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Background studies for new physics searches with the CMS and PPS detectors

Presentation by

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MOTIVATION

- This search is mainly motivated by scenarios beyond the Standard Model that feature extended Higgs sectors, such as the two Higgs-doublet model (2HDM)[1] and models that feature two Higgs doublet sectors extended with SM gauge singlets [2-4].

- The latter classes of models are particularly interesting for this search, as they allow new (pseudo)scalar states at different mass scales. [5]

- The new pseudo scalar can be produced by gluon fusion and, to a different extent, by photon fusion.

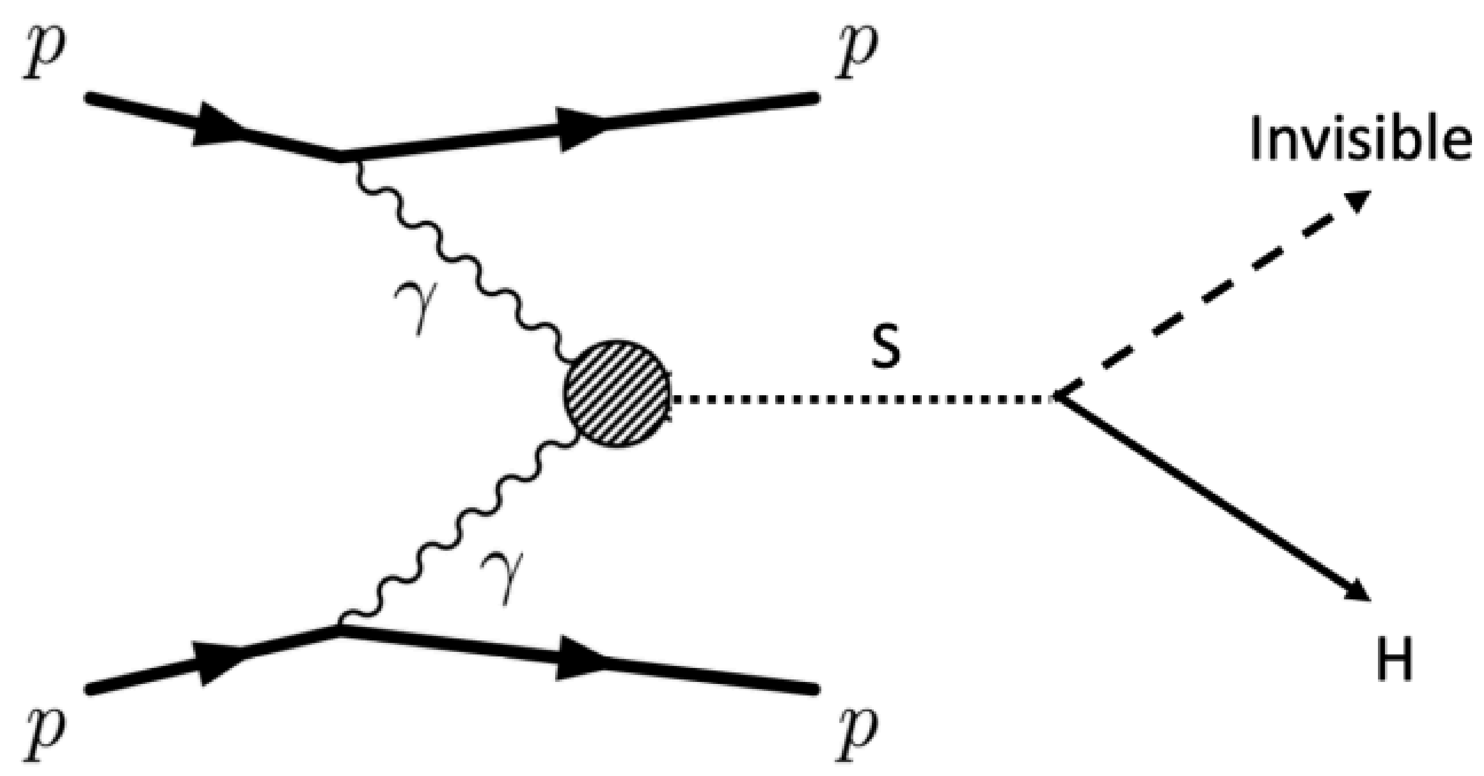
- The expected cross-section for a TeV-scale resonance is rather suppressed, but the effective couplings can be improved by introducing new vector-like fermions coupled with the Higgs sector. [6,7]

- Appropriately choosing the gauge quantum numbers of the new exotic states could improve the photon fusion cross section with respect to gluon fusion, as well as induce effective couplings of the new scalars with the gauge bosons.

- DM Higgs-portal [8]

ANALYSIS

- We decided to analyze the 2018 sample because the proton reconstruction is well-defined in the Physics Object Groups (POG), and the Roman Pots have pixels at both stations of each arm.
- We decided to analyze only the Multi configuration since it has the best resolution and the rules of the GOP are well understood.
- The idea is that the two photons create a resonance with a width below the PPS resolution that can be seen as a peak in the proton mass spectrum at the PPS resolution.
- The scalar decays into a Higgs + an invisible particle (X).
- The idea is to select a central object, namely a Higgs decaying into two b-Jets.
- Match all kinematics up to a certain level and then proceed with a bump search on the pileup background (as in Z+X).
- Apply a statistical analysis to the proton mass spectrum.
- Although the background templates in this analysis are fully modeled from data, specific Monte Carlo (MC) models are employed for validation purposes and to show our level of understanding of the efficiencies of the central (CMS) reconstructed objects and triggers.



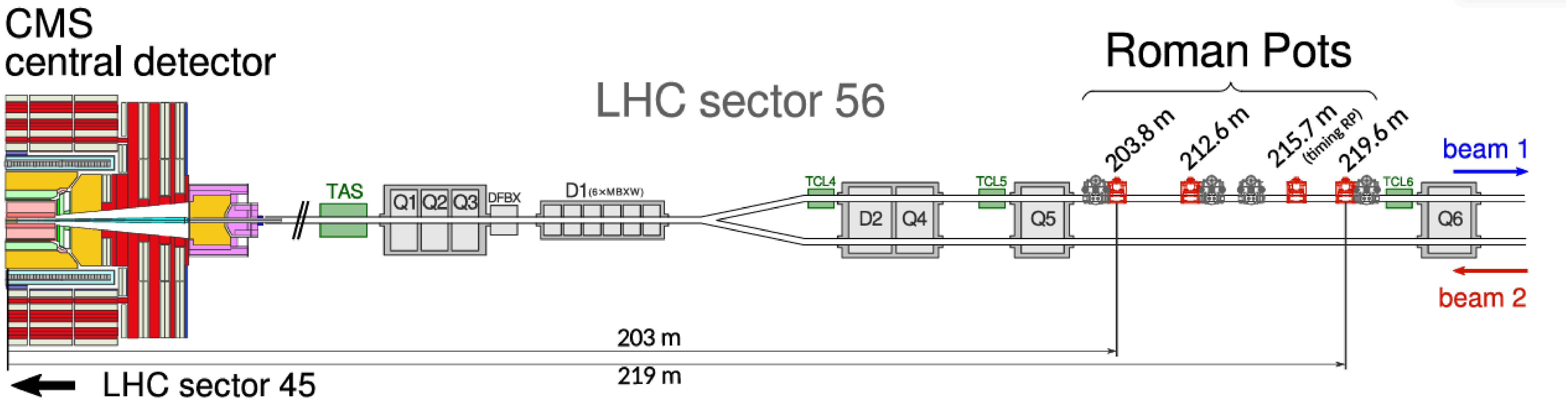
p = proton momentum

$\zeta = \Delta p / p$ $\qquad$ $M_S = \sqrt{\zeta_1 \zeta_2 s}$

- This search focuses on the production of a massive scalar particle from the proton photo-production observed by PPS.
- The Scalar field can be seen as a portal to the (invisible) Dark Sector.
- We can measure the full kinematics of an eventual invisible particle from measurements of protons and central objects.

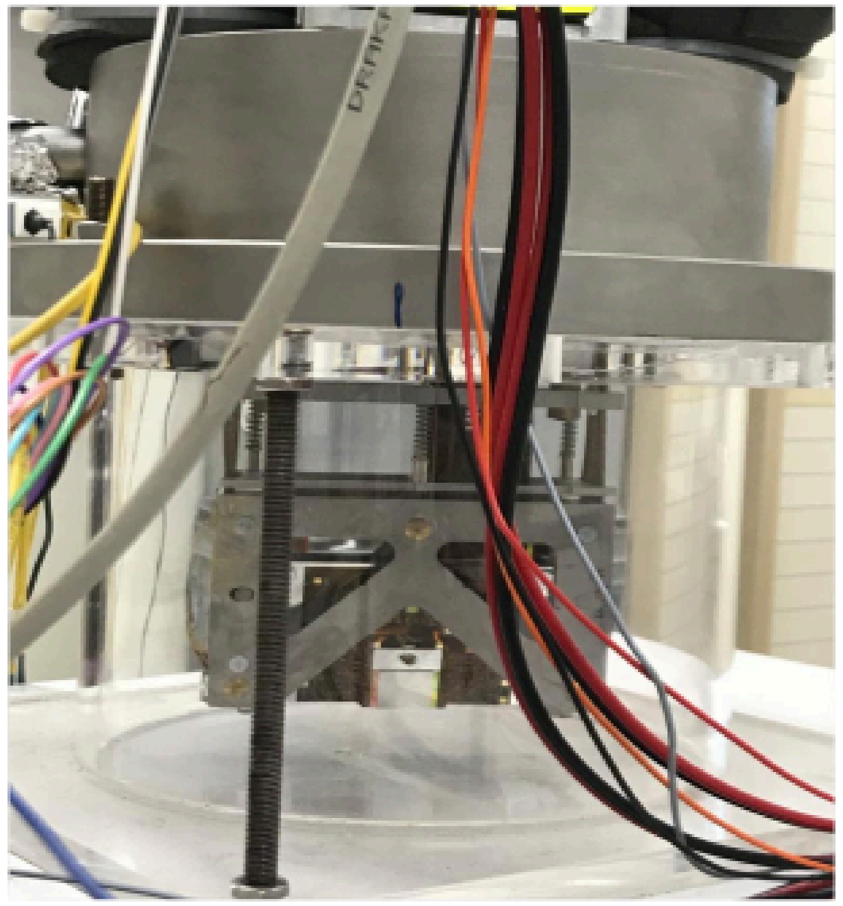
The largest Branching Ratio (BR) of the Higgs is the decay into two b quarks, so this analysis focuses on studying this case. Although the poor resolution of the jet reconstruction reduces the ability to identify a missing particle, the well-resolved scalar particle kinematics by PPS is an exceptional search tool for such a phenomenon.

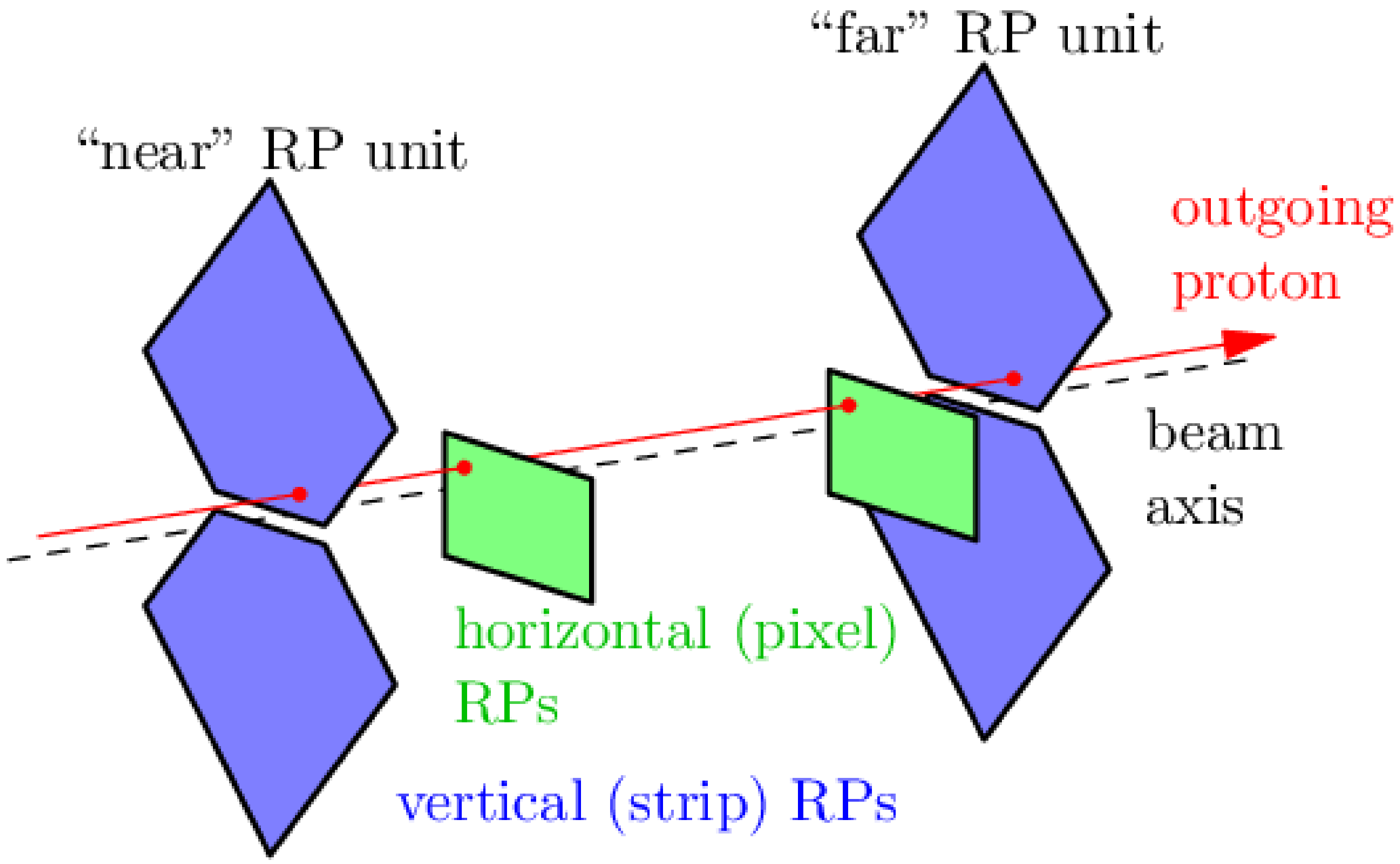
CMS and TOTEM first joined forces on special Runs and data acquisition integration, still in Run 2, which gradually ended in an agreement on a new collaboration. This new collaboration, called the Proton Precision Proton Spectrometer (CT-PPS or PPS hereafter), proposed a physics program that extended the CMS acceptances to tag scattered protons and measure unique core processes.



[9] CMS, TOTEM Collaboration, "Proton reconstruction with the CMS-TOTEM Precision Proton Spectrometer", JINST 18 (2023), no. 09, P09009, doi:10.1088/1748-0221/18/09/P09009, arXiv:2210.05854.

For tracking in 2018, silicon pixel 3D detectors completely replaced strips, which had characterized the RPs (except for vertical Roman Pots, which are still characterized by strips, but these are only used for alignment). Unlike strips, pixels have the ability to resolve multiple traces. The objective of this detector is to measure the displacement of the proton with respect to the beam, which translates into fractional momentum loss. This device is able to calculate the fractional momentum loss, denoted ξ, for the two outgoing protons.





[10] Tumasyan, et al. Collaboration, T. T. (2023). Proton reconstruction with the CMS-TOTEM Precision Proton Spectrometer. Journal of Instrumentation, 18(09), P09009. doi:10.1088/1748-0221/18/09/P09009

There are six pixel layers in each Pot, each with dimensions of 100x150 μm^2 , providing high granularity. The resolution is less than 30 μm and, to optimize both resolution and efficiency, the layers are rotated by approximately 18°.

BACKGROUND STUDIES

For the ongoing analysis, the main background is expected to come from events with high missing energy. Signal and background events are simulated in the PPS detector; this is essential for acceptance considerations. TTbar, V+jets, and QCD are identified as the most significant background contributors to this analysis. Monte Carlo samples for the background of this process are being studied.

- MC: Current work focused on QCD

TRIGGER SELECTION APPLIED

- HLT_Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ_Mass3p8>0
- HLT_Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ_Mass8>0
- HLT_IsoMu24>0
- HLT_IsoMu27>0
- HLT_IsoMu24_eta2p1>0

HLT Trigger	lum_{HLT}/lum_{2018}	*Absolute* Eff.	Eff. *after Prescale*
HLT*Dijet70-Mu5	0.0278	0.5%	0.013900%
HLT*Dijet70-Mu5-noalgo	0.0278	0.8%	0.022240%
HLT*Dijet40-Mu5	0.0057	4%	0.022800%
HLT*Dijet40-Mu5-noalgo	0.0057	8%	0.045600%
HLT*Dijet20-Mu5	0.0009	10%	0.009000%
HLT*Dijet20-Mu5-noalgo	0.0009	19%	0.000171%
HLT-Mu17*Mu8*Mass3p8	1	0.14%	0.14%
HLT-Mu17*Mu8*Mass8	1	0.14%	0.14%
HLT-IsoMu24-eta2p1	1	0.5%	0.5%
HLT-IsoMu24	1	0.5%	0.5%
HLT-IsoMu27	1	0.4%	0.4%

STATIC CUTS

These cuts are the same for all data sets, regardless of the scalar mass or phase space available. This is why we call them “static” cuts.

- Missing_Mass(dijet) > 0

A negative mass is not physically allowed, this value results from an incorrect reconstruction, so we exclude these cases.

- | Dijetη | < 2.4

This value is the limit within which the particle can be detected within the CMS.

- 85 GeV < dijetMass < 150 GeV

This is a window for the Higgs mass. From the simulations, this distribution lies almost entirely within the 85 to 150 GeV range (in all data sets).

- $\pi - |\pi - |Dijet\Phi - Met\Phi|| > 2.3$

Describes the angle between the X particle and the Higgs, the range is between 0 and π, the interaction results in being back to back.

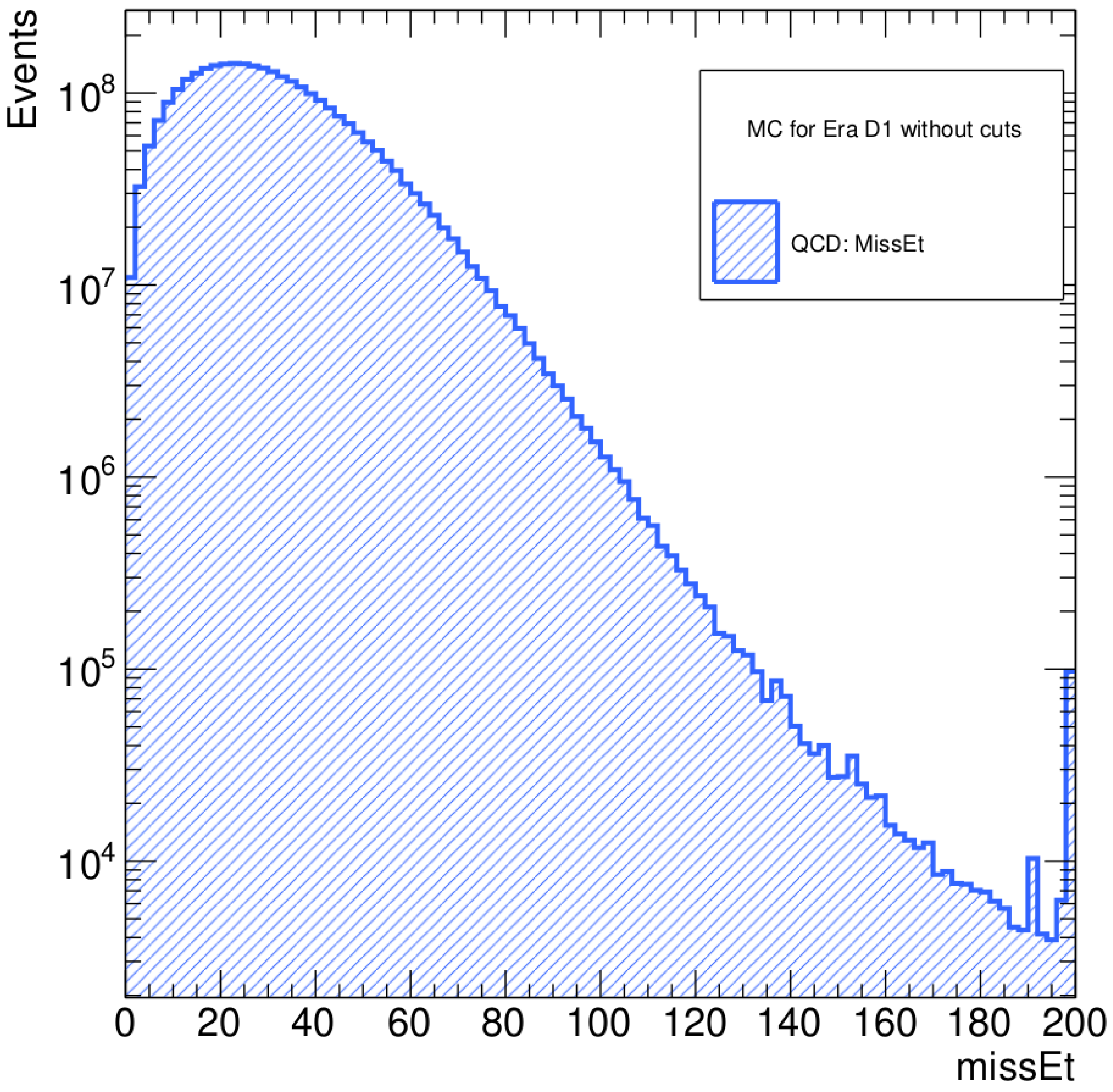
- leadingJetBtag> 0.8 && secondJetBtag>0.8

Efficiencies are calculated with a cutoff of the b-labeling estimator greater than 0.8. With this cutoff, approximately 25% of the signal remains, while the remaining background is an order of magnitude lower, around 3%.

The labeling estimator b> 0.8 selects the signal, while the labeling estimator b < 0.2 selects the background.

- PileUp weight, Corresponding cross-section normalization factor and percentage proton efficiency (27.6%) applied

- No selection or cut applied



- PileUp weight, Corresponding cross-section normalization factor and percentage proton efficiency (27.6%) applied

Trigger selection applied:

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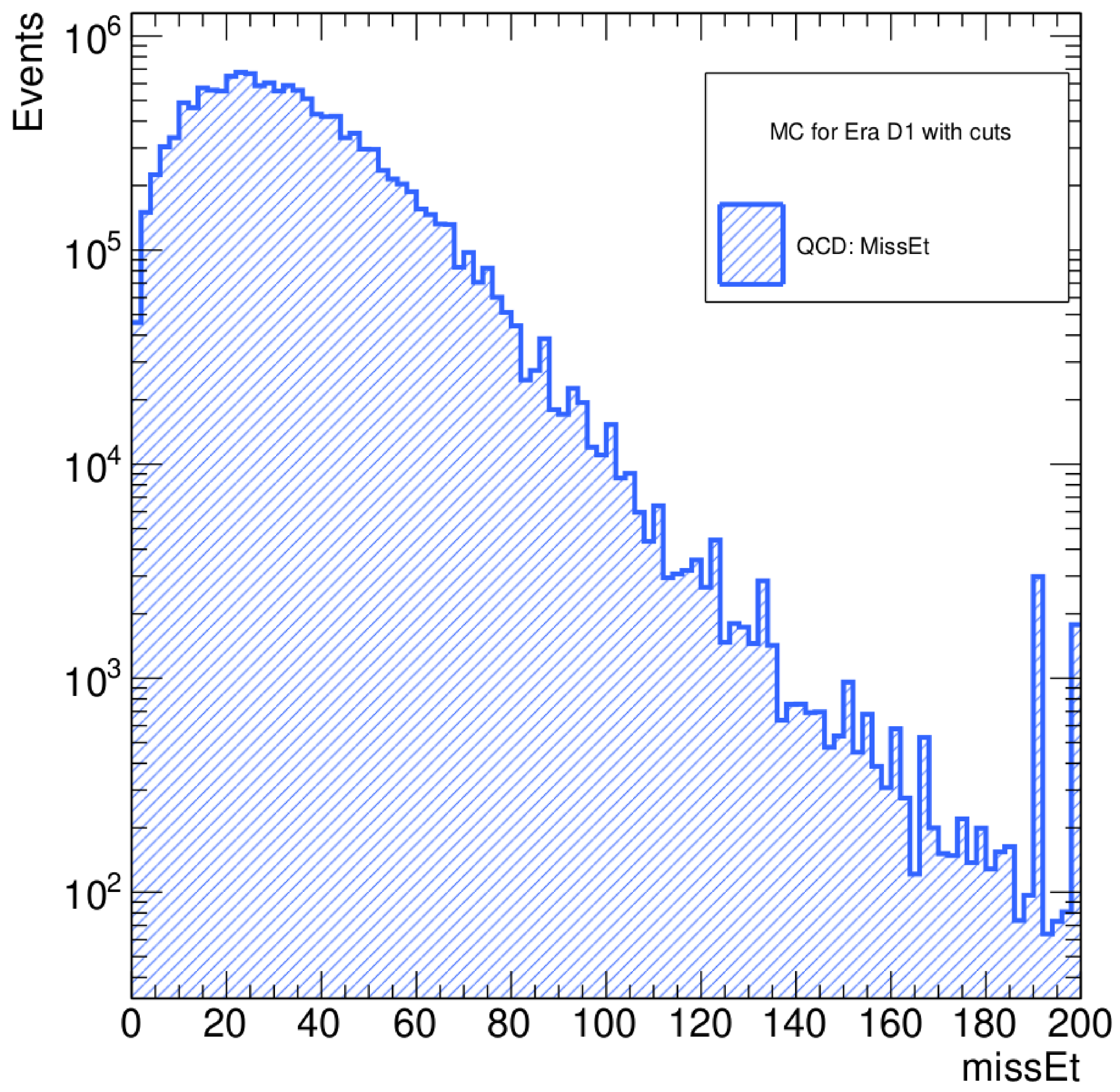
- HLT_Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ_Mass8>0
- HLT_IsoMu24>0
- HLT_IsoMu27>0
- HLT_IsoMu24_eta2p1>0



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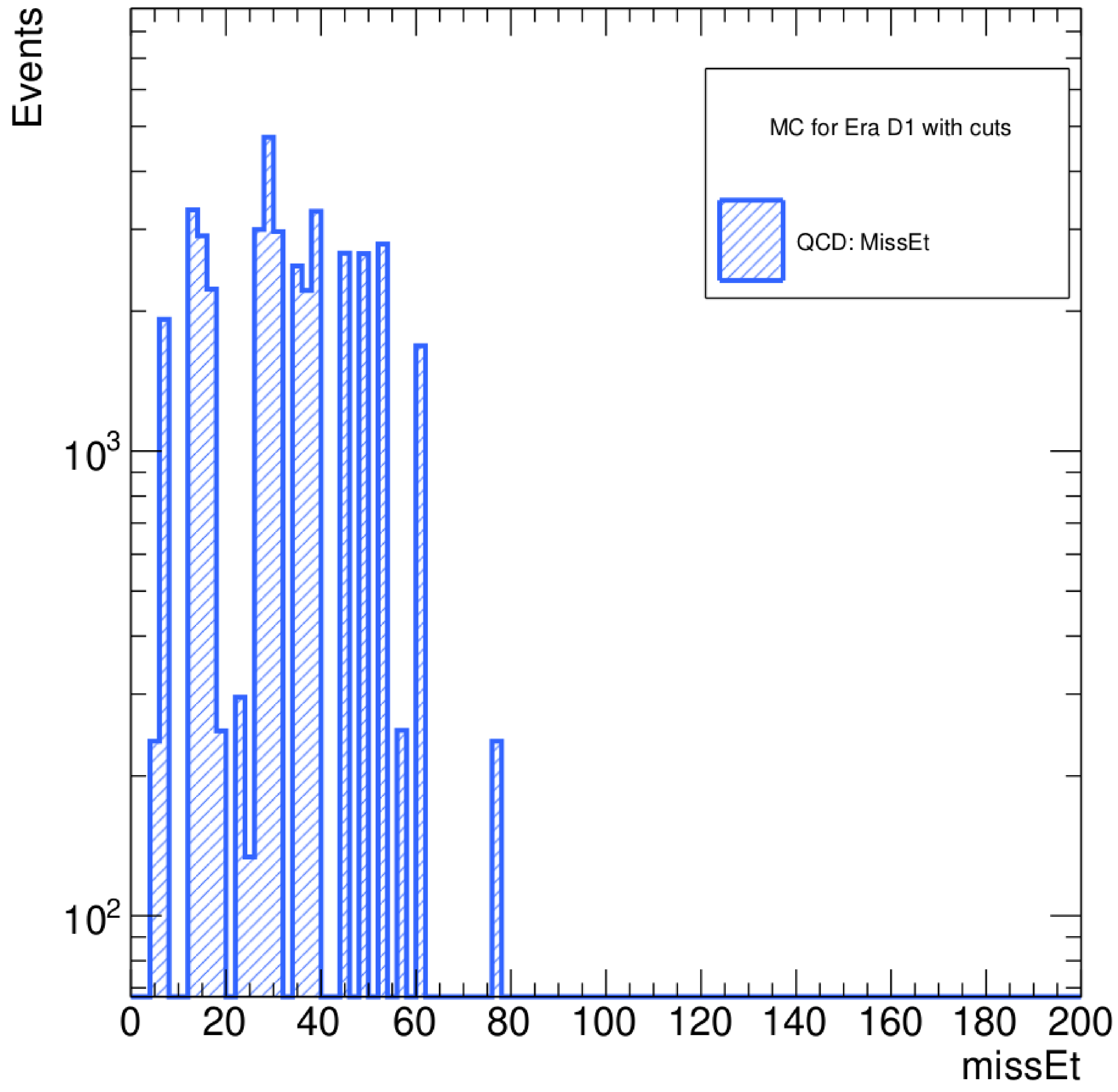
- HLT_Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ_Mass8>0
- HLT_IsoMu24>0
- HLT_IsoMu27>0
- HLT_IsoMu24_eta2p1>0

Cuts:

- Missing_Mass(dijet) > 0
- | Dijetη | < 2.4
- 85 GeV < dijetMass < 150 GeV
- π -|π- |DijetΦ – MetΦ|| > 2.3
- leadingJetBtag> 0.8 && secondJetBtag>0.8



OUTLOOK & CONCLUSION

- One of the most important aspects related to our analysis is the study and understanding of the background. This study is especially crucial to demonstrate our level of understanding of central reconstructed object (CMS) and trigger efficiencies.

- The review and implementation of data-driven methods are ongoing to address the problem of low statistics.

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Thank you!