

Z bosons produced in association with charm @ LHCb

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February 15, 2022



Intrinsic Charm

PDF fits have typically assumed all charm in the proton arises perturbatively; however, non-perturbative *intrinsic* charm is also possible — perhaps even expected.*

$$|p\rangle = |uud\rangle + \epsilon |uudc\bar{c}\rangle?$$

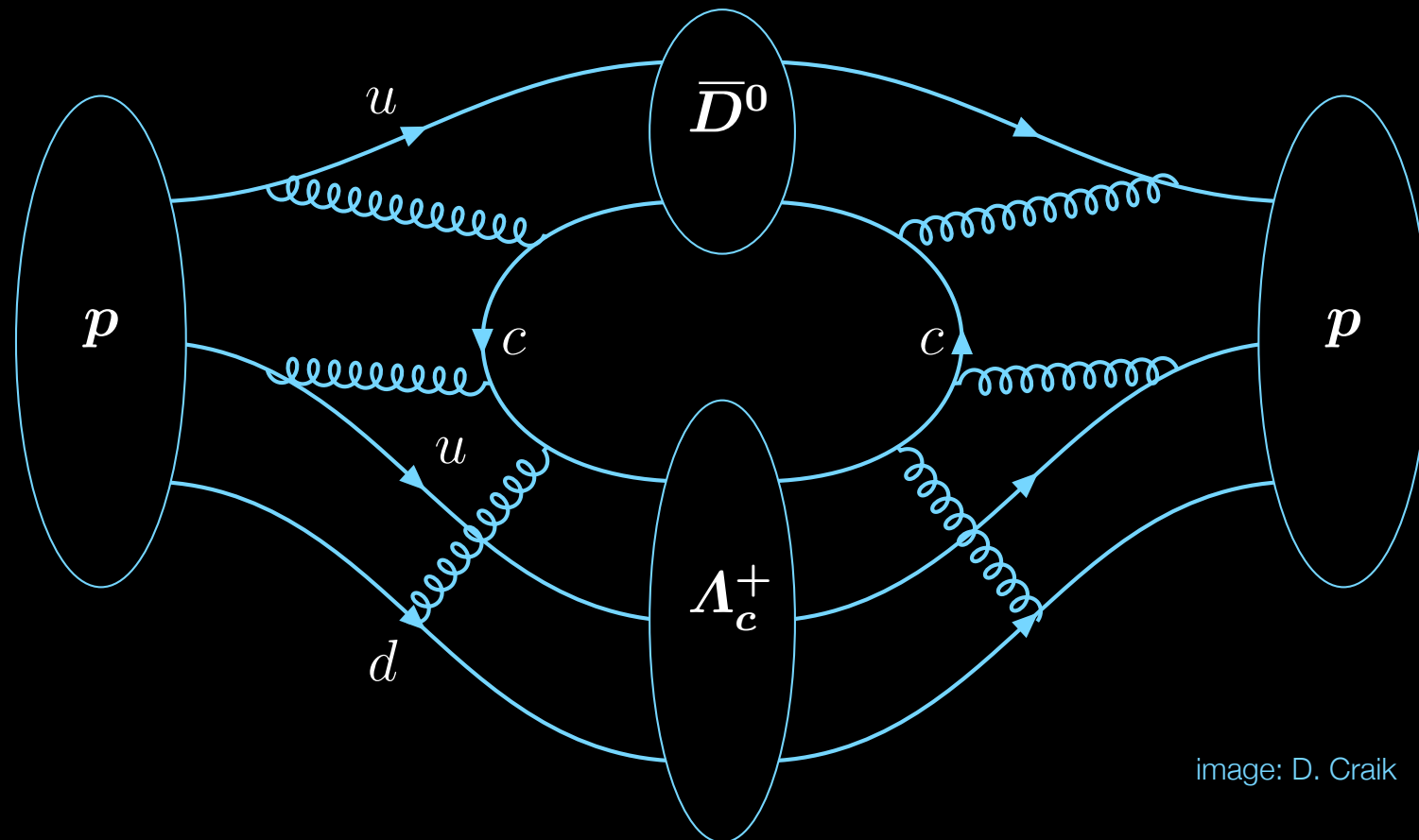


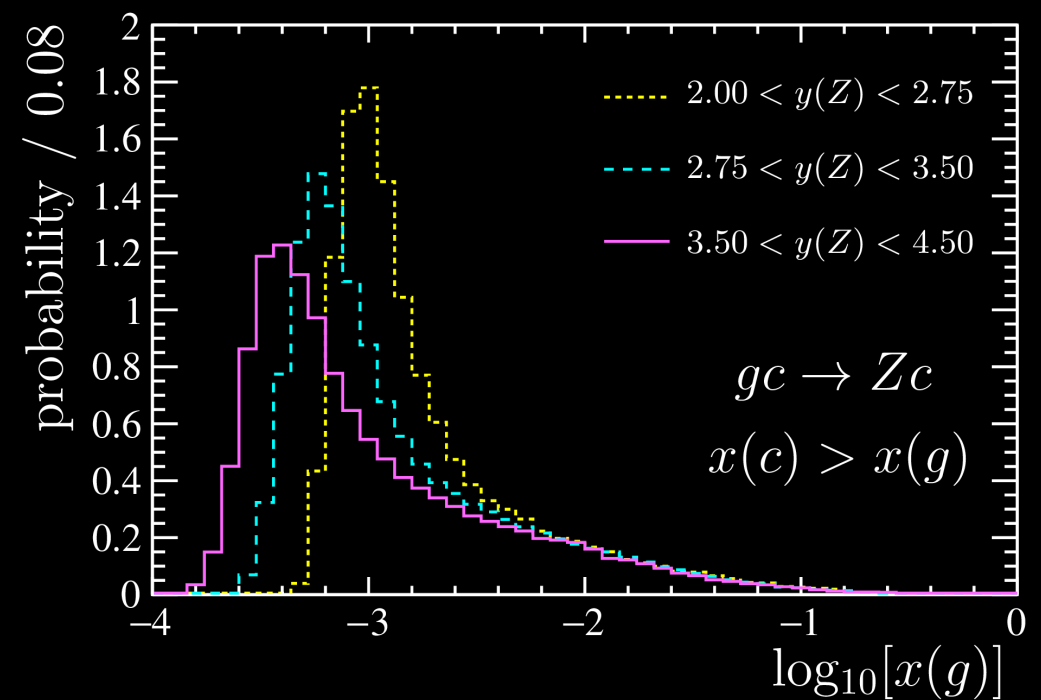
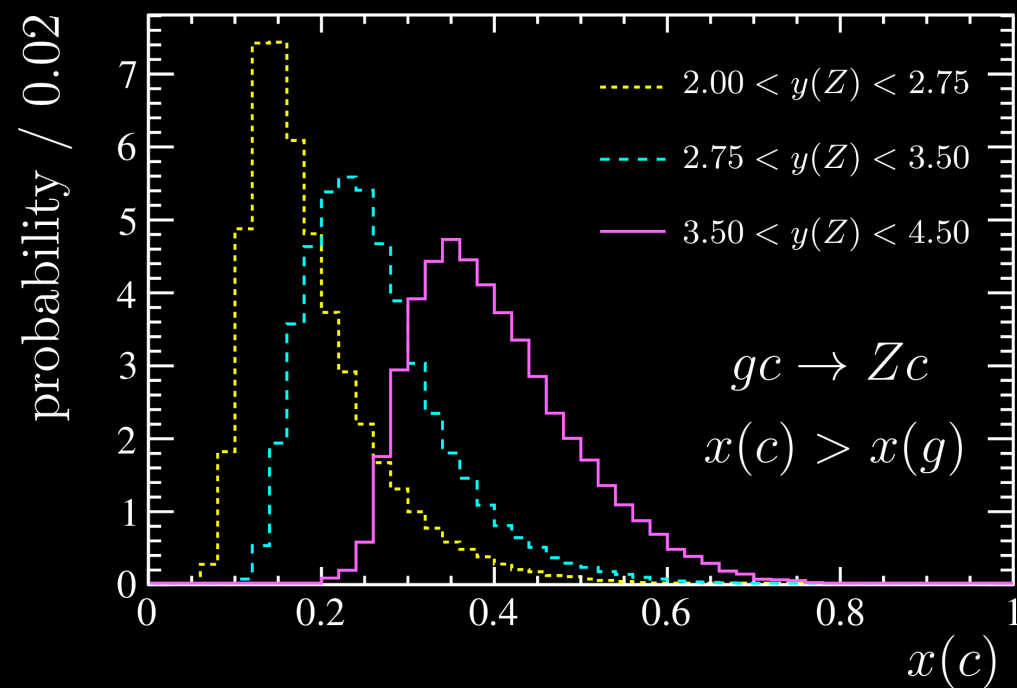
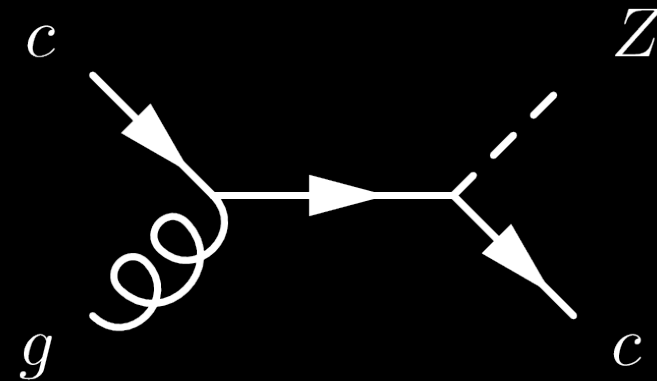
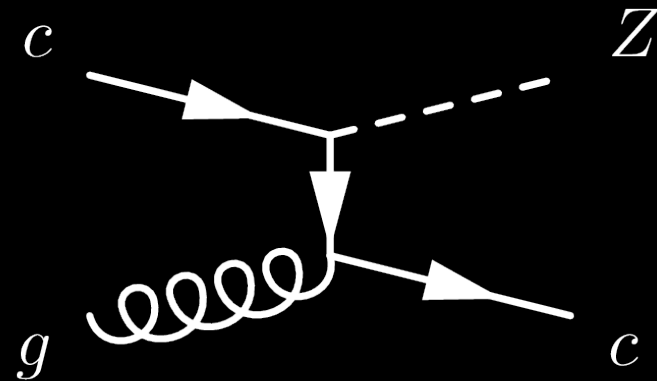
image: D. Craik

Expect intrinsic charm to be at large x (~ 0.4) due to the large charm mass (heuristic: make the c and \bar{c} as on-shell as possible).

*BHPS: Brodsky, Hoyer, Peterson, Sakai, PLB 93 (1980) 451; Brodsky, Peterson, Sakai, PRD 23 (1981) 2745.

Forward Z+c

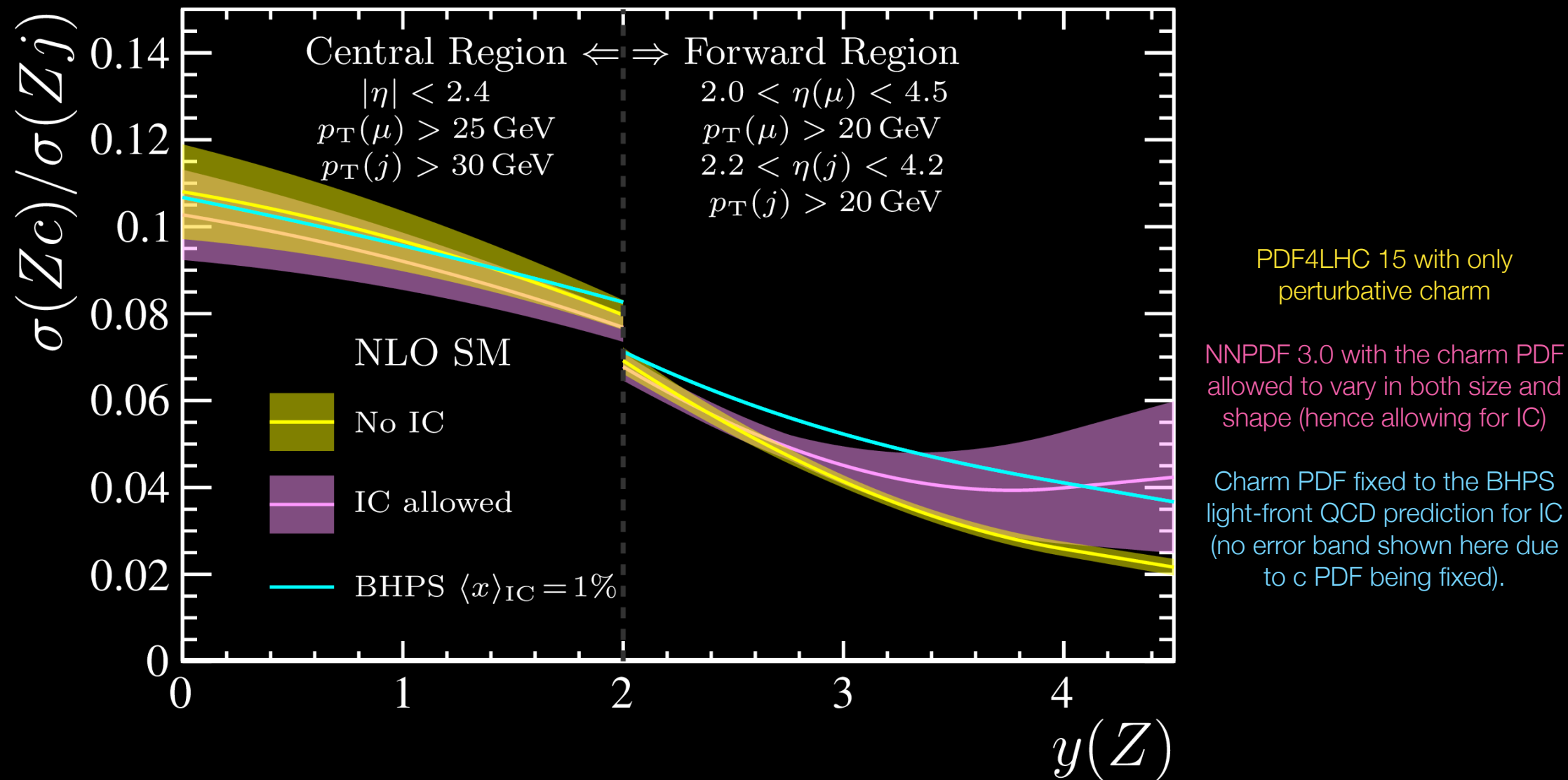
A leading-order production mechanism of Z+c is gluon-charm scattering, which in the forward region probes valence-like large- x charm.



The forward-most LHCb $y(Z)$ bin probes the $x \sim 0.4$ charm content of the proton.

Forward Z+c

NLO SM predictions* show that the forward LHCb region is much more sensitive to intrinsic charm than the central region for differential measurements vs $y(Z)$.

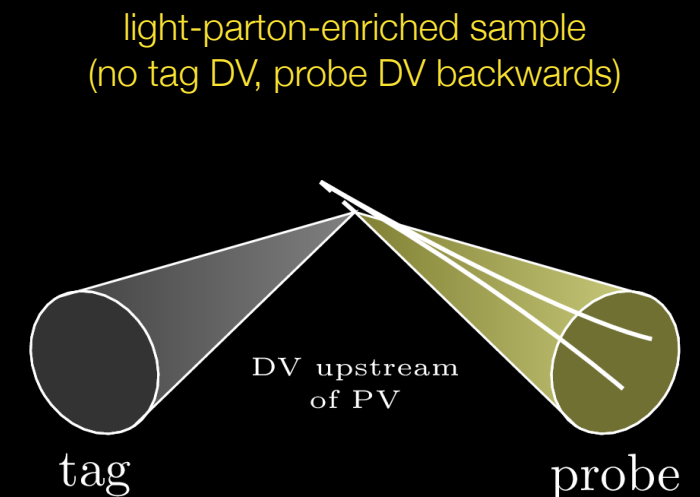
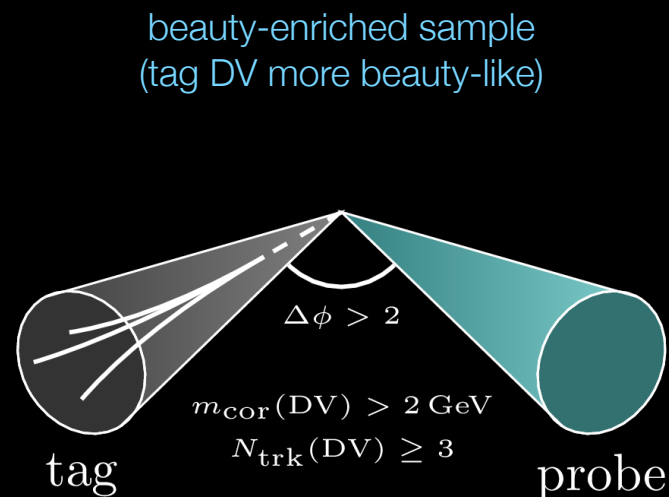
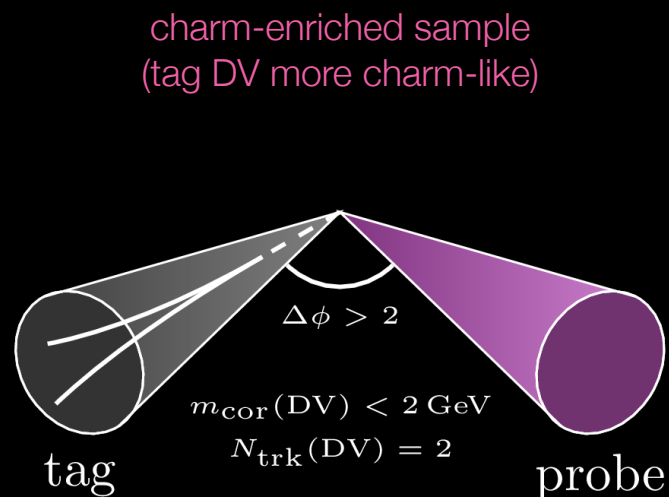
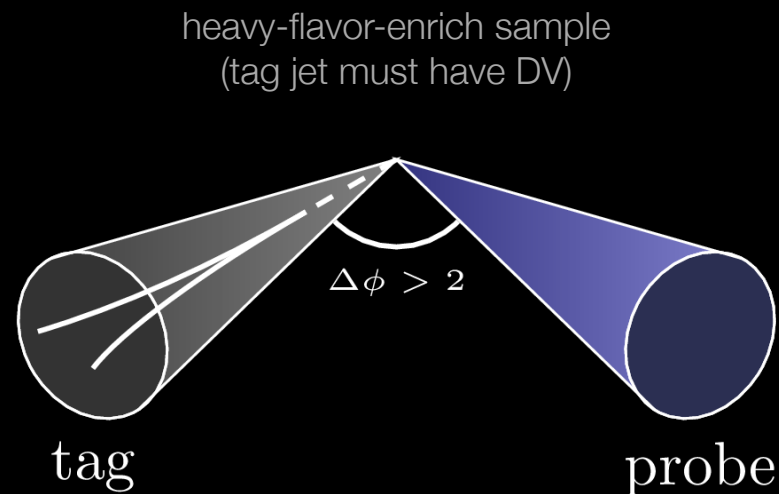


The broadening of the error band that arises in the forward region when allowing for IC is due to the lack of sensitivity to valence-like IC from previous experiments.

*Boettcher, Ilten, MW, 1512.06666.

Charm Tagging

Charm-tagging is based on the presence and properties of a displaced vertex (DV) inside the jet cone (done statistically, i.e. by fitting DV property distributions).

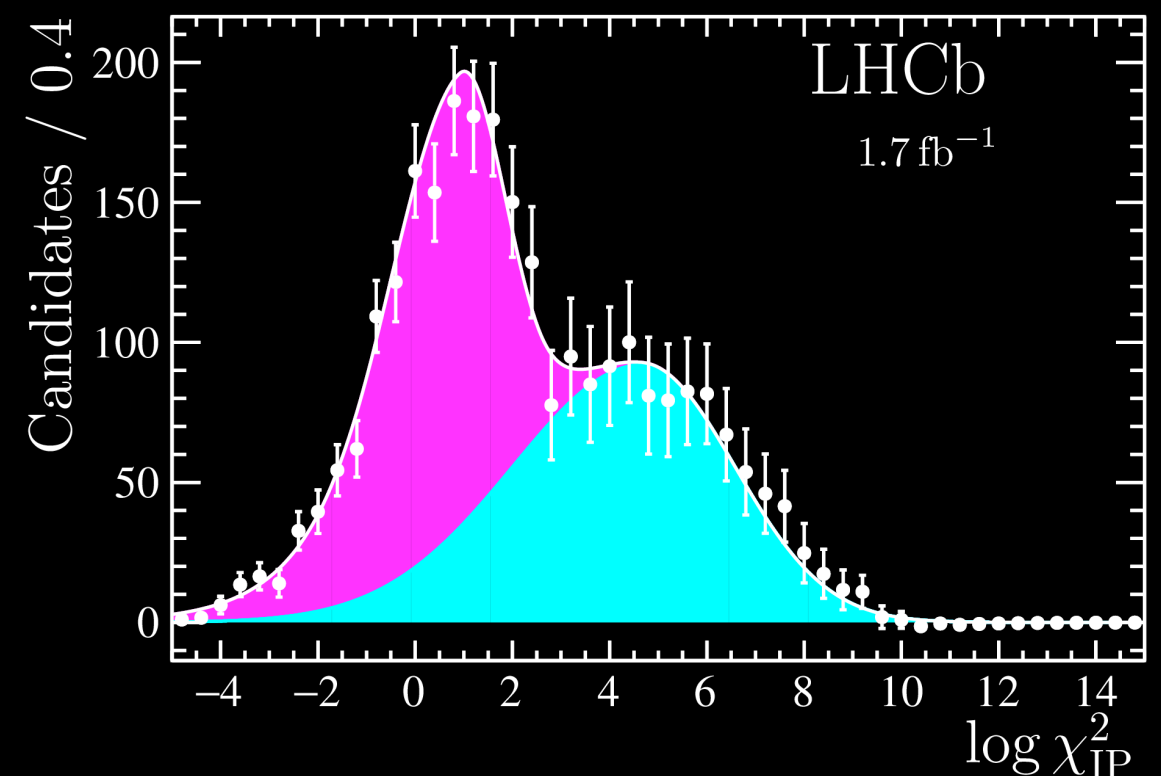
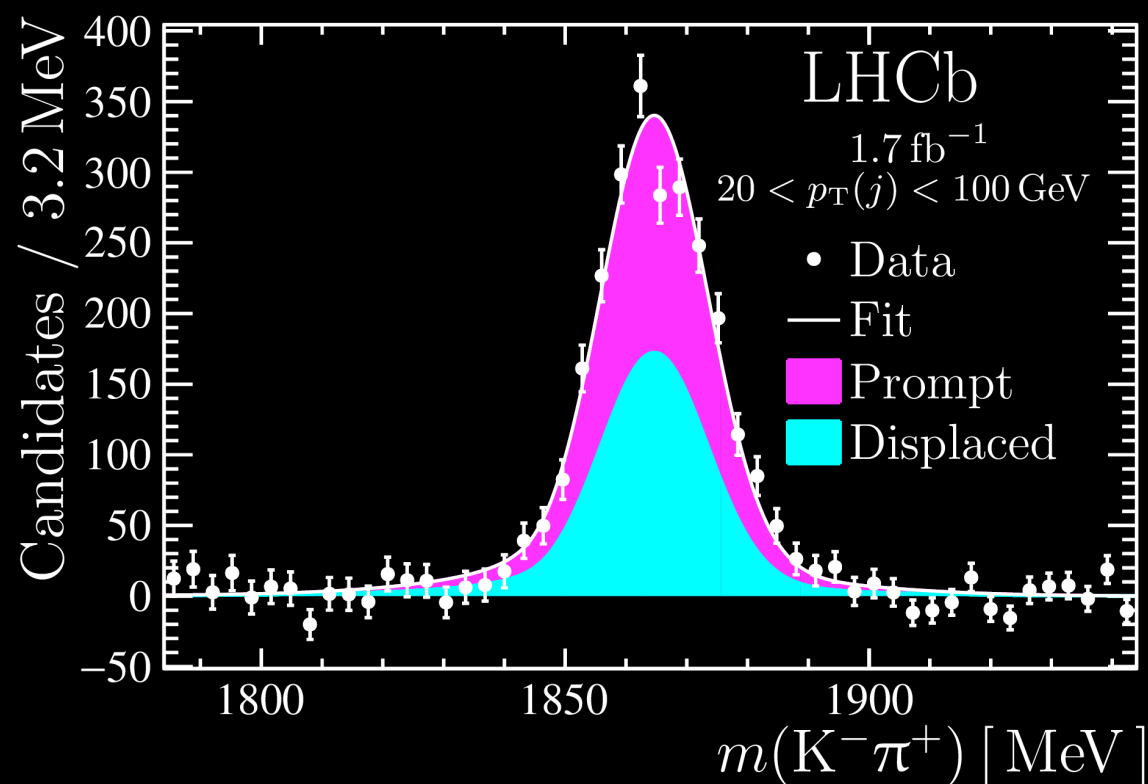


The performance is determined in data using back-to-back di-jet samples. Further flavor-enriched samples used to calibrate the DV-property PDFs.

Charm Tagging

The total number of c jets in the sample is determined using exclusive D decays, the LHCb acceptance and efficiency of which is taken from simulation. The fragmentation and branching fractions are obtained from the PDG (with minor updates).

$$\epsilon(c \text{ tag}) = n(c \text{ tag})/n(c) = n(c \text{ tag})\epsilon(D \rightarrow K\pi)f(c \rightarrow D)\mathcal{B}(D \rightarrow K\pi)/n_{\text{prompt}}(D \rightarrow K\pi)$$

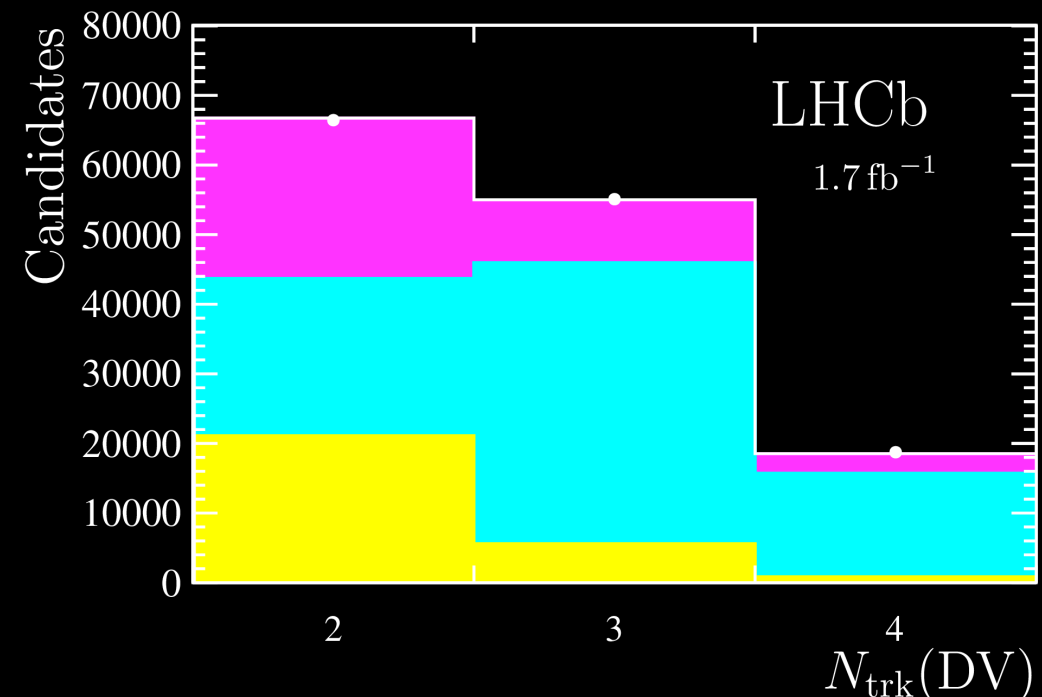
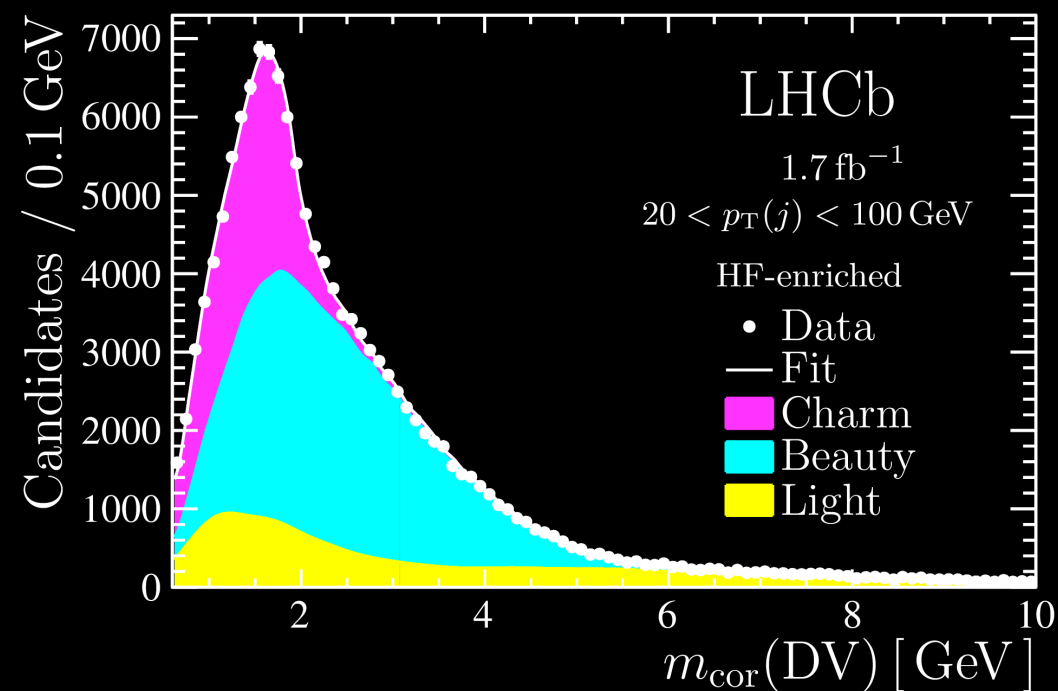


Prompt D yields obtained by fitting the 2-D mass vs IP chi-square distributions (shown here with non- D combinatorial backgrounds subtracted).

Charm Tagging

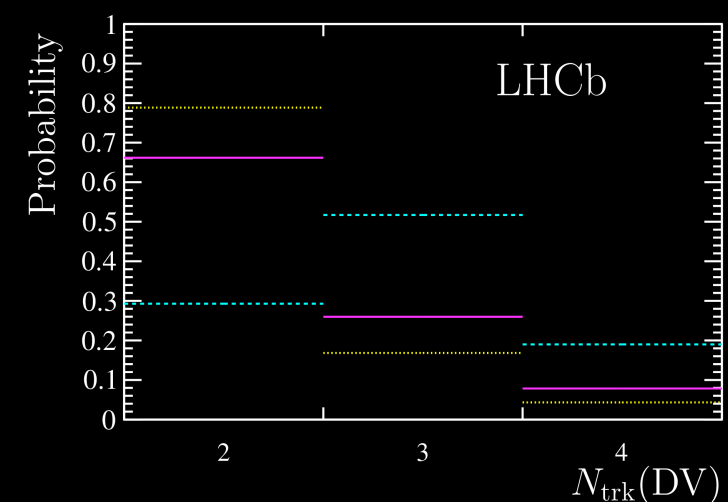
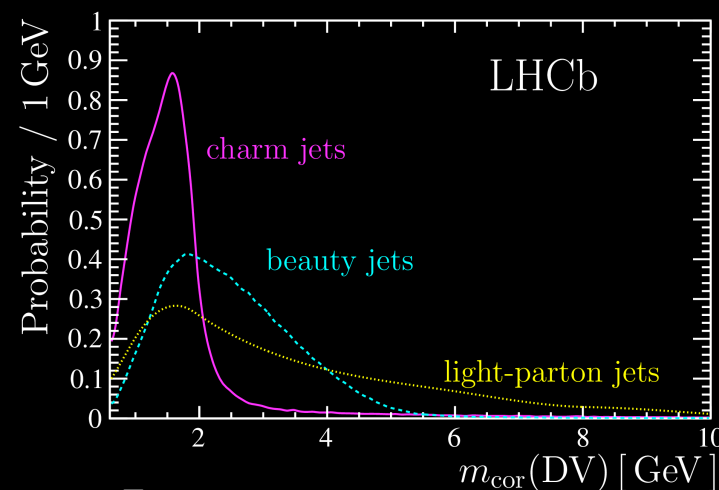
A 2-D fit is performed to DV properties to determine the DV-tagged charm yield.

$$\epsilon(c \text{ tag}) = n(c \text{ tag})/n(c) = n(c \text{ tag})\epsilon(D \rightarrow K\pi)f(c \rightarrow D)\mathcal{B}(D \rightarrow K\pi)/n_{\text{prompt}}(D \rightarrow K\pi)$$



DV templates calibrated on further flavor-enriched dijet samples.

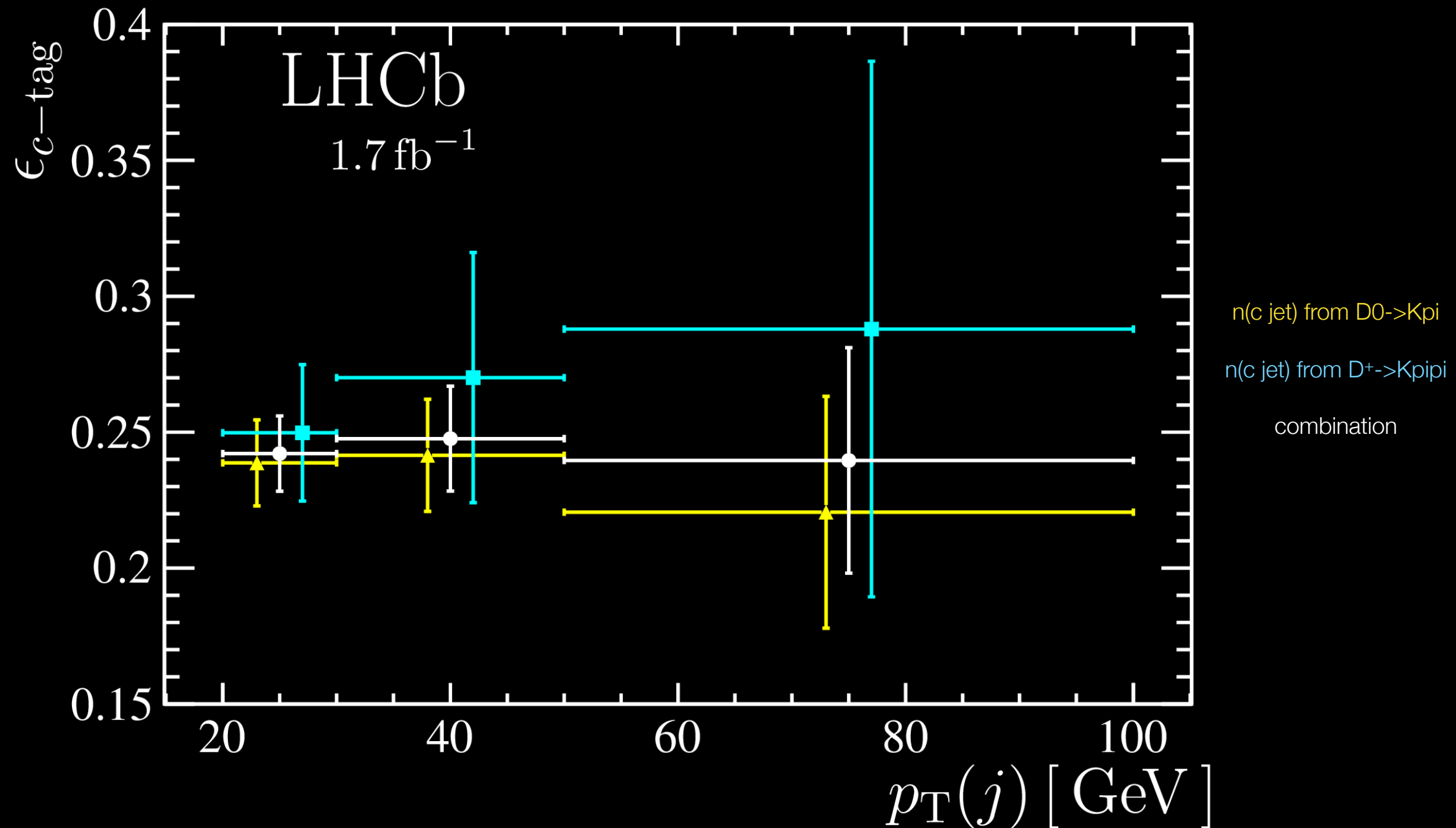
$$m_{\text{cor}} = \sqrt{m(\text{DV})^2 + p_{\perp}(\text{DV})^2 + p_{\perp}(\text{DV})}$$



Charm Tagging

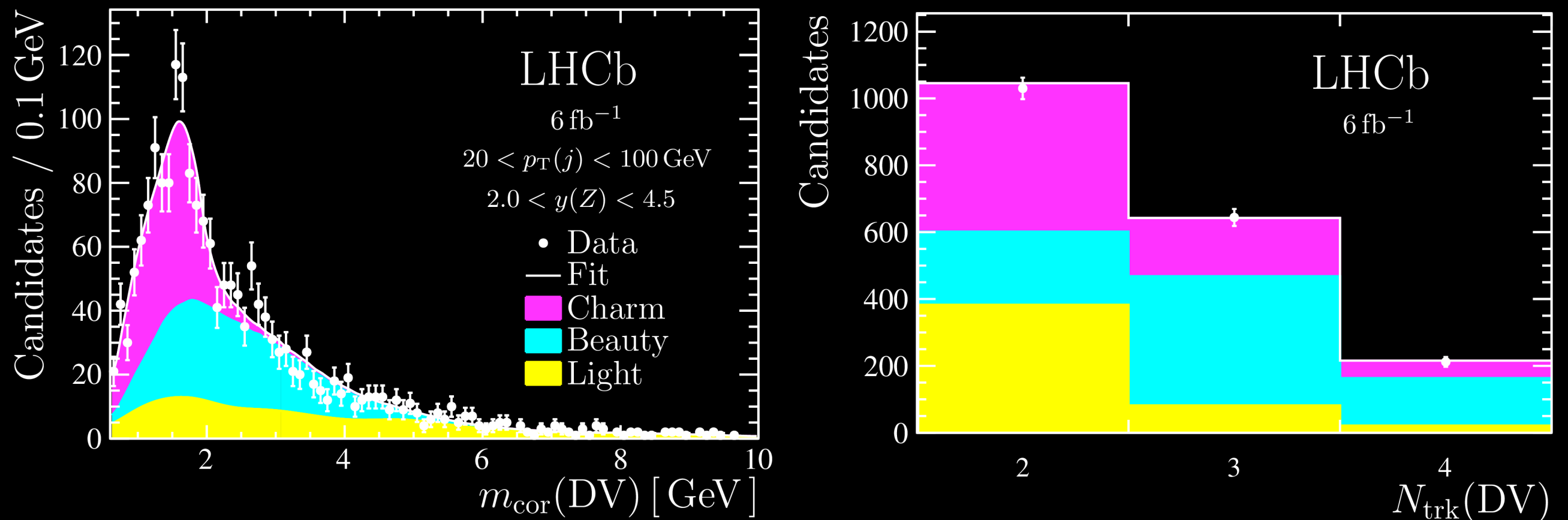
Charm DV-tagging performance found to be consistent with MC in each bin to $\sim 0.5\sigma$.

$$\epsilon(c \text{ tag}) = (24.0 \pm 0.6 \pm 1.4) \%$$



Charm-Tagged Z+c Yield

The DV-based charm-tagging algorithm is applied to the Z+jet sample to obtain the DV-tagged charm yield in bins of $[y(Z), p_T(\text{jet})]$, which is then corrected for efficiency.



The inclusive Z+j and efficiency-corrected Z+c yields in $[y(Z), p_T(\text{jet})]$ bins are then unfolded (separately) to account for jet p_T resolution (and scale) — and finally integrated within the fiducial region to obtain Z+c/Z+j.

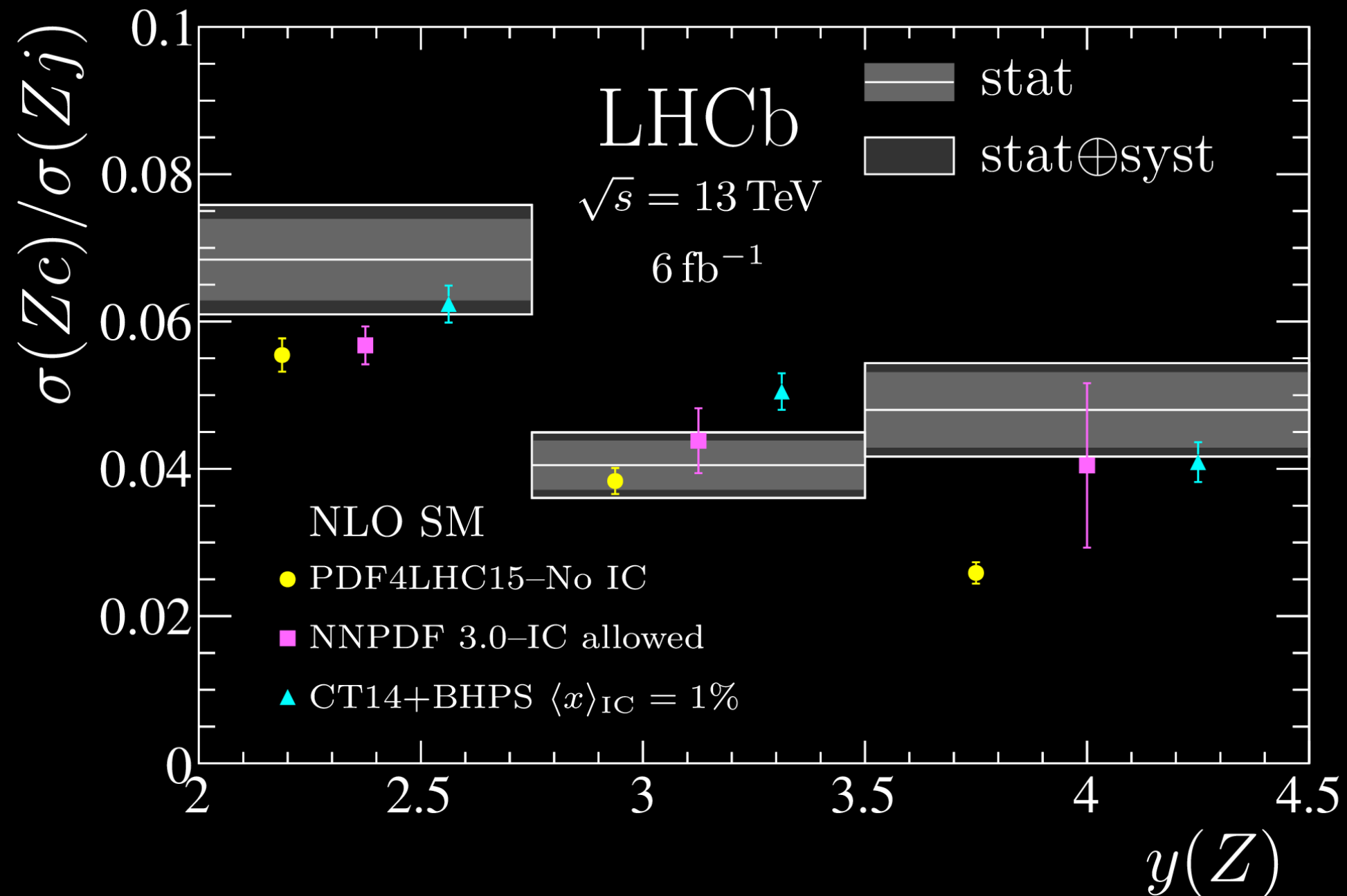
Systematic Uncertainties

As expected, c -tagging is the dominant uncertainty.

Source	Relative Uncertainty
c tagging	6–7%
DV-fit templates	3–4%
Jet reconstruction	1%
Jet p_T scale & resolution	1%
Total	8%

Results

The observed spectrum exhibits a sizable enhancement at forward $y(Z)$ consistent with the effect expected from valence-like IC (though more peaked to larger x than in the BHPS model; good agreement with the NNPDF IC allowed prediction).



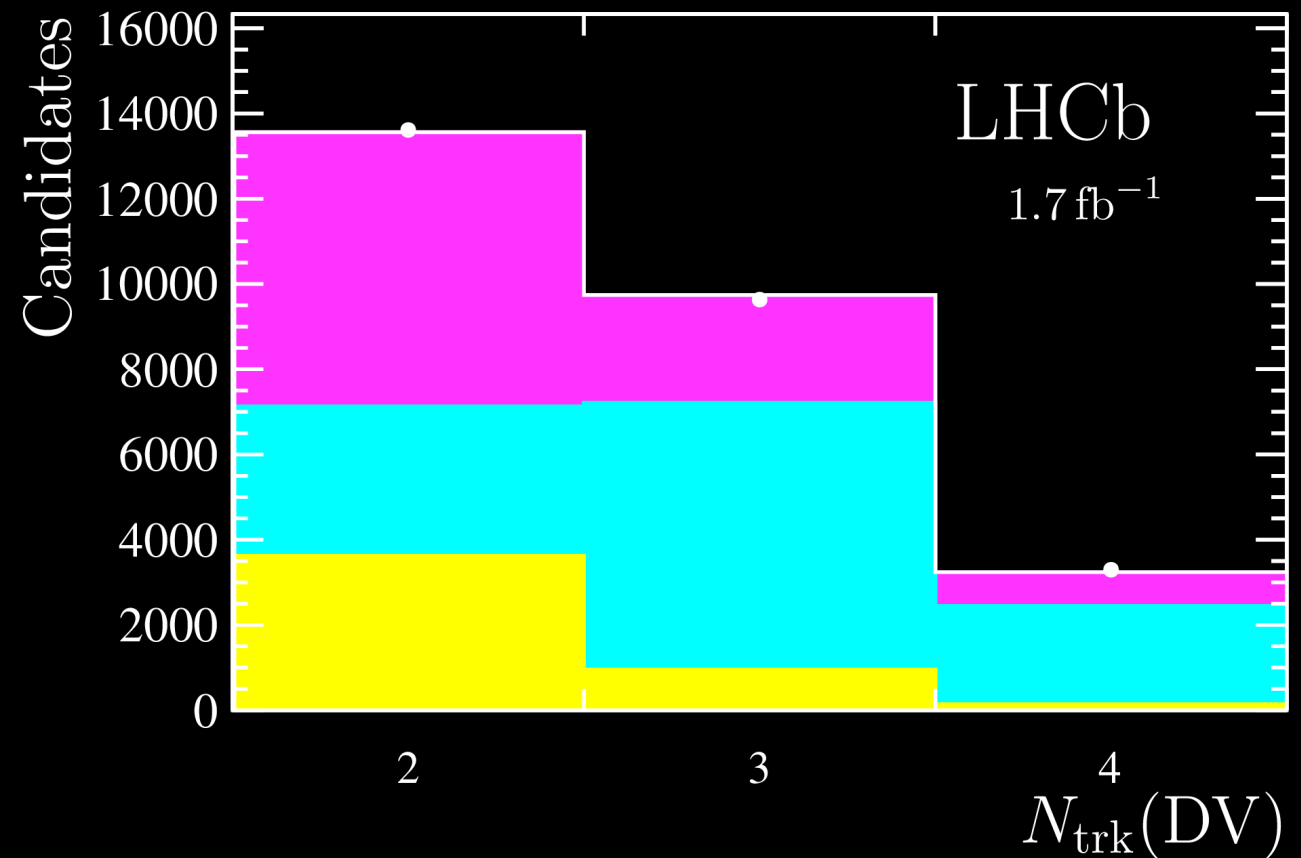
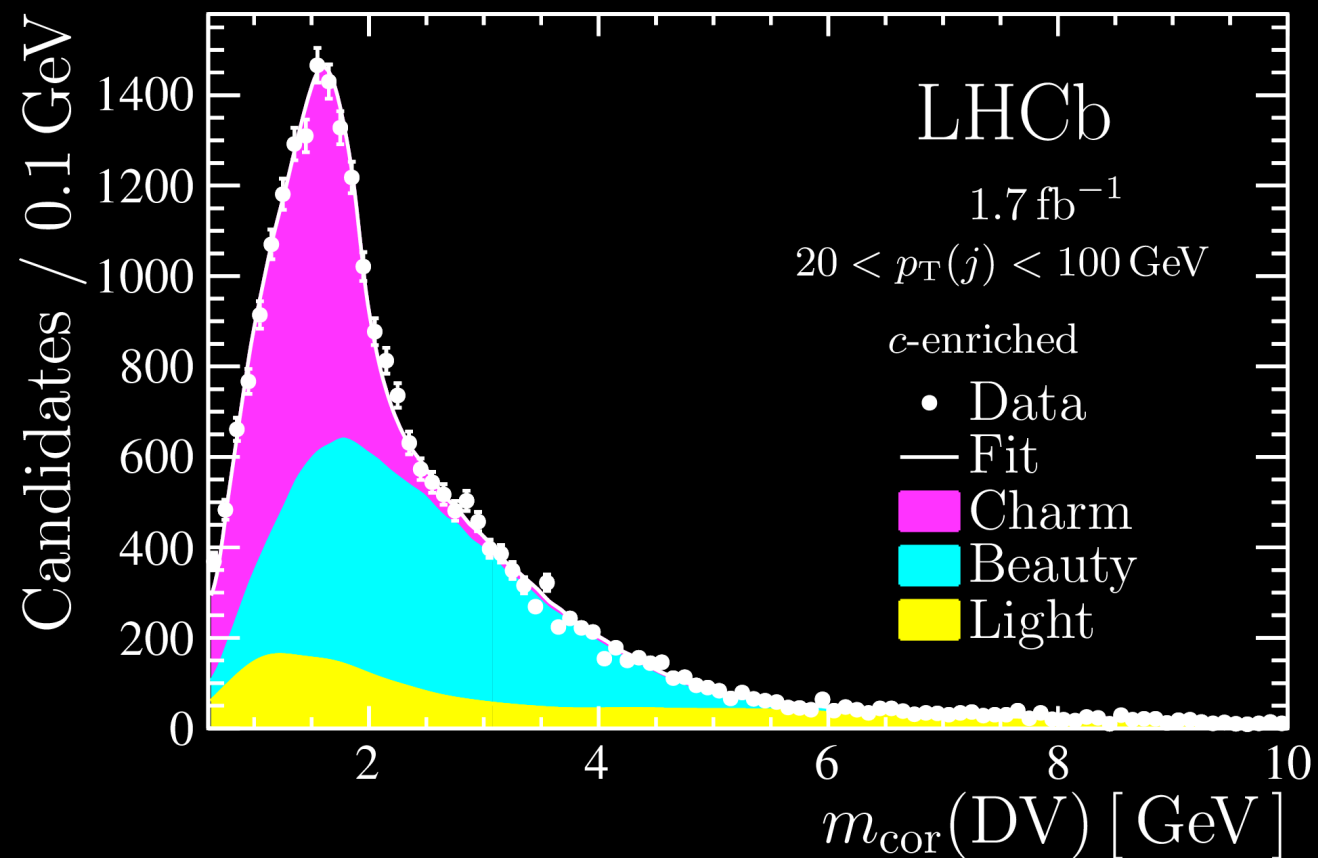
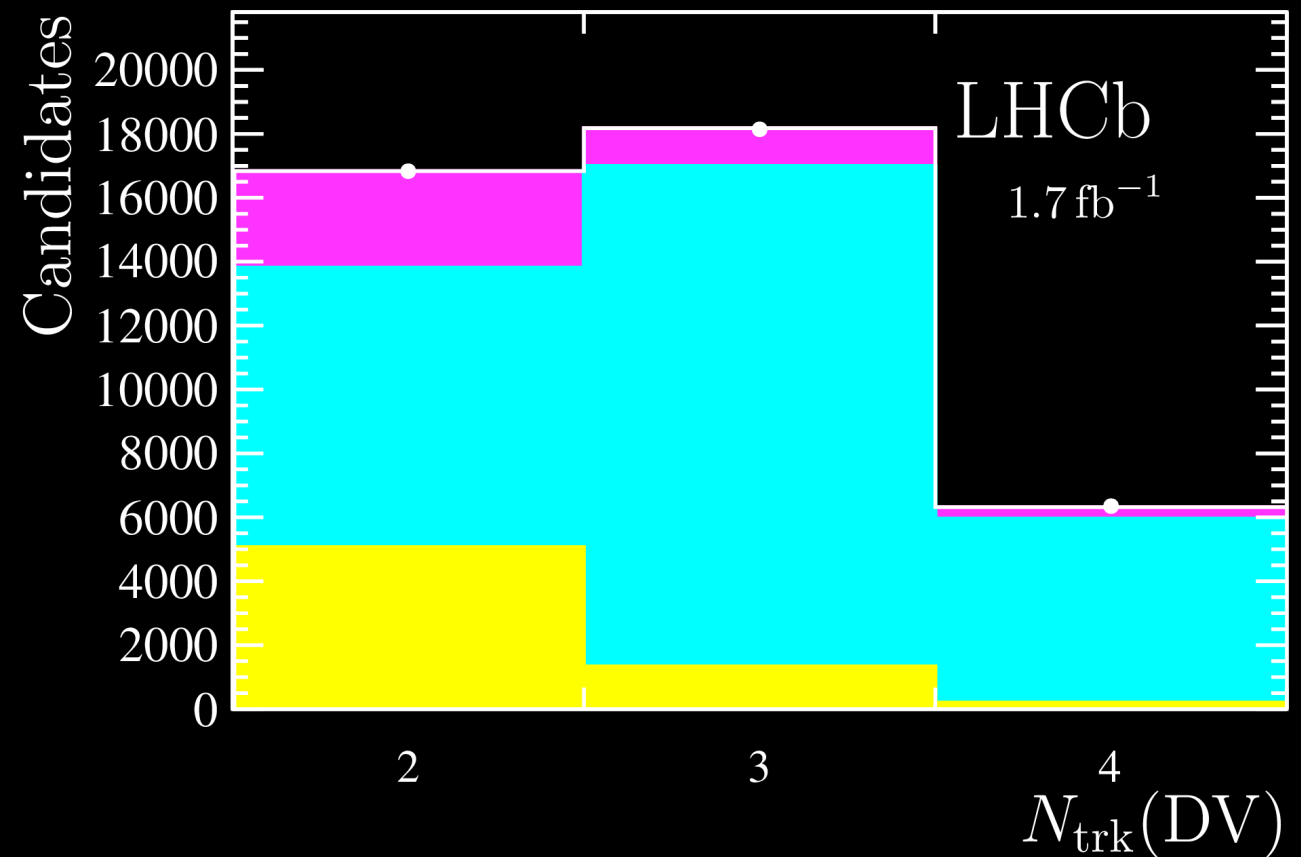
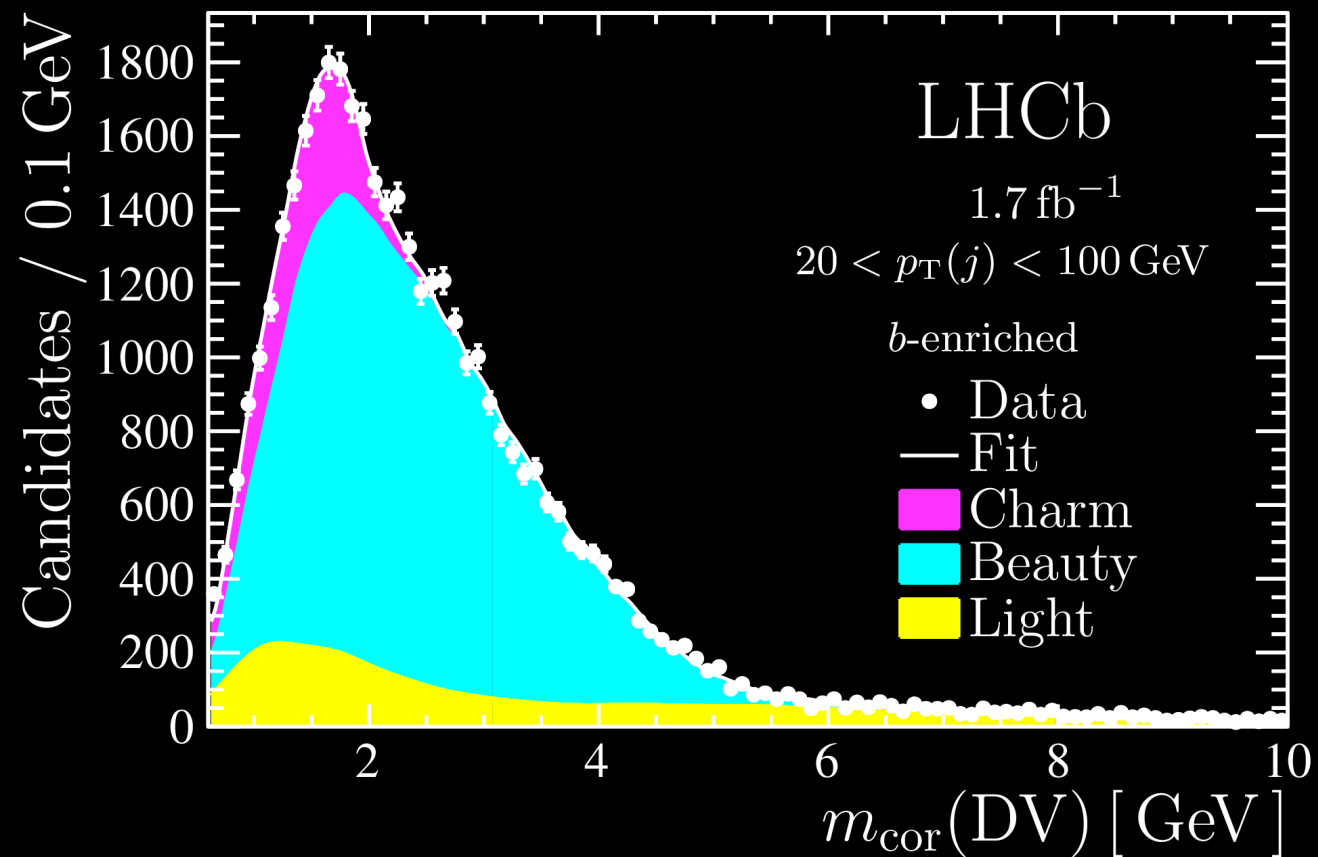
Looking forward to seeing global PDF fits include our results!

The background is a highly textured, abstract painting. It features a palette dominated by deep blues, purples, and yellows. The brushstrokes are thick and expressive, creating a sense of depth and movement. The overall composition suggests a complex, perhaps technological or architectural, environment, with light filtering through various structures. The text is centered over this artwork.

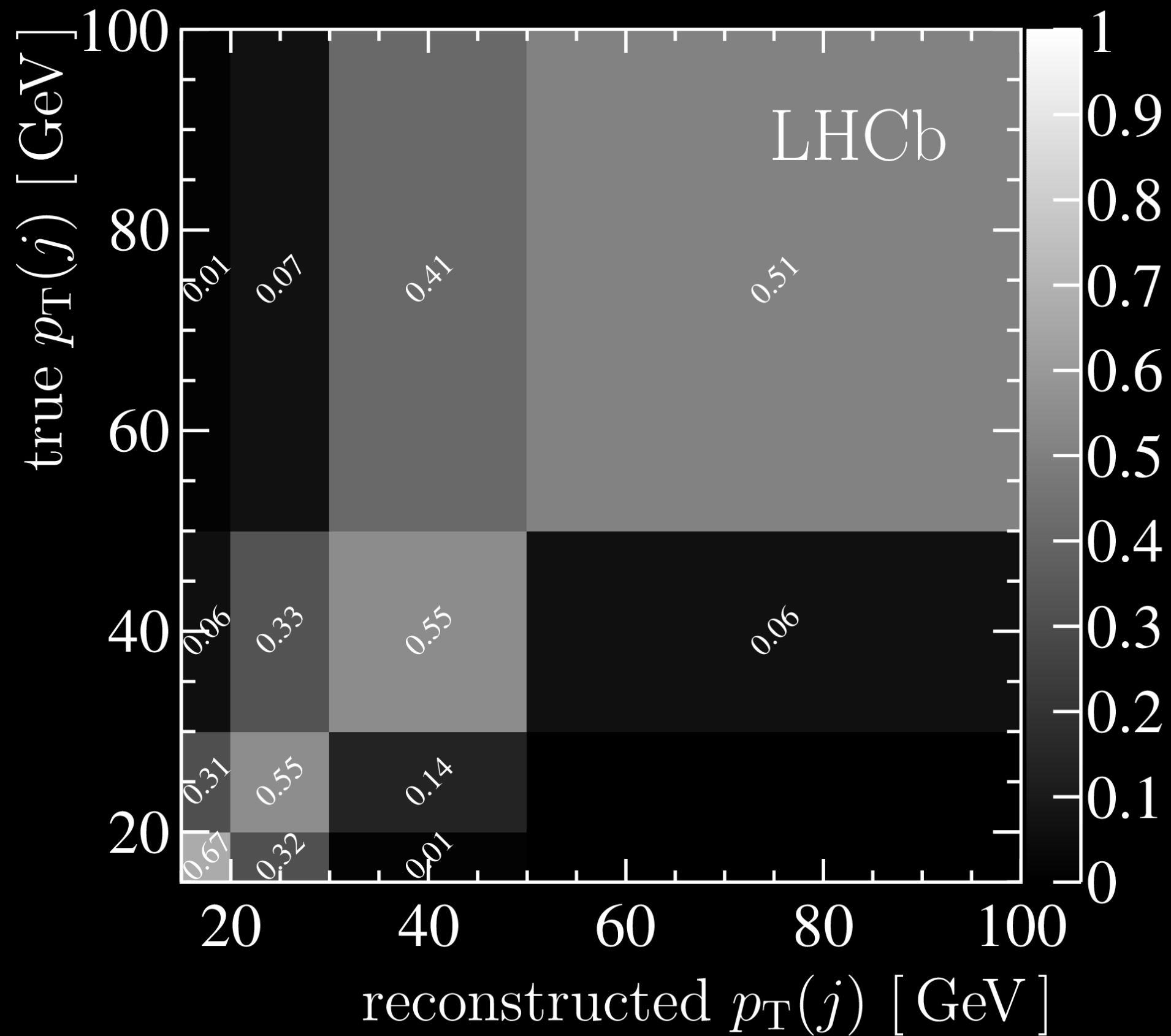
Thanks!

Questions?

DV Template Calibration



Unfolding



Results

All modern PDFs without IC give consistent predictions (all fail to describe LHCb data).

