Measurement of the forward energy flow in pp collisions with the LHCb experiment

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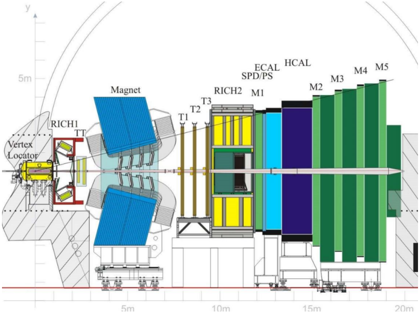
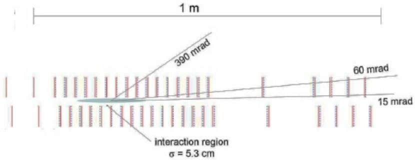
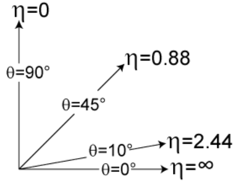
LHCb experiment





↑ VELO coverage; ↓ pseudorapidity



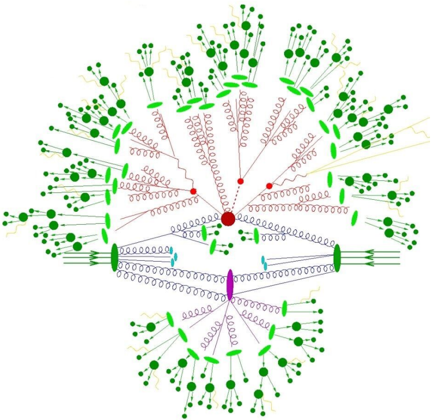
- Forward pseudorapidity, η coverage: of 2.0$< \eta <$5.0
- Backwards coverage -3.5$< \eta <$-1.5 (VELO only)
- Impact parameter resolution of 20μm
- Momentum resolution of 0.4(0.8)% at low(high) momentum

Inelastic hadron-hadron scattering

- In *Quantum Chromodynamics* (QCD) the final state of a proton-proton collision can be represented as a superposition of parton hard and soft scattering
- The hard scattering process can be successfully described using perturbative QCD
- The soft component includes the **underlying event**, which cannot be described using the same method
- **Experimental results are relied upon for description of the soft component and constraints of theoretical models**

Multi parton interactions (MPIs)

- MPIs are the **main contributors** to the **underlying event**
- These predominantly occur at large values of η, ie. the forward (backward) region
- Studying the energy production at large values of η can be used to investigate MPIs and differentiate between theoretical models
- **Measurement of forward energy flow at LHCb** is such a study



Hard process, **underlying event**, **fragmentation** and **hadron decays**

A.Kusina, ICHEP 2010, Paris

Measurement of forward energy flow

- Forward energy flow is a measure the energy production (dE_{total}) in a given interval of pseudorapidity ($d\eta$) normalized to the number of pp interactions (N_{int})

$$\frac{1}{N_{int}}\frac{dE_{total}}{d\eta} = \frac{1}{\Delta\eta}(\frac{1}{N_{int}}\sum_{i=1}^{N_{part,\eta}} E_{i,\eta}), \tag{1}$$

- Charged and neutral components investigated separately

- Similar analysis was carried out for Run-I data collected during the low luminosity run in 2010 [doi:10.1140/epjc/s10052-013-2421-y]

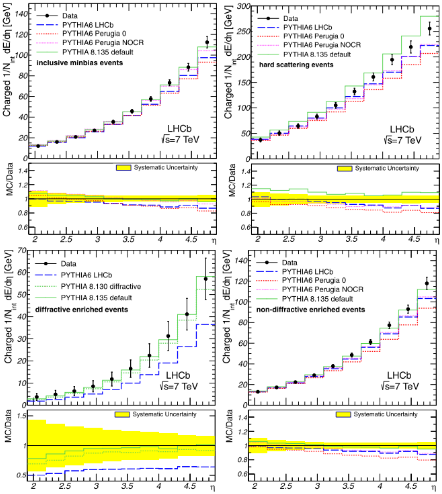
Forward energy flow: Event classes

1. Inclusive minimum bias:
   - Incl. min-bias events with **no more than 1** reconstructed primary vertex and **at least 1** track with $p > 2$ GeV/c
   - This class in then further split into three sub-classes
2. Hard scattering:
   - Incl. min-bias events with **at least 1** track with $p_T > 3$ GeV/c
   - Used to probe the energy production the 'hardest' events
3. Diffractive enriched:
   - Incl. min-bias events with **no** tracks in the backwards region (-3.5$< \eta <$-1.5)
   - Used to investigate the energy production in events containing large rapidity gaps
4. Non-diffractive enriched:
   - Incl. min-bias events with **at least 1 track** in the backwards region (-3.5$< \eta <$-1.5)
   - Show the energy production in a data set with the diffractive events subtracted

Forward energy flow: Run-I results

Charged energy flow at $\sqrt{s}$ =7 TeV compared to different PYTHIA tunes →

- Largest discrepancies can be seen for hard scattering and diffractive events
- These differences increase with η
- Similar situation observed when comparing results with cosmic ray models

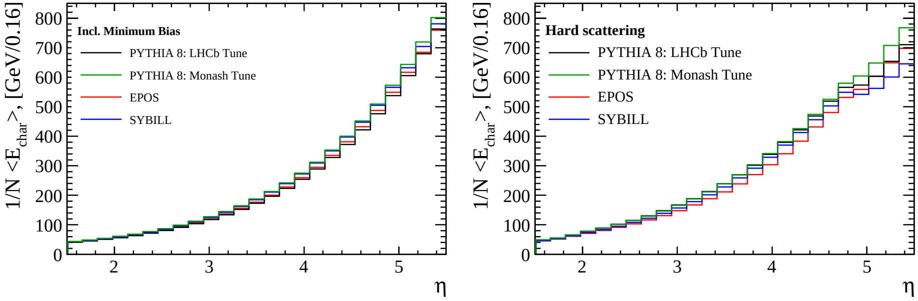


[doi:10.1140/epjc/s10052-013-2421-y]

Forward energy flow: Run-II strategy

- Follow the Run-I analysis in event selection requirements and classes with minor tweaks
- Use particle flow algorithm [doi:10.1016/j.nima.2009.09.009]
- Perform full detector unfolding for resolution and acceptance effects
- More thorough and stringent systematic checks
  (Huge statistics - analysis is systematically limited)
- Compare the corrected distributions to updated theoretical predictions

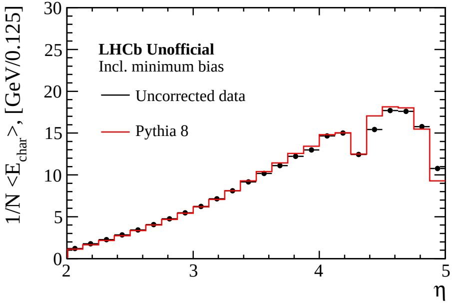
Theoretical predictions

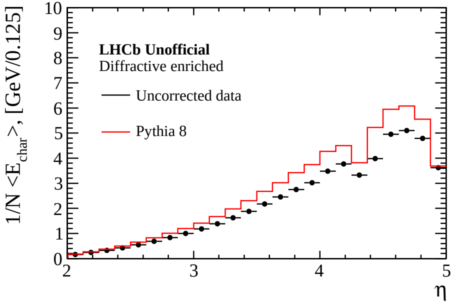


- Theory distributions have been obtained: two PYTHIA tunes and two cosmic ray models, EPOS[DOI:10.1103/PhysRevC.92.034906] and SYBILL[DOI:10.1103/PhysRevD.80.094003]
- Inclusive minimum-bias and hard scattering classes shown above
- Variation between models increases with increasing η; hard scattering events show larger discrepancy

Systematics, Status and Results

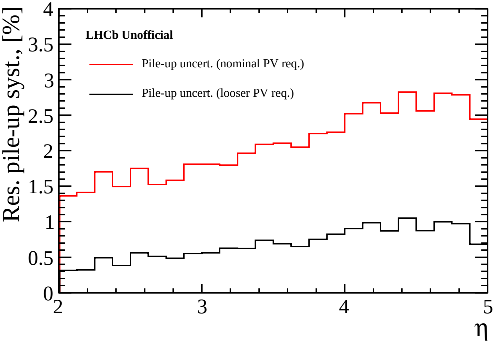
- Distributions of uncorrected charged energy flow at $\sqrt{s}$= 13 TeV for inclusive minimum bias and diffractive enriched event classes shown for data and Monte-Carlo
- It can be seen that at this stage the inclusive min-bias events are well simulated, whilst for diffractive events MC overshoots the data





Systematics, Status and Results

- **Residual pile-up:** $\longrightarrow$
  - Pile-up suppressed by $N_{rec,PV} < 1$
  - Residual pile-up arises from unreconstructed PVs
  - PV re-finding done with looser requirements



- Bkg. from fake tracks:
  - Reconstructed tracks with no generator level match

- Standard LHCb routines used to estimate the tracking uncertainty

- Full detector unfolding to be performed next!

Systematics, Status and Results

- Residual pile-up:
  - Pile-up suppressed by $N_{rec,PV} < 1$
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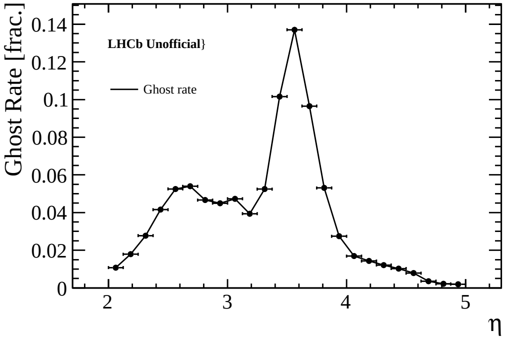
- **Background from fake tracks:** $\rightarrow$
  - **Reconstructed tracks with no generator level match**



- Standard LHCb routines used to estimate the tracking uncertainty
  - Small differences in tracking efficiency between data and MC

- Full detector unfolding to be performed next!

Conclusions

- Study of the forward energy flow at $\sqrt{s}$= 13 TeV is being done
- The event selection and classes follow a similar analysis carried out in Run-I
- Run-II measurement includes more thorough systematic analysis and higher statistics
- This measurements is of considerable importance for our understanding of QCD processes at large distance scales
- Furthermore, it is of great use in tuning MC generators in order to provide HEP analyses with better quality input
- The analysis is progressing well and results are expected in 2016.

Backup

Event classes and selection

Event Class	Criteria at detector level	Criteria at generator level
Inclusive minimum-bias	$N_{long} > 0$ in $2.0 < \eta < 5.0$ with p>2GeV/c, χ^2/NDF<3, $d_0 < 1$ cm, $\lvert z_0 \rvert < 25$ cm. $N_{rec,PV} < 2$, $\lvert \bar{z}_0 \rvert < 10$ cm. $N_{tracks\_per\_VELO\_seg.} = 1$.	$N_{char} > 0$ in $2.0 < \eta < 5.0$. $N_{pp,inel}$ per BX $= 1$.
Hard scattering	inclusive events with at least 1 track having p_T >3 GeV/c, χ^2/NDF<3 in $2.0 < \eta < 5.0$	$N_{char} > 0$ in $2.0 < \eta < 5.0$ with p_T >3 GeV/c, $N_{pp,inel}$ per BX $= 1$.
Diffractive enriched	inclusive events with $N_{tracks} = 0$ in $-3.5 < \eta < -1.5$	inclusive events with $N_{char} = 0$ in $-3.5 < \eta < -1.5$
Non-diffractive enriched	inclusive events with $N_{tracks} > 0$ in $-3.5 < \eta < -1.5$	inclusive events with $N_{char} > 0$ in $-3.5 < \eta < -1.5$