

CMS plans for VBS $ZZ \rightarrow 4l$

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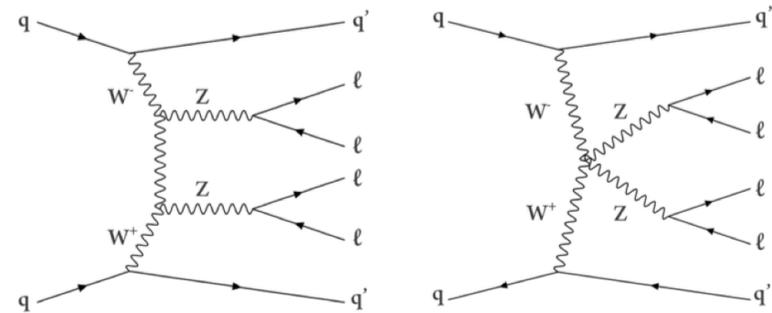
LLR-École polytechnique, CNRS&IN2P3

HL/HE LHC WG1 meeting – Electroweak physics, 01/03/2018

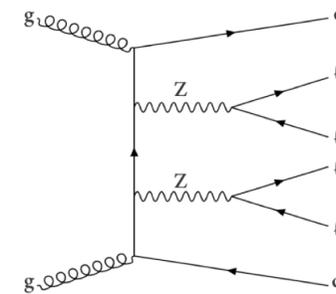
VBS in the fully leptonic ZZ channel

- ❑ First LHC result in this channel published last summer based on CMS 2016 data (35.9/fb)
- ❑ **Clean leptonic signature** $pp \rightarrow ZZjj \rightarrow lll'l'jj$, very low reducible backgrounds (estimated from data)
- ❑ Fully reconstructed final state gives precise access to **scattering energy** (m_{4l}) and bosons **polarizations** via lepton angular distributions
- ❑ Low cross section x branching ratio
 - ❑ Efficient lepton reconstruction and selection is crucial
 - ❑ event efficiency $\sim (\text{lepton efficiency})^4$
 - ❑ **Acceptance increase** for HL-LHC detectors

(some) EW contributions – α_{EW}^6

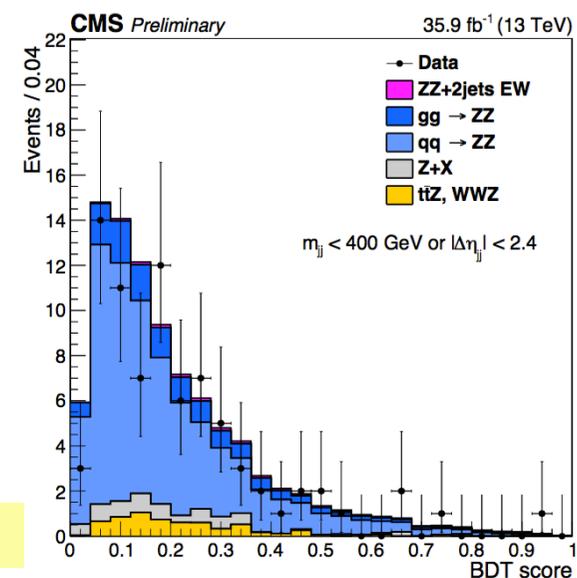
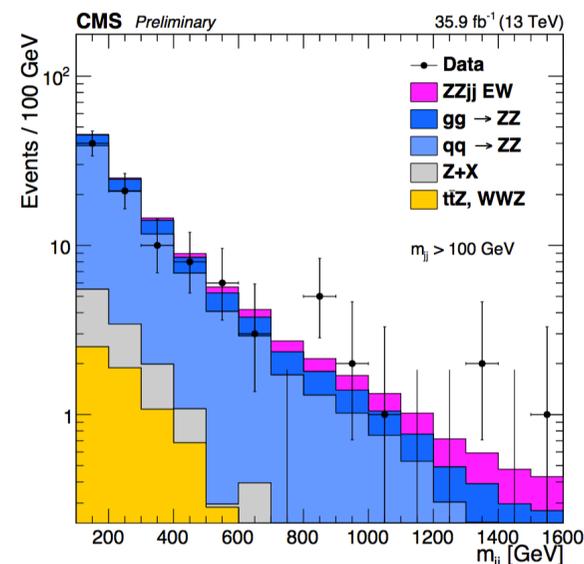


Mixed QCD-EW contributions - $\alpha^2 \alpha_{EW}^4$ (QCD bkg)



CMS 2016 analysis

- ❑ Low statistics, don't want to throw away events
=> multivariate classifier (BDT)
- ❑ Optimized for separation of EW signal from QCD-induced production
- ❑ $p_{Tj1,2} > 30$ GeV, $p_T(\text{lepton}) > 7(5)$ GeV, $|\eta(\text{lepton})| < 2.5(2.4)$, $m_{jj} > 100$ GeV
- ❑ Input variables: m_{jj} , $\Delta\eta_{jj}$, z_1^* , z_2^* , $R(p_T)$, dijet p_T balance, m_{4l} (no 3rd jet veto)
- ❑ BDT performance checked against Matrix Element Approach
- ❑ Signal extracted from **template fit of the BDT distributions to the data**
- ❑ Background validated in QCD enriched CR ($m_{jj} < 400$ GeV or $|\Delta\eta_{jj}| < 2.4$)



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CMS 2016 results

- Template fit of the BDT spectrum, using the full BDT spectrum to **constrain the QCD normalization from data**

- Signal strength:

$$\mu = 1.39^{+0.72}_{-0.57} (\text{stat}) \quad ^{+0.46}_{-0.31} (\text{syst}) = 1.39^{+0.86}_{-0.65}$$

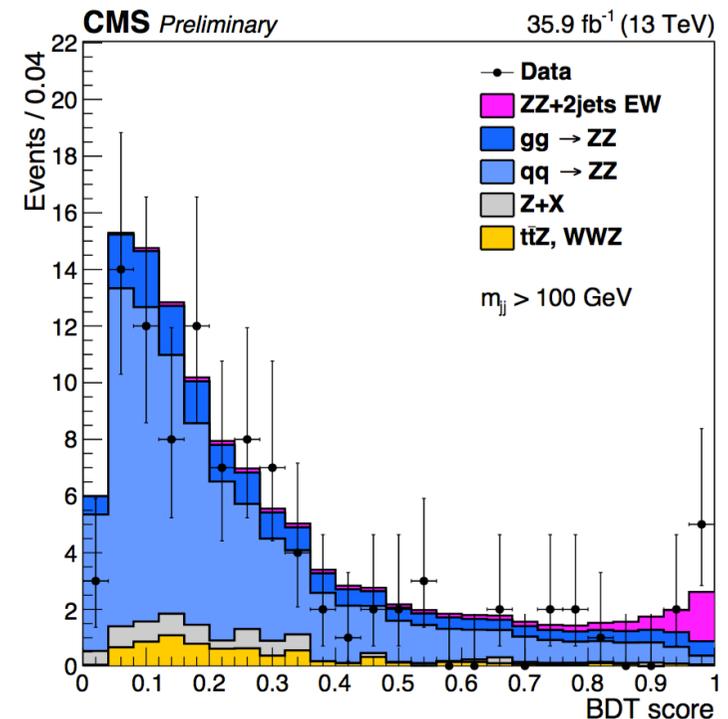
- Observed significance: **2.7σ** (expected 1.6σ)

- Fiducial cross section:

$$\sigma_{\text{EW}}(\text{pp} \rightarrow \text{ZZjj} \rightarrow \ell\ell\ell'\ell'jj) = 0.40^{+0.21}_{-0.16} (\text{stat}) \quad ^{+0.13}_{-0.09} (\text{syst}) \text{ fb}$$

- The measurement is **(for now) statistically limited**

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Expectation for 3/ab

- Event counts, 13 TeV, 35.9/fb for ZZjj ($m_{jj} > 100$ GeV, BDT fit) and VBS-enriched ($m_{jj} > 400$ GeV and $|\Delta\eta| > 2.4$) selections:

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Selection	$q_t\bar{q}_tZ$ and WWZ	QCD ZZjj	Z + X	Total bkg.	EW ZZjj	Total expected	Data
ZZjj	7.1 ± 0.8	97 ± 14	6.6 ± 2.5	111 ± 14	6.2 ± 0.7	117 ± 14	99
VBS signal-enriched	0.9 ± 0.2	19 ± 4	0.7 ± 0.3	20 ± 4	4 ± 0.5	25 ± 4	19

- Simply scaling by the luminosity ratio, not accounting for 13 TeV \rightarrow 14 TeV nor HL-LHC detector/environment:

	EW signal yield (events/3/ab)	EW signal stat. uncertainty (%)	QCD bkg yield (events/3/ab)	QCD bkg stat. uncertainty (%)
ZZjj	518	4%	8105	1%
VBS signal-enriched	334	5%	1588	2.5%

- Naive scaling show that the measurement will become **systematic limited for luminosity $> \sim 500/\text{fb}$**

Dominant uncertainties

- ❑ Naïve scaling of yields shows that the measurement will become systematic limited for $L > \sim 500/\text{fb}$
 - ❑ We should aim at reducing dominant systematic uncertainties

- ❑ Dominant systematic uncertainties in the 2016 analysis:
 - ❑ **ggZZ loop modeling (normalization and shape):** data (CR, on the sum qqZZ + ggZZ) + theory?
 - ❑ Jet energy scale: experiment
 - ❑ Signal PDF and QCD scales: data (PDF fits, other similar EW processes, eg WW?) + theory?
 - ❑ QCD scales qqZZ: data (CR, on the sum qqZZ+ggZZ) + theory?
- ❑ Other uncertainties:
 - ❑ ttZ, WWZ QCD scales and PDF: probably can expect also here improvement from data and theory by $3/\alpha_b$

CMS Plan for VBS ZZ

- ❑ Establish precise projection of current analysis scaled with luminosity (same detector)
- ❑ Establish projection as function of dominant (theory) uncertainty, ie ggZZ yield
- ❑ Assess precision that can be obtained using data (CR) with 3/ab (+theory?)
- ❑ Prospective analysis with HL/HE LHC configuration (Delphes)
- ❑ Separation of the longitudinal component (ongoing activity within VBSCan)
- ❑ Significance for VBS ZZ and VBS $Z_L Z_L$ @ 3/ab