Heavy flavour production studies at CMS

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on behalf of the CMS Collaboration

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INFN
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CMS
Compact Muon Solenoid

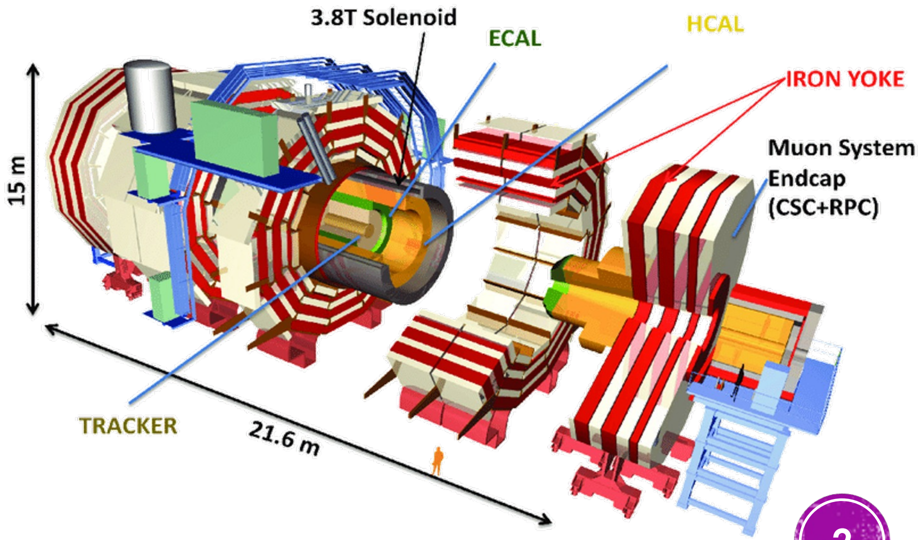
Heavy flavour physics in CMS

- Measurements and observations of heavy flavour production provide **important tests of QCD** and give insight into particle production at colliders

- **Hadronization challenging** to understand -> measurements needed

- Form **baseline or background** for other physics studies at the LHC

- LHC provides access to **wide kinematic range** with a **very high production cross section** if compared to e^+e^- colliders.



Outline

- Open charm production cross section
- Triple J/ψ production
- Dependence of f_s/f_u on B meson kinematic

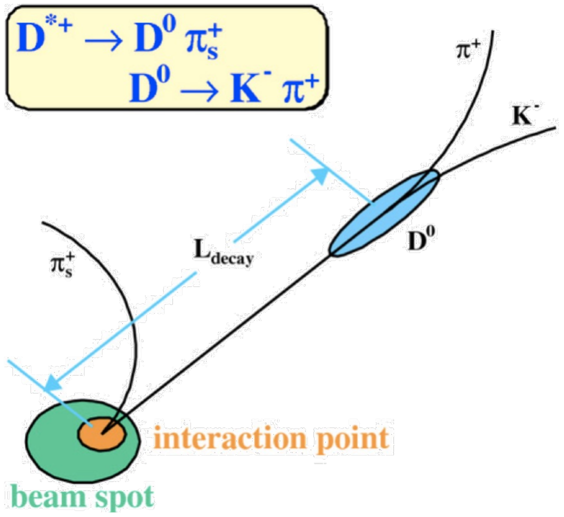
Open charm production cross section

JHEP11(2021)225

Open charm mesons reconstructed:

- $D^{*+} \rightarrow D^0\pi^+_{slow} \rightarrow K^-\pi^+\pi^+_{slow}$
- $D^0 \rightarrow K^-\pi^+$
- $D^+ \rightarrow K^-\pi^+\pi^+$

+ c.c.



Analysed data: pp collisions at $\sqrt{s}$ = 13 TeV collected in 2016

Phase space: 4 < p_T (D) < 100 GeV && $|\eta|$ < 2.1

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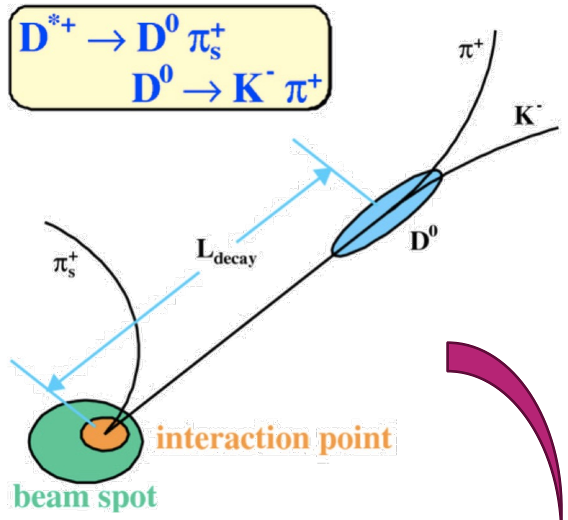

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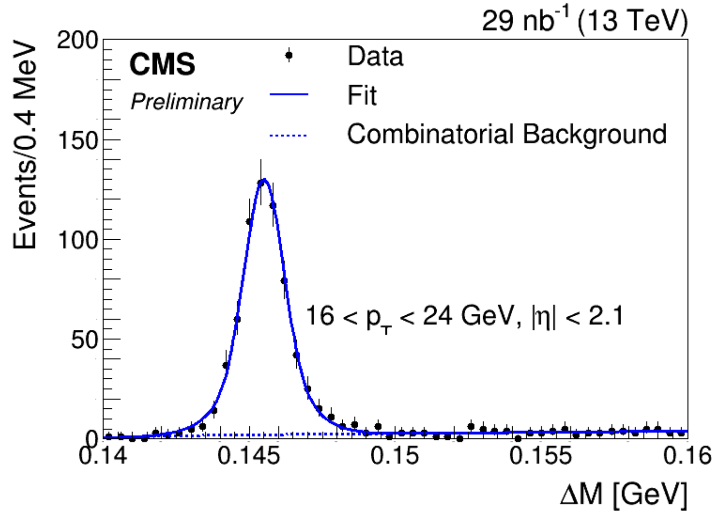

Only prompt mesons are signal ⇒ **possible contamination**: charm mesons coming from B meson decays

Evaluated on MC as: $contamination = \frac{N_{sec}}{N_{prompt}+N_{sec}}$ ~10-15%

Open charm production cross section

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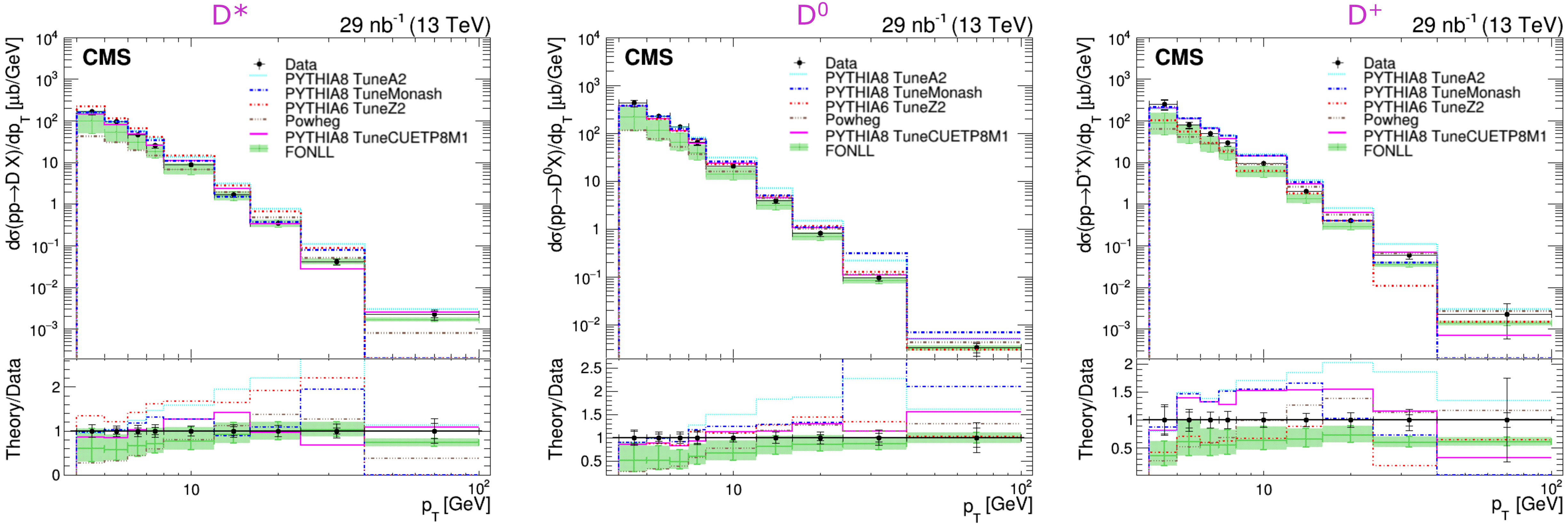

Data are compared to different MC and FONLL predictions (fixed-order next-to-leading-logarithm):

- Pythia predictions are very sensitive to the specific tune
- Powheg heavly underestimates data at low p_T
- FONLL tends to underestimate data $\Longrightarrow$ data points on the upper edge

Open charm production cross section

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A **comparison of CMS data with the previous results obtained by the other LHC collaborations** has been performed to **study how the cross section evolves** with the center of mass energy and w.r.t. the different kinematic region analysed

FONLL predictions used for this comparison

- NLO + fragmentation fraction
- FONLL calculations are developed to obtain stable and reliable predictions in the conditions $p_{T,Q} \approx m_Q$

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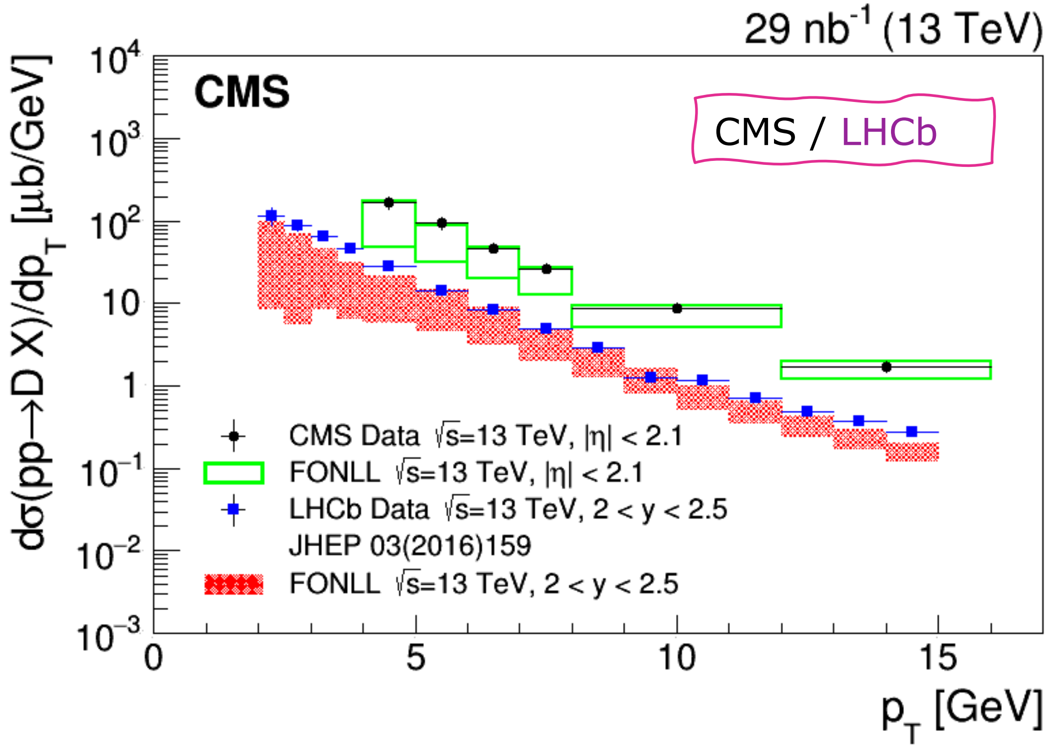

Triple J/ψ production

nature.com/articles/s41567-022-01838-y

In 2021 CMS reported about the observation of **triple J/ψ production in a single pp collision** with a statistical significance above five standard deviations.

This phenomenon is not (only) interesting per se, but because it is a **probe for triple parton scattering**.

When protons collide, mostly one parton
of each proton undergoes a hard scattering
$\Rightarrow$ **single parton scattering** (SPS)

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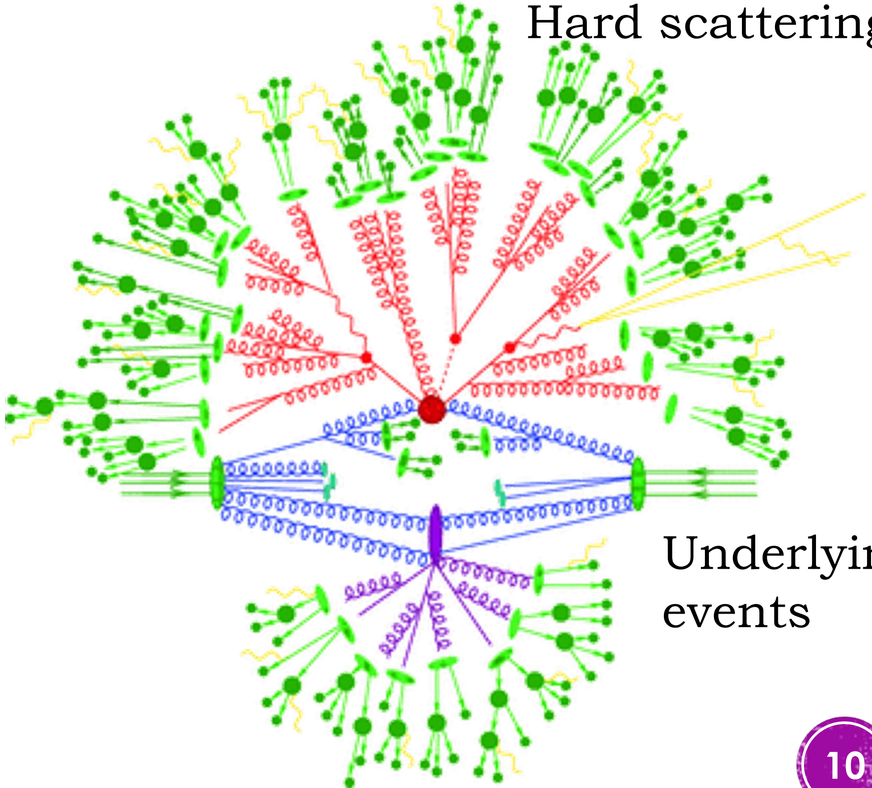
As the collision energy increases the densities of gluons and sea quarks probed inside each proton grow rapidly
$\Rightarrow$ **double (triple) parton scattering** – DPS (TPS) – can occur



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In the assumption of factorization, the DPS cross section to produce two charmonium mesons ψ_1 and ψ_2 can be written as:

$$\sigma_{DPS}^{pp\to\psi_1\psi_2 X} = \left(\frac{m}{2}\right)\frac{\sigma_{SPS}^{pp\to\psi_1 X}\sigma_{SPS}^{pp\to\psi_2 X}}{\sigma_{eff,DPS}}$$

SPS cross section for the ψ_2 (ψ_1) production

Combinatorial factor:
m=1 if $\psi_1 = \psi_2$,
m=2 otherwise

Effective cross section in a purely geometric approach is determined from the pp transverse overlap.
It contains all the neglected / unknown parton correlations, so far considered constant and invariant on $\sqrt{s}$ and final state.

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Similarly, for TPS $\sigma_{TPS}^{pp\to\psi_1\psi_2\psi_3X} = \left(\frac{m}{3!}\right)\frac{\sigma_{SPS}^{pp\to\psi_1X}\,\sigma_{SPS}^{pp\to\psi_2X}\,\sigma_{SPS}^{pp\to\psi_3X}}{\sigma_{eff,TPS}^2}$

$\sigma_{eff,\,TPS}$ is strictly related to $\sigma_{eff,\,DPS} \Rightarrow \sigma_{eff,\,TPS} = \kappa\sigma_{eff,\,DPS}$
with $\kappa = 0.82 \pm 0.11$

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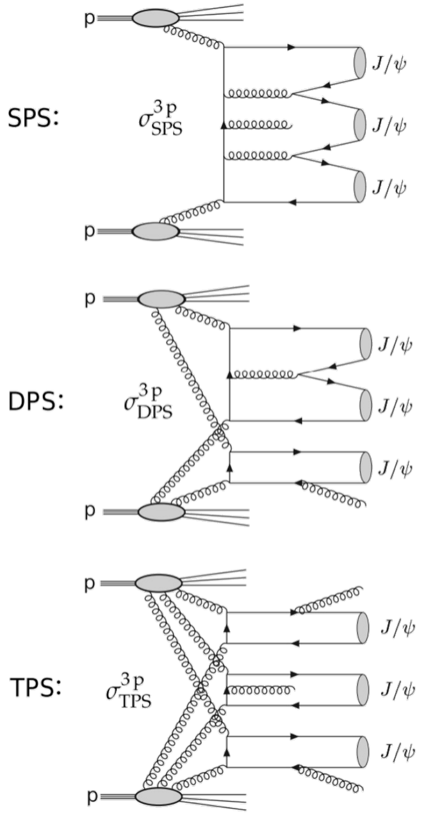

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For triple J/ψ production SPS contribution is negligible wrt DPS and TPS
$\Longrightarrow pp \to J/\psi J/\psi J/\psi X$ **is a golden channel for the study of TPS**,
and for an independent measurement of $\sigma_{eff,\,DPS}$

Triple J/ψ production

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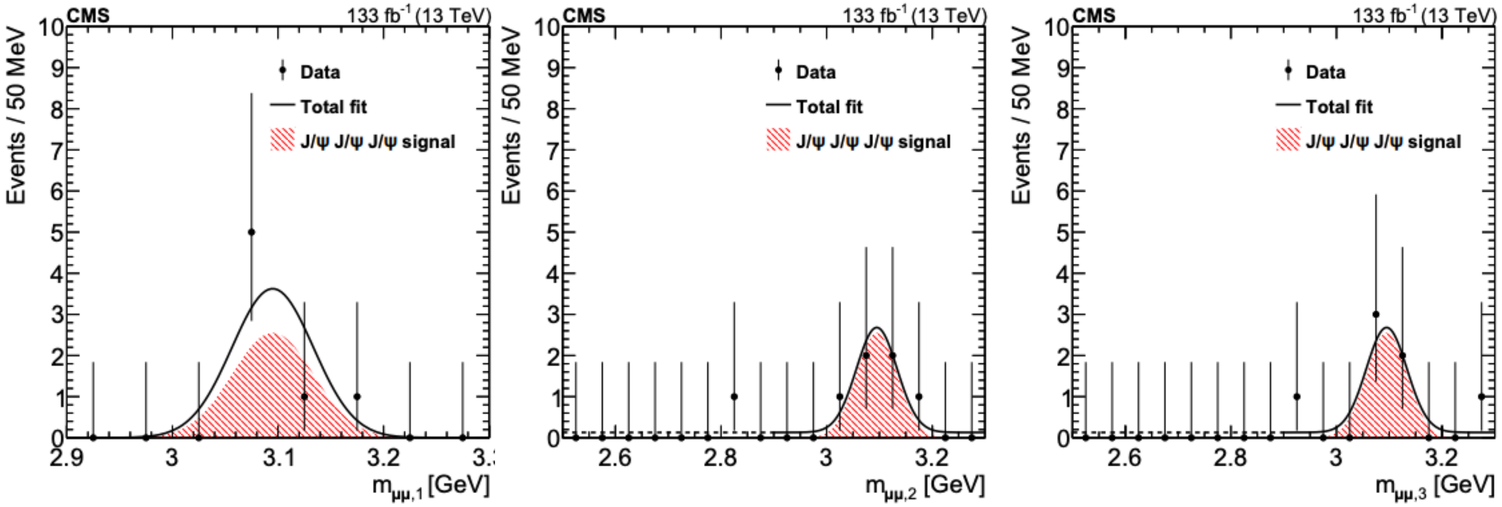
The measurement has been performed on CMS Run2 data (133 /fb @13 TeV)

All the three J/ψ have been reconstructed starting from the $\mu^+\mu^-$ final state
$\Longrightarrow$ 6 muons means a very clear and clean signature.

Both prompt and nonpropt J/ψ are included

Signal yield is extracted with a 3D unbinned extended maximum likelihood fit of the $m_{\mu^+\mu^-}$ distributions of all J/ψ candidates in the event over the $2.9 < m_{\mu^+\mu^-} < 3.3$ GeV range.



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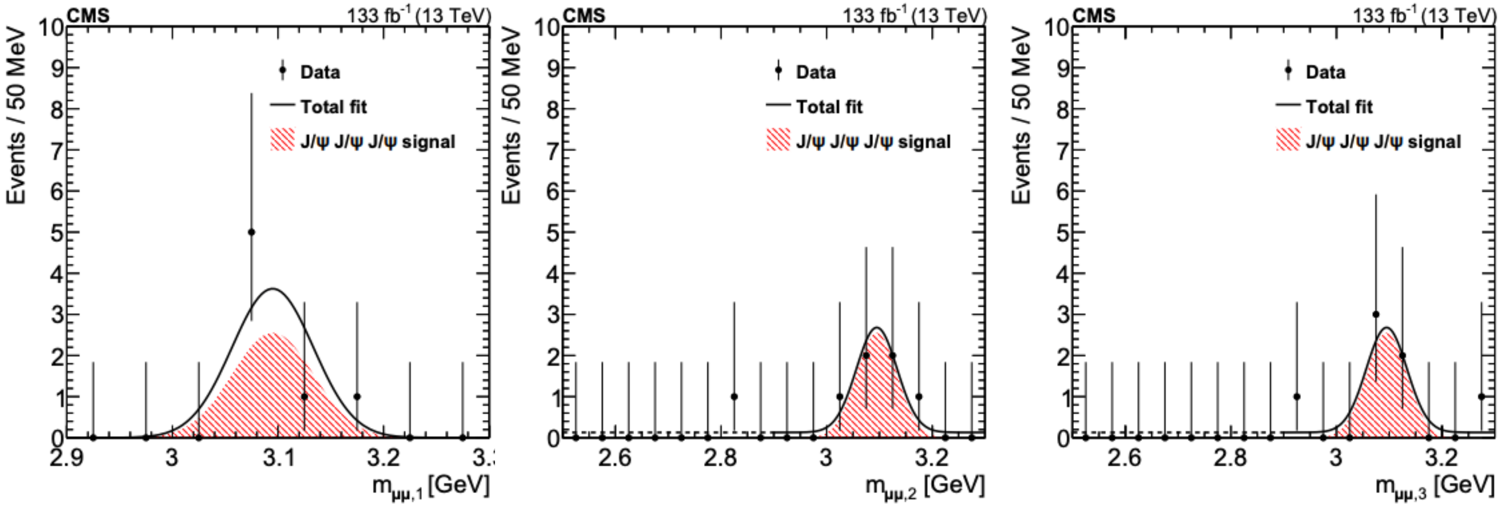

The signal yield is $\boldsymbol{N_{sig}^{3J/\psi} = 5.0^{+2.6}_{-1.9}}$ with $1.0^{+1.4}_{-0.8}$ background events.

The statistical **significance of the signal** is evaluated using various methods, anyway **above 5σ**

Triple J/ψ production

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- SPS cross sections derived from MC
- in a baseline approach that ignores parton correlations, one can extract the value of the effective DPS cross section that yields the experimentally measured $\sigma_{tot}^{3J/\psi}$ value

$\Rightarrow \sigma_{eff,\,DPS} = 2.7^{+1.4}_{-1.0}(exp)^{+1.5}_{-1.0}(theo)mb$

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SPS is negligible, as expected

DPS accounts for ~ 74%

1 event out of 5, is interpreted as TPS process!!!

Process:	3 prompt	2 prompt+1 nonprompt	1 prompt+2 nonprompt	3 nonprompt	Total
$\sigma_{SPS}^{3J/\psi}$ (fb)	<0.005	5.7	0.014	12	18
$N_{SPS}^{3J/\psi}$	0.0	0.10	0.0	0.22	0.32
$\sigma_{DPS}^{3J/\psi}$ (fb)	8.4	8.9	90	95	202
$N_{DPS}^{3J/\psi}$	0.15	0.16	1.65	1.75	3.7
$\sigma_{TPS}^{3J/\psi}$ (fb)	6.1	19.4	20.4	7.2	53
$N_{TPS}^{3J/\psi}$	0.11	0.36	0.38	0.13	1.0
$\sigma_{tot}^{3J/\psi}$ (fb)	15	34	110	114	272
$N_{tot}^{3J/\psi}$	0.3	0.6	2.0	2.1	5.0

Triple J/ψ production

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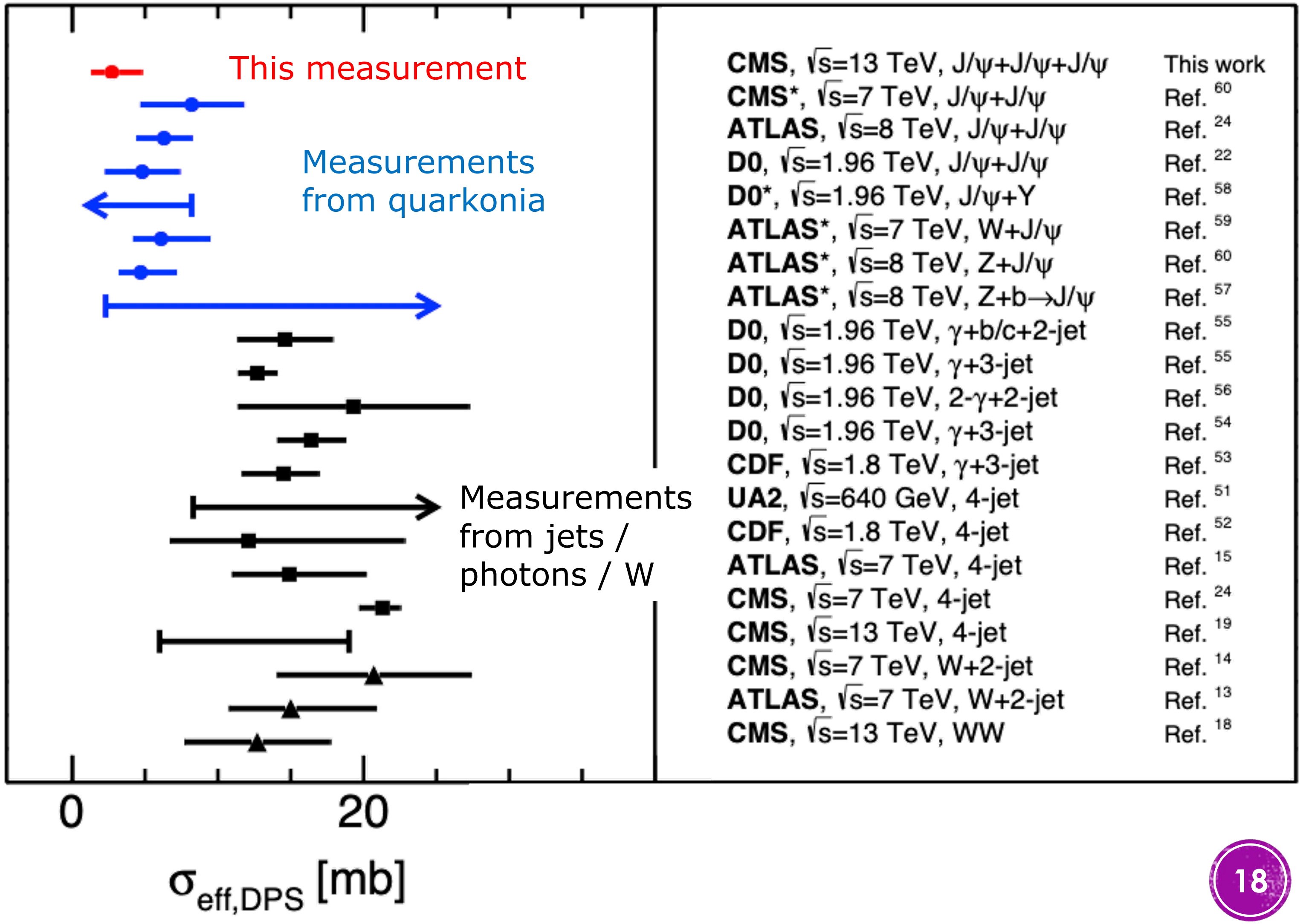
The **approximation of constant $\sigma_{eff,DPS}$ is not valid.**

There is a trend, the nature is under study

LHCb measurements at forward rapidities lead to values of $\sigma_{eff,DPS} \approx 15$ mb

$\Longrightarrow$ confirm dependence of the $\sigma_{eff,DPS}$ on the relevant parton species and x fractions probed



Dependence of f_s/f_u on B meson kinematic

arXiv:2212.02309
Accepted by PRL

Following the **evidence of non universality**, CMS studied the dependence of the ratio between the B_s^0 and B^+ hadron production fractions **f_s/f_u**, on B p_T and y

- decay channels $B_s^0 \to J/\psi(\to \mu^+\mu^-)\phi(\to K^+K^-)$ and $B^+ \to J/\psi(\to \mu^+\mu^-)K^+$ are used
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The ratio of the efficiency-corrected meson yields $\mathcal{R}_s = (N_{B_s^0}/\epsilon_{B_s^0})/(N_{B^+}/\epsilon_{B^+})$ proportional to the f_s/f_u ratio

$$\Longrightarrow \mathcal{R}_s = f_s/f_u \frac{\mathcal{B}(J/\psi\phi)\mathcal{B}(\phi\to K^+K^-)}{\mathcal{B}(B^+\to J/\psi K^+)}$$

*As a cross check also the f_d/f_u ratio is measured, using the $B^0 \to J/\psi(\to \mu^+\mu^-)K^{*0}$ decays, results in backup.

Dependence of f_s/f_u on B meson kinematic

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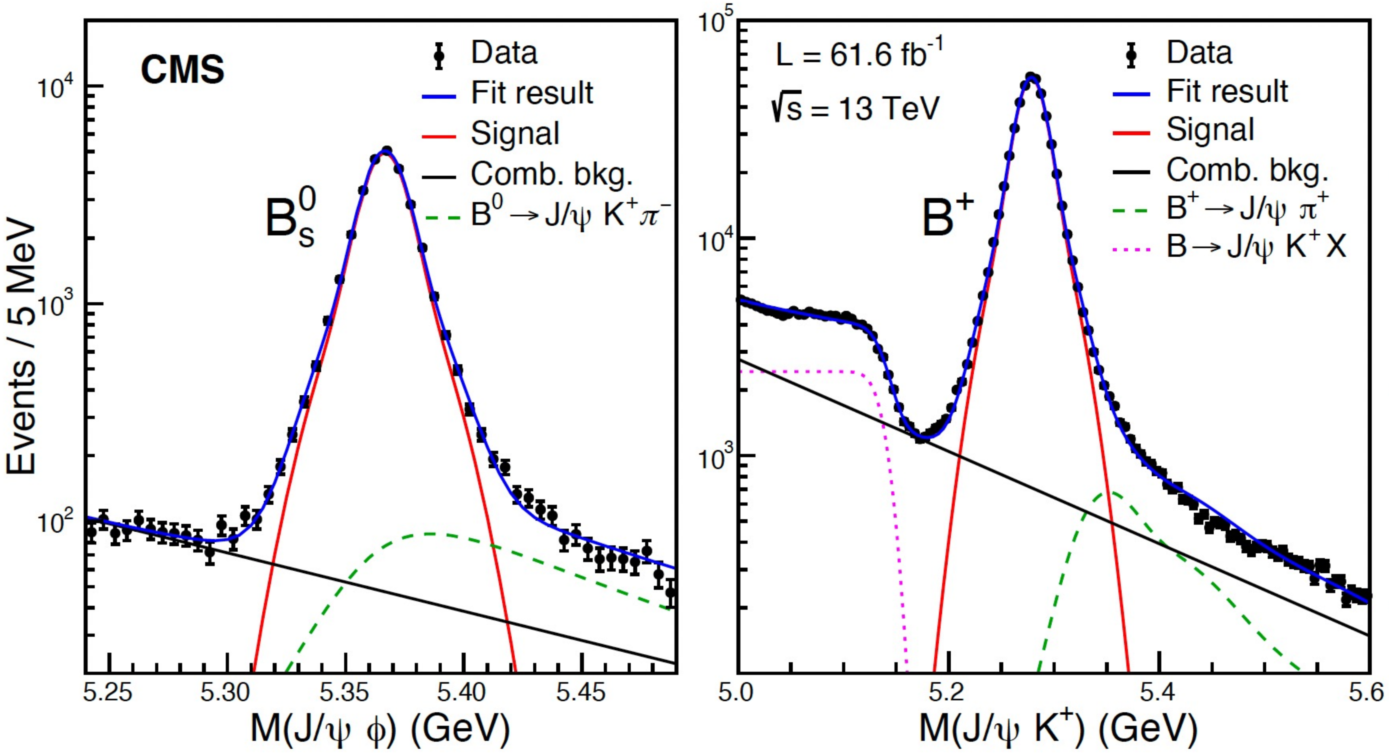
B meson are selected with $12 < p_T < 70$ GeV, $|y| < 2.4$, a decay length larger than 5 times its uncertainty, and a dimuon-plus-track(s) vertex χ^2probability > 10%.

Meson yields measured by fitting the invariant mass distributions.

- for 12 p_T bins (integrated over y)
- or 7 $|y|$ bins (integrated over p_T)

ranges defined to keep a similar number of events in each bin.

20–23 GeV pT bin



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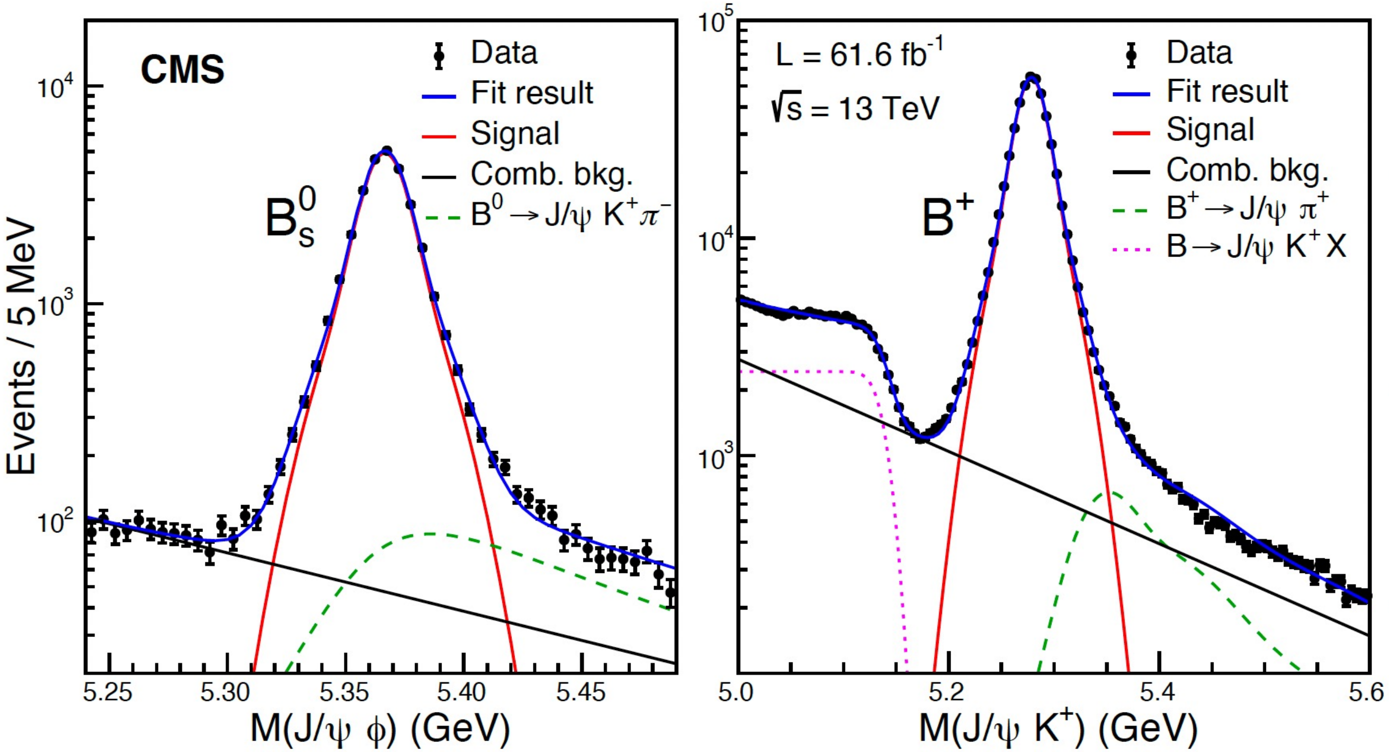
ranges defined to keep a similar number of events in each bin.

The ratio of detection efficiencies $\epsilon_{B_s^0}/\epsilon_{B^+}$ is needed to convert the ratios of signal event yields into $\mathcal{R}_s$ observable.

$\Longrightarrow$ Efficiencies are evaluated in simulations

20–23 GeV pT bin



Signal peak is fitted by the sum of 2 Gaussians with common mean and independent widths. Combinatorial background is fitted by an exponential function

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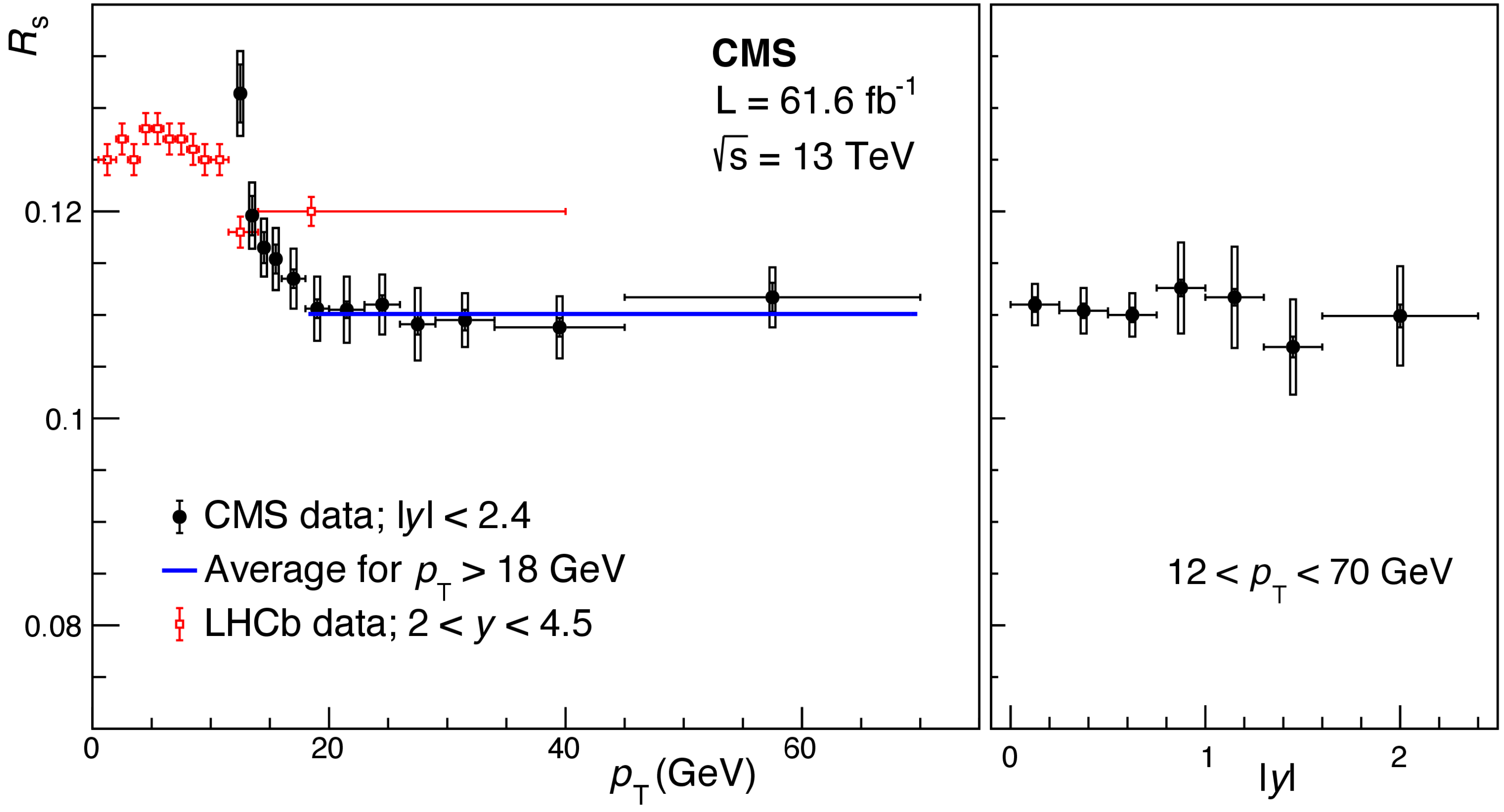

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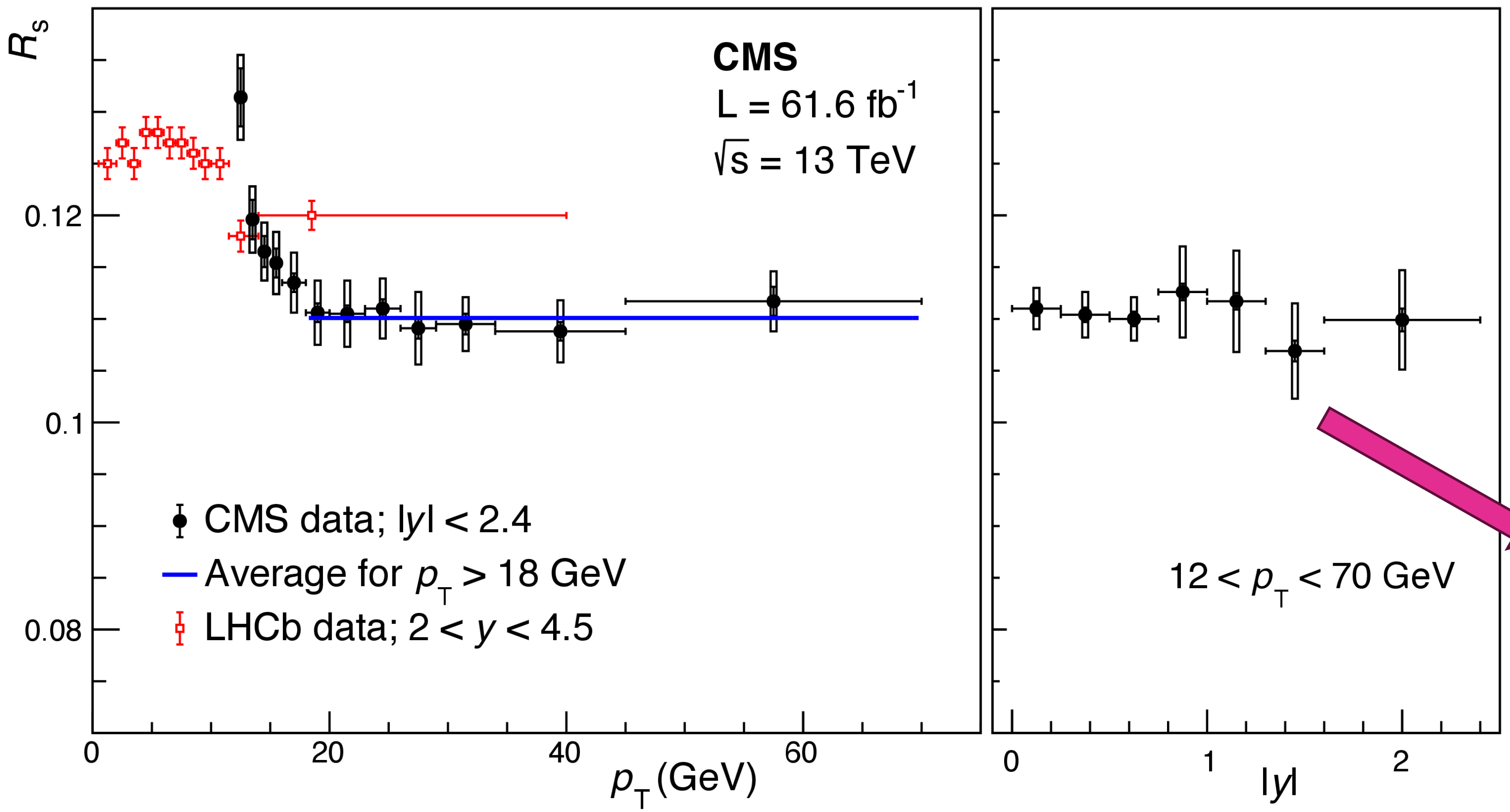

No dependence on |y|

Dependence of f_s/f_u on B meson kinematic

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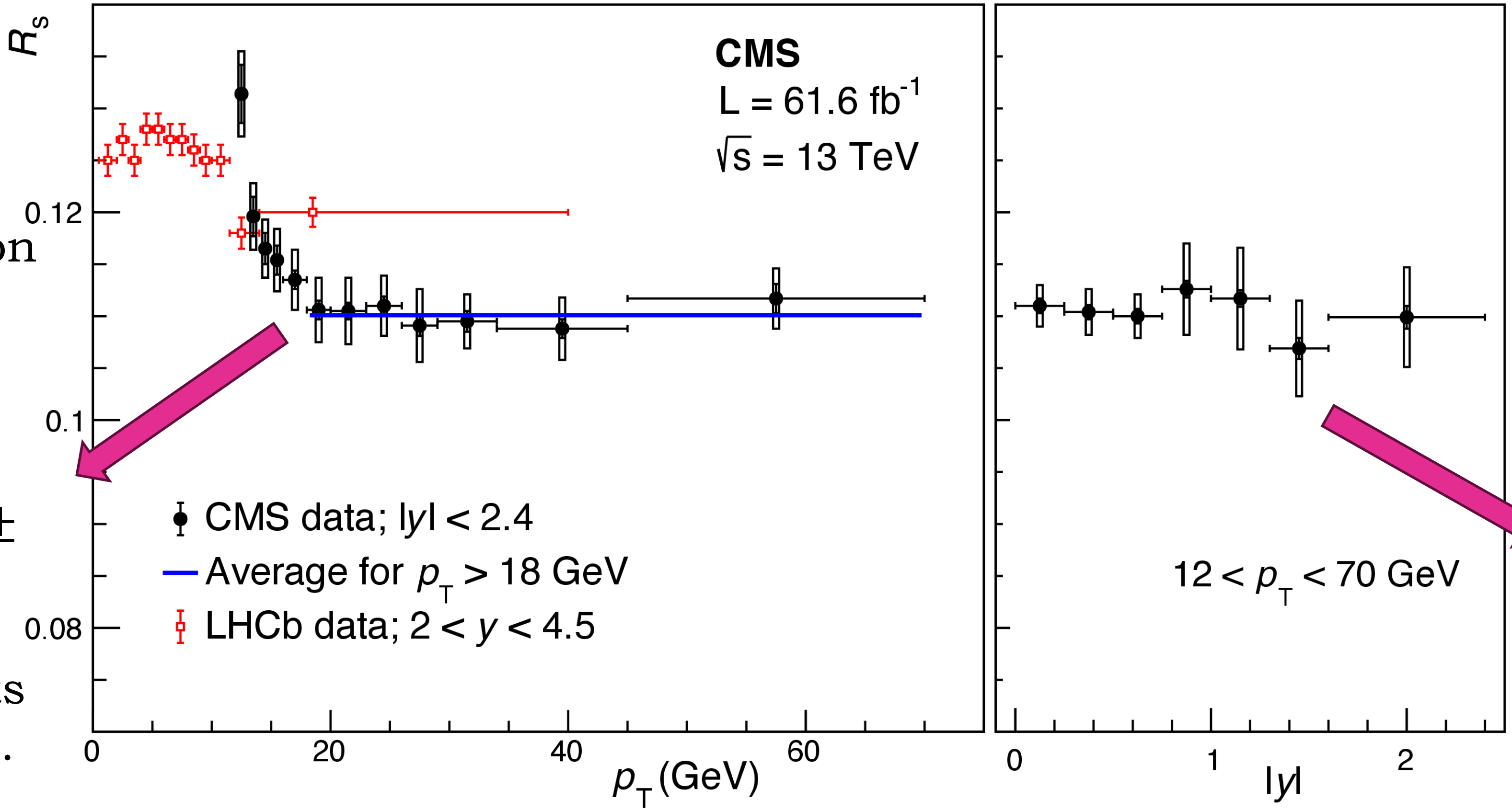
Clear dependence on pT, with a flat trend for higher p_T

Medium for p_T > 18 GeV is $\mathcal{R}_s = 0.1102 \pm 0.0027$

LHCb measurements confirm CMS points.



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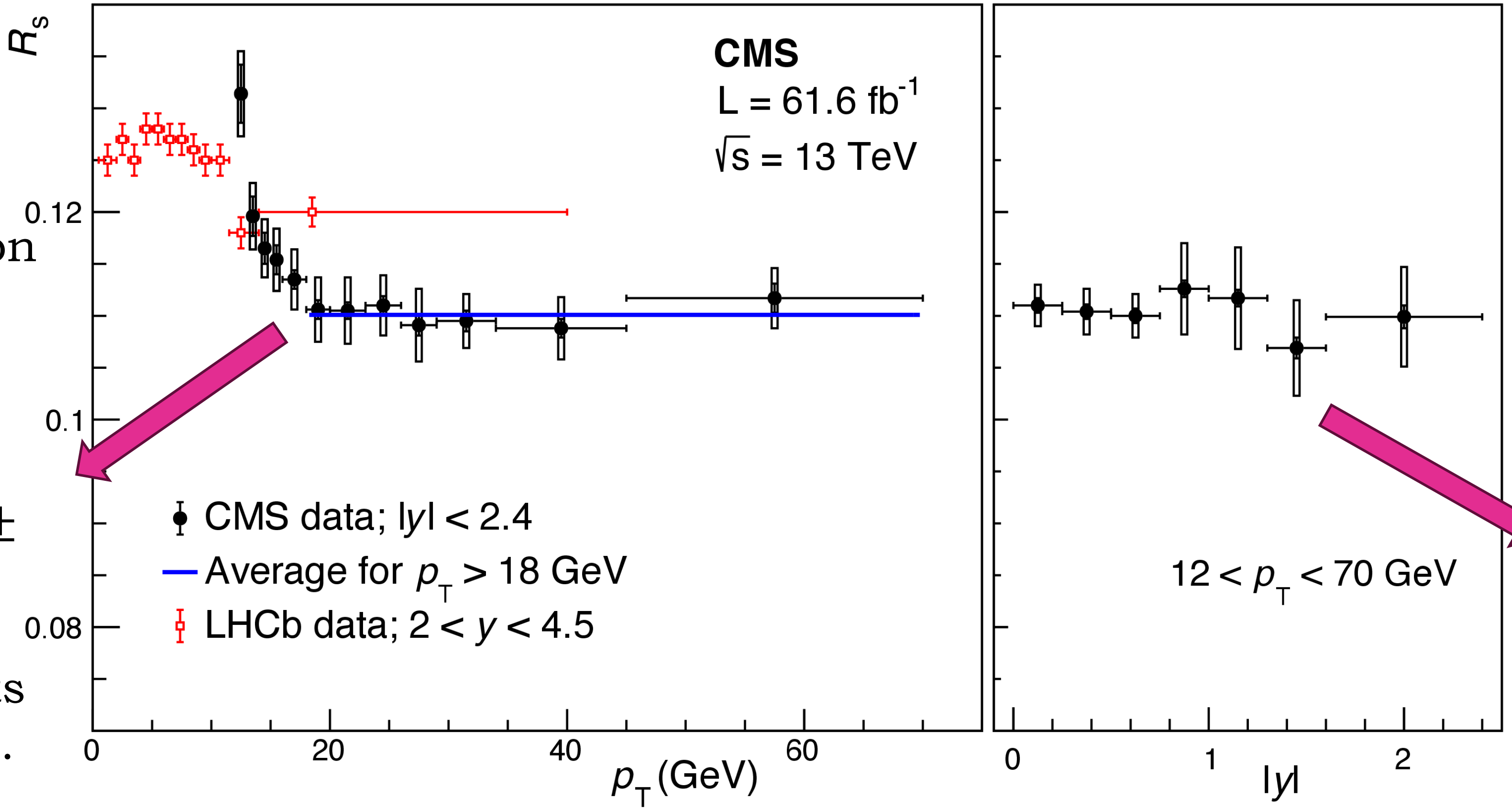


No dependence on |y|

Measurement important per se, and crucial for measuring the B decay rates such as $B_s^0 \to \mu\mu$

Flavour physics group in CMS is active and competitive

Open charm production cross section measurement put the basis for possible measurement of total charm cross section in CMS

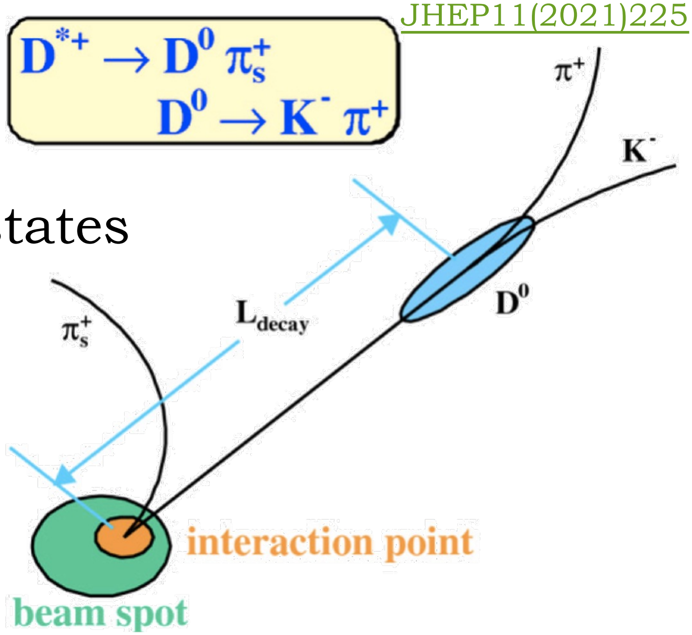
Triple J/Psi production observation can be the key for accessing triple parton scattering for the first time

Observation of f_s/f_u **dependence on B meson kinematic** is of crucial importance for the $B_s^0 \to \mu\mu$ decay measurement

backup

Open charm production cross section

JHEP11(2021)225



- **"prompt"** produced mesons $\Longrightarrow$ coming from PV or charm excited states
- D^0 decay length $c\tau \approx 10^{-2}$cm $\Longrightarrow$ Decay vertex != generation vertex

Selection applied:

- Look for "high quality" tracks -> no PID in CMS
- Secondary reconstructed vertex with CL > 1%
- Parallel direction of the meson w.r.t. the PV-SV distance
- Cuts on the decay length

Open charm production cross section - Selection

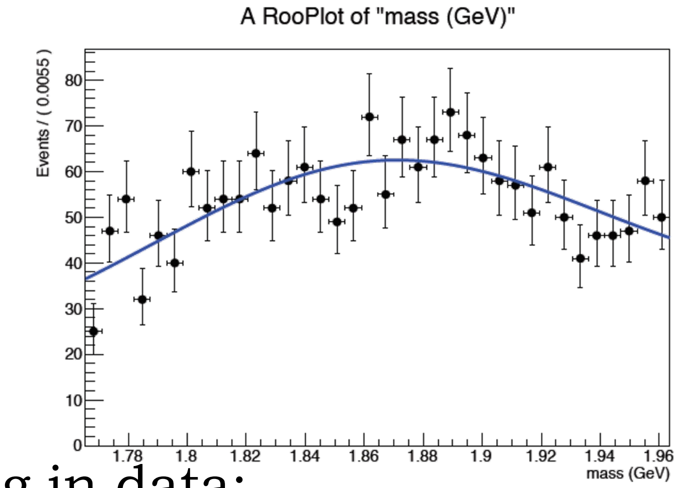
Variables	D^{*+}	D^0	D^+
PV selection:	largest $\sum p_T^2$	largest $\sum p_T^2$	largest $\sum p_T^2$
Tracks: $p_T{}^{min}$ [GeV]	0.5 (0.3 for the π_s)	0.8	0.7
Tracks: reduced χ^2	< 2.5 (3 for the π_s)	< 2.5	< 2.5
Tracks: N Tracker Hits	≥ 5 (> 2 for the π_s)	≥ 5	≥ 5
Tracks: N Pixel Hits	≥ 2 (none for the π_s)	≥ 2	≥ 2
Tracks: IP_{xy} [cm]	< 0.1 (sig. < 3 for π_s)	< 0.1	< 0.1
Tracks: IP_z [cm]	< 1 (sig. < 3 for π_s)	< 1	< 1
$\lvert M_{cand} - M^{PDG} \rvert$ [GeV]	< 0.023	< 0.10	< 0.10
SV fit CL	$> 1\%$	$> 1\%$	$> 1\%$
Pointing, $cos\Phi$	> 0.99	> 0.99	> 0.99
L significance:	> 3	> 5	> 10
Arbitration	min ΔM	min $\lvert$M(Kπ) - M^{PDG}(D^0)$\rvert$	min $\lvert$M(K$\pi\pi$) - M^{PDG}(D$^+$)$\rvert$

k/pi swap treatment in the D0 reconstruction

Since CMS has not a PID we have an ambiguation in the $K^{+}\pi^{-}$ and $K^{-}\pi^{+}$ states.

We manually assign the mass hypothesis to the tracks according to the charge, but since the D^0 is a neutral particle the disambiguation between D^0 and $\overline{D^0}$ has to be explicitly done.

Contribution of the wrong mass assignment evaluated in a MB MC sample using the gen level info as truth



Gaussian contribution (σ =0.075 +/- 0.007 GeV) to be considered as signal component.

⟹ A third wide gaussian has been added in the signal shape modelling in data:

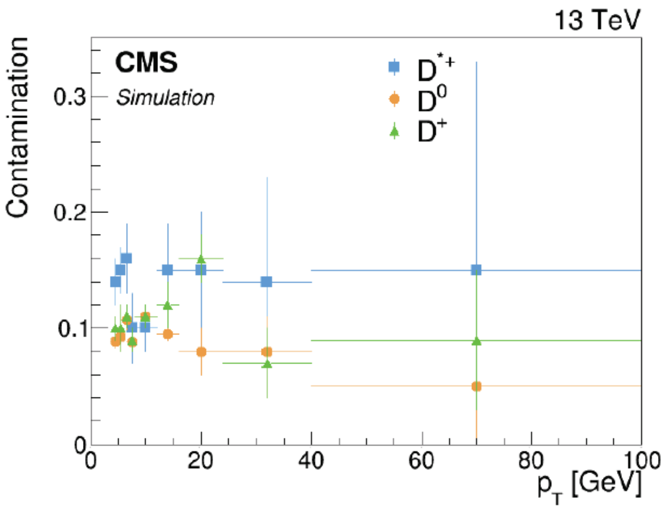
- Width obtained bin by bin from MC
- Normalization defined w.r.t. to the other two gaussians in data, so that for every bin the integral for the two contributions (wide and thin) is the same.

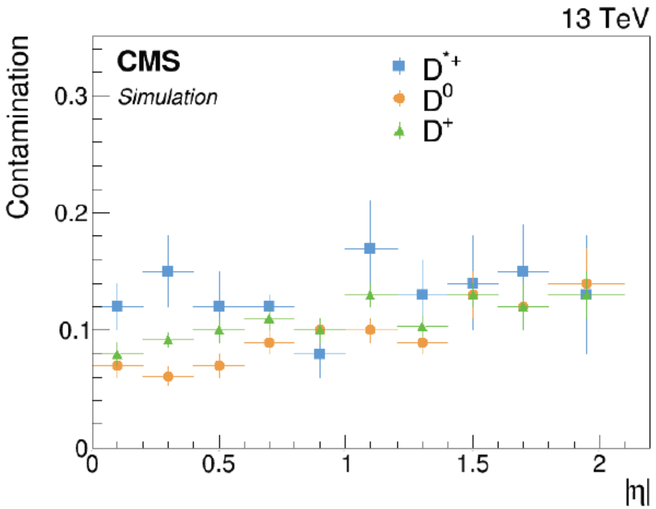
Signal yield taken from the thin contribution to avoid double counting.

Open charm production cross section

Only prompt mesons are signal ⇒ **possible contamination**: charm mesons coming from B meson decays

Contribution evaluated on MC as: $contamination = \frac{N_{sec}}{N_{prompt}+N_{sec}} \sim 10\text{-}15\%$





The visible cross section is corrected bin-by-bin for this contribution

Systematic Uncertainties

- **Luminosity** – measured by CMS for 2016 => 2.5%
- **BR** – uncertainties taken from the latest PDG edition
- **Tracking** - 2.3% per track
  - For the D* an additional 5.2 % has been introduced for the slow pion
- **Slow pion pT cut** - affect only the fit D* pt bin
- **MC statistics** - the statistical error from the enriched MC
- **Contamination** - the statistical error from the MinBias MC
- **Signal yield instability** - due to the dynamic inefficiency in the tracking during the 2016 data taking -> evaluated including the different PU scenario for each run
- **PU reweighting** - Bin by bin the statistical error related to the weight w=data/MC has been evaluated. The cross section is calculated using the upper and lower values.
- **L/sigmaL cut** - several studies done to check for possible bias of the cut -> we conclude that it is not possible to isolate and directly quantify the L/sigma systematic, since it can't be disentangled by the fit method effects.
- **Fit modelling** – Signal and background alternative models:
  - Signal: a single gaussian, a 3gaussian sum and a crystal ball function were used for the signal description. The biggest deviation between the three is taken as syst.
  - Background: a fourth degree polynomial was used for the bkg description
  - In addition to that has been found that the peaking background has a no negligible contribution for the D+ meson, while it is flat for the other two particles

Systematic uncertainties

	Relative uncertainties (%)		
	D^{*+}	D^0	D^+
Signal efficiency calculation	0.3	0.3	3.5
Secondary decay contamination	2.9	0.8	1.4
PU reweighting	1.0	1.0	2.0
Branching fraction	1.1	0.8	1.7
Tracking efficiency	9.4	4.2	6.1
Signal modeling	3.6	5.0	4.2
Background modeling	1.2	4.8	8.0
Luminosity	2.5	2.5	2.5
Time-dependent inefficiencies	1.4	1.4	1.4
Total	11.0	8.7	12.2

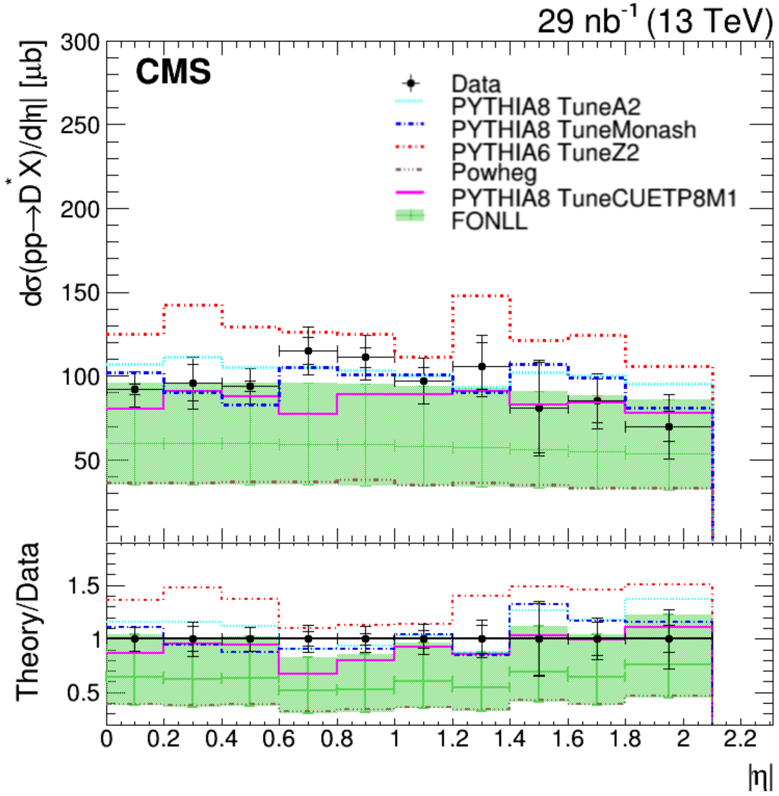
The dominant ones are:

- Tracking efficiency
- Signal / bkg modelling

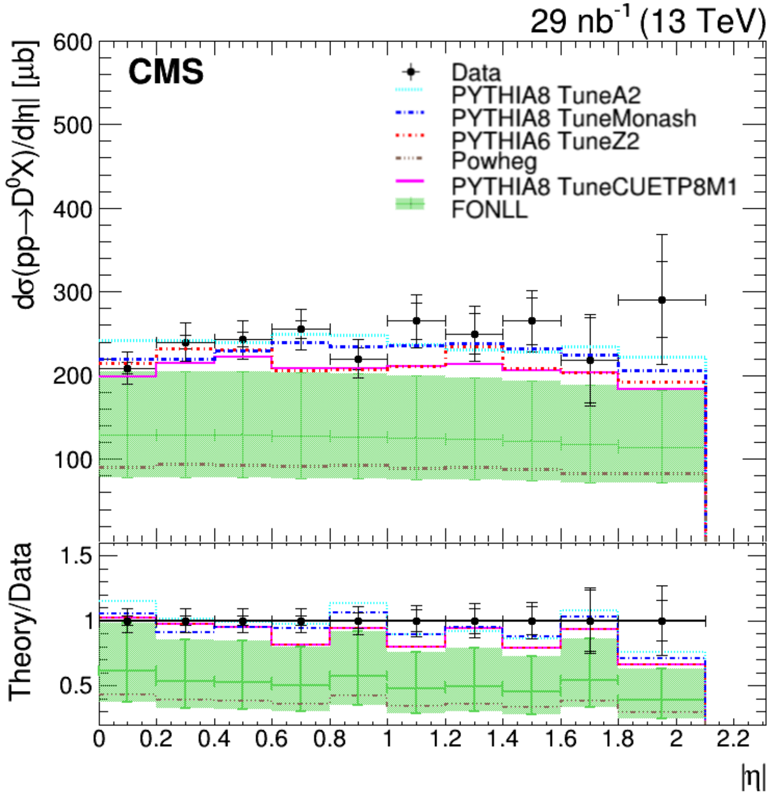
Data taking instability -> due to tracker inefficiency during the 2016 data taking

Results

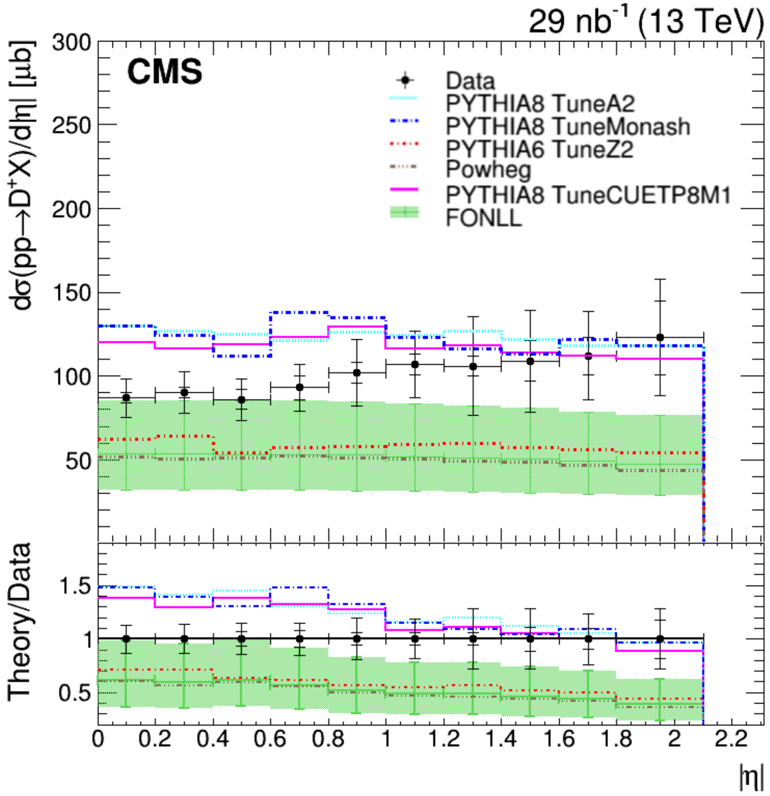
D*



D^0



D^+



MC and theory models used to compare data

The cross-section values are compared to

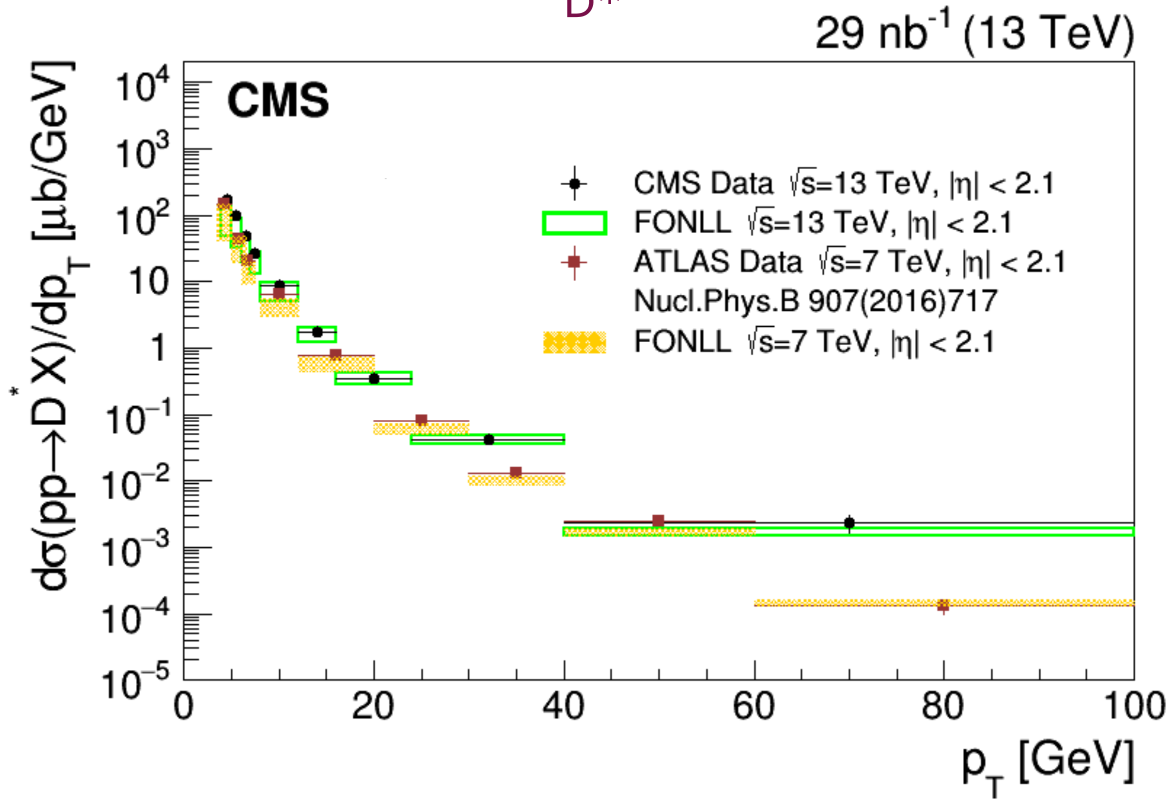
- FONLL predictions [1] shown as boxes representing the upper and lower limit for a given bin
  - Central values: mb = 4.75 GeV for bottom, mc = 1.5 GeV for charm, μR = μF = μ0 = sqrt(m2 + pT2)
    Scales uncertainties: μ0/2 < μR, μF < 2μ0 with 1/2 < μR/μF < 2.
    Mass uncertainties: mb = 4.5, 5.0 GeV for bottom, mc = 1.3, 1.7 GeV for charm, summed in quadrature to scales uncertainties.
    PDFs uncertainties: calculated according to the individual PDF set recipe, and summed in quadrature to scales and mass uncertainties.
    No fragmentation fractions (unless specified above) are included for the heavy quark -> heavy hadron fragmentation. This means that all heavy quarks are hadronised as if they fragmented into the chosen heavy hadron. To construct the proper mixing, the correct fragmentation fraction (FF) must be provided and the results summed separately. The D0 and D+ already include feedown from D*. The correct branching ratios (BR) for decays into leptons and other hadrons are instead provided by default.
- Pythia 8 (several tunes) [3]
- Powheg [4]

[1] The pT spectrum in heavy-flavour hadroproduction, M.Cacciari, S.Frixione, P.Nason, JHEP (9805) (1998) 007
[3] A Brief Introduction to PYTHIA 8.1, T. Sjostrand, S.Mrenna P.Skands, arXiv:0710.3820
[4] Jet pair production in POWHEG, S. Alioli, K. Hamilton, P. Nason, C. Oleari, E. Re, JHEP 1104 (2011) 081

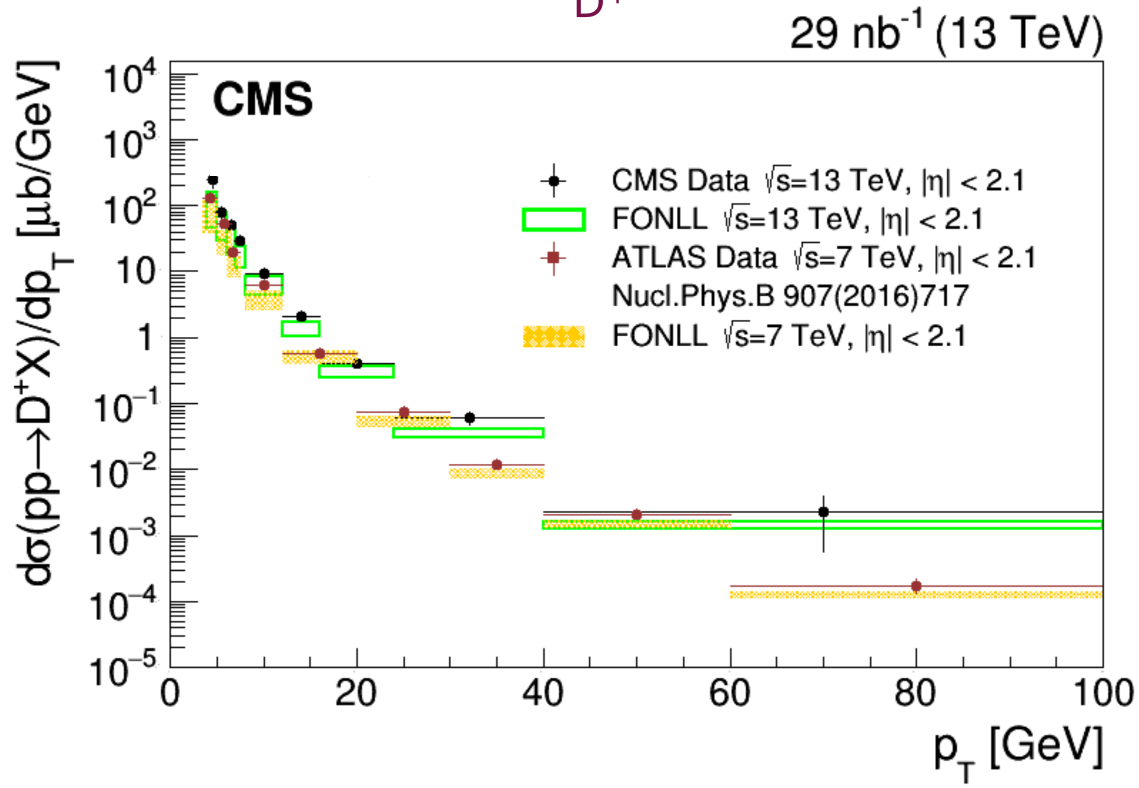
Comparison with measurements done at 7 TeV

- ATLAS

D*



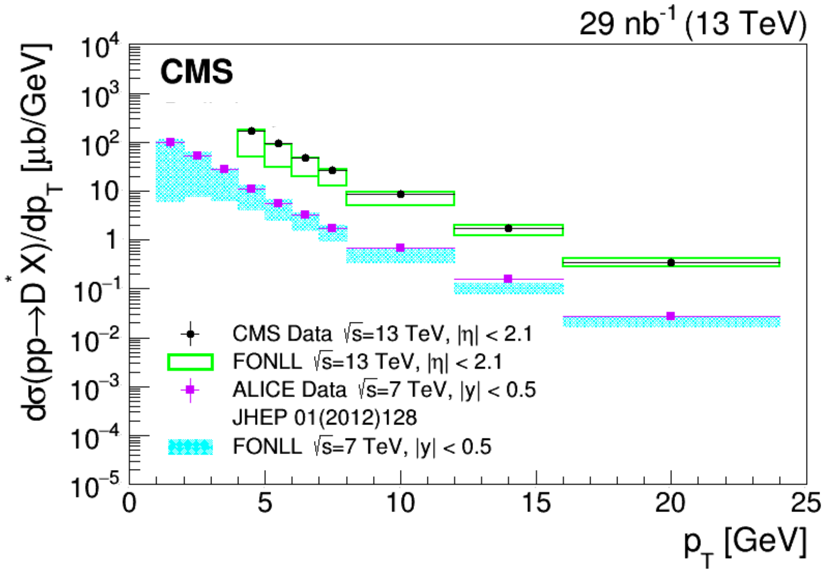
D+



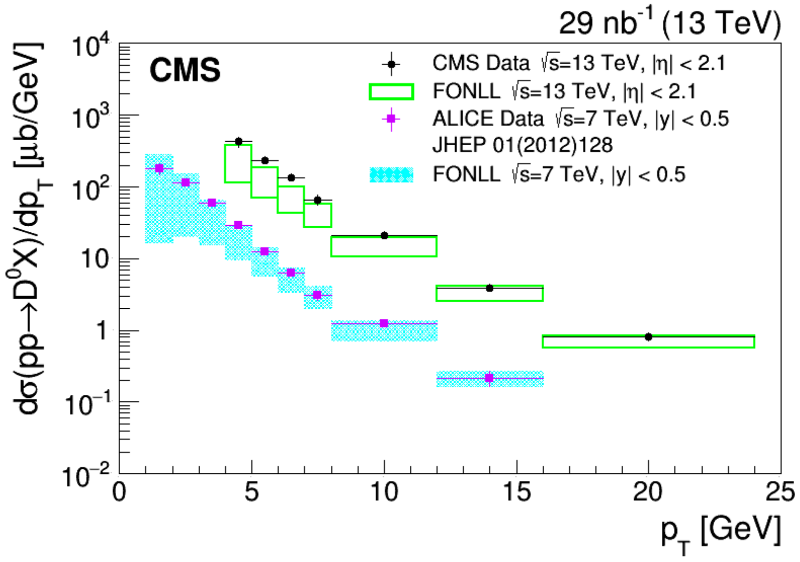
Same kinematic range but different binning
We can directly see how the cross section scales with the center of mass energy

Comparison with measurements done at 7 TeV

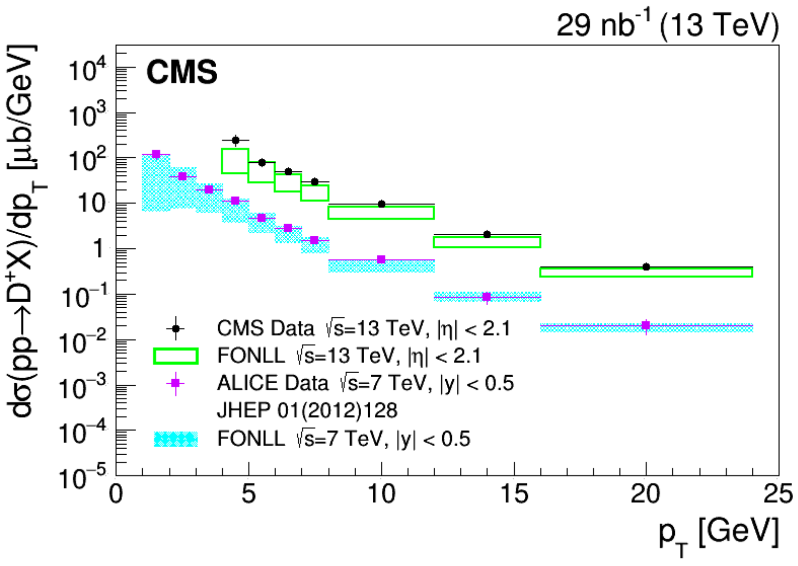
D^*



D^0



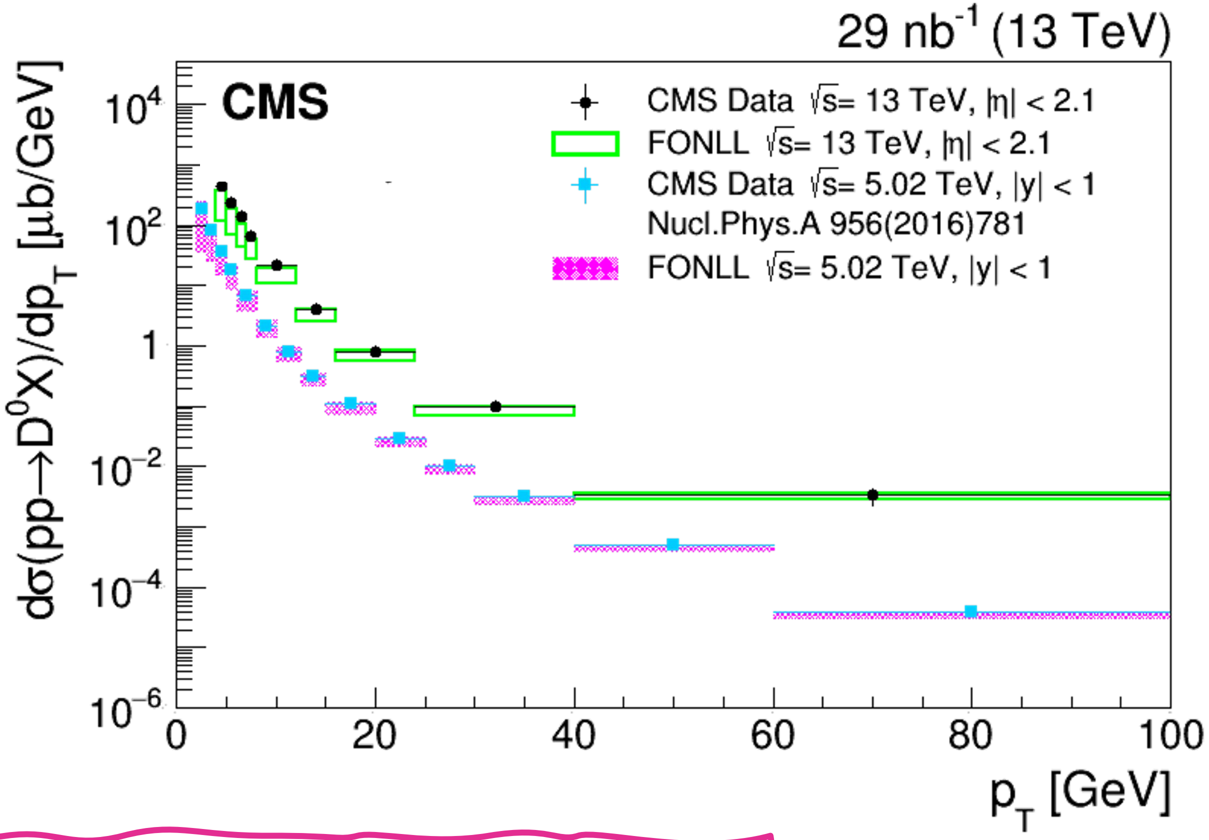
D^+



Different kinematic range CMS data shown only for pT < 24 GeV
Factor 2 since the cc are not included in ALICE

Comparison with measurement done at 5.02 TeV

- CMS group performed a Pb-Pb measurement at 5.02 TeV and used the pp cross section to normalise

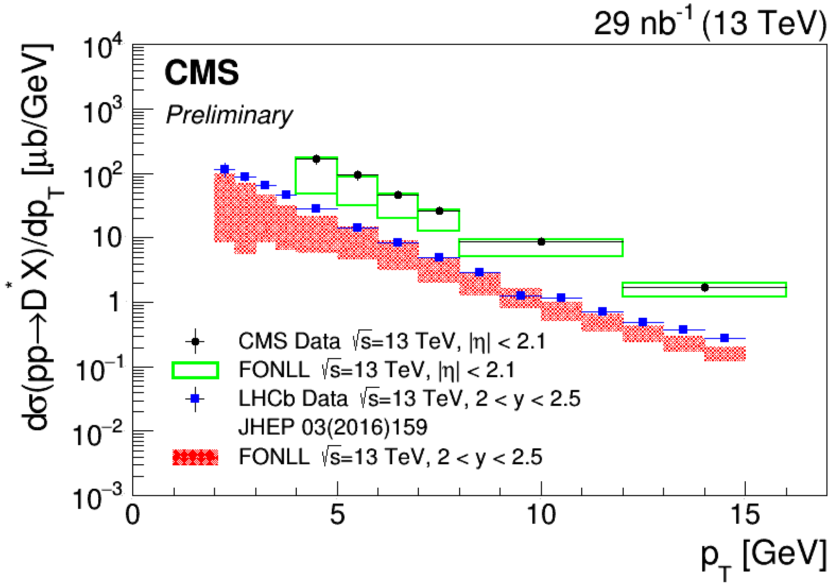


Different kinematic range and binning
Evolution (theory / data) in good agreement

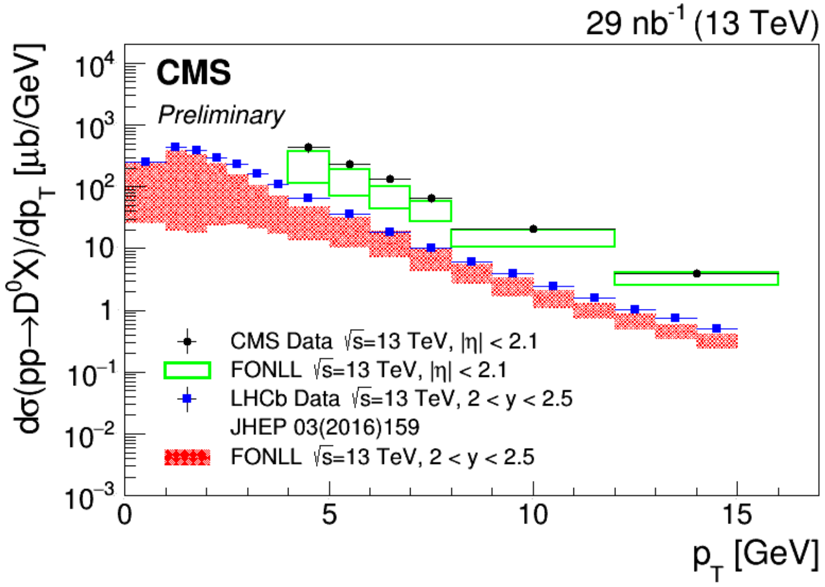
Comparison with measurement done at 13 TeV

- LHCb

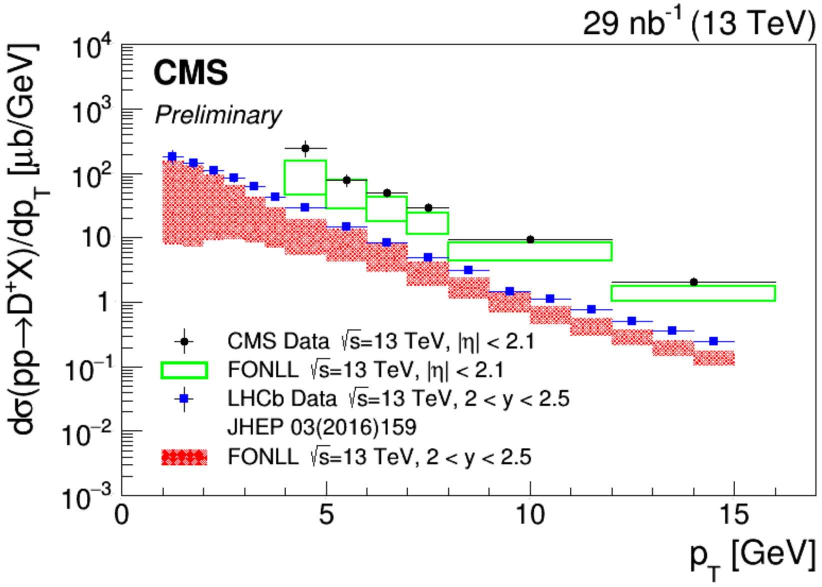
D^*



D^0

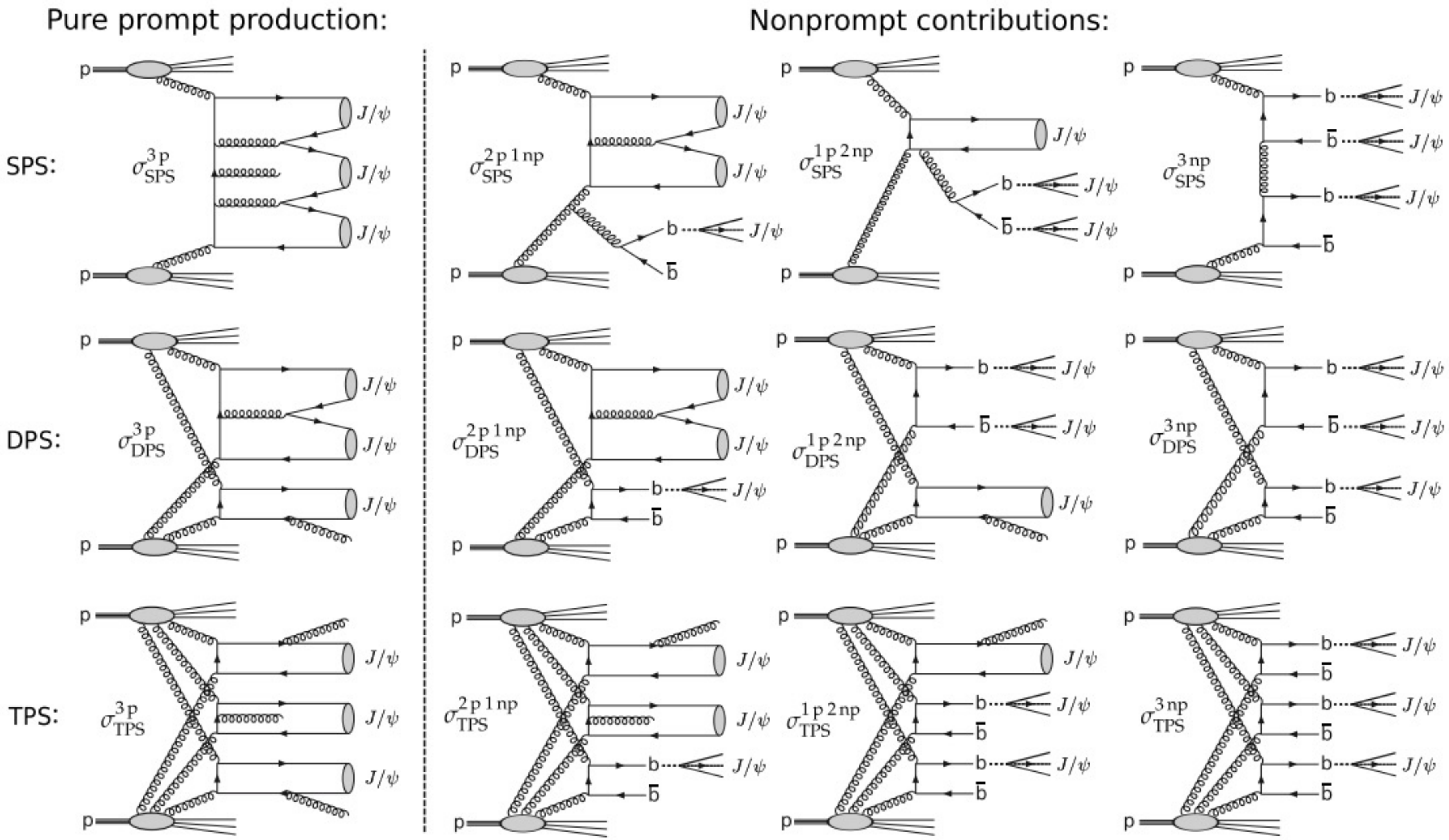


D^+



Complementary acceptance => Only the first y bin is shown for LHCb
CMS data are reported only for pT < 16 GeV to have a better comparison.
-> **Good agreement in the scale for the three mesons**

Triple J/ψ production



Triple J/ψ production

The total inclusive triple-J/ψ cross section is expected to correspond to the sum of the contributions from the SPS, DPS, and TPS with both prompt (p) and nonprompt (np) contributions

$$\sigma^{3J/\psi}_{tot} = \sigma^{3J/\psi}_{SPS} + \sigma^{3J/\psi}_{DPS} + \sigma^{3J/\psi}_{TPS}$$
$$= \left(\sigma^{3p}_{SPS} + \sigma^{2p1np}_{SPS} + \sigma^{1p2np}_{SPS} + \sigma^{3np}_{SPS}\right)$$
$$+ \left(\sigma^{3p}_{DPS} + \sigma^{2p1np}_{DPS} + \sigma^{1p2np}_{DPS} + \sigma^{3np}_{DPS}\right) + \left(\sigma^{3p}_{TPS} + \sigma^{2p1np}_{TPS} + \sigma^{1p2np}_{TPS} + \sigma^{3np}_{TPS}\right)$$

Under the simplest assumption of factorization in terms of SPS cross sections

$$\sigma^{3J/\psi}_{TPS} = \frac{\mathfrak{m}_3}{\sigma^2_{eff,TPS}}\left[\left(\sigma^{1p}_{SPS}\right)^3 + \left(\sigma^{1np}_{SPS}\right)^3\right] + \frac{\mathfrak{m}_2}{\sigma^2_{eff,TPS}}\left[\left(\sigma^{1p}_{SPS}\right)^2\sigma^{1np}_{SPS} + \sigma^{1p}_{SPS}\left(\sigma^{1np}_{SPS}\right)^2\right]$$

$$\sigma^{3J/\psi}_{DPS} = \frac{\mathfrak{m}_1}{\sigma_{eff,DPS}}\left[\sigma^{2p}_{SPS}\sigma^{1p}_{SPS} + \sigma^{2p}_{SPS}\sigma^{1np}_{SPS} + \sigma^{1p}_{SPS}\sigma^{1p1np}_{SPS} + \sigma^{1p1np}_{SPS}\sigma^{1np}_{SPS} + \sigma^{1p}_{SPS}\sigma^{2np}_{SPS} + \sigma^{2np}_{SPS}\sigma^{1np}_{SPS}\right]$$

Triple J/ψ production

Considering the momentum fraction

$$x = \sqrt{p_{T,V}^2 + m_V^2 + e^{\eta}}/\sqrt{s}$$

At midrapidity (|η| < 2.5), quarkonia are produced mostly in gluon-gluon scatterings carrying a fraction $x \approx 5\times10^{-4}$, whereas mostly quarks with $x \approx 10^{-2}$ participate in the production of EW bosons.

In LHCb measurements of double-quarkonia and quarkonia-plus charm at forward rapidities (η ≈ 2–4.5), processes that originate in parton scatterings with asymmetric fractional momenta $x_1 \approx 10^{-4}$ and $x_2 \approx 10^{-2}$, lead to values of $\sigma_{eff,\,DPS} \approx 15$ mb, larger than those measured at midrapidity for similar final states.

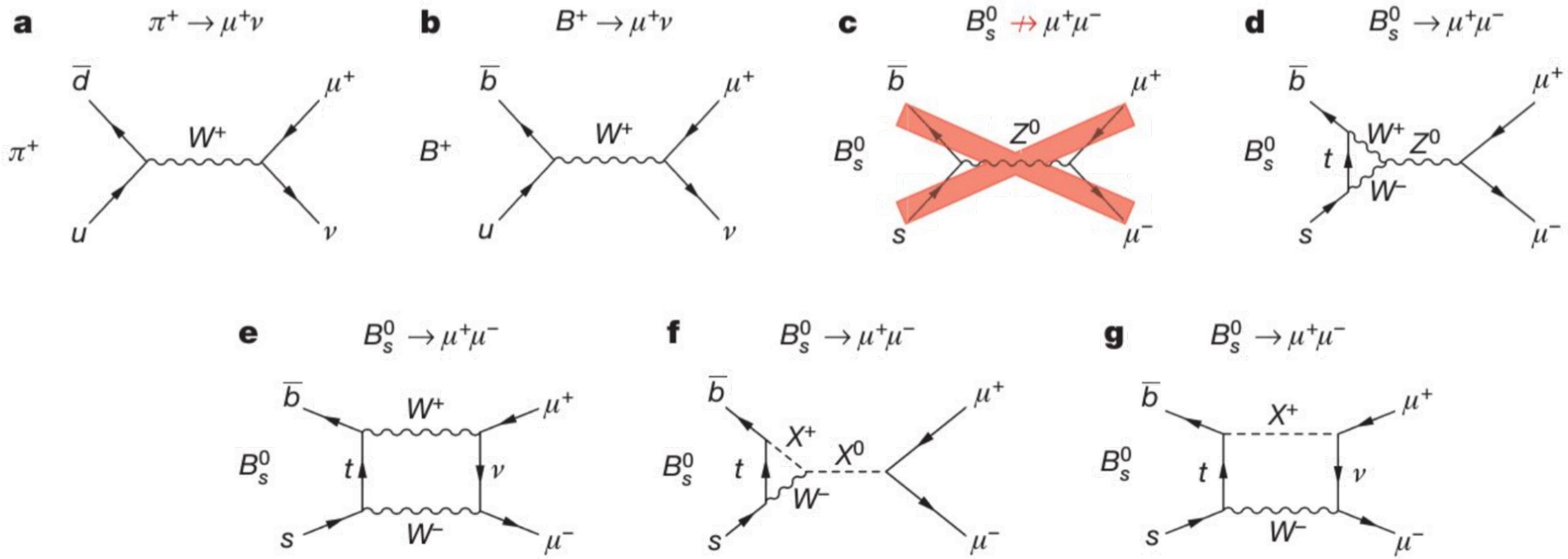
⇒seems to confirm the **dependence of the effective DPS cross section on the relevant parton species and x fractions probed**

Dependence of f_s/f_u on B meson kinematic

Motivation

Essential for measuring b-hadron cross sections and branching fractions (e.g $B_s \to \mu^+\mu^-$)

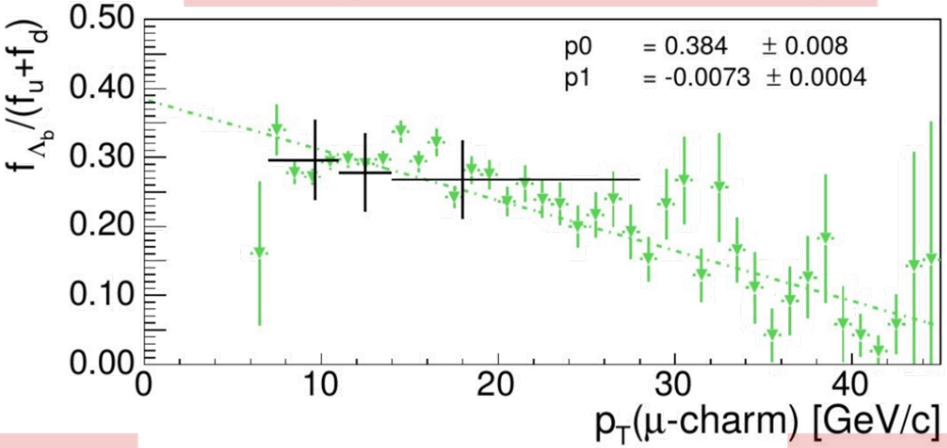
$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = \frac{N_S}{N_{obs}^{B^+}} \boxed{\frac{f_u}{f_s}} \frac{\varepsilon_{tot}^{B^+}}{\varepsilon_{tot}} \mathcal{B}(B^+ \to J/\psi K^+)\, \mathcal{B}(J/\psi \to \mu^+\mu^-)$$



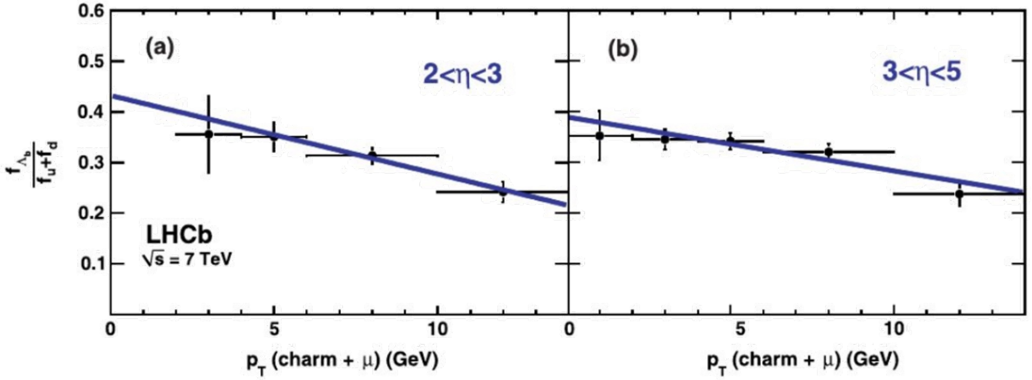
Dependence of f_s/f_u on B meson kinematic

Motivation: non-universality

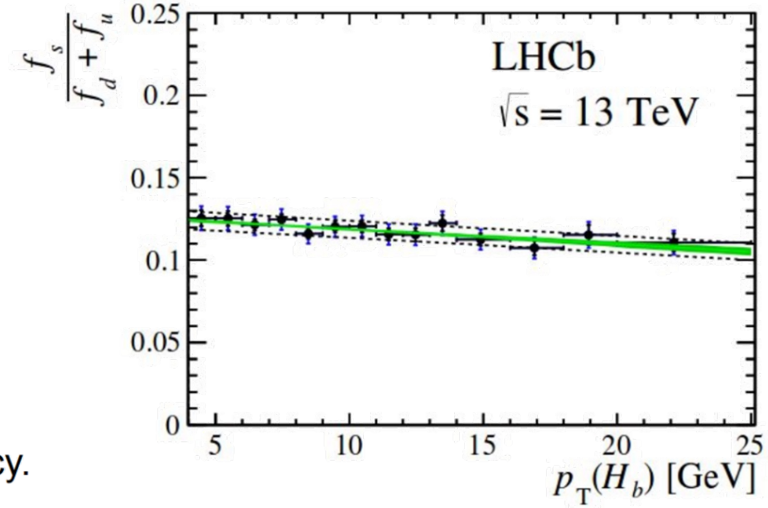
CDF: Phys. Rev. D77 , 072003 (2008)



Phys. Rev. D85, 032008 (2012)



Phys. Rev. D 100, 031102 (2019)



Fragmentation fractions were considered with no kinematical dependency.
This seems not to hold anymore.

Dependence of f_s/f_u on B meson kinematic

A measurement fs/fu implies extracting the B_s and B^+ yields, as function of p_T and rapidity. Preliminary results are shown below

$$\frac{f_s}{f_u} = \frac{N_{B^0_s}}{N_{B^+}} \frac{\mathcal{B}(B^+ \to J/\psi K^+)}{\mathcal{B}(B^0_s \to J/\psi \phi)\mathcal{B}(\phi \to K^+K^-)} \frac{\varepsilon_u}{\varepsilon_s}$$

Channel	Value
$B^+ \to J/\psi K^+$	$(1.026 \pm 0.031) \times 10^{-3}$
$B^0_s \to J/\psi \phi(1020)$	$(1.08 \pm 0.08) \times 10^{-3}$
$\phi(1020) \to K^+K^-$	$(48.9 \pm 0.5)\%$

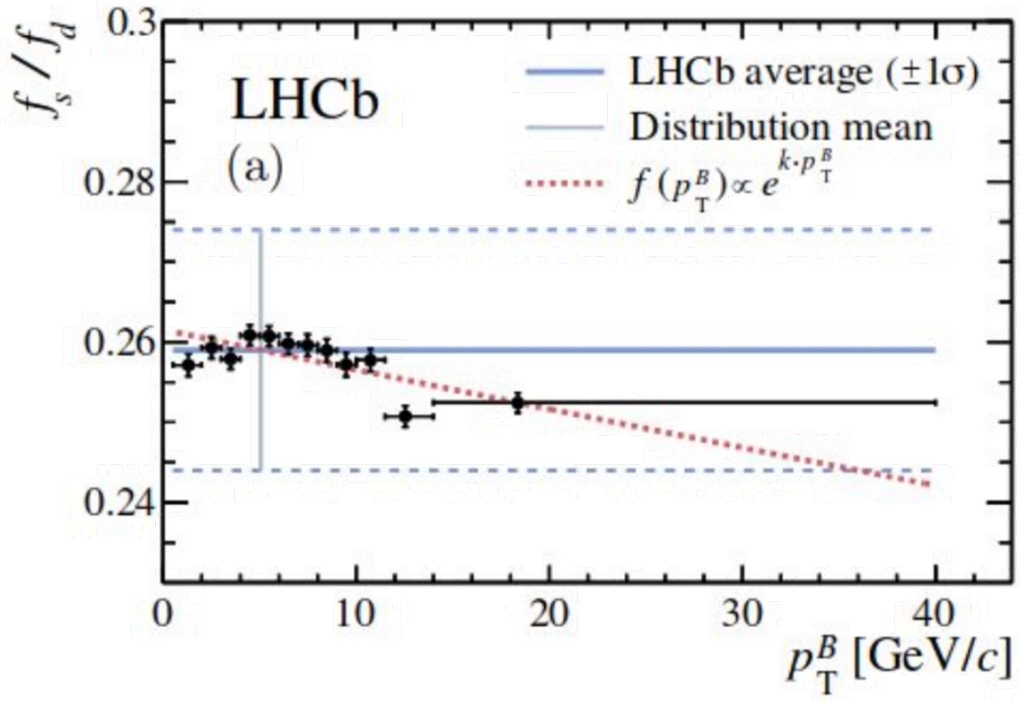
Branching fraction values from PDG

Given the close relationship between fs(fu) and B_s (B^+) branching fraction measurements, we actually measure:

$$\mathcal{R} = \frac{f_s}{f_u} \times \frac{\mathcal{B}(B^0_s \to J/\psi\phi(1020)) \times \mathcal{B}(\phi(1020) \to K^+K^-)}{\mathcal{B}(B^+ \to J/\psi K^+)} = \frac{N_{B^0_S}}{N_{B^+}} \frac{\epsilon_{B^+}}{\epsilon_{B^0_S}}$$

Dependence of f_s/f_u on B meson kinematic

Motivation: non-universality



The ratio of the B_s^0 and B^+ fragmentation fractions f_s and f_u is studied with $B_s^0 \to J/\psi\phi$ and $B^+ \to J/\psi K^+$ decays using data collected by the LHCb experiment in proton-proton collisions at 7, 8 and 13 TeV center-of-mass energies. The analysis is performed in bins of B-meson momentum, longitudinal momentum, transverse momentum, pseudorapidity and rapidity. The fragmentation-fraction ratio f_s/f_u is observed to depend on the B-meson transverse momentum with a significance of $6.0\,\sigma$. This dependency is driven by the 13 TeV sample (8[illegible] σ) while the results for the other collision energies are not significant when considered separately. Furthermore the results show a $4.8\,\sigma$ evidence for an increase of f_s/f_u as a function of collision energy.

[Phys. Rev. Lett. 124, 122002 (2020)]

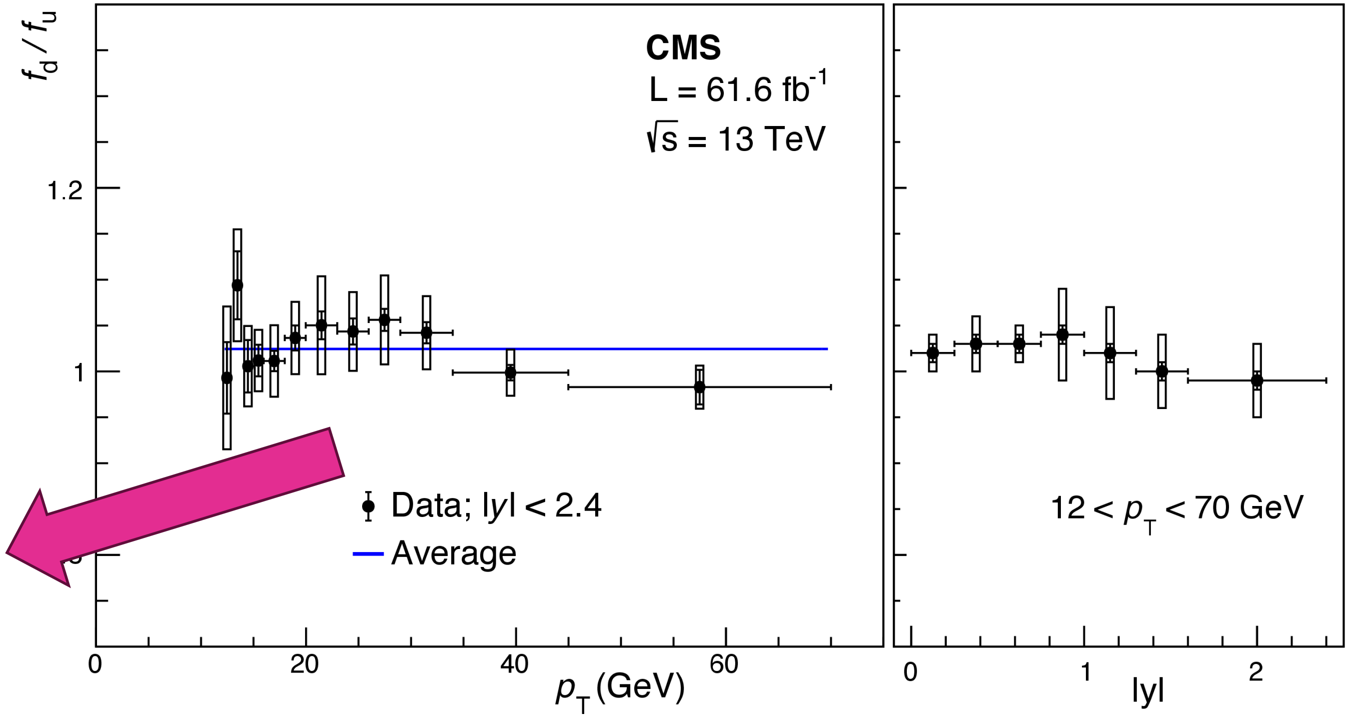
6 sigma observation on p_T dependence

Dependence of f_s/f_u on B meson kinematic

The analysis also includes a measurement of the ratio between the B^0 and B^+ fractions, f_d/f_u, using the B^0 yield determined with $B^0 \to J/\psi(\to \mu^+\mu^-)K^{*0}$ events, where the K^{*0} mesons are reconstructed in the $K^{*0} \to \pi^- K^+$ decay channel

$$\mathcal{R}_d = \frac{N_{B^0}}{\epsilon_{B^0}} \Bigg/ \frac{N_{B^+}}{\epsilon_{B^+}} = f_d/f_u \, \frac{\mathcal{B}(B^0 \to J/\psi\, K^{*0})\mathcal{B}(K^{*0} \to \pi^- K^+)}{\mathcal{B}(B^+ \to J/\psi\, K^+)}$$

Under the assumption of strong isospin symmetry, the f_d/ f_u ratio is predicted to be independent of kinematic variables and identical to unity



$\Rightarrow$ no dependence on p_T or $|y|$ is observed. The average over all the p_T points is 1.015 ± 0.051, compatible with 1