INVESTIGATING ANOMALOUS BUMP AIR SHOWERS WITH SKA-LOW

UPDATE 5

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USING ANOMALOUS AIR SHOWERS TO INDEPENDENTLY STUDY HADRONIC MODELS AND MASS COMPOSITION

PAPER 1

INTRODUCTION

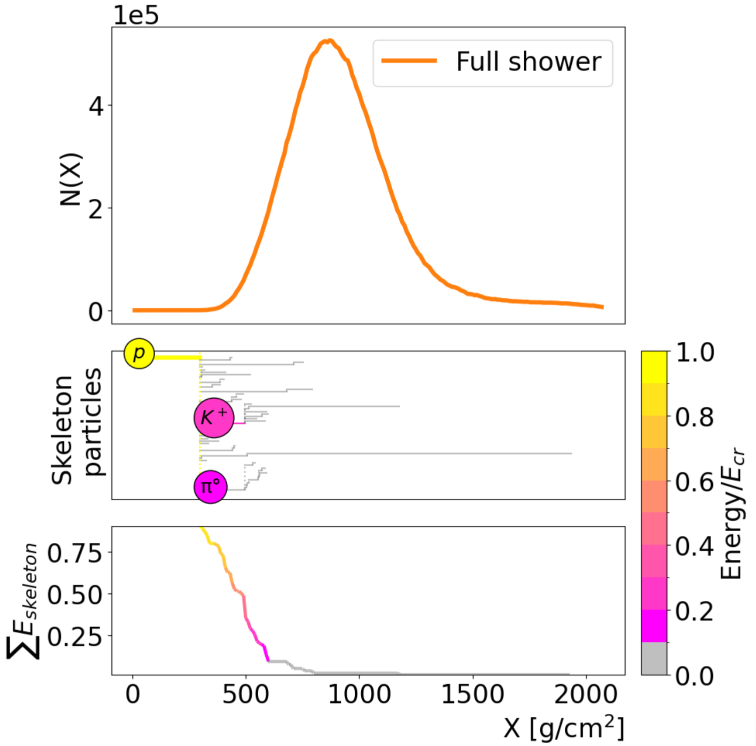
CONEX SIMULATIONS

10.000 simulations of each combination:

- Energies: 10^6, 10^6.5, 10^7, 10^7.5,
  10^8, 10^8.5 & 10^9 GeV
- Primaries: P, He, C & Fe
- Models: QGSIII (01), SIBYLL (2.3e) & EPOS (LHC-R)

So in total 840.000 simulations.

Simulated using my custom CORSIKA/CoREAS.
Creates a skeleton of a shower.

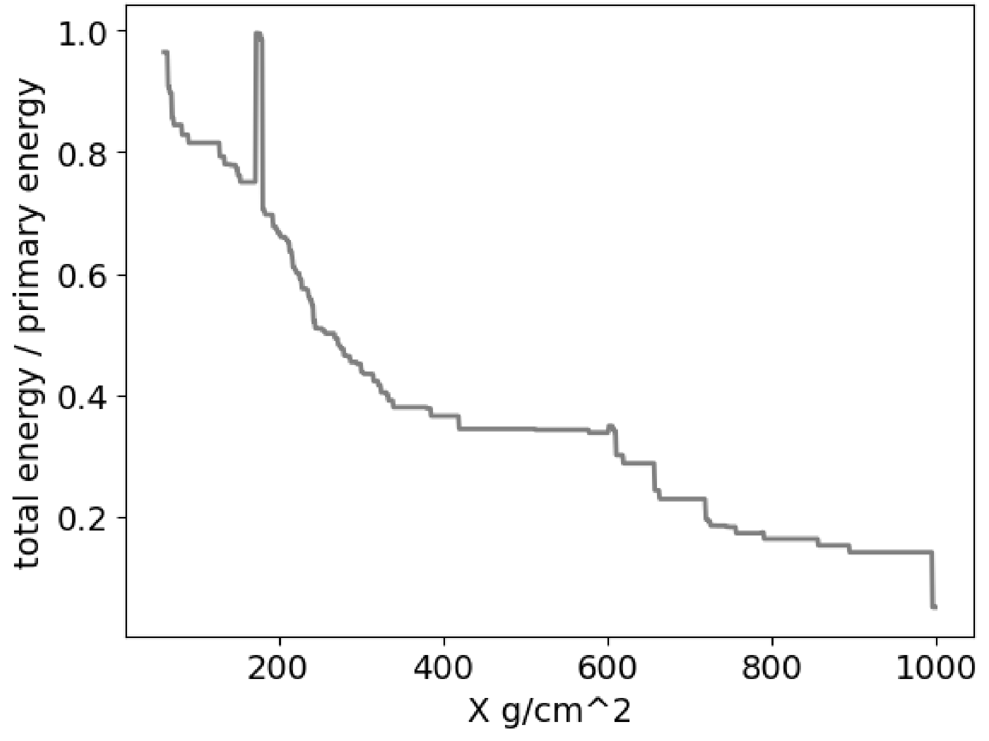


FUNKY CONEX ERROR?

Conex simulation causes a problem.

Peaked caused by instant decay.

Does not impact results!



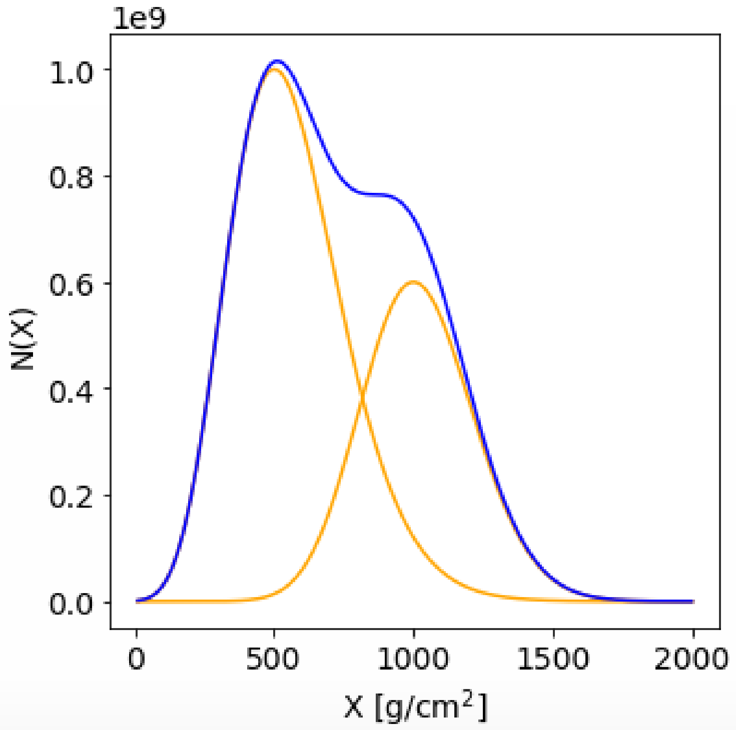
ANOMALOUS SHOWERS

ANOMALOUS SHOWERS

We define anomalous showers as showers were high-energy secondaries cause the longitudinal profile to deviate from the universal profile

Use the Akaike Information Criterion (AIC) to compare single Giasser Hillas fits to double Giasser Hillas fits.

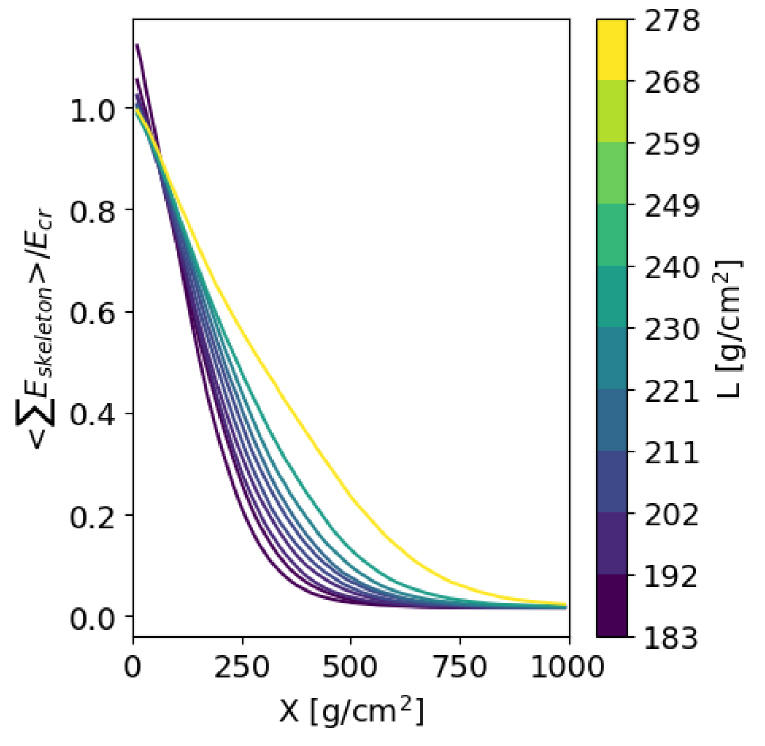
We need to ensure that both showers are physical!



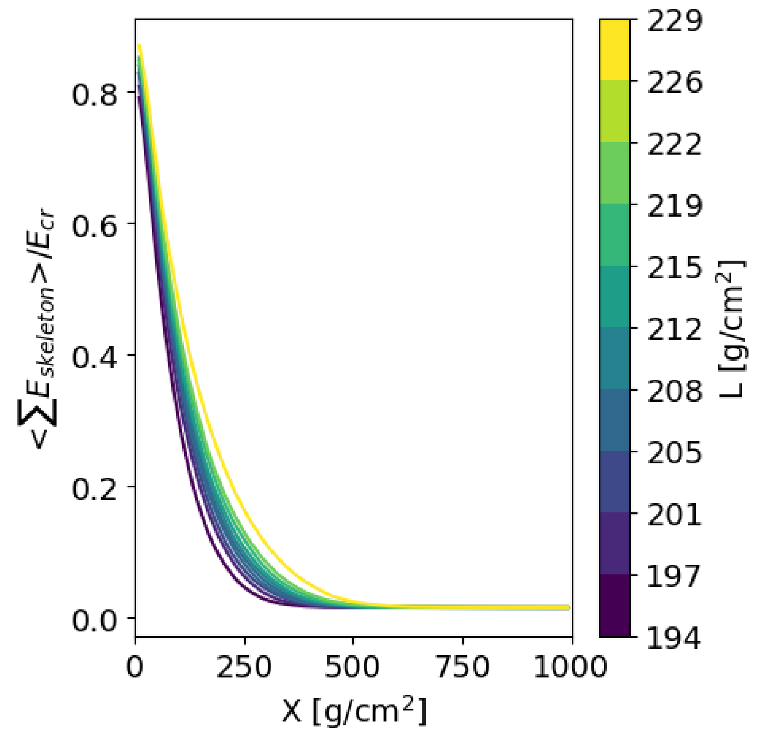
BASIC SHOWERS

Find limits on L & R that make showers 'basic'.
Remove the showers with significant influence from skeleton particles.

Proton



Iron



10^6 GeV
QGSJETIII

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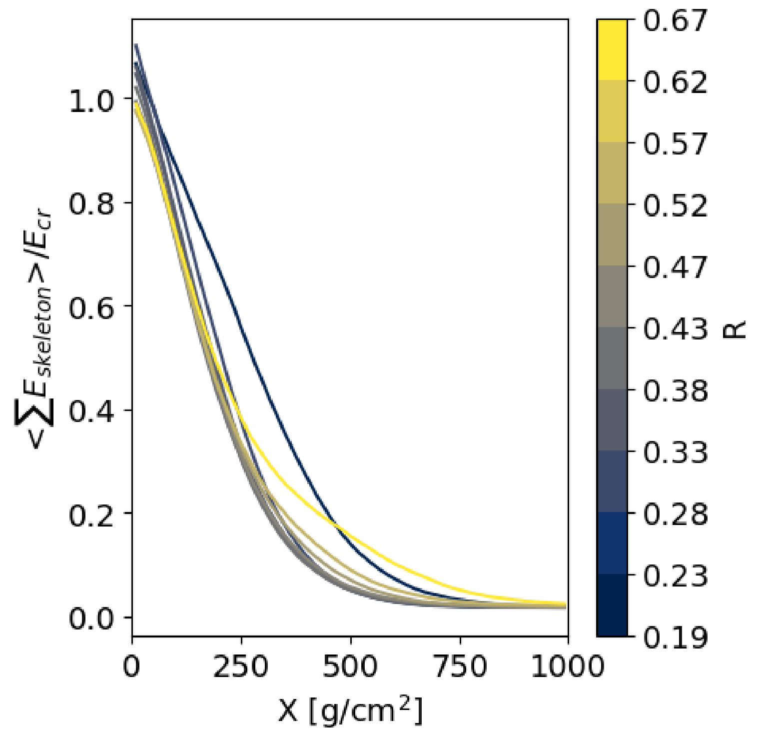
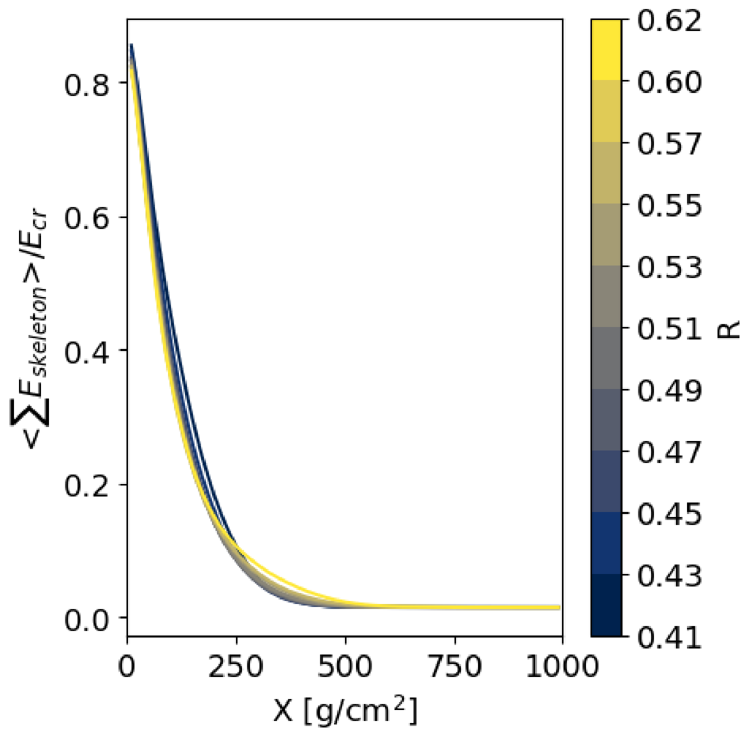
BASIC SHOWERS

R is more complicated. High R means initial growth isn't exp due to skeleton particles still traveling. While Low R means after X_max some skeleton particles still exist.

Proton



Iron



10^6 GeV
QGSJETIII

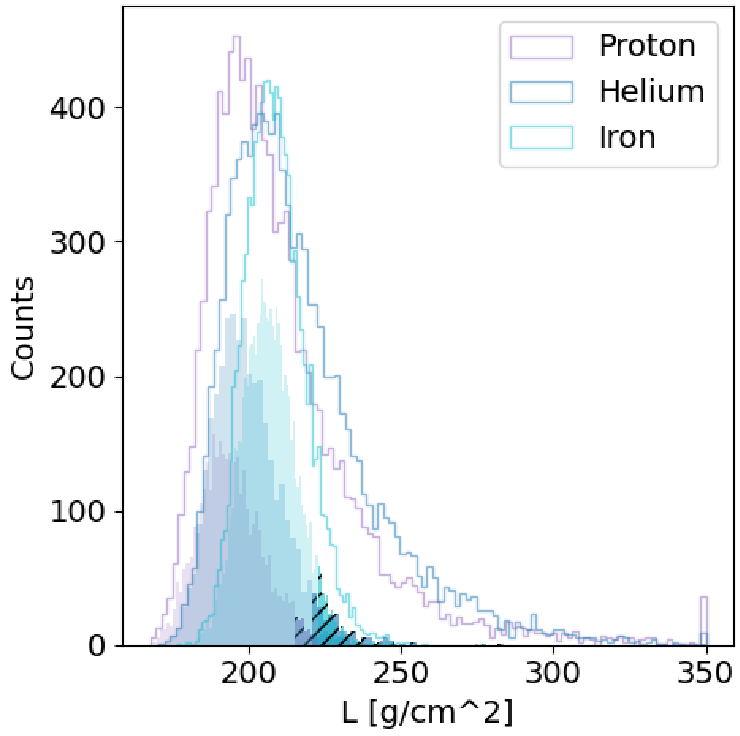
BASIC SHOWERS

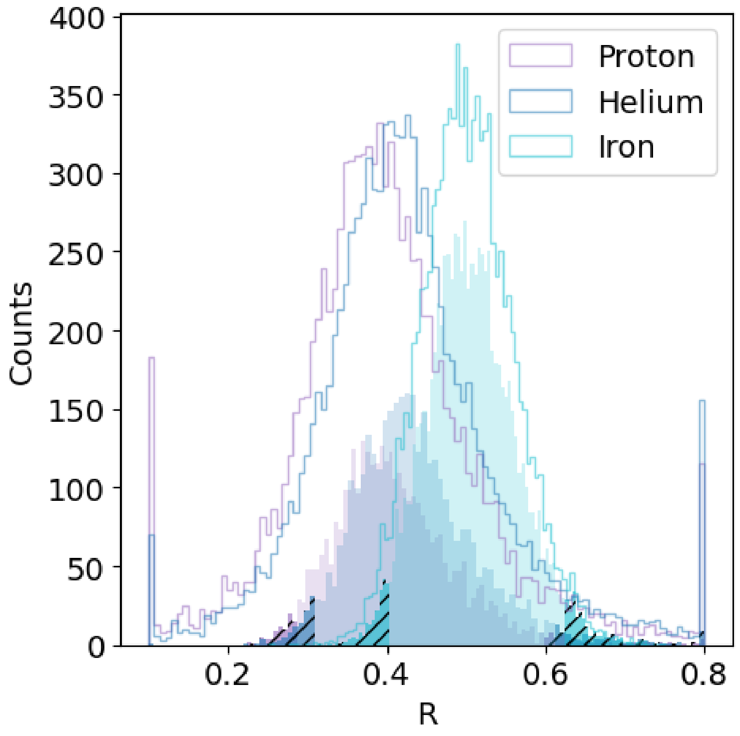
For L we take the [0, 0.95] after the cut while for R [0.025, 0.975].
Removing outliers.

$$\sum_{skeletons} E_i > 0.3\ E_{primary}$$
$$at\ X > 0.3\ X_{max}$$

Ensuring the data set
Is only basic showers.

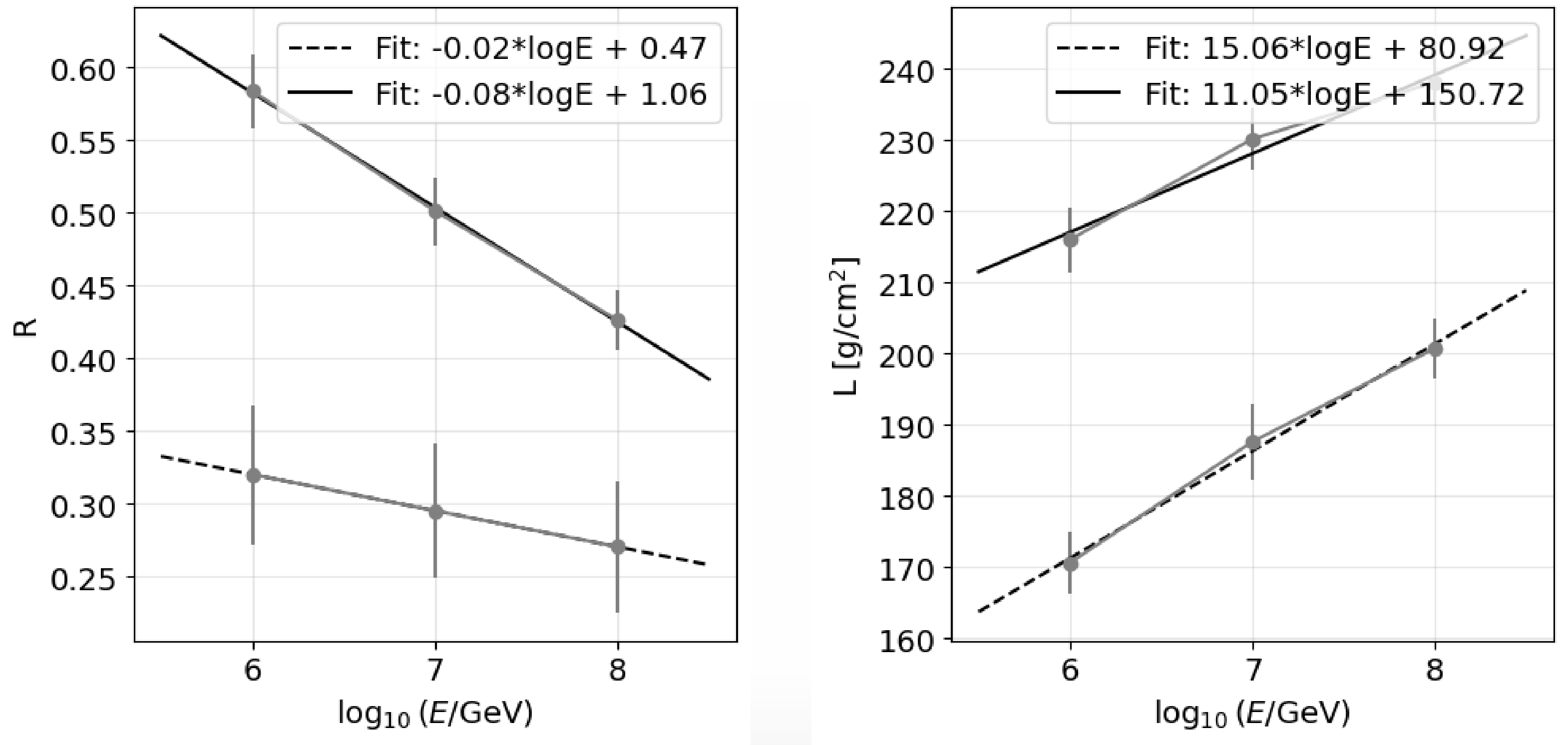
10^6 GeV
QGSJETIII





BASIC SHOWERS

Average over all models and primaries at a given energy.
Generalise to all energies using a linear fit.



DEFINITIONS

Bounds: $[N_{max}, X_{max}, R, L]$

Fit every shower 4 times:

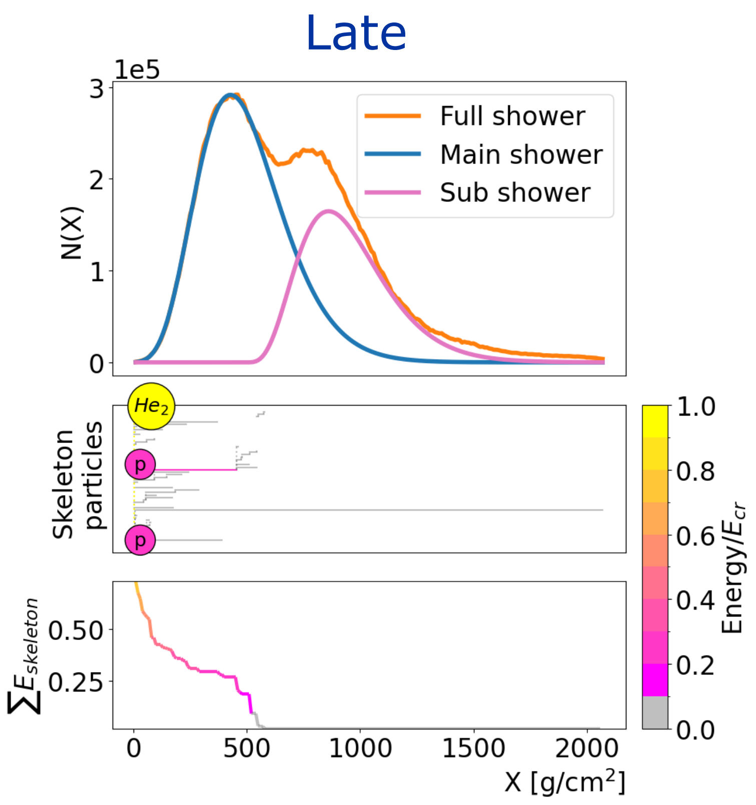
- Normal Giasser Hillas
- Restricted Giasser Hillas
- Double normal Giasser Hillas
- Double restricted Giasser Hillas

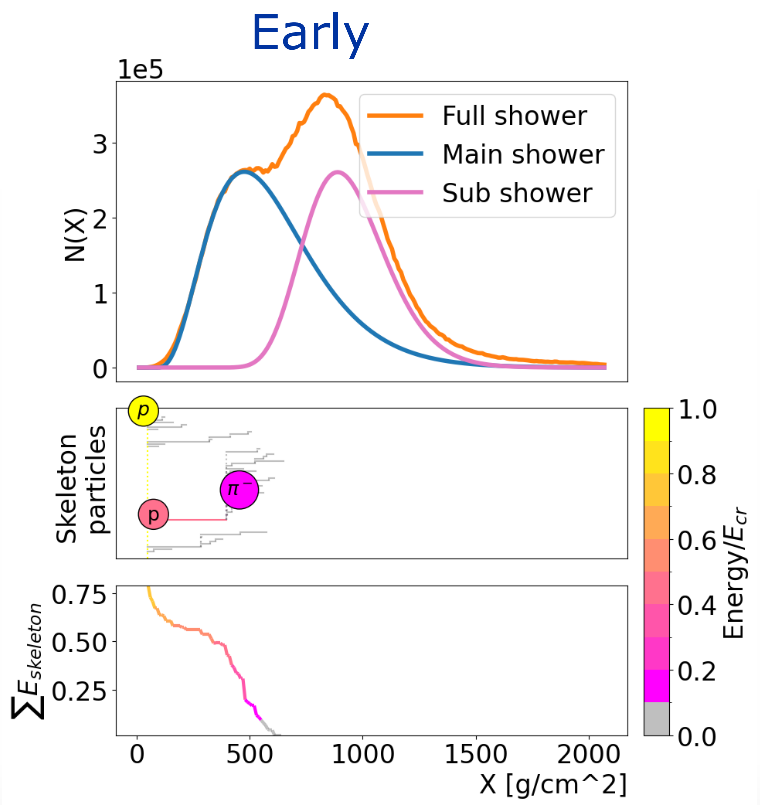
Normal:
Lower: $[0.1\ N_{max}, X_{min}, 0.1, 100]$
Upper: $[N_{max}, X_{max}, 0.8, 350]$

Restricted:
Lower: $[0.1\ N_{max}, X_{min}, R_{min}, L_{min}]$
Upper: $[N_{max}, X_{max}, R_{max}, L_{max}]$

DOUBLE BUMP SHOWERS

Using AIC method an unrestricted double Giasser Hillas fit is better than single.

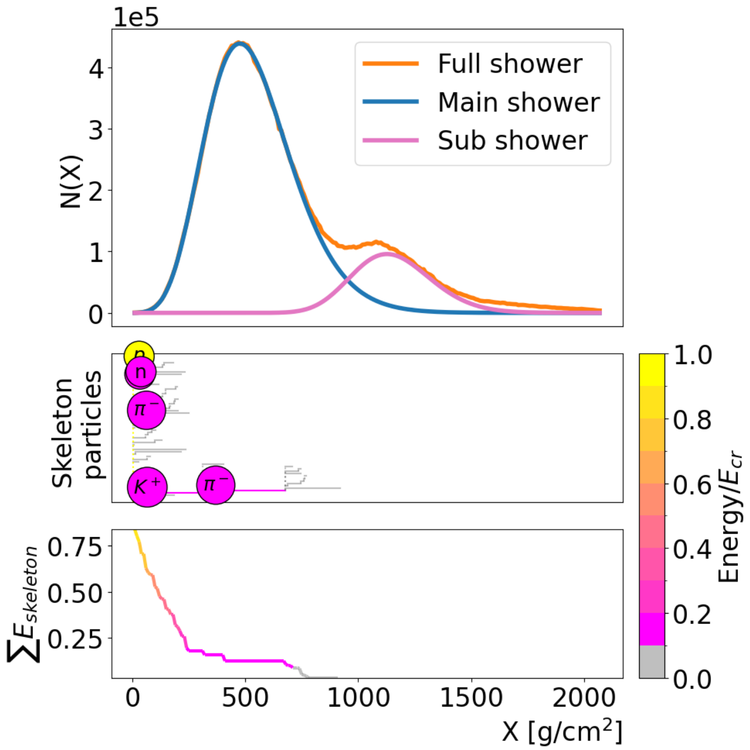




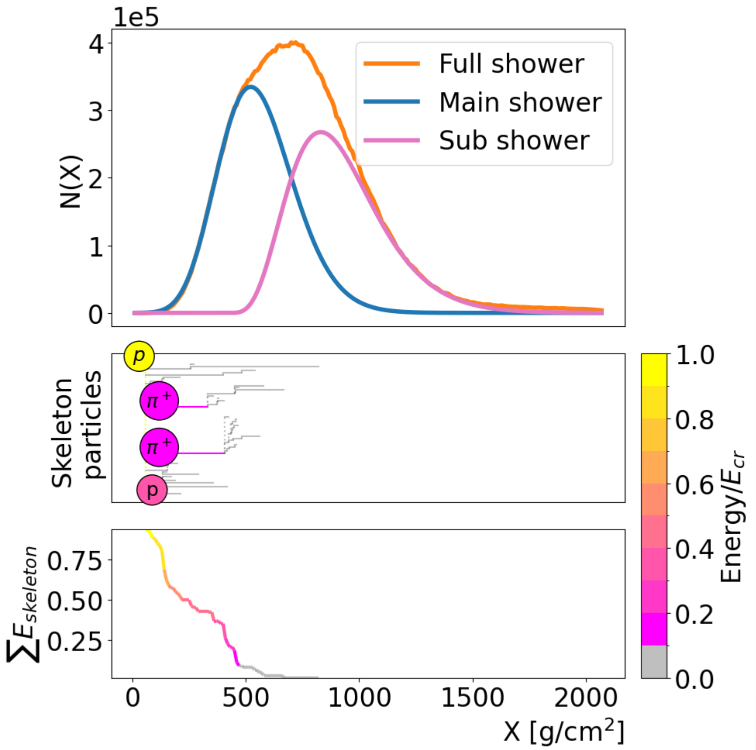
DOUBLE BUMP SHOWERS

Things aren't always simple.
We can find 2 extra causes of double bump showers.

Ladder

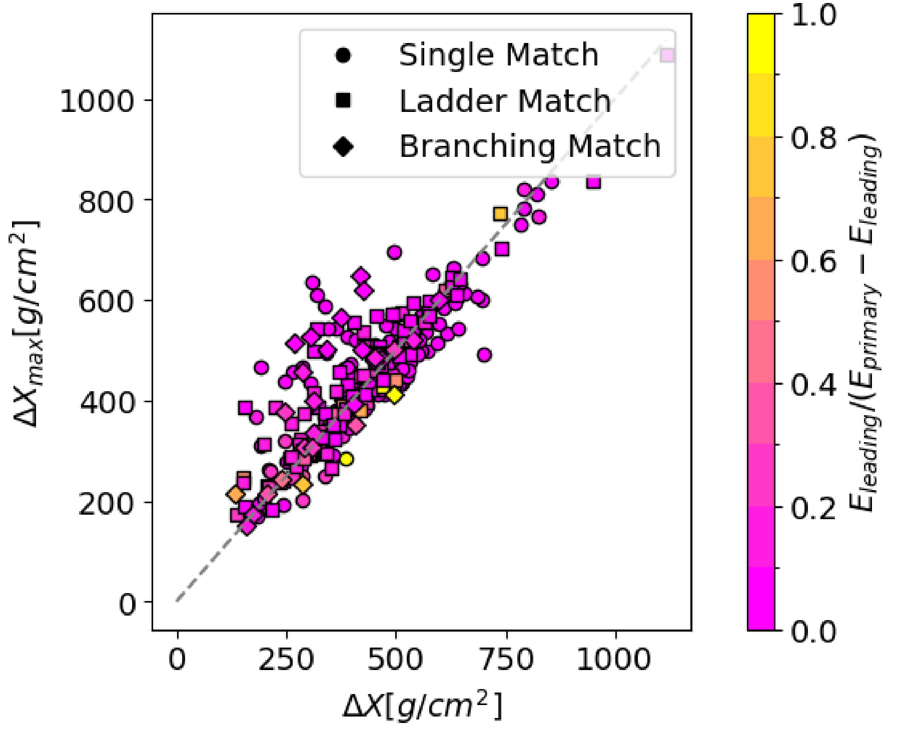


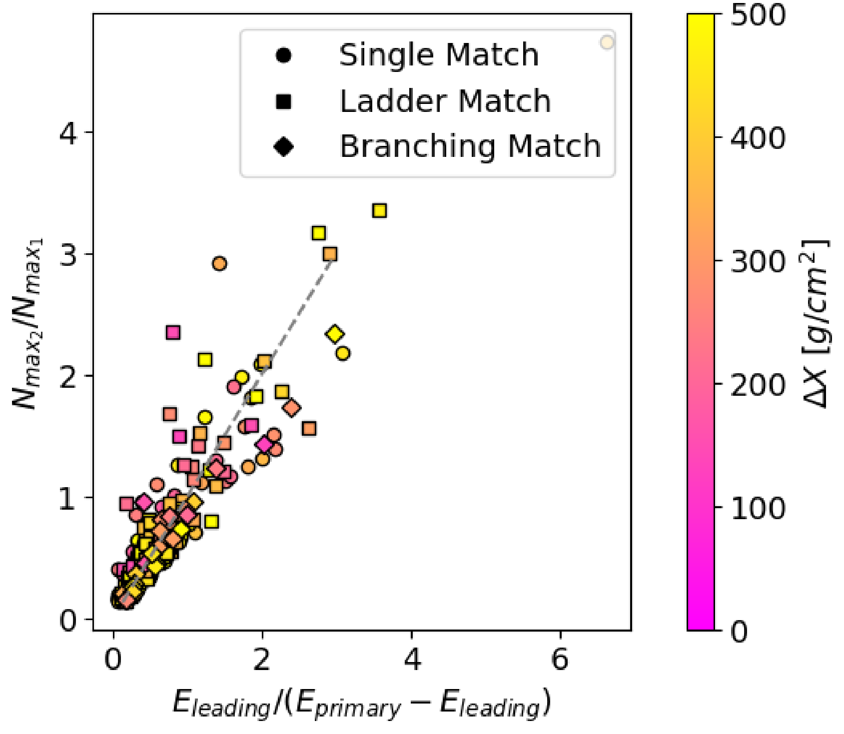
Branch



DOUBLE BUMP SHOWERS

Important test, almost all DB showers (0.95) can be refitted with 10%.
The Single/Ladder/Branch ratio is constant.





10^6 GeV
QGSJETIII

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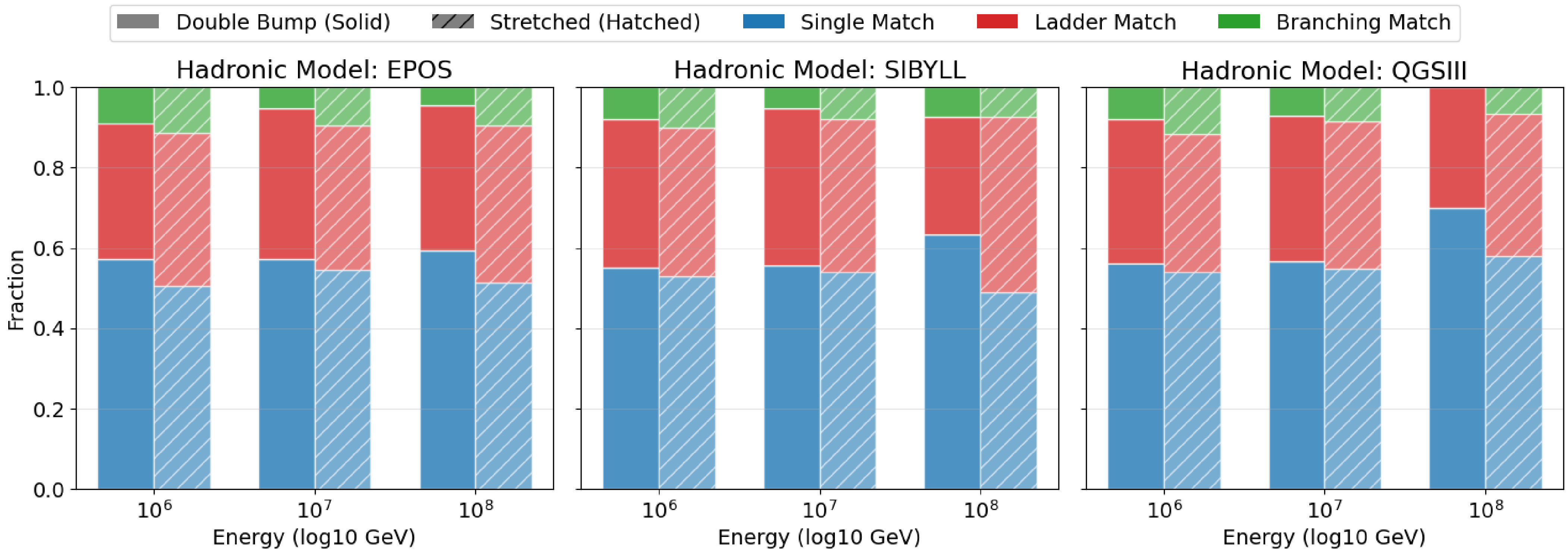
DOUBLE BUMP SHOWERS



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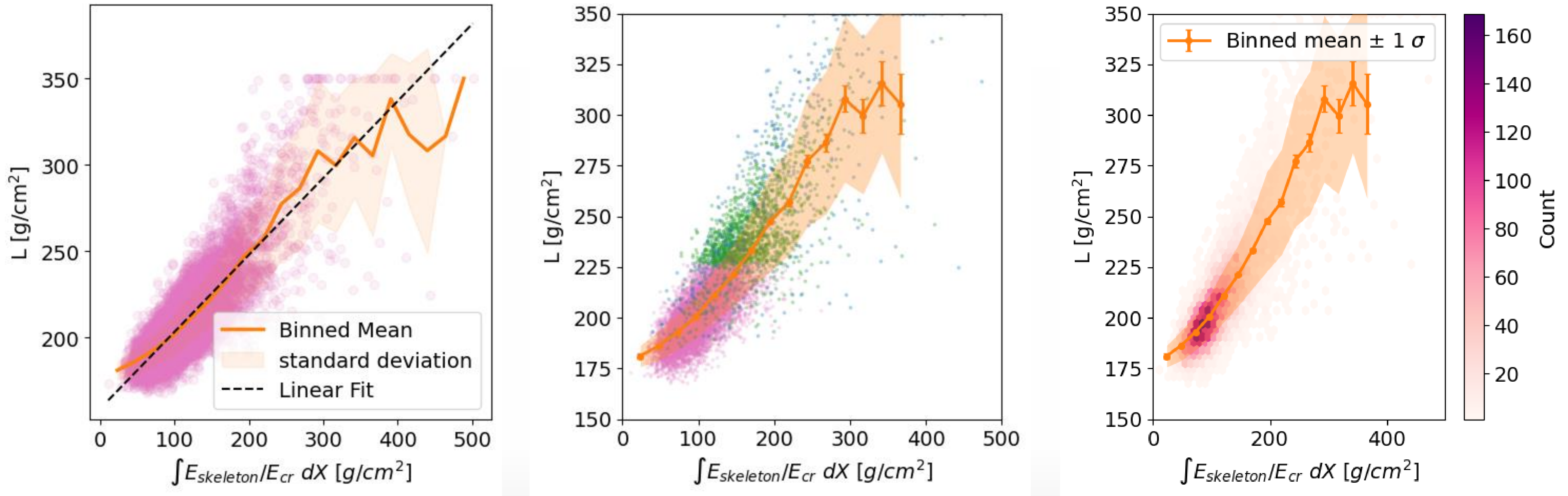
STRETCHED SHOWERS

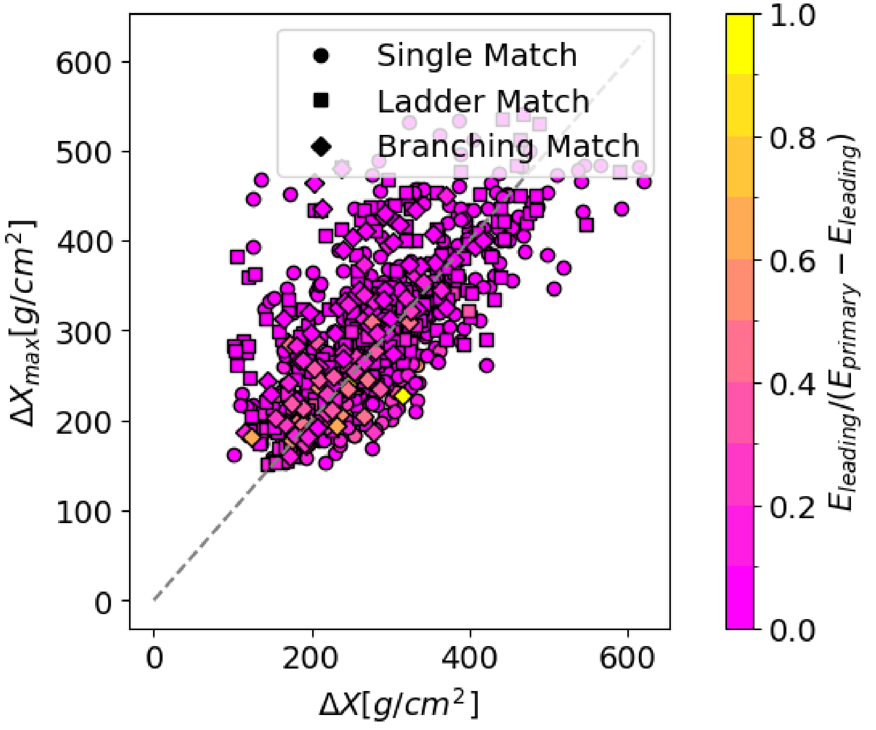
Stretched showers are caused by the gradual energy deposit of the skeleton particles into lower energy particles.

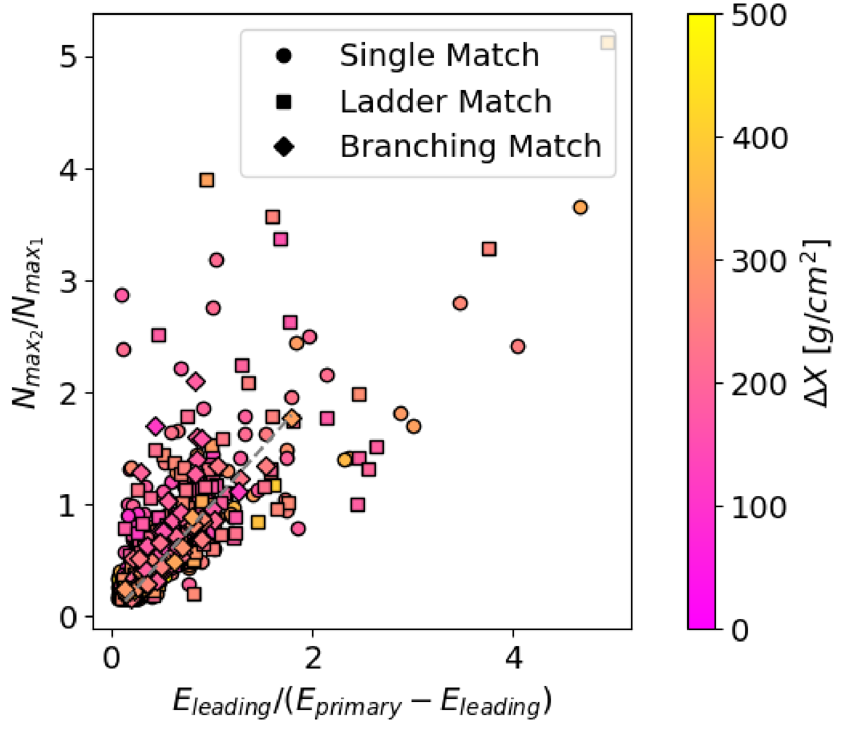
10^6 GeV
QGSJETIII



STRETCHED SHOWERS

The classification does not work.
A few particles are unable to explain the structure.





10^6 GeV
QGSJETIII

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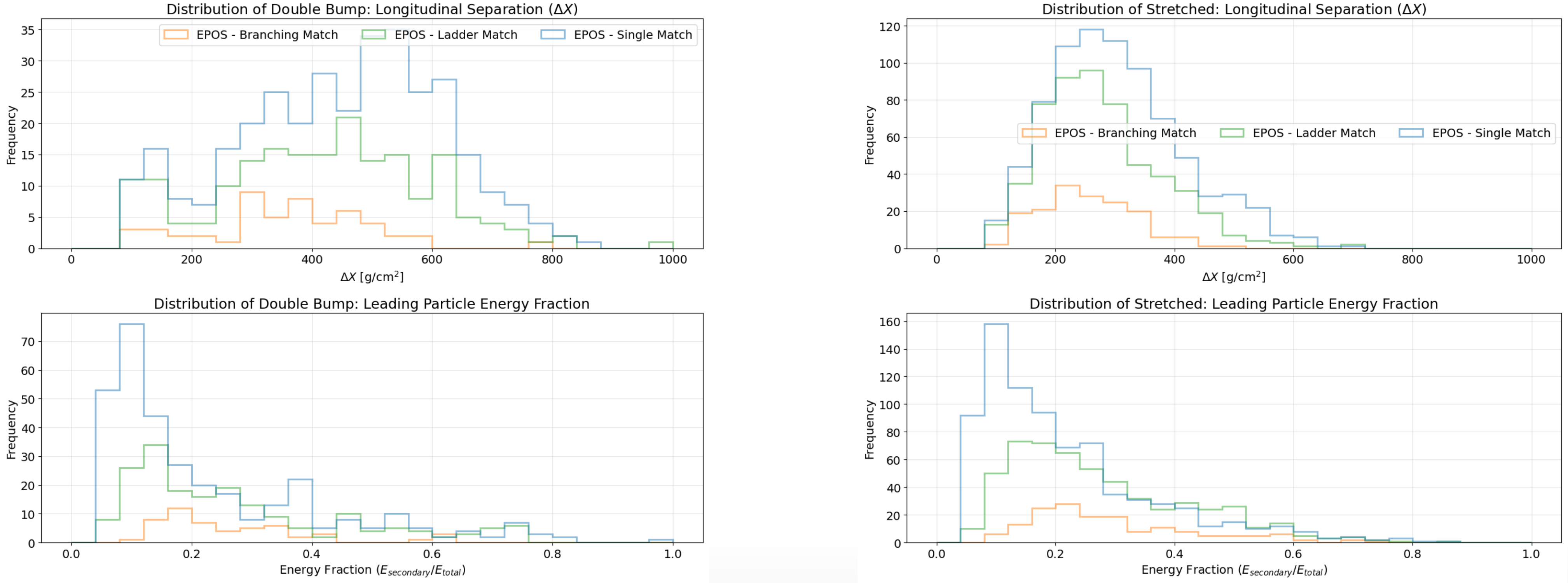
COMPARING BOTH

10^6 GeV
Proton



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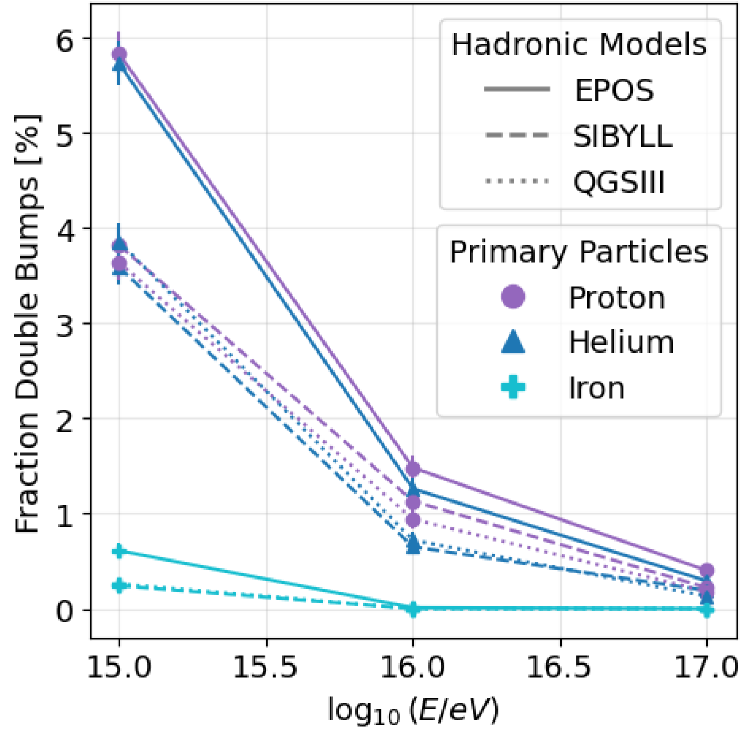
ANALYSIS

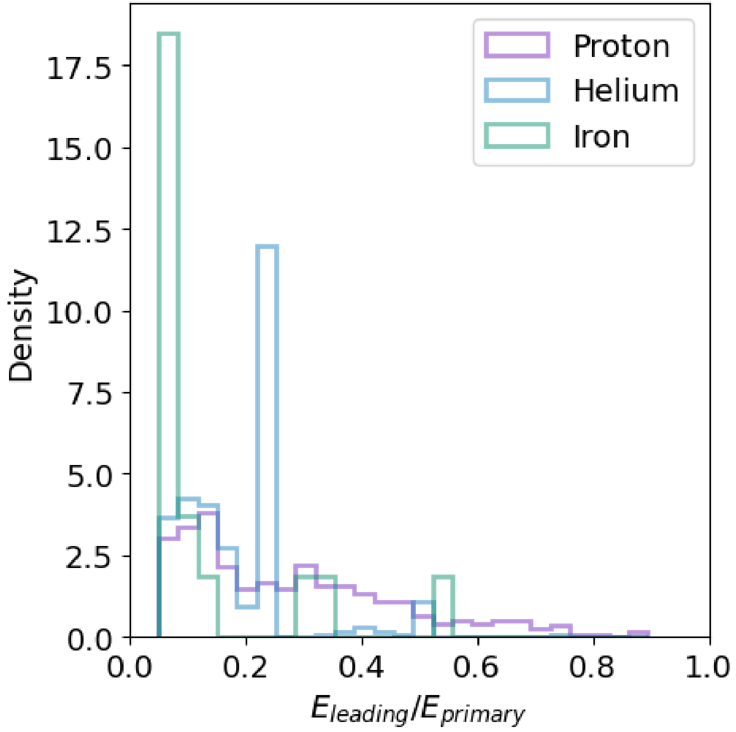
DOUBLE BUMP SHOWERS

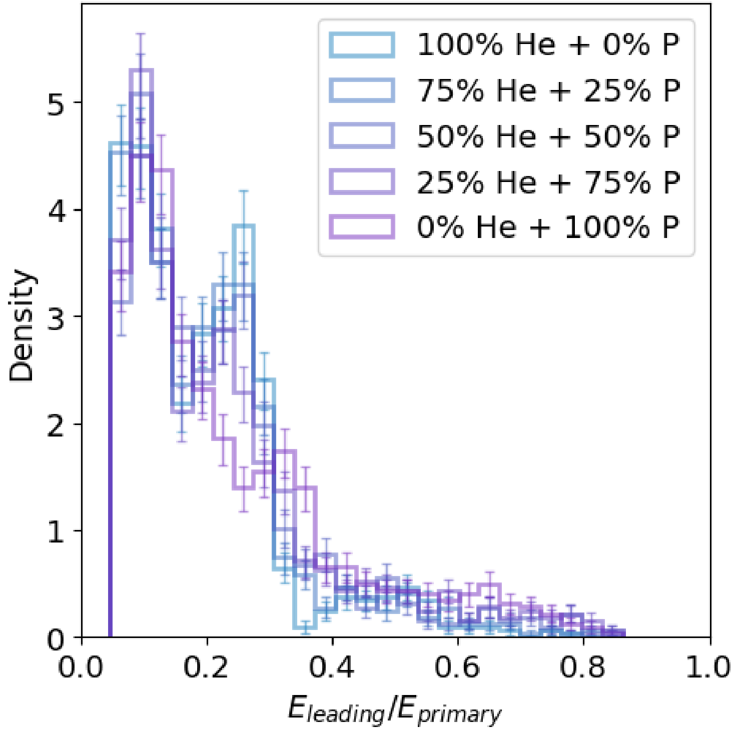
The fraction of double bumps goes down with energy.
Heavier elements have less double bumps.
The total amount of double bumps depends on the hadronic model.



DOUBLE BUMP SHOWERS

Due to nuclear fragmentation we get a unique Helium signature.
A nucleon with 25% of the energy travels a significant distance.
Unlikely for Proton.





10^6 GeV
QGSJETIII

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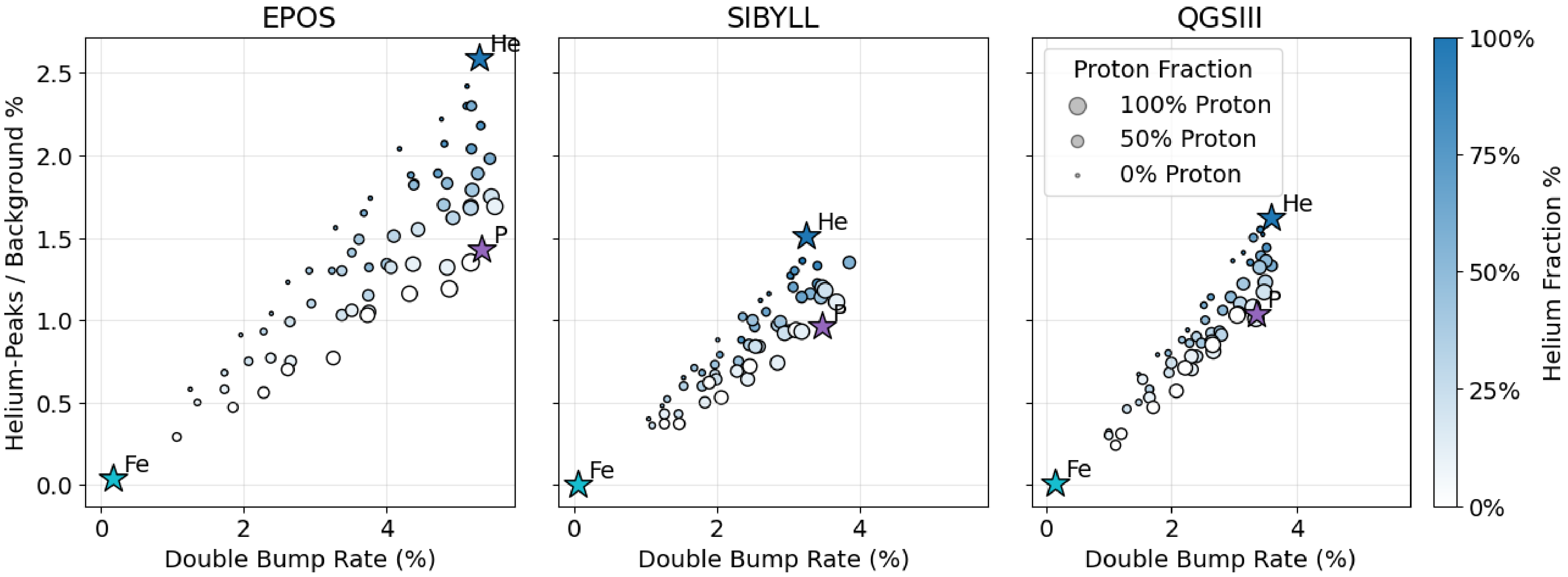
DOUBLE BUMP SHOWERS

We use the double bump fraction to separate heavy and light elements.
We use the 'Helium peak' to separate Proton and Helium.

Every dot is a mass composition Model with 10^4 showers.
Jump between model is 10%.

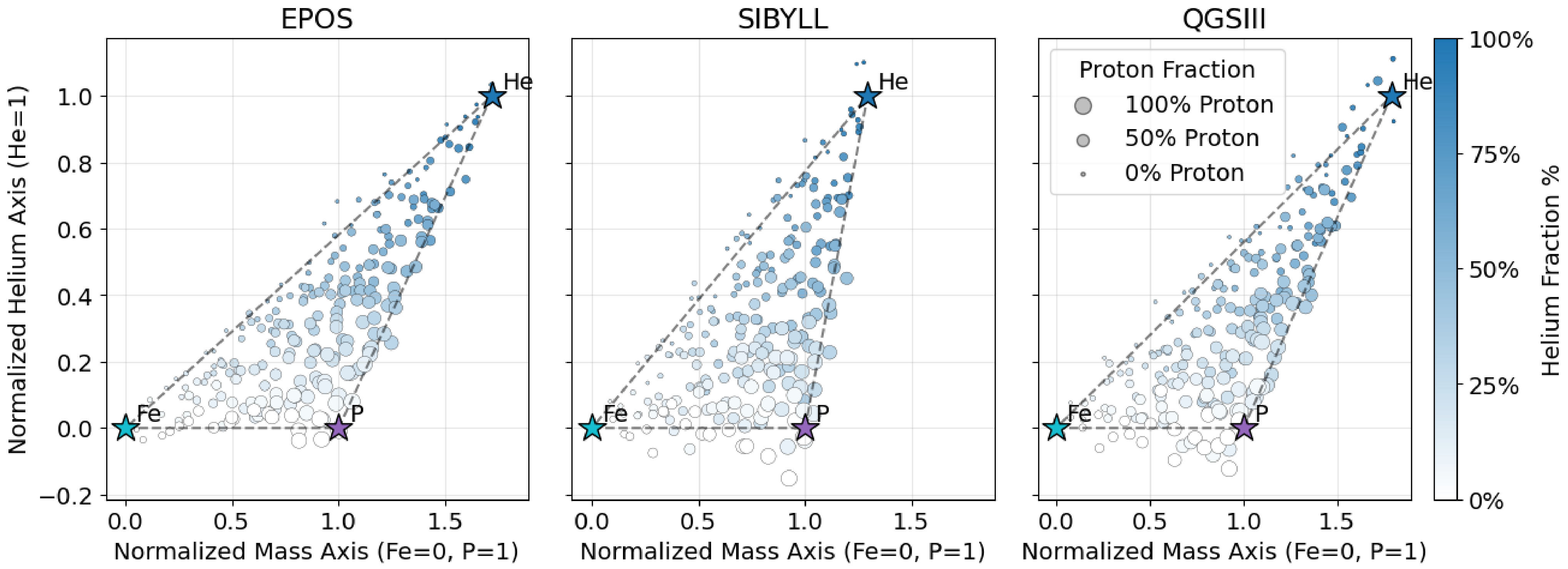


10^6 GeV
QGSJETIII

DOUBLE BUMP SHOWERS

To remove the hadronic interaction models influence we normalize the triangle.
The Helium sensitive parameter is now the ’y’ value of a measurement.

Every dot is a mass composition Model with 10^4 showers.
Jump between model is 5%.

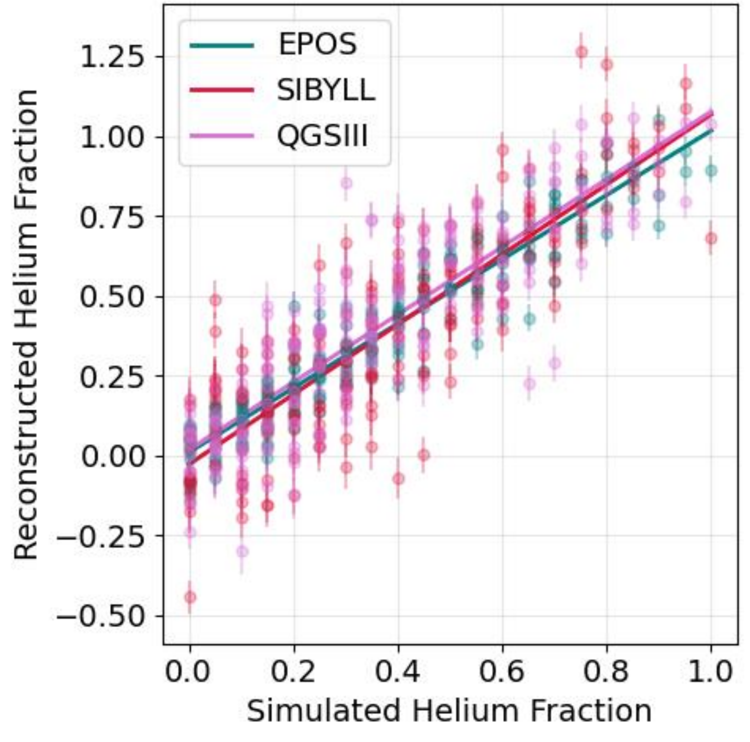


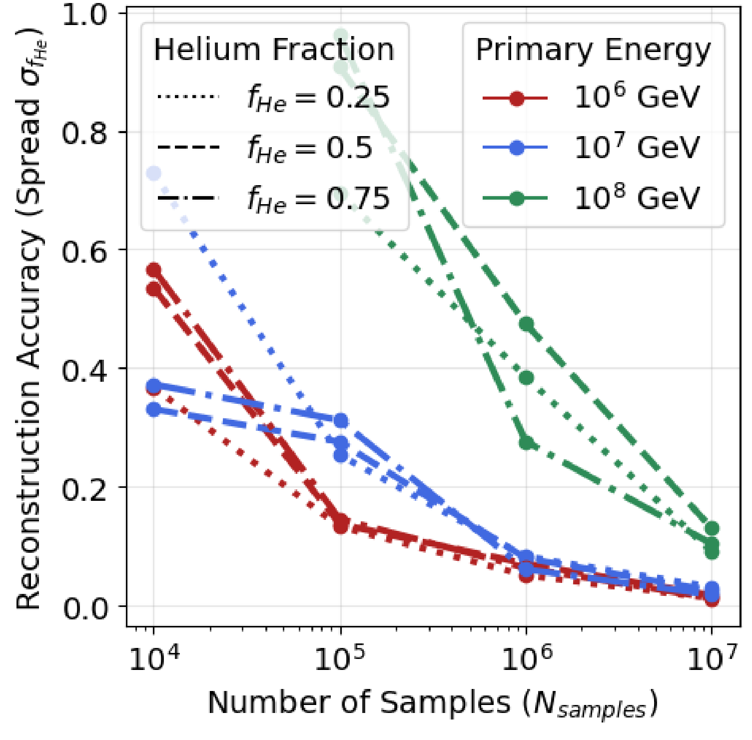
10^6 GeV
QGSJETIII

DOUBLE BUMP SHOWERS

We see no trend between hadronic models.
The accuracy is defined as the biggest difference for a given simulated Helium fraction.

Every dot is a mass composition Model with 10^4 showers.
Jump between model is 5%.



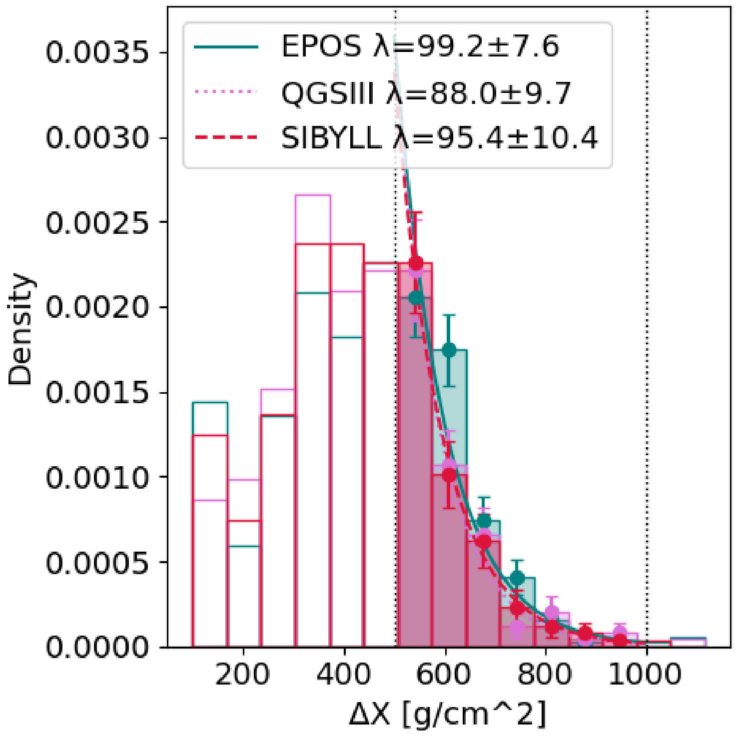


10^6 GeV
QGSJETIII

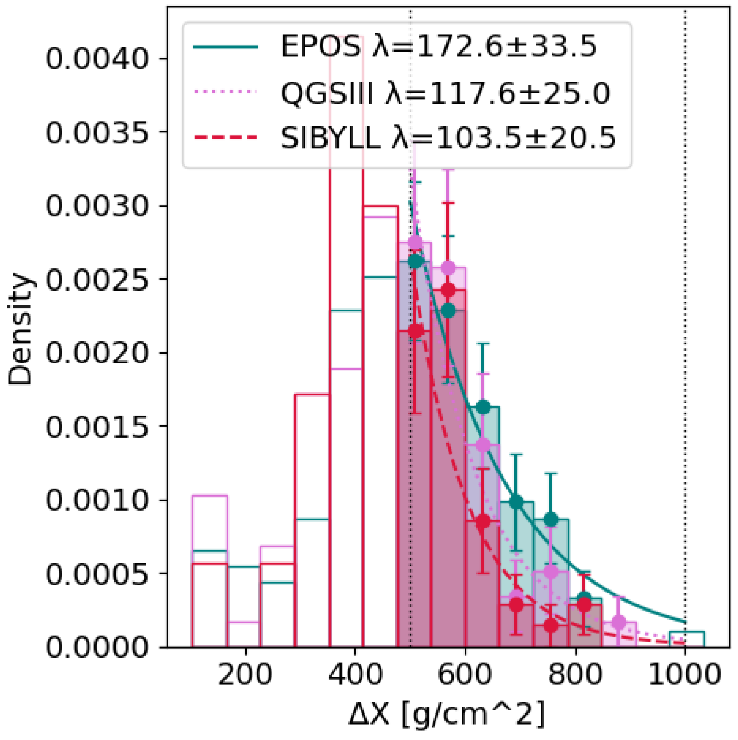
DOUBLE BUMP SHOWERS

When looking at double bump dominated section we can fit an exponential decay.
We can only look at $\Delta X > 500$ because other wise stretched showers.

10^6 GeV



10^7 GeV



Proton

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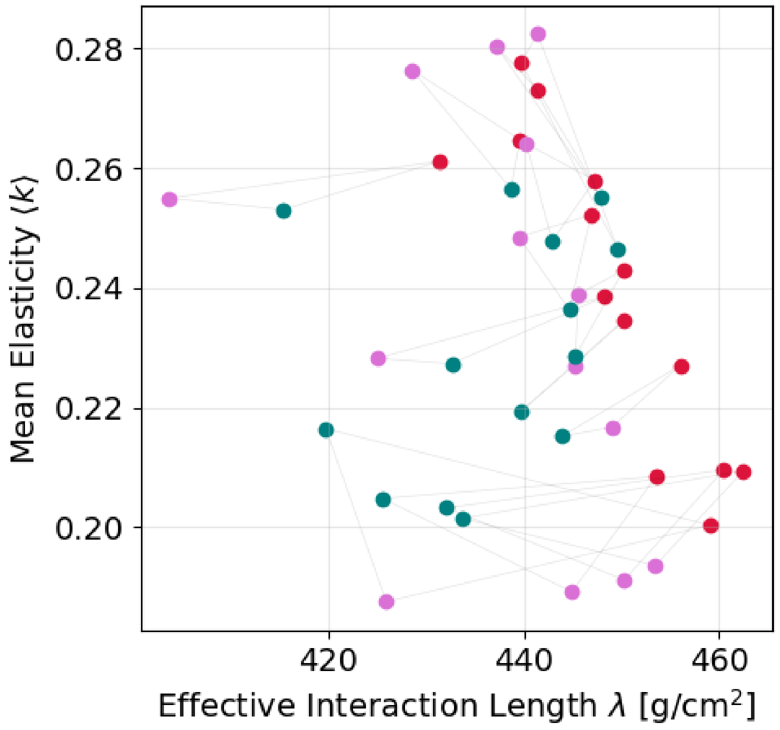
DOUBLE BUMP SHOWERS

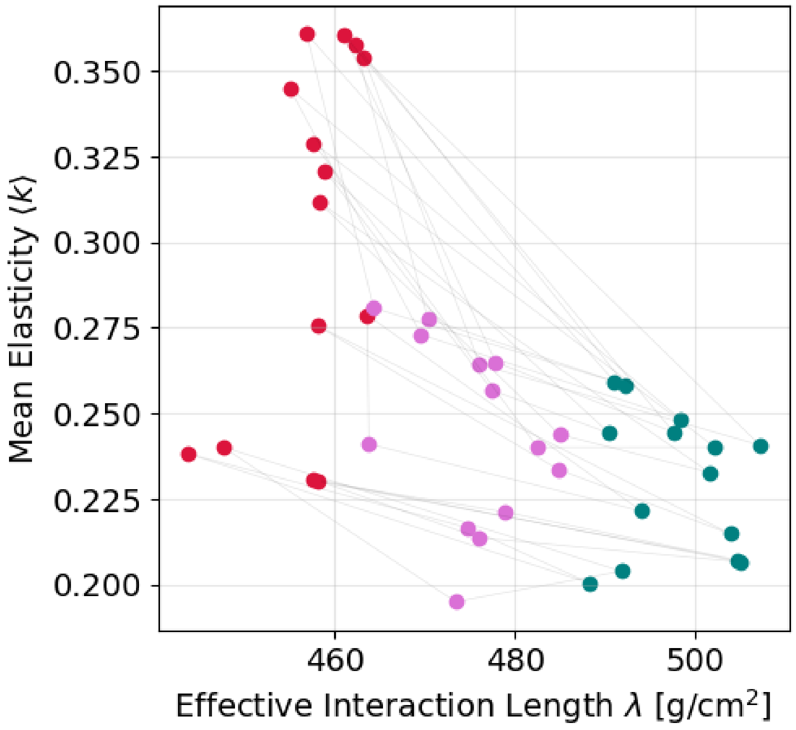
To consider all the double bumps use the mean interaction length.
Connecting lines are the same mass composition model.

Every dot is a mass composition Model with 10^5 showers.
Jump between model is 25%.

10^6 GeV



10^7 GeV



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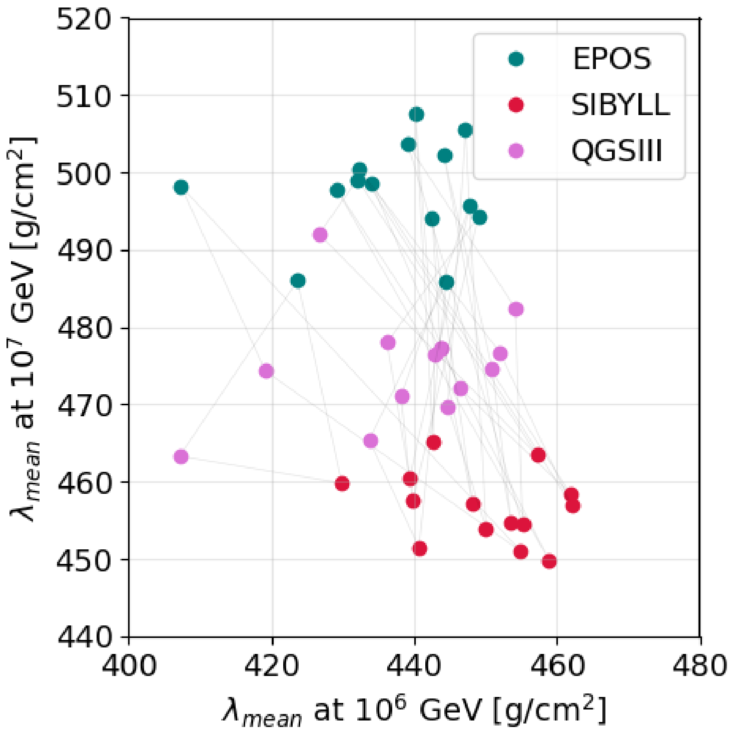
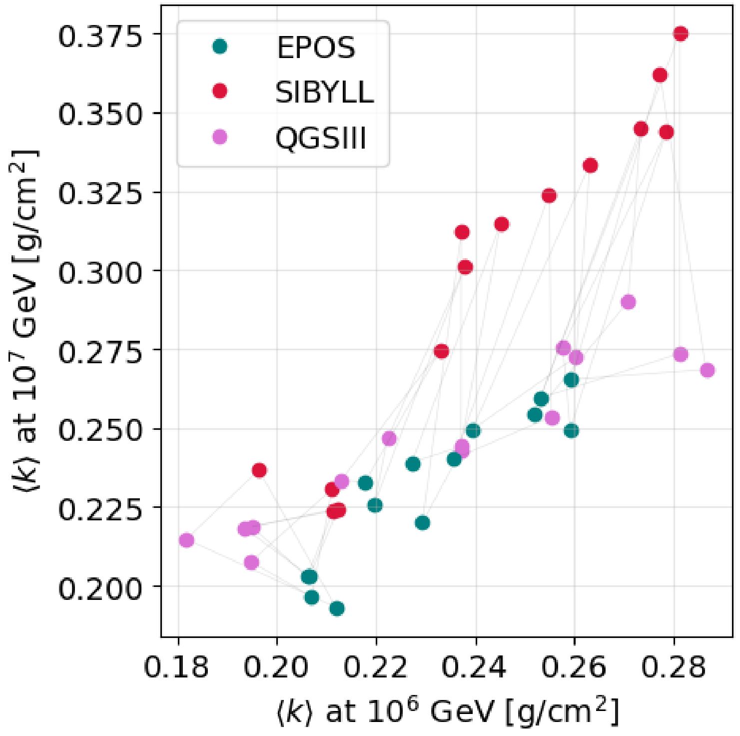
DOUBLE BUMP SHOWERS

We can test the evolution of the parameters in terms of energy.
And we see a cleaner separation.

Every dot is a mass composition Model with 10^5 showers.
Jump between model is 25%.

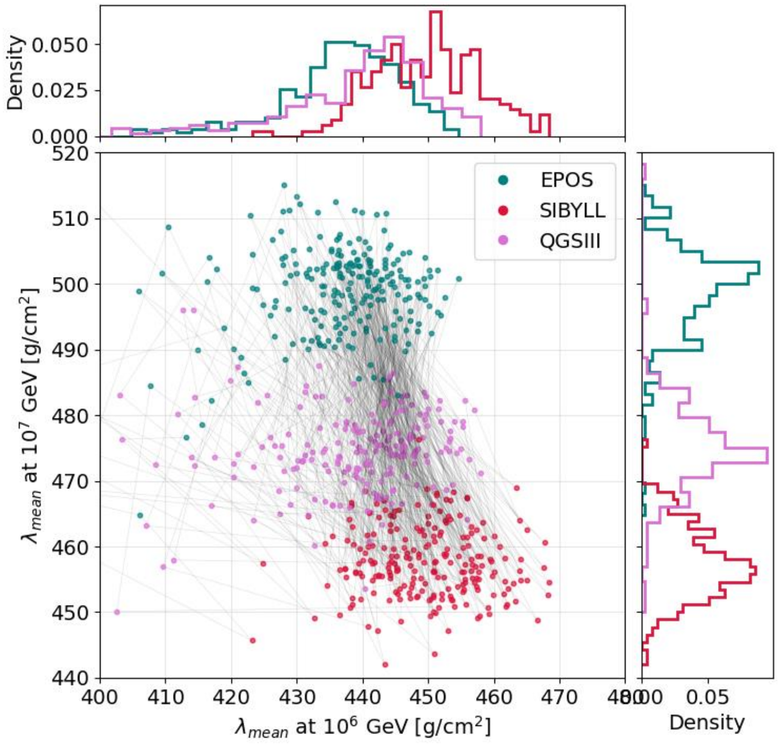


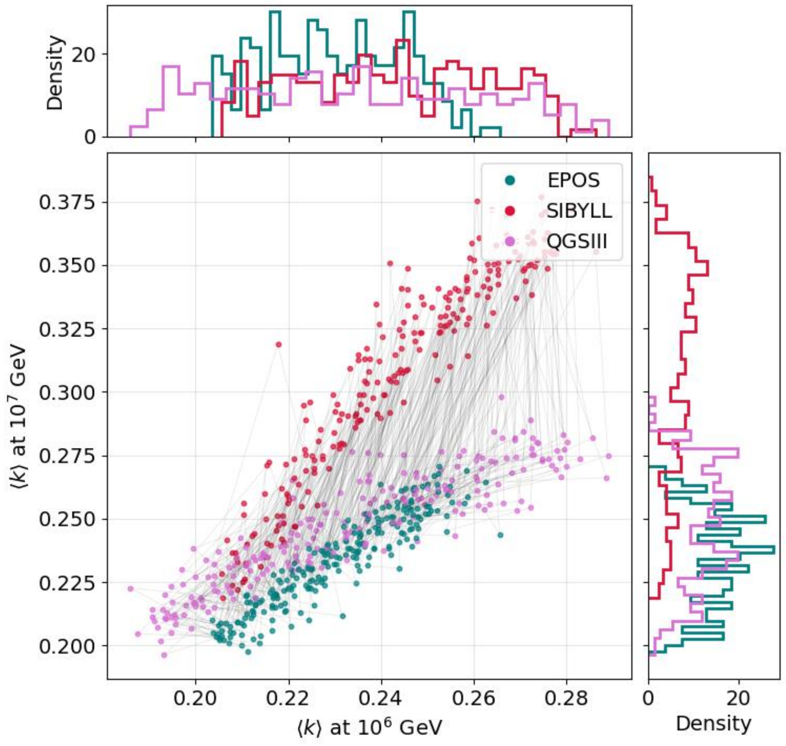


DOUBLE BUMP SHOWERS

By looking at higher energies the mean interaction length is a good separator for all models. When it comes mean elasticity SIBYLL is elongated.

Every dot is a mass composition Model with 10^5 showers.
Jump between model is 5%.





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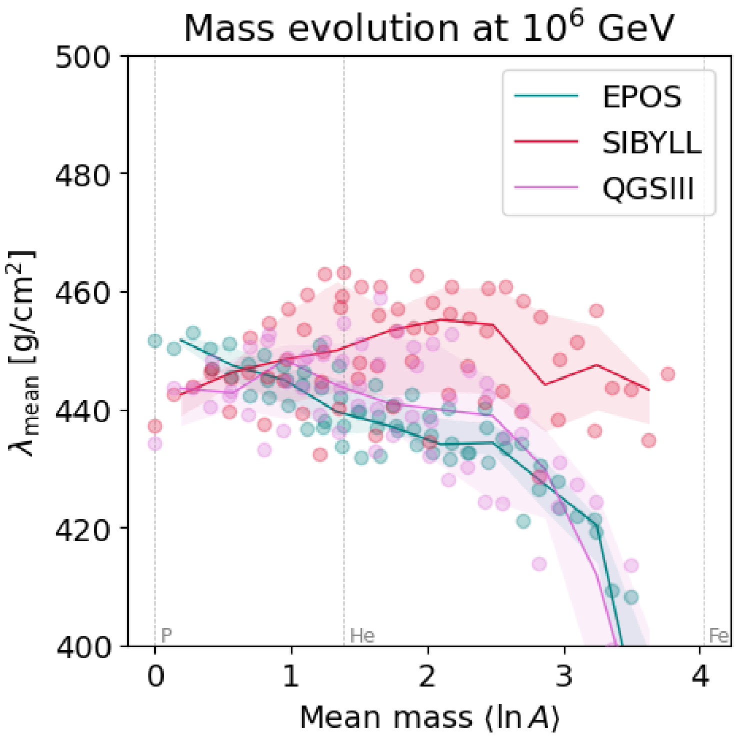
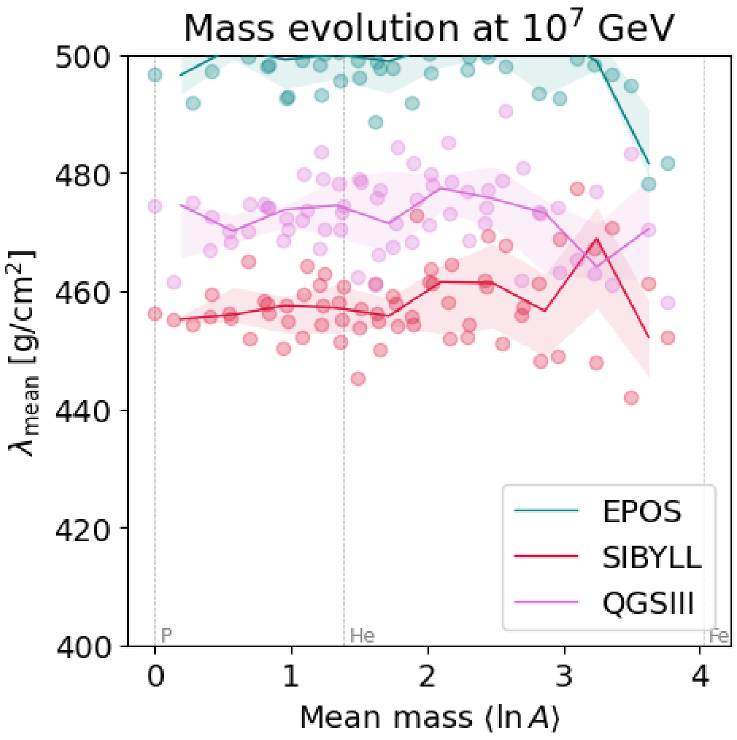
DOUBLE BUMP SHOWERS

We can look at the mass evolution. Where at 10^7 GeV we see a clean separation Independent of the primary.

Every dot is a mass composition Model with 10^5 showers.
Jump between model is 10%.





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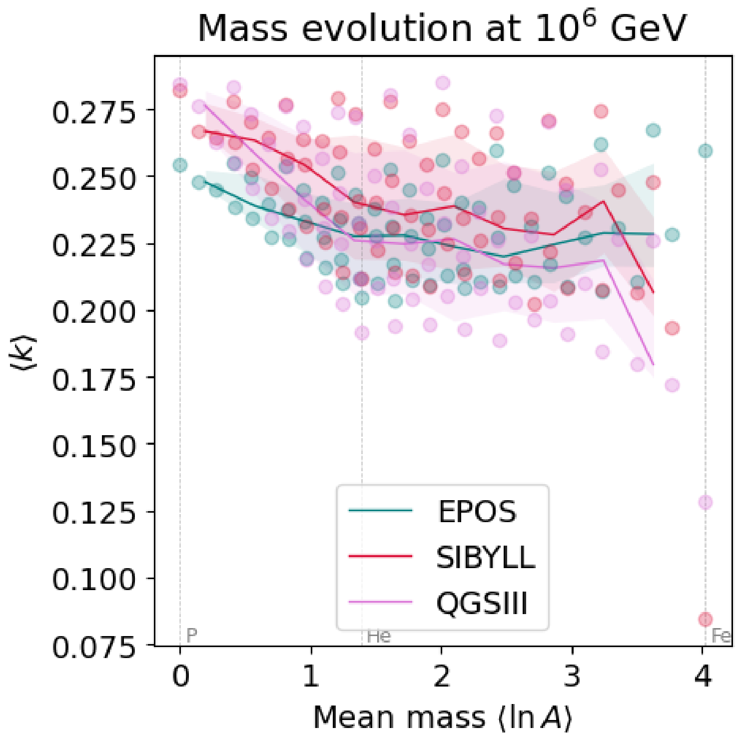
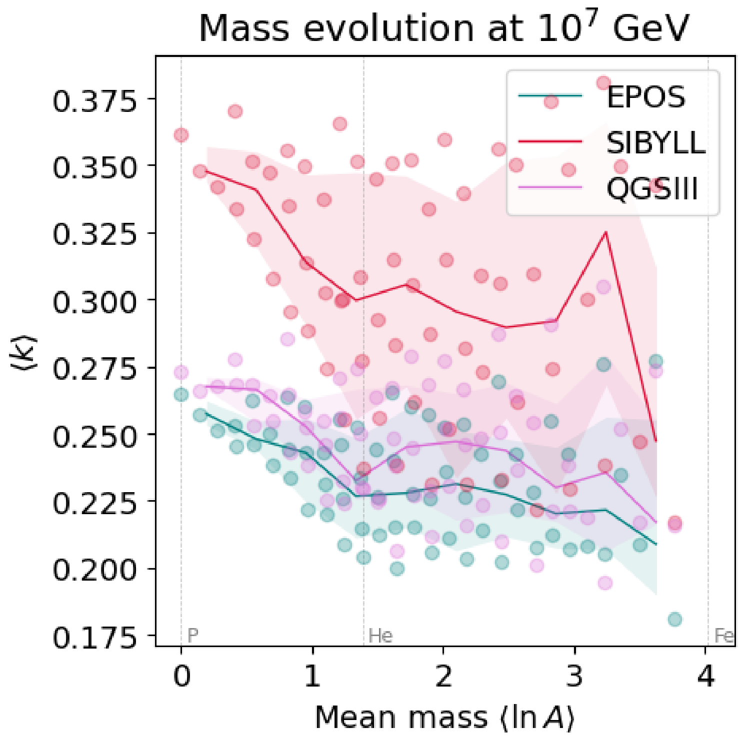
DOUBLE BUMP SHOWERS

We can look at the mass evolution. At 10^7 we see the broad spread for SIBYLL.

Every dot is a mass composition Model with 10^5 showers.
Jump between model is 10%.





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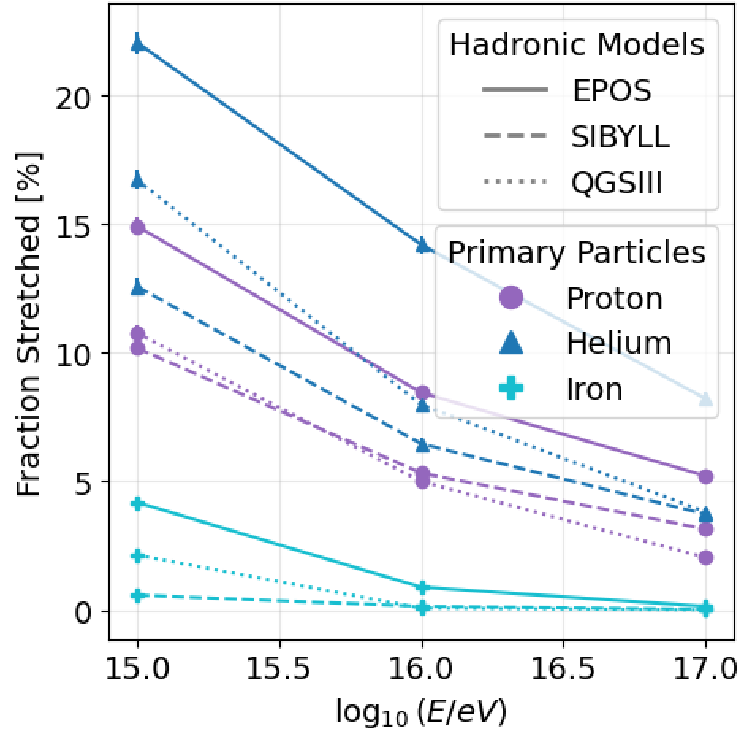
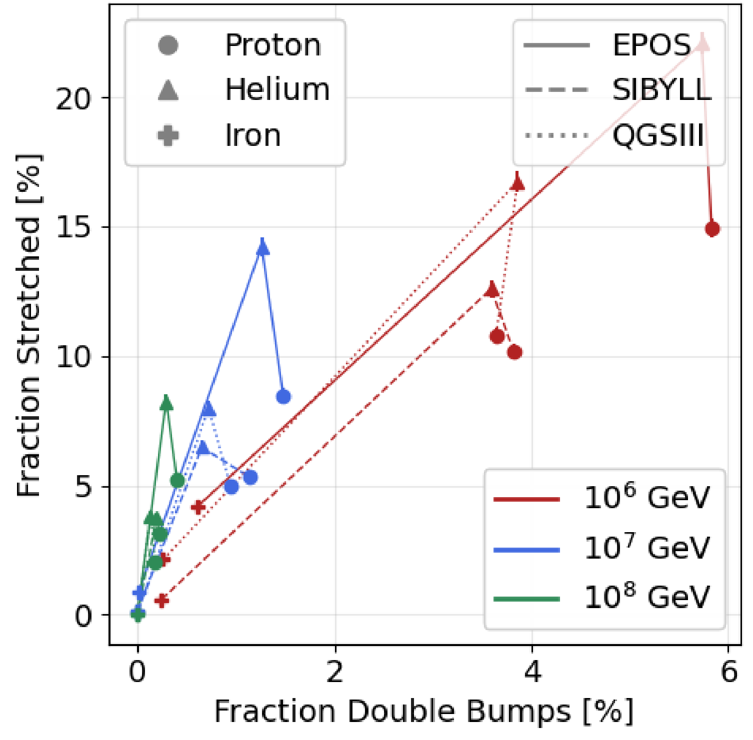
STRETCHED SHOWERS

Stretched showers occur an order of magnitude more offend.
Proton clearly doing something strange (nuclear fragmentation).





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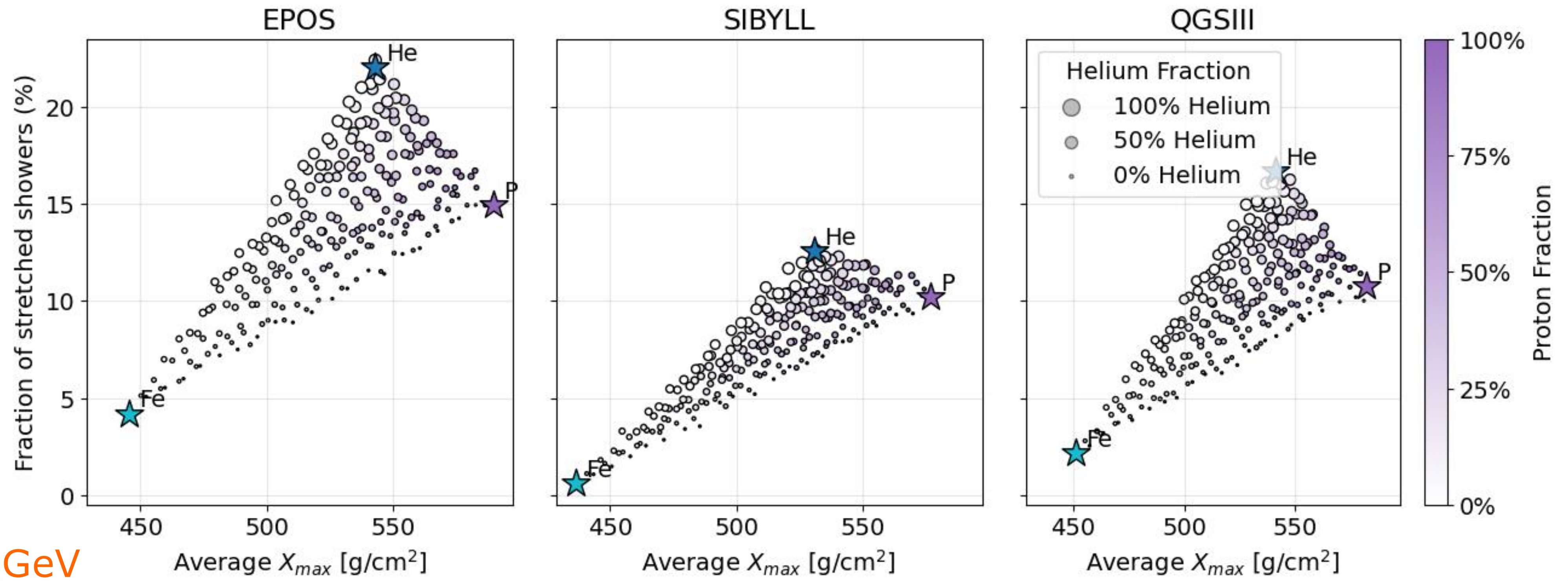
STRETCHED SHOWERS

We can use X_max to separate heavy and light elements.
We then use the fraction of stretched showers to separate Proton and Helium.



10^6 GeV

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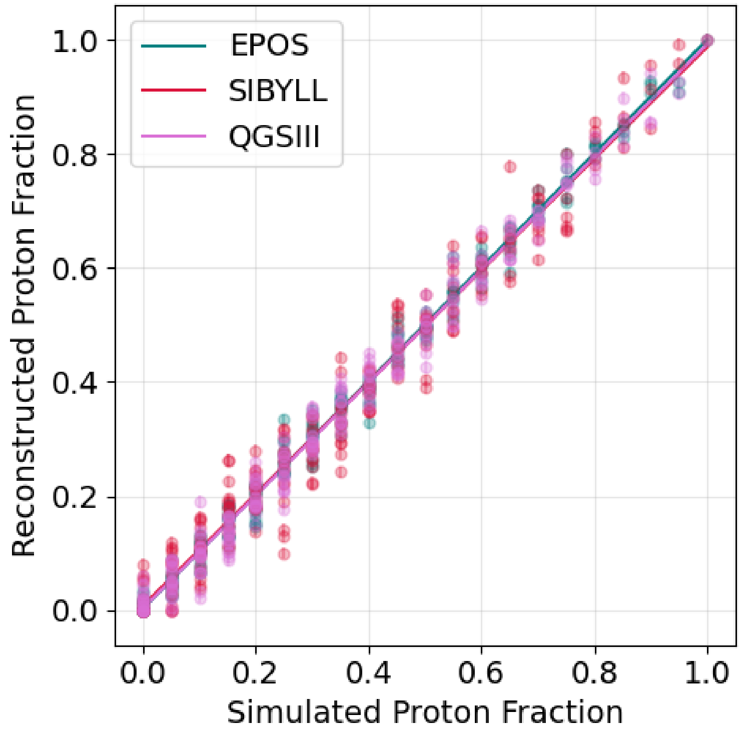
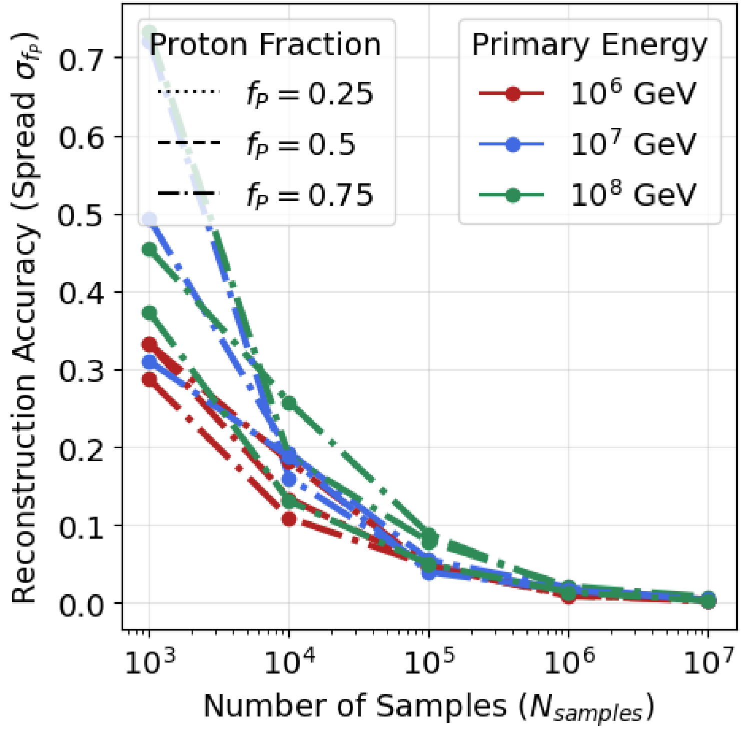
STRETCHED SHOWERS

We see no trend between hadronic models.
The accuracy is defined as the biggest difference for a given simulated Proton fraction.





10^6 GeV

TO-DO

I would like to find a way to use stretched showers for hadronic models stuff.

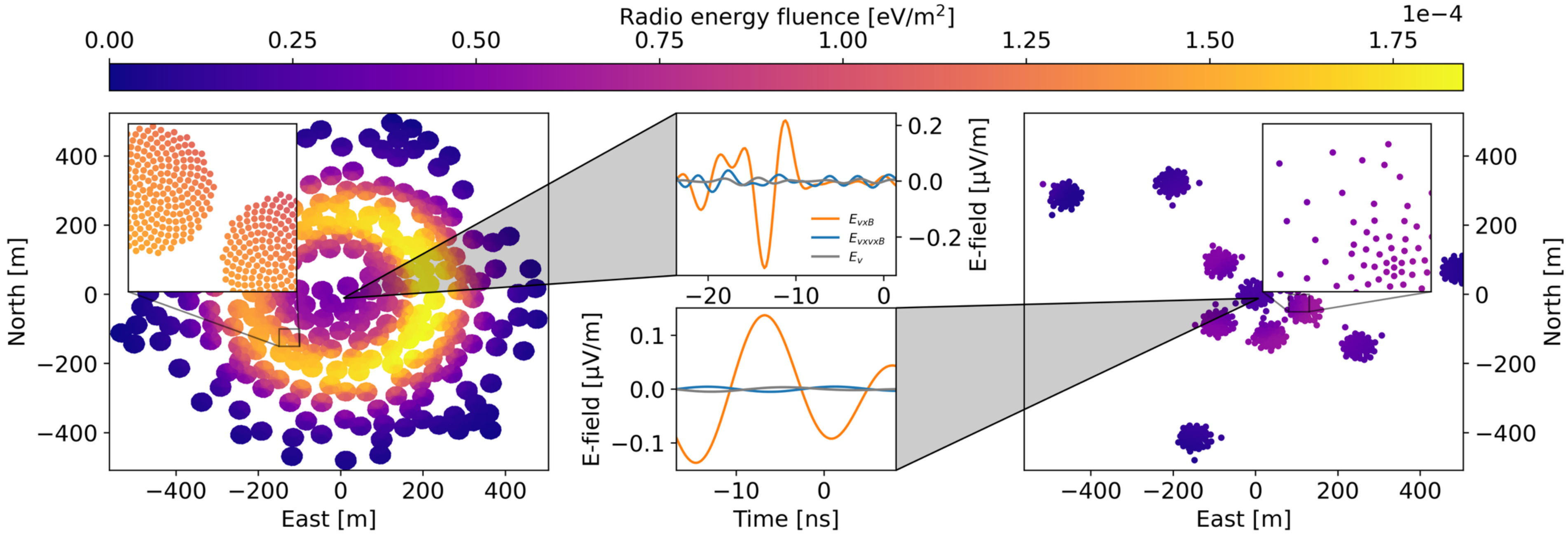
Finish paper?

THE RADIO PART

PAPER 2

FROM LOFAR TO SKA

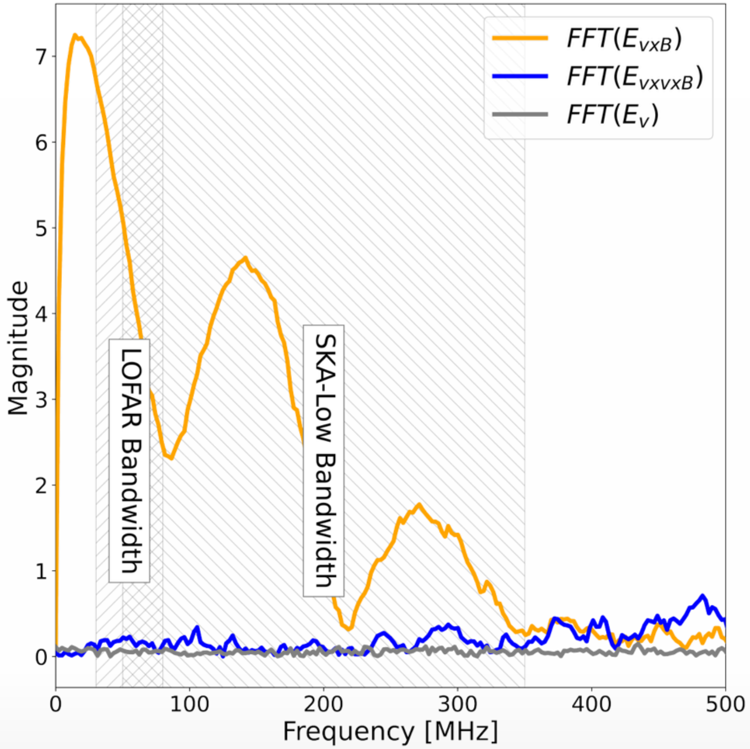
More antenna's!
More Bandwidth!
More fun?



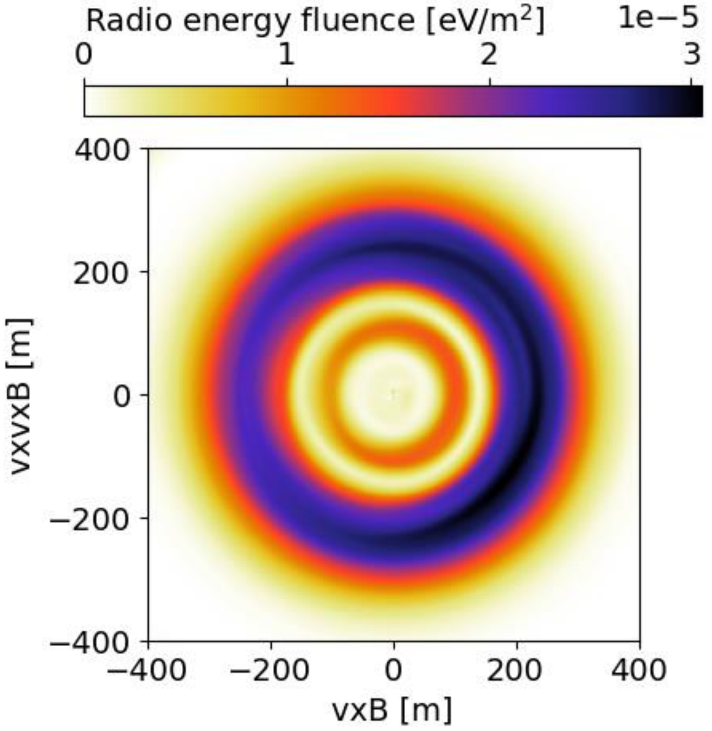
RADIO OF DB

Filtered: 200-250 MHz

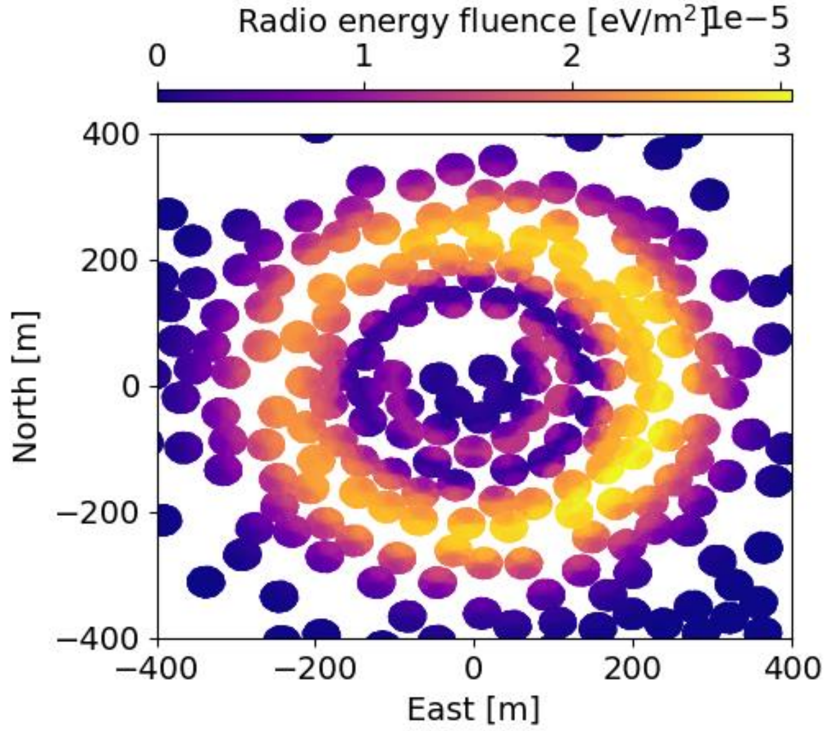
FFT in 1 antenna



Full radio footprint



SKA-simulated signal



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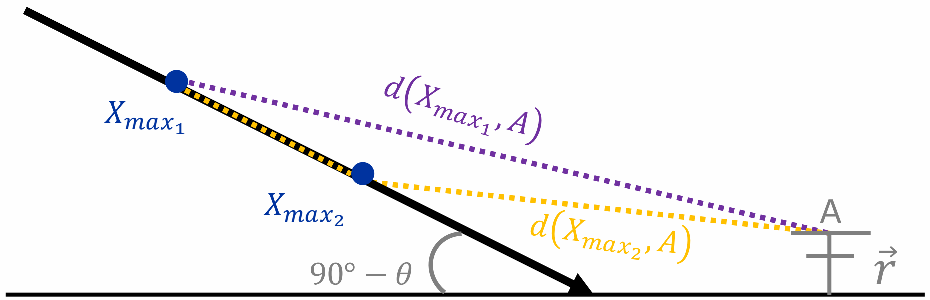
PREDICTING DESTR. INTERFERENCE

Using: θ, φ, X_{max_1}, X_{max_2}

Predict: $f_{destr.}(\vec{r})$



Time delay in an antenna:

Viewing 2 peaks as emitters

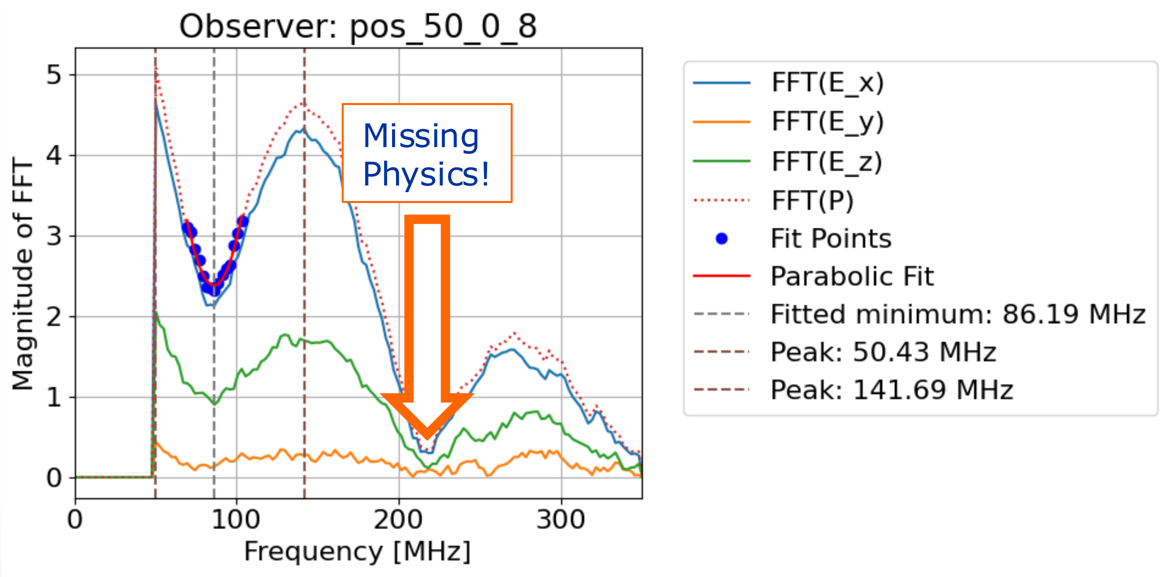
$$\begin{cases} \dfrac{d(X_{max_1}, A)}{c/n(h)} \\ \dfrac{d(X_{max_1}, X_{max_2})}{v} + \dfrac{d(X_{max_2}, A)}{c/n(h)} \end{cases}$$

Freq at which we get destr. Interference:

$$\Delta T(\vec{r}) = \frac{\Delta\phi}{\omega} \Rightarrow \begin{cases} \Delta\phi = 0 \; const. (mod\ 2\pi) \\ \Delta\phi = \pi \; destr. (mod\ 2\pi) \end{cases}$$

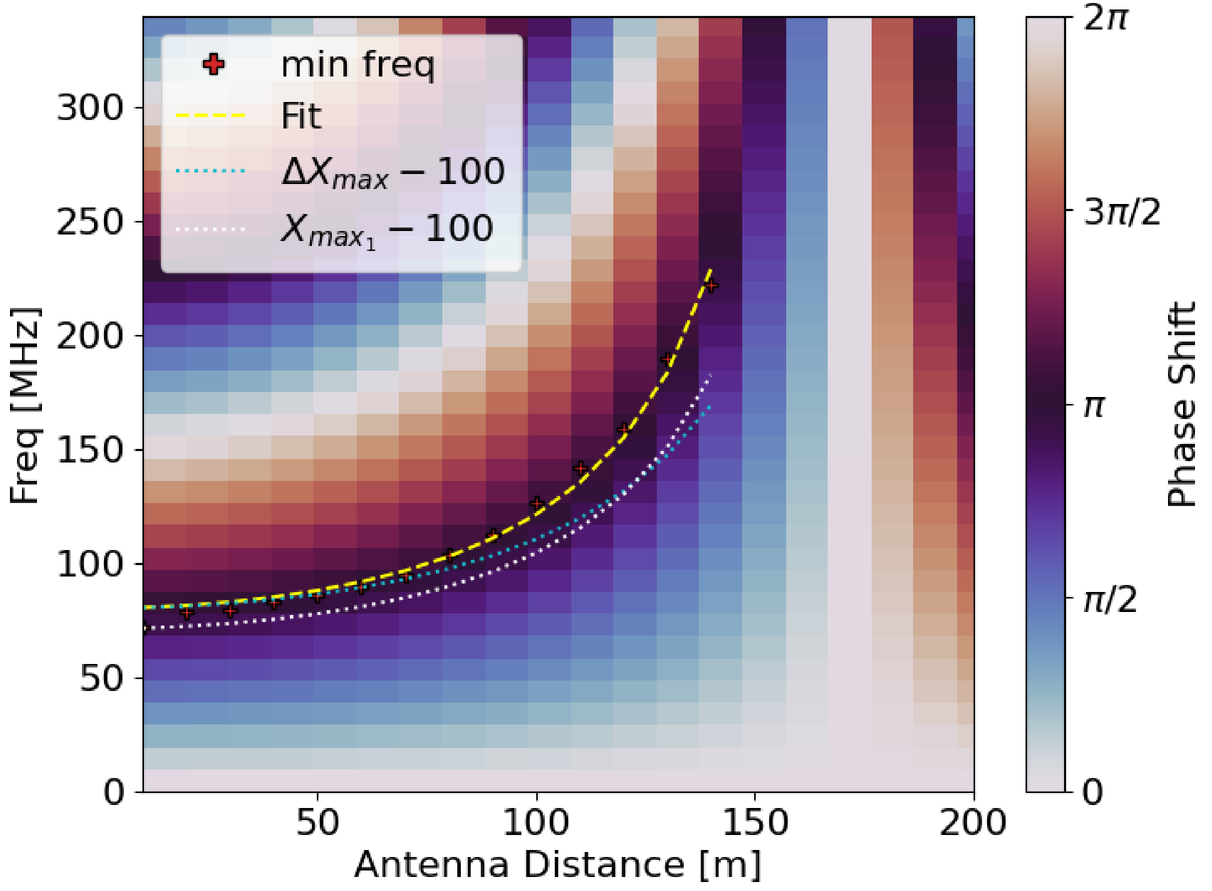
$$\rightarrow \Delta T_{destr.}(\vec{r}) \sim \frac{\pi}{\omega} = \frac{1}{2\, f_{destr.}}$$

$$\rightarrow f_{destr.} = \frac{1}{2\, \Delta T_{destr.}(\vec{r})}$$



FITTING THE DIP

IT WORKSSS!



The low freq. (antennas close to the core) values are measure ΔX. Need higher freq.'s (antenna's closer to Cherenkov ring) Needed for actual X_{max_1} and X_{max_2} values.

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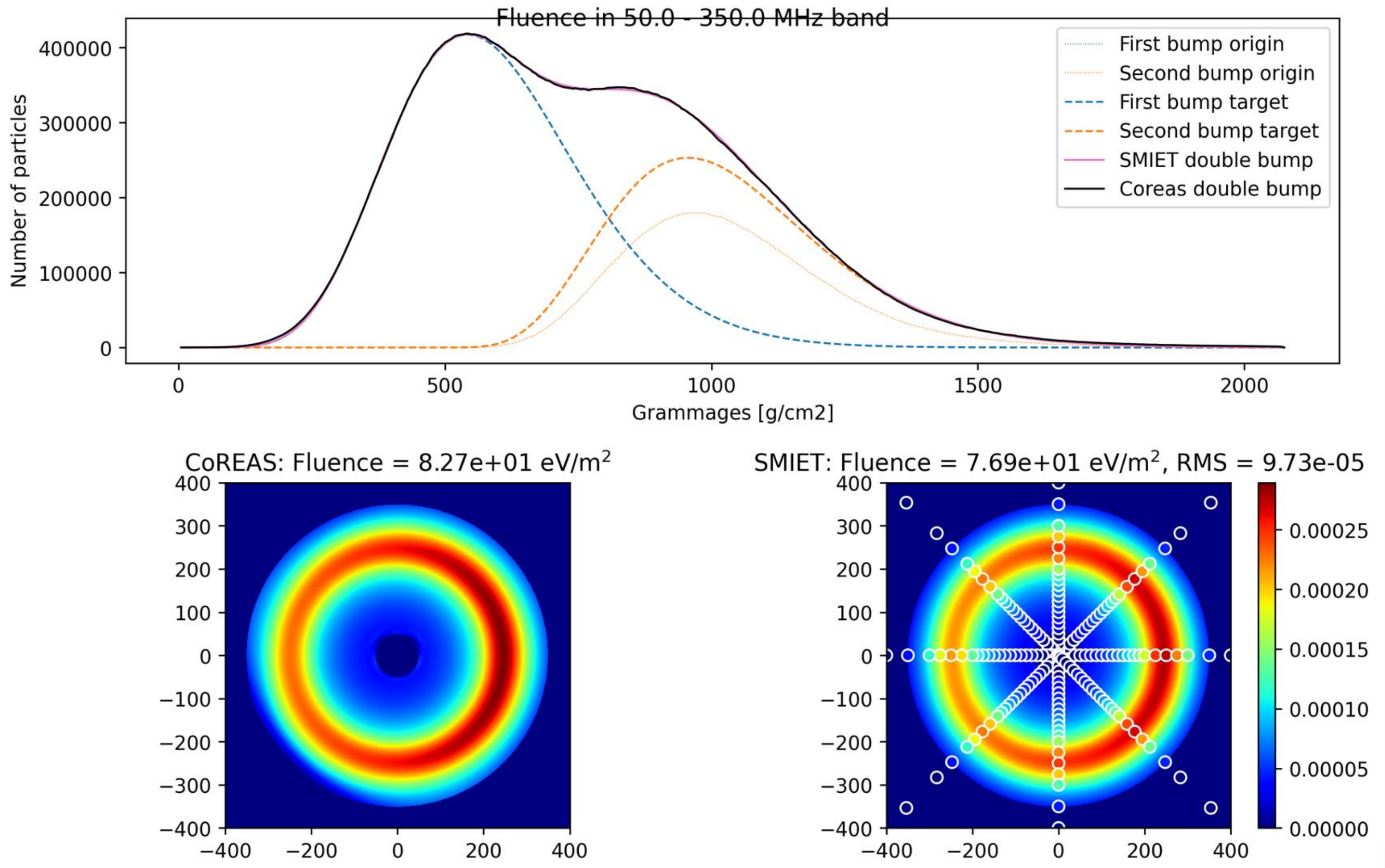
USING SMIET TO MAKE ARTIFICIAL DOUBLE BUMPS

Careful:
-Trace summing on sub sampling Time scales
-origin needs to 'cover' the target
-R/L restricted!



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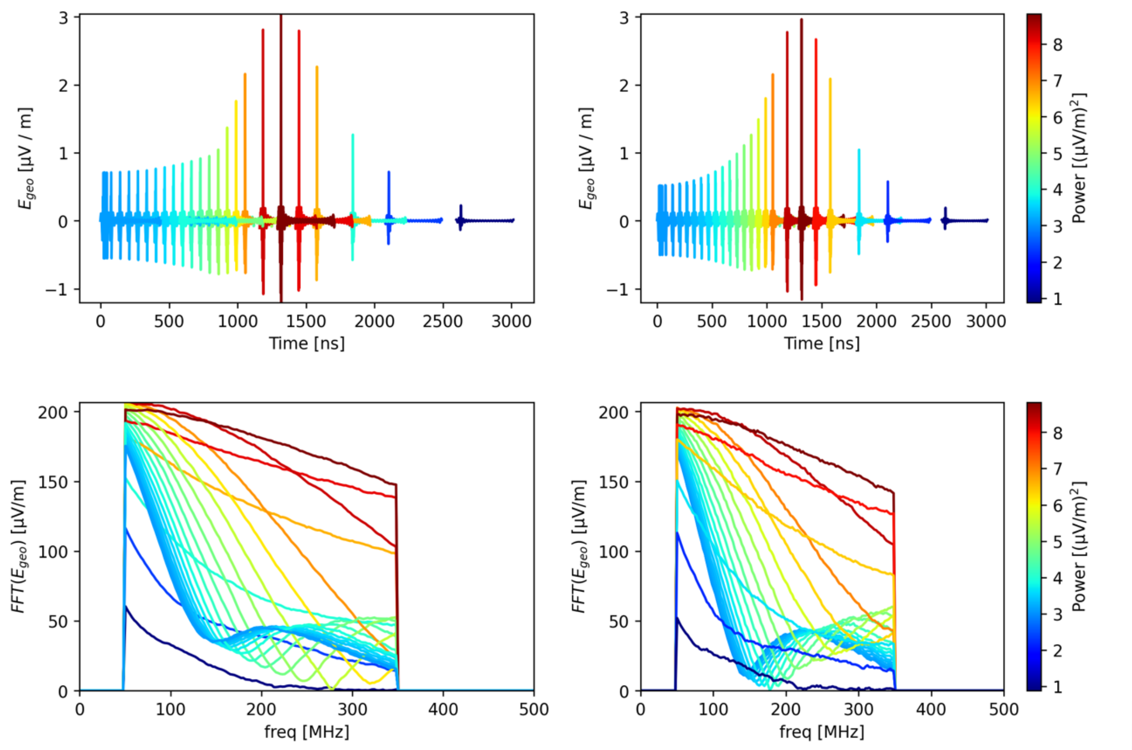
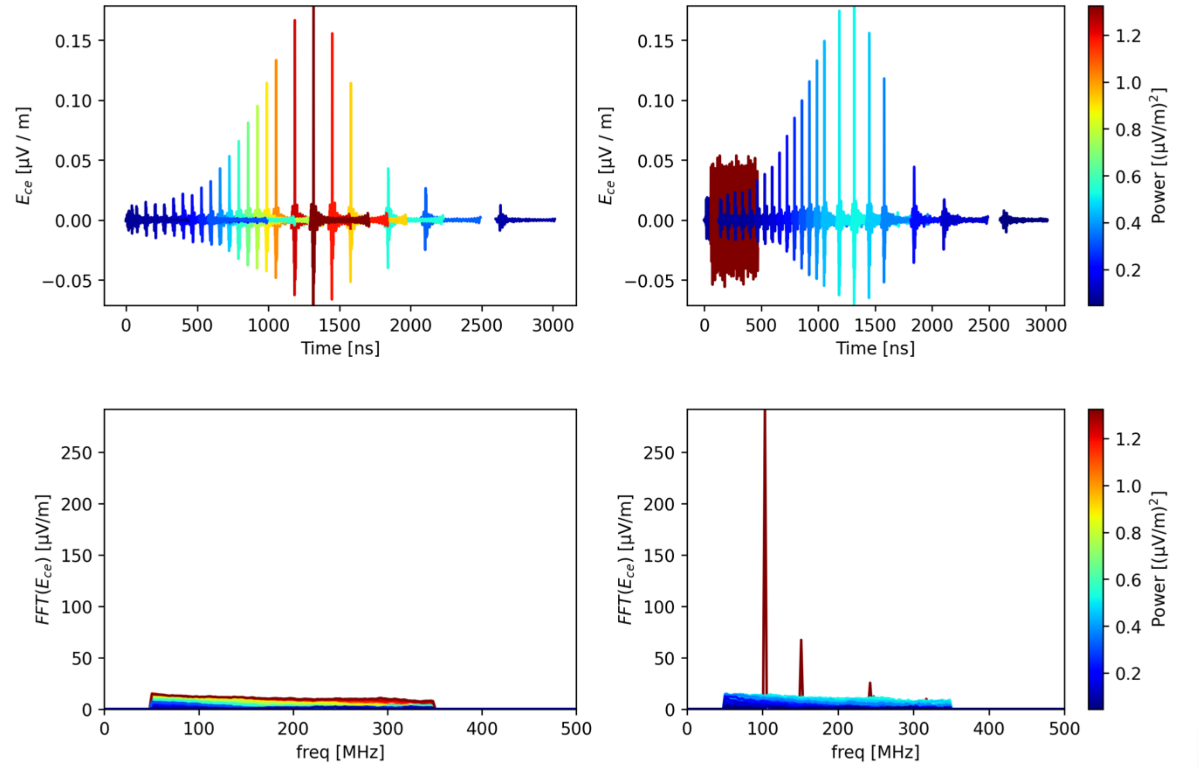
USING SMIET TO MAKE ARTIFICIAL DOUBLE BUMPS

We need to cut the core antenna’s.





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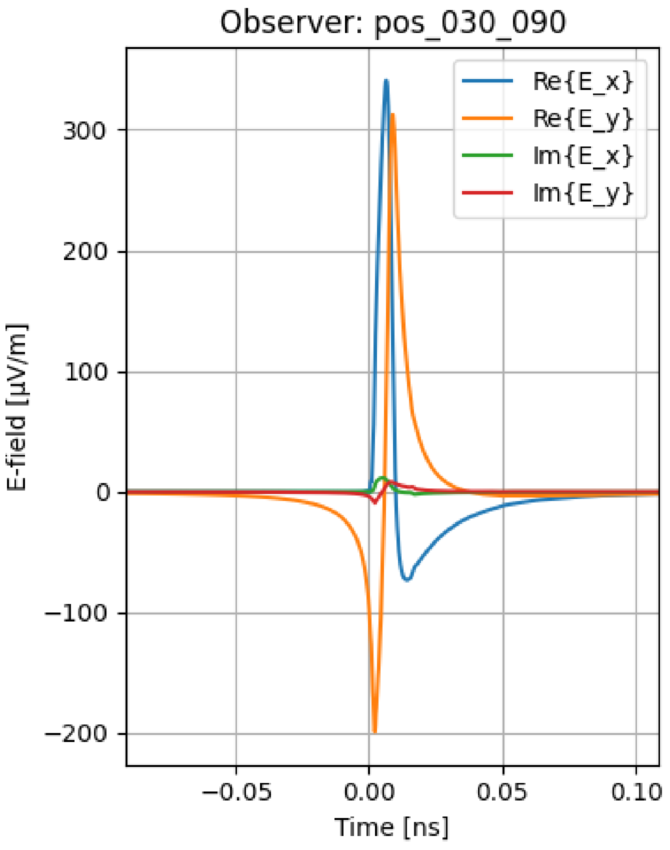
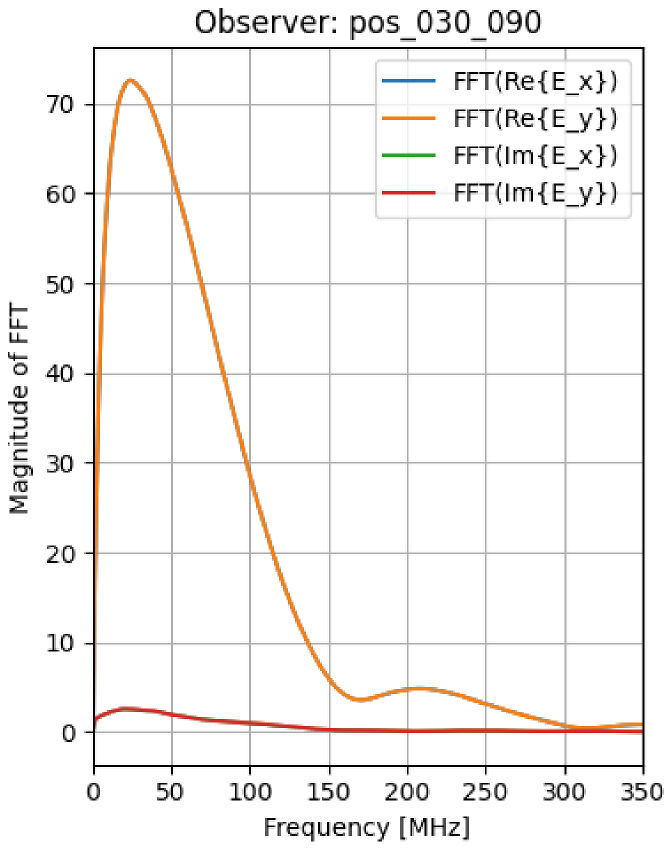
MGMR3D



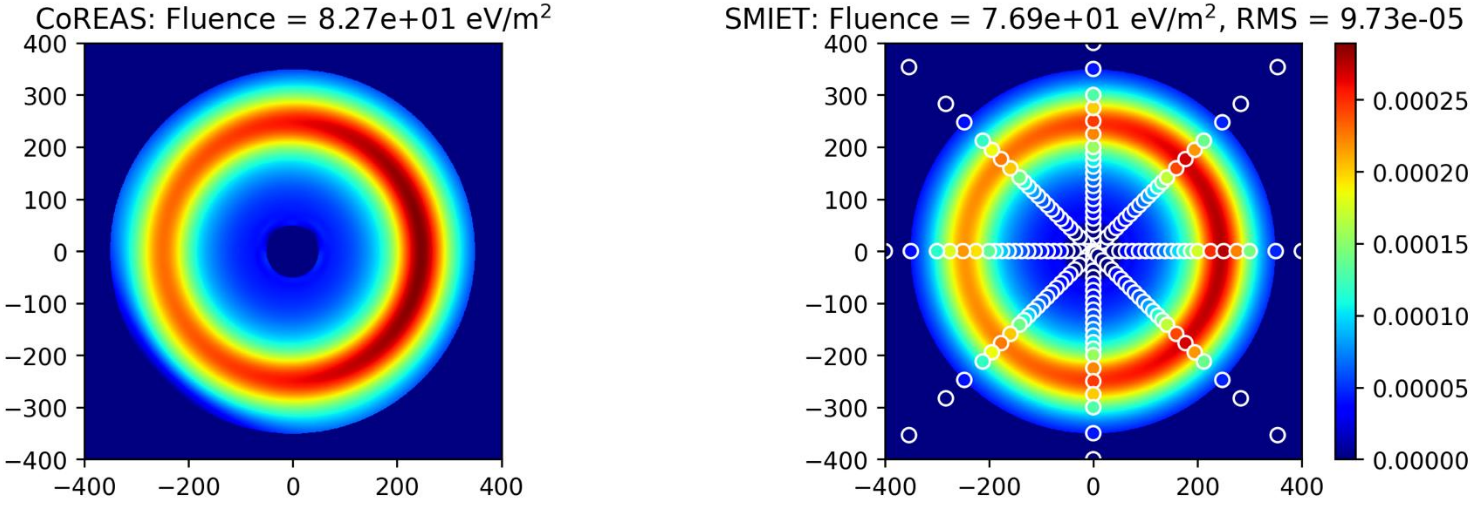
Observer: pos_030_090
Re{E_x}
Re{E_y}
Im{E_x}
Im{E_y}
E-field [µV/m]
300
200
100
0
−100
−200
−0.05
0.00
0.05
0.10
Time [ns]



Observer: pos_030_090
FFT(Re{E_x})
FFT(Re{E_y})
FFT(Im{E_x})
FFT(Im{E_y})
Magnitude of FFT
70
60
50
40
30
20
10
0
0
50
100
150
200
250
300
350
Frequency [MHz]

FINDING N_{max_1} AND N_{max_2}

Compare the fluence across a plane.



$$RMS = \sum (f_{SIM}(\bar{r}) - f_{SMIET}(\bar{r}))^2$$

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FINDING N_{max_1} AND N_{max_2}

Create a grid of $N_{max_1}, N_{max_2}, L_1, L_2$ to find the Lowest RMS value.
It seems this didn't always work because of the destructive interference.

Create a grid of $N_{max_1}, N_{max_2}, X_{max_1}, X_{max_2}$ to find the Lowest RMS value.
Holding R & L constant.

FINDING N_{max_1} AND N_{max_2}

Varying:

- N_{max_1}
- N_{max_2}
- L_1
- L_2

$X_{max_i} = Fit$

$R_i = 0.33$

Best fit:
N_max_1 = 3.667e+05
N_max_2 = 1.889e+05
L_1 = 1.778e+02
L_2 = 1.667e+02
RMS = 2.6334e-06

Ratios
N_max_1 ratio = 0.938
N_max_2 ratio = 1.089
L_1 ratio = 0.925
L_2 ratio = 0.946

Closest grid point
N_max_1 = 4.111e+05
N_max_2 = 1.889e+05
L_1 = 1.944e+02
L_2 = 1.778e+02
RMS = 7.9392e-04

Ratios
N_max_1 ratio = 1.052
N_max_2 ratio = 1.089
L_1 ratio = 1.011
L_2 ratio = 1.01

Varying:

- N_{max_1}
- N_{max_2}
- X_{max_1}
- X_{max_2}

$L_i = 186$

$R_i = 0.37$

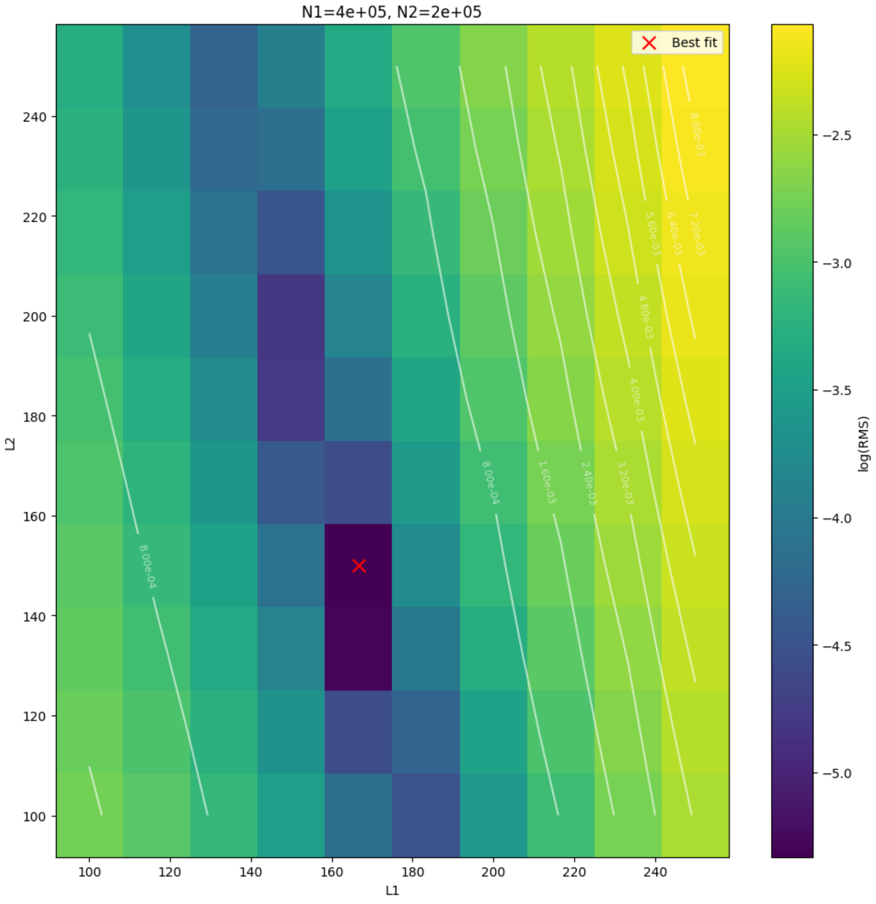
Best fit:
N_max_1 = 4.000e+05
N_max_2 = 2.000e+05
X_max_1 = 5.000e+02
X_max_2 = 1.100e+03
RMS = 1.7505e-05

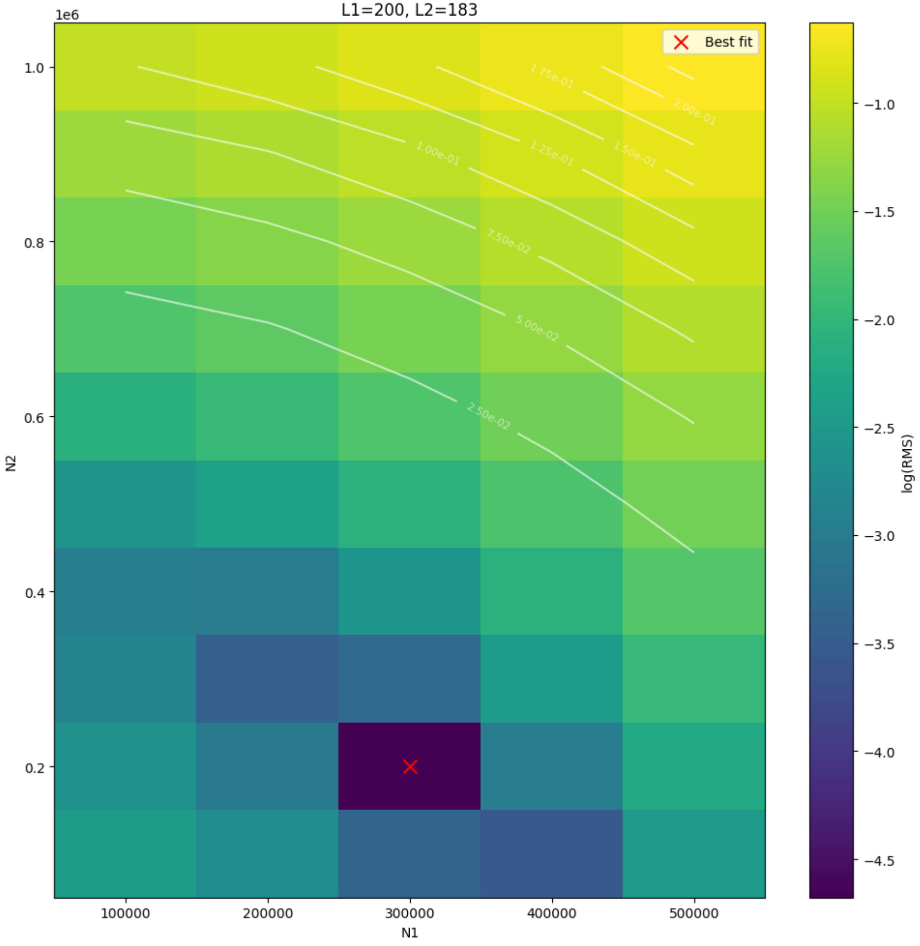
Ratios
N_max_1 ratio = 1.023
N_max_2 ratio = 1.153
X_max_1 ratio = 0.984
X_max_2 ratio = 1.017

Closest grid point
N_max_1 = 4.000e+05
N_max_2 = 2.000e+05
X_max_1 = 5.000e+02
X_max_2 = 1.100e+03
RMS = 1.7505e-05

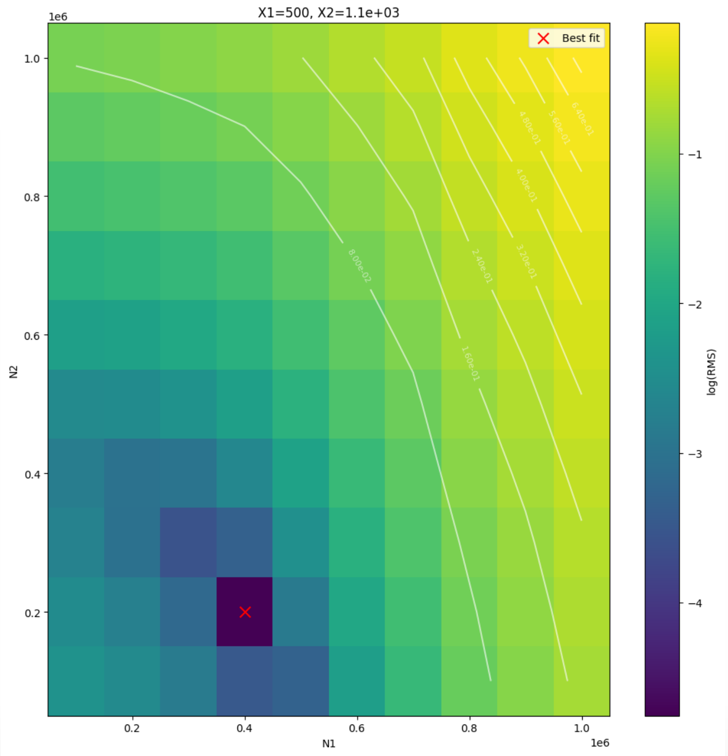
Ratios
N_max_1 ratio = 1.023
N_max_2 ratio = 1.153
X_max_1 ratio = 0.984
X_max_2 ratio = 1.017

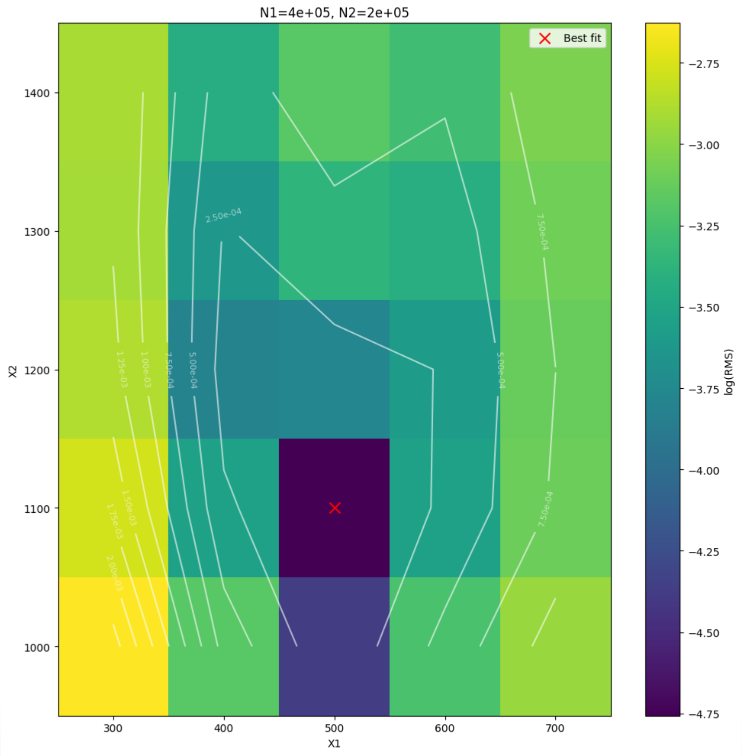
FINDING N_{max_1} AND N_{max_2}





FINDING N_{max_1} AND N_{max_2}





TO-DO

Make the radio signal realistic.

Test the $N_{max_1}, N_{max_2}, X_{max_1}, X_{max_2}$ in all cases and general in NuRadio.

Make a version that does it with electric fields.

Write paper (again).