The total cross-section

• $\sigma_{tot} = \sigma_{el} + \sigma_{diff} + \sigma_{jets} + \sigma_{EW} + \sigma_{bsm} + \dots$



Monte Carlo simulations

- The final states of high energy collisions ("*events*") are single samples from the distributions (differential cross-sections) predicted by Quantum Field theory.
- These final states are, in general, very complex.
- So is the response of the detector to those collisions.
- It would be impossible to understand the detected events except through detailed, iterative comparisons with detailed simulations.
- The heart of these simulations is the "event loop".
- The simulations generate single events using (pseudo-)random numbers to sample the QFT predictions and fix other variables that are essentially random; hence, "Monte Carlos".
- A Monte Carlo is actually an extremely elaborate integral:
 N = Σ_{fs} ∫ σ d(phase space of final state)
- Phase space is all possible configuration of final state momenta, consistent with energy-momentum conservation.
- Sum over all final states that we choose to observe, consistent with all known conservation laws and dynamical laws.

Monte Carlo simulations

- Monte Carlo is in two parts: physics (event) simulation, and detector response simulation.
- The detector response is based on an elaborate and detailed program called GEANT.
 - Complete description of the detector geometry, materials, active elements
 - All the ways that particles can interact with the material: bremsstrahlung, ionization, dE/dx, hadronic showers, EM showers
- The physics simulation is based (for LHC) on Pythia (and other similar programs).
 - choice of initial state partons based on parton distribution functions in the proton
 - hard scattering sub-process
 - parton shower and fragmentation
 - hadronization
 - resonance and heavy particle decays
 - Rigorous energy-momentum conservation

Pythia



- Download from http://home.thep.lu.se/~torbjorn/Pythia.html
- Install in linux or MacOS
- Study <u>A Brief Introduction to PYTHIA 8.1</u> and/or the Pythia 8.1 Intro and Tutorial
- Look at (and if you want, run through) the Pythia 8 Worksheet
- Run (all of) the examples
- Examine the results! What do events look like? What do the histograms tell us?
- What are the reported cross-sections for the different final states / processes?

From the Pythia manuals

In	No.	Subprocess	Reference
+	1	$f_i \overline{f}_i \rightarrow \gamma^* / Z^0$	[Eic84]
+	2	$f_i \overline{f}_j \rightarrow W^+$	[Eic84]
+	- 3	$f_i \overline{f}_i \rightarrow h^0$	[Eic84]
	4	$\gamma W^+ \rightarrow W^+$	
+	5	$\dot{Z}^0 Z^0 \rightarrow h^0$	[Eic84, Cha85]
	6	$Z^0W^+ \rightarrow W^+$	
	7	$W^+W^- \rightarrow Z^0$	
+	8	$W^+W^- \rightarrow h^0$	[Eic84, Cha85]
+	10	$f_i f_j \rightarrow f_k f_l \ (QFD)$	[Ing87a]
+	11	$f_i \underline{f}_j \rightarrow f_i \underline{f}_j (QCD)$	[Com77, Ben84, Eic84]
+	12	$f_i \underline{f}_i \rightarrow f_k f_k$	[Com77, Ben84, Eic84]
+	13	$f_i f_i \rightarrow gg$	[Com77, Ben84]
+	14	$f_i f_i \rightarrow g \gamma$	[Hal78, Ben84]
+	15	$f_i \overline{f}_i \rightarrow gZ^0$	[Eic84]
+	16	$f_i \overline{f}_j \rightarrow gW^+$	[Eic84]
	17	$f_i \overline{f}_i \rightarrow gh^0$	
+	18	$f_i \bar{f}_i \rightarrow \gamma \gamma$	[Ber84]
+	19	$f_i \overline{f}_i \rightarrow \gamma Z^0$	[Eic84]
+	20	$f_i \bar{f}_j \rightarrow \gamma W^+$	[Eic84, Sam91]
	21	$f_i \tilde{f}_i \rightarrow \gamma h^0$	5 · · ·
+	22	$f_i \overline{f}_i \rightarrow Z^0 Z^0$	[Eic84, Gun86]
+	23	$f_i \overline{f}_j \rightarrow Z^0 W^+$	[Eic84, Gun86]
+	24	$f_i \overline{f}_i \rightarrow Z^0 h^0$	[Ber85]
+	25	$f_i \bar{f}_i \rightarrow W^+W^-$	[Bar94, Gun86]
+	26	$f_i \overline{f}_i \rightarrow W^+ h^0$	[Eic84]
	27	$f_i \tilde{f}_i \rightarrow h^0 h^0$	L 1
+	28	$f_i g \rightarrow f_i g$	[Com77, Ben84]
+	- 29	$f_i g \rightarrow f_i \gamma$	[Hal78, Ben84]
+	- 30	$f_i g \rightarrow f_i Z^0$	[Eic84]
+	31	$f_i g \rightarrow f_k W^+$	[Eic84]
+	32	$f_i g \rightarrow f_i h^0$	[Bar88]
+	- 33	$f_i \gamma \rightarrow f_i g$	[Duk82]
+	34	$f_i \gamma \rightarrow f_i \gamma$	[Duk82]
+	35	$f_i \gamma \rightarrow f_i Z^0$	[Gab86]
+	36	$f_i \gamma \rightarrow f_k W^+$	[Gab86]
	- 37	$t_i \gamma \rightarrow f_i h^0$	

Table 1

Currently implemented processes, complete with respect to groups, but with some individual processes missing for lack of space (represented by "..."). In the names, a "2" separates initial and final state, an "(s:X)", "(t:X)" or "(l:X)" occasionally appends info on an s- or t-channel- or loop-exchanged particle X.

ProcessGroup	ProcessName					
SoftQCD	minBias,elastic, singleDiffractive,					
	doubleDiffractive					
HardQCD	gg2gg, gg2qqbar, qg2qg, qq2qq, qqbar2gg,					
	qqbar2qqbarNew, gg2ccbar, qqbar2ccbar,					
	gg2bbbar, qqbar2bbbar					
PromptPhoton	qg2qgamma, qqbar2ggamma, gg2ggamma,					
	ffbar2gammagamma, gg2gammagamma					
WeakBosonExchange	<pre>ff2ff(t:gmZ), ff2ff(t:W)</pre>					
WeakSingleBoson	<pre>ffbar2gmZ, ffbar2W, ffbar2ffbar(s:gm)</pre>					
WeakDoubleBoson	ffbar2gmZgmZ, ffbar2ZW, ffbar2WW					
WeakBosonAndParton	qqbar2gmZg, qg2gmZq, ffbar2gmZgm, fgm2gmZf					
	qqbar2Wg, qg2Wq, ffbar2Wgm, fgm2Wf					
Charmonium	gg2QQbar[3S1(1)]g, qg2QQbar[3PJ(8)]q,					
Bottomonium	gg2QQbar[3S1(1)]g, gg2QQbar[3P2(1)]g,					
Тор	gg2ttbar, qqbar2ttbar, qq2tq(t:W),					
	<pre>ffbar2ttbar(s:gmZ), ffbar2tqbar(s:W)</pre>					
FourthBottom, FourthTop, FourthPair (fourth generation)						
HiggsSM	ffbar2H, gg2H, ffbar2HZ, ff2Hff(t:WW),					
HiggsBSM	h, H and A as above, charged Higgs, pairs					
SUSY	qqbar2chi0chi0 (not yet completed)					
NewGaugeBoson	ffbar2gmZZprime, ffbar2Wprime, ffbar2R0					
LeftRightSymmmetry	ffbar2ZR, ffbar2WR, ffbar2HLHL,					
LeptoQuark	ql2LQ, qg2LQl, gg2LQLQbar, qqbar2LQLQbar					
ExcitedFermion	dg2dStar, qq2uStarq, qqbar2muStarmu,					
ExtraDimensionsG*	gg2G*, qqbar2G*,					

a single pythia event: $gg \rightarrow tt$

	PYTHIA	Event Listing	(naru proc	000,										
no	id	name	status	mot	hers	daugł	hters	co	lours	p_x	p_y	p_z	e	m
0	90	(system)	-11	0	0	0	0	0	0	0.000	0.000	0.000	14000.000	14000.000
1	2212	(p+)	-12	0	0	3	0	0	0	0.000	0.000	7000.000	7000.000	0.938
2	2212	(p+)	-12	0	0	4	0	0	0	0.000	0.000	-7000.000	7000.000	0.938
3	21	(g)	-21	1	0	5	6	101	102	0.000	0.000	267.353	267.353	0.000
4	21	(g)	-21	2	0	5	6	103	101	0.000	0.000	-111.641	111.641	0.000
5	6	(t)	-22	3	4	11	12	103	0	-5.871	36.280	87.367	194.164	169.457
6	-6	(tbar)	-22	3	4	13	14	0	102	5.871	-36.280	68.344	184.831	167.752
7	2	(u)	-21	1	0	9	10	106	0	0.000	0.000	2463.446	2463.446	0.000
8	21	(g)	-21	2	0	9	10	107	106	0.000	0.000	-0.200	0.200	0.000
9	2	u	23	7	8	0	0	107	0	-0.837	21.543	934.764	935.013	0.330
10	22	gamma	23	7	8	0	0	0	0	0.837	-21.543	1528.481	1528.634	0.000
11	24	(W+)	-22	5	0	15	16	0	0	42.629	8.698	101.674	136.365	79.780
12	5	b	23	5	0	0	0	103	0	-48.500	27.582	-14.307	57.799	4.800
13	-24	(W-)	-22	6	0	17	18	0	0	16.544	9.702	98.824	128.436	79.761
14	-5	bbar	23	6	0	0	0	0	102	-10.673	-45.982	-30.480	56.394	4.800
15	-1	dbar	23	11	0	0	0	0	104	0.911	-6.926	-12.213	14.074	0.330
16	2	u	23	11	0	0	0	104	0	41.718	15.624	113.888	122.291	0.330
17	1	d	23	13	0	0	0	105	0	-10.230	-31.329	42.560	53.830	0.330
18	-2	ubar	23	13	0	0	0	0	105	26.774	41.031	56.264	74.606	0.330
	End PYT	THIA Event Lis Event Listing	ting	event)										
 	End PYT PYTHIA id	THIA Event Lis Event Listing name	ting (complete status	event) mot					 	 р х			 	
 no 0	End PYT PYTHIA id 90	THIA Event Lis Event Listing name (system)	ting (complete status -11	event) mot 0	 hers	 daugł 0	hters	 co. 0	 lours 0	p_x 0.000	р_у о.ооо	p_z 0.000	e 14000.000	m 14000.000
no 0 1	End PY PYTHIA id 90 2212	THIA Event Lis Event Listing name (system) (p+)	ting (complete status -11 -12	event) mot O O	 hers 0 0	 daugi 0 883	hters	 co. 0	lours 0 0	p_x 0.000 0.000	p_y 0.000 0.000	p_z 0.000 7000.000	e 14000.000 7000.000	 m 14000.000 0.938
no 0 1 2	End PY PYTHIA id 90 2212 2212	THIA Event Lis Event Listing name (system) (p+) (p+)	ting (complete status -11 -12 -12	event) mot O O O	 hers 0 0	 daugł 0 883 884	hters 0 0 0	 co. 0 0	lours 0 0 0	p_x 0.000 0.000 0.000	p_y 0.000 0.000 0.000	p_z 0.000 7000.000 -7000.000	e 14000.000 7000.000 7000.000	m 14000.000 0.938 0.938
no 0 1 2 3	End PY PYTHIA id 90 2212 2212 212 21	THIA Event Lis Event Listing name (system) (p+) (p+) (g)	ting (complete status -11 -12 -12 -21	event) mot 0 0 11	 hers 0 0 0 11	daugi 0 883 884 5	hters 0 0 0 6	 co 0 0 101	lours 0 0 102	p_x 0.000 0.000 0.000 0.000 0.000	p_y 0.000 0.000 0.000 0.000 0.000	p_z 0.000 7000.000 -7000.000 267.353	e 14000.000 7000.000 7000.000 267.353	m 14000.000 0.938 0.938 0.000
no 0 1 2 3 4	End PY PYTHIA id 90 2212 2212 21 21 21	THIA Event Lis Event Listing name (system) (p+) (p+) (g) (g)	ting (complete status -11 -12 -12 -21 -21	event) mot 0 0 11 12	 hers 0 0 11 0	daugi 0 883 884 5 5	hters 0 0 0 6 6	 co 0 0 101 103	lours 0 0 0 102 101	p_x 0.000 0.000 0.000 0.000 0.000 0.000	p_y 0.000 0.000 0.000 0.000 0.000 0.000	p_z 0.000 7000.000 -7000.000 267.353 -111.641	e 14000.000 7000.000 7000.000 267.353 111.641	m 14000.000 0.938 0.938 0.000 0.000
no 0 1 2 3 4 5	End PY PYTHIA id 90 2212 2212 21 21 21 6	THIA Event Lis Event Listing name (system) (p+) (p+) (g) (g) (t)	ting (complete status -11 -12 -12 -21 -21 -22	 event) 0 0 11 12 3	chers 0 0 11 0 4	daugł 0 883 884 5 5 13	hters 0 0 0 6 6 13	 0 0 101 103 103	lours 0 0 102 101 0	p_x 0.000 0.000 0.000 0.000 0.000 0.000 -5.871	p_y 0.000 0.000 0.000 0.000 0.000 0.000 36.280	p_z 0.000 7000.000 -7000.000 267.353 -111.641 87.367	e 14000.000 7000.000 7000.000 267.353 111.641 194.164	m 14000.000 0.938 0.938 0.000 0.000 169.457
no 0 1 2 3 4 5 6	End PY PYTHIA id 90 2212 2212 21 21 21 6 -6	THIA Event Lis Event Listing name (system) (p+) (p+) (g) (g) (t) (tbar)	ting (complete status -11 -12 -12 -21 -21 -22 -22	event) mot 0 0 11 12 3 3	 Chers 0 0 11 0 4 4	daugh 0 883 884 5 5 13 14	nters 0 0 6 6 13 14	 0 0 101 103 103 0	lours 0 0 102 101 0 102	p_x 0.000 0.000 0.000 0.000 0.000 -5.871 5.871	p_y 0.000 0.000 0.000 0.000 0.000 36.280 -36.280	p_z 0.000 7000.000 -7000.000 267.353 -111.641 87.367 68.344	e 14000.000 7000.000 7000.000 267.353 111.641 194.164 184.831	m 14000.000 0.938 0.938 0.000 0.000 169.457 167.752
no 0 1 2 3 4 5 6 7	End PY PYTHIA id 90 2212 2212 21 21 21 6 -6 2	THIA Event Listing name (system) (p+) (g) (g) (t) (tbar) (u)	ting (complete status -11 -12 -12 -21 -21 -22 -22 -22 -21	event) mot 0 0 11 12 3 3 22	chers 0 0 11 0 4 4 22	daugh 0 883 884 5 5 13 14 9	nters 0 0 6 13 14 10	co 0 101 103 103 0 106	lours 0 102 101 0 102 0	p_x 0.000 0.000 0.000 0.000 0.000 -5.871 5.871 0.000	p_y 0.000 0.000 0.000 0.000 0.000 36.280 -36.280 0.000	p_z 0.000 7000.000 -7000.000 267.353 -111.641 87.367 68.344 2463.446	e 14000.000 7000.000 267.353 111.641 194.164 184.831 2463.446	m 14000.000 0.938 0.938 0.000 0.000 169.457 167.752 0.000
no 0 1 2 3 4 5 6 7 8	End PY PYTHIA id 90 2212 2212 21 21 21 6 -6 2 21	THIA Event Listing name (system) (p+) (g) (g) (t) (tbar) (u) (g)	ting (complete status -11 -12 -12 -21 -21 -22 -22 -22 -21 -21	event) mot 0 11 12 3 22 23	Chers 0 0 11 0 4 4 22 0	daugh 0 883 884 5 5 13 14 9 9	nters 0 0 6 13 14 10	co 0 101 103 103 0 106 107	lours 0 102 101 0 102 0 102 0 106	p_x 0.000 0.000 0.000 0.000 0.000 -5.871 5.871 0.000 0.000	p_y 0.000 0.000 0.000 0.000 0.000 36.280 -36.280 0.000 0.000	p_z 0.000 7000.000 -7000.000 267.353 -111.641 87.367 68.344 2463.446 -0.200	e 14000.000 7000.000 267.353 111.641 194.164 184.831 2463.446 0.200	m 14000.000 0.938 0.938 0.000 0.000 169.457 167.752 0.000 0.000
no 0 1 2 3 4 5 6 7 8 9	End PY PYTHIA id 90 2212 2212 21 21 21 6 -6 2 21 21 21	THIA Event Listing name (system) (p+) (g) (g) (t) (tbar) (u) (g) (u) (u)	ting (complete status -11 -12 -21 -21 -22 -22 -22 -21 -21 -21	event) mot 0 11 12 3 22 23 7	chers 0 0 11 0 4 4 22 0 8	daugh 0 883 884 5 5 13 14 9 9 24	nters 0 0 6 13 14 10 24	co. 0 101 103 103 0 106 107 107	lours 0 102 101 0 102 0 106 0	p_x 0.000 0.000 0.000 0.000 -5.871 5.871 0.000 0.000 -0.837	p_y 0.000 0.000 0.000 0.000 36.280 -36.280 0.000 0.000 21.543	p_z 0.000 7000.000 -7000.000 267.353 -111.641 87.367 68.344 2463.446 -0.200 934.764	e 14000.000 7000.000 267.353 111.641 194.164 184.831 2463.446 0.200 935.013	m 14000.000 0.938 0.938 0.000 169.457 167.752 0.000 0.000 0.330
no 0 1 2 3 4 5 6 7 8 9 10	End PY PYTHIA id 90 2212 2212 21 21 21 6 -6 2 21 2 21 2 21	THIA Event List Event Listing name (system) (p+) (p+) (g) (g) (t) (tbar) (u) (g) (u) (g) (u) (gamma)	ting (complete status -11 -12 -21 -21 -22 -22 -22 -21 -21 -21	event) mot 0 11 12 3 22 23 7 7	Chers 0 0 11 0 4 4 22 0 8 8	daugh 0 883 884 5 5 13 14 9 9 24 25	nters 0 0 6 13 14 10 24 25	co. 0 101 103 103 0 106 107 107 0	lours 0 102 101 0 102 0 106 0 0	p_x 0.000 0.000 0.000 0.000 -5.871 5.871 0.000 0.000 -0.837 0.837	p_y 0.000 0.000 0.000 0.000 36.280 -36.280 0.000 0.000 21.543 -21.543	p_z 0.000 7000.000 -7000.000 267.353 -111.641 87.367 68.344 2463.446 -0.200 934.764 1528.481	e 14000.000 7000.000 267.353 111.641 194.164 184.831 2463.446 0.200 935.013 1528.634	m 14000.000 0.938 0.938 0.000 169.457 167.752 0.000 0.000 0.330 0.000
no 0 1 2 3 4 5 6 7 8 9 10 11	End PY PYTHIA id 90 2212 2212 21 21 21 6 -6 2 21 2 21 2 22 21	THIA Event Listing name (system) (p+) (g) (g) (t) (tbar) (u) (g) (u) (g) (u) (gamma) (g)	ting (complete status -11 -12 -21 -21 -22 -22 -22 -21 -21 -23 -23 -23 -42	event) mot 0 11 12 3 22 23 7 7 16	chers 0 0 11 0 4 4 22 0 8 8 0	daugh 0 883 884 5 5 13 14 9 24 25 3	nters 0 0 6 13 14 10 24 25 3	co. 0 101 103 103 0 106 107 107 0 101	lours 0 102 101 0 102 0 106 0 106 0 102	p_x 0.000 0.000 0.000 0.000 -5.871 5.871 0.000 0.000 -0.837 0.837 -0.000	p_y 0.000 0.000 0.000 0.000 36.280 -36.280 0.000 21.543 -21.543 0.000	p_z 0.000 7000.000 -7000.000 267.353 -111.641 87.367 68.344 2463.446 -0.200 934.764 1528.481 267.353	e 14000.000 7000.000 267.353 111.641 194.164 184.831 2463.446 0.200 935.013 1528.634 267.353	m 14000.000 0.938 0.938 0.000 169.457 167.752 0.000 0.000 0.330 0.000 0.000
no 0 1 2 3 4 5 6 7 8 9 10 11 12	End PY PYTHIA id 90 2212 2212 21 21 21 6 -6 2 21 2 22 21 21 21	THIA Event Listing name (system) (p+) (g) (g) (t) (tbar) (u) (g) (u) (g) (u) (gamma) (g) (g)	ting (complete status -11 -12 -21 -21 -22 -22 -22 -21 -21 -23 -23 -23 -42 -41	event) mot 0 11 12 3 22 23 7 7 16 17	chers 0 0 11 0 4 4 22 0 8 8 0 17	daugh 0 883 884 5 5 13 14 9 24 25 3 15	nters 0 0 6 13 14 10 24 25 3 4	co 0 0 101 103 103 0 106 107 107 0 101 108	lours 0 102 101 0 102 0 106 0 102 102 101	p_x 0.000 0.000 0.000 0.000 -5.871 5.871 0.000 -0.837 0.837 -0.000 0.000	p_y 0.000 0.000 0.000 0.000 36.280 -36.280 0.000 21.543 -21.543 0.000 -0.000	p_z 0.000 7000.000 -7000.000 267.353 -111.641 87.367 68.344 2463.446 -0.200 934.764 1528.481 267.353 -170.759	e 14000.000 7000.000 267.353 111.641 194.164 184.831 2463.446 0.200 935.013 1528.634 267.353 170.759	m 14000.000 0.938 0.938 0.000 169.457 167.752 0.000 0.000 0.330 0.000 0.000 0.000
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Integrated cross section in Pythia

	* PYTHIA Process Initialization		*****
	 We collide p+ with p+ at a CM energy of 1.400e+04	GeV	
ntegrated	 Subprocess Code		 Estimated
oss section	 	 	(max (mb)
	' gg->ttbar 601	i	4.481e-06
in Dirthia	q qbar -> t tbar 602	Ι	6.994e-07
	q q -> t q (t-channel W+-) 603	Ι	4.295e-06
5	f fbar -> t tbar (s-channel gamma*/ZO) 604	I	6.022e-09
	f fbar -> t qbar (s-channel W+-) 605	I	1.185e-07
		Ι	1
PYTHIA Event and Cross Section Stat			· *

Subprocess Code I Number of events siqma +- delta Selected Tried Accepted | (estimated) (mb) First hard process: $q q \rightarrow t t bar$ 601 I 1492 152 134 I 3.505e-12 3.370e-13 229 25 18 I 4.796e-13 8.485e-14 q qbar -> t tbar 602 I 1376 59 $q q \rightarrow t q (t-channel W+-)$ 603 I 47 1 1.151e-12 1.439e-13 f fbar \rightarrow t tbar (s-channel gamma*/20) 1 Ω 0 | 0.000e+00 0.000e+00 604 | f fbar -> t gbar (s-channel W+-) 42 2 3.241e-14 3.252e-14 605 I 1 | sum 3140 238 200 I 5.168e-12 4.790e-13

pythia example main11/out11 (Top:all; $Ecm_{min} > 40$, $pt_{min} > 20$) $\sigma = 5 \times 10^{-12}$ mb, L = 1×10³⁴ /cm²/s, dN/dt = 5×10⁻⁵/s $\sigma = 5 \times 10^{-6}$ mb, L = 1×10³⁴ /cm²/s, dN/dt = 50/s

Fun with Pythia

- Run Pythia and understand the output.
 - a. Download from <u>http://home.thep.lu.se/~torbjorn/Pythia.html</u>
 - b. Install, compile and build it in linux or MacOS, following the instructions on that web page.
 - c. Study <u>A Brief Introduction to PYTHIA 8.1</u> and/or the Pythia 8.1 Intro and Tutorial
 - d. Look at (and if you want, run through) the Pythia 8 Worksheet
 - e. Run (all of) the examples (by typing "./runmains"). Not all of the programs will run; some require additional infrastructure.
 - f. Examine the results! What do events look like? Trace through and diagram the chain from parent to child, from the initial hard scatter, through the parton shower, the hadronization, and decay to final state particles. Doing this for one whole event is maybe too big a job; try to follow one branch of the parton shower all the way to the end.
 - g. Look at the output of ALL the jobs that ran through (some won't run). For each job, write down the hard scattering process, the initial cross-section estimate, and the final computer cross-section with error. Jot down the histograms that were made and note their overall shape. Try to construct a "total cross-section".
 - h. What are the reported cross-sections for the different final states / processes?
 - i. How does the program simulate the detector response?
 - j. What do the histograms tell us? Look at the output of a bunch of jobs, at the resulting histograms. How were these histograms made?
- Try to modify the code for one of the jobs, to make one or two additional histograms of quantities of interest.

A good first exercise

- Use Pythia to answer the question: what threshold do I need to place on "missing E_T" before a SUSY signal stands out over the QCD background?
- SUSY with "R-parity" has a "lightest supersymmetric particle" (LSP) which is a neutral, weakly-interacting massive particle (a "neutralino").
- The LSP is a perfect candidate for the dark matter! (This is a very significant observation; we will explore it later).
- So processes in which supersymmetric particles are produced (especially strongly interacting ones, like gluinos or squarks) lead to a decay chain which ultimately ends in a pair of LSPs exiting the detector, carrying away momentum and energy, undetected. This is the missing energy signature for SUSY at the LHC.
- Because it is difficult to measure energy flow along the beamline (so much energy escapes undetected at small angles), LHC detectors are best at measuring momentum flow transverse to the beampipe (p_t).
- If all final state (~stable) particles are observed (ie, no neutrinos or neutralinos), Pythia will report Sum(p_x) = 0, Sum(p_y) = 0. VERIFY THIS.
- If there are neutrinos or neutralinos in the final state, they leave no trace in the detector; p_x and p_y will be unbalanced, and there will be "missing E_t " MET = sqrt((Sum(p_x))² + (Sum(p_y))²).
- HISTOGRAM THIS, for "HardQCD:all" (background) and SUSY:all (signal).
- Now normalize the histograms by cross-section, to dσ/d(MET), and superimpose them (on a semilogy scale!).
- Try to answer the above question.