Study of the acceptance for ZZ to four lepton events produced in pp collisions at $\sqrt{s} = 13 TeV$ in the ATLAS detector at CERN.

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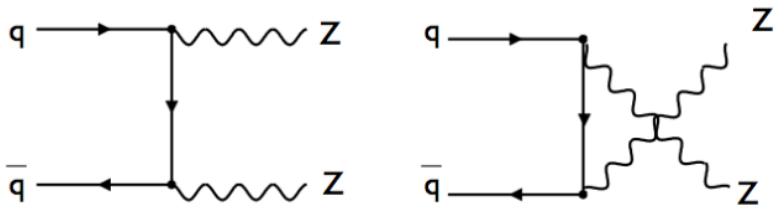
Introduction

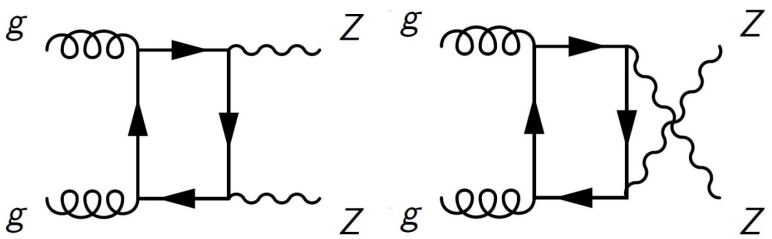
ZZ production

- Standard Model ZZ production (lowest level diagrams):



Standard Model Production

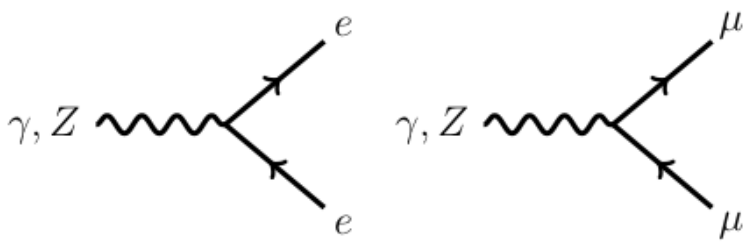
$q\bar{q}$ u and t channels



gg initiated processes contribute $\approx 6\%$

- ZZ production is also possible through Higgs decay and non SM sources.

We are interested in leptonic decays where lepton is either e or μ



ZZ production measurement

$$N^{signal}_{pp\to ZZ\to 4\ell} = \mathbb{L} \cdot \sigma^{tot}_{pp\to ZZ} \cdot BR_{ZZ\to 4\ell} \cdot A_{ZZ} \cdot Czz$$

- $\mathbb{L}$: Integrated Luminosity
- $\sigma^{tot}_{pp\to ZZ}$: total cross section of ZZ production
- $BR_{ZZ\to 4\ell}$: branching ratio of the two Z bosons to decay to either electrons or muons
- A_{ZZ}: Acceptance correction for the geometrical and kinematic criteria

$$A_{ZZ} = \frac{\text{fiducial events}}{\text{total events}}$$

- Czz: Efficiency correction for detector ability to reconstruct these objects

$$C_{ZZ} = \frac{\text{reconstructed events}}{\text{fiducial generated events}}$$

Fiducial and total cross section

Fiducial Cross Section —extrapolation→ **Total Cross Section**

- the measured cross section :

$$\sigma^{fid}_{pp\to ZZ\to 4\ell} = \frac{N_{obs} - N_{bkg}}{\mathbb{L} \cdot C_{ZZ}}$$

corresponds to the reduced phase-space of the actual measurement

- it is a fraction of the total cross section

$$\sigma^{fid}_{pp\to ZZ\to 4\ell} = \sigma^{tot}_{pp\to ZZ} \cdot BR_{ZZ\to 4\ell} \cdot A_{ZZ}$$

- Extrapolate the "fiducial" to the "total cross section" for ZZ production
- $\sigma^{tot}_{pp\to ZZ\to 4\ell} = \frac{N_{obs} - N_{bkg}}{\mathbb{L} \cdot A_{ZZ} \cdot C_{ZZ}}$

*include branching ratio

Acceptance Factor A_{ZZ}

$$A_{zz} = \frac{\sigma^{fid}_{pp\to ZZ\to 4\ell}}{\sigma^{tot}_{pp\to ZZ\to 4\ell}}$$

Calculation of Extrapolation factor A_{ZZ}

Monte Carlo generators used:

- **MCFM 6.8** : A_{ZZ} nominal value,$2e2\mu$ channel only
- **POWHEG (for the $q\bar{q}$ processes) and SHERPA (for the gg processes)** : cross-check and to estimate the correction for the same flavor channels.

We generate samples of ZZ events. Z mass range: $66 - 116 GeV$

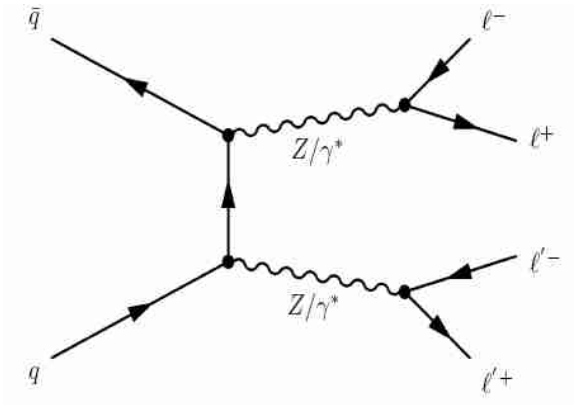
- **For the** $2e2mu$ **channel**: each lepton pair must have invariant mass in the range ($66, 116 GeV$)
- **In the** $4e$ **and** 4μ **channels**:
  first we must form the correct pairs and then apply the mass cut
  $\Rightarrow$From all possible SFOC lepton pairs we select the pairing that is minimizing $|m_{\ell\ell} - m_Z| + |m_{\ell'\ell'} - m_Z|$

MCFM,Monte Carlo event generator:

- process used: $pp \to ZZ \to e^- e^+ \mu^- \mu^+$. $4e$ and 4μ decay channels **not available in MCFM**
- parton level
- predictions can be NLO or LO
- produces weighted events
- handy tool to study easily the pdf and scale uncertainties on the cross section
- efficient in generating very large statistics

Calculation of A_{ZZ} and its systematic uncertainties

Fiducial phase space definition



Fiducial phase space (subset of the total MCFM sample):

- All leptons must have $P_T > 5$ GeV and $|\eta| < 2.7$
- The three highest-P_T leptons must satisfy $P_T > 20$, 15, 10 GeV
- $\Delta R(\ell_i \ell'_j) > 0.2$ (0.1) between any two different (same) flavour leptons i, j
- All possible SFOC dileptons in the final selected quadruplet have mass > 5 GeV

Study of gg contribution with MCFM

*gg initiated processes are calculate in LO, gg initiated cross sections are scaled by an NLO k-factor of 1.67 ± 0.14.

The folowing table is obtained using MCFM and for $2e2\mu$ channel only.

configuration	σ_{tot} $[fb]$	σ_{fid} $[fb]$	A_{ZZ}
with gg (Nominal MCFM weights)	32.66 ± 0.039	18.936 ± 0.028	0.5798 ± 0.0006
only gg	2.157 ± 0.003	1.512 ± 0.002	0.701 ± 0.0005
without gg	30.503 ± 0.036	17.424 ± 0.026	0.5712 ± 0.0006
with gg·1.67	34.1051 ± 0.041	19.949 ± 0.03	0.5849 ± 0.0006

Correction from dilepton mass to Z mass

$$\begin{aligned} N_{observed} - N_{bkg} =& \mathbb{L} \cdot \sigma_{pp\to ZZ} \cdot BR_{ZZ\to 2e2\mu} \cdot A_{ZZ}(2e2\mu) \cdot C_{ZZ}(2e2\mu) \\ &+ \mathbb{L} \cdot \sigma_{pp\to ZZ} \cdot BR_{ZZ\to 4e} \cdot Dzz \cdot A_{ZZ}(4e) \cdot C_{ZZ}(4e) \\ &+ \mathbb{L} \cdot \sigma_{pp\to ZZ} \cdot BR_{ZZ\to 4\mu} \cdot Dzz \cdot A_{ZZ}(4\mu) \cdot C_{ZZ}(4\mu) \end{aligned}$$

- A correction to A_{ZZ} should be provided in the $4e$ and 4μ channels because of the pairing algorithm bias and interference effects.
- The correction factor D_{ZZ} is calculated by :

$$D_{ZZ} = \frac{\sigma^{tot}_{ZZ}(4e) + \sigma^{tot}_{ZZ}(4\mu)}{\sigma^{tot}_{ZZ}(2e2\mu)}$$

- The ratio is found using POWHEG$q\bar{q}$ and SHERPA gg initiated samples:

	$\sigma_{tot}(2e2\mu)$ [fb]	$\sigma_{tot}(4e)$[fb]	$\sigma_{tot}(4\mu)$ [fb]	D_{ZZ}
POWHEG($q\bar{q}$)+ SHERPA(gg)	32.67 ± 0.11	16.86 ± 0.08	16.97 ± 0.08	1.036 ± 0.005

PDF uncertainty

From the CT10 family set variations.

A_{ZZ} is also calculated using MSTW and NNPDF23 PDF sets and the deviations from CT10 value are calculated.

PDF set	$2e2\mu$	
CT10	0.5849 ± 0.0006	
CT10 variations	$+0.002, -0.0025$	$(+0.34\%, -0.43\%)$
CT10-MSTW (MSTW2008nnlo68cl)	$+0.001$	0.17%
CT10-NNPDF23 (NNPDF23_nlo_as_0118)	-0.001	0.17%

Renormalization and factorization scale uncertainty

To find renormalization and factorization scale uncertainty

- $\mu_R = \mu_f = 1.0 \cdot m_{ZZ}$, is chosen as the nominal value.
- independent samples varying μ_R, μ_f together and independently around the nominal value
- The absolute uncertainty is the difference between the nominal A_{ZZ} value and the values computed from the other samples.

The maximum positive and negative deviations are taken as the uncertainty on A_{ZZ}

The folowing table is obtained using MCFM and for $2e2\mu$ channel only

μ_R/m_{ZZ}	μ_f/m_{ZZ}	$\Delta A_{ZZ}(2e2\mu)$
1.0	1.0	*nominal*
0.5	0.5	-0.0037 $\pm$0.0006
2.0	2.0	-0.0020 $\pm$0.0006
1.0	0.5	+0.0049 $\pm$0.0006
1.0	2.0	-0.0018 $\pm$0.0006
0.5	1.0	+0.0016 $\pm$0.0006
2.0	1.0	-0.0027 $\pm$0.0006

Generator uncertainty

Uncertainty due to the choise of MC generator

A_{ZZ} is estimated using POWHEG($q\bar{q}$) and SHERPA(gg). The difference between the MCFM value and this one is taken as the uncertainty.

	$A_{ZZ}(2e2\mu)$
POWHEG(qq)+SHERPA(gg)	0.5887 ± 0.0017
MCFM(qq+1.76gg)	0.5849 ± 0.0006
MCFM(qq+1.76gg)-POWHEG(qq)+SHERPA(gg)	-0.0038 ± 0.0018

Results

Results

Nominal value of A_{ZZ} for the $2e2\mu$ channel and its total uncertainty.

	Nominal	total unc.
A_{ZZ}	0.5849	$^{+0.0064}_{-0.0065}$

Contributions to the total uncertainty

Source	Abs. Unc.	Rel. Unc.
Statistical	$^{+0.0006}_{-0.0006}$	$^{+0.1\%}_{-0.1\%}$
CT10 error set	$^{+0.0020}_{-0.0025}$	$^{+0.34\%}_{-0.43\%}$
QCD scale	$^{+0.0046}_{-0.0044}$	$^{+0.79\%}_{-0.75\%}$
Generator	± 0.0038	$\pm 0.63\%$
Total	$^{+0.0064}_{-0.0065}$	$^{1.1\%}_{-1.12\%}$

A_{ZZ} for the $4e$ and the 4μ channel

The value estimated for the $2e2\mu$ channel is multiplied with D_{ZZ} before it is used for extrapolation

Cross sections at $\sqrt{s} = 13\,TeV$, $\mathbb{L} = 3.2\ fb^{-1}$

A_{ZZ}	0.39 ± 0.02
$C_{ZZ}(4e)$	0.55 ± 0.02
$C_{ZZ}(4\mu)$	0.81 ± 0.03
$C_{ZZ}(2e2mu)$	0.63 ± 0.02

Observed events

Channel	Events
$4e$	15
$4mu$	30
$2e2\mu$	18
Total	63

Total expected background

$0.62^{+1.08}_{-0.11}$

	Measurement	$\mathcal{O}(\alpha_s^2)$ prediction
$\sigma^{\text{fid}}_{ZZ\to e^+e^-e^+e^-}$	$8.4\ ^{+2.4}_{-2.0}(\text{stat.})\ ^{+0.4}_{-0.2}(\text{syst.})\ ^{+0.5}_{-0.3}(\text{lumi.})$ fb	$6.9^{+0.2}_{-0.2}$ fb
$\sigma^{\text{fid}}_{ZZ\to e^+e^-\mu^+\mu^-}$	$14.7\ ^{+2.9}_{-2.5}(\text{stat.})\ ^{+0.6}_{-0.4}(\text{syst.})\ ^{+0.9}_{-0.6}(\text{lumi.})$ fb	$13.6^{+0.4}_{-0.4}$ fb
$\sigma^{\text{fid}}_{ZZ\to \mu^+\mu^-\mu^+\mu^-}$	$6.8\ ^{+1.8}_{-1.5}(\text{stat.})\ ^{+0.3}_{-0.3}(\text{syst.})\ ^{+0.4}_{-0.3}(\text{lumi.})$ fb	$6.9^{+0.2}_{-0.2}$ fb
$\sigma^{\text{fid}}_{ZZ\to \ell^+\ell^-\ell'^+\ell'^-}$	$29.7\ ^{+3.9}_{-3.6}(\text{stat.})\ ^{+1.0}_{-0.8}(\text{syst.})\ ^{+1.7}_{-1.3}(\text{lumi.})$ fb	$27.4^{+0.9}_{-0.8}$ fb
σ^{tot}_{ZZ}	$16.7\ ^{+2.2}_{-2.0}(\text{stat.})\ ^{+0.9}_{-0.7}(\text{syst.})\ ^{+1.0}_{-0.7}(\text{lumi.})$ pb	$15.6^{+0.4}_{-0.4}$ pb

- new results compatible with last year
- now in the process of being approved by the SM group and be circulated in ATLAS in the next few weeks, aiming for a publication.

Conclusion

- We estimated the value of the extrapolations factor A_{ZZ} and its systematic uncertainties for the $2e2\mu$ channel using MCFM 6.8
- For the same flavor channels we corrected the value to take into account the pairing algorithm bias
- The cross sections were scaled to match NLO predictions
- The result is used in the extrapolation of the $ZZ \rightarrow 4\ell$ cross section in 13 TeV pp collisions with the ATLAS detector

Thank you for your attention