# Results of proton and helium analyses

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I. Summary of helium spectrum analysis using the equivalent analysis to protons
II. Investigation of highest energy region
III. SPS2015 beam test analysis for helium spectrum
IV. Latest results based on SPS2015 beam calibration
V. Summary and conclusion

# I. Summary of helium spectrum analysis using the equivalent analysis to protons

**Reference: HeliumAnalysis-rev190823.pdf**

1. The same analysis as protons is applied to helium.
2. Energy dependent cuts are defined using helium simulation.
3. Systematic uncertainties are estimated in the same way as protons.
4. Corrections determined by proton beam test are applied.

# Event Selection

Same as protons, but energy dependent threshold for TASC hit consistency cut, IMC shower start cut, and charge cut are defined using helium simulation.

| No. | Selection | Description |
|---|---|---|
| (1-LE) | Offline trigger for LE trigger | $Q_{\mathrm{IMC-X7+X8}} > 5$ [MIP], $Q_{\mathrm{IMC-Y7+Y8}} > 5$ [MIP], and $Q_{\mathrm{TASC-X1}} > 10$ [MIP] |
| (1-HE) | Offline trigger for HE trigger | $Q_{\mathrm{IMC-X7+X8}} > 50$ [MIP], $Q_{\mathrm{IMC-Y7+Y8}} > 50$ [MIP], and $Q_{\mathrm{TASC-X1}} > 100$ [MIP] |
| (2) | Geometry condition | Acceptance Type (A) |
| (3) | Fit Flag | $f_{\mathrm{KF}} = 3\|6\|9\|12$ |
| (4) | Electron rejection | $C^{\mathrm{mol}}_{\mathrm{IMC}} < 0.7$ |
| (5) | Off-acceptance cut-I | $F^{\mathrm{max}}_{E} < 0.4$ |
| (7) | Off-acceptance cut-III | $R^{\mathrm{max}}_{\mathrm{edge}} < 0.4$ |
| (8)*1 | Requirement on track consistency with TASC energy deposits | $\|\Delta_{\mathrm{TASC-X1}}\| < d^{X}_{\mathrm{thd}}(E_{\mathrm{obs}})$ [cm] and $\|\Delta_{\mathrm{TASC-Y1}}\| < d^{Y}_{\mathrm{thd}}(E_{\mathrm{obs}})$ [cm] |
| (9)*2 | Shower development in IMC | $N_{\mathrm{IMC-8}} > n_{\mathrm{thd}}(E_{\mathrm{obs}})$ [MIP] |
| (10)*3 | Charge cut | $z^{\mathrm{CHD}}_{\mathrm{thd-1}} < Z_{\mathrm{CHD}} < z^{\mathrm{CHD}}_{\mathrm{thd-2}}$ and $z^{\mathrm{IMC}}_{\mathrm{thd-1}} < Z_{\mathrm{IMC}} < z^{\mathrm{IMC}}_{\mathrm{thd-2}}$ |

*1: $d^{X,Y}_{\mathrm{thd}}(E_{\mathrm{obs}})$ are set to 95% efficiency.

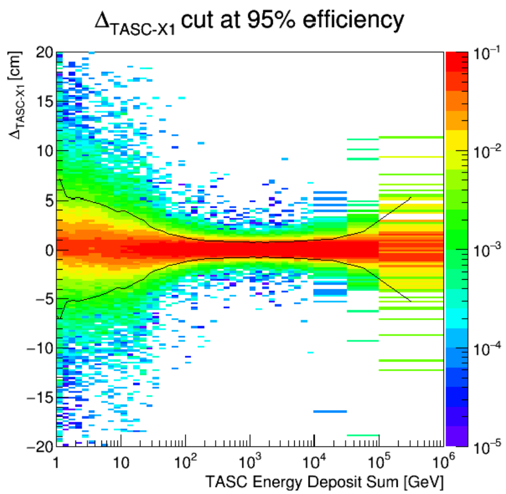
*2: $n^{X,Y}_{\mathrm{thd}}(E_{\mathrm{obs}})$ are set to 99% efficiency.

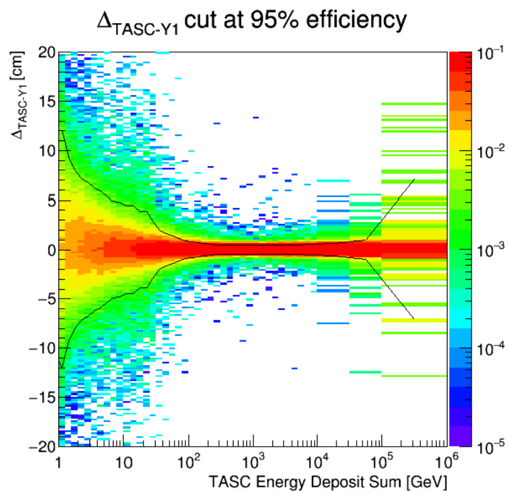
*3: $z^{\mathrm{CHD}}_{\mathrm{thd-1}}$ and $z^{\mathrm{IMC}}_{\mathrm{thd-1}}$ are set to 98% efficiency, and $z^{\mathrm{CHD}}_{\mathrm{thd-2}}$ and $z^{\mathrm{IMC}}_{\mathrm{thd-2}}$ are set to 95% efficiency.

Exactly the same as proton analysis [rows (1-LE) to (7)]

Determined using helium MC data sample while the algorithm is same [rows (8) to (10)]

# Threshold for TASC hit consistency and IMC shower start cuts

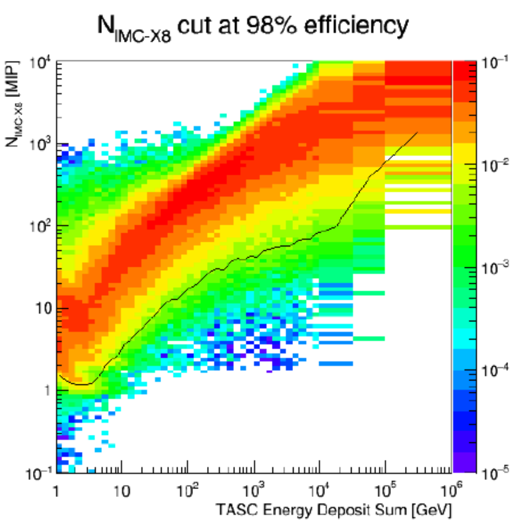


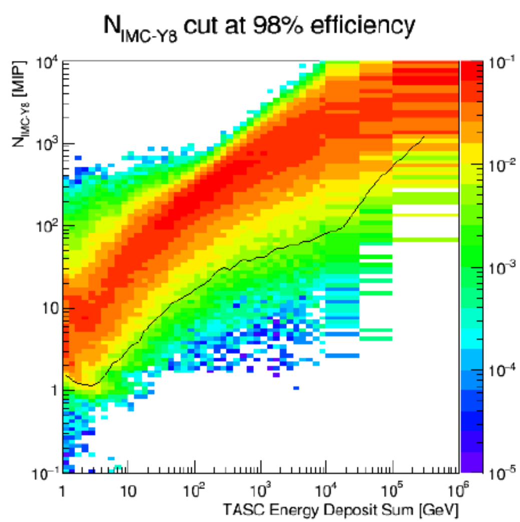



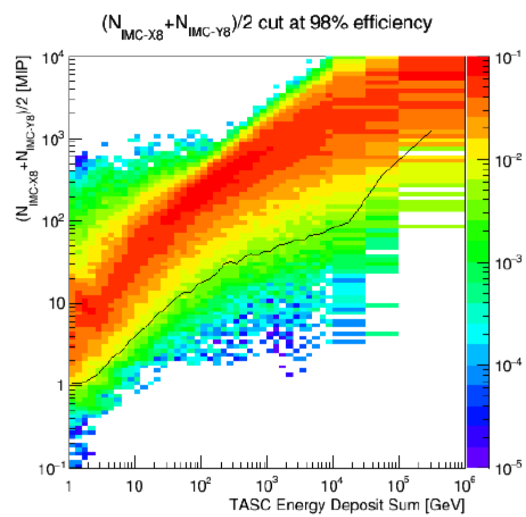

TASC hit consistency cut threshold

These are similar to proton's case, but defined independently using helium simulation.

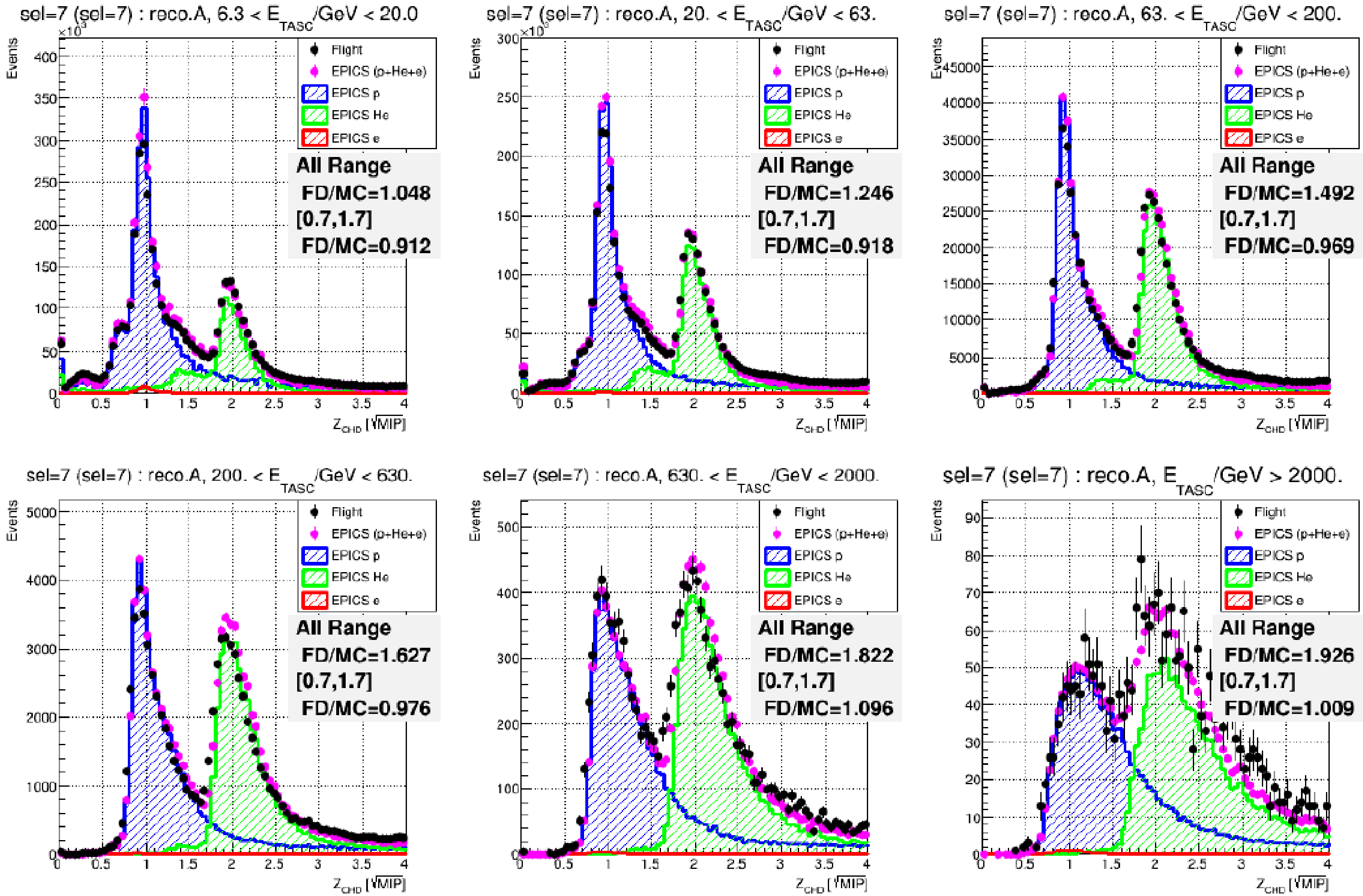
IMC shower start cut threshold



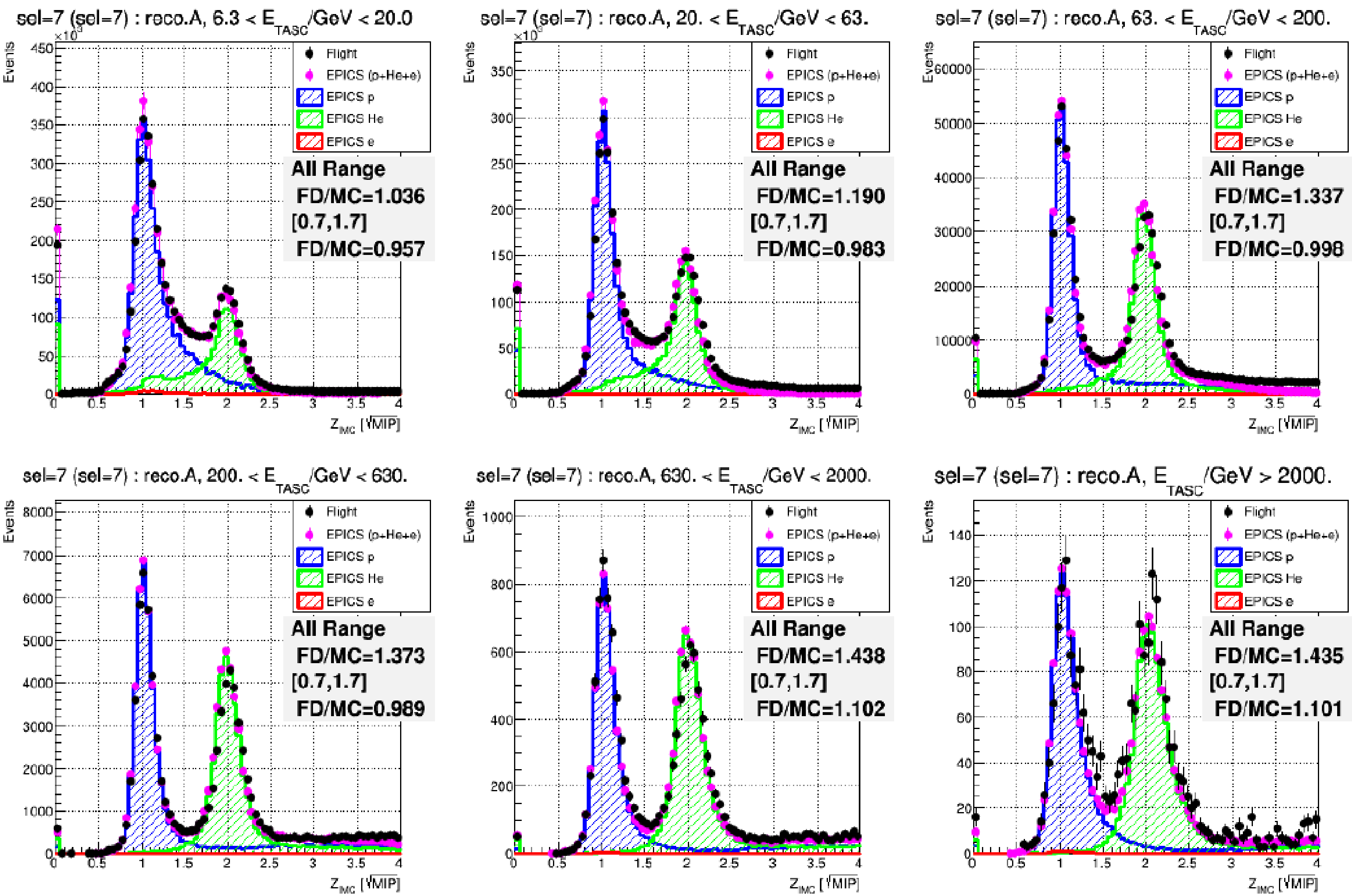



# CHD Charge Distribution (HE Analysis)



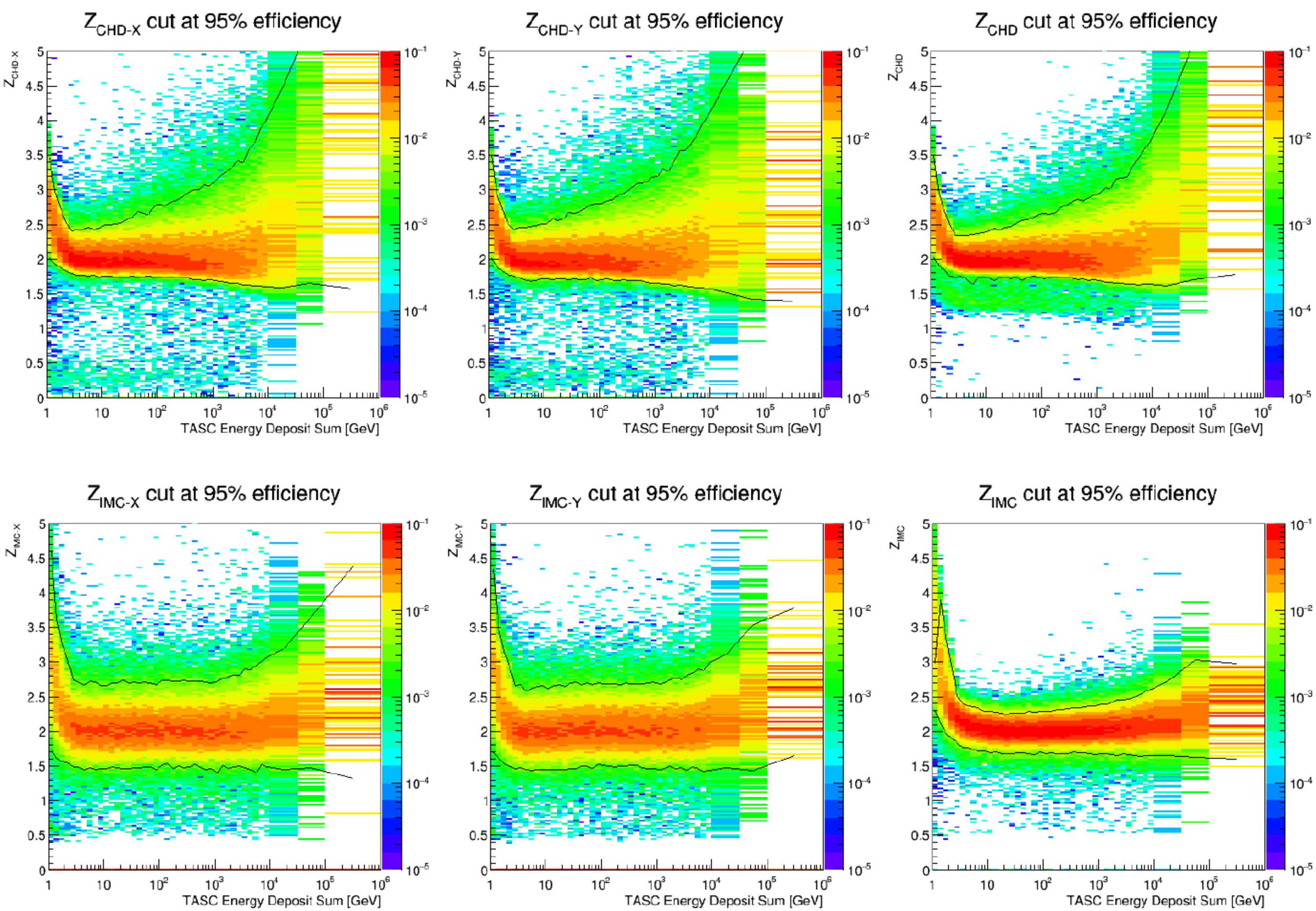

Charge correction functions are the same as proton analysis

# IMC Charge Distribution (HE Analysis)



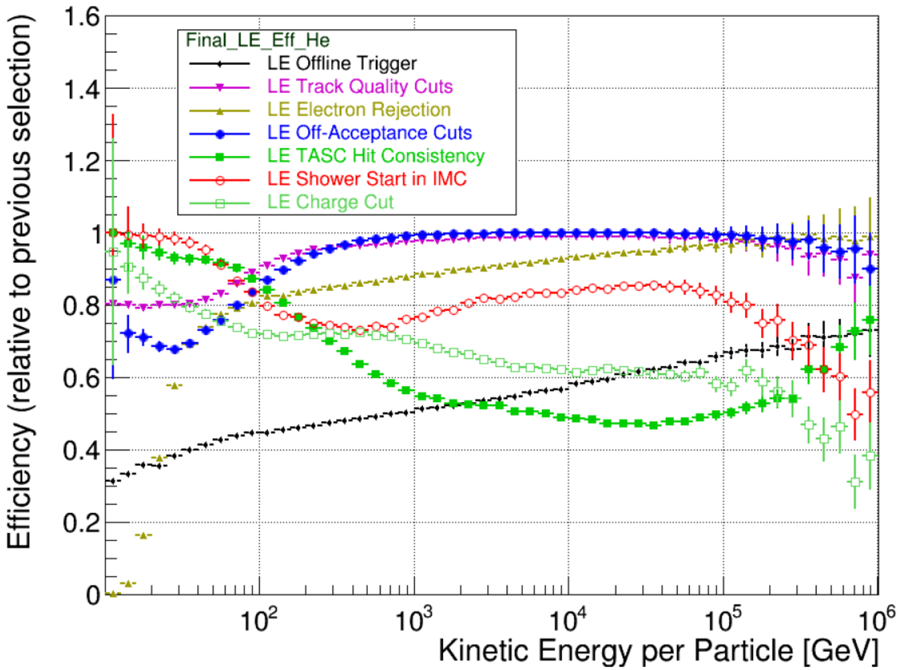

Charge correction functions are the same as proton analysis

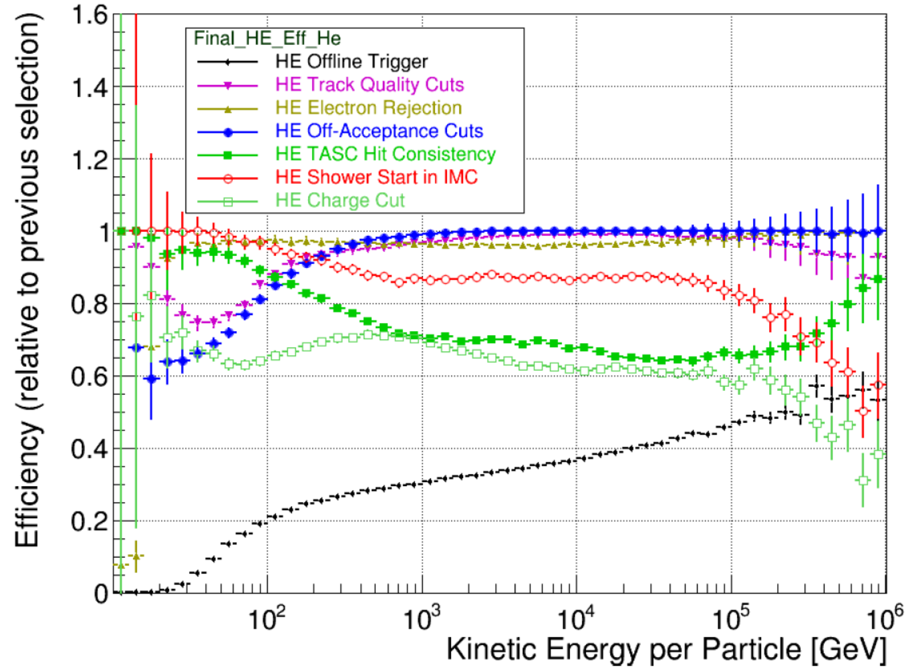
# Threshold for CHD & IMC Charge cuts




These are similar to proton's case, but defined independently using helium simulation. In the very low energy region, charge correction is not done well but they are very low energy and we don't have sufficient flight data.

# Event Selection Efficiencies for Each Selection Step



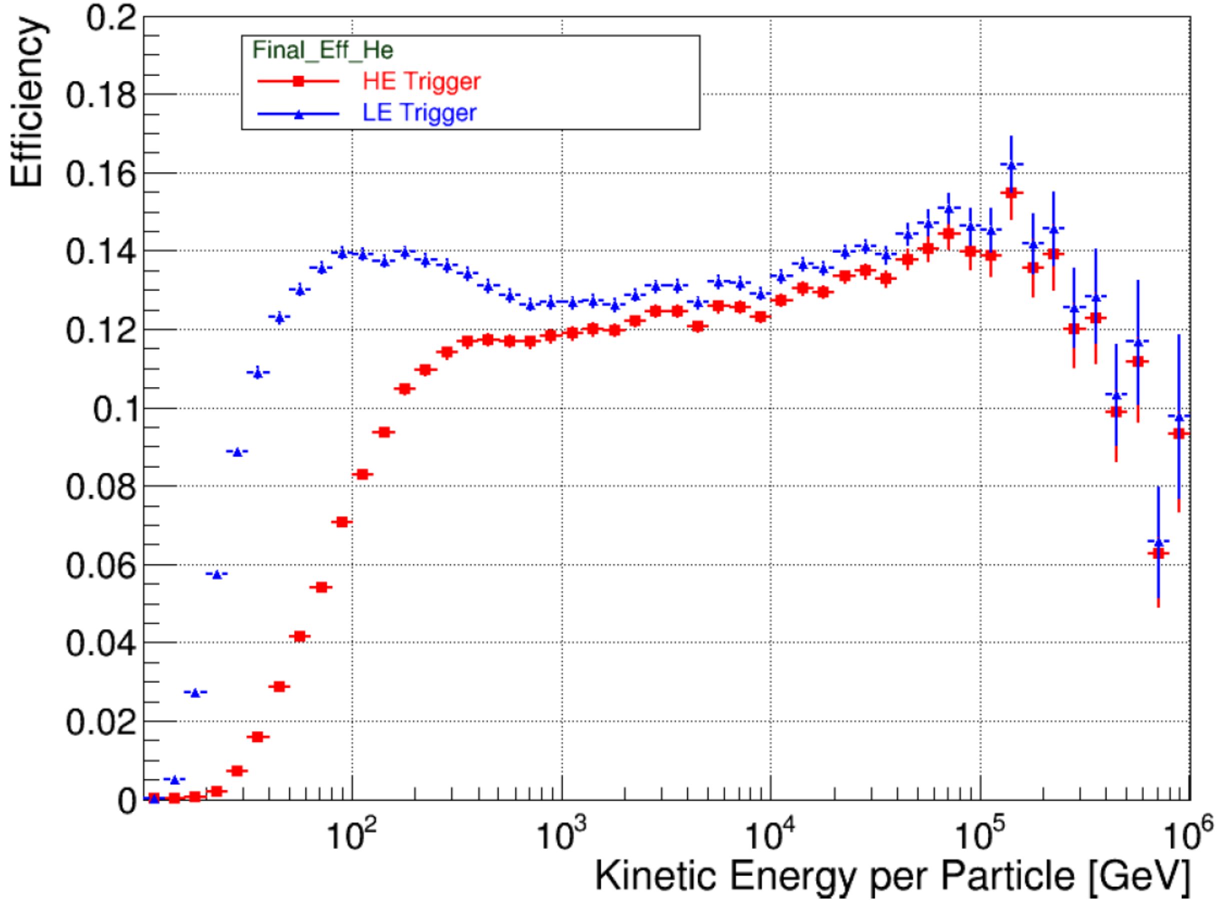

To be checked in detail:

1. Lower efficiency of electron rejection cut in LE analysis.
2. The changing efficiencies above 100 TeV for IMC shower start and TASC hit consistency cuts.
3. Efficiency drop of charge cut above 100 TeV.

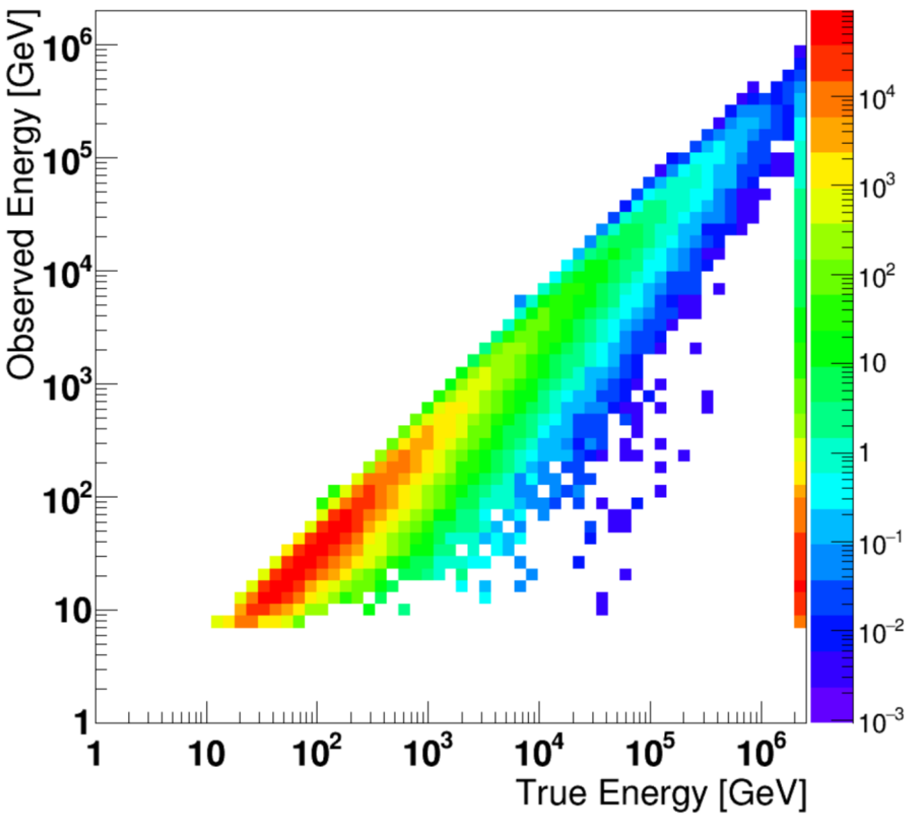
# Detection Efficiency

At around 100 GeV, there is a strange bump in LE analysis

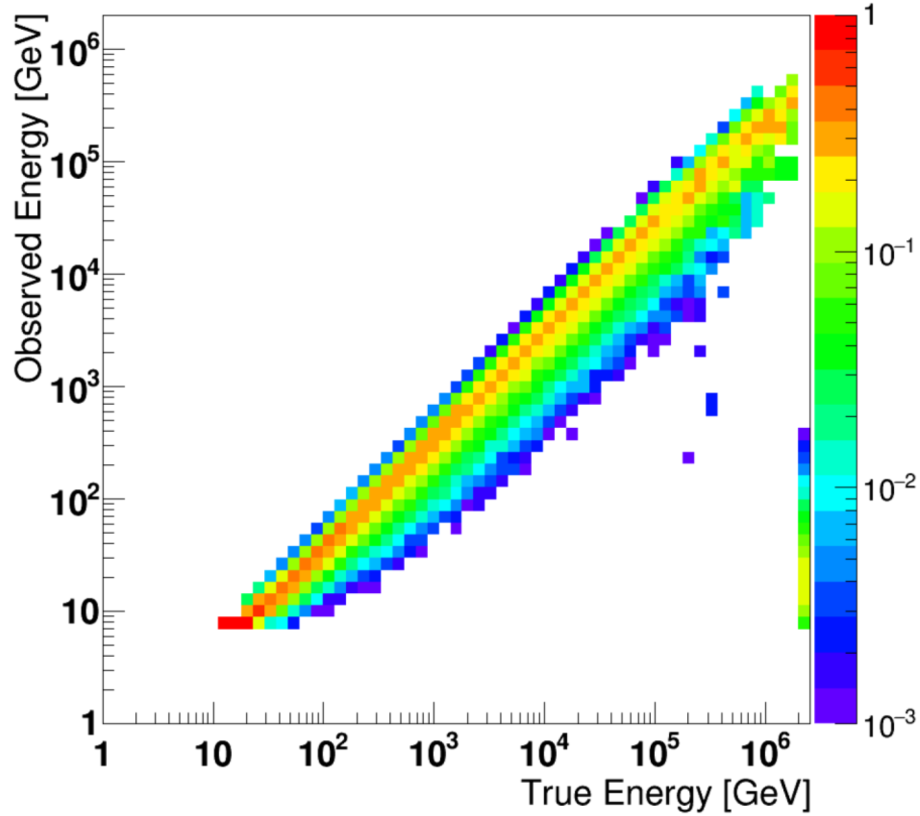
Above 100 TeV, there is an efficiency loss



# Energy Unfolding: Response and Unfolding Matrixes

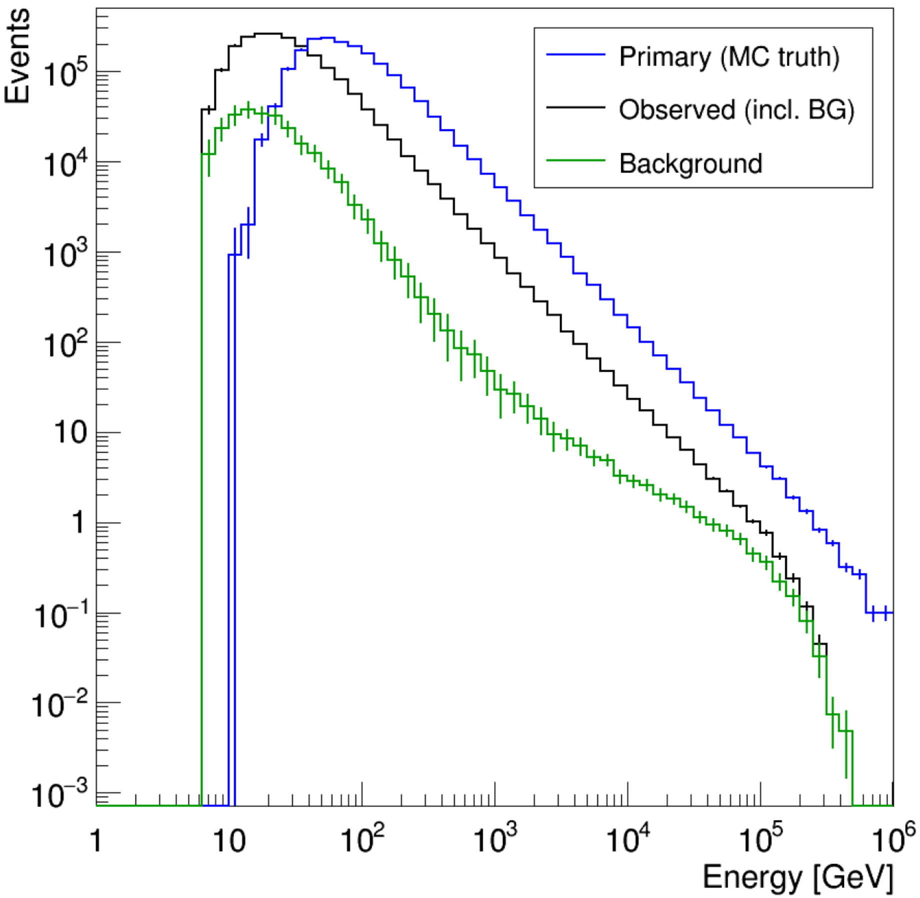



Due to the spectrum normalization, the values in the response matrix gets smaller at higher energies.

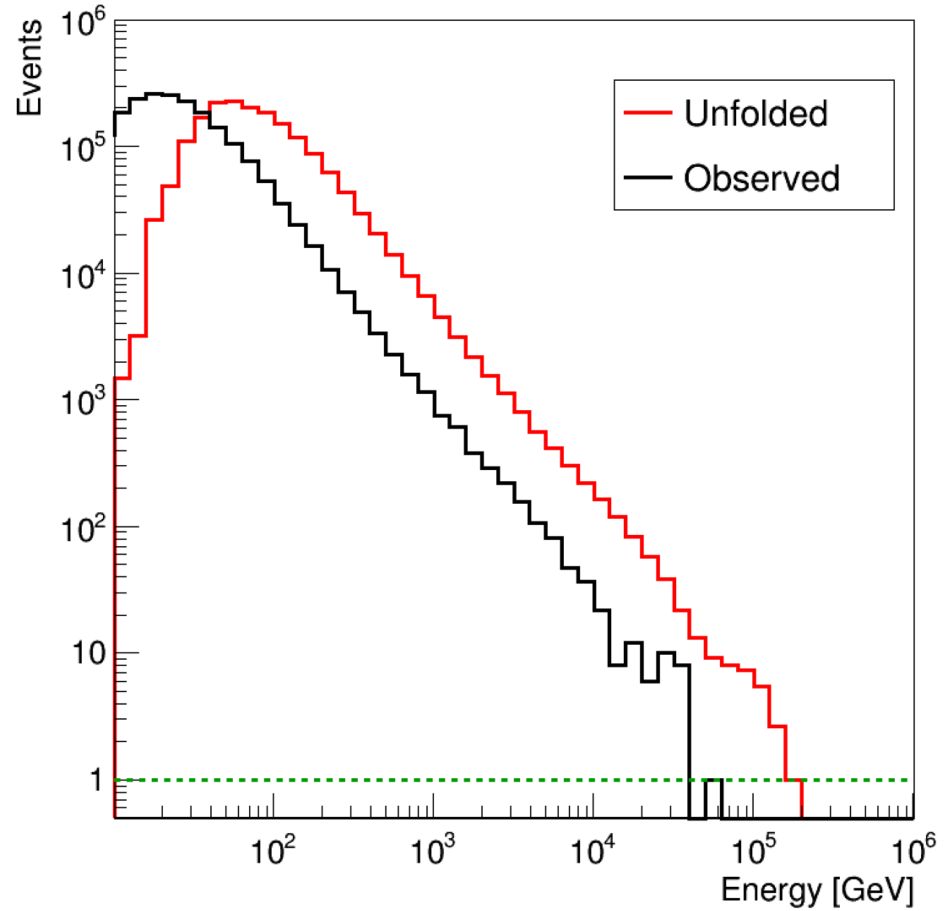



Significant bin-to-bin migration up to +-2 bins.

# Energy Unfolding:
# Energy Deposit & Unfolded Spectra



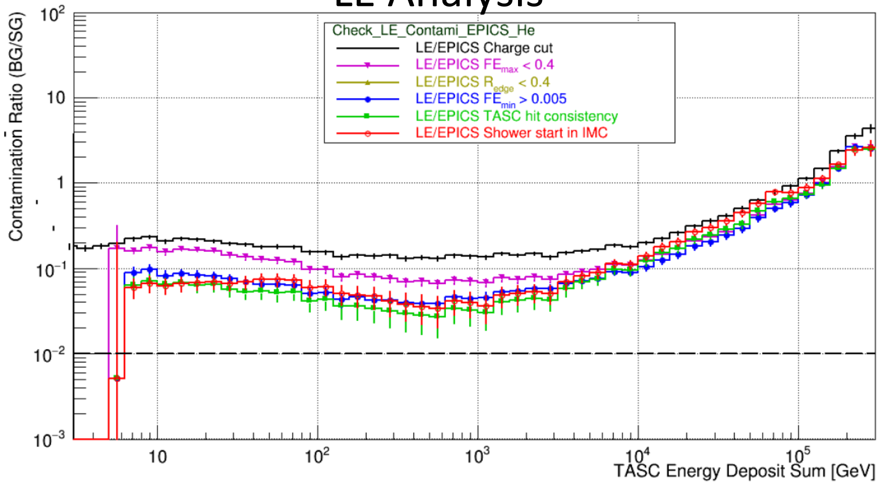

Estimated contamination above 100 TeV energy deposit sum is too high and needs to be addressed.



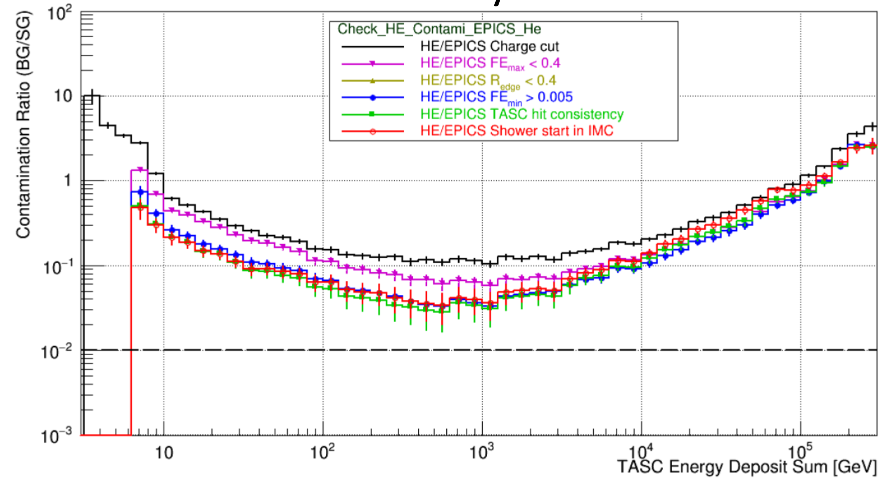

After some softening around 10 TeV in energy deposit sum distribution, number of helium candidate events is somewhat constant in 20-40 TeV region.

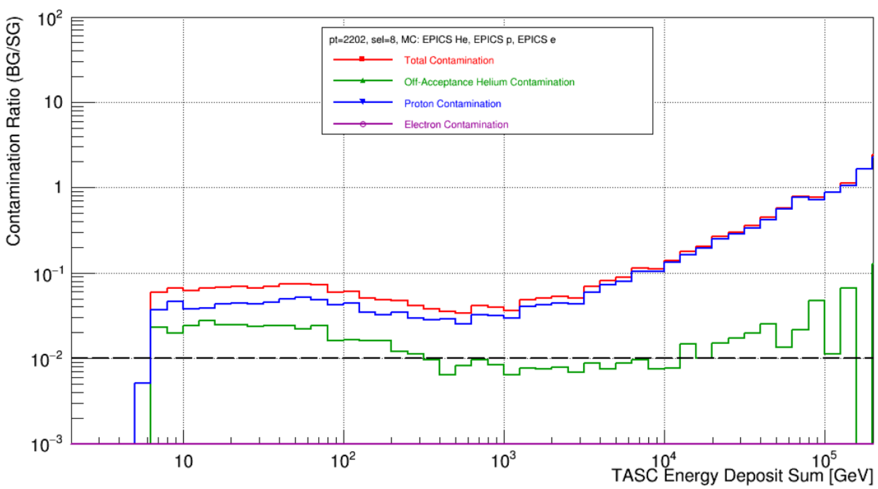
# Background Contamination

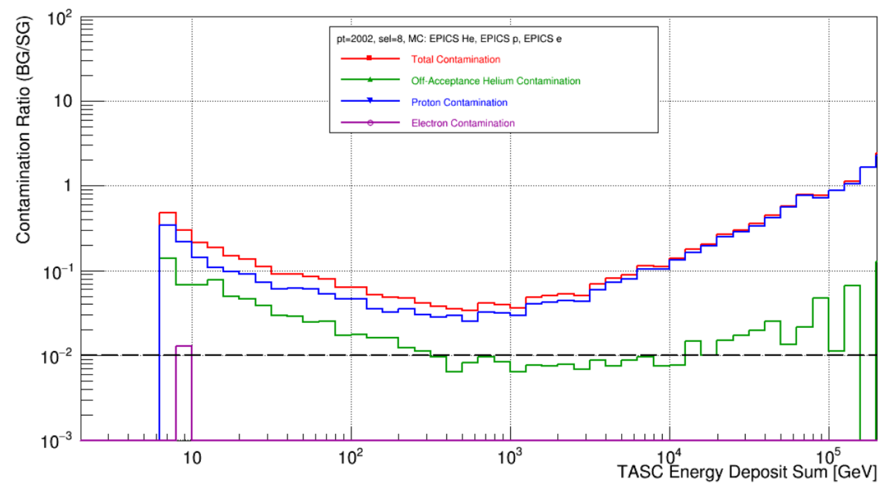
## LE Analysis




## HE Analysis



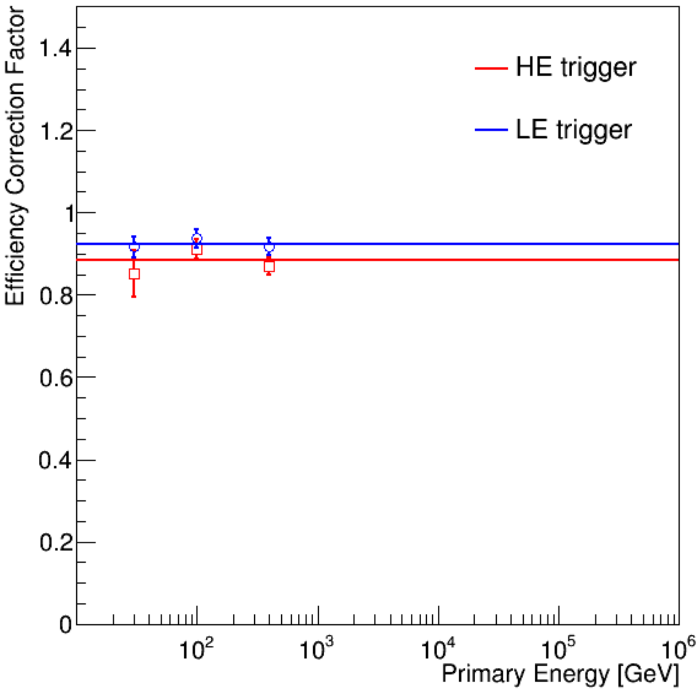



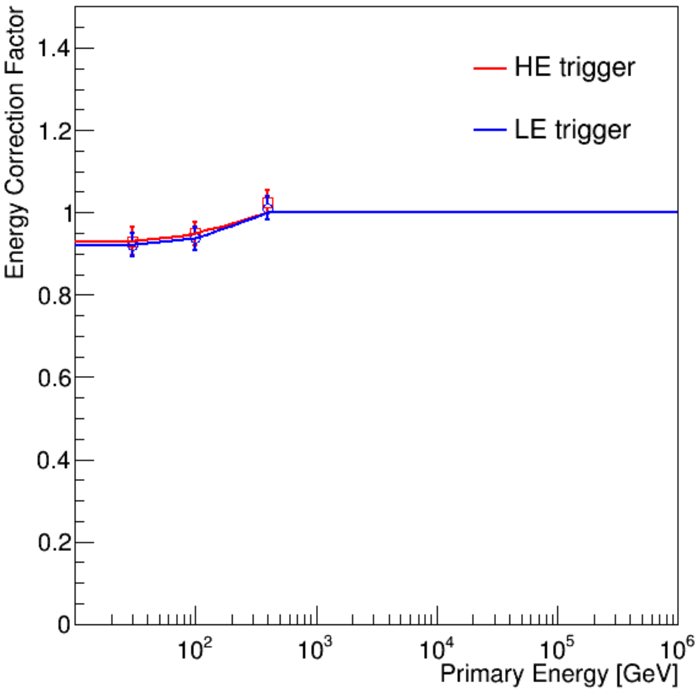

Protons are the most relevant source of contamination in the whole energy region.

Needs to refine charge cut in the higher energy region to avoid too large contamination from protons

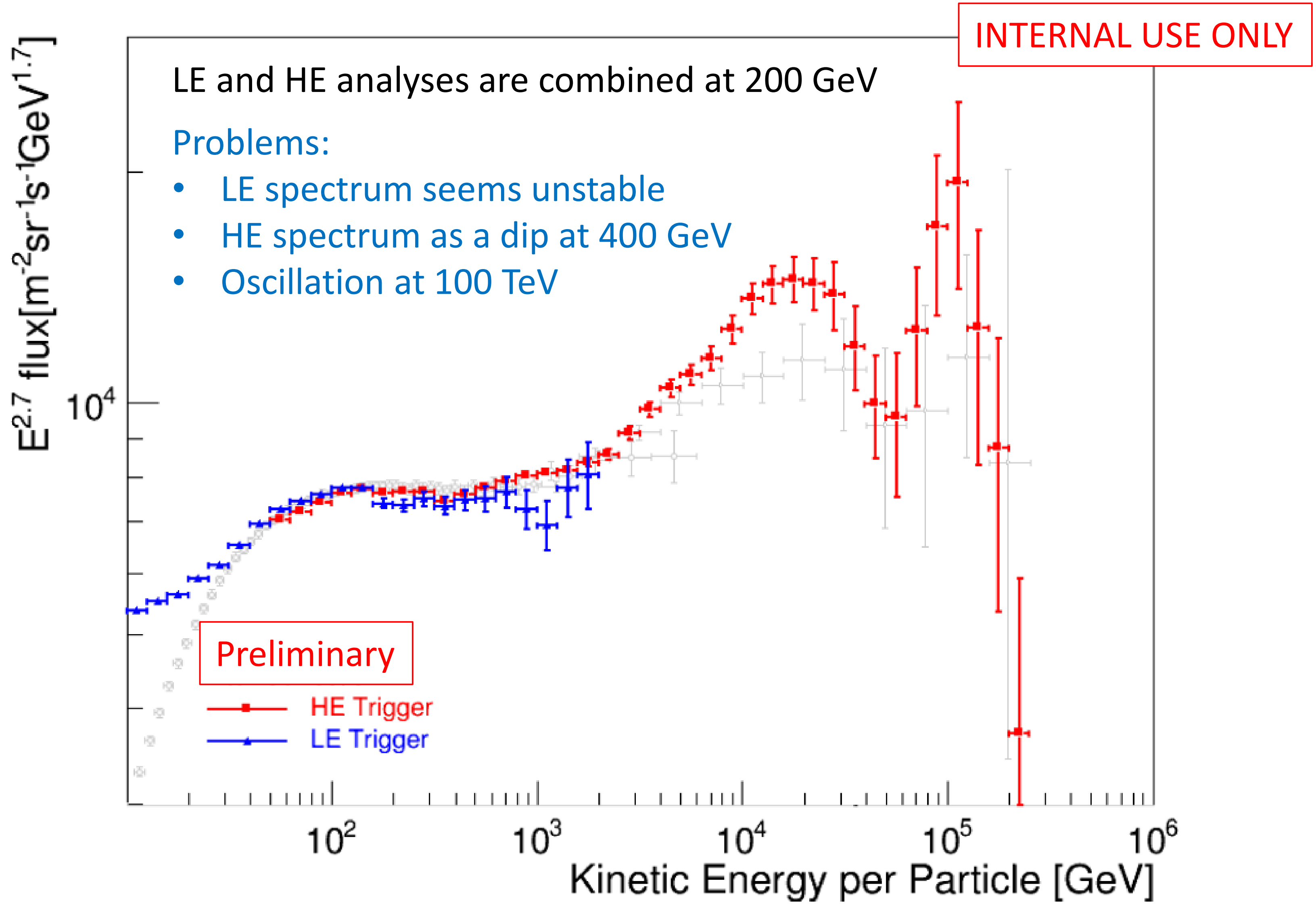
# Corrections from Beam Test

- Assumed to be the same as protons
  - Energy dependent energy correction
  - Energy independent efficiency correction



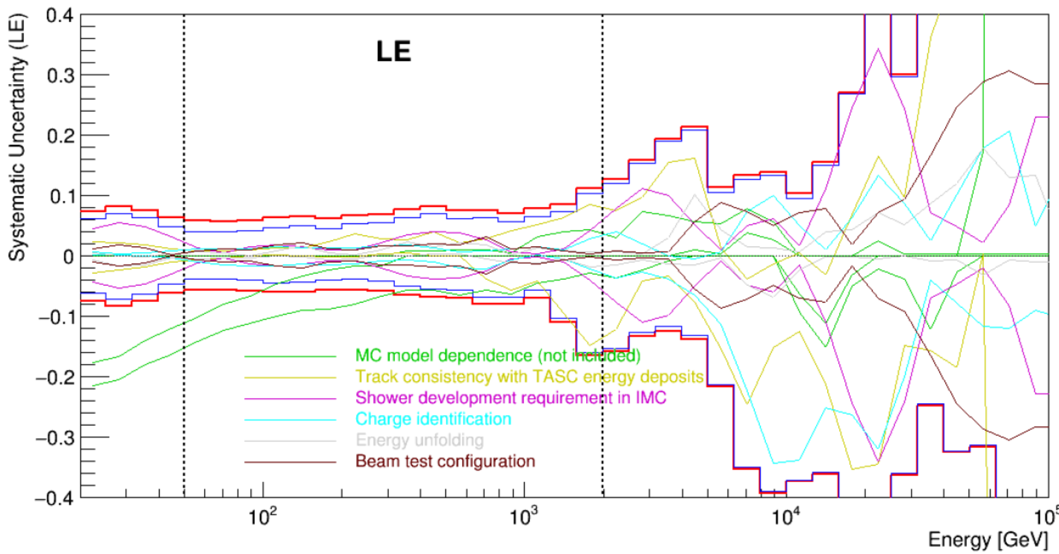
# Comparison between LE and HE Spectrum

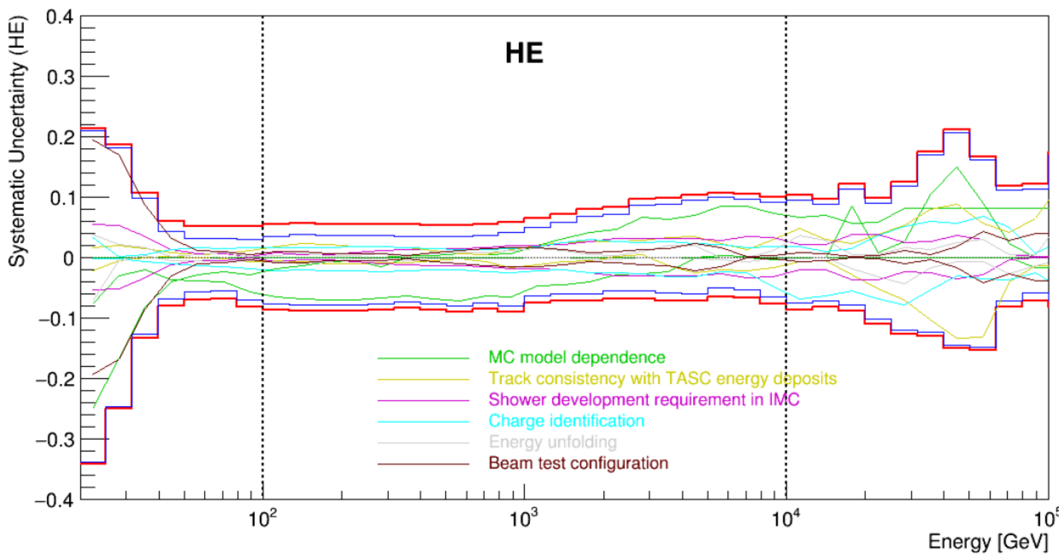


# Systematics

- Considered sources of systematic errors are also same as proton analysis.
- Systematics related to event selection are estimated using helium MC as signal and proton/electron MC as background (should be valid).
- Systematics related to beam test are identical to proton analysis and based on proton test beam.

# Breakdown of Energy-Dependent Systematic Uncertainties



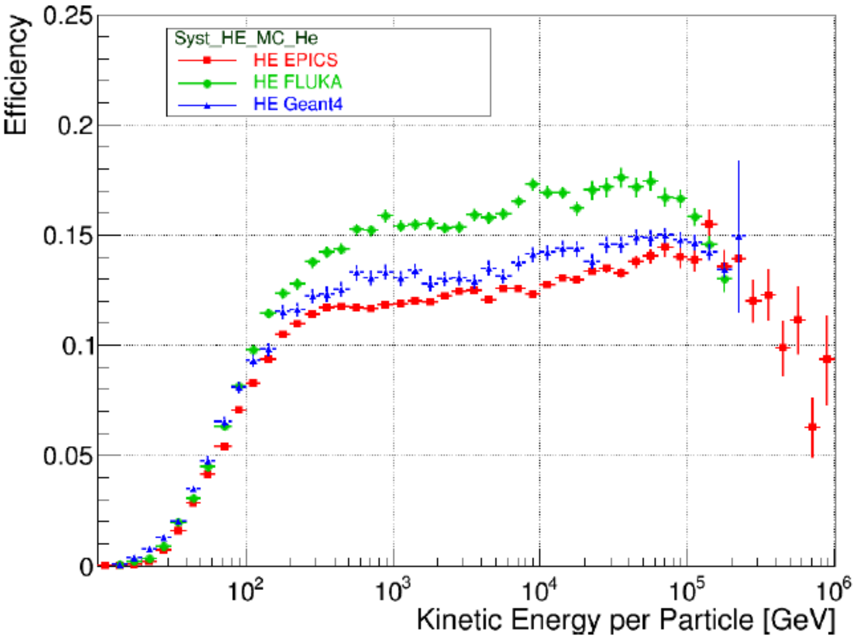



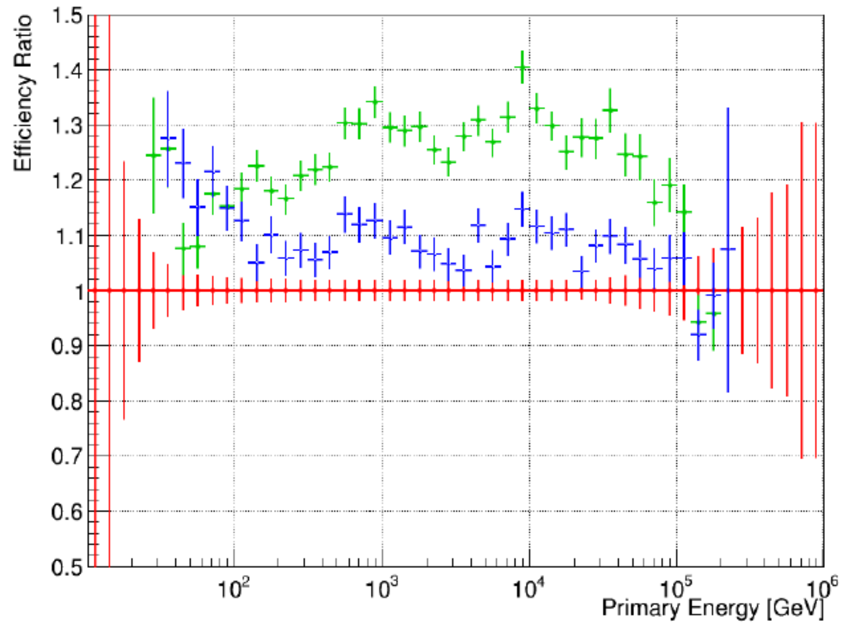

Estimated energy-dependent systematics are at the same order of proton’s case

# MC Model Dependence: Efficiency

HE analysis

EPICS: RED
FLUKA: GREEN
Geant4: BLUE



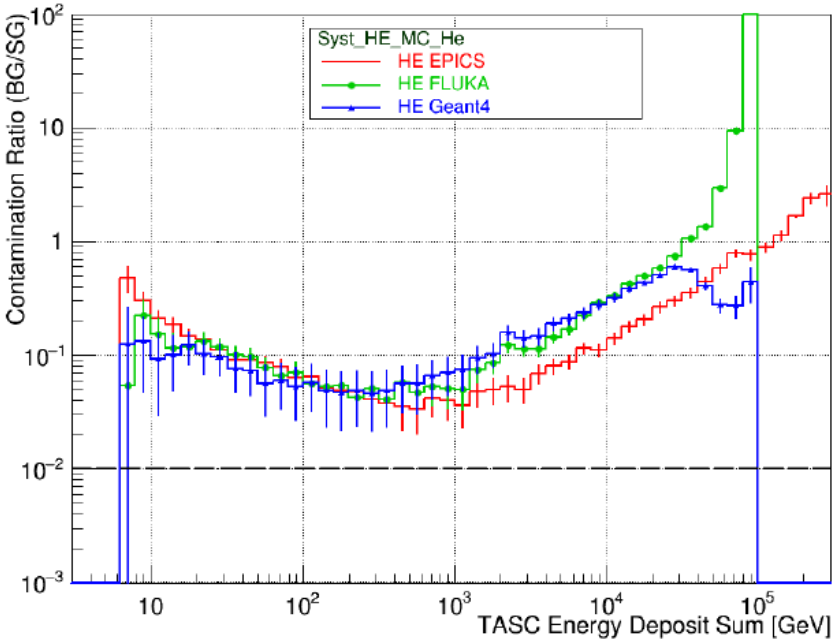



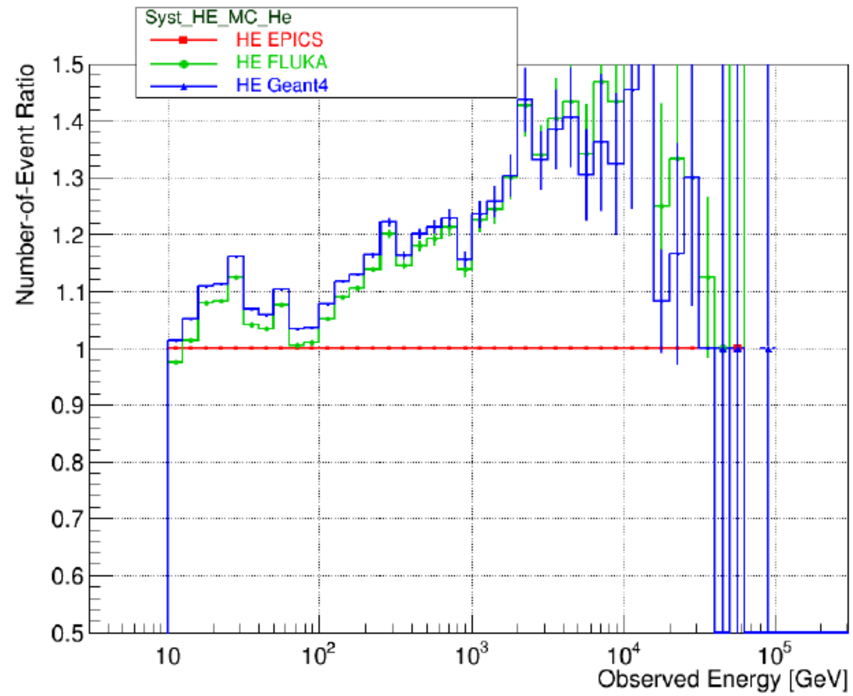

FLUKA's efficiency is quite high compared to EPICS & Geant4

# MC Model Dependence: Background

HE analysis

EPICS: RED
FLUKA: GREEN
Geant4: BLUE



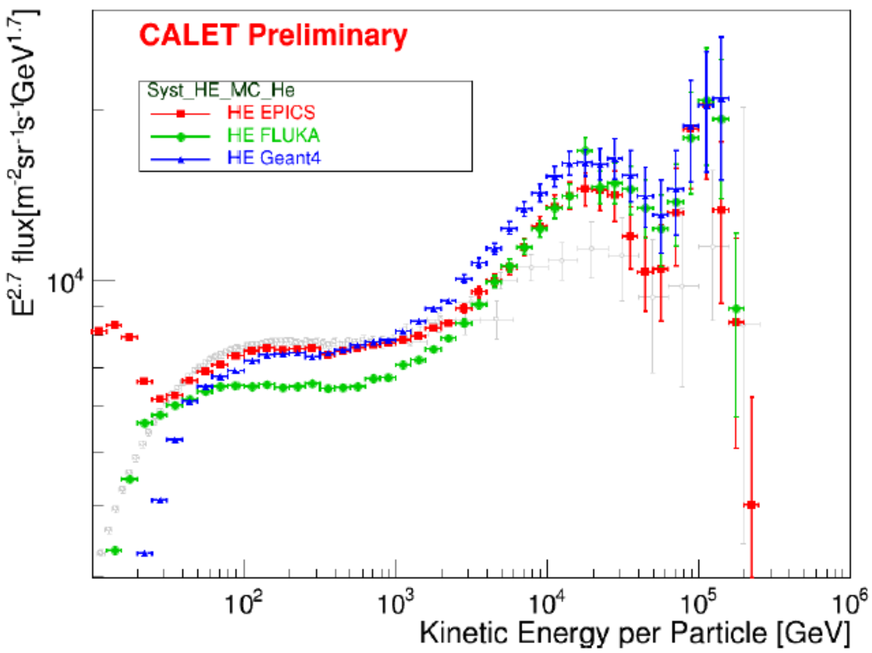



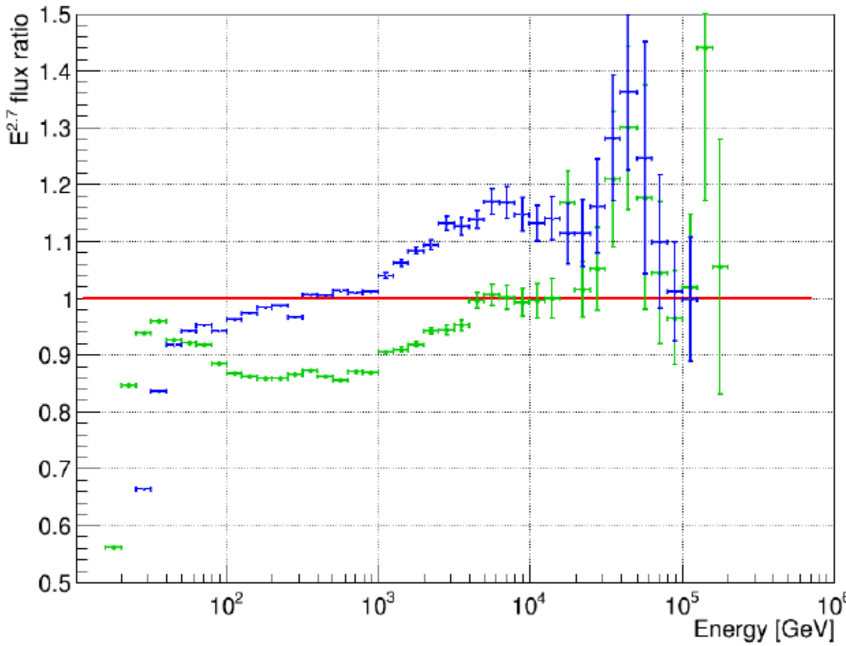

The difference in the ratio of observed energy distribution comes from the different energy dependent cut threshold.

# MC Model Dependence: Flux

EPICS: RED
FLUKA: GREEN
Geant4: BLUE

HE analysis




The spectrum difference between MC models are very similar to proton's case.

# Helium Spectrum w/ Systematics

Tentative

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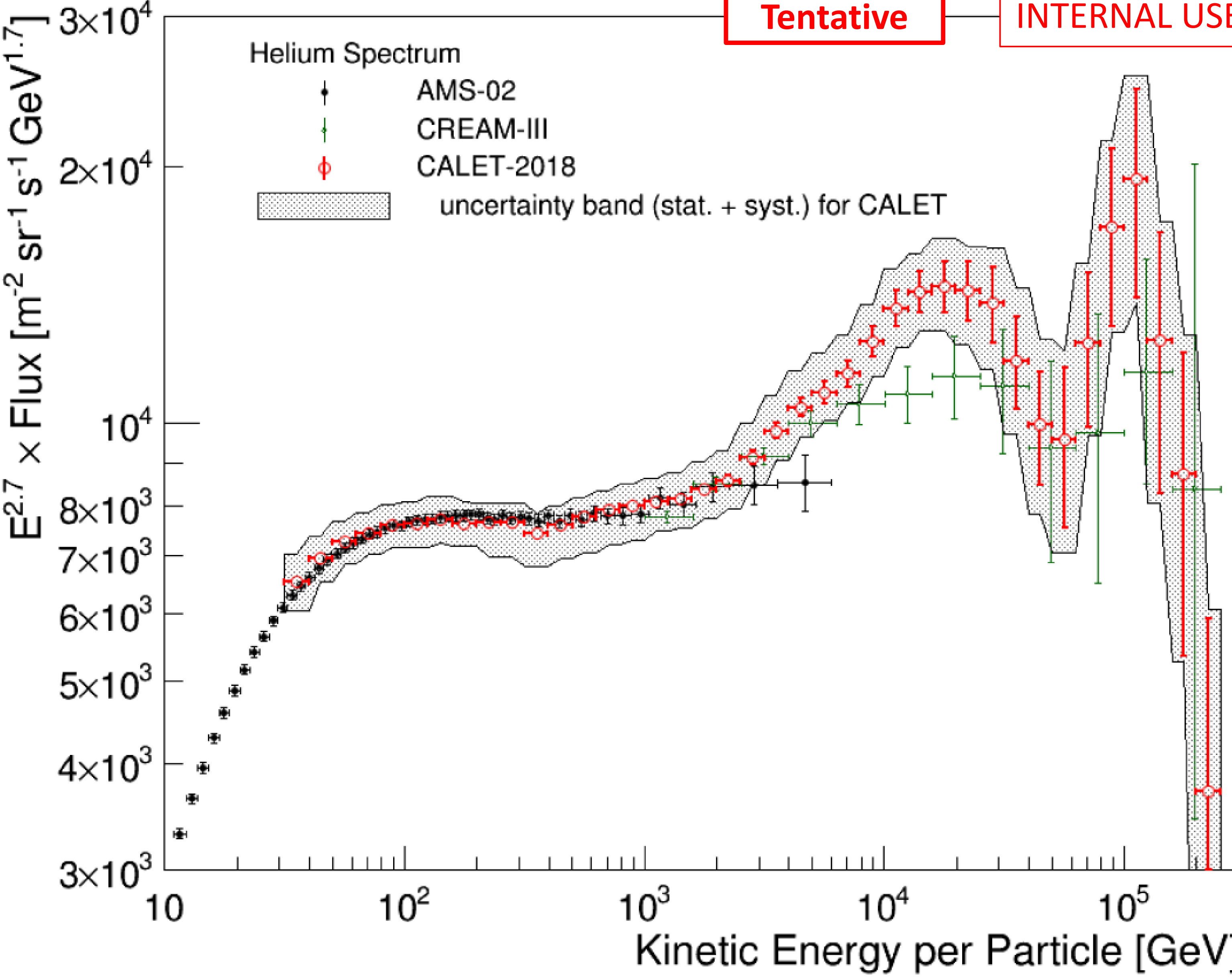

# Comparison with DAMPE

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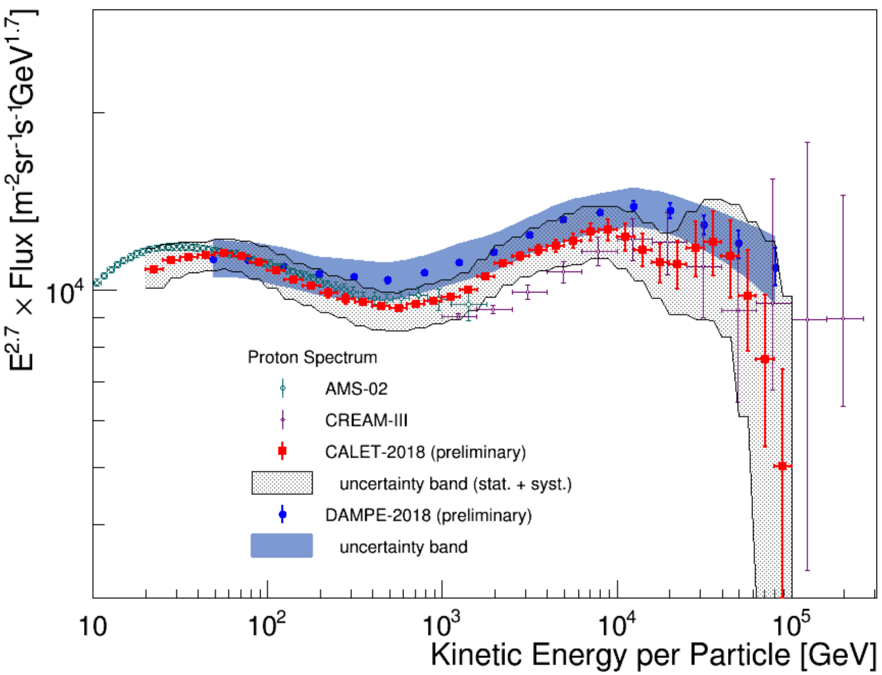
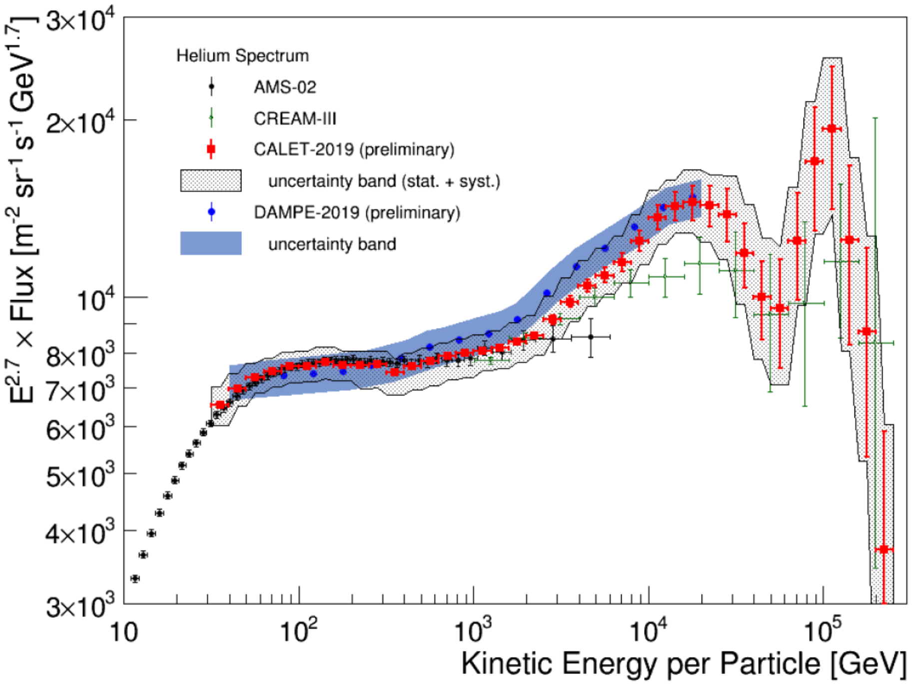
DAMPE's spectra are quite similar to the ATIC spectra

Proton




Helium




Behavior at the highest energy region must be carefully examined.

# II. Investigation of highest energy region

**Apparent problems at the highest energy region:**

- **Efficiency drop above 100 TeV**
- **Strange structure at 100 TeV region in helium spectrum**

1. Highest energy event examples
   - Directly check the tracking performance
2. Proton + helium spectrum
   - Reduces the uncertainties related to background rejection
3. Early interaction selection to ensure high tracking efficiency even at the highest energy region
   - Strong shower core exists in the multiple layers of IMC when interaction occurs at shallower IMC layers.
4. Template Fitting
   - Especially at the highest energy region, assumed spectrum might be not accurate enough to estimate background contamination

# Highest Energy Event Check

Uploaded to: /mnt/CALET_PUB/CoWorking/wasedacoc/L2rc/HEevents

(please check README.dat there)

*.dat => contains event info shown in the left
*_L2.root => L2 file corresponding to dat file

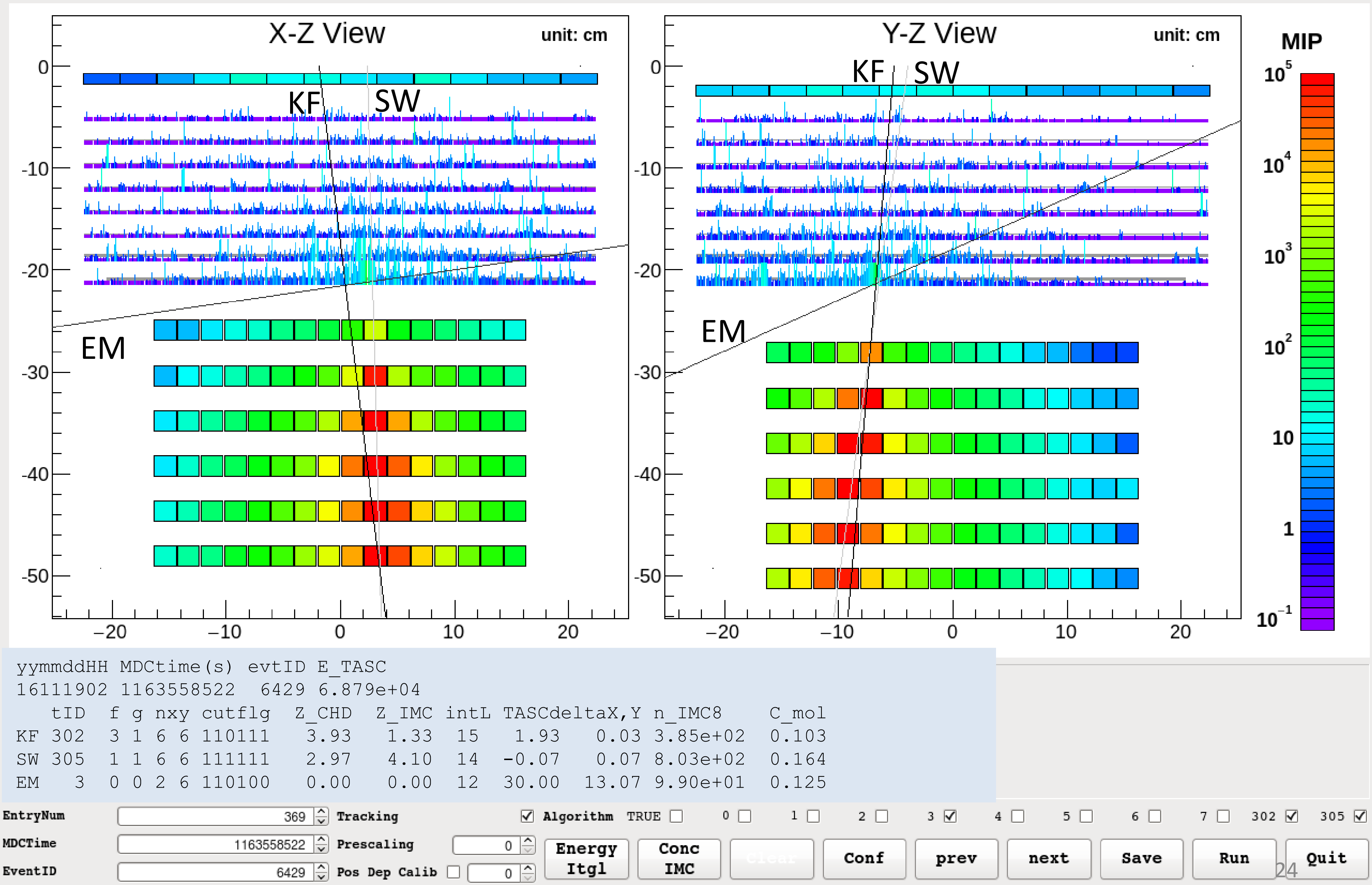
```
HE events (Edep>10TeV) are selected using shower track
to study tracking performance at the highest energy region.

HEevents/CandidatesAll_10TeV_try67_live62_pt1002.dat
HEevents/CandidatesAll_10TeV_try67_live62_pt1002_L2.root

-> The event satisfies the following condition is stored:
   1. geometry A with shower tracking (ID=305)
   2. off-acceptance cut (same as proton PRL paper)
   3. E_TASC > 10 TeV (E_TASC refers to the TASC energy sum)


yymmddHH MDCtime(s) evtID E_TASC
16111902 1163558522  6429 6.879e+04

   tID  f g nxy cutflg  Z_CHD  Z_IMC intL TASCdeltaX,Y n_IMC8    C_mol
KF 302  3 1 6 6 110111   3.93   1.33  15   1.93   0.03 3.85e+02  0.103
SW 305  1 1 6 6 111111   2.97   4.10  14  -0.07   0.07 8.03e+02  0.164
EM   3  0 0 2 6 110100   0.00   0.00  12  30.00  13.07 9.90e+01  0.125
```

```
cutflg:
bit 6      Good track flag requirement
bit 5      IMC Moliere concentration
           requirement
bit 4      TASC delta cut
bit 3      IMC shower start cut
bit 2      CHD charge cut
bit 1      IMC charge cut
```

Most Events are OK, but there are some exceptions.
Because of intrinsic difficulty in tracking for highest energy light nuclei, it is inevitable to mis-reconstruct some of them.
=> efficiency drop must be accepted

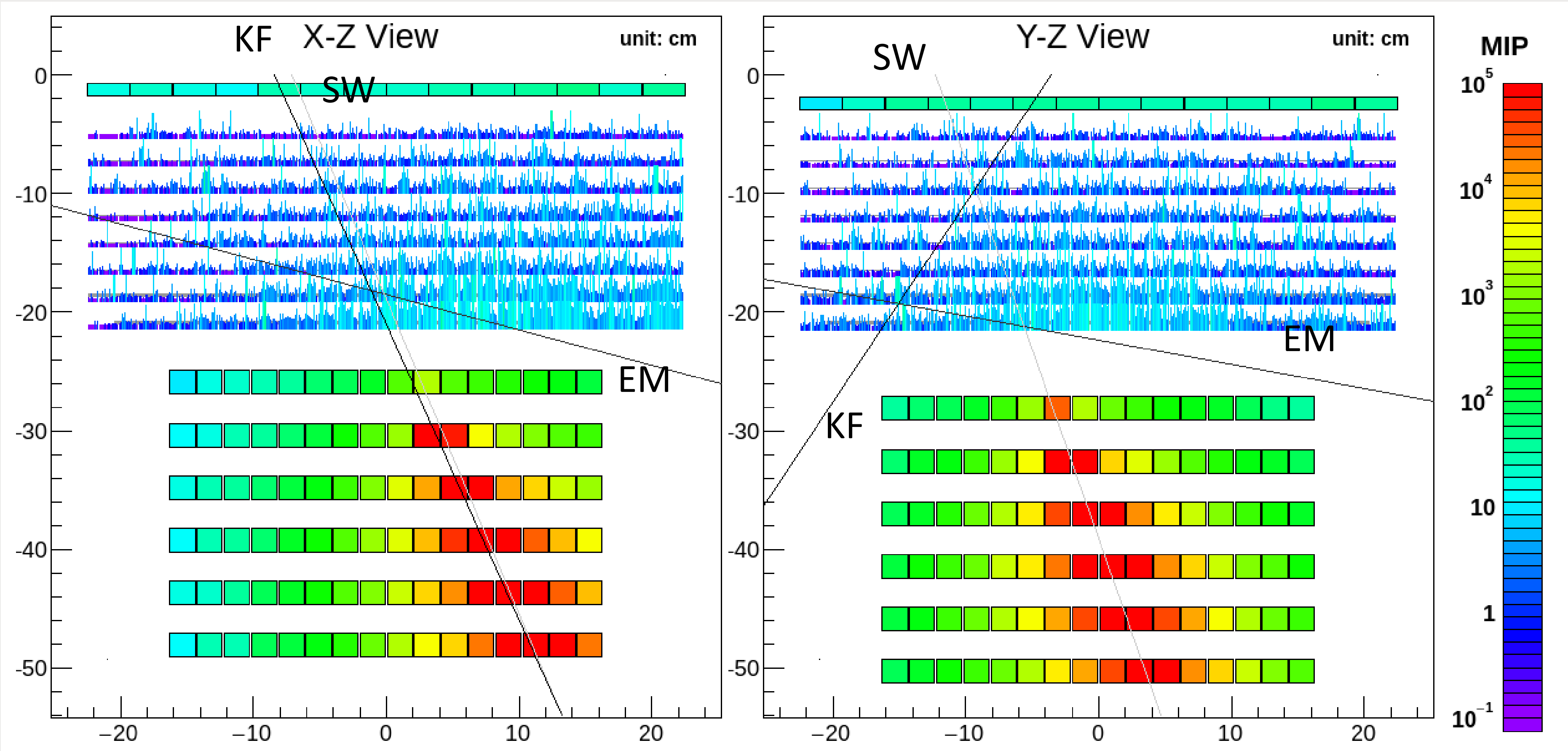
# Some Exceptions

PASS03.1

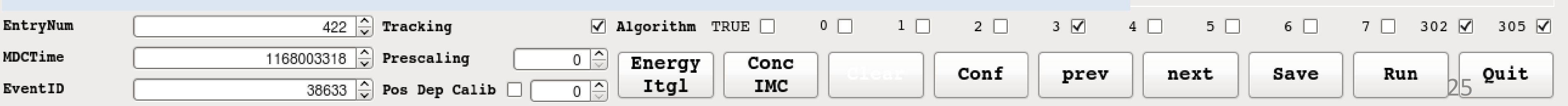


# Exceptions: continues

PASS03.1




```
yymmddHH MDCtime(s) evtID E_TASC
17010913 1168003318 38633 2.630e+05
   tID   f g nxy cutflg  Z_CHD  Z_IMC intL TASCdeltaX,Y n_IMC8   C_mol
KF 302   3 0 5 6 110111   6.69   1.71   4   2.26  17.53 1.25e+02  0.046
SW 305   1 1 6 6 110111   6.91   5.20  16   1.62   0.66 4.42e+02  0.060
EM   3   0 0 5 2 110000   0.00   0.00  12 -20.41 -31.22 4.50e+01  0.031
```



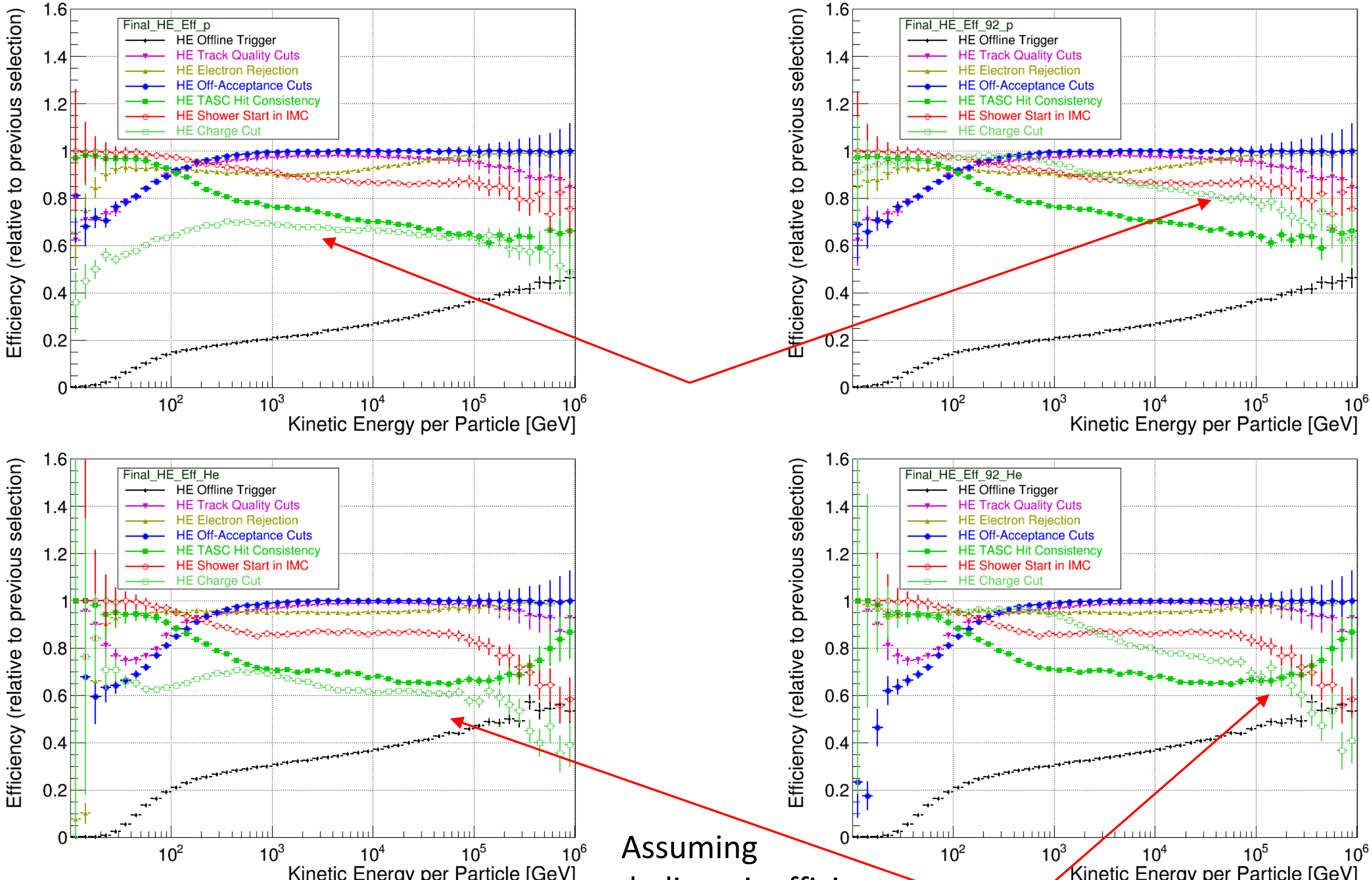
# Proton + Helium Analysis

Since protons and helium are the most dominant species up to 100 TeV region, it would be a good consistency study to check proton + helium spectrum including the 100 TeV region.

- Uses very loose charge cut:
  - 0.5 < Z_CHD < 5.5 && 0.5 < Z_IMC < 4.5
  - While the shower tracking has limited charge resolution, it should be sufficient to identify proton or helium from heavier elements such as carbon and oxygen.
- Other than charge cut, the analysis is the same as that of protons or helium.
- Overall efficiency assuming helium is higher than that assuming protons.
- By comparing the sum of the separately obtained proton and helium spectra with p+He spectrum obtained by assuming protons or helium, it is possible to check the behavior in the 100 TeV region.

# Efficiency Breakdown (KF)

p or He | p+He

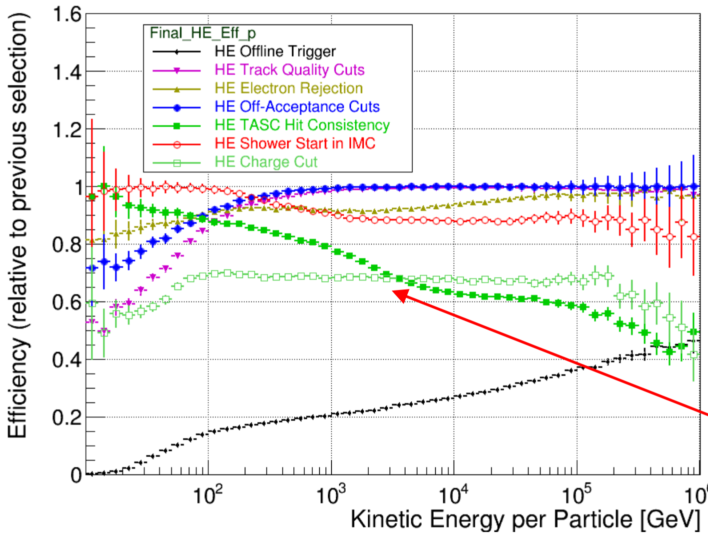



Assuming helium, inefficiency at E>100TeV remains

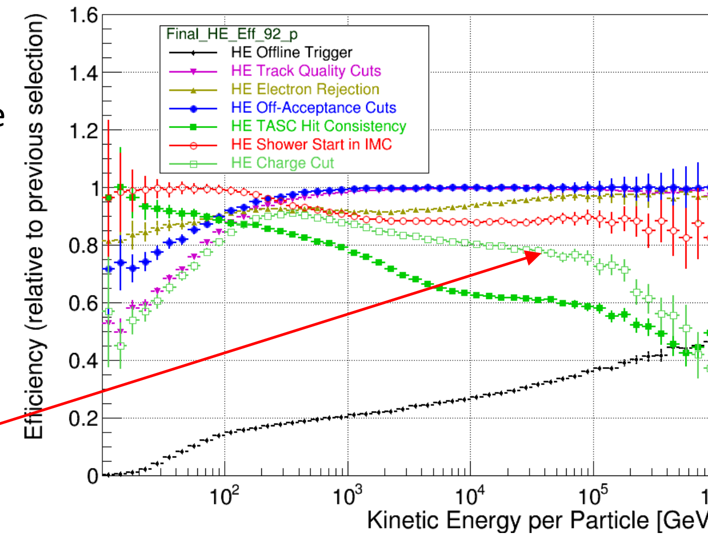
# Efficiency Breakdown (SW)

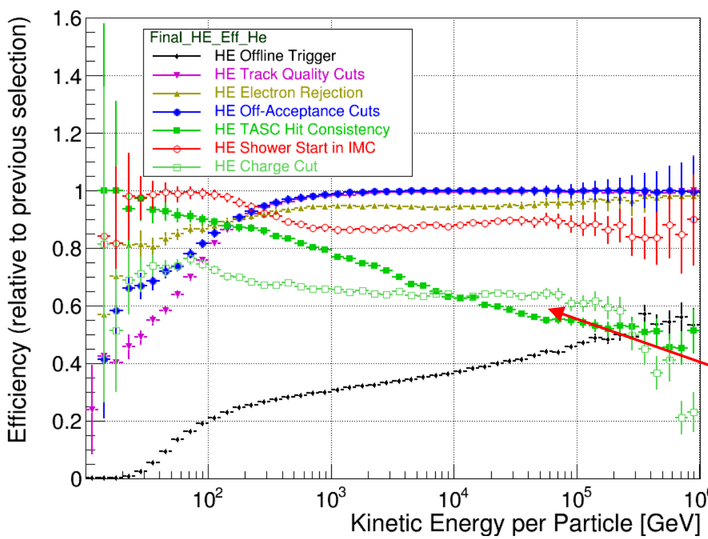
p or He

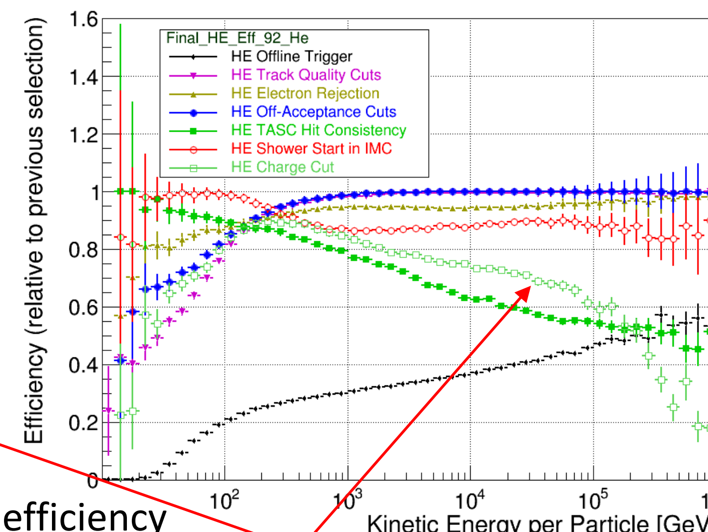
p+He




Low eff. of TASC delta cut should be improved

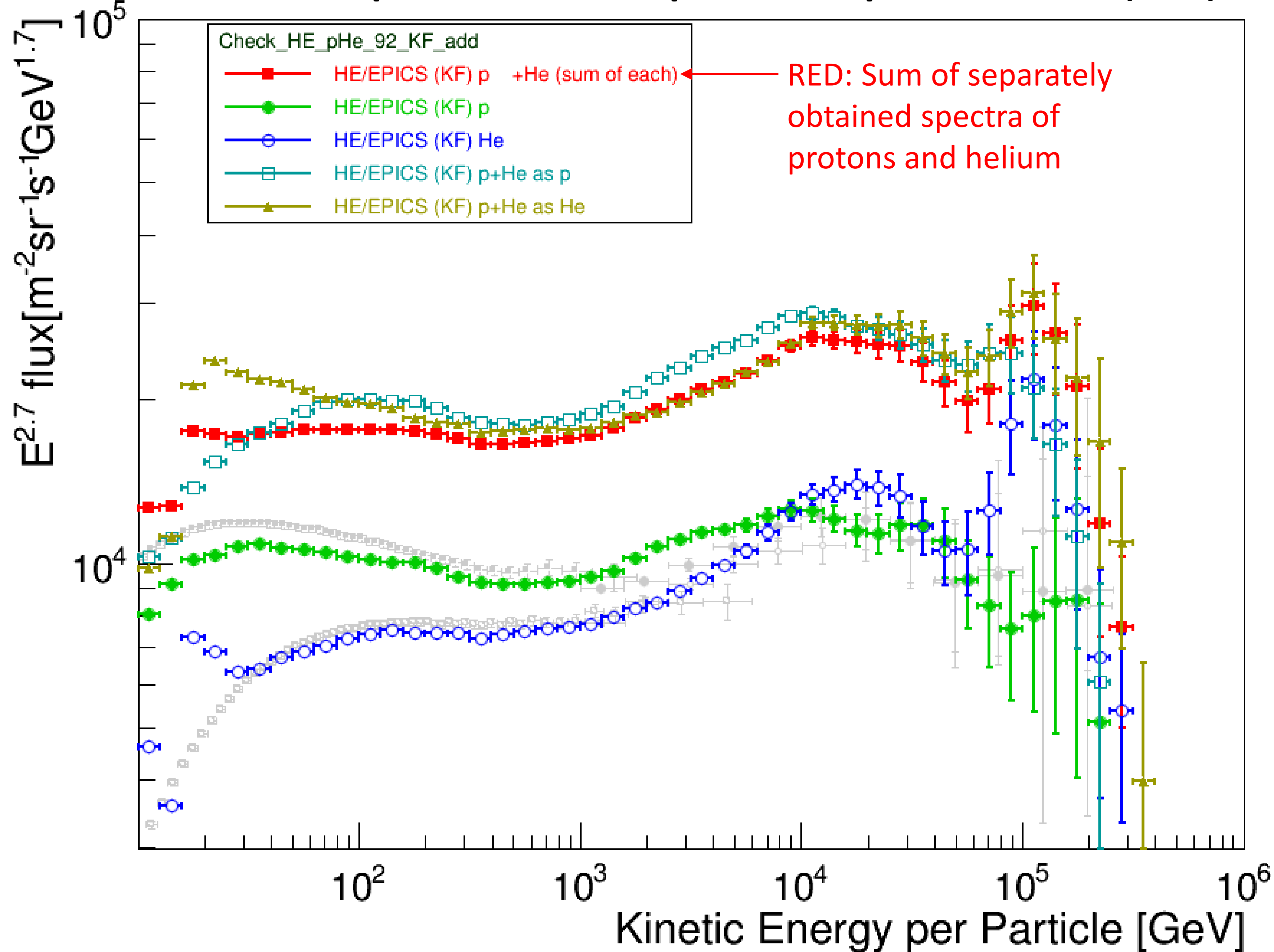


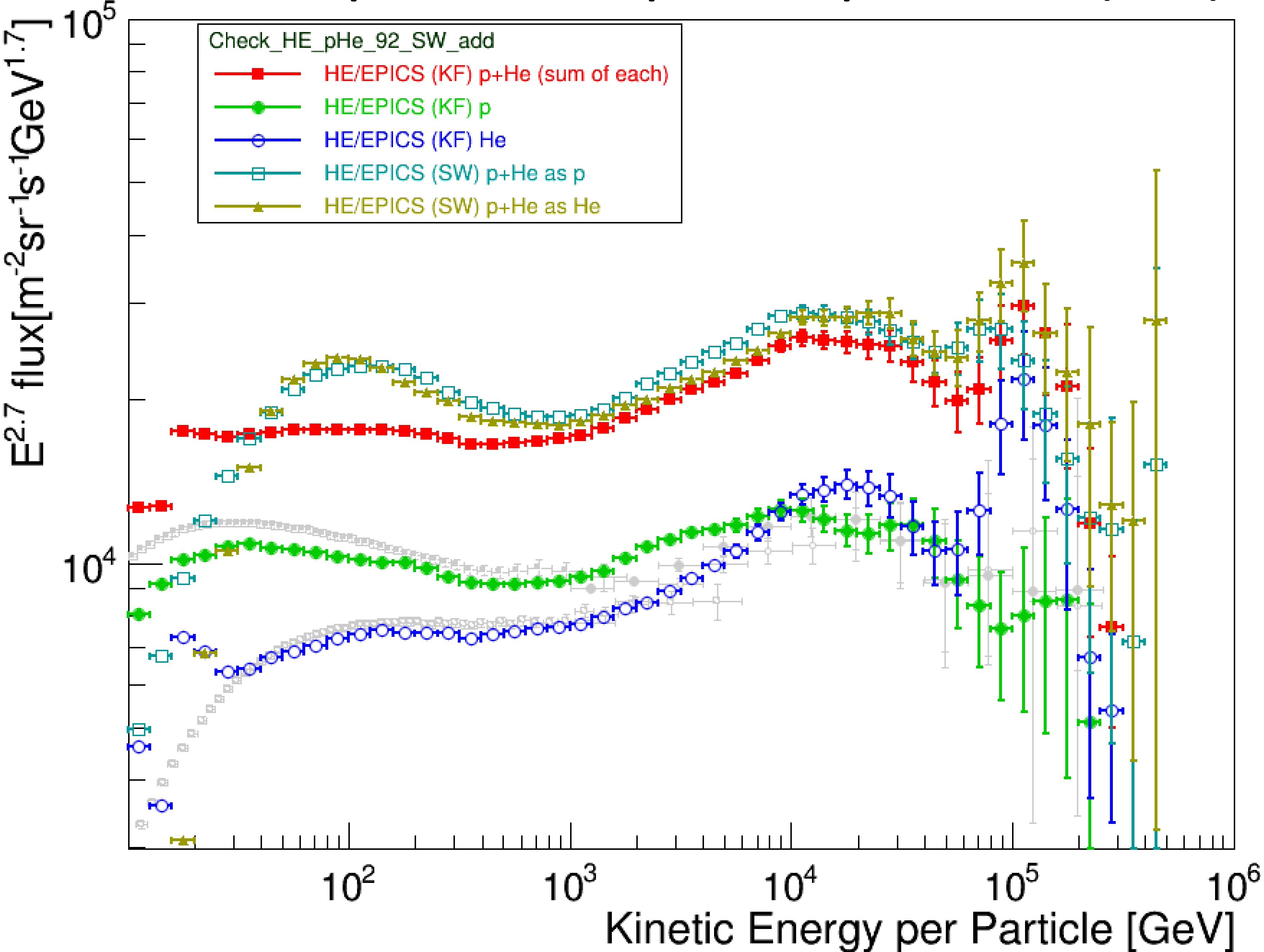

Assuming helium, inefficiency at E>100TeV remains

# Comparison of p+He Spectrum (KF)



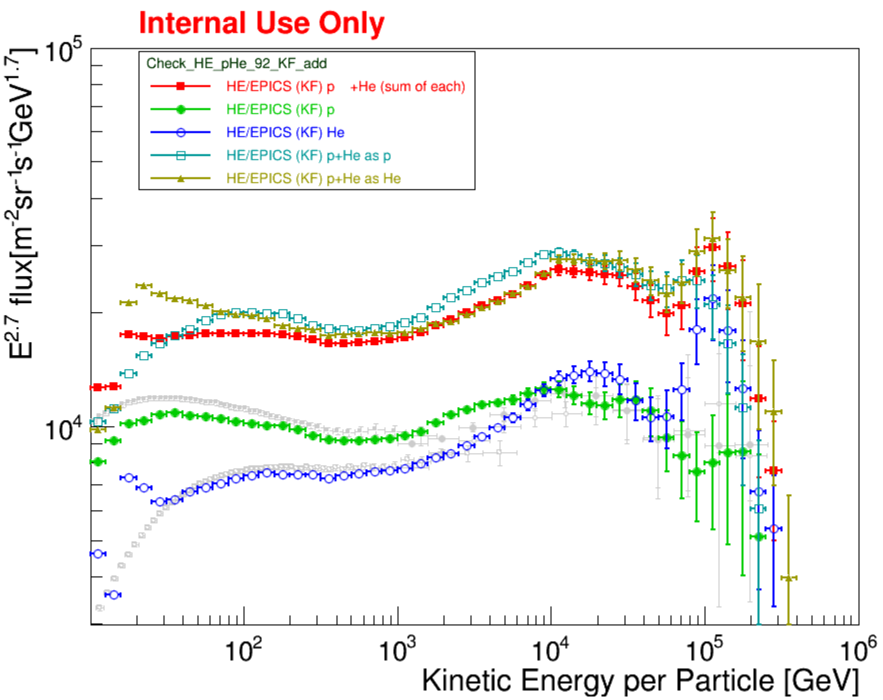

RED: Sum of separately obtained spectra of protons and helium

# Comparison of p+He Spectrum (SW)

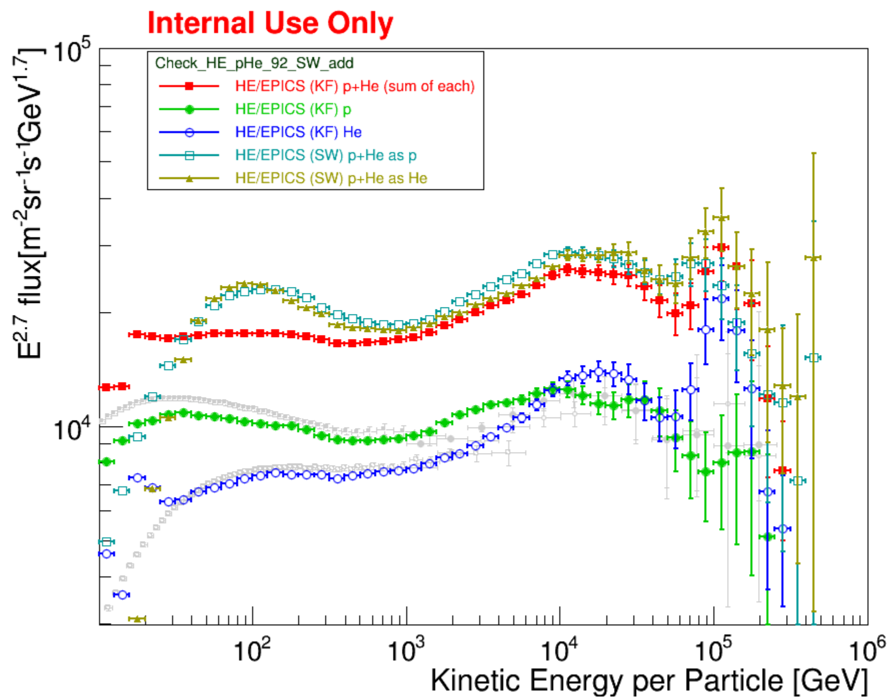


# Side-by-Side Comparison of KF and Shower Tracking

**KF**

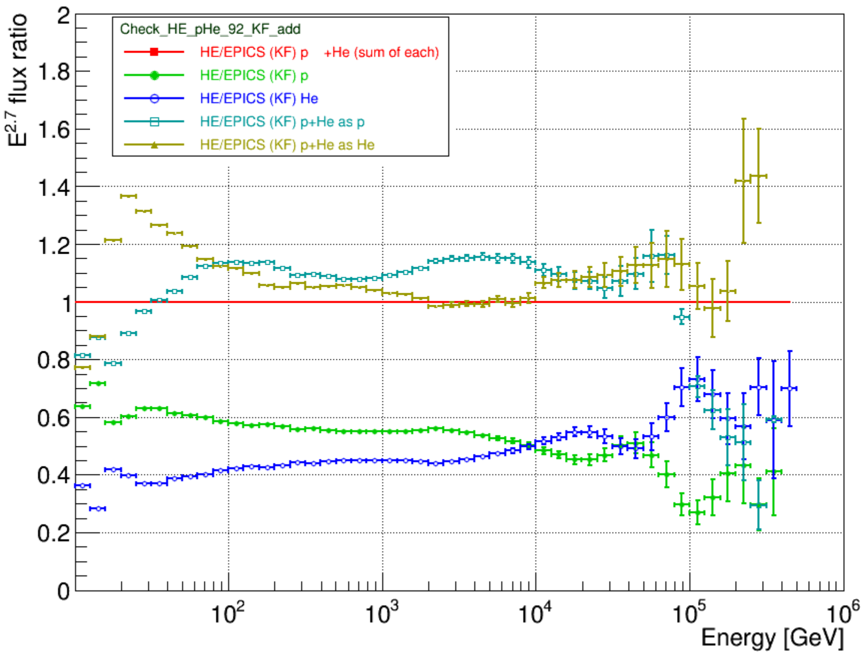



**SW**

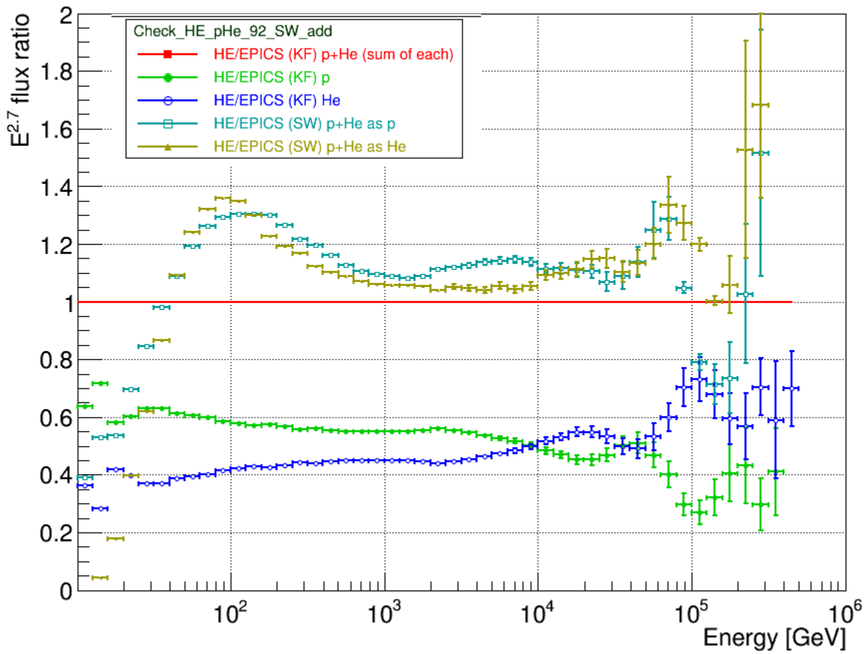


# Side-by-Side Comparison of KF and Shower Tracking (rel. diff.)

**KF**

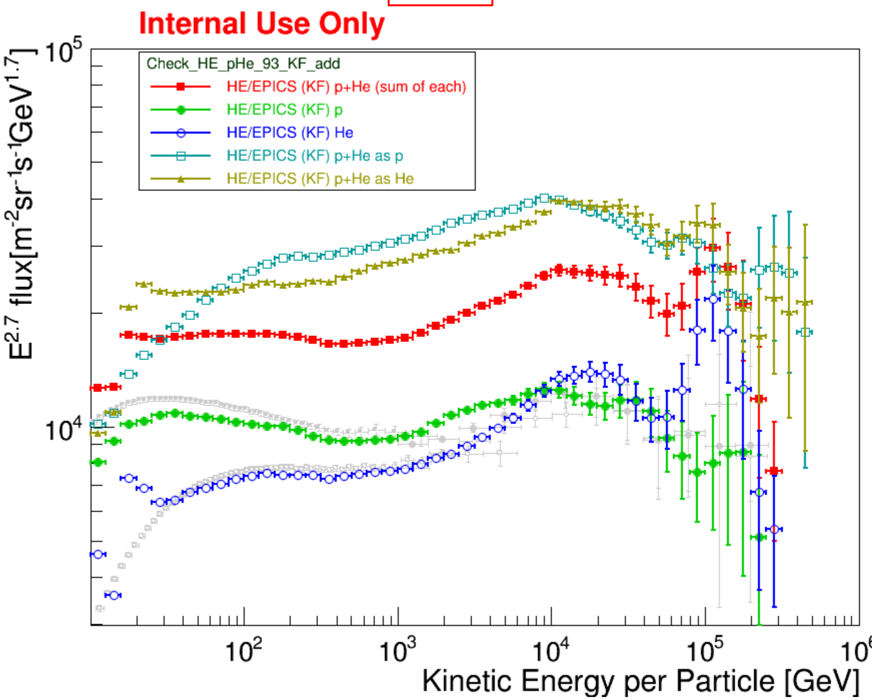



**SW**

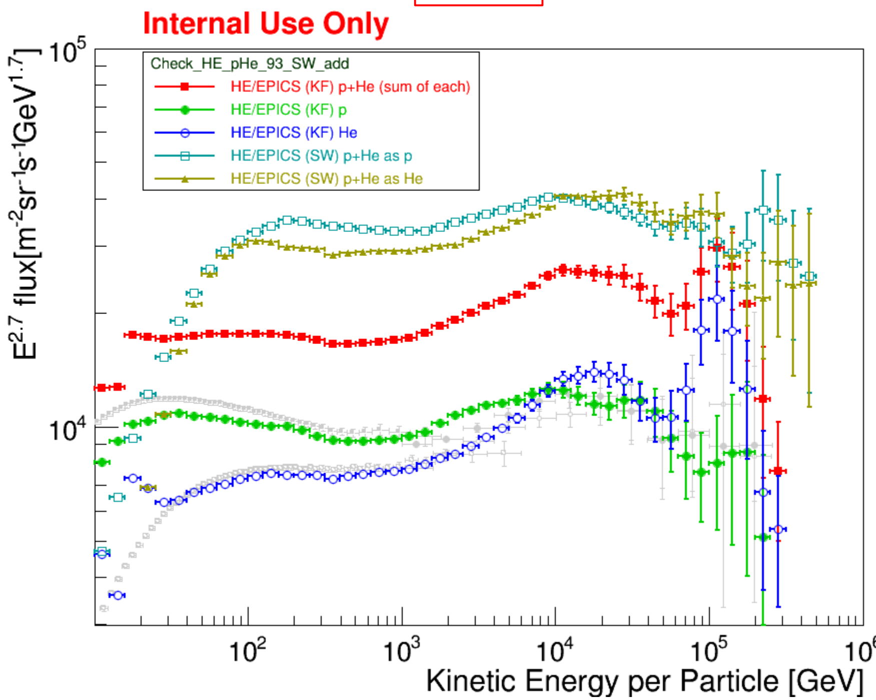


# Very Loose Charge Cut (0.5<Z<10): Comparison between KF and Shower Tracking

**KF**




**SW**




Probably due to inclusion of interacting particles in the CHD and/or upper layer of IMC

# Proton + Helium Analysis: Summary

- In the p+He spectrum, there are no big difference between sum of separately measured spectra and p+He selected by loose charge cut.
- However, the charge cut efficiency especially for Shower tracking at E>100TeV starts dropping.
  - Extremely loose charge cut (0.5<Z<10) gives much higher flux all over the energy range

Heavier particles (C, O, etc.) might also be important and/or too loose charge cut might introduce other background such as mis-reconstructed events

- There may be some room for improvements.
  - Charge consistency between XY12 vs XY34?
  - Simple charge determination only with XY12?

# Further study of highest energy region using early interaction

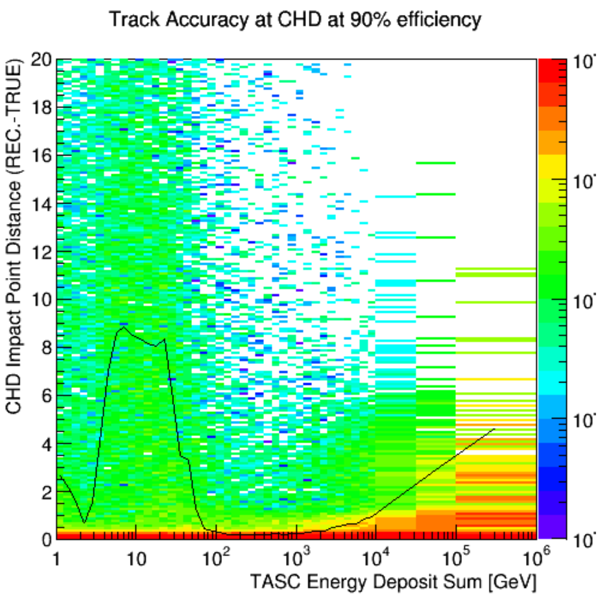
- One very important uncertainty at the highest energy region must be tracking because it becomes much more difficult due to the presence of so many backscattering hits.
- One approach is to use shower track and loose charge cut to identify proton + helium. However, very loose cut may not work as it contains many misidentified events(?).
  - I still work on this study, but unfortunately, it seems that the results are not so clear cut.
- During the study of p+He spectrum, I found that tracking accuracy could be very good if it is possible to select the interaction point as shallow as possible, while keeping the charge determination capability with IMC in an acceptable range.

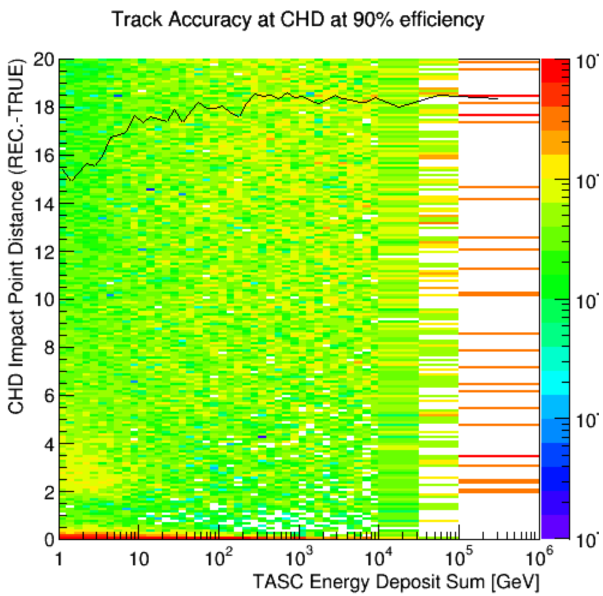
# CHD Impact Point Difference between Reconstructed and Truth

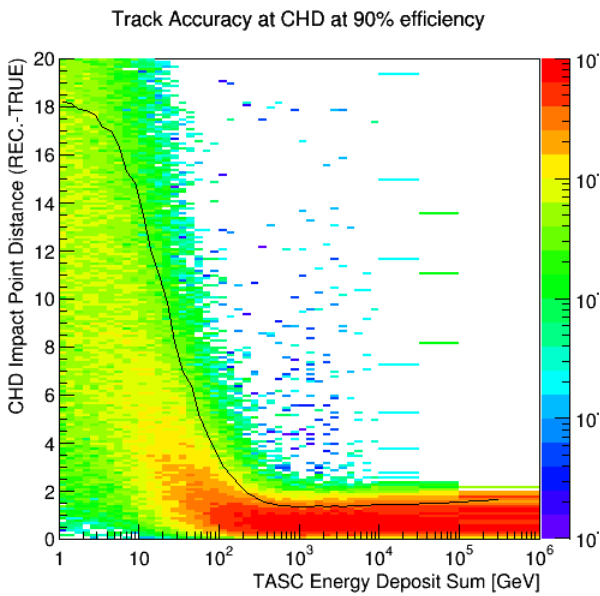
int=3

**EPICS Protons, true acceptance A, interaction occurs just before IMC $8^{th}$ layer**

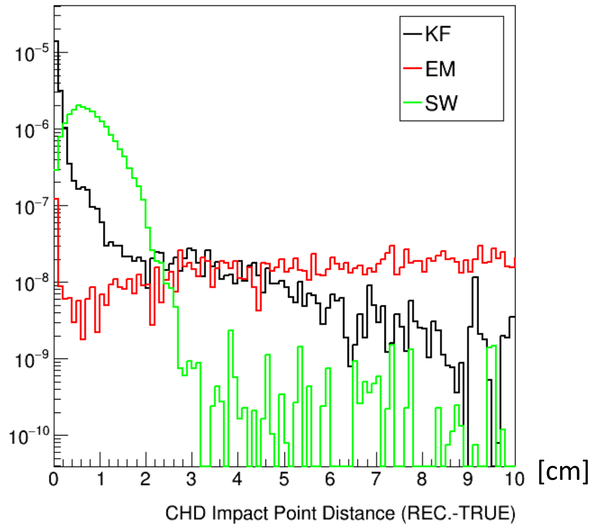
**KF** | **EM** | W $1X_0$ | **SW**



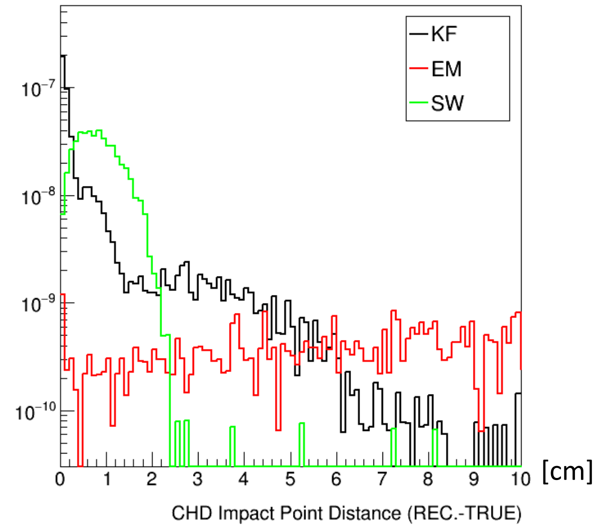



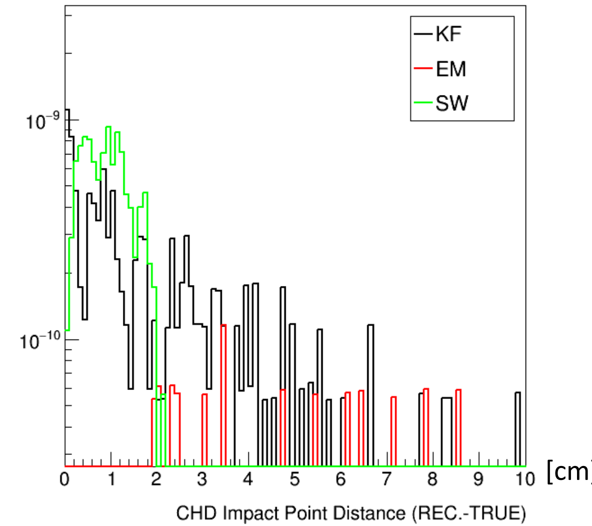

1.0 < E/TeV < 10.0 int:3




10.0 < E/TeV < 100.0 int:3




100.0 < E/TeV < 1000.0 int:3

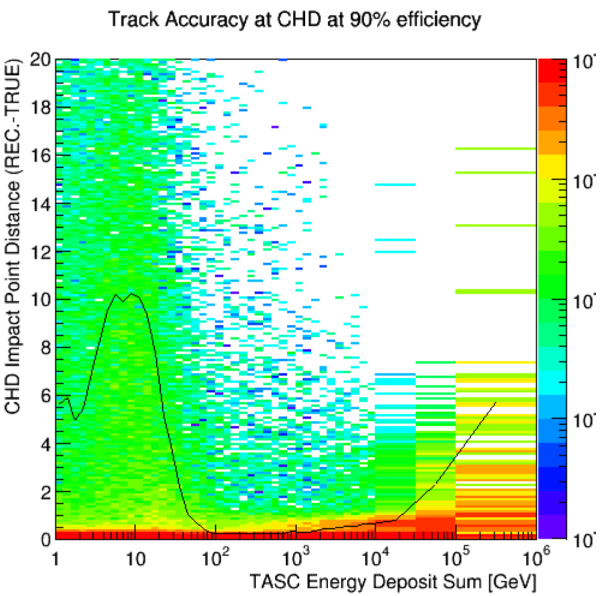


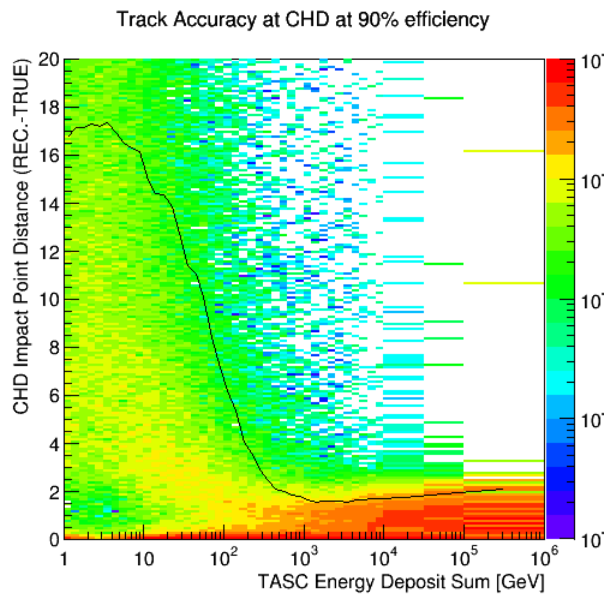
# CHD Impact Point Difference between Reconstructed and Truth

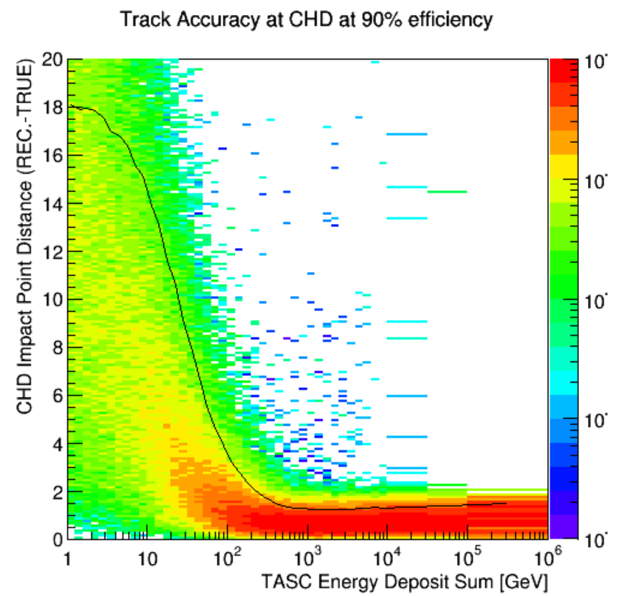
int=4

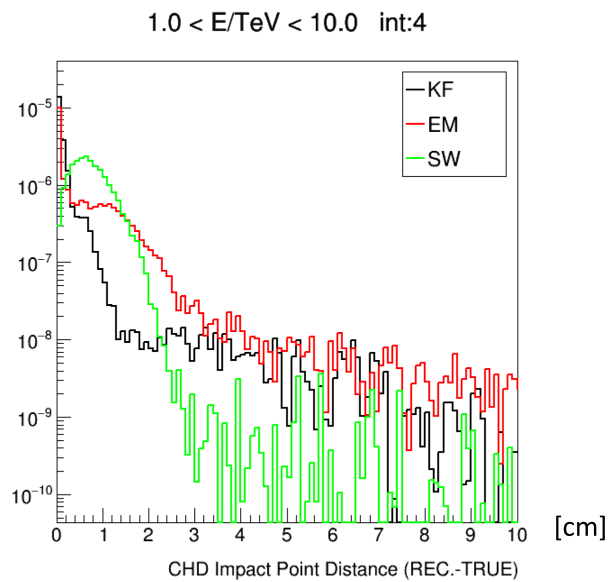
## <u>EPICS Protons, true acceptance A, interaction occurs just before IMC 7th layer</u>

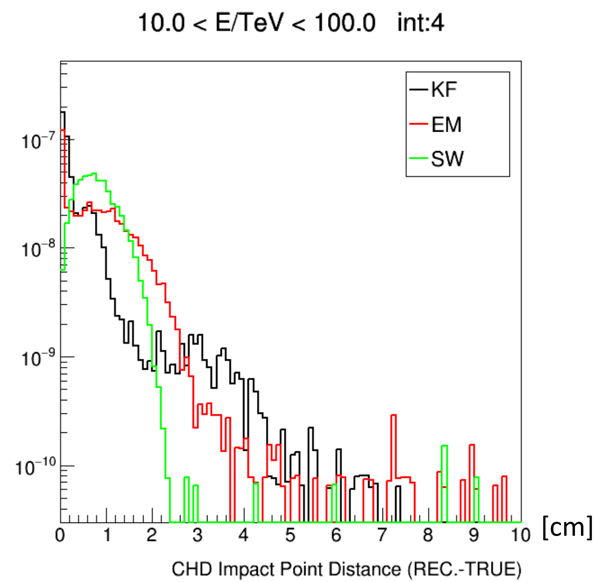
**KF** **EM** W $1X_0$ **SW**

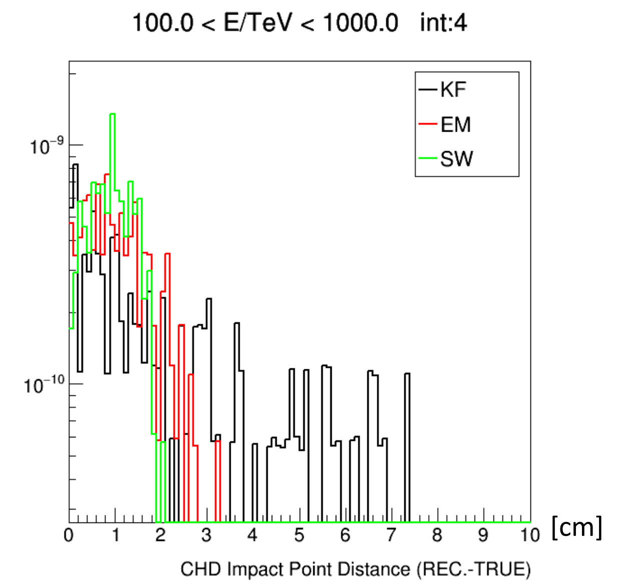


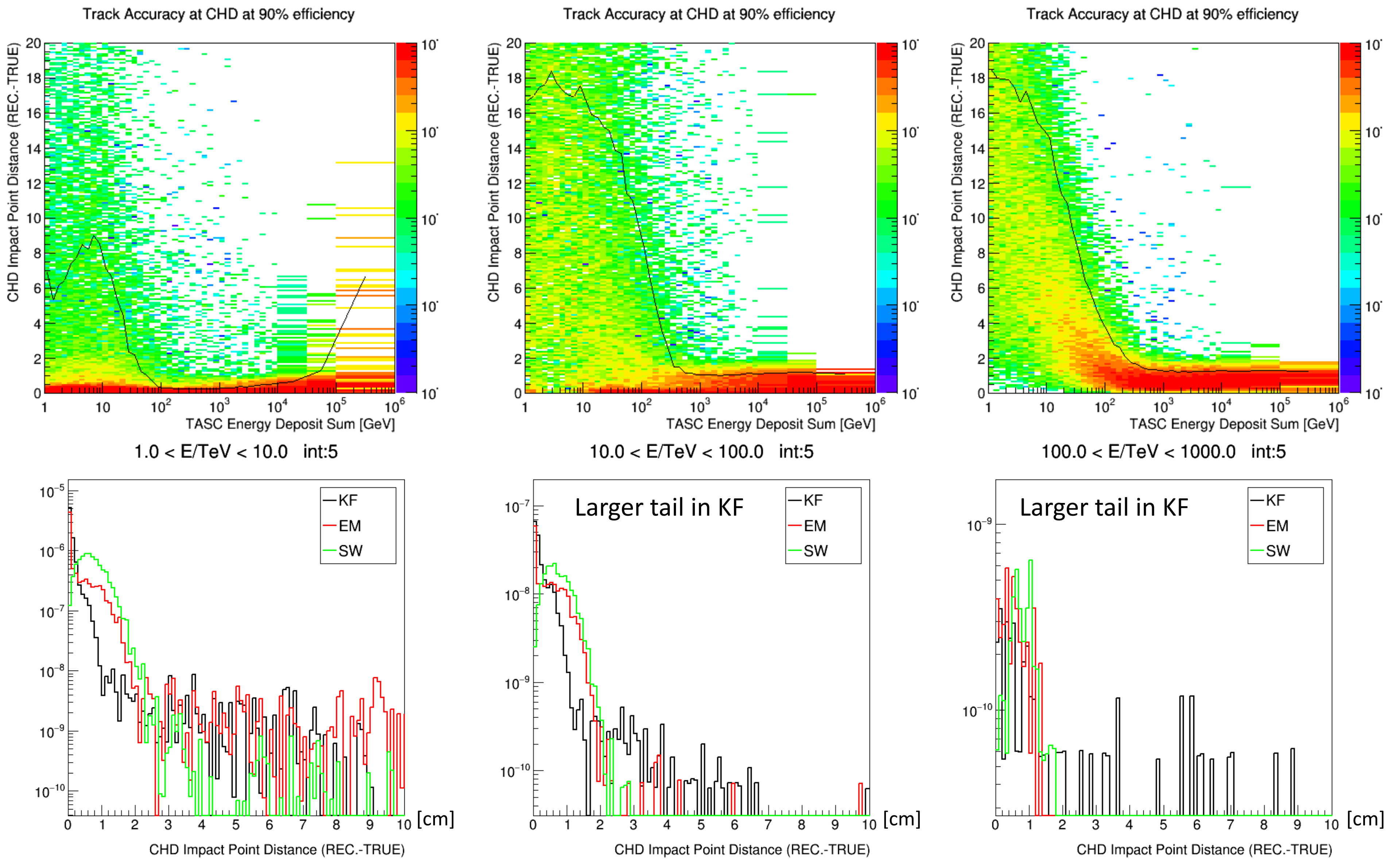



# CHD Impact Point Difference between Reconstructed and Truth

int=5

**EPICS Protons, true acceptance A, interaction occurs just before IMC $6^{th}$ layer**

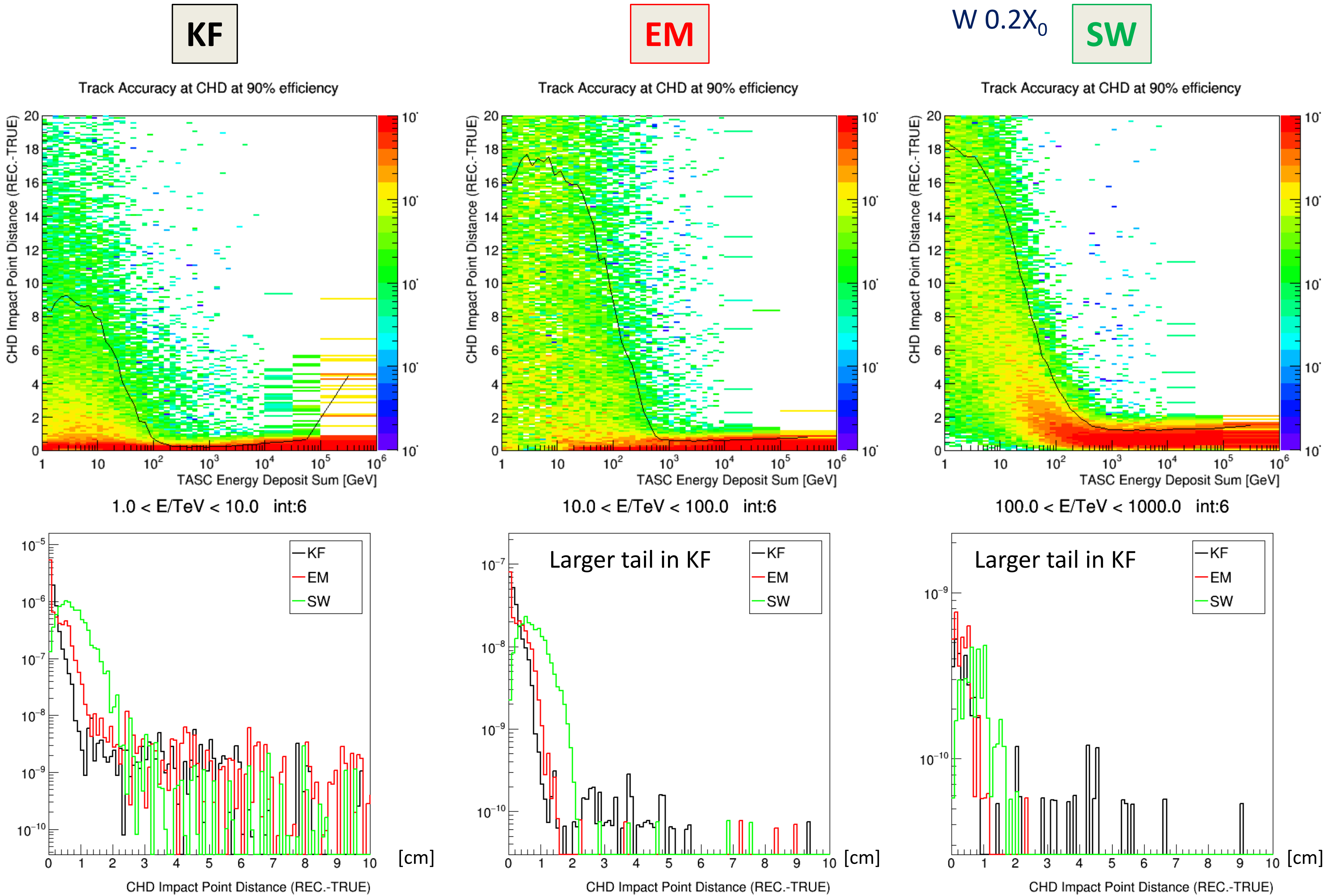
**KF** **EM** W $0.2X_0$ **SW**



# CHD Impact Point Difference between Reconstructed and Truth

int=6

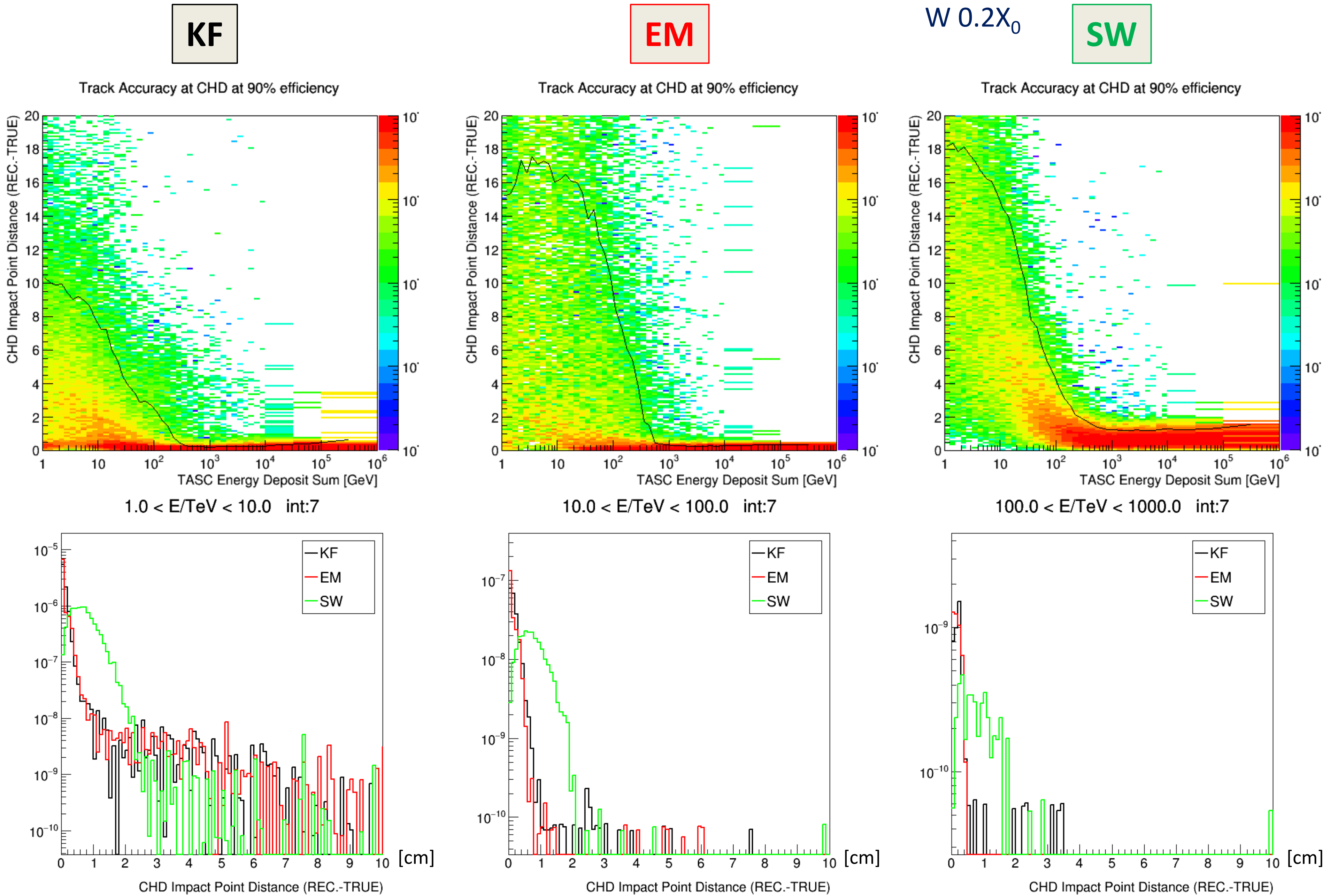
**EPICS Protons, true acceptance A, interaction occurs just before IMC 5th layer**



# CHD Impact Point Difference between Reconstructed and Truth

int=7

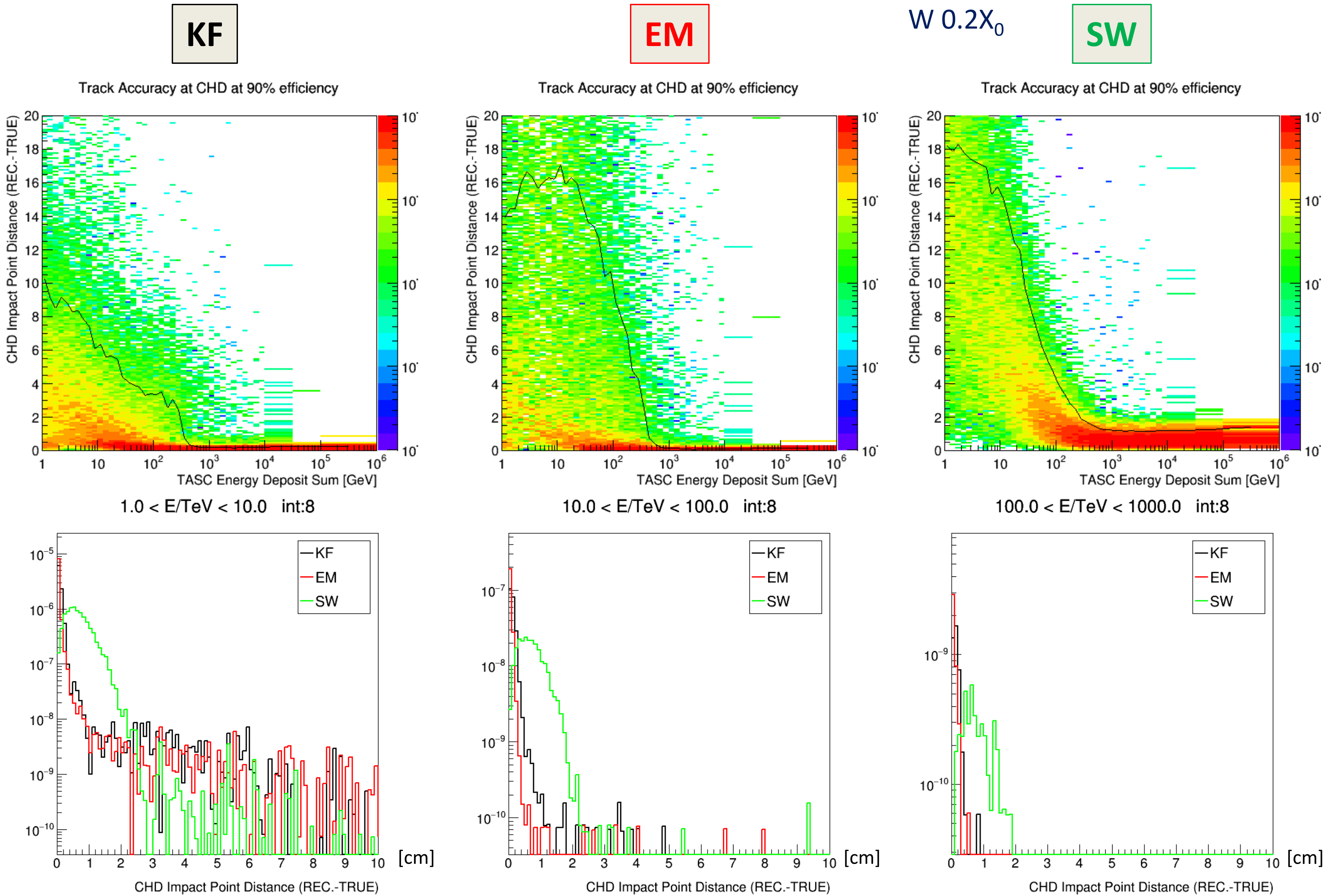
**EPICS Protons, true acceptance A, interaction occurs just before IMC 4th layer**



# CHD Impact Point Difference between Reconstructed and Truth

**int=8**

## EPICS Protons, true acceptance A, interaction occurs just before IMC 3rd layer

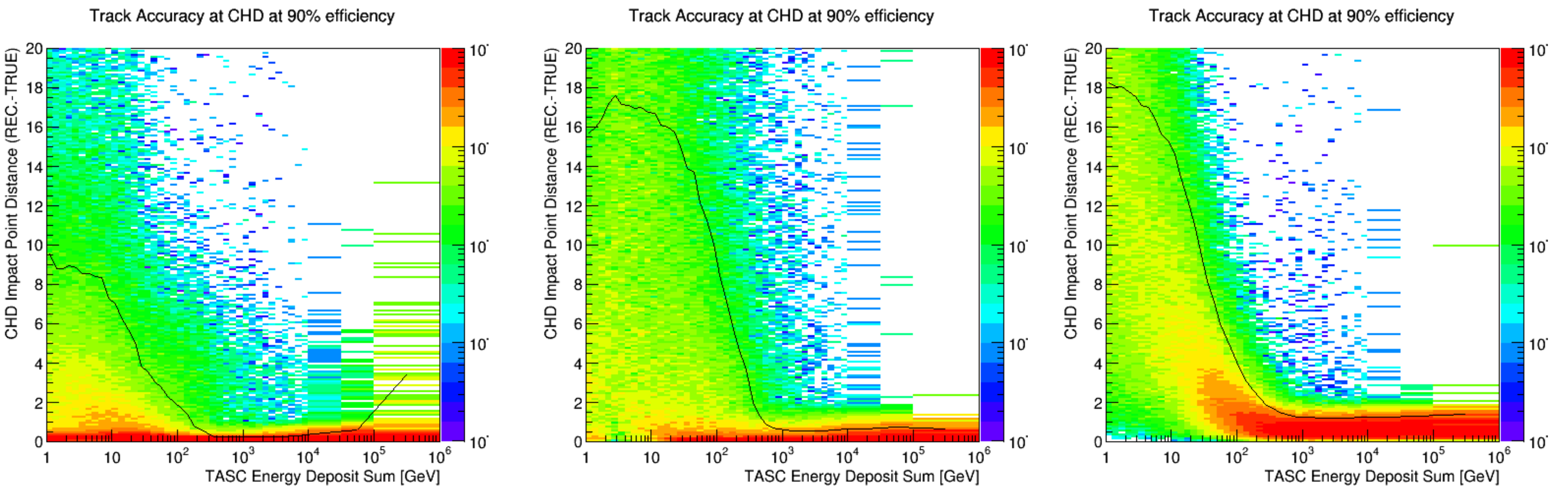


# CHD Impact Point Difference between Reconstructed and Truth

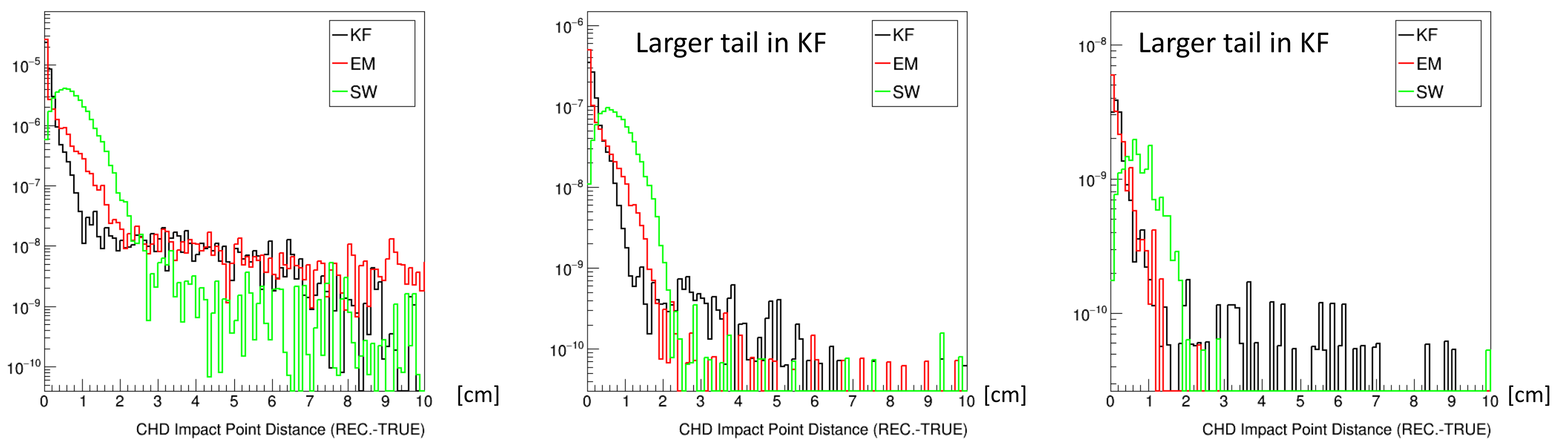
**int=9**

## EPICS Protons, true acceptance A, interaction occurs just before IMC 3-6th layer

**KF** **EM** W $0.8X_0$ **SW**




1.0 < E/TeV < 10.0 int:9 | 10.0 < E/TeV < 100.0 int:9 | 100.0 < E/TeV < 1000.0 int:9

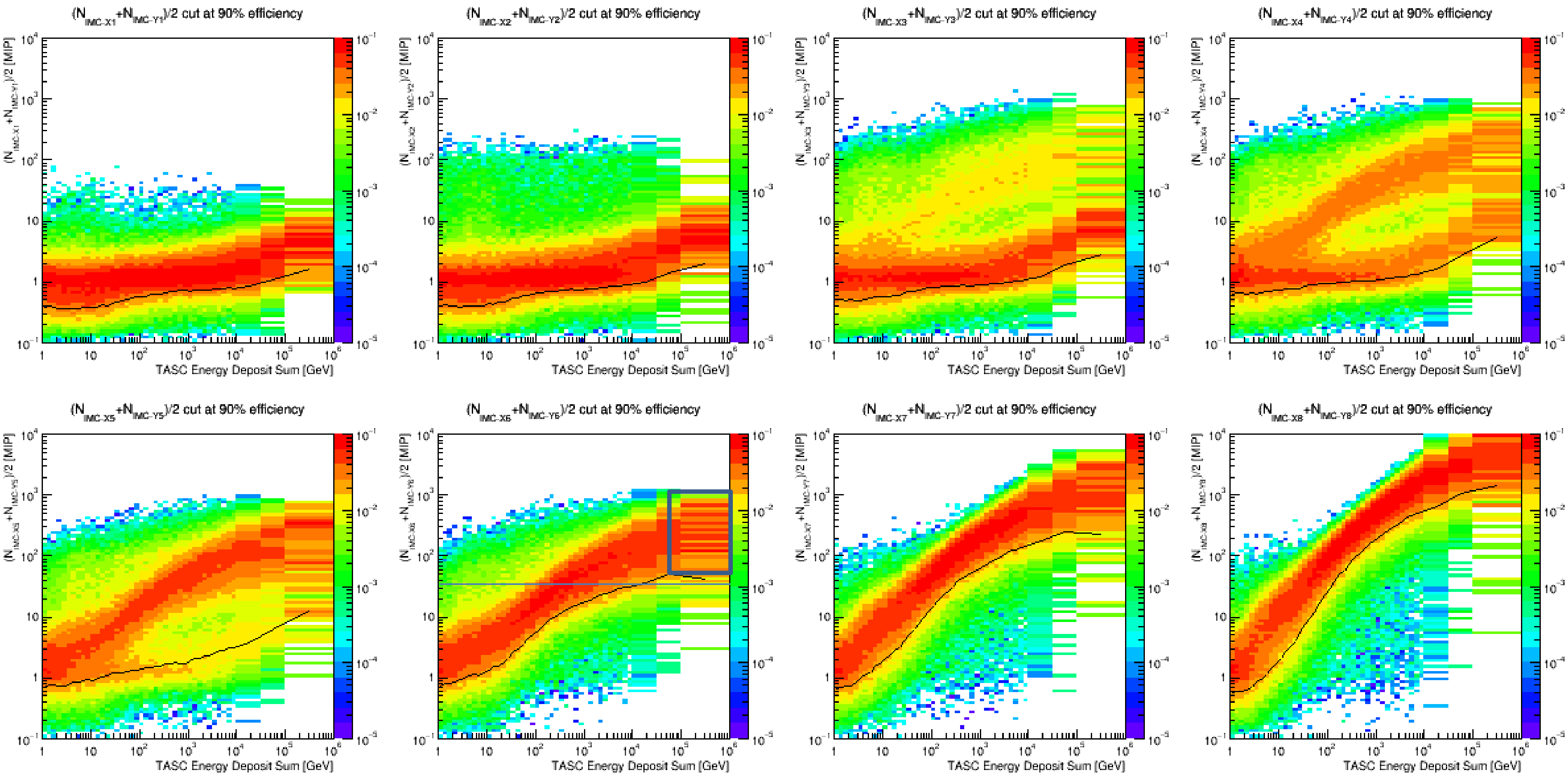


# Interaction Point Selection

- To take advantage of better tracking accuracy of EM tracking in the case of interaction in the shallow IMC layers (not too shallow, of course), it is crucial to select interaction point with high accuracy.
- In principle, it is possible to select interaction point by requiring high energy deposit around the shower axis.
  - To avoid the dependence on the MC models, now we use the sum of +-9 fibers.
  - For higher energies and for better resolution, this is bad choice. +-1 fibers around the shower axis should have better performance.
- It is also important to check the IMC charge resolution in this case.
  - IMC charge will be determined by 1$^{st}$ and 2$^{nd}$ layers.

# KF Tracking: Interacting just before 3rd-6th IMC Layers

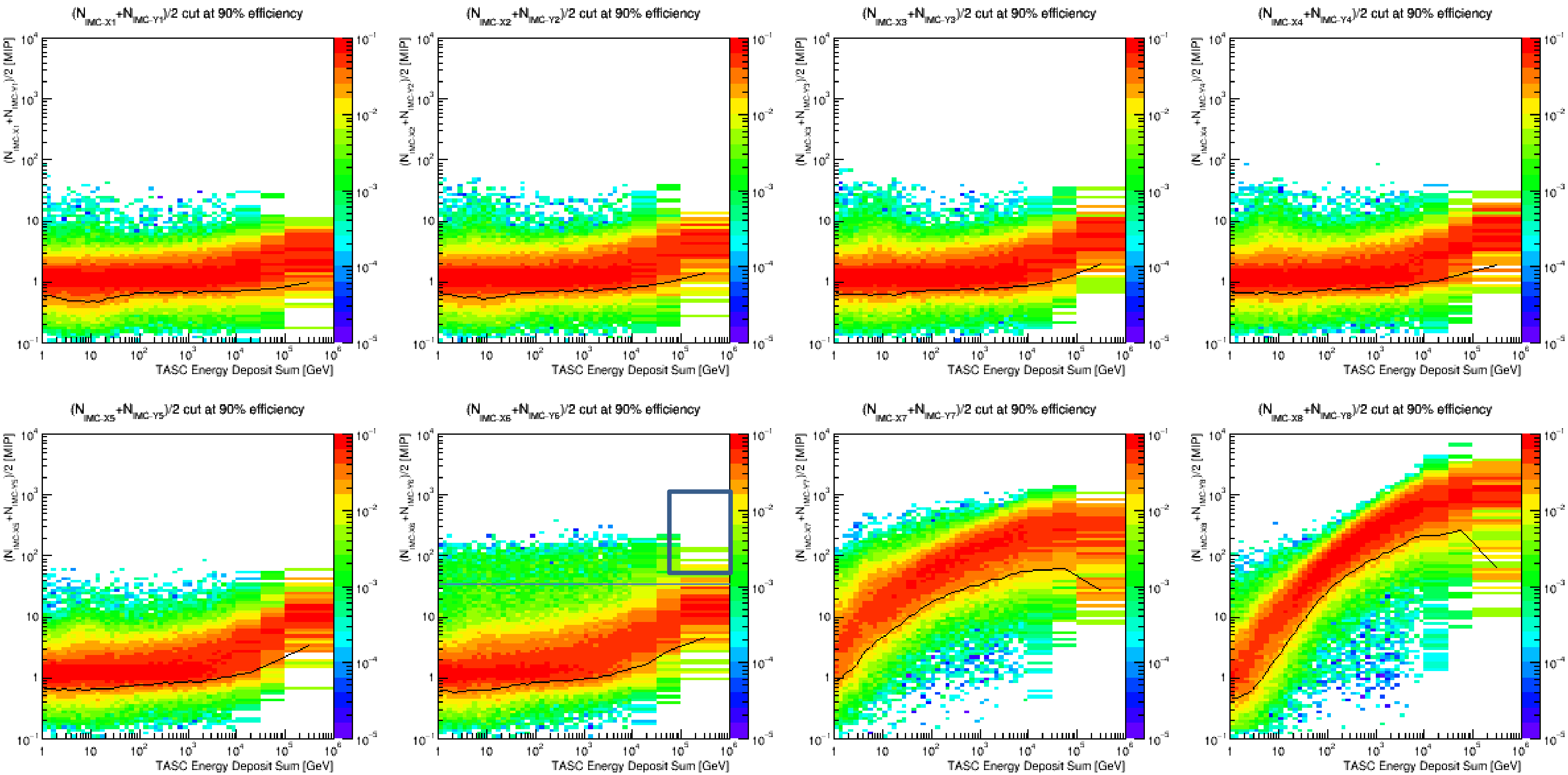
Shower Axis +- 1 fibers



int=4

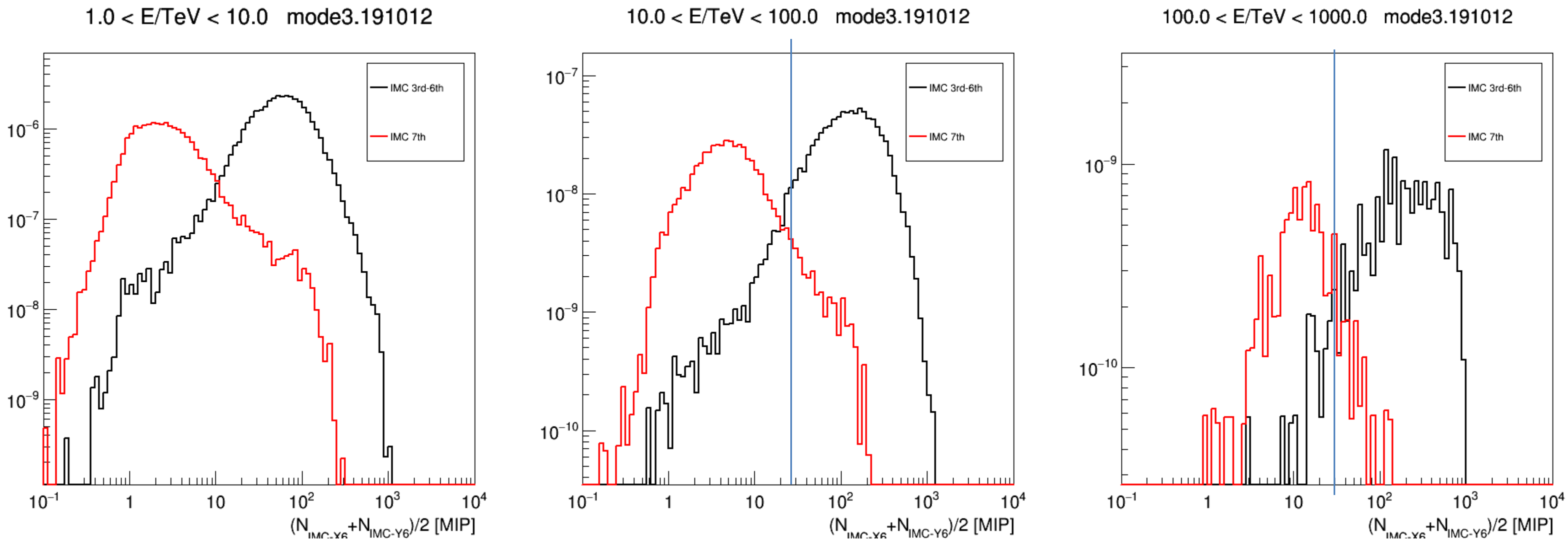
# KF Tracking: Interacting just before 7th IMC Layers

Shower Axis +- 1 fibers



# KF: Discrimination of Interaction Point

Shower Axis +- 1 fibers



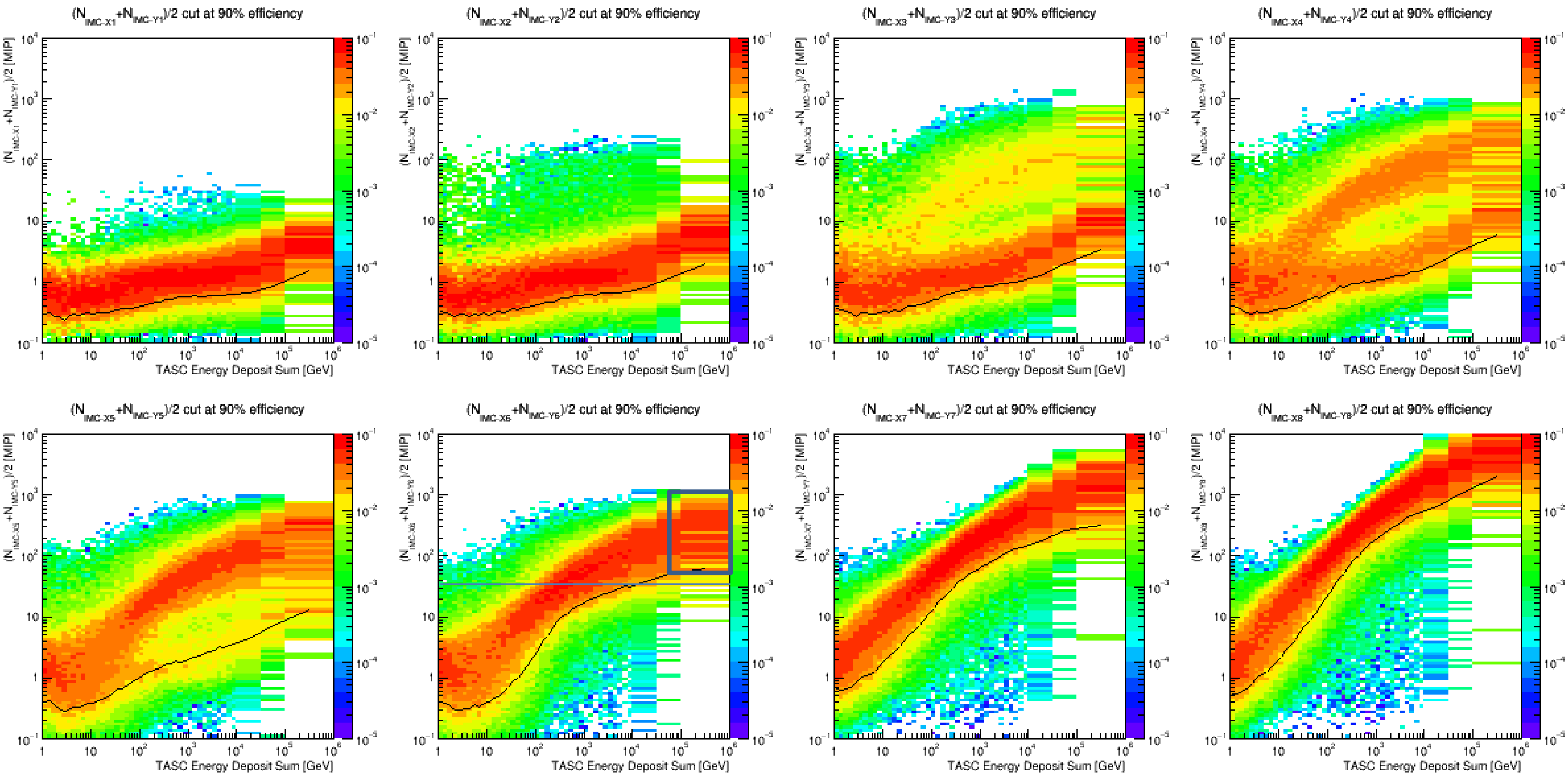

**Interacting just before $3^{rd}$-$6^{th}$ IMC Layers**

**Interacting just before $7^{th}$ IMC layer**

Rejection of late interaction event is quite good int=9

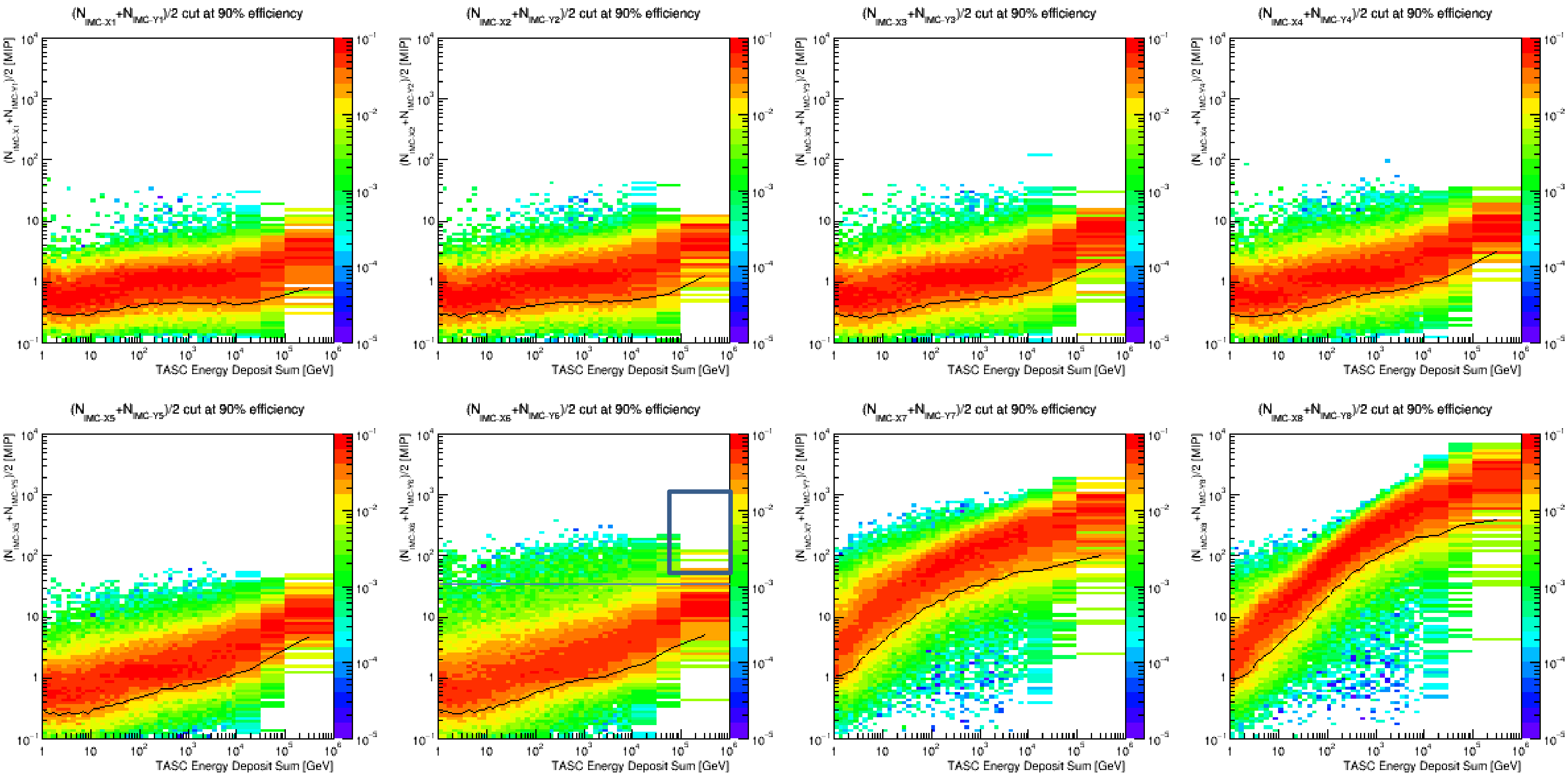
# EM Tracking: Interacting just before 3rd-6th IMC Layers

Shower Axis +- 1 fibers



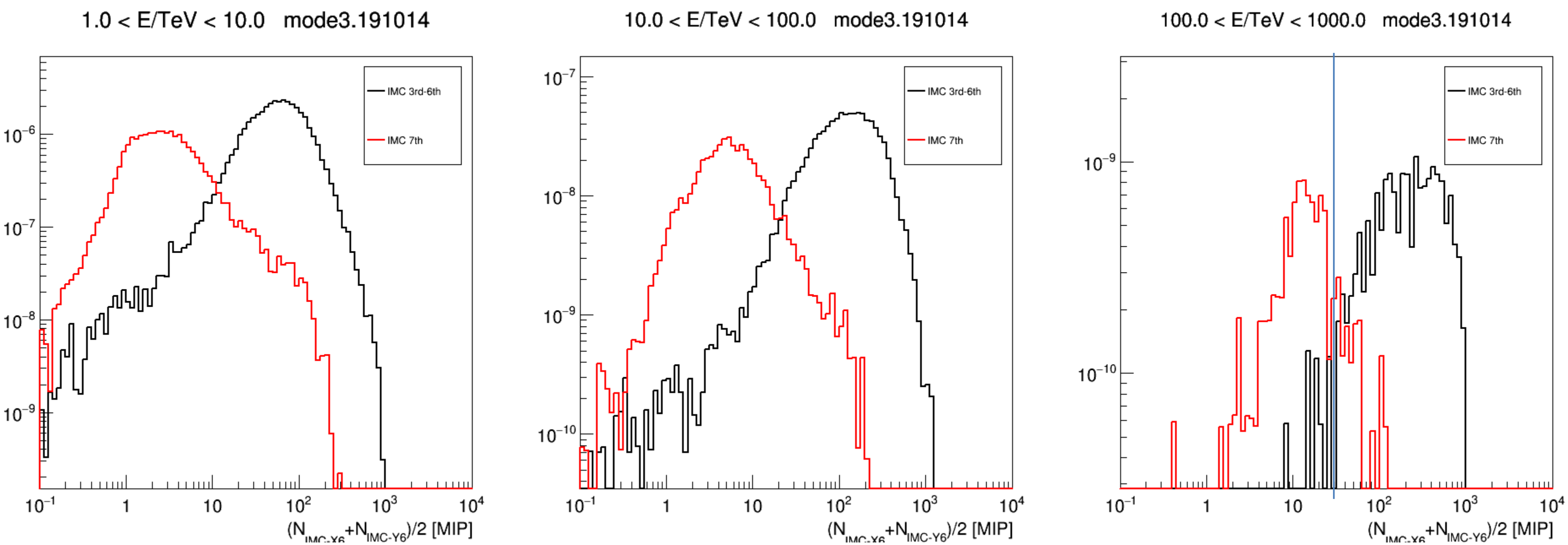
# EM Tracking: Interacting just before 7th IMC Layers

Shower Axis +- 1 fibers



# EM: Discrimination of Interaction Point

Shower Axis +- 1 fibers

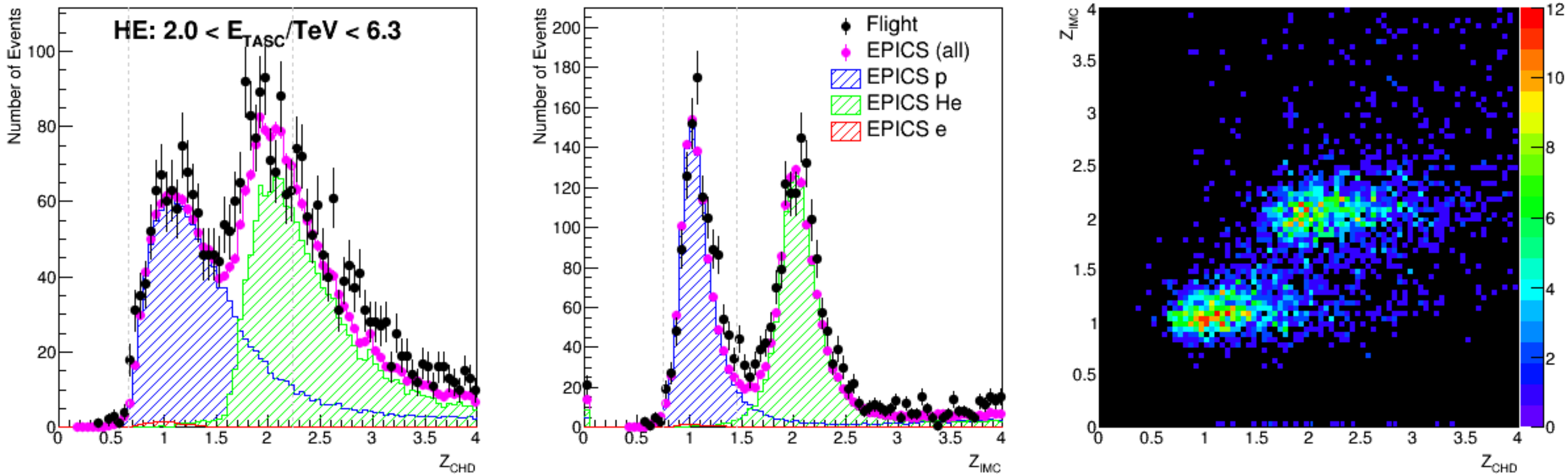



**Interacting just before 3rd-6th IMC Layers**

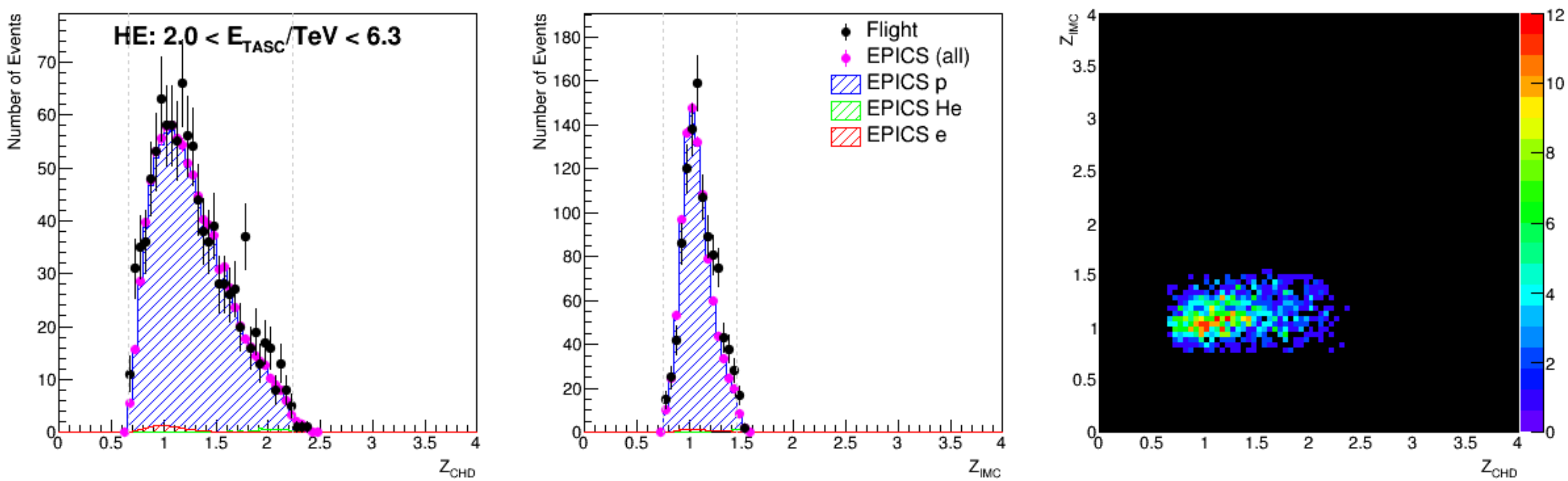
**Interacting just before 7th IMC layer**

Rejection of late interaction event is quite good (similar to KF)

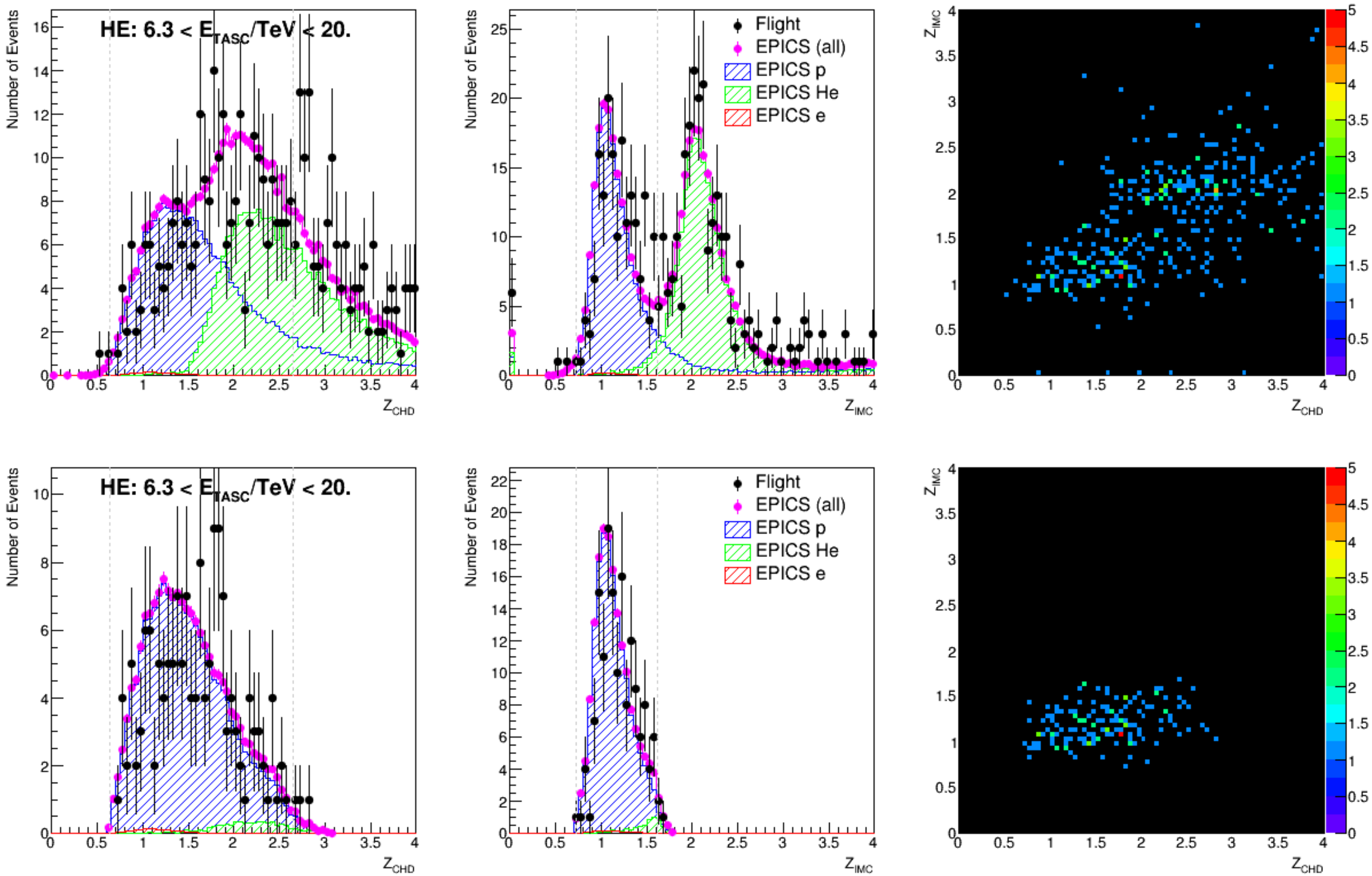
# KF w/ $Z_{IMC}$ : Late Interaction Case (PRL ver.)




**After Z-cut**

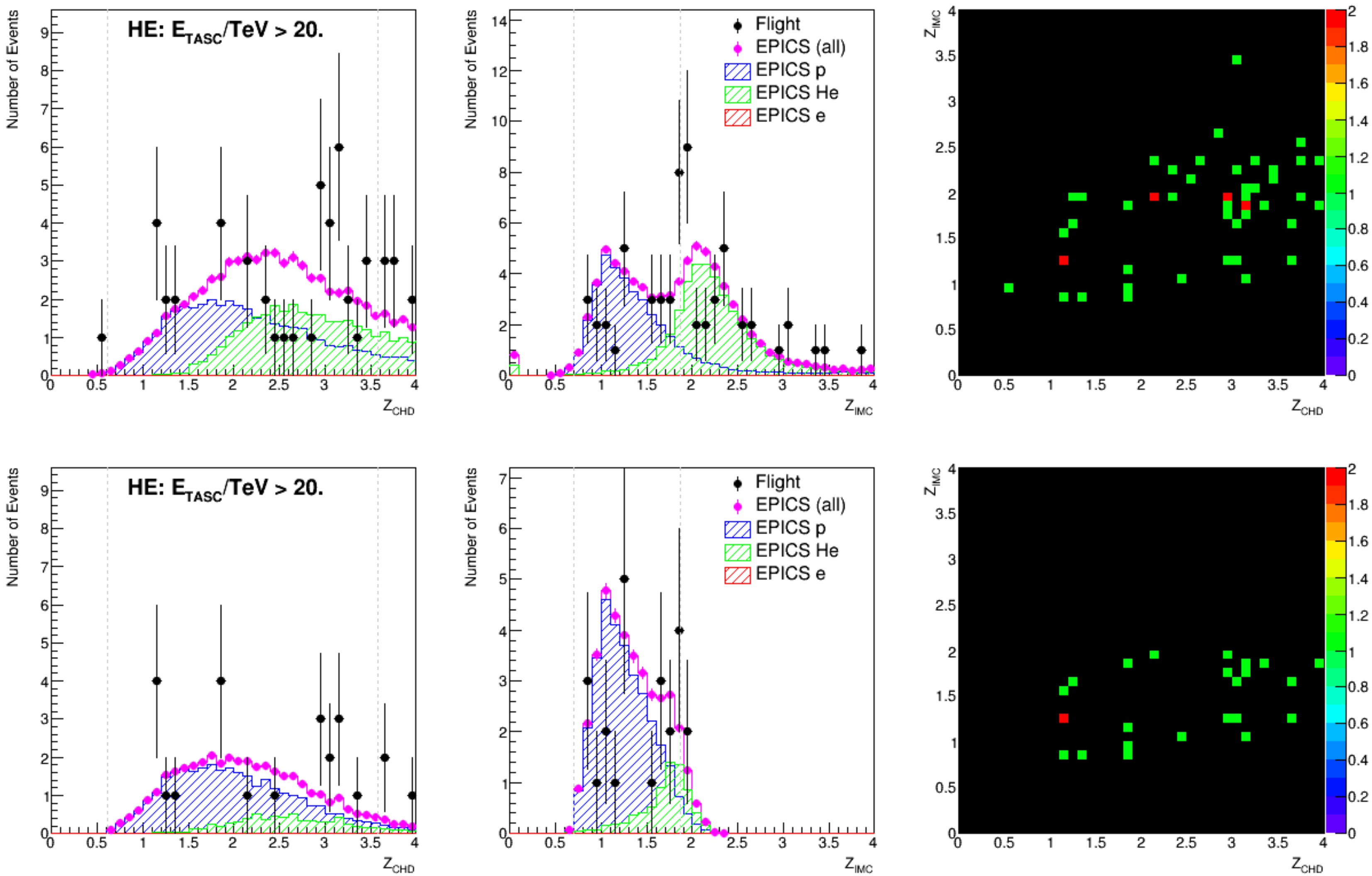


# KF w/ $Z_{IMC}$ : Late Interaction Case (PRL ver.)



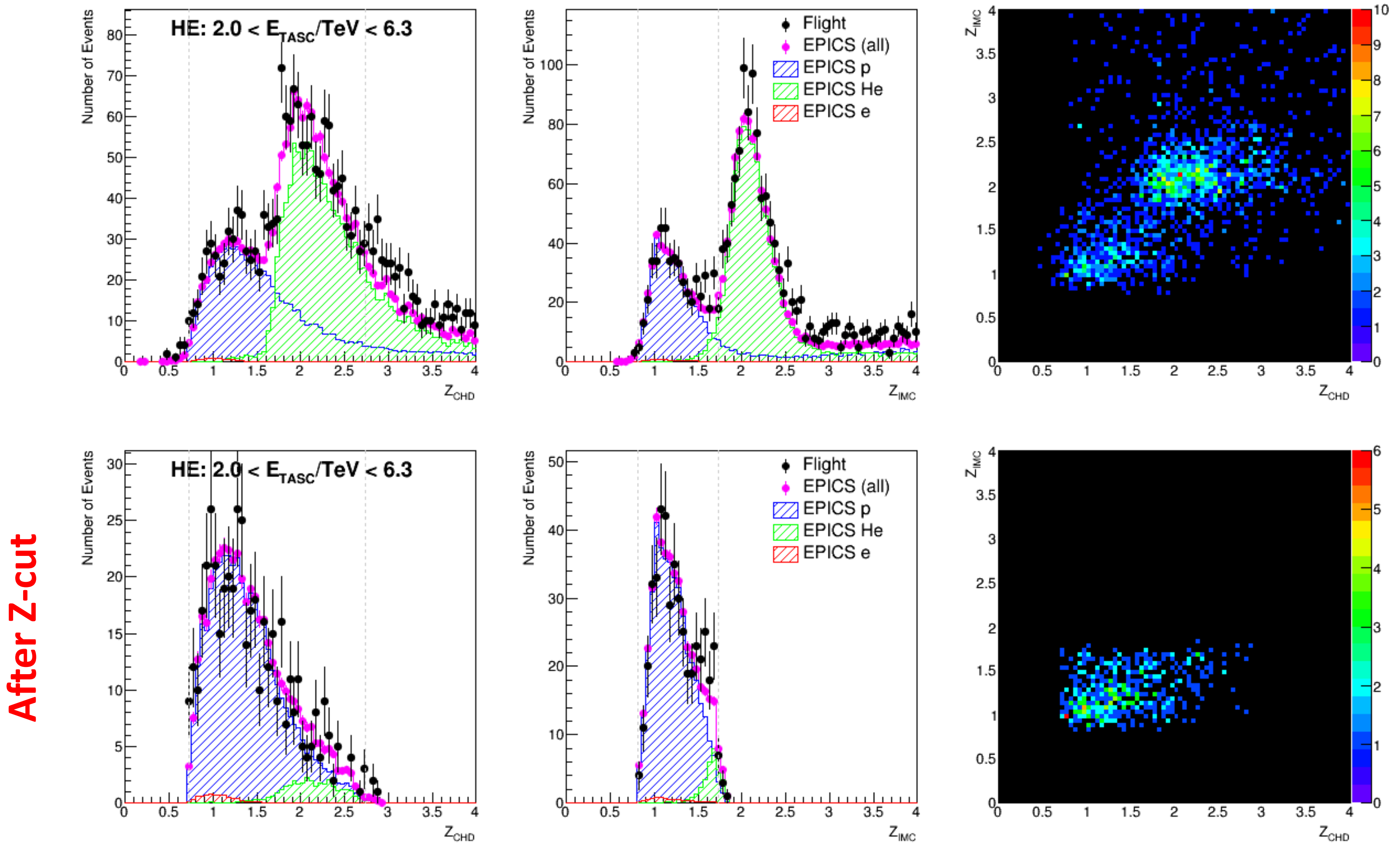

**After Z-cut**

# KF w/ $Z_{IMC}$ : Late Interaction Case (PRL ver.)




After Z-cut

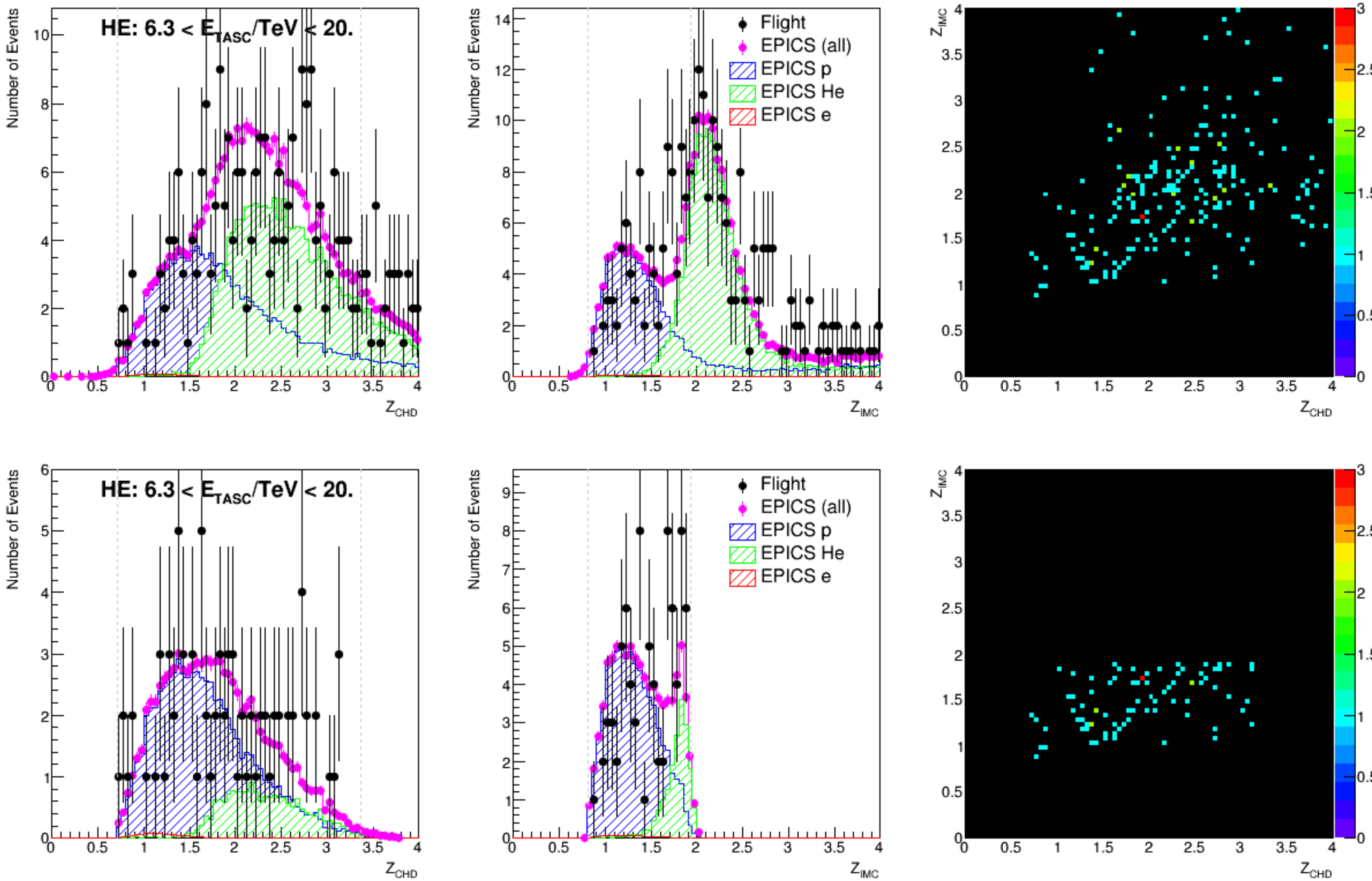
# KF w/ $Z_{IMC-12}$ : Early Interaction Case




IMC charge cut at 80% efficiency for "target" events

# KF w/ $Z_{IMC-12}$ : Early Interaction Case

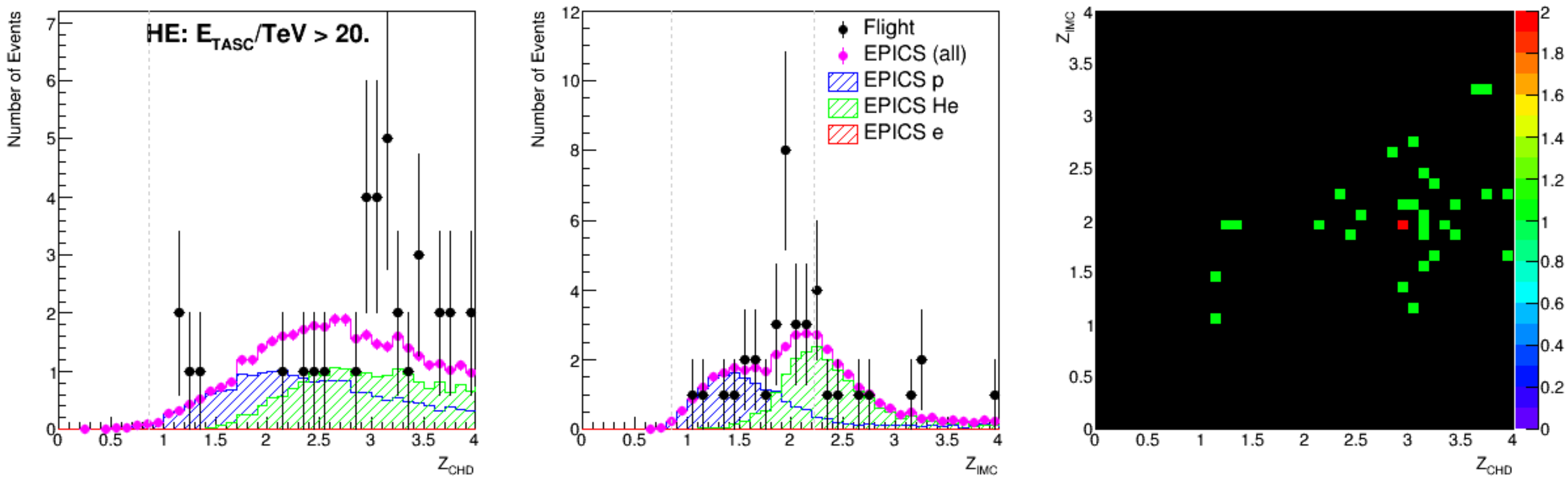
**After Z-cut**



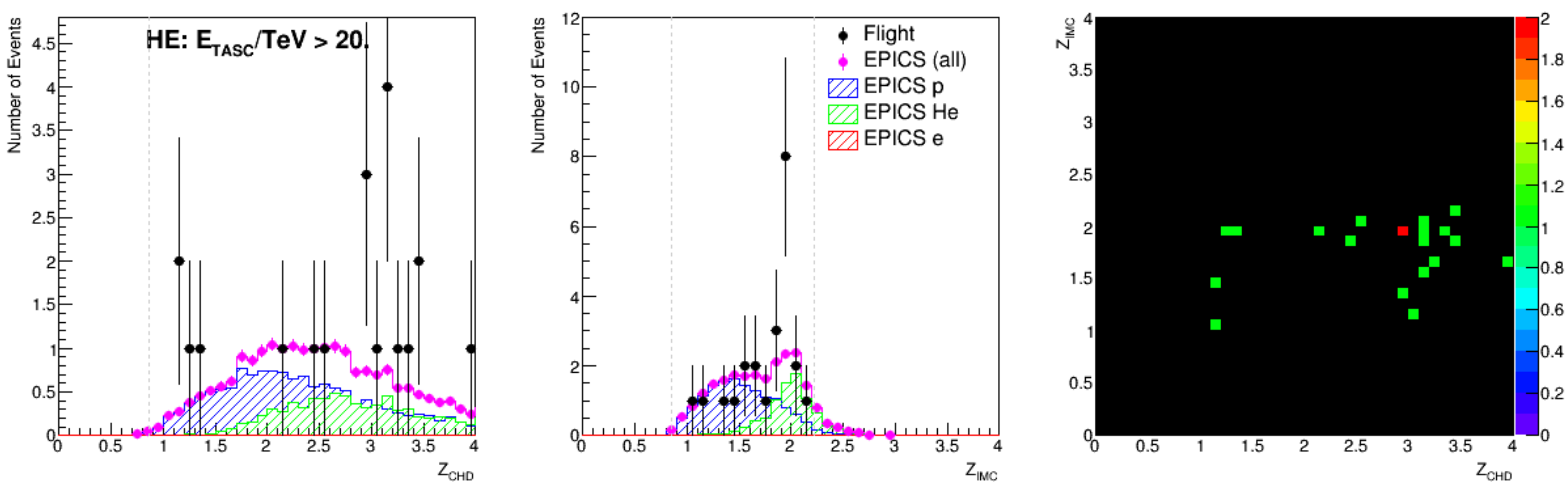

IMC charge cut at 80% efficiency for “target” events

# KF w/ $Z_{IMC-12}$ : Early Interaction Case

No energy dependence adjustment done



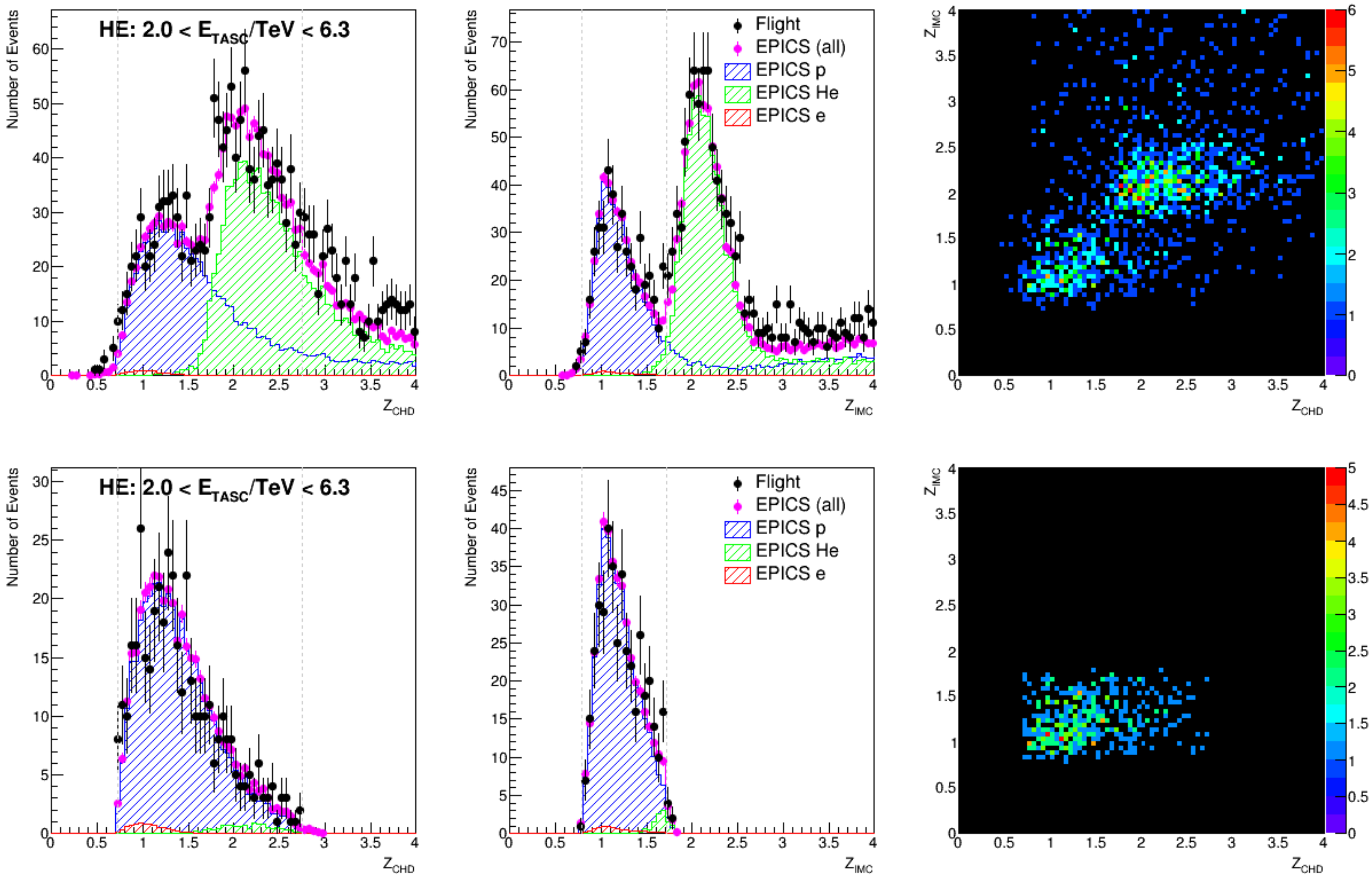

**After Z-cut**




IMC charge cut at 80% efficiency for “target” events

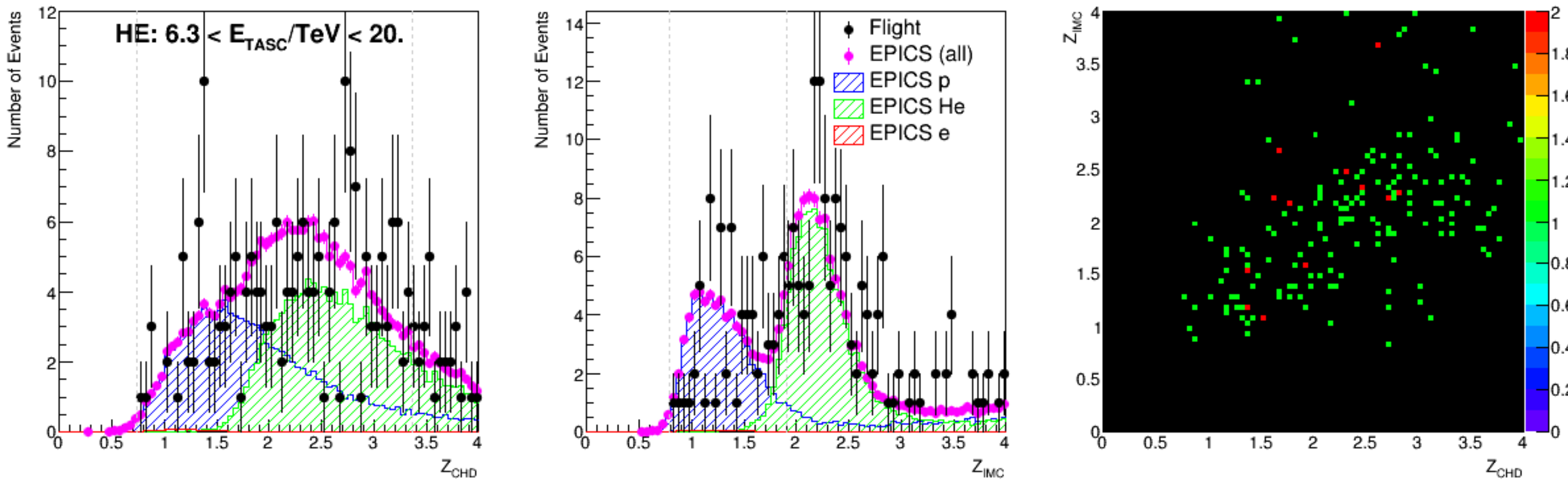
# EM w/ $Z_{IMC-12}$ : Early Interaction Case

**After Z-cut**

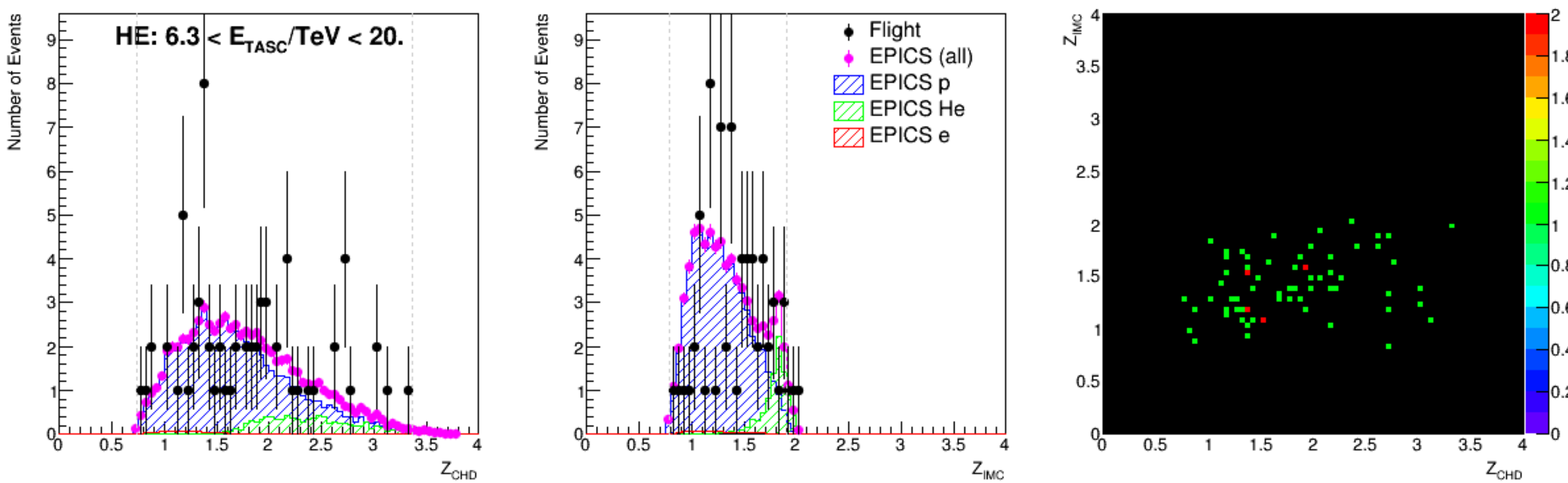



IMC charge cut at 80% efficiency for “target” events

# EM w/ $Z_{IMC-12}$ : Early Interaction Case

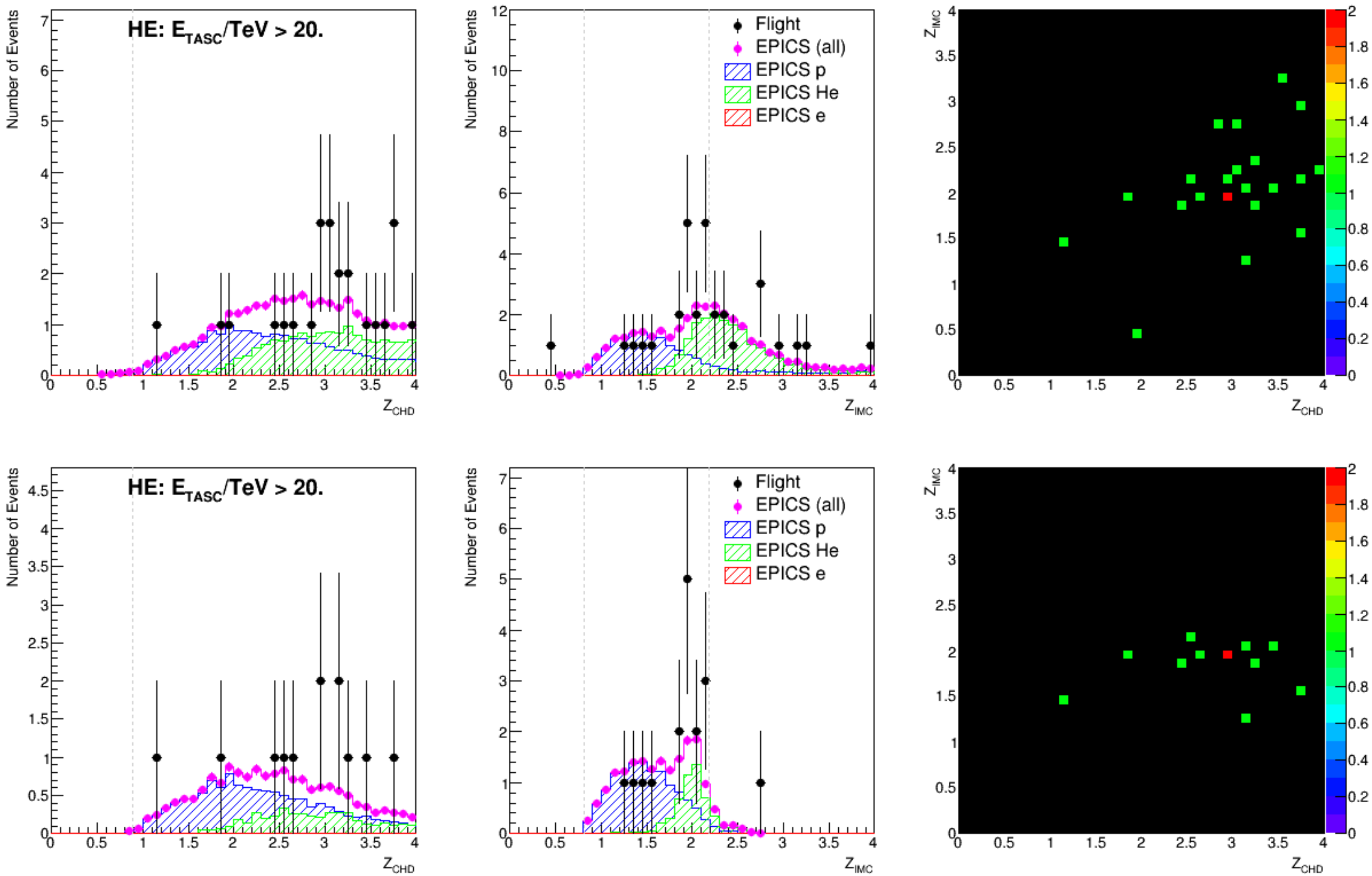



After Z-cut




IMC charge cut at 80% efficiency for “target” events

# EM w/ $Z_{IMC\text{-}12}$ : Early Interaction Case

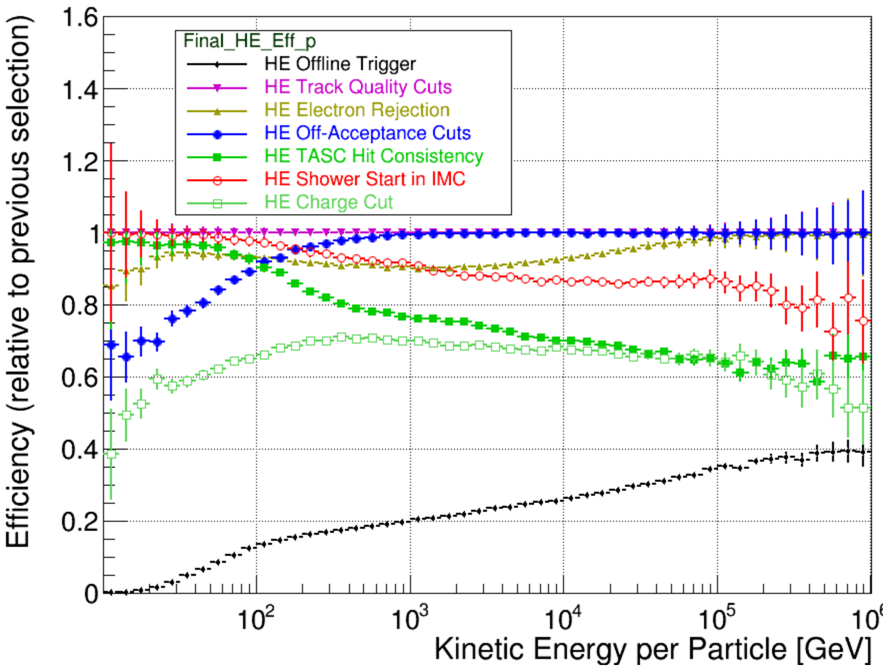



**After Z-cut**

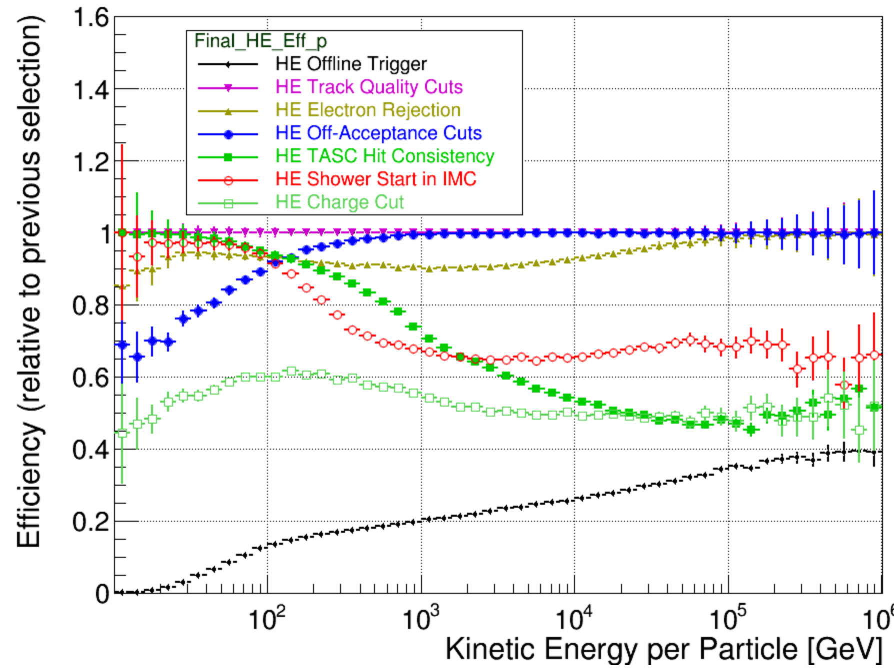
IMC charge cut at 80% efficiency for "target" events

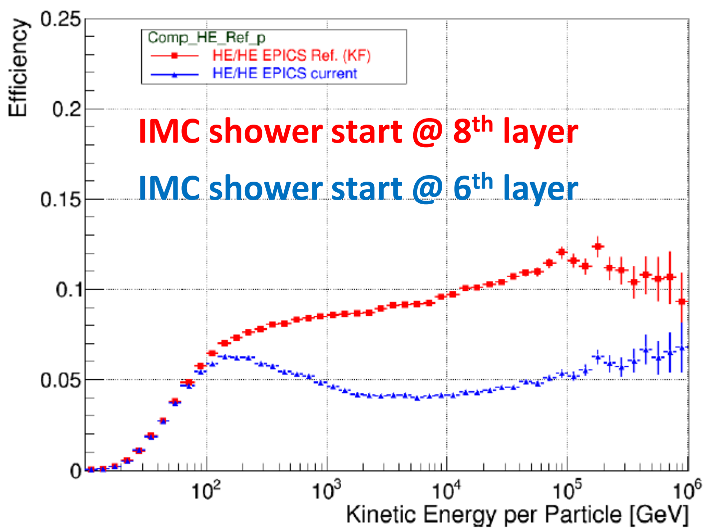
# KF: Cut-by-Cut Efficiency Comparison (p)

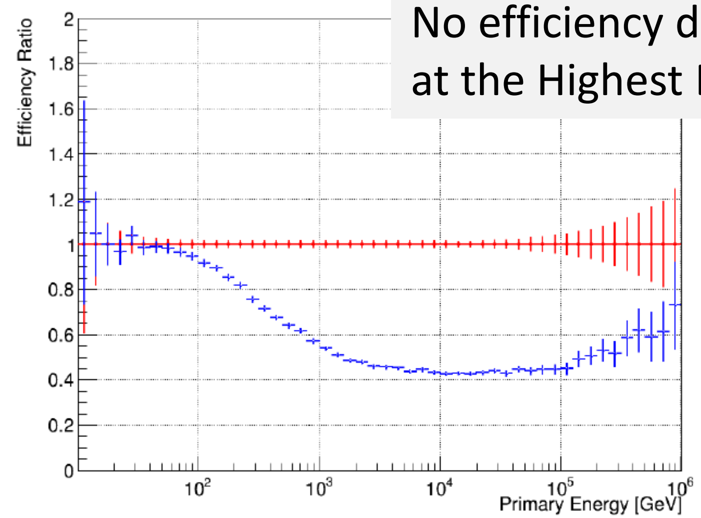
**IMC shower start @ 8th layer**




**IMC shower start @ 6th layer**

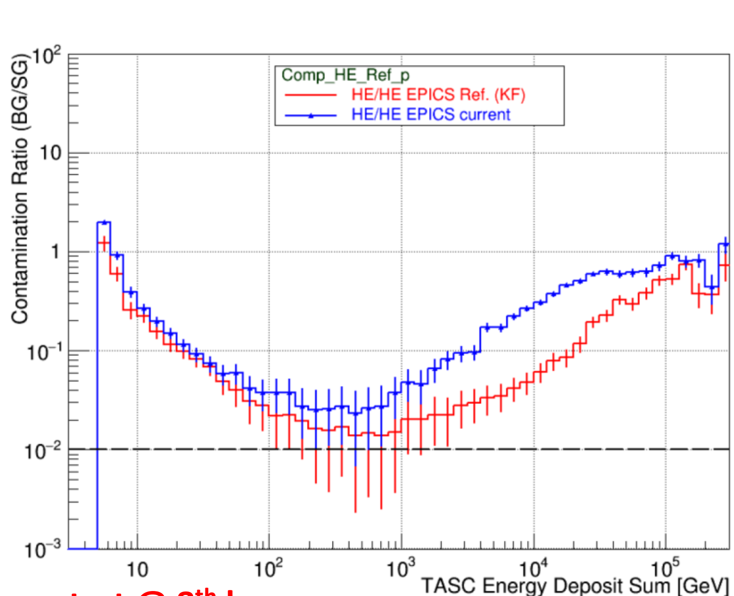


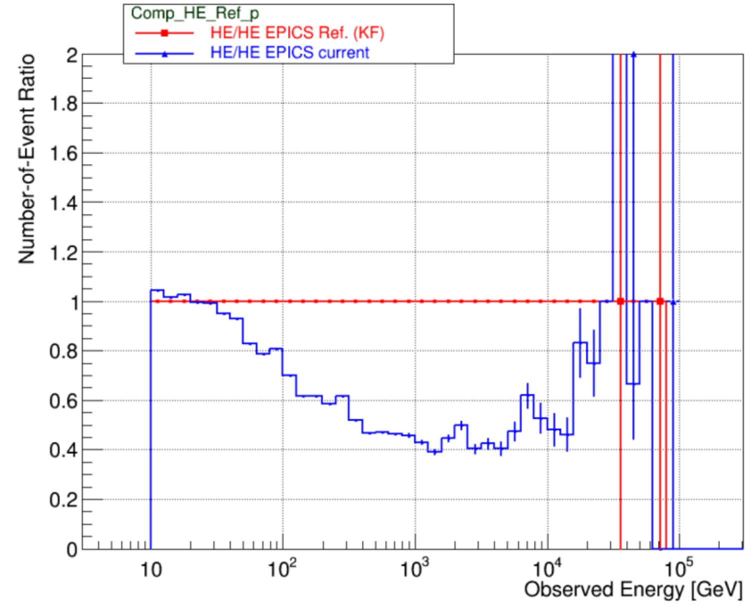




No efficiency drop
at the Highest Energy Region

# KF: BG, Observed E, Flux Comparison (p)

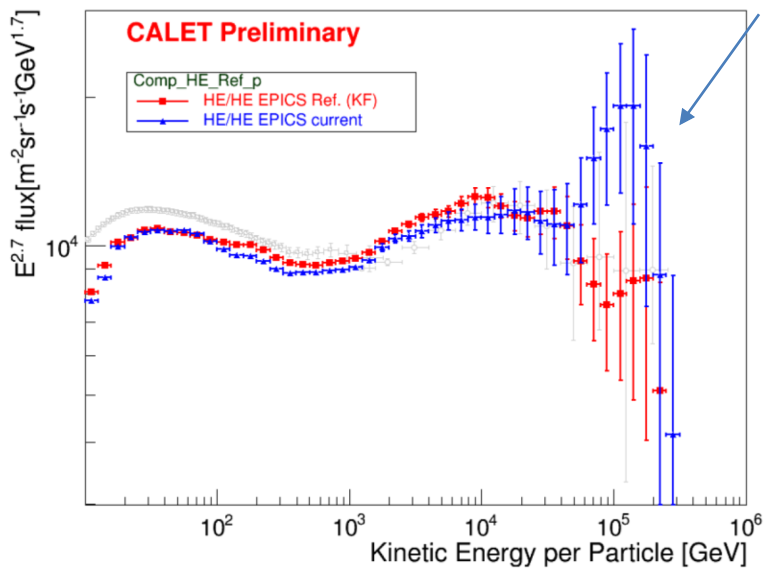


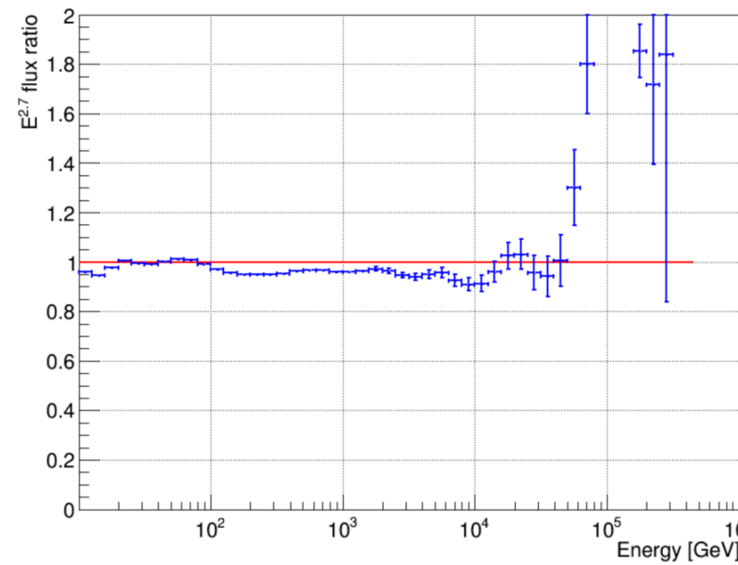




**IMC shower start @ 8th layer**

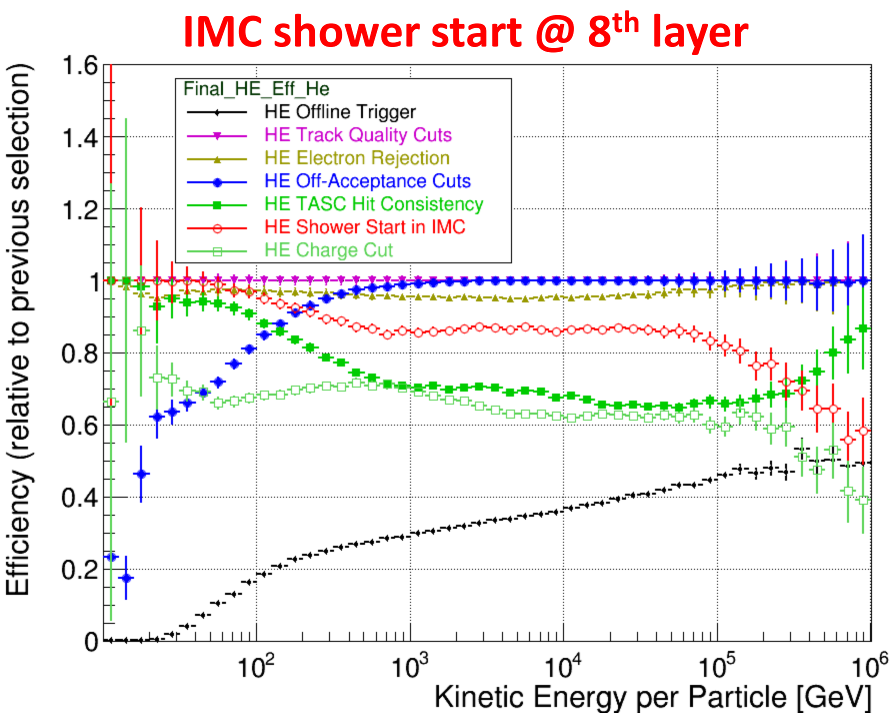
**IMC shower start @ 6th layer**

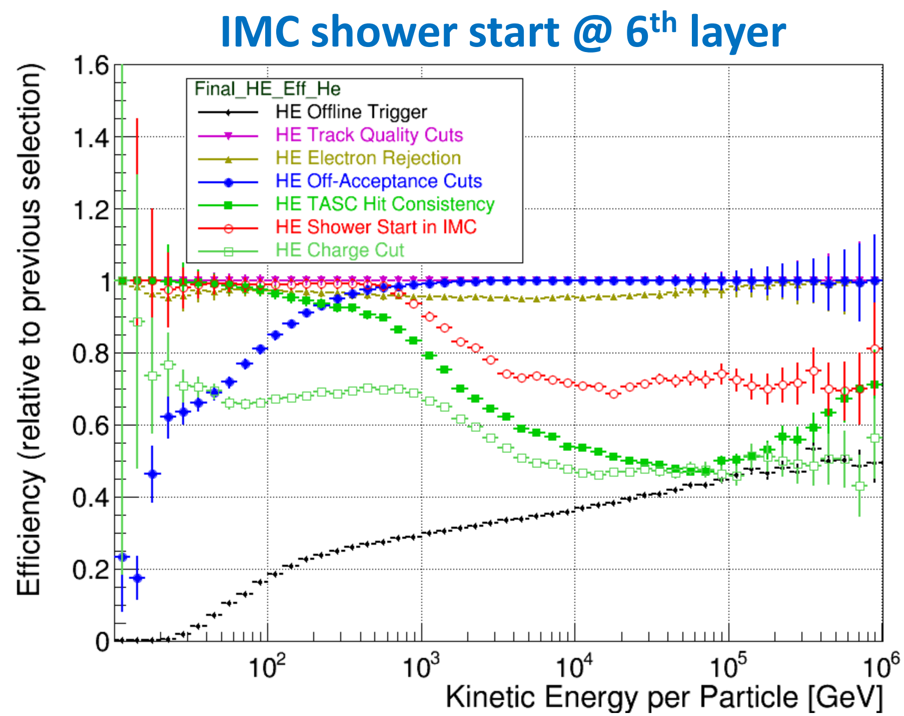
**Helium contamination?**

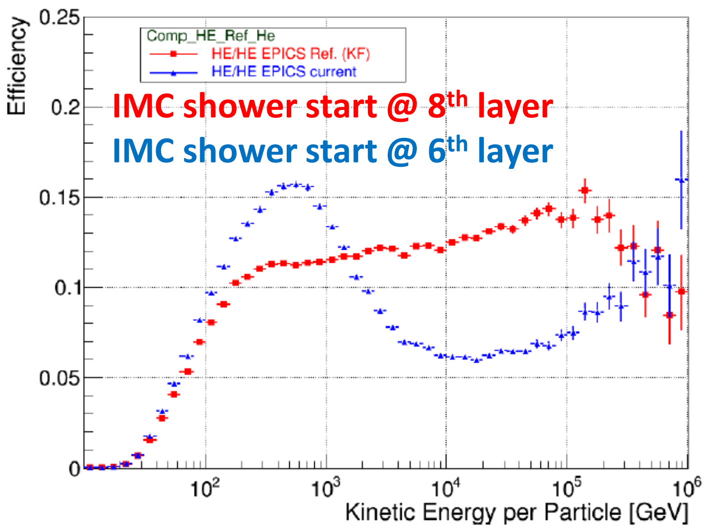


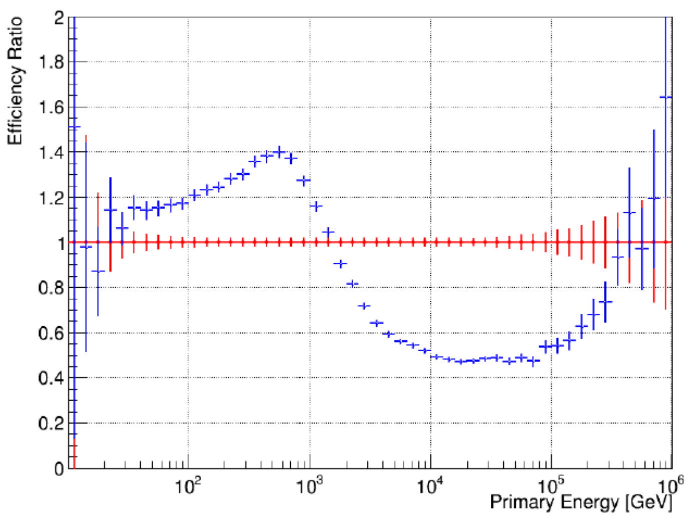



# KF: Cut-by-Cut Efficiency Comparison (He)

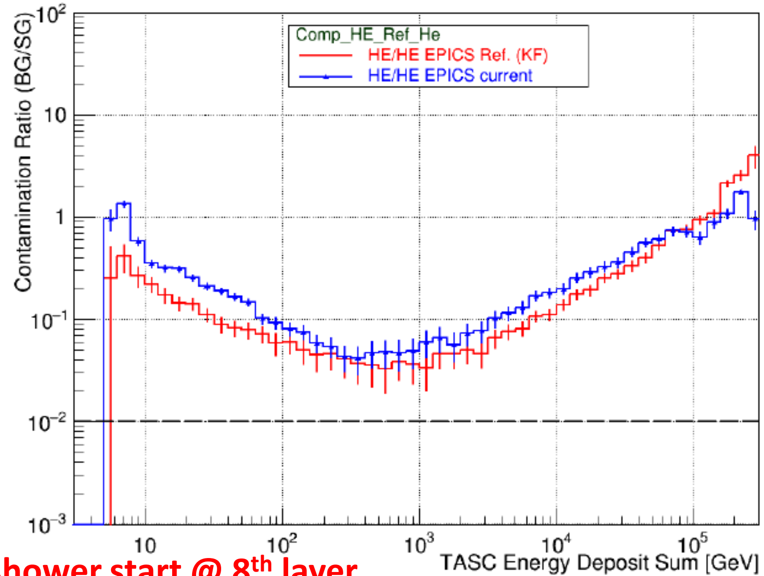


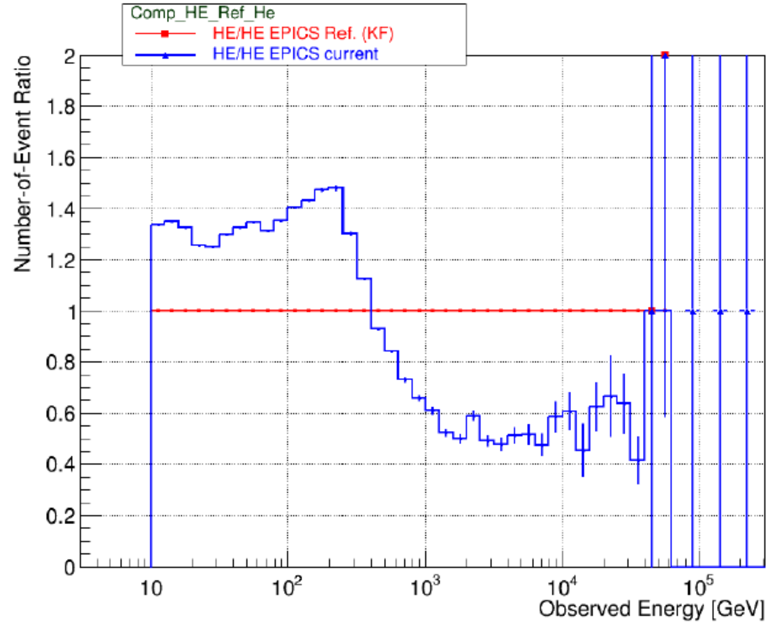



# KF: BG, Observed E, Flux Comparison (He)

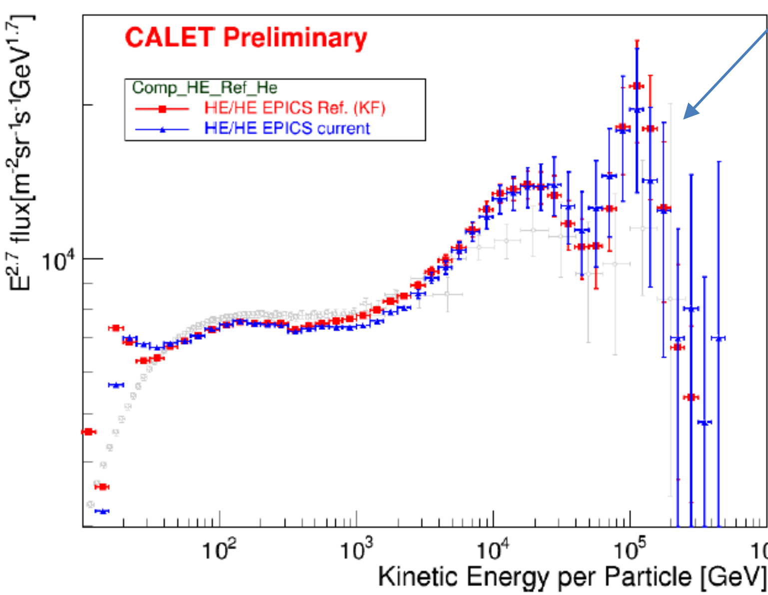


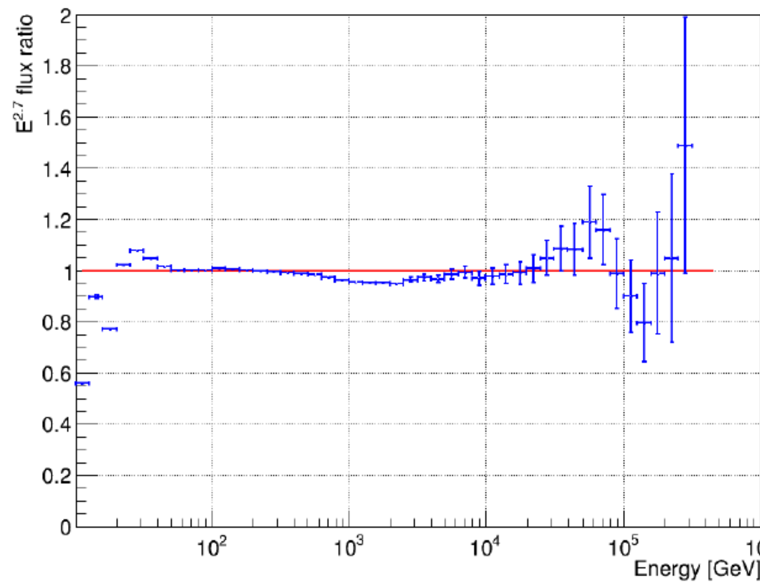




IMC shower start @ 8th layer

IMC shower start @ 6th layer

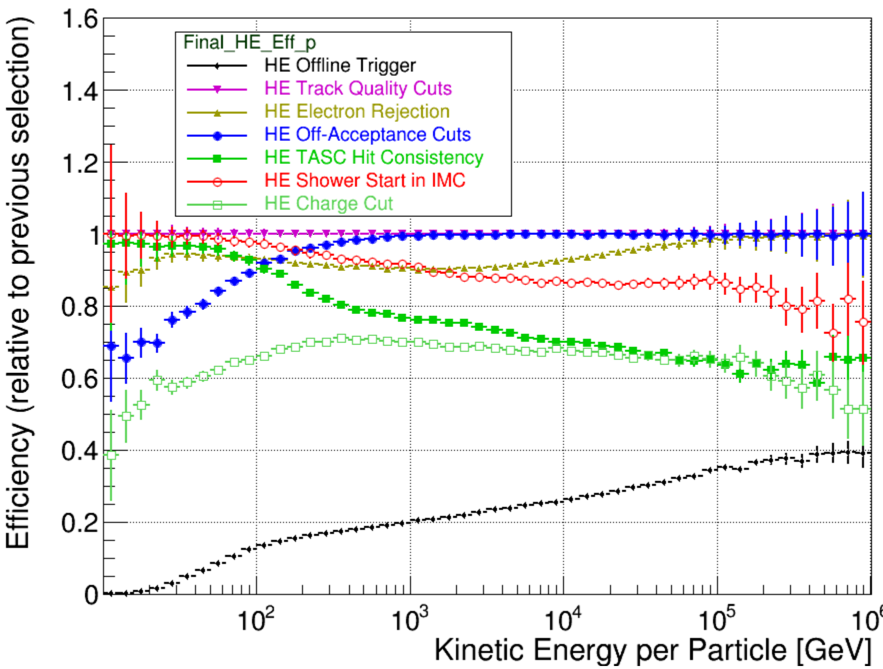
**Helium excess reproduced**



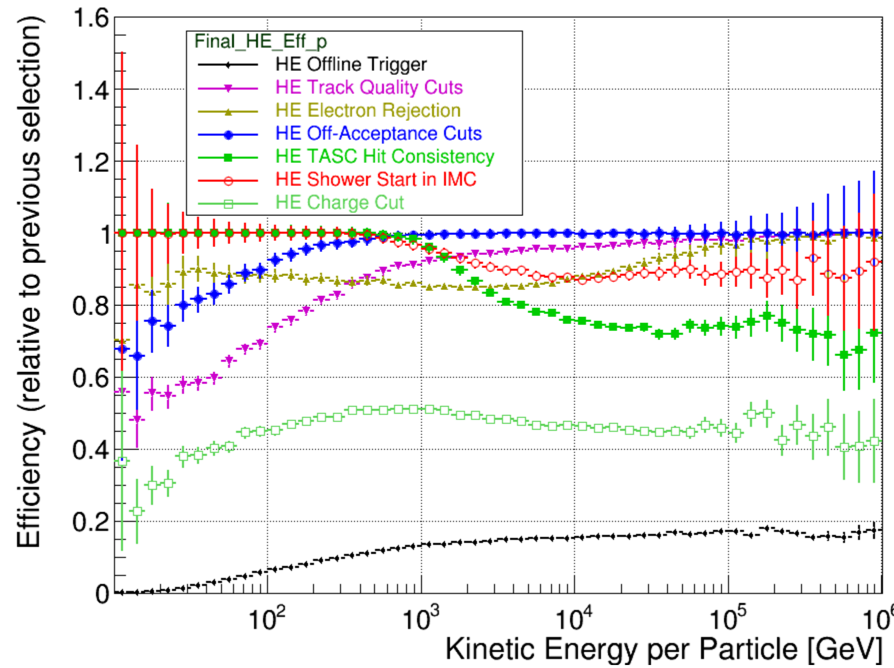



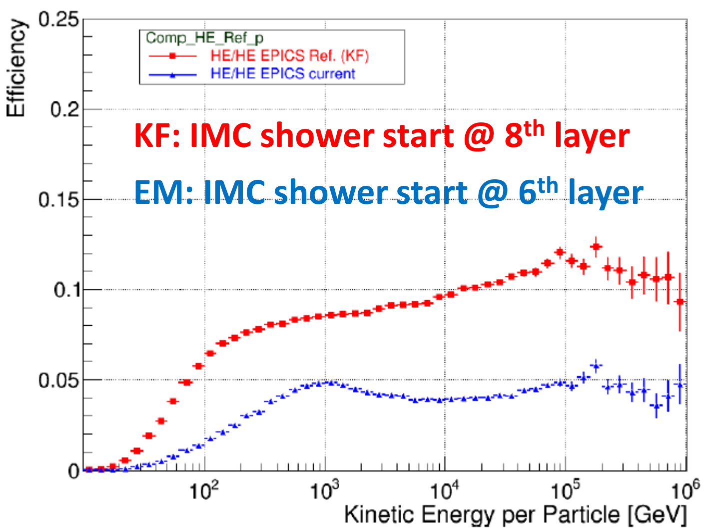
# EM: Cut-by-Cut Efficiency Comparison (p)

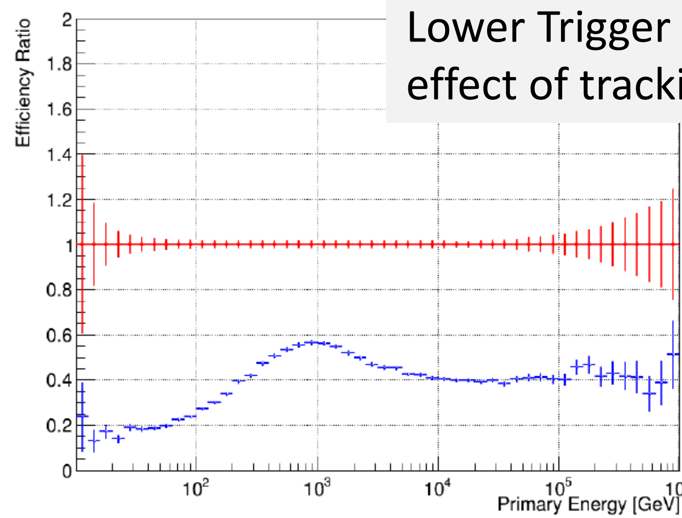
**KF: IMC shower start @ 8th layer**




**EM: IMC shower start @ 6th layer**

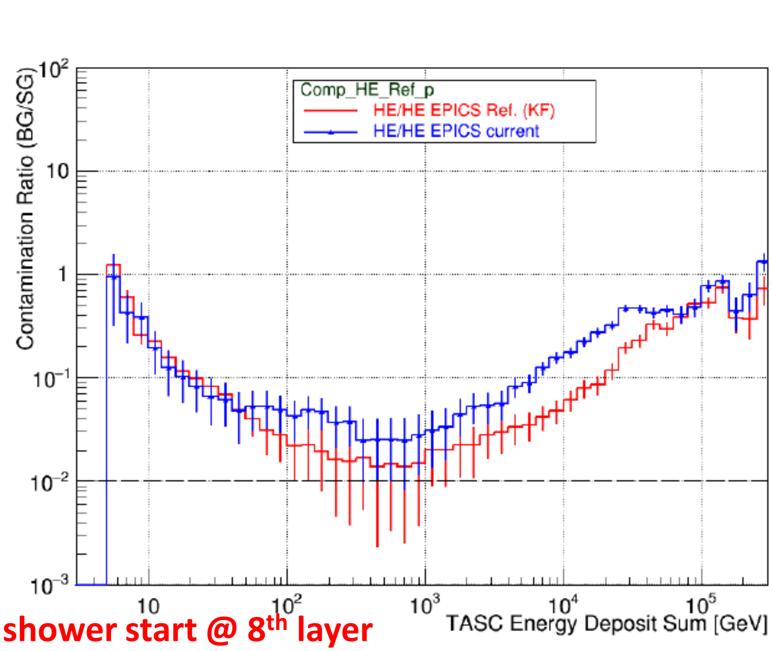


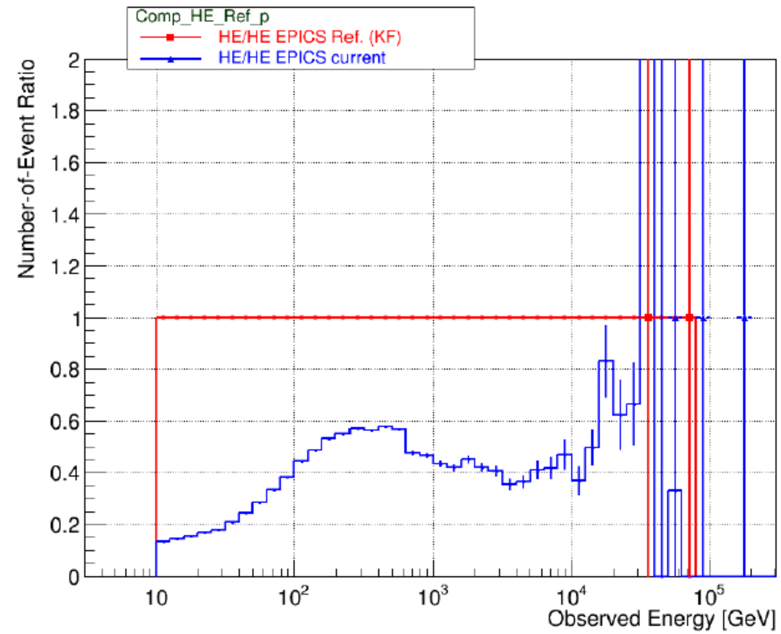




Lower Trigger Eff. Includes the effect of tracking efficiency

# EM: BG, Observed E, Flux Comparison (p)

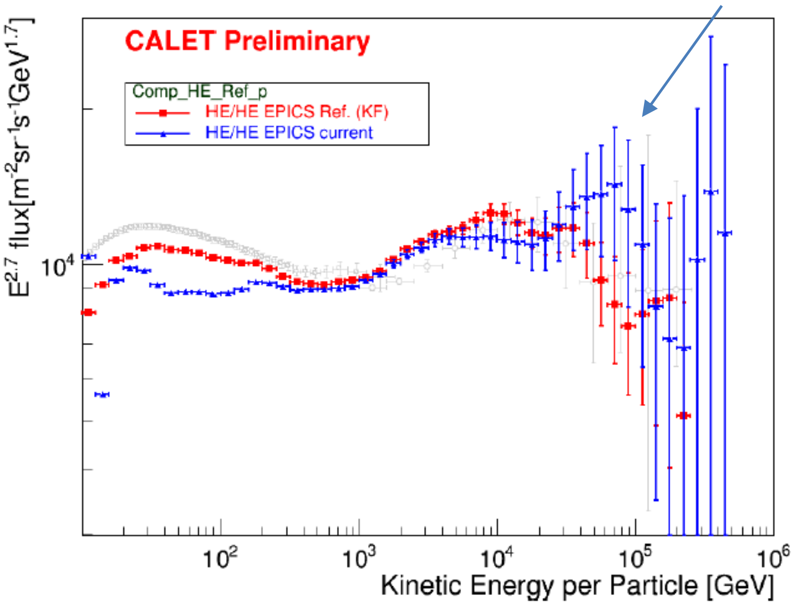


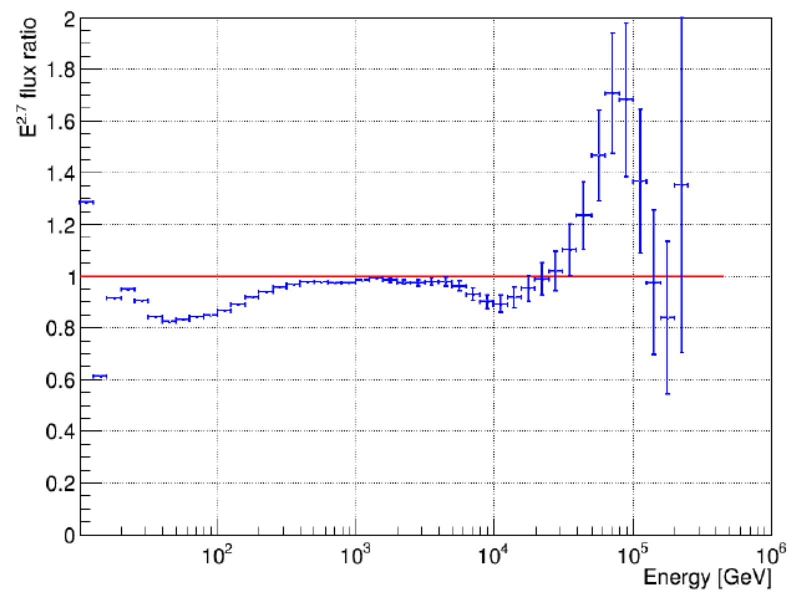




**IMC shower start @ 8th layer**

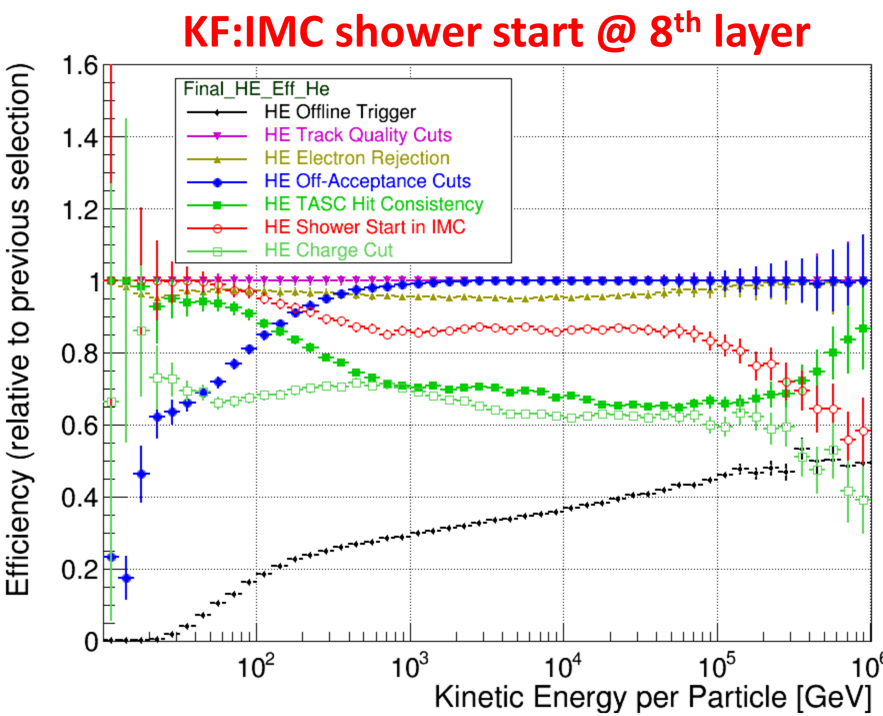
**IMC shower start @ 6th layer**

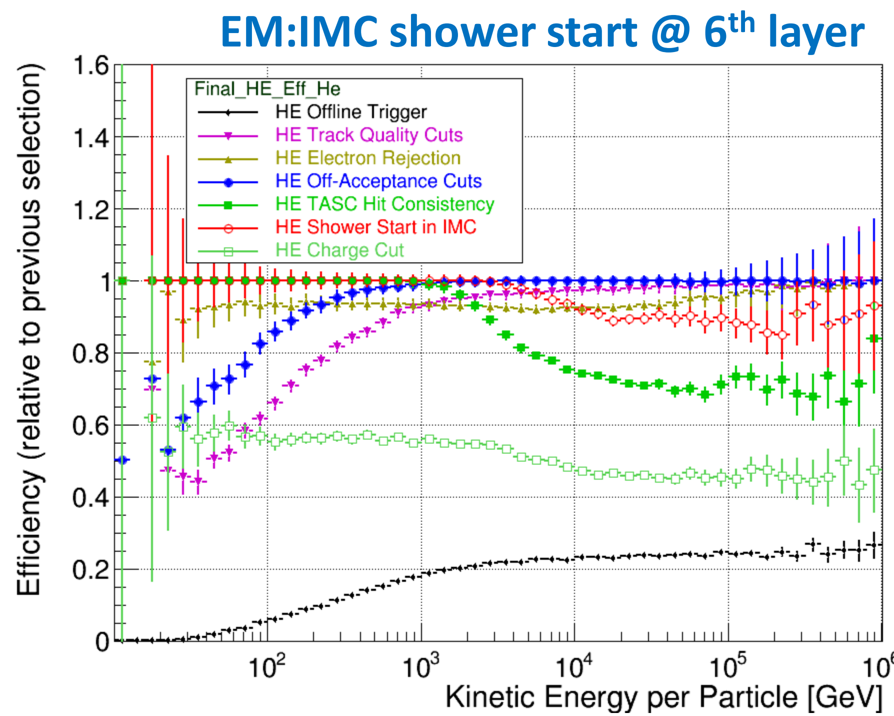
**Helium contamination?**

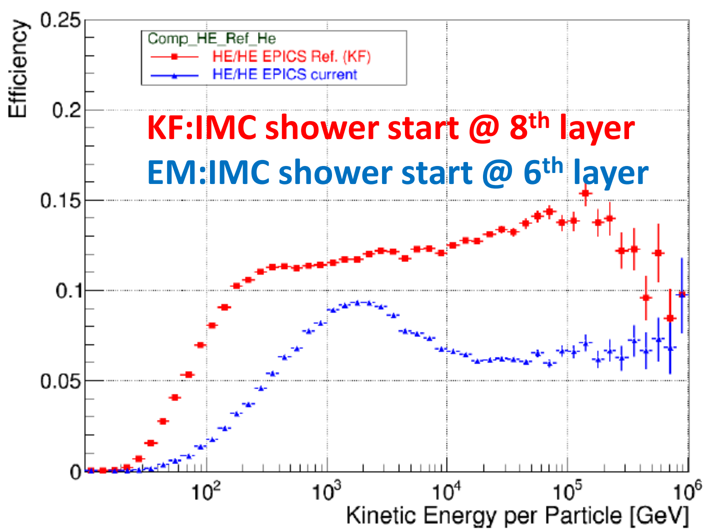


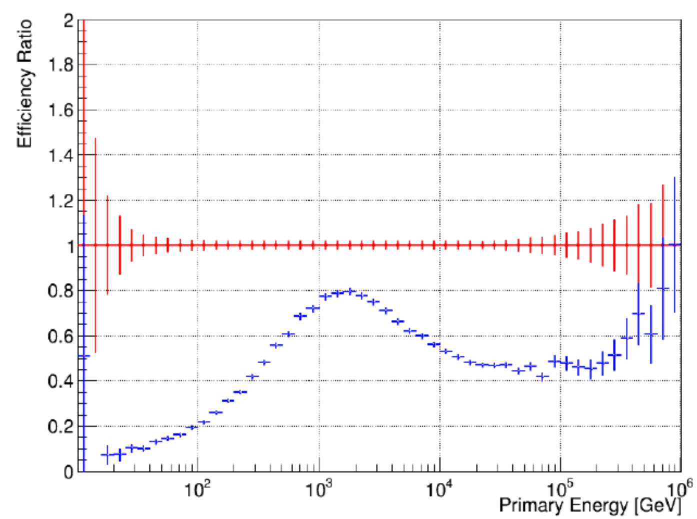



# EM: Cut-by-Cut Efficiency Comparison (He)

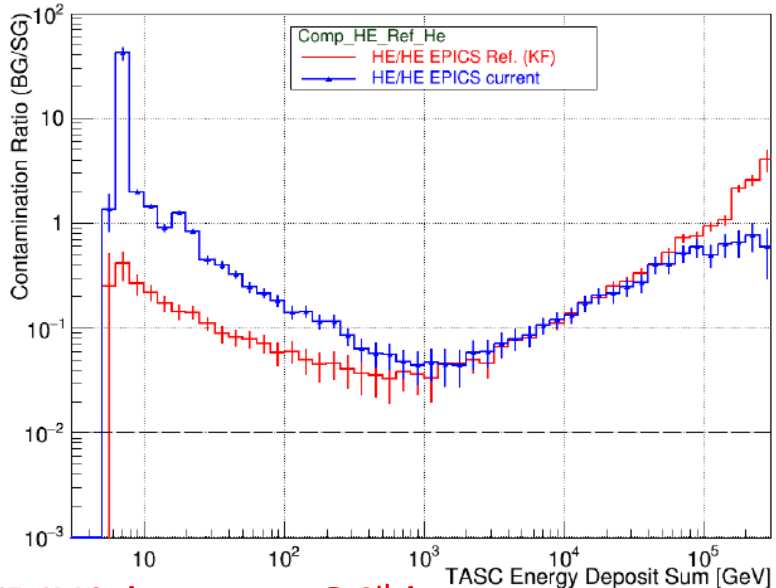


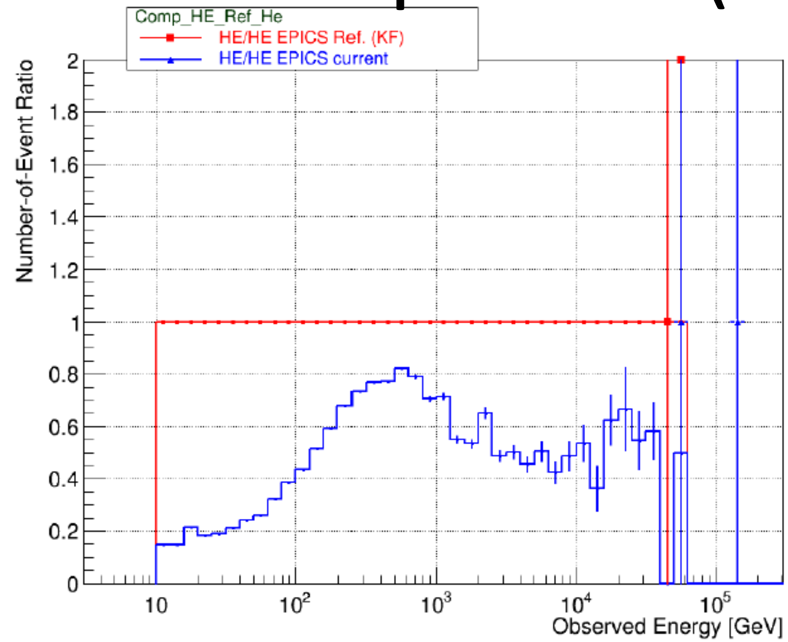



# EM: BG, Observed E, Flux Comparison (He)

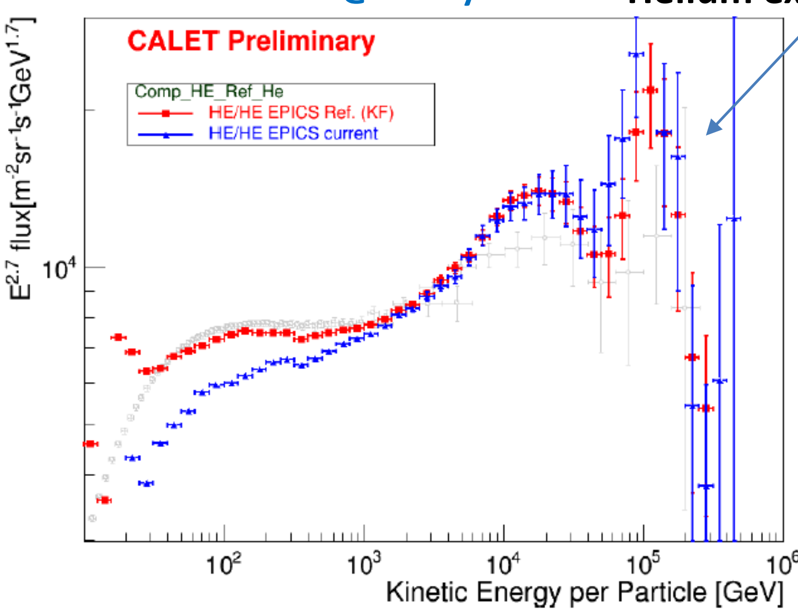


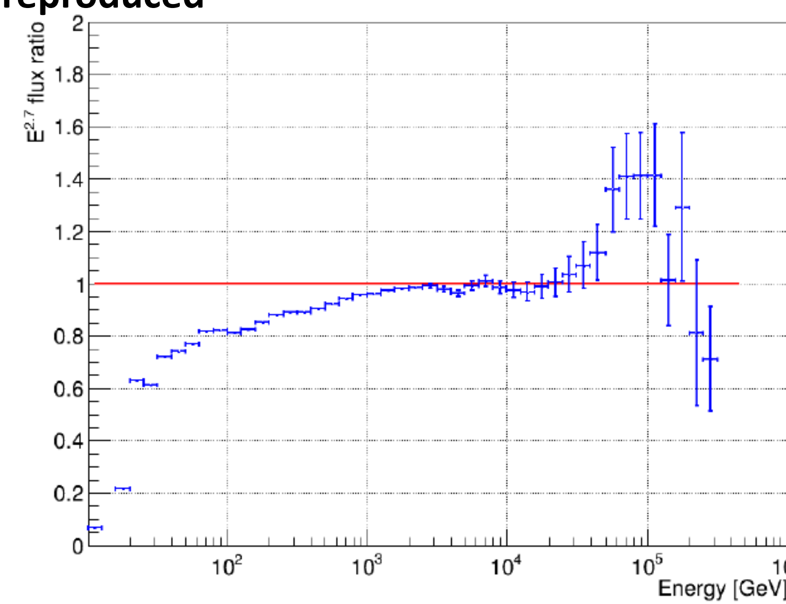




**KF: IMC shower start @ 8th layer**

**EM: IMC shower start @ 6th layer**

**Helium excess reproduced**



# Conclusion: Early Interaction Selection

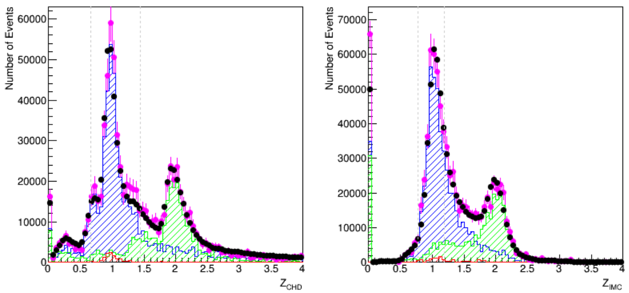
- Proton flux at 100 TeV region differs from the original selection, which is due most likely to the higher helium contamination.
  - To confirm this, template fit to accurately estimate the helium background is necessary.
  - Currently, the helium contamination is estimated as a ratio of MC protons to helium where CREAM-III spectra are assumed.
- Helium spectrum is mostly consistent with the original selection.
  - The peak-like structure at 100 TeV exists regardless of early interaction selection or tracking algorithms.
- Tracking efficiency seems to be quite reliable at the highest energy region.

# Template Fitting

- To estimate the helium background in proton analysis, template fitting is used.
- This should be more and more important at higher energy region where the helium contamination becomes not negligible.
- It should be noted, though, that the template fitting is more and more difficult at higher energies due to less and less statistics.

# Examples of Template Fitting for Protons

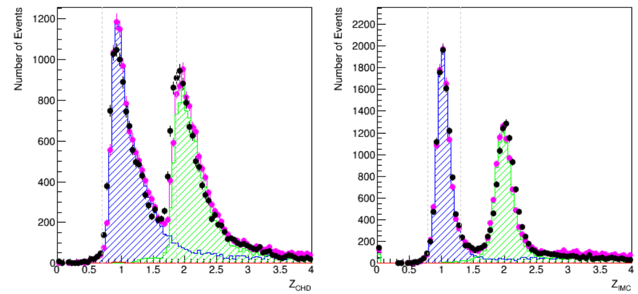
KF tracking, normal event selection (beam config.)




**HE: sel=7 (pt=1001) (sel=7)**
**7.9 GeV < $E_{TASC}$ < 10.0 GeV**
**Energy bin: 9-9**

Flight
EPICS (all)
EPICS p
EPICS He
EPICS e

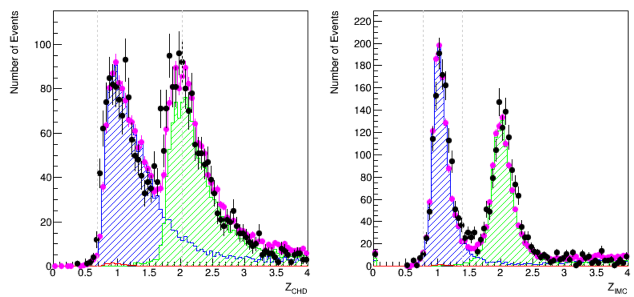
**$\chi^2$/NDF=1.296e+00**
**e: 1.000 (fixed)**
**p: 0.966±0.021**
**He: 1.251±0.034**




**HE: sel=7 (pt=1001) (sel=7)**
**251.2 GeV < $E_{TASC}$ < 316.2 GeV**
**Energy bin: 24-24**

Flight
EPICS (all)
EPICS p
EPICS He
EPICS e

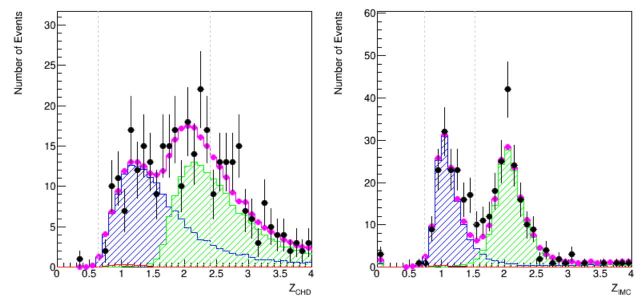
**$\chi^2$/NDF=5.630e+00**
**e: 1.000 (fixed)**
**p: 0.997±0.011**
**He: 0.922±0.010**




**HE: sel=7 (pt=1001) (sel=7)**
**1000.0 GeV < $E_{TASC}$ < 1258.9 GeV**
**Energy bin: 30-30**

Flight
EPICS (all)
EPICS p
EPICS He
EPICS e

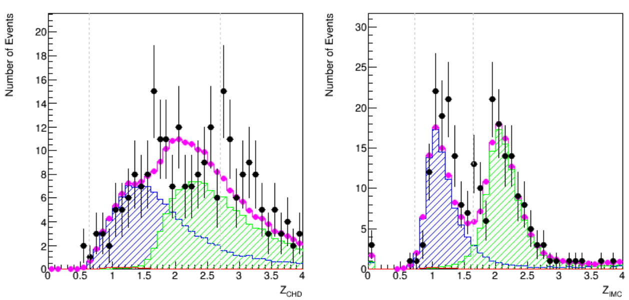
**$\chi^2$/NDF=2.078e+00**
**e: 1.000 (fixed)**
**p: 1.088±0.025**
**He: 0.953±0.023**




**HE: sel=7 (pt=1001) (sel=7)**
**5011.9 GeV < $E_{TASC}$ < 7943.3 GeV**
**Energy bin: 37-38**

Flight
EPICS (all)
EPICS p
EPICS He
EPICS e

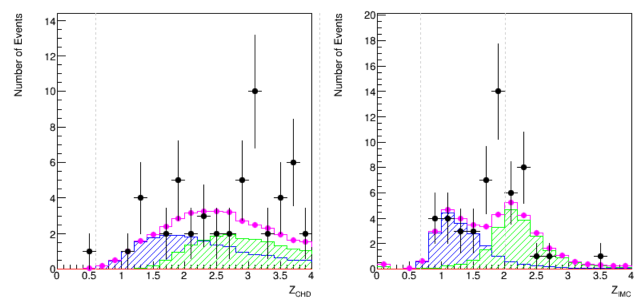
**$\chi^2$/NDF=8.325e-01**
**e: 1.000 (fixed)**
**p: 0.835±0.056**
**He: 0.951±0.062**




**HE: sel=7 (pt=1001) (sel=7)**
**7943.3 GeV < $E_{TASC}$ < 19952.6 GeV**
**Energy bin: 39-42**

Flight
EPICS (all)
EPICS p
EPICS He
EPICS e

**$\chi^2$/NDF=8.214e-01**
**e: 1.000 (fixed)**
**p: 0.769±0.066**
**He: 0.914±0.073**

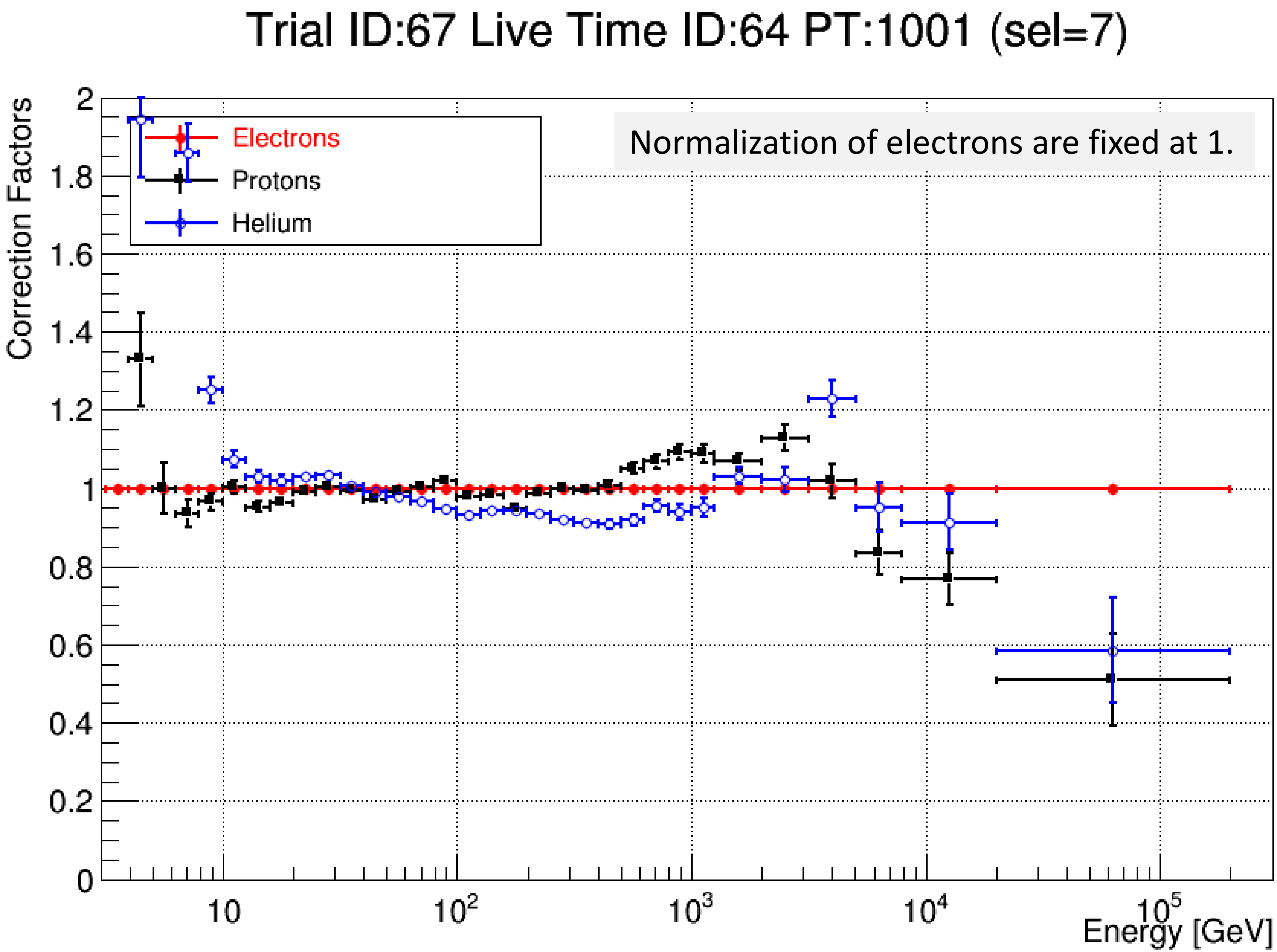



**HE: sel=7 (pt=1001) (sel=7)**
**19952.6 GeV < $E_{TASC}$ < 199526.2 GeV**
**Energy bin: 43-52**

Flight
EPICS (all)
EPICS p
EPICS He
EPICS e

**$\chi^2$/NDF=1.014e+00**
**e: 1.000 (fixed)**
**p: 0.508±0.117**
**He: 0.585±0.134**

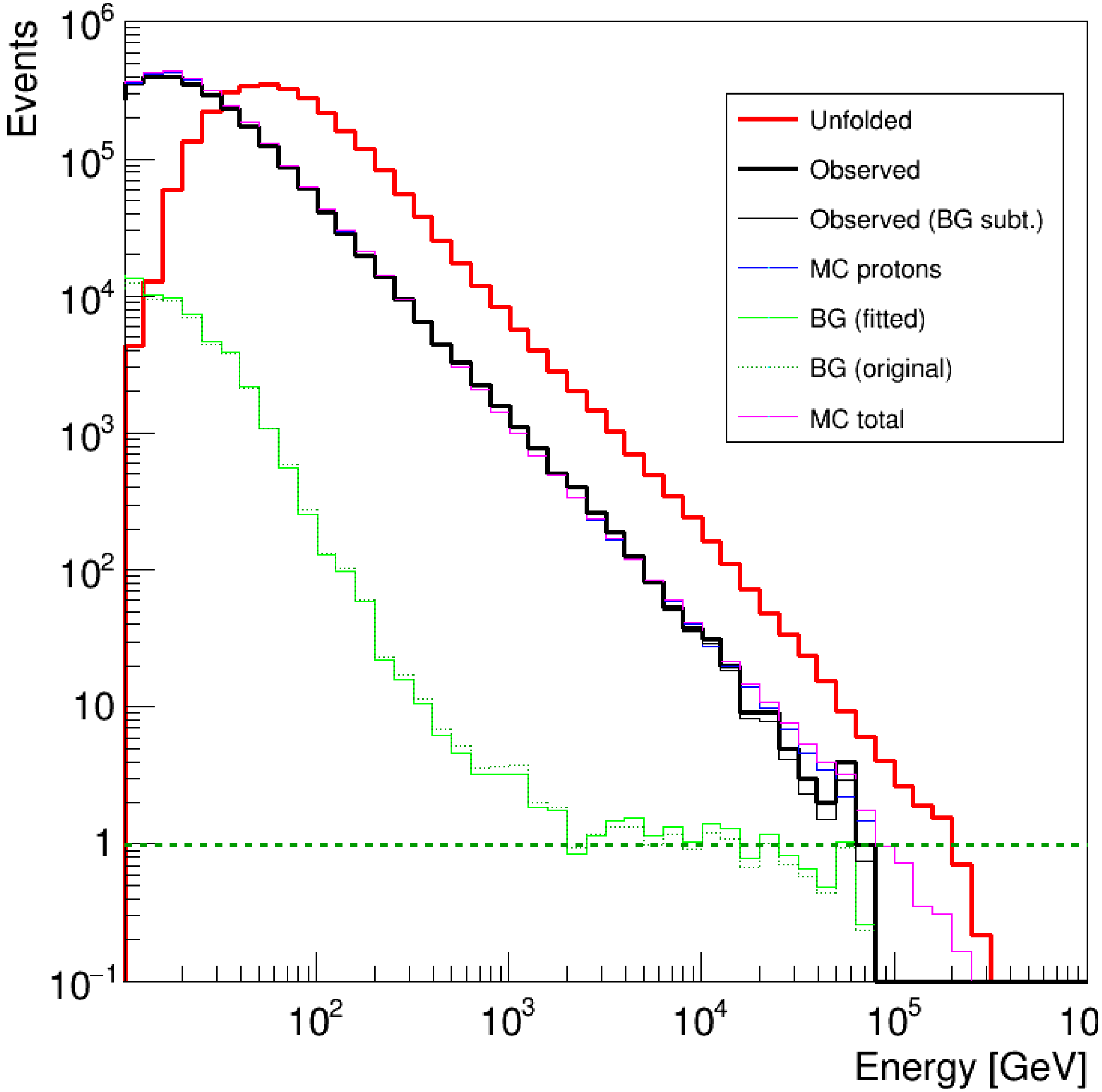
# Summary of Template Fitting



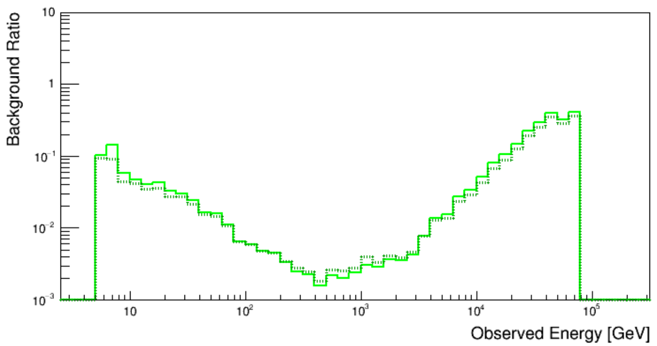
# Background Estimation & Subtraction using Template Fitting

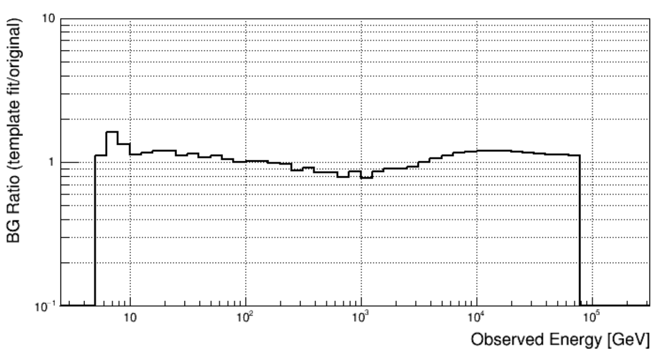
1. factE (fixed to 1.0), factP, factH obtained by interpolating the results of template fitting.
2. For each bin, helium & electron are subtracted; number of events to be subtracted are calculated as follows:
   - N = N_obs * (N_p * factP / (N_p * factP + N_h * factH + N_e * factE)
   - N_p includes off-acceptance protons and this contribution is subtracted in the unfolding procedure.
3. Edep distribution of N and N_p * factP are passed to RooUnfold
   - In the normal case, N_obs and (N_p + N_h + N_e) are passed to RooUnfold.

# Observed Spectra and Subtraction of Background (Helium + Electrons)



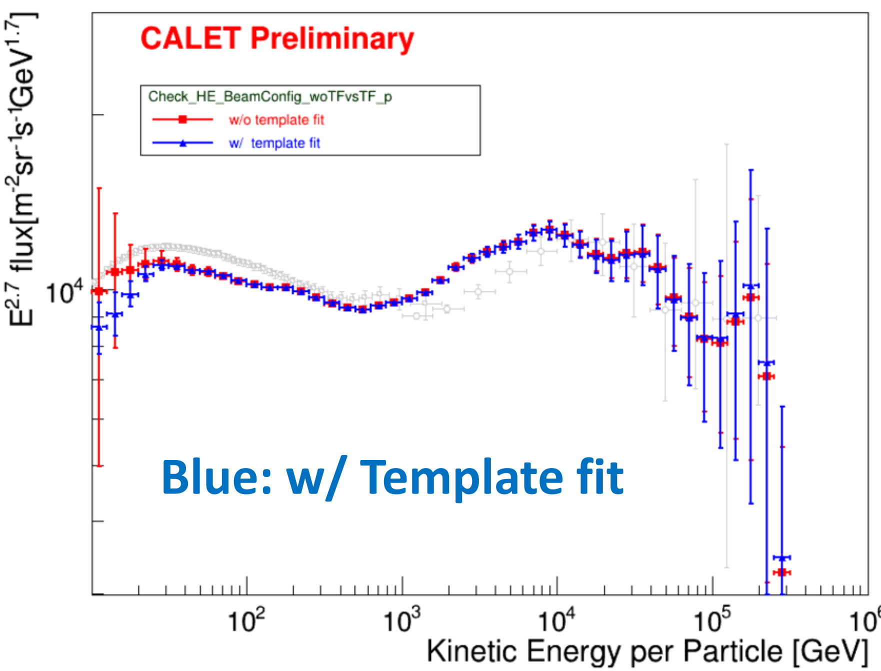

Because of the relatively low background level, the effect of template fitting is not so large. However, in the 10 TeV Edep region, results of template fitting obtained more helium background than original estimation.

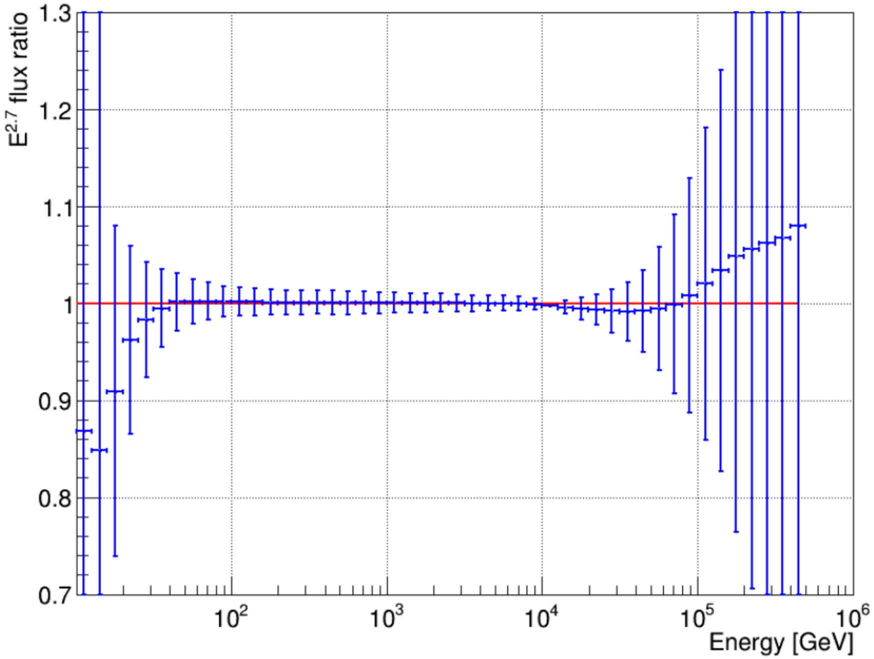


# Comparison of Proton Spectra w/ and w/o Template Fitting

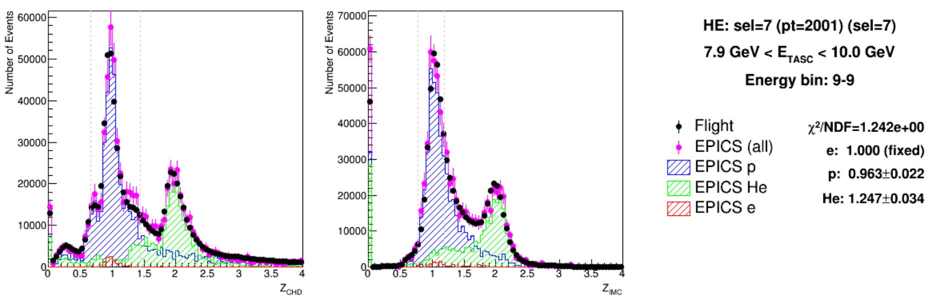
Not large effect. This is as expected, but at 20-100 TeV region, lower flux was obtained with template fitting due to large helium contribution (as expected). However, 100 TeV region gave higher flux.
Even if the factor for helium and protons are fixed to 1, the difference at 100 TeV region remains. This means the higher flux at 100 TeV region is related to unfolding method (or my treatment of BG before passing it to RooUnfold). Considering very large errors, this might come from null data bin effects.

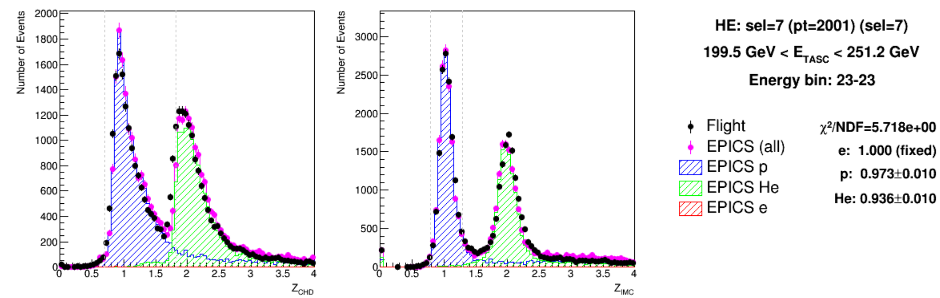


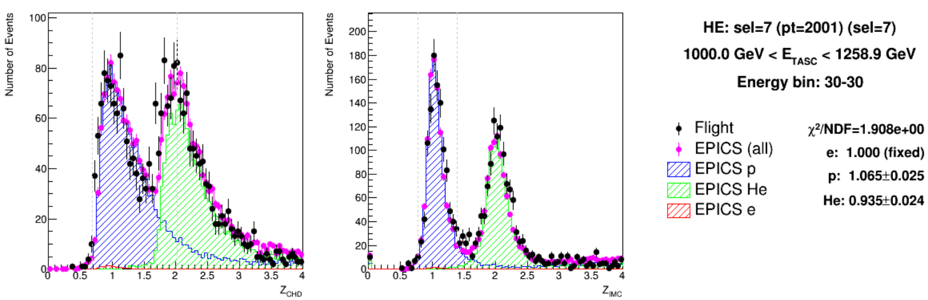



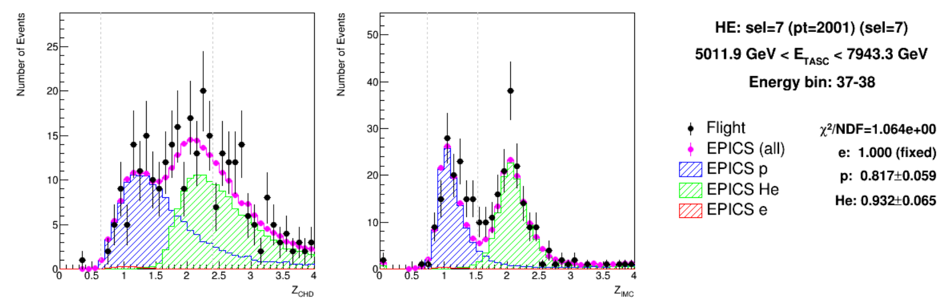
# Examples of Template Fitting for Helium

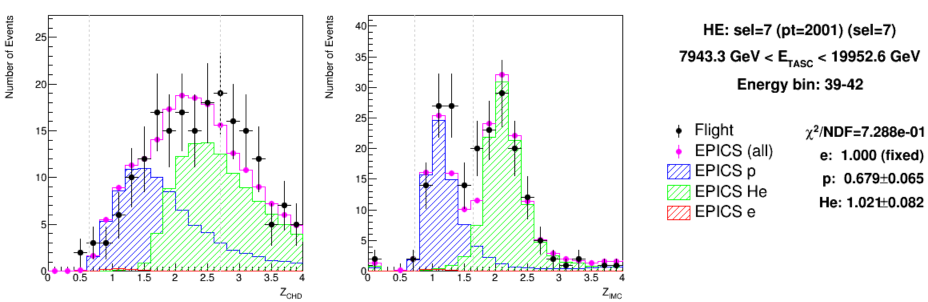
KF tracking, normal event selection (beam config.)

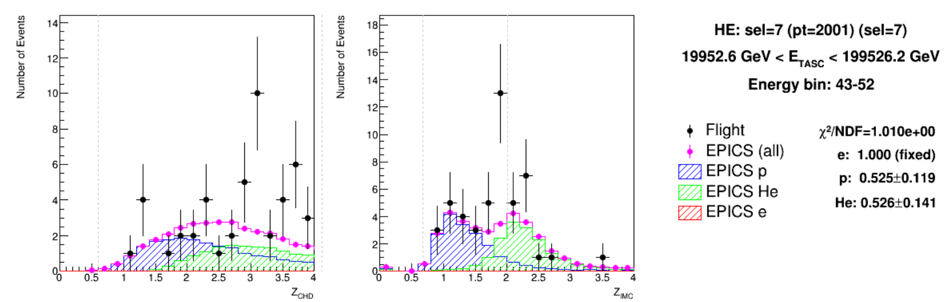


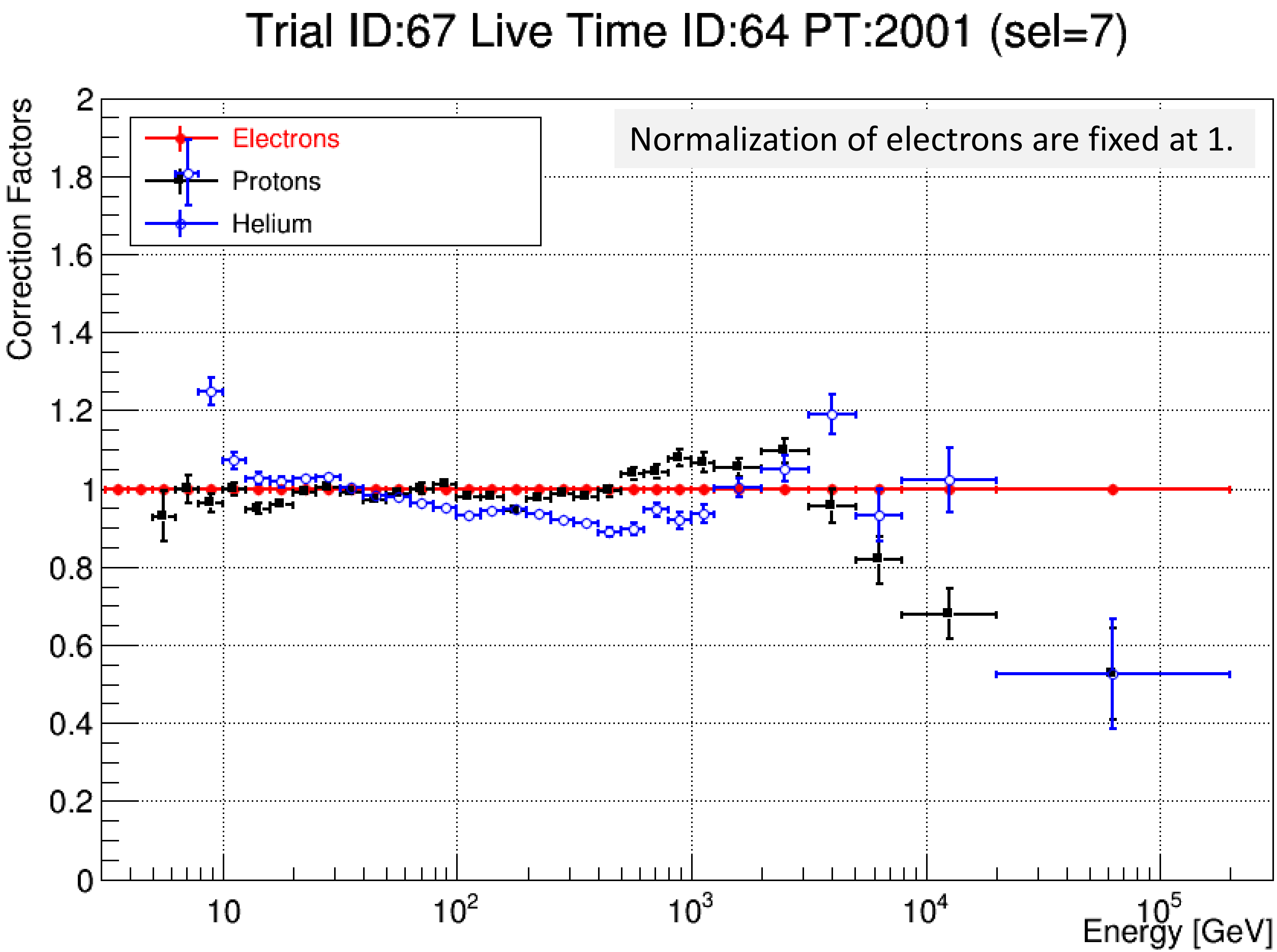



# Summary of Template Fitting

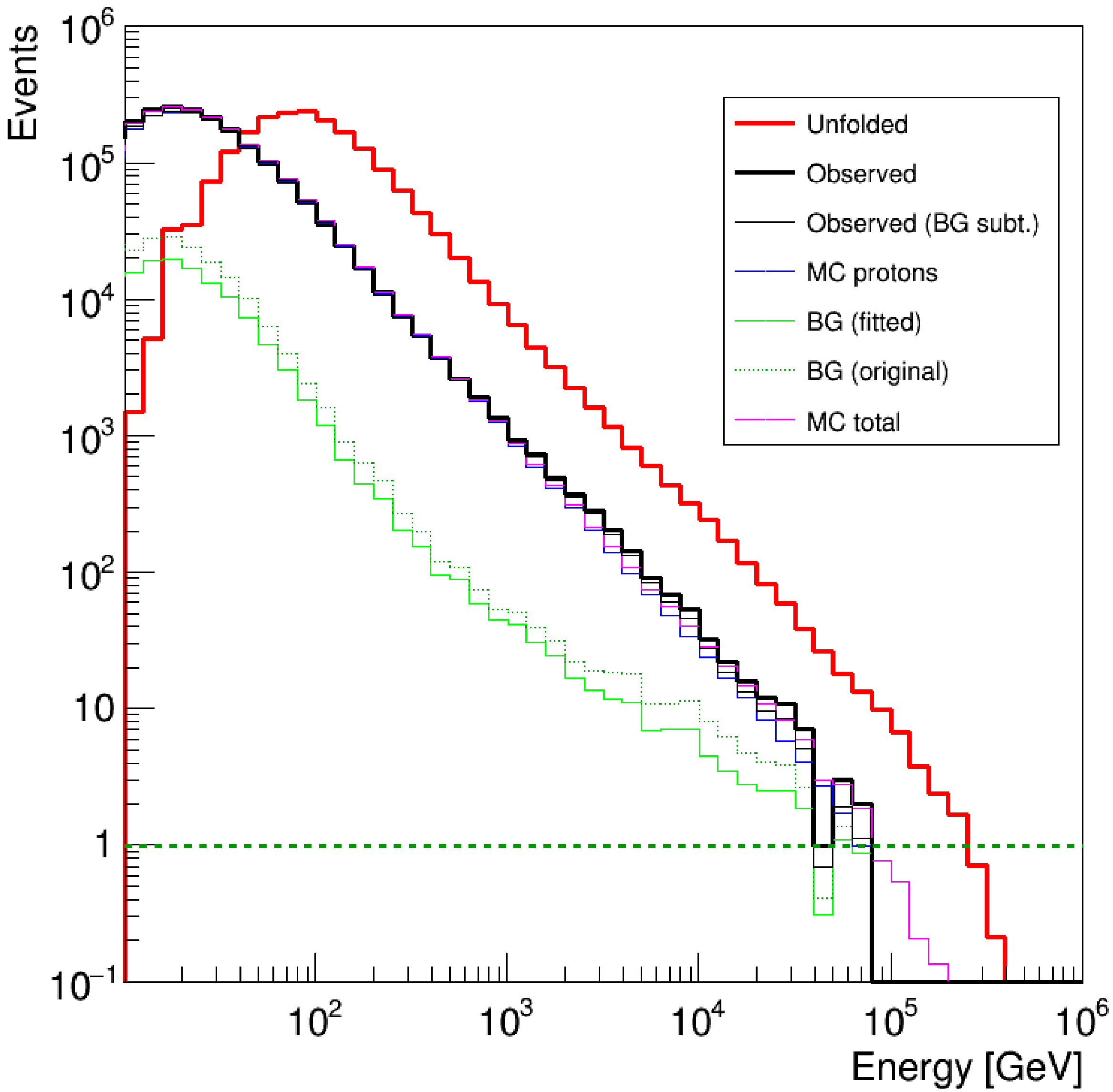


Same manner as protons

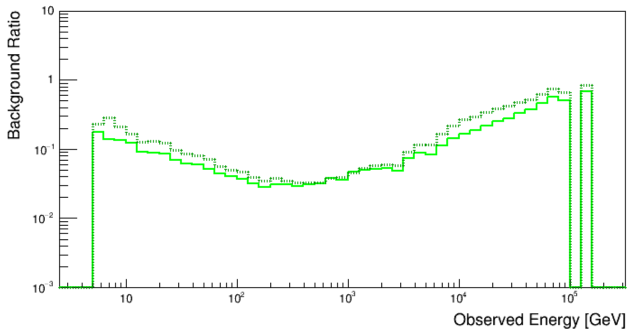
# Background Estimation & Subtraction using Template Fitting

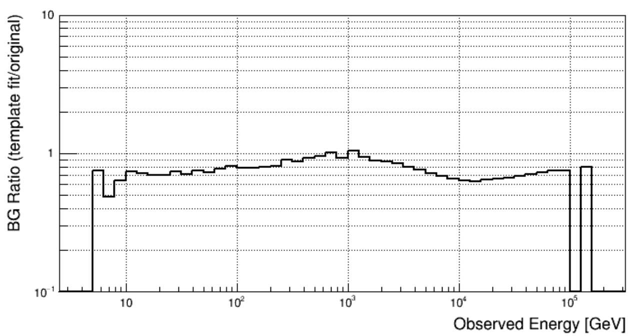
1. factE (fixed to 1.0), factP, factH obtained by interpolating the results of template fitting.
2. For each bin, proton & electron are subtracted; number of events to be subtracted are calculated as follows:
   - N = N_obs * (N_h * factH / (N_p * factP + N_h * factH + N_e * factE)
   - N_h includes off-acceptance helium and this contribution is subtracted in the unfolding procedure.
3. Edep distribution of N and N_h * factH are passed to RooUnfold
   - In the normal case, N_obs and (N_h + N_p + N_e) are passed to RooUnfold.

# Observed Spectra and Subtraction of Background (Proton + Electrons)




Because of the relatively low background level, the effect of template fitting is not so large. However, in the 10 TeV Edep region, results of template fitting obtained **less proton** background than original estimation.

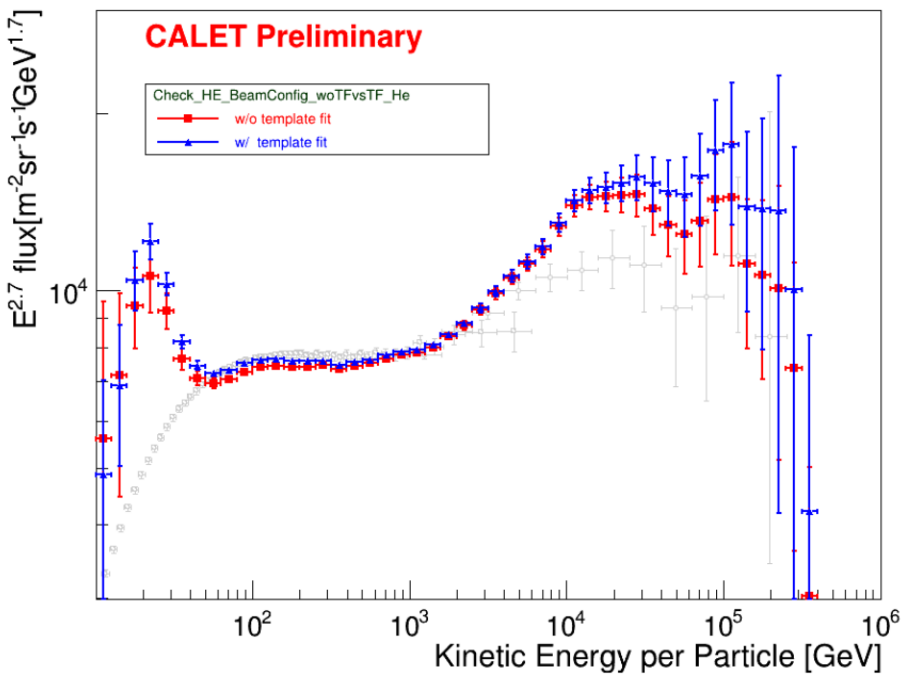


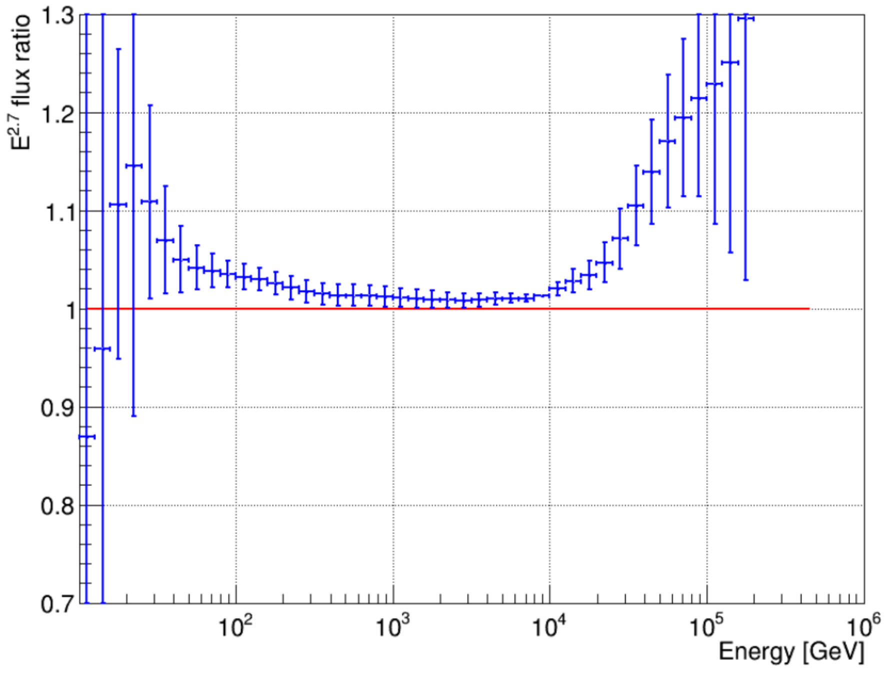



# Comparison of Spectra w/ and w/o Template Fitting (Helium)

Not large effect, but surely larger than that for protons. This is as expected because protons are the most dominant cosmic rays. In addition to that, significantly higher flux was obtained with template fitting above 20 TeV region, due to less background contribution (this is also as expected).

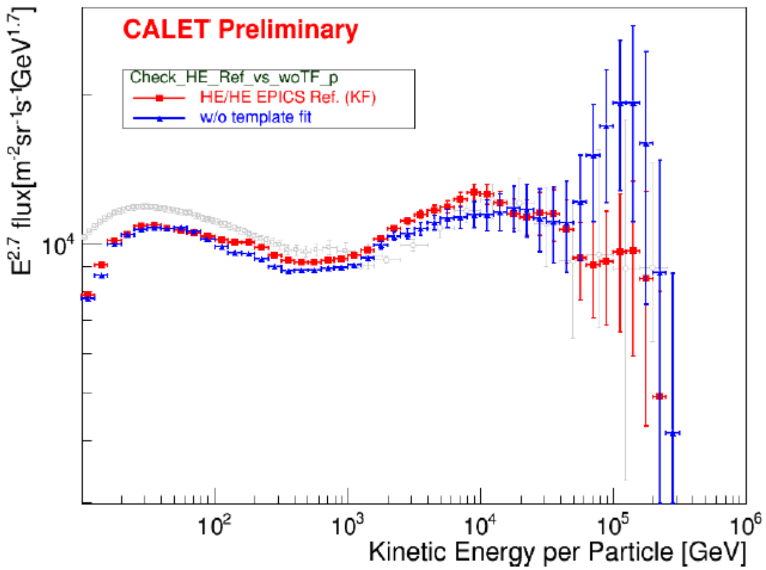
The strange peak at 100 TeV region was somewhat mitigated by using PASS04.

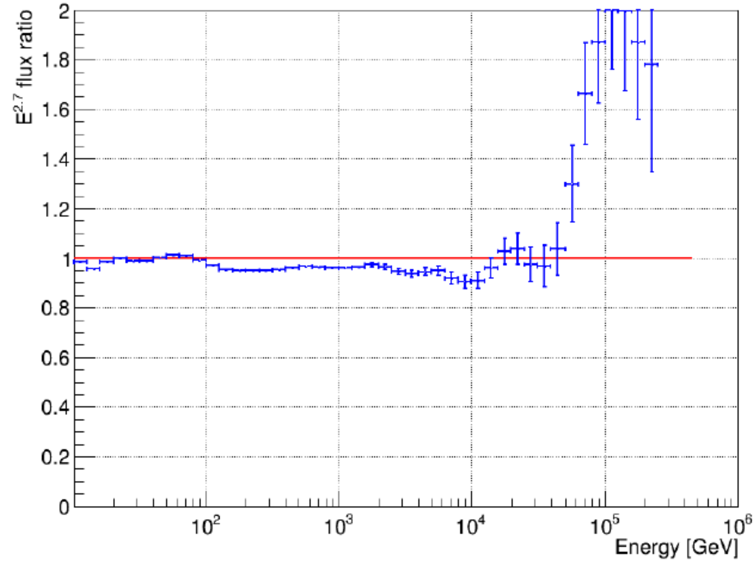


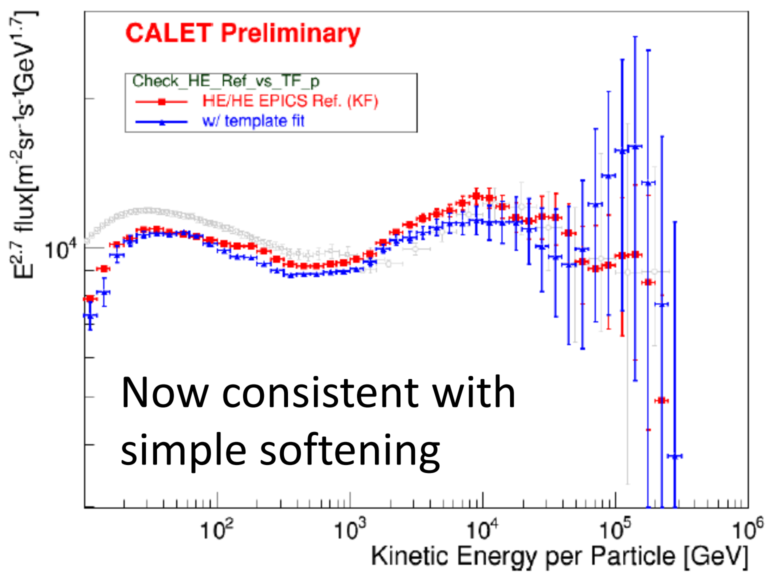
# Effect of Template Fit for Early Interaction Case

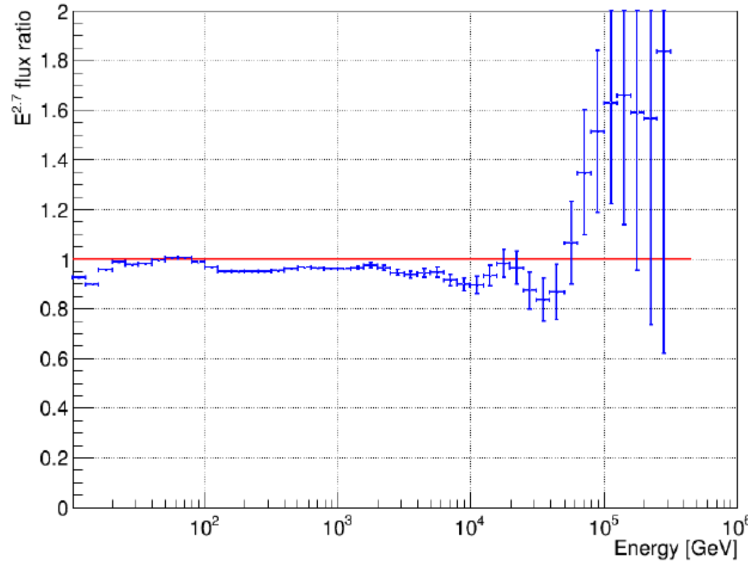
Red: Reference
Blue: w/o Template fit




Red: Reference
Blue: w/ Template fit



# III. SPS2015: Helium Data Analysis

- Analysis framework
  - Same as Akaike-san's heavy ion beam test analysis, which is similar to the SPS2012 framework.
- Analysis setup
  - Calibration: by Akaike-san
  - MC: EPICS rev21, C8.02EP9.22 (old version)
  - Energy: 13, 19, 150GeVA
  - Tracking: UH tracking, but not used for event selection
  - PID: Silicon Detector for 13,19GeVA, CHD for 150GeVA
- Purpose
  - Obtain correction factors (or validation) for trigger efficiency and energy response
  - Same analysis as SPS2012 will be carried out

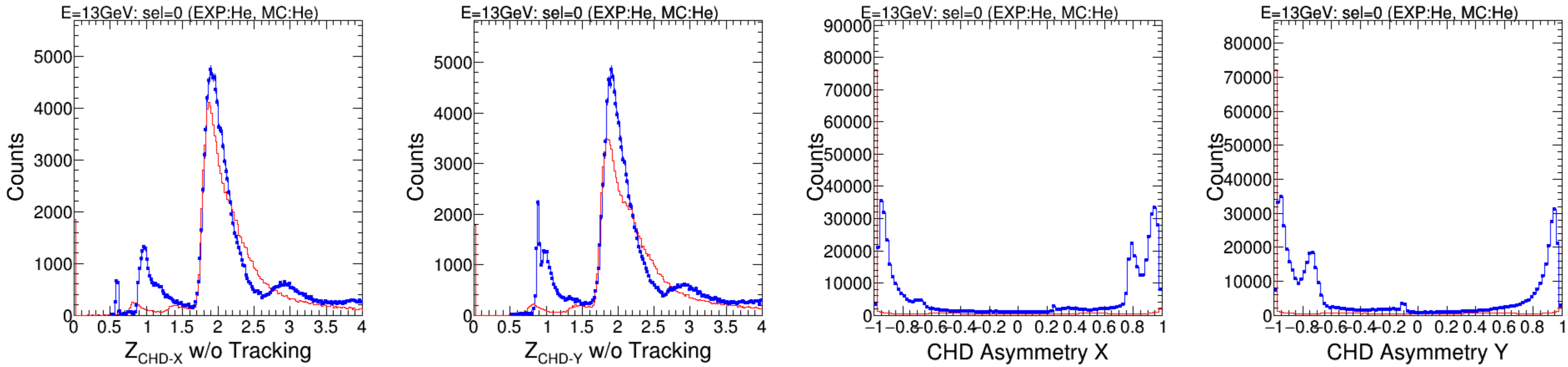
# SPS2015: Event Selection

- Following Paolo and Gabriele's study, CHD charge and CHD asymmetry are used to select helium; they do not depend on tracking.
- While we have silicon charge detector in 13 and 19 GeVA setup, there is no charge detector in 150 GeVA setup; to account for this, severer charge cut is applied on CHD in 150 GeVA data.

# Event Selection for 13 GeVA

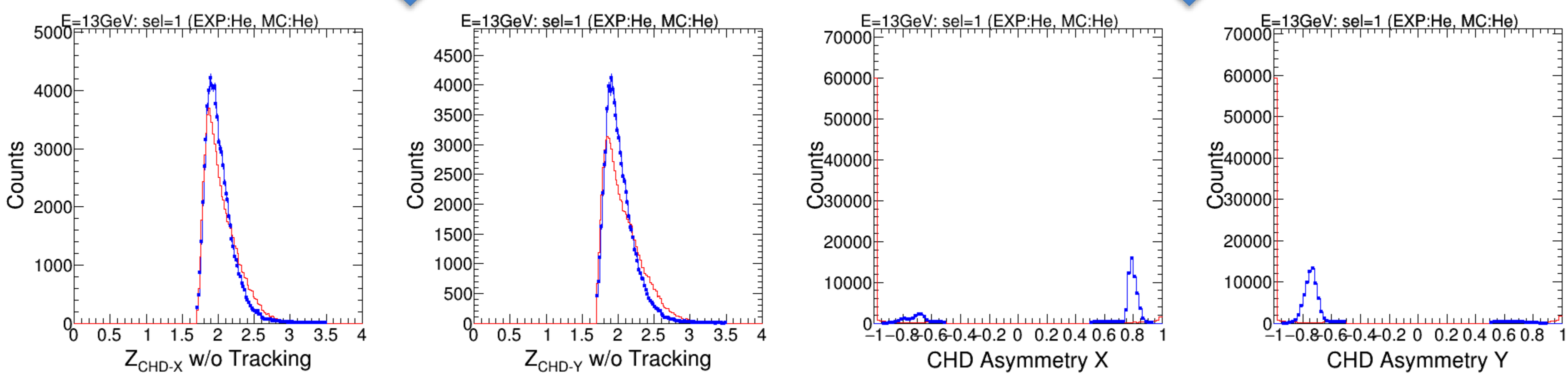
Since CHD distribution is not match very well, loser cuts are applied (Si tag is also used)

CHD asymmetry is defined following Paolo's definition (EXP show complicated structure)




Remove Z=3 while keeping landau tail

MC: helium only

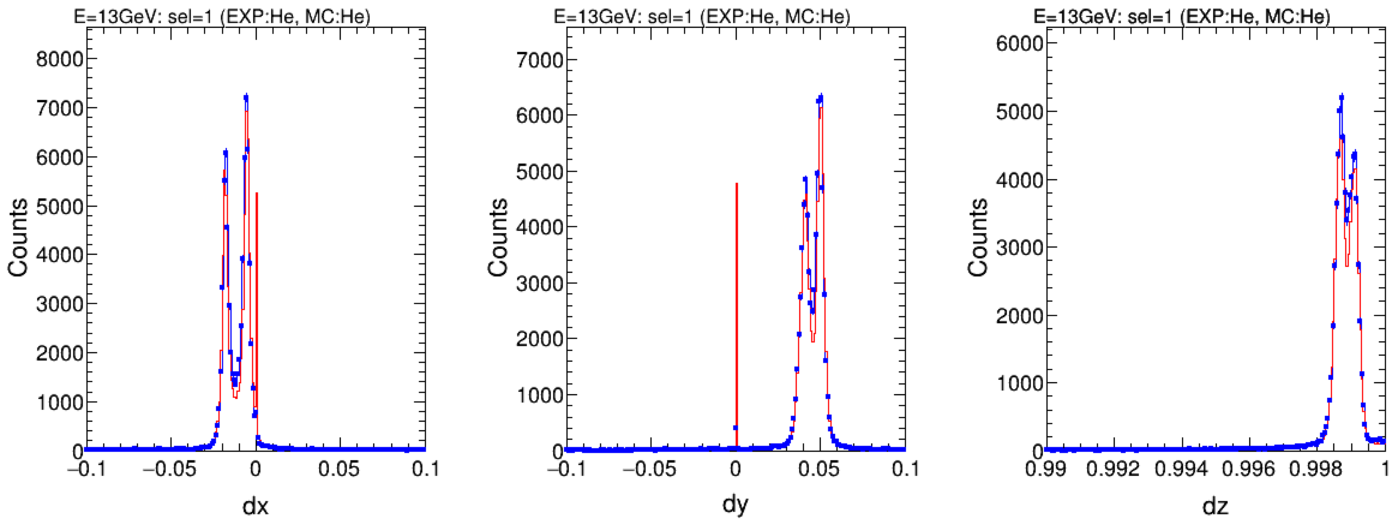


# Event Reconstruction for 13 GeVA

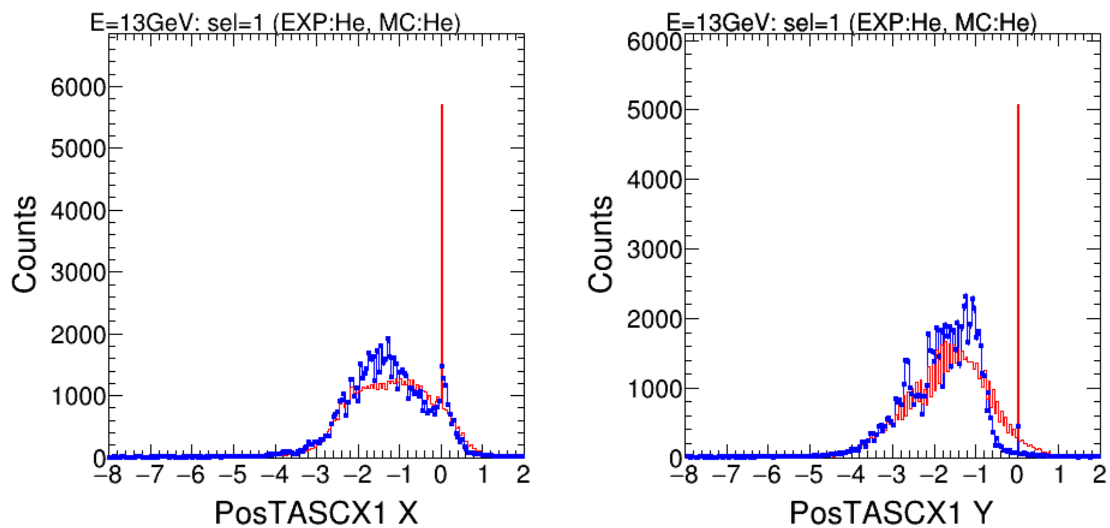
Track direction is compared after event selection. For not reconstructed events, (0,0,1) are stored.

MC data are quite well tuned to match the EXP distributions

MC: helium only



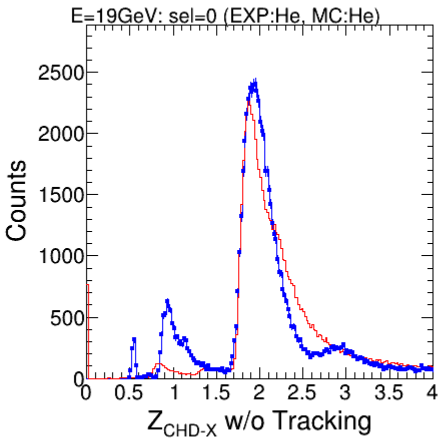

Impact point at the TASC-X1 is compared. For not reconstructed events (0,0) are stored.

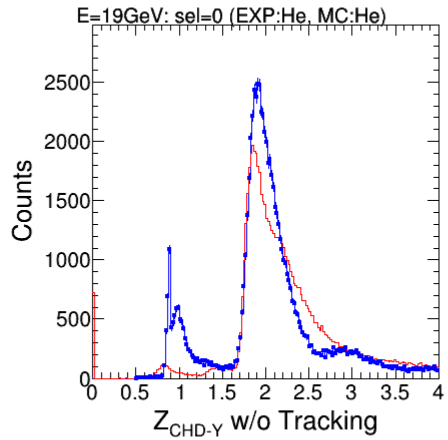


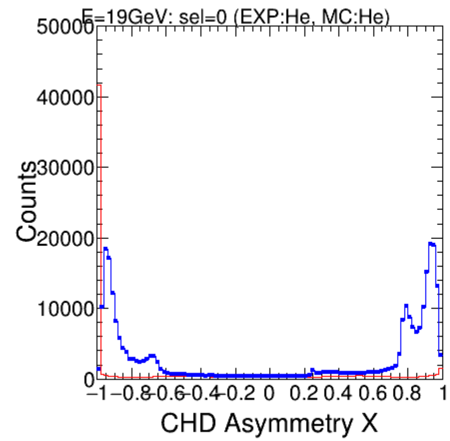
# Event Selection for 19 GeVA

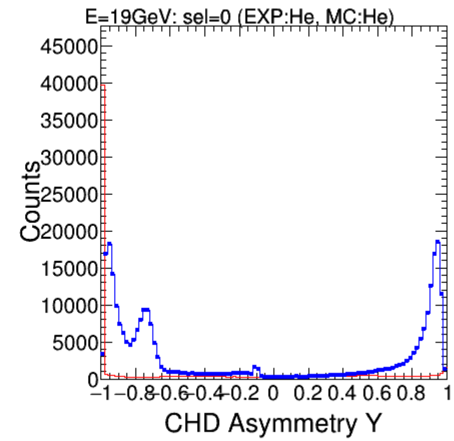
Since CHD distribution is not match very well, loser cuts are applied (same as 13 GeVA)

Same cut is applied as 13 GeVA.



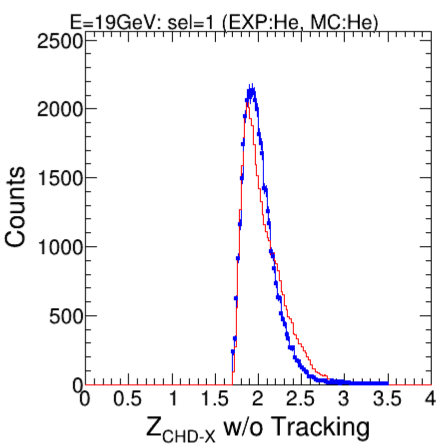



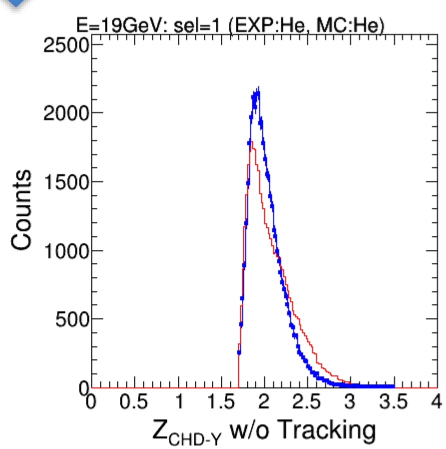



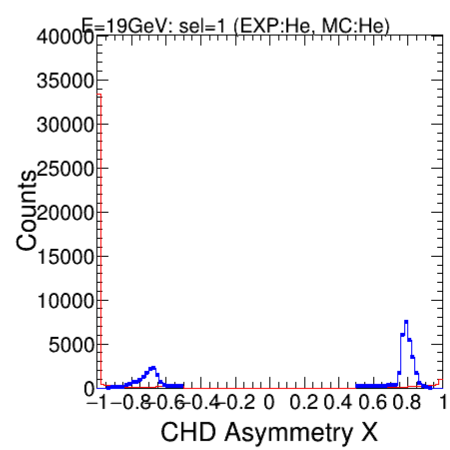



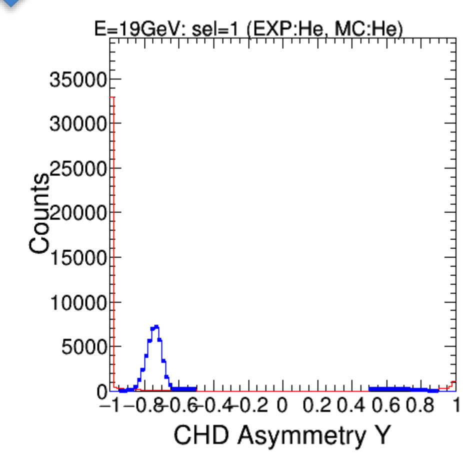

Remove Z=3 while keeping landau tail

MC: helium only



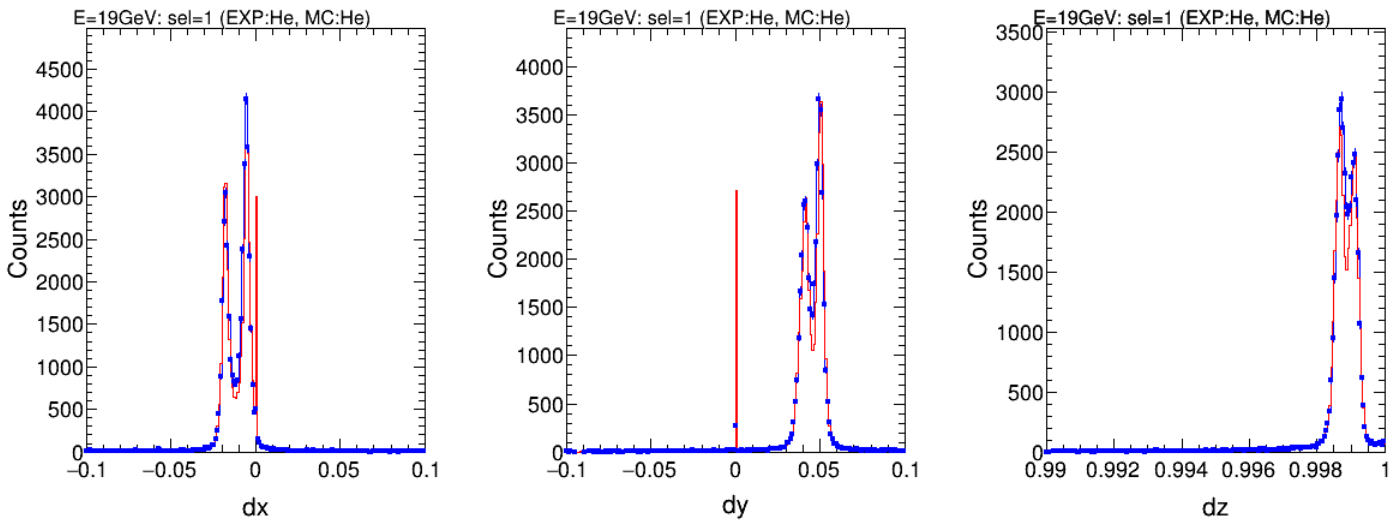



# Event Reconstruction for 19 GeVA

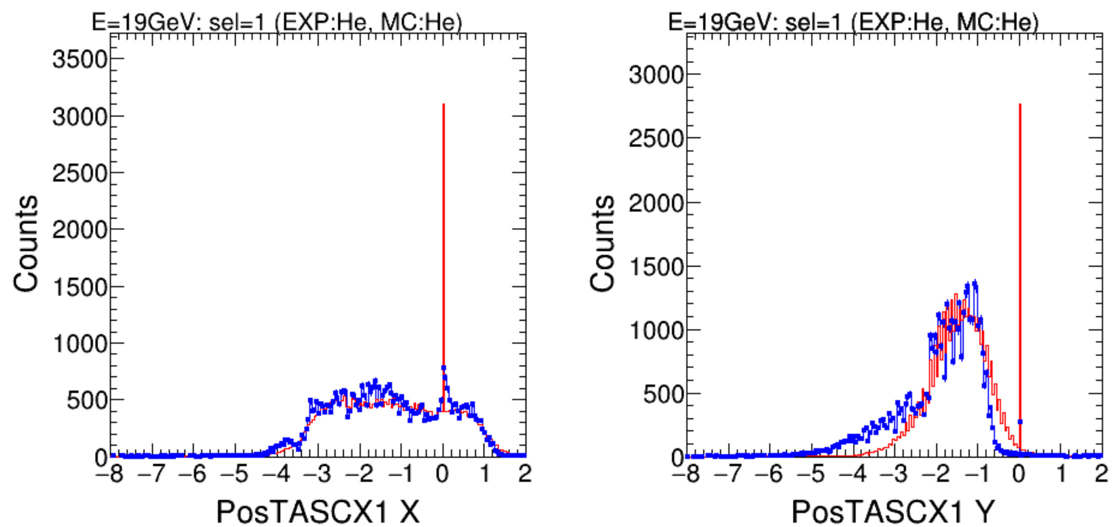
Track direction is compared after event selection. For not reconstructed events, (0,0,1) are stored.

MC data are quite well tuned to match the EXP distributions

MC: helium only



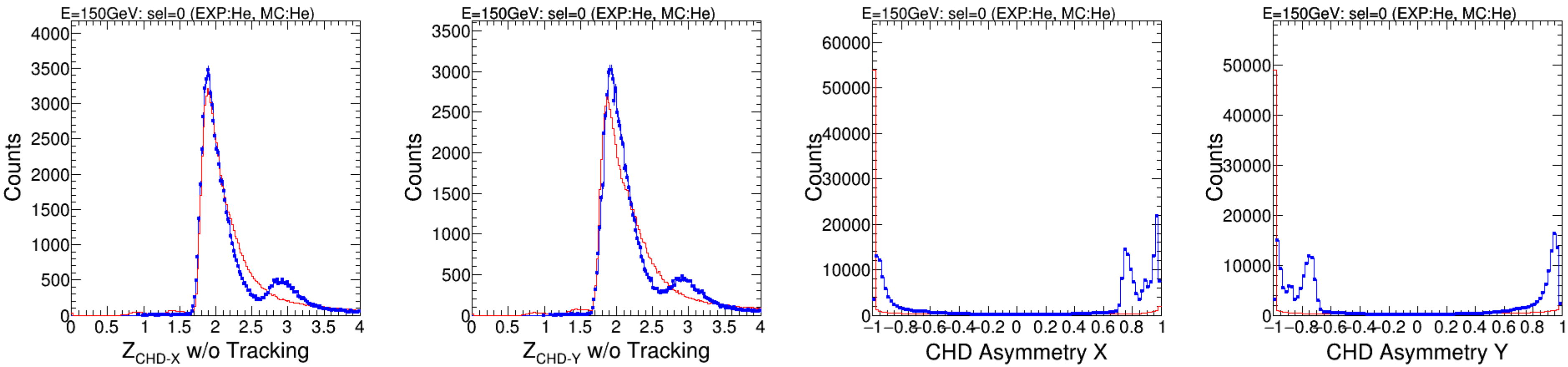

Impact point at the TASC-X1 is compared. For not reconstructed events (0,0) are stored.



# Event Selection for 150 GeVA

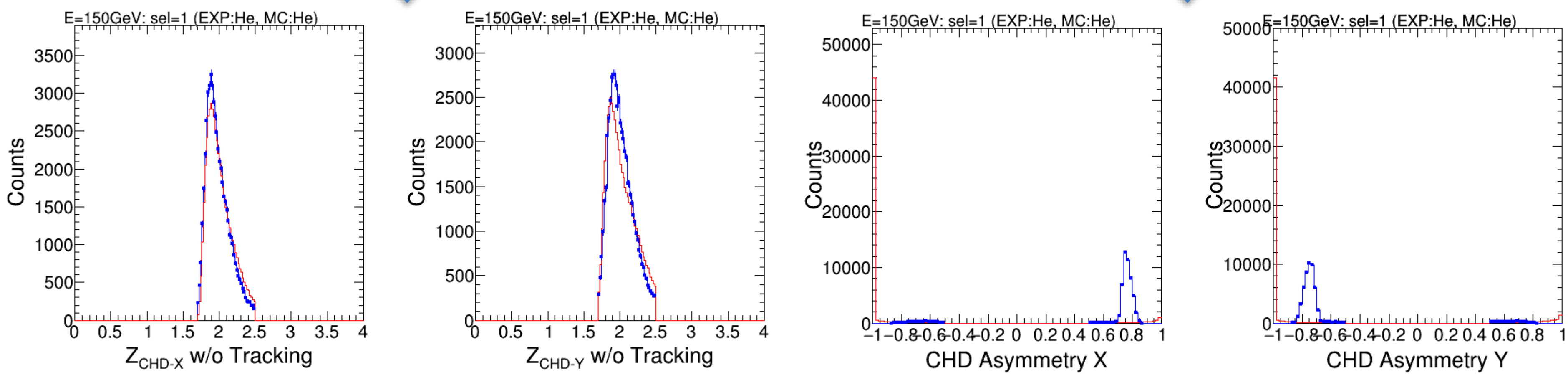
Because no Si charge tag is available, severer CHD cut is used to define clean helium events

Same cut is applied as 13, 19 GeVA for CHD asymmetry.




Simple box cut used

MC: helium only

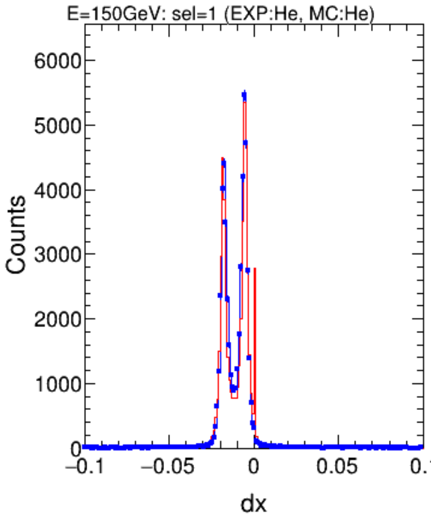


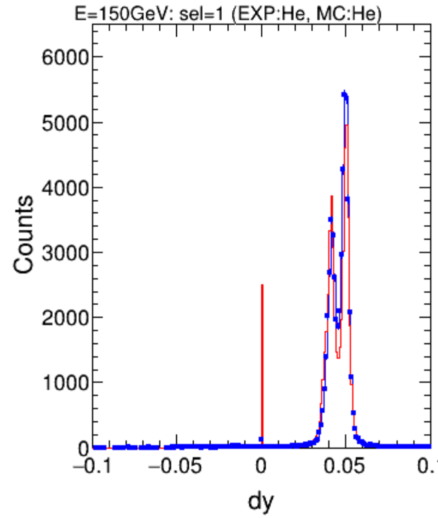
# Event Reconstruction for 150 GeVA

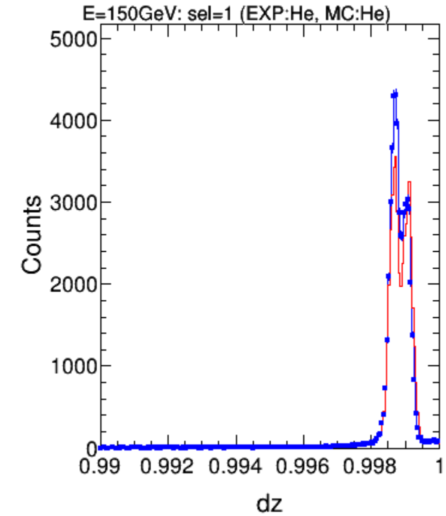
Track direction is compared after event selection. For not reconstructed events, (0,0,1) are stored.

MC data are quite well tuned to match the EXP distributions

MC: helium only

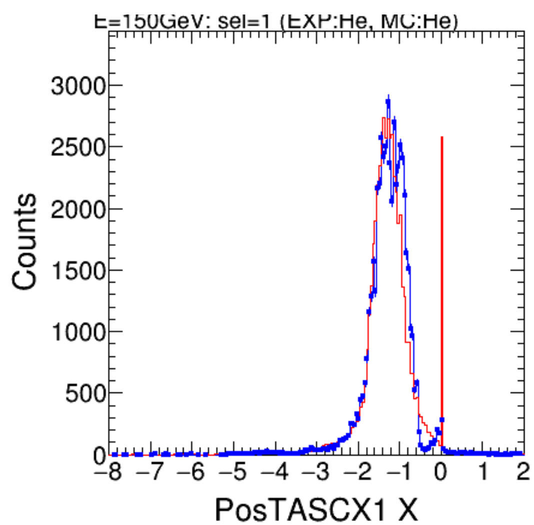


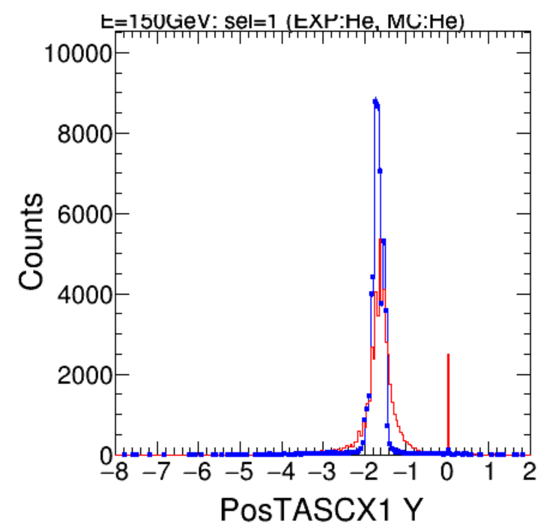




Impact point at the TASC-X1 is compared. For not reconstructed events (0,0) are stored.

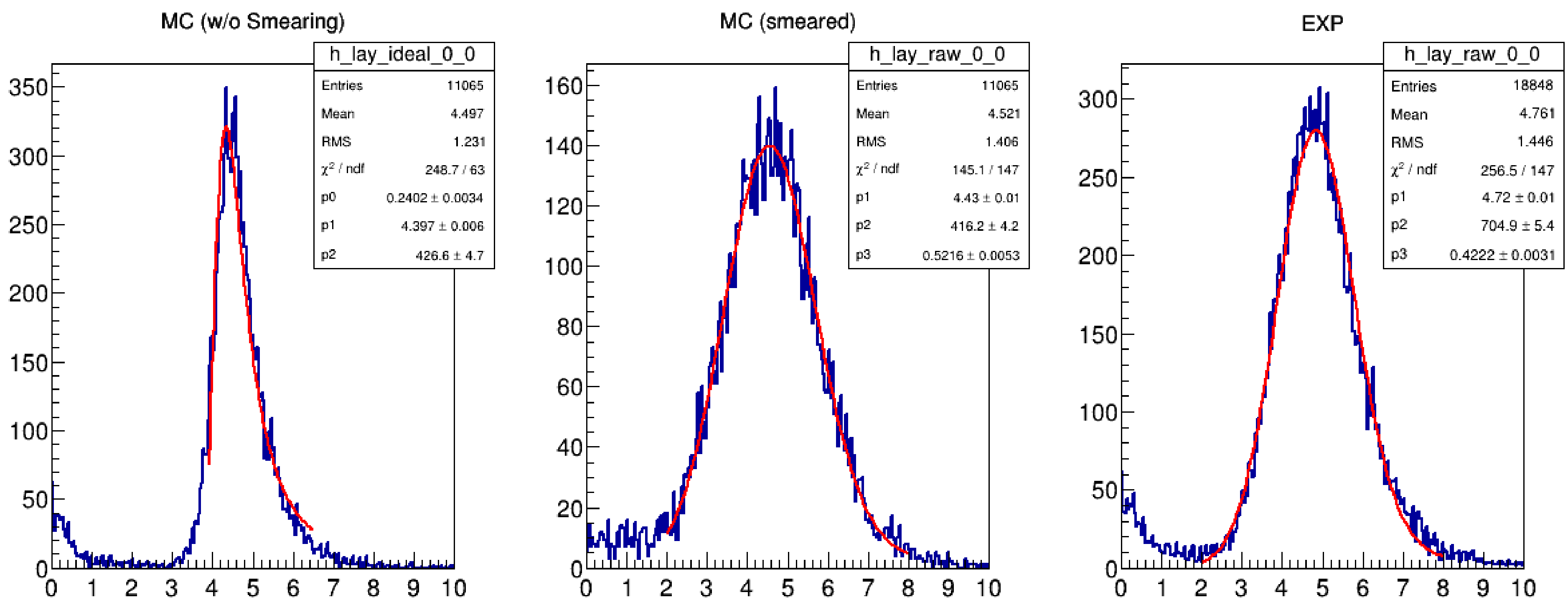
150GeVA events are somewhat more focused.



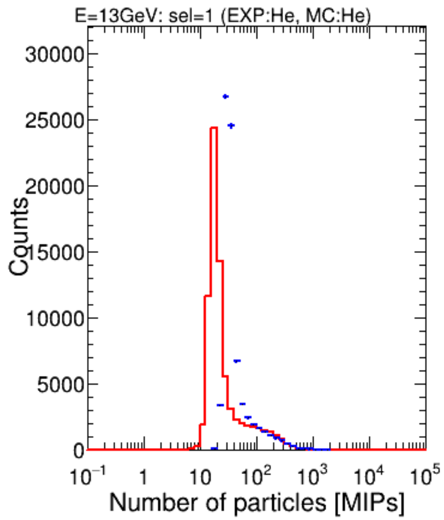



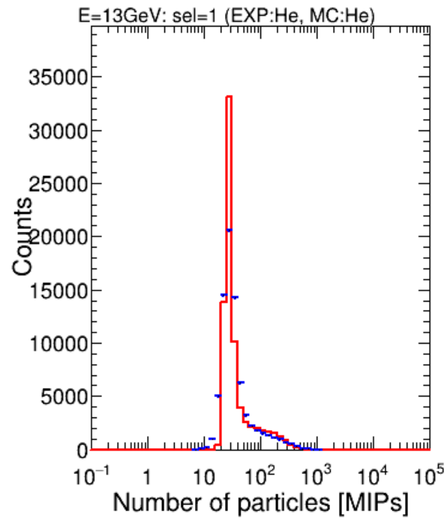
# TASC-X1 Gain Re-Calibration for 13 GeVA

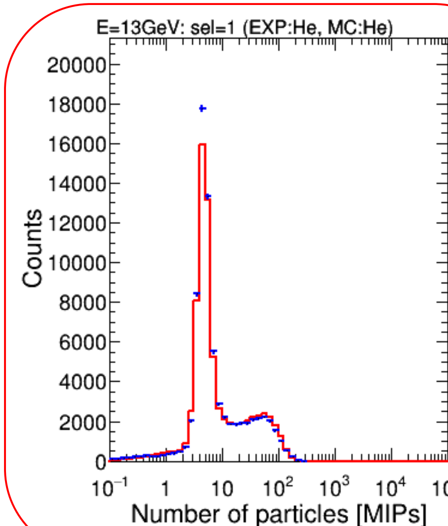
1. Using MC true energy deposit distribution, TASC MIP peak is retrieved.
2. EXP distribution is also fitted with two kind of noise components, i.e., constant (pedestal) noise and photoelectron statistics (proportional to sqrt(Edep)). NOTE: pedestal noise is fixed to measured value in the fit shown below.
3. The obtained MPV ratio is then used to correct for the EXP gain while noise information is used to smear MC.



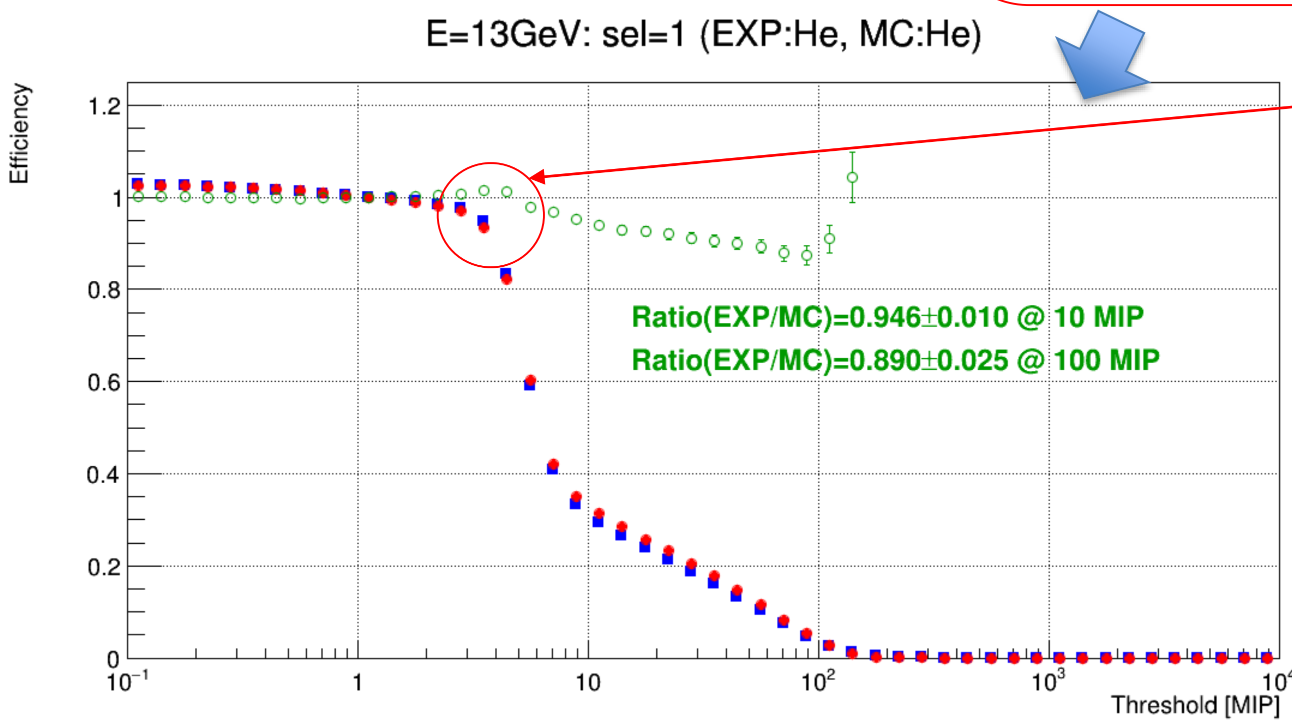
# SPS2015 Trigger Efficiency Comparison: Helium 13 GeVA



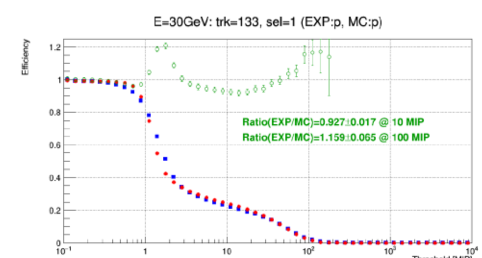




As a function of threshold, trigger efficiency is extracted for both of EXP and MC using TASC-X1 distribution



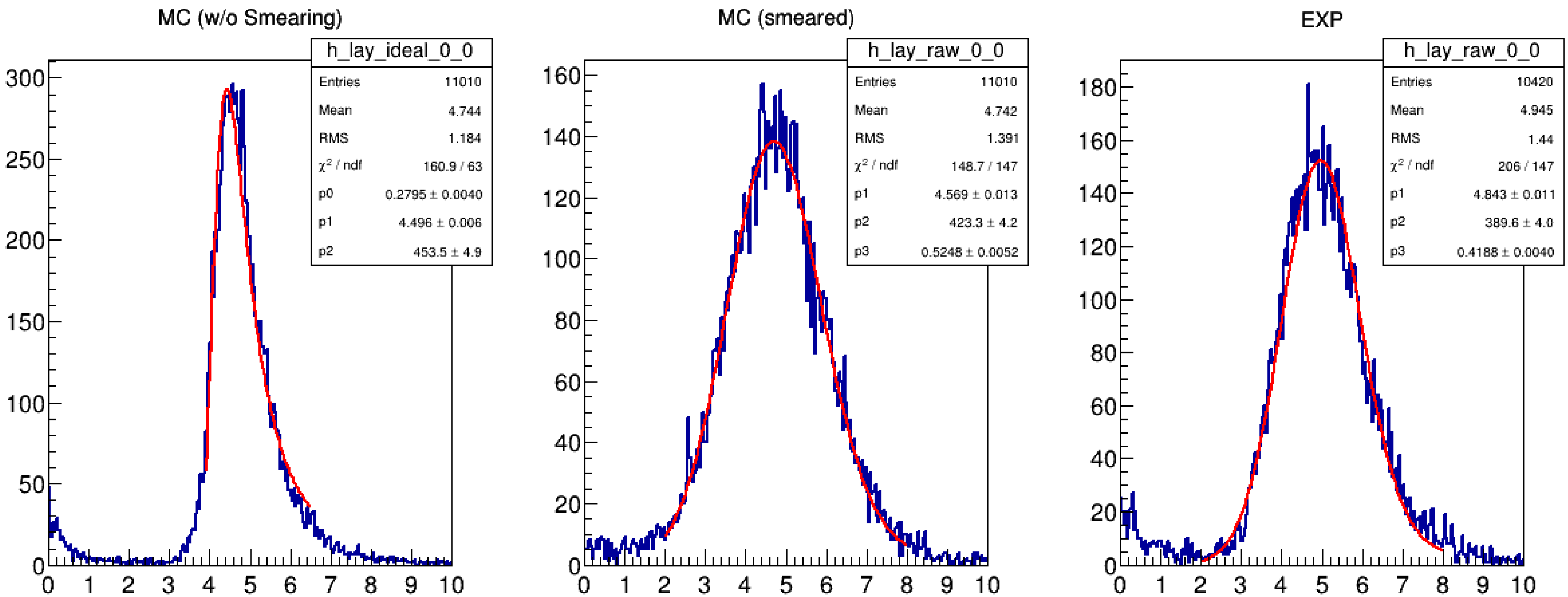

Because of gain adjustment, this part shows quite good agreement. Otherwise, it shows much bigger oscillation (example below).



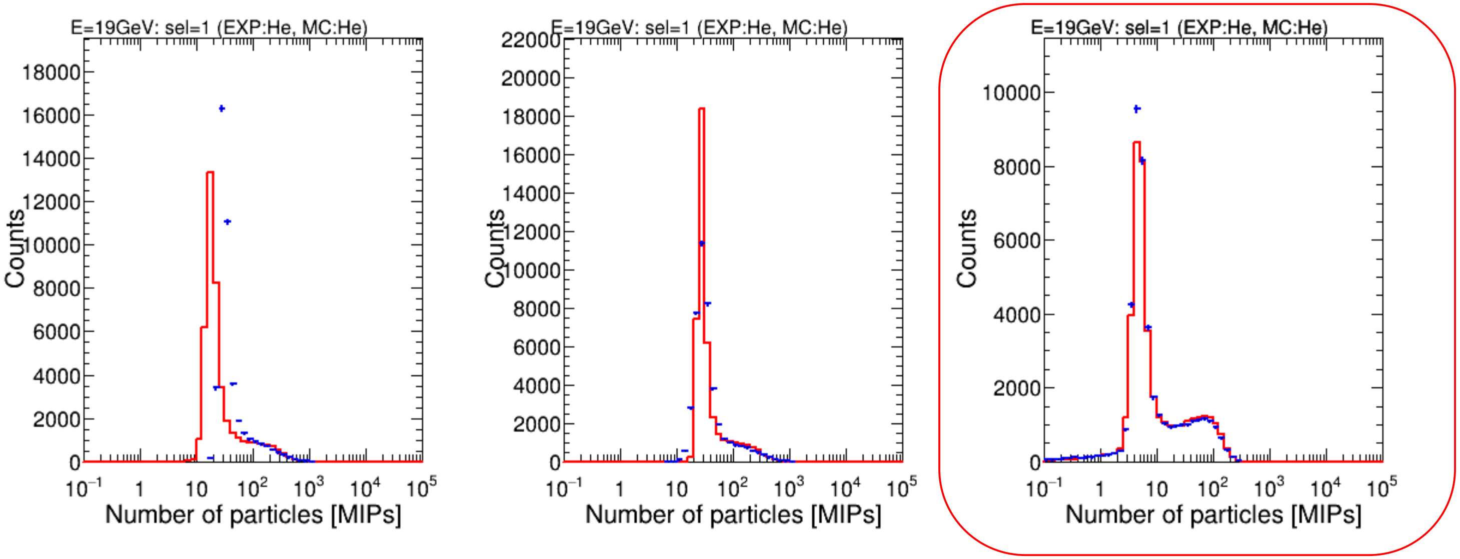
# TASC-X1 Gain Re-Calibration for 19 GeVA

(SAME PROCEDURE AS 13 GeVA IS APPLIED)

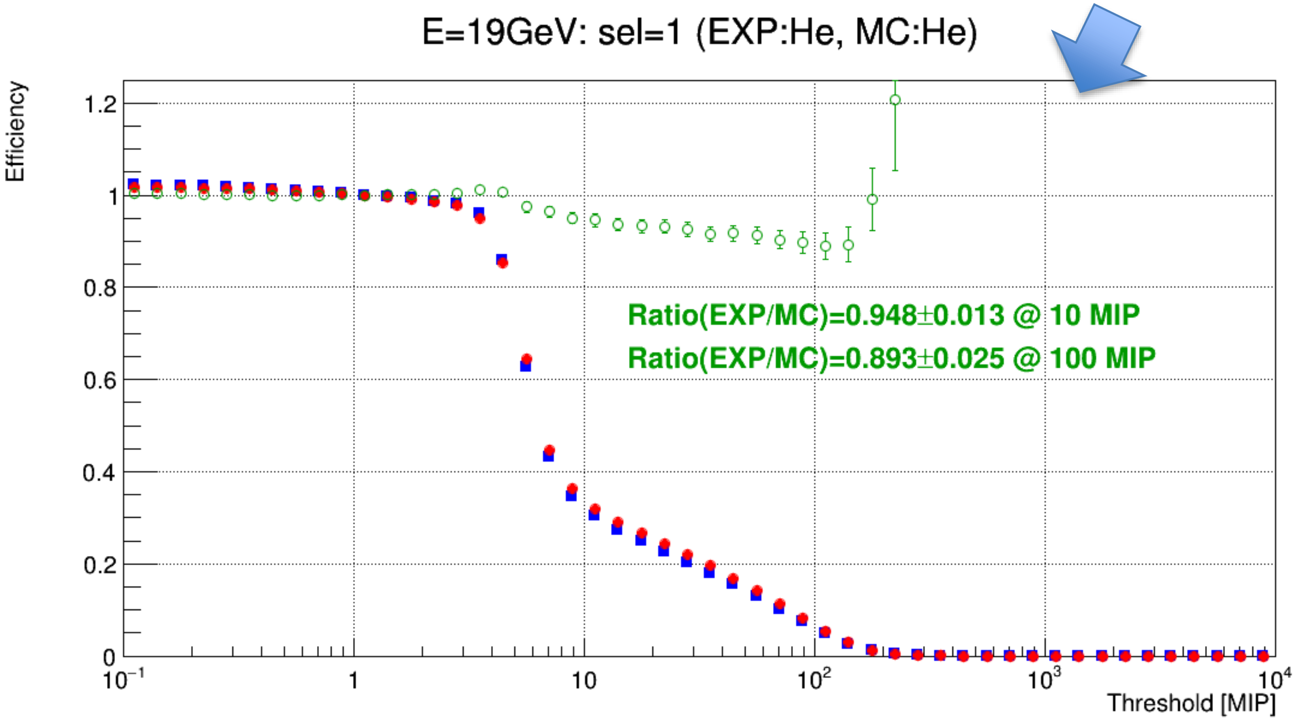
1. Using MC true energy deposit distribution, TASC MIP peak is retrieved.
2. EXP distribution is also fitted with two kind of noise components, i.e., constant (pedestal) noise and photoelectron statistics (proportional to sqrt(Edep)). NOTE: pedestal noise is fixed to measured value in the fit shown below.
3. The obtained MPV ratio is then used to correct for the EXP gain while noise information is used to smear MC.



# SPS2015 Trigger Efficiency Comparison: Helium 19 GeVA



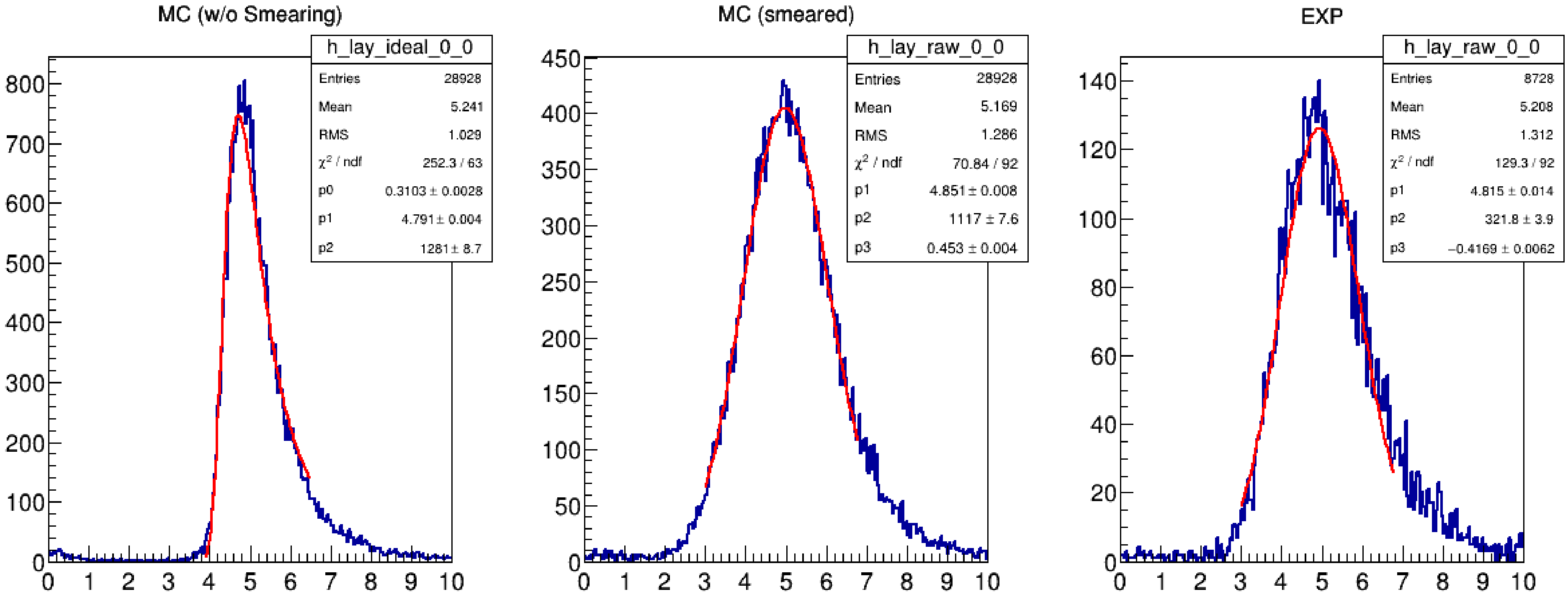

As a function of threshold, trigger efficiency is extracted for both of EXP and MC using TASC-X1 distribution



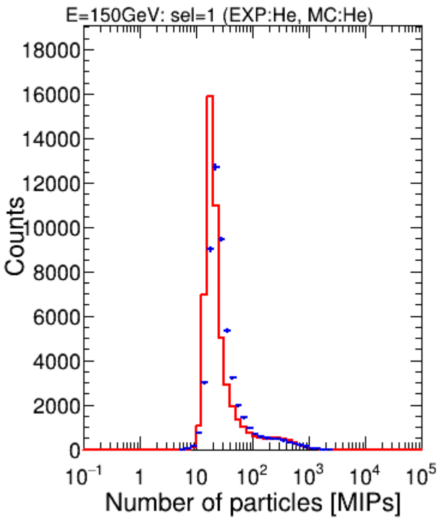
# TASC-X1 Gain Re-Calibration for 150 GeVA

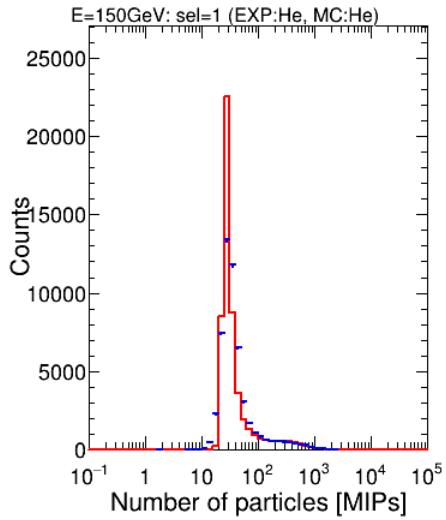
(SAME PROCEDURE AS 13 GeVA IS APPLIED)

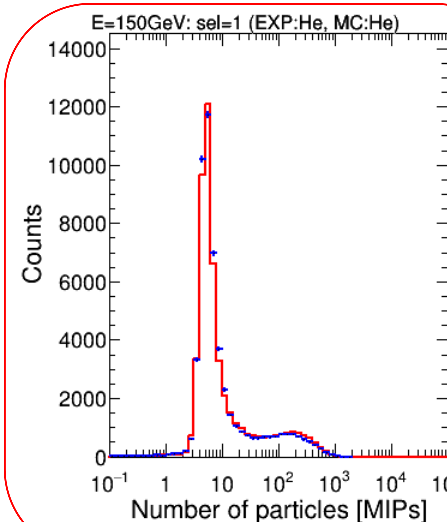
1. Using MC true energy deposit distribution, TASC MIP peak is retrieved.
2. EXP distribution is also fitted with two kind of noise components, i.e., constant (pedestal) noise and photoelectron statistics (proportional to sqrt(Edep)). NOTE: pedestal noise is fixed to measured value in the fit shown below.
3. The obtained MPV ratio is then used to correct for the EXP gain while noise information is used to smear MC.



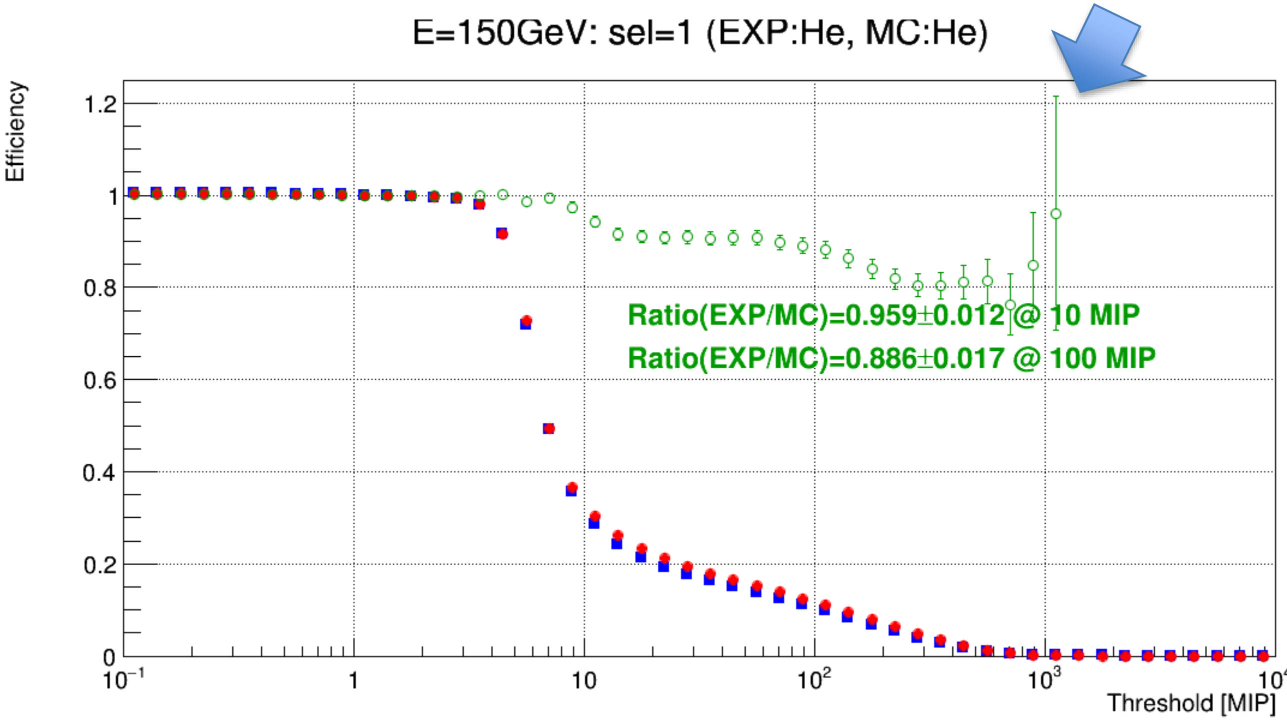
# SPS2015 Trigger Efficiency Comparison: Helium 150 GeVA



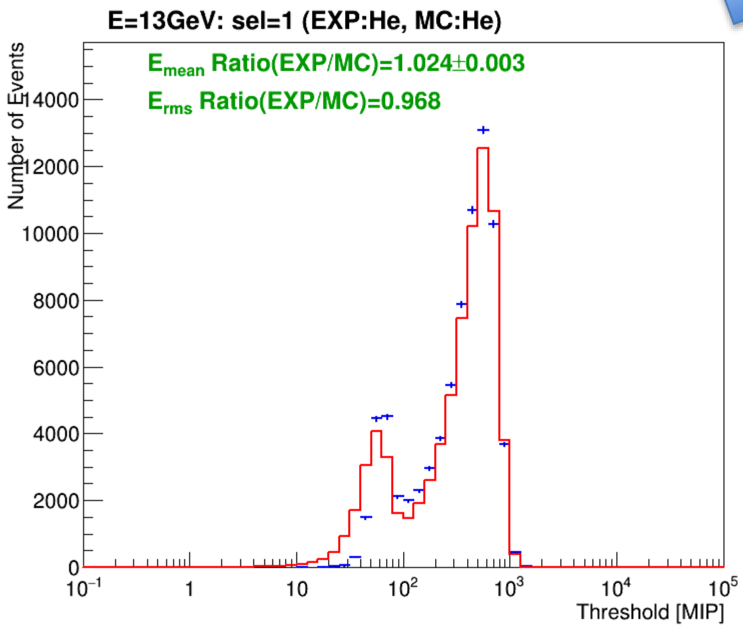




As a function of threshold, trigger efficiency is extracted for both of EXP and MC using TASC-X1 distribution

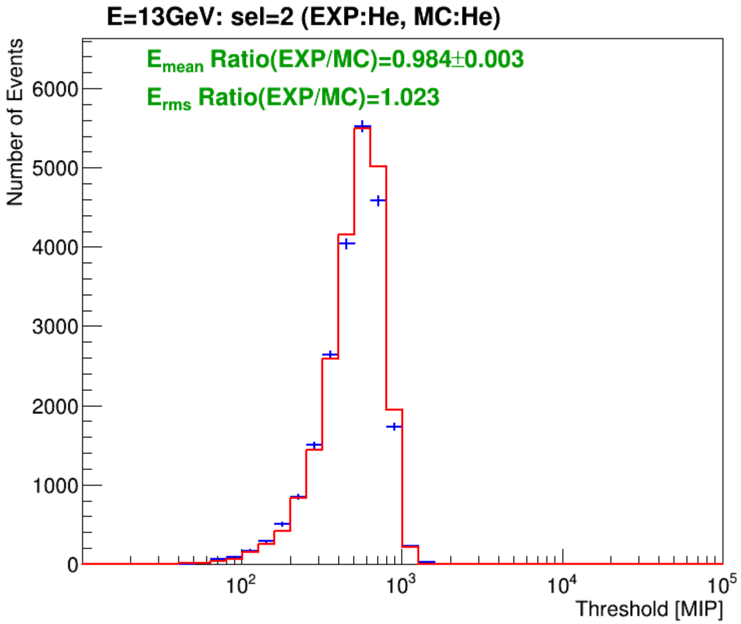


# SPS2015 Energy Deposit Comparison: Helium 13 GeVA

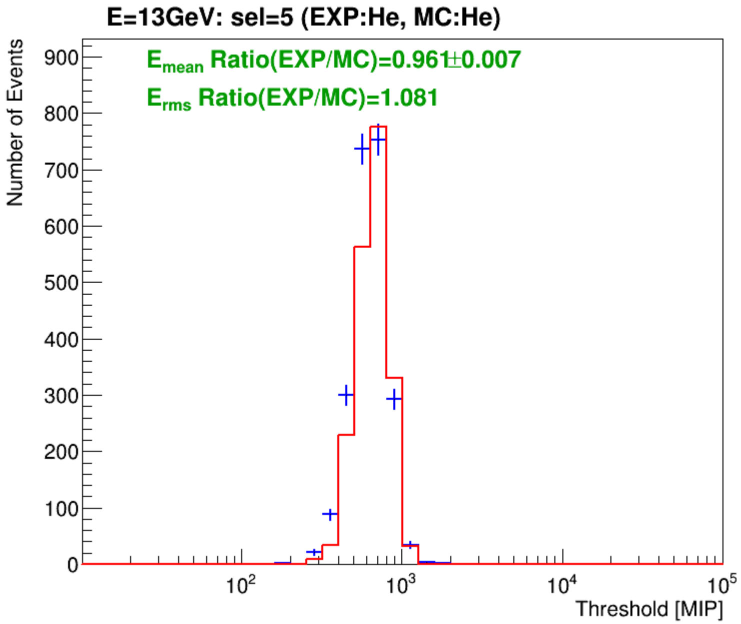
No Offline Trigger w/ TASC-X1




**LE Trigger**
**(10MIP or more @ TASC-X1)**

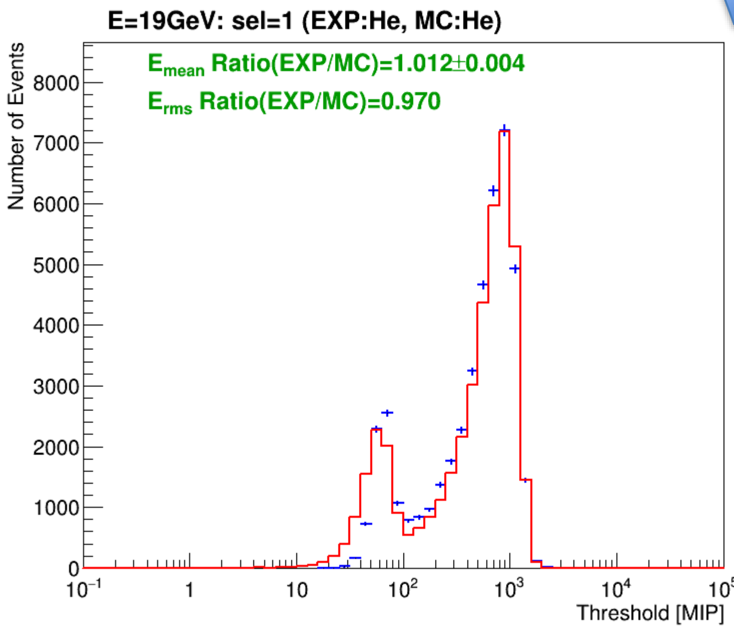



**HE Trigger**
**(100MIP or more @ TASC-X1)**

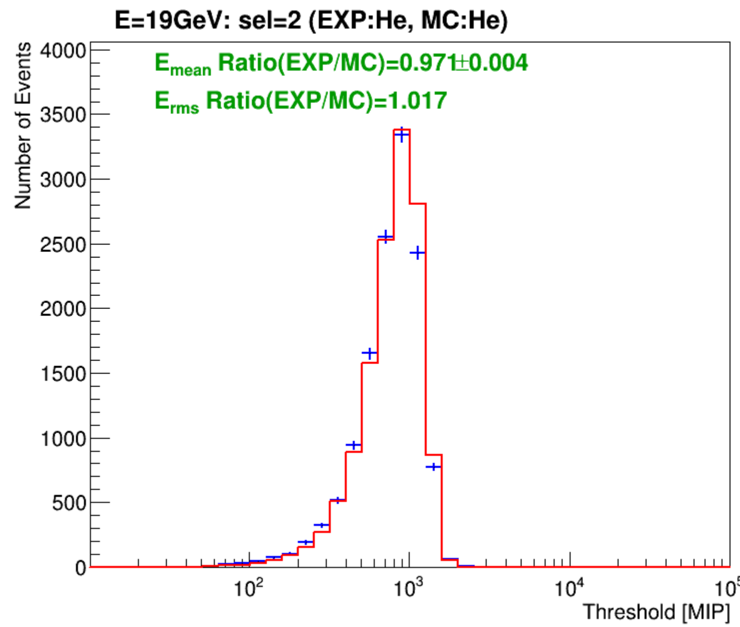


# SPS2015 Energy Deposit Comparison: Helium 19 GeVA

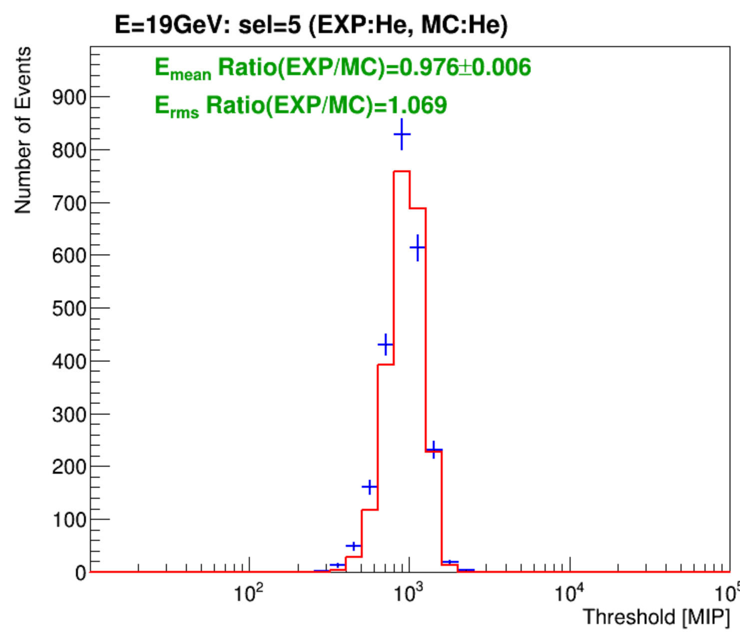
No Offline Trigger w/ TASC-X1




**LE Trigger**
**(10MIP or more @ TASC-X1)**

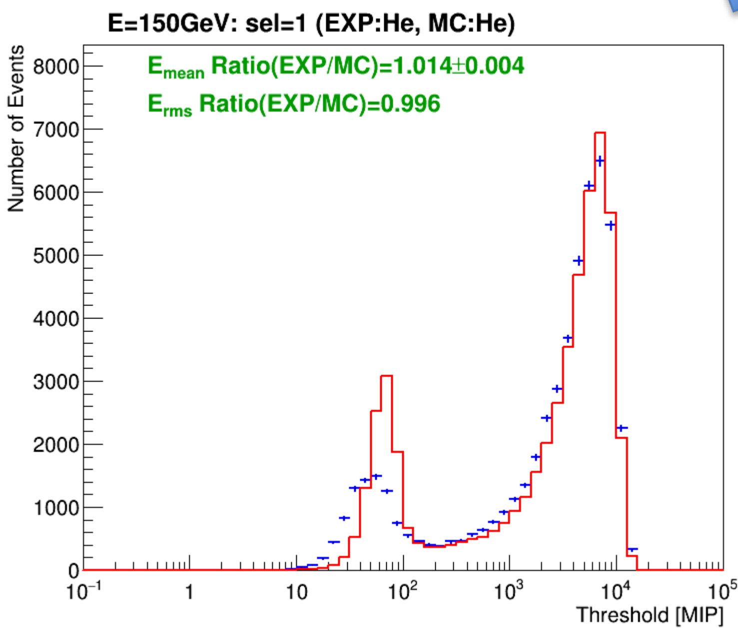



**HE Trigger**
**(100MIP or more @ TASC-X1)**

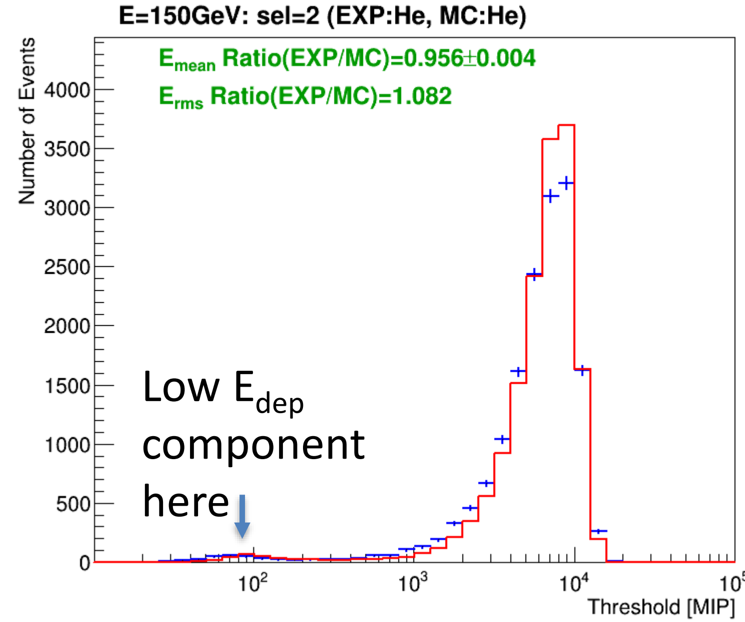


# SPS2015 Energy Deposit Comparison: Helium 150 GeVA

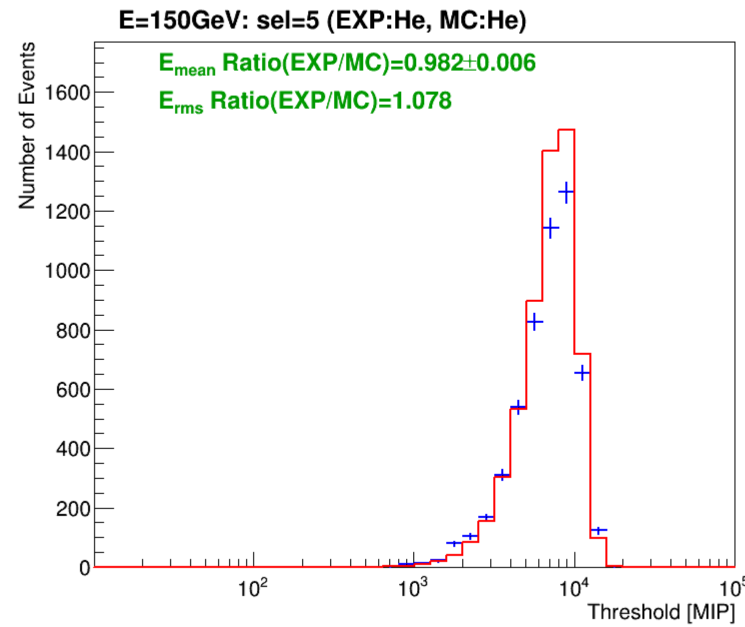
No Offline Trigger w/ TASC-X1



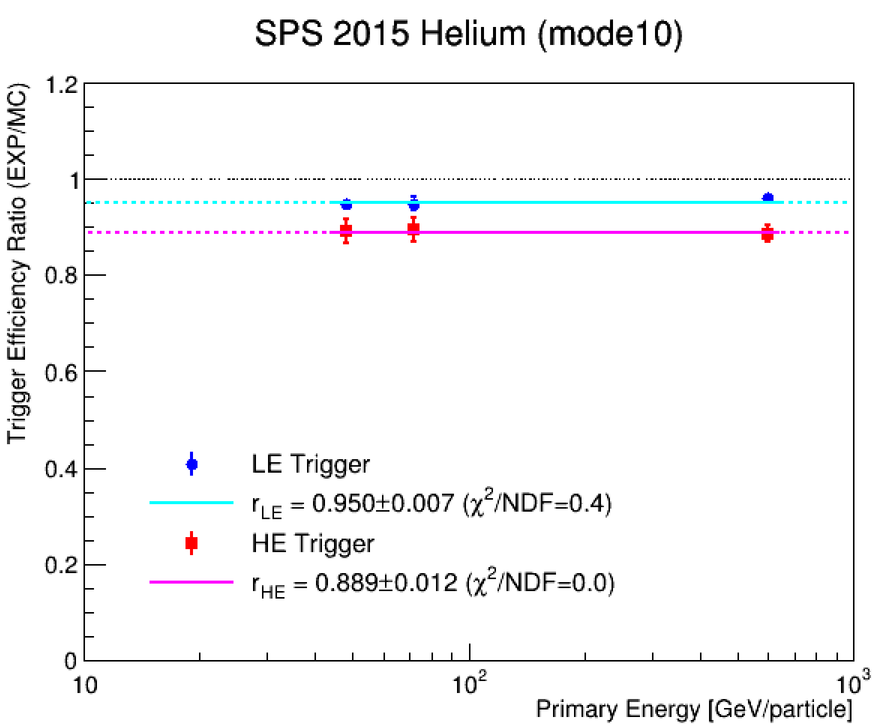

**LE Trigger**
**(10MIP or more @ TASC-X1)**

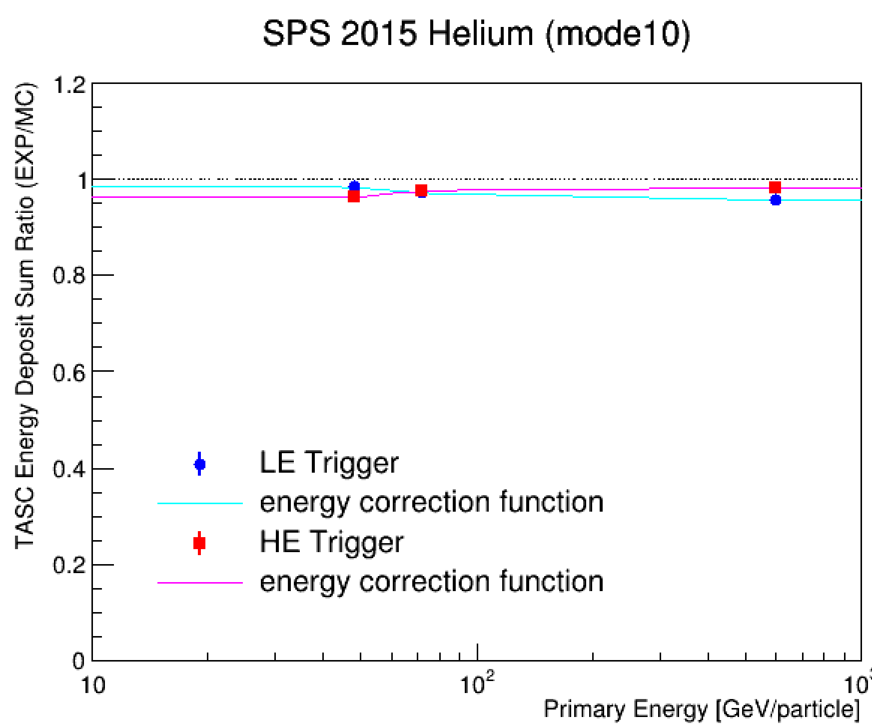



**HE Trigger**
**(100MIP or more @ TASC-X1)**



# SPS2015: Corrections for Trigger & Energy Response for Helium Nuclei

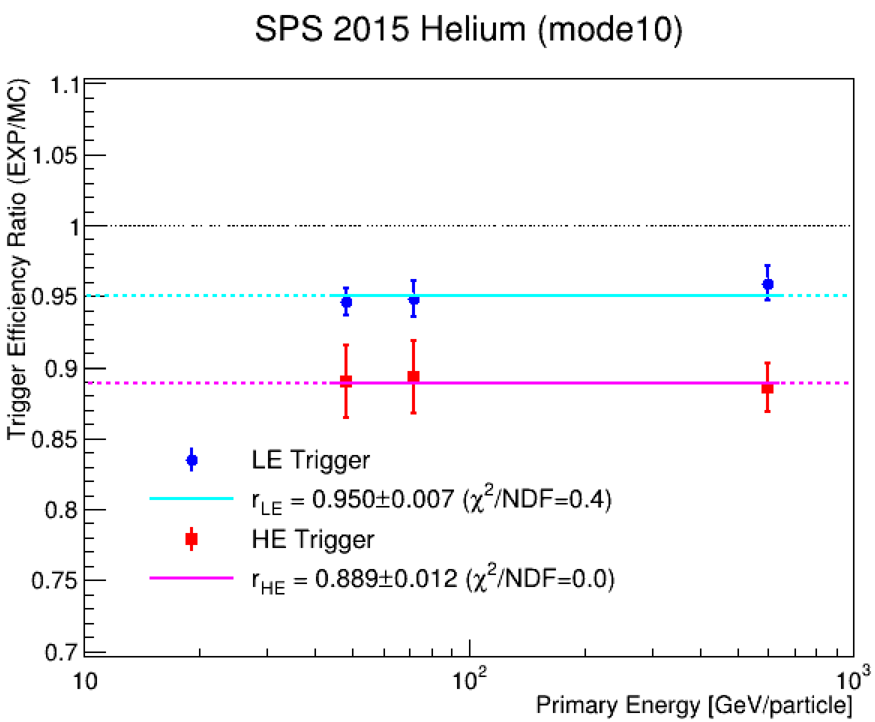


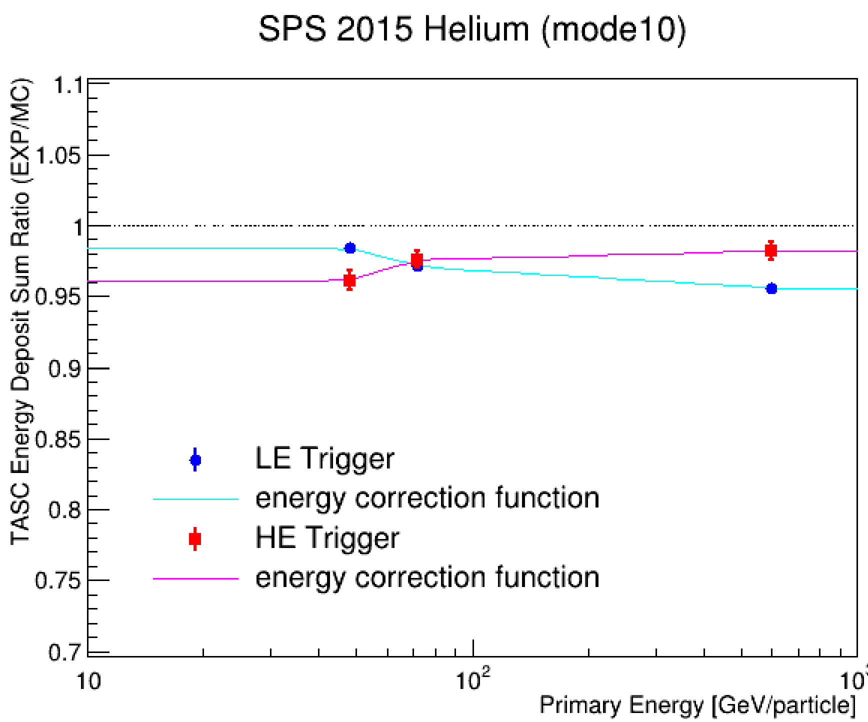




- Efficiency corrections are consistent with constant
- Energy correction functions have opposite trend between LE and HE triggers.

# SPS2015: Corrections for Trigger & Energy Response for Helium Nuclei

**Close-up view!**



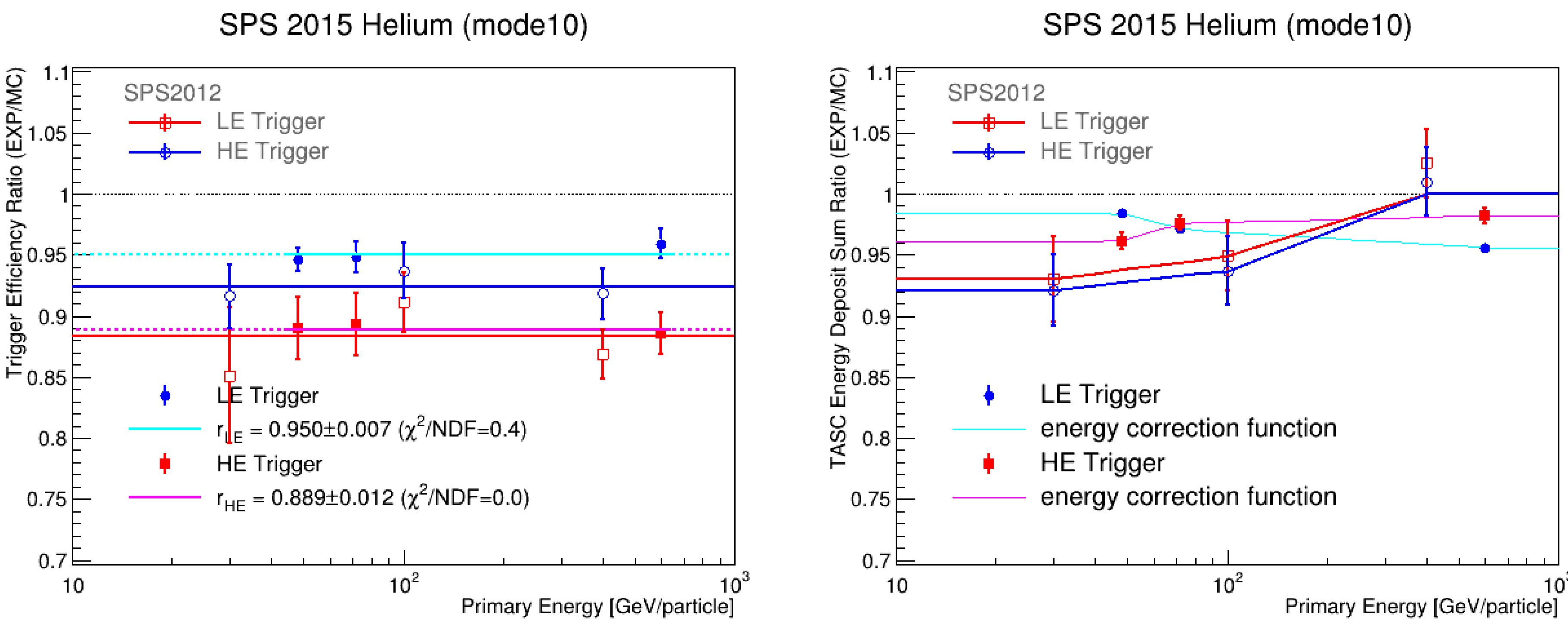




- Efficiency corrections are consistent with constant.
- Energy correction functions have opposite trend between LE and HE triggers.

# SPS2015: Corrections for Trigger & Energy Response for Helium Nuclei

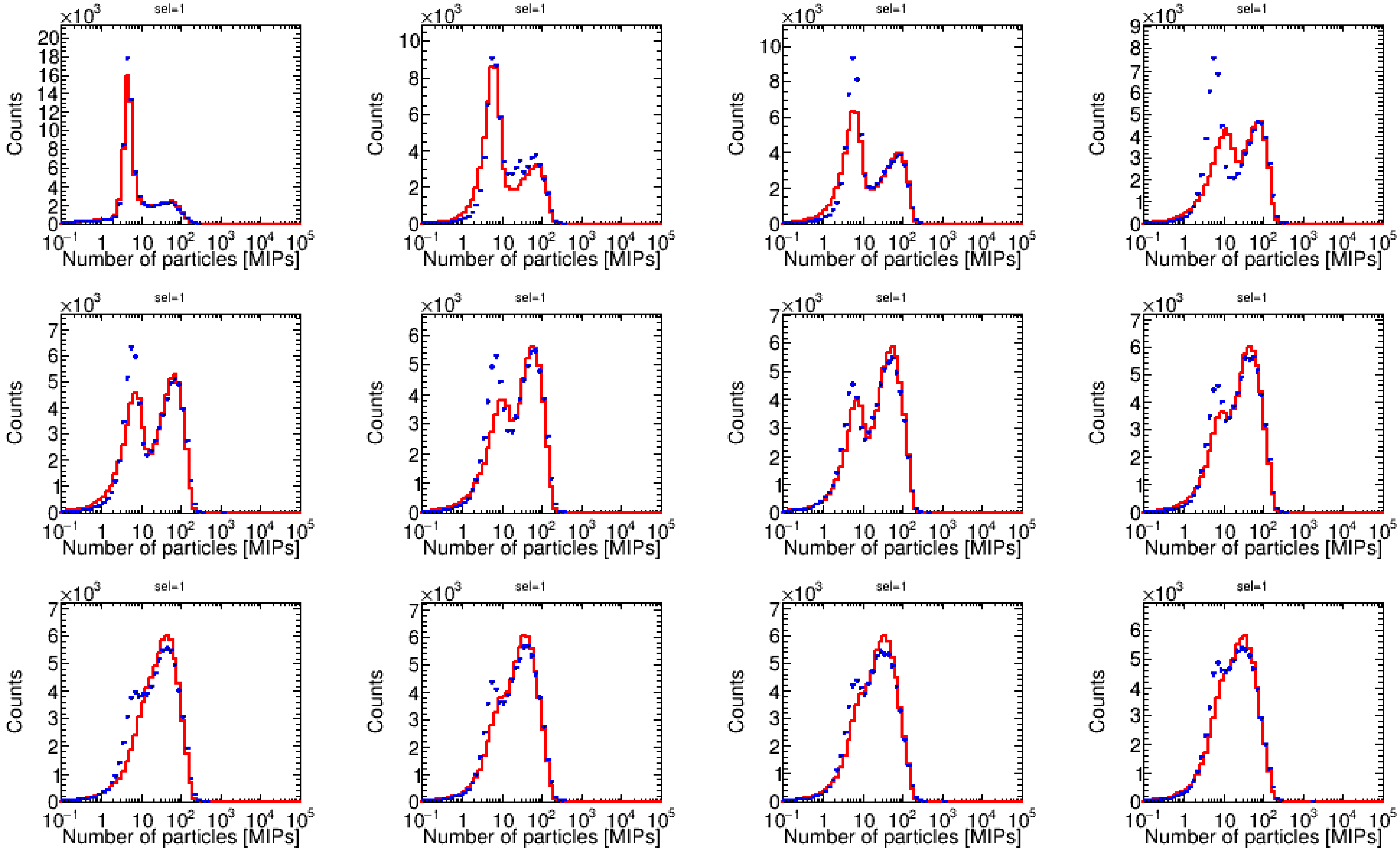
**Close-up view!**

## Comparison with SPS2012 for protons (Open Symbols)

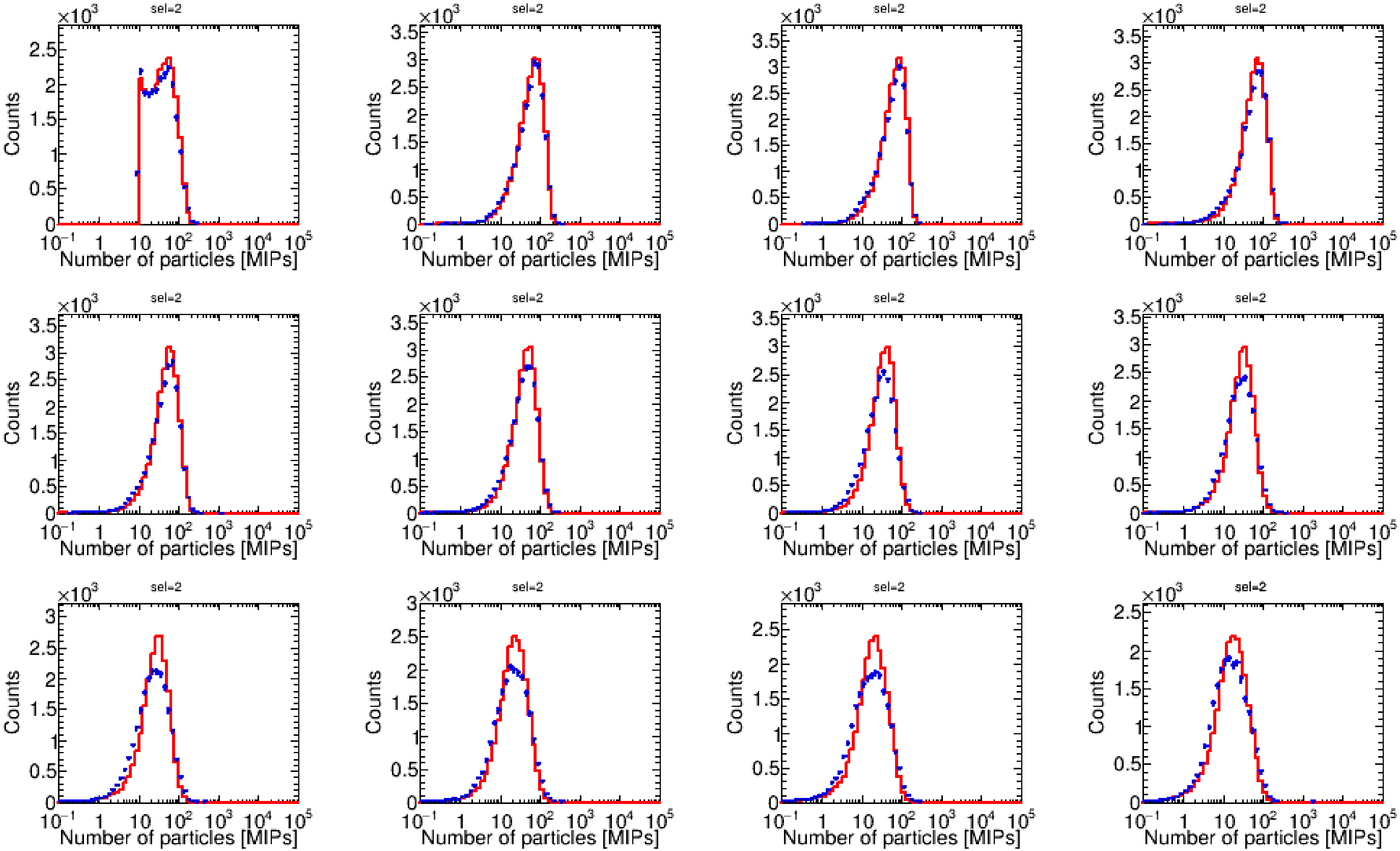



- Efficiency correction is similar to that for protons (SPS2012), while correction is smaller for LE trigger.
- Energy response correction is smaller than that for protons.
  => need to check layer-by-layer TASC energy deposit distributions

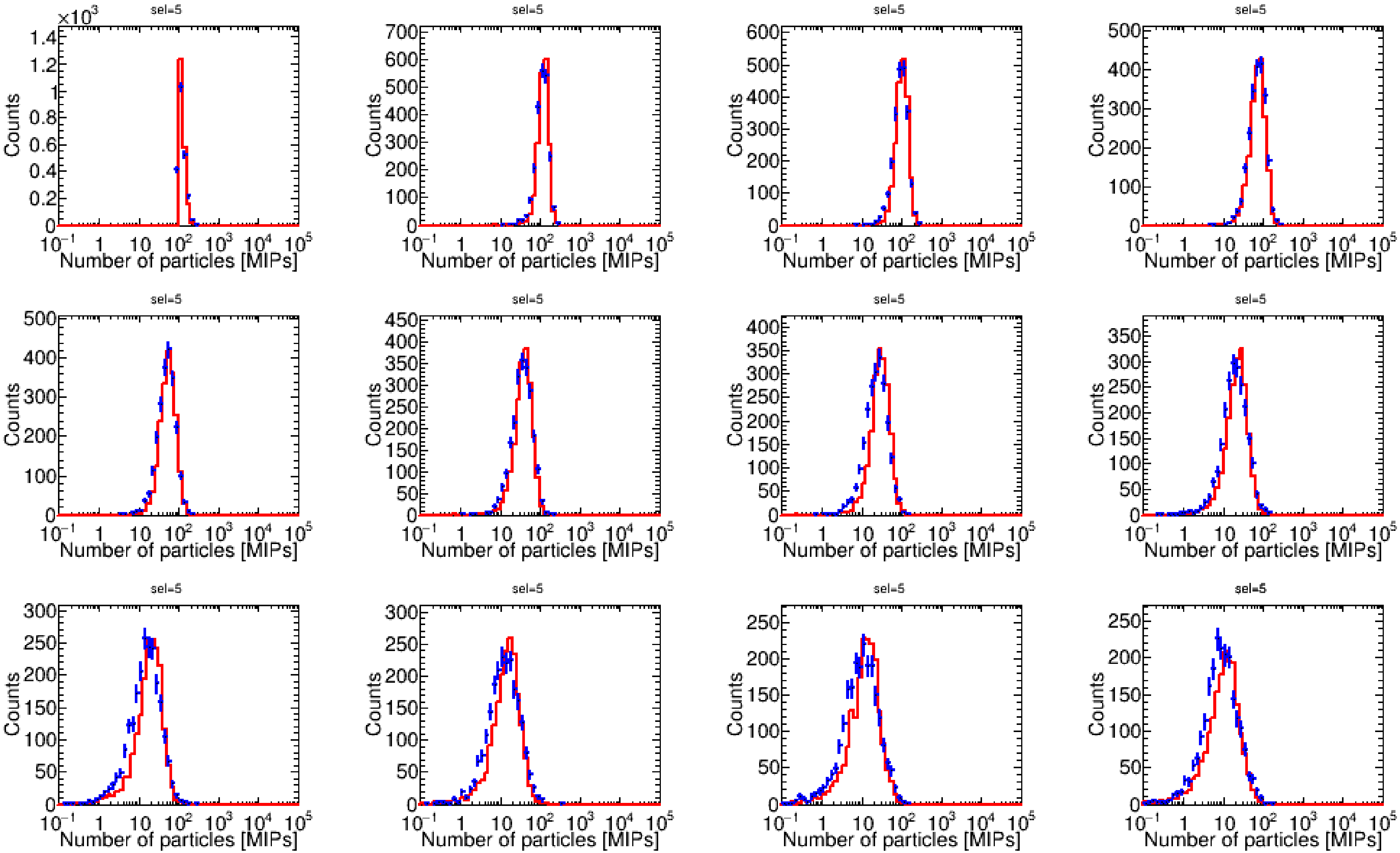
# SPS2015: TASC Layer-by-Layer Energy Deposit Distribution for Helium at 13 GeVA (NO Offline Trigger)



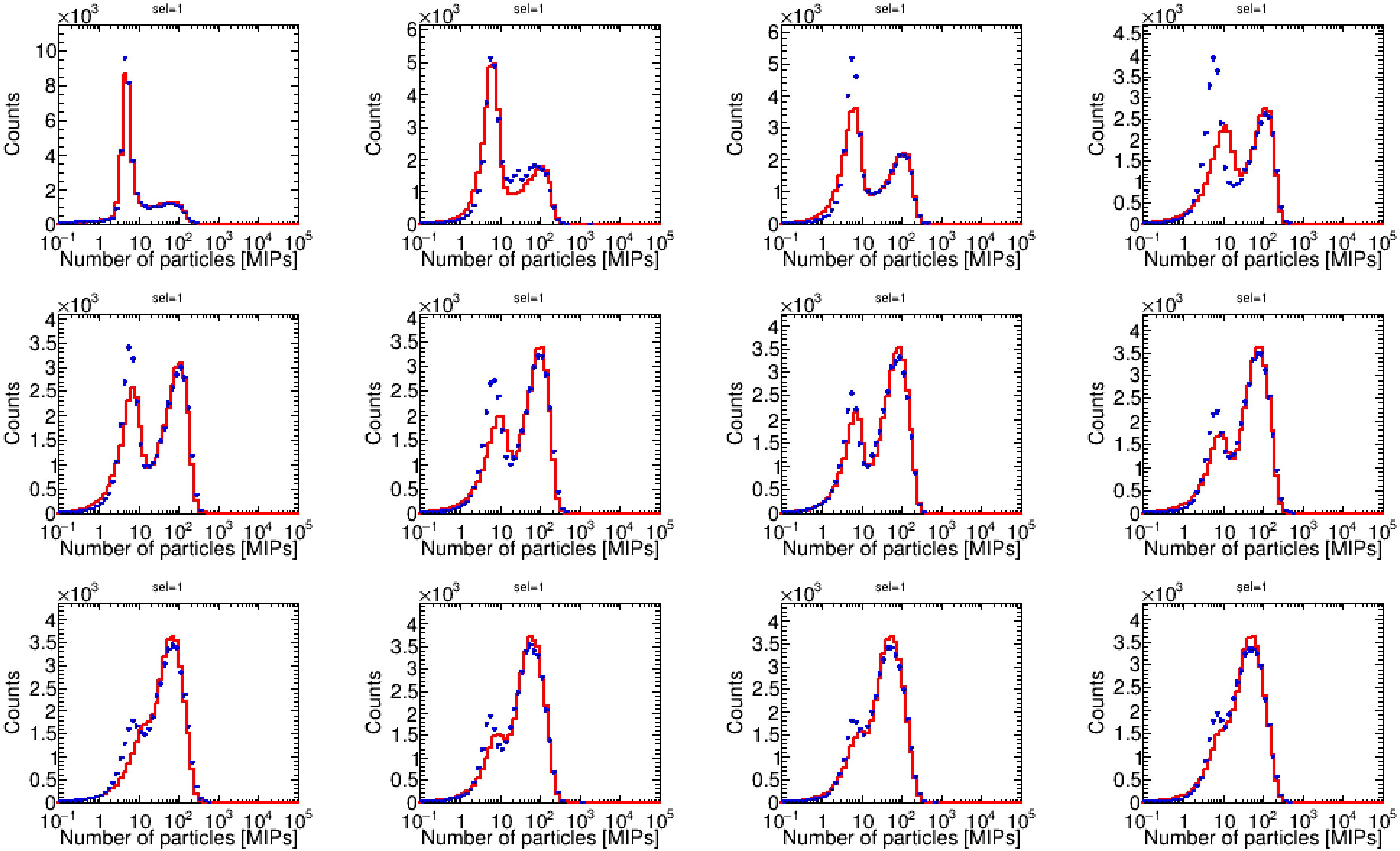
# SPS2015: TASC Layer-by-Layer Energy Deposit Distribution for Helium at 13 GeVA (10 MIP Offline Trigger)



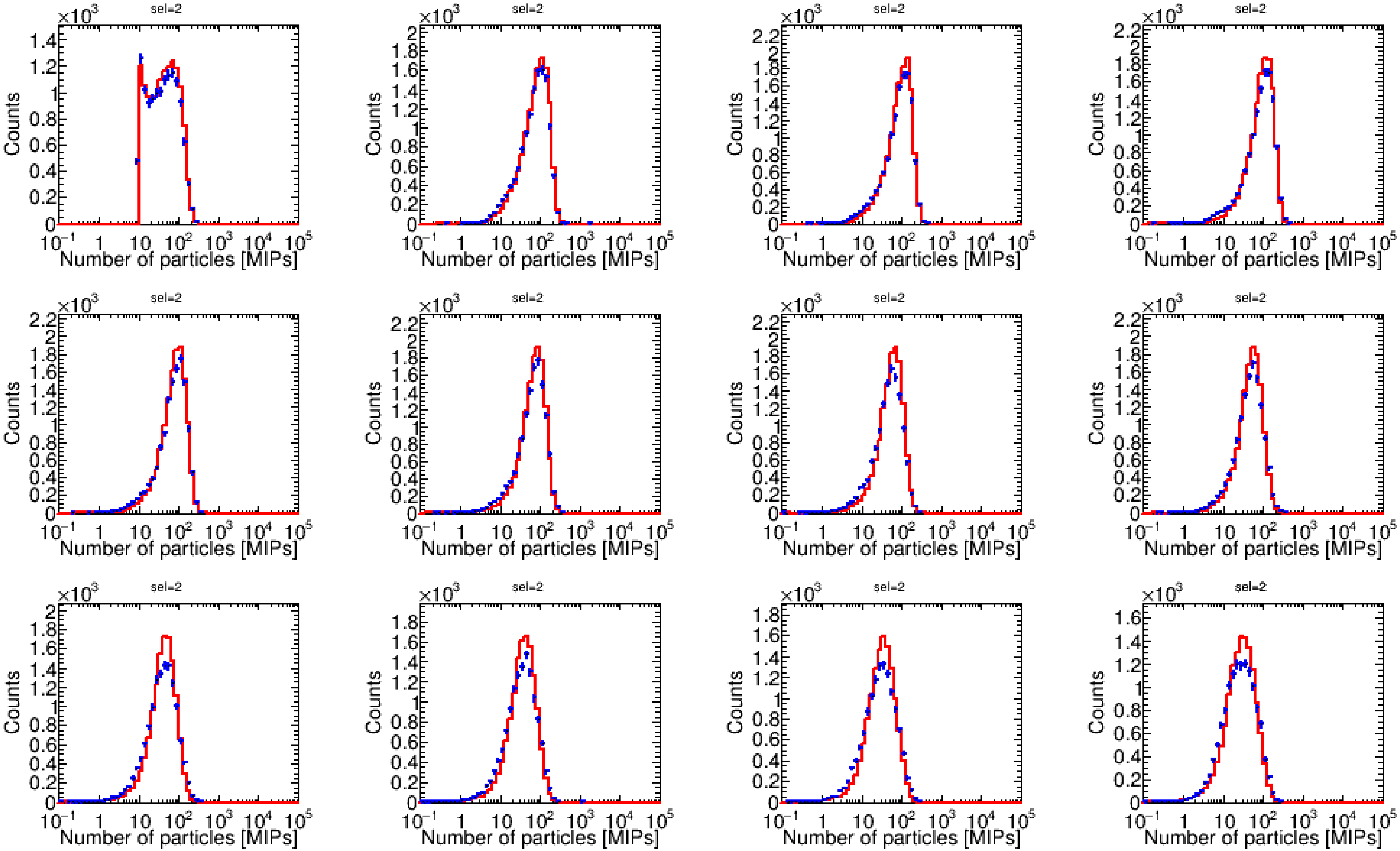
# SPS2015: TASC Layer-by-Layer Energy Deposit Distribution for Helium at 13 GeVA (100 MIP Offline Trigger)



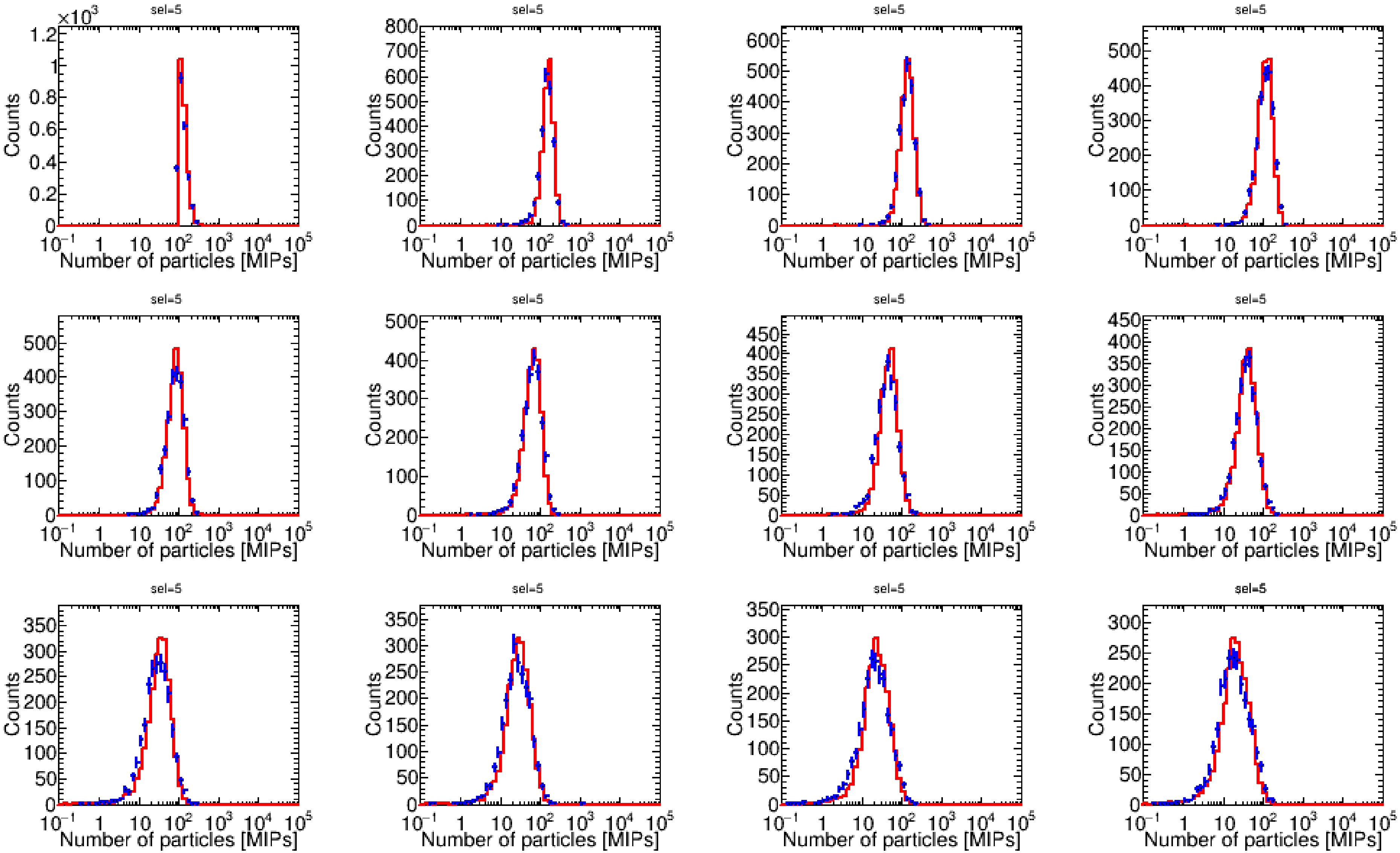
# SPS2015: TASC Layer-by-Layer Energy Deposit Distribution for Helium at 19 GeVA (NO Offline Trigger)



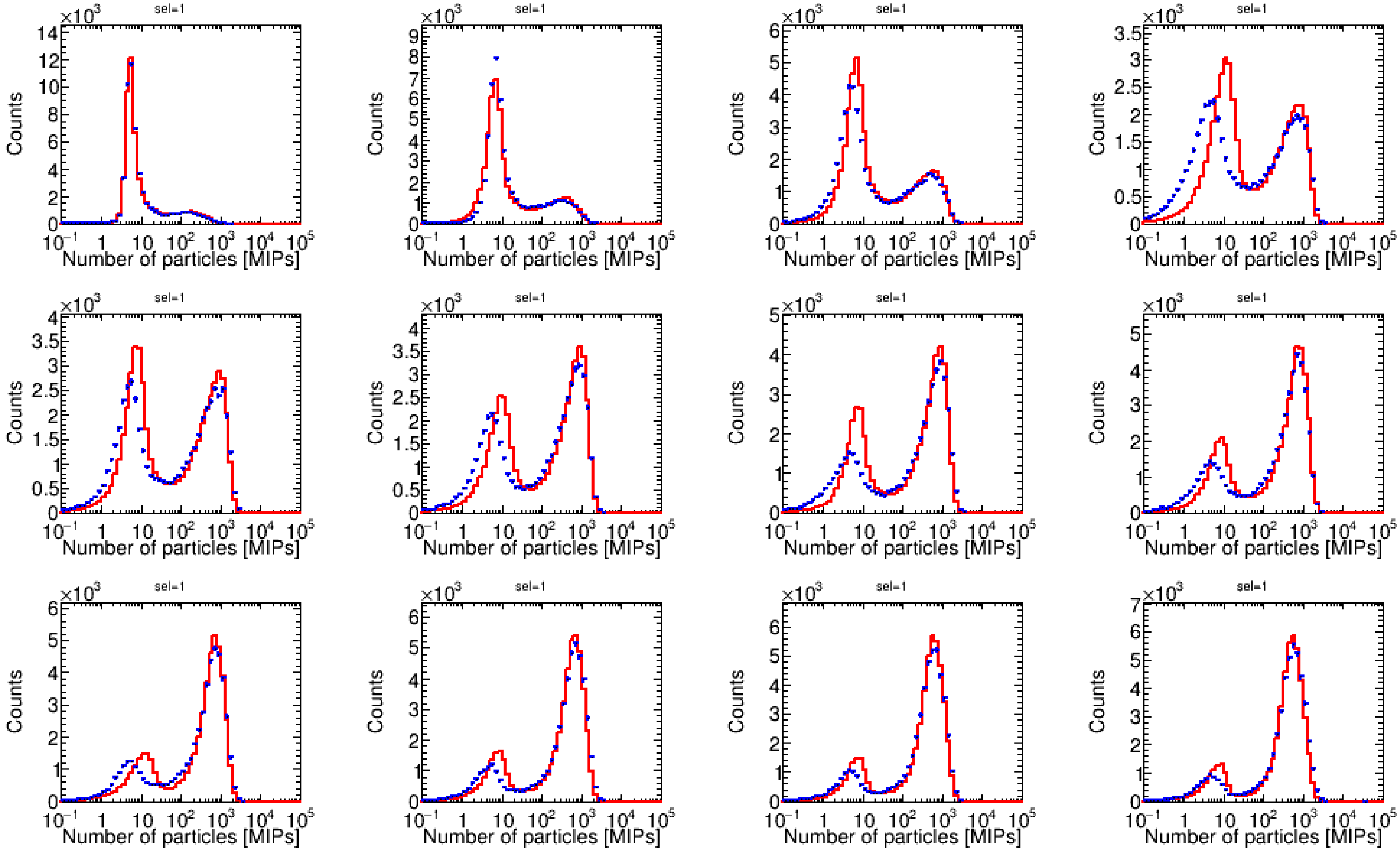
# SPS2015: TASC Layer-by-Layer Energy Deposit Distribution for Helium at 19 GeVA (10 MIP Offline Trigger)



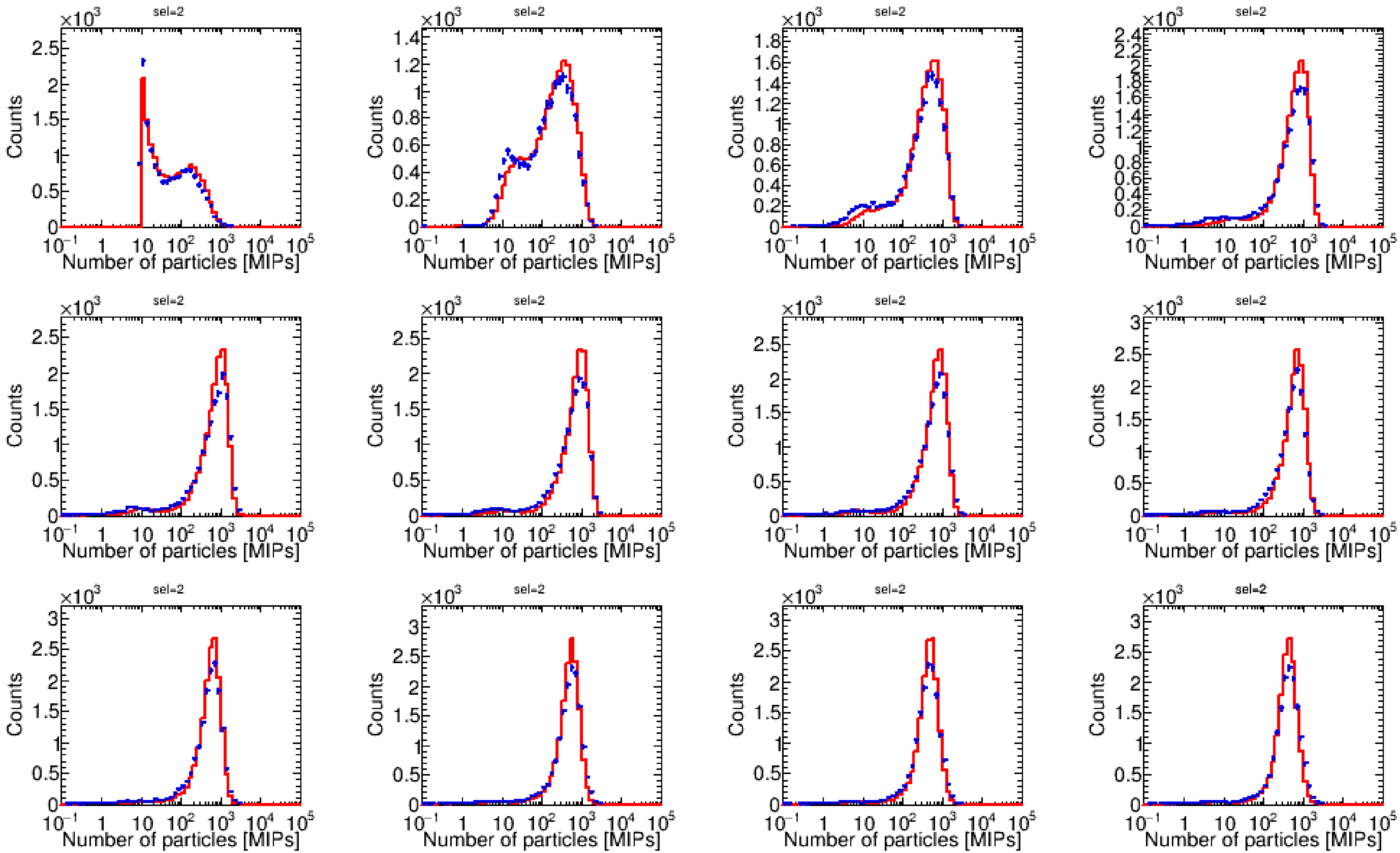
# SPS2015: TASC Layer-by-Layer Energy Deposit Distribution for Helium at 19 GeVA (100 MIP Offline Trigger)



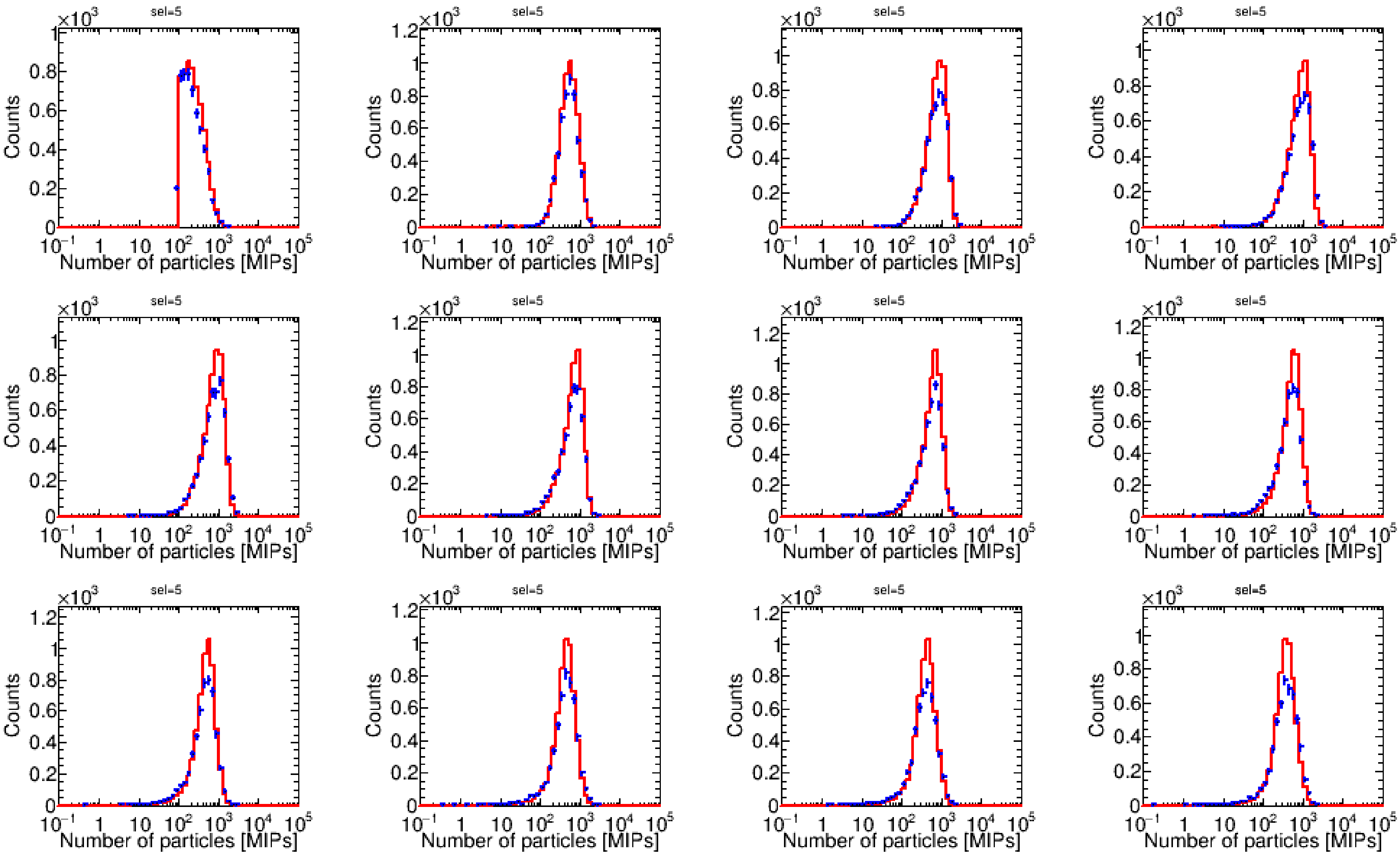
# SPS2015: TASC Layer-by-Layer Energy Deposit Distribution for Helium at 150 GeVA (NO Offline Trigger)



# SPS2015: TASC Layer-by-Layer Energy Deposit Distribution for Helium at 150 GeVA (10 MIP Offline Trigger)



# SPS2015: TASC Layer-by-Layer Energy Deposit Distribution for Helium at 150 GeVA (100 MIP Offline Trigger)

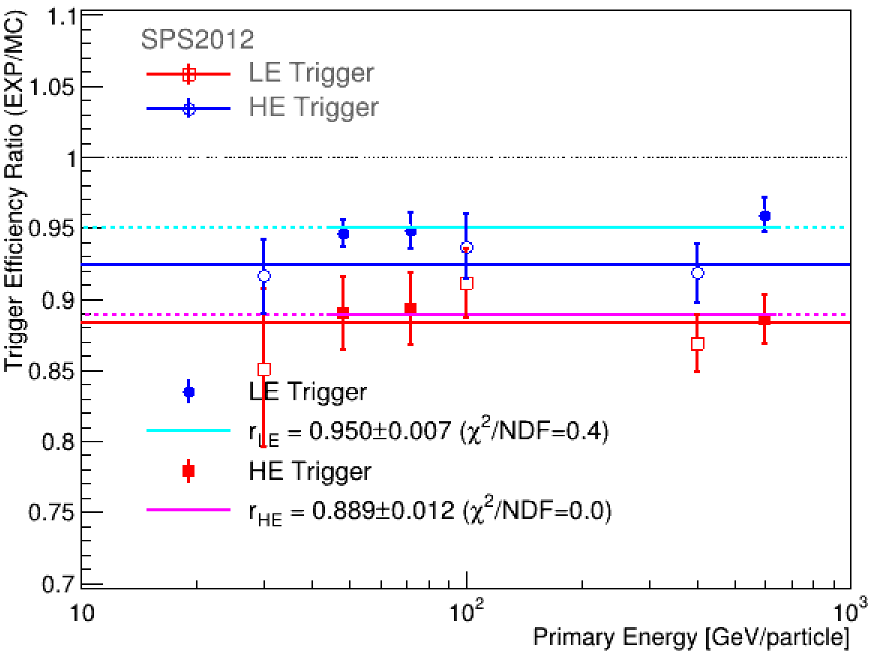


# SPS2015: Corrections for Trigger & Energy Response for Helium Nuclei

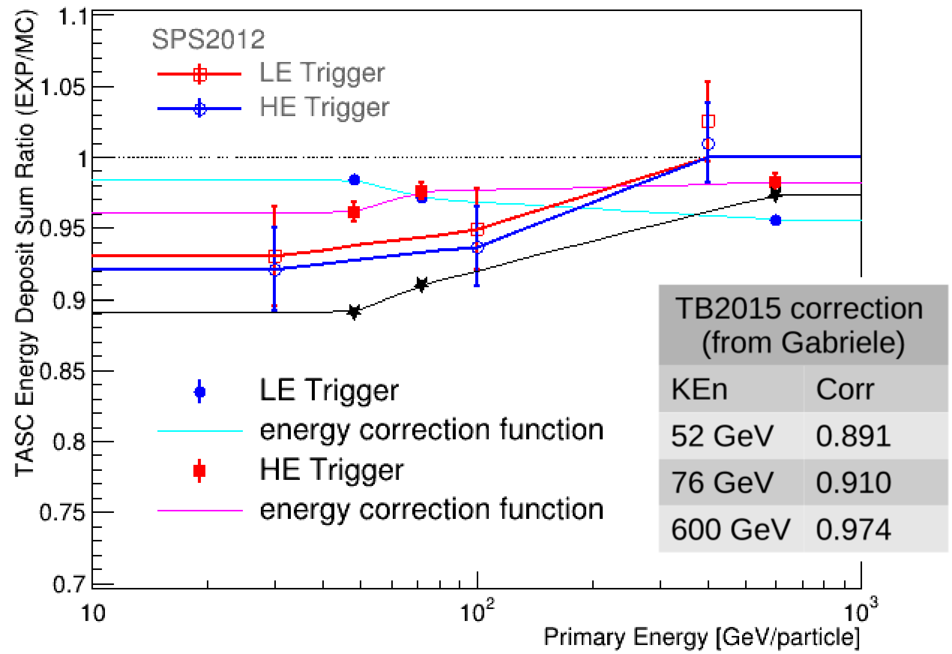
**Close-up view!**

### Comparison with SPS2012 for protons (Open Symbols) and Gabriele's

SPS 2015 Helium (mode10)




SPS 2015 Helium (mode10)

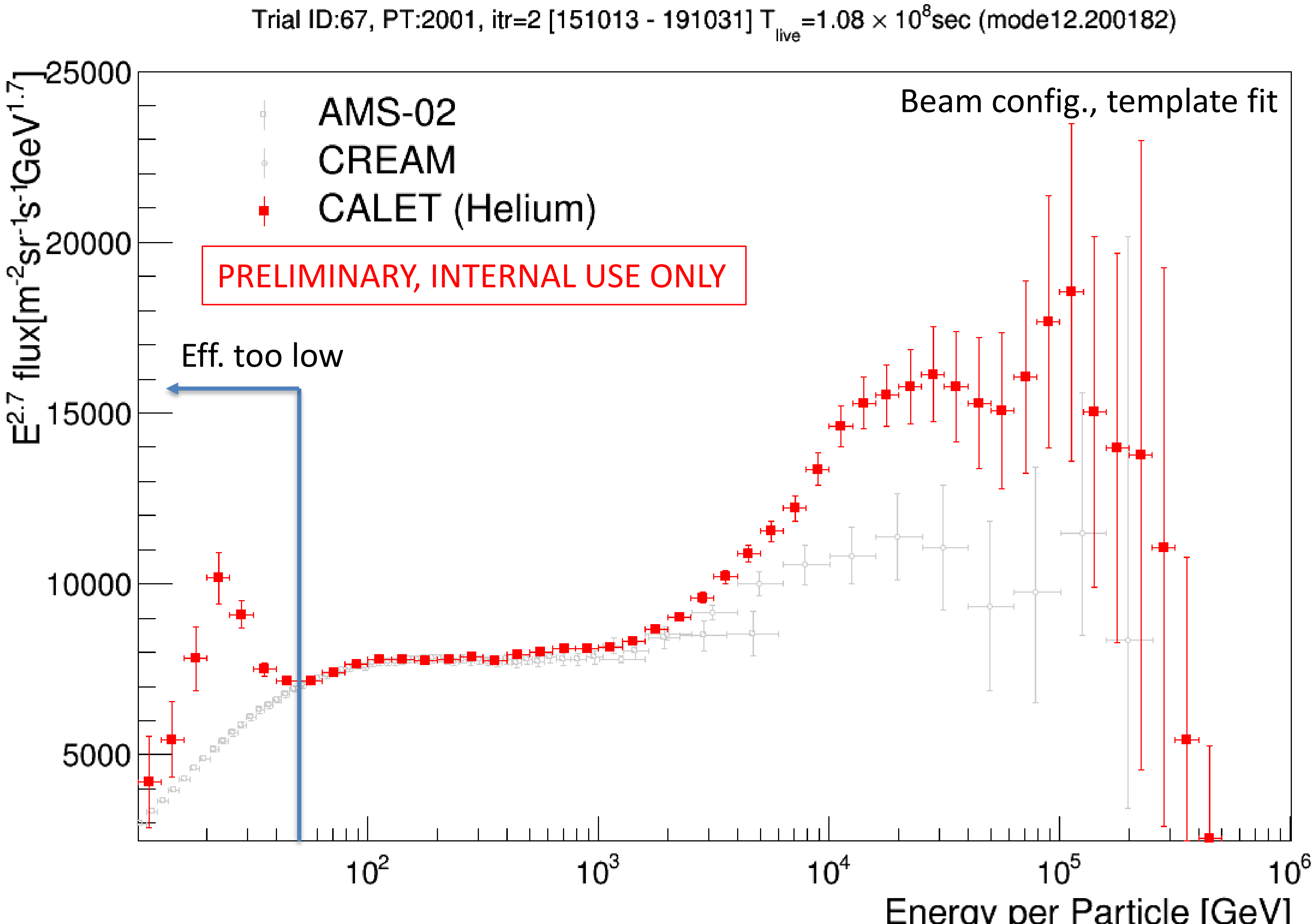



| TB2015 correction (from Gabriele) | |
|---|---|
| KEn | Corr |
| 52 GeV | 0.891 |
| 76 GeV | 0.910 |
| 600 GeV | 0.974 |

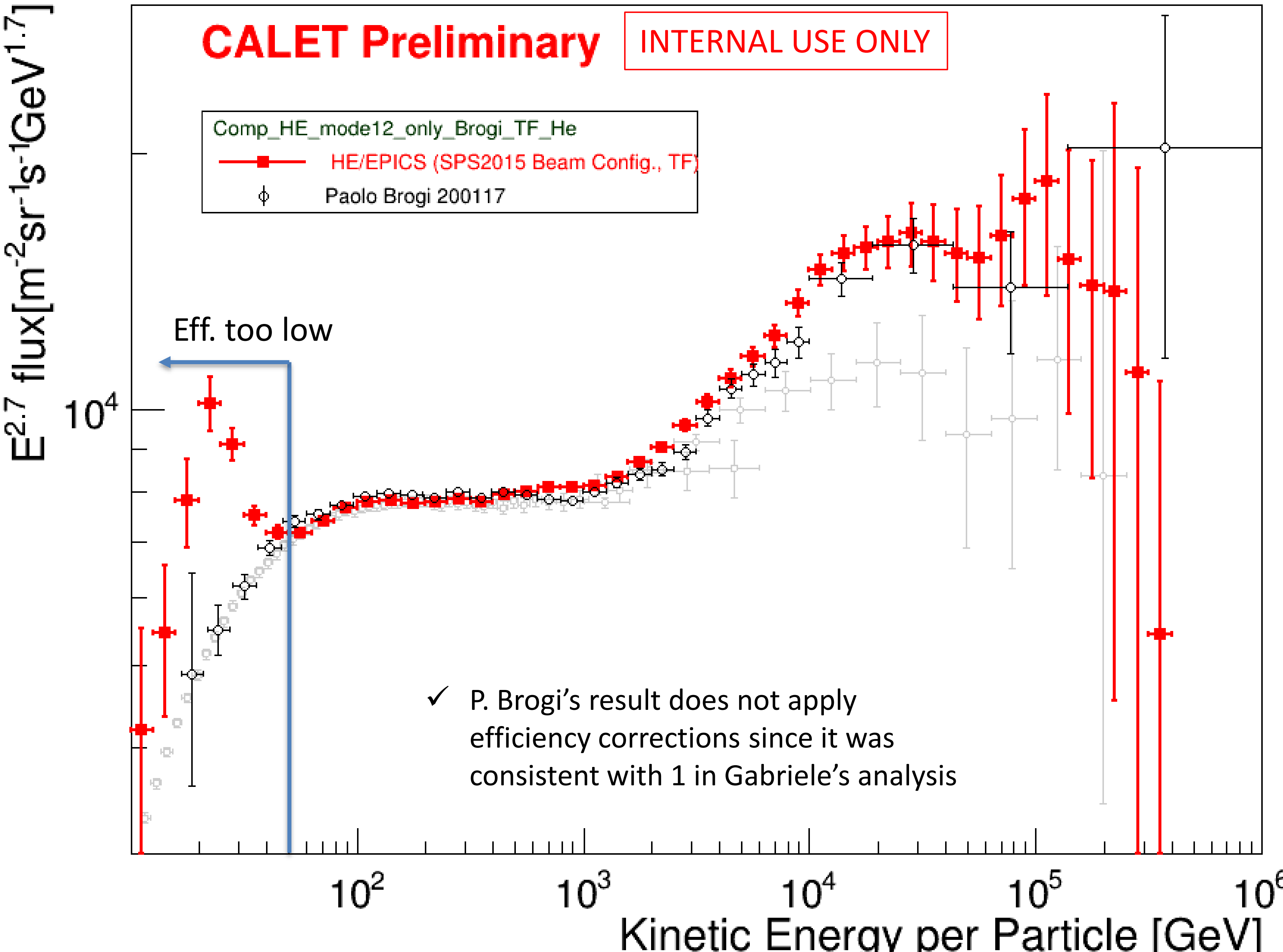
- Considering the layer-by-layer inconsistencies in 13 and 19 GeV data, there remains calibration issues for APD channels (Akaike-san also pointed this out).
  [NOTE] X1 is recalibrated by using penetrating helium in the same runs.
- Then, it would be very reasonable to use Gabriele's results for energy response corrections.

Ref: HeAnalysis_Icupdate_061219_PB.pdf

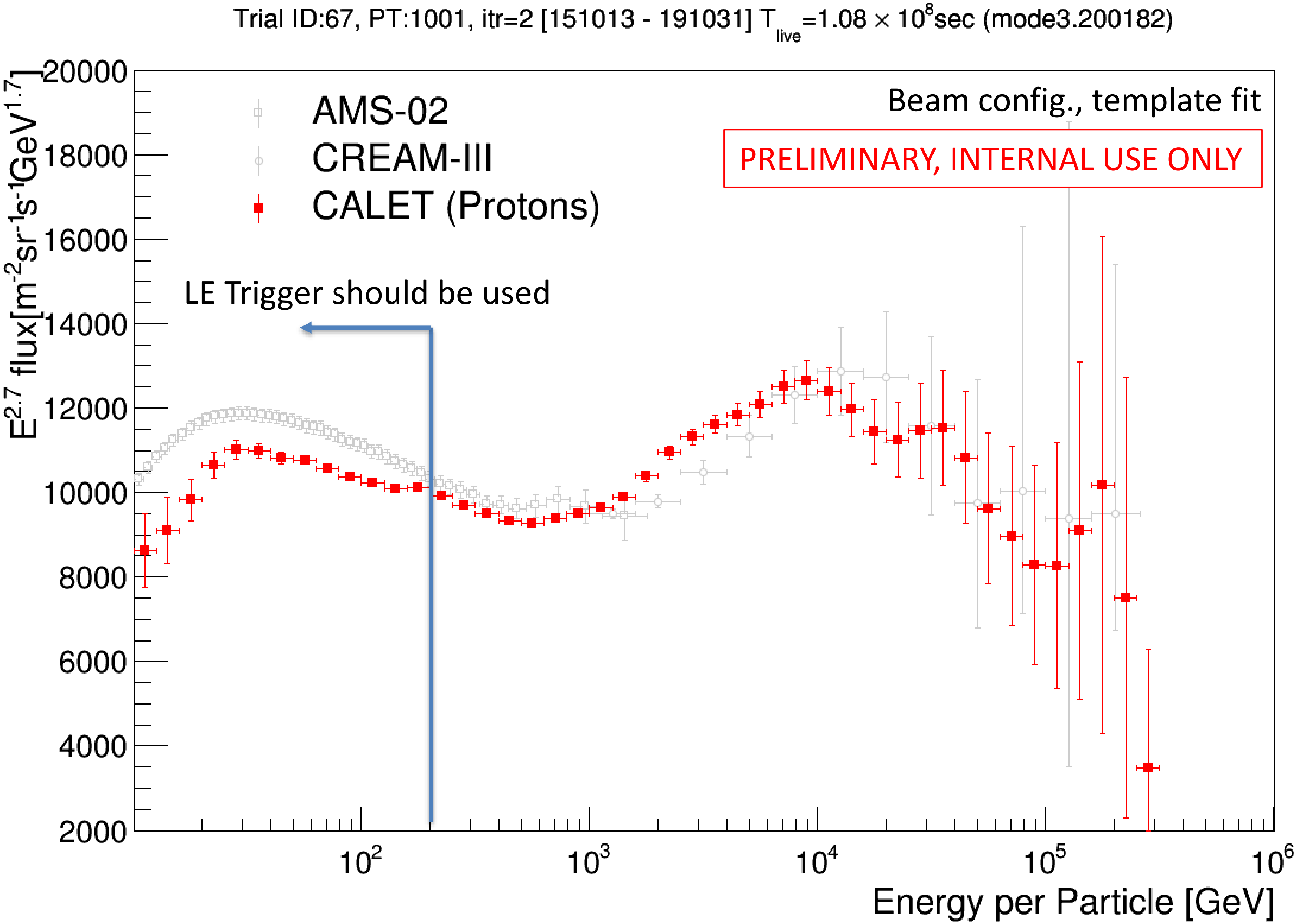
# Latest Result based on SPS2015 Beam Calibration



# Latest Result based on SPS2015 Beam Calibration

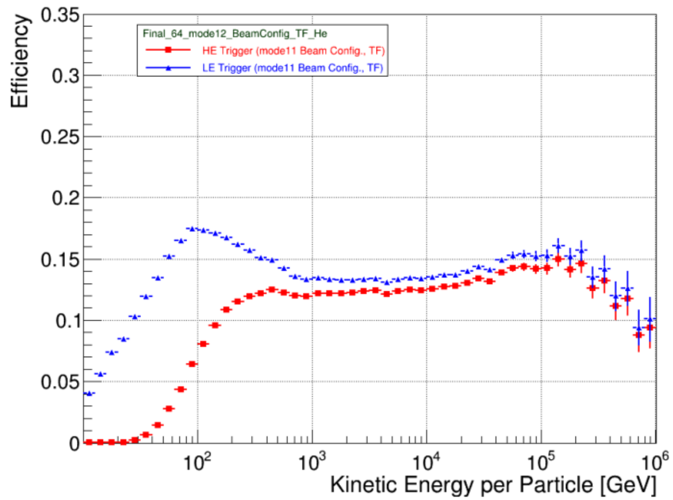


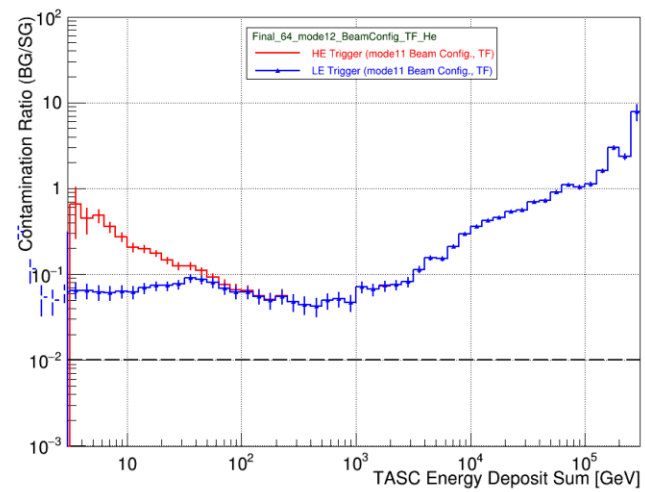
# Latest Result for Protons (same analysis as PRL)

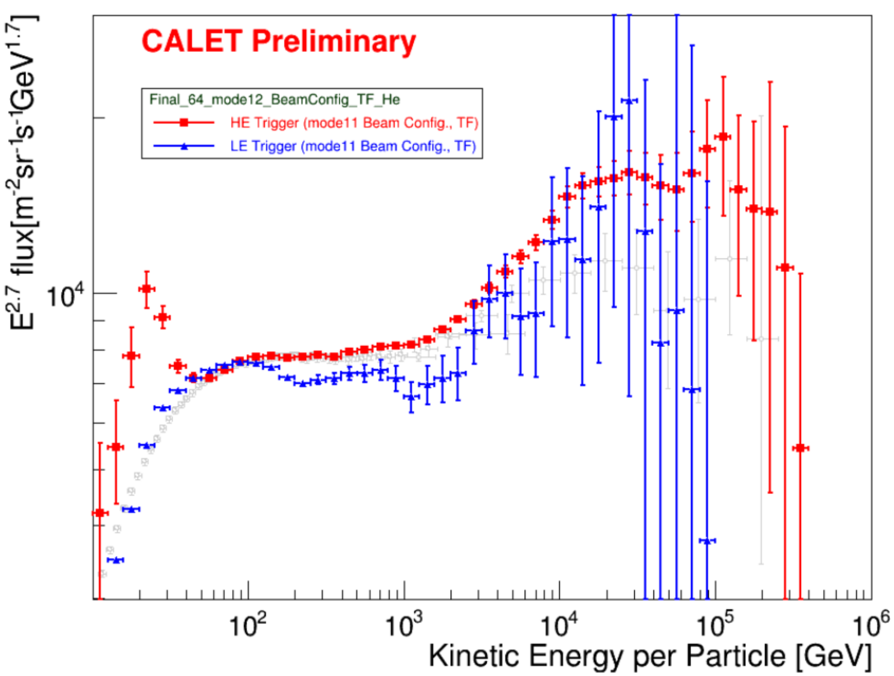


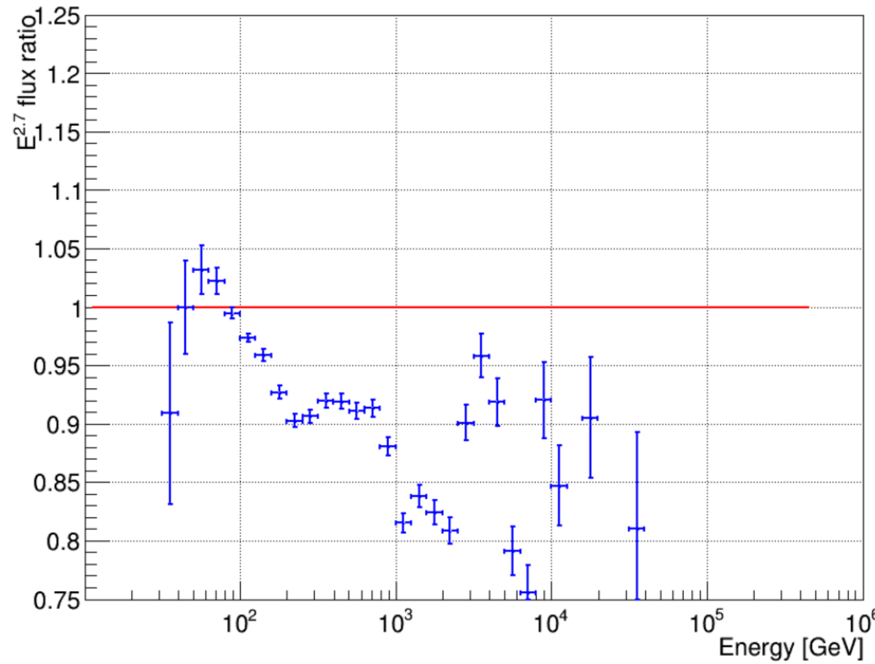
# Remaining Issue: Inconsistency between LE and HE Analysis

LE spectrum shows lower flux above a few hundred GeV => fragmentation?



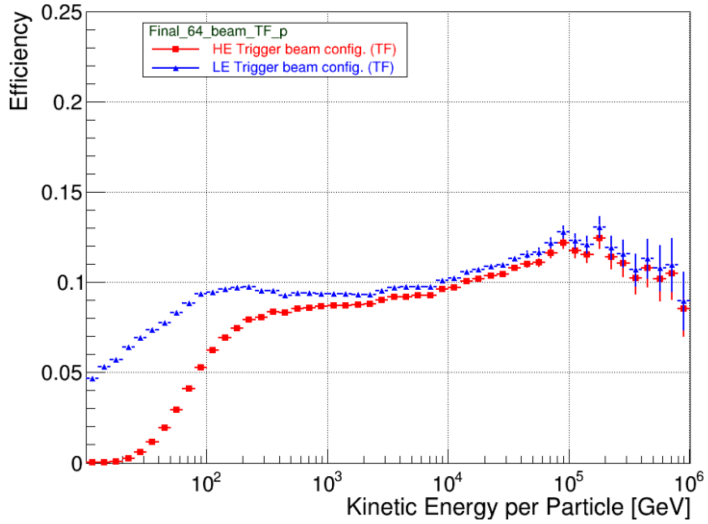



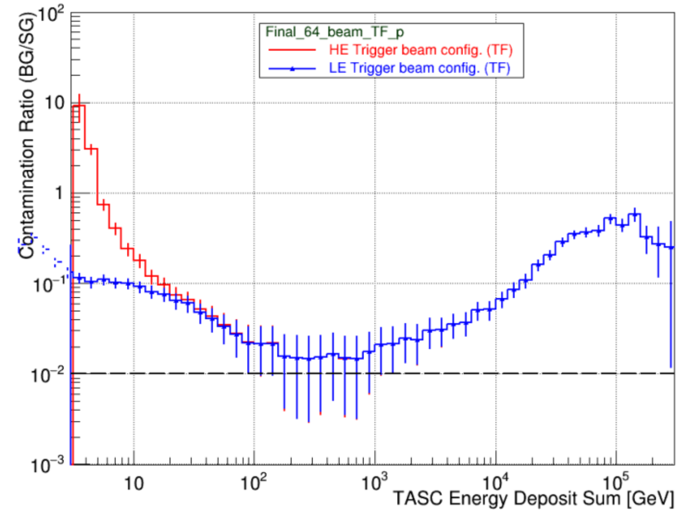



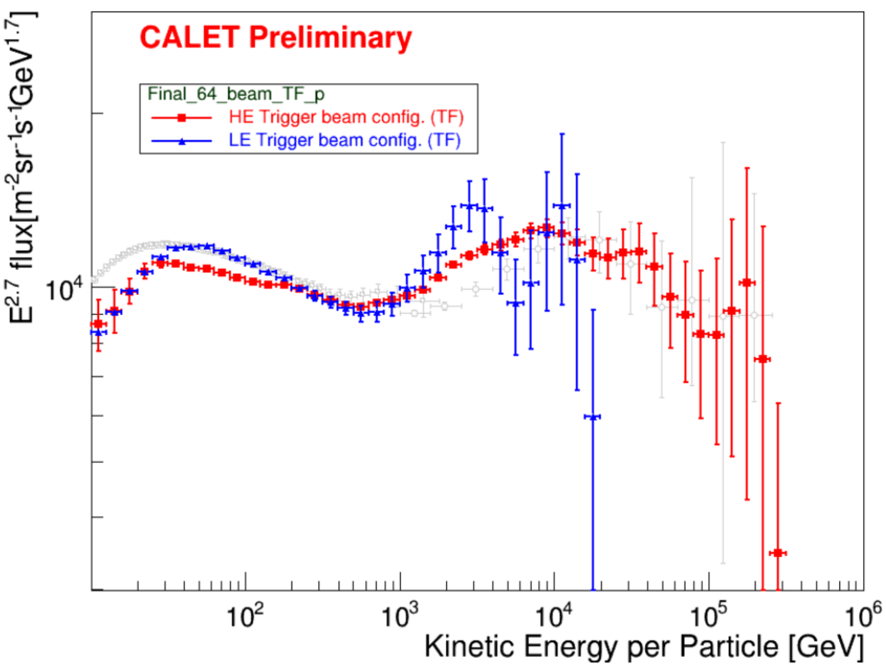



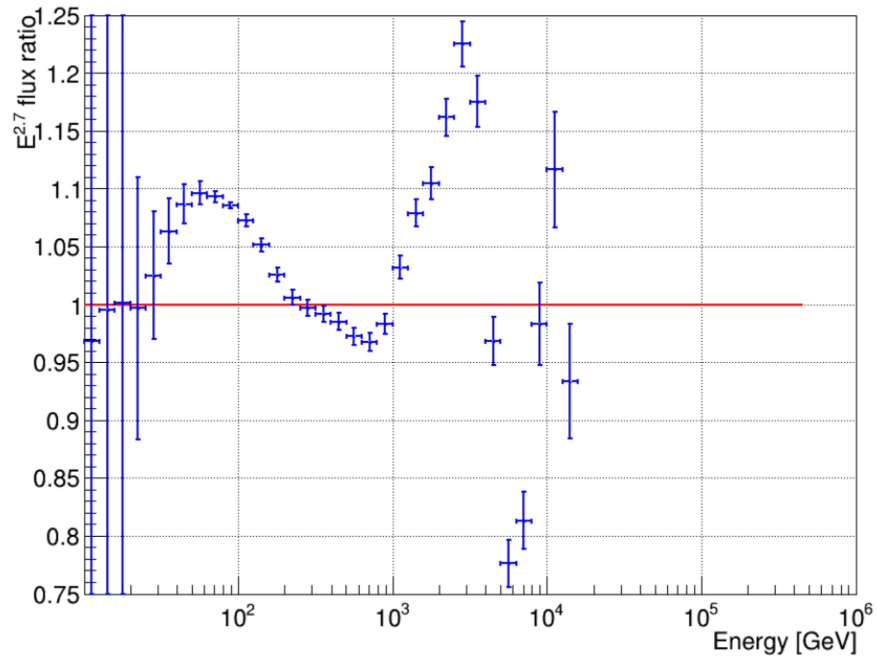
# Protons: NO Inconsistency between LE and HE Analysis

LE and HE spectra are consistent with each other in 200-1000 GeV region within errors



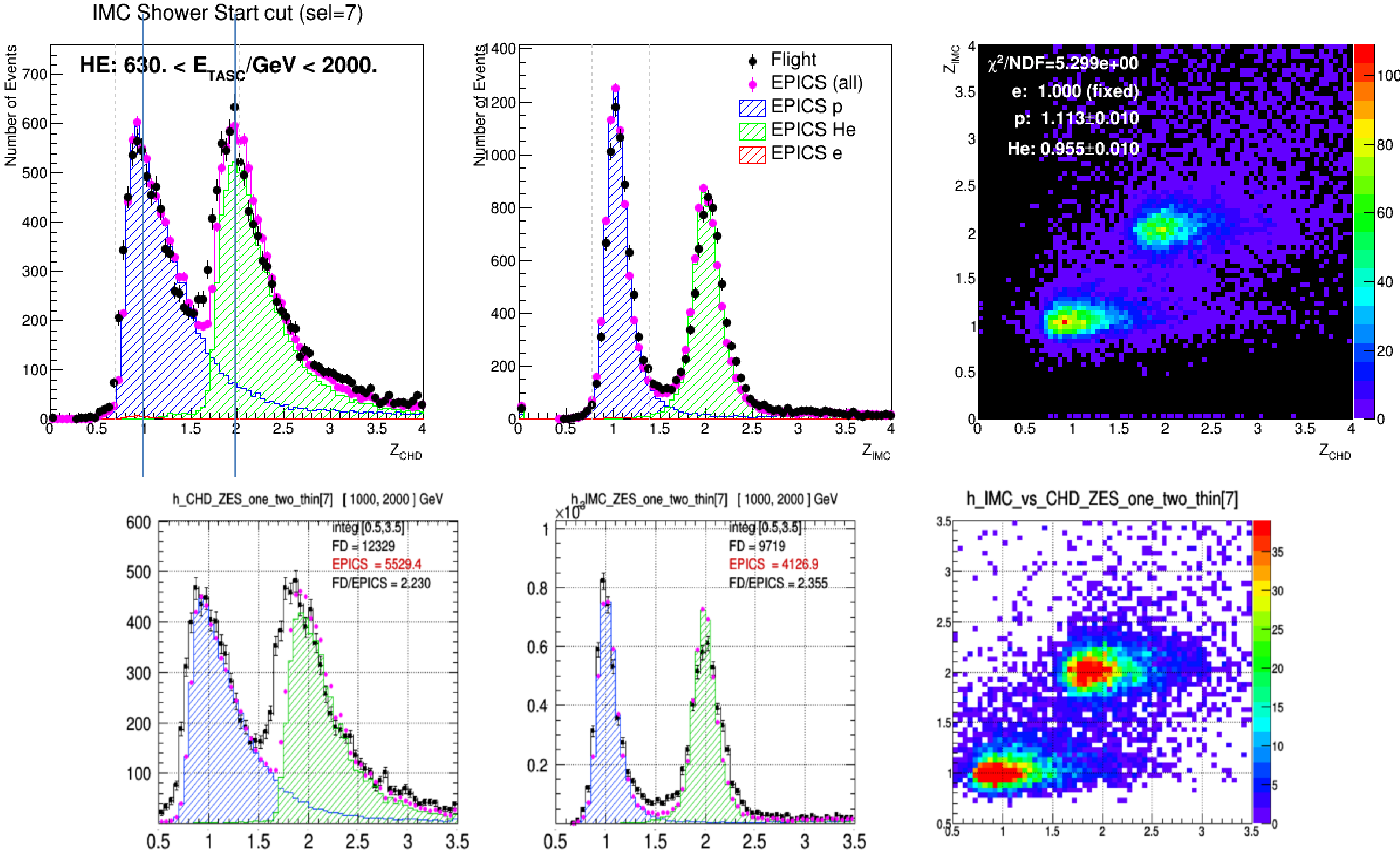



# Summary and Conclusion

1. Helium analysis based on the equivalent event selection to protons gave quite convincing result for HE trigger up to a few $10^{th}$ of TeV.
2. Highest energy region spectra were intensively checked and confirmed to be reasonable.
3. Based on SPS2015 beam test data, helium spectrum is updated.
    1. Remaining issue: LE/HE inconsistency
4. Systematic errors can be estimated in the same manner as protons given the fact that the analysis procedure is equivalent.

# backup

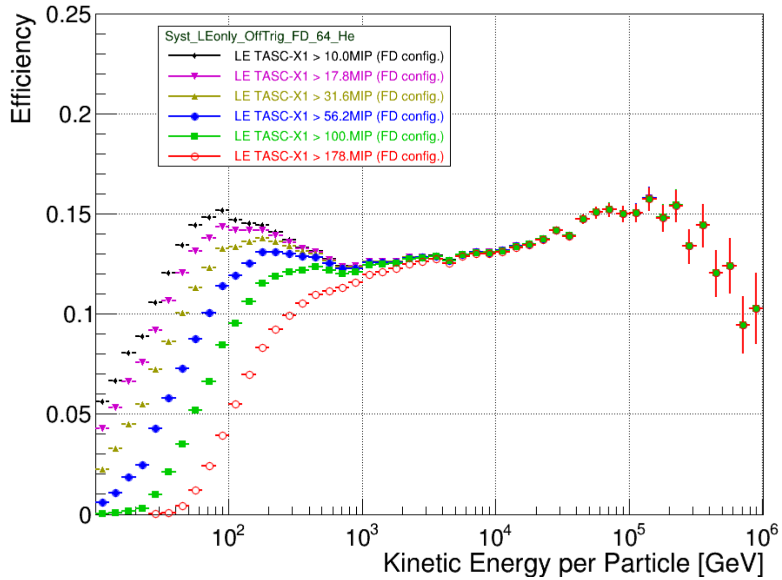
# Comparison of Charge Distribution



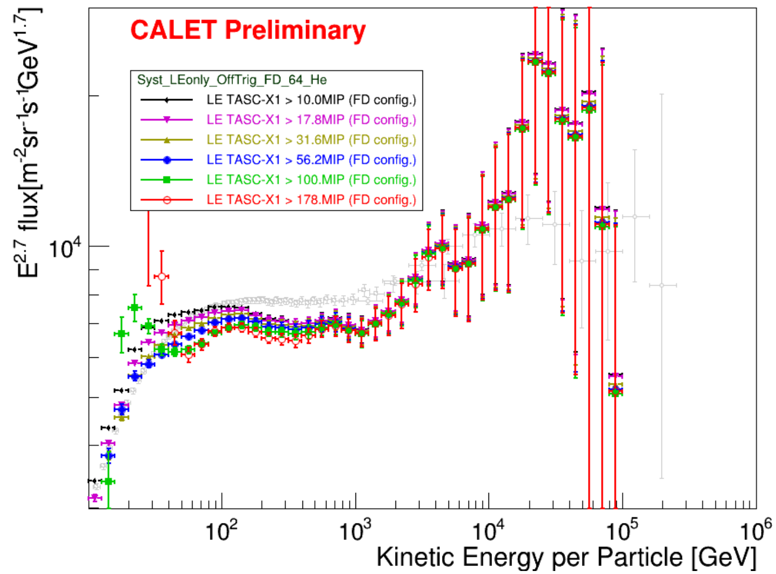

2020-01-10-proton-Pier.pdf pp.4

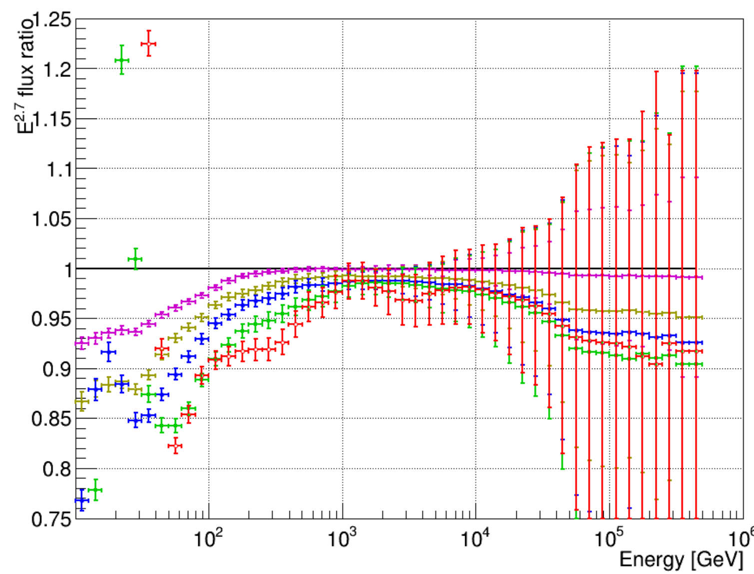
# Offline Trigger Threshold Scan (Helium)

Check_LEonly_OffTrig_FD_64_He-200122.pdf





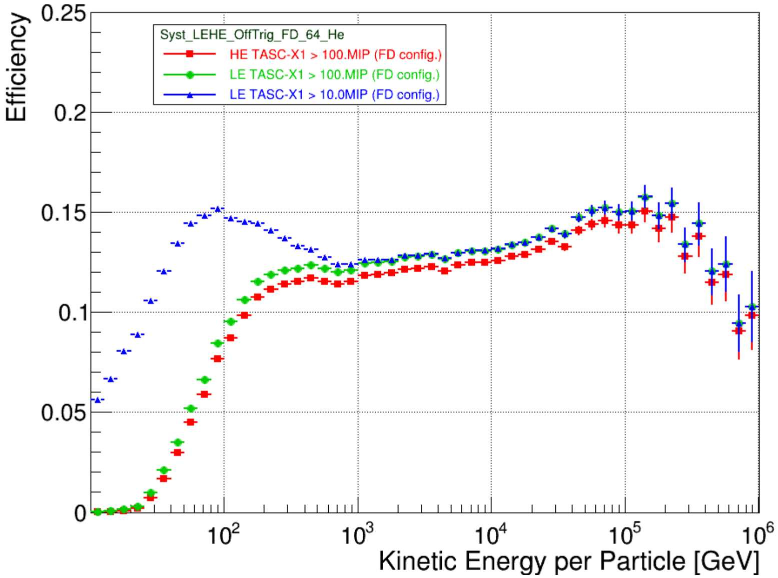



Similar trend with the proton case

# Offline Trigger Threshold Scan (Helium)

Check_LEHE_OffTrig_FD_64_He-200122.pdf



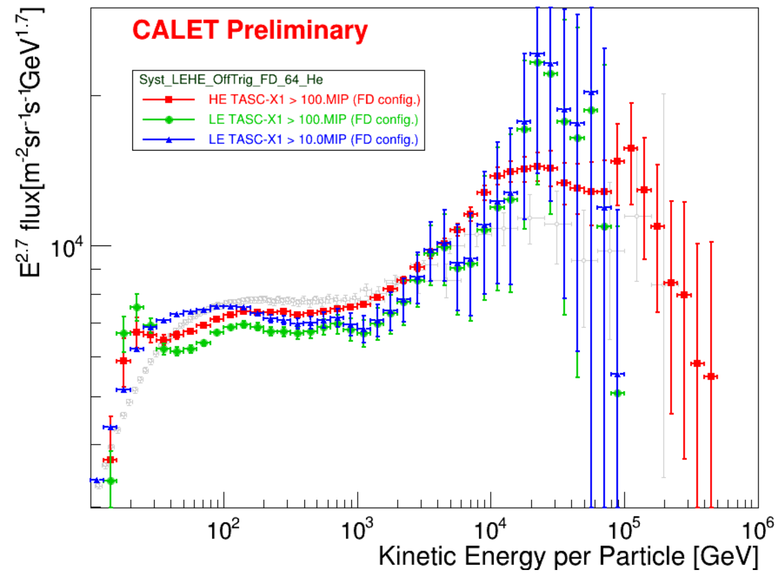

Syst_LEHE_OffTrig_FD_64_He

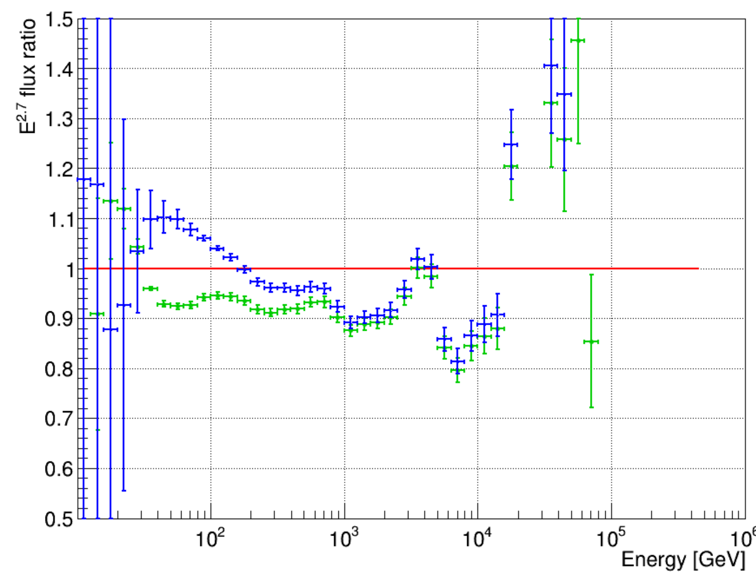
HE TASC-X1 > 100.MIP (FD config.)

LE TASC-X1 > 100.MIP (FD config.)

LE TASC-X1 > 10.0MIP (FD config.)

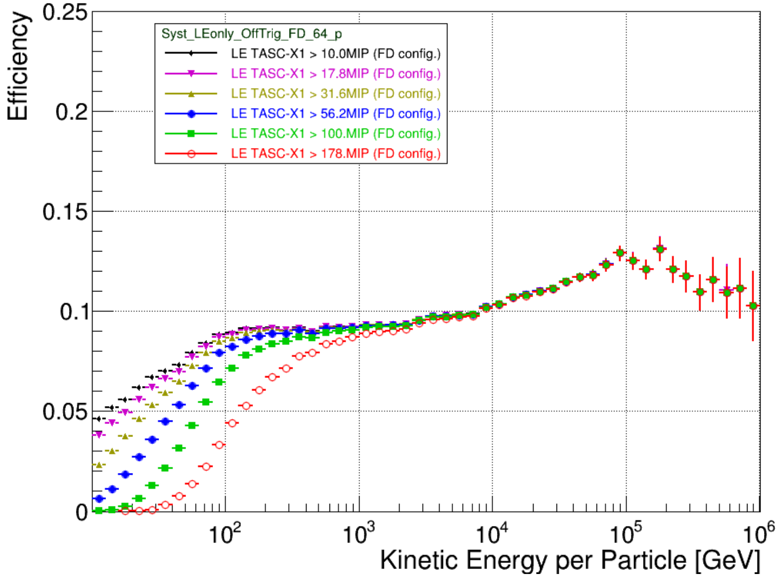
LE 100MIP threshold should use the same efficiency correction as HE. Difference between LE-10MIP and LE-100MIP indicates the different corrections for LE and HE triggers.

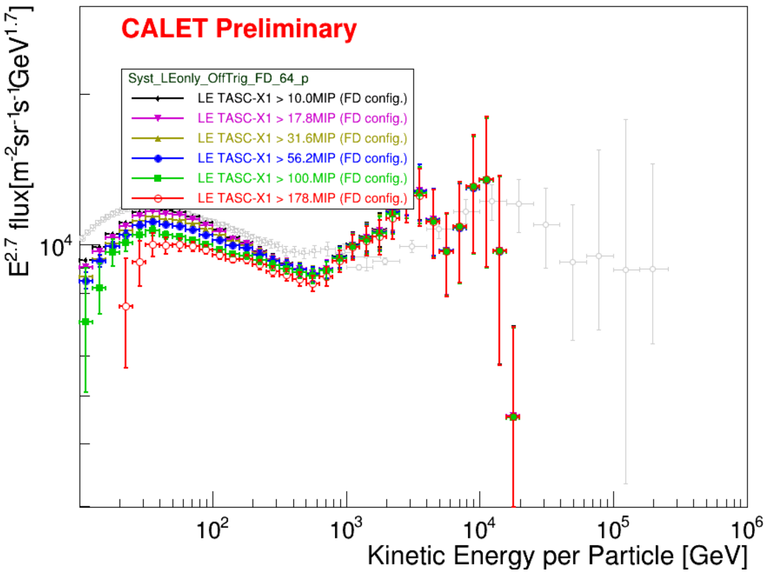


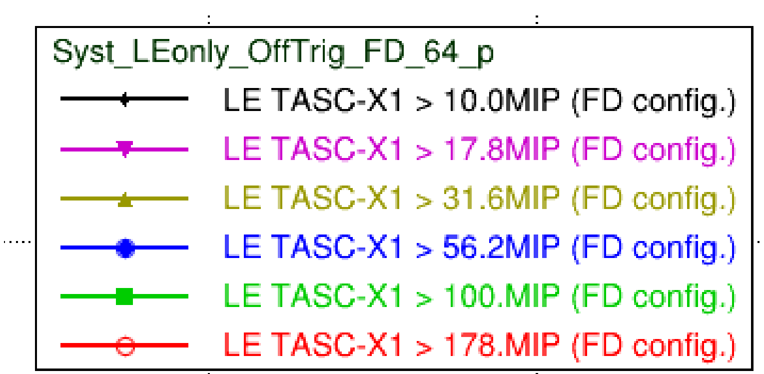



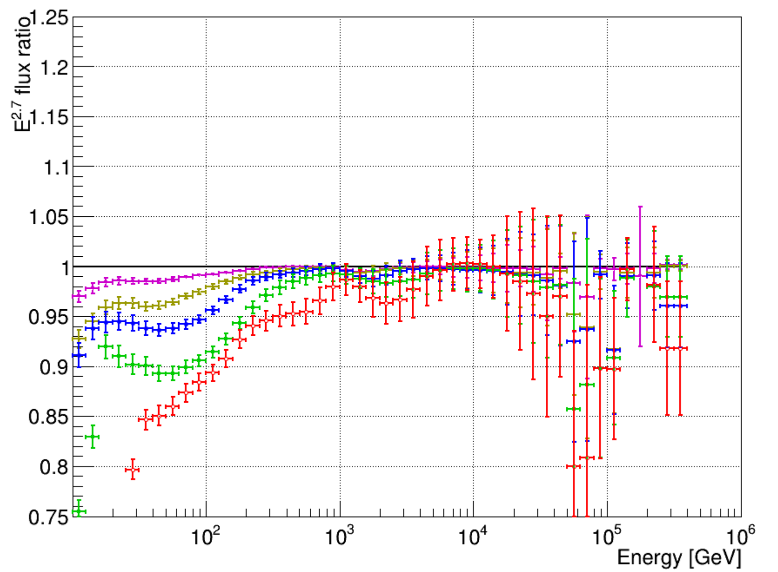
# Offline Trigger Threshold Scan (Proton)

Check_LEonly_OffTrig_FD_64_p-200122.pdf



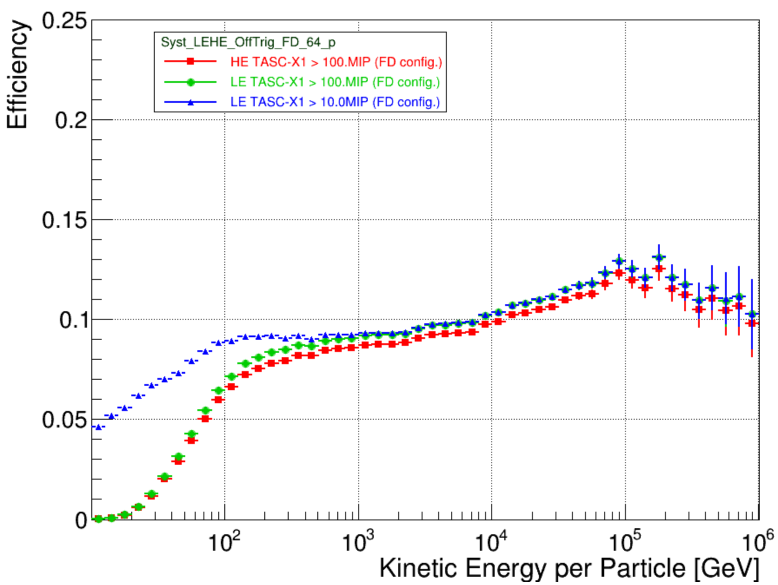



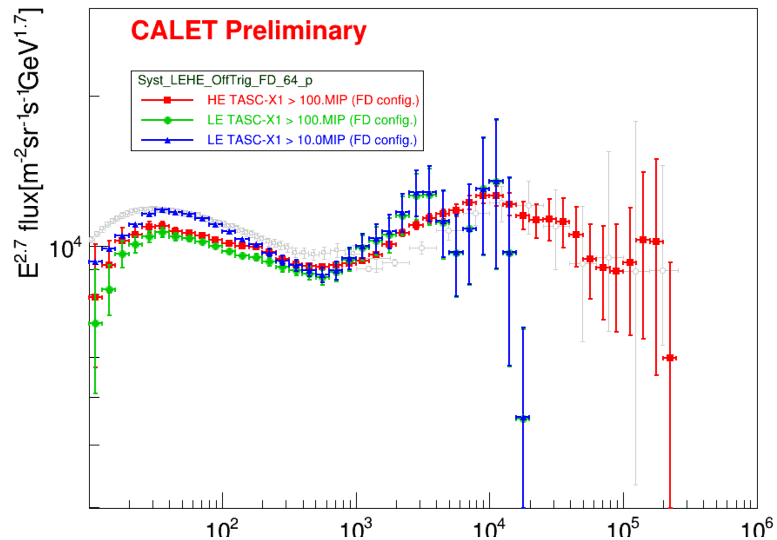



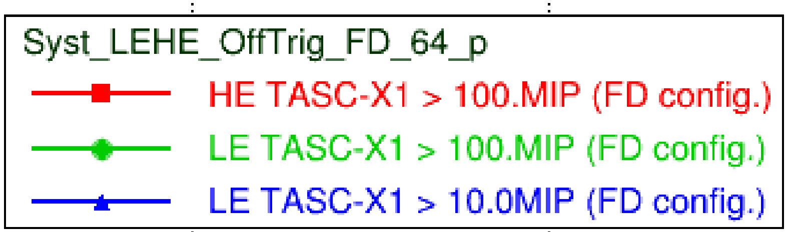



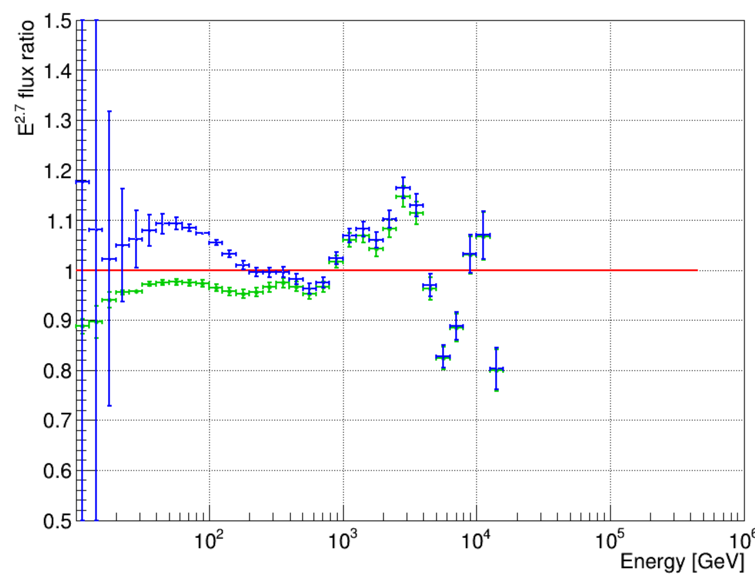
# Offline Trigger Threshold Scan (Proton)

Check_LEHE_OffTrig_FD_64_He-200122.pdf



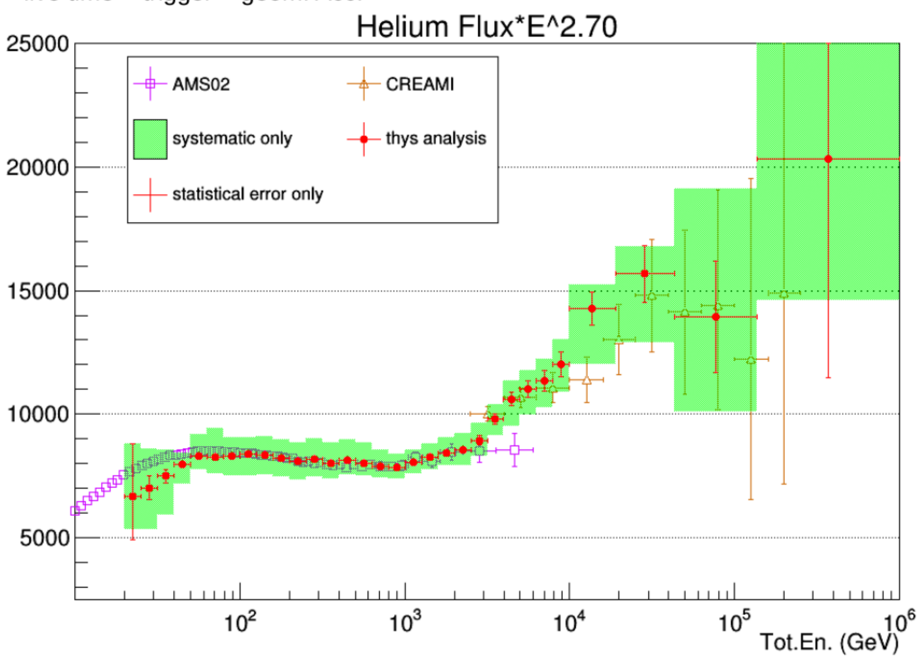




LE 100MIP threshold should use the same efficiency correction as HE.

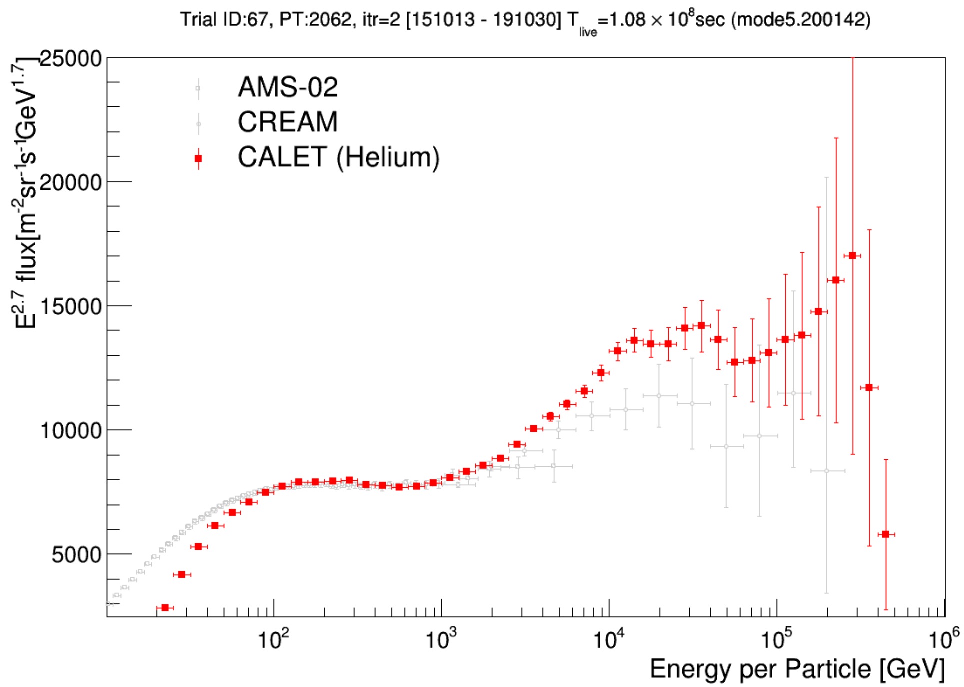
# Reproducing Paolo Brogi's Results

EPICS: KF, fitflag=3, fE0<0.3, fE1<0.3, Z-cut ($1.5<Z_{CHD}<2.5$, $1.5<Z_{IMC}<2.5$)
No efficiency correction, TB2015 correction (from Gabriele)

Preliminary Flux with systematic error:
unfolding + shower energy correction + charge cut + charge cont. + acceptance cont
+ live time + trigger + geom. Acc.



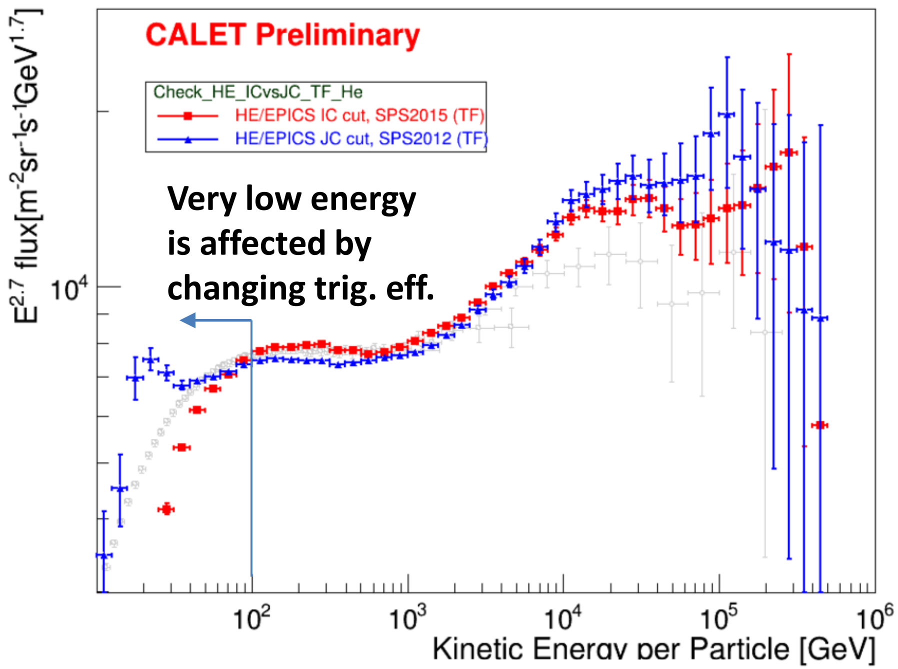

Full statistics (4 years)
HeAnalysis_Icupdate_100120_PB.pdf, pp.17

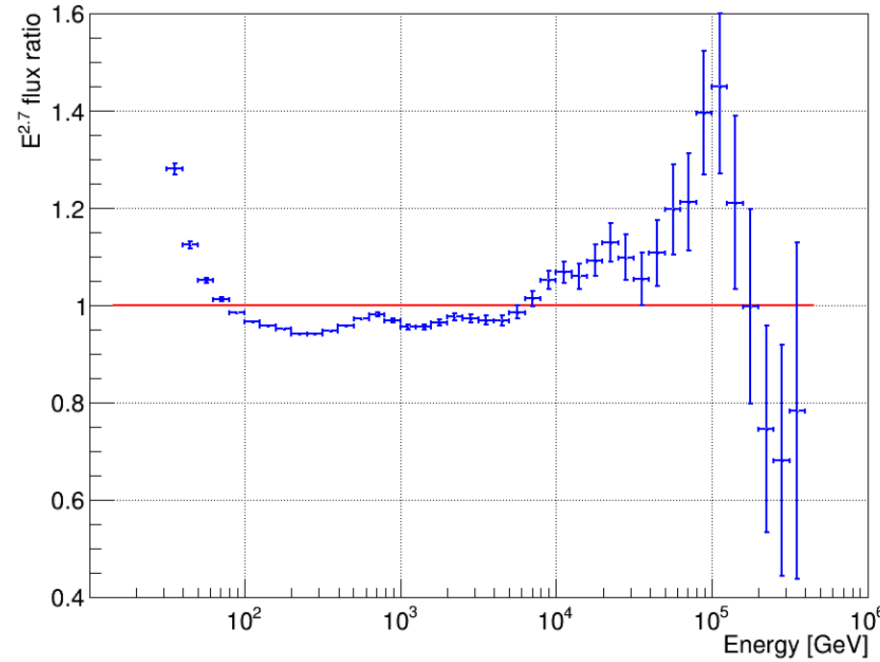



Very well reproduced under the same selection criteria and corrections

# Comparison between IC and JC

Check_HE_ICvsJC_TF_He-200142.pdf



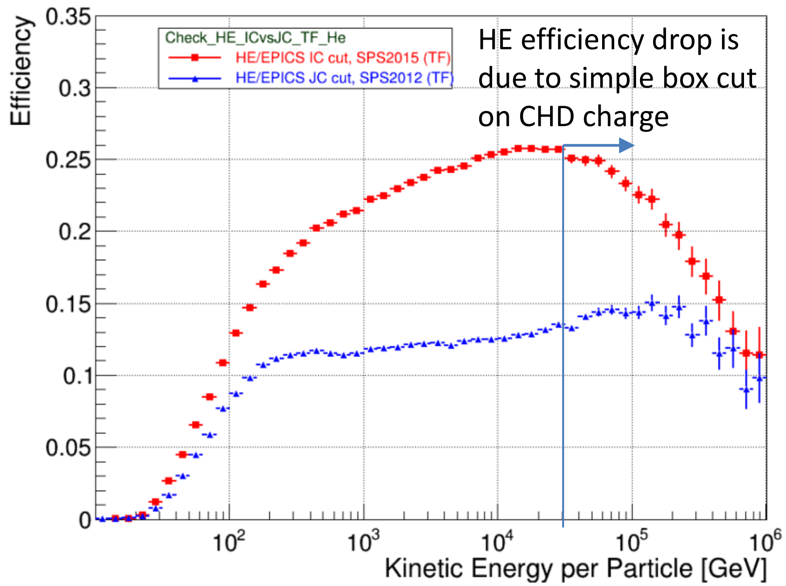


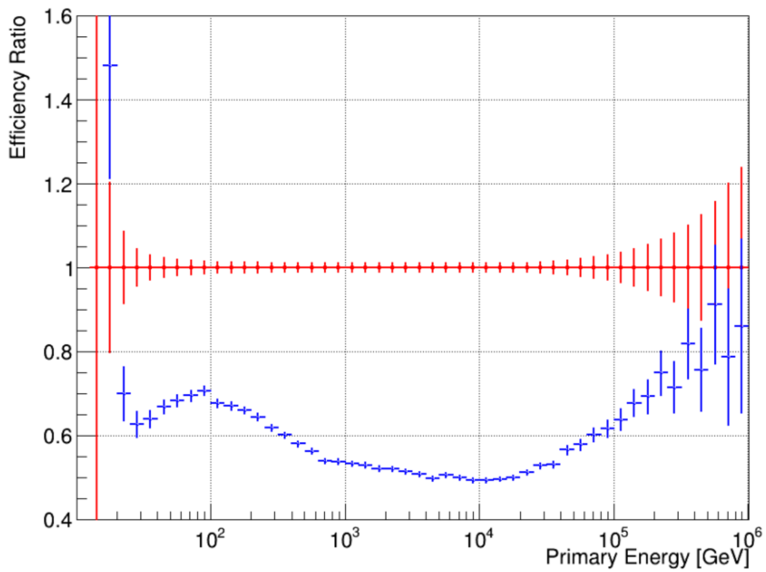
Corrections obtained from helium beam @ SPS2015
- Efficiency: No correction
- Energy: 0.891@52GeV, 0.910@76GeV, 0.974@600GeV
  … from Gabriele

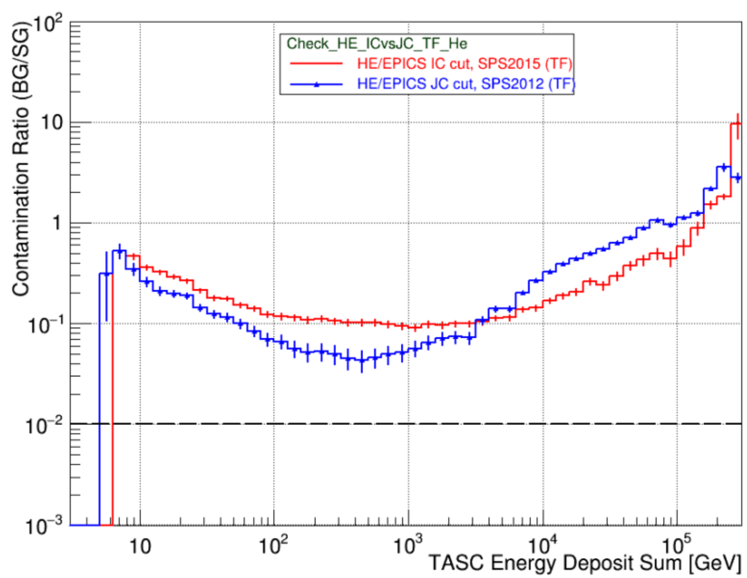
Corrections obtained from proton beam @ SPS2012
- Efficiency: 11% for HE trigger
- Energy: 0.921@30GeV, 0.937@100GeV, 1.000@400GeV

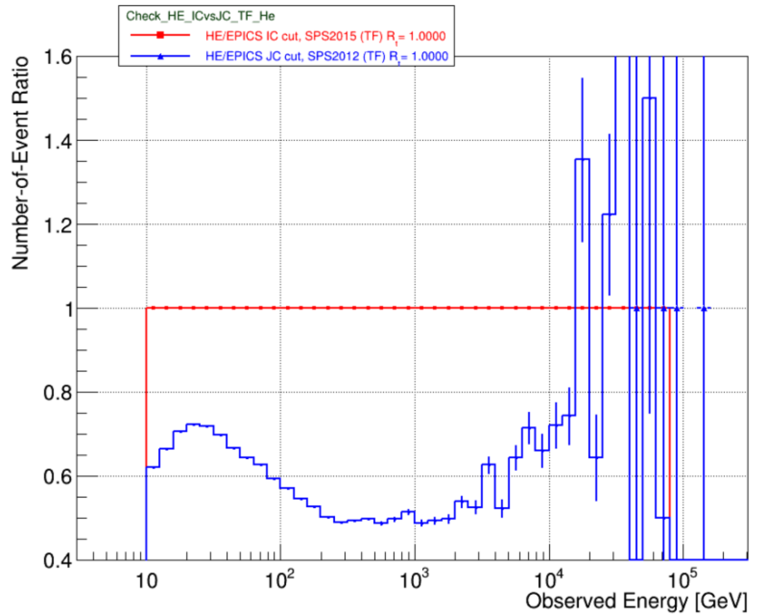
Use of TASC delta and IMC Shower start cuts

# Comparison between IC and JC



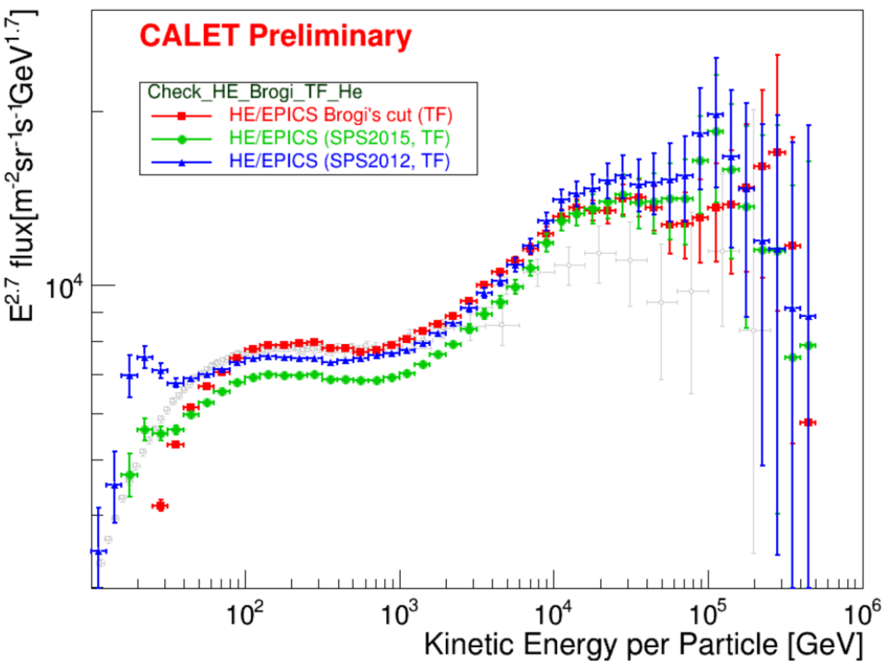



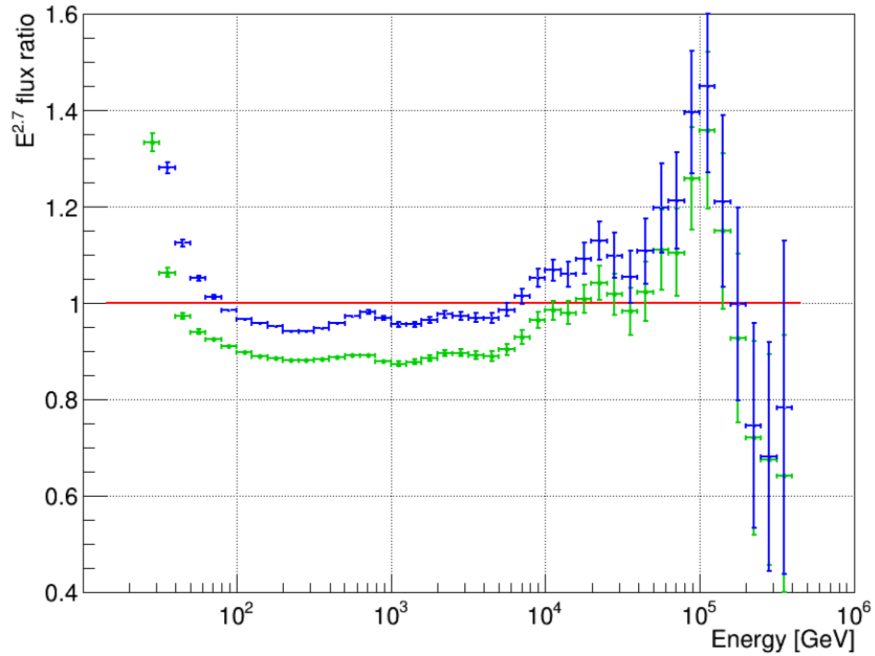



# Comparison between IC and JC under the same corrections

Check_HE_Brogi_TF_He-200142.pdf

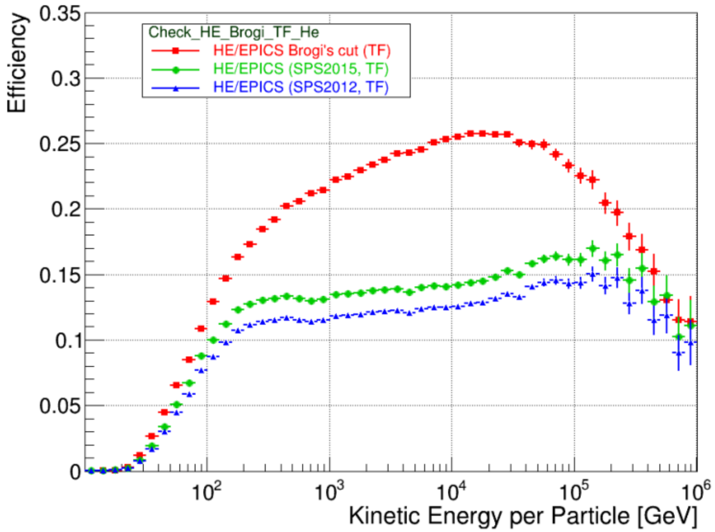


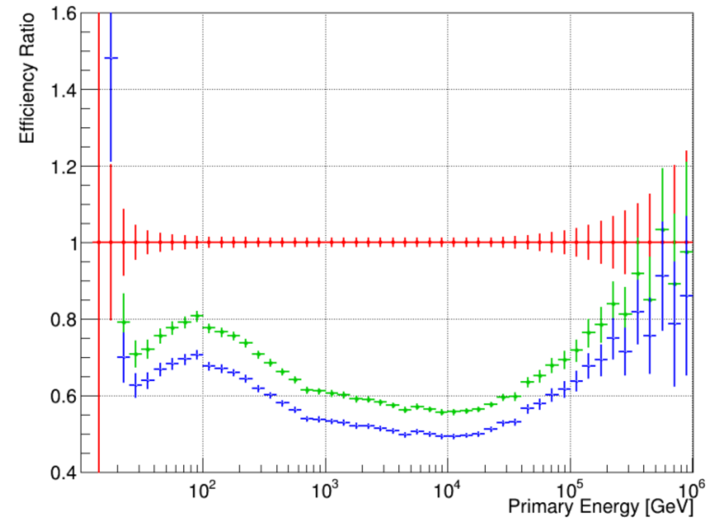



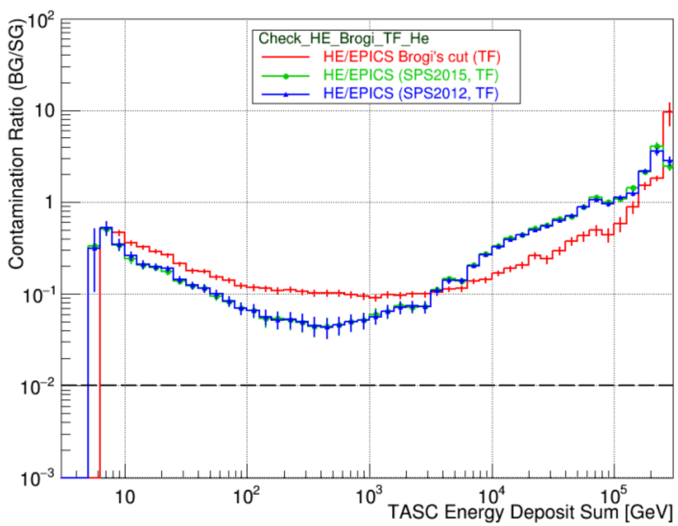


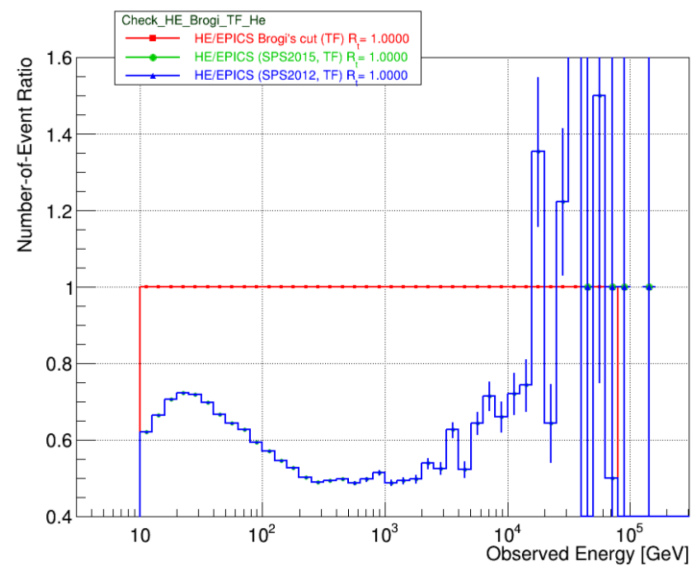
under the same condition, the difference between IC and JC analysis is ~12%.

# Comparison between IC and JC under the same corrections

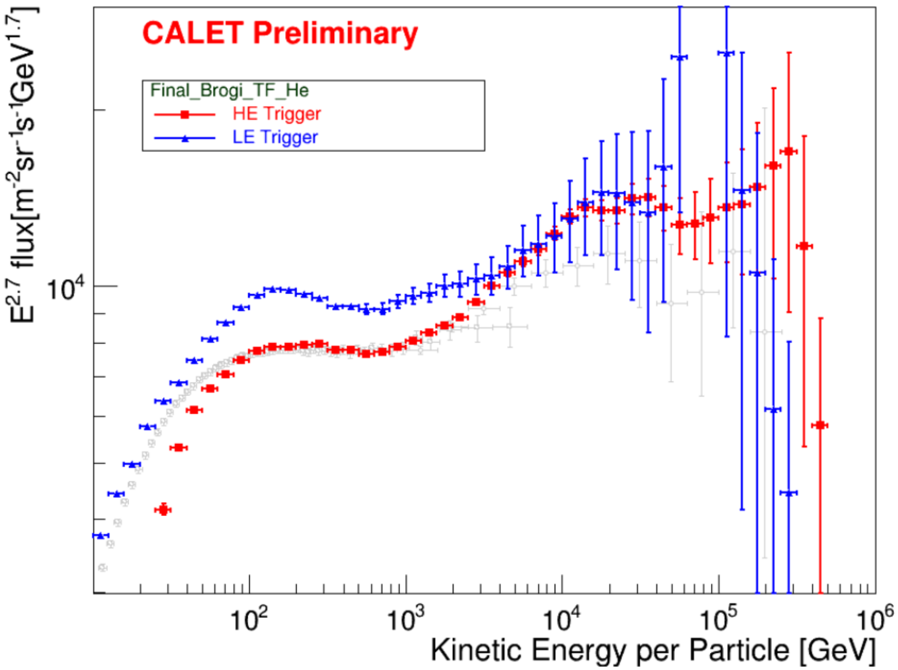


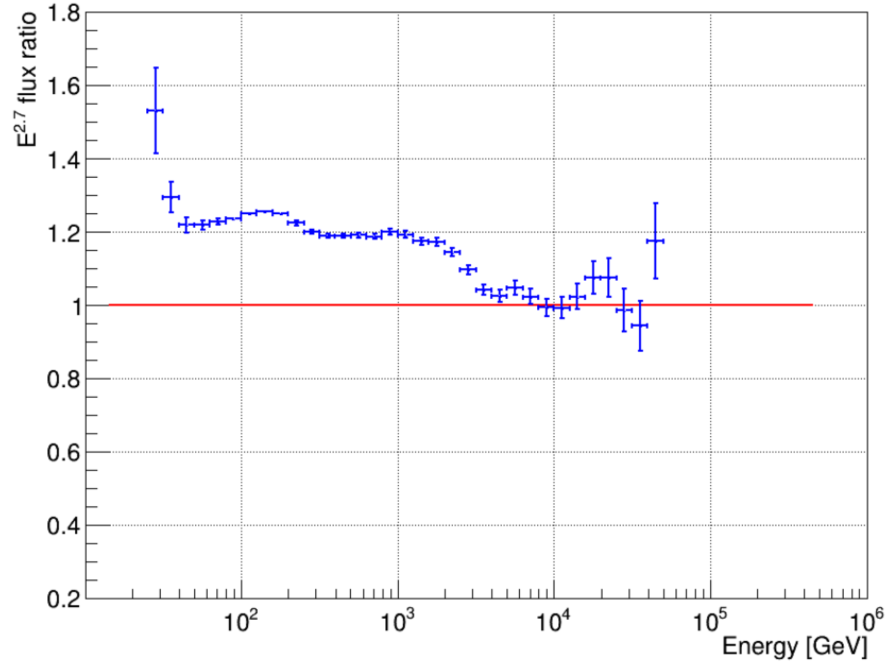



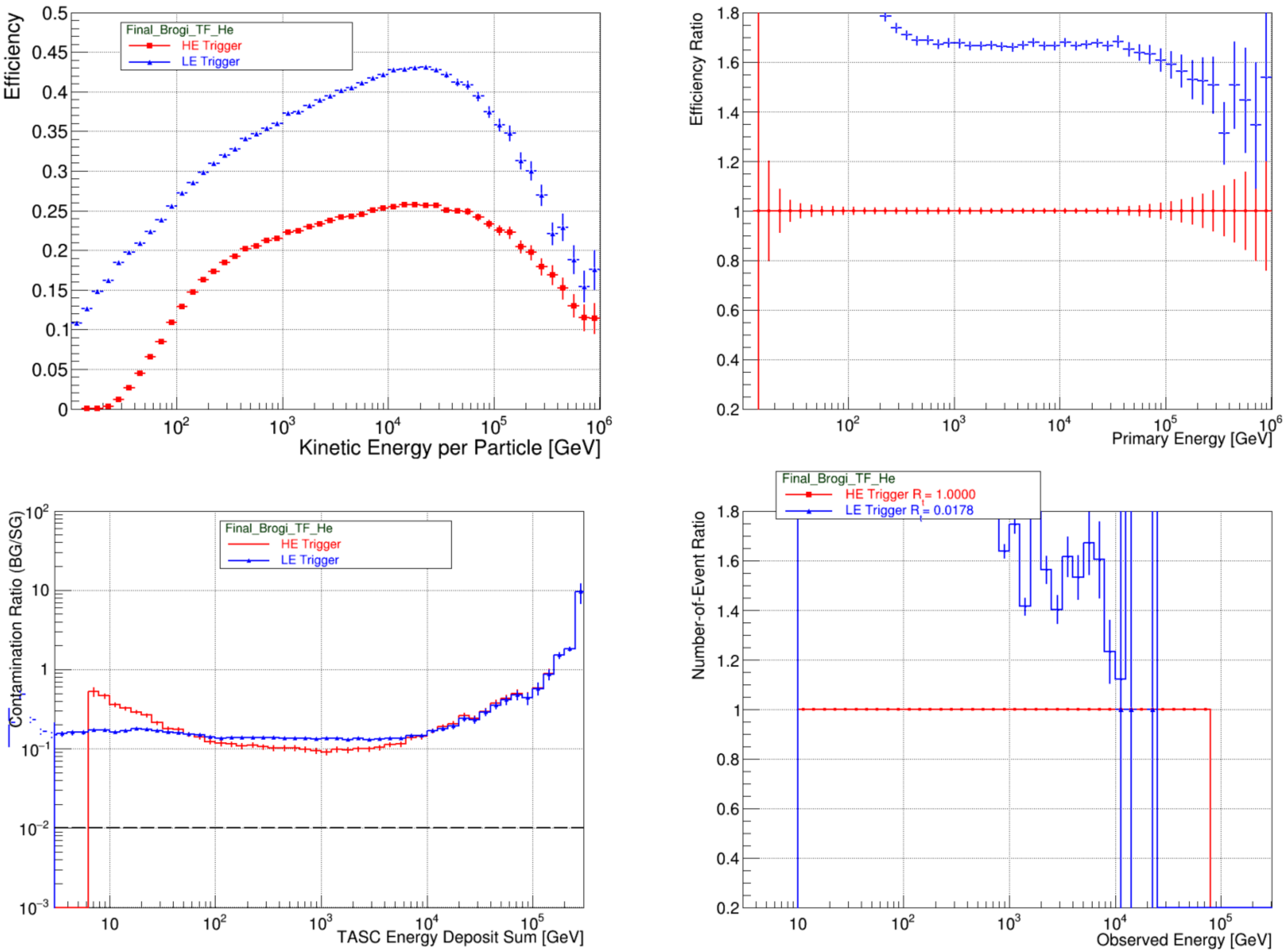
# Consistency between HE and LE Analysis with Paolo Brogi's Cut



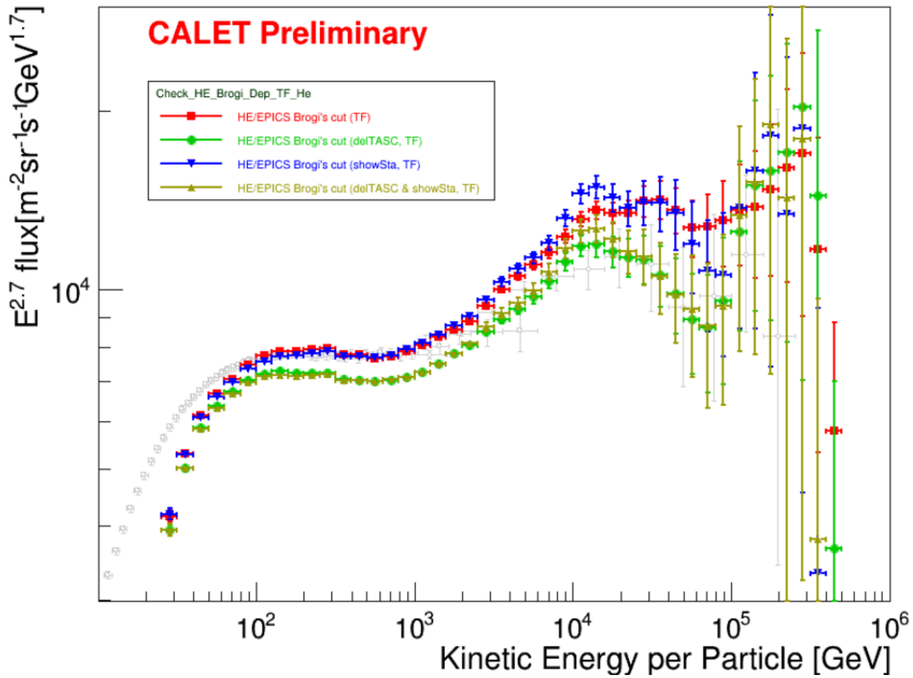

- Not so consistent with each other
- Backscattering? … difficult to explain the trend

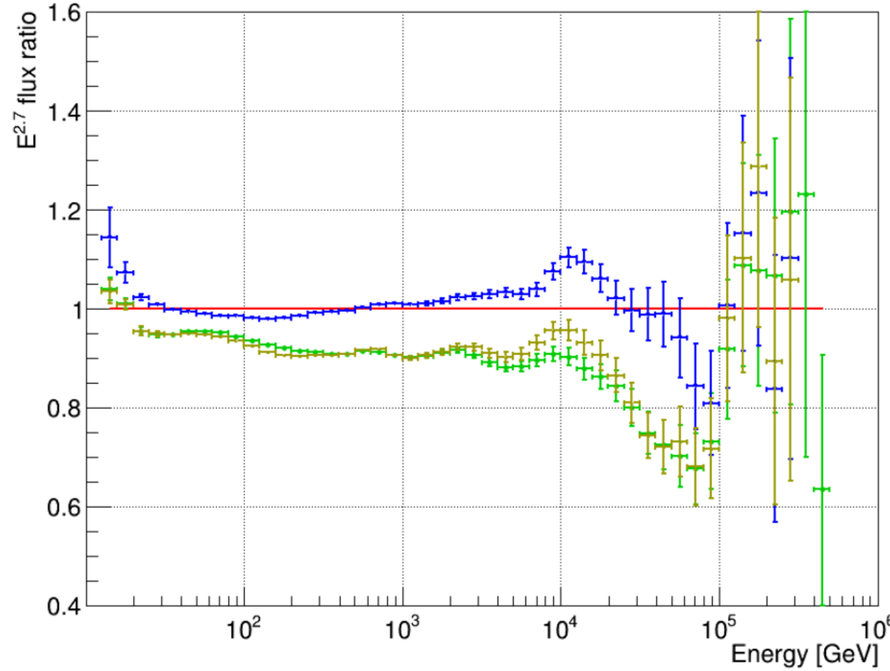
# Consistency between HE and LE Analysis with Paolo Brogi's Cut

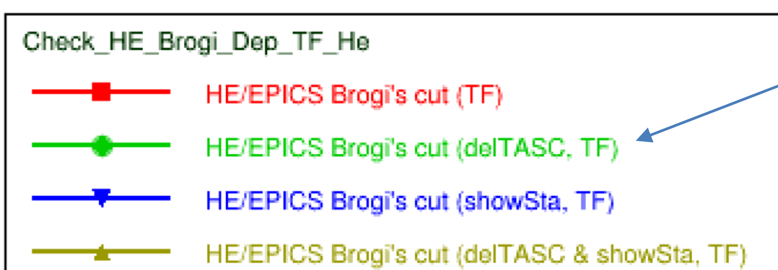


# Paolo Brogi's Cut+:
# TASC Delta and/or Shower Start

Check_HE_Brogi_Dep_TF_He-200142.pdf



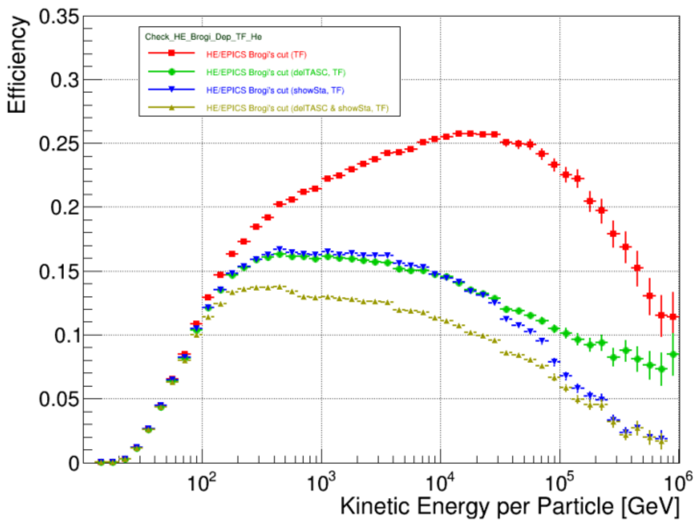



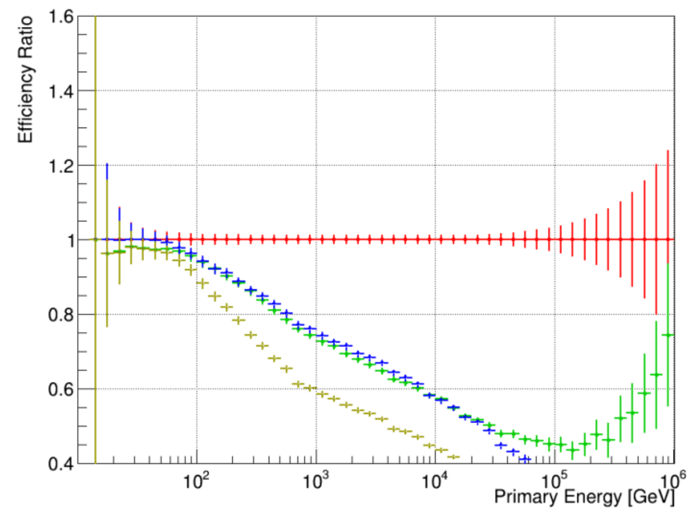



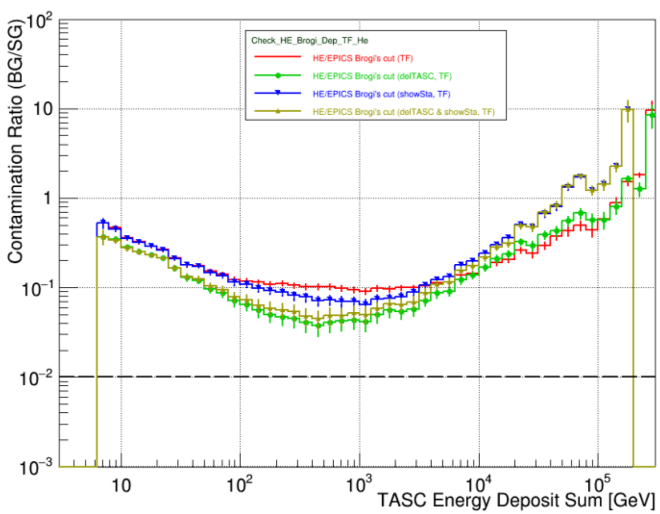

TASC Delta cut has a strong impact on flux

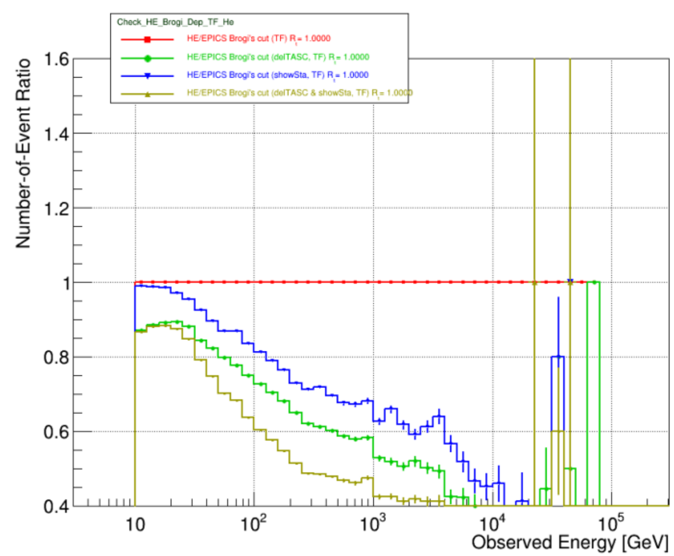
TASC hit consistency with track extrapolation

# Paolo Brogi’s Cut+: TASC Delta and/or Shower Start



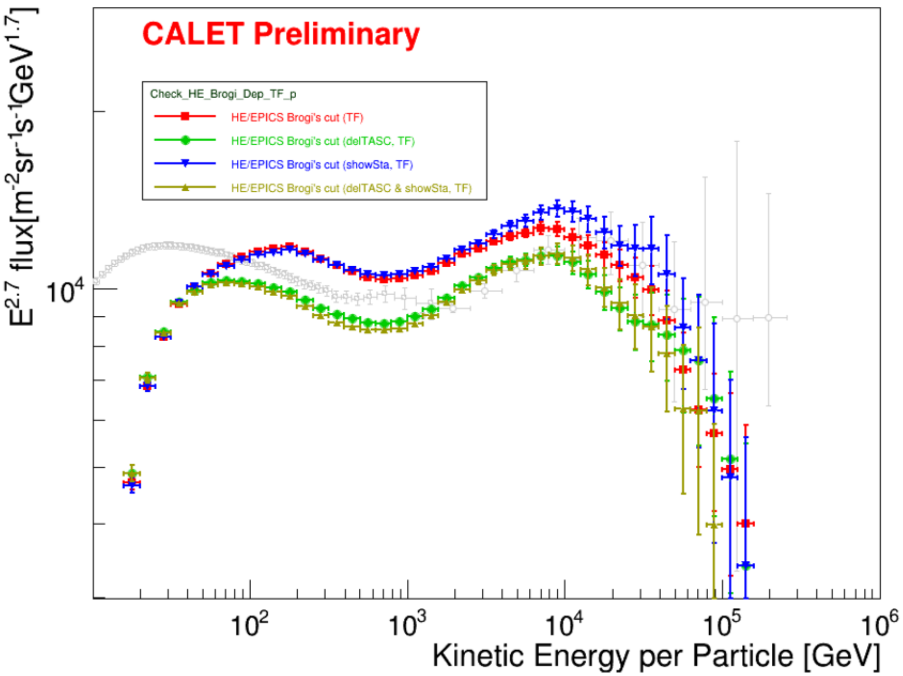



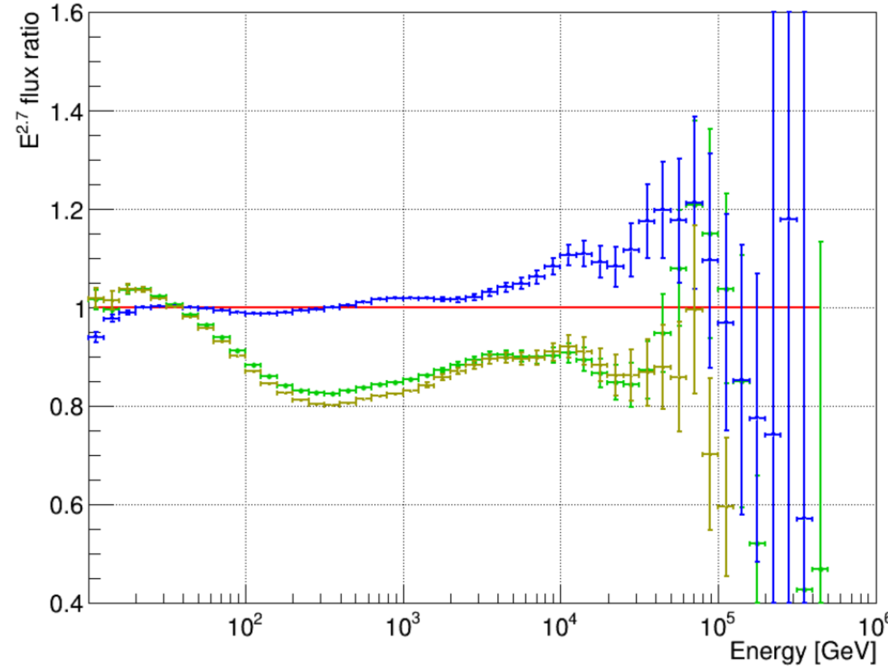



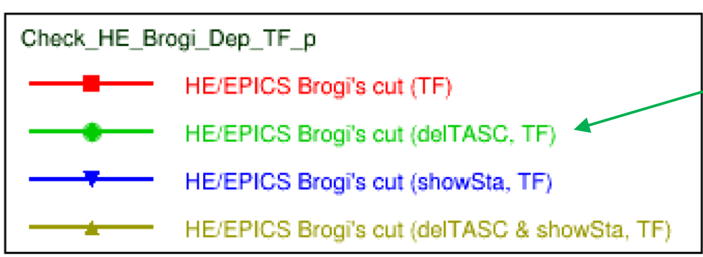



# Paolo Brogi's Cut+ (for protons): TASC Delta and/or Shower Start

Check_HE_Brogi_Dep_TF_p-200142.pdf



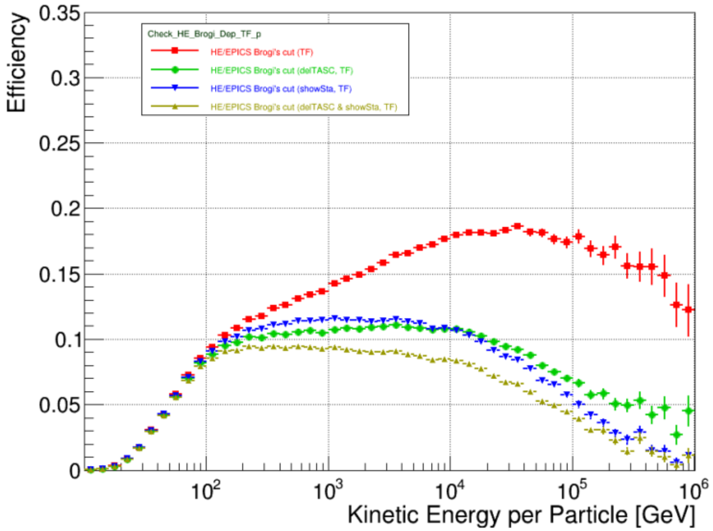



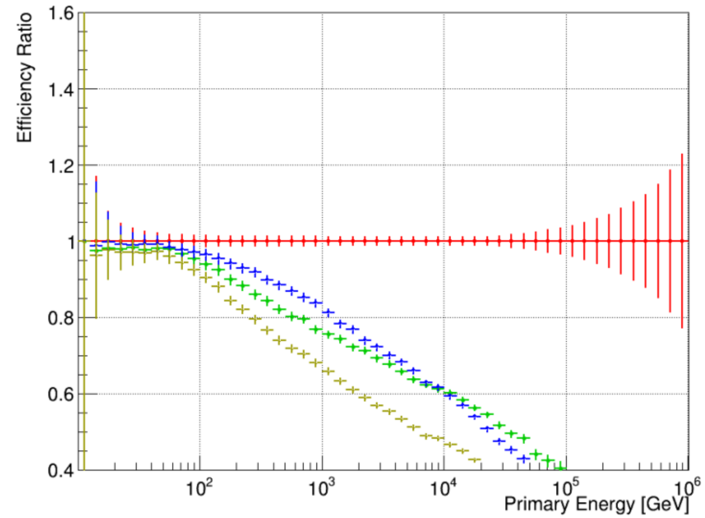



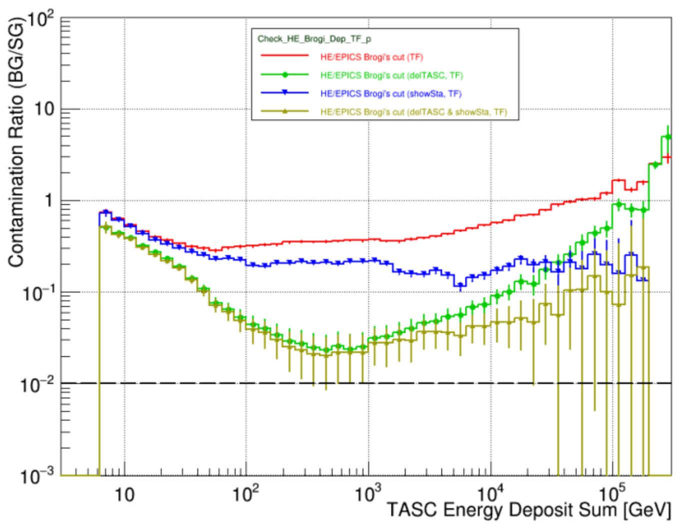

TASC Delta cut has even stronger impact on flux

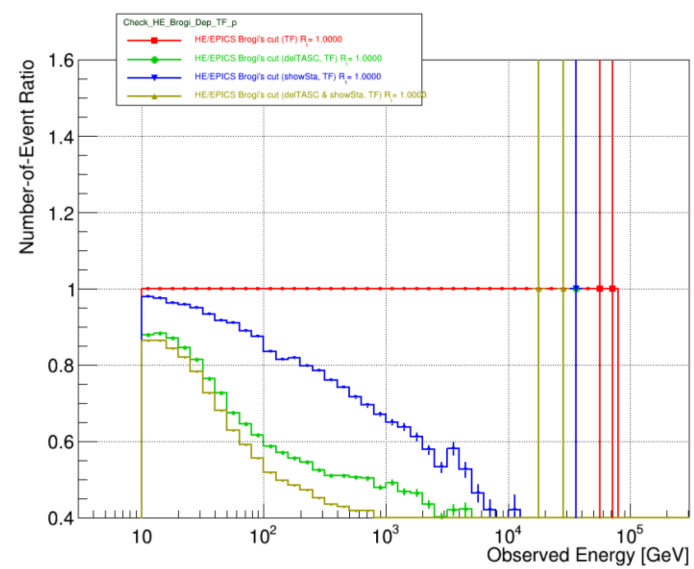
TASC hit consistency with track extrapolation

# Paolo Brogi's Cut+ (for protons): TASC Delta and/or Shower Start

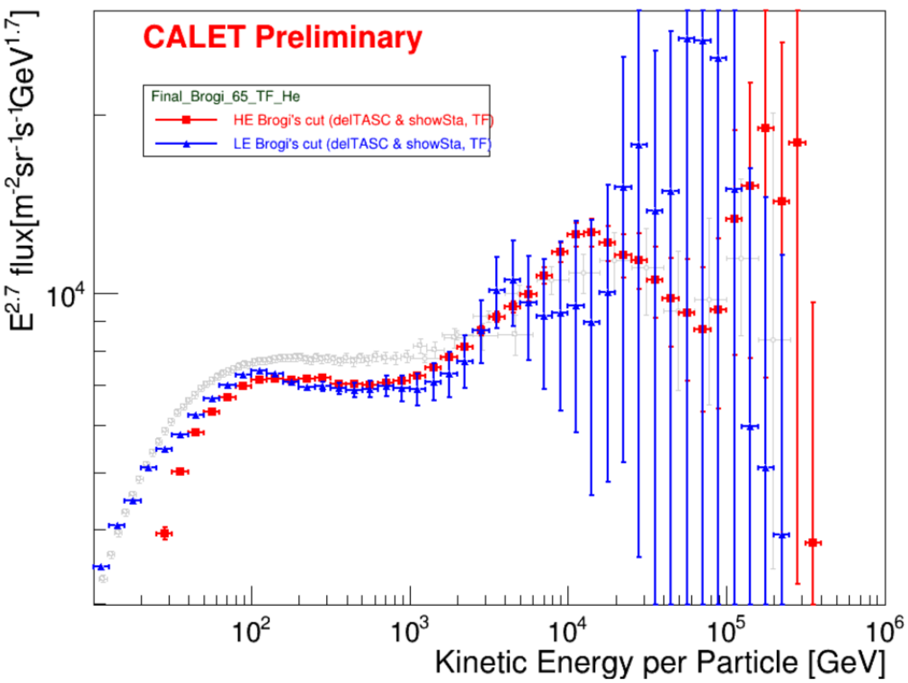


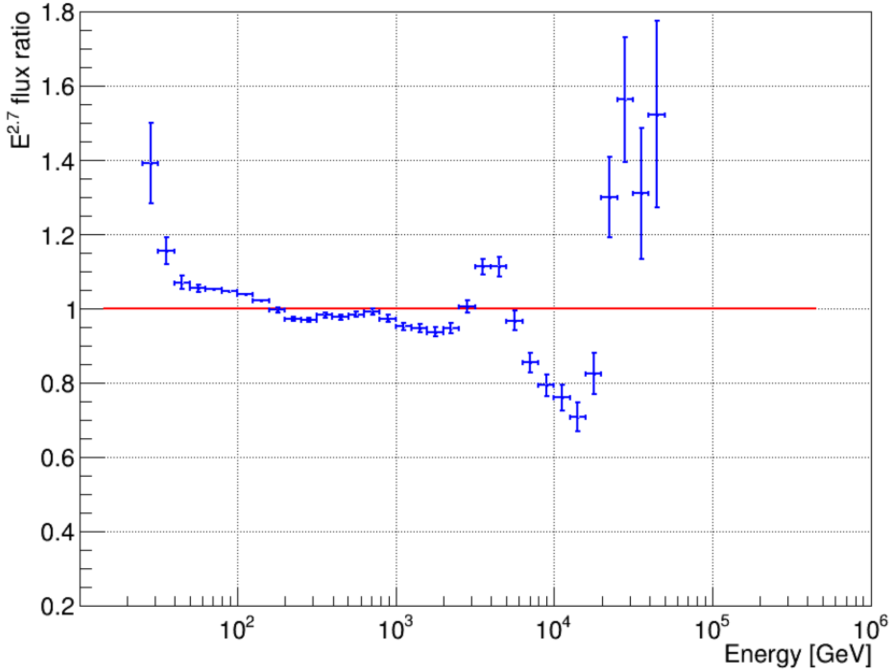



# LE&HE Consistency w/ Paolo Brogi's cut + TASC delta & Shower Start cuts




Consistency between LE and HE is quite good even though TASC delta cut is applied

# LE&HE Consistency w/ Paolo Brogi's cut + TASC delta & Shower Start cuts