ATLAS
Underlying Event study
and an alternative
Delta phi analysis

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Joint LHC Underlying Event and Minimum Bias workshop,
7th September 2010
Outline

• Underlying Event analysis
• Delta phi analysis, looking closer at $\Delta \phi$ distributions
Data and selection criteria

Data:
900 GeV: December 2010
7 TeV: March 30th – April 7th

EVENT SELECTION:
• MBTS_1 trigger
• reconstructed vertex
• no second vertex with 4 or more tracks
• at least 2 selected tracks

TRACK SELECTION:
• $p_T > 500$ MeV
• $|\eta| < 2.5, 2.0, 1.0$
• at least 1 Pixel hit
• B-layer hit required if it is expected
• at least 6 SCT hits
• $|d_0| < 1.5$mm, $|z_0 \sin \theta| < 1.5$mm
• for $p_T > 10$ GeV: $\chi^2$ probability $> 0.01$
Definition: Delta phi, $\Delta \phi$

PARTICLE MOMENTA IN THE $x$-$y$ PLANE:

LEADING PARTICLE: PARTICLE WITH LARGEST $p_T$

$\Delta \phi$: the ANGLE between the leading particle and any other particle,

$\phi_{\text{LEADING PARTICLE}} - \phi_{\text{OTHER PARTICLE}}$
Track based UE study

Track with the highest $p_T$ tells the direction of the hard scatter.

Why?
- Best use of the limited statistics.
- Easier to correct back to hadron level.

Is this good?
Yes, it is: leading track is very often included in the leading jet.

Leading track: $p_T > 1.0$ GeV

ATLAS-CONF-2010-081
Corrected to the hadron level

- The distributions are corrected back to the hadron level and can be directly compared with the output of MC generators

- **Event level corrections:**
  - trigger inefficiency
  - vertex inefficiency
  - no particle with $p_T > 1.0$ GeV reconstructed

- **Track level correction:** efficiency, non-primaries, outside kinematic range

- **Unfolding factor:** account for resolution effects (bin migrations)
Underlying Event - Results

- 14 slides of plots:
  - $<N_{ch}>$ vs. $p_T^{lead}$
  - $<\Sigma p_T>$ vs. $p_T^{lead}$
  - Std. Dev. $N_{ch}$ vs. $p_T^{lead}$
  - Std. Dev. $\Sigma p_T$ vs. $p_T^{lead}$
  - $<p_T>$ vs. $p_T^{lead}$
  - $<p_T>$ vs. $N_{ch}$
  - $N_{non-leading tracks}$ vs. $\Delta \phi$
\(<N_{ch}>\) in transverse region

- All tunes are too low
- Best tunes are 10%-15% below the data

"Best tune": estimated by eye, sometimes difficult to decide; DON'T TAKE TOO SERIOUSLY
\textbf{\(<N_{\text{ch}}\)> in toward and away}

- generally a better agreement between data and MC than in the transverse region
\( <N_{ch}>: \) ratio 7 TeV / 900 GeV

- Pythia ATLAS MC09 tune: comparison of 900 GeV and 7 TeV plots
- the tune is below the data, but gets the ratio quite correct (only slightly underestimates)
$<\Sigma p_T>$ in transverse region

- very similar to the $<N_{ch}>$ plots
- best tunes 10% below the data
\[ \langle \Sigma p_T \rangle \text{ in toward and away reg.} \]

- generally a better agreement between data and MC than in the transverse region
$\langle \Sigma p_T \rangle$: ratio 7 TeV / 900 GeV

- Pythia ATLAS MC09 tune: underestimates the data, but gets the increase from 900 GeV to 7 TeV roughly right.
Std. Deviations in transv.r.

- MCs do a reasonably good job
$<p_T>$ in transverse region

- good description by most tunes: mostly within 5% from the data
$\langle p_T \rangle$ in toward and away reg.

- Here tunes tend to be higher than the data.
\[ \langle p_T \rangle: \text{ratio 7 TeV} / \text{900 GeV} \]

- A good description of the ratio by Pythia tune
  ATLAS MC09
\( <p_T> \) vs. \( N_{ch} \) in transverse r.

- Tunes ATLAS MC09 and Perugia0 are too high, others are fine
\( \langle p_T \rangle \) vs. \( N_{ch} \) in toward & away

- the leading track is included, that's why you see the spike in “toward”
  - ATLAS MC09 and Perugia0 are too high, others are fine
  - The shapes are different than in data
\(<p_T>\) vs. \(N_{ch}\): ratio 7 TeV / 900 GeV

- Here the ratios between the two energies are slightly worse described.
Angular distributions - $\Delta\phi$

- $\Delta\phi$ shapes are not well described by MC tunes.
- The next part of the talk will give more insight into the $\Delta\phi$ shapes.
Angular distributions: $\Delta \phi$

- Take a closer look into the $\Delta \phi$ shape
- Define variables in a way to minimise the systematic error
- Systematic uncertainty small – a few percent in the most sensitive bins
- Three eta ranges: $|\eta| < 1.0$, 2.0, 2.5
- ATLAS-CONF-2010-082
**Δφ crest shape**

**Δφ** is the ABSOLUTE VALUE of the angle between the tracks

**Raw Δφ distribution:**

- Subtract the minimum and normalise to 1:

- This is one of the two observables in this measurement.
- **Tests the shape** of the event: systematic uncertainties are greatly reduced!

U. Bitenc: UE and Delta phi at ATLAS

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**Graphs:**

- **Left Graph:**
  - Data, √s = 7 TeV
  - p_T > 500 MeV, |η| < 2.5
  - ATLAS Preliminary

- **Right Graph:**
  - CREST SHAPE
  - Data, √s = 7 TeV
  - p_T > 500 MeV, |η| < 2.5
  - ATLAS Preliminary

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Definition: Same side, Opposite side

SAME SIDE

LEADING PARTICLE (LARGEST $p_T$)

$\eta = 0$

OPPOSITE SIDE

PARTICLE MOMENTA IN THE $z$-$y$ PLANE:

Same side:
$\eta_{\text{LEADING PARTICLE}} \times \eta_{\text{OTHER PARTICLE}} > 0$

Opposite side:
$\eta_{\text{LEADING PARTICLE}} \times \eta_{\text{OTHER PARTICLE}} < 0$
“Same minus opposite”

Raw $\Delta\phi$ distributions for both regions:

- Subtract the “opposite side” distribution from the “same side distribution” and normalise to 1.0:

- This is the second observable in this measurement.

- **Tests the shape** of the event: systematic uncertainties are greatly reduced!

U. Bitenc: UE and Delta phi at ATLAS
MC: generated vs. reconstructed $\Delta\phi$

- Without applying any corrections the reconstructed distributions agree reasonably well with the generated ones.
- For $|\eta| < 1.0$ these discrepancies are even smaller.
Corrections applied

• Correct for tracking efficiency and presence of non-primary tracks
• Correct for lost leading tracks

→ Compare the corrected distributions directly to the output of MC generators
Results: **900 GeV**

- $|\eta|<1.0$: MC descriptions are $\sim$OK
- $|\eta|<2.5$: MC descriptions are OFF
- This is true for all the tunes (no tune describes the shapes)
Results: 7 TeV

- MCs are \( \sim \) OK for \(|\eta| < 1.0\), but not for \(|\eta| < 2.5\)
- Shapes for 7 TeV different than for 900 GeV
- At 7 TeV tunes are closer together, but not closer to the data
color reconnections, $|\eta| < 2.5$

- MCs are $\sim$OK for $|\eta|<1.0$, but not for $|\eta|<2.5$
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$p_T$ ordered tunes, $|\eta| < 2.5$

- At 7 TeV tunes are closer together, but not closer to the data
- Sensitive to shower parameters
- P HARD good for “crest” at 900 GeV, but not for 7 TeV “Same minus Opposite”
Conclusions

- Track based UE study results shown:
  - pre-LHC MCs too low in the transverse region, but better in forward and away

- $\Delta\phi$ shape studied using new variables
  - variables robust by construction
  - Pythia tunes fail to describe $\Delta\phi$ distributions