EXO-12-041 Preapproval

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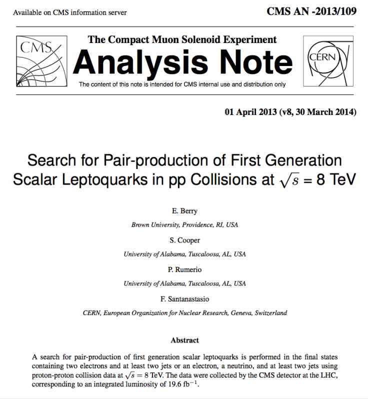
Analysis documentation

- CADI: EXO-12-041
- Preapproval Q/A twiki: LQ1-EXO-12-041-QuestionsBeforePreapproval
- Target: combined paper with second generation
  - EXO-12-042: approved
  - Using same ntuples and similar methods

EXO-12-041


Available on CMS information server CMS AN -2013/109

The Compact Muon Solenoid Experiment
Analysis Note
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Search for Pair-production of First Generation Scalar Leptoquarks in pp Collisions at $\sqrt{s}$ = 8 TeV

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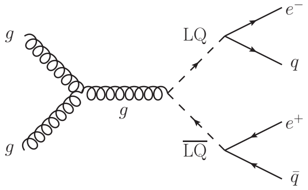
Abstract

A search for pair-production of first generation scalar leptoquarks is performed in the final states containing two electrons and at least two jets or an electron, a neutrino, and at least two jets using proton-proton collision data at $\sqrt{s} = 8$ TeV. The data were collected by the CMS detector at the LHC, corresponding to an integrated luminosity of 19.6 fb^{-1}.

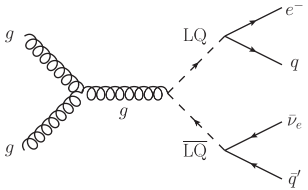
Theory

- Search for a scalar boson carrying both baryon and lepton number and fractional charge
- Leptoquark searches are traditionally grouped into generations
- This search is for pair-production of first generation leptoquarks
- $\beta = \mathrm{BR}(\mathrm{LQ} \to e^{\pm}q)$ is treated as a free parameter, leading to two separate analyses:
  - $\beta = 1.0$: *eejj* final state
  - $\beta = 0.5$: *eνjj* final state

eejj final state



eνjj final state



Analysis strategy

- Define SM-dominated preselection for each analysis
- Optimize final selection using $S/\sqrt{S+B}$
    - Optimize a different selection for each LQ mass
- For *eejj* ($\beta = 1.0$) analysis, optimize cuts on:
    - $S_\mathrm{T} = p_\mathrm{T}(e_1) + p_\mathrm{T}(e_2) + p_\mathrm{T}(j_1) + p_\mathrm{T}(j_2)$
    - $m_\mathrm{ej}^\mathrm{min}$
    - m_ee
- For *eνjj* ($\beta = 0.5$) analysis, optimize cuts on:
    - $S_\mathrm{T} = p_\mathrm{T}(e) + \not{E}_\mathrm{T} + p_\mathrm{T}(j_1) + p_\mathrm{T}(j_2)$
    - m_ej
    - $m_{\mathrm{T},\ \mathrm{e}\nu}$
    - $\not{E}_\mathrm{T}$
- Set limit in plane of M_{LQ} vs. β

Datasets: all 8 TeV data

Run era	Run range	$\mathcal{L}_{int}(\mathrm{pb}^{-1})$
/Run2012A-recover-06Aug2012-v1/	190782 - 190949	82
/Run2012A-13Jul2012-v1/	190645 - 193621	808
/Run2012B-13Jul2012-v1/	193834 - 196531	4430
/Run2012C-24Aug2012-v1/	198049 - 198522	495
/Run2012C-EcalRecover_11Dec2012-v1/	201191	134
/Run2012C-PromptReco-v2/	198941 - 203002	6390
/Run2012D-PromptReco-v1/	203894 - 208686	7270
Total integrated luminosity ($\mathcal{L}_{int}$)		19.6 fb^{-1}

Primary datasets include:

- /ElectronHad/ for LQ search
- /SingleMu/ for $t\bar{t}$ bkgd in *eejj* analysis only
- /Photon/ + /SinglePhoton/ for QCD bkgd

Datasets: background Monte Carlo

Dataset name	cross section [pb]
/DY1JetsToLL_M-50_TuneZ2Star_8TeV-madgraph/	666.30
/DY2JetsToLL_M-50_TuneZ2Star_8TeV-madgraph/	214.97
/DY3JetsToLL_M-50_TuneZ2Star_8TeV-madgraph/	60.69
/DY4JetsToLL_M-50_TuneZ2Star_8TeV-madgraph/	27.36
/W1JetsToLNu_TuneZ2Star_8TeV-madgraph/	6663.
/W2JetsToLNu_TuneZ2Star_8TeV-madgraph/	2159.
/W3JetsToLNu_TuneZ2Star_8TeV-madgraph/	640.
/W4JetsToLNu_TuneZ2Star_8TeV-madgraph/	264.
/TTJets_FullLeptMGDecays_8TeV-madgraph/	26.18
/TTJets_SemiLeptMGDecays_8TeV-madgraph/	103.71
/TTJets_HadronicMGDecays_8TeV-madgraph/	104.10
/WW_TuneZ2star_8TeV_pythia6_tauola/	57.1
/WZ_TuneZ2star_8TeV_pythia6_tauola/	32.3
/ZZ_TuneZ2star_8TeV_pythia6_tauola/	8.26
/Tbar_tW-channel-DR_TuneZ2star_8TeV-powheg-tauola/	11.1
/Tbar_t-channel_TuneZ2star_8TeV-powheg-tauola/	30.7
/Tbar_s-channel_TuneZ2star_8TeV-powheg-tauola/	1.76
/T_tW-channel-DR_TuneZ2star_8TeV-powheg-tauola/	11.1
/T_t-channel_TuneZ2star_8TeV-powheg-tauola/	56.4
/T_s-channel_TuneZ2star_8TeV-powheg-tauola/	3.79
/G_Pt-XtoY_TuneZ2star_8TeV_pythia6/	Various

- From `Summer12` MC production campaign
- Reweighted to model `PU_S10`
- Various generators (see dataset name), `CTEQ6L1` PDFs

Datasets: signal Monte Carlo

M_{LQ} (GeV)	$\sigma(\mu = M_{\mathrm{LQ}})$ [pb]	$\delta(PDF)$ [pb]	$\sigma(\mu = M_{\mathrm{LQ}}/2)$ [pb]	$\sigma(\mu = M_{\mathrm{LQ}} \times 2)$ [pb]
300	1.89	0.214	1.63	2.13
350	0.77	0.102	0.663	0.866
400	0.342	0.052	0.295	0.385
450	0.163	0.0278	0.14	0.183
500	0.082	0.0155	0.0704	0.0922
550	0.0431	0.00893	0.037	0.0485
600	0.0235	0.0053	0.0201	0.0265
650	0.0132	0.00322	0.0113	0.0149
700	0.00761	0.002	0.00648	0.00858
750	0.00448	0.00126	0.00381	0.00506
800	0.00269	0.00081	0.00228	0.00304
850	0.00164	0.000527	0.00139	0.00186
900	0.00101	0.000347	0.000856	0.00115
950	0.000634	0.000231	0.000534	0.000722
1000	0.000401	0.000155	0.000337	0.000458
1050	0.000256	0.000105	0.000214	0.000293
1100	0.000165	7.18e-05	0.000138	0.000189
1150	0.000107	4.92e-05	8.88e-05	0.000123
1200	6.96e-05	3.4e-05	5.77e-05	8.04e-05

- From `Summer12` MC production campaign
- Reweighted to model `PU_S10`
- Generated with `Pythia`, `CTEQ6L1` PDFs, rescaled to NLO

Object selection

- Electrons:
  - HEEP v4.1 ID
- Muons:
  - Tight ID
- Jets:
  - Particle flow jets
  - Anti-k_T, $R = 0.5$
  - Particle flow loose ID

- $\not{E}_{\mathrm{T}}$:
  - Particle flow $\not{E}_{\mathrm{T}}$
  - Recommended filters
  - Corrections:
    - Type-0 correction
    - Type-1 correction
    - xy-shift correction

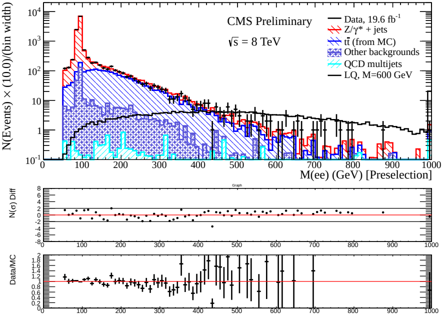
eejj preselection definition

- Exactly two electrons: $p_T > 45$ GeV and $|\eta| < 2.5$
- At least two jets
- $p_T(j_1) > 125$ GeV and $|\eta| < 2.4$
- $p_T(j_2) > 45$ GeV and $|\eta| < 2.4$
- $m_{ee} > 50$ GeV
- $S_T = p_T(e_1) + p_T(e_2) + p_T(j_1) + p_T(j_2) > 300$ GeV
- Muon veto
- Trigger (efficiency, below, applied as scale factor to signal): $97.4 \pm 0.56\%$ ($95.8 \pm 1.35\%$) efficient on HEEP electrons in barrel (endcap)

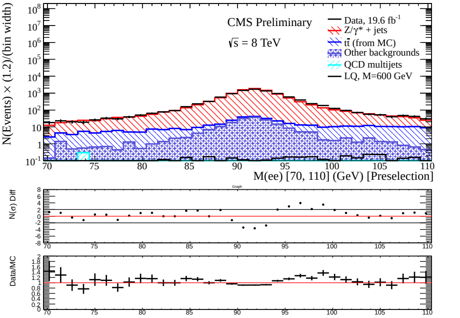
HLT path	Run range
HLT_Ele30_CaloIdVT_TrkIdT_PFJet100_PFJet25_v3	190456 - 190738
HLT_Ele30_CaloIdVT_TrkIdT_PFJet100_PFJet25_v4	190782 - 191419
HLT_Ele30_CaloIdVT_TrkIdT_PFNoPUJet100_PFNoPUJet25_v4	191691 - 194225
HLT_Ele30_CaloIdVT_TrkIdT_PFNoPUJet100_PFNoPUJet25_v5	194270 - 196531
HLT_Ele30_CaloIdVT_TrkIdT_PFNoPUJet100_PFNoPUJet25_v6	198022 - 199608
HLT_Ele30_CaloIdVT_TrkIdT_PFNoPUJet100_PFNoPUJet25_v7	199698 - 202504
HLT_Ele30_CaloIdVT_TrkIdT_PFNoPUJet100_PFNoPUJet25_v8	202970 - 208686

eejj preselection: m_{ee}

Electron pair inv. mass

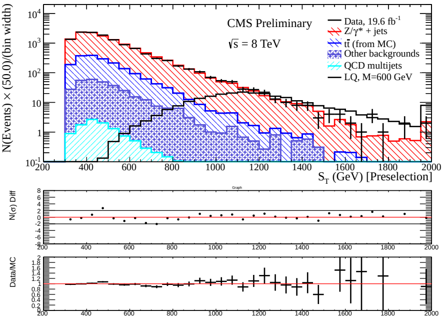


Electron pair inv. mass (zoomed)

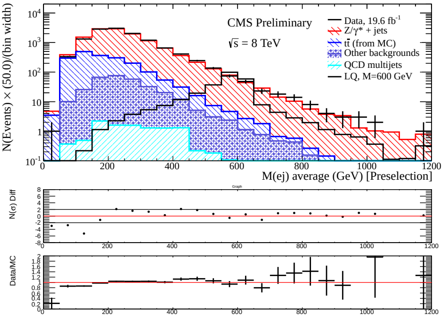


eejj preselection: S_T and m_{ej}

S_T



m_{ej}



eejj backgrounds

Backgrounds include:

- Z^0+jets : shape from MC, normalization from data (dominant background)
- $t\bar{t}$: shape and normalization from data
- QCD multijets: shape and normalization from data
- Other backgrounds: shape and normalization from MC

QCD background: overview

- Similar to method used by `EXO-12-061` ($Z' \to ee$)
- Events are selected within the `Photon` primary dataset
  - Prescaled single photon triggers select events online
  - *eejj* sample: two loose electrons, two jets
  - *eνjj* sample: one loose electron, large $\not\!\!E_T$, two jets
- Selected events are weighted to estimate QCD bkgd:

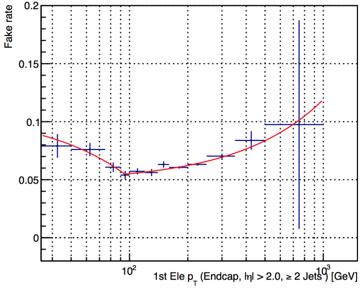
$$N^{QCD}_{eejj} = \sum_{\substack{\text{loose} \\ eejj\text{ events}}} P(e_{1,\text{ tight}} | e_{1,\text{ loose}} : p_T, \eta) \cdot P(e_{2,\text{ tight}} | e_{2,\text{ loose}} : p_T, \eta)$$

$$N^{QCD}_{enujj} = \sum_{\substack{\text{loose} \\ e\nu jj\text{ events}}} P(e_{1,\text{ tight}} | e_{1,\text{ loose}} : p_T, \eta)$$

QCD background: fake rate calculation

- Define fake rate calculation sample:
  - Single photon trigger (see backup)
  - Exactly one loose electron
  - $N(\text{jets})$ with $p_T > 40$ GeV, where $N(\text{jets}) = \{0, 1, 2, 3\}$
- Fake rate = fraction of events with HEEP electron
  - Non-QCD events subtracted using MC
- Fake rate depends on: $p_T(e)$, $\eta(e)$, and $N(\text{jets})$
  - Bin results in $p_T(e)$ and fit (see plot at right)
  - Repeat study for $N(\text{jets}) = \{0, 1, 2, 3\}$
  - Repeat study for barrel electrons, inner endcap electrons ($|\eta| < 2.0$), and outer endcap electrons ($|\eta| > 2.0$)
- Closure test suggests uncertainty of 60% (30%) in the *eejj* (*eνjj*) analysis
- Contribution from QCD is 1% (3%) of total background in the *eejj* (*eνjj*) analysis

Fake rate for loose electrons in events with $N(\text{jets}) \geq 2$ and $|\eta(e)| > 2.0$



$t\bar{t}$ background in *eejj* analysis: overview

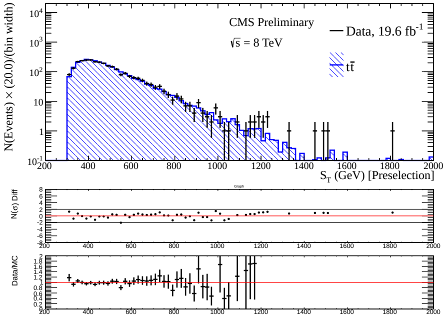
- $t\bar{t}$ background estimated using $e\mu jj$ events in data
- Selected using single muon trigger (see backup)
- Events are scaled:

$$N^{\text{data}}_{eejj} = \mathcal{C} \times N^{\text{data}}_{e\mu jj} = \frac{1}{2} \times \frac{\epsilon^{\text{trigger}}_{ee}}{\epsilon^{\text{trigger}}_{e\mu}} \times \frac{\epsilon^{\text{reco/ID/Iso}}_{e}}{\epsilon^{\text{reco/ID/Iso}}_{\mu}} \times N^{\text{data}}_{e\mu jj}$$

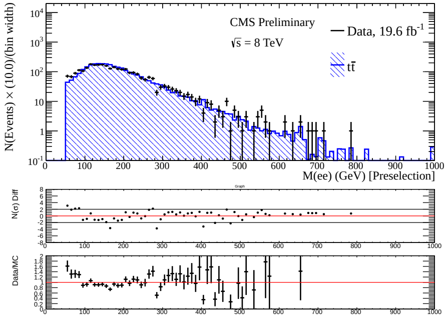
- $\epsilon^{\text{trigger}}_{ee} > 99.8\%$, taken as 1.0
- $\epsilon^{\text{trigger}}_{e\mu}$ varies with $|\eta(\mu)|$:
  - 0.94 for $0.0 < |\eta(\mu)| \leq 0.9$
  - 0.84 for $0.9 < |\eta(\mu)| \leq 1.2$
  - 0.82 for $1.2 < |\eta(\mu)| \leq 2.1$
- $\frac{\epsilon^{\text{reco/ID/Iso}}_{e}}{\epsilon^{\text{reco/ID/Iso}}_{\mu}} = 0.974 \pm 0.011$ (stat), taken from MC

$t\bar{t}$ background in *eejj* analysis: compare with MC

S_{T}



m_{ee}

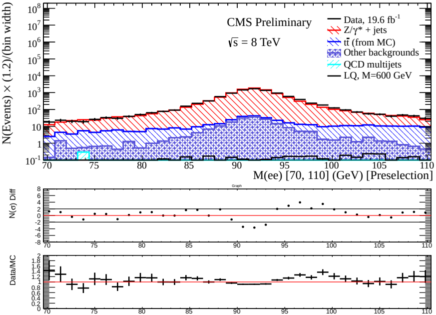


- $e\mu jj$ data events predict 1579.6 ± 29.3 $t\bar{t}$ events at preselection
- *eejj* MC events predicts 1582.2 ± 13.8 $t\bar{t}$ events at preselection

Z^0+jets background in *eejj* analysis

Z^0+jets control region

- Z^0+jets MC rescaled to fit data
- Select events passing *eejj* preselection and $70 < m_{ee} < 110$
- Hold all backgrounds fixed, except Z^0+jets
- Rescale Z^0+jets MC so that N(data) and N(MC) agree:



$$\mathcal{R}_{Z^0} = \frac{N_{\text{data}} - (N_{\text{Others}} + N_{\text{QCD}})}{N_{Z^0}} = 0.97 \pm 0.01\ (\text{stat}) \pm 0.00004\ (\text{syst})$$

eejj final selection optimization table

- Optimize S_T , m_{ej}^{min} , m_{ee} after *eejj* preselection
  - *e*-*j* pairs are chosen to minimize the difference between the mass of each pair
  - m_{ej}^{min} is the smallest of the two mass pairs
- Optimization figure of merit is $S/\sqrt{S+B}$
- Results:

	LQ mass (*eejj*)														
	300	350	400	450	500	550	600	650	700	750	800	850	900	950	$\geq$ 1000
S_T [GeV]	435	485	535	595	650	715	780	850	920	1000	1075	1160	1245	1330	1425
m_{ee} [GeV]	110	110	115	125	130	140	145	155	160	170	175	180	190	195	205
m_{ej}^{min} [GeV]	50	105	160	205	250	290	325	360	390	415	435	450	465	470	475

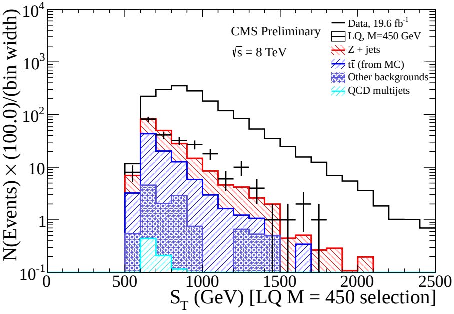
eejj final selection table

M_{LQ}	LQ Signal	Z^0+jets	$t\bar{t}$ (from data)	QCD (from data)	Other	Data	Total background
Presel	-	10538.4 ± 35.8	1566.6 ± 29.2	10.87 ± 0.10	303.8 ± 7.4	12442	12419.6 ± 46.8
300	13560.2 ± 80.1	462.2 ± 7.4	724.3 ± 19.8	5.282 ± 0.052	62.1 ± 4.6	1244	$1253.94 \pm 21.67 \pm 42.92$ (syst)
350	6473.9 ± 33.3	332.1 ± 6.2	352.0 ± 13.8	3.215 ± 0.036	37.7 ± 3.6	736	$725.10 \pm 15.57 \pm 26.41$ (syst)
400	3089.3 ± 15.0	203.2 ± 4.8	153.7 ± 9.1	1.696 ± 0.023	23.8 ± 2.9	389	$382.40 \pm 10.72 \pm 16.28$ (syst)
450	1508.1 ± 7.2	112.9 ± 3.5	86.9 ± 6.9	0.890 ± 0.016	11.8 ± 2.0	233	$212.44 \pm 7.99 \pm 9.96$ (syst)
500	767.4 ± 3.6	66.5 ± 2.7	47.2 ± 5.1	0.485 ± 0.011	7.4 ± 1.6	148	$121.61 \pm 5.96 \pm 5.89$ (syst)
550	410.5 ± 1.9	37.4 ± 2.1	25.8 ± 3.7	0.2758 ± 0.0084	3.7 ± 1.1	81	$67.24 \pm 4.40 \pm 3.31$ (syst)
600	225.7 ± 1.0	22.2 ± 1.6	14.2 ± 2.8	0.1527 ± 0.0065	3.12 ± 1.00	57	$39.66 \pm 3.35 \pm 2.00$ (syst)
650	125.85 ± 0.58	14.0 ± 1.2	5.4 ± 1.7	0.0760 ± 0.0040	1.05 ± 0.47	36	$20.49 \pm 2.14 \pm 1.01$ (syst)
700	72.88 ± 0.33	8.16 ± 0.93	4.3 ± 1.5	0.0448 ± 0.0029	0.21 ± 0.12	17	$12.74 \pm 1.80 \pm 0.71$ (syst)
750	43.10 ± 0.20	4.88 ± 0.69	1.55 ± 0.90	0.0258 ± 0.0023	0.078 ± 0.038	12	$6.53 \pm 1.13 \pm 0.45$ (syst)
800	26.17 ± 0.12	2.93 ± 0.52	1.04 ± 0.73	0.0193 ± 0.0022	0.078 ± 0.038	7	$4.06 \pm 0.90 \pm 0.24$ (syst)
850	15.978 ± 0.072	2.34 ± 0.48	0.52 ± 0.52	0.0111 ± 0.0015	0.042 ± 0.028	5	$2.91 \pm 0.71 \pm 0.17$ (syst)
900	9.813 ± 0.044	1.23 ± 0.36	0.52 ± 0.52	0.0069 ± 0.0012	0.022 ± 0.020	3	$1.77 \pm 0.63 \pm 0.11$ (syst)
950	6.086 ± 0.028	0.89 ± 0.29	$0.00000^{+1.14000}_{-0.00}$	0.00451 ± 0.00085	0.022 ± 0.020	1	$0.912^{+1.178}_{-0.295} \pm 0.05$ (syst)
1000	3.860 ± 0.018	0.56 ± 0.22	$0.00000^{+1.14000}_{-0.00}$	0.00374 ± 0.00082	0.0025 ± 0.0025	1	$0.567^{+1.162}_{-0.223} \pm 0.05$ (syst)
1050	2.576 ± 0.011	0.56 ± 0.22	$0.00000^{+1.14000}_{-0.00}$	0.00374 ± 0.00082	0.0025 ± 0.0025	1	$0.567^{+1.162}_{-0.223} \pm 0.05$ (syst)
1100	1.6936 ± 0.0072	0.56 ± 0.22	$0.00000^{+1.14000}_{-0.00}$	0.00374 ± 0.00082	0.0025 ± 0.0025	1	$0.567^{+1.162}_{-0.223} \pm 0.05$ (syst)
1150	1.1272 ± 0.0047	0.56 ± 0.22	$0.00000^{+1.14000}_{-0.00}$	0.00374 ± 0.00082	0.0025 ± 0.0025	1	$0.567^{+1.162}_{-0.223} \pm 0.05$ (syst)
1200	0.7498 ± 0.0030	0.56 ± 0.22	$0.00000^{+1.14000}_{-0.00}$	0.00374 ± 0.00082	0.0025 ± 0.0025	1	$0.567^{+1.162}_{-0.223} \pm 0.05$ (syst)

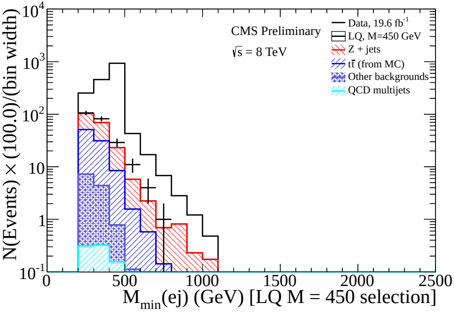
- Broad excess of data w.r.t. total background
- Most significant for $M_{\mathrm{LQ}} = 650$ GeV selection

eejj final selection (450): S_T and m_{ej}^{min}

S_T

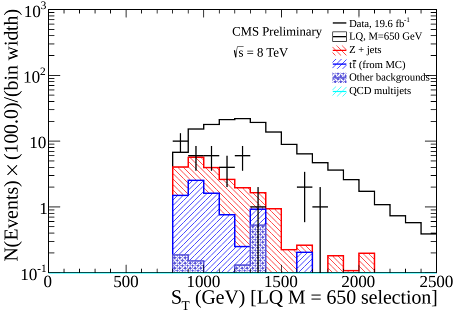


m_{ej}^{min}

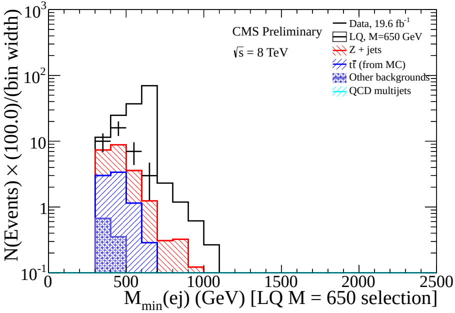


eejj final selection (650): S_T and m_{ej}^{min}

S_T



m_{ej}^{min}

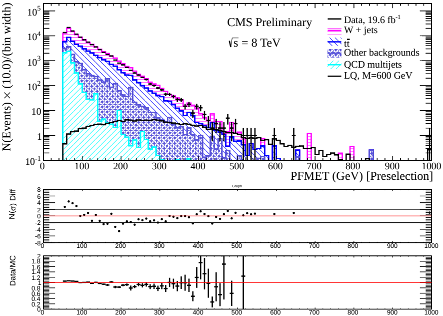


$e\nu jj$ preselection definition

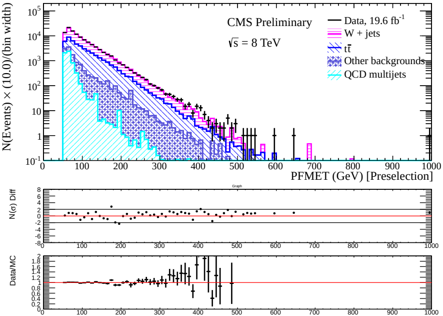
- Exactly one electron: $p_T > 45$ GeV and $|\eta| < 2.2$
- $\not{E}_T > 55$ GeV
- At least two jets
- $p_T(j_1) > 125$ GeV and $|\eta| < 2.4$
- $p_T(j_2) > 45$ GeV and $|\eta| < 2.4$
- $|\Delta\phi(e, \not{E}_T)| > 0.5$
- $|\Delta\phi(j_1, \not{E}_T)| > 0.5$
- $m_{T,\,e\nu} > 50$ GeV
- $S_T = p_T(e_1) + \not{E}_T + p_T(j_1) + p_T(j_2) > 300$ GeV
- Muon veto
- Same trigger as *eejj* analysis

$e\nu jj$ preselection: $\not\!\!E_T$

$\not\!\!E_T$
(as used in analysis)



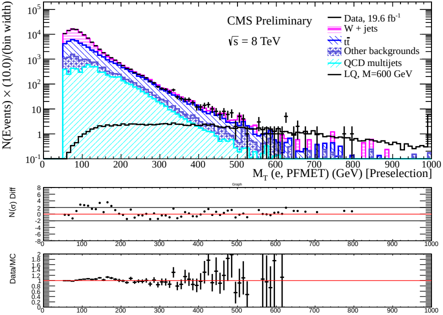
$\not\!\!E_T$
(reweighted)



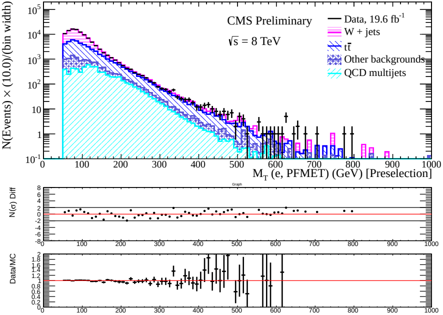
Reweighting investigated but not used in main analysis (backup)

$e\nu jj$ preselection: $m_{\mathrm{T},\, e\nu}$

Electron-$\not{E}_\mathrm{T}$ transverse mass (as used in analysis)



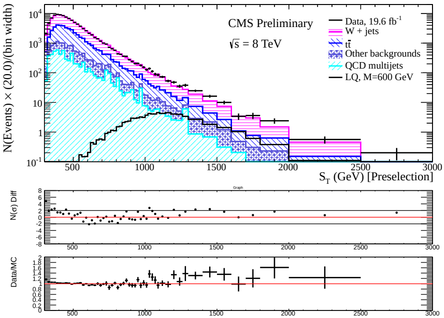
Electron-$\not{E}_\mathrm{T}$ transverse mass (reweighted)



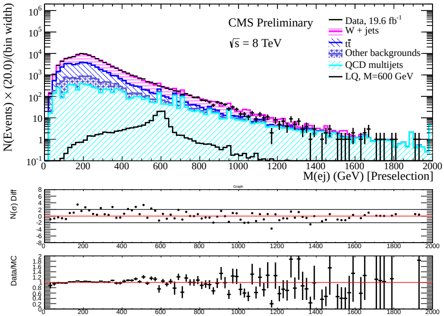
Reweighting investigated but not used in main analysis (backup)

eνjj preselection: S_T and m_{ej}

S_T



m_{ej}



$e\nu jj$ backgrounds

Backgrounds include:

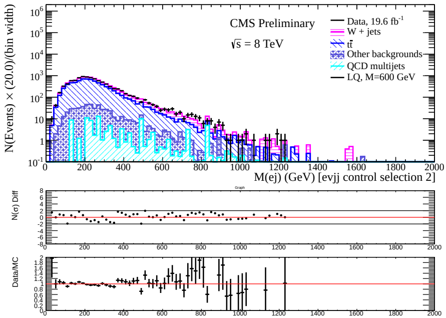
- $t\bar{t}$: shape from MC, normalization from data (dominant background)
- $W^{\pm}$+jets : shape from MC, normalization from data
- QCD multijets: shape and normalization from data (same as *eejj*)
- Other backgrounds: shape and normalization from MC

W$^{\pm}$+jets and $t\bar{t}$ backgrounds in *eνjj* analysis

- MC is rescaled to fit data
- Two selections:
  - Sel. 1: W$^{\pm}$+jets dominates
    - *eνjj* preselection
    - $50 < m_{\mathrm{T},\,e\nu} < 110$ GeV
    - N(jets) < 4
  - Sel. 2: $t\bar{t}$ dominates
    - *eνjj* preselection
    - $50 < m_{\mathrm{T},\,e\nu} < 110$ GeV
    - N(jets) ≥ 4
- Solve system of equations:

$$N^1_{\text{data}} = \mathcal{R}_{t\bar{t}} N^1_{t\bar{t}} + \mathcal{R}_W N^1_W + N^1_{\text{QCD}} + N^1_{\text{Others}}$$
$$N^2_{\text{data}} = \mathcal{R}_{t\bar{t}} N^2_{t\bar{t}} + \mathcal{R}_W N^2_W + N^2_{\text{QCD}} + N^2_{\text{Others}}$$

m_{ej} in selection 2



$$\mathcal{R}_{t\bar{t}} = 0.97 \pm 0.02\ (\text{stat}) \pm 0.01\ (\text{syst})$$
$$\mathcal{R}_{\text{W}} = 0.85 \pm 0.01\ (\text{stat}) \pm 0.01\ (\text{syst})$$

$e\nu jj$ final selection optimization table

- Optimize S_{T} , m_{ej} , $m_{\mathrm{T,\,e}\nu}$, and $\not\!\!E_{\mathrm{T}}$ after *eejj* preselection
  - *e*-*j* and $\not\!\!E_{\mathrm{T}}$-*j* pairs are chosen to minimize the difference between the transverse mass of each pair
  - m_{ej} is the mass of the *e*-*j* pair
  - $\not\!\!E_{\mathrm{T}}$ is optimized to reduce QCD background
- Optimization figure of merit is $S/\sqrt{S+B}$
- Results:

	LQ Mass (evjj)													
	300	350	400	450	500	550	600	650	700	750	800	850	900	$\geq$ 950
S_{T} [GeV]	495	570	645	720	800	880	960	1040	1120	1205	1290	1375	1460	1545
$\not\!\!E_{\mathrm{T}}$ [GeV]	90	95	100	110	115	125	135	145	155	170	180	195	210	220
m_{ej} [GeV]	195	250	300	355	405	455	505	555	600	645	695	740	780	825
$m_{\mathrm{T,\,e}\nu}$ [GeV]	125	150	175	200	220	240	255	270	280	290	295	300	300	300

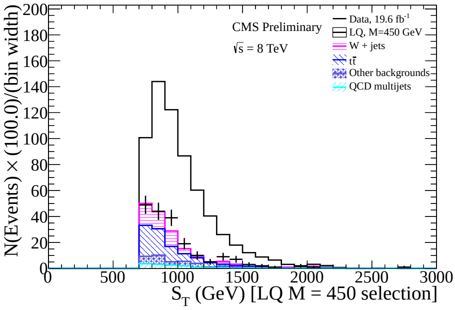
$e\nu jj$ final selection table

M_{LQ}	LQ Signal	$W^{\pm}$+jets	$t\bar{t}$	QCD	Other	Data	Total background
Presel	-	58284.8 ± 197.0	32196.7 ± 69.8	5950.5 ± 20.1	6590.8 ± 231.6	105164	103022.8 ± 312.6
300	4765.5 ± 51.1	822.1 ± 22.4	1191.3 ± 12.0	117.9 ± 1.5	210.5 ± 7.7	2455	$2341.90 \pm 26.58 \pm 163.90$ (syst)
350	2168.4 ± 21.6	275.9 ± 14.5	441.4 ± 7.2	59.11 ± 0.97	102.1 ± 5.4	908	$878.55 \pm 17.08 \pm 58.66$ (syst)
400	971.1 ± 9.6	110.4 ± 7.8	184.2 ± 4.7	32.88 ± 0.69	51.5 ± 3.8	413	$378.98 \pm 9.91 \pm 24.79$ (syst)
450	469.7 ± 4.6	53.1 ± 5.8	74.7 ± 3.0	14.13 ± 0.42	25.7 ± 2.7	192	$167.64 \pm 7.06 \pm 11.01$ (syst)
500	232.7 ± 2.3	20.5 ± 3.3	34.4 ± 2.0	7.76 ± 0.30	15.3 ± 2.1	83	$77.99 \pm 4.41 \pm 4.83$ (syst)
550	121.4 ± 1.2	8.6 ± 1.8	14.9 ± 1.4	3.89 ± 0.21	7.8 ± 1.6	44	$35.24 \pm 2.76 \pm 2.18$ (syst)
600	66.37 ± 0.66	2.3 ± 1.0	7.08 ± 0.93	2.29 ± 0.17	4.6 ± 1.2	28	$16.27 \pm 1.84 \pm 0.96$ (syst)
650	37.22 ± 0.37	0.41 ± 0.29	3.82 ± 0.70	1.18 ± 0.12	2.13 ± 0.92	18	$7.54 \pm 1.20 \pm 0.52$ (syst)
700	21.74 ± 0.21	0.41 ± 0.29	2.61 ± 0.60	0.85 ± 0.10	0.58 ± 0.24	6	$4.45 \pm 0.71 \pm 0.34$ (syst)
750	12.90 ± 0.13	$0.00^{+0.94}_{-0.00}$	1.75 ± 0.47	0.514 ± 0.091	0.27 ± 0.15	4	$2.535^{+1.062}_{-0.504} \pm 0.20$ (syst)
800	7.610 ± 0.075	$0.00^{+0.94}_{-0.00}$	1.10 ± 0.37	0.317 ± 0.067	0.27 ± 0.15	3	$1.696^{+1.019}_{-0.404} \pm 0.13$ (syst)
850	4.713 ± 0.046	$0.00^{+0.94}_{-0.00}$	0.90 ± 0.34	0.117 ± 0.029	0.140 ± 0.087	2	$1.153^{+0.999}_{-0.353} \pm 0.08$ (syst)
900	2.929 ± 0.028	$0.00^{+0.94}_{-0.00}$	0.37 ± 0.21	0.076 ± 0.024	0.084 ± 0.069	1	$0.530^{+0.962}_{-0.226} \pm 0.04$ (syst)
950	1.839 ± 0.018	$0.00^{+0.94}_{-0.00}$	0.37 ± 0.21	0.069 ± 0.023	0.084 ± 0.069	1	$0.524^{+0.962}_{-0.226} \pm 0.04$ (syst)
1000	1.306 ± 0.012	$0.00^{+0.94}_{-0.00}$	0.37 ± 0.21	0.069 ± 0.023	0.084 ± 0.069	1	$0.524^{+0.962}_{-0.226} \pm 0.04$ (syst)
1050	0.9022 ± 0.0076	$0.00^{+0.94}_{-0.00}$	0.37 ± 0.21	0.069 ± 0.023	0.084 ± 0.069	1	$0.524^{+0.962}_{-0.226} \pm 0.04$ (syst)
1100	0.6225 ± 0.0050	$0.00^{+0.94}_{-0.00}$	0.37 ± 0.21	0.069 ± 0.023	0.084 ± 0.069	1	$0.524^{+0.962}_{-0.226} \pm 0.04$ (syst)
1150	0.4308 ± 0.0032	$0.00^{+0.94}_{-0.00}$	0.37 ± 0.21	0.069 ± 0.023	0.084 ± 0.069	1	$0.524^{+0.962}_{-0.226} \pm 0.04$ (syst)
1200	0.2971 ± 0.0022	$0.00^{+0.94}_{-0.00}$	0.37 ± 0.21	0.069 ± 0.023	0.084 ± 0.069	1	$0.524^{+0.962}_{-0.226} \pm 0.04$ (syst)

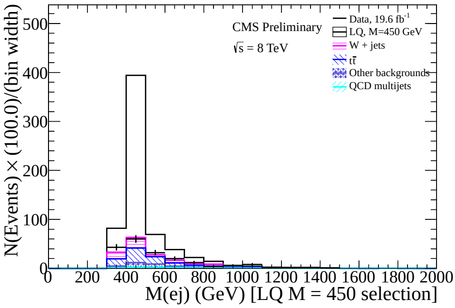
- Broad excess of data w.r.t. total background (as in *eejj*)
- Most significant for $M_{\mathrm{LQ}} = 650$ GeV selection (as in *eejj*)

$e\nu jj$ final selection (450): S_T and m_{ej}

S_T

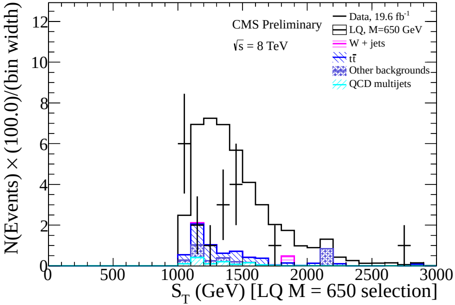


m_{ej}

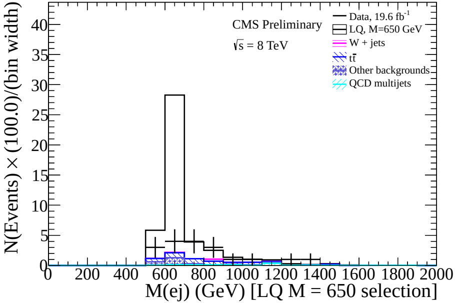


$e\nu jj$ final selection (650): S_T and m_{ej}

S_T



m_{ej}



Systematic uncertainties

- Background MC shape:
  - $W^{\pm}$+jets (5.9%) in *eνjj*
  - $t\bar{t}$ (8.2%) in *eνjj*
  - Z^0+jets (8.7%) in *eejj*
- Jet energy scale:
  taken from GlobalTag
- Jet energy resolution:
  eta-dependent, 5-30%
- Electron energy scale:
  0.4% barrel, 4.1% endcap
- Electron energy resolution:
  0.6% barrel, 1.5% endcap
- Background MC normalization:
  - $W^{\pm}$+jets (2%) in *eνjj*
  - $t\bar{t}$ (2%) in *eνjj*
  - Z^0+jets (1%) in *eejj*
- QCD normalization:
  60% (30%) in *eejj* (*eνjj*)
- $t\bar{t}$ normalization in *eejj* : 2%
- Electron reco/ID/Iso effi:
  4% (2%) in *eejj* (*eνjj*) signal
- Pileup
- Luminosity: 2.6%
- MC statistics: Dominates

Systematic uncertainties: *eejj* for $M_{LQ} = 650$ GeV

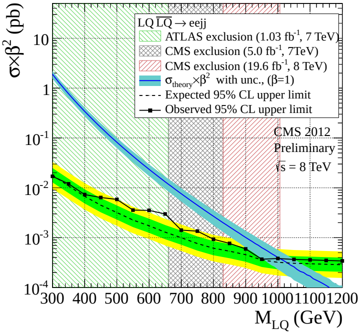
Systematic	Signal (%)	Background (%)
Electron efficiency	4.00%	0.00%
Electron energy scale	0.33%	1.45%
Electron energy resolution	0.02%	0.04%
Jet energy scale	0.30%	0.52%
Jet energy resolution	0.01%	0.23%
Pileup	0.04%	0.38%
Luminosity	2.60%	0.10%
Z normalization	0.00%	0.75%
Z shape	0.00%	5.94%
$t\bar{t}$ estimate	0.00%	0.52%
QCD multijet estimate	0.00%	0.11%
Total	4.79%	6.23%

Systematic uncertainties: $e\nu jj$ for $M_{LQ} = 650$ GeV

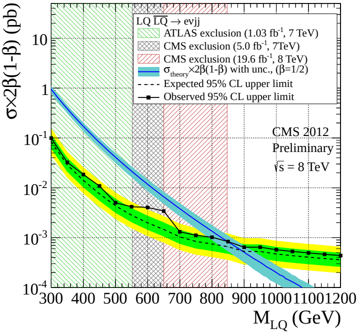
Systematic	Signal (%)	Background (%)
Electron efficiency	2.00%	0.00%
Electron energy scale	1.09%	1.38%
Electron energy resolution	0.08%	0.68%
Jet energy scale	1.56%	2.15%
Jet energy resolution	0.09%	0.46%
Pileup	0.14%	1.18%
Luminosity	2.60%	0.47%
W normalization	0.00%	0.12%
W shape	0.00%	0.44%
$t\bar{t}$ normalization	0.00%	1.50%
$t\bar{t}$ shape	0.00%	3.00%
QCD multijet estimate	0.00%	4.71%
Total	3.8%	6.5%

Results: standalone limits, including systematics

$\beta = 1.0$: *eejj* analysis



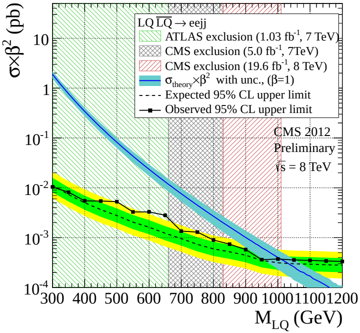
$\beta = 0.5$: *eνjj* analysis

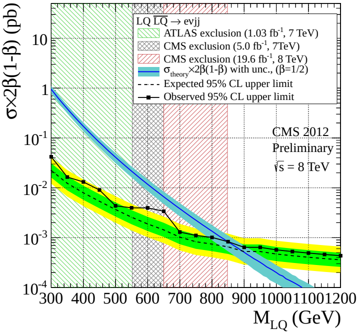


- Expected limits: $M_{LQ} < 1030$ (890) GeV for *eejj* (*eνjj*)
- Observed limits: $M_{LQ} < 1005$ (845) GeV for *eejj* (*eνjj*)

Results: standalone limits, without systematics

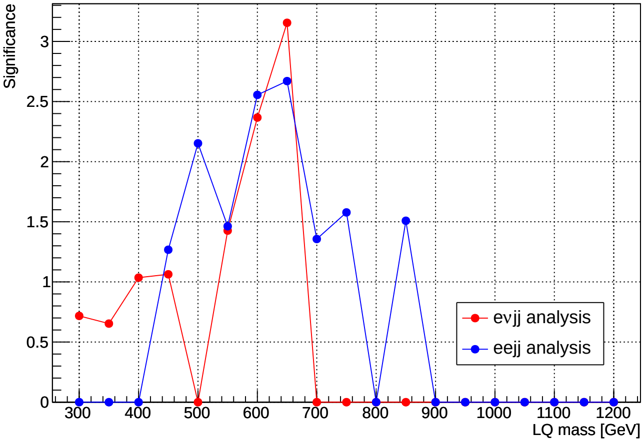
$\beta = 1.0$: *eejj* analysis, no syst. $\beta = 0.5$: *eνjj* analysis, no syst.





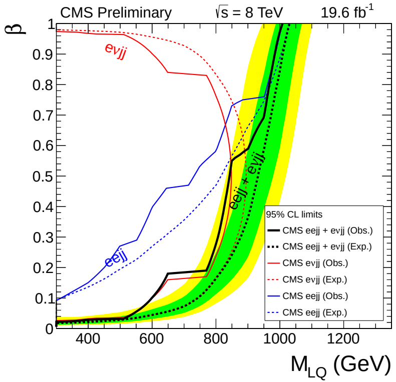
- Expected limits: $M_{LQ} < 1030$ (895) GeV for *eejj* (*eνjj*)
- Observed limits: $M_{LQ} < 1010$ (850) GeV for *eejj* (*eνjj*)

Results: significance (no look-elsewhere applied)



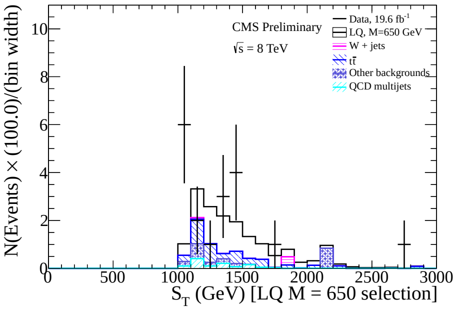
Results: combined limits, including systematics

- Made with asymptotic CLs
- Obs. limits unchanged
- $e\nu jj$ excess has strongest effect on combined limit discrepancy
- Limits at $\beta = 0.15$:
  - Exp.: $M_{LQ} < 790$ GeV
  - Obs.: $M_{LQ} < 635$ GeV

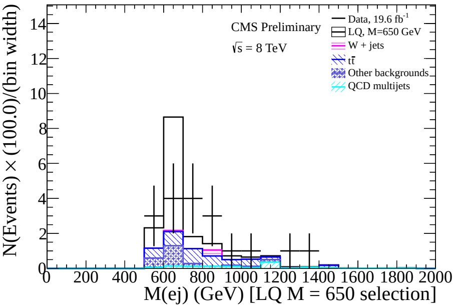


Results: $\beta = 0.15$, $M_{LQ} = 650$ (1/3)

S_T

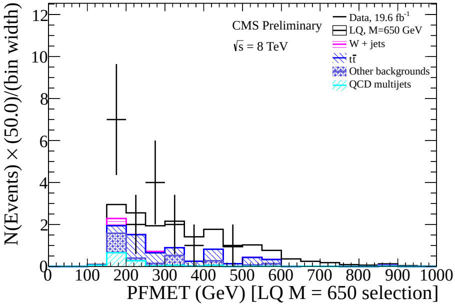


m_{ej}

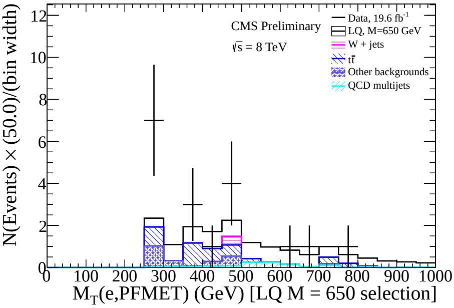


Results: $\beta = 0.15$, $M_{LQ} = 650$ (2/3)

$\not{E}_T$

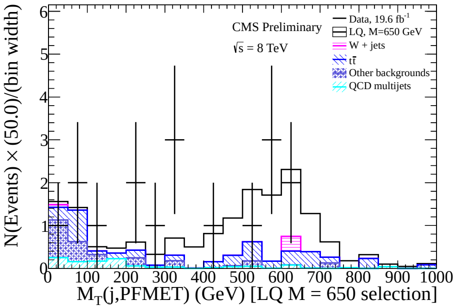


$m_{T,\,e\nu}$



Results: $\beta = 0.15$, $M_{LQ} = 650$ (3/3)

$m_{\mathrm{T,\ j}\nu}$



Overview of checks

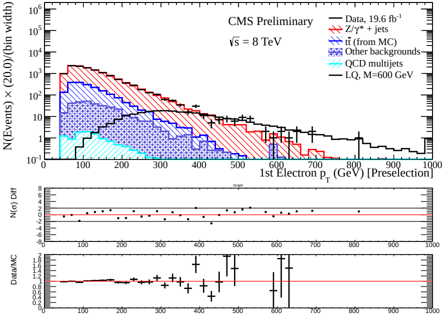
- **Problem with analysis code?** No
  W_R analysis (*eejj* final state) reproduced the excess (J. Pastika, B. Dahmes)
- **Problem with ECAL?** No
  ECAL DPG says these events are ok. Electrons are spread in η and ϕ. See backup.
- **Problem with unstable running conditions?** No
  Excesses are flat vs run period. See backup.
- **Problem with signal trigger?** No
  eejj excess persists with `HLT_DoubleEle33_CaloIdL_GsfTrkIdVL`.
- **Problem with single object mis-measurement (eejj analysis only)?** No
  Events in *eejj* excess do not have an excess of single objects (electrons, jets) aligned with $\not{E}_T$.
- **Problem modeling $\not{E}_T$ and $m_{T,\,e\nu}$ ($e\nu jj$ analysis only)?** ...
  Discrepancy between data and MC in $\not{E}_T$ and $m_{T,\,e\nu}$ distributions at $e\nu jj$ preselection, but reweighting $m_{T,\,e\nu}$ and $\not{E}_T$ at preselection increases the final selection discrepancy. See backup.
- **Problem with electrons from pileup?** No
  Electrons in excess have low d_Z w.r.t. primary vertex
- **Problem with data-driven $t\bar{t}$ background estimate?** No
  Results with $t\bar{t} \rightarrow eejj$ MC agree within statistics
- **Problem with your data-driven QCD background estimate?** No
  Excess is almost entirely OS electron pairs. Contribution from QCD is predicted to be « 1 event.
- **Problem with your various MC background estimates?** No
  Background for final selection optimized for $M_{LQ} = 650$ GeV is cross-checked using only data. See backup.

Conclusion

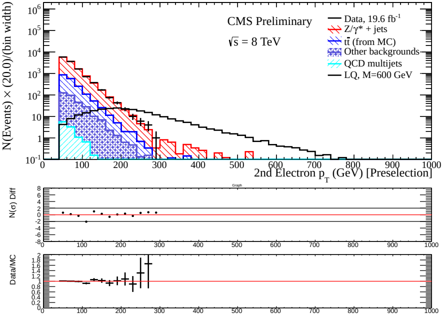
- A search was carried out for first generation LQs in two channels:
  - $\mathrm{LQ\overline{LQ}} \rightarrow eejj$ ($\beta = 1.0$)
  - $\mathrm{LQ\overline{LQ}} \rightarrow e\nu jj$ ($\beta = 0.5$)
- Both channels set world's best limits at 95% CL:
  - Exp. limits: $M_{LQ} < 1030$ (890) GeV for $\beta = 1.0$ (0.5)
  - Obs. limits: $M_{LQ} < 1005$ (845) GeV for $\beta = 1.0$ (0.5)
- Both channels observe a broad excess with greatest significance at $M_{LQ} = 650$ GeV.
- Lower-than-expected limits at $\beta = 0.15$:
  - Exp.: $M_{LQ} < 790$ GeV
  - Obs.: $M_{LQ} < 635$ GeV
- Results have been extensively cross checked
- We ask for the pre-approval of this analysis

eejj preselection: electron p_T

Leading electron p_T

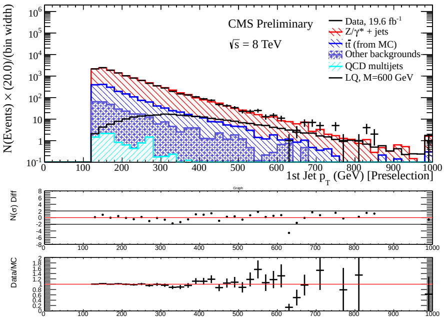


Second leading electron p_T

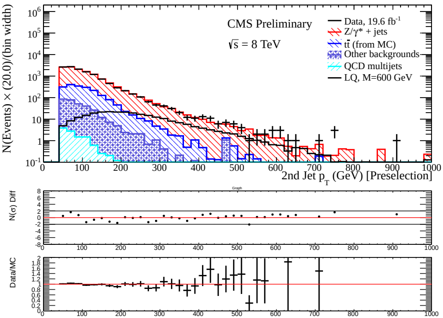


eejj preselection: jet p_T

Leading jet p_T

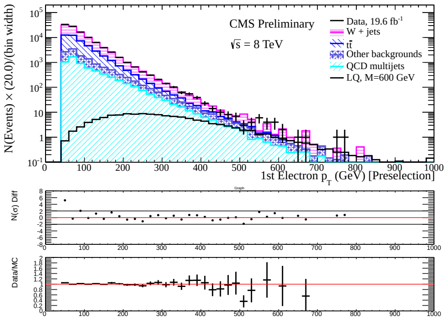


Second leading jet p_T



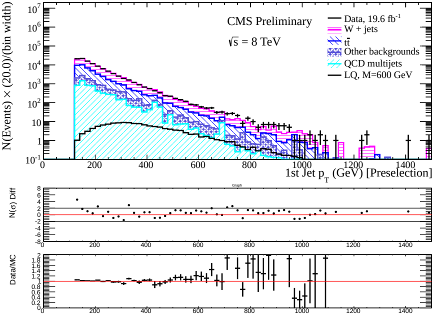
$e\nu jj$ preselection: electron p_T

Electron p_T

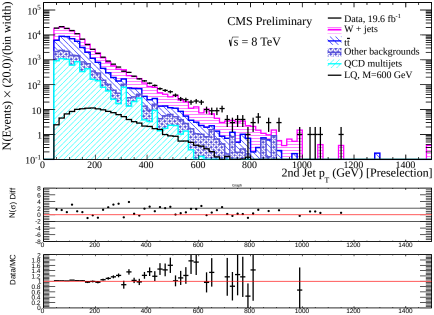


$e\nu jj$ preselection: jet p_T

Leading jet p_T



Second leading jet p_T



$t\bar{t}$ background in *eejj* analysis: weights

Muon $\lvert\eta\rvert$ range	Weight applied to $e\mu jj$ events
$0.0 < \lvert\eta\rvert \leq 0.9$	$\mathcal{C} = 0.458 \pm 0.005$ (stat) ± 0.005 (syst)
$0.9 < \lvert\eta\rvert \leq 1.2$	$\mathcal{C} = 0.409 \pm 0.005$ (stat) ± 0.005 (syst)
$1.2 < \lvert\eta\rvert \leq 2.1$	$\mathcal{C} = 0.400 \pm 0.005$ (stat) ± 0.005 (syst)

$t\bar{t}$ background in *eejj* analysis: triggers

HLT path	Run range
HLT_Mu40_eta2p1_v9	190456 - 196531
HLT_Mu40_eta2p1_v10	198063 - 199608
HLT_Mu40_eta2p1_v11	199698 - 208686

QCD background: triggers

HLT path	Run range	Effective $\mathcal{L}_{int}(\mathrm{pb}^{-1})$
HLT_Photon30_CaloIdVL_v11	190456 - 190738	0.029672
HLT_Photon30_CaloIdVL_v12	190782 - 191419	0.086121
HLT_Photon30_CaloIdVL_v13	191691 - 196531	0.690924
HLT_Photon30_CaloIdVL_v14	198022 - 208686	2.043
HLT_Photon50_CaloIdVL_v7	190456 - 190738	0.231664
HLT_Photon50_CaloIdVL_v8	190782 - 191419	0.669828
HLT_Photon50_CaloIdVL_v9	191691 - 196531	5.374
HLT_Photon50_CaloIdVL_v10	198022 - 208686	15.894
HLT_Photon75_CaloIdVL_v10	190456 - 190738	1.385
HLT_Photon75_CaloIdVL_v11	190782 - 191419	4.019
HLT_Photon75_CaloIdVL_v12	191691 - 196531	32.243
HLT_Photon75_CaloIdVL_v13	198022 - 208686	95.363
HLT_Photon90_CaloIdVL_v7	190456 - 190738	2.769
HLT_Photon90_CaloIdVL_v8	190782 - 191419	8.038
HLT_Photon90_CaloIdVL_v9	191691 - 196531	69.509
HLT_Photon90_CaloIdVL_v10	198022 - 208686	198.024
HLT_Photon135_v4	190456 - 190738	96.404
HLT_Photon135_v5	190782 - 191419	398.151
HLT_Photon135_v6	191691 - 196531	543.603
HLT_Photon135_v7	198022 - 208686	12581
HLT_Photon150_v1	190456 - 190738	96.404
HLT_Photon150_v2	190782 - 191419	398.151
HLT_Photon150_v3	191691 - 196531	4824.
HLT_Photon150_v4	198022 - 208686	14304

QCD background: closure test method (1/2)

- Define closure test sample:
  - Single photon trigger (same as calculation)
  - Exactly two loose electrons
  - At least one jet
  - $m_{ee} > 110$ GeV, to improve QCD purity
  - $\not{E}_T < 100$ GeV, to improve QCD purity
- Subtract contribution from non-QCD processes using MC
- Predict N(events) with exactly one HEEP electron and at least one jet with fake rate:

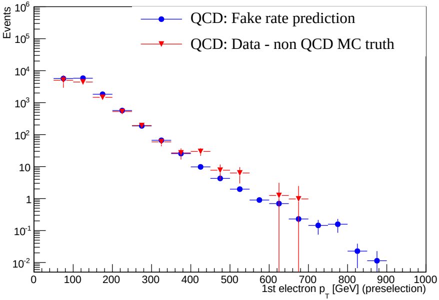
$$N_{eejj}^{QCD} = \sum_{\substack{\text{loose} \\ eejj \text{ events}}} P(e_{1,\text{ tight}} | e_{1,\text{ loose}} : p_T, \eta) \cdot P(e_{2,\text{ tight}} | e_{2,\text{ loose}} : p_T, \eta)$$

QCD background: closure test method (2/2)

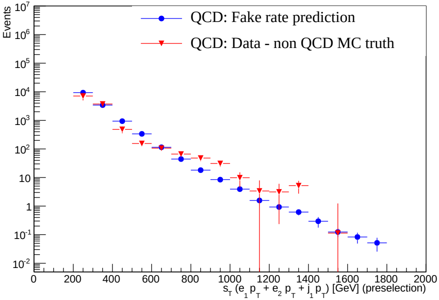
- Finally, compare predicted vs observed N(events) with exactly one HEEP electron:
  - N(predicted) $= 13100 \pm 400$
  - N(observed) $= 12100 \pm 400$
  - N(predicted)/N(observed) $= 1.08 \pm 0.05$
- After applying $S_T = p_T(e_1) + p_T(e_2) + p_T(j) > 450$ GeV (comparable to final selection S_T cut), agreement worsens:
  - N(predicted) $= 599 \pm 53.6$
  - N(observed) $= 876 \pm 46.7$
  - N(predicted)/N(observed) $= 1.46 \pm 0.15$
- Best agreement given 1σ fluctuation at $S_T > 450$ is 30%, so we assign a systematic uncertainty of 30% per electron to the QCD background estimate.

QCD background: closure test plots

Leading electron p_T

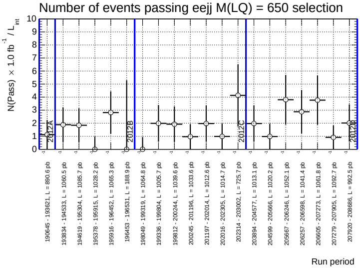


S_T

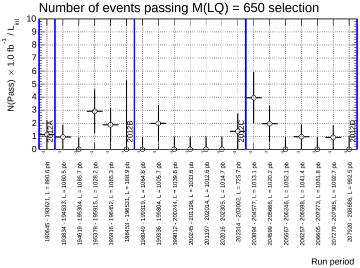


Run period dependence

Events passing *eejj*
$M_{LQ} = 650$ GeV selection



Events passing $e\nu jj$
$M_{LQ} = 650$ GeV selection



Events passing final selection in both analyses are evenly distributed in time

Data-driven background using muons: overview

- Use muon events to simulate electron events:
  - $eejj$ analysis: use $\mu\mu jj$ events

$$N^{\text{data}}_{eejj} = \mathcal{C}_{\mu\mu jj} \times N^{\text{data}}_{\mu\mu jj} = \left(\frac{\epsilon^{\text{trigger}}_{ejj}}{\epsilon^{\text{trigger}}_{\mu}} \times \frac{\epsilon^{\text{reco/ID/Iso}}_{eejj}}{\epsilon^{\text{reco/ID/Iso}}_{\mu\mu jj}} \right) \times N^{\text{data}}_{\mu\mu jj}$$

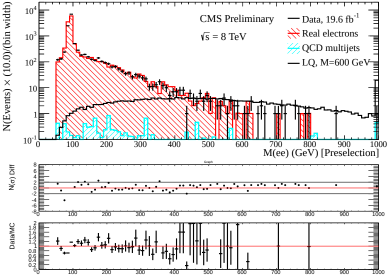
  - $e\nu jj$ analysis: use $\mu\nu jj$ events

$$N^{\text{data}}_{e\nu jj} = \mathcal{C}_{\mu\nu jj} \times N^{\text{data}}_{\mu\nu jj} = \left(\frac{\epsilon^{\text{trigger}}_{ejj}}{\epsilon^{\text{trigger}}_{\mu}} \times \frac{\epsilon^{\text{reco/ID/Iso}}_{e\nu jj}}{\epsilon^{\text{reco/ID/Iso}}_{\mu\nu jj}} \right) \times N^{\text{data}}_{\mu\nu jj}$$

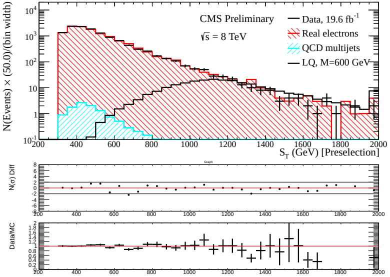
- Still use QCD fake rate method to model "fake" electrons
- Only used as a cross-check!

Data-driven background using muons: *eejj* (1/2)

m_{ee} at *eejj* preselection



S_T at *eejj* preselection



- "Real electrons": *eejj* events with no fake electrons (modeled with $\mu\mu jj$)
- Difference in muon vs. electron p_T resolution $\Longrightarrow$ difference in m_{ee} peak

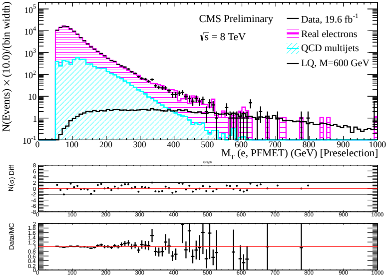
Data-driven background using muons: *eejj* (2/2)

M_{LQ}	LQ Signal	Real electrons (from data)	QCD (from data)	Data	Total Background
Presel	-	12399.1 ± 110.7	10.87 ± 0.10	12442	12410.0 ± 110.7
300	12855.1 ± 75.9	1146.7 ± 33.6	5.282 ± 0.052	1244	1152.02 ± 33.63
350	6137.3 ± 31.6	677.3 ± 25.8	3.215 ± 0.036	736	680.54 ± 25.84
400	2928.6 ± 14.2	353.0 ± 18.7	1.696 ± 0.023	389	354.66 ± 18.65
450	1429.7 ± 6.8	201.4 ± 14.1	0.890 ± 0.016	233	202.24 ± 14.10
500	727.5 ± 3.4	126.3 ± 11.2	0.485 ± 0.011	148	126.78 ± 11.16
550	389.2 ± 1.8	70.0 ± 8.3	0.2758 ± 0.0084	81	70.25 ± 8.30
600	213.96 ± 0.98	43.4 ± 6.5	0.1527 ± 0.0065	57	43.56 ± 6.54
650	119.31 ± 0.55	26.6 ± 5.1	0.0760 ± 0.0040	36	26.67 ± 5.12
700	69.09 ± 0.32	16.7 ± 4.1	0.0448 ± 0.0029	17	16.77 ± 4.06
750	40.86 ± 0.19	10.8 ± 3.3	0.0258 ± 0.0023	12	10.85 ± 3.26
800	24.81 ± 0.11	8.8 ± 2.9	0.0193 ± 0.0022	7	8.85 ± 2.94
850	15.147 ± 0.068	5.9 ± 2.4	0.0111 ± 0.0015	5	5.89 ± 2.40
900	9.303 ± 0.042	4.9 ± 2.2	0.0069 ± 0.0012	3	4.91 ± 2.19
950	5.770 ± 0.026	4.9 ± 2.2	0.00451 ± 0.00085	1	4.90 ± 2.19
1000	3.659 ± 0.017	2.0 ± 1.4	0.00374 ± 0.00082	1	1.97 ± 1.39
1050	2.442 ± 0.011	2.0 ± 1.4	0.00374 ± 0.00082	1	1.97 ± 1.39
1100	1.6055 ± 0.0068	2.0 ± 1.4	0.00374 ± 0.00082	1	1.97 ± 1.39
1150	1.0686 ± 0.0044	2.0 ± 1.4	0.00374 ± 0.00082	1	1.97 ± 1.39
1200	0.7108 ± 0.0029	2.0 ± 1.4	0.00374 ± 0.00082	1	1.97 ± 1.39

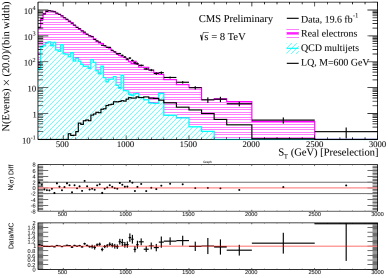
- 36 events observed at M(LQ) = 650
- MC analysis predicts 20.49 ± 2.14 (stat) ± 1.01 (syst)
- DD analysis (this table) predicts 26.67 ± 5.12 (stat)

Data-driven background using muons: $e\nu jj$ (1/2)

$m_{T,\,e\nu}$ at $e\nu jj$ preselection



S_T at $e\nu jj$ preselection



- "Real electrons": $e\nu jj$ events with no fake electrons (modeled with $\mu\nu jj$)
- $m_{T,\,e\nu}$ in $\mu\nu jj$ events reweighted to match data

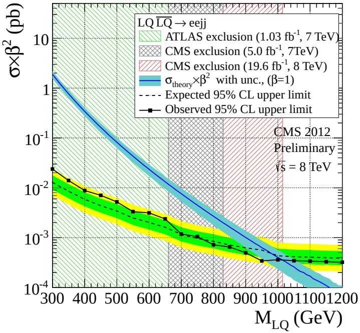
Data-driven background using muons: $e\nu jj$ (2/2)

M_{LQ}	LQ Signal	Real electrons (from data)	QCD (from data)	Data	Total Background
Presel	-	99103.1 ± 323.9	5950.5 ± 20.1	105164	105053.6 ± 324.5
300	4641.6 ± 49.8	2346.6 ± 51.1	117.9 ± 1.5	2455	2464.50 ± 51.11
350	2112.1 ± 21.1	827.0 ± 29.3	59.11 ± 0.97	908	886.15 ± 29.31
400	945.8 ± 9.3	343.0 ± 18.4	32.88 ± 0.69	413	375.86 ± 18.38
450	457.5 ± 4.5	144.5 ± 11.8	14.13 ± 0.42	192	158.64 ± 11.81
500	226.7 ± 2.2	77.8 ± 8.6	7.76 ± 0.30	83	85.55 ± 8.60
550	118.2 ± 1.2	28.3 ± 5.2	3.89 ± 0.21	44	32.18 ± 5.17
600	64.65 ± 0.64	13.2 ± 3.5	2.29 ± 0.17	28	15.53 ± 3.54
650	36.25 ± 0.36	9.5 ± 3.0	1.18 ± 0.12	18	10.65 ± 3.00
700	21.18 ± 0.21	4.7 ± 2.1	0.85 ± 0.10	6	5.58 ± 2.12
750	12.56 ± 0.12	1.8 ± 1.3	0.514 ± 0.091	4	2.32 ± 1.28
800	7.412 ± 0.073	0.90 ± 0.90	0.317 ± 0.067	3	1.22 ± 0.90
850	4.591 ± 0.045	$0.000^{1.14}_{-0.00}$	0.117 ± 0.029	2	$0.117^{+1.140}_{-0.029}$
900	2.853 ± 0.028	$0.000^{1.14}_{-0.00}$	0.076 ± 0.024	1	$0.076^{+1.140}_{-0.024}$
950	1.791 ± 0.017	$0.000^{1.14}_{-0.00}$	0.069 ± 0.023	1	$0.069^{+1.140}_{-0.023}$
1000	1.272 ± 0.011	$0.000^{1.14}_{-0.00}$	0.069 ± 0.023	1	$0.069^{+1.140}_{-0.023}$
1050	0.8788 ± 0.0074	$0.000^{1.14}_{-0.00}$	0.069 ± 0.023	1	$0.069^{+1.140}_{-0.023}$
1100	0.6063 ± 0.0049	$0.000^{1.14}_{-0.00}$	0.069 ± 0.023	1	$0.069^{+1.140}_{-0.023}$
1150	0.4196 ± 0.0032	$0.000^{1.14}_{-0.00}$	0.069 ± 0.023	1	$0.069^{+1.140}_{-0.023}$
1200	0.2894 ± 0.0021	$0.000^{1.14}_{-0.00}$	0.069 ± 0.023	1	$0.069^{+1.140}_{-0.023}$

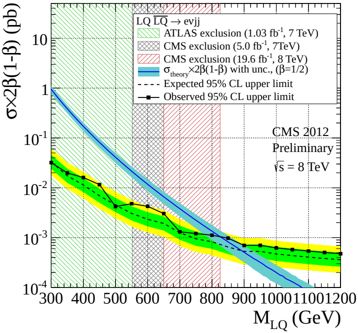
- 18 events observed at M(LQ) = 650
- MC analysis predicts 7.54 ± 1.20 (stat) $\pm$ 0.52 (syst)
- DD analysis (this table) predicts 10.65 ± 3.00 (stat)

Data-driven background using muons: limits

$\beta = 1.0$: *eejj* analysis, μ-bkgd.



$\beta = 0.5$: *eνjj* analysis, μ-bkgd.



- Expected limits: $M_{LQ} < 980$ (890) GeV for *eejj* (*eνjj*)
- Observed limits: $M_{LQ} < 1015$ (825) GeV for *eejj* (*eνjj*)

Data-driven background using muons: conclusion

- Data-driven predictions agree with MC predictions at final selection ($M_{LQ} = 650$ GeV) within stat. uncertainties in both analyses
- Conclusion: Data-driven background prediction confirms MC background prediction
- However:
    - Data-driven prediction mean values are higher than MC
    - Data-driven stat uncertainty is larger than MC
    - So the significance of the excess with data-driven background estimates is less than the significance with MC background estimates
    - And the sensitivity of the analysis with data-driven background estimates is worse than the sensitivity with MC background estimates

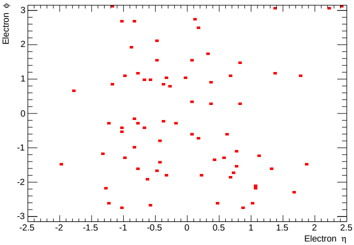
Comparison with LQ2

M_{LQ}	*eejj* Total Background	*eejj* Data	$\mu\mu jj$ Total Background	$\mu\mu jj$ Data
300	1444.96 ± 13.65	1539	$1415 \pm 20 \pm 45$ (syst)	1461
350	726.71 ± 9.78	759	$730 \pm 15 \pm 16$ (syst)	714
400	399.70 ± 7.23	423	$384.8 \pm 10.7 \pm 9.3$ (syst)	394
450	208.02 ± 5.18	235	$205.3 \pm 7.6 \pm 5.5$ (syst)	210
500	118.74 ± 4.00	145	$121.6 \pm 5.7 \pm 4.8$ (syst)	128
550	71.50 ± 3.25	94	$68.1 \pm 4.2 \pm 2.7$ (syst)	75
600	42.44 ± 2.40	67	$44.7 \pm 3.4 \pm 2.0$ (syst)	44
650	26.99 ± 1.93	43	$28 \pm 2.6 \pm 1.3$ (syst)	24
700	16.42 ± 1.52	22	$18.6 \pm 2.2 \pm 1.3$ (syst)	15
750	10.27 ± 1.23	14	$9.32\ ^{+1.29}_{-1.22} \pm 0.87$ (syst)	11
800	5.08 ± 0.77	10	$6.53\ ^{+1.2}_{-1.13} \pm 0.85$ (syst)	9
850	2.97 ± 0.54	4	$3.88\ ^{+1.0}_{-0.92} \pm 0.67$ (syst)	5
900	1.71 ± 0.41	3	$1.47\ ^{+0.81}_{-0.37} \pm 0.43$ (syst)	3
950	1.04 ± 0.31	1	$0.83\ ^{+0.91}_{-0.26} \pm 0.29$ (syst)	1
1000	0.62 ± 0.24	0	$0.383\ ^{+0.894}_{-0.171} \pm 0.031$ (syst)	0
1050	0.62 ± 0.24	0	$0.383\ ^{+0.894}_{-0.171} \pm 0.031$ (syst)	0
1100	0.62 ± 0.24	0	$0.383\ ^{+0.894}_{-0.171} \pm 0.031$ (syst)	0
1150	0.62 ± 0.24	0	$0.383\ ^{+0.894}_{-0.171} \pm 0.031$ (syst)	0
1200	0.62 ± 0.24	0	$0.383\ ^{+0.894}_{-0.171} \pm 0.031$ (syst)	0

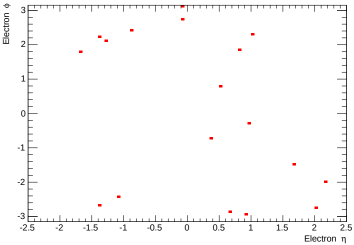
- Apply S_T , m_{ej}^{min} , and $m_{\ell\ell}$ cuts from LQ2 (`EXO-12-042`)
- *eejj* bkgd prediction, $\mu\mu jj$ bkgd prediction, and $\mu\mu jj$ data agree well
- Discrepancy comes from *eejj* data

Electron η vs. ϕ

Events passing *eejj*
$M_{LQ} = 650$ GeV selection



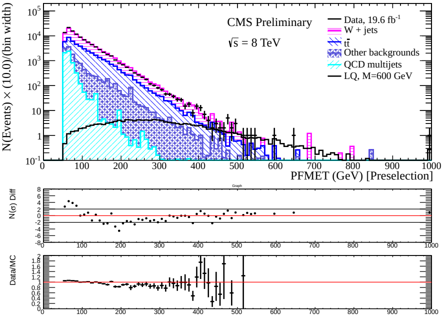
Events passing *eνjj*
$M_{LQ} = 650$ GeV selection



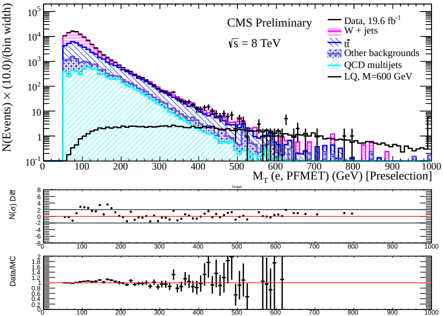
Electrons in events passing final selection in both analyses are evenly distributed in the ECAL

$\not\!\!E_T$ and $m_{T,\,e\nu}$ before reweighting

$\not\!\!E_T$ before reweighting



$m_{T,\,e\nu}$ before reweighting



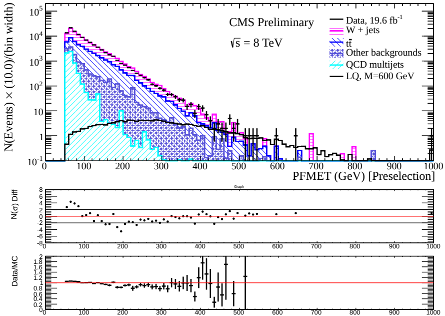
Can we improve agreement in these distributions by reweighting?

Reweighting method

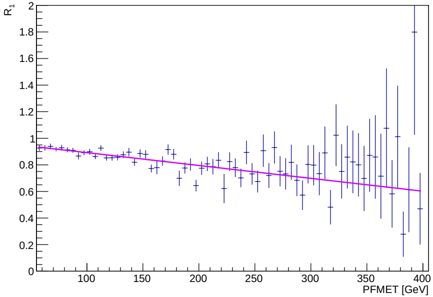
- Find weight functions for both $\not{E}_T$ and $m_{T,\, e\nu}$ at $e\nu jj$ preselection:
  1. Do not apply any $W^{\pm}$+jets or $t\bar{t}$ rescaling
  2. Find and apply weight function for $\not{E}_T$ first
  3. Then find and apply weight function for $m_{T,\, e\nu}$
  4. Finally, find and apply new $W^{\pm}$+jets and $t\bar{t}$ rescaling
- Compare $m_{T,\, e\nu}$ and $\not{E}_T$ dists. before and after reweighting
- Repeat final selection for both *eejj* and $e\nu jj$ analysis

Find $\not{E}_T$ function

$\not{E}_T$ before reweighting



$\not{E}_T$ reweighting function



Get reweighting function by fitting:

$$\mathcal{R}_1(\not{E}_T) = \frac{N_{i,\text{Data}}(\not{E}_T) - N_{i,\text{QCD}}(\not{E}_T)}{N_{i,\text{W+jets}}(\not{E}_T) + N_{i,t\bar{t}}(\not{E}_T) + N_{i,\text{Other}}(\not{E}_T)}$$

$\not\!\!E_T$ function details

- Use the following linear fit function to define $\not\!\!E_T$ reweighting:

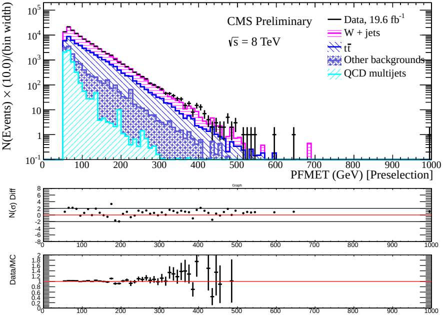
$$w_1(\not\!\!E_T) = a_0 + a_1 \cdot \not\!\!E_T$$

- Fit returns the following parameters:

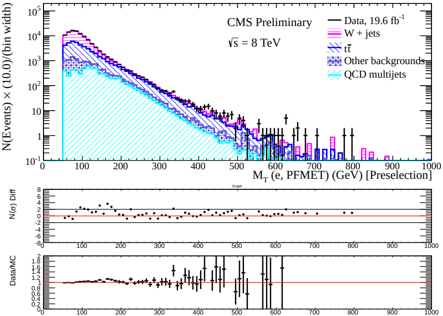
Parameter symbol	Parameter title	Mean value	Uncertainty
a_0	Linear offset	0.989	0.0112
a_1	Linear slope	$-9.67 \cdot 10^{-4}$	$8.86 \cdot 10^{-5}$

Apply $\not\!\!E_T$ function

$\not\!\!E_T$ after $\not\!\!E_T$ reweighting



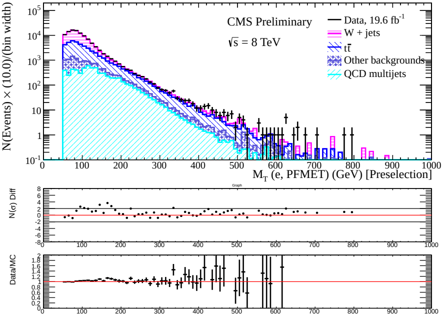
$m_{T,\,e\nu}$ after $\not\!\!E_T$ reweighting



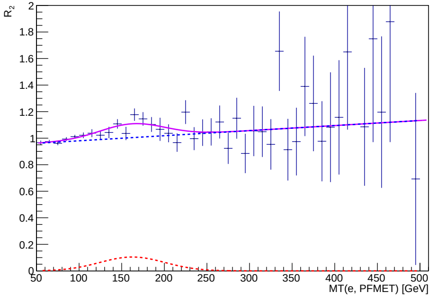
$\not\!\!E_T$ distribution improved, but $m_{T,\,e\nu}$ still needs help

Find $m_{\mathrm{T},\,e\nu}$ function

$m_{\mathrm{T},\,e\nu}$ after $\not{E}_{\mathrm{T}}$ reweighting



$\not{E}_{\mathrm{T}}$ reweighting function



Get reweighting function by fitting:

$$\mathcal{R}_2(m_{\mathrm{T},\,e\nu}) = \frac{\mathrm{N}_{i,\mathrm{Data}}(m_{\mathrm{T},\,e\nu}) - \mathrm{N}_{i,\mathrm{QCD}}(m_{\mathrm{T},\,e\nu})}{\mathrm{N}_{i,\mathrm{W+jets}}(m_{\mathrm{T},\,e\nu}) + \mathrm{N}_{i,t\bar{t}}(m_{\mathrm{T},\,e\nu}) + \mathrm{N}_{i,\mathrm{Other}}(m_{\mathrm{T},\,e\nu})}$$

$m_{\mathrm{T},\, e\nu}$ function details

- Use the following linear fit function to define $m_{\mathrm{T},\, e\nu}$ reweighting:

$$w_2(m_{\mathrm{T},\, e\nu}) = b_0 + b_1 \cdot m_{\mathrm{T},\, e\nu} + B \cdot e^{-\frac{1}{2}\cdot\left(\frac{m_{\mathrm{T},\, e\nu} - \mu}{\sigma}\right)^2}$$

- Fit returns the following parameters:

Parameter symbol	Parameter title	Mean value	Uncertainty
b_0	Linear offset	.942	0.0181
b_1	Linear slope	$3.82 \cdot 10^{-4}$	$1.68 \cdot 10^{-4}$
B	Gaussian constant	0.104	0.0279
μ	Gaussian width	38.2	11.6
σ	Gaussian mean	162	10.1

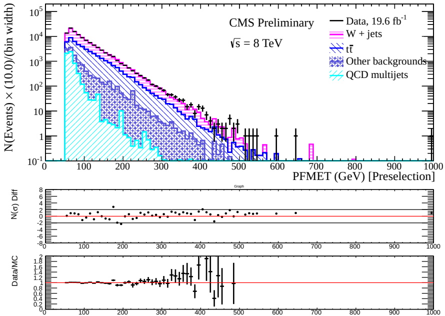
Rescale W$^{\pm}$+jets and $t\bar{t}$

- First apply $w_{\text{total}} = w_1(\not{E}_{\text{T}}) \cdot w_2(m_{\text{T, e}\nu})$ to each MC event
- Then rescale W$^{\pm}$+jets and $t\bar{t}$ as before
- Note: no W$^{\pm}$+jets and $t\bar{t}$ rescaling applied so far

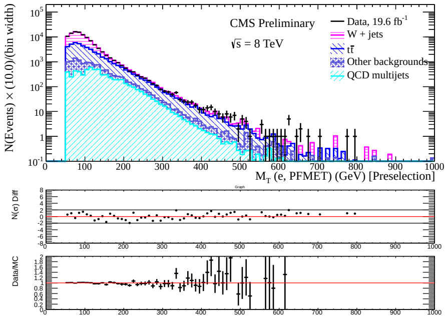
$$N^1_{\text{data}} = \mathcal{R}_{t\bar{t}} N^1_{t\bar{t}} + \mathcal{R}_W N^1_W + N^1_{\text{QCD}} + N^1_{\text{Others}} \quad \mathcal{R}_{t\bar{t}} = 1.08 \pm 0.03\ (\text{stat}) \pm 0.01\ (\text{syst})$$
$$N^2_{\text{data}} = \mathcal{R}_{t\bar{t}} N^2_{t\bar{t}} + \mathcal{R}_W N^2_W + N^2_{\text{QCD}} + N^2_{\text{Others}} \quad \mathcal{R}_{\text{W}} = 0.97 \pm 0.02\ (\text{stat}) \pm 0.01\ (\text{syst})$$

Apply $\not{E}_T$ and $m_{T,\,e\nu}$ reweights and rescale MC

$\not{E}_T$ after all reweighting



$m_{T,\,e\nu}$ after all reweighting



Agreement much better in both $\not{E}_T$ and $m_{T,\,e\nu}$ distributions after reweighting and rescaling

$e\nu jj$ final selection before reweighting

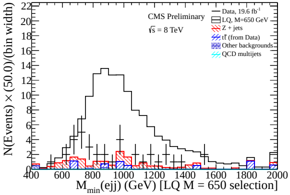
M_{LQ}	LQ Signal	W$^{\pm}$+jets	$t\bar{t}$	QCD	Other	Data	Total background
Presel	-	58284.8 ± 197.0	32196.7 ± 69.8	5950.5 ± 20.1	6590.8 ± 231.6	105164	103022.8 ± 312.6
300	4765.5 ± 51.1	822.1 ± 22.4	1191.3 ± 12.0	117.9 ± 1.5	210.5 ± 7.7	2455	$2341.90 \pm 26.58 \pm 163.90$ (syst)
350	2168.4 ± 21.6	275.9 ± 14.5	441.4 ± 7.2	59.11 ± 0.97	102.1 ± 5.4	908	$878.55 \pm 17.08 \pm 58.66$ (syst)
400	971.1 ± 9.6	110.4 ± 7.8	184.2 ± 4.7	32.88 ± 0.69	51.5 ± 3.8	413	$378.98 \pm 9.91 \pm 24.79$ (syst)
450	469.7 ± 4.6	53.1 ± 5.8	74.7 ± 3.0	14.13 ± 0.42	25.7 ± 2.7	192	$167.64 \pm 7.06 \pm 11.01$ (syst)
500	232.7 ± 2.3	20.5 ± 3.3	34.4 ± 2.0	7.76 ± 0.30	15.3 ± 2.1	83	$77.99 \pm 4.41 \pm 4.83$ (syst)
550	121.4 ± 1.2	8.6 ± 1.8	14.9 ± 1.4	3.89 ± 0.21	7.8 ± 1.6	44	$35.24 \pm 2.76 \pm 2.18$ (syst)
600	66.37 ± 0.66	2.3 ± 1.0	7.08 ± 0.93	2.29 ± 0.17	4.6 ± 1.2	28	$16.27 \pm 1.84 \pm 0.96$ (syst)
650	37.22 ± 0.37	0.41 ± 0.29	3.82 ± 0.70	1.18 ± 0.12	2.13 ± 0.92	18	$7.54 \pm 1.20 \pm 0.52$ (syst)
700	21.74 ± 0.21	0.41 ± 0.29	2.61 ± 0.60	0.85 ± 0.10	0.58 ± 0.24	6	$4.45 \pm 0.71 \pm 0.34$ (syst)
750	12.90 ± 0.13	$0.00^{+0.94}_{-0.00}$	1.75 ± 0.47	0.514 ± 0.091	0.27 ± 0.15	4	$2.535^{+1.062}_{-0.504} \pm 0.20$ (syst)
800	7.610 ± 0.075	$0.00^{+0.94}_{-0.00}$	1.10 ± 0.37	0.317 ± 0.067	0.27 ± 0.15	3	$1.696^{+1.019}_{-0.404} \pm 0.13$ (syst)
850	4.713 ± 0.046	$0.00^{+0.94}_{-0.00}$	0.90 ± 0.34	0.117 ± 0.029	0.140 ± 0.087	2	$1.153^{+0.999}_{-0.353} \pm 0.08$ (syst)
900	2.929 ± 0.028	$0.00^{+0.94}_{-0.00}$	0.37 ± 0.21	0.076 ± 0.024	0.084 ± 0.069	1	$0.530^{+0.962}_{-0.226} \pm 0.04$ (syst)
950	1.839 ± 0.018	$0.00^{+0.94}_{-0.00}$	0.37 ± 0.21	0.069 ± 0.023	0.084 ± 0.069	1	$0.524^{+0.962}_{-0.226} \pm 0.04$ (syst)
1000	1.306 ± 0.012	$0.00^{+0.94}_{-0.00}$	0.37 ± 0.21	0.069 ± 0.023	0.084 ± 0.069	1	$0.524^{+0.962}_{-0.226} \pm 0.04$ (syst)
1050	0.9022 ± 0.0076	$0.00^{+0.94}_{-0.00}$	0.37 ± 0.21	0.069 ± 0.023	0.084 ± 0.069	1	$0.524^{+0.962}_{-0.226} \pm 0.04$ (syst)
1100	0.6225 ± 0.0050	$0.00^{+0.94}_{-0.00}$	0.37 ± 0.21	0.069 ± 0.023	0.084 ± 0.069	1	$0.524^{+0.962}_{-0.226} \pm 0.04$ (syst)
1150	0.4308 ± 0.0032	$0.00^{+0.94}_{-0.00}$	0.37 ± 0.21	0.069 ± 0.023	0.084 ± 0.069	1	$0.524^{+0.962}_{-0.226} \pm 0.04$ (syst)
1200	0.2971 ± 0.0022	$0.00^{+0.94}_{-0.00}$	0.37 ± 0.21	0.069 ± 0.023	0.084 ± 0.069	1	$0.524^{+0.962}_{-0.226} \pm 0.04$ (syst)

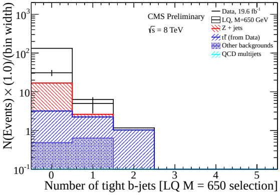
$e\nu jj$ final selection after reweighting

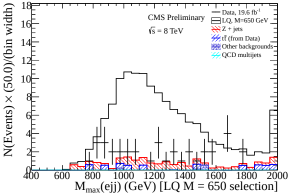
M_{LQ}	W+Jets	$t\bar{t}$	QCD	Other	Data	Total BG
Presel	59725.3 ± 201.9	33176.5 ± 71.7	5950.5 ± 20.1	5943.8 ± 205.5	105164	104796.0 ± 297.6
300	859.6 ± 23.1	1233.0 ± 12.4	117.9 ± 1.5	187.6 ± 6.907	2455	2398.04 ± 27.16
350	280.4 ± 14.4	446.3 ± 7.3	59.11 ± 0.97	88.6 ± 4.649	908	874.28 ± 16.83
400	108.5 ± 7.7	180.6 ± 4.6	32.88 ± 0.69	43.7 ± 3.229	413	365.71 ± 9.55
450	50.5 ± 5.5	70.8 ± 2.8	14.13 ± 0.42	21.3 ± 2.257	192	156.75 ± 6.62
500	19.0 ± 3.0	31.6 ± 1.9	7.76 ± 0.30	12.4 ± 1.734	83	70.81 ± 3.93
550	7.9 ± 1.7	13.3 ± 1.2	3.89 ± 0.21	6.3 ± 1.288	44	31.36 ± 2.43
600	2.2 ± 0.9	6.13 ± 0.80	2.29 ± 0.17	3.5 ± 0.959	28	14.08 ± 1.57
650	0.43 ± 0.30	3.22 ± 0.59	1.18 ± 0.12	1.59 ± 0.736	18	6.43 ± 1.00
700	0.43 ± 0.30	2.17 ± 0.50	0.85 ± 0.10	0.35 ± 0.150	6	3.80 ± 0.61
750	$0.00^{+0.94}_{-0.00}$	1.49 ± 0.41	0.514 ± 0.091	0.117 ± 0.061	4	$2.116^{+1.025}_{-0.420}$
800	$0.00^{+0.94}_{-0.00}$	0.87 ± 0.30	0.317 ± 0.067	0.116 ± 0.061	3	$1.308^{+0.986}_{-0.313}$
850	$0.00^{+0.94}_{-0.00}$	0.70 ± 0.27	0.117 ± 0.029	0.054 ± 0.032	2	$0.874^{+0.975}_{-0.278}$
900	$0.00^{+0.94}_{-0.00}$	0.27 ± 0.16	0.076 ± 0.024	0.019 ± 0.012	1	$0.366^{+0.948}_{-0.159}$
950	$0.00^{+0.94}_{-0.00}$	0.27 ± 0.16	0.069 ± 0.023	0.019 ± 0.012	1	$0.359^{+0.948}_{-0.159}$
1000	$0.00^{+0.94}_{-0.00}$	0.27 ± 0.16	0.069 ± 0.023	0.019 ± 0.012	1	$0.359^{+0.948}_{-0.159}$
1050	$0.00^{+0.94}_{-0.00}$	0.27 ± 0.16	0.069 ± 0.023	0.019 ± 0.012	1	$0.359^{+0.948}_{-0.159}$
1100	$0.00^{+0.94}_{-0.00}$	0.27 ± 0.16	0.069 ± 0.023	0.019 ± 0.012	1	$0.359^{+0.948}_{-0.159}$
1150	$0.00^{+0.94}_{-0.00}$	0.27 ± 0.16	0.069 ± 0.023	0.019 ± 0.012	1	$0.359^{+0.948}_{-0.159}$
1200	$0.00^{+0.94}_{-0.00}$	0.27 ± 0.16	0.069 ± 0.023	0.019 ± 0.012	1	$0.359^{+0.948}_{-0.159}$

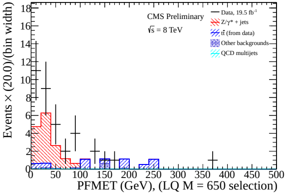
- Discrepancy at 650 selection increases after reweighting
- No change made to the analysis

eejj extra plots









$e\nu jj$ extra plots