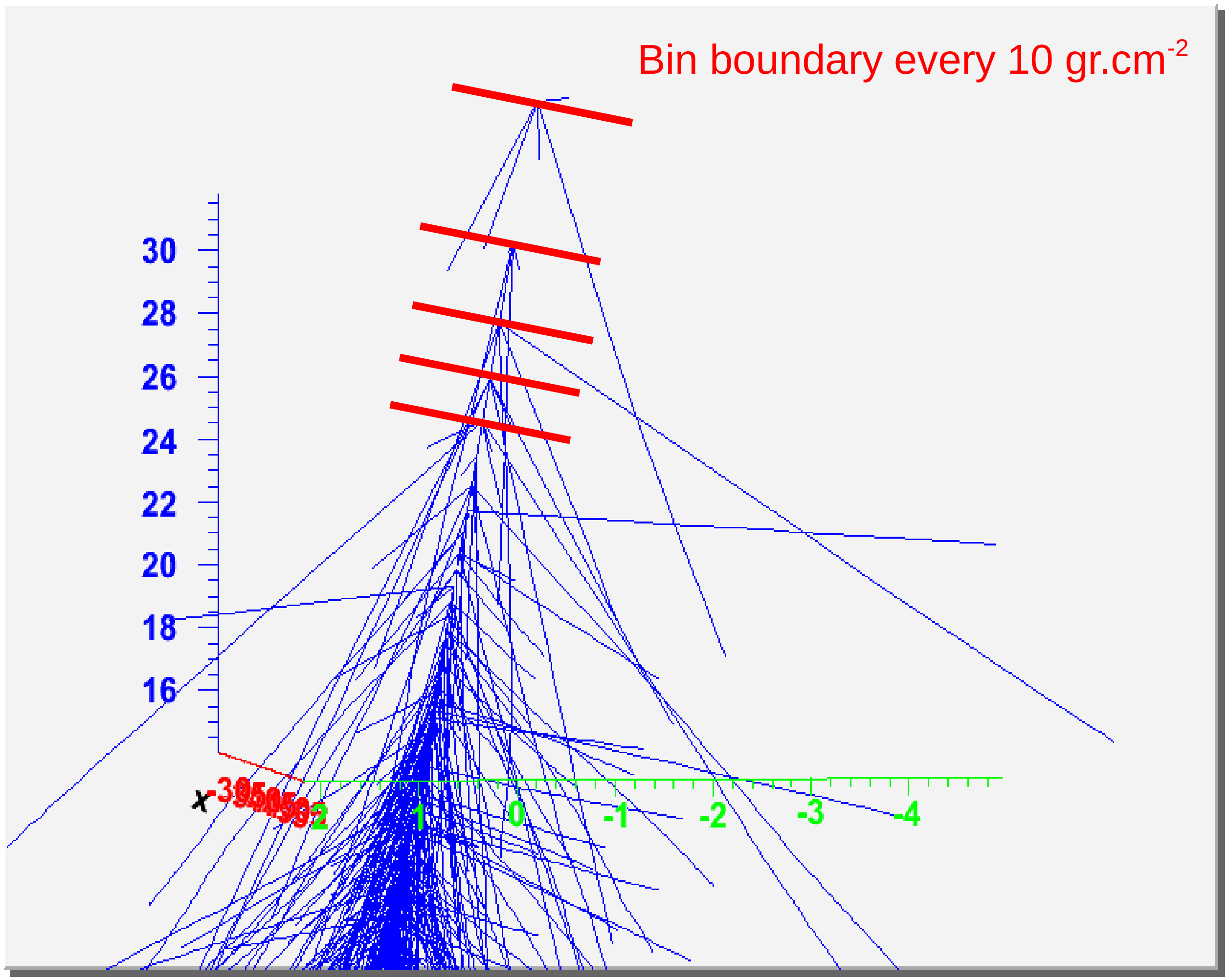
Example :
3D View with COAST



- **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

Example :
3D View with COAST

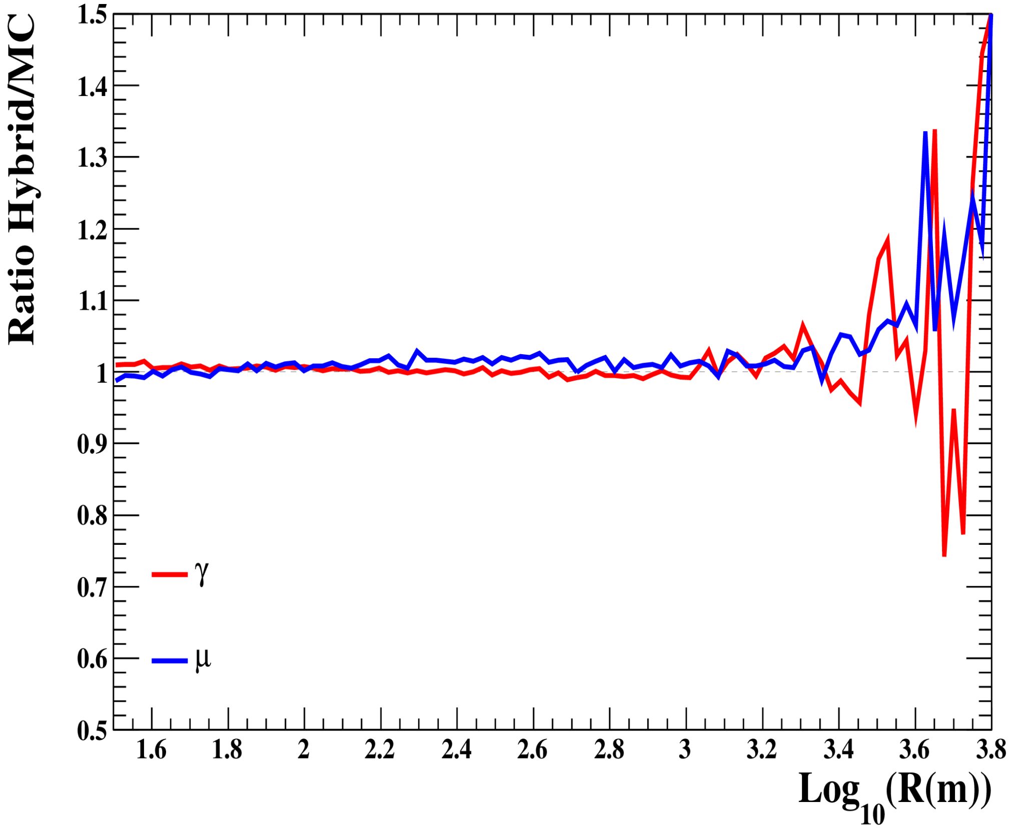


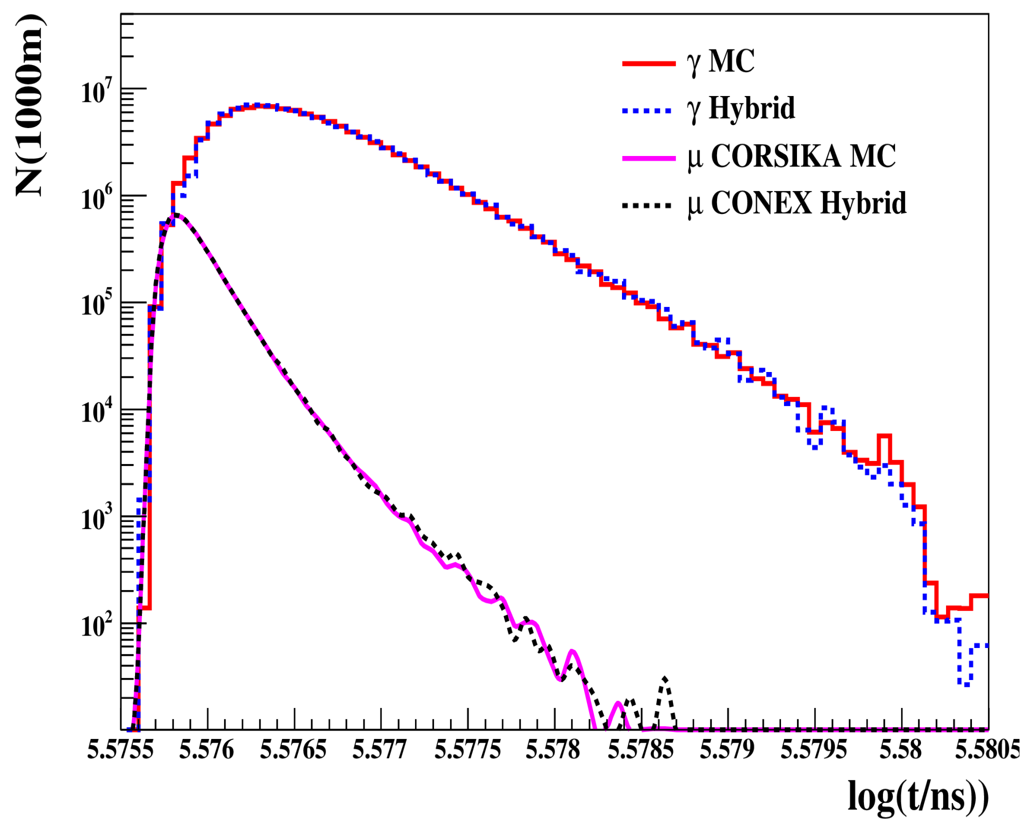
- **3D muons : Cascade equation only for hadrons**
  - Muon tracks start from bin boundaries
  - Muons generated with realistic angular distribution

Blue : CORSIKA muons

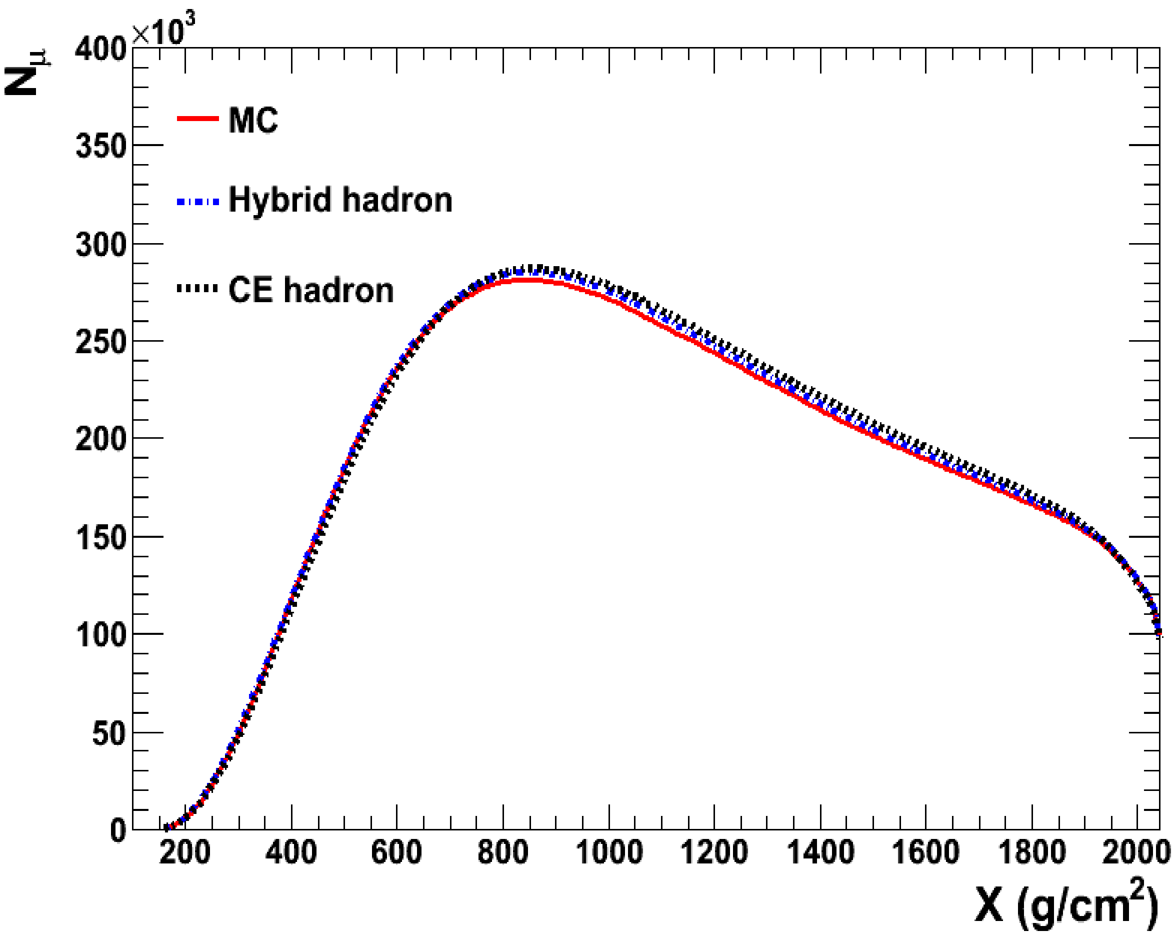
Example

- 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_{max}=670(MC) / 673(Hyb) g/cm^2





Example :
1 shower with different thresholds



Same profile within 3%

Proton @ 0.1 EeV EGS4 off

QGSJET + GHEISHA

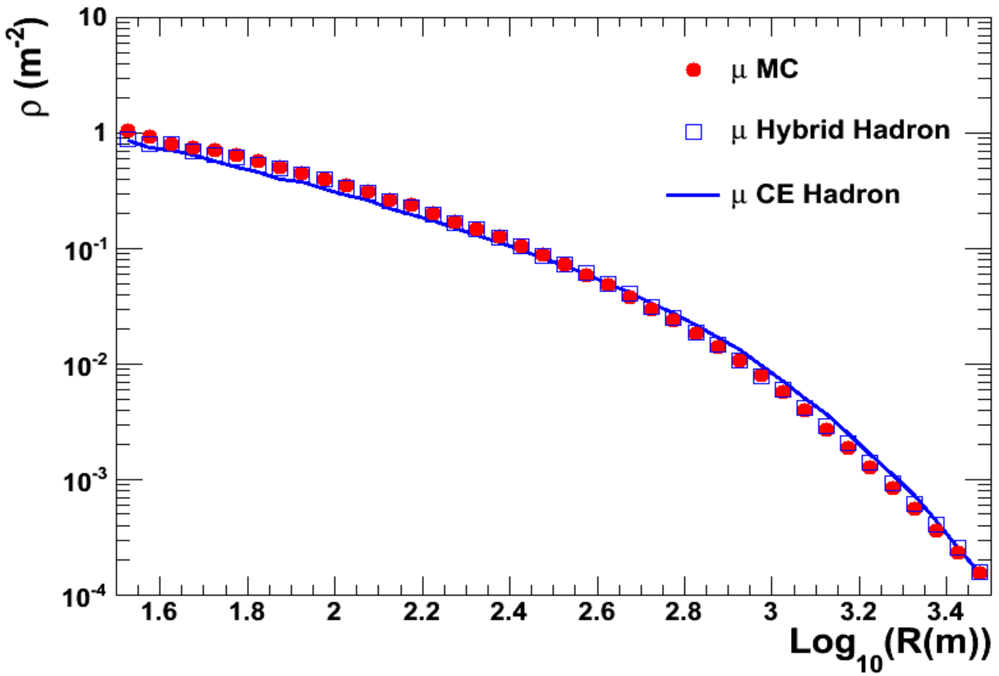
- MC : CONEX MC FOR E > 1 TeV
  CORSIKA FOR E < 1 TeV
- Hybrid hadron : CONEX MC < 1 TeV
  100 GeV < hadronic CE < 1TeV
  CORSIKA < 100 GeV
- CE hadron : CONEX MC < 1 TeV
  CORSIKA only for muons (all E)

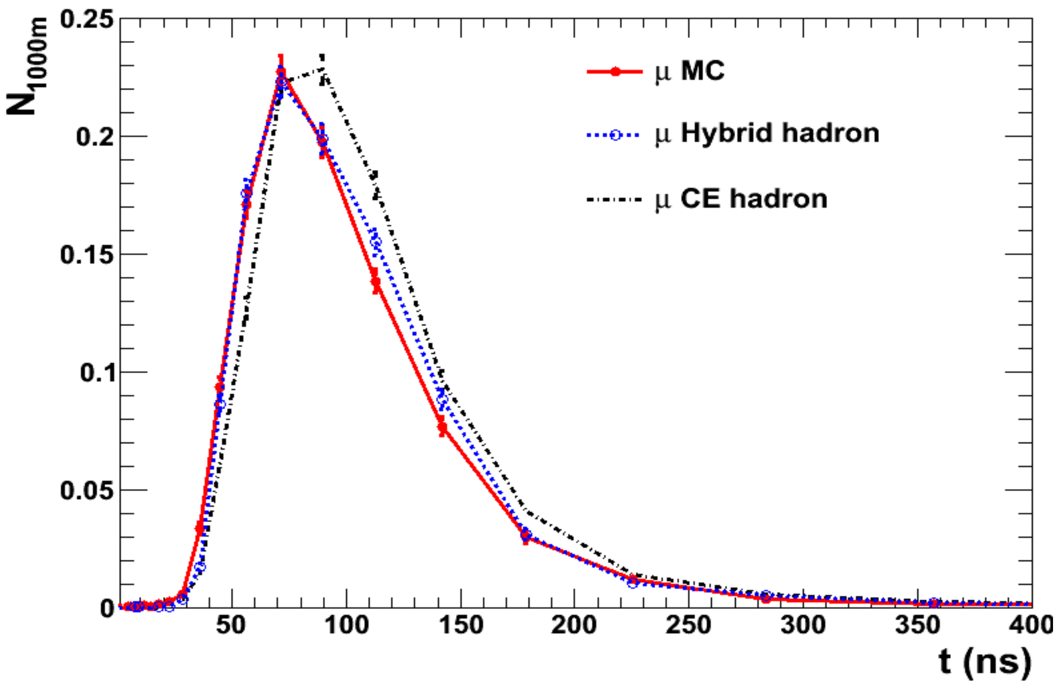
One shower, same random numbers

1 shower with different thresholds

Proton @ 0.1 EeV EGS4 off

QGSJET + GHEISHA





Reasonable results for CE but hadronic MC needed for precise results