Results of helium analysis

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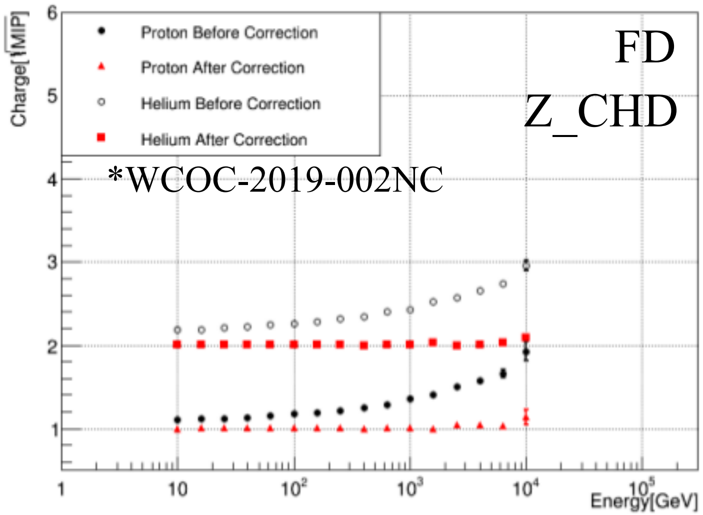
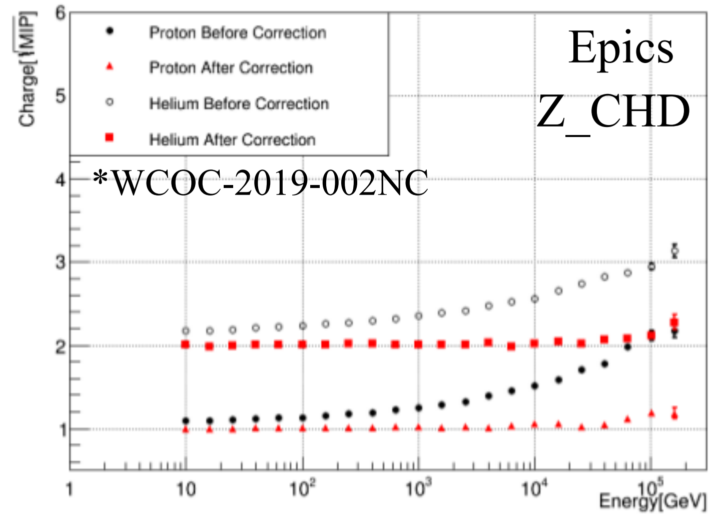
Analysis overview:

- 49 months of Flight Data (PASS4) → 201510-to-201910;
- Epics protons (Cosmos8.00 Epics9.20) → 10 GeV to 1 PeV;
- Epics helium (Cosmos8.02 Epics9.22) → 10 GeV to 1 PeV;
- HET: L2 trigger (FD) + Offline trigger confirmation (FD & MC);
- Track quality cut (FF=3);
- Geometrical acceptance cut (Acc. A1);
- Additional preselection: Off-Acceptance Rejection cuts (fE0<0.3 & fE1<0.3) + Tot. Edep. > 10 GeV + electron rejection cut (fE11<0.01&fE1RM>0.075);
- Charge cut on IMC/CHD charge corrected for Energy Shift (IC-ES for IMC and JC-ES for CHD);
- TB correction for trigger not needed (~1);
- TB correction for energy shower applied;
- The TASC logs 11-12-13 of layer 9 were removed from the deposited energy calculation (in this analysis) both in FD and MC simulation;
- Background subtraction from residual contaminations (off-acc., charge);
- Unfolding with iterative Bayes method (RooUnfold)
- Preliminary evaluation of systematics;
- Preliminary flux;

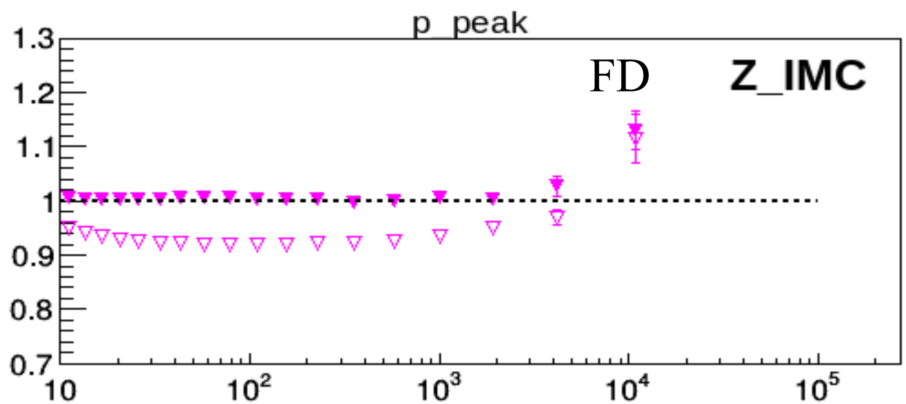
Energy-Shift corrected charges

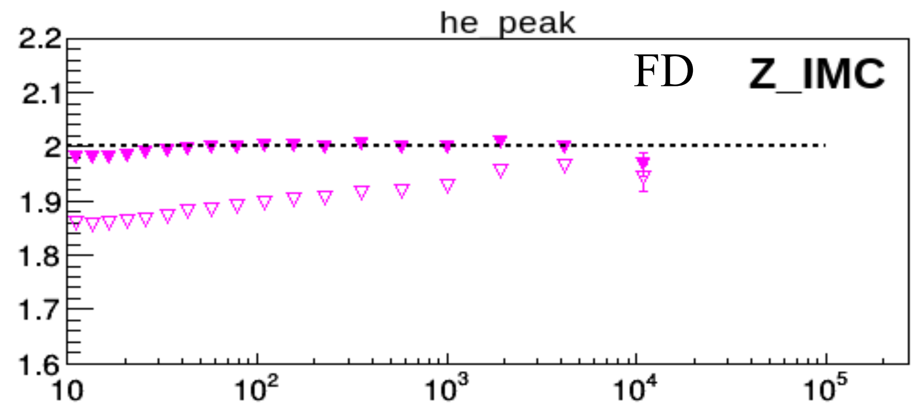
For CHD: recalculated JC-ES correction using JC-correction functions

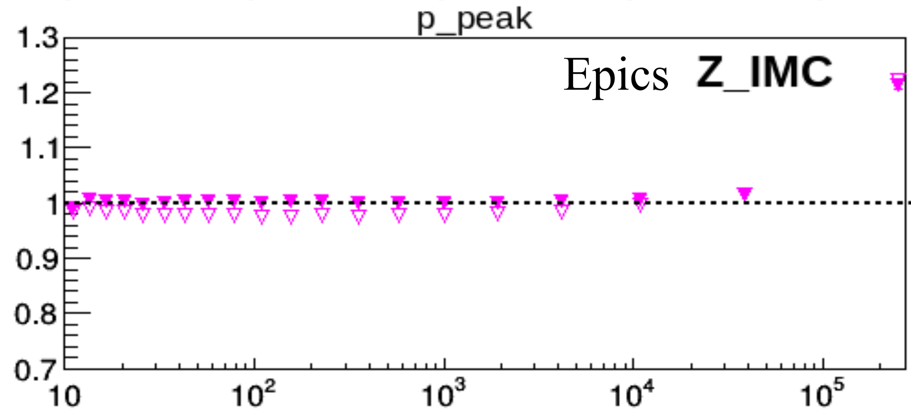


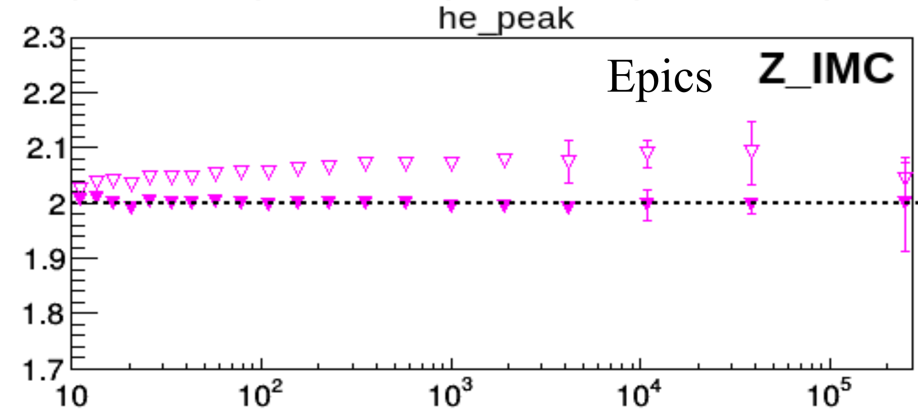


For IMC: IC-ES correction with JC method (IC-IMC charge is slightly different from JC one)



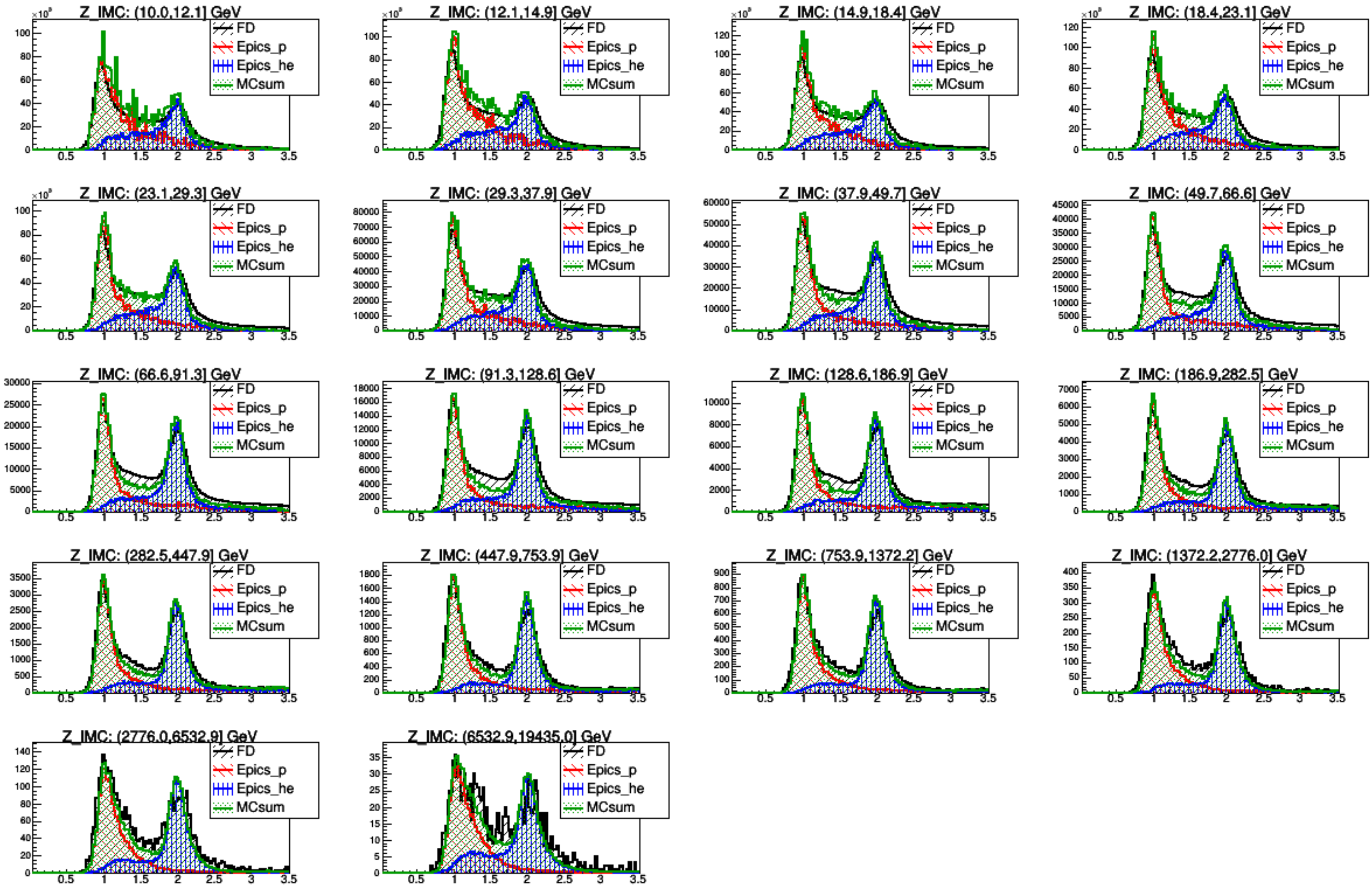






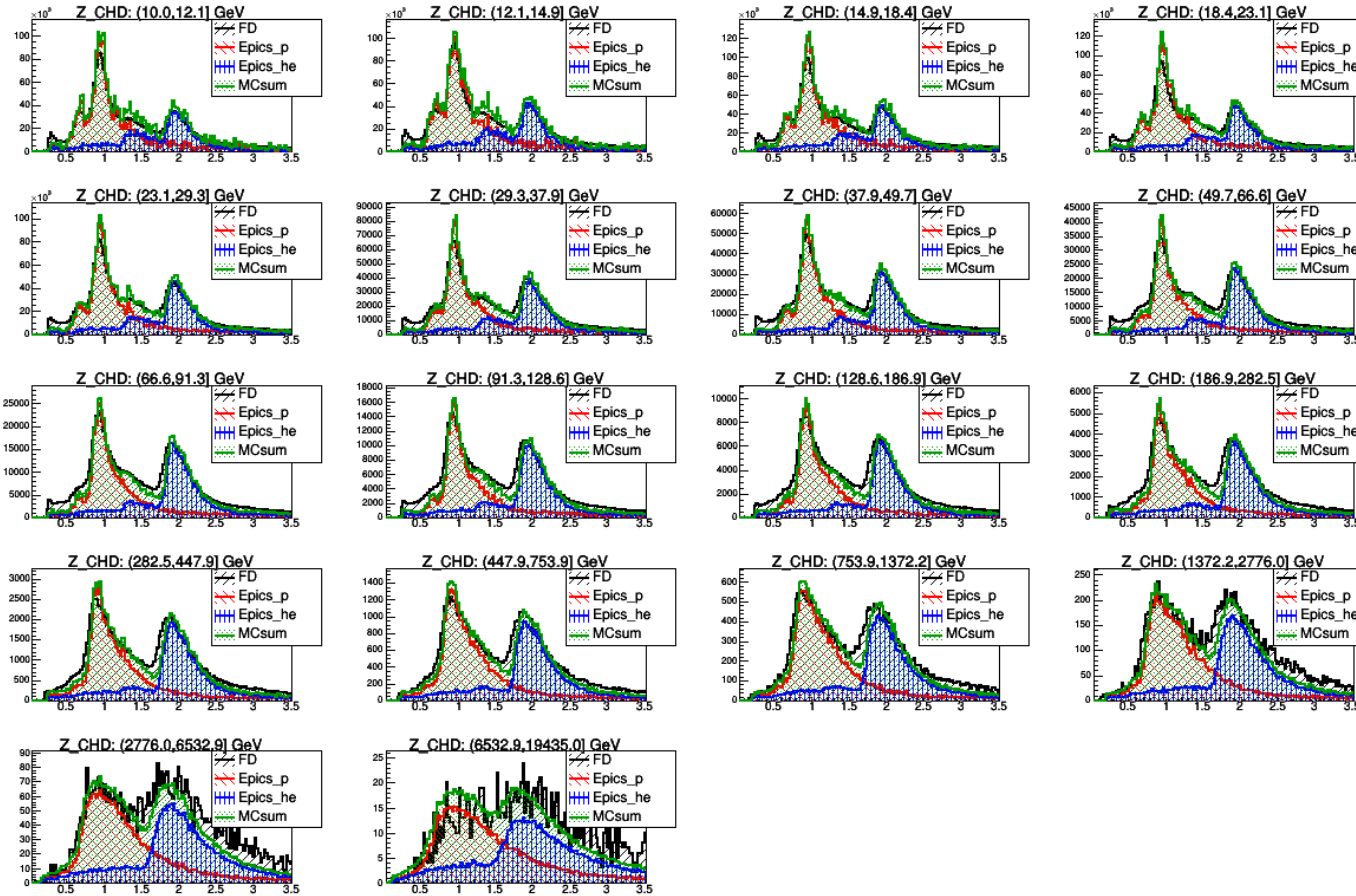
FD-MC charge comparison: IMC both views w/ IC-ES

Standard Pre-selection: Trg. HET; FF=3; Reco. ACC. = A1; fE0<0.3&fE1<0.3.



FD-MC charge comparison: CHD both views w/ JC-ES

Standard Pre-selection: Trg. HET; FF=3; Reco. ACC. = A1; fE0<0.3&fE1<0.3.



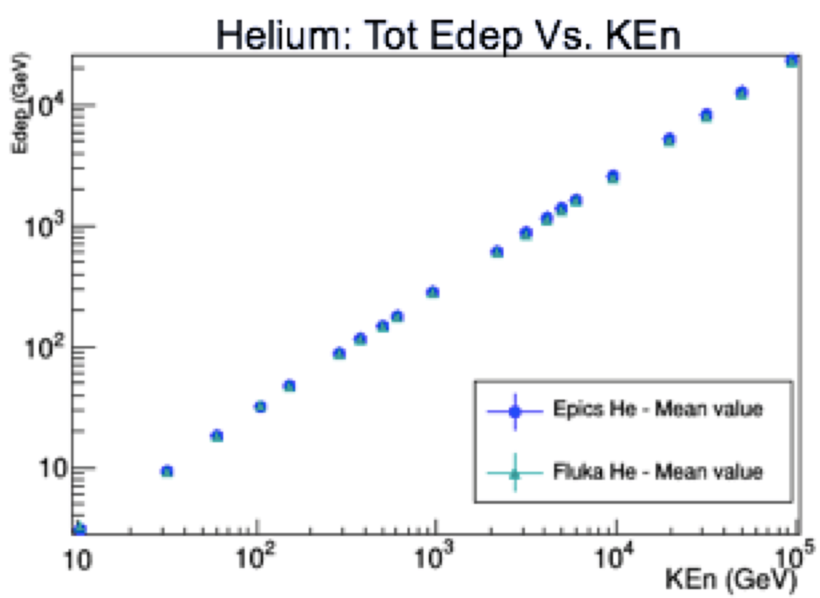
TB shower energy corrections

TB2015 correction for He (from G. Bigongiari analysis)	
KEn	CF
52 GeV	0.891
76 GeV	0.910
600 GeV	0.974

TB2012 correction for p (from proton paper)	
KEn	CF
30 GeV	0.921
100 GeV	0.937
400 GeV	1.0

The standard shower energy correction is applied multiplying the total TASC energy deposit (of MC) by the correction factor (CF) found with TB analysis: the CF is calculated (in the same way as for the proton published paper) with a logarithmic interpolation between the 3 points and is assumed to be equal to 0.891/0.921 below 52/30 GeV and 0.974/1.0 above 600/400 GeV for helium/proton.

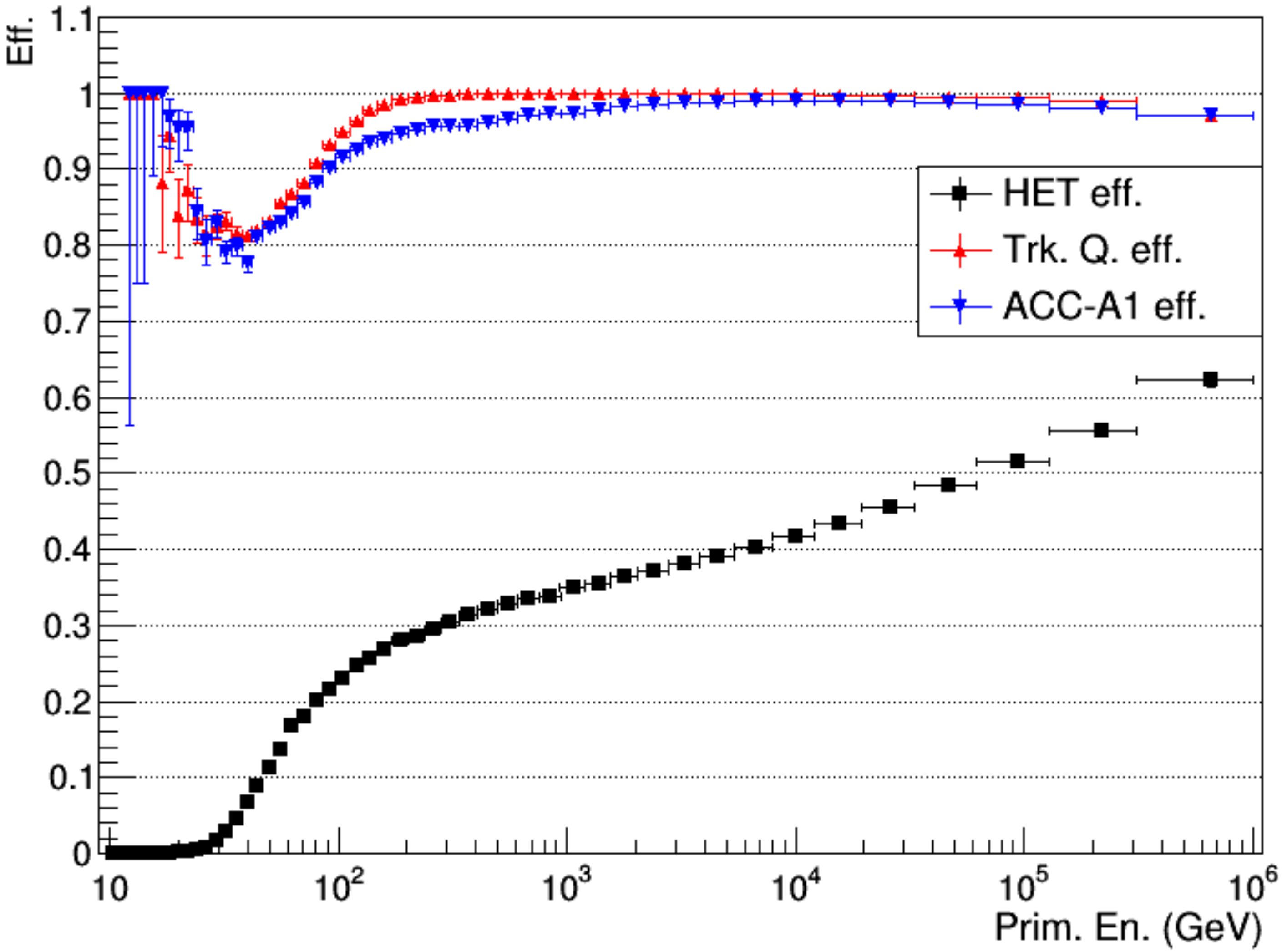
The TB2015 correction factor used in this analysis as been evaluated with **Fluka** MC, but very similar behaviour is expected with **Epics** MC, see G. Bigongiari presentation at this TIM.



Very similar behaviour of dep. en. vs kin. en. of helium nuclei in both Epics and Fluka

Preliminary event selection efficiency:

- Trigger (HET) + offline confirmation (100 MIPs TASC-X1, 50 MIPs IMC-X78 and IMC-Y78);
- Track Quality cut = Kalman filter track is required in each view (FF3);
- reconstructed acceptance A1;



Epics He
MC is used

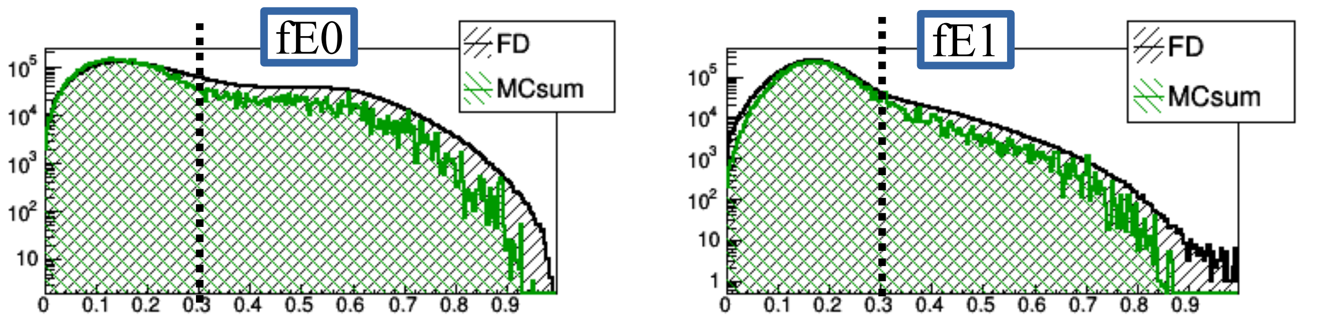
HET efficiency is calculated starting from true ACC. A1 events.

TQ cut efficiency is calculated from HET events.

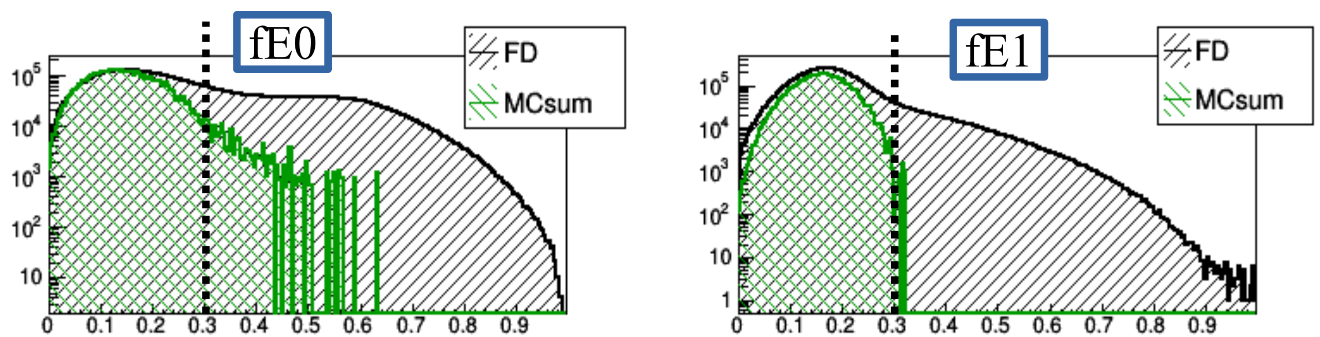
Reco. ACC. A1 eff. is calculate from HET and TQ events.

Additional pre-selection (i)

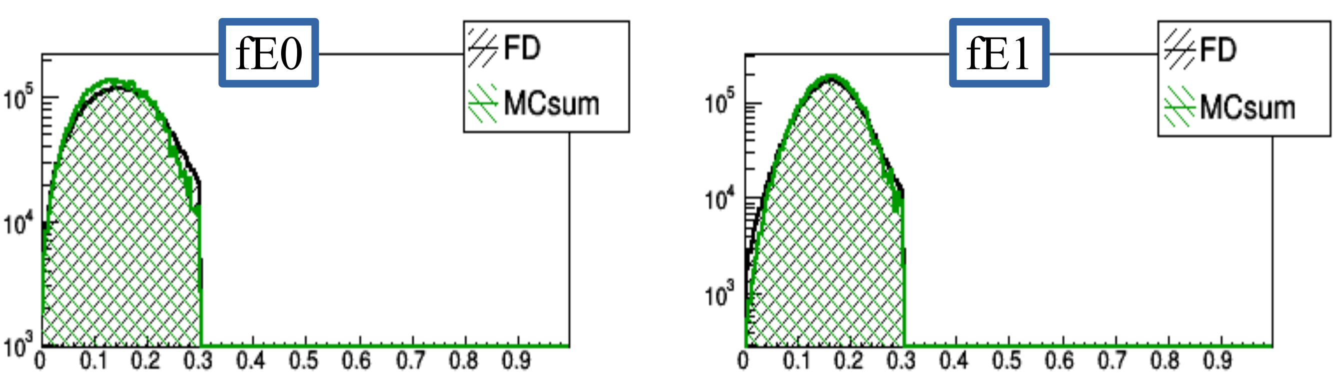
Electron cut (fE11<0.01&fE1RM>0.075); TASCedep<10 GeV; fE0<0.3&fE1<0.3 (OAR cuts); Helps reduce contamination from off-acceptance events and reject electron from the proton sample, that is used for background subtraction.



fE of first 2 TASC layers for all pre-selected events, black is data and green is MC (p + He).



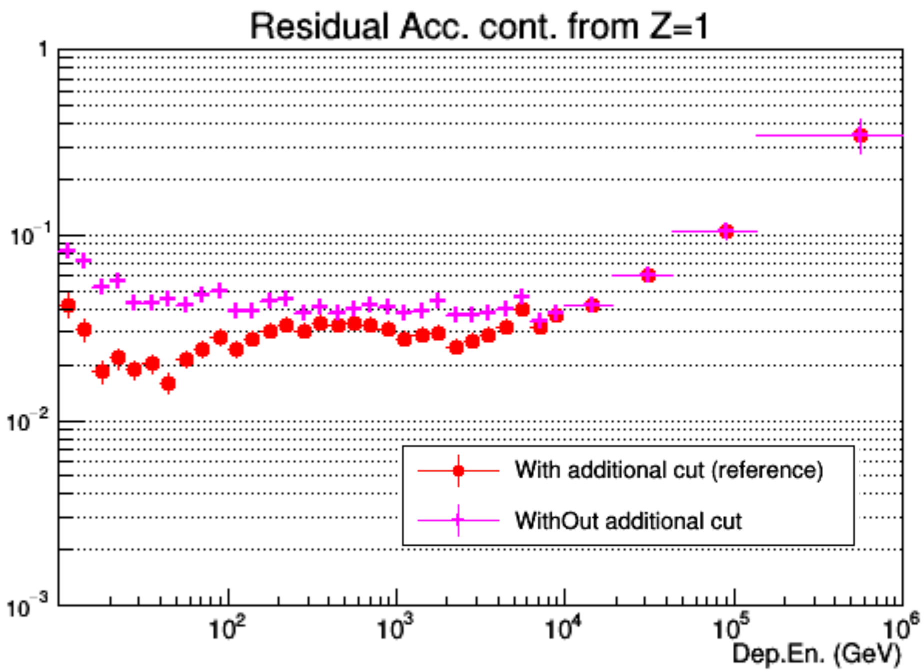
fE of first 2 TASC layers for all pre-selected events, black is data and green is MC (p + He) for true acc. A1 events only.

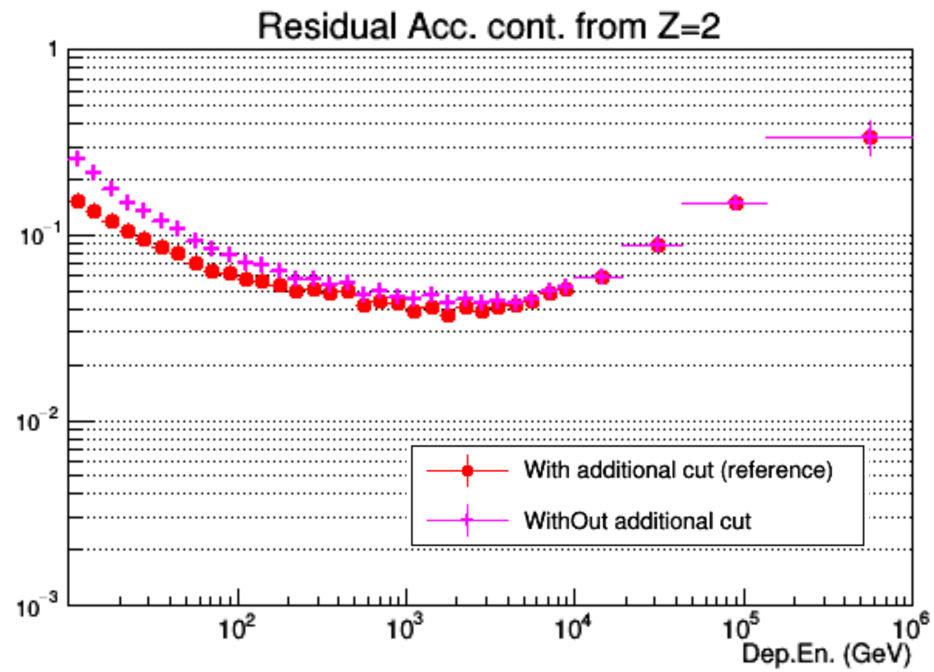


fE of first 2 TASC layers after additional pre-selection.

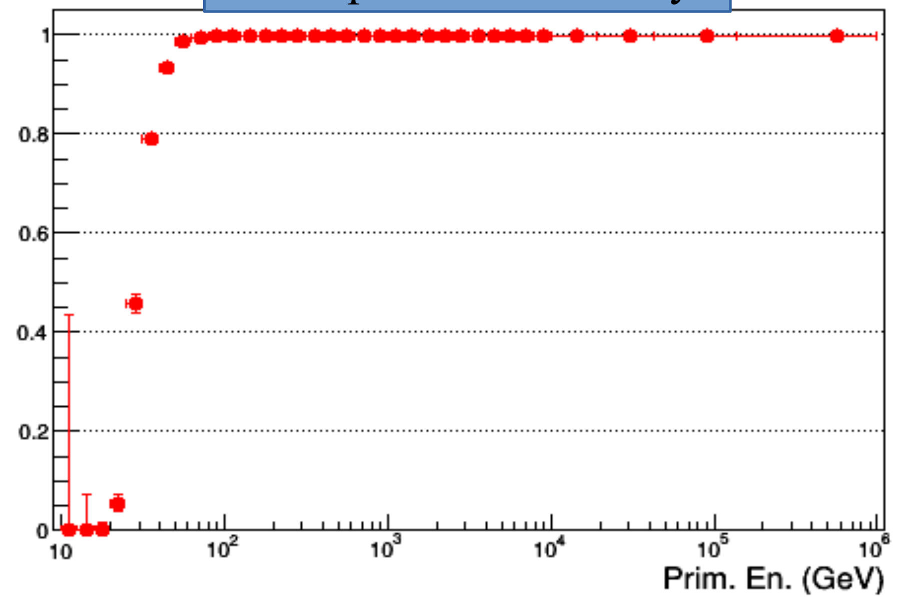
Additional pre-selection (ii)

Residual acceptance contamination with and without additional pre-selection:





Add. pre-sel. efficiency

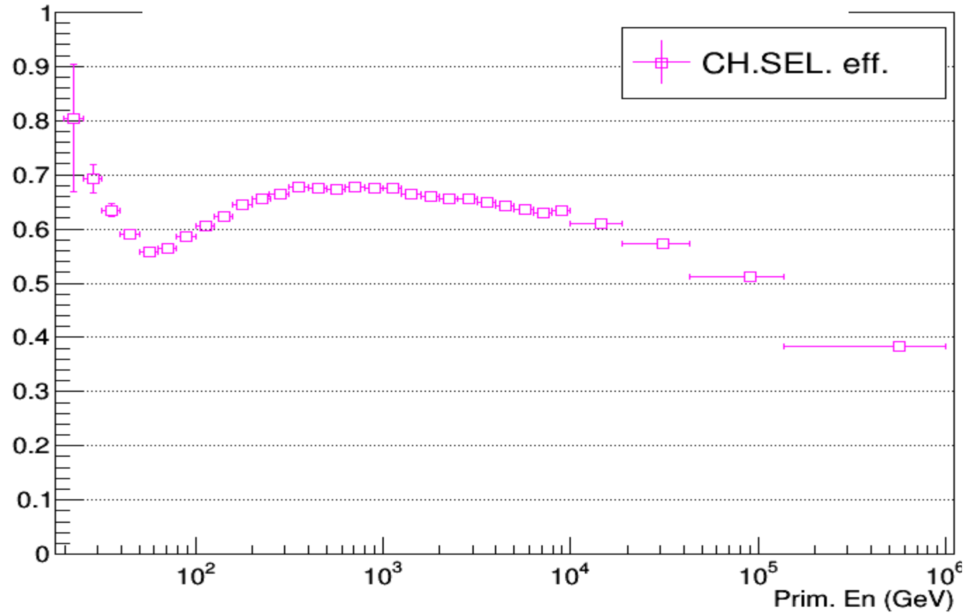


Charge selection

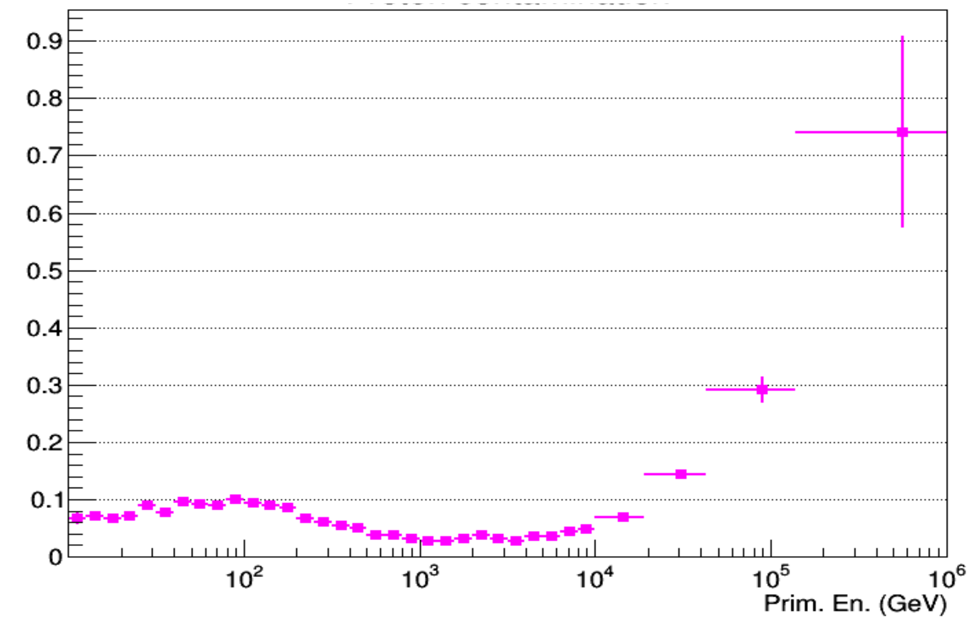
CHD and IMC charge corrected for Energy Shift (IC-ES for IMC and JC-ES for CHD)

Box cut: (1.7< CHD mean < 3.5) && (1.5 < IMC truncated mean < 3.5);

Charge selection efficiency



Residual proton contamination



Charge and off-acceptance contamination correction (i)

The charge contamination of proton events reconstructed as helium, it is calculated using Epics MC as:

$$C^{Z:1\to 2}_{A\to A} = \left(\frac{\frac{dN}{dE}^{Z:1\to 2}_{A\to A}}{\frac{dN}{dE}^{Z:1\to 1}_{A\to A}} \right)^{MC}$$

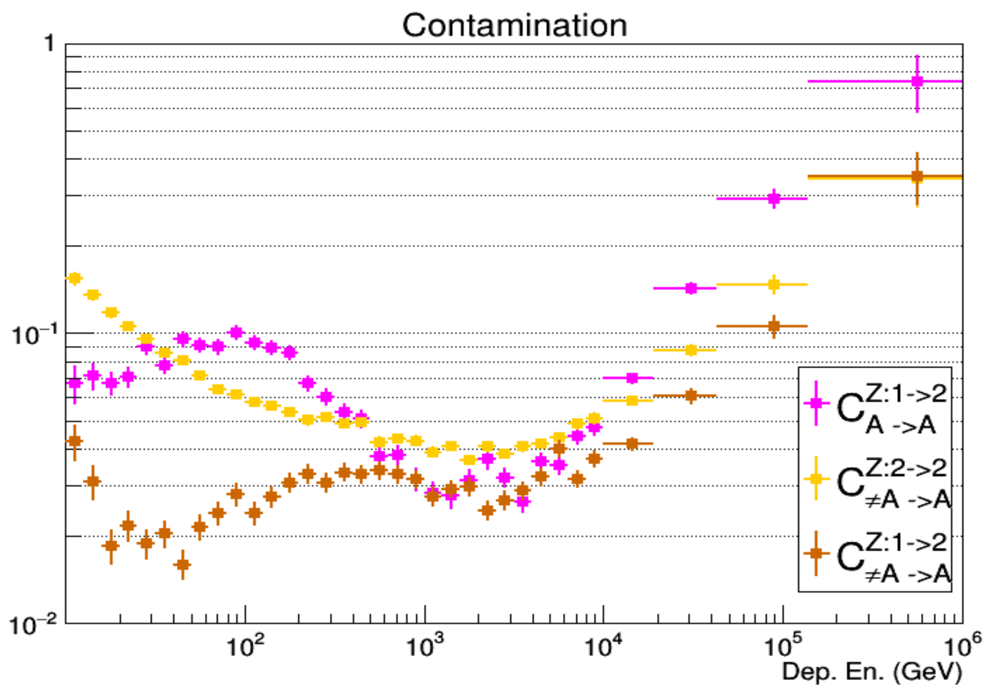
where:
$\frac{dN}{dE}^{Z:1\to 2}_{A\to A}$ is the distribution of the number of proton events (generated in acceptance A) that pass the selection of the helium analysis for each bin of deposited energy;
$\frac{dN}{dE}^{Z:1\to 1}_{A\to A}$ is the distribution of proton events (in acceptance A) that pass the same pre-selection but the proton charge cut.

The off-acceptance contamination of proton and helium events from acceptance ≠A reconstructed as helium in acc. A, it is calculated as:

$$C^{Z:2\to 2}_{\neq A\to A} = \left(\frac{\frac{dN}{dE}^{Z:2\to 2}_{\neq A\to A}}{\frac{dN}{dE}^{Z:2\to 2}_{A\to A} + \frac{dN}{dE}^{Z:2\to 2}_{\neq A\to A}} \right)^{MC} \quad \text{and} \quad C^{Z:1\to 2}_{\neq A\to A} = \left(\frac{\frac{dN}{dE}^{Z:1\to 2}_{\neq A\to A}}{\frac{dN}{dE}^{Z:1\to 1}_{A\to A} + \frac{dN}{dE}^{Z:1\to 1}_{\neq A\to A}} \right)^{MC}$$

where:
$\frac{dN}{dE}^{Z:1\to 2}_{\neq A\to A}$ ($\frac{dN}{dE}^{Z:2\to 2}_{\neq A\to A}$) is the distribution of proton (helium) events, generated outside the acceptance A, that pass the helium selection;
$\frac{dN}{dE}^{Z:1\to 1}_{A\to A} + \frac{dN}{dE}^{Z:1\to 1}_{\neq A\to A}$ ($\frac{dN}{dE}^{Z:2\to 2}_{A\to A} + \frac{dN}{dE}^{Z:2\to 2}_{\neq A\to A}$) are the distributions of proton (helium) events, generated on the whole generation surface, that pass the proton (helium) charge cut.

Charge and off-acceptance contamination correction (ii)



The distribution of background events is then evaluated multiplying the contaminations calculated with MC for the number of proton/helium events measured in the FD:

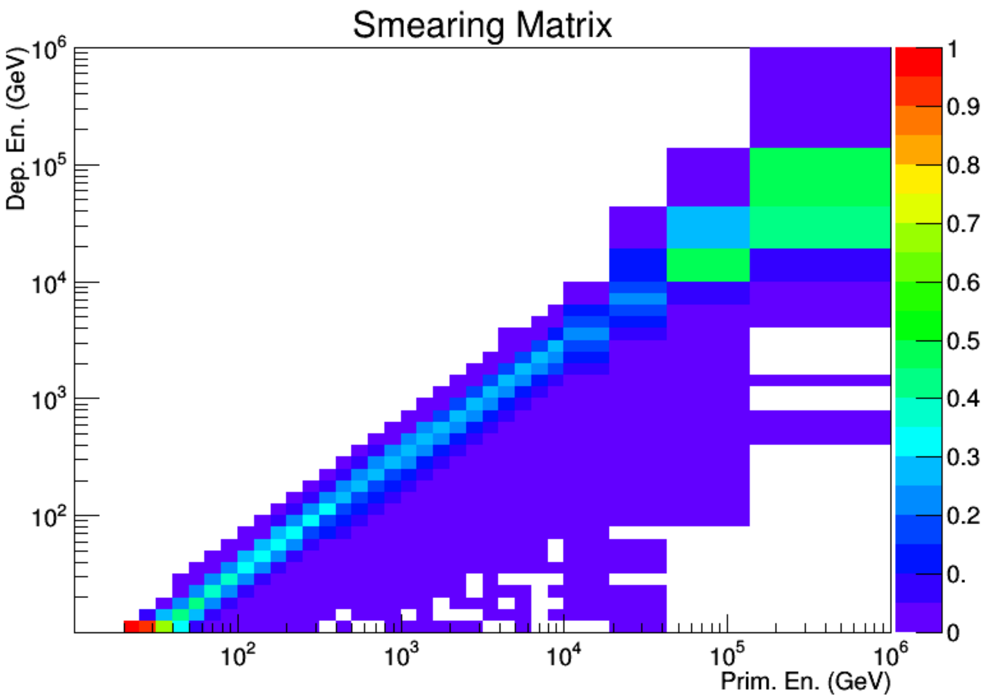
$$\frac{dB}{dE} = C^{Z:1\to 2}_{A\to A} \cdot \frac{dN}{dE}^{FD}_{Z=1} + C^{Z:1\to 2}_{\neq A\to A} \cdot \frac{dN}{dE}^{FD}_{Z=1} + C^{Z:2\to 2}_{\neq A\to A} \cdot \frac{dN}{dE}^{FD}_{Z=2}$$

Then it is subtracted to the measured dN/dE, before unfolding:

$$\frac{dN}{dE}^{FD-corr}_{Z=2} = \frac{dN}{dE}^{FD}_{Z=2} - \frac{dB}{dE}$$

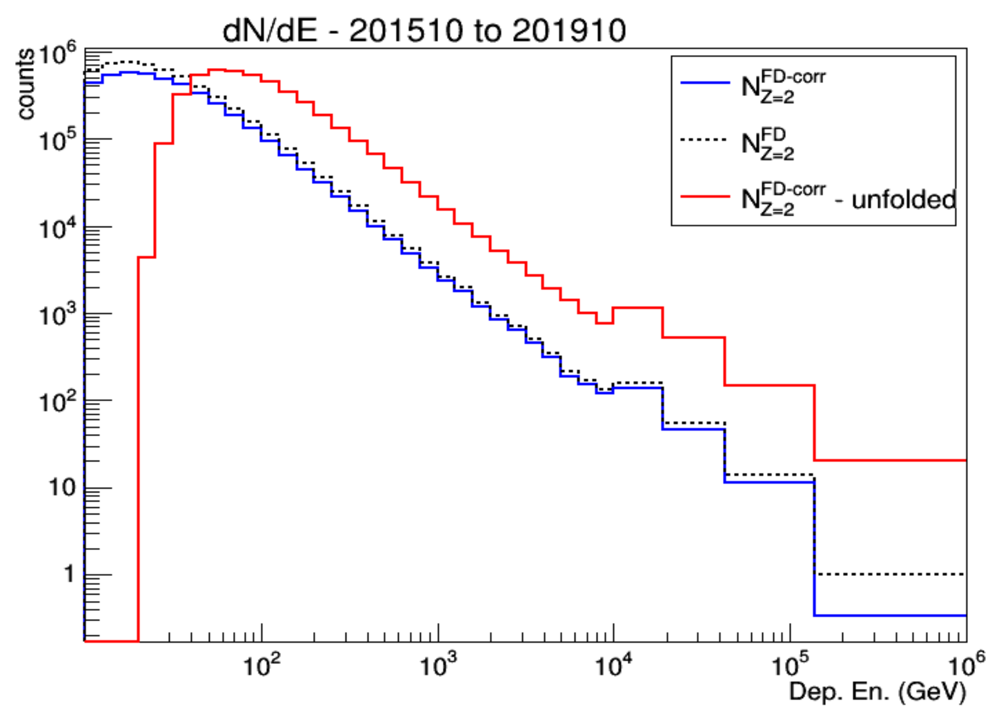
Unfolding

The unfolding is performed by an iterative method based on the Bayes theorem, which is implemented inside the RooUnfold package.



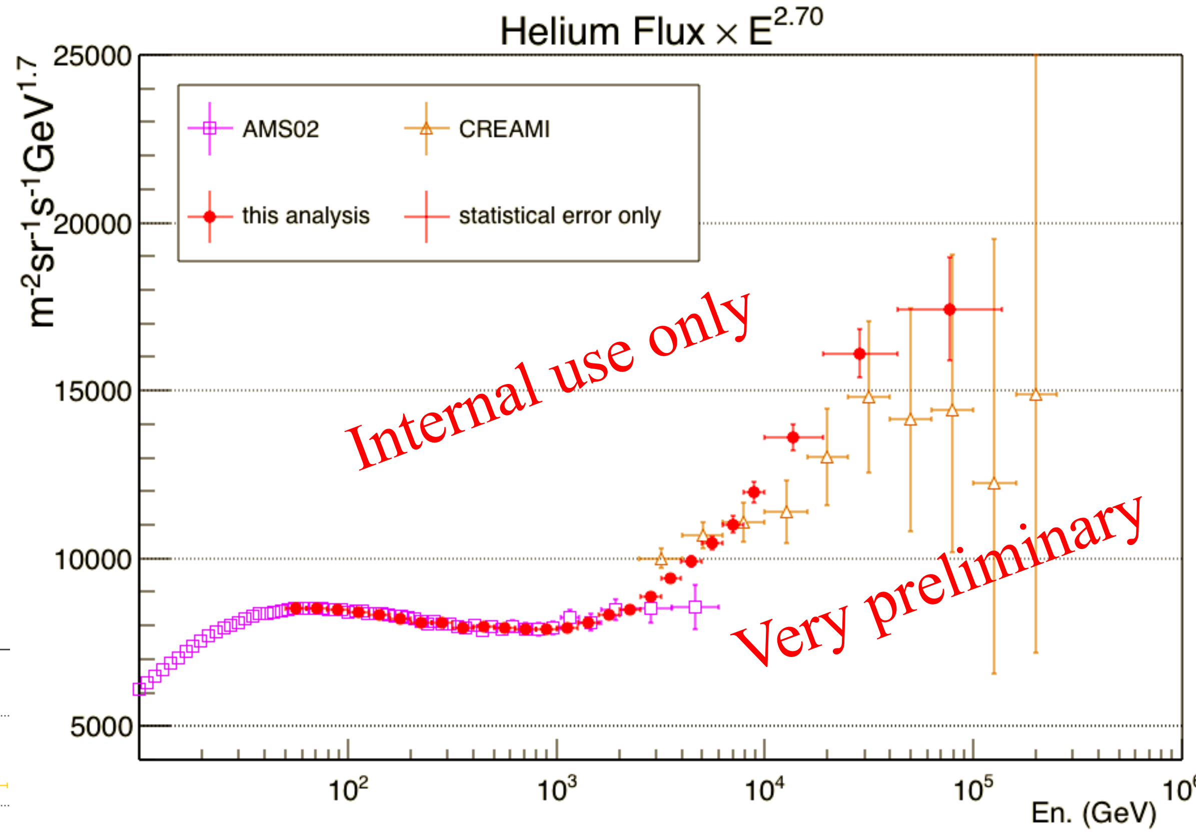
Smearing matrix: deposited energy versus primary energy; calculated with helium Epics MC.
Each column is normalized to 1.

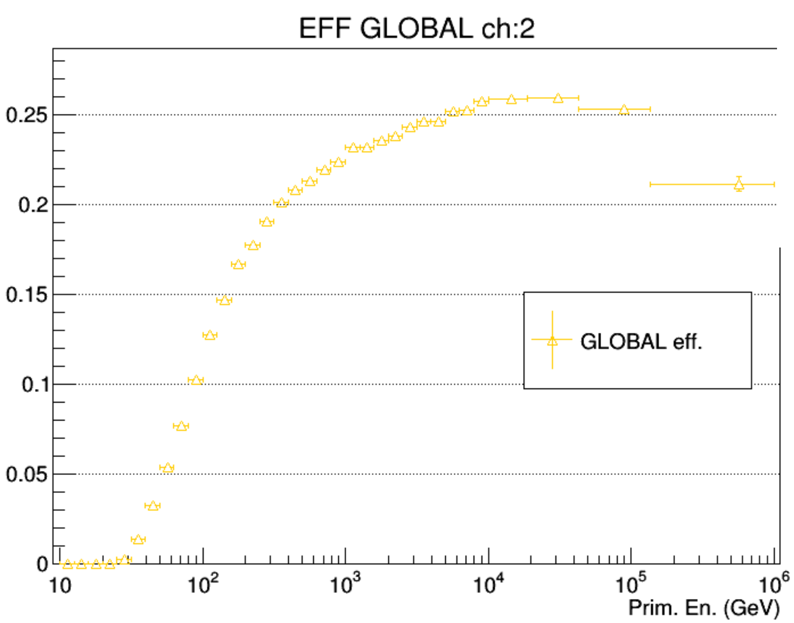
dN/dE distributions of helium events from FD sample (201510-201910):
The dashed black line represents the measured distribution, the blue line the dN/dE after background subtraction and the red line shows the unfolded distribution.



Updated IC helium flux measurement

$$\Phi_i = \frac{N_i}{A\ \varepsilon_i\ T\ \Delta E_i},$$



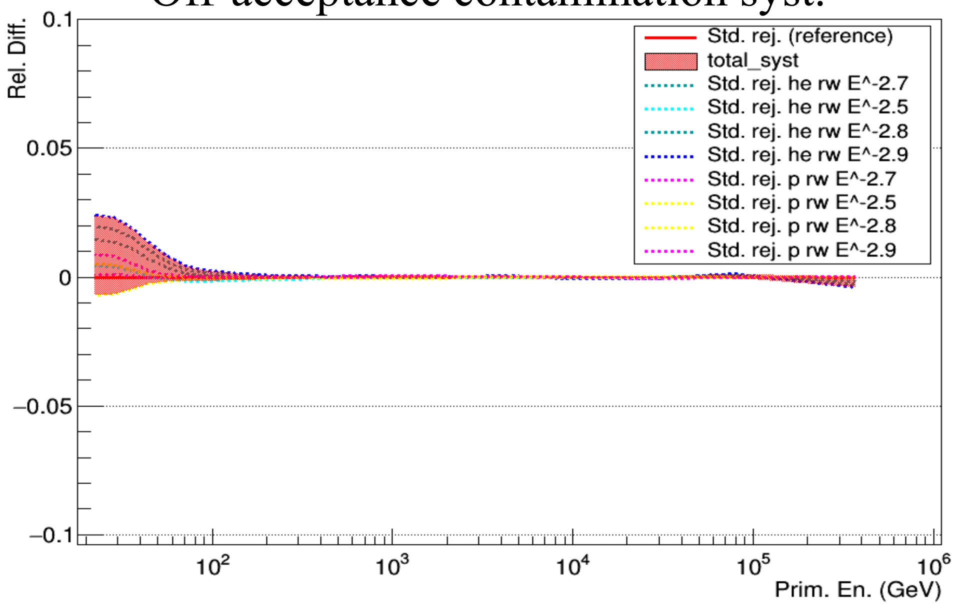


- Acc. A1 = 0.0510;
- 49 months of data 201510 to 201910;
- LT: 107859867 s;
- 23 Eq. prob. (in E^{-1}) bins from ~50 GeV to 10^4 GeV;
- 3 Eq. prob. (in $E^{-1.35}$) bins from 10^4 GeV to ~ 10^5 GeV;
- point set to the bin geometrical mean;
- Bayes deconvolution with 2 iterations;
- trigger efficiency correction **not** needed;
- energy shower correction from TB2015 (Fluka).

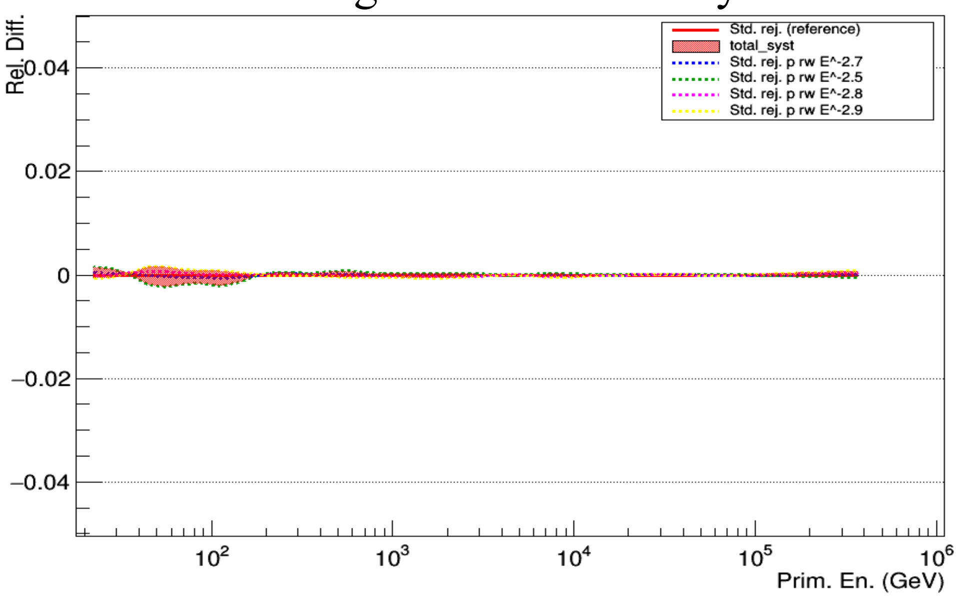
Preliminary systematic error evaluation: background subtraction

The charge and off-acceptance contaminations correction depend slightly on the proton and helium MC reweighting.
The systematic error related to this aspect is evaluated as the maximum difference with respect to the reference flux (calculated with AMS02+CREAMI fit reweighting) and each other flux calculated varying the MC reweighting from $E^{-2.5}$ to $E^{-2.9}$.
At present this systematic error has been evaluated using the PASS3.1 FD from 201512 to 201810, calculation with full statistic of PASS4 data is ongoing, even if no major differences are expected.

Off-acceptance contamination syst.



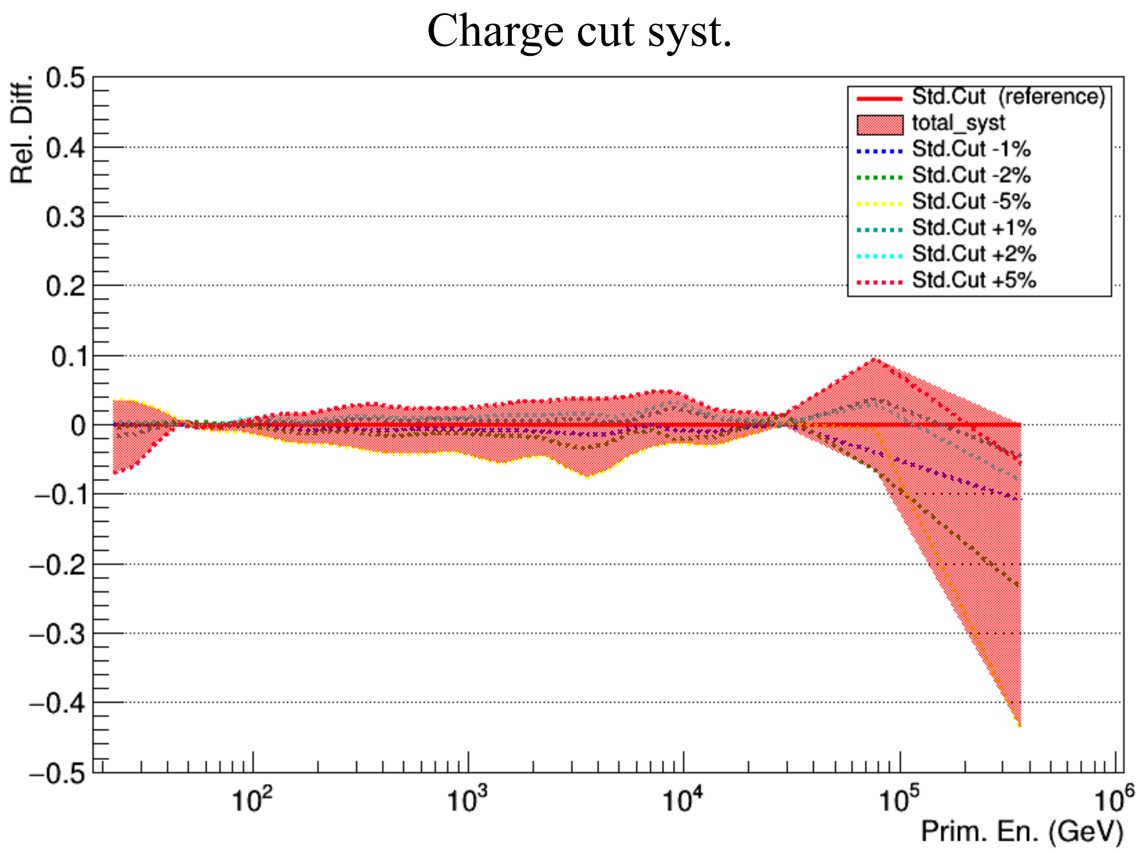
Charge contamination syst.



Preliminary systematic error evaluation: charge cut

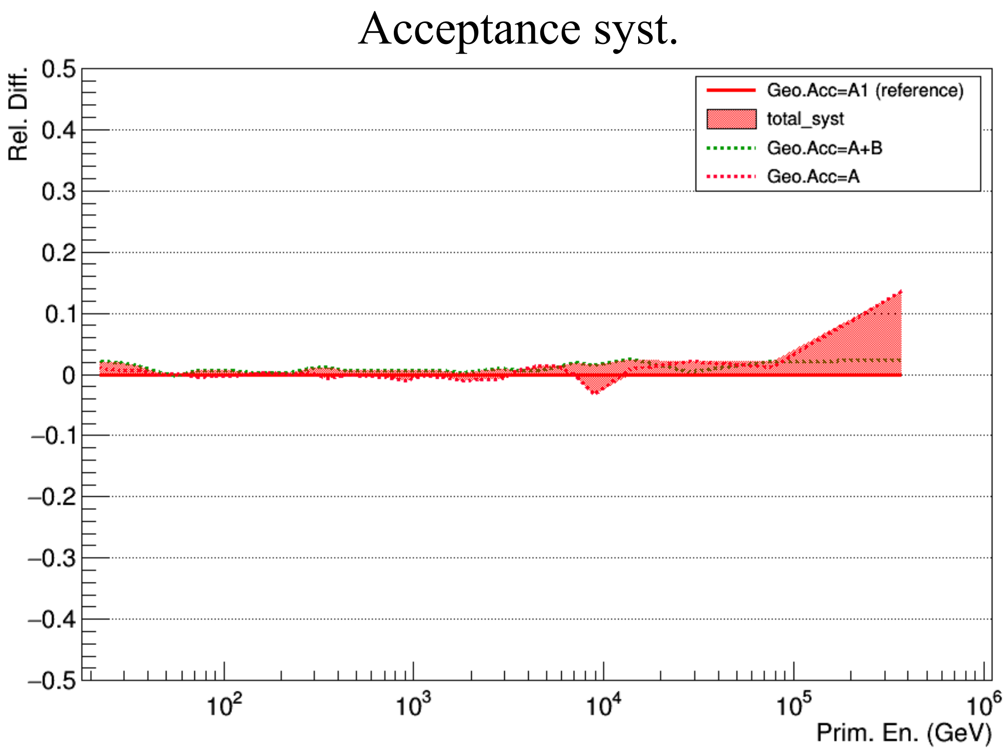
The systematic error related to the charge cut is evaluated as the maximum difference with respect to the reference flux (calculated with the standard cut) and each other flux calculated with a tighter (-1%,-2%, -5%) or a broader cut (+1%,+2%,+5%).

At present this systematic error has been evaluated using the PASS3.1 FD from 201512 to 201810, calculation with full statistic of PASS4 data is ongoing, even if no major differences are expected.



Preliminary systematic error evaluation: acceptance

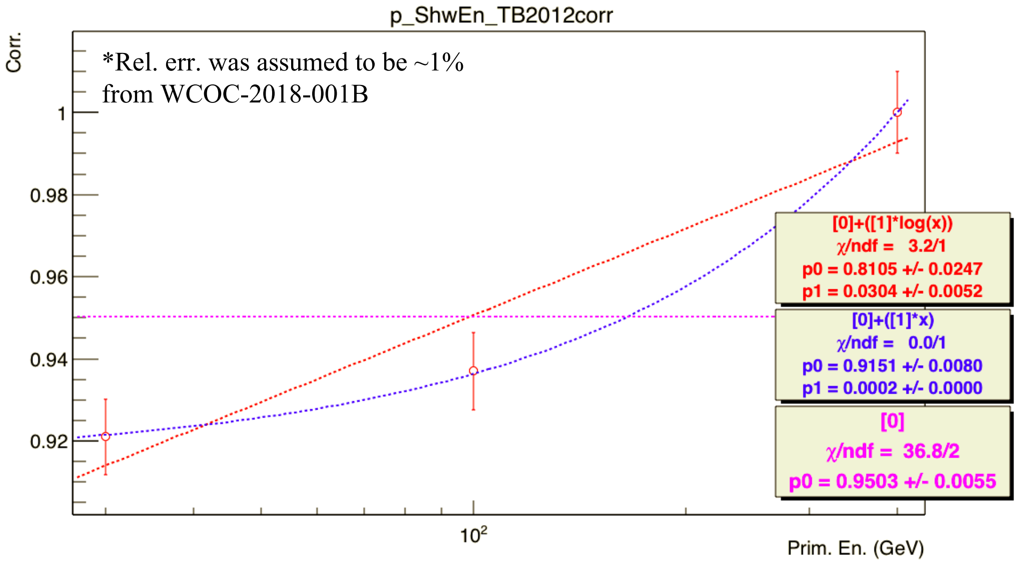
The systematic error related to the selected acceptance is evaluated as the maximum difference with respect to the reference flux (calculated with the acc. A1) and the other fluxes calculated with the narrower acc. A or the wider acc. A+B.
At present this systematic error has been evaluated using the PASS3.1 FD from 201512 to 201810, calculation with full statistic of PASS4 data is ongoing, even if no major differences are expected.

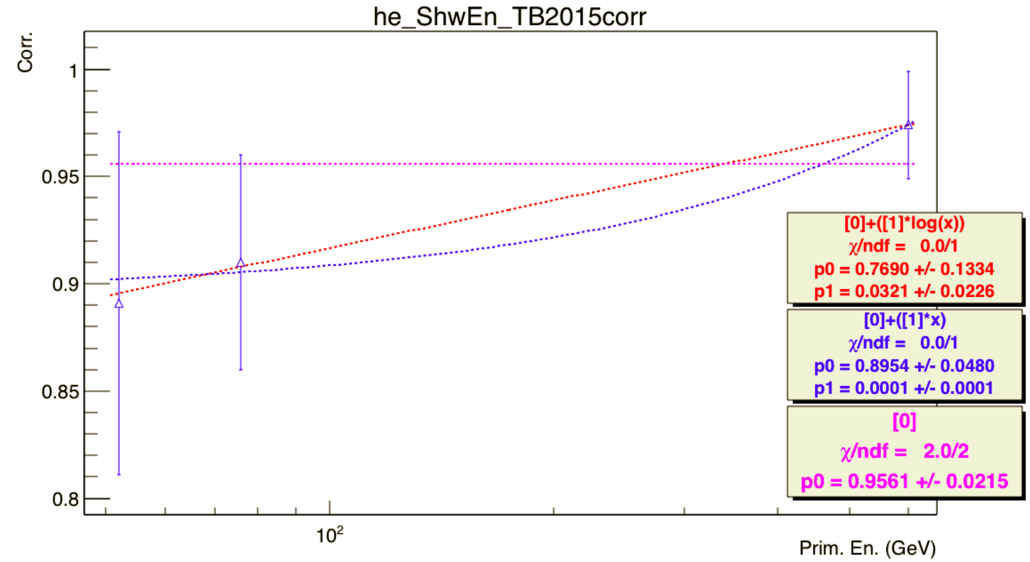


Preliminary systematic error evaluation: energy shower correction (i)

In order to evaluate the systematic error related to the energy shower correction, both of proton and helium nuclei, I have tried to model the shower energy correction in several ways.
In particular, I have tried:

- Liner and logarithmic interpolation;
- Linear and logarithmic fit;
- Fit with a constant;

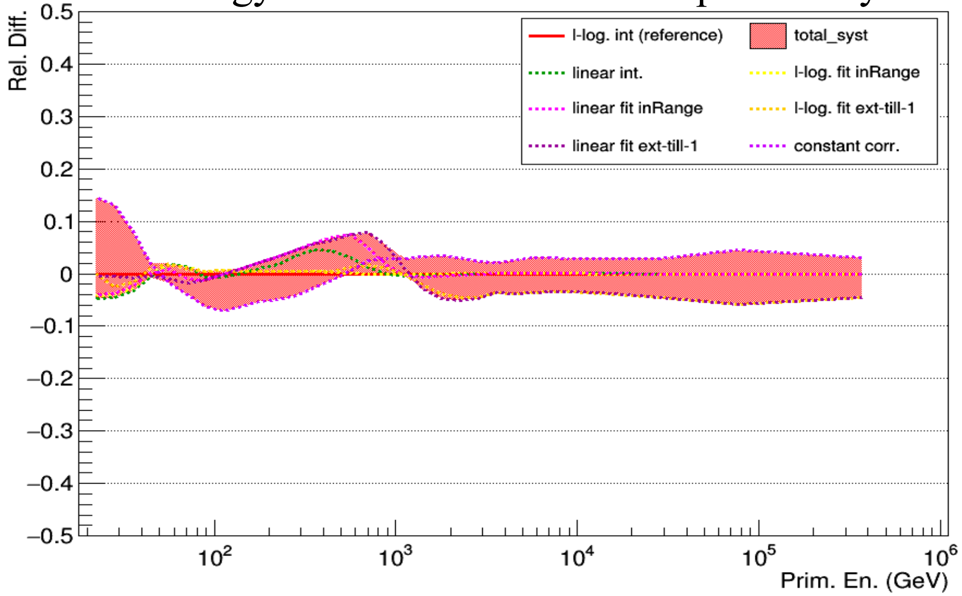




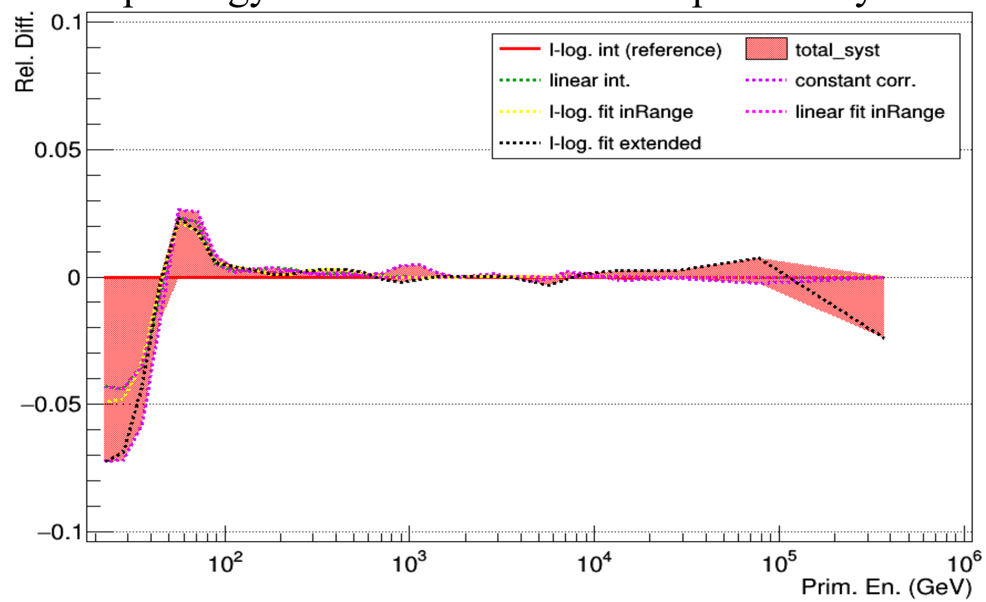
The systematic error related to the energy shower correction is evaluated as the maximum difference with respect to the reference flux (calculated with the logarithmic interpolation) and the other fluxes calculated with the different models, or with the same logarithmic interpolation but different value of the TB correction factors (nominal value +/- the estimated error).
At present this systematic error has been evaluated using the PASS3.1 FD from 201512 to 201810, calculation with full statistic of PASS4 data is ongoing, even if no major differences are expected.

Preliminary systematic error evaluation: energy shower correction (ii)

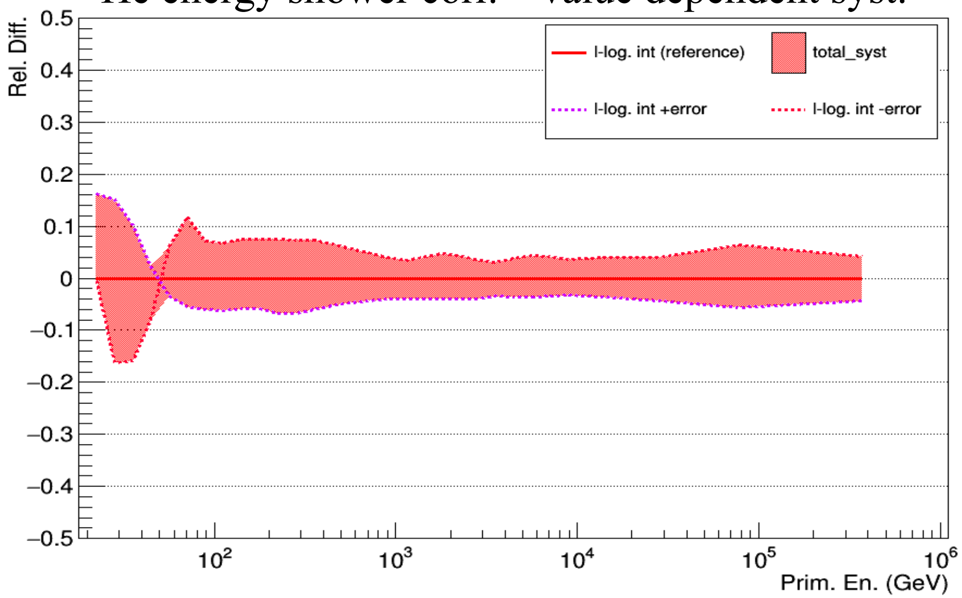
He energy shower corr. – model dependent syst.



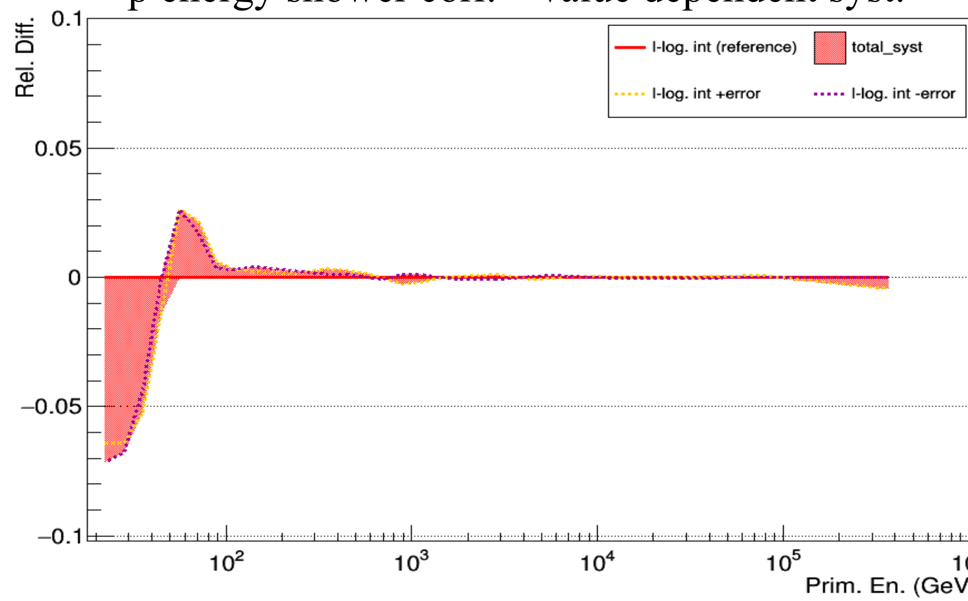
p energy shower corr. – model dependent syst.



He energy shower corr. – value dependent syst.



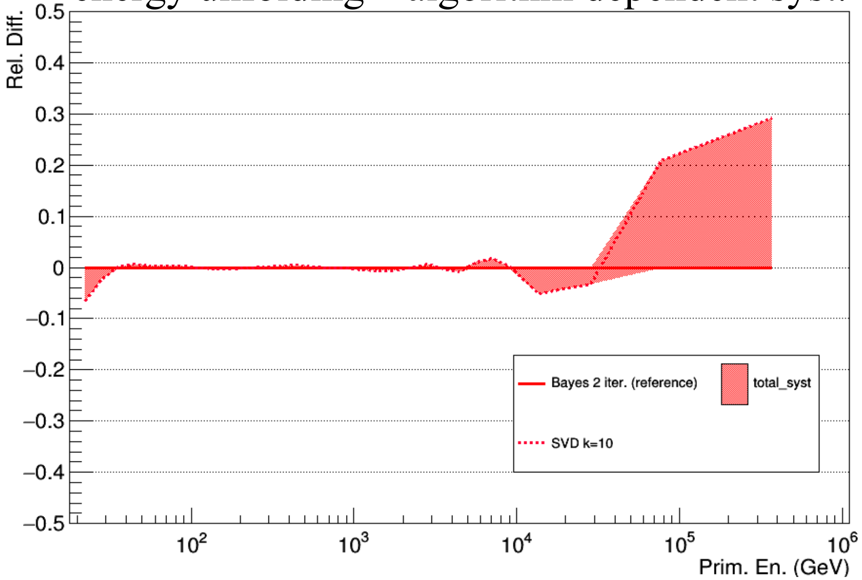
p energy shower corr. – value dependent syst.



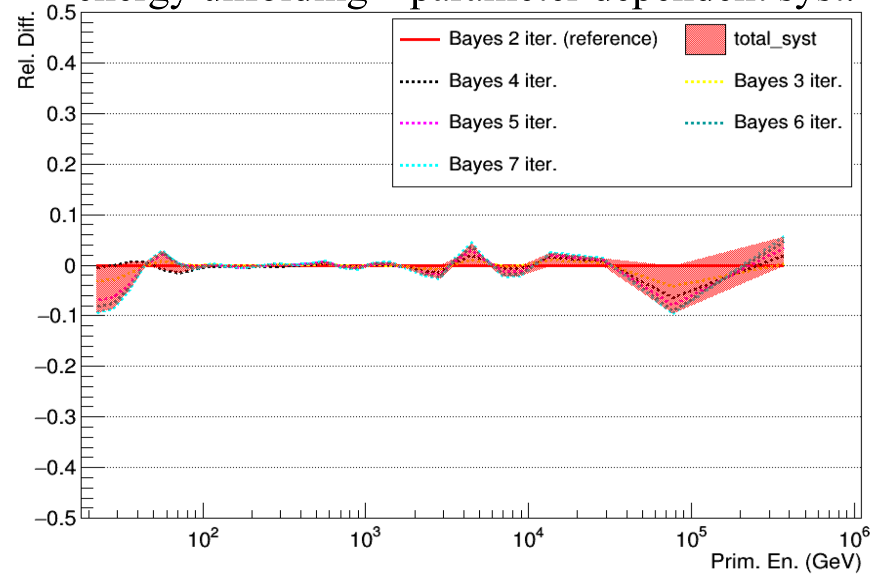
Preliminary systematic error evaluation: unfolding

The systematic error related to the unfolding procedure is evaluated as the maximum difference with respect to the reference flux (calculated with Bayes unfolding 2 iter.) and each other flux calculated with a different algorithm (SVD) or a different number of iterations or a different MC re-weighting.

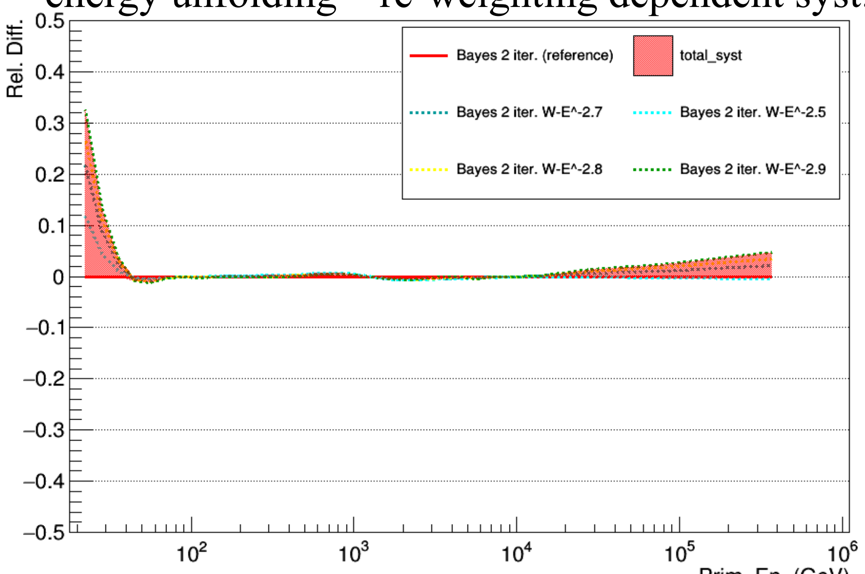
energy unfolding – algorithm dependent syst.



energy unfolding – parameter dependent syst.



energy unfolding – re-weighting dependent syst.

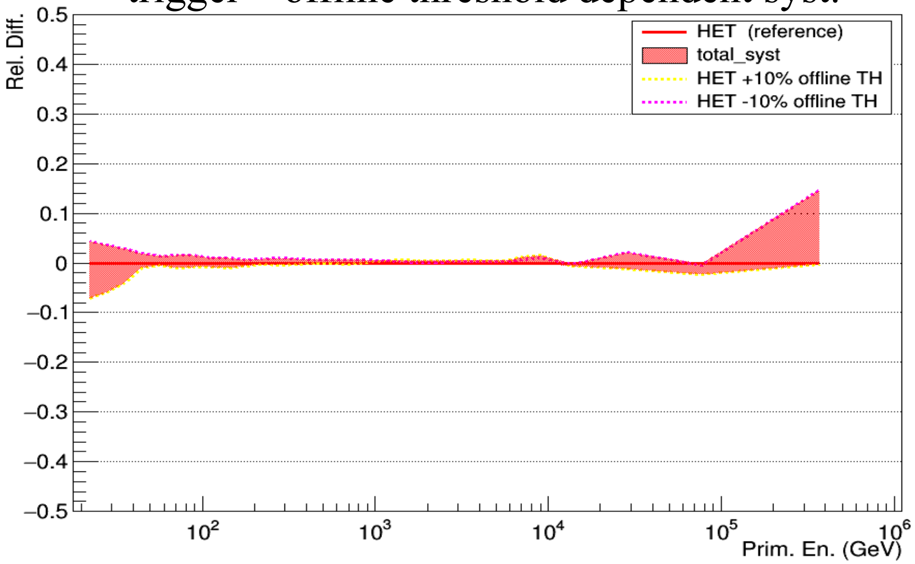


At present this systematic error has been evaluated using the PASS3.1 FD from 201512 to 201810, calculation with full statistic of PASS4 data is ongoing, even if no major differences are expected.

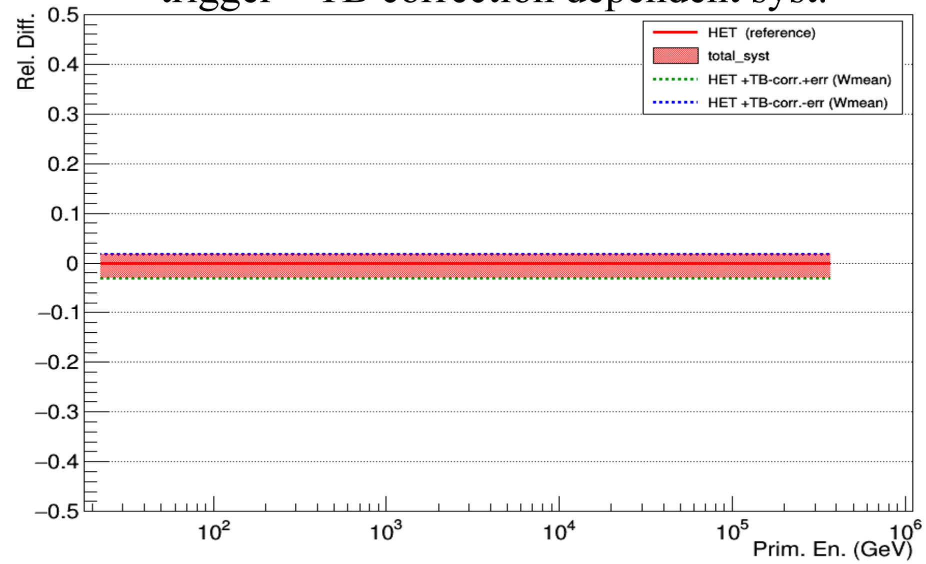
Preliminary systematic error evaluation: trigger

The systematic error related to the trigger cut is evaluated as the maximum difference with respect to the reference flux (calculated with the standard trigger) and the other fluxes calculated with a different offline trigger confirmation (+/- 10% offline thresholds) or the TB trigger correction.
TB trigger correction it is compatible with 1, and thus is not applied in this analysis, but has an uncertainty of about +2%,-3% that is considered in the systematic error calculation increasing the trigger efficiency of about ~2% or reducing it by ~3%.

trigger – offline threshold dependent syst.



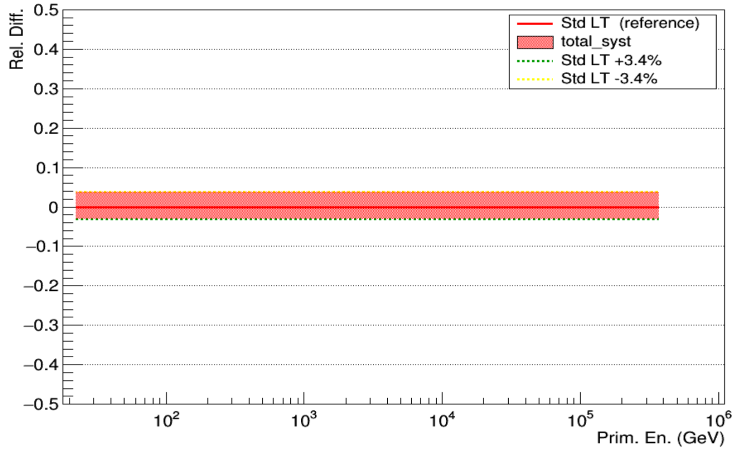
trigger – TB correction dependent syst.



At present this systematic error has been evaluated using the PASS3.1 FD from 201512 to 201810, calculation with full statistic of PASS4 data is ongoing, even if no major differences are expected.

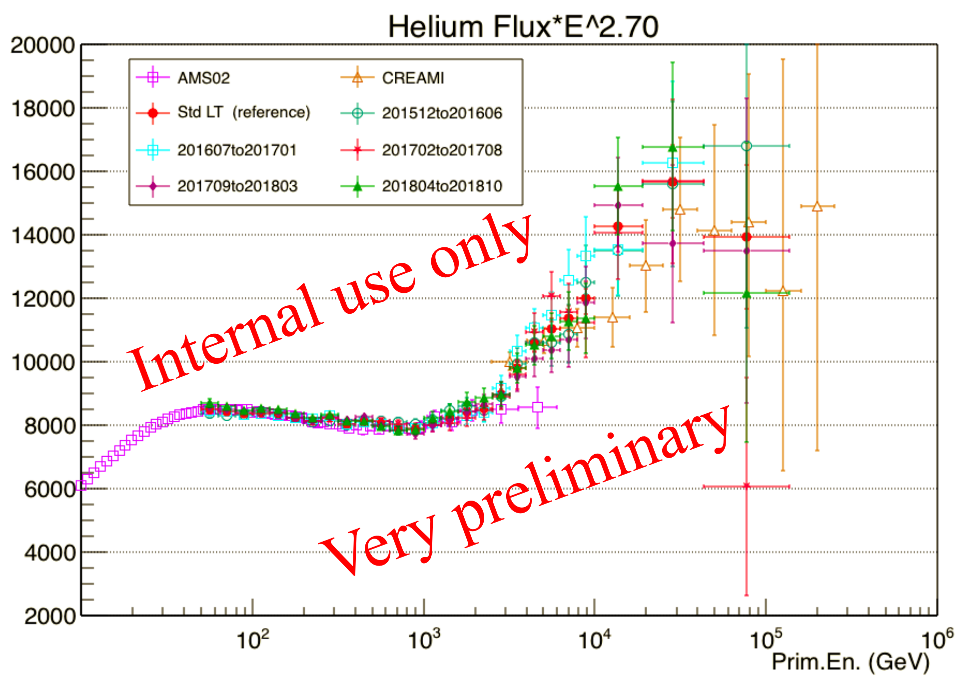
Preliminary systematic error evaluation: Live time

The systematic error related to the live time calculation is considered to be the same of previous publications, that was estimated in +/- 3.4%



Flux stability in time:

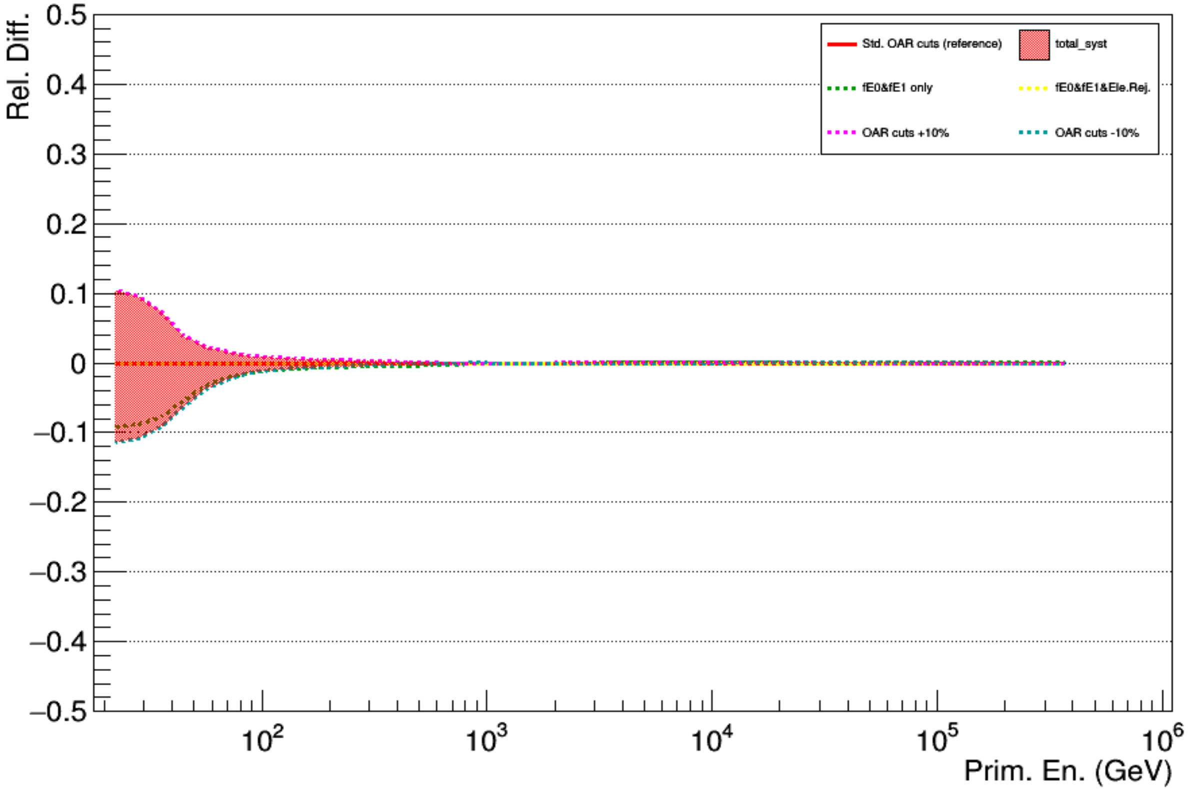
A preliminary evaluation of flux stability in time has been made computing the flux in 5 different period of 7 months each, the results are found to be compatible inside the statistical errors.



made with PASS3.1-FD
the calculation with PASS4 data is ongoing: no major differences are expected.

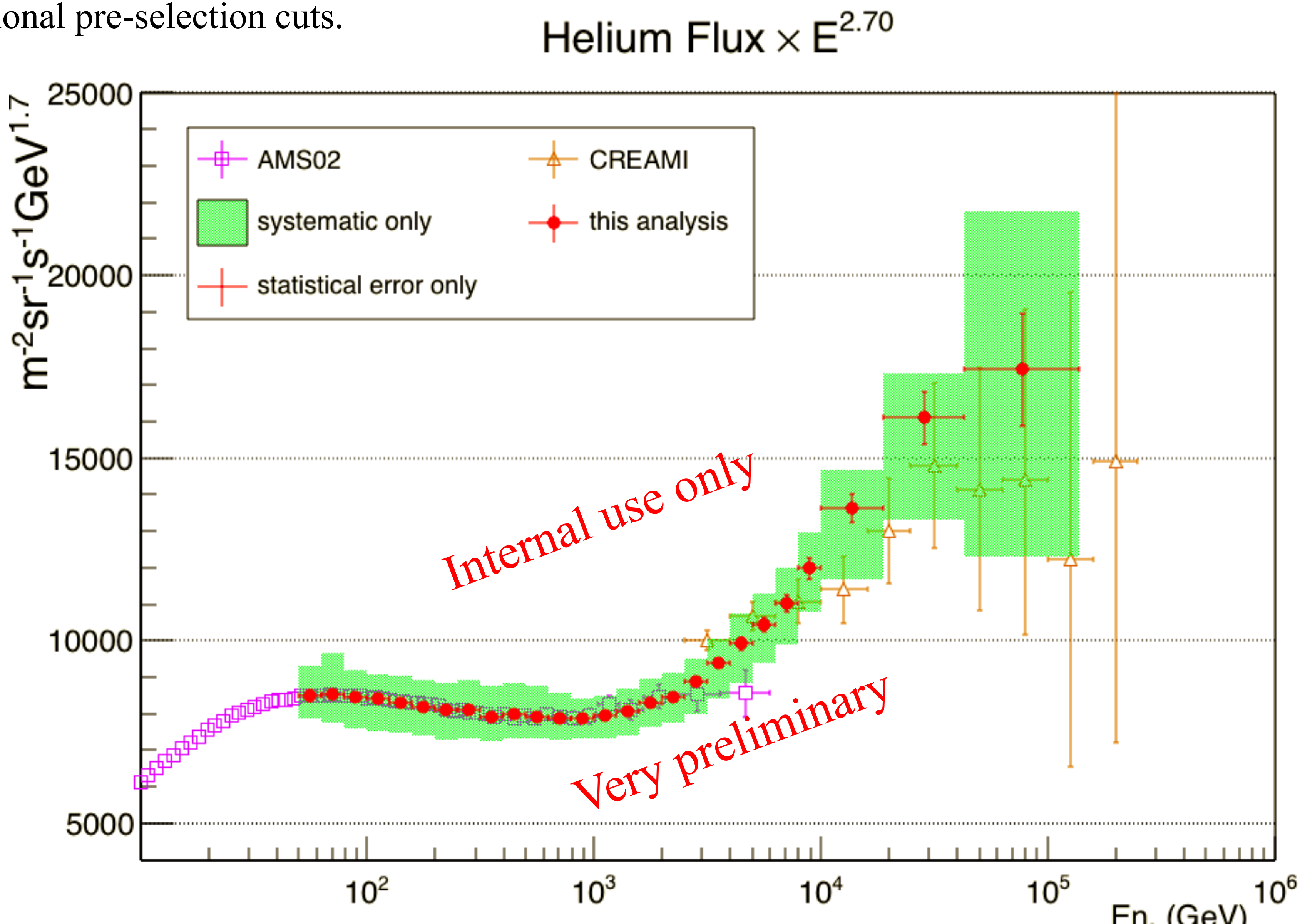
Preliminary systematic error evaluation: additional pre-selection

The systematic error related to the additional pre-selection cuts it is evaluated as the maximum difference with respect to the reference flux (calculated with the standard selection) and each other flux calculated varying the OAR cuts by +/- 10% and removing the other additional cuts one by one.



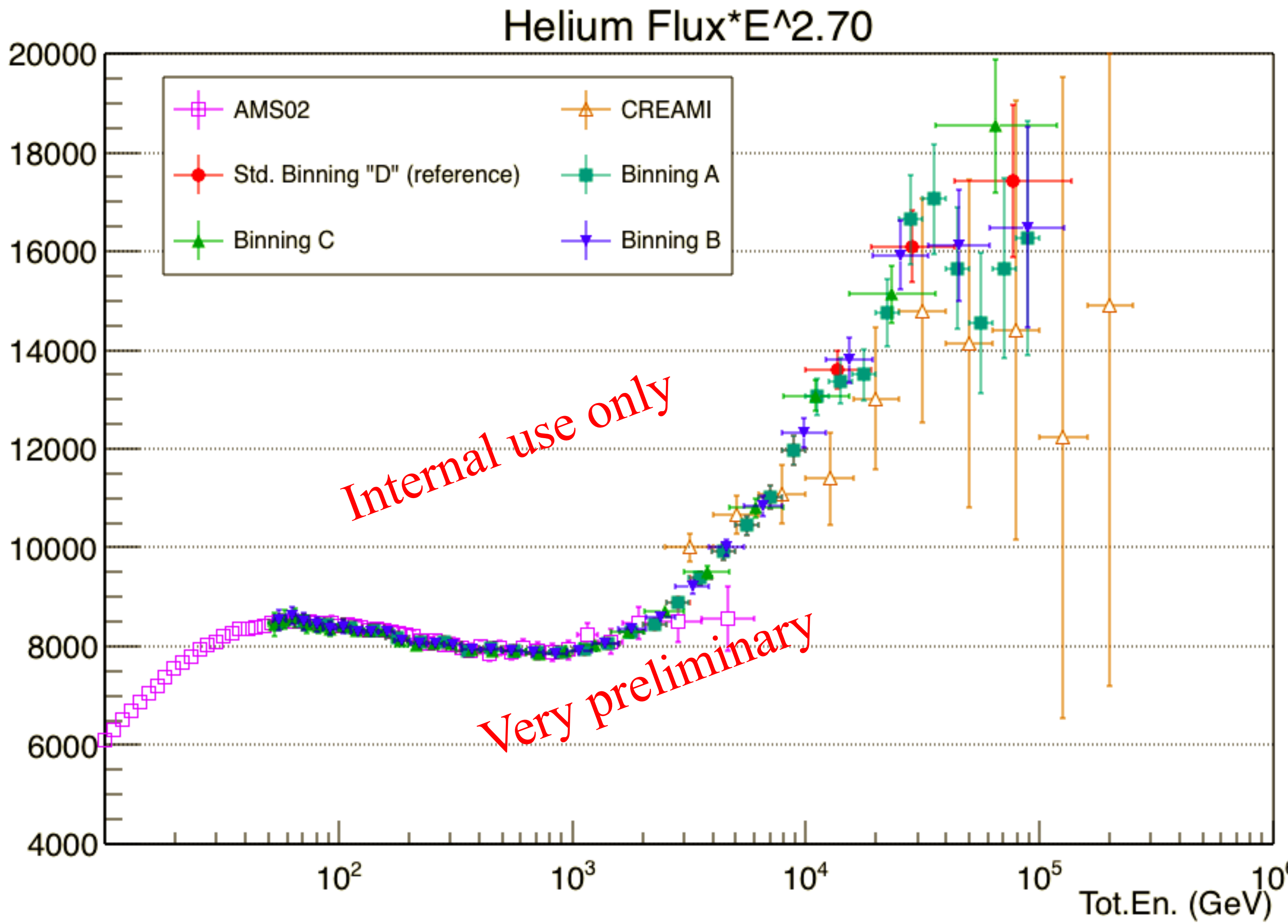
Preliminary helium flux with systematic

The preliminary measurement of the helium flux with 49 months of PASS4-FD (201510-201910) it is shown together with the statistical uncertainty (red line) and the total systematic uncertainty (square root of the sum of squares) evaluated at present, that include the contributions from: energy shower correction, charge cut, unfolding, background subtraction, acceptance, trigger, live time, additional pre-selection cuts.



Effects of binning on preliminary Helium Flux

- Binning A = 50 equal log bin with step 0.1 (equi-populated for f(E) = E^-1) "reference"
- Binning B = 50 equi-populated bins for f(E) = E^-1.25;
- Binning C = 50 equi-populated bins for f(E) = E^-1.35;
- Binning D (**standard**) = 34 bins, the first 30 are equi-populated for f(E) = E^-1 and the last 4 equi-populated for f(E) = E^-1.35
- Bins are calculated starting from 10 GeV up to 1 PeV, but only the range 50 GeV – 100 TeV it is shown.



Conclusions:

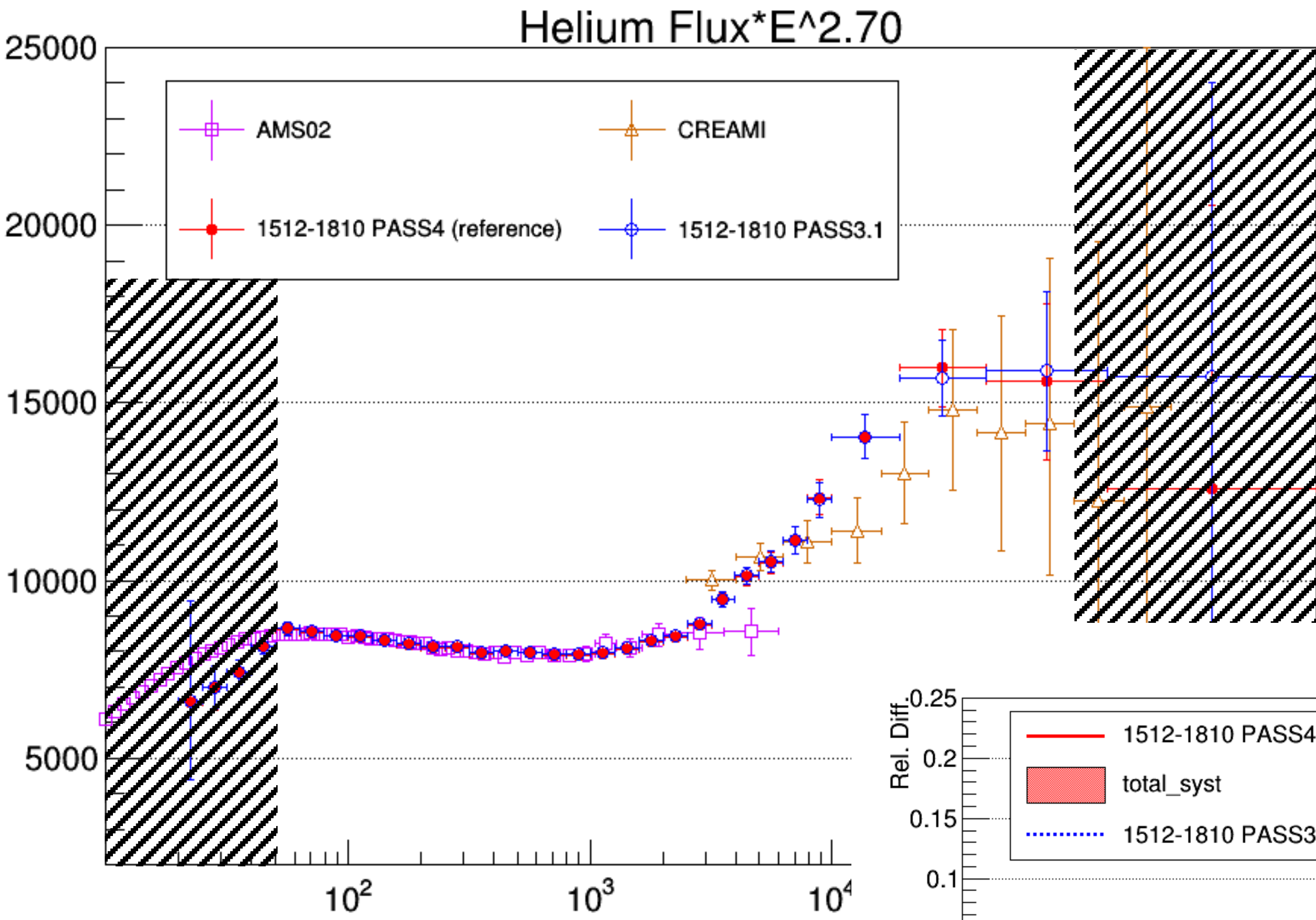
- a new energy shower correction (TB2015) has been applied;
- preliminary measurement of helium flux and preliminary systematic evaluation has been accomplished;
- the larger systematic uncertainties are related to energy shower correction (He) and charge cut (nevertheless inside 10%);

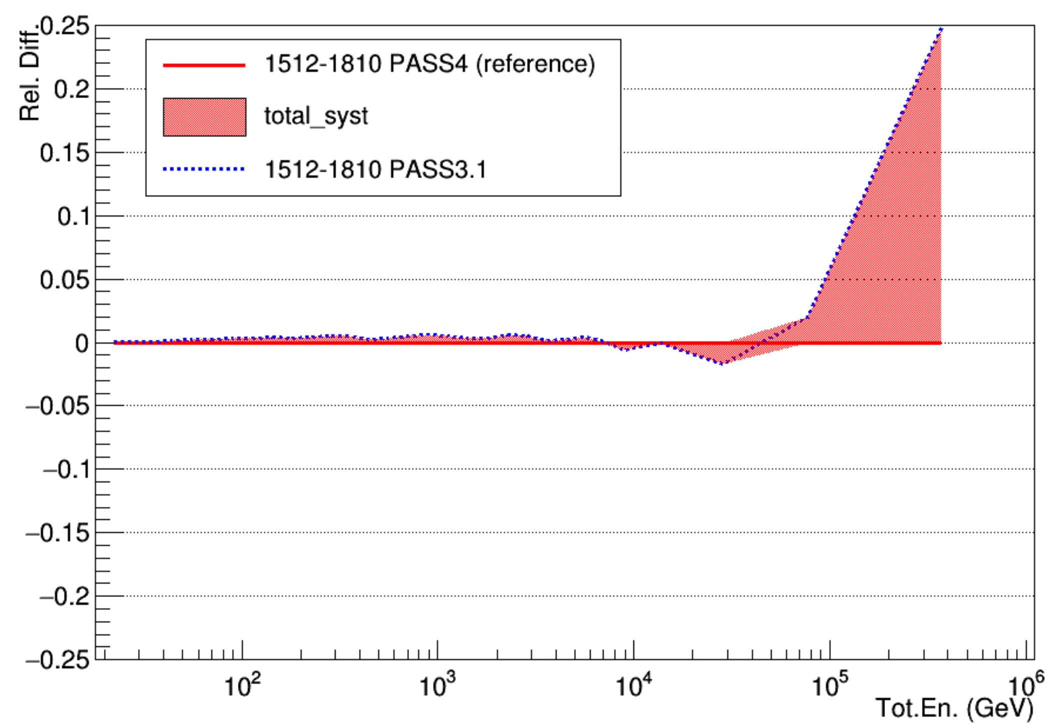
To do:

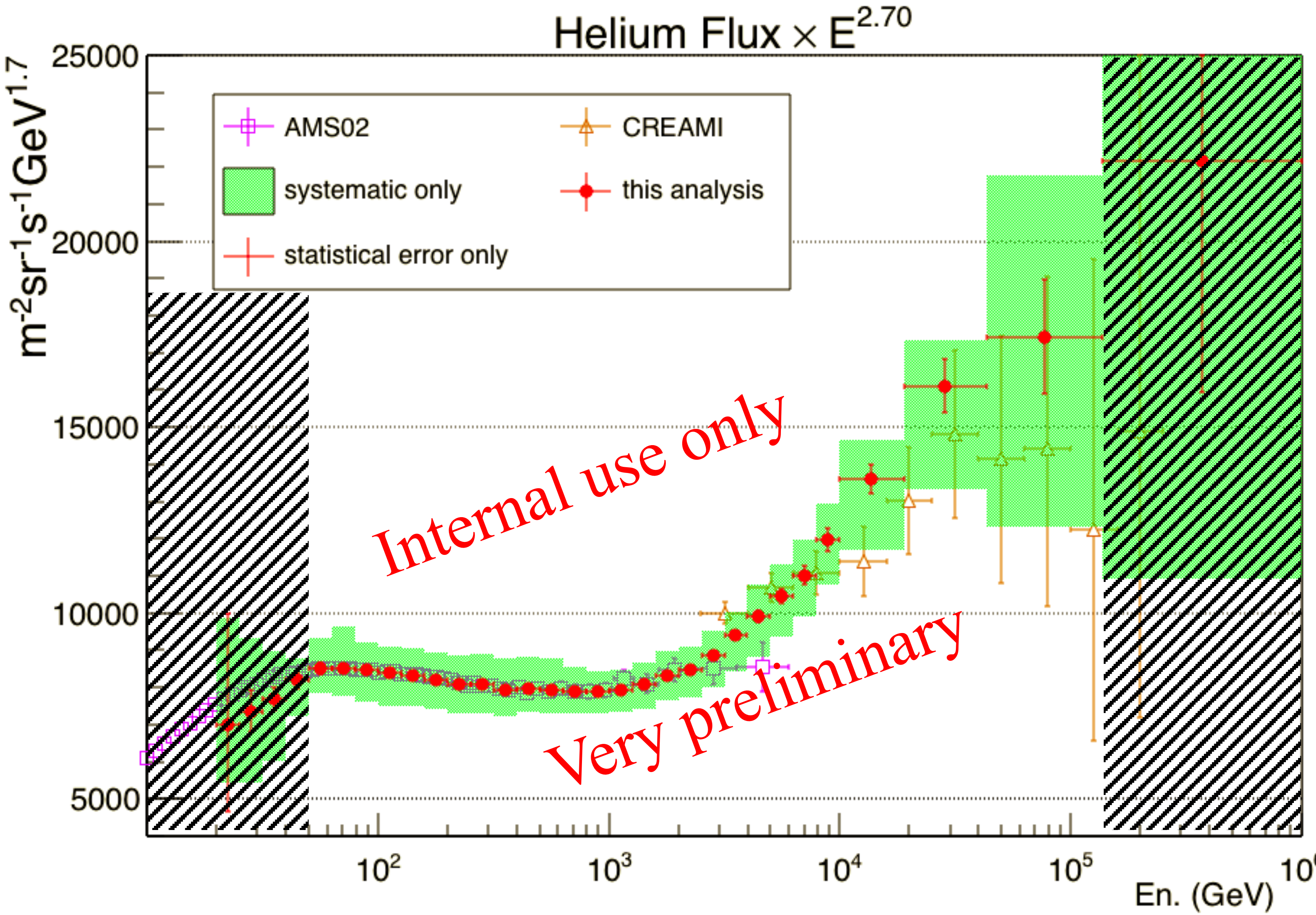
- evaluate missing systematics (MC model, tracking);
- recalculate systematics with PASS4 data;
- improve MC statistics;
- possibly improve: systematics, off-acc rej., charge cut.

BACKUP

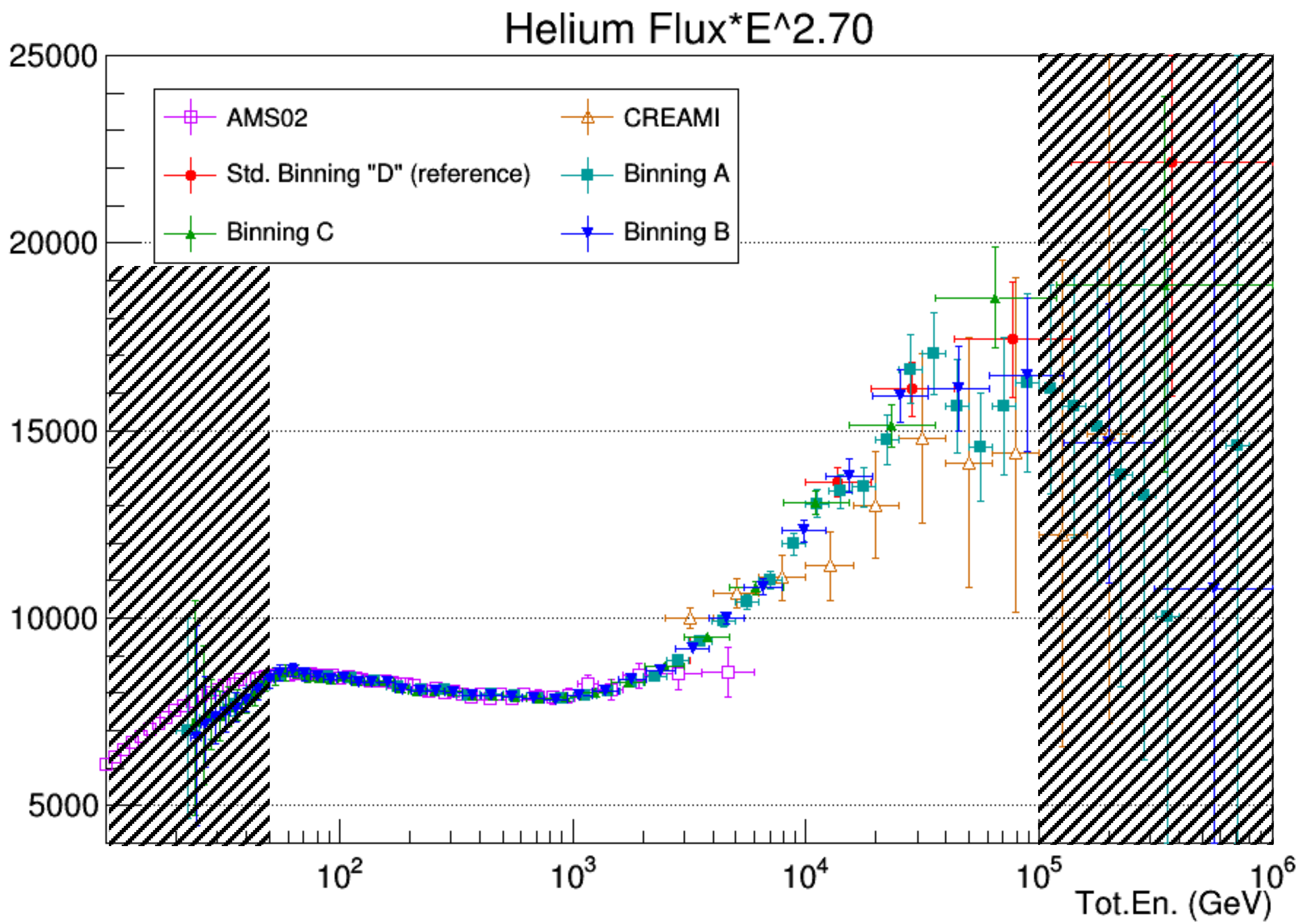
PASS4-FD vs PASS3.1-FD







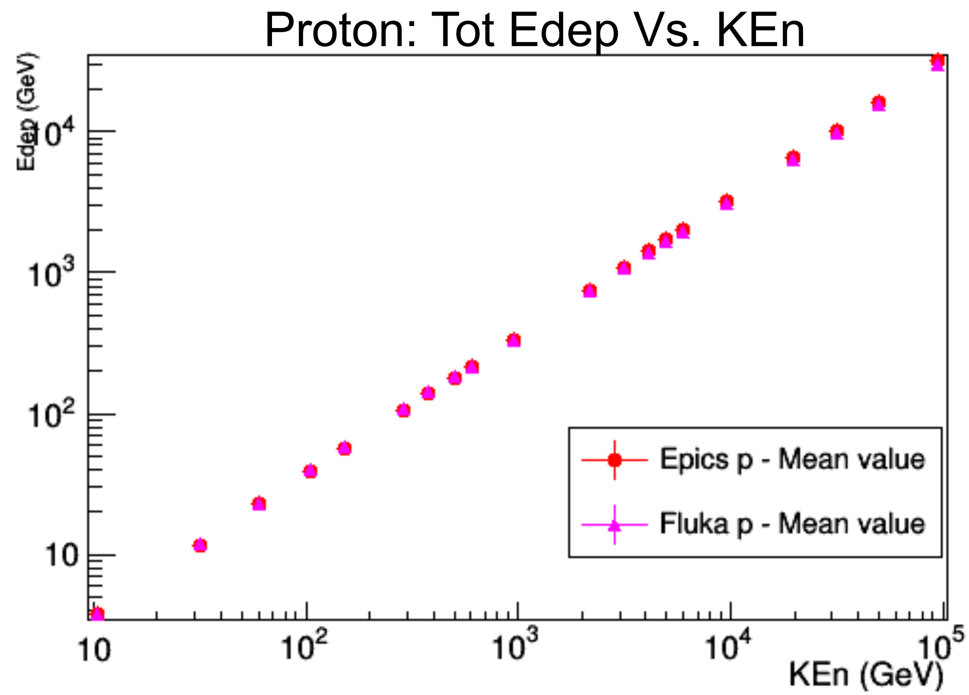
Helium Flux × $E^{2.70}$
$m^{-2}sr^{-1}s^{-1}GeV^{1.7}$
25000
20000
15000
10000
5000
AMS02
CREAMI
systematic only
this analysis
statistical error only
Internal use only
Very preliminary
10^2
10^3
10^4
10^5
10^6
En. (GeV)

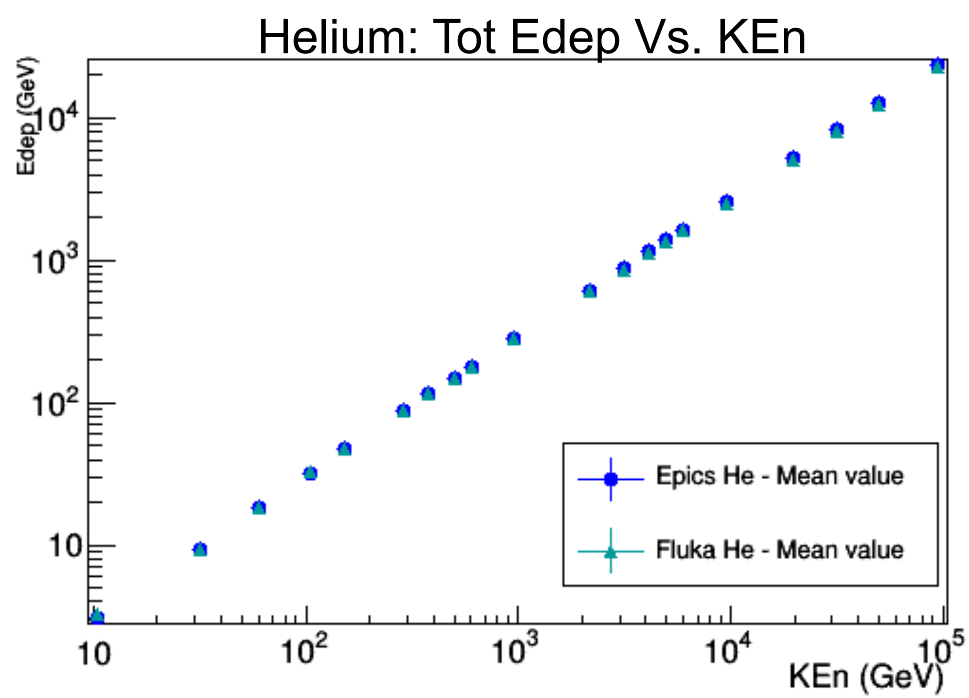


Helium Flux*E^2.70
25000
20000
15000
10000
5000
AMS02
Std. Binning "D" (reference)
Binning C
CREAMI
Binning A
Binning B
10^2
10^3
10^4
10^5
10^6
Tot.En. (GeV)

Epics VS Fluka

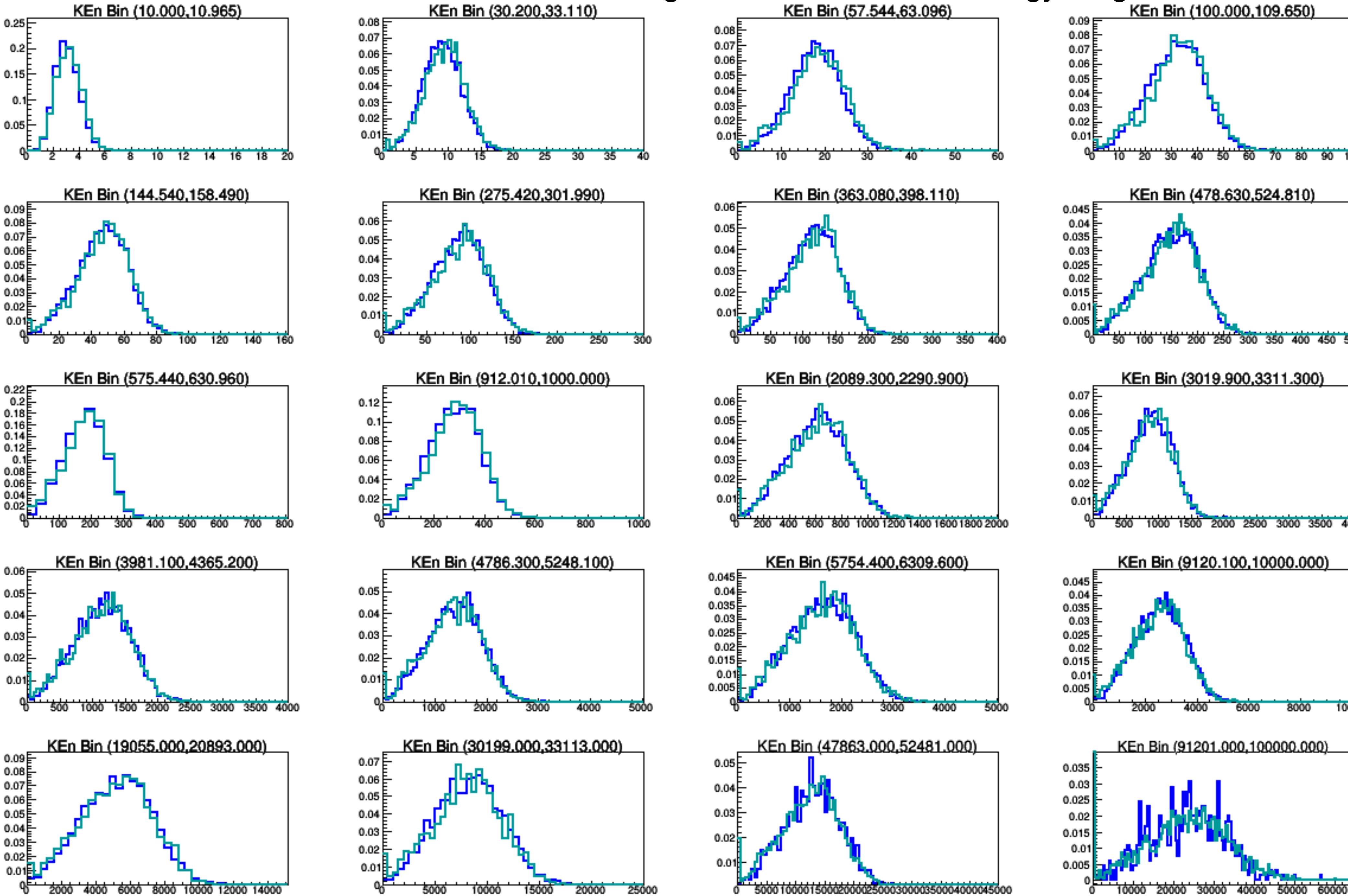
Very similar behaviour, for both proton and helium!





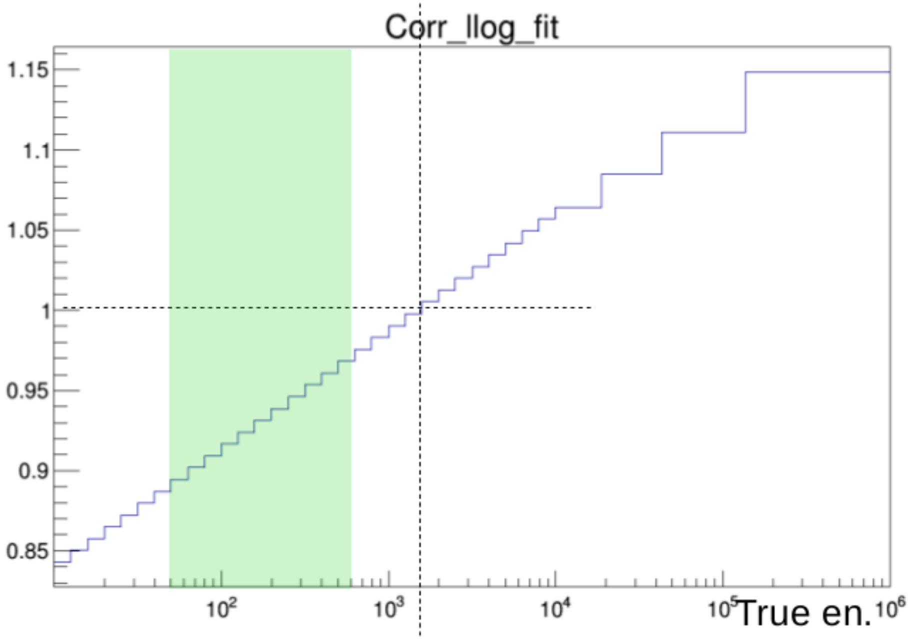
Helium: Epics VS Fluka (TASC total edep)

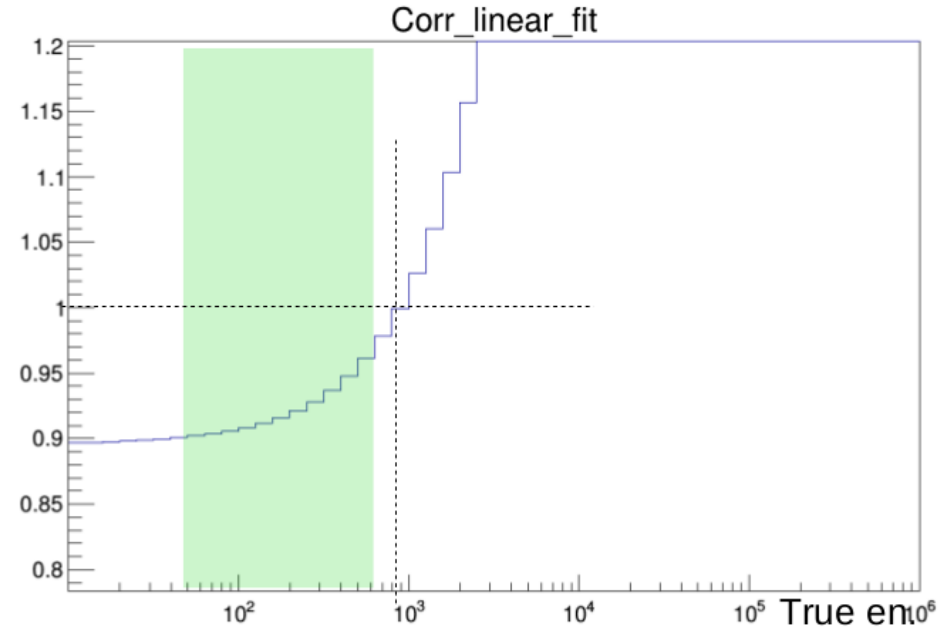
Quite similar behaviour for interacting events in the whole energy range



Blue is Epics and cyan is Fluka - All histograms are normalized to 1

Shower energy models: correction parameters (helium)

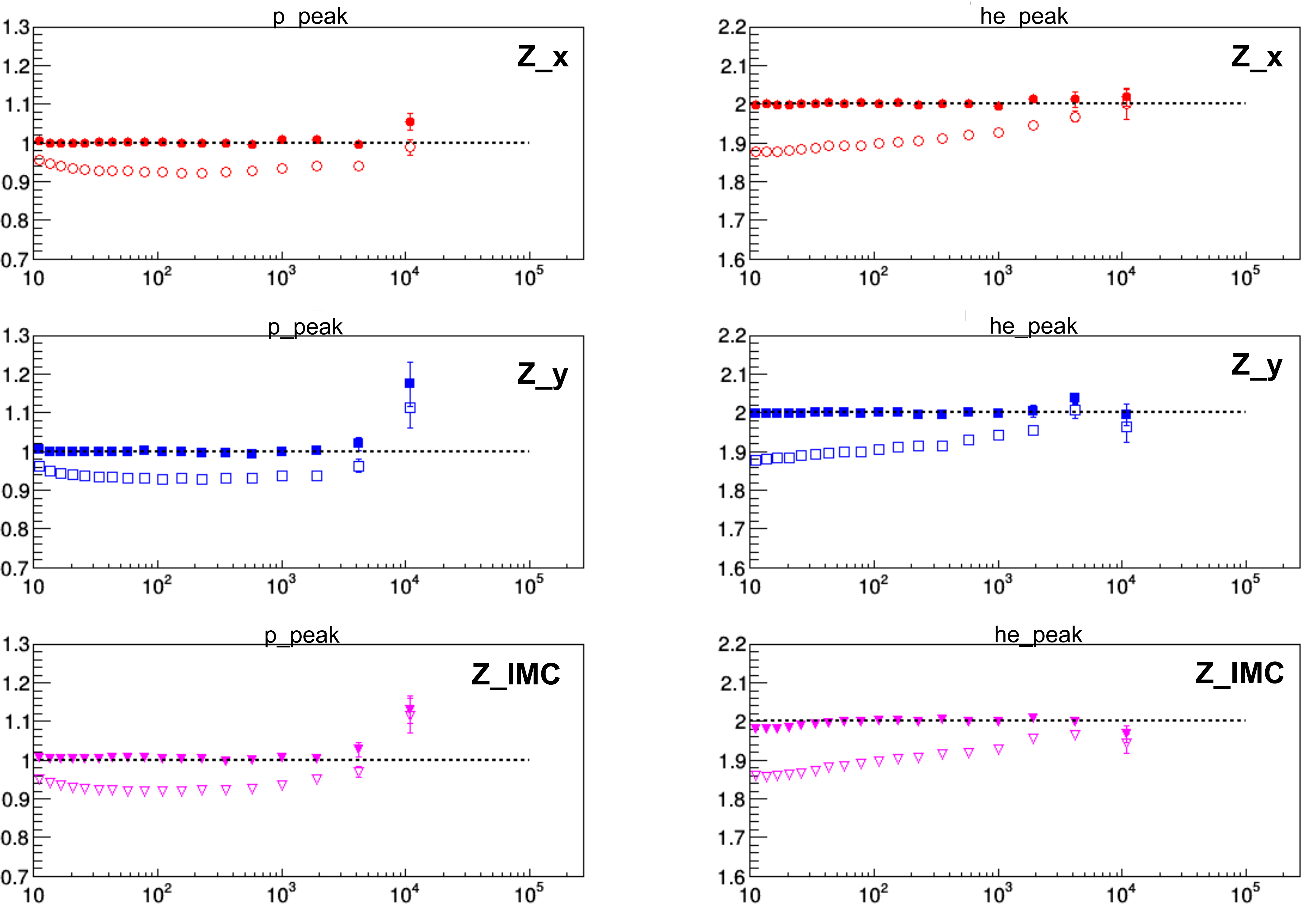




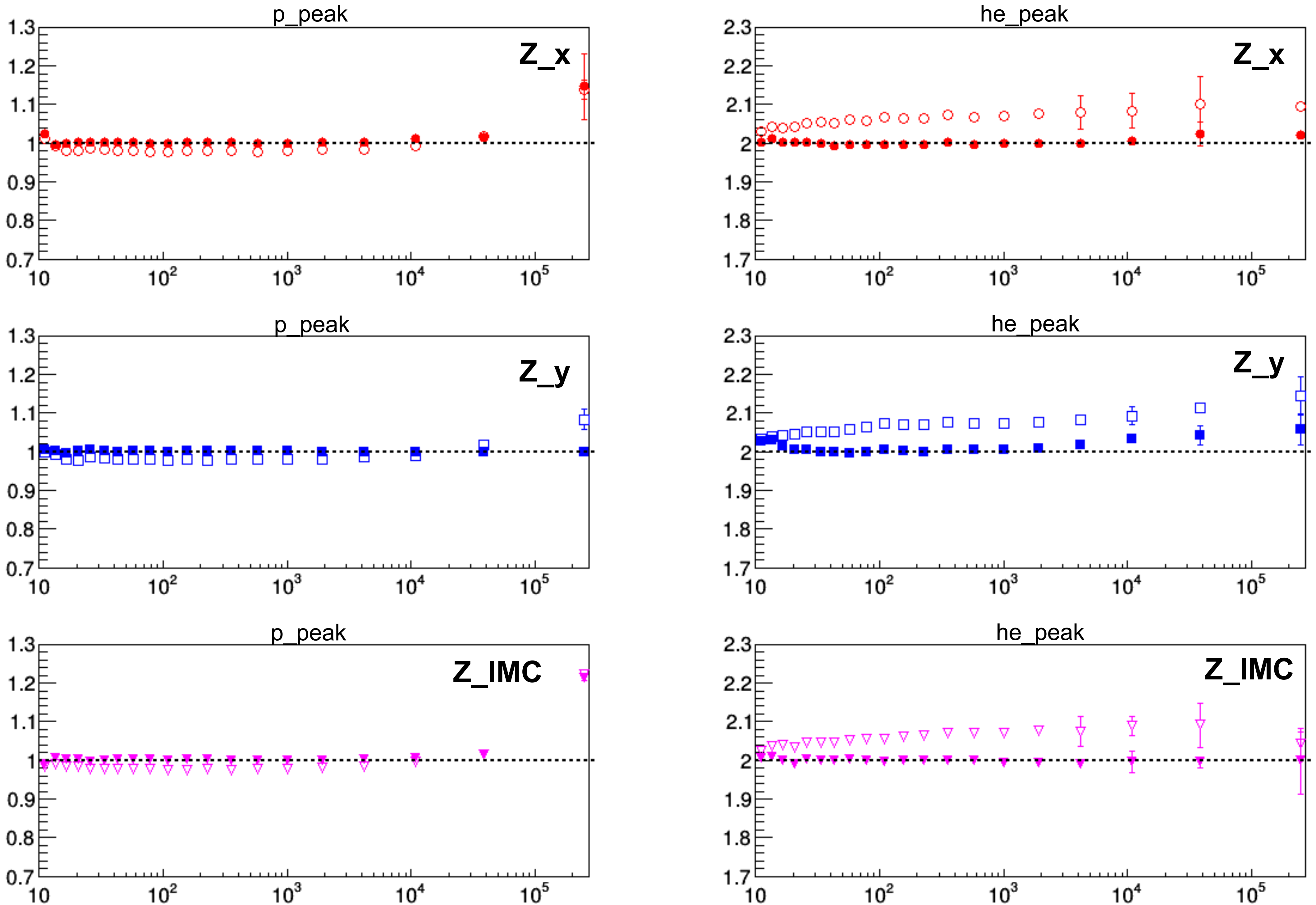
- Green shadow represents the range in which TB correction is evaluated.
- On y axis there is the “boosting” factor applied to MC deposited energy.
- The applied correction is continuous, here is represented in bins for simplicity.
- Makes sense to me extend the logarithmic and linear fit corrections above (and below) the “range” in which they are calculated, at least till 1.

True en.

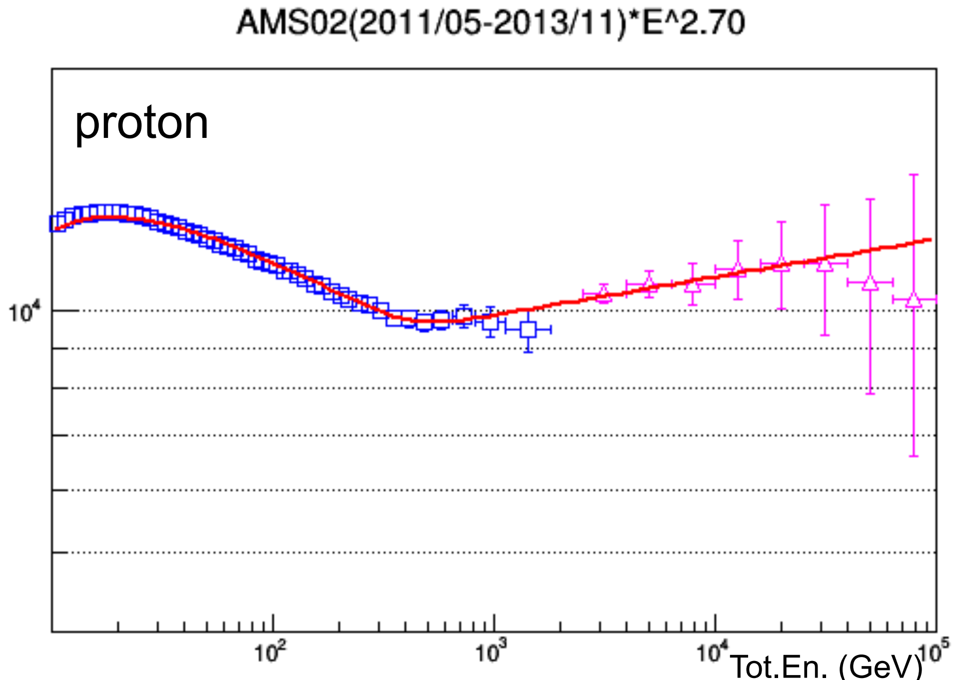
Flight Data: peak position before (open markers) and after (solid markers) ES correction, for different charges

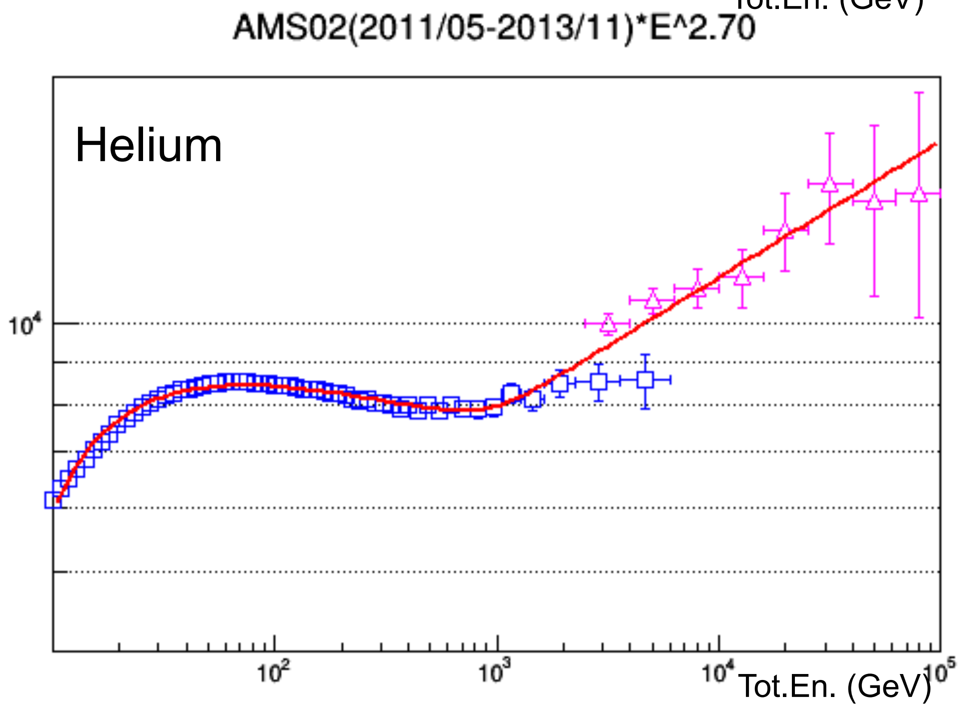


Epics MC: peak position before (open markers) and after (solid markers) ES correction, for different charges



NeW Re-Weighting with AMS02 + CREAMI fitted function – modelling also below 50 GeV ("Pacini" model – Gabriele fits)





Original AMS02 parametrization:

$$\Phi = C\left(\frac{R}{45\,\mathrm{GV}}\right)^{\gamma}\left[1+\left(\frac{R}{R_0}\right)^{\Delta\gamma/s}\right]^{s}$$

New parametrization:

$$\Phi = p0\left(\frac{x}{45.}\right)^{p1}\left[1+\left(\frac{x}{p2}\right)^{(p3/p4)}\right]^{p4}\left(1 \quad \frac{p5}{x} \quad \frac{p6}{x^2}\right)$$

Proton parameters:
p0 = 0.4545;
p1 = -2.846;
p2 = 430.;
p3 = 0.1927;
p4 = 0.04003;
p5 = 2.547;
p6 = -1.841;

Helium parameters:
p0 = 0.3163;
p1 = -2.761;
p2 = 904.;
p3 = 0.2264;
p4 = 0.05299;
p5 = 4.14;
p6 = 0.;