Searches for Jets + Missing E_T with Leptons at CMS

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on behalf of
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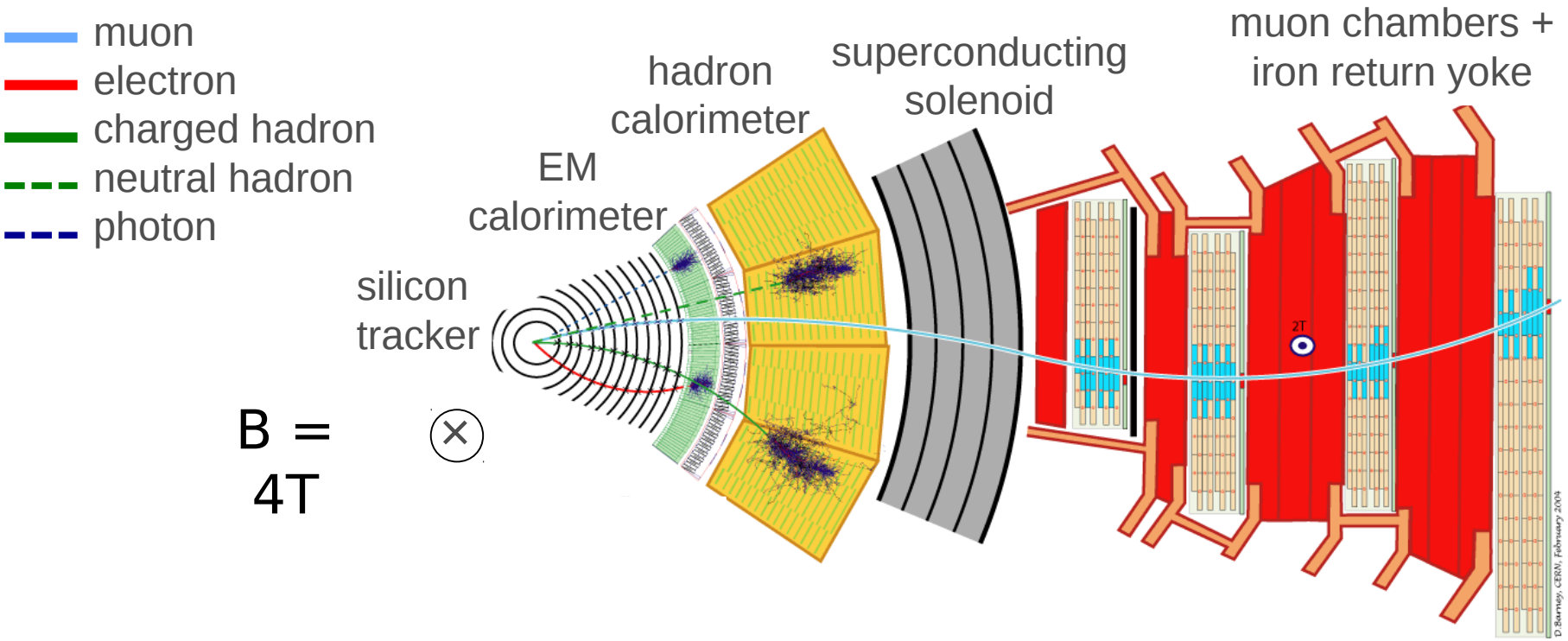
Introduction to SUSY searches at CMS

- CMS SUSY searches cover as many final states as possible
- All CMS SUSY searches utilize **data-driven** background predictions
- This talk focuses on two searches utilizing leptons in the final state
  - Search with single lepton plus jets plus MET
  - Search with Z boson plus jets plus MET
- Because SUSY typically does not produce resonances (like Z-prime), first approach is to look for excess yield in tails of SM kinematical distributions
  - MET $\equiv$ missing transverse energy (neutrinos)
  - $H_T \equiv$ scalar sum jet P_T
- https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

CMS Detector



SUSY searches presented here rely most critically on:

electrons: tracks matched to clusters in EM calorimeter

muons: minimum ionizing tracks, penetrate deep into muon system

jets / HT: constructed with combined tracking + calo info

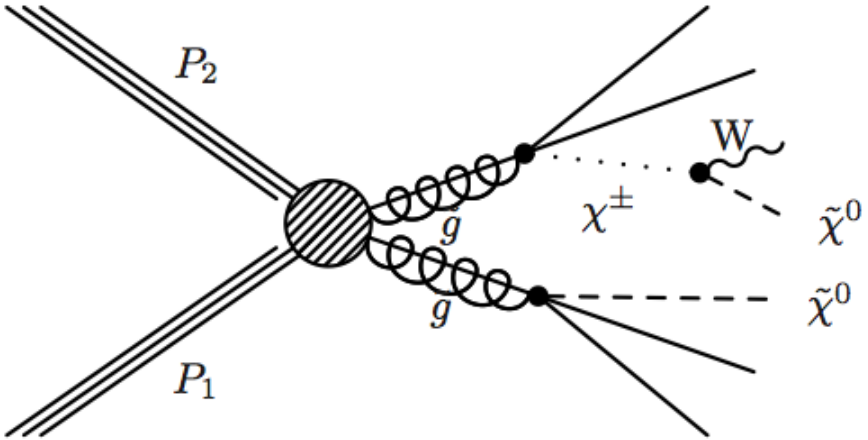
MET: constructed with combined tracking + calo info, hermetic detector

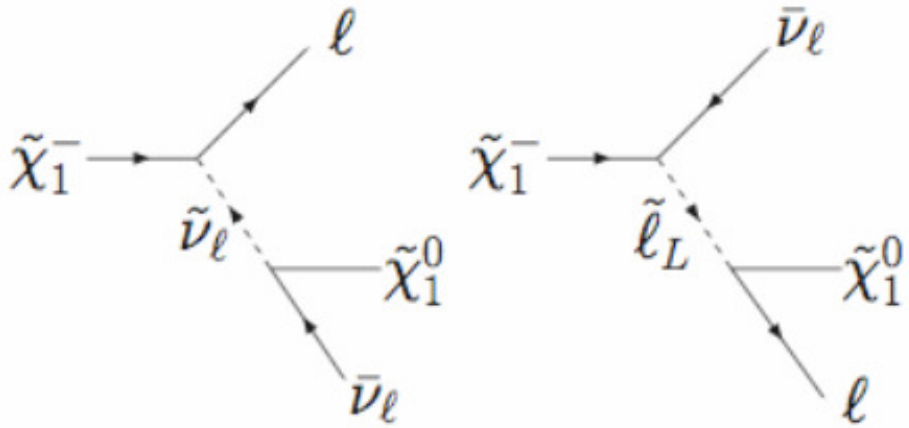
Outline

- Introduction
- Single-Lepton Search
- Search with Z bosons
  - Jet-Z balance (JZB)
  - MET Templates
- Interpretations of Searches

Single Lepton Search

- Final state is a single lepton (e or μ only) + jets + MET
- Requiring a single isolated lepton significantly suppresses QCD background
- Potentially enhanced new physics branching ratio vs dilepton
  - But at the cost of more W+Jets and $t\bar{t}$ background
- Must understand tails of MET and H_T in SM backgrounds
  - Do not rely on MC bc theoretical uncertainty (ISR, jet multiplicity), and detector effect (fake MET, leptons)





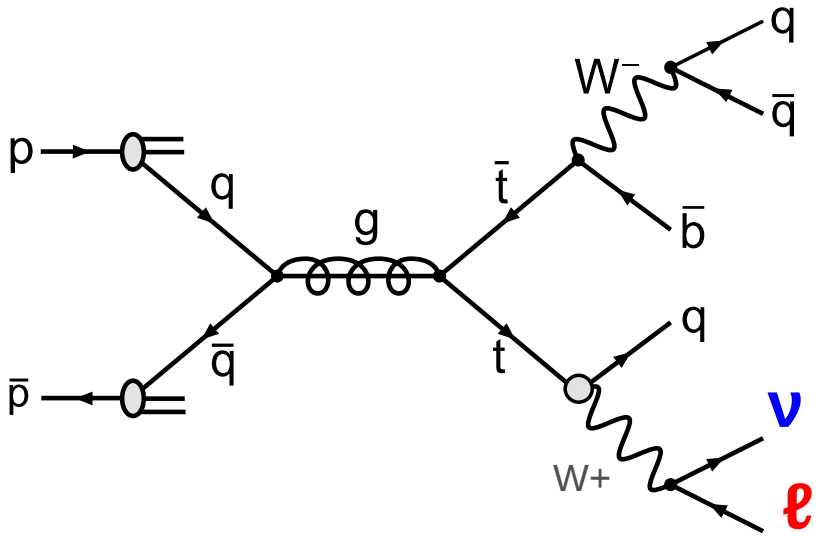
Single Lepton Backgrounds

- W+jets and $t\bar{t} \rightarrow$ lepton+jets : $\sim$75%
  - Estimate using two independent **data-driven** techniques:
    - Lepton P_T spectrum
    - Lepton Projection (L_P)
- $t\bar{t} \rightarrow$ dileptons : $\sim$10%
  - One lost lepton (outside acceptance or fails ID)
  - Estimate from dilepton **data** by scaling by probability to lose lepton
- $t\bar{t}$, W+Jets $\rightarrow \tau \rightarrow e$ or μ : $\sim$15%
  - Lepton P_T spectrum doesn't model this background due to τ decay
  - Estimate using μ plus jets **data** replacing μ with τ response
- QCD ($\lesssim$1%) : estimate from data using 2D extrapolation in isolation vs MET
- Other Backgrounds ($\lesssim$1%) DY, single top : use MC

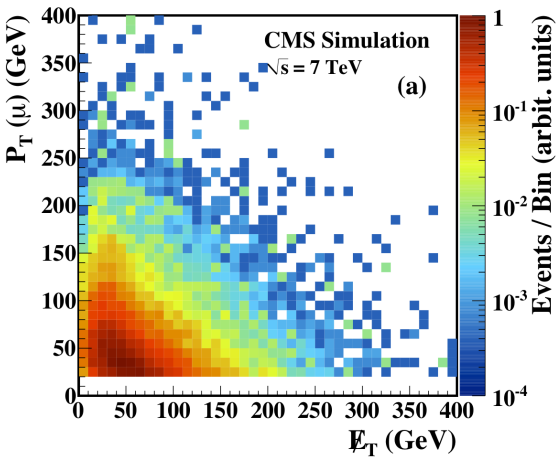
Single Lepton: Lepton P_T Spectrum Method

- For both $t\bar{t}$ and W+jets, $P_T(\nu) \approx P_T(\ell)$ on average
- Use lepton P_T to predict shape and normalization of MET distribution for dominant background
- Up to polarization effects which are well understood and can be reliably corrected for
- In SUSY scenario with LSP, MET from LSP is in excess of prediction

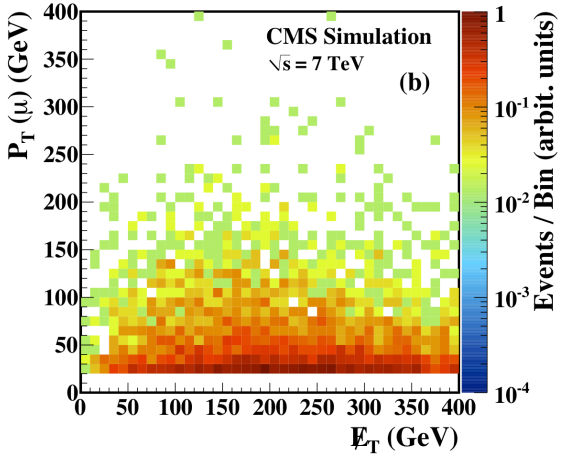
SM background: $t\bar{t} \rightarrow$ lepton+jets



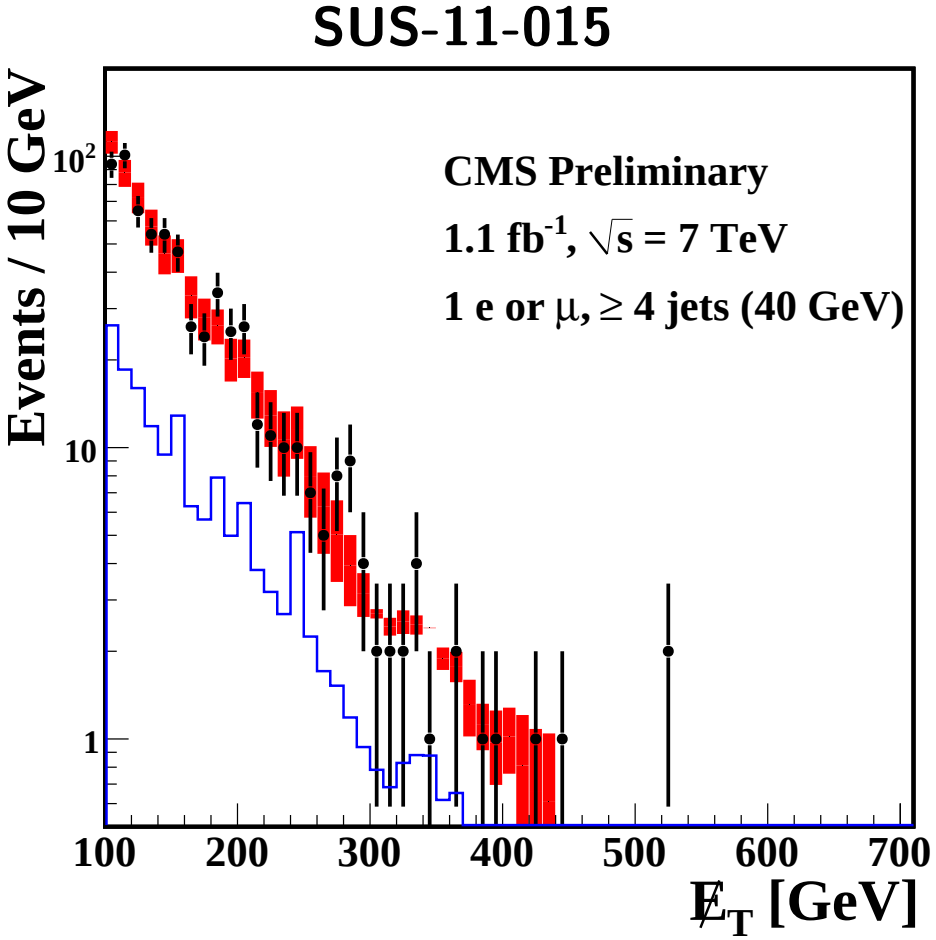
SM ($t\bar{t}$ +W+jets)



Example SUSY Scenario



Single Lepton: Results



data

total background prediction

dilepton+τ prediction

- 2 signal regions ($H_T > 500$ GeV): MET $>$ 250 GeV (loose) and MET $>$ 350 GeV (tight)
- MET distribution agrees well with prediction
- No evidence for new physics

	MET $>$ 250 GeV	MET $>$ 350 GeV
predicted	$49.8 \pm 8.8 \pm 10.8$	$12.1 \pm 4.3 \pm 3.6$
observed	52	8

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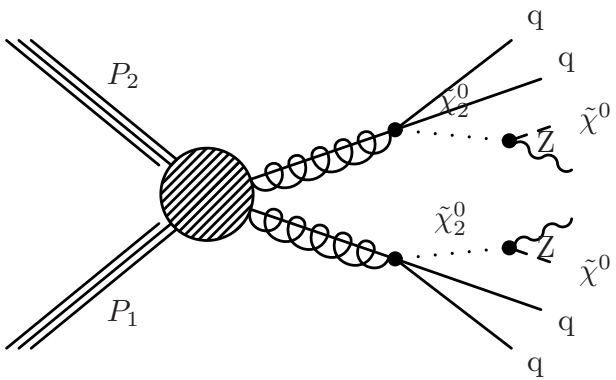
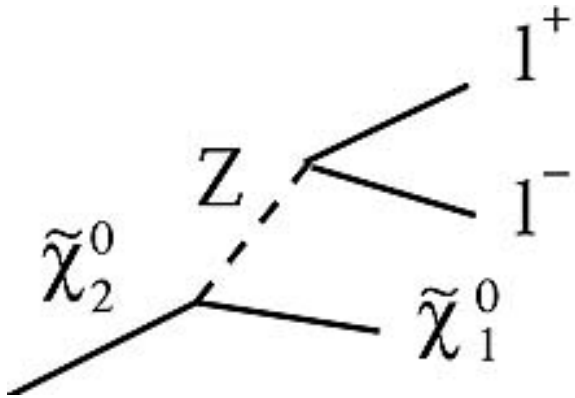
Search with Z bosons

- Leptonic Zs are clean signature with very little background
  - QCD, W+Jets contributions are ∼zero: main SM contributions are Z+Jets and $t\bar{t} \rightarrow$ dileptons
  - Allows much looser H_T requirements than most other SUSY searches
  - Potential probe of new physics' coupling to EWK sector

- Two independent, complementary **data driven** background estimation techniques for Z+Jets background:
  - Jet-Z Balance: JZB
    - Use Z boson P_T to discriminate between signal and background
  - MET Templates
    - Model instrumental (fake) MET using QCD or photon plus jets control sample
- Estimate $t\bar{t}$ background using opposite-flavor ($e\mu$) control sample

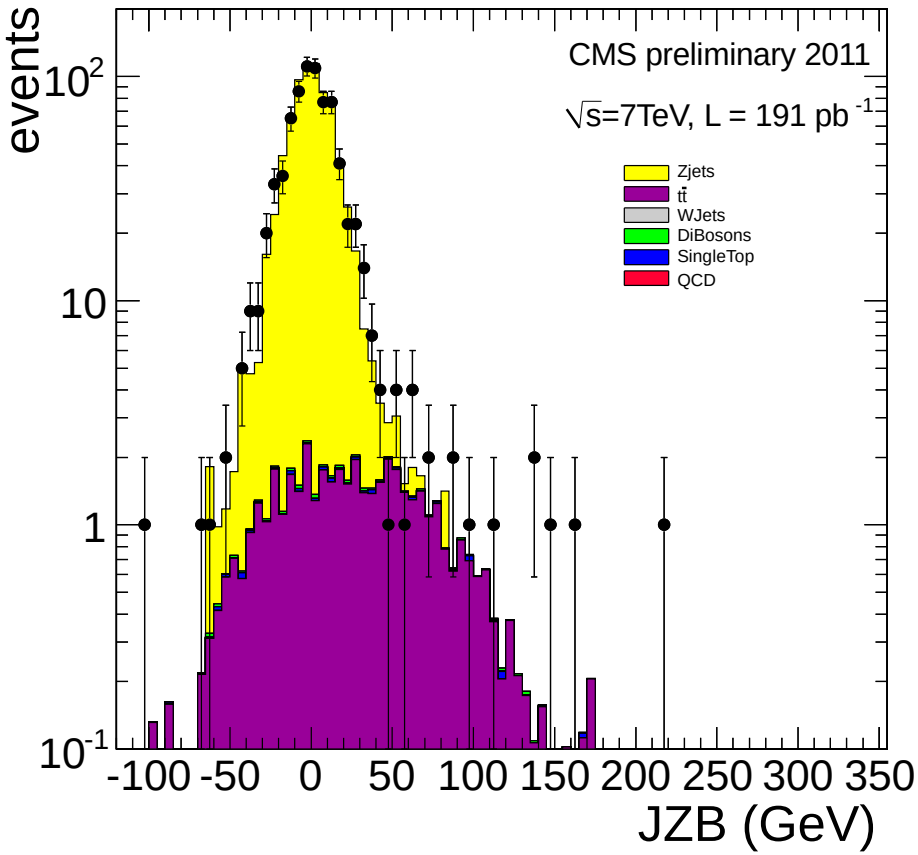




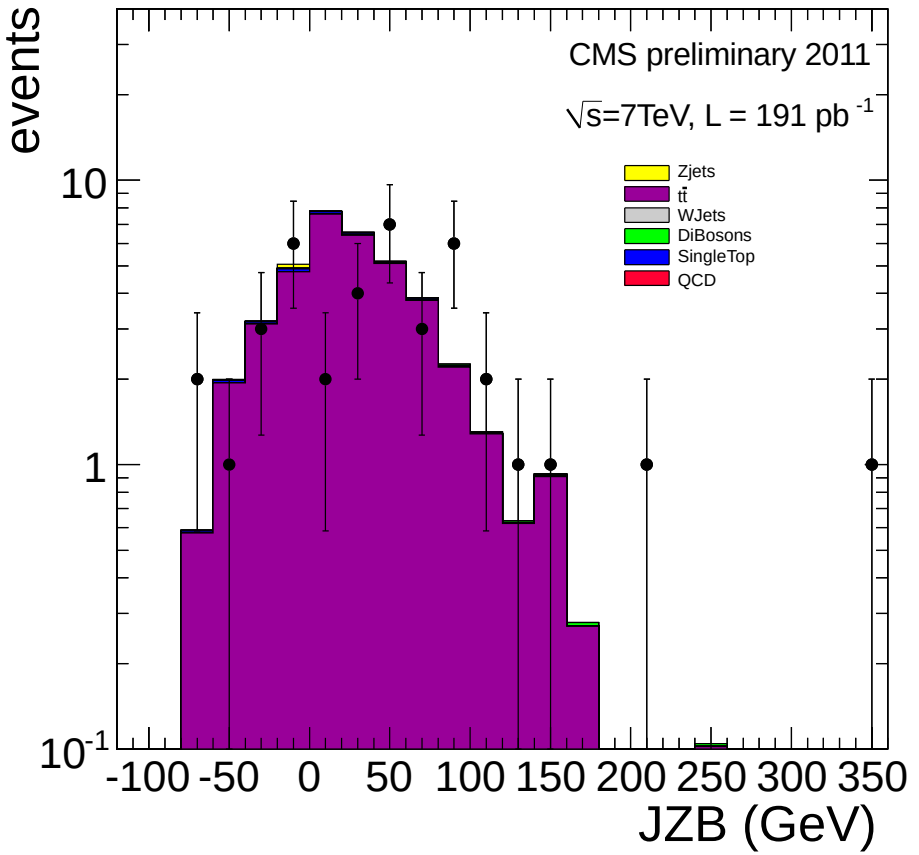
Jet-Z Balance (JZB)

- JZB $\equiv |\sum \vec{p}_T(jet)| - |\vec{p}_T(Z)|$
- JZB is symmetric about $\sim$0 for SM Z+Jets (fake MET)
- JZB is preferentially positive for new physics with real MET since jets balance Z+MET

Same-Flavor Leptons

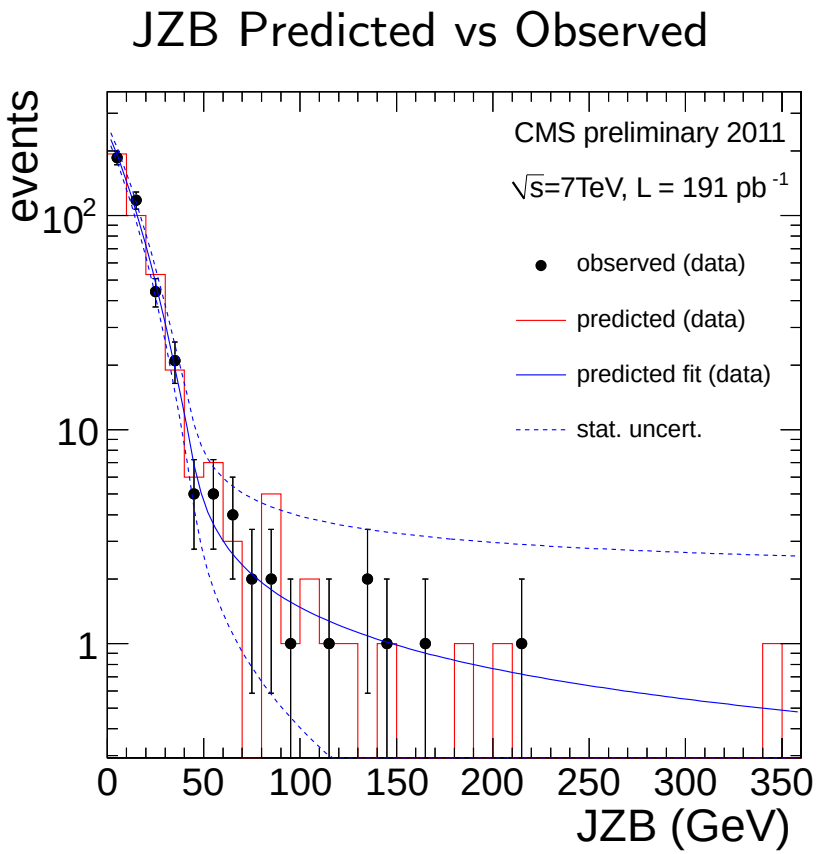


Opposite-Flavor Leptons



Jet-Z Balance (JZB) (2)

- JZB is used to make a **data-driven** background estimation:
  - OF dileptons and $JZB < -X$ SF are used to predict $JZB > X$ SF
  - OF used to predict $t\bar{t}$ contribution since for $t\bar{t}$, N(OF) = N(SF)
  - $JZB^{pred}_{bkgd} = JZB^{pos}_{OF} + |JZB^{neg}_{SF} - JZB^{neg}_{OF}|$
- Signal regions are JZB > 50, 100



Jet-Z Balance Results (SUS-11-012)

- The predicted number of events with uncertainties are used to derive model-independent upper limits (UL) on new physics contributions in the signal regions

Region	Observed	Predicted	UL
JZB > 50	20	24 ± 6 (stat) ± 1.4 (peak) $^{+1.2}_{-2.4}$ (sys)	11.1
JZB > 100	6	8 ± 4 (stat) ± 0.1 (peak) $^{+0.4}_{-0.8}$ (sys)	6.6

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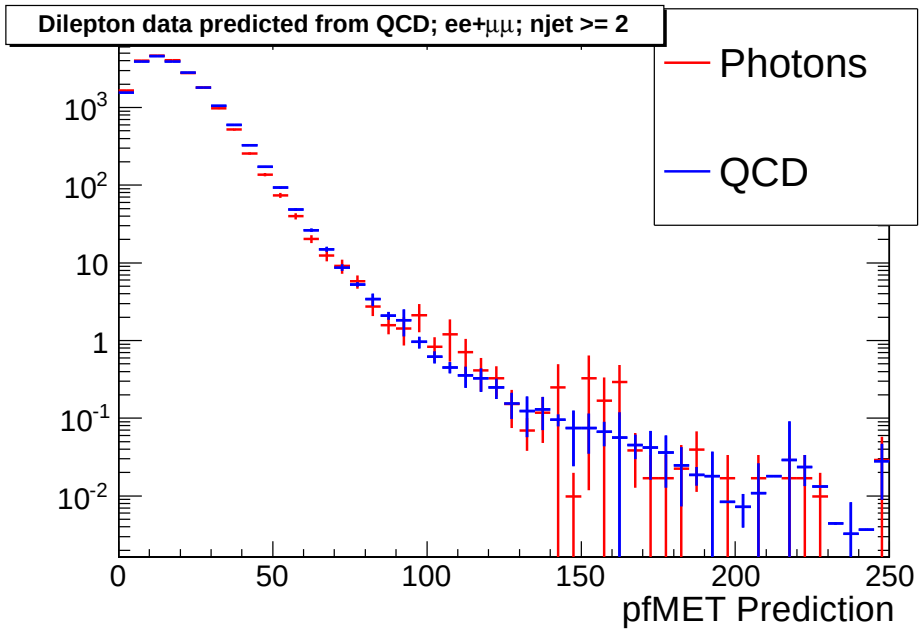
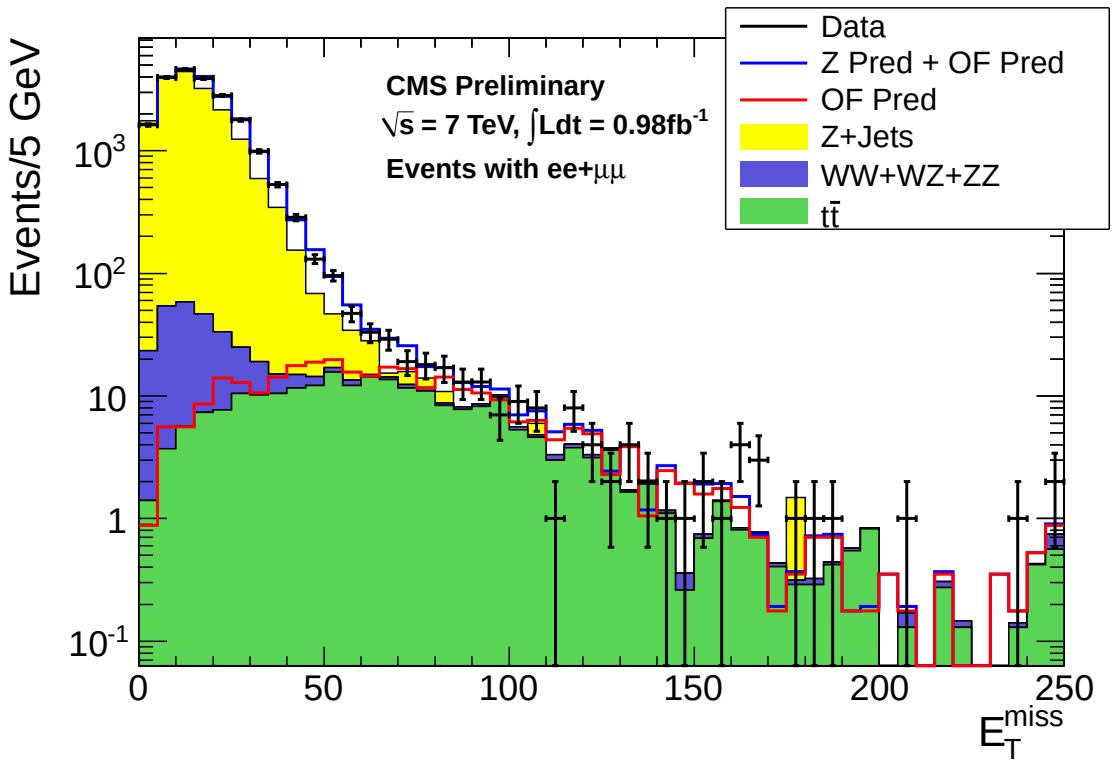
Search in Z+jets using MET Templates

- Z + jets is a process with no MET–enters a MET selection only via fake MET from jet mismeasurement
- Model jet mismeasurement in **data-driven** way: use photon + jets or QCD control sample
  - Plot MET in bins of Njet and H_T – the MET templates
  - Prediction is formed by adding the template which corresponds to MET and H_T in each Z event
  - Consistent predictions using either QCD or photon data



MET Templates Results (SUS-11-017)

- $t\bar{t}$ background is predicted using $e\mu$ data (subtraction)
- Total prediction consistent with data $\rightarrow$ No evidence for new physics



	MET $>$ 30 GeV	MET $>$ 60 GeV	MET $>$ 100 GeV	MET $>$ 200 GeV
Z Pred	2060 $\pm$ 29.1 $\pm$ 309	60.8 $\pm$ 4.1 $\pm$ 9.1	5.1 $\pm$ 1.0 $\pm$ 0.8	0.09 $\pm$ 0.04 $\pm$ 0.01
$t\bar{t}$ Pred	246.6 $\pm$ 6.3 $\pm$ 22.2	152.5 $\pm$ 4.9 $\pm$ 13.7	50.6 $\pm$ 2.8 $\pm$ 4.6	3.2 $\pm$ 0.7 $\pm$ 0.3
Prediction	2307 $\pm$ 29.7 $\pm$ 310	213.0 $\pm$ 6.4 $\pm$ 16.5	55.7 $\pm$ 3.0 $\pm$ 4.6	3.3 $\pm$ 0.7 $\pm$ 0.3
Data	**2287**	**206**	**57**	**4**
UL	498	37	20	5.9

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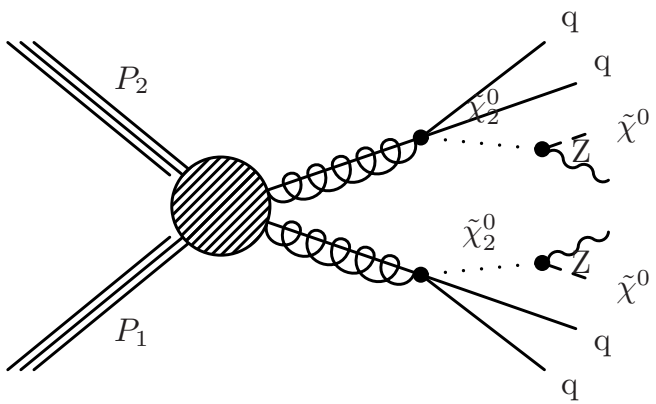
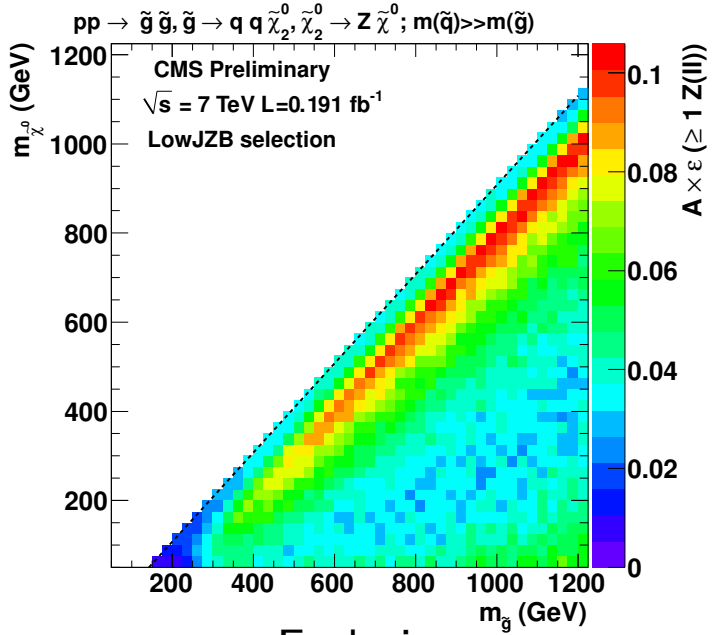
Interpretation: Efficiency Models and Simplified Models

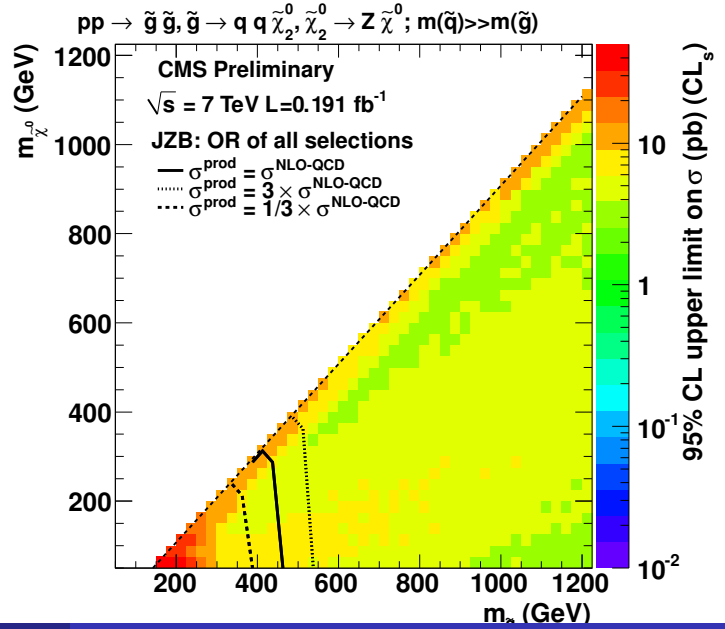
- Provide Efficiency Models
  - Approximate generated-to-reconstructed efficiencies for physics objects
  - Apply to generic model
- Simplified Models
  - Model with single new diagram parameters are particle masses
  - Can be combined using efficiencies provided to place limits on other models
  - Also provide exclusion contours (shown for JZB analysis)



Efficiencies



Exclusion

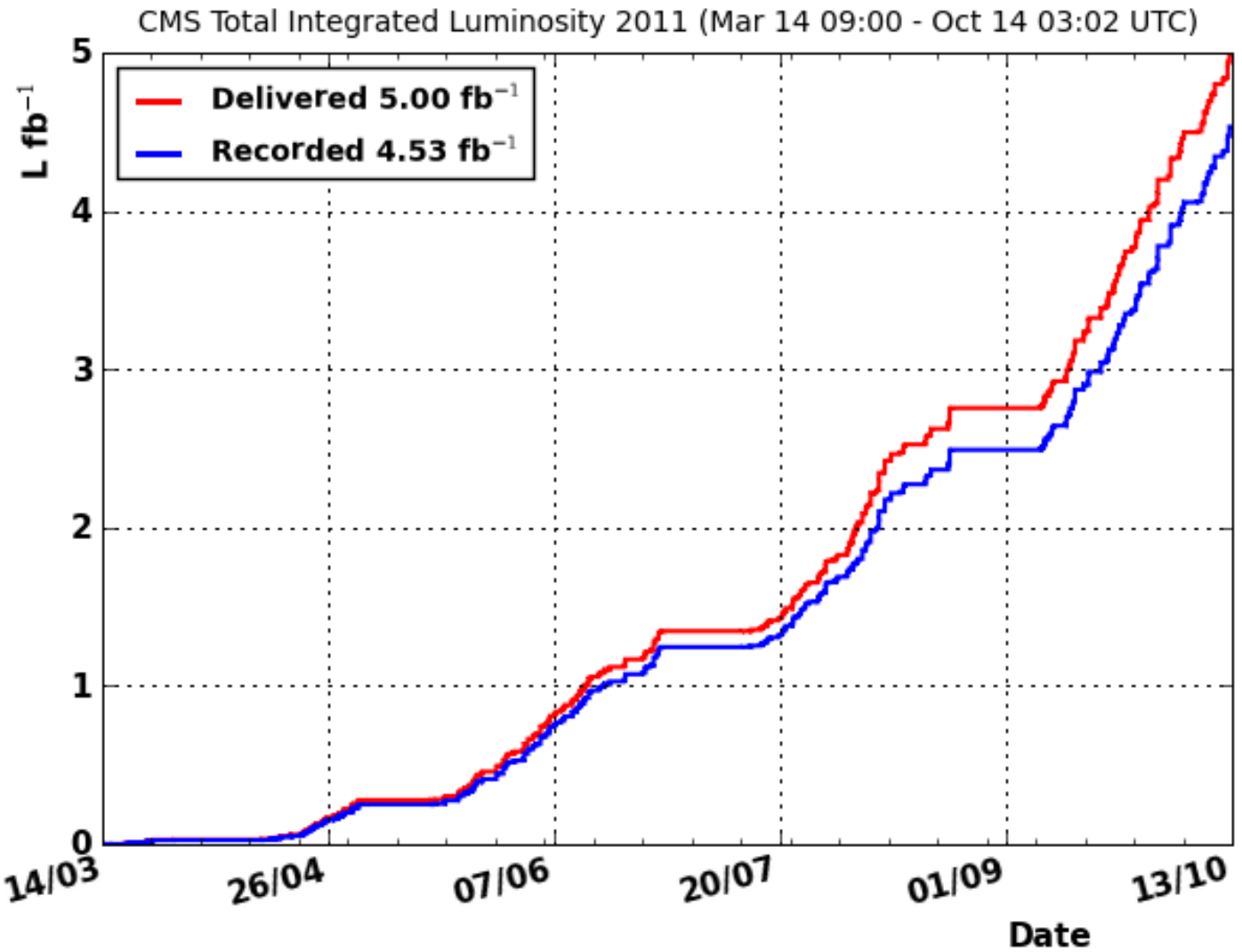


Outlook + Conclusion

- Searches performed so far in CMS focus on SUSY with large cross-section at high MET and H_T
  - This is the case for all final states: all hadronic, photon, single lepton, dilepton, multilepton
  - No evidence for new physics
- More Data: already ~5/fb recorded
  - Publications to come early 2012
- Further refinements/other approaches:
  - Single Lepton analysis:
    - Require b-tag in order to suppress W+Jets
  - Z analyses:
    - Veto b-tag in order to suppress $t\bar{t}$
  - Electroweak production (small xsection, low/no H_T)
  - R-parity violating models (low/no MET)
  - Low mass stop/sbottom, compressed spectra, small mass splitting

BACKUP SLIDES

LHC Luminosity

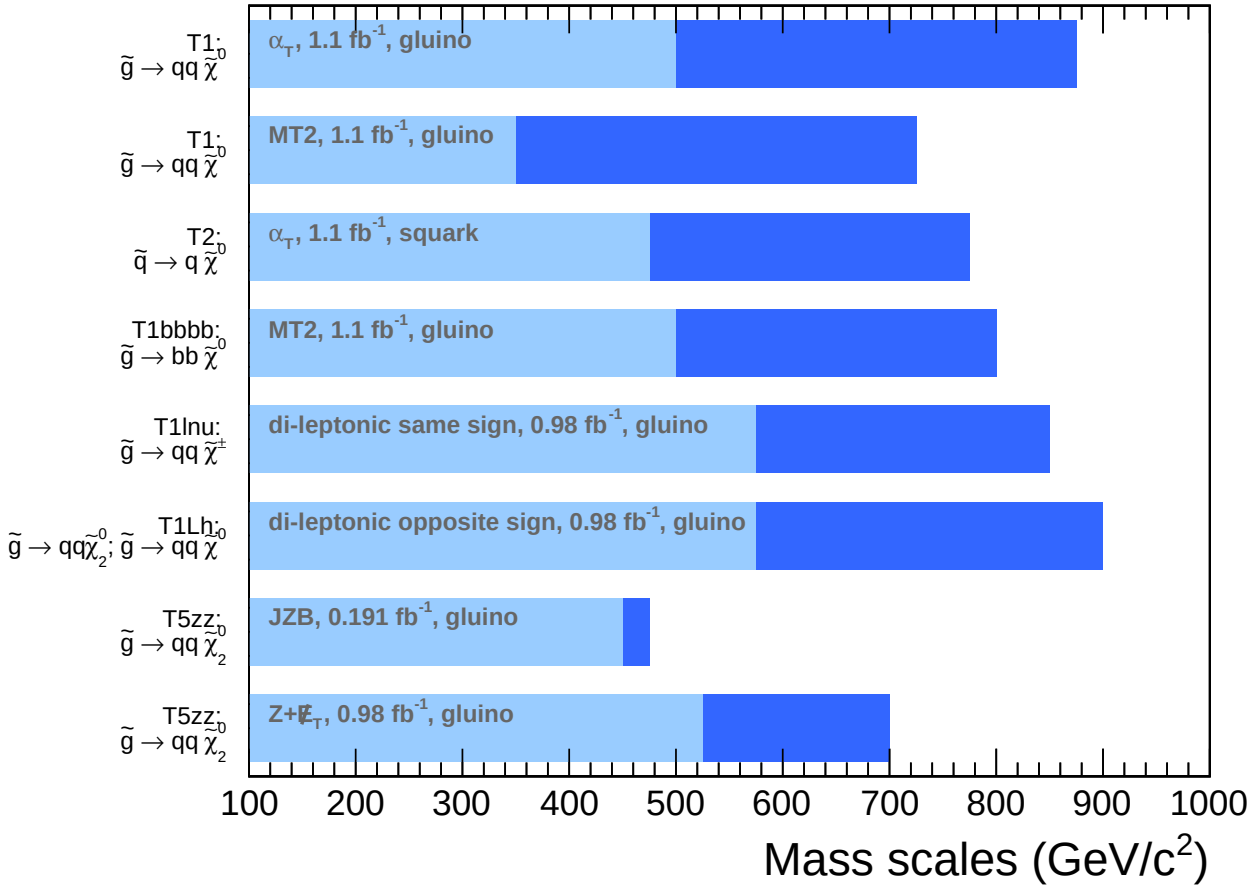


CMS SUSY/Exotica Analyses

all-hadronic	inclusive jets+MHT	SUS-11-004	1.1 fb-1
(0-leptons)	αT + HT	SUS-11-003	1.1 fb-1
	MT2	SUS-11-005	1.1 fb-1
	razor	arXiv:1107.1279	35 pb-1
	b-jets + MET	arXiv:1106.3272	35 pb-1
single lepton	e/μ + jets + MET	SUS-11-015	1.1 fb-1
di-lepton	opposite-sign	SUS-11-011	0.98 fb-1
	Z + (MET templates)	SUS-11-017	0.98 fb-1
	Z + (JZB)	SUS-11-012	0.19 fb-1
	same-sign	SUS-11-010	0.98 fb-1
mullti-lepton	≥3 leptons	arXiv:1106.0933	35 pb-1
lepton+photon	e/μ + γ + MET	arXiv:1105.3152	35 pb-1
photons	γ/γγ + jets + MET	SUS-11-009	1.1 fb-1
long-lived	displaced fermions	EXO-11-004	1.1 fb-1
particles	stopped gluinos	EXO-11-020	0.89 fb-1
	R-hadrons	EXO-11-022	1.1 fb-1

CMS Simplified Model Exclusion Summary

Ranges of exclusion limits for gluinos and squarks, varying $m(\tilde{\chi}^0)$
CMS preliminary



For limits on $m(\tilde{g})$, $m(\tilde{q}) >> m(\tilde{g})$ (and vice versa). $\sigma^{prod} = \sigma^{NLO\text{-}QCD}$.

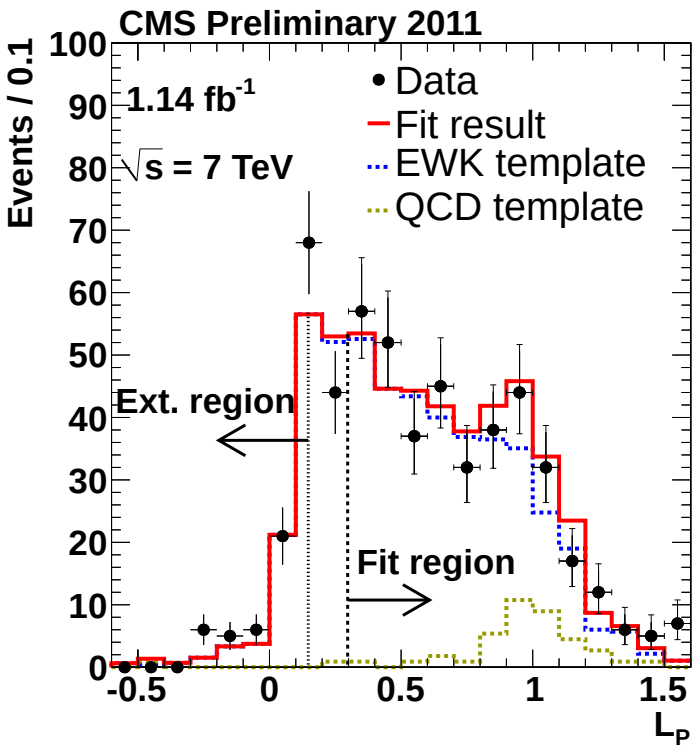
$m(\tilde{\chi}^\pm), m(\tilde{\chi}^0_2) \equiv \frac{m(\tilde{g}) + m(\tilde{\chi}^0)}{2}$.

$m(\tilde{\chi}^0)$ is varied from 0 GeV/c^2 (dark blue) to $m(\tilde{g})$-200 GeV/c^2 (light blue).

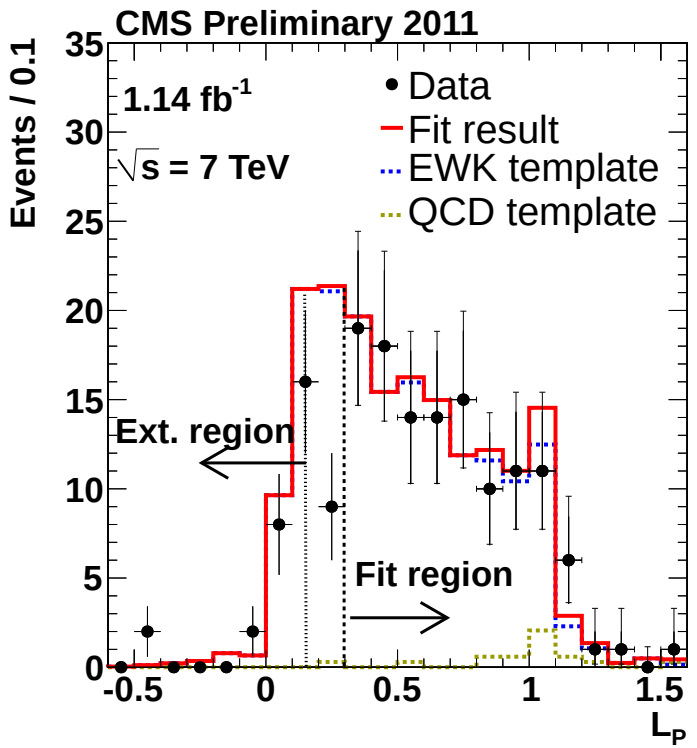
Single Lepton Analysis: Lepton Projection (L_P) Method

- $L_P = \frac{\vec{p}_T(lep)\cdot\vec{p}_T(W)}{|\vec{p}_T(W)|^2}$
  - L_P peaks near zero for SUSY due to large MET relative to lep P_T
  - SM W, $t\bar{t}$ have broad $L_P$distribution
- Fit L_P in control region ($L_P > 0.3$) and extrapolate to signal region ($L_P < 0.15$) in bins of $S_T^{lep} = P_T(lep) + MET$

$150 < S_T^{lep} < 250$



$250 < S_T^{lep} < 350$



Single Lepton Analysis Selections

- Lepton: exactly one isolated e or μ, $P_T > 20$ GeV
  - μ: relative isolation < 0.1, $|\eta| < 2.1$
  - e: relative isolation < 0.07 for $|\eta| < 1.5$, < 0.06 for $1.4 < |\eta| < 2.4$, $|\eta| < 2.4$
- Jets: at least three jets of $|\eta| < 2.4$
  - $P_T > 40$ GeV for N jet counting
  - $P_T > 20$ GeV for H_T

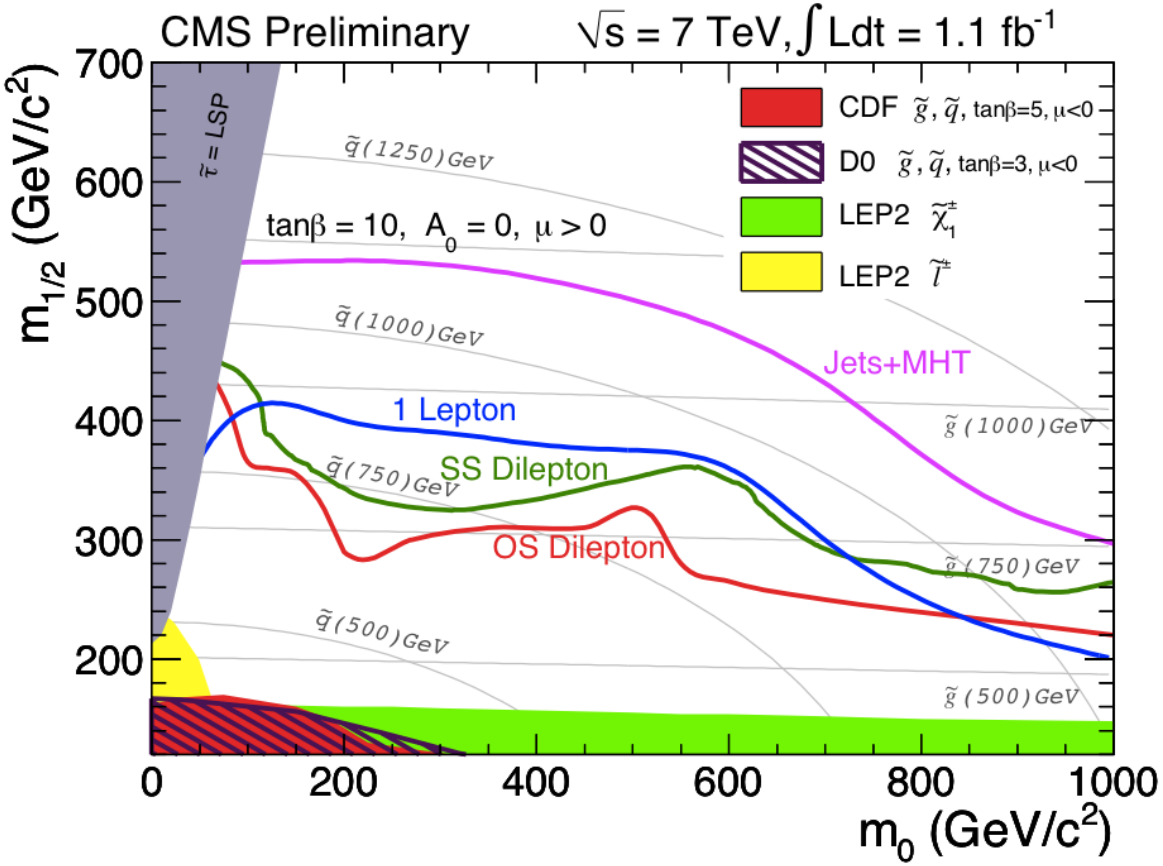
Z Analysis Selections

- JZB
  - Leptons: at least two opposite-sign, same flavor e or μ, $P_T > 20$ GeV, $|\eta| < 2.4$, dilepton invariant mass between 71 and 111
  - Jets: at least three jets of $P_T > 30$ GeV, $|\eta| < 3.0$

- MET Templates
  - Leptons: at least two opposite-sign, same flavor e or μ, $P_T > 20$ GeV, $|\eta| < 2.4$, relative isolation < 0.15, dilepton invariant mass between 81 and 101
  - Jets: at least two jets of $|\eta| < 3.0$
    - $P_T > 30$ GeV for N jet counting
    - $P_T > 15$ GeV for H_T

Interpretation of Results: CMSSM

- Constrained minimal SUSY extension to SM: 5 parameters (m_0, $M_{\frac{1}{2}}$, $\tan\beta$, A_0, sign(μ))



- All hadronic has best sensitivity to this particular model, but at large m_0 and small $M_{\frac{1}{2}}$, leptonic analyses are competitive