CORSIKA simulation of background in Baikal experiment.

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CORSIKA Cosmic Ray Simulation Workshop
Karlsruhe, 17 June 2019

Gigaton Volume Detector (GVD) in Lake Baikal

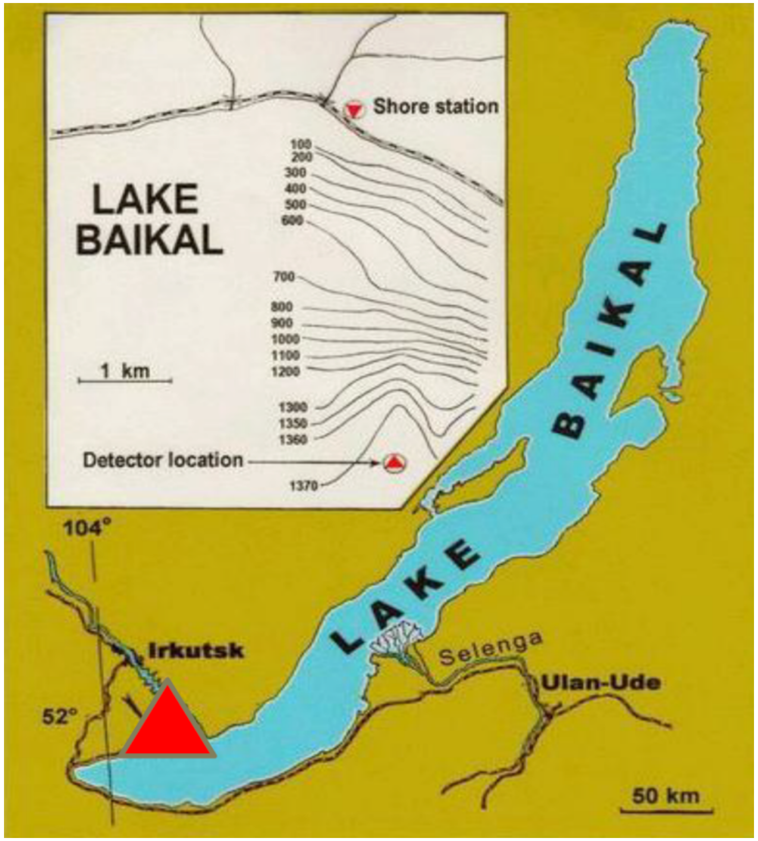
Objectives:

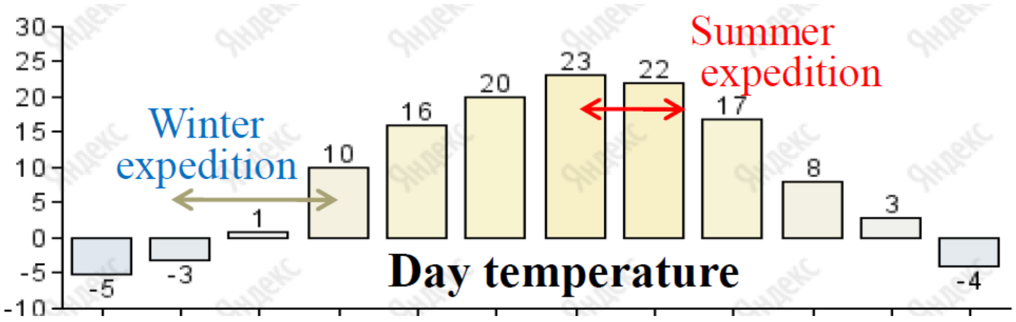
- km3-scale 3D-array of photo sensors
- flexible structure allowing an upgrade and/or a rearrangement of the main building blocks (clusters)
- high sensitivity and resolution of neutrino energy, direction and flavor content

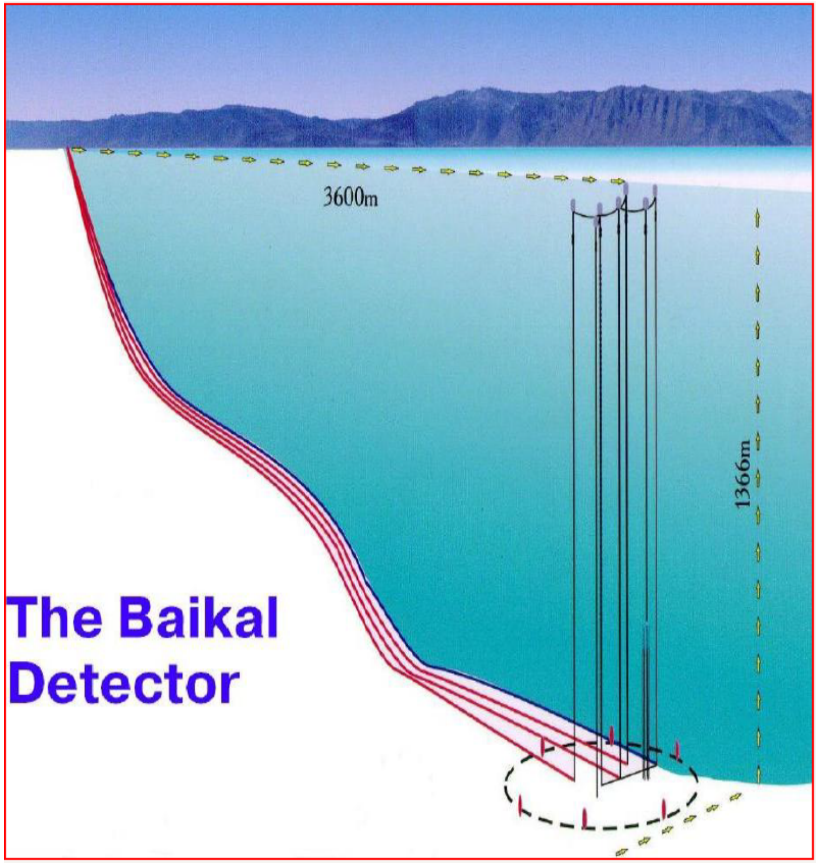
Central Physics Goals:

- Investigate Galactic and extragalactic neutrino “point sources” in energy range > TeV
- Diffuse neutrino flux – energy spectrum, local and global anisotropy, flavor content
- Transient sources (GRB, …)
- Dark matter – indirect search

Site properties – 106 km КБЖД

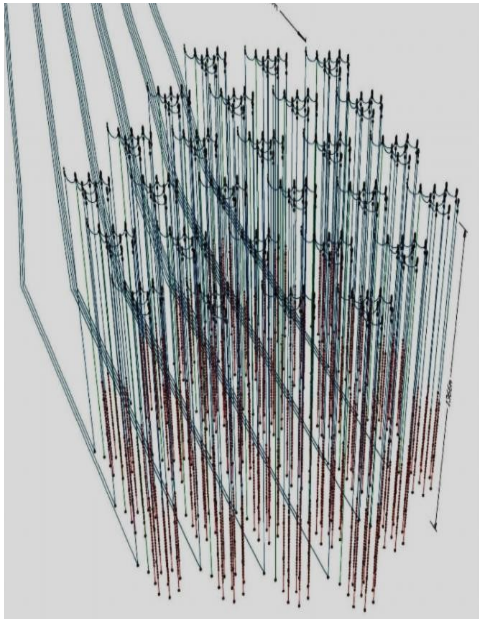


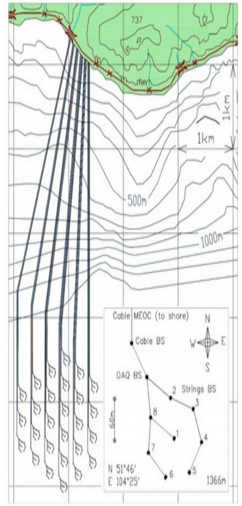




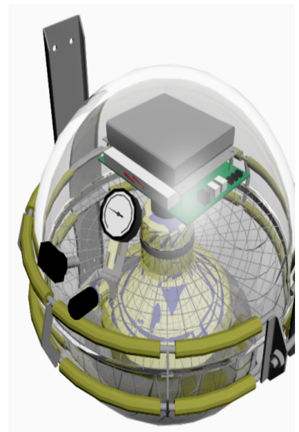
Location: 104°25’ E, 51°46’ N

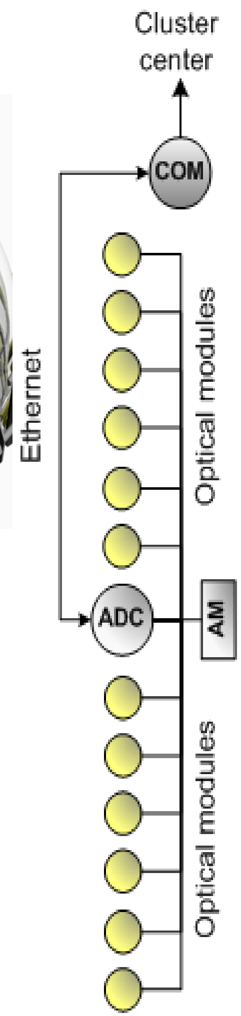
Gigaton Volume Detector (Lake Baikal)

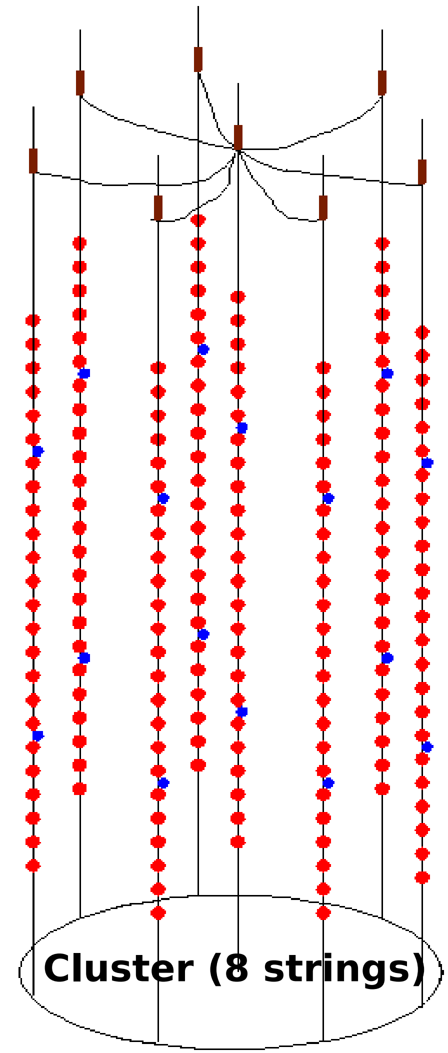




Optical module







	GVD	4*GVD
OMs	2302	10368
Clusters (8 Strings)	12	27
Sections (12 OMs)	2/Str.	4/Str.
Depths, m	950 – 1300	600 – 1300
Instr. volume	0.4 km^3	1.5 km^3

Old NT200:
volume ~ 0.0001 km^3

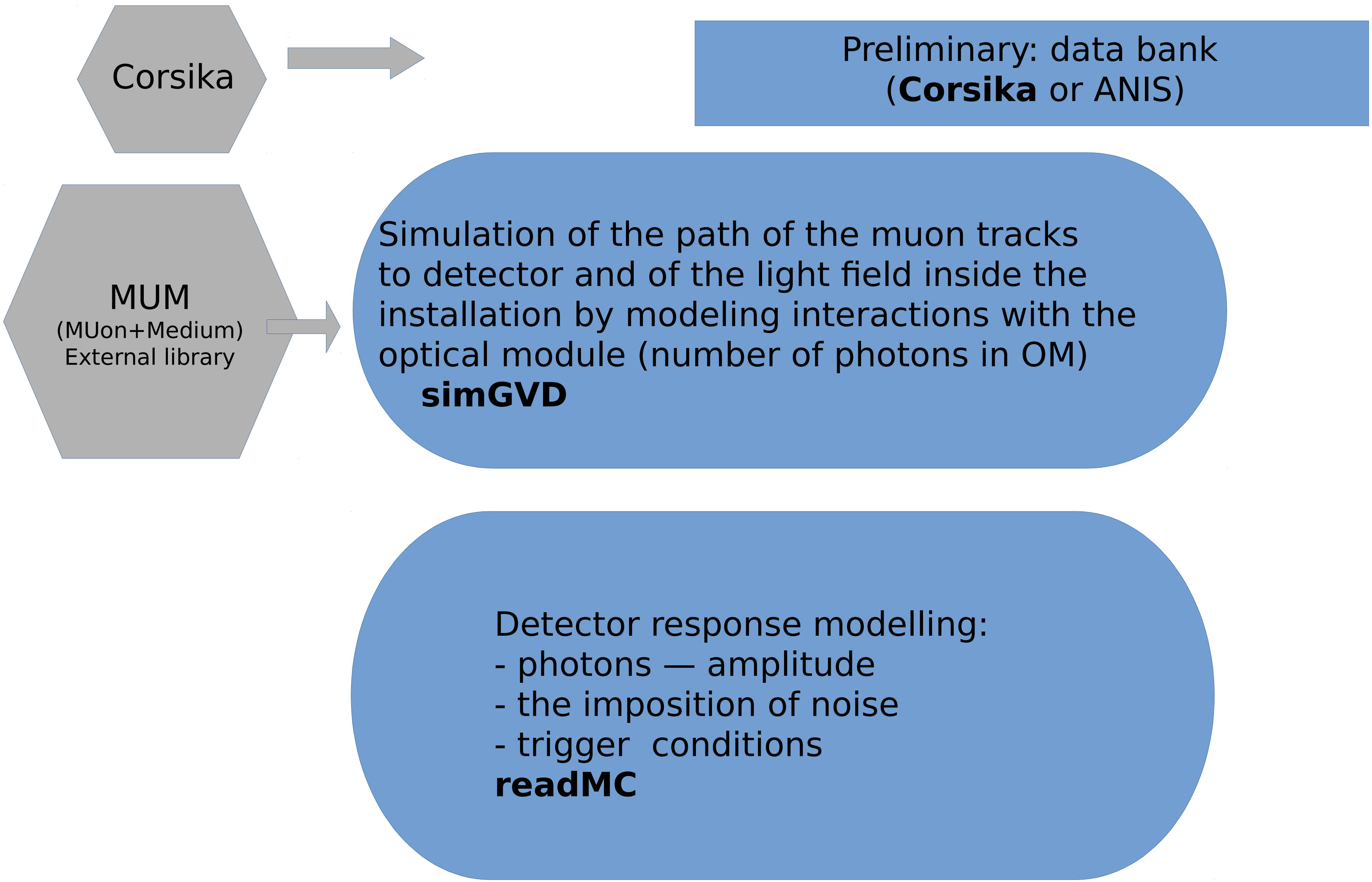
The chain of MC simulations for Baikal experiment

The main goal of MC simulations is to study the muon tracks produced by the flow of astrophysical neutrinos in Earth's atmosphere, distinguishing it from the background produced by other sources in the Baikal experiments.

- Modelling of atmospheric muons flux at the sea level
- Muon trasnport up to detector
- Simulation the interaction with media producing secondary muons
- Simulation of detector response on Cherenkov radiation including electronic system performance

The simulation chain starts by simulation of the transport the primary muons through the Earth's atmosphere up to the sea level by **Corsika SW package.**

The phases of simulation :



What we simulate and what we take as a primaries

Simulating response of the detector for the following fluxes:

- **Neutrino:**
  - **Atmospheric flux (background and calibration source)**
  - **E^{-2} flux (point sources)**
  - **(ANIS)**
-
-
- **Muons:**
  -
  - **From cosmic rays (muon bundles) — CORSIKA data bank**

How we make the simulation

Stage 0

Initial fluxes

File (CORSIKA)

Stage 1

- Propagation to the site
  - [MUM] — with 2 medium
- Light sources along the muon track [MUM]
  - Cherenkov cone
  - Point showers
  - Long showers: spline/split/treat like point-like
- Propagation of photons through water
- Number of photons to PMT

File (DAT)

Stage 2

- Adding noise (poisson - non-poisson)
- Applying channel mask
- Applying trigger conditions

File (wout)

Usage, results and storages

Usually run locally, but also in a GRID (for huge statistics)

*.DAT (1'st stage out)
We have get ~100 days simulation for Cluster-2015
~1 year for Cluster-2016

Using **baikal-fs.jinr.ru** as a primary data storage.
List of actual *WOUT* files:
http://baikal.jinr.ru/wiki/Simulation_GVD:_MC-data-files-description

format description and packages location

WOUT format description can be found on our WIKI-page:

http://baikal.jinr.ru/wiki/Simulation_GVD:_MC_data_format

CORSIKA data-bank location:

baikal-fs.jinr.ru:/data1/kostya/cors.new.fm4.emucut-120gev.v4

Subverion (svn):

1'st stage simulation package:

http://baikal.jinr.ru/svn/SVN_sim/mu_simulation.v0/trunk/simGVD_x64/

2'd stage simulation package:

http://baikal.jinr.ru/svn/SVN_sim/mu_simulation.v0/trunk/MC_Read_mask_and_OM_noise_x64/

addition libraries and data files:

baikal-fs.jinr.ru:/data1/kostya/store/

MC-simulation of GVD
(BAIKAL collaboration)

Obligated packages and libraries:

-
- [MC-simulation stage I]
- http://baikal.jinr.ru/svn/SVN_sim/mu_simulation.v0/trunk/simGVD_x64/
  - cernlib
  - MUM package
  - Outer libraries (bailib1 и negbi)
  - Outer *.data files with cross-sections data (not included in svn)
-
- [MC-simulation stage II] trigger, noise and configuration applied
- http://baikal.jinr.ru/svn/SVN_sim/mu_simulation.v0/trunk/MC_Read_mask_and_OM_noise_x64/
-

MC-program stage I

init_const Setting of some parameters for medium (water), cherenkov's angle etc

read_data Reading the parameters of Optical modules from files. Coordinates, sencitivity

dialog Setting the number of events, parameters of MC simulation and names of outer files from console

init_work Presetting some parameters and MUM package initialization

lhbook Histograms ititialization (cernlib)

init_files Outer files initialization

Writing histograms to *.out file

Outgoing datafile close

Log-file creating (number of events, area of simulation, double integral over energy and angle for presetted neutrino spectrum etc)

Next slide

file: baikal3e3b.f

* some procedures in the program code have «misspelled» names. It is made to easy find them in the program code.

- Getting (or randomizing) incoming track angles

- Setting the type of incoming particle (variants is as follows):

file: sim3h1.f

- 1) single muon (procedure: **singlemu**)
- 2) muon bundle parametrization (procedure: **grpfast**)
- 4) reading from file, [corsika data bank] (procedure: **grpread**)

3) the other variant of muon bundle parametrization (procedure: **grpmodel**) **file: sbas1.f**

Neutrino spectrum simulation **file: munu4w_osc.f (atmospheric neutrino from lower 2pi)** OR **munu7w_osc.f (e^{-2} spectrum)**

- S
Determining the time delay of the muons in bundle (procedure: **zerotime1**)

- Calculating the muon propagation through medium (ground/water) to the detector volume (procedure: muon path)

- Simulating the point interactions over the muon track inside the detector volume (bremmstrahlung, photonuclear interactions, pair productions, secondary electrons) (procedure: **catastloss**). For secondary electrons additionaly the angle between the track of the primary particle and the secondary shower is calculated (procedure: **ang_int**)

- Long showers (up to 20 meters) devided to pieces with 1m length each wich treated as point sources in further calculations. Energy and light field of these «point sources» are calculated via splines(procedure: **rearrange_showers**). **file: long_shower.f**

MUM usage

- Checking if OM hit for each source for the whole array using the OM sencitivity data and OM+source mutual disposition (procedure: **channel**)

- Check if the enough number of OM hit to pass the trigger condition (procedure: **response1**)
- Histogram updating (procedure: **statgen**) **file: baikal3e3b.f**

- Event data writing **(procedure: evout)** **file: newout4_1.f**

Files **sbas1.f** contains the muon bundle parametrization according to:
Известия РАН, сер. физ., 1994, И2, с. 123-126

File **munu4w_osc.f** contains the atmospheric (anti)neutrino flux simulation in two variants: 1) Butkevich et al. (Sov. J. Nucl. Phys. 50 (1) 1989
2) Phys.Rew D53(1996) 1314-1423, hep-ph/9509423 (Bartol neutrino flux)
second variant is by default
File **munu7w_osc.f** contains the neutrino flux with the E^{-2} spectrum,
integral ower it is normalized to 1.

Manual for output data format can be found the following collaboration wiki page:
http://baikal.jinr.ru/wiki/Simulation_GVD:_MC_data_format

MUM package is dedicated to calculate muon propagation from surface to the detector volume through the medium (water/ground) designed in BAIKAL collaboration and presented in the following paper: I.A.Sokalski, E.V.Bugaev, S.I.Klimushin, "MUM: flexible precise Monte Carlo algorithm for muon propagation through thick layers of matter", Phys. Rev. D64:074015 (2001) [hep-ph/0010322]
Manual for this package is included in it's files.

Databank of atmospheric muons used as an input source is made by CORSIKA package version 5.

List of files of the MC-programm,
Which contains the FORTRAN code:

baikal3e3b.f
bspl2.f
emu_minimal.f
long_shower.f
munu4w_osc.f
munu7w_osc.f
munu8w_osc.f
muon_path_2.f
newout4_1.f
sbas1.f
sim3h1.f
simspe.f
snu_tot_2.f
snu_tot.f
su_dif_2.f
user2a_t.f

Corsika SW package

Air Shower Simulation Program for detailed simulation of extensive air showers initiated by high energy cosmic ray particles. Is one of the most commonly used air shower Monte Carlo programs.The interpretation of EAS measurements strongly depends on detailed air shower simulations.
Protons, light nuclei up to iron, photons, and many other particles may be treated as primaries. The particles are tracked through the atmosphere until they undergo reactions with the air nuclei or - in the case of instable secondaries - decay.

The hadronic interactions at high energies may be described by several reaction models alternatively based on the Gribov-Regge theory, or as a minijet model. The neXus model extends far above a simple combination of QGSJET and VENUS routines. The most recent EPOS model is based on the neXus framework but with important improvements concerning hard interactions and nuclear and high-density effect. HDPM is inspired by findings of the Dual Parton Model and tries to reproduce relevant kinematical distributions being measured at colliders.

Hadronic interactions at lower energies are described either by the GHEISHA interaction routines, by a link to FLUKA, or by the microscopic UrQMD model.

In particle decays all decay branches down to the 1 % level are taken into account. For electromagnetic interactions a taylor made version of the shower program EGS4 or the analytical NKG formulas may be used. Options for the generation of Cherenkov radiation and neutrinos exist. CORSIKA may be used up to and beyond the highest energies of 100 EeV.

The main source of uncertainty in the prediction of shower observables for different primary particles and energies is currently dominated by differences between hadronic interaction models. After recent updates taking into account the LHC data together with more precise air shower introduced new constraints. New generation of hadronic interaction models is released in CORSIKA. Sibyll 2.3c and DPMJETIII.17-1 available in 2017 with improved description of particle production and in particular the production of charmed particles.

CORSIKA

- need a new databank for high-energy atmospheric muons
  CORSIKA 5 → CORSIKA 7
- have number of files for P, He, O, Fe with 1TeV threshold

- have a Cors7Read utility

- need a utility to compose a mixed databank
- verification criteria of CORSIKA simulated data
  - still working on test utilities
  - upgrade next steps of simulation chain:
    MUM → PROPOSAL
    FTN → C++

CORSIKA-7 package

- **Ver 7.56**
- Ver 7.63
- **Ver 7.64**

High Energy Models:

- DPMJET
- QGSJET-II-04
- SIBYLL 2.3c
- VENUS
- EPOS
- NEXUS

Low Energy Models:

- GHEISHA 2002d
- FLUKA 2011
- URQMD

Databank

Baikalweb: compact output

/home/vahab/cors7/root_files:

cors7.56 cors7.63 cors7.64

Baikalweb: standard output

/home/slavo/Corsika/root.corsika.all.combinations.and.species/out:

fluka gheisha urqmd

Considered primary particles:

Proton, Helium, Oxygen and Iron

COSRSIKA7.56 : shower parameters

./cors756.exe < input_file > output.txt

Input params

'coconut'

NSHOW 10000000 number of showers to generate
PRMPAR 5626 particle type of prim. Particle (Fe)

ESLOPE -2.67 primary energy spectrum
ERANGE 56.E3 112.E7 energy range of primary particle

THETAP 0. 90. range of zenith angle (limits depend on CURVED and UPWARD options)

PHIP -180. 180. range of azimuth angle

SEED 119101 0 0 seed for 1. random Hadron
SEED 0 0 0 seed for 2. random e/m
SEED 0 0 0 seed for 3. random Cherenkov
MAGNET 19.26 57.132 magnetic field at the BAIKAL

ECUTS 120. 120. 120. 120. energy cuts for hadr+neut mu el pho

ZENITH ANGLE DEPENDENCE FOR VOLUME DETECTOR

PARTICLE OUTPUT IS

WRITTEN IN COMPACT FORM

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CURVED VERSION WITH SLIDING PLANAR

ATMOSPHERE

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SLANT DEPTH FOR LONGITUDINAL

DISTRIBUTIONS

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UPWARD VERSION FOR UPWARD GOING PARTICLES

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Changes

- **1**— Range of azimuth angle (degree):
  PHIP 0. 0. $\longrightarrow$ PHIP -180. 180.
- **2**— Energy range of primary particle:
  ERANGE 2.4E2 2.E7 $\longrightarrow$ ERANGE 1.E3 2.E7
- **3**— Two extra options: SLANT & UPWARDS

SLANT:
With the SLANT option the longitudinal distributions are along the shower axis instead of vertical depth bins used in the standard case. This slant depth scale is more appropriate to investigations of very inclined showers.

UPWARDS:
The UPWARD option is appropriate for the upward traveling particles. For primary particles the zenith angle is restricted to $0^0 < \theta < 70^0$ and $110^0 < \theta < 180^0$. The UPWARD option might be combined with the CURVED option. This enables to start showers with arbitrary zenith angles $0^0 < \theta < 180^0$ and secondary particles with arbitrary zenith angles are followed.

RUNNR	344000	number of run				
EVTNR	10	number of first shower event				
NSHOW	10000000	number of showers to generate				
PRMPAR	14	particle type of prim. particle (p)				
ESLOPE	-2.67	slope of primary energy spectrum	⟺	ESLOPE	-1.	
ERANGE	2.4E2 2.E7	energy range of primary particle	⟺	ERANGE	1.E3	2.E7
ATMOD	6	select SP atmosphere (Apr)				
THETAP	0. 90.	range of zenith angle (degree)				
PHIP	0. 0.	range of azimuth angle (degree)	⟺	PHIP	-180.	180.
SEED	4891 0 0	seed for 1. random number sequence				
SEED	0 0 0	seed for 2. random number sequence				
SEED	0 0 0	seed for 3. random number sequence				
OBSLEV	4.55e4	observation level (in cm)				
ELMFLG	F F	em. interaction flags (NKG,EGS)				
RADNKG	200.E2	outer radius for NKG lat.dens.distr.				
FIXCHI	0.	starting altitude (g/cm**2)				
MAGNET	19.26 57.132	magnetic field at the BAIKAL array				
HADFLG	0 0 0 0 0 0	flags for hadr. interaction				
ECUTS	120. 120. 120 120.	energy cuts for hadr+neut mu el pho				
MUADDI	F	additional info for muons				
MUMULT	T	muon multiple scattering angle				
LONGI	F 20. F F	longit.distr. & step size & fit & out				
MAXPRT	1	max. number of printed events				
ECTMAP	1.E4	cut on gamma factor for printout				
STEPFC	10.0	mult. scattering step length fact.				
DEBUG	F 60 F 1000000	debug flag and log.unit for out				
DIRECT	./	output directory				
USER	you	user				
EXIT		terminates input				

Muon multiplicity

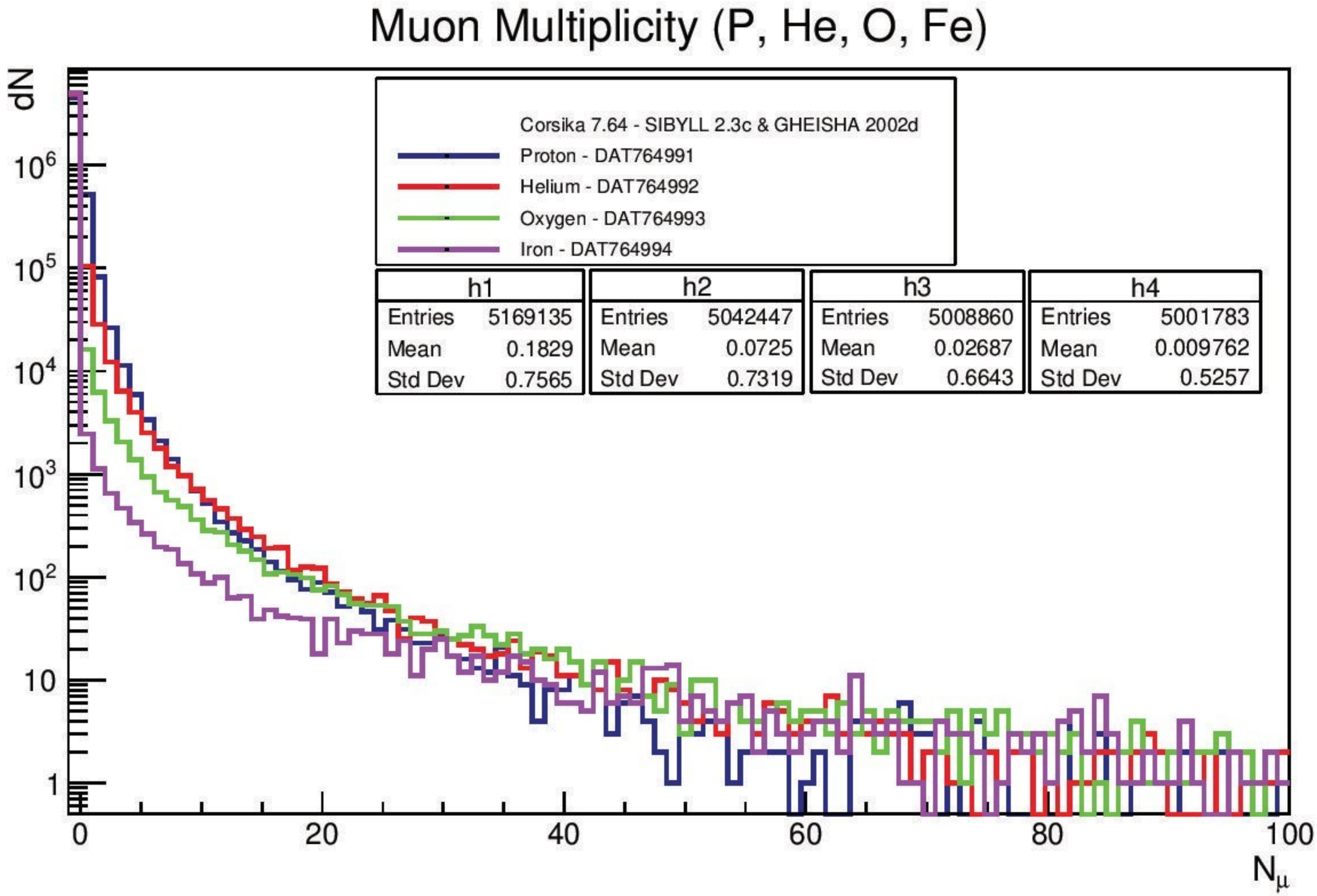
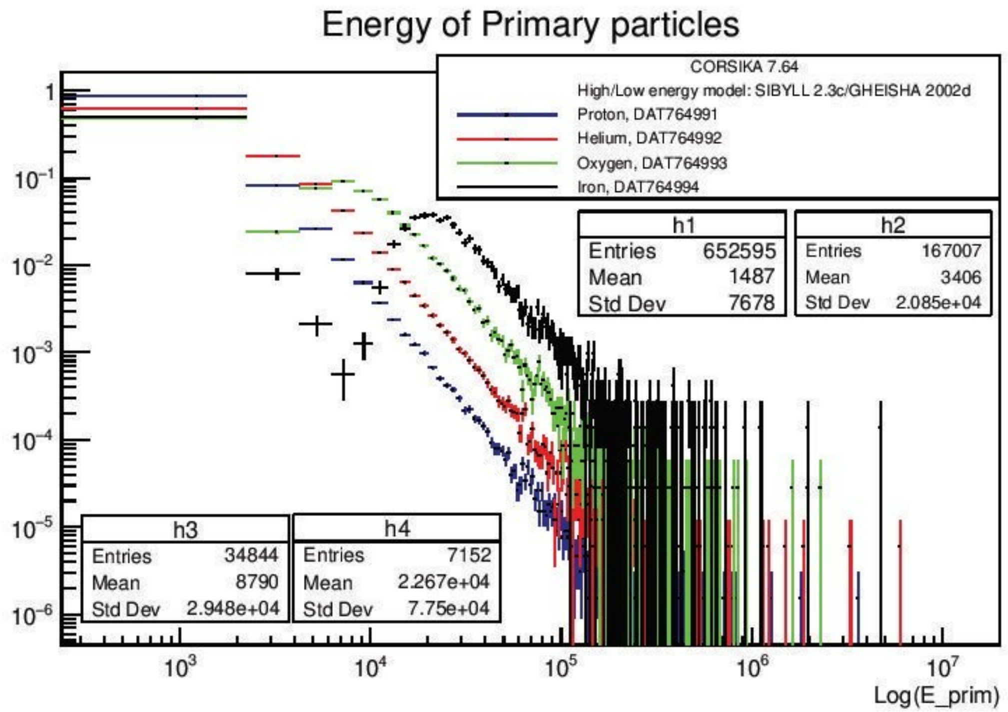
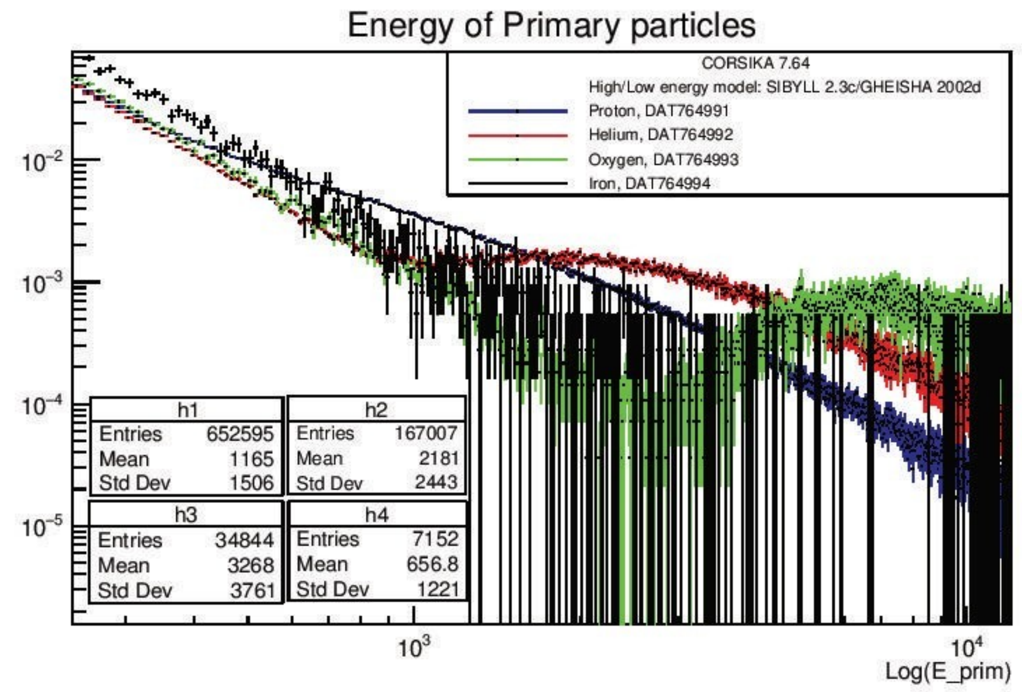


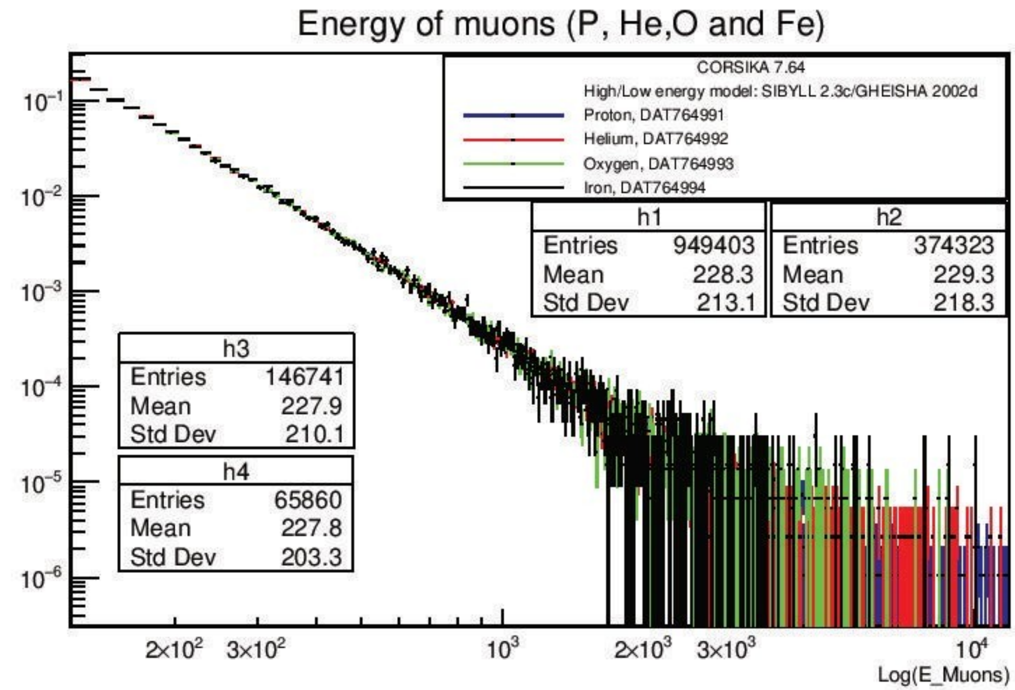
Figure: Muon multiplicity of 4 primary particles (CORSIKA 7.64)

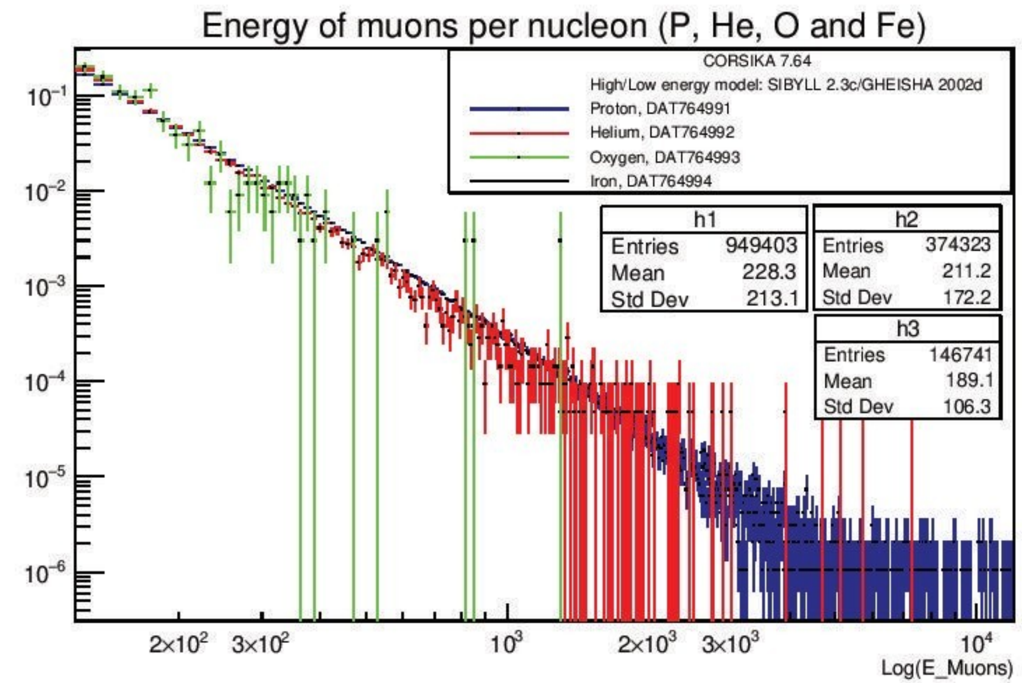
Energy of Primary particles (P, He,O and Fe)



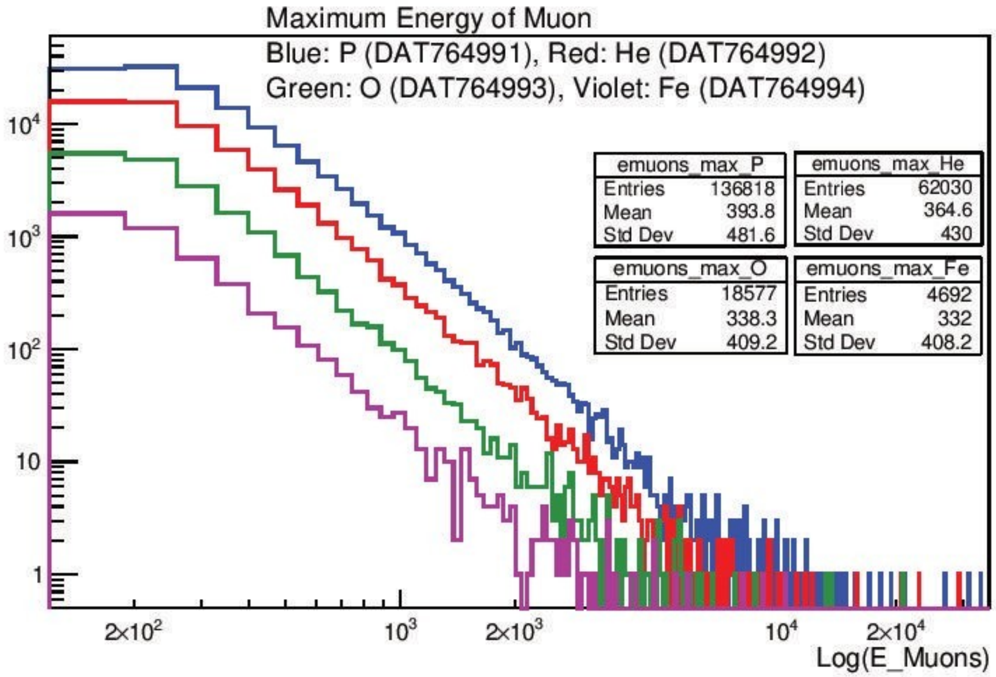


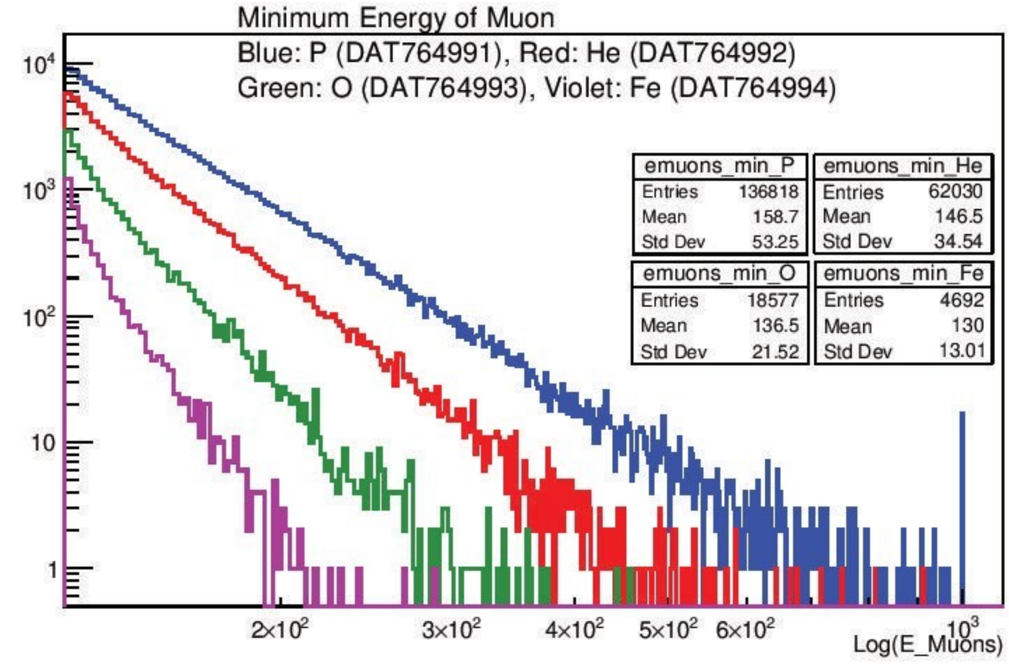
Energy of muons (per ucleon) for P, He,O and Fe



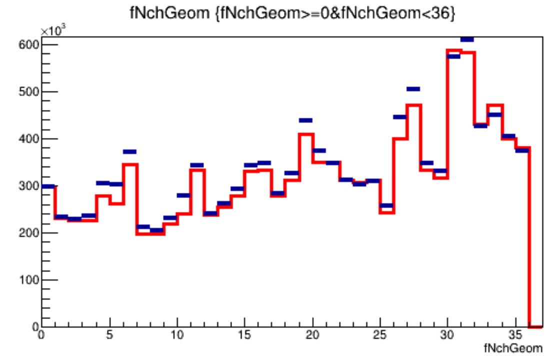


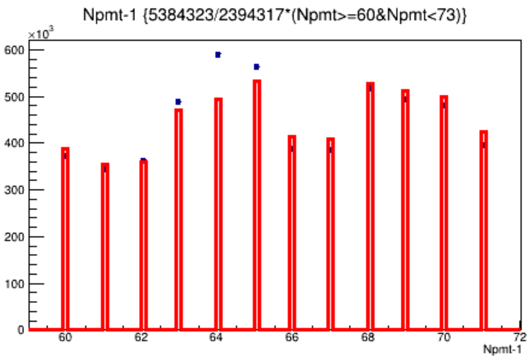
Max & Min Energy of muons for P, He,O and Fe

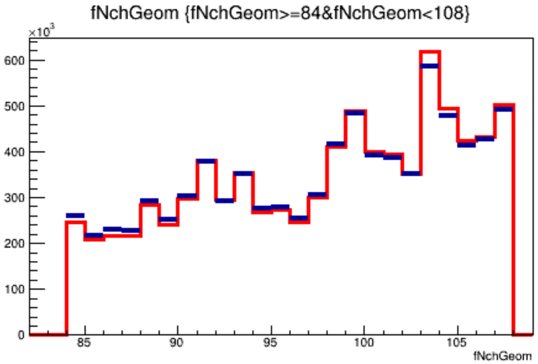


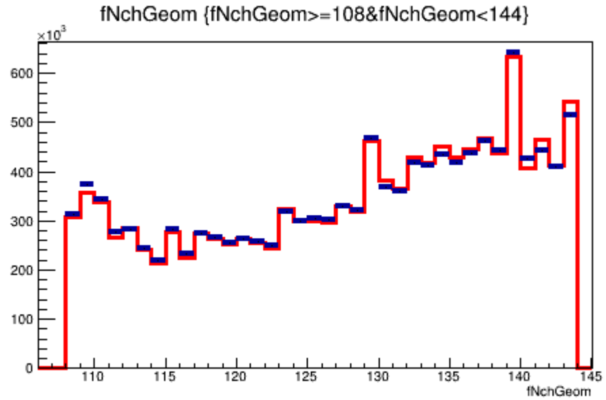


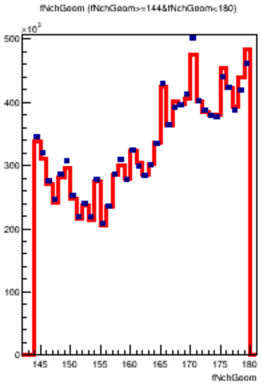
Comparison of MC (red) and experimental data (grey) -channel rates

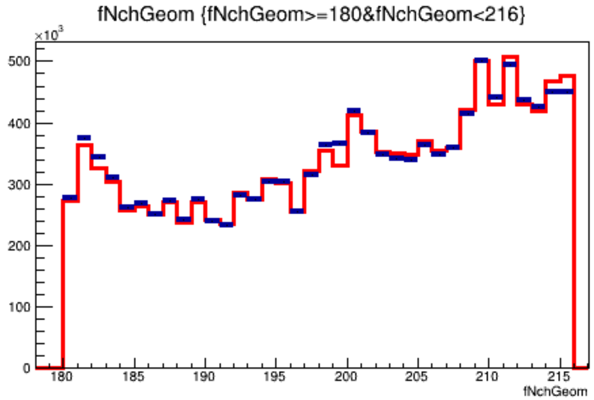


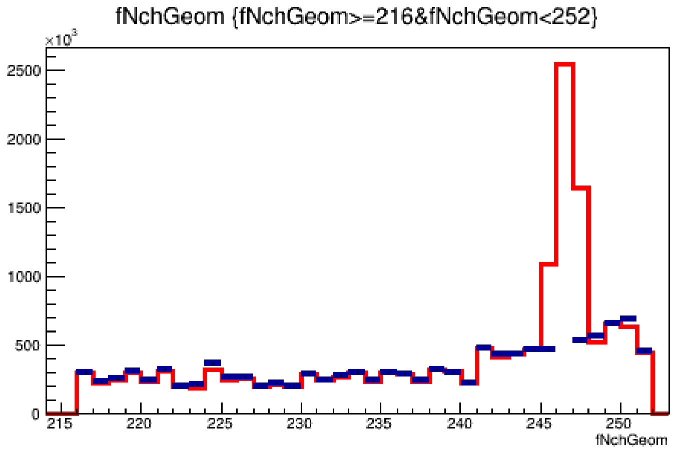


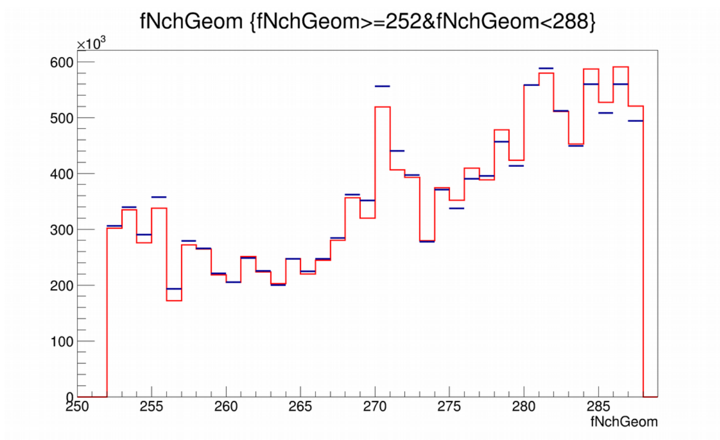













Thank you!