WG2 Forward Charm Production Summary

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Penn State University

Forward Physics Facility Theory Workshop, CERN, September 19, 2023

WG2: Forward Charm Production

Convener: **Anna Stasto**

Previous convener: **Mary Hall Reno**, last update June 9, 2023, 6th FPF meeting

https://indico.cern.ch/event/1275380/contributions/5379620/

Usual meetings: **Mondays 12:30 EDT**

Recent presentations:

Akitaka Ariga : ***NA65/DsTau experiment***

Timothy Hobbs: ***CT18FC: the enduring nonperturbative charm problem***

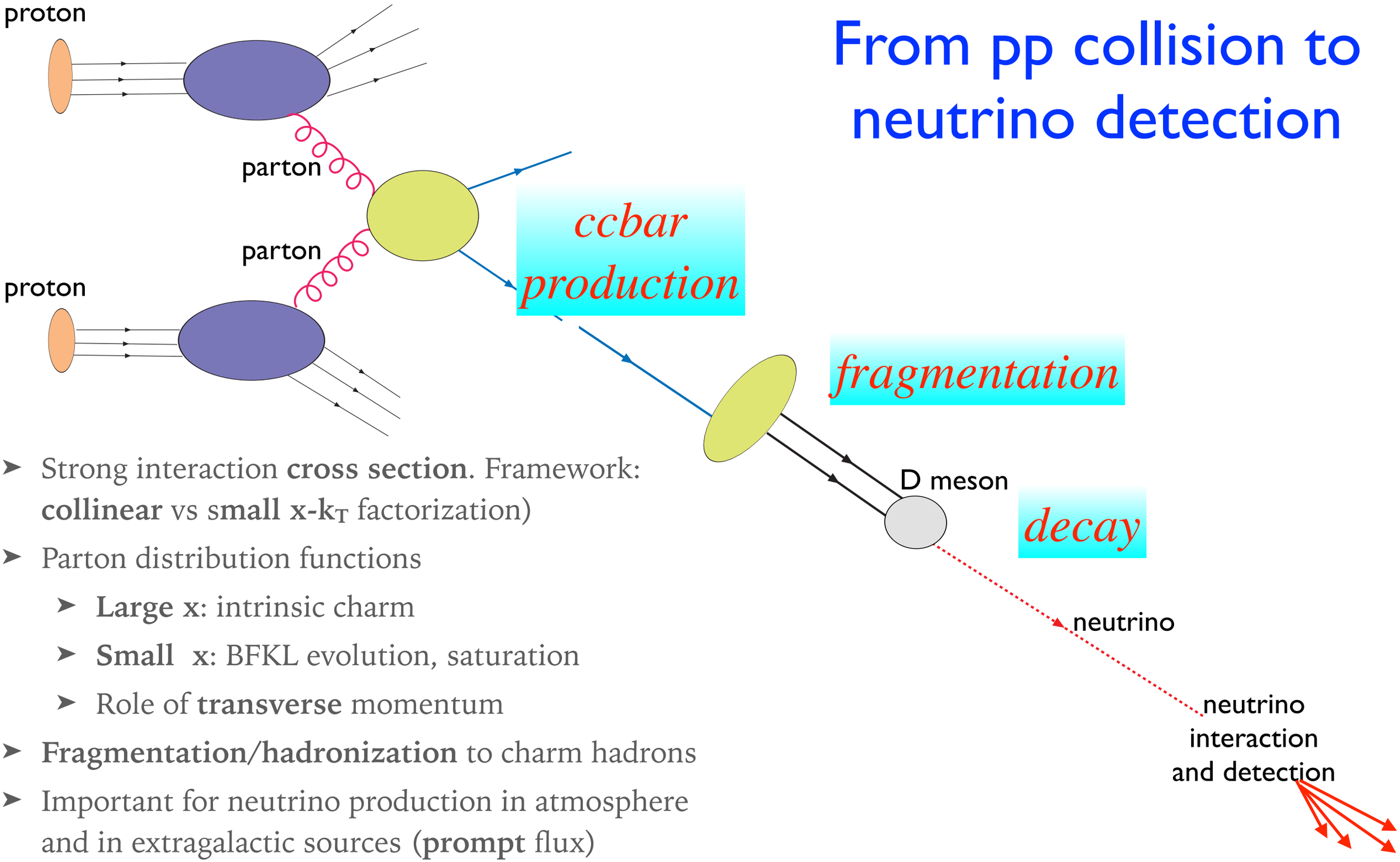
Kazuhiro Watanabe: ***Forward heavy flavor production and CGC in pp collisions***

Presentations at this workshop (SM parallel session) relevant for forward charm:

Atri Bhachattarya, Keping Xie, Timothy Hobbs

also **Toni Makela, Max Fieg**

Forward charm production : questions



From pp collision to neutrino detection

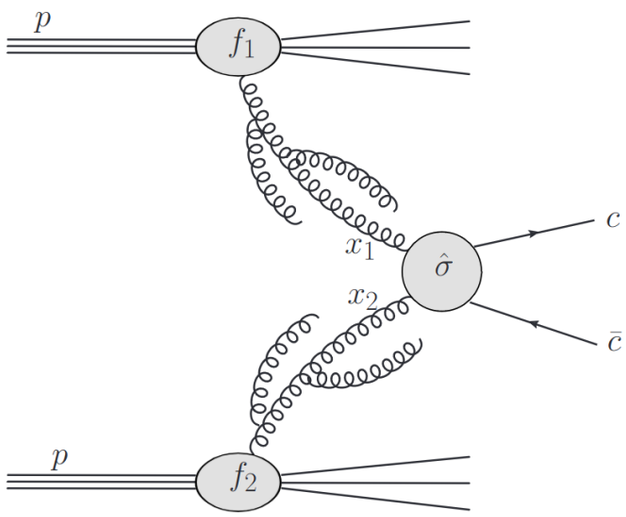
- Strong interaction **cross section**. Framework: **collinear** vs **small x-k_T** factorization)
- Parton distribution functions
  - **Large x**: intrinsic charm
  - **Small x**: BFKL evolution, saturation
  - Role of **transverse** momentum
- **Fragmentation/hadronization** to charm hadrons
- Important for neutrino production in atmosphere and in extragalactic sources (**prompt** flux)

Factorization : collinear vs kT

QCD schemes:

$$pp \to c\bar{c}$$

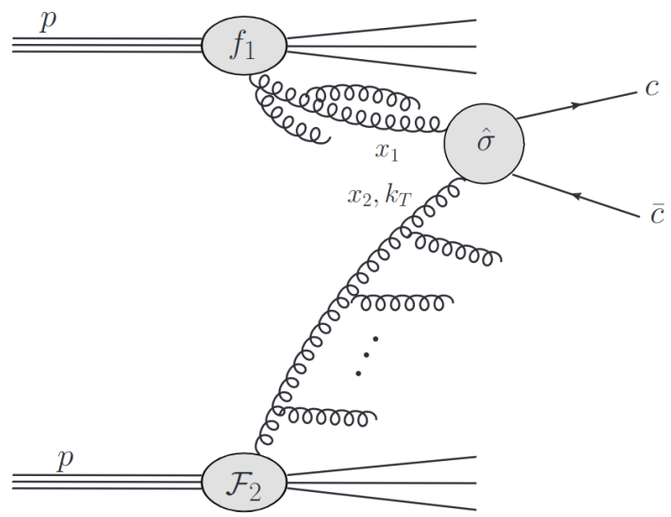
Collinear factorisation



$$\sigma \simeq \hat{\sigma}^{\mathrm{on-shell}} \otimes f_1 \otimes f_2$$

NLO accuracy (at least).
Developed mass schemes
PDFs from **global** fits (many data)
Need extrapolation to small x (DGLAP may not be sufficient)
Usually **twist-2**, no power corrections included

***k*T factorisation**



$$\sigma \simeq \hat{\sigma}^{\mathrm{off-shell}} \otimes f_1 \otimes \mathcal{F}_2$$

LO matrix elements, only gluon fusion
Uses mixed : collinear (large x) and small x unintegrated gluons (matching ?)
Can use both gluons off-shell but limited to mid-rapidity (not very forward).
Extrapolation to small x via **evolution**
Natural extension to include **higher twists**

Description of 13 and 7 TeV data

Collinear vs k_T factorisation @ 13 TeV

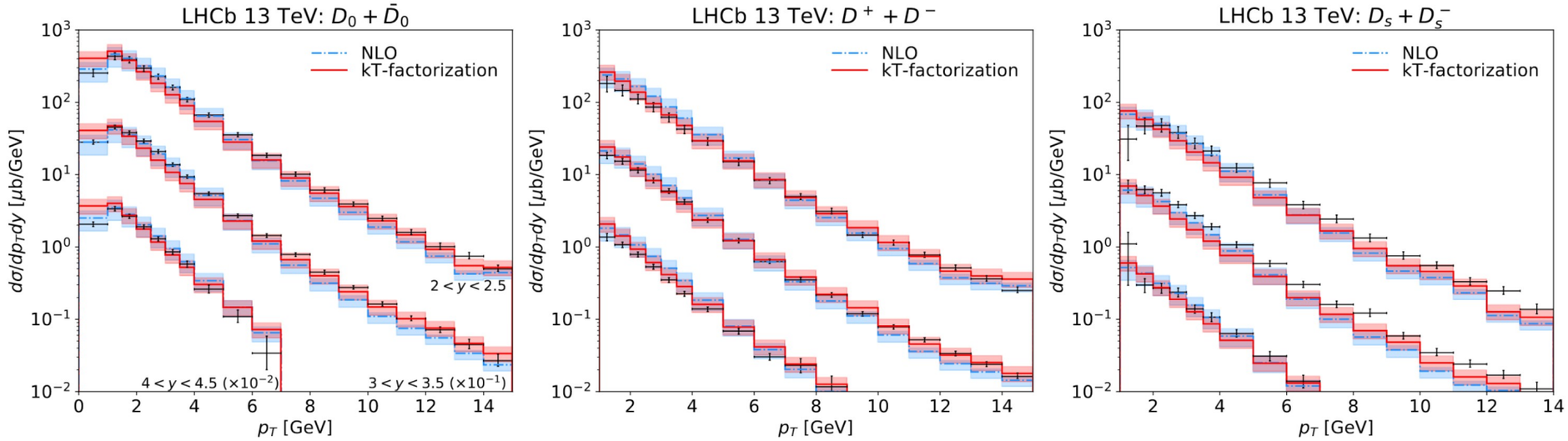
A.Bhachattarya

Good description of 13 TeV and 7 TeV (no fitting to 7) data

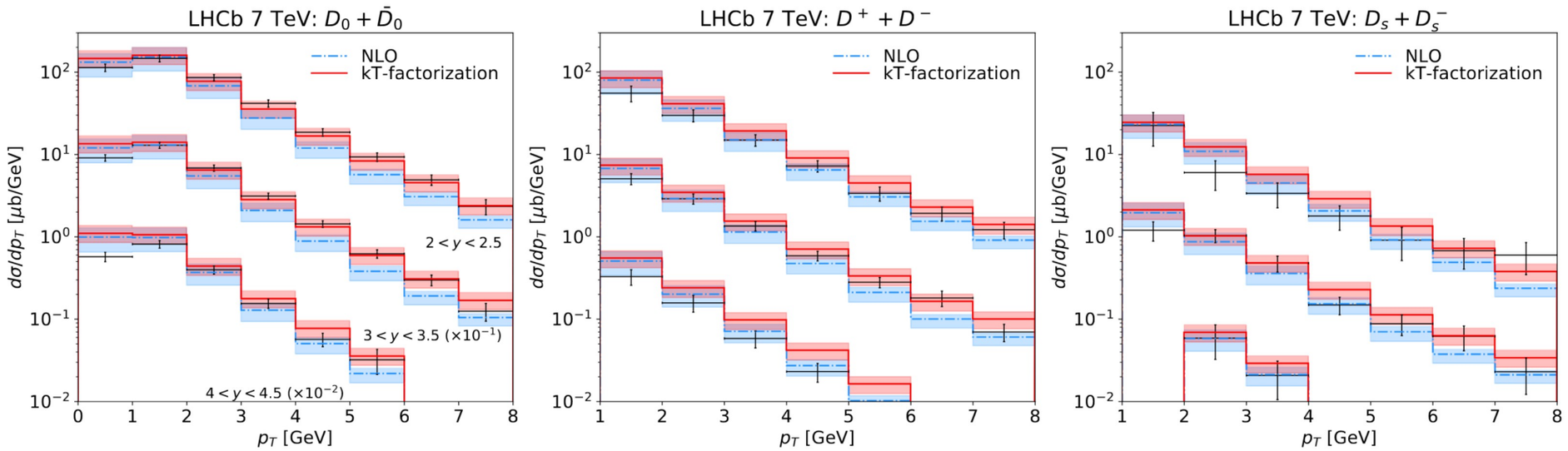
However:

collinear needs k_T smearing to describe the data

k_T-factorization needs k-factor of 2.3



Collinear vs k_T factorisation @ 7 TeV

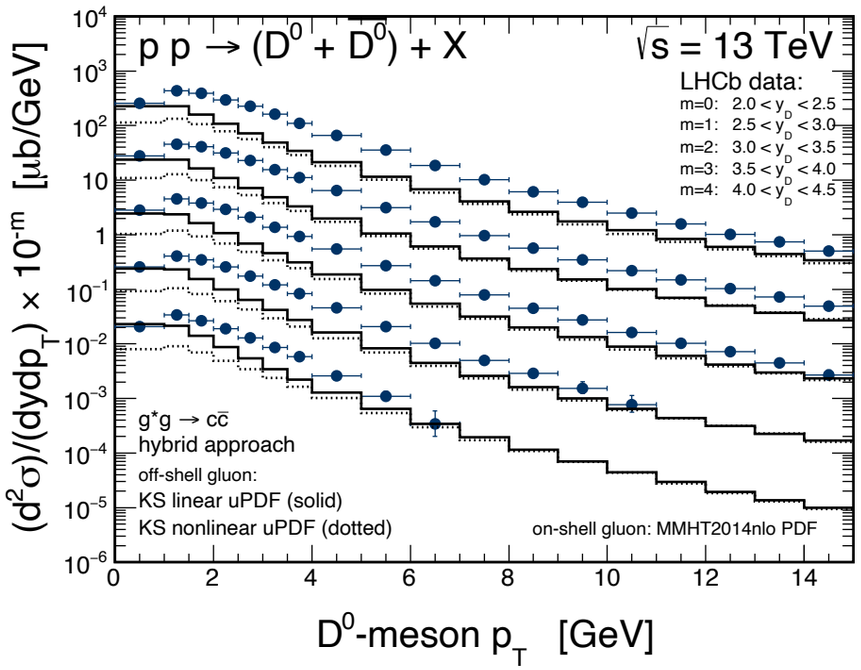


Small x approaches to forward charm hadroproduction

Need for k factor present in other small-x calculations using hybrid(on-off-shell) factorization

Missing NLO contributions

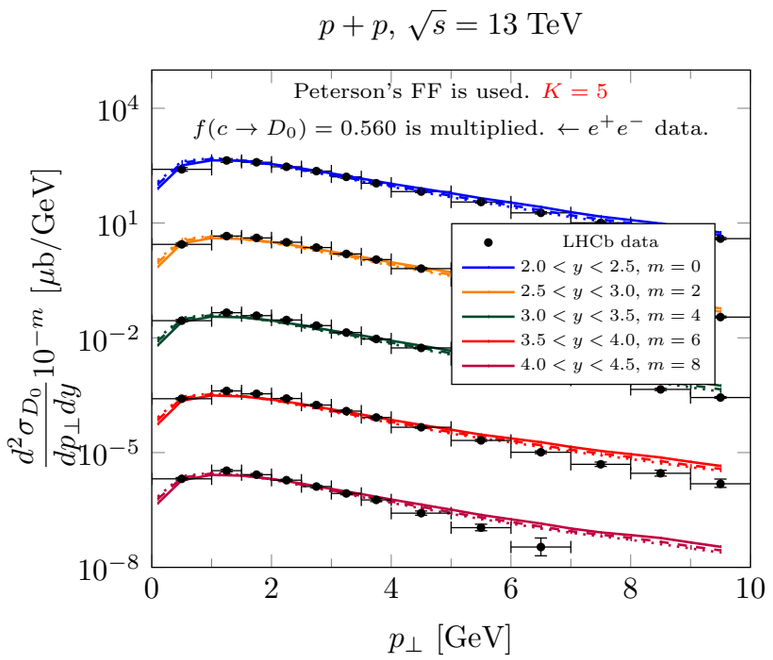
Maciula, Szczurek

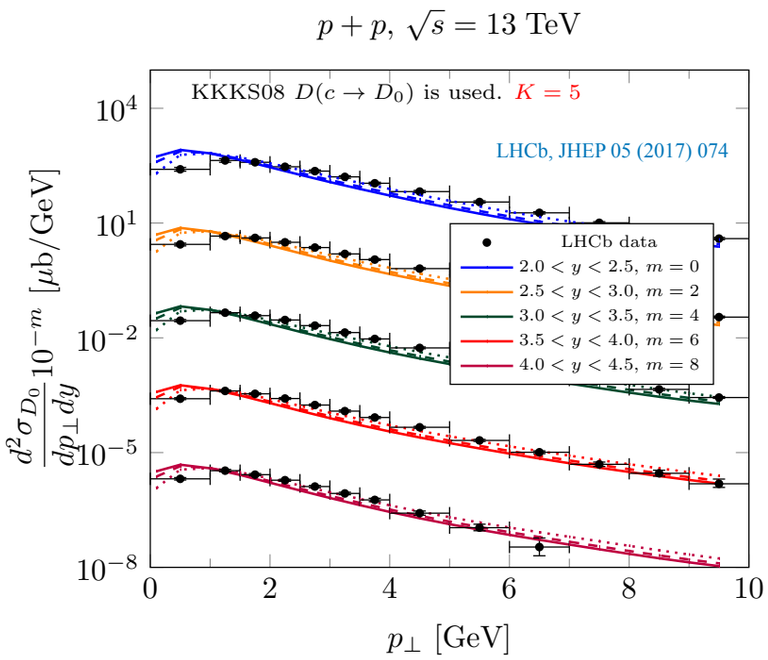


CGC calculation

K. Watanabe

Ma, Tribedy, Venugopalan, **KW**, PRD98, no.7, 074025 (2018)

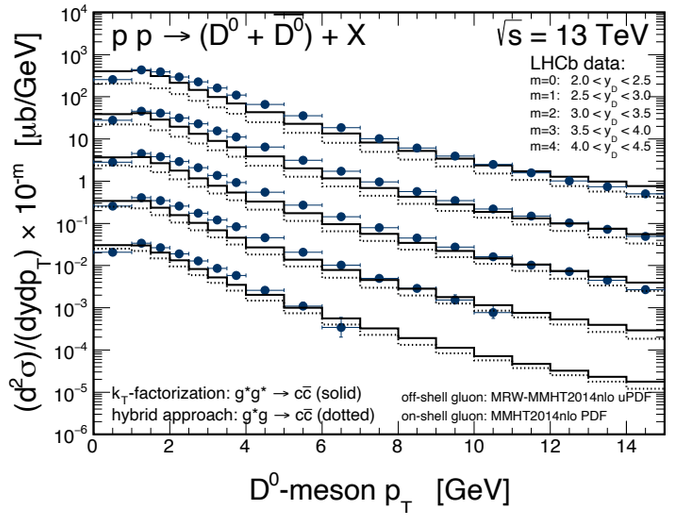




The shape of D_0's spectrum is OK at low p_T, modulo normalization.

Though double off-shell seem to be closer to the data(different gluon)

Applicable at not-so forward rapidity

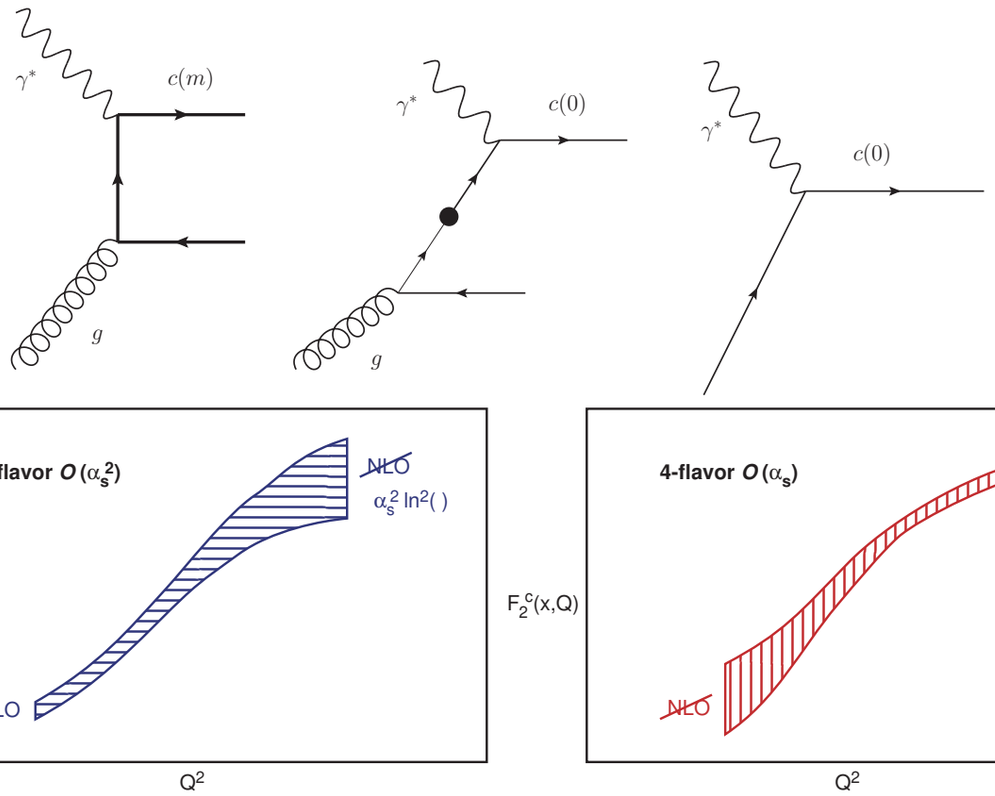


Maciula, Szczurek

Mass schemes

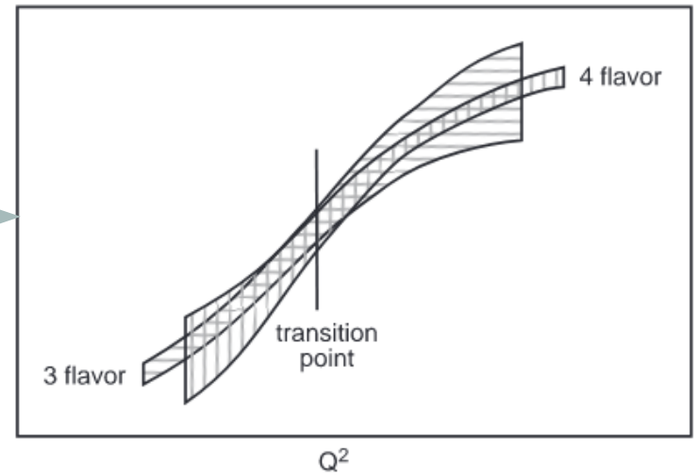
ACOT scheme

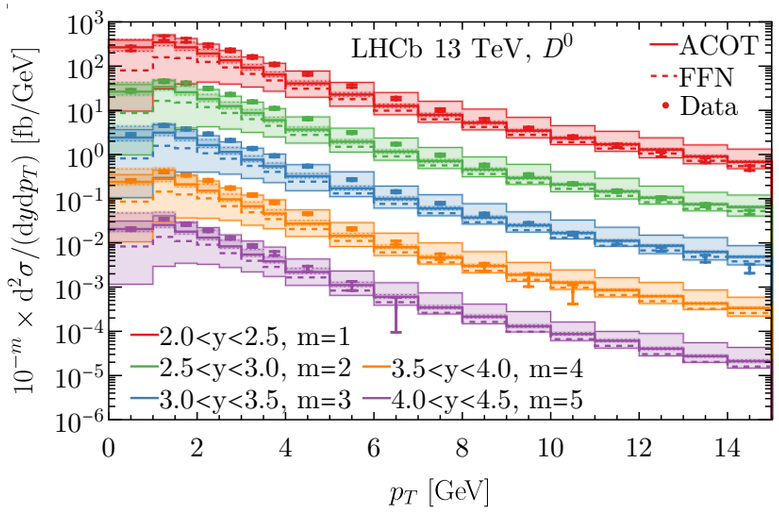
K.Xie



[W. Tung, et al., 0110247]

matching





Better description of LHCb data

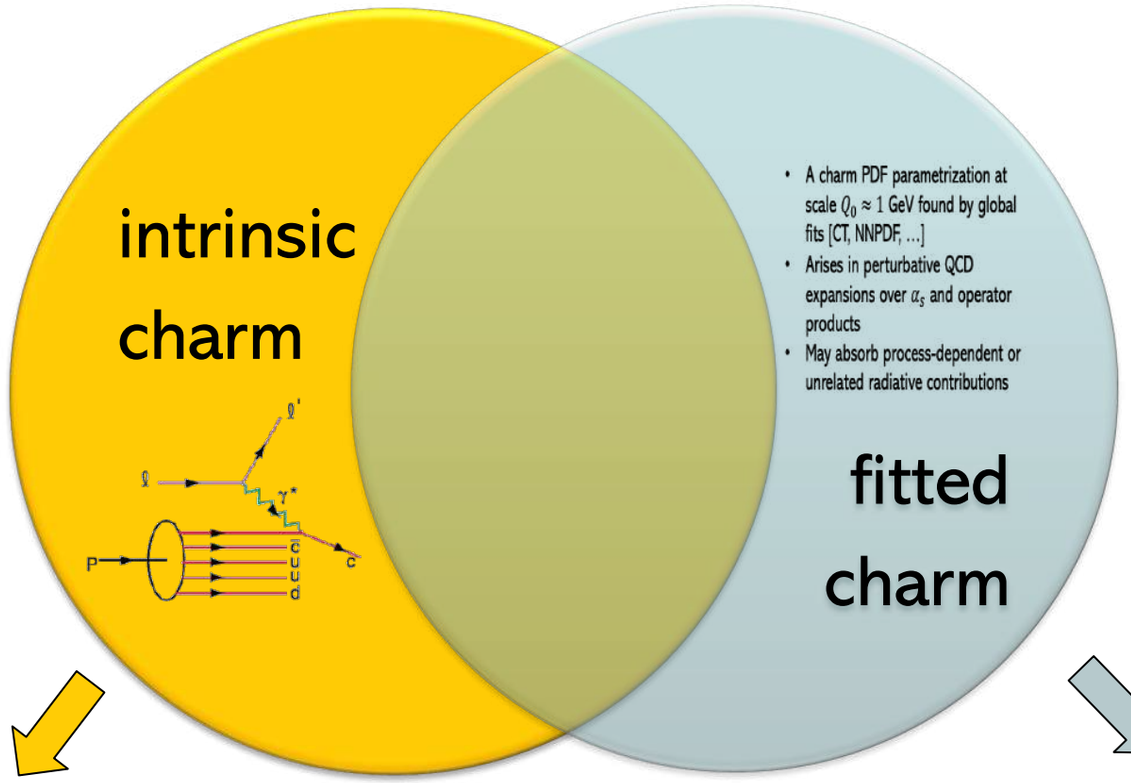
Impact at low p_T

Relevant for forward production

Intrinsic/fitted charm

challenging to formulate a rigorous definition of intrinsic charm

T.Hobbs



- The concept of nonperturbative methods
- Can refer to a component of the hadronic Fock state or the type of the hard process
- Predicts a typical enhancement of the charm PDF at $x \gtrsim 0.2$

Connection?

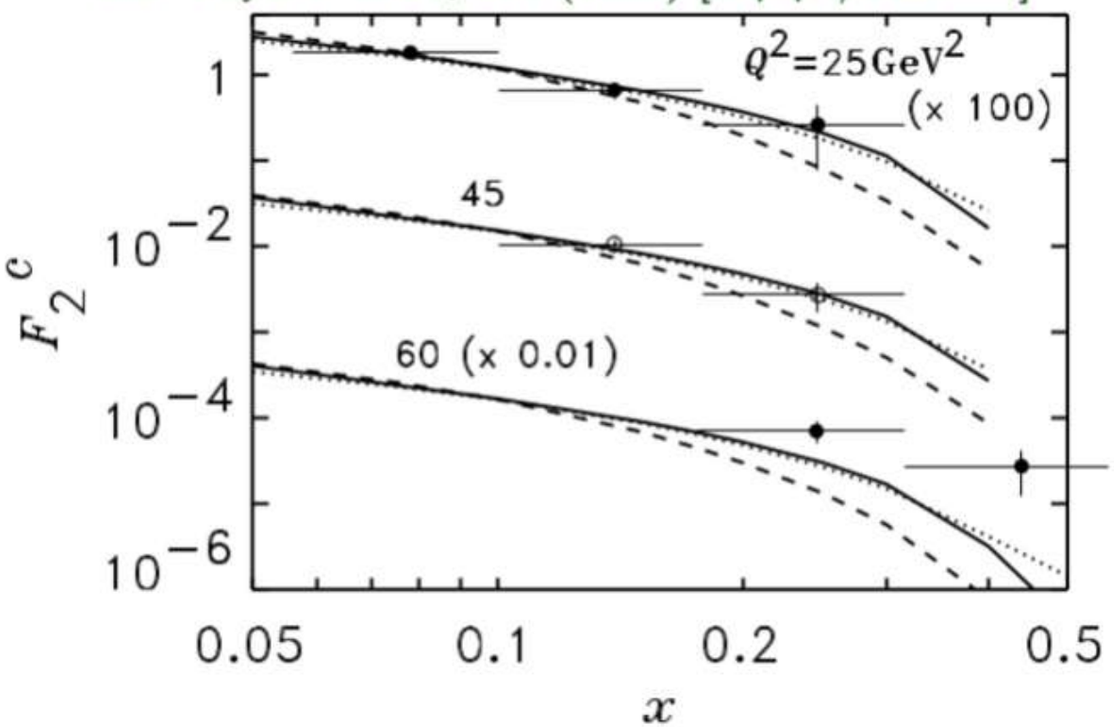
- A charm PDF parametrization at scale $Q_0 \approx 1$ GeV found by global fits [CT, NNPDF, …]
- Arises in perturbative QCD expansions over α_s and operator products
- May absorb process-dependent or unrelated radiative contributions

2023-06-19 T. Hobbs, WG2-FPF 2023 9

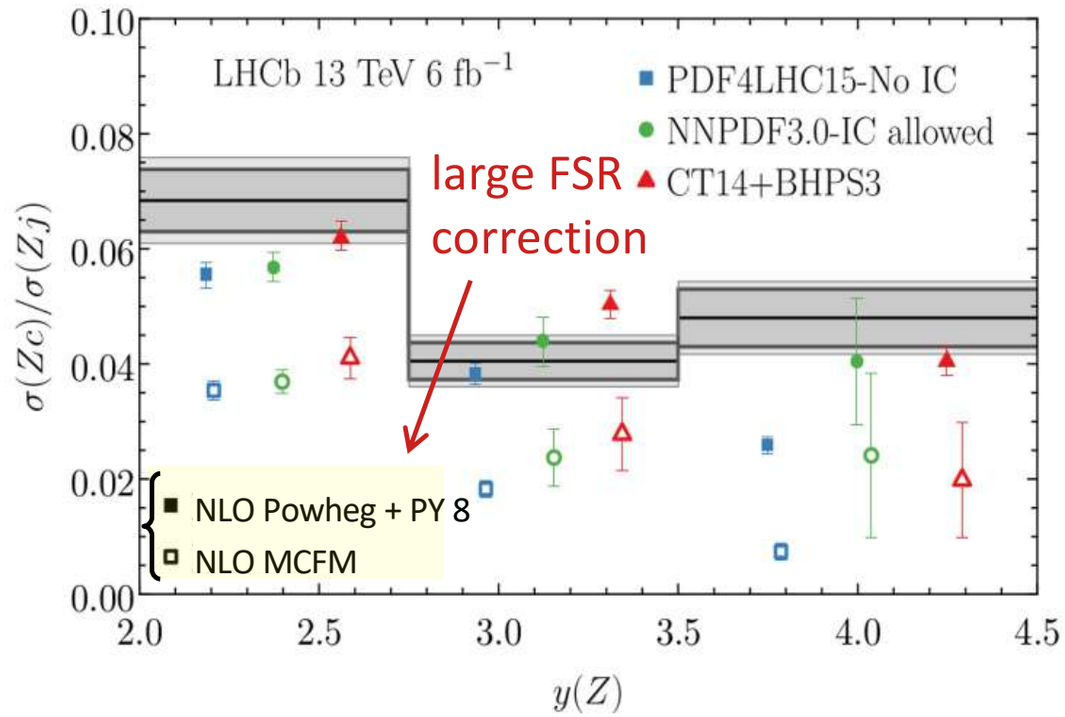
Intrinsic/fitted charm

Experimental data (old EMC and new LHCb) intriguing
Theoretical interpretation difficult

F. M. Steffens, W. Melnitchouk and A. W. Thomas,
Eur. Phys. J. C **11**, 673 (1999) [hep-ph/9903441].



2022 LHCb 13 TeV data: (*Z*+*c*) / (*Z*+*jet*) ratios; 3 rapidity bins



CT18 Fitted Charm analysis:

- size, shape of nonpert charm remains indeterminate *T.Hobbs*

  → theoretical ambiguities in relation between FC/IC unresolved

  → need more sensitive data; FC currently consistent with zero

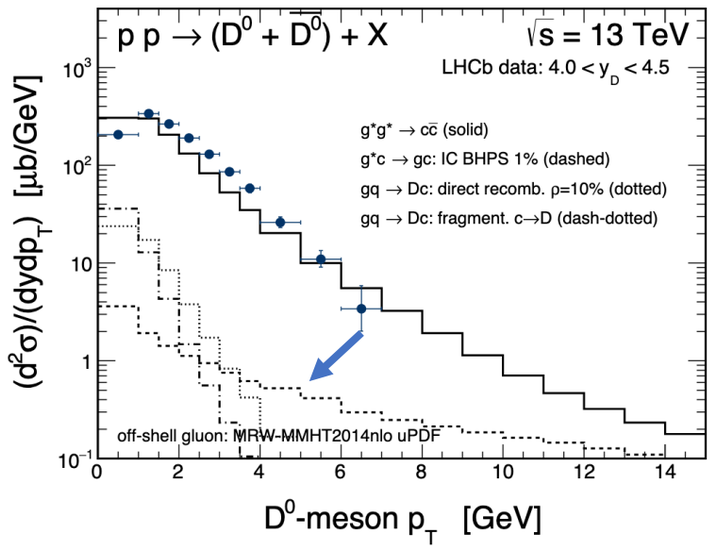
concordance with enlarged error estimates: $\langle x \rangle_{\rm FC} \sim 0.5\%$, well below evidence-level

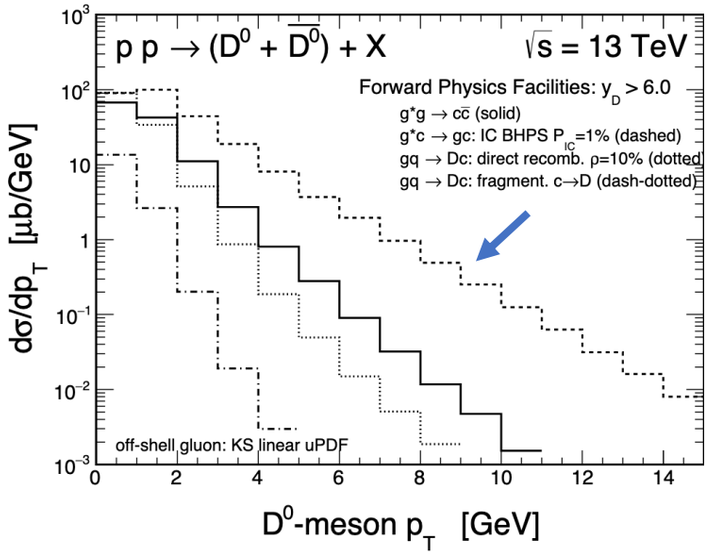
Intrinsic/fitted charm

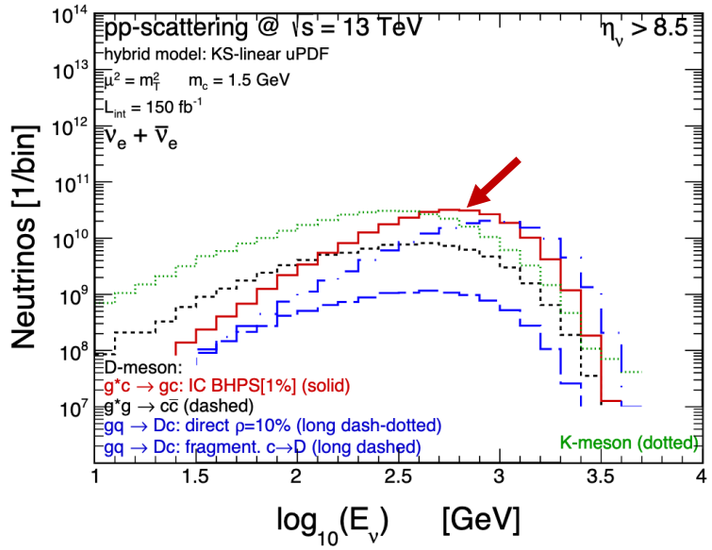
M.Hall-Reno, 6th FPF Workshop

dashed histograms: intrinsic charm contributions

low pT to forward neutrinos





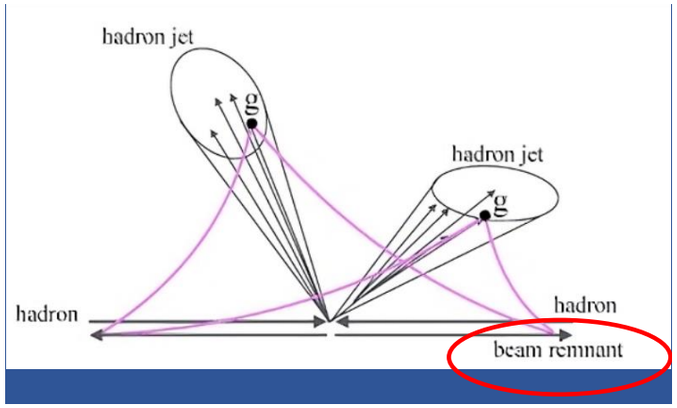


Maciula, Szczurek, Phys. Rev. D 107 (2023) 034002

Intrinsic charm (at 1%): irrelevant for the mid-rapidity, may become important

Fragmentation/hadronization

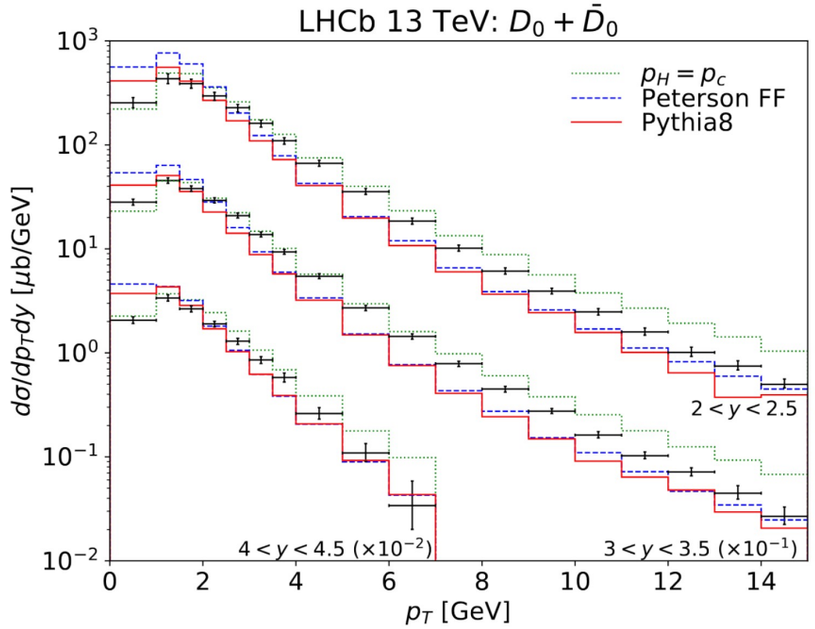
M.Fieg

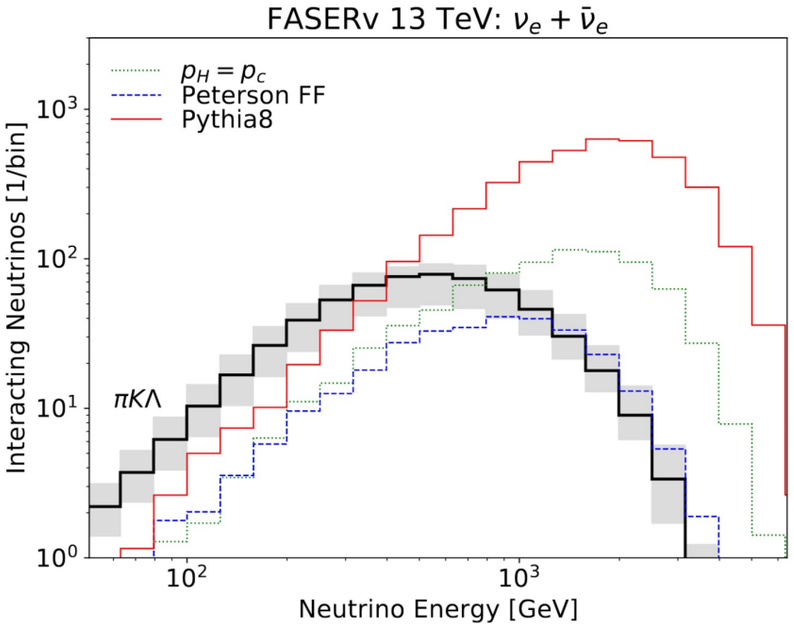


Beam remnant effects

Fragmentation schemes

A.Bhachattarya





Fragmentation functions and PYTHIA8 both describe LHCb data
PYTHIA8 (mode2) : more energy to the charm meson, effects of beam remnant
Large differences at forward rapidities: orders of magnitude
Fragmentation functions may not be sufficient for forward rapidities: process dependent hadronization

Summary: goals for WG2

- **Compare** different predictions of neutrino fluxes from forward charm.
  - Different inputs from theory: production of charm, small x evolution, large x (intrinsic charm), fragmentation, decay.
- **Document** forward charm production predictions and their corresponding neutrino flux evaluations.
- Longer term:
  - Project how measurements of other experiments could impact predictions of neutrino fluxes at the FPF.
  - Conversely, how the physics potential associated with measurements at FPF could impact other experiments (ex. EIC) and observations (astroparticle).

If you would like to contribute to WG2 please contact us !