Electroweak production of *Zjj* and hadronic activity in *Zjj* events at CMS

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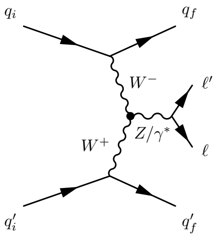
for the CMS collaboration

Universiteit Antwerpen

50th Rencontres de Moriond on "EW Interactions and Unified Theories"

Electroweak production of Z+2 jets

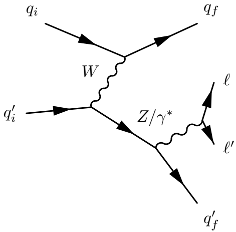


vector boson fusion

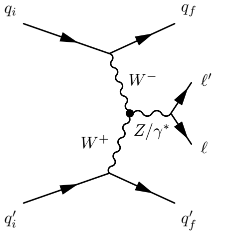
Features of vector boson fusion $WW \to Z$ are:

- Central Z decay associated with **energetic forward-backward quark jets**
- A large η separation between the jets
- A **large invariant dijet** mass
- Pure electroweak process: **surpresssed color exchange** between the tagging quarks

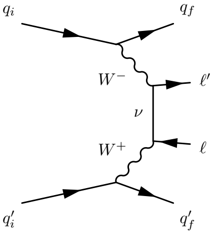
Electroweak production of Z+2 jets



bremsstrahlung



vector boson fusion



multiperipheral

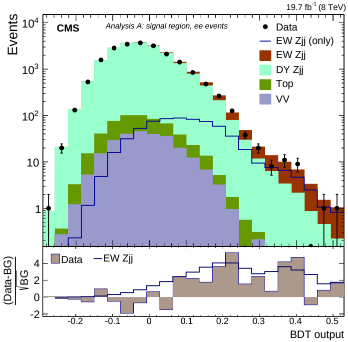
- Not only VBF, but also other pure electroweak processes lead to the same *lljj* final state
- Large negative **interference effects** between these diagrams

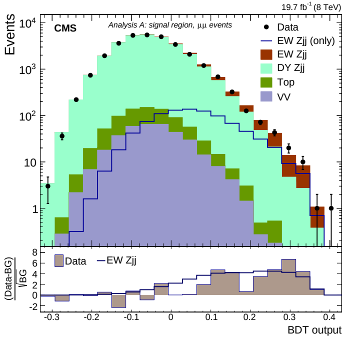
Analysis strategy

Signal is covered by large Drell-Yan background

- Use Boosted Decision Tree technique to extract signal
- Signal and background strenghts fitted from discriminator output with a CLs method
- Systematics included as nuisances
- Confirm signal in both *ee* and $\mu\mu$ modes
- Use both Monte Carlo based and data-driven background models

Monte Carlo based analysis



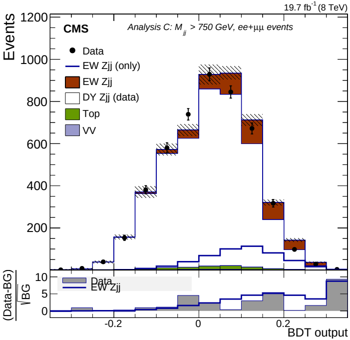


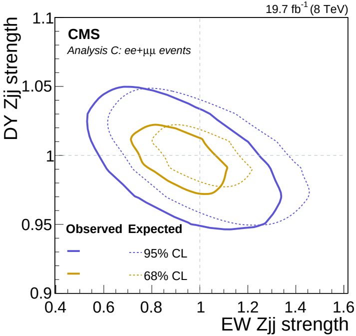
$Z \to ee$ **channel** $Z \to \mu\mu$ **channel**

$$\text{Signal: } \frac{\sigma}{\sigma_{SM}} = 0.84 \pm 0.07 \pm 0.19$$

Information about the input variables and systematics in the back-up slides

Data-driven analysis

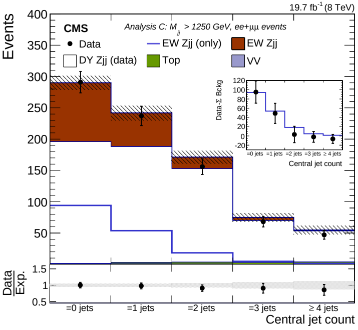


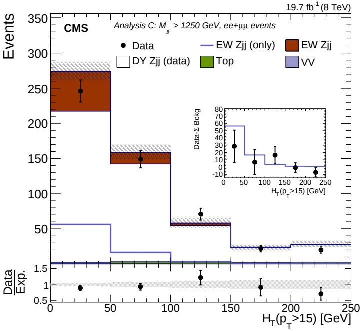


$$\text{Signal: } \frac{\sigma}{\sigma_{SM}} = 0.88 \pm 0.16 \pm 0.18$$

$\Rightarrow$ DY *Zjj* background model was built from γjj data, with $p_T(\gamma)$ reweighted to $p_T(Z)$

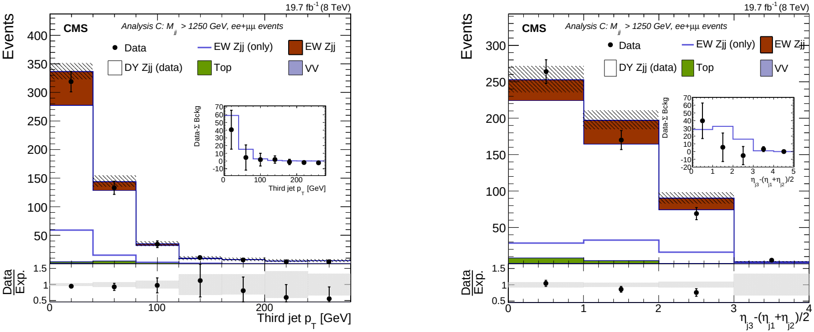
Jets falling in the VBF rapidity gap





- Use of a relative pure signal region ($M_{jj} > 1250$ GeV)
- Count jets with $p_T > 15$ GeV which fall between the two tagging jets

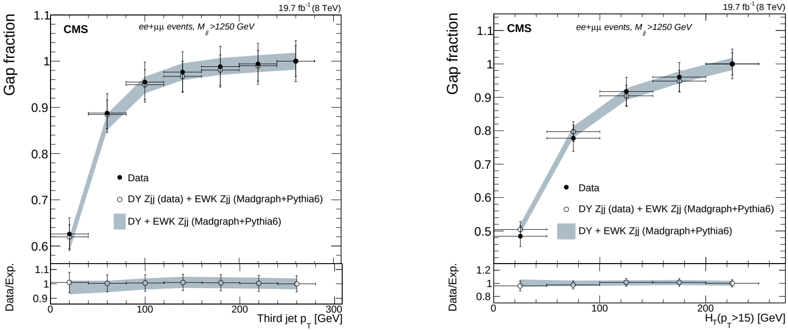
3rd jet kinematics



- p_T of 3rd jet is in good agreement with MC prediction
- Small disagreement for Zeppenfeld variable of the 3rd jet: $y^*_{j3} = y_{j3} - \frac{y_{j1}+y_{j2}}{2}$

Gap fraction: hadronic veto efficiencies

Fraction of events which do not pass a given threshold:



- ▶ Nice agreement between data and simulation for central jet vetoes!

Conclusions

- Confirmed **observation of electroweak *Zjj* production at 8 TeV**

  Electroweak $pp \rightarrow lljj$ cross section
  defined for $p_{Tj} > 25$ GeV, $|\eta_j| < 5$, $M_{jj} > 120$ GeV, $m_{ll} > 50$ GeV:
  $\sigma = 174 \pm 15$ (stat) ± 40 (syst) fb
  in good agreement with $\sigma_{th} = 208 \pm 11$ fb prediction

- Produced results on the **hadronic activity** in the central region between the two tagging jets

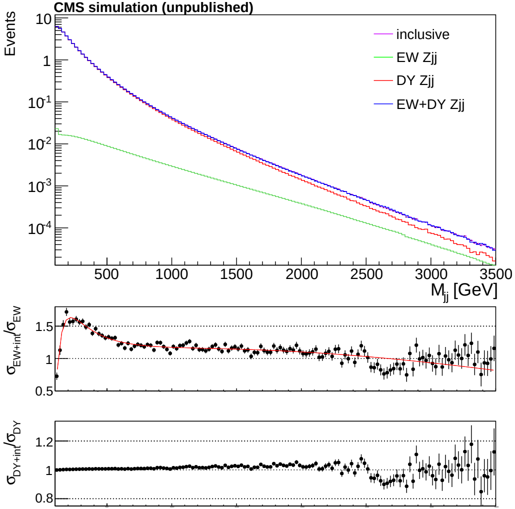
Eur. Phys. J. C. (2015) 75:66

arXiv:*1410.3153*

Paper for 7 TeV analysis: **JHEP 10 (2013) 062**, arXiv:*1305.7389*

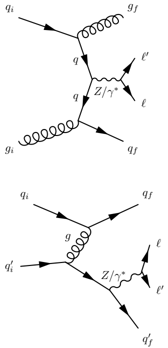
Back-up slides

Interference with DY background



Interference between the electroweak and DY production of *Zjj*

Representive diagrams for DY background:



Selection and BDT variables

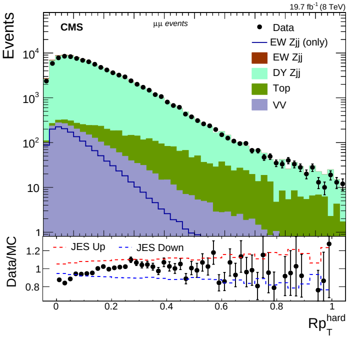
Analysis	A	B	C
Channels	ee, $\mu\mu$	$\mu\mu$	ee, $\mu\mu$ binned in M_{jj}
Selection	$p_{T j_1, j_2} > 50, 30\,\mathrm{GeV}$		
	$Rp_T^{hard} < 0.14$, $\lvert y^* \rvert < 1.2$, $M_{jj} > 200\,\mathrm{GeV}$		$p_{TZ} > 50\,\mathrm{GeV}$, $\lvert y_Z \rvert < 1.4442$, $M_{jj} > 450\,\mathrm{GeV}$
Jets	PF	JPT	PF
Variables used			
M_{jj}	•	•	•
$p_{T j_1}, p_{T j_2}$		•	•
η_{j_1}, η_{j_2}			•
$\Delta_{rel}(jj) = \frac{\lvert \vec{p}_{T j_1} + \vec{p}_{T j_2} \rvert}{p_{T j_1} + p_{T j_2}}$			•
$\Delta\eta_{jj}$		•	
$\lvert \eta_{j_1} \rvert + \lvert \eta_{j_2} \rvert$	•	•	•
$\Delta\phi_{jj}$		•	•
$\Delta\phi_{Z,j_1}$		•	
y_Z	•	•	
z_Z^*	•		
p_{TZ}	•	•	
Rp_T^{hard}		•	
q/g discriminator	•		•
DY Zjj model	MC-based	MC-based	From data

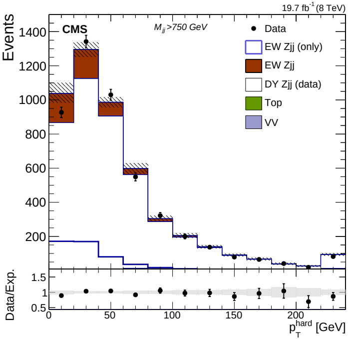
$$R(p_T^{hard}) = \frac{\lvert \vec{p}_{Tj1} + \vec{p}_{Tj2} + \vec{p}_{TZ} \rvert}{p_{Tj1} + p_{Tj2} + p_{TZ}}$$

$$y^* = y_Z - \frac{y_{j1} + y_{j2}}{2}$$

$$z^* = \frac{y^*}{\Delta y_{jj}}$$

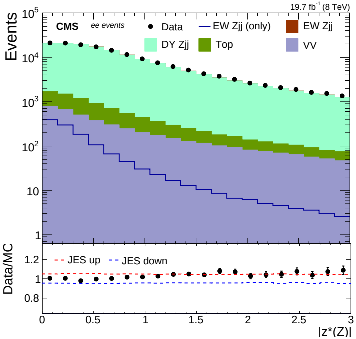
$R(p_T^{hard})$





$$R(p_T^{hard}) = \frac{|\vec{p}_{Tj1}+\vec{p}_{Tj2}+\vec{p}_{TZ}|}{p_{Tj1}+p_{Tj2}+p_{TZ}}$$

z^*



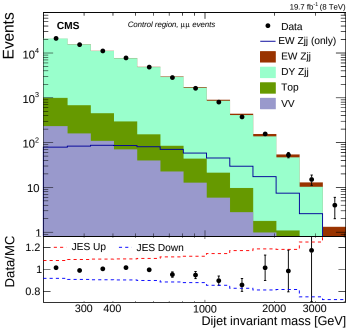
$$| z^* | < 0.5 \Rightarrow y_{j1} < y_Z < y_{j2}$$

$| z^* | > 0.5 \Rightarrow Z$ not between tagging jets

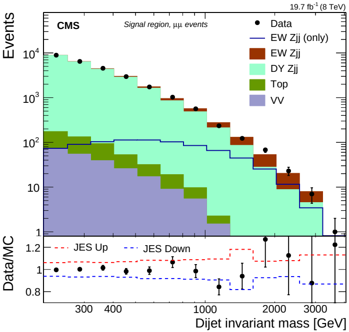
$$z^* = 0.5 \Rightarrow y_Z = y_{j1}$$

$$z^* = -0.5 \Rightarrow y_Z = y_{j2}$$

dijet invariant mass



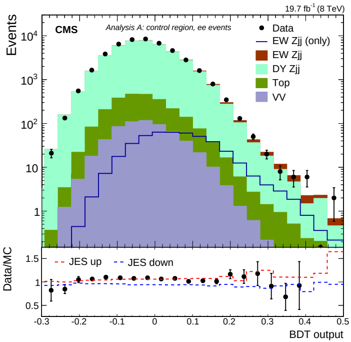
control region



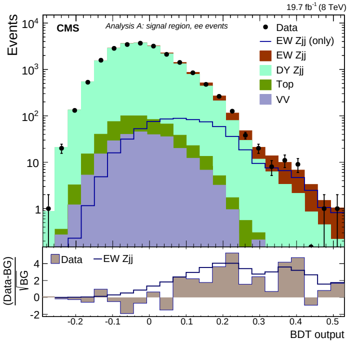
signal region

BDT's and fit results

Analysis A: electron channel, particle flow jets, simulation-based background



control region

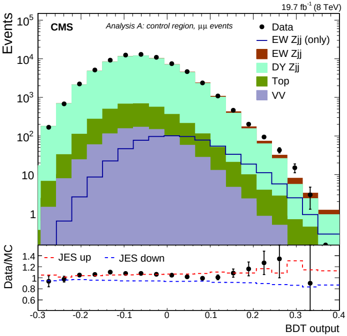


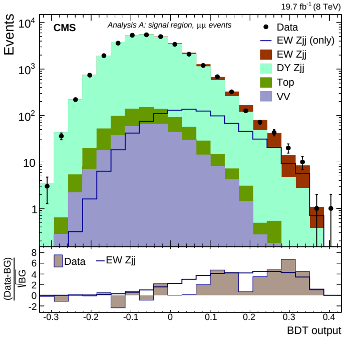
signal region

Signal: $\mu = 0.82 \pm 0.11 \pm 0.19$

BDT's and fit results

Analysis A: muon channel, particle flow jets, simulation-based background



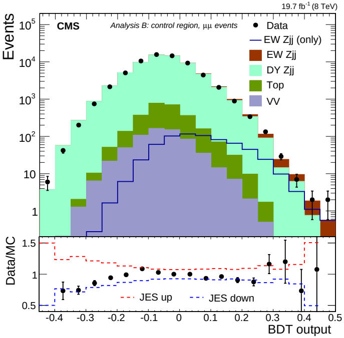


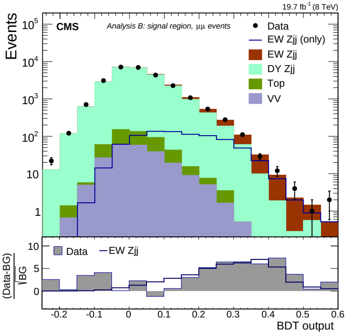
control region **signal region**

Signal: $\mu = 0.86 \pm 0.10 \pm 0.18$

BDT's and fit results

Analysis B: muon channel, jet-plus-track jets, simulation-based background



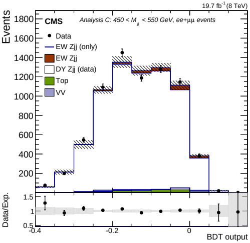


control region **signal region**

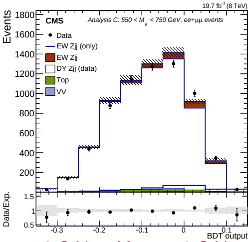
Signal: $\mu = 0.89 \pm 0.09 \pm 0.17$

BDT's and fit results

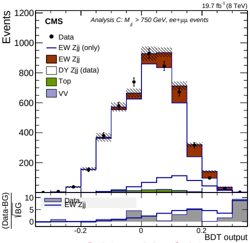
Analysis C: electron + muon channel, particle flow jets, data-driven background



550 GeV $< M_{jj} <$ 750 GeV



450 GeV $< M_{jj} <$ 550 GeV



750 GeV $< M_{jj}$ GeV

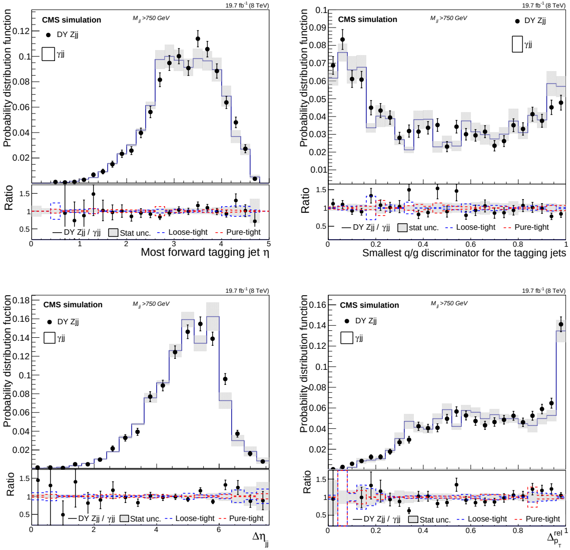
Signal: $\mu = 0.88 \pm 0.16 \pm 0.18$

Uncertainties

	Analysis A			Analysis B	Analysis C		
	ee	$\mu\mu$	ee + $\mu\mu$	$\mu\mu$	ee	$\mu\mu$	ee + $\mu\mu$
Luminosity	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Trigger/lepton selection	0.04	0.04	0.04	0.04	0.04	0.04	0.04
JES+residual response	0.06	0.05	0.05	0.04	0.06	0.05	0.05
JER	0.02	0.02	0.02	0.02	0.04	0.04	0.03
Pileup	0.01	0.02	0.02	0.01	0.01	0.01	0.01
DY Zjj	0.07	0.05	0.07	0.08	0.14	0.12	0.13
q/g discriminator	<0.01	<0.01	<0.01	—	<0.01	<0.01	<0.01
Top, dibosons	0.01	0.01	0.01	0.01	<0.01	<0.01	<0.01
Signal acceptance	0.03	0.04	0.04	0.04	0.06	0.06	0.06
DY/EW Zjj interference	0.14	0.14	0.14	0.13	0.06	0.08	0.08
Systematic uncertainty	0.19	0.18	0.19	0.17	0.17	0.17	0.18
Statistical uncertainty	0.11	0.10	0.07	0.09	0.24	0.21	0.16
$\mu = \sigma/\sigma_{th}$	0.82	0.86	0.84	0.89	0.91	0.85	0.88

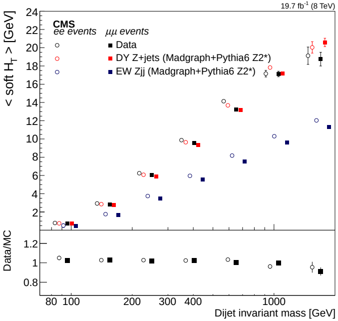
Excellent agreement between the different analyse methods!

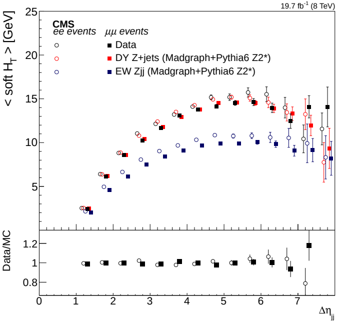
MC closure for data-driven DY+2 jets



The distributions for γjj events are in good agreement with the DY simulation

Central hadronic activity with track-jets

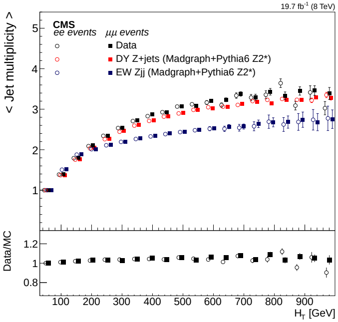


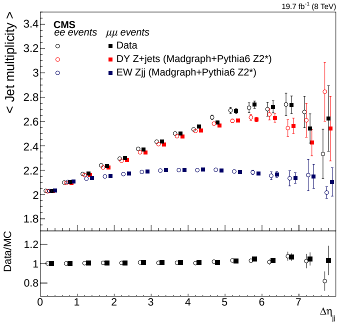


- Use of high-purity tracks associated with the primary vertex, and not associated with the 2 leptons or the 2 jets
- Clustering of these tracks into soft track-jets with anti-k_T algorithm
- $H_T(3)$: Scalar sum of 3 leading (p_T-ordered) soft track jets in the central region between the 2 tagging jets

Note: contribution of electroweak Zjj is $\sim 20\%$ for $M_{jj} > 1$ TeV, and $\sim 5\%$ for $|\Delta\eta_{jj}| > 4$

Radiation patterns in Z+jets events



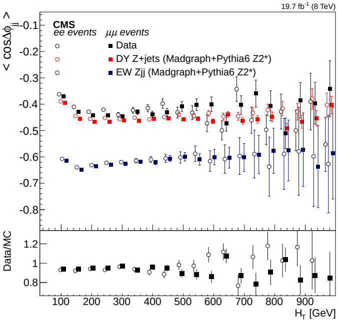


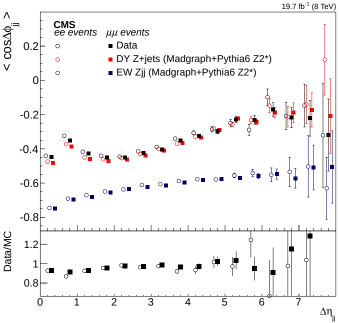
average jet multiplicity
vs.
total H_T of jets

average jet multiplicity
vs.
$\Delta\eta$ of two leading jets

Selection: jets with $p_{Tj} > 40$ GeV and $\mid \eta_j \mid < 4.7$ in Z+jet events

Radiation patterns in Z+jets events





average cos $cos(\Delta\phi_{jj})$
vs.
total H_T of jets

average $\cos(\Delta\phi_{jj})$
vs.
$\Delta\eta$ of two leading jets

Selection: jets with $p_{Tj} > 40$ GeV and $\mid \eta_j \mid < 4.7$ in Z+jet events