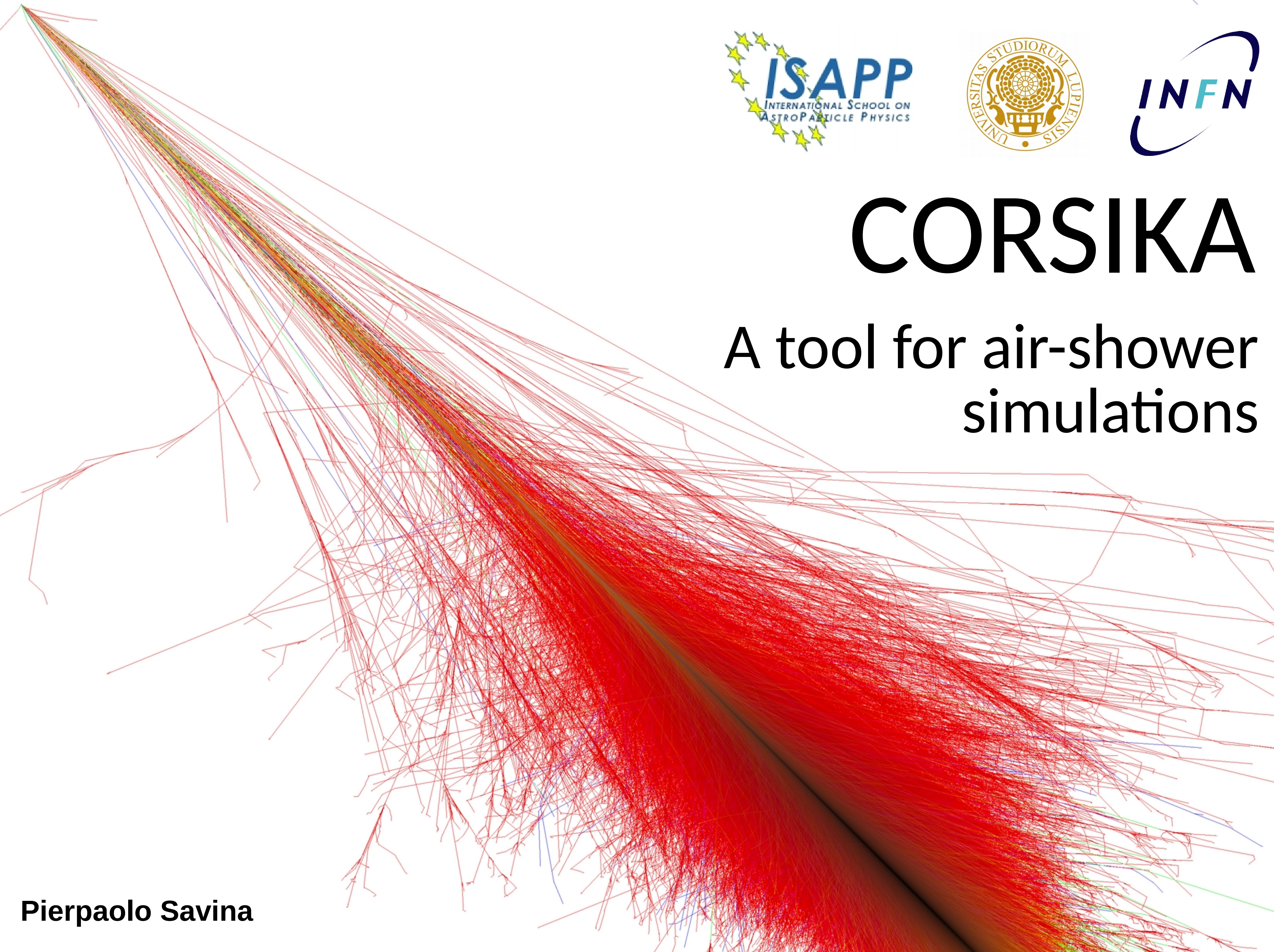


CORSIKA

A tool for air-shower simulations

Pierpaolo Savina

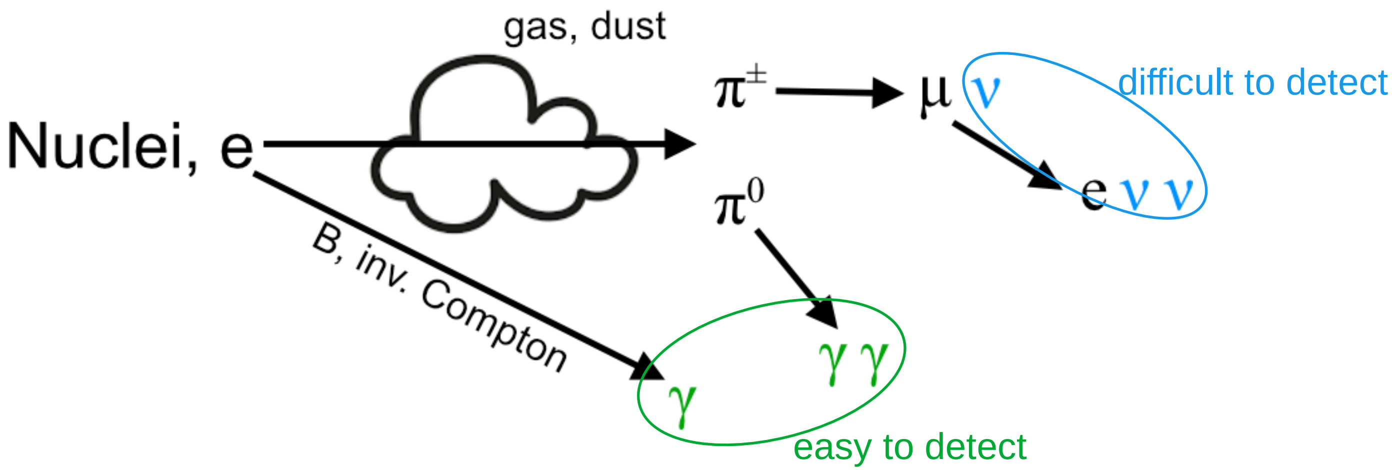
OUTLINE INTRODUCTION

Energy range of astroparticle physics:
From few GeV up to ~100 EeV. → High energy cosmic rays detection techniques:
Indirect measurement (Extensive Air Showers).

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

Identify the primary particle by measuring the shower:

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



multi-messengers astophysics:

CR, gamma and neutrinos likely from same sources.

Neutral particle point back to sources but huge background.

OUTLINE SIMULATIONS

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.

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).

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

OUTLINE | CORSIKA

KASKADE: experiment to measure cosmic rays composition in Karlsruhe

Cosmic **R**ay **Si**mulation for **KA**SCADE

consistent results in different experiments.

Models:

e.m. : **EGS4**

low-E hadronic: **FLUKA**
UrQMD
GHEISHA

high-E hadronic: **QGSJET**
EPOS-LHC
DPMJET
SIBILL

recommended

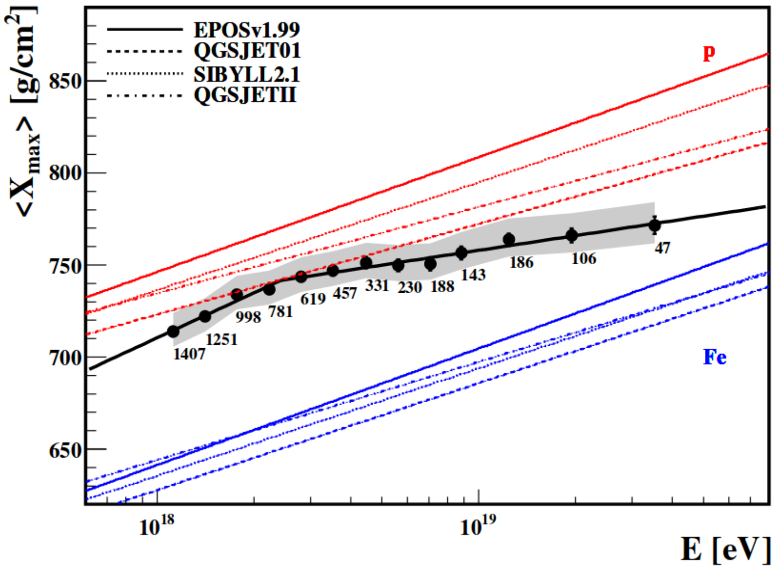
Models tuned at collider energies then extrapolated in the energy range considered

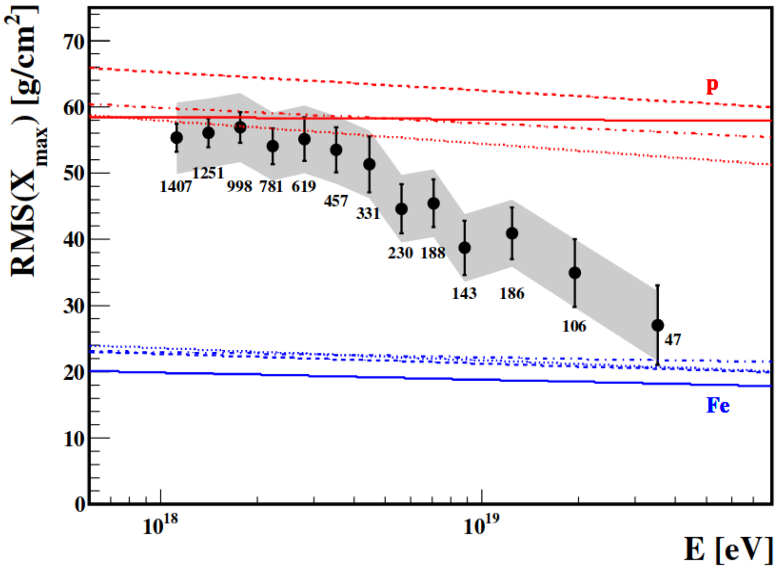
references:
CORSIKA
physics manual
user guide

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).

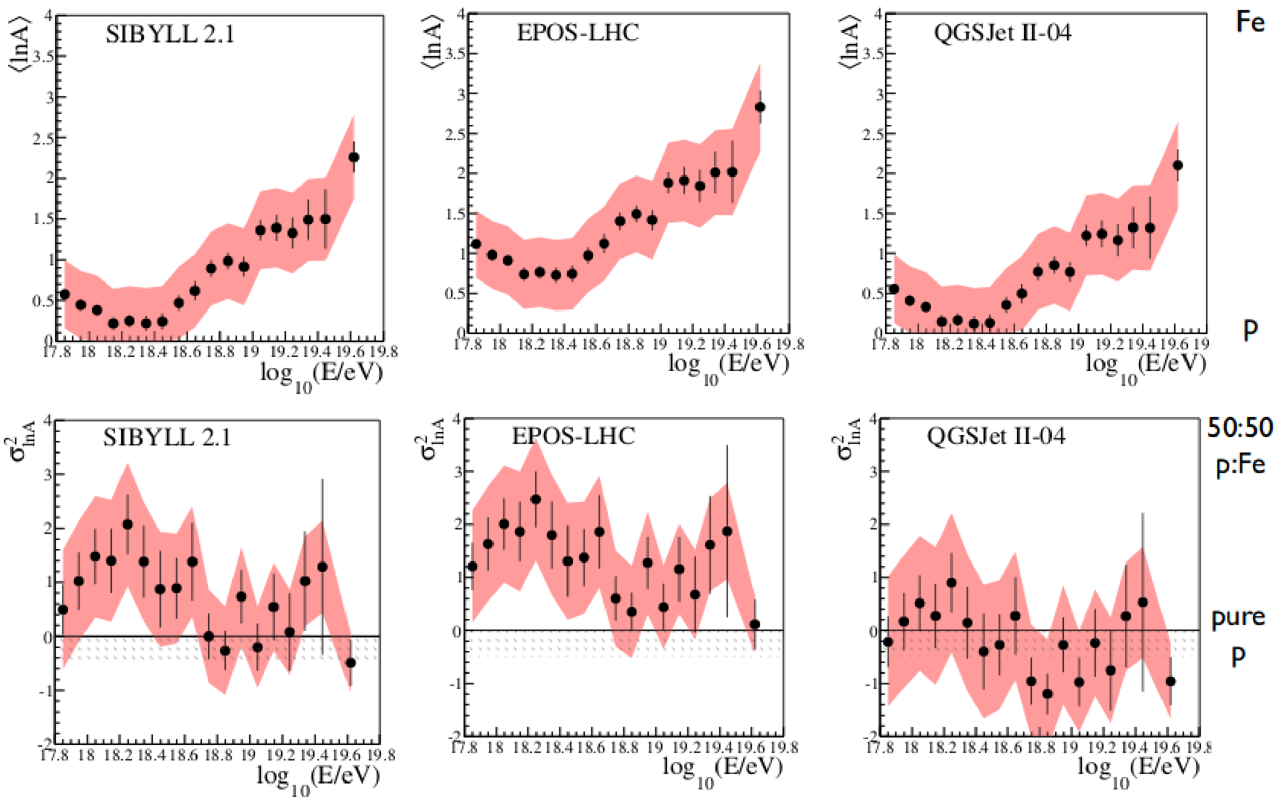
OUTLINE CORSIKA LIMITATIONS I





composition seems to turn heavier.

Data do not fit to primary simulations.

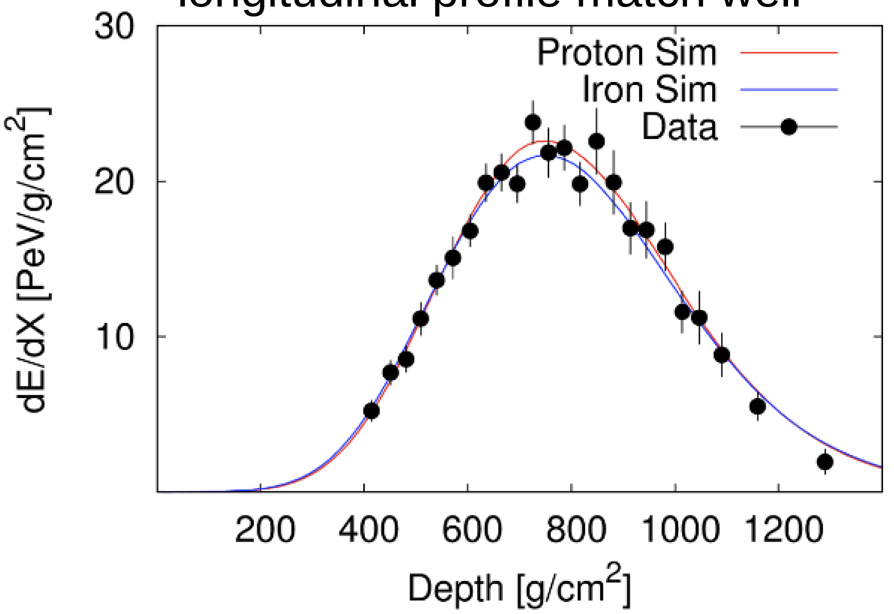


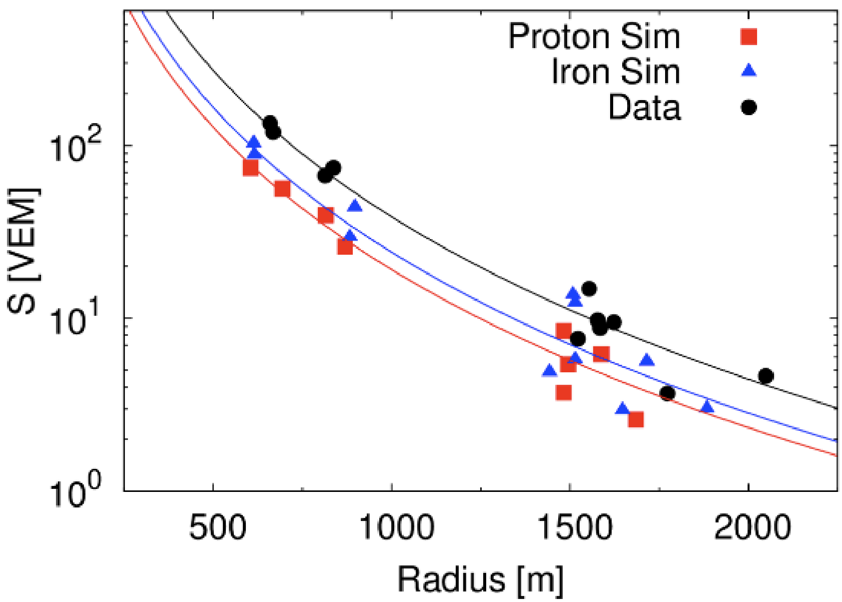
$\langle \ln A \rangle$ transition from medium ——► light ——► heavy

$\sigma^2_{\langle \ln A \rangle}$ transition from mixed ——► pure

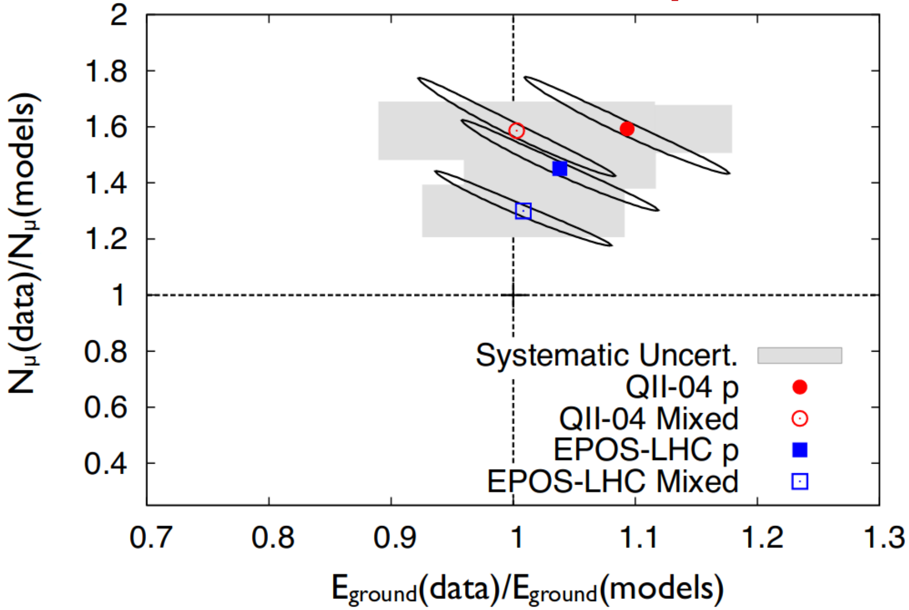
OUTLINE CORSIKA LIMITATIONS II

longitudinal profile match well

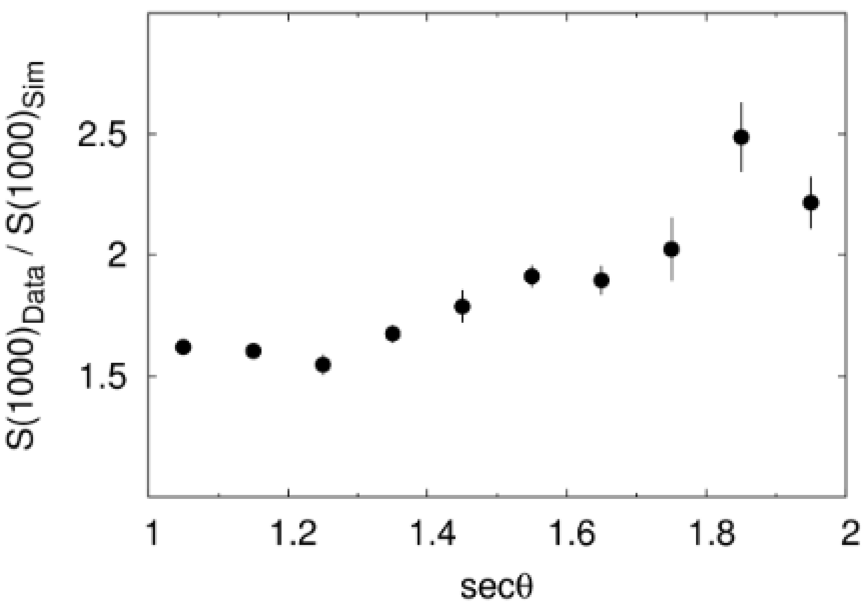




lower number of muons produced



less signals at the ground
in simulations



THE FUTURE

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

INSTALLATION | LET'S START

Download*:
1. ftp corsika76900.tar.gz from here;
2. use login and password from CORSIKA mailing list;

Unpack:
1. tar zxvf 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.

INSTALLATION COMPATIBILITY MODE

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

```
$ ./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]") |
|                                                                          |
|==========================================================================|




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

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

   (only one choice possible):
```

INSTALLATION | MODEL 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):
```

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.

```
--------------------------------------------------------------------------------
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):
```

INSTALLATION | GEOMETRY

Detector geometry only change the angular distribution of showers.

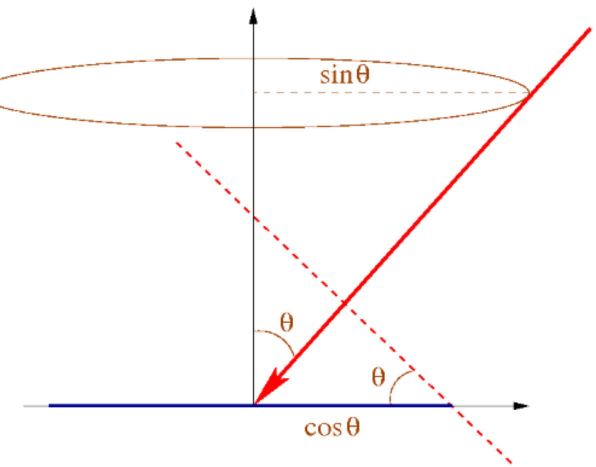
```
--------------------------------------------------------------------------------
Which detector geometry do you have ?
   1 - horizontal flat detector array [DEFAULT]
   2 - non-flat (volume) detector geometry
   3 - vertical string detector geometry

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

   (only one choice possible):
```

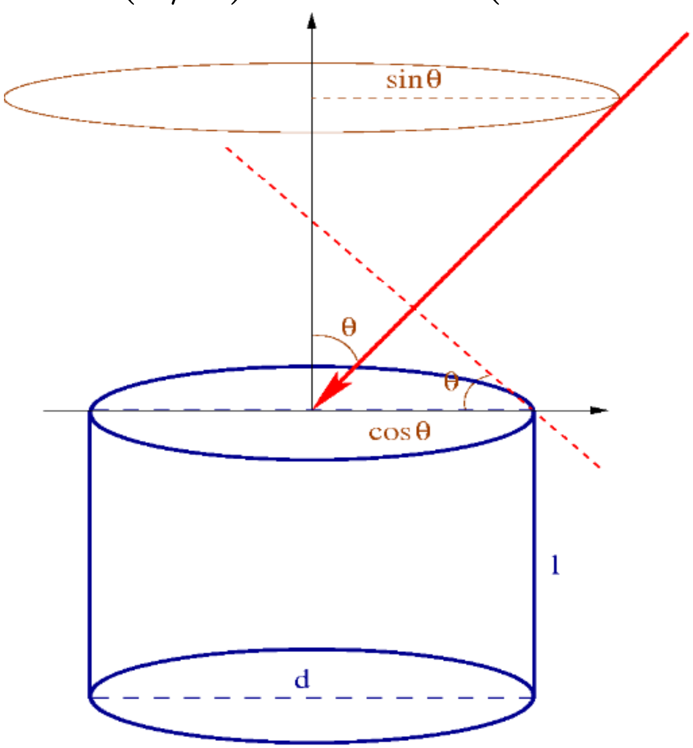
Flat experiment

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



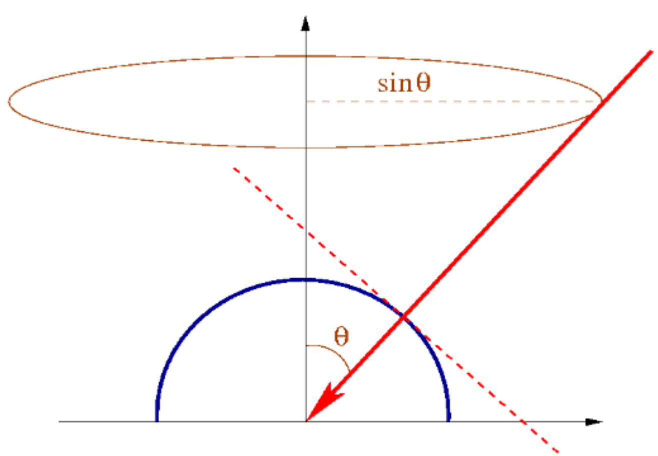
Vertical string detector

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



Non-flat experiment

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



INSTALLATION 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-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
   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
```

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.

INSTALLATION | 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):
```

source not saved by default.
using “k” source can be saved to check what is used in the code.

```
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
```

incompatible option or missing declaration reported here

INSTALLATION | RUNNING

if no compilation error this output should appear:

```
--> "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-epos > 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

EXERCISE STEERING CARD

```
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
```

EXERCISE 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

compile coast:

go under corsika-76900/coast and then:
make
make install

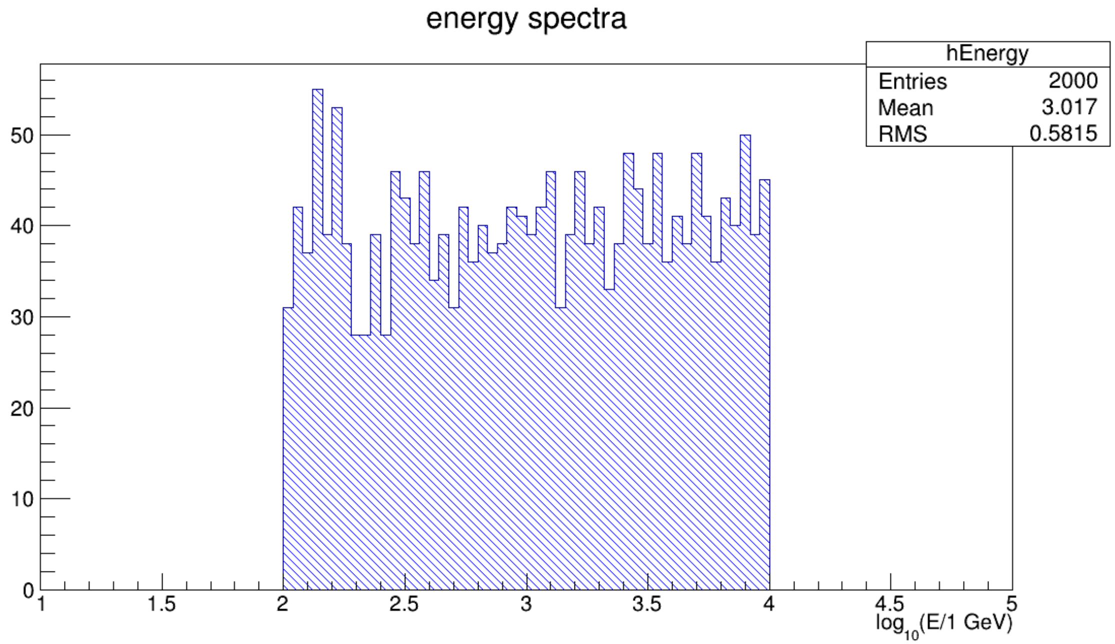
different examples to read the output files:

- 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*

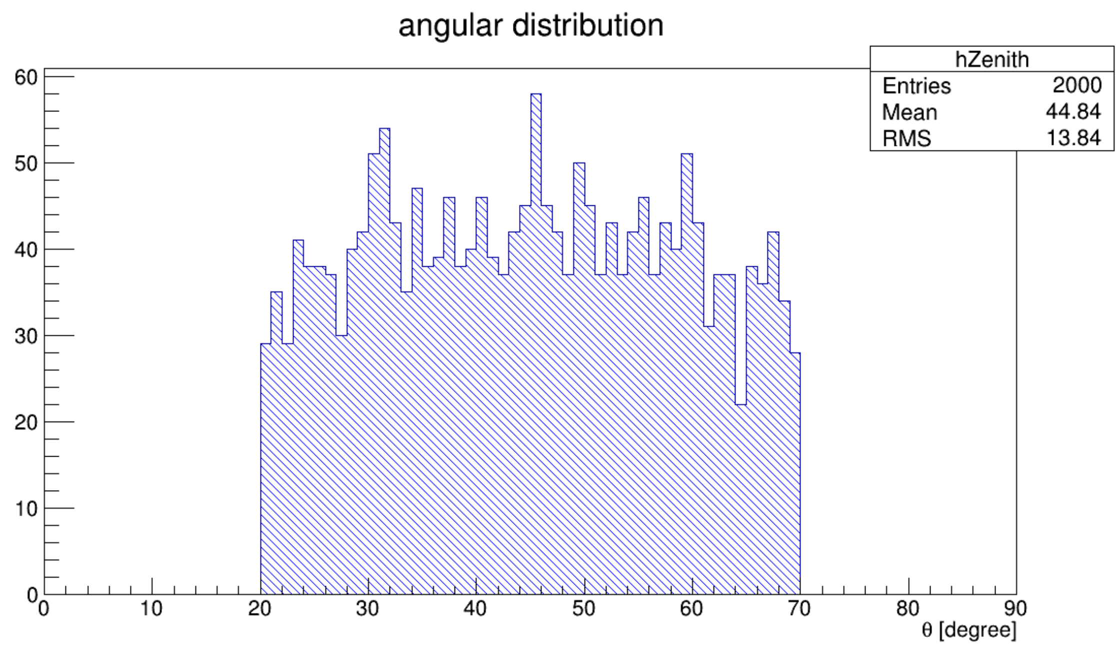
Compile
type: **make**

* only for a chosen shower

EXERCISE READ OUTPUT II (COAST)

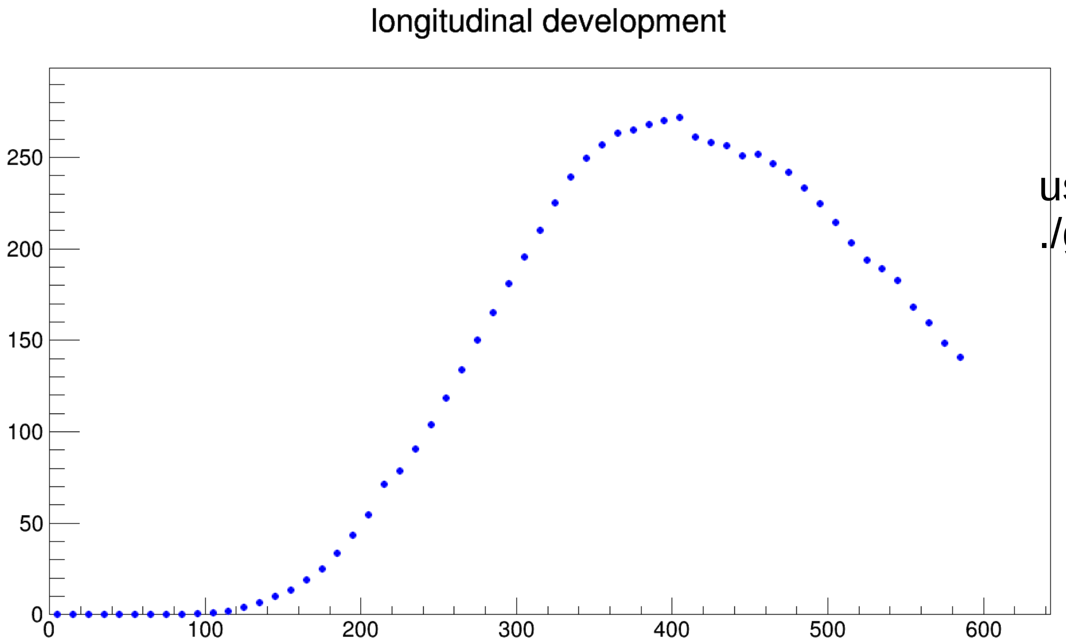


usage
./energySpectra <corsika file name>

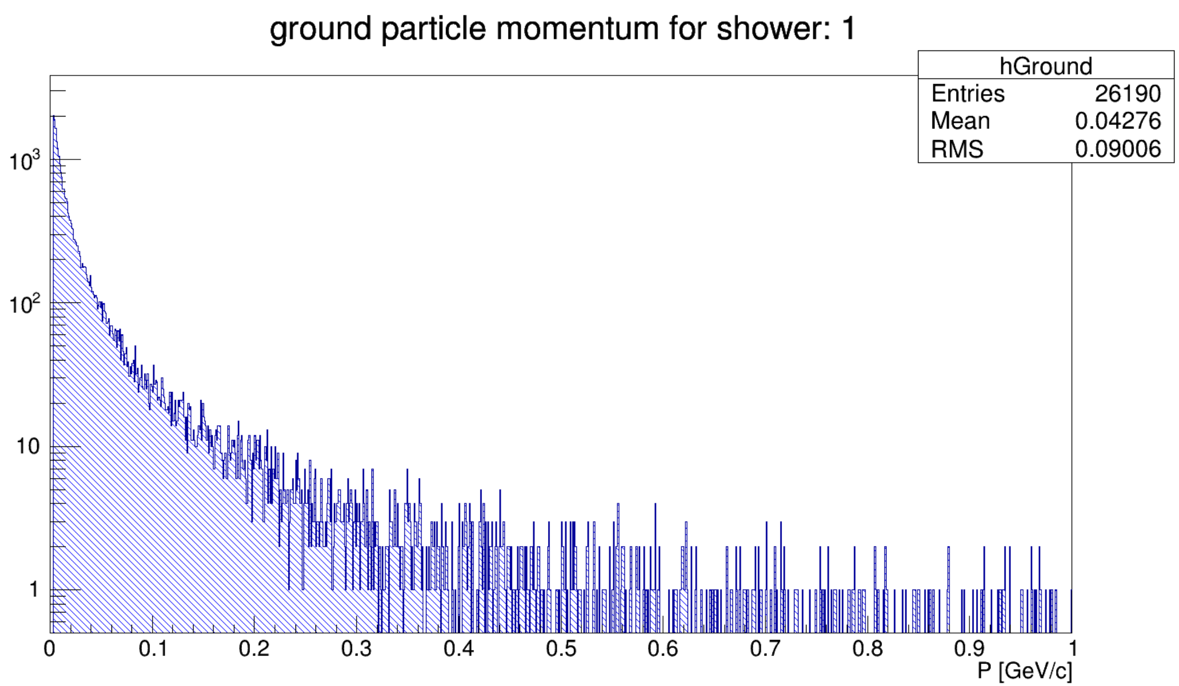


usage
./angularDistribution <corsika file name>

EXERCISE READ OUTPUT II (COAST)

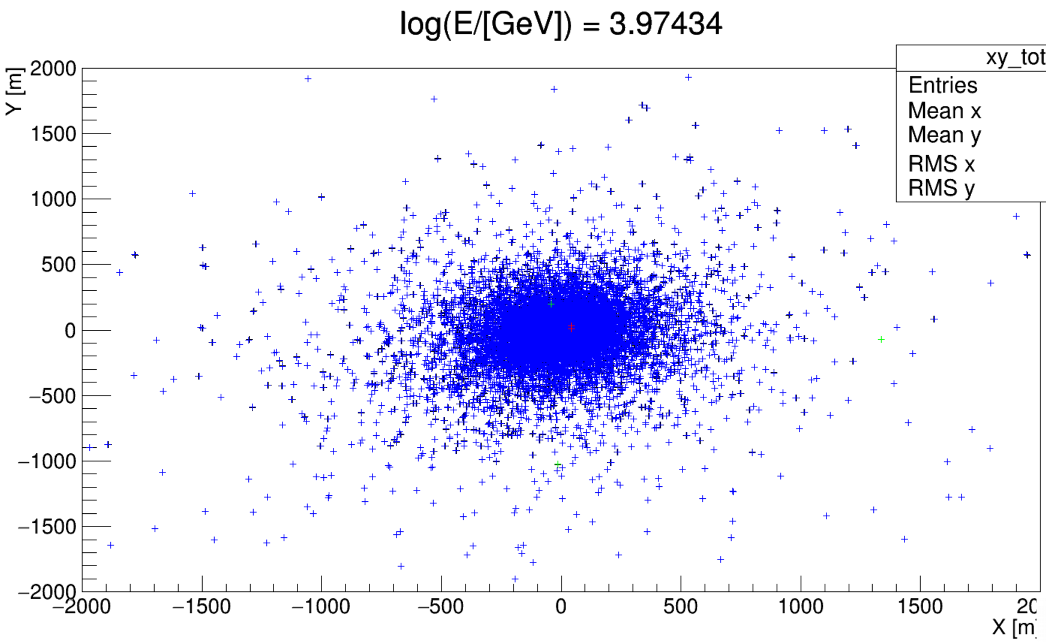


usage
./groundMomenta -n <#shower> <corsika file name>

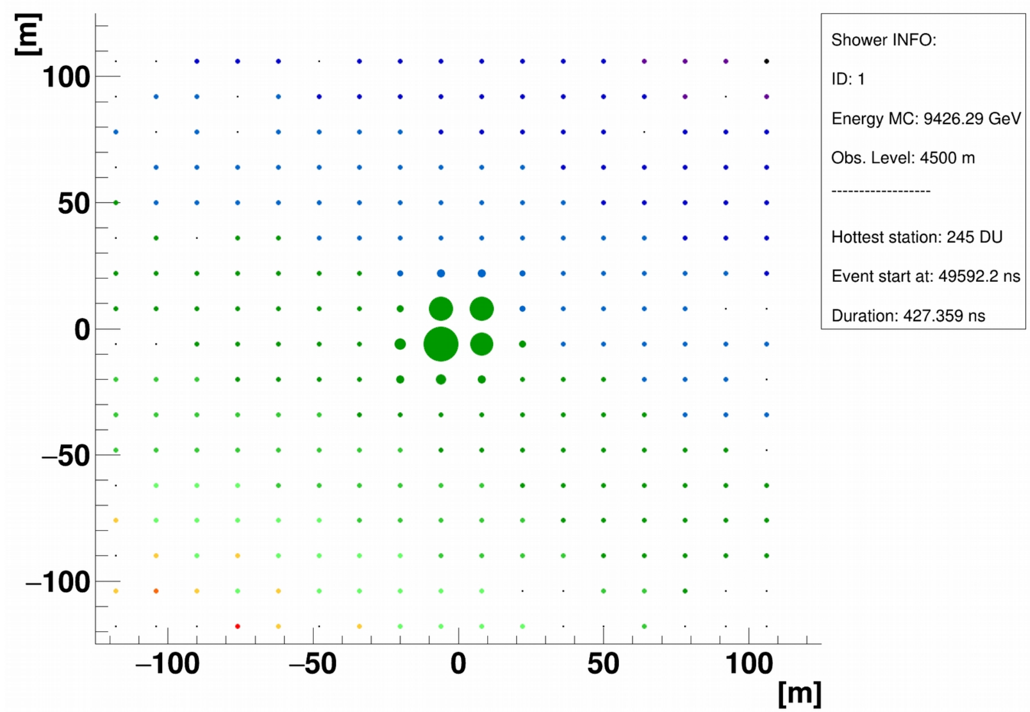


usage
./groundMomenta -n <#shower> <corsika file name>

EXERCISE READ OUTPUT III (COAST)



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



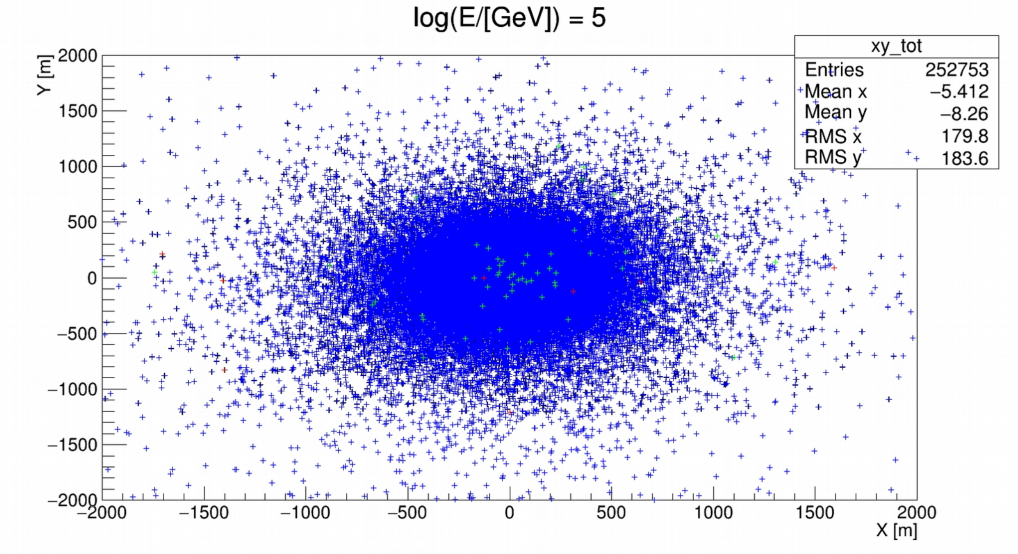
usage
./dummySim -n <#shower> <corsika file name>

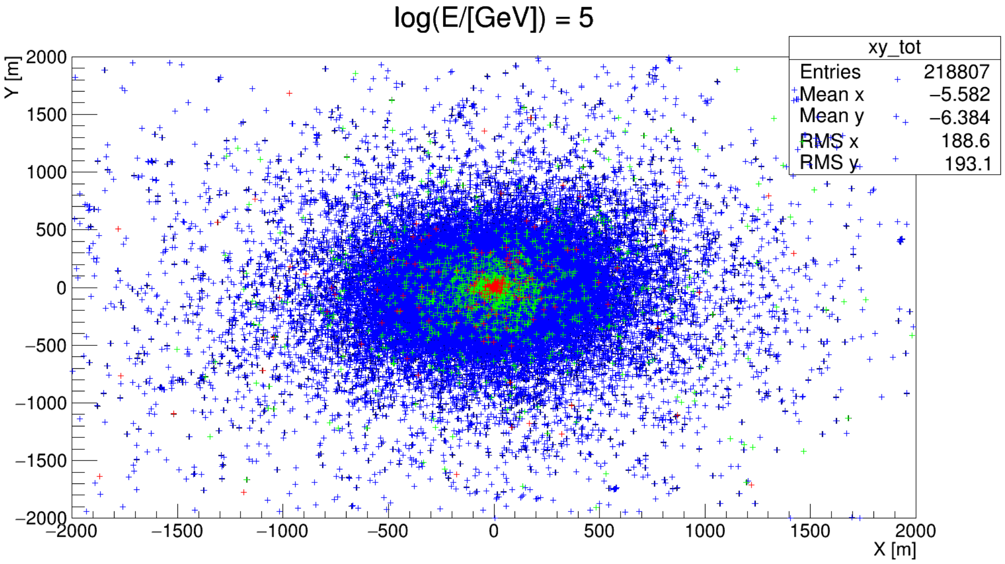
EXERCISE PHOTON vs PROTON

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.





EXERCISE READ OUTPUT I (PYTHON)

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