COSMOS

~ another air shower MC simulation tool ~

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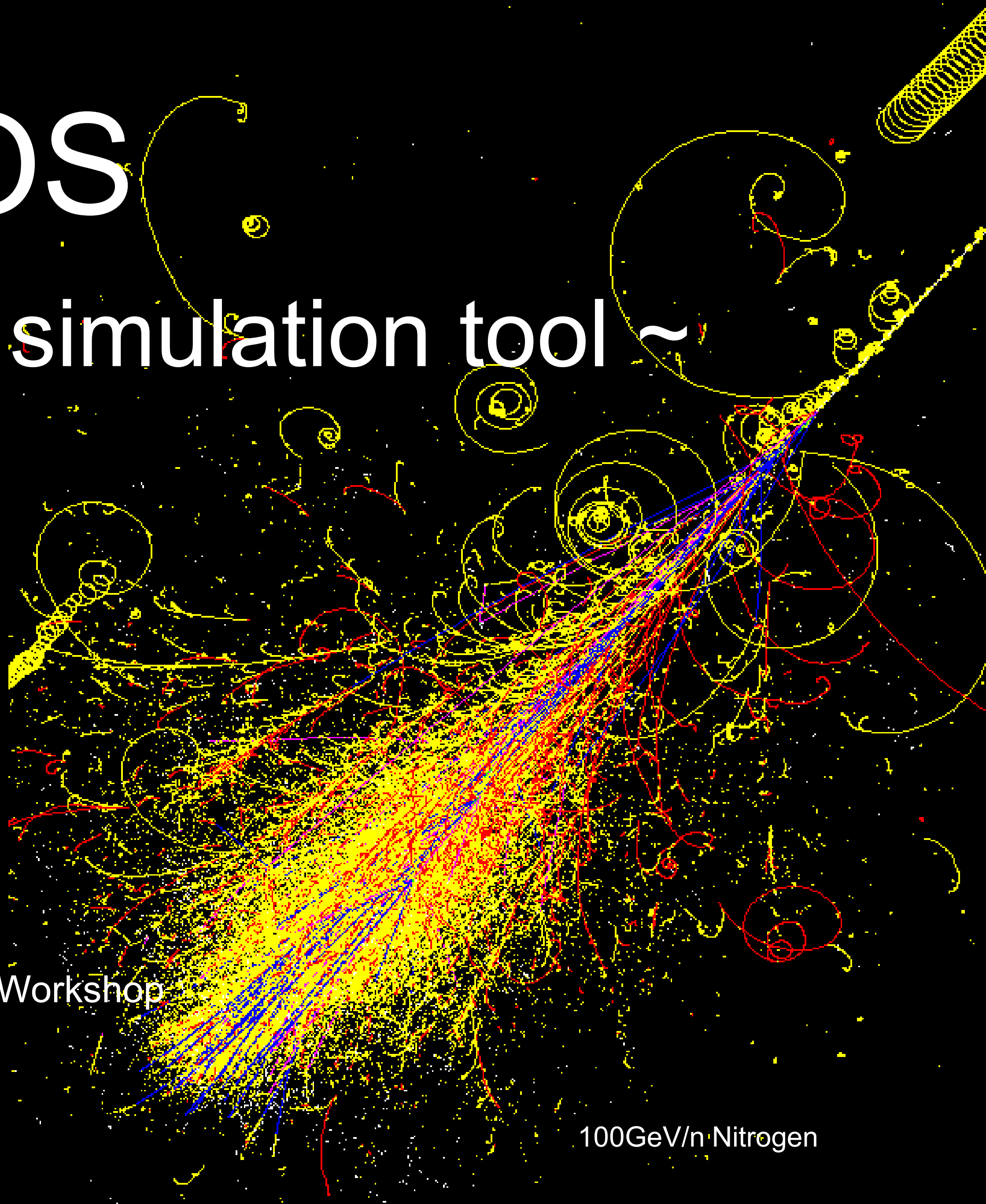
for the COSMOS X development team

CORSIKA 8 Air-Shower Simulation and Development Workshop
12-15 July 2022
Max Planck Institute for Nuclear Physics



Introduction of COSMOS

Air shower MC simulation tool
The origin goes back to 1970's.

Many applications such as,

- Air shower observation
- Hadron interaction
- Atmospheric neutrino
- Muon tomography

…

ICRC1979 paper

70 HE5-4

Extensive Simulation of Gamma and Hadron Families I

-- Assumption and Procedure --

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Abstract

Detailes of the assumptions and procedures of a Monte-Carlo simulation of the family phenomena are described. Present experimental and theoretical knowledges are incorpolated as much as possible.

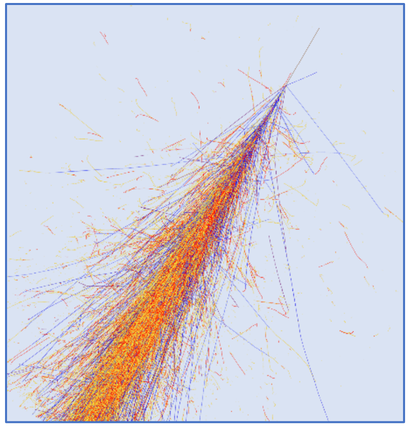
1. Introduction

It was more than 10 years ago when the Monte-Carlo method was first applied to the simulation of atmospheric cosmic-ray behaviour relevant to emulsion chamber observations by using a small computor [1]. The area of the emulsion chamber experiments at Mt.Chacaltaya and Mt.Norikura had been an order of 10 m^2 or less, or highest energy events were of $\Sigma E_\gamma \lesssim 100$ TeV. The simulation itself was relevant to such observations.

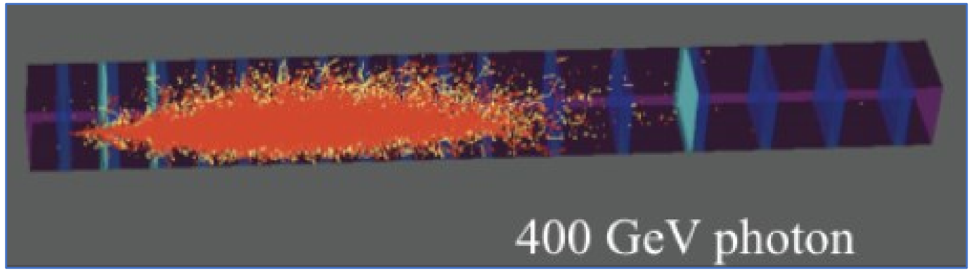
Since then, the number of experimental sites for emulsion chambers has been increasing

COSMOS to COSMOS X

Air shower simulation

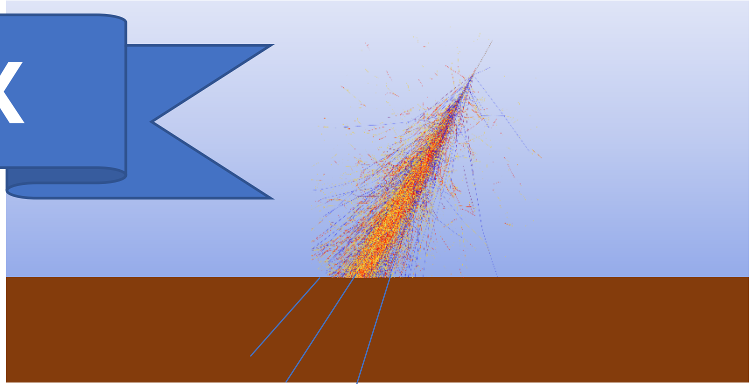


Detector simulation



COSMOS X

(eXtended COSMOS)



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COSMOS X as a general purpose air shower simulation tool

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COSMOS X general features

- Monte Carlo cascade shower simulator for cosmic ray study
- Fortran
- Supported compilers
  - Intel Fortran
  - GFortran (since COSMOS v8 in 2017)
- Computing technique
  - Thinning
  - Parallel computing (MPI)
  - Skelton-smach-fleh method
  - Hybrid AS size computing (MC+approx. B)

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Physics processes (1)

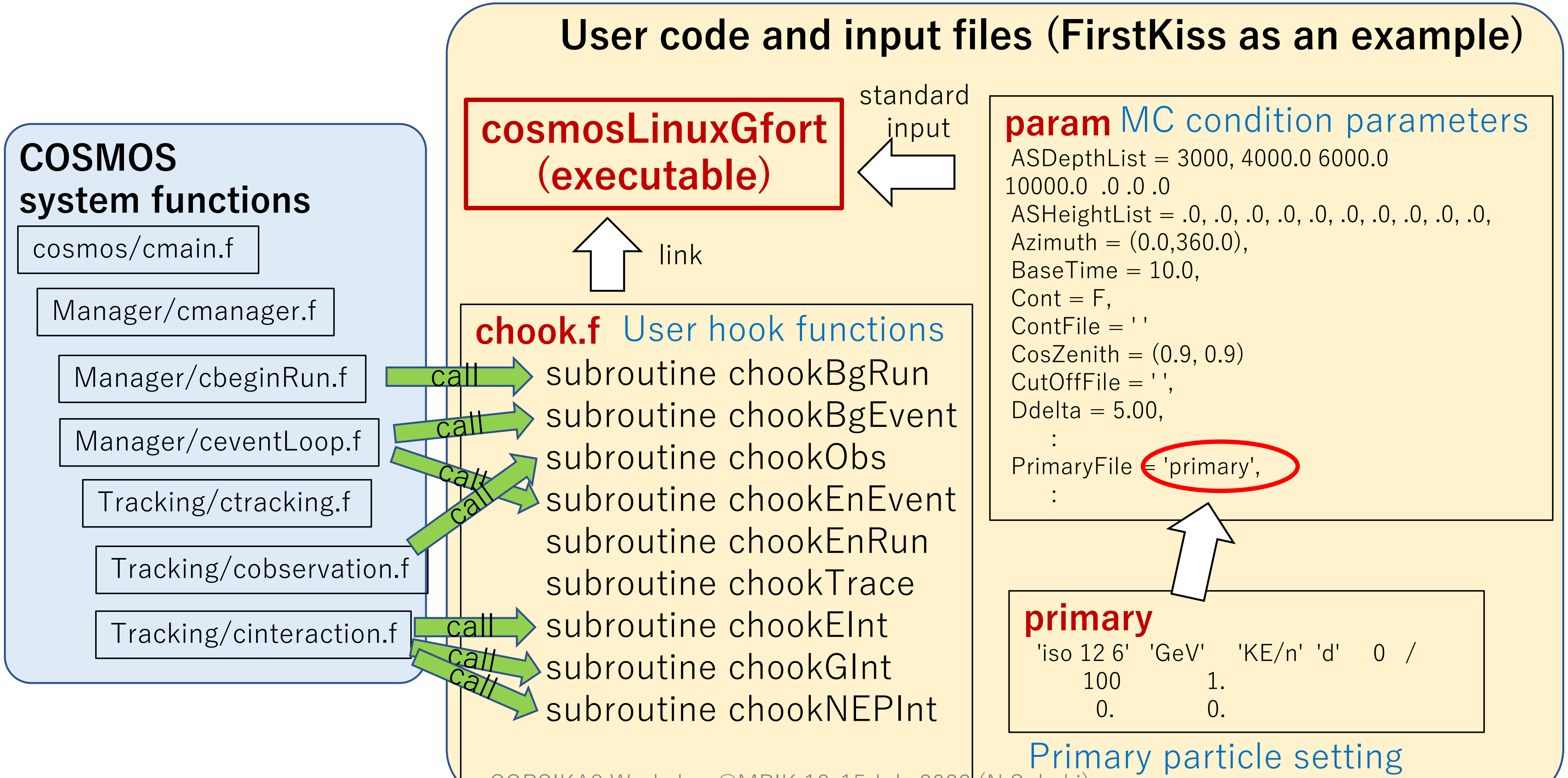
- EM
  - Photoelectric eff., Rayleigh scat., Compton scat.
  - Pair creation
  - Brems., e+ annihilation, Bhabha, Moller scat.
  - Synchrotron
  - Photo-hadron prod.
  - LPM effect on brems. and pair.
  - Multiple scat.
  - Cherenkov light prod.
- Muon
  - Brems, pair, nucl. in.
  - Polarization, stopping mu- capture

Physics processes (2)

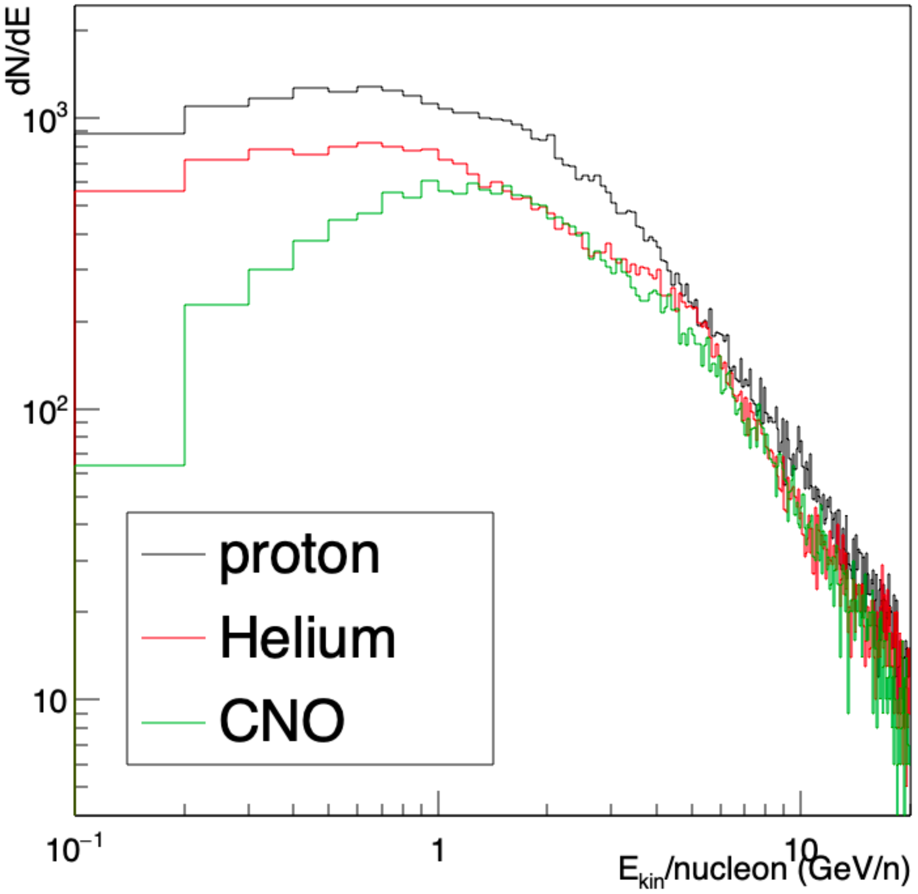
- Hadron
  - High energy
    - Dpmjet3
    - QGSJet-II (03,04)
    - EPOS (w, w/o LHC tuned)
    - Sibyll (2.1,2.3c,2.3d)
  - Low Energy
    - JAM
    - PHITS
    - Sofia
    - Fritiof
    - Nucrin

Structure of COSMOS X

Provide a collection (library) of particle tracking and interaction routines



Primary particle definition

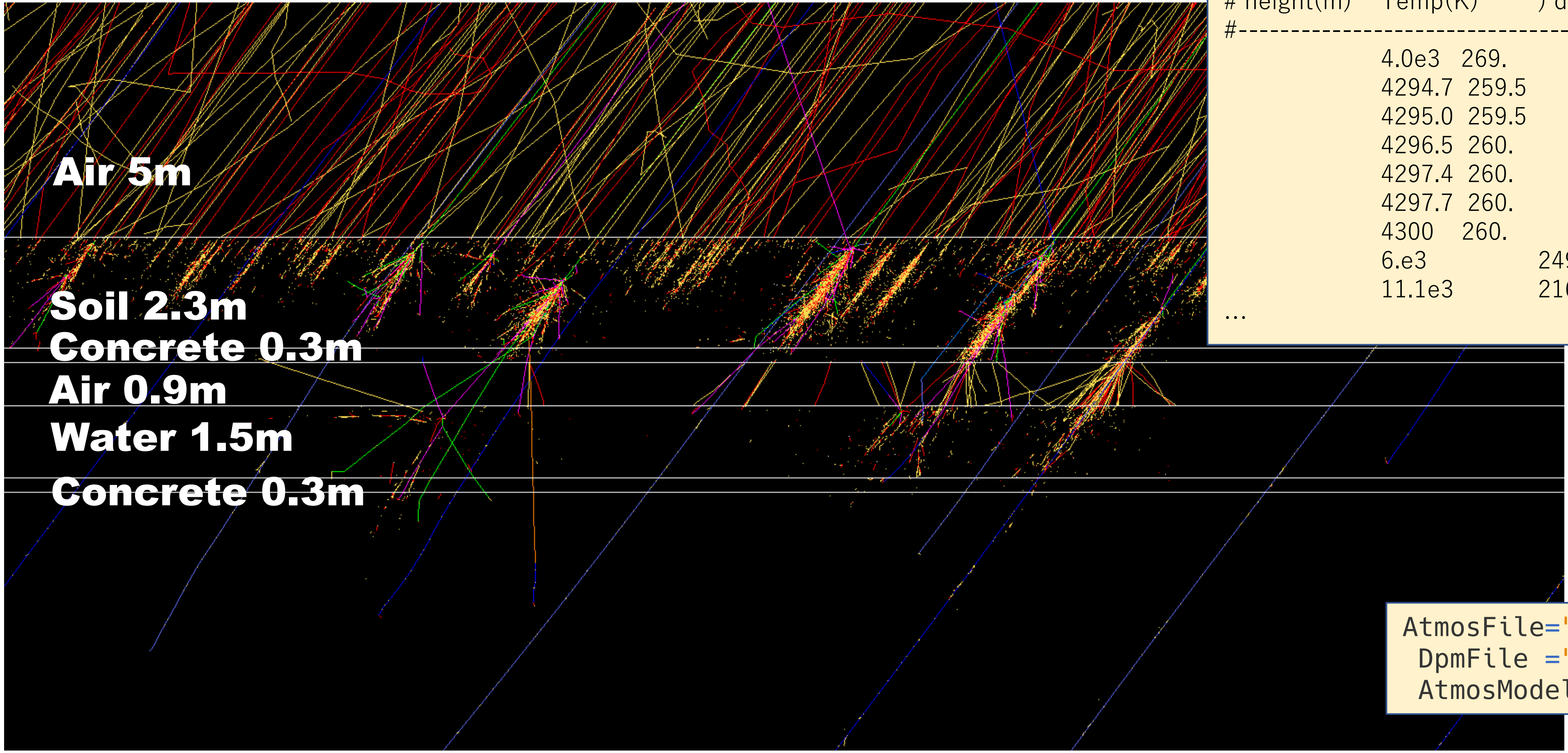


‘primary’ file

```
 'p'    'GeV'     'KE/n'  'd'     0   /
        0.1      1.2
        0.2      1.5
        .3       1.7
        .4       1.9
        .5       1.93
        .6       1.9
        .8       1.8
        1.5      1.5
        2.       1.25
        3.       .8
        4.       .55
        10.      .1
        20.      .02
        100.     2.8e-4
        0        0
 'He'   'GeV'    'KE/n'  'd'     0  /
        .1       .7
        .2       1.
        .4       1.2
        .6       1.25
        .8       1.2
        1.       1.15
        2.       .7
        5.       0.35
        10.      0.065
        30.      .008
        100.     2.e-4
         0         0
 'CNO'  'GeV'    'KE/n'  'd'     0 /
         .1      .013
        .2       .28
        .3       .4
        .5       .65
        .8       .8
        1.       .85
        1.3      .88
        2.0      .75
        4.       .35
        6.       .2
        10.      .07
        20.      .012
         0         0
```

Ex.1 non-air material

10 TeV proton shower



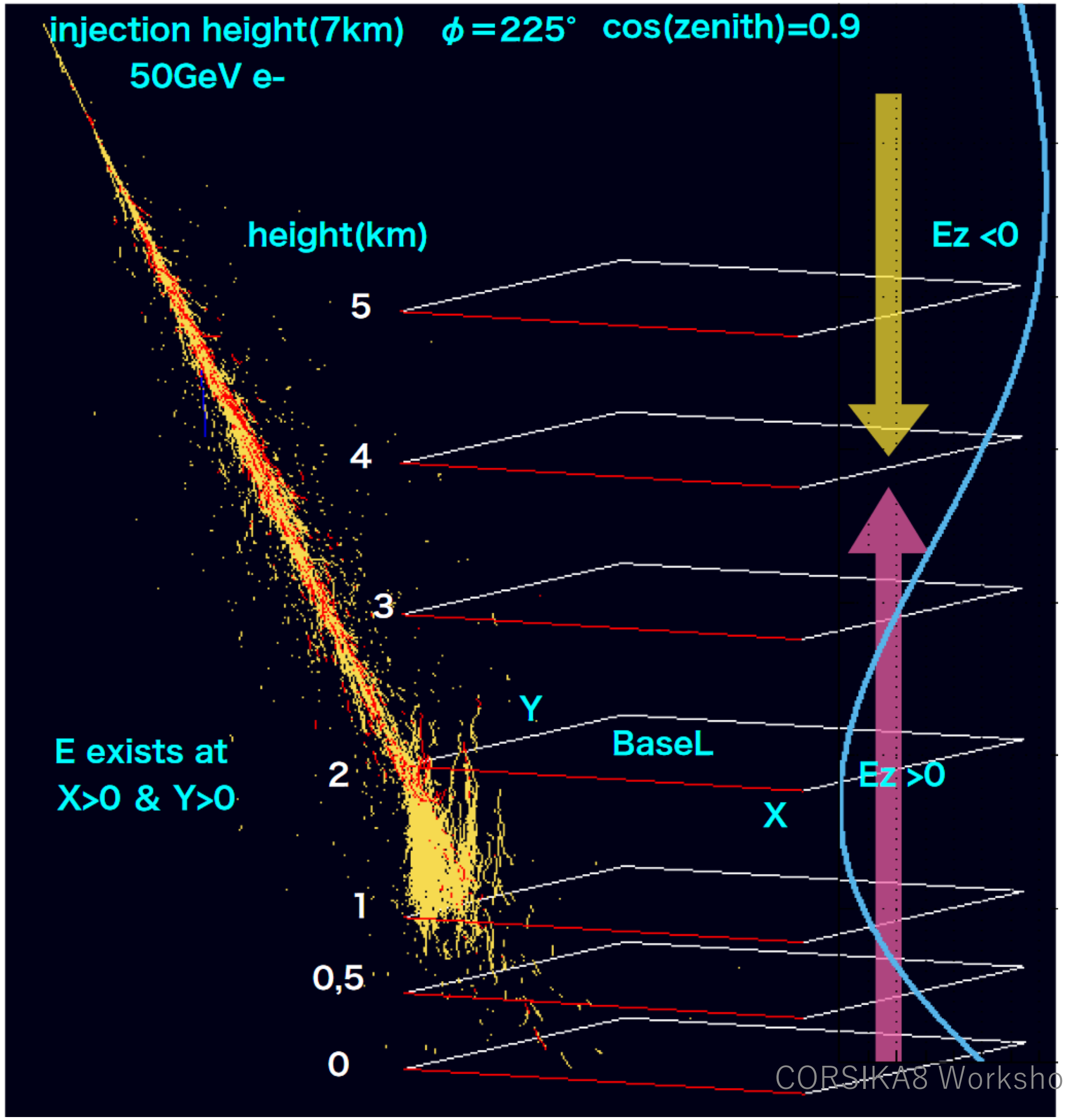
Atmosphere structure
with water tank under ground
(Y8JAir.d,partial)

```
# height(m)   Temp(K)      ) density(kg/m3)   media
#-----------------------------------------------------------------
              4.0e3   269.        9.15e-1    SiO2
              4294.7  259.5        0.79255    concrete
              4295.0  259.5        0.79255    H2O
              4296.5  260.        0.79255    Air
              4297.4  260.        0.7925    concrete
              4297.7  260.        0.7925    SiO2
              4300    260.        0.7925    Air
              6.e3            249.187       6.6011e-1
              11.1e3          216.65        0.35932
...
```

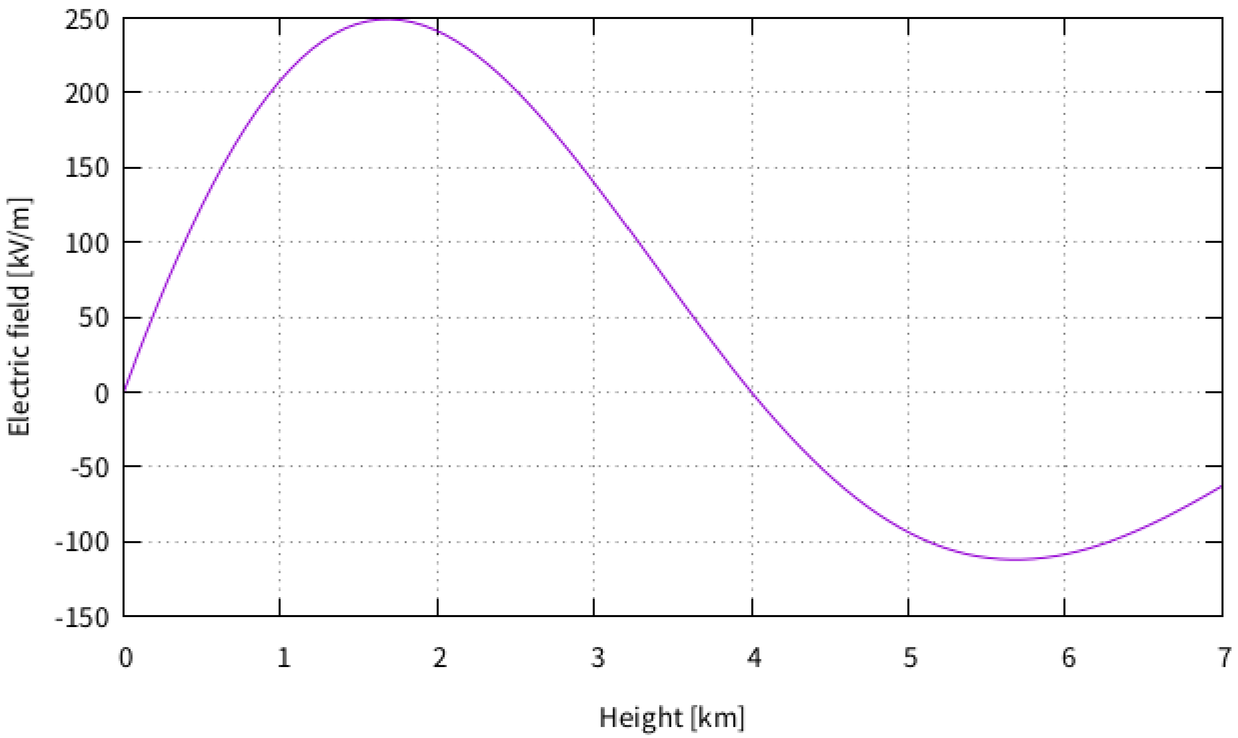
Parameter file
(partial)

```
AtmosFile="Y8JAir.d"
 DpmFile ="dpmjet.inp"
 AtmosModel = 1
```

Ex.2 Electric field

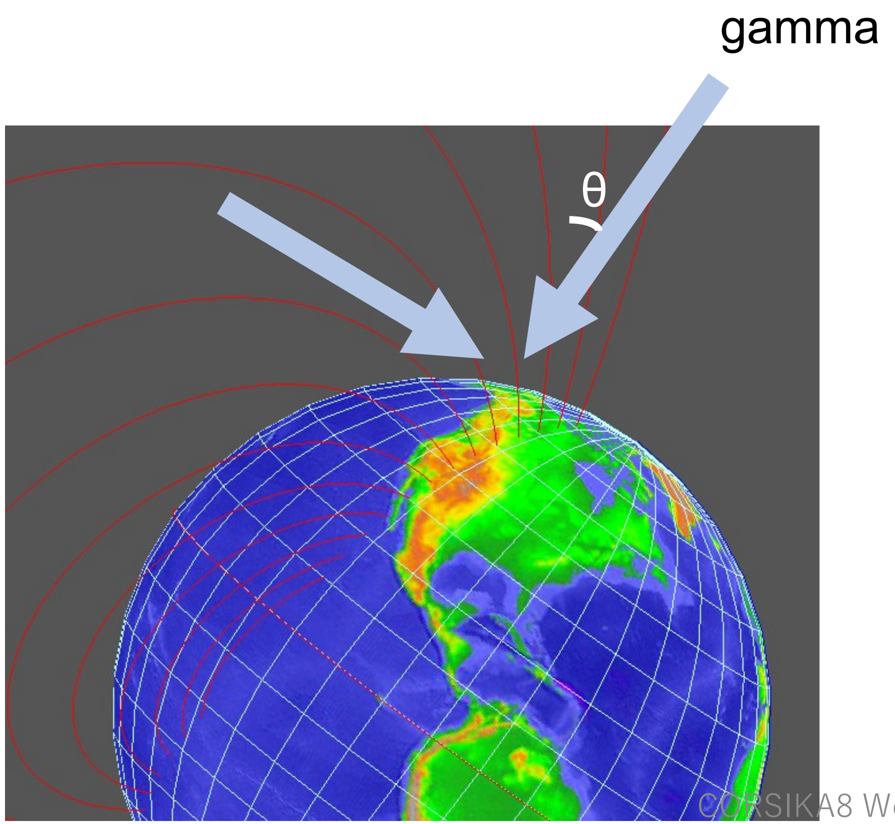


Arbitrary electric field is defined in cmyEfield.f for x,y>0



Ex.3 UHE gamma in geomag.(1)

Probability of pair creation in geomag. changes depending on Bsinθ



To see the effect on gamma shower by geomag field quickly, showers by low energy electron are calculated analytically. (“Hybrid AS”)

Parameter file (partial)

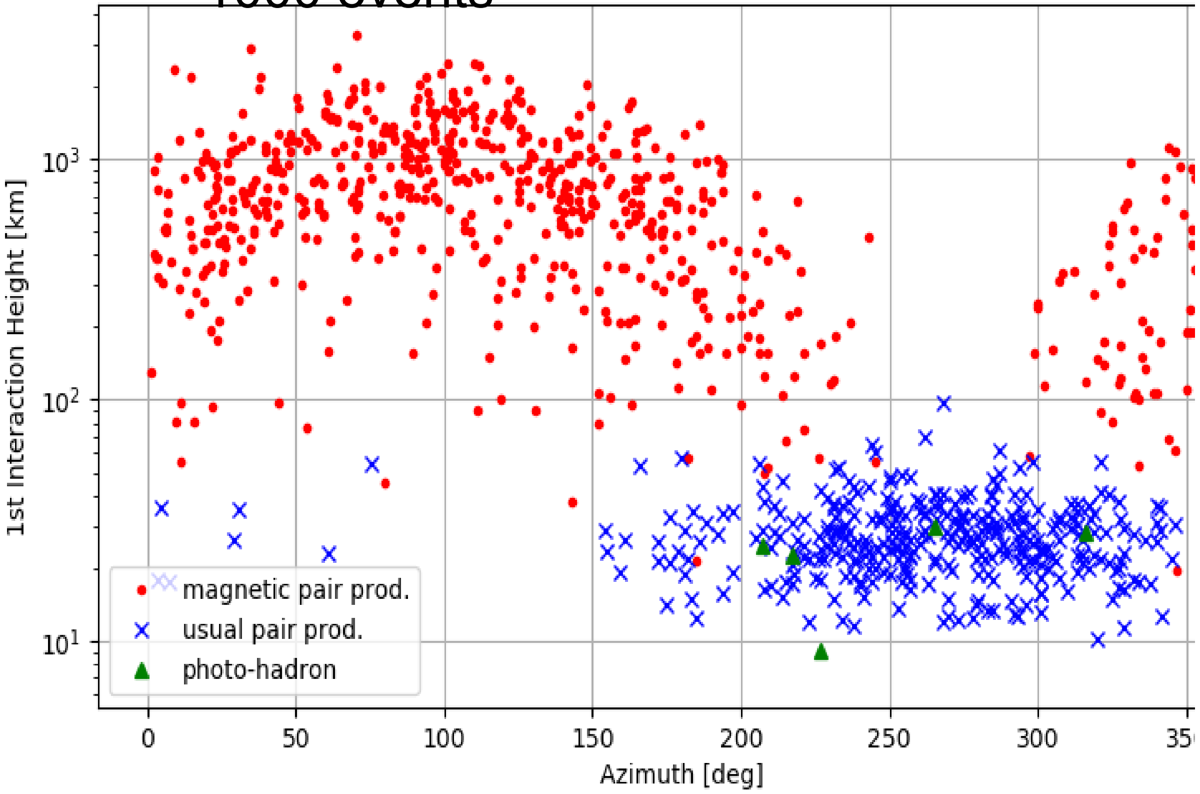
```
Generate ='as'

HeightOfInj = 5000e3,
LatitOfSite = 39.3
LongitOfSite = -112.9
LpmEffect = T,

WaitRatio = 0.005
```

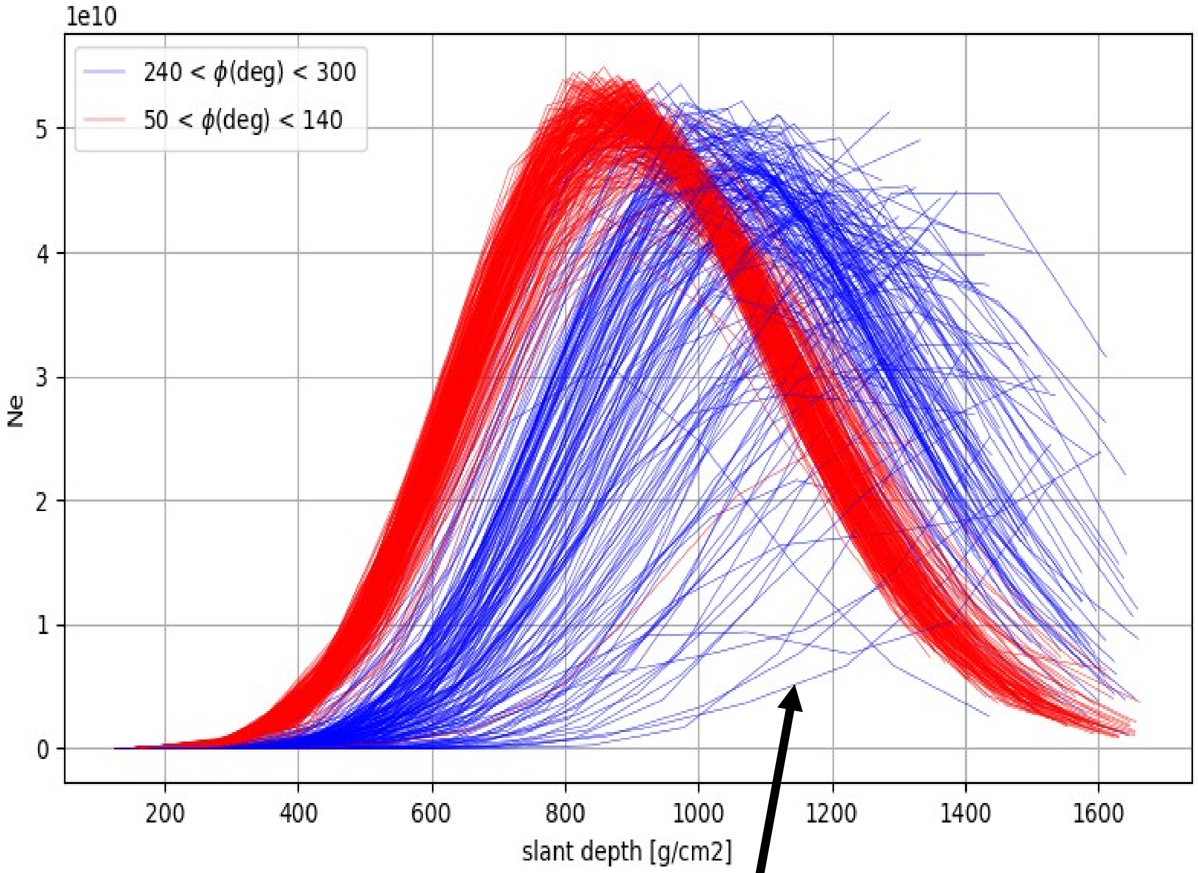
←if electron energy is low enough, use analytic solution

←The threshold energy to use analytic solution. Eth=Eprimary*WaitRatio

Ex.3 UHE gamma in geomag.(2)

E=7x10^{19}eV
cos(zenith)=0.6~0.8
1000 events

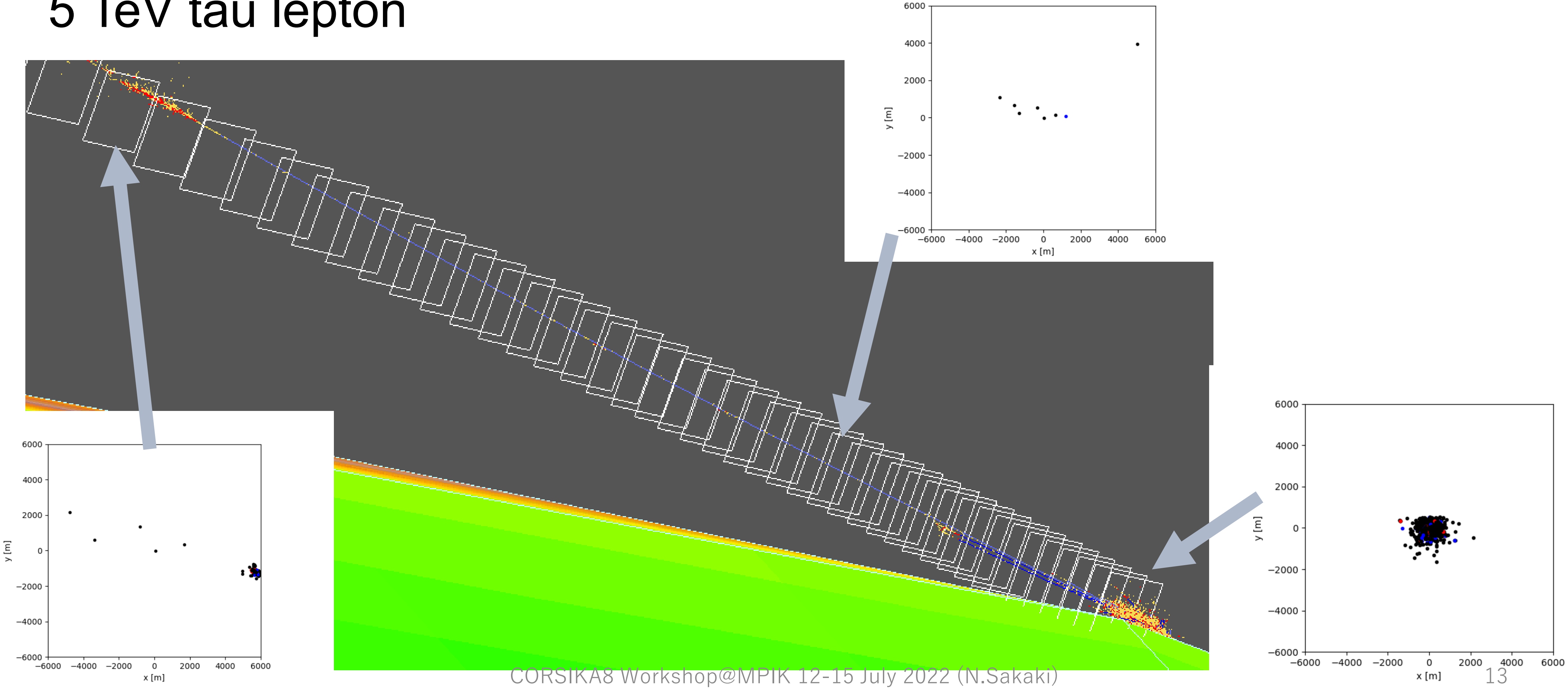




Development suppressed by LPM effect

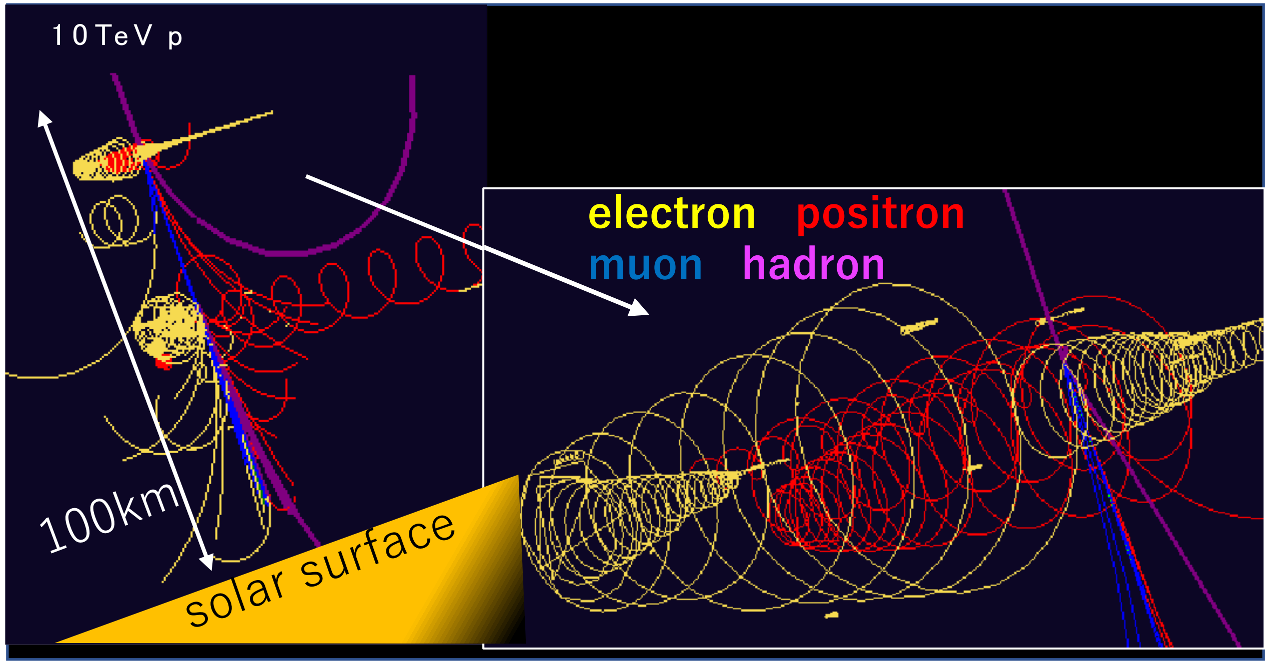
Ex.4 Upgoing tau shower

5 TeV tau lepton



Applications

- Cascade shower at Sun, other planets,…



- Neutrino observation under ground, water, ice
- Cascade shower in thunder clouds
- …

Summary

- COSMOS X is combination of air shower (COSMOS) and detector (EPICS) MC simulation tools.
- Applicable environment:
  - Non-air material: any gas, liquid, solid
  - Under arbitrary magnetic and electric fields
  - Non-earth conditions: Sun, Mars, Jupiter, SNR,…
- http://cosmos.icrr.u-tokyo.ac.jp/COSMOSweb/