Early QCD measurements with ATLAS

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Representing the ATLAS collaboration
Outline

• Minimum bias
• Underlying event
• Di-jet azimuthal decorrelations
• Jets – high-x gluon pdf and jet energy scale

All results for 14TeV unless otherwise stated
Main reference (unless otherwise stated): Expected performance of the ATLAS experiment: detector, trigger and physics: arXiv 0901.0512
ATLAS: on one slide

Magnetic Field
2T solenoid plus air core toroid

Inner Detector
\( \sigma/p_T \sim 0.05\% \ p_T(\text{GeV}) + 0.1\% \)
Tracking in range \( |\eta| < 2.5 \)

EM Calorimetry
\( \sigma/E \sim 10\%/\sqrt{E(\text{GeV})} + 0.7\% \ |\eta| < 3.2 \)
(Fine granularity up to \( |\eta| < 2.5 \))

Hadronic Calorimetry
\( \sigma/E \sim 50\%/\sqrt{E(\text{GeV})} + 3\% \ |\eta| < 3.2 \)

Calorimetry
Covers \( |\eta| < 4.9 \) for \( E_T \)

Muon Spectrometer
\( \sigma/p_T \sim 2-7\% \)
Covers \( |\eta| < 2.7 \)

Precision physics in \( |\eta|<2.5 \)

See Alan Watson’s talk for more details

Early QCD measurements with ATLAS, DIS09, Madrid April 2009
Measurement of properties of minimum bias events

First measurement at LHC
- Measure charged particle distributions: rapidity distribution and pt-spectrum
- Multiplicity distributions and <pt> as a function of multiplicity
- Overlap with underlying event studies
- Large uncertainties on model predictions
Soft pp collisions

<table>
<thead>
<tr>
<th>pp collisions at $\sqrt{s} = 14$TeV</th>
<th>PYTHIA6.323</th>
<th>PHOJET1.12</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\sigma_{\text{tot}}$</td>
<td>101.5 mb</td>
<td>119.1 mb</td>
</tr>
<tr>
<td>$\sigma_{\text{elas}}$</td>
<td>22.2 mb</td>
<td>34.5 mb</td>
</tr>
<tr>
<td>$2^*\sigma_{\text{SD}}$</td>
<td>14.4 mb</td>
<td>11.0 mb</td>
</tr>
<tr>
<td>$\sigma_{\text{DD}}$</td>
<td>10.3 mb</td>
<td>4.1 mb</td>
</tr>
<tr>
<td>$\sigma_{\text{ND}}$</td>
<td>54.7 mb</td>
<td>69.5 mb</td>
</tr>
</tbody>
</table>

Minimum bias
Made up of combination of non-diffractive and diffractive

Early QCD measurements with ATLAS, DIS09.
Large uncertainties on predictions
\(\sigma_{\text{inel}}\): 79-85mb \(\sim\) 7%
\(\sigma_{\text{diff}}/\sigma_{\text{inel}}\): 0.2-0.3 \(\sim\) 50%
dN_{\text{ch}}/d\eta_{(\text{nsd} \eta=0)}\): 5-7 \(\sim\) 33%
\(<\text{pt}>\) at \(\eta=0\): 550-640MeV \(\sim\) 15%
What are minimum bias events?

- Minimum bias are inelastic collisions of two protons
  - Includes very rare high-pt scatters and very common low-pt scatters

- Minimum bias is an experimental definition
  - Defined by experimental trigger and analysis

- Relation between experiment and physics is:

\[
\sigma_{\text{measured}} = f_{\text{sd}} \sigma_{\text{sd}} + f_{\text{dd}} \sigma_{\text{dd}} + f_{\text{nd-inelastic}} \sigma_{\text{nd-inelastic}}
\]

\( f_i \) are the efficiencies for different physics processes determined by the trigger

Need to understand what is measured to allow comparison to previous results often presented for non-single diffractive (NSD) events
ATLAS minbias triggers

For operating luminosity $10^{33}$-10$^{34}$cm$^{-2}$s$^{-1}$ use random trigger

For early running up to $\sim 10^{30}$cm$^{-2}$s$^{-1}$, number of events/crossing $<< 1$

Require triggers for minimum bias
Inner detector spacepoints and tracks $|\eta| < 2.5$
Trigger scintillators (MBTS) 2.1$< |\eta| < 3.8$
LUCID 5.6$< |\eta| < 5.9$
ZDC $|\eta| > 8.3$
Trigger efficiencies

Results calculated using PYTHIA at 14TeV

<table>
<thead>
<tr>
<th>Efficiency</th>
<th>MBTS_1_1</th>
<th>MBTS_2</th>
<th>SP+EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>ND</td>
<td>0.99</td>
<td>1.0</td>
<td>1.0</td>
</tr>
<tr>
<td>SD</td>
<td>0.45</td>
<td>0.69</td>
<td>0.57</td>
</tr>
<tr>
<td>DD</td>
<td>0.54</td>
<td>0.83</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Trigger efficiency for different physics processes

- MBTS_1_1=1 hit in each side – level 1
- MBTS_2=2 hits on any side – level 1
- SP+EF= Random trigger – level 1
- Inner detector spacepoints (level 2)+tracks (event filter)

Trigger acceptance of different physics processes
(Efficiency scaled by fraction of total cross-section)

NSD Trigger acceptance ~90% of total rate

<table>
<thead>
<tr>
<th>Acceptance</th>
<th>MBTS_1_1</th>
<th>MBTS_2</th>
<th>SP+EF</th>
</tr>
</thead>
<tbody>
<tr>
<td>ND</td>
<td>0.69</td>
<td>0.70</td>
<td>0.70</td>
</tr>
<tr>
<td>SD</td>
<td>0.08</td>
<td>0.12</td>
<td>0.10</td>
</tr>
<tr>
<td>DD</td>
<td>0.07</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>Total</td>
<td>0.84</td>
<td>0.92</td>
<td>0.88</td>
</tr>
<tr>
<td>NSD/total</td>
<td>0.90</td>
<td>0.87</td>
<td>0.89</td>
</tr>
</tbody>
</table>

Early QCD measurements with ATLAS, DIS09, Madrid April 2009
Low pt tracking

- $p_T$ problem
  - Need to extrapolate by $\sim x2$
  - Need to understand low pt charged track reconstruction

Early QCD measurements with ATLAS, DIS09, Madrid April 2009
Minimum bias distributions

ATLAS has the tools to trigger on and reconstruct minimum bias events.

Minimum bias sample
Selected by MBTS_2
Corrections for:
- track reconstruction
- vertex reconstruction

Distributions have $p_T > 150\text{MeV}$

NSD sample
Corrected for trigger bias
-- change trigger bias

with ATLAS, DIS09, Madrid April 2009

<table>
<thead>
<tr>
<th>Track selection cuts</th>
<th>2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mis-estimate of secondaries</td>
<td>1.5%</td>
</tr>
<tr>
<td>Vertex reconstruction</td>
<td>0.1%</td>
</tr>
<tr>
<td>Mis-alignment</td>
<td>6%</td>
</tr>
<tr>
<td>Beam-gas &amp; pile-up</td>
<td>1%</td>
</tr>
<tr>
<td>Particle composition</td>
<td>2%</td>
</tr>
<tr>
<td>Diffractive cross-sections</td>
<td>4%</td>
</tr>
</tbody>
</table>

Total: 8%
The underlying event

Average charged particle density in transverse region

Extrapolation of UE to LHC energies is unknown
The UE depends on
- Multiple interactions
- Radiation
- PDFs
- String formation

UE affects
- Lepton isolation
- Top
- Jet energy at low $P_T$

Early QCD measurements with ATLAS, DIS09, Madrid April 2009
PYTHIA-(new)Tune vs Jimmy-Tune

New PYTHIA tune (ATLAS-PHYS-PROC-2009-045)
Shorter strings and change in matter distribution

Good agreement between PYTHIA6.416-Tuned and Jimmy4.3 for $P_T^{leading jet} > 6$ GeV at Tevatron Energies

hep-ph/0604120

Early QCD measurements with ATLAS, DIS09, Madrid April 2009
MAX/MIN Transverse Region

- Split transverse region into min and max
  - Max is sensitive to radiation
  - Min is closer to soft beam-beam remnant
- New PYTHIA UE model has a single description of MPI, ISR and FSR

\[ \langle N_{\text{chg}} \rangle \text{ in TransMAX & TransMIN} \]

\[ \langle p_T^{\text{sum}} \rangle \text{ in TransMAX & TransMIN} \]

PYTHIA6.416-newTune provides reasonable description of \( \langle N_{\text{chg}} \rangle \) and \( \langle p_T^{\text{sum}} \rangle \) in both TransMAX and TransMIN regions

Early QCD measurements with ATLAS, DIS09, Madrid April 2009
UE Energy Extrapolation

Comparison of PYTHIA(new-tune) to JIMMY in MAX/MIN regions

• Important to determine energy extrapolation of UE
  • Extrapolate tuning at 1800 GeV to 630 GeV,
  • Use MAX/MIN Analysis in Transverse Regions

• Good agreement between PYTHIA-(new)Tune and Jimmy for both MAX/MIN Regions
  • good extrapolation to lower energies
LHC Predictions at $\sqrt{s}=14$ TeV

**PYTHIA6.416-newTune vs Jimmy 4.3**

- $<N_{\text{chg}}>$ Predictions for LHC → PYTHIA-newTune and Jimmy predict same particle density
- $<P_T^{\text{sum}}>$ Predictions for LHC → PYTHIA-newTune predicts harder particles

Early QCD measurements with ATLAS, DIS09, Madrid April 2009
LHC Predictions at $\sqrt{s}=10$ TeV

Particle Density plateau at $\sqrt{s}=10$ TeV reduced by 16% wrt $\sqrt{s}=14$ TeV 1-10pb$^{-1}$ with minimum bias trigger probes to Pt-leading jet $\sim$50GeV

Early QCD measurements with ATLAS, DIS09, Madrid April 2009
Early QCD measurements with ATLAS, DIS09, Madrid April 2009

UE Reconstruction in ATLAS

ATL-PHYS-PUB-2005-015

Selecting the underlying event:

i. Jet events:
   \( N_{\text{jet}} > 1 \),
   \( |\eta_{\text{jet}}| < 2.5 \),
   \( E_{T_{\text{jet}}} > 10 \text{ GeV} \),

ii. Tracks:
   \( |\eta_{\text{track}}| < 2.5 \),
   \( p_{T_{\text{track}}} > 1.0 \text{ GeV/c} \)

ATLAS reconstructed track distributions for the UE well reproduce the MC event generator predictions

Jet measurements of early data will extend considerably our knowledge of the UE

Early QCD measurements with ATLAS, DIS09, Madrid April 2009
Effect of underlying event in jet reconstruction

Fragmentation reduces the amount of energy in jet cone

• Underlying event and fragmentation have the opposite effect
• Precise behaviour depends on the jet algorithm used
  • Frag. corrections for Cone DR=0.7 jets smaller than for Cone DR=0.4 jets, UE corrections larger due to the larger cone size
  • KT D=0.4 shows the lowest combined corrections (Frag. and UE effects cancel out).
  • KT D=0.6 jets is comparable to Cone DR=0.4 jets.
  • (Except for Cone DR=0.7 jets), non-perturbative effects are negligible for jets with $p_T>40$ GeV (PYTHIA).

Early QCD measurements with ATLAS, DIS09, Madrid April 2009
Azimuthal dijet decorrelation

Early measurement to benchmark generators particularly parton showers/higher orders

\[ \Delta \phi_{\text{dijet}} = \pi \] 
\[ 2\pi/3 < \Delta \phi_{\text{dijet}} < \pi \] 
\[ \Delta \phi_{\text{dijet}} \sim 2\pi/3 \] 
\[ \pi/2 < \Delta \phi_{\text{dijet}} < 2\pi/3 \]
Reconstructed di-jet azimuthal decorrelations

Selecting di-jet events:

Cone jet algorithm (R=0.7)

$N_{\text{jets}} = 2,$

$|\eta_{\text{jet}}| < 0.5,$

$E_{T,\text{jet}}^{\text{jet #2}} > 80 \text{ GeV},$

Two analysis regions:

$300 < E_{T}^{\text{MAX}} < 600 \text{ GeV}$

$600 < E_{T}^{\text{MAX}} < 1200 \text{ GeV}$
Jet cross-section and High-x gluon pdf

Jet cross-section theoretical uncertainty is dominated by high-x gluon pdf uncertainty. This limits the ability to search for new physics with high $P_T$ jets.

K. Rabbertz
4th LHC-HERA workshop
Determining the jet energy scale

Determine jet-energy scale (JES) uncertainty using in-situ methods

- Z-jets
  10 GeV < P_T < 100-200 GeV
  1% statistical uncertainty on JES with 300 pb⁻¹
  Systematics: ISR/FSR+UE ~ 5-10% at low P_T, reducing to 1-2% for P_T ~ 100-200 GeV

- γ-jets
  100-200 < P_T < 500 GeV
  1-2% statistical uncertainty on JES with 100 pb⁻¹
  Systematics from physics effects: ISR/FSR+UE ~ 1-2%
Jet energy scale

\( P_T > 500 \text{GeV} \)

- Use multi-jet \( P_T \)-balance: balance low-\( P_T \) jets with known JES against high-\( P_T \) jet with unknown JES
- Statistical uncertainty \( \sim 2\% \) for 1fb-1
- Systematics: JES uncertainty on low energy jets \( P_T > 40 \text{GeV} \) \( \sim 7\% \) for 400-1100\( \text{GeV} \)
- So total uncertainty is \( \sim 8\% \) dominated by low energy JES
- Makes measurement of high-\( x \) gluon pdf “challenging”
- Dominated by physics effects that may be better understood with data?

\[
B'_\Sigma = \frac{P_T^{\text{jet1}}}{\text{non-leading jets} \mid \sum P_T}
\]
Summary and Conclusions

- Minimum bias distributions can be measured and compared to previous NSD data and can discriminate between models
- Underlying event models have been tuned using tevatron data for current physics studies
- Underlying event can be measured with early data and can discriminate between models
- Comparisons of underlying event and minimum bias data will allow the energy evolution of the soft processes to be measured
- Understanding the underlying event is important for jet reconstruction
- Azimuthal decorrelations can be used to benchmark Monte Carlos with early data
- Jet energy scale for high-$P_t$ jets is challenging but can be improved with data
  - Extrapolation of jet energy scale to high $P_t$ jet is limited by the understanding of low $P_t$ jets
  - Measurements of underlying event and ISR/FSR from early data will help to improve this
- Thank you for your attention
Extra slides
MBTS

- Trigger scintillation counters mounted on end of LAr calorimeter covering same radii as ID
  - Cover $2<|\eta|<4$
- Can be used for first data BUT!
  - Not rad-hard
  - Uses 1/8\textsuperscript{th} of tilecal readout
  - Lifetime unknown
- At L1 S/N is ‘modest’
  - Now in simulation can be tuned to measurement in the summer
- Can do better at L2 with precision readout
Inner Detector Trigger at L2

Use pixel and SCT spacepoints to reject empty events
Empty: Interaction ~ 94:6
Still have large beamgas contribution

L1 random trigger
Top Physics – tt

Main goal, so far, has been to estimate uncertainties on reconstructed top parameters from UE (MPI) and ISR/FSR (coupled together)

- variations on UE, ISR/FSR affect observables on which selections cuts are applied: jet multiplicity, particles $p_T$ etc.
- potentially a serious impact on top reconstructed parameters (e.g. $M_{\text{top}}$, $\sigma_{tT}$)
- ISR and FSR PYTHIA parameters have been varied to give smallest and largest values of reconstructed top mass
  - Max ISR, Min FSR ($\Lambda_{\text{ISR}}*2$, ISR cutoff $-0.5*\text{ISR cutoff}$, $\Lambda_{\text{FSR}}*0.5$) → Max $M_{\text{top}}$
  - Min ISR, Max FSR ($\Lambda_{\text{ISR}}*0.5$, ISR cutoff $+0.5*\text{ISR cutoff}$, $\Lambda_{\text{FSR}}*2$) → Min $M_{\text{top}}$

- up to ~10% change in the Selection Efficiency from Min-Max $M_{\text{top}}$ samples
- contributing ~10% on syst. uncertainty on early data $\sigma_{tT}$
- visible effect on reconstructed $M_{\text{top}}$:
  - MC-Truth: ~5 GeV (hadronic $M_{\text{top}}$) and ~1-2 GeV (leptonic $M_{\text{top}}$)

MC-level Plots
For semi-leptonic tt̄ events (Cone $\Delta R=0.4$ truth jets)
**New underlying event model: PYTHIA6.3**


**Why do we need a new UE model?**

- hadron collisions are complex. Present models need to be improved! (more detail & more precision)
- extrapolations to the LHC energies require better physical insight. Simple parametrization is not enough!
- uncertainties in UE predictions for the LHC impact on cuts applied to possible discovery channels.

**New ISR and FSR parton showers**

- new model for multiple parton-parton interactions
- description of parton showers & MPI has been unified