Search for Anomalous Production of Multileptons at CMS using 4.98 fb^{-1}

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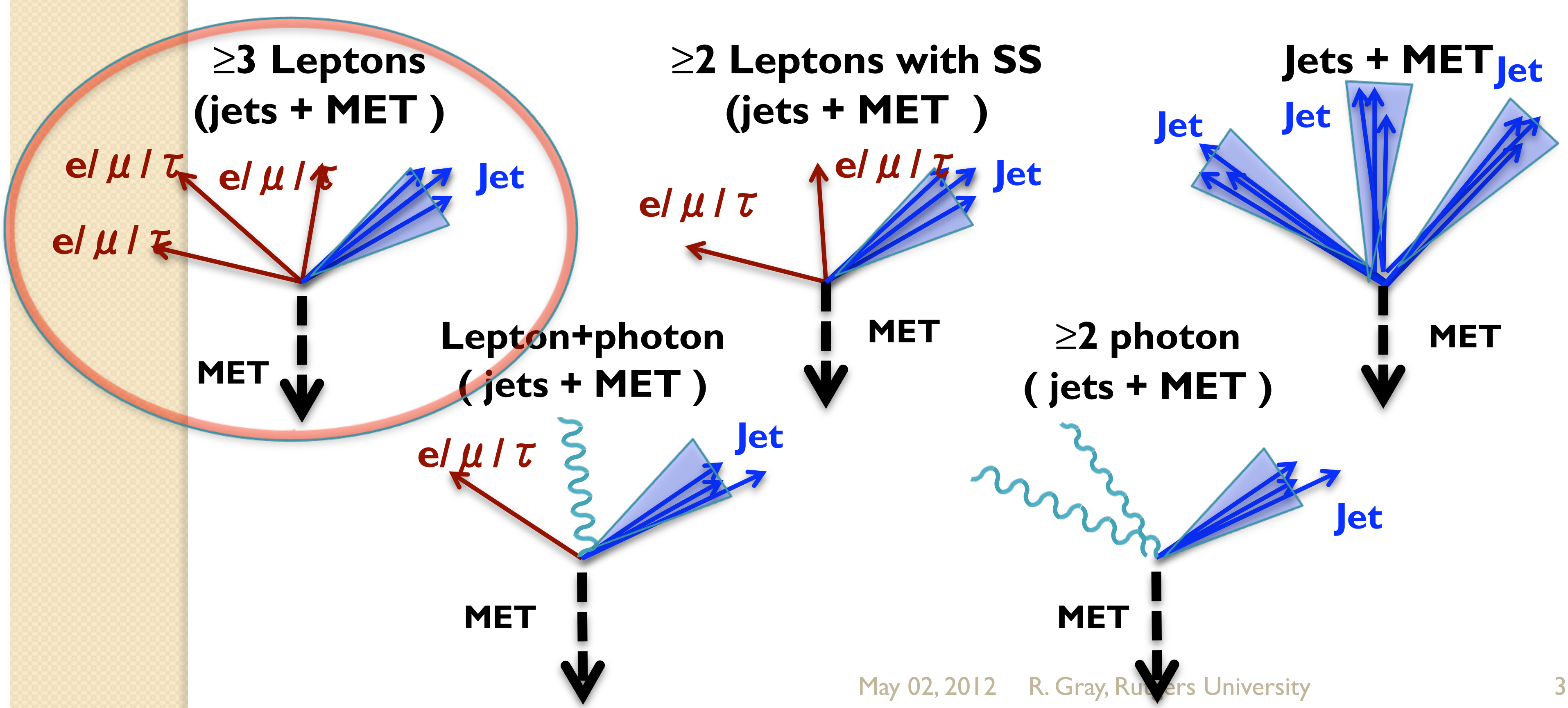
BNL Workshop on SUSY with 5 fb^{-1} at the LHC
May 02, 2012

Outline for today

- Introduction
- Search for Anomalous Production of Multileptons
- Interpretation
- Conclusion

Searching for New Physics

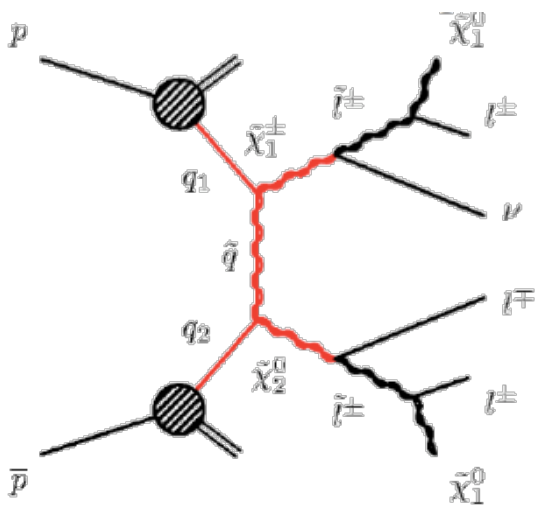
- **Expect majority of events at LHC explained by Standard Model**
- **Look where new physics contributions could be ≥ SM**
  - **Different scenarios produce different interesting final states.**
  - **We don't know what we're looking for!**
- **Some Examples :**



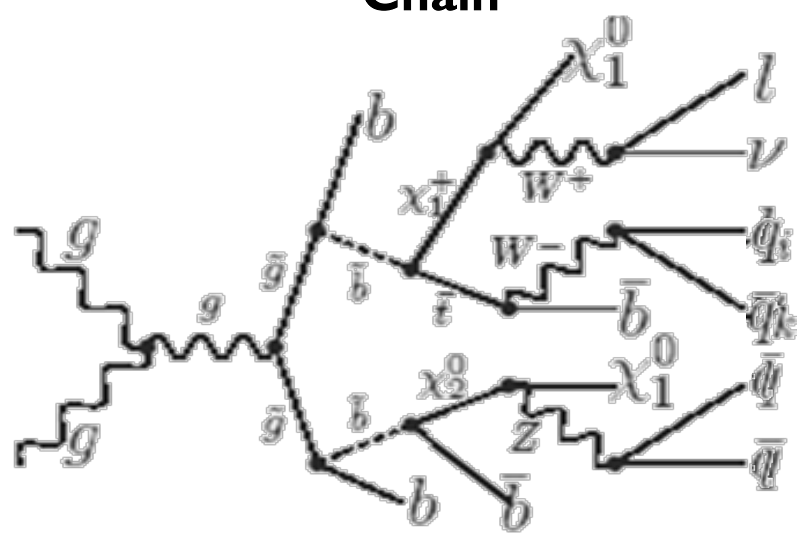
MultiLepton Production at 7 TeV

- **Will not go into model details here**
- **Leptons produced directly from heavy parents or in a long chain of decays**

Leptons Directly from Parent Particles



Leptons from Complicated Chain



Multileptons Produced with MET &/or HT

SM backgrounds removed by cutting on MET or H_T

H_T is the scalar sum of jet E_T

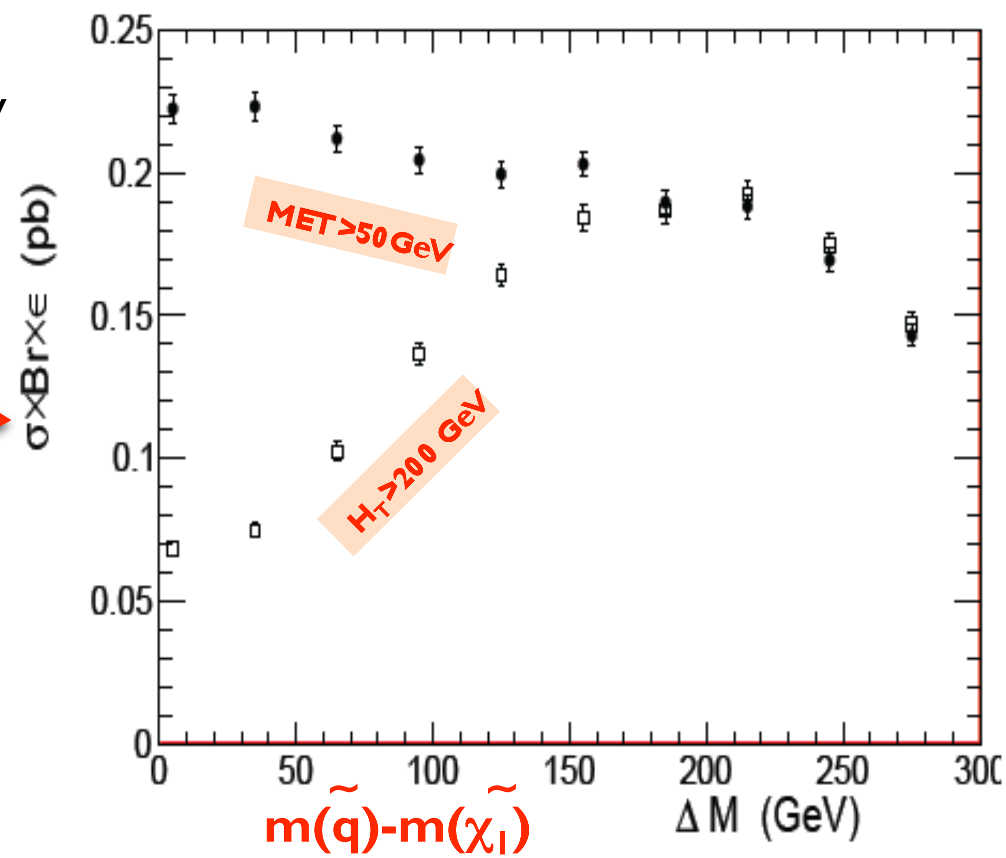
$$H_T = \sum_i E_T(\mathrm{Jet}_i)$$

MET is Missing Transverse Momentum

$$\mathrm{MET} = |\sum_i \vec{p}_T(i)|$$

WARNING: Some models have both H_T and MET, but some only have H_T or MET. Cannot rely on just one of these variables.

Example:
slepton co-NLSP scenario
m(q)=500. Small mass difference can cut off jet production.



Analysis Guidelines

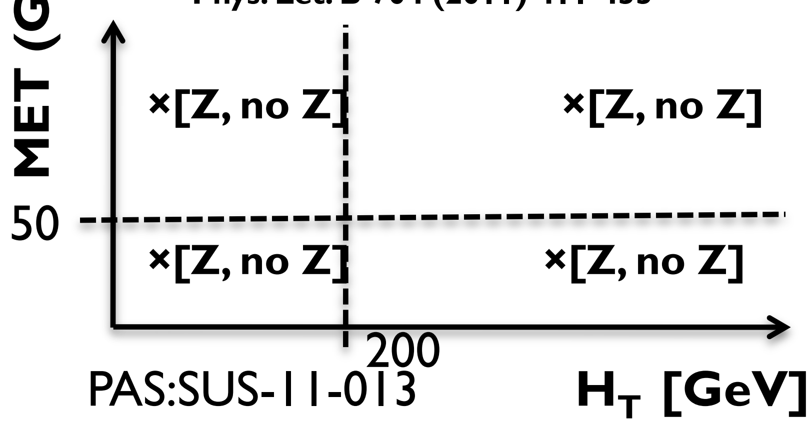
- Attempt to cover a wide range of multilepton models
  - We use various SUSY models as guides and benchmarks
    - (CMSSM, GMSB, R-parity violating)
  - However, we don't tune selections for a particular model
  - Selections based on background/detector considerations.
  - We're looking for anomalous production!
- This approach has already paid off:
  - This analysis found first ZZ→4μ event
    - (animation available on youtube), Oct 10, 2010 (10/10/2010).
  - Rediscovered a Standard Model background that impacts the Higgs→WW searches.
    - Seen at LEP, but forgotten over time.
    - Until recently left out of searches in both ATLAS and CMS
    - Once found, prompted changes to CMS/ATLAS H→WW searches.
    - Will mention in more detail later in the talk.

CMS 2011 4.98 fb^{-1} Multilepton

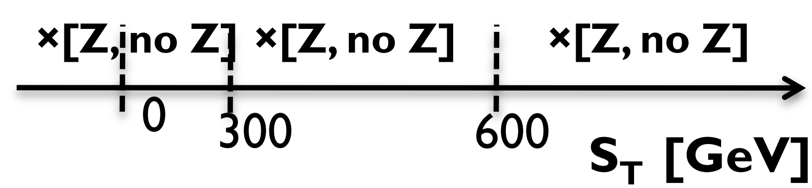
- Two multilepton analyses to cover wide range of scenarios.
  - Same lepton selection, backgrounds, triggers, code
  - 3 or ≥4 leptons (e, μ, and τ), bin in M(l+l-) and number OSSF pairs
  - Different strategies for isolating new physics from SM.
    - MET=Missing Transverse Momentum
    - $H_T = \Sigma p_T(\text{jets})$, $|\eta| < 2.5$ and $p_T > 40$ GeV
    - $S_T = MET + H_T + \Sigma p_T(\text{iso-leptons})$

SUSY Multilepton 2011

based on CMS 2010 Analysis:
Phys. Let. B 704 (2011) 411-433



RPV/Exotic Multilepton 2011

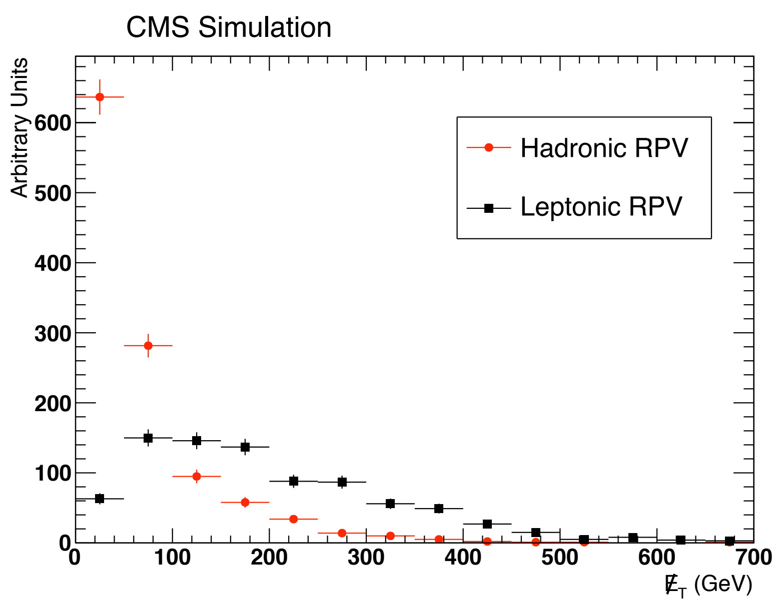


PAS:EXO-11-045

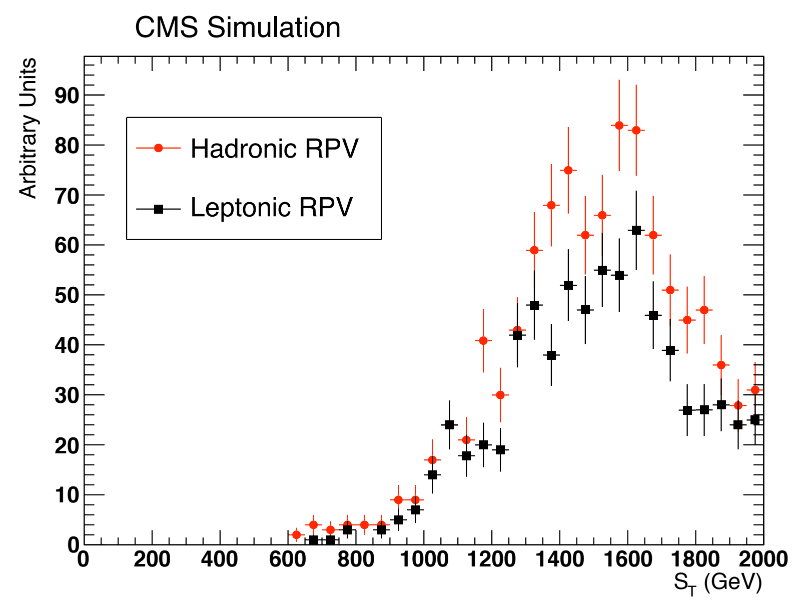
S_T Instead of MET or H_T

- 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 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

- 3 and $\geq$4 lepton combinations with e, μ, and $\leq$2 τ's
  - Select on single and dilepton triggers.
  - Cut events if M(l+l-) < 12 GeV (J/ψ, Upsilon, Υ*)
  - In low S_T (or low MET&HT) cut events where M(ll) off Z and M(lll) on Z
- Bin instead of cut! Poor S/B bins act as control channels.
  - # 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

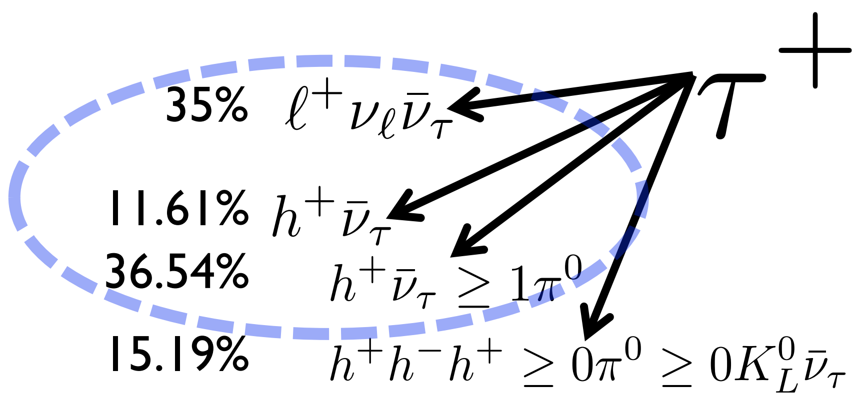
Lepton Selection: (e, μ , τ)

- 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	$\mu\mu$	ee	e μ
Leading e/ μ	> 35	> 85	>20	>20	>20
Next-to-leading e/ μ	NA	NA	>10	>10	>10

Primary Triggers

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



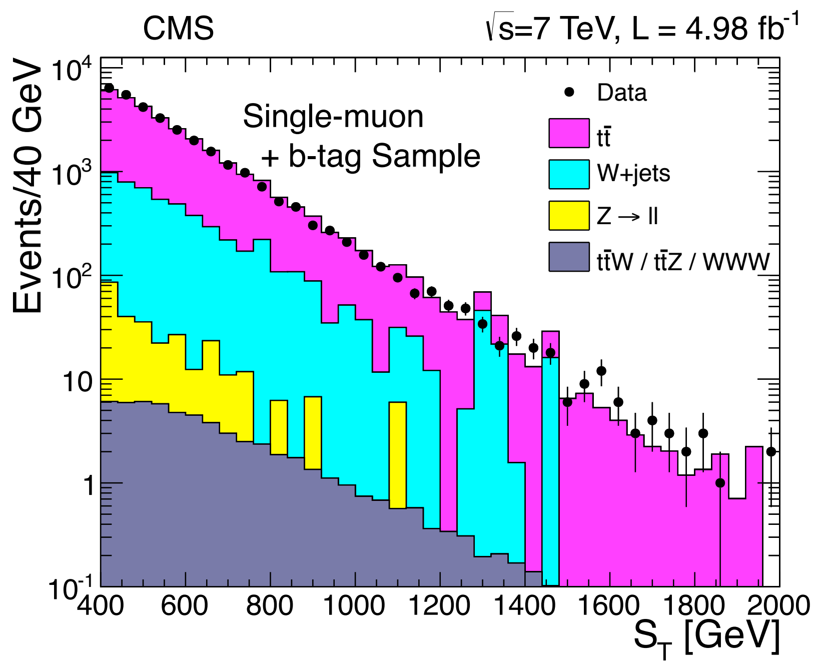
Background Predictions

- The same background 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 control regions
    - Systematic for kinematics 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+γ Asymmetric Conversion $\gamma \rightarrow e^+e^-$ or $\gamma \rightarrow \mu^+\mu^-$
    - Estimate number dileptons+photon conversion from data.

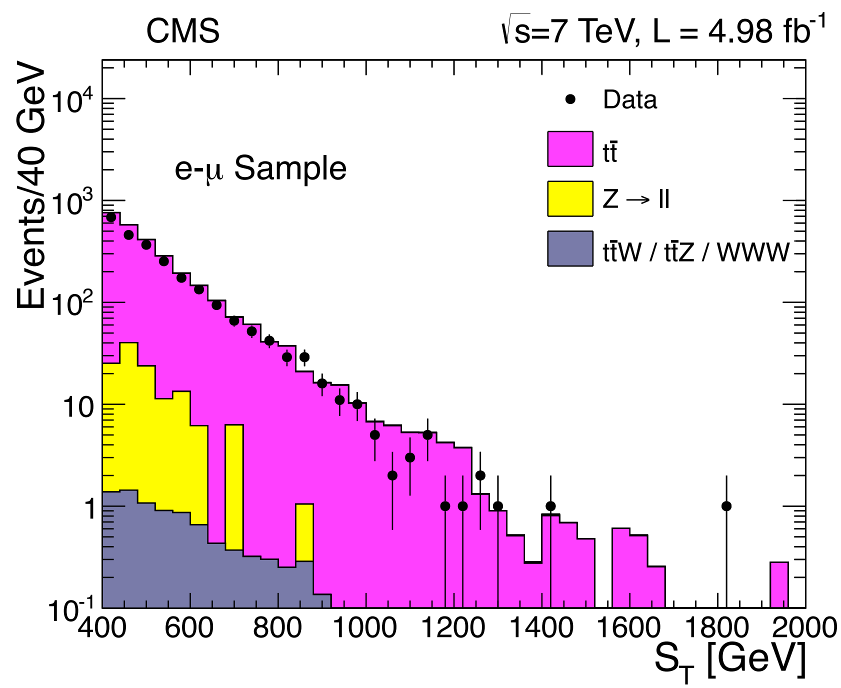
Monte Carlo Background Validation

TTbar MC Validation with Data

- Validate MC background predictions in control regions.
- Example: Validate TTbar with following control data sets
  - 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.



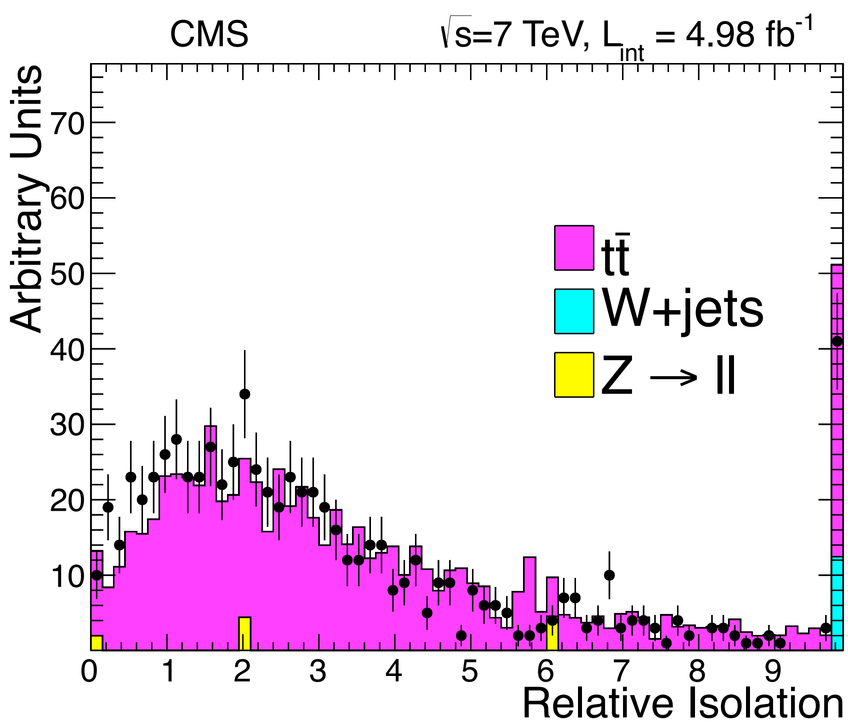
S_T distribution in 1-lepton sample



S_T distribution in e+μ - sample.

TTbar MC Validation with Data (cont..)

- TTbar has known jet composition (mostly b-jets)
  - No reason that MC shouldn't be able to get this for this analysis.
  - Semileptonic decays of heavy flavor measured at B-factories.
- Isolation of leptons from jets in TTbar
  - 1 lepton + ≥3 jets (≥1 b-jet), test μ with large impact parameter.
    - Require test μ far from leading tagged b-jet. ($\Delta R > 0.6$)



Integrals from Isolation plot:

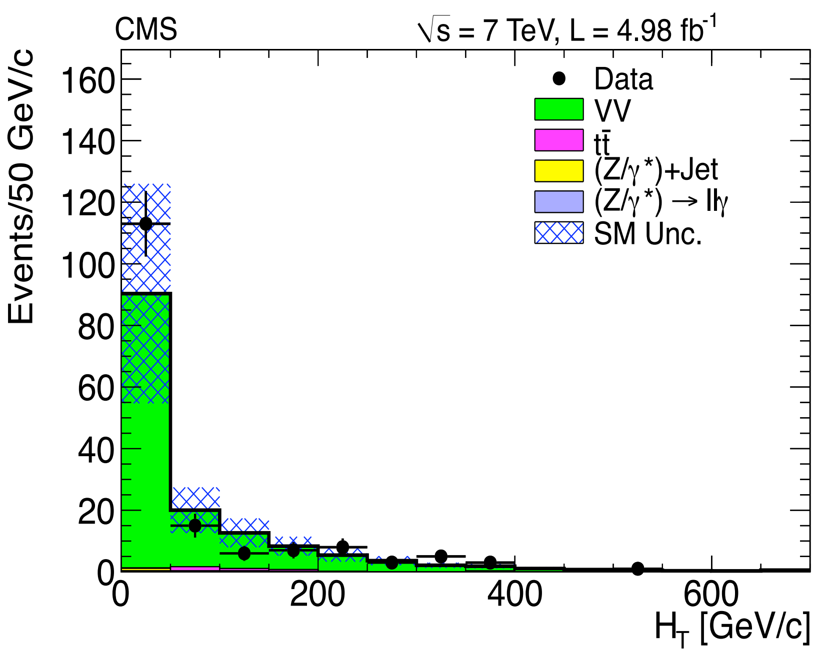
Isolation Range	Data	MC
0.0-0.15	10	13
0.0-inf	733	745

Isolated Bin (Most important!)

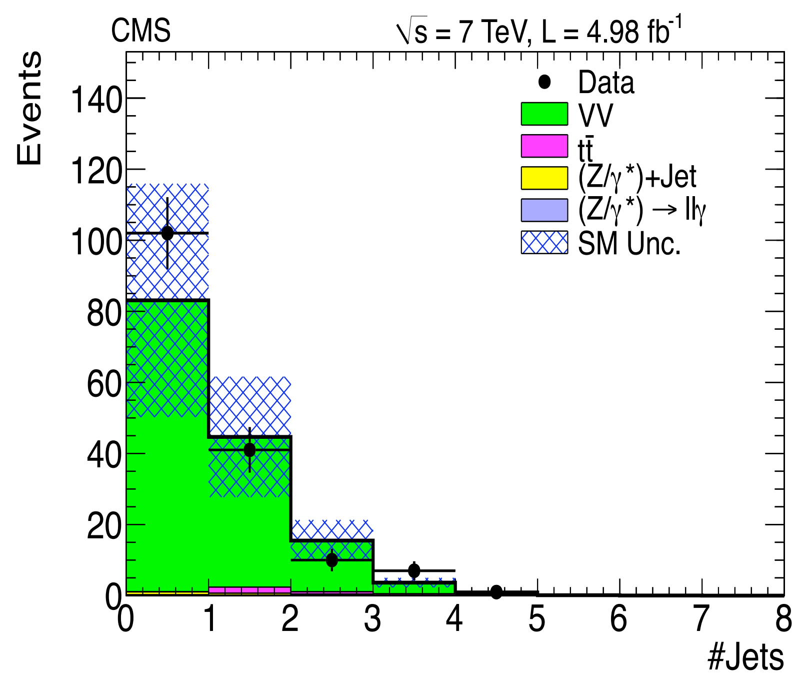
Cross check heavy flavor semileptonic branching fractions

W±Z MC Validation with Data

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



H_T distribution of WZ control data



Number of jets in WZ control data

Blue hash bands are uncertainties (syst+stat) on background.

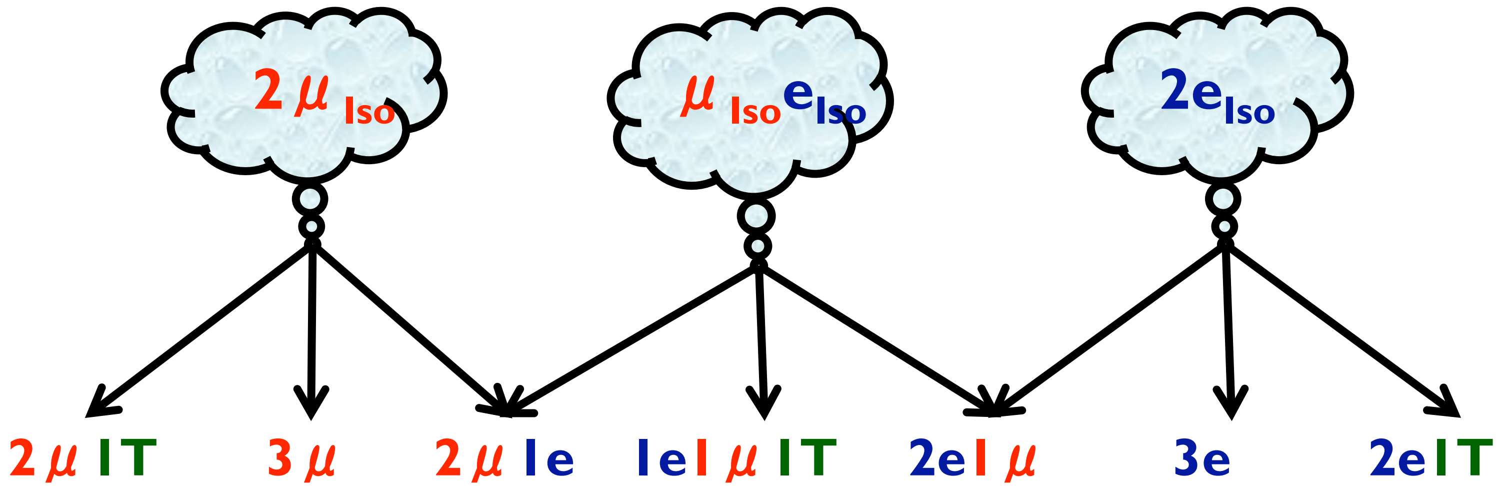
Data Driven Background Estimation

Fundamentals of Fully Data Driven (DD) Predictions

- Pick a proxy object to treat like a lepton
  - Example: track, non-isolated lepton, loosened ID, etc.
- In control data measure Proxy→ Fake factor
  - Proxy→Fake factor has many aliases "fake rate", "Tight Loose Ratio", "conversion factor"….
    - Depends on spectra, flavor, resolution, branching fraction….
  - Test in 2nd control set for "closure test"
  - Apply to a "seed" data set to get prediction in signal region.
- Systematics: Do key features in control data match seed?
  - Primary source of systematic uncertainty.
  - Especially important for this analysis!

Data Driven Predictions

- Use 2L data as a seed to predict ≥3L background
  - Example: 2e to predict 2e1 μ background
  - Effects like pileup are automatically included.

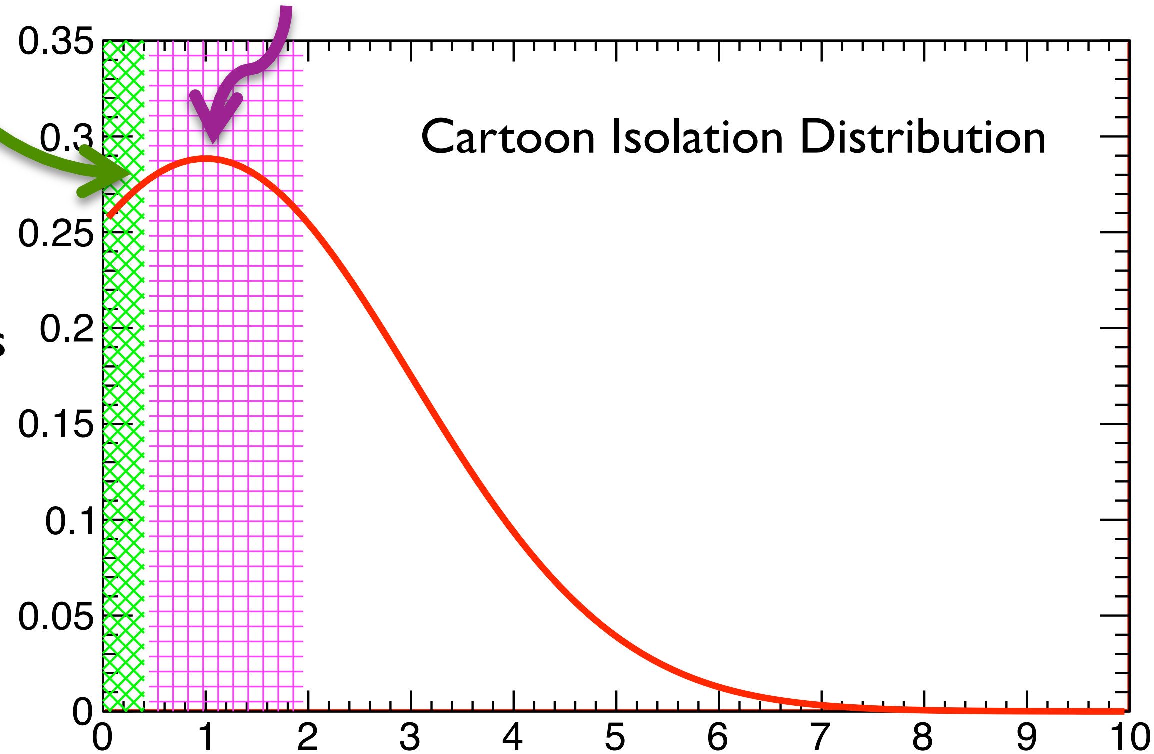


- Apply background estimation procedures to seeds.
  - Predict fake Tau using isolation side band. (~25% systematic)
    - Systematic from how well we understand isolation distribution.
  - Predict e or μ from jet using isolated tracks (~15% systematic)
    - Systematic from how well you understand types of jets in data set.
  - Predict assymmetric conversions using photons. (~100% systematic)
    - Large systematic due to difficulty in testing method beyond control.

Tau Background (Cartoon)

- Use isolation side band to predict Fake
  - Define f_T to convert sideband to isolated

#ISO = f_T x #SB



We measure f_T in dijet data and apply it to nonisolated τ candidates in l^+l^- data.

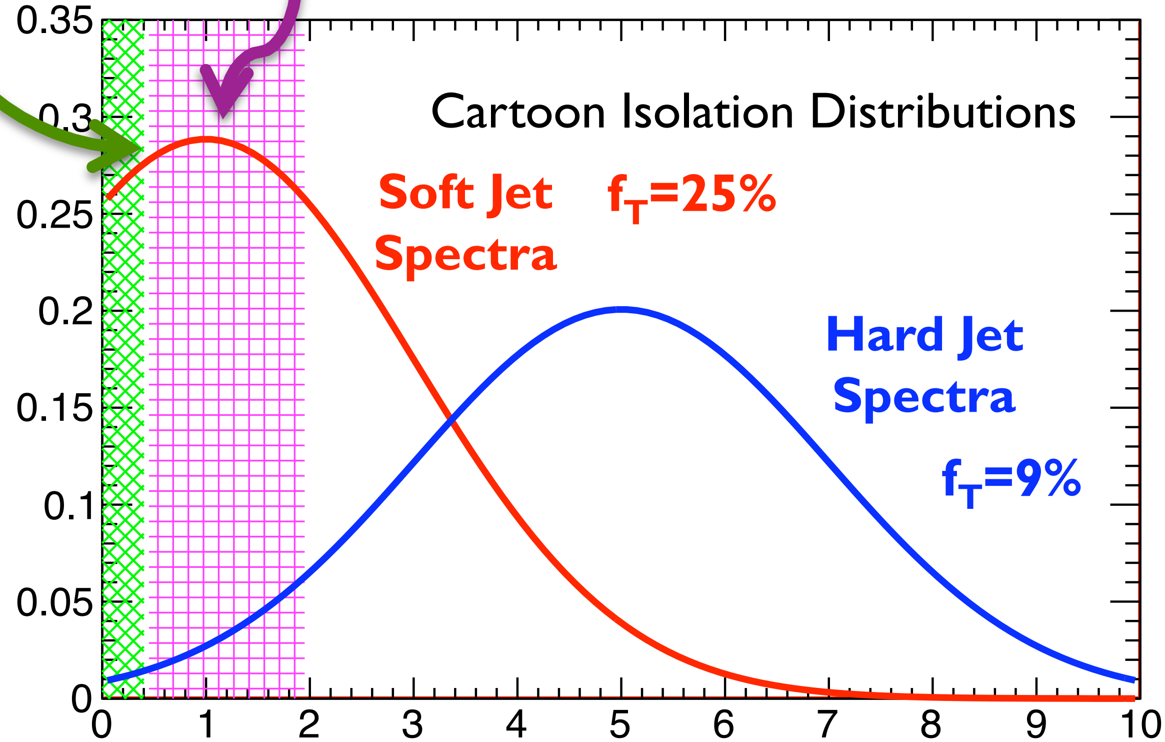
Tau Background Problem (Cartoon)

- Isolation shape can change dramatically!
  - f_T changes between dijet and dilepton data!!

#ISO = f_T x #SB

We need a way to parameterize changes in f_T between different data sets.

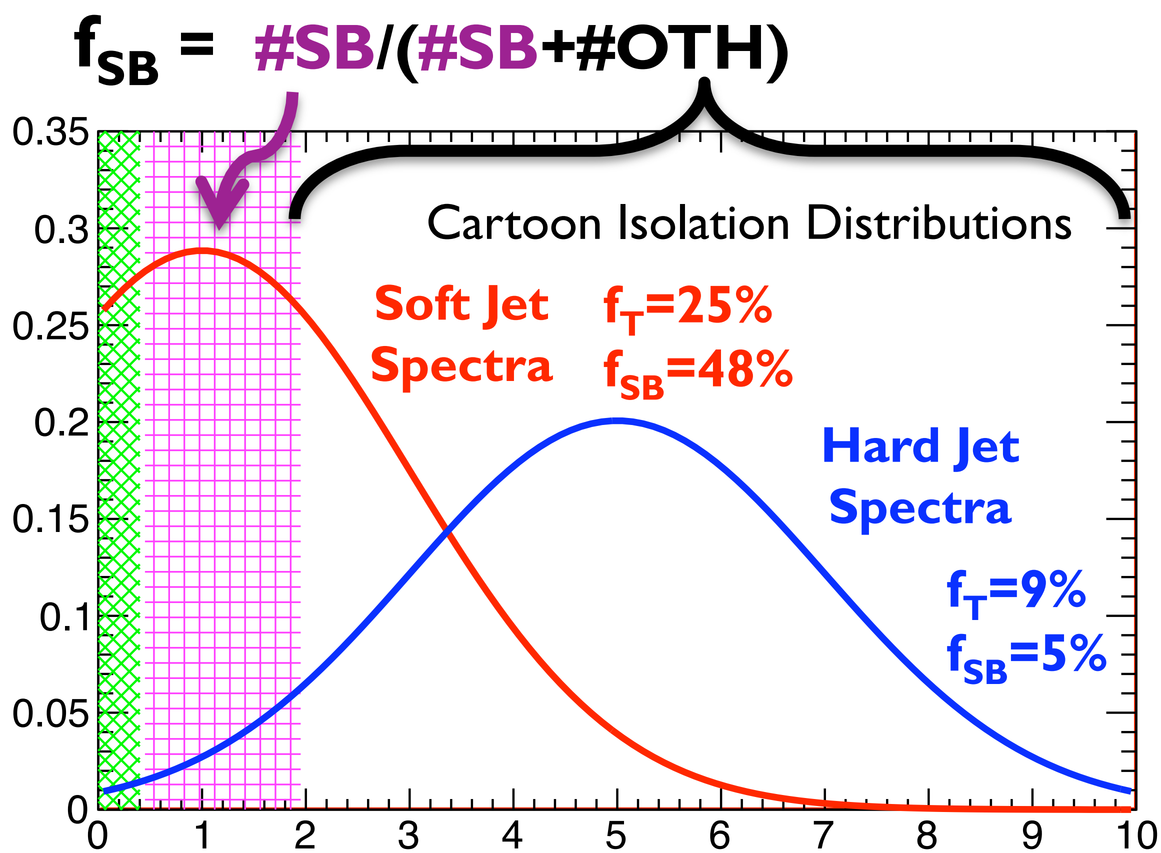
Need to match dijet data to conditions in dilepton data.



Tau Background Solution (Cartoon)

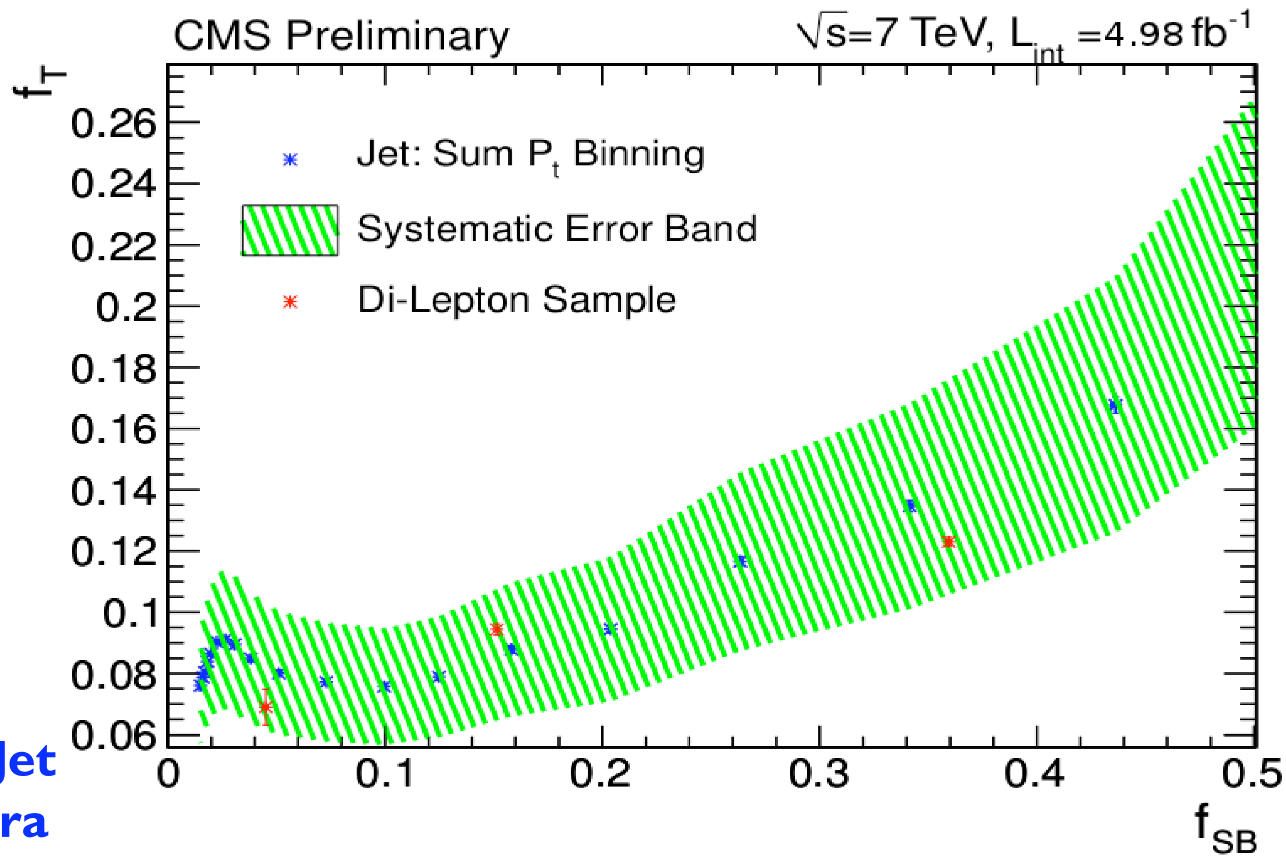
- Define f_{SB} (0-1) to test isolation shape
  - f_{SB} approaches zero as jets become harder

Use f_{SB} to check for changes in the shape of the fake τ isolation distribution.



Tau: f_T vs f_{SB} (Data)

- Bin dijet data and plot f_T vs f_{SB}
- In dilepton use f_{SB} to predict f_T



Hard Jet Spectra

Soft Jet Spectra

Isolated Track→e/μ Scale Factor

- Isolated tracks ($\pi^{\pm}$) as proxy for e/μ from jets
  - Isolation related systematics are ~same as e/μ
  - However! Track→e/μ sensitive to average jet flavor

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

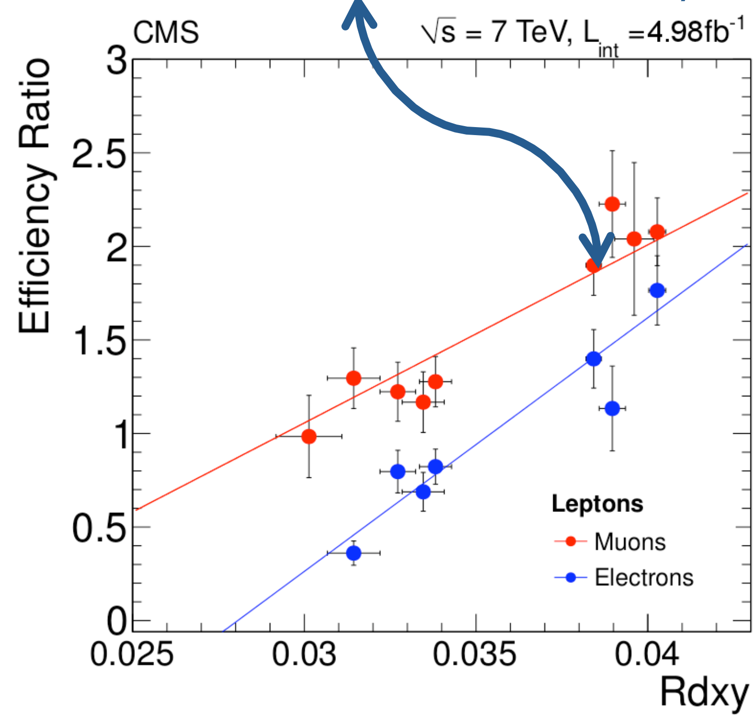
Non isolated leptons and tracks measured in seed to reduce dependence on control data.

Ratio of lepton to track isolation efficiencies. Parameterize in di-jet data as a function of R_{dxy}

Heavy Flavor produces displaced vertices and non-isolated tracks with large dxy

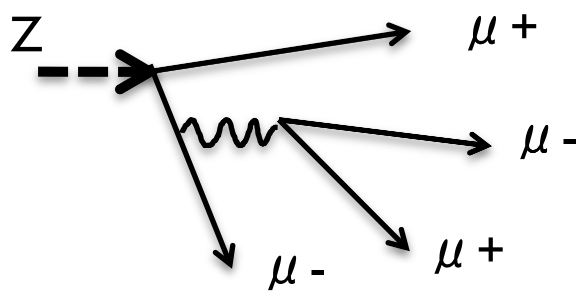
R_{dxy}=N(|dxy|>0.02cm)/N(|dxy|<0.02cm)

A sample of pure b-jets has Rdxy~30%
A sample of pure uds jets has Rdxy~3%



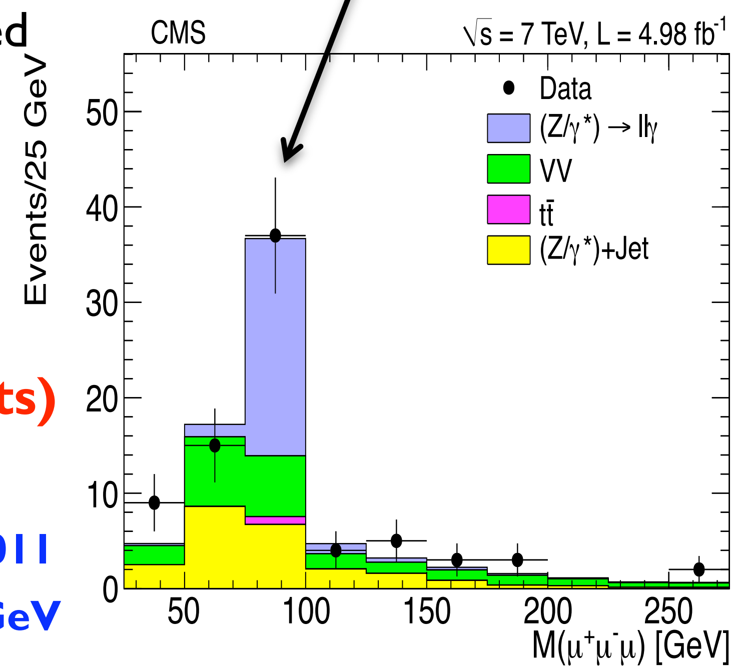
Asymmetric Photon Conversions to $\mu^+\mu^-$

- **Two types of asymmetric photon conversions:**
  - **External: Due to interactions in material, gives only e+e-**
  - **Internal: Feynman level (γ*) gives e+e- and $\mu^+\mu^-$**



In asymmetric conversion only 3 of 4μ are reconstructed

Peak removed in Low S_T bin (75-105)

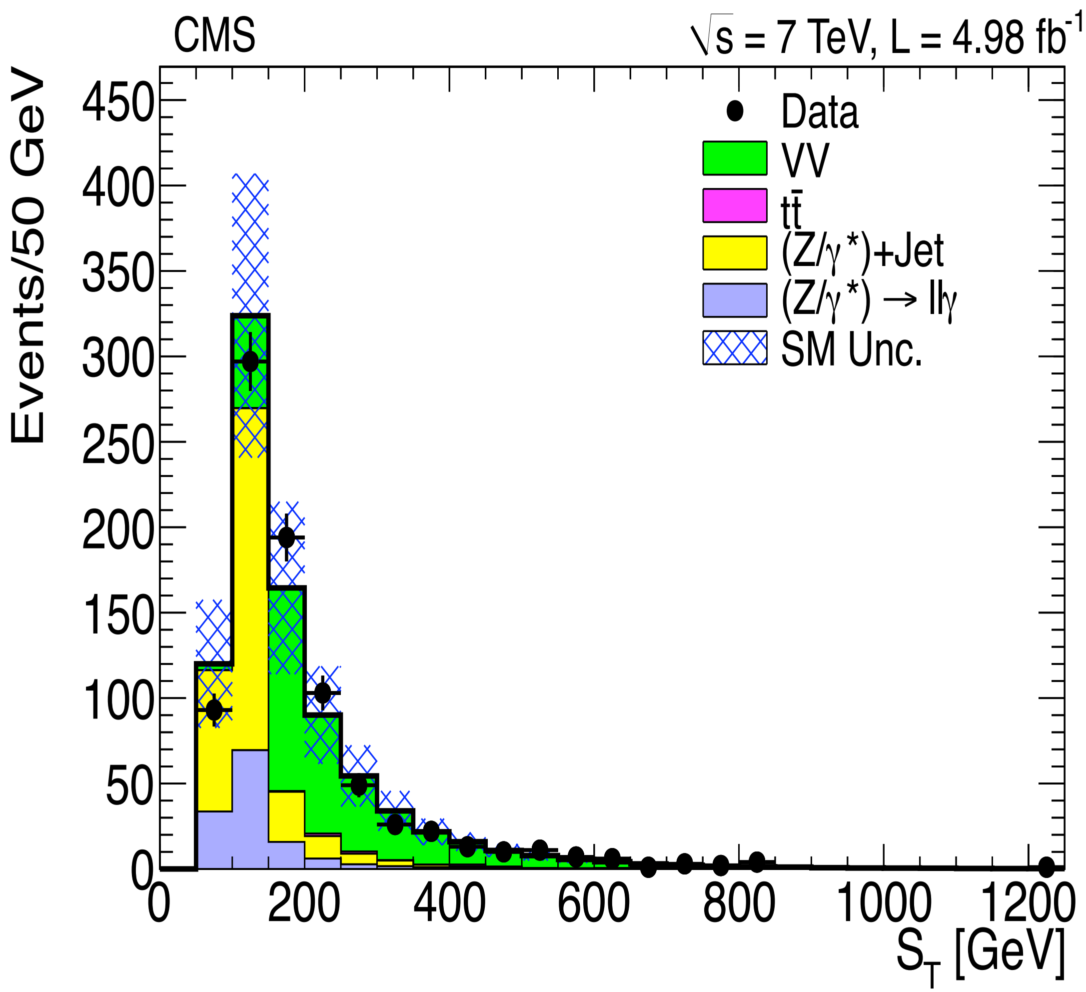


Internal Conversion shape obtained from $\mu^+\mu^-\gamma$

- **2011 Observation of Z→4μ**
  - **Seen at LEP, but not published.**
  - **Analogous to π^0 → e+e- γ**
  - **Observe 3μ Z peak (4th μ failed cuts)**
  - **Also be W→2μ +neutrino! (Higgs!!)**
    - **Left out of Higgs search prior to mid 2011**
    - **Important background for Higgs ~130 GeV**
    - **Cuts added to remove background**
    - **hep-ph:arXiv:1110.1368 R. C. Gray et. al.**

$L=4.98\ fb^{-1}$ 7 TeV Results

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



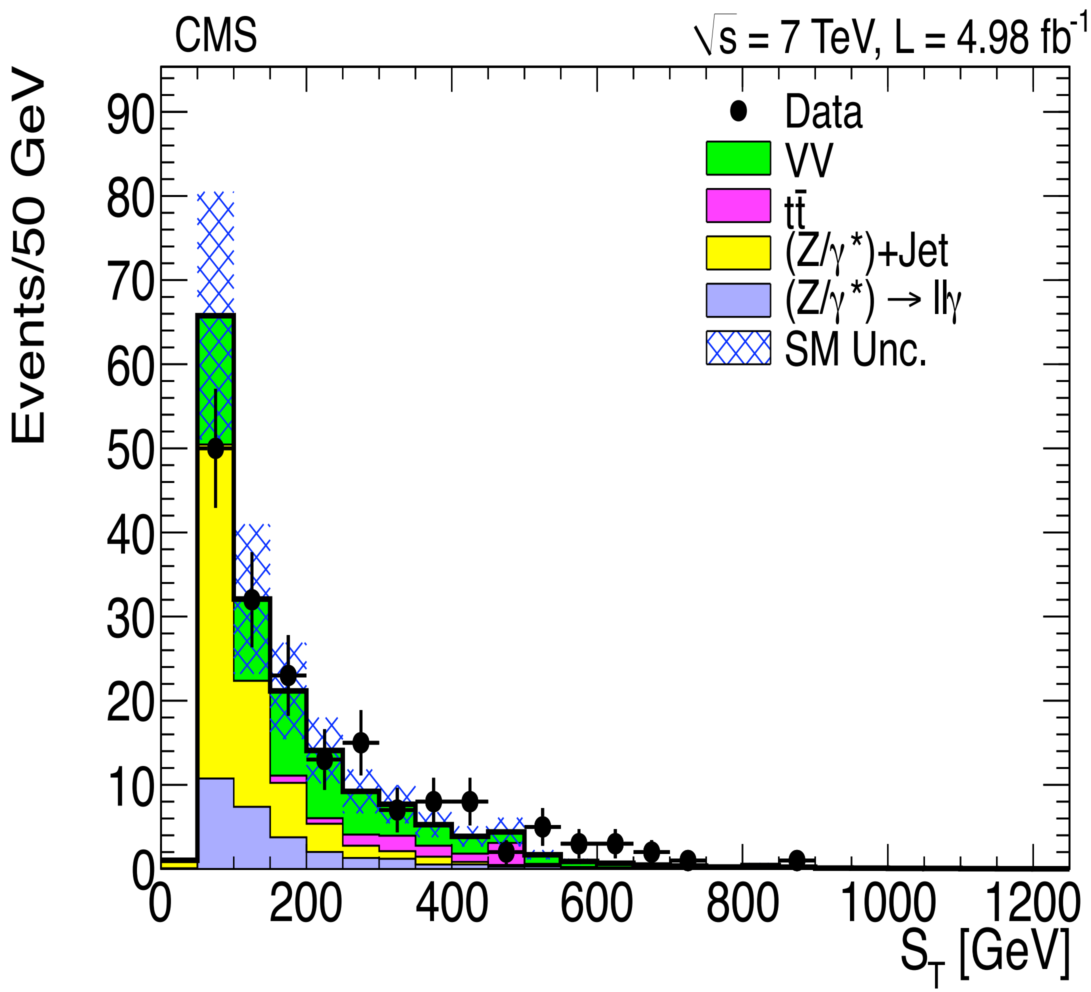
S_T distribution of three lepton events that have a Z candidate.

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.

Blue bands are background uncertainties (syst+stat).

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



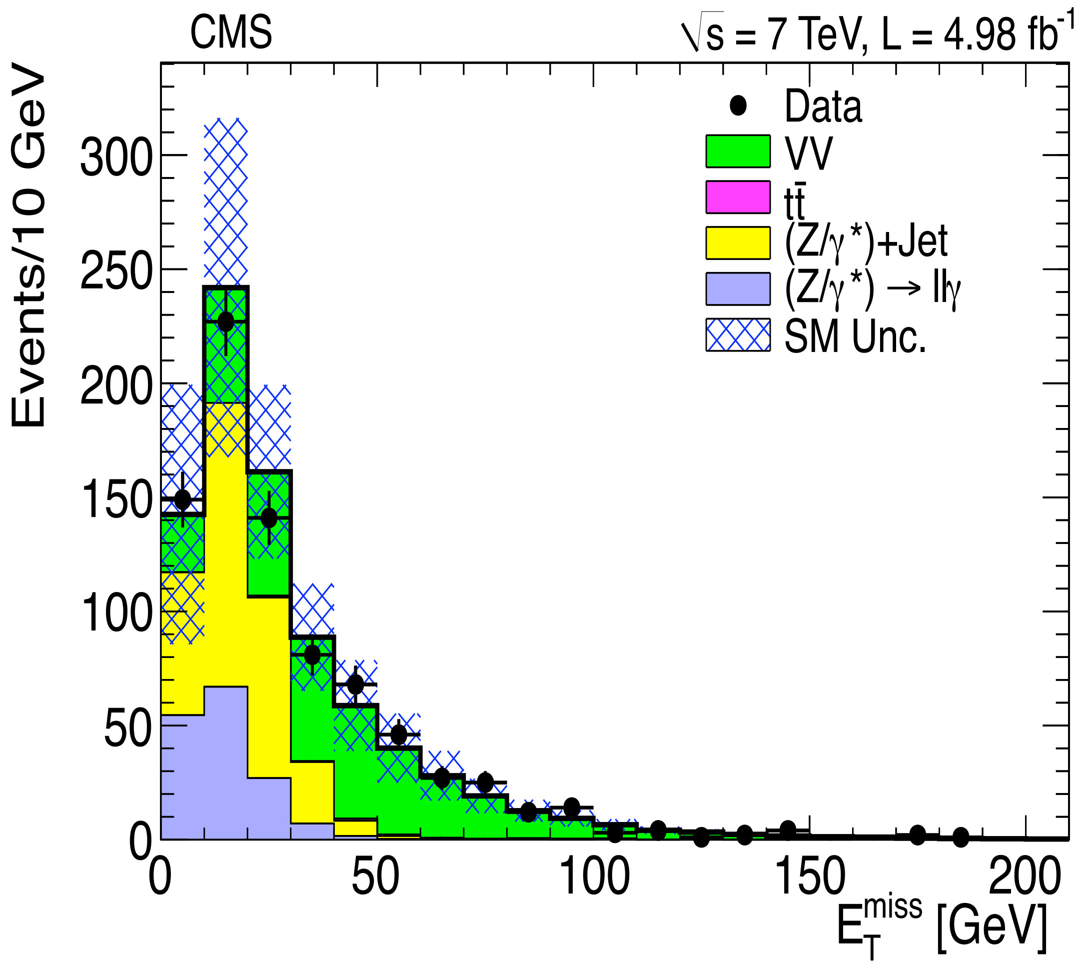
S_T distribution of three lepton events that have a an l+l- pair, but does not make a Z.

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.

Blue bands are background uncertainties.

Three Lepton MET Dist with l^+l^- on Z (H_T<200 Control Channel)

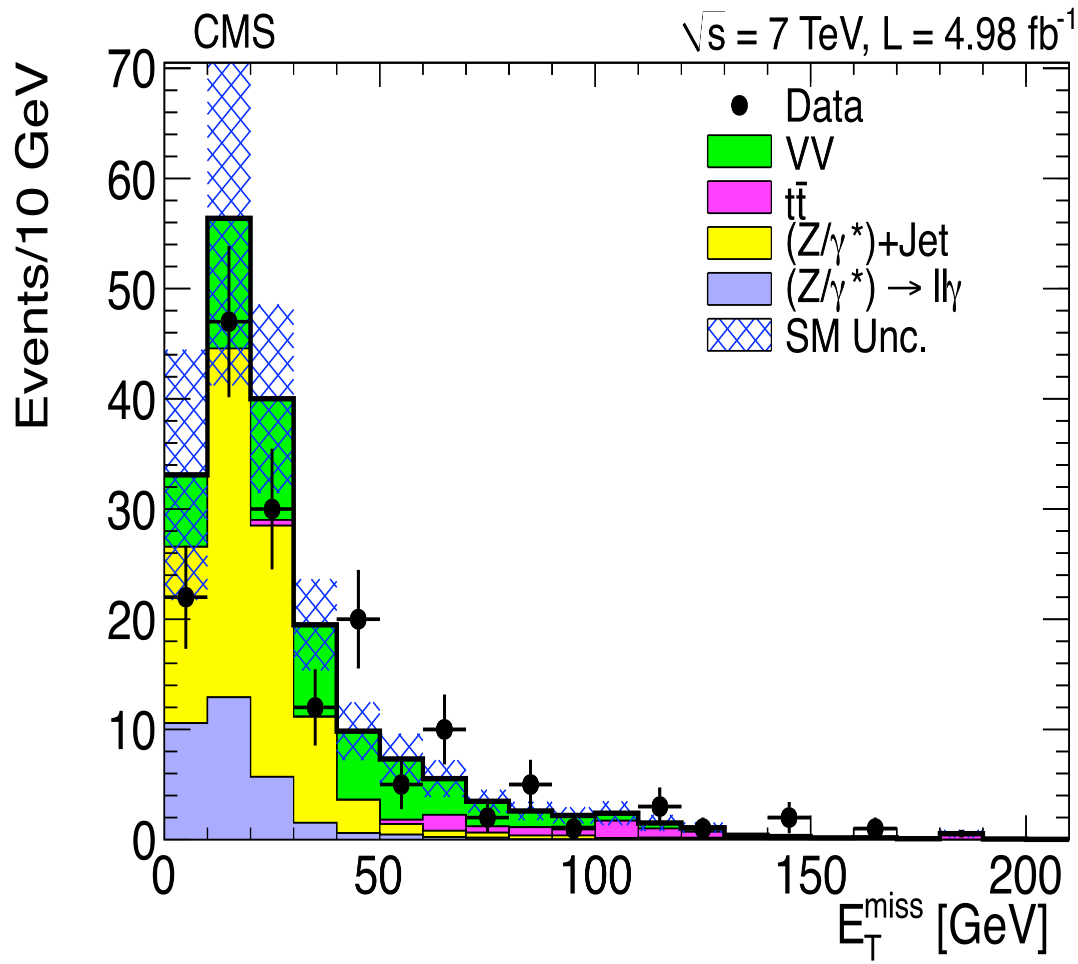


MET distribution of three lepton events that have a l+l- pair that makes a Z.

The yellow and light blue histograms are data driven predictions.

Blue bands are background uncertainties (syst+stat)

Three Lepton MET Dist with l^+l^- off Z (H_T<200 Signal Channel)



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

The yellow and light blue histograms are data driven predictions.

Blue bands are background uncertainties (syst+stat)

EXO-11-045 Results Summarized

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

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		0.0009 ± 0.0009	0	0.01 ± 0.09	0	0.17 ± 0.07	0
300-600	DY0		0.004 ± 0.002	0	0.27 ± 0.10	0	2.5 ± 1.1	2
0-300	DY0		0.04 ± 0.02	0	2.98 ± 0.48	0	3.4 ± 1.0	4
> 600	DY1		0.009 ± 0.004	1	0.09 ± 0.07	0	0.11 ± 0.05	0
>600	DY1	Z	0.09 ± 0.01	1	0.48 ± 0.14	0	0.42 ± 0.15	0
300-600	DY1		0.06 ± 0.02	0	0.83 ± 0.24	1	0.92 ± 0.29	1
300-600	DY1	Z	0.42 ± 0.10	0	3.9 ± 1.1	5	3.4 ± 0.9	3
0-300	DY1		0.08 ± 0.04	0	5.4 ± 2.2	7	13.6 ± 6.4	19
0-300	DY1	Z	0.75 ± 0.32	2	16.9 ± 4.6	19	60 ± 31	95
>600	DY2		0.02 ± 0.01	0	--	--	--	--
>600	DY2	Z	0.84 ± 0.32	0	--	--	--	--
300-600	DY2		0.19 ± 0.08	0	--	--	--	--
300-600	DY2	Z	7.4 ± 3.0	3	--	--	--	--
0-300	DY2		2.3 ± 1.0	1	--	--	--	--
0-300	DY2	Z	27 ± 11	29	--	--	--	--
4-body			39 ± 12	37	30.8 ± 5.2	32	84 ± 32	124

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		1.12 ± 0.43	2	11.0 ± 3.2	17	22.3 ± 6.0	20
300-600	DY0		7.3 ± 3.0	5	96 ± 31	113	181 ± 24	157
0-300	DY0		13.3 ± 4.1	17	413 ± 63	522	2016 ± 253	1631
>600	DY1		3.3 ± 0.9	6	13.0 ± 2.3	10	--	--
>600	DY1	Z	17.6 ± 5.6	17	39.0 ± 4.7	35	--	--
300-600	DY1		24.6 ± 6.4	32	141 ± 27	159	--	--
300-600	DY1	Z	97 ± 29	89	462 ± 41	441	--	--
0-300	DY1		147 ± 36	126	2981 ± 418	3721	--	--
0-300	DY1	Z	797 ± 189	727	15751 ± 2452	17631	--	--
3-body			1108 ± 195	1021	19906 ± 2489	22649	2220 ± 255	1808

Exclusion contours from a multichannel likelihood from the 54 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 later in talk.

SUS-11-013 Results Summarized

$(MET)\times(H_T)\times(llll, lll\tau, ll\tau\tau, lll, ll\tau, l\tau\tau)$

Number of Tau candidates (0,1,2) →

≥4 Leptons

Selection			4(e/μ)		3(e/μ)+T		2(e/μ)+2T	
MET?	HT?	Z?	SM	Obs	SM	Obs	SM	Obs
MET>50	HT>200	NoZ	0.017 ± 0.005	0	0.08 ± 0.06	0	0.6 ± 0.6	0
MET>50	HT>200	Z	0.20 ± 0.04	0	0.25 ± 0.11	0	0.7 ± 1.0	0
MET>50	HT<200	NoZ	0.19 ± 0.07	1	0.56 ± 0.16	3	1.4 ± 0.6	1
MET>50	HT<200	Z	0.74 ± 0.20	1	2.2 ± 0.6	4	1.1 ± 0.7	0
MET<50	HT>200	noZ	0.006 ± 0.001	0	0.13 ± 0.08	0	0.25 ± 0.07	0
MET<50	HT>200	Z	0.78 ± 0.31	1	0.52 ± 0.20	0	1.13 ± 0.42	0
MET<50	HT<200	NoZ	2.4 ± 1.0	1	3.7 ± 1.2	5	10.5 ± 3.2	17
MET<50	HT<200	Z	35 ± 14	33	16.1 ± 4.9	20	42 ± 16	62
SUM	4-body		39 ± 15	37	23.6 ± 5.1	32	58 ± 16	80

3 Leptons

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	1.5 ± 0.5	2	30.3 ± 9.6	33	13.5 ± 2.6	15
MET>50	HT<200	n/a	6.5 ± 2.3	7	140 ± 37	159	106 ± 16	82
MET<50	HT>200	n/a	1.2 ± 0.7	1	16.5 ± 4.5	16	31.9 ± 4.8	18
MET<50	HT<200	n/a	11.6 ± 3.6	14	354 ± 55	446	1025 ± 171	1006
MET>50	HT>200	noZ	4.8 ± 1.3	8	31.0 ± 9.5	16	--	--
MET>50	HT>200	Z	17.8 ± 6.0	20	24.0 ± 4.9	13	--	--
MET>50	HT<200	noZ	25.9 ± 7.3	30	106 ± 27	114	--	--
MET<50	HT>200	noZ	4.4 ± 1.5	11	51.8 ± 6.2	45	--	--
MET>50	HT<200	Z	126 ± 47	141	115 ± 16	107	--	--
MET<50	HT>200	Z	18.4 ± 4.5	15	244 ± 24	166	--	--
MET<50	HT<200	noZ	142 ± 36	123	2906 ± 412	3721	--	--
MET<50	HT<200	Z	749 ± 181	657	15516 ± 2421	17857	--	--
SUM	3-body		1109 ± 191	1029	19533 ± 2457	22693	1177 ± 172	1121

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.

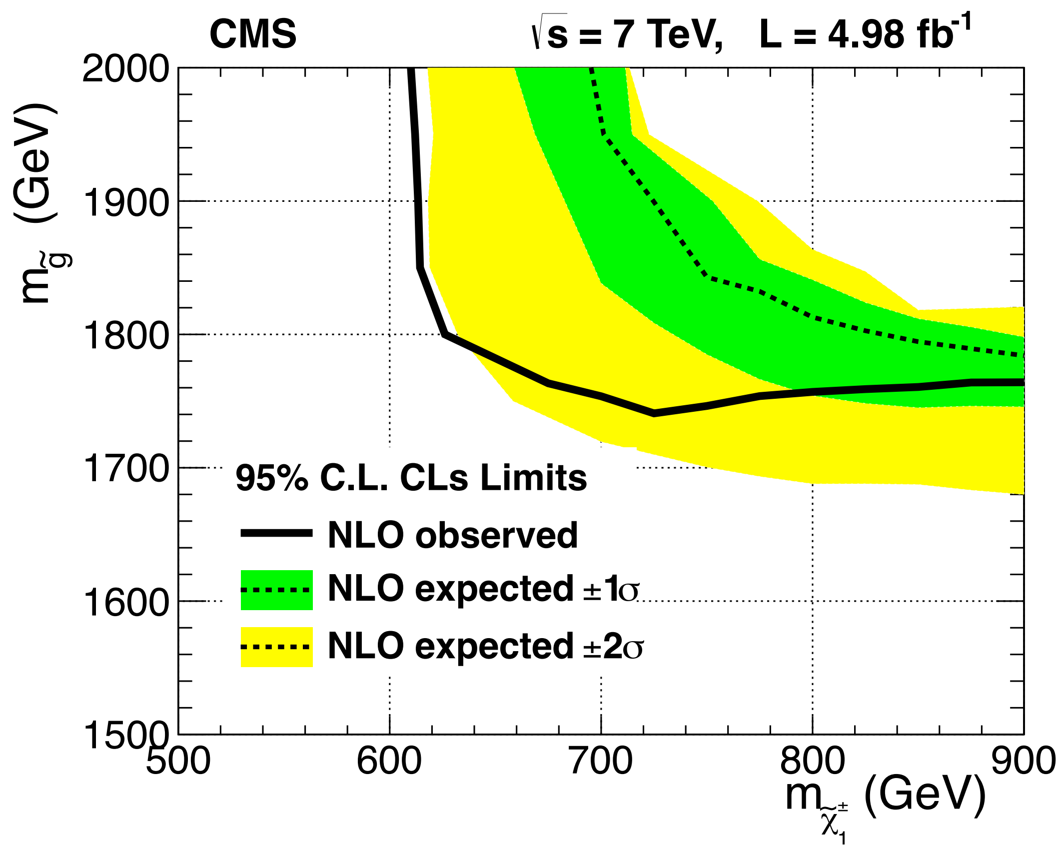
The same background estimation techniques are applied to all bins.

Produced from same package as EXO-11-045

Slepton CO-NLSP

Sleptons share the role of Next to lightest super partner (NLSP) above the gravitino. Result is that in most cases each event produces 4 or more leptons.

Contours made using MET vs HT table

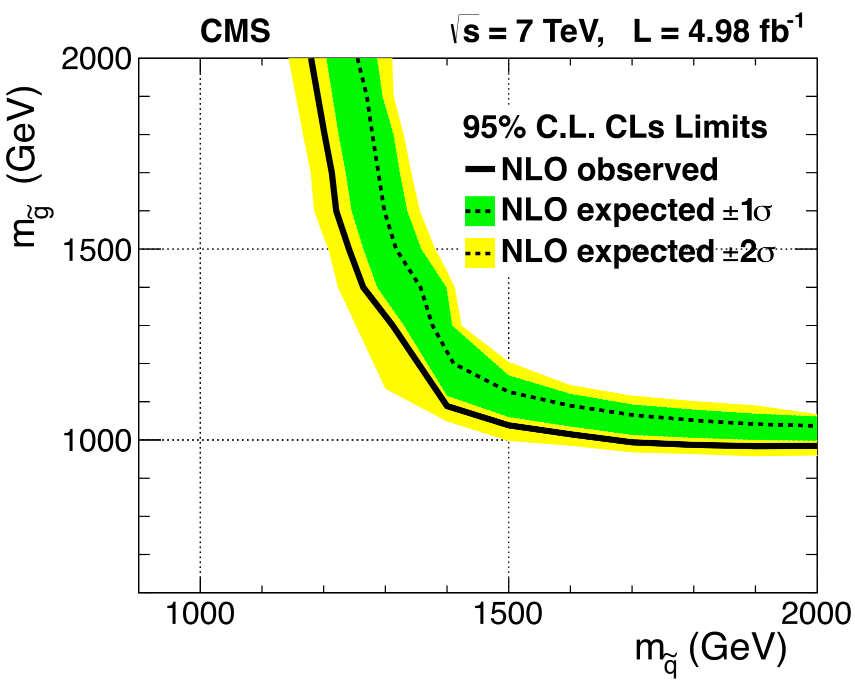


See model description http://lhcnewphysics.org/web/Topology_Sets.html under GMSB inspired slepton co-NLSP

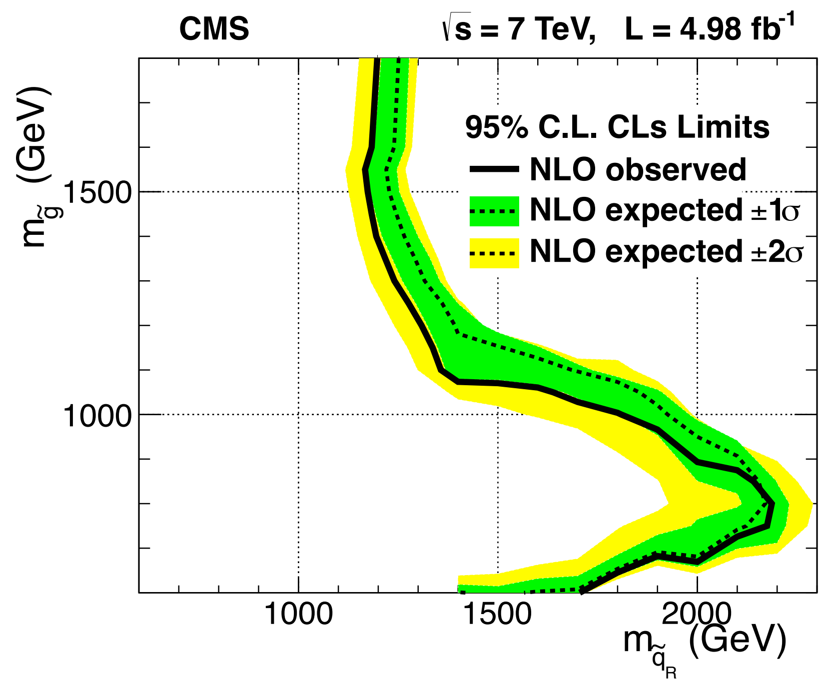
Leptonic and Hadronic RPV

Contours made using S_T table

Leptonic RPV



Hadronic RPV



Conclusions

- Presented ≥3 lepton search with 4.98 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, on/off Z.
  - Two types of event level binning explored: MET vs H_T or S_T
  - Background and signal channels are simultaneously examined.
  - Observed Z→4L
  - High statistic bins are in good agreement with SM
  - Set new limits on SUSY scenarios that produce multileptons both R-parity conserving and R-parity violating models.
- Good agreement between observations and SM predictions for high statistic channels.
- More than 1 fb^{-1} of 8 TeV 2012 data currently on disk! We will continue to search for new physics!

BACKUP

4 Lepton (e/ μ / τ) S_T

Selection			4(e/μ)		3(e/μ)+T		2(e/μ)+2T	
ST	DYpairs	Z?	SM	Obs	SM	Obs	SM	Obs
> 600	DY0		0.0009 ± 0.0009	0	0.01 ± 0.09	0	0.17 ± 0.07	0
300-600	DY0		0.004 ± 0.002	0	0.27 ± 0.10	0	2.5 ± 1.1	2
0-300	DY0		0.04 ± 0.02	0	2.98 ± 0.48	0	3.4 ± 1.0	4
> 600	DY1		0.009 ± 0.004	1	0.09 ± 0.07	0	0.11 ± 0.05	0
>600	DY1	Z	0.09 ± 0.01	1	0.48 ± 0.14	0	0.42 ± 0.15	0
300-600	DY1		0.06 ± 0.02	0	0.83 ± 0.24	1	0.92 ± 0.29	1
300-600	DY1	Z	0.42 ± 0.10	0	3.9 ± 1.1	5	3.4 ± 0.9	3
0-300	DY1		0.08 ± 0.04	0	5.4 ± 2.2	7	13.6 ± 6.4	19
0-300	DY1	Z	0.75 ± 0.32	2	16.9 ± 4.6	19	60 ± 31	95
>600	DY2		0.02 ± 0.01	0	--	--	--	--
>600	DY2	Z	0.84 ± 0.32	0	--	--	--	--
300-600	DY2		0.19 ± 0.08	0	--	--	--	--
300-600	DY2	Z	7.4 ± 3.0	3	--	--	--	--
0-300	DY2		2.3 ± 1.0	1	--	--	--	--
0-300	DY2	Z	27 ± 11	29	--	--	--	--
4-body			39 ± 12	37	30.8 ± 5.2	32	84 ± 32	124

3 Lepton (e/ μ / τ) S_T

Selection			3(e/μ)		2(e/μ)+T		1(e/μ)+2T	
ST	DYpairs	Z?	SM	Obs	SM	Obs	SM	Obs
>600	DY0		1.12 ± 0.43	2	11.0 ± 3.2	17	22.3 ± 6.0	20
300-600	DY0		7.3 ± 3.0	5	96 ± 31	113	181 ± 24	157
0-300	DY0		13.3 ± 4.1	17	413 ± 63	522	2016 ± 253	1631
>600	DY1		3.3 ± 0.9	6	13.0 ± 2.3	10	--	--
>600	DY1	Z	17.6 ± 5.6	17	39.0 ± 4.7	35	--	--
300-600	DY1		24.6 ± 6.4	32	141 ± 27	159	--	--
300-600	DY1	Z	97 ± 29	89	462 ± 41	441	--	--
0-300	DY1		147 ± 36	126	2981 ± 418	3721	--	--
0-300	DY1	Z	797 ± 189	727	15751 ± 2452	17631	--	--
3-body			1108 ± 195	1021	19906 ± 2489	22649	2220 ± 255	1808

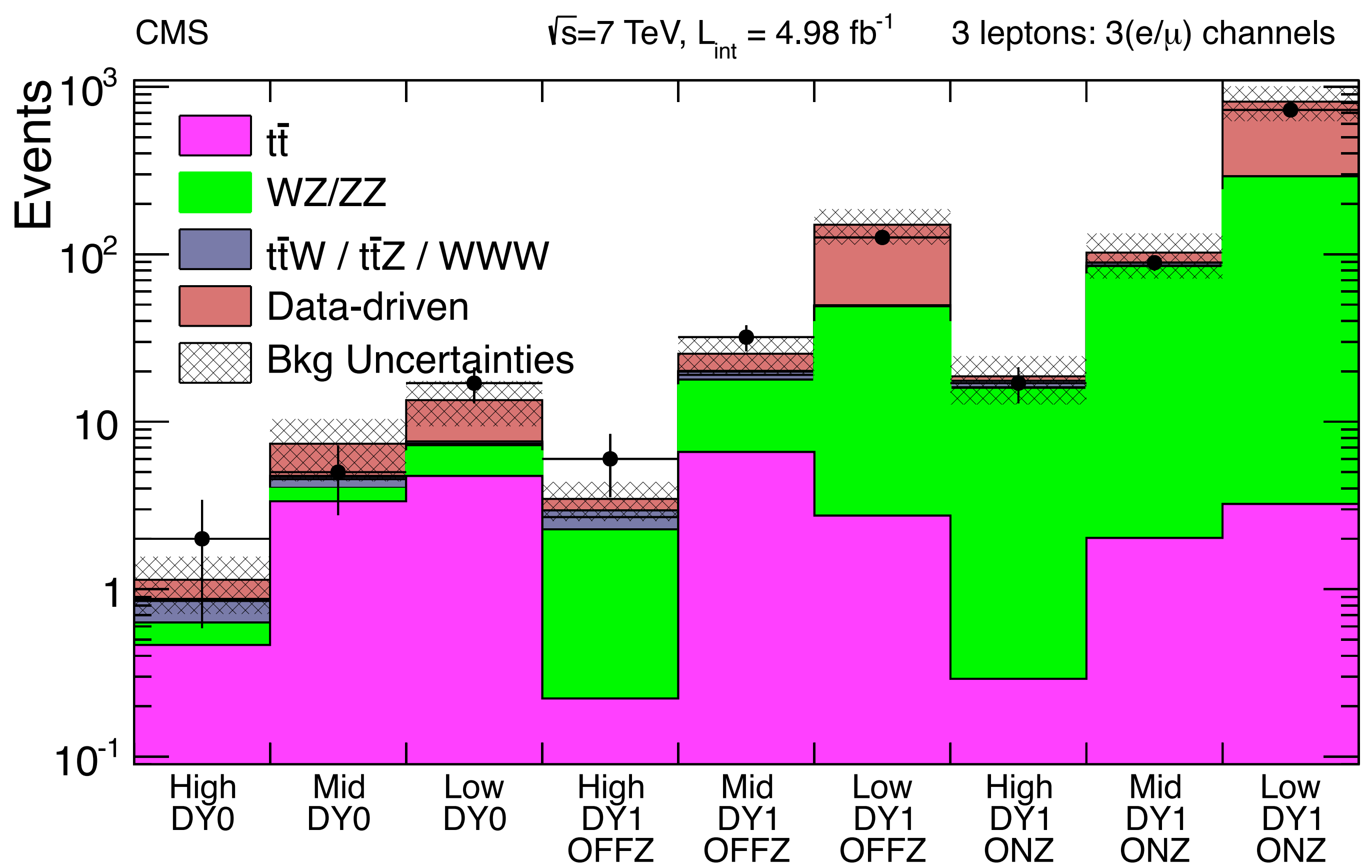
4 Lepton (e/ μ / τ) MET vs H_T

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	0.017 ± 0.005	0	0.08 ± 0.06	0	0.6 ± 0.6	0
MET>50	HT>200	Z	0.20 ± 0.04	0	0.25 ± 0.11	0	0.7 ± 1.0	0
MET>50	HT<200	NoZ	0.19 ± 0.07	1	0.56 ± 0.16	3	1.4 ± 0.6	1
MET>50	HT<200	Z	0.74 ± 0.20	1	2.2 ± 0.6	4	1.1 ± 0.7	0
MET<50	HT>200	noZ	0.006 ± 0.001	0	0.13 ± 0.08	0	0.25 ± 0.07	0
MET<50	HT>200	Z	0.78 ± 0.31	1	0.52 ± 0.20	0	1.13 ± 0.42	0
MET<50	HT<200	NoZ	2.4 ± 1.0	1	3.7 ± 1.2	5	10.5 ± 3.2	17
MET<50	HT<200	Z	35 ± 14	33	16.1 ± 4.9	20	42 ± 16	62
SUM	4-body		39 ± 15	37	23.6 ± 5.1	32	58 ± 16	80

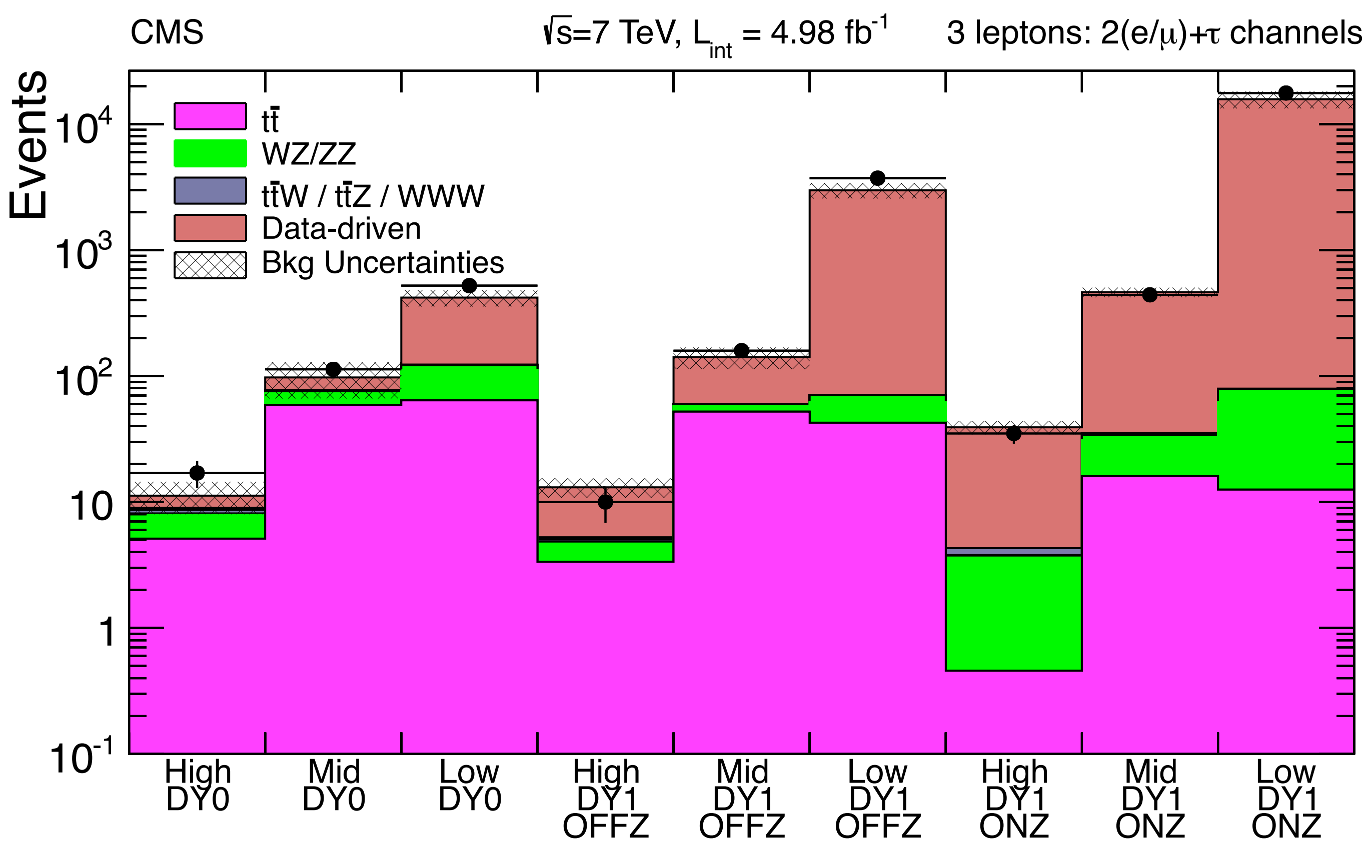
3 Lepton (e/ μ / τ) MET vs H_T

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	1.5 ± 0.5	2	30.3 ± 9.6	33	13.5 ± 2.6	15
MET>50	HT<200	n/a	6.5 ± 2.3	7	140 ± 37	159	106 ± 16	82
MET<50	HT>200	n/a	1.2 ± 0.7	1	16.5 ± 4.5	16	31.9 ± 4.8	18
MET<50	HT<200	n/a	11.6 ± 3.6	14	354 ± 55	446	1025 ± 171	1006
MET>50	HT>200	noZ	4.8 ± 1.3	8	31.0 ± 9.5	16	--	--
MET>50	HT>200	Z	17.8 ± 6.0	20	24.0 ± 4.9	13	--	--
MET>50	HT<200	noZ	25.9 ± 7.3	30	106 ± 27	114	--	--
MET<50	HT>200	noZ	4.4 ± 1.5	11	51.8 ± 6.2	45	--	--
MET>50	HT<200	Z	126 ± 47	141	115 ± 16	107	--	--
MET<50	HT>200	Z	18.4 ± 4.5	15	244 ± 24	166	--	--
MET<50	HT<200	noZ	142 ± 36	123	2906 ± 412	3721	--	--
MET<50	HT<200	Z	749 ± 181	657	15516 ± 2421	17857	--	--
SUM	3-body		1109 ± 191	1029	19533 ± 2457	22693	1177 ± 172	1121

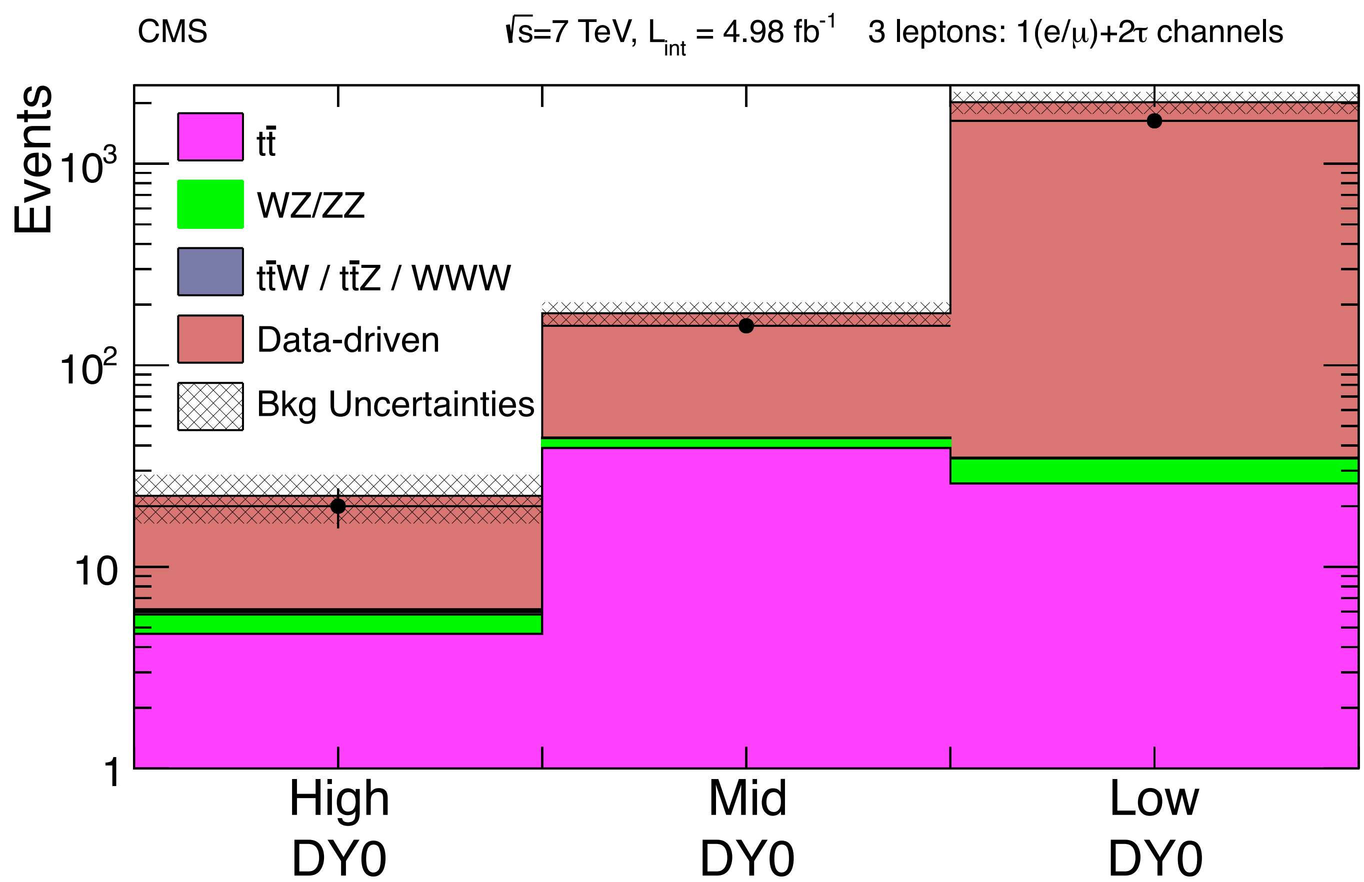
3(e/ μ) S_T Analysis



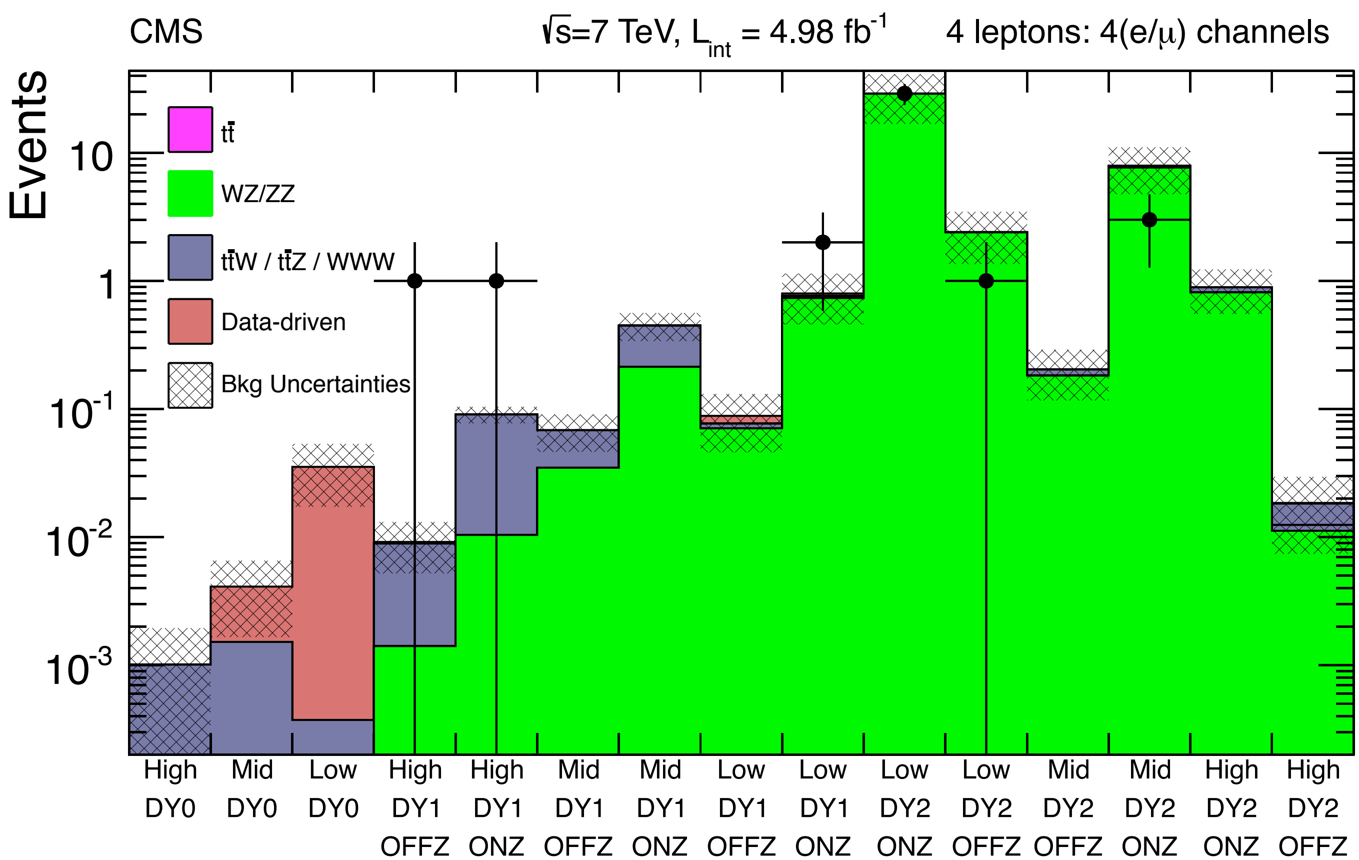
2(e/ μ)+1 Tau S_T Analysis



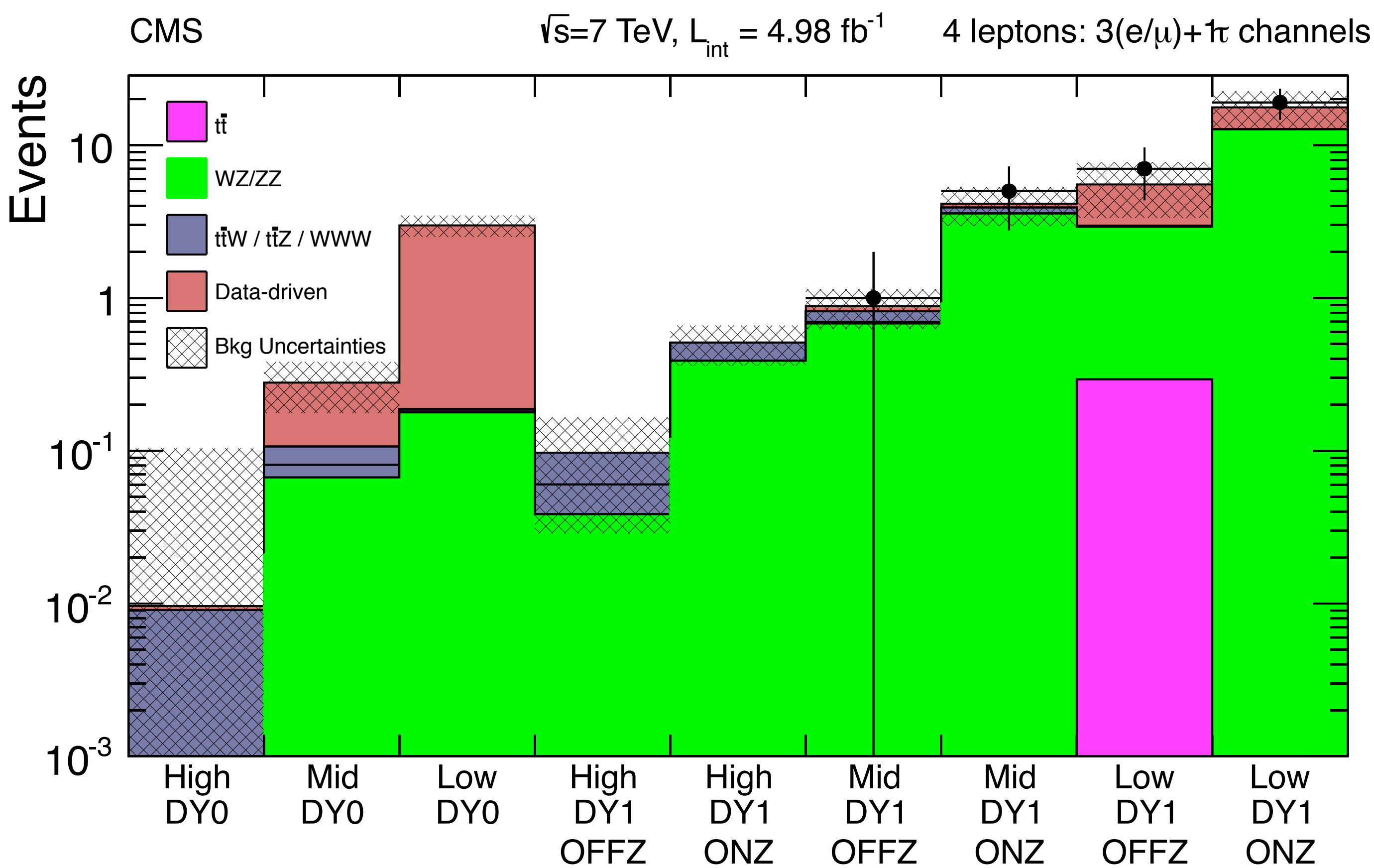
1(e/ μ)+2Tau S_T Analysis



4(e/ μ) S_T Analysis



$3(e/\mu)+1$ Tau S_T Analysis



2(e/ μ)+2Tau S_T Analysis