Search for Contact Interactions in dilepton final states with the ATLAS detector

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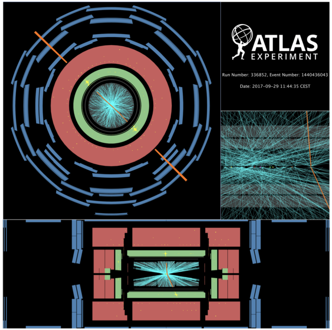
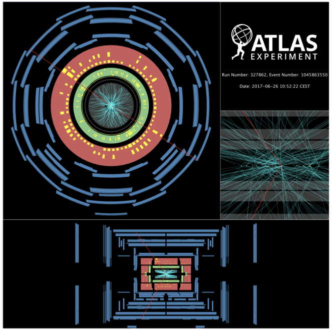
IoP APP/HEPP Conference

arXiv:1903.06248



$M_{ee} = 4.06\text{TeV}$



$M_{\mu\mu} = 2.75\text{TeV}$

ATLAS EXPERIMENT

ROYAL HOLLOWAY UNIVERSITY OF LONDON

April 10, 2019

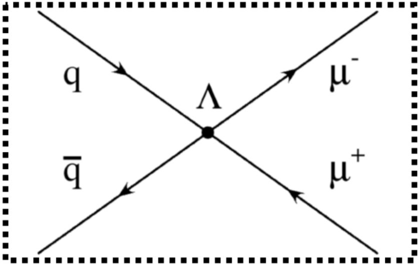
Motivation

New interactions can be detected at an energy much lower than that required to produce direct evidence of the interaction

- e.g. Charged weak interaction responsible for nuclear β decay

Can be described by the four-fermion Contact Interaction (CI)

- Quark and lepton compositeness
- Evidence of new gauge bosons



Contact Interactions

New interactions or compositeness in the process qq $\rightarrow \ell^+\ell^-$ can be described by the Contact Interaction Lagrangian:

$$\mathcal{L} = \frac{g^2}{\Lambda^2} \Big[\; \eta_{\mathrm{LL}} \, (\overline{q}_{\mathrm{L}}\gamma_\mu q_{\mathrm{L}}) \, (\overline{\ell}_{\mathrm{L}}\gamma^\mu \ell_{\mathrm{L}}) + \eta_{\mathrm{RR}} \, (\overline{q}_{\mathrm{R}}\gamma_\mu q_{\mathrm{R}}) \, (\overline{\ell}_{\mathrm{R}}\gamma^\mu \ell_{\mathrm{R}}) \\ + \eta_{\mathrm{LR}} \, (\overline{q}_{\mathrm{L}}\gamma_\mu q_{\mathrm{L}}) \, (\overline{\ell}_{\mathrm{R}}\gamma^\mu \ell_{\mathrm{R}}) + \eta_{\mathrm{RL}} \, (\overline{q}_{\mathrm{R}}\gamma_\mu q_{\mathrm{R}}) \, (\overline{\ell}_{\mathrm{L}}\gamma^\mu \ell_{\mathrm{L}}) \Big] \, ,$$

Phys.Rev.Lett 50 (1983) 811–814

The cross-section for qq $\rightarrow \ell^+\ell^-$ in the presence of contact interactions:

$$\sigma_{\mathrm{tot}}(m_{\ell\ell}) = \sigma_{\mathrm{DY}}(m_{\ell\ell}) - \eta_{ij}\frac{F_{\mathrm{I}}}{\Lambda^2} + \frac{F_{\mathrm{C}}}{\Lambda^4}$$

Contact Interactions

New interactions or compositeness in the process qq $\to \ell^+\ell^-$ can be described by the Contact Interaction Lagrangian:

$$\mathcal{L} = \frac{g^2}{\Lambda^2}\left[\eta_{\rm LL}\,(\bar{q}_{\rm L}\gamma_\mu q_{\rm L})(\bar{\ell}_{\rm L}\gamma^\mu \ell_{\rm L}) + \eta_{\rm RR}\,(\bar{q}_{\rm R}\gamma_\mu q_{\rm R})(\bar{\ell}_{\rm R}\gamma^\mu \ell_{\rm R}) \right.$$
$$\left. + \eta_{\rm LR}\,(\bar{q}_{\rm L}\gamma_\mu q_{\rm L})(\bar{\ell}_{\rm R}\gamma^\mu \ell_{\rm R}) + \eta_{\rm RL}\,(\bar{q}_{\rm R}\gamma_\mu q_{\rm R})(\bar{\ell}_{\rm L}\gamma^\mu \ell_{\rm L})\right],$$

- CI energy scale characterised by Λ
- $\eta_{ij} \to$ The i and j define the chiral structure
- The sign of $\eta_{ij} \to$ determines the interference
  - Constructive ($\eta_{ij} = -1$)
  - Destructive ($\eta_{ij} = +1$)

$$\sigma_{\rm tot}(m_{\ell\ell}) = \sigma_{\rm DY}(m_{\ell\ell}) - \eta_{ij}\frac{F_{\rm I}}{\Lambda^2} + \frac{F_{\rm C}}{\Lambda^4}$$

- $q\bar{q} \to Z/\gamma^* \to \ell^+\ell^-$, Drell–Yan (DY)
- Interference between the DY and CI
- Pure CI process

Search Strategy

Physics target:

- Search for non resonant (CI) signatures in dilepton final states
- *ee* and $\mu\mu$ (inclusive)

Observable:

- Dilepton invariant mass (m_{ll}) spectrum

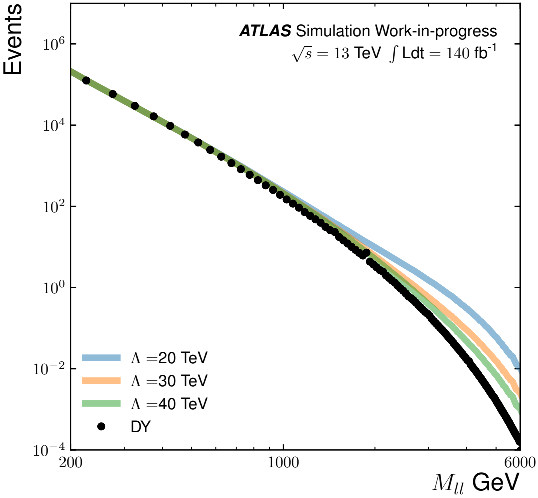
Event Selection:

- Two same flavor leptons $225 < m_{ll} < 6000$

Background:

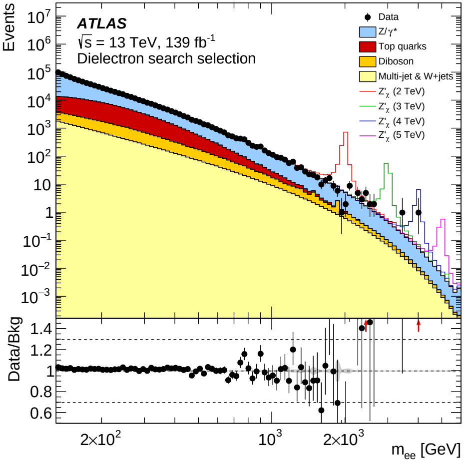
- Functional fit to data spectrum in **fit region** and extrapolated to a high mass **signal region**

Non-resonant features are expected as broad excesses in the M_{ll} spectrum

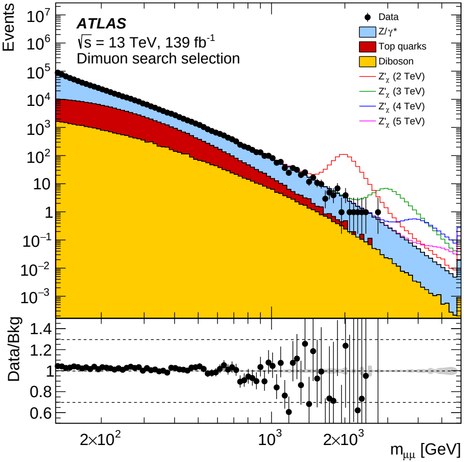


Search Backgrounds

Dielectron channel



Dimuon channel



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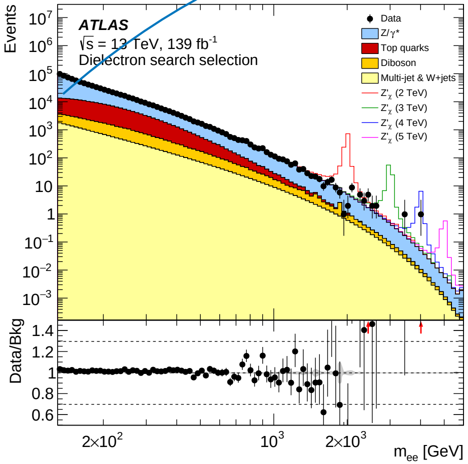
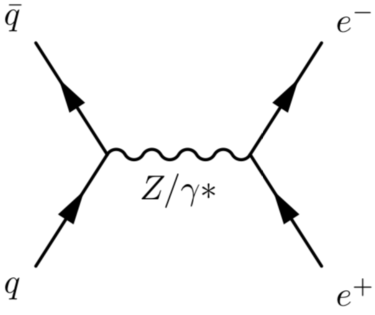
Search Backgrounds

Dielectron channel



DY



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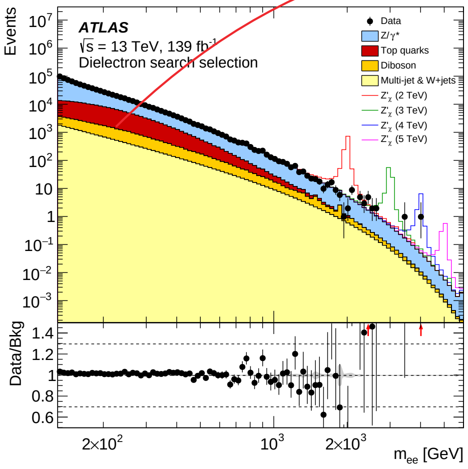
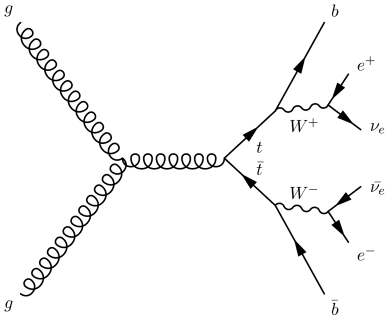


Top



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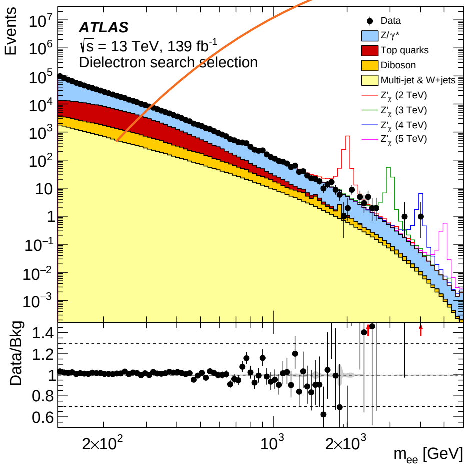
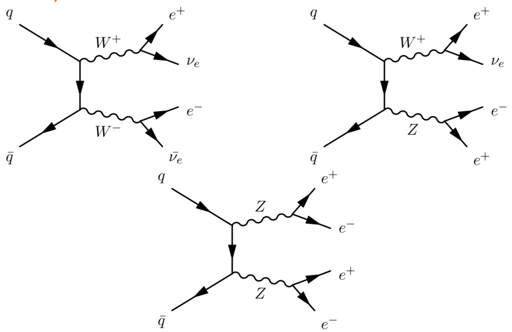
Dielectron channel



Diboson



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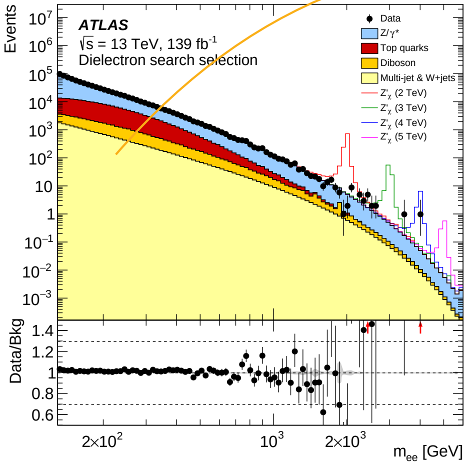
Search Backgrounds

Dielectron channel



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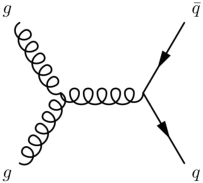
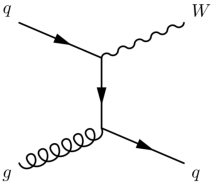
Multi-jet & W + Jets





Background estimation

Background model is fit to data in a **fit region**, and then extrapolated to a **Signal region**

$$f_{BW} = \frac{\Gamma_Z}{((M_Z - x)^2 - (\Gamma_Z)^2)}$$

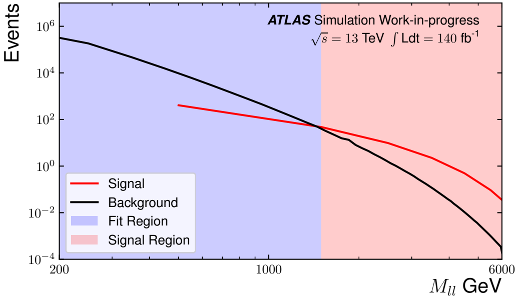
$$f_{Bkg} = f_{BW}\ (1 - \tfrac{x}{13})^{p0}\ \tfrac{x}{13}^{\sum_{i=1}^{4} p_i\ \log(\frac{x}{13})^{i-1}}$$

MC is used to optimize the analysis strategy

- Estimate mismodelling of fit
- Define fit region

Defining two regions

- **Fit region** constrain parameters of background estimation
- **Signal region** integrate fit and data yields as a single bin



Uncertainties Summary

Two types of uncertainties

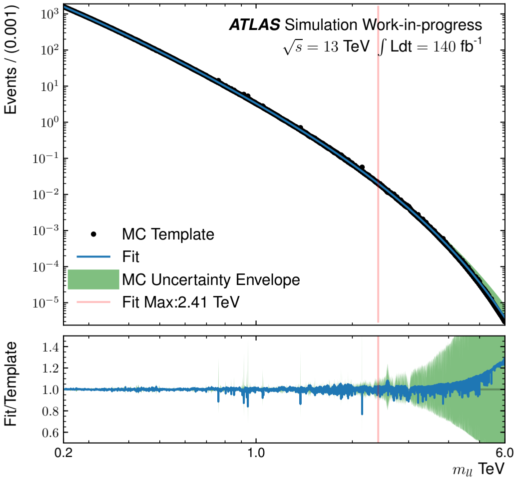
1. **MC-uncertainty**

- Understand how robust the background model is against variations in the MC distribution
  - Several systematics influence the background MC
  - The systematic varied MC are fit
  - The envelope of the fits is taken

Measured on background-only fits:

- Mainly affected by fit range

MC uncertainty



Uncertainties Summary

Two types of uncertainties

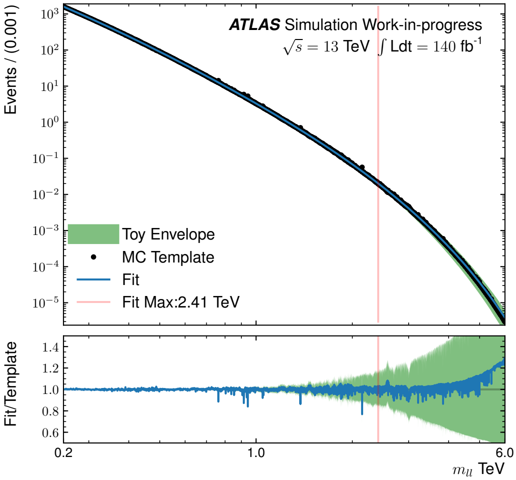
2. **Fit-uncertainty**

- Understand impact of statistical fluctuations in the fit region on the background model
  - Ensemble of 1000 statistical toys is drawn from the MC
  - The toy distributions are fit
  - The error band contains $\pm 1\sigma$ variation of the toys

Measured on background-only fits:

- Mainly affected by fit range

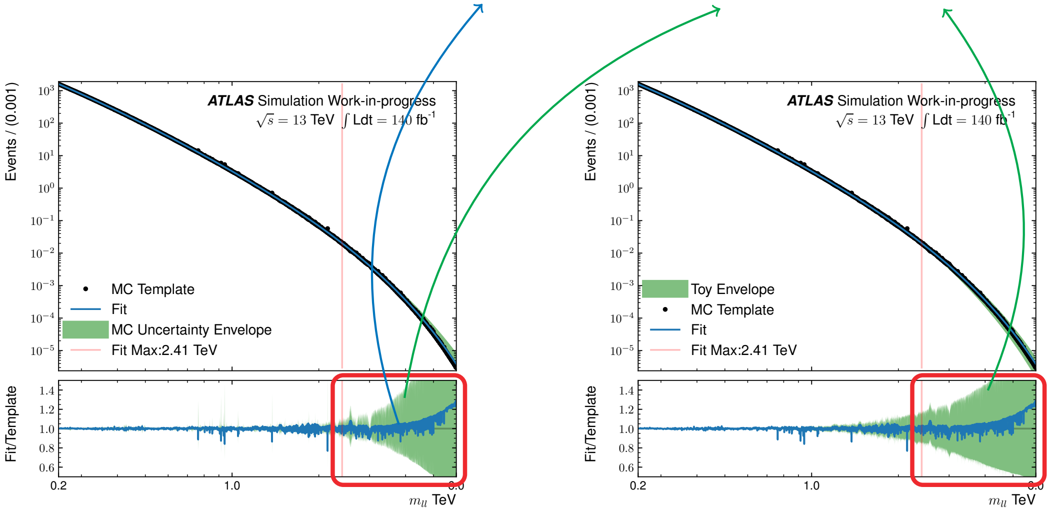
Fit uncertainty



Statistical Model

Using simple poisson counting experiment in signal region

$$L = Pois(S + (1 + \theta_{MC} + \theta_{fit}) \underbrace{B}) \times Gaus(\theta_{MC}, \underbrace{\sigma_{MC}}) \times Gaus(\theta_{fit}, \underbrace{\sigma_{fit}})$$



Statistical Model

Using simple poisson counting experiment in signal region

$$L = Pois(S + (1 + \theta_{MC} + \theta_{fit})\, B) \times Gaus(\theta_{MC}, \sigma_{MC}) \times Gaus(\theta_{fit}, \sigma_{fit})$$

- $\theta \rightarrow$ Nuisance parameters
  - proportional scales (-1,1) for the background
- S $\rightarrow$ The parameter of interest to estimate
- $\sigma_{MC} \rightarrow$ MC Uncertainty
- $\sigma_{fit} \rightarrow$ Fit Uncertainty

Limits based on signal events are set in the **signal region**

- Model independent
- Interpreted as lower limit on CI scale Λ

Optimization procedure

Fit region

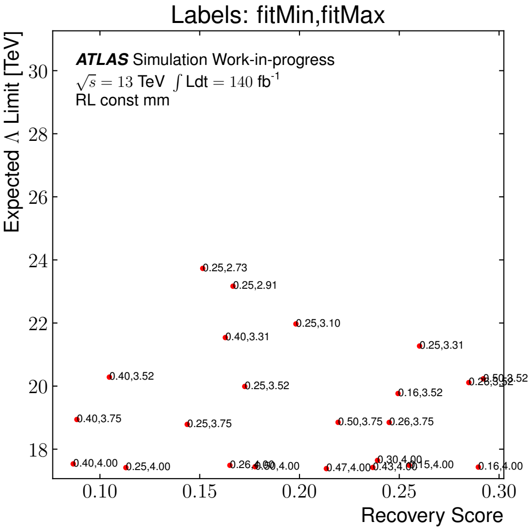
- **Fit Min:** start of fit
- **Fit Max:** end of fit

Balance two criteria

- Maximize expected limit
- Minimize signal recovery bias
  - Recovery score

Full systematics included in optimization

- Shows clear trade-off between limit and recovery bias during optimization
- Can still maintain sensitivity with good signal recovery

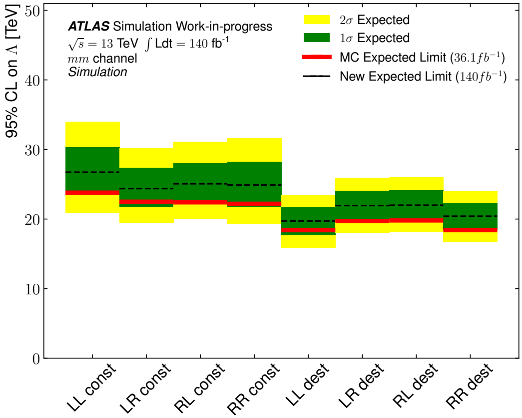


Results

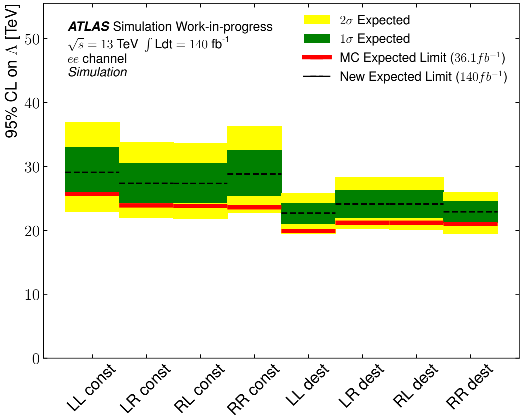
CLs limits produced at 140 fb^{-1}

- Compared with previous analysis results at 36.1 fb^{-1}

$\mu\mu$



ee



Summary

- Outlined new analysis strategy for CI search
  - Allows for model independent limits
  - Less reliant on MC and on the very high PDF uncertainty at high $m_{\ell\ell}$
  - Will cope well as we move to higher luminosity
- Produced expected limits for *ee* and $\mu\mu$ channels
  - Show an increase of 2-3 TeV
- The analysis aims for a full Run-2 publication

Model	Expected Limit on Λ [TeV]	
	ee	$\mu\mu$
LL const	29.1	26.7
LL dest	22.7	19.7
LR const	27.4	24.4
LR dest	24.1	22.0
RL const	27.3	25.1
RL dest	24.1	22.0
RR const	28.8	24.9
RR dest	22.9	20.4

Questions or Comments

BACKUP

Event Selection

- At least one pp interaction vertex is reconstructed
- Primary vertex: highest $\sum p_T^2$ using tracks with p_T >0.5 GeV

Electrons

- $E_T > 30$ GeV
- $|\eta| < 1.37$ or $|\eta| > 1.52$
- *medium* ID (93% efficient for $E_T > 80$ GeV)

Muons

- $p_T > 30$ GeV
- $|\eta| < 2.5$
- *high-pt* ID: three hits required in MS, some veto areas (69% η averaged efficiency at 1 TeV)
- *good muon* selection: q/p uncertainty passes p_T-dependent threshold

- $|z_0 \sin(\theta)| < 0.5$ mm constraint on the longitudinal impact parameter
- $|d_0/\sigma(d_0)| < 5(3)$ for $e(\mu)$ constraint on the traverse impact parameter
- Both e and μ pass a 99% efficient isolation requirement

Event selection

- Must have two same-flavor leptons
- If additional leptons, pick same-flavor pair with largest E_T (p_T) for ee ($\mu\mu$)
- If two different flavors are found, ee is used because of the better resolution
- For dimuon pairs, an opposite charge requirement is applied

Data

Used for:

- Background modeling
- Limit setting

MC

Used for:

- Testing background function
- Measuring resolution, acceptance
- Interpreting limits to a particular signal model/width

Samples:

Background Process	ME Generator and ME PDFs	PS and non-perturbative effect with PDFs
NLO Drell–Yan	Powheg-Box [21,22], CT10 [23], Photos	Pythia v8.186 [24], CTEQ6L1 [25,26], EvtGen1.2.0
$t\bar{t}$	Powheg-Box, NNPDF3.0NLO [27]	Pythia v8.230, NNPDF23LO [28], EvtGen1.6.0
Single top s-channel, Wt	Powheg-Box, NNPDF3.0NLO	Pythia v8.230, NNPDF23LO, EvtGen1.6.0
Single top t-channel	Powheg-Box, NNPDF3.04fNLO, MadSpin	Pythia v8.230, NNPDF23LO, EvtGen1.6.0
Diboson (WW, WZ and ZZ)	Sherpa 2.1.1 [29], CT10	Sherpa 2.1.1, CT10
Signal Process		
LO Drell–Yan	Pythia v8.186, NNPDF23LO	Pythia v8.186, NNPDF23LO, EvtGen1.2.0

Signal Injection