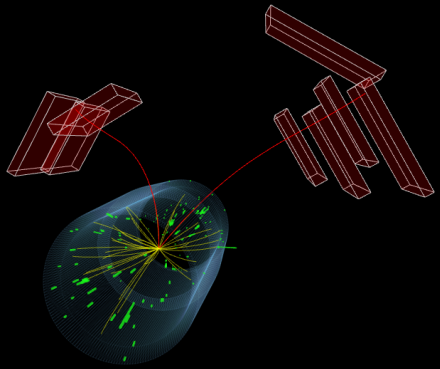
Heavy Flavour Production at CMS

D Meson Production

B Meson Production &
Rare B Meson Decays to Two Muons

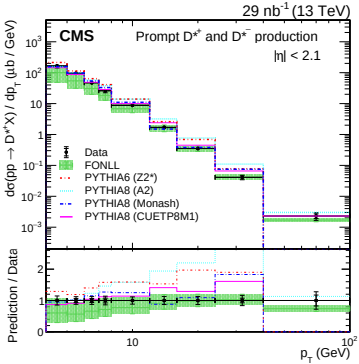


Yewon Yang on behalf of the CMS Collaboration
DIS2023, 30.03.23

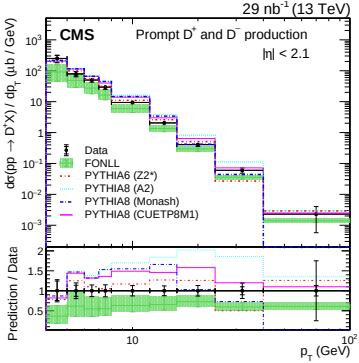
Prompt D^*, D^+ and D^0 production at 13 TeV (CMS-BPH-18-003; arXiv:2107.01476)

- charm mass close to QCD scale Λ_{QCD}
  - gives large theory uncertainties
  - measurement with much smaller uncertainties to be given as constraints on production cross sections
- prompt D meson (D^*, D^+ and D^0) production from CMS at 13 TeV in $|\eta| < 2.1$
  - shows best description in upper edge of FONLL(NLO+NLL) QCD prediction

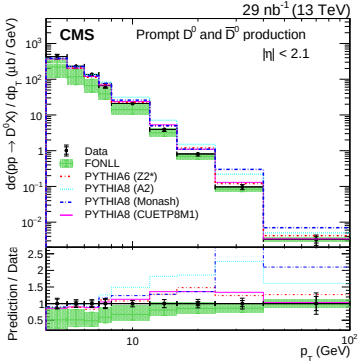
$\mathbf{D^{*\pm} \to D^0 \pi_s^\pm \to K^\mp \pi^\pm \pi_s^\pm}$



$\mathbf{D^\pm \to K^\mp \pi^\pm \pi^\pm}$

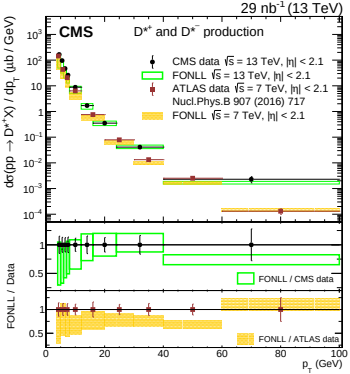


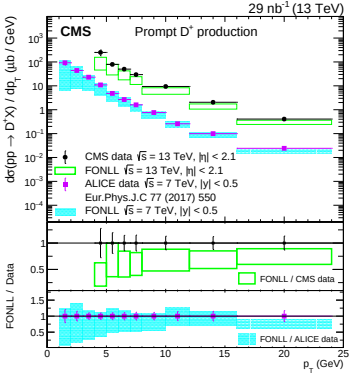
$\mathbf{D^0 \to K^\mp \pi^\pm}$

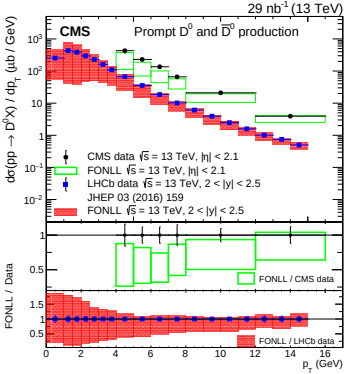


Prompt D^*, D^+ and D^0 production at 13 TeV (CMS-BPH-18-003; arXiv:2107.01476)

- CMS measurement consistent with other measurements at LHC in different kinematic ranges







✔ all data consistent with upper edge of FONLL prediction uncertainty band

D^* RECONSTRUCTION AT 0.9 TEV (CMS-DP-2022-024)

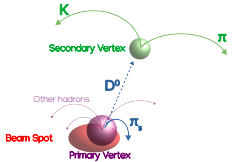
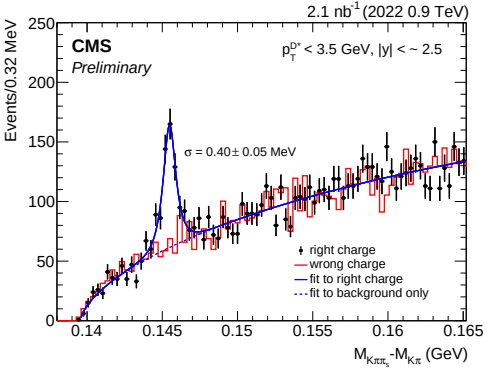
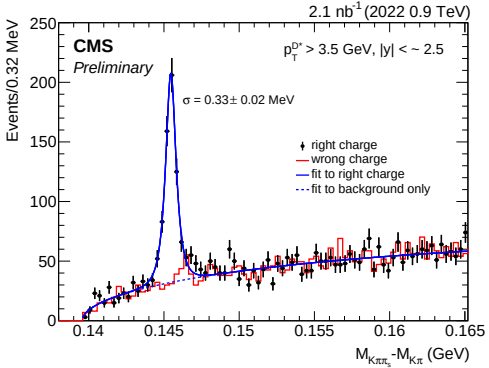


Illustration of the performance of the CMS tracker and reconstruction on early Run 3 data, on the example of D* meson reconstruction





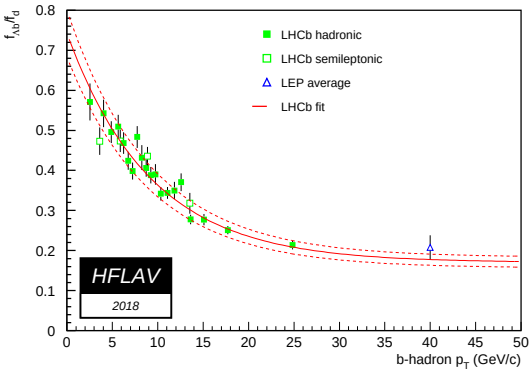
✔ ready for D^* cross section determination at 0.9 TeV (never being measured from any experiment)

B Meson Production Fractions, f_s/f_u & f_d/f_u

CMS-BPH-21-001; arXiv:2212.02309

Analysis Motivation

- b hadron production fractions known to be $f_u \sim 0.4$, $f_d \sim 0.4$, $f_s \sim 0.1$ and $f_{\Lambda_b^0(\text{baryon})} \sim 0.1$ †
  from LEP/Tevatron
- different results of measurement from LHC
  - significant p_T dependence of ratios observed at low p_T in $2 < y < 4.5$ from LHCb
  - complementary measurement for $|y| < 2.4$ from CMS
- B_s^0 branching fraction not precisely known
  - most measurements are normalised to B^+ and B^0
  - f_s/f_u and f_d/f_u‡ are inputs for $\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ and $\mathcal{B}(B^0 \to \mu^+\mu^-)$

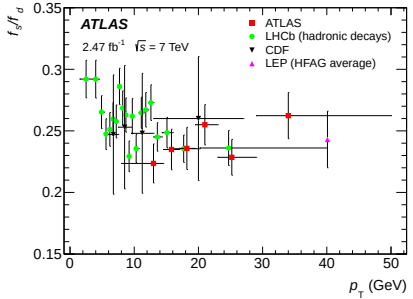


Heavy Flavor Averaging Group, arXiv:1909.12524

†ratio of B^+, B^0, B_s^0 and baryon production to b hadron, respectively
‡f_d/f_u assumed to be 1 in strong isospin symmetry

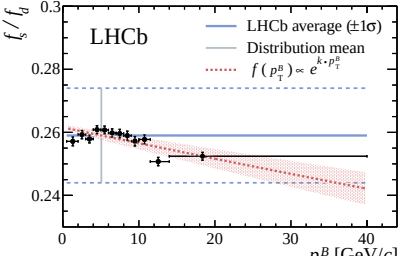
Status of f_s/f_u Measurement in LHC

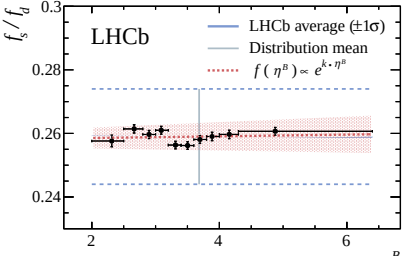
f_s/f_d measurement (2015)



ATLAS Collaboration, arXiv:1507.08925

More precise f_s/f_d measurement from LHCb (2019)



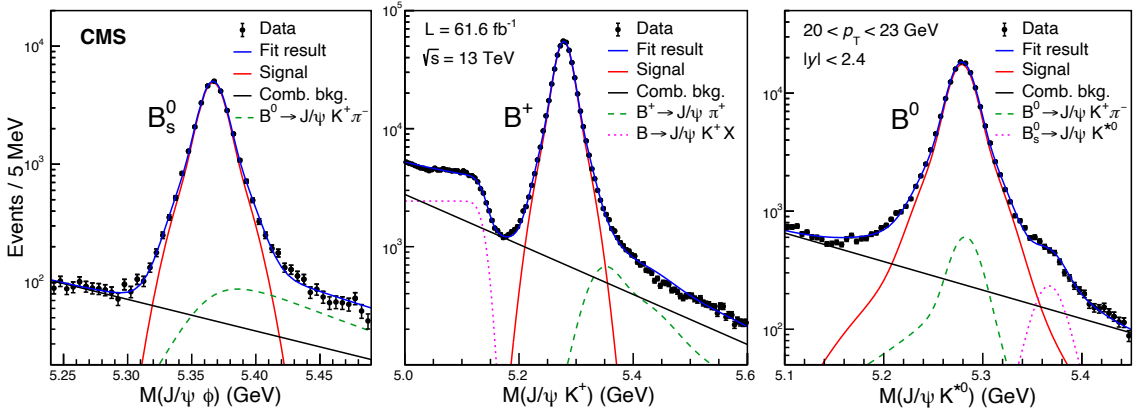


LHCb Collaboration, arXiv:1910.09934

✔ LHCb reported linear p_T dependence of f_s/f_d (or f_s/f_u) (most recent results from LHCb in BackUp slide 19) and no rapidity dependence in forward rapidity

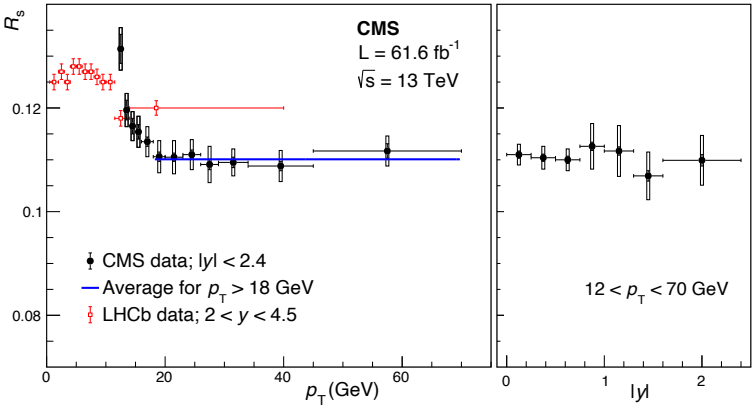
B_s^0, B^+ and B^0 Yields (CMS)

- with reconstruction of $B_s^0 \to J/\psi\ \phi$, $B^+ \to J/\psi\ K^+$ and $B^0 \to J/\psi\ K^{*0}$



Result for R_s

- $R_s \equiv \dfrac{N_{B_s^0}}{\epsilon_{B_s^0}} \Big/ \dfrac{N_{B^+}}{\epsilon_{B^+}} = \dfrac{f_s}{f_u} \dfrac{\mathcal{B}(B_s^0 \to J/\psi\ \phi)\mathcal{B}(\phi \to K^+K^-)}{\mathcal{B}(B^+ \to J/\psi\ K^+)}$

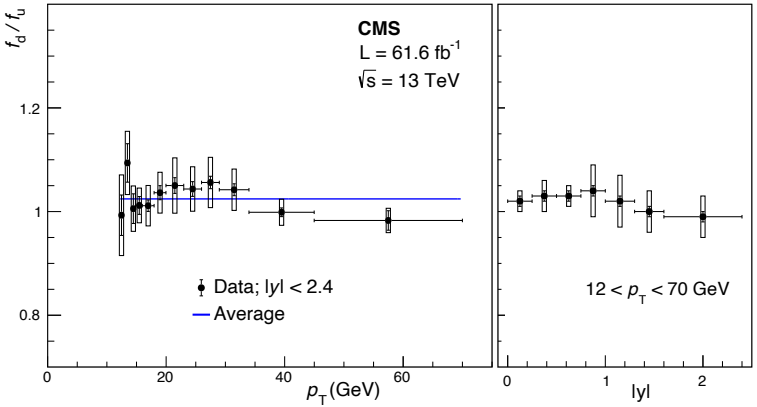


✔ results compatible with LHCb
  → no rapidity dependence
  → clear p_T-dependence at low p_T

✔ asymptotically flat trend at high-p_T

Result for f_d/f_u

- $R_d \equiv \dfrac{N_{B^0}}{\epsilon_{B^0}} \Big/ \dfrac{N_{B^+}}{\epsilon_{B^+}} = \dfrac{f_d}{f_u} \dfrac{\mathcal{B}(B^0 \to J/\psi\ K^{*0})\mathcal{B}(K^{*0} \to \pi^- K^+)}{\mathcal{B}(B^+ \to J/\psi\ K^+)}$



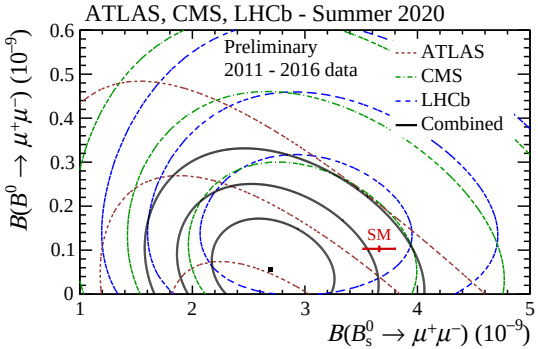
- ✔ 1.015 ± 0.051 (averaged)
- ✔ consistent with unity as expected from strong isospin symmetry

$B_s^0 \to \mu^+\mu^-$ & $B^0 \to \mu^+\mu^-$

CMS-BPH-21-006; arXiv:2212.10311

Rare B Meson Decays in LHC

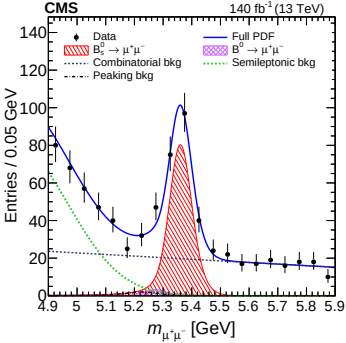
- $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ strongly suppressed in SM
  - $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.66 \pm 0.14) \times 10^{-9}$
  - $\mathcal{B}(B^0 \to \mu^+\mu^-) = (1.03 \pm 0.05) \times 10^{-10}$
  - sensitive probe to BSM
- until recently, most precise measurement from a combined analysis in LHC
  - $\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ showing 2.4σ from SM
  - no significant detection of $B^0 \to \mu^+\mu^-$
- latest measurement from LHCb (2021)†
  - $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left[3.09^{+0.46}_{-0.43}(stat)^{+0.15}_{-0.11}(syst)\right] \times 10^{-9}$

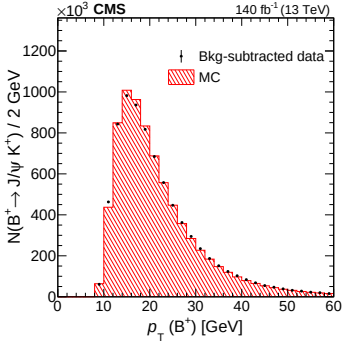


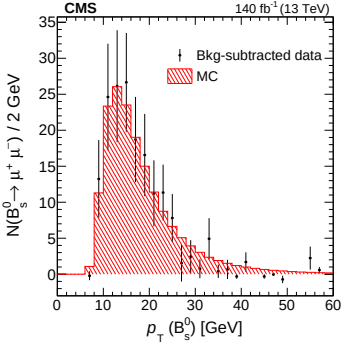
CMS-PAS-BPH-20-003; LHCb-CONF-2020-002; ATLAS-CONF-2020-049

† arXiv:2108.09283

Measurement of $\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ and $\mathcal{B}(B^0 \to \mu^+\mu^-)$ (CMS)



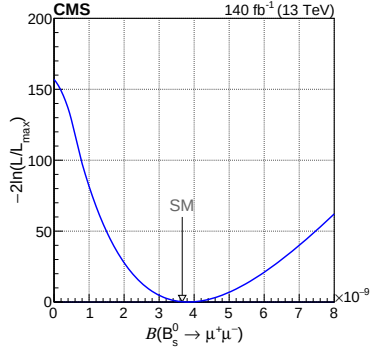


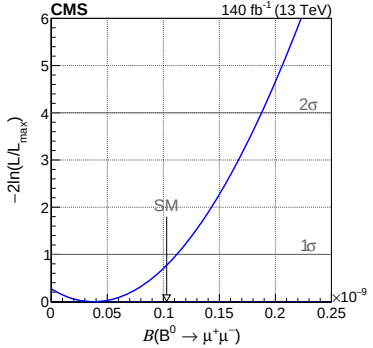


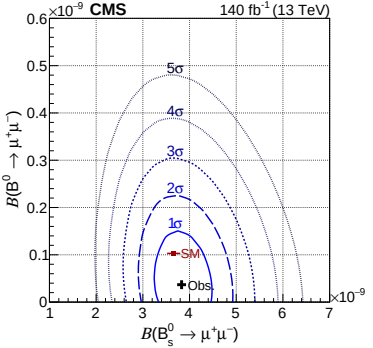
- $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \mathcal{B}(B^+ \to J/\psi\ K^+) \dfrac{N_{B_s^0 \to \mu^+\mu^-}}{N_{B^+ \to J/\psi\ K^+}} \dfrac{\epsilon_{B^+ \to J/\psi\ K^+}}{\epsilon_{B_s^0 \to \mu^+\mu^-}} \dfrac{f_u}{f_s}$, $f_s/f_u = 0.231 \pm 0.008^{\dagger}$
- $\mathcal{B}(B^0 \to \mu^+\mu^-) = \mathcal{B}(B^+ \to J/\psi\ K^+) \dfrac{N_{B^0 \to \mu^+\mu^-}}{N_{B^+ \to J/\psi\ K^+}} \dfrac{\epsilon_{B^+ \to J/\psi\ K^+}}{\epsilon_{B^0 \to \mu^+\mu^-}} \dfrac{f_u}{f_d}$, $f_d/f_u \equiv 1$

†derived by applying p_T-dependent f_s/f_u measurement from LHCb (latest results in BackUp slide 19)

Result of $\mathcal{B}(B_s^0 \to \mu^+\mu^-)$ and $\mathcal{B}(B^0 \to \mu^+\mu^-)$







✔ $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left[3.83^{+0.38}_{-0.36}(stat)^{+0.19}_{-0.16}(syst)^{+0.14}_{-0.13}(f_s/f_u)\right] \times 10^{-9}$ †

→ shift $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = 2.69^{+0.37}_{-0.35} \times 10^{-9}$ (PDG) to a larger value but more close to SM prediction ‡

✔ $\mathcal{B}(B^0 \to \mu^+\mu^-) = \left[0.37^{+0.75}_{-0.67}(stat)^{+0.08}_{-0.09}(syst)\right] \times 10^{-10}$ ($< 1.9 \times 10^{-10}$ at 95% CL) §

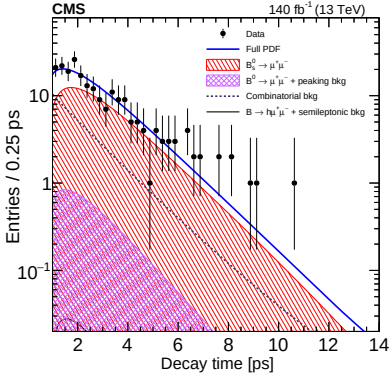
† $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \left[2.9 \pm 0.6(stat) \pm 0.3(syst) \pm 0.2(f_s/f_u)\right] \times 10^{-9}$ (previous CMS measurement – arXiv:1910.12127)

‡ $\mathcal{B}(B_s^0 \to \mu^+\mu^-) = (3.66 \pm 0.14) \times 10^{-9}$

§ $\mathcal{B}(B^0 \to \mu^+\mu^-) < 3.6 \times 10^{-10}$ at 95% CL (previous CMS measurement – arXiv:1910.12127)

Effective Lifetime of $B_s^0 \to \mu^+\mu^-$

- significant deviation of $\tau(B_s^0 \to \mu^+\mu^-)$ to $\tau(B_{s,H}^0)$ indicates BSM contribution
  - effective lifetimes of B_s^0 are 1.624 ± 0.009 ps ($B_{s,H}^0$) and 1.429 ± 0.007 ps ($B_{s,L}^0$)
  - $B_s^0 \to \mu^+\mu^-$ predicted to be CP-odd and long-lived in SM



✔ $\tau = 1.83^{+0.23}_{-0.20}(stat)^{+0.04}_{-0.04}(syst)$ ps †

✔ consistent with 1.624 ± 0.009 ps

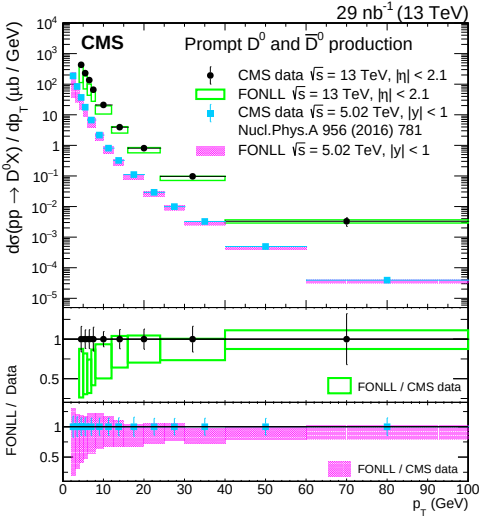
† $\tau = 1.70^{+0.60}_{-0.43}(stat) \pm 0.09(syst)$ ps (previous CMS measurement – arXiv:1910.12127)

Summary & Conclusion

- Measurement of D mesons in CMS were shown at 13 TeV and 0.9 TeV
  - prompt D^*, D^+ and D^0 production at 13 TeV show best description in upper edge of FONLL QCD prediction, which is consistent with all the other LHC measurements
  - measurement of D^* production at 0.9 TeV is ready to be performed for the first time in LHC
- Measurement of B meson production fraction ratios in CMS were shown at 13 TeV
  - f_s/f_u shows clear p_T dependence which is asymptotically flat at high-p_T and no significant rapidity dependence
  - f_d/f_u agrees with assumption of strong isospin symmetry
- Most precise measurements of $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ given from CMS show closer results to SM predictions and stronger constraints on new physics contributions

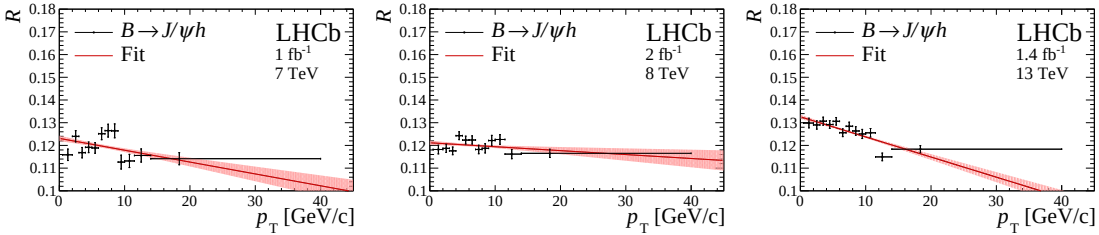
BackUp

Prompt D^0 Production in CMS



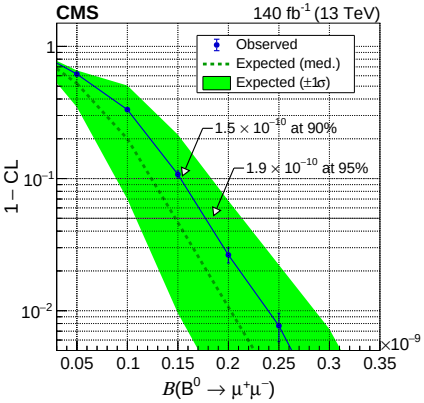
CMS-BPH-18-003

f_s/f_d Measurement from LHCb (2021)



LHCb Collaboration, arXiv:2103.06810

Upper Limits on $\mathcal{B}(B^0 \to \mu^+\mu^-)$



CMS-BPH-21-006

- ✔ $\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.5 \times 10^{-10}$ at 90% CL
- ✔ $\mathcal{B}(B^0 \to \mu^+\mu^-) < 1.9 \times 10^{-10}$ at 95% CL