Search for Anomalous Multilepton Production and RPV at CMS using 2.1 fb^{-1}

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on behalf of the CMS Collaboration

New Results Released for:

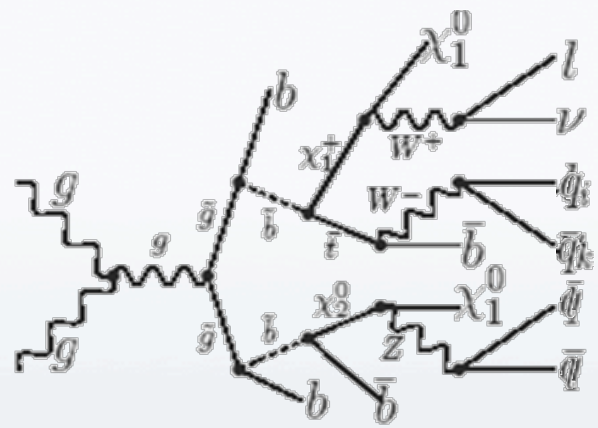
Berkeley Workshop on Searches for Super Symmetry at the LHC

Outline for today

- Introduction
- Search for Anomalous Production of Multileptons
- Interpretation as R-Parity Violating SUSY
- Conclusion

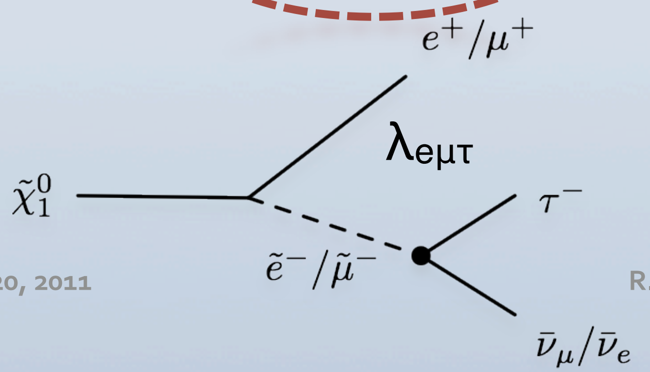
MultiLepton Signatures at the LHC

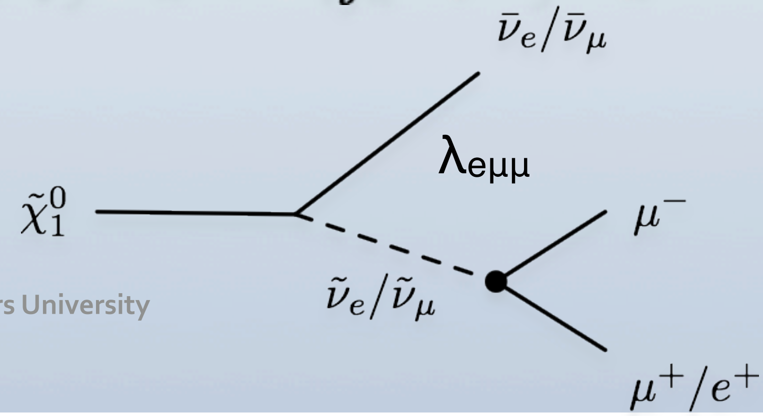
- At 7 TeV Leptons produced in a long chain
  - Beyond classic trilepton signature pp→$\chi^0_2\chi^+_1$
  - Multileptons can be strongly produced.
  - Parent energy distributed between leptons, jets, and **MET**, depending on mass spectrum.
  - R-parity conservation → stable, invisible **LSP**



- But R-Parity need not be conserved!
  - Non-zero RPV couplings allow final state to be entirely SM particles.
  - Proton decay limits allow one of these to be non-zero.

$$W = \lambda_{ijk} L_i L_j \bar{E}_k + \lambda'_{ijk} L_i Q_j \bar{D}_k + \lambda''_{ijk} \bar{U}_i \bar{D}_j \bar{D}_k$$





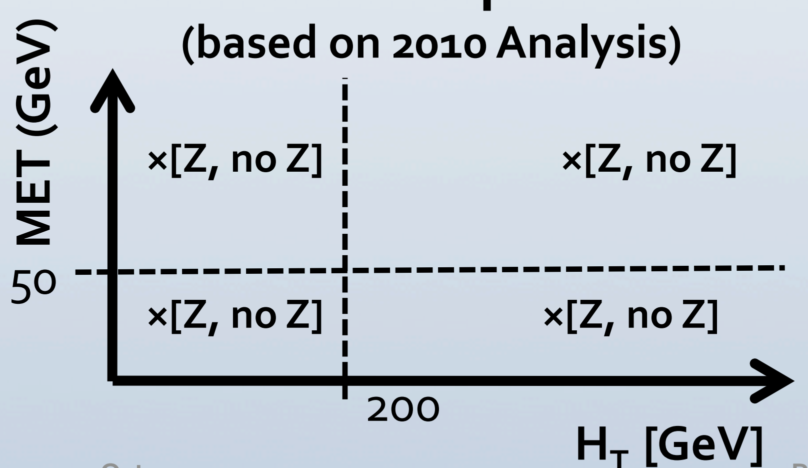
Multilepton Search Strategies at CMS

- In 2010 we showed the energy in MET and Jets varied dramatically with mass spectra in different SUSY scenarios.

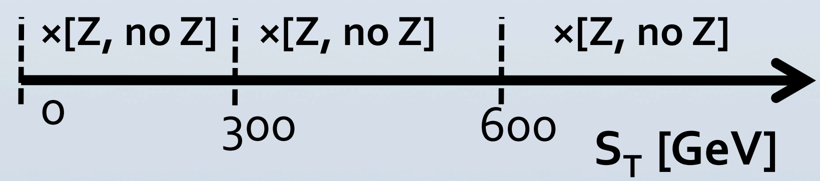
- CMS has two different analyses to cover this.
  - Same lepton selection, backgrounds, triggers.
  - Different strategies for isolating new physics from SM.
    - MET=Missing Transverse Momentum
    - $H_T = \Sigma p_T(\text{jets})$, $|\eta| < 2.5$ and $p_T > 40$ GeV
    - $S_T = MET + H_T + \Sigma p_T(\text{iso-leptons})$.. ATLAS known as "effective mass scale"

SUSY Multilepton 2011

(based on 2010 Analysis)



RPV/Exotic Multilepton 2011

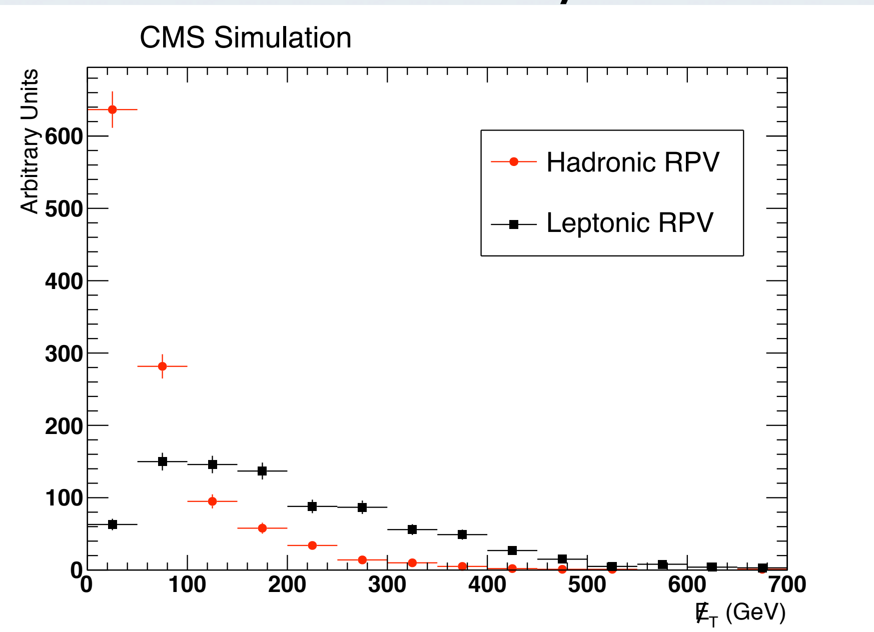


Focus for this Talk

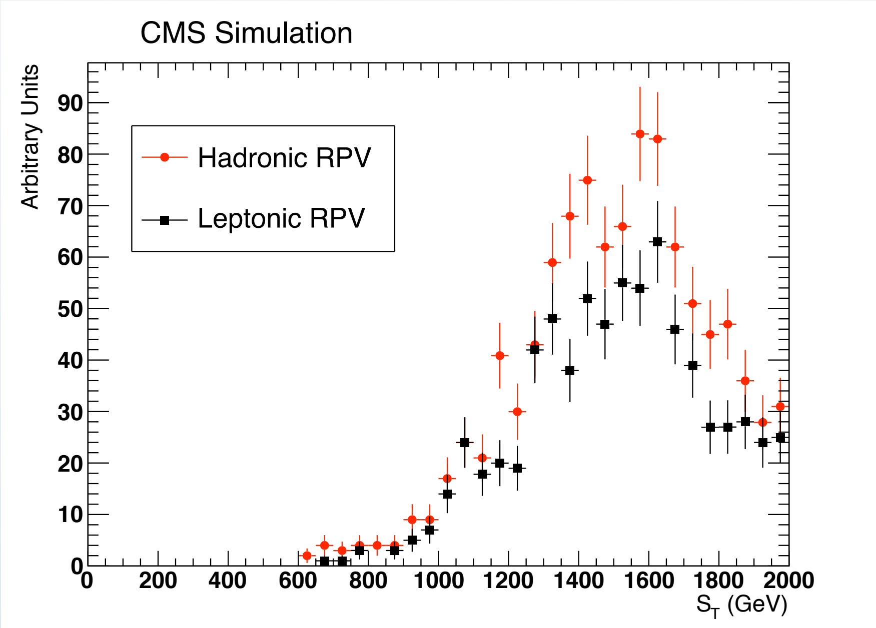
S_T Instead of MET or H_T

- Unlike MET or H_T, S_T is ~insensitive to how parent decays.
  - Consider two types of RPV SUSY: Leptonic and Hadronic
    - MET distributions are very different, but S_T is almost the same.
  - S_T Analysis can be sensitive to a wider range of models
  - S_T distribution for a process gives information about mass scale of the new physics.
    - Peak is ~ M(parents) - < M(invisible daughters) >

MET Distributions very different

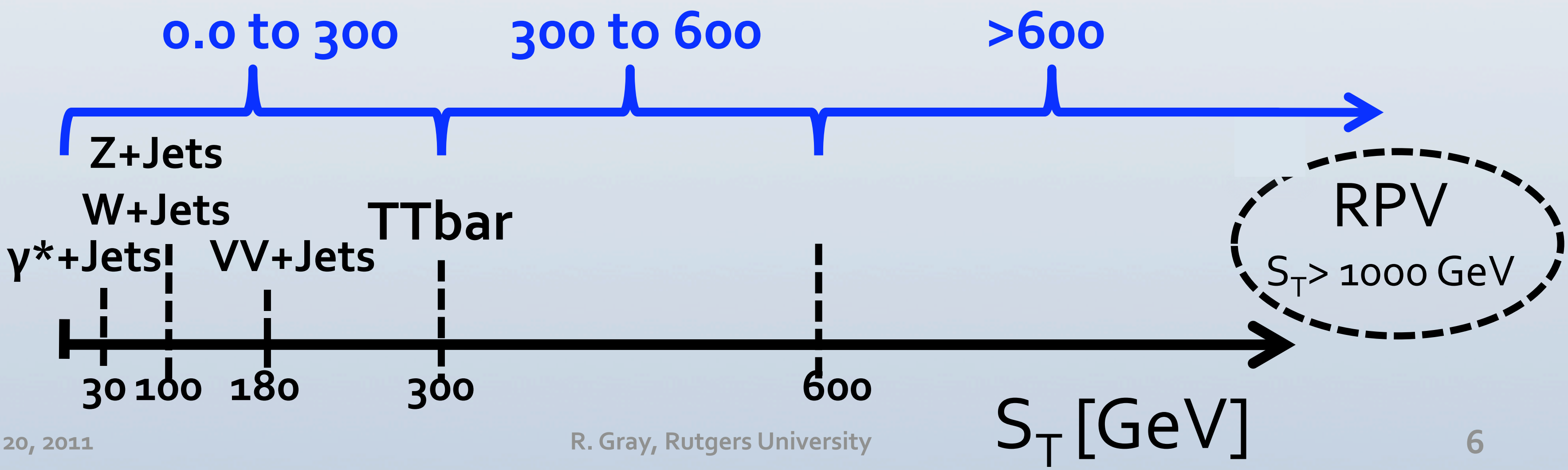


S_T Distributions same



Event Selection

- Include 3 and ≥4 lepton combinations with e, μ, and ≤2 τ's
  - Select on single and dilepton triggers.
  - Cut events where M(l+l-) < 12 GeV (J/ψ, Upsilon, Υ*)
  - In low S_T cut events where M(ll) off Z and M(lll) on Z
- Bin instead of cut! High background bins test SM predictions
  - # Unique Drell Yan candidates (e+e−, μ+μ-): 4 leptons can be DY=0,1,2
  - Is there a Z candidate? M(l+l-) 75-105 GeV
  - 3 bins of S_T :

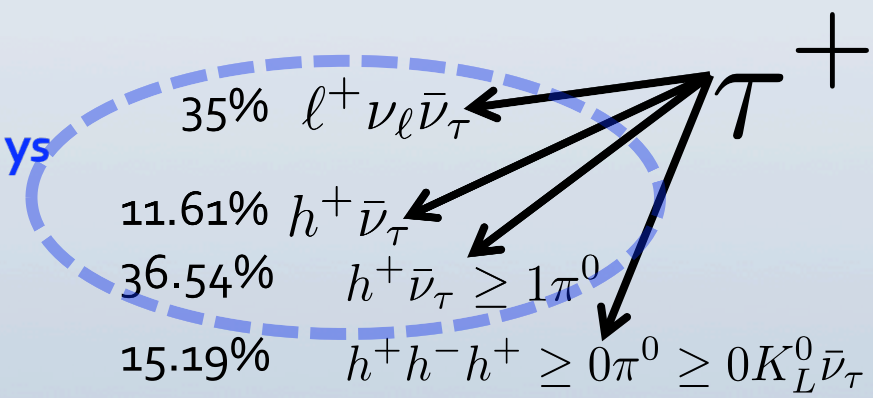


Lepton Selection: (e, μ, τ)

- Electrons and Muons:
  - $p_T > 8$ GeV, $|\eta| < 2.1$
  - Require Relative isolation < 15% and total isolation < 10 GeV
    - Isolation for μ(e) is sum of tracker, calo transverse energy in $\Delta R < 0.3(0.4)$
    - Relative isolation is total isolation divided by lepton p_T
  - Additional p_T requirements from trigger thresholds:

Lepton\Trigger Type	μ	e	μμ	ee	e μ
Leading e/μ	> 20	> 70	>15	>20	>20
Next-to-leading e/μ	NA	NA	>10	>10	>10

- Tau Leptons:
  - Tau are unstable and decay
  - Leptonic decays fall under e/μ
  - Accept "single prong" hadronic decays
    - Isolated track (no π^0)
    - HPS Algorithm (with π^0)
  - Visible $p_T > 8/15$ GeV, $|\eta| < 2.1$

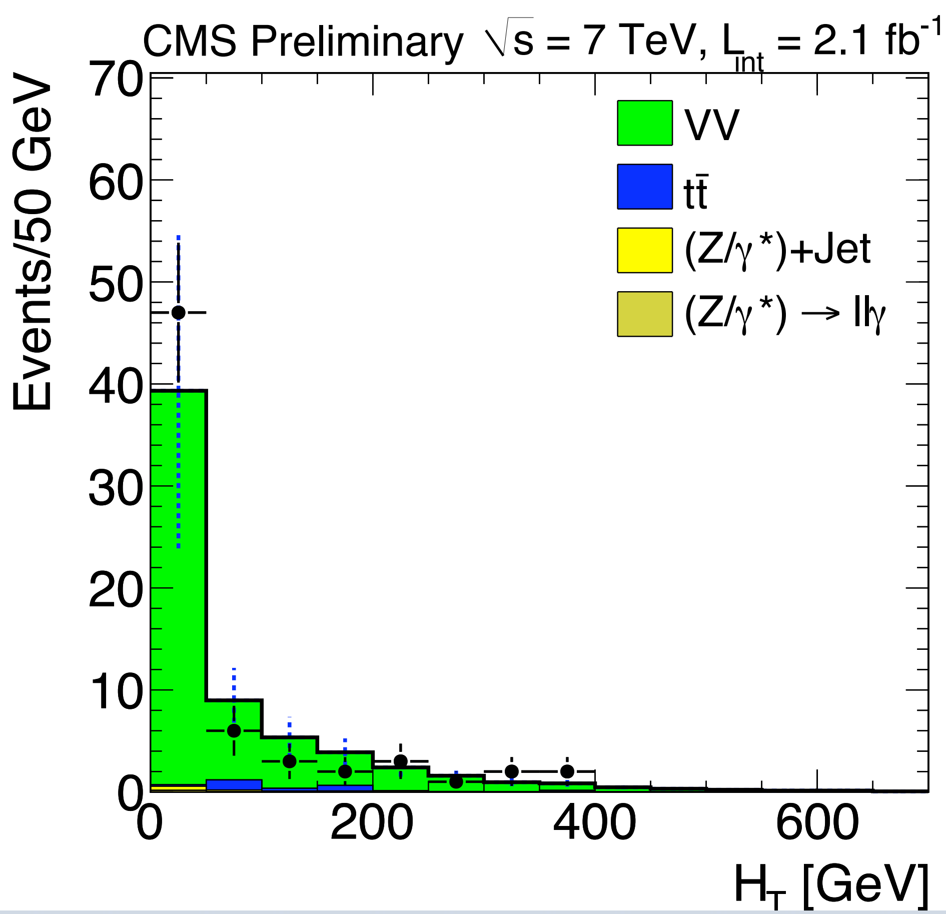


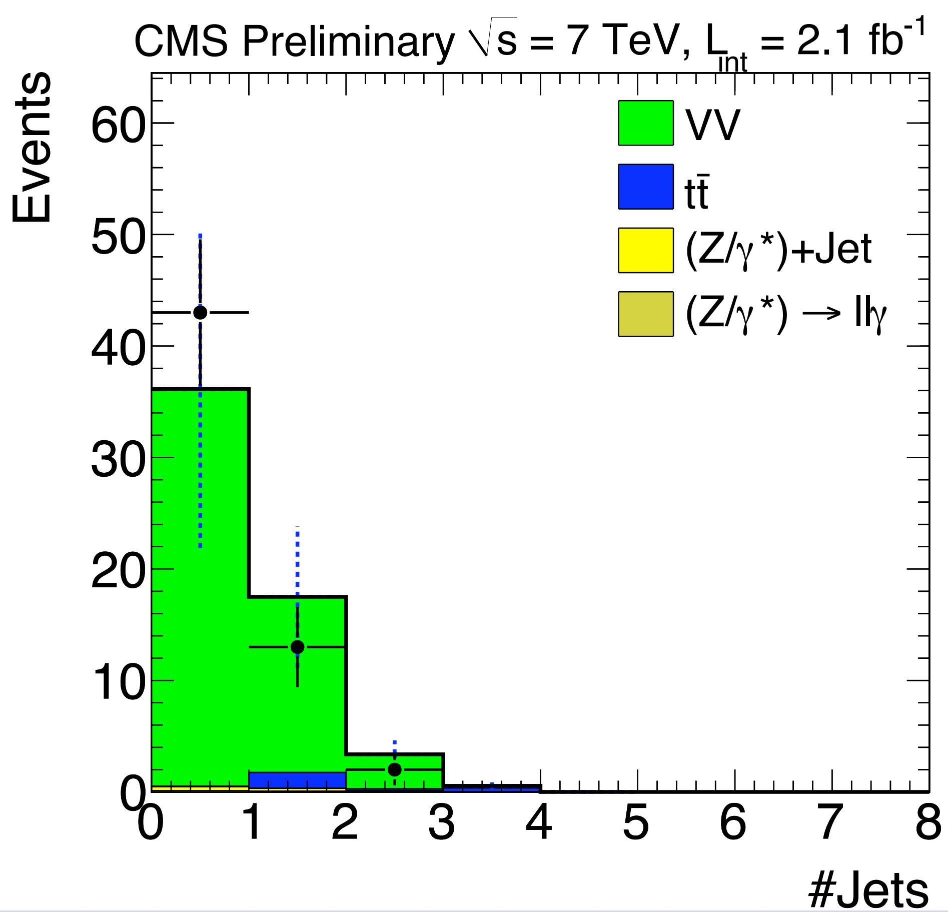
Background Predictions

- The same background estimation methods used in all channels.
- Monte Carlo Predictions (MC)
  - TTbar and Irreducible backgrounds: WZ+Jets, ZZ+Jets
    - Corrected to match efficiency measurements.
    - Scale to match in 3 lepton + MET with Z control
    - Systematic to cover S_T and off Z extrapolation as well as fake rates for ttbar.
- Other backgrounds are "Data Driven"
  - Z+Jets, WW+Jets, W+Jets, QCD
    - No MC required. Use dilepton data, estimate number of 3rd and 4th lepton candidates from jets.
  - Z+Photon Asymmetric Conversion $\gamma \to e^+e^-$ or $\gamma \to \mu^+\mu^-$
    - Estimate number dileptons+photon conversion from data.

W±Z MC Validation with Data

- Validate WZ with control data set
  - 3 e/μ, Z candidate, $H_T < 200$ GeV and MET > 50 GeV



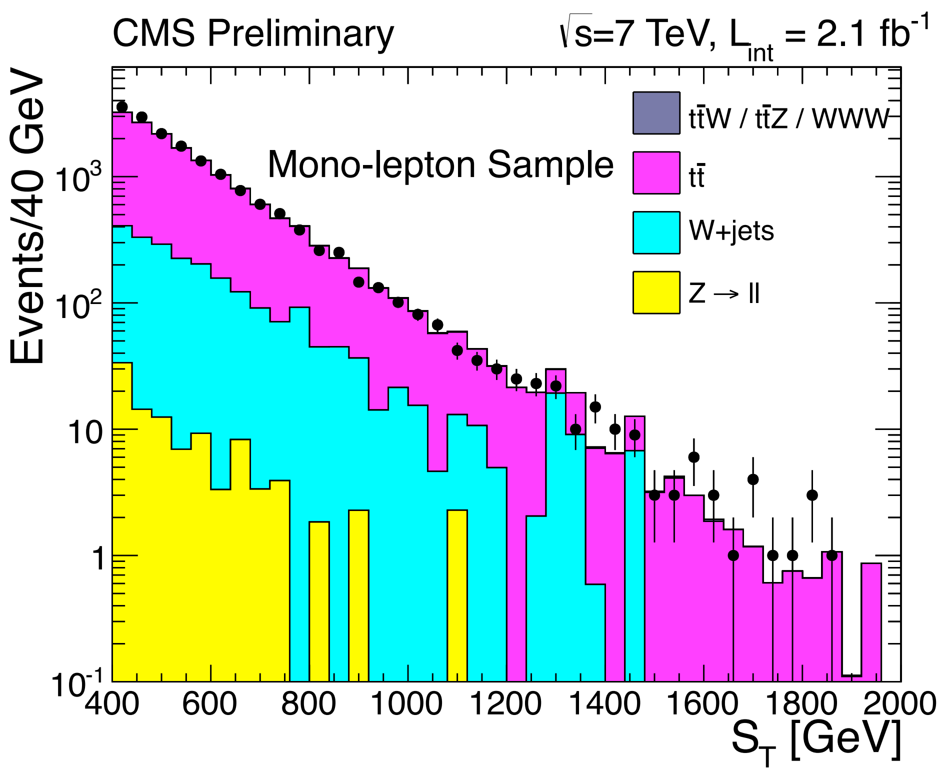


H_T distribution of WZ control data **Number of jets in WZ control data**

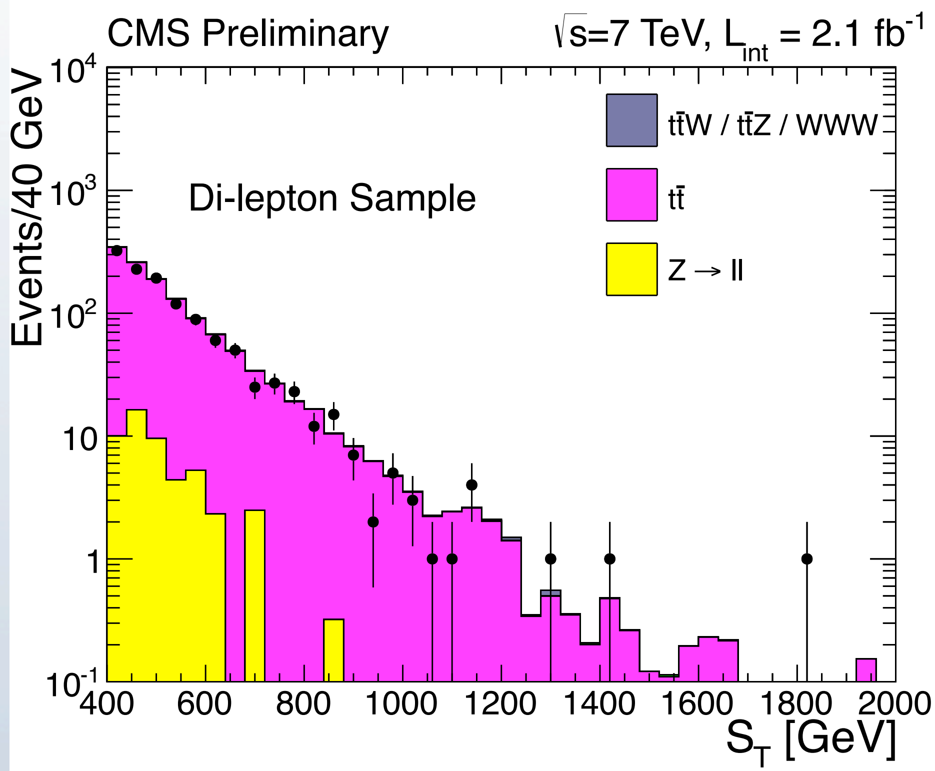
Blue dotted lines are uncertainties (syst+stat) on background.

TTbar MC Validation with Data

- **Validate TTbar with control data set**
  - **1 lepton ($p_T > 30$) + ≥3 jets (≥1 b-jet), or dilepton 1 e + 1 μ**
  - **$S_T > 400$ GeV**
  - **Test the overall number of TTbar and S_T tails.**



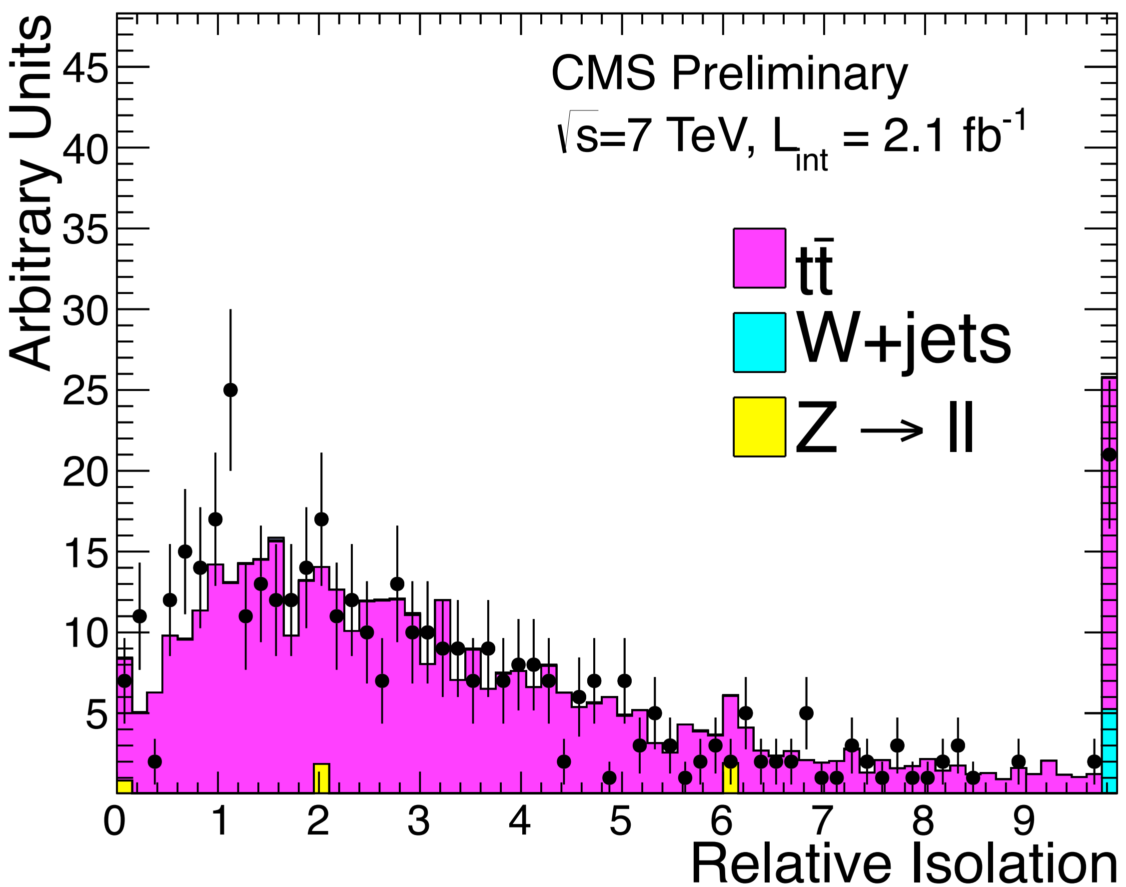
S_T distribution in 1-lepton sample



S_T distribution in e+μ- sample.

TTbar MC Validation with Data (cont..)

- Isolation of leptons from jets in TTbar with control data set
  - 1 lepton + ≥3 jets (≥1 b-jet), test μ with large impact parameter.
    - Require test μ far from leading tagged b-jet. (ΔR > 0.6)



Integrals from Isolation plot:

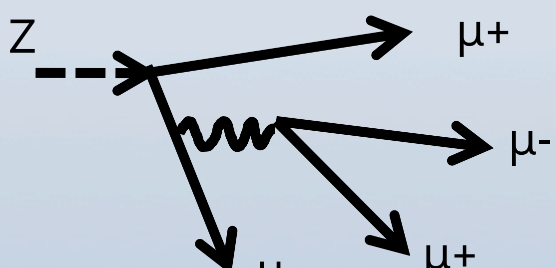
Isolation Range	Data	MC
0.15-0.45	13	11
0.0-0.15	7	8
0.0-0.45	20	20
0.0-1.05	78	66

Data Driven Background Predictions

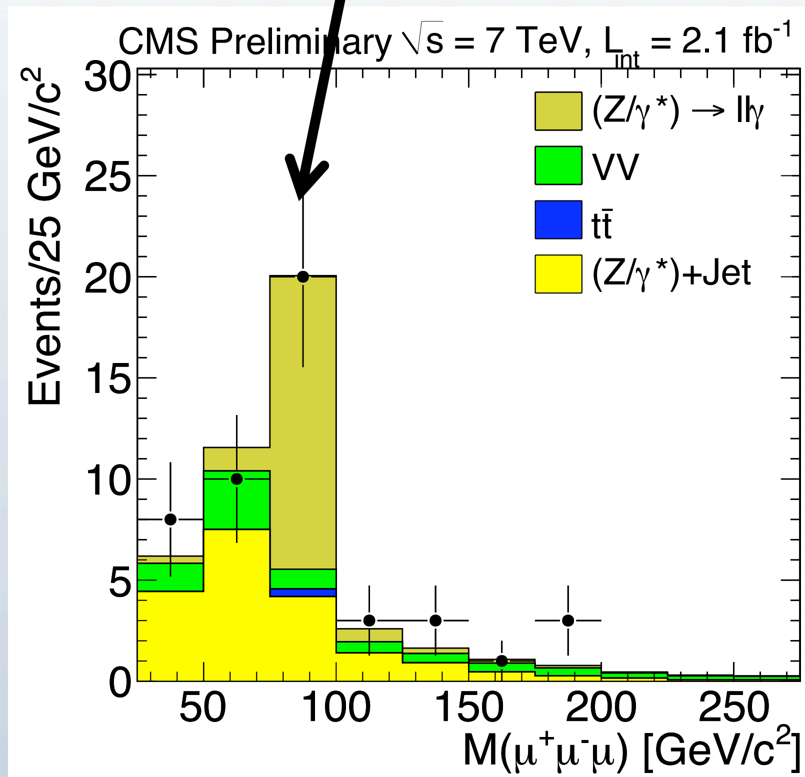
- Number e/μ from jets proportional to number k/π from jets.
  - Count isolated tracks to imply number of leptons from jets.
  - Determine conversion factor in di-jet data.
  - Use impact parameter distribution of tracks to understand systematic.
- Use isolation side band for fake Tau background.
  - Use di-jet data to parameterize conversion factor.
  - Use region beyond sideband to understand systematic.
- Asymmetric conversion background proportional to photons.
  - Count photons, treat them as leptons.
  - Determine a conversion factor from $Z \rightarrow l^+l^-$ +FSR
    - Process creates a 3 body Z peak.
    - Look for 3 body Z peak with $l^+l^-\gamma$ and compare to $l^+l^-l^\pm$

Asymmetric Photon Conversions to $\mu^+\mu^-$

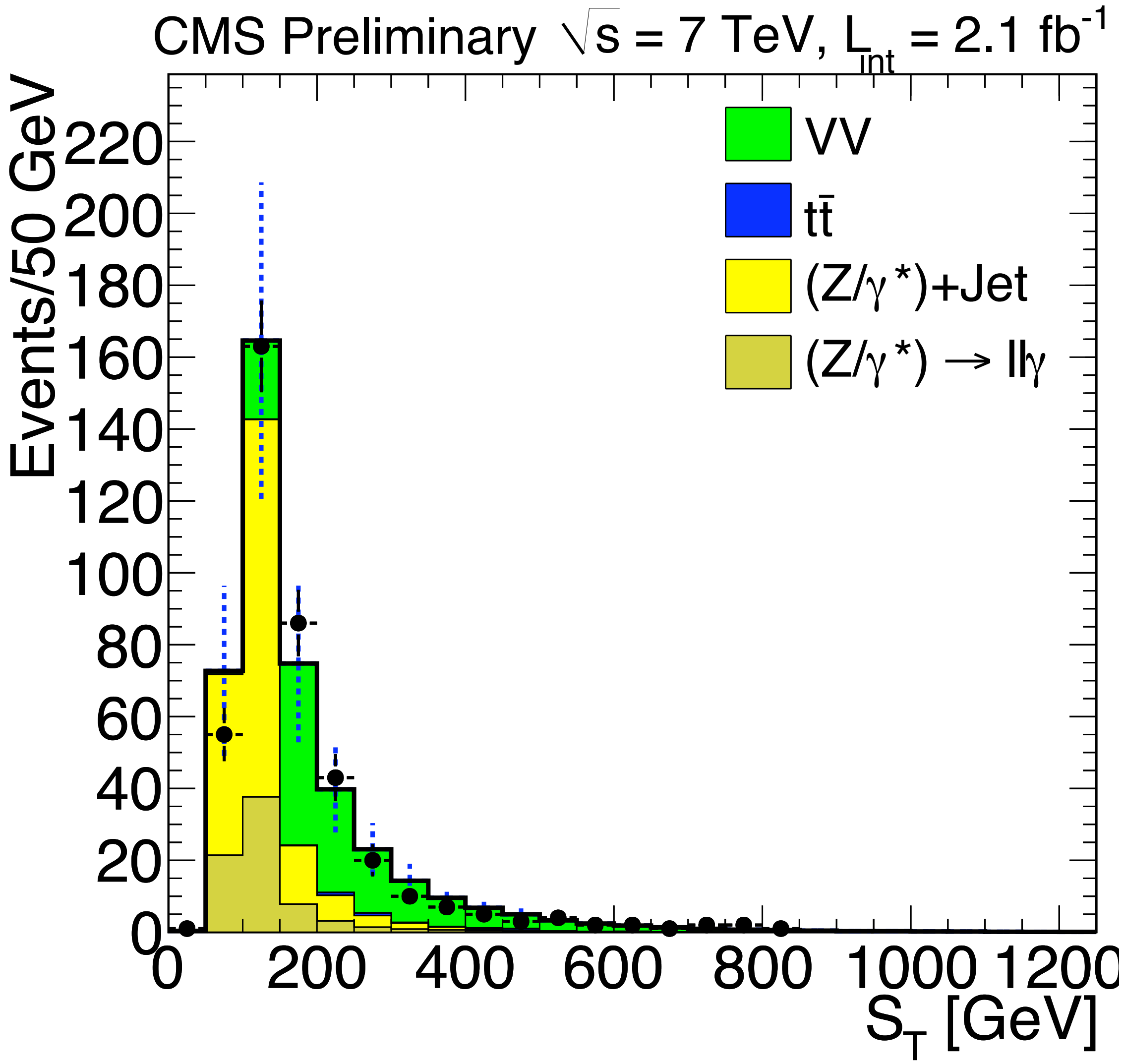
- **Two types of asymmetric photon conversions:**
  - **External: Due to interactions in material, gives only e+e-**
  - **Internal: Feynman level (Y*) gives e+e- and μ+μ-**
- **2011 Z→4μ dalitz decay visible.**
  - **Seen at LEP, but not published.**
  - **Analogous to π⁰ → e+e-γ**
  - **Observe 3μ Z peak (4^{th} μ failed cuts)**
  - **If we see Z→3μ, there should also be W→2μ+neutrino! (Higgs!!)**
    - **hep-ph:arXiv:1110.1368 R. C. Gray et. al.**



Peak removed in Low S_T bin (75-105)



Three Lepton S_T Distributions with l^+l^- on Z (Background Test)



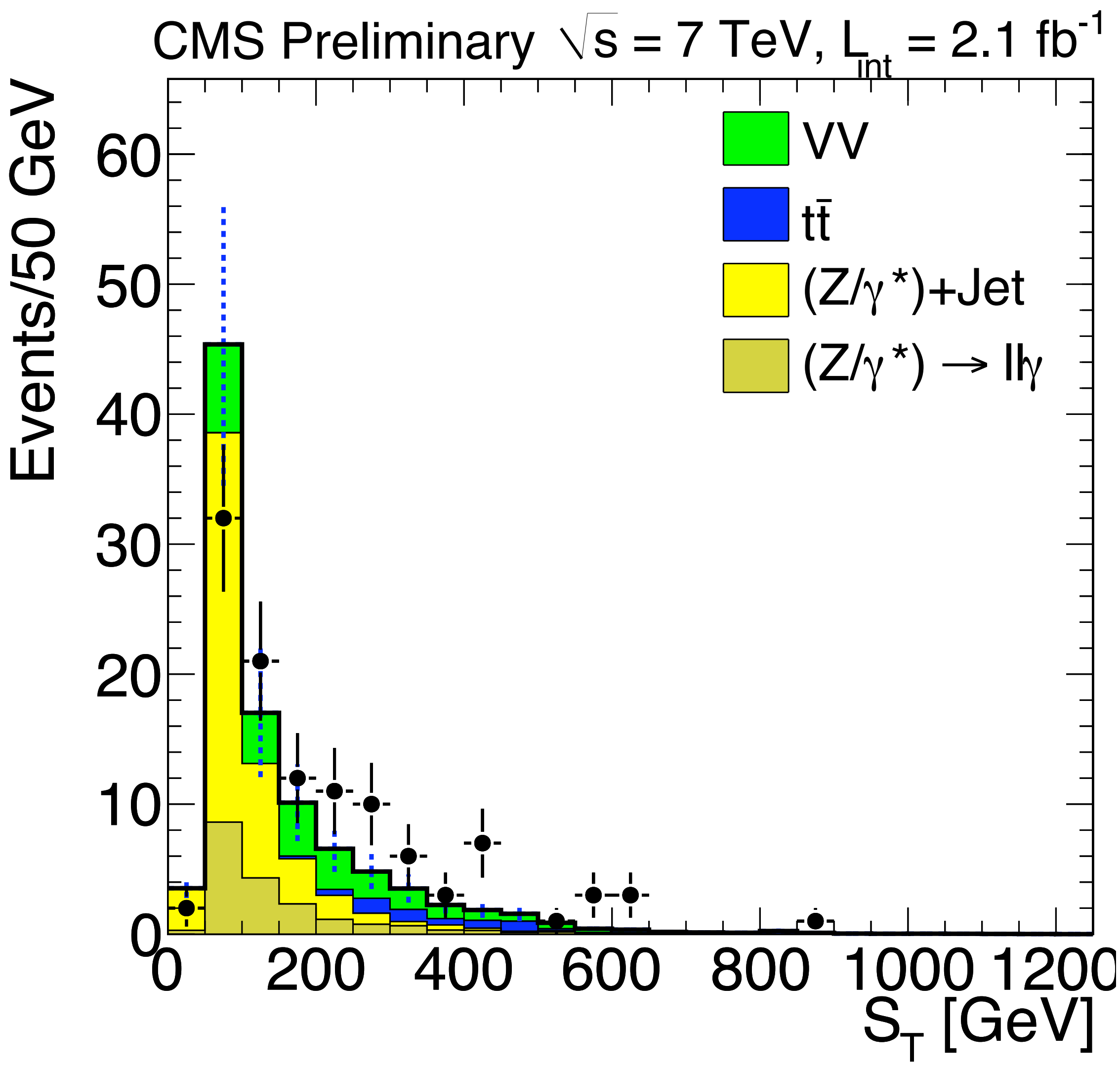
S_T distribution of three lepton events that have a Z candidate.

If we assume new physics does not come with Z's, this is a good test that the SM predictions are working.

The yellow histograms are data driven predictions.

Dashed blue lines are background uncertainties.

Three Lepton S_T Distributions with l^+l^- off Z (Signal Channel)



S_T distribution of three lepton events that have a an l+l- pair, but does not make a Z.

One of our signal channels. New physics would be seen as an excess of events at large S_T

The yellow histograms are data driven predictions.

Dashed blue lines are background uncertainties.

Results Summarized in 52 bins

$(N_{DY})x(S_T)x(llll, lll\tau, ll\tau\tau, lll, ll\tau, l\tau\tau)$

Number of Tau candidates (0,1,2) →

≥4 Leptons

Selection			4(e/μ)		3(e/μ)+T		2(e/μ)+2T	
ST	DYpairs	Z?	SM	Obs	SM	Obs	SM	Obs
> 600	DY0		0.0000 ± 0.0007	0	0.00 ± 0.09	0	0.09 ± 0.07	0
300-600	DY0		0.001 ± 0.002	0	0.11 ± 0.10	0	0.68 ± 0.30	0
0-300	DY0		0.02 ± 0.02	0	1.69 ± 0.27	0	1.34 ± 0.41	4
> 600	DY1		0.002 ± 0.001	1	0.02 ± 0.07	0	0.10 ± 0.07	0
>600	DY1	Z	0.010 ± 0.004	1	0.22 ± 0.10	0	0.15 ± 0.07	0
300-600	DY1		0.008 ± 0.003	0	0.20 ± 0.09	0	0.45 ± 0.19	0
300-600	DY1	Z	0.27 ± 0.11	0	1.38 ± 0.38	2	1.52 ± 0.44	2
0-300	DY1		0.03 ± 0.01	0	2.2 ± 1.4	4	10.0 ± 7.8	10
0-300	DY1	Z	0.37 ± 0.13	0	6.6 ± 1.5	14	30 ± 22	56
>600	DY2		0.005 ± 0.002	0	--	--	--	--
>600	DY2	Z	0.33 ± 0.13	0	--	--	--	--
300-600	DY2		0.022 ± 0.009	0	--	--	--	--
300-600	DY2	Z	2.2 ± 0.9	1	--	--	--	--
0-300	DY2		0.04 ± 0.02	0	--	--	--	--
0-300	DY2	Z	7.2 ± 2.9	10	--	--	--	--
4-body			10.4 ± 3.1	13	12.4 ± 2.1	20	44 ± 23	72

3 Leptons

Selection			3(e/μ)		2(e/μ)+T		1(e/μ)+2T	
ST	DYpairs	Z?	SM	Obs	SM	Obs	SM	Obs
>600	DY0		0.53 ± 0.25	2	5.5 ± 1.9	10	15.5 ± 3.6	10
300-600	DY0		3.8 ± 1.5	3	45 ± 15	63	114 ± 16	106
0-300	DY0		6.4 ± 2.0	9	236 ± 42	291	2054 ± 404	1590
>600	DY1		1.34 ± 0.40	4	8.8 ± 1.6	5	--	--
>600	DY1	Z	7.9 ± 2.6	8	18.5 ± 2.7	21	--	--
300-600	DY1		10.2 ± 2.8	20	64 ± 12	71	--	--
300-600	DY1	Z	43 ± 13	31	222 ± 23	216	--	--
0-300	DY1		85 ± 21	88	2004 ± 441	2579	--	--
0-300	DY1	Z	381 ± 92	368	7839 ± 1725	9611	--	--
3-body			539 ± 95	533	10443 ± 1781	12867	2184 ± 404	1706

Exclusion contours from a multichannel likelihood from the 52 channels shown here.

The signal model defines which bins are signal bins and which are control bins.

The same background estimation techniques are applied to all bins.

MET vs H_T tables in extra slides. Produced by same overall package.

3(e/μ) Lepton Results

Selection			3(e/μ)	
ST	DYpairs	Z?	SM	Obs
>600	DY0		0.53 ± 0.25	2
300-600	DY0		3.8 ± 1.5	3
0-300	DY0		6.4 ± 2.0	9
>600	DY1		1.34 ± 0.40	4
>600	DY1	Z	7.9 ± 2.6	8
300-600	DY1		10.2 ± 2.8	20
300-600	DY1	Z	43 ± 13	31
0-300	DY1		85 ± 21	88
0-300	DY1	Z	381 ± 92	368
3-body			539 ± 95	533

High S_T Control Channel

Mid S_T Control Channel

Low S_T Control Channels

- Control channels have been highlighted. Other channels are potential signal channels.

All 3 Lepton Results

- Below shows results including channels with Tau
  - All bins are exclusive.

Selection			3(e/μ)		2(e/μ)+T		1(e/μ)+2T	
ST	DYpairs	Z?	SM	Obs	SM	Obs	SM	Obs
>600	DY0		0.53 ± 0.25	2	5.5 ± 1.9	10	15.5 ± 3.6	10
300-600	DY0		3.8 ± 1.5	3	45 ± 15	63	114 ± 16	106
0-300	DY0		6.4 ± 2.0	9	236 ± 42	291	2054 ± 404	1590
>600	DY1		1.34 ± 0.40	4	8.8 ± 1.6	5	--	--
>600	DY1	Z	7.9 ± 2.6	8	18.5 ± 2.7	21	--	--
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0-300	DY1	Z	381 ± 92	368	7839 ± 1725	9611	--	--
3-body			539 ± 95	533	10443 ± 1781	12867	2184 ± 404	1706

4(e/μ) Lepton Results

Selection			4(e/μ)	
ST	DYpairs	Z?	SM	Obs
> 600	DY0		0.0000 ± 0.0007	0
300-600	DY0		0.001 ± 0.002	0
0-300	DY0		0.02 ± 0.02	0
> 600	DY1		0.002 ± 0.001	1
>600	DY1	Z	0.010 ± 0.004	1
300-600	DY1		0.008 ± 0.003	0
300-600	DY1	Z	0.27 ± 0.11	0
0-300	DY1		0.03 ± 0.01	0
0-300	DY1	Z	0.37 ± 0.13	0
>600	DY2		0.005 ± 0.002	0
>600	DY2	Z	0.33 ± 0.13	0
300-600	DY2		0.022 ± 0.009	0
300-600	DY2	Z	2.2 ± 0.9	1
0-300	DY2		0.04 ± 0.02	0
0-300	DY2	Z	7.2 ± 2.9	10
4-body			10.4 ± 3.1	13

- Two events in very low background channels.
- These could become interesting if we see more with additional data.

High S_T Control Channel

Mid S_T Control Channel

Low S_T Control Channels

All 4 Lepton Results

- Below shows results including channels with Tau
  - All bins are exclusive.

Selection			4(e/μ)		3(e/μ)+T		2(e/μ)+2T	
ST	DYpairs	Z?	SM	Obs	SM	Obs	SM	Obs
> 600	DY0		0.0000 ± 0.0007	0	0.00 ± 0.09	0	0.09 ± 0.07	0
300-600	DY0		0.001 ± 0.002	0	0.11 ± 0.10	0	0.68 ± 0.30	0
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> 600	DY1		0.002 ± 0.001	1	0.02 ± 0.07	0	0.10 ± 0.07	0
>600	DY1	Z	0.010 ± 0.004	1	0.22 ± 0.10	0	0.15 ± 0.07	0
300-600	DY1		0.008 ± 0.003	0	0.20 ± 0.09	0	0.45 ± 0.19	0
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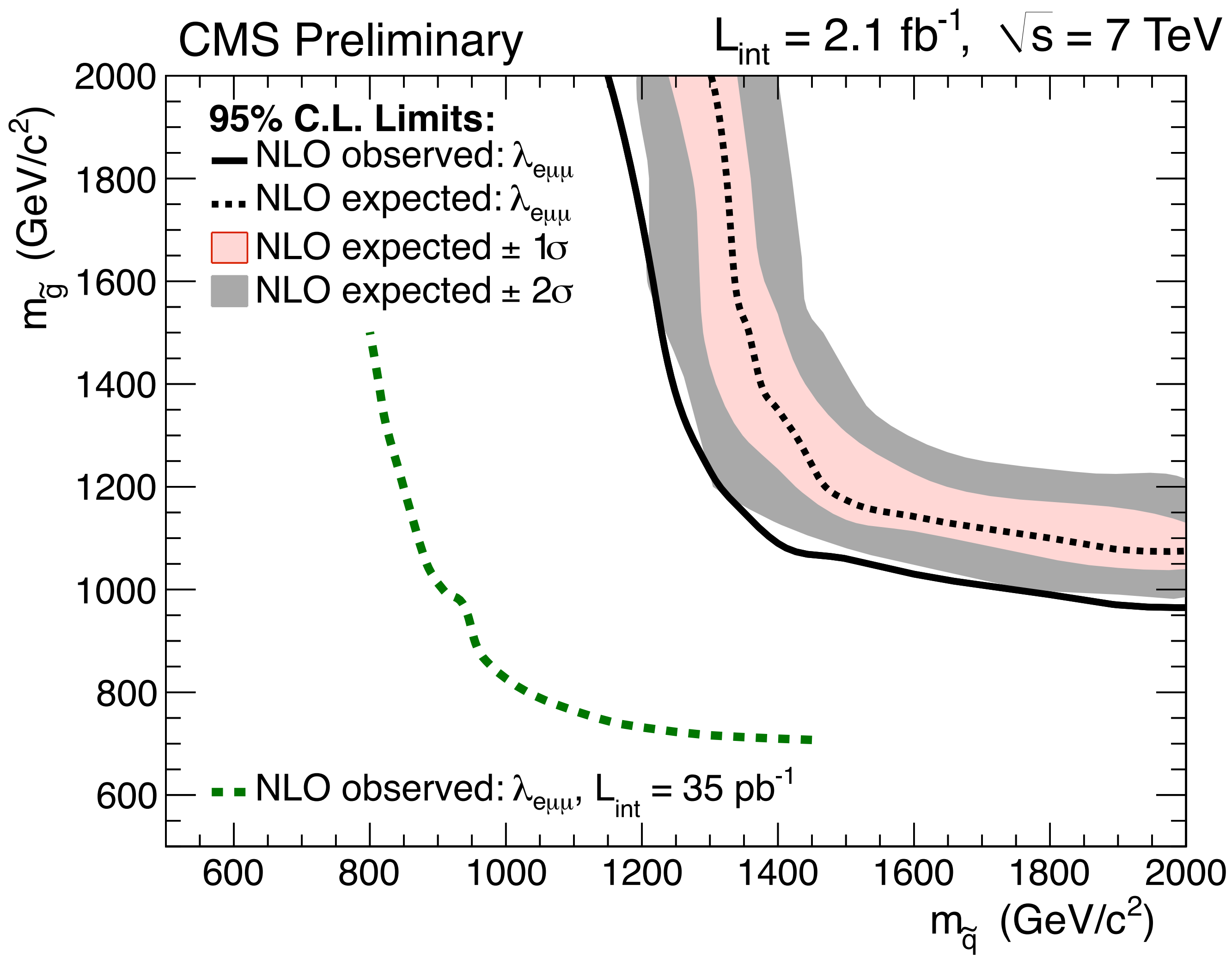
>600	DY2	Z	0.33 ± 0.13	0	--	--	--	--
300-600	DY2		0.022 ± 0.009	0	--	--	--	--
300-600	DY2	Z	2.2 ± 0.9	1	--	--	--	--
0-300	DY2		0.04 ± 0.02	0	--	--	--	--
0-300	DY2	Z	7.2 ± 2.9	10	--	--	--	--
4-body			10.4 ± 3.1	13	12.4 ± 2.1	20	44 ± 23	72

RPV $\lambda_{e\mu\mu}$ Exclusion Contour



Exclusion contour for RPV coupling λeμμ.

Plotted in Mgluino vs Msquark.

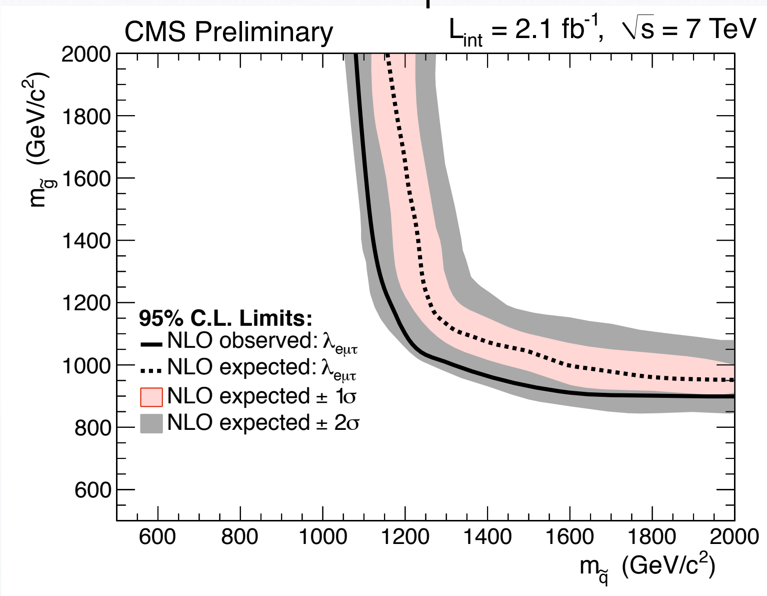
Everything below solid black line is excluded.

Dashed green line is our 2010 Multilepton Result.

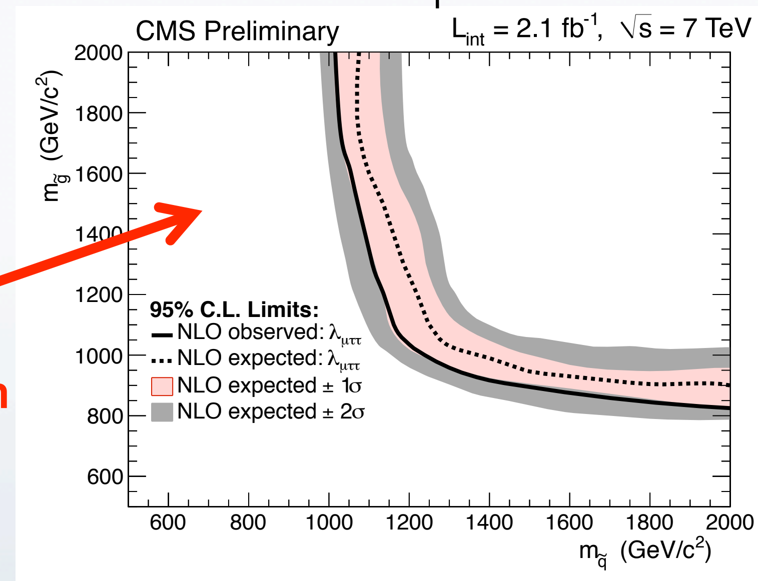
We show observed, expected, and ±1σ and ±2σ bands on expected.

Other RPV Exclusion Contours

Exclusion for $\lambda_{e\mu\tau}$ Coupling

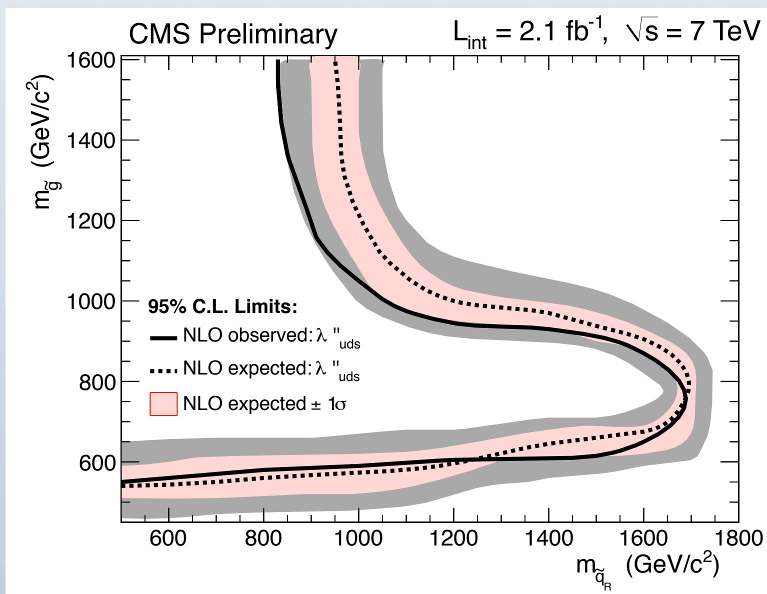


Exclusion for $\lambda_{\mu\tau\tau}$ Coupling



Tau reconstruction important for $\lambda_{\mu\tau\tau}$

Exclusion for Hadronic λ''_{uds} Coupling



Hadronic RPV has little MET.

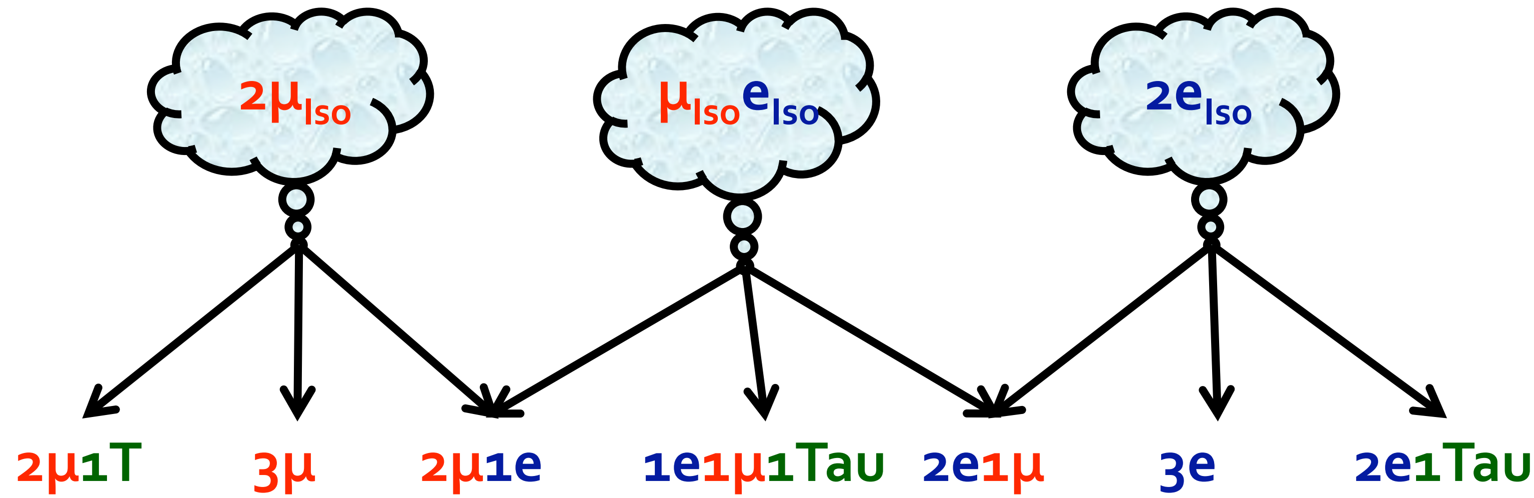
Conclusions

- Presented ≥3 lepton search with 2.1 fb-1 of 2011 data
  - Use combination of MC and data-driven for SM background. The same methods/MC are used in each channel.
  - Data binned in number DY candidates, S_T, on/off Z.
  - Background and signal channels are simultaneously examined.
  - High statistic bins are in good agreement with SM
  - Set new limits on RPV scenarios that produce multileptons
- Good agreement between observations and SM predictions for high statistic channels.
- More than 3 fb^{-1} of additional luminosity currently on disk, we will continue to search for new physics!

BACKUP

Data Driven Predictions

- Use 2L data as a seed to predict ≥3L background
  - Example: 2e(SS) to predict 2e(SS)μ background



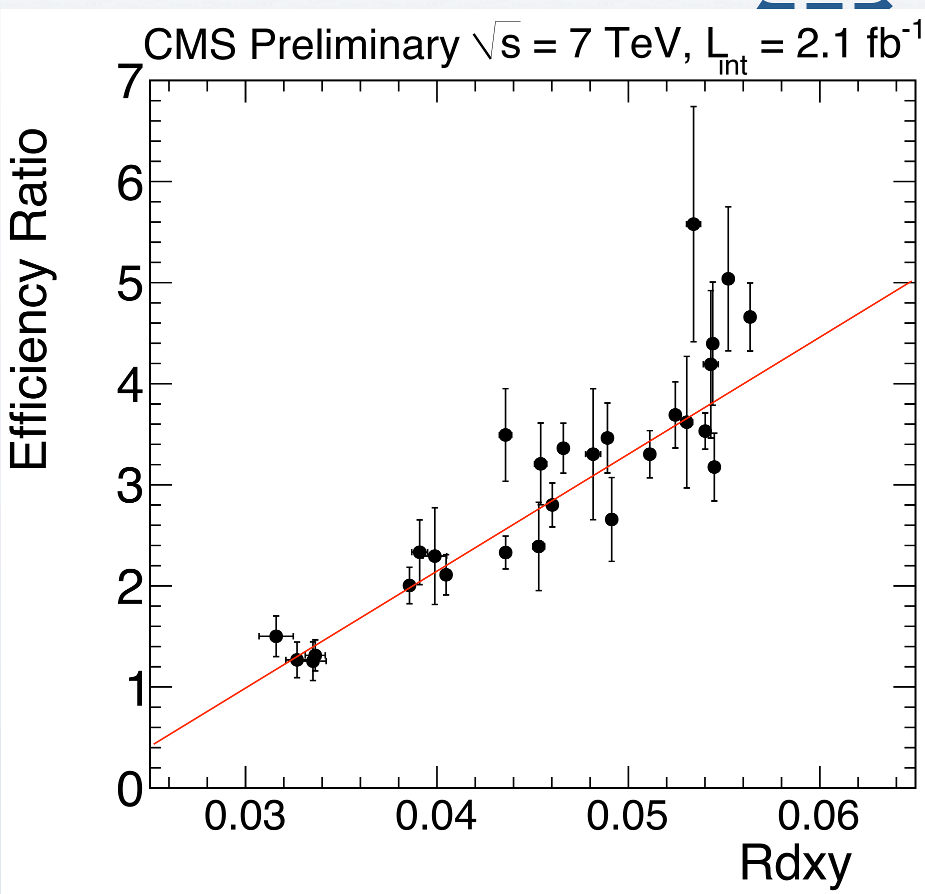
- Apply background estimation procedures to seeds.
  - Predict e or μ from jet using isolated tracks (~15% systematic)
  - Predict fake Tau using isolation side band. (~25% systematic)
  - Predict leptons from conversions using photons. (~100% systematic)

Isolated Track→e/μ Scale Factor

- **Conversion Factor (f_L), in terms of:**
  - Non-isolated leptons (N_L), Non-isolated tracks (N_T), Ratio isolation efficiencies. ($\varepsilon^{\mu}_{Iso}/\varepsilon^{T}_{Iso}$)

$$f_\mu = \frac{N_\mu^{Iso}}{N_T^{Iso}} = \frac{N_\mu}{N_T} \times \frac{\epsilon_{Iso}^{\mu}}{\epsilon_{Iso}^{T}}$$

Parameterize in di-jet data as a function of R_{dxy} (fraction of non-isolated tracks with large impact parameter)

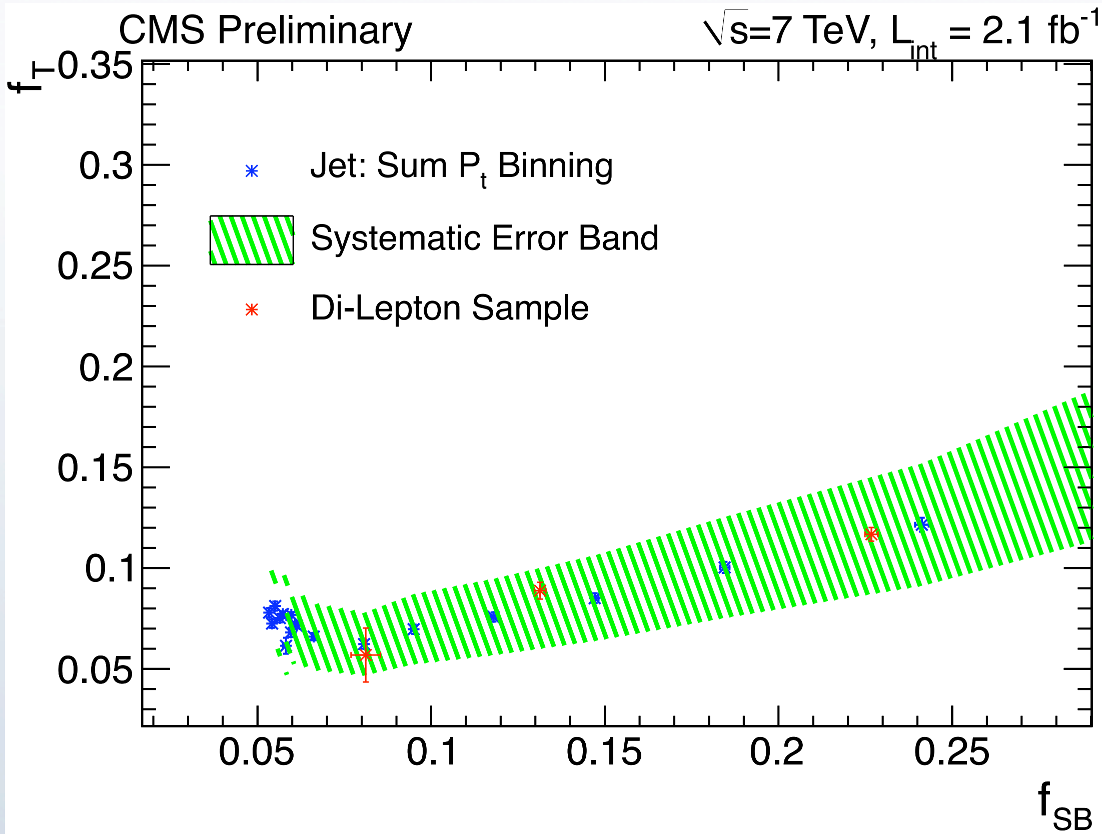


Tau Background Estimation

"f_T vs f_{SB}" Examples

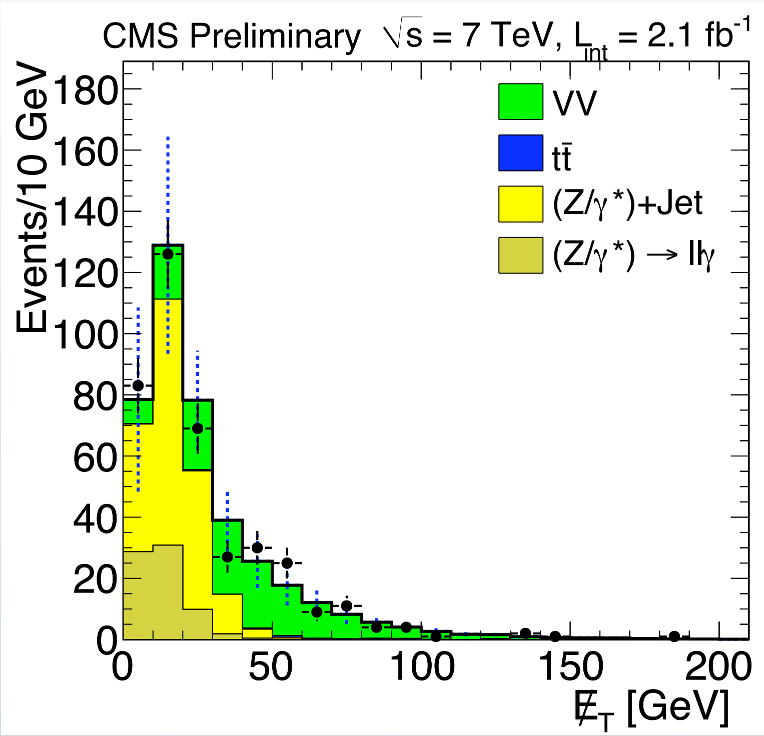
- Isolated (Iso): 0.00-0.15
- Side Band (SB): 0.20-0.50
- Other (O): Everything Else
- Use N_{SB} and N_O to predict N_{iso}
- Define f_T: $N_{Iso} = f_T \times N_{SB}$
- Define f_{SB}: $f_{SB} = N_{SB}/(N_{SB}+N_O)$
- Measure in Data:

  f_T vs f_{SB}

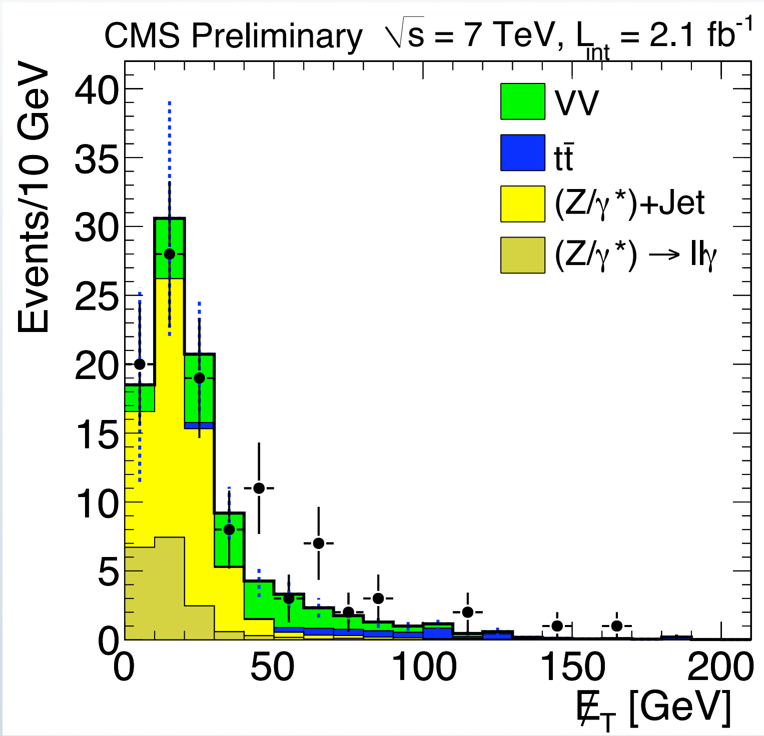


MET Distribution
3(e/μ), DY=1, HT<200 GeV

on Z

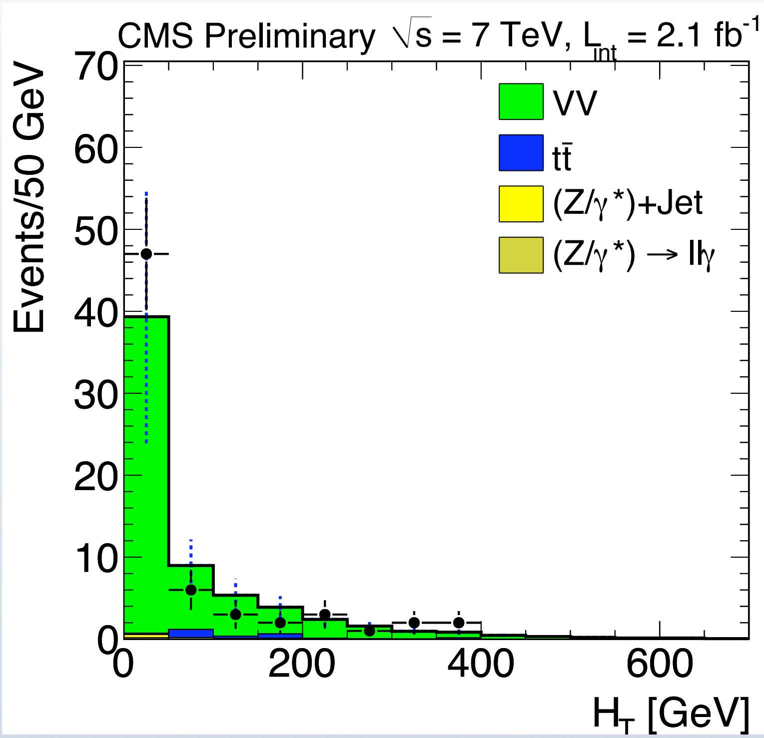


off Z

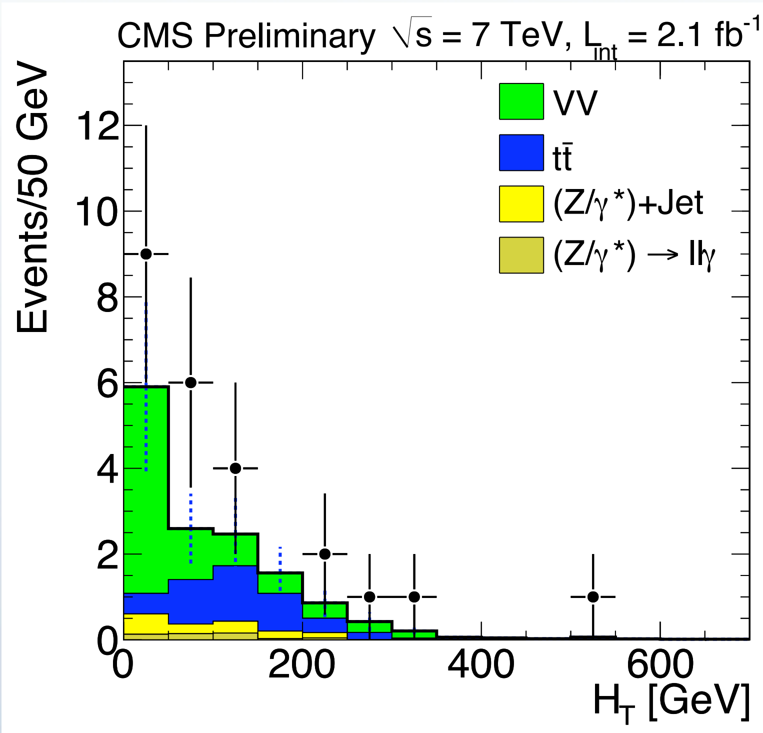


H_T Distribution
3(e/μ), DY=1, MET > 50 GeV

on Z



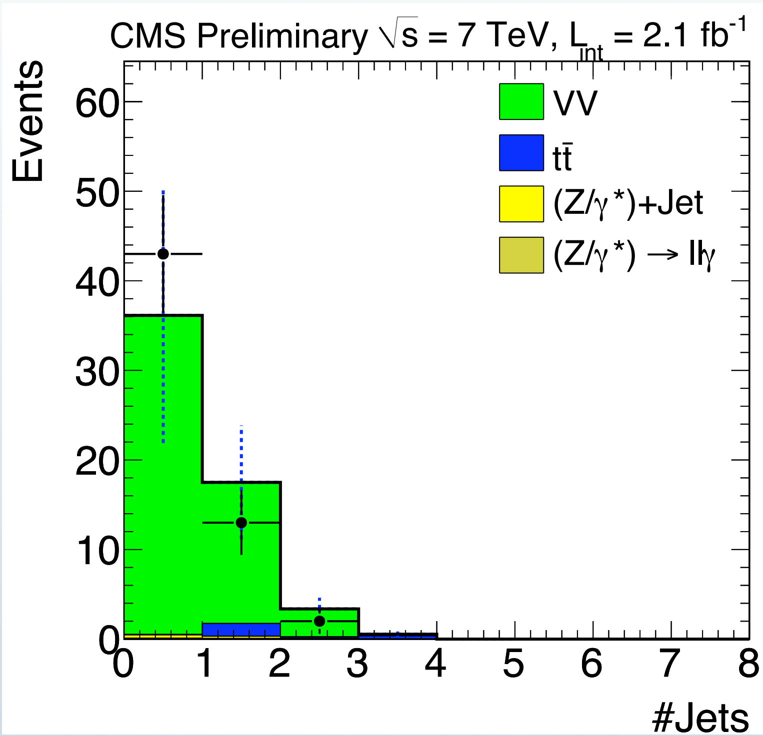
off Z



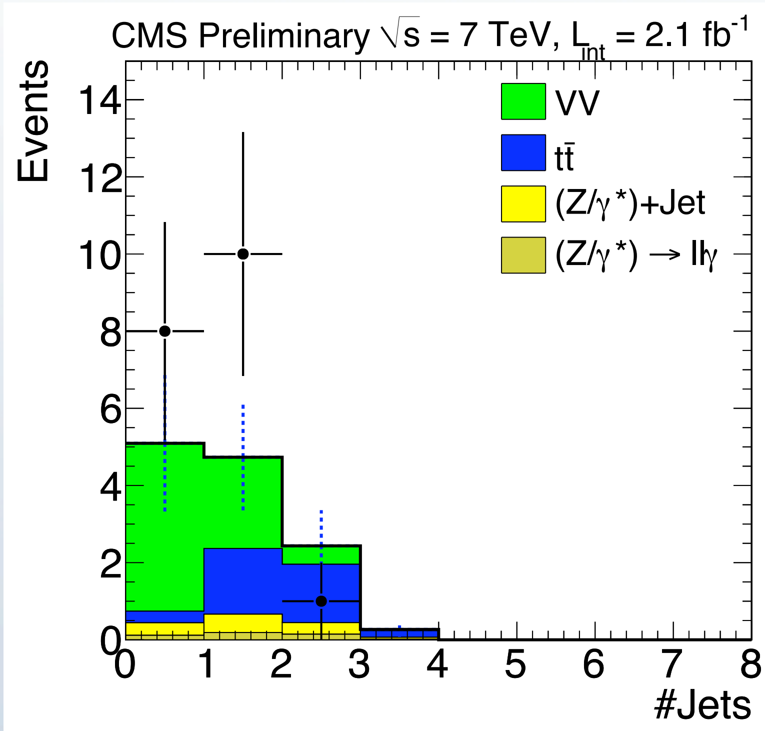
Jets p_T > 40 GeV

3(e/μ), DY=1, MET > 50 GeV, HT < 200 GeV

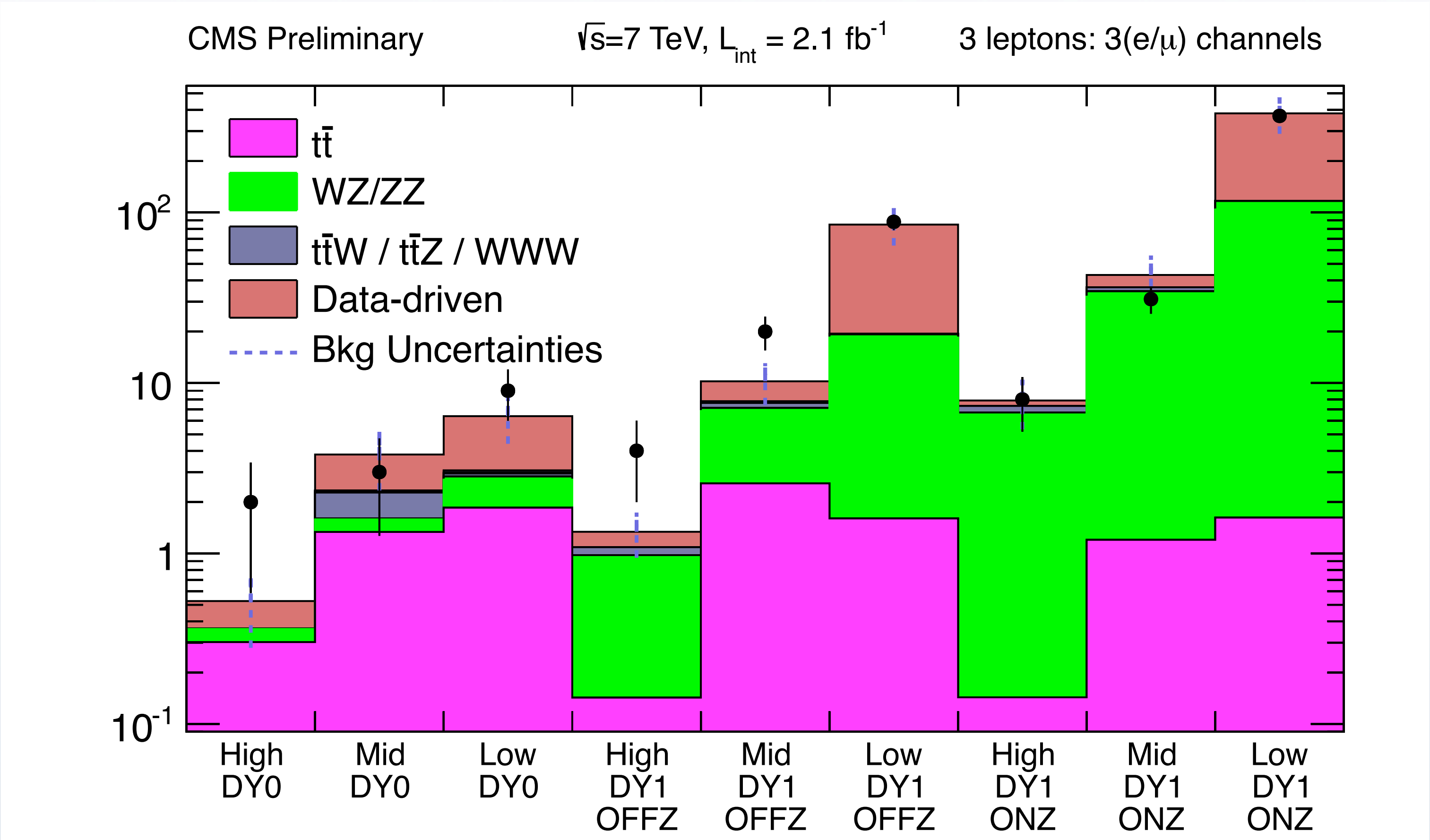
on Z



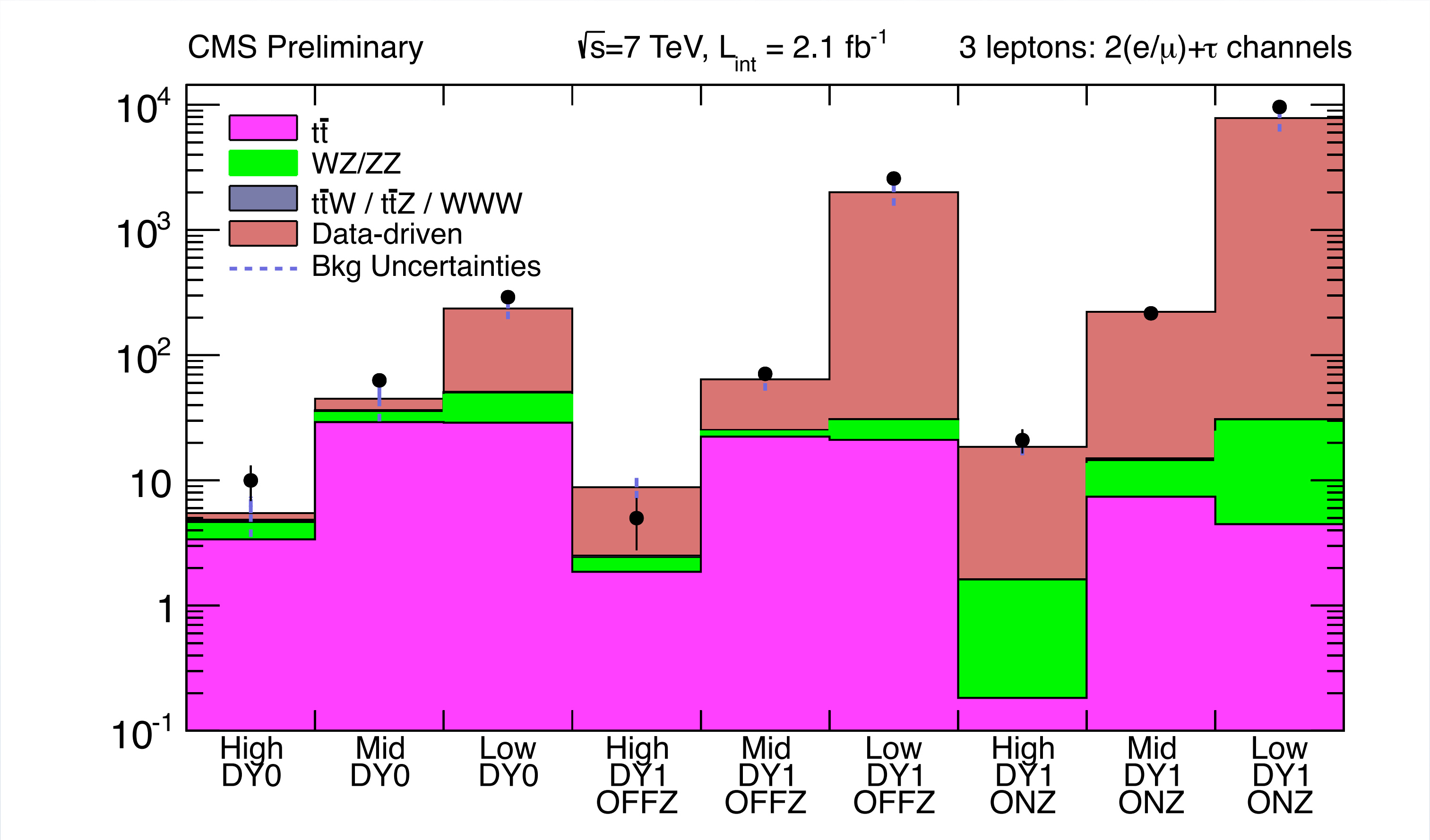
off Z



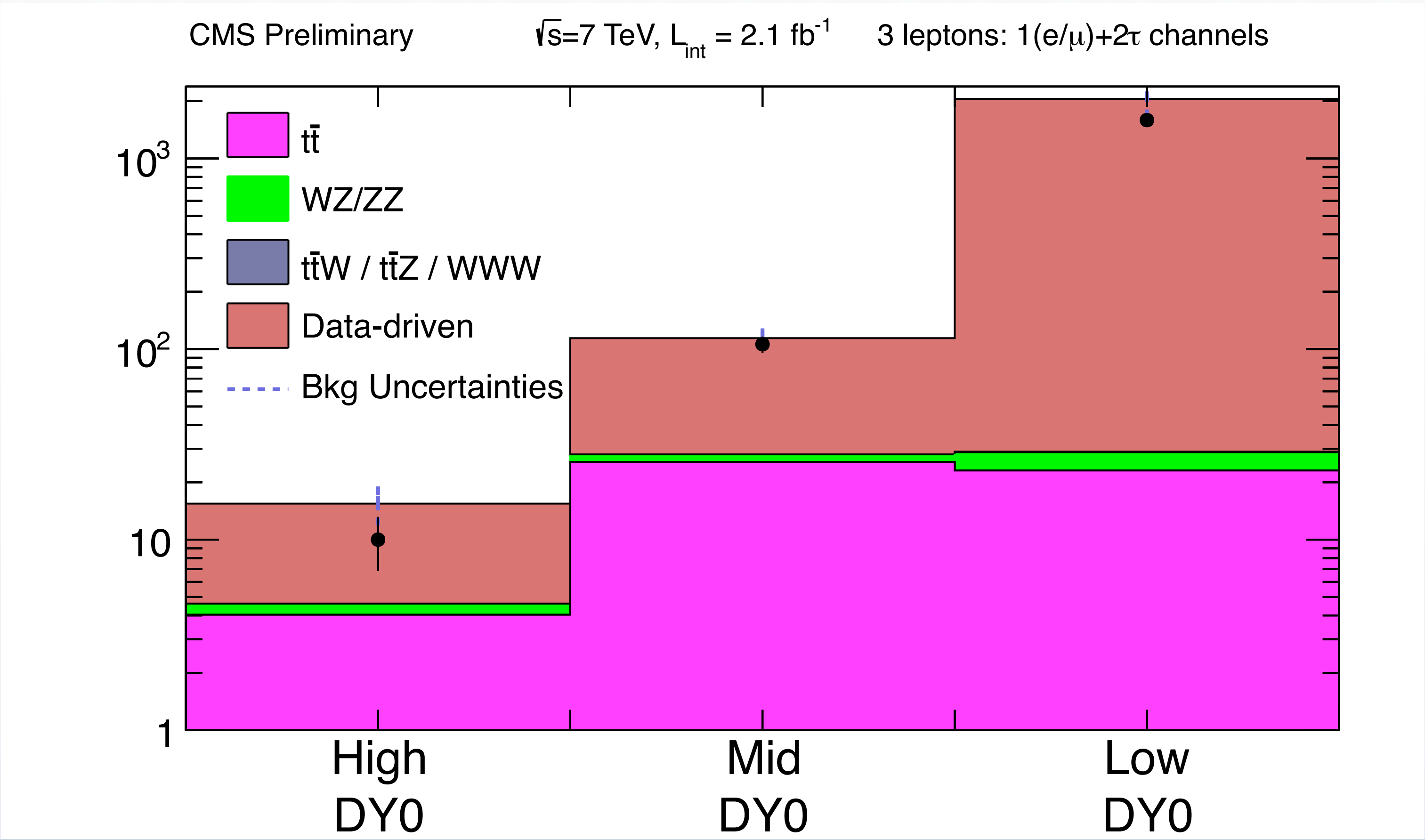
3(e/μ) S_T Analysis



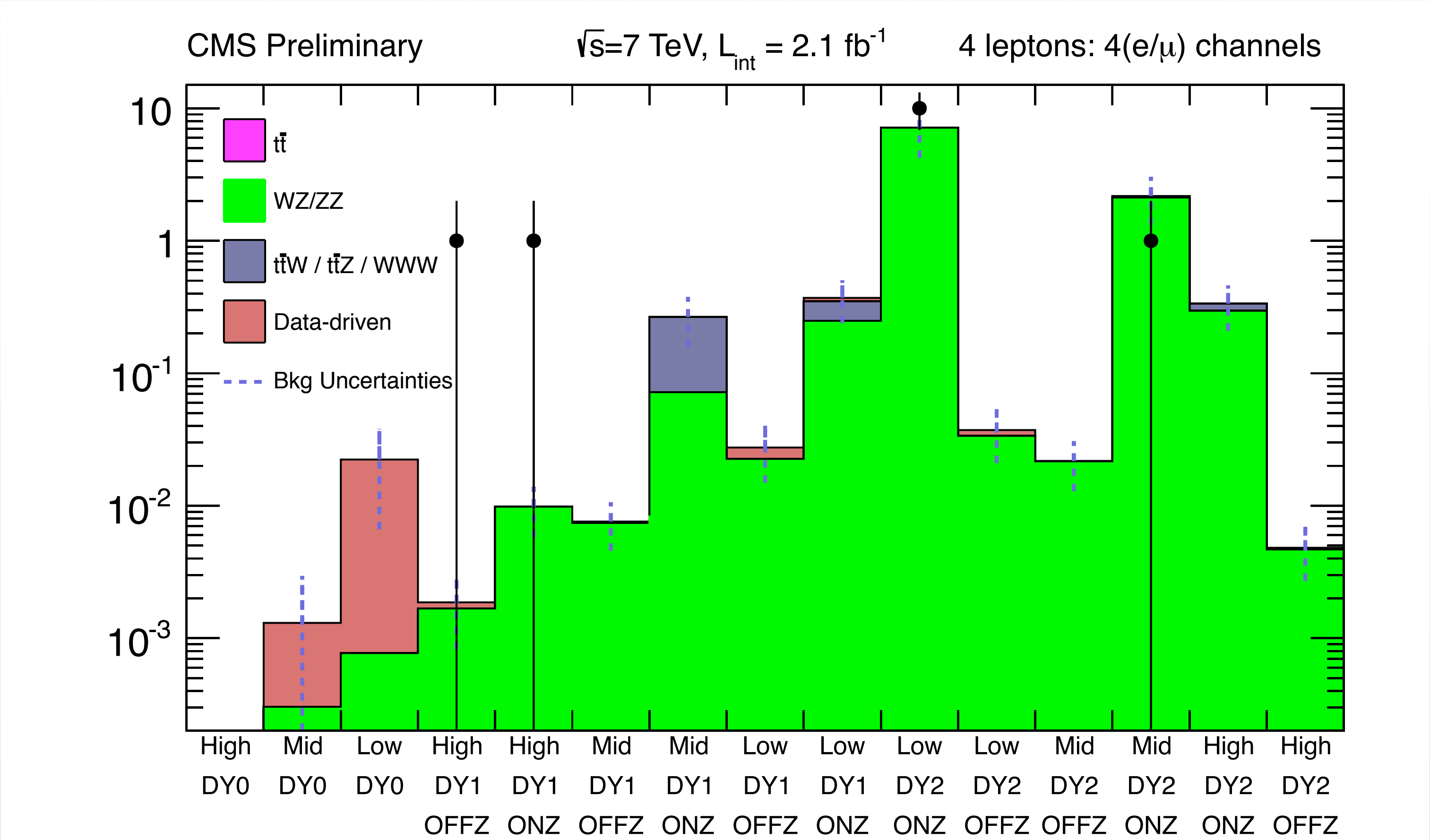
2(e/μ)+1Tau S_T Analysis



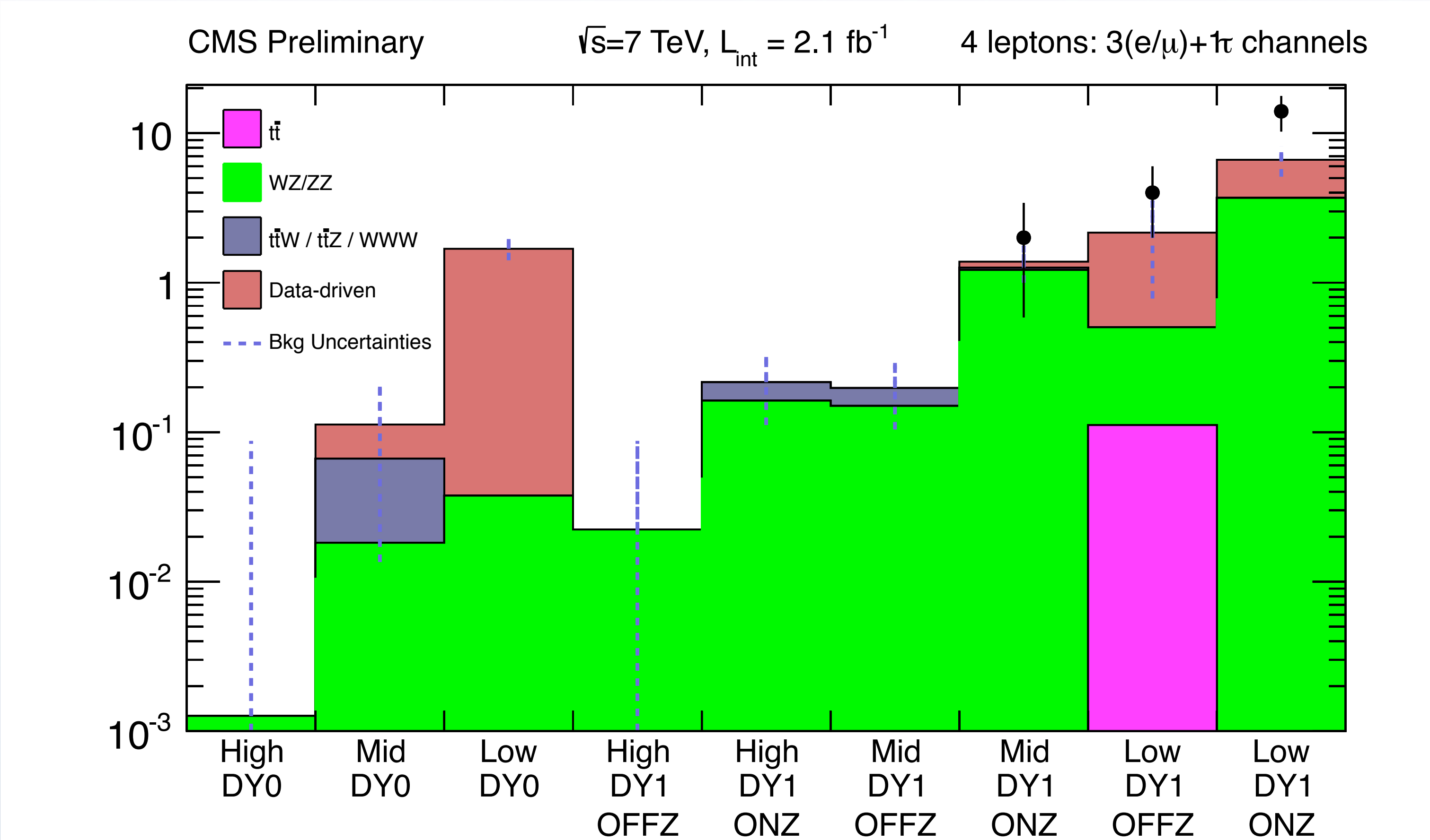
1(e/μ)+2Tau S_T Analysis



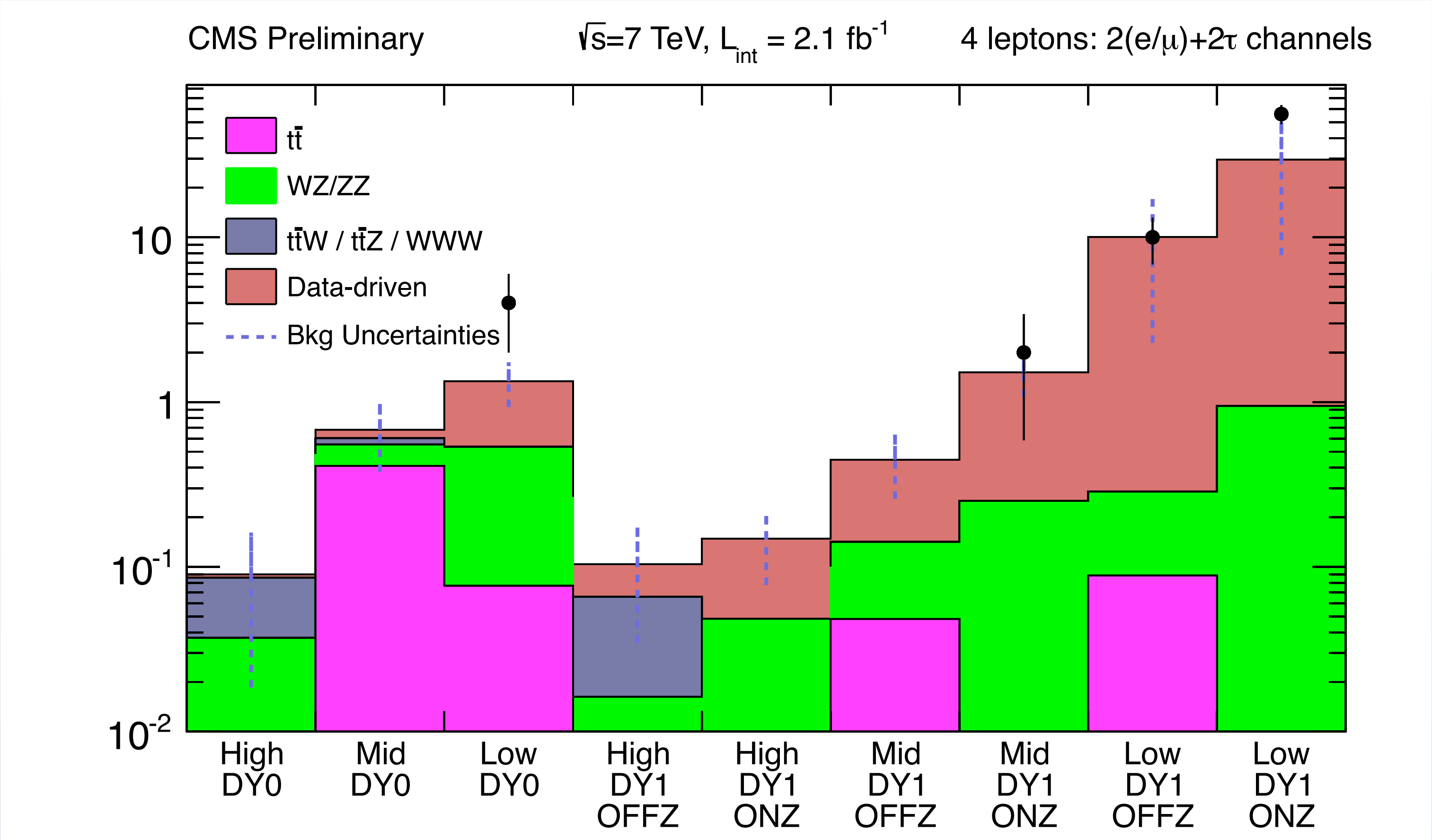
4(e/μ) S_T Analysis



3(e/μ)+1 Tau S_T Analysis



2(e/μ)+2Tau S_T Analysis



MET vs H_T 3 Lepton

Selection			3(e/μ)		2(e/μ)+T		1(e/μ)+2T	
MET?	HT?	Z?	SM	Obs	SM	Obs	SM	Obs
MET>50	HT>200	n/a	0.87 ± 0.33	2	14.3 ± 4.8	21	10.4 ± 2.2	12
MET>50	HT<200	n/a	3.7 ± 1.2	4	68 ± 17	88	100 ± 17	76
MET<50	HT>200	n/a	0.50 ± 0.33	1	7.7 ± 2.3	12	24.7 ± 4.0	22
MET<50	HT<200	n/a	5.0 ± 1.7	7	208 ± 39	245	1157 ± 323	976
MET>50	HT>200	noZ	1.9 ± 0.5	5	10.8 ± 3.3	7	--	--
MET>50	HT>200	Z	8.1 ± 2.7	8	11.2 ± 2.5	10	--	--
MET>50	HT<200	noZ	11.6 ± 3.2	19	52 ± 13	64	--	--
MET<50	HT>200	noZ	2.0 ± 0.7	5	26.6 ± 3.3	24	--	--
MET>50	HT<200	Z	57 ± 21	58	44.1 ± 7.0	47	--	--
MET<50	HT>200	Z	8.2 ± 2.0	6	119 ± 14	90	--	--
MET<50	HT<200	noZ	82 ± 21	86	1965 ± 438	2566	--	--
MET<50	HT<200	Z	359 ± 89	335	7740 ± 1698	9720	--	--
SUM	3-body		539 ± 94	536	10267 ± 175	12894	1291 ± 324	1086

MET vs H_T 4 Lepton

Selection			4(e/μ)		3(e/μ)+T		2(e/μ)+2T	
MET?	HT?	Z?	SM	Obs	SM	Obs	SM	Obs
MET>50	HT>200	NoZ	0.003 ± 0.002	0	0.01 ± 0.05	0	0.30 ± 0.22	0
MET>50	HT>200	Z	0.06 ± 0.04	0	0.13 ± 0.10	0	0.15 ± 0.23	0
MET>50	HT<200	NoZ	0.014 ± 0.005	1	0.22 ± 0.10	0	0.59 ± 0.25	0
MET<50	HT>200	NoZ	0.43 ± 0.15	0	0.91 ± 0.28	2	0.34 ± 0.15	0
MET>50	HT<200	Z	0.0013 ± 0.0008	0	0.01 ± 0.05	0	0.18 ± 0.07	0
MET<50	HT>200	Z	0.28 ± 0.11	1	0.13 ± 0.10	0	0.52 ± 0.19	0
MET<50	HT<200	NoZ	0.08 ± 0.03	0	0.73 ± 0.20	4	6.9 ± 3.8	6
MET<50	HT<200	Z	9.5 ± 3.8	11	5.7 ± 1.4	14	21 ± 11	39
SUM	4-body		10.4 ± 3.8	13	7.8 ± 1.5	20	30 ± 12	45