Soft QCD Measurements at 900 GeV and 7 TeV with ATLAS

Hard Core

*Rick Field's
Pictorial
Representation*

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$$\sigma_{\text{tot}} = \sigma_{\text{EL}} + \sigma_{\text{SD}} + \sigma_{\text{DD}} + \sigma_{\text{HC}}$$

Why is “Soft QCD” Interesting?

- It is non-perturbative physics and has an interesting phenomenology
  - Beam remnants
  - Multiple Parton Interactions
  - Color recombination
  - => all adding up to a colorless system
- It is an essential ingredient for precision high p_T physics
  - Causes an experimental bias such as in jet trigger and from pile up due to multiple interactions in the same bunch crossing
  - Top mass, Jet p_T energy scale, Isolation cone energy

Measurement done using charged tracks :

“easy” to control systematics and provides an inclusive measurement

The ATLAS Detector

Minimum
Bias Trigger
Scintillators
(MBTS)
 $2.09 < \eta < 3.84$

Use Charged Particle Multiplicity Distributions to Probe Soft QCD

Inclusive Distributions

$$\frac{1}{N_{\text{ev}}} \cdot \frac{dN_{\text{ch}}}{d\eta}, \quad \frac{1}{N_{\text{ev}}} \cdot \frac{1}{2\pi p_{\text{T}}} \cdot \frac{d^2 N_{\text{ch}}}{d\eta dp_{\text{T}}}, \quad \frac{1}{N_{\text{ev}}} \cdot \frac{dN_{\text{ev}}}{dn_{\text{ch}}} \quad \text{and} \quad \langle p_{\text{T}} \rangle \text{ vs. } n_{\text{ch}}$$

Underlying event:

- transverse region should be most sensitive
- Should be ~independent of energy scale

Analysis overview:

- Trigger and event selection
- Track reconstruction and determination of efficiency
- Unfolding from track to hadron level (using Monte Carlo)
- No model dependent corrections (e.g. for SD contribution)
- Compare to Monte Carlo phenomenological models based on PYTHIA – using PYTHIA to provide relative weighting of SD, DD, and ND in the MC distributions.

Trigger and event selection

- Data:
  - ~455K events at $\sqrt{s} = 900$ GeV, 400K events at $\sqrt{s} = 7$ TeV
- Trigger:
  - Require ≥ 1 MBTS counter to fire on either side
- Event:
  - Reconstructed vertex from ≥ 2 tracks with $p_T > 100$ MeV
  - No additional primary interaction
  - At least one track passing track selection cuts
- Primary track selection:
  - $p_T > 500$ MeV, $|\eta| < 2.5$
  - Minimum number of hits in pixel (1) and SCT (6) tracking systems
  - Transverse impact parameter $|d_0| < 1.5\text{mm}$
  - Longitudinal impact parameter $|z_0| \cdot \sin\theta < 1.5\text{mm}$

Trigger efficiency ~99.5%

Cosmic ray back ground $< 10^{-6}$ and beam backgrounds $< 0.1\%$

Pileup removal ~0.1%, residual rate from pileup ~0.01%

Efficiency Corrections From Monte Carlo

Parameterize Reconstruction efficiency as a function of η and p_T

Use Monte Carlo to correct for residual contribution from non-primary tracks (such as from nuclear interactions, K_S and Λ decays, and π decays)

Trigger & Vertex efficiency ~ 0.995 determined from data

$\sim$ Global systematic $\sim 3\%$ from material description

Correct reconstructed track distributions to hadron level (charged particles with lifetime $> 3 \cdot 10^{-11}$ s)

$1/N_{ev} dN_{ch}/d\eta$: 900 GeV and 7 TeV

1.33 ± 0.04

2.42 ± 0.08

MC09c is best

but overall no Monte Carlo gives a “perfect” description of the data

$\langle P_t \rangle$ vs n_{ch} : 900 GeV and 7TeV

No single model is best: all disagree with data for high charged particle multiplicity & disagreement increases for $\sqrt{s} = 7$ TeV

p_T spectrum $1/N_{ev} (1/2\pi p_T) d^2N_{ch}/d\eta dp_T$

Significant disagreement for $p_T > 2 \text{ GeV}$ – the hard part of the PYTHIA model for soft processes

Underlying Event

UE = “everything” – “hard scatter” = beam-beam remnants+ MPI+ ISR

Study:

Charged particle density, transverse momentum sum, average P_t

Transverse region considered most sensitive to UE

Transverse Region Particle Densities

- All tunes underestimate particle density by $\sim 10\text{-}15\%$ in the plateau region
- There is a factor of ~ 2 increase in activity going from $\sqrt{s} = 900 \text{ GeV}$ to 7 TeV ; all tunes predict a comparable relative increase
- In the plateau region the measured density corresponds to ~ 2.5 particles per unit η at $\sqrt{s} = 900 \text{ GeV}$ and 5 particles per unit η at $\sqrt{s} = 7 \text{ TeV}$

Transverse Region $\langle \Sigma P_t \rangle$ Density

- Conclusion is similar to that for particle densities
  - all tunes underestimate the scalar sum P_t in the transverse region
  - Roughly a factor of 2 increase in sum P_t in the plateau region going from $\sqrt{s} = 900 \text{ GeV}$ to 7 TeV

Underlying Event Particle Densities by Region and E_{CM}

- MC09 (our best description at present) underestimates the particle densities in all regions
- the largest disagreement between data and MC is in the transverse region

Particle Density Angular Correlation

Define the event orientation by the azimuthal angle of the track with the highest P_t

Note that plot is reflected about $\phi=0$; highest p_T track is not included

- Monte Carlo tunes only reproduce the general features
  - Disagreement in rates both in the transverse region (UE) and in the Toward and Away regions (MPI/Hard Core)

PYTHIA Tune to ATLAS Min Bias Data and Underlying Event

Input to Tune:

- ATLAS UE data and charged particle densities at 0.9 and 7 TeV
- CDF Run I & Run II: min bias, UE, Z P_t
- D0 Run II dijet angular correlations

Tune to reduced phase space ($n_{\text{ch}} \geq 6$) to insure no contribution from SD

Significant improvement over pre-LHC tunes

Summary

- Soft QCD is defined experimentally by the trigger and event selection – “min bias”. This analysis is done in a well defined region of phase space without model dependent corrections such as from SD processes
- Charged track distributions are used to study the characteristics of min bias events and compared them to phenomenological models within PYTHIA
  - $\langle p_T \rangle$, N_{ch} , $\langle p_T \rangle$ vs N_{ch} , dN_{ch}/dh , dN_{ch}/dp_T
  - Underlying event distributions in transverse, towards and away regions
- None of the pre-LHC tunes provided “perfect” agreement with the experimental data, though they come close to describing several kinematic distributions as well as the increase in densities with $\sqrt{s}$.
- Used these measurement to obtain a new PYTHIA tune. This does a good job of describing the experimental data (*though still has problems with parts of the underlying event*)

Perhaps we need to
change our thinking of
“Soft QCD”

Additional Information

- Phys Lett B, Vol 688, 2010 (21-24)
- ATLAS-CONF-2010-031
- ATLAS-CONF-2010-024
- ATLAS-CONF-2010-029
- ATLAS-CONF-2010-031

Backup

Track Reconstruction Efficiency: Based entirely on Monte Carlo (for now)

Excellent agreement between MC and Data

Global systematic uncertainty $\sim 3\%$, dominated by material description

Comparison to Monte Carlos

- PYTHIA 6.4, MC09
  - ATLAS tune to CDF data
  - Pt ordered shower & color reconnection
  - MRST LO* PDF
- PYTHIA DW
  - Rick Field tune
  - Maximal ISR
  - Virtuality ordered shower
- PYTHIA Perugia
  - Peter Skands tune
  - Tevatron and SppS min bias data
  - Pt ordered shower
  - CTEQ5L PDF

Parameter changes from MC09c to AMBT1

Parameter	related model	MC09c value	scanning range	AMBT1 value
PARP(62)	ISR cut-off	1.0	fixed	1.025
PARP(93)	primordial kt	5.0	fixed	10.0
PARP(77)	CR suppression	0.0	0.25 – – – 1.15	1.016
PARP(78)	CR strength	0.224	0.2 – – – 0.6	0.538
PARP(83)	MPI (matter fraction in core)	0.8	fixed	0.356
PARP(84)	MPI (core of matter overlap)	0.7	0.0 – – – 1.0	0.651
PARP(82)	MPI (p_T^{min})	2.31	2.1 – – – 2.5	2.292
PARP(90)	MPI (energy extrapolation)	0.2487	0.18 – – – 0.28	0.250

Diffractive Contribution

Inclusive Charged Particle Spectrum at $\sqrt{s}=900$ GeV Compared to Other Experimental Data

CMS $dN_{ch}/d\eta|_{\eta=0}$ corrected for NSD

$$1.202 \pm 0.043 \text{ (syst)}$$

ATLAS equivalent result using PYTHIA DW tune to determine NSD correction

$$1.240 \pm 0.04 \text{ (syst)}$$