Measurements of the cross section and branching fraction of Z→4l in 7 and 8 TeV pp collisions with the ATLAS detector

Bing Li
University of Science and Technology of China
Institute of Physics, Academia Sinica

On behalf of the ATLAS Collaboration

Epiphany
Cracow, 8-10, Jan. 2014

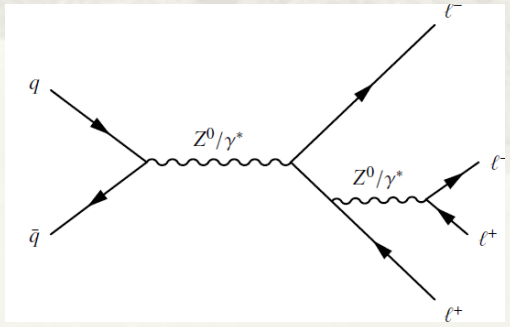
Physics Motivation

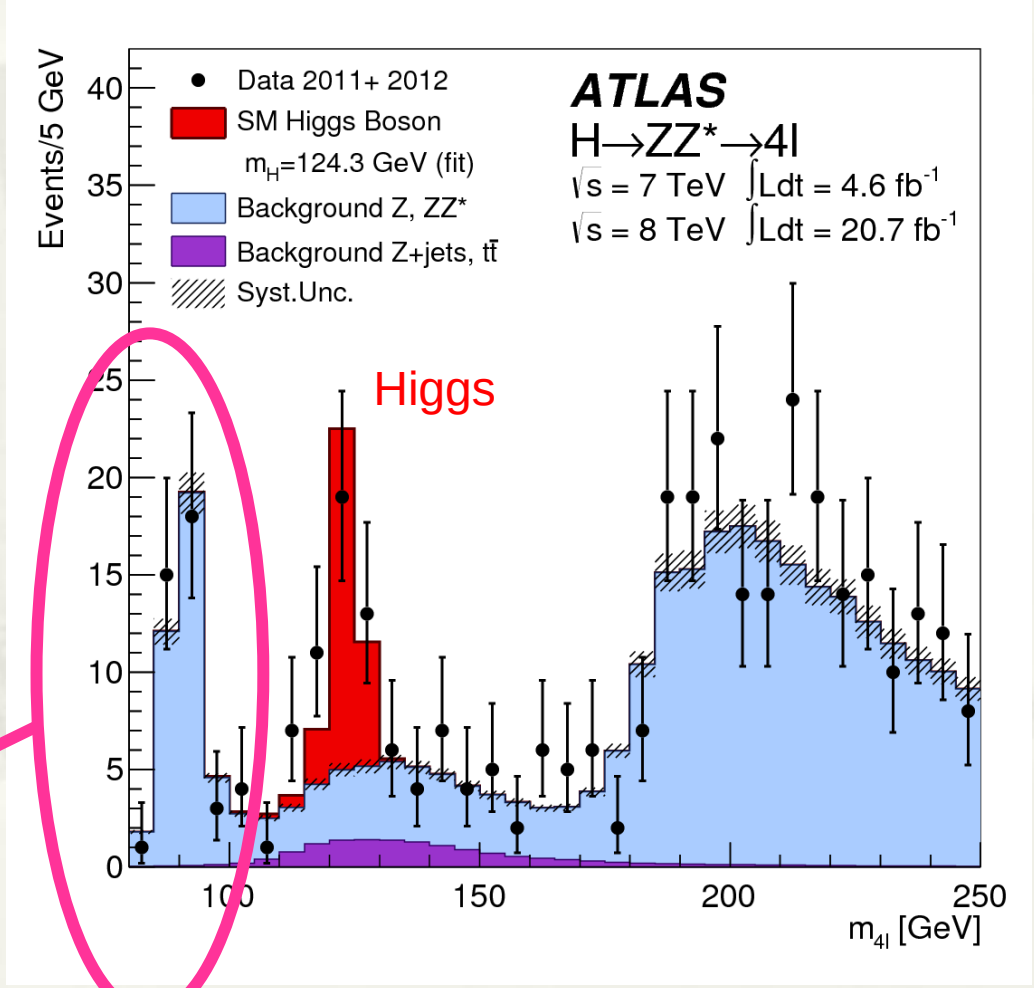
Single resonant Z boson is clearly observed in 4l final state, which serves as a standard candle for lepton detections in Higgs discovery.

Report the first measurement in ATLAS on
1) The production cross-section of Z→4l
2) The branching fraction of Z→4l

In phase-space:
$m_{2l} > 4$ GeV, and $76 < m_{4l} < 106$ GeV

Dominant process for Z→4l (92%)





Signal is modeled by Powheg

Analysis Overview

- The measurement is based on data with integrated luminosity of 4.6 fb^{-1} at 7TeV and 20.7 fb^{-1} at 8 TeV
- Signal modeling: Powheg + Pythia Monte Carlo (MC), to determine the signal acceptance
- SM cross-section calculations: MCFM, Powheg
- Subtract the t-ch contributions in BR extraction
- Low background (< 1%), estimated using data-driven and MC simulations.
  - Z+jets and $t\bar{t}$: estimated with data-driven method
  - WZ, gg→ZZ and τ decays from Z: MC estimation

Methodology

- Measure the cross section in a fiducial volume close to event selection

$$\sigma^{Fid}_{Z\to 4l} = \frac{N_{obs} - N_{bkg}}{Lumi \cdot C_{Z\to 4l}}$$

Efficiency correction for detector effects

- Extrapolate to final defined phase space:

$$\sigma^{PS}_{Z\to 4l} = \frac{\sigma^{Fid}_{Z\to 4l}}{A_{Z\to 4l}}$$

$m_{2l} > 4$ GeV and $76 < m_{4l} < 106$ GeV

Acceptance from phase space to the detection fiducial volume

Event Selection

- Require single OR di-lepton trigger fired
- 4 isolated leptons with pT>20, 15, 10(8), 7(4) GeV

  e(μ), e(μ)
- Leading lepton pair with m_{12} > 20 GeV, sub-leading lepton pair with m_{34} > 5 GeV
- $\Delta R(l, l) > 0.1$ (0.2) for all same (different) flavor lepton pairs
- Remove event if any same-flavor opposite-sign (SFOS) lepton pair with $m_{ll} < 5$ GeV
- $80 < m_{4l} < 100$ GeV

Fiducial Volume Definition

- Close to event selections at reconstruction level
- Lepton pT > 20, 15, 10(8), 7(4) GeV for e(μ)
- $|\eta| < 2.5(2.7)$ for e(μ)
- $\Delta R(l, l) > 0.1$ (0.2) for all same (different) flavor lepton pairs
- $m_{ll} > 20$ GeV for at least one SFOS lepton pair, $m_{ll} > 5$ GeV for all SFOS lepton pair
- $80 < m_{4l} < 100$ GeV
- Final phase space: $m_{ll} > 4$ GeV and $76 < m_{4l} < 106$ GeV

$$C_{4\ell} = \frac{\text{Expected number of events passing the full event selection at reconstruction level}}{\text{Expected number of events passing the F.V. selection at the truth level}}$$

$$A_{4\ell} = \frac{\text{Expected number of events passing the F.V. selection at the truth level}}{\text{Expected number of events in defined P.S.}}$$

Background Estimation

- Z+jets and $t\bar{t}$ (estimated using a data driven method)
  - build control regions with 4 leptons where 2 "bad" leptons (b) fail isolation or impact parameter criteria
  - electron fake dominated by Z+jets events; muon fake dominated by events from $t\bar{t}$
  - obtain ***fake factors*** from Z + jets and eμ + bb $(t\bar{t})$ control samples, where jets (or bb) are lepton-like objects
  - extrapolate the background from control region to signal region

$$N_{bkg} = \sum_{k} f(x_{b1,k}) f(x_{b2,k})$$

f: flavor and pT dependent

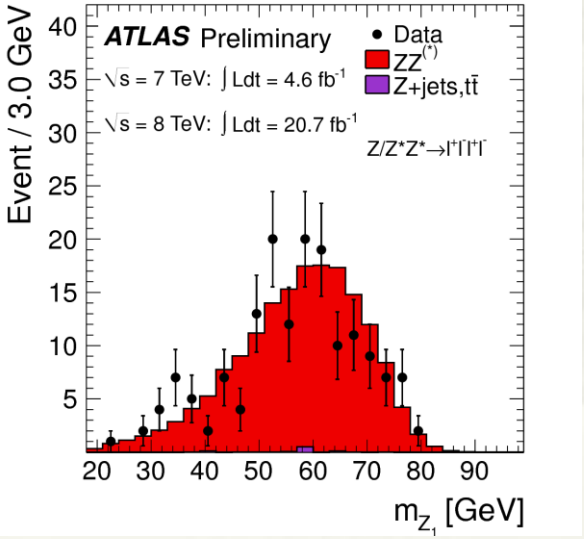
- Other backgrounds (WZ, gg→ZZ, τ decays from Z→4l) are estimated from simulations

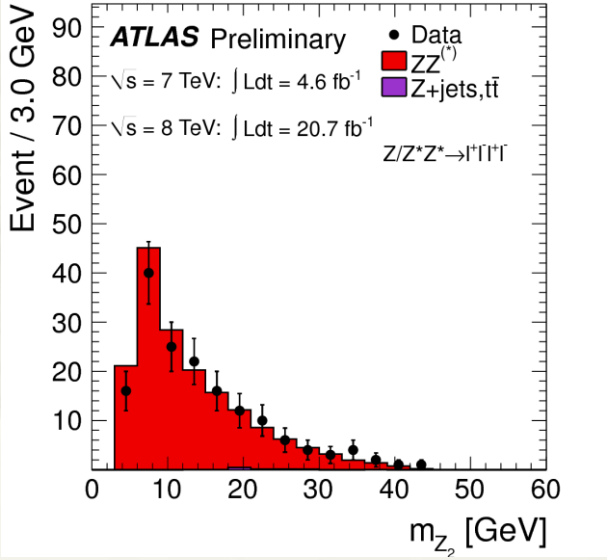
Observed and Predicted Events

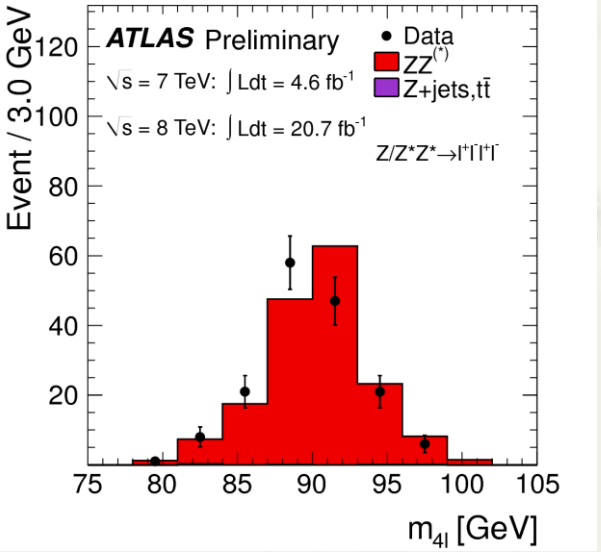
$\sqrt{s}$	Channel	Data	Total expected	MC signal ($Z/ZZ \to 4\ell$)	Backgrounds
7 TeV	$eeee$	1	1.8	1.7 ± 0.3	0.11 ± 0.05
	$ee\mu\mu$	7	7.9	7.7 ± 0.4	0.16 ± 0.09
	$\mu\mu ee$	5	3.3	3.2 ± 0.3	0.06 ± 0.03
	$\mu\mu\mu\mu$	8	11	11.4 ± 0.3	0.05 ± 0.04
	Combined	21	24	23.9 ± 1.2	0.38 ± 0.17
8 TeV	$eeee$	13	15	15.1 ± 2.5	0.17 ± 0.05
	$ee\mu\mu$	45	43	42.7 ± 2.3	0.33 ± 0.13
	$\mu\mu ee$	14	20	19.6 ± 2.1	0.13 ± 0.06
	$\mu\mu\mu\mu$	69	67	66.7 ± 2.0	0.22 ± 0.06
	Combined	141	145	144 ± 8	0.85 ± 0.25

higher efficiency and looser cuts for muon

more events in muon channel







Summary of Systematics

$\sqrt{s}$	Source of uncertainty	$eeee$	$\mu\mu\mu\mu$	$\mu\mu ee$	$ee\mu\mu$
7 TeV	Lepton trigger	0.4%	0.8%	0.8%	0.3%
	Lepton ID and reconstruction	14%	0.4%	9.6%	4.5%
	Energy/momentum scale & resolution	0.3%	0.2%	0.2%	0.5%
	isolation and impact parameter	2.2%	0.4%	1.6%	0.9%
	QCD Scale	0.4%	0.3%	0.6%	0.3%
	PDF	1.6%	1.1%	1.1%	1.3%
	Experimental uncertainty (total)	15%	1.0%	9.8%	4.6%
	Theoretical uncertainty (total)	1.7%	1.2%	1.3%	1.3%
8 TeV	Lepton trigger	0.7%	1.0%	0.9%	0.7%
	Lepton ID and reconstruction	16%	0.1%	10%	4.5%
	Energy/momentum scale & resolution	0.4%	0.2%	0.4%	0.5%
	isolation and impact parameter	2.2%	0.4%	1.6%	0.9%
	QCD Scale	0.4%	0.4%	0.6%	0.3%
	PDF	1.6%	1.2%	1.4%	1.5%
	Experimental uncertainty (total)	16%	1.1%	10%	4.6%
	Theoretical uncertainty (total)	1.6%	1.3%	1.6%	1.6%

Experimental uncertainties dominated by electron ID and reconstruction

Cross Section Results

	Phase space cross section (fb)
7 TeV measured	114±27(stat.) ±7(syst.) ±2(lumi.)
7 TeV NLO SM prediction	132.0±3.0
8 TeV measured	150±13(stat.) ±7(syst.) ±5(lumi.)
8 TeV NLO SM prediction	153.8±3.7

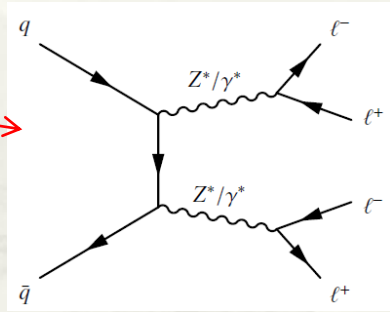
- Statistical uncertainty dominant
- Systematic uncertainties mainly from
  - lepton identification and reconstruction efficiencies: ~10% from 4 electron case
  - theoretical uncertainties (QCD scale and PDF): ~1.5%
  - luminosity: 1.8% for 7 TeV, 3.6% for 8 TeV
- Good agreement from measurements compared to SM prediction

Z→4l Branching Ratio

- Branching ratio
  - t-channel subtracted for BR calculation

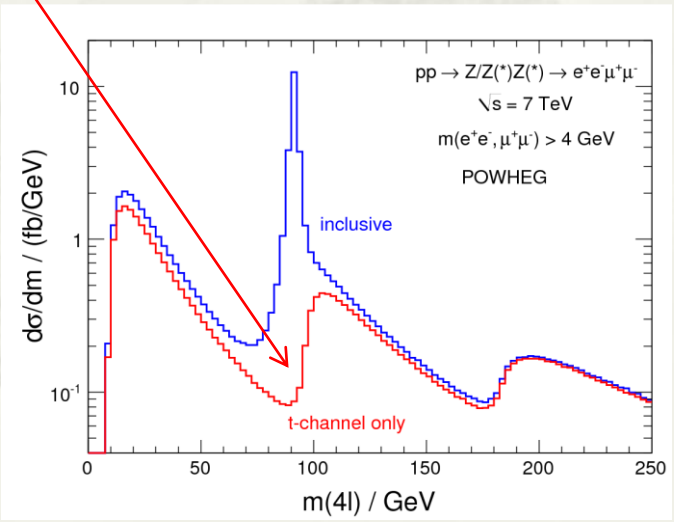
$$BR = \frac{\sigma^{PS}_{z\to 4l} \cdot (1 - f_t)}{\sigma_{pp\to Z}}$$

t-channel contribution, 8.0(8.8)% for same(diff) flavor channel



27.7±0.6 nb for 7 TeV
32.2±0.8 nb for 8 TeV

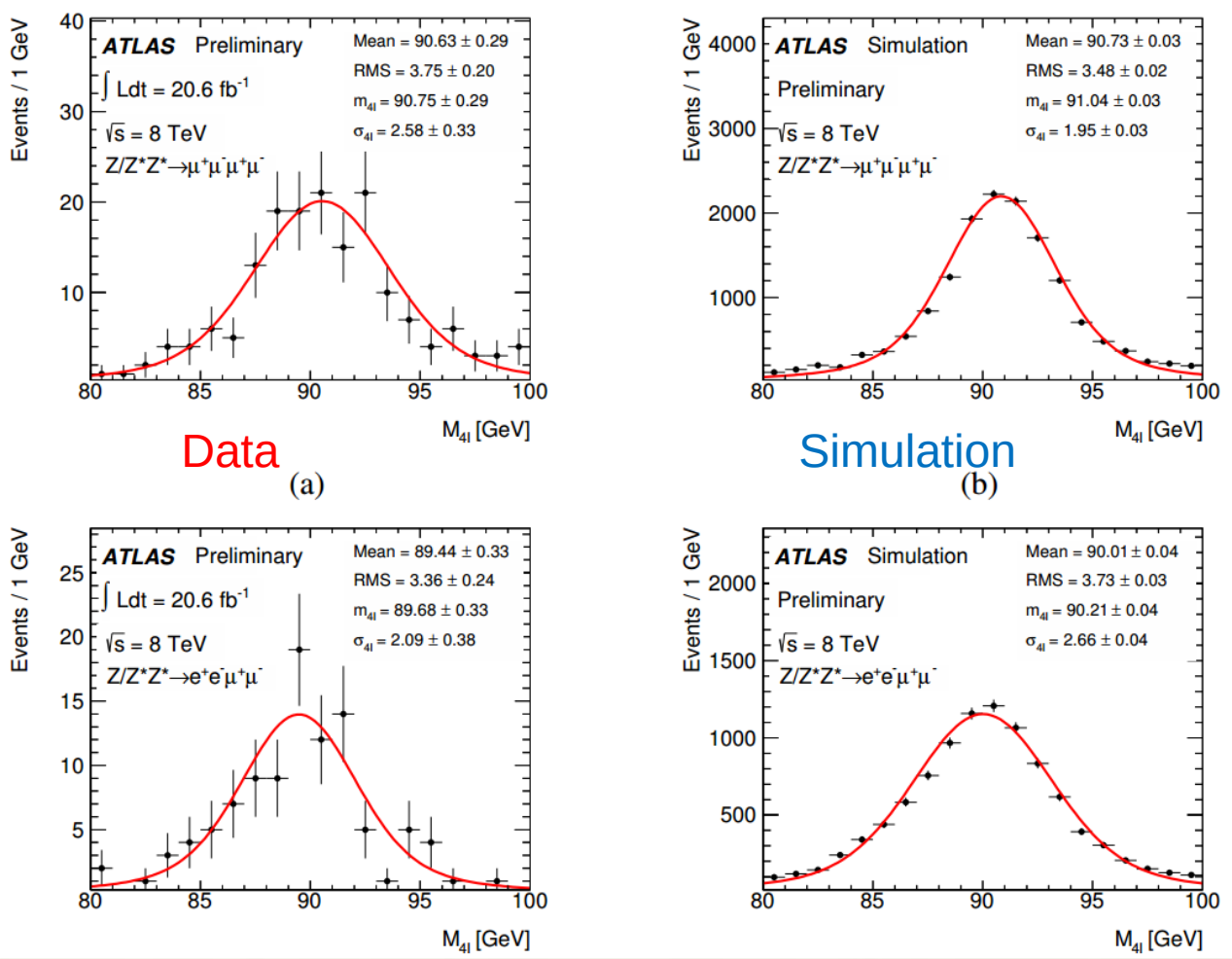
	Branching fraction
7 TeV measured	(3.8±0.9) x 10^{-6}
8 TeV measured	(4.2±0.4) x 10^{-6}
Combined measured	(4.2±0.4) x 10^{-6}
NLO SM prediction	(4.37±0.03) x 10^{-6}



Study of Z→4l mass scale and resolution

- Signal model used in mass fitting is BreitWigner convoluted with Gaussian
  - **BW(x, M_Z, Γ_Z)*Gauss(x, m_{4l}, σ_{4l})**
- The fitting parameters are
  - M_Z: fixed in fit - using signal MC mass peak value
  - Γ_Z : fixed, PDG Z width, 2.49 GeV
  - m_{4l}: 4 lepton invariant mass from fitting
  - σ_{4l}: 4 lepton mass resolution from fitting

Mass Fitting Results



The analysis used relaxed cut on $M_{Z2} > 1$ GeV to increase statistic for mass fitting

Show data compare MC in mass fitting: μμμμ (top row) and eeμμ (bottom row)

left: Data
right: simulation

Data consistent with MC simulations

Summary

- Cross section measurements of single resonant Z → 4l, with full datasets collected by the ATLAS detector in 7 TeV and 8 TeV pp collisions at the LHC
- The measured cross-sections and branching fraction are in good agreement with the SM prediction (with NLO calculations)
- Fits of the Z → 4l resonant spectra. Data and MC agree in mass scale and resolution

References

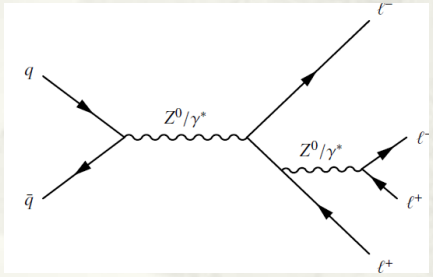
* ATLAS-CONF-2013-055
  * https://cds.cern.ch/record/1551514

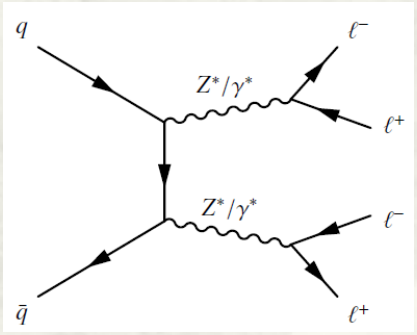
* ATLAS Collaboration, Measurements of Higgs boson production and couplings in diboson final states with the ATLAS detector at the LHC, *Phys. Lett. B 726 (2013), pp. 88-119*

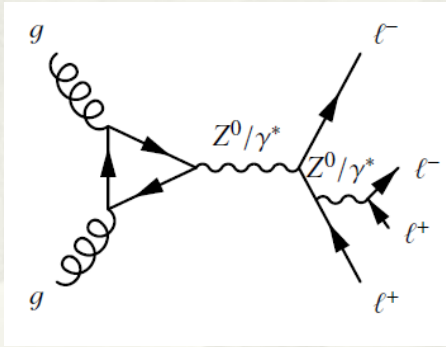
Backup Slides

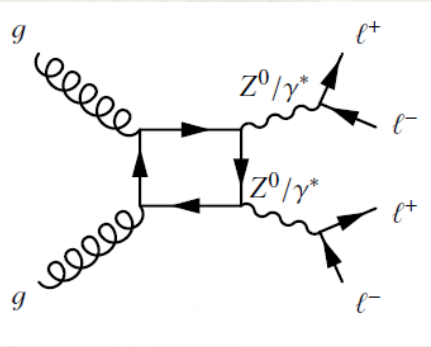
Physics Goals

- Single Z production cross-section measurements in four lepton final states
- Interpreting the cross-section measurement in branching ratio of Z decays to 4 leptons
- Provide a *standard candle* for lepton identification and measurement to calibrate the H→ ZZ*→ 4l measurement









s-channel -- dominant t-channel -- 8% suppressed << 1%

interference between s and t channel < 0.2%

Detailed Event Selection

Event Preselection	
Electrons	H4l2011Defs and Multilepton (2012) quality GSF electrons with $E_T > 7$ GeV and $\|\eta\| < 2.47$
Muons	Combined, segment-tagged, calo-tagged ($p_T > 15$ GeV), and stand-alone muons with $p_T > 4$ GeV and $\|\eta\| < 2.7$
Event Selection	
Quadraplet selection	Two pairs of same-flavour opposite-charge leptons. The three leading leptons in the quadruplet have $p_T > 20$, 15, and 10 GeV. If the third lepton is a muon it may have $p_T > 8$ GeV Pick the pair that has M_{Z1} nearest Z-mass, and then M_{Z2} nearest.
Kinematic selection	Leading di-lepton pair must have inv. mass $M_{Z1} > 20$ GeV Sub-leading di-lepton pair must have inv. mass $M_{Z2} > 5$ GeV No same-flavor opposite-charge di-lepton giving $M_{\ell^+\ell^-} < 5$ GeV (J/ψ veto) $\Delta R(\ell, \ell') > 0.1$ (0.2) for all same-flavor (opposite-flavor) leptons in the quadruplet.
Isolation	Lepton track isolation ($\Delta R = 0.20$): $\Sigma p_T / p_T < 0.15$ Lepton calorimeter isolation ($\Delta R = 0.20$) : $\Sigma E_T / E_T < 0.30$ except < 0.15 for stand-alone muons and in 2012 < 0.20 for electrons,
Impact parameter significance	Apply impact parameter significance cut to all leptons of the quadruplet. For electrons : $d_0/\sigma_{d_0} < 6.5$ For muons : $d_0/\sigma_{d_0} < 3.5$
Four-body mass	$80 < m_{4\ell} < 100$ GeV

DD Background Estimation: Brief Description

- Signal: Z → eeee, eeμμ, μμee and μμμμ
- QCD Backgrounds: mainly from b-jets, and also from light jets

- Using data-driven method to estimate the background using 3 control samples:
  - **Control samples in 4 lepton signal region**: select events with $ll + xx$, where l is so-called 'good' lepton selected with the standard lepton selection criteria as the Z→ 4l selection; ***x*** is so-called 'bad' lepton with some inverted lepton selection criteria.
  - **Fake lepton rich control samples:** two samples are used in this analysis: (1) ttbar tagged by two good electron and muon in events + x'x' (x' are leptons with relaxed cuts, dominantly from b-jets); (2) Z tagged by two good lepton pair with Z mass constraint + x' (x' dominantly from light jet);
  - **Determine fake-factor**: f = N(l)/N(x) as a function of lepton pT.
  - **Determine the background in signal region: $N_{bkg} = N(llx_1x_2)* f_1*f_2$ (where f is flavor and pT dependent)**

Mass Fitting of the Z→4l Peak

- **First fit MC Single Z signal:**
  - simple Gaussian fit [85-95] GeV to obtain the reconstructed central mass value, with fixed width (PDG Z width, 2.49 GeV)
  - Using Sherpa MC events (with mllmin = 0.25 GeV)
- **Then, fit Data and MC:**
  - Fitting function-BreitWigner convoluted with Gaussian:

    $BW(x, M_Z, \Gamma_Z) * Gauss(x, m_{4l}, \sigma_{4l})$
  - Mz: fixed, using the fitted mass from MC signal
  - Γ_Z Gz: fixed, PDG Z width, 2.49 GeV
  - m_{4l}: 4 lepton invariant mass from fitting
  - σ_{4l}: 4 lepton mass resolution from fitting

Mass Fitting for μμee and eeee