Determination of the $\mathrm{Z} \to \mu^+\mu^-$ resonance peak position in the CMS 2012 DoubleMuParked Open Data skim

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Abstract

The dimuon invariant-mass spectrum is reconstructed from a skim of the CMS DoubleMuParked primary dataset recorded in 2012 at $\sqrt{s} = 8\,\mathrm{TeV}$ and released as Open Data. Events with exactly two opposite-charge muons with $p_\mathrm{T} > 20\,\mathrm{GeV}$ and $|\eta| < 2.4$ are selected, and the position of the Z resonance peak is extracted with a binned χ^2 fit of a Voigtian signal plus an exponential background in the 85–97 GeV range. The fitted peak position is $m_{\mu\mu}^{\mathrm{peak}} = 91.002 \pm 0.041\,(\mathrm{stat}) \pm 0.122\,(\mathrm{syst})\,\mathrm{GeV}$, where the systematic uncertainty covers only the fit-range variation. The result lies 2.0 per mille below the world-average Z-boson mass, as expected in the absence of muon momentum-scale and final-state-radiation corrections; no competitive Z mass measurement is claimed.

1 Introduction

The decay $\mathrm{Z} \to \mu^+\mu^-$ provides one of the cleanest signatures at a hadron collider: a narrow resonance at $m_\mathrm{Z} = 91.1880 \pm 0.0020\,\mathrm{GeV}$ [1] on top of a small, smoothly falling Drell–Yan continuum and misreconstruction background. This note documents a self-contained determination of the dimuon peak position in proton–proton collision data recorded by the CMS detector [2] and released through the CERN Open Data portal [3].

The emphasis is on reproducibility: every number quoted in this note is generated by `analysis.py` and imported as a LaTeX macro from the accompanying `results.json`, so the note and the analysis code cannot drift apart. The full regeneration procedure is given in the bundle `README`.

2 Detector and data

CMS is a general-purpose detector at the CERN LHC, featuring a silicon tracker and muon chambers embedded in a 3.8 T solenoidal field; muons are reconstructed by combining tracker and muon-system information, with coverage up to $|\eta| = 2.4$ [2].

The input is `zmumu_skim.root`, a skim of the CMS 2012 DoubleMuParked primary dataset ($\sqrt{s} = 8\,\mathrm{TeV}$) published on the CERN Open Data portal and converted to a flat NanoAOD-like format with the CMS `AOD2NanoAODOutreachTool` [3]. The skim contains 83343 events with per-muon branches `Muon_pt`, `Muon_eta`, `Muon_phi`, `Muon_mass`, and `Muon_charge`. Only raw event counts are used: no luminosity normalization, pile-up reweighting, or trigger-efficiency correction is applied, none of which affects the position of the resonance peak.

3 Event selection

Muons are required to have $p_T > 20\,\mathrm{GeV}$, well onto the trigger plateau of the double-muon parked stream, and $|\eta| < 2.4$, matching the muon-system acceptance [2]. Events must contain exactly two such muons, and the pair must have opposite charge, as expected for $Z \to \mu^+\mu^-$ decays. The dimuon invariant mass $m_{\mu\mu}$ is computed from the four-momentum sum of the two muons, and the spectrum is analyzed in the $60 \leq m_{\mu\mu} < 120\,\mathrm{GeV}$ window. The cutflow is given in Table 1.

The kinematics of the selected muons are shown in Fig. 1. Both muon p_T spectra exhibit the Jacobian peak near $m_Z/2$ expected for the two-body decay of a resonance produced close to rest, and the pseudorapidity distribution is central and symmetric — both as expected for $Z \to \mu^+\mu^-$, giving confidence that the selection isolates the intended process.

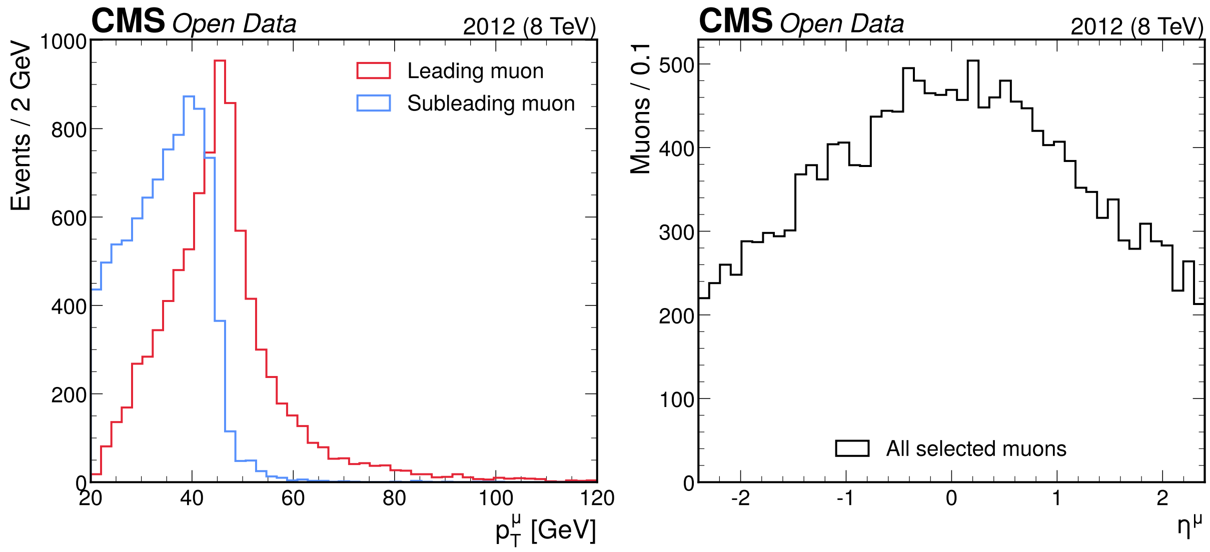

Figure 1: Kinematics of the muons after the full selection: p_T of the leading and subleading muon (left), showing the Jacobian peak near $m_Z/2$, and pseudorapidity of all selected muons (right).

Table 1: Event selection and yields. Raw (unweighted) event counts.

Selection	Events
All events in skim	83343
Exactly two muons with $p_T > 20\,\mathrm{GeV}$, $\lvert\eta\rvert < 2.4$	11983
Opposite charge	10420
$60 \leq m_{\mu\mu} < 120\,\mathrm{GeV}$	8589

4 Analysis method

The selected masses are histogrammed in 0.5 GeV bins and fitted by minimizing a χ^2 with Poisson bin uncertainties, using the model

$$\frac{\mathrm{d}N}{\mathrm{d}m} = n_{\mathrm{sig}}\, V(m - \mu;\, \sigma,\, \Gamma_Z/2) \;+\; n_{\mathrm{bkg}}\, f_{\mathrm{bkg}}(m), \tag{1}$$

where V is a Voigtian — a Breit–Wigner convolved with a Gaussian resolution of width σ — and f_{bkg} is a falling exponential normalized over the fit range, so that n_{sig} and n_{bkg} are yields in that range. The Breit–Wigner width is fixed to the world-average Z width $\Gamma_Z = 2.4955$ GeV [1], while the peak position μ, the resolution σ, the two yields, and the background slope are floated. The nominal fit uses the 85–97 GeV core of the peak, excluding the low-mass tail populated by final-state radiation (FSR), which the symmetric Voigtian does not model. The full-window spectrum on a logarithmic scale, with the fit range indicated, is shown in Fig. 2: the FSR tail below the fit range and the smoothly falling continuum on both sides are clearly visible.

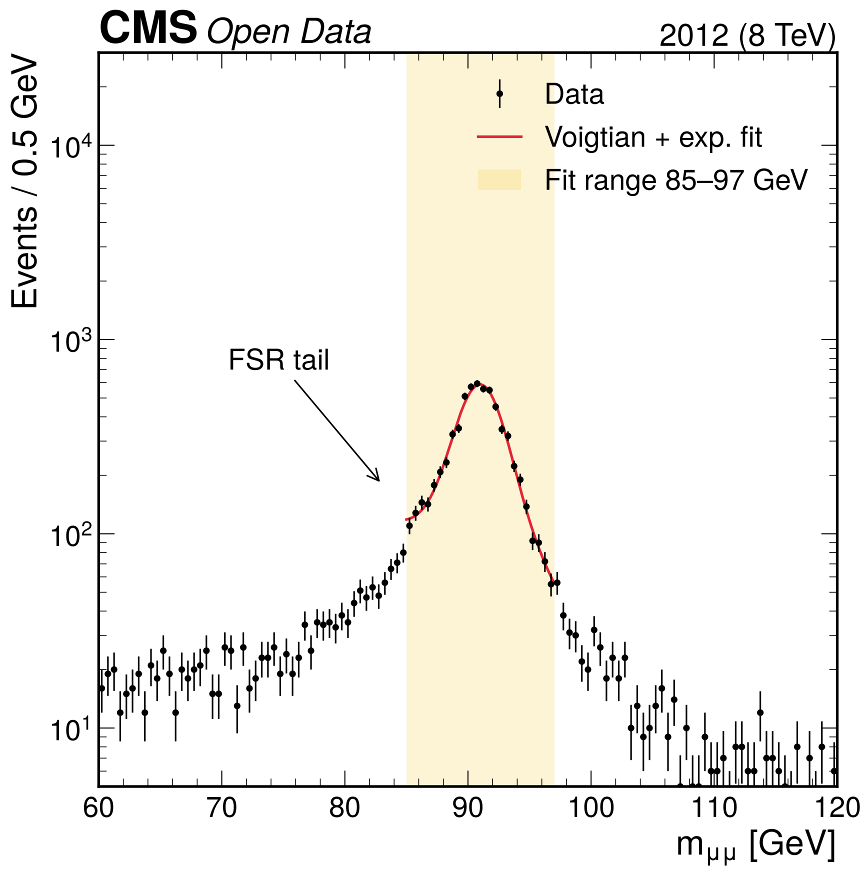

Figure 2: Dimuon invariant-mass spectrum over the full 60–120 GeV window on a logarithmic scale. The shaded band marks the nominal 85–97 GeV fit range; the low-mass shoulder excluded from the fit is populated by FSR.

5 Systematic uncertainties

The only systematic uncertainty that is evaluated is the sensitivity of the peak position to the choice of fit range: the fit is repeated with three alternative ranges, and the largest absolute shift of the fitted peak, 0.122 GeV, is taken as the uncertainty. The variations are summarized in Table 2 and visualized in Fig. 3; the assigned uncertainty covers all three alternative results. The widest range, 80–100 GeV, reaches into the FSR shoulder that the symmetric Voigtian does not model, which both pulls the peak down and degrades the fit quality — the behaviour that motivates the choice of the narrower nominal range.

As a cross-check of the histogramming choice, the nominal fit is repeated with half the bin width (240 bins): the peak moves by +2 MeV, negligible compared with the statistical uncertainty, and no additional uncertainty is assigned.

The following are explicitly *not* evaluated: the muon momentum-scale and resolution calibration (the dominant systematic in a genuine Z mass measurement), the modeling of FSR, the

Table 2: Fit-range variations. The shift is quoted with respect to the nominal fitted peak position.

Fit range [GeV]	$m_{\mu\mu}^{\text{peak}}$ [GeV]	Shift [MeV]	χ^2/ndf
85–97 (nominal)	91.002 ± 0.041	—	1.32
80–100	90.880 ± 0.036	-122	2.48
83–99	90.926 ± 0.037	-77	2.17
86–96	91.011 ± 0.046	$+8$	1.53

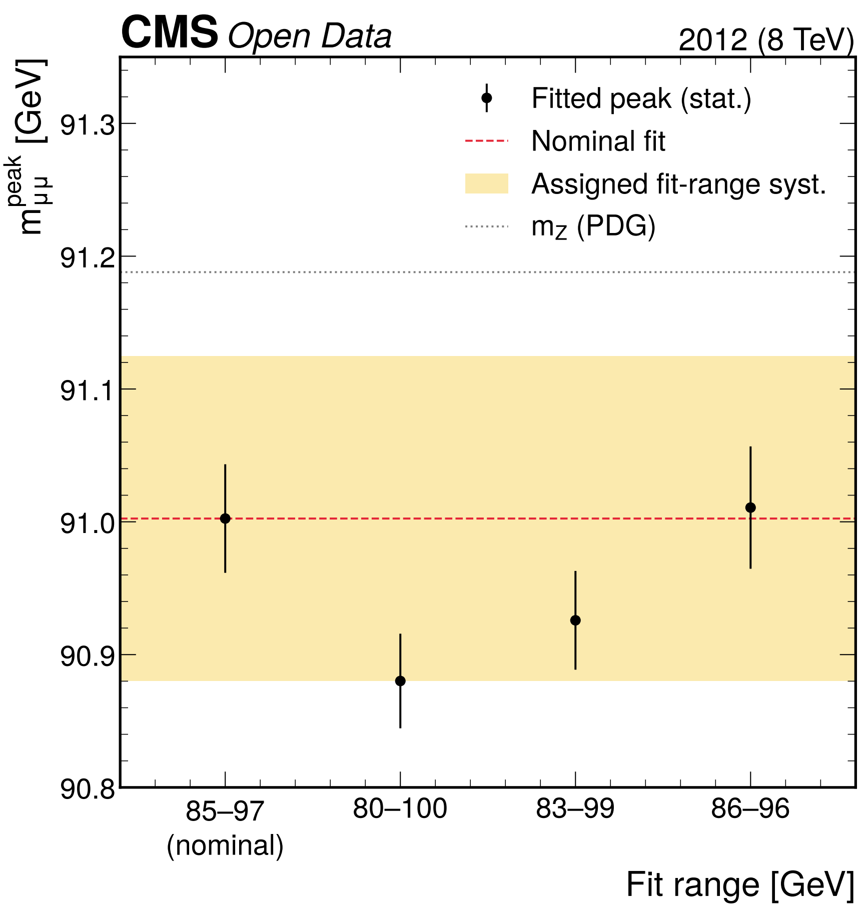

Figure 3: Fitted peak position for the nominal and alternative fit ranges, with statistical uncertainties. The band is the assigned fit-range systematic uncertainty; the dotted line marks the world-average Z-boson mass, from which the uncorrected reconstructed peak is expected to deviate.

choice of signal parameterization (a symmetric Voigtian with Γ_Z fixed) and of the background shape, and alignment- or charge-dependent momentum biases. For this reason the result is presented as a determination of the reconstructed peak position, not as a Z mass measurement.

6 Results

The nominal fit converges with $\chi^2/\mathrm{ndf} = 25.1/19 = 1.32$ and yields

$$m_{\mu\mu}^{\mathrm{peak}} = 91.002 \pm 0.041\,(\mathrm{stat}) \pm 0.122\,(\mathrm{syst})\,\mathrm{GeV}, \tag{2}$$

with a Gaussian resolution $\sigma = 1.19 \pm 0.07$ GeV and fitted yields of 6446 ± 191 signal and 978 background events in the fit range. The spectrum and fit are shown in Fig. 4, together with the per-bin pulls: no structure is visible across the fit range and the largest pull is $2.3\,\sigma$, consistent with the quoted χ^2/ndf.

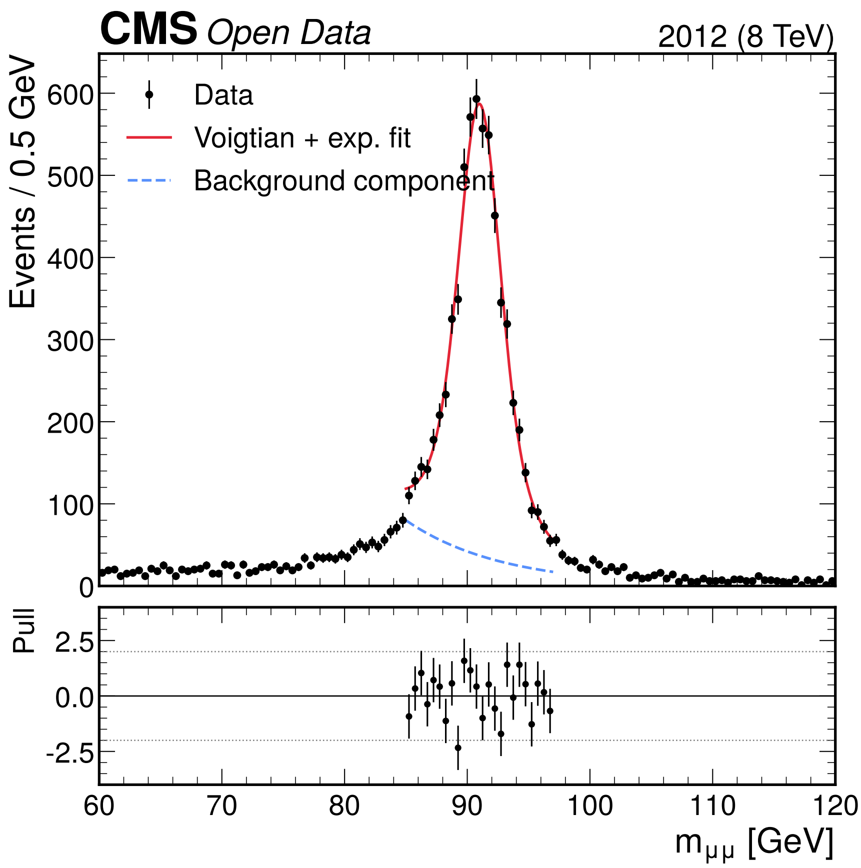

Figure 4: Top: dimuon invariant-mass spectrum after the full selection (points with statistical uncertainties), with the Voigtian-plus-exponential fit in the 85–97 GeV range (solid line) and its background component (dashed line). Bottom: per-bin pulls of the fit; the dotted lines mark $\pm 2\sigma$.

Compared with the world-average Z-boson mass $m_Z = 91.1880 \pm 0.0020$ GeV [1], the difference $m_{\mu\mu}^{\mathrm{peak}} - m_Z$ is -186 MeV, i.e. 2.0 per mille. The magnitude is comparable to the combined quoted uncertainties, and the sign is the one expected from the two dominant effects deliberately left uncorrected: unrecovered FSR photons, which shift the reconstructed peak below the pole, and the uncalibrated muon momentum scale of this open-data skim.

7 Summary

The $Z \to \mu^+\mu^-$ resonance is reconstructed in the CMS 2012 `DoubleMuParked` Open Data skim, with 8589 selected events in the 60–120 GeV window, and its peak position is determined to be $91.002 \pm 0.041\,(\mathrm{stat}) \pm 0.122\,(\mathrm{syst})$ GeV, in per-mille-level agreement with the world-average Z mass. The result validates the public skim, the selection, and the fitting chain; it does not claim a competitive Z mass measurement, since the muon momentum scale and FSR are left uncorrected. The entire analysis is reproducible from `analysis.py` as described in the bundle `README`.

References

[1] S. Navas et al. Review of particle physics. *Phys. Rev. D*, 110(3):030001, 2024.

[2] S. Chatrchyan et al. The CMS Experiment at the CERN LHC. *JINST*, 3:S08004, 2008.

[3] Kati Lassila-Perini, Clemens Lange, Edgar Carrera Jarrin, and Matthew Bellis. Using CMS Open Data in research – challenges and directions. *EPJ Web Conf.*, 251:01004, 2021.