Searches with leptons in the final state @ CMS

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LHCp 2024, 4th June 2024, Boston
Introduction

• Direct searches for BSM physics remains a key part of the CMS physics program
  • an extensive searches for NEW Physics in which leptons provide clear signatures

• Many exotic BMS extension from few GeV up to TeV scale
  • Dark Photon & Extended Higgs sector (10.1007/JHEP12(2023)070)
  • New resonances (arXiv:2402.11098)
  • Heavy gauge bosons (CMS-PAS-EXO-21-015 & CMS-PAS-EXO-21-016)
  • SUSY (recent results covered in Carlos’, Victor’s and Weijie’s talks)
  • ...

• In this talk, the focus is on lately realised or published results
  • full Run-2 (2016-2018) up to 140/fb @ √s = 13 TeV
  • New result from for Run-3 @ √s = 13.6 TeV in Anne’s and Raphael’s talks
Low mass di-muon with scouting

Search for prompt low-mass dimuon resonances with scouting 10.1007/JHEP12(2023)070
Objects are reconstructed at trigger level to take trigger decision
- We can store the **trigger objects** and use them to do analysis
  - Physics objects saved (PF candidates, Jets, ...) reconstructed at HLT

**Scouting**

- Traditional muon triggers
  - $p_T > 15$ GeV

- Sacrifice event content to lower trigger thresholds (more physics possibilities)

- Scouting muon triggers
  - $p_T > 3$ GeV
  - $m_{\mu\mu} \sim 200$ MeV

**Data flow for a typical 2018 data-taking scenario**

- **Level 1 Trigger**
  - Coarse reconstruction, limited detector systems
  - ~100 kHz

- **High Level Trigger**
  - Full detector information and online resolution

- **Standard data stream**
  - ~1 kHz, ~1000 MB/s

- **Parking data stream**
  - ~3 kHz, ~2000 MB/s

- **Scouting data stream**
  - ~5 kHz, ~40 MB/s

- **Prompt offline reconstruction**
- **Delayed offline reconstruction**
- **No offline reconstruction**

**Scouting Paper**

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Low mass di-muon with scouting - Model

- Mainly targeting light mediators (short-lived)

- A challenging search with traditional trigger strategies
  - Low-pt objects, very high trigger rate with traditional triggers
Low mass di-muon with scouting - Scouting Trigger

Mainly targeting light mediators (short-lived)

A challenging search with traditional trigger strategies

Low-pt objects, very high trigger rate with traditional triggers

CMS Preliminary

96.6 fb^{-1} (13 TeV)

Run 2 dimuon events collected in the standard and scouting datasets

- Standard single and double muon triggers
- Scouting double muon triggers

60 fb^{-1} (13 TeV, 2018)

Scouting Dimuon Events

\( p_T(\ell) > 3 \text{ GeV}, \gamma_T(\ell) < 2.4, \text{ opposite sign} \)

L1-Trigger Selection Requirements
Limits are set for $m_{\mu\mu}$ in [1.1, 2.6] and [4.2, 7.9] GeV
Search for resonant signatures in the multilepton final state

X\phi family

arXiv:2402.11098
Sub. to PRD

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**Xϕ family - Model**

- Search for resonant signature of ϕ boson in multilepton events
- ϕ is produced in association with ttbar pair or W/Z bosons
- Scalar(S), pseudoscalar (PS) and Higgs-like (H) coupling scenarios are probed

**Complementary signatures:**
- 0 / 1+ b-jets,
- low/high ST,
- 3 or 4 leptons,
- with/without MET

\[
\begin{align*}
\text{For S/ PS : } & \sigma(Wϕ/Zϕ) \sim \Lambda^{-2} \\
\sigma(ttϕ) & \sim g_{s/ps}^2 \\
\text{For Higgs-like: } & \sigma(Wϕ/Zϕ) \sim \sin^2 \theta \\
\Lambda & \text{ effective coupling mass scale, } \\
\theta & \text{ mixing angle, } g \text{ Yukawa coupling to top quark}
\end{align*}
\]
**X\phi family - Results**

- **Resonant \( X\phi \rightarrow ee/\mu\mu \)**
  - Dilepton mass is the final discriminator distribution
  - \( \phi \) mass is probed in the mass range of 15-76 GeV and 106-366 GeV (Z mass window excluded)

- **Semiseronant \( X\phi \rightarrow \tau\tau \)**
  - Mass spectra are defined depending on the flavor of leptons used to reconstruct the \( \phi \) mass
    - two \( \tau_l \) leptons \( \rightarrow M_{\tau\tau} \), light lepton + \( \tau_l \) \( \rightarrow M_{ll} \), two light lepton \( \rightarrow M_{ll} \)
  - \( W\phi, Z\phi \) and \( tt\phi \rightarrow \tau\tau \) are the first direct constraints on an extension of the SM with light boson in leptonic decay channels and this mass range.

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Search for VBF Zprime to tau tau (WW)

Other result with τ lepton in the final state in Carlos’ talk
**VBF Z’ (WW/ττ) - Model**

- Search in the $e\mu$, $e\tau$, $\mu\tau$, and $\tau\tau$ final states, with emphasis on 3rd generation
- VBF topology -> require a pair of well separated & in the opposite plane ($|\Delta\eta_{jj}|>4.2$ & $|\eta_1\eta_2|<0$) jets with high mass ($m_{jj}>500$ GeV)

\[ m_{\text{recog} Z'} = (E_{\ell_1} + E_{\ell_2} + p_{\text{miss}} T)^2 - (\vec{p}_{\ell_1} + \vec{p}_{\ell_2} + \vec{p}_{\text{miss}} T)^2 \]
VBF $Z'$ (WW/$\tau\tau$) - $M_{Z'}$

- Search in the $e\mu$, $e\tau_h$, $\mu\tau_h$, and $\tau_h\tau_h$ final states, with emphasis on 3rd generation
- VBF topology -> require a pair of well separated & in the opposite plane ($|\Delta\eta_{jj}|>4.2$ & $|\eta_1\eta_2|<0$) jets with high mass ($m_{jj}>500$ GeV)
- Boost to the $Z'$ => $p_T^{\text{miss}}$ from $\tau$ decay is collinear with $Z'$

\[
m_{Z'}^{\text{reco}} = \sqrt{(E_{\ell 1} + E_{\ell 2} + p_T^{\text{miss}})^2 - (\vec{p}_{\ell 1} + \vec{p}_{\ell 2} + \vec{p}_T^{\text{miss}})^2}
\]

Background estimation:
Non-prompt background estimated by loose-tight method from sidebands
Prompt background estimated by MC and normalized from data
VBF $Z'$ (WW/$\tau\tau$) - Results

- Interpretation relies on the Sequential Standard Model and four independent parameters:
  - $Z'$ couplings to 1st+2nd ($g_l$) and 3rd ($g_h$) generations
  - Coupling to $W$ ($k_V$)
  - $Z'$ mass ($m_{Z'}$)
- First interpretations of VBF produced $Z'$ at the LHC
Search for Heavy Neutral Resonances Decaying to Tau Lepton Pairs

Other result with $\tau$ lepton in the final state in Carlos' talk
**Z'→ττ - Model**

- Search in the $e\tau_h$, $\mu\tau_h$, and $\tau_h\tau_h$ final states
  - $Z'$ not boosted -> high $M_{Z'}$ two back to back $\tau$

Background estimation:
- $DY,W,tt$ estimated by MC and normalized from data in CR
- QCD estimated with ABCD method
### $Z'\rightarrow\tau\tau - M_{Z'}$

- Search in the $e\tau_h, \mu\tau_h, \text{and } \tau_h\tau_h$ final states
- $Z'$ not boosted $\rightarrow$ high $M_{Z'}$ two back to back $\tau$

$$m_{Z'}^{\text{reco}} = \sqrt{(E^\text{vis}_1 + E^\text{vis}_2 + |p^{Z'\text{miss}}|)^2 - |p_1^{\text{vis}} + p_2^{\text{vis}} + p^{Z'\text{miss}}|^2}$$

$$p^{Z'\text{miss}} = (- (\vec{p}_{1T}^{\text{vis}} + \vec{p}_{2T}^{\text{vis}}), 0)$$

**Background estimation:**
- DY, W, tt estimated by MC and normalized from data
- QCD estimated with ABCD method
Z'→ττ - Results

- Interpretation relies on Sequential Standard Model-like interpretation:
  - Limits in mass range from 400 GeV to 4 TeV
  - Most stringent limits for Z'→ττ
Summary

- CMS performed many resonant and non-resonant searches beyond Standard Model with leptons in the final state
  - Only some publications were discussed today. Full list of publications can be found Exotica Publications page and preliminary results Recent Exotica Preliminary Results.
  - 3 New results with $\tau$ in final state
    - CMS-PAS-EXO-21-015 & CMS-PAS-EXO-21-016 this talk
    - CMS-PAS-EXO-22-007 in Carlos’ talk
  - Run3 is bringing: more data, new triggers, analsys techniques
    - Two results in Anne’s and Raphael’s talk
  - Stay tuned for new results
Backup
DY $Z' \rightarrow \tau \tau$ vs. VBF $Z'$ Complementarity

- **DY $Z' \rightarrow \tau^+ \tau^-$** search in events with no jets from vector boson fusion (VBF) processes ($| \Delta \eta(j_1, j_2) | > 3.8$ and $m(j_1, j_2) > 500$ GeV), ensuring mutually exclusive with $Z' \rightarrow \tau^+ \tau^-$ and $WW(e\mu)$ searches in VBF processes. Possible to investigate $Z'$ in parameter space of $g_{Z'qq}, g_{Z'\tau\tau}, g_{Z'ww}$

- When $g_q$ is suppressed, existing bounds on $m(Z')$ from DY searches are weak (below 400 GeV, see [1])

- VBF $Z'$ process has similar or larger cross section compared to DY when $g_q$ is small [2]
VBF $Z'$ provides the best sensitivity when $g_q$ is less than 0.3 \cite{2}.

Investigating $Z'$ in parameter space of $g_{z'qq}$, $g_{z'\tau\tau}$, $g_{z'ww}$.