Recent results from CMS on SUSY searches in leptonic final states

2nd International Conference on Particle Physics, 20-25 June 2011, Istanbul

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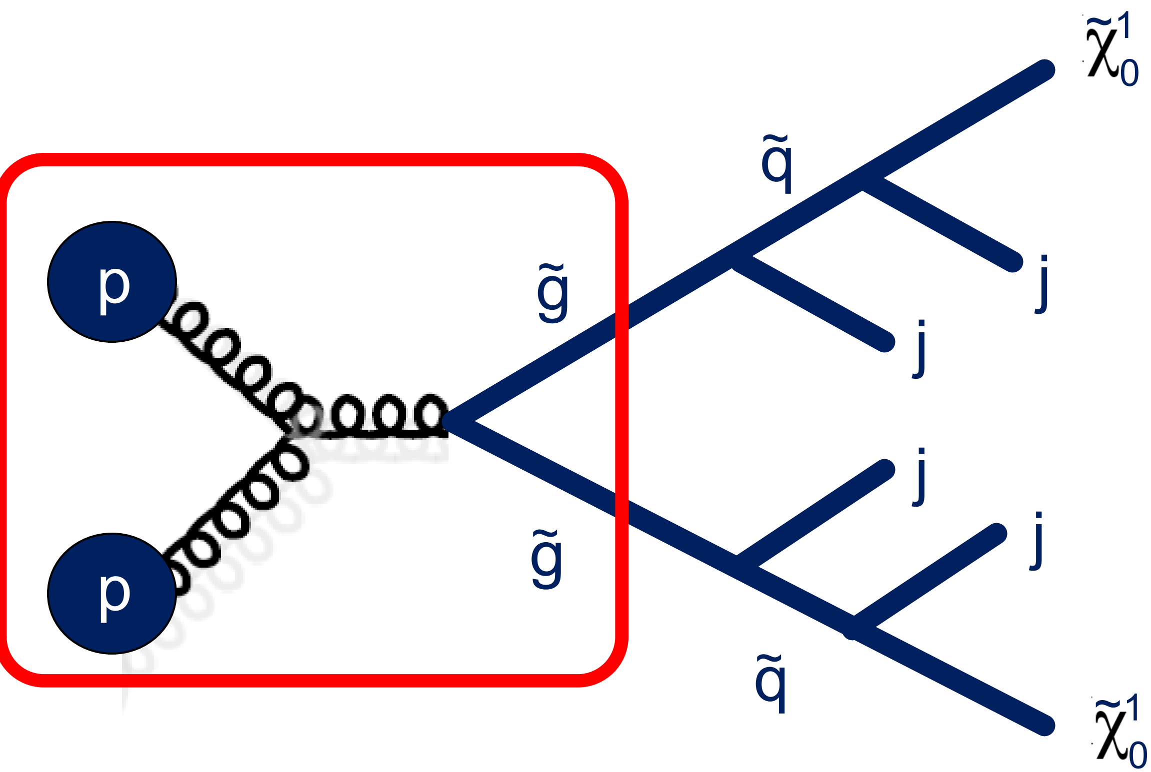
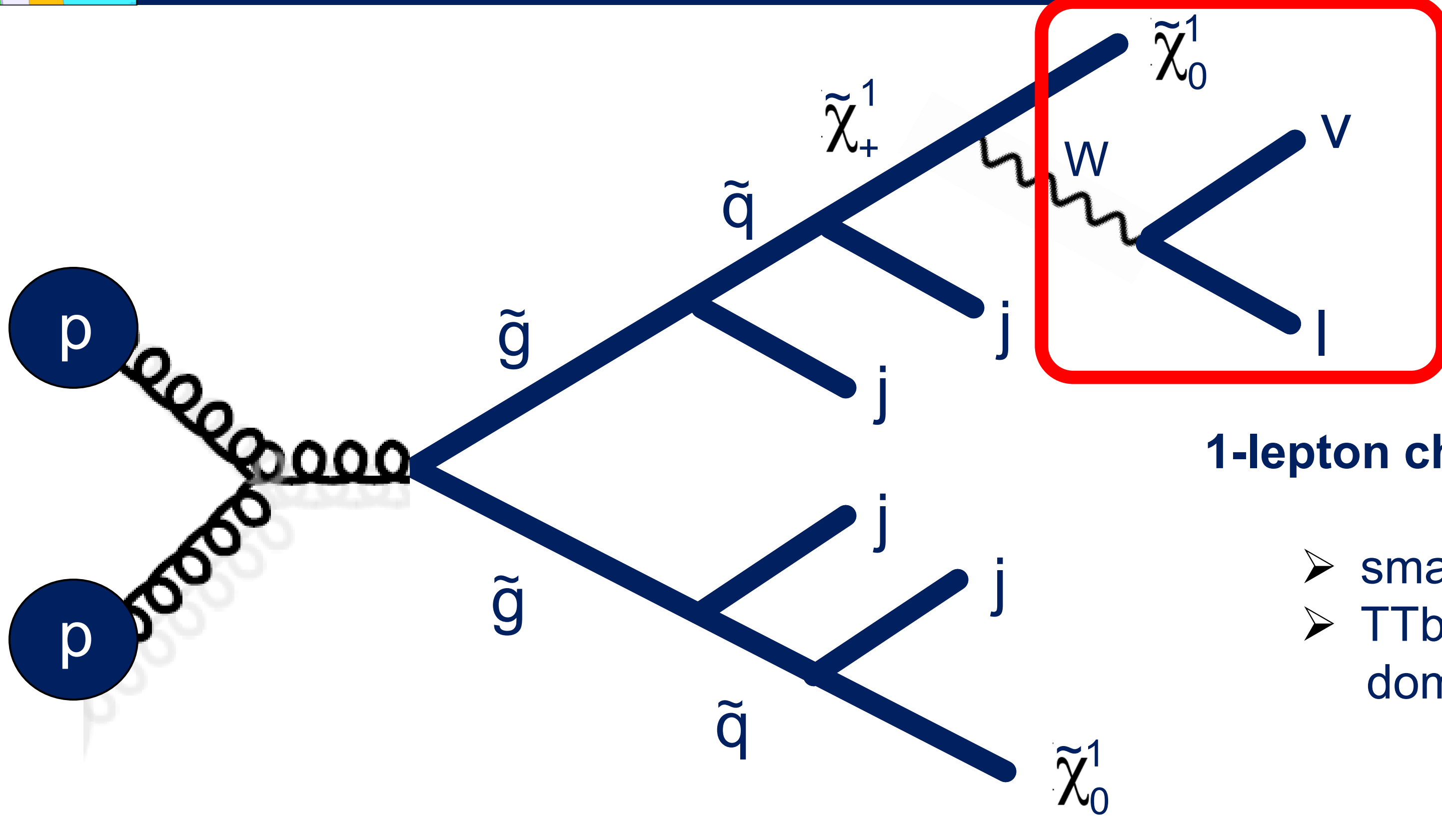
Overview



- At the LHC, colored production of squarks and gluinos will be dominant
- followed by cascade decays involving jets and (di-) leptons, photons, ...
- Under moderate assumptions (e.g. R-parity) there is a stable LSP

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

single lepton channel

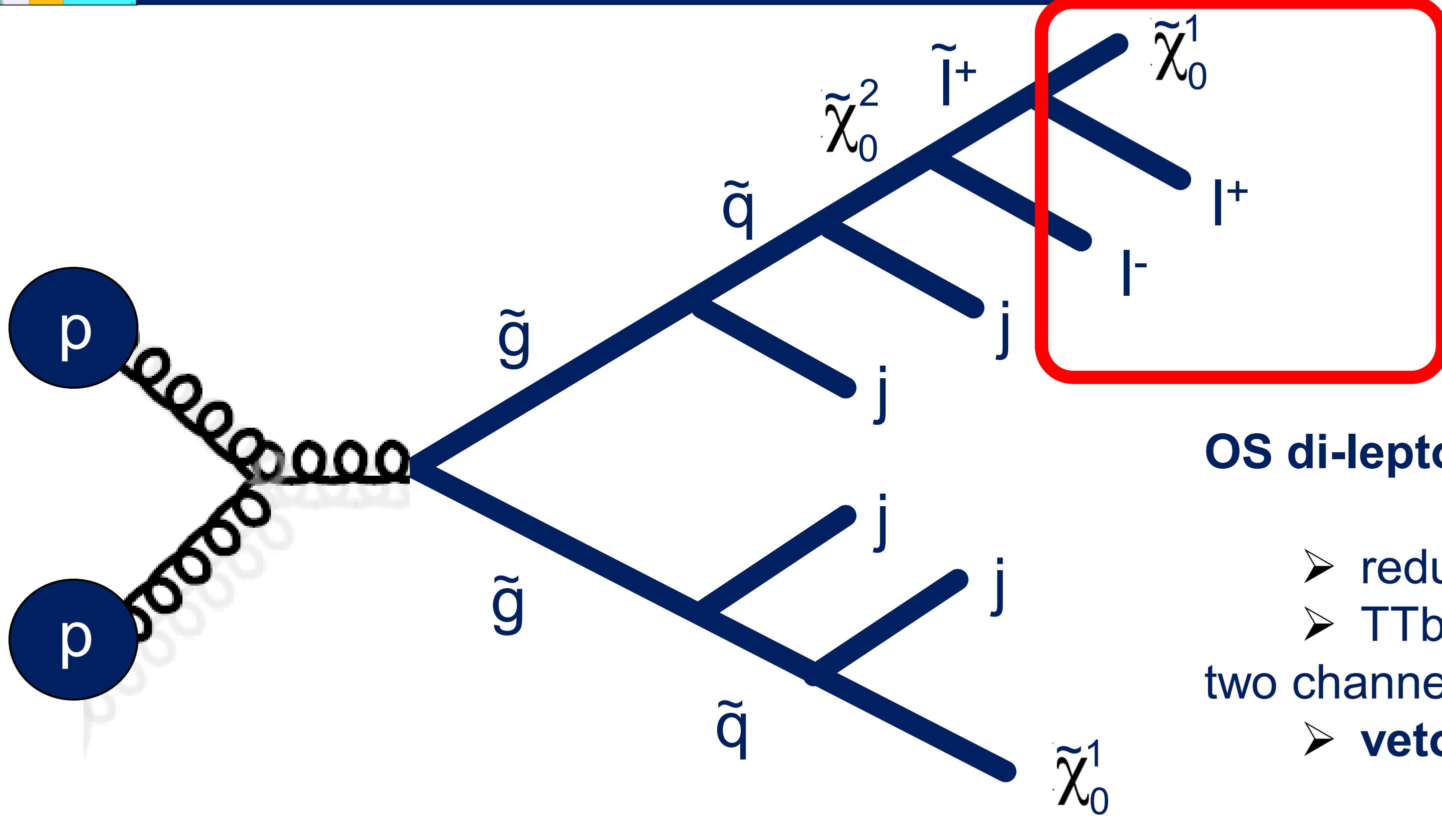


1-lepton channel

- small QCD background
- TTbar and W+Jets dominate

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

OS dilepton channel



OS di-lepton channel

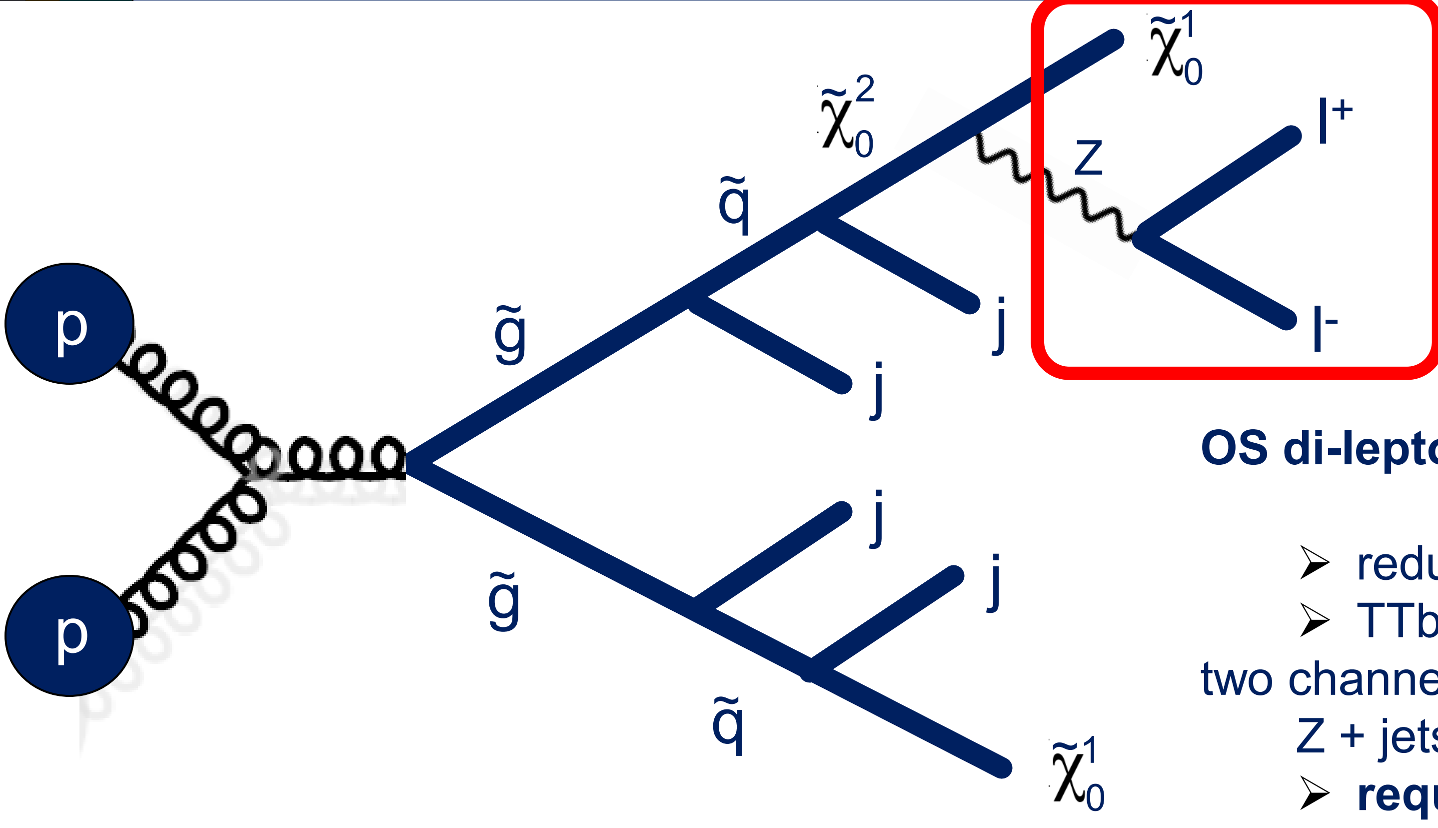
- reduced W background
- TTbar dominates

two channels:

- **veto $m(l^+l^-) \sim m_Z$**

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

OS dilepton channel



OS di-lepton channel (JZB)

- reduced W background
- TTbar dominates

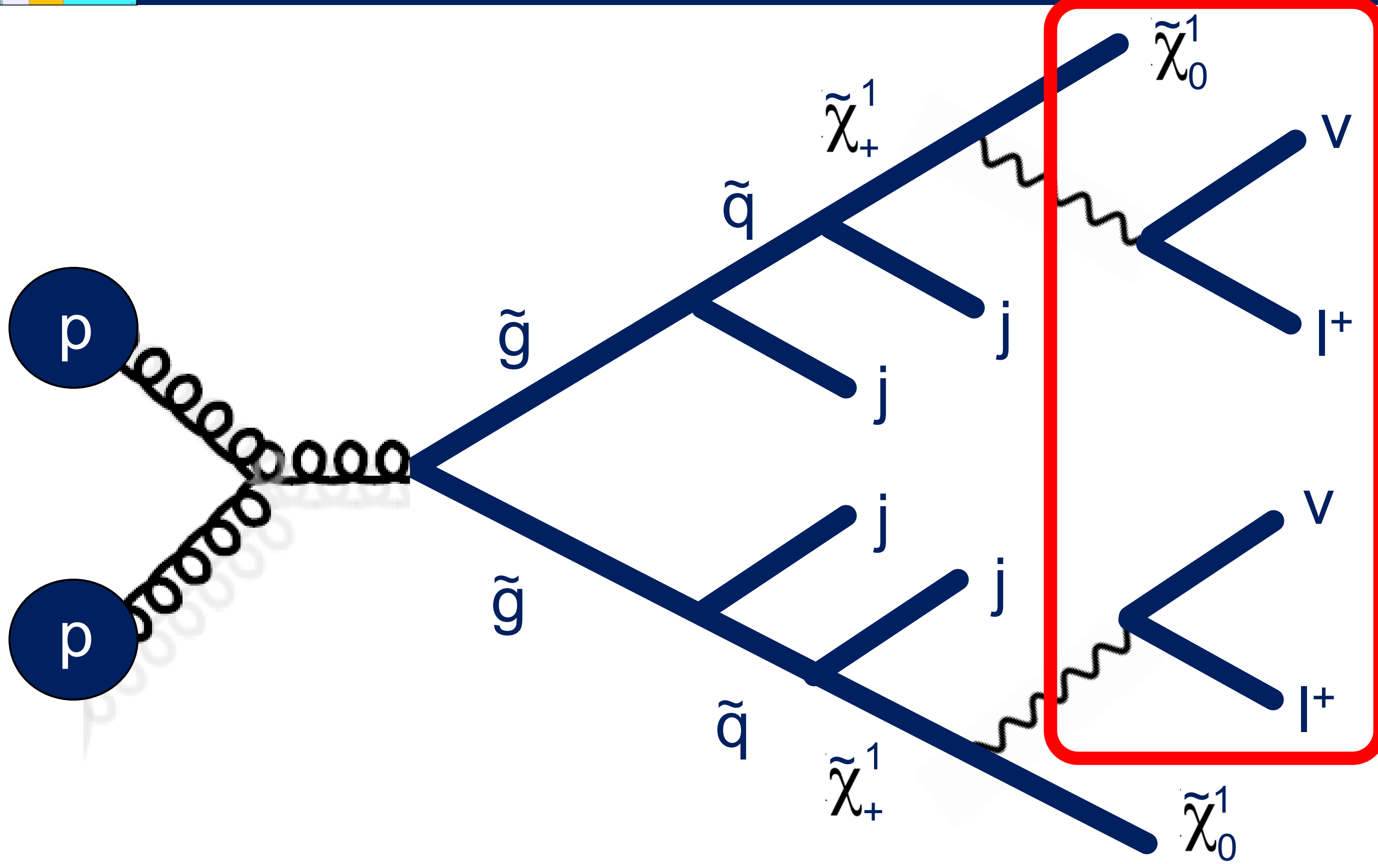
two channels:

Z + jets + MET

- **require $m(l^+l^-) \sim m_Z$**
- **see backup; 191 pb^{-1}**

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

SS dilepton channel

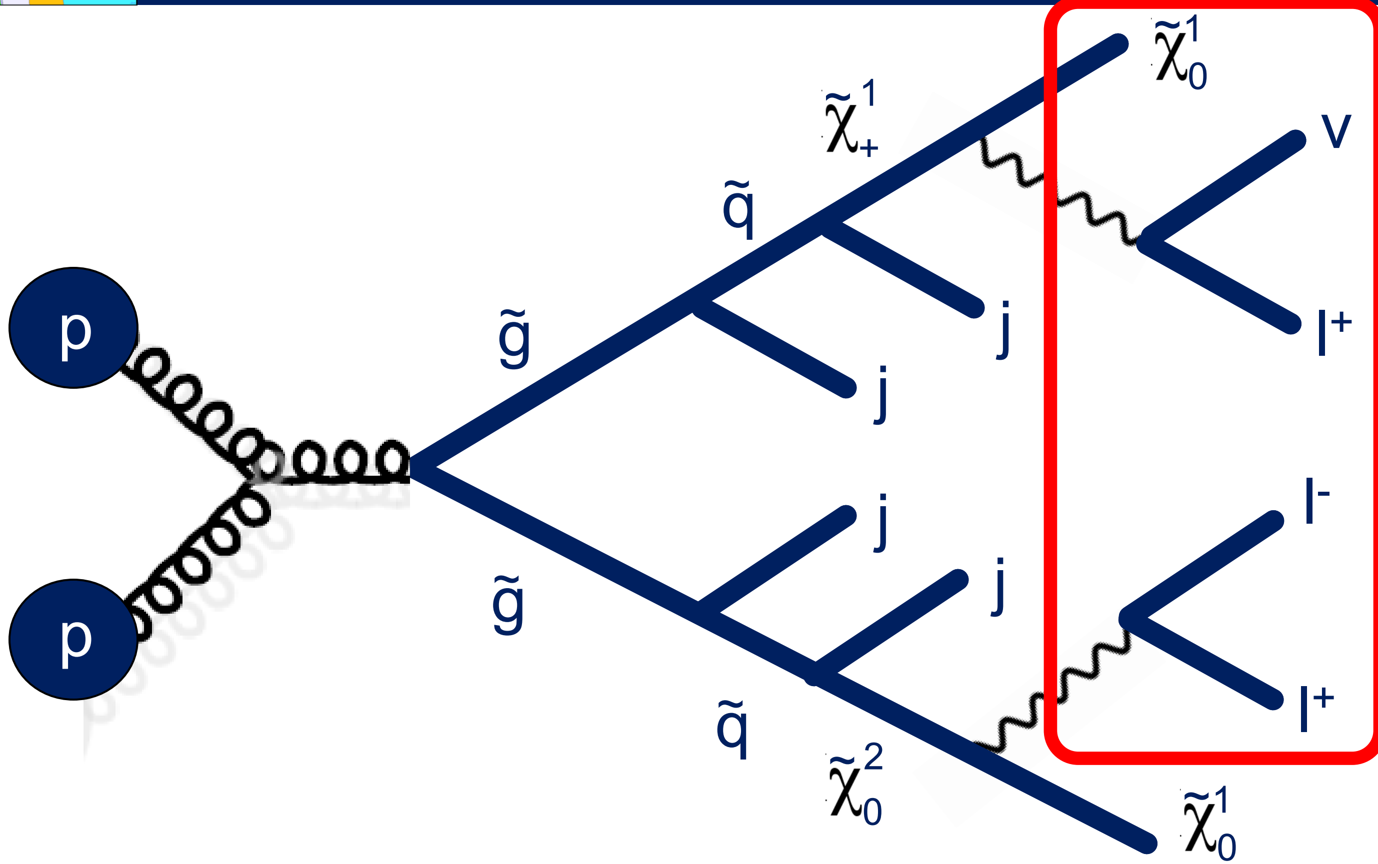


SS di-lepton channel

- very little SM background (tau final state)

0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

multilepton channel



multi lepton channel

- very little SM background
- many channels (tau final state)

in general we have

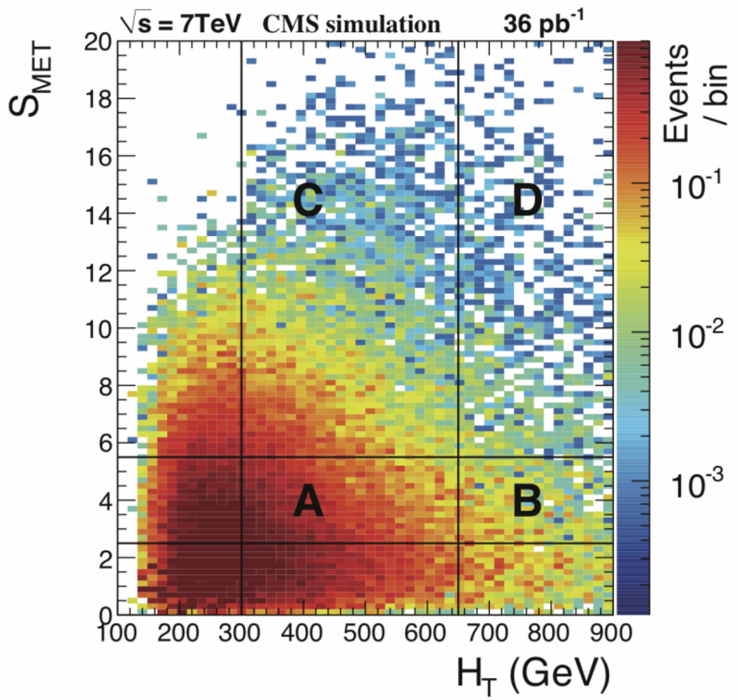
- multiple methods of data-driven background estimation for each channel

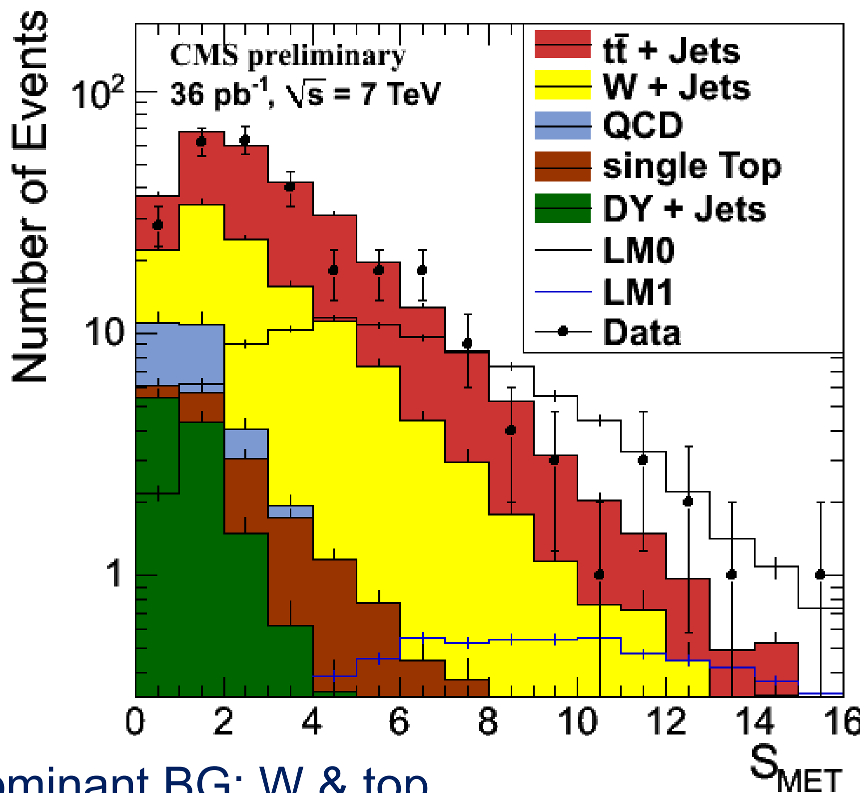
0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

single lepton: matrix method

- **pre-selection: one energetic lepton**
  =1 e P_T>20 GeV or μ P_T>15 GeV
  ≥4 jets, p_T>30 GeV, |η|<2.4

- **signal selection (D):**
  H_T>650 GeV
  MET /$\sqrt{H_T}$ > 5.5

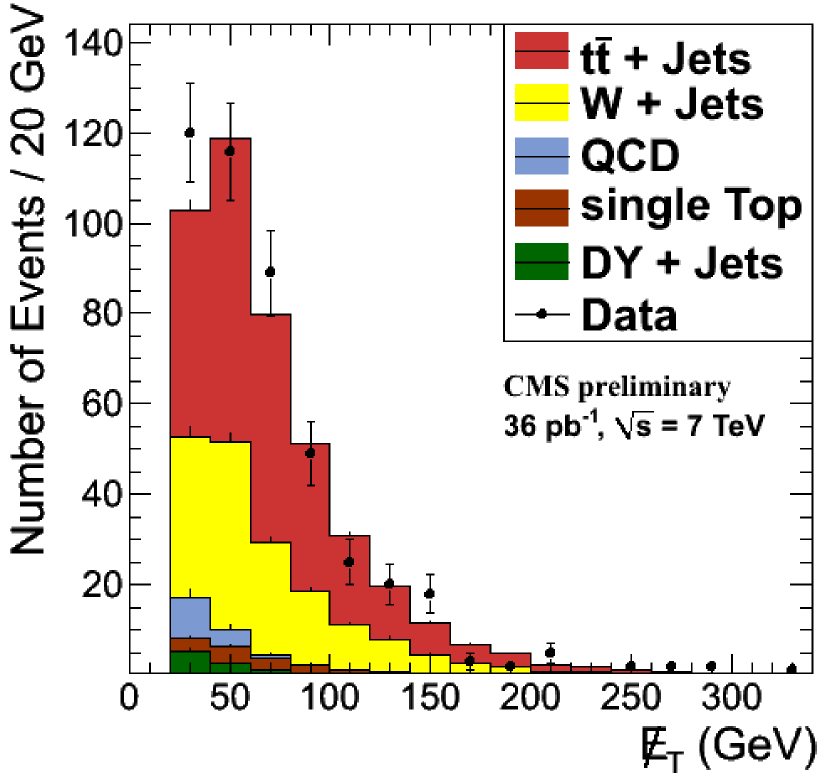


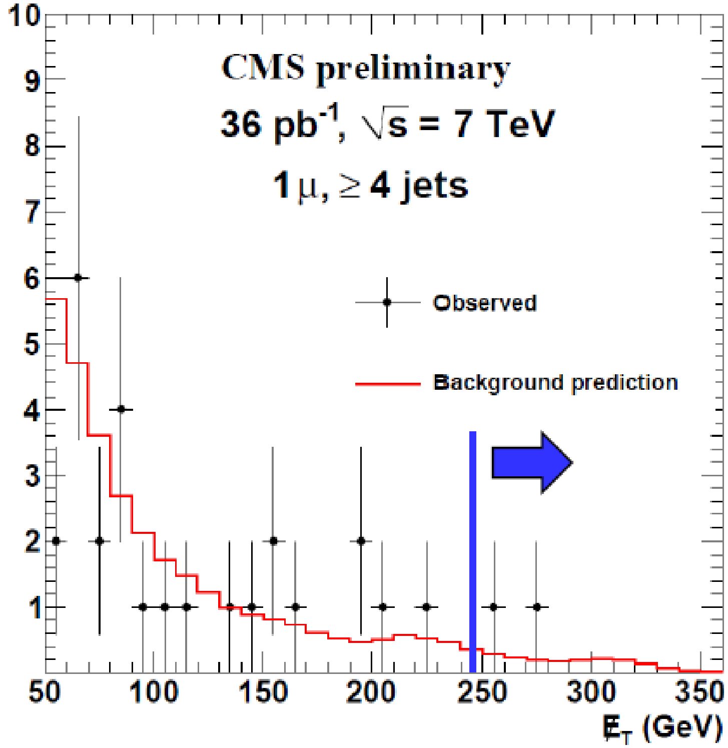


- Dominant BG: W & top
- matrix (ABCD) method: use nearly uncorrelated variables. Exploits the hadronic event properties $H_T = \Sigma_{jets}\, p_T$ vs. S_{MET} = MET /$\sqrt{H_T}$
  Small QCD contribution estimated separately
- Calculate Bkg-prediction from Bkg dominated control regions: $D_{pred.}$ = B C / A

2^{nd} method: lepton spectrum

- **pre-selection:**
  =1 e or μ, P_T>20 GeV
  ≥4 jets, E_T>30 GeV, |η|<2.4
- **signal selection:**
  H_T>500 GeV , MET > 250





- Lepton spectrum method: use the fact that, for W decays, charged lepton and neutrino P_T spectrum are similar
- Idea: Take μ-P_T spectrum as model for MET Correct for acceptance, efficiency, polarization effects
- MET resolution worse than e/μ: smear μ-P_T

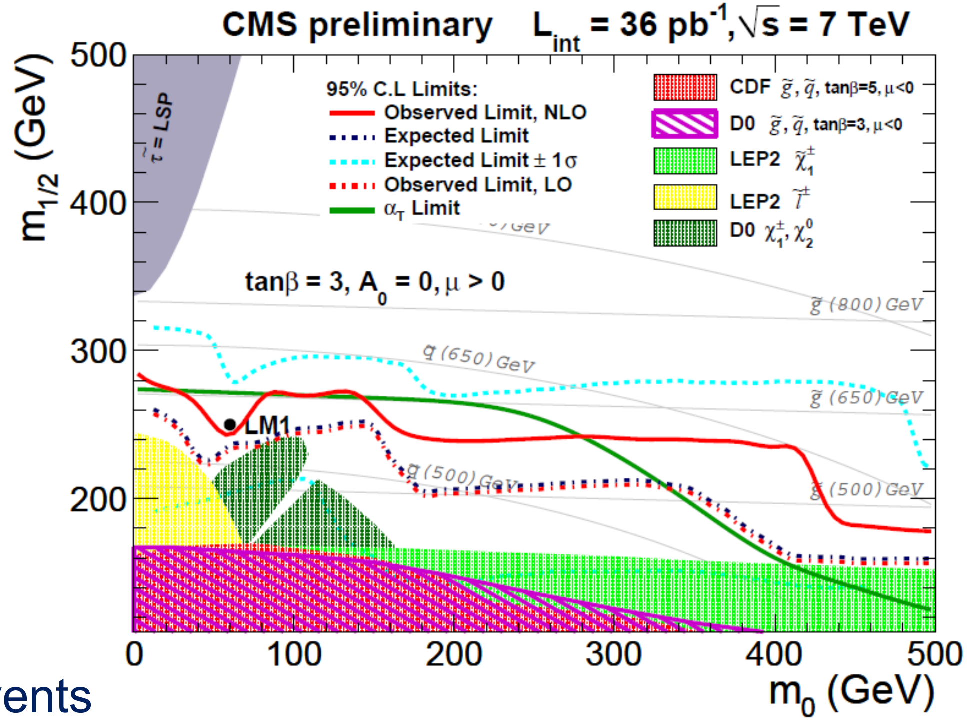
single lepton: results

signal yields for ABCD method

μ channel: total SM MC	93.1 ± 1.1	8.7 ± 0.4	37.6 ± 0.7	3.4 ± 0.2	3.5 ± 0.2
μ channel: data	98	4	41	5	1.7 ± 0.9
e channel: total SM MC	76.8 ± 1.5	6.5 ± 0.3	29.5 ± 0.7	2.9 ± 0.2	2.5 ± 0.1
e channel: data	80	4	30	2	1.5 ± 0.8

signal yields for lepton spectrum method

Sample	$\ell = \mu$	$\ell = e$
Predicted SM 1 ℓ	1.7 ± 1.4	1.2 ± 1.0
Predicted SM dilepton	$0.0^{+0.8}_{-0.0}$	$0.0^{+0.6}_{-0.0}$
Predicted single τ	0.29 ± 0.22	$0.32^{+0.38}_{-0.32}$
Predicted QCD background	0.09 ± 0.09	$0.0^{+0.16}_{-0.0}$
Total predicted SM	2.1 ± 1.5	1.5 ± 1.2
Observed signal region	2	0



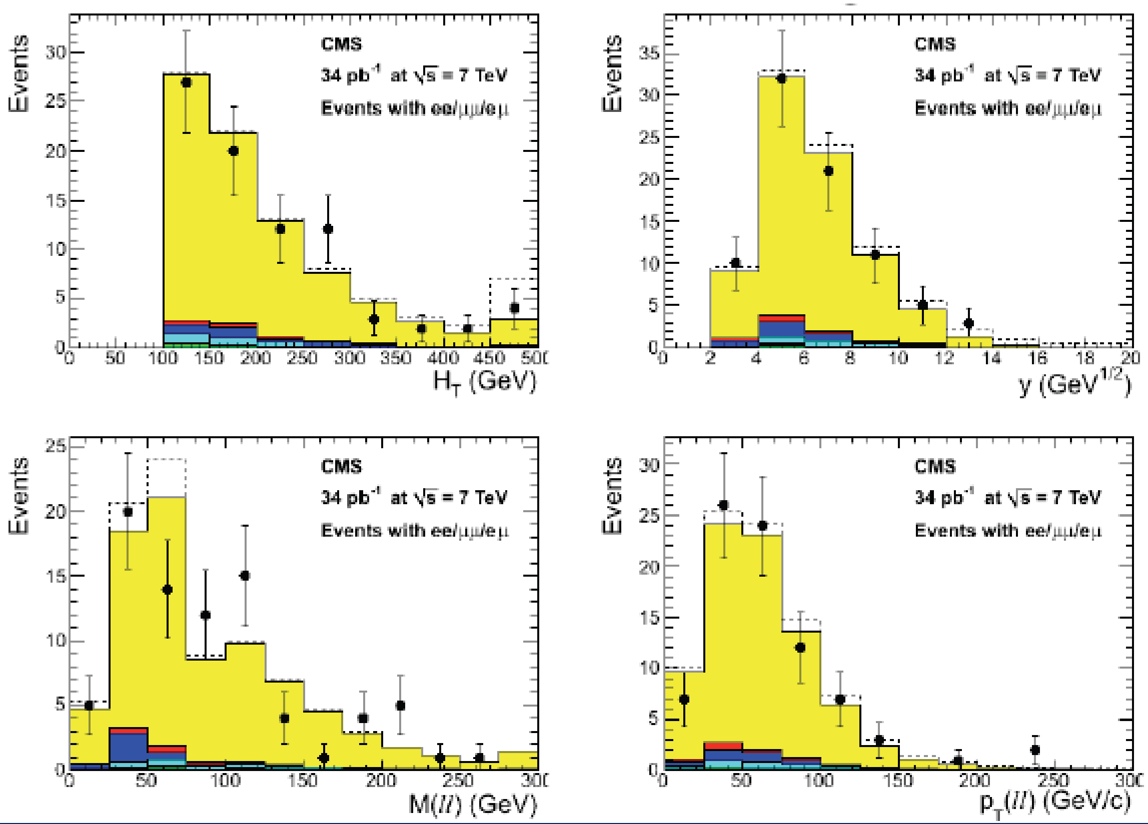
- Set limits in cMSSM plane.
- Limits similar to hadronic α_T search in cMSSM (tan β = 3 exclusion plot)
- Observed limit based on 2 observed events in e+μ channel.

OSDL: search strategy

- **Signal selection:**
  - $P_T(\mu,e)>10/20$GeV (ee/eμ/μμ)
  - **Z-Veto: $|m_{ll} - m_Z| > 20$ GeV**
  - 2 jets > 30 GeV
  - $H_T > 300$ GeV
  - MET/ $\sqrt{HT} > 8.5$

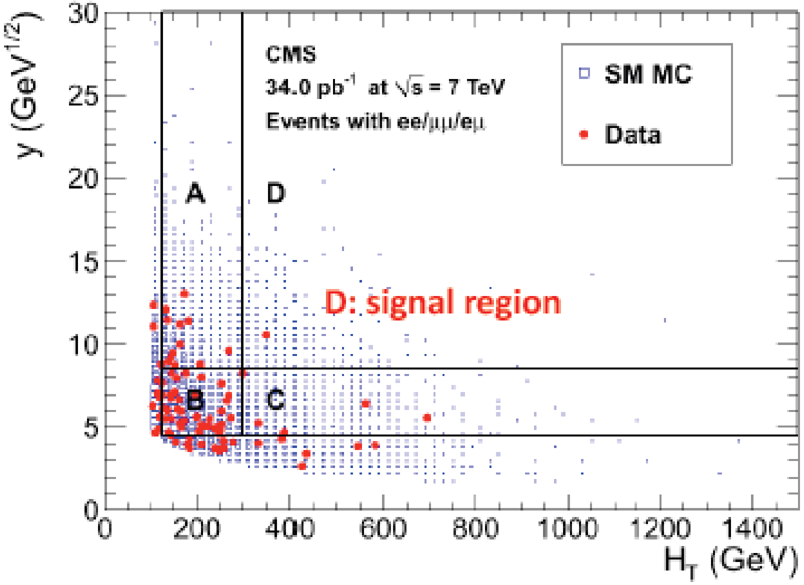
Background prediction:

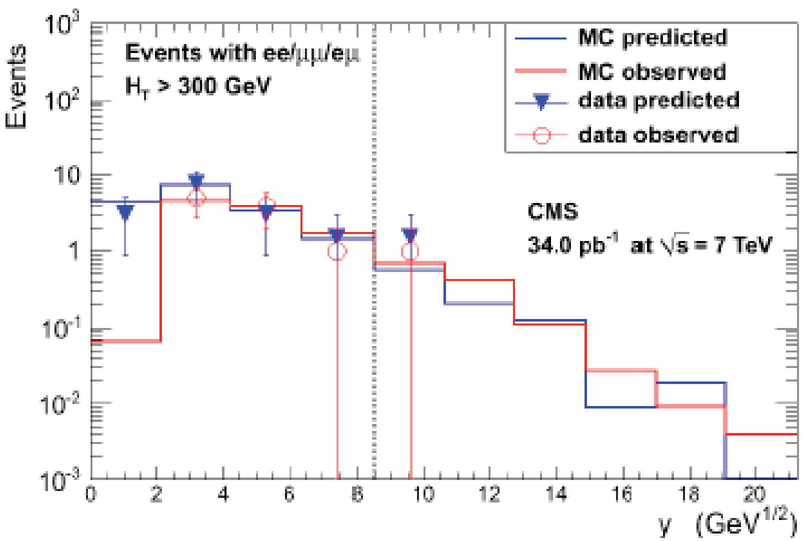
- ttbar (dominant)
  - Matrix method in H_T and S_{MET} (y)
  - pT(ll) method (di-lepton spectrum m.)
  - OF subtraction (hadr. triggered)
- QCD (small) estimation
  - 'tight-to-loose'



Good Data/MC agreement in control regions!

OSDL: results





- **matrix method:**
  (uncorr. variables: H_T and S_{MET} = y)

	$N_{D,pred.}$	$N_{D,obs}$
MC	1.27±0.05	1.27±0.10
Data	1.30±0.78	1

- **pT(ll) method:**
  Exploits the fact that
  the lepton and neutrino get the same boost in ttbar and W+Jets

  Model MET from p_T of di-lep. system

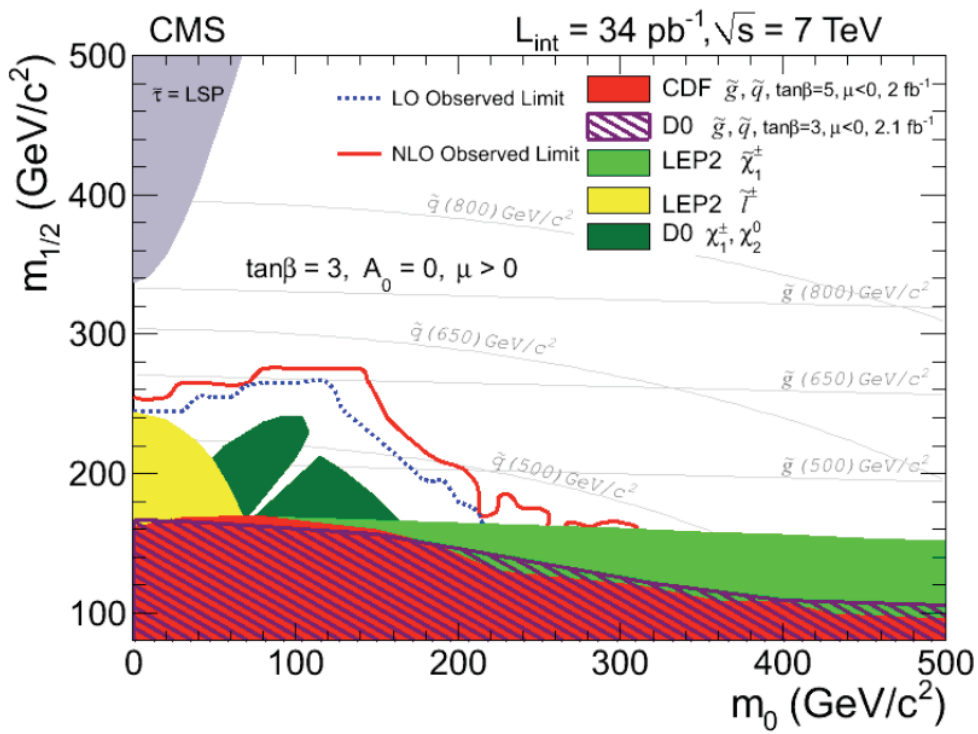
  Correct for differences (e.g. polarization)

	predicted	obs.
Data	2.1±2.1(stat) ±0.6(sys)	1

OSDL: results

	predicted
pT(ll)	2.1±2.1(stat) ±0.6(sys)
ABCD	1.3±0.8(stat) ±0.3(sys)
Average	1.4±0.8
observed	1

Upper limit on non-SM event count in signal region is 4



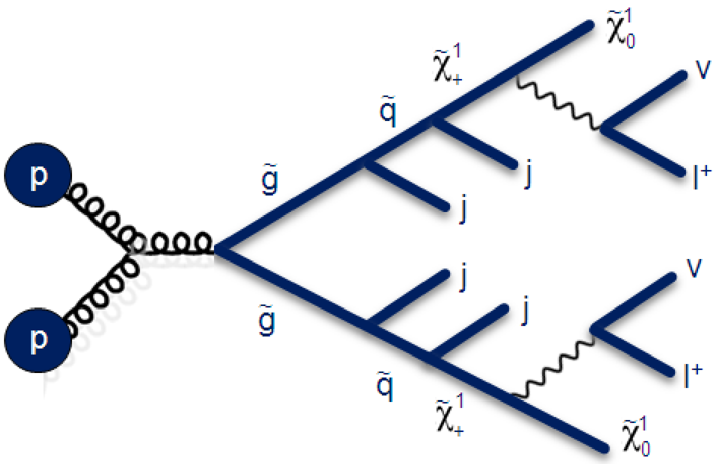
cross-check: OF subtraction

(signal region: MET>150 GeV H_T> 350 GeV)

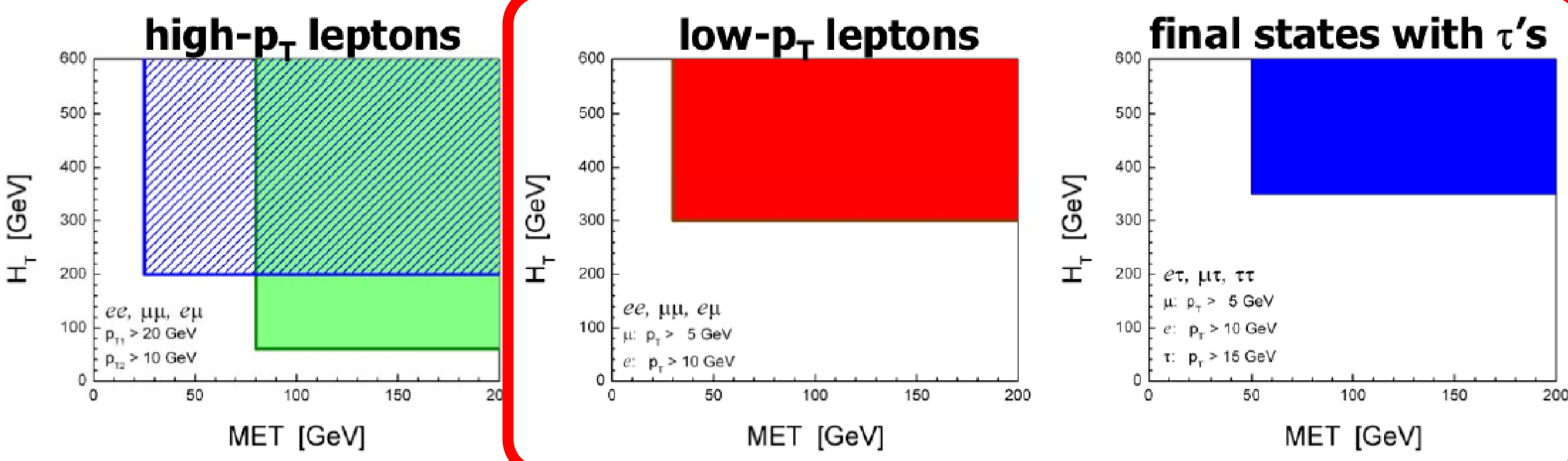
	predicted	
channel	ee	μμ
OF subtr.	0.4 + 1.0 – 0.4	0.5 + 1.2 – 0.4
observed	0	0

- All three methods give consistent estimates of SM background

same-sign dilepton search



- example: Gluino production will give SS:OS = 1:1
- Very little SM background
  Leading in μ channel:
    ttbar with a SS fake μ from a decay in a jet (i.e. *not* charge-mis-ID)
- Pursue two trigger strategies:
    lepton or hadron triggers
    focus on **hadron triggers**:
      allow low-p_T leptons and taus



SSDL Bkg. prediction

Backgrounds:

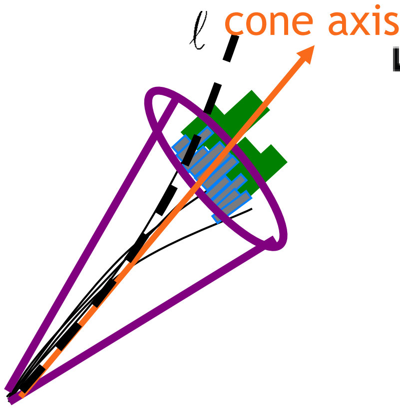
- Prompt SS leptons (WW/WZ/ZZ)
  very small: take from MC (<0.1)
- charge mis-ID (for electron channel)
  use the ratio SS/OS for ee events in a
  Z mass window to estimate charge mis-ID rate.
  Result from measurement: 0.012 ± 0.006
- dominating background:
  non-prompt leptons from jets (WJets, TTbar, QCD)
  measure from data!

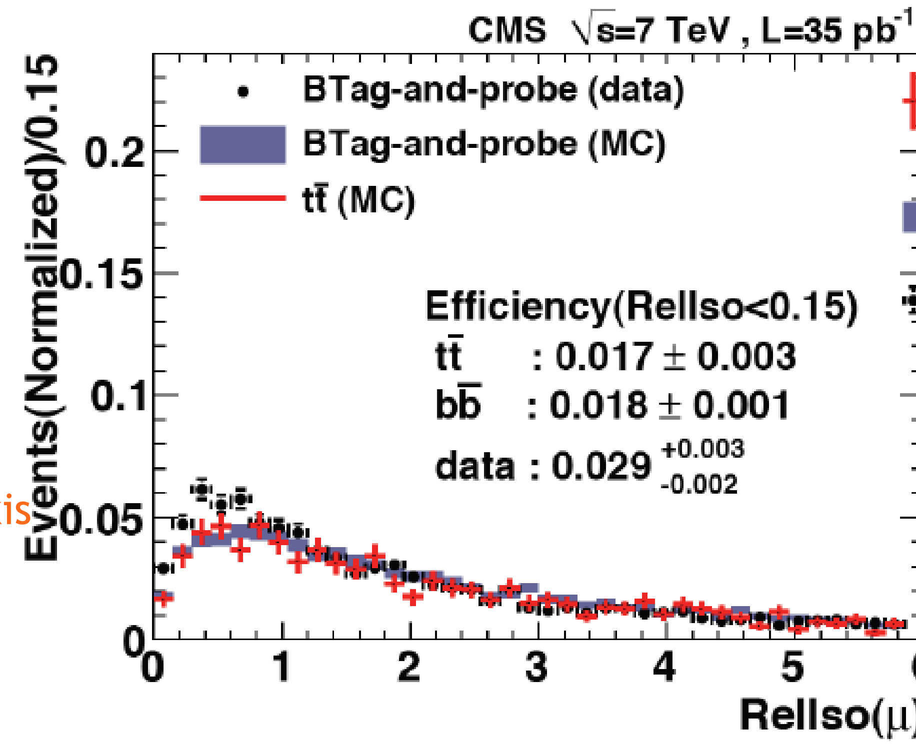
lepton fakes: tag and probe

- Use relative isolation (RelIso) to distinguish prompt leptons from non-prompt ones:

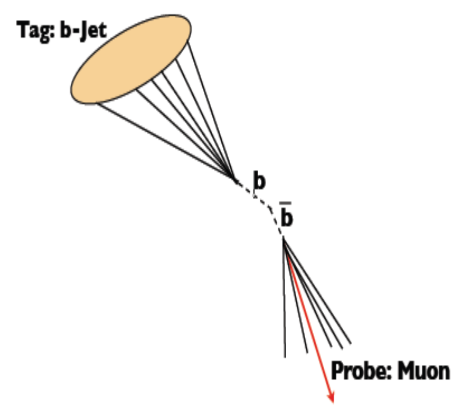
$$\text{RelIso} = \frac{\sum_{\Delta R<0.3} P_T^{\text{Track}} + E_T^{\text{ECAL}} + E_T^{\text{HCAL}}}{P_T^{\ell}}$$

- Use Tag & Probe method to measure relIso templates in bbBar enriched control sample





- We tag a b-jet and study relIso in the probe-jet

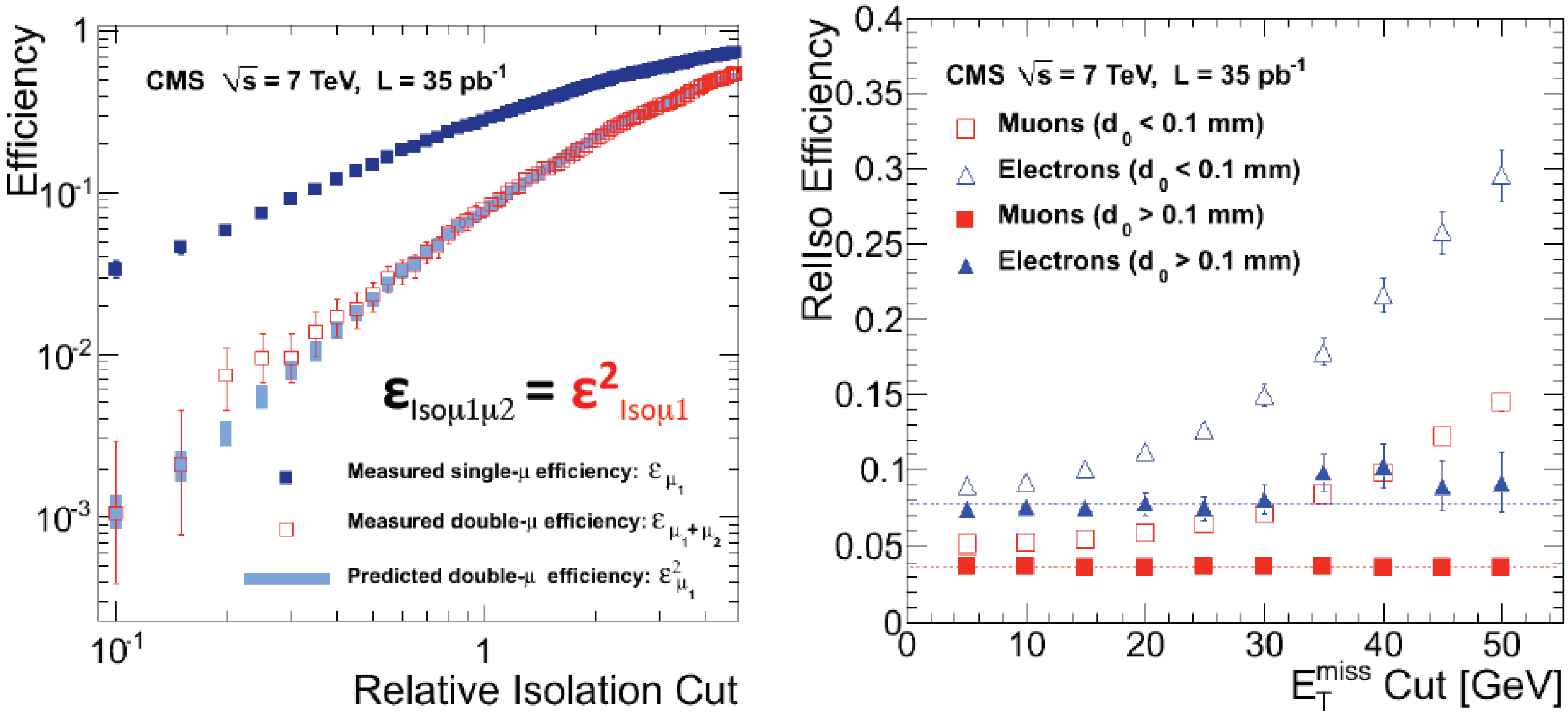


- Fix normalization in sideband (one lepton fails isolation criterion)

- **Prediction: 0.52 ± 0.24(stat) ± 0.26(sys)**

QCD: Factorization of selection cuts

- Study events with two fakes; uncorrelated cuts: Iso of lepton 1 and 2, MET



- If the assumption holds: $N_{pred} = N_{preselected}\ \varepsilon_{Iso1}\varepsilon_{Iso2}\varepsilon_{MET}$
- Left: Factorization of μ isolation cuts
- Right: RelIso efficiency as fkt. of MET (reduce W with impact parameter cut)
- **Prediction: 0.18 ± 0.12(stat.) ± 0.12(sys.)**

fake tau Bkg.: Tight-to-Loose method

- The largest source of background for the hadronic τ channels is due to fake τ.
- define loose selection by turning off NN requirement in tau-ID
- $\varepsilon_{T/L}$ = *"probability of a loose tau to become tight"* is measured in a multi-jet sample in bins of p_T and η
- Sideband used for normalization: **All cuts** except one τ satisfies **only loose requirements**
- Reweight the side-band yield by $\varepsilon_{T/L}$ to get fake tau prediction

MC-Closure:

	Simulation Only SM		Data Relaxed selection	
Channel	Observed	Predicted	Observed	Predicted
$\tau\tau$	0.08±0.03	0.15±0.15	14	14.0±4.3±2.6
$e\tau$	0.35±0.12	0.30±0.11	1	0.8±0.4±0.1
$\mu\tau$	0.47±0.15	0.49±0.20	2	2.9±0.6 ±0.4

Prediction:

0.28 ± 0.14(stat) ± 0.09(sys)

Signal efficiency parameterization

- **Acceptance model** defined wrt. **stable generator particles**

H_T: calculated from u,d,c,s,b,g p_T>30 in final state, resolution ~ 20-30%

MET: calculated from non-interacting particles resolution ~ 10 %

(H_T and MET resolutions depend on H_T)

- Lepton efficiencies:

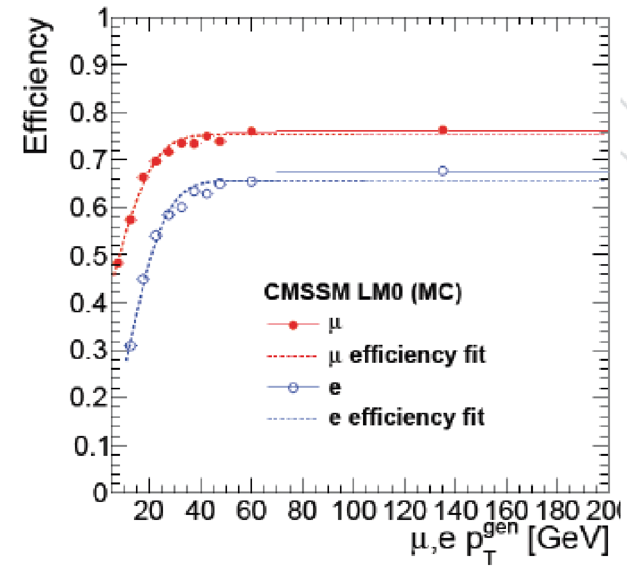
$$\epsilon(x) = \mathrm{par}(1) + \mathrm{par}(2) \cdot \left(\mathrm{erf}\left(\frac{x - x_0}{\mathrm{par}(3)}\right) - 1\right)$$

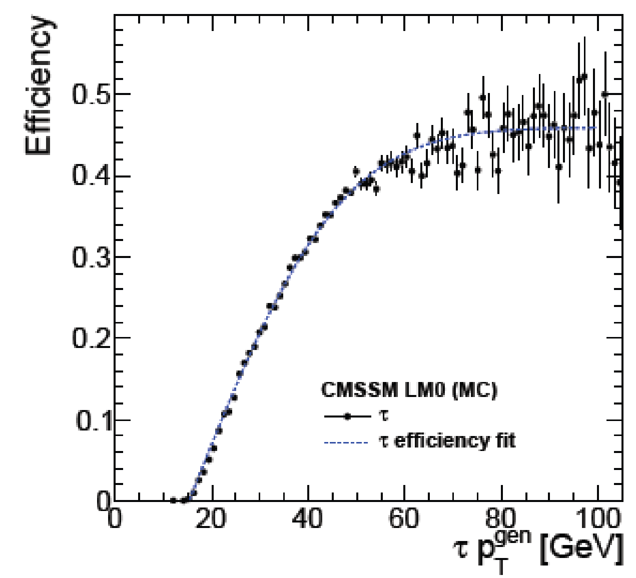
- Isolation corrections:

$$\Delta\varepsilon = -0.10 \frac{<n> - 25}{15}$$

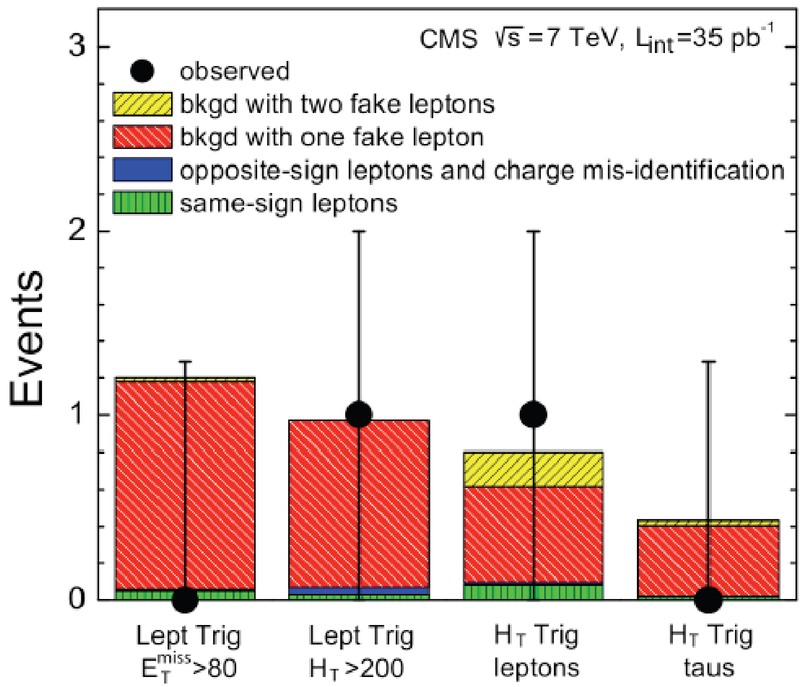
where <n> is the avarage number of stable charged particles $|\eta|<2.4$ p_T>3 GeV

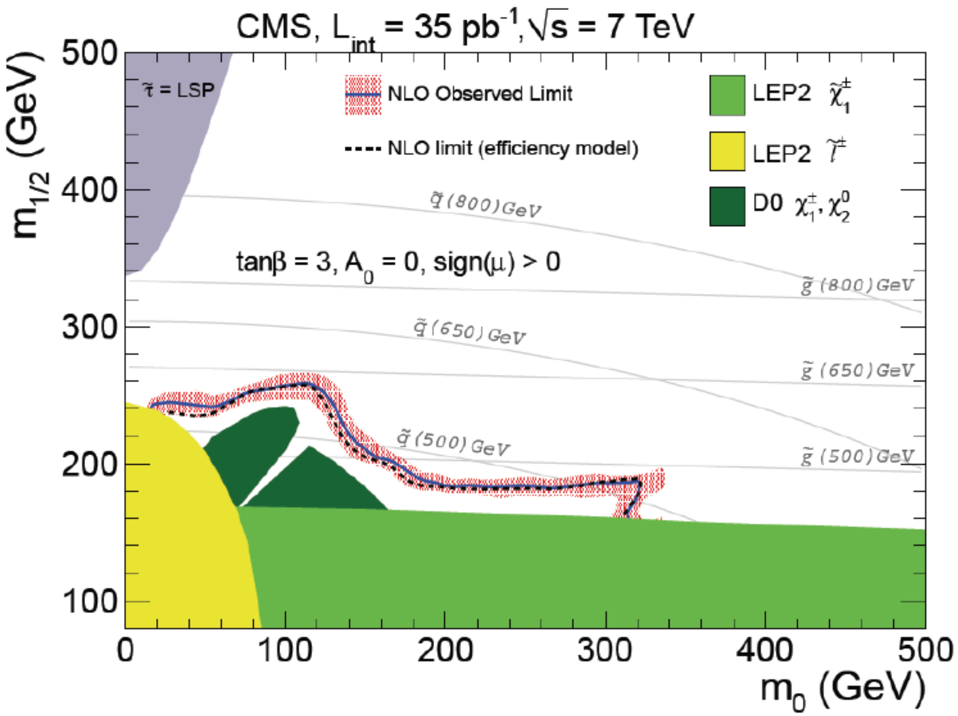
→ efficiency model to interface with theory!





SSDL results





95% CL upper limits on σ x BR x A:

3.1, 4.3, 4.4, 3.4

observed events in signal regions:

0 1 1 0

no excess seen!

result are used to set limits

good agreement with efficiency model

Multi lepton channels

- Include most of
  3L and ≥4L combinations
  - μμμ,eee,μμe,eeμ
  - μμτ,eeτ,eμτ
  - μττ,eττ
  - All ≥4L combinations with ≤2τ
- Low SM backgrounds for multi-lepton channels
  Reduce backgrounds further
  by requiring one or more of
  - $H_T > 200$ GeV
  - MET > 50 GeV
  - Veto $m(l^+l^-) < 12$ GeV
  - Veto Z's: $75 < m(l^+l^-) < 105$ GeV

  55 channels considered!

Results for multi leptons

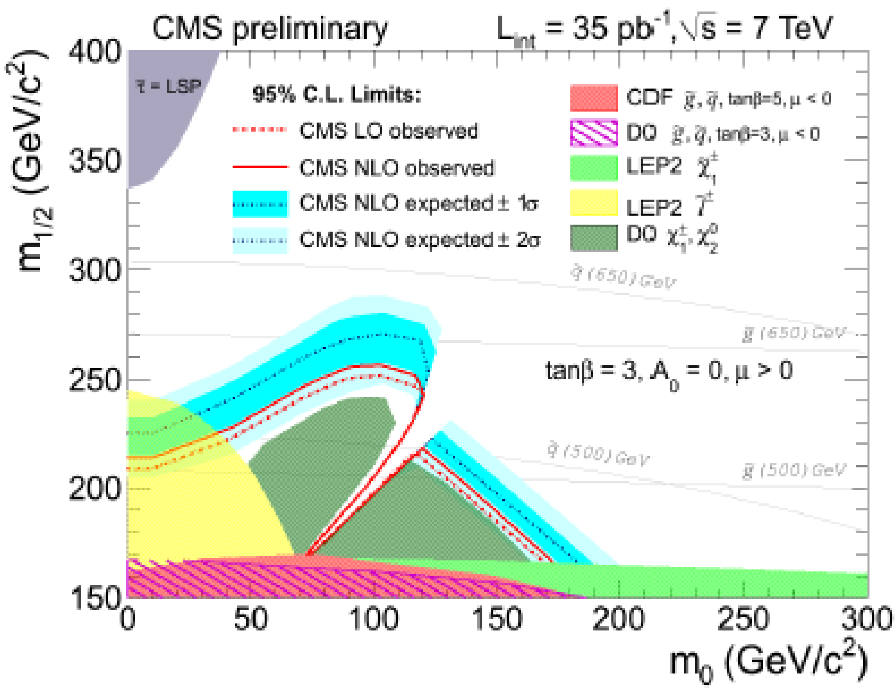
	After Lepton ID Requirement					MET > 50 GeV		H_T > 200 GeV		ML01 Signals	
	Z+jets	tt	VV+jets	ΣSM	Data	ΣSM	Data	ΣSM	Data	MET > 50	H_T > 200
Channel						3-lepton channels					
ll(OS)e	1.7	0.1	1.2	4.4 ± 1.5	6	0.1 ± 0.1	0	0.2 ± 0.1	1	121.4	141.5
ll(OS)μ	2.83	0.2	1.7	4.7 ± 0.5	6	0.10 ± 0.1	0	0.1 ± 0.1	0	123.6	120.8
ll(OS)T	121.5	0.5	0.7	123 ± 16	127	0.4 ± 0.1	0	–	–	80.5	–
ll(OS)τ	476	2.7	3.9	484 ± 77	442	–	–	0.6 ± 0.2	1	–	68
ll′T	0.72	0.5	0.2	1.7 ± 0.7	3	0.4 ± 0.2	2	–	–	18.6	–
ll′τ	4.7	2.9	0.6	11.2 ± 2.5	10	–	–	0.4 ± 0.1	1	–	12.3
ll(SS)l′	0.13	0.1	0.0	0.2 ± 0.1	0	0.2 ± 0.1	0	0	0	2.8	2.8
ll(SS)T	0.25	0.0	0.1	0.7 ± 0.4	3	0.1 ± 0.1	0	–	–	9.0	–
ll(SS)τ	1.4	0.0	0.1	3.0 ± 1.1	3	–	–	0.0 ± 0.1	0	–	6.9
Σ lll(T)	127.1	1.4	3.8	135 ± 16	145	1.3 ± 0.2	2	–	–	355.9	–
Σ lll(τ)	486.8	6.0	7.5	507 ± 77	467	–	–	1.3 ± 0.3	3	–	349.5
lTT	47.1	0.33	0.1	48 ± 9	30	0.4 ± 0.1	0	–	–	8.0	–
Channel						4-lepton channels					
llll	0	0	0.2	0.2 ± 0.1	2	0	0	0	0	163.9	149.2
lllT	0	0	0.1	0.1 ± 0.1	0	0	0	–	–	62.3	–
lllτ	0	0	0.1	0.1 ± 0.1	0	–	–	0	0	–	33.2
llTT	0	0	0	0.0 ± 0.1	0	0	0	–	–	20.6	–
llττ	3.1	0.1	0.1	3.2 ± 0.7	5	–	–	0	0	–	16.8
Σ llll(T)	0	0	0.3	0.3 ± 0.1	2	0	0	–	–	246.8	–
Σ llll(τ)	3.1	0.1	0.4	3.5 ± 0.7	5	–	–	0	0		199.2

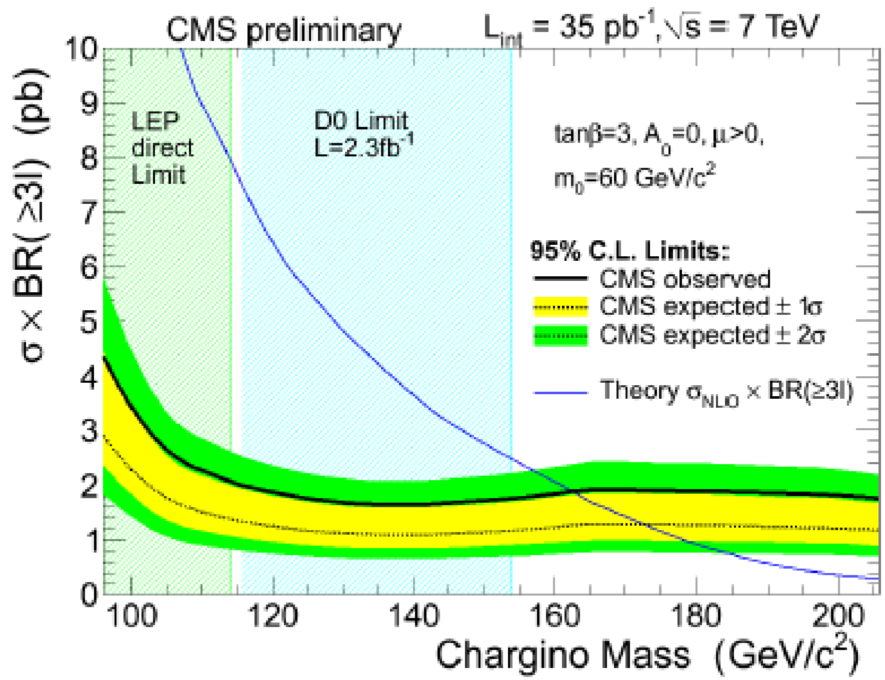
ML01: m_0 = 60 GeV, $m_{1/2}$ = 230 GeV, A_0 = 0, tan *β = 3, μ > 0.*

Very good agreement after pre-selection, no signal excess in signal regions

(T ... hadronic tau decay with one charged track, τ ... including decays with three charged tracks)

Results for multi leptons





Extend reach beyond Tevatron with 35pb^{-1}.

(All LHC and Tevatron results are given for the other MSSM parameters fixed at tan β = 3, A_0 = 0, μ >0)

Charginos with m < 163 GeV excluded, exceeding LEP and D0 Limits

Summary

- CMS preformed a variety of SUSY searches with 35 - 191 pb^{-1}
- Multiple methods for data-driven background estimations have been developed, validated and used for 2010/11 data
- We have not seen significant evidence for BSM
- 2011 is going to be *the* year for early SUSY

References

latest public results of CMS:
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults

Search for new physics with opposite-sign di-leptons at the LHC, CMS PAS SUS-10-007, Published by JHEP

Search for new physics with same-sign di-leptons at the LHC, CMS PAS SUS-10-004, Published by JHEP

Search for new physics with single-leptons at the LHC, CMS PAS SUS-10-006

Search for multi-leptons at the LHC, CMS SUS-10-008

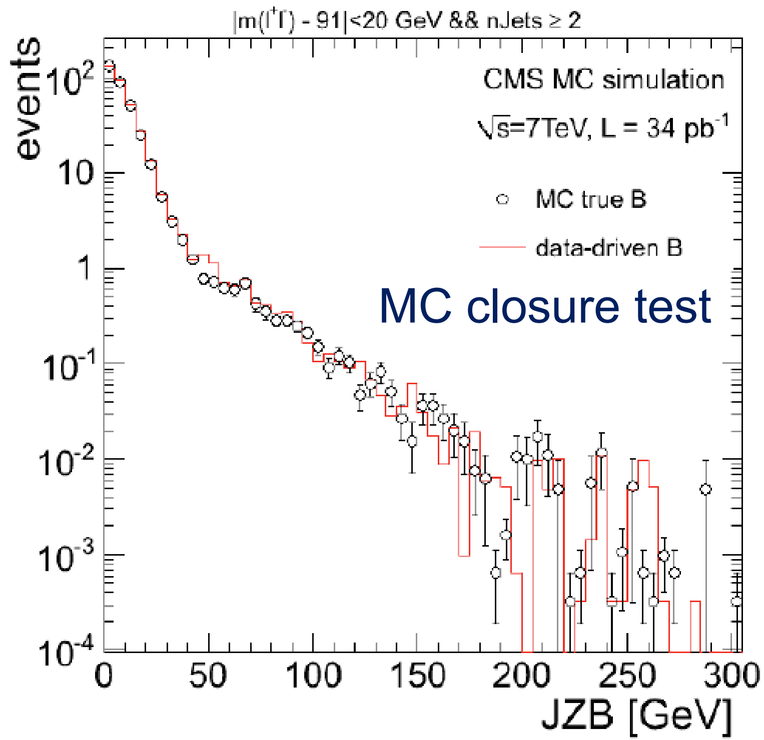
Search for Physics Beyond the Standard Model in Z + MET + Jets events at the LHC, CMS PAS-SUS-10-010 , SUS-11-012

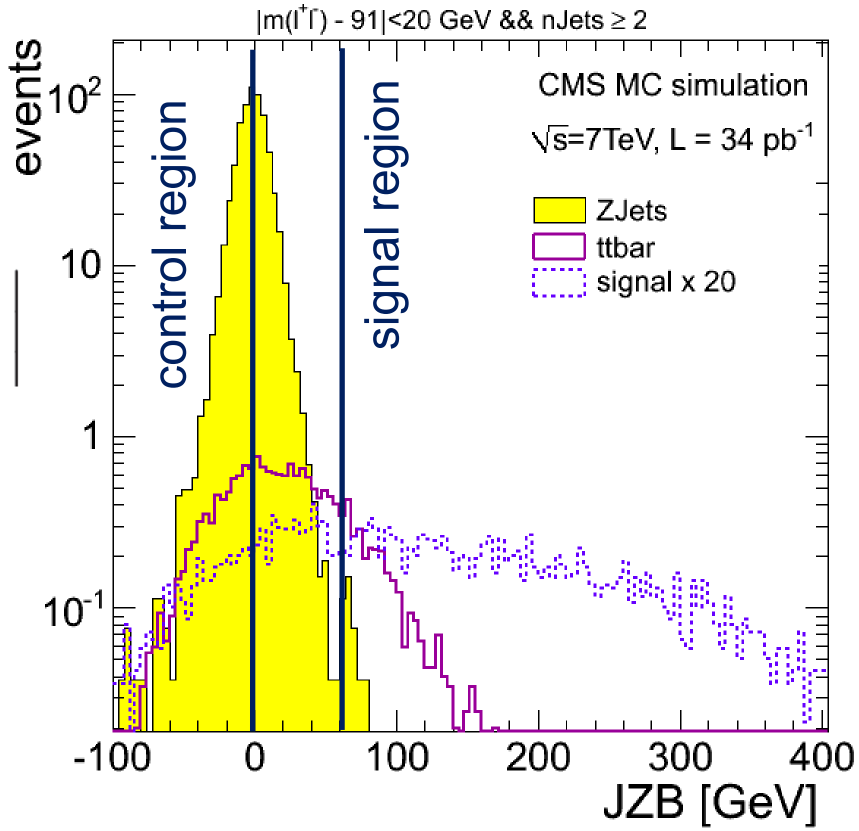
Backup

Z+Jets+MET search with JZB

- **Signal selection:**
  - $P_T(\mu,e)>10/20$GeV (same flavour)
  - Z-requirement: $|m_{ll} - m_Z| < 20$ GeV
  - ≥2 Jets with $p_T > 30$ GeV
  - **Jet-Z Balance:**

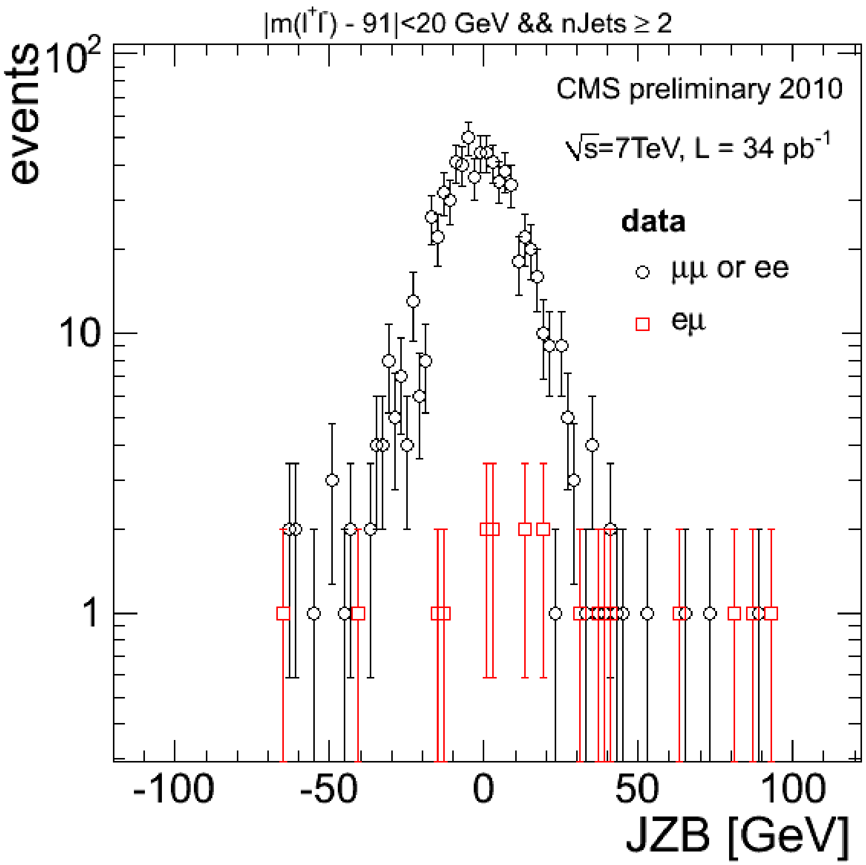
$$JZB = \left|\sum_{\text{iets}} \vec{p_T}\right| - \left|\vec{p_T}^{(Z)}\right|$$

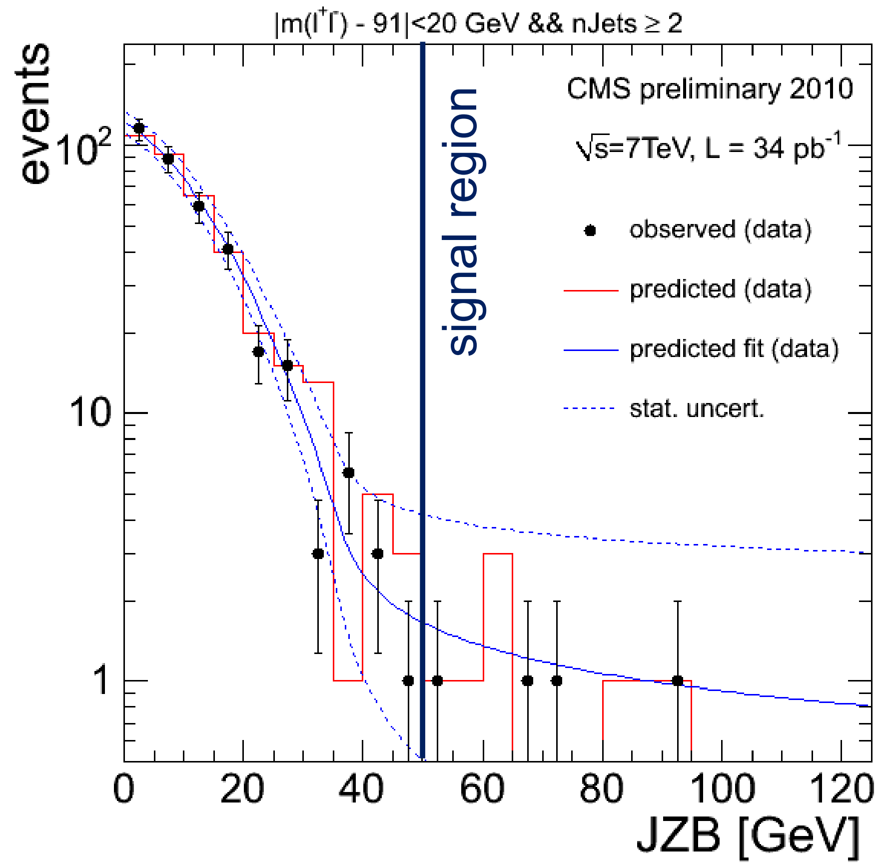




- Dominant backgrounds: Z+Jets, ttbar
  - Use JZB<0 to predict Z+Jets in JZB>0
  - Use eμ pairs to predict ttbar in JZB>0
  - Deviation of JZB peak is found iteratively (Gaussian fit in ±10GeV) and corrected for. Uncertainty propagated to result.

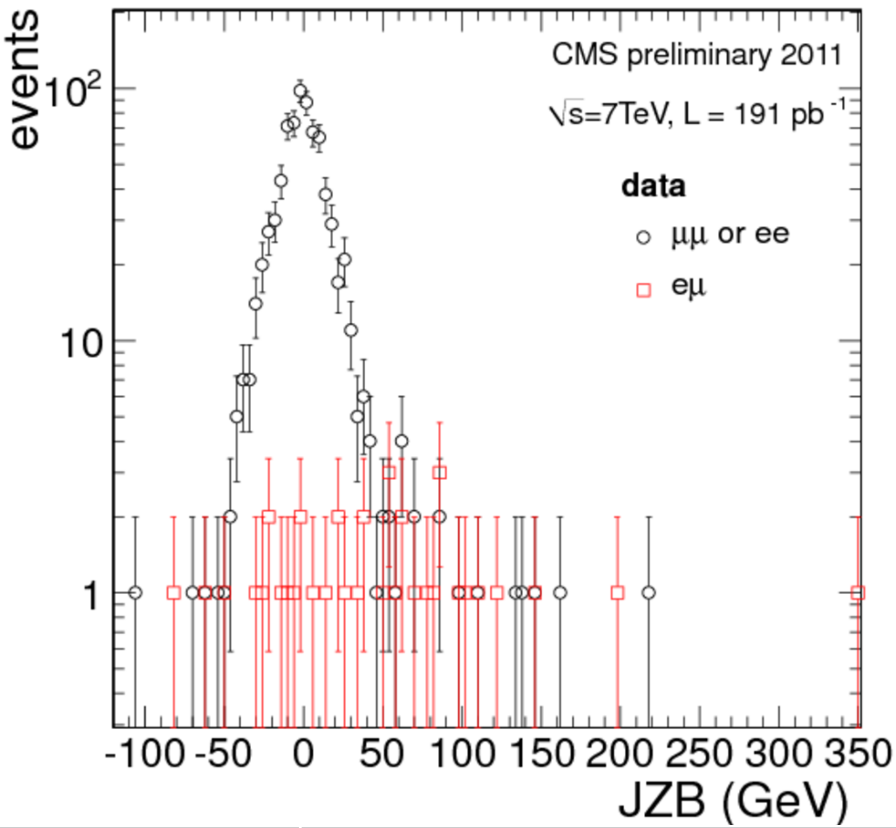
JZB: results with 34 pb^{-1}

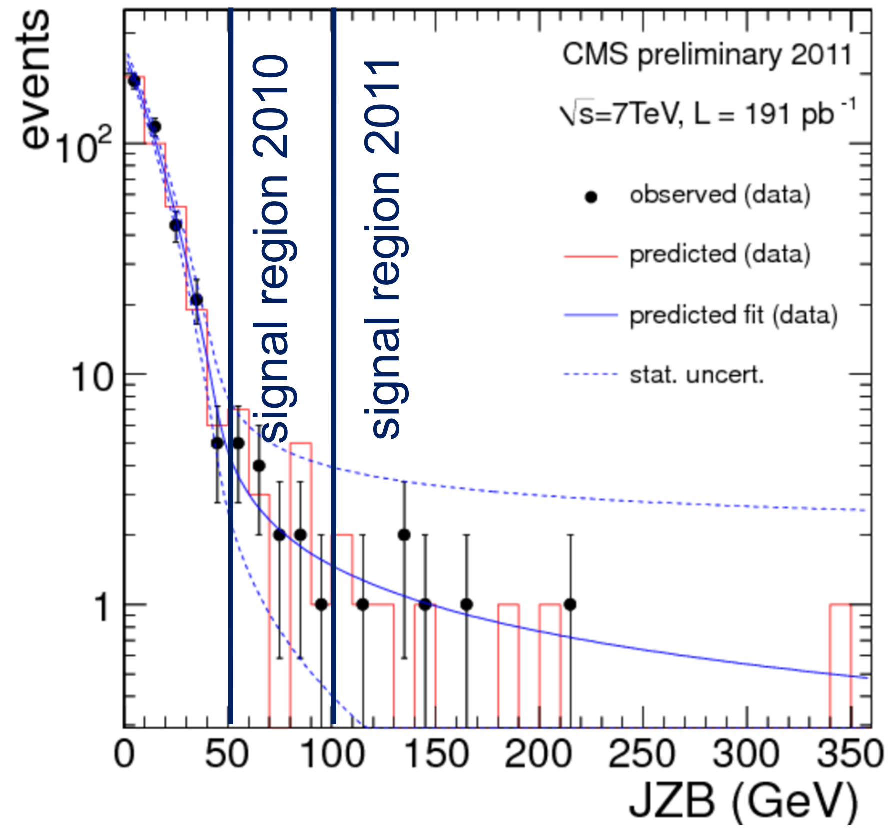




	predicted	obs.	MC
Data	8±3 (stat) ±1(peak) ±3.2(sys)	4	5.5±0.2

JZB: results with 191 pb^{-1}





	predicted	obs.	MC
JZB>50	24 ± 6 (stat) ± 1.4 (peak) ± 2.4 (sys)	20	16 ± 1.2
JZB>100	8 ± 4 (stat) ± 0.1 (peak) ± 0.8 (sys)	6	3.6 ± 0.4

→ CS limits in backup

Limits of JZB and 191 pb^{-1}

Table 3: Final selection efficiencies with total statistical and systematic errors, and corresponding observed and expected upper limits (UL) on ($\sigma \times$ BR $\times$ acceptance) for the LM4 and LM8 scenarios, in the reference region, $JZB > 50$ GeV, and in the search region, $JZB > 100$ GeV. The last column contains the predicted ($\sigma \times$ BR $\times$ acceptance) at NLO obtained from Monte Carlo simulation.

Scenario	Efficiency [%]	Upper limits [pb]		Prediction [pb]
		Observed	Expected	
		Reference region		
LM4	$91.9 \pm 0.7(\text{stat}) \pm 5.2(\text{syst})$	0.064	$0.090^{+0.053}_{-0.036}$	0.015
LM8	$88.5 \pm 0.9(\text{stat}) \pm 5.3(\text{syst})$	0.067	$0.087^{+0.054}_{-0.031}$	0.006
		Search region		
LM4	$90.4 \pm 0.9(\text{stat}) \pm 7.4(\text{syst})$	0.040	$0.050^{+0.022}_{-0.017}$	0.012
LM8	$85.3 \pm 1.1(\text{stat}) \pm 7.8(\text{syst})$	0.043	$0.046^{+0.035}_{-0.014}$	0.005

Background predicitons

Use Tag&Probe Method to measure object selection efficiencies
- correct MC to measured efficiency if needed

Important Backgrounds:
- Z+jets (+single fake) dominating
- double vector boson production (VV+jets),
- tt +Jets
- QCD multijets

Irreducible Background ZW+Jets and ZZ+Jets are taken from MC
- Corrected for efficiency measurements

The rest: Z+Jets, W+Jets and QCD are completely Data-Driven.
- No MC required
- Different Methods used for cross check (fakeable object method, matrix method in relIso,..)