Studies of soft QCD at LHCb

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On behalf of LHCb collaboration

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Designed to look for physics beyond the SM by studies of CP violation and rare decays using $b$ & $c$ hadrons

LHCb detector

Forward coverage 15-300(250) mrad, high precision tracking and vertexing, excellent PID → Perfect tool for particle production studies in the forward region
Phase space coverage

Soft QCD physics results very interesting due to the unique phase space coverage in $\eta$, LHCb fully instrumented in an $\eta$ range from 2 to 5.
LHCb Soft-QCD results

2010:
- $K_S^0$ x-section @ 0.9 TeV, Phys. Lett. B 693 (2010) 69-80;

2011:
- $V^0$ ratios: baryon vs. meson suppression & baryon number transport at @ 0.9 TeV and 7 TeV; JHEP 1108 (2011) 034.

2012:
- Measurement of forward energy flow LHCb-CONF-2012-012 @ 7 TeV
- Particle ratios at 0.9 & 7 TeV, arXiv:1206.5160.
Forward energy flow

- Energy flow (EF) at high $\eta$ - directly sensitive to the amount of parton radiation and Multiple Parton Interaction (MPI).
- EF measurements results useful both for the collision physics and for the ultra-high energy cosmic-ray interaction models.
- EF defined as:

$$\frac{1}{N_{\text{int}}} \frac{dE_{\text{tot}}}{d\eta}$$

$dE_{\text{tot}}$ is the total energy of stable particles in the $\eta$ bin

$N_{\text{int}}$ number of inelastic $pp$ interactions

Experimentally determined for a $\Delta \eta$ bin:

$$\frac{1}{\Delta \eta} \left( \frac{1}{N_{\text{int}}} \sum_{i=1}^{N_{\text{part,}\eta}} E_{i,\eta} \right)$$

$E_{i,\eta}$ energy of an individual particle
Data and event sample

✓ 0.1 nb$^{-1}$ low luminosity LHC run @7 TeV
✓ Events with at least one track segment.

- **Inclusive MB**
  at least one well reconstructed track $p_T > 2$ GeV/c
- **Hard scattering**
  at least one well reconstructed track $p_T > 3$ GeV/c
- **Diffractive enriched**
  inclusive MB with no tracks in $-3.5 < \eta < -1.5$
- **Non-diffractive enriched**
  inclusive MB with at least one track in $-3.5 < \eta < -1.5$
Charged EF → the energy flow carried by the charged particles, based on p measurement

Total EF → data constrained MC estimate of neutral component

Correction for detector effects - bin-by-bin from simulation

Systematic uncertainties:
✓ tracking
✓ multiple interaction events (5% of events)
✓ simulation model
Corrected charged energy flow compared with PYTHIA generator predictions.

All PYTHIA 6 tunes used underestimate the charged EF at high $\eta$ for all the type of events studied.

PYTHIA 8 describes the best the charged EF for diffractive enriched events. 

*LHCb-CONF-2012-012*
Corrected charged EF vs. cosmic ray generators predictions.

Cosmic-ray models overestimate the charged EF.

SYBILL/EPOS best description of the inclusive MB charged EF.

QGSJETII-03 reasonable description of the charged EF in hard scattering.

Diffractive charged EF is underestimated by the cosmic-ray models.

LHCb-CONF-2012-012
Corrected total EF compared with PYTHIA generator predictions.

Total EF underestimated at high $\eta$ by all the PYTHIA6 tunes used and for all event categories studied.

PYTHIA 8 describes well the total EF for diffractive enriched events.

*LHCb-CONF-2012-012*

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R. Muresan - Studies of soft QCD at LHCb
Corrected total EF compared with cosmic ray generators predictions.

Cosmic-ray models overestimate the total EF.

SYBILL/EPOS the best description of the total EF for inclusive MB events.

QGSJETII-03 reasonable description of the total EF for hard scattering events.
Prompt hadron production ratios

- Charged particle production ratios:

\[
\begin{align*}
\frac{\bar{p}}{\bar{p}', \pi^-} & \quad \frac{p + \bar{p}}{p', \pi^+} & \quad \frac{K^+ + K^-}{\pi^+ + \pi^-} & \quad \frac{p + \bar{p}}{K^+ + K^-}
\end{align*}
\]

- 0.3 nb\(^{-1}\) of data @0.9 TeV and 1.8 nb\(^{-1}\) low luminosity LHC run.
- Important input for model building and generator tuning.

0.9 TeV farther from the beam in \(y\) compared with other measurements;

7 TeV, overlap in rapidity loss with previous measurements, probing energy scale violation.
Prompt hadron production ratios

- Simulated events used to calculate efficiencies and estimate systematic uncertainties.
- PID calibration using data samples of
  \[ K_S^0 \rightarrow \pi^+\pi^-, \Lambda \rightarrow p\pi^-, \phi \rightarrow K^+K^- \]
- Corrections applied for:
  ✓ effects of non-prompt contamination,
  ✓ geometrical acceptance losses,
  ✓ track finding inefficiency.
- Systematic uncertainties:
  ✓ PID (most important – size of calibration sample),
  ✓ interaction x-section & amount of material,
  ✓ tracking & non-prompt contamination.
The ratios differ from unity especially at high $p_T$ and high $\eta$. The behaviour is well described by all the generator tunes.
Tendency for data to lie significantly higher than Perugia 0 and Perugia NOCR PYTHIA 6 tunes, excess strangeness being produced compared to some MC predictions.
Tendency for measurements to lie significantly higher than Perugia 0 and Perugia NOCR tune, excess strangeness seems to be produced compared to some MC predictions.

Baryon suppression

Data lie in most cases significantly higher than predictions – especially at high $p_T$ and high $\eta$. 

$LHCb$-$PAPER$-$2011$-$037$ ($arXiv$:1206.5160)
Baryon suppression

Data lie in most cases significantly higher than predictions – especially at high $p_T$ and high $\eta$.

$LHCb$-PAPER-2011-037 (arXiv:1206.5160)

JHEP 1108 (2011) 034
Agreement with simulation generally good, but results hard to interpret.
At 0.9 TeV the $\bar{p}/p$ ratio $\gtrsim$ from 0.8 to 0.4 in the highest $p_T$ and $\eta$ bin. Data usually below LHCb MC and Perugia 0 predictions closer to Perugia NOCR PYTHIA 6 tunes.
At 0.9 TeV the $\bar{p}/p$ ratio \( \Psi \) from around 0.8 to around 0.4 in the highest $p_T$ and $\eta$ bin. Data below LHCb MC and Perugia 0 predictions closer to Perugia NOCR.
LHCb results cover a larger rapidity loss than any other single experiment and significantly improve the measurement precision in the region $\Delta y = y_b - y < 6.5$. 

**JHEP 1108 (2011) 034.**
Summary

Pythia 6 tunes underestimate the energy flow at high $\eta$ while most of the cosmic ray generators overestimate them. None of the generators investigated describe the energy flow correctly for all the classes of events studied -> results input for model tuning.

Measurements of: $\frac{\bar{p}_\text{t}}{p}K^{-}\pi^{-}$, $\frac{p+\bar{p}}{p}K^{+}K^{-}$, $\frac{p+\bar{p}}{p}\pi^{+}\pi^{-}$ were presented @ 0.9 and 7 TeV (first such studies at this energy). No single tune is able to describe well all the observables, largest discrepancies for $\frac{p+\bar{p}}{p}K^{+}K^{-}$, $\frac{\pi^{+}+\pi^{-}}{\pi^{+}+\pi^{-}}$ has been studied as function of rapidity loss over a range from 3.1 to 6.3, more precise results than previous measurements.
LHCb is not only a b&c-physics experiment but provides also an excellent environment for soft-QCD studies at high rapidities/pseudorapidities.

Stay tuned! for our future soft-QCD studies exploiting also the data @ 2.76 and 8 TeV