# Energetic Pions, Differences For The Hadronic Interaction Models

### **Motivation**

"Effect of the uncertainty in the hadronic interaction models on the estimation of the sensitivity of the Cherenkov Telescope Array" by Michiko Ohishi et al.

Predicts "~30% differences in the estimated gamma-ray sensitivity in the 1 - 30 TeV region"



### Goals:

-Recreate the plots and methods -Propose accurate uncertainties for background events dependent on the models -include updated/different models

### Cosmic Ray Monte Carlo package (CRMC)

-dowload and documentation at https://web.ikp.kit.edu/rulrich/crmc.html

-simulates particle collisions

-many different starting configurations possible (momenta, particle types, etc.)

-many different models possible (qgsjetII.03/04,sibyll2.3,Epos1.99/LHC,pythia)

### The Output

#### E 0 7 17

#### U GEV MM

A 0 GenCrossSection 3.03984261e+10 0.00000000e+00 -1 -1 P 1 0 2212 0.0000000000000000e+00 0.0000000000000e+00 1.9999996943362259e+01 2.0021994083191210e+01 9.3827998638153076e-01 4 V -1 0 [1,2] 0 -7,1010173652644171e-13 -4,9115041460962017e-13 0.00000000000000e+00 0.00000000000000e+00 P 3 -1 2218 3.4971567988395691e-01 -4.6587398648262024e-01 1.9825745197268609e+00 2.8137446952542446e+00 1.9097690582275391e+00 2 P 4 -1 221 -1.6727232933044434e-01 1.4424820244312286e-01 1.0745226553616332e+01 1.0761450839294897e+01 5.4785299301147461e-01 2 P 5 -1 2214 -1.8244336545467377e-01 3.2162576913833618e-01 7.2721993712126487e+00 7.3850820168220830e+00 1.2319999933242798e+00 2 V -2 0 [3] @ -6.1940199063553747e-13 -6.1197612732585838e-13 5.1418633419047416e-13 7.2975259963987642e-13 P 6 -2 2114 7.8662347793579102e-01 -2.2637072205543518e-01 1.4793495892073181e+00 2.0919654372103249e+00 1.2319999933242798e+00 2 P 7 -2 211 -4.3690773844718933e-01 -2.3950332403182983e-01 5.0322482543064451e-01 7.2177924136371829e-01 1.3957017660140991e-01 1 V -3 0 [4] @ -1.9894079716920032e-09 1.7188873657758563e-09 1.2793228262830299e-07 1.2812544894450540e-07 P 8 -3 22 8.1344880163669586e-02 -1.8979825079441071e-02 2.8478920728196366e-01 2.9678631348695517e-01 0.00000000000000e+00 1 P 9 -3 22 -2.4861723184585571e-01 1.6322803497314453e-01 1.0460437107775167e+01 1.0464664275794593e+01 0.00000000000000e+00 1 V -4 0 [5] @ 2.0916573594681465e-12 1.5415827251882841e-12 1.5404994873179212e-12 1.5644118724735215e-12 P 10 -4 2212 -3.5739997029304504e-01 2.1000677347183228e-01 5.3974704862966663e+00 5.4940781362260598e+00 9.3827998638153076e-01 1 P 11 -4 111 1.7495658993721008e-01 1.1161897331476212e-01 1.8747288869988223e+00 1.8910038827788682e+00 1.3497659564018250e-01 2 V -5 0 [6] @ -2.1378341805156076e-13 -7.2870312214923239e-13 1.2770057550583666e-12 1.8084644175302558e-12 P 12 -5 2112 8.7677687406539917e-01 -2.2323083877563477e-01 1.2199765638562652e+00 1.7859743317803751e+00 9.3957000970840454e-01 1 P 13 -5 111 -9.0153411030769348e-02 -3.1398646533489227e-03 2.5937291027044995e-01 3.0599098716024364e-01 1.3497659564018250e-01 2 V -6.0 [11] @ 9.0087632997892797e-06 5.7474189816275612e-06 9.6532417028961863e-05 9.7370439309575979e-05 P 14 -6 22 3.5485491156578064e-02 7.8020788729190826e-02 3.8720259573009363e-01 3.9657573513349370e-01 0.0000000000000e+00 1 P 15 -6 22 1.3947109878063202e-01 3.3598184585571289e-02 1.4875261178517236e+00 1.4944279764155726e+00 0.000000000000000e+00 1 V -7 0 [13] @ -2.7599147870205343e-05 -9.6122448667301796e-07 7.9403219885903131e-05 9.3674662826716281e-05 P 16 -7 22 2.6705512776970863e-02 1.6171928495168686e-02 1.1545001840329717e-01 1.1959691648723833e-01 0.0000000000000e+00 1 P 17 -7 22 -1.1685892939567566e-01 -1.9311793148517609e-02 1.4392292185992933e-01 1.8639410444221127e-01 0.000000000000000e+00 1 E 1 8 22 U GEV MM A 0 GenCrossSection 3.03984261e+10 0.00000000e+00 -1 -1 P 2 0 2212 0.0000000000000000e+00 0.0000000000000e+00 1.4324156656713482e-07 9.3827998638154175e-01 9.3827998638153076e-01 4 V -1 0 [1,2] @ -1.3555517385660520e-12 -1.1666814975046236e-13 0.00000000000000e+00 0.0000000000000e+00 P 3 -1 31214 3.4312832355499268e-01 -2.3965820670127869e-01 8.6226775511548794e+00 8.7998308179309674e+00 1.7062476873397827e+00 2 P 4 -1 31214 -6.0300529003143311e-01 -7.9705059528350830e-02 1.0233257318217621e+01 1.0411743651849092e+01 1.8206818103790283e+00 2 P 5 -1 111 -1.3871575891971588e-01 -6.2353359535336494e-03 7.9470192151385610e-01 8.1795523509270029e-01 1.3497659564018250e-01 2 P 6 -1 211 2.2520960867404938e-01 1.7676916718482971e-01 -5.9722892867539117e-02 3.2405765603570152e-01 1.3957017660140991e-01 1 P 7 -1 111 6.8188183009624481e-02 1.1569449305534363e-01 3.8190560685534192e-01 4.2673811400394895e-01 1.3497659564018250e-01 2 P 8 -1 211 1.0519491136074066e-01 3.3134937286376953e-02 2.7180294784564050e-02 1.7995137139319270e-01 1.3957017660140991e-01 1 V -2 0 [3] @ -1.3420403026723204e-12 -1.2610519453757491e-13 3.3953592565364187e-13 3.4651170543457584e-13 P 9 -2 2112 -7.7241942286491394e-02 -2.8193891048431396e-01 3.6930685766923799e+00 3.8219109333145642e+00 9.3957000970840454e-01 1 P 10 -2 221 4.2037028074264526e-01 4.2280703783035278e-02 4.9296088060018874e+00 4.9779197174127887e+00 5.4785299301147461e-01 2 V -3 0 [4] @ 2.6410687872790994e-13 1.4073476135552723e-14 3.1860904960345330e-12 3.2416616264784507e-12 P 11 -3 2212 -1.8711513280868530e-01 8.3505153656005859e-02 6.6197192772928419e+00 6.6890236826176439e+00 9.3827998638153076e-01 1 P 12 -3 -213 -4.1589015722274780e-01 -1.6321021318435669e-01 3.6135386096489528e+00 3.7227205372259355e+00 7.7548998594284058e-01 2

### -.hepmc3 format

-multitude of properties (for particles and "events")

-main work is parsing through this data

-models at the moment:

eposlhc; ggsjetl104, sibyl12.3

-various bottlenecks are: simulating time, processing time, data storage

(~4-8 Gb for 2e+06 interaction events, dep. on model)

# The Main Plots

How are they created and weighted?

What regions are interesting?



"Multiplicity of an event": The number of end product +ve pions created by an interaction event

### Changing behaviour for minimal decay length

-High and Low E/E<sub>0</sub> regions dominated by the decay of resonances (at least using Eposlhc)



### The Multiplicity Plot

-Low multiplicity events dominate the high end (last decade) of  $E/E_0$ 

-Very different results for different models expected here



# What is Still to Do?

-Rinse and repeat for the different hadronic interaction models (especially for pythia)

-How do the air showers differ for different hadronic interaction models?

-What uncertainties for gamma-ray like air showers arise from these differences? (and what are the corresponding uncertainties in the gamma-ray like backgrounds arising from these model differences?)

### Question to the Audience

-How can I (crudely) model the detector? ie. which of the pions produced will have their momenta and energy measured by LHCf, and with what accuracy?

-How can data be stored to be most accessible/useful to others in the group?