ANALYSIS OF MUON AND DIMUON SPECTRUMS

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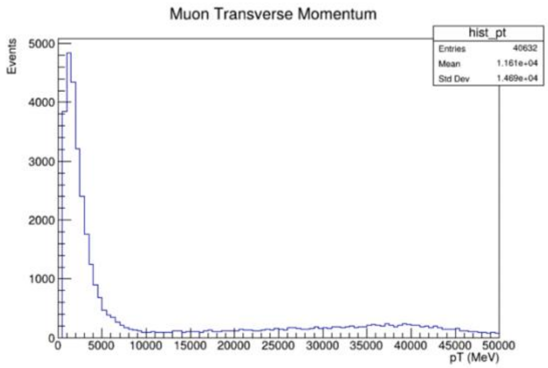
Abstract

This study analyzes muon kinematic distributions and the dimuon invariant mass spectrum using data from high-energy collisions. The kinematic distributions of transverse momentum, pseudorapidity, and angular variables shows a predominance of low-momentum muons emitted at extreme angles. The dimuon invariant mass spectrum reveals resonances, including the J/ψ, Y, and Z bosons, as expected from Standard Model processes. Additionally, evidence for the W boson is observed through its mass distribution. The results are supported by real CMS data, which exhibit similar resonances and trends. However, an unexpected excess is observed around 700 GeV. This anomaly aligns with previous ATLAS findings in four-top-quark production and may indicate contributions from new physics.

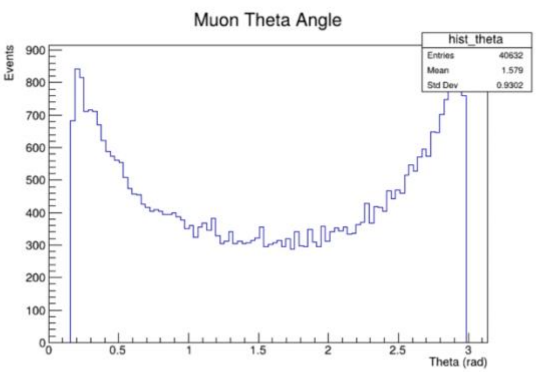
Muon Kinematic Distributions

Muon Transverse Momentum



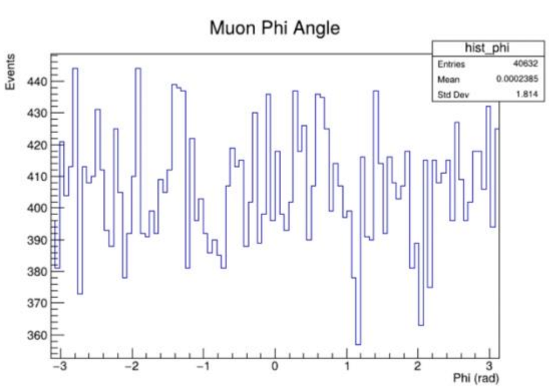
The muon transverse momentum distribution is highly skewed, with most muons exhibiting low momentum and peaking below 5000 MeV. A smaller fraction of high-energy muons extends the distribution's tail, likely resulting from energetic collisions. The mean transverse momentum of 11.6 GeV and a standard deviation of 14.6 GeV indicate a broad range of values.

Muon Theta Angle



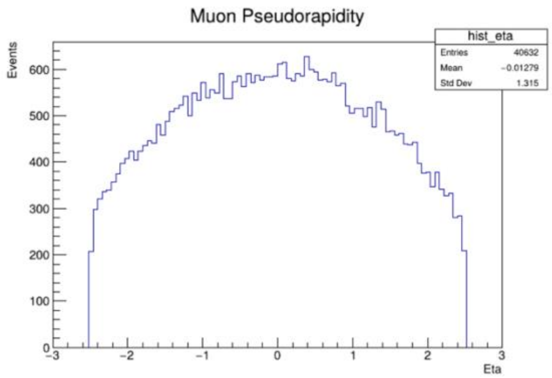
The theta (θ) angle distribution shows a dip at the center, around 1.5 radians, and strong peaks at low values and near π, indicating that most muons are emitted at angles relative to the beamline. This is concurrent with certain decay processes, such as those from hadrons and bosons, that emit muons at extreme angles, creating enhanced counts near $\theta = 0$ and $\theta = \pi$.

Muon Phi Angle



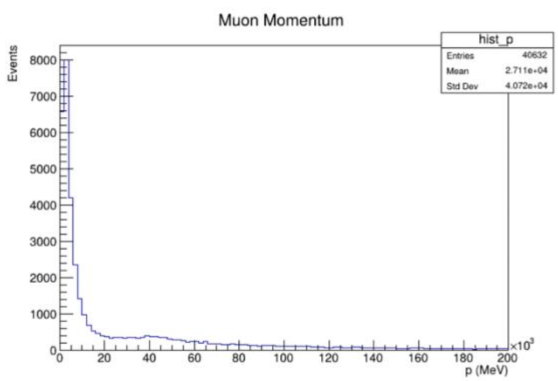
The azimuthal angle (ϕ) distribution is largely uniform from -π to π, indicating isotropic muon production.

Muon Pseudorapidity



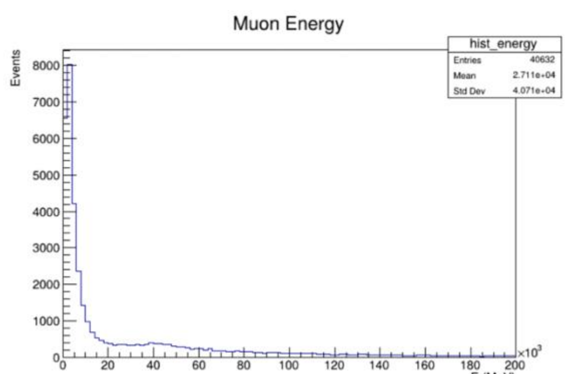
The pseudorapidity (η) distribution exhibits a bell-like shape centered around η ≈ 0, indicating that most muons are produced near mid-rapidity. This symmetric pattern aligns with expectations from high-energy collisions, where particle production is concentrated in the central region.

Muon Momentum



The total momentum (p) distribution is sharply peaked at low values and gradually decreases at higher momenta, with some muons exceeding 100 GeV. This reflects the prevalence of low-momentum muons.

Muon Energy



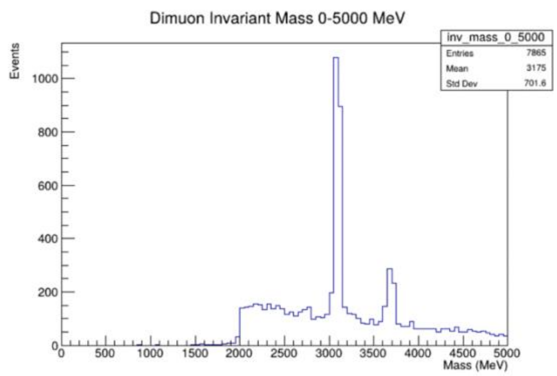
The muon energy distribution mirrors the momentum spectrum, with a sharp peak at low values and a long tail extending to higher energies. This pattern reflects the dominance of low-energy muons, concurrent with the prevalence of low-momentum muons.

Conclusion

The analysis of muon kinematic distributions describes their production and detection in high-energy collisions. The majority of muons are soft and centrally produced, with a smaller fraction exhibiting high-energy characteristics. The theta and pseudorapidity distributions indicate a preference for production at extreme angles. The nearly uniform phi distribution supports the assumption of isotropic muon emission.

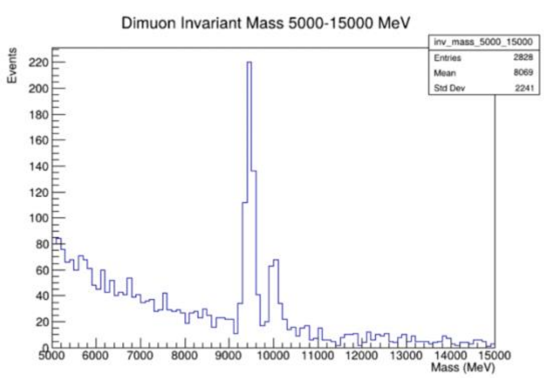
Dimuon Invariant Mass Spectrum

0 - 5000 MeV



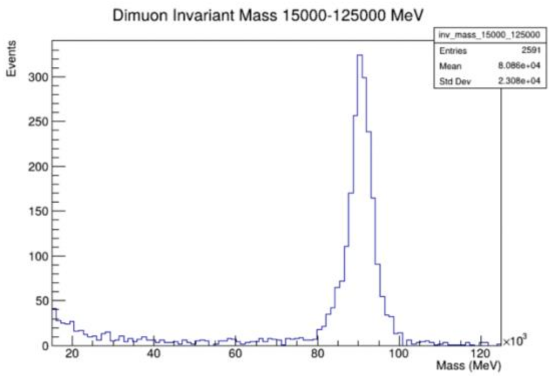
The first histogram, covering the mass range from 0 to 5000 MeV, shows significant peaks corresponding to well-known quarkonium states. The most prominent peak appears at approximately 3097 MeV, which is identified as the J/ψ meson. This particle is a bound state of a charm quark (c) and an anti-charm quark (c̄), forming a charmonium system. Additionally, another peak is observed at around 3686 MeV, corresponding to the ψ(2S) meson, the first excited state of J/ψ. The presence of these peaks aligns with expectations, as charmonium states predominantly decay into dimuon pairs.

5000 - 15000 MeV



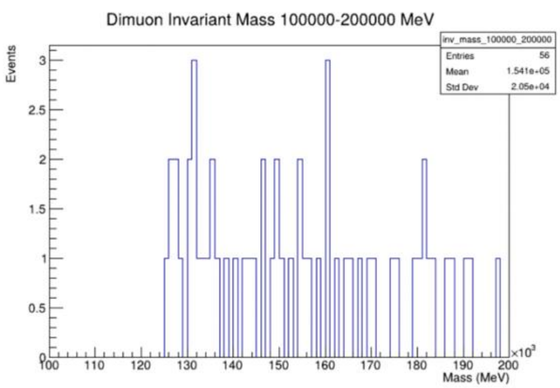
The second histogram, spanning from 5000 to 15000 MeV, exhibits a dominant peak at approximately 9460 MeV. This peak corresponds to the Υ(1S) meson, the ground state of bottomonium, a bound state of a bottom quark (b) and an anti-bottom quark (b̄). Additionally, a smaller peak appears at around 10023 MeV, which is identified as the Υ(2S) and Υ(3S) excited states of bottomonium.

15000 - 125000 MeV



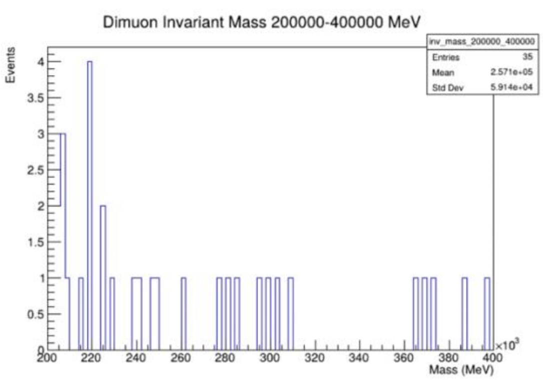
In the third histogram, covering the range from 15000 to 125000 MeV, a large peak emerges at approximately 91000 MeV (91 GeV). This peak is attributed to the Z boson.

100000 - 200000 MeV



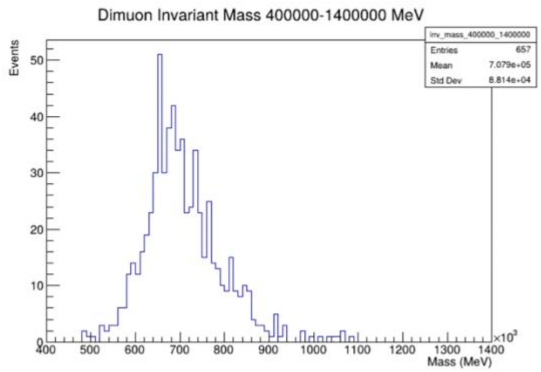
In the fourth histogram, from 100000 to 200000 MeV, no distinct peaks are observed. The event count in this mass range is relatively low, with only 56 recorded events, showing that very few high-energy dimuon pairs were produced within this range.

200000 - 400000 MeV



Similarly, the fifth histogram, from 200000 to 400000 MeV, lacks clear peaks and features only 35 recorded events. The low number of events suggests that dimuon pairs with such high invariant masses are rare in this dataset.

400000 - 1400000 MeV

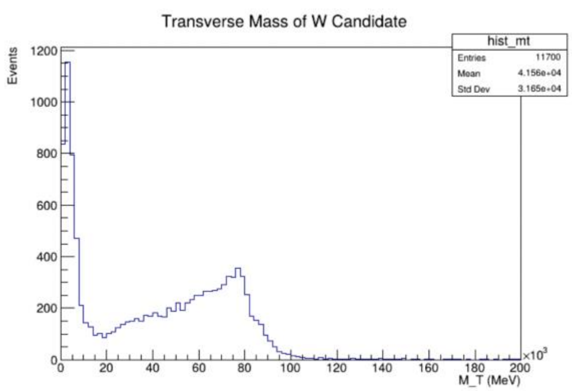


The final histogram, covering the highest mass range from 400000 to 1400000 MeV, shows a broad peak around 700000 MeV (700 GeV). However, this does not correspond to any known Standard Model behaviors. One potential interpretation of this feature is the presence of a hypothetical new boson.

Conclusion

The analysis of the dimuon invariant mass spectrum across different energy ranges shows several resonances, such as the identification of J/ψ, ψ(2S), Υ(1S), Υ(2S), Υ(3S), and Z boson. The lack of significant features in certain higher-energy regions is expected based on Standard Model predictions, while the presence of a broad peak at 700 GeV is interesting.

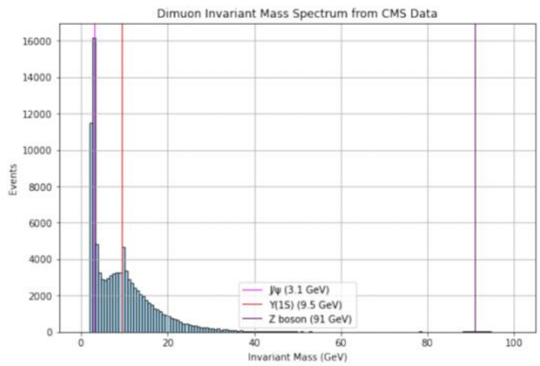
W Boson Evidence



In high-energy particle collisions, the presence of the W boson can be inferred through its decay into a charged lepton and a neutrino ($W \rightarrow \ell\nu$). Since neutrinos escape undetected, their presence is deduced from missing transverse momentum ($\not{p}_T$).

In the histogram of the transverse mass distribution, a characteristic broad peak is observed around 80 GeV, which aligns with the known mass of the W boson (~80.4 GeV). The sharp drop-off above this value is a result of the undetected neutrino, further supporting the presence of the W boson.

Dimuon Invariant Mass Spectrum from CMS Data

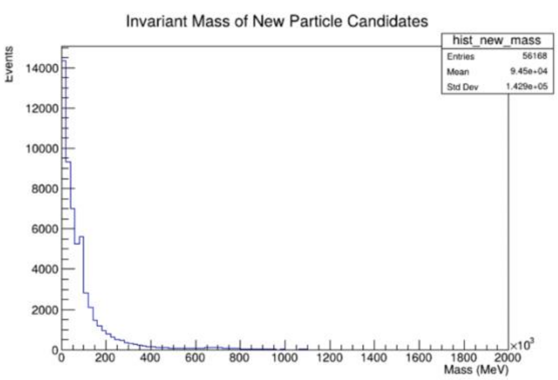


This dimuon invariant mass spectrum is derived from a small subset of real CMS data.

A clear peak is observed at around 3.1 GeV, which is consistent with the mass of the J/ψ meson, a resonance composed of a charm-anticharm quark pair that decays into dimuon pairs. Another peak appears at approximately 9.5 GeV, corresponding to the Υ(1S) resonance, a bottomonium state that also decays into dimuon pairs. Additionally, a peak around 91 GeV aligns with the mass of the Z boson, a particle that can decay into muon pairs.

In addition to these peaks, the histogram reveals a smoothly decreasing distribution of events as the invariant mass increases, showing that low-mass resonances are more frequently produced in the dataset than high-mass particles such as the Z boson.

New Particle Candidates



The dimuon invariant mass spectrum shows several features that correspond to Standard Model phenomena, as well as potential signs of new physics. A prominent peak at 3.1 GeV is observed, which aligns with the known J/ψ meson, a resonance consisting of a charm quark and antiquark. Additionally, 9.5 GeV matches the mass of the Υ meson, a bottomonium state. The peak around 91 GeV corresponds to the Z boson, which decays into the dimuon.

However, the spectrum also reveals a small excess around 500-800 GeV, which deviates from Standard Model expectations. The existence of such a resonance suggests new physics beyond the Standard Model.

A similar approach was taken by ATLAS in their observation of four-top-quark production, for which they used machine-learning techniques to isolate rare events. In that study, the measured four-top production rate was found to be 1.9 times the Standard Model prediction, implying contributions from new particles or forces. Notably, the four-top system has a total particle mass of nearly 700 GeV, which is within the range of the unexpected excess observed in the dimuon invariant mass spectrum.

Conclusion

This study presents a detailed analysis of muon kinematic properties and dimuon invariant mass distributions in high-energy collisions. The kinematic distributions reveal that most muons are produced with low transverse momentum and are preferentially emitted at extreme angles, as indicated by peaks in the theta distribution. The pseudorapidity distribution is centered around mid-rapidity, while the azimuthal distribution remains uniform, consistent with isotropic muon production.

The dimuon invariant mass spectrum successfully demonstrates the J/ψ, Y, and Z bosons. Additionally, W boson production is inferred from the transverse mass distribution, which exhibits the characteristic cutoff near 80 GeV due to the undetected neutrino. A comparison with real CMS data reinforces these findings.

Beyond these Standard Model confirmations, an unexpected excess is observed around 700 GeV in the dimuon spectrum. This feature aligns with previous ATLAS results on four-top-quark production, which suggested possible contributions from new physics.