Recent results from CMS on SUSY searches in leptonic final states

8th VIENNA CENTRAL EUROPEAN SEMINAR
on Particle Physics and Quantum Field Theory

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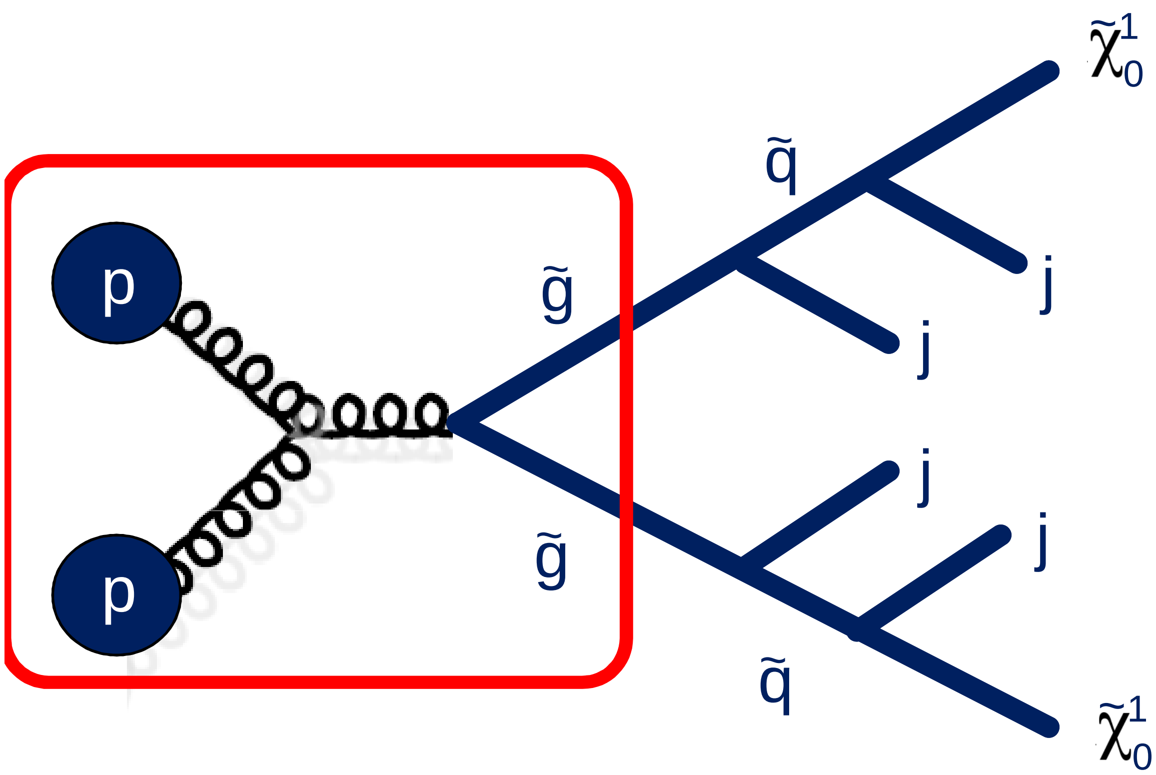
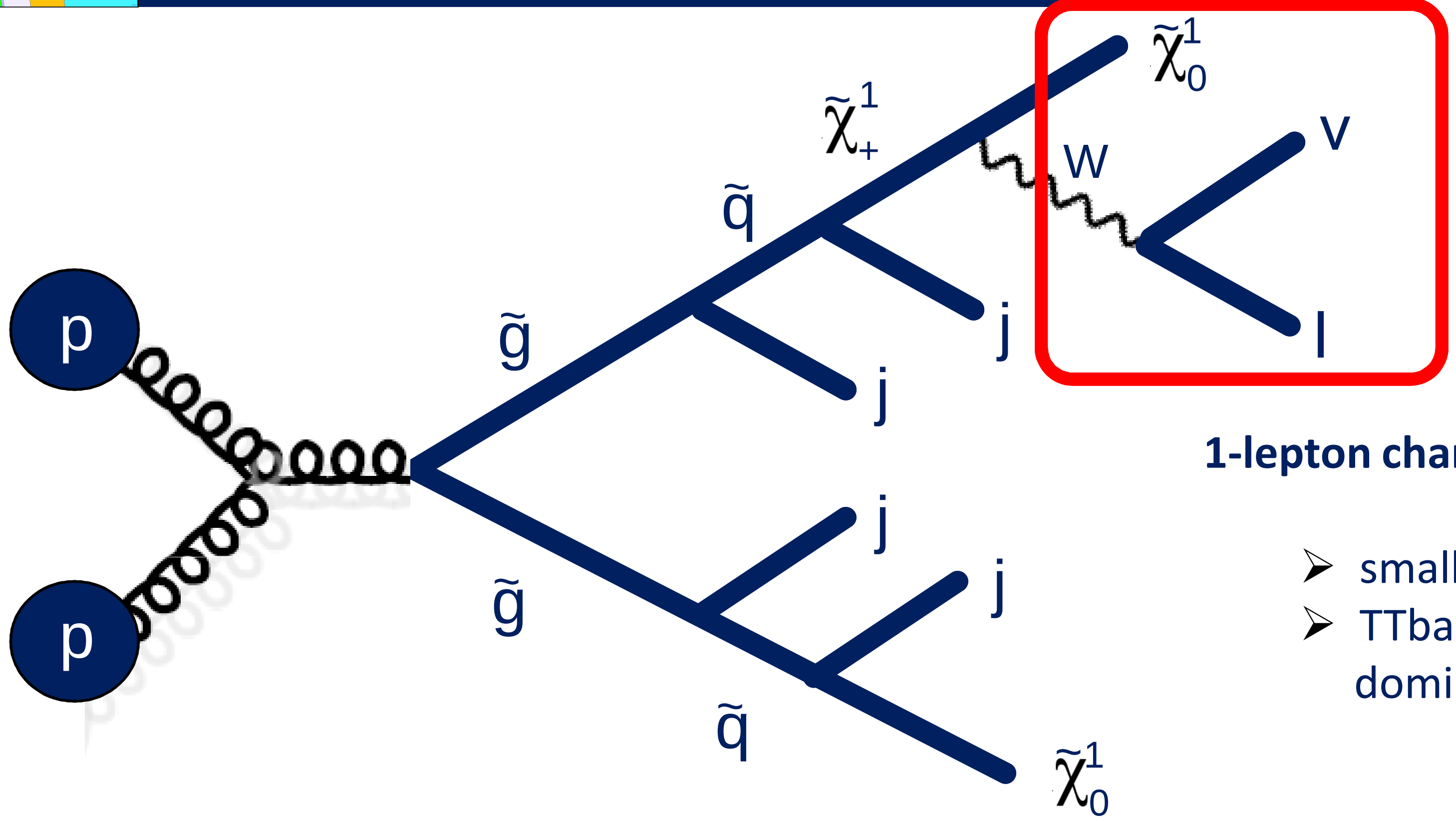
Overview



- 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 responsible for MET

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

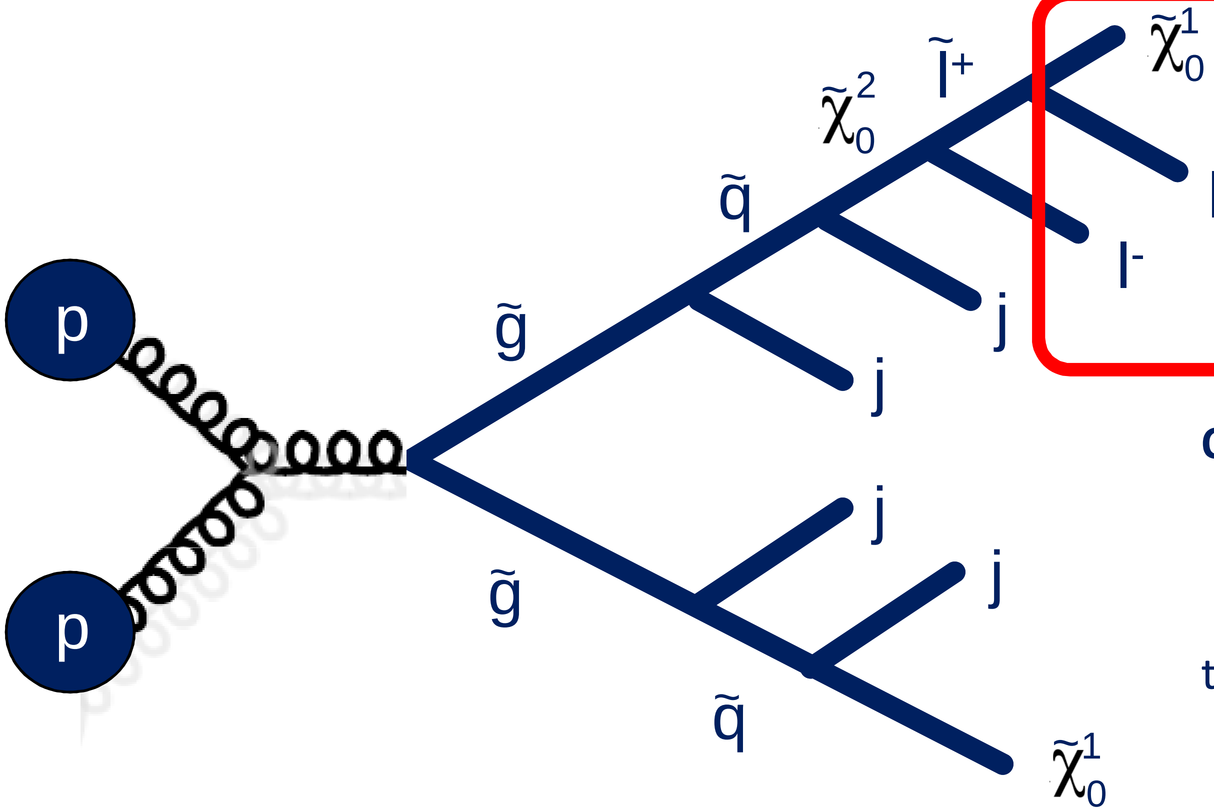


1-lepton channel

- 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

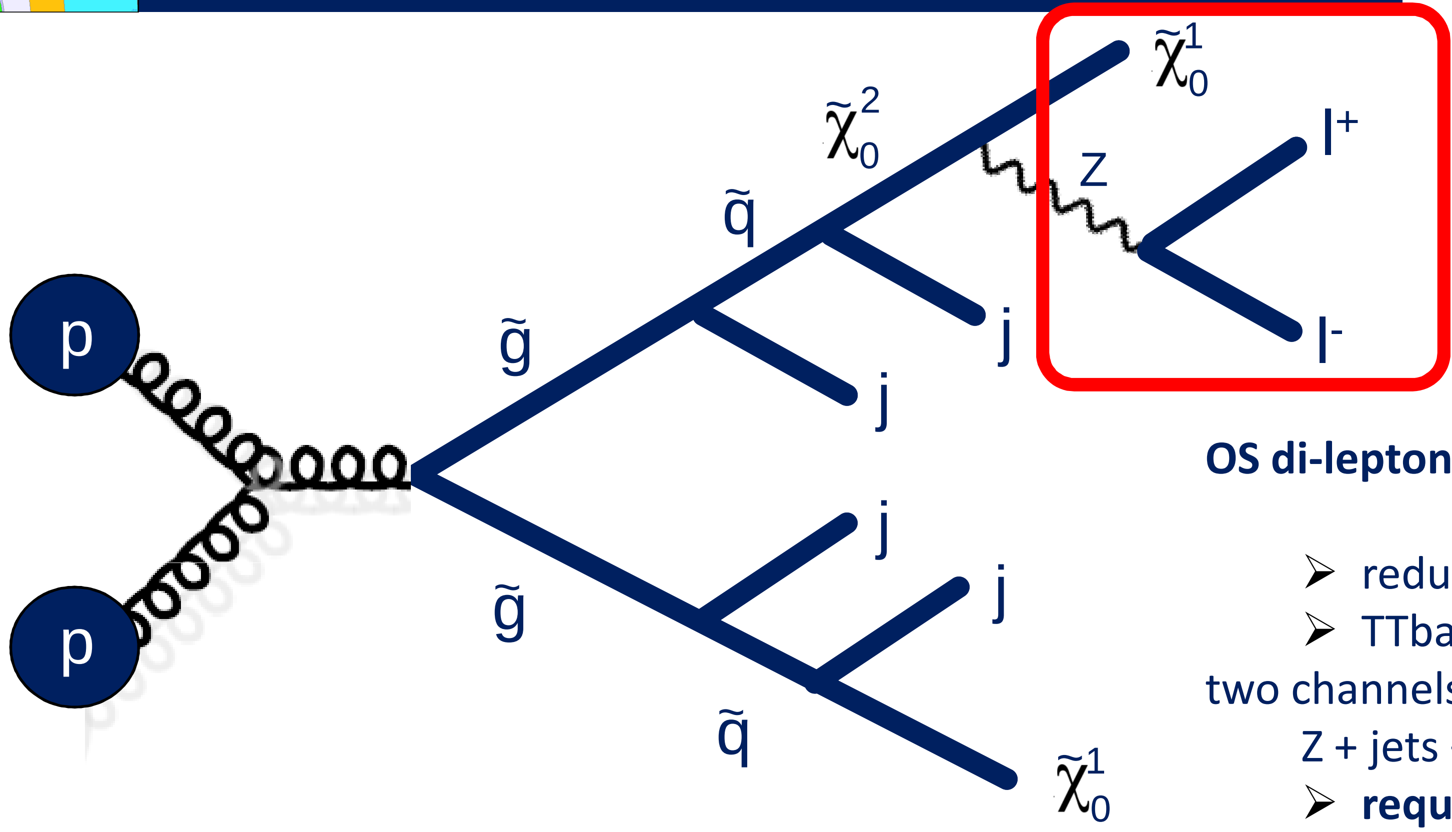
- reduced W background
- TTbar dominates

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

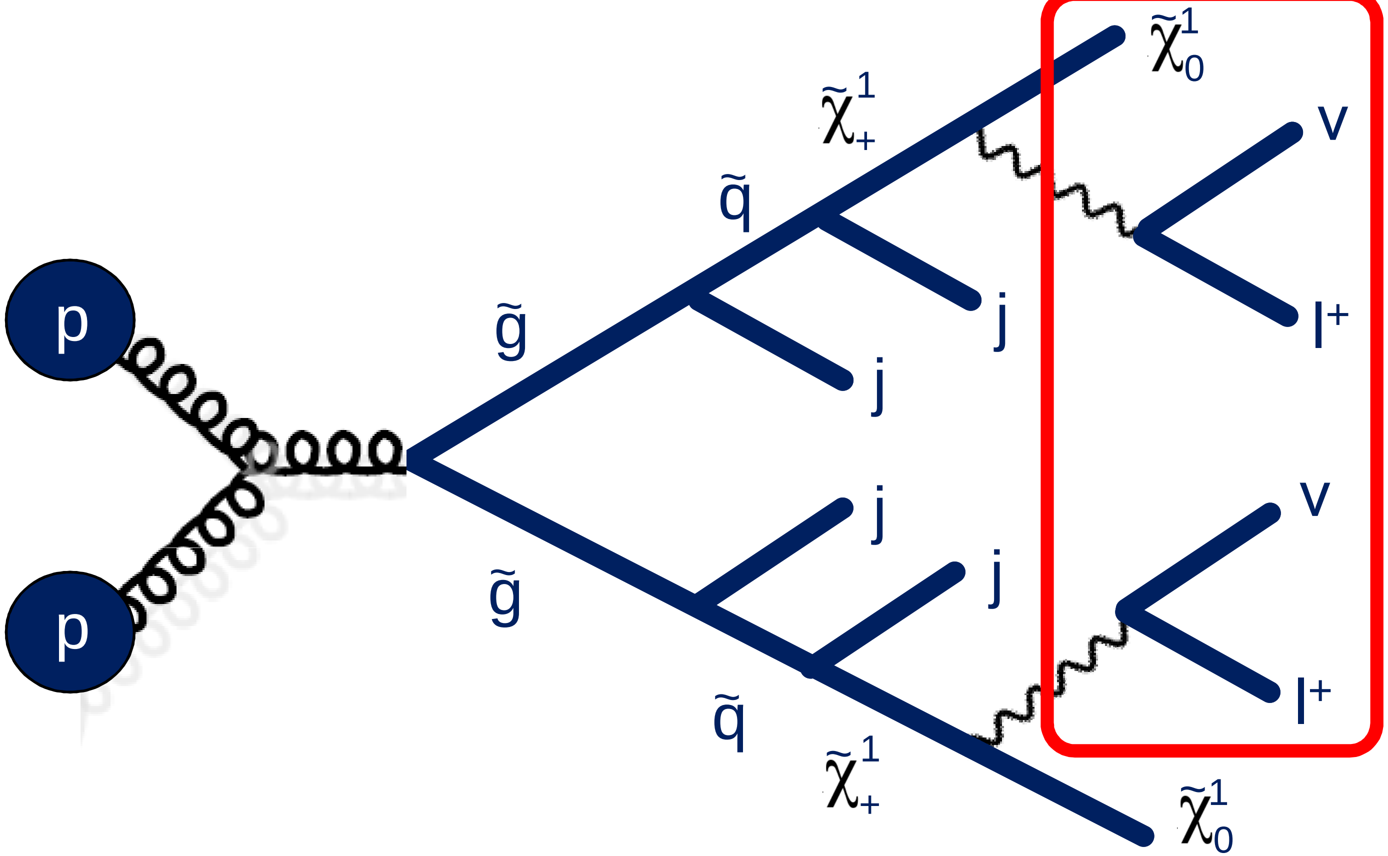
two channels:

Z + jets + MET

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

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

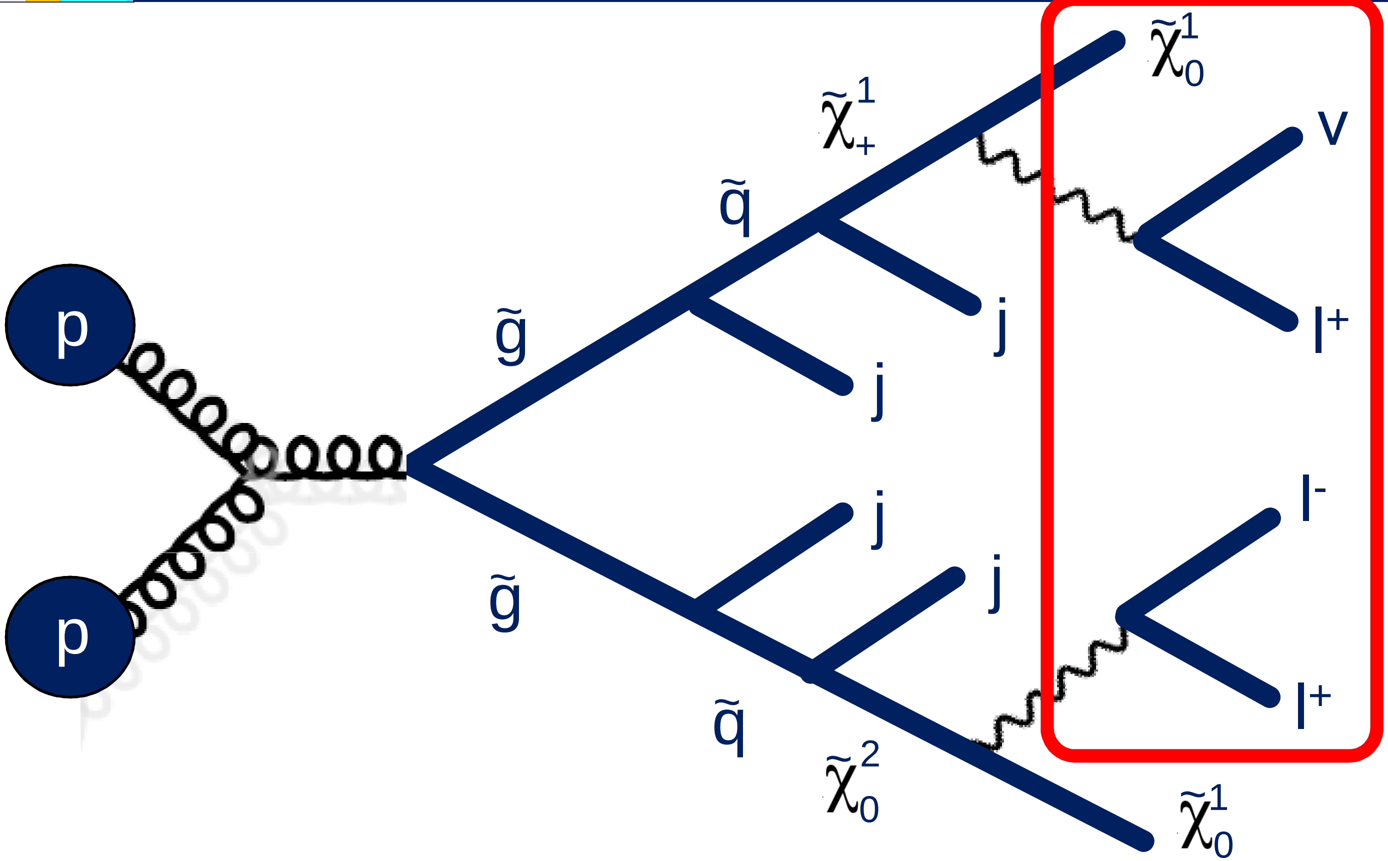


SS di-lepton channel

- 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

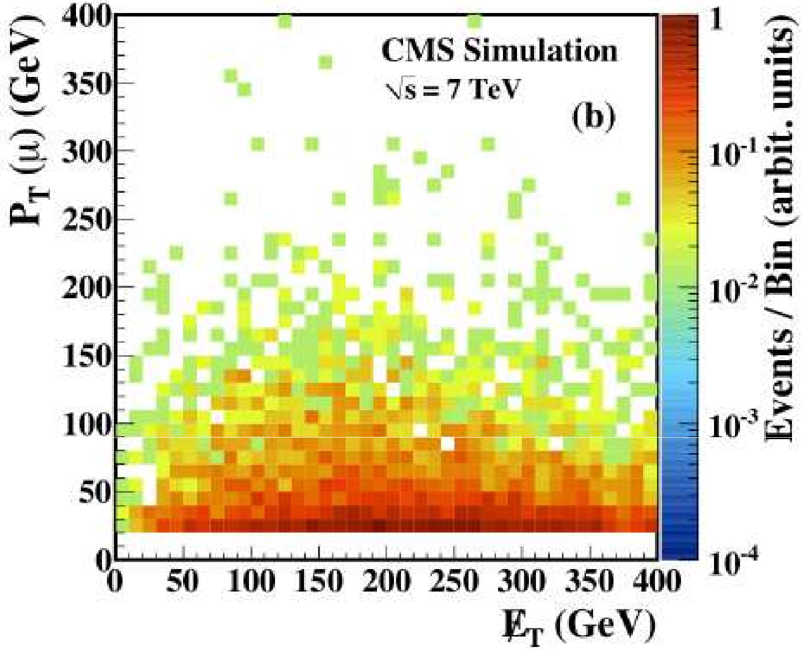
Parametrization

- detector response
- simplified models

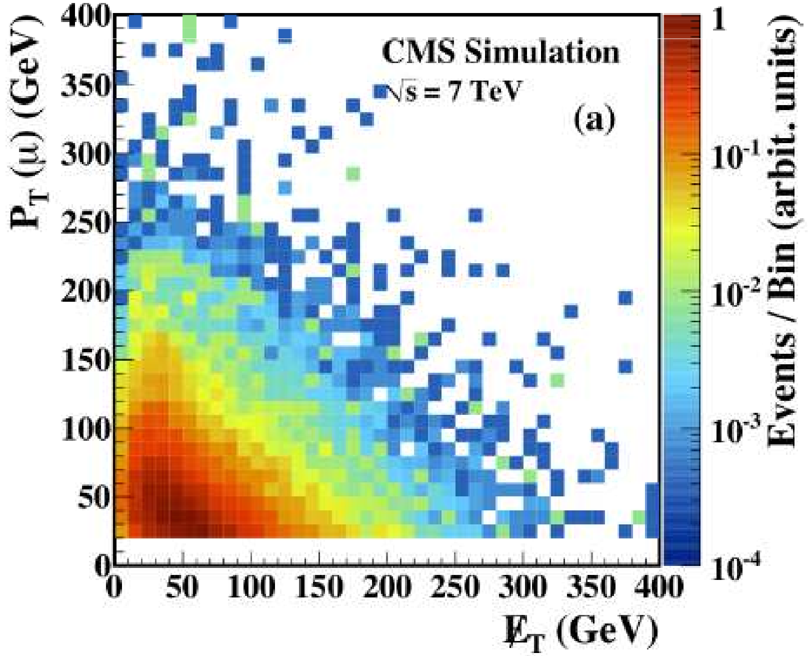
0-leptons	1-lepton	OSDL	SSDL	≥3 leptons	2-photons	γ+lepton
Jets + MET	Single lepton + Jets + MET	Opposite-sign di-lepton + jets + MET	Same-sign di-lepton + jets + MET	Multi-lepton	Di-photon + jet + MET	Photon + lepton + MET

- **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 (scalar sum of jet p_Ts),
  - MET > 250 (loose) or 350 GeV (tight)

Example SUSY Scenario



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



- Lepton spectrum (LS) 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
- MET resolution worse than e/μ: smear μ-P_T
- 2^{nd} method: Lepton projection (LP)

single lepton: results

Background contributions

W+Jets and **TTbar** → **lepton** + jets: **~ 75%**

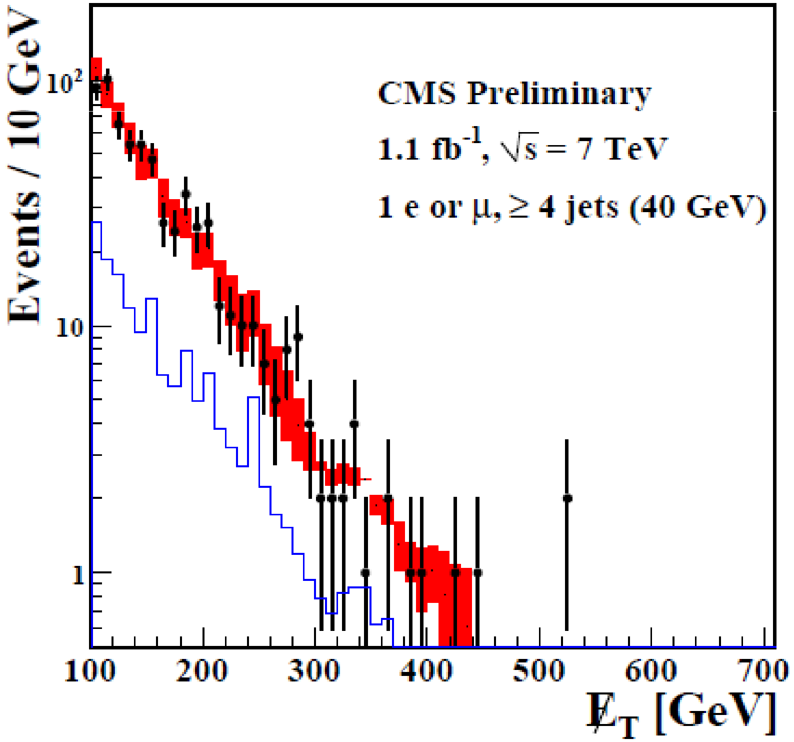
tt dilepton with one **lost lepton** (ID or accaptance): **~ 10%**

estimated from dilepton data by scaling with probability to lose lepton

tt, W+Jets → τ → (e, μ): **~ 15%**

estimate with μ + jets data by replacing the μ with the τ response

SUS-11-015



data

total background prediction

dilepton+τ prediction

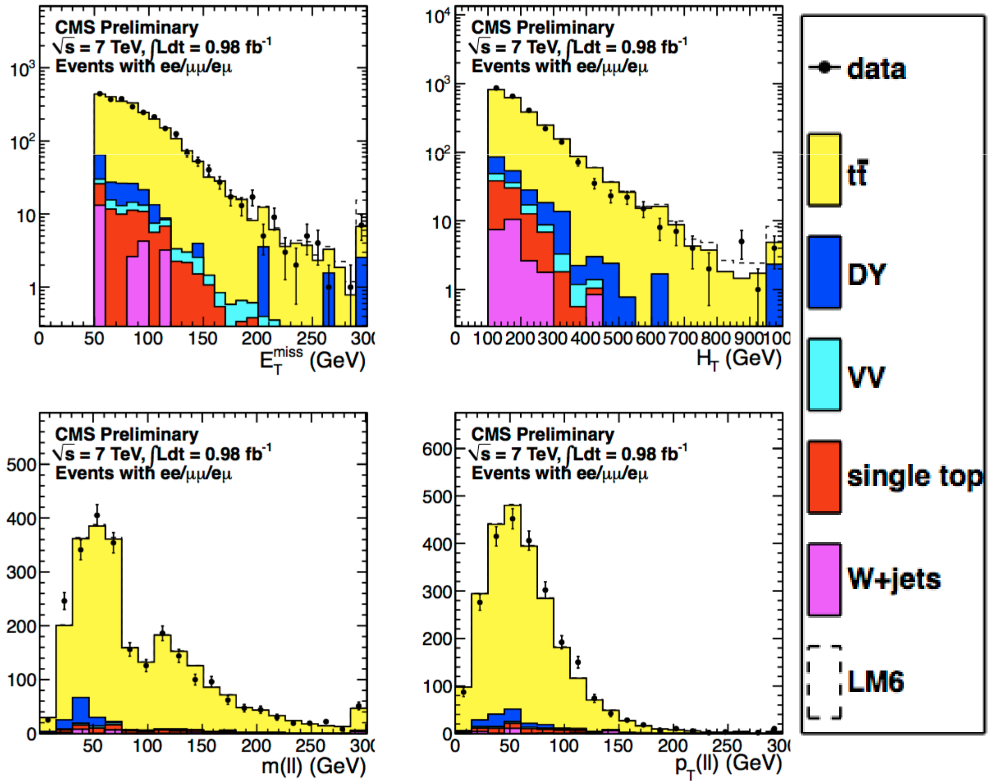
Event counts in signal region:

	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

- no excess seen
- set limits in cMSSM plane

OSDL: search strategy

- **Signal selection:**
  - $P_T(\mu,e)$>10/20GeV (ee/eμ/μμ)
  - **Z-Veto: $|m_{ll} - m_Z| > 20$ GeV**
  - 2 jets > 30 GeV
  - H_T > 100 GeV E_T^{miss} > 50 GeV



Background prediction:

- ttbar (dominant)
  - Matrix method in H_T and S_{MET} (y)
    - exploit that y = MET/ $\sqrt{HT}$ and HT are nearly uncorrelated
  - pT(ll) method (di-lepton spectrum m.)
  - OF subtraction
- QCD (small) estimation 'tight-to-loose'

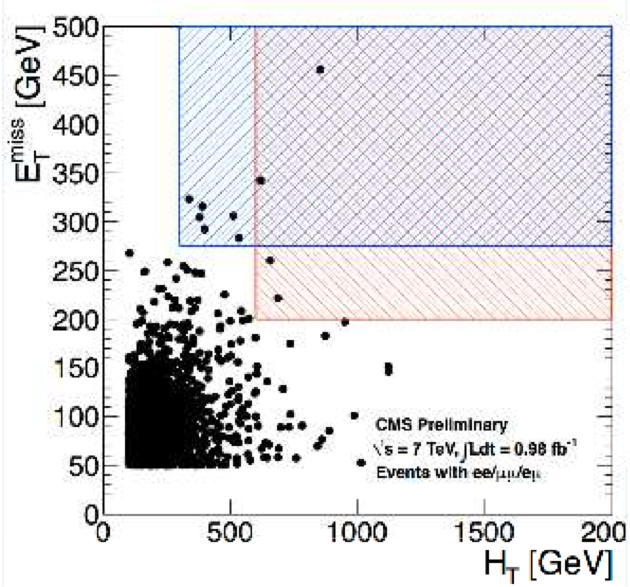
Good Data/MC agreement in preselection regions!

2 search regions defined

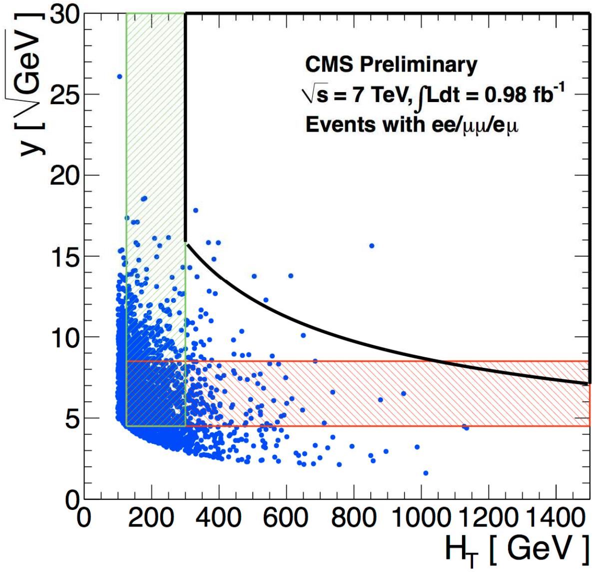
high E_T^{miss}
- H_T > 300 GeV E_T^{miss} > 275 GeV

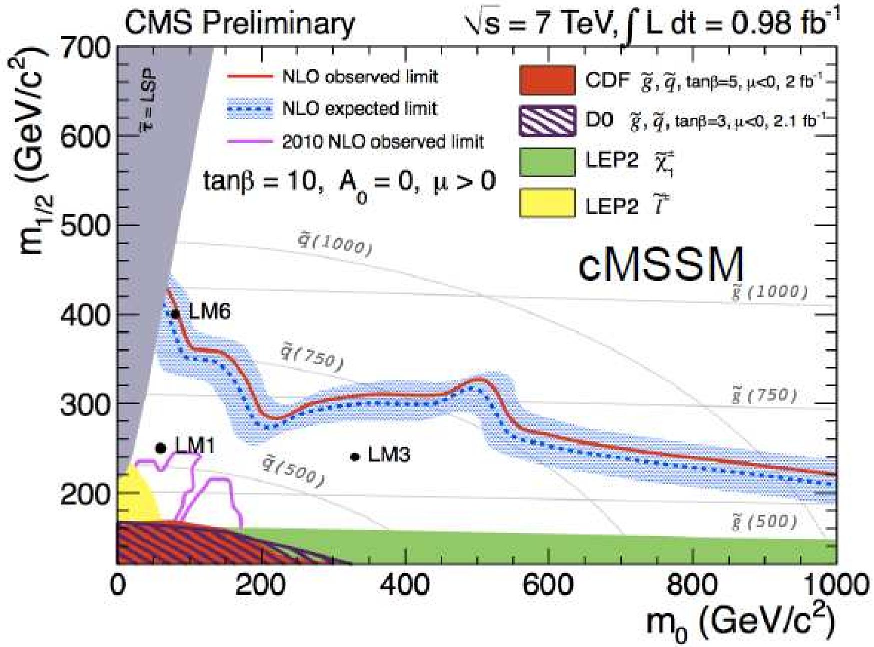
high H_T
- H_T > 600 GeV E_T^{miss} > 200 GeV

OSDL: results



	high E_T^{miss} signal region	high H_T signal region
observed yield	8	4
MC prediction	7.3 ± 2.2	7.1 ± 2.2
ABCD′ prediction	4.0 ± 1.0 (stat) ± 0.8 (syst)	4.5 ± 1.6 (stat) ± 0.9 (syst)
$p_T(\ell\ell)$ prediction	14.3 ± 6.3 (stat) ± 5.3 (syst)	10.1 ± 4.2 (stat) ± 3.5 (syst)
N_{bkg}	4.2 ± 1.3	5.1 ± 1.7
non-SM yield UL	10	5.3
LM1	49 ± 11	38 ± 12
LM3	18 ± 5.0	19 ± 6.2
LM6	8.1 ± 1.0	7.4 ± 1.2

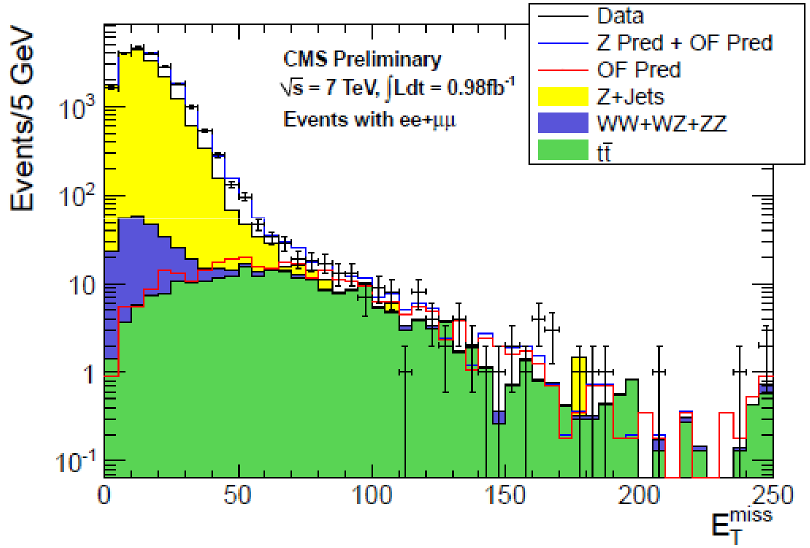


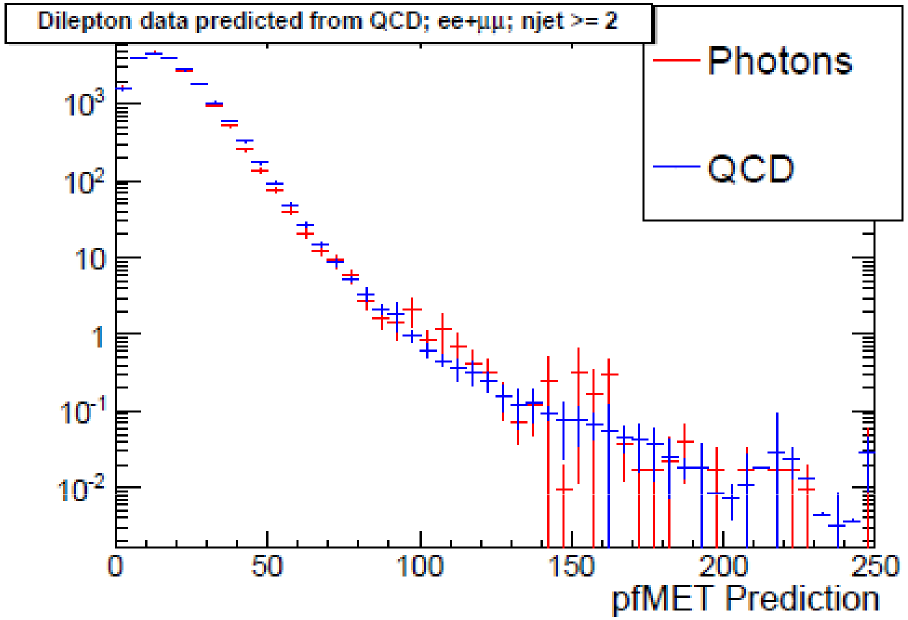


E_T^{miss} templates for Z+jets

- Z + Jets has no genuine E_T^{miss}, only fake E_T^{miss} from the Jet system
- Fake E_T^{miss} can be measured in **photon** or **QCD templates** in bins of HT and njet.

t-tbar background estimated from **eµ data**



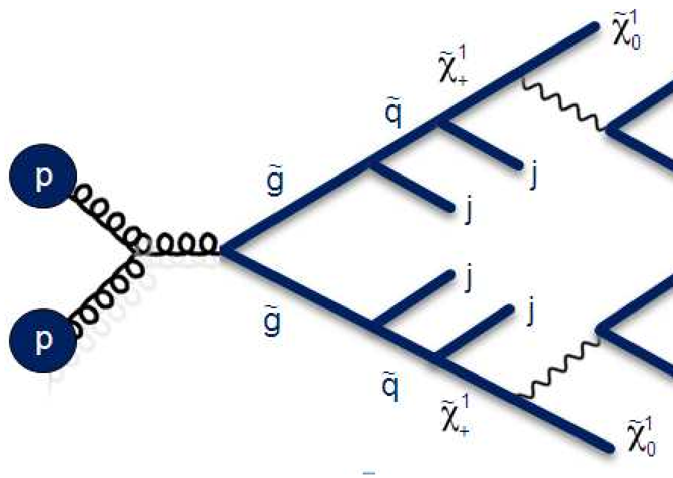


2^{nd} method using Z-jets balancing (→ backup)

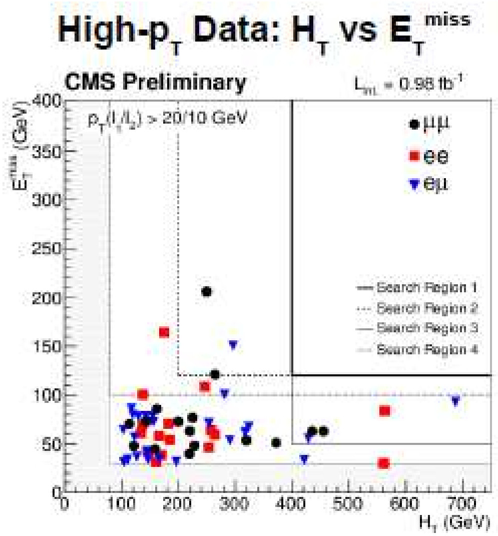
Prediction consistent with SM!

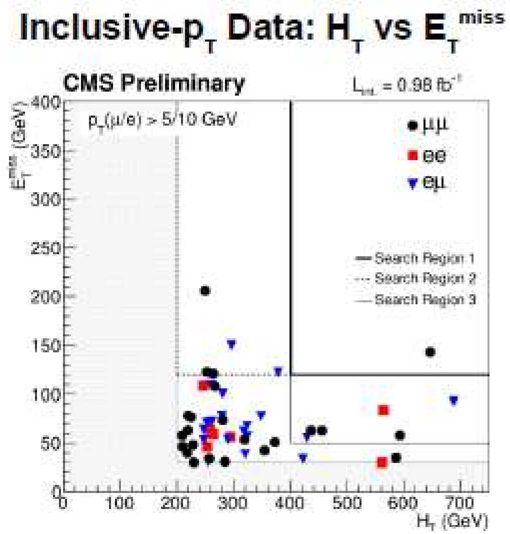
	MET > 30 GeV	MET > 60 GeV	MET > 100 GeV	MET > 200 GeV
Z Pred	2060 ± 29.1 ± 309	60.8 ± 4.1 ± 9.1	5.1 ± 1.0 ± 0.8	0.09 ± 0.04 ± 0.01
$t\bar{t}$ Pred	246.6 ± 6.3 ± 22.2	152.5 ± 4.9 ± 13.7	50.6 ± 2.8 ± 4.6	3.2 ± 0.7 ± 0.3
Prediction	2307 ± 29.7 ± 310	213.0 ± 6.4 ± 16.5	55.7 ± 3.0 ± 4.6	3.3 ± 0.7 ± 0.3
Data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

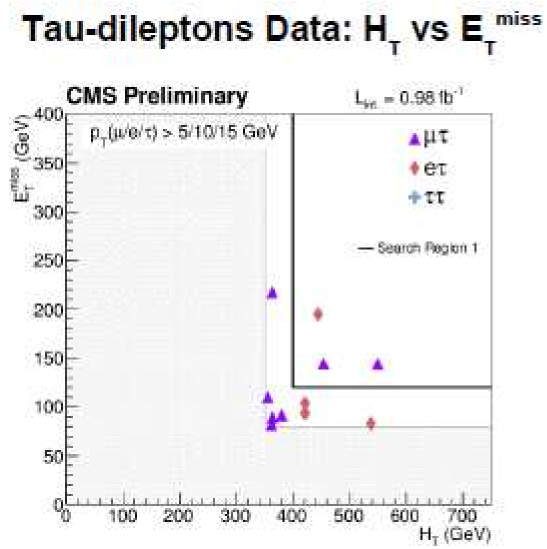
same-sign dilepton search



- 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 ajet (i.e. *not* charge-mis-ID)
- Pursue different trigger strategies:
  inclusive dilepton: HT and di.-lep
  high-p_T di.-lep: no H_T requirement
  tau dileptons: H_T, MET and (l or 2 had. τ)







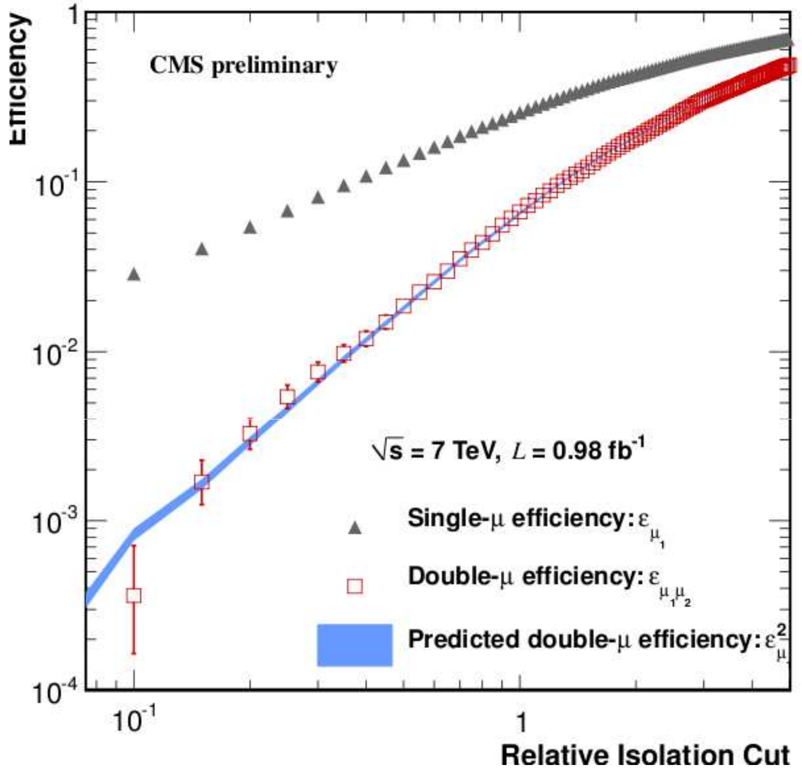
SSDL Bkg. prediction

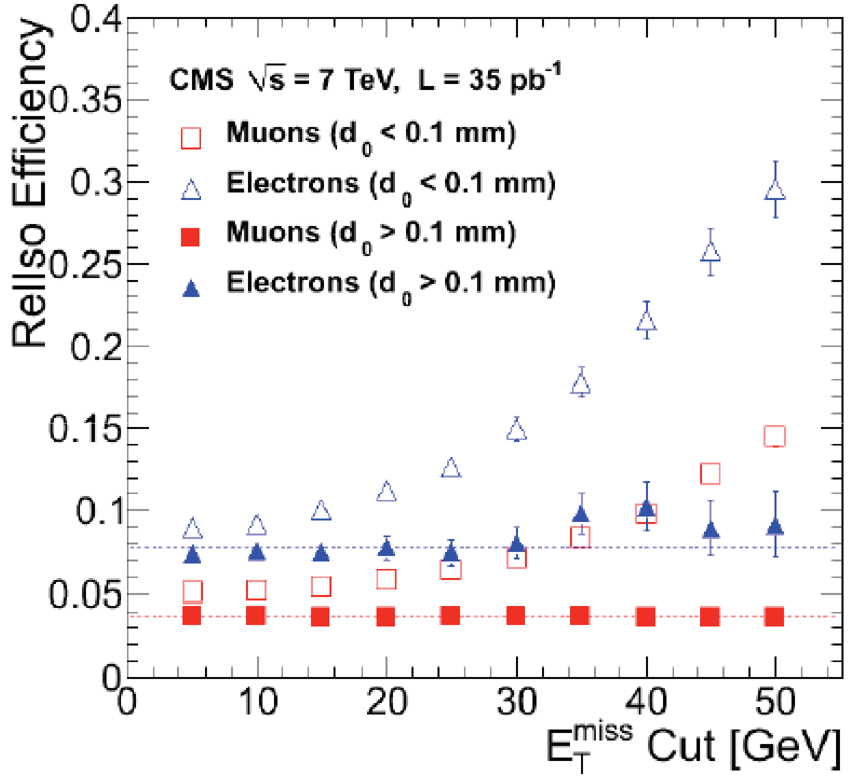
Backgrounds:

- Prompt SS leptons (WW/WZ/ZZ)
  very small, never measured in pp: take from MC
- 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: $2 \cdot 10^{-4}$ to $3 \cdot 10^{-3}$
- dominating background:
  non-prompt leptons from jets (WJets, TTbar, QCD)
  measure from data with tight-to-loose method.

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)

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:

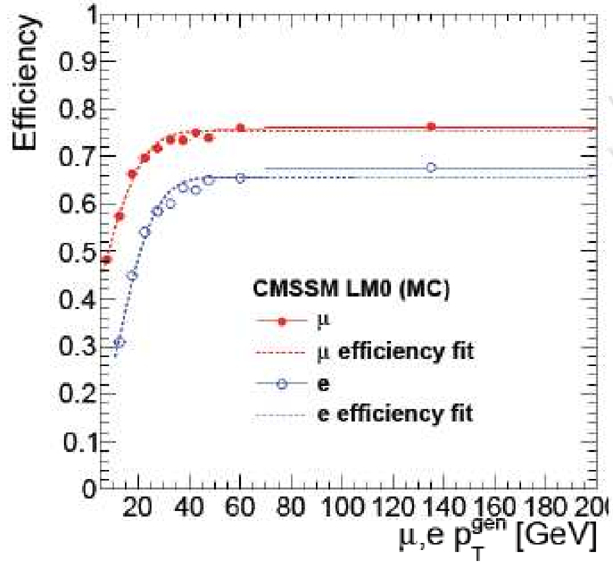
$$\epsilon(x) = \mathrm{par}(1) + \mathrm{par}(2) \cdot \left(\mathrm{erf}\left(\frac{x - x_0}{\mathrm{par}(3)}\right) - 1\right)$$

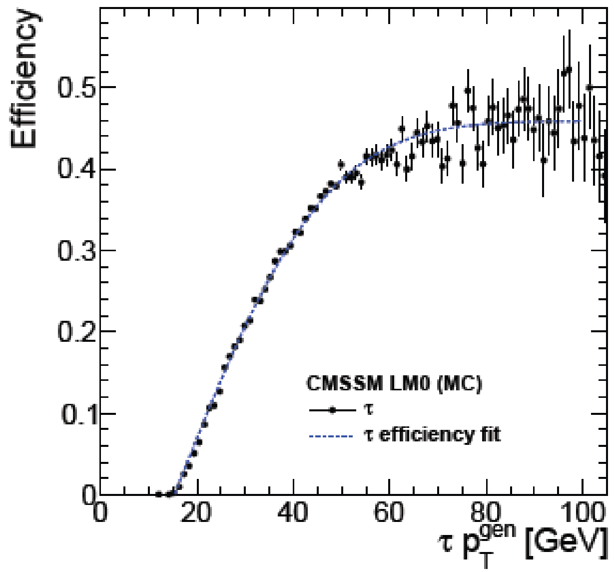
- Isolation corrections:

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

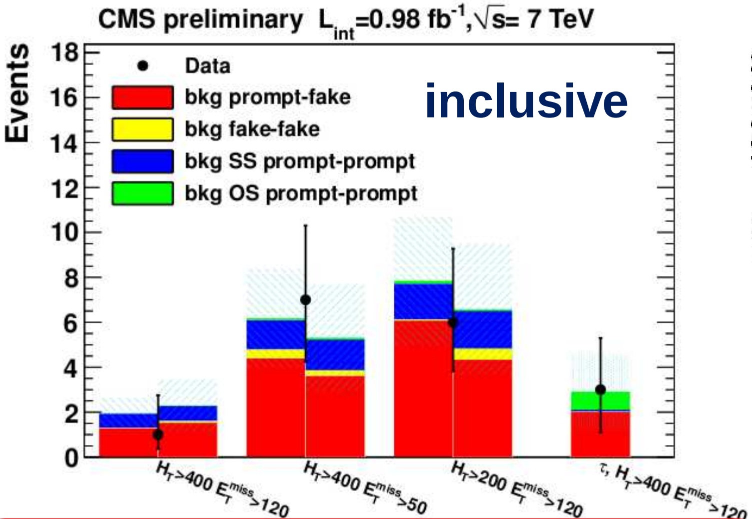
where <n> is the avarage number of stable charged particles $|\eta|<2.4$ $p_T>3$ GeV

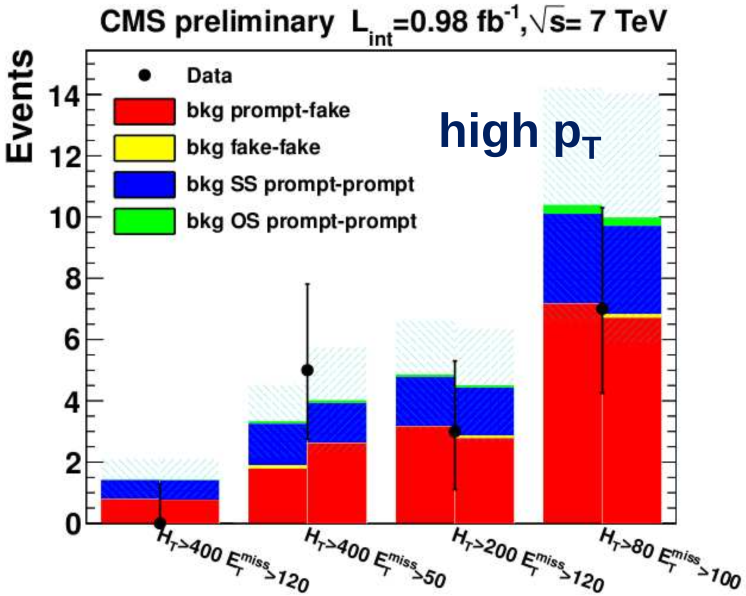
→ efficiency model to interface with theory!

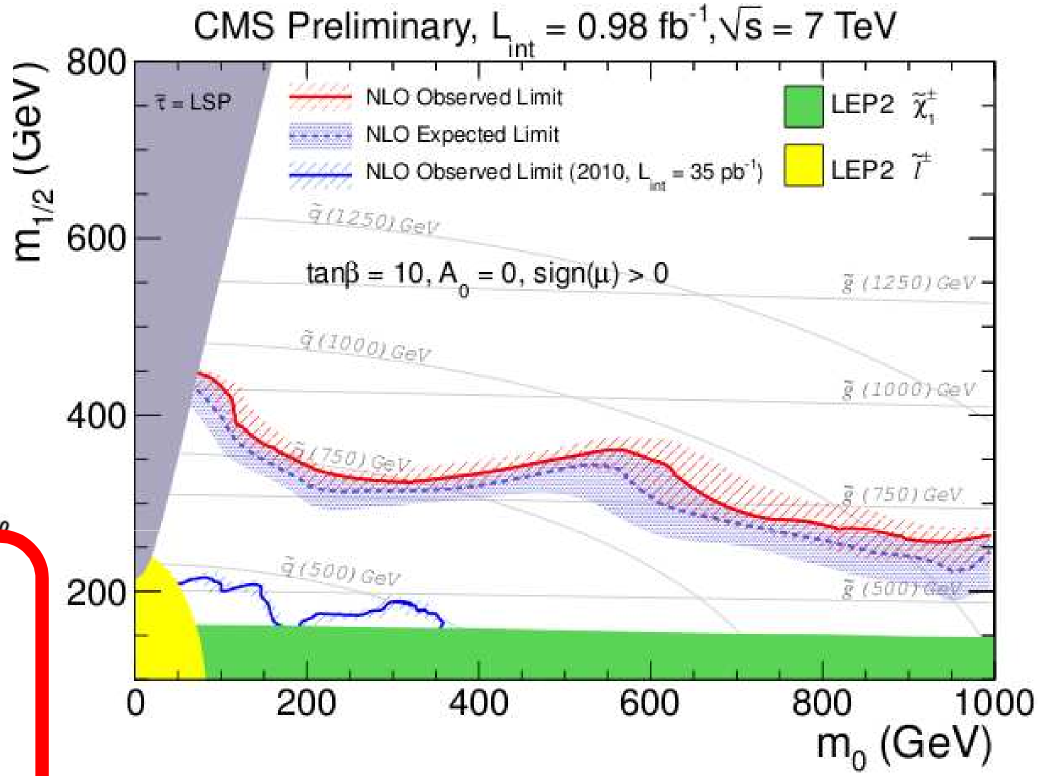




SSDL results





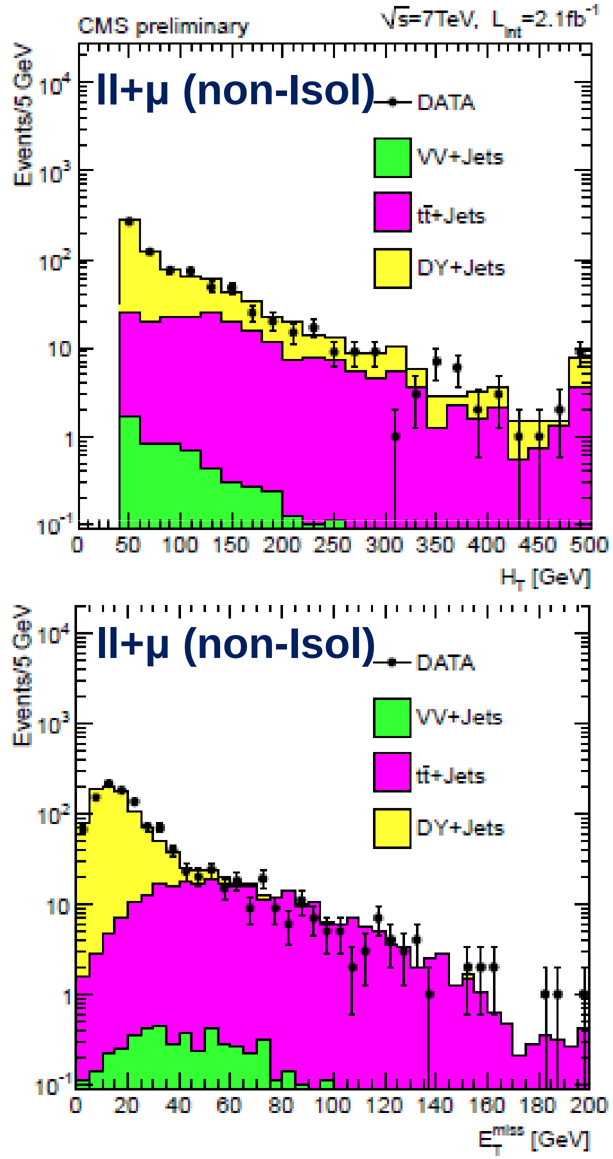


Exclusion region in the CMSSM for the signal region 1 (high-H_T high- E_T^{miss}) of the high-pT search (left)

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

52 channels considered!

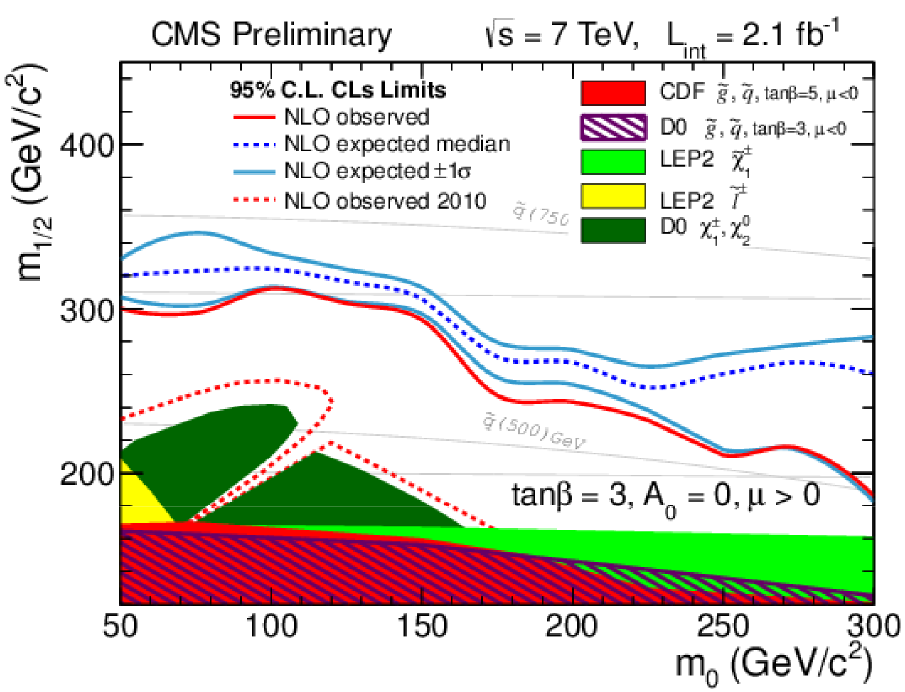


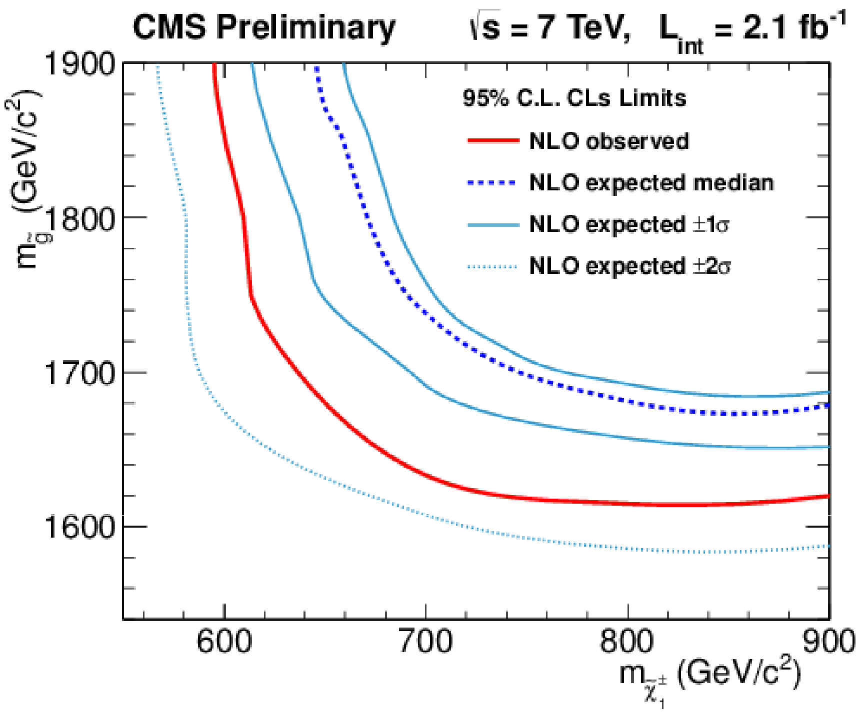
Results for multi leptons

Selection	N(τ)=0 obs	N(τ)=0 expected SM	N(τ)=1 obs	N(τ)=1 expected SM	N(τ)=2 obs	N(τ)=2 expected SM
≥FOUR Lepton Results						
MET>50,H_T >200,noZ	0	0.003 ± 0.002	0	0.01 ± 0.05	0	0.30 ± 0.22
MET>50,H_T >200, Z	0	0.06 ± 0.04	0	0.13 ± 0.10	0	0.15 ± 0.23
MET>50,H_T <200,noZ	1	0.014 ± 0.005	0	0.22 ± 0.10	0	0.59 ± 0.25
MET>50,H_T <200, Z	0	0.43 ± 0.15	2	0.91 ± 0.28	0	0.34 ± 0.15
MET<50,H_T >200,noZ	0	0.0013 ± 0.0008	0	0.01 ± 0.05	0	0.18 ± 0.07
MET<50,H_T >200, Z	1	0.28 ± 0.11	0	0.13 ± 0.10	0	0.52 ± 0.19
MET<50,H_T <200,noZ	0	0.08 ± 0.03	4	0.73 ± 0.20	6	6.9 ± 3.8
MET<50,H_T <200, Z	11	9.5 ± 3.8	14	5.7 ± 1.4	39	21 ± 11
THREE Lepton Results						
MET>50,H_T >200,no-OSSF	2	0.87 ± 0.33	21	14.3 ± 4.8	12	10.4 ± 2.2
MET>50,H_T <200,no-OSSF	4	3.7 ± 1.2	88	68 ± 17	76	100 ± 17
MET<50,H_T >200,no-OSSF	1	0.50 ± 0.33	12	7.7 ± 2.3	22	24.7 ± 4.0
MET<50,H_T <200,no-OSSF	7	5.0 ± 1.7	245	208 ± 39	976	1157 ± 323
MET>50,H_T >200,noZ	5	1.9 ± 0.5	7	10.8 ± 3.3	–	–
MET>50,H_T >200, Z	8	8.1 ± 2.7	10	11.2 ± 2.5	–	–
MET>50,H_T <200,noZ	19	11.6 ± 3.2	64	52 ± 13	–	–
MET<50,H_T >200,noZ	5	2.0 ± 0.7	24	26.6 ± 3.3	–	–
MET>50,H_T <200, Z	58	57 ± 21	47	44.1 ± 7.0	–	–
MET<50,H_T >200, Z	6	8.2 ± 2.0	90	119 ± 14	–	–
MET<50,H_T <200,noZ	86	82 ± 21	2566	1965 ± 438	–	–
MET<50,H_T <200, Z	335	359 ± 89	9720	7740 ± 1698	–	–
Totals 4L	13.0	10.4 ± 3.8	20.0	7.8 ± 1.5	45	30 ± 12
Totals 3L	536	539 ± 94	12894	10267 ± 1754	1086	1291 ± 324

no excess beyond SM seen.

Results for multi leptons



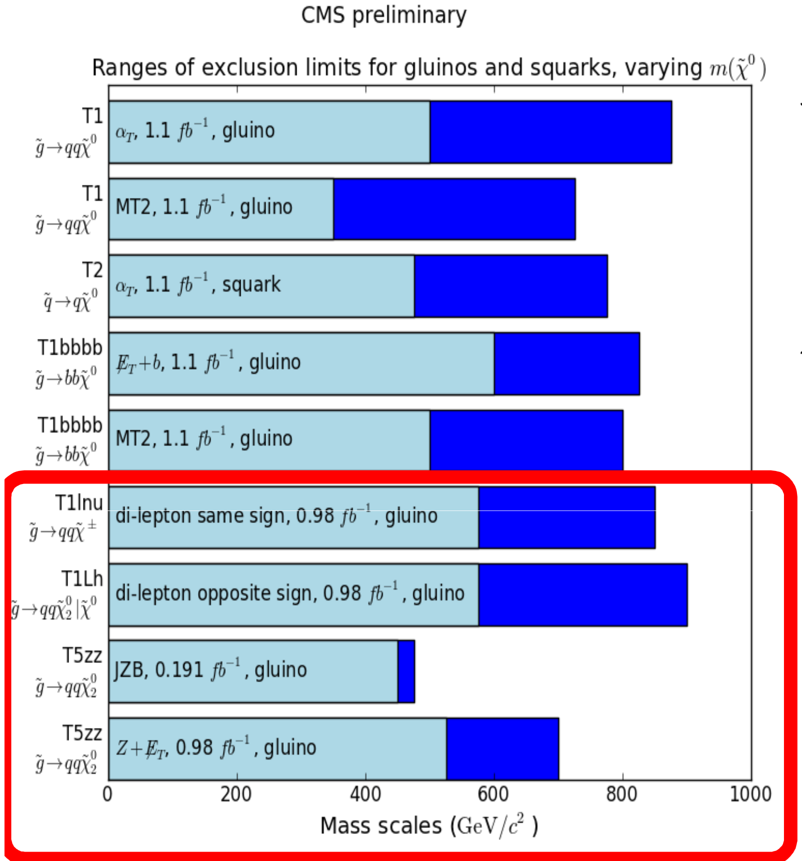


Set limits in cMSSM plane

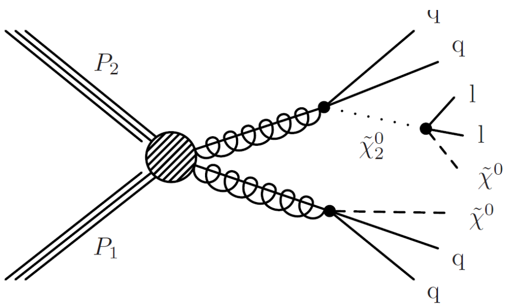
(All LHC and Tevatron results are given for the other MSSM parameters fixed at tan β = 3, A_0 = 0, μ >0)

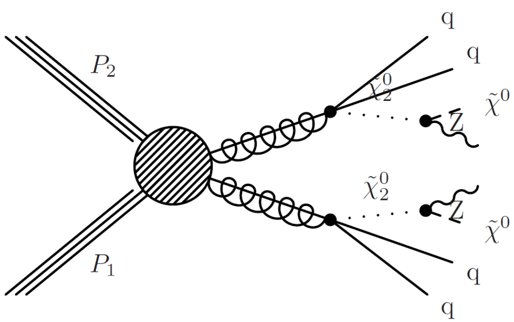
GMSB scenario with slepton co-NLSP decaying into l + gravitino. The next higher state is a bino-like neutralino, leading to a four lepton + MET final state.

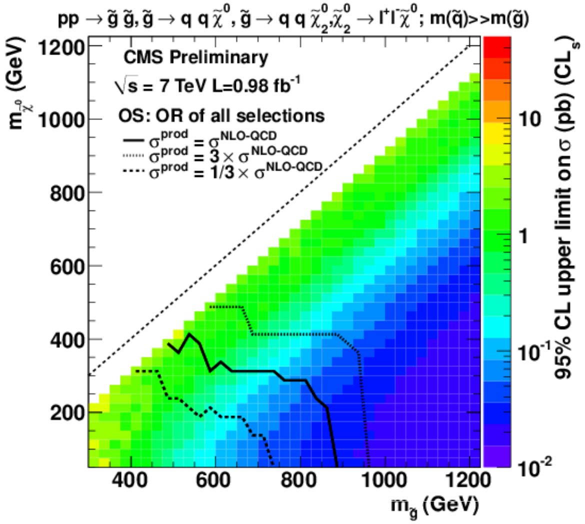
Simplified models

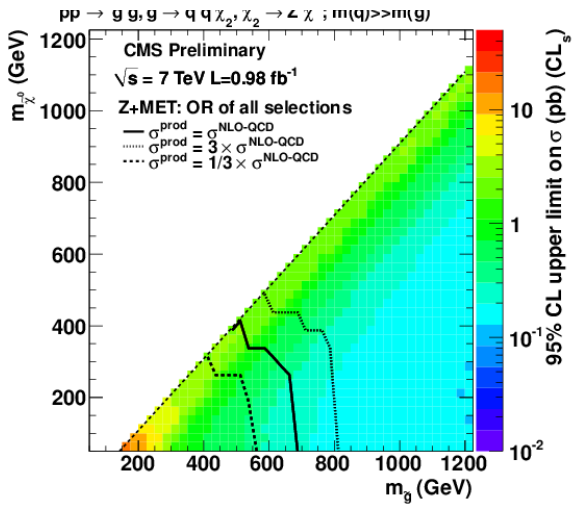


leptonic searches









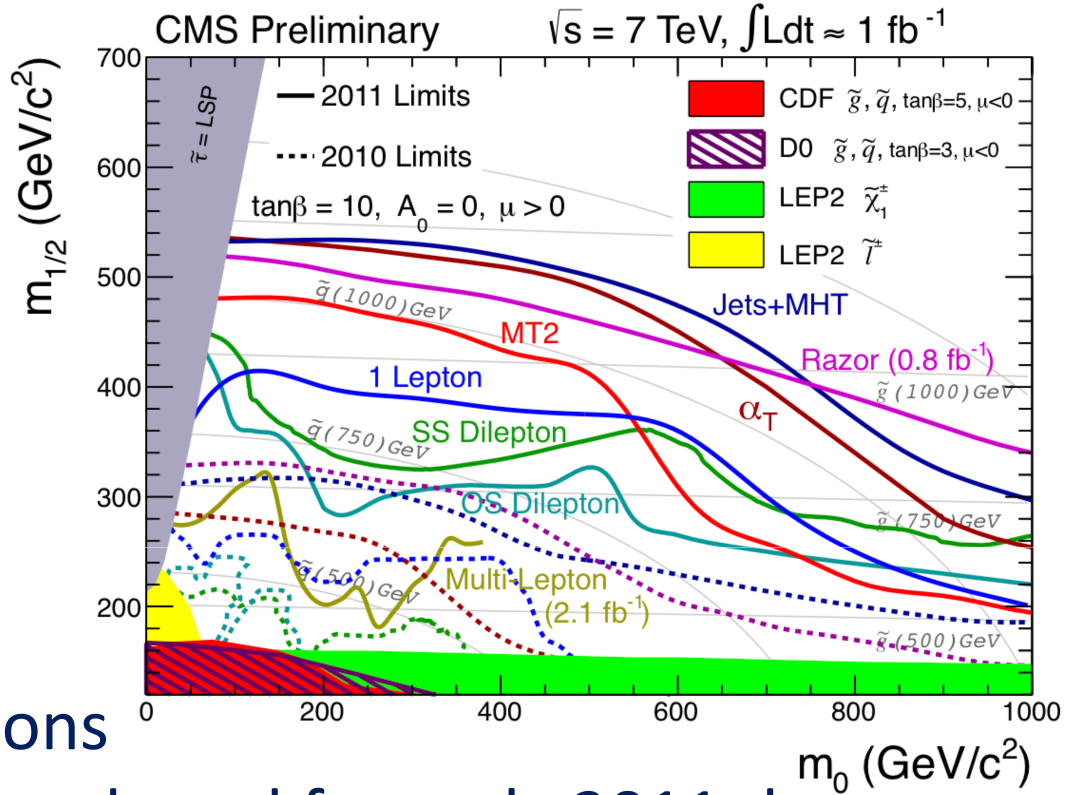
For limits on $m(\tilde{g}), m(\tilde{q}) >> m(\tilde{g})$ (and vice versa). $\sigma^{prod} = \sigma^{NLO-QCD}$.

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

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

Summary

- CMS preformed a variety of SUSY searches with up to 2 fb^{-1}



- Multiple methods for data-driven background estimations have been validated and used for early 2011 data

- We have not seen significant evidence for BSM

- Almost **5fb^{-1}** are being **analyzed** right now!

References

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

Further interpretation of SUSY searches, CMS PAS SUS-11-001

Search for supersymmetry in events with opposite-sign dileptons and missing energy, CMS PAS SUS-11-011

Search for supersymmetry in events with same-sign dileptons and missing energy, CMS PAS SUS-11-010

Search for supersymmetry in events with a Z boson and missing energy, CMS PAS SUS-11-012, SUS-11-017

Search for supersymmetry in events with three or more leptons and missing energy, CMS PAS SUS-11-013

Backup

lepton fakes: tight to loose (TL)

Three methods for fake lepton predictions **prompt-fake**, **fake-fake**

Tight to Loose (TL)

ratio measured in QCD multijet;

two sets of loose definition (A1/2):

(different isolation requirements)

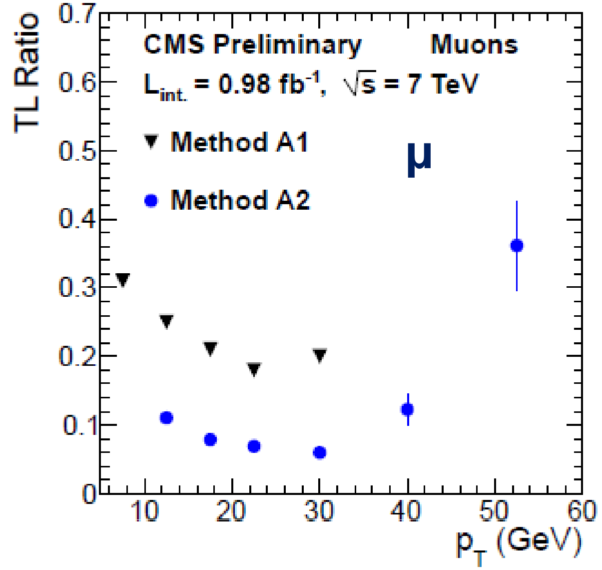
Factorization Method (next slide):

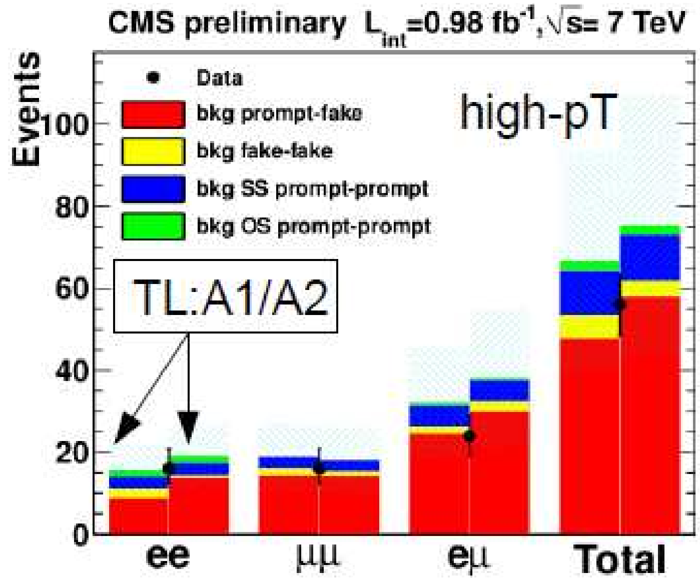
factorize isolation and E_T^{miss} efficiency

B Tag-and-Probe:

relax isolation

requirement and measure efficiency in a b-enriched control sample





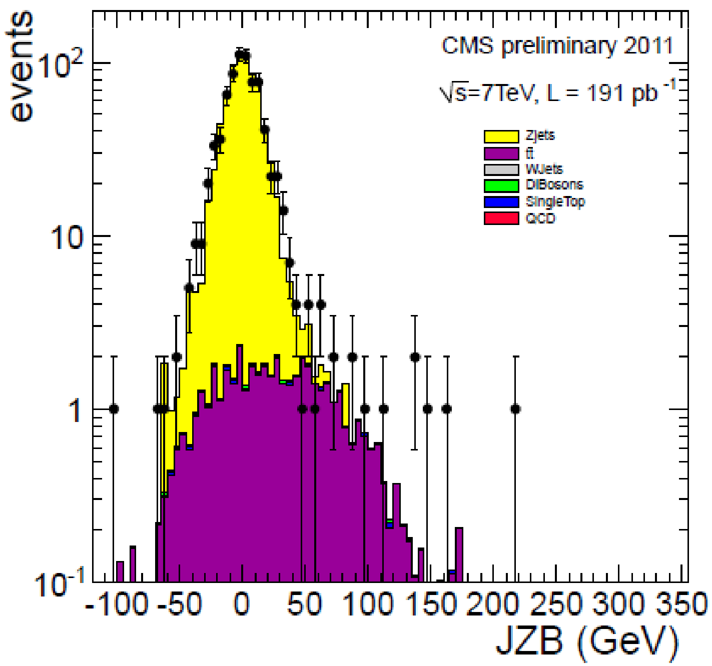
Z+Jets+MET search with JZB

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

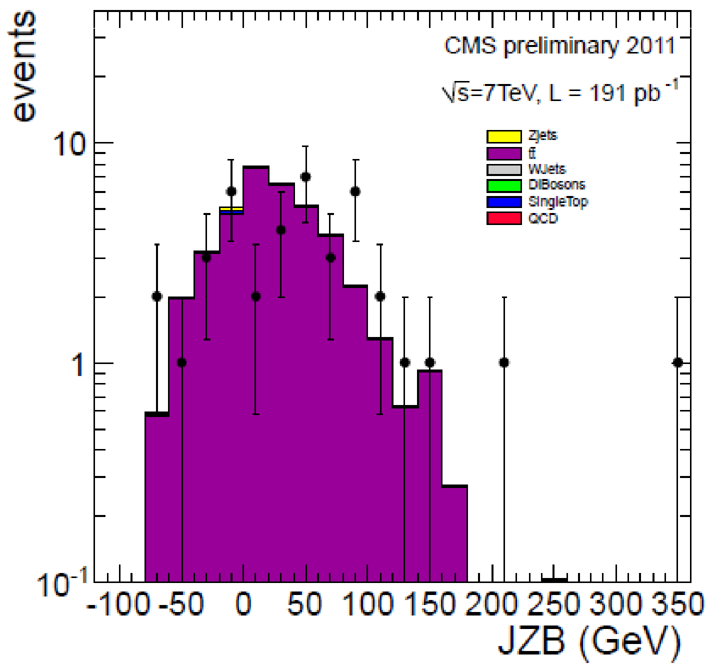
$$JZB = \left|\sum_{\text{jets}} \vec{p_T}\right| - \left|\vec{p_T}^{(Z)}\right|$$

- Dominant backgrounds: Z+Jets, ttbar
  - Use JZB<0 to predict Z+Jets in JZB>0
  - Use eμ pairs to predict ttbar in JZB>0
  - new physics is preferentially positive for JZB since jets balance Z+MET

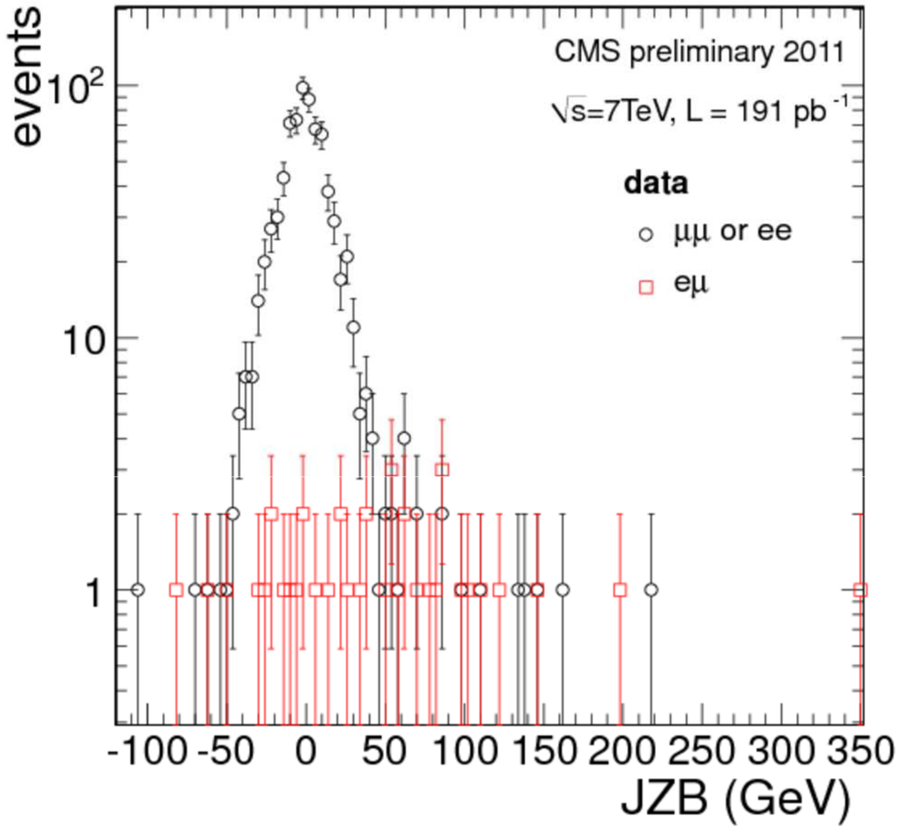
Same-Flavor Leptons

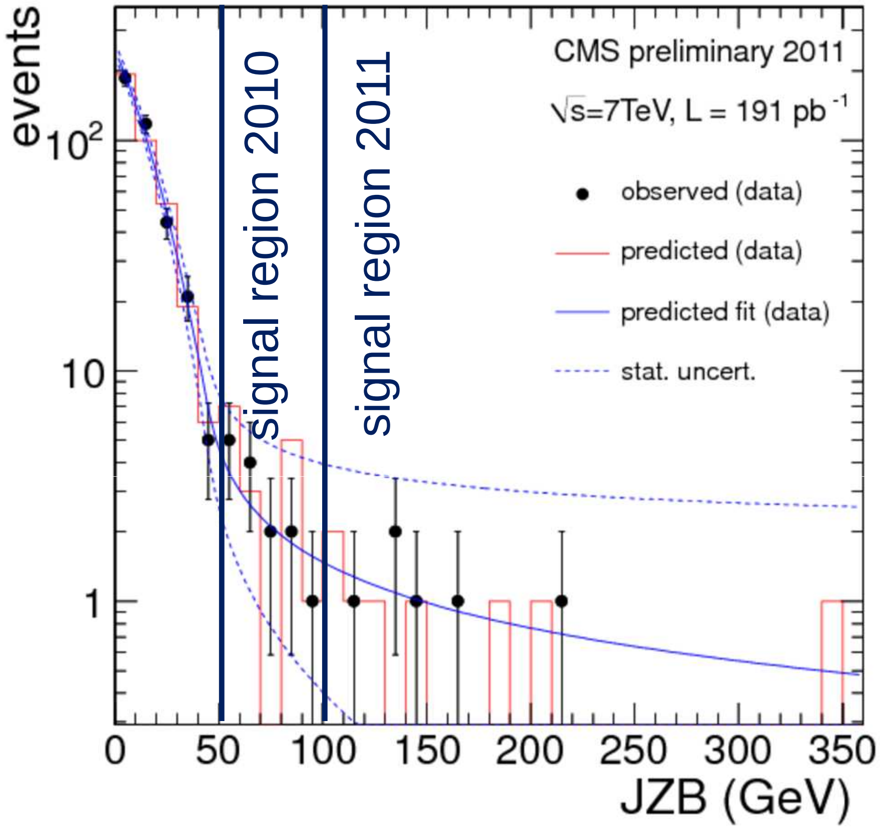


Opposite-Flavor Leptons



JZB: results with 191 pb^{-1}





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