On the acceptance extension of electron analysis

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Outline

- **The Firenze CALET team** involved in electron analysis is working on the **acceptance extension** (from Acc A to Acc ?) of the electron analysis
- The starting point is *CALET PRL 120, 261102*, where the energy flux was computed using:
  - A+B below 475 GeV
  - A+B+C+D above 475 GeV
- The **main aim** of our work is to give an independent measurement that, even with lower statistics, could be used to **crosscheck or improve the PRL result**

Idea

	PRL result	This analysis
Strategy	The analysis is divided into **four sub-analysis**, one for each acceptance, which are combined in the end	The analysis is **unique**, relative to an acceptance redefinition, a bit larger than acceptance A
Advantages	• **We completely exploit CALET geometric factor** • We optimize the analysis for each acceptance	• We have a simple, unique procedure • **We have a better control on the result**
Disadvantages	• Different corrections, functions, variables must be defined for each one of the four acceptances • Careful optimization of all sub-analyses takes time	• Only a subset of CALET geometric factor is used • Corrections, functions and variables must be a compromise between event categories

Challenge

OBSERVATION *Treatment of Helium background*:

- The electron (e) signal has both proton (p) and Helium (He) background, which must be suppressed
- p background is unavoidable before rejection (*e.g.* BDT), but He background can be suppressed using **charge cut**
- Making use of an efficient charge cut that remove He at the beginning, the validation of the whole analysis is dramatically simplified, because it allows us to consider only one source of background (p) over the signal (e)

REQUIREMENT *The new acceptance must be defined in a way that allows us to neglect He background after Charge cut, without a dramatic decrease of electron selection efficiency.*

Study of Charge Reconstruction

Charge reconstruction

MOTIVATION Charge reconstruction was deeply studied for events crossing CHD, but in order to extend the acceptance we need to study charge reconstruction for events crossing IMC, but not necessarily CHD

For this purpose:

- We look for the first IMCiX-IMCiY layers traversed by the incoming particle in the detector
- We consider the energy deposit within 5 fibers from the reconstructed track on IMCiX and IMCiY
- We define an IMC charge completely equivalent to CHD charge using IMC layer *i*

$$IMC_i = \sqrt{[0.5*(IMCiX^2 + IMCiY^2)]} * \cos(\theta)$$

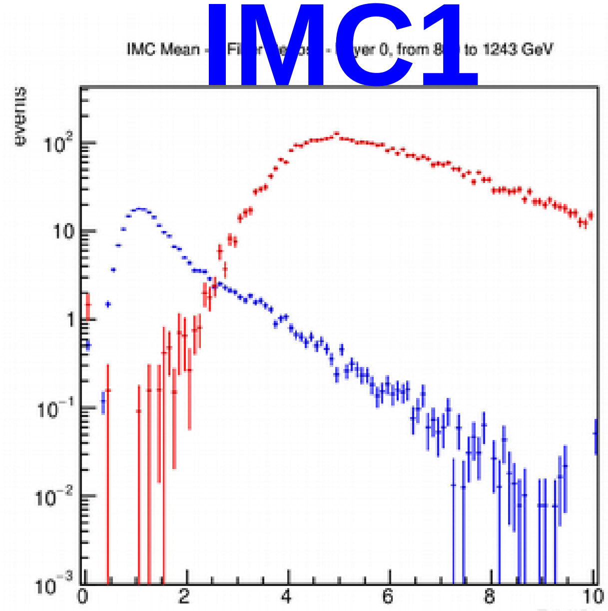
800 GeV < E < 1243 GeV

Charge in IMCX

Electron
Helium

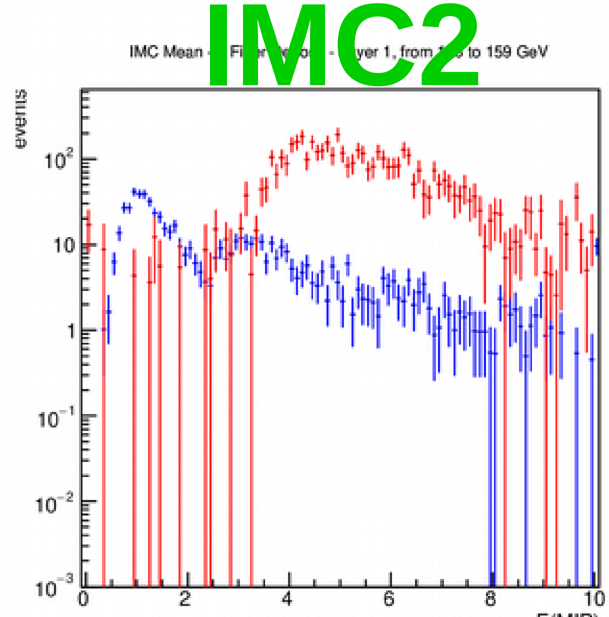
Particle enters the detector before IMCX but after IMC(X-1)

IMC1



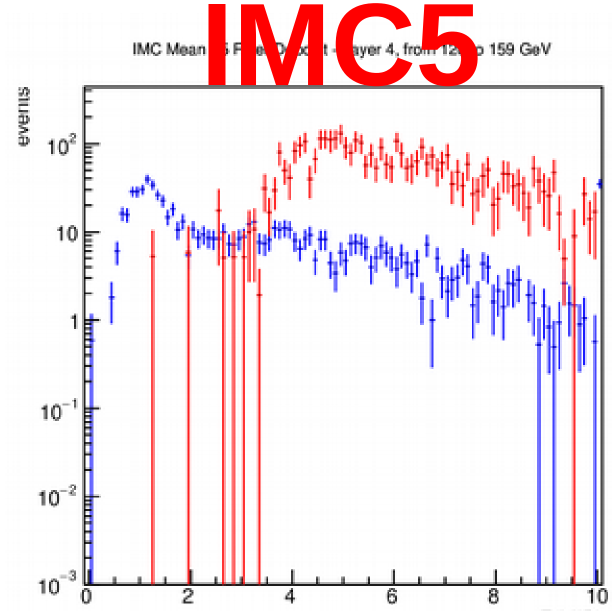
IMC Charge

IMC2



IMC Charge

IMC5



IMC Charge

Good separation

Bad separation

Good separation, large tails

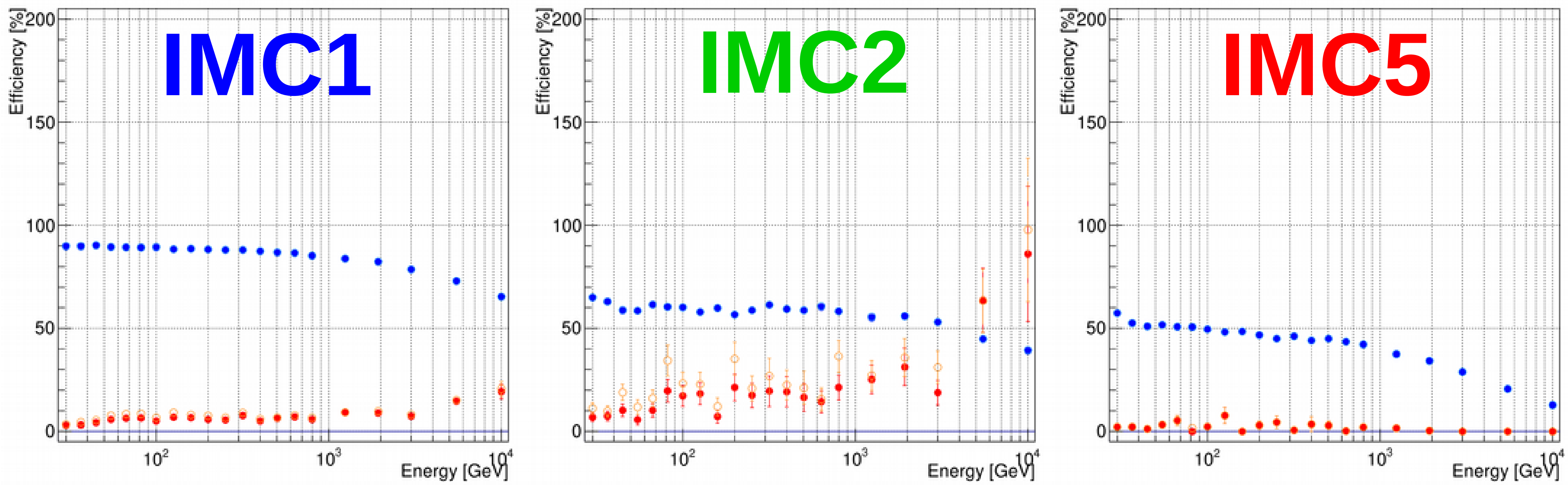
Electron selection

<u>IMC charge < 2.5 MIP</u>

- Efficiency (N_e^{cut}/N_e^{tot})
- Contamination (N_{He}^{cut}/N_e^{cut})

N_e^{tot} = number of *e* above 0 MIP

N_e^{cut} = number of *e* in [0.3, thr] MIP



Contamination < 10% Efficiency < 80%	Contamination < 30% Efficiency < 50%	Contamination < 5% Efficiency < 50%

Some comments

SUMMARY Charge reconstruction in IMC using only the first IMCiX-IMCiY layers traversed by the incoming particle in the detector does not lead to good performances

OBSERVATION In order to increase reconstruction performances we can use all IMC layers, starting from the entrance one, that have the same W thickness (0.2 X_0) between them:

- IMC1X,IMC1Y,IMC2X,... IMC6Y for entrance before IMC1
- IMC2X,... IMC6Y for entrance before IMC2

...

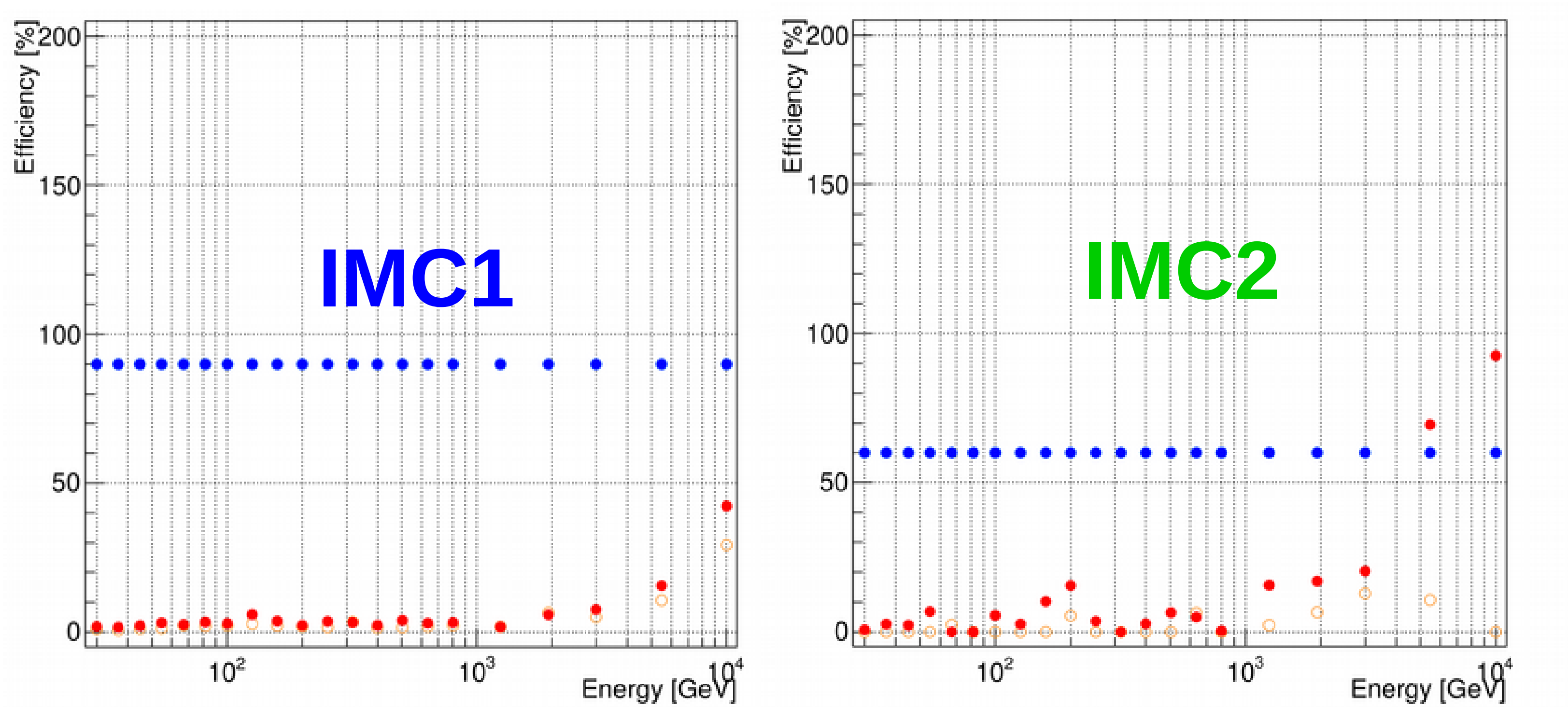
- IMC5X,... IMC6Y for entrance before IMC5

STRATEGY The IMC charge is obtained from **BDT** applied to all these variables (+ track length before first IMC layers), <u>separately training each sample according to the first IMCiX-IMCiY layers traversed by the incoming particle in the detector</u>

BDT charge

- Efficiency (N_e^{test}/N_e^{total})
- Contamination $(N_{He}^{test}/N_e^{test})$
- Efficiency $(N_e^{train}/N_e^{total})$
- Contamination $(N_{He}^{train}/N_e^{train})$

N_e^{test} = number of *e* above threshold in test sample
N_e^{total} = number of *e* events in the all sample (test or train)

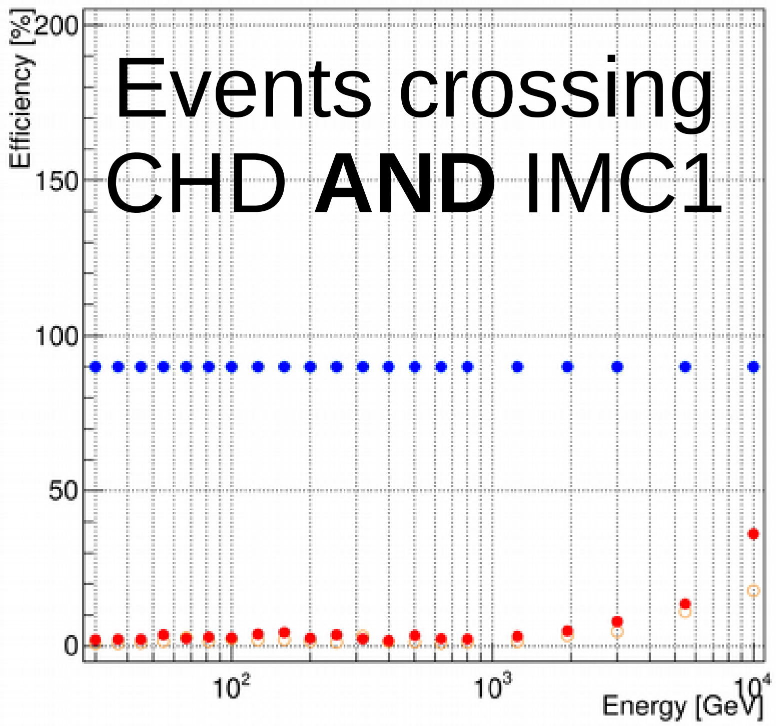


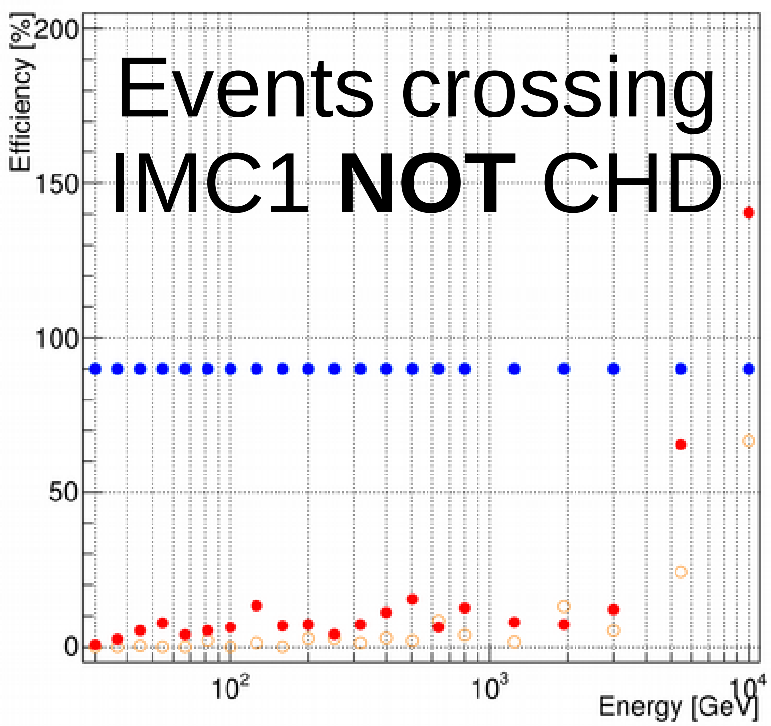
Despite a clear improvement, we were not able to get low **<u>He contamination</u>** and high **<u>e efficiency</u>**

BDT charge

- Efficiency (N_e^{test}/N_e^{total})
- Contamination (N_{He}^{test}/N_e^{test})
- Efficiency (N_e^{train}/N_e^{total})
- Contamination ($N_{He}^{train}/N_e^{train}$)

N_e^{test} = number of *e* above threshold in test sample
N_e^{total} = number of *e* events in the all sample (test or train)





Furthermore, the best reconstruction performances are obtained for the events crossing CHD as well

Definition of a new Acceptance

Some comments

SUMMARY Charge reconstruction in IMC is very difficult and is working only for events where the incident particle transverses IMC1: however, even in this case, we need to use information from IMC1X,...,IMC6Y, eventually correct MC charge for each layer and finally apply BDT algorithm

QUESTION Which is the relative gain in statistics?

METHOD Considering the events belonging to Acceptance *(A) OR (B) OR (C) OR (D)*, we can study which is the **relative gain in statistics** respect to Acceptance A using one of this three extended acceptances:

- E - Particles crossing CHD
- F - Particles crossing IMC1
- G - All Particles (A+B+C+D)

Idea

The relative gain in statistics is expressed in terms of relative gain in the geometric factor (GF) and in the effective geometric factor (EGF = GF x ε).

For our computation, we assume that the difference in selection efficiency ε is due to **charge selection** only, whereas all others selections do not have any impact.

We roughly assume ε:

- **100%** if charge is reconstructed using **CHD**
- **90%** if charge is reconstructed using **IMC1**
- **60%** if charge is reconstructed using **IMC2, 3, 4** or **5**

Estimation

	EGF	Relative σ_{STAT} in Acc X / Relative σ_{STAT} in Acc A (1/√EGF)
Acc G/A	2.00	0.71
Acc F/A	1.60	0.79
Acc E/A	1.55	0.80

NOTE Using the reconstruction methods currently available, we can reduce statistical uncertainty by at most 30% if we consider the analysis based on Acceptance G (A+B+C+D), but it is challenging

CONCLUSION Given the 20% reduction in statistical uncertainty and the relative simplicity of the analysis, in this work we decided to study the **feasibility of an analysis based on Acceptance E**

Setting up the analysis for Acceptance E

Acceptance E

	x < A [cm]	y < B [cm]	@ z [cm]
CHD X	44.969	45.0	0.7005
CHD Y	45.0	44.969	1.8535

AND

	Trk.Len. > C [cm]
TASC	26.42

	Fraction of other acceptances
A	100%
B	100%
C	0%
D	33%

Expected geometric factor (to be confirmed in future using simulations)
642 cm^2sr

Preselection

- HET Software trigger
- Good Kalman filter track in IMC
- Track inside Acceptance E
- Charge cut CHD < 3.5 MIP
- TASC Consistency < 2 cm
- TASC Concentration < 0.8
- Shower Track < 10°
- Gamma Fit Consistency
- Shower Concentration > 0.5

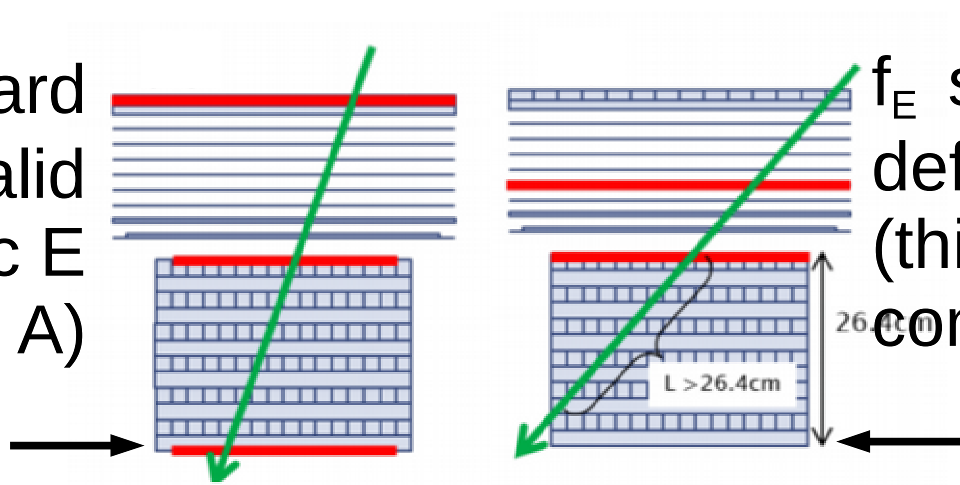
f_E definition

MOTIVATION The variable f_E ($dE_{TASC\text{-}Y6}/\Sigma_I dE_{TASC\text{-}i}$) must be redefined because the particle can exit before TASC6Y.

STRATEGY We defined and test 3 different f_E:

- Standard approach: F_E from TASC Y6 (as in Acc A)
- Alternative approach: F_E from the last TASC layer transversed for at least half the log depth, appropriately correcting the energy deposit in it for the fraction of transversed log depth

f_E standard definition is valid (this event in Acc E comes from Acc A)



f_E standard definition isn't valid (this event in Acc E comes from Acc D)

TASC-Y6

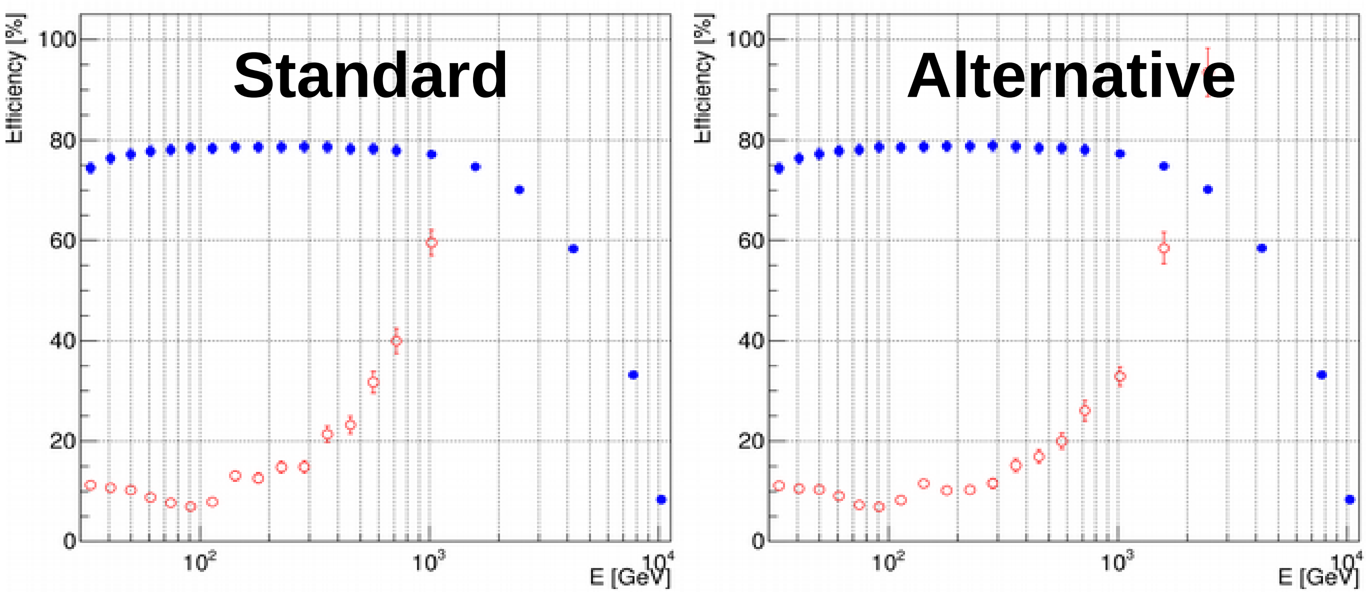
TASC-Y6

K cut rejection

$K = \log_{10}(f_E) + 0.65 x R_E$

Efficiency (N_e^{cut}/N_e^{tot})

Contamination (N_p^{cut}/N_e^{cut})



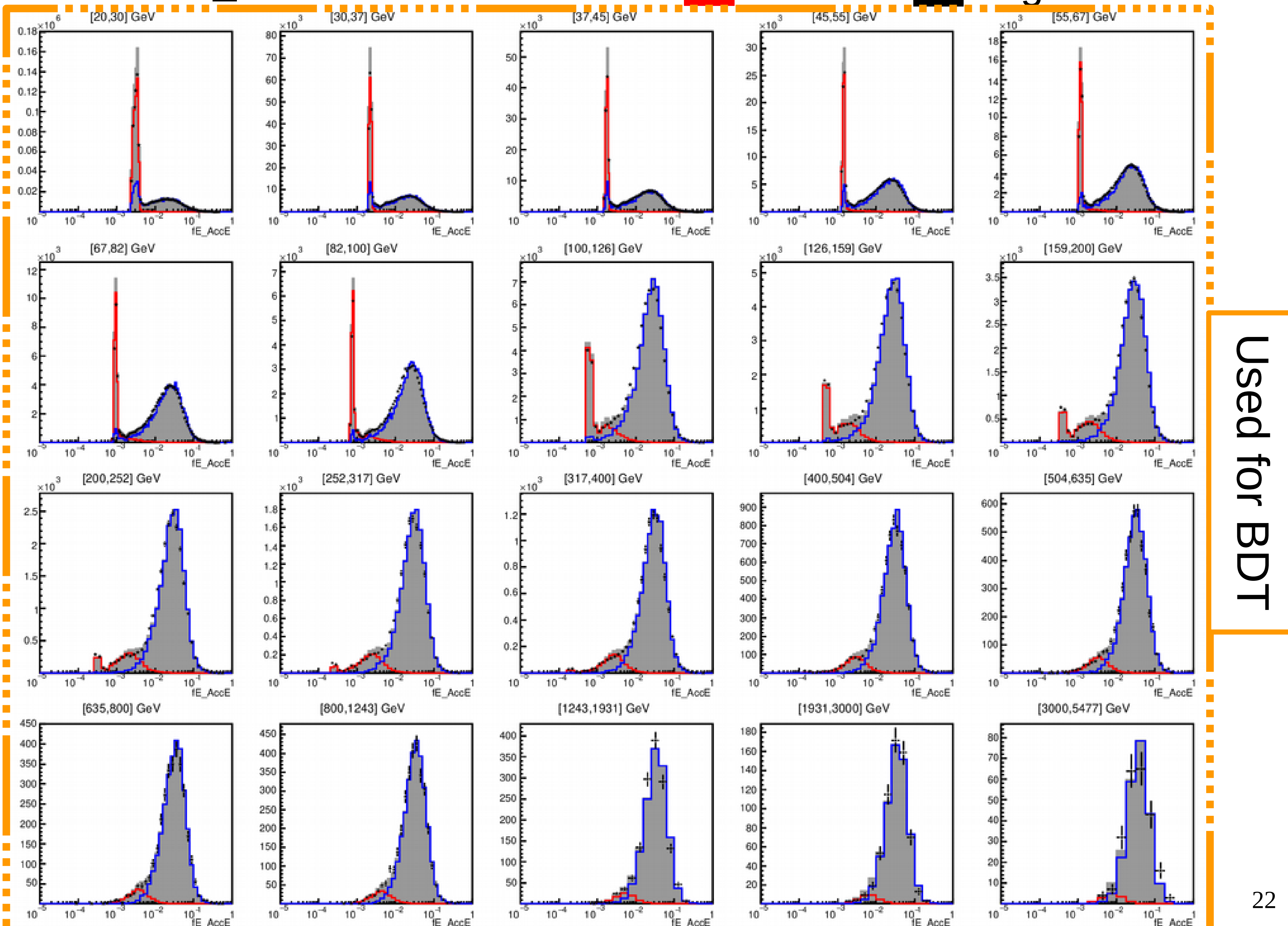
As expected, the Standard approach obviously fails, whereas the Alternative approach is the best one

Alternative f_E definition is used in this analysis

FD-MC distributions comparison after Preselection

f_E

EPICS

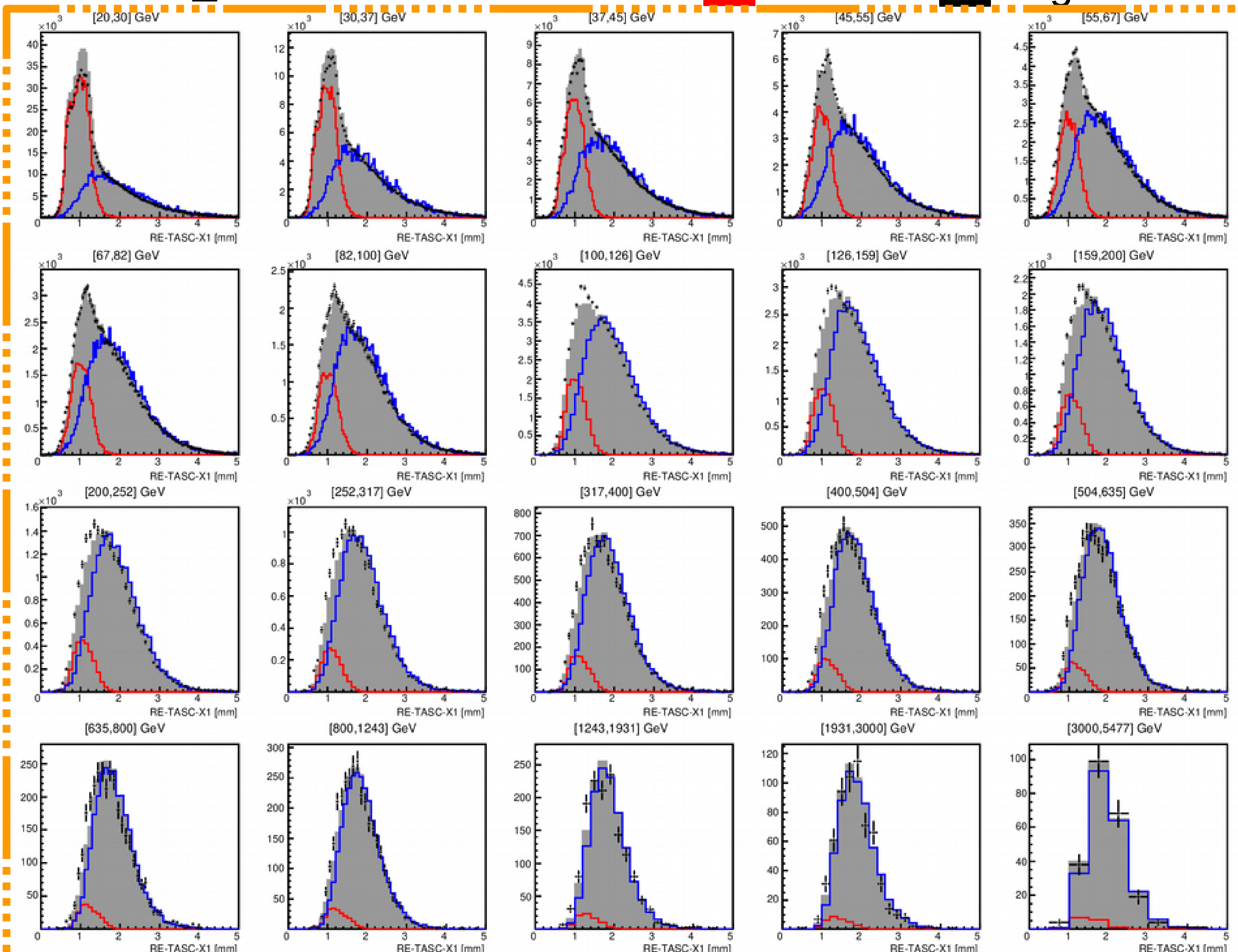


Proton
Electron
Proton+Electron
Flight Data
[20,30] GeV
[30,37] GeV
[37,45] GeV
[45,55] GeV
[55,67] GeV
[67,82] GeV
[82,100] GeV
[100,126] GeV
[126,159] GeV
[159,200] GeV
[200,252] GeV
[252,317] GeV
[317,400] GeV
[400,504] GeV
[504,635] GeV
[635,800] GeV
[800,1243] GeV
[1243,1931] GeV
[1931,3000] GeV
[3000,5477] GeV
fE_AccE
Used for BDT

$R_E[0]$

EPICS

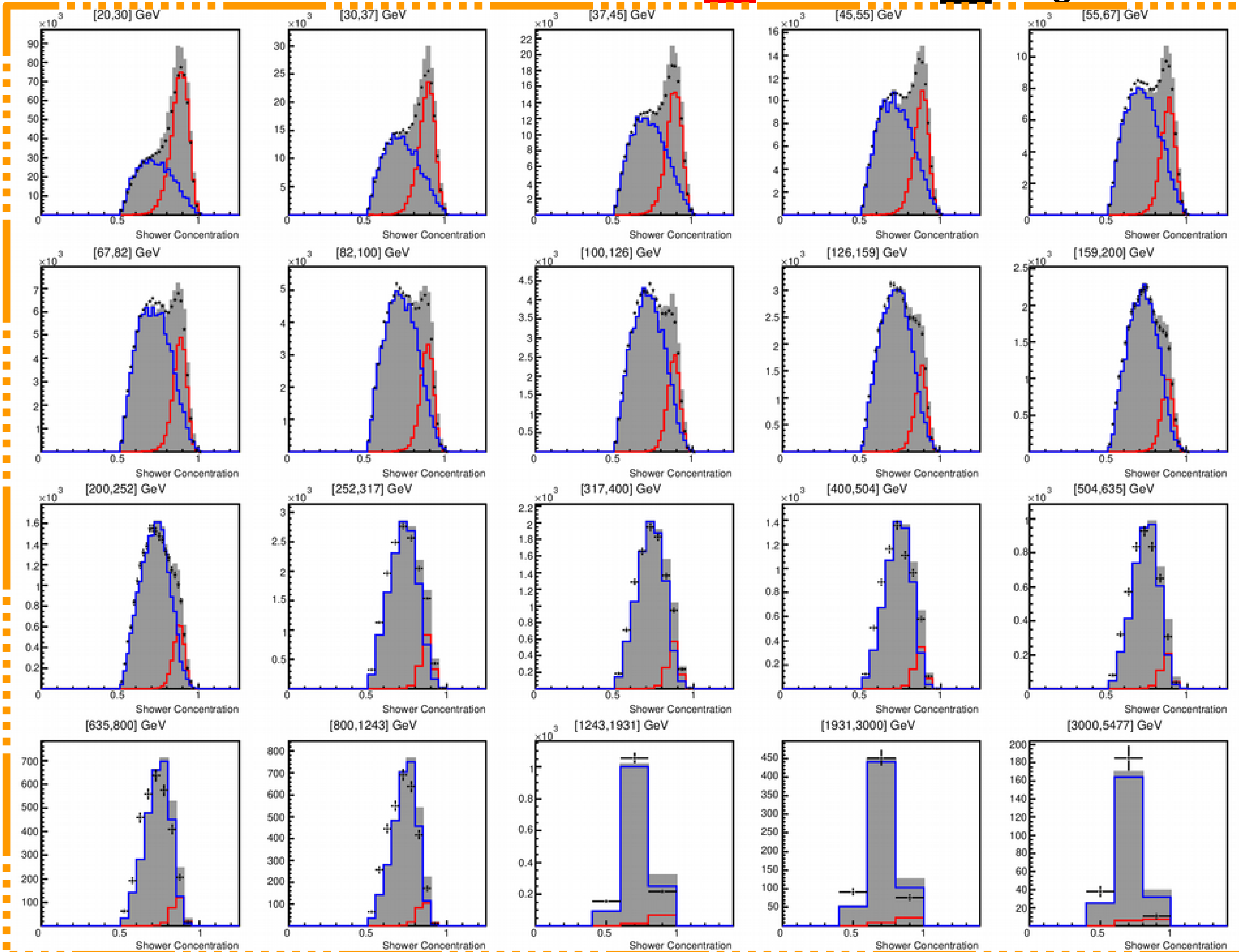
Proton
Electron
Proton+Electron
Flight Data



Used for BDT

IMCShowerConc **EPICS**

Proton
Electron
Proton+Electron
Flight Data

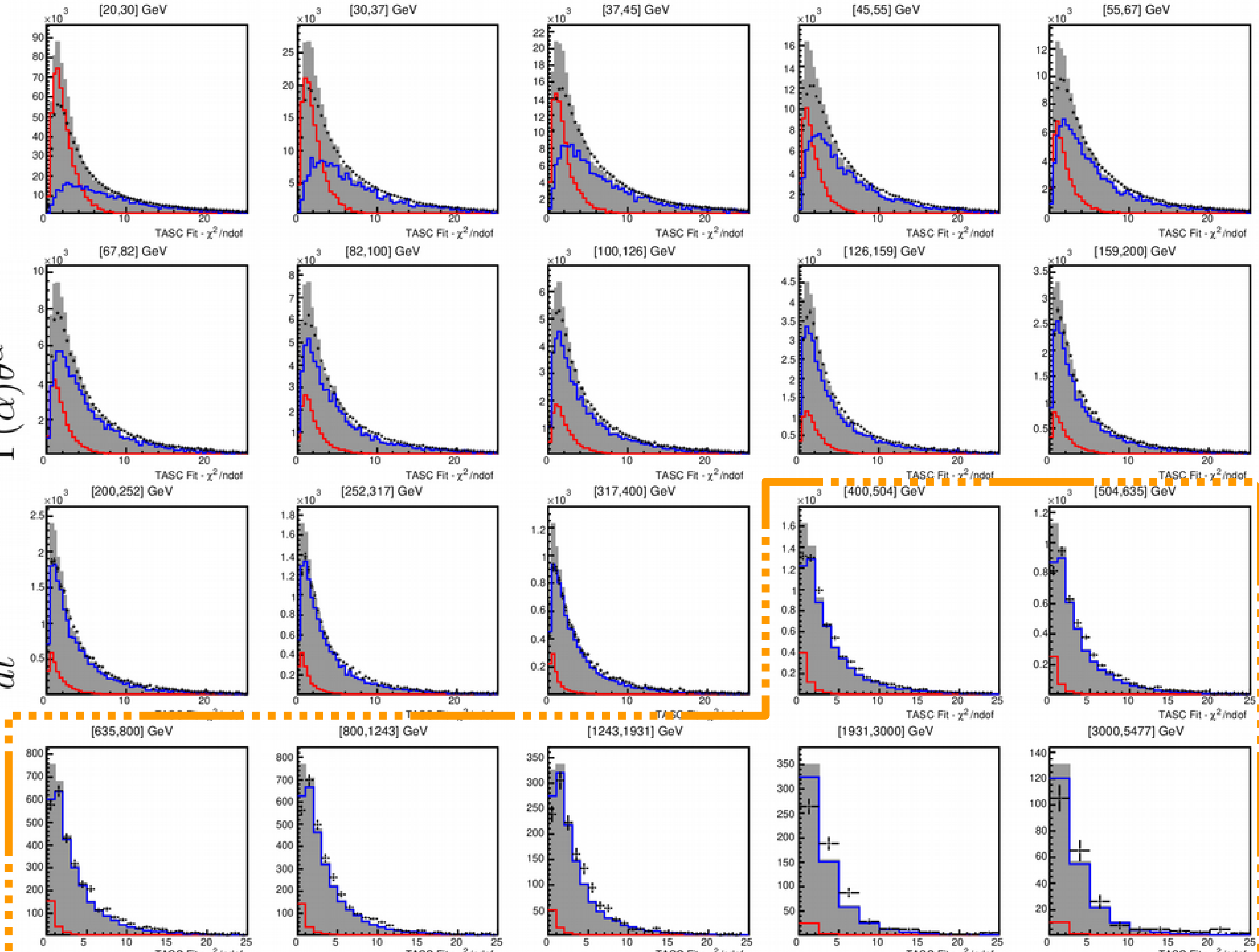


Used for BDT

TASCFit - χ^2/ndof EPICS

Proton
Electron
Proton+Electron
Flight Data

$$\frac{dE}{dt} = E_0 \frac{(t-t_0)^{\alpha-1} e^{\frac{(t-t_o)}{\theta}}}{\Gamma(\alpha)\theta^\alpha}$$



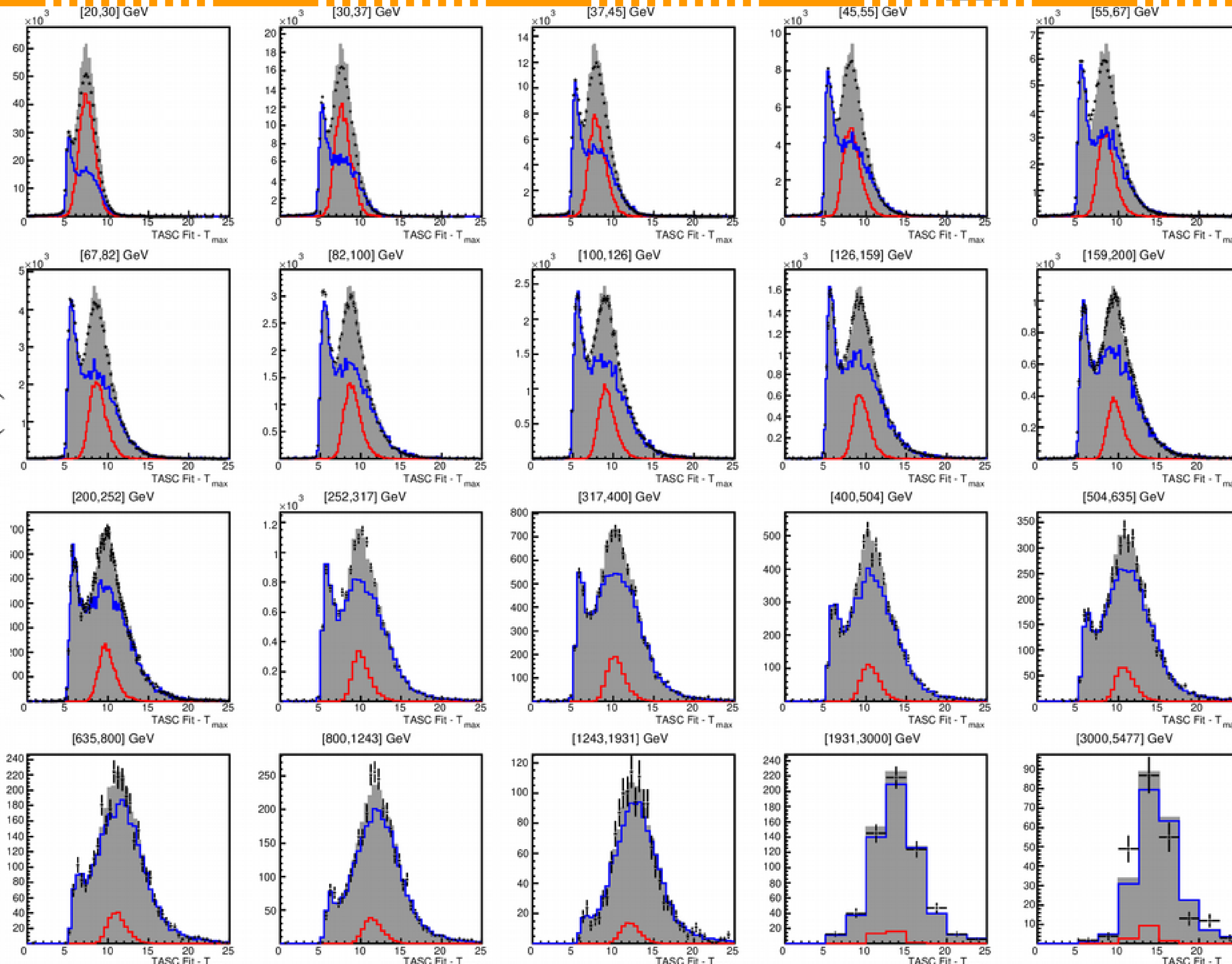
Used for BDT

TASCFit - T_{max}

EPICS

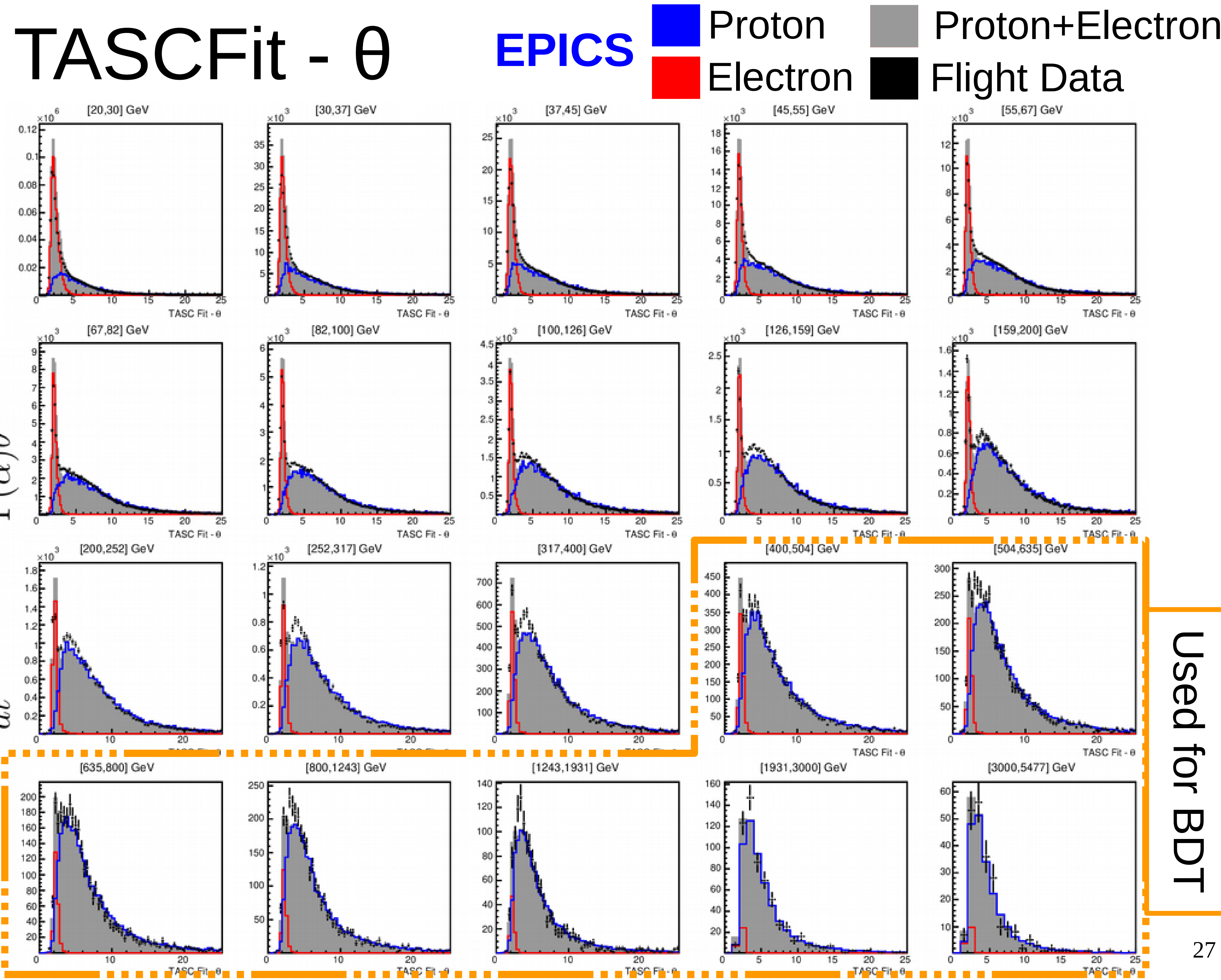
Proton · Electron · Proton+Electron · Flight Data

$$\frac{dE}{dt} = E_0 \frac{(t-t_0)^{\alpha-1} e^{\frac{(t-t_o)}{\theta}}}{\Gamma(\alpha)\theta^\alpha}$$



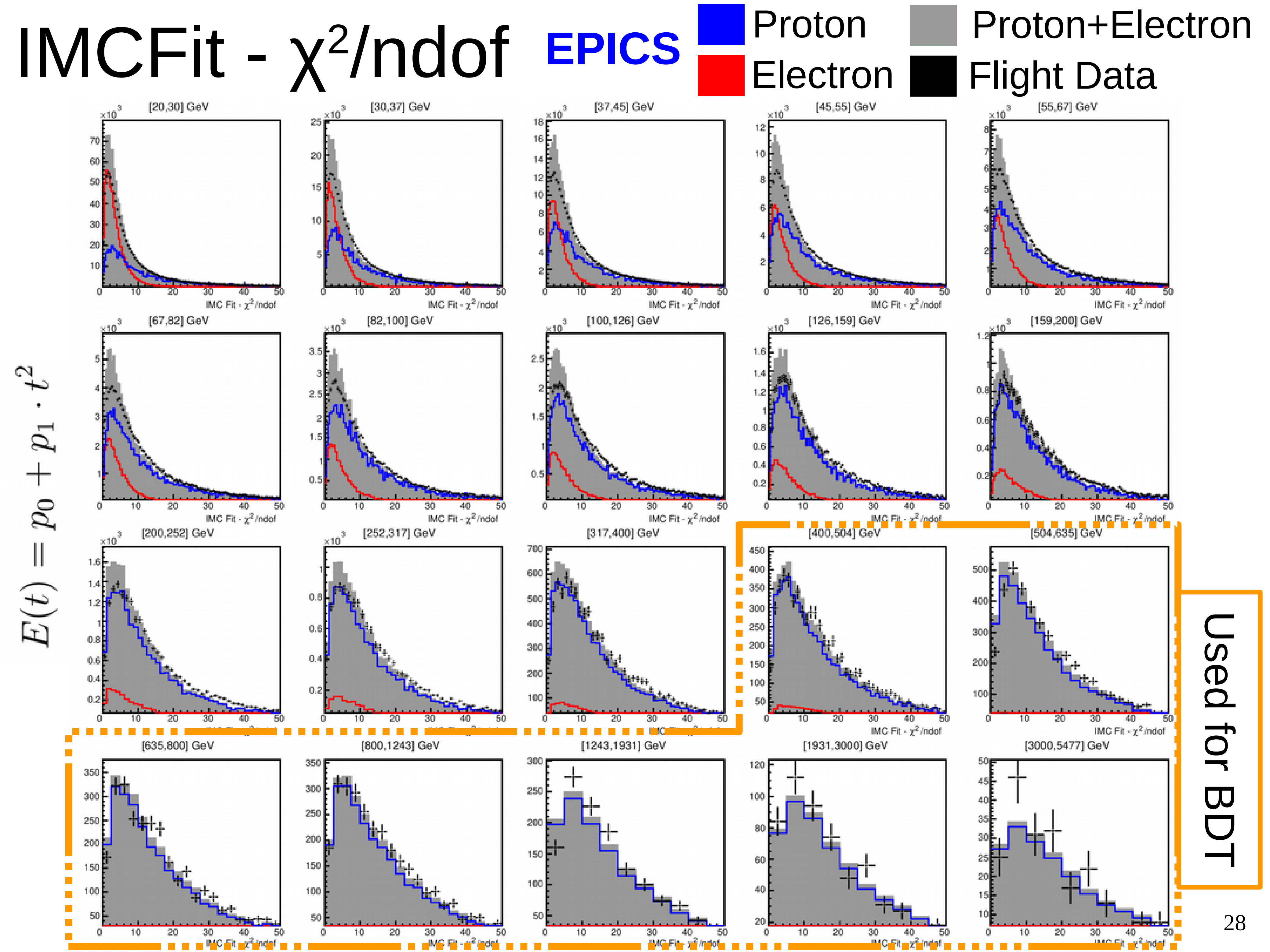
Used for BDT

TASCFit - θ



$$\frac{dE}{dt} = E_0 \frac{(t-t_0)^{\alpha-1} e^{\frac{(t-t_0)}{\theta}}}{\Gamma(\alpha)\theta^{\alpha}}$$

IMCFit - χ^2/ndof

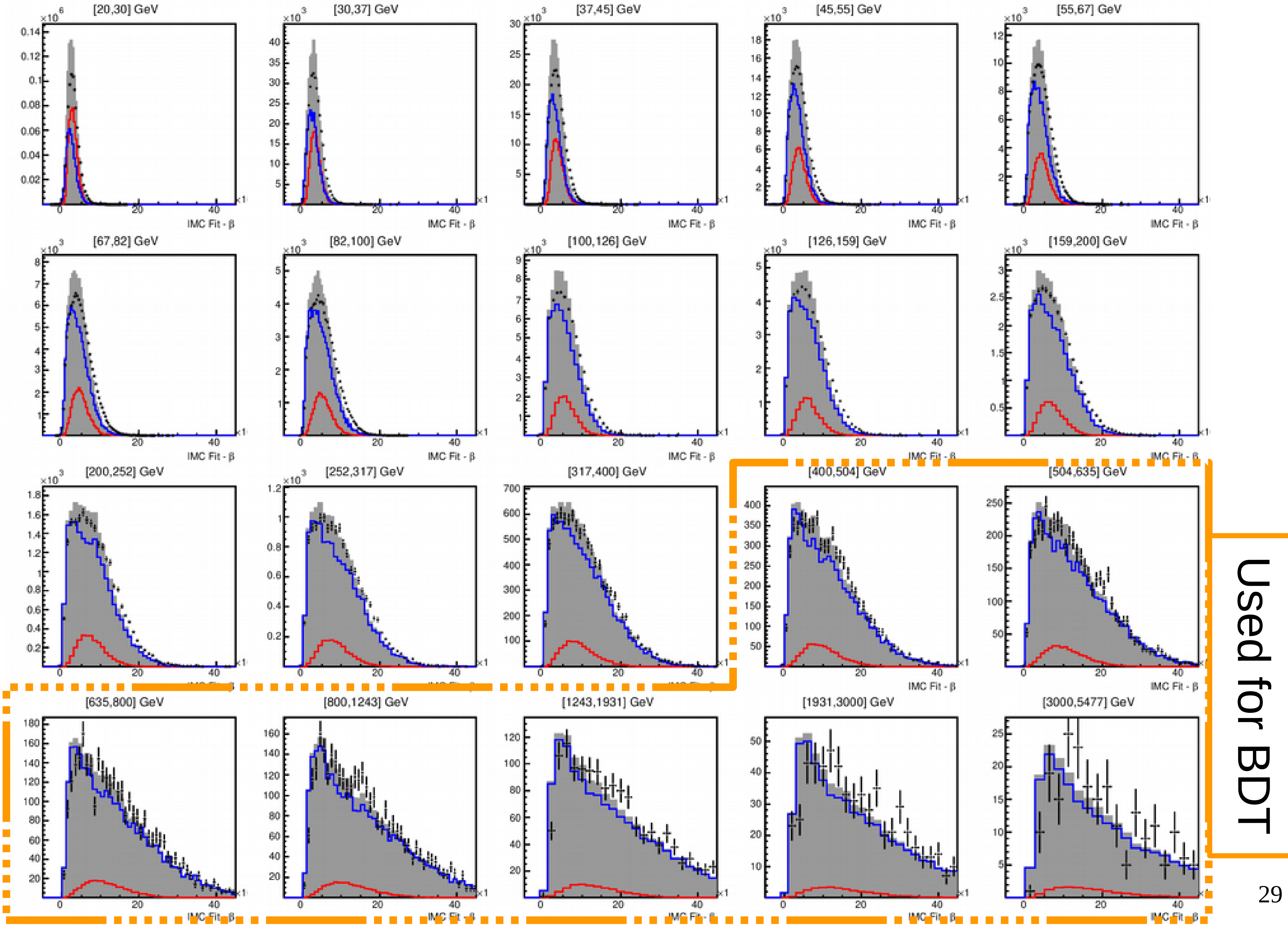


IMCFit - p1

EPICS

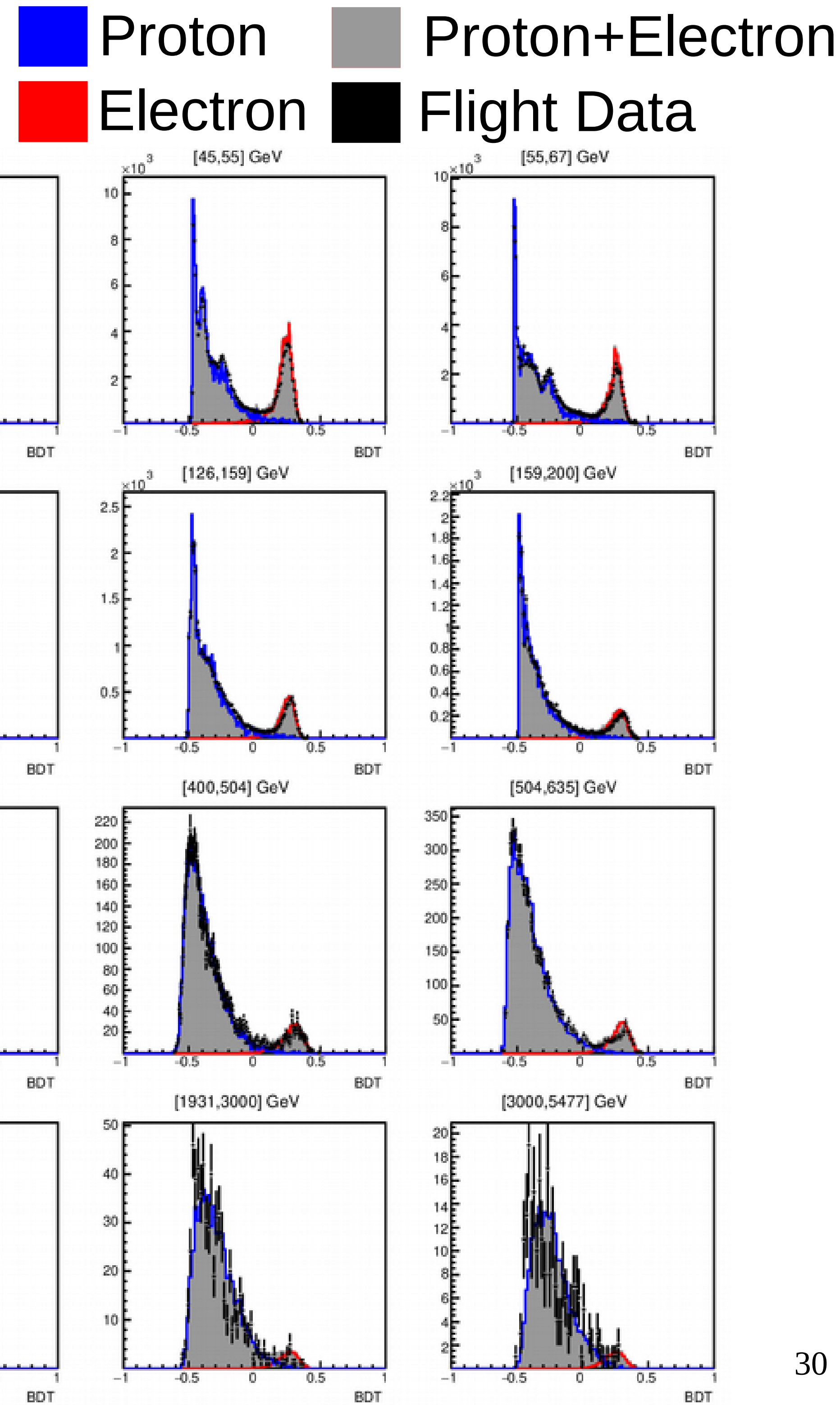
Proton | Electron | Proton+Electron | Flight Data

$$E(t) = p_0 + p_1 \cdot t^2$$



BDT

EPICS


Proton
Electron
Proton+Electron
Flight Data
[20,30] GeV
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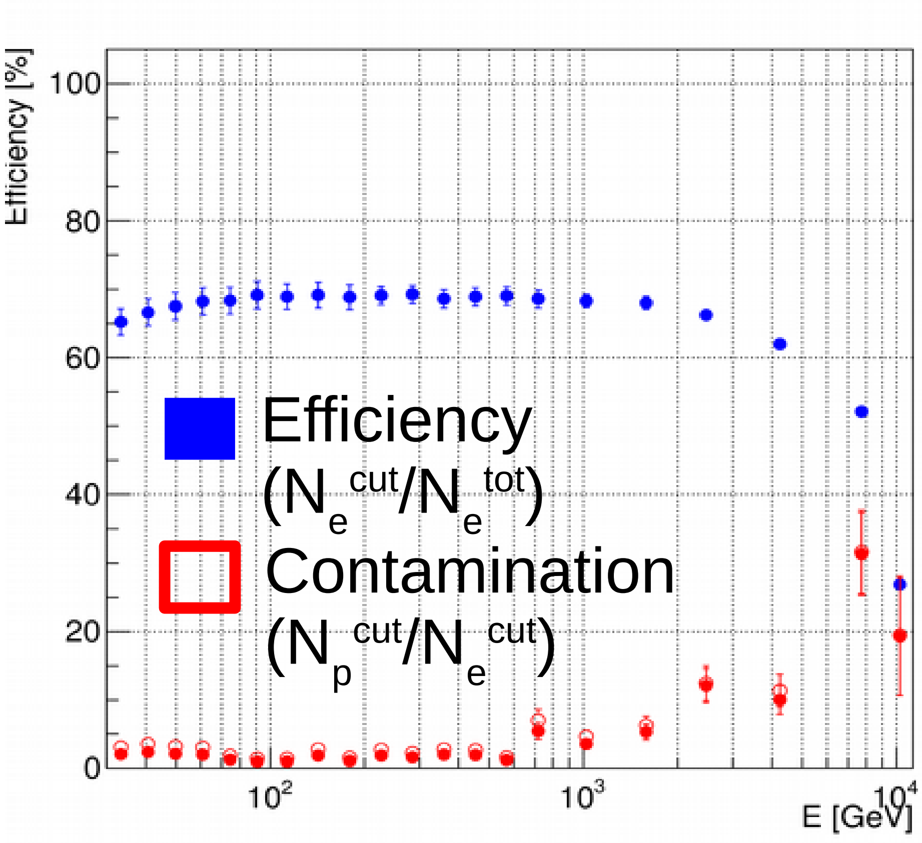
[200,252] GeV
[252,317] GeV
[317,400] GeV
[400,504] GeV
[504,635] GeV
[635,800] GeV
[800,1243] GeV
[1243,1931] GeV
[1931,3000] GeV
[3000,5477] GeV
BDT

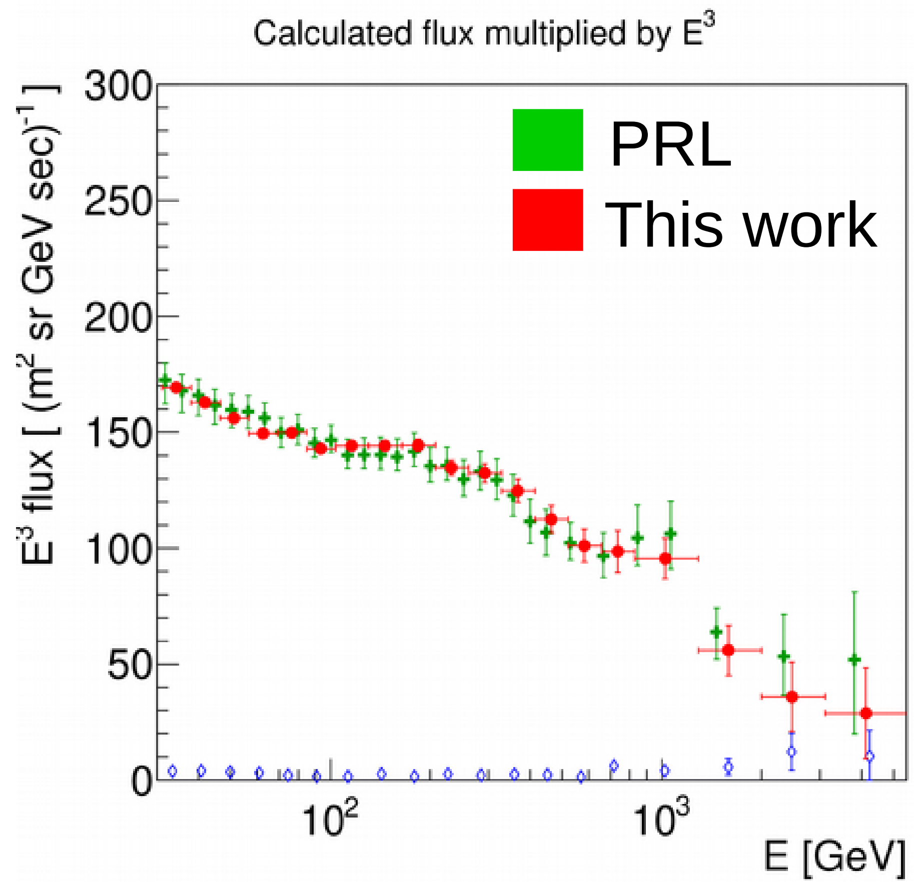
Preliminary Electron Flux in Acceptance E

Preliminary Flux in Acceptance E

Statistical Uncertainty only

After BDT





See Lorenzo's talk for detailed discussion of the electron flux

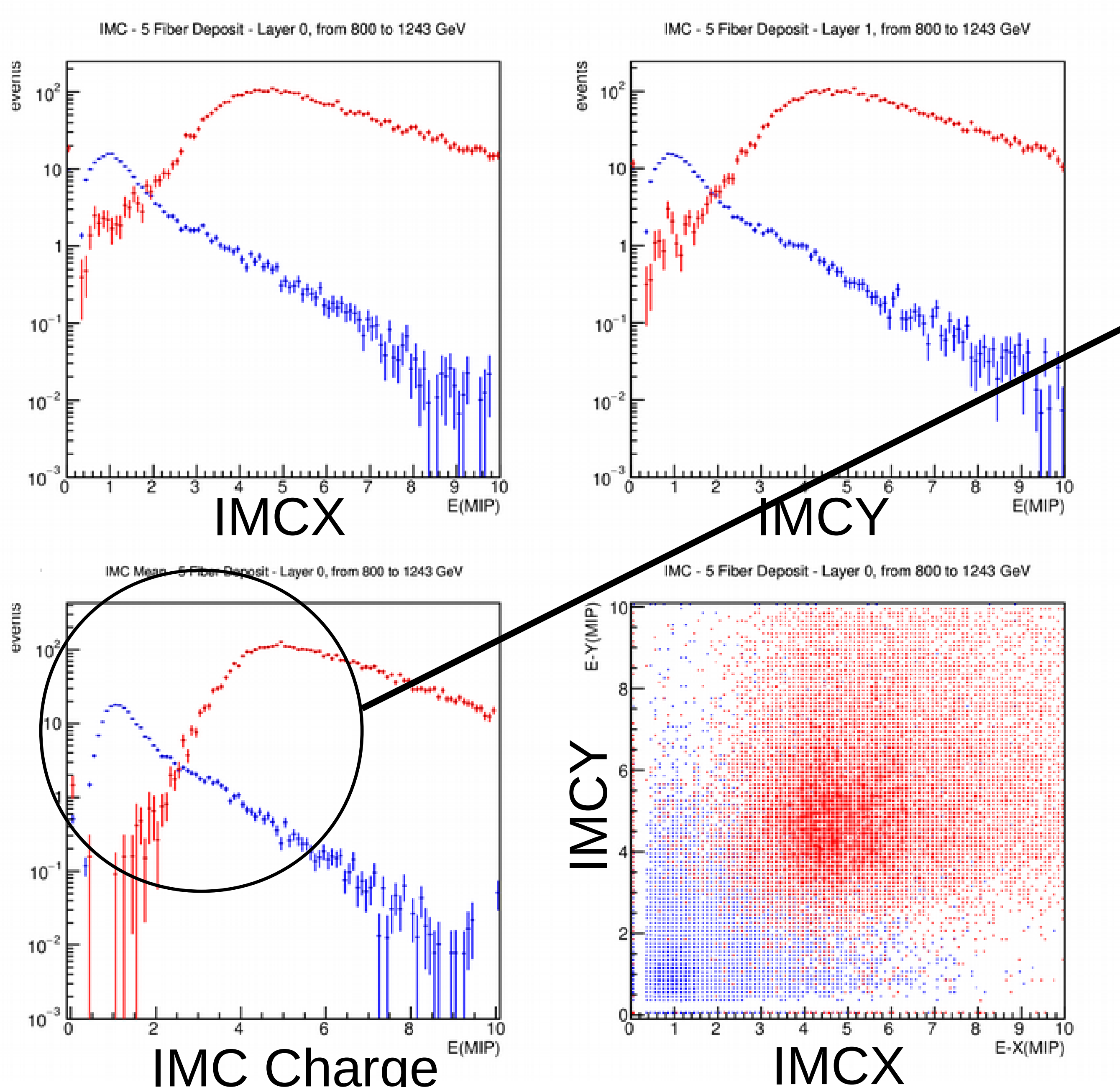
Back Up

EPICS

800 GeV < E < 1243 GeV

Charge in IMC1

Electron
Helium



Good separation

MEANING

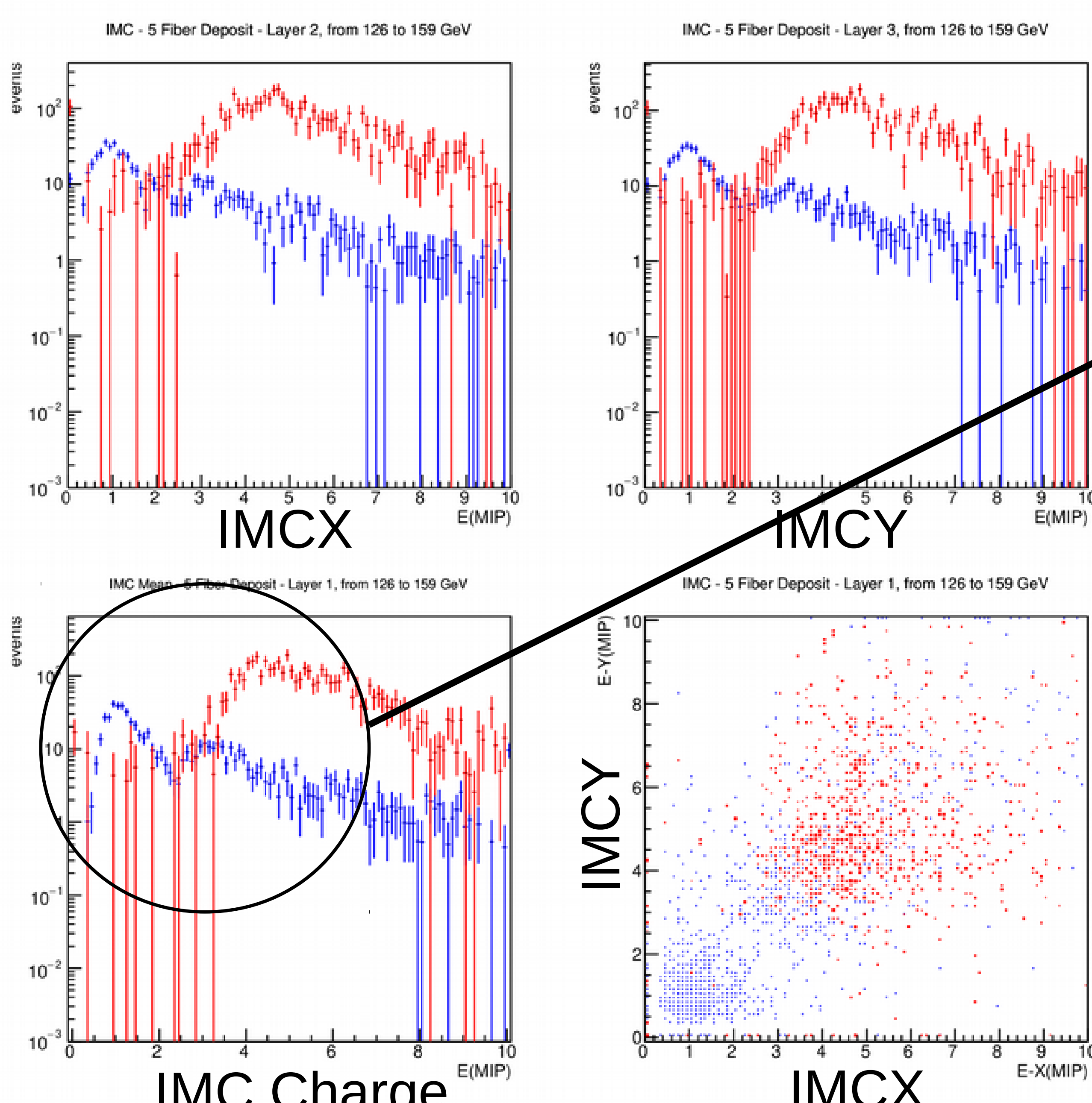
This is the charge reconstructed in the first IMC layer (IMC1) in events where the incident particle enters CALET before IMC1 (before or after CHD)

EPICS

800 GeV < E < 1243 GeV

Charge in IMC2

Electron
Helium



Bad separation

MEANING

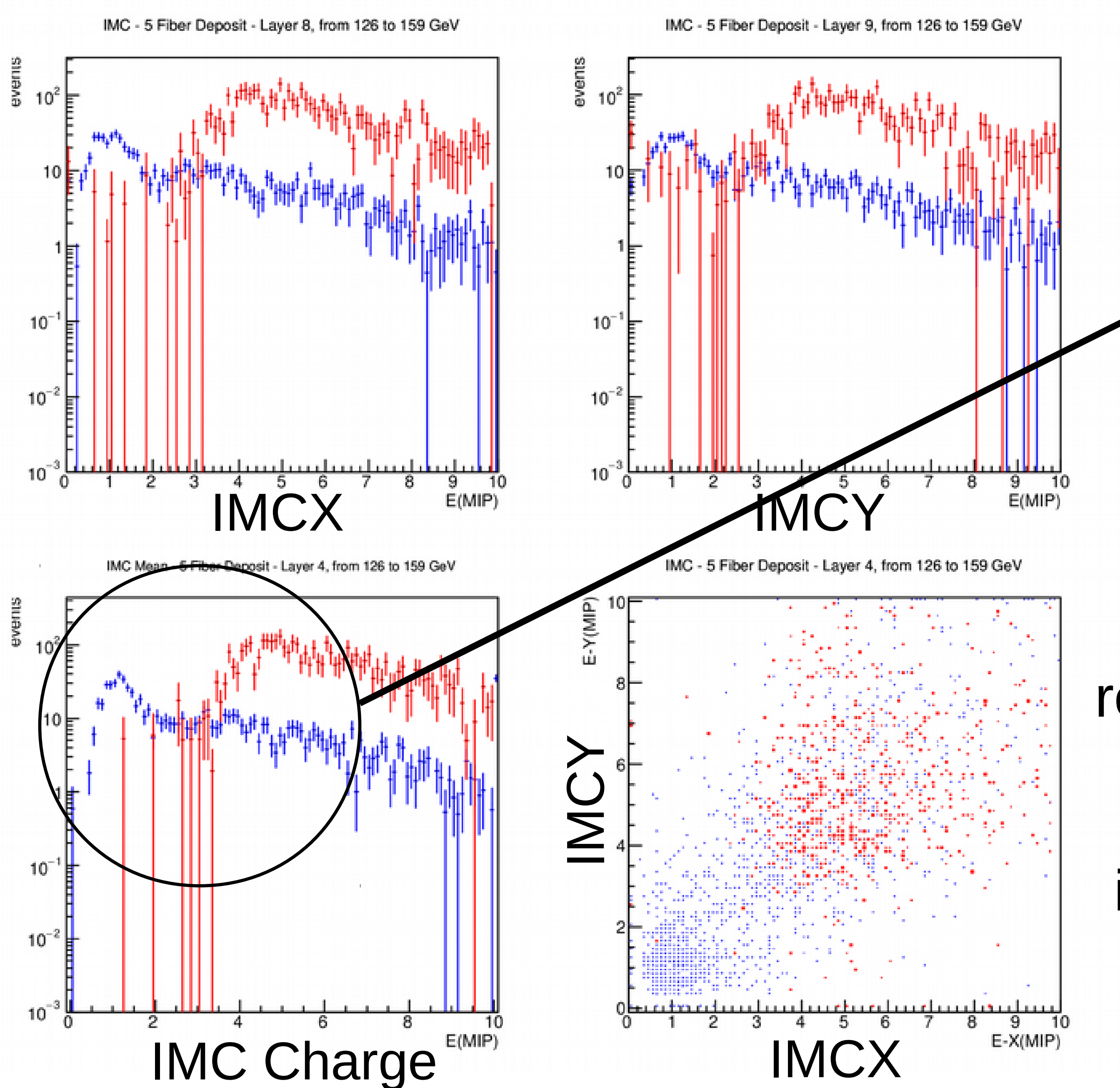
This is the charge reconstructed in the <u>second IMC layer</u> (IMC2) in events where the incident particle enters CALET before IMC2 (after IMC1)

EPICS

800 GeV < E < 1243 GeV

Charge in IMC5

Electron
Helium



Good separation,
Large tails

MEANING

This is the charge reconstructed in the fifth IMC layer (IMC5) in events where the incident particle enters CALET before IMC5 (after IMC4)

IMC1

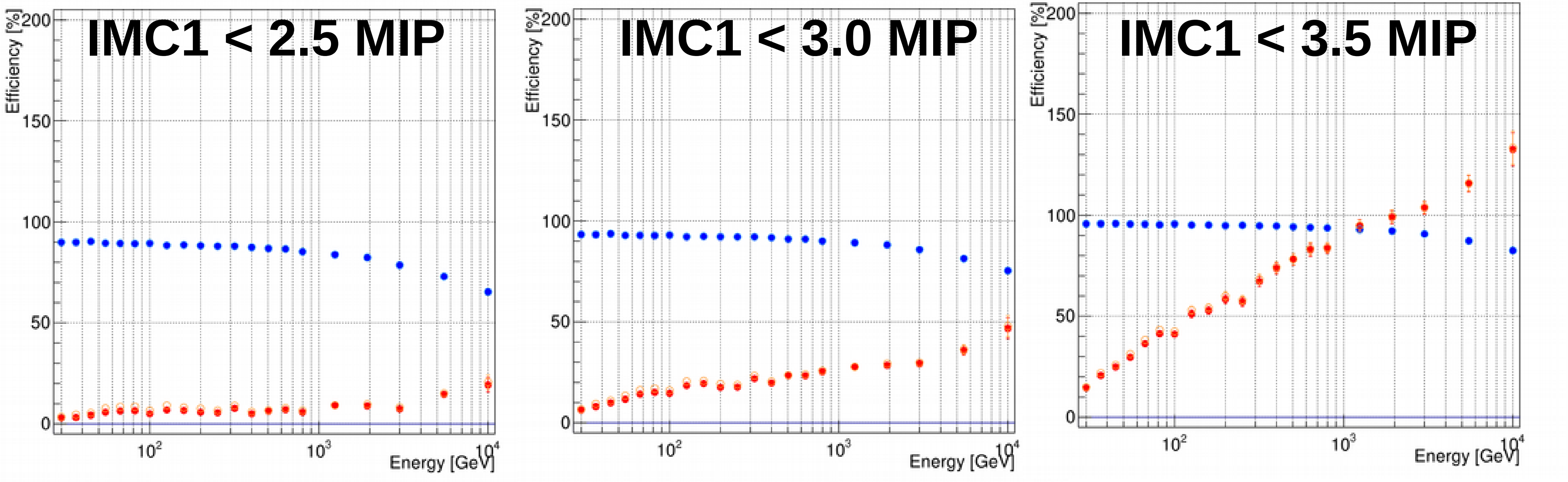
Variable MIP Threshold on **IMC** variable using **5 fibers**

- Efficiency (N_e^{cut}/N_e^{tot}) — filled blue
- Contamination (N_{He}^{cut}/N_e^{cut}) — filled red
- Efficiency (N_e/N_e^{tot}) — open cyan
- Contamination (N_{He}/N_e) — open orange

N_e^{tot} = number of *e* above 0 MIP

N_e = number of *e* in [0, thr] MIP

N_e^{cut} = number of *e* in [0.3, thr] MIP



If we want to keep **He contamination** below 10%, we cannot get an **e efficiency** higher than 80%

IMC2

Variable MIP Threshold on **IMC** variable using **5 fibers**

Efficiency (N_e^{cut}/N_e^{tot})

Contamination (N_{He}^{cut}/N_e^{cut})

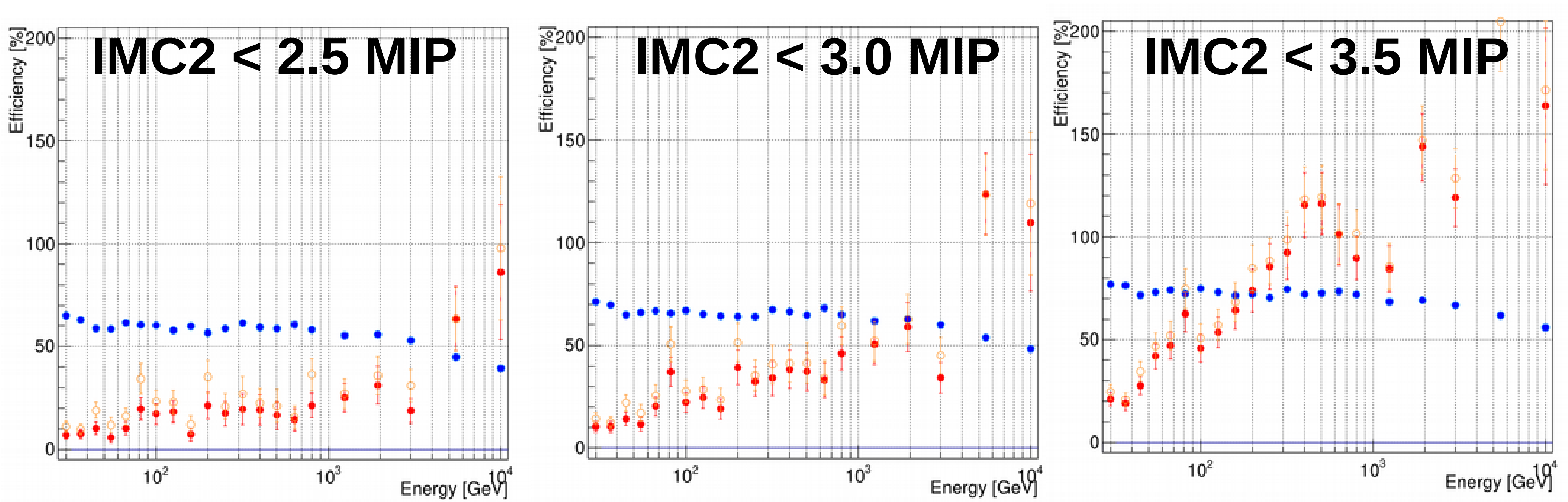
Efficiency (N_e/N_e^{tot})

Contamination (N_{He}/N_e)

N_e^{tot} = number of *e* above 0 MIP

N_e = number of *e* in [0, thr] MIP

N_e^{cut} = number of *e* in [0.3, thr] MIP

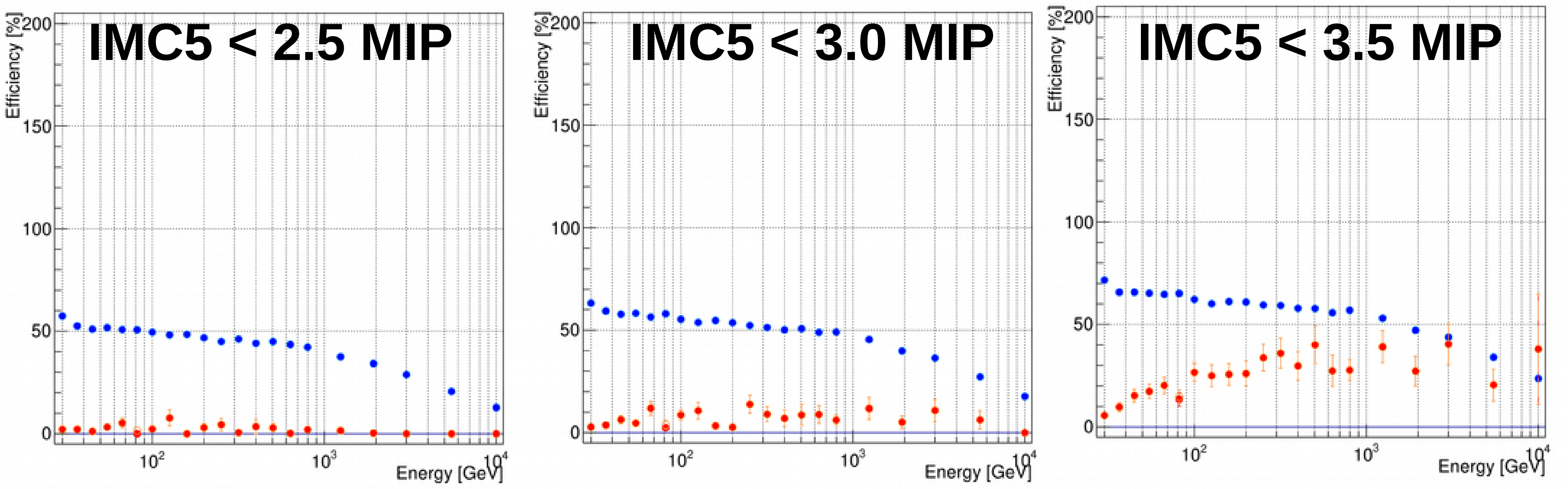


The minimum **He contamination** is 30%, but it corresponds that **e efficiency** of 50%

Variable MIP Threshold on **IMC** variable using **5 fibers**

- Efficiency (N_e^{cut}/N_e^{tot})
- Contamination (N_{He}^{cut}/N_e^{cut})
- Efficiency (N_e/N_e^{tot})
- Contamination (N_{He}/N_e)

N_e^{tot} = number of *e* above 0 MIP
N_e = number of *e* in [0, thr] MIP
N_e^{cut} = number of *e* in [0.3, thr] MIP



It is possible to keep **He contamination** below 5%, but large tails limit **e efficiency** below 50%

IMC2

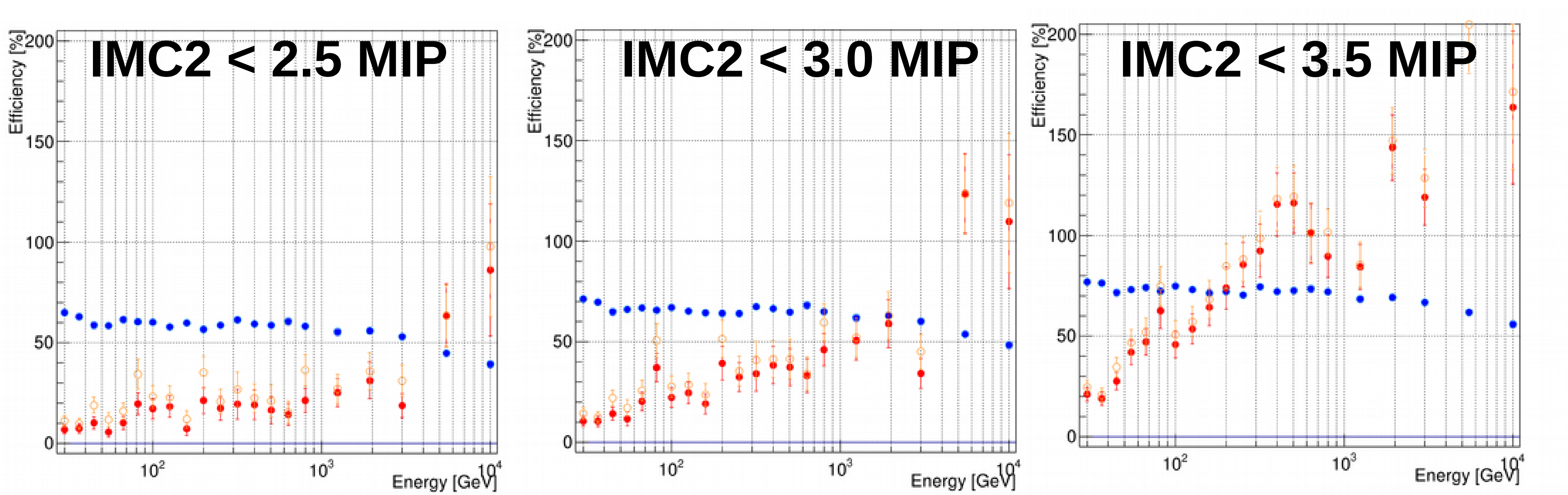
Variable MIP Threshold on **IMC** variable using **5 fibers**

- Efficiency (N_e^{cut}/N_e^{tot}) (filled blue)
- Contamination (N_{He}^{cut}/N_e^{cut}) (filled red)
- Efficiency (N_e/N_e^{tot}) (open cyan)
- Contamination (N_{He}/N_e) (open orange)

N_e^{tot} = number of *e* above 0 MIP

N_e = number of *e* in [0, thr] MIP

N_e^{cut} = number of *e* in [0.3, thr] MIP



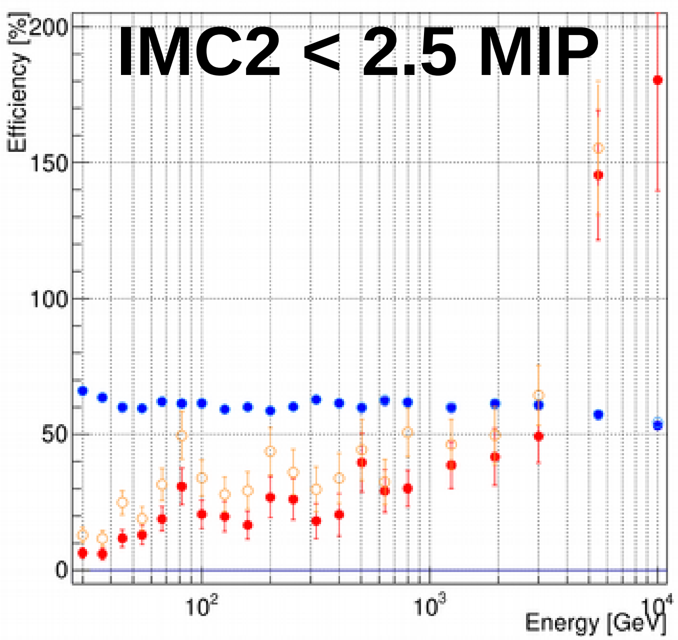
Variable MIP Threshold on **IMC** variable using **2 fibers**

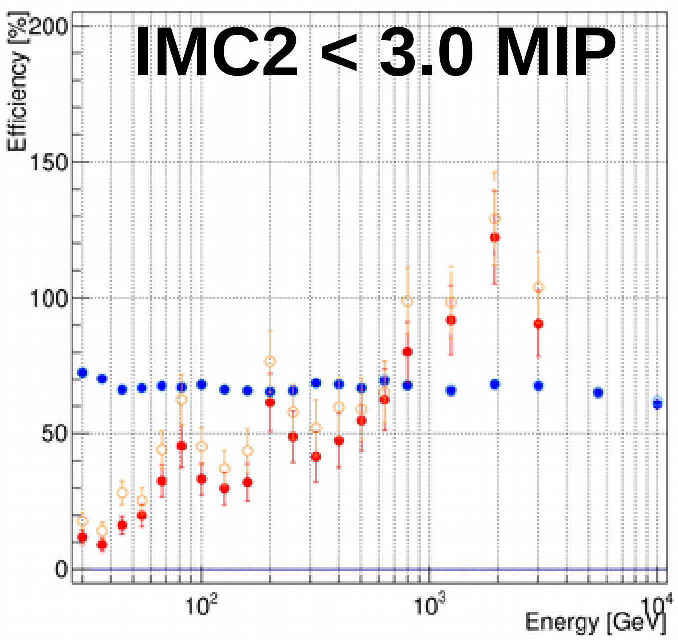
- Efficiency (N_e^{cut}/N_e^{tot}) (blue filled)
- Contamination (N_{He}^{cut}/N_e^{cut}) (red filled)
- Efficiency (N_e/N_e^{tot}) (cyan open)
- Contamination (N_{He}/N_e) (orange open)

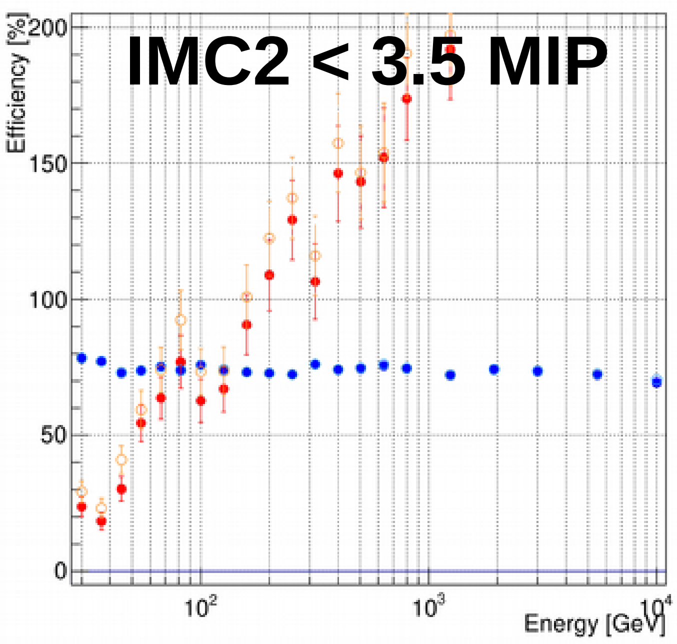
N_e^{tot} = number of *e* above 0 MIP

N_e = number of *e* in [0, thr] MIP

N_e^{cut} = number of *e* in [0.3, thr] MIP







IMC2

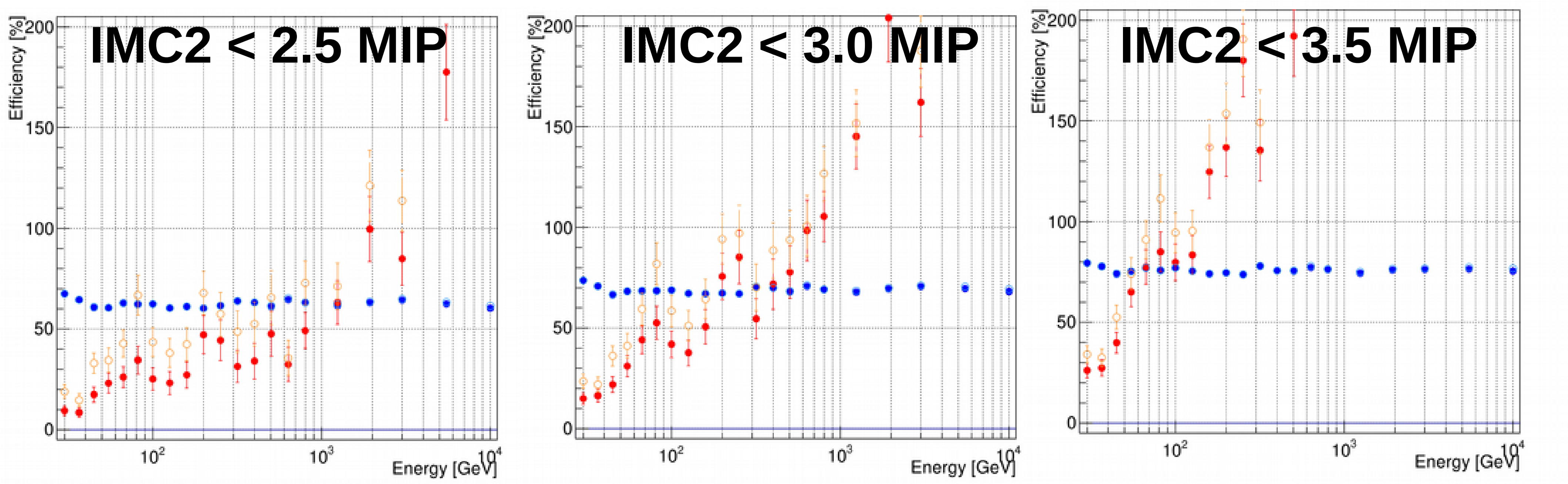
Variable MIP Threshold on **IMC** variable using **1 fibers**

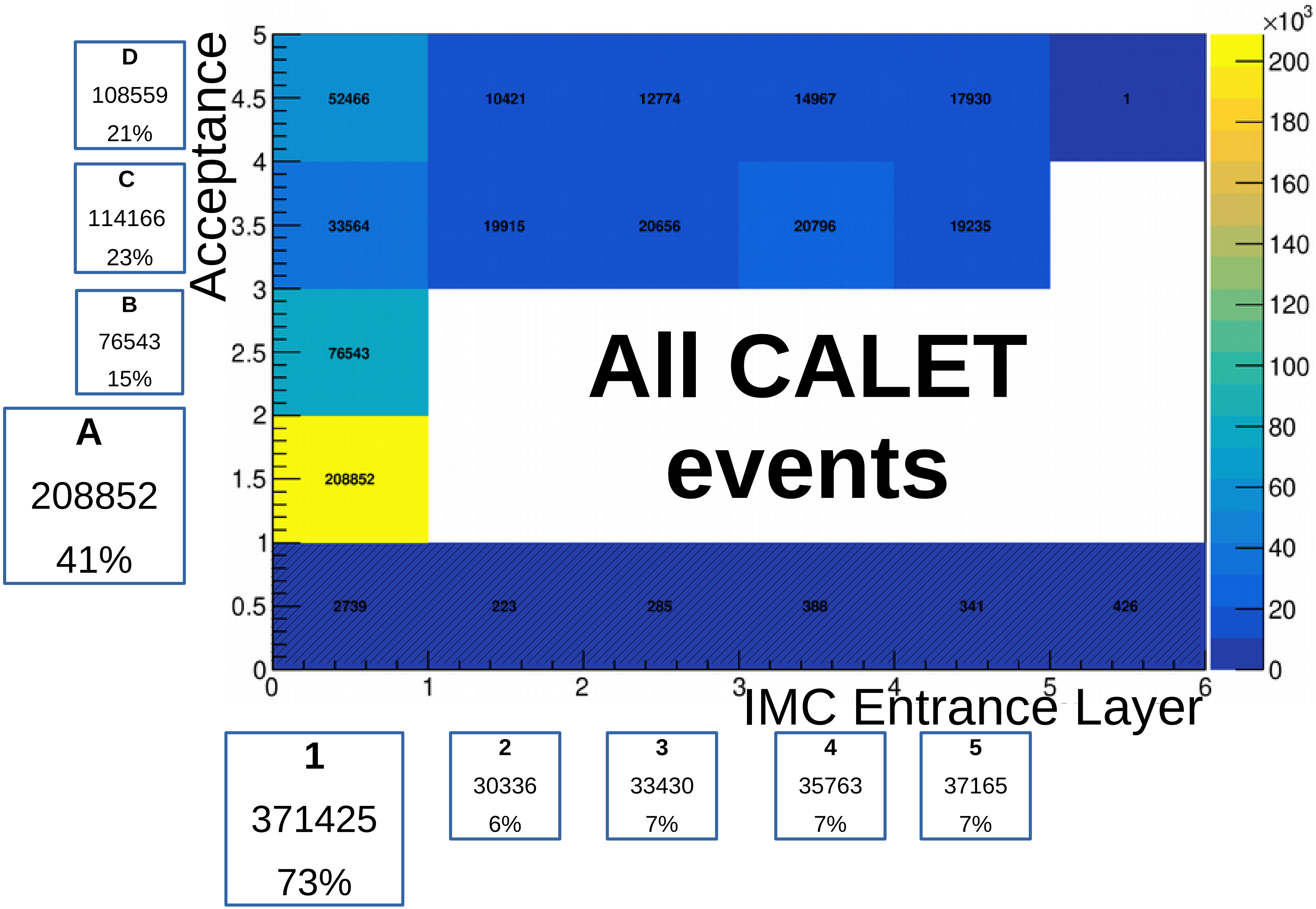
- Efficiency (N_e^{cut}/N_e^{tot}) (blue, filled)
- Contamination (N_{He}^{cut}/N_e^{cut}) (red, filled)
- Efficiency (N_e/N_e^{tot}) (cyan, open)
- Contamination (N_{He}/N_e) (orange, open)

N_e^{tot} = number of *e* above 0 MIP

N_e = number of *e* in [0, thr] MIP

N_e^{cut} = number of *e* in [0.3, thr] MIP





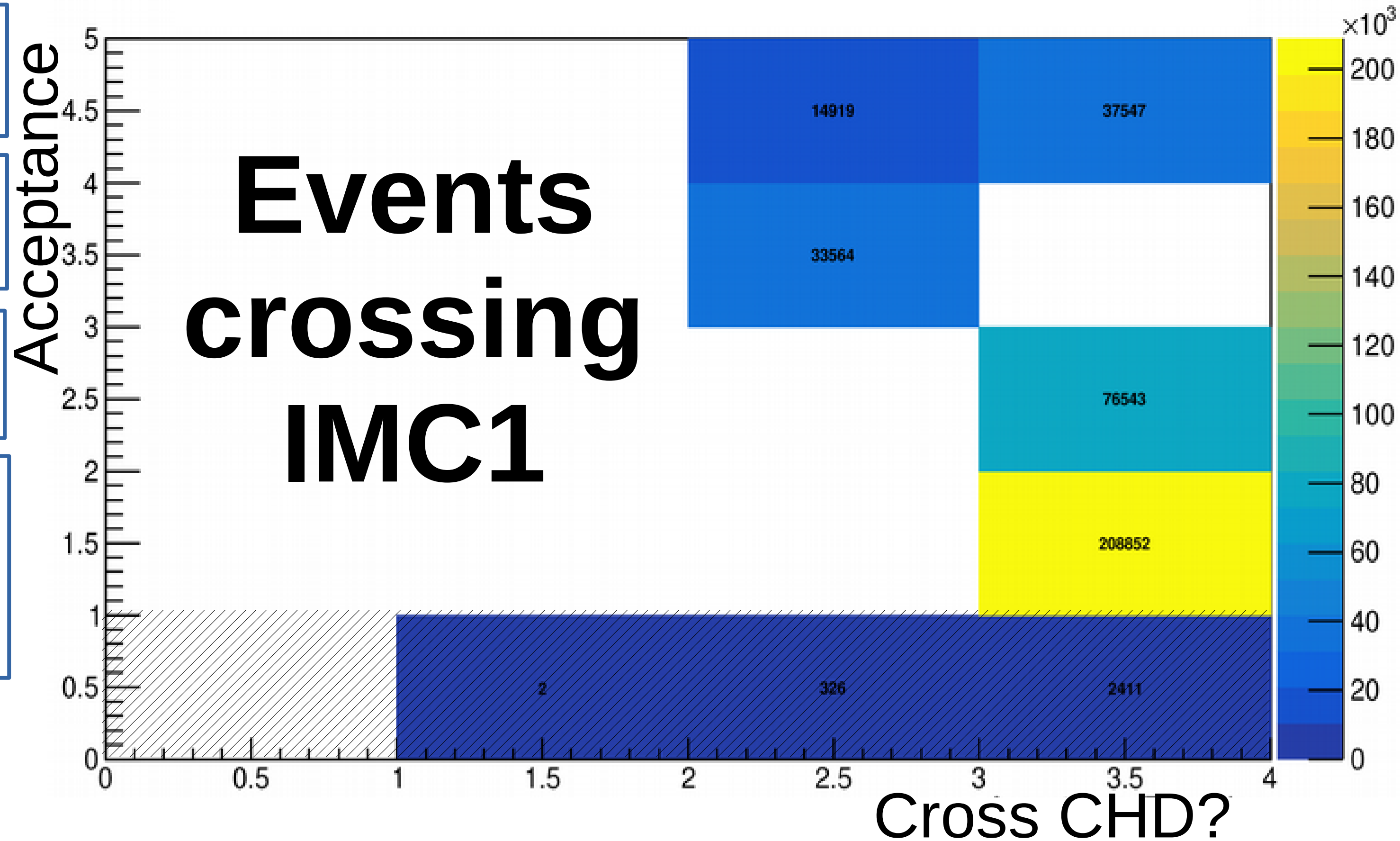
	Relative GF	Relative EGF
Acc G/A	100%/41% = 2.44	[73%x90%+27%x60%] / 41% = 2.00
Acc F/A	73%/41% = 1.78	[73%x90%] /41% = 1.60
Acc E/A	?	?

D
52466
14%

C
33564
9%

B
76543
21%

A
208852
56%



NO	YES
48483	322942
13%	87%

	Relative GF	Relative EGF
Acc G/A	100%/41% = 2.44	[73%x90%+27%x60%] / 41% = **2.00**
Acc F/A	73%/41% = 1.78	[73%x90%] /41% = **1.60**
Acc E/A	87%x73%/41% = 1.55	[87%x73%x100%] /41% = **1.55**

Explanation of Preselection

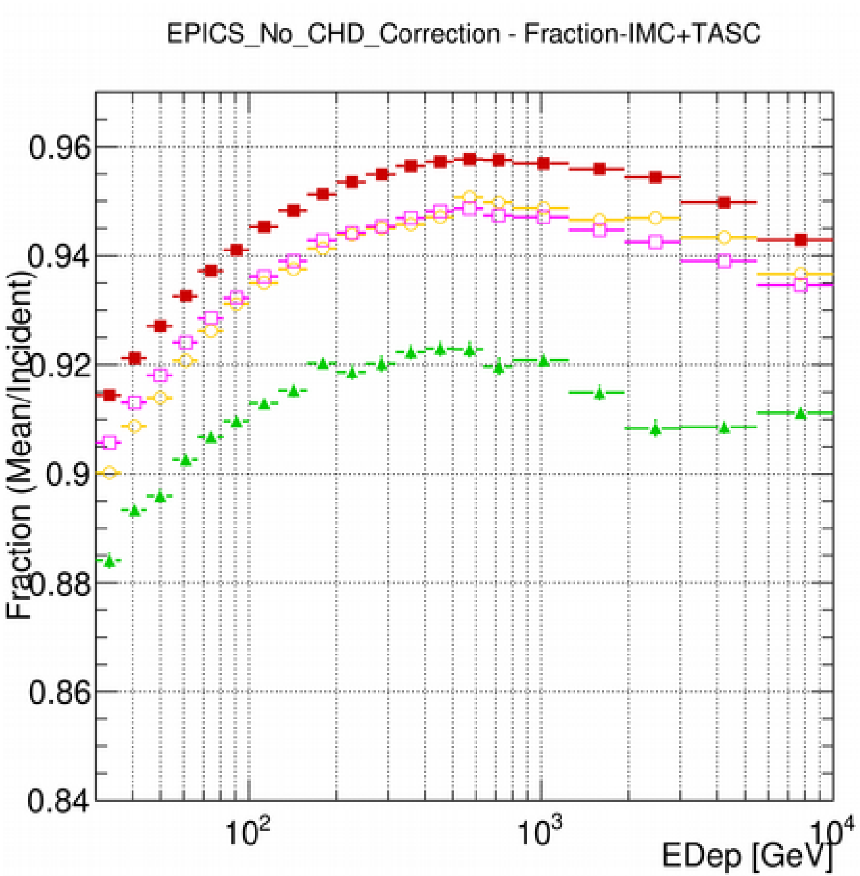
In all cases preselections are separately required on both x and y views using OR condition:

- TASC Concentration = $TASC_{X(Y)}^{MAX}/\Sigma_{i=0}^{6} TASC_{X(Y)}$
- Shower Track = $|\theta_{X(Y)}^{DIAGONAL} - \theta_{X(Y)}^{KF}|$
- Shower Concentration = $IMC_{X8(Y8)}^{9Fibers}/IMC_{X8(Y8)}^{Total}$

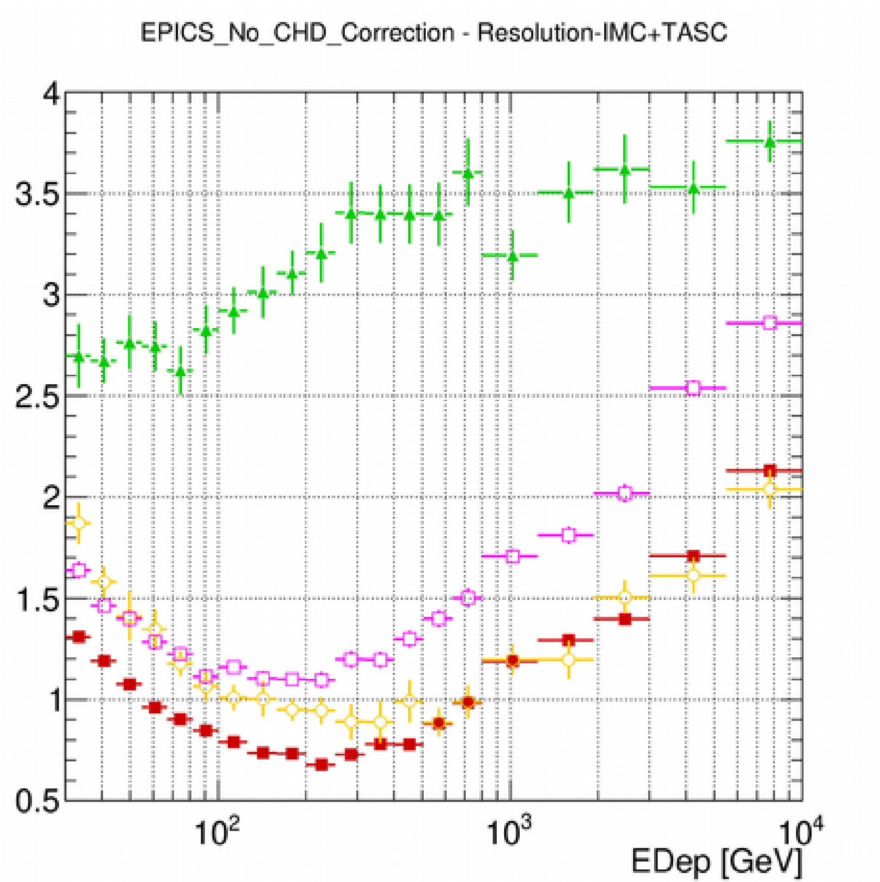
Energy Function (After all preselections)

Acc A∩E
Acc B∩E
Acc D∩E
Acc E

Fraction of deposited energy



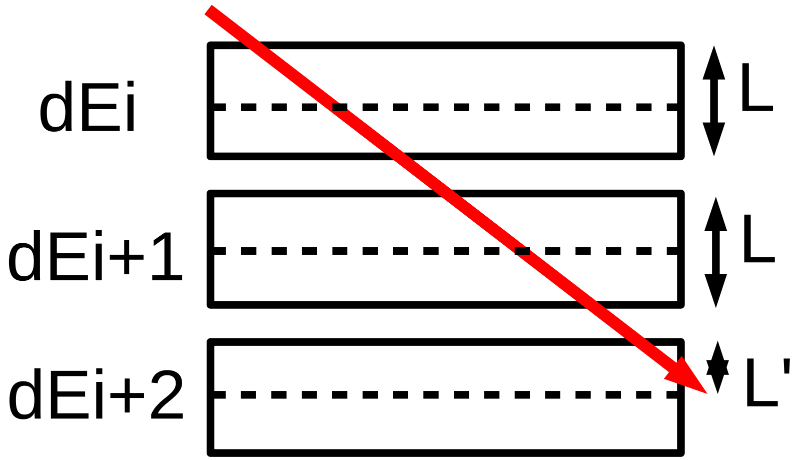
Energy resolution



As expected, Acceptance B is the most different one because of the limited lateral containment... However, it does not strongly affect energy resolution, so that function ■ can be used for all events in Acceptance E

Alternative f_E definition

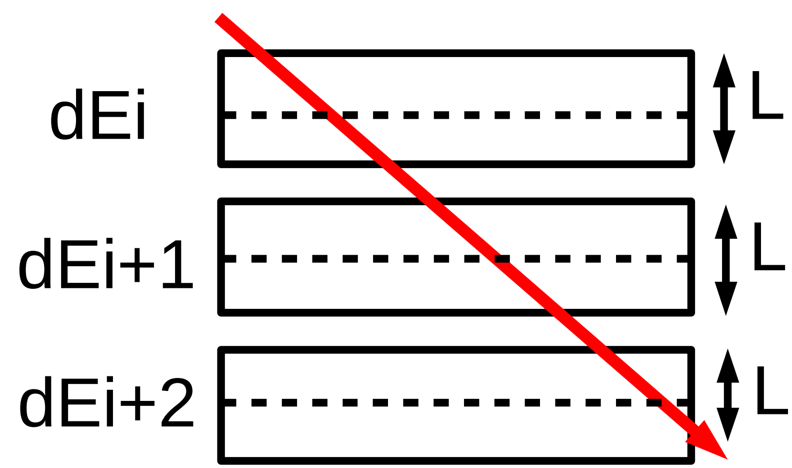
Event Category I



Layer i+2 is transversed for L'<L/2, therefore the last layer is **i+1**.
f_E is computed as if TASC is made of only layers **X1,Y1,...,i+1**

Event Category II

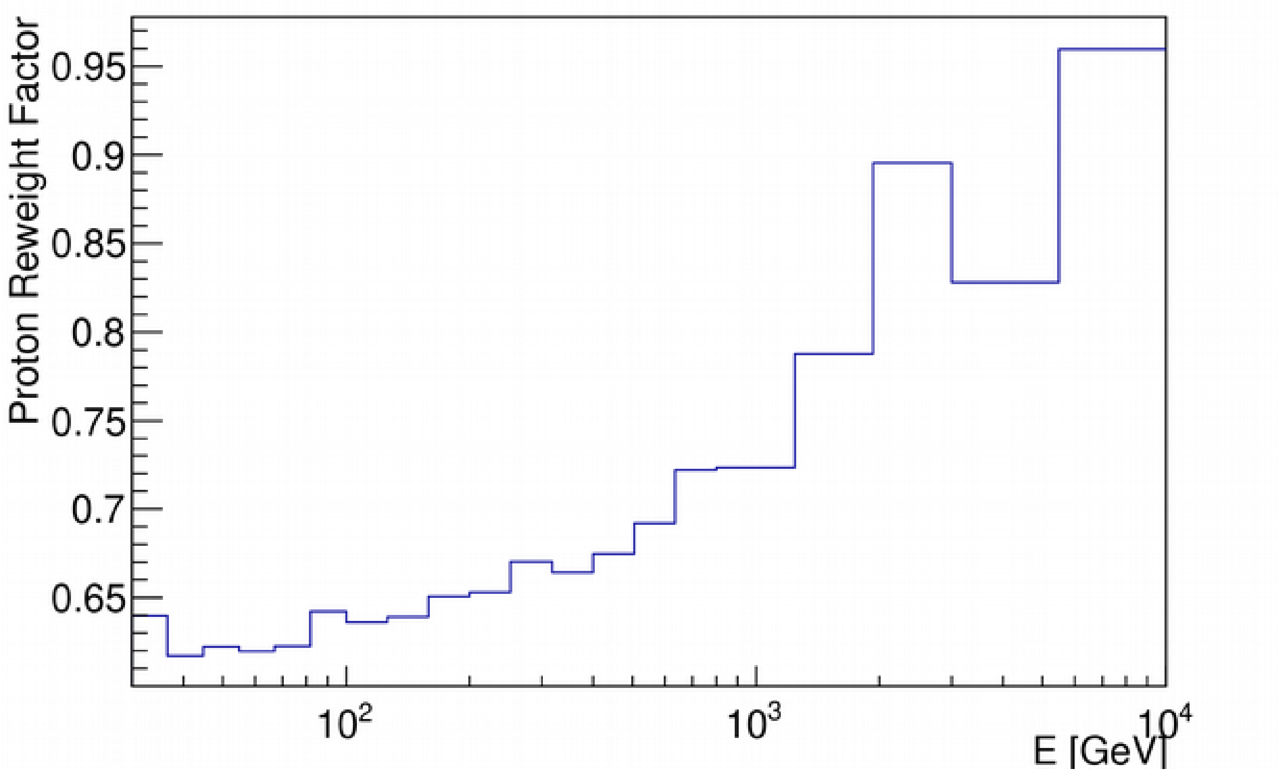
Layer i+2 is transversed for L'>L/2, therefore the last layer is **i+2**.
The energy deposited dEi+2 is corrected to **dEi+2' = dEi+2 * L/L'**
f_E is computed as if TASC is made of only layers **X1,Y1,...,i+2**



Proton Reweight Factor

MOTIVATION The proton weight factor applied to simulations based on AMS measurements does not lead to a good MC-FD agreement of our distributions

SOLUTION A proton reweight factor is computed rescaling proton distributions to data, by simpling considering the integral of f_E distributions above 0.01

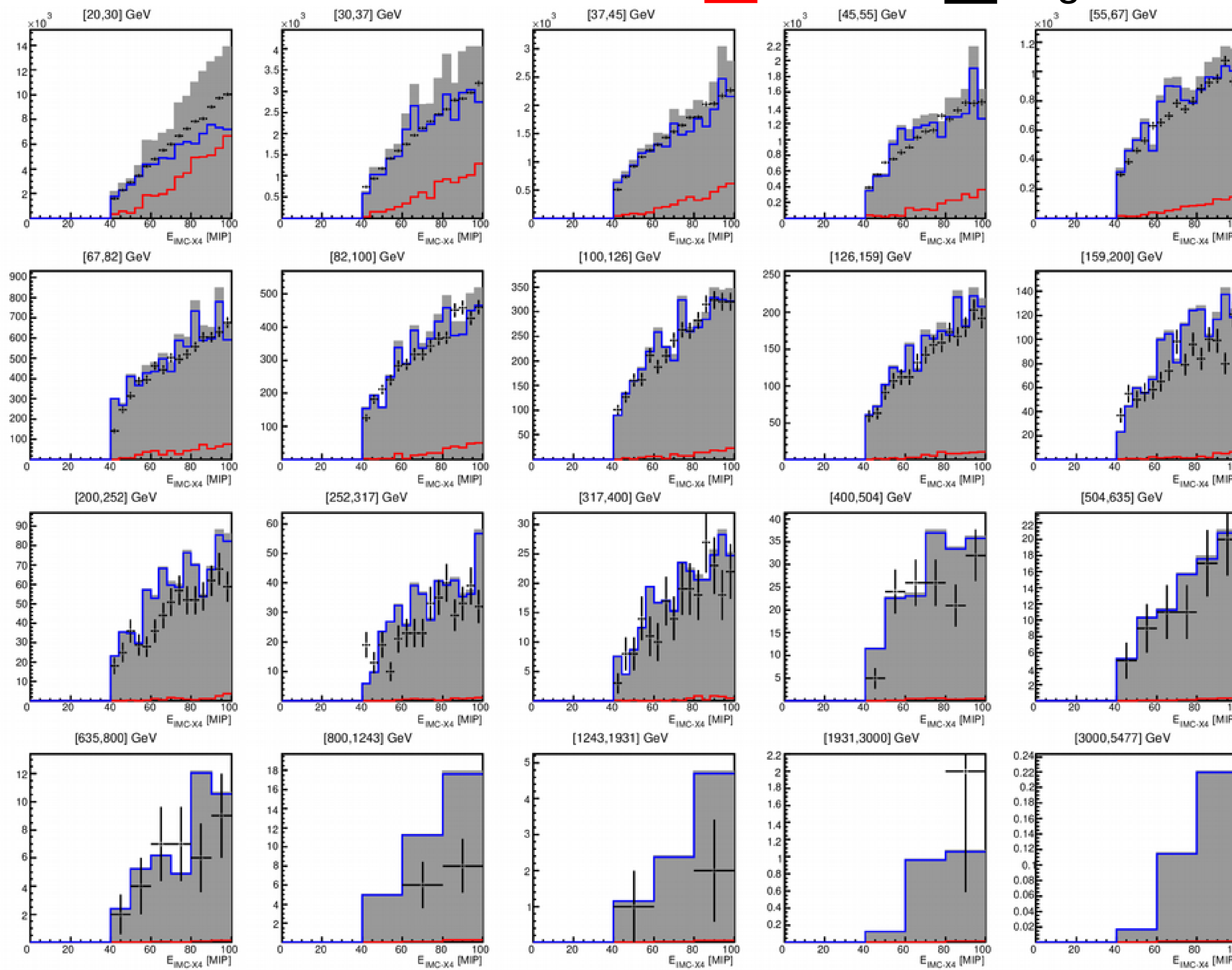


Trigger - IMCX4

EPICS

Proton
Electron
Proton+Electron
Flight Data

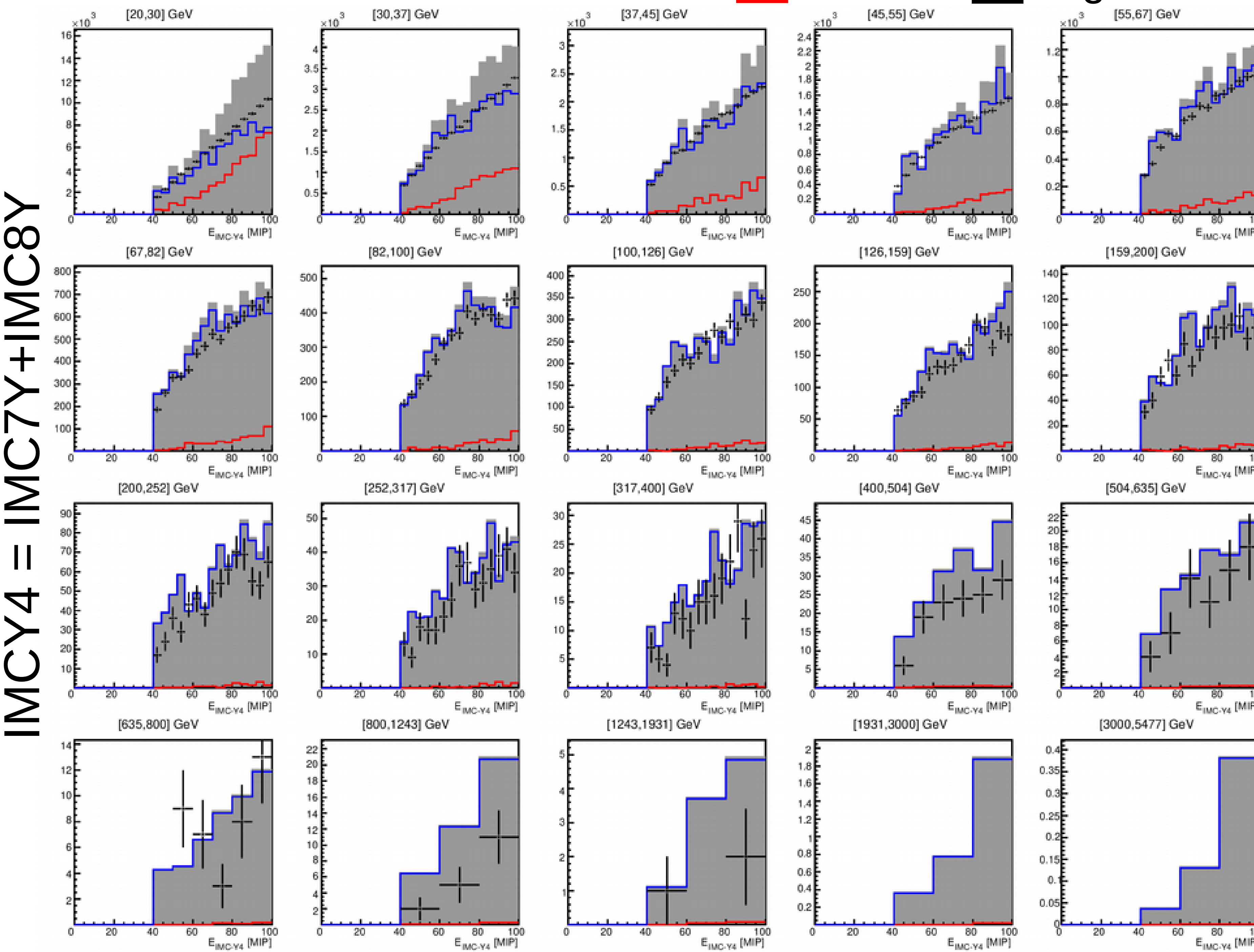
IMCX4 = IMC7X+IMC8X



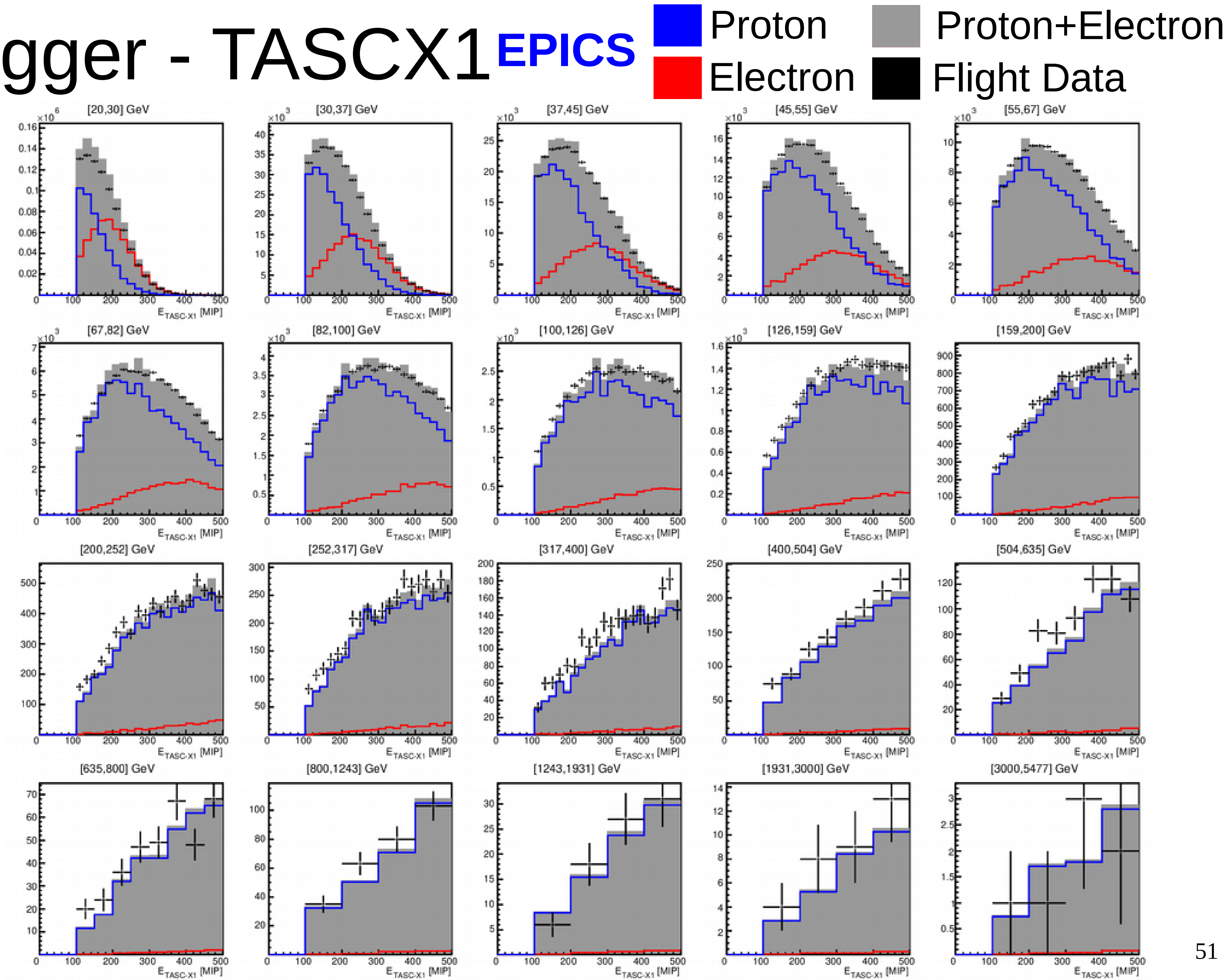
Trigger - IMCY4

EPICS

Proton | Electron | Proton+Electron | Flight Data



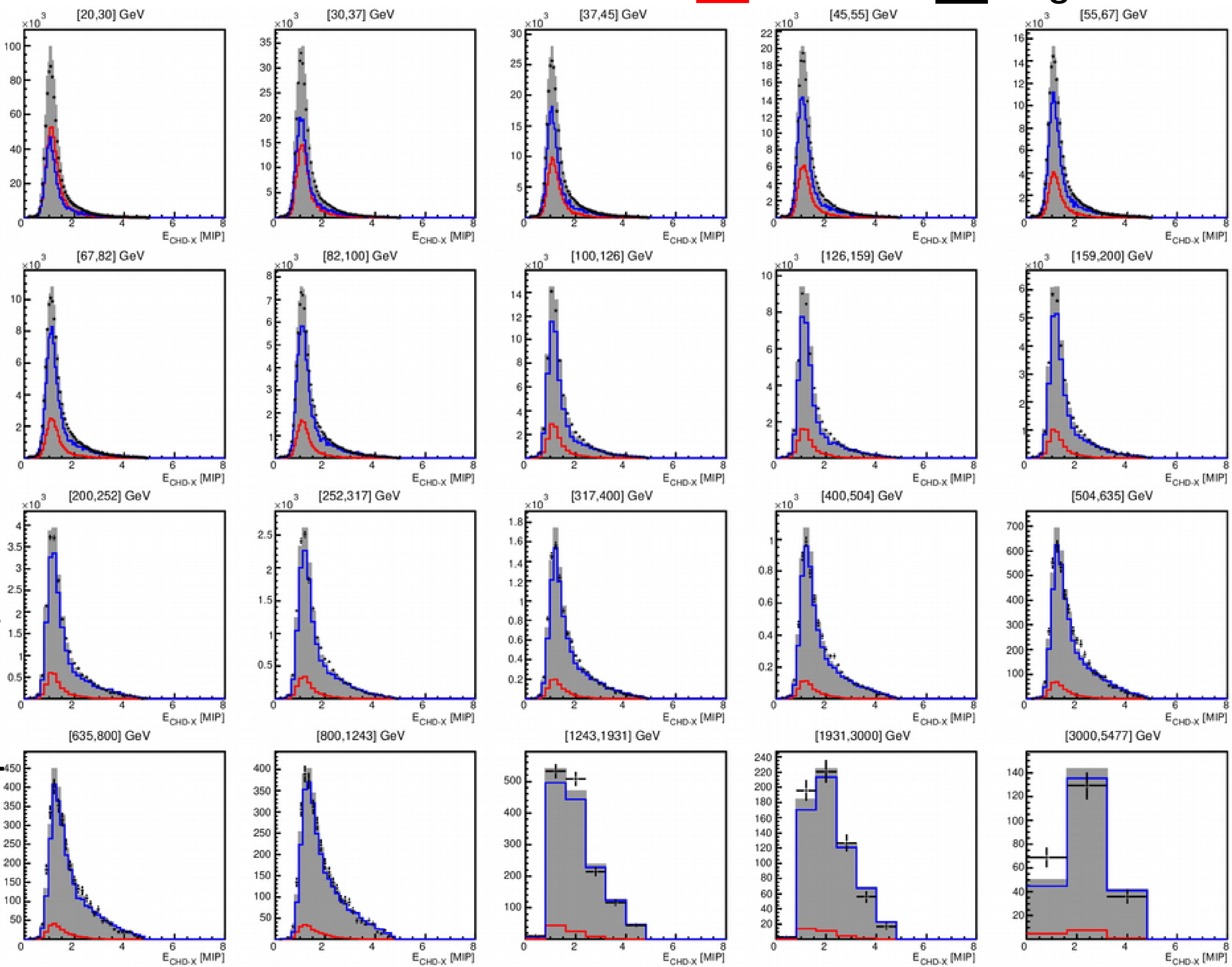
Trigger - TASCX1



Charge - CHDX1 **EPICS**

Proton
Electron
Proton+Electron
Flight Data

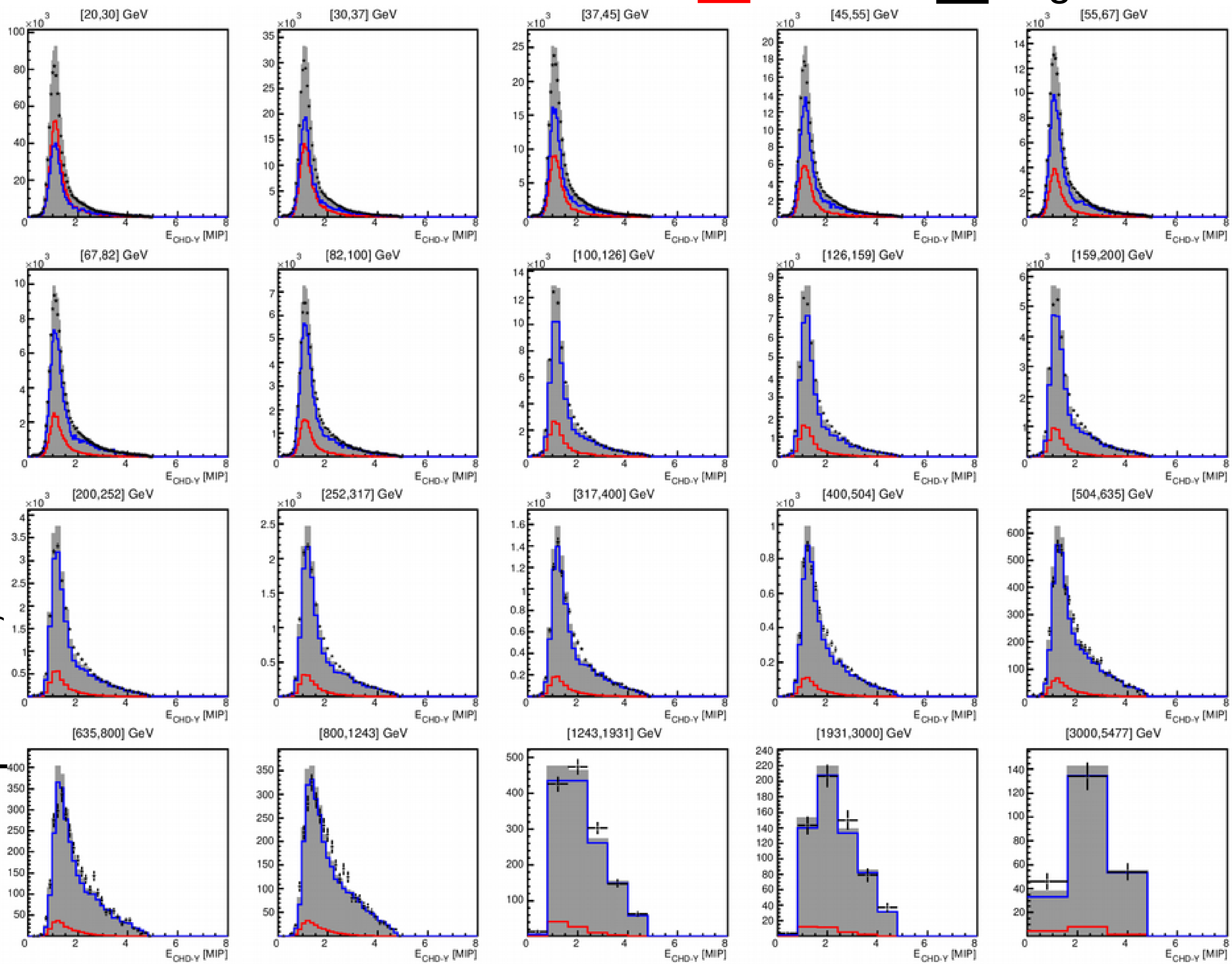
NB Correction applied to protons, but not to electrons



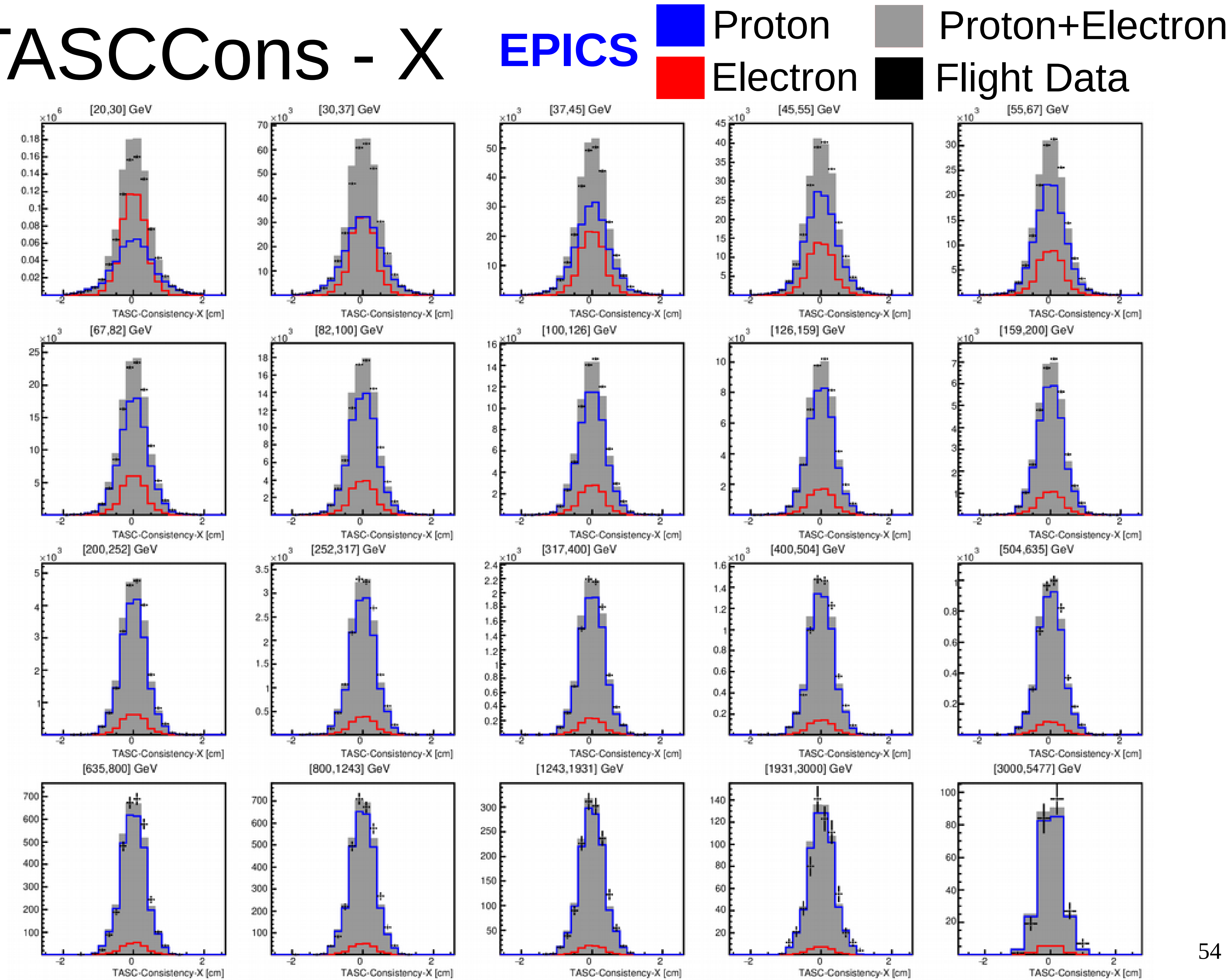
Charge - CHDY1 **EPICS**

Proton
Electron
Proton+Electron
Flight Data

NB Correction applied to protons, but not to electrons



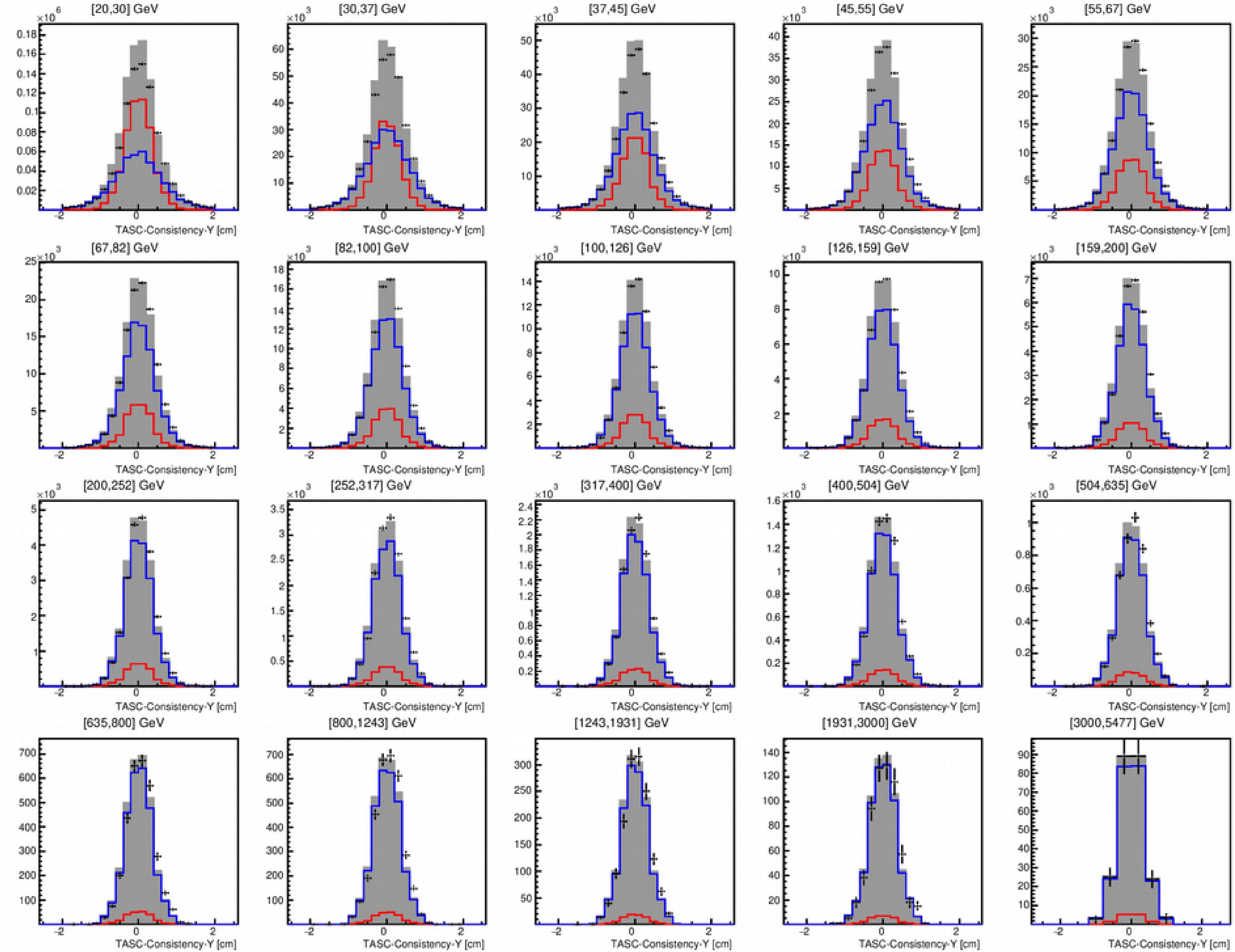
TASCCons - X



EPICS
Proton
Electron
Proton+Electron
Flight Data
[20,30] GeV
[30,37] GeV
[37,45] GeV
[45,55] GeV
[55,67] GeV
[67,82] GeV
[82,100] GeV
[100,126] GeV
[126,159] GeV
[159,200] GeV
[200,252] GeV
[252,317] GeV
[317,400] GeV
[400,504] GeV
[504,635] GeV
[635,800] GeV
[800,1243] GeV
[1243,1931] GeV
[1931,3000] GeV
[3000,5477] GeV
TASC-Consistency-X [cm]

TASCCons - Y

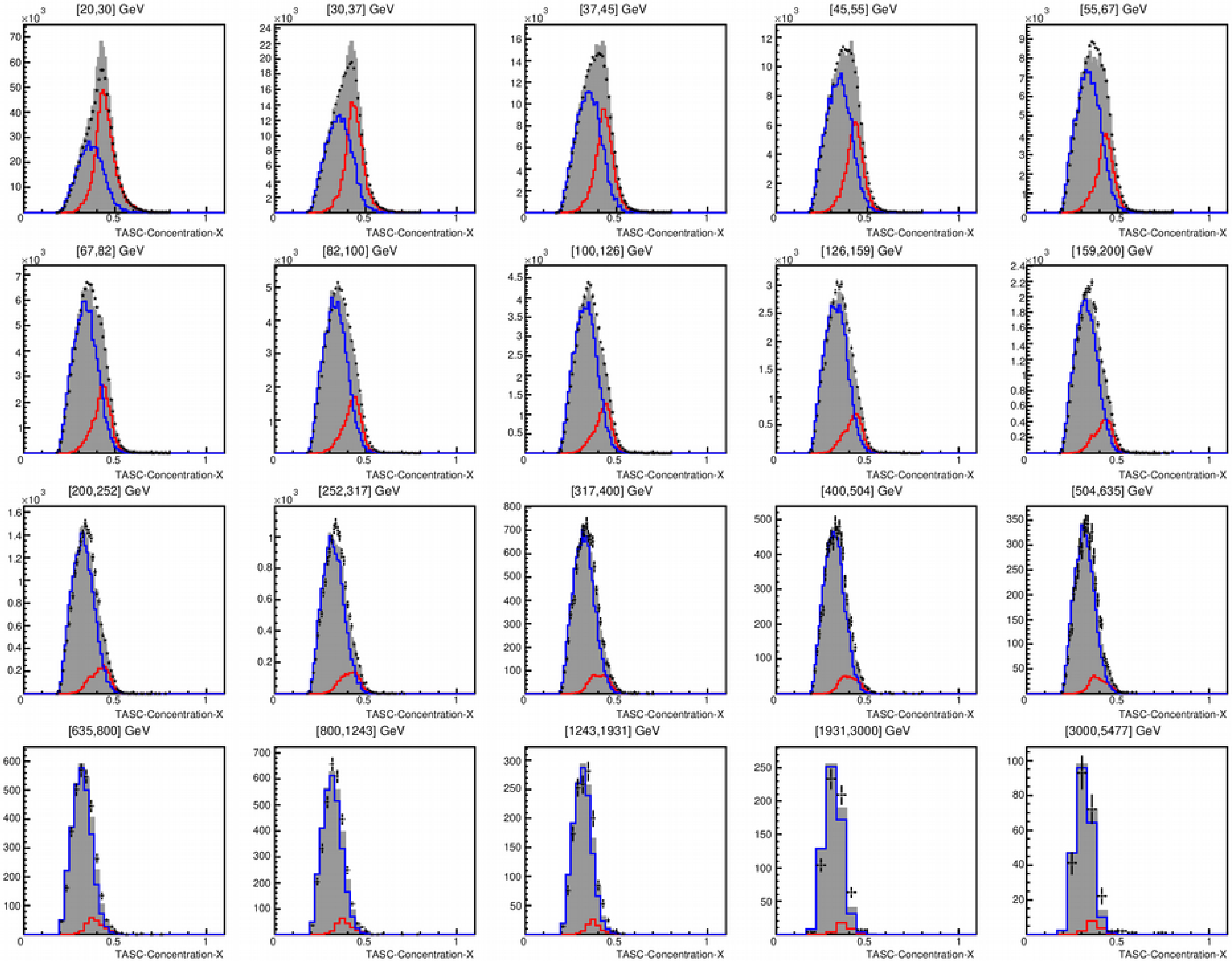
EPICS Proton Electron Proton+Electron Flight Data



LayConc - X

EPICS

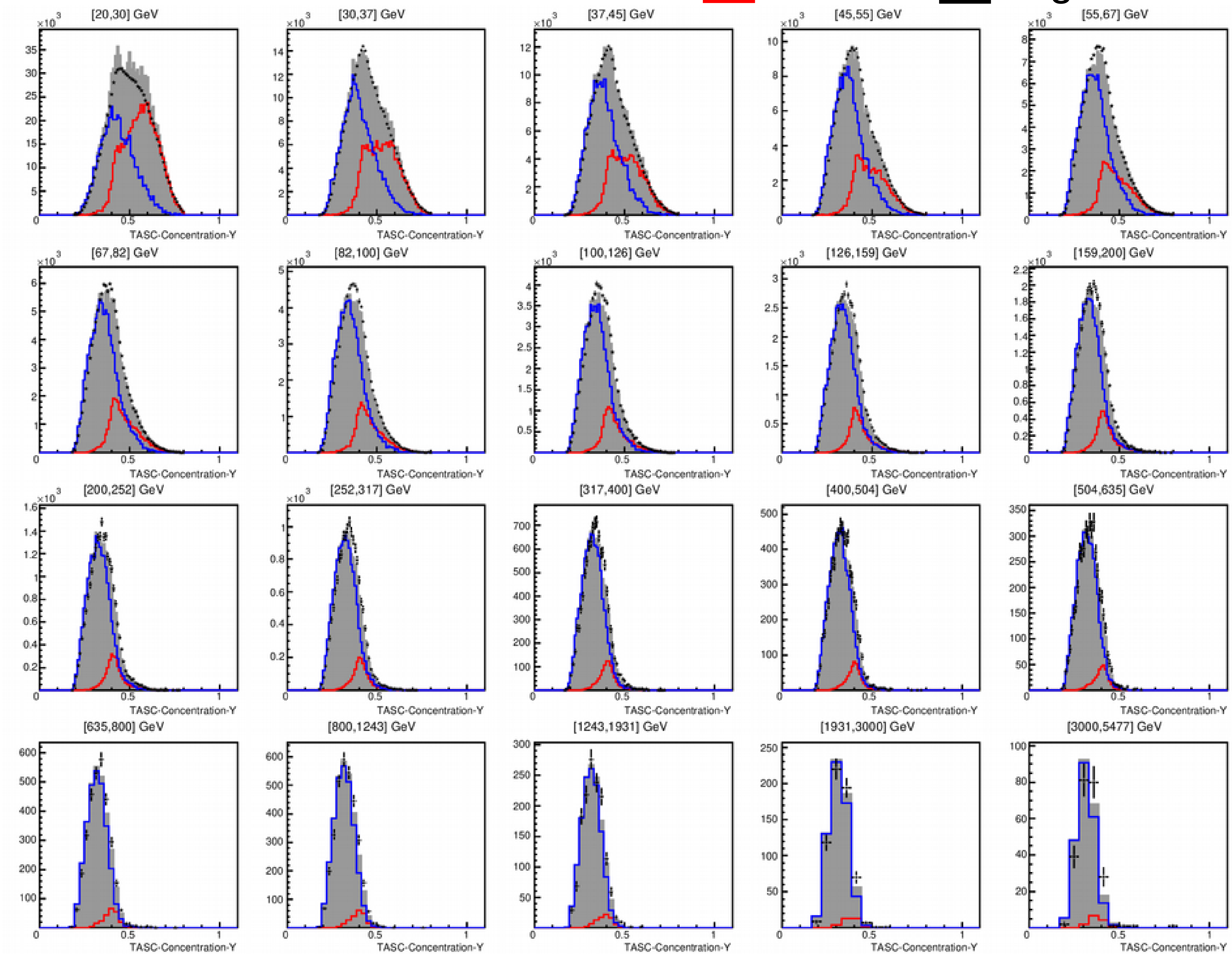
Proton
Electron
Proton+Electron
Flight Data



LayConc - Y

EPICS

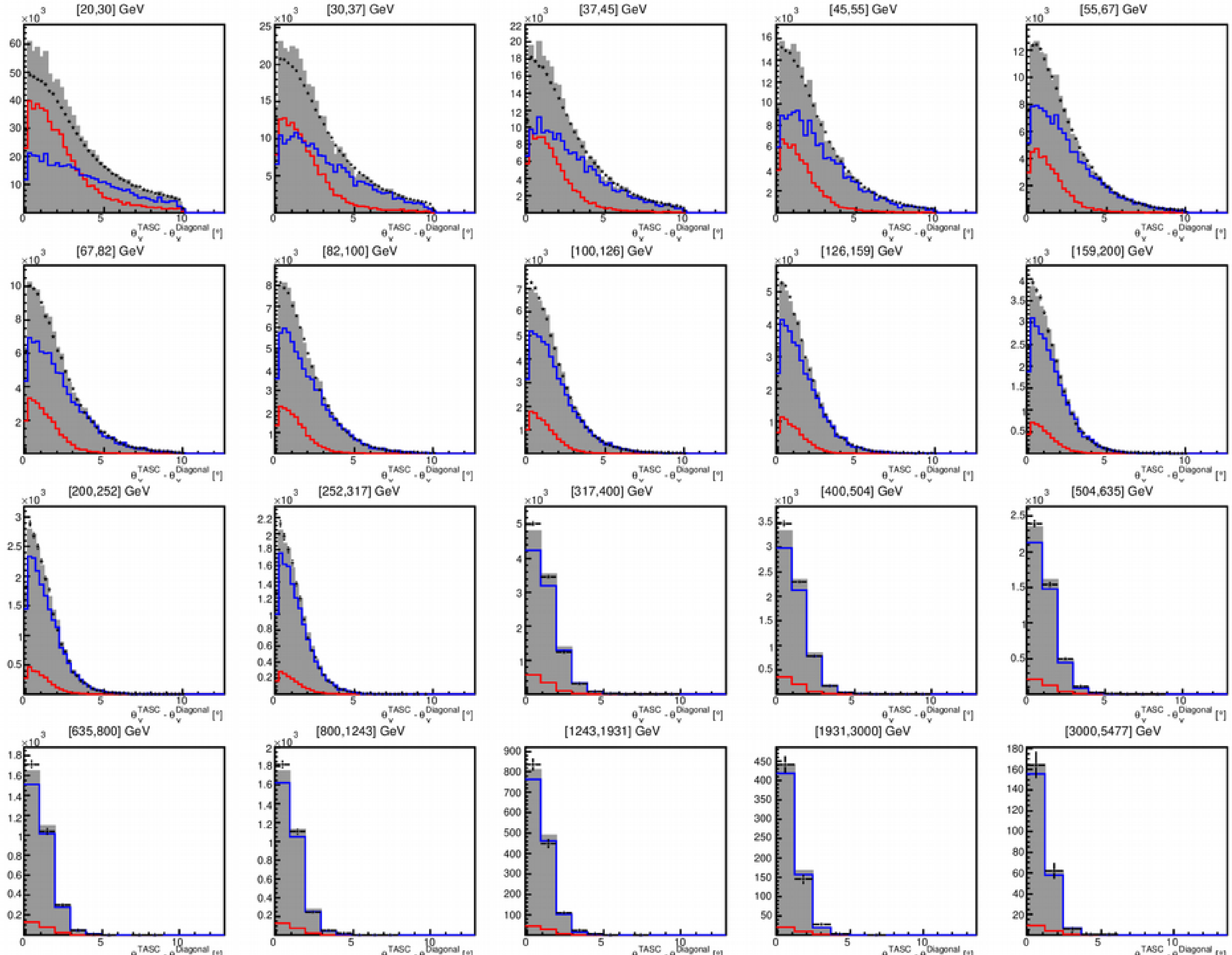
Proton · Electron · Proton+Electron · Flight Data



ShowerTrack - X

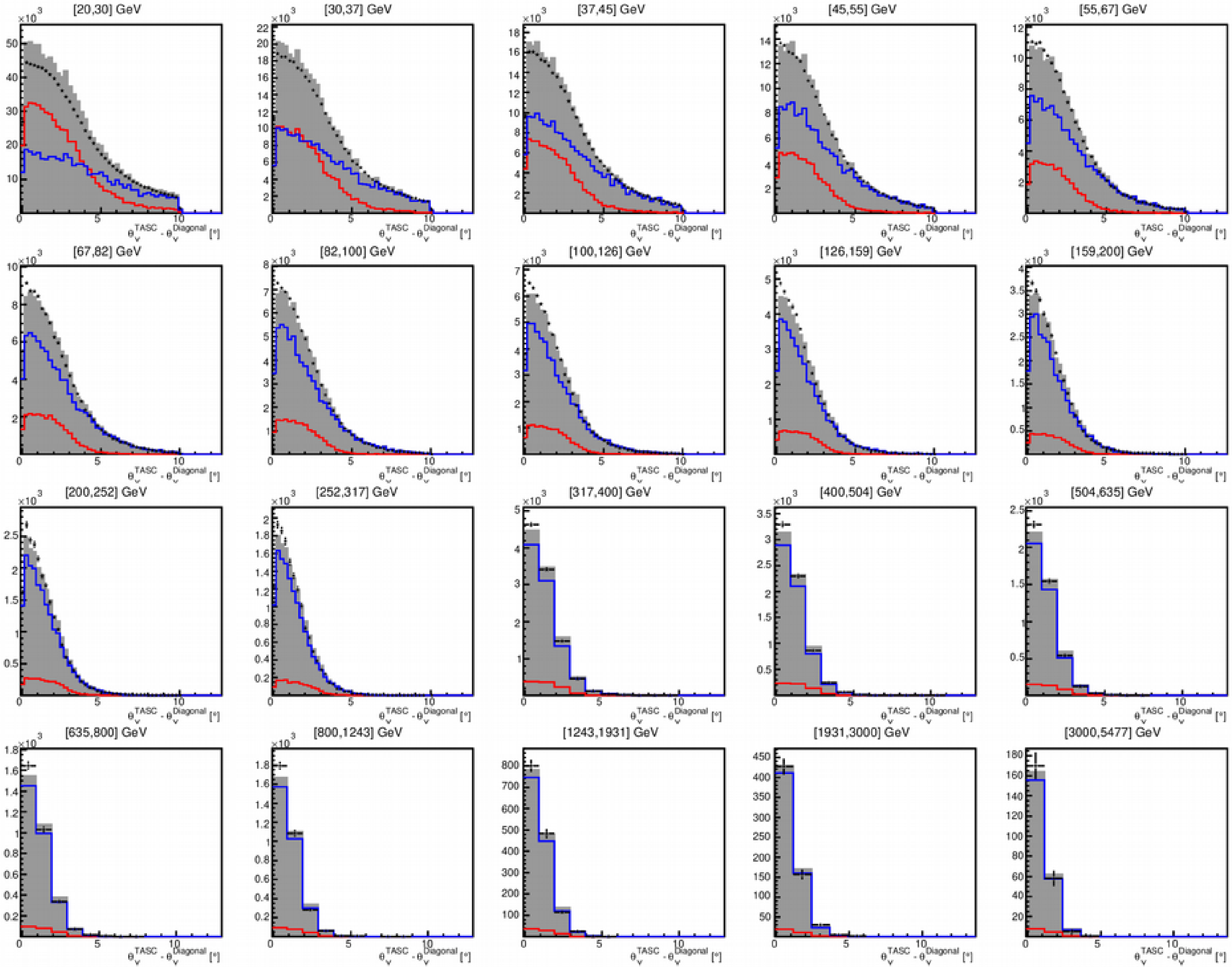
EPICS

Proton | Proton+Electron
Electron | Flight Data

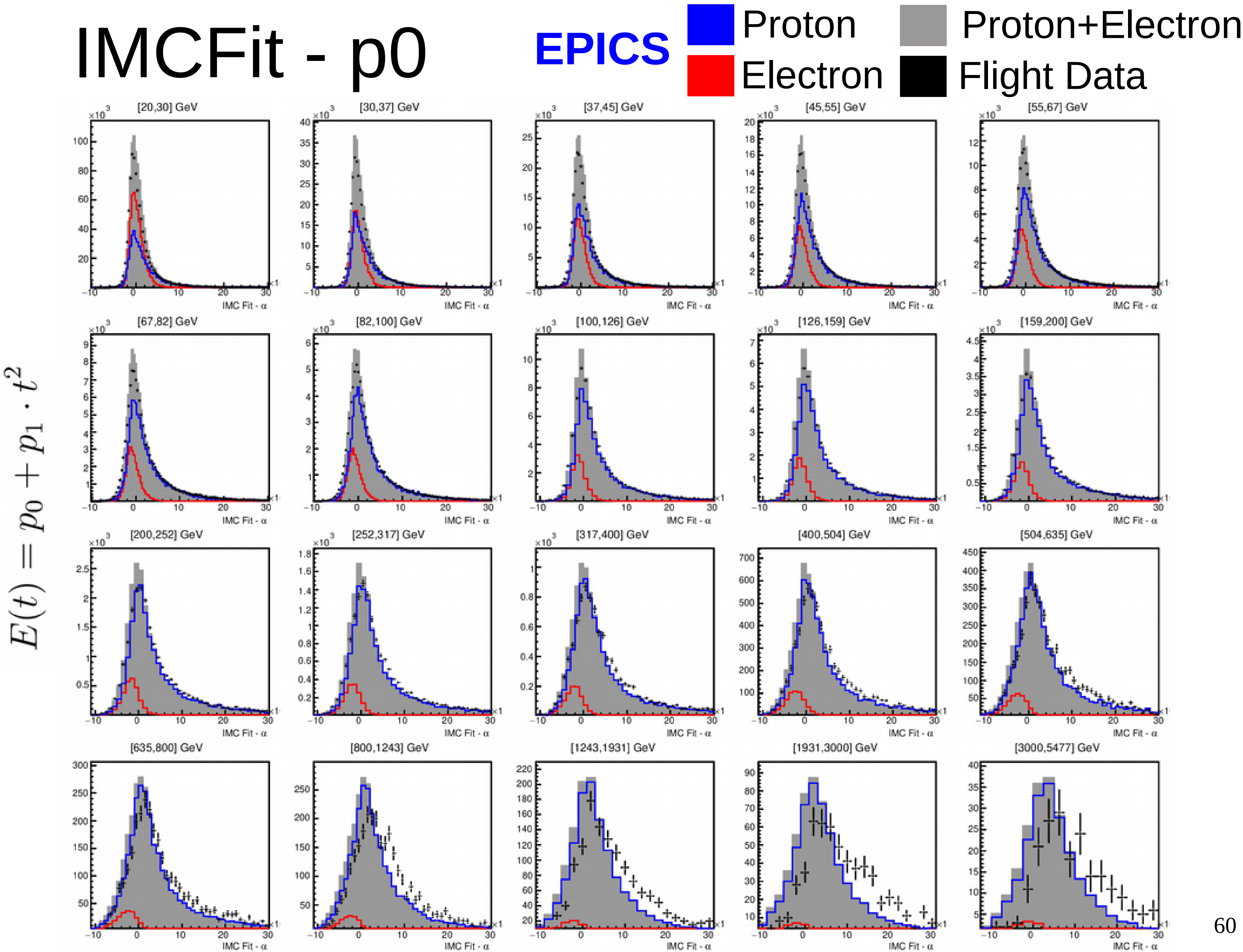


ShowerTrack - Y **EPICS**

Proton
Electron
Proton+Electron
Flight Data



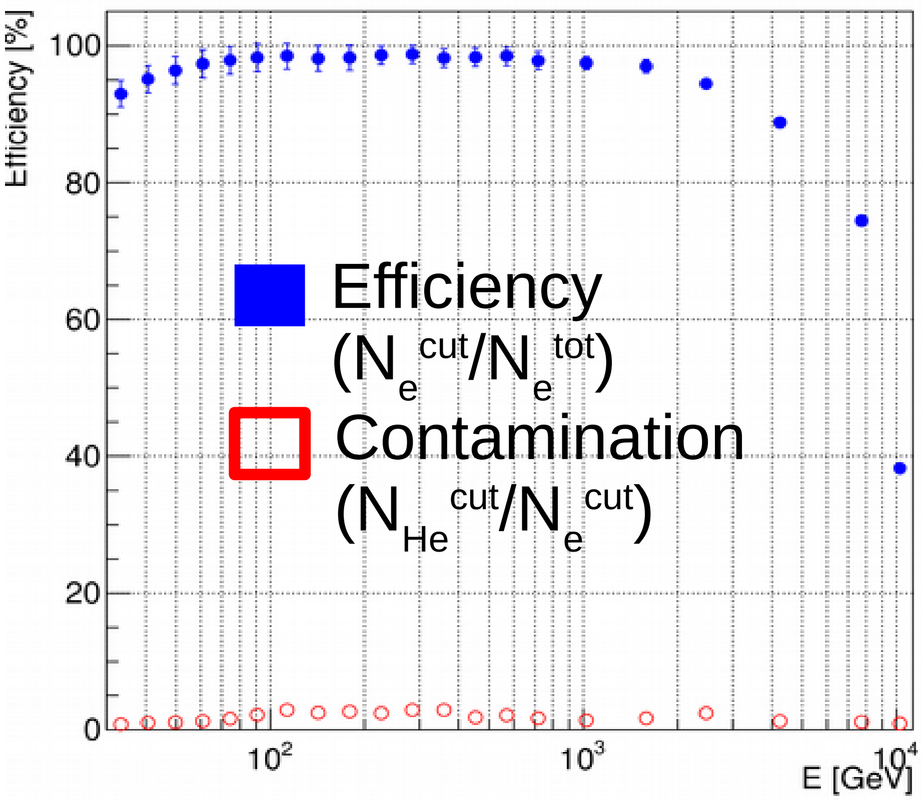
IMCFit - p0



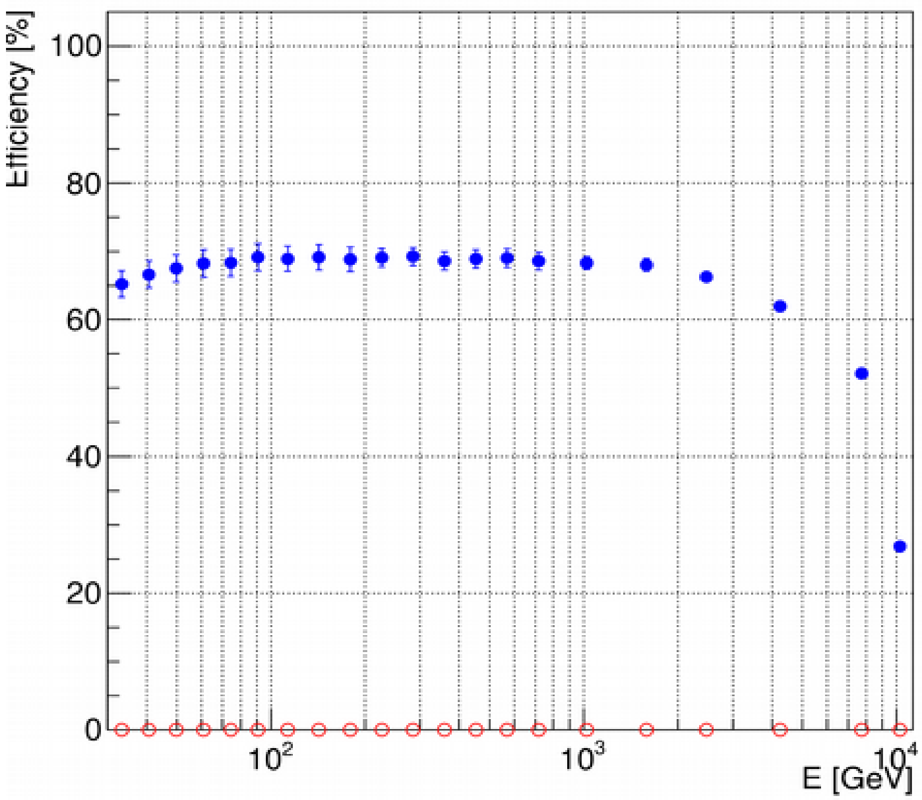
EPICS
Proton
Proton+Electron
Electron
Flight Data
$E(t) = p_0 + p_1 \cdot t^2$
[20,30] GeV
[30,37] GeV
[37,45] GeV
[45,55] GeV
[55,67] GeV
[67,82] GeV
[82,100] GeV
[100,126] GeV
[126,159] GeV
[159,200] GeV
[200,252] GeV
[252,317] GeV
[317,400] GeV
[400,504] GeV
[504,635] GeV
[635,800] GeV
[800,1243] GeV
[1243,1931] GeV
[1931,3000] GeV
[3000,5477] GeV
IMC Fit - α

Residual Helium contamination

Before BDT



After BDT



Proton in Acc B identified as Electron after K cut