$t/\bar{t} + DM$ analysis
CMS Exotica 2019 Workshop

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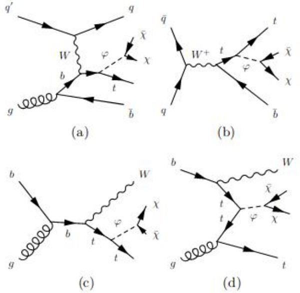
Analysis reminder

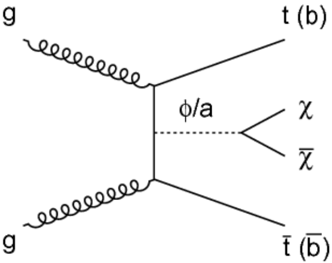
Simplified model being considered:

- Spin 1/2 DM χ (1 GeV, Dirac fermion)
- Spin 0 scalar (S)/pseudoscalar (PS) mediator ϕ (Yukawa-like structure of such interactions $\rightarrow$ gain from the coupling of the mediator to top quarks)
- Mediator mass $\in [10, 500]$ GeV
- Coupling g_χ mediator/DM set to 1 (same for all g_q couplings)

t+DM models



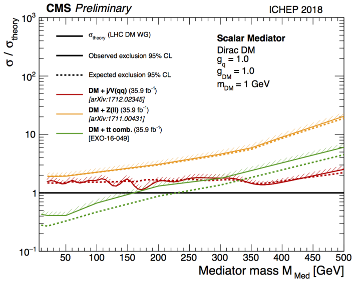
$t\bar{t}$+DM model



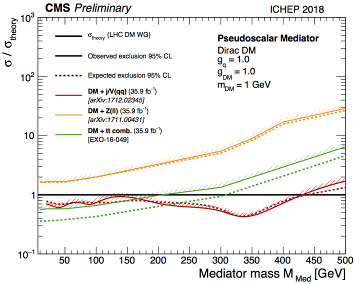
2016 $t\bar{t}$+DM analysis

Combination of the three final states (hadronic, semileptonic, dileptonic) of the $t\bar{t}$+DM search published as ‣ CMS-EXO-16-049

Scalar mediator



Pseudoscalar mediator

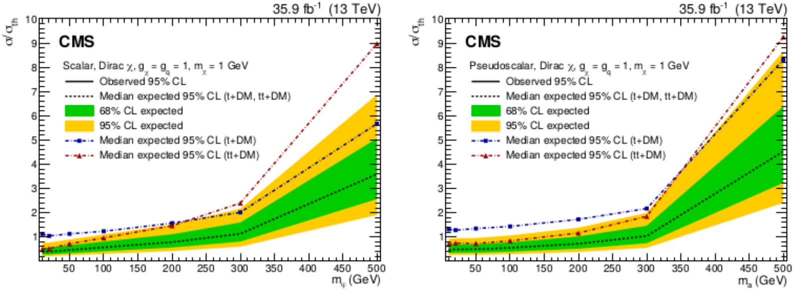


Scalar (pseudoscalar) mediators excluded up to 165 (223) GeV at 95% CL.

2016 $t/\bar{t}$+DM analysis

This process improves by a factor 2 the limits obtained by the $t\bar{t}$ analysis on its own. Published as ▸ CMS-EXO-18-010

- Only considering semi-leptonic and hadronic final states
- Usually lower production cross-section than the $t\bar{t}$ + DM (30-100%)



Scalar (pseudoscalar) mediators excluded up to 290 (300) GeV at 95% CL.

Analysis strategy

Run II legacy paper expected to combine both the t+DM and $t\bar{t}$+DM analyses, and the 3 different final states (hadronic, one and two leptons).

This talk is mostly focused on:

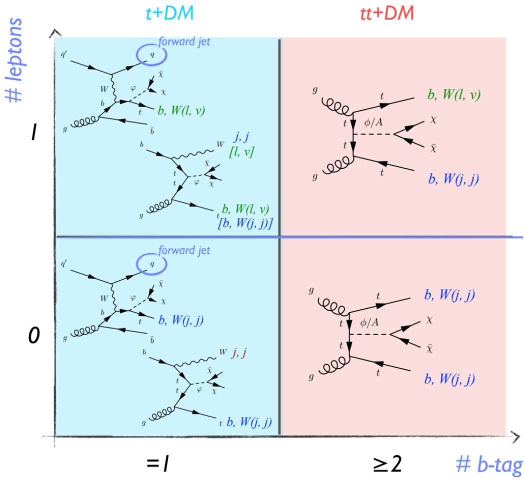
- **Explaining** the global strategy and status of the analysis
- **Show** the latest news and plans for each final state
- **Display** the two leptons final state latest distributions for 2016, 2017 and 2018

The objects will be common, while control and signal regions will be decided to make them orthogonal between the channels (b-jet categorization to **improve the sensitivity** by defining enriched single top/$t\bar{t}$ regions).

Hadronic final state

Semileptonic final state

Event selection



→ Object definitions can be found in the backup

Single lepton

- Single lepton trigger
- 1 isolated lepton (e, μ)
- $\geq$ 2 jets
- MET $>$ 160 GeV
- $+\ 0, \geq 1$ forward jets ($|\eta| > 2.4$)

All hadronic

- MET trigger
- Leptons veto (e, μ)
- $\geq$ 3 jets
- MET $>$ 250 GeV
- $+\ 0, \geq 1$ forward jets

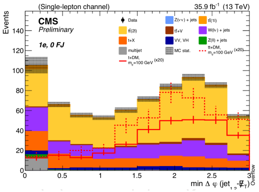
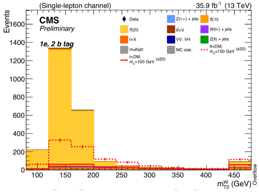
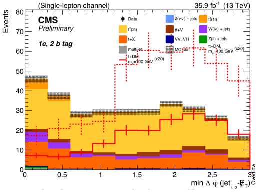
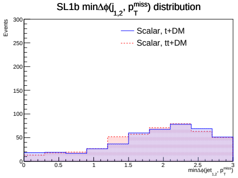
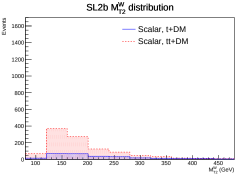
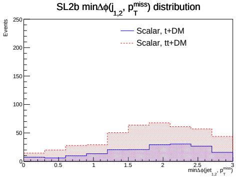
Current status

New framework to employ nanoAOD validated using privately produced nanoAODv5 t/t+DM signal samples for 2016 (m_χ = 1GeV, m_ϕ = 100GeV) from 2016 miniAOD.

The goal was to **reproduce** signal yields and shapes from EXO-18-010:

- Object definition implemented from nanoAOD as close as possible to 2016 analysis (miniAOD)
- Agreement in terms of yields within a few %
- Good agreement in terms of shape distribution also achieved (see next slides)
- Checked impact of different JEC/JetIDs between miniAOD and nanoAOD
- Work on-going to include minor SFs/corrections in analysis framework

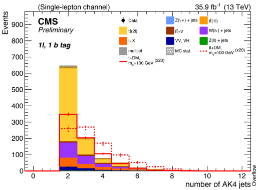
Single lepton discriminating variables

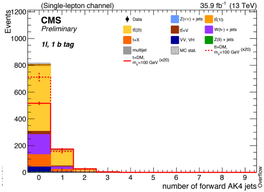
	Angle highest p_T jet/MET	m_T of particle decaying into W+b	Angle highest p_T jet/MET
EXO-18-010			
New framework			

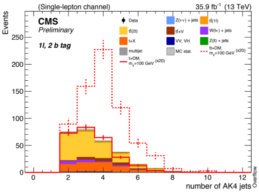
→ The validation leads to a **good agreement in terms of yields and shapes** for these discriminating variables.

Single lepton framework validation results

EXO-18-010

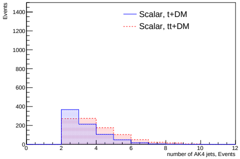




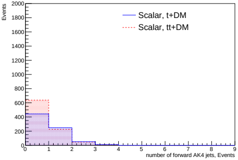


New framework

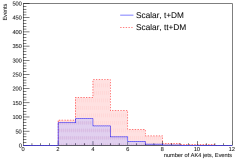
SL1b central jets distribution



SL1b forward jets distribution



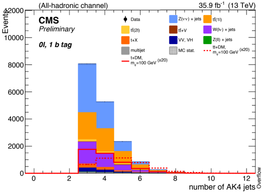
SL2b central jets distribution

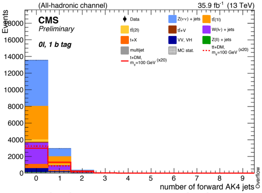


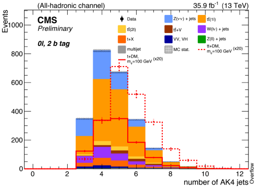
$\rightarrow$ The validation leads to a **good agreement in terms of yields and shapes**.

All hadronic framework validation results

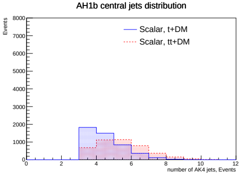
EXO-18-010

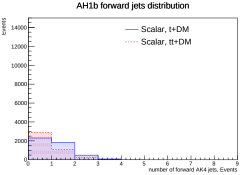


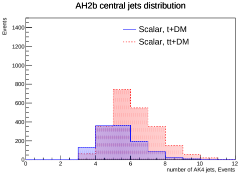




New framework







Next steps for this channel:

- Proceed to process 2017/2018 data
- As a starting point the 2016 strategy will be considered
- Investigate possible re-optimization of the analysis as well as the inclusion of the resolved toptagger both for 1b and 2b categories

Dileptonic final state

Samples used

Data

Datasets built to avoid any eventual double counting. All Run2 data taking years considered:

- 35.9 fb^{-1} for 2016
- 41.5 fb^{-1} for 2017
- 59.5 fb^{-1} for 2018

Monte-Carlo

The major backgrounds have been considered, read from NanoAOD.

Background	Name	Cross-section (pb)
Drell-Yan	DYJetsToLL_M10to50	18610
	DYJetsToLL_M50	6189
Top	TTJets, TTTo2L2Nu	831.7, 87.3
Others	Single top, TTZ, WW2l, ZZ4l, ZZ2l, WZ3l,...	//

Signal

Privately produced nanoAOD signal samples for 2016 currently used (all possible decays considered)

Objects

Leptons

- Two tight leptons selected
- Tight POG WP for muons, MVA WP90 for electrons.

Scale factors

- Jet energy corrections, leptons, b-jet and pile up SF all applied

MET

- Puppi MET currently considered instead of the PfType1MET

b-tag

- Considering deep CSV b-tag loose WP instead of CSVv2 (to be optimized)

Triggers

- Single and double lepton triggers combined to gain statistics (listed in the back up)

Data/MC regions defined

Three different regions defined to display our data/MC distributions:

Inclusive region

- Exactly 2 tight leptons (p_T >25 and 20 GeV)
- $|\eta| < 2.5$
- $m_{ll} > 20$ GeV

Drell-Yan region

- Inclusive region
- njet ≥ 2 (jets $p_T > 30$ GeV, $\eta < 2.5$)
- Puppi MET < 50 GeV
- $60 \leq m_{ll} < 120$ GeV

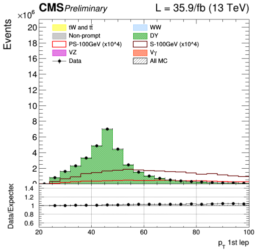
Top region (blinded)

- Inclusive region
- Puppi MET > 50 GeV
- Z Veto (76-106 GeV)
- njet ≥ 2 (jets $p_T > 30$ GeV, $\eta < 2.5$)

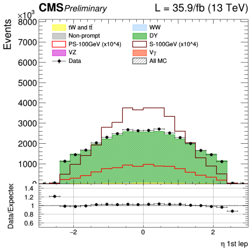
Top region similar to the 2016 signal region, so our blinding policy allows us to only look at 1/4 of the data.

Inclusive region (2016, // channel)

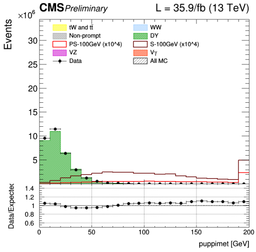
Leading p_T



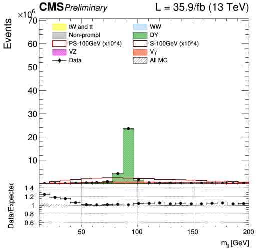
Leading η



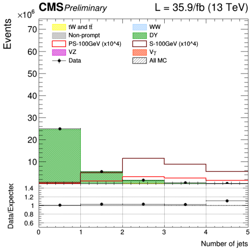
Puppi MET



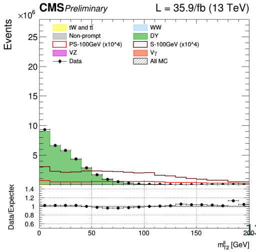
m_{ll}



nJet

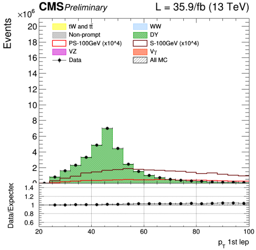


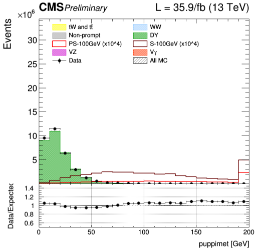
m_{T2}^{ll}



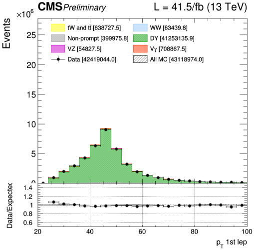
Year by year comparison (inclusive region)

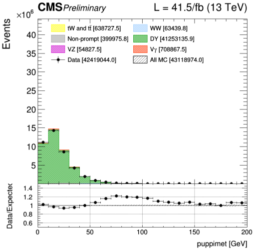
2016



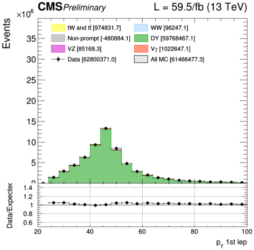


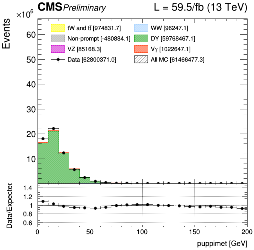
2017





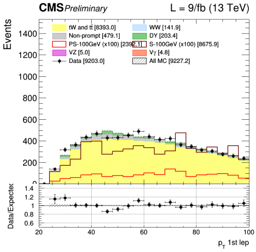
2018



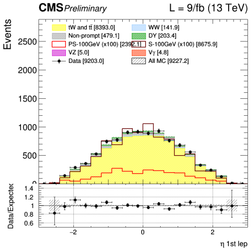


Top region (2016, $e\mu + \mu e$ channels, blinded)

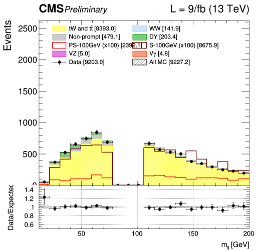
Leading p_T



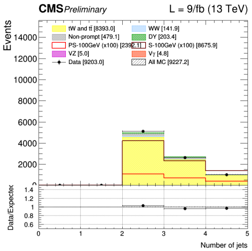
Leading η



m_{ll}

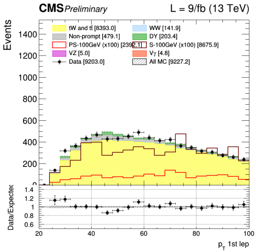


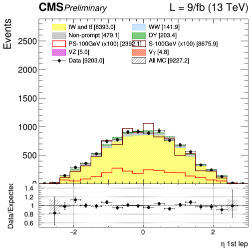
nJet



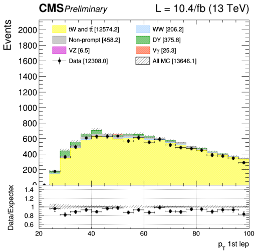
Year by year comparison (top blinded region)

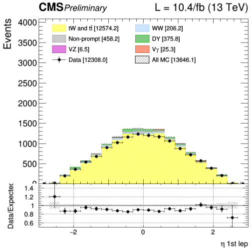
2016



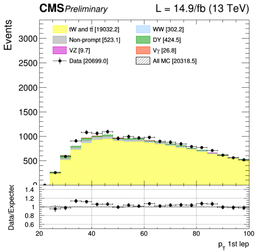


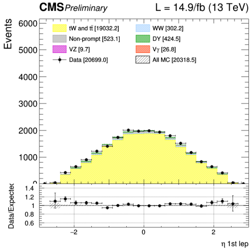
2017





2018





Signal samples status

Signal sample status

We plan to produce privately from the $t\bar{t} + DM$ and $t + DM$ gridpacks 1 or 2 mass points in order to have some signal to optimize the analysis.

We are moving to the randomized sampling method where all mass points are generated together.

$t\bar{t} + DM$ samples

The ttDM signal samples has now been **submitted centrally**.

$t + DM$ samples

The gridpacks production for $t + DM$ is **on-going** and should be ready by next week for a central submission later on.

Plans and prospects

For the Run II legacy paper, both the t+DM and the $t\bar{t}$+DM analyses will be combined. In practice, this means that:

- Objects will be synchronized
- Control and signal regions will be designed in an orthogonal way (b-jet categories for sure, additional categorization might be needed)

Global strategy improvement with respect to 2016:

- Search for new discriminating variables
- Deep CSV instead of CSVv2
- Top tagger improvement for the hadronic final state (and adapt it for the t+DM analysis)
- First ever look at the dileptonic final state for the t+DM

Discussion still on-going with ATLAS on **signal cross-section synchronization**.

The analysis plans to target the beginning of 2020 for the pre-approval.

Thank you!

EXO-18-010 objects

Datasets and objects definition for the semi-leptonic and all hadronic channels, as found in EXO-18-010.

Datasets and object definition

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sign off from EXO object experts

- *Data: 03Feb2017 re-miniAOD*
  - 35.9/fb Golden JSON
  - MET, SingleMuon, SingleElectron datasets
- *MC: Summer16 samples*
  - *top p_T re-weighting* for $t\bar{t}$ samples (POWHEG)
  - *NLO QCD and EWK K-factors* (same as for mono-jet analysis) for V+jets (LO H_T-binned)
  - data/MC efficiency scale factors for trigger, lepton ID, b-tagging and pile-up from official POG recommendations (when available)

- *Electrons (Muons)*
  - PF based isolation with R=0.3 (0.4) and effective area ($\Delta\beta$) correction
  - Cut based ID “Tight” WP for selection, p_T>30 GeV
  - “Veto” (“Loose”) WP for rejecting events with extra leptons, p_T>10 GeV
- *Jets*
  - *Central:* AK4 CHS jets passing “Loose” PFJet ID with p_T>30 GeV, $|\eta|$<2.4
  - *Forward:* AK4 CHS jets passing “Loose” PFJet ID with p_T>30 GeV, 2.4 < $|\eta|$< 4
  - b-tagging with CSVv2M WP (0.8484)
- *Missing energy*
  - Type-1 corrected PFMET
  - Use collection with ghost muon fix
  - Moriond 2017 recommended MET filters applied

2016 triggers

- HLT_Mu17_TrkIsoVVL_Mu8_TrkIsoVVL
- HLT_Mu17_TrkIsoVVL_TkMu8_TrkIsoVVL

DoubleMu

- HLT_IsoTkMu24
- HLT_IsoMu24

SingleMu

- HLT_Mu8_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL
- HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL

MuonEG

- HLT_Ele23_Ele12_CaloIdL_TrackIdL_IsoVL_DZ

DoubleEG

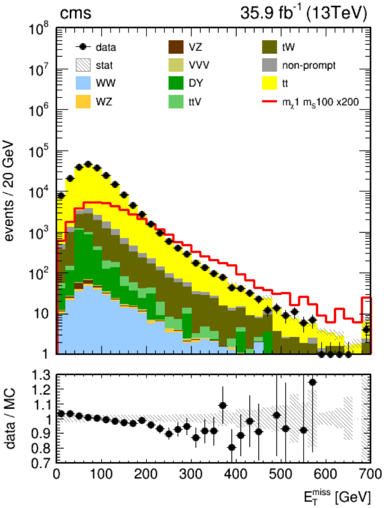
- HLT_Ele27_WPTight_Gsf
- HLT_Ele25_eta2p1_WPTight_Gsf

SingleEle

2016 MC samples

Process	Samples	Cross-section (pb)
Drell-Yan	DYJetsToLL_M-10to50	18610
	DYJetsToLL_M-50_ext2	6025
Top	TTTo2L2Nu	87.3
	ST_s-channel	3.36
	ST_t-channel_antitop, ST_t-channel_top	26.38, 44.33
	ST_tW_antitop, ST_tW_top	35.60, 35.60
WW	WWTo2L2Nu	12.18
VgS	Wg_MADGRAPHMLM	405
	WZTo3LNu_mllmin01	58.59
VZ	ZZTo2L2Nu	0.56
	ZZTo2L2Q	3.22
	ZZTo4L	1.21
	WZTo2L2Q	5.59
Non-prompt	Data-driven (tight-to-loose method)	//

2016 MET Data/MC



2017 triggers

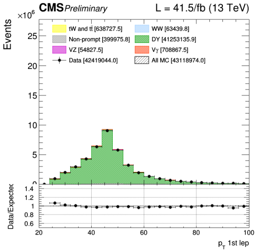
• HLT_Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ	DoubleMu
• HLT_IsoMu27	SingleMu
• HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL_DZ • HLT_Mu12_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ	MuonEG
• HLT_Ele23_Ele12_CaloIdL_TrackIdL_IsoVL	DoubleEG
• HLT_Ele35_WPTight_Gsf	SingleEle

2017 MC samples

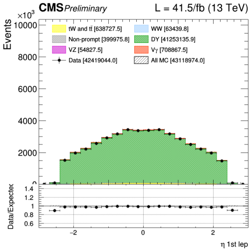
Process	Samples	Cross-section (pb)
Drell-Yan	DYJetsToLL_M-10to50-LO	18610
	DYJetsToLL_M-50	6189
Top	TTTo2L2Nu	87.3
	ST_s-channel	3.36
	ST_t-channel_antitop, ST_t-channel_top	26.38, 44.33
	ST_tW_antitop, ST_tW_top	35.60, 35.60
WW	WWTo2L2Nu	12.18
VgS	Wg_MADGRAPHMLM	405
	ZGToLLG	131
VZ	ZZTo2L2Nu	0.56
	ZZTo2L2Q	3.22
	ZZTo4L	1.21
	WZTo2L2Q	5.59
VVV	ZZZ	0.01
	WZZ	0.06
	WWZ	0.16
	WWW	0.18
Non-prompt	Data-driven (tight-to-loose method)	//

Inclusive region (2017, // channel)

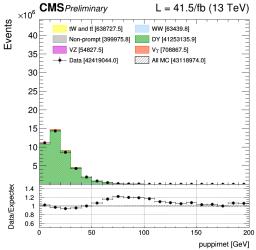
Leading p_T



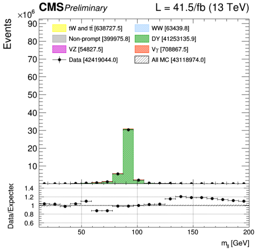
Leading η



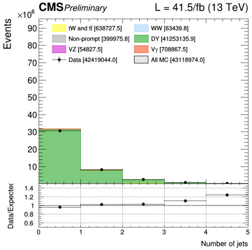
Puppi MET



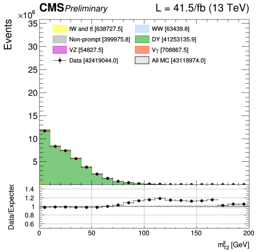
m_{ll}



nJet

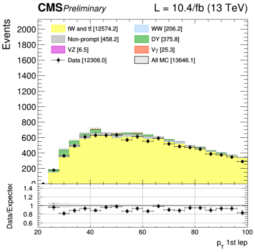


m_{T2}^{ll}

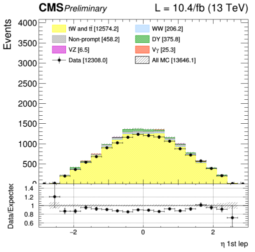


Top region (2017, $e\mu + \mu e$ channels, blinded)

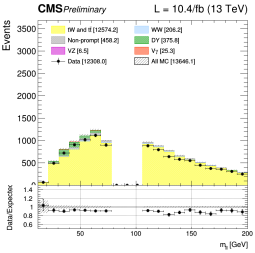
Leading p_T



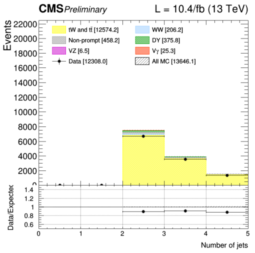
Leading η



m_{ll}



nJet



2018 triggers

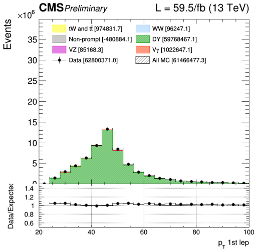
- HLT_Mu17_TrkIsoVVL_Mu8_TrkIsoVVL_DZ_Mass3p8 } DoubleMu
- HLT_IsoMu24 } SingleMu
- HLT_Mu23_TrkIsoVVL_Ele12_CaloIdL_TrackIdL_IsoVL
- HLT_Mu12_TrkIsoVVL_Ele23_CaloIdL_TrackIdL_IsoVL_DZ } MuonEG
- HLT_Ele23_Ele12_CaloIdL_TrackIdL_IsoVL } DoubleEG
- HLT_Ele32_WPTight_Gsf } SingleEle

2018 MC samples

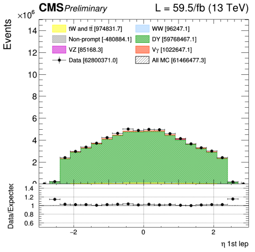
Process	Samples	Cross-section (pb)
Drell-Yan	DYJetsToLL_M-10to50-LO	18610
	DYJetsToLL_M-50_ext	6189
Top	TTTo2L2Nu	87.3
	ST_s-channel	3.36
	ST_t-channel_antitop, ST_t-channel_top	26.38, 44.33
	ST_tW_antitop_ext1, ST_tW_top_ext1	35.60, 35.60
WW	WWTo2L2Nu	12.18
VgS	Wg_MADGRAPHMLM	405
	Zg	131
	WZTo3LNu_mllmin01	58.59
VZ	ZZTo2L2Nu_ext1	0.56
	ZZTo2L2Q	3.22
	ZZTo4L_ext1	1.21
	WZTo2L2Q	5.59
Non-prompt	Data-driven (tight-to-loose method)	//

Inclusive region (2018, // channel)

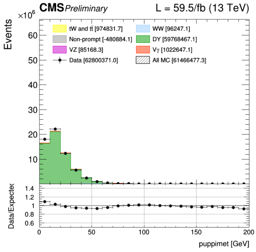
Leading p_T



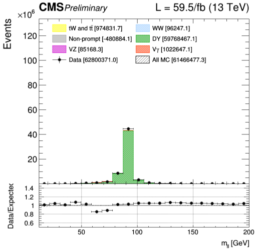
Leading η



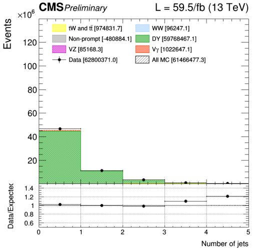
Puppi MET



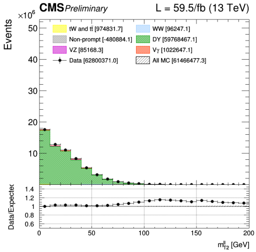
m_{ll}



nJet

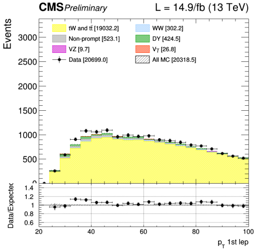


m_{T2}^{ll}

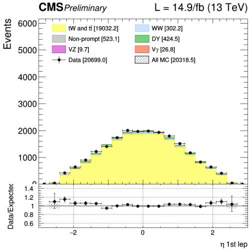


Top region (2018, $e\mu + \mu e$ channels, blinded)

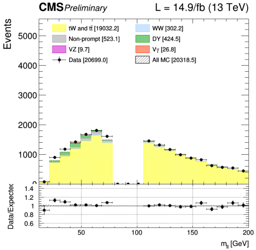
Leading p_T



Leading η



m_{ll}



nJet