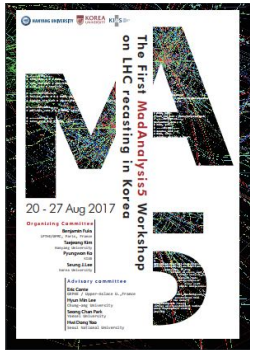
Validation of the MadAnalysis 5 implementation of CMS-EXO-16-052

Dajeong Jeon, Seulgi Kim, Sang Man Lee,
Ian J. Watson, Sam Bein, Jory Sonneveld

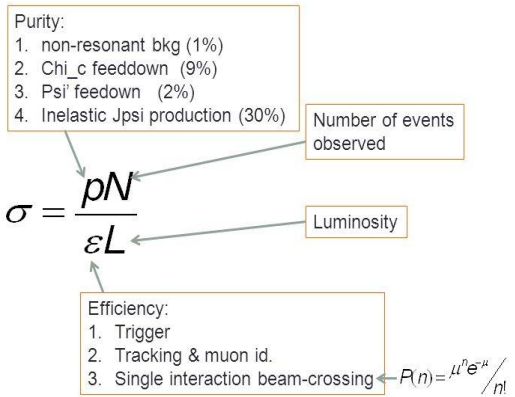


Introduction

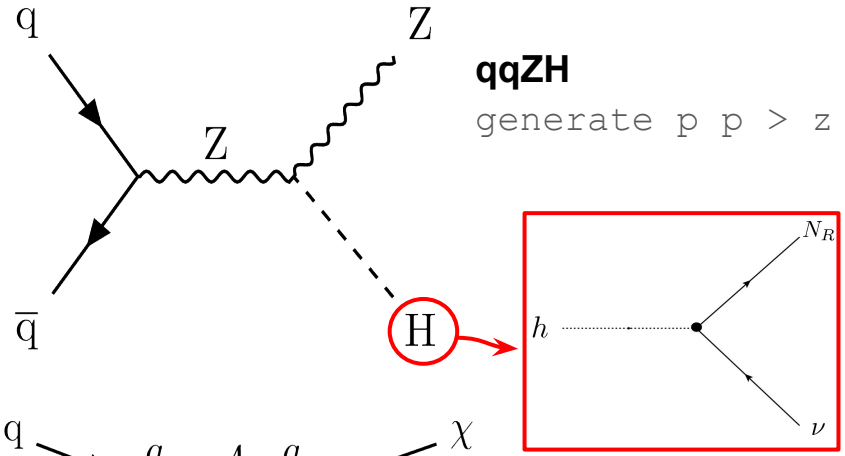
- The theoretically favored possibility is that DM make the form of weakly interacting massive particles (WIMPs).
- In this scenario, a Z boson, produced in proton-proton collisions, recoils against a pair of DM particles $\chi\overline{\chi}$.
- 13 TeV corresponding integrated luminosity 35.9 /pb

CMS-EXO-16-052

Process	ee	$\mu\mu$	ee+$\mu\mu$
qqZH(125)	69.3 ± 2.3	89.3 ± 3.1	158.6 ± 5.4
ggZH(125)	18.4 ± 2.0	24.3 ± 2.9	42.7 ± 4.9
DM, vector mediator $m_{\text{med}} = 500\,\text{GeV}$, $m_{\text{DM}} = 150\,\text{GeV}$	40.9 ± 1.6	57.9 ± 2.3	98.8 ± 3.9
DM, axial-vector mediator $m_{\text{med}} = 500\,\text{GeV}$, $m_{\text{DM}} = 150\,\text{GeV}$	27.5 ± 1.1	38.0 ± 1.5	65.5 ± 2.6
ZZ	162.3 ± 4.0	217.5 ± 5.4	379.8 ± 9.4
WZ	70.4 ± 2.9	92.1 ± 3.9	162.5 ± 6.8
Nonresonant bkg.	32.1 ± 6.4	41.0 ± 8.2	74.8 ± 15.0
Drell–Yan	35.6 ± 14.4	22.9 ± 9.3	72.0 ± 29.2
Other bkg.	1.1 ± 0.1	1.4 ± 0.1	2.6 ± 0.2
Total bkg.	310.4 ± 19.5	381.3 ± 15.7	691.7 ± 34.8
Data	292	396	688

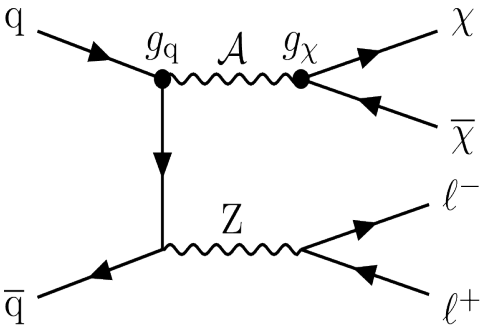


Introduction - Signal



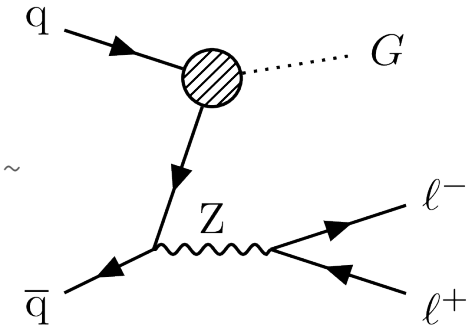
qqZH

```
generate p p > z vl vl~
```



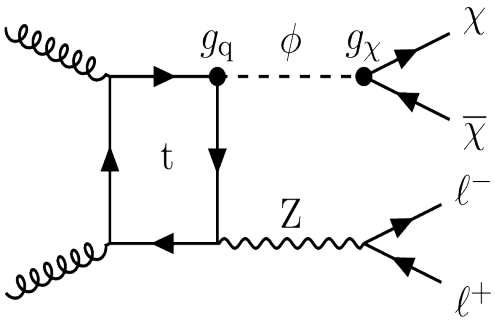
DM
vector mediator

```
generate p p > xd
xd~ z [QCD]
```



DM
axial -vector
mediator

```
generate p p > xd
xd~ z [QCD]
```



ggZH

```
generate p p > xd xd~ l+ l- [QCD]
add process p p > xd xd~ l+ l- j [QCD]
```

Introduction - Cutflow

Objects	Selections
Triggers	Single and double lepton triggers
Primary vertex	the one with largest $\sum p_{\mathrm{T}}^2$
Jets	PF jets, anti-k_{T}, $\Delta R = 0.4$
$E_{\mathrm{T}}^{\mathrm{miss}}$	Type-1 PF $E_{\mathrm{T}}^{\mathrm{miss}}$
B-tagging	CSVv2 *"Medium"*
Electrons	*"Medium"* ID & PF isolation
Muons	*"Tight"* ID, Impact parameter cuts & PF isolation

Table 2: Summary of object selection for the analysis.

Variable	Selection	Reject
N_ℓ	== 2	WZ, VVV
p_{T}^{ℓ}	>25/20 GeV (electrons)	QCD
	>20 GeV (muons)	QCD
Z boson requirement (GeV)	$\lvert m_{\ell\ell} - m_{\mathrm{Z}} \rvert < 15$ GeV	WW, top-quark
Jet counting	≤ 1 jet with $p_{\mathrm{T}}^{\mathrm{j}} > 30$ GeV	$Z/\gamma^* \to \ell^+\ell^-$, top-quark, VVV
$p_{\mathrm{T}}^{\ell\ell}$ (GeV)	> 60	$Z/\gamma^* \to \ell^+\ell^-$
B-tagging veto	CSV2 < 0.8484	Top-quark, VVV
Tau veto	0 τ_{h} candidates with $p_{\mathrm{T}}^{\tau} > 18$ GeV	WZ
$E_{\mathrm{T}}^{\mathrm{miss}}$ (GeV)	> 100	$Z/\gamma^* \to \ell^+\ell^-$, WW, top-quark
$\Delta\phi_{\ell\ell, E_{\mathrm{T}}^{\mathrm{miss}}}$	> 2.6	$Z/\gamma^* \to \ell^+\ell^-$
$\lvert E_{\mathrm{T}}^{\mathrm{miss}} - p_{\mathrm{T}}^{\ell\ell} \rvert / p_{\mathrm{T}}^{\ell\ell}$	< 0.4	$Z/\gamma^* \to \ell^+\ell^-$
$\Delta\phi_{\mathrm{jet}, E_{\mathrm{T}}^{\mathrm{miss}}}$	> 0.5	$Z/\gamma^* \to \ell^+\ell^-$, WZ
$\Delta R_{\ell\ell}$	< 1.8	WW, top-quark

Introduction - Cutflow

Objects	Selections
Triggers	Single and double lepton triggers
Primary vertex	~~the one with largest $\sum p_T^2$~~
Jets	PF jets, ~~anti-k_T~~, $\Delta R = 0.4$
E_T^{miss}	Type-1 PF E_T^{miss}
B-tagging	~~CSVv2 "Medium"~~
Electrons	"*Medium*" ID & PF isolation
Muons	"*Tight*" ID, ~~Impact parameter cuts &~~ PF isolation

Table 2: Summary of object selection for the analysis.

Variable	Selection	Reject
N_ℓ	$== 2$	WZ, VVV
p_T^ℓ	>25/20 GeV (electrons)	QCD
	>20 GeV (muons)	QCD
Z boson requirement (GeV)	$\lvert m_{\ell\ell} - m_Z \rvert < 15$ GeV	WW, top-quark
Jet counting	≤ 1 jet with $p_T^j > 30$ GeV	$Z/\gamma^* \to \ell^+\ell^-$, top-quark, VVV
$p_T^{\ell\ell}$ (GeV)	> 60	$Z/\gamma^* \to \ell^+\ell^-$
~~B-tagging veto~~	~~CSV2 < 0.8484~~	~~Top-quark, VVV~~
Tau veto	0 τ_h candidates with $p_T^\tau > 18$ GeV	WZ
E_T^{miss} (GeV)	> 100	$Z/\gamma^* \to \ell^+\ell^-$, WW, top-quark
$\Delta\phi_{\ell\ell, E_T^{miss}}$	> 2.6	$Z/\gamma^* \to \ell^+\ell^-$
$\lvert E_T^{miss} - p_T^{\ell\ell} \rvert / p_T^{\ell\ell}$	< 0.4	$Z/\gamma^* \to \ell^+\ell^-$
$\Delta\phi_{jet, E_T^{miss}}$	> 0.5	$Z/\gamma^* \to \ell^+\ell^-$, WZ
$\Delta R_{\ell\ell}$	< 1.8	WW, top-quark

Program Details

- MG5_aMC_**v2_6_0**, Pythia**8**, Delphes-**3.4.1**
- UFO files: http://feynrules.irmp.ucl.ac.be/wiki/DMsimp
- 10,000 events are used for the analysis
- Editing of cards
  - Shower card

```
pdfcode      = 1     //0
Qcut         = 30.0  //50.0
njmax        = 1     //0
```

  - Run card

```
10000 = nevents              // 1000
PYTHIA8   = parton_shower    //HERWIG6
3         = ickkw            //0
1.0  = jetradius             // 0.7
```

- Madspin card

```
decay z > l+ l-     //decay z > all all
```

- Param card

```
5.000000e+02 # MY1 //1.000000e+03
1.500000e+02 # set of param :1*MXr,
1*MXc, 1*MXd //1.000000e+01
```

Results

process	MG5	Official
qqZH	110.7	69.3 ± 2.3
ggZH	0.013	18.4 ± 2.0
DM vector	13.63	40.9 ± 1.6
DM Axial vector	15.03	27.5 ± 1.1
bkg	310.4 ± 19.5	
data	292	

ee channel

process	MG5	Official
qqZH	182.4	89.3 ± 3.1
ggZH	0.0165	24.3 ± 2.9
DM vector	19.478	57.9 ± 2.3
DM Axial vector	19.73	38.0 ± 1.5
bkg	381.3 ± 15.7	
data	396	

mm channel

process	MG5	Official
qqZH	293.1	158.6 ± 5.4
ggZH	0.0295	42.7 ± 4.9
DM vector	33.11	98.8 ± 3.9
DM Axial vector	34.77	65.5 ± 2.6
bkg	691.7 ± 34.8	
data	688	

total

Results in the DMsimp_s_spin1-vector for p p > xd xd~ l+ l- [QCD] , p p > xd xd~ l+ l- j [QCD]

Available Results

Run	Collider	Banner	Cross section (pb)	Events	Data	Output	Action
run_01	p p 6500.0 x 6500.0 GeV	tag_1	0.1253 ± 0.00041	10000	parton aMC@NLO	LHE summary	remove run
					shower aMC@NLO	HEPMC	remove run

ex)
35.9 x 125.3 x 37/4688 = ?

Results

process	MG5	Official
qqZH	110.7	69.3 ± 2.3
ggZH	0.013	18.4 ± 2.0
DM vector	13.63	40.9 ± 1.6
DM Axial vector	15.03	27.5 ± 1.1

ee channel

process	MG5	Official
qqZH	182.4	89.3 ± 3.1
ggZH	0.0165	24.3 ± 2.9
DM vector	19.478	57.9 ± 2.3
DM Axial vector	19.73	38.0 ± 1.5

mm channel

process	MG5	Official
qqZH	293.1	158.6 ± 5.4
ggZH	0.0295	42.7 ± 4.9
DM vector	33.11	98.8 ± 3.9
DM Axial vector	34.77	65.5 ± 2.6

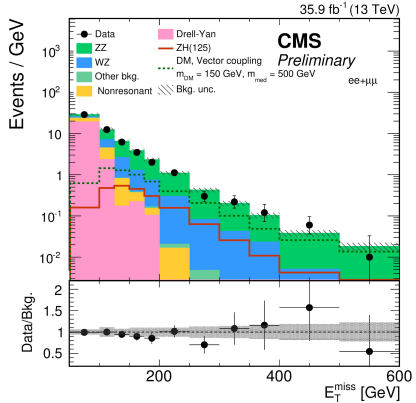
total

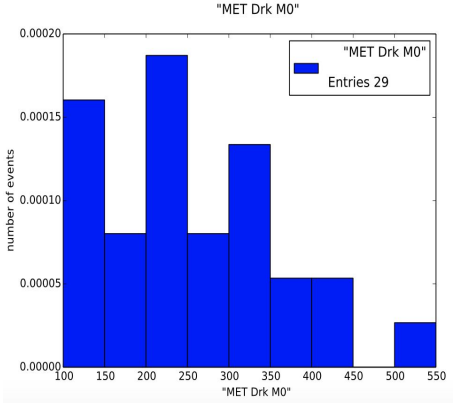
~184%

~144745.7%

~298.4%

~188.7%





What is next ?

- Correct and validate the Analysis so that we are able obtain more accurate results

- Create expected and observed 95% CL upper limits on the signal strength as a function of the mediator mass