Mass Composition

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HISTORY

Caterina, Francesco, Sergio
Fraction Fit (extensive study of the frequentist approach)

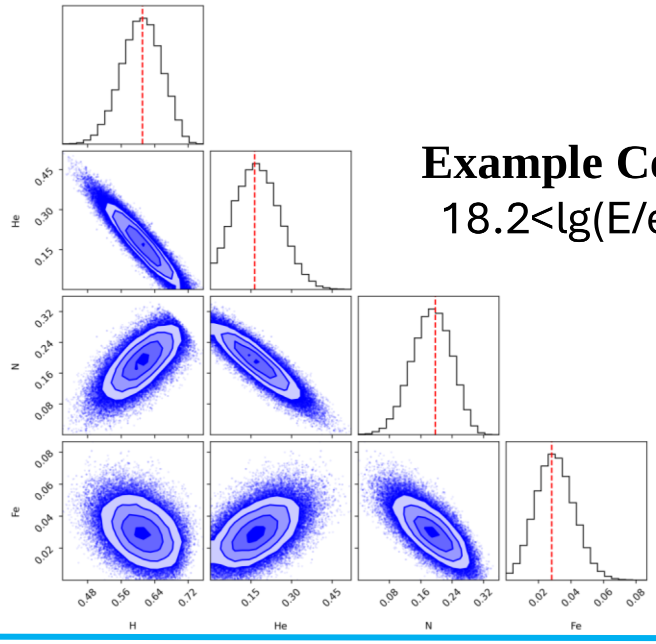
Fabio, Francesco, Sergio, Denise
Fraction Fit SD / (frequentist and bayesian approach, fit with Gumbel/templates)

Igor, Carmelo
Fraction Fit FD / (bayesian approach, test with new likelihoods with Gumbel/templates, fit with more then five elements)

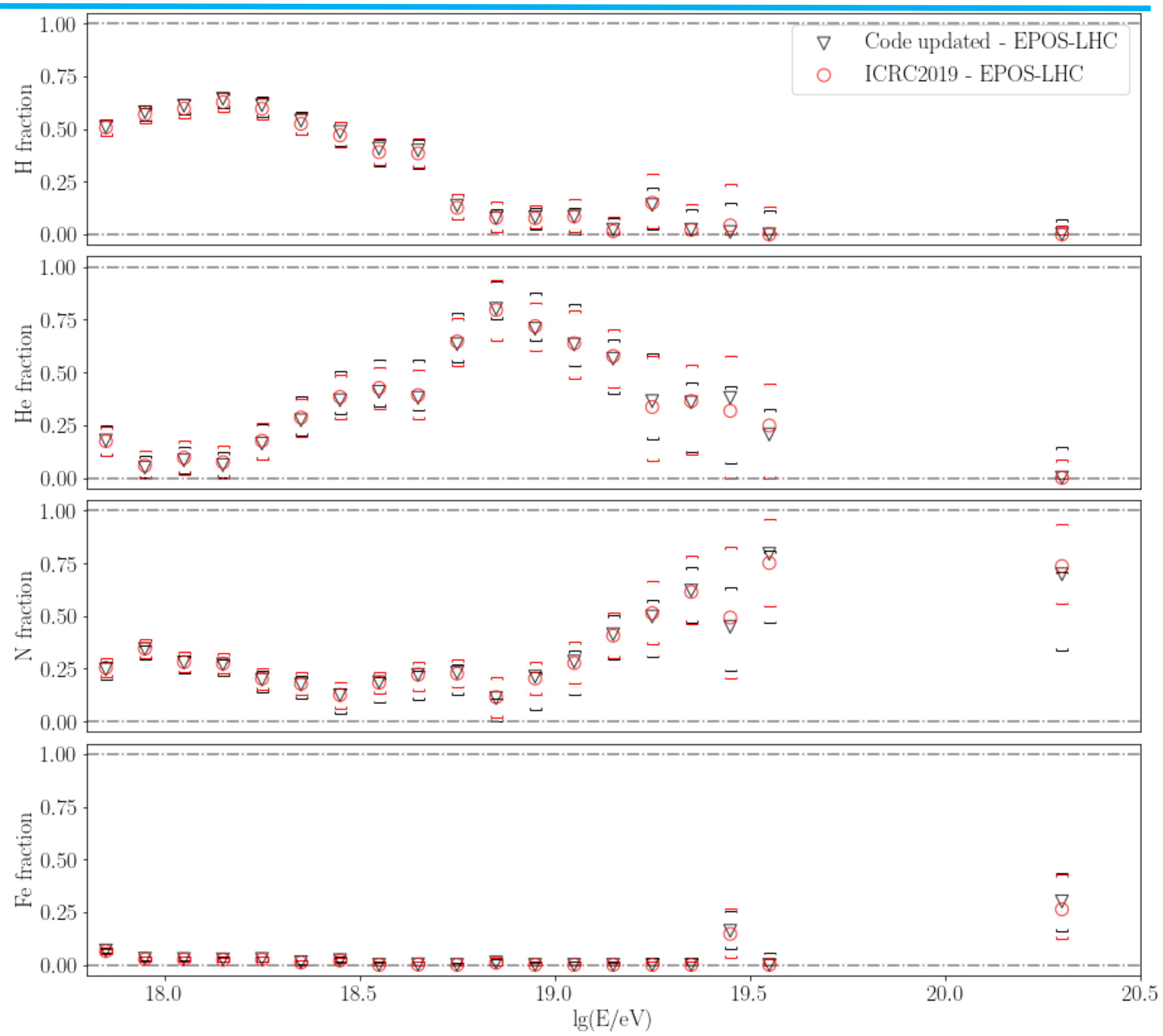
United efforts to have GAPs and new public code release

INTRODUCTION

- Frequentist approach compatible with Bayes for **FD**
- Bayes approach used for SD (and for FD) in the next analysis
- The v3r99p3 NN data (**hybrids calibrated**) are used from https://www.auger.unam.mx/AugerWiki/XmaxMomentsDNN
- **Distributions** built from the released data are **corrected** for the composition bias and the hadronic-interaction model bias, due to the hybrid calibration



Example Corner plot
18.2<lg(E/eV)<18.3



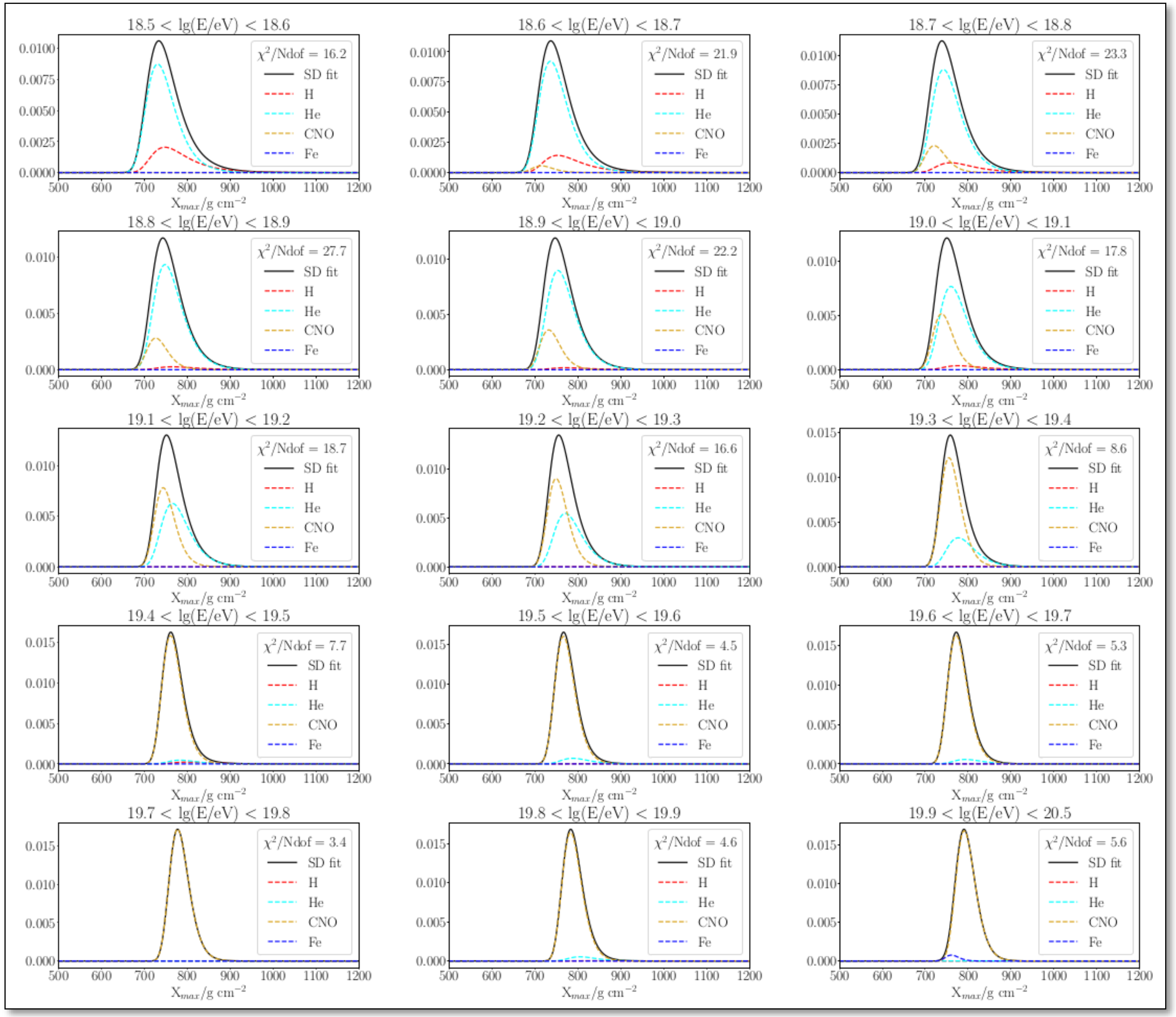
Center of the energy bin used instead of the average energy per bin, it will be updated in the final images with the average energy!!!

SD-NN mass fractions fit

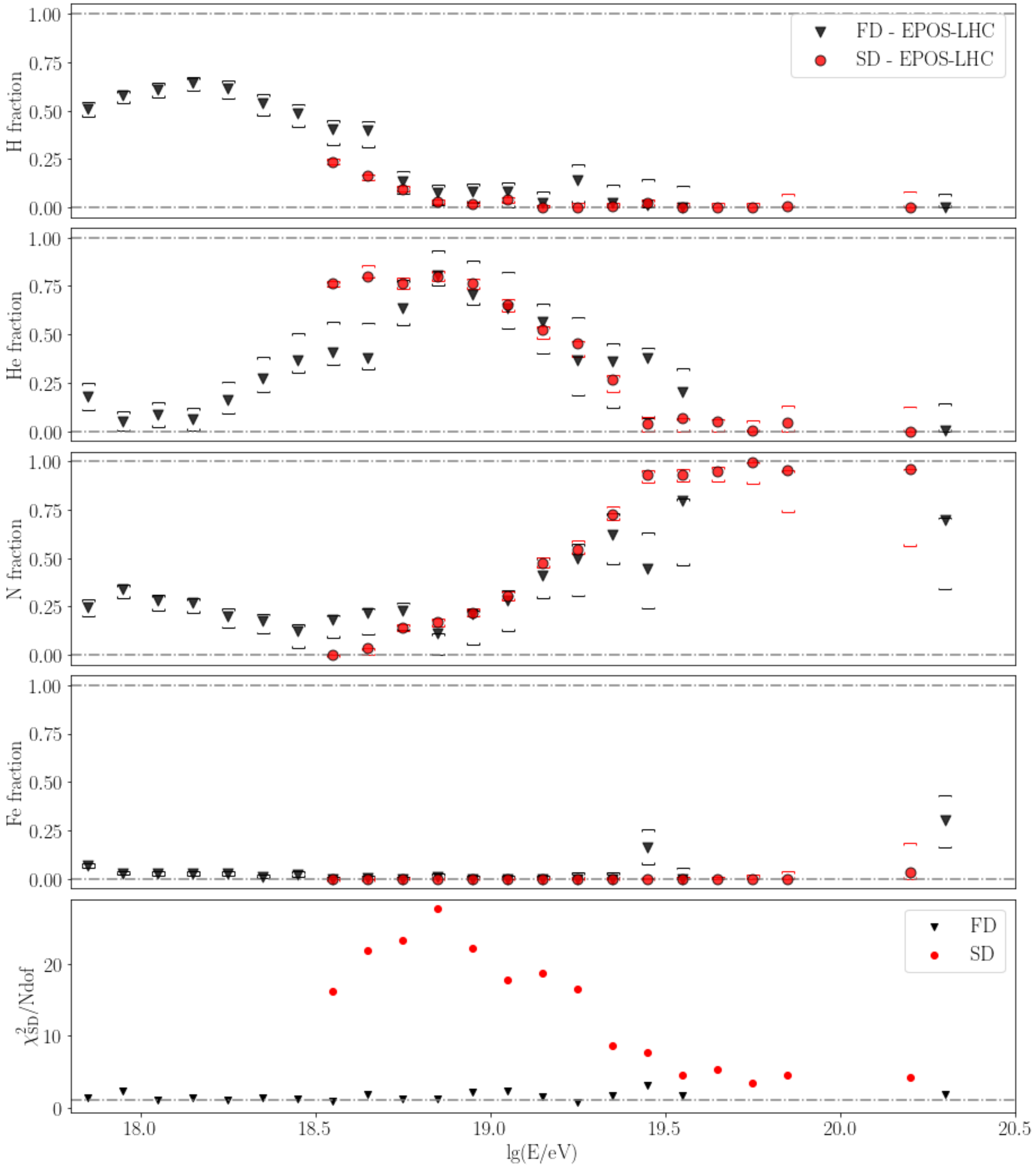
- Estimate a resolution of the method in a similar way done for other methods (universality, GAP2019_035), by using the sample of golden hybrids events, **is not possible.**

- **Equivalently, SD-NN distributions turn out to be narrower than Gumbel distributions without detector effects.**

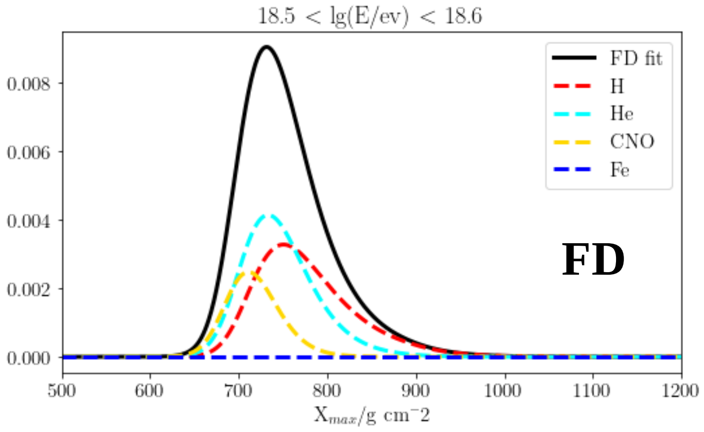
- Therefore, we proceeded to explore the behavior of the fraction fit without making any correction for the resolution

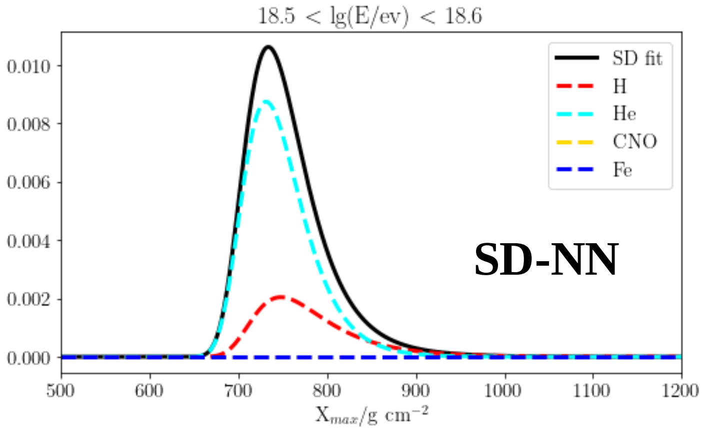


Comparison with FD fractions



- SD and FD fractions overplotted
- Although SD follows the trend of FD, the fit for SD is not optimal:
  - The reduced chi square (as well as the p-value) suggests that the fit does not fit the data well
  - Due to the fact that the SD-NN distributions are tighter then FD ones, the number of masses that can be fit is lower.

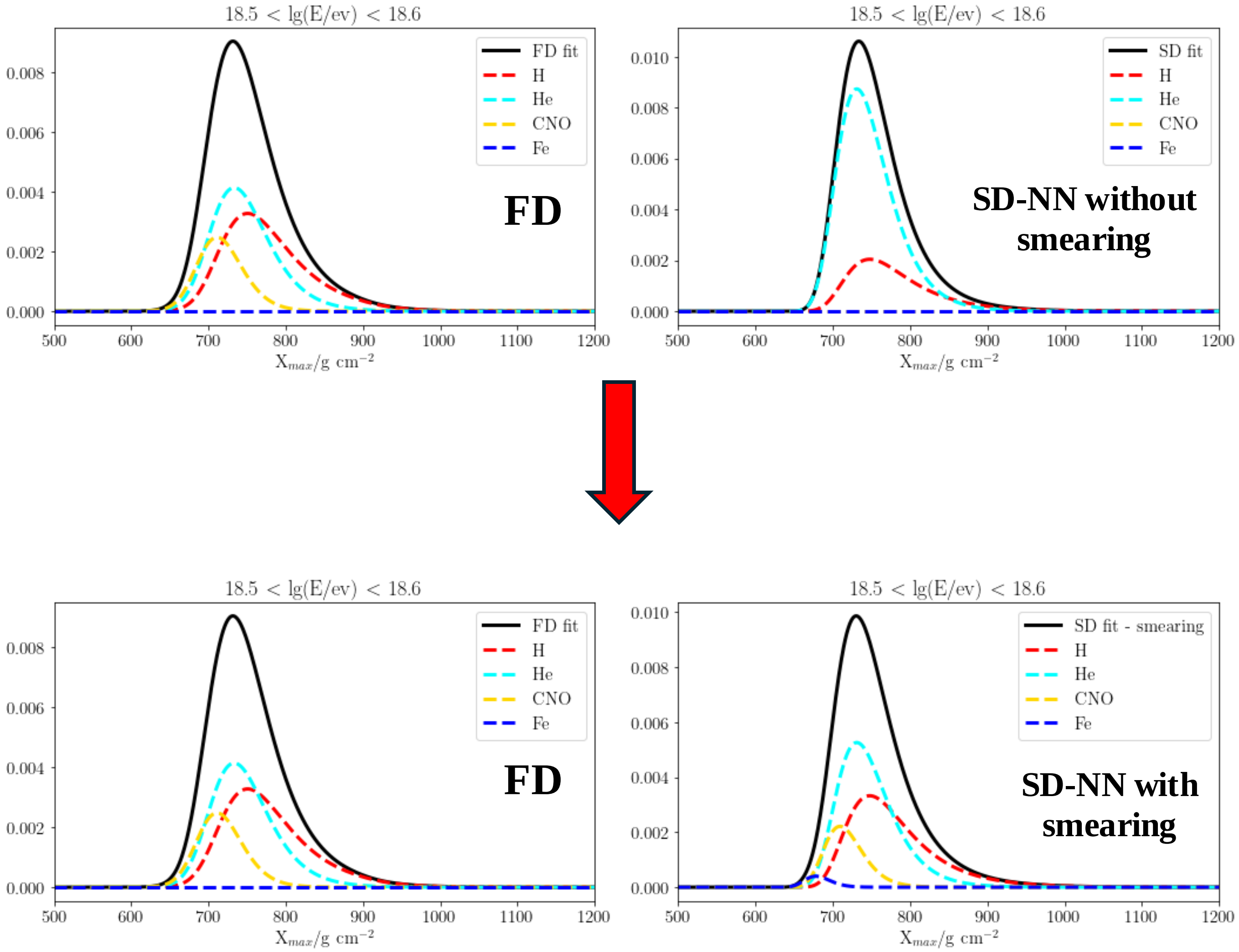




SMEARING

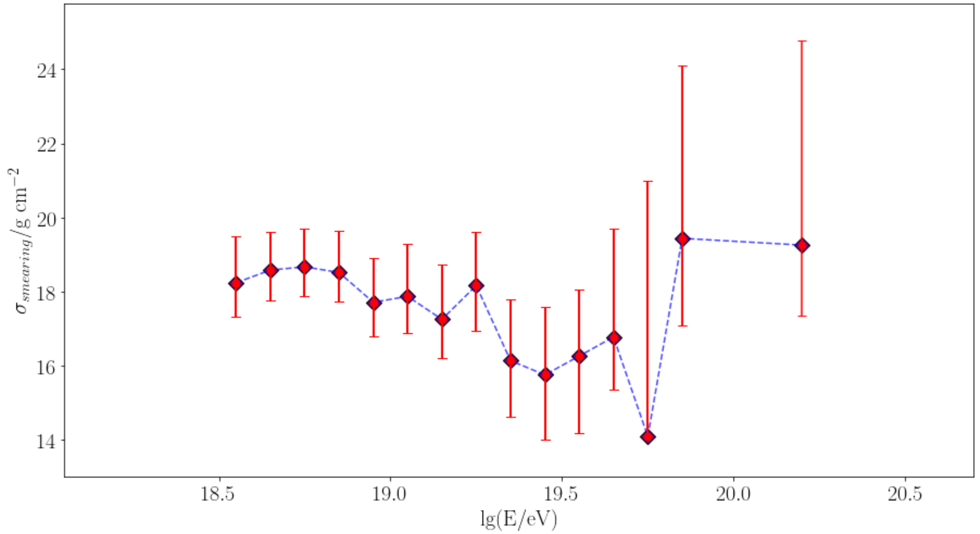
- Introducing a simple broadening of the NN data distributions to see the effects on the fit quality and results

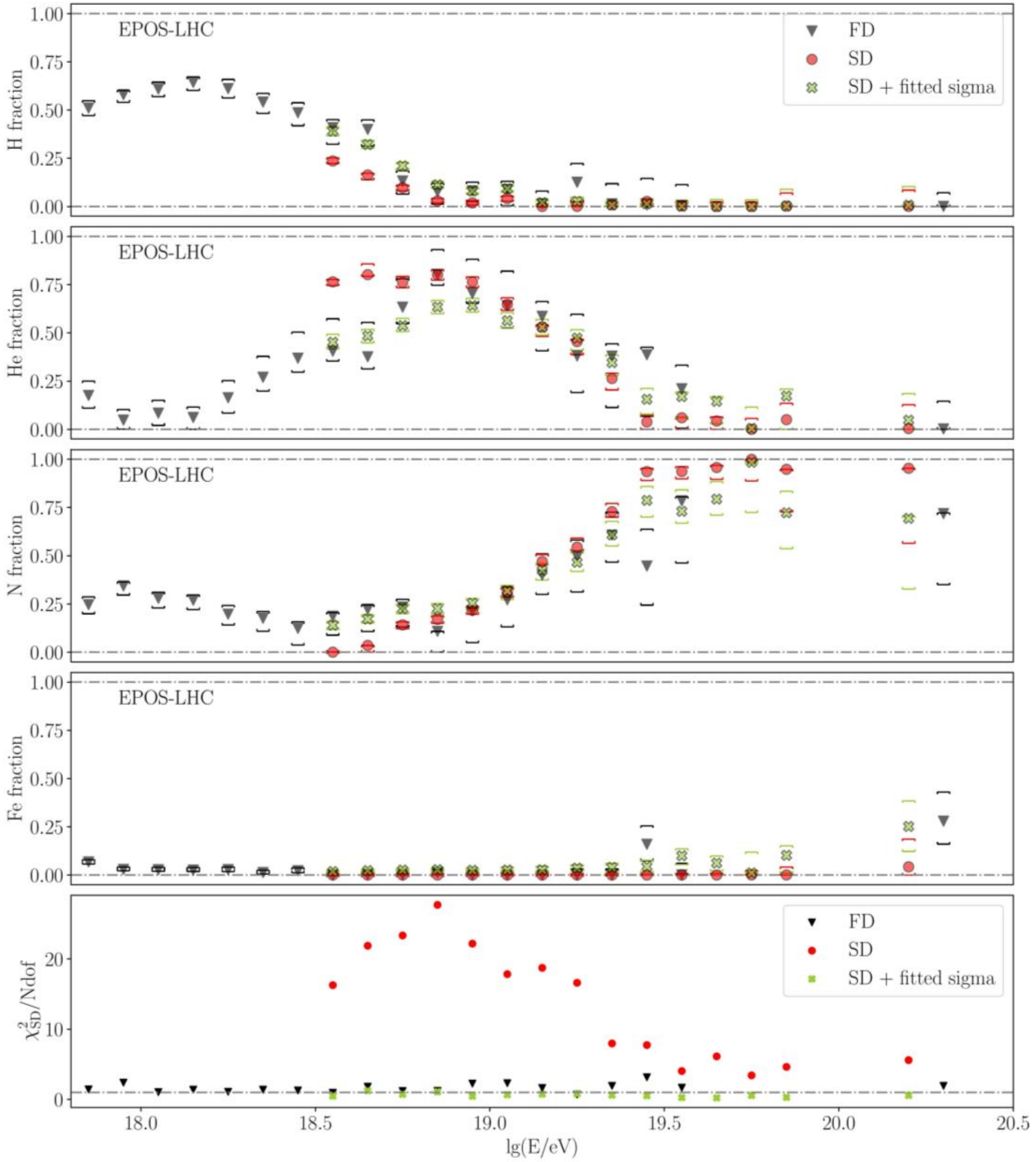
- A Gaussian smearing was introduced for SD-NN X_{max} data distributions



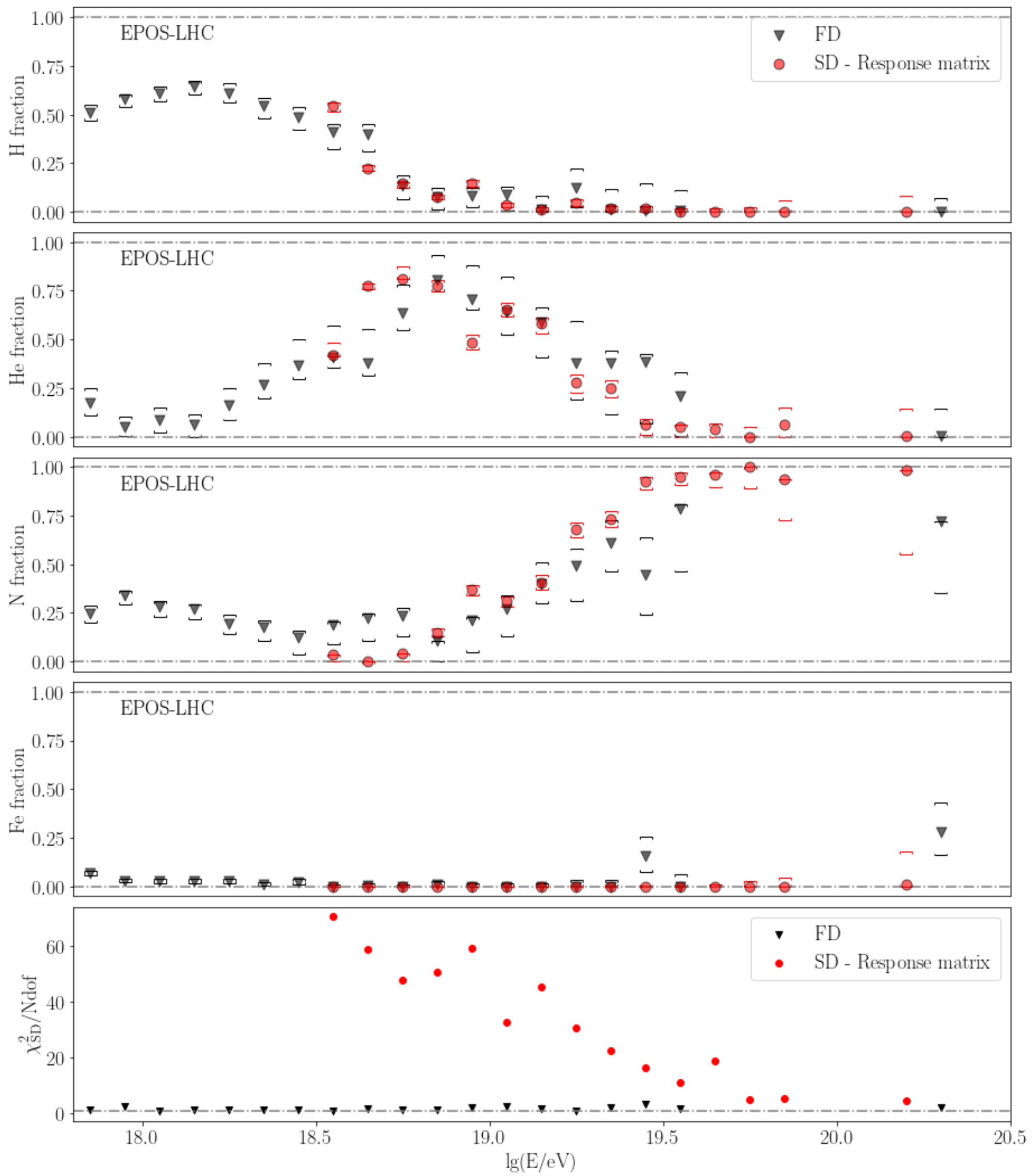
FIT SIGMA TOGETHER WITH FRACTIONS

- Incorporated smearing directly into the fitting process.
- Added sigma as a parameter in the fit for dynamic optimization.
- Gaussian convolution of Xmax distributions.
- The result shows, as expected, better agreement with the FD data
- The sigma appears to have a decreasing trend with energy

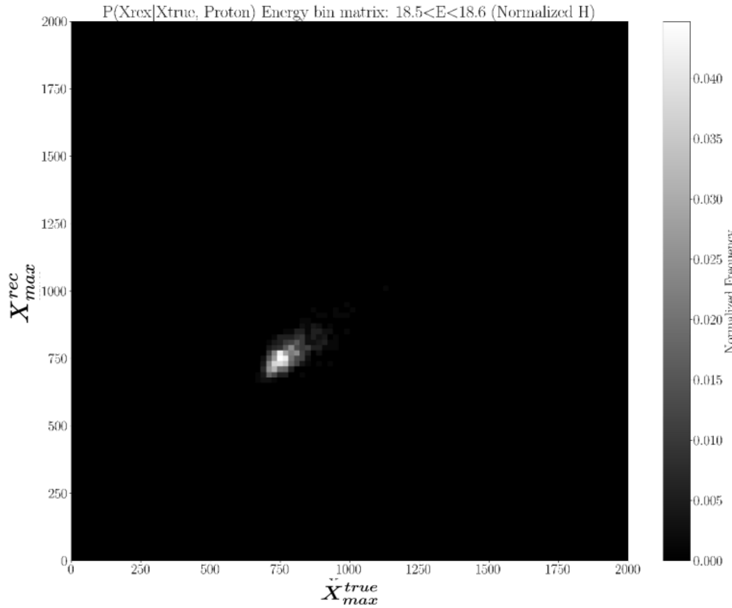


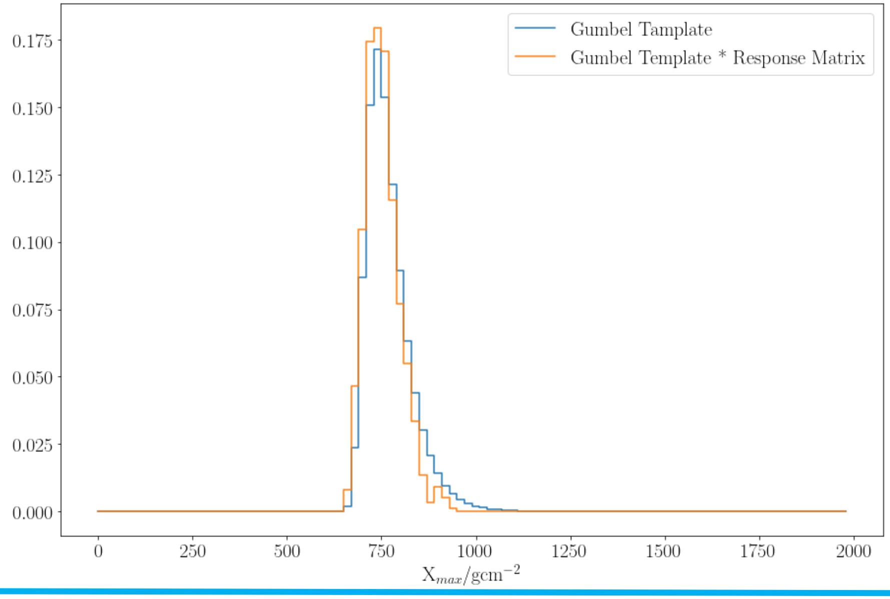


SIMULATIONS (early studies)



$$\vec{\mathbf{V}} = \hat{\mathbf{R}} \cdot \vec{\mathbf{G}}$$





ALTERNATIVE LIKELIHOOD FOR TEMPLATE MASS COMPOSITION ANALYSIS

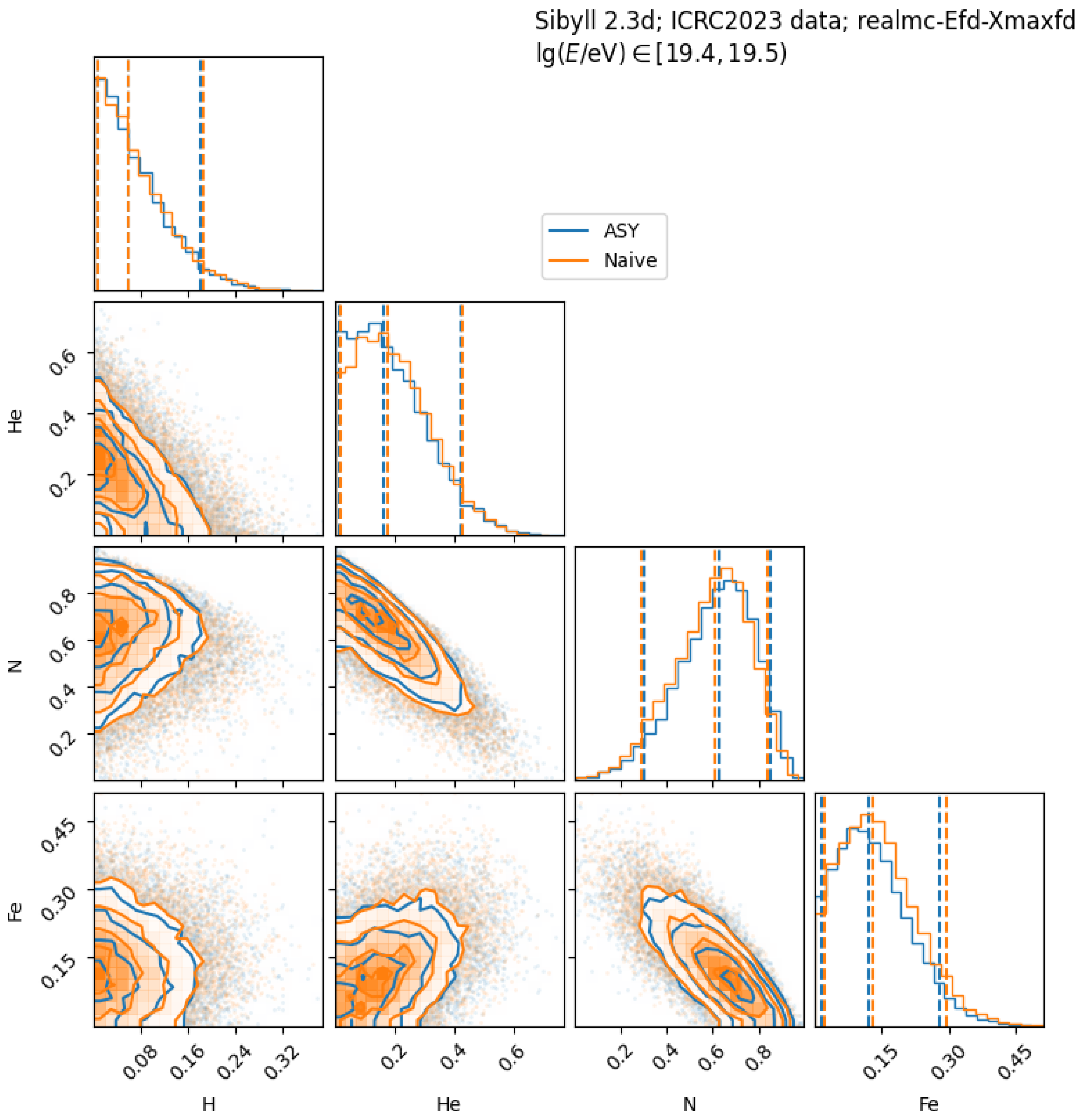
- **Motivation**: the Poissonian likelihood does not account for fluctuations in Monte-Carlo templates → it might lead to biased results under some conditions, e.g.
  - Finer binning in X_{max}
  - Multidimensional analysis (e.g. FD and DNN X_{max} distributions fit together)

- **Methods**: the problem is known in HE physics, there are several approaches, e.g. Argüelles, Schneider, and Yuan 2019 (ASY)

- **Conclusions**
  - The standard Poissonian likelihood performs well under a wide variety of conditions
  - The ASY results are harder to interpret
  - For a simple mass composition analysis, the switch is probably not worth the effort, but might be useful for higher-dimensional case

ALTERNATIVE LIKELIHOOD FOR TEMPLATE MASS COMPOSITION ANALYSIS

Image: comparison between the standard Poissonian likelihood and ASY likelihood in the context of Bayesian analysis of mass composition



FRACTION FITS OF THE FD XMAX DISTRIBUTIONS USING 26 NUCLEI

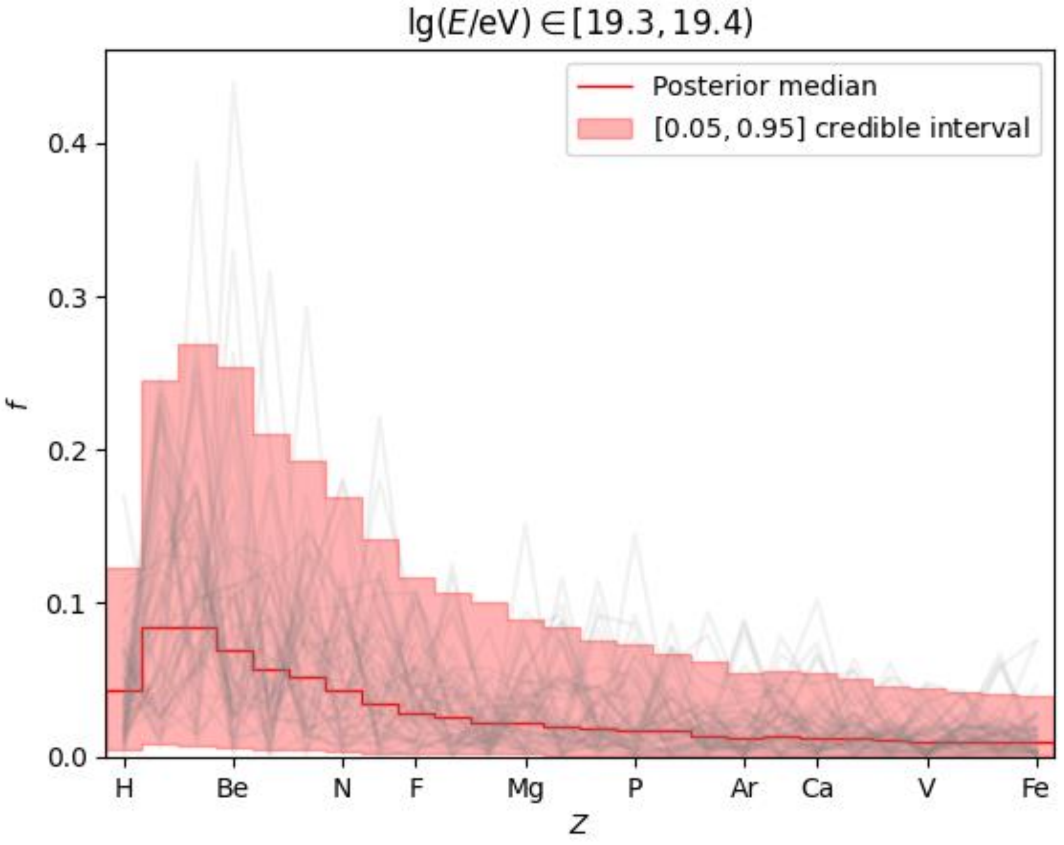
Motivation: there are claims that the 4 standard primaries do not represent the whole composition well; do we gain anything by including more primaries?

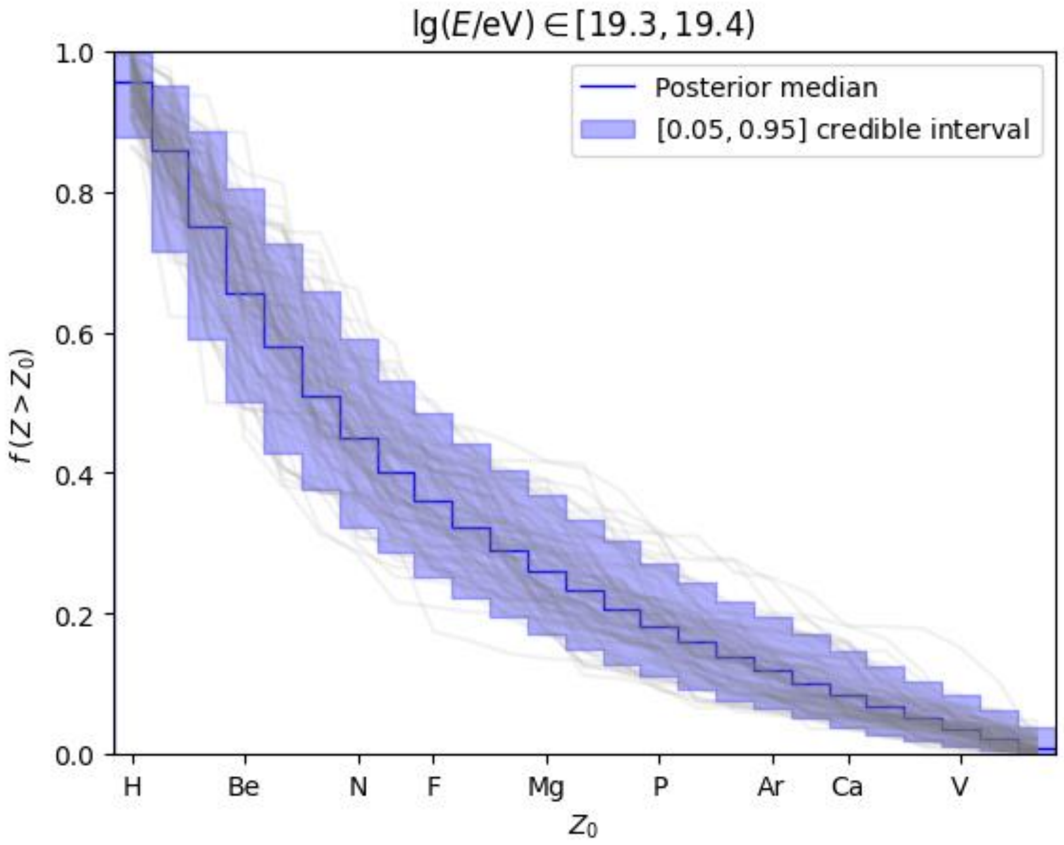
Method: Gumbel parametrization and Bayesian inference scale easily to 26 primaries (standard isotopes or H to Fe); however, the results are trickier to interpret, as almost all individual fractions are consistent with zero.

Conclusions:
- All primaries indeed are not easily represented by a group of just 4 primaries
- Inference with 26 (and possibly more) primaries is possible, although it requires more attention to MCMC convergence
- Proton upper limits might also be affected by the number of primaries in the analysis, but this requires further study

FRACTION FITS OF THE FD XMAX DISTRIBUTIONS USING 26 NUCLEI

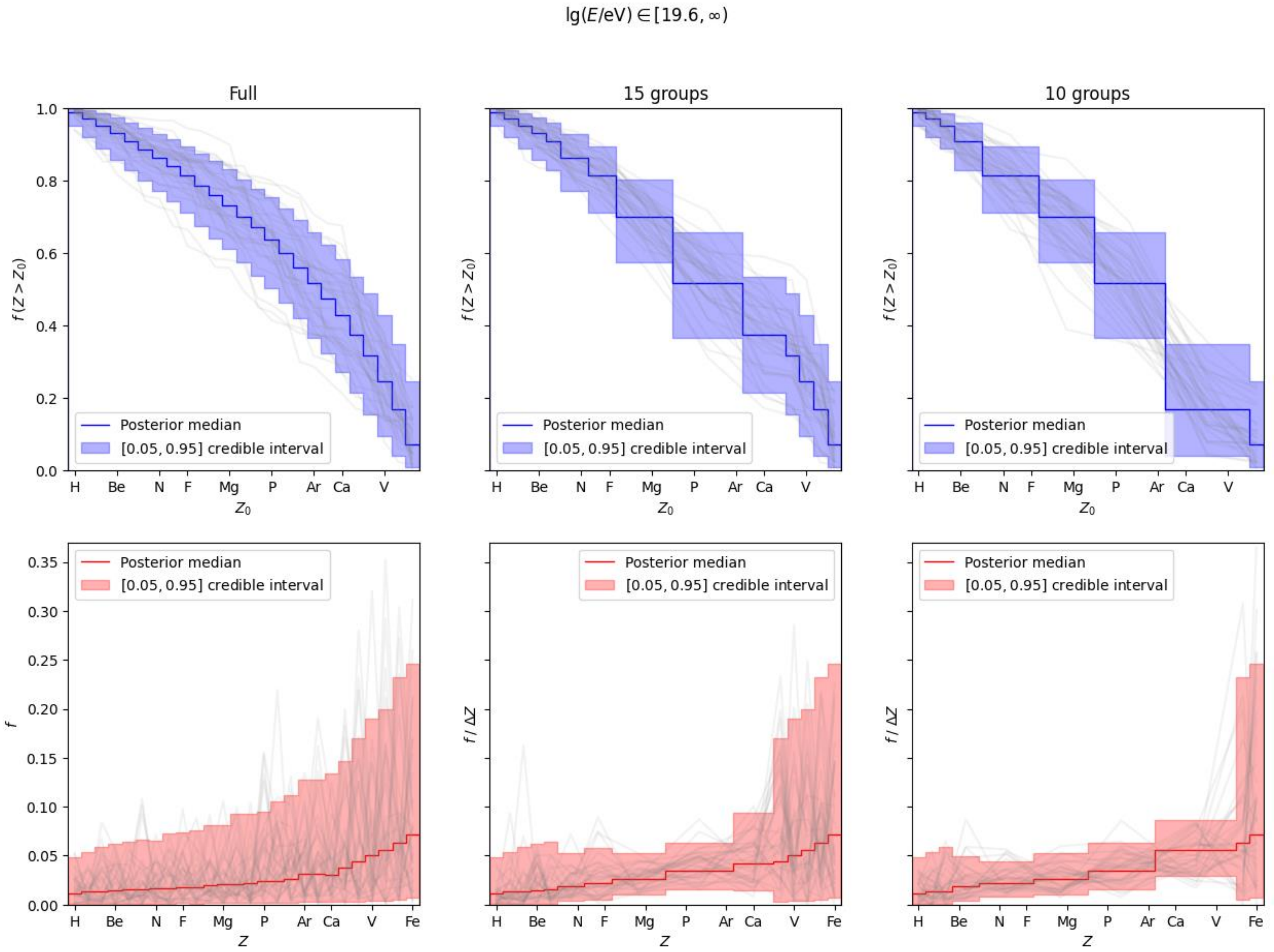
Cumulative fractions as an alternative representation of the results





FRACTION FITS OF THE FD XMAX DISTRIBUTIONS USING 26 NUCLEI

Progressive grouping guided by making the groups as uncorrelated as possible in the posterior distribution



CONCLUSION

- An attempt of using SD-NN X_{max} distributions for mass fractions fitting has been done

- The SD-NN X_{max} **distributions appear narrower** than the FD X_{max} corrected for acceptance and resolution.

- The SD fit result is **not satisfactory**, nevertheless, the trend follows the FD one.

- **It is important to emphasize that, to correctly perform the fit:**

  - **CORSIKA+Offline simulations should be fed into NN;**
  - **The single mass distributions in output from NN should be parametrized** to produce the appropriate model p.d.f
  - Currently these kinds of simulations are partly available (more information needed) and are being studied

- ASY likelihood could be useful for higher-dimensional case

- Inference with 26 (and possibly more) primaries is possible, although it requires more attention to MCMC convergence