Charm in the Proton and LHCb

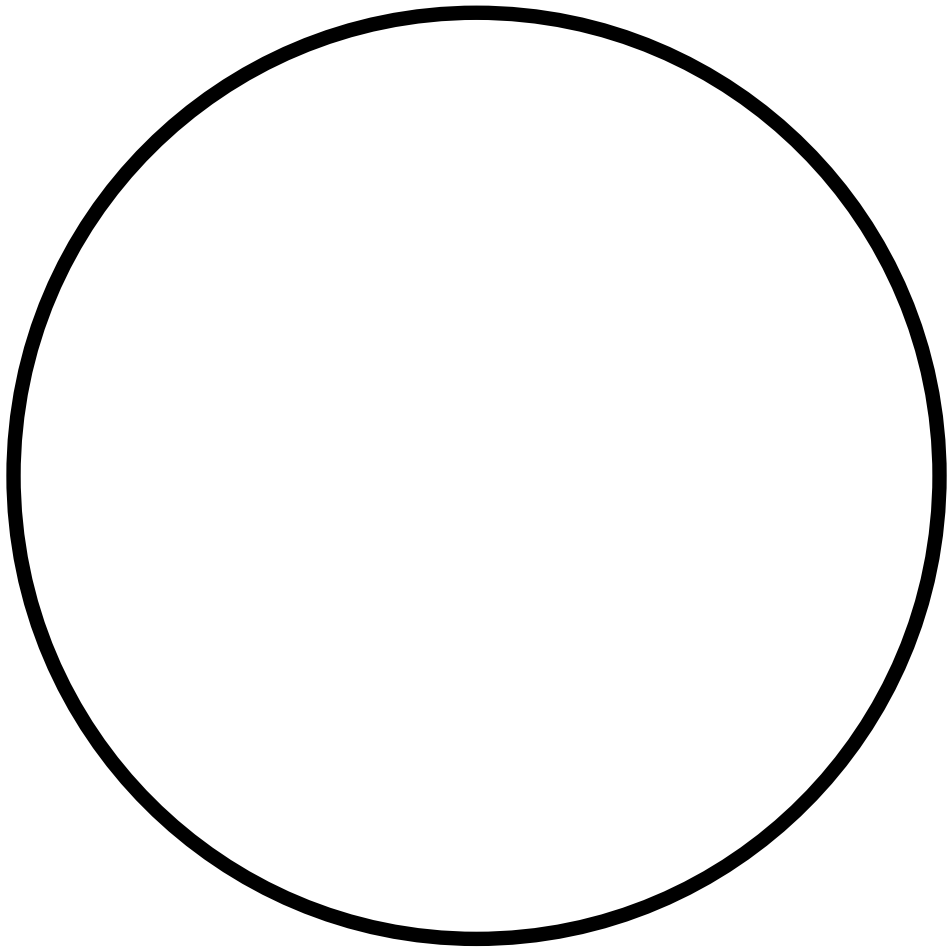
Philip Ilten

University of CINCINNATI

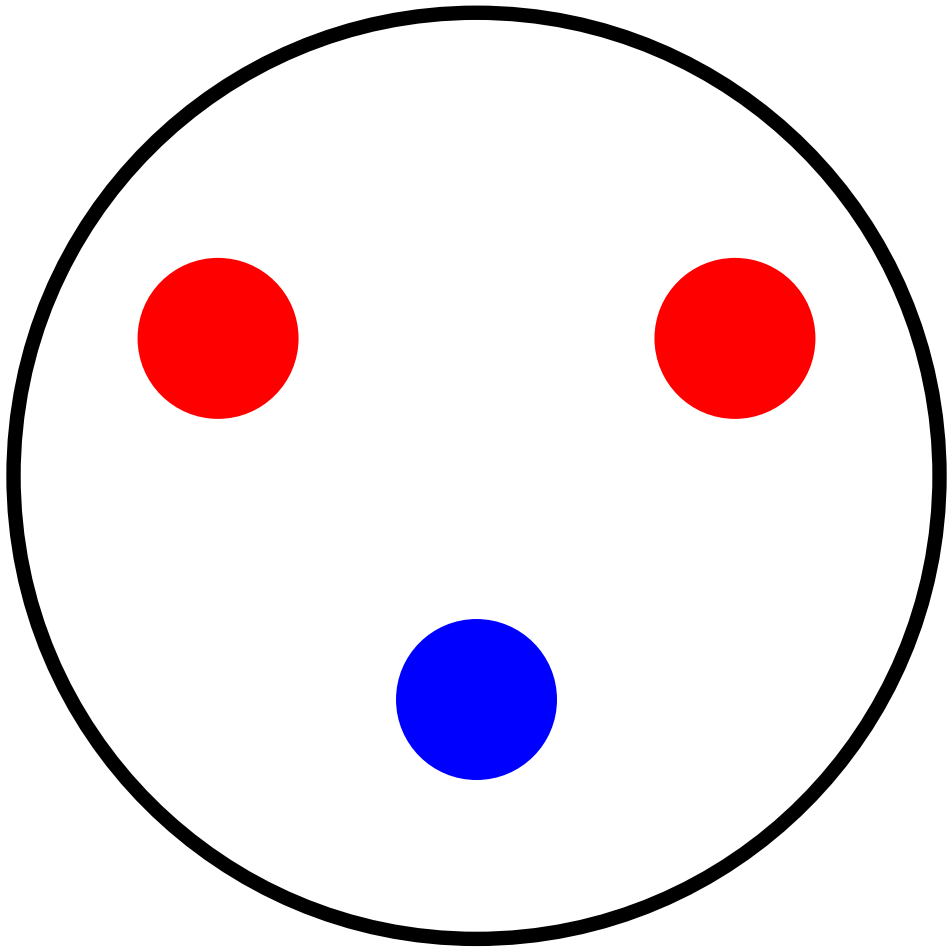
April 6, 2022

Birmingham Seminar

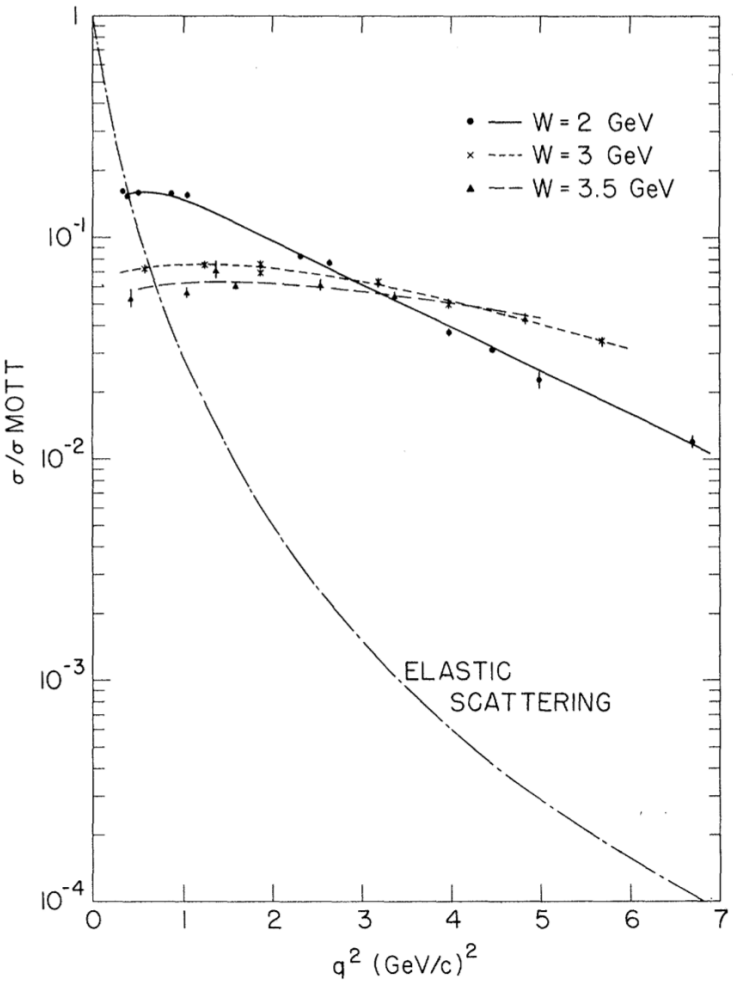
Three Quarks for Muster Mark

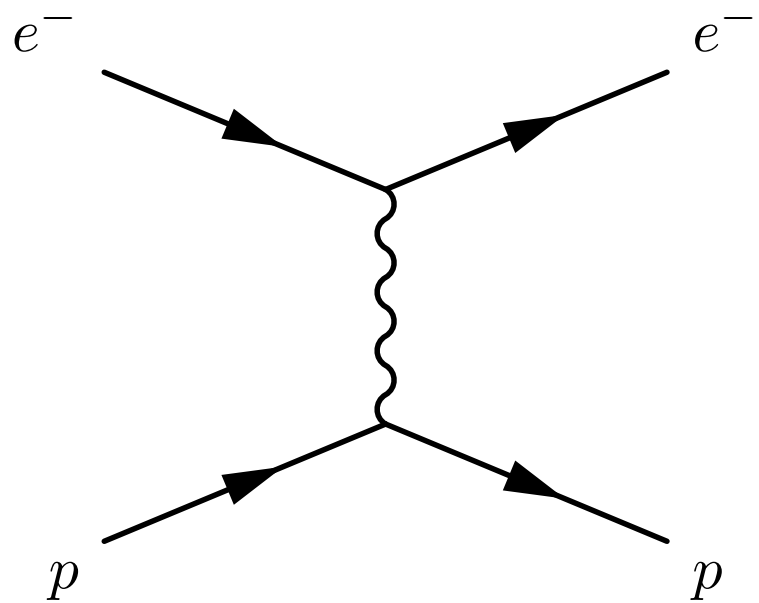


Three Quarks for Muster Mark



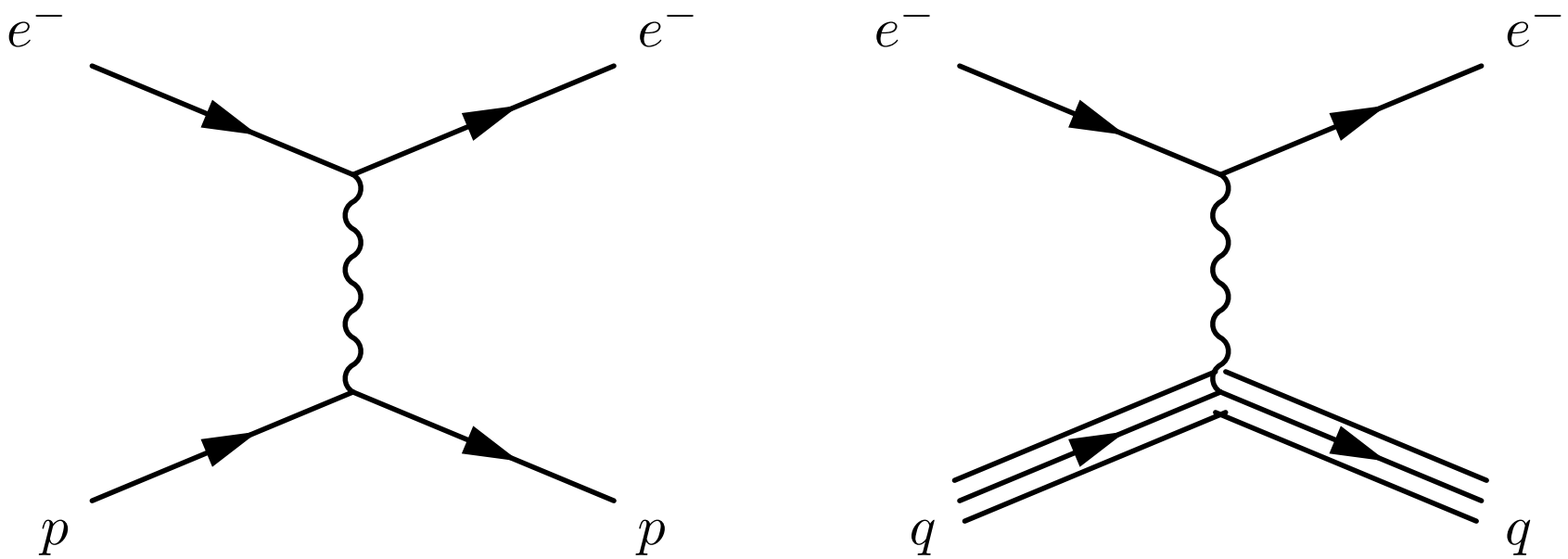
Confirmed!





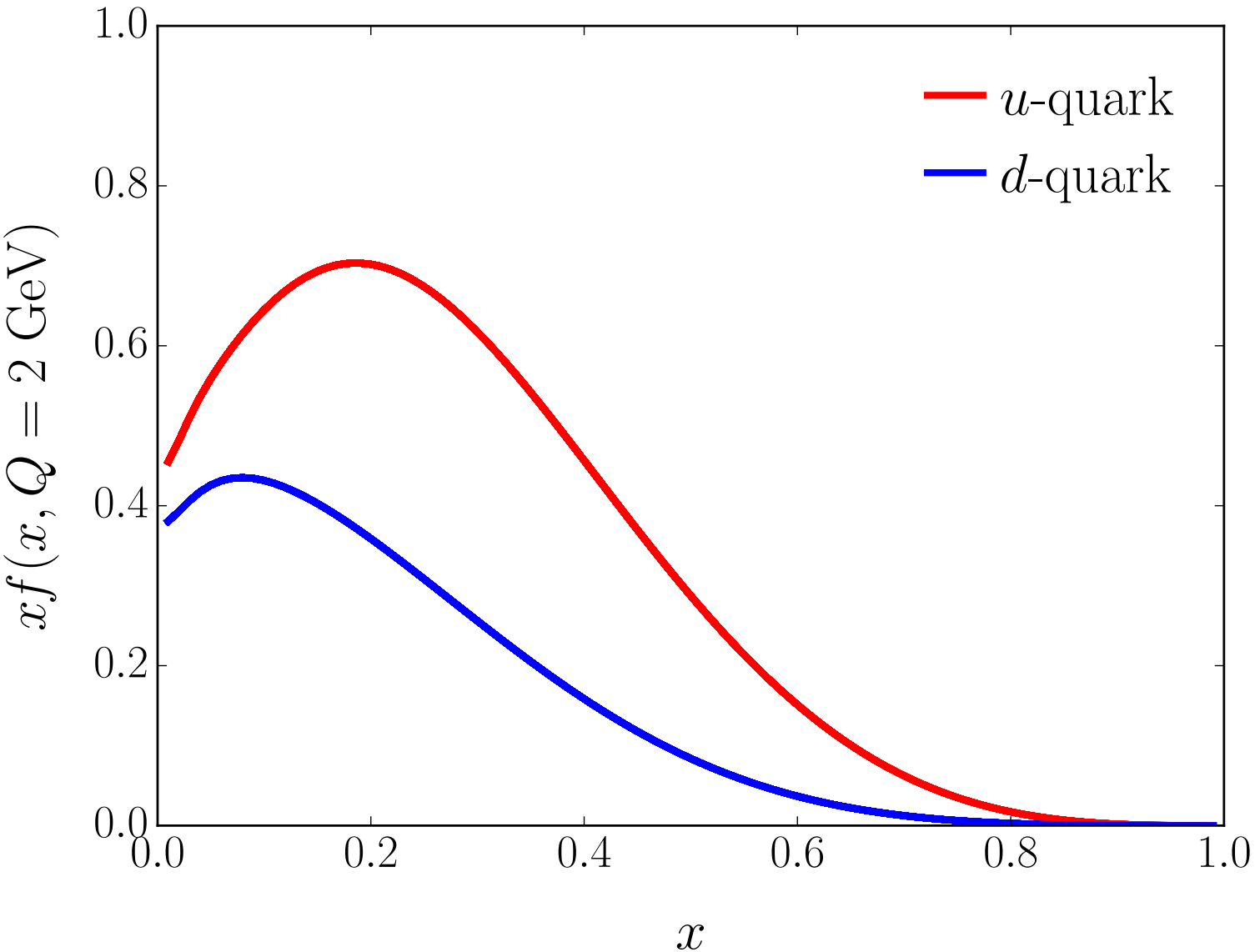
Observed Behavior of Highly Inelastic Electron-Proton Scattering
Phys. Rev. Lett. 23, 935 (1969)

Factorisation

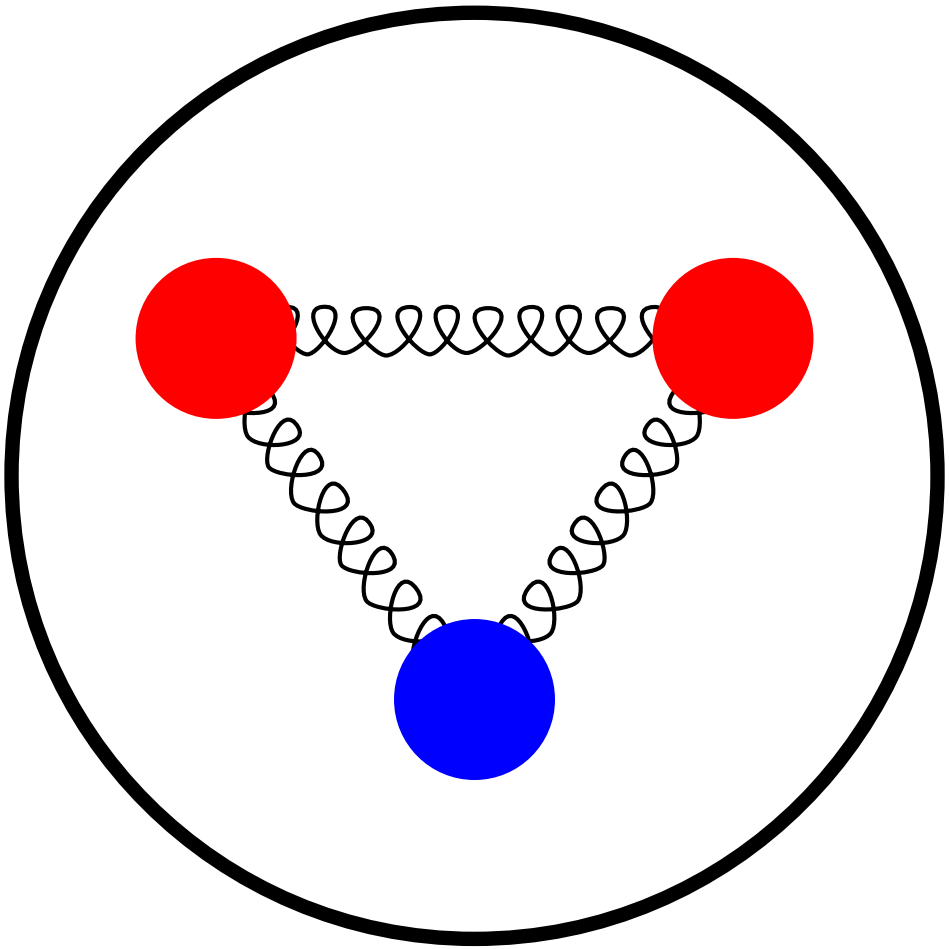


$$\sigma(s) \to \int_0^1 \mathrm{d}x\, f(x, Q^2)\hat{\sigma}(xs)$$

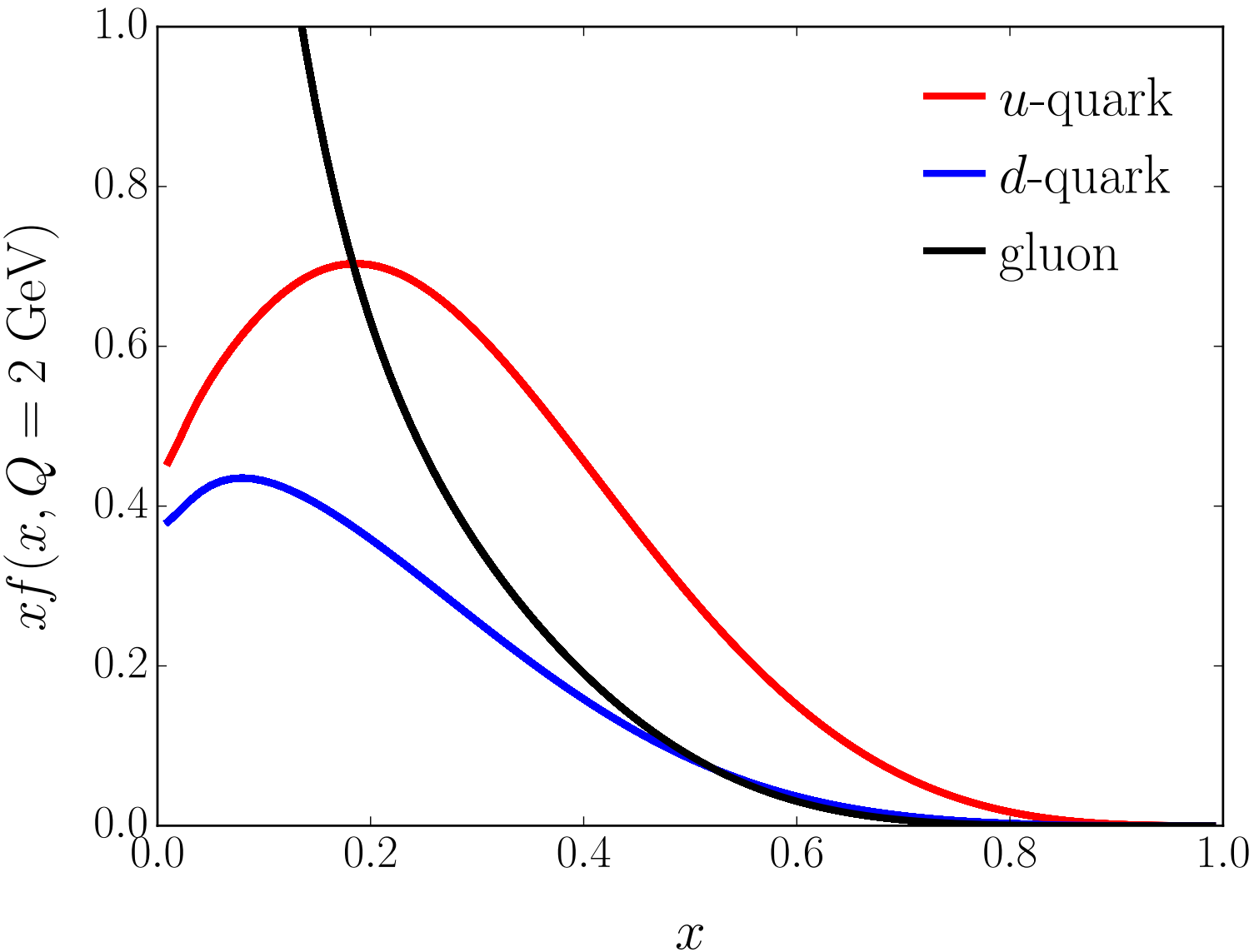
Factorisation



Gluons



Gluons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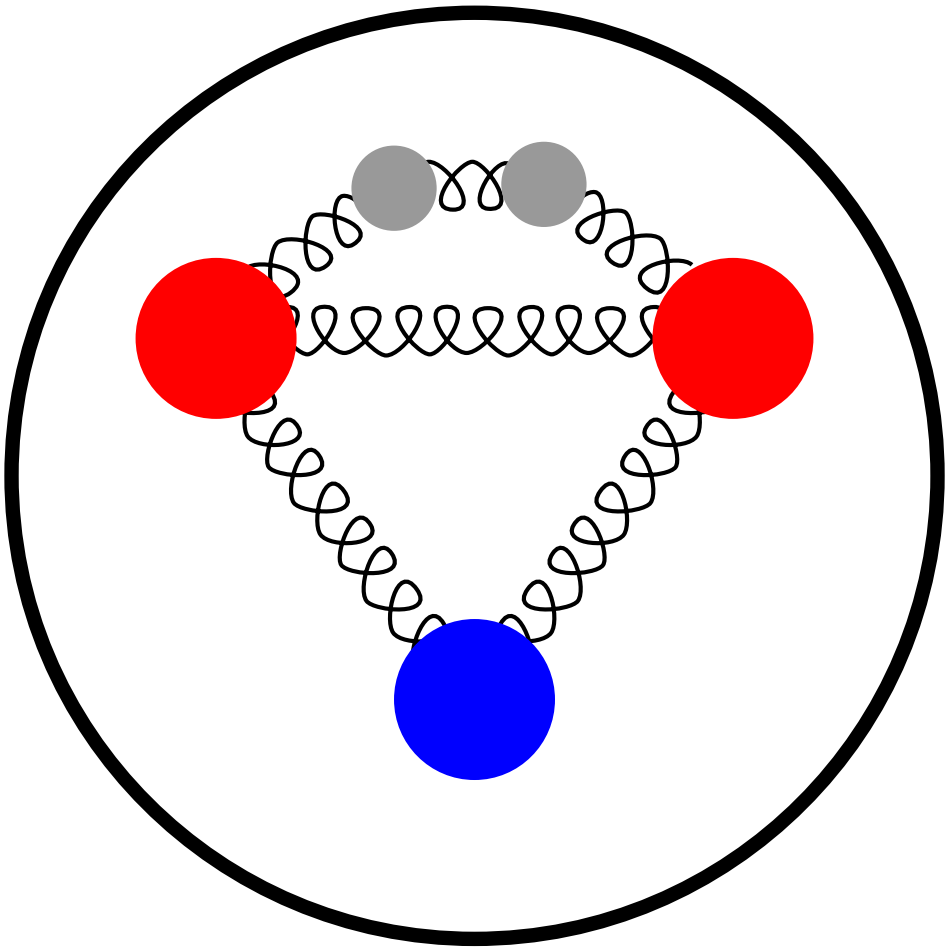
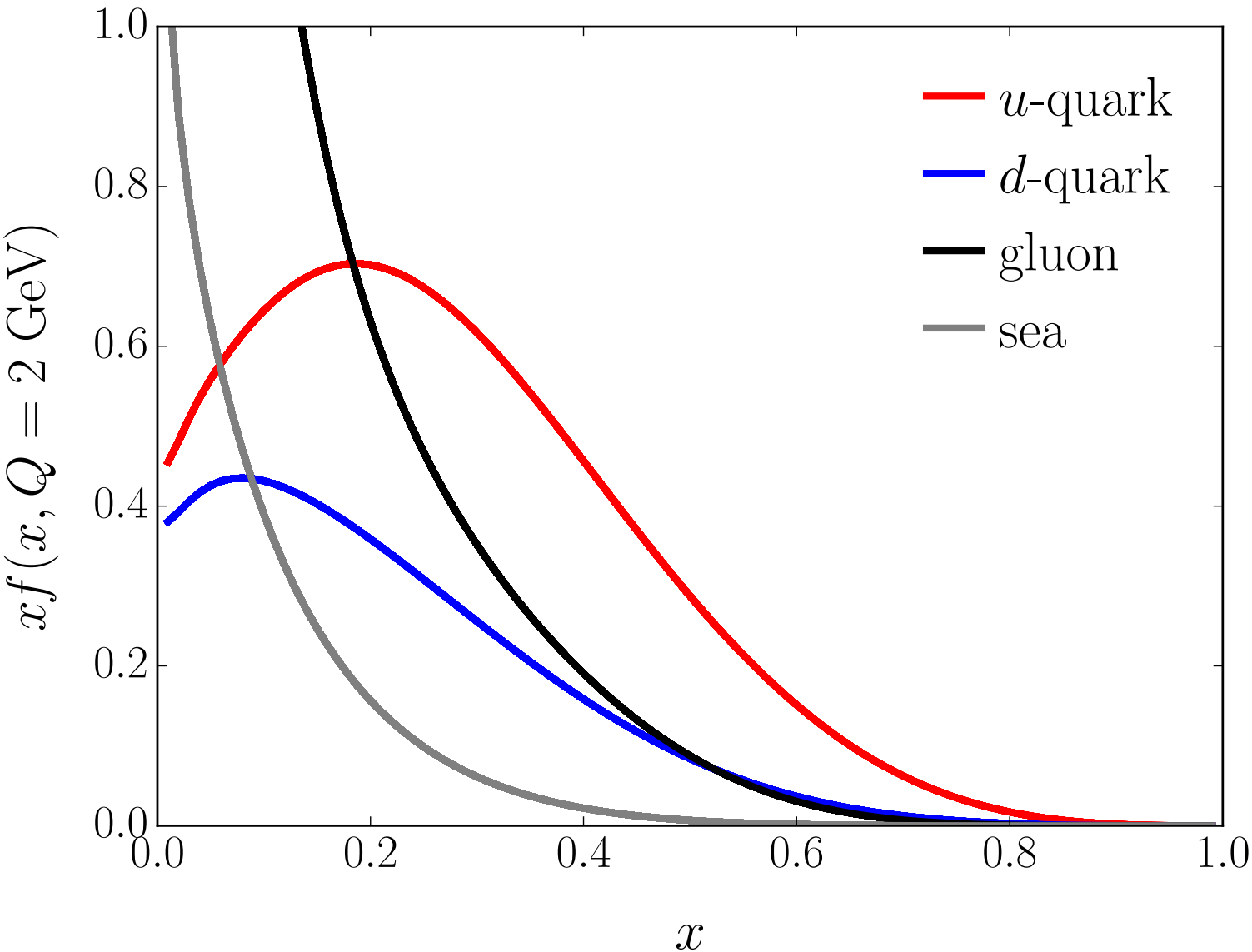
0.8
0.6
0.4
0.2
0.0
0.0
0.2
0.4
0.6
0.8
1.0
$xf(x, Q = 2\ \mathrm{GeV})$
x
u-quark
d-quark
gluon

The Sea



The Sea


1.0
0.8
0.6
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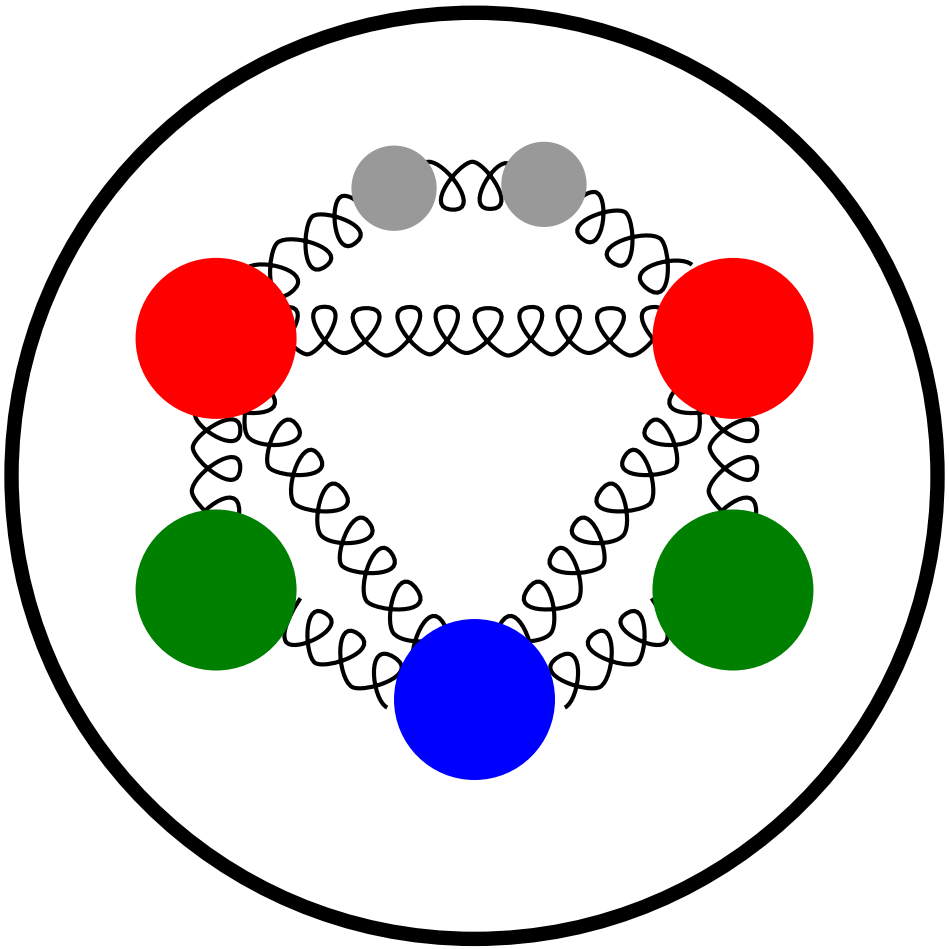
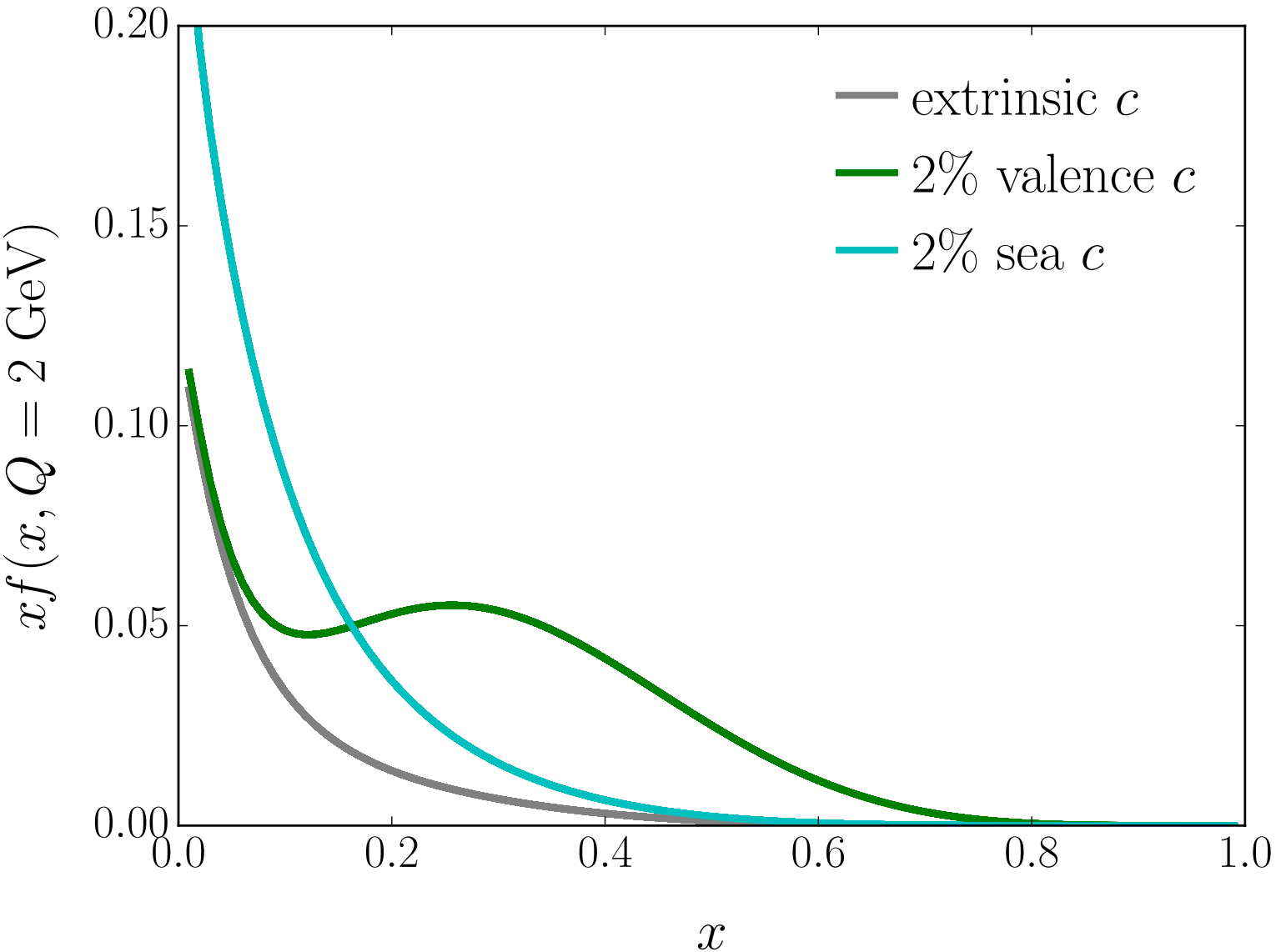
0.0
0.2
0.4
0.6
0.8
1.0
$xf(x, Q = 2\ \mathrm{GeV})$
x
u-quark
d-quark
gluon
sea

Intrinsic Charm

Why Not Charm?

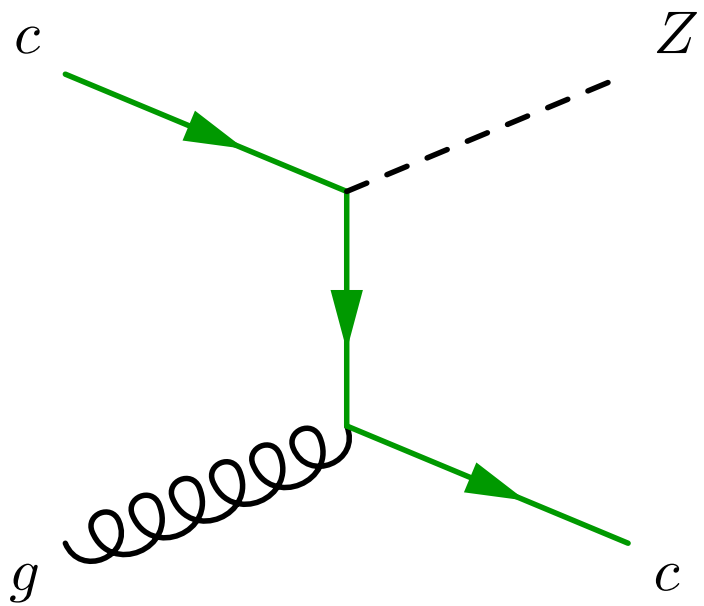


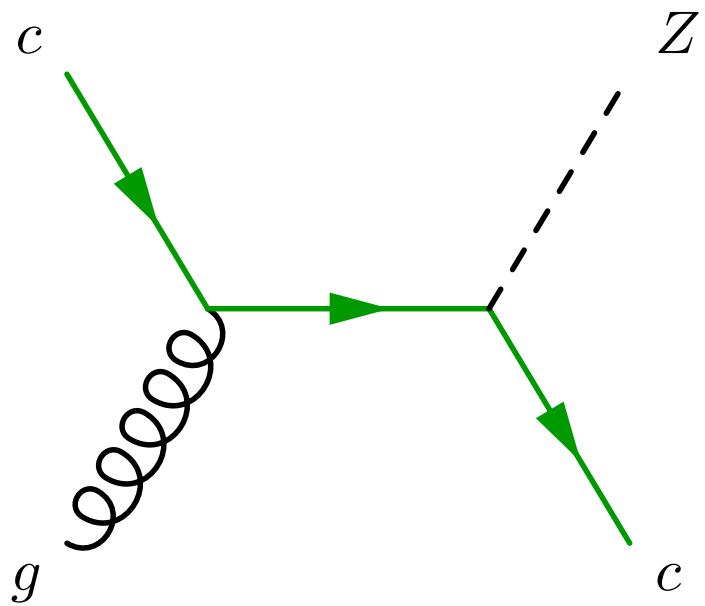
Why Not Charm?



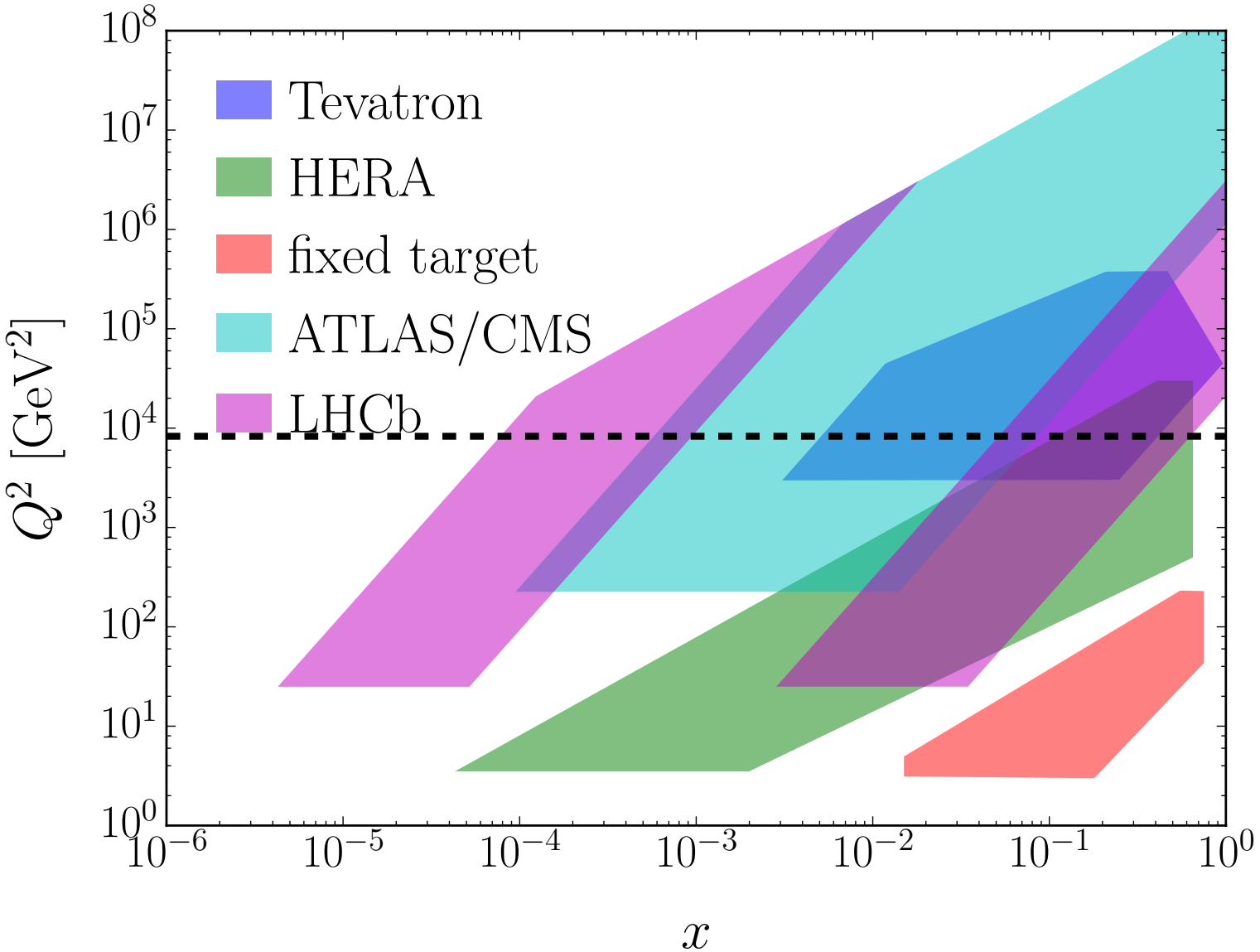
A Possible Probe

PRD 93 (2016) 074008





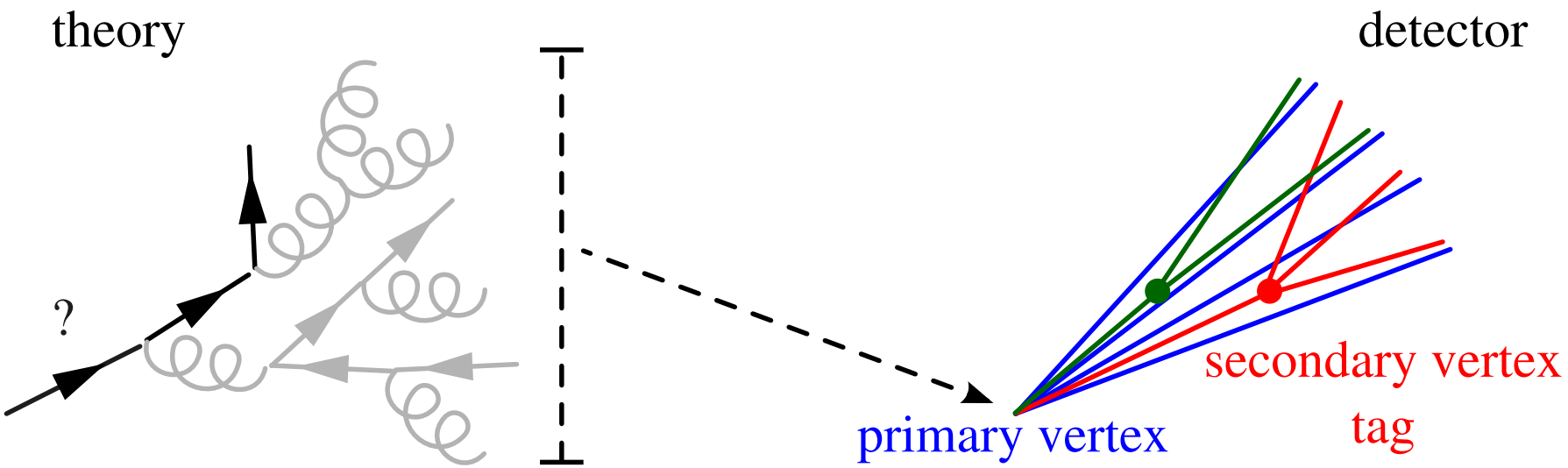
What Can We See?

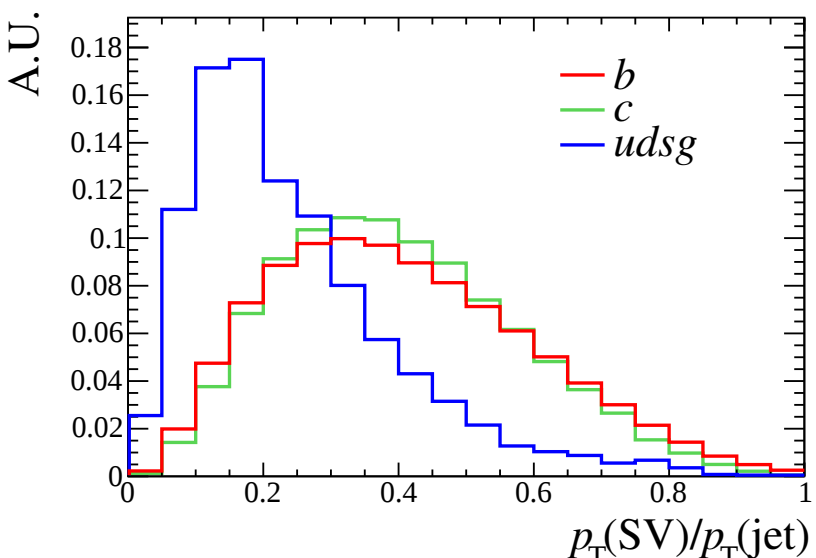


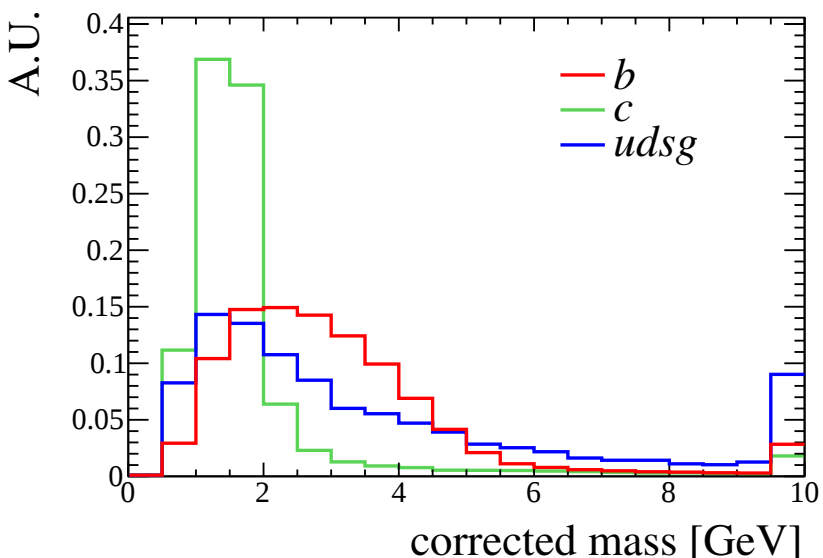
Charming Jets

From Theory to Detector

JINST 10 P06013

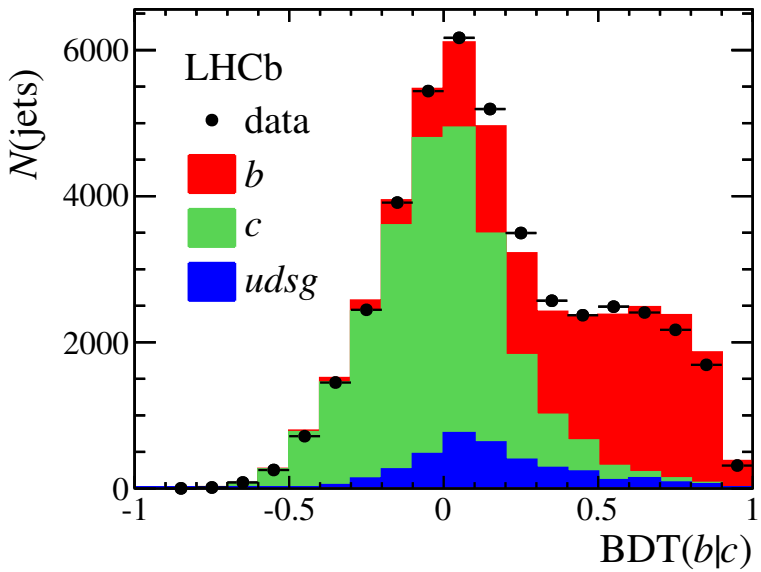


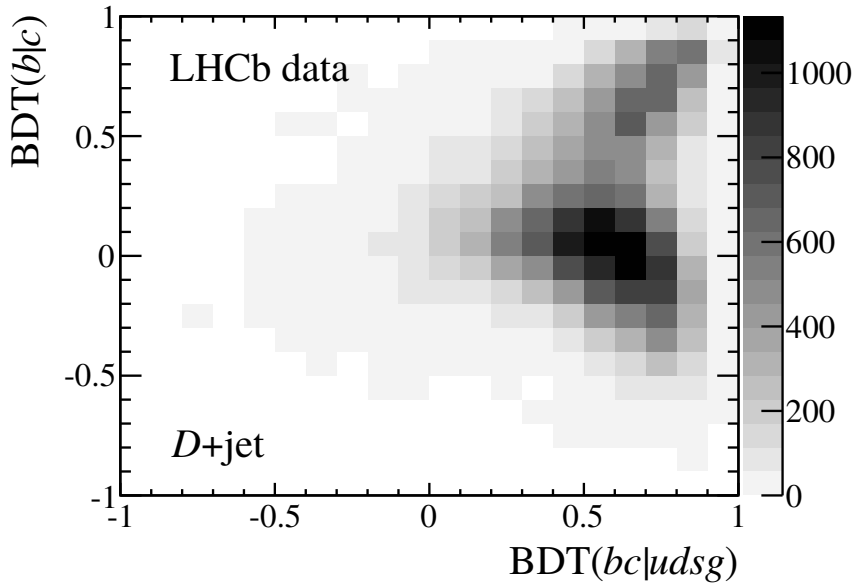


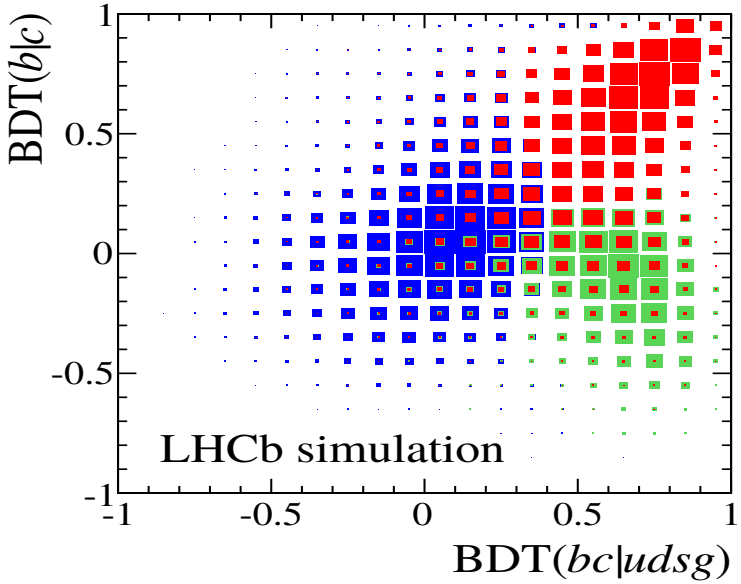


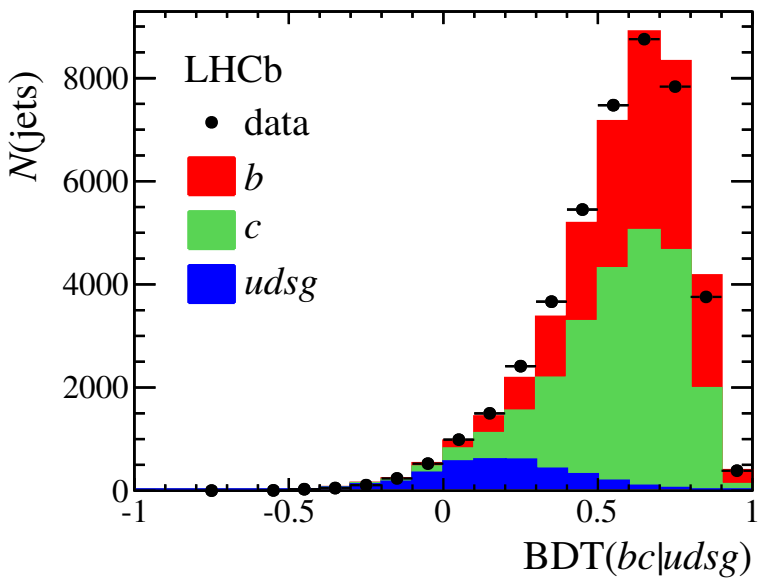
Some Machine Learning

JINST 10 P06013



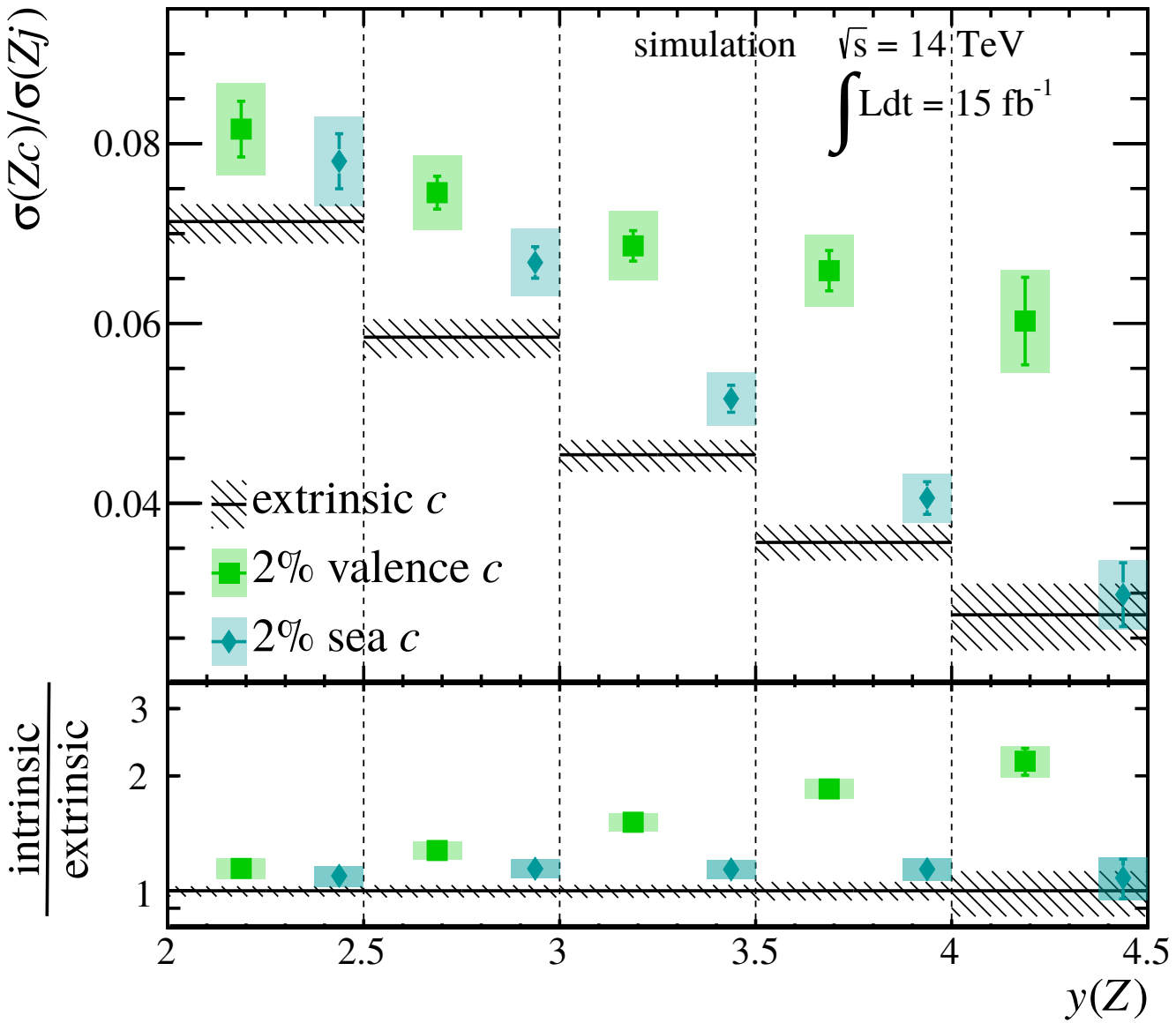






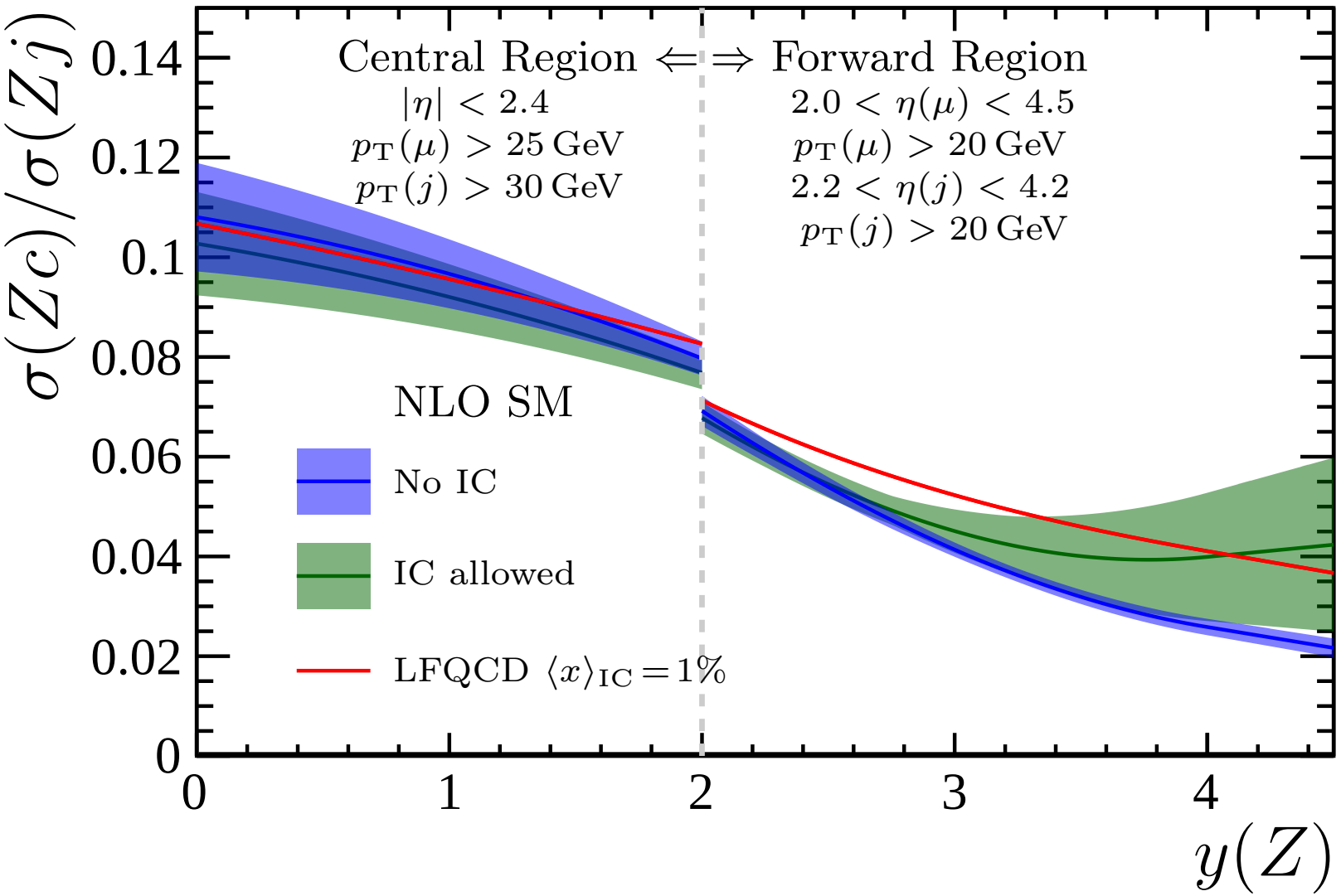
Some Expectations

PRD 93 (2016) 074008



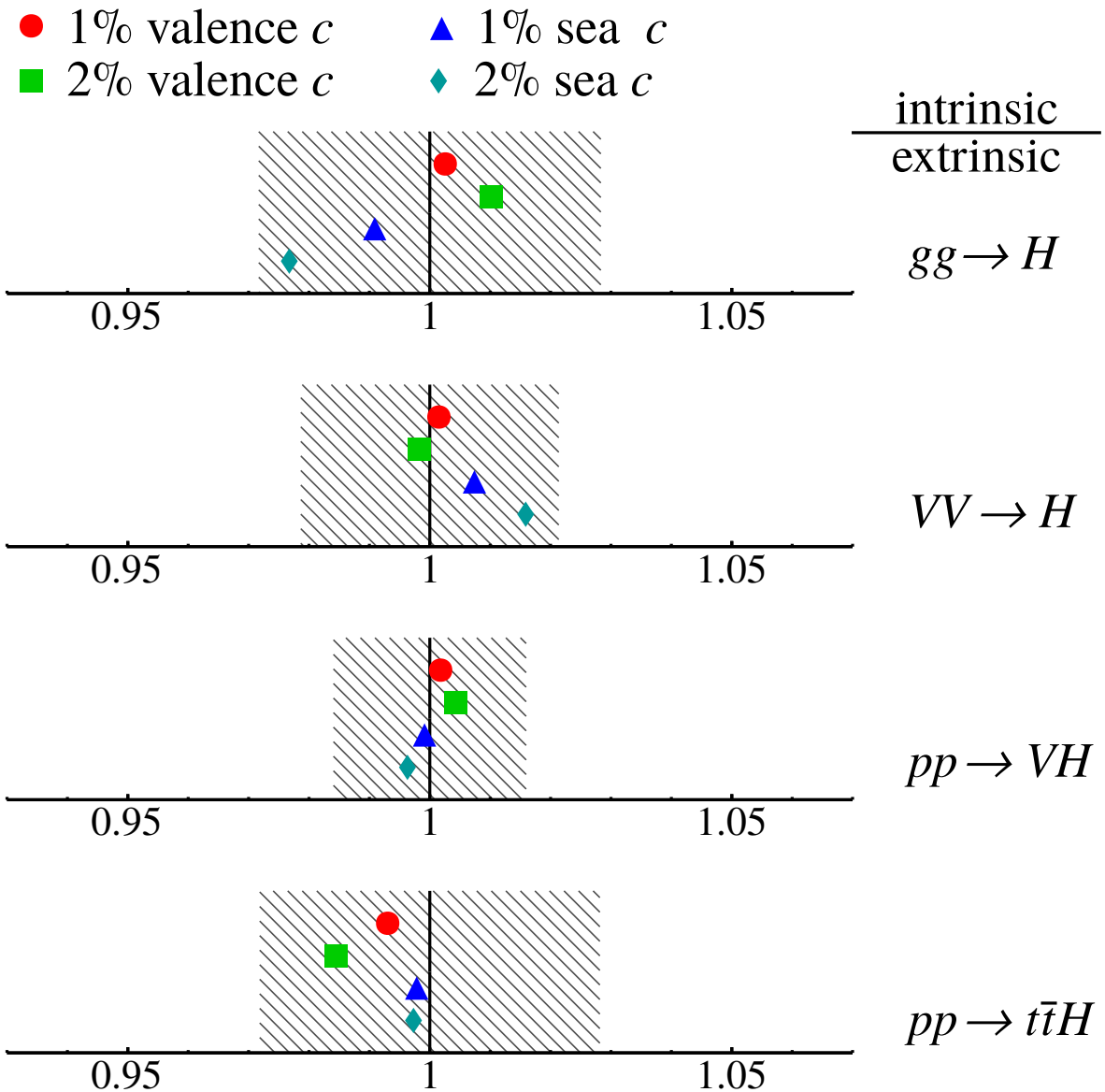
Why Not Central?

PRL 128 (2022) 082001



Some Side Effects

PRD 93 (2016) 074008

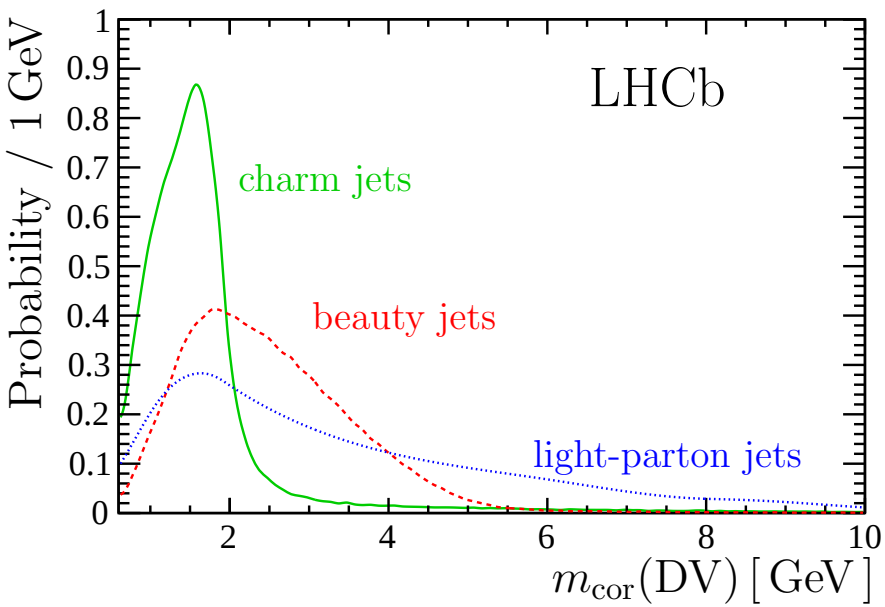


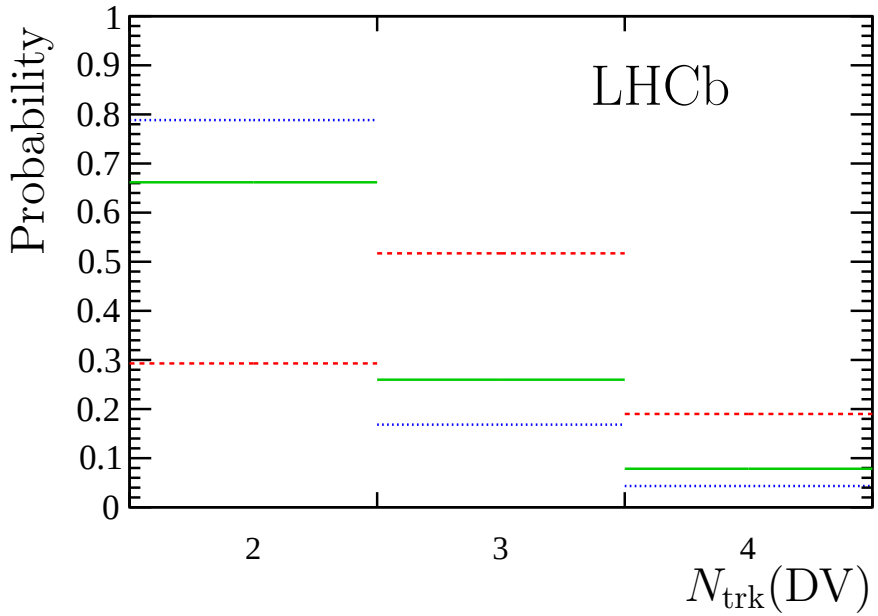
Doing Even Better

Changing Things Up

LHCb-DP-2021-006

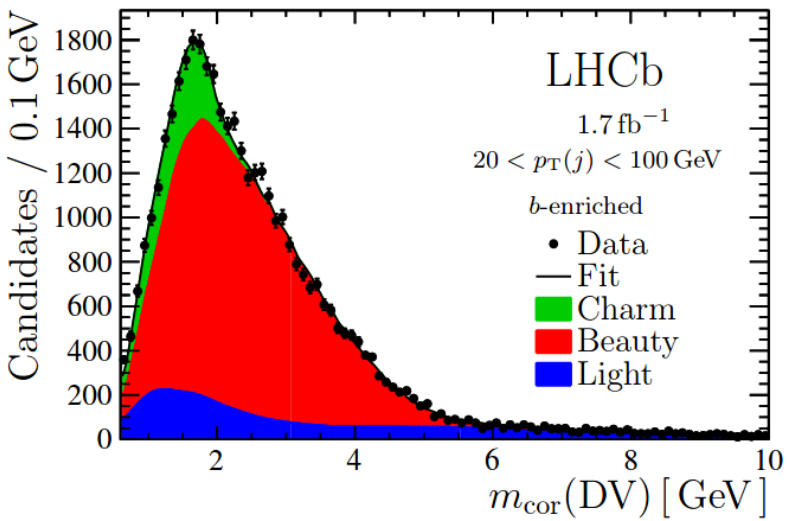
- busier environment during Run 2
- dedicated charm tagging can do better
- full particle flow at software trigger level

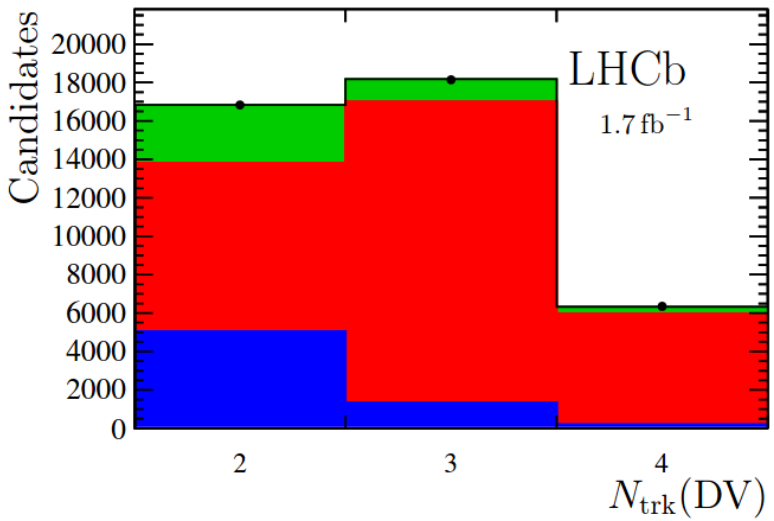


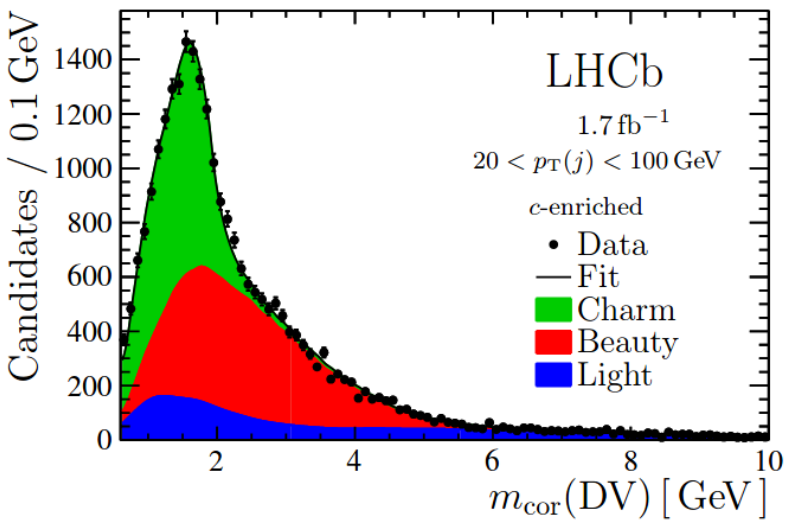


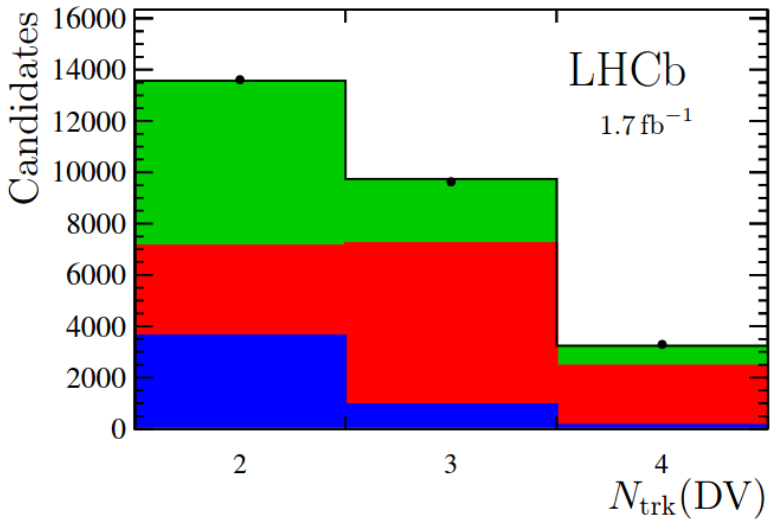
Iterative Templates

LHCb-DP-2021-006





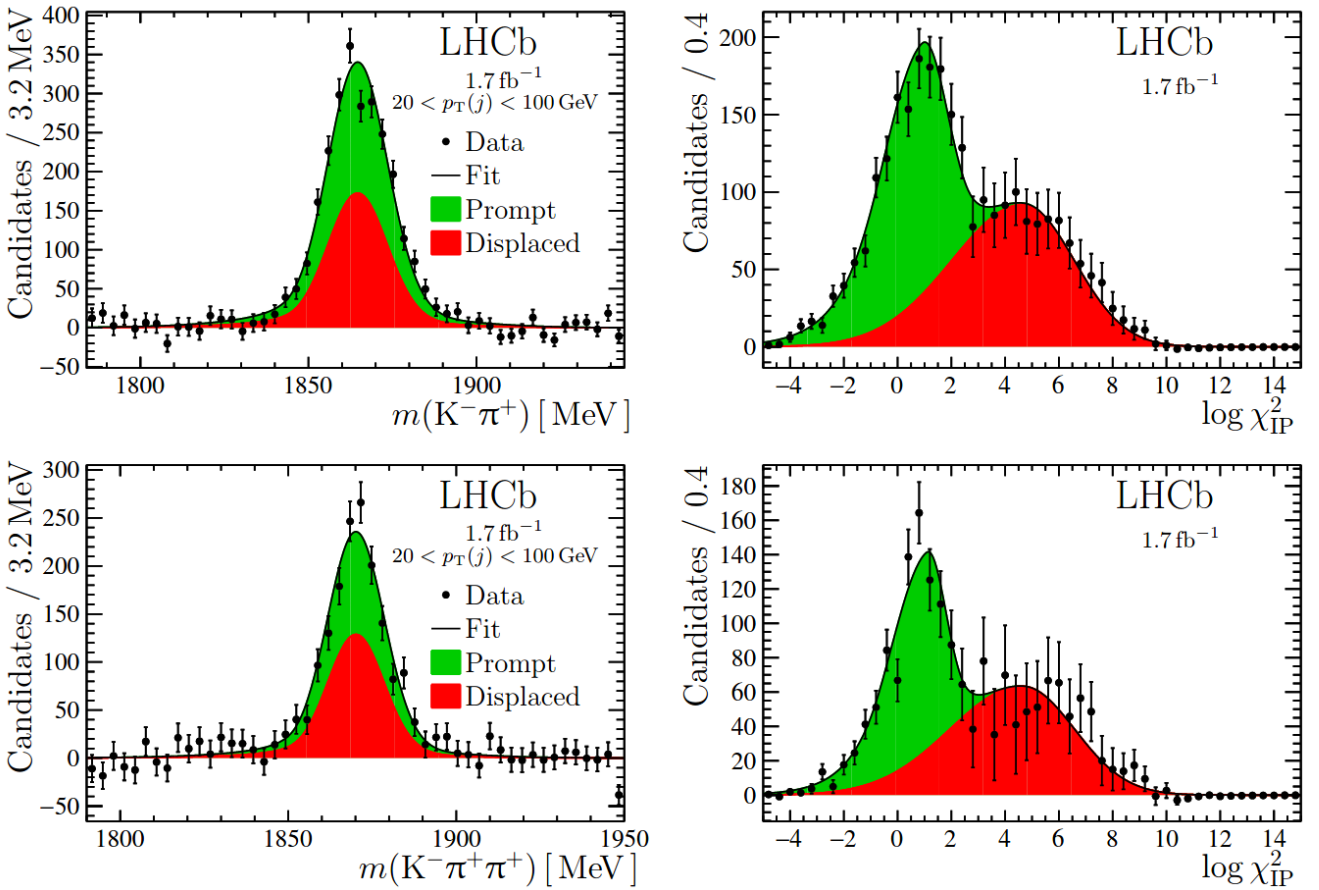




Efficiencies

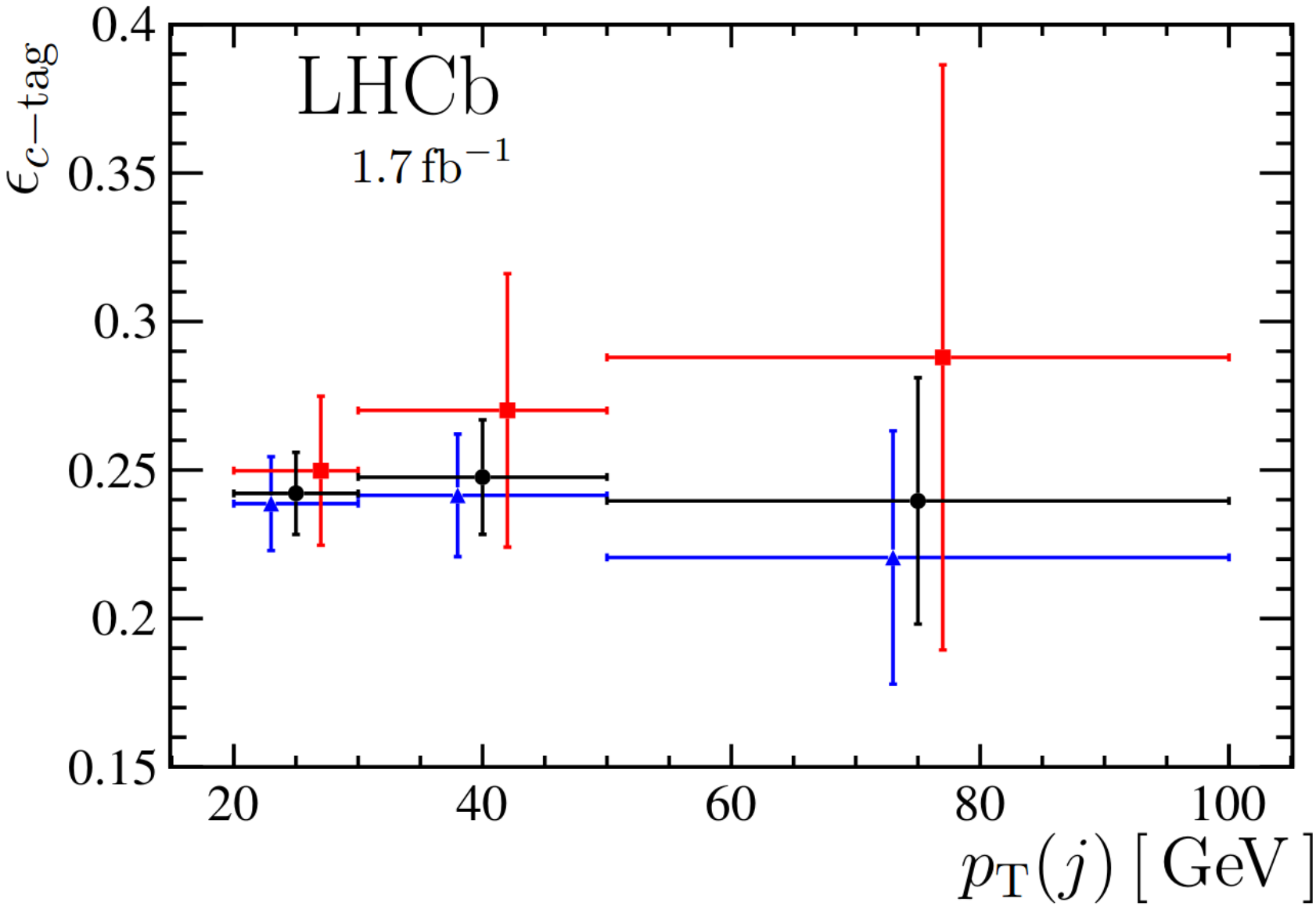
LHCb-DP-2021-006

$$\varepsilon_c = \frac{N_{c\text{-tag}}}{N_c} \qquad N_c = \frac{N_{\text{prompt-}D}}{\varepsilon_D f_{c\to D} \mathcal{B}_D}$$



Efficiencies

LHCb-DP-2021-006



Systematics

LHCb-DP-2021-006

Source	Uncertainty (%)		
	D^0	D^+	Combination
D fit models	4	5–18	3–6
D efficiency method	1–2	3–8	1–2
Simulation sample size	1	2–4	1
Particle identification	1–2	4–7	1–2
Modeling detector response	2	2	2
Fragmentation & branching fractions	2	3	1
2015-16 *vs* 2017-18	2	2	2
Total	5–6	9–21	5–7

The Real Deal

All In

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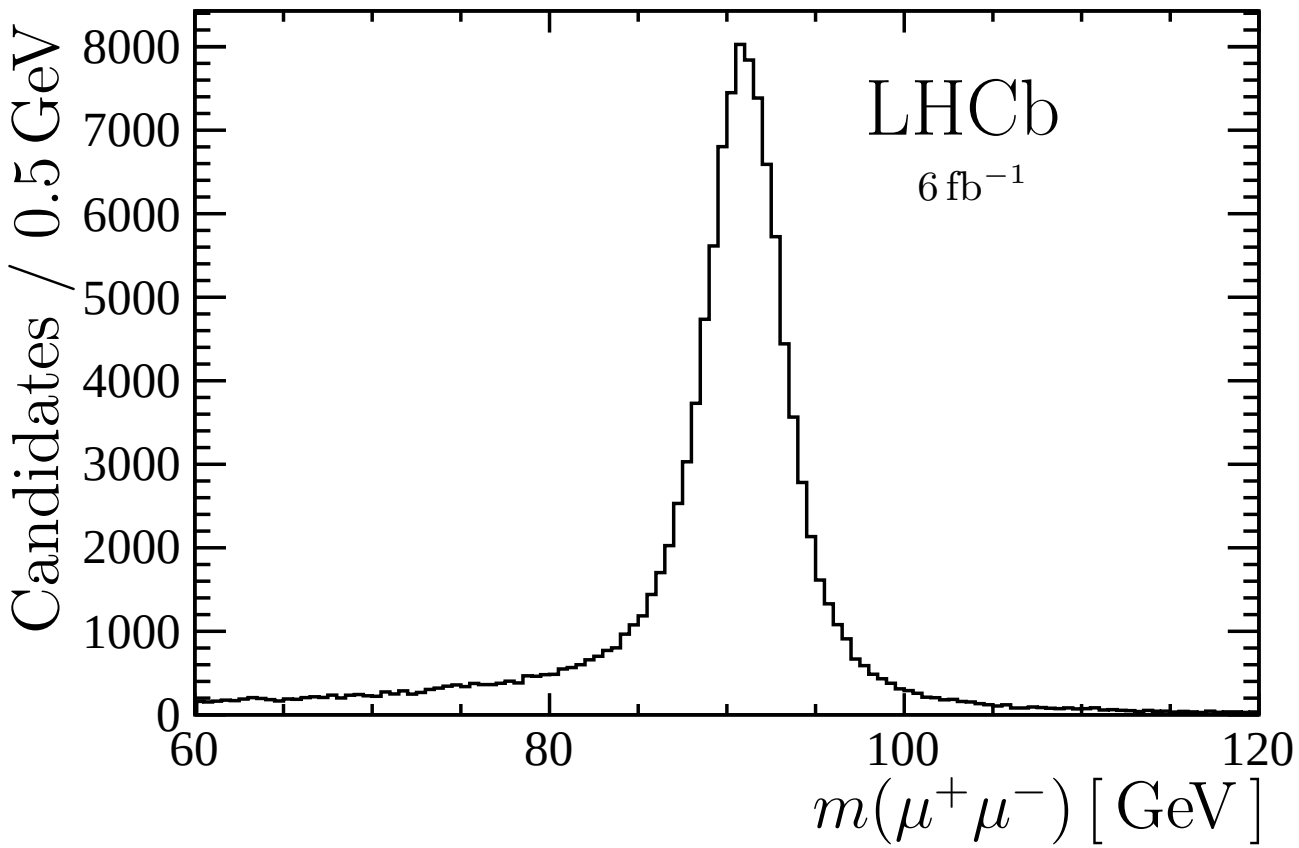
Z bosons	$p_{\mathrm{T}}(\mu) > 20\,\mathrm{GeV},\ 2.0 < \eta(\mu) < 4.5,\ 60 < m(\mu^+\mu^-) < 120\,\mathrm{GeV}$
Jets	$20 < p_{\mathrm{T}}(j) < 100\,\mathrm{GeV},\ 2.2 < \eta(j) < 4.2$
Charm jets	$p_{\mathrm{T}}(c\text{ hadron}) > 5\,\mathrm{GeV},\ \Delta R(j, c\text{ hadron}) < 0.5$
Events	$\Delta R(\mu, j) > 0.5$



Stats Problems

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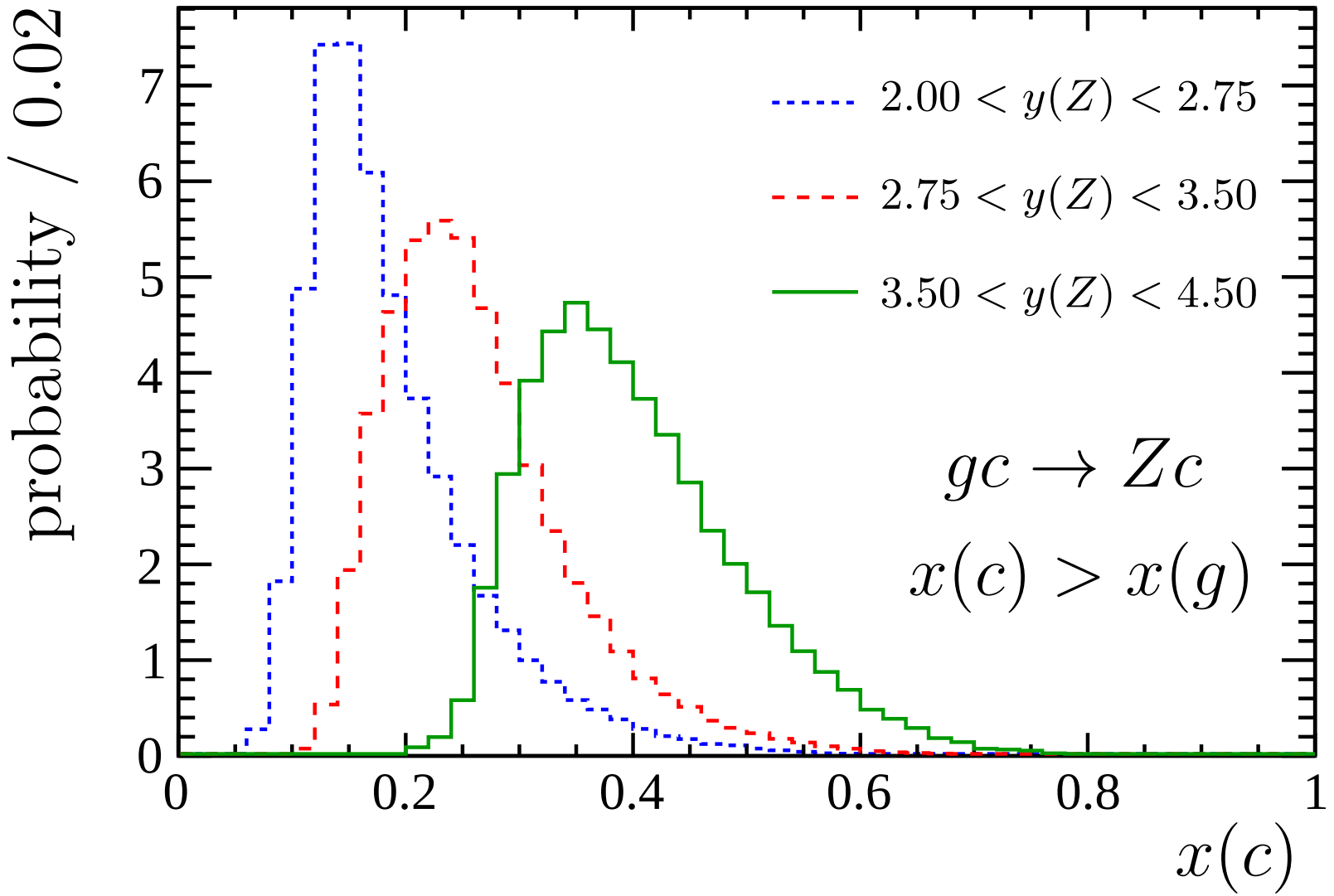

A Charming Fit

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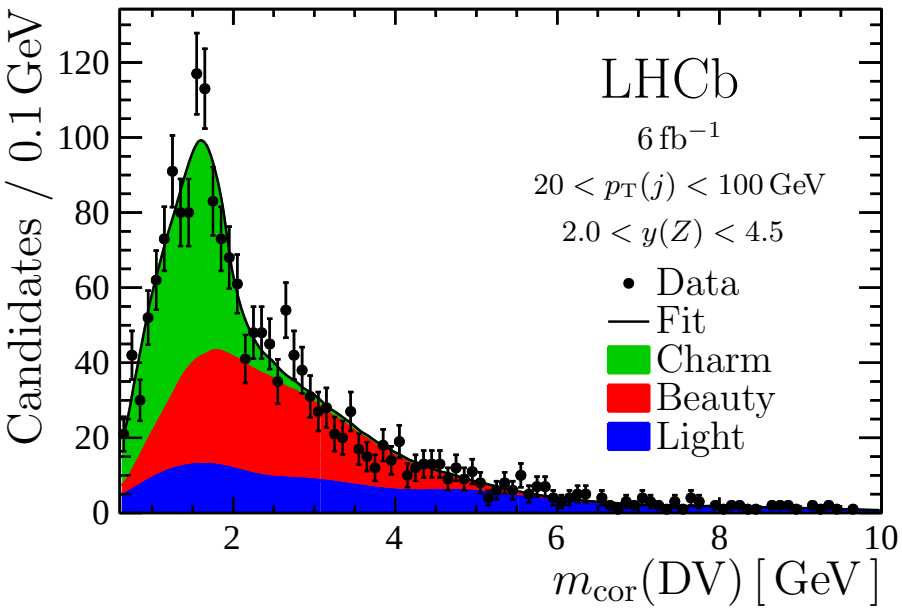

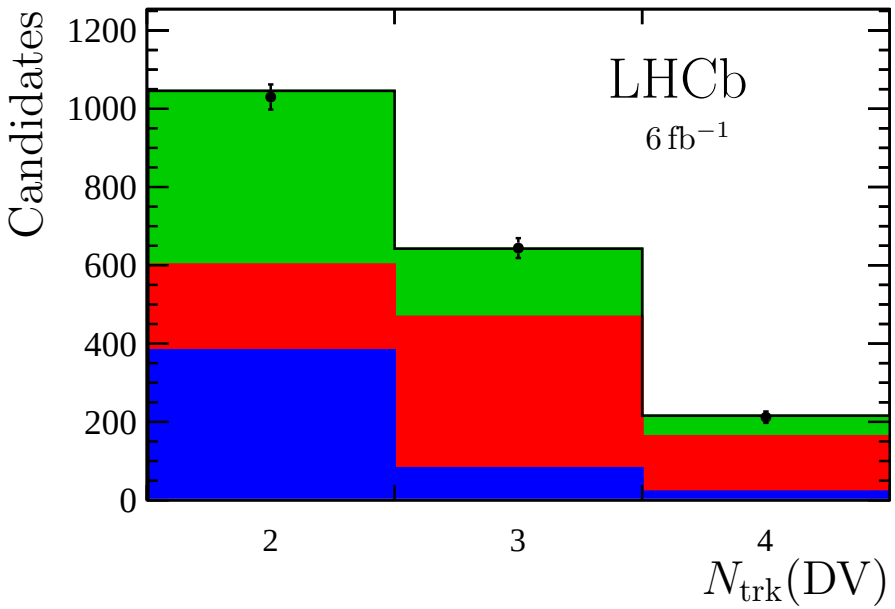

Veggies Before Dessert

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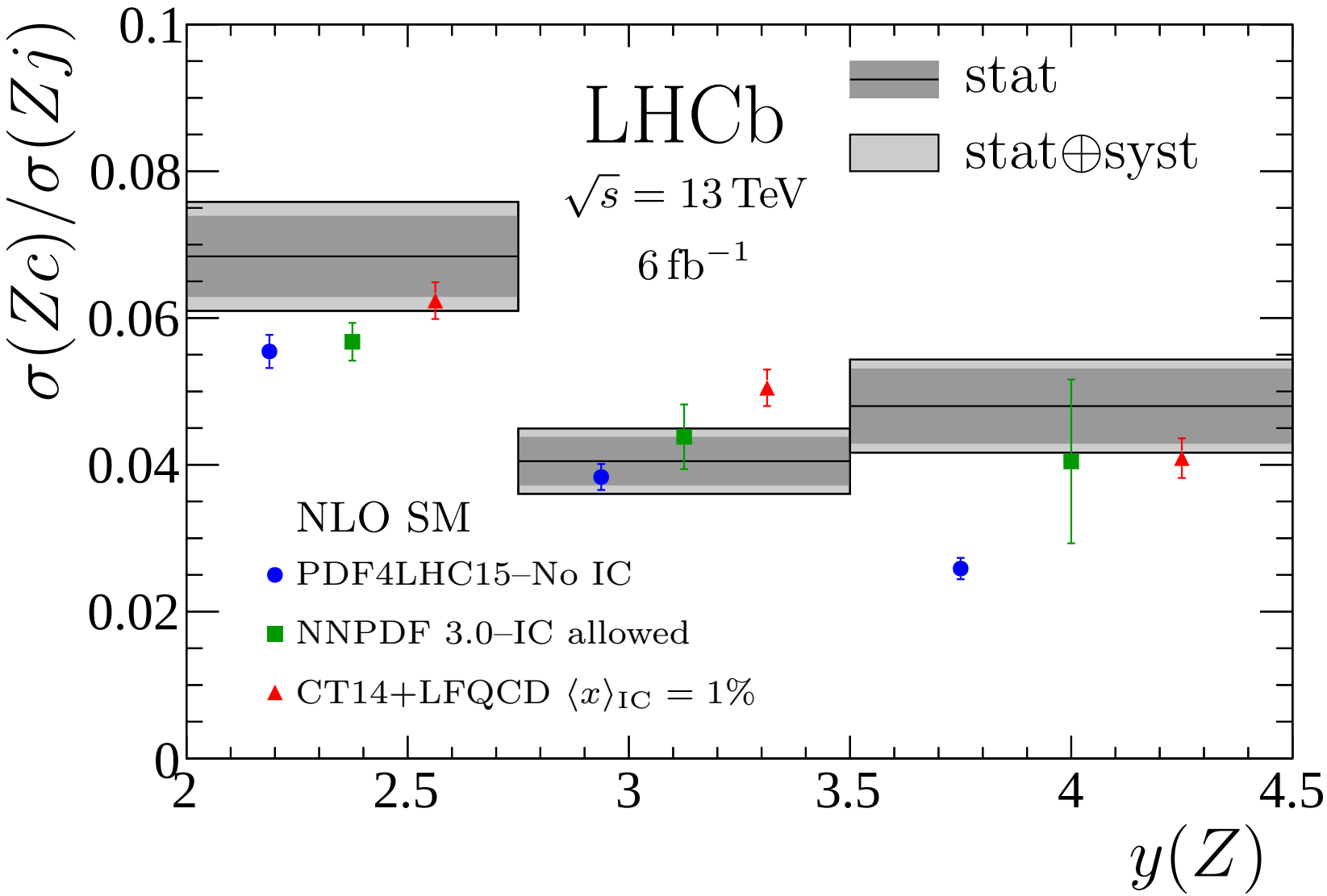
Source	Relative Uncertainty
c tagging	6–7%
DV-fit templates	3–4%
Jet reconstruction	1%
Jet p_{T} scale & resolution	1%
Total	8%

The Dessert

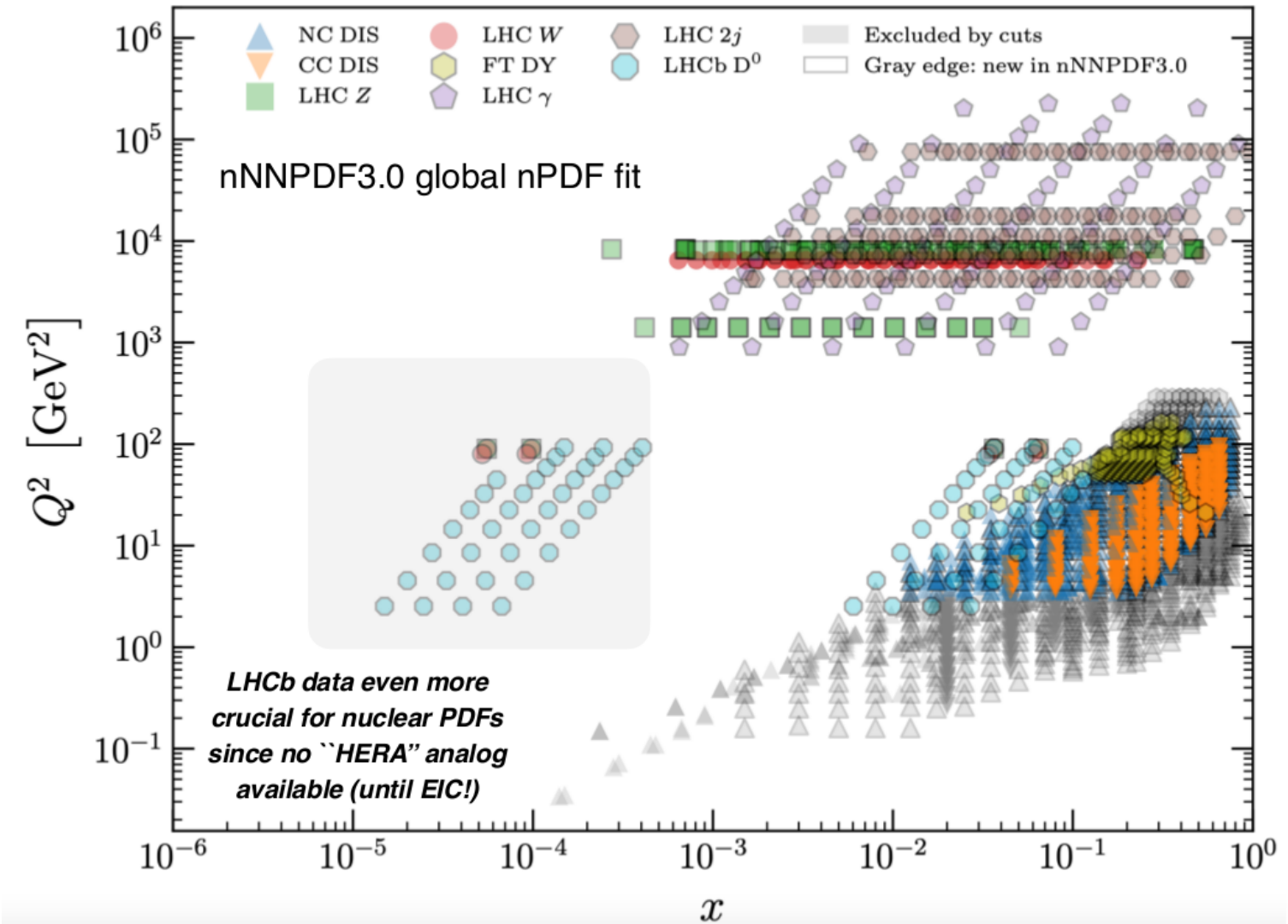
PRL 128 (2022) 082001



Expert Interpretation

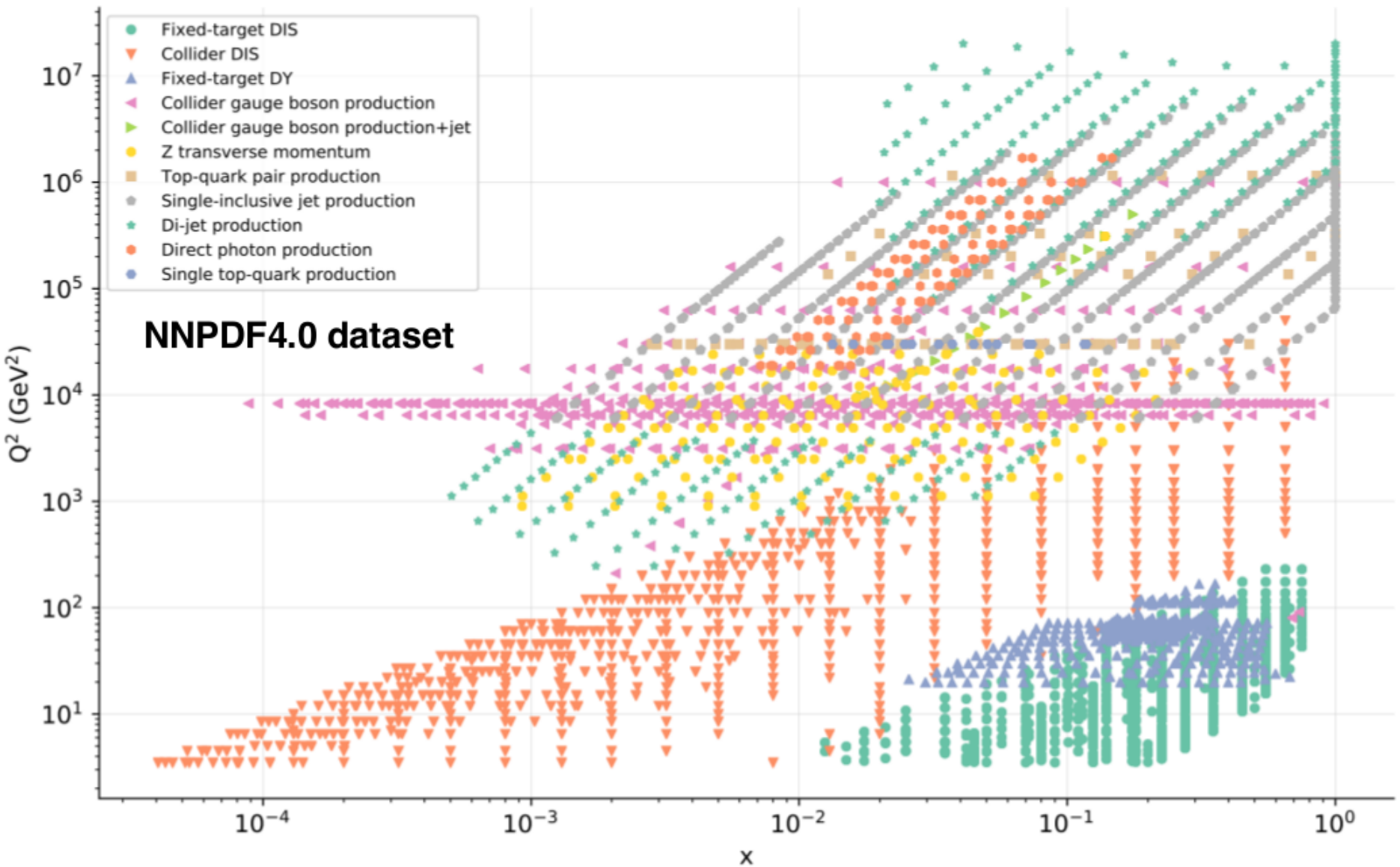
LHCb and NNPDF

R. Rojo



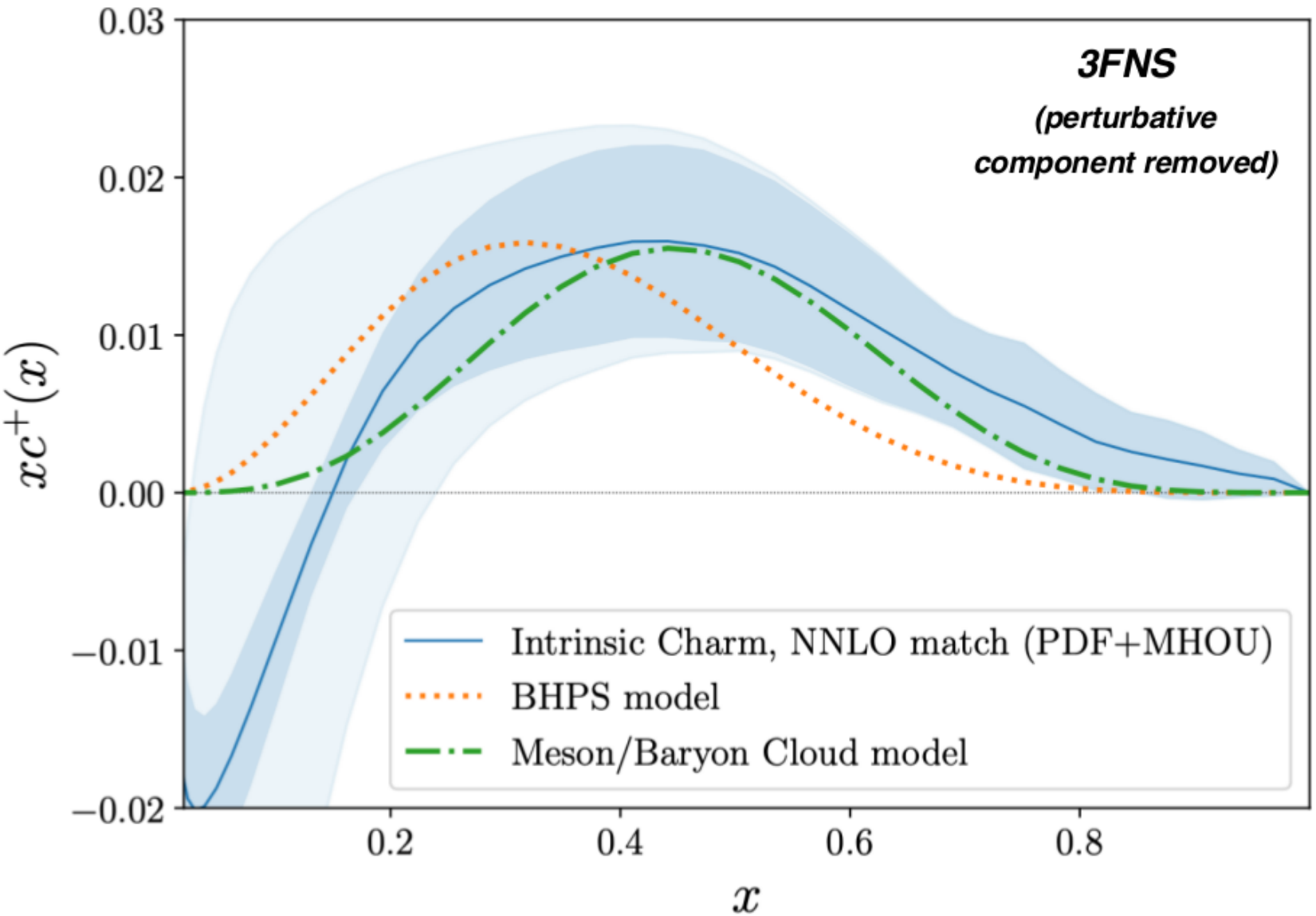
Indirect IC Constraints

R. Rojo



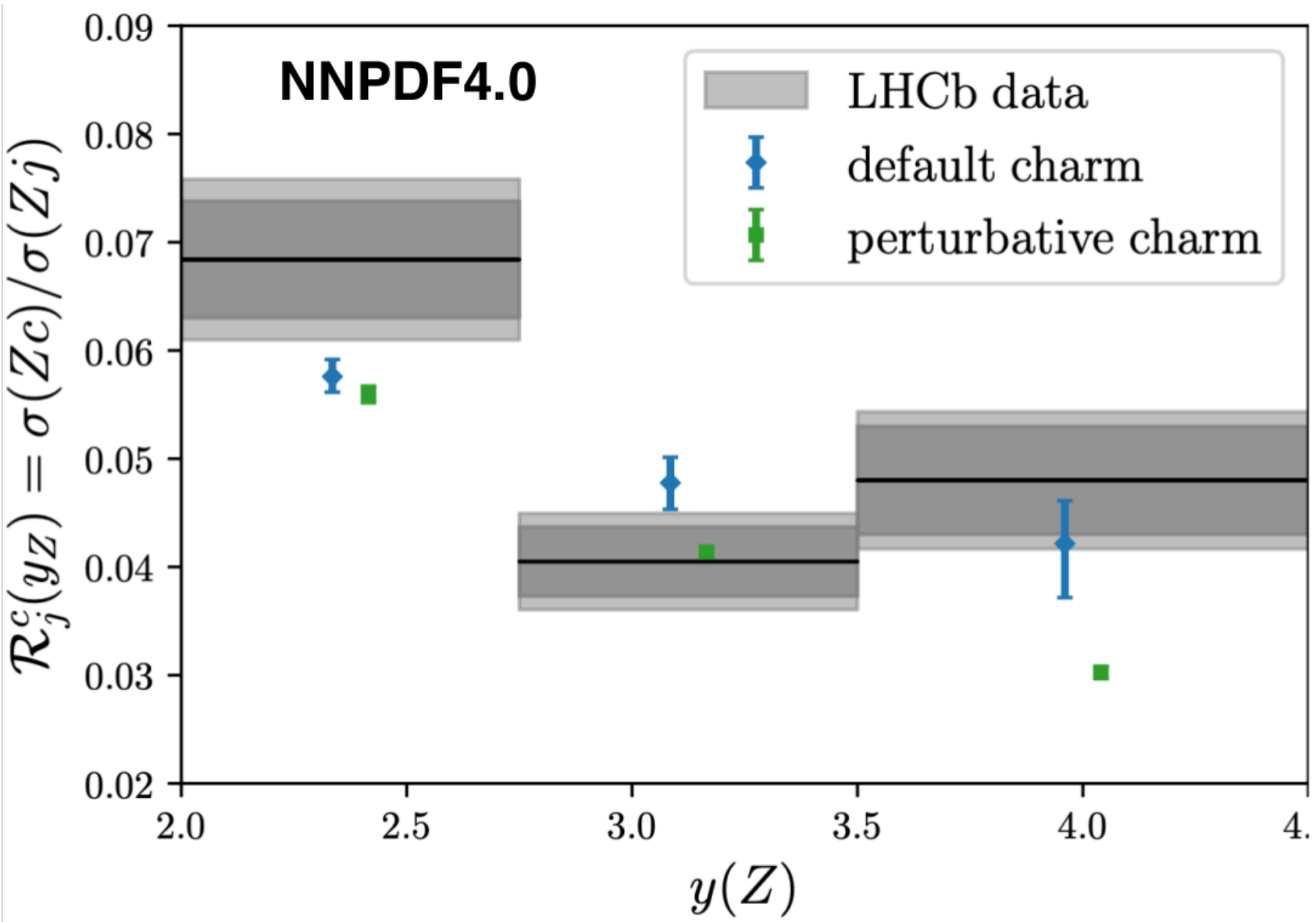
Fitting Charm

R. Rojo



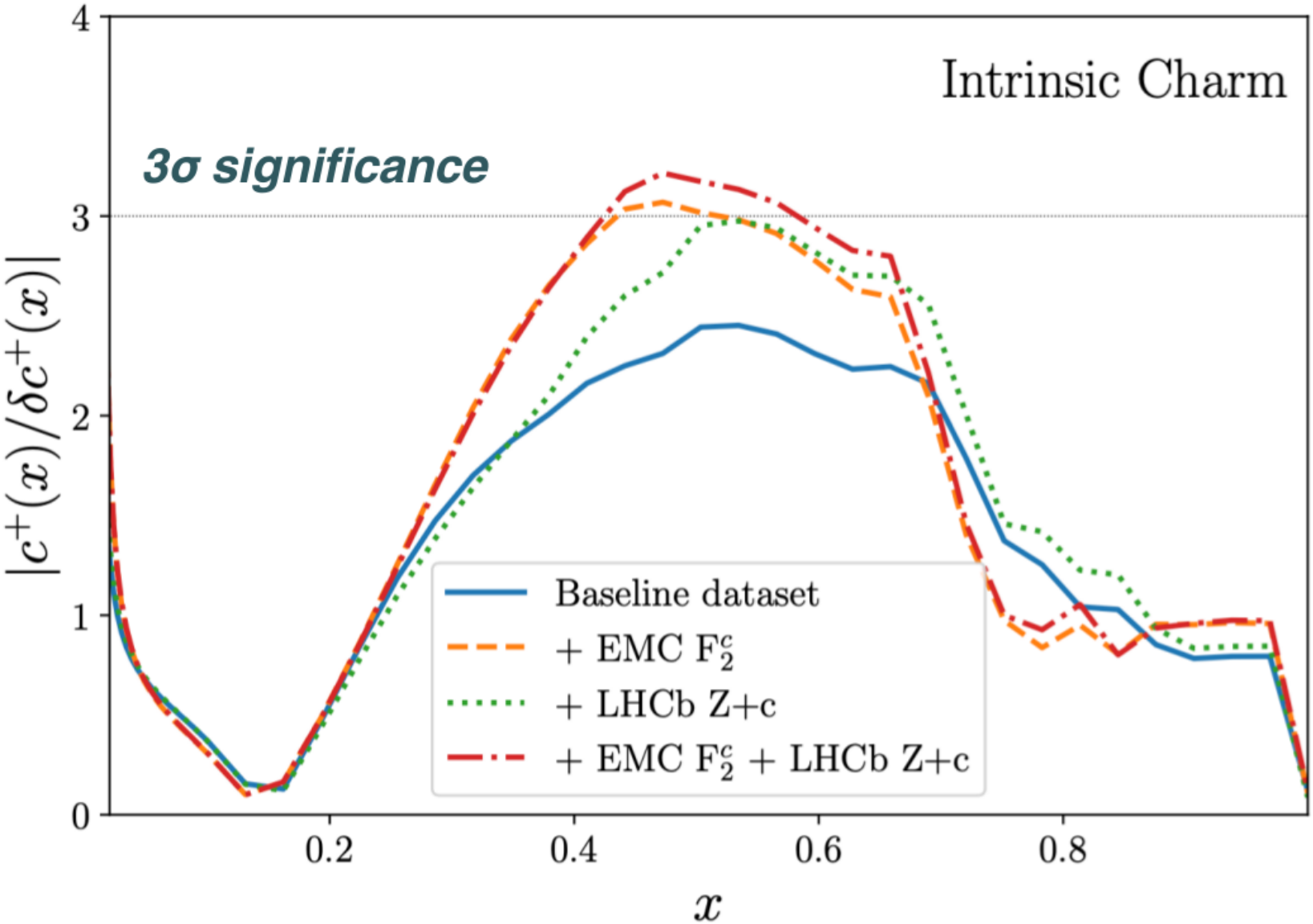
LHCb Data

R. Rojo



Significance

R. Rojo



The End

Conclusions

- $Z + c$ can probe intrinsic charm in the proton
- full particle flow and jet tagging in LHCb Run 2 trigger
- new, more efficient, charm tagging algorithm
- LHCb $\sigma(Zc)/\sigma(Zj)$ is not consistent with perturbative charm
- NNPDF fits estimate IC carries 0.5% of proton momentum from LHCb measurement

Thank You!