Friedrich-Alexander-Universität
Erlangen-Nürnberg

Reconstructing proton air showers using H.E.S.S.

Benedetta Bruno, Jonas Glombitza, Stefan Funk for the H.E.S.S. Collaboration

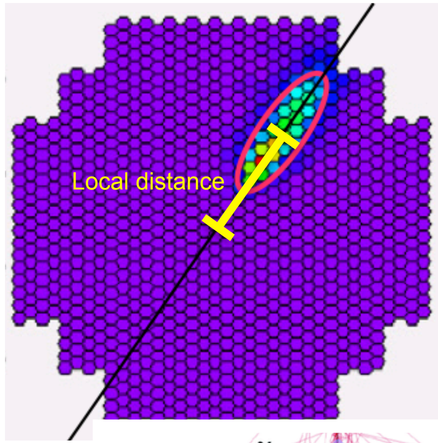
High-energy astrophysics in the multi-messenger era - Workshop
08.04.24

Changes in the reconstruction chain

Setting pre- and post- selection cuts on the important variables

- Pre-selection cuts to assure a first good selection of events
  - multiplicity=4
  - local distance < 0.525 m
  - size > 100 p.e.

- The optimisation lead to the following post-selection cuts:
  - ArrayImpactParameter < 200 m
  - Mean and Sigma of the core goodness < 25 m



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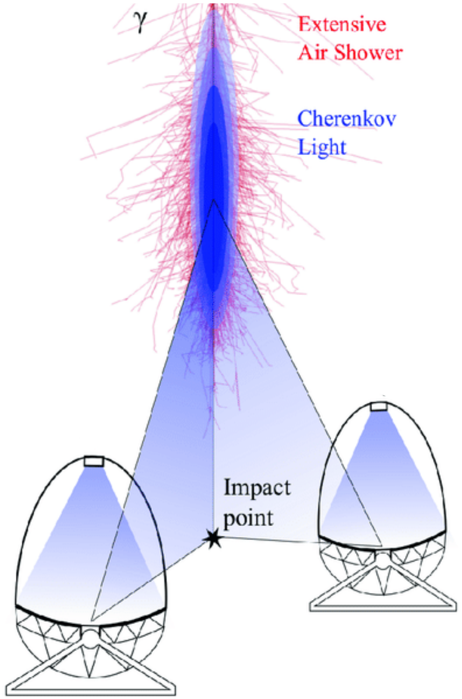
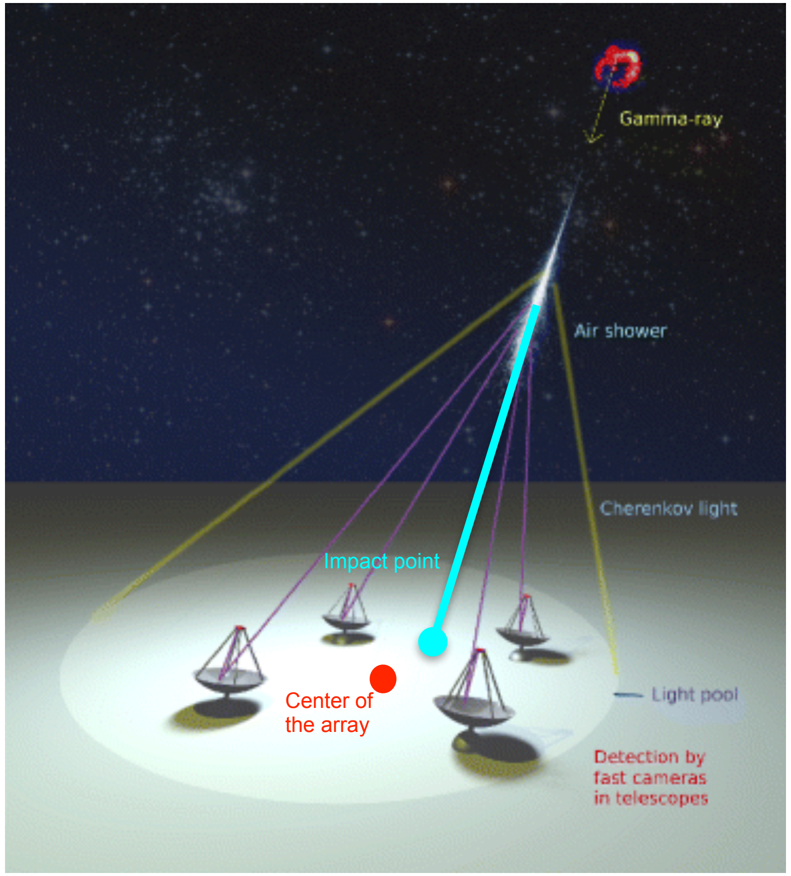


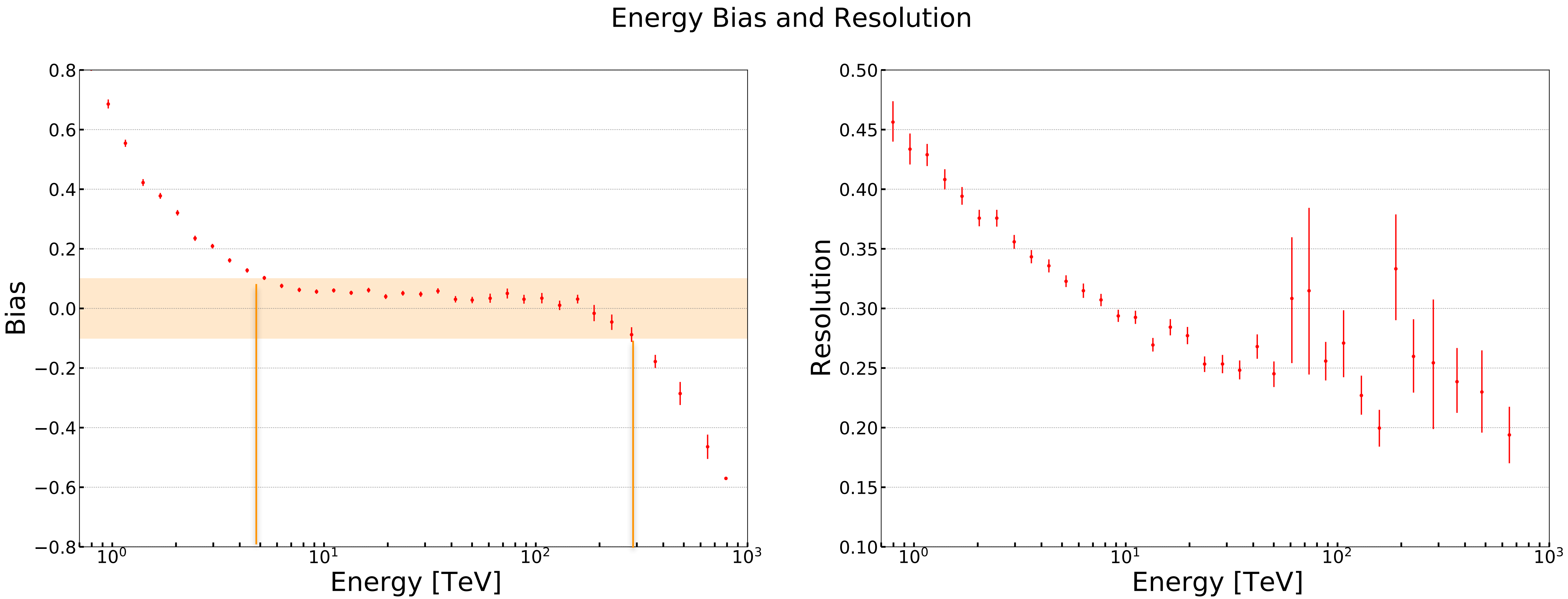
https://arxiv.org/abs/2201.04719



Völk, H.J., Bernlöhr, K. Imaging very high energy gamma-ray telescopes. Exp Astron **25**, 173–191 (2009)

All cuts results with all the simulations

Protons simulations with 0,10,20,30deg, 0,180deg; energy range 200 GeV - 1 PeV



Bias within ~10% in [5, 300] TeV, resolution < ~35% above 3 TeV

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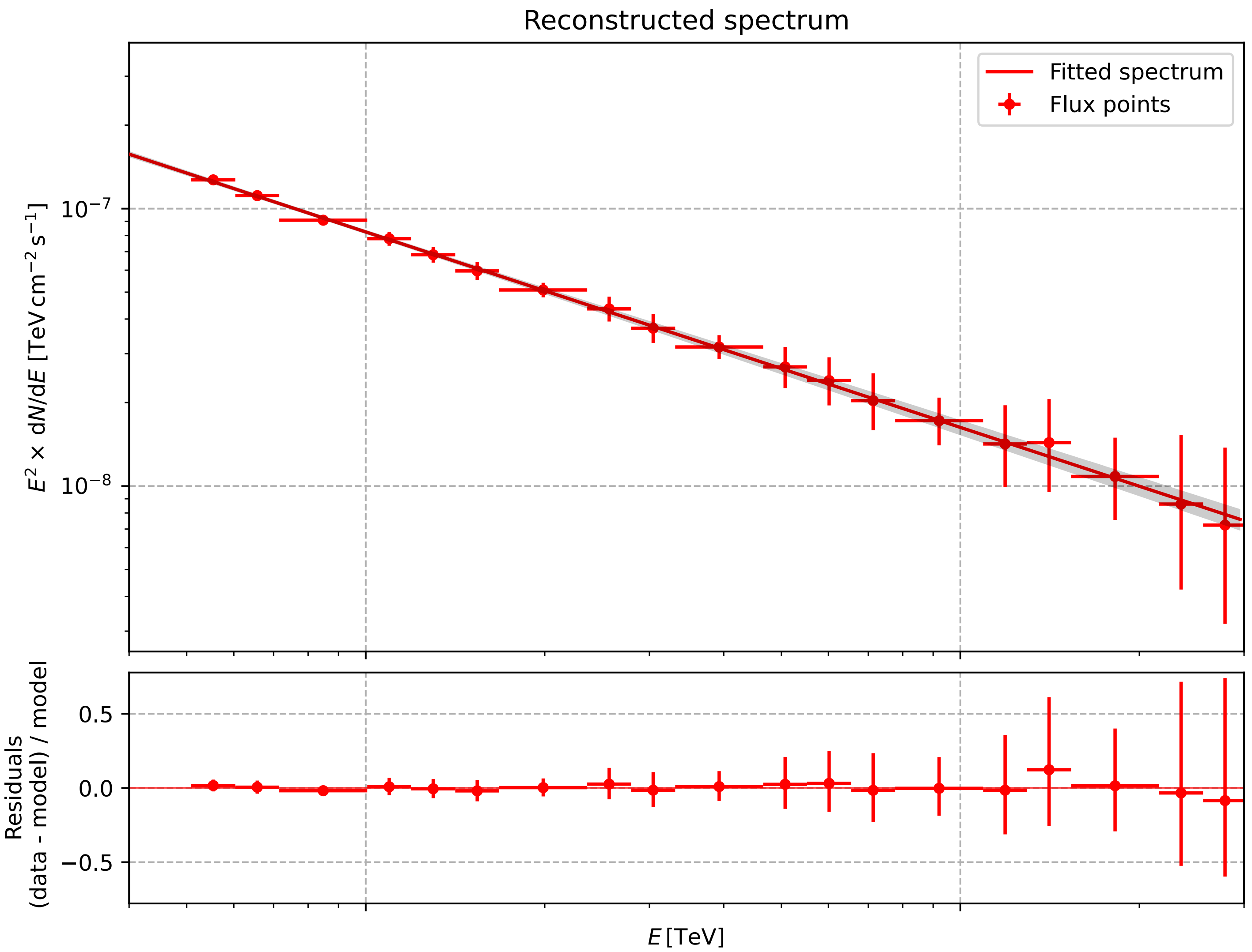
Reconstructed spectrum with a realistic observation time for the amount of events and index weight

Protons simulations with 0,10,20,30deg, 0,180deg; energy range 200 GeV - 1 PeV

Fitting the spectrum weighted to resemble the real CR spectrum **index** with a power-law model:

Index	2.705 ± 0.025
Amplitude	$(2.605 \pm 0.143) \cdot 10^{-7}$ $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{TeV}^{-1}$
Reference energy	1.0 TeV



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Investing the effect of hadronic models on IACT images

Benedetta Bruno, Rodrigo G. Lang, Luan Arbeletche
High-energy astrophysics in the multi-messenger era - Workshop

08.04.24

Goal of the project

- The development of hadronic showers in the atmosphere can be modelled by different hadronic models

- At high energies the models are extrapolated from particle accelerators data

- Search for differences between the models by looking directly at IACT images

Simulations

Different primaries with zenith 20deg, azimuth 180deg

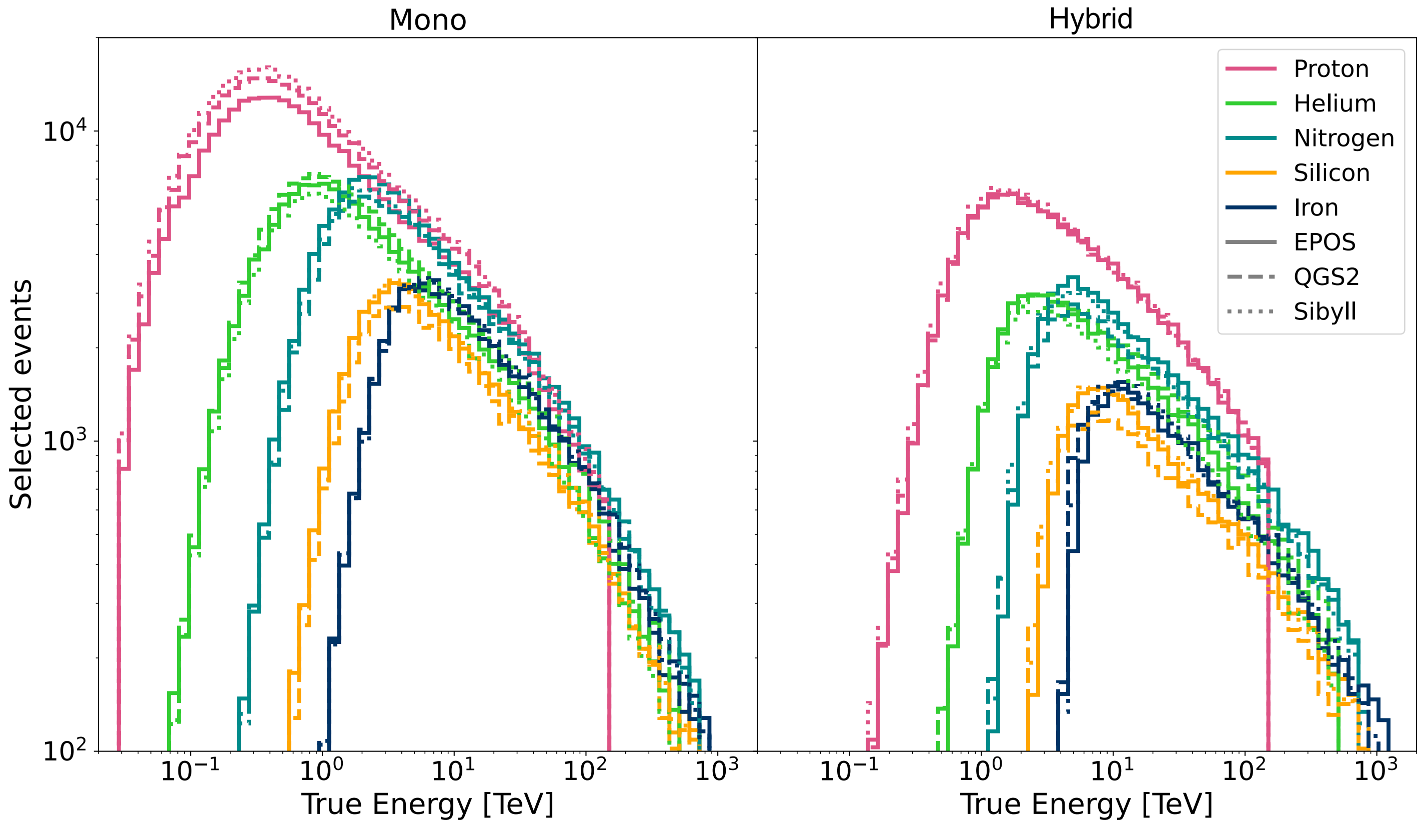
Primary	Energy range [TeV]	# Simulated showers	# mono events	# hybrid events
Proton	0.03 - 150	$\sim 51 \cdot 10^6$	$\sim 33 \cdot 10^4$	$\sim 13 \cdot 10^4$
Helium	0.03 - 500	$\sim 30 \cdot 10^6$	$\sim 13 \cdot 10^4$	$\sim 50 \cdot 10^3$
Nitrogen	0.04 - 800	$\sim 30 \cdot 10^6$	$\sim 12 \cdot 10^4$	$\sim 50 \cdot 10^3$
Silicon	0.05 - 1000	$\sim 13 \cdot 10^6$	$\sim 53 \cdot 10^3$	$\sim 23 \cdot 10^3$
Iron	0.06 - 1200	$\sim 13 \cdot 10^6$	$\sim 52 \cdot 10^3$	$\sim 23 \cdot 10^3$

Models implemented in CORSIKA used for the simulations:

- QGSJET-II04
- EPOS-LHC
- Sibyll 2.3d

Detector response of the latest status of H.E.S.S. given by sim_telarray

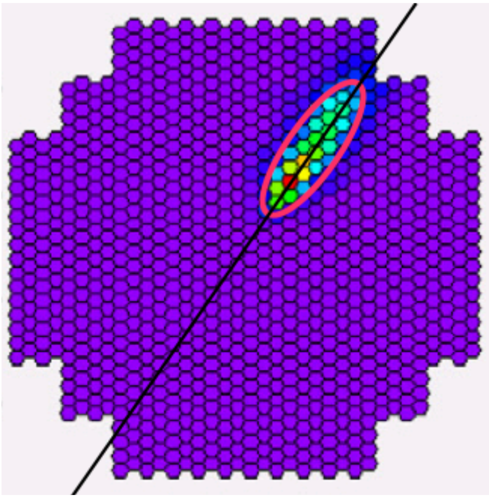
Simulations data calibrated and cleaned



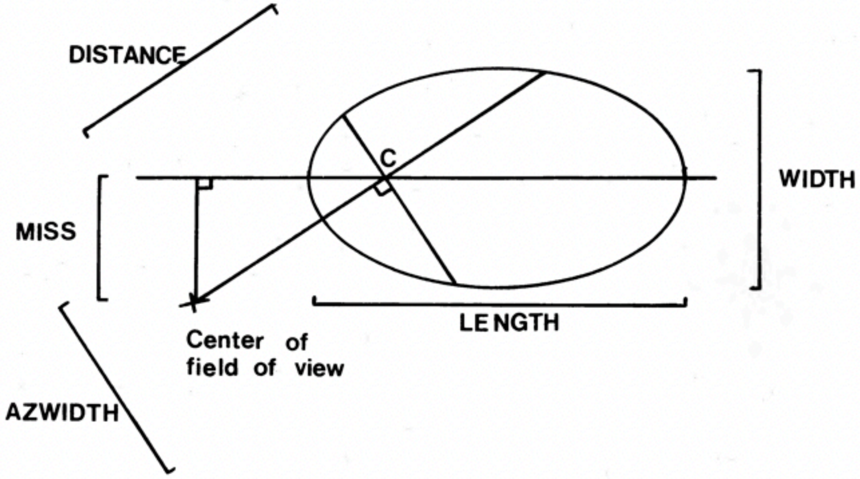
Low-level variables

Definition of the variables

Hillas parameters like width and size



deNaurois+ 2015 C.R. Phys. 16 610



Weekes+ 1989

Density $$D = \frac{\text{Size}}{\text{Width} \cdot \text{Length}}$$

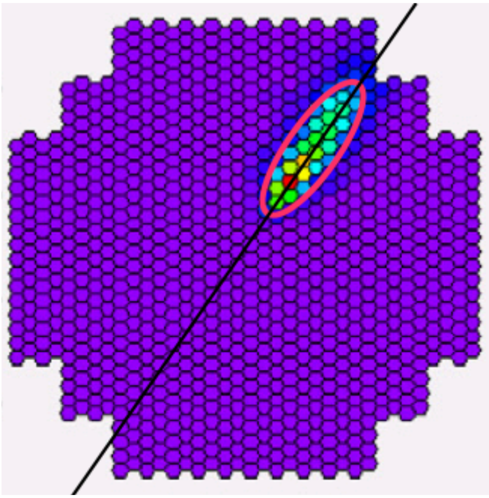
Length over size $$L/S = \frac{\text{Length}}{\log(\text{Size})}$$

Number of pixels that survives the cleaning process

Low-level variables

Definition of the variables

Hillas parameters like width and size



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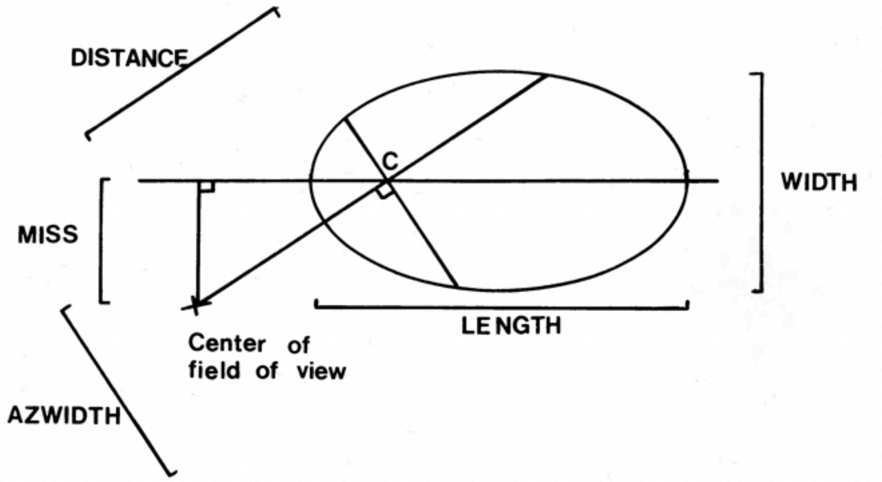


Weekes+ 1989

Density $$D = \frac{\text{Size}}{\text{Width} \cdot \text{Length}}$$

Length over size $$L/S = \frac{\text{Length}}{\log(\text{Size})}$$

Number of pixels that survives the cleaning process

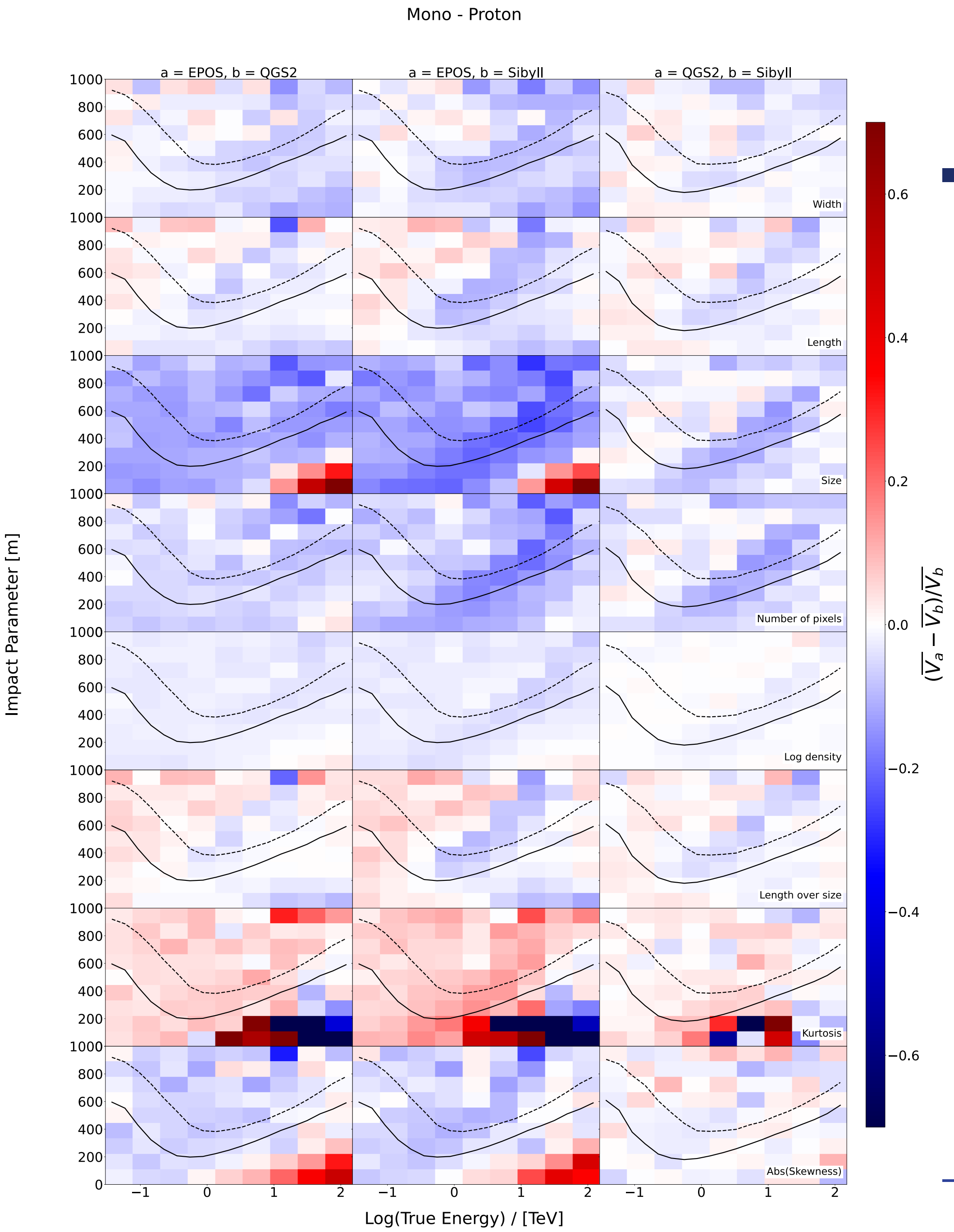
$\frac{\overline{V_a} - \overline{V_b}}{\overline{V_b}}$, V is one of the variable

a and b are two models

Low-level results

Mono

- 2D histogram in energy and impact parameter of all the variables (the rows)
- Each column is a comparison between two models
- Solid and dashed lines indicate the 68% and 95% containment radius for the Monte Carlo true impact parameter



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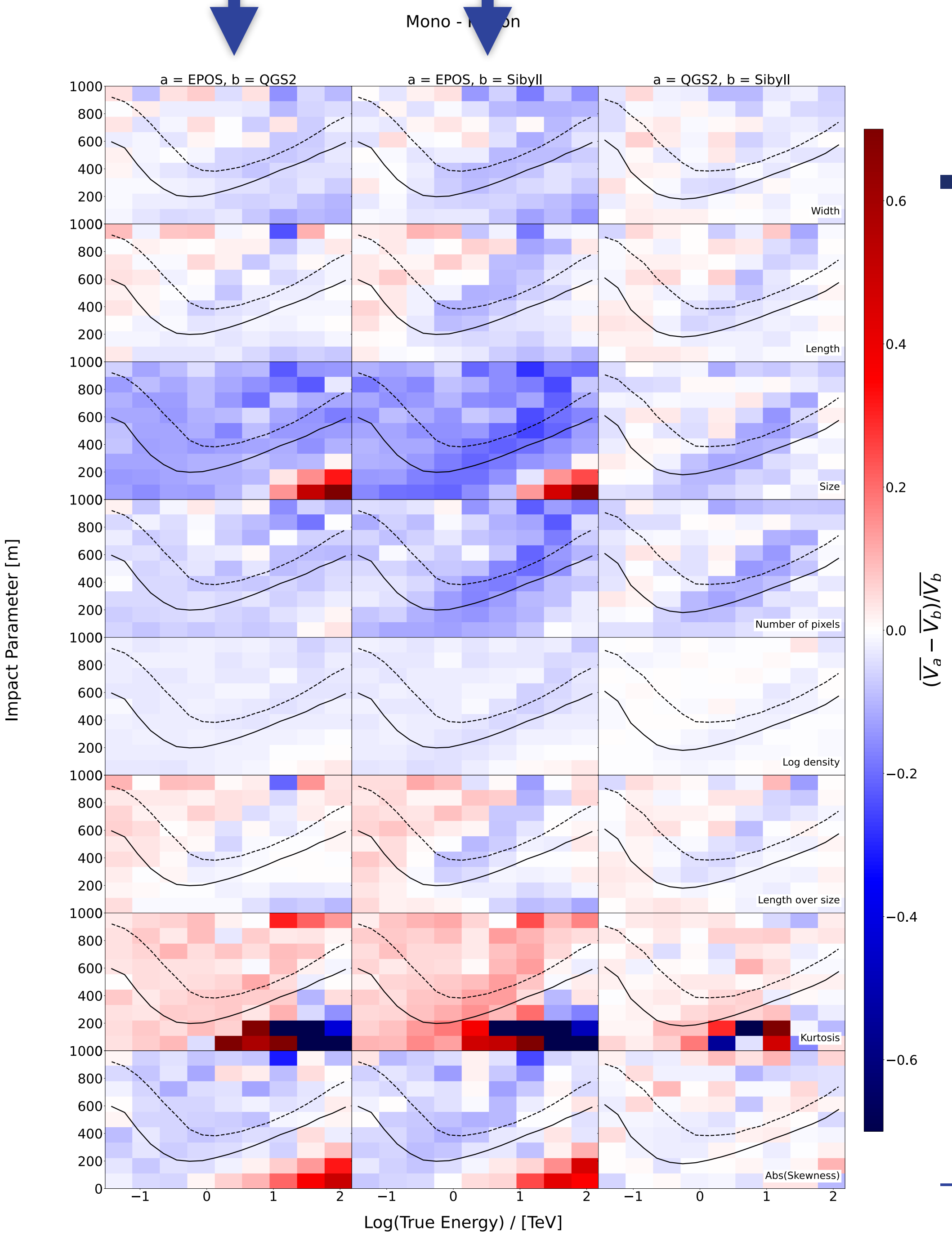
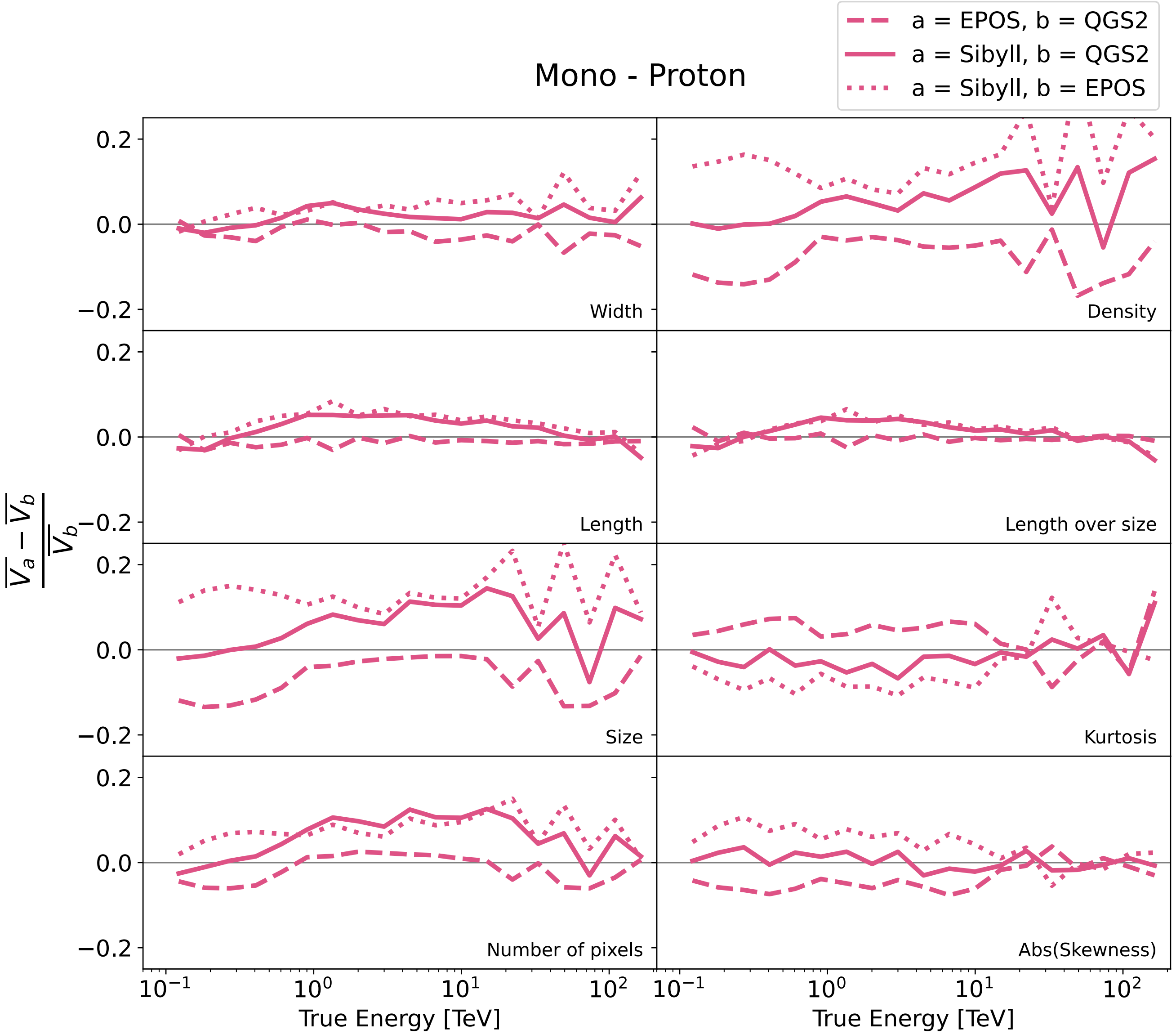


Low-level results

Mono

- 1D histogram in energy of all the variables
- Each line is a comparison between two models
- In each bin, the values are calculated by selecting events around 1σ of the mean of the impact parameter.



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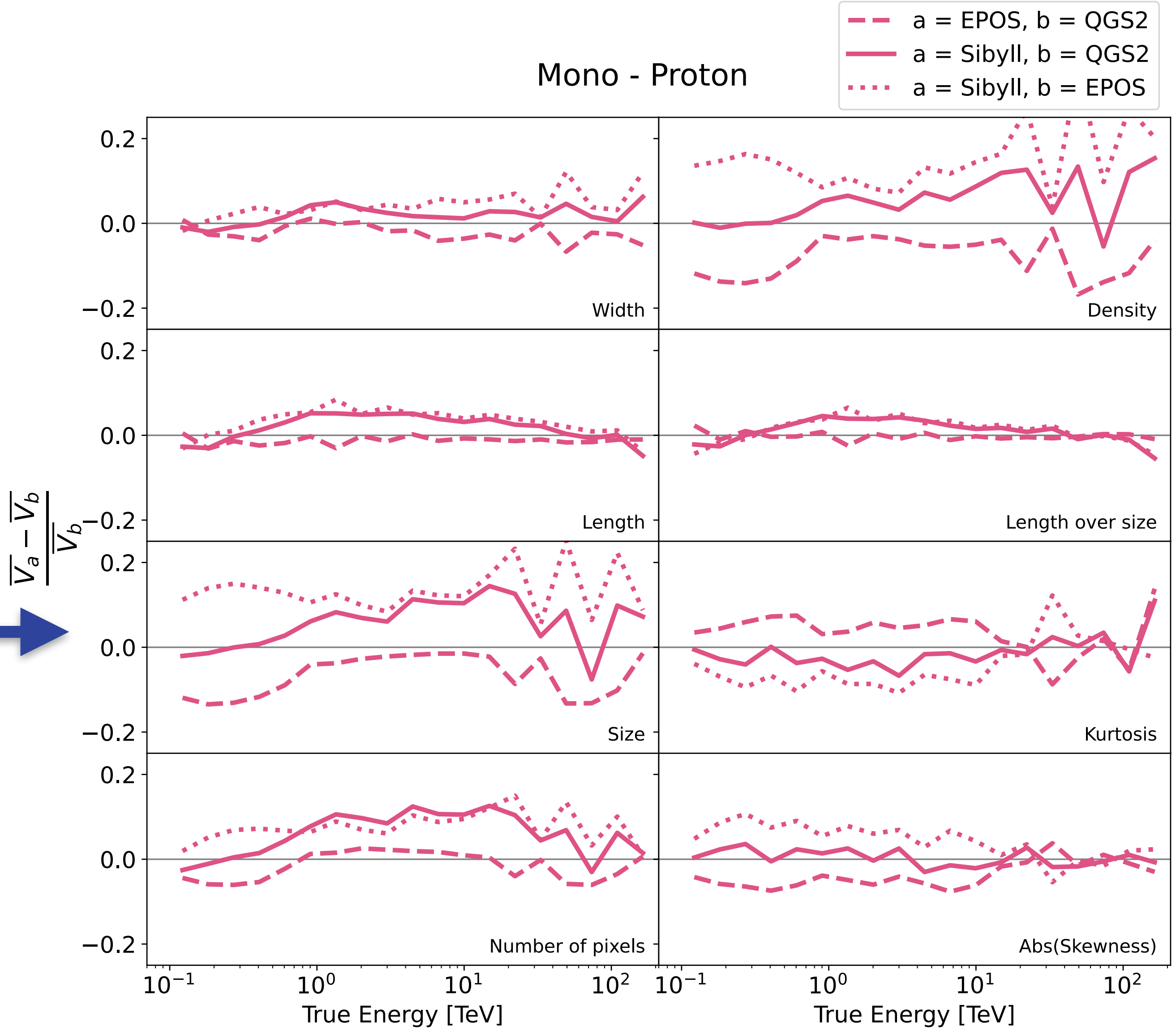
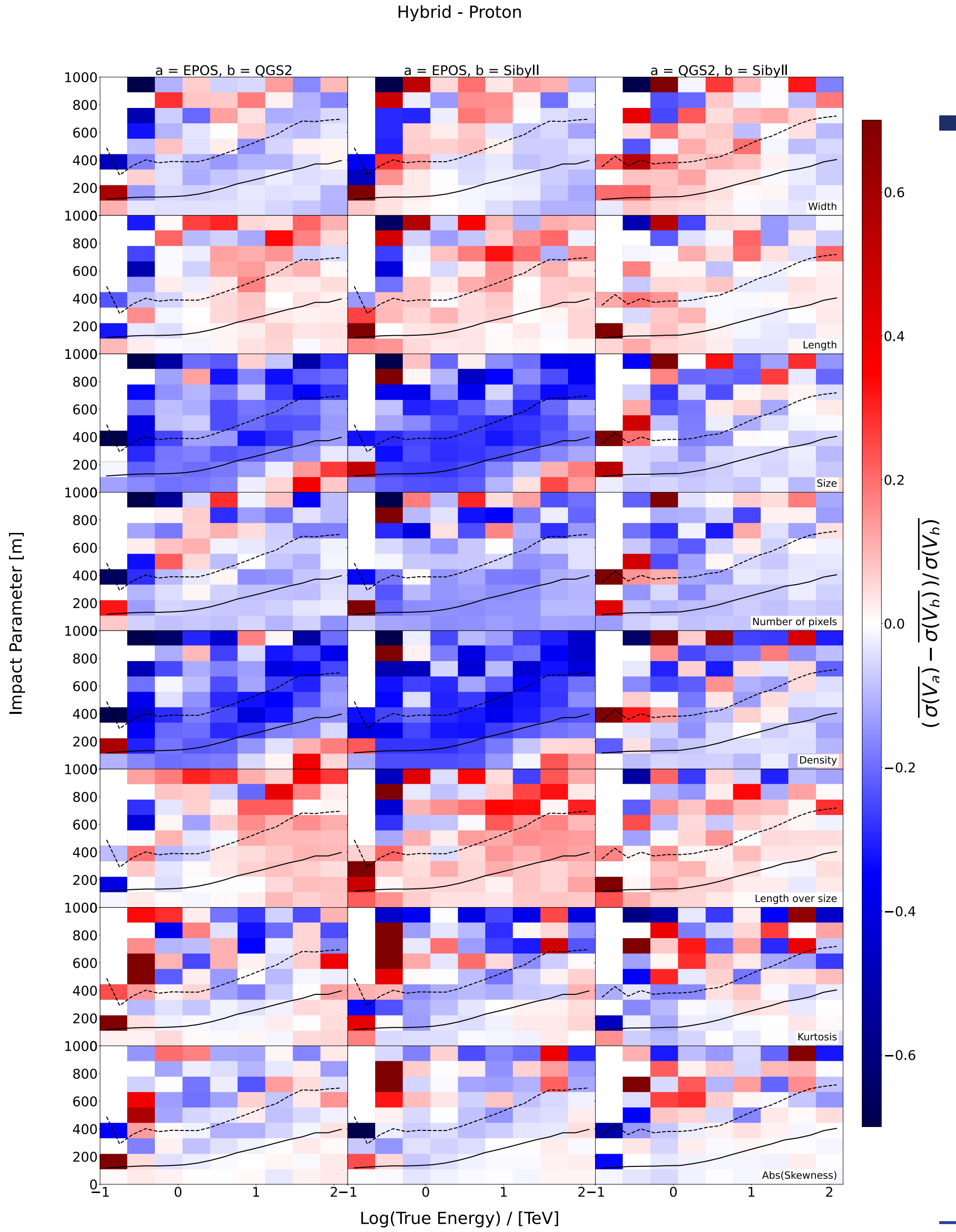
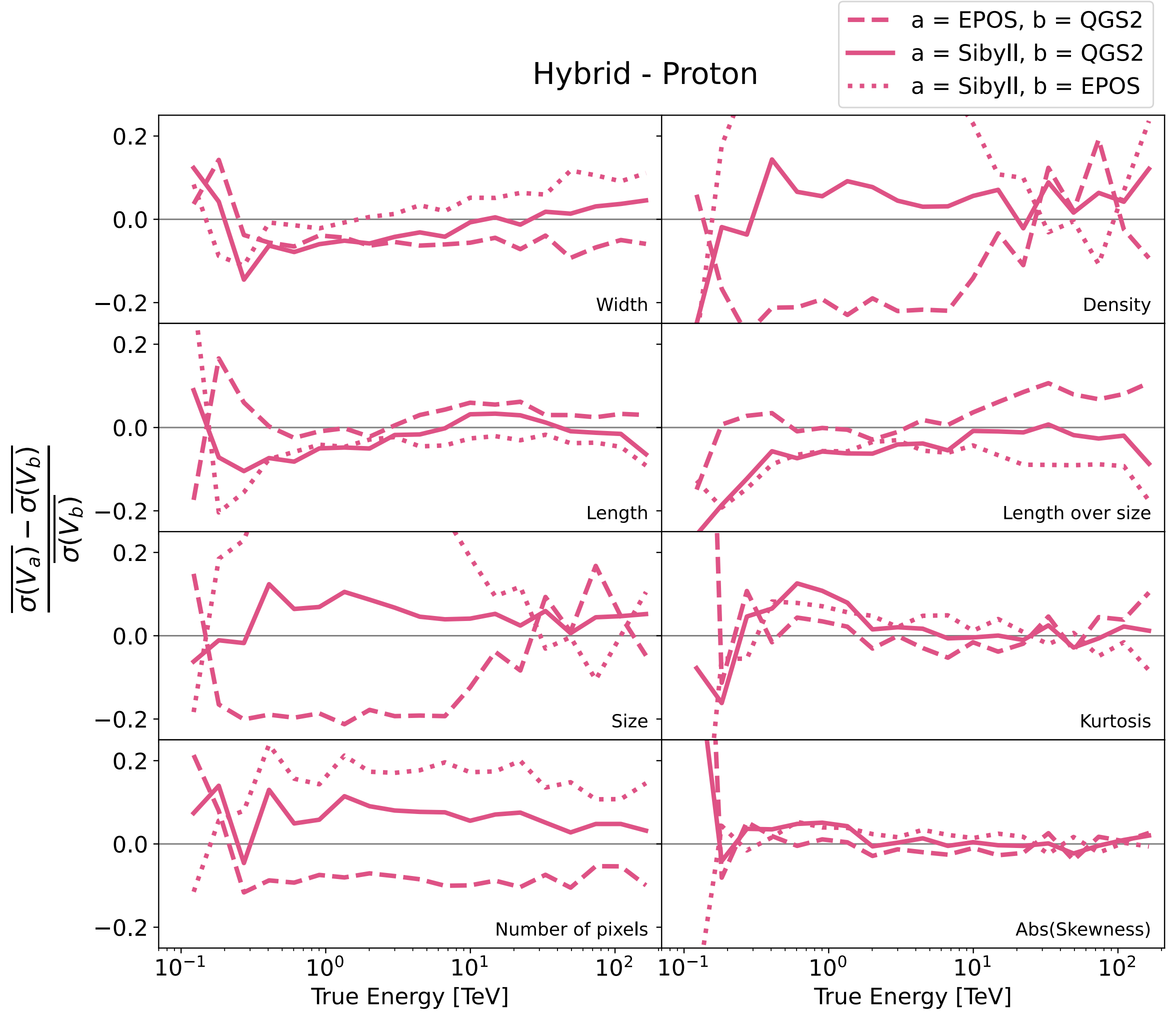


Low-level results

$$\frac{\overline{\sigma(V_a)} - \overline{\sigma(V_b)}}{\overline{\sigma(V_b)}}$$

Hybrid





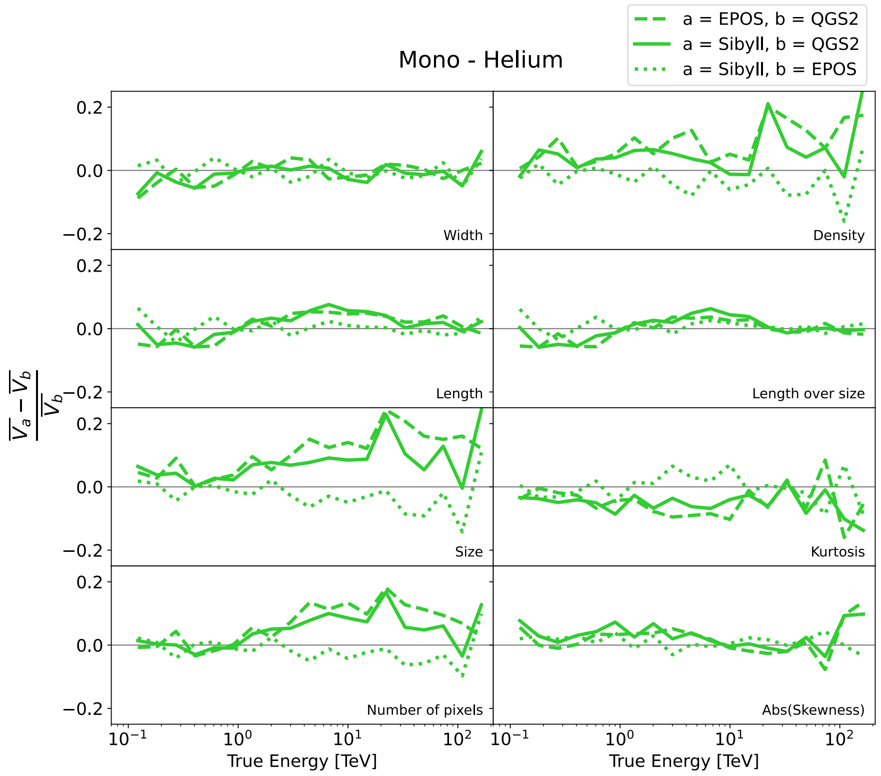
Low-level results

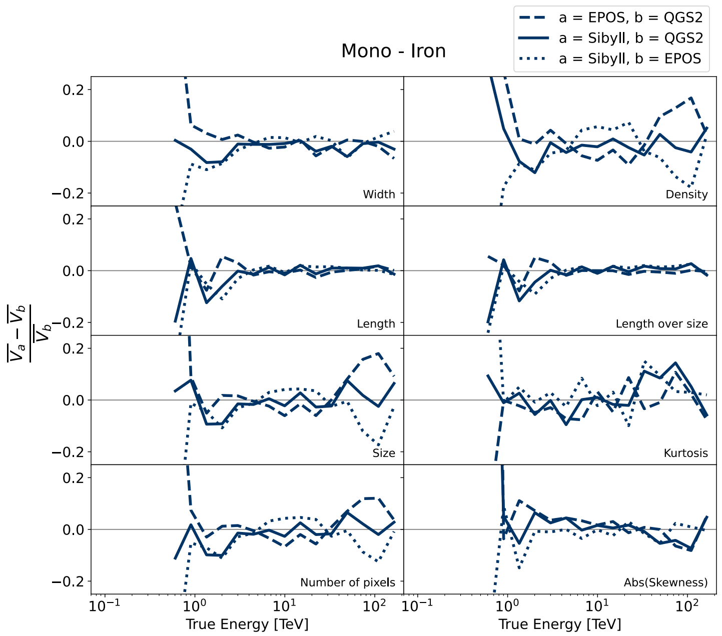
Conclusions

- For protons both using hybrid and mono, the model which differs the most from the other seems to be EPOS, while QGS2 and Sybill are harder to distinguish one from the other

- However, when looking at other primaries, the model which differs the most results to be QGS2

- Iron images don't show any clear differences between the models

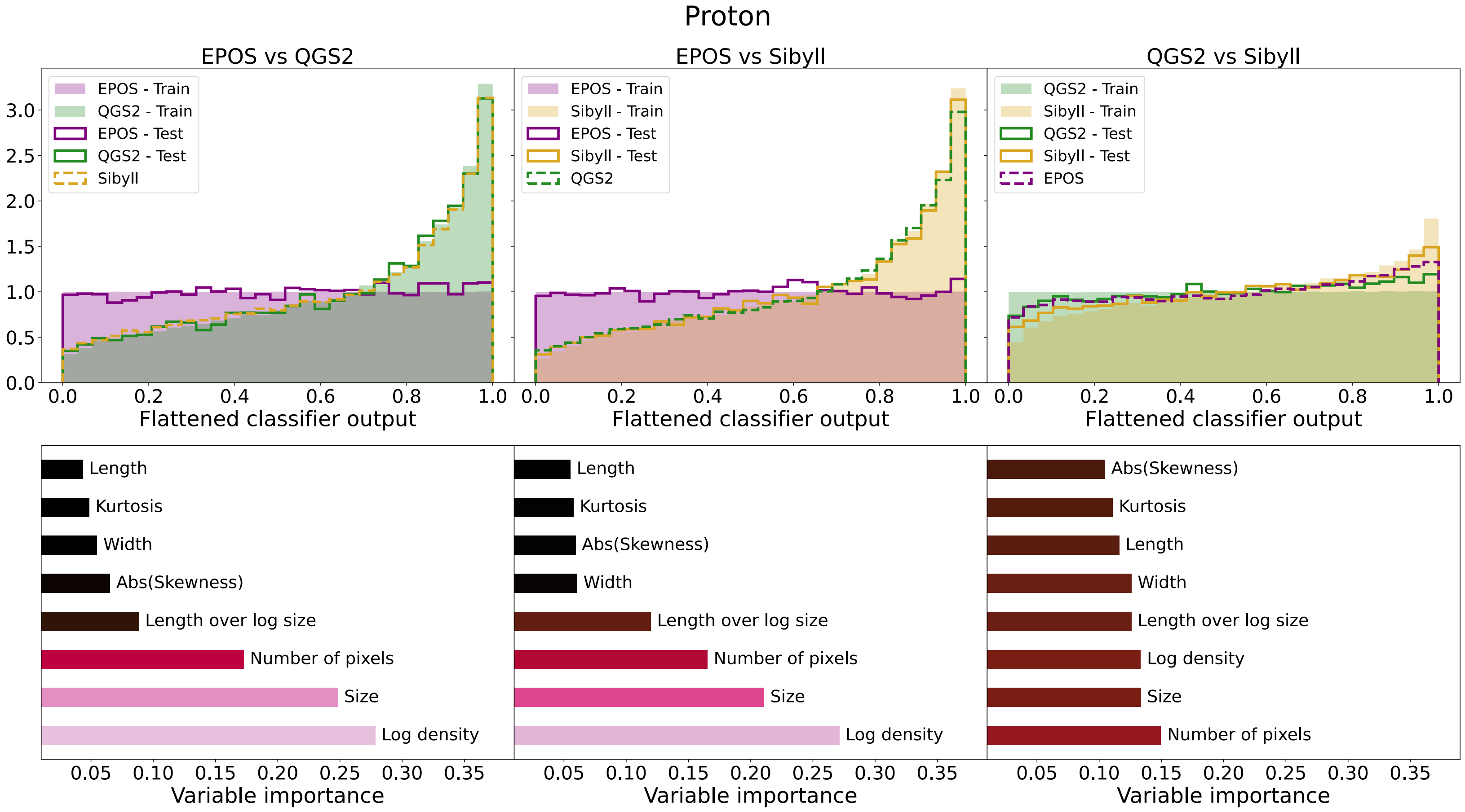




High-level results

Mono

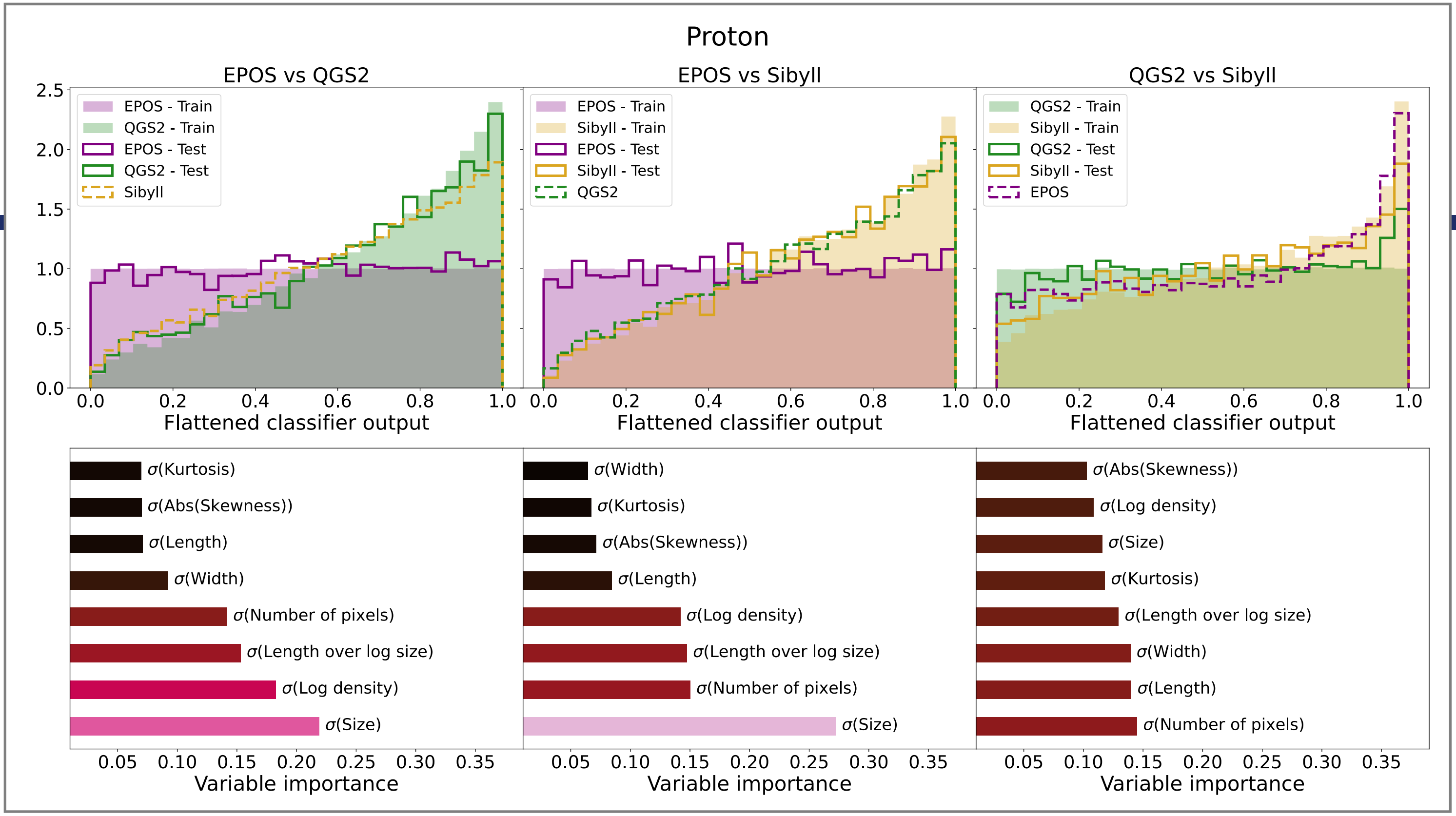
- Trained BDTs to understand the differences between the models taking into account all the variables
- The distributions, one flattened and the other not, represent the different models
- The more the distribution are overlapping, the more hard is to distinguish the two model



High-level results

Hybrid

- Results similar as what the low-level variables were indicating, both for mono and hybrid and for all the other primaries



High-level results

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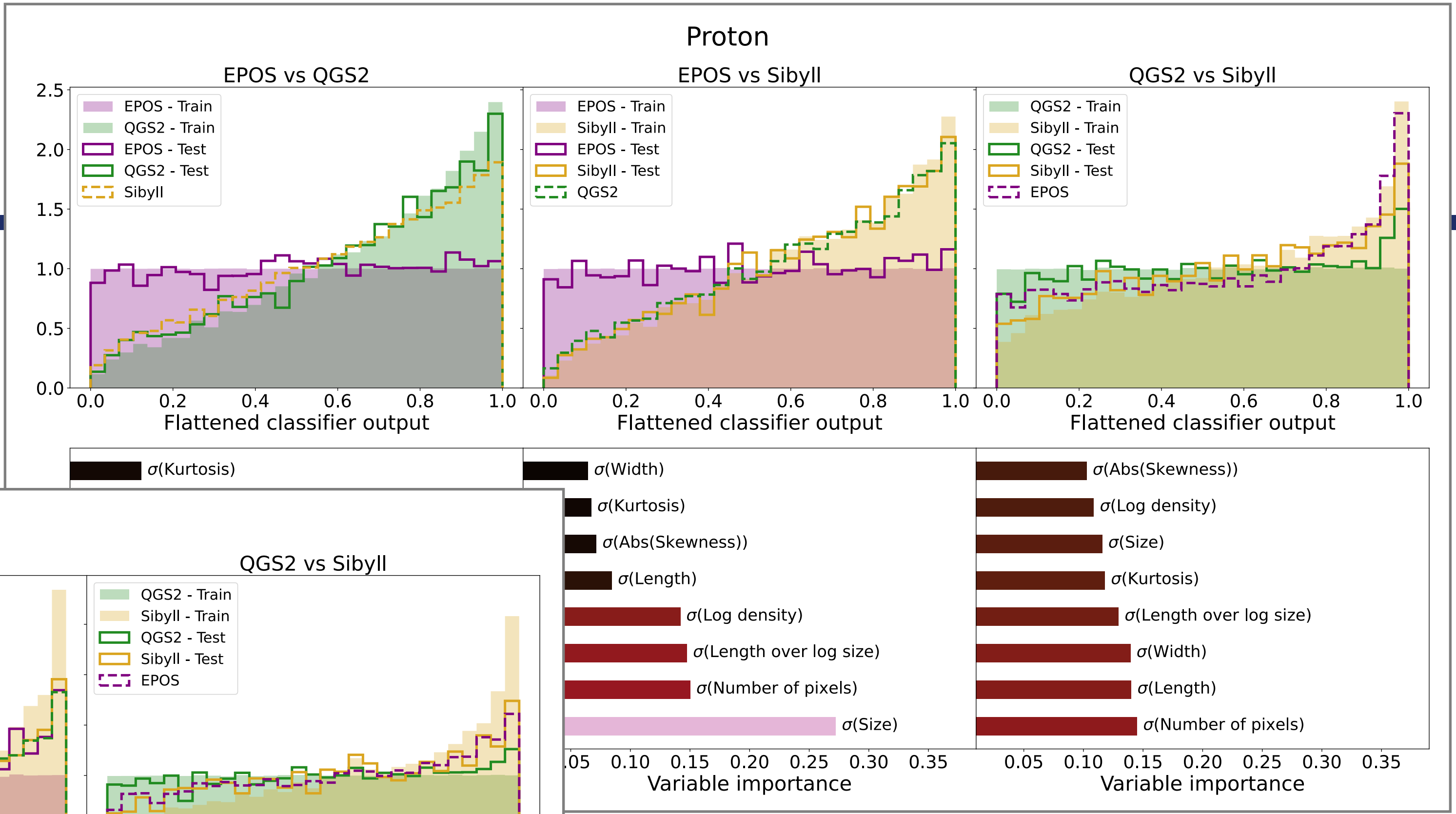
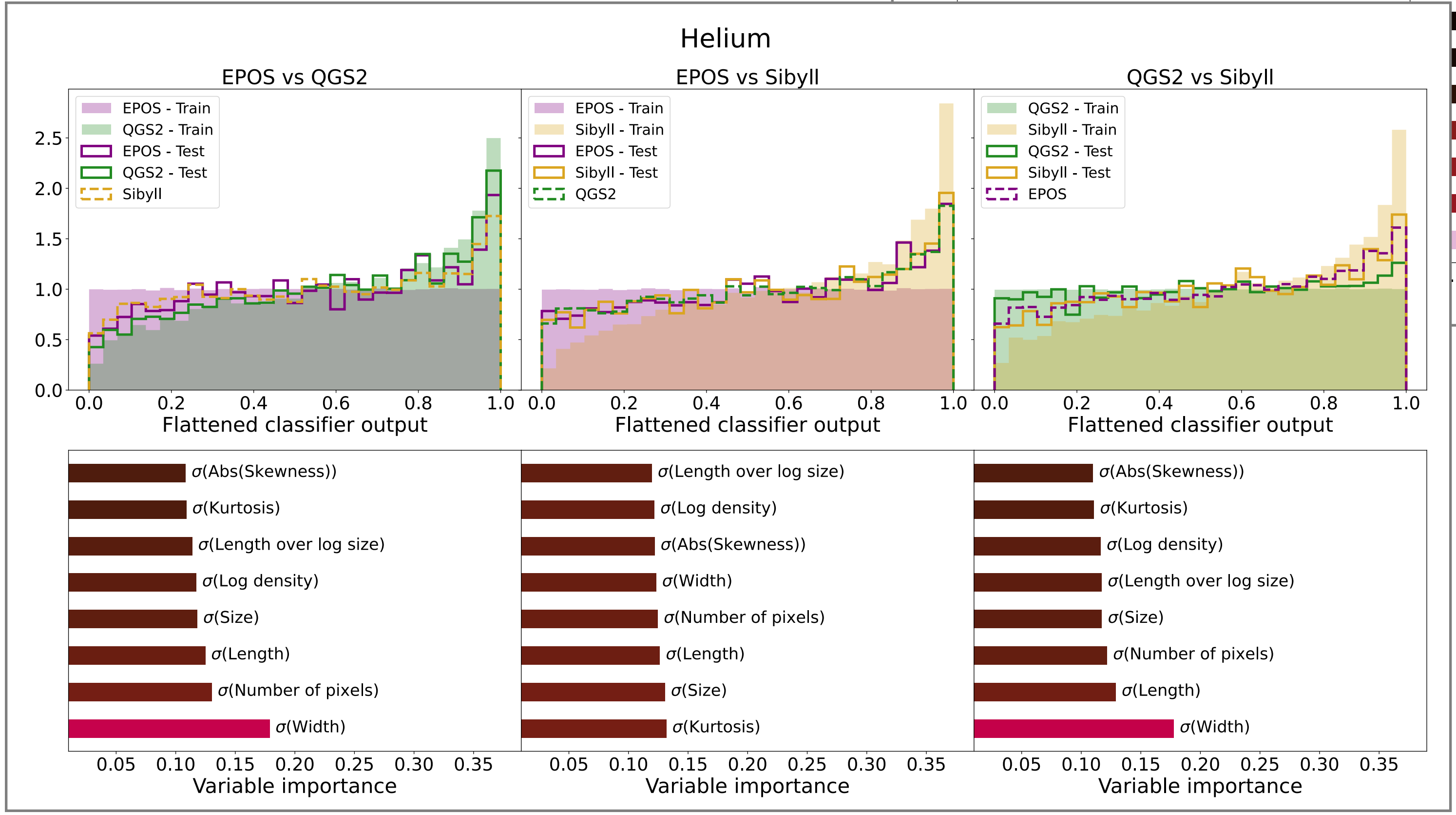
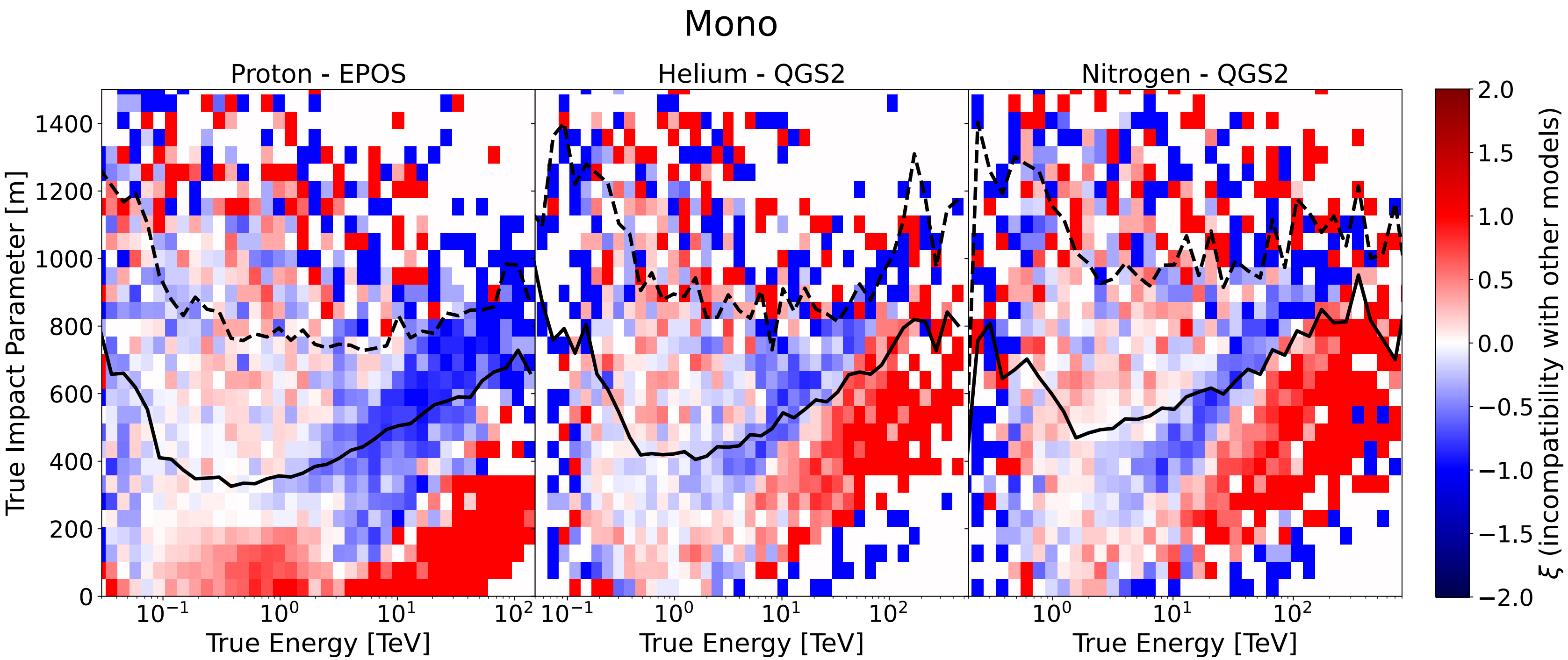




Conclusions

Computing the “incompatibility” parameter based on the BDT results for each primary and for the two configuration:
<u>the more red, the more different from the other models</u>



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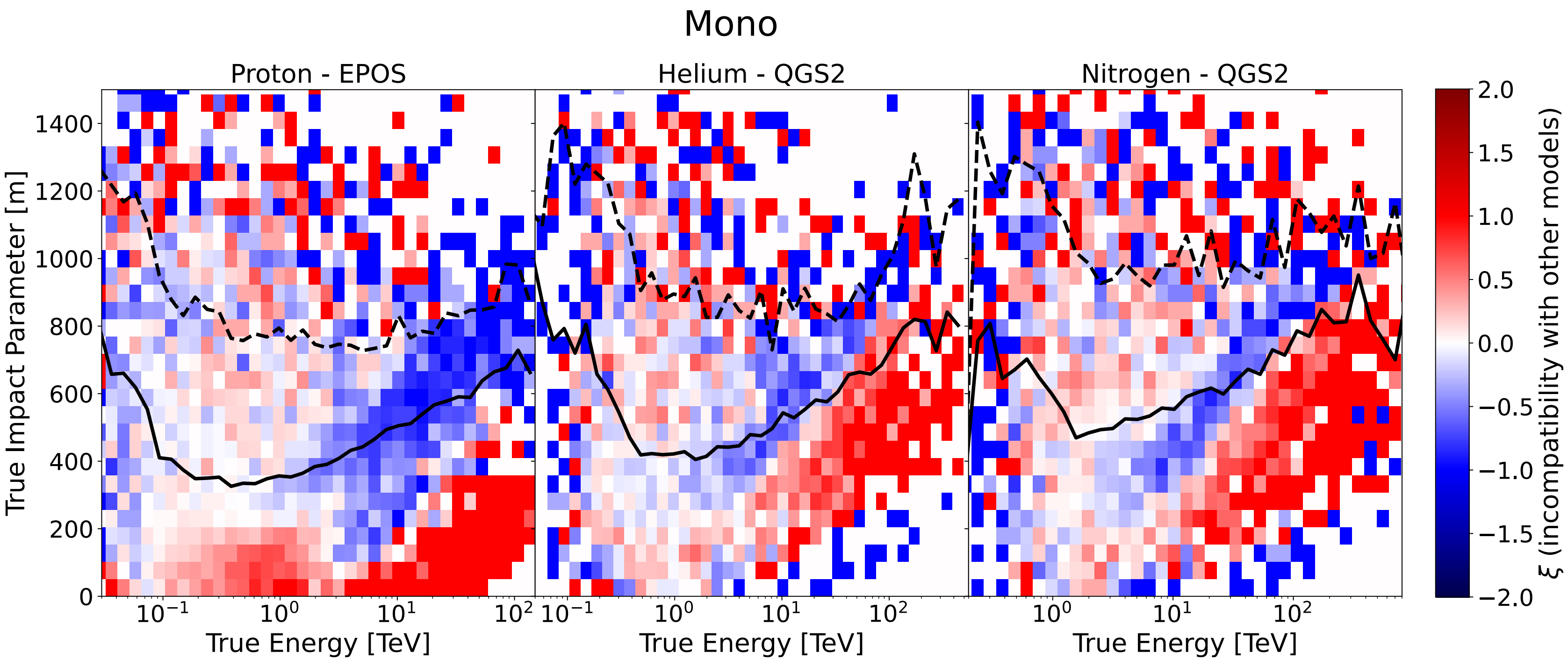
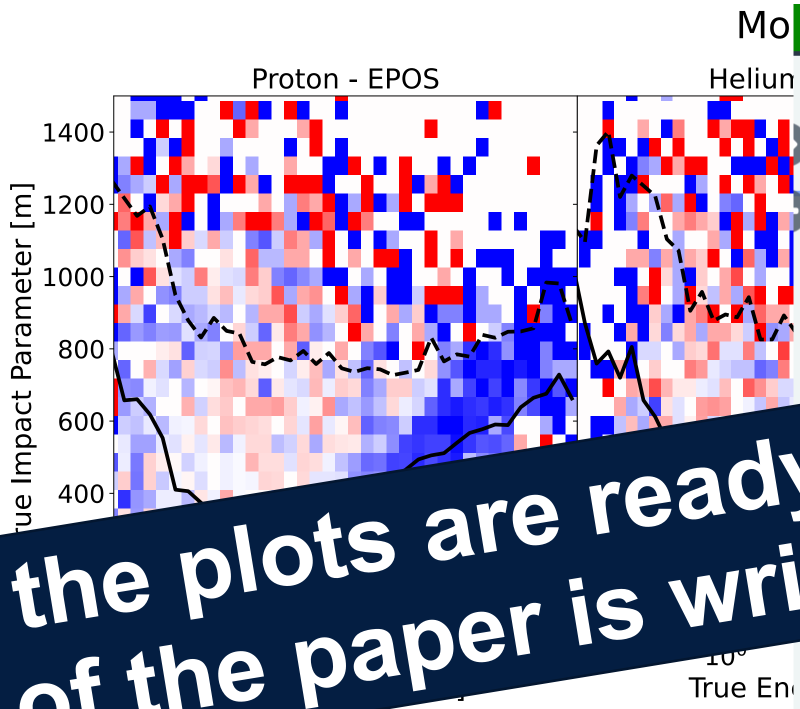


- EPOS is the model that shows more incompatibility with the other models for proton
- QGS2 is the model that shows more incompatibility with the other models for helium, nitrogen and silicon
- Iron doesn't show any evidence of differences between the three models

Conclusions

Computing the "incompatibility" parameter based on the BDT results for each primary and for the two configuration:
<u>the more red, the more different from the other models</u>



All the plots are ready, ~60% of the paper is written!

he same quantity for the same set of variables as in Figure 2 is shown here only in n each bin, the values are calculated by selecting events around 0.5σ of the mean of rameter. Solid, dashed, and dotted lines indicate the pair of different models being rding to the legend on the top right of the plot.

to the comparison between Sibyll 2.3d and QGSJET-II04 is more or less always in the middle. this means that the two models are more in agreement with each other than when these same models are compared to EPOS-LHC.

When checking the 2D- and 1D-histograms for other primaries in the A, it is possible to note that for helium, nitrogen, and silicon the variables size and number of pixels are again the most important ones and that the model which differs the most from the other two is QGSJET-II04. Regarding iron, there are no clear hints of differences between the models in both plots.

3.2 Hybrid

Since hadronic showers result asymmetric in the camera images from different telescopes, computing the mean of the variables for each telescope and for each event would not provide valuable results and would actually end up in a loss of information. Instead, to fully exploit the hybrid configuration, for each variable, the standard deviation among CT1-4 was computed for each event ($\sigma(V)$), then the average among all the events was taken to compare

– 5 –

one model to the other. The resulting 2D- and 1D-histograms as before are shown in Figure 4 and Figure 5.

The 2D-histograms look more chaotic with the hybrid configuration, but it is still possible to spot some differences along the 68% and 95% containment radius for some variables like density, number of pixels, and size. Again, those differences are more visible only in the first two columns, making EPOS-LHC the model that differs the most from the others.

This is also confirmed by the hybrid 1D-histogram, where the solid line for the same three mentioned parameters, is the closest to zero, meaning that QGSJET-II04 and Sibyll 2.3d are harder to distinguish

- EPOS is the mod … shows more incompatibility with the other mod
- QGS2 is the model that shows more incompatibility with the other mod silicon
- Iron doesn't show any evidence of differences between the three mode

Backup

Incompatibility