Production of Z bosons in association with a D meson

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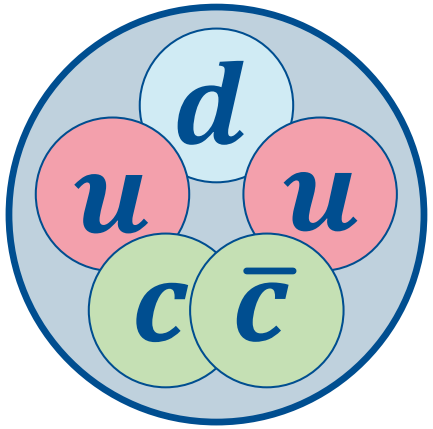
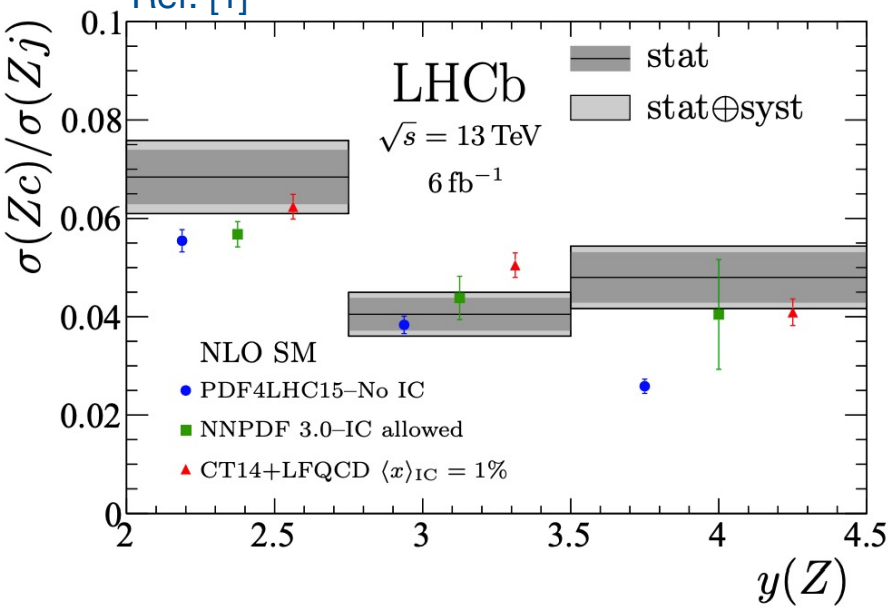
Motivation



Ref. [1]



- Previous LHCb studies of $Z + c$-jets yield results that could be explained by the proton having an intrinsic charm content
  - Proton contains a charm quark content that is equivalent to the $|uud\rangle$ picture
- Occurs at large values of Bjorken-x, i.e. when the c-quark carries a large fraction of the proton's overall momentum
- Existence of intrinsic charm hotly disputed

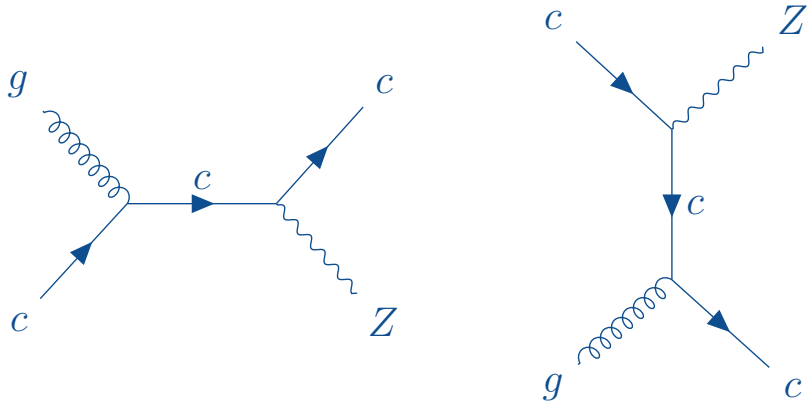
How can we observe this?

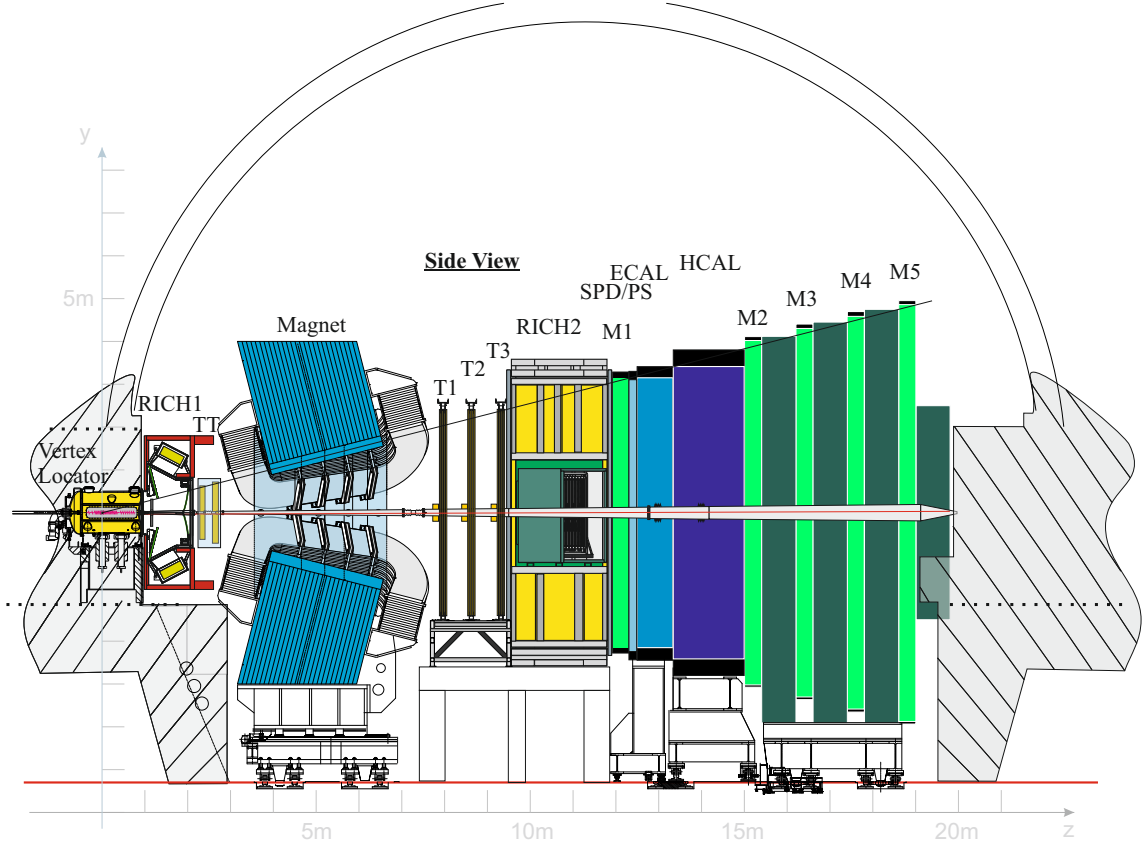
The intrinsic charm quark valence distribution of the proton, NNPDF Collaboration, Ref. [2]

We provide a first quantitative indication that the wave function of the proton contains unequal distributions of charm quarks and antiquarks, i.e. a nonvanishing intrinsic valence charm distribution. A significant nonvanishing valence component cannot be perturbatively generated, hence our results reinforce previous evidence that the proton contains an intrinsic (i.e., not radiatively generated) charm quark component. We establish our result through a determination of the parton distribution functions (PDFs) of charm quarks and antiquarks in the proton. We propose two novel experimental probes of this intrinsic charm valence component: D-meson asymmetries in $Z+c$-jet production at the LHCb experiment, and flavor-tagged structure functions at the Electron-Ion Collider.

How can we observe this?

- Forward coverage of LHCb ⇒ measurements of highly boosted Z bosons possible
- Following Feynman diagrams probe the large-x region:





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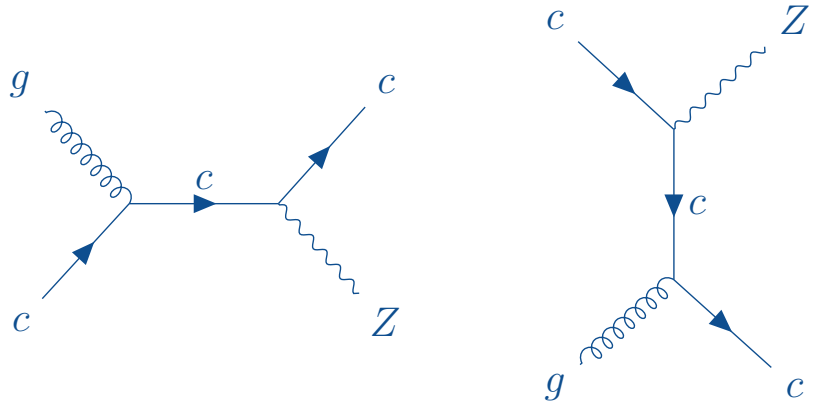
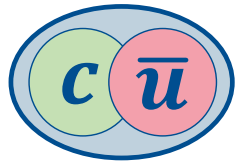
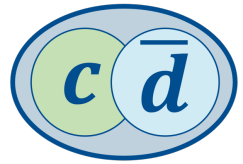
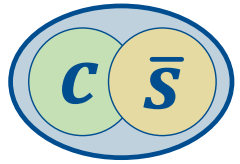




$D^0 \to K^-\pi^+$



$D^+ \to K^-\pi^+\pi^+$

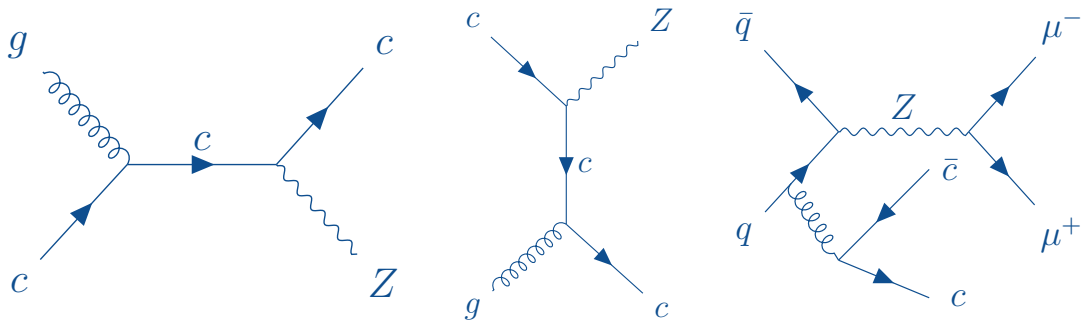


$D_s^+ \to K^-K^+\pi^+$

- c-quarks hadronise to form D mesons, which are reconstructed from a selection of kaons and pions
- Z boson reconstructed using $Z \to \mu^+\mu^-$ channel

$Z + D$ production mechanisms

- **Single parton scattering (SPS):** Z boson and D meson produced in same parton-parton interaction



- **Double parton scattering (DPS):** Z boson and D meson produced in separate parton-parton interactions

- $Z + D$ production cross-section for DPS events:

$$\sigma_{\mathrm{DPS}}^{Z+D} = \frac{\sigma^{Z}\sigma^{D}}{\sigma_{\mathrm{eff}}}$$

- Can determine expected cross-section from DPS events ⇒ subtract this from measured cross-section to give contribution from SPS events

What do we expect to see?

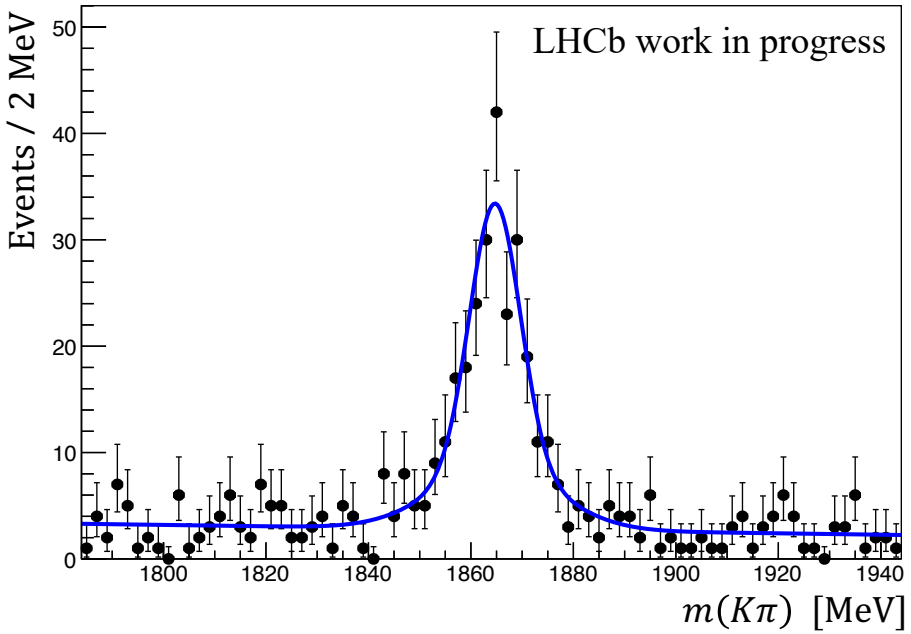
An intrinsic charm component would show up as a larger than expected contribution from SPS events.

Signal yields

What do we expect to see?

An intrinsic charm component would show up as increased event yields in some regions of kinematic variables.

$D^0 \to K^-\pi^+$



- Signal yield obtained from fit to D meson mass peak:
  - **Signal:** double Gaussian
  - **Background:** first-order polynomial
- Determine signal yield as a function of the rapidity of the Z boson ($y(Z)$)
- Do we observe an enhancement in $N(Z+D)/N(Z)$ for large $y(Z)$?

Summary

- Studying $Z + D$ production at LHCb provides access to the intrinsic charm content of the proton
- $Z + D^0$ and $Z + D^+$ events were observed during Run 1
- Updated analysis with larger Run 2 dataset allows production mechanisms and kinematic properties of the events to be studied
- Further studies with Run 3 dataset necessary to determine full picture

References

[1] LHCb Collaboration. “Study of Z bosons produced in association with charm in the forward region”. *Phys. Rev. Lett.* 128 (2022) arXiv: 2109.0804 [hep-ex]

[2] R.D. Ball *et al.* “The intrinsic charm quark valence distribution of the proton” (2023). arXiv: 2311.00743 [hep-ex]

[3] R. Gauld *et al.* “NNLO QCD predictions for Z-boson production in association with a charm jet within LHCb fiducial region”. *Eur. Phys. J. C* 83 (2023) arXiv: 2302.12488 [hep-ph]

[4] LHCb Collaboration. “Observation of associated production of a Z boson with a D meson in the forward region”. JHEP 091 (2014). arXiv: 1401.3245 [hep-ex]