Brief summary of today's mtg of the LHC Heavy Flavour WG*

* http://lpcc.web.cern.ch/LPCC/index.php?page=hf_wg

May 4 2017

M.L. Mangano
TH Department, CERN

- b-hadron fragmentation fractions (f_s, $f_{\Lambda b}$, …)
  - LHC input to HFLAV averages
- production cross section measurements

LHC HF WG mtg on B production

Thursday 4 May 2017, 09:00 → 13:00 Europe/Zurich

https://indico.cern.ch/event/628495/timetable/

09:05 → 10:35 **current measurements of production fractions and HF cross sections from the LHC experiments**

- 09:05 **ATLAS**
  Speaker: Sandro Palestini (CERN)
  SP-ATLAS-HFWG.pdf

- 09:35 **CMS**
  Speakers: Alberto Sanchez Hernandez (Centro de Investigación y de Estudios Avanzados del IPN (MX)) , Ilse Kratschmer (Austrian Academy of Sciences (AT)) , Stefano Argiro (Universita di Torino and INFN (IT))
  HFWG-Production-4...

- 10:05 **LHCb**
  Speaker: Siim Tolk (University of Cambridge (GB))
  2017_04_LHC_HF_T...

10:35 → 10:55 **HFLAV perspective**
Speakers: Olivier Schneider (CERN) , Olivier Schneider (Ecole Polytechnique Federale de Lausanne (CH))
HFLAV_fractions_O...

10:55 → 11:15 **Theory perspective**
Speaker: Michelangelo Mangano (CERN)
mangano-HFWG.pdf

11:15 → 12:00 **Round table: combining LHC results and plans**

Ongoing ATLAS XS analyses

Sandro Palestini
for the ATLAS Collaboration

Analysis ongoing: B hadron pair production

(to be made public very soon)

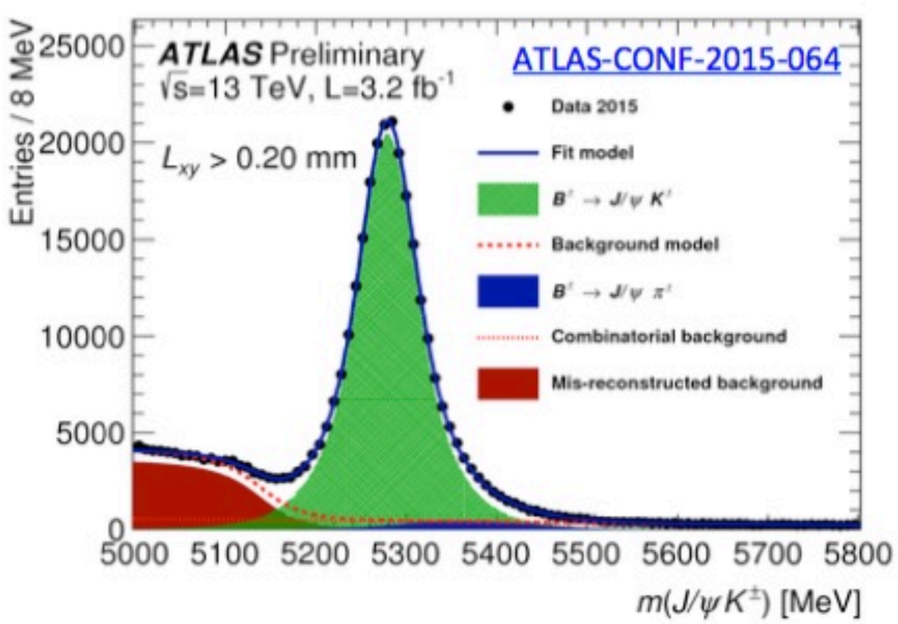
- 8 TeV data, 11 fb^{-1}
- B hadrons selected through: (a) inclusive decay to J/psi and (b) inclusive decays to muons
- The distribution of correlated kinematical variables between J/ψ and 3rd muon (ΔR, total p_T, invariant mass, etc.) are studied and compared with generators: Pythia8 in different configurations, Herwig, Sherpa, MadGraph_aMC@NLO+Pythia8

Ongoing: B_c/B^+ relative production

- 8 TeV data, about 20 fb^{-1}
- $J/\psi\ \pi^+$ vs. $J/\psi\ K^+$
- Bins 13-22 GeV and > 22 GeV in p_T, < 0.75 and 0.75-2.3 in $|\eta|$
- ≈ 800 B_c and ≈ 400,000 B^+ candidates

Ongoing: B+ production cross section at 13 TeV

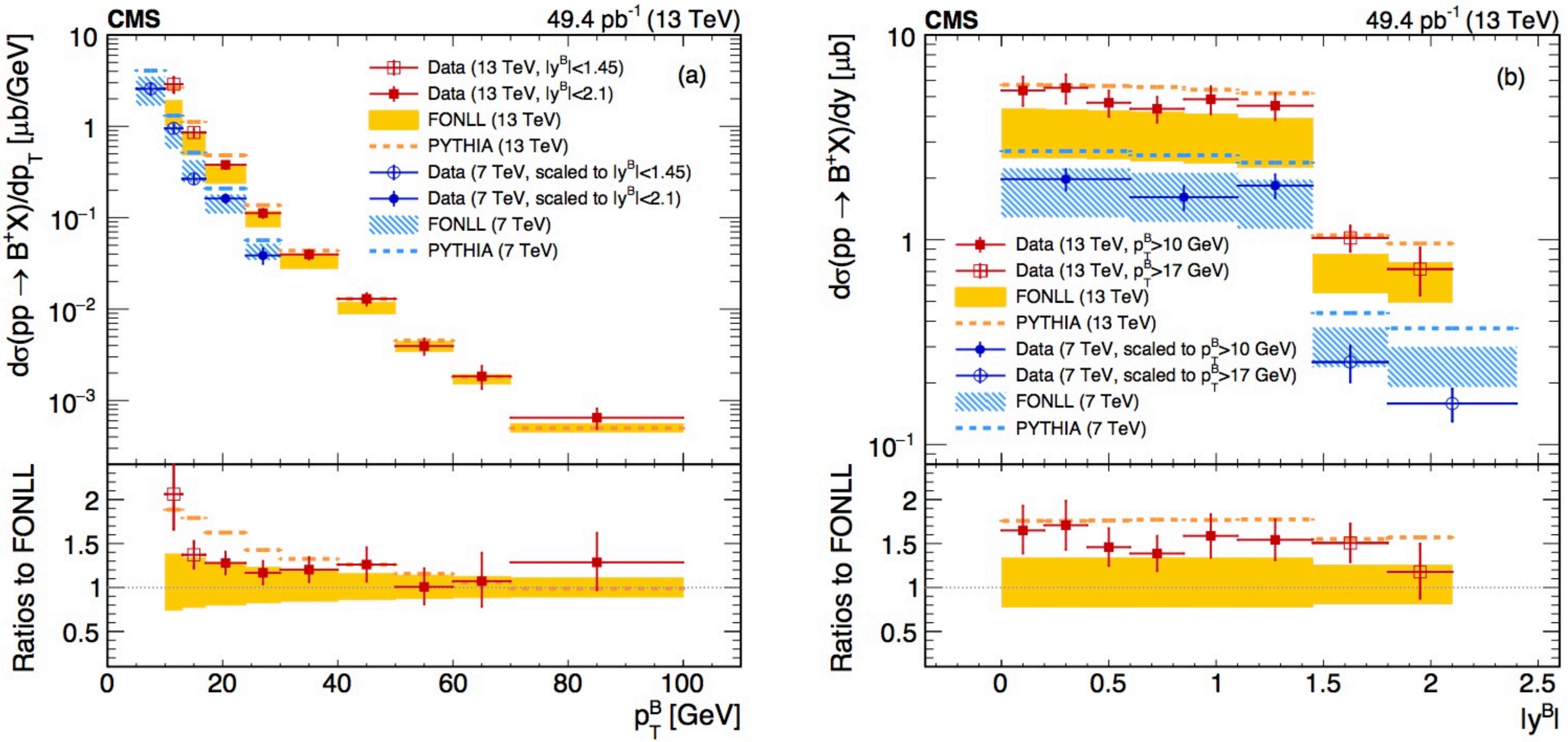
- $J/\psi\ (\mu^+\mu^-)\ K^+$ as usual
- 2015 data (3fb^{-1}): 4 GeV p_T threshold on muons
- Expect $d\sigma/dp_T$ in 9-250 GeV range, and $d\sigma/d\eta$ in $|\eta| < 2.2$ range
- Expected uncertainties ≤ 10%



Recent CMS XS results

Ilse Kratschmer,
Stefano Argiro,
Alberto Sanchez Hernandez

CMS bottom XS's at 13 TeV



CMS, arXiv:1609.00873

CMS B_c/B^+ XS ratio

✓ **Measurement of the ratio $\mathcal{B}(B_c^+ \to J/\psi\pi^+\pi^+\pi^-)/\mathcal{B}(B_c^+ \to J/\psi\pi^+)$ and the production cross sections times branching fractions of $B_c^+ \to J/\psi\pi^+$ and $B^+ \to J/\psi K^+$ in pp collisions at $\sqrt{s}$ = 7 TeV - J. High Energy Phys. 01 (2015) 063:** B^+_c mesons with pT > 15 GeV and |y| < 1.6 are studied in a data sample with an integrated luminosity of 5.1 fb^{-1}

$$R_{c/u} = \frac{\sigma(B_c^+)\mathcal{B}(B_c^+ \to J/\psi\pi^+)}{\sigma(B^+)\mathcal{B}(B^+ \to J/\psi K^+)} = \frac{Y_{B_c^+ \to J/\psi\pi^+}}{Y_{B^+ \to J/\psi K^+}},$$

Systematic uncertainties in the measurement

Systematic source	%
Fit variant	5.3
MC sample size	2.1
Efficiency binning	3.1
Total uncertainty	6.5
B_c lifetime	10.4

$R_{c/u}$ =[0.48±0.05(stat)±0.03(syst)±0.05(τ_{B_c})]%

CMS, arXiv:1410.5729

TH perspective

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- Key ingredient is the assumed correlation between theoretical systematics at different beam energies and across the rapidity range:
  - m_Q is obviously fully correlated
  - QCD scale variations: correlated at any give p_T value
  - PDFs: fully correlated
  - BRs, fragmentation fractions and frag functions fully correlated

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- At this time, we need to build confidence that our assumptions about theoretical systematics are robust

Key references to recent TH work exploring these ideas

- Charm production in the forward region: constraints on the small-x gluon and backgrounds for neutrino astronomy. R.Gauld et al. arXiv:1506.08025
- [CMN] Gluon PDF constraints from the ratio of forward heavy-quark production at the LHC at root(S)=7 and 13 TeV, M.Cacciari M.Mangano and P.Nason, arXiv:1507.06197
- Impact of heavy-flavour production cross sections measured by the LHCb experiment on parton distribution functions at low x, PROSA Collaboration (Zenaiev et al.), arXiv:1503.04581
- [GR] Precision determination of the small-x gluon from charm production at LHCb, R.Gauld and J.Rojo, arXiv:1610.09373
- [G] Understanding forward B-hadron production, R.Gauld, arxiv:1703.03636

Systematics of charm XS's at 13 TeV

[CMN]

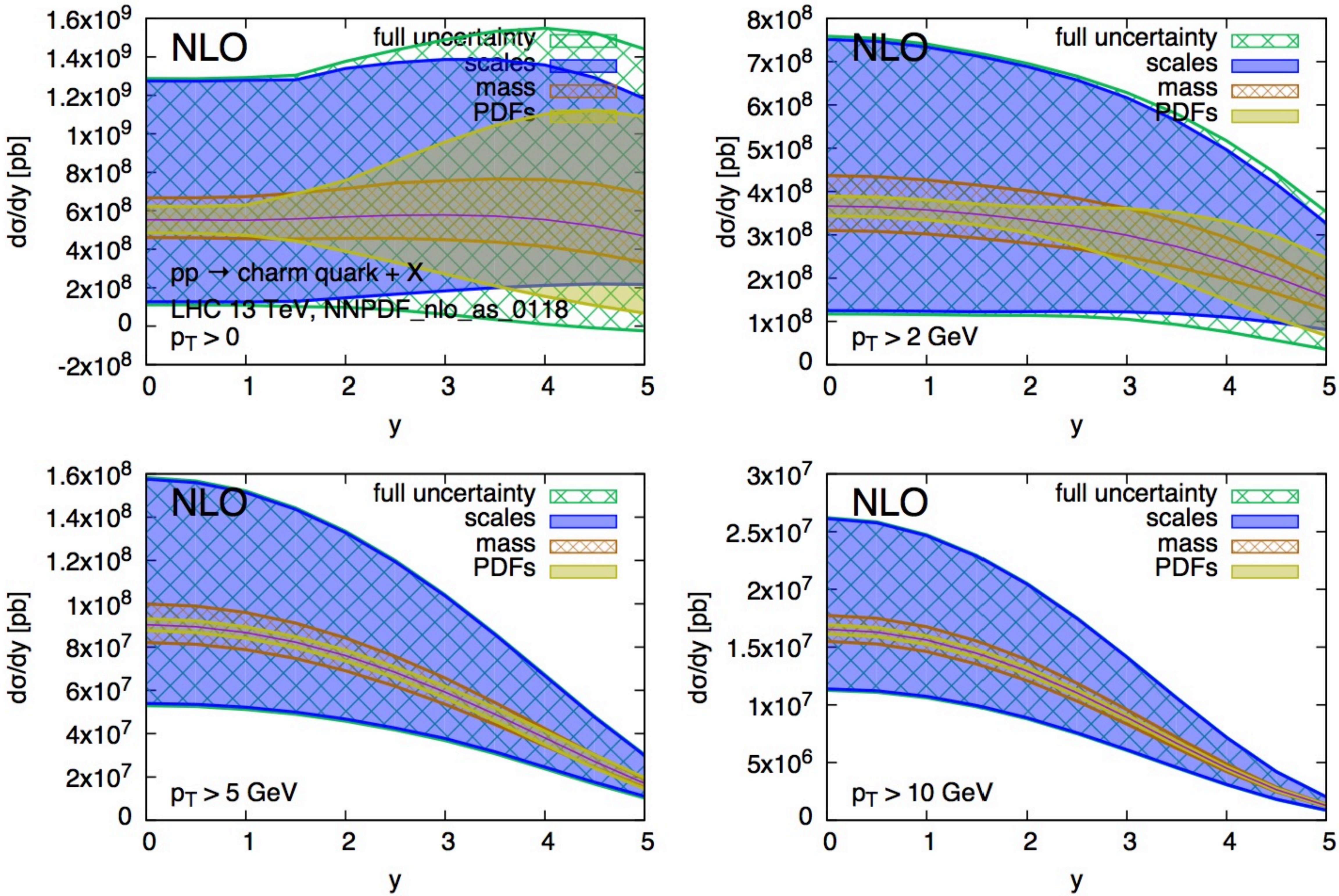
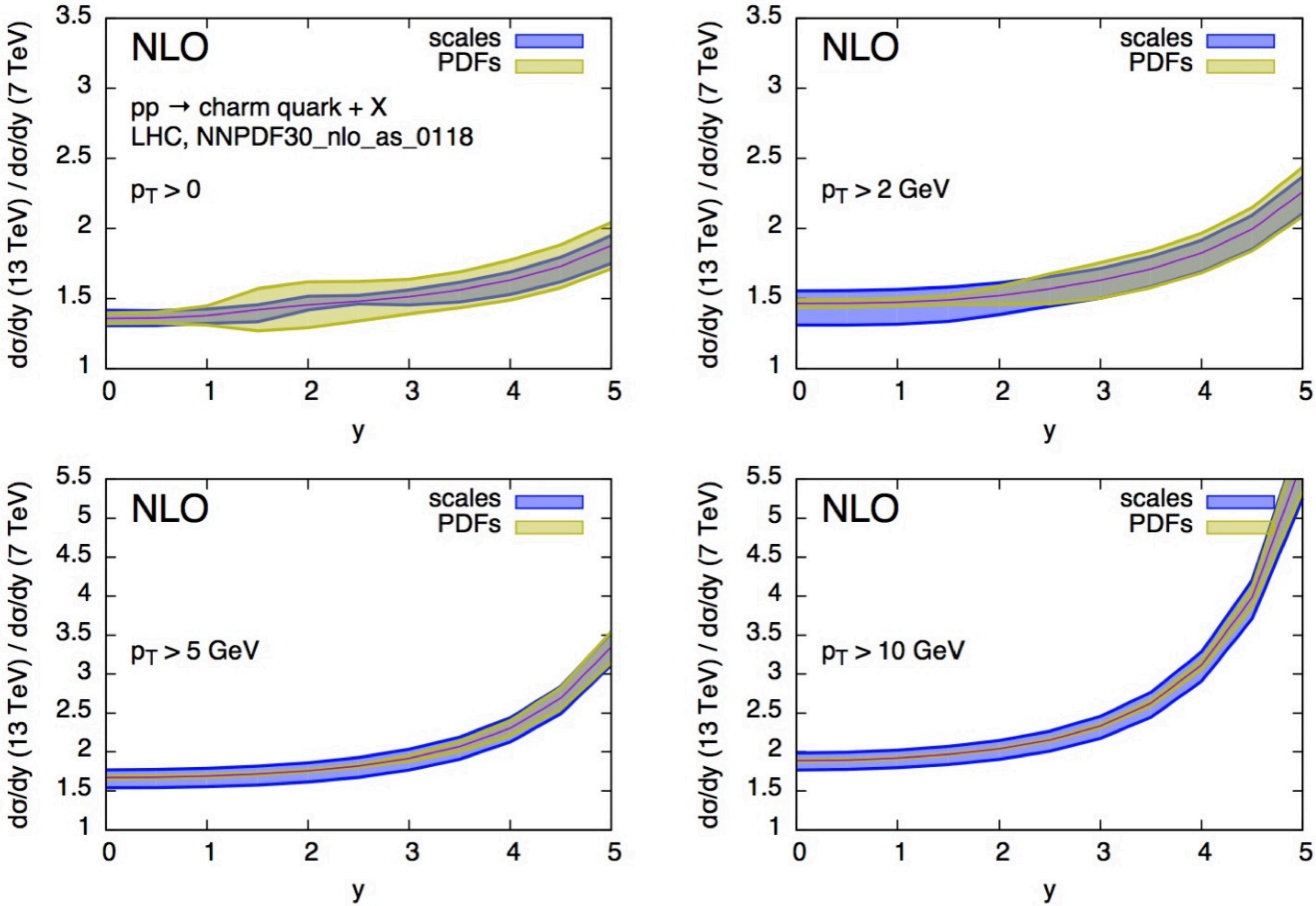


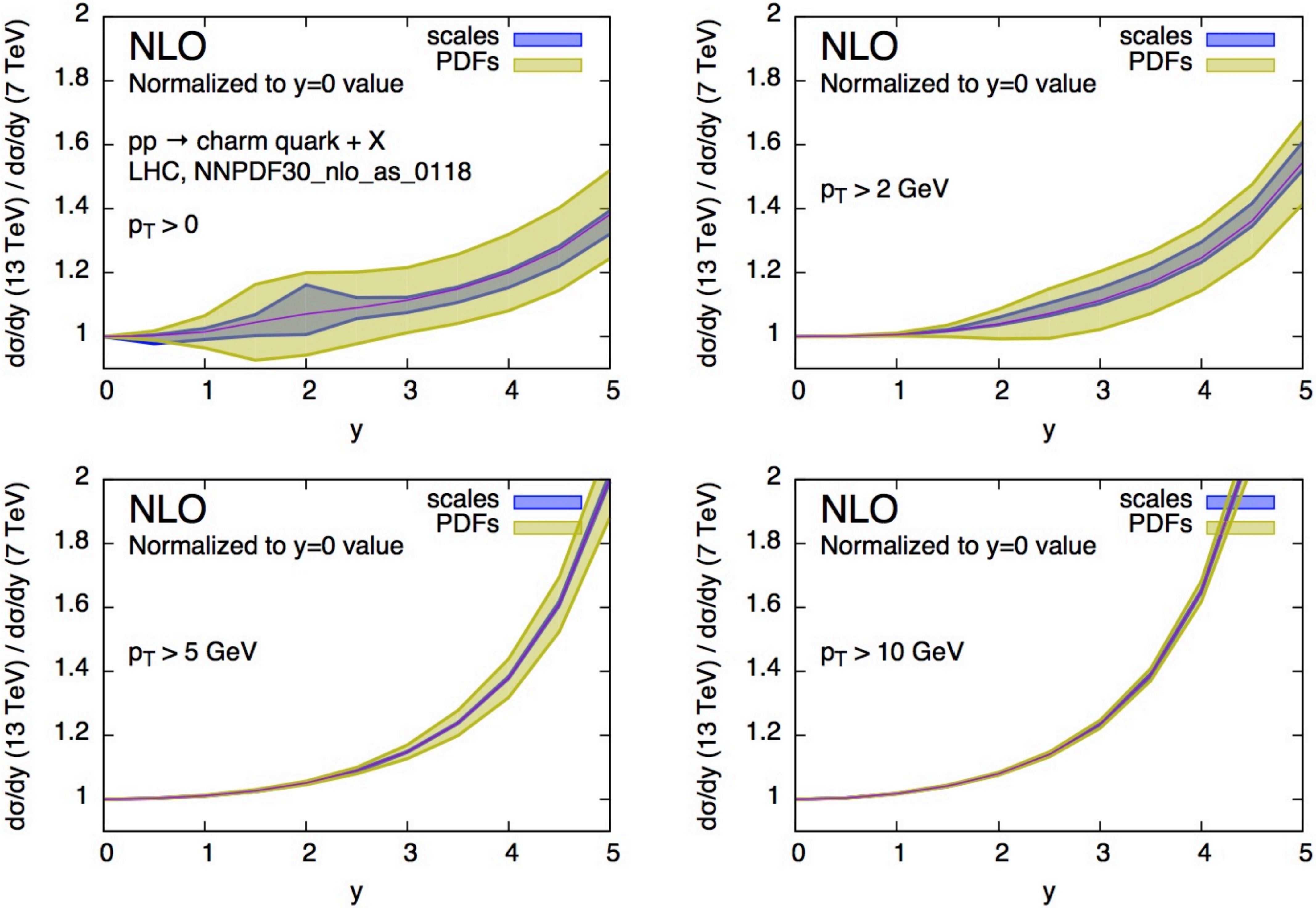
Figure 2: Charm quark rapidity distributions at $\sqrt{S} = 13$ TeV.

Systematics of ratio of charm XS's at 13/7 TeV [CMN]



Systematics of ratio of charm XS's at 13/7 TeV, scaled to ratio at y=0

[CMN]



=> all that's left is the PDF systematics!

=> useful probe of PDF behaviour!

Impact of LHCb charm XS measurements at 5, 7 and 13 TeV on gluon PDF

LHCb arXiv:1610.02230

[GR]

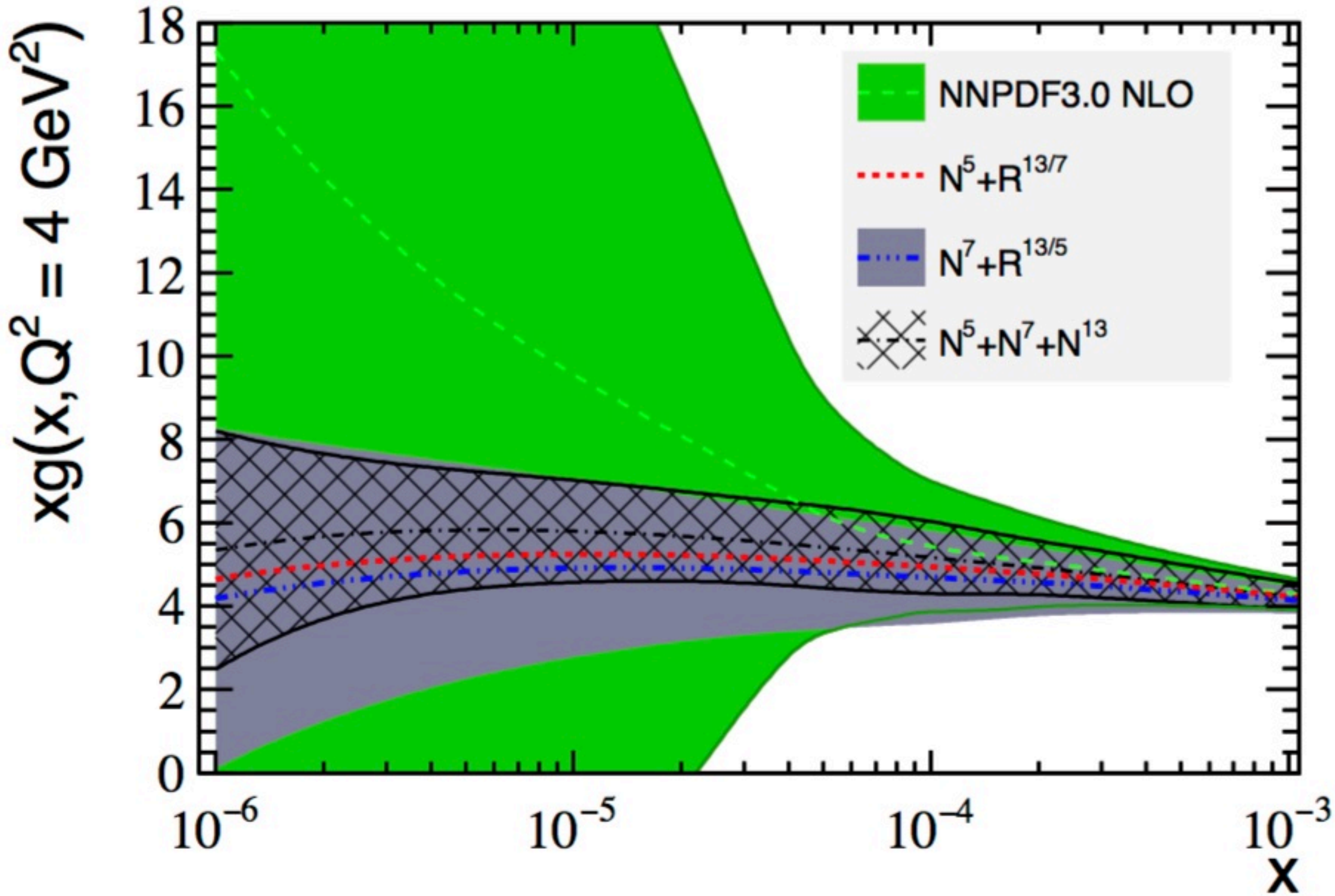


FIG. 2: The NLO gluon in NNPDF3.0 and for various combinations of LHCb data included, at $Q^2 = 4$ GeV^2.

Discussion points at the mtg

Exptl side

- Match XS's at the ATLAS/CMS-LHCb boundary, η~2-2.5:
  - should be possible for pt > O(10-20 GeV): triggerable at ATLAS/CMS, enough stat in run 2 for LHCb
  - explore use of low-pileup data (special runs, 5 TeV pp ref run for HI,…) and dedicated triggers to allow ATLAS/CMS can go down in p_T
- Measurement of fragmentation functions (eg b-hadron momentum fraction in b-jets, including bjets from top decays) for various b-hadron types (including frag function for polarized Λ_b)

TH side

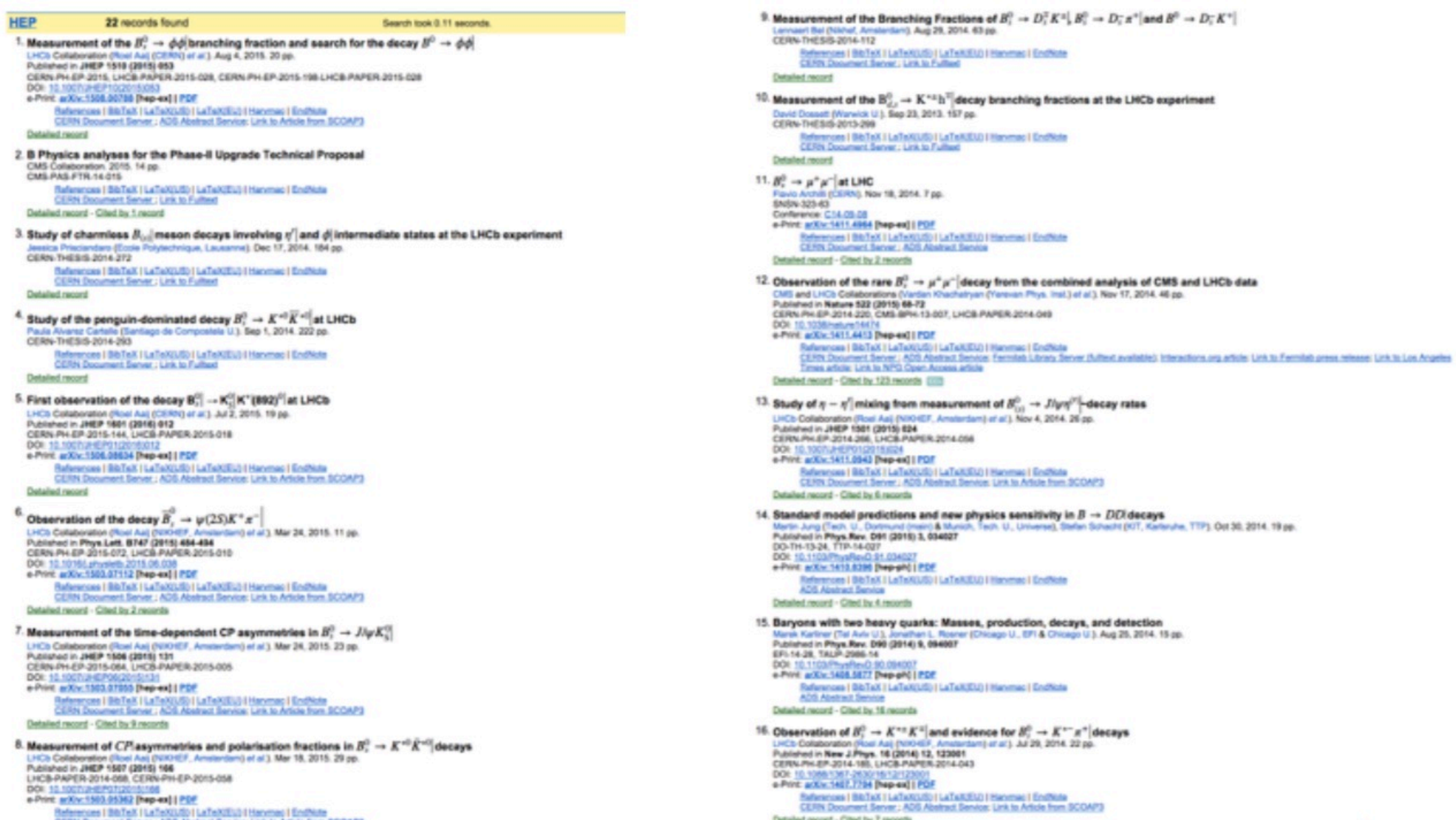
- Verify consistency between charm and bottom XS ratios: e.g. double ratios [σ(b@13)/σ(b@7)] / [σ(c@13)/σ(c@7)] can reduce even further the exptl syst (e.g. lumi), and have a reduced PDF sensitivity
- NNLO, to validate assumptions abut scale correlations at NLO, to give more robust predictions

Fragmentation fractions

The (experimental) motivation

Siim Tolk
on behalf of LHCb

- Search for new physics in any Bs branching fraction relies on the knowledge of the B-production fractions (e.g. Bs->mumu, but also many other analysis:
- 35 citations to the LHCb's relative Bs and Bd production fraction combination (LHCb-CONF-2013-011:https://inspirehep.net/search?ln=en&p=refersto%3Arecid%3A1258307)



..and more.

— knowledge of b-hadron fractions still very important to measure branching fraction ratios of two different b-hadron species

- e.g. $B(B_s \to \mu^+\mu^-)/B(B^0 \to K^+\pi^-)$ and $B(B_s \to \mu^+\mu^-)/B(B^+ \to J/\psi K^+)$

Olivier Schneider

Key challenges for measurements

- Knowledge of absolute BRs for selected decay modes (from TH, data?)
- Modeling dependence of acceptance for different decay modes

Key issue about frag fractions

- (non-)universality:
  - environment (e.g. ee vs pp vs ppbar vs HI) and $\sqrt{S}$ dependence?
  - kinematical depedence (p_T and η) dependence?
  - …

Example: ATLAS

f_s/f_d ratio

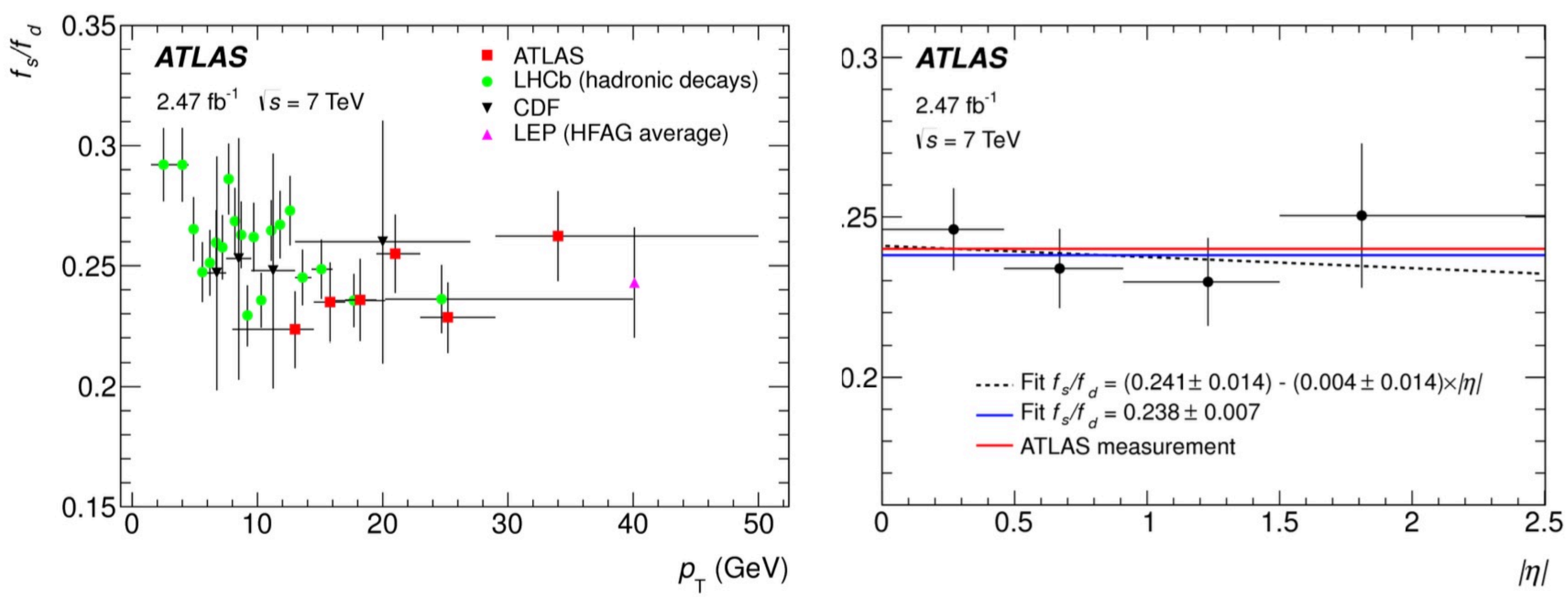
- 7 TeV data, 2.5 fb^{-1}
- B^0_s to $J/\psi(\mu^+\mu^-)\ \phi(\mu^+\mu^-K^+K^-)$ vs. B^0 to $J/\psi\ K^*(\mu^+\mu^-K^+\pi^-)$
- The directly measured quantity is

  $f_s \times BR(B^0_s \to J/\psi\ \phi)\ /\ f_d \times BR(B^0 \to J/\psi\ K^*)$,

  which is measured with 5% total uncertainty.

  (and found consistent with being uniform in p_T = 8-50 GeV)
- Using a prediction of the ratio of the branching fractions, the ratio f_s/f_d is extracted, with an additional theory uncertainty of 7%

  [X. Liu, W. Wang and Y. Xie, Phys.Rev. D89, 094019 (2014), pQCD computation]



Phys.Rev.Lett. 115 (2015) 262001

f_s/f_d = 0.240 ± 0.004(stat) ± 0.010(syst) ± 0.017(theory) on average, lower but compatible with LHCb value of 0.259 ± 0.015, which is measured in a different kinematical region.

Example: LHCb

- Determine f_s/f_d from the relative yield of
  - $B_s \to D^+_s \pi^-$ and $B_d \to D^+ K^-$ (flavour symmetric);
  - $B_s \to D^+_s \pi^-$ and $B_d \to D^+ \pi^-$ (abundant, small non-factorisable corrections from C and E).

- The f_s/f_d is calculated from:

$$\frac{f_s}{f_d} = 0.0743 \times \frac{\tau_{B^0}}{\tau_{B_s^0}} \times \left[\frac{1}{\mathcal{N}_a \mathcal{N}_F} \frac{\epsilon_{DK}}{\epsilon_{D_s\pi}} \frac{N_{D_s\pi}}{N_{DK}}\right] \frac{\mathcal{B}(D^-)}{\mathcal{B}(D_s^-)}$$

  - The non-factorizable effects described by N_a = 1.00(2) **[Nucl.Phys.B591:313-418]**
  - The B-to-D form factor ratio, N_F can be calculated in lattice-QCD:

	$N_F(m^2_\pi / m^2_K)$	$N_F(m^2_\pi / m^2_\pi)$	
MILC	$1.046(44)_{stat}(15)_{syst}$	$1.054(47)_{stat}(17)_{syst}$	**https://arxiv.org/pdf/1202.6346.pdf**
HPQCD	$1.000(23)_{stat}(57)_{syst}$	$1.046(23)_{stat}(57)_{syst}$	**https://arxiv.org/pdf/1703.09728.pdf**

(new)

- Additional correction due to W-exchange in $B_d \to D^+ \pi^-$: N_E=0.966(75)

$$\begin{aligned}\frac{f_s}{f_d} &= (0.261 \pm 0.004 \pm 0.017) \times \frac{1}{\mathcal{N}_a \mathcal{N}_F} \\ &= 0.238 \pm 0.004 \pm 0.015 \pm 0.021\,,\end{aligned}$$

(stat) (syst) (theo)

Further alternative

PRD 85, 032008 (2012)

The B_s and Λ_b production relative to the light B mesons, B^0 and B^+ can be also determined from the **semi-leptonic decays**

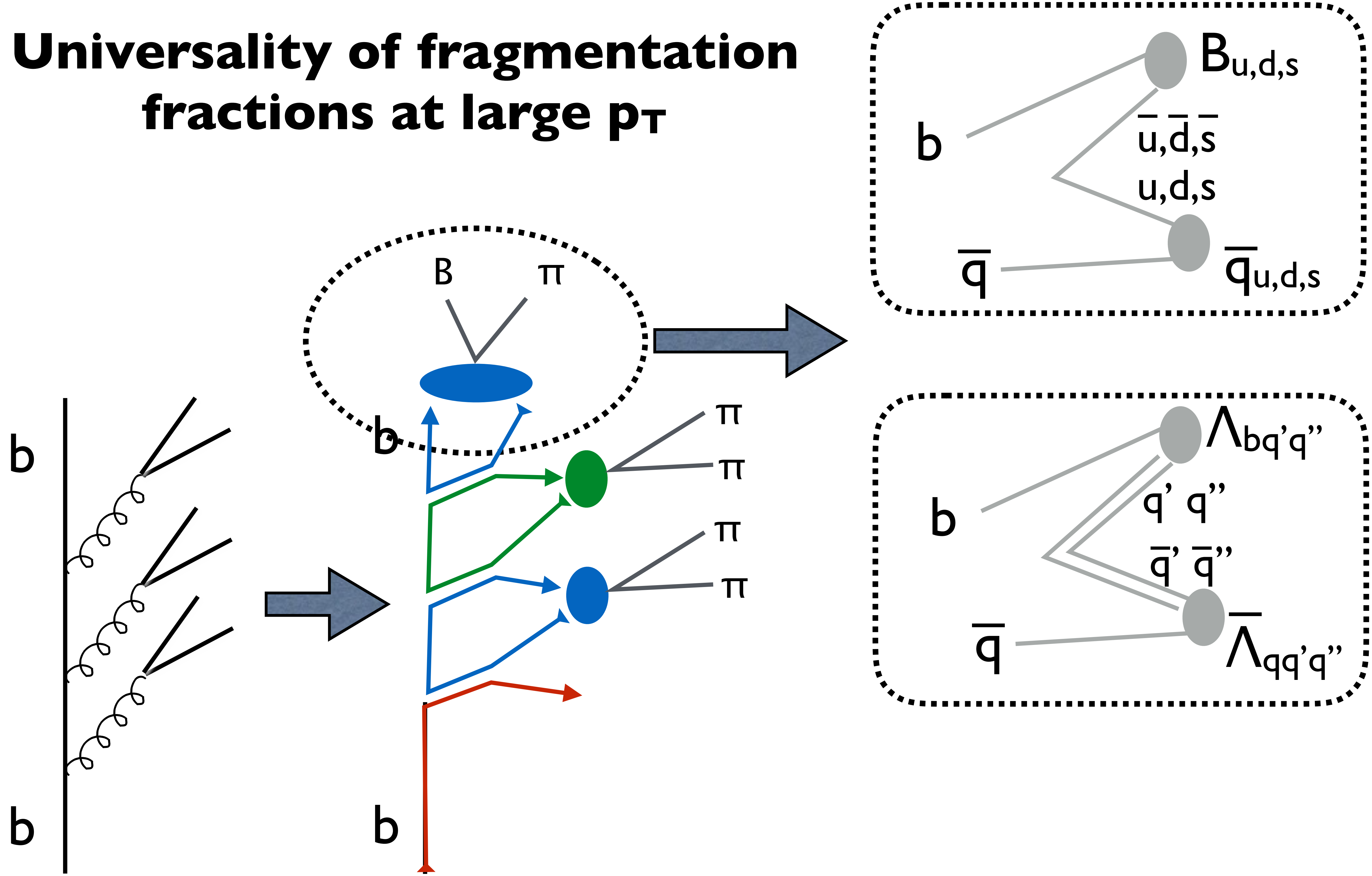
The equation for the ratio $f_s/(f_u + f_d)$ is

$$\frac{f_s}{f_u + f_d} = \frac{n_{\text{corr}}(\overline{B}{}^0_s \to D\mu)}{n_{\text{corr}}(B \to D^0\mu) + n_{\text{corr}}(B \to D^+\mu)} \frac{\tau_{B^-} + \tau_{\overline{B}{}^0}}{2\tau_{\overline{B}{}^0_s}}. \quad (5)$$

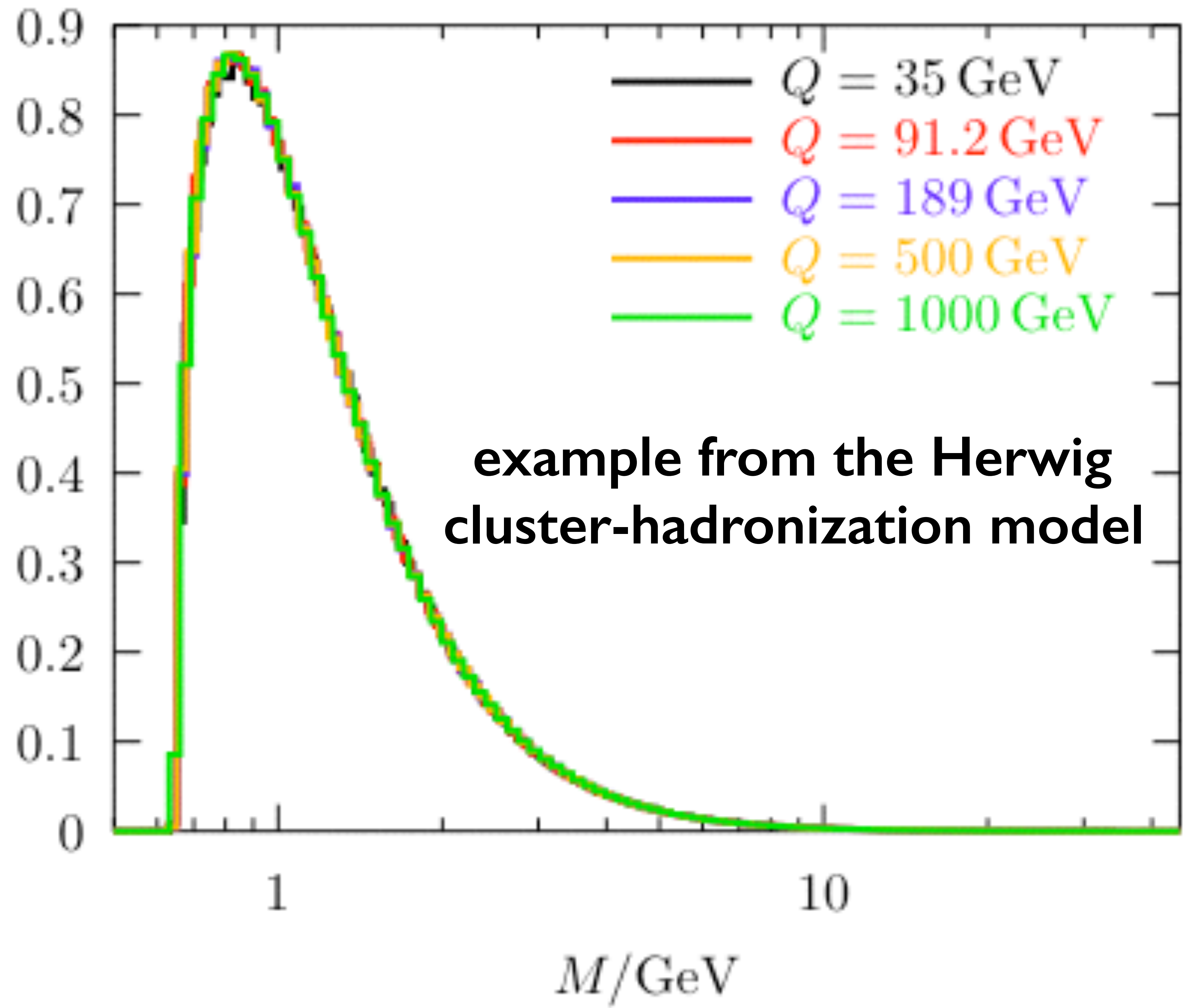
where $\overline{B}{}^0_s \to D\mu$ represents $\overline{B}{}^0_s$ semileptonic decays to a final charmed hadron, given by the sum of the contributions shown in Eqs. 3 and 4, and the symbols τ_{B_i} indicate the B_i hadron lifetimes, that are all well measured [1]. We use the average $\overline{B}{}^0_s$ lifetime, 1.472 ± 0.025 ps [1]. This equation assumes equality of the semileptonic widths of all the b meson species. This is a reliable assumption, as corrections in HQET arise only to order $1/m_b^2$ and the SU(3) breaking correction is quite small, of the order of 1% [11, 12, 13].

[Bigi et al arXiv:1105.4574]

Universality of fragmentation fractions at large p_T



The relative probabilities of forming various hadron types are phenomenological parameters. They may depend on the mass of the color-singlet cluster. But since the mass distribution of these clusters is, at large p_T, independent of p_T, one can consider these fragmentation fractions as constant.

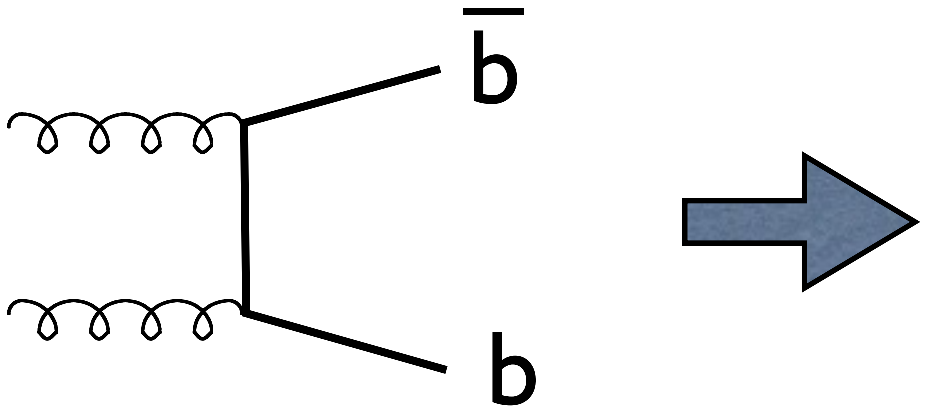


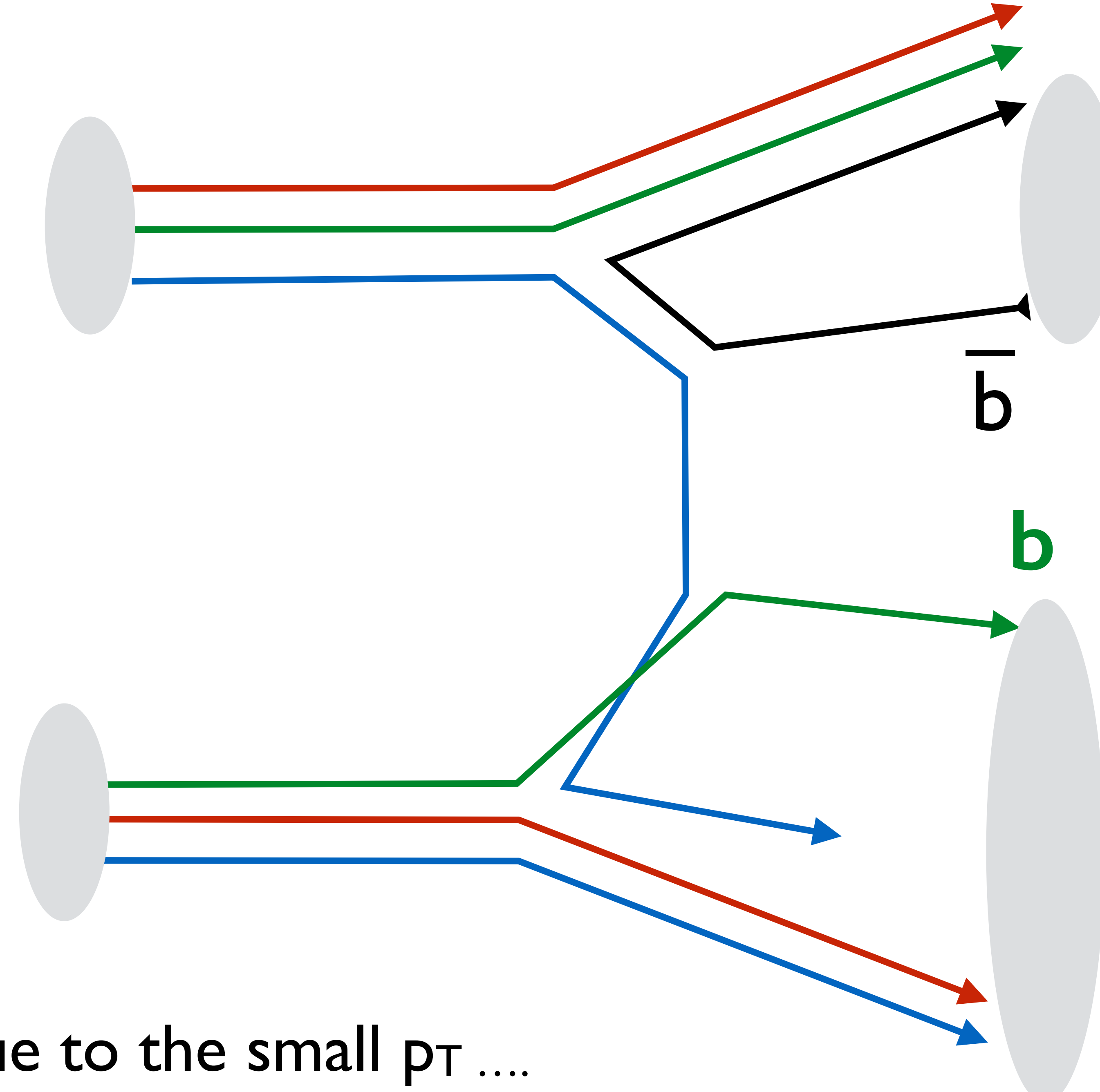
M=color-singlet cluster mass distributions, in $e^+e^- \to$ hadrons, for different CoM energies Q.

The shape is independent of Q, supporting the belief that at large p_T fragmentation fractions are constant and independent of production environment (eg LEP vs LHC)

Among other things, this implies that f_s/f_d or $f_{\Lambda b}/f_d$ should not grow at large p_T

At small p_T



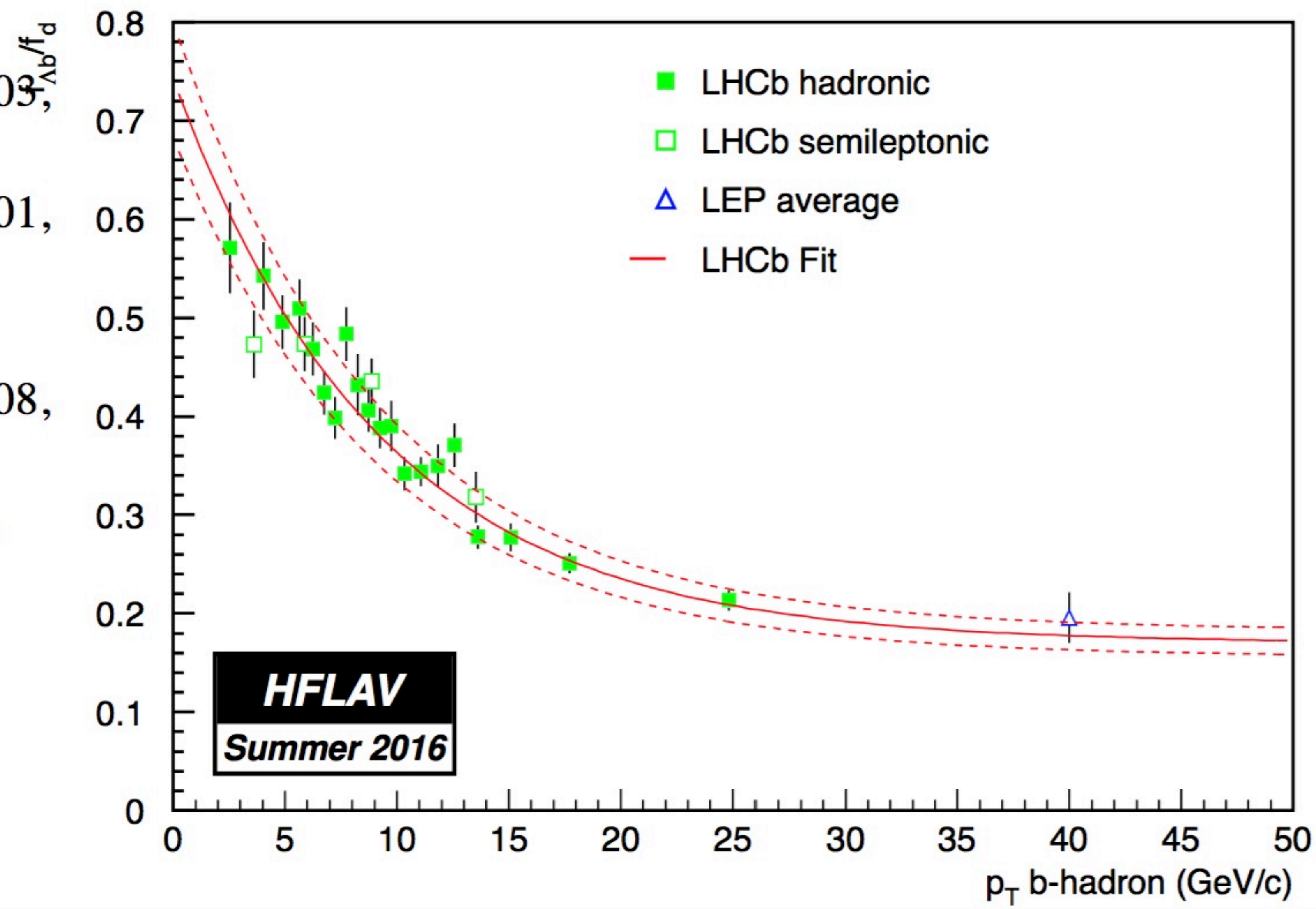


- The b quarks may not radiate due to the small p_T ....
  - … and may find their color-partner outside the "b-jet"
- The hadronization is then more sensitive to interactions with the beam fragments, particularly at small p_T and large y:
  - the cluster invariant mass distribution may be different than at high p_T
  - differences can emerge in the hadronization of b and bbar quarks

HFLAV fractions

p_T dependence

- $f(\Lambda_b)/f(B^0)$ is clearly observed to depend on the p_T of the b hadron with respect to the colliding beams
  - CDF:
    - PRD 77 (2008) 072003, arXiv:0801.4375
    - PRD 79 (2009) 032001, arXiv:0810.3213
  - LHCb:
    - PRD 85 (2012) 032008, arXiv:1111.2357
    - JHEP 08 (2014) 143, arXiv:1405.6842 (also η dependence)



- This implies that $f(B_s)/f(B^0)$ must also depend on p_T

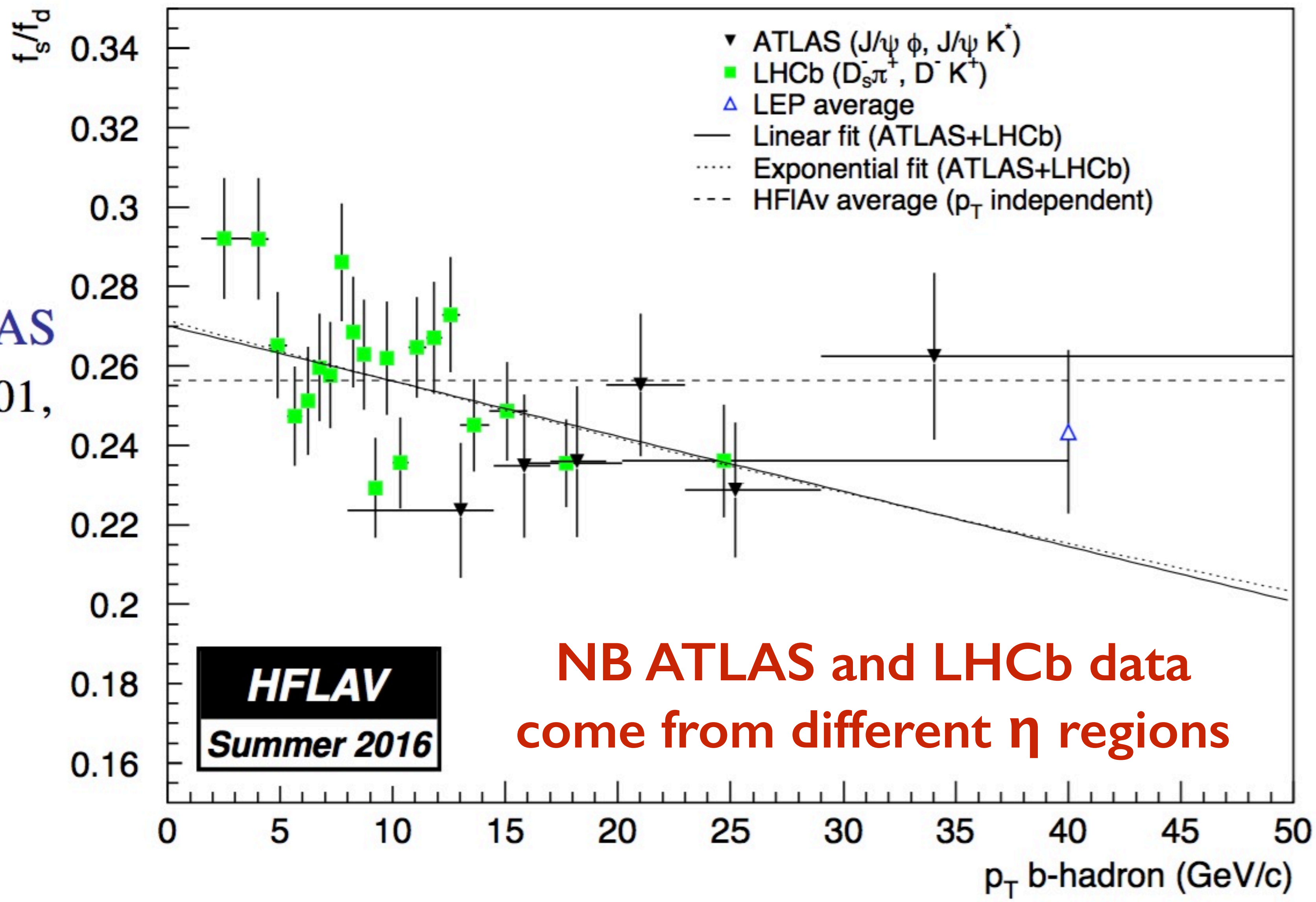
❑ Observed p_T dependence of $f(B_s)/f(B^0)$ not very striking

— Evidence from LHCb

- JHEP 04 (2013) 001, arXiv:1301.5286

— No evidence from ATLAS

- PRL 115 (2015) 262001, arXiv:1507.08925



NB ATLAS and LHCb data come from different η regions

Up-coming f_s/f_d measurements @LHCb

- Semi-leptonic and hadronic f_s/f_d Run2 updates are planned (for the absolute $f_s\backslash f_d$)
- The 13TeV / 7TeV f_s/f_d ratio will be also probed using the ratio of $B_s \to J/\psi\phi$ / $B^0 \to J/\psi K^+$ decays

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- Absolute knowledge of BRs not crucial to extract kinematical dependence: can use high-statistics modes with small modeling dependence (acceptance correct's) to study kin-dependence over broadest ranges
  - ➡ test behaviour at large p_T, E_{beam} independence
  - ➡ consider different production environments, e.g.
    - in addition to p_T shape, study $f_{s,\Lambda b}/f_d(z)$, $z=p_{T(b)}/p_{T(jet)}$
    - use b's from top dec's, charm in W decays in ttbar events,…

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    - use b's from top dec's, charm in W decays in ttbar events,…
- These effects cannot be calculated from first principles, but can be described by MCs in a phenomenological way, subject to tuning. Measurements of $f_H(p_T,y,z,\ldots)$ are crucial to shed some more light on the hadronization process and help improve the models