# Jets produced in association with W and Z bosons in CMS

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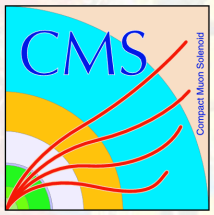
On behalf of the CMS Collaboration





# Introduction:



A study of W/Z production in association with jets in proton-proton collisions at $\sqrt{s}$ = 7 TeV is presented. The results are obtained with data collected by the CMS experiment over the 2010 LHC run, corresponding to an integrated luminosity of about 36 $pb^{-1}$, and have been published in [1].

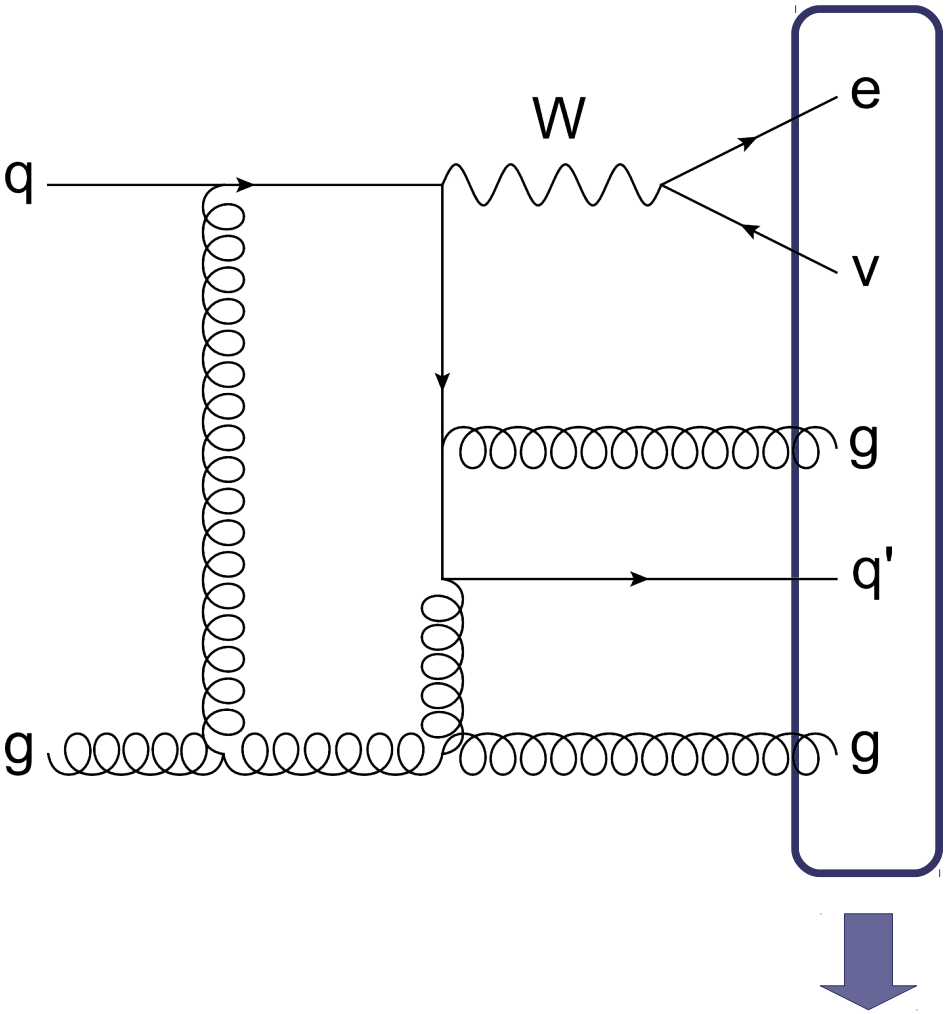
**Outline of the talk:**

- Event selection and jet reconstruction.
- Signal yields extraction.
- Efficiencies measurement.
- Main results: jet multiplicity exclusive cross sections, W/Z ratio.

[1] The CMS Collaboration. *Jet Production Rates in Association with W and Z Bosons in pp Collisions at $\sqrt{s}$ = 7 TeV.* J. High Energy Phys. (CERN-PH-EP-2011-125).

# The reason for W/Z + Jets...






Processes involving QCD + EWK physics with jets, leptons and missing $E_T$ in final states.

Calculations are very difficult:

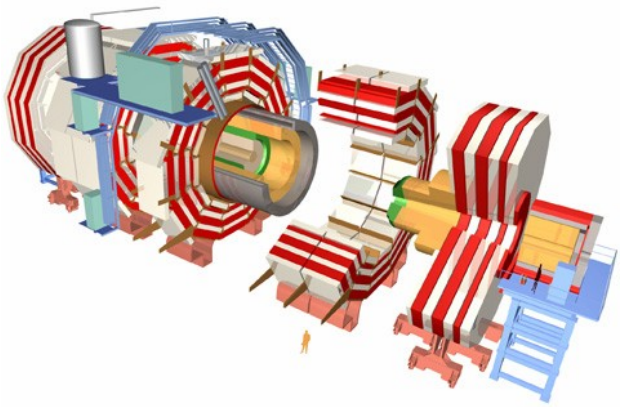
- NLO calculations: available up to 3 (Z) and 4 (W) jets.
- Matrix element + parton shower (common used tool): tree level only.

High theoretical uncertainties: cross-check with data is an **important test for Standard Model**!

**Major background to many searches for new physics!**

# The CMS detector

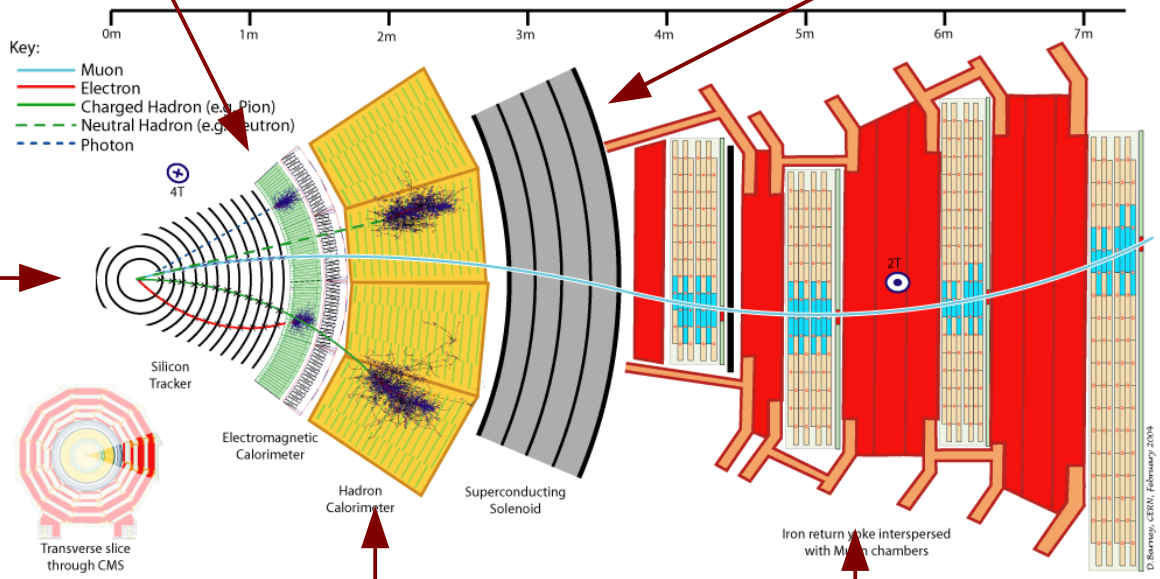




ECAL (EB+EE):

- ~75000 $PbWO_4$ crystals
- energy resolution ~ 0.5% at 100 GeV

Superconducting solenoid generating 3.8 T magnetic field




Tracker:

- made of pixel and micro-strip detectors.
- spatial resolution ranging from 10μm to 30μm.
- Acceptance: $|\eta| < 2.4$.

HCAL (HB+HE+HO):

- lead and plastic scintillator sampling calorimeter
- energy resolution ~ 5% at 100 GeV

Muon detector:

consisting of drift tubes (DT), cathode strip chambers (CSC) and resistive plate chambers (RPC).

# Event selection: $Z \rightarrow ee$



Events selected in 2010 dataset (~36 $pb^{-1}$) using the lowest unprescaled single electron trigger: $p_T$ threshold varying from 10 to 17 GeV depending on instantaneous luminosity.

**Leading electron:**

- transverse momentum: $p_T > 20$ GeV.
- acceptance: $|\eta| < 1.44$ (barrel), or $1.56 < |\eta| < 2.5$ (endcaps).
- matched to trigger candidate.
- **tight** cuts (~80% efficiency) on lepton isolation, identification and conversion rejection variables.

**Sub-leading electron:**

- transverse momentum: $p_T > 10$ GeV.
- Acceptance: $|\eta| < 1.44$ (barrel), or $1.56 < |\eta| < 2.5$ (endcaps).
- **loose** cuts (~95% efficiency) on lepton isolation, identification and conversion rejection variables.

**$60\ \text{GeV} < m_{ee} < 120\ \text{GeV}$** → The event is classified as **$Z \rightarrow ee$**

# Event selection: W → eν



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- Accept… arrel), or 1.56… aps).
- **loose** cuts (~95% efficiency) on lepton isolation, identification and conversion rejection variables.

Z veto

**$m_T > 20$ GeV and no additional muons (top veto)**

→ The event is classified as **W → eν**

# Event selection: $Z \rightarrow \mu\mu$



Events selected in 2010 dataset (~36 $pb^{-1}$) using the lowest unprescaled single muon trigger: $p_T$ threshold varying from 9 to 15 GeV depending on instantaneous luminosity.

**Leading muon:**

- transverse momentum: $p_T > 20$ GeV.
- acceptance: $|\eta| < 2.1$.
- matched to trigger candidate.
- well isolated and satisfying quality criteria to avoid muons from secondary decays.

**Sub-leading muon:**

- transverse momentum: $p_T > 10$ GeV.
- acceptance: $|\eta| < 2.4$ (barrel).
- well isolated and satisfying quality criteria to avoid muons from secondary decays.

**$60\ \text{GeV} < m_{\mu\mu} < 120\ \text{GeV}$** → The event is classified as **$Z \rightarrow \mu\mu$**

# Event selection: $W \rightarrow \mu\nu$



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- transverse momentum: $p_T > 10$ GeV.
- accepta
- well iso ng quality criteria to avoid muons from secondary decays.

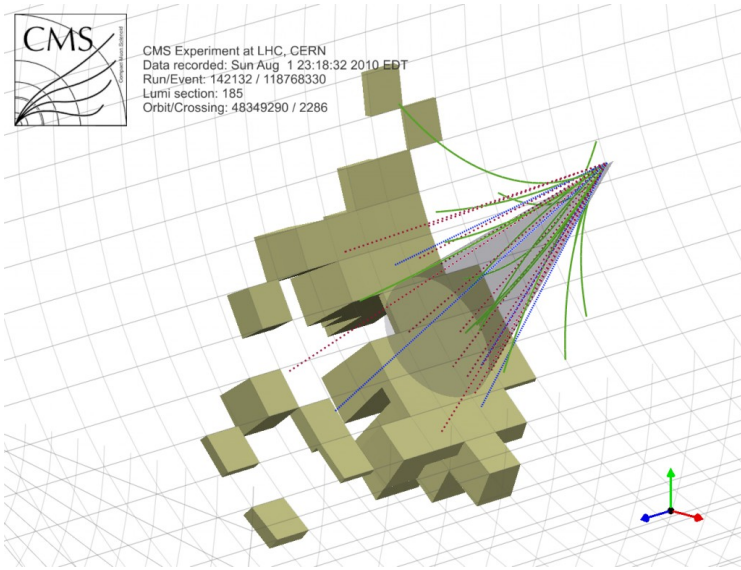
Z veto

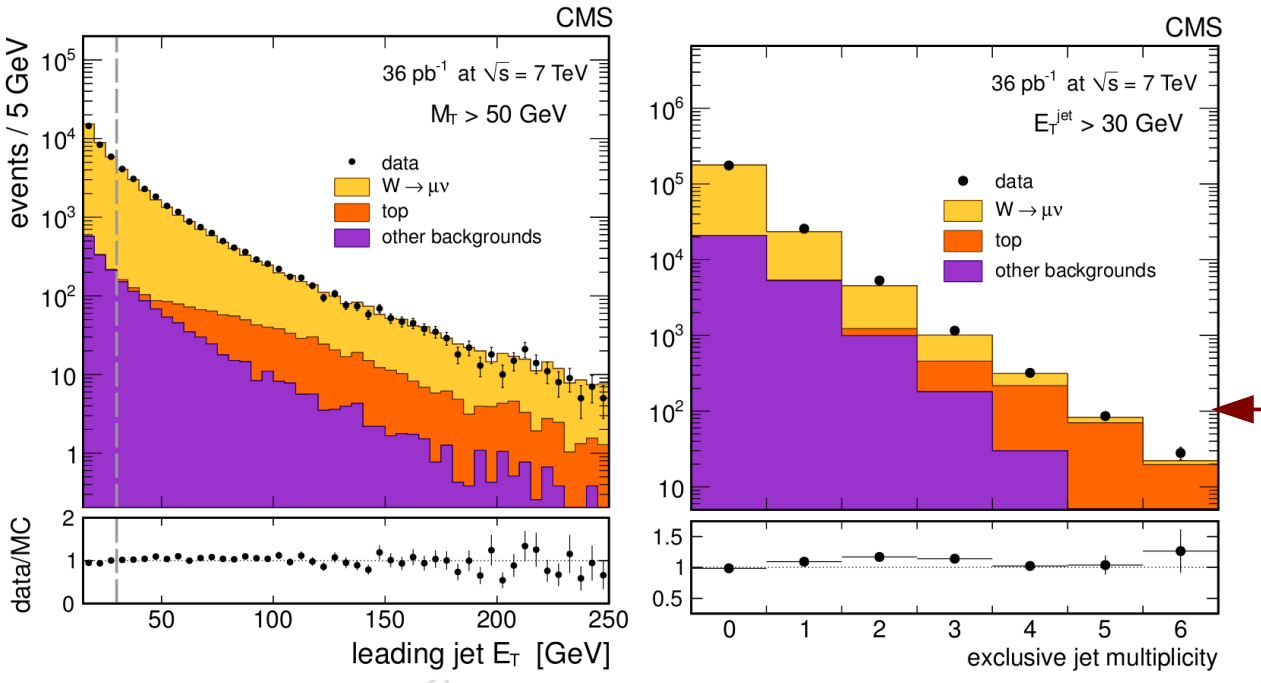
**$m_T > 20$ GeV** ⇒ The event is classified as **$W \rightarrow \mu\nu$**

# Jet reconstruction



- Clusterization algorithm: *anti-$k_T$* (cone size $\Delta R = 0.5$) applied to Particle Flow candidates. Isolated leptons removed from jet collection.
- Acceptance: $|\eta| < 2.4$ (i.e. tracker acceptance).
- Transverse momentum: $p_T > 30$ GeV.
- Jet energy is calibrated to remove detector effects (JEC).
- Pile-up contribution to jet energy removed via *FastJet* algorithm.




Data is compared to MadGraph simulation, scaled to NNLO cross section.

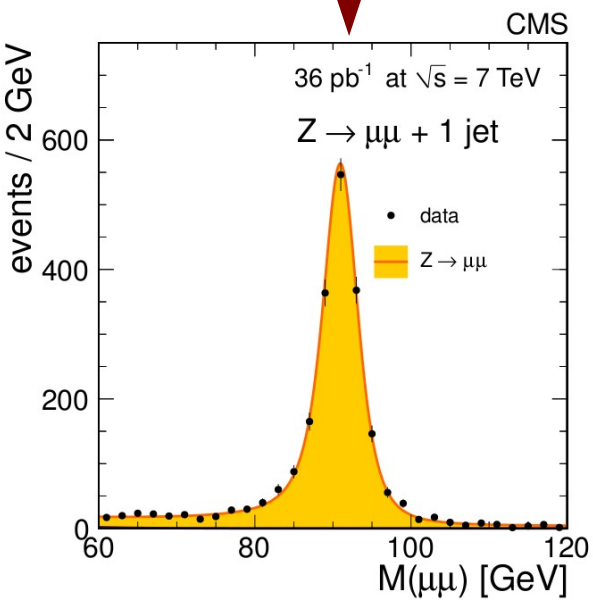
# Signal extraction

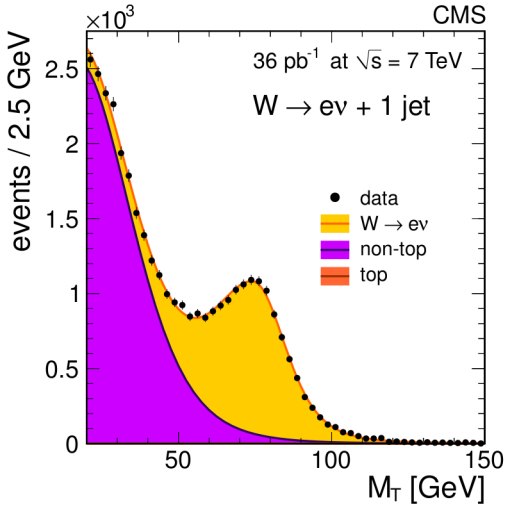


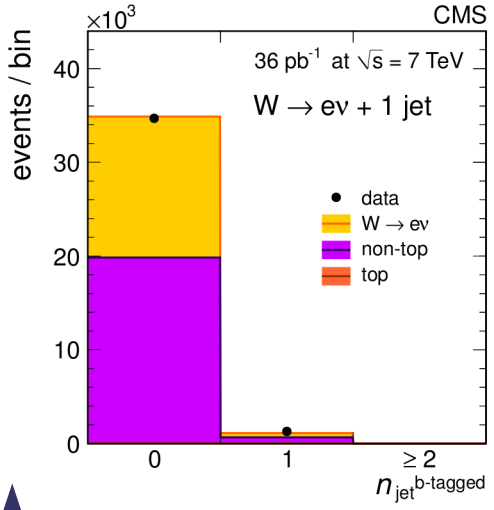
Both signal yields estimated with un unbinned ML fit to the $M_{ll}$ distribution (Z+Jets sample) and to the $M_T$ distribution (W+Jets sample).

Z+Jets sample:

- background (mainly W+Jets and t-tbar) is very low and non-peaking: exponential parametrization.
- Z peak signal: asymmetric gaussian parametrization.




W+Jets sample:

- heavy background from t-tbar and QCD.
- 2-dimensional fit to the $M_T$ and # of b-tagged jet distributions.

more details in the poster:
"Study of W and jets associated production with CMS"-S. Gonzi

# Efficiencies

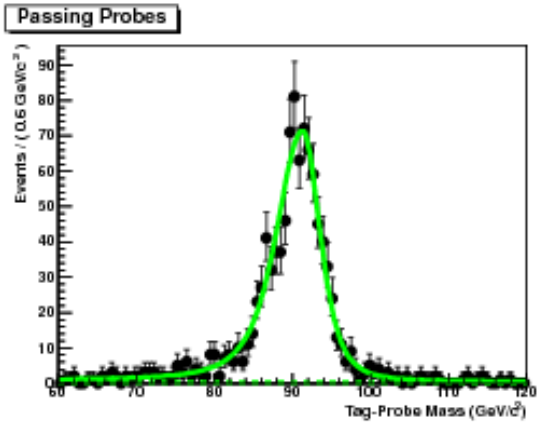
Efficiencies are measured as a function of # jets, with a data-driven Tag&Probe method on a sample of Z candidates.

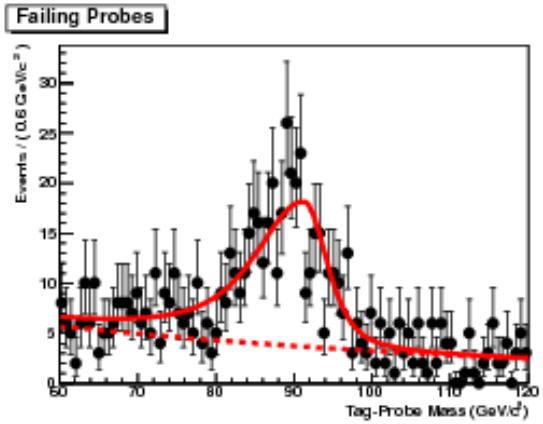
Contributions to the global efficiency:

- High Level Trigger (only one leg)
- Reconstruction process
- Offline selection

$$\epsilon_{tot} = \epsilon_{HLT} \times \epsilon_{RECO} \times \epsilon_{Offline}$$

Signal yields are extracted from the distribution of events with a passing probe and a failing probe:




Simultaneous fit, with the efficiency as a floating parameter:

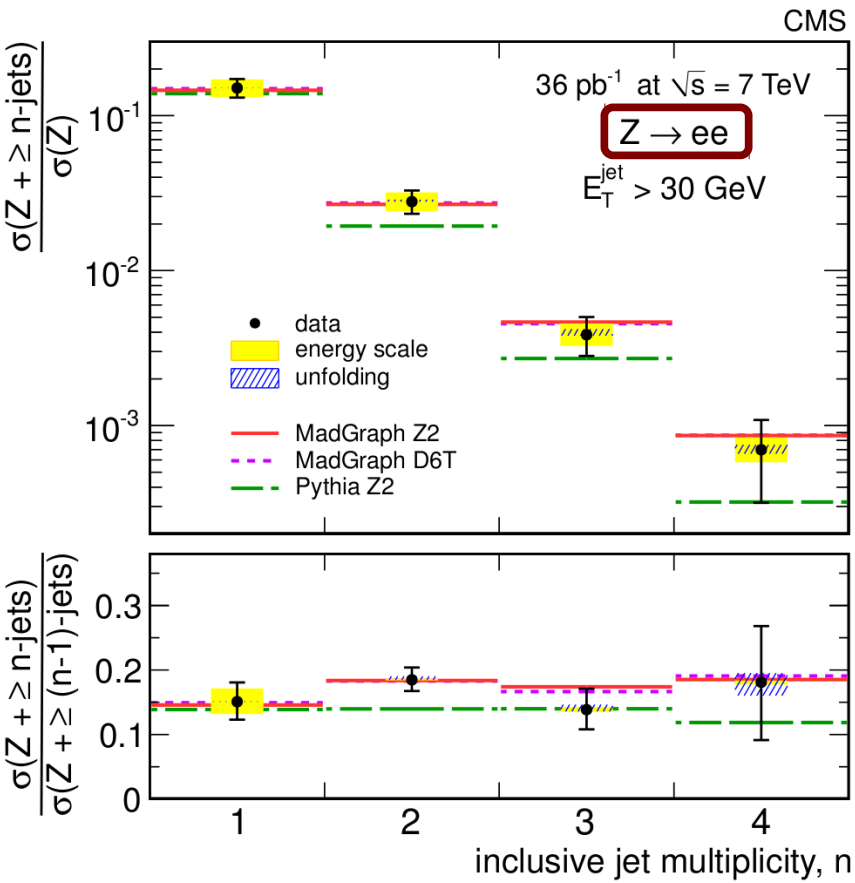
$$\epsilon = \frac{n_{passing}}{n_{passing} + n_{failing}}$$

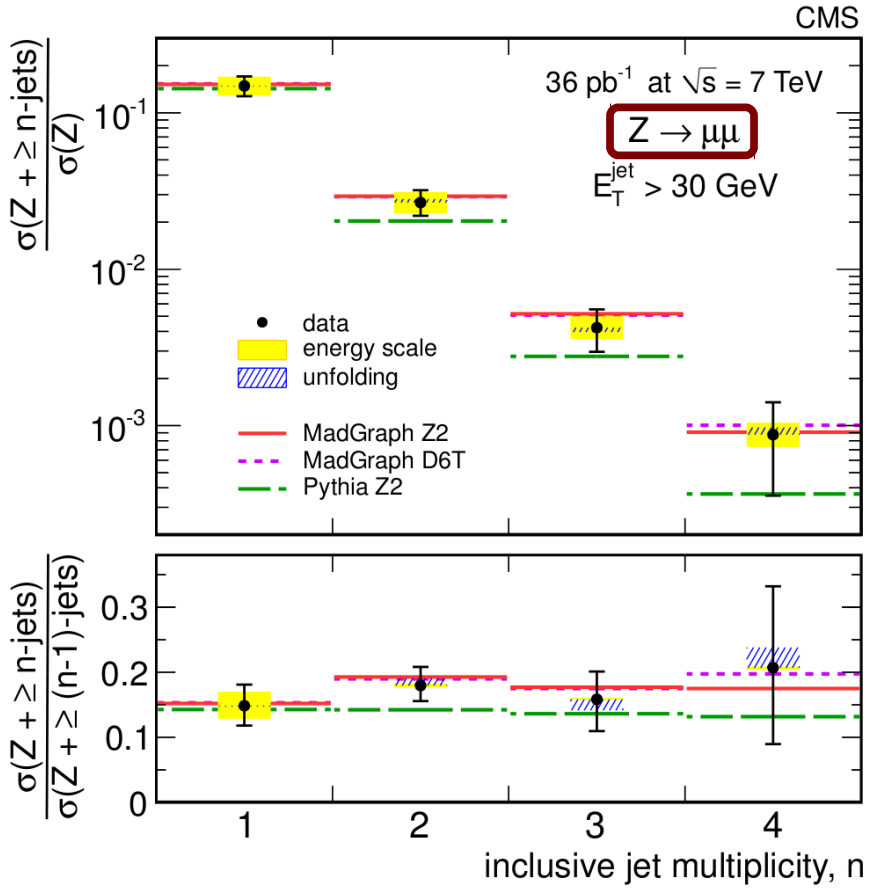
Left tail parameter of signal distribution is estimated from simulations.
For # jets > 2 multiplicity bins (few statistics), use parameters estimated from lower jet multiplicities.

# Results: Z + Jets



Exclusive cross sections as a function of the number of associated jets: all the results are presented in terms of ratios, in order to reduce systematics.

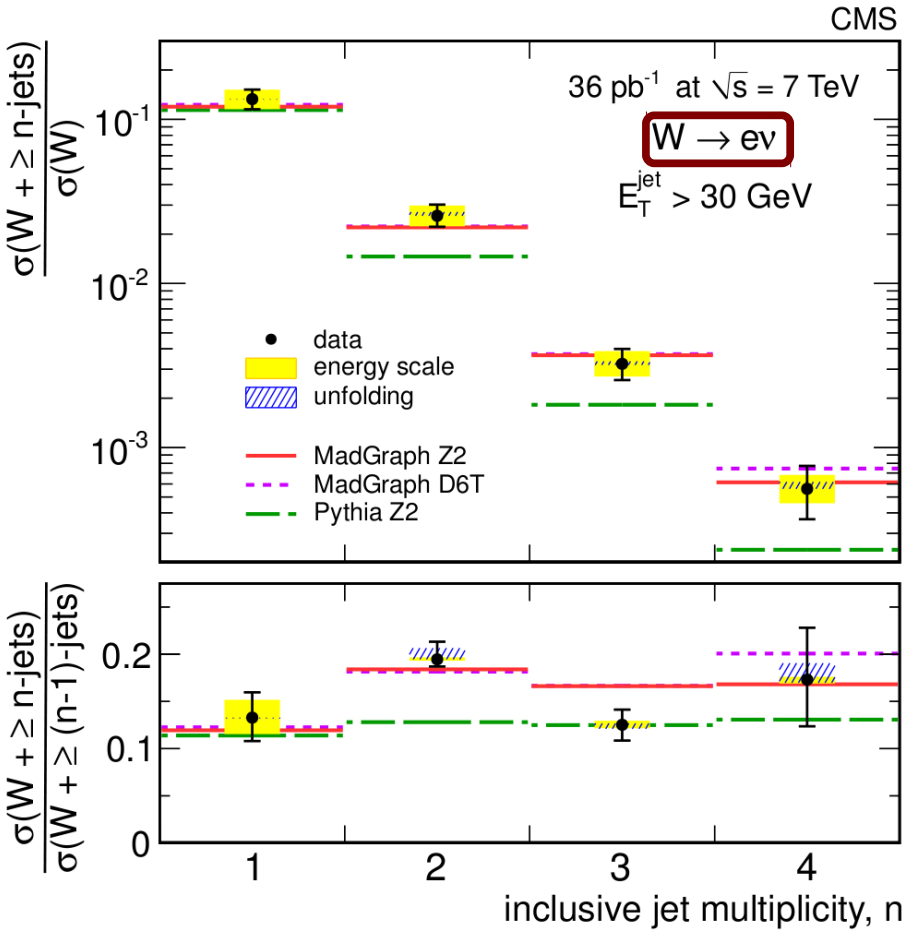



- Yields corrected with **efficiencies** calculated on data and **unfolded** to remove detector effects.
- Results are compared with `PYTHIA` (PS only) and `PYTHIA+MadGraph` (ME+PS)

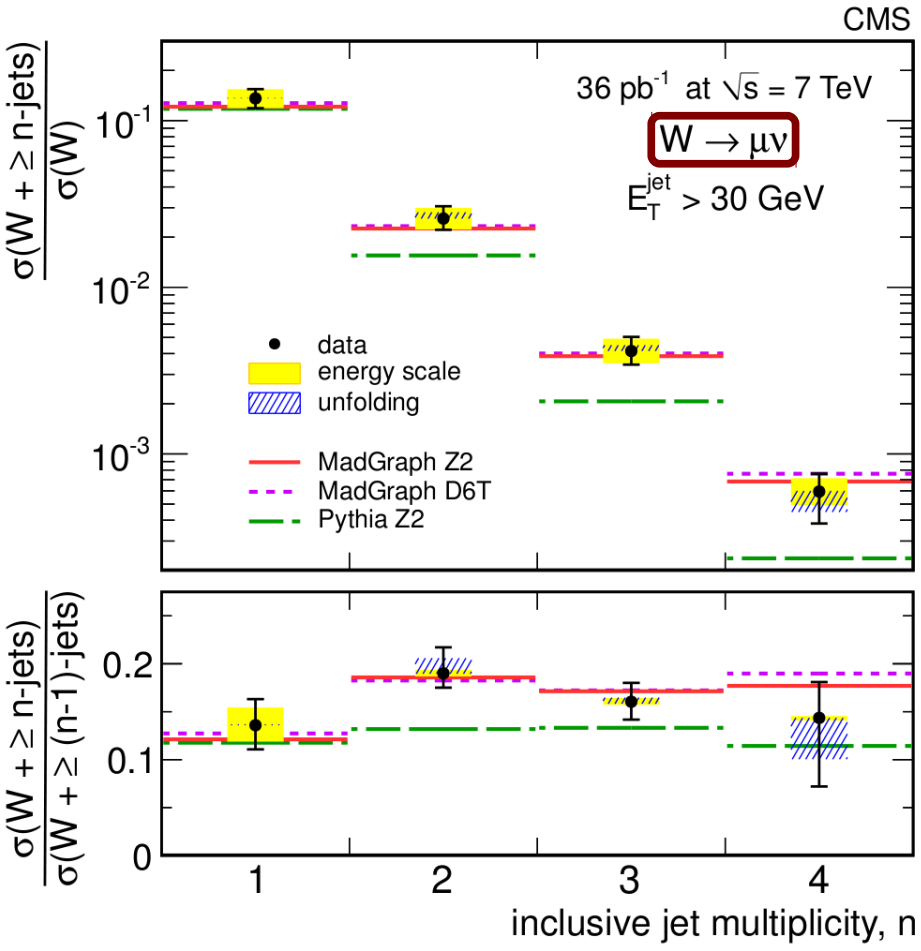
# Results: W + Jets






- Similar results to Z + Jets: worse sample purity is compensated by higher statistics.
- Matrix element calculation yields a good agreement with data: scaling between exclusive jet multiplicity cross sections is well behaved.

- Yields corrected with **efficiencies** calculated on data and **unfolded** to remove detector effects.
- Results are compared with `PYTHIA` (PS only) and `PYTHIA+MadGraph` (ME+PS).



# Results: cross section scaling

Jet multiplicity exclusive cross sections are used to test scaling hypothesis:

$$\frac{\sigma\left(V+(\geq n)\,Jets\right)}{\sigma\left(V+(\geq n-1)\,Jets\right)}=\alpha+\beta\times n$$

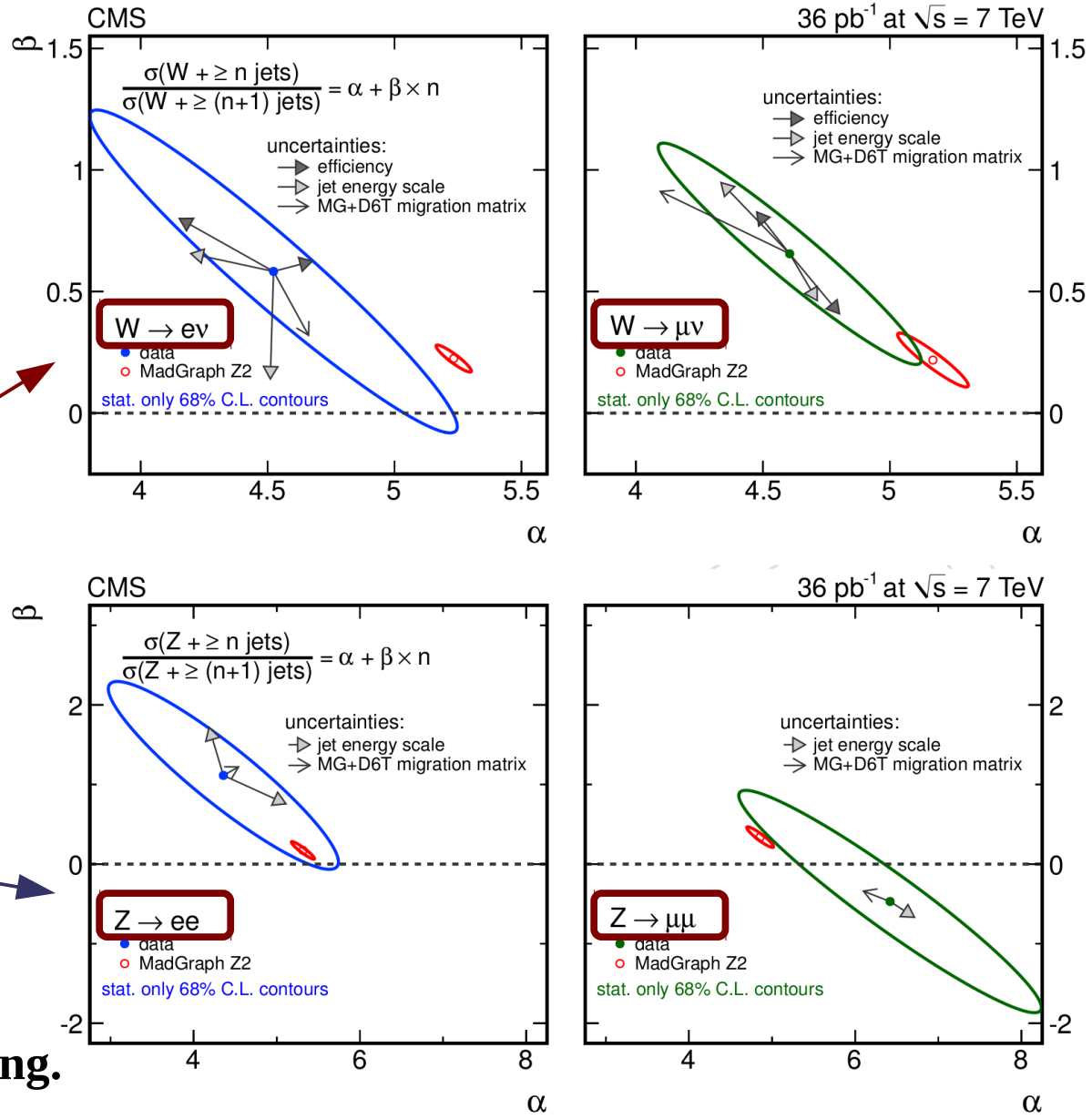
("Berends-Giele scaling")

both with W + Jets cross sections

and Z + Jets ones.

β is consistent with zero within uncertainties:

➡ **no violation to the expected scaling.**

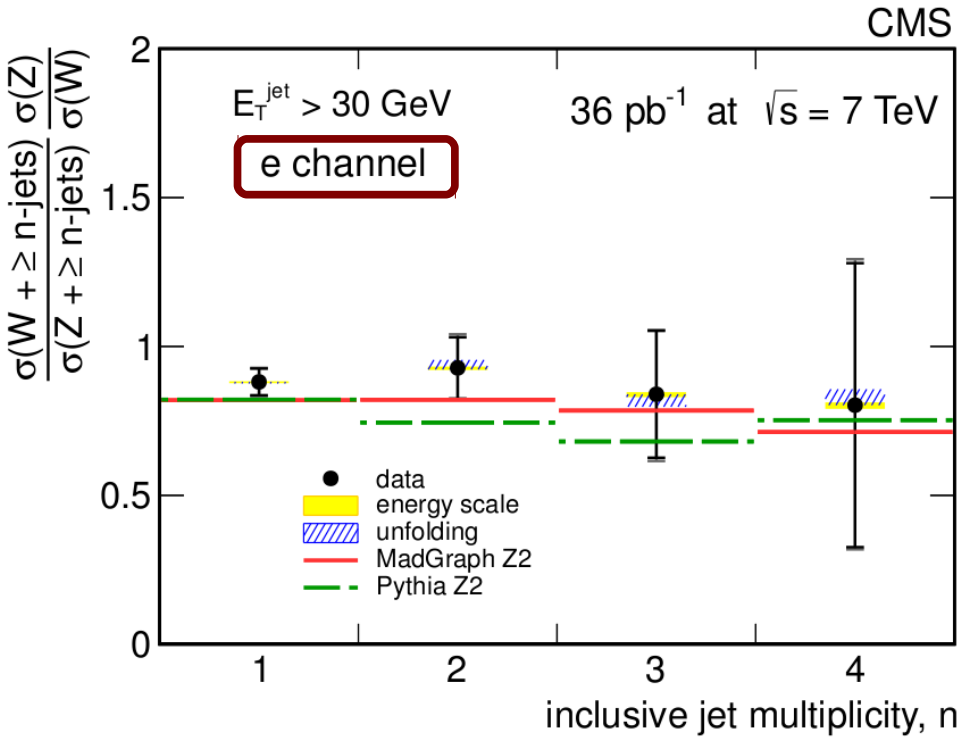


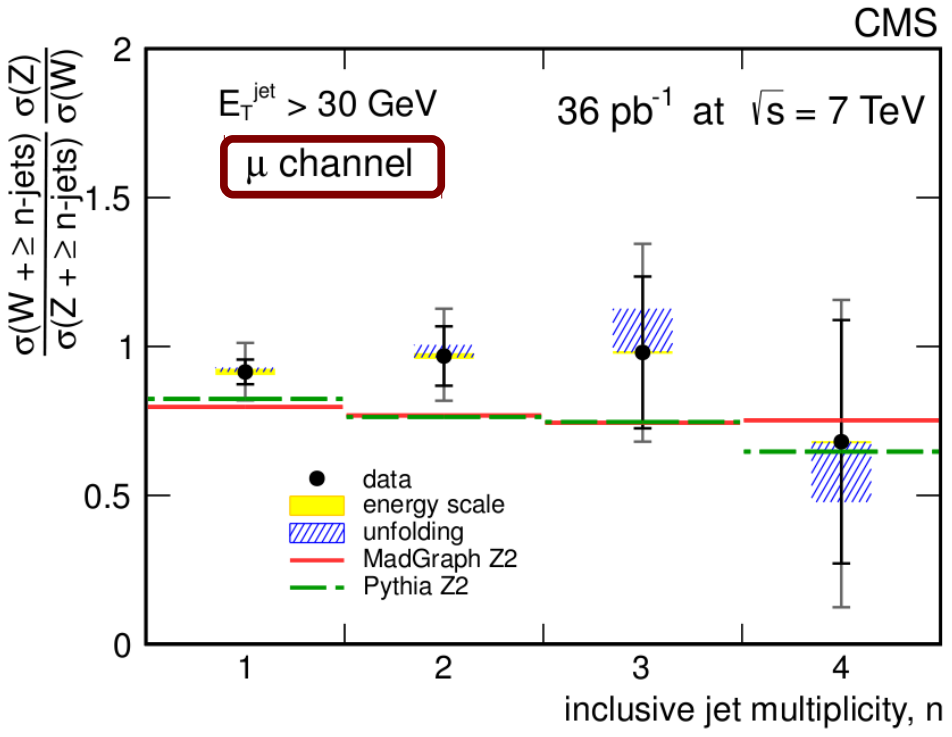
# Results: W/Z ratio



Cross sections measured from W+Jets and Z+Jets samples are used to calculate the ratio:

$$\frac{\sigma\left(W+(\geq n)\,Jets\right)}{\sigma\left(Z+(\geq n)\,Jets\right)}$$




- Event selection needs to be consistent between the W and Z (first leg) candidates.
- W/Z ratio is independent from the jet multiplicity.

➡ **Good agreement with Standard Model predictions!**

# Conclusions



**In this talk:**

- Most relevant steps of the W/Z + Jets event selection and analysis.
- Main results with 2010 dataset (~36 $pb^{-1}$): many other interesting measurements have been done.

⟹ (e.g. dedicated poster: “Measurements of associated production of vector bosons and heavy flavours with the CMS detector” - S. Casasso)

**In the future:**

- Exciting new results are expected with 2011(-2012) data: differential cross sections, angular correlations, etc. etc.
- Fascinating new challenges expected with the analyis of 2011(-2012) data (high luminosity and pile-up, complex triggers...): stay tuned!