Measurement of the production cross sections of a Z boson and one or more b jets at √s=7TeV

Adrien Caudron *(Université catholique de Louvain, Belgium)* on behalf of *CMS collaboration*

Abstract: The Z(ll)+b-jets cross-section with exactly one or at least 2 b-jets is measured at 7 TeV with the CMS detector at LHC. The production of a Z boson with at least one b jet is of interest for precisions test of perturbative QCD and as background for many searches. The results are compared to various theoretical predictions, especially including different generator schemes. Kinematic properties are also compared with the predictions from MADGRAPH event generator using the PYTHIA parton shower simulation.

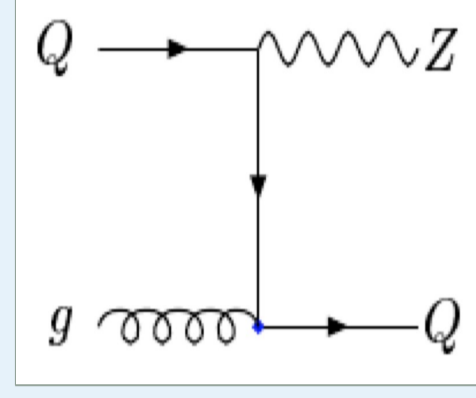## 0. Motivations and Theory

Z+1b : perturbative QCD test
Different simulation approaches for the production of b-quarks: 4F vs 5F, tree-level vs NLO.

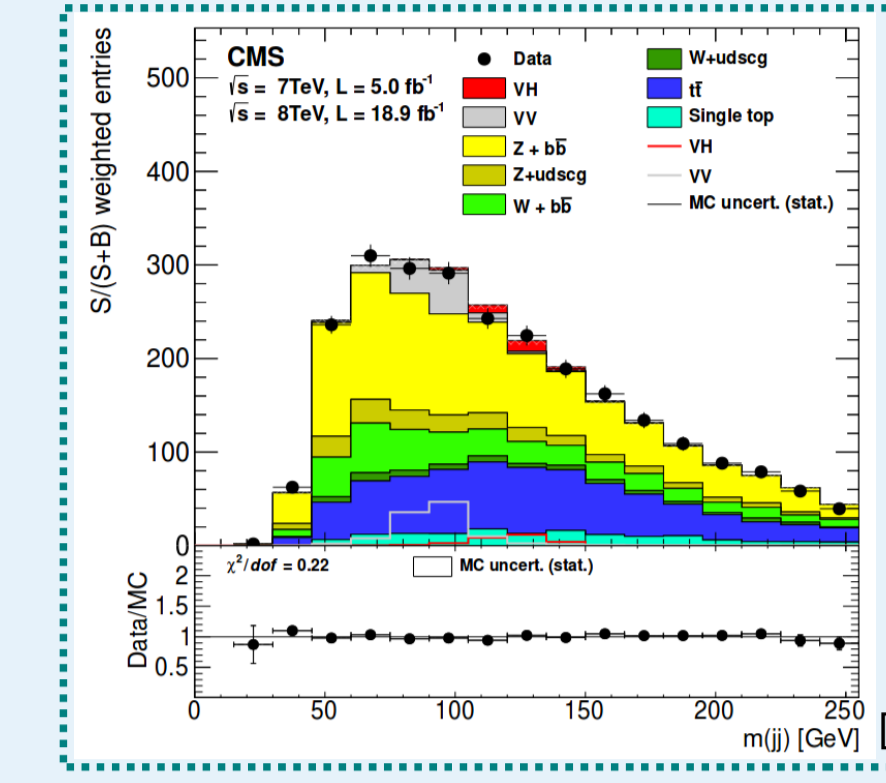**Four flavor scheme (4F) massive b quarks**
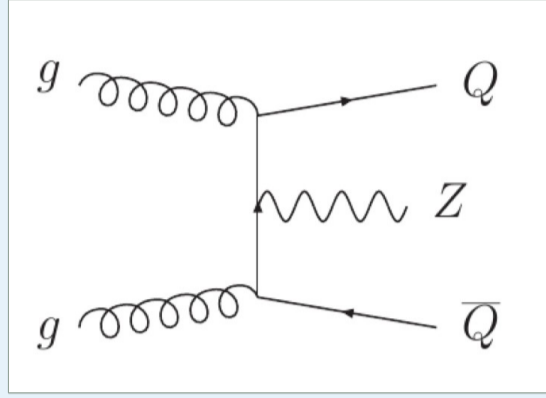
[1]

Five flavor scheme (5F) b is massless

[2]

Z+2b: main background for searches
- **SM Higgs**
  - Z(ll)H(bb)
- **Exotics**
  - b' search ...
- **SUSY like heavy Higgs**
- **Other BSM processes**
  - H→Z+A(bb) ...

Invariant Mass of bb in the V+H(bb) search channel.

Z+bb (yellow) is one of the main backgrounds
[3]

1. Selection

2 isolated leptons
$p_T > 20$ GeV
$|\eta| < 2.4$
e^+e^- or $\mu^+\mu^-$ pairs
$76 < M_{ll} < 106$ GeV

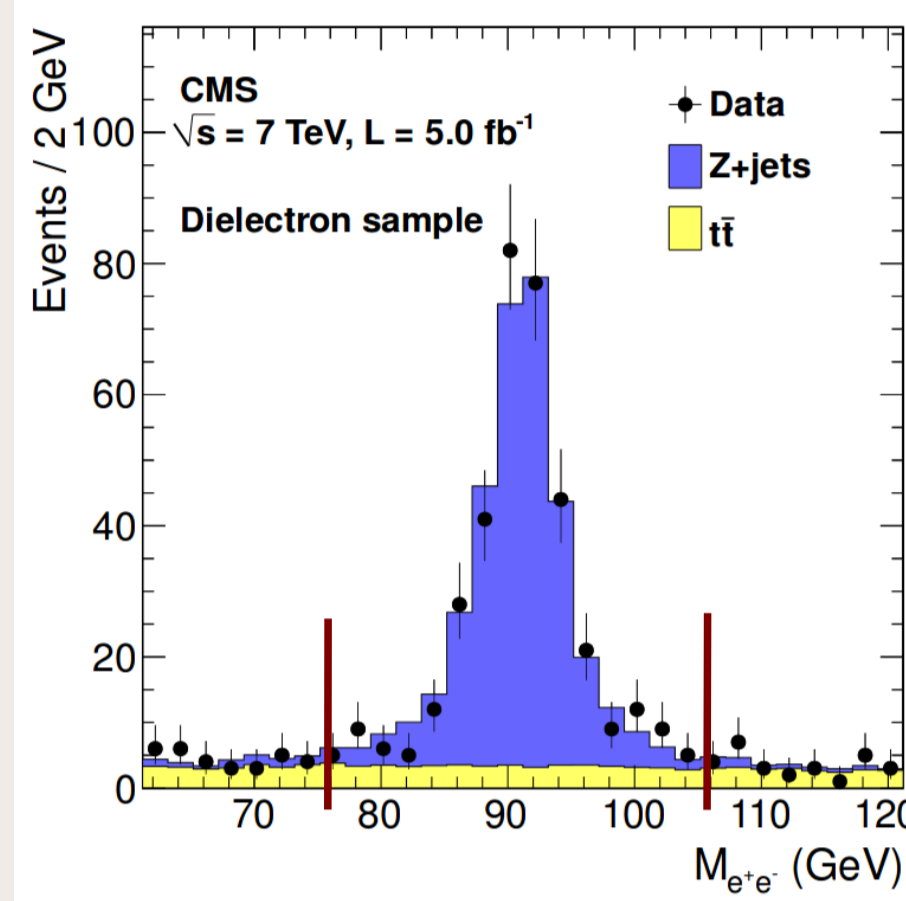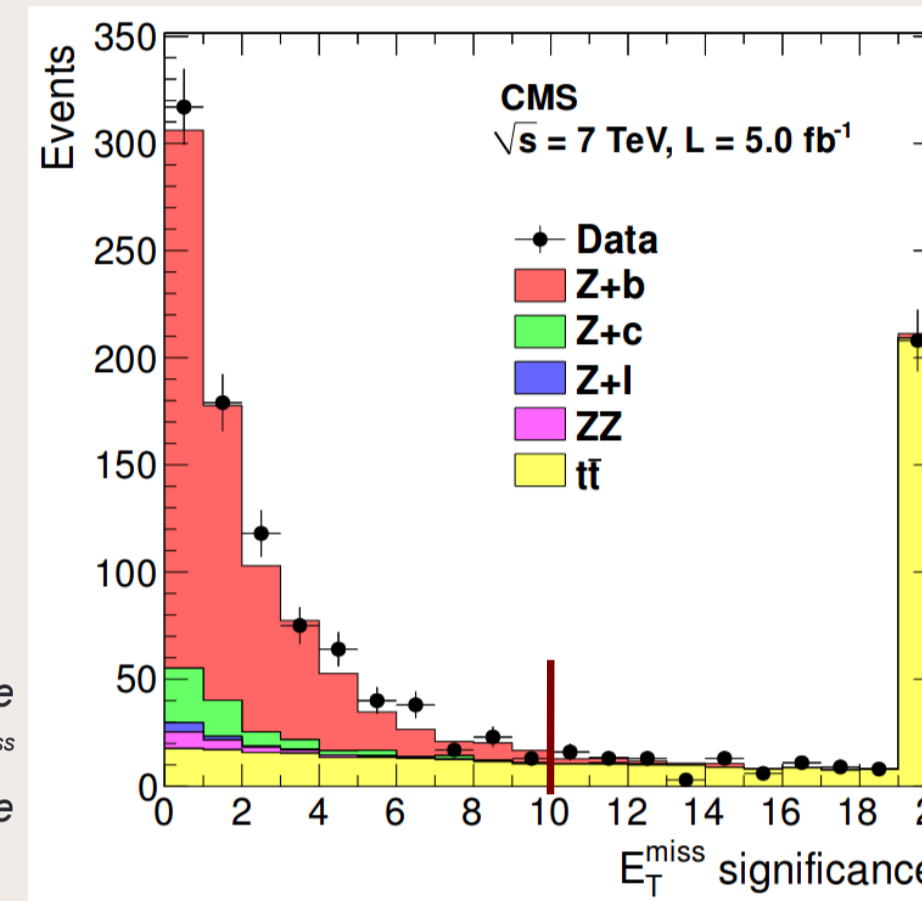*Fig.: Invariant dilepton mass after fit of the TTbar fraction*

+

1 or 2 jets ...
$p_T > 25$ GeV
$|\eta| < 2.1$
$\Delta R(j,l) > 0.5$
+ if 2 jets :
E_T^{miss} significance cut < 10

Fig: E_T^{miss} significance : give the compatibility of the measured E_T^{miss} with 0, low value means compatible with no real E_T^{miss}

+

... b-tagged (SSV) : [3]
Detached secondary vertex
b-tag efficiency ~55%
udsg-mistag ~1%

Fig: B-tagging performance : mistag efficiency versus b-tag efficiency
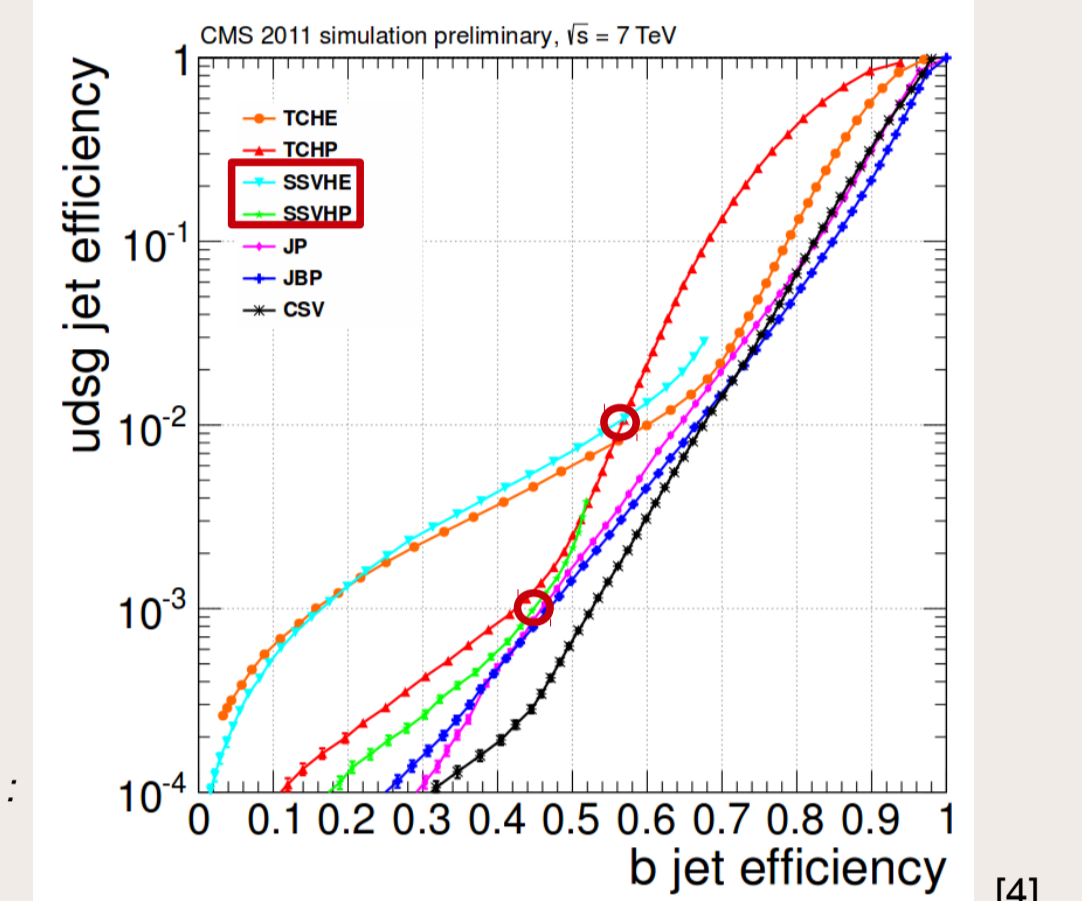
[4]

2. Background estimation

- **TTbar:**
  * estimated with fit to M(ll) in the mass range [60-120]
    - Template are taken from simulation for tt and from data for DY
    → Fraction of TTbar $f_{tt}^{Z+1,2b}$

- **Z+ ucdsg: (b-purity)**
  * fit to SV mass of the 1 or 2 b-tagged jets
    - b, c, light flavour templates from multi-jets simulation
    → Event purity $p_b^{Z+1,2b}$

- **ZZ : from CMS measurement**
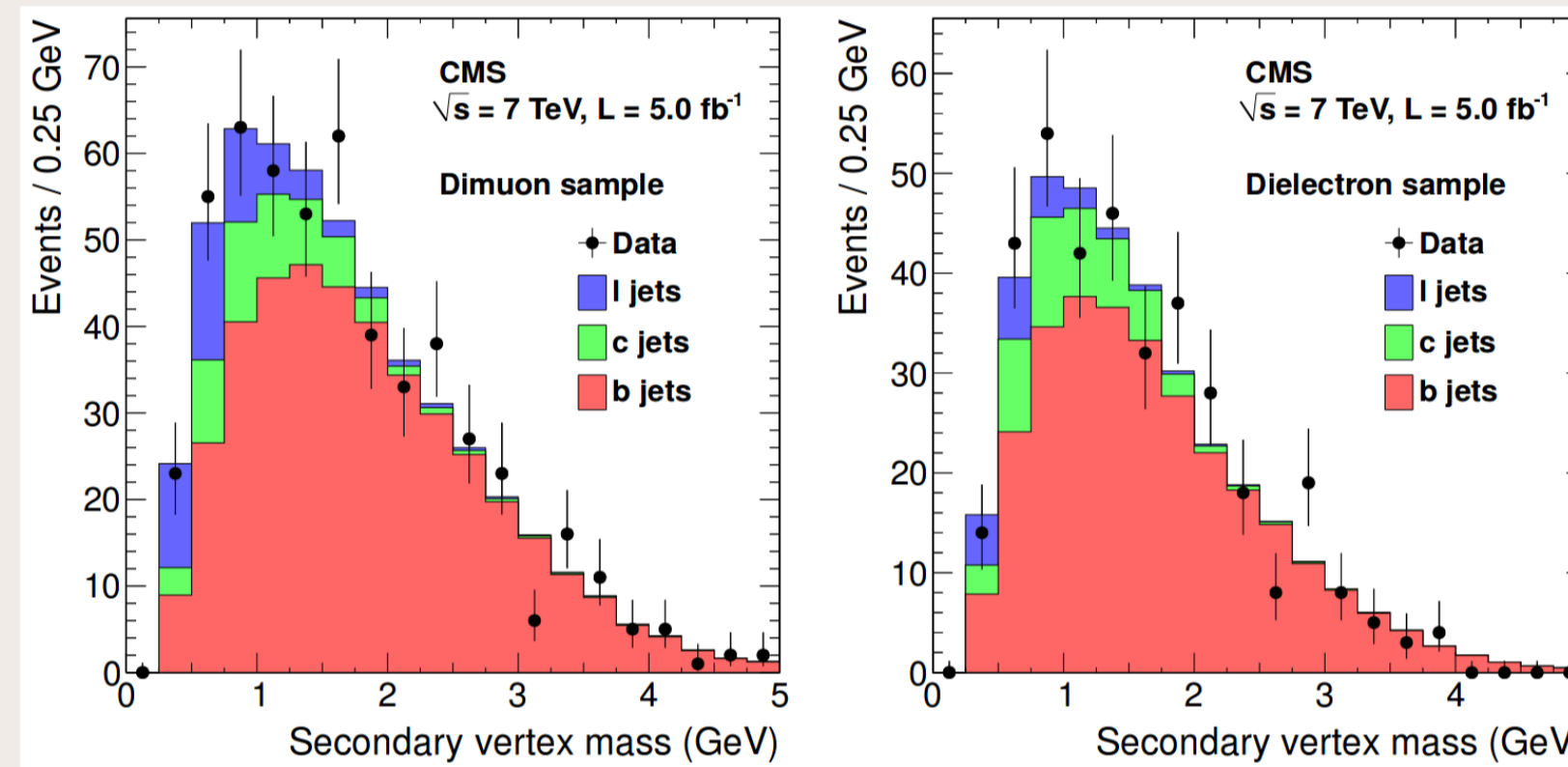 * normalized to data using CMS cross section measurement $N_{ZZ}^{Z+1,2b}$

Fig.: SV mass of the leading and sub-leading b-jets after fit

Background fractions

WP	$p_b^{Z+1,2b}$	$f_{tt}^{Z+1,2b}$	$N_{ZZ}^{Z+1,2b}$
Z($\mu\mu$)+1b-jet	$(53.7 \pm 1.1)\%$	$(5.2 \pm 0.7)\%$	73 ± 24
Z(ee)+1b-jet	$(55.0 \pm 1.3)\%$	$(5.0 \pm 0.7)\%$	56 ± 19
Z($\mu\mu$)+2b-jets	$(75.1 \pm 6.4)\%$	$(13.0 \pm 1.9)\%$	12 ± 4
Z(ee)+2b-jets	$(74.1 \pm 7.3)\%$	$(14.0 \pm 2.3)\%$	8 ± 3

Signal extraction

$$N_{sig}^{Z+1,2b} = N_{rec}^{Z+1,2b} \times (P_b^{Z+1,2b} - f_{tt}^{Z+1,2b}) - N_{ZZ}^{Z+1,2b}$$

3.a Unfolding

Unfold observed yields → Particle level yields :
b-tagged jets → # reconstructed b-jets → # generated b-jets

Generated signal definition:
- **1 Z candidate from opposite charged leptons in the detector acceptance**
  - Use of 'dressed leptons': adding to the lepton all generator-level photons within a cone of dR<0.1
- **1 or 2 generated b-jets in the detector acceptance matched with a B-hadron within dR<0.5**
  - In case of MCFM: 1 or 2 partons are required

A 2x2 matrix equation is used
account for migrations between different b-jet multiplicities

$$\begin{pmatrix} \sigma(Z+1b) \\ \sigma(Z+2b) \end{pmatrix} = \frac{1}{\mathcal{L}} \times \mathbf{E}_r^{-1} \times \mathbf{E}_l^{-1} \times \mathbf{E}_b^{-1} \times \mathbf{E}_m^{-1} \begin{pmatrix} N_{sig}^{Z+1b} \\ N_{sig}^{Z+2b} \end{pmatrix}$$

$\mathbf{E}_r$: detector resolution
Correct for migration in/out acceptance

$\mathbf{E}_l$: lepton selection efficiency
Scale MC to data expectations

$\mathbf{E}_b$: b-tagging efficiency
Scale MC to data expectations

$\mathbf{E}_m$: E_T^{miss} significance efficiency
Correct for E_T^{miss} significance cut in Z+2b case

3.b Systematics

	$\mu\mu$ (%)		ee (%)	
	Z+1b	Z+2b	Z+1b	Z+2b
Uncorrelated				
b purity	3.0	12.7	3.3	15.1
tt	1.7	3.8	1.7	4.8
Dilepton selection	1.0	1.0	2.0	2.0
MC statistics	0.9	4.2	1.2	5.1
Correlated				
b-tagging efficiency	3.6	9.0	3.6	9.0
Jet energy scale	2.0	3.6	2.0	3.6
Theory	1.8	3.0	1.8	3.0
Luminosity	2.2	2.2	2.2	2.2
ZZ	0.4	1.2	0.5	1.4
Jet energy resolution	0.6	0.7	0.6	0.7
Pileup	0.3	0.3	0.3	0.3
Mistag	0.0	0.1	0.0	0.1
Total stat. uncertainty	0.9	4.5	1.0	5.4
Total syst. uncertainty	6.3	17.4	6.7	19.8

Main systematics

4. Measured Cross Section

Measured cross sections are compatible between both channels and combined in a single measurement

Cross section	Measured	MADGRAPH (5F)	aMC@NLO (5F)	MCFM (parton level)	MADGRAPH (4F)	aMC@NLO (4F)
σ_{Z+1b} (pb)	$3.52 \pm 0.02 \pm 0.20$	3.66 ± 0.22	$3.70^{+0.23}_{-0.26}$	$3.03^{+0.30}_{-0.36}$	$3.11^{+0.47}_{-0.81}$	$2.36^{+0.47}_{-0.37}$
σ_{Z+2b} (pb)	$0.36 \pm 0.01 \pm 0.07$	0.37 ± 0.07	$0.29^{+0.04}_{-0.04}$	$0.29^{+0.04}_{-0.04}$	$0.38^{+0.06}_{-0.10}$	$0.35^{+0.08}_{-0.06}$
σ_{Z+b} (pb)	$3.88 \pm 0.02 \pm 0.22$	4.03 ± 0.24	$3.99^{+0.25}_{-0.29}$	$3.23^{+0.34}_{-0.40}$	$3.49^{+0.52}_{-0.91}$	$2.71^{+0.52}_{-0.41}$
$\sigma_{Z+b/Z+j}$ (%)	$5.15 \pm 0.03 \pm 0.25$	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(ll)+1b: only 1 b in the acceptance
- Z(ll)+2b: at least 2 b in the acceptance
- Z(ll)+b: sum of Z(ll)+1b and Z(ll)+2b
- Z(ll)+j: at least one jet in the acceptance

- Measurement dominated by systematics
- Z+2 b → good agreement within uncertainties.
- 5F scheme → good agreement within uncertainties for all measurement.
- MCFM and 4F scheme → for Z+1b, some disagreements are visible, up to > 2 standard deviations for aMC@NLO.
  - Same conclusion for Z+b/Z+j → disagreements specific to the modelling of the Z+b-jets final state

5. Data / MC comparisons of kinematic variables
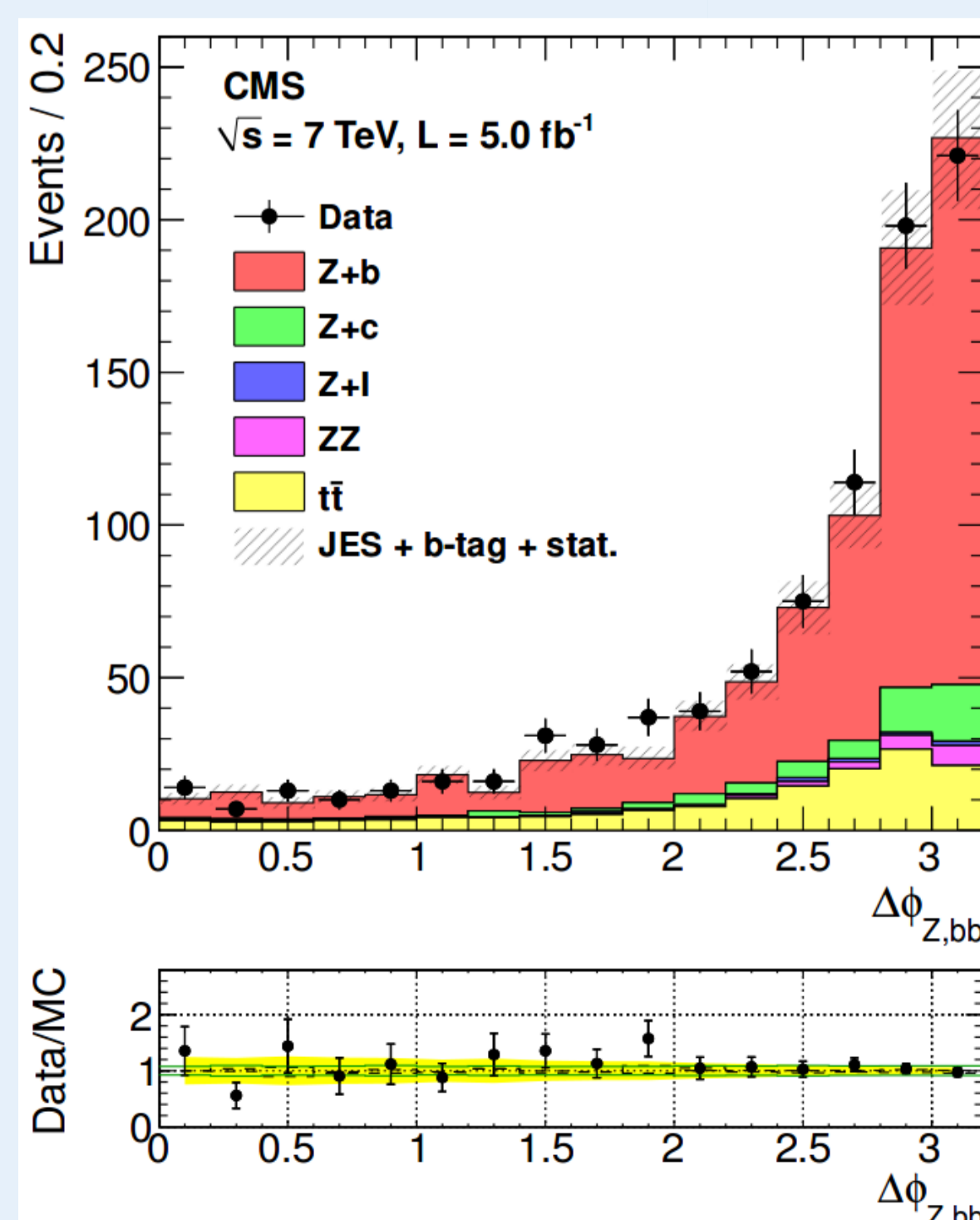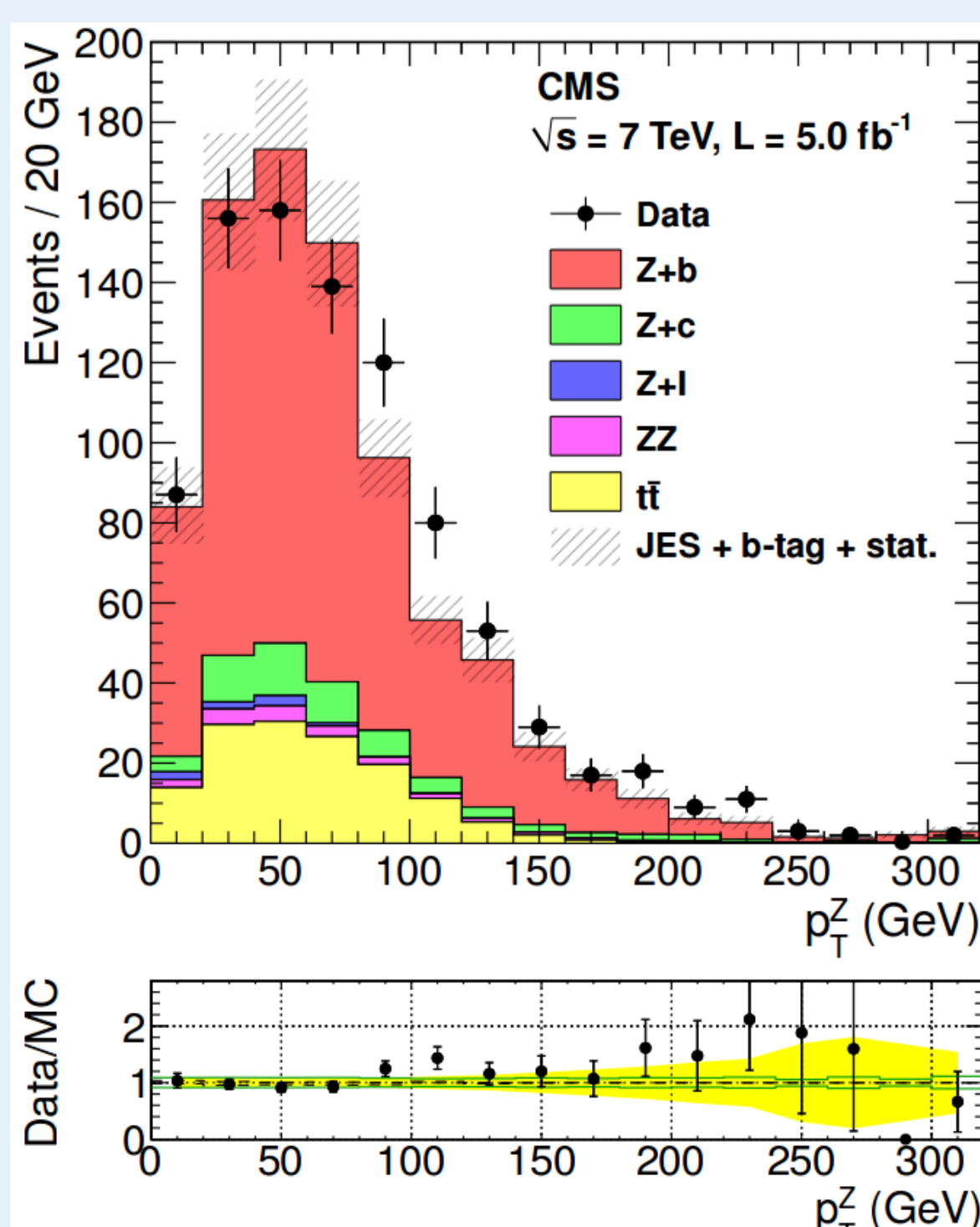
→ **p_T(Z) spectrum:**
- show a harder spectrum in data compared to the expectation from simulation
- Strong motivations to study:
  → **4 Flavour** simulation (massive b quarks)
  → **NLO** effects
    => In both cases we expect a harder p_T(Z) spectrum.

→ **ΔΦ(Z,bb) :**
- Good agreement is observed
- Sensitive to Multiple Parton Interactions and light radiations.

References
Measurement of the production cross sections for a Z boson and one or more b jets in pp collisions at √s = 7 TeV arXiv:1402.1521. CMS-SMP-13-004. CERN-PH-EP-2014-005, Submitted to JHEP
[1] : *W and Z/∗ boson production in association with a bottom-antibottom pair* (arXiv:hep-ph/1106.6019)
[2] : *Associated Production of a Z Boson and a Single Heavy-Quark Jet* (arXiv:hep-ph/0312024)
[3] : *Search for the standard model Higgs boson produced in association with a W or a Z boson and decaying to bottom quarks* Phys. Rev. D 89, 012003
[4] : *b-Jet Identification in the CMS Experiment* BTV-11-004