Measurement of light composition energy spectrum with the LHAASO experiment

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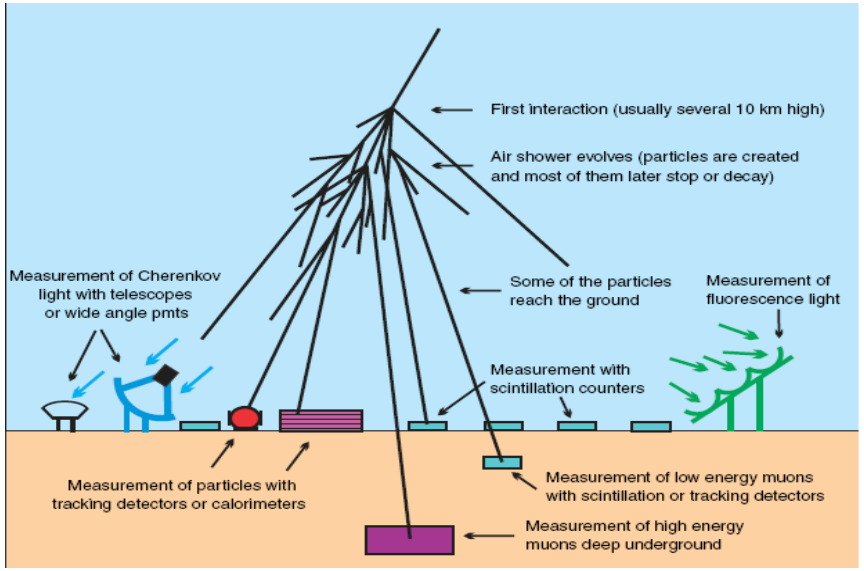
Outline

Background

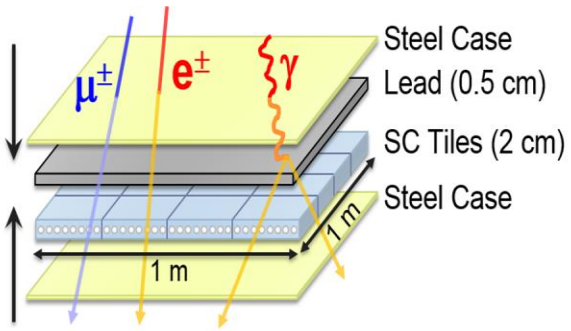
Due to the low flux, CRs with energies higher than 100TeV can only be detected by ground-based experiments.

Their primary energies and composition is unknow . It can only be reconstructed based on characteristics of the hadronic showers.

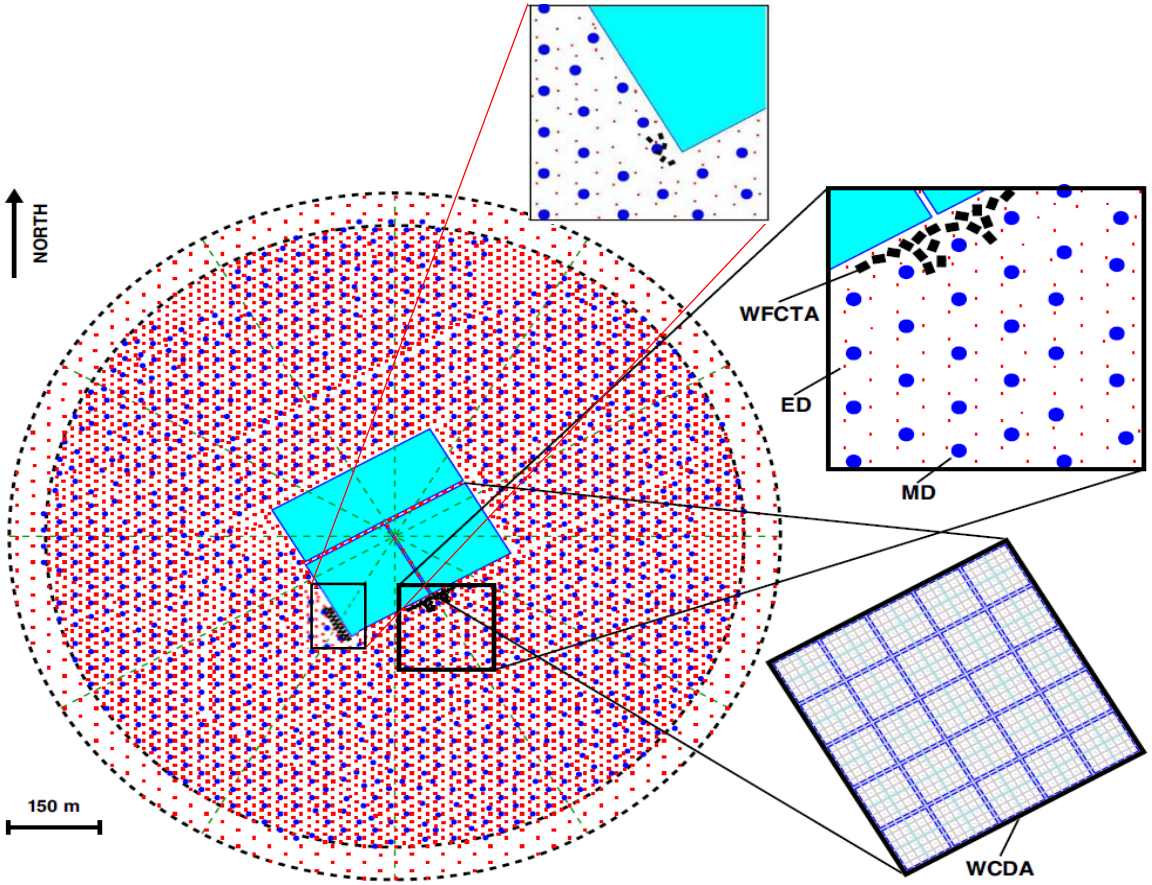


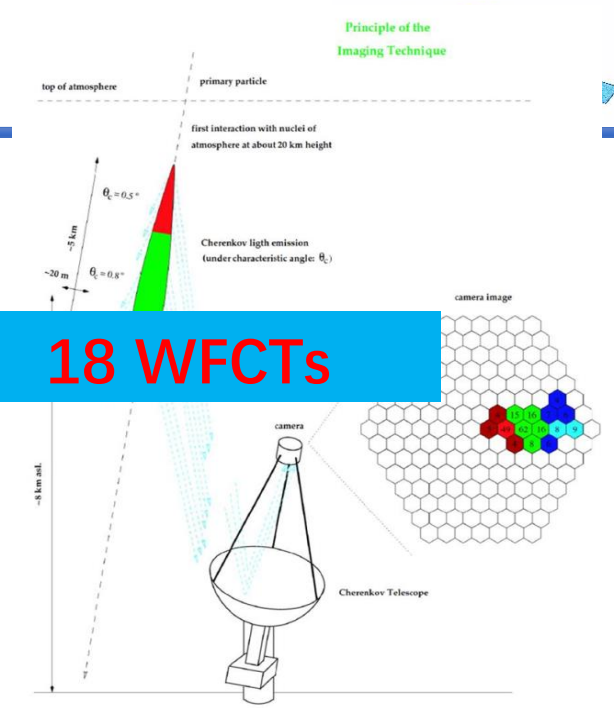
- The absolute energy scale is uncertain
- Composition and energies are dependent on each other
- Dependent on hadronic models
- Composition discrimination is difficult
- Can LHAASO solve these difficulties?

LHAASO INTRODUCTION



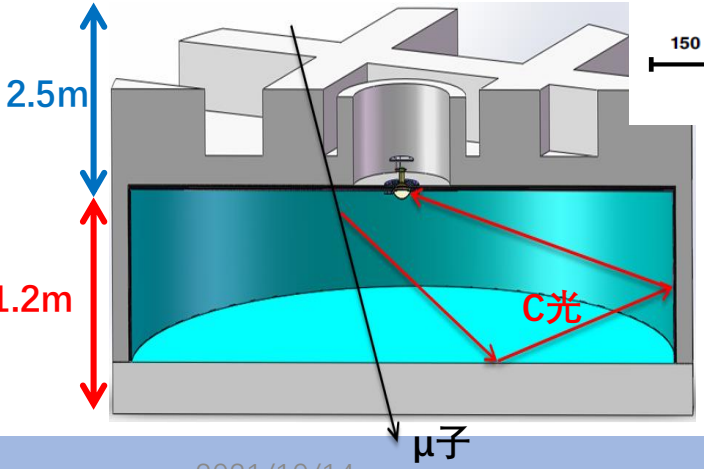
5195:**EDs**



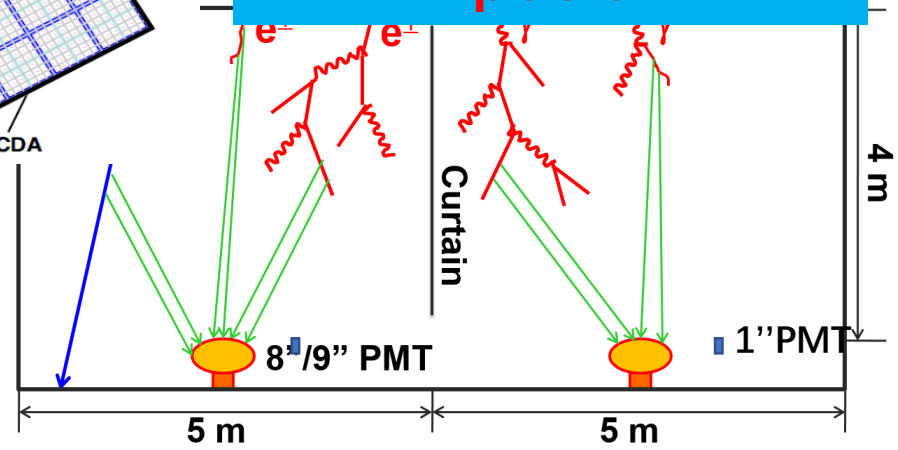


18 WFCTs

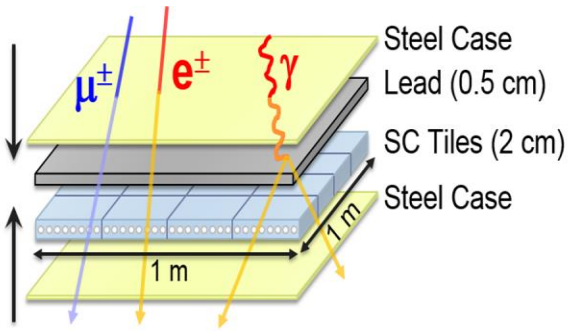
1171**MDs**



3 WCDA water pools



LHAASO INTRODUCTION



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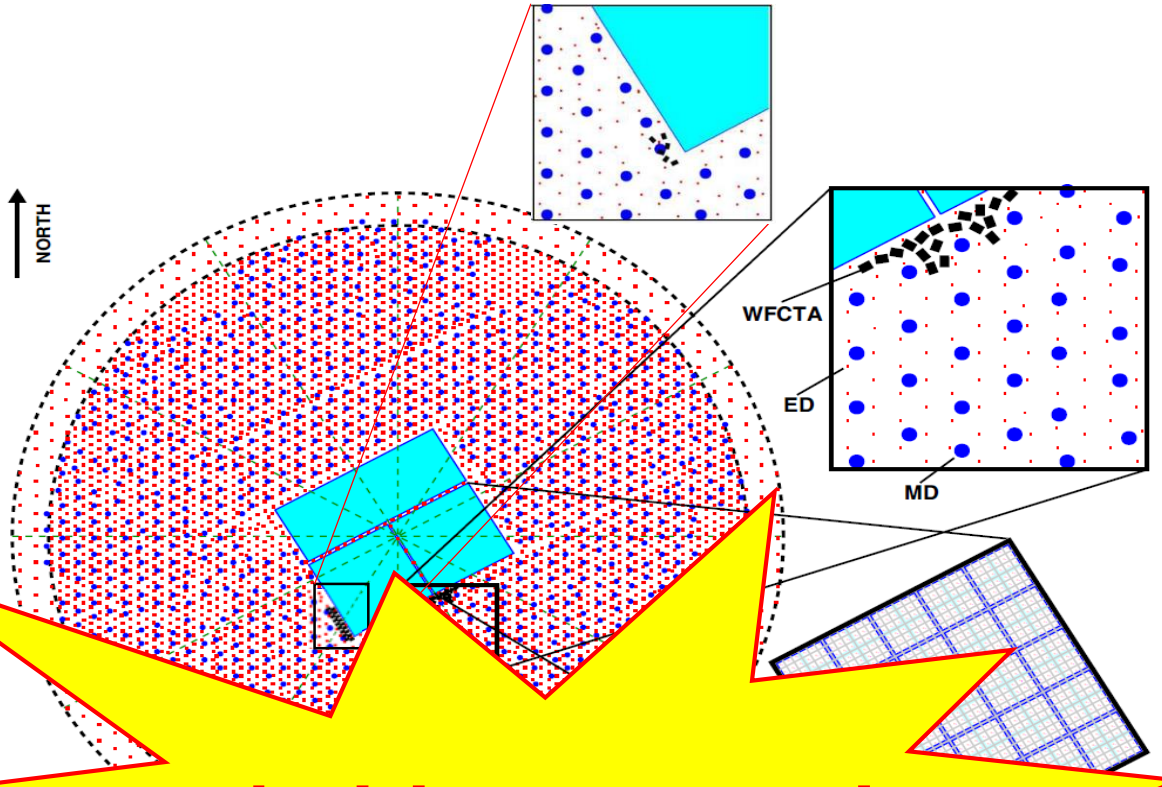
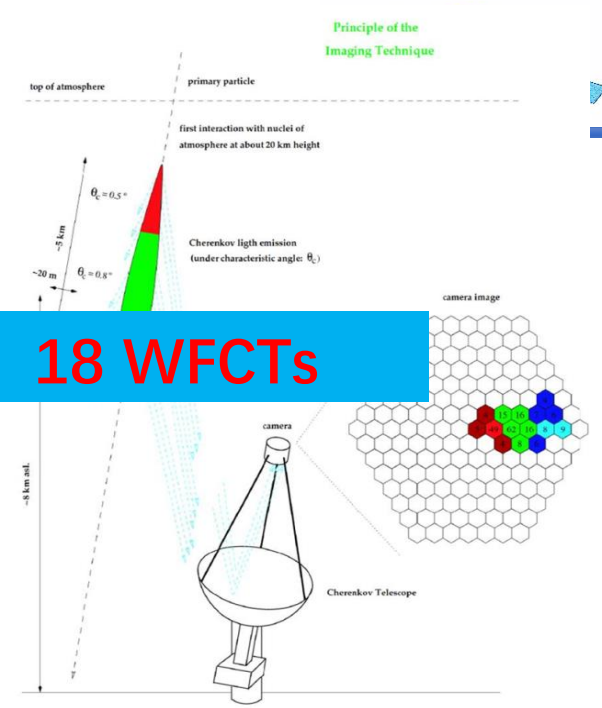
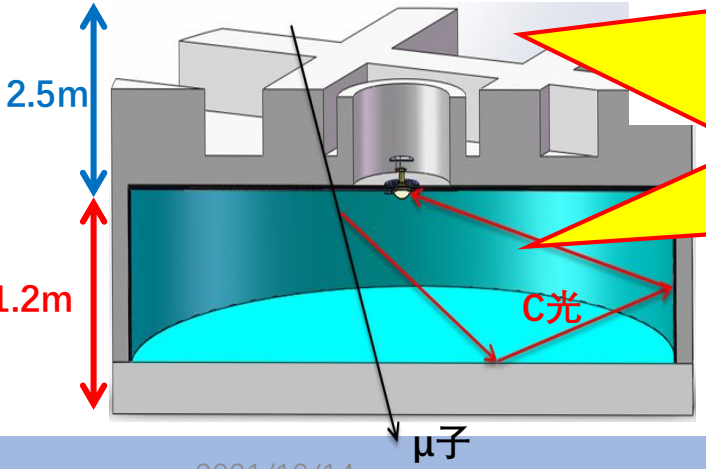




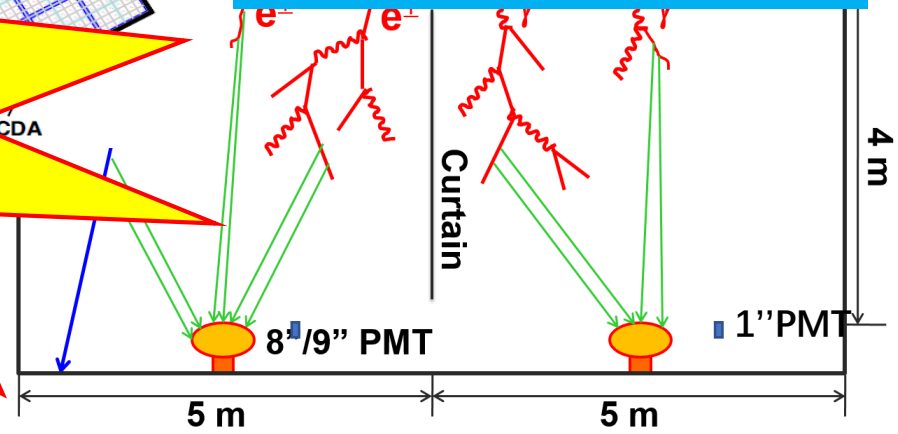
18 WFCTs

3 WCDA water pools

1171**MDs**



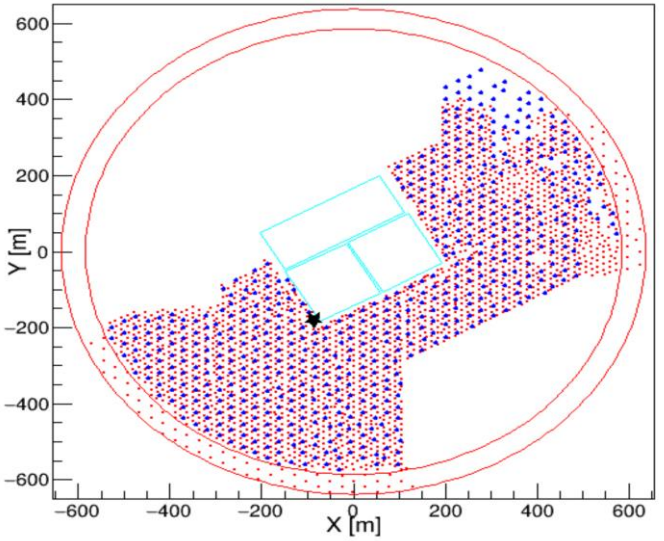
Hybrid detectors provide multi-parameter

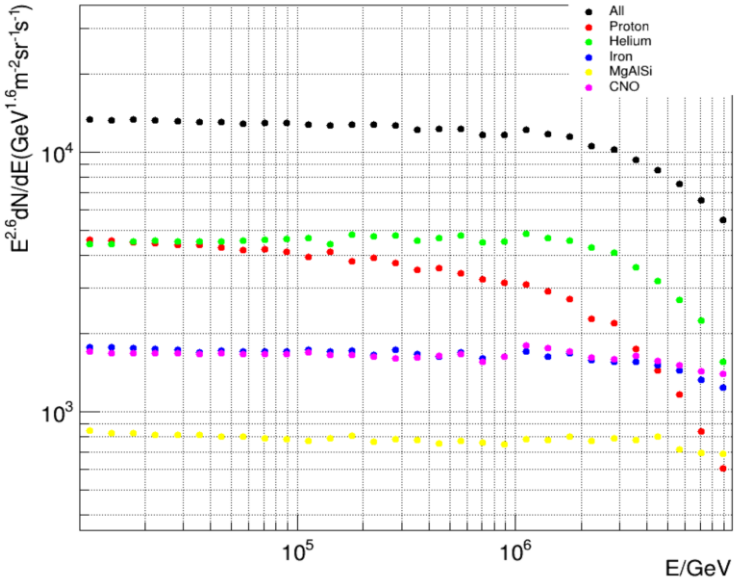


Data introduction and Comparison

- **Introduction to experiment**
  - Date: 2020.11.1-2020.11.30;2021.1.1-2021.2.28
  - Weather: clear and moonless night
  - Effective observation time: 189.6h

- **Introduction to MC**
  - Joint data:6 $WFCTA$ && $\frac{1}{2}KM2A$
  - Energy:10TeV-10PeV
  - Composition: Proton Helium Iron CNO MgAlSi
  - Hadronic interaction model: QGSJET_FLUKA
  - Zenith:$20^{\circ}\sim40^{\circ}$ && Azimuth:$-85^{\circ}\sim95^{\circ}$
  - Sampling area:$\pm$300m
  - Spectrum index： -1
  - Composition model : Gaisser model





Data introduction and Comparison

Event selection

KM2A array :

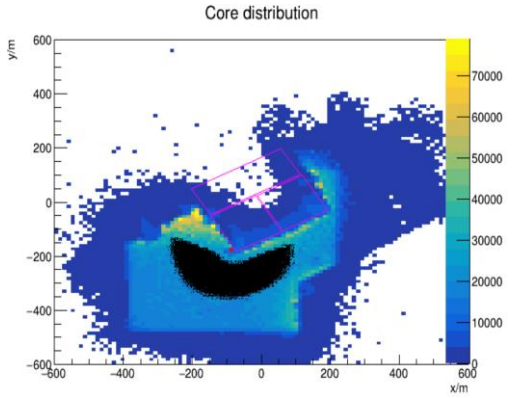
- Successful reconstruction : $theta_{rec} > 0$
- Trigger detector : $NtrigE > 20$
- Number of muon (40-200):$Nu > 0$
- Number of Electromagnetic particle : $NpE2 > 20$ && $\frac{NpE1}{NpE2} > 2$

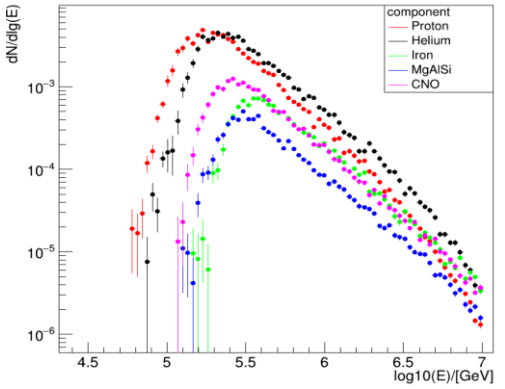
WFCTA array :

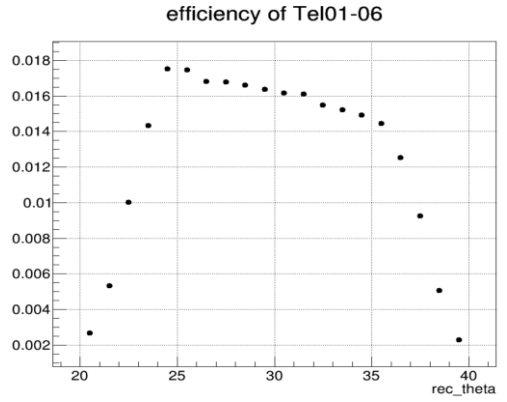
- Npix of Cherenkov image : N$pix > 10$

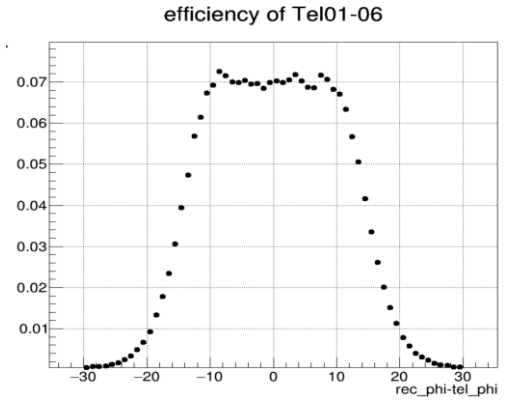
Geometry Filter :

- Reconstruction core: cut pool edge events && cut events far from telescope: $\sqrt{(x+86)^2+(y+180)^2} < 200$
- The distance from the telescope to the center of the shower : $50m < RecR_p < 150m$
- $25° < theta_{rec} < 35°$ && $-10° < phi_{rec} - phi_{tel} < 10°$





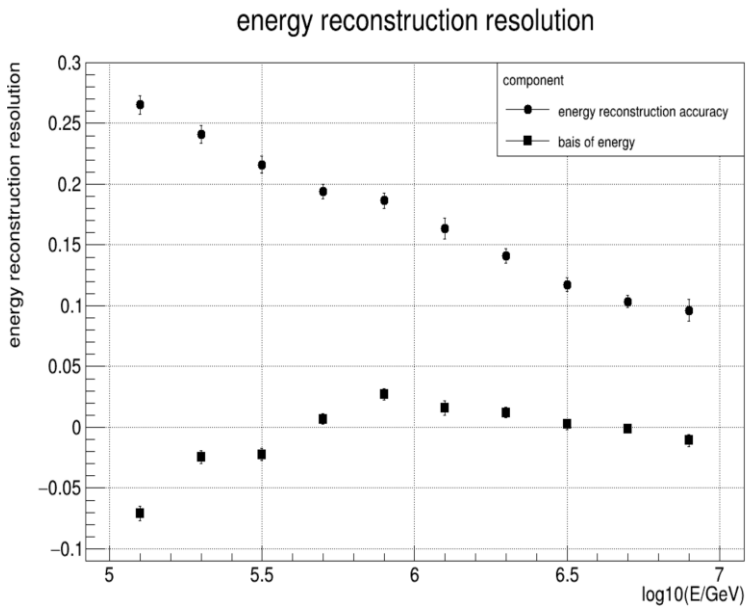


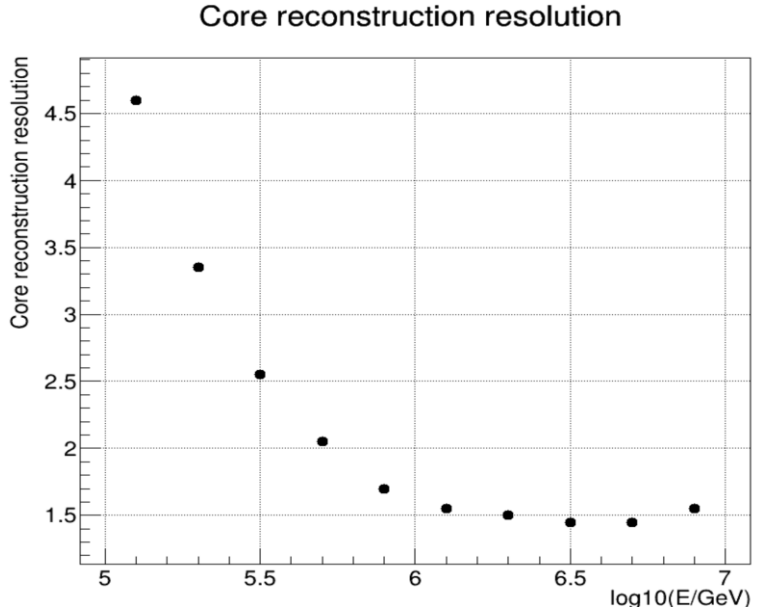


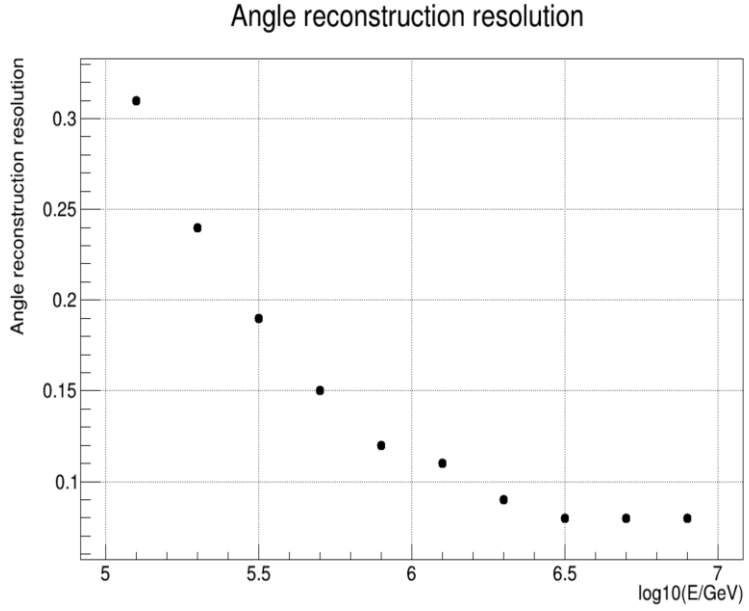
Data introduction and Comparison

- **Reconstruction resolution after filter**

$$(E_{rec} = \frac{1}{1.013} \times (log10\sqrt{ANpE2 \times ANuM3} + 1.722))$$



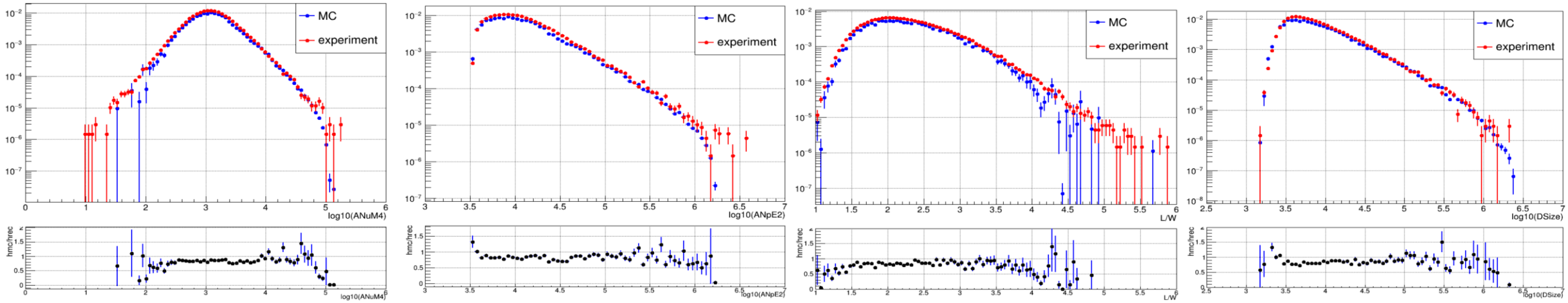




※ Resolution of energy reconstruction is 15% with energy higher than 1PeV
※ Resolution of core reconstruction is 1.5m with energy higher than 1PeV
※ Resolution of angular reconstruction is 0.1° with energy higher than 1PeV

◌ The reconstruction resolutions are improve with energy increasing

Comparison between simulation and data



- ✓ ANuM4: In circle 30-380; density of muon * area
- ✓ ANpE2: In circle 40-200; density of Electromagnetic particles * area
- ✓ $\frac{Length}{Width}$: Length and width ratio of Cherenkov image
- ✓ Size: Total size of Cherenkov photons detected by WFCTA

- MC simulation and data are consistent within 25%
  - Event rate of MC :0.14Hz ; event rate of experiment :0.16Hz

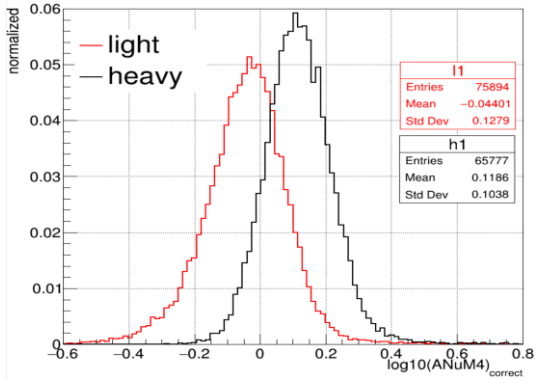
Parameters sensitive to compositions

I. Sensitive parameter in KM2A array: Muon $(\mathrm{N}_\mu = A(\frac{E}{\mathrm{AC}})^\beta = A^{1-\beta}(\frac{E}{C})^\beta)$

N_μ is sensitive compositions, but energy dependent

Step1: reconstruct energy

Step2: energy correction for muon

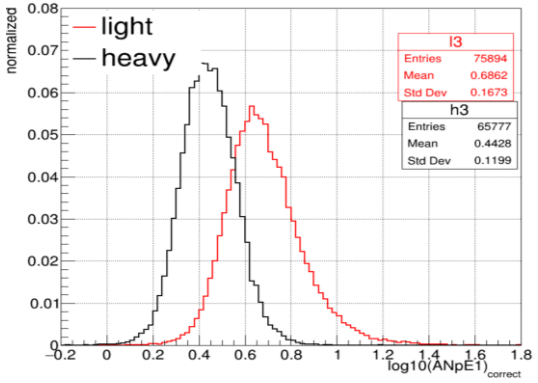


II. Sensitive parameter in KMA array: Electromagnetic particles

$\mathrm{N_e} \approx \frac{\mathrm{a}}{\mathrm{gE_c^e}}(\mathrm{AE_c^\pi})^{-\mathrm{b}}\mathrm{E_0^{1+b}}$

Step1: reconstruct energy

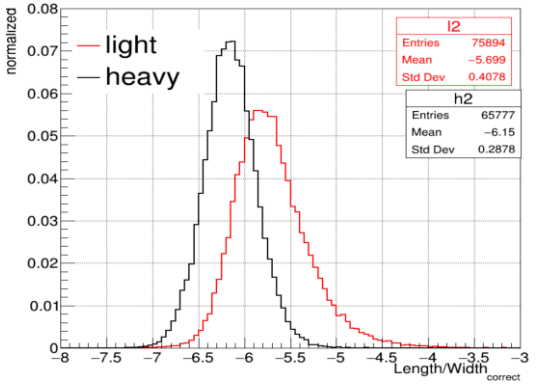
Step2: energy correction for electromagnetic particles



III. Sensitive parameter in WFCTA array: $\boldsymbol{\frac{Length}{Width}}$

Step1: Rp correction for $\frac{L}{W}$ && Rp correction for Size

Step2: After Rp correction , Size correction for $\frac{L}{W}$

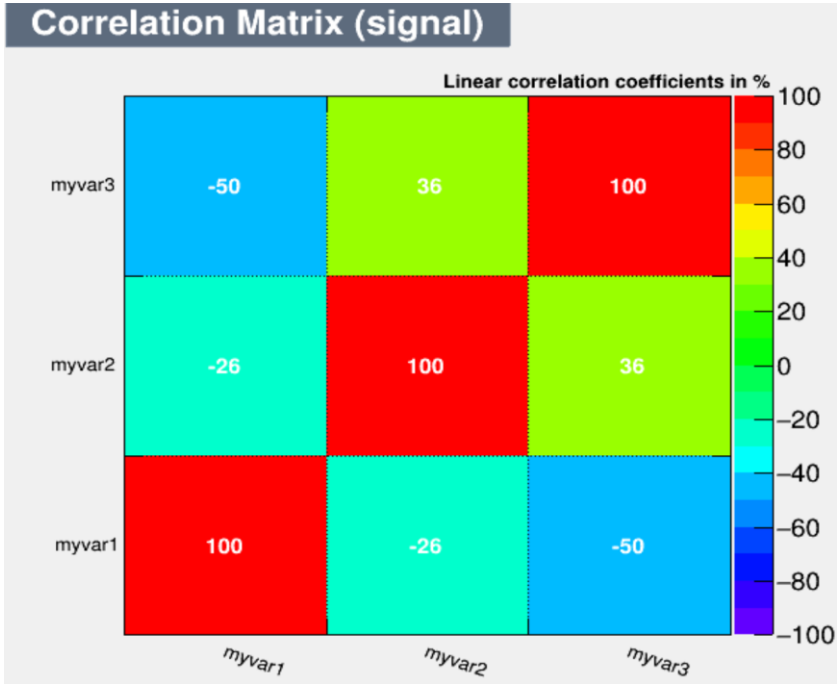


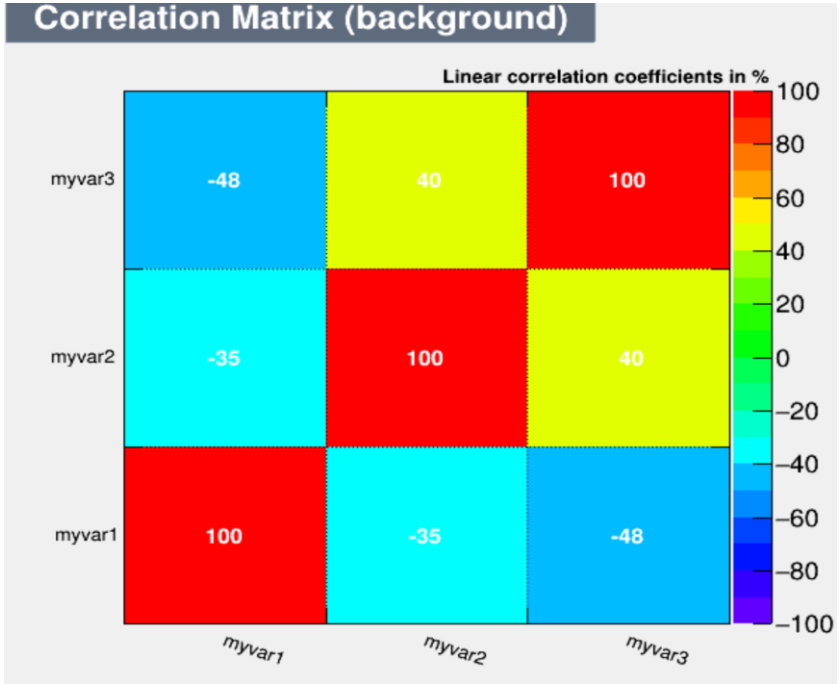
Multiple Variable Analysis(Classification)

Input variables

Signal : Proton + Helium
Background : Iron + MgAlSi + CNO

- Myvar1: $ANuM4_{correct}$
- Myvar2: $\frac{Length}{Width}_{correct}$
- Myvar3: $ANpE1_{correct}$

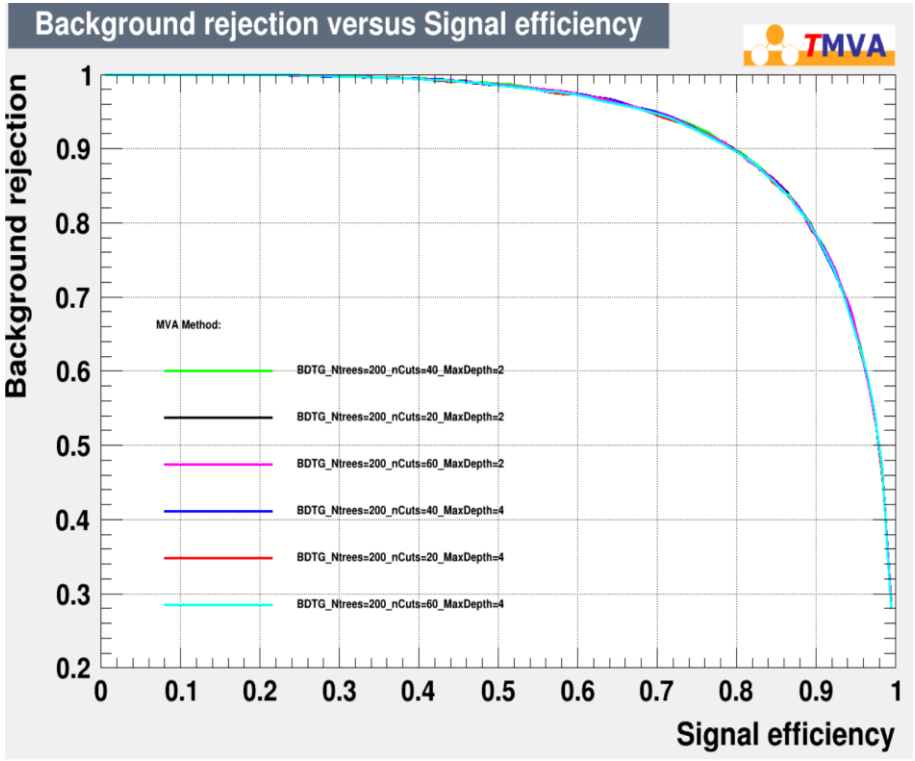




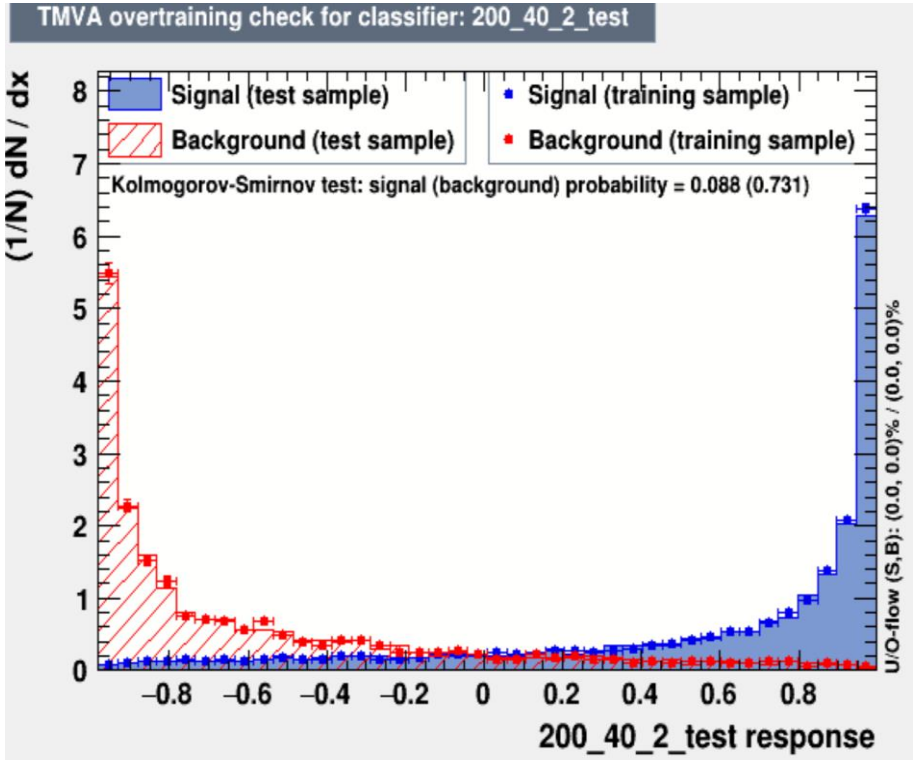
Weak correlation between the three variables

Multiple Variable Analysis(Classification)

Receiver Operating Characteristic(ROC)



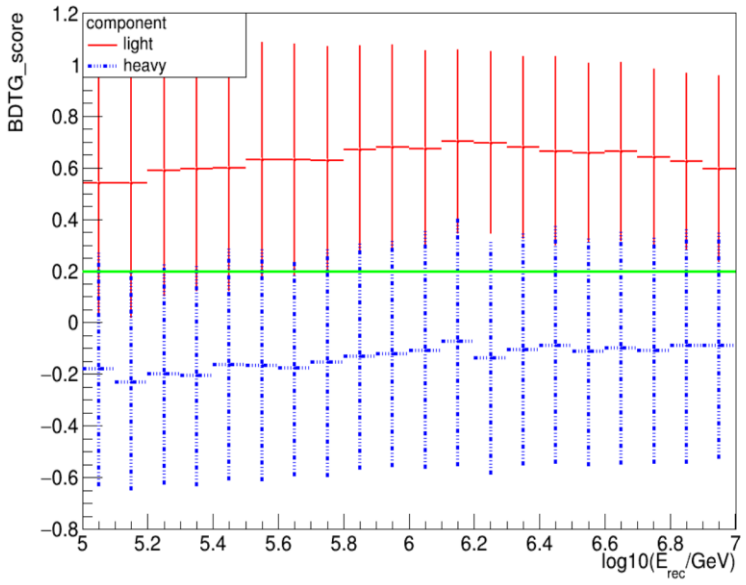
TMVA comparison

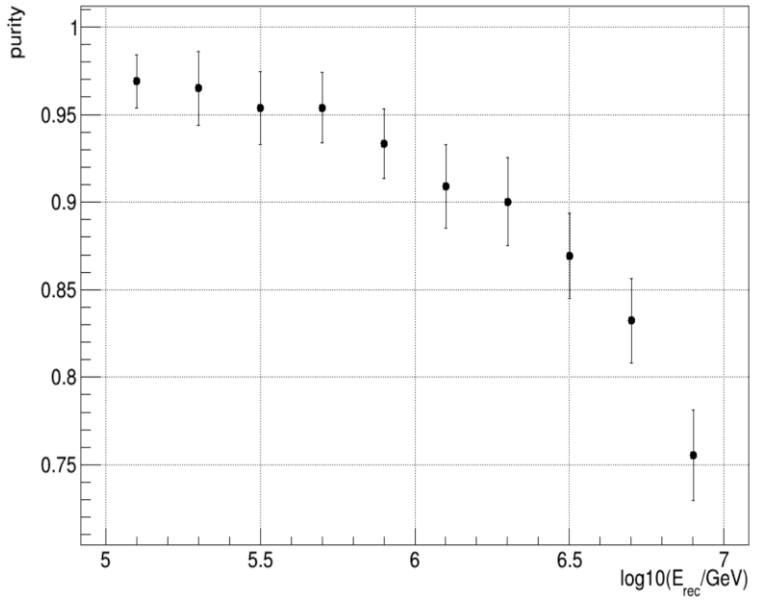


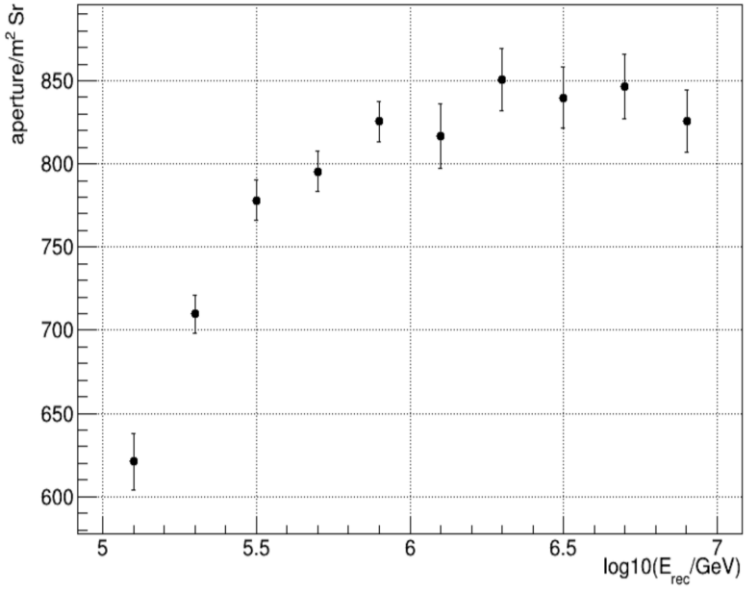
The training results are in good agreement with the test results

Multiple Variable Analysis(Application)

Input data:MC data





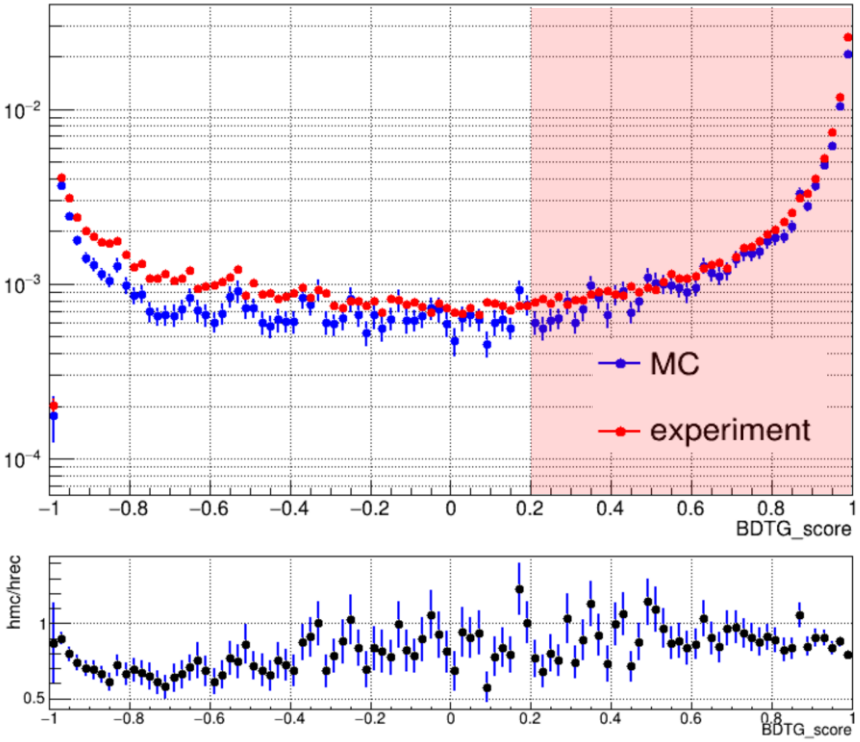


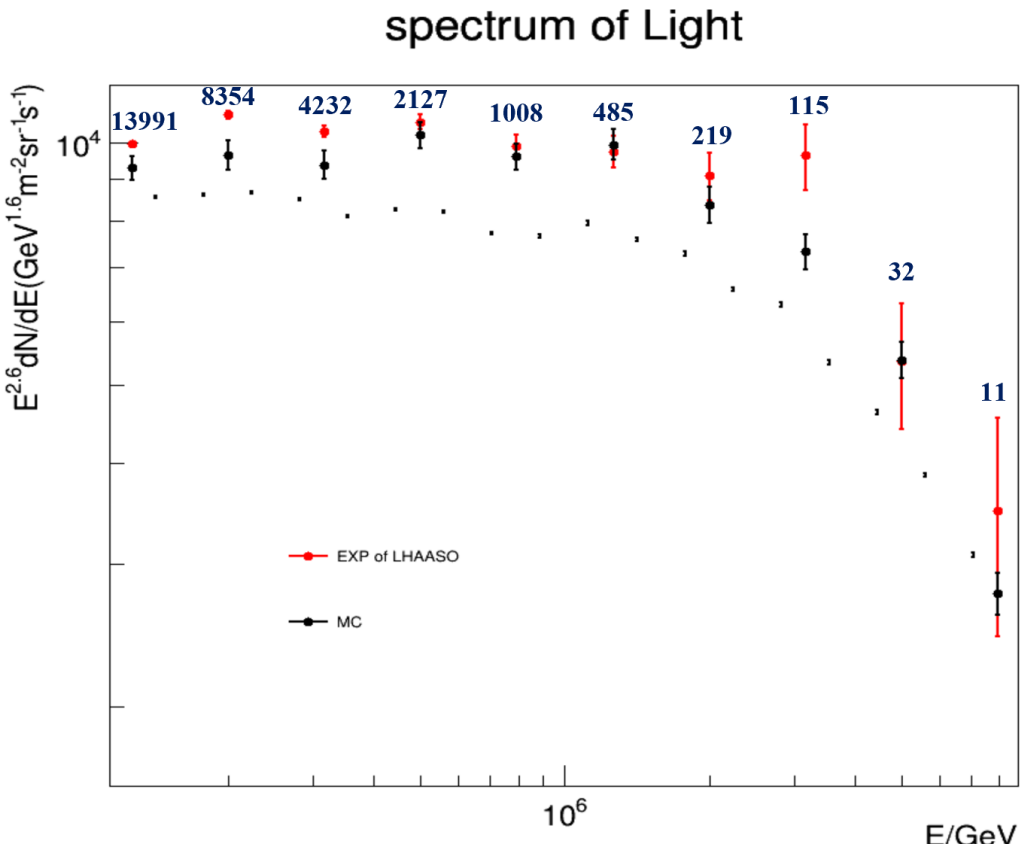
MVA cut: BDTG_score>0.2

$$purity = \frac{signal}{signal + background}$$

$$Aperture = \frac{event_{select}}{event_{throw}} \times S_{throw} \times \Omega$$

Identify experiment data by MVA





- ✓ Score distribution of experiment and MC
- ✓ Preliminary results of light component energy spectrum

Summary and next step

Summary:

- Purity of light compositions decrease in high energy Maybe:
  - * poor identification of L/W in high energy
  - * The proportion of heavy nuclear components increases in high energy
- Purity >75% and Aperture ≈850($m^2 Sr$)
- BDTG_score is related to energy

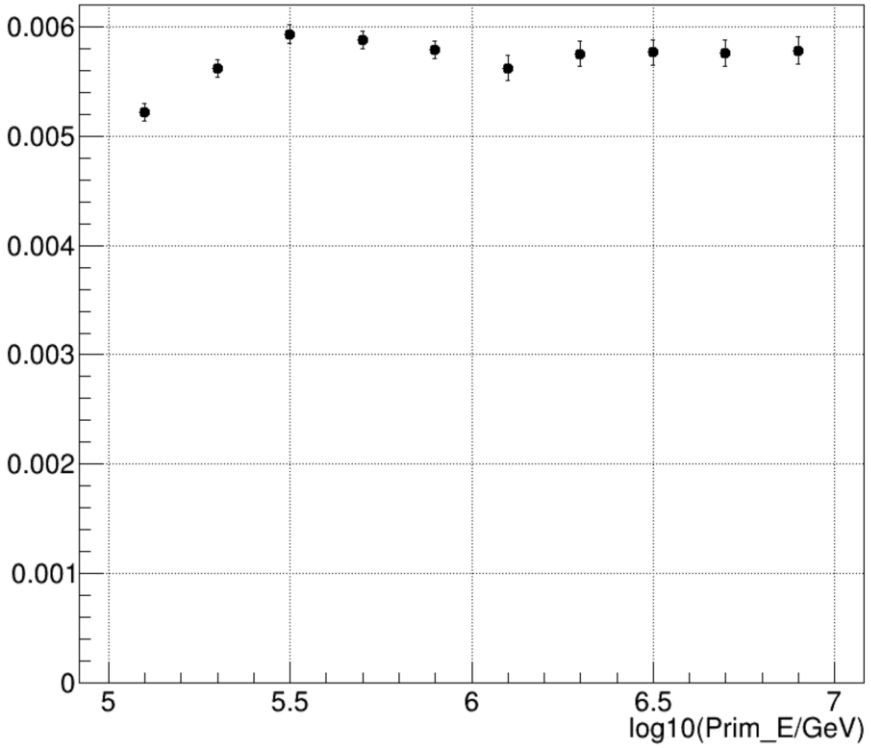
Next Step:

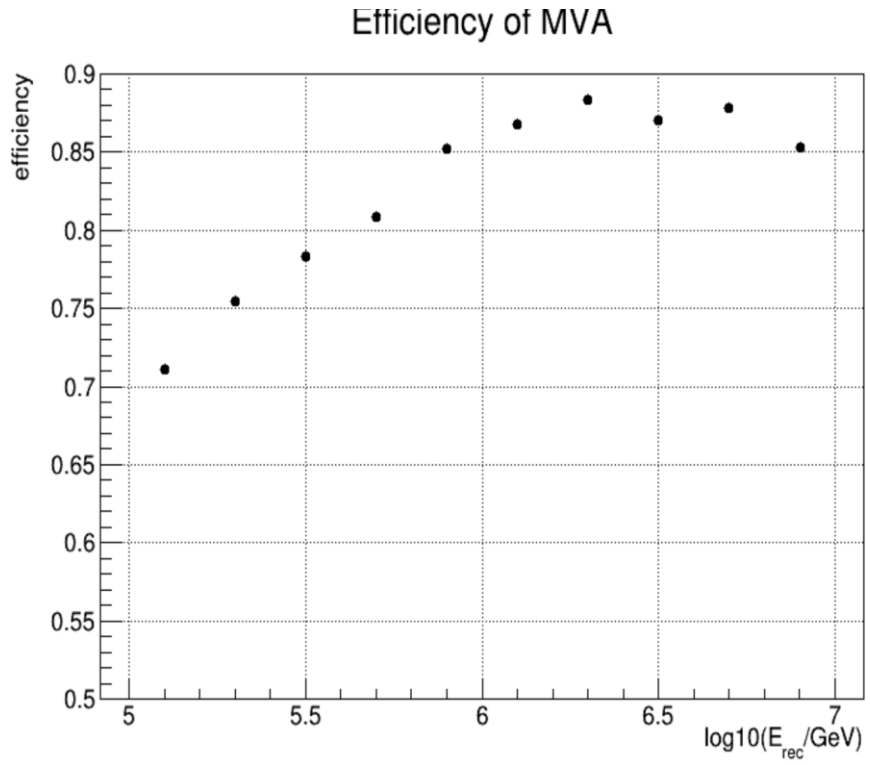
- Use the combined data from six telescopes to measurement light composition energy spectra
- Improve MC data of WFCTA
- Study other variables to identify compositions
- Study system uncertainties caused by composition models and hadronic models

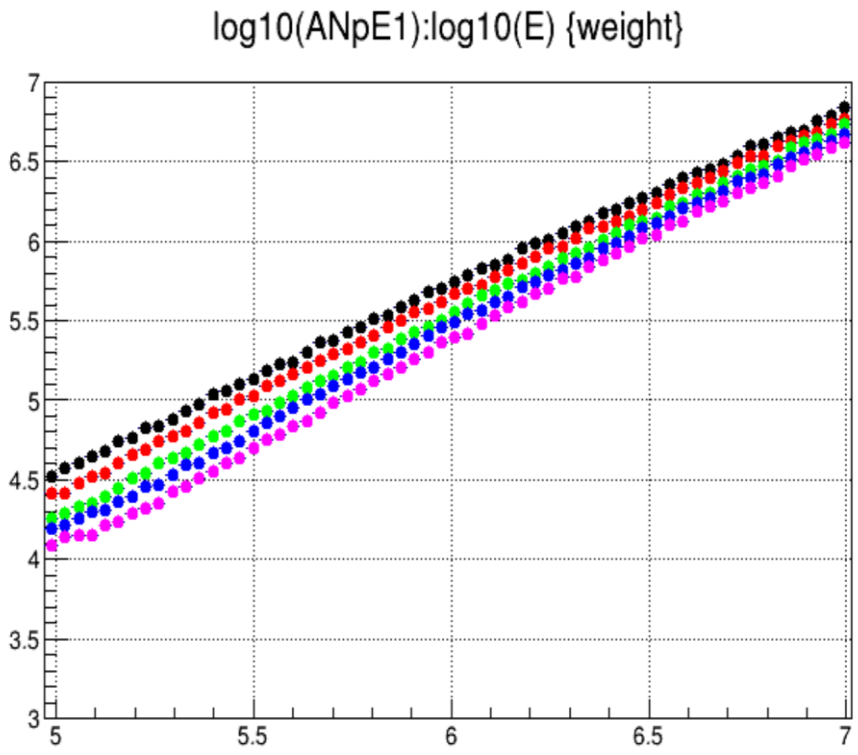
THANKS

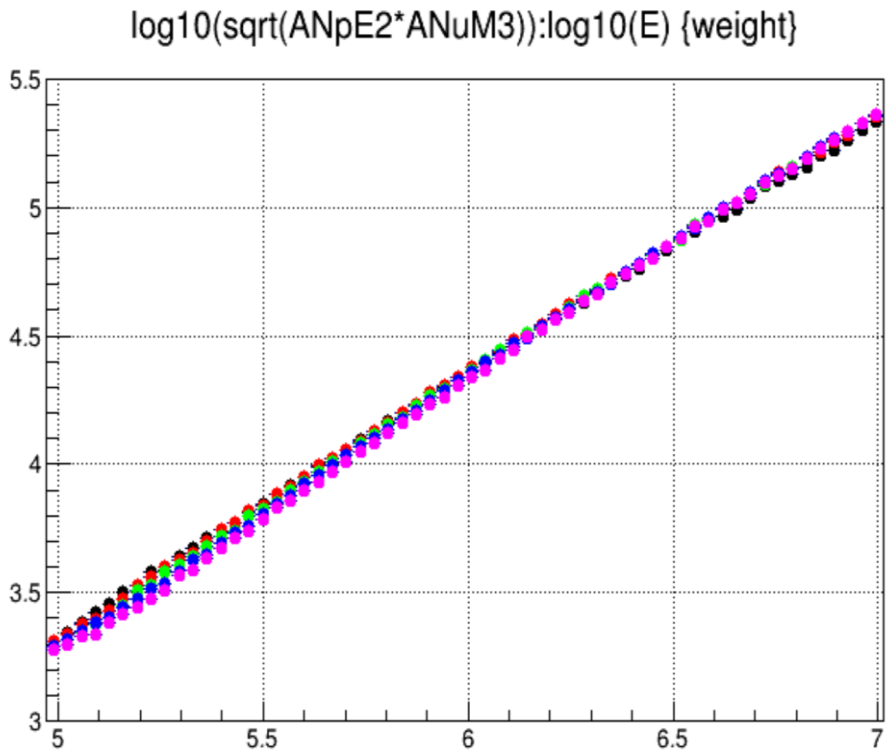
BACK UP

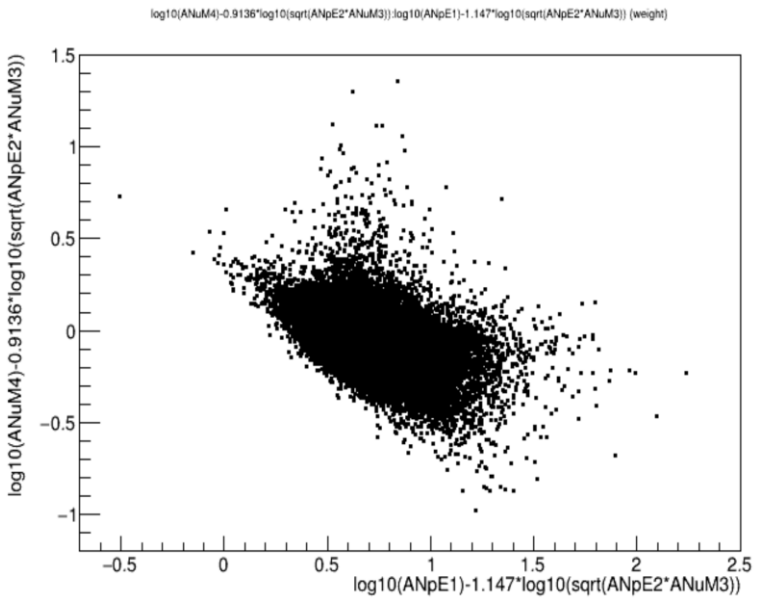
事例挑选效率和MVA挑选效率

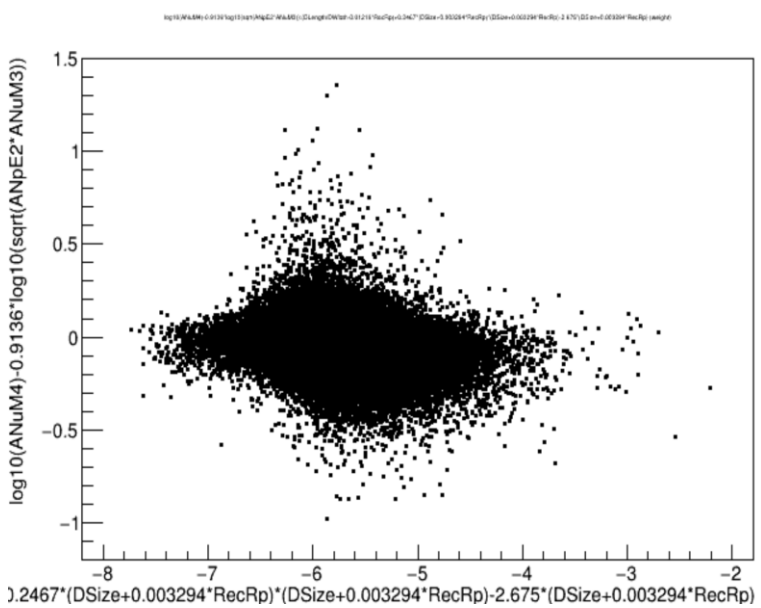


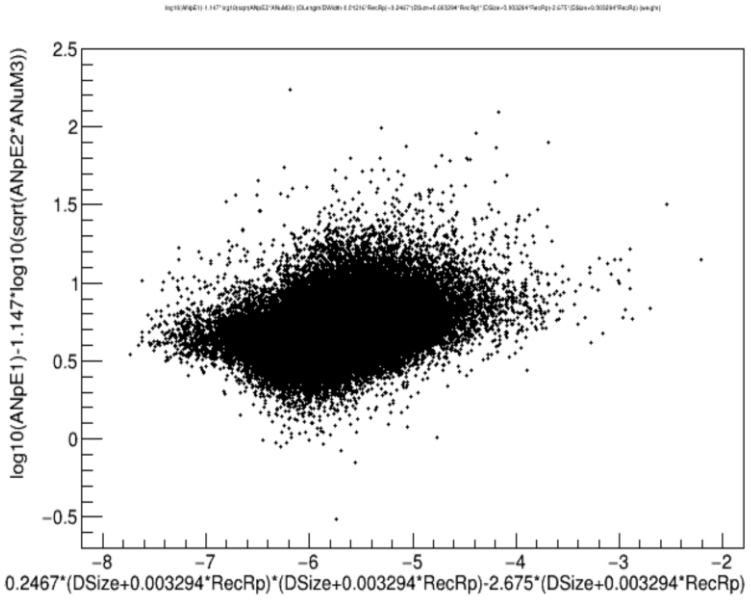


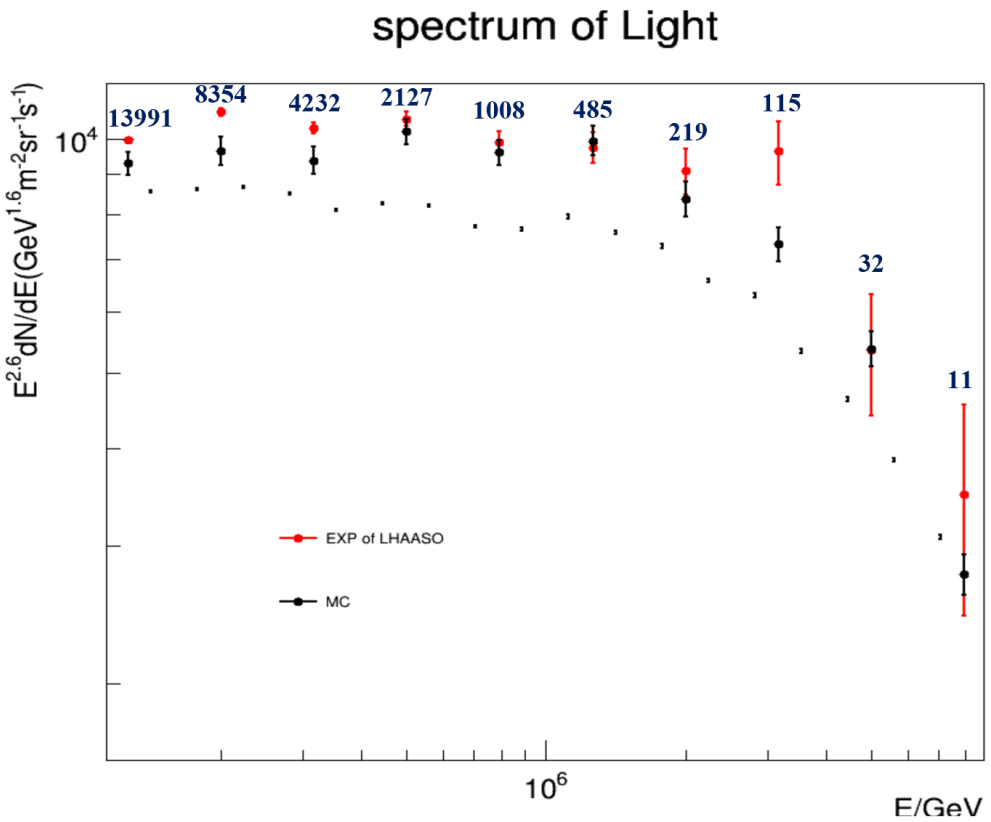

log10(ANpE1):log10(E) {weight}
7
6.5
6
5.5
5
4.5
4
3.5
3
5
5.5
6
6.5
7

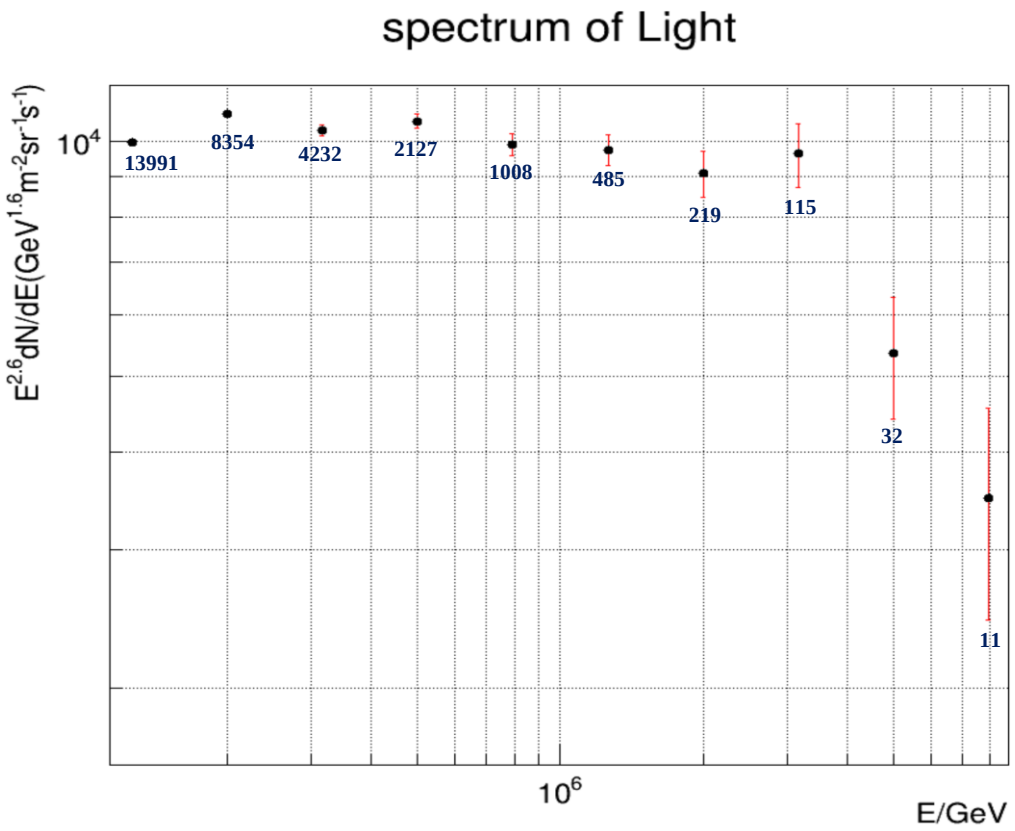

log10(sqrt(ANpE2*ANuM3)):log10(E) {weight}
5.5
5
4.5
4
3.5
3
5
5.5
6
6.5
7


log10(ANuM4)-0.9136*log10(sqrt(ANpE2*ANuM3)):log10(ANpE1)-1.147*log10(sqrt(ANpE2*ANuM3)) (weight)
log10(ANuM4)-0.9136*log10(sqrt(ANpE2*ANuM3))
log10(ANpE1)-1.147*log10(sqrt(ANpE2*ANuM3))

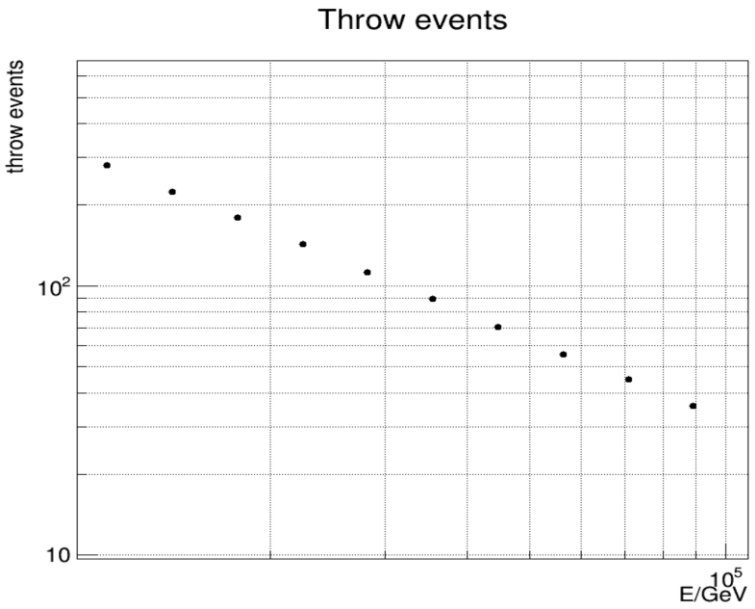

log10(ANuM4)-0.9136*log10(sqrt(ANpE2*ANuM3))
0.2467*(DSize+0.003294*RecRp)*(DSize+0.003294*RecRp)-2.675*(DSize+0.003294*RecRp)

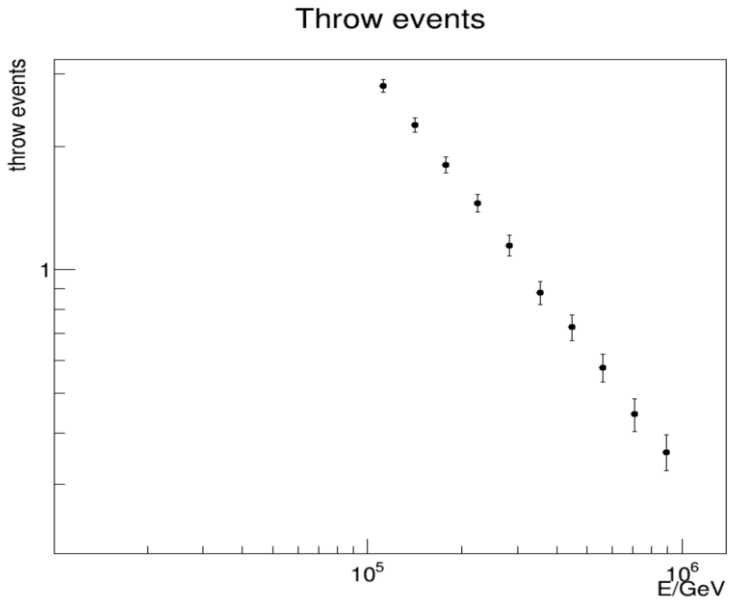

log10(ANpE1)-1.147*log10(sqrt(ANpE2*ANuM3))
0.2467*(DSize+0.003294*RecRp)*(DSize+0.003294*RecRp)-2.675*(DSize+0.003294*RecRp)

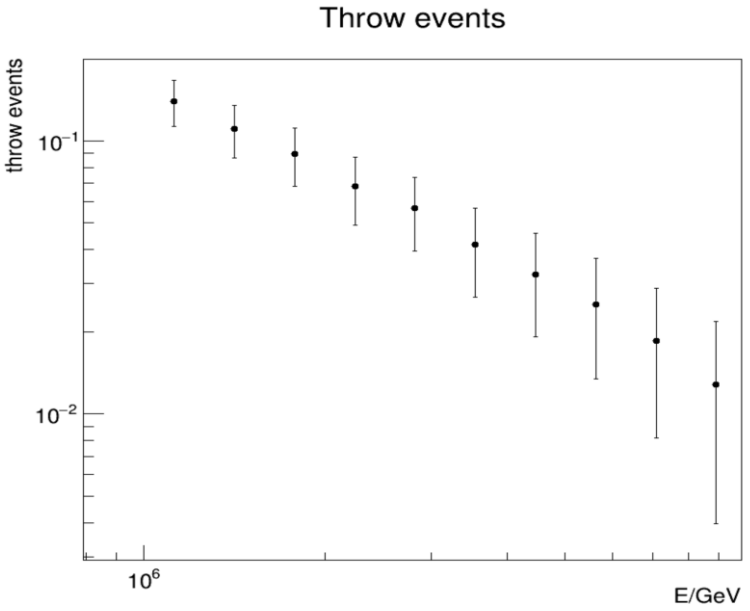

spectrum of Light
$E^{2.6}dN/dE(GeV^{1.6}m^{-2}sr^{-1}s^{-1})$
10^4
13991
8354
4232
2127
1008
485
219
115
32
11
EXP of LHAASO
MC
10^6
E/GeV


spectrum of Light
$E^{2.6}dN/dE(GeV^{1.6}m^{-2}sr^{-1}s^{-1})$
10^4
13991
8354
4232
2127
1008
485
219
115
32
11
10^6
E/GeV

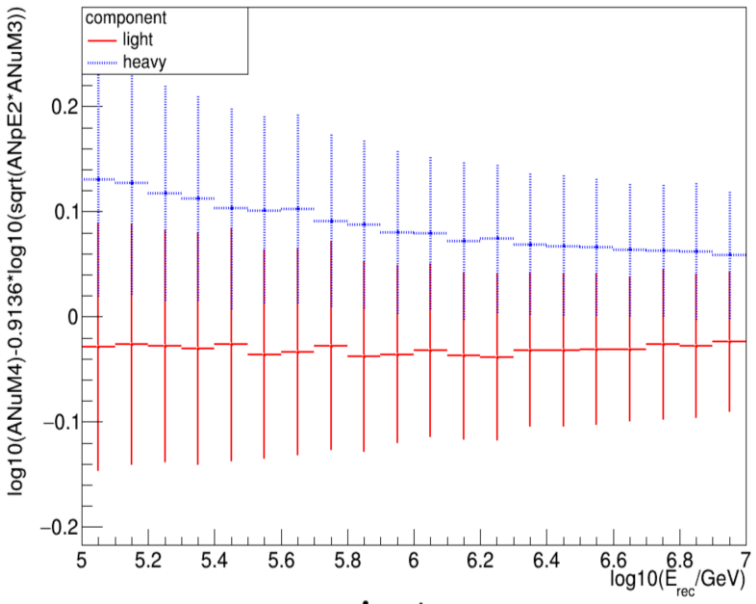
Throw events of Light composition

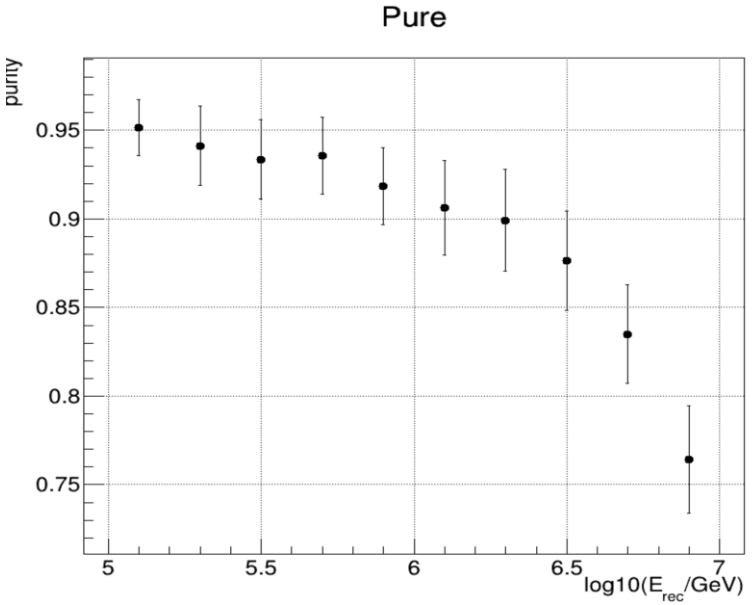


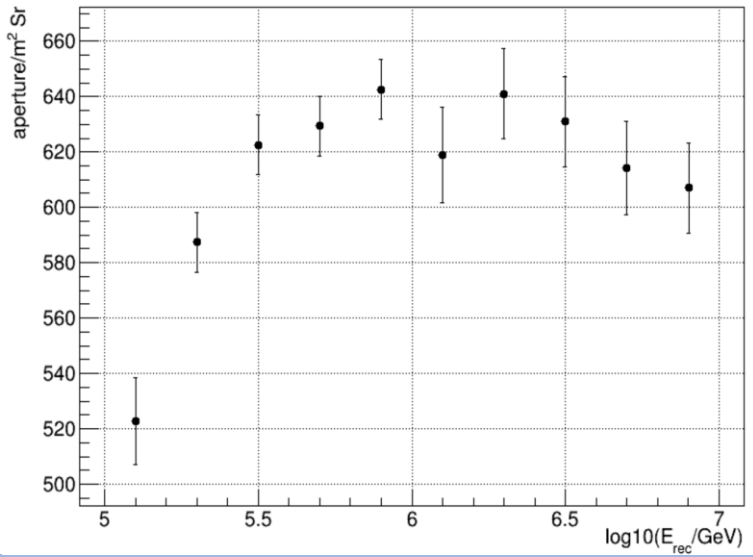


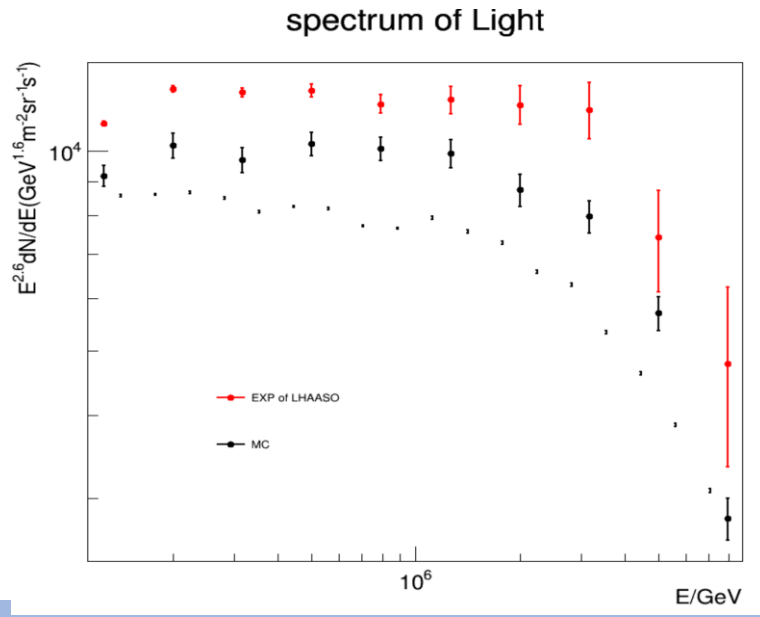


ANuM4<0

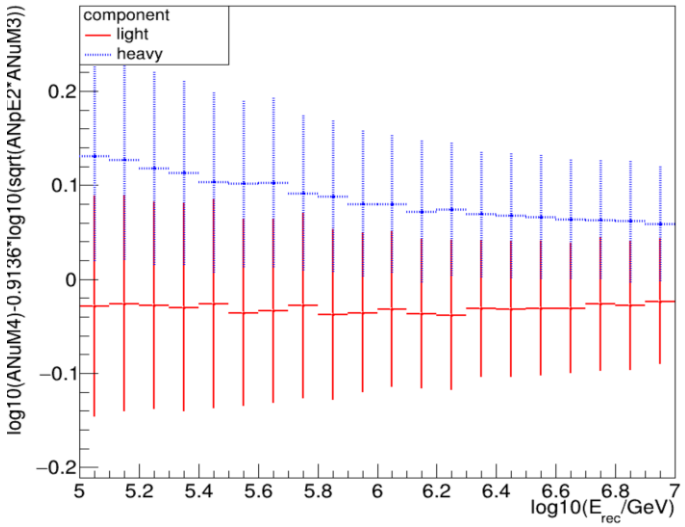

component
light
heavy
log10(ANuM4)-0.9136*log10(sqrt(ANpE2*ANuM3))
log10(E_rec/GeV)

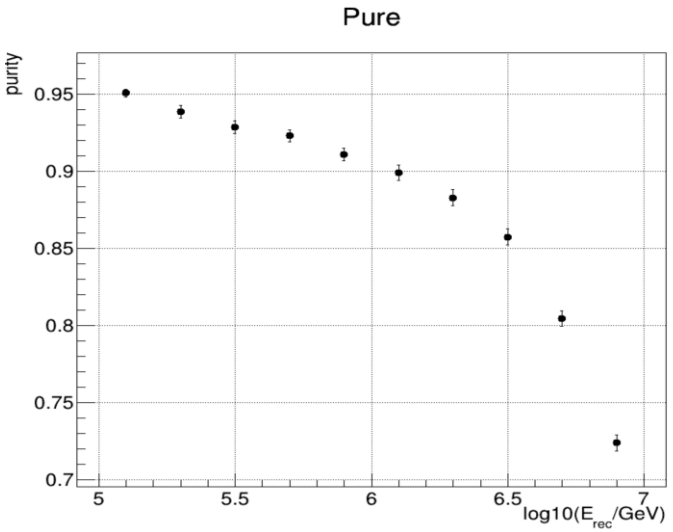

Pure
purity
log10(E_rec/GeV)

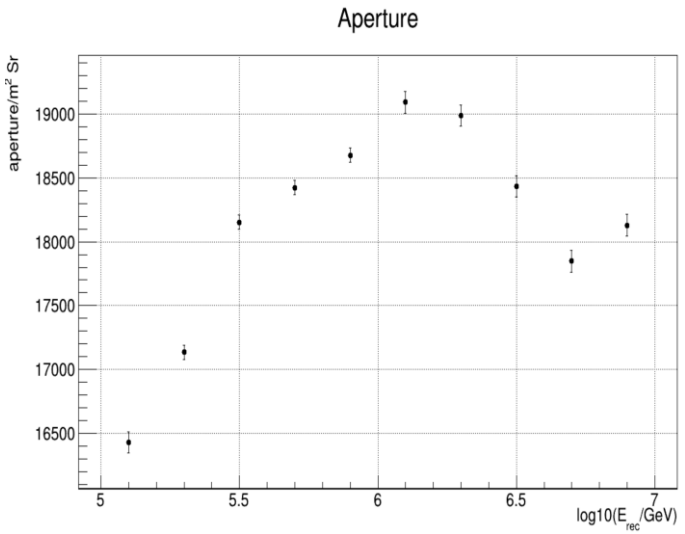

Aperture
aperture/m² Sr
log10(E_rec/GeV)

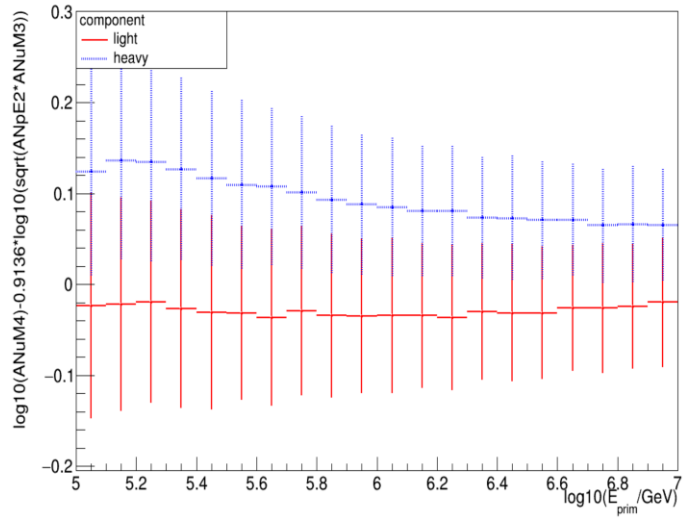

spectrum of Light
E^2.6dN/dE(GeV^1.6m^-2sr^-1s^-1)
EXP of LHAASO
MC
E/GeV

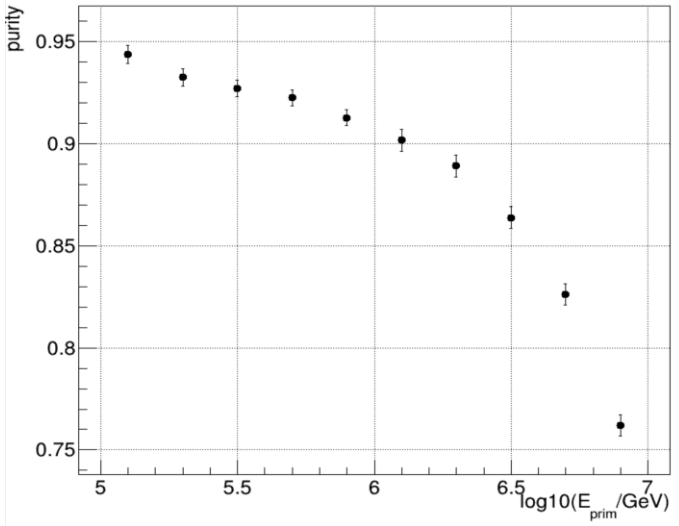
只做Km2A和芯位筛选，第一行重建能量，第二行原初能量

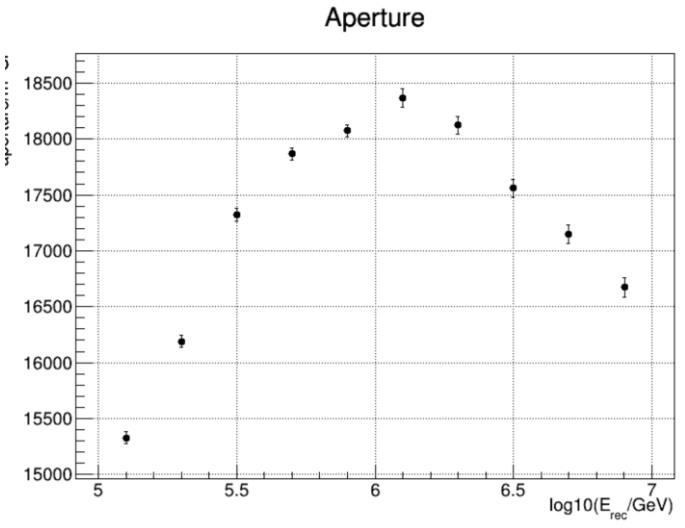


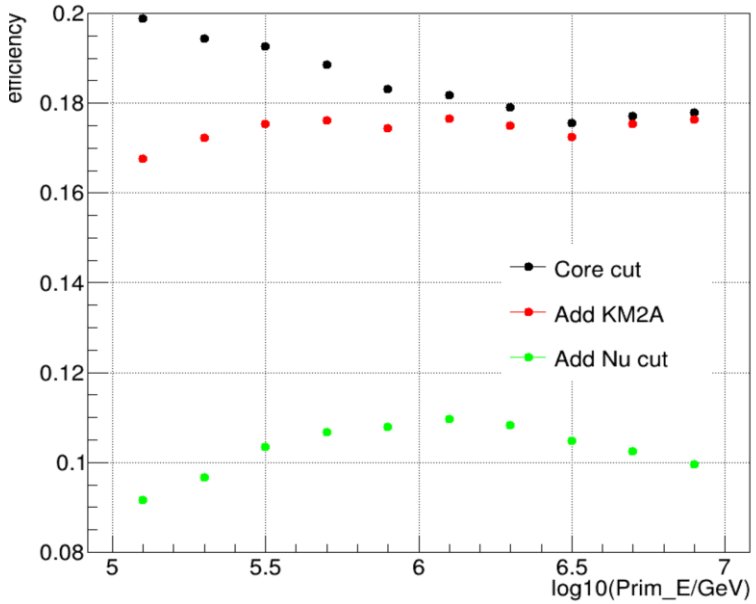


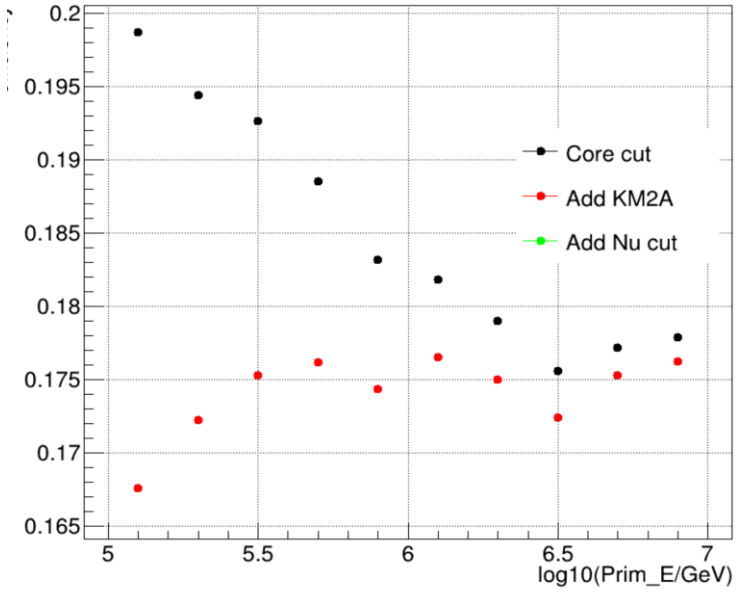


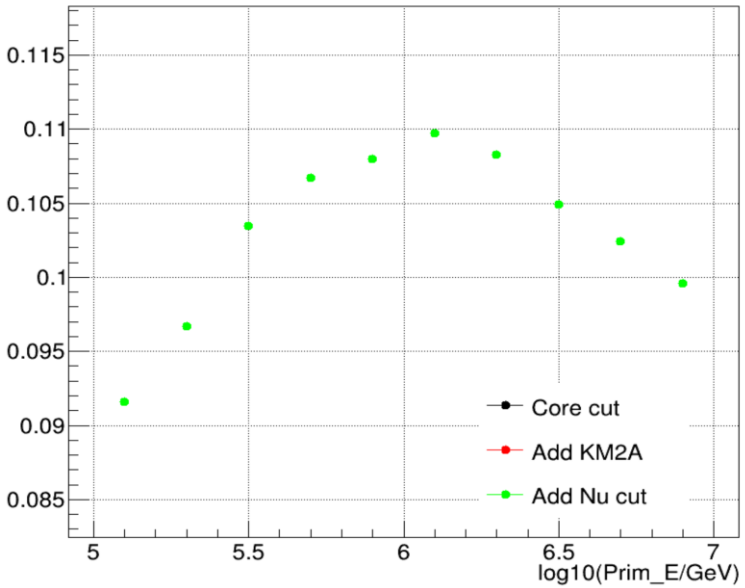




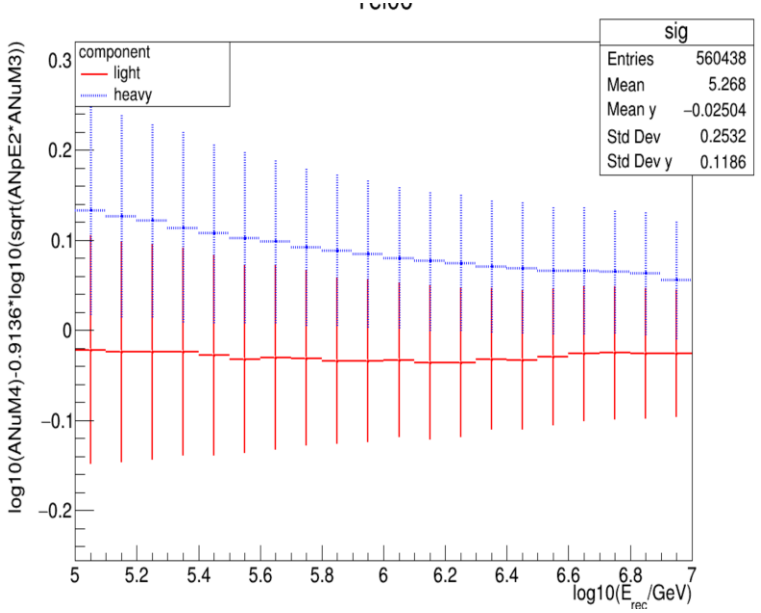


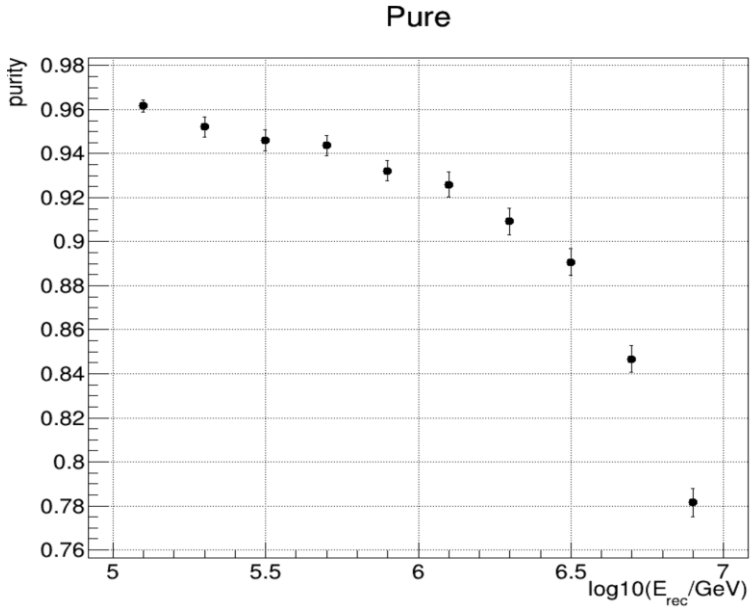

emciency
0.2
0.18
0.16
0.14
0.12
0.1
0.08
5
5.5
6
6.5
7
log10(Prim_E/GeV)
Core cut
Add KM2A
Add Nu cut

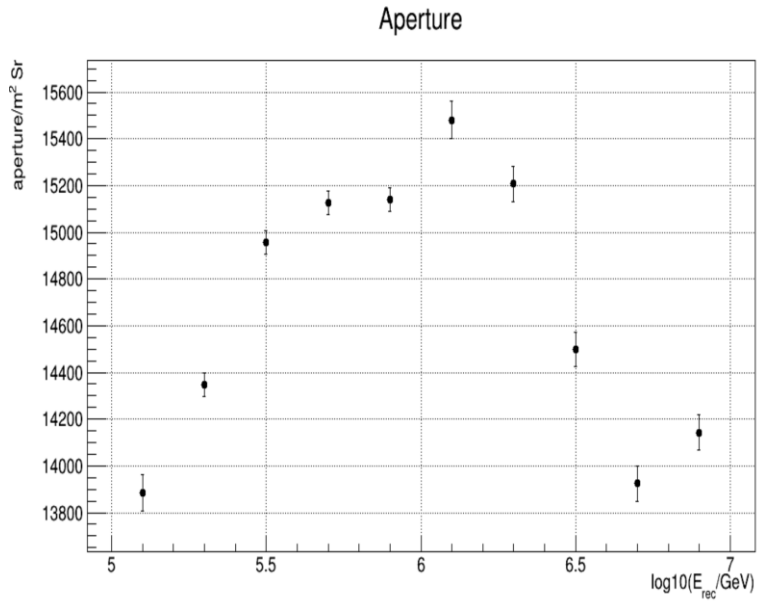

0.2
0.195
0.19
0.185
0.18
0.175
0.17
0.165
5
5.5
6
6.5
7
log10(Prim_E/GeV)
Core cut
Add KM2A
Add Nu cut

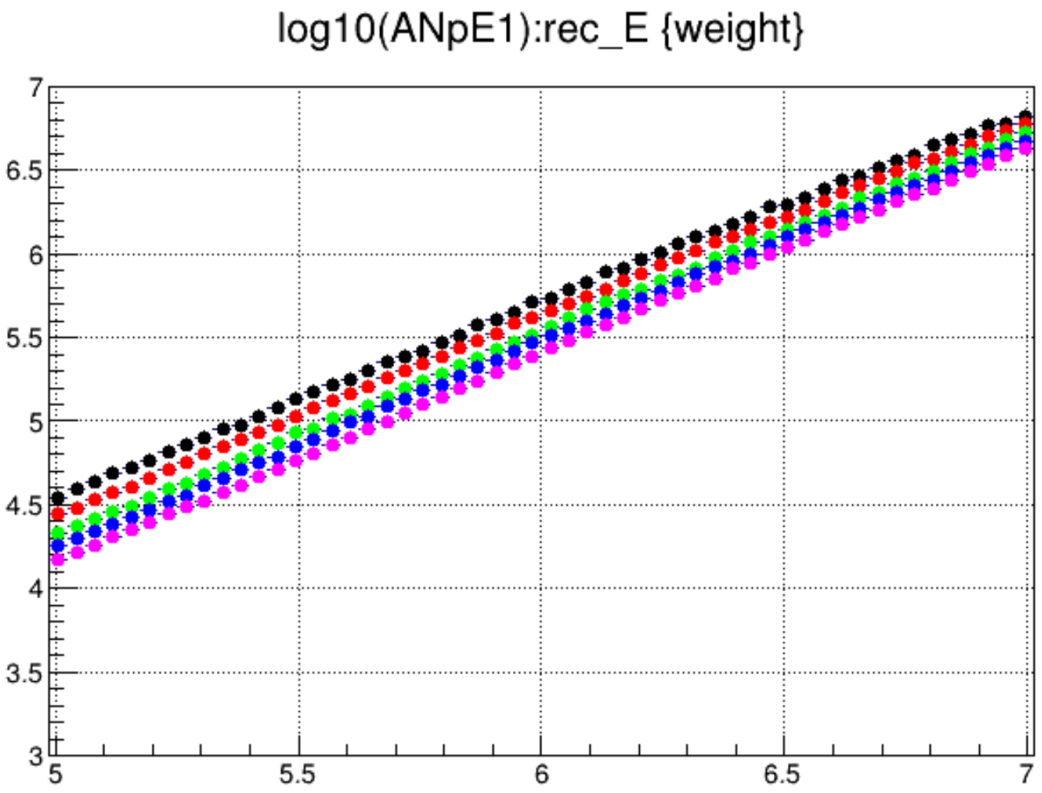

0.115
0.11
0.105
0.1
0.095
0.09
0.085
5
5.5
6
6.5
7
log10(Prim_E/GeV)
Core cut
Add KM2A
Add Nu cut

只做Km2A和芯位筛选，横坐标重建能量，Nu<-0.025








log10(ANpE1):rec_E {weight}
7
6.5
6
5.5
5
4.5
4
3.5
3
5
5.5
6
6.5
7