Energy range of astroparticle physics: From few GeV up to ~100 EeV.

Identify the primary particle by measuring the shower:

- Energy → shower size
- Direction → arrival timing
- Type → shape and particle contents

High energy cosmic rays detection techniques: Indirect measurement (Extensive Air Showers).

Extensive Air Showers (EAS): result of many inter-dependent sub processes.

- CR, gamma and neutrinos likely from same sources.
- Neutral particle point back to sources but huge background.

multi-messengers astrophysics:
**Computer simulation**: reproduction of the behavior of a system using a computer to simulate the outcomes using a model associated to the system.

Complex problems (EAS simulations) broken down in smaller sub-problems.

**Mathematical model**: description of a system using mathematical concept and language.

Monte Carlo Techniques: algorithms that rely on repeated random sampling to obtain numerical results. Their essential idea is using randomness to solve problems.

used when is impractical to do a full simulation. Models are based on simplifications, assumptions and approximations.

More simplifications lead to smaller “confidence level” (more verification needed).
Cosmic Ray Simulation for KASCADE

Models:

- e.m.: EGS4
- low-E hadronic: FLUKA, UrQMD, GHEISHA
- high-E hadronic: QGSJET, EPOS-LHC, DPMJET, SIBILL

consistent results in different experiments.

Models tuned at collider energies then extrapolated in the energy range considered.

Fair agreement from $10^{12}$ to $10^{20}$ eV.

much better agreement at low energies where data constrains extrapolations. At highest energies considerable extrapolation needed (high uncertainties).
composition seems to turn heavier.

Data do not fit to primary simulations.

\[ \langle \ln A \rangle \text{ transition from medium} \rightarrow \text{light} \rightarrow \text{heavy} \]

\[ \sigma^2 \langle \ln A \rangle \text{ transition from mixed} \rightarrow \text{pure} \]
CORSIKA LIMITATIONS II

Longitudinal profile match well

Lower number of muons produced

Less signals at the ground in simulations
CORSIKA is a prime tool of astroparticle physics.

references:
CORSIKA physics manual
user guide

CORSIKA is needed for the future experiments. An upgrade is underway:

Next generation CORSIKA
**Download**:  
1. ftp corsika76900.tar.gz from [here](#);  
2. use login and password from CORSIKA mailing list;  

**Unpack**:  
1. tar zxf corsika76900.tar.gz  
2. change directory into corsika/corsika-76900  

**Compile**:  

Linux:  

```
./coconut
```

Different compiler:  
standard $F77, $FFLAGS, $CC, ...

* not needed for the school. A tarball is on your virtual machine.
Choose compilation mode of the machine:

[2] if you don’t care about compatibility

Must be the same used for FLUKA or ROOT if used
**INSTALLATION | MODEL SELECTION**

**HIGH-E Hadronic**

**Up to date:**
EPOS-LHC, QGSJetII-04, Sybill2.3c (DPMJETIII to come)

**Reference:**
QGSJet01

Others for special use.

**LOW-E Hadronic**

GHEISHA: too old (only for test)

**FLUKA** (recommended): can be installed defining `$FLUPRO` to point to the fluka installation path. Subscription to FLUKA needed.
Detector geometry only change the angular distribution of showers.

**Flat experiment**

$$I \propto \cos(\theta) \sin(\theta)$$

**Non-flat experiment**

$$I \propto \sin(\theta)$$

**Vertical string detector**

$$I \propto (d/2)^2 \pi \sin \theta \cdot (\cos \theta + 4/\pi l/d \sin \theta)$$
no additional option will be used for the exercises.

2 useful options will be described.

Ask to the tutors, check ISAPP 2018 LHC school, or check the manual to know more.

2a) THINNING: save time computation by reducing the number of particles; a particle randomly selected carry a weight related to all particles produced at the same time to conserve energy.

a) CONEX: use cascade equations to reduce simulation time.
source not saved by default.
using “k” source can be saved to check what is used in the code.

incompatible option or missing declaration reported here
if no compilation error this output should appear:

```bash
--> "corsika76400Linux_EPOS_gheisha" successfully installed in :
    /storage/gpfs_data/auger/psavina/Software/hands_onISAPP/corsika-76400/run/

--> You can run CORSIKA in /storage/gpfs_data/auger/psavina/Software/hands_onISAPP/corsika-76400/run/ using for instance :
    ./corsika76400Linux_EPOS_gheisha < all-inputs-eos > output.txt
```

CORSIKA installed in the run subdirectory.
EXERCISE

WHAT WE WILL DO

- Install CORSIKA from tar file.
- Produce different binaries.
- Edit a steering card.
- Run a simulation.
- Analyze the output.
EXERCISE

INSTALL

· Start the Virtual Machine
· Run <setup corsika>
· Go to the work directory
· type tar -zxvf corsika-76900.tar.gz
· Go to “corsika-76900”
· Type ./coconut
· Choose the following options:
  QGSJetII-04 (High energy model)
  UrQMD* (Low energy model)
  Flat detector
EXERCISE

RUN

to run (general case):
`./corsika_executable < datacard`

our case
`./corsika76900Linux_QSJII_urqmd < all-inputs`

two files generated:

```
DAT000002 ➔ binary containing particles at obs. lev.
DAT000002.long ➔ longitudinal distribution
```
<table>
<thead>
<tr>
<th>Variable</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RUNNR</td>
<td>2</td>
<td>run number</td>
</tr>
<tr>
<td>EVTNR</td>
<td>1</td>
<td>number of first shower event</td>
</tr>
<tr>
<td>NSHOW</td>
<td>1</td>
<td>number of showers to generate</td>
</tr>
<tr>
<td>PRMPAR</td>
<td>14</td>
<td>particle type of prim. particle</td>
</tr>
<tr>
<td>ESLOPE</td>
<td>-2.7</td>
<td>slope of primary energy spectrum</td>
</tr>
<tr>
<td>ERANGE</td>
<td>1.E4 1.E4</td>
<td>energy range of primary particle</td>
</tr>
<tr>
<td>THETAP</td>
<td>20. 20.</td>
<td>range of zenith angle (degree)</td>
</tr>
<tr>
<td>PHIP</td>
<td>-180. 180.</td>
<td>range of azimuth angle (degree)</td>
</tr>
<tr>
<td>SEED</td>
<td>1 0 0</td>
<td>seed for 1. random number sequence</td>
</tr>
<tr>
<td>SEED</td>
<td>2 0 0</td>
<td>seed for 2. random number sequence</td>
</tr>
<tr>
<td>OBSLEV</td>
<td>110.E2</td>
<td>observation level (in cm)</td>
</tr>
<tr>
<td>FIXCHI</td>
<td>0.</td>
<td>starting altitude (g/cm**2)</td>
</tr>
<tr>
<td>MAGNET</td>
<td>20.0 42.8</td>
<td>magnetic field centr. Europe</td>
</tr>
<tr>
<td>HADFLG</td>
<td>0 0 0 0 0 2</td>
<td>flags hadr.interact.&amp;fragmentation</td>
</tr>
<tr>
<td>ECUTS</td>
<td>0.3 0.3 0.003 0.003</td>
<td>energy cuts for particles</td>
</tr>
<tr>
<td>MUADDI</td>
<td>T</td>
<td>additional info for muons</td>
</tr>
<tr>
<td>MUMULT</td>
<td>T</td>
<td>muon multiple scattering angle</td>
</tr>
<tr>
<td>ELMFLG</td>
<td>T T</td>
<td>em. interaction flags (NKG,EGS)</td>
</tr>
<tr>
<td>STEPFC</td>
<td>1.0</td>
<td>mult. scattering step length fact.</td>
</tr>
<tr>
<td>RADNKG</td>
<td>200.E2</td>
<td>outer radius for NKG lat.dens.distr.</td>
</tr>
<tr>
<td>LONGI</td>
<td>T 10. T T</td>
<td>longit.distr. &amp; step size &amp; fit &amp; out</td>
</tr>
<tr>
<td>ECTMAP</td>
<td>1.E4</td>
<td>cut on gamma factor for printout</td>
</tr>
<tr>
<td>MAXPRT</td>
<td>1</td>
<td>max. number of printed events</td>
</tr>
<tr>
<td>DIRECT</td>
<td>./</td>
<td>output directory</td>
</tr>
<tr>
<td>USER</td>
<td>you</td>
<td>user</td>
</tr>
<tr>
<td>DEBUG</td>
<td>F 6 F 1000000</td>
<td>debug flag and log.unit for out</td>
</tr>
<tr>
<td>EXIT</td>
<td></td>
<td>terminates input</td>
</tr>
</tbody>
</table>
EDIT THE STEERING CARD

copy the example steering card:
cp all-inputs exercise.inp

edit exercise.inp with the editor you prefer.
change the options:

RUNNR 1
NSHOW 50
ESLOPE -1
ERANGE 1E2 1E4
THETAP 20. 70.
OBSLEV 410000

then run CORSIKA using the new data card:
./corsika76400Linux_QJSII_ urqmd < exercise.inp
EXERCISE | READ OUTPUT I (COAST)

git repository here:
git clone https://gitlab.com/psavina_public_projects/corsika-hands_on /home/isapp/hand-on

2 output files created:
- DAT000001
- DAT000001.long

move the files to the work directory:
/home/isapp/hands-on

different examples to read the output files:
- energySpectra.cc ➤ energy spectrum of the generated showers
- angularDistribution.cc ➤ angular distribution of the generated shower
- groundMomenta.cc ➤ momentum distribution of the ground particles*
- footprint.cc ➤ plot the footprint*
- dummySim.cc ➤ simulation of a over-simplified detector*
- longReader.cc ➤ plot of the longitudinal development of the shower*

Compile
type: make

* only for a chosen shower

compile coast:
go under corsika-76900/coast and then:
make
make install
EXERCISE | READ OUTPUT II (COAST)

energy spectra

```
usage
./energySpectra <corsika file name>
```

angular distribution

```
usage
./angularDistribution <corsika file name>
```
usage
./groundMomenta -n <#shower> <corsika file name>

longitudinal development

ground particle momentum for shower: 1

<table>
<thead>
<tr>
<th>hGround</th>
<th>Entries</th>
<th>Mean</th>
<th>RMS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>26190</td>
<td>0.04276</td>
<td>0.08006</td>
</tr>
</tbody>
</table>

usage
./groundMomenta -n <#shower> <corsika file name>
usage
./footprint -n <#shower> <corsika file name>

usage
./dummySim -n <#shower> <corsika file name>
EXERCISE PHOTON vs PROTON

Generate:
a photon (PRMPAR 1)
a proton (PRMPAR 14)

with:
energy 20 TeV
zenith 20°
add FIXHEI 1500000 0 (to fix the first interaction point)
(change also RUNNR to change the output filename)

compare the two showers.
git repository from Lukas Nellen at:
https://github.com/lukasnellen/corsika_reader

C++ stand-alone and python bindings

already installed on your virtual machine.

export LD_LIBRARY_PATH and PYTHONPATH:

export PYTHONPATH=/home/isapp/corsika/reader-install/lib
export LD_LIBRARY_PATH=/home/isapp/corsika/reader-install/lib

Some example under:

/home/isapp/corsika/reader-install/share/examples
THANKS FOR THE ATTENTION