Charged Particle Multiplicity in pp Collisions at $\sqrt{s} = 13$ TeV

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Charged Particle Multiplicity IN PP COLLISIONS AT $\sqrt{S} = 13$ TEV OUTLINES

- **Standard model**
- **THE SCHEMA of ATLAS DETECTOR**
- **Jet definition**
- **Minimum bias and underlying event**

- **Event generator monte carlo simulation Pythia 8 and Herwig++**
- **Study charged particle multiplicity distribution**
- **Jet particle multiplicity**

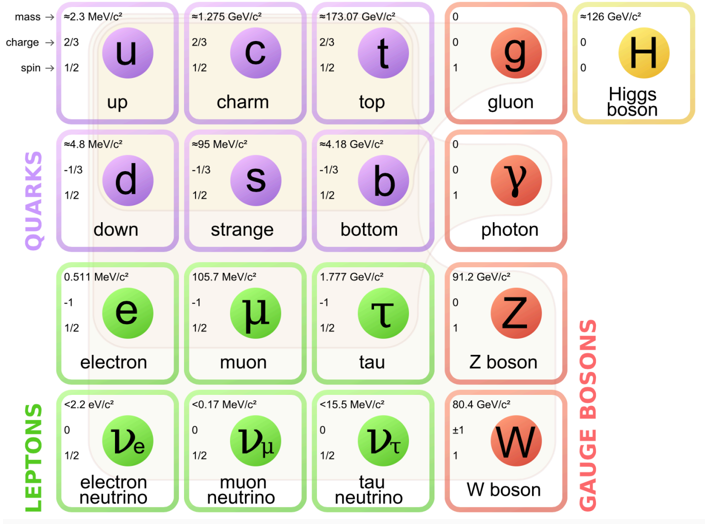
STANDARD MODEL

Standard Model
is the theory of the electromagnetic, weak and strong interactions

There are six quarks (up u, down d, charm c, strange s, top t, bottom b), and six leptons (electron, electron neutrino, muon, muon neutrino, tau, tau neutrino)

Gauge bosons are the force carriers that conciliate strong, weak, and electromagnetic interaction between the fermions

The Higgs, is needed to understand and the properties of the other particles, such as mass



STANDARD MODEL

$g\,g \rightarrow q\,qbar$,
where *q* by default is a light quark (*u, d, s*)

Fermions (spin 1/2)

	Quarks			Leptons		
Generation	Flavour	Electric charge	Mass	Flavour	Electric charge	Mass
1^{st}	u	$+2/3e$	$2.3^{+0.7}_{-0.5}$ MeV	ν_e	0	< 2 eV
	d	$-1/3e$	$4.8^{+0.5}_{-0.3}$ MeV	e	$-1e$	511.0 keV
2^{nd}	c	$+2/3e$	1.28 ± 0.03 GeV	ν_μ	0	< 2 eV
	s	$-1/3e$	95 ± 5 GeV	μ	$-1e$	105.7 MeV
3^{rd}	t	$+2/3e$	173.2 ± 1.2 GeV	ν_τ	0	< 2 eV
	b	$-1/3e$	4.18 ± 0.03 GeV	τ	$-1e$	1776.8 ± 0.2 MeV

Top quark mass study qqbar/gg → t tbar

Bosons

Spin 1	Mass	Interaction	Spin 0	Mass	couples to
γ	0	electromagnetic			
Z^0	91.188 ± 0.002 GeV	weak	H^0	125.7 ± 0.4 GeV	mass
$W^\pm$	80.385 ± 0.015 GeV				
$g(8)$	0	strong			

MONTO CARLO GENERATOR
PYTHIA 8, HERWIG++
RIVET

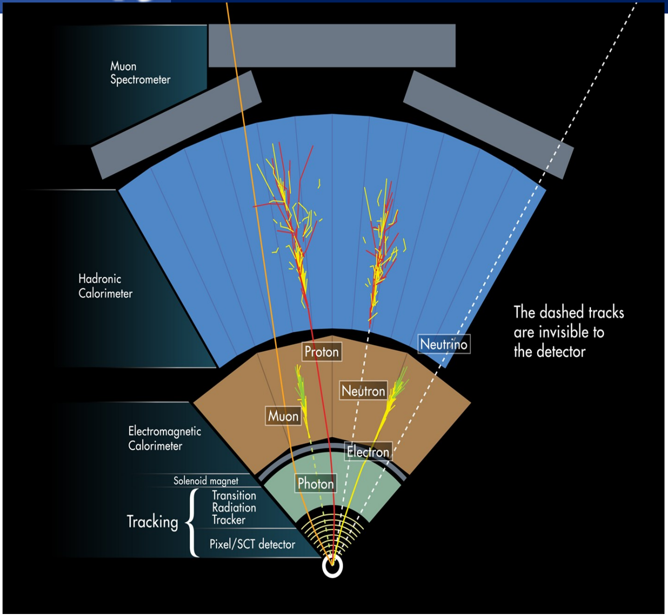
THE PYTHIA 8 program is used to generate events in high-energy physics between elementary particles

HERWIG++ is an event generator for the simulation of high-energy physics events with different decays of hadron-hadron, lepton-lepton, and lepton-hadron collisions

Generator	*Version*	*Tunes*
Pythia 8	8.186	2C (CTEQ6l1)
Pythia 8	8.186	2M (MRST LO**)
Herwig++	2.7.1	UE-EE-5-CTEQ6L1 (CTEQ6l1)
Herwig++	2.7.1	UE-EE-5 (MRST LO**)

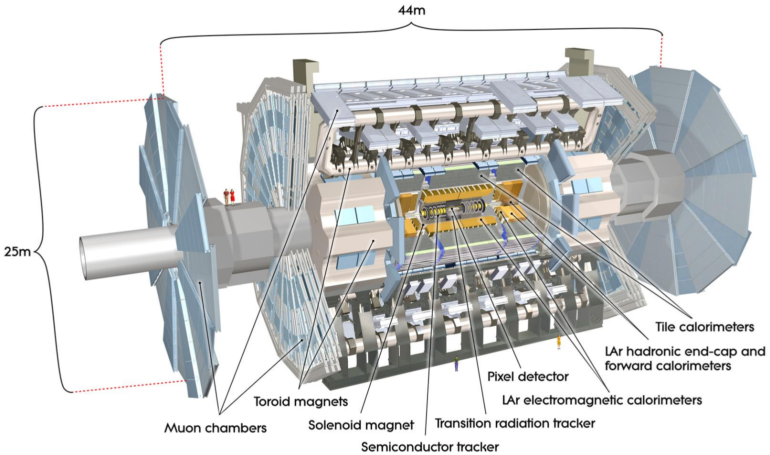
RIVET is a C++ class library, which supports simulation-level analyses by using calculation tools to validate different event generator models with least effort and accurate results

THE SCHEMA OF ATLAS DETECTOR



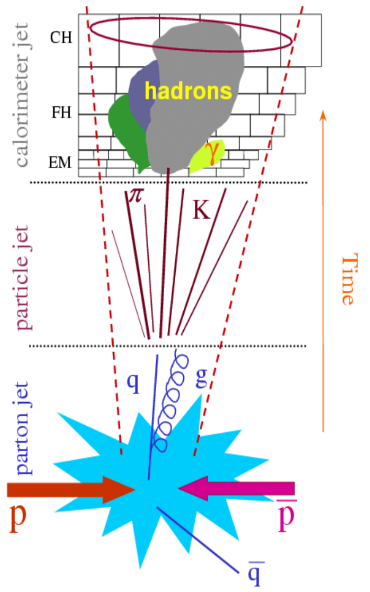
Some subatomic particles can be observed in the detector; such as electrons, protons, neutrons, muons and charged poins because of their long life-time and electric charge; which cause signals in the detector

The ATLAS detector is used as a model to define acceptances in this study



Inner detector: to measure the momentum of each charged particle
Calorimeter: to measure the energies that carried by the particles
Muon spectrometer to identifies and to measures the momenta of the muons
Magnet system: bending the charged particles to measure their momentum

Jets



DETECTOR-LEVEL JETS are formed from the observable quantities in a detector

PARTICLE JETS form from the final state hadrons and their stable decay products.

PARTONS JETS are produced during the scattering process.

As the scattered quarks and gluons move from the initial collision, this process of hadron formation repeats, creating collimated spray of particles called a "JET"

PDF AND TUNES

Standard Model and beyond the Standard Model processes predictions need Parton Distribution Functions (PDFs). of the proton, where the parton density function fi(x, Q2) provides the possibility of finding a parton of flavour i (quarks or gluon) in the proton. A parton is carrying a fraction x of the proton momentum where Q is the the energy scale of the hard

A TUNE is a particular configuration or set of values of the parameters of the particular Monte Carlo model that control multi-parton interaction (MPI)

The 2C and 2M tunes are used with the parton density functions CTEQ 6L1 and the MRST LO** PDF sets

PDF and Tunes
Pythia 8

Parton Distribution Functions (PDFs)

t1 = MultipartonInteractions:pT0Ref
t2 = MultipartonInteractions:ecmPow
t3 = MultipartonInteractions:a1
t4 = BeamRemnants:reconnectRange

name-PDF	t1	t2	t3	t4
MB tune A2-CTEQ6L1	2.18	0.22	0.06	1.55
MB tune A2-MSTW2008LO	1.90	0.30	0.03	2.28
UE tune AU2-CTEQ6L1	2.13	0.21	0.00	2.21
UE tune AU2-MSTW2008LO	1.87	0.28	0.01	5.32
UE tune AU2-CT10	1.70	0.16	0.10	4.67
UE tune AU2-MRST2007LO*	2.39	0.24	0.01	1.76
UE tune AU2-MRST2007LO**	2.57	0.23	0.01	1.47

PDF and Tunes
Pythia 8

Parameter	2C	2M	4C	4Cx
SigmaProcess:alphaSvalue	0.135	0.1265	0.135	0.135
SpaceShower:rapidityOrder	on	on	on	on
SpaceShower:alphaSvalue	0.137	0.130	0.137	0.137
SpaceShower:pT0Ref	2.0	2.0	2.0	2.0
MultipartonInteractions:alphaSvalue	0.135	0.127	0.135	0.135
MultipartonInteractions:pT0Ref	2.320	2.455	2.085	2.15
MultipartonInteractions:ecmPow	0.21	0.26	0.19	0.19
MultipartonInteractions:bProfile	3	3	3	4
MultipartonInteractions:expPow	1.60	1.15	2.00	N/A
MultipartonInteractions:a1	N/A	N/A	N/A	0.15
BeamRemnants:reconnectRange	3.0	3.0	1.5	1.5
SigmaDiffractive:dampen	off	off	on	on
SigmaDiffractive:maxXB	N/A	N/A	65	65
SigmaDiffractive:maxAX	N/A	N/A	65	65
SigmaDiffractive:maxXX	N/A	N/A	65	65

PDF AND TUNES
PREPACKAGED SET OF PARAMETER

1	original values before any tunes
2	Tune 1
3	Tune 2C (CTEQ 6L1)
4	Tune 2M (MRST LO**)
5	Tune 4C
6	Tune 4Cx
7	ATLAS MB tune A2-CTEQ6L1
8	ATLAS MB tune A2-MSTW2008LO
9	ATLAS UE tune AU2-CTEQ6L1
10	ATLAS UE tune AU2-MSTW2008LO
11	ATLAS UE tune AU2-CT10
12	ATLAS UE tune AU2-MRST2007LO*
13	ATLAS UE tune AU2-MRST2007LO**

6:m0 = 172.5
23:m0 = 91.1876
24:m0 = 80.399

#CTau lifetime cut
ParticleDecays:limitTau0 = on
ParticleDecays:tau0Max = 10.0

Tune A2 settings

Tune:pp = 5
PDF:useLHAPDF = on
PDF:LHAPDFset = MSTW2008lo68cl.LHgrid
MultipartonInteractions:bProfile = 4
MultipartonInteractions:a1 = 0.03
MultipartonInteractions:pT0Ref = 1.90
MultipartonInteractions:ecmPow = 0.30
BeamRemnants:reconnectRange = 2.28
SpaceShower:rapidityOrder=off

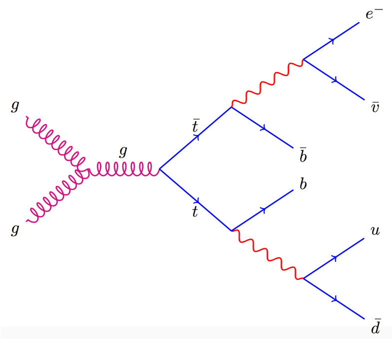
PDF AND TUNES
PREPACKAGED SET OF PARAMETER
HERWIG++

```
#----------------------------------------------------------
# Technical parameters for this run
#----------------------------------------------------------
cd /Herwig/Generators
set LHCGenerator:NumberOfEvents 10000000
set LHCGenerator:RandomNumberGenerator:Seed 31122001
set LHCGenerator:PrintEvent 10
set LHCGenerator:MaxErrors 1000000

set LHCGenerator:DebugLevel 0
set LHCGenerator:DumpPeriod -1
set LHCGenerator:DebugEvent 0


#----------------------------------------------------------
# LHC physics parameters (override defaults here)
#----------------------------------------------------------
set LHCGenerator:EventHandler:LuminosityFunction:Energy
13000.0

# Intrinsic pT tune extrapolated to LHC energy
set /Herwig/Shower/Evolver:IntrinsicPtGaussian 2.2*GeV
```

http://projects.hepforge.org/herwig/trac/wiki/MB_UE_tunes

```
#----------------------------------------------------------
# Matrix Elements for hadron-hadron collisions
#----------------------------------------------------------
cd /Herwig/MatrixElements/
insert SimpleQCD:MatrixElements[0] MEMinBias

# Need this cut only for min bias
cd /Herwig/Cuts
set JetKtCut:MinKT 0.0*GeV
set QCDCuts:MHatMin 0.0*GeV
set QCDCuts:X1Min 0.055
set QCDCuts:X2Min 0.055

# MPI model settings
set /Herwig/UnderlyingEvent/MPIHandler:IdenticalToUE 0

cd /Herwig/Generators

#insert LHCGenerator:AnalysisHandlers 0
/Herwig/Analysis/HepMCFile
#set /Herwig/Analysis/HepMCFile:PrintEvent 1000000
#set /Herwig/Analysis/HepMCFile:Format GenEvent
#set /Herwig/Analysis/HepMCFile:Units GeV_mm
#set /Herwig/Analysis/HepMCFile:Filename events.fifo
#----------------------------------------------------------
# Save run for later usage with 'Herwig++ run'
#----------------------------------------------------------
saverun LHC-MB LHCGenerator
```

Charged particle multiplicity



Charged particle multiplicity in $t\bar{t}$ production in Herwig++ and Pythia 8

The Phase space of charged-particle multiplicity distributions defined as follow:
$n_{ch} \geq 1, n_{ch} \geq 6$, $P_T > 500$ MeV and $|\eta| < 3$ at $\sqrt{s} = 13$ TeV

The distribution at low number of charged particles

The distribution when the number of charged particles increases

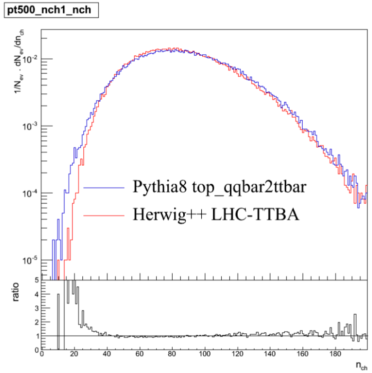
Systematic uncertainty

Comparisons between Herwig++ and Pythia 8:
Pythia 8 8.186 Top:qqbar2ttbar && Herwig++ 2.7.1 LHC-TTBA
Pythia 8 8.186 Top:qqbar2ttbar && Herwig++ 2.7.1 LHC.in
included MEHeavyQuark (qqbar/gg → t tbar)

CHARGED-PARTICLE MULTIPLICITY DISTRIBUTIONS

Variations (Distribution) are very high and wide

The uncertainty is up to +40 %

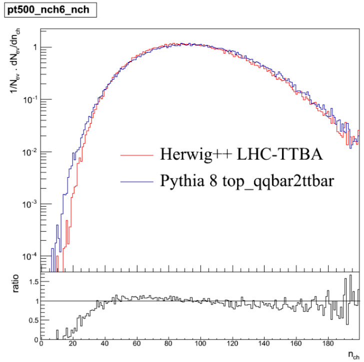


The uncertainty varies from +50 % to +20 %

Pythia 8 Top:qqbar2ttbar
Herwig++ LHC-TTBA

the variations decreased

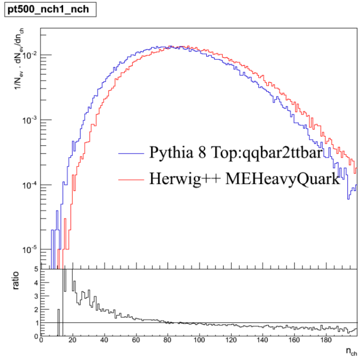
Variations (Distribution) are very high and wide



Variations are very high

The uncertainty varies from -10 % to +15 %

Variations are very high

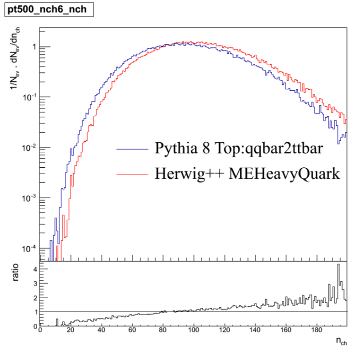


The uncertainty varies from +50 % to -20 %

Variations are very high

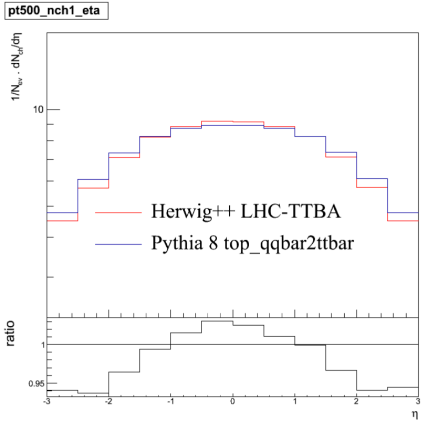
Variations are very high

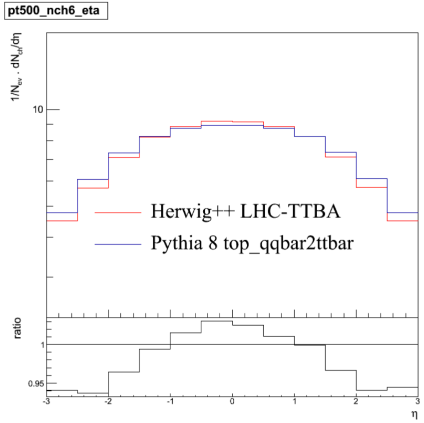
Pythia 8 Top:qqbar2ttbar
Herwig++ MEHeavyQuark

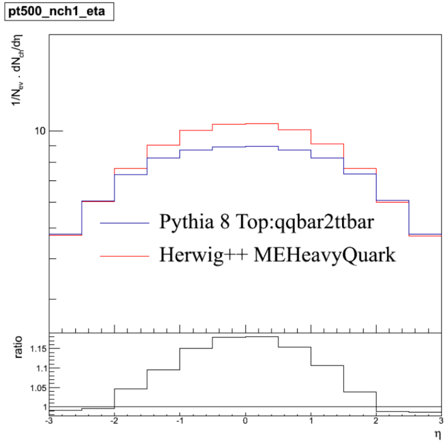


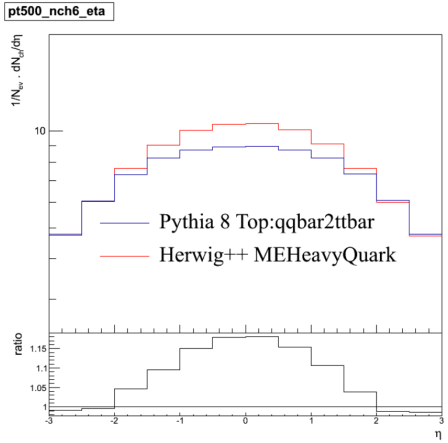
The uncertainty varies from -10 % to +40 %

CHARGED-PARTICLE MULTIPLICITIES AS A FUNCTION OF THE PSEUDORAPIDITY









uncertainty for the highest inclusive phase-space region is 0.3 %.

uncertainty for the highest inclusive phase-space region is 10.15 %.

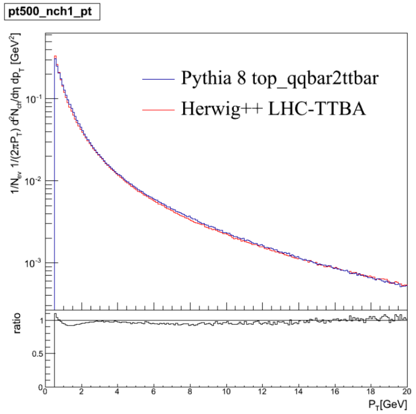
The mean particle density varies from 8 to 10

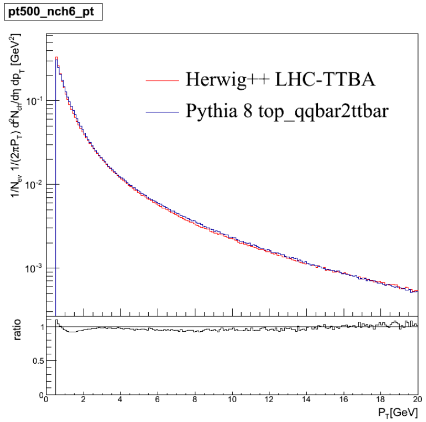
```
less variation
Pythia 8 Top:qqbar2ttbar
Herwig++ LHC-TTBA
```

The mean particle density decreases at higher values of |η|

```
More variation
Pythia 8 Top:qqbar2ttbar
Herwig++ MEHeavyQuark
```

CHARGED-PARTICLE MULTIPLICITIES AS A FUNCTION OF THE TRANSVERSE MOMENTUM

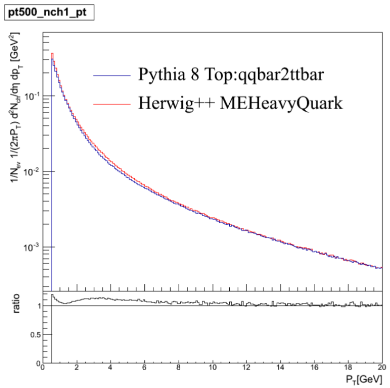


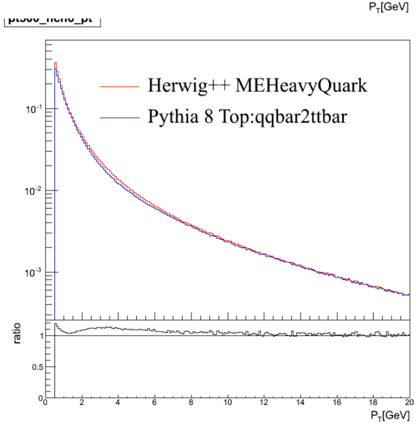



```
Pythia 8 Top:qqbar2ttbar
Herwig++ LHC-TTBA
```

The charge density is very high at low pt region and decreases at high pt

Models tend to under-predict the number of low P_T particles

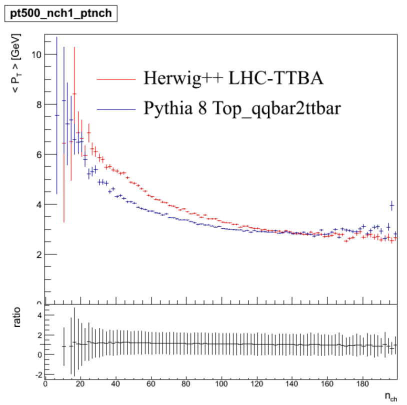


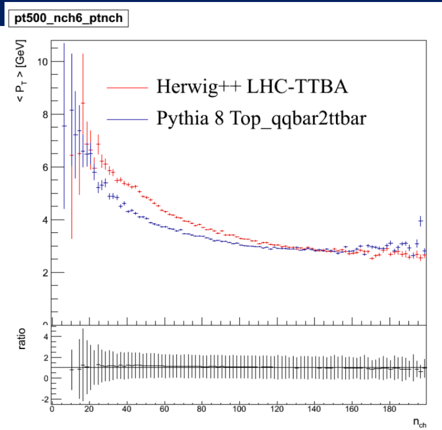



```
Pythia 8 Top:qqbar2ttbar
Herwig++ MEHeavyQuark
```

The uncertainty is measured for the range -0,02% for $p_T = 1$ GeV to -0.3 % for $p_T = 2$

AVERAGE TRANSVERSE MOMENTUM AS A FUNCTION OF THE NUMBER OF CHARGED PARTICLES IN THE EVENT



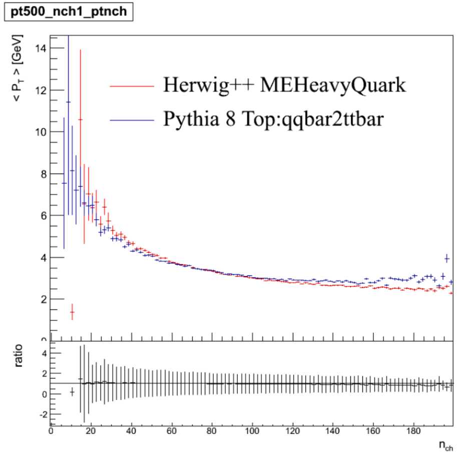


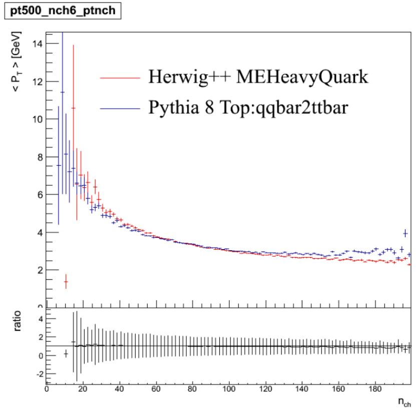
the models vary widely

Pythia 8 Top:qqbar2ttbar
Herwig++ LHC-TTBA

the models vary widely

Distribution well agree between most of the models



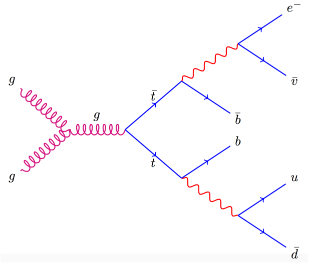


Pythia 8 Top:qqbar2ttbar
Herwig++ MEHeavyQuark

Systematic Uncertainties is very high in the rang from 20% to 40%

bin ($20 < n_{ch} < 80$)

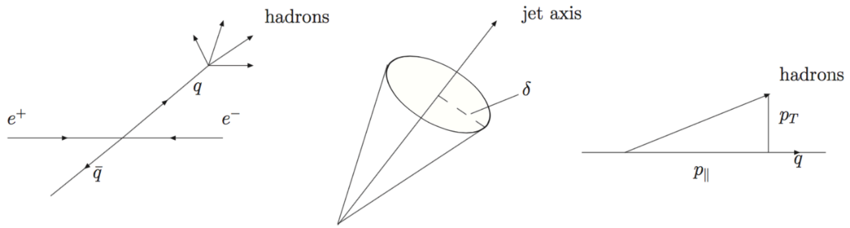
Comparison between two different PDF in Herwig++ (ttbar Jet)



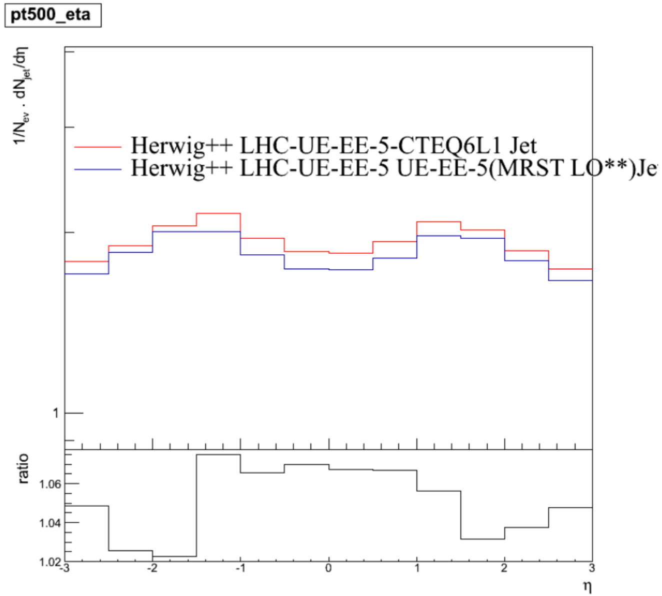
set /Herwig/Particles/t/t->b,u,dbar;:OnOff Off
set /Herwig/Particles/tbar/tbar->nu_ebar,e-,bbar;:OnOff Off

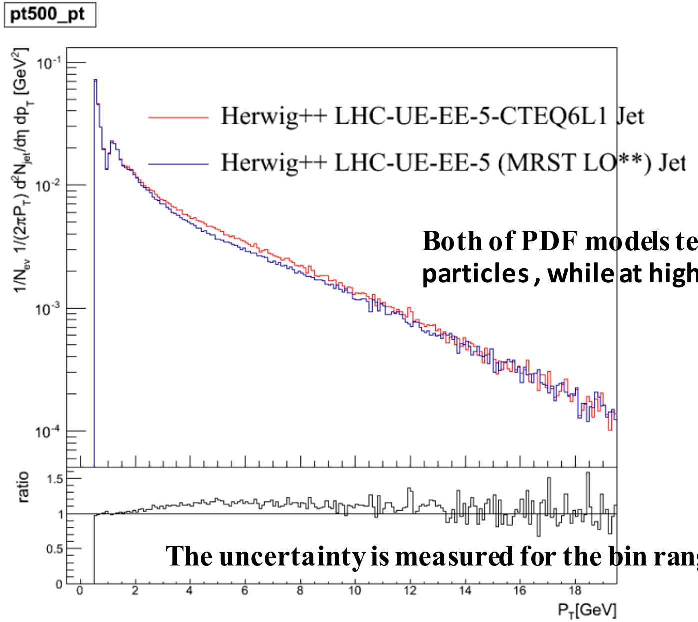
Jet charged particle multiplicity in Herwig++ with two different PDF UE- EE-5-CTEQ6l1,and UE-EE-5

In Herwig++ the number of the jets is less than Pythia 8 where there are more mimiumm bias events and less number of the tracks



Comparison between two different PDF in Herwig++(ttbar Jet)





Both of PDF models tend to over-predict the number of low PT particles, while at higher PT the PDF do not vary widely

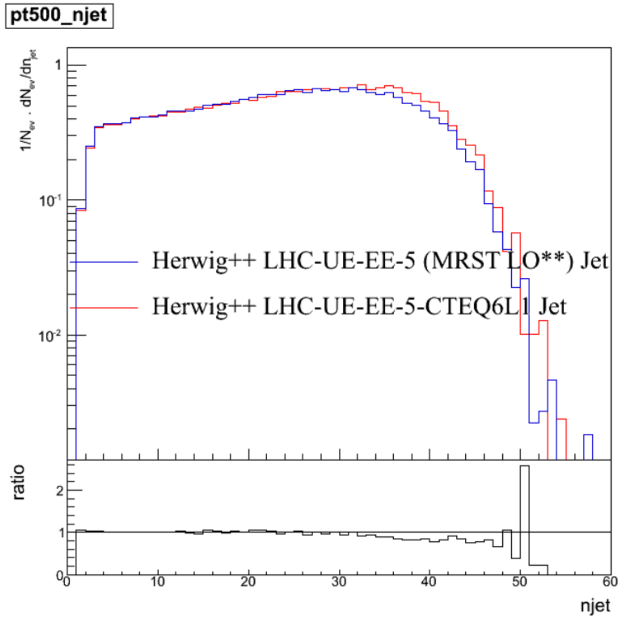
The uncertainty is measured for the bin range ($1 < p_T < 13$ GeV) (10 % to 20 %)

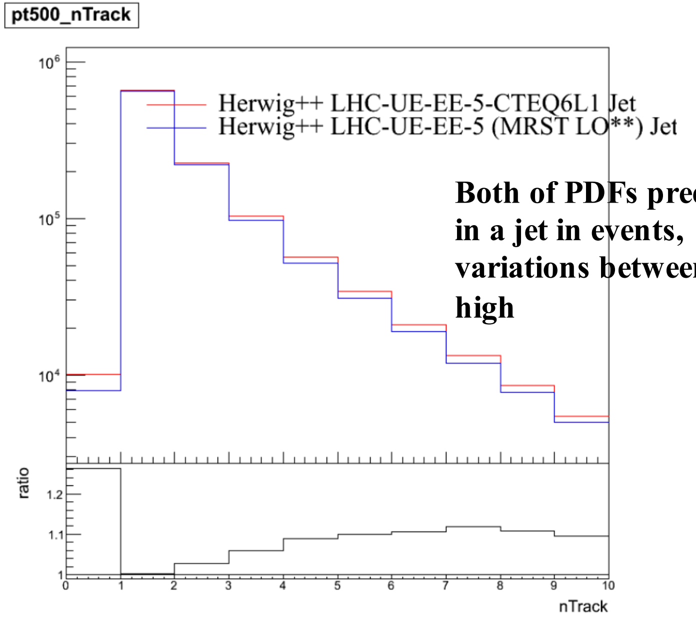
The mean particle density is getting low
in the central region
low statistic at the central region
The entire uncertainty on Nev at $\sqrt{s} = 13$ TeV
for the highest inclusive phase-space region is
(+1.5 % to -1.5 %)

At low P_T region the charge density is very high
and decreases at high pt region where the statistical
is getting low

"Herwig++ LHC-UE-EE-5-CTEQ6L1 Jet
"Herwig++ LHC-UE-EE-5 UE-EE-5 (MRST LO**) Jet"

Comparison between two different PDF (ttbar Jet)





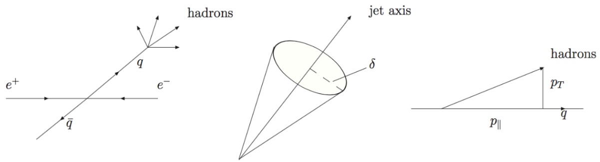
Both of PDFs predicted more tracks in a jet in events, and the variations between the PDFs are high

Number of the jets almost the same for the both PDFs. Both of PDFs predicted more jets in events at $n_{Jet} \geq 35$, and the variations between the PDFs are big

Systematic uncertainty is over predict

systematic uncertainties is decreases for both $n_{Jet} \geq 35$ (- 0.4%)

"Herwig++ LHC-UE-EE-5-CTEQ6L1 Jet
"Herwig++ LHC-UE-EE-5 UE-EE-5 (MRST LO) Jet"**



CONCLUSIONS

The distribution of particle multiplicity in high energy inelastic processes provides essential information on the dynamics of strong interactions.

The principal features of multiplicity predicted by QCD are observed qualitatively both in pp and hadron-initiated processes

The multiplicity is used to select or to describe events, e.g. as a trigger for specific processes, as an input for kinematic variables' spectra. The distribution of multiplicity, its mean value and multiplicity fluctuations are the essential characteristics of the collision dynamics. However, the multiplicity distribution tells us just about the averaged, integrated numbers, while deeper information comes from the moments of the distribution, which measure particle correlations