STUDY OF THE $X_{max} - N_\mu$ ANTICORRELATION IN SEARCH OF PHYSICAL PROPERTIES OF THE FIRST INTERACTIONS

ISABEL GOOS, TANGUY PIEROG, XAVIER BERTOU

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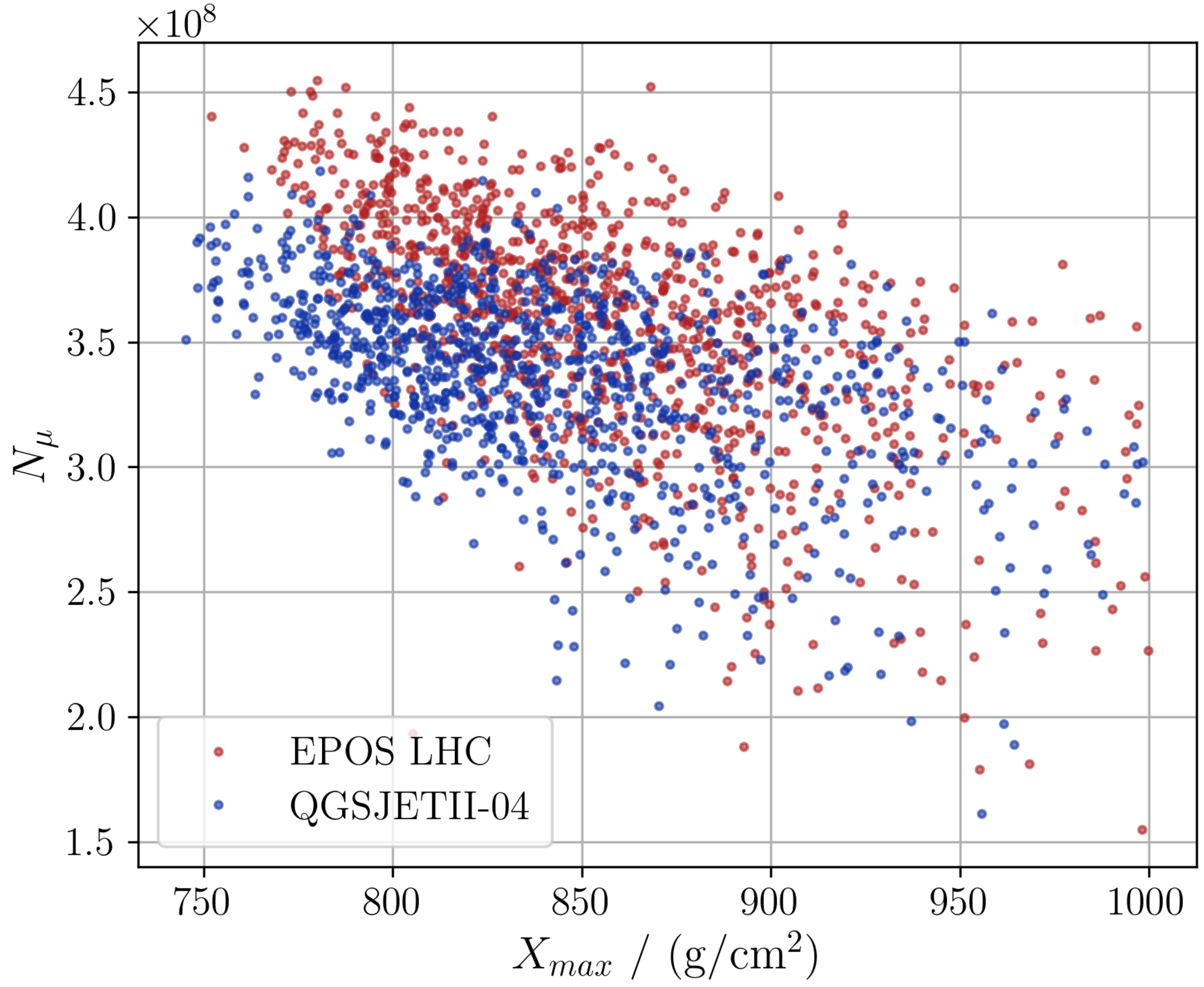
THE TASK



Theoretical interest: deduce something about physical parameters of the shower (mainly first interaction) and thus understanding the spread and the anti-correlation

Practical interest: incorporate this new knowledge in the reconstruction of showers

THE EQUATIONS

$$\xi_c^\pi = \frac{\left(1-(1-f_{ch}^{en})\kappa\right)^{n_d} E_0}{\left(1+N_{ch}^{FI}\right)\left(1+N_{ch}\right)^{n_d-1}}$$

$$\lambda_{int} = \lambda_{dec}$$

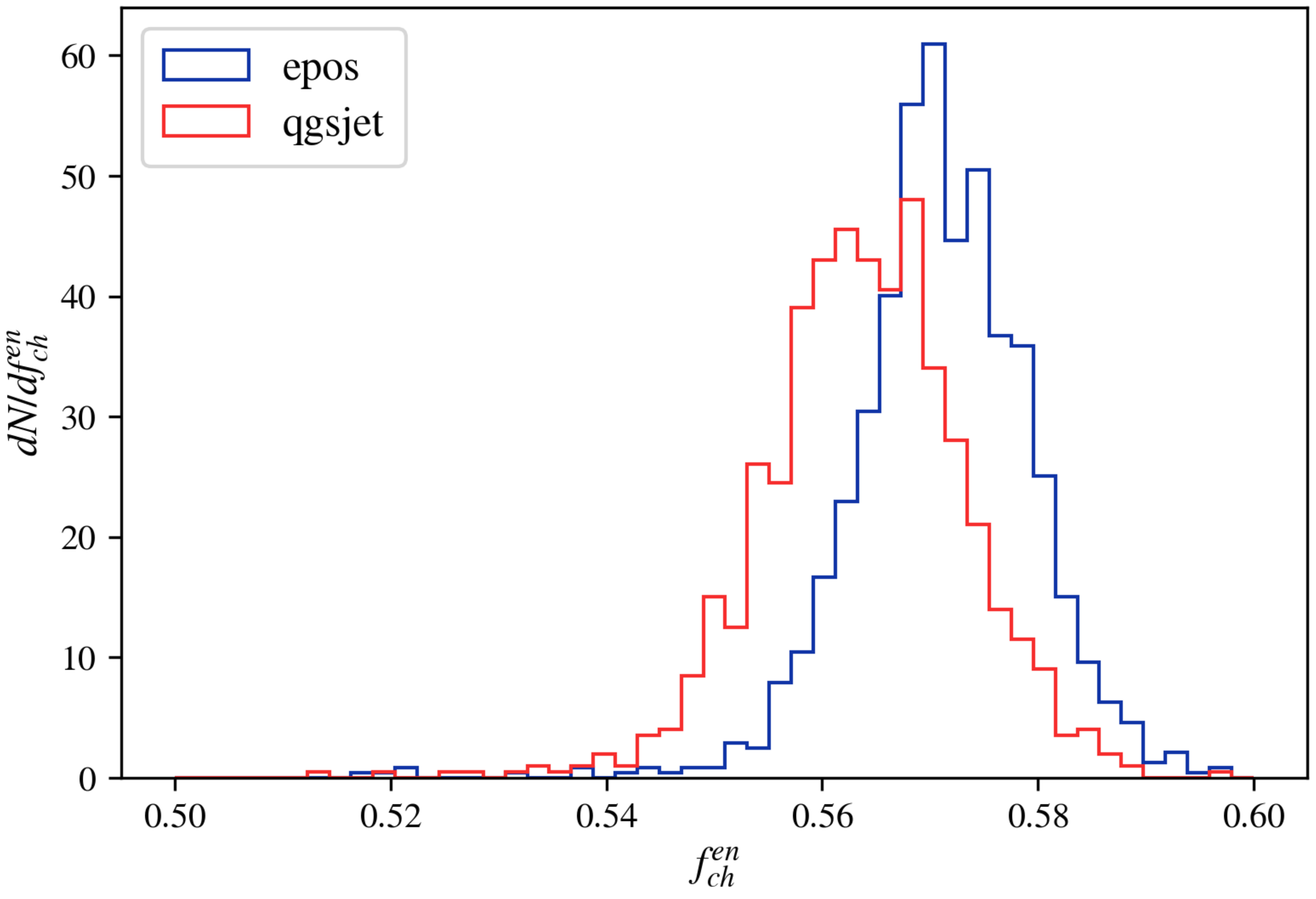
$$\frac{h_0}{n_d\cos(\theta)} = c\tau_\pi \frac{\left[\left(1-(1-f_{ch}^{en})\kappa\right)^{n_d} E_0\right] / \left[\left(1+N_{ch}^{FI}\right)\left(1+N_{ch}\right)^{n_d-1}\right]}{m_\pi c^2}$$

$$\Rightarrow \frac{h_0}{\cos(\theta)}\frac{m_\pi c^2}{c\tau_\pi E_0}\frac{1+N_{ch}^{FI}}{1+N_{ch}} = n_d\left(\frac{1-(1-f_{ch}^{en})\kappa}{1+N_{ch}}\right)^{n_d} = n_d \exp\left(n_d \ln\left(\frac{1-(1-f_{ch}^{en})\kappa}{1+N_{ch}}\right)\right)$$

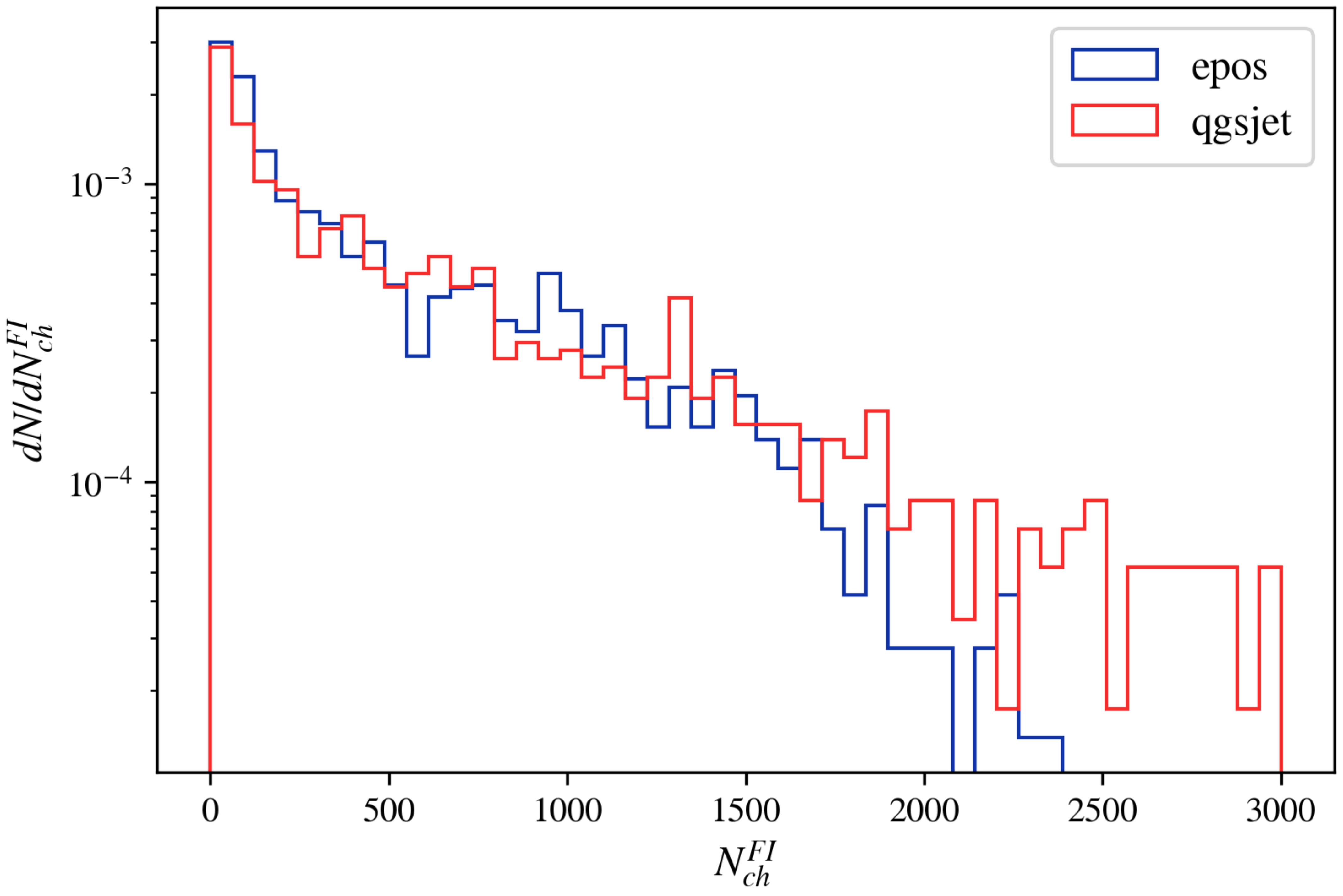
$$\therefore n_d = W_{-1}\left(\ln\left(\frac{1-(1-f_{ch}^{en})\kappa}{1+N_{ch}}\right)\cdot\frac{h_0}{\cos(\theta)}\frac{m_\pi c^2}{c\tau_\pi E_0}\frac{1+N_{ch}^{FI}}{1+N_{ch}}\right) / \ln\left(\frac{1-(1-f_{ch}^{en})\kappa}{1+N_{ch}}\right)$$

$$N_\mu^{Gr} = \left(1+N_{ch}^{FI}\right)\left(1+N_{ch}\right)^{n_d-1}$$

TEST ON DIFFERENT PARAMETER VALUES

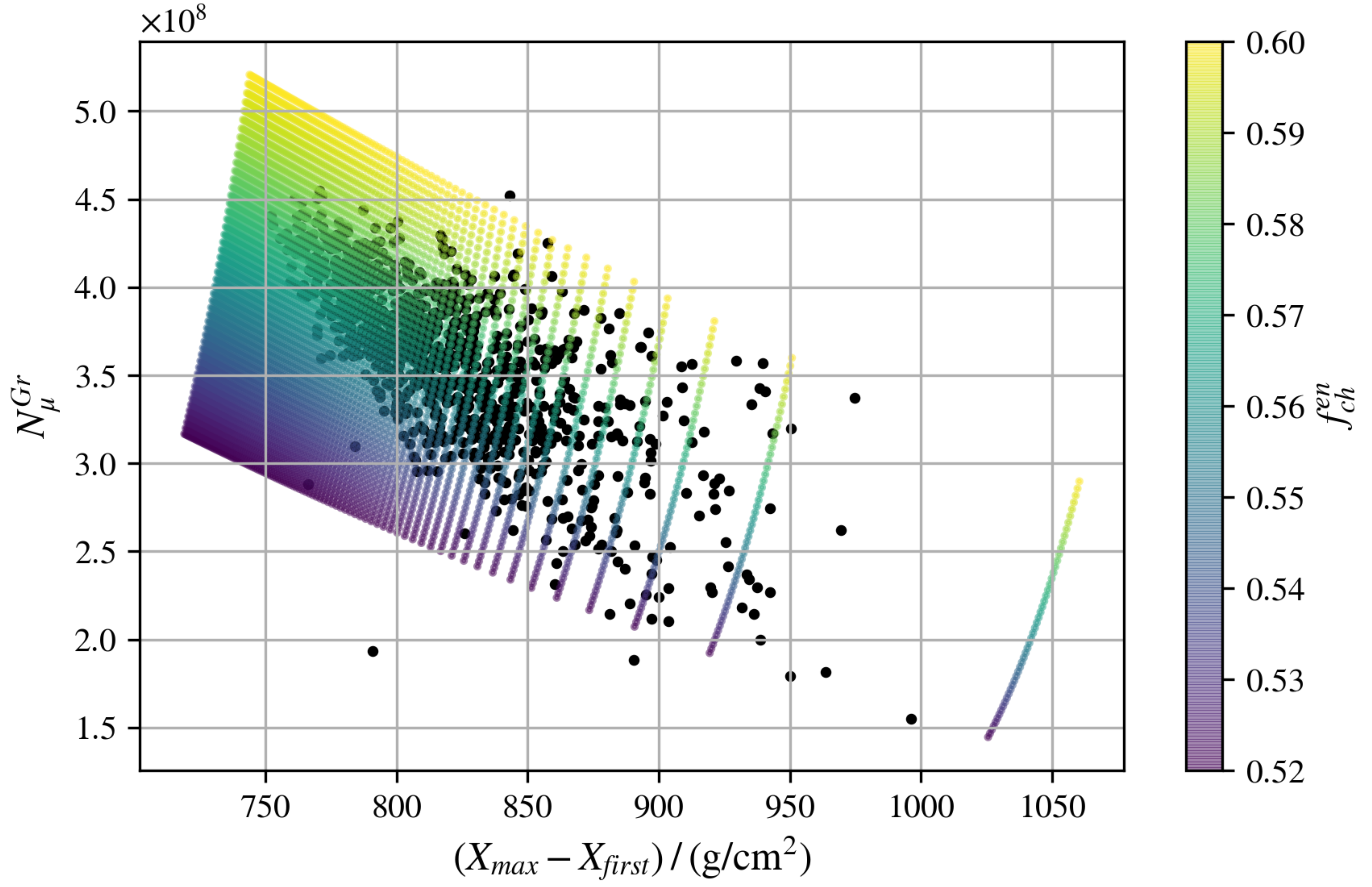


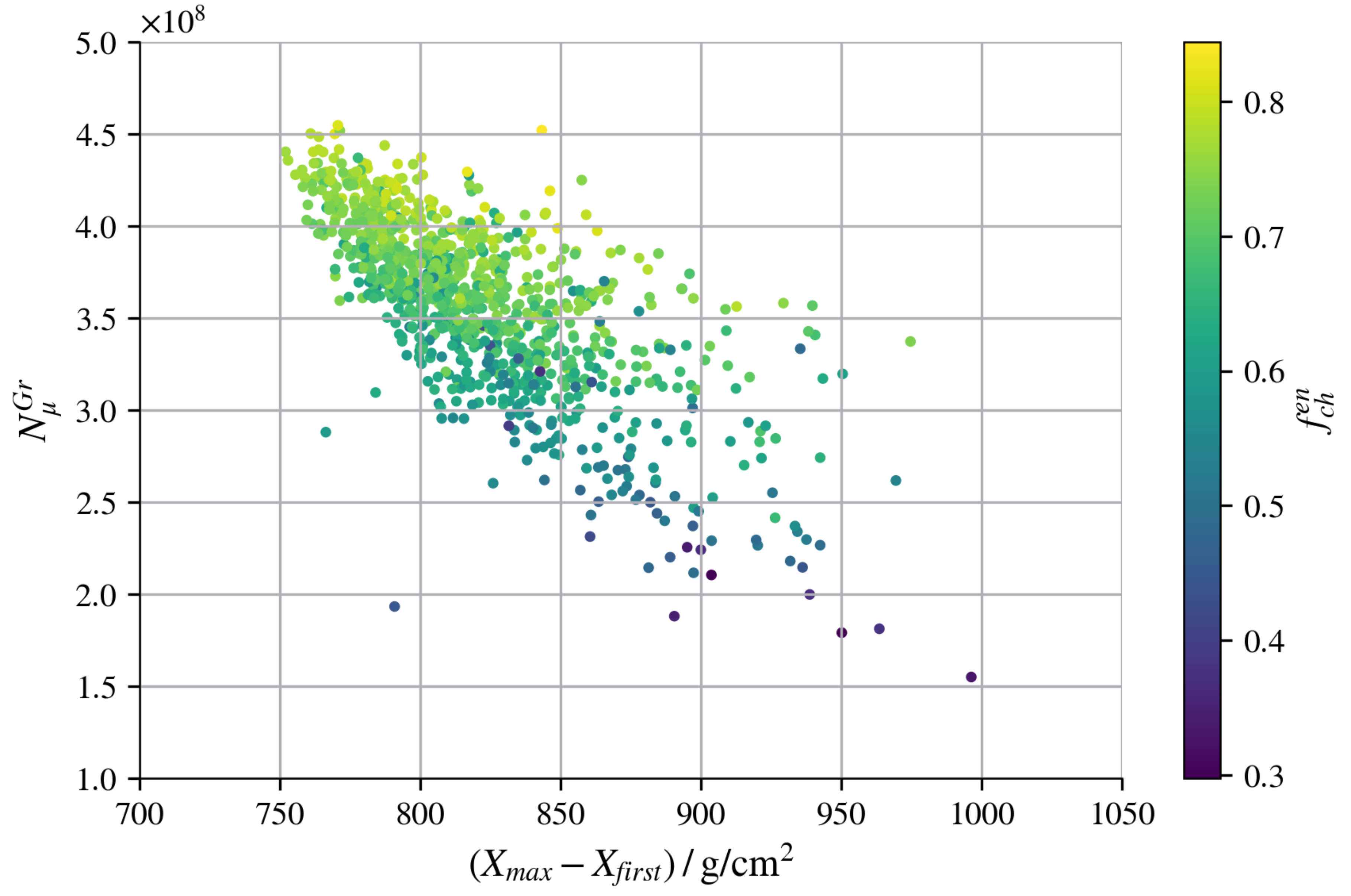
f_{ch}^{en} from 0.55 to 0.6



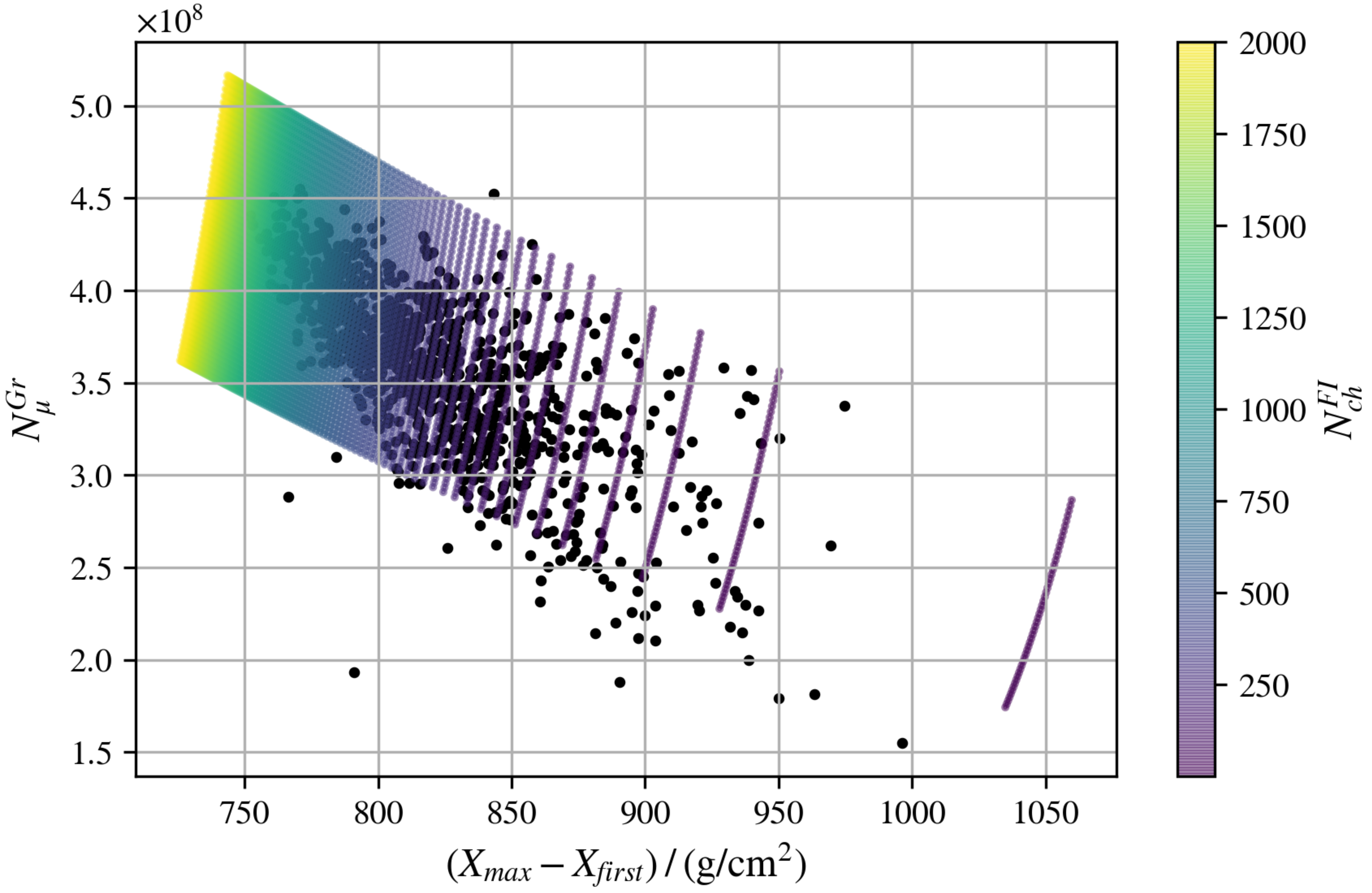
N_{ch}^{FI} from 0 to 2000

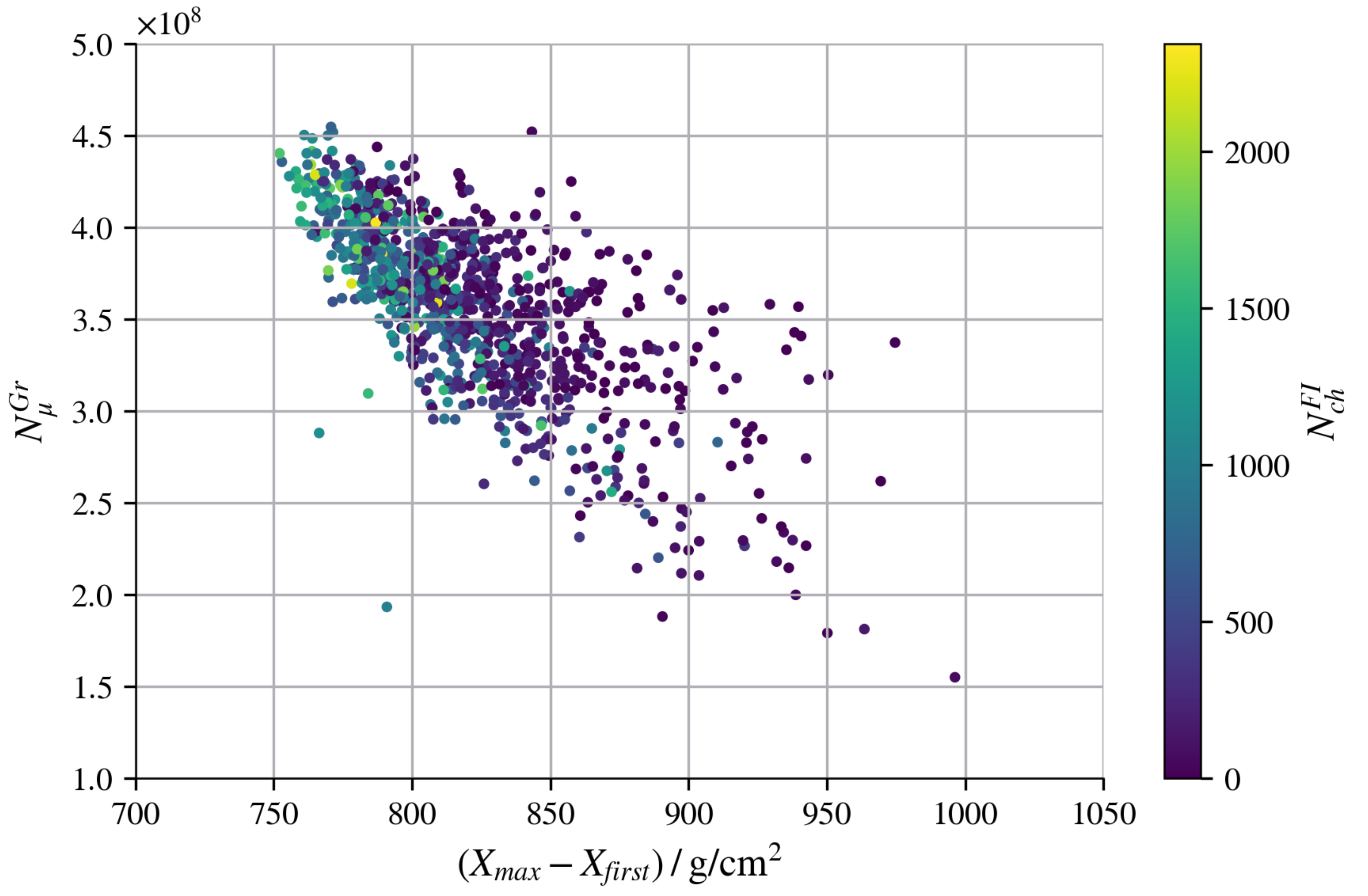
TEST ON DIFFERENT PARAMETER VALUES



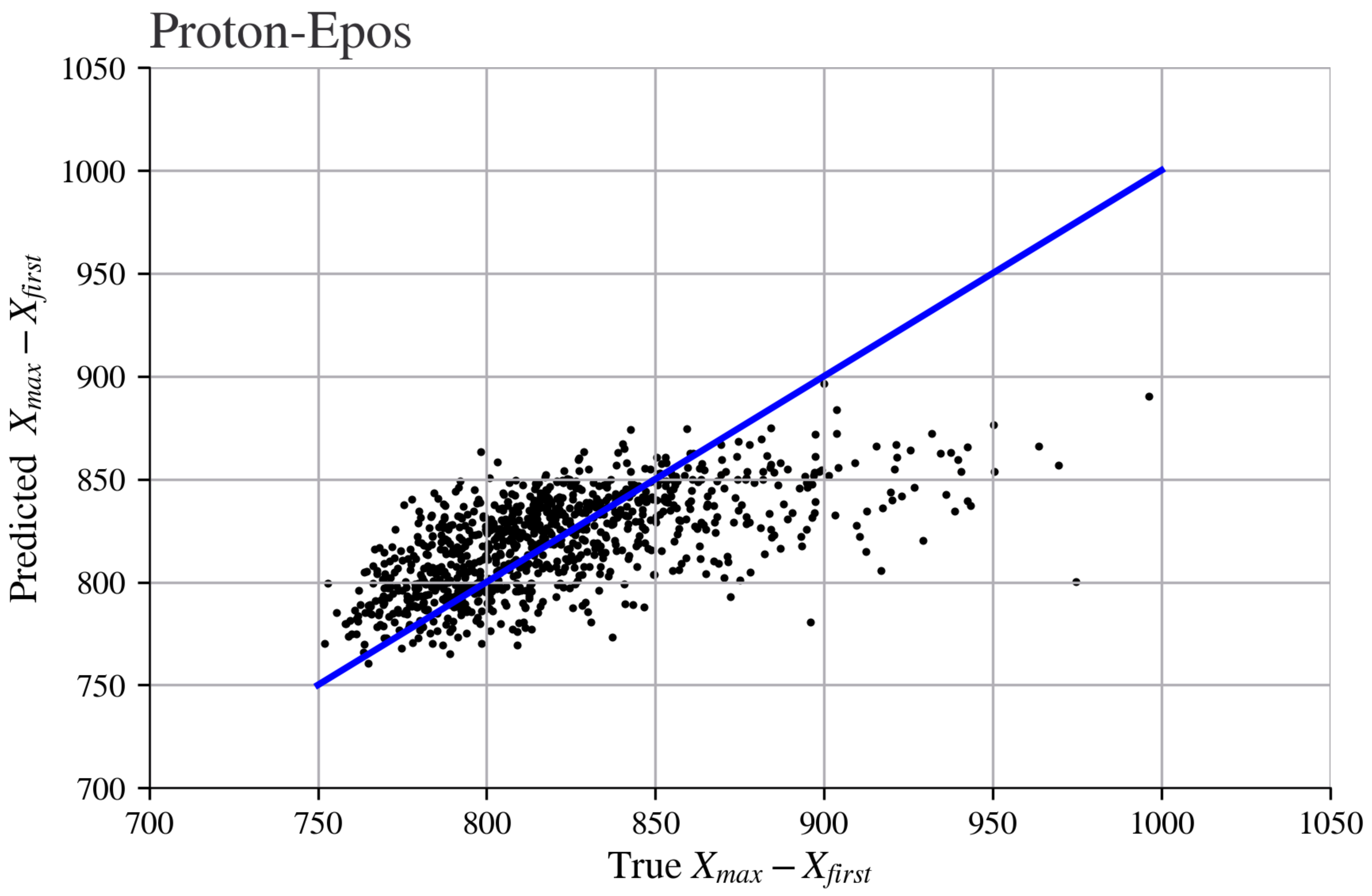


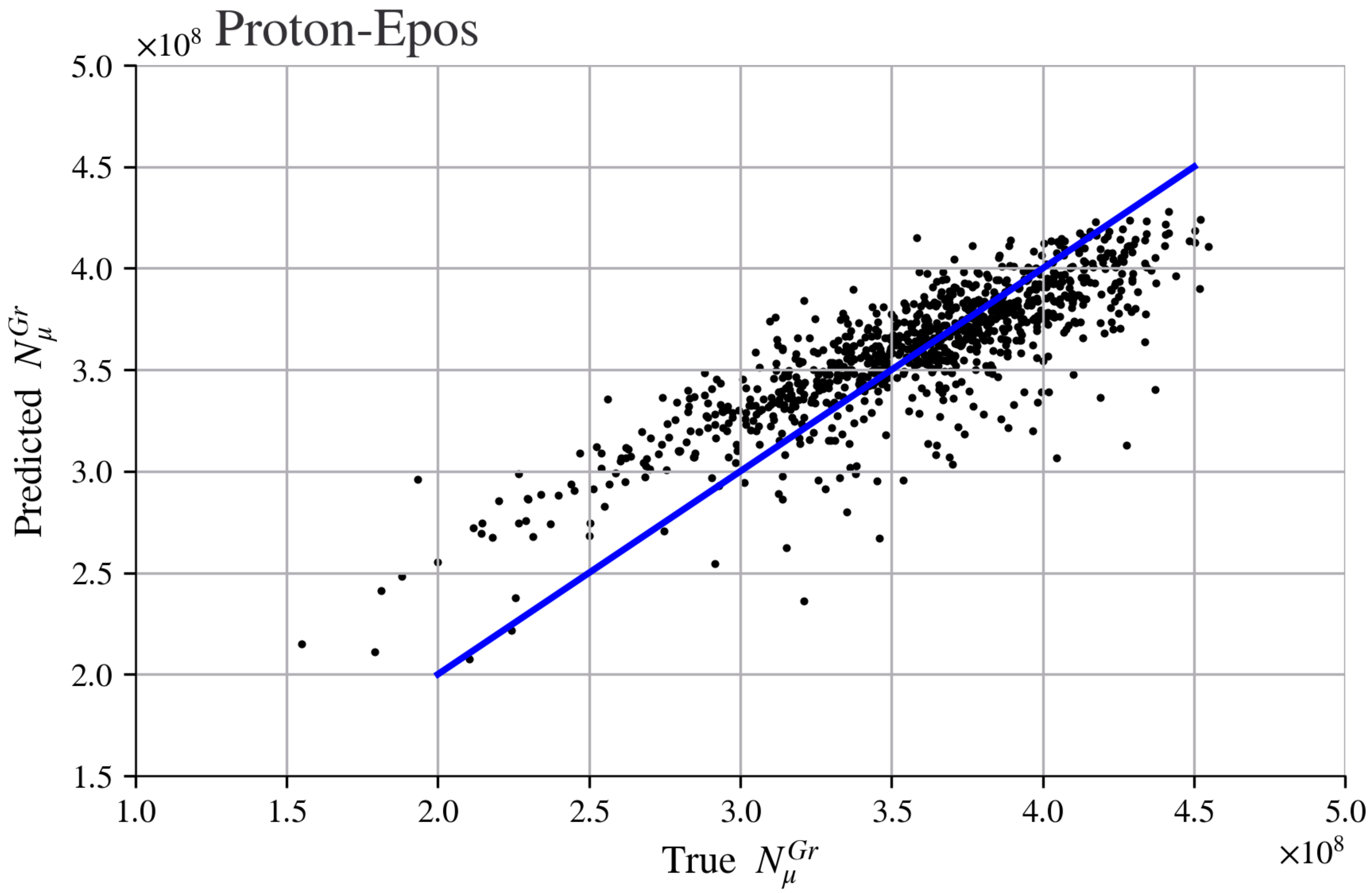
TEST ON DIFFERENT PARAMETER VALUES



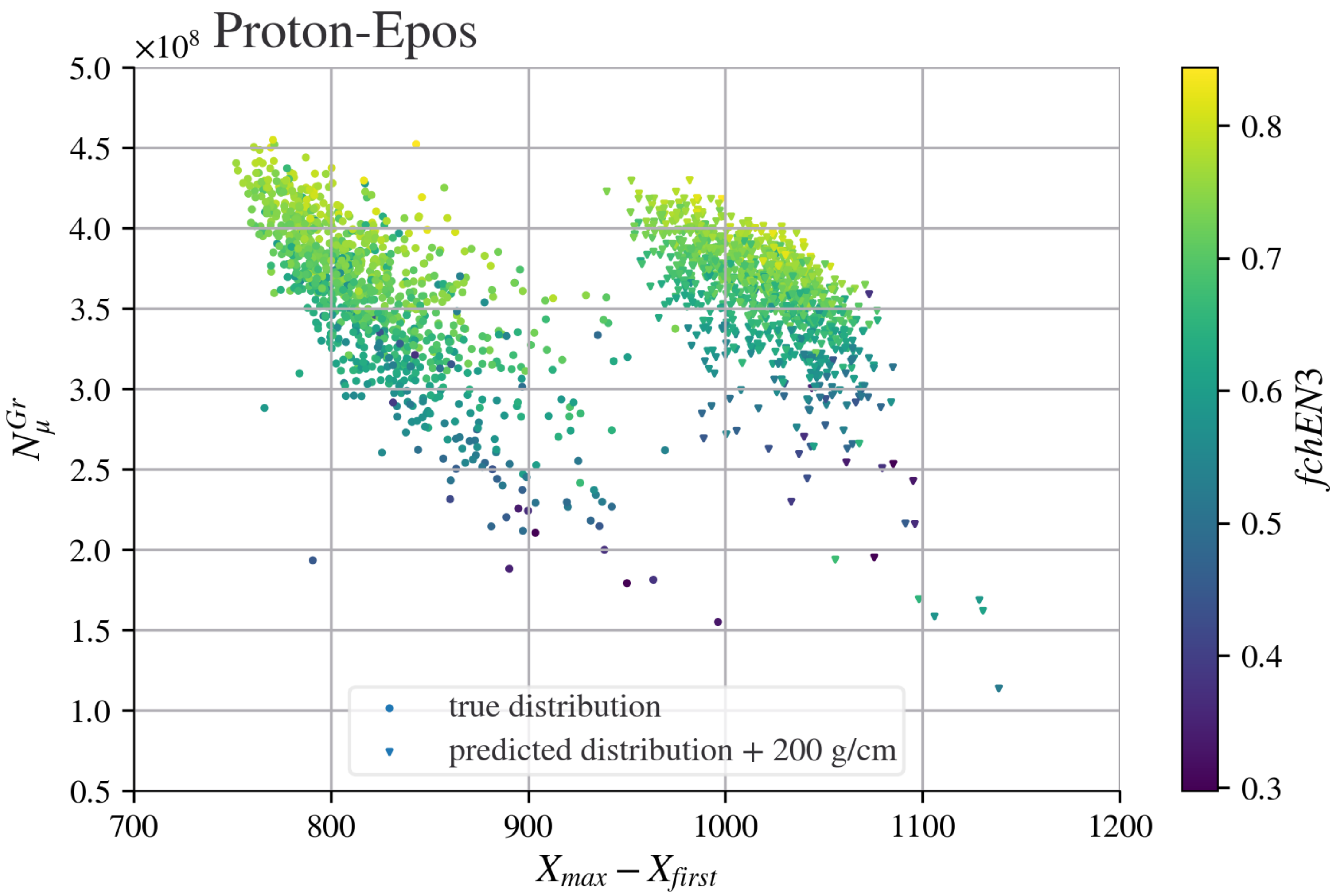


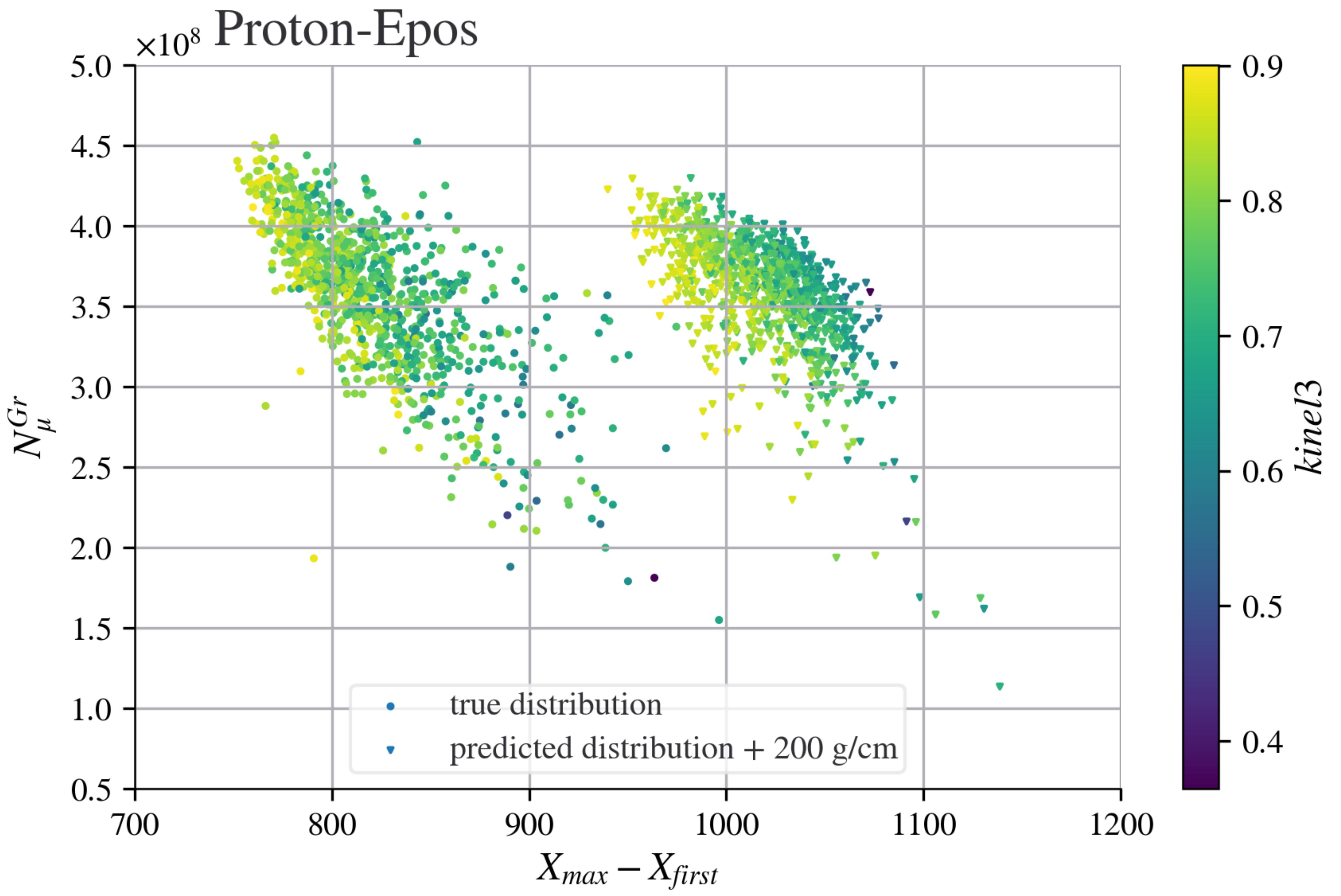
TEST ON PARAMETERS FROM SIMULATIONS – EPOS



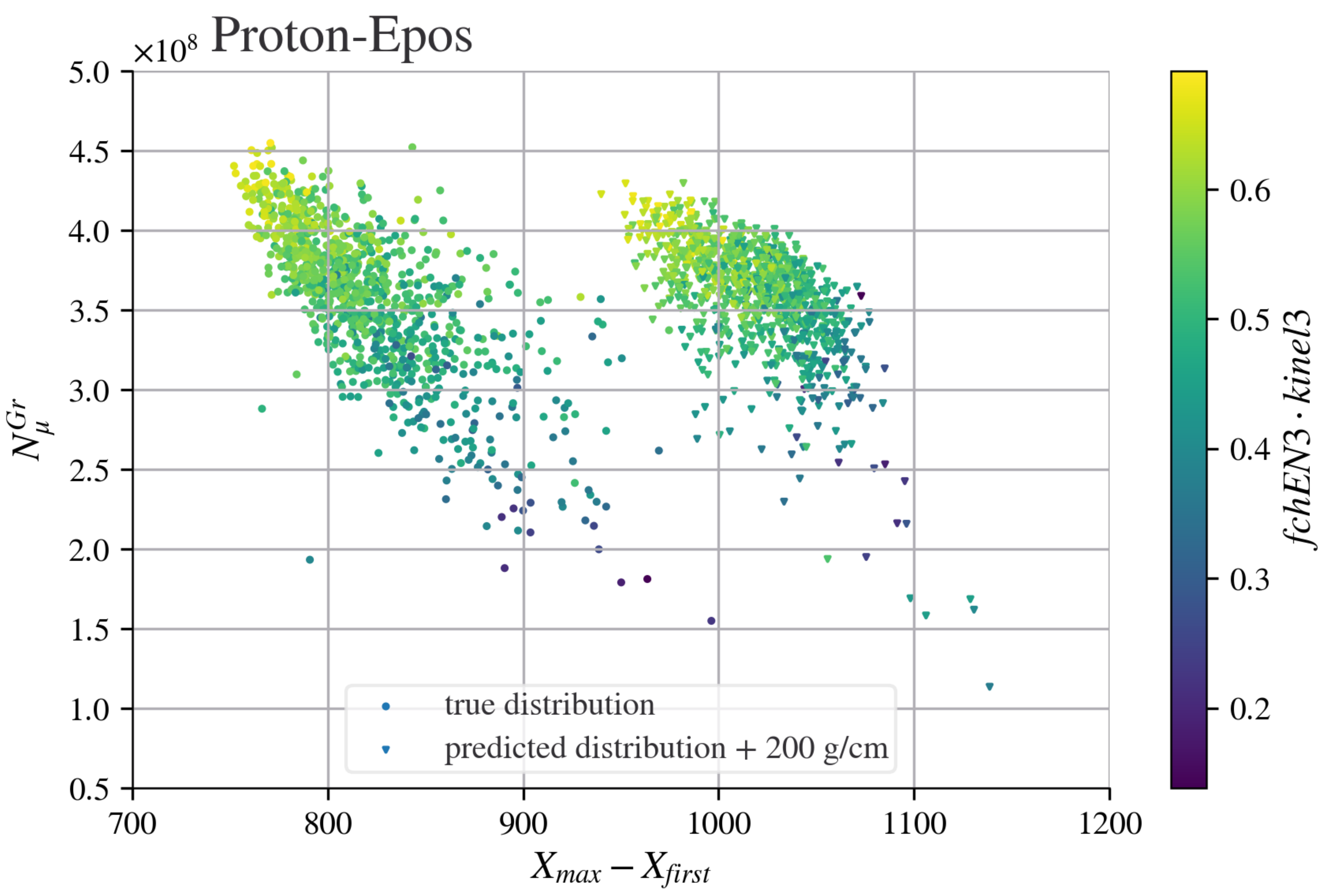


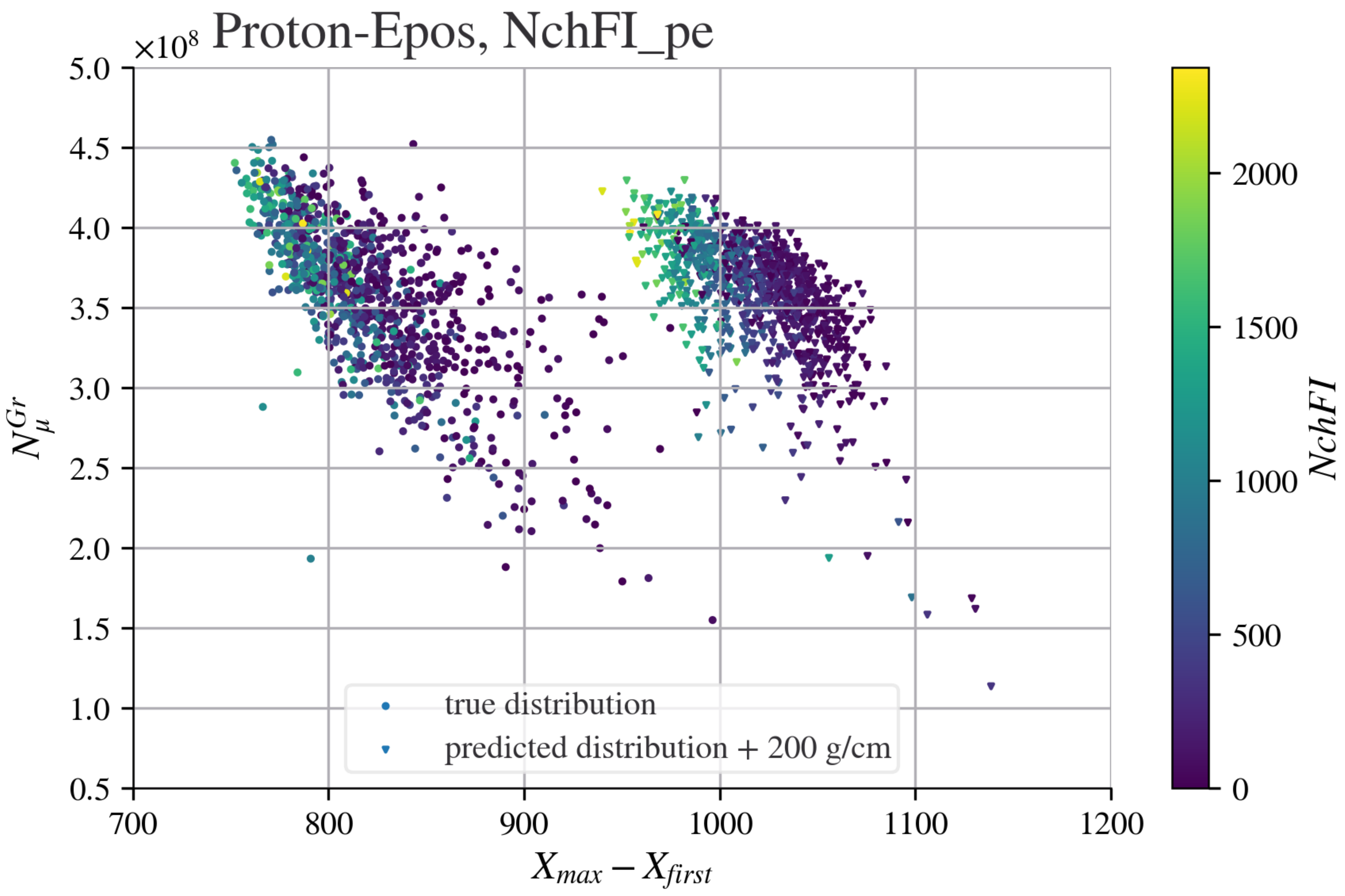
ARE THE PARAMETER EQUALLY DISTRIBUTED?





ARE THE PARAMETER EQUALLY DISTRIBUTED?



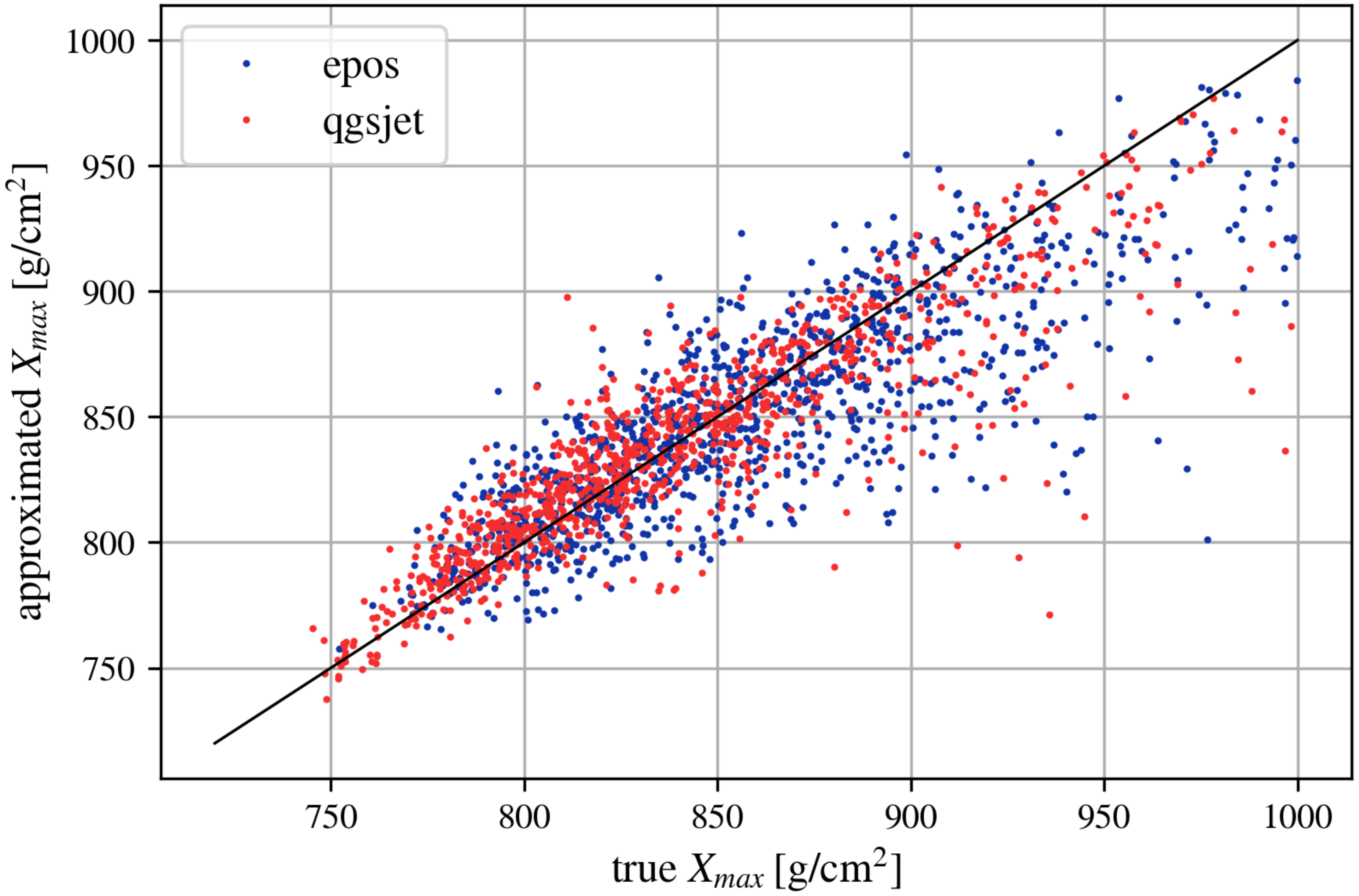


THE MODEL-FEATURE SELECTION AND TRAINING

Features: ~hadronic multiplicity from the first interaction, ~its fraction of energy, point of first interaction (they are uncorrelated) 🔀 use of random forests for getting feature importances

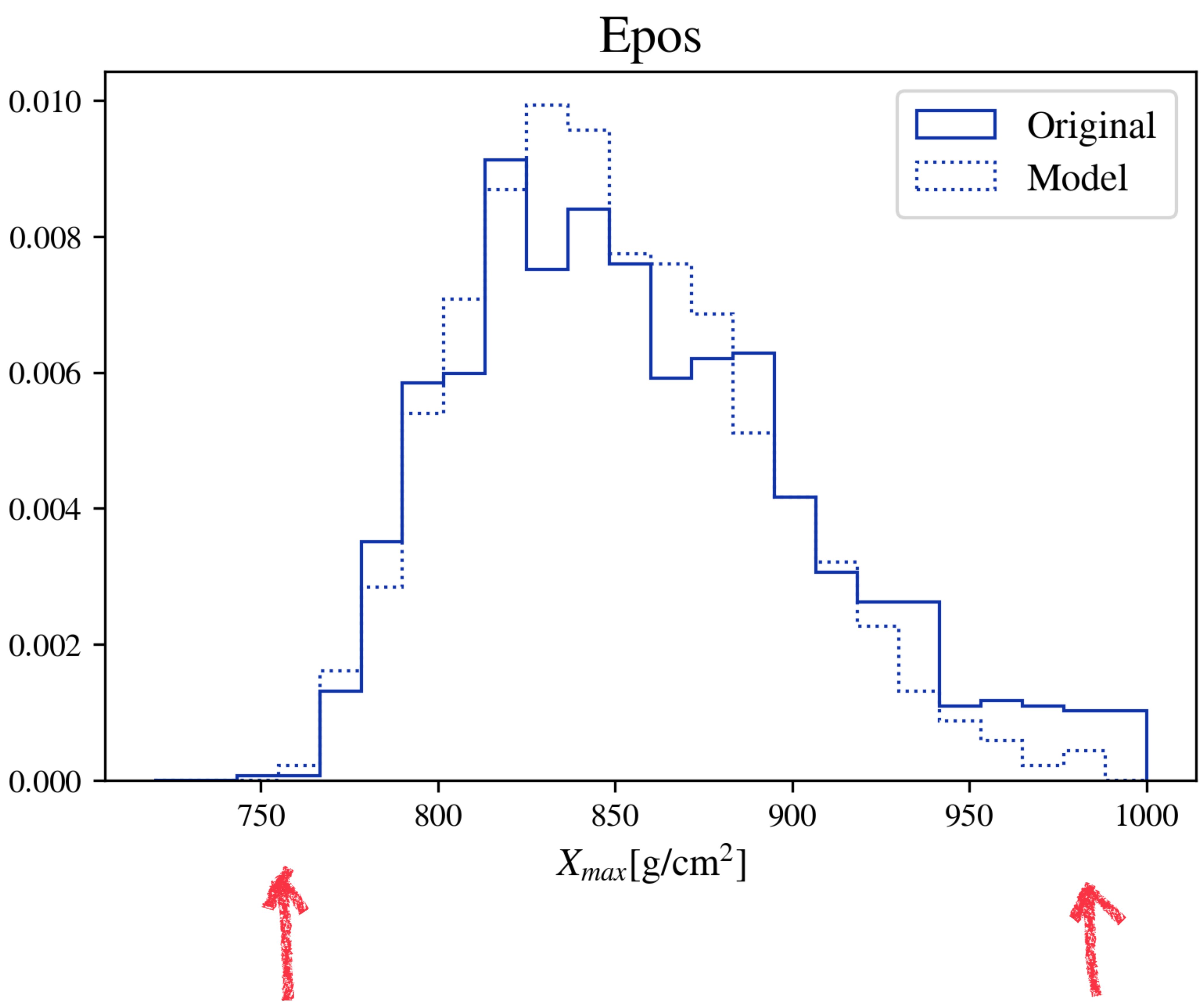
Training: great care not to overfit using small number of nodes and layers, early stopping, kernel regularizar. Mean absolute error since the distributions have outliers. I need a universal model so a hyperparameter search is good but not enough.

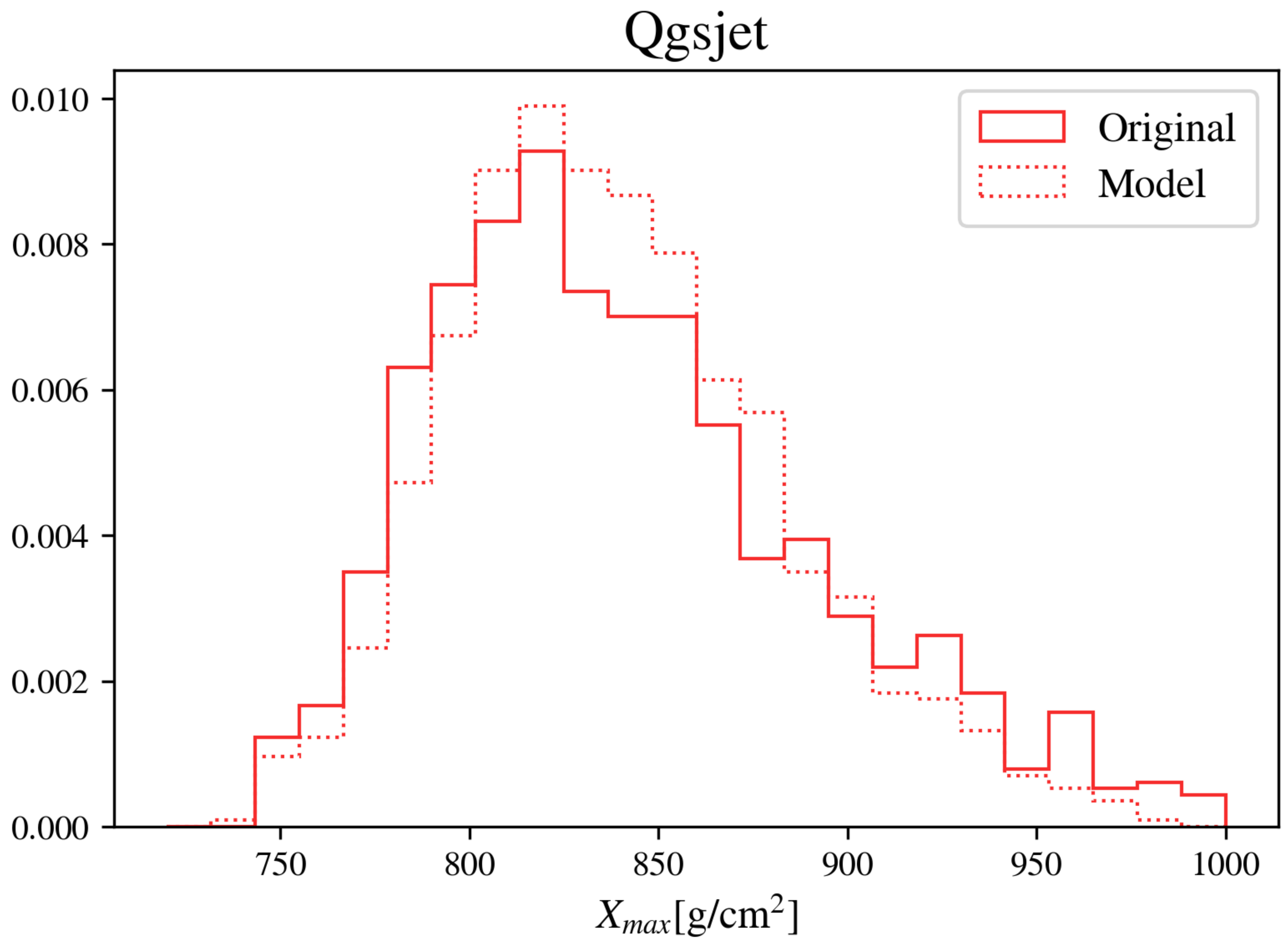
PREDICTABILITY



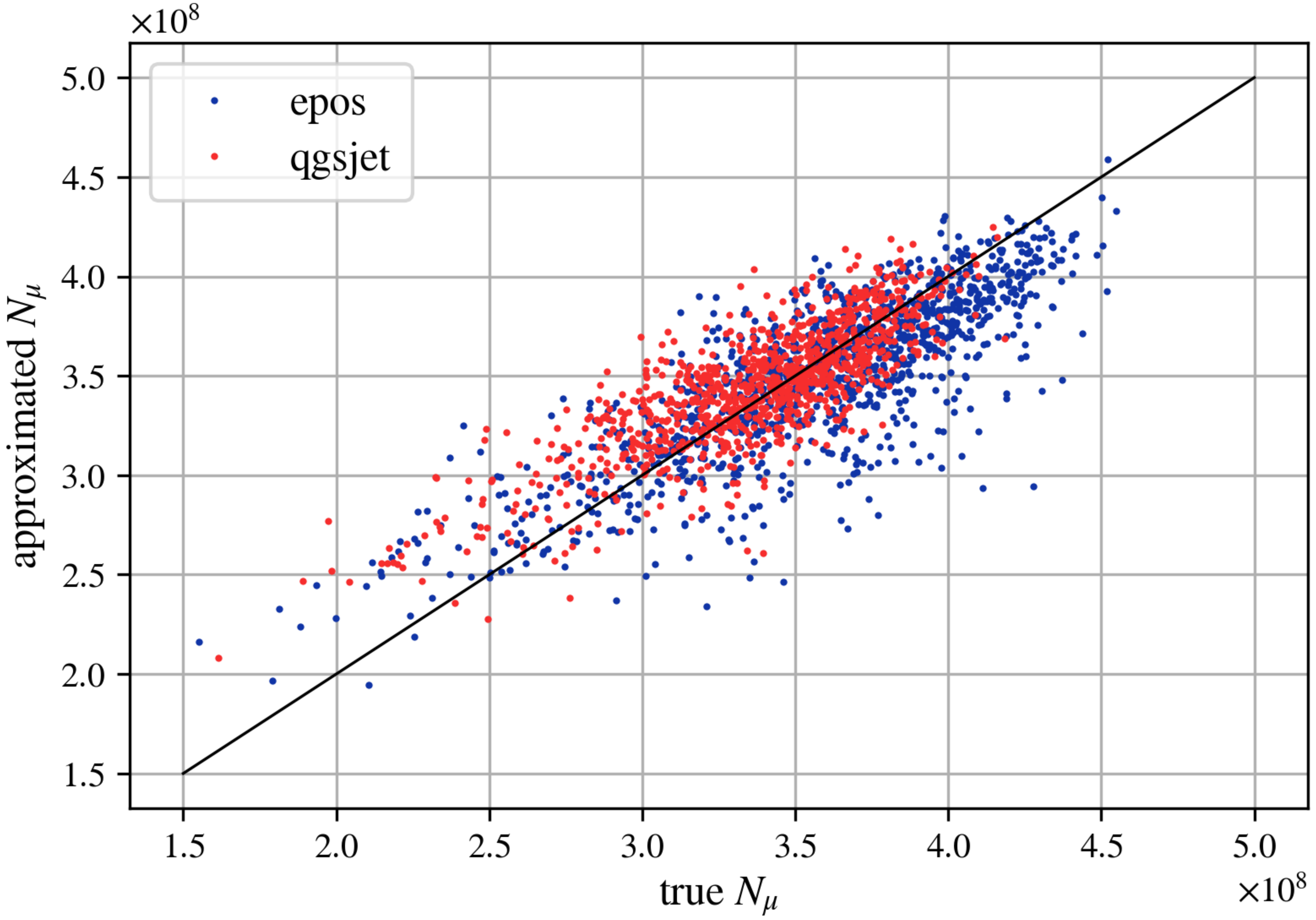
Universality visible: no dependence on the model

PREDICTABILITY



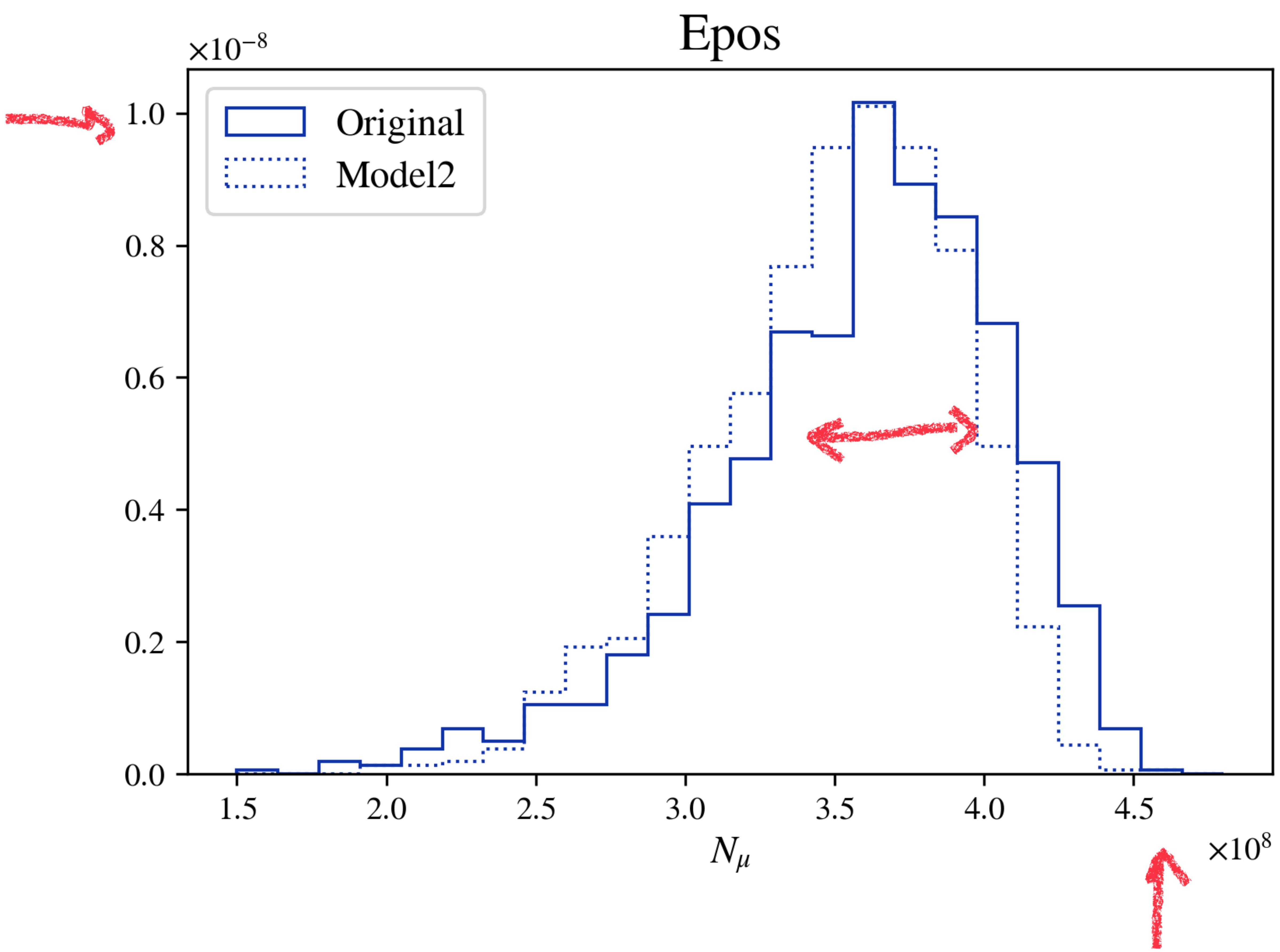


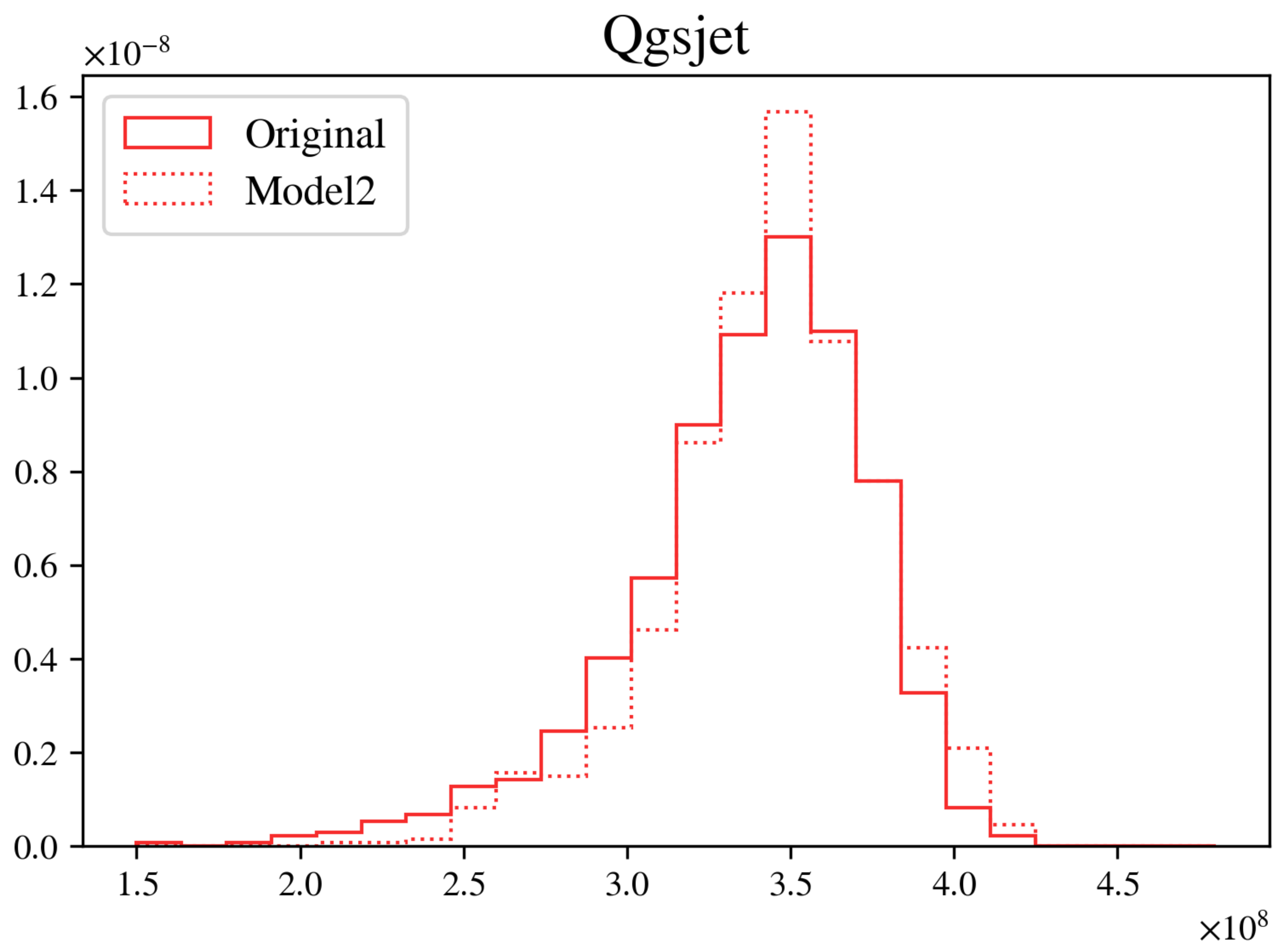
PREDICTABILITY



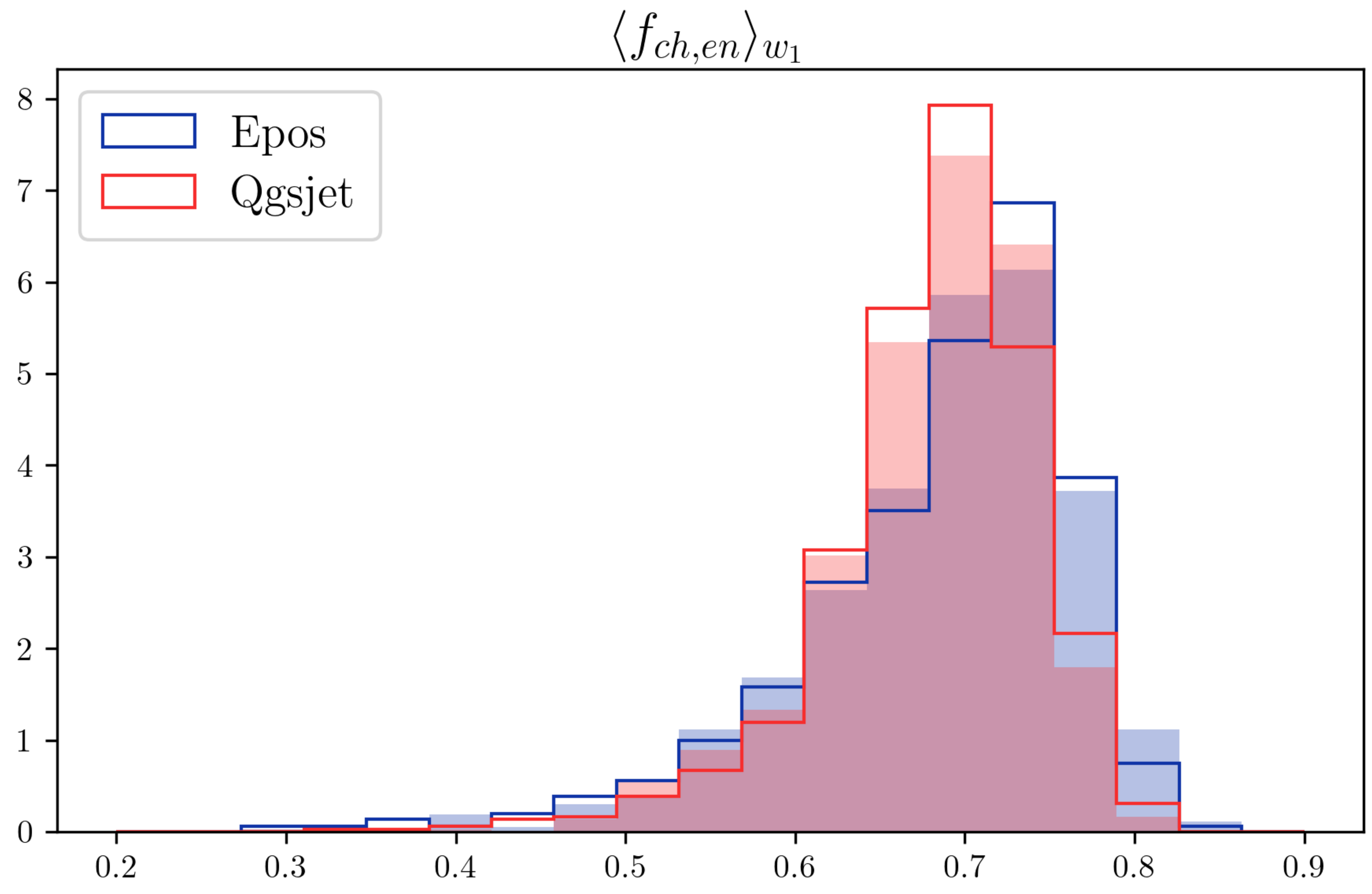
Universality visible: only slight dependence on the model

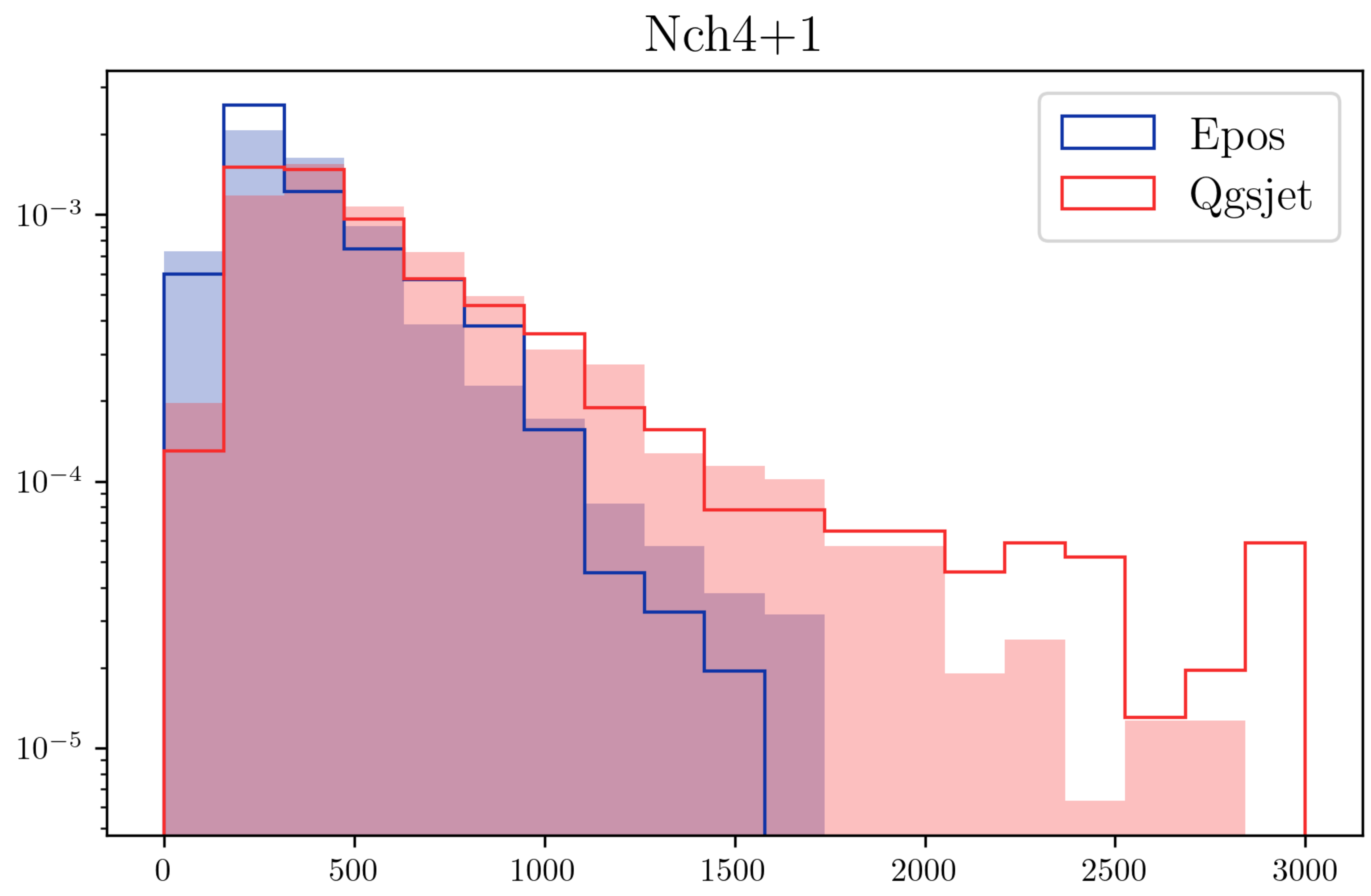
PREDICTABILITY



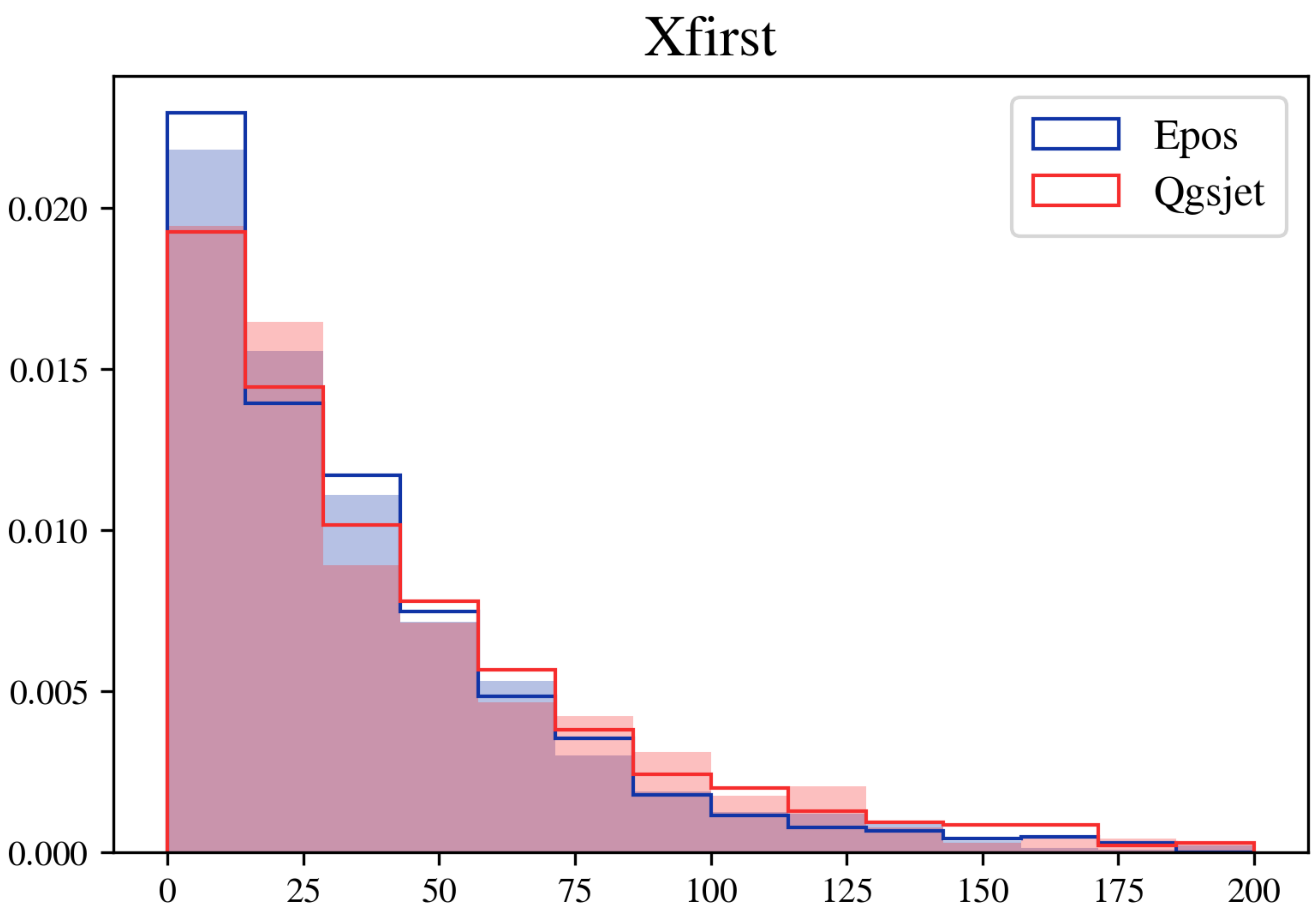


PARAMETER DISTRIBUTIONS



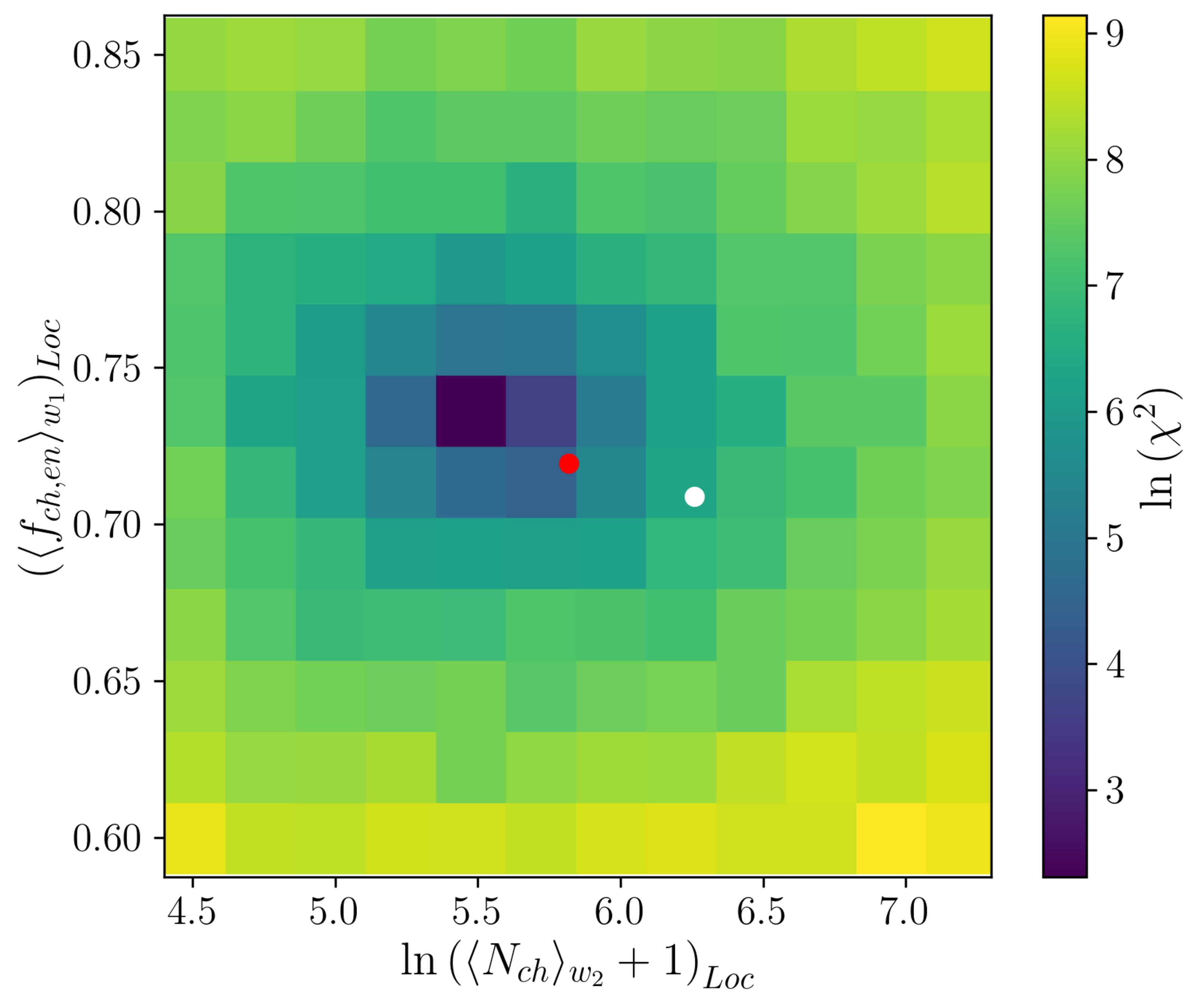


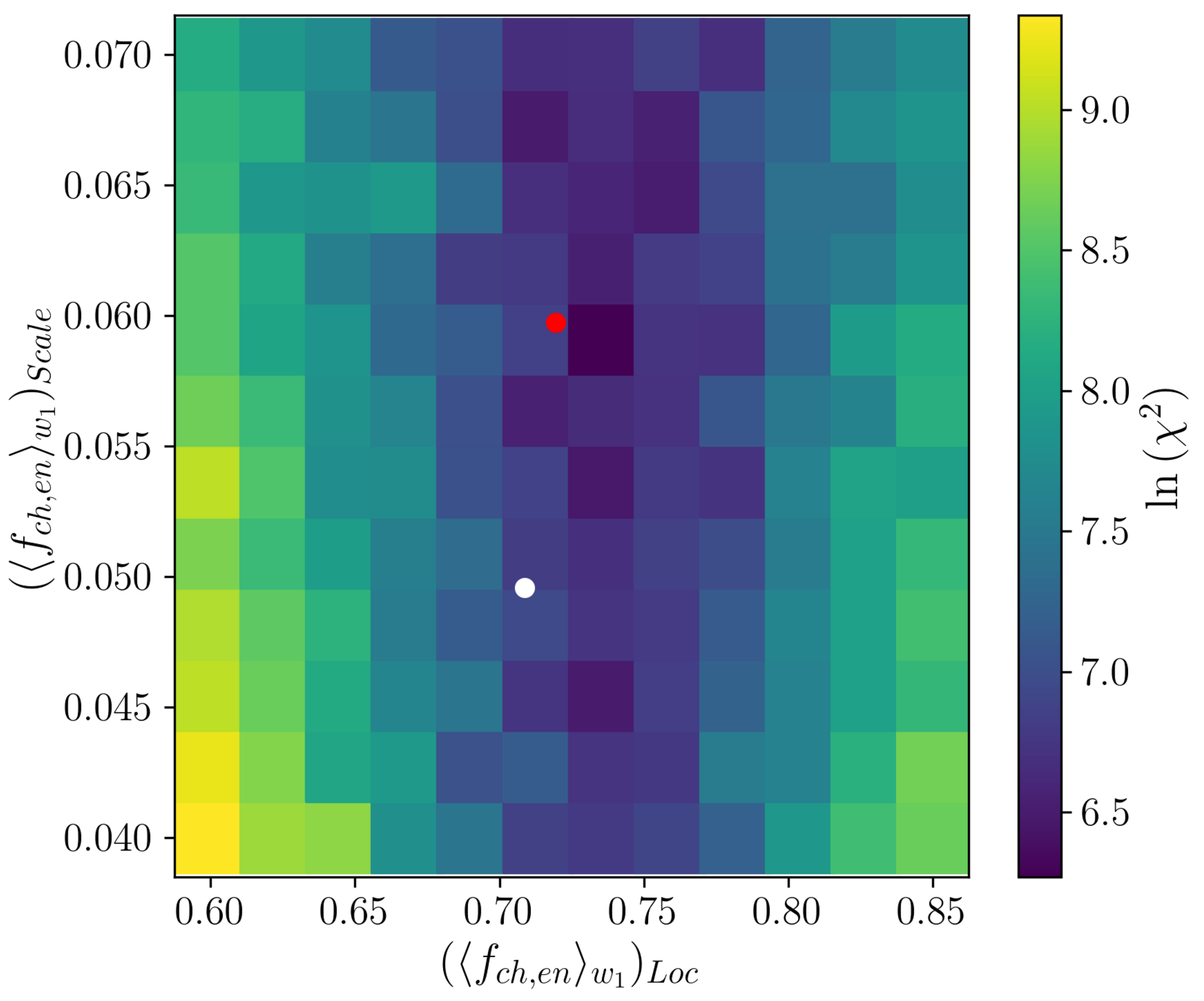
PARAMETER DISTRIBUTIONS

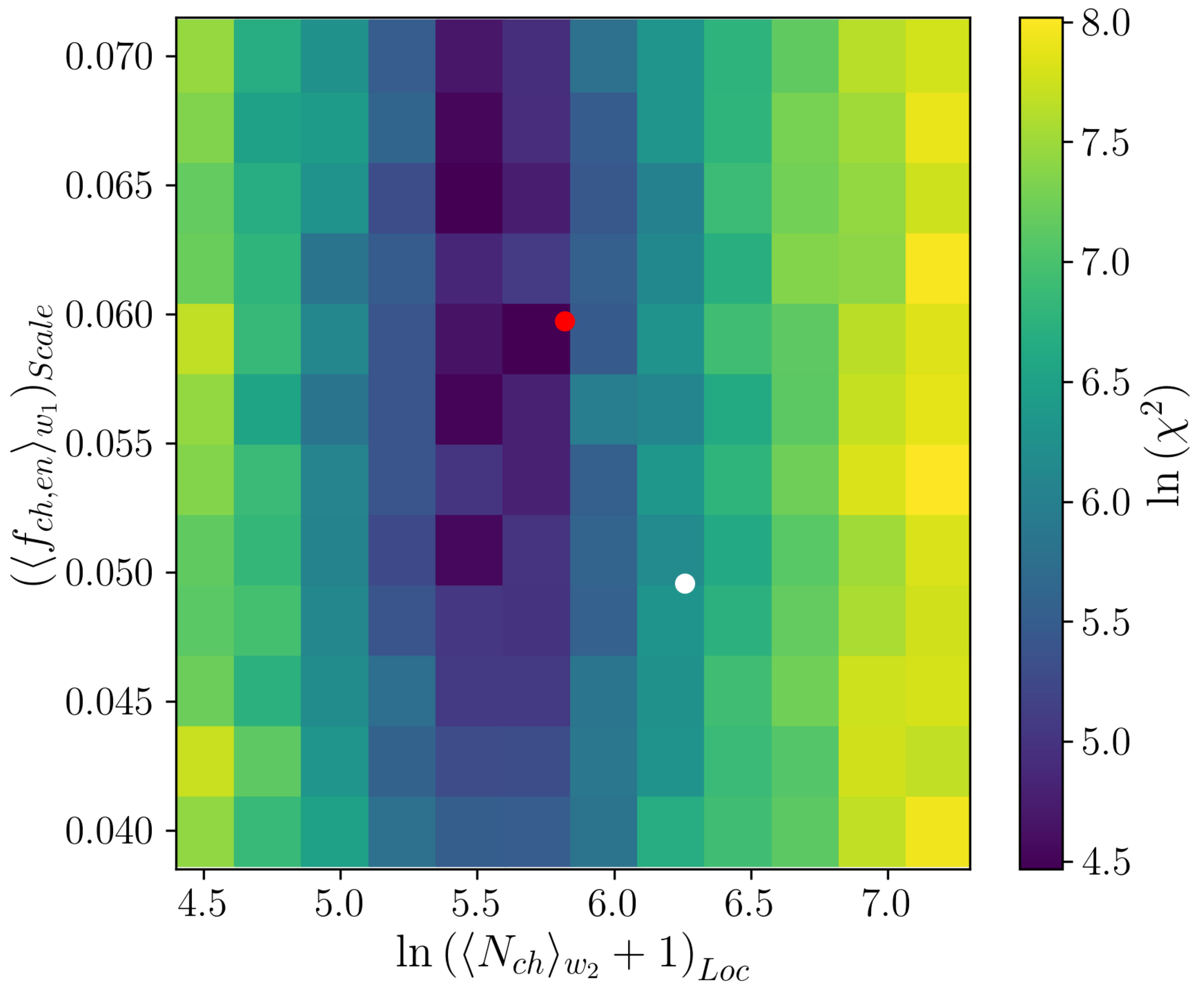


Next step: I generate artificial distributions (varying the shift and the scale) that I feed to the neural network. I get corresponding $X_{max} - N_\mu$ anti correlations. Using different moments of this distributions I am working on a chi-square approach in order to have a program where I can insert values from Auger data.

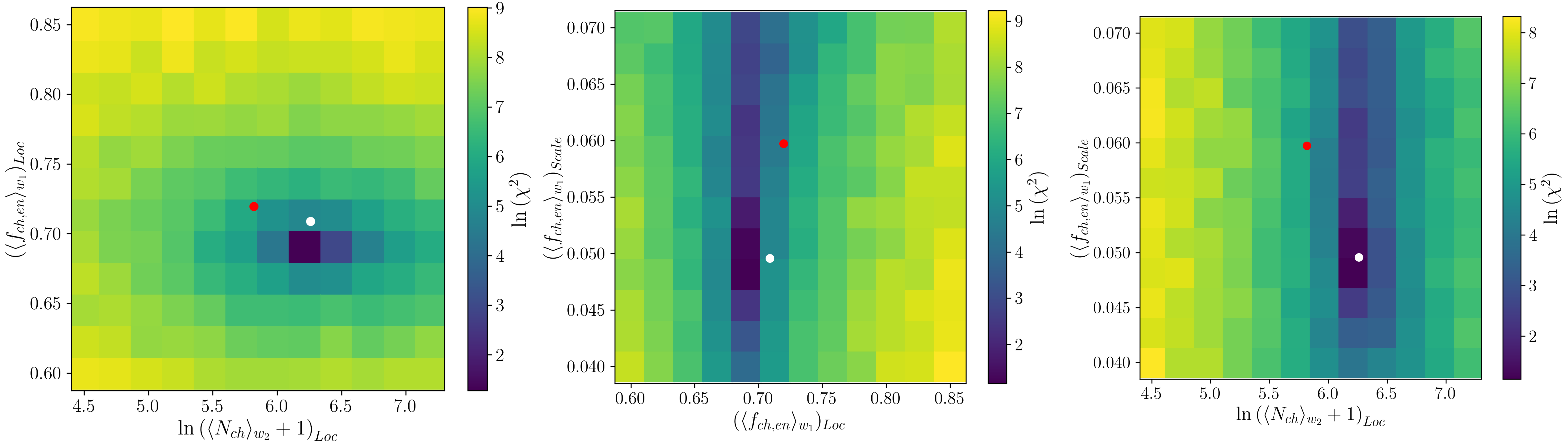
RESULTS


0.85
0.80
0.75
0.70
0.65
0.60
$(\langle f_{ch,en} \rangle_{w_1})_{Loc}$
4.5
5.0
5.5
6.0
6.5
7.0
$\ln(\langle N_{ch} \rangle_{w_2} + 1)_{Loc}$
9
8
7
6
5
4
3
$\ln(\chi^2)$


0.070
0.065
0.060
0.055
0.050
0.045
0.040
$(\langle f_{ch,en} \rangle_{w_1})_{Scale}$
0.60
0.65
0.70
0.75
0.80
0.85
$(\langle f_{ch,en} \rangle_{w_1})_{Loc}$
9.0
8.5
8.0
7.5
7.0
6.5
$\ln(\chi^2)$


0.070
0.065
0.060
0.055
0.050
0.045
0.040
$(\langle f_{ch,en} \rangle_{w_1})_{Scale}$
4.5
5.0
5.5
6.0
6.5
7.0
$\ln(\langle N_{ch} \rangle_{w_2} + 1)_{Loc}$
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
$\ln(\chi^2)$

RESULTS


$\ln(\langle N_{ch}\rangle_{w_2}+1)_{Loc}$
$(\langle f_{ch,en}\rangle_{w_1})_{Loc}$
$(\langle f_{ch,en}\rangle_{w_1})_{Scale}$
$\ln(\chi^2)$

Conclusions:

We have a model that predicts very well N_μ and X_{max} as a function of a few parameters and also the $X_{max} - N_\mu$ distribution as a function of the parameter distributions. It works well when extending to other energies and angles.

I generate artificial distributions (varying the shift and the scale) that I feed to the neural network. I get corresponding $X_{max} - N_\mu$ anti correlations. Using different moments of this distributions I am working on a chi-square approach in order to have a program where I can insert values from Auger data

Work in progress: Repeat this procedure for the energy region of interest in order to apply to data.

THANK YOU FOR YOUR ATTENTION!

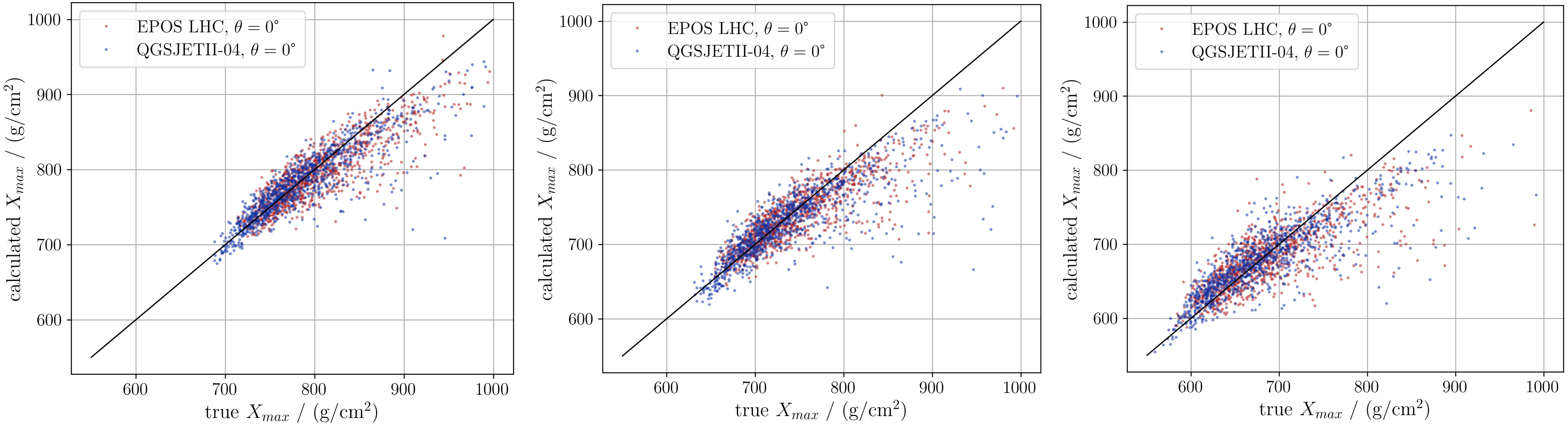
Isa

PREDICTABILITY

$$X_{max} = X_{first} + \lambda_r \ln(E_0/(3N_{ch}\xi_c^e))$$

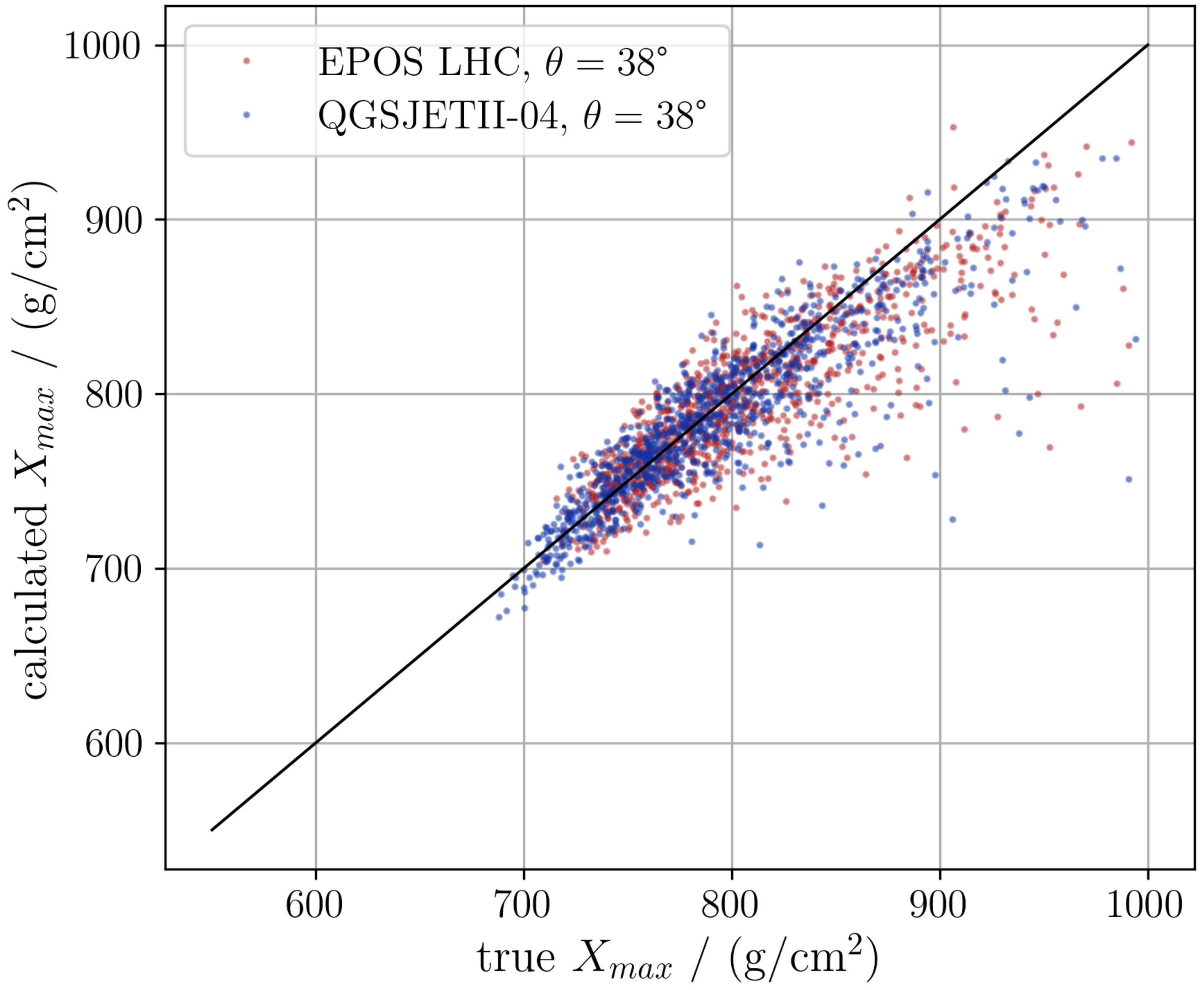
$$10 \cdot E_0 \longrightarrow + \lambda_r \ln(10) + \delta X$$

$\ln(E/eV) = 19$ $\ln(E/eV) = 18$ $\ln(E/eV) = 17$

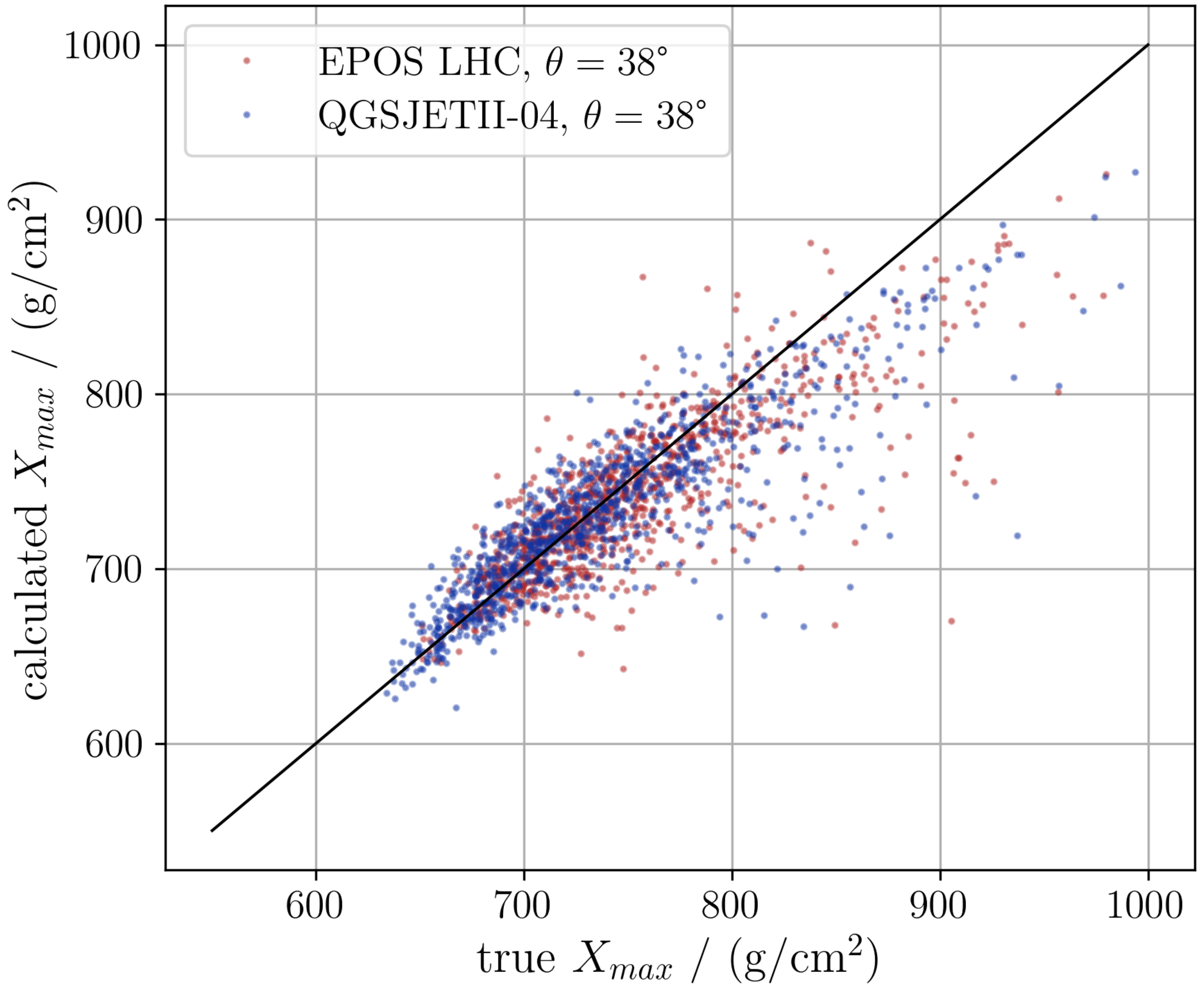


PREDICTABILITY

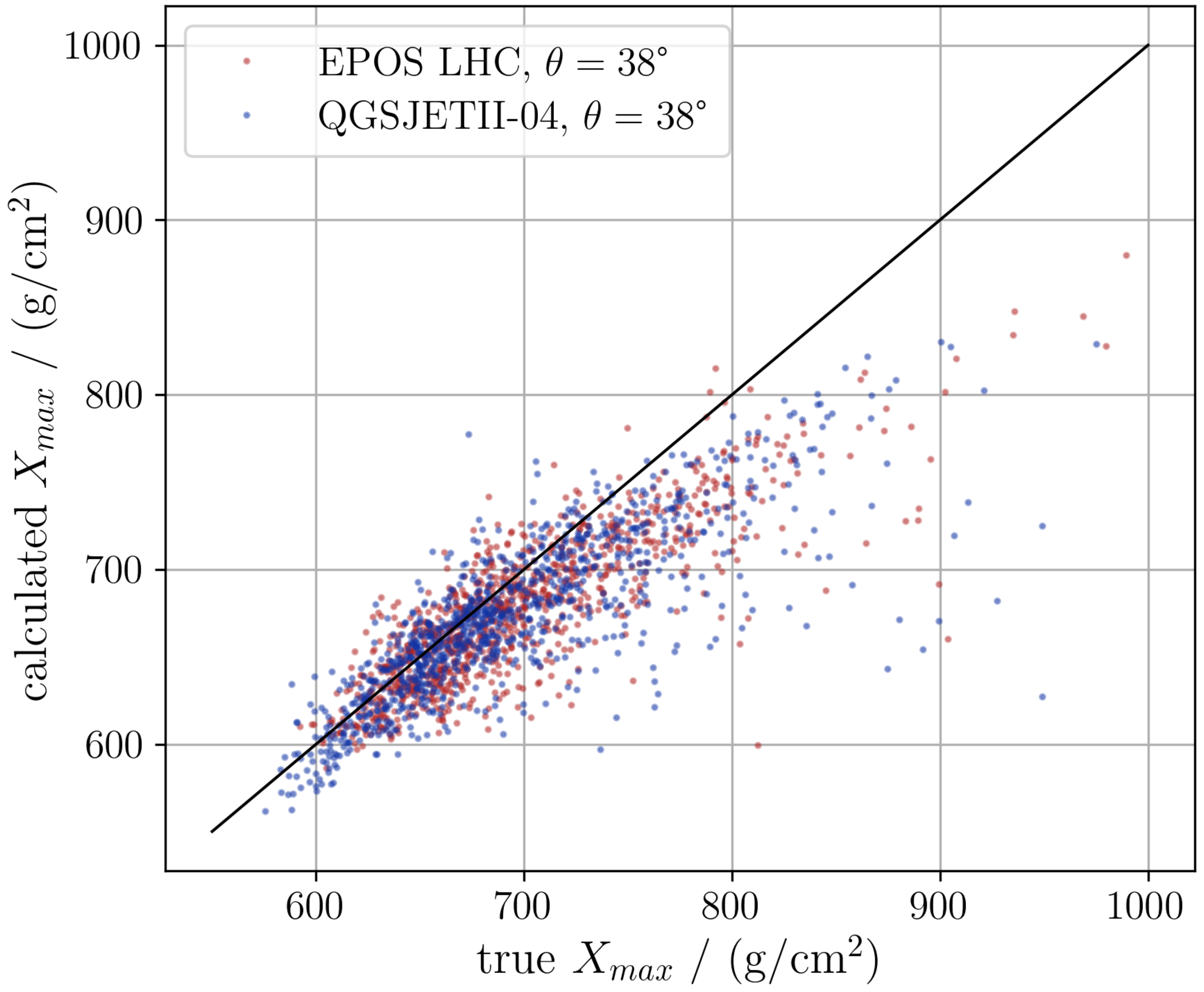
$\ln(E/eV) = 19$



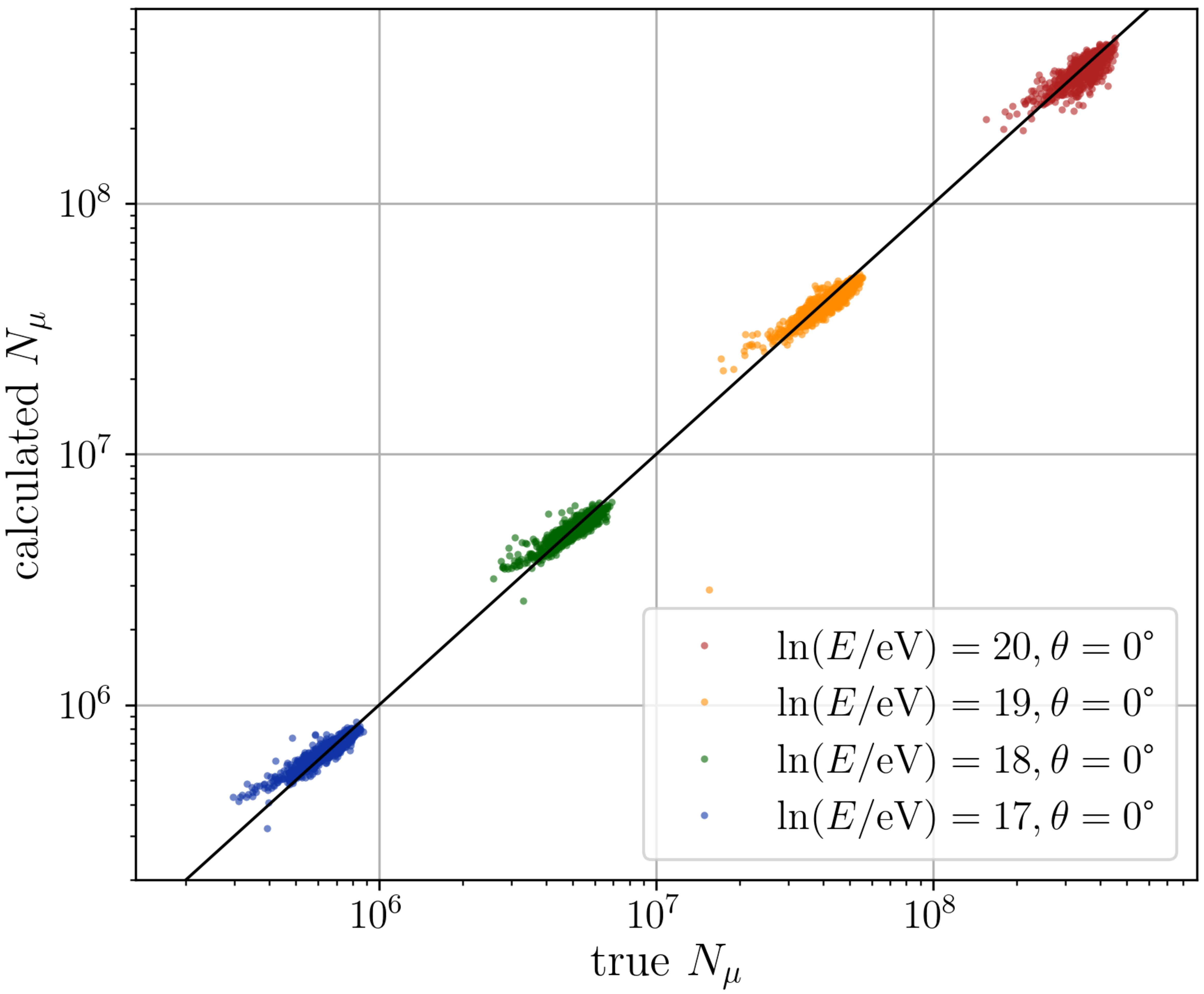
$\ln(E/eV) = 18$



$\ln(E/eV) = 17$



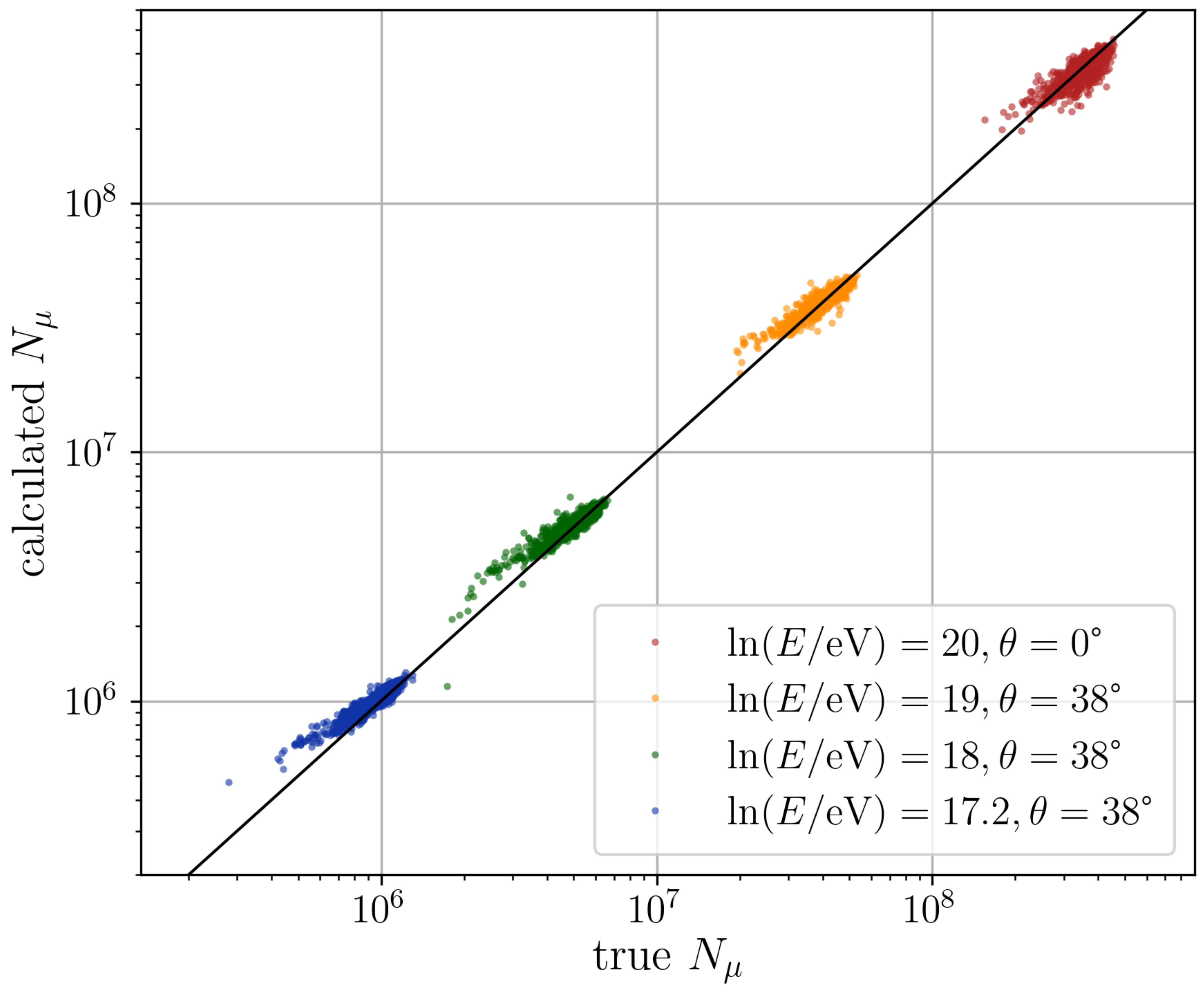
PREDICTABILITY



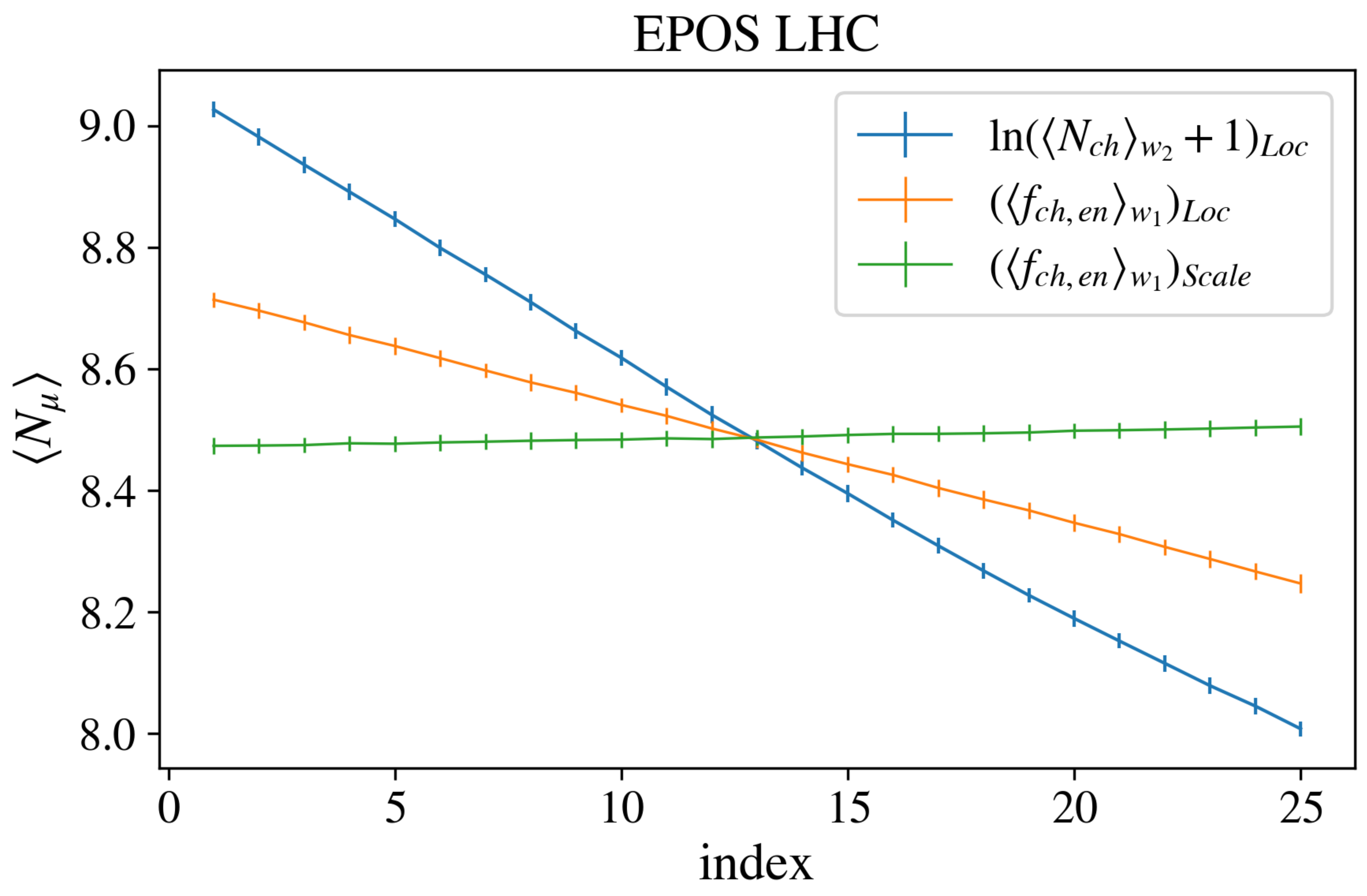
$$N_\mu = \left(\frac{E_0}{\xi_c^\pi}\right)^\beta$$

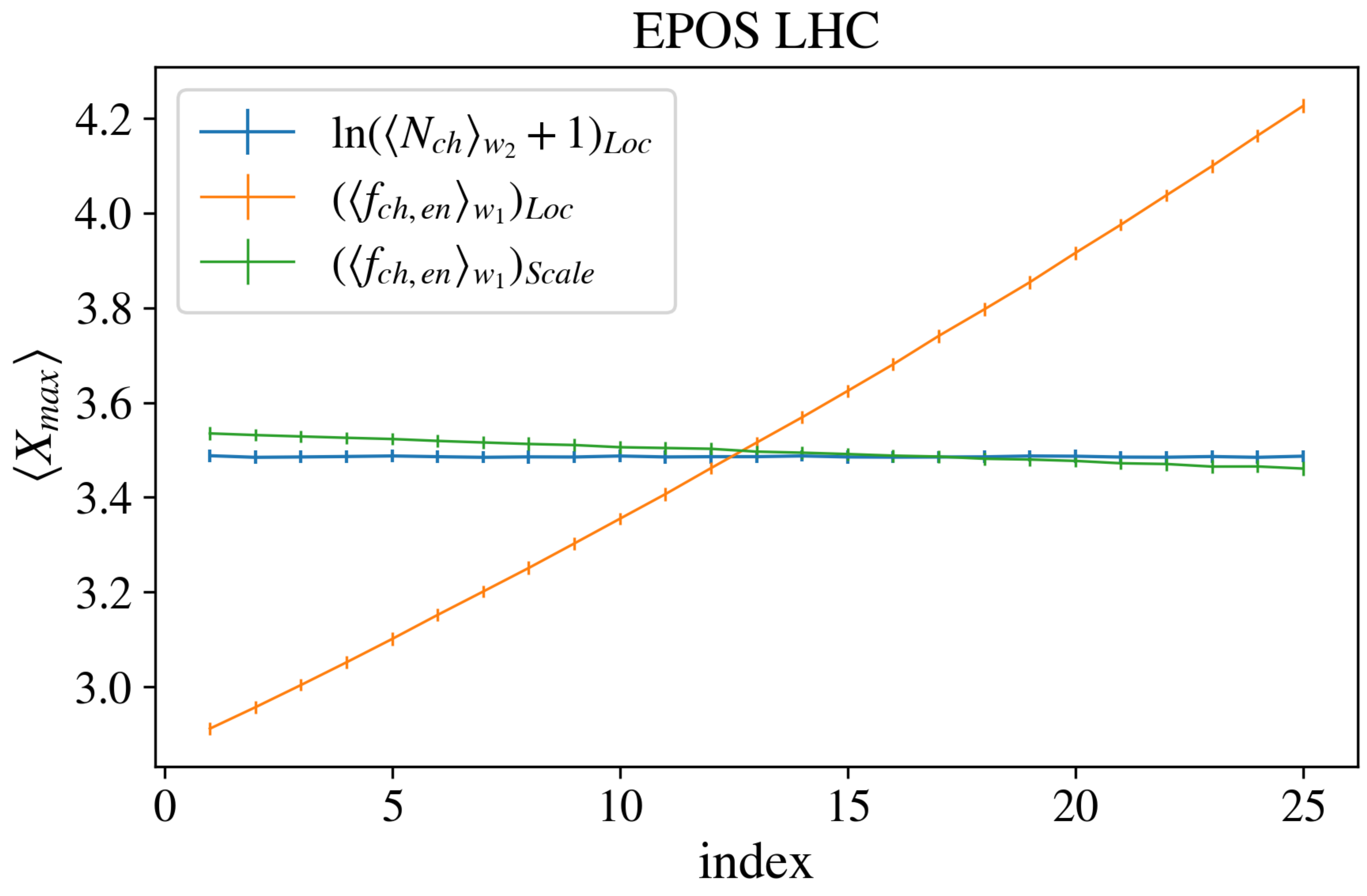
$$10 \cdot E_0 \longrightarrow \cdot\, 10^{\beta+\delta\beta}$$

PREDICTABILITY

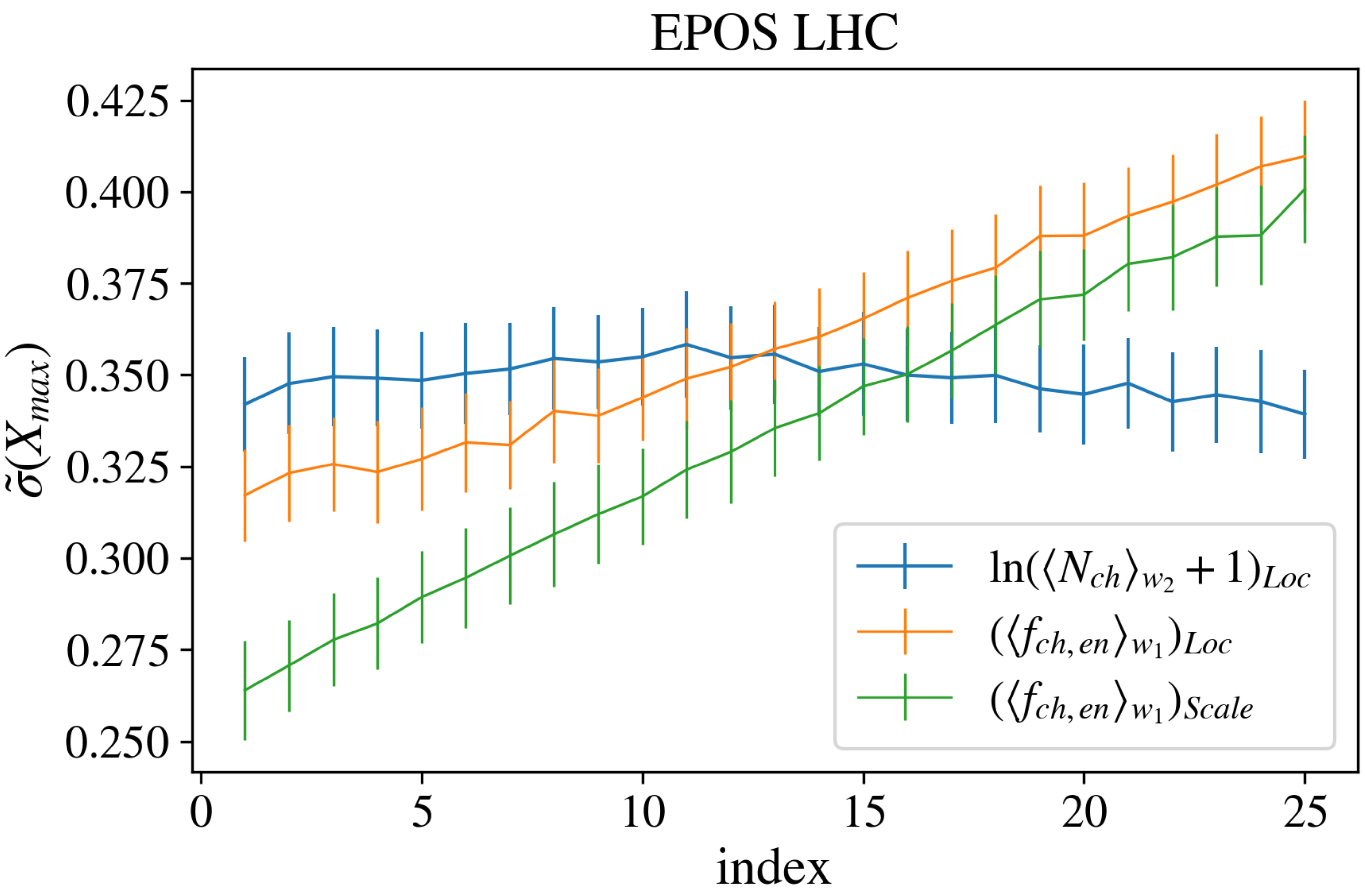


RESULTS


EPOS LHC
$\langle N_\mu \rangle$
9.0
8.8
8.6
8.4
8.2
8.0
0
5
10
15
20
25
index
$\ln(\langle N_{ch} \rangle_{w_2} + 1)_{Loc}$
$(\langle f_{ch,en} \rangle_{w_1})_{Loc}$
$(\langle f_{ch,en} \rangle_{w_1})_{Scale}$


EPOS LHC
$\langle X_{max} \rangle$
4.2
4.0
3.8
3.6
3.4
3.2
3.0
0
5
10
15
20
25
index
$\ln(\langle N_{ch} \rangle_{w_2} + 1)_{Loc}$
$(\langle f_{ch,en} \rangle_{w_1})_{Loc}$
$(\langle f_{ch,en} \rangle_{w_1})_{Scale}$

RESULTS



EPOS LHC
0.425
0.400
0.375
0.350
0.325
0.300
0.275
0.250
$\tilde{\sigma}(X_{max})$
0
5
10
15
20
25
index
$\ln(\langle N_{ch}\rangle_{w_2}+1)_{Loc}$
$(\langle f_{ch,en}\rangle_{w_1})_{Loc}$
$(\langle f_{ch,en}\rangle_{w_1})_{Scale}$