

Determination of the $Z \rightarrow \mu^+ \mu^-$ 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 $\sqrt{s} = 8$ TeV and released as Open Data. Events with exactly two opposite-charge muons with $p_T > 20$ 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 $m_{\mu\mu}^{\text{peak}} = 91.002 \pm 0.041$ (stat) ± 0.122 (syst) 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 $Z \rightarrow \mu^+ \mu^-$ provides one of the cleanest signatures at a hadron collider: a narrow resonance at $m_Z = 91.1880 \pm 0.0020$ 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 $\text{\LaTeX}$ 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 `zmuu_skim.root`, a skim of the CMS 2012 DoubleMuParked primary dataset ($\sqrt{s} = 8$ 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 $p_T > 20$ 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 $Z \rightarrow \mu^+\mu^-$ 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 $60 \leq m_{\mu\mu} < 120$ GeV window. The cutflow is given in Table 1.

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

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

$$\frac{dN}{dm} = n_{\text{sig}} V(m - \mu; \sigma, \Gamma_Z/2) + n_{\text{bkg}} f_{\text{bkg}}(m), \quad (1)$$

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.

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 (80–100, 83–99, and 86–96 GeV, as defined in `analysis.py`), and the largest absolute shift of the fitted peak, 0.122 GeV, is taken as the uncertainty.

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 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 $\chi^2/\text{ndf} = 25.1/19 = 1.32$ and yields

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

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. 1.

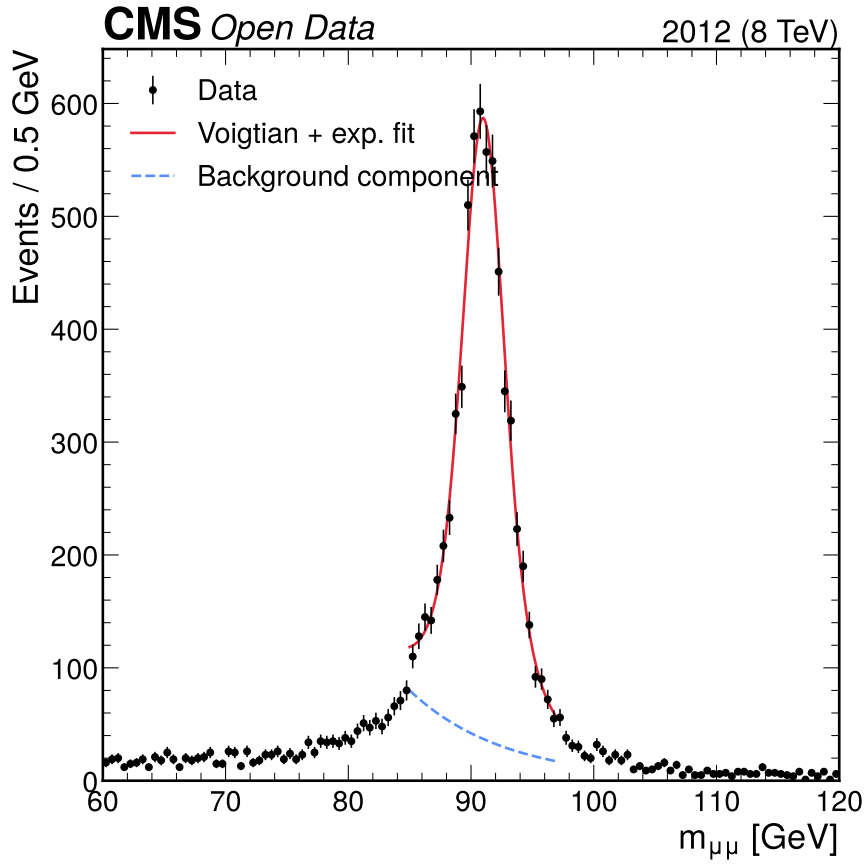


Figure 1: Dimuon invariant-mass spectrum after the full selection (points with statistical uncertainties), with the Voigtian-plus-exponential fit in the 85–97 GeV range (solid line) and its background component (dashed line).

Compared with the world-average Z-boson mass $m_Z = 91.1880 \pm 0.0020$ GeV [1], the difference $m_{\mu\mu}^{\text{peak}} - m_Z$ 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 $Z \rightarrow \mu^+ \mu^-$ 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 ± 0.041 (stat) ± 0.122 (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.