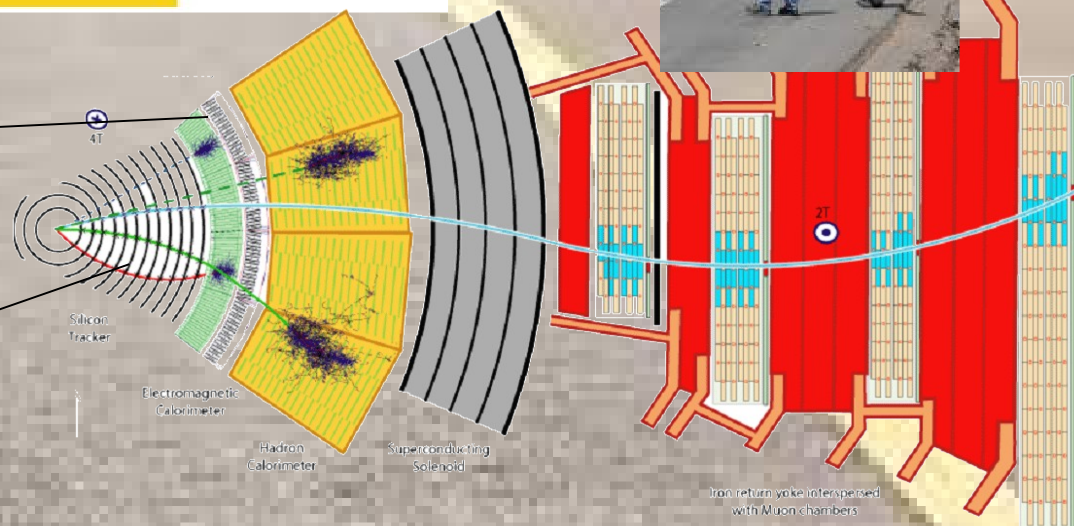


V+heavy flavor jets and constraints to PDFs in CMS

Juan Pablo Fernández Ramos (CIEMAT)

LHC-EW WG: Jets and EW bosons
30th March 2020

Introduction

- Measurements of σ(pp→Z/W+c/b) provide tests QCD predictions. **Results sensitive to hard scattering process & associated soft QCD radiation** (input to theory refinement & validation of MC techniques)

- Allows better understanding of proton structure.

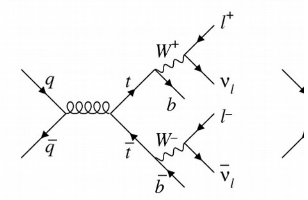
  Z/W+c/b jets tests PDF for s,c,b.

- Background to some SM processes and in searches

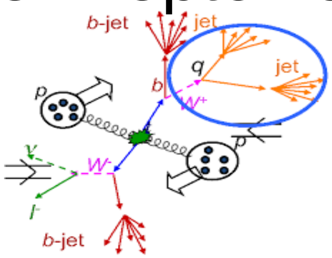
Mentioning ...

SAMPLES

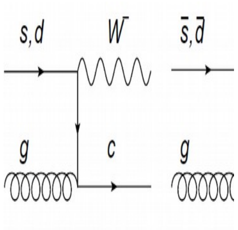
ttbar dileptonic



ttbar semileptonic



W+charm



WAYS to IDENTIFY HF

- **SV channel**
  SV-in-jet
- **HF-tagging**
- **SL channel**
  μ-in-jet

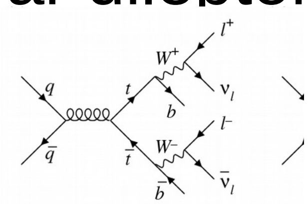
VARIABLES

- **SV mass**
- **ΔR(c-jet,jet)**
- **Closest jet flavor**
- **Discriminants**
  - **Deep Neural Nets**

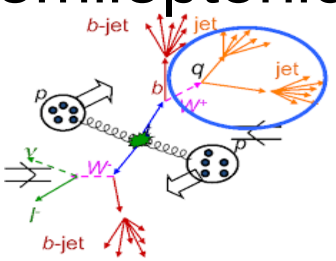
What can we do with all this?

SAMPLES

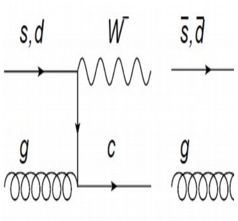
ttbar dileptonic



ttbar semileptonic



W+charm



WAYS to IDENTIFY HF

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  μ-in-jet

VARIABLES

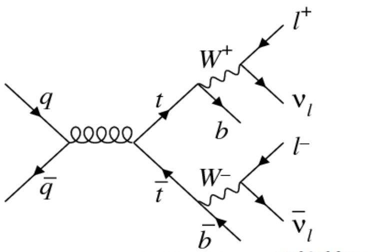
- **SV mass**
- **ΔR(c-jet,jet)**
- **Closest jet flavor**
- **Discriminants**
- **Deep Neural Nets**

SCENARIO (SUBTRACTION)

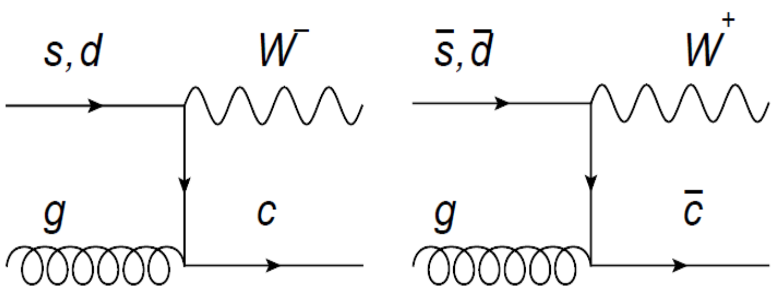
- **OS-SS**
- **OS-SS** (struck through)

Given a certain technique we are looking at properties of heavy flavor (HF) jets on ttbar (dileptonic and semileptonic) & W+charm for calibration purposes and then performing the particular analysis

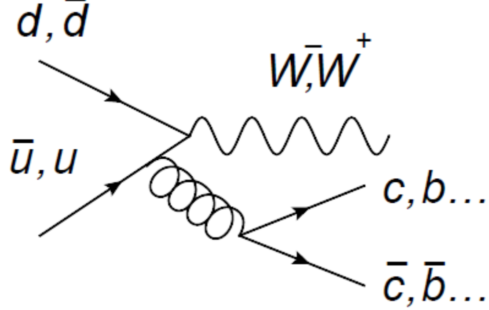
A technique : Opposite sign (OS) – same sign (SS) bkg. subtraction



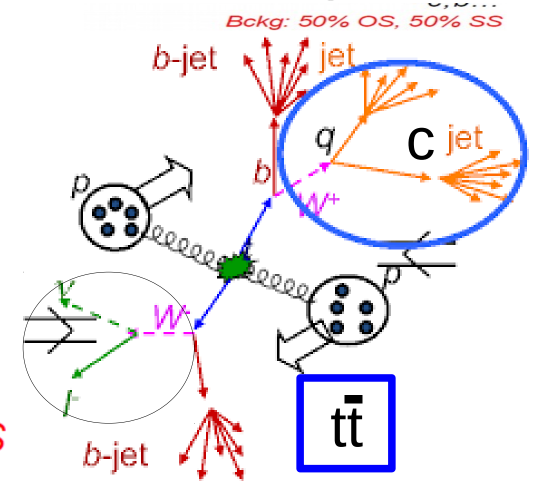
- Used for background suppresion



OS event **W+c** OS event



Bckg: 50% OS, 50% SS



$t\bar{t}$

- Signal is always OS (sign of electric charges of W and c are opposite)
- Background is 50% OS, 50% SS
- OS – SS to get rid of symmetric background
  - SS distributions are subtracted from OS distributions

OS-SS turns HF-jets → c-jets enriched

OS-SS turns b-jets in $t\bar{t}$ → performance of b vs $\bar{b}$

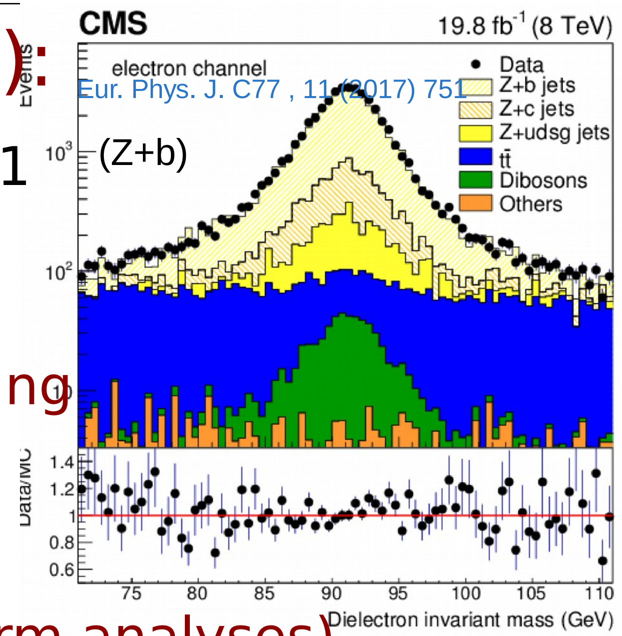
Mentioning ways (tools/experimental techniques) to not only **identify the HF** but also **determine its charge**

Ask for tagger with charge to be used for OS-SS

Samples and Strategy (exp. introduction):

How are the measurements done from the experimental point of view ?

Analysis strategy (our final state):

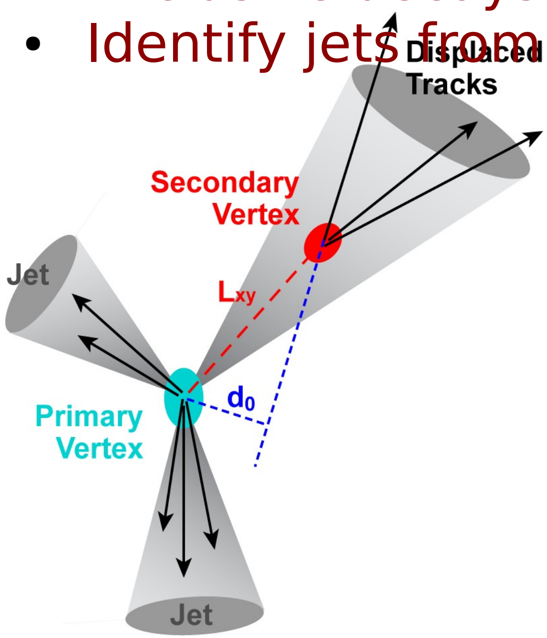


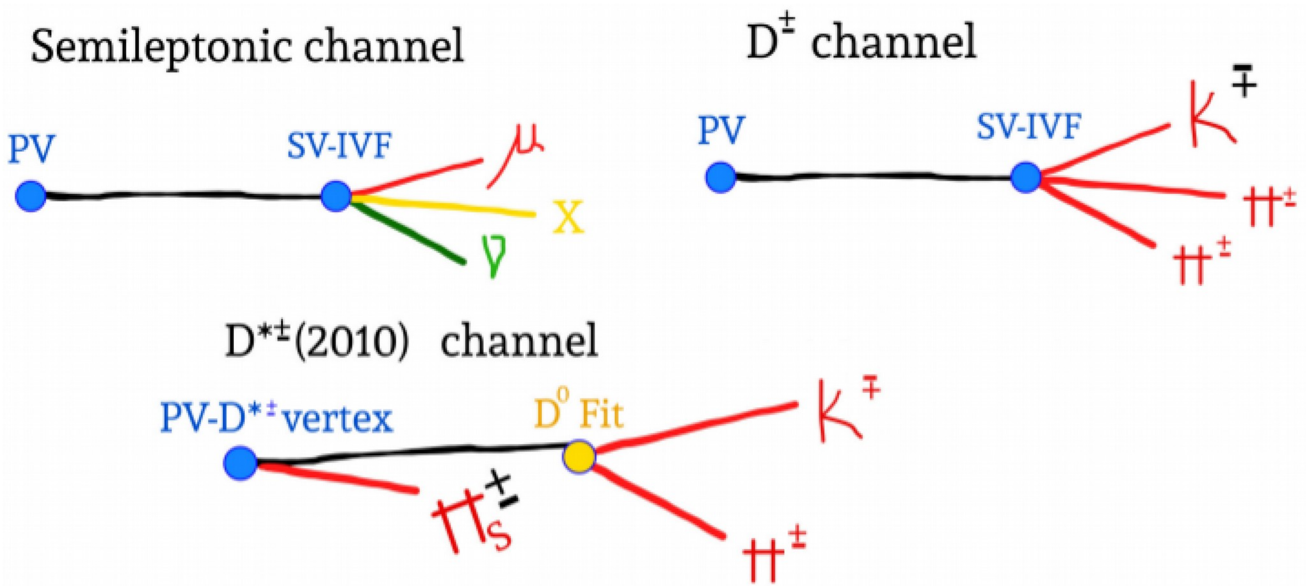
$Z \rightarrow l^+l^-$, $W^+ \rightarrow l^+\nu$ with $p_T(l)>20$ GeV & $|\eta(l)|<2.1$

Dilepton invariant mass: [70,110] GeV

Identify heavy hadrons in final states by taking advantage of long life of heavy hadrons:

- Displaced tracks or tracks forming a SV
- Lepton in jet (charm and bottom analyses)
- Exclusive decays in jet ($D^{*+/-}$ and $D^{+/-}$ in charm analyses)
- Identify jets from HF using std CMS c/b tagging algorithms





p_T^{jet} >25 GeV & $|\eta^{jet}|<2.5$

Samples

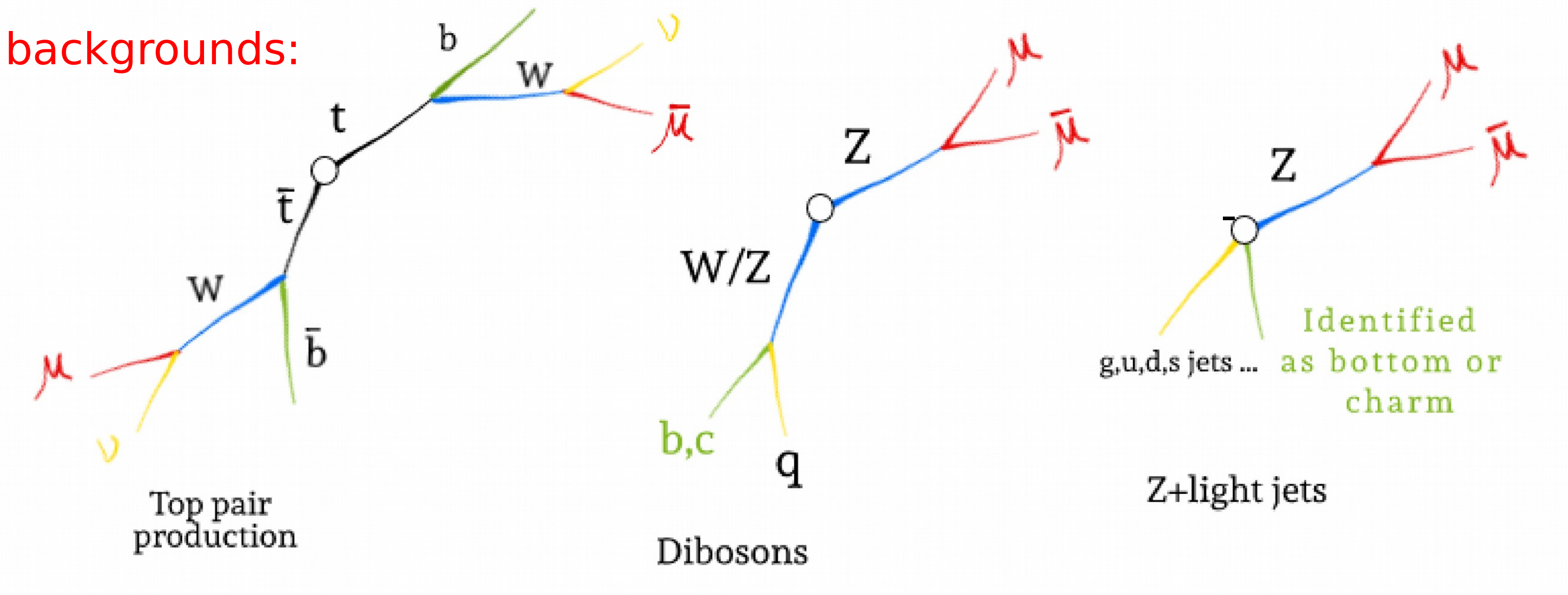
DATA: 2016 13 TeV (36 fb-1) or 2012 8 TeV (20 fb-1)

MC: W/DY+jets generated w. MADGRAPH + PYTHIA

Cross section normalized to σ(pp→Z/W+X) at NNLO calculated with FEWZ

Primary signal contribution:g-g & q-q processes (<5% from MPI)

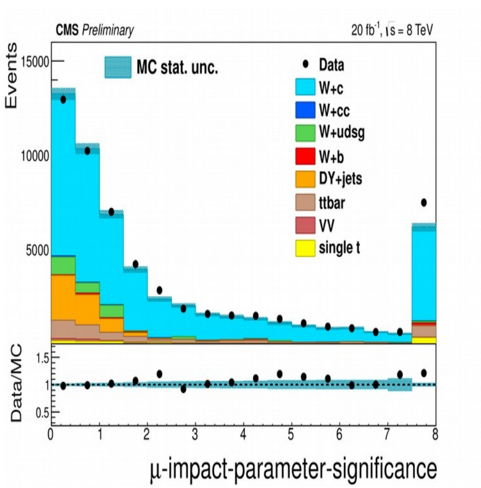
Main backgrounds:

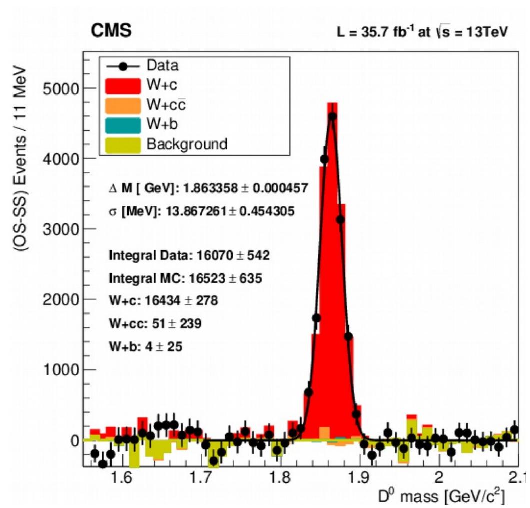


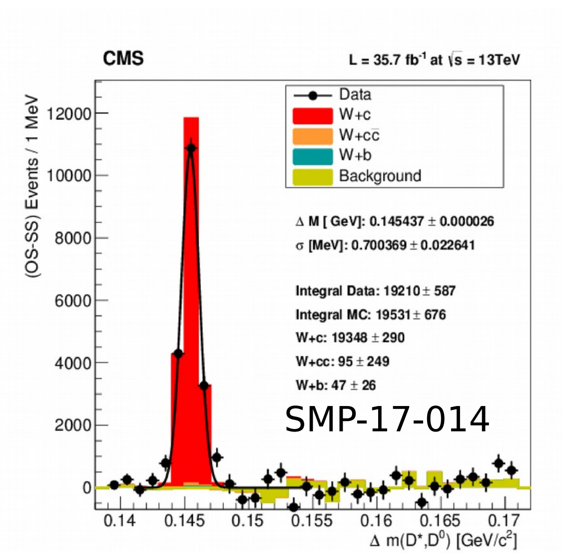
Selection of W+c samples

- W→ eν, μν plus jets with similar selection to Z+HF
- Identification of heavy flavor jet: **μ or SV in jet from D-hadron inclusive decays or $D^{*\pm}$**
- OS–SS subtraction to remove symmetric backgrounds

After OS-SS subtraction the purity in W+c of the resulting sample is > 80% (SL and SV channels) and >98% ($D^{\pm}$ and $D^{*\pm}$ channels)







For OS-SS subtraction in the c→ **μ in jet** case we use the electric charges of W→e(μ) & **μ in jet**

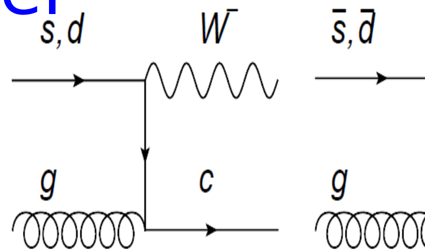
- OS : $Q_{W\to e(\mu)} \neq Q_{\mu \text{ in jet}}$ SS : $Q_{W\to e(\mu)} = Q_{\mu \text{ in jet}}$

Results :

Comparison with predictions

Results: σ(W+c) @ 13 TeV

Charm from D* channel

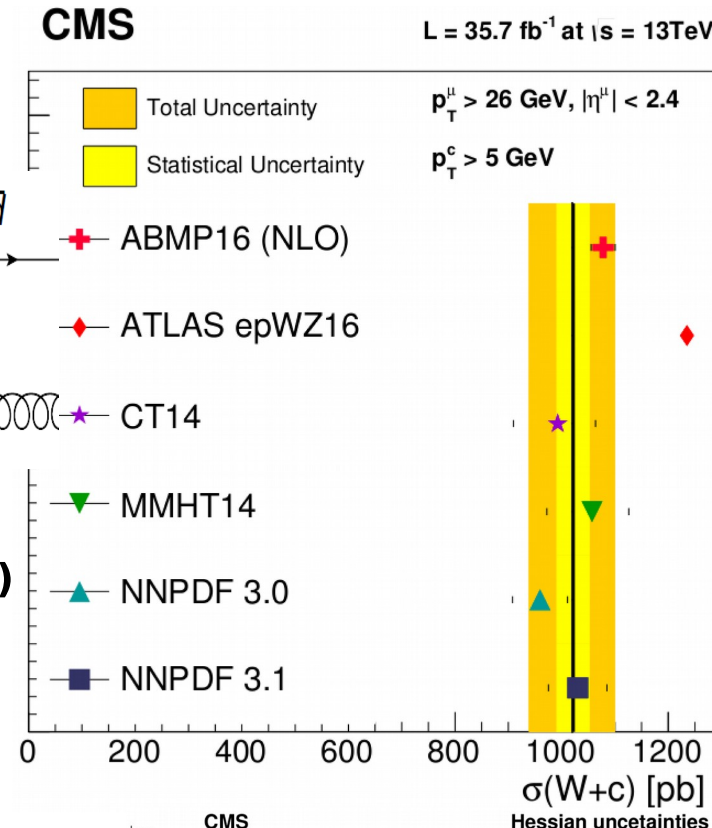


$$\sigma = N_{(W+D^*)data} / L\, B\, A_c\, \varepsilon_c$$

$$A_c\, \varepsilon_c = N_{W+D^*(reco)} / N_{W+c(gen)}$$

$\sigma(W+c) = 1026 \pm 31(stat)^{+76}_{-72}(syst)$ pb

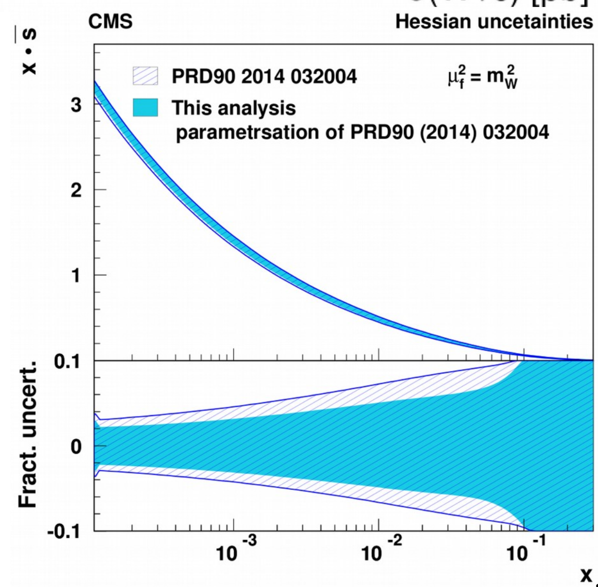
$\sigma(W^+ + c)/\sigma(W^- + c) = 0.968 \pm 0.055(stat)^{+0.015}_{-0.028}(syst)$



In good agreement with the theoretical predictions at NLO using different PDF sets

(except for ATLASepWZ16nnlo PDF)

From a QCD analysis at NLO together with inclusive DIS measurements and earlier results from CMS on W+c production and the lepton charge asymmetry in W-production : The strange quark distribution and strangeness suppression factor agree with results from neutrino-scattering experiments.



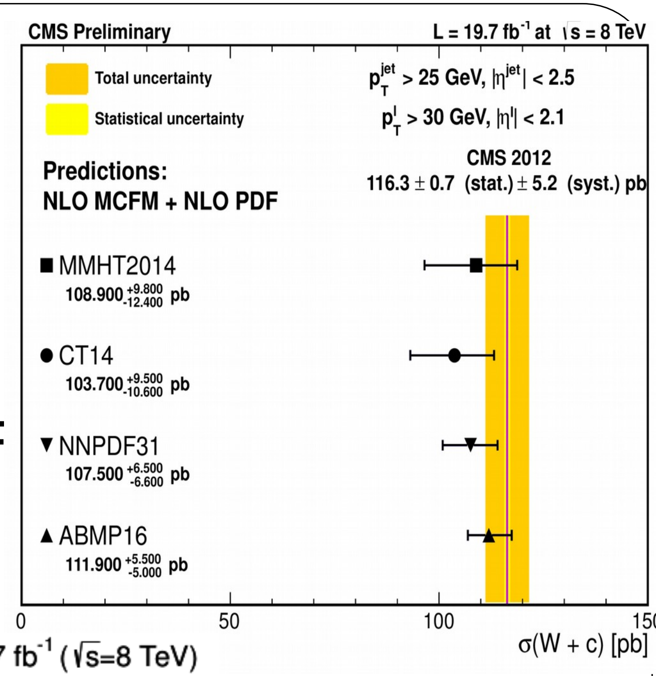
Results: σ(W+c) @ 8 TeV

$$\sigma = N_{(W+c)data} / L\, B\, A_c\, \varepsilon_c$$

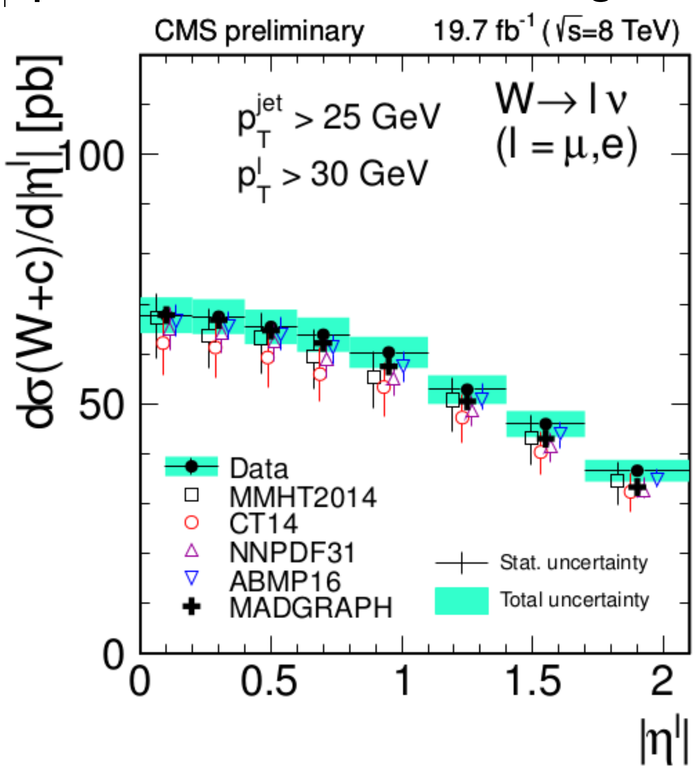
$$A_c \varepsilon_c = N_{W+c(reco)} / N_{W+c(gen)}$$

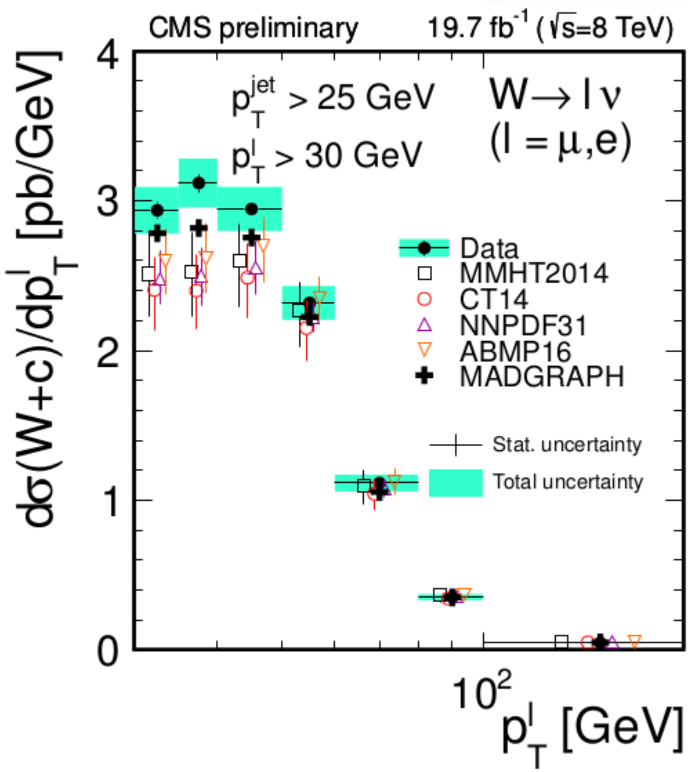
σ(W+ c)=116.3±0.7(stat)±5.2(syst) pb

σ(W⁺+c)/σ(W⁻+c)= 0.986±0.011(stat)± 0.013(syst



In good agreement with the theoretical predictions at NLO using different PDF sets





Charm from SL and SV channels

Another technique :

σ(Z+HF): Different contributions (from Z+c and Z+b ,production) present

Modeling strategy needed :

(I) choose the variables to separate the different contributions

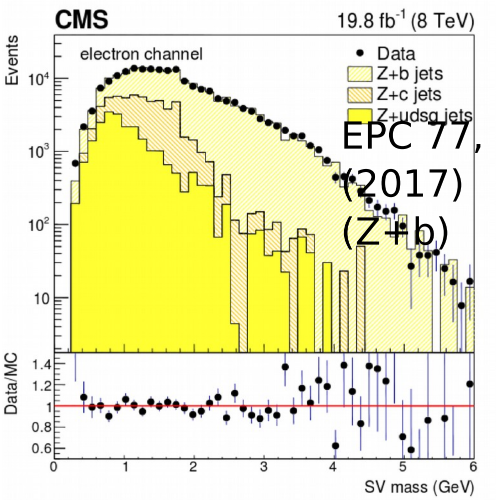
(II) make sure we model properly each of them

This is called template modeling and has two parts:

- Modeling properly the shape
- Accurate determination of tagging efficiency

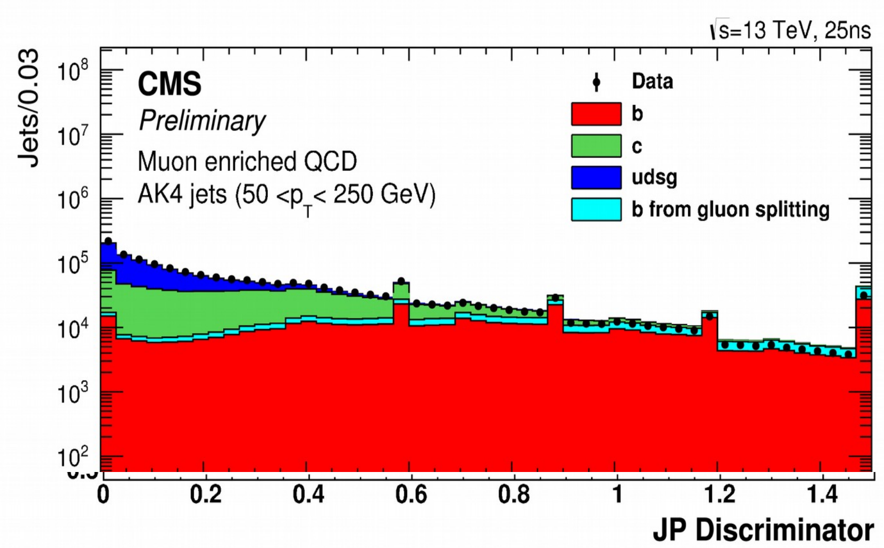
b/c/l separation (discriminants)

- Invariant mass of all charged particles attached to the reconstructed secondary vertex

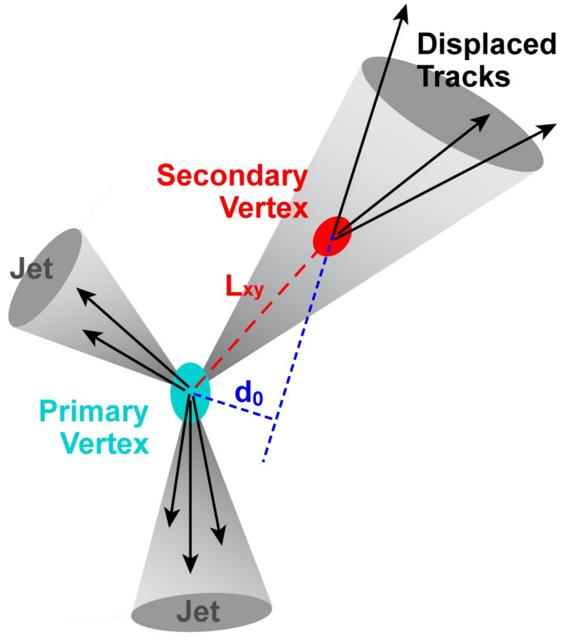


EPC 77, 751 (2017) (Z+b)

- JP : likelihood estimate of prob. of jet constituents to come from primary vertex



The larger the IP of a track the more incompatible w.r.t. PV



Template modeling:

- sometimes is data driven
- or from MC

Signal extraction (Z+c)

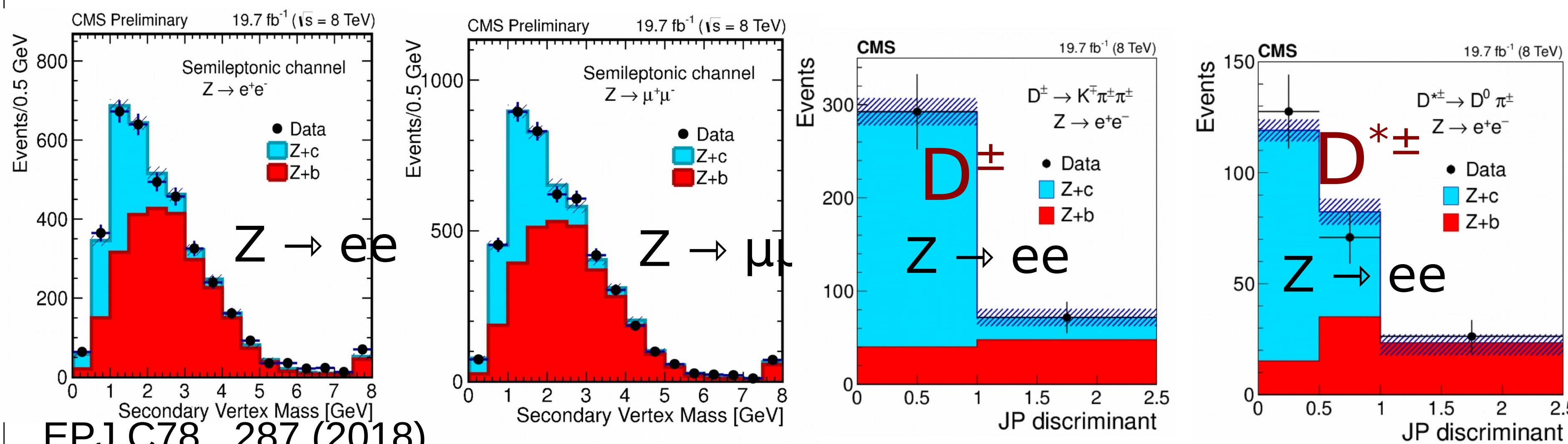
Z: Total # of observed Z+c/Z+b extracted from a χ^2 minimization fit of the Z+c/Z+b templates to the experimental distributions of vertex mass and JP discriminants

$$\chi^2 = \sum_i \frac{(n_i^{data} - \mu_{\mathrm{Z+c}} N_i^{\mathrm{Z+c}} - \mu_{\mathrm{Z+b}} N_i^{\mathrm{Z+b}})}{(\sigma_i^d)^2 + (\sigma_i^{\mathrm{MC}})^2}$$

n_i = Number of events in data (after subtraction of remaining background from Z+light, $t\bar{t}$ and VV)

N_i^{Z+c}, N_i^{Z+b} = Number of Z+c, Z+b

Parameters to fit: μ_{z+c} & μ_{z+b}



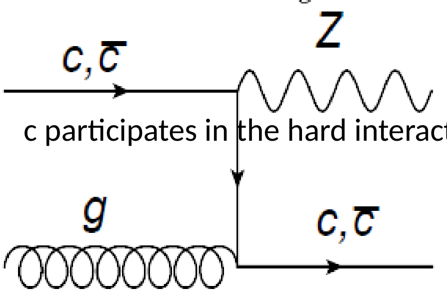
EPJ C78, 287 (2018)

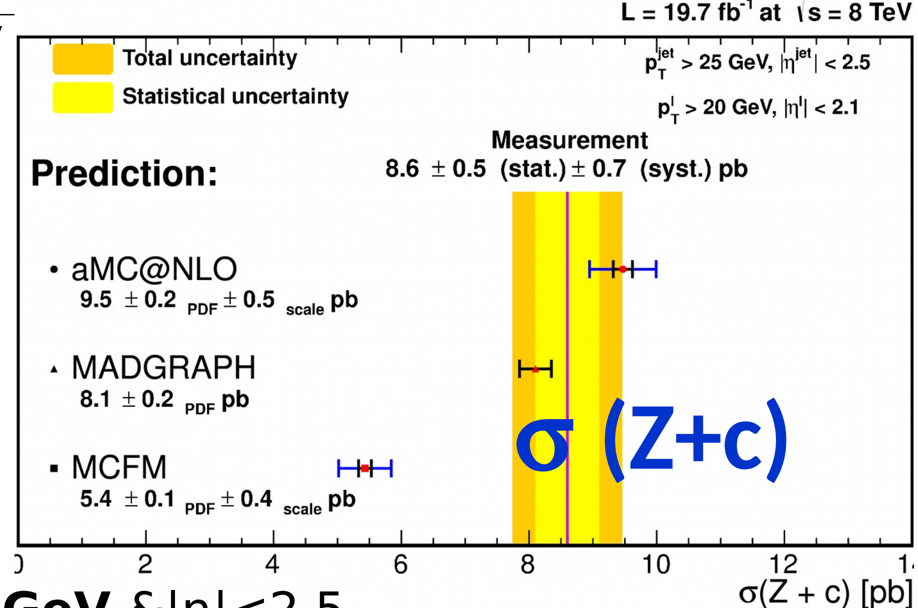
c/b separation clearer in the D* mode (the soft pion comes from the PV for c→ D* and not for b→ B→D*)

μ_{z+c} & μ_{z+b} in the 0.9-1.1 range

Results: σ(Z+c) @ 8 TeV

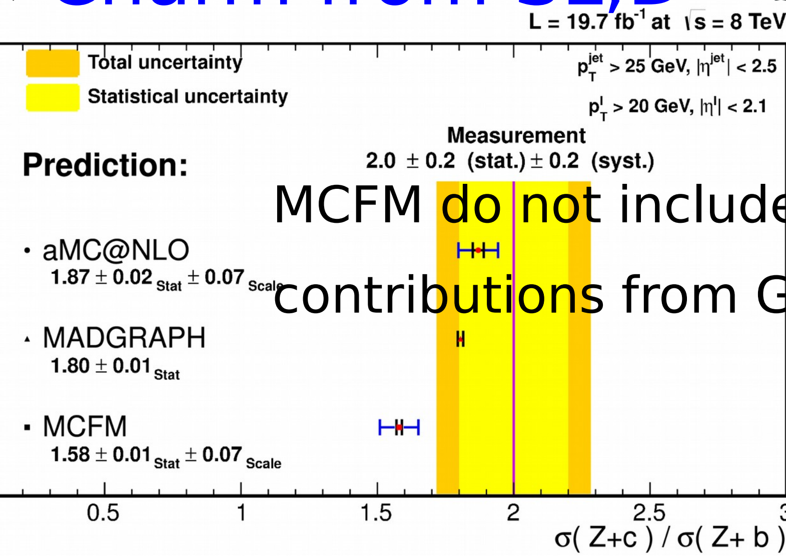
$$\sigma(\mathrm{Z+c}) = \frac{N^{fitted}_{Z+c}}{\epsilon_c^{Z+c}\mathcal{L}} \quad ;$$





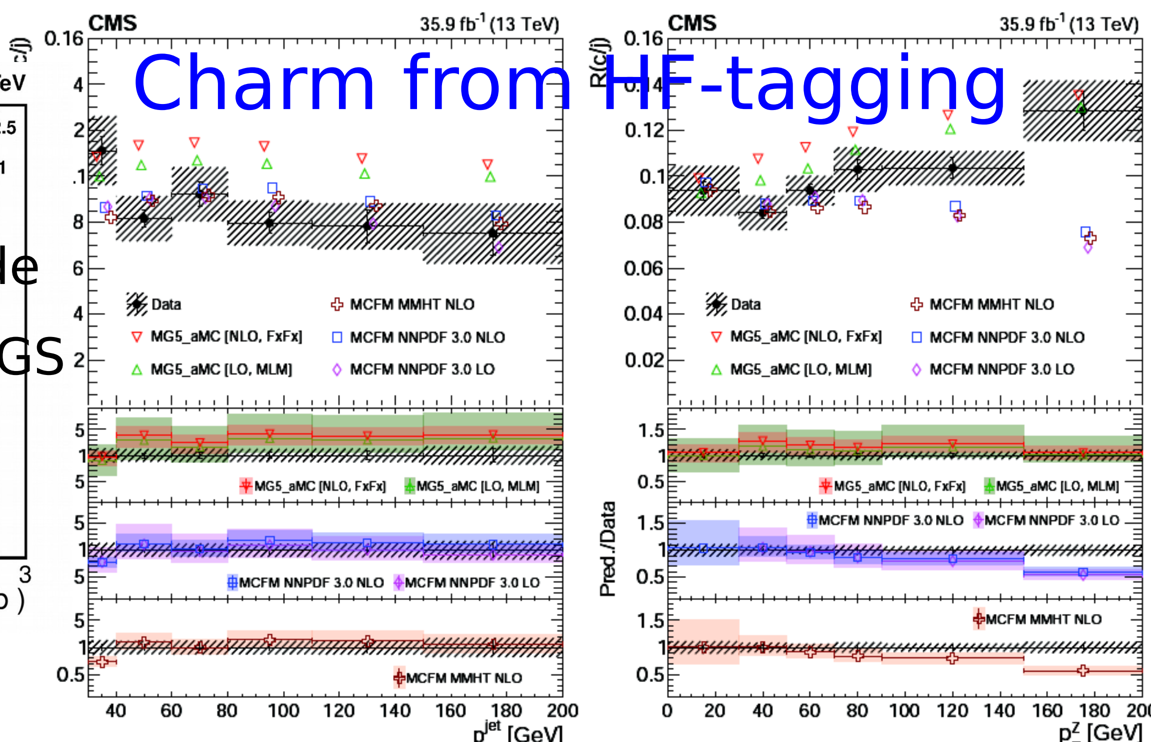
μ,e(pT)>25 GeV & |η|<2.1, **jet(pT)>25 GeV** &|η|<2.5

Charm from SL,D*±



MCFM do not include contributions from GS

Charm from HF-tagging

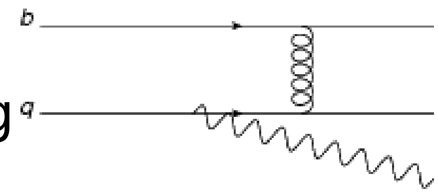


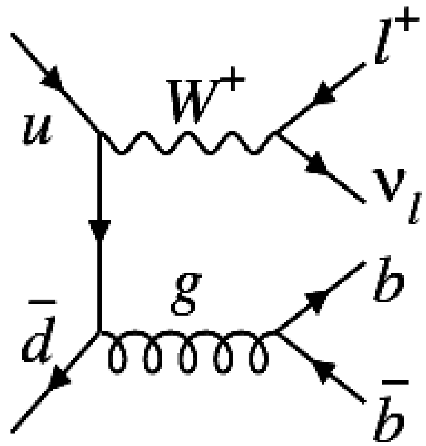
EPJ C, Vol. 78, 287 (2018)

https://arxiv.org/abs/2001.06899

W+b**b**

Physics Letters B 735: 204-225 (2014) at √s = 7 TeV

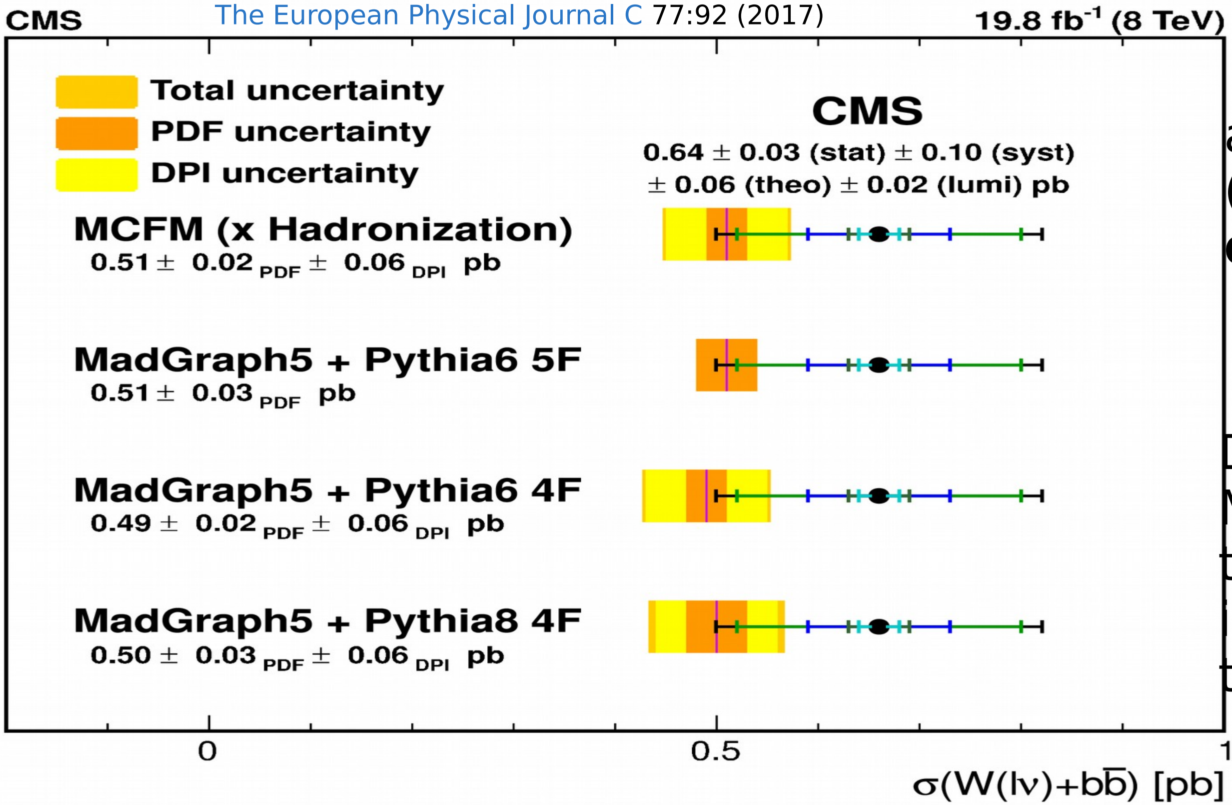




Primary contribution is g splitting

W+b**b** production is a background in H+Z/W (H→ b**b**)

The European Physical Journal C 77:92 (2017)



Use W → μν and **2 b-tagged jets** (**jets originated from b quarks**)

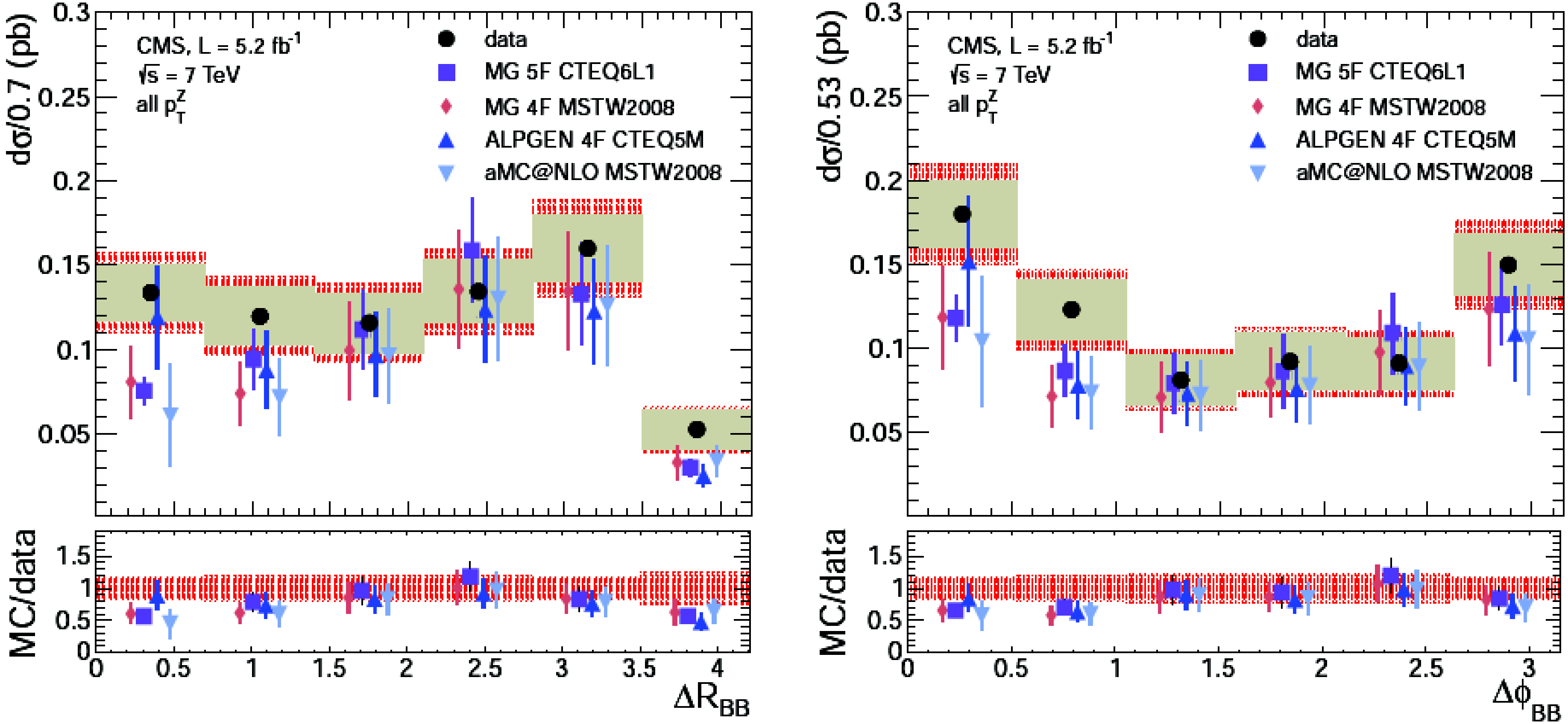
Data is in agreement with MC and theory. Large errors though (large SFs in VH(bb) analysis from this bakcground source).

ATLAS W+b differs from predictions (difference larger in the production of events with a collinear b**b** pair reconstructed as 1 jet JHEP 06 (2013) 084)

topology afflicted by significant theoretical uncertainties

JHEP 06 (2014), 120 (Z+bb @ 7TeV)

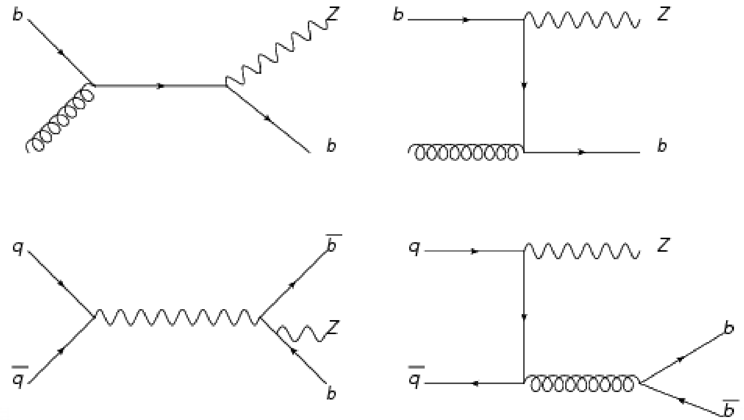
The b-hadrons are identified by means of displaced secondary vertices, without the use of reconstructed jets



5FS-based theoretical calculations may not be well suited to describe the collinear production of b-hadrons

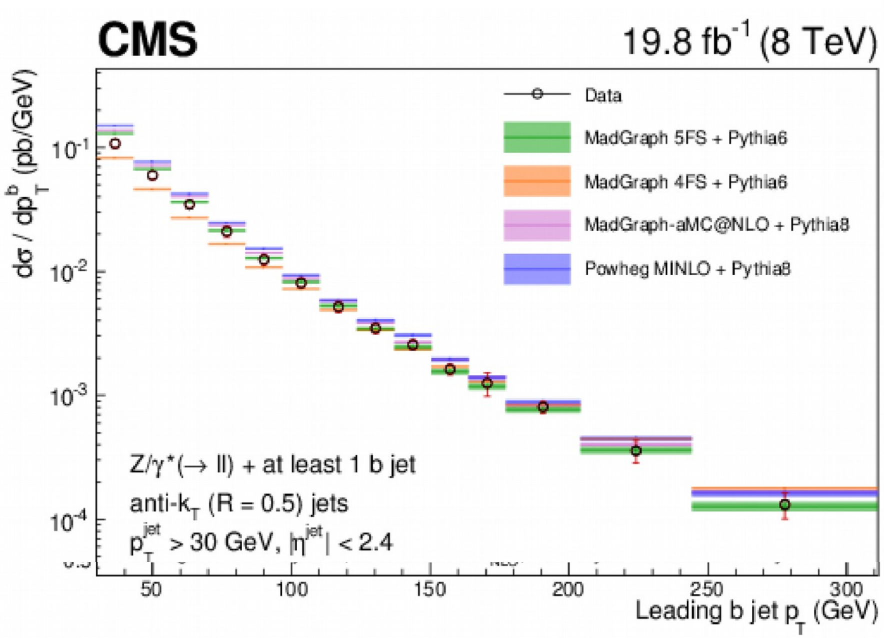
Z+b**b**

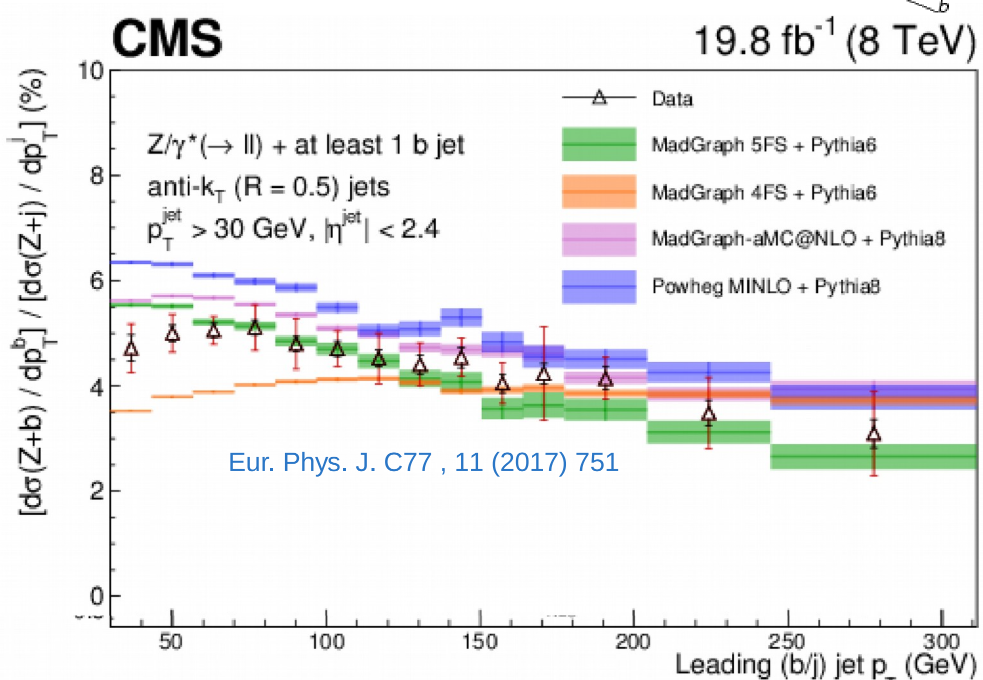
Primary contribution:



Use Z → ll (ee or μμ)

and **1 or 2 b-tagged** jets & ΔR(l, j) > 0.5



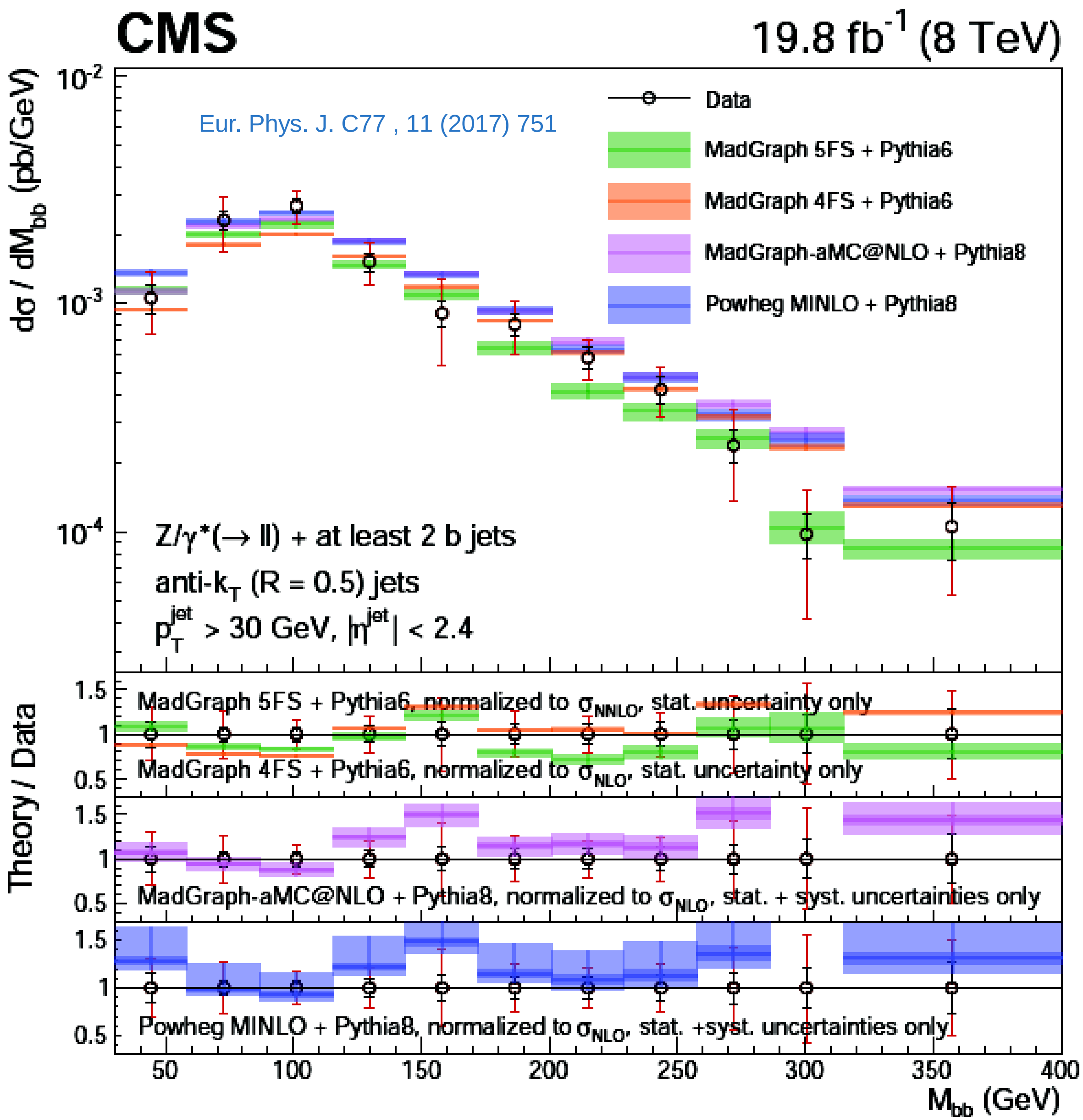


Testing two different flavour schemes for the choice of initial-state partons.

Agreement with 5FS-based theoretical calculations.4FS better@lowjet pt

- Z + two b-jets : agreement in the dijet mass distribution

Z+b**b**



Current and future analyses using full Run II

- W+c
- W+cc
- W^+W^- (W->cs)
- W+b
- Z+HF inclusive or exclusive channels
- γ + HF

Validate your templates

Conclusions

Evaluated W/Z + heavy hadron associated production, inclusive and differential (more in back-up)

Agreement with predictions from MadGraph5 amc@nlo and Madgraph renormalized to a FEWZ calculation.

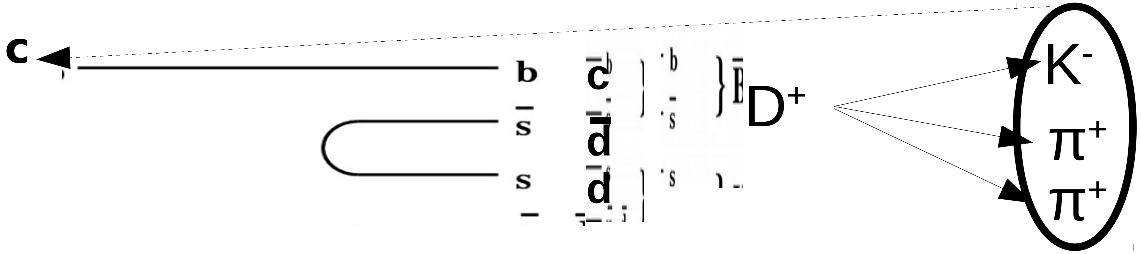
There has been a lot of improvement in the last decades and there is more to come from both , theoretical and experimental results

Back up

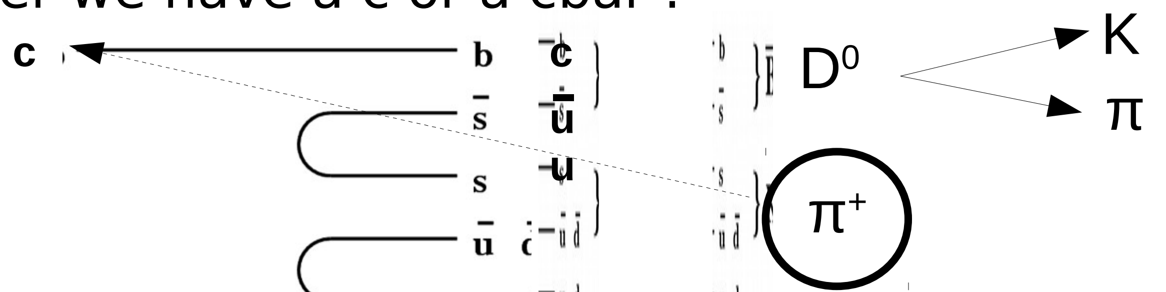
Charm charge determination of W+c samples

- In the SL(D^*) channel the charm charge is that of the $\mu(D^*)$

- In the SV channel, the charge of the SV vertex : $\sum^{\text{Vertex-tracks}} q_{tracks}$



- If vertex-charge == 0 use charge of closest PV-track ($p_T > 0.3$ && $\Delta R(\text{track, IVF-vertex}) < 0.1$). The sign of that track, the closest track to the $\text{Charm}_{\text{hadron}}$ in the process of fragmentation, tells you whether we have a c or a cbar :

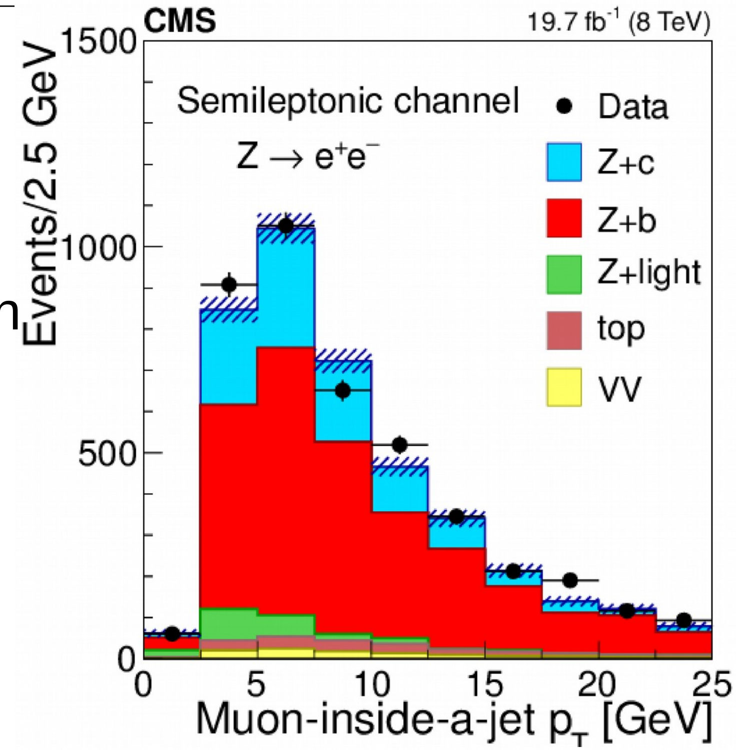


- Charge definition: OS if charges of the SV and the lepton from the W decay are opposite.

- OS : $Q_{W\to e(\mu)} \neq Q_{SV}$ SS : $Q_{W\to e(\mu)} = Q_{SV}$

Semileptonic selection for Z and W analysis (SL channel)

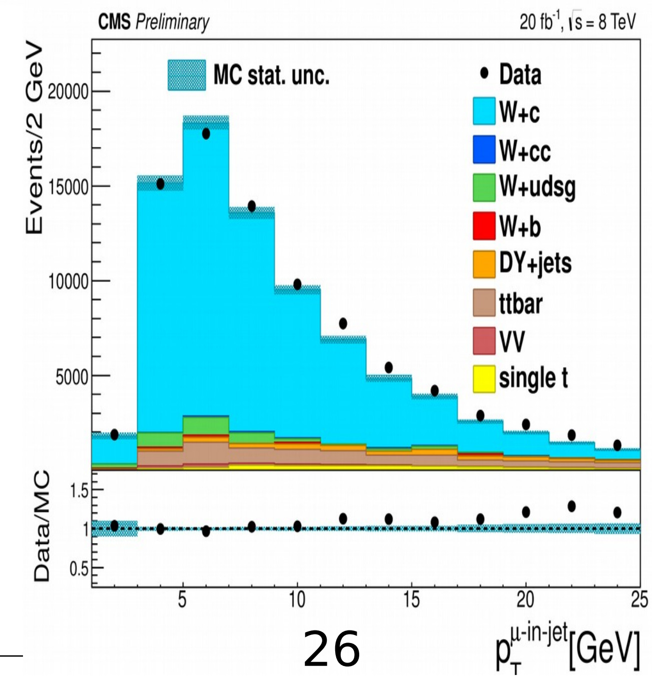
- μ inside a jet (taking part of a secondary vertex for Z). This reduces the light contribution more than standard b-tagging algorithms.
- $p_T^{\mu} < 25$ GeV, with $p_T^{\mu}/p_T^{jet} < 0.6$, $|\eta^{\mu}| < 2.5$
- non-isolated, $I_{comb}/p_T^{\mu} > 0.2$



Semileptonic candidates:

4145 $Z \rightarrow e^+e^-$ 5258 $Z \rightarrow \mu^+\mu^-$

52K $W \rightarrow e\upsilon$ 32K $W \rightarrow \mu\upsilon$



Relative contributions:

Z+c:25% Z+b:65% Z+light:5% Others:5%

W+c:80% W+b:0.5% W+light:4% top:10% Others:6%

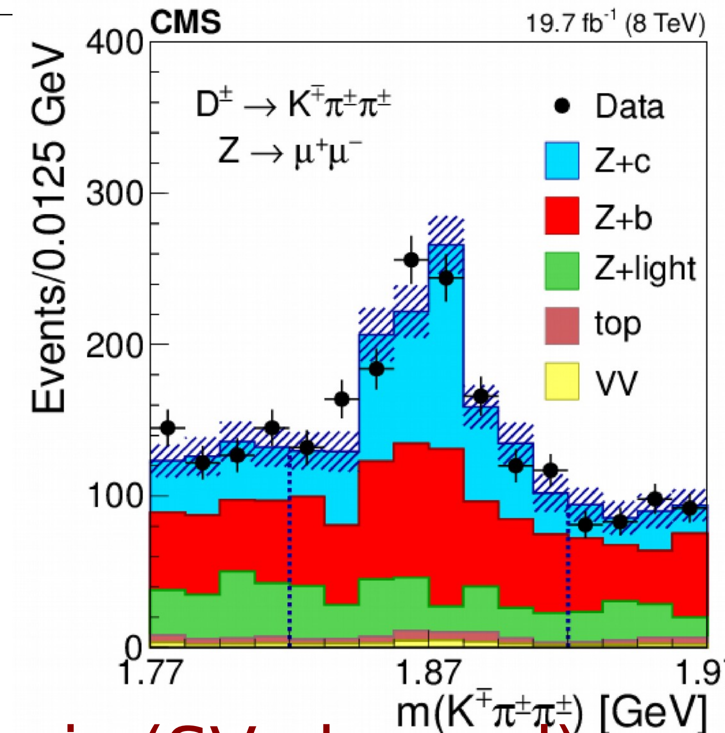
$D^{\pm}$ Selection for Z analysis ($D^{\pm}$)

Use jets with a 3 tracks secondary vertex & search for $D^{\pm} \rightarrow K^{\mp}\pi^{\pm}\pi^{\pm}$ resonant peak.

Non resonant bkg. in the signal region subtracted from the neighboring sidebands

490 ± 48 $D^{\pm}$ ($Z \rightarrow \mu^{+}\mu^{-}$) 375 ± 44 $D^{\pm}$ ($Z \rightarrow e^{+}e^{-}$)

Z+c: ~60% Z+b: ~35% Others:<5%

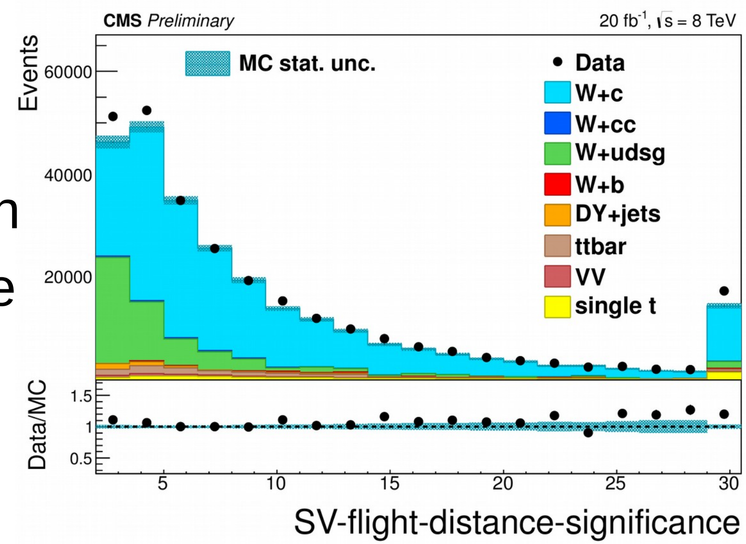


Exclusive D selection for W analysis (SV channel)

- Reconstructed secondary vertex in jet
- Vertex_mass>0.55 GeV and SV flight distance significance>3.5 to reduce light jet contamination
- In case of several jets with SV in the event, take the **highest p_T jet**

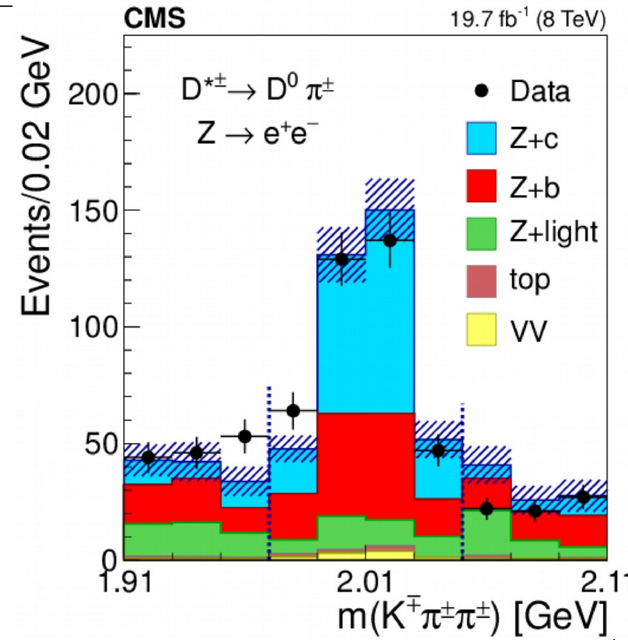
117K $W \rightarrow e\upsilon$ 131K $W \rightarrow \mu\upsilon$

W+c:75% W+b:0.5% W+light:15% top:6% Others:3.5%

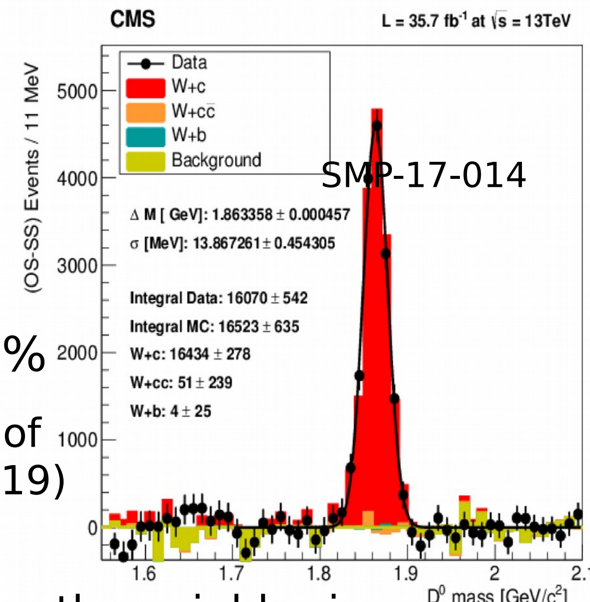


$D(2010)^{*\pm}$ Selection for Z (W) analysis ($D^{*\pm}$ channel)

- $D^{*\pm} \to D^0 \pi_s^{\pm} [D^0 \to K^- \pi^+ (+c.c.)]$ decay chain.
- Kaon: track with sign opposite to π_s



- D^0 vertex with $L_{xy}/\sigma(L_{xy})>3(0)$, D^0 vertex prob.>0.05
- $p_T(D^*)>0(4)$ && $p_T(D^*)/\Sigma p_{T(cone\ 0.4)} > 0(0.2)$
- $p_T(K)>1.75(1)$, $p_T(\pi)>0.75(1)$, $p_T(\pi_s)>0.5(0.35)$ GeV
- $|\Delta R(D^*, jet)| < 0.5$, $|\Delta R(D^0, \pi_s)| < 0.1(0.15)$.
- $|m(D^0)-1.865|<100(35)$ MeV, $|\Delta m-145|< 5$ (1) MeV
- Signal region : $1.97 < m(D^*) < 2.05$ GeV
- Sidebands : $0.06 < |m(D^{*\pm})-2.01| < 0.12$ GeV



After sideband subtraction: 309 ± 22 $D^{*\pm}(Z \to \mu^+\mu^-)$
234 ± 22 $D^{*\pm}(Z \to e^+e^-)$

Z+c:~65% Z+b:~30% Z+light:<1% Others(tt+VV):<4%

- The simulation is reweighted to match the experimental values of $c \to D^{*\pm} \to D^0 \pi_s^{\pm} [D^0 \to K^- \pi^+]$ (PDG+L.Gladilin,Eur.Phys.J.C75(2015)19)

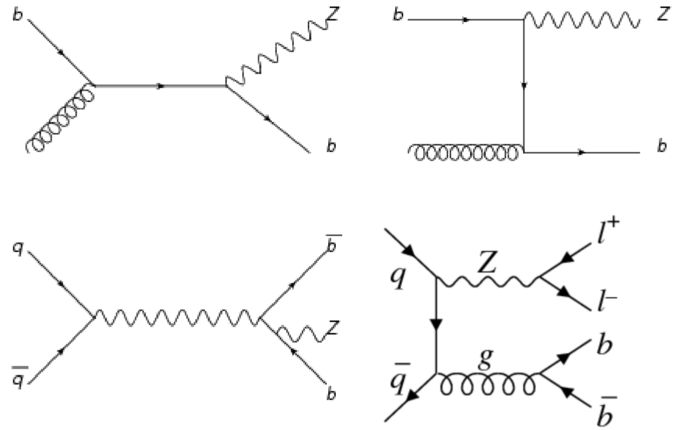
Non resonant background in the signal region subtracted from the neighboring sidebands (wrong charge $D^0 \to K^- \pi^- (+c.c.)$ in W+c analysis)

$19.2 \pm 0.6 \times 10^3$ $D^{*\pm}$ $(W \to \mu\nu)$

Z+b**b**

JHEP 06 (2014) 120 at √s = 7 TeV

Primary contribution:



Use Z → ll (ee or μμ)

and **1 or 2 b-tagged** jets & ΔR(l, j) > 0.5

Testing two different flavour schemes for the choice of initial-state partons.

cross sec.	Measured (pb)	MADGRAPH (5F)	aMC@NLO (5F)	MCFM (parton level)	MADGRAPH (4F)	aMC@NLO (4F)
sZ+1b	3.52±0.28	3.66±0.22	$3.70^{+0.23}_{-0.26}$	$3.03^{+0.30}_{-0.36}$	$3.11^{+0.47}_{-0.81}$	$2.36^{+0.47}_{-0.37}$
sZ+2b	0.36±0.07	0.37±0.07	0.29±0.04	0.29±0.04	$0.38^{+0.06}_{-0.10}$	$0.35^{+0.08}_{-0.06}$
sZ+b	3.88±0.22	4.03±0.24	$3.99^{+0.25}_{-0.29}$	$3.23^{+0.34}_{-0.40}$	$3.49^{+0.52}_{-0.91}$	$2.71^{+0.52}_{-0.41}$
sZb/Zj(%)	5.15±0.25	5.35±0.11	$5.38^{+0.34}_{-0.39}$	$4.75^{+0.24}_{-0.27}$	$4.63^{+0.69}_{-1.21}$	$3.65^{+0.70}_{-0.55}$

Z+1b data favors five-flavour scheme(b massless).Z+2b favors 4FS .

~2σ data vs MCFM (parton-level) cross section difference specific to the modeling of the Z+b-jets final state.

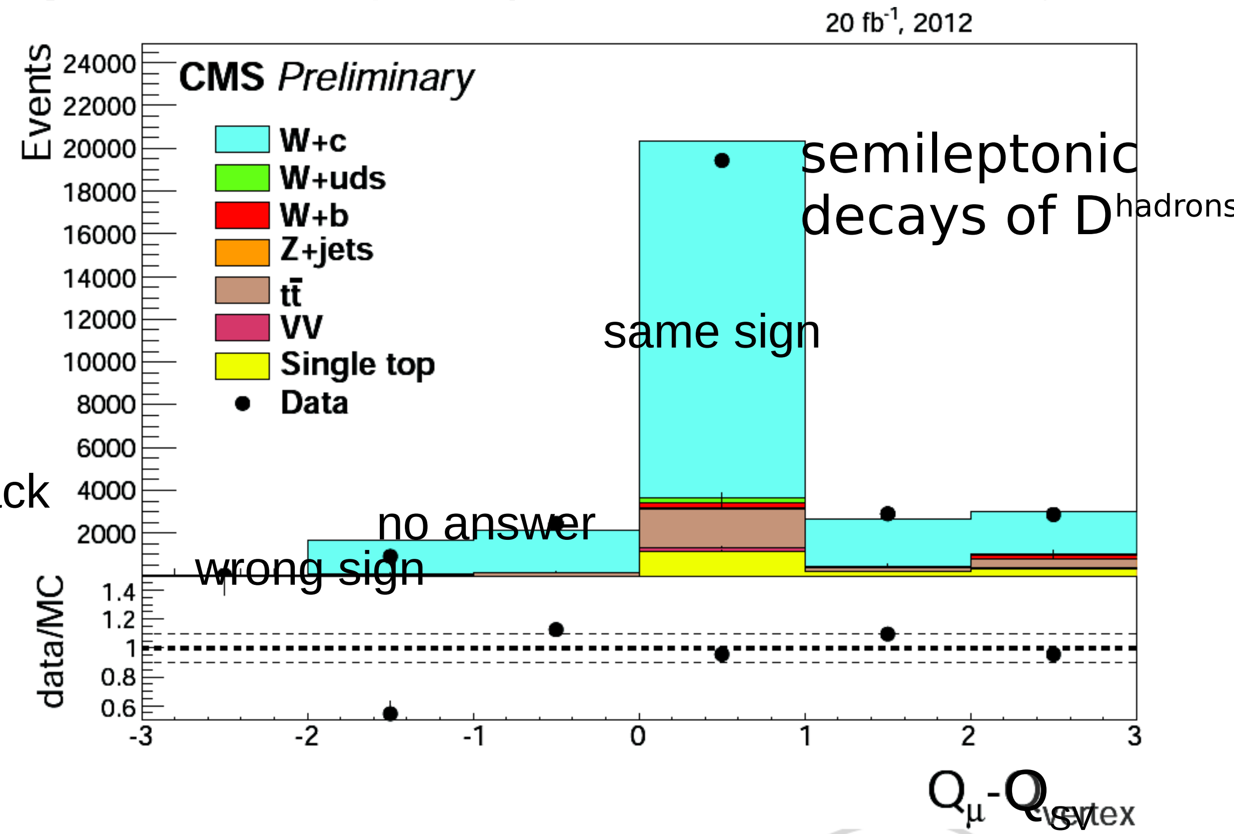
Test of Q_{SV} algorithm

- **Using semileptonic sample for test** (sample with a muon in a jet & IVF-vertex) :

  test of $Q_{\mu\text{-in-jet}} - Q_{SV}$

  - 70%: 0 → same sign
  - 10%: 2 or -2 → wrong sign
  - 20%: 1 or -1 → no answer

(no answer → no nearby PVtrack with $p_T > 0.3$ && ΔR(track, IVF-vertex)<0.1)



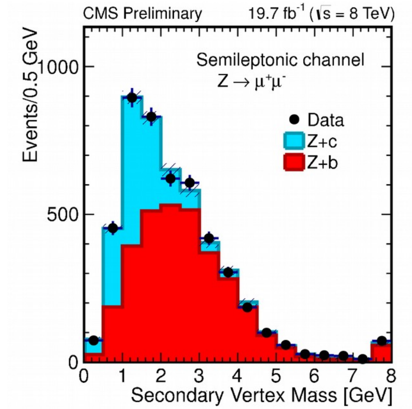
- When the algorithm gives an answer: right 87% of the times, wrong 13% (after OS(87%)-SS(13%) subtraction we are left with 74% of the answers).

Z+c Selection: b/c separation (discriminants)

- Vertex mass (for semileptonic mode)

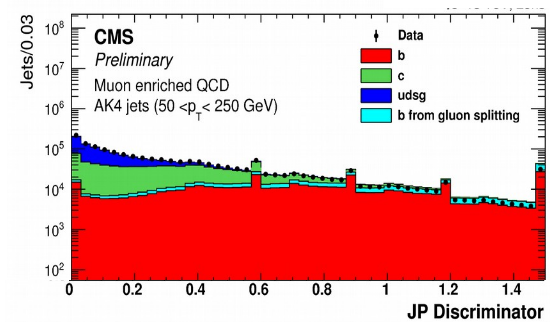
$$M^{\text{corr}}_{\text{vertex}} = \sqrt{M^2_{\text{vertex}} + p^2_{\text{vertex}} \sin^2\theta} + p_{\text{vertex}} \sin\theta,$$

Correction included to account for unidentified neutral decay products



- JP (for D hadron modes): likelihood estimate of prob. of jet tracks to come from primary vertex

The larger the IP of a track the more inconsistent w.r.t. PV



Modeling strategy

- Z+c :

  Shape : data driven (W+charm) [1st time]

  Normalization taken from MC after applying vertex-efficiency corrections

- Z+b :

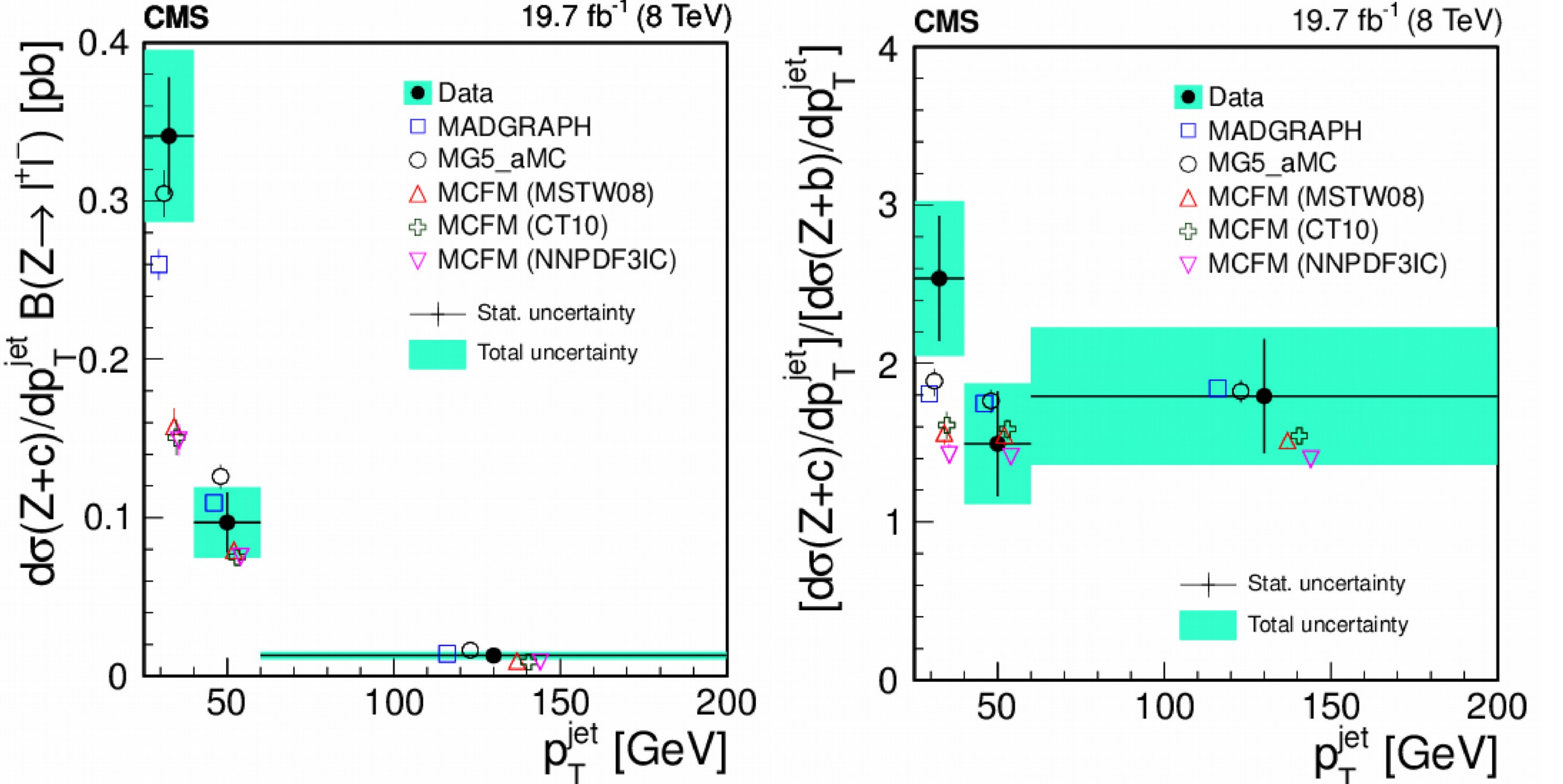
  Shape : from MC but corrected with data (ttbar)

  Normalization from MC after vertex-efficiency corrections

- Z+light and Dibosons: shape and normalization from MC
- ttbar: Data driven

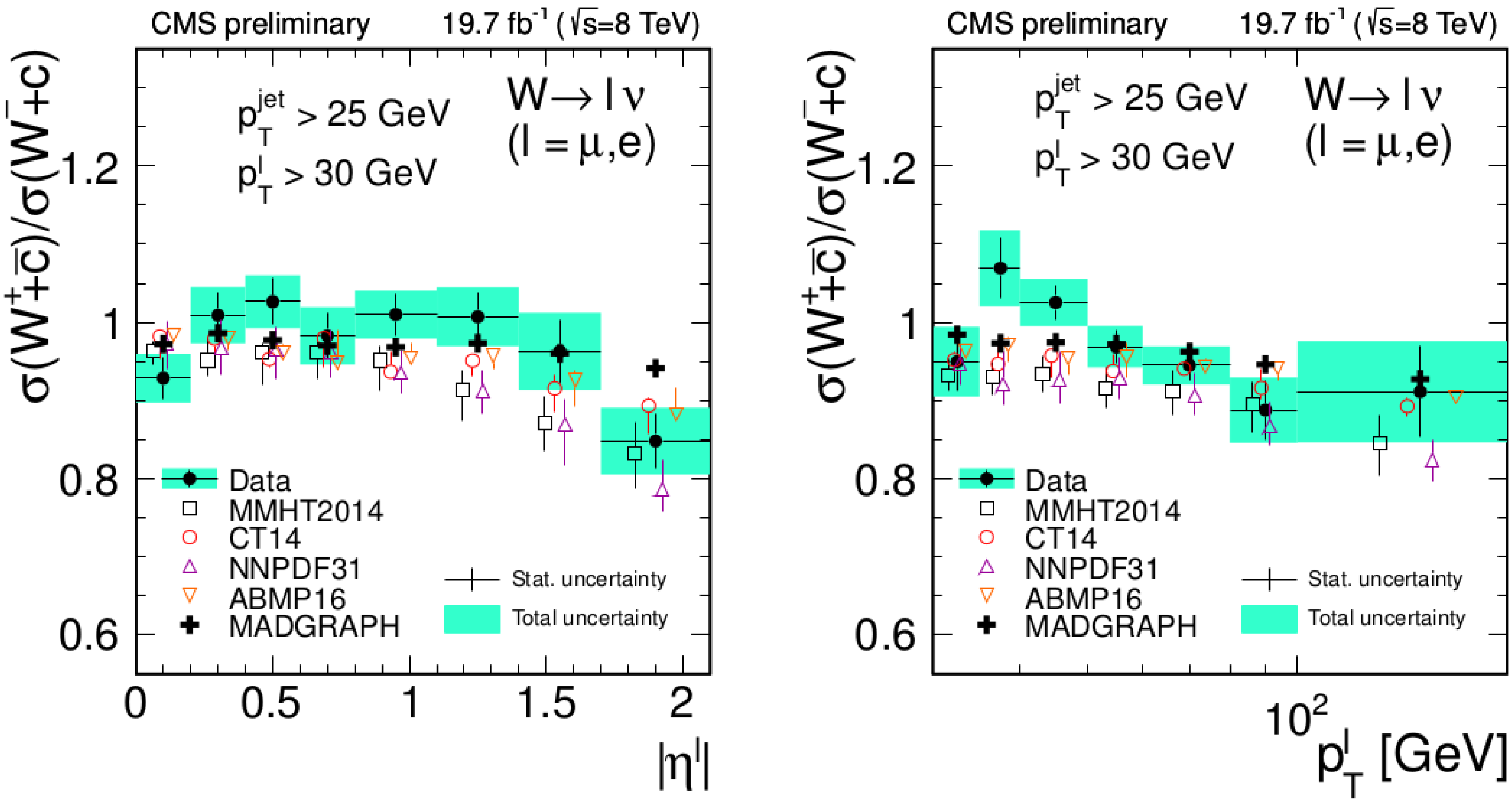
Differential cross sections as a function of p_T^{jet}

Bins [GeV] : 25-40, 40-60 and 60-200



If the proton momentum fraction taken by the charm quark component (intrinsic + perturbative) is of ~2%,an increase in the production of Z+c events with a $p_T^Z \approx 100$ GeV of at least 20–25% would be expected. No increase in the production rate in the highest p_T^{jet} bin is observed (in agreement with current upper limits on IC component)

- Comparison with MCFM (differential cross section ratio)



Preselection

Preselection of Z$\rightarrow$ ee and Z$\rightarrow$ $\mu\mu$ plus jets

- Z$\rightarrow$ ee:
  - Dielectron trigger thres-hold of 17 and 8 GeV
  - Electron Id Medium WP
  - pT(e)> 20 GeV, $|\eta(e)| < 2.1$
  - Isolated: Icomb/pT <0.15
  - Energy scale corrected
  - MC corrected for differences in Electron Id and Iso efficiencies
- Z$\rightarrow\mu\mu$:
  - DiMuon trigger thres-hold of 17 and 8 GeV
  - Tight selection
  - pT(e)> 20 GeV, $|\eta(e)| < 2.1$
  - Isolated: Icomb/pT <0.2
  - Momentum scale and resolution corrected (Rochester correction)
  - MC corrected for differences in Muon Trigger, Id and Iso

- Jets:
  - Jets anti-kT, R=0.5
  - JEC corrected, both in data and MC
  - pT(jet) > 25 GeV, $|\eta(jet)| < 2.5$

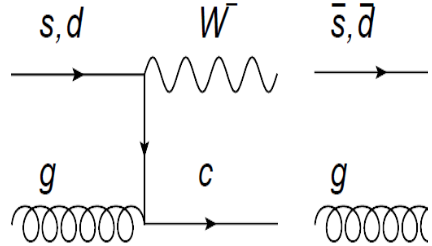
Cross section determination

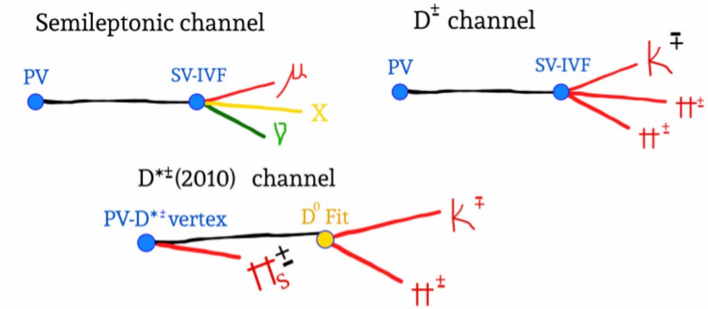
$$\sigma(\mathrm{Z}+\mathrm{c}) = \frac{N^{fitted}_{\mathrm{Z+c}}}{\epsilon_c^{\mathrm{Z+c}}\mathcal{L}} \quad ;$$

Semileptonic mode			
Channel	$N^{\mathrm{signal}}_{\mathrm{Z+c}}$	$\mathcal{C}_{\mathrm{Z+c}}$ (%)	$\sigma(\mathrm{Z+c})$ [pb]
$\mathrm{Z}\to \mathrm{e^+e^-}$	1066 ± 95	0.63 ± 0.03	$8.6 \pm 0.8 \pm 1.0$
$\mathrm{Z}\to \mu^+\mu^-$	1449 ± 144	0.81 ± 0.03	$9.1 \pm 0.9 \pm 1.0$
$\mathrm{Z}\to \ell^+\ell^-$	$\sigma(\mathrm{Z+c}) = 8.8 \pm 0.6\,(\mathrm{stat}) \pm 1.0\,(\mathrm{syst})$ pb		
Channel	$N^{\mathrm{signal}}_{\mathrm{Z+b}}$	$\mathcal{C}_{\mathrm{Z+b}}$ (%)	$\sigma(\mathrm{Z+c})/\sigma(\mathrm{Z+b})$
$\mathrm{Z}\to \mathrm{e^+e^-}$	2606 ± 114	2.90 ± 0.08	$1.9 \pm 0.2 \pm 0.2$
$\mathrm{Z}\to \mu^+\mu^-$	3240 ± 147	3.93 ± 0.10	$2.2 \pm 0.3 \pm 0.2$
$\mathrm{Z}\to \ell^+\ell^-$	$\sigma(\mathrm{Z+c})/\sigma(\mathrm{Z+b}) = 2.0 \pm 0.2\,(\mathrm{stat}) \pm 0.2\,(\mathrm{syst})$		
$\mathrm{D}^{\pm}$ mode			
Channel	$N^{\mathrm{signal}}_{\mathrm{Z+c}}$	$\mathcal{C}_{\mathrm{Z+c}}$ (%)	$\sigma(\mathrm{Z+c})$ [pb]
$\mathrm{Z}\to \mathrm{e^+e^-}$	276 ± 55	0.13 ± 0.02	$10.9 \pm 2.2 \pm 0.9$
$\mathrm{Z}\to \mu^+\mu^-$	316 ± 75	0.18 ± 0.02	$8.8 \pm 2.0 \pm 0.8$
$\mathrm{Z}\to \ell^+\ell^-$	$\sigma(\mathrm{Z+c}) = 9.7 \pm 1.5\,(\mathrm{stat}) \pm 0.8\,(\mathrm{syst})$ pb		
$\mathrm{D}^{*\pm}(2010)$ mode			
Channel	$N^{\mathrm{signal}}_{\mathrm{Z+c}}$	$\mathcal{C}_{\mathrm{Z+c}}$ (%)	$\sigma(\mathrm{Z+c})$ [pb]
$\mathrm{Z}\to \mathrm{e^+e^-}$	151 ± 31	0.11 ± 0.01	$7.3 \pm 1.5 \pm 0.5$
$\mathrm{Z}\to \mu^+\mu^-$	247 ± 28	0.14 ± 0.01	$9.3 \pm 1.1 \pm 0.7$
$\mathrm{Z}\to \ell^+\ell^-$	$\sigma(\mathrm{Z+c}) = 8.5 \pm 0.9\,(\mathrm{stat}) \pm 0.6\,(\mathrm{syst})$ pb		
Combination			
$\mathrm{Z}\to \ell^+\ell^-$	$\sigma(\mathrm{Z+c}) = 8.8 \pm 0.5\,(\mathrm{stat}) \pm 0.6\,(\mathrm{syst})$ pb		

W+c

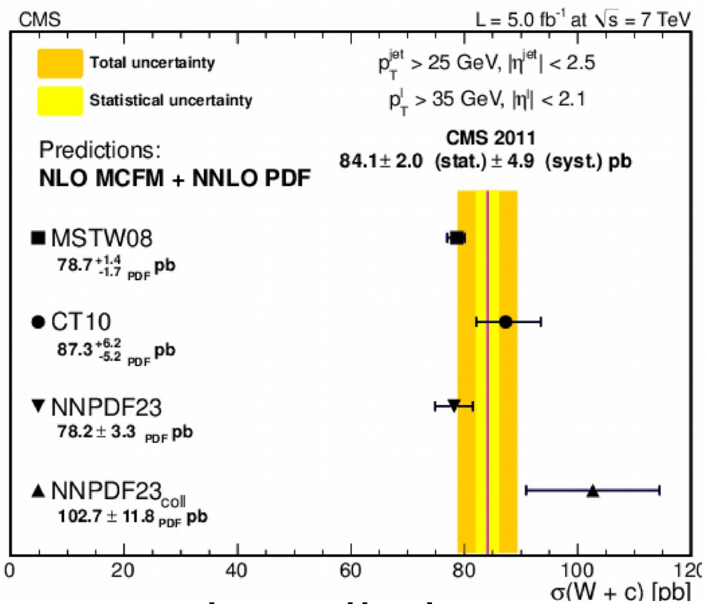
- W→ eν or μν

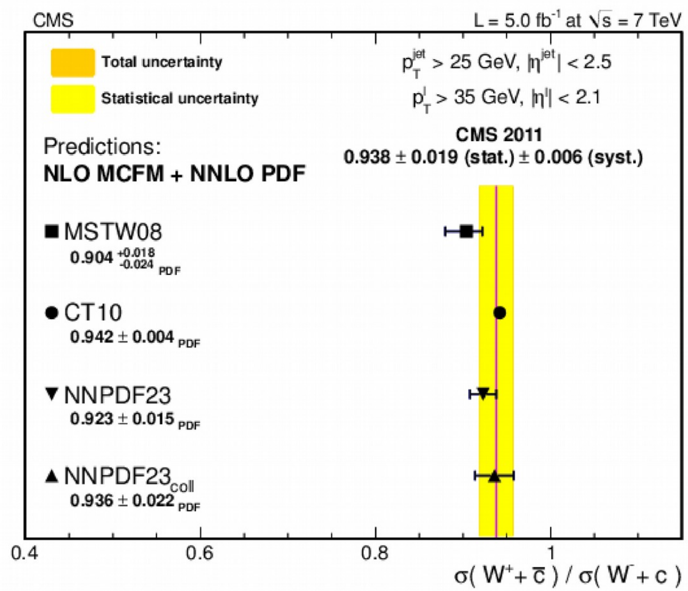


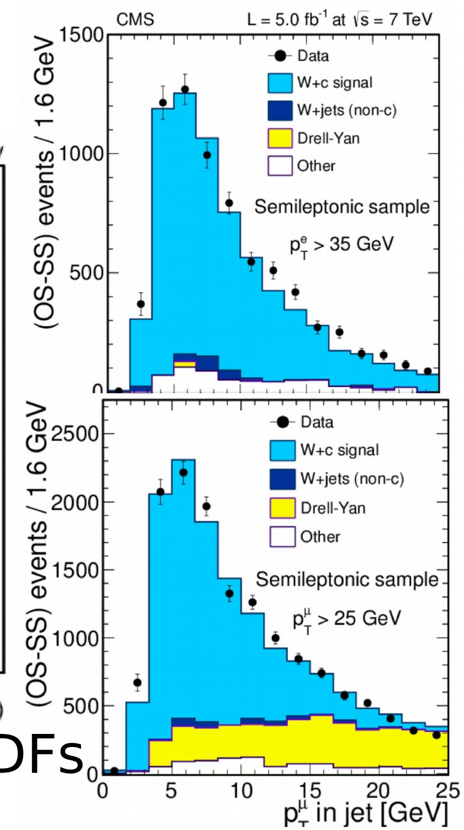


Identification of heavy flavor: **μ in jet or D-hadron**

The MCFM predictions for this process do not include contributions from gluon splitting into a cc pair





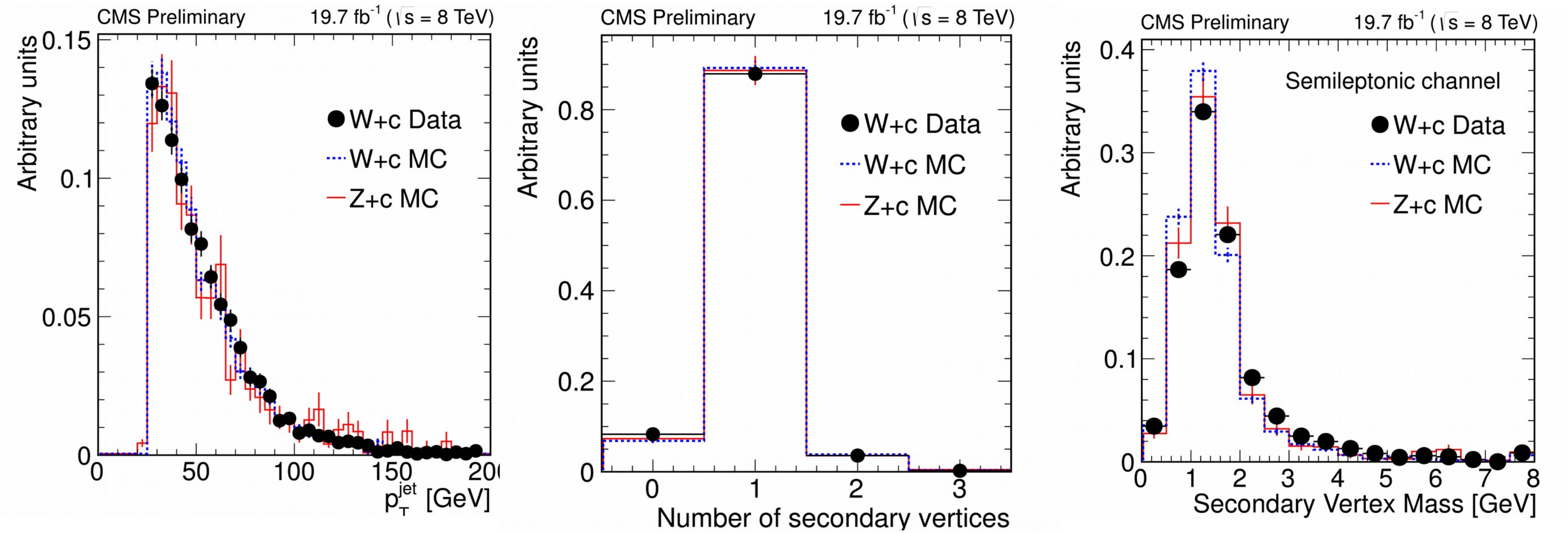


Data and predictions agree->validation of strange PDFs

First evidence for an asymmetry in the W^++c and W^-+c production.

Template (shape) modeling for Z+c

Comparison of c-jets from Z+c and W+c processes
(data from W+c : after subtraction of remaining (little) background)



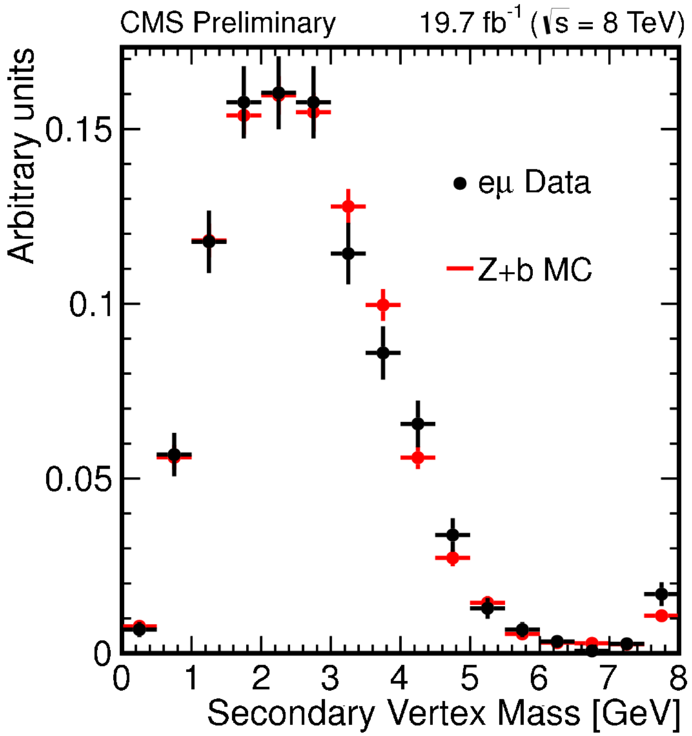
- *Agreement in general distributions (p_T^{jet} , N_{SV})*
- Discriminant distributions (SV-mass and JP) **W+c MC** and **Z+c MC** agree
- JP prob **W+c MC** and **W+c data** agree and validates the **Z+c MC** description
- SV-mass **W+c MC** and **W+c data** do not agree

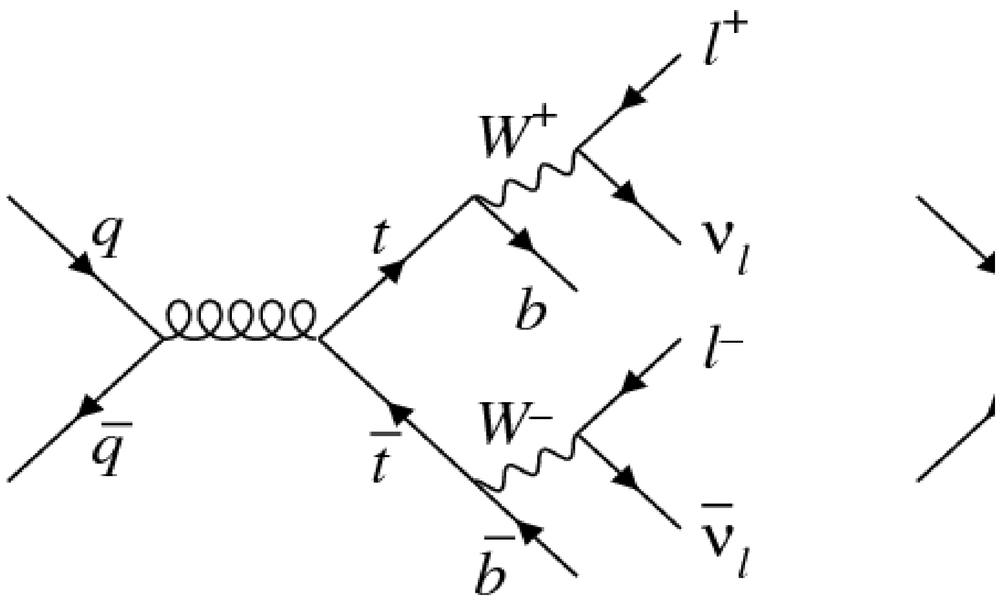
The shape is not well modeled by the **W+c MC**. We take the shape of SV-mass from **W+c data** since there is agreement in the kinematic properties between **Z+c MC** and **W+c MC**

More template modeling from data

For Z+c,Z+b,W+b,W+c templates from b-jets taken from $t\bar{t}$ production.

Using *a* sample where the two W bosons from the top(antitop) quark decay leptonically into leptons of different flavour.





Identification of heavy flavor: **muon inside the jet**

HF and charge identificacion

Semileptonic c,b → μ decay (**SL channel**):

- Tight μ that satisfies:
  - Is one of the PF constituents of a jet with p_T(jet)≥25 GeV, |η(jet)|≤2.5
  - Non-isolated μ (isolation≥0.2) with p_T(μ)≤25 GeV, |η(μ)|≤2.1.
- If several non-isolated μ candidates take the one with **highest p_T**

– **Charge identification** of the charm quark through the charge of the μ-in-jet

– **Charge definition**: SS if the μ-in-jet has the same charge than the lepton from the W decay

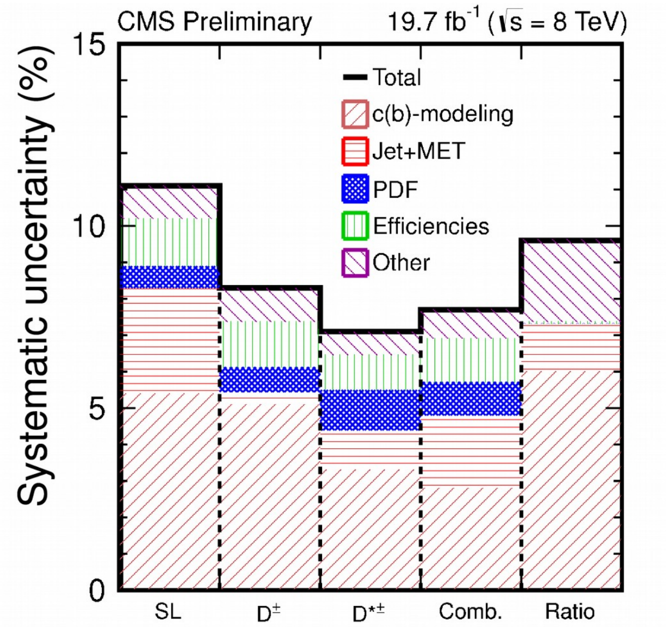
$$OS \rightarrow Q_{W\rightarrow e,\mu} \neq Q_{\mu\text{-in-jet}} \qquad SS \rightarrow Q_{W\rightarrow e,\mu} = Q_{\mu\text{-in-jet}}$$

HF identificacion
Inclusive HF hadron decays (SV channel):

- Reconstructed secondary vertex (SSV or IVF) in jet

- In case of several jets with SV in the event, take the **highest p_T jet**

Systematic uncertainties



- **PU** : uncertainties in the evaluation of the pileup profile (assuming a different inelastic cross section)
- **PDFs** (**PDFNNPDF & PDFCT10**) : reweighted DY MC according to the new PDF's : NNPDF23_nnlo & PDFCT10
- **Jet Energy scale and Resolution** (**JES & JER**) :
  - Change scale and resolution correction factors by their uncertainties
- **Branching ratios of D→Xμ hadrons and fragmentation c→D** (**BRFRAG**): We reweight the simulation to match the PDG on D-hadron channels. The syst comes from uncertainty on those reweighting factors For semileptonic channel the systematic comes from the difference between the BR from inclusive or exclusive individual contributions
- **Missing-et** : Misestimations on the Missing transverse energy: modify the missing E_t by 10% of the unclustered missing E_t.
- **Cgluon-splitting,** misestimation of the contribution to our background from gluon-splitting from charm : increase a factor 50 % the weight on events with 2c with ΔR (jet,c) < 0.5
- **Bgluon-splitting,** increase 50% the weight on events with 2b w. ΔR(jet,b) < 0.5
- **c-(b-) tagging efficiency**. Repit analysis with efficiency increased by its error
- **Shape** (semileptonic mode) : change Z+b template correction factor by its error
- **Lepton efficiencies** :change efficiencies by their errors
- **Luminosity** : 2.6 %

Previous measurements at hadron colliders:

1) D0@Tevatron: σ(ppbar - Z+c+X)/σ(ppbar-Z+b+X) and σ(ppbar-Z+c+X**)/**σ**(**ppbar-Z+jets+X), pT(jet) > 20 GeV

2) CDF@Tevatron: σ(ppbar-Z+D*+X)/σ(ppbar-Z+X), pT(D*) > 3 GeV [σ(ppbar-W+D*+X)/σ(ppbar-W+X) as well]

3) LHCb@LHC: Evidence and σ(pp-Z+D0+X) andσ(pp-Z+D+X) in the forward region