Investigation of shower shape variables in the ATLAS Fast Calorimeter Simulation

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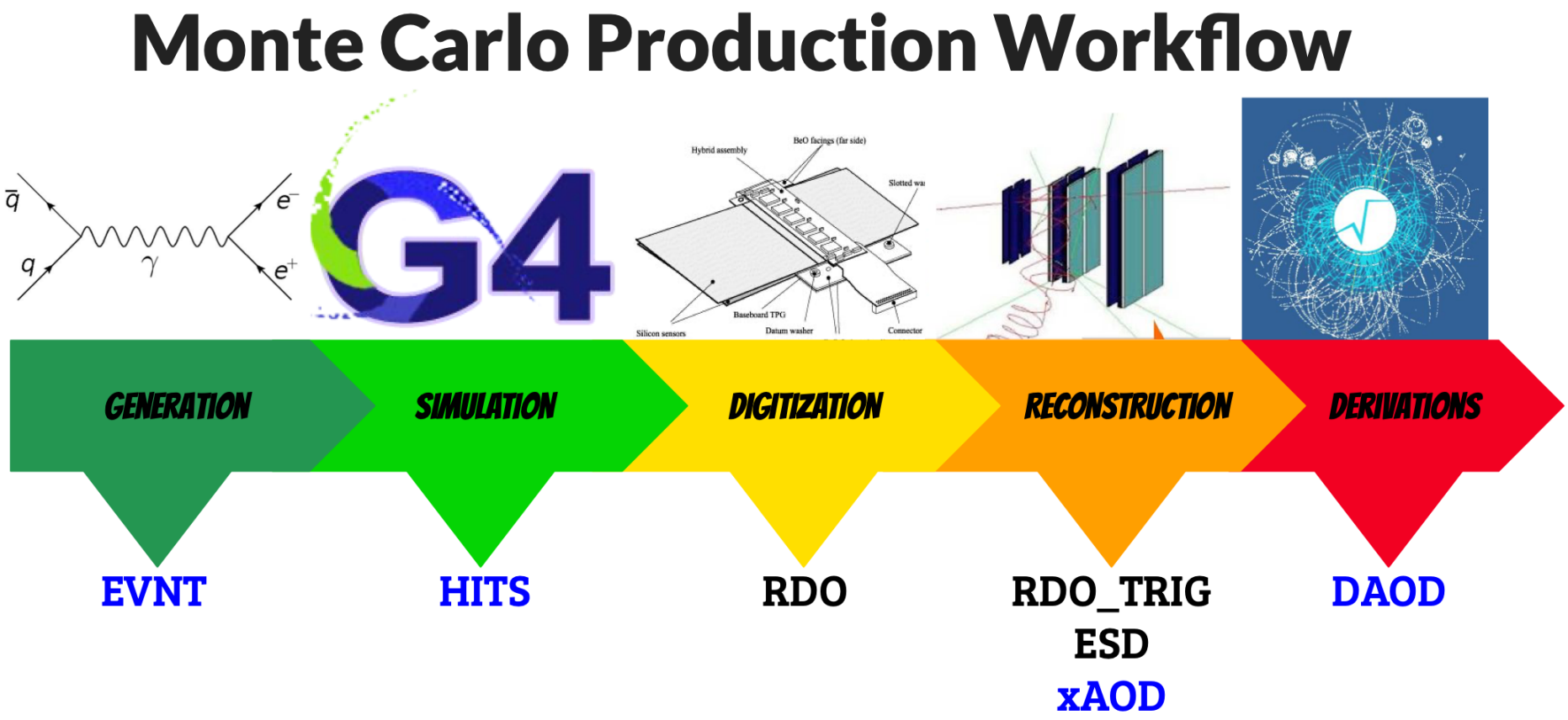
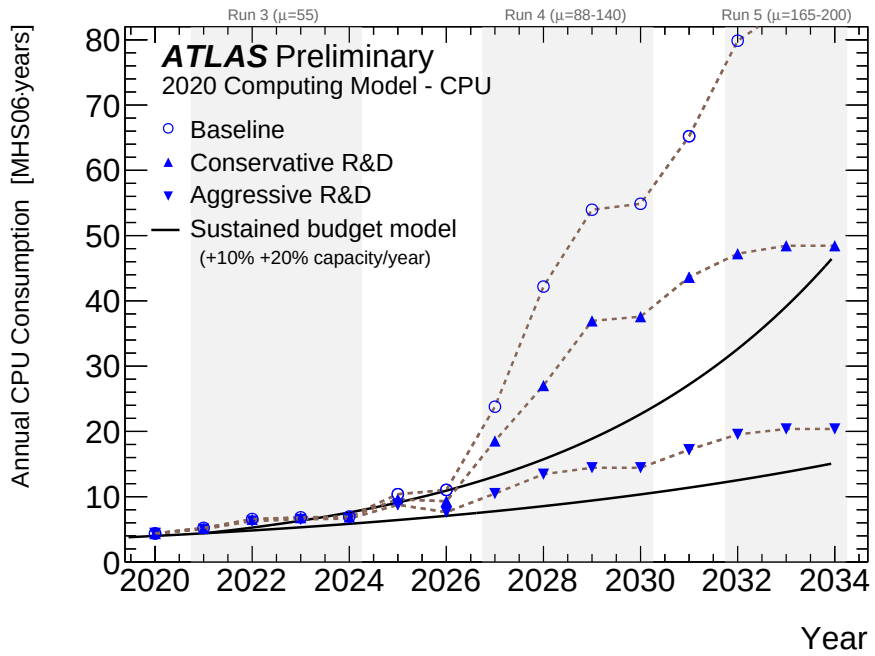
What is FastCaloSim and why do we need it?

In order to compare theoretical predictions with data:



What is FastCaloSim and why do we need it?

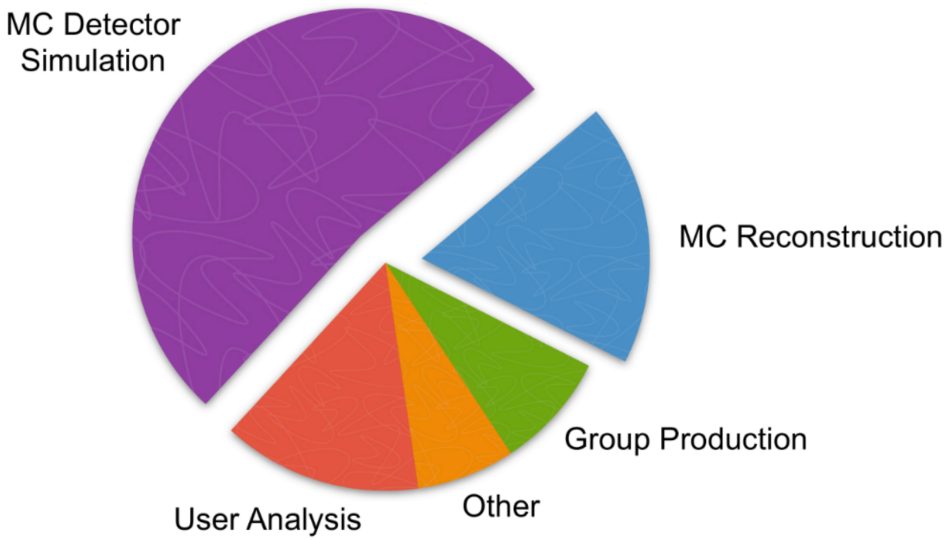
- Geant4: very good and detailed simulation of the detector response, but relatively slow
- in Run 3 and 4: higher integrated luminosity and number of collisions per bunch crossing
  $\rightarrow$ we will not be able to keep up with increased luminosity



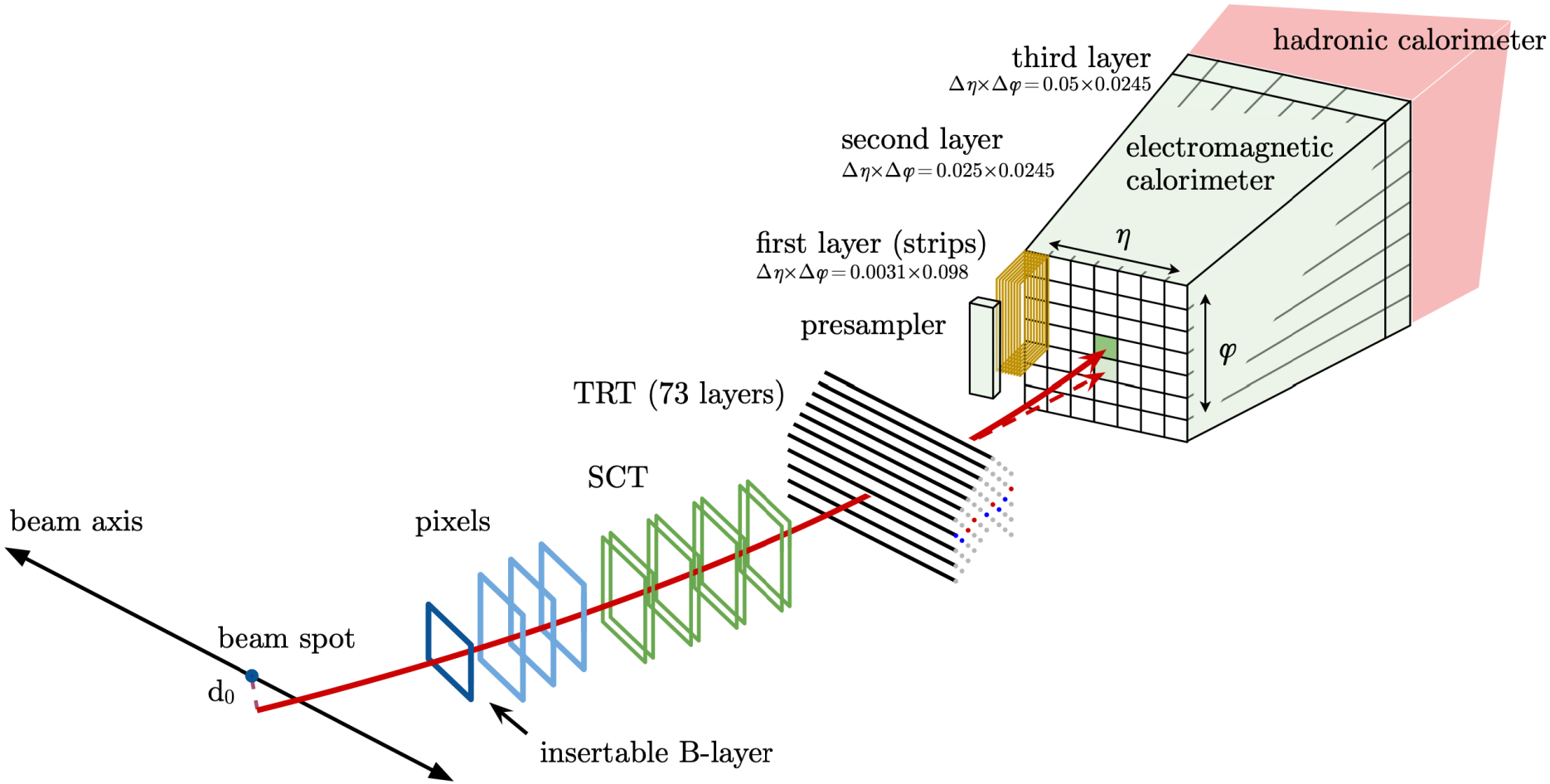
What is FastCaloSim and why do we need it?

- most of the computing power is used for the detector simulation
- $\sim$ 80% of the detector simulation is spent on the calorimeter simulation
  $\rightarrow$ reduce simulation time for the calorimeter

$\Rightarrow$ Fast Calorimeter Simulation (FastCaloSim): $\mathcal{O}(500)$ faster

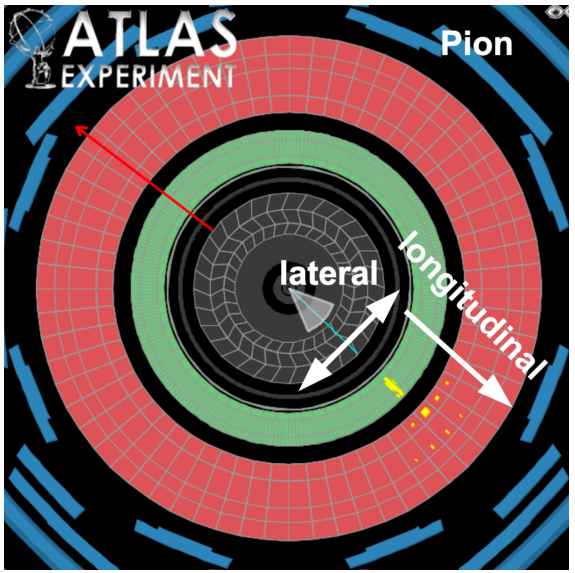


The ATLAS calorimeter



The approach of FastCaloSim

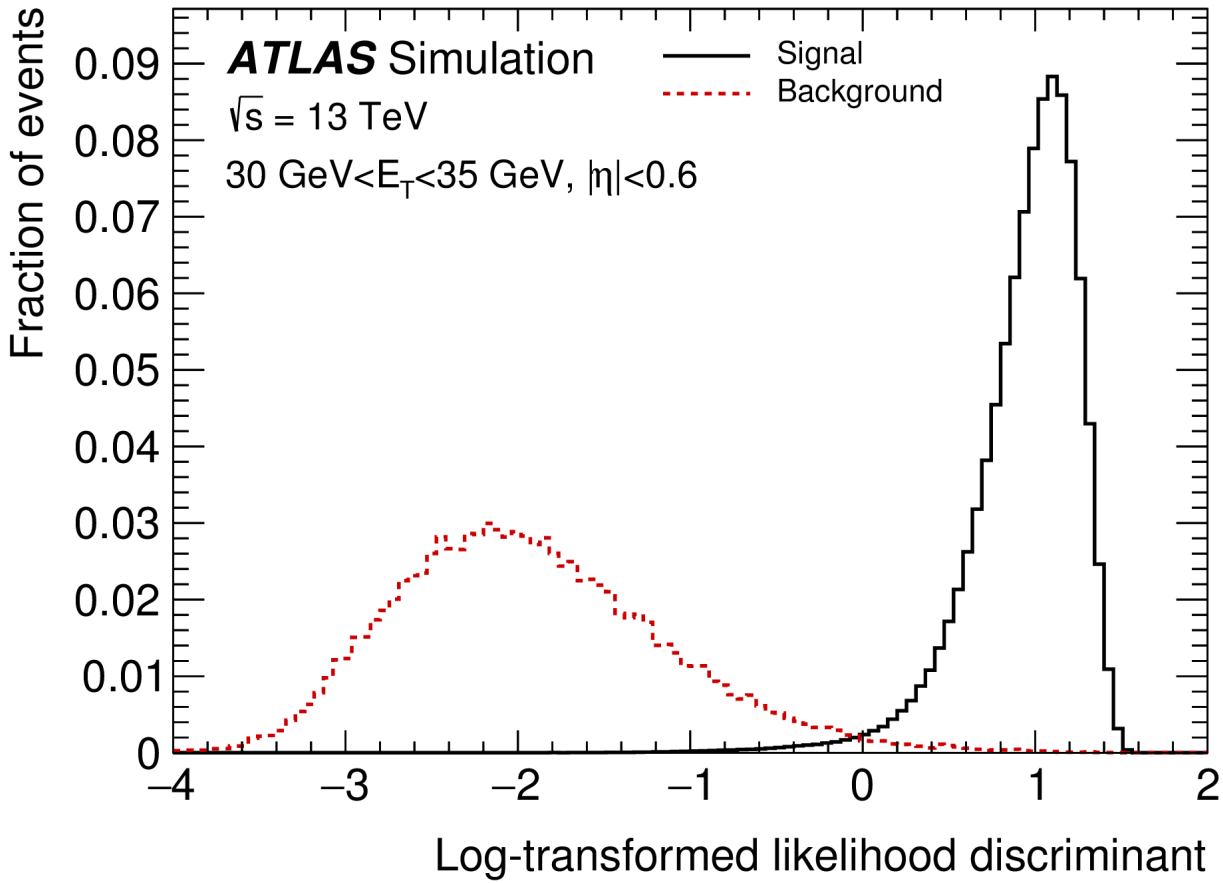
- Atlfast-III (AF3):
  - **FastCaloSimV2: parametrised modelling**
  - FastCaloGan: Generative Adversarial Network
- full simulation of the ID and parametrised simulation of the calorimeter
- instead of simulating interactions of particles travelling through detector: parametrise detector response of single particles (lateral & longitudinal)
- electromagnetic showers: electrons & photons
  hadronic showers: pions
- 17 bins of energy (16 MeV−4 TeV), 100 bins of $|\eta|$ $(0 - 5.0)$



Particle Identification

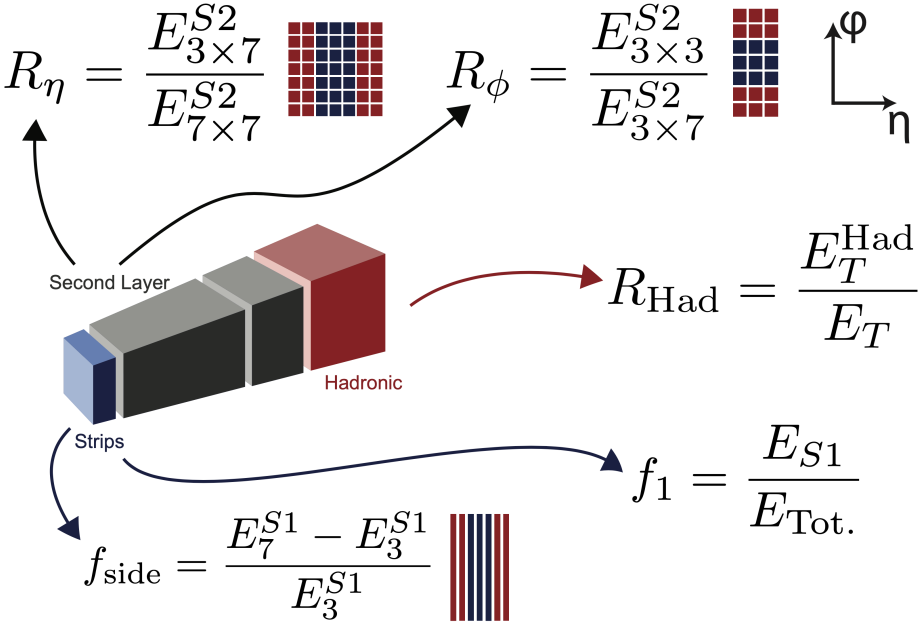
- electron identification with likelihood discriminate formed from discriminating variables
- cut-based photon identification with the discriminating variables

for electrons:



Examples of shower shape variables

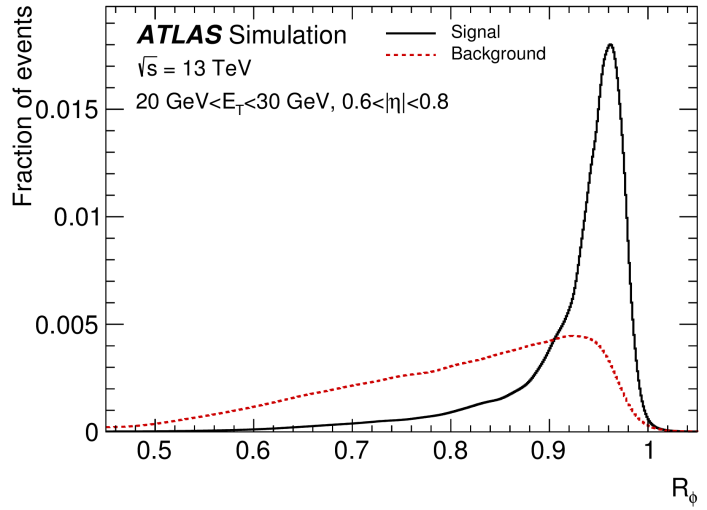
$$R_\eta = \frac{E^{S2}_{3\times7}}{E^{S2}_{7\times7}} \qquad R_\phi = \frac{E^{S2}_{3\times3}}{E^{S2}_{3\times7}}$$



$$R_{\mathrm{Had}} = \frac{E_T^{\mathrm{Had}}}{E_T}$$

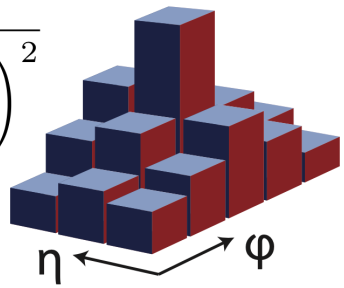
$$f_1 = \frac{E_{S1}}{E_{\mathrm{Tot.}}}$$

$$f_{\mathrm{side}} = \frac{E^{S1}_7 - E^{S1}_3}{E^{S1}_3}$$



$$w_{\eta,2} = \sqrt{\frac{\sum E_i \eta_i^2}{\sum E_i} - \left(\frac{\sum E_i \eta_i}{\sum E_i}\right)^2}$$

Width in a 3×5 (Δη×Δφ) region of cells in the second layer.

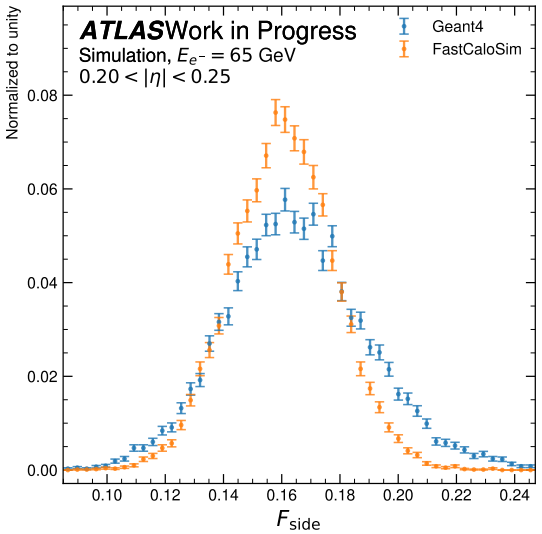


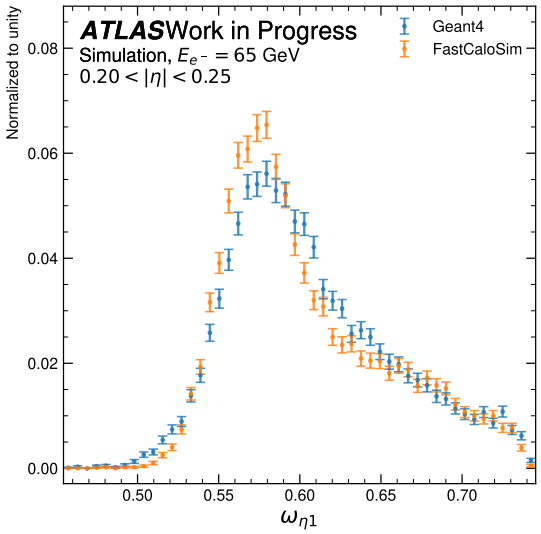
$$\sqrt{\frac{\sum E_i \cdot (i - i_{\max})^2}{\sum E_i}} = \begin{cases} w_{\eta 1} & \text{(with 3 strips in total)} \\ w_{\mathrm{stot}} & \text{(typically 20 strips)} \end{cases}$$

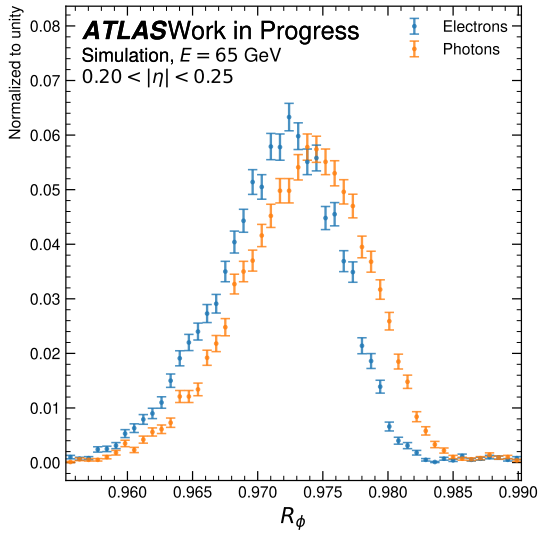
Motivation of my Bachelor's thesis

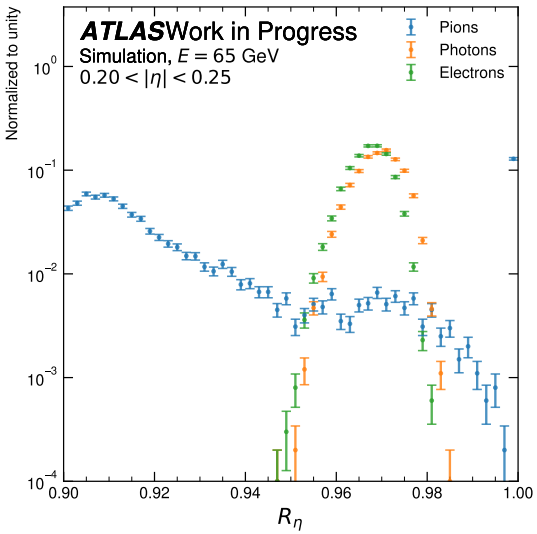
- to improve FastCaloSim the shower shape variables should be tuned to real data (Joshuas work)
- full simulation + reconstruction is very slow $\rightarrow$ impractical for that purpose
- goal: implement the shower shape variables in the FastCaloSim stand-alone simulation (faster)
  $\Rightarrow$ allow easy access to shower shape variables for FastCaloSim developers

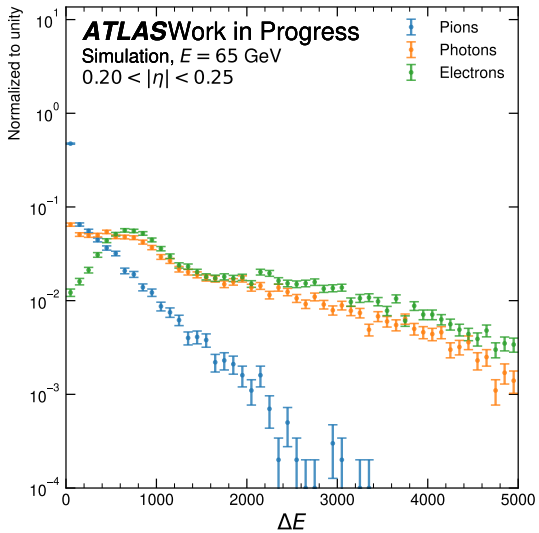
Shower shape variables





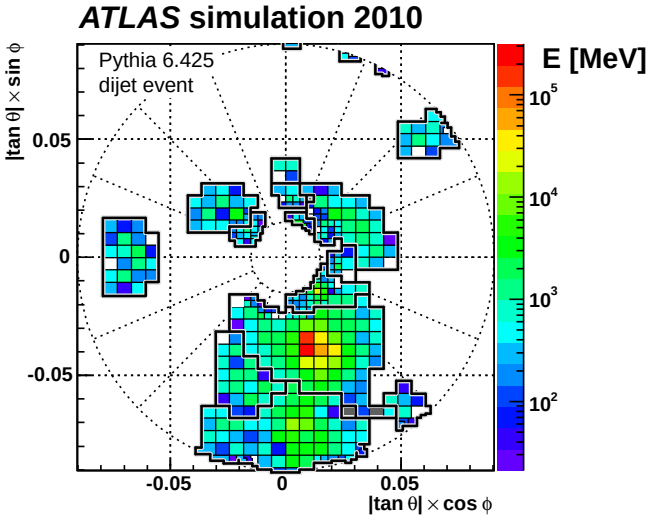


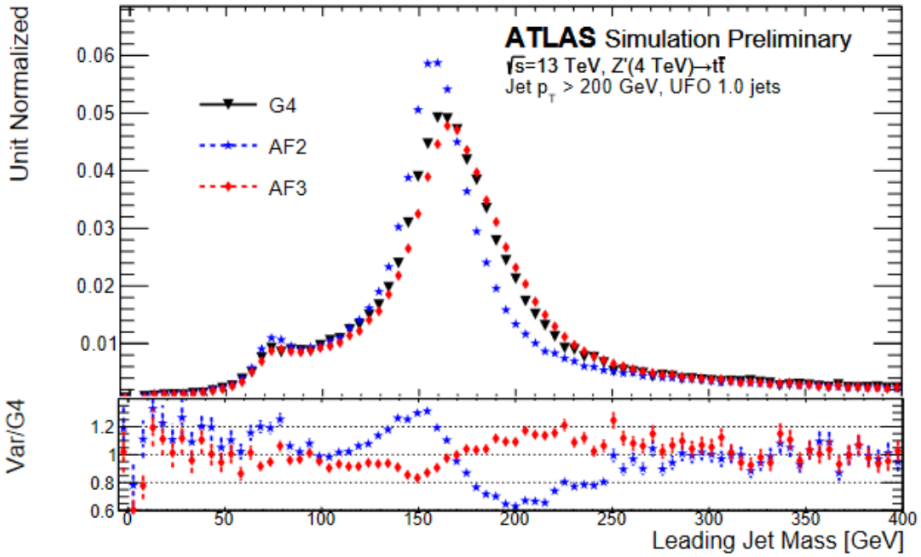


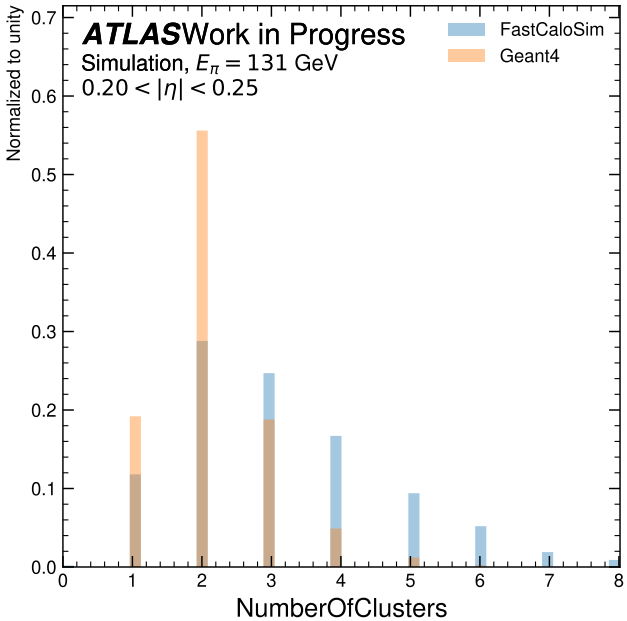


The simple clustering algorithm in my class

- seedlist with threshold t_{seed}
- add neighbours if energy is above threshold t_{core}
- iteratively add neighbours of neighbours etc.
- merge neighbouring clusters







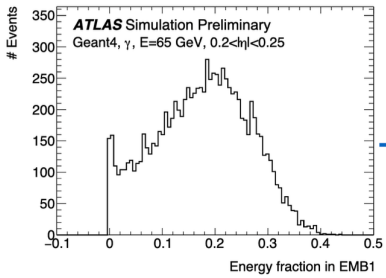
Summary

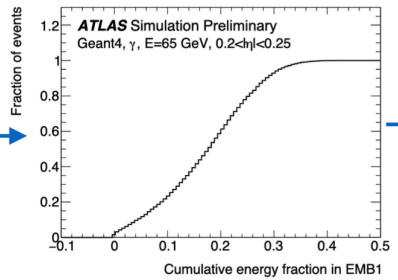
- implemented a shower shape class, which
  - calculates the shower shape variables and
  - stores the values in TTrees
- implemented most of the variables
- compared distributions for Geant4/FastCaloSim, photons/electrons and EM-showers/hadronic showers
- implemented a simple clustering algorithm
- shower shape variables and clustering algorithm can be utilised by the entire FastCaloSim team

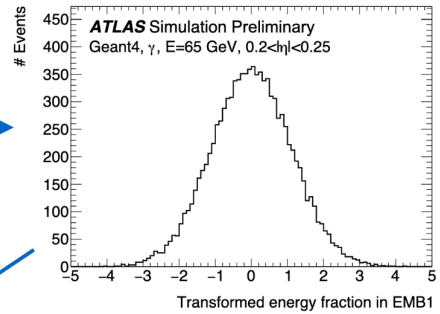
Backup

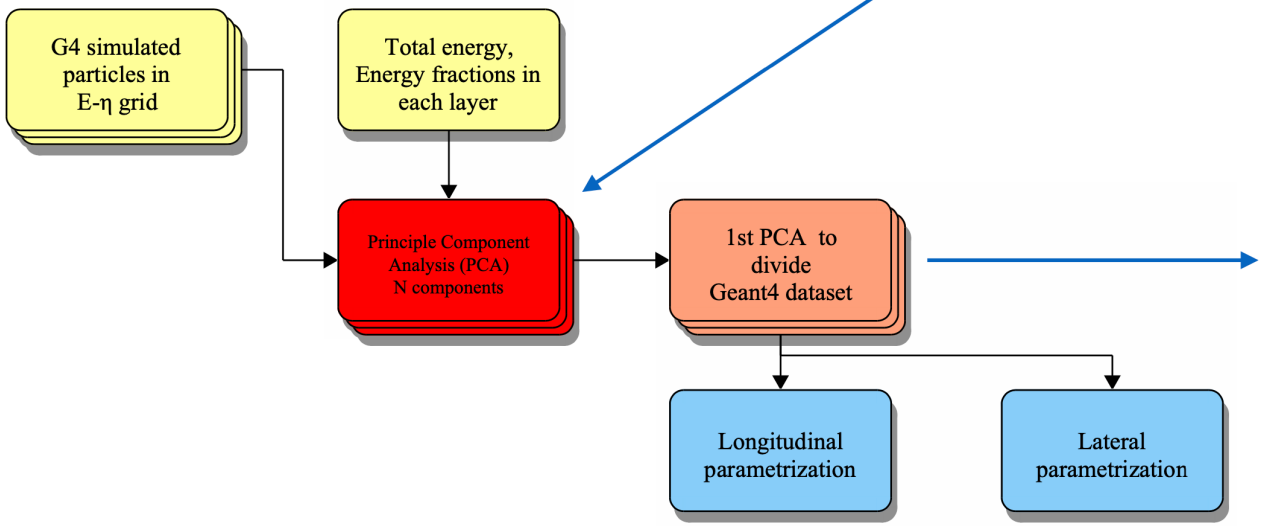
Energy decorrelation using PCA

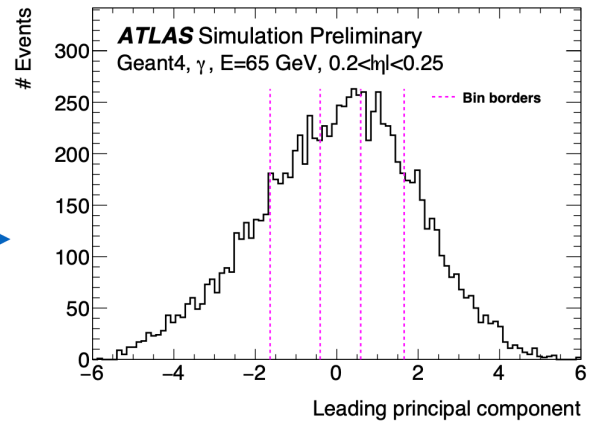
- highly correlated layers → Principal Component Analysis (PCA)





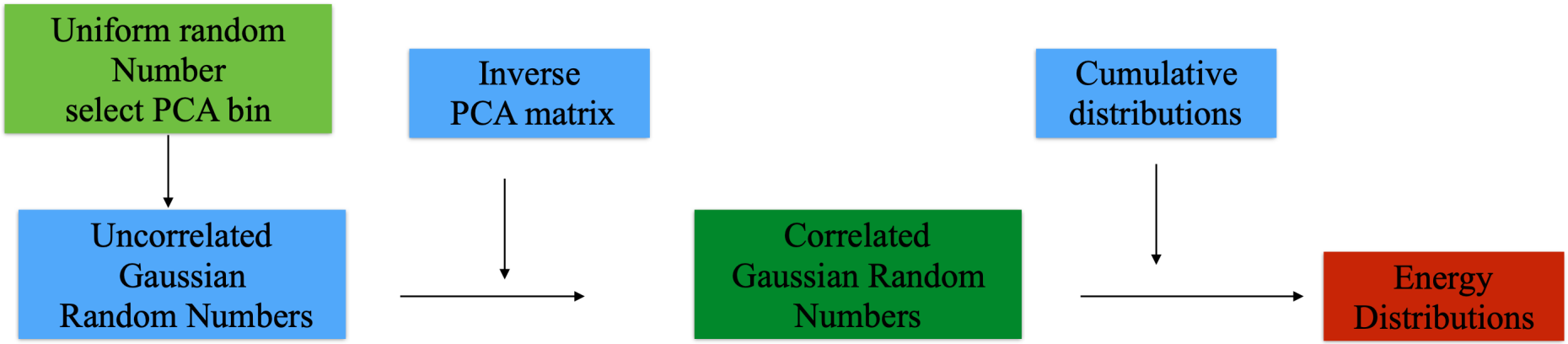




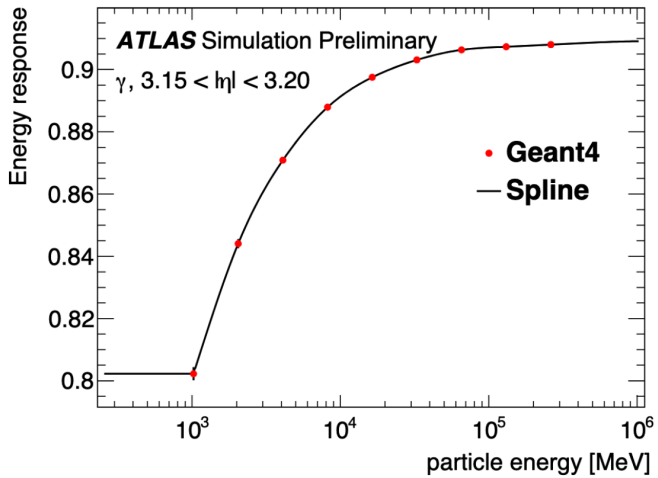


Energy parametrisation and interpolation

During simulation, chain is performed backwards:



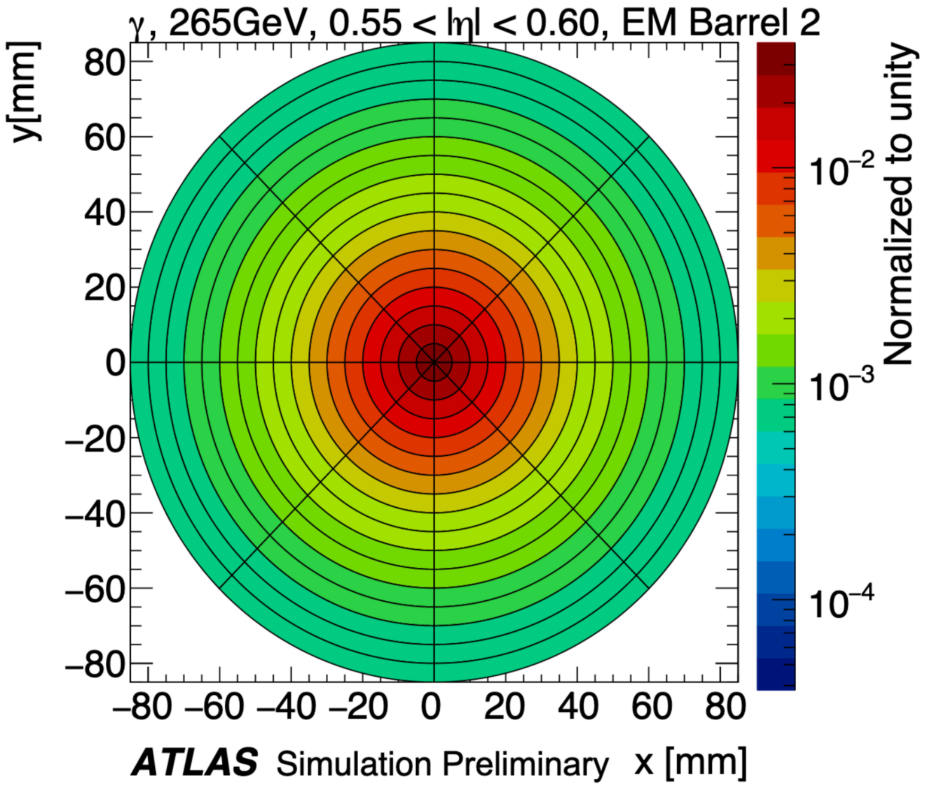
Interpolate energy response using splines:



Lateral shape parametrisation

- construct average lateral shower shape for each particle, energy, η, calorimeter layer and bin of 1st PCA
- during simulation draw N_{hits} randomly from 2D shape histograms
- draw random hits with

$$E_{\text{hit}} = \frac{E_{\text{layer}}}{N_{\text{hits}}^{\text{layer}}} \cdot w$$



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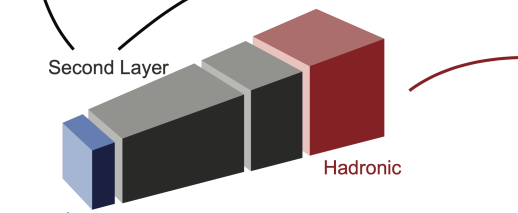

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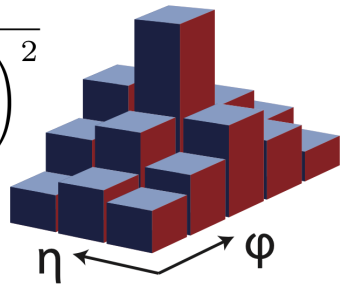

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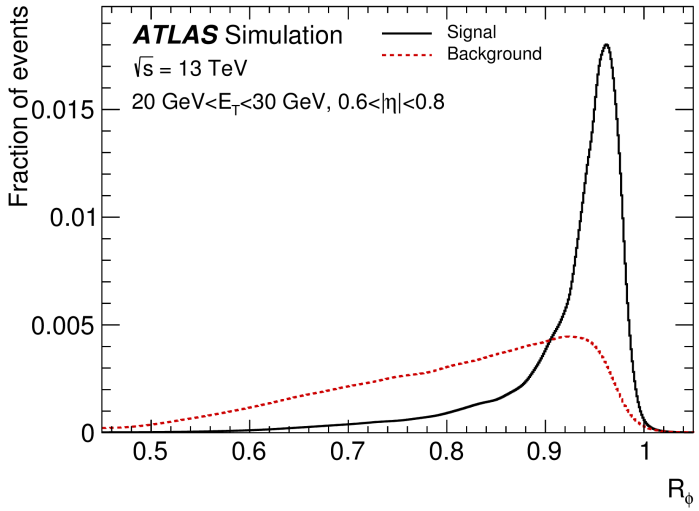
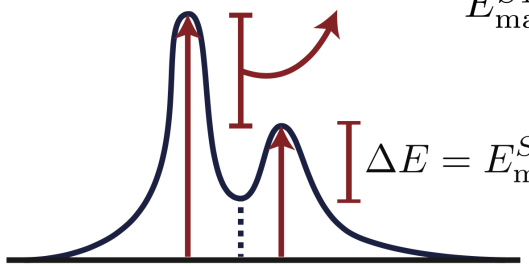


$$E_{\mathrm{ratio}} = \frac{E^{S1}_{\mathrm{max},1} - E^{S1}_{\mathrm{max},2}}{E^{S1}_{\mathrm{max},1} + E^{S1}_{\mathrm{max},2}}$$



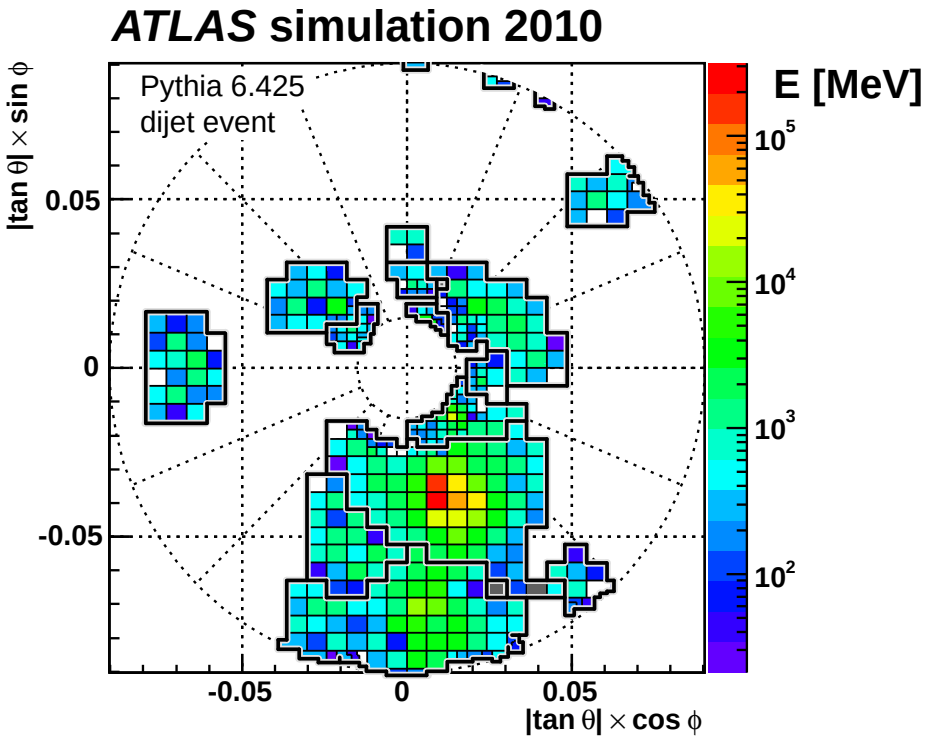
$$\Delta E = E^{S1}_{\mathrm{max},2} - E^{S1}_{\mathrm{min}}$$

Note: E_{ratio} is actually based on clustering → our E_{ratio} in the stand-alone FastCaloSim (no clustering) is shifted but has a similar shape. Only the shape is relevant to us when changing something in the code.

The topological clustering algorithm

First Step - Cluster maker:

- **Finding seeds:** cells with a signal to noise ratio above the seed threshold t_{seed}
- **Finding neighbours:**
  - add neighbour cells in the proto-cluster if their signal to noise ratio is above a threshold t_{cell}
  - repeat procedure with a neighbour seed list (threshold $t_{\text{neighbour}}$) until the seed list is empty
- **Finalising:** remove all with E_T less than a threshold



Clustering at ATLAS

two calorimeter clustering algorithms for the individual calorimeter cell signals $\rightarrow$ input for particle identification:

- sliding-window algorithm
- **topological algorithm**

idea of the topological algorithm: group neighbouring cells into clusters that have significant energies compared to expected noise in two steps:

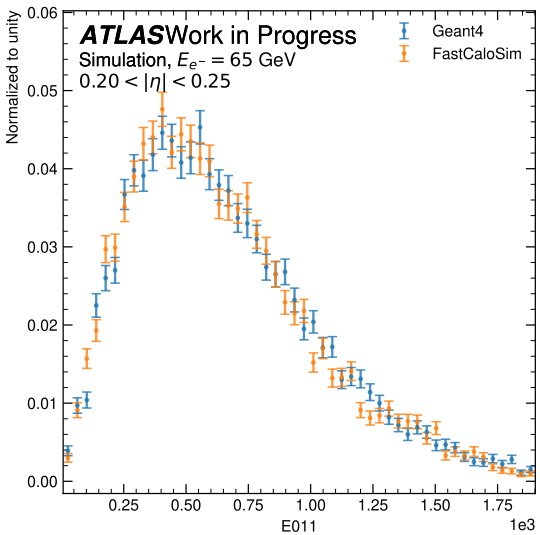
1. cluster maker
2. cluster splitter

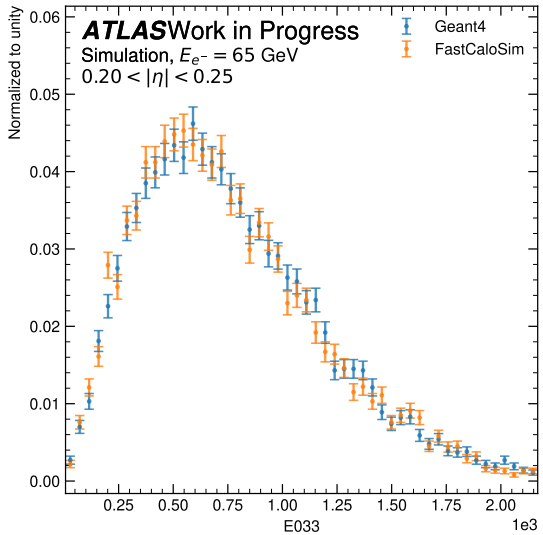
The topological clustering algorithm

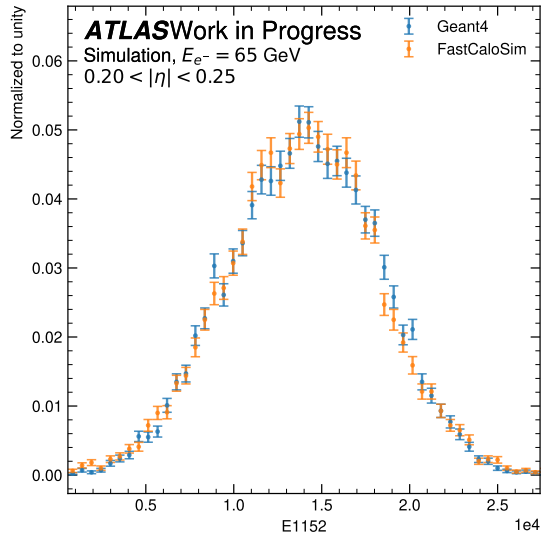
Second step - cluster splitter: clusters are not always isolated but can be adjacent or even overlap $\rightarrow$ they need to be separated for the individual particles

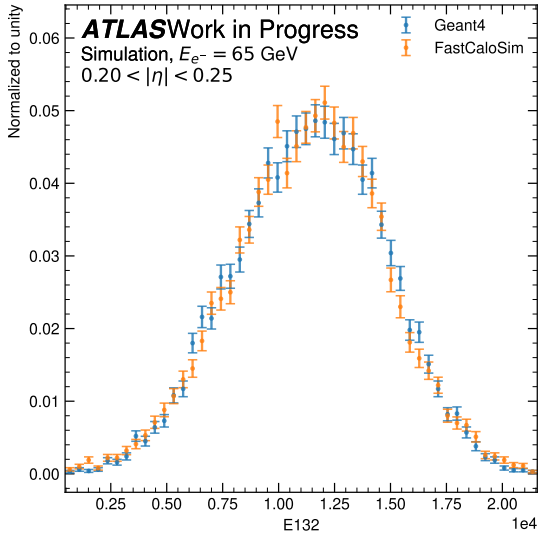
- **Finding local maxima:** $E > 500\,\text{MeV}$, energy greater than of any neighbouring cell
- **Finding neighbours:** build clusters around the local maximum with the cells originally used only, no threshold, no merging; shared cells are removed from the neighbour list and the proto-clusters and added to a shared cell list
- **Shared cells:**
  - iteratively add neighbours that are in the original cell set and which have not been assigned to any proto-cluster
  - associate them with the two proto-clusters with the most energetic neigbours that shared the original cell
  - add each cell in the expanded shared cell list to its two adjoining proto-clusters with weights

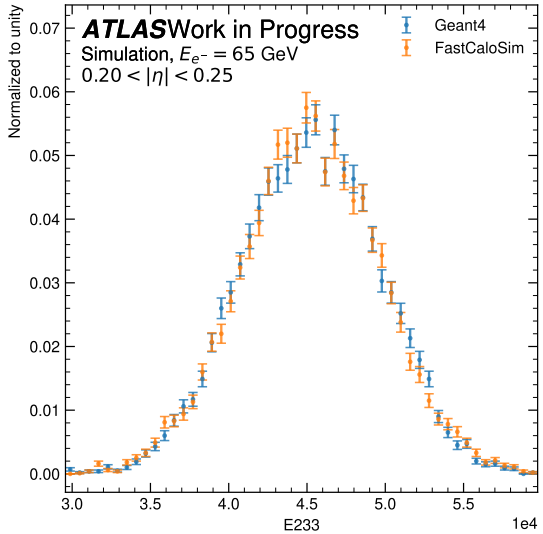
Energy window variables for electrons

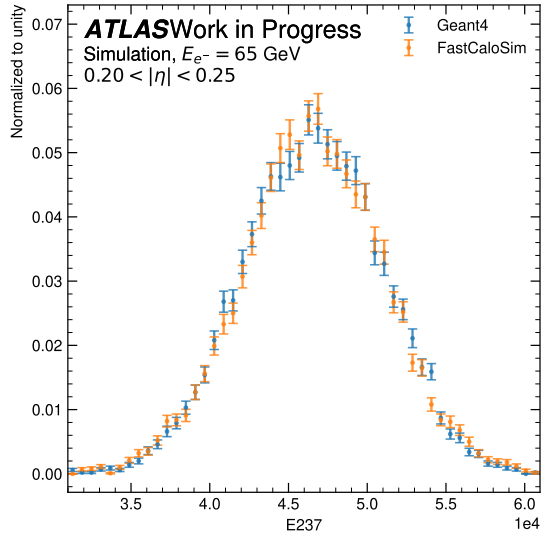




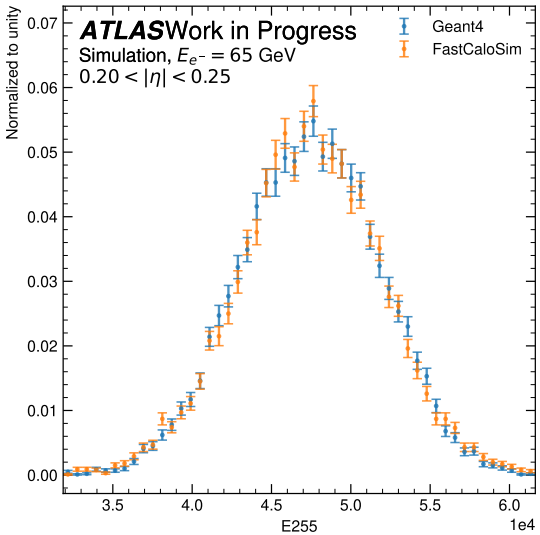


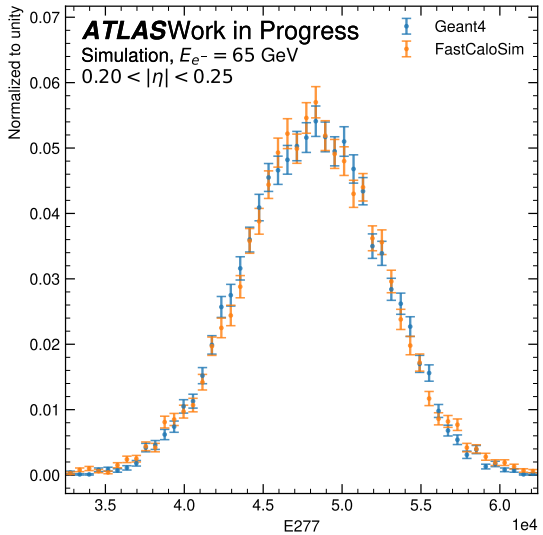


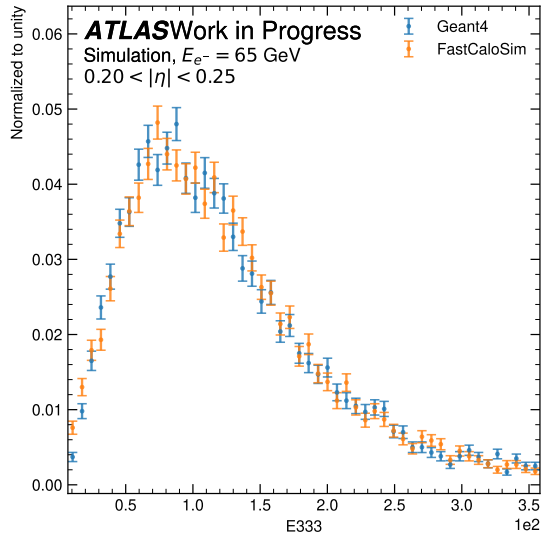


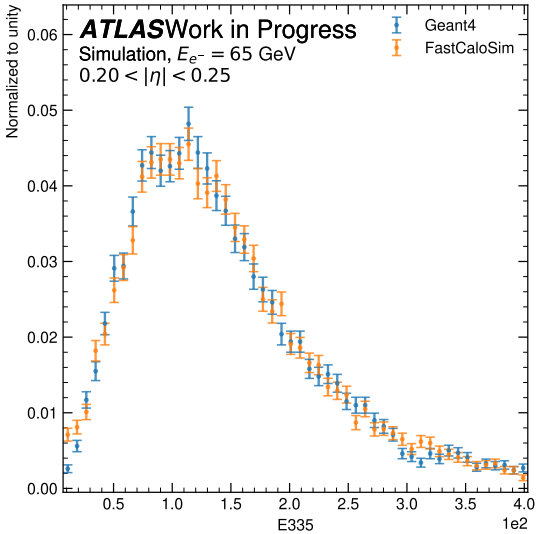


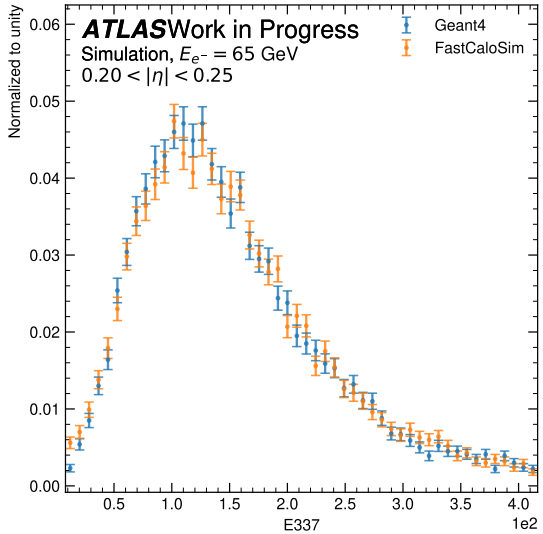
Energy window variables for electrons

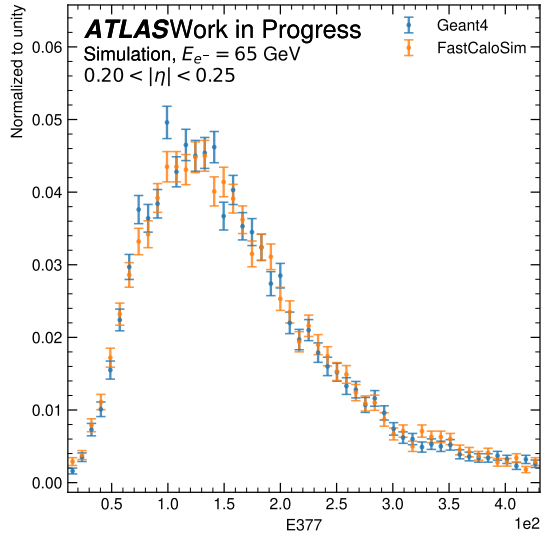




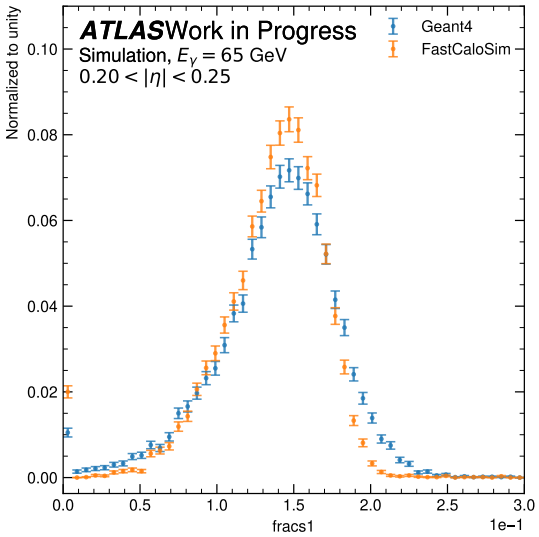


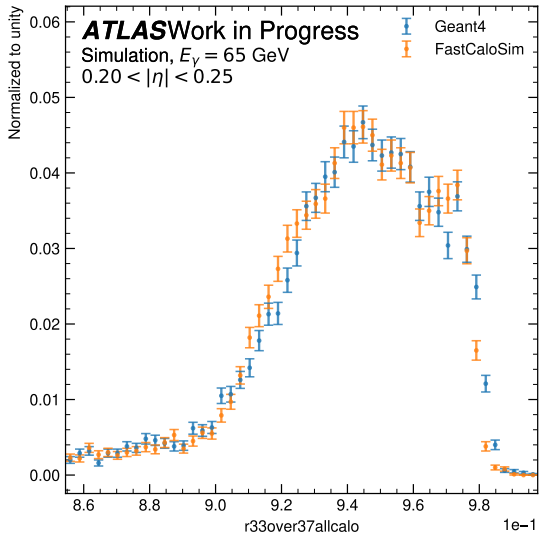


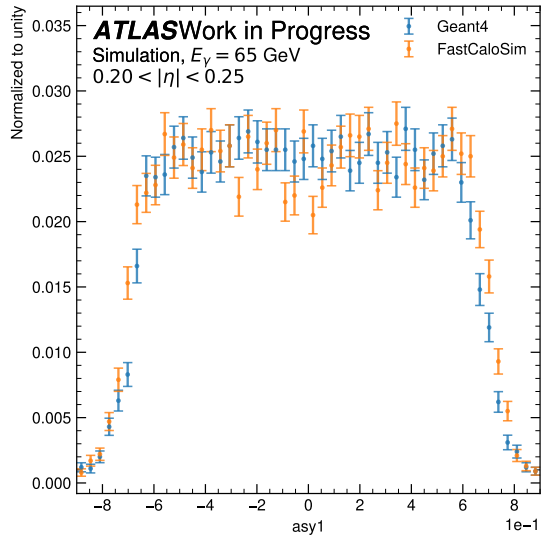


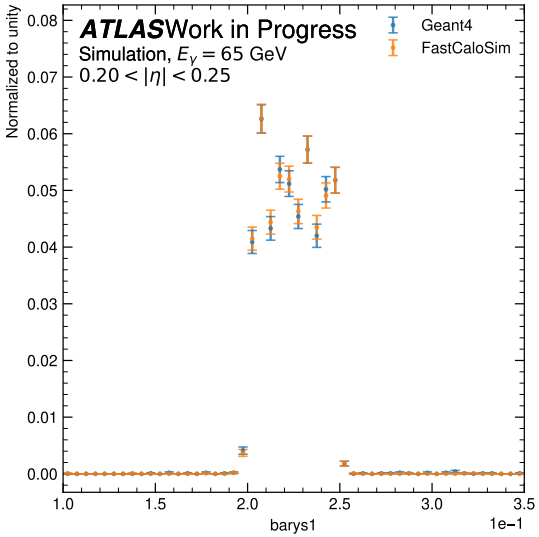


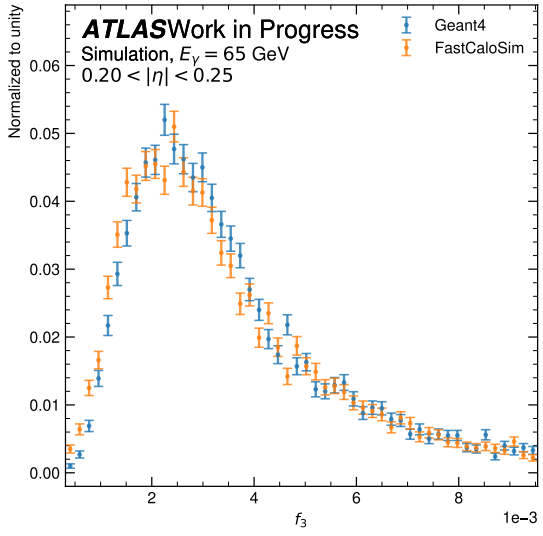
New shower shape variables for photons

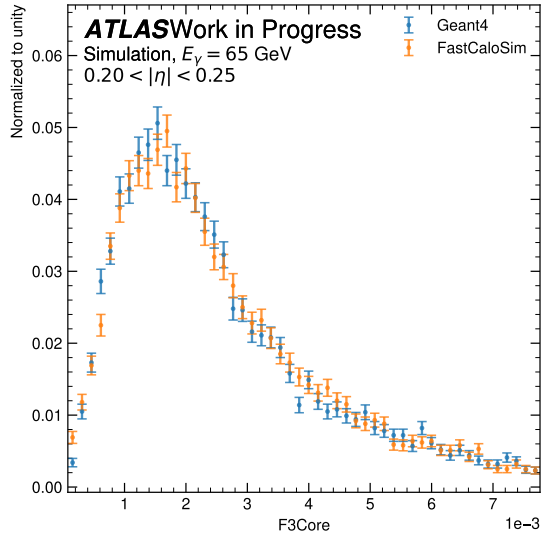




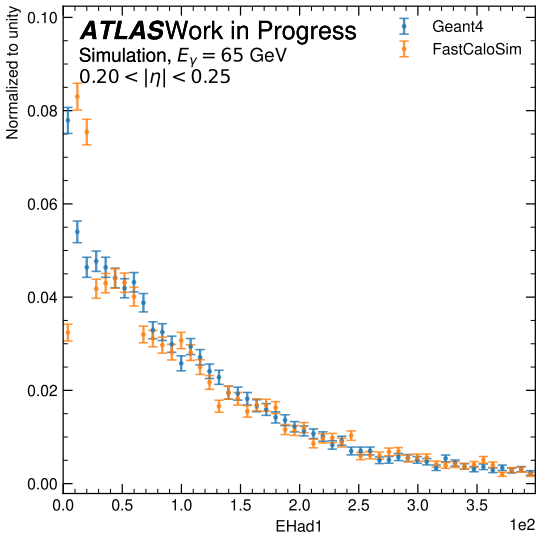


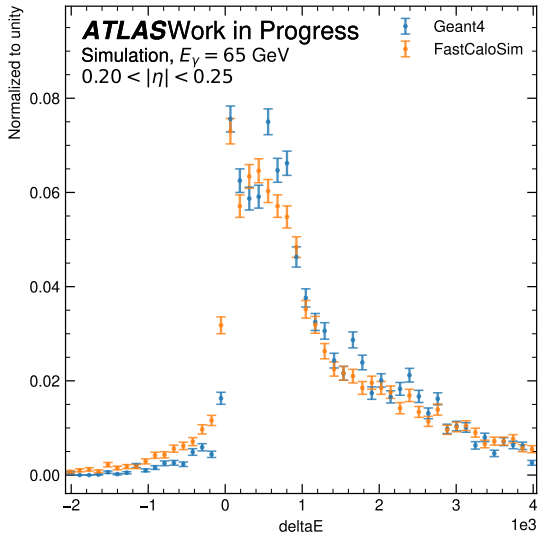


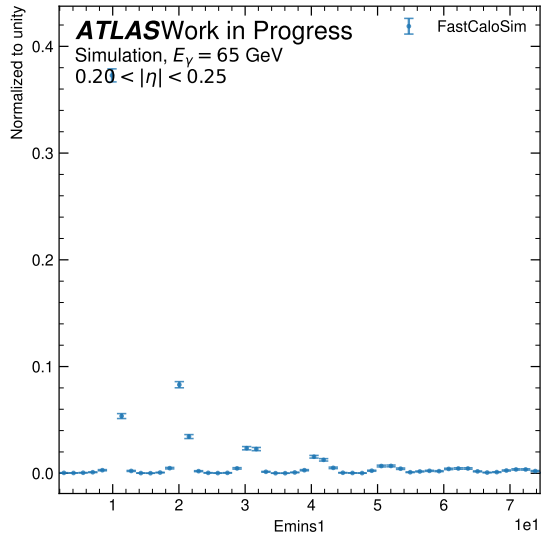


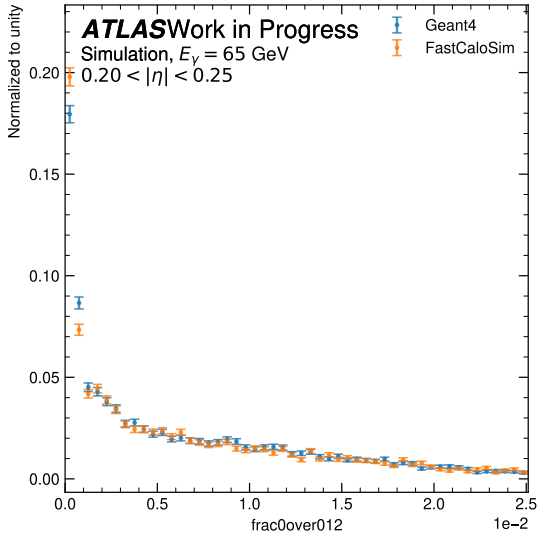


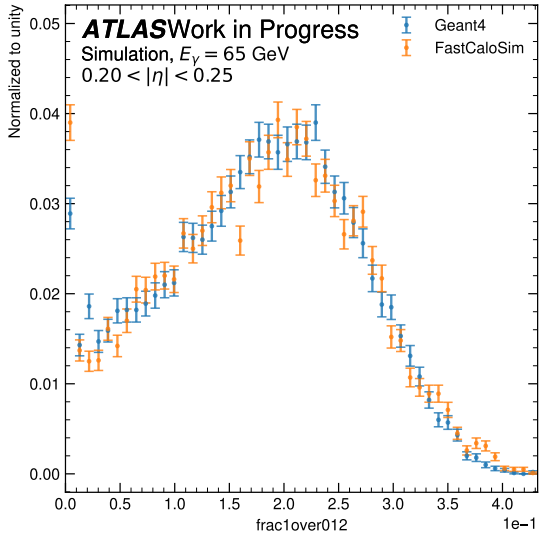
New shower shape variables for photons

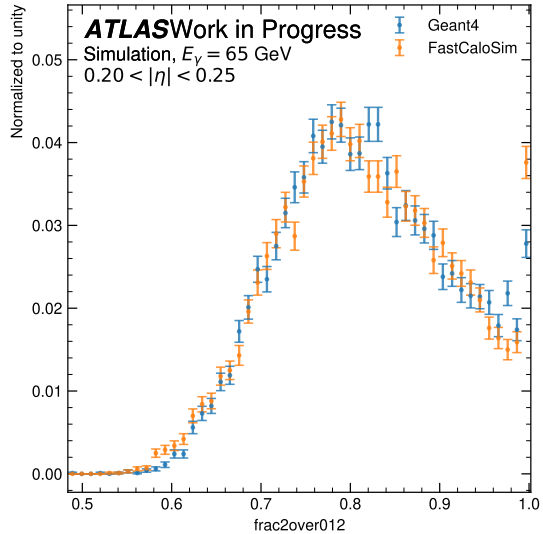




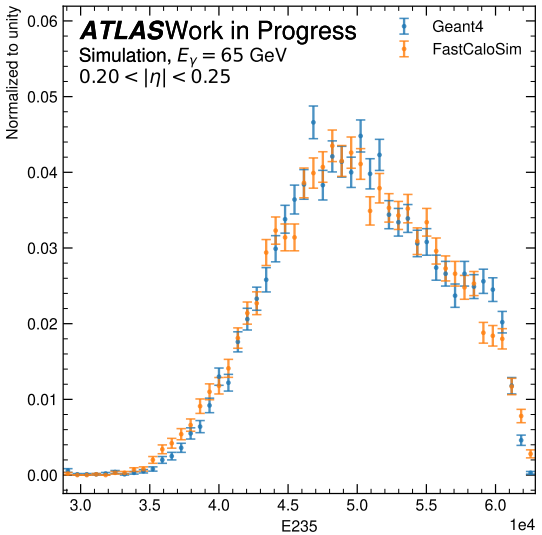


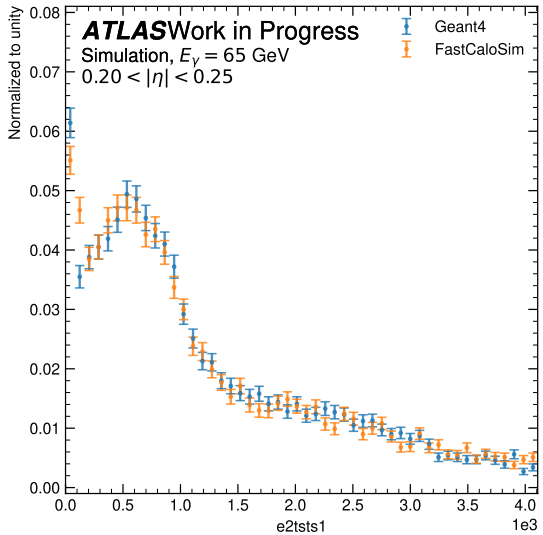


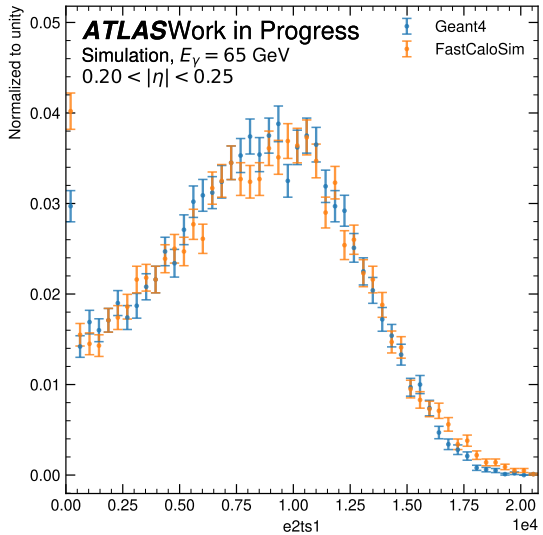


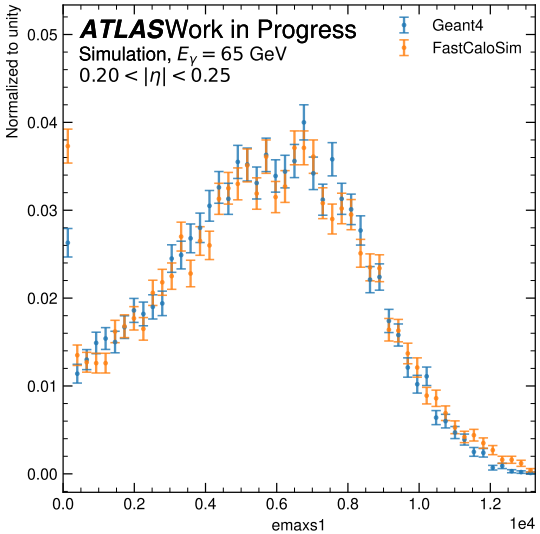


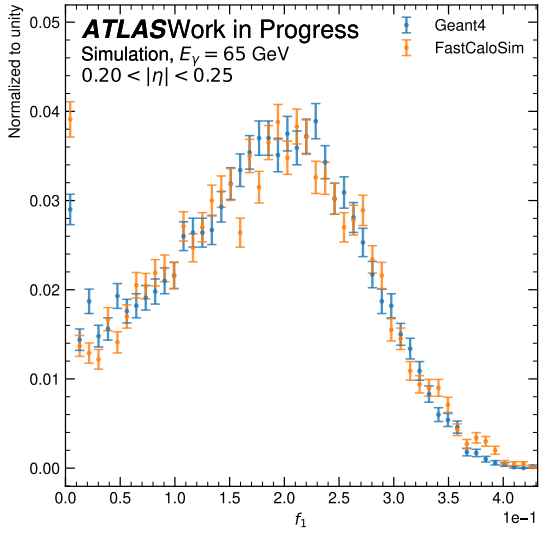
New shower shape variables for photons

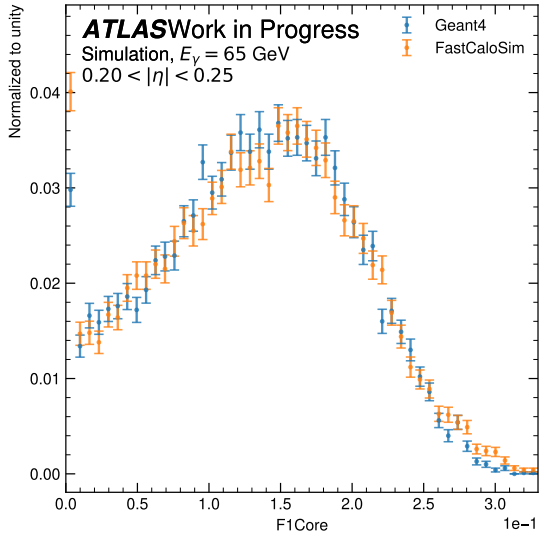




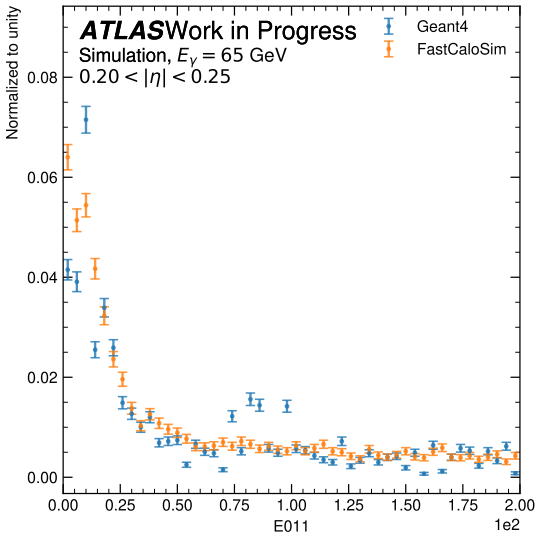


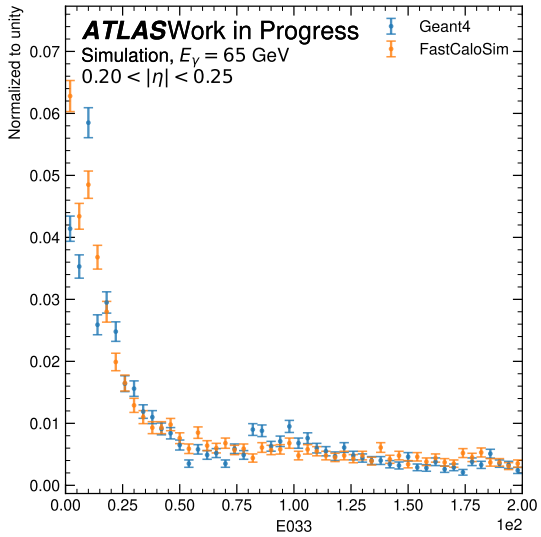


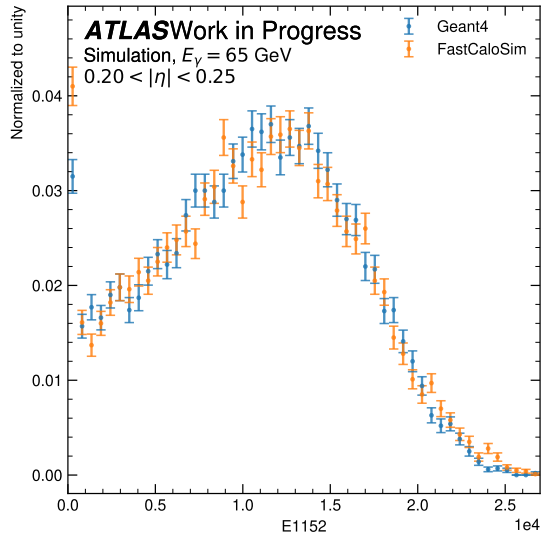


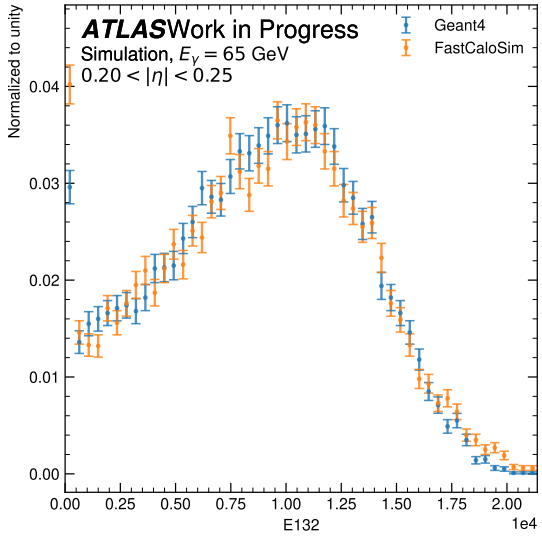


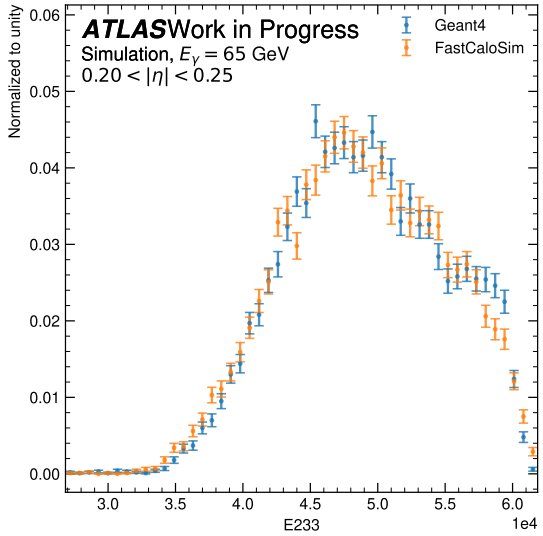
Energy window variables for photons

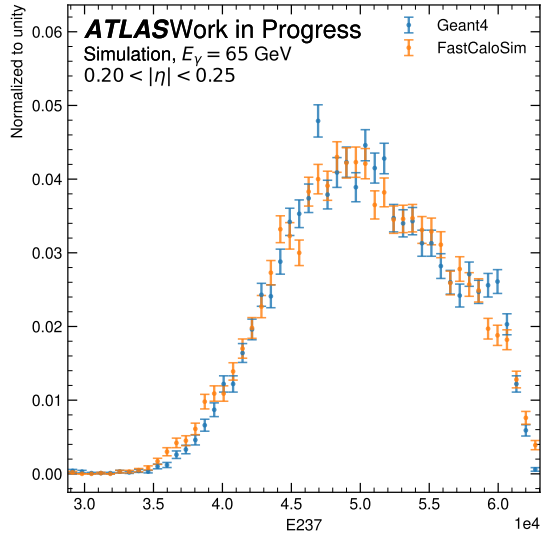




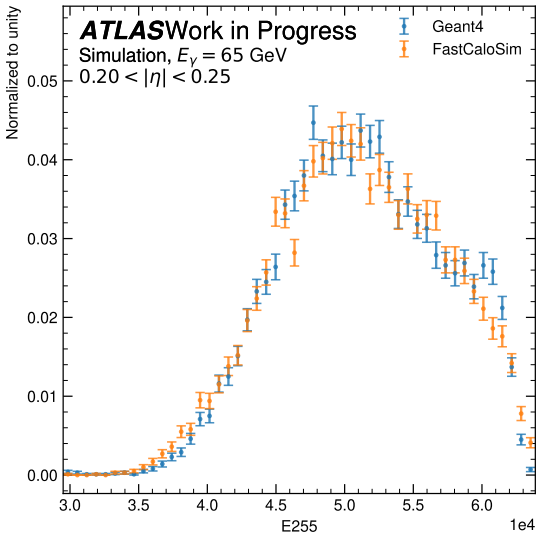


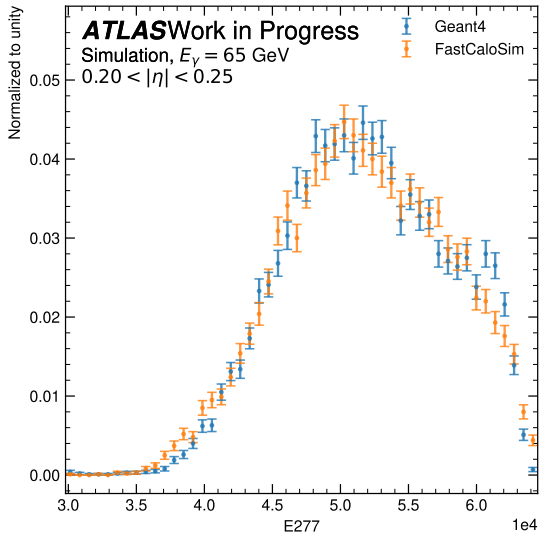


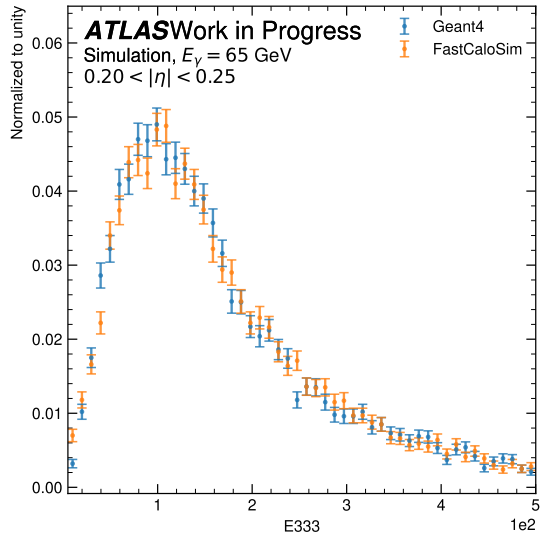


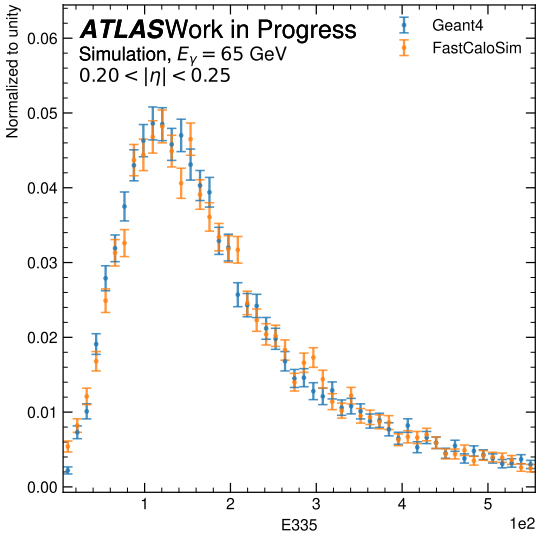


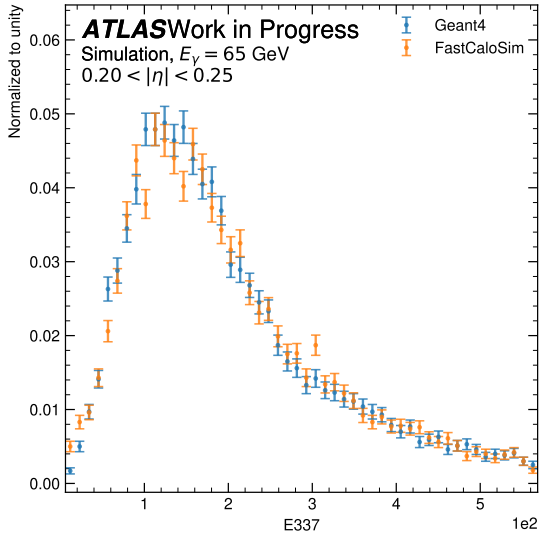
Energy window variables for photons

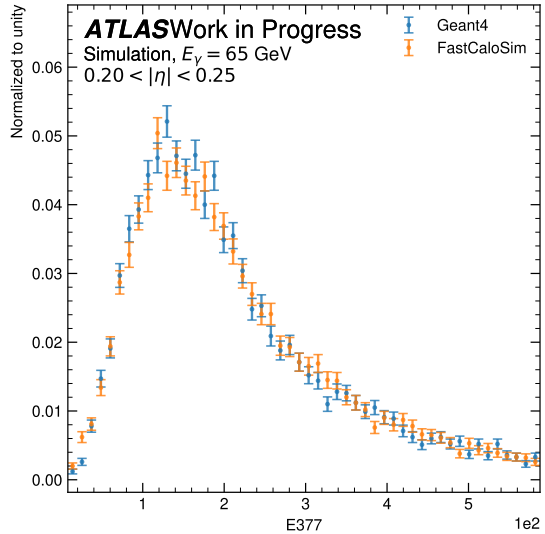




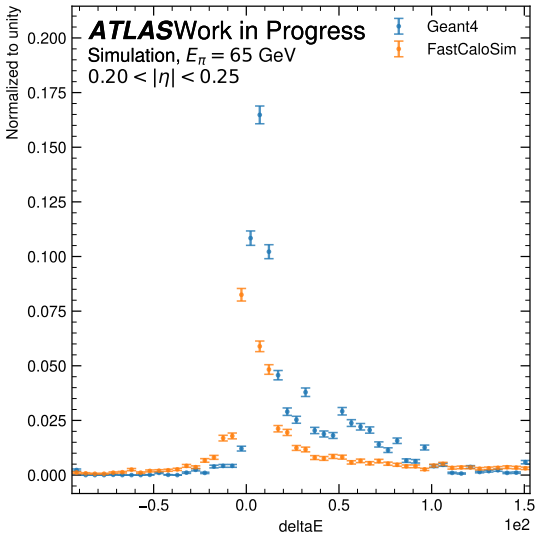


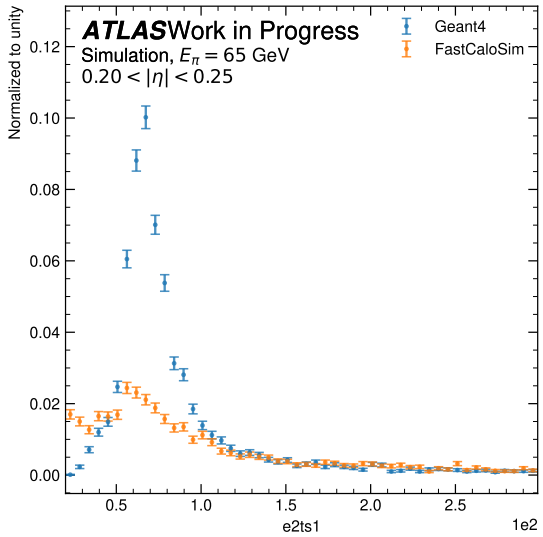


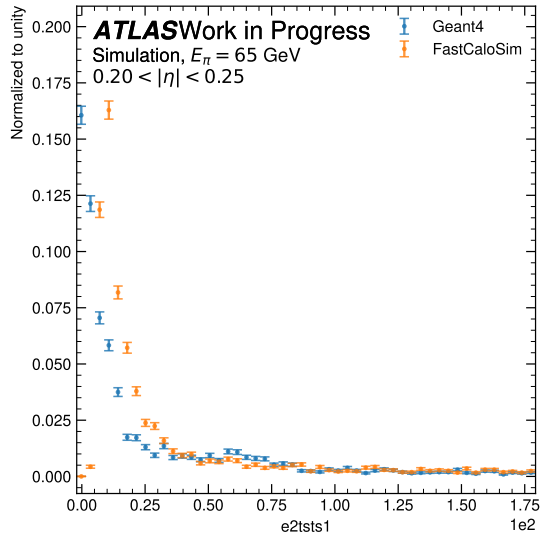


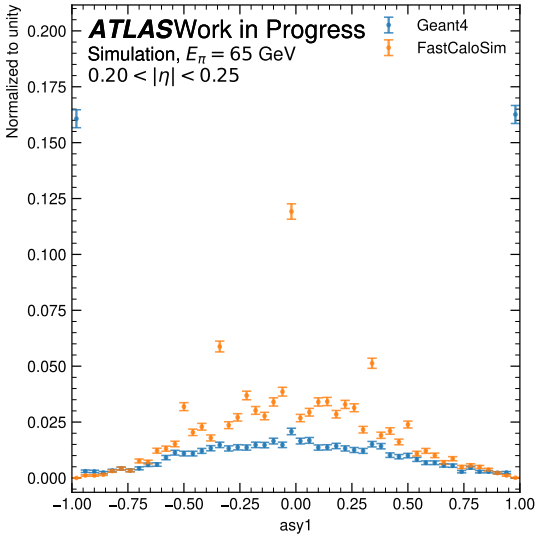


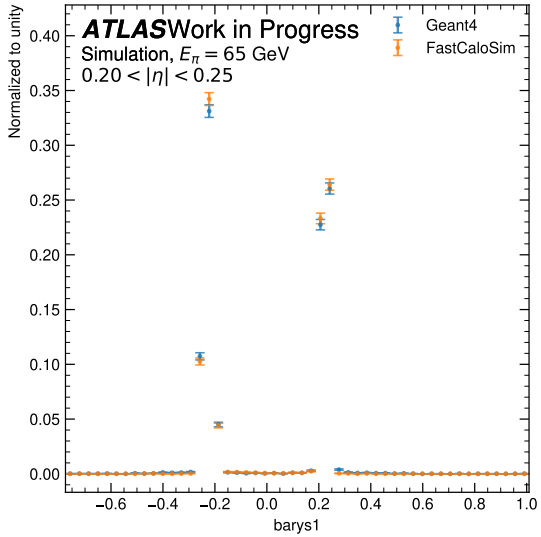
Shower shape variables for pions

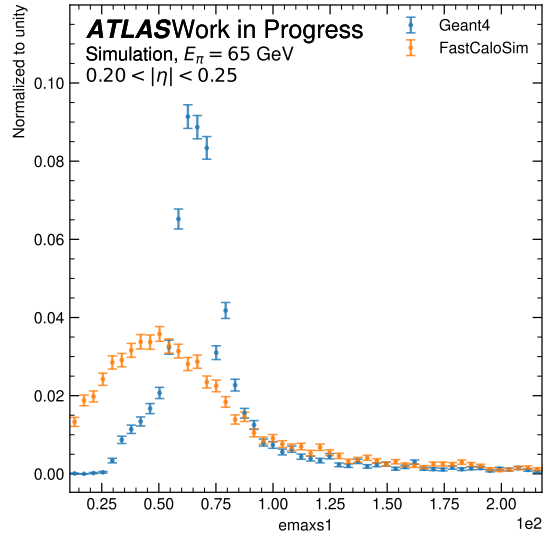












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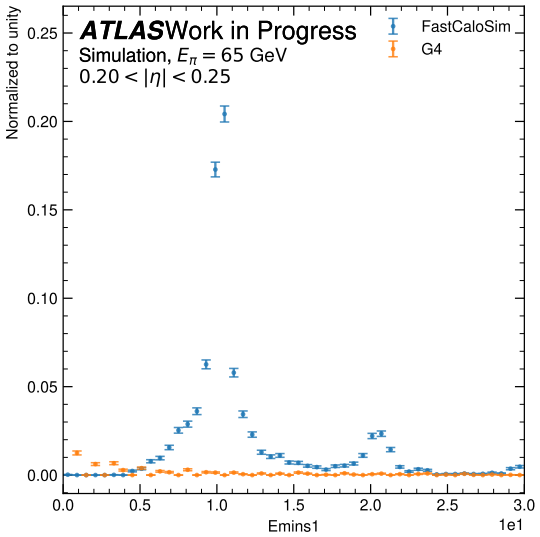

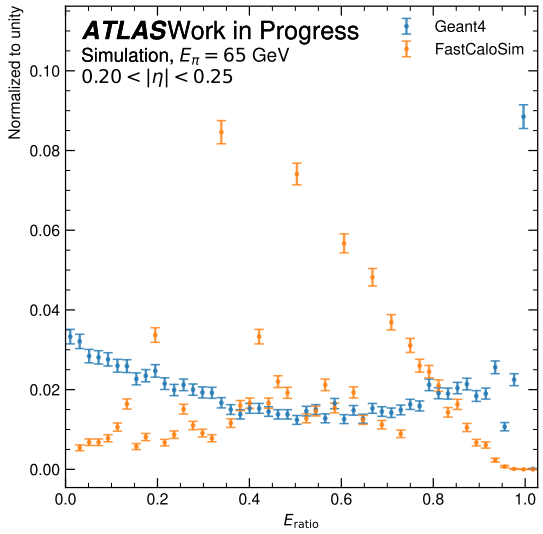

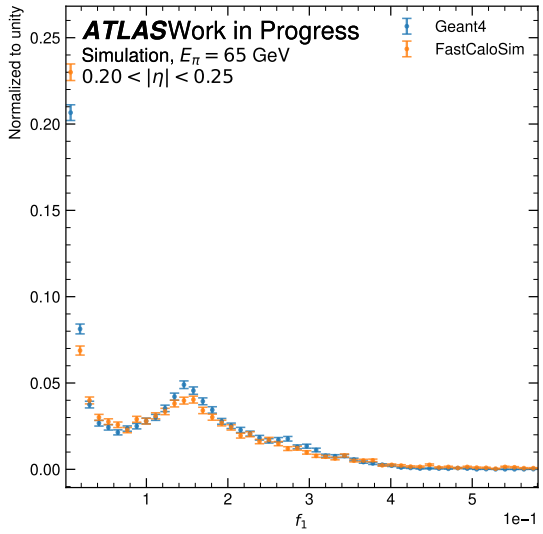

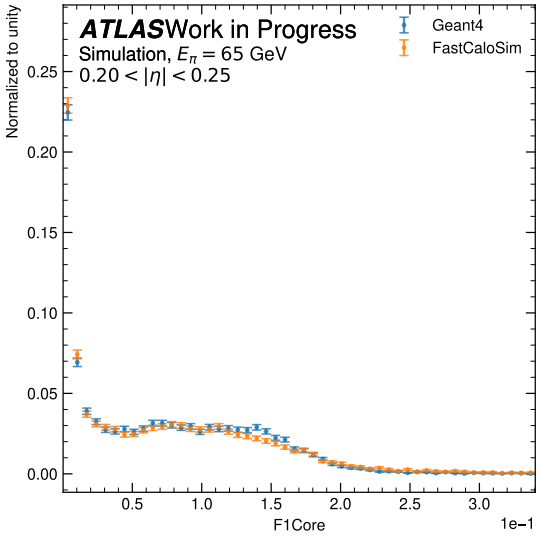

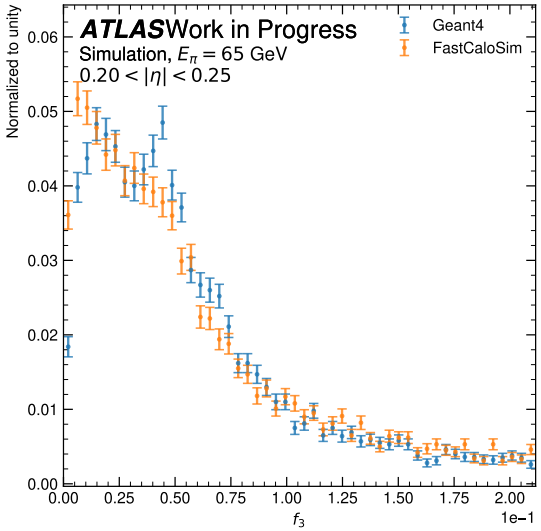

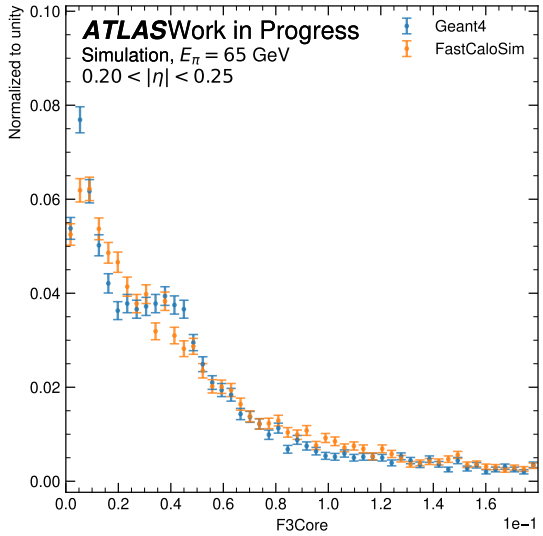

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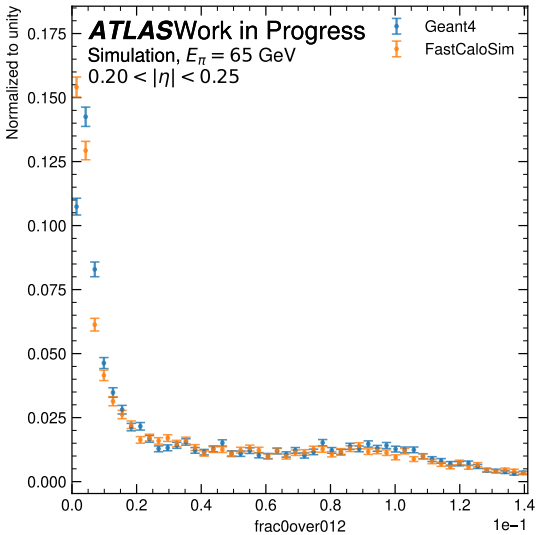

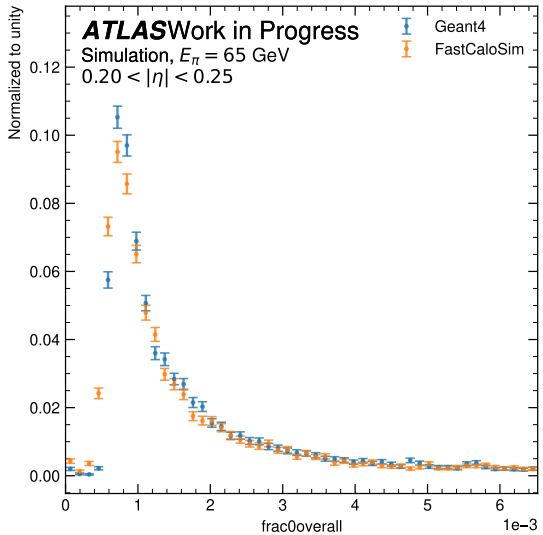

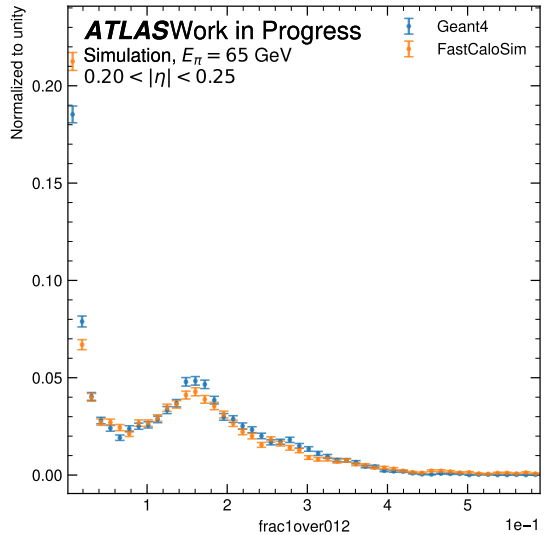

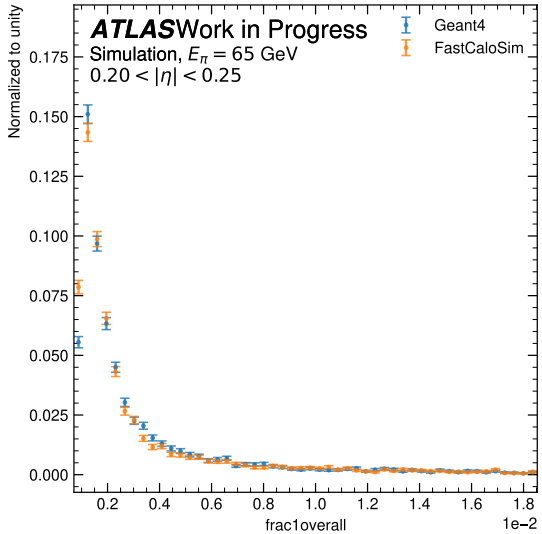

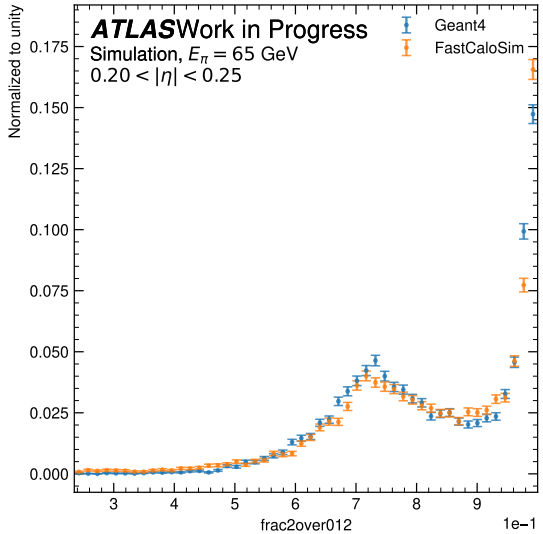

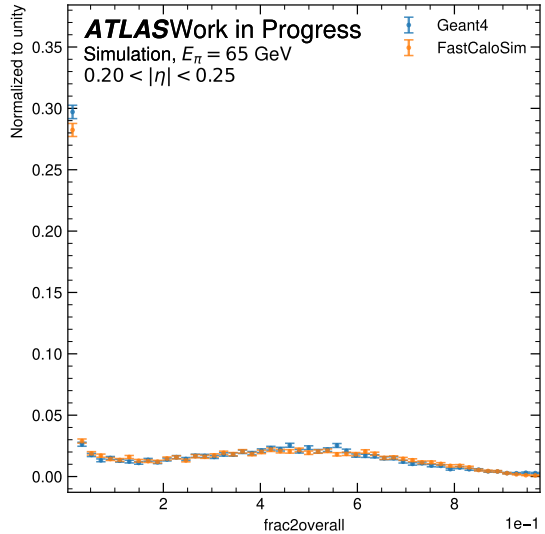

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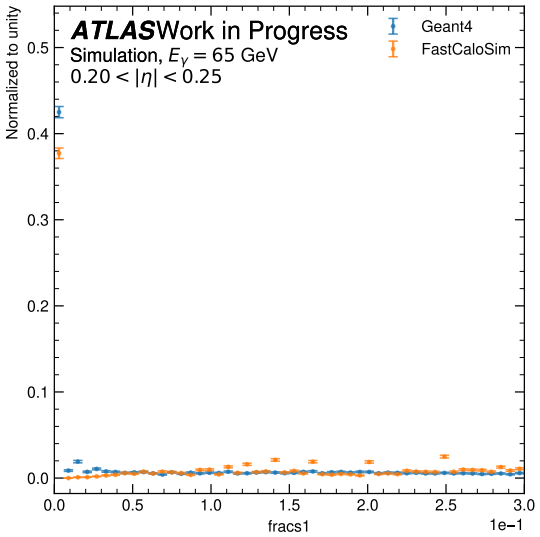

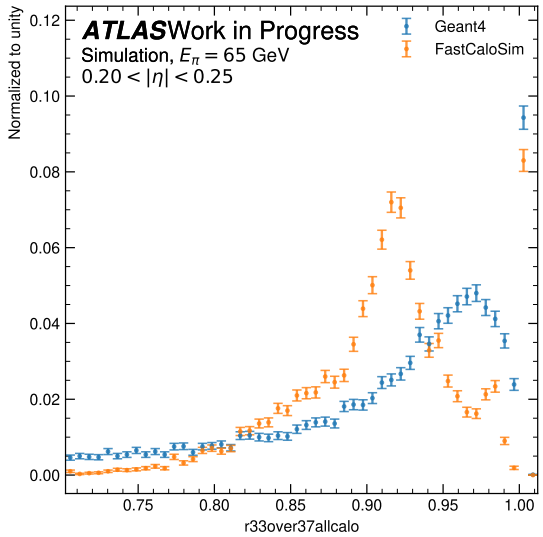

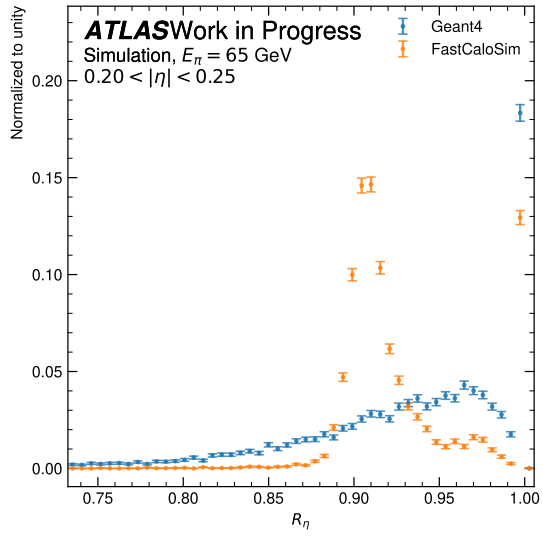

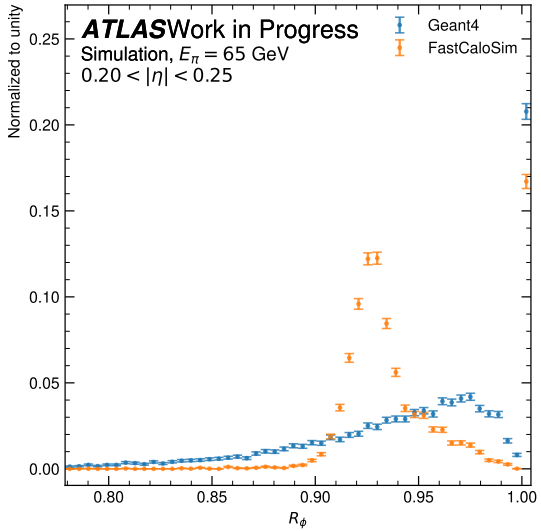

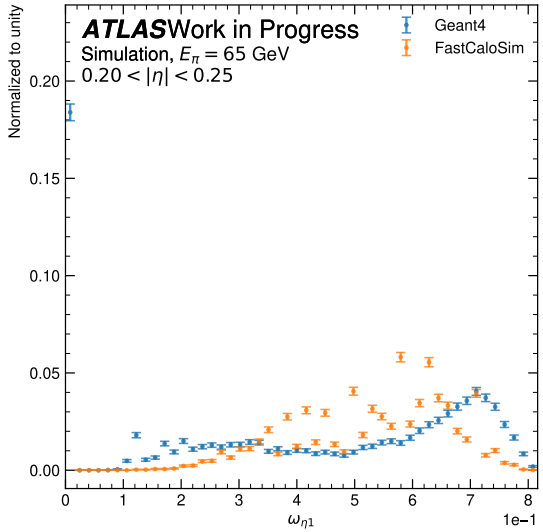

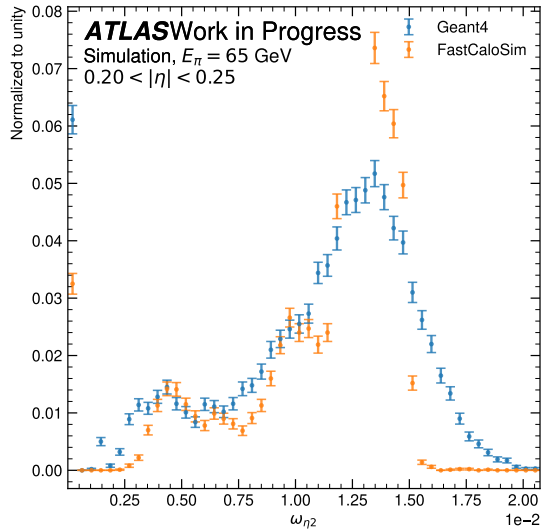

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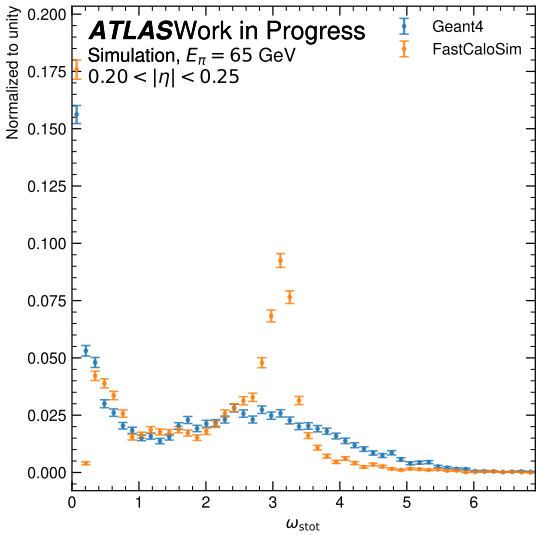
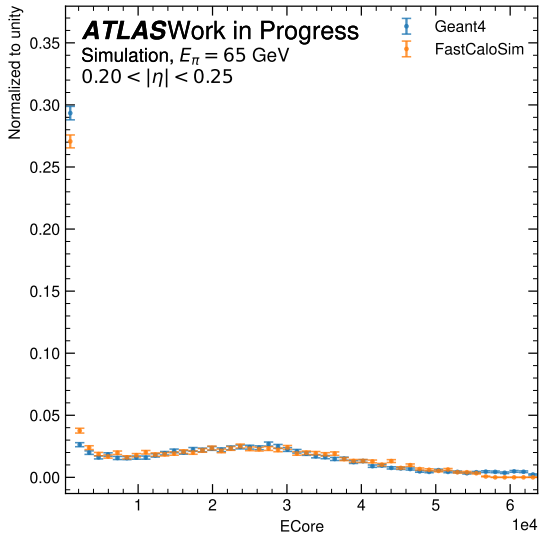
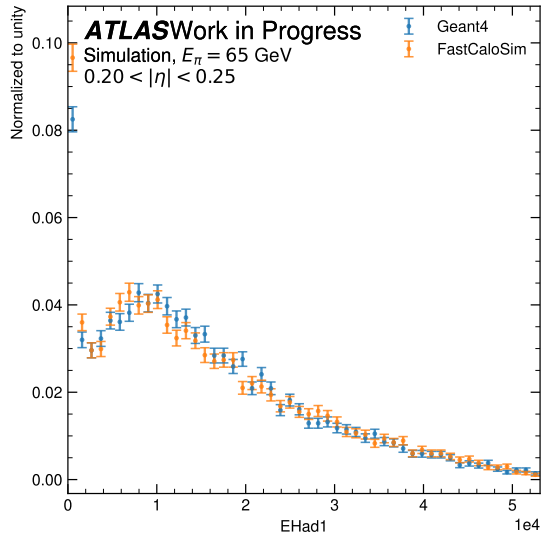
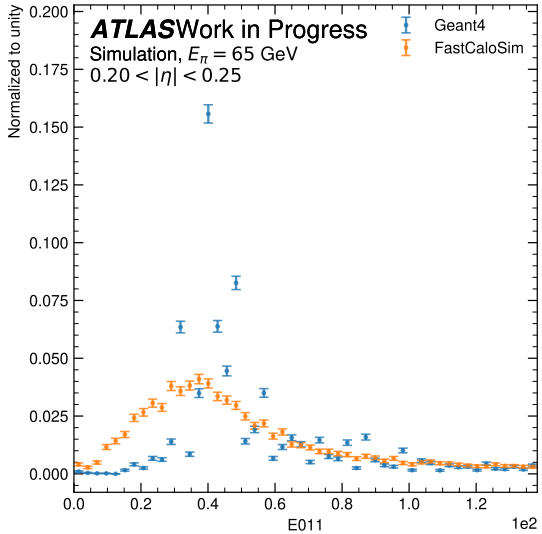
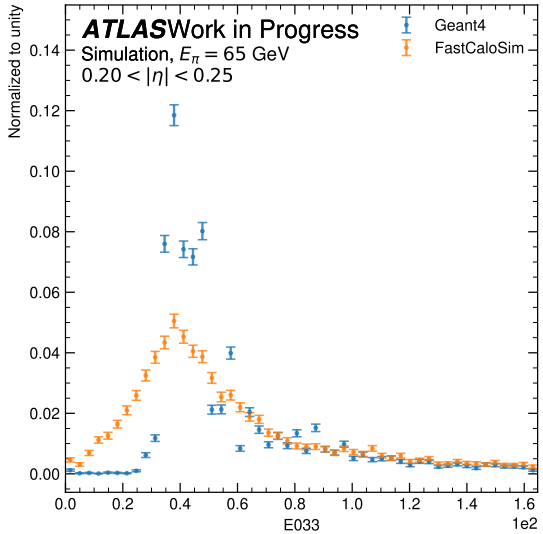
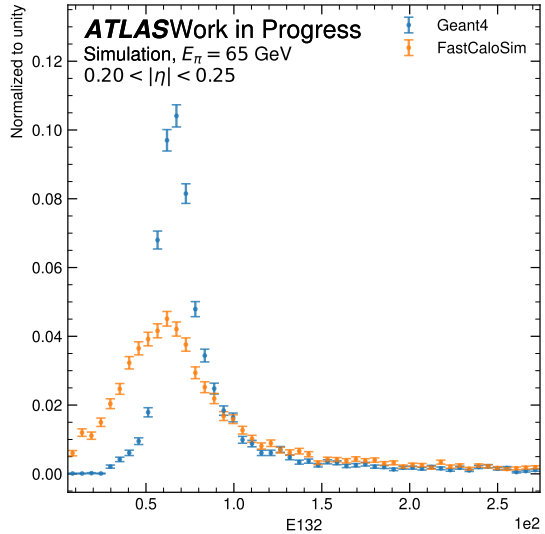




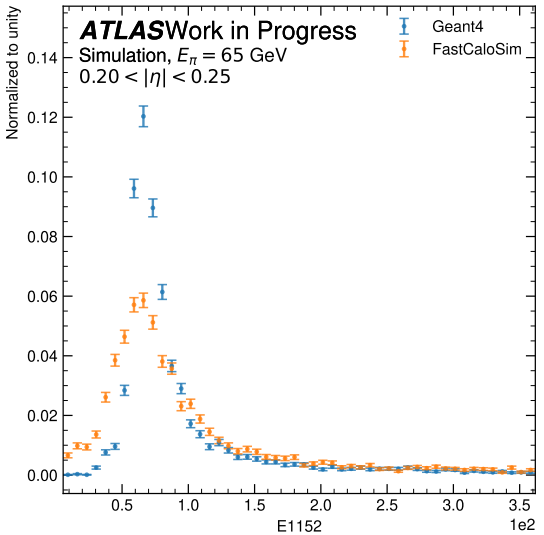


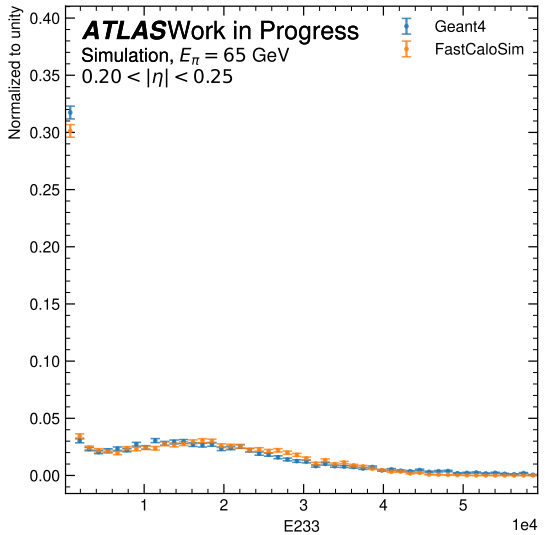


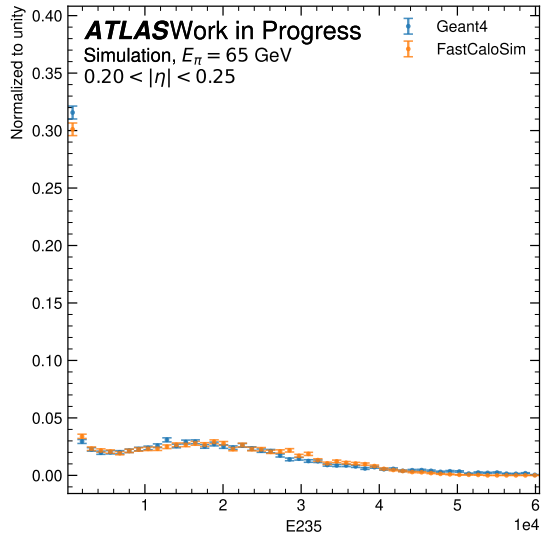


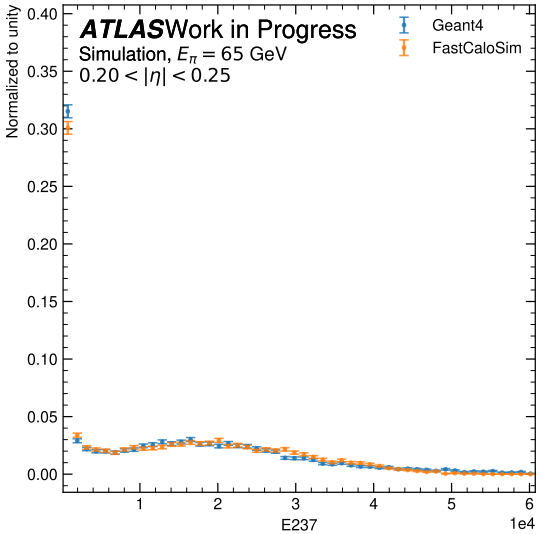


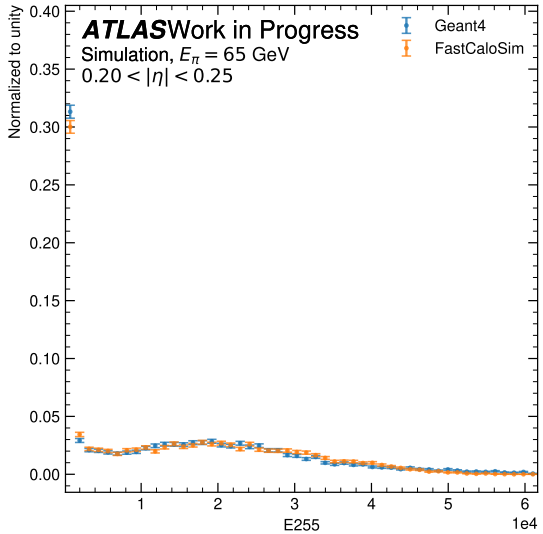
Energy window variables for pions

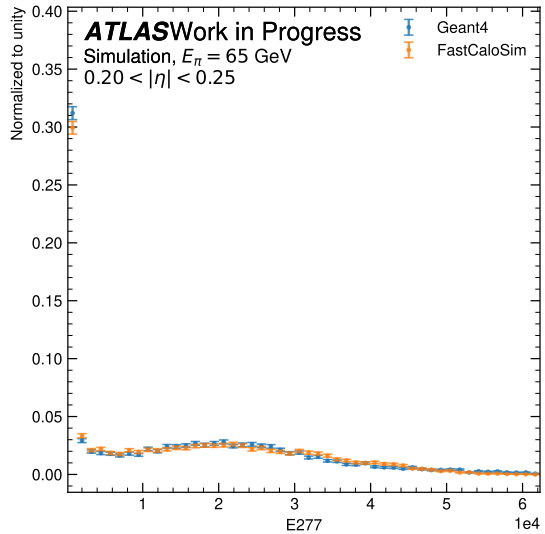




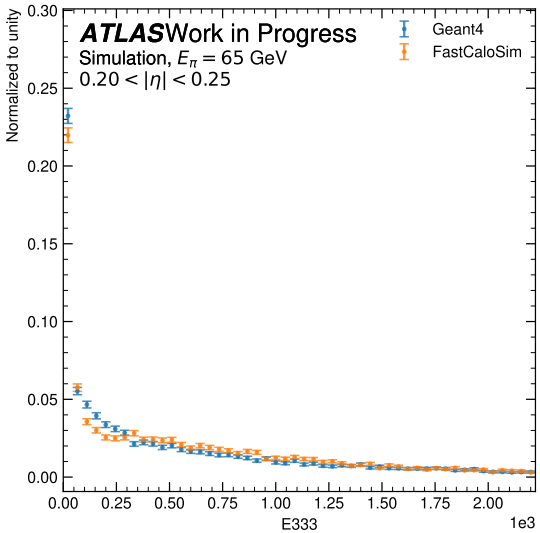


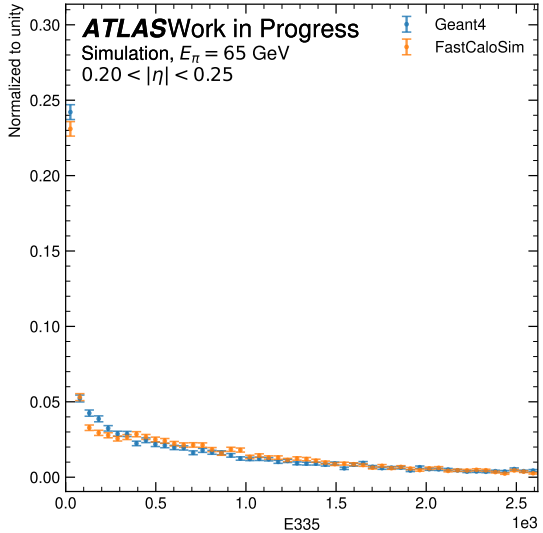


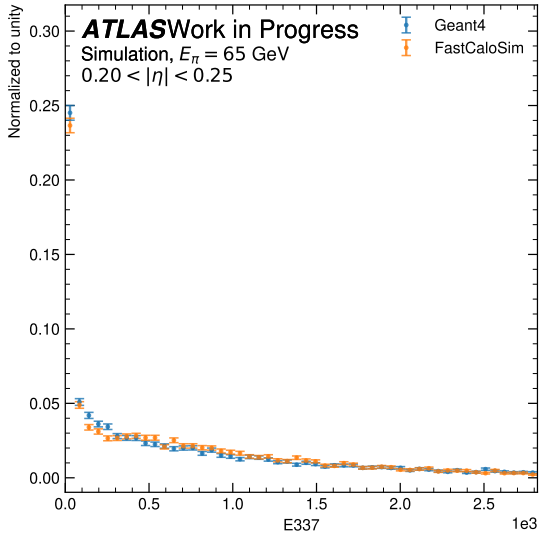


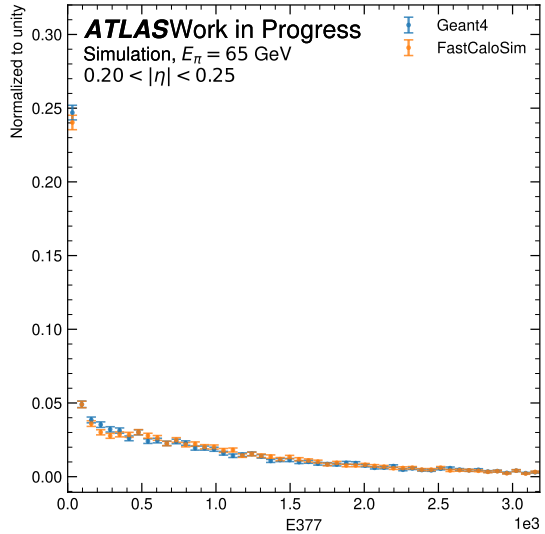


Energy window variables for pions









Means for electrons

Table 1: Electrons

variable	sim	mean	mean_error	rms	rms_error
E011	FCS	661.396000	3.947510	394.751000	2.791310
E011	G4	674.864000	3.980930	398.093000	2.814940
E033	FCS	775.496000	4.464080	446.408000	3.156580
E033	G4	782.072000	4.410990	441.099000	3.119040
weta1	FCS	0.604149	0.000499	0.049948	0.000353
weta1	G4	0.606610	0.000507	0.050708	0.000359
Wtots1	FCS	1.680870	0.000969	0.096949	0.000686
Wtots1	G4	1.684550	0.001336	0.133594	0.000945
Eratio	FCS	0.413612	0.001730	0.172953	0.001223
Eratio	G4	0.410286	0.001711	0.171135	0.001210
f1	FCS	0.229644	0.000665	0.066524	0.000470
f1	G4	0.230775	0.000646	0.064552	0.000456
E132	FCS	11371.500000	34.275600	3427.560000	24.236500
E132	G4	11388.900000	33.369500	3336.950000	23.595800
E1152	FCS	13900.800000	42.838100	4283.810000	30.291100
E1152	G4	13979.000000	41.971300	4197.130000	29.678200
fracs1	FCS	0.160675	0.000179	0.017862	0.000126
fracs1	G4	0.165532	0.000260	0.026041	0.000184
emaxs1	FCS	6959.120000	22.213200	2221.320000	15.707100
emaxs1	G4	6927.570000	21.343400	2134.340000	15.092100
EHad1	FCS	135.658000	4.475390	447.539000	3.164580
EHad1	G4	111.020000	2.812470	281.247000	1.988720
F1Core	FCS	0.171247	0.000535	0.053530	0.000379
F1Core	G4	0.171078	0.000519	0.051912	0.000367
r33over37allcalo	FCS	0.922188	0.000303	0.030308	0.000214
r33over37allcalo	G4	0.921918	0.000310	0.030994	0.000219
ECore	FCS	62732.100000	15.261000	1526.100000	10.791200
ECore	G4	62783.500000	15.113400	1511.340000	10.686800
Emins1	FCS	243.949000	5.027150	502.715000	3.554730
Emins1	G4	73.558500	2.952580	295.258000	2.087790
asy1	FCS	0.004258	0.003948	0.394791	0.002792
asy1	G4	-0.001840	0.003860	0.385979	0.002729
barys1	FCS	0.003510	0.002252	0.225156	0.001592
barys1	G4	0.003518	0.002252	0.225156	0.001592
e2tsts1	FCS	1858.020000	13.818500	1381.850000	9.771150
e2tsts1	G4	1859.070000	13.338300	1333.830000	9.431600
e2ts1	FCS	10509.800000	32.935300	3293.530000	23.288800
e2ts1	G4	10514.500000	31.885600	3188.560000	22.546500
deltaE	FCS	1614.070000	14.674800	1467.480000	10.376600
deltaE	G4	1691.910000	14.077000	1407.700000	9.953950
Reta	FCS	0.967163	0.000045	0.004548	0.000032
Reta	G4	0.967490	0.000052	0.005223	0.000037
Rphi	FCS	0.971439	0.000050	0.004967	0.000035
Rphi	G4	0.971965	0.000053	0.005322	0.000038
weta2	FCS	0.010698	0.000014	0.001436	0.000010
weta2	G4	0.010722	0.000015	0.001463	0.000010
E233	FCS	45195.100000	44.881700	4488.170000	31.736200
E233	G4	45202.700000	44.577300	4457.730000	31.520900
E235	FCS	46260.800000	45.170700	4517.070000	31.940500
E235	G4	46247.900000	44.638100	4463.810000	31.563900
E255	FCS	47395.600000	45.491200	4549.120000	32.167100
E255	G4	47372.900000	44.697900	4469.790000	31.606200
E237	FCS	46515.100000	45.220500	4522.050000	31.975700
E237	G4	46495.300000	44.638800	4463.880000	31.564400
E277	FCS	48084.300000	45.642700	4564.270000	32.274300
E277	G4	48044.600000	44.701900	4470.190000	31.609000
E333	FCS	145.386000	1.438160	143.816000	1.016930
E333	G4	148.701000	1.551040	155.104000	1.096750
E335	FCS	170.320000	1.626240	162.624000	1.149920
E335	G4	169.837000	1.620110	162.011000	1.145590
E337	FCS	180.121000	1.693160	169.316000	1.197240
E337	G4	177.977000	1.636440	163.644000	1.157140
E377	FCS	191.369000	1.757200	175.720000	1.242530
E377	G4	187.006000	1.649560	164.956000	1.166420
f3	FCS	0.003102	0.000029	0.002883	0.000020
f3	G4	0.003158	0.000027	0.002729	0.000019
F3Core	FCS	0.002265	0.000023	0.002292	0.000016
F3Core	G4	0.002316	0.000025	0.002534	0.000018
frac0overall	FCS	0.013275	0.000075	0.007520	0.000053
frac0overall	G4	0.013323	0.000071	0.007123	0.000050
frac1overall	FCS	0.229219	0.000666	0.066558	0.000471
frac1overall	G4	0.230416	0.000646	0.064562	0.000457
frac2overall	FCS	0.752309	0.000691	0.069128	0.000489
frac2overall	G4	0.751384	0.000672	0.067183	0.000475
frac0over012	FCS	0.013339	0.000075	0.007545	0.000053
frac0over012	G4	0.013384	0.000071	0.007147	0.000051
frac1over012	FCS	0.230282	0.000665	0.066507	0.000470
frac1over012	G4	0.231427	0.000645	0.064517	0.000456
frac2over012	FCS	0.756379	0.000708	0.070758	0.000500
frac2over012	G4	0.755189	0.000688	0.068773	0.000486

Means for photons

Table 2: Photons

variable	sim	mean	mean_error	rms	rms_error
E011	FCS	325.16	4.077270	407.727000	2.883070
E011	G4	351.227	3.986940	398.694000	2.819190
E033	FCS	384.775	4.628870	462.887000	3.273110
E033	G4	403.093	4.513620	451.362000	3.191610
weta1	FCS	0.566373	0.000963	0.096306	0.000681
weta1	G4	-nan	0.000000	0.000000	0.000000
Wtots1	FCS	1.62027	0.002749	0.274910	0.001944
Wtots1	G4	-nan	0.000000	0.000000	0.000000
Eratio	FCS	0.45002	0.001973	0.197348	0.001395
Eratio	G4	-nan	0.000000	0.000000	0.000000
f1	FCS	0.17639	0.000924	0.092352	0.000653
f1	G4	0.174869	0.000881	0.088053	0.000623
E132	FCS	8832.8	46.730700	4673.070000	33.043600
E132	G4	8781.03	44.122100	4412.210000	31.199000
E1152	FCS	10624.5	57.638500	5763.850000	40.756600
E1152	G4	10599	55.014300	5501.430000	38.901000
fracs1	FCS	0.135587	0.000402	0.040225	0.000284
fracs1	G4	-nan	0.000000	0.000000	0.000000
emaxs1	FCS	5570.39	29.087000	2908.700000	20.567600
emaxs1	G4	5513.97	27.041300	2704.130000	19.121100
EHad1	FCS	198.881	7.918160	791.816000	5.598980
EHad1	G4	171.743	7.237360	723.736000	5.117580
F1Core	FCS	0.133186	0.000718	0.071758	0.000507
F1Core	G4	0.132051	0.000671	0.067066	0.000474
r33over37allcalo	FCS	0.937972	0.000309	0.030898	0.000218
r33over37allcalo	G4	0.938656	0.000318	0.031818	0.000225
ECore	FCS	62677.4	19.192100	1919.210000	13.570900
ECore	G4	62797.4	22.183000	2218.300000	15.685700
Emins1	FCS	194.76	4.311340	431.134000	3.048580
Emins1	G4	54.8446	2.385690	238.569000	1.686940
asy1	FCS	0.00216521	0.004250	0.425041	0.003005
asy1	G4	-nan	0.000000	0.000000	0.000000
barys1	FCS	0.00352776	0.002251	0.225143	0.001592
barys1	G4	0.00352803	0.002254	0.225400	0.001594
e2tsts1	FCS	1387.16	12.993800	1299.380000	9.188030
e2tsts1	G4	1357.71	12.354300	1235.430000	8.735840
e2ts1	FCS	8195.78	43.772300	4377.230000	30.951700
e2ts1	G4	8137.68	41.208000	4120.800000	29.138400
deltaE	FCS	1192.4	13.466500	1346.650000	9.522230
deltaE	G4	1242.53	12.304100	1230.410000	8.700340
Reta	FCS	0.969258	0.000050	0.005010	0.000035
Reta	G4	0.969553	0.000073	0.007350	0.000052
Rphi	FCS	0.97339	0.000051	0.005107	0.000036
Rphi	G4	0.973891	0.000064	0.006375	0.000045
weta2	FCS	0.0104774	0.000015	0.001514	0.000011
weta2	G4	0.0104965	0.000015	0.001548	0.000011
E233	FCS	48836.9	61.465300	6146.530000	43.462500
E233	G4	49036.9	60.548900	6054.890000	42.814500
E235	FCS	49904.3	61.754000	6175.400000	43.666700
E235	G4	50081.3	60.538400	6053.840000	42.807100
E255	FCS	51044	62.016500	6201.650000	43.852300
E255	G4	51210.8	60.464300	6046.430000	42.754700
E237	FCS	50156	61.789200	6178.920000	43.691600
E237	G4	50329.2	60.497200	6049.720000	42.778000
E277	FCS	51727.6	62.108800	6210.880000	43.917600
E277	G4	51881.4	60.333400	6033.340000	42.662100
E333	FCS	219.414	2.658060	265.806000	1.879530
E333	G4	219.183	2.715510	271.551000	1.920160
E335	FCS	251.909	2.952830	295.283000	2.087960
E335	G4	246.128	2.828760	282.876000	2.000230
E337	FCS	263.477	3.046130	304.613000	2.153940
E337	G4	255.755	2.857480	285.748000	2.020540
E377	FCS	276.539	3.150170	315.017000	2.227510
E377	G4	266.056	2.880510	288.051000	2.036830
f3	FCS	0.00447558	0.000052	0.005239	0.000037
f3	G4	0.00448346	0.000053	0.005256	0.000037
F3Core	FCS	0.00344598	0.000043	0.004310	0.000030
F3Core	G4	0.00345465	0.000047	0.004683	0.000033
frac0overall	FCS	0.00721981	0.000080	0.008029	0.000057
frac0overall	G4	0.007034	0.000076	0.007551	0.000053
frac1overall	FCS	0.17591	0.000919	0.091869	0.000650
frac1overall	G4	0.174465	0.000879	0.087936	0.000622
frac2overall	FCS	0.809326	0.000951	0.095071	0.000672
frac2overall	G4	0.81129	0.000912	0.091195	0.000645
frac0over012	FCS	0.0072652	0.000081	0.008102	0.000057
frac0over012	G4	0.00708808	0.000077	0.007748	0.000055
frac1over012	FCS	0.176968	0.000926	0.092587	0.000655
frac1over012	G4	0.175441	0.000882	0.088176	0.000624
frac2over012	FCS	0.815767	0.000985	0.098455	0.000696
frac2over012	G4	0.817471	0.000939	0.093872	0.000664

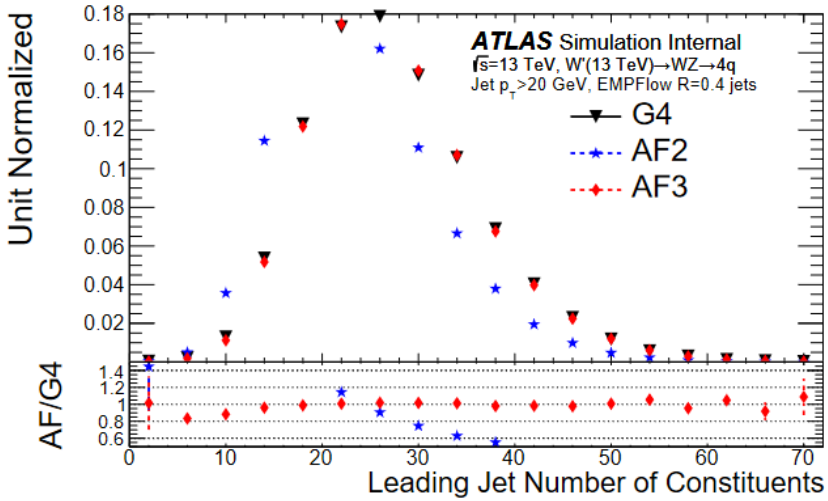
Means for pions

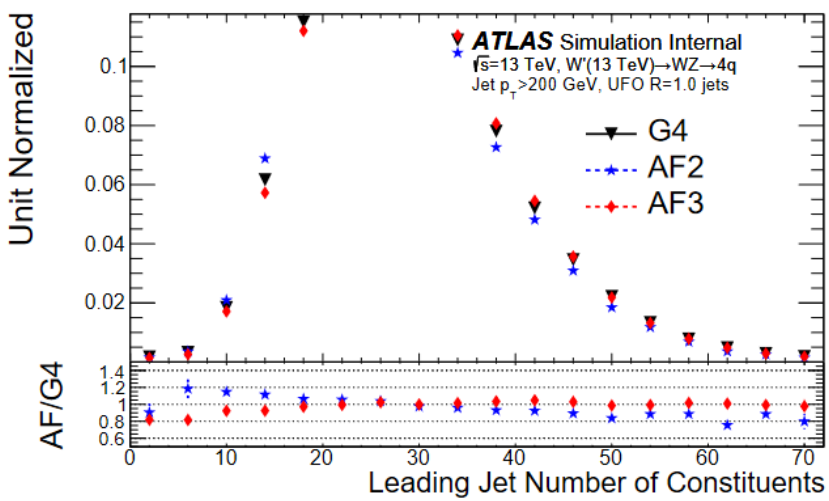
Table 3: Pions

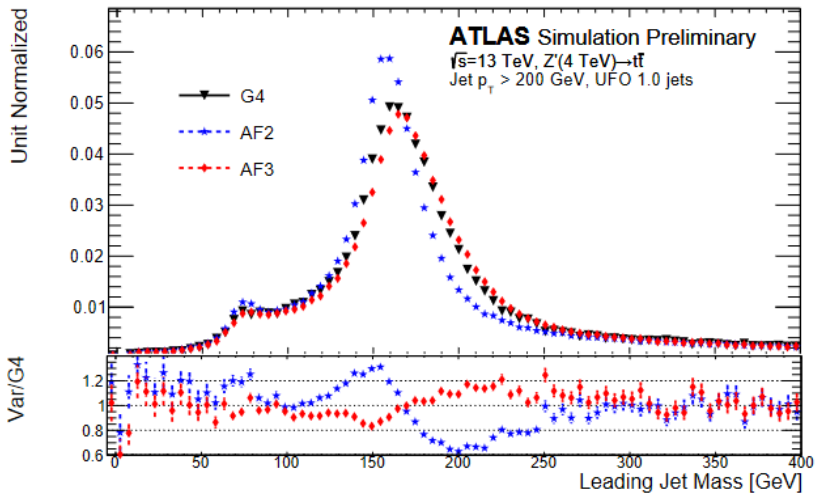
variable	sim	mean	mean_error	rms	rms_error
E011	FCS	220.016	3.765150	376.515000	2.662360
E011	G4	210.448	3.928800	392.880000	2.778080
E033	FCS	301.737	5.408410	540.841000	3.824320
E033	G4	311.139	6.059710	605.971000	4.284860
weta1	FCS	0.38346	0.002641	0.264110	0.001868
weta1	G4	-nan	0.000000	0.000000	0.000000
Wtots1	FCS	1.91198	0.013683	1.368280	0.009675
Wtots1	G4	-nan	0.000000	0.000000	0.000000
Eratio	FCS	0.444896	0.002651	0.265097	0.001875
Eratio	G4	0.498995	0.003322	0.332244	0.002349
f1	FCS	0.124249	0.001236	0.123645	0.000874
f1	G4	0.120753	0.001025	0.102514	0.000725
E132	FCS	1130.15	17.487800	1748.780000	12.365800
E132	G4	1143.87	19.848000	1984.800000	14.034600
E1152	FCS	1725.38	27.984900	2798.490000	19.788300
E1152	G4	1881.41	31.331700	3133.170000	22.154900
fracs1	FCS	0.168719	0.001903	0.190254	0.001345
fracs1	G4	0.179582	0.002465	0.246452	0.001743
emaxs1	FCS	702.634	10.447200	1044.720000	7.387280
emaxs1	G4	607.647	10.518800	1051.880000	7.437910
EHad1	FCS	15488.2	124.231000	12423.100000	87.844800
EHad1	G4	15815	124.758000	12475.800000	88.217500
F1Core	FCS	0.0761826	0.000797	0.079659	0.000563
F1Core	G4	0.0709065	0.000631	0.063052	0.000446
r33over37allcalo	FCS	0.909606	0.000577	0.057688	0.000408
r33over37allcalo	G4	0.90585	0.000944	0.094430	0.000668
ECore	FCS	17307.6	155.472000	15547.200000	109.936000
ECore	G4	17722	163.930000	16393.000000	115.916000
Emins1	FCS	25.976	0.636222	63.622200	0.449877
Emins1	G4	2.33796	0.386771	38.677100	0.273488
asy1	FCS	-0.00584202	0.003546	0.354580	0.002507
asy1	G4	-nan	0.000000	0.000000	0.000000
barys1	FCS	0.00184079	0.002250	0.224955	0.001591
barys1	G4	0.00215782	0.002314	0.231389	0.001636
e2tsts1	FCS	219.621	3.752270	375.227000	2.653250
e2tsts1	G4	267.715	5.024250	502.425000	3.552680
e2ts1	FCS	1036.98	16.337300	1633.730000	11.552200
e2ts1	G4	1072.55	18.426300	1842.630000	13.029400
deltaE	FCS	194.05	3.761330	376.133000	2.659660
deltaE	G4	175.126	4.050710	405.071000	2.864280
Reta	FCS	0.926959	0.000370	0.036972	0.000261
Reta	G4	0.927604	0.000719	0.071932	0.000509
Rphi	FCS	0.944269	0.000304	0.030429	0.000215
Rphi	G4	0.942711	0.000612	0.061180	0.000433
weta2	FCS	-nan	0.000000	0.000000	0.000000
weta2	G4	-nan	0.000000	0.000000	0.000000
E233	FCS	12662.9	118.774000	11877.400000	83.986100
E233	G4	12978.9	131.706000	13170.600000	93.130000
E235	FCS	13407.4	126.170000	12617.000000	89.215600
E235	G4	13661.5	136.316000	13631.600000	96.389800

variable	sim	mean	mean_error	rms	rms_error
E255	FCS	14293.4	134.911000	13491.100000	95.396700
E255	G4	14465.6	141.706000	14170.600000	100.201000
E237	FCS	13653.6	128.595000	12859.500000	90.930700
E237	G4	13882.1	137.676000	13767.600000	97.351700
E277	FCS	15035	142.175000	14217.500000	100.533000
E277	G4	15114.3	145.875000	14587.500000	103.149000
E333	FCS	781.66	9.510210	951.021000	6.724740
E333	G4	886.662	12.815600	1281.560000	9.061970
E335	FCS	881.665	10.798400	1079.840000	7.635650
E335	G4	951.936	13.184700	1318.470000	9.322980
E337	FCS	926.176	11.373400	1137.340000	8.042200
E337	G4	977.789	13.287300	1328.730000	9.395520
E377	FCS	998.068	12.293900	1229.390000	8.693130
E377	G4	1019.41	13.407600	1340.760000	9.480590
f3	FCS	0.0949133	0.001251	0.125109	0.000885
f3	G4	0.0934013	0.001128	0.112795	0.000798
F3Core	FCS	0.0702192	0.000924	0.092425	0.000654
F3Core	G4	0.0765076	0.001050	0.104996	0.000742
frac0overall	FCS	0.00944844	0.000176	0.017629	0.000125
frac0overall	G4	0.00897227	0.000168	0.016842	0.000119
frac1overall	FCS	0.0475436	0.000744	0.074422	0.000526
frac1overall	G4	0.0475623	0.000739	0.073864	0.000522
frac2overall	FCS	0.305366	0.002723	0.272252	0.001925
frac2overall	G4	0.302723	0.002704	0.270413	0.001912
frac0over012	FCS	0.0517523	0.000699	0.069901	0.000494
frac0over012	G4	0.0495765	0.000591	0.059052	0.000418
frac1over012	FCS	0.133371	0.001286	0.128615	0.000909
frac1over012	G4	0.128587	0.001050	0.104987	0.000742
frac2over012	FCS	0.814876	0.001631	0.163066	0.001153
frac2over012	G4	0.821836	0.001404	0.140401	0.000993

Jets in AtlFast3







Likelihood identification

- goal: discriminate between signal and background
  - signal L_S: prompt electrons L_B:
    - combination of jets
    - electrons from photon conversion
    - non-prompt electrons from decay of hadrons containing heavy flavours
- define different variables i to discriminate with value x_i for each variable
- $L_{S(B)}(\boldsymbol{x}) = \prod_{i=1}^{n} P_{S(B),i}(x_i)$
  $\boldsymbol{x}$: vector of quantities, $P_{S,i}(x_i)$: value of the signal pdf for quantity i at value x_i
- for each candidate: form discriminant $d_L = \frac{L_S}{L_S+L_B}$ and transformation $d'_L = -\tau^{-1}\ln(d_L^{-1} - 1)$, $\tau = 15$