First Run 2 Soft QCD
Results from ATLAS

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Soft-QCD

\[ \sigma_{\text{total}} = \sigma_{\text{el}} + \sigma_{\text{inel}} \]
Soft-QCD

\[ \sigma_{\text{total}} = \sigma_{\text{el}} + \sigma_{\text{sd}} + \sigma_{\text{dd}} + \sigma_{\text{nd}} \]
Soft-QCD

Interesting part!

No hard scatter
Soft-QCD

Underlying event = BBR + MPI + (ISR + FSR)

BBR: Beam-beam remnants
MPI: Multiple Parton interactions
ISR/FSR: Initial/Final state radiation
Glossary

- **Minimum-bias (MB):** Pretty much everything, exact definition trigger dependent.

- **Underlying event (UE):** background to events with an identified hard scatter (more like the actual interesting events we want to look at)

- **Pileup (PU):** (uncorrelated) separate collisions within the same/different bunch crossing we can’t differentiate because of our finite detector resolution (more like “isotropic” min-bias events).
Soft QCD

• Pedestal activity to all physics processes
• Not perturbative processes
• Cant subtract the contribution on an event-by-event basis
• Modelled in Monte Carlo Generators
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Detour: Event Generators

• We want realistic simulation of the collision events. To devise analysis strategy, background model, study/remove detector effect, etc.

• The hard scattering part can be calculated theoretically (in some order).

• The soft part is not calculable, so we use phenomenological models implemented in Monte Carlo.

Actually two step process, but not going to discuss detector simulation!
• Ultimate goal: models need to describe real data.

• “Free” parameters control all these aspects of the models, which cannot be derived analytically.

• A bunch of correlated (or anti-correlated) parameters describe one aspect, so have to change them simultaneously.

Tune: A particular optimized parameter setting in a particular MC generator to match the simulation with available data. Differ according to which datasets are included.
Would the Run 1 catastrophe happen all over again?
Charged Particle Distributions

Pythia8 tunes and Epos do well for left, only A2 is bad on right

arXiv:1606.01133
Charged Particle Distributions

Similar trends, none of the models do well over the whole range

arXiv:1606.01133
Charged Particle Distributions

Epos is best for both, A2 and Monash are competitive

arXiv:1606.01133
Charged Particle Distributions

Correlation depends on colour reconnection

arXiv:1606.01133
Dependence on E.C.M

About 20% increase from going from 7 to 13 TeV

Most models get the trend right

arXiv:1606.01133
Underlying Event
Underlying Event

Overall decent agreement, MB tunes do better for lower lead $p_T$, while UE tunes for higher...
Underlying Event

Tunes get the energy extrapolation roughly right
Inelastic pp Cross-Section

Require two MBTS hits

Constrain diffractive events fraction by hit on one side

Define using the larger mass:

\[ \tilde{\xi} = \frac{\tilde{M}_X^2}{s} \]

Calculated essentially by a counting experiment

\[
\sigma_{\text{inel}}(\tilde{\xi} > 10^{-6}) = \frac{N - N_{\text{BG}}}{\epsilon_{\text{trig}} \times L} \times \frac{1 - f_{\tilde{\xi} < 10^{-6}}}{\epsilon_{\text{sel}}} 
\]
Inelastic pp Cross-Section

Extrapolated to total inelastic cross-section using MC models

Largest uncertainty on luminosity

arXiv:1606.02625
In high multiplicity events there is an enhancement in the particle production at $\Delta \phi \approx 0$ over wide range of $\Delta \eta$.

First seen in HI collisions, also at TeV by CMS.

Needs dedicated HM trigger.
Summary

- Soft QCD is fun (and useful).
- Tuning is fun too, but hard to get everything right.
- Generators contain a lot under their hood, and it is good to have some understanding of it.
- The improved modelling of low $p_T$ processes is feeded back to full event generation, where it affects high $p_T$ part of the event, especially for precision measurements.
Supporting Material
NEW PREDICTIONS (10 years)

1. QCD tests & applications will greatly improve, incorporating NLO, NNLO,...and a theory of fragmentation and hadronization.
2. Atlas and CMS will discover a candidate Higgs particle.
3. There will be convincing evidence for Susy particles.
4. Plans will be underway to build a LC (at Cern) to explore the superworld and the US will join CERN.
5. There will be direct detection of the Dark Matter wind.
6. Alice will see a crossover to the perturbative quark-gluon plasma.
7. Some new Z mesons will be discovered.
8. Gravitational waves and B modes will be observed.
9. String theory will start to be a theory with predictions.
10. We will have a plausible explanation of why $\Lambda$ is so small.

David Gross at EPS 2011
A Note on the Models

“The predictions of the model are reasonable enough physically that we expect it may be close enough to reality to be useful in designing future experiments and to serve as a reasonable approximation to compare to data. We do not think of the model as a sound physical theory . . .”

– Richard Feynman and Rick Field, 1978
Monte Carlo Models

- Leading order/Parton shower models: Trying to build up a complex 2->N final state by showers.

- Pieces of a Parton-Shower MC Generator: (2->2 hard scattering), ISR, FSR, MPI, Fragmentation, Hadronization.

- Examples: Pythia, Herwig family.

- Higher order/Multileg generators: Sherpa, Alpgen, MC@NLO, Madgraph, Powheg ...

- Generators used mostly for a specific process: Phojet (diffractive), HIJING (heavy ion), AcerMC (top), JHU (spin and polarization information)....
One of the hardest measurements:

**Signal:** $ttH(bb)$

*important for measuring Yukawa couplings*

**BG:** $ttbb$
One of the hardest measurements:

Signal: $ttH(bb)$

$tt$ + $(DPI) \ bb$
Hard Process

Parton Shower

Hadronization

Decays

Multi Parton Interaction

From Frank Krauss
Charged Particle Distributions

About 10M events, using low μ run

Tracks with $p_T > 0.5$ GeV and $|\eta| < 2.5$

Remove primary charged particles with $30 < \tau < 300$ ps (strange baryons)