Missing Mass Searches in Dimuon Events with CT-PPS

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Dark Matter (DM) is an established explanation of observed phenomena e.g. in astrophysics (galaxy rotation curves), but the search for dark matter particles has been unsuccessful so far.
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Searches for DM candidates:

- Candidates should be heavy and weakly interacting
- Could be produced in colliders, but can not be directly observed in the detectors
- If produced together with Standard Model particles the unknown particles can be seen as a momentum imbalance
Motivation

Problem with the main LHC experiments

The LHC experiments are only sensitive to missing transverse momentum, which can be small in Beyond Standard Model processes → These processes can not be seen.

→ Both protons stay intact → The total momentum of the protons is known, not just $p_T$ → $X$ contains the Beyond Standard Model particles as missing mass

Need very forward proton detectors to measure proton momentum precisely
Motivation

Problem with the main LHC experiments
The LHC experiments are only sensitive to missing transverse momentum, which can be small in Beyond Standard Model processes → These processes can not be seen.

Solution
Instead search for processes $pp \rightarrow p + X + p$

- Both protons stay intact → The total momentum of the protons is known, not just $p_T$
- $X$ contains the Beyond Standard Model particles as missing mass
- Need very forward proton detectors to measure proton momentum precisely
The TOTEM Experiment
The CMS-TOTEM Precision Proton Spectrometer (CT-PPS) consists of a silicon tracking system to measure the position and direction of the protons, and timing detectors to reduce pileup.
Considered Processes

Standard Model Signal Process

SUSY Signal Process
Background Processes

Drell Yan (DY) Background
Background Processes

Drell Yan (DY) Background

Decay of two W bosons
Background Processes

Drell Yan (DY) Background

Invariant Mass of the two muons in the data shows a large amount of DY background at the Z mass.
Event signature

Muons leave a signal in the CMS detector,
Protons leave signals in the Roman Pots of TOTEM
Muon selection

Two muons with opposite charge and $p_T > 40\text{GeV}$ chosen by the CMS trigger

Variables: $p_T, p_x, p_y, p_z, \phi, E$
MC simulation

DY processes are the main background. Use Monte Carlo generated events from process $Z/\gamma^* \rightarrow l^+l^-$ to find the best cuts on the data.

Invariant Mass:

![Invariant Mass MC prediction without cuts.](image)

Invariant Mass MC prediction without cuts.
MC simulation

DY processes are the main background. Use Monte Carlo generated events from process $Z/\gamma^* \rightarrow l^+l^-$ to find the best cuts on the data.

Invariant Mass:

Invariant Mass MC prediction without cuts.

Cut for $M < 80\text{GeV}$ and $M > 105\text{GeV}$

Invariant Mass MC prediction with cuts.
MC simulation

Difference in angle $\phi$ between the muons:

$\Delta\phi$ MC prediction without cuts.
MC simulation

Difference in angle $\phi$ between the muons:

\[ \Delta \phi \text{ MC prediction without cuts.} \]

\[ \Delta \phi \text{ MC prediction with cuts.} \]

Cut for $\Delta \phi < 2.7$
Cuts on Data

Applying these cuts to the same histograms in the datafile:

Measured $\Delta \phi$ with cuts.

Measured Invariant Mass with cuts.

Compared to the MC predicted distribution there are more events at lower $\Delta \phi$ \rightarrow signal is visible
Missing Mass:

\[ M^2 = (13\text{TeV} - (E_1^\mu + E_2^\mu + |p_{z}^{\text{Prot1}}| + |p_{z}^{\text{Prot2}}|)^2 - (p_{x}^{\mu 1} + p_{x}^{\mu 2})^2 \\
- (p_{y}^{\mu 1} + p_{y}^{\mu 2})^2 - (p_{z}^{\mu 1} + p_{z}^{\mu 2} + p_{z}^{\text{Prot1}} + p_{z}^{\text{Prot2}})^2 \]
Proton selection

Protons hits are measured by Roman Pots, detectors inside of the beam vacuum pipe.
Proton selection

The Roman Pots each have a probability of a background proton hit of 30%.

Proton selection:

Two protons:

Three protons:

Four protons:
Results

- MC predictions allow one to select cuts on the data to reduce DY background by 98%
- Scaling the MC to the same sample size as the data:
  - Number of Z background events: 1569
  - Signal + Background in data: 2257

Outlook:

- Proton selection should reduce background even more, requires a more precise simulation
- Reconstructing vertex position to reduce background protons (pile-up)
- Need good timing resolution of around 10ps, for a vertex resolution of 2mm
Thank you for your attention.
Backup
Cross-sections

Measured for $pp \rightarrow pp\mu\mu$: $\sigma = 3.38 \text{pb}^{+0.58}_{-0.55}$