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LHCb for astroparticle physics: Inclusive production of prompt charged particles

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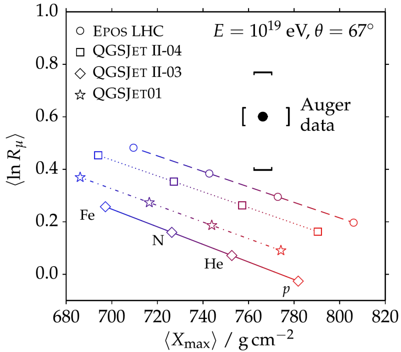
Motivation

- Cosmic rays as messengers of the high-energy universe
- Indirect detection of cosmic rays through air showers
- Simulations necessary to infer mass composition from number of produced muons or depth of shower maximum [CERN-LPCC-2018-07 (2018)]
- Discrepancy in number of produced muons between air-shower data and simulations (muon puzzle)
- Model uncertainties due to lack of data related to multi-particle production in forward direction at TeV scale
- Benefit from forward particle-identification system of the LHCb experiment and suitable energies



[Phys. Rev. D 91, 032003 (2015)]

Data set and selection

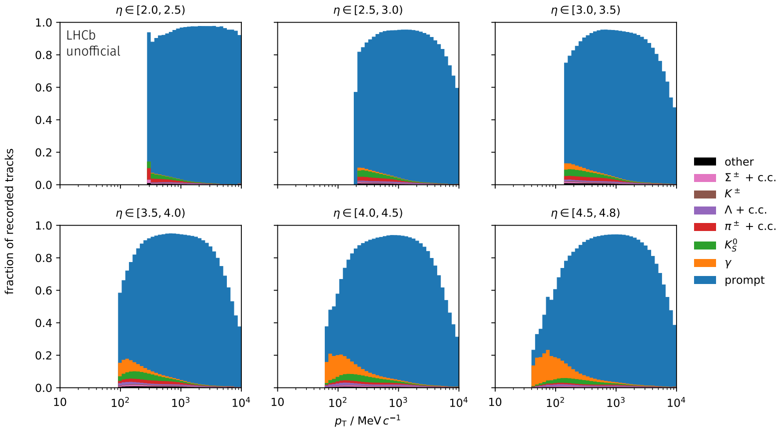
- Measure cross-section of inclusive production of prompt charged long-lived particles in bins of transverse momentum p_{T} and pseudorapidity η
- Use early-measurement proton-proton collision data recorded in 2015 at a centre-of-mass energy of $13\,\mathrm{TeV}$ without trigger bias and corresponding simulations
- Apply basic candidate selection
  - Use only tracks traversing the whole tracking system
  - Reduce number of tracks not corresponding to real particles (ghost tracks)
- Take into account effect of candidate selection by introducing correction factor C obtained from simulation:

$$C_{\mathrm{sim}} = \frac{N_{\mathrm{sim}}}{N_{\mathrm{gen,\,sim}}} \quad \rightarrow \quad N_{\mathrm{gen}} \approx \frac{N}{C_{\mathrm{sim}}}$$

N	Number of candidate tracks
N_{gen}	Real number of prompt charged particles

Origin of reconstructed tracks

- Study background composition using simulation



- White area adding bins up to unity representing ghost tracks
- Deduce non-negligible contributions

Correction-factor calibration

- Adjust correction factor to capture differences between data and simulation by defining proxies $\mathcal{P}_i$ with $i \in \{\mathrm{ghost}, V^0, \mathrm{material}\}$ replacing unknown ratios R_i in data:

$$\frac{N_i}{\varepsilon N_{\mathrm{gen}}} =: R_i = \frac{\mathcal{P}_i}{\mathcal{P}_{i,\,\mathrm{sim}}} R_{i,\,\mathrm{sim}} \quad \rightarrow \quad C = C_{\mathrm{sim}} \frac{\varepsilon}{\varepsilon_{\mathrm{sim}}} \frac{1 + \sum_i \frac{\mathcal{P}_i}{\mathcal{P}_{i,\,\mathrm{sim}}} R_{i,\,\mathrm{sim}}}{1 + \sum_i R_{i,\,\mathrm{sim}}}$$

N_{ghost}	Number of ghost tracks passing the candidate selection
N_{V^0}	Number of tracks from K^0_{S}, Λ and $\overline{\Lambda}$ (V^0) decays passing the candidate selection
N_{material}	Number of tracks from material interactions passing the candidate selection
ε	Track-reconstruction efficiency

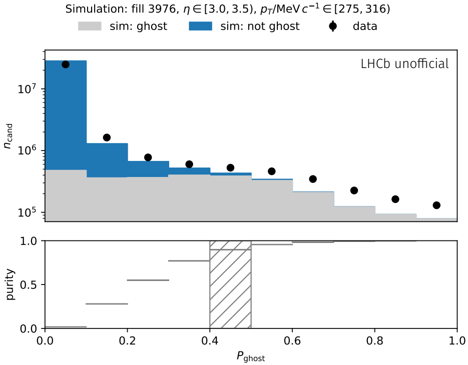
- Differential cross-section:

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}\eta} = \frac{N - N_{\text{beam-gas}}}{C\,\Delta p_{\mathrm{T}}\,\Delta\eta\,\mathcal{L}}$$

$N_{\text{beam-gas}}$	Number of candidate tracks produced in interactions of both beams with residual gas in the beam pipe
$\mathcal{L}$	Integrated luminosity

Proxy for ghost tracks

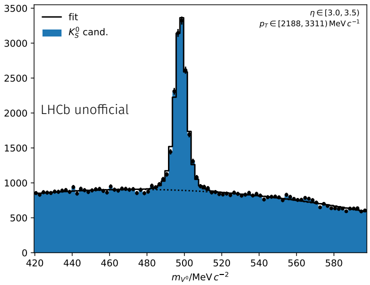
- Assign weights to the simulated events adjusting the detector occupancy for evaluation of all three proxies
- Information from tracking system combined in ghost probability P_{ghost} for each reconstructed track
- Contribution of ghost tracks to candidate tracks approximately proportional to number of tracks with high P_{ghost} values
- Divide P_{ghost} distribution into ten bins
- Choose lowest bin above maximal selected value $P_{\mathrm{ghost}} = 0.3$ with ghost-track purity greater than $90\,\%$ to obtain proxy for each kinematic bin
- Determine systematic uncertainty by instead selecting all bins with ghost-track purity greater than $90\,\%$

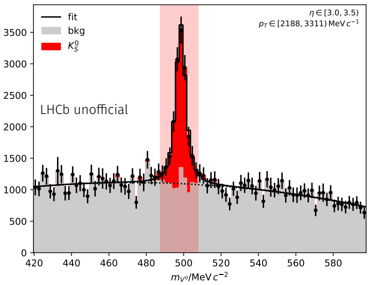


Proxy for V^0 decays

- Form pairs of oppositely charged tracks using topological and kinematic requirements to select $K_S^0 \to \pi^+\pi^-$, $\Lambda \to p\pi^-$ and $\overline{\Lambda} \to \overline{p}\pi^+$ candidates
- Fit invariant-mass distributions in data and simulation in kinematic bins by describing the signal with Student's t function and the background with a polynomial

K_S^0 Data

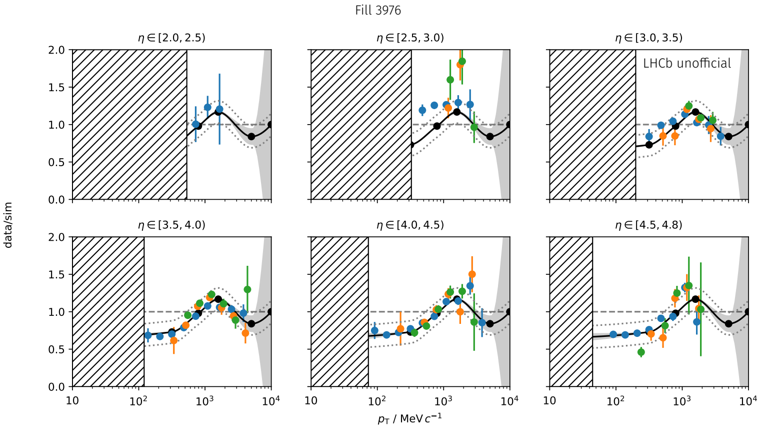




K_S^0 Simulation

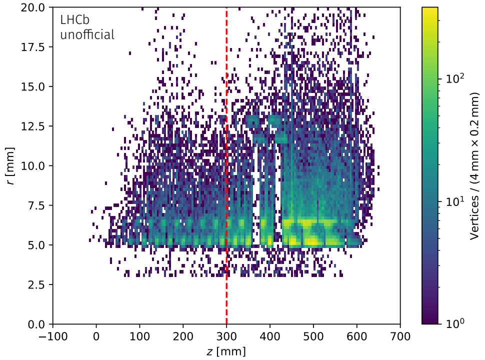
Proxy for V^0 decays

- Calculate proxy ratio as ratio of V^0 signal yields between data and simulation
- Perform combined fit to V^0-yield ratios with monotonic cubic Hermite spline based on tuned knots
- Assign systematic uncertainty to take into account variations not reflected by statistical uncertainty



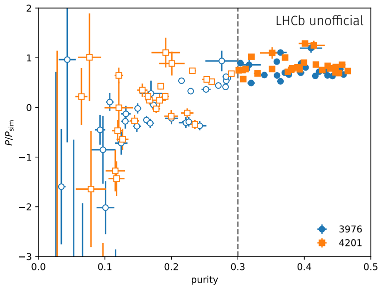
Proxy for material interactions

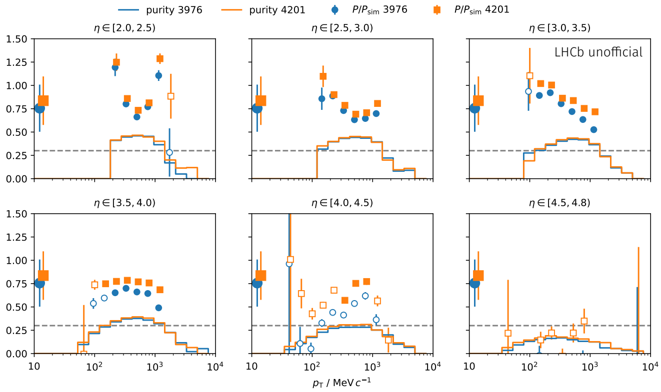
- Choose number of tracks produced in interactions of charged pions with the detector material as proxy
- Scale also number of tracks from conversions of photons (mostly originating from neutral-pion decays) with this proxy
- Select candidate vertices formed by three tracks and separated from beam axis
- Apply topological and kinematic requirements optimised using simulation



Proxy for material interactions

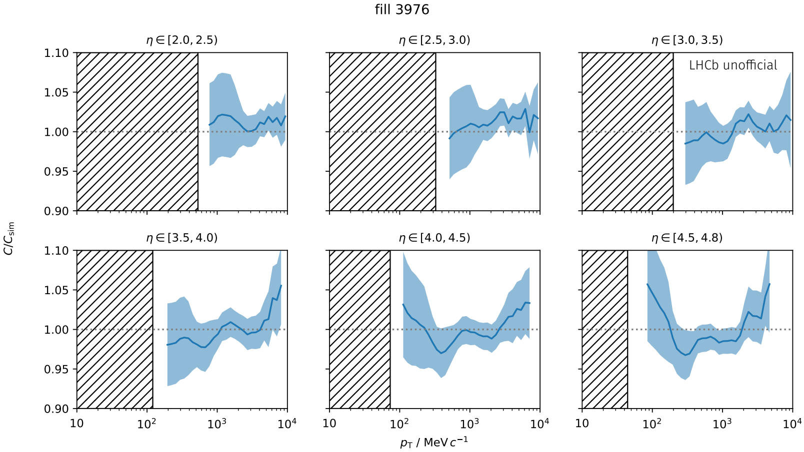
- Introduce purity threshold for evaluation of proxy ratio
- Use obtained ratio in bins with sufficiently high purity and use average value of ratio otherwise
- Determine systematic uncertainty by varying proxy-selection requirements





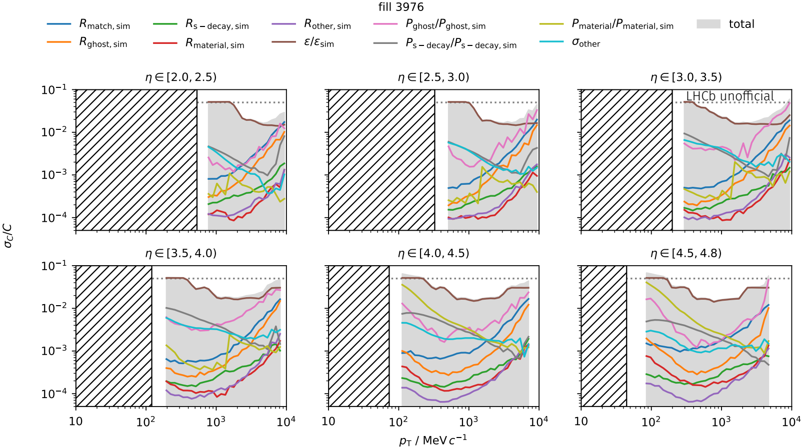
Result for adjusted correction factor

- Data-over-simulation ratios of track-reconstruction efficiency provided by the LHCb tracking group
- Include systematic uncertainties for proxy determination and track reconstruction



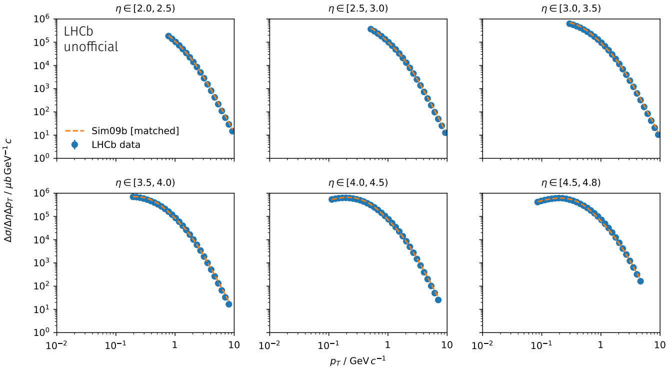
Result for adjusted correction factor

- Total relative uncertainty below $5\,\%$ in almost all kinematic bins
- Largest contribution to total uncertainty from track-reconstruction efficiency



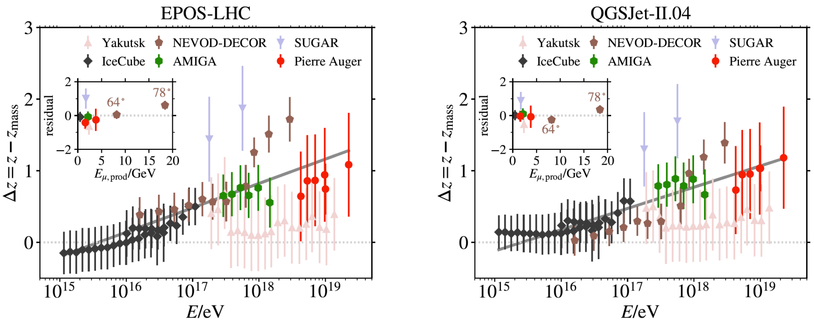
Summary and outlook

- Determined result for differential cross-section of prompt-charged-particle production
- Achieved relative uncertainty below $5\,\%$ enabling tuning of air-shower simulations
- Analysis almost ready for review
- Analyse subsequently proton-lead collision data recorded in 2016 at a nucleon-nucleon centre-of-mass energy of $8.16\,\mathrm{TeV}$ with the same strategy
- Addition of particle-identification information to strategy as long-term aim



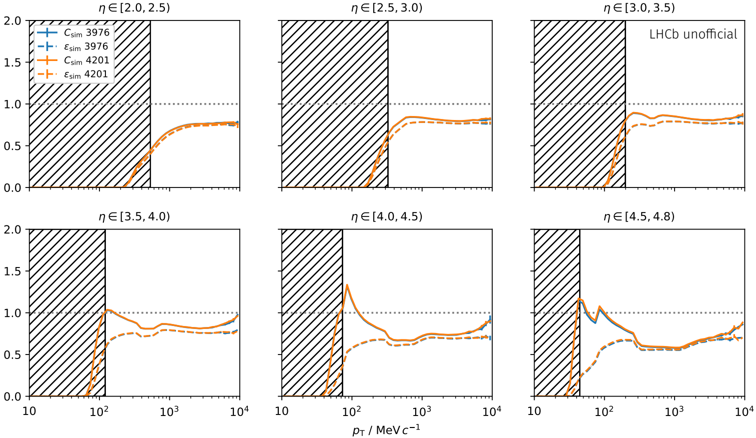
Backup

Energy-dependent trend of muon deficit in simulations for two different models

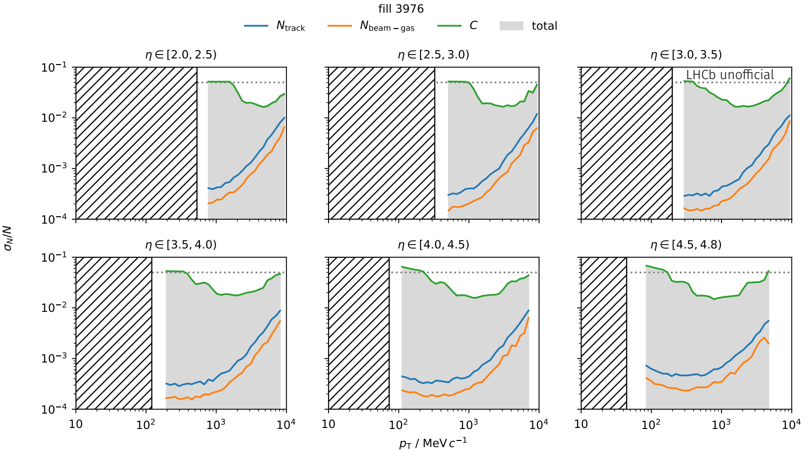


[PoS ICRC2019, 214 (2019)]

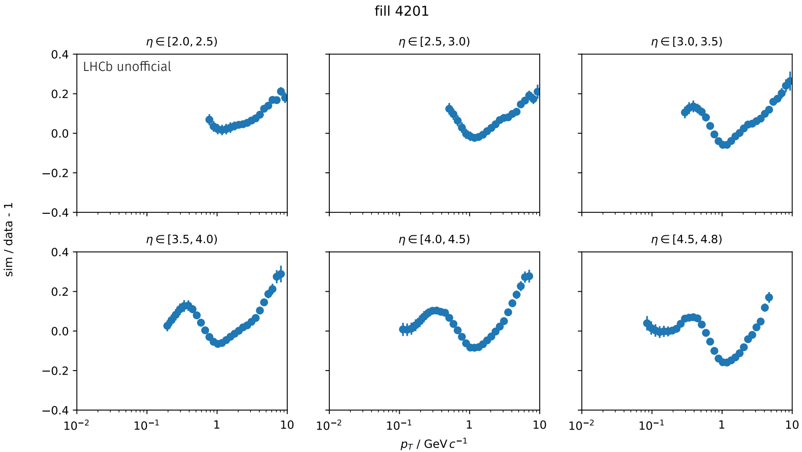
Correction factor and track-reconstruction efficiency from simulation



Relative uncertainties affecting final result



Ratio of cross-section from simulation and final result



Comparison of final results for both magnet polarities