SUSY searches in same-sign dilepton and in multilepton final states

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for CMS Collaboration

SEARCH Workshop
University of Maryland

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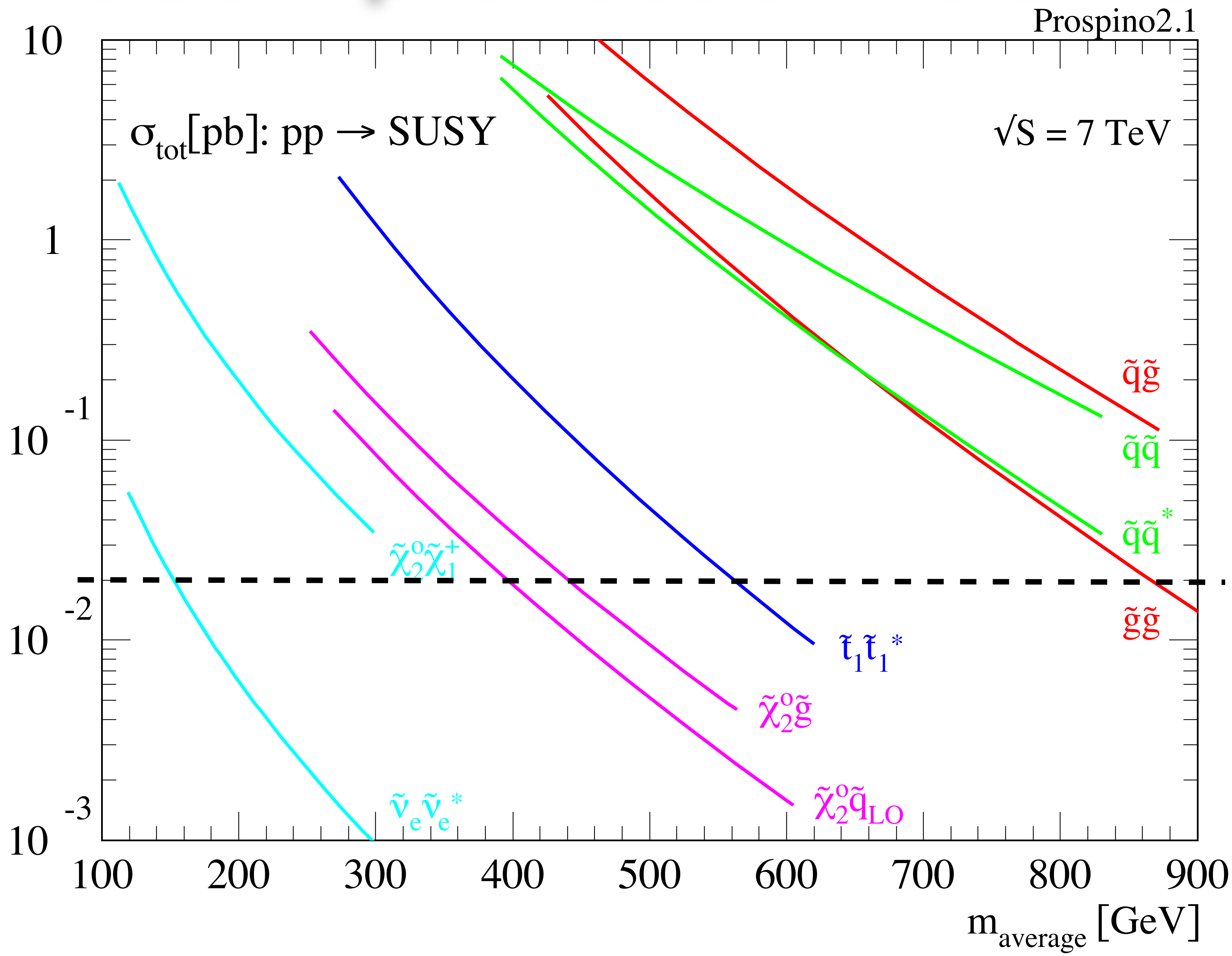
Prerequisites

- LHC with pp collisions at center-of-mass 7 TeV
- CMS detector with analyzed LHC collision data
  - ✓ About 5 fb^{-1} of data
- Supersymmetry as a motivation to look for physics beyond the standard model

Outline

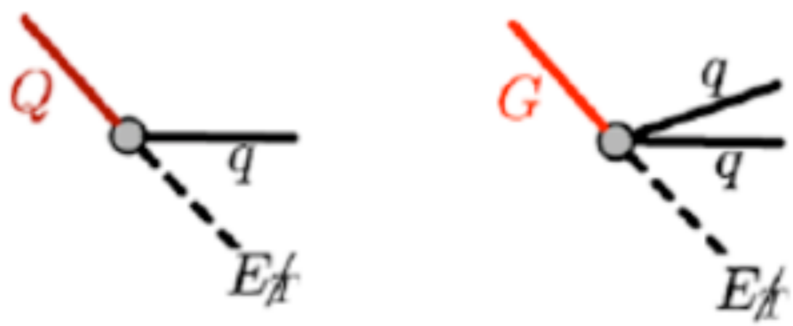
- Analyses in same-sign dilepton final states with jets and missing energy
  - ✓ Inclusive analysis without jet flavor tagging CMS-PAS-SUS-11-010
  - ✓ Analysis in events with (at least two) b-jets CMS-PAS-SUS-11-020
  - ➡ All SUSY interpretations here made just for R-parity conserving models
- Analysis in multilepton final states
  - ✓ General search in multileptons CMS-PAS-SUS-11-013, EXO-11-045
  - ➡ Includes constraints on R-parity conserving and violating cases
- Note: Ricardo Vasquez talk yesterday on exotica searches in final states overlapping with analyses here
  - ✓ $T\to tZ$ search ($pp\to T\bar{T}$) in (Z dilepton)+lepton+jets PRL 107, 271802 (2011)
  - ✓ $pp\to b'\bar{b}'$ search $b'\to tW$ in trileptons, same-sign dileptons and b-jet(s) EXO-11-036

SUSY: production at LHC

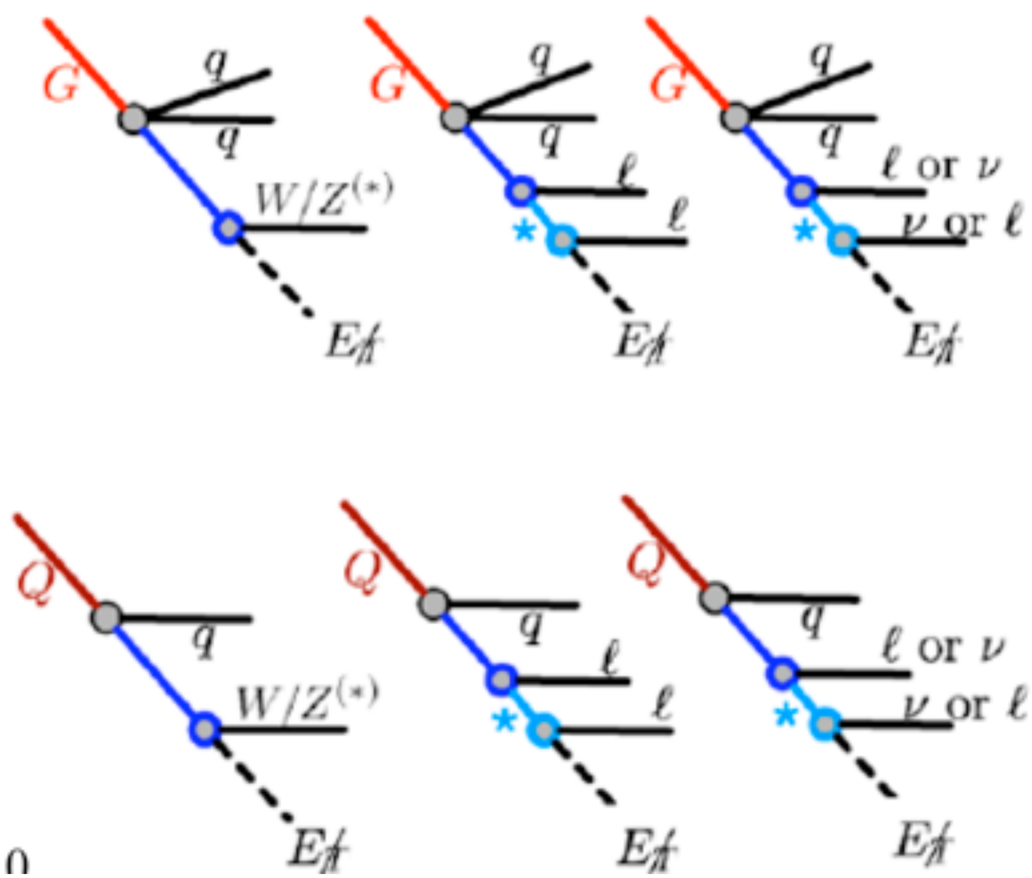


- Eyeball the sensitivity from 100 events line (σ~20 fb for 2011)

SUSY final states



$\tilde{q} \rightarrow q\tilde{\chi}_1^0$ $\tilde{g} \rightarrow q\bar{q}\tilde{\chi}_1^0$

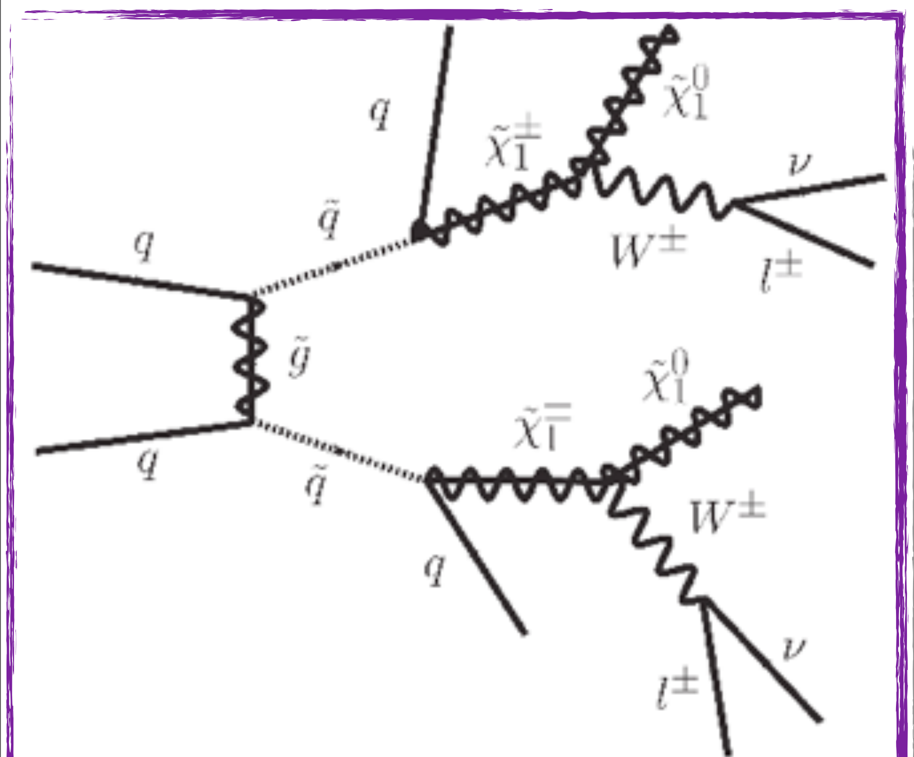


- Consider squark/gluino production
- Direct steps down to LSP produce jets and energy imbalance (MET) in the final state
- More intermediate steps provide a slew of signatures involving leptons, jets, and MET
- Note: leptons considered for signal are not from jet fragmentation/quark decays, only from W/Z, chargino, sleptons directly
- It's important to look for different topologies.
  - ✓ *Some have higher cross sections but higher backgrounds or systematic*
  - ✓ *Some have smaller rates but smaller backgrounds*

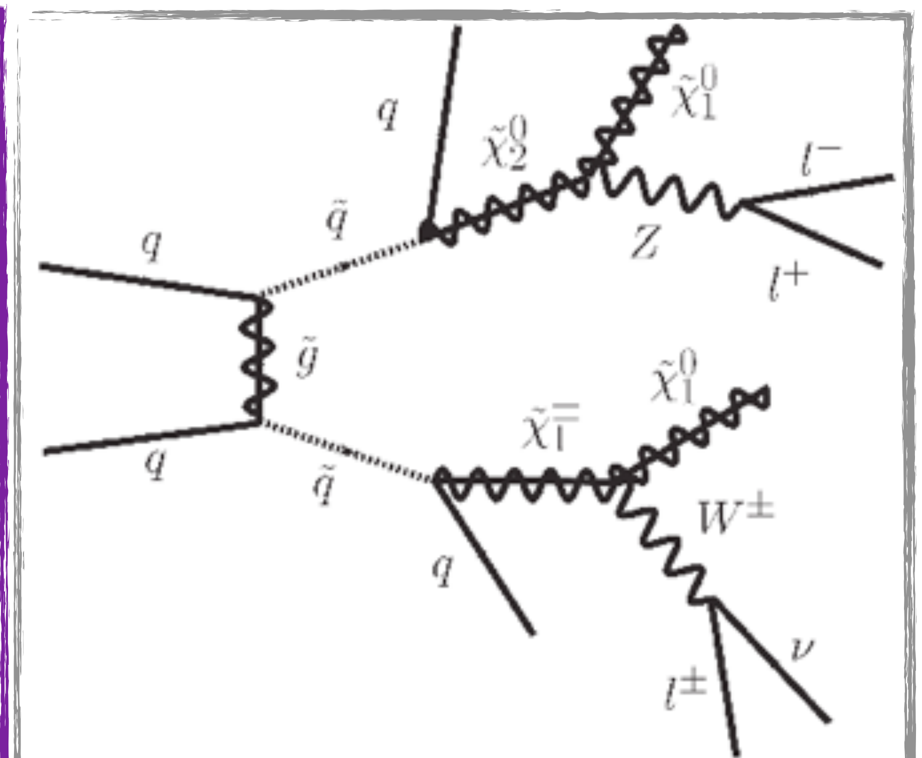
SUSY: di/multi-leptons

- Plenty of ways to get multiple leptons in SUSY
- Start from colored superpartners ==> pick up leptons from decays of charginos/neutralinos directly, or W/Z or sleptons coming off of them
  - ✓ All cases here give extra jets
  - ✓ R-parity conservation gives Missing Energy from LSP
  - ✓ R-parity violation means no MET from LSP, but still some MET from W/chargino decays

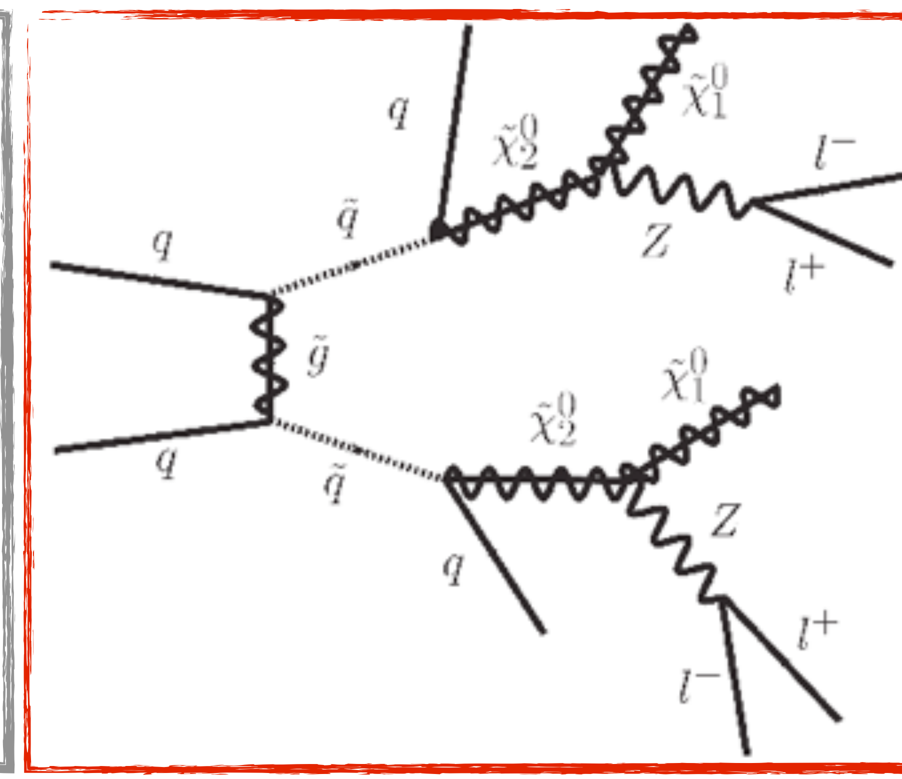
Same-sign dilepton



Tri-lepton



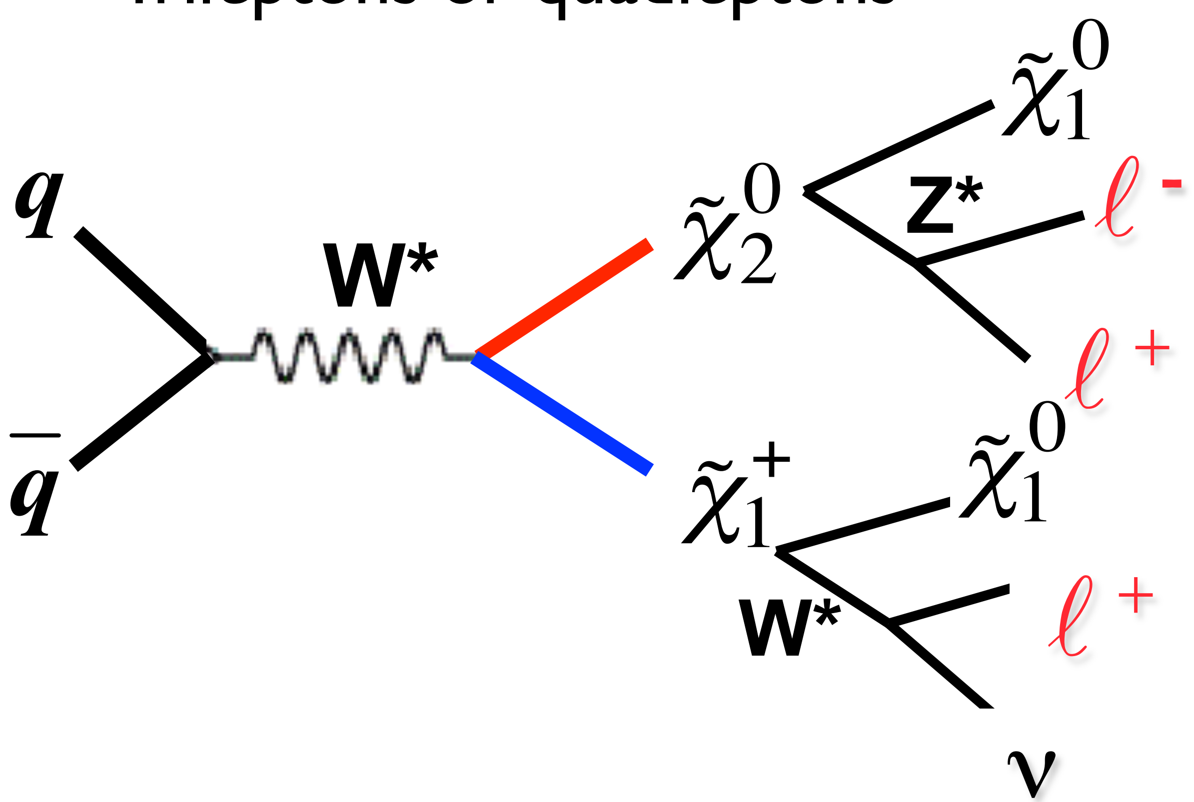
Four-lepton



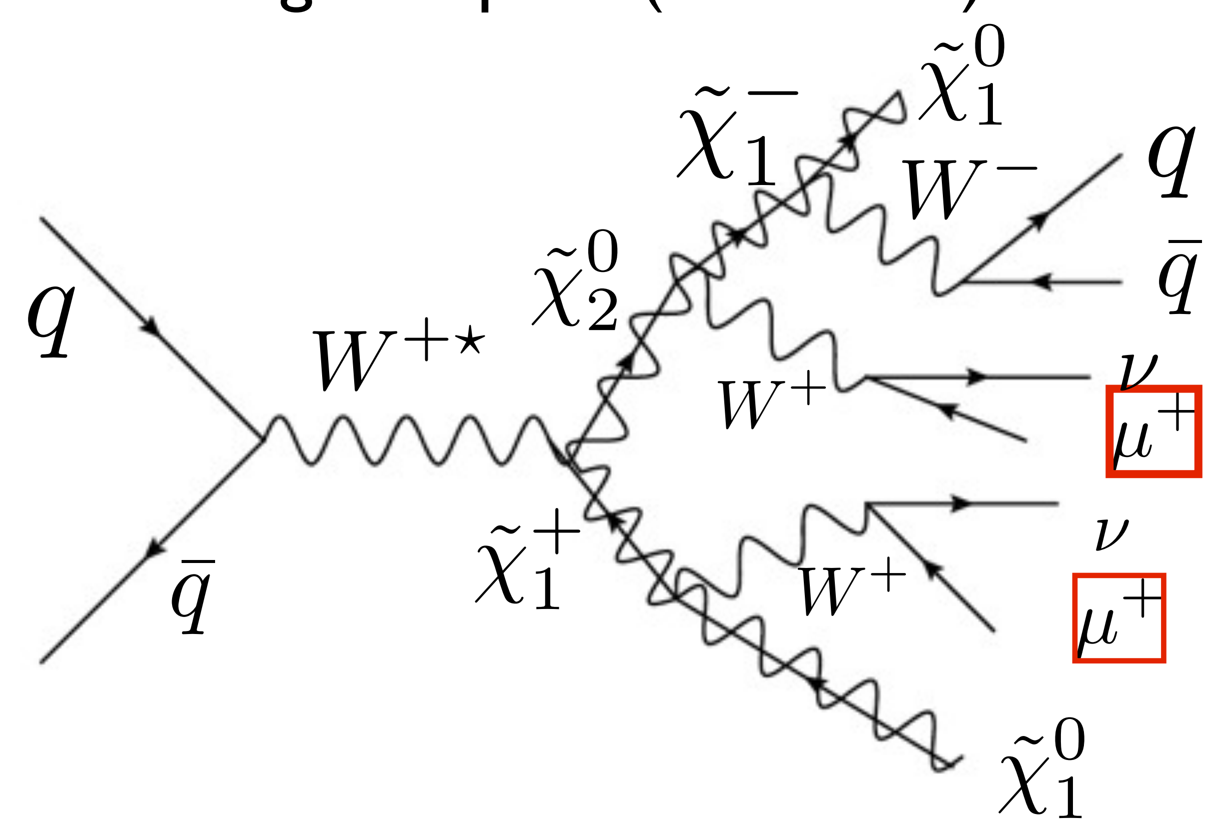
SUSY: di/multi-leptons

- Plenty of ways to get multiple leptons in SUSY
- Start from no-color superpartners ==> same ways to get leptons
  - ✓ 3 or more leptons more "natural" than same-sign only
  - ✓ Fewer jets, if any
  - ✓ Similar situation with MET for R-parity conserving or violating cases

Trileptons or quadleptons

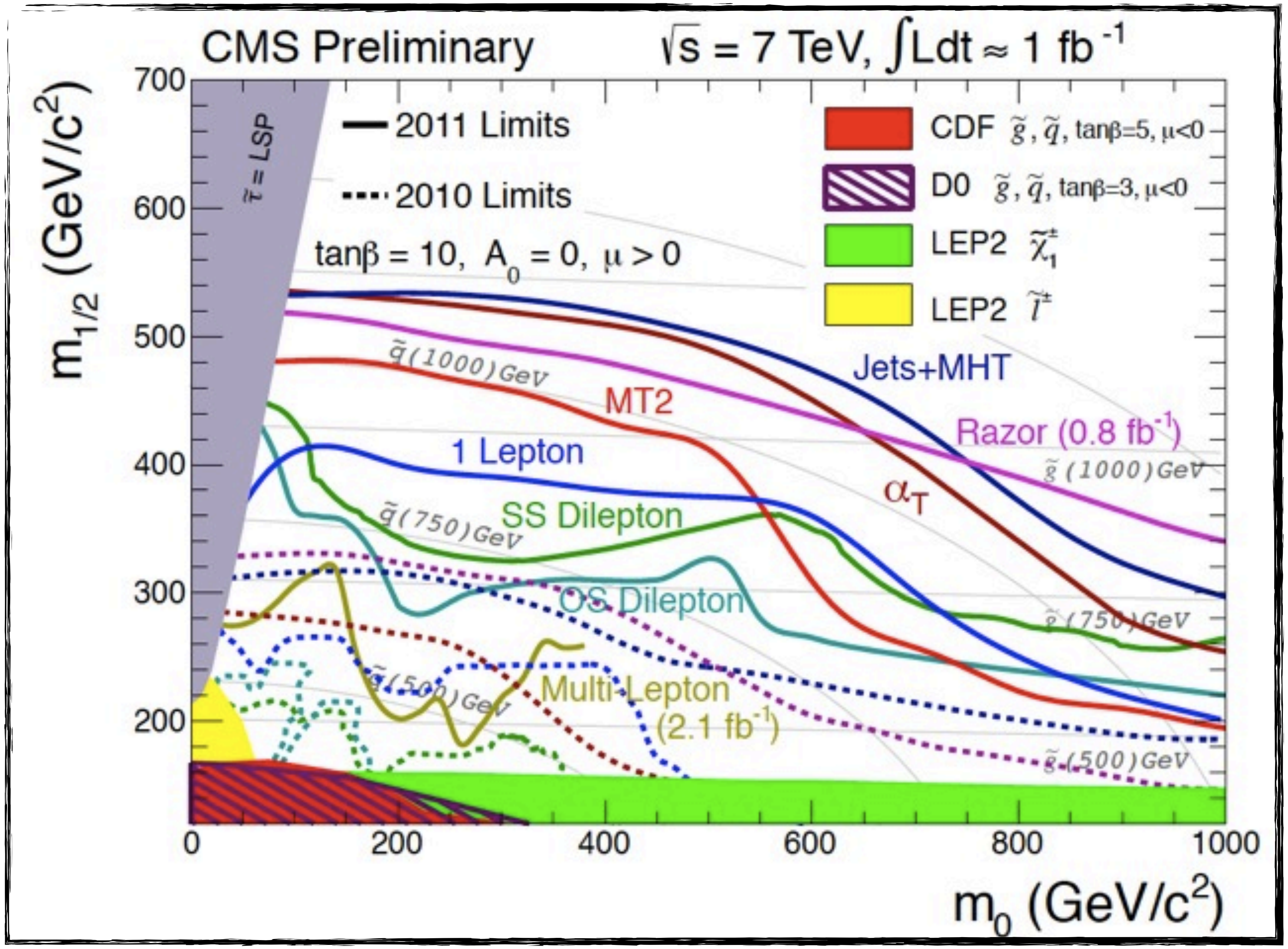


Same-sign dilepton (less trivial)



Sensitivity in CMSSM, Summer 11

- "classic" slice in cMSSM
  - ✓ **Lower sensitivity in multileptons (vs same-sign dileptons)**
    - from looser jets+met cuts and lower branching fractions
    - Slightly better than expected for SS and the opposite for multileptons



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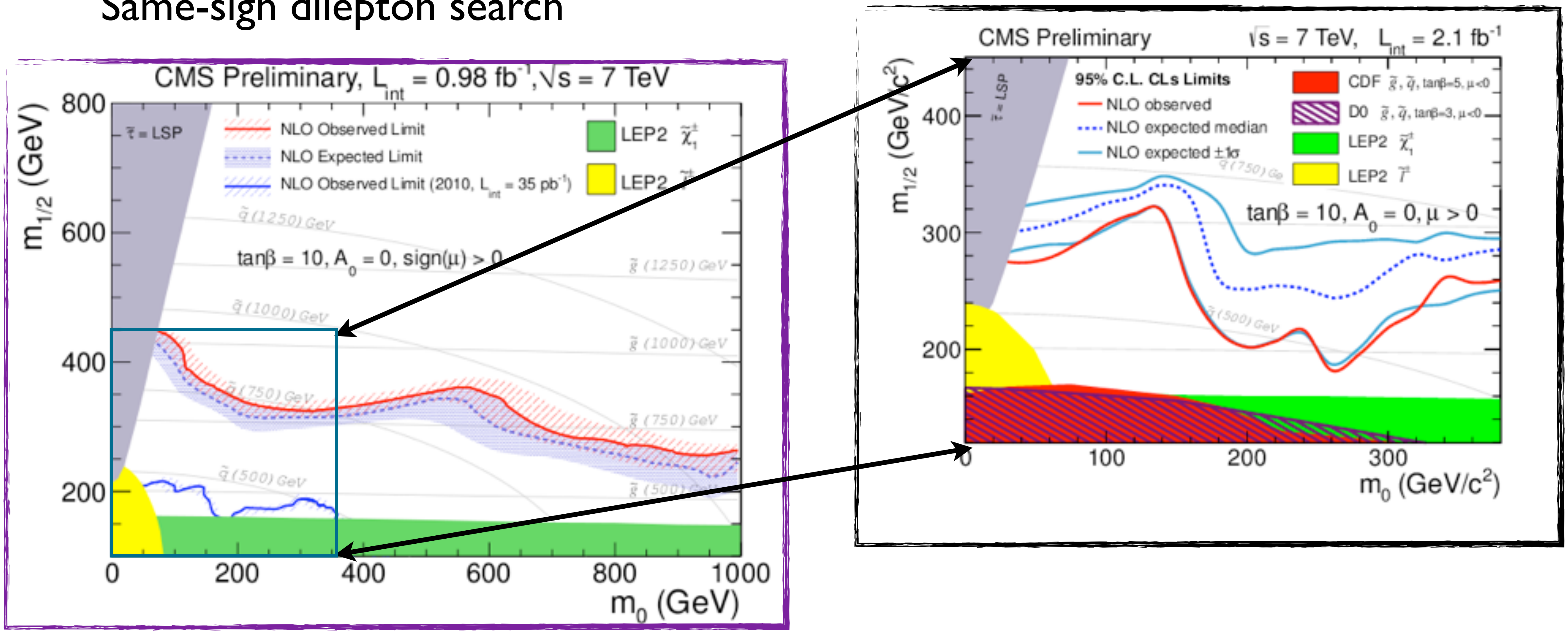
Multilepton search

Same-sign dilepton search



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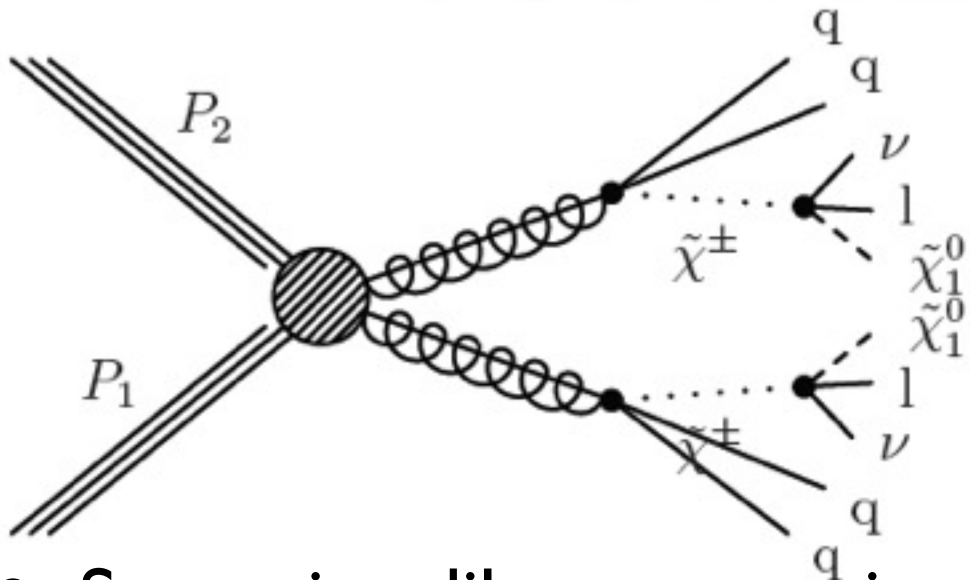
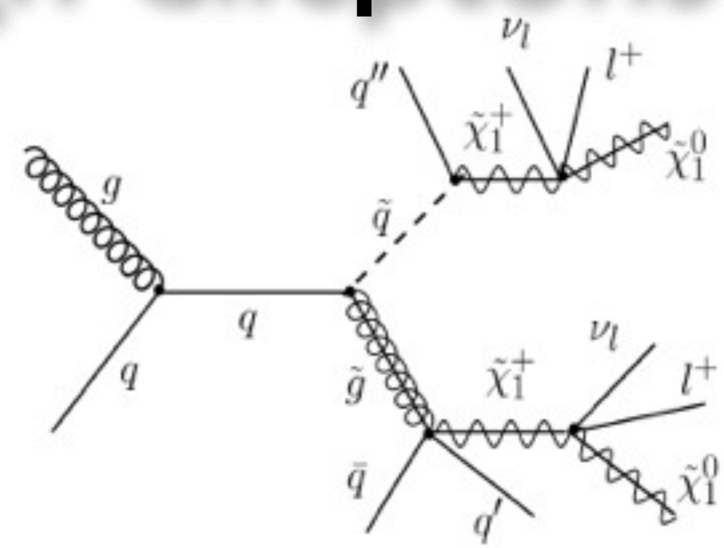
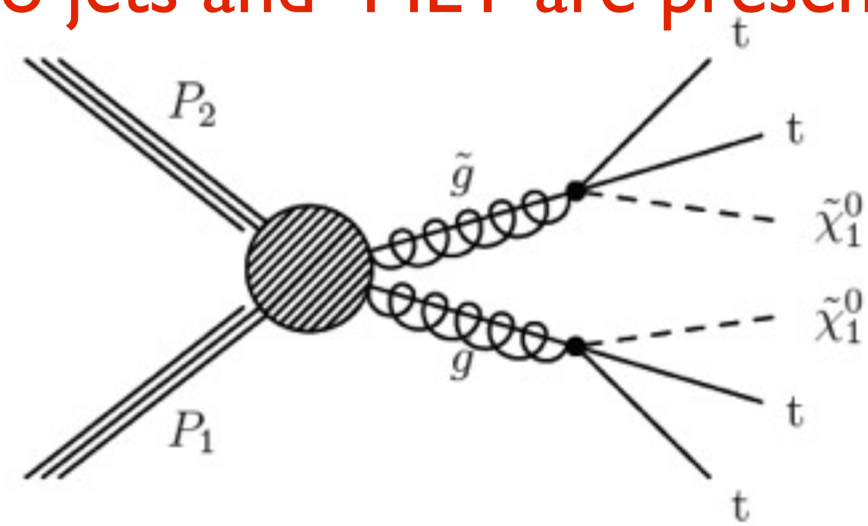
Move along to analyses details

SUSY: same-sign dileptons





- Same-sign dileptons are in many configurations in squark/gluino production
  - ✓ squarks (same sign), squark-gluino, gluino pairs all have like-sign dileptons
  - ✓ as long as there is a charged current exchange (either a W or a chargino in the intermediate state)
- Remarkable signatures include stop and sbottom quarks as they additionally include b-quarks in the final states, and give Ws themselves
- In all cases: at least two jets and MET are present !



Same-sign dilepton analyses

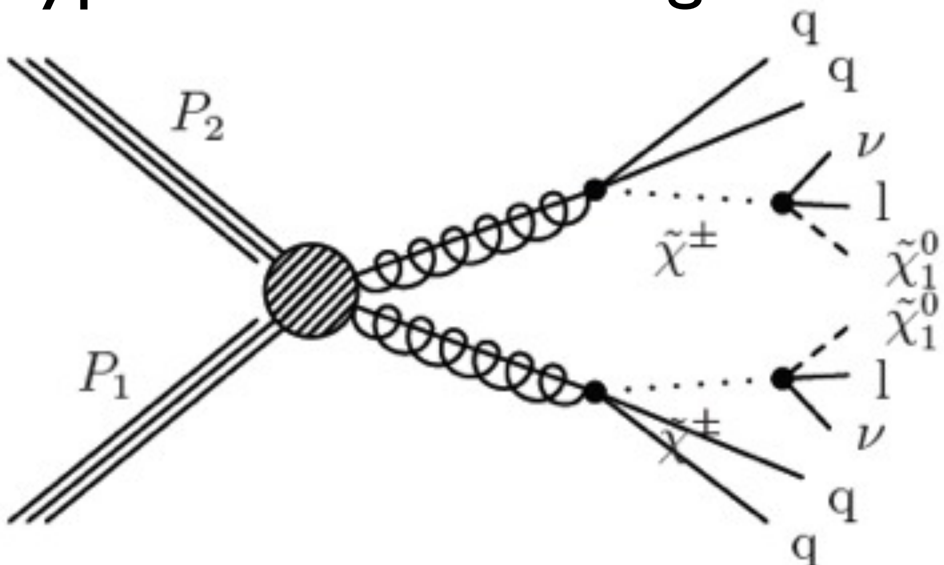
- **<u>Inclusive analysis with SS+jets+MET</u> CMS-PAS-SUS-11-010**
- Pre-selections
- Backgrounds
  - ✓ Sources with genuine lepton <== from Simulation
  - ✓ jet→ misidentified lepton <== from Data
  - ✓ charge mis-ID: opposite-sign→ same-sign <== calibrate in Data
- Slice it up: signal regions
- Interpretation in cMSSM
- Outreach for theorists

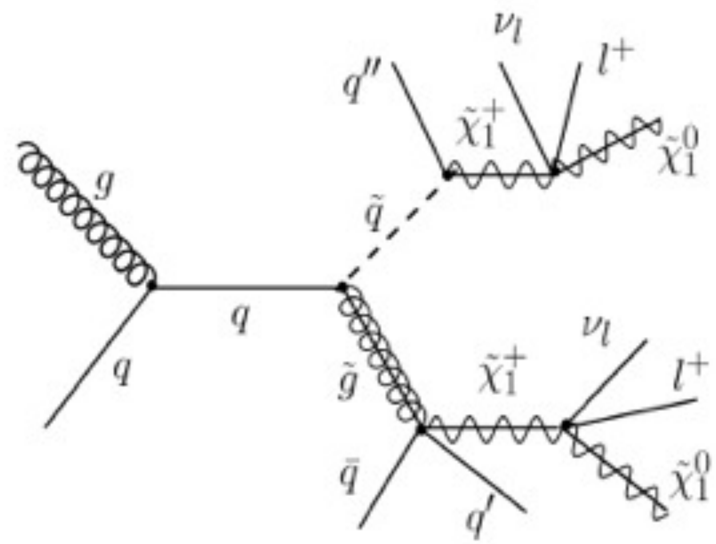
- **<u>Analysis with SS+bjets+(jets)+MET</u> CMS-PAS-SUS-11-020**
- Winning over jet→ misID lepton background
- Slicing and interpretation

SS dileptons: cover lepton phase space

SUS-11-010

- Typical modes leading to the same-sign final states





- Kinematics in sequential decays can push leptons to have lower momenta
  - ✓ Small mass splittings in SUSY particle spectrum can easily do that
  - ✓ Balance these with requirements on more jet energy (use HT=sum jet PT) or more MET

➡ The solution is to reduce lepton thresholds and split into categories

- a) e/μ mix: Both lepton pt>10 GeV, at least one pt>20 GeV
- b) e/μ mix: Both lepton pt as low as 5 (10) GeV for muons (electrons)
  - ✳ **Here always require HT>200 GeV to cope with trigger rates**
- c) (e/μ)τ and ττ mix: select τ pt>15 GeV; e pt>10 GeV; and μ pt>5 GeV
  - ✳ **Here always require HT>350 GeV and MET>80 GeV forced by the trigger**

✓ All events have to have at least two jets (HT>80 GeV) and MET>30 GeV

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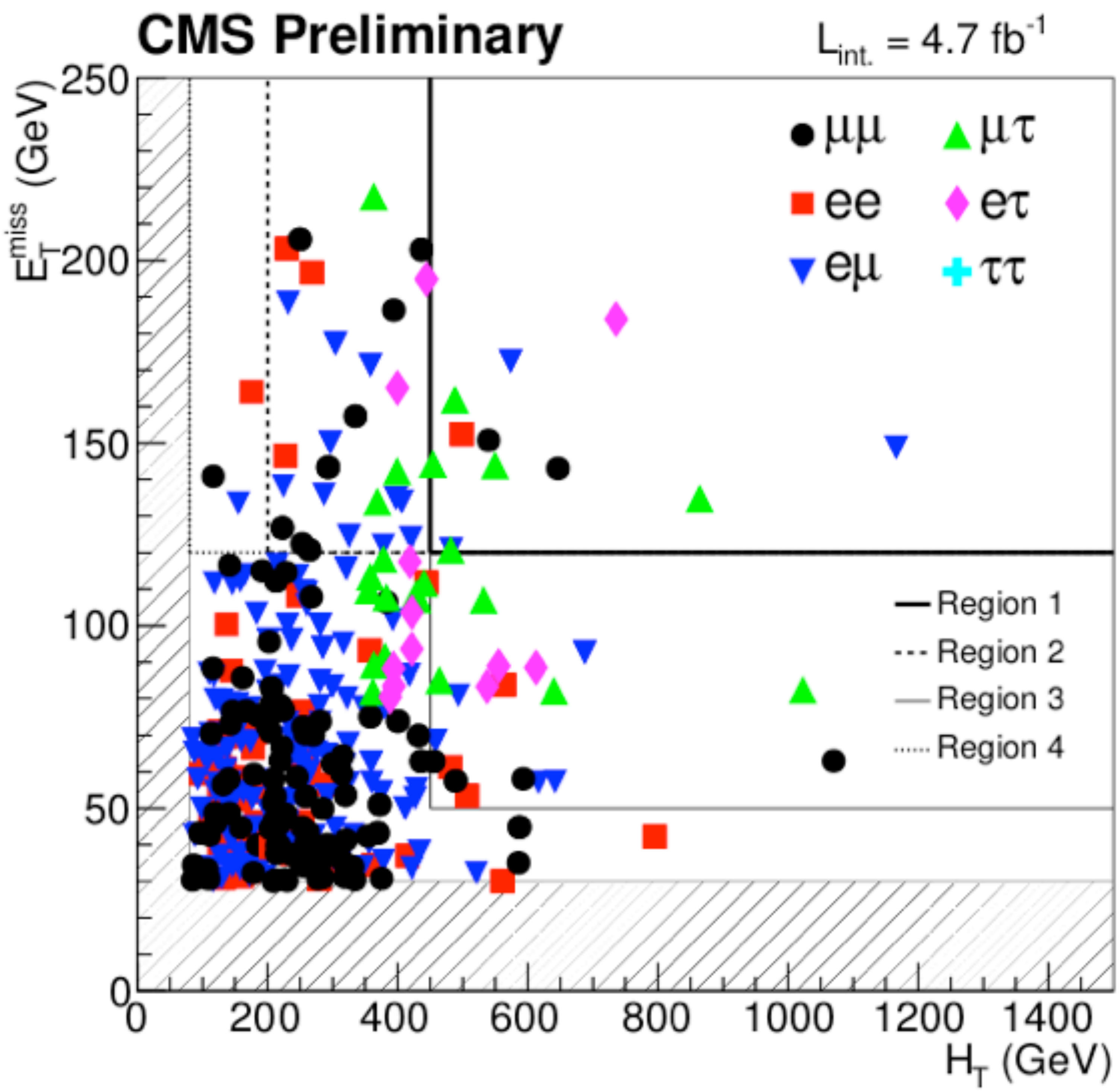
Observed events scatter

- Slice and dice to improve sensitivity to model points
  - ✓ Reg.1: HT> 400 GeV, MET > 120 GeV
    - ✳ **the only place for ττ and τ(e/μ)**
  - ✓ Reg.2: HT> 200 GeV, MET > 120 GeV
  - ✓ Reg.3: HT> 400 GeV, MET > 50 GeV
  - ✓ Reg.4: HT> 80 GeV, MET > 120 GeV
    - ✳ **only in ptMin/Max>10/20 GeV**



Backgrounds for same-sign analyses

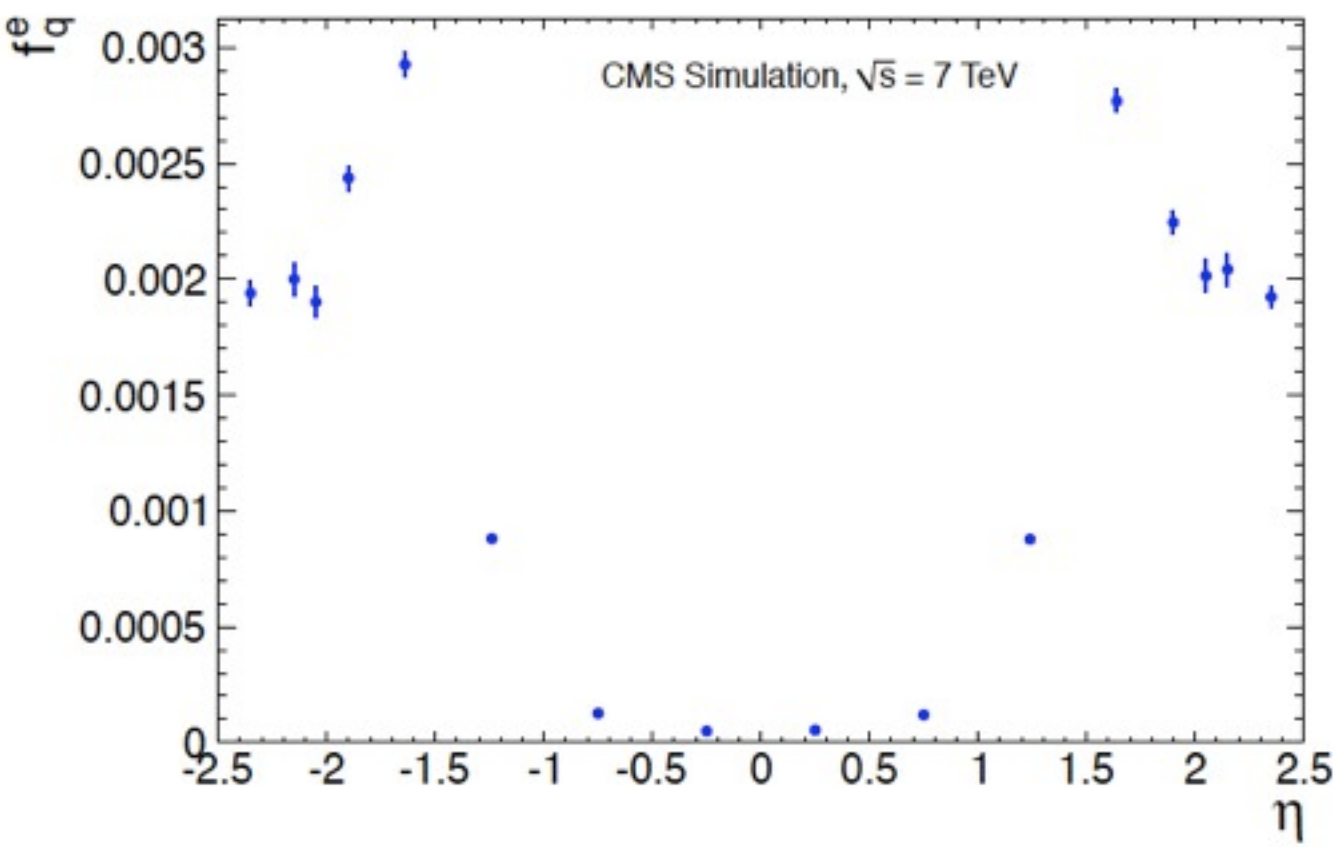
- Charge reconstruction
  - ✓ Calibrate using data
- jet → lepton prediction
  - ✓ Rely on data as much as possible
- Account for rare Standard Model processes
  - ✓ Predict with simulation until we can measure them

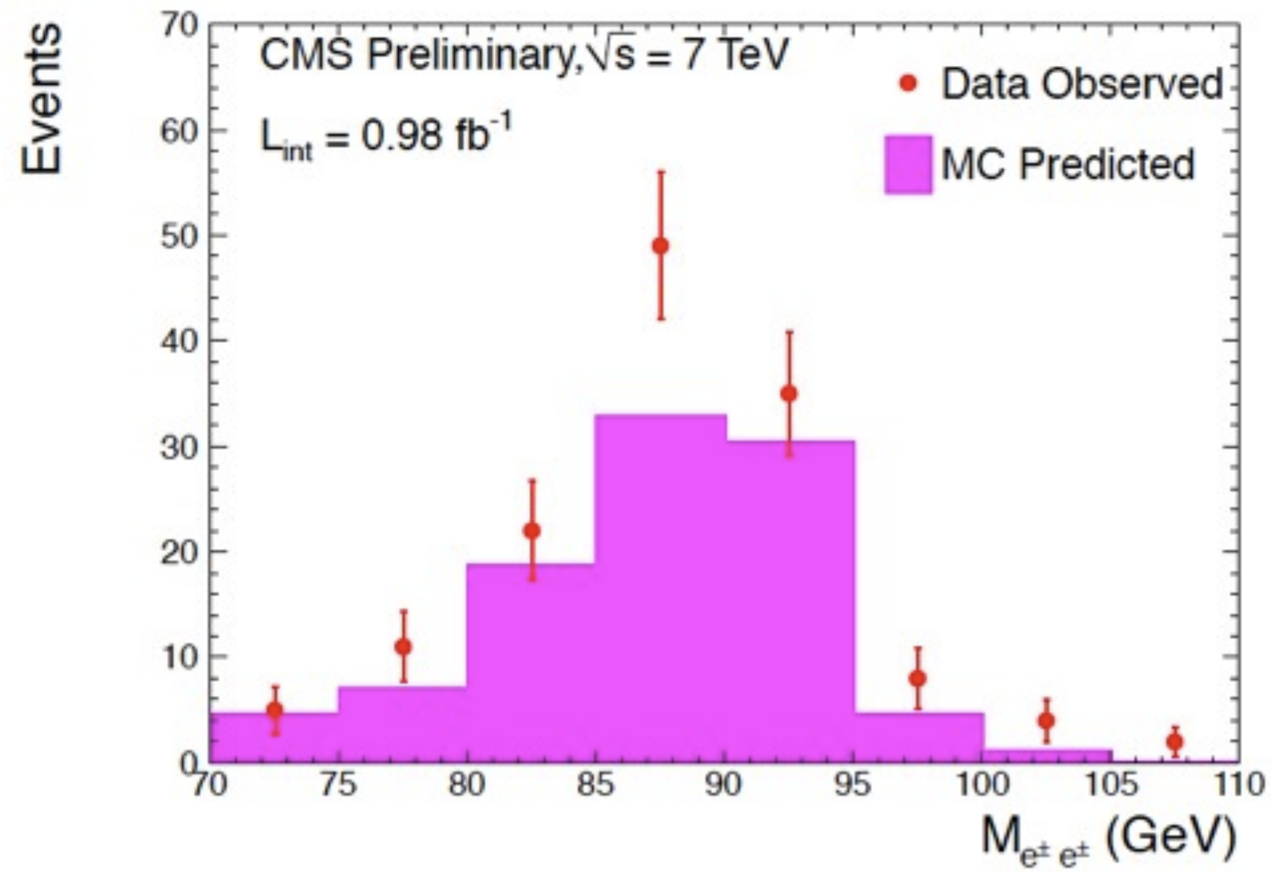
Charge reconstruction

- Charge identification in CMS differs for electrons and muons
- For electrons the rate of charge misreconstruction is about 10^{-3}
- For muons the rate expected in simulation is about 10^{-5}
  - ✓ Ignored/negligible, compared to that for electrons

- Electron bremsstrahlung in the tracker material is the main source of charge confusion
  - ✓ The mis-ID increases with rapidity, due to more material
  - ✓ It also increases with momentum, as the mean deflection in B-field decreases
  - ✓ Note, at least up to 2011 we had about x10 smaller electron charge mis-ID than ATLAS
  - ✓ Even with brem, measurement of electron momentum is primarily from ECAL.
    - This means the $Z \to ee$ mass is not distorted and can be used as a standard candle

Electron charge mis-ID calibration

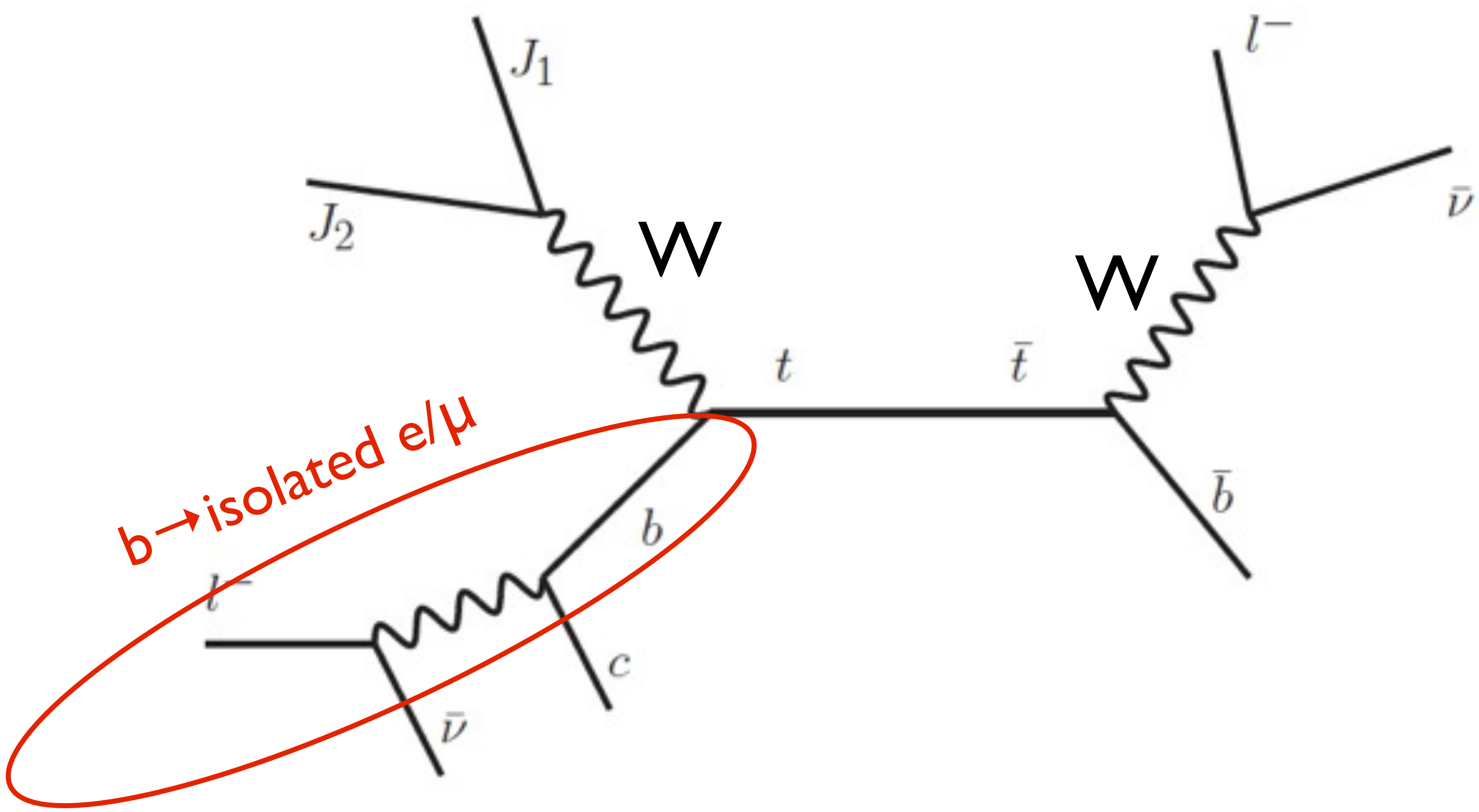




- Use simulated charge mis-ID, function of direction and momentum
- Calibrate on data
  - ✓ Look at opposite-sign Zee, scale by charge mis-ID rate, compare with observed
- See good agreement. It works !

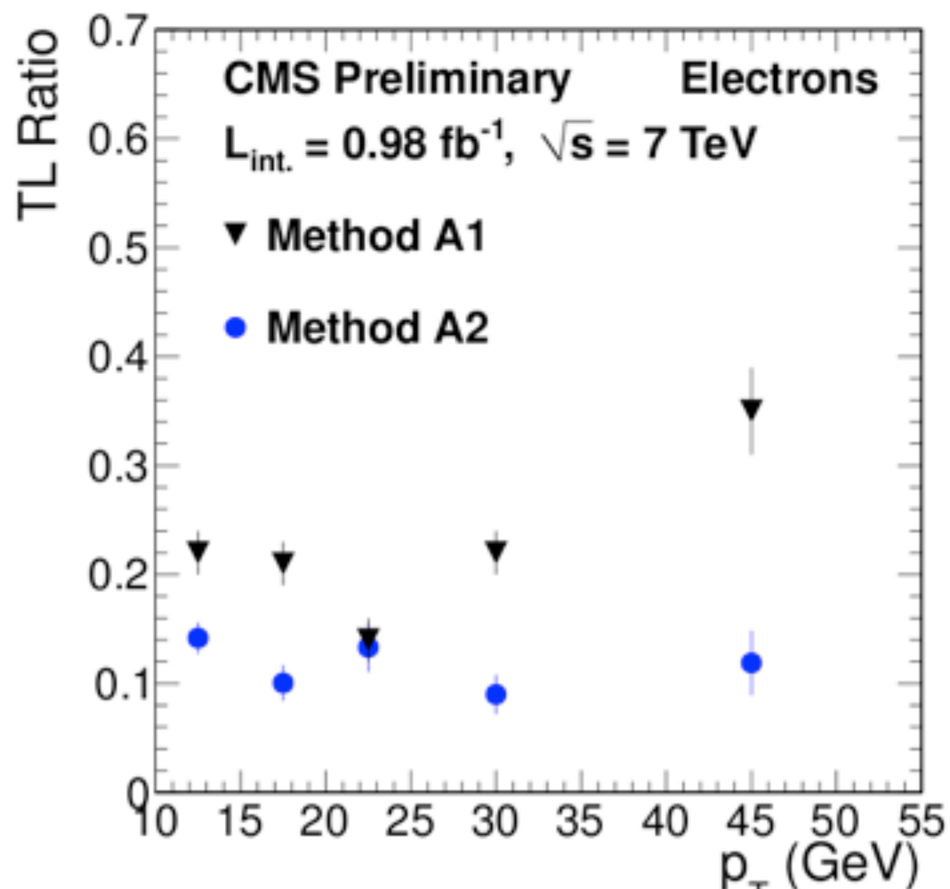
top-pair backgrounds: jet→ leptons

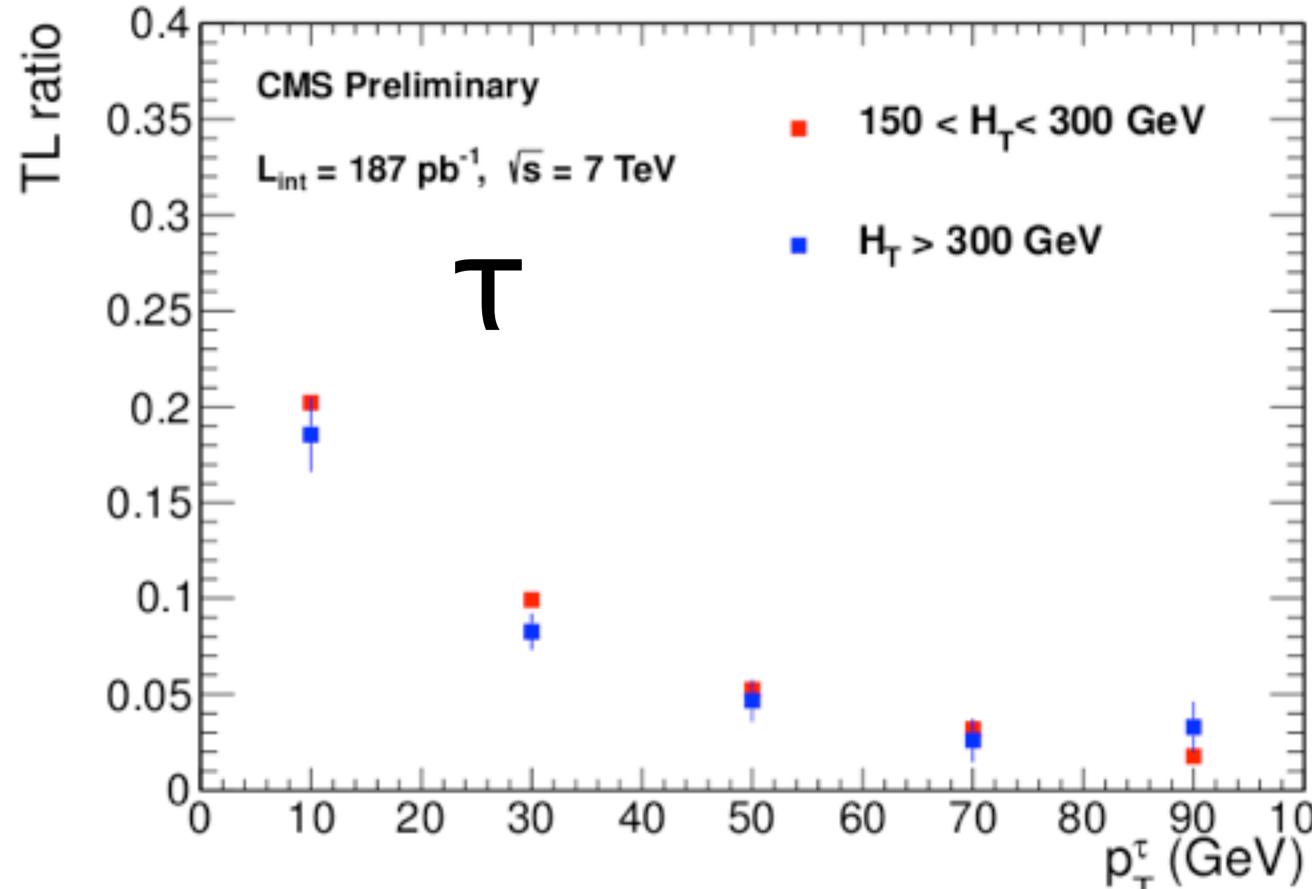
- Important background for all analyses with leptons
- Most of this background is from top-pair events
  - ✓ Note, not all is from b->e/μ, some can come from charm in W, or just light flavor
  - ✓ Muons are almost all from b, so says simulation !



jet → lepton background

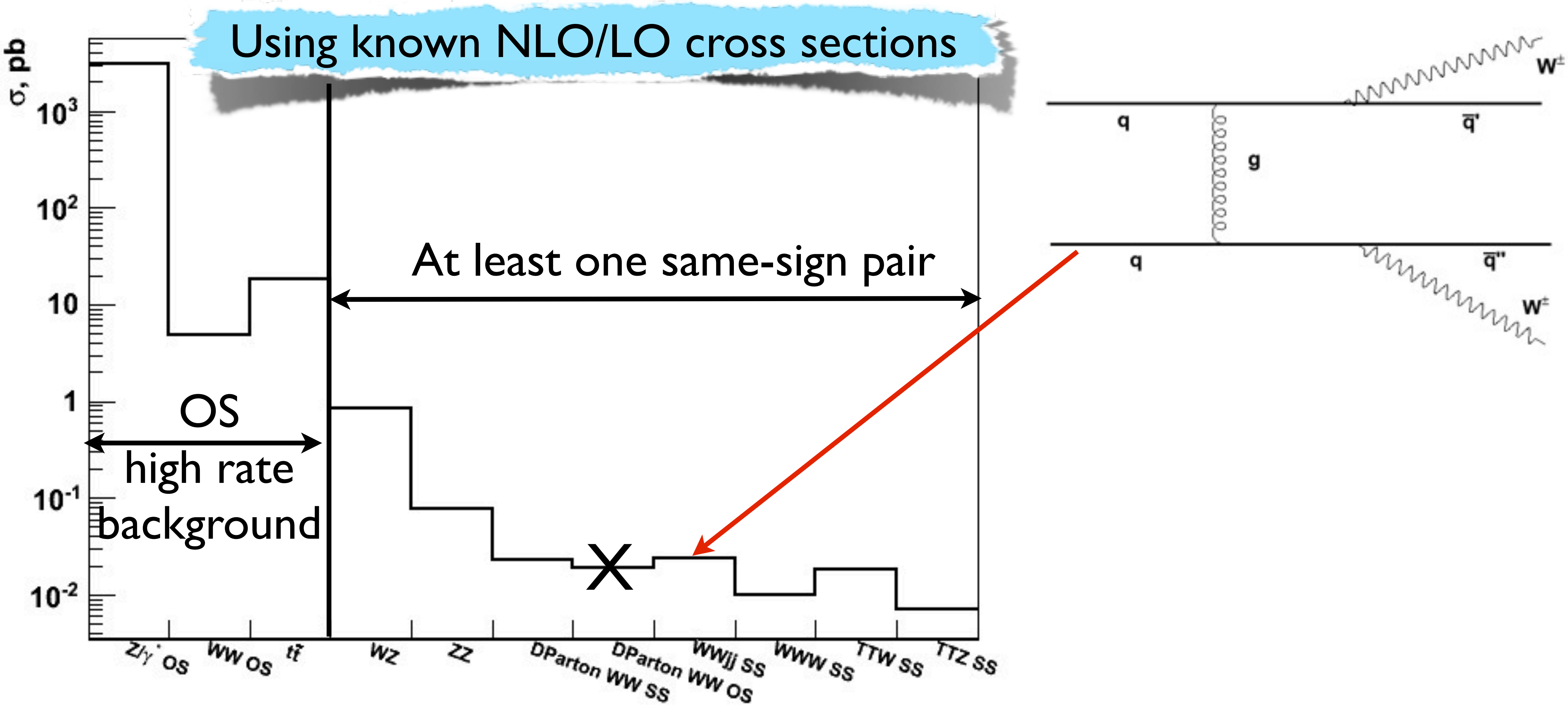
- A jet is a jet is a jet
  - ✓ Isolation distribution is about the same for all kind of jets leading to an isolated lepton
    - Including b→ e/μ
- **Step 1**: measure [(loosely isolated)→ (isolated)] lepton probability in multijet events with just one lepton. Try alternative loose selections





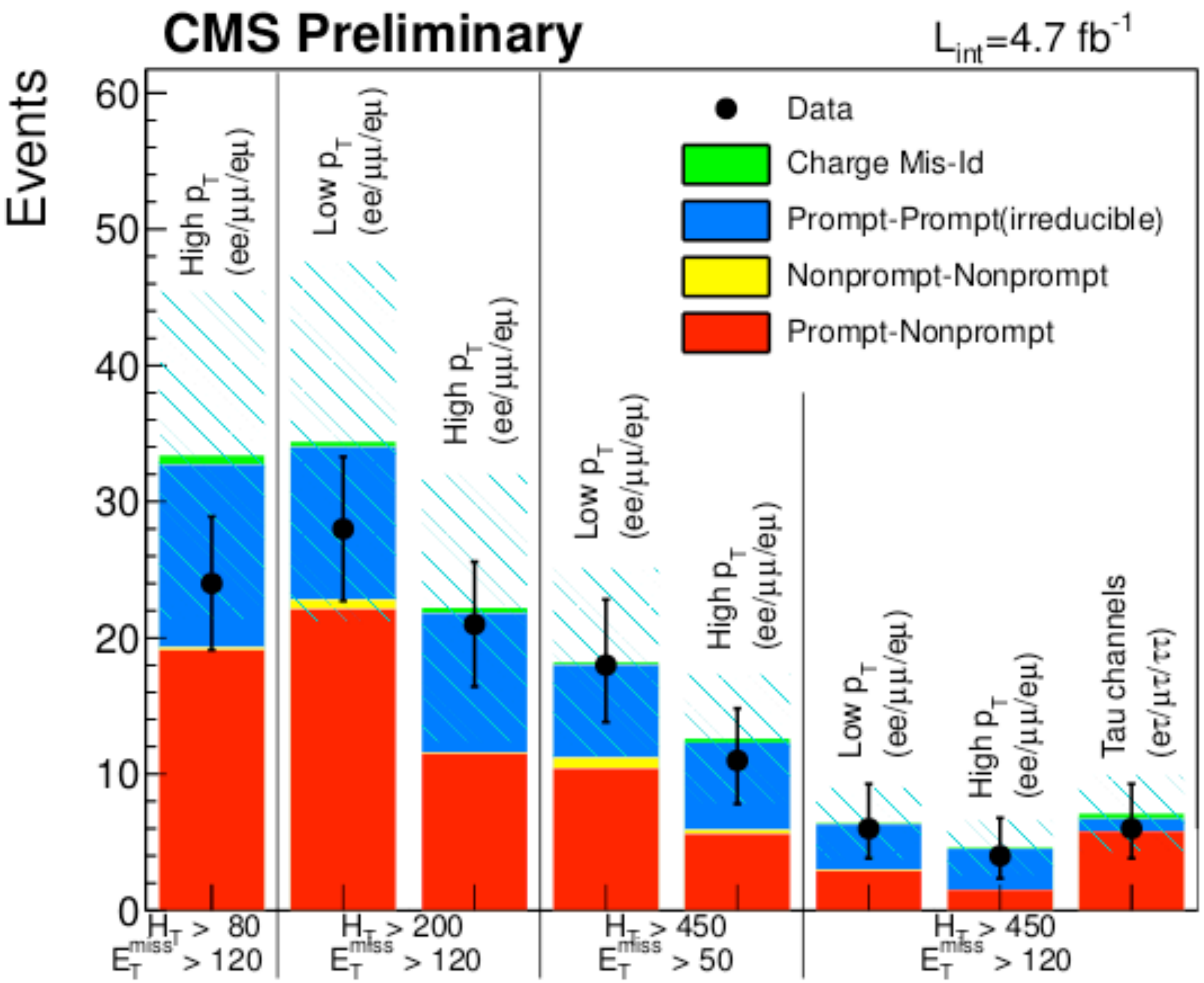
- **Step 2**: relax dilepton selections to the looser isolation in step 1, scale the number of loose leptons using probability from step 1

Same-sign dileptons in SM



- In SM only W and Z boson decays are of any interest
- WZ and ZZ above have extra lepton ==> extra Z rejected for SS analysis
- TTW and TTZ
  - ✓ Note, these naturally have 2 b-quarks

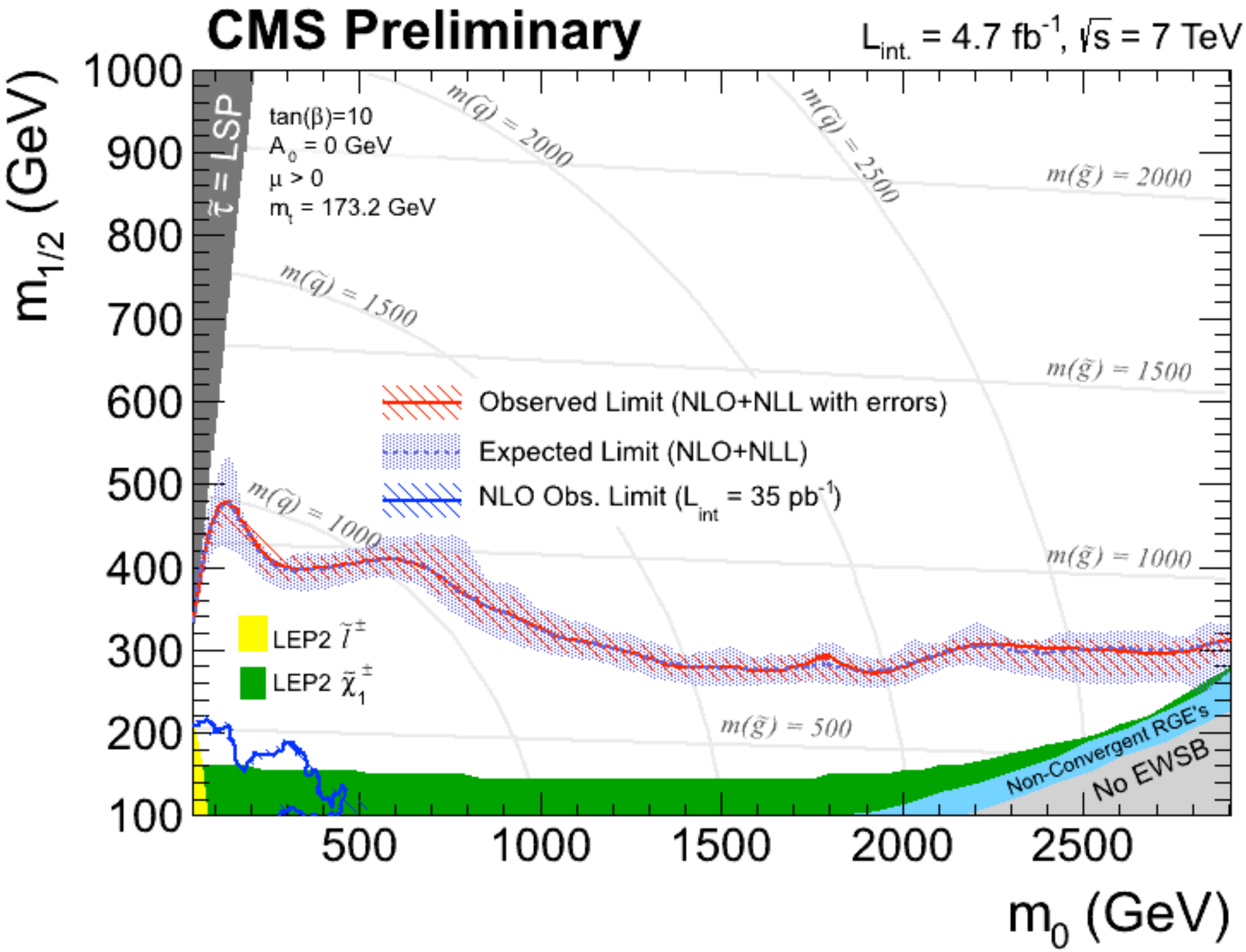
SS dileptons: results (I)



Region	Mode or p_T threshold			Total	UL 95% CL
	$p_T^{\ell 1,\ell 2} > 20, 10$ GeV				
	ee	$\mu\mu$	$e\mu$		
1	6.7 ± 2.7	8.3 ± 3.1	18.3 ± 6.9	33.2 ± 12.0	
	5	7	12	24	14.0
2	4.2 ± 1.7	5.9 ± 2.3	11.9 ± 4.5	22.1 ± 9.8	
	4	6	11	21	16.3
3	3.7 ± 1.5	3.0 ± 1.2	5.8 ± 2.3	12.5 ± 4.7	
	4	2	5	11	9.9
4	1.1 ± 0.8	1.1 ± 0.6	2.5 ± 1.1	4.6 ± 2.0	
	1	0	3	4	6.1
	$p_T^{e,\mu} > 10, 5$ GeV				
	ee	$\mu\mu$	$e\mu$		
2	4.3 ± 1.7	13.9 ± 6.0	16.1 ± 6.2	34.3 ± 13.2	
	4	10	14	28	17.4
3	3.3 ± 1.5	6.3 ± 2.8	8.6 ± 3.5	18.2 ± 6.9	
	4	6	8	18	14.3
4	1.0 ± 0.8	2.3 ± 1.2	3.1 ± 1.4	6.4 ± 2.6	
	1	2	3	6	7.4
	$p_T^{\tau,e,\mu} > 15, 10, 5$ GeV				
	$e\tau$	$\mu\tau$	$\tau\tau$		
4	2.6 ± 1.0	4.4 ± 2.2	0.0 ± 0.1	7.1 ± 2.8	
	1	5	0	6	7.1

- Good agreement in all selections
  - ➡ Set upper limits on possible signal

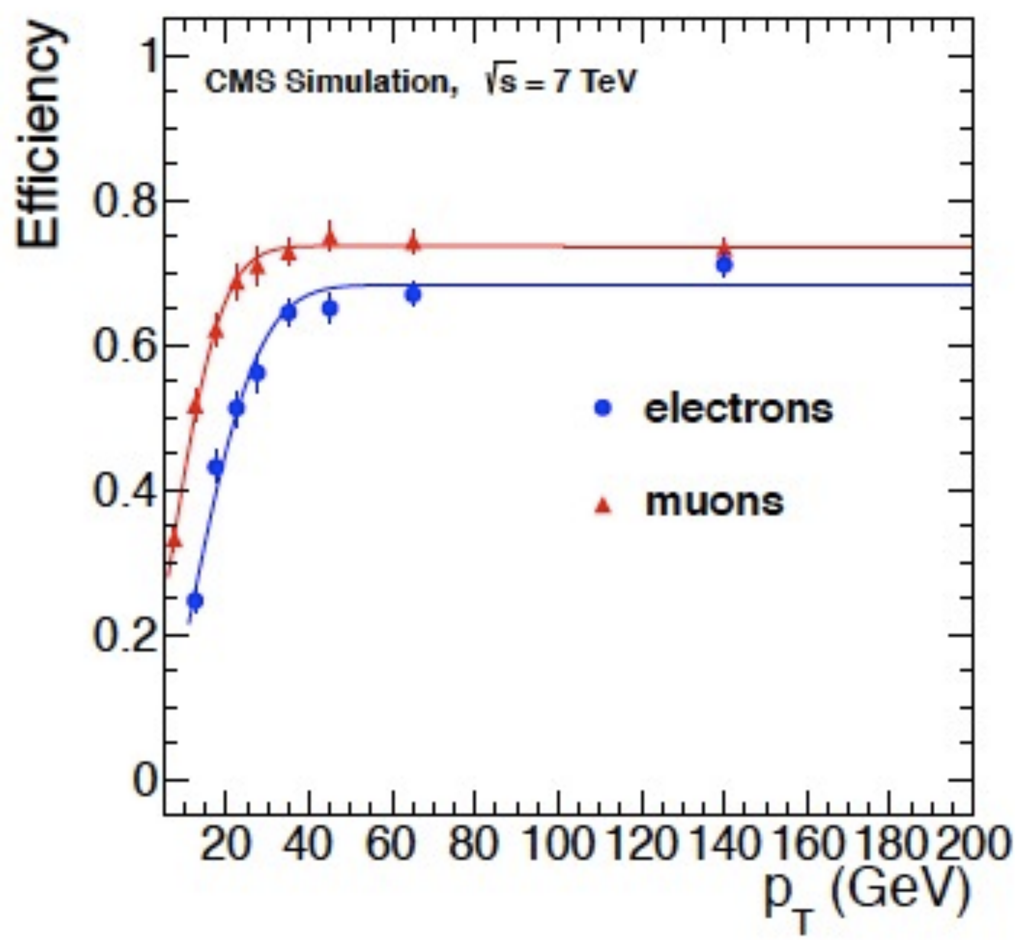
SS dileptons: interpretation in cMSSM

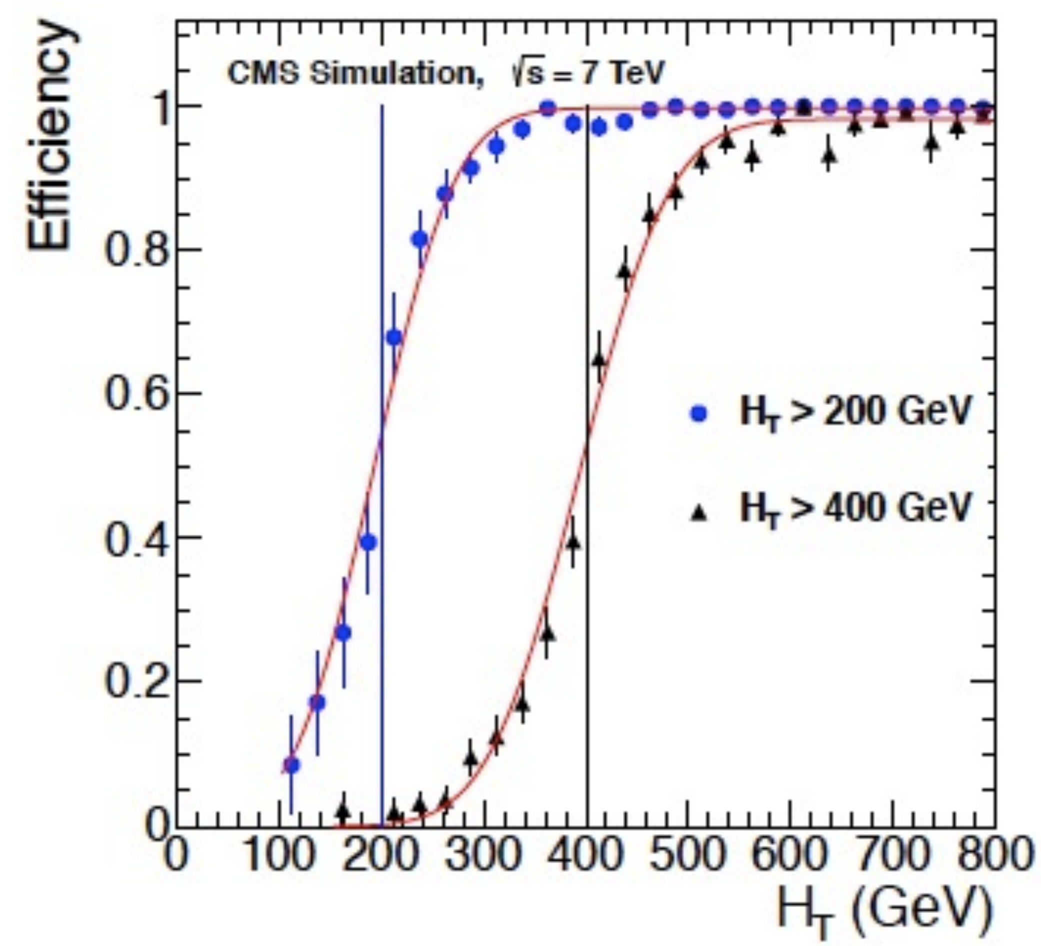


- Extend to about 1 TeV in gluino/squark masses

Outreach

- The interpretation on last page is quite specific and implies someone had to use the full detector simulation/response in analysis
- We provide information (efficiency/response curves) for each given selection as a function of generator level (hard scattering) kinematics





- Can be used to emulate selection efficiency for any model

Same-sign dilepton analyses

- **Inclusive analysis with SS+jets+MET CMS-PAS-SUS-11-010**
- Pre-selections
- Backgrounds
  - ✓ Sources with genuine lepton <== from Simulation
  - ✓ jet→ misidentified lepton <== from Data
  - ✓ charge mis-ID: opposite-sign→ same-sign <== calibrate in Data
- Slice it up: signal regions
- Interpretation in cMSSM
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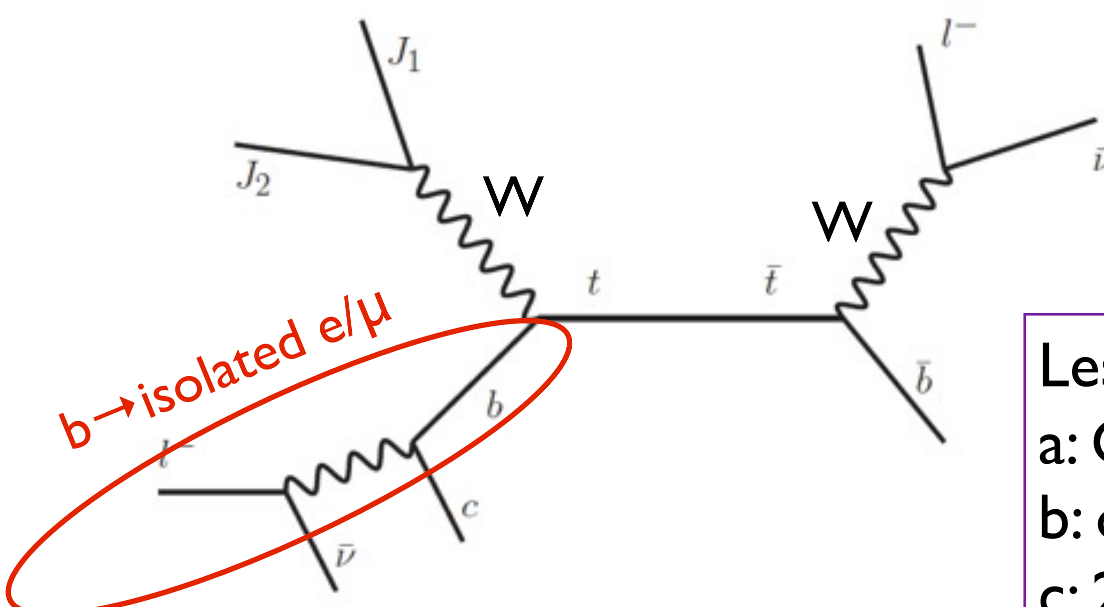
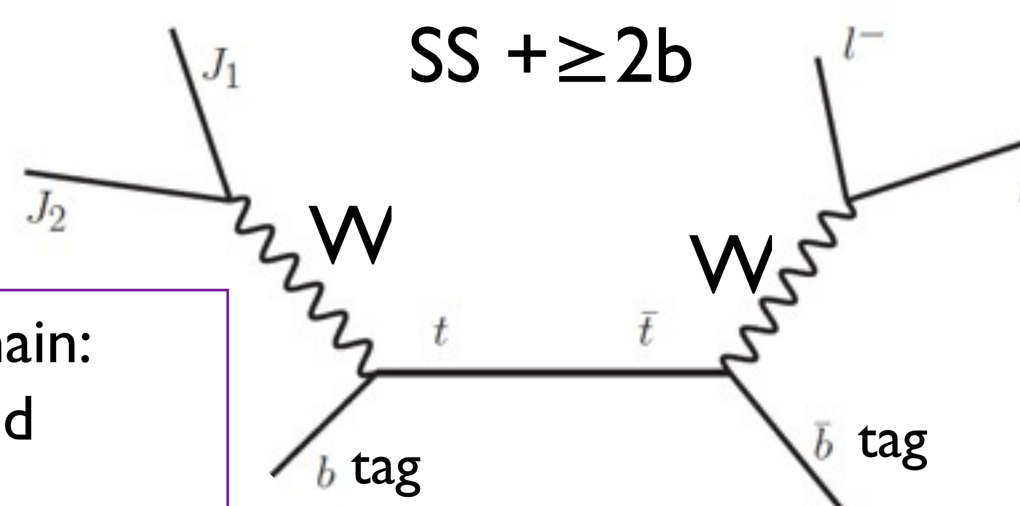
- **Analysis with SS+bjets+(jets)+MET CMS-PAS-SUS-11-020**
- Winning over jet→ misID lepton background
- Slicing and interpretation

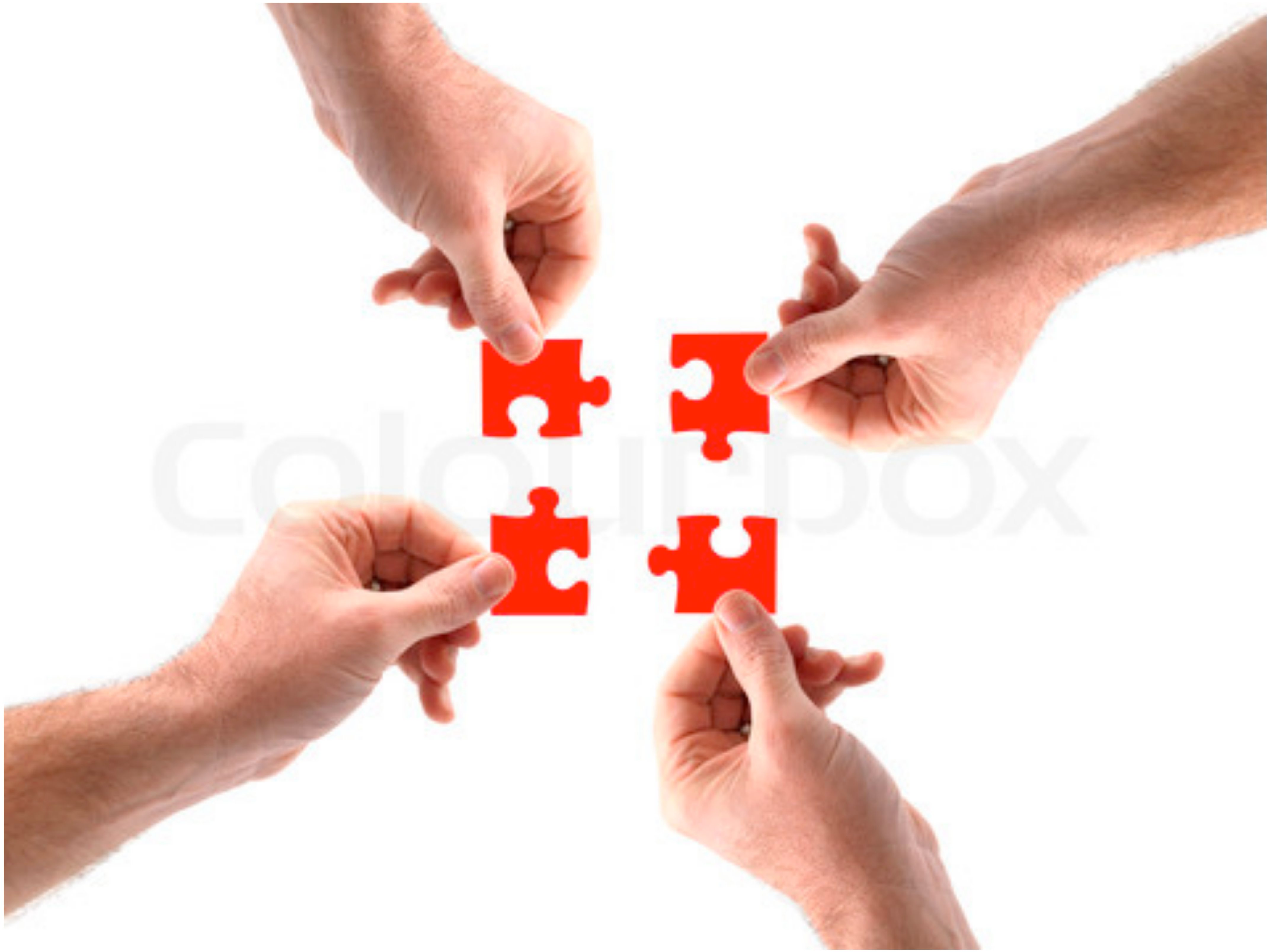
SS dileptons: just add some bees

- Recall: many SUSY final states "naturally" have 3rd generation (s)quarks
- Improve sensitivity by further rejecting ttbar b→e/μ background
- The solution is simple: ask for two b-tagged jets
  - ✓ Now b-jet can't be both a source of a lepton and a b-tag
    - ◉ Compared to signal/real same-sign bgds, this background is reduced by about x10!
    - ◉ ttW+ttZ now about 50% of all background (still too small to observe in 2011)
- This selection works for a slew of signal modes in final states with multiple top quarks or b+W



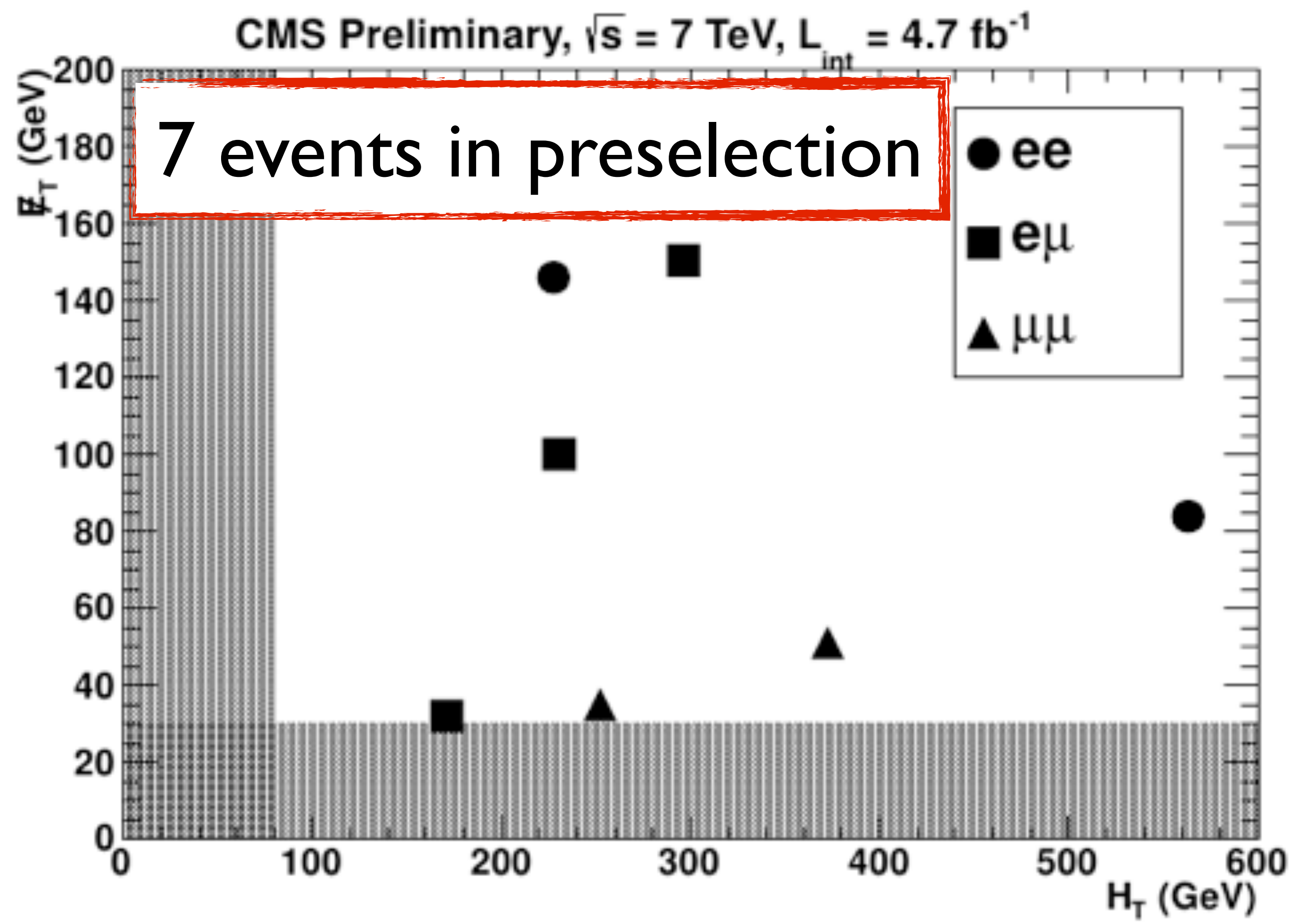
Less frequent bgds remain:
a: OS → SS charge misid
b: other jet → e/μ fake
c: 2-strike: (b→ e/μ)X(j→ btag)





SS with bees: preselect, slice and dice

- Start from the inclusive SS analysis
- Use only e/μ mix
- Require both leptons pt>20 GeV, now that most signal is from Ws
- Apply tighter cut on isolation
- … after the 2 b-tag requirement, HT>80 GeV, and MET>30 GeV

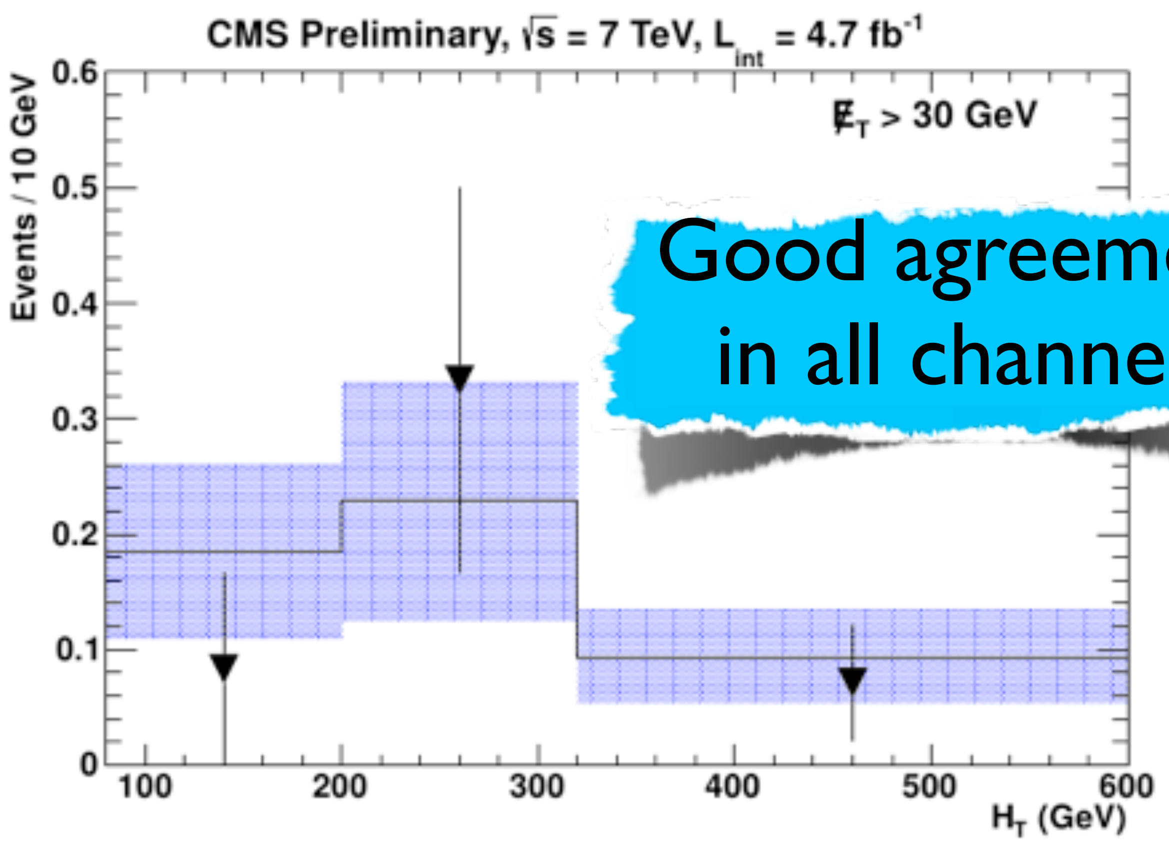


- Slice-n-dice
  - ✓ 1: HT>80 GeV; MET> 30 GeV
  - ✓ 2: HT>80 GeV; MET> 30 GeV , only ++
    - uu→ ()→ tt or alike
  - ✓ 3: HT>200 GeV; MET>120 GeV
  - ✓ 4: HT>200 GeV; MET> 50 GeV
  - ✓ 5: HT>320 GeV; MET> 50 GeV
  - ✓ 6: HT>320 GeV; MET>120 GeV
  - ✓ 7: HT>200 GeV; MET>120 GeV; 3+ btags

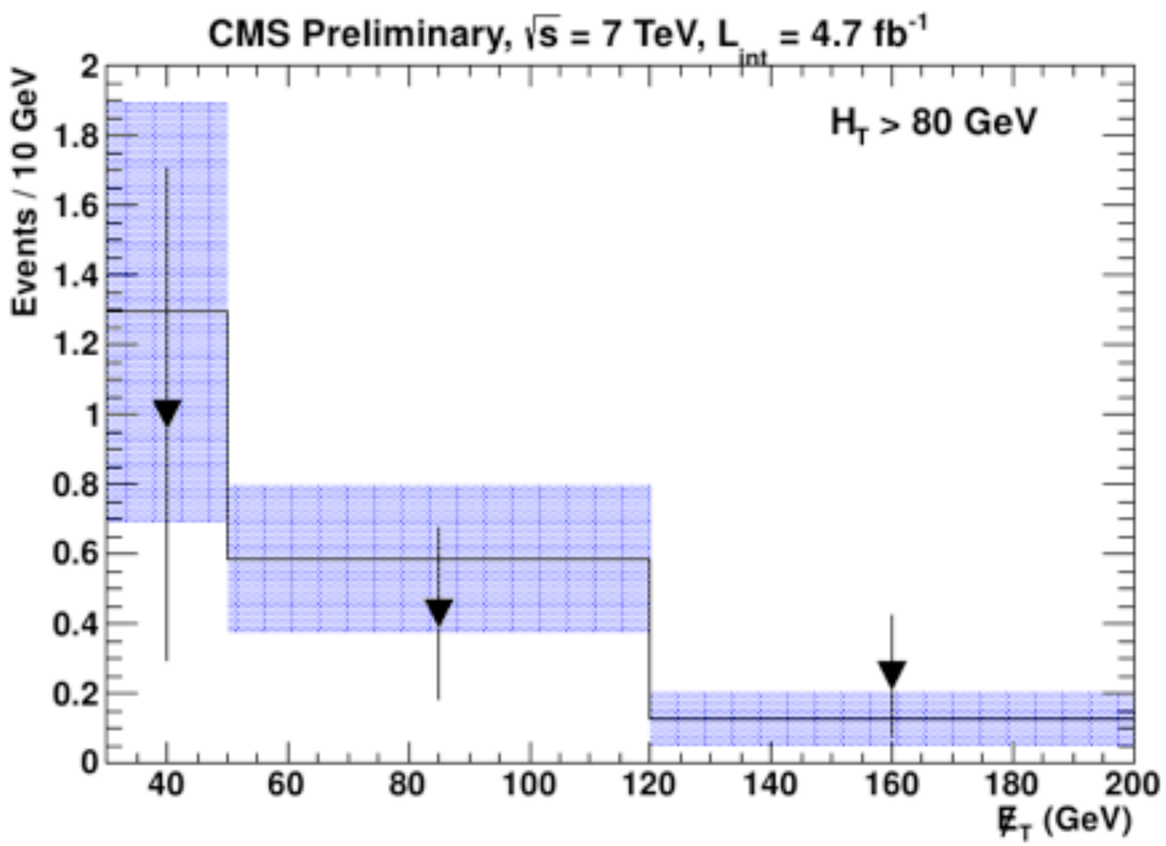
➡ Compared to inclusive SS, less backgrounds → looser HT cut is feasible

SS with bees: results

	SR1	SR2	SR3	SR4	SR5	SR6	SR7
No. of jets	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3
No. of btags	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3
Lepton charges	$++/--$	$++$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$
$\not{E}_T$	≥ 30 GeV	≥ 30 GeV	≥ 120 GeV	≥ 50 GeV	≥ 50 GeV	≥ 120 GeV	≥ 50 GeV
H_T	≥ 80 GeV	≥ 80 GeV	≥ 200 GeV	≥ 200 GeV	≥ 320 GeV	≥ 320 GeV	≥ 200 GeV
q-flip BG	1.1 ± 0.2	0.5 ± 0.1	0.05 ± 0.01	0.3 ± 0.1	0.12 ± 0.03	0.026 ± 0.009	0.008 ± 0.004
Fake BG	3.4 ± 2.0	1.8 ± 1.2	0.32 ± 0.50	1.5 ± 1.1	0.81 ± 0.78	0.15 ± 0.45	0.15 ± 0.45
Rare SM BG	3.2 ± 1.6	2.1 ± 1.1	0.56 ± 0.28	2.0 ± 1.0	1.04 ± 0.52	0.39 ± 0.20	0.11 ± 0.06
Total BG	7.7 ± 2.6	4.4 ± 1.6	0.9 ± 0.6	3.7 ± 1.5	2.0 ± 0.9	0.6 ± 0.5	0.3 ± 0.5
Event yield	7	5	2	5	2	0	0
N_{UL} (12% unc.)	7.4	6.9	5.2	7.3	4.7	2.8	2.8
N_{UL} (20% unc.)	7.7	7.2	5.4	7.6	4.8	2.8	2.8
N_{UL} (30% unc.)	8.1	7.6	5.8	8.2	5.1	2.8	2.8



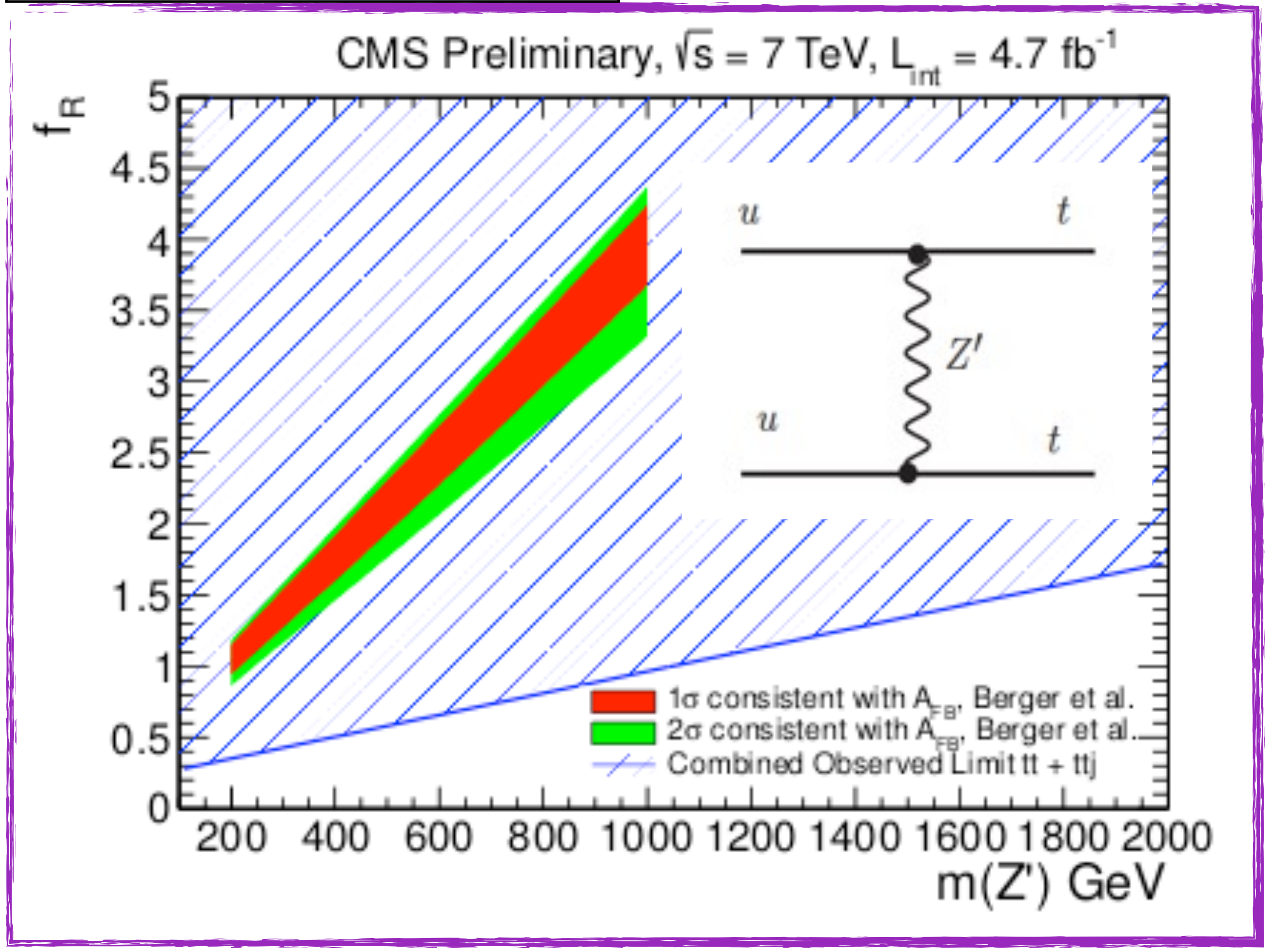
Good agreement in all channels



SS with bees: interpretation

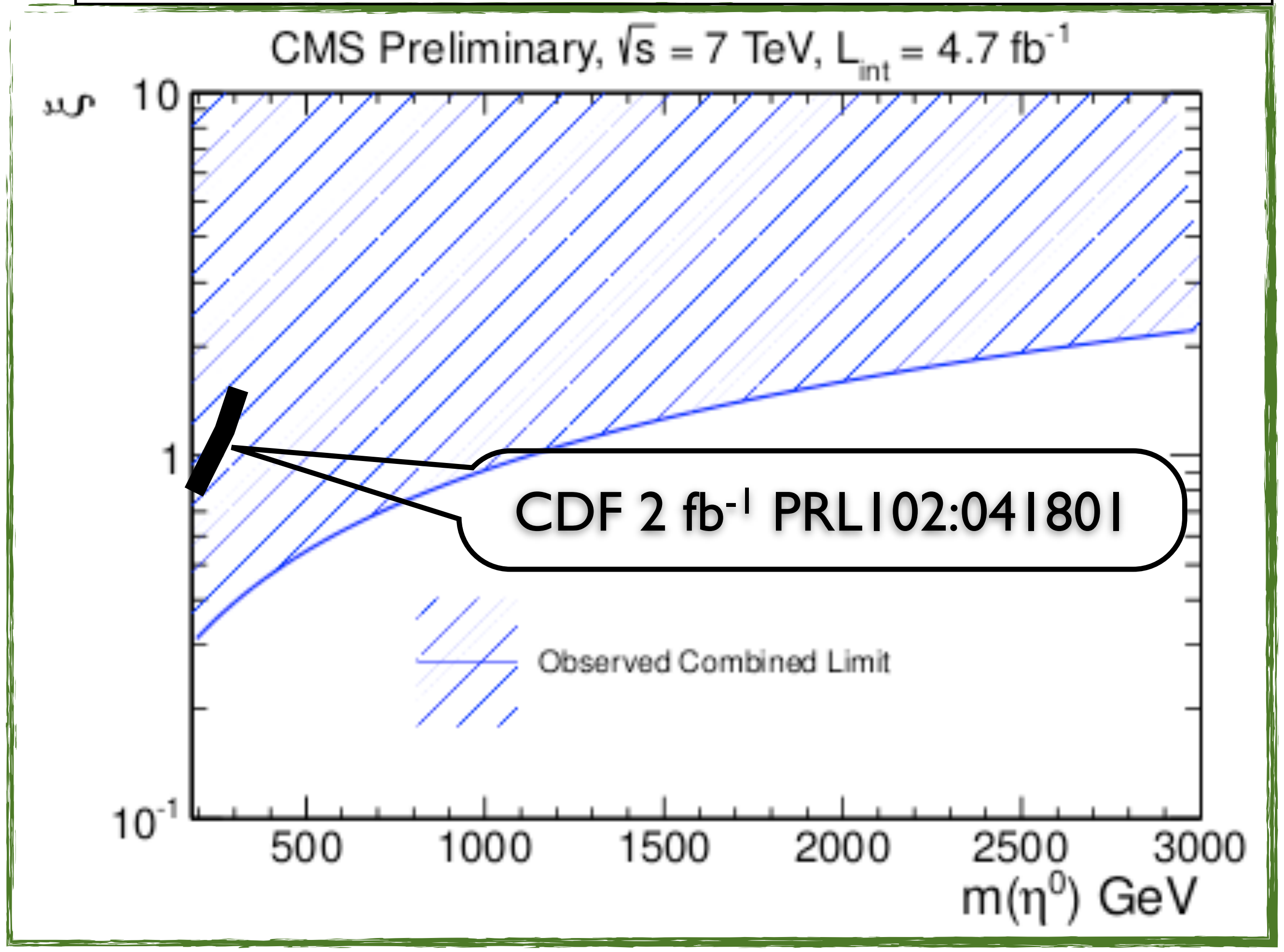
- Same-sign top-quark pair production: pp → tt
  - ✓ Use region 2 (HT>80 GeV, MET>30 GeV) with ++: 5 observed vs 4.4±1.6 expected
- Two models with similar final state kinematics

Z' with uZt_R coupling



Region consistent with Tevatron top A_{FB} is excluded with a large margin

SU(2)-doublet scalar Φ with $u\Phi t_R$ coupling

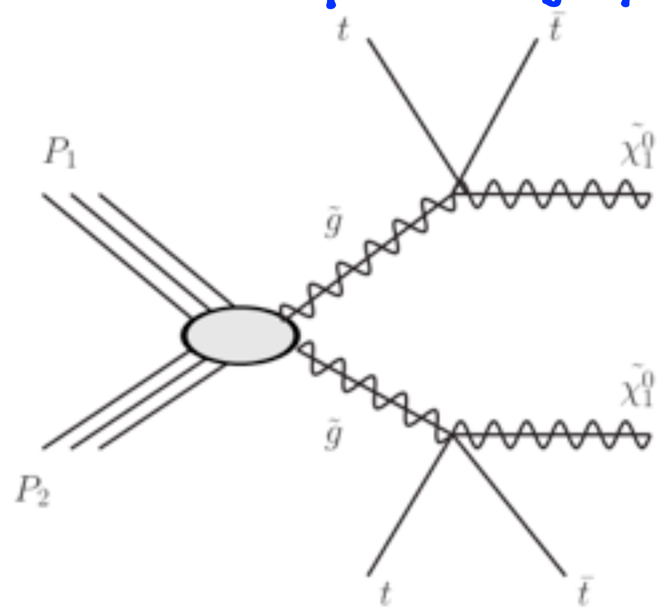


Substantially improved constraints

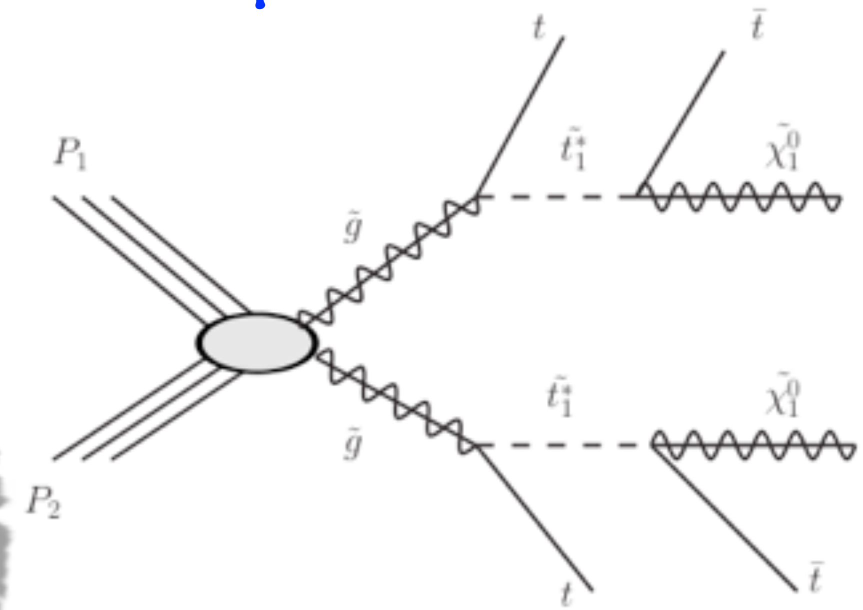
SS with bees: SUSY stop production

- Consider two cases of gluino pair production: $pp \rightarrow \tilde{g}\tilde{g} \rightarrow t\bar{t}t\bar{t}\tilde{\chi}_1^0\tilde{\chi}_1^0$

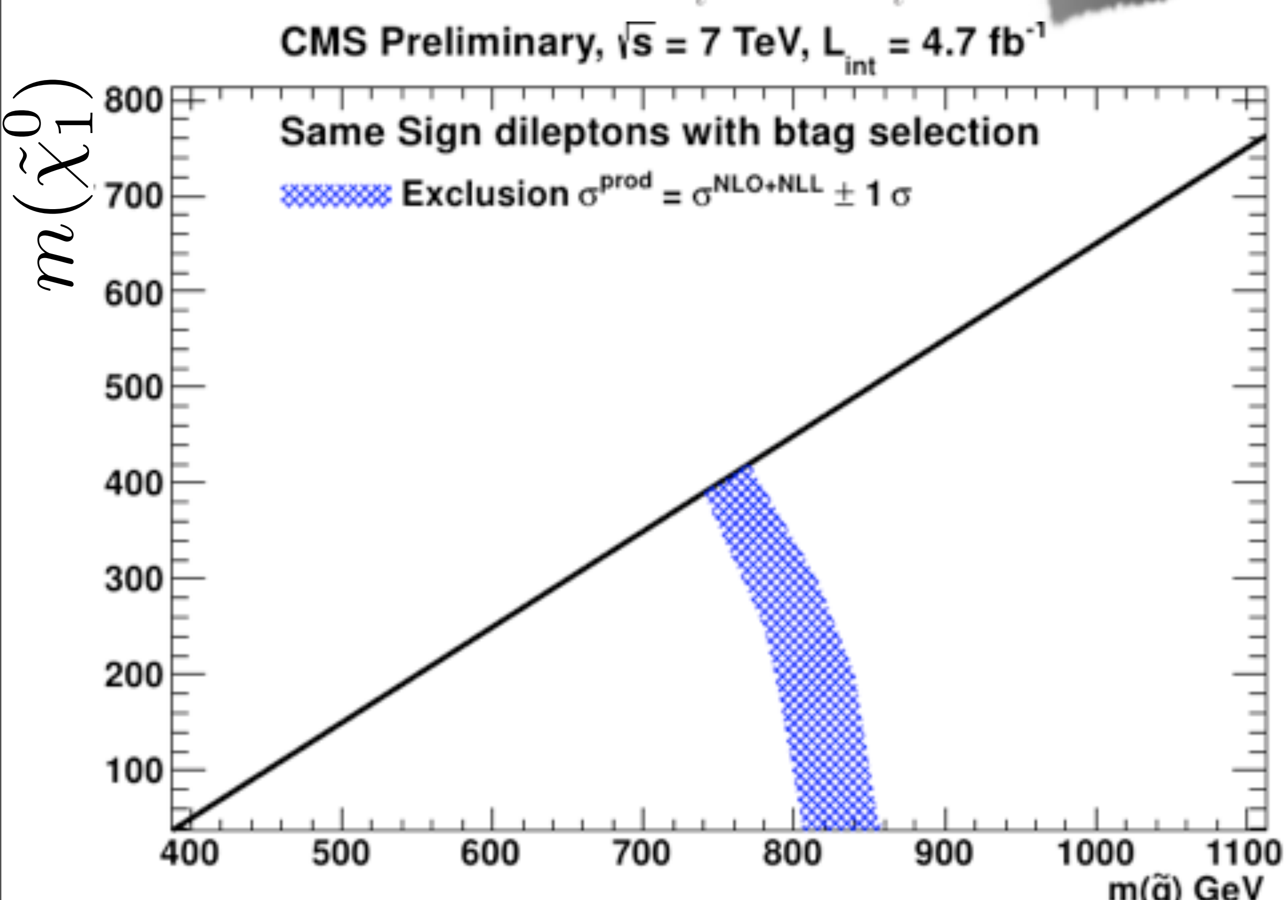
✓ A1: the stops are highly virtual

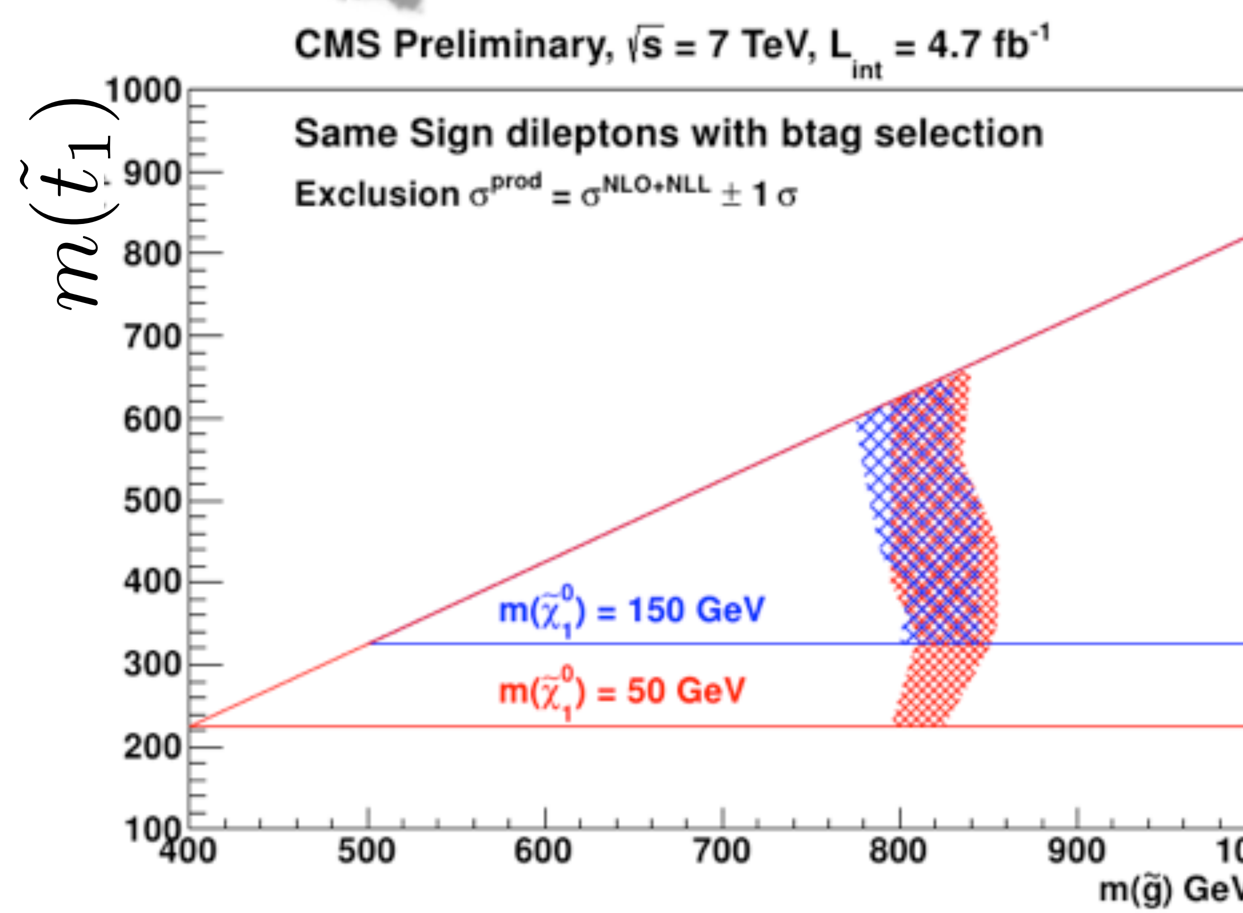


A2: the stops are on-shell



Gluinos below ~800 GeV are excluded

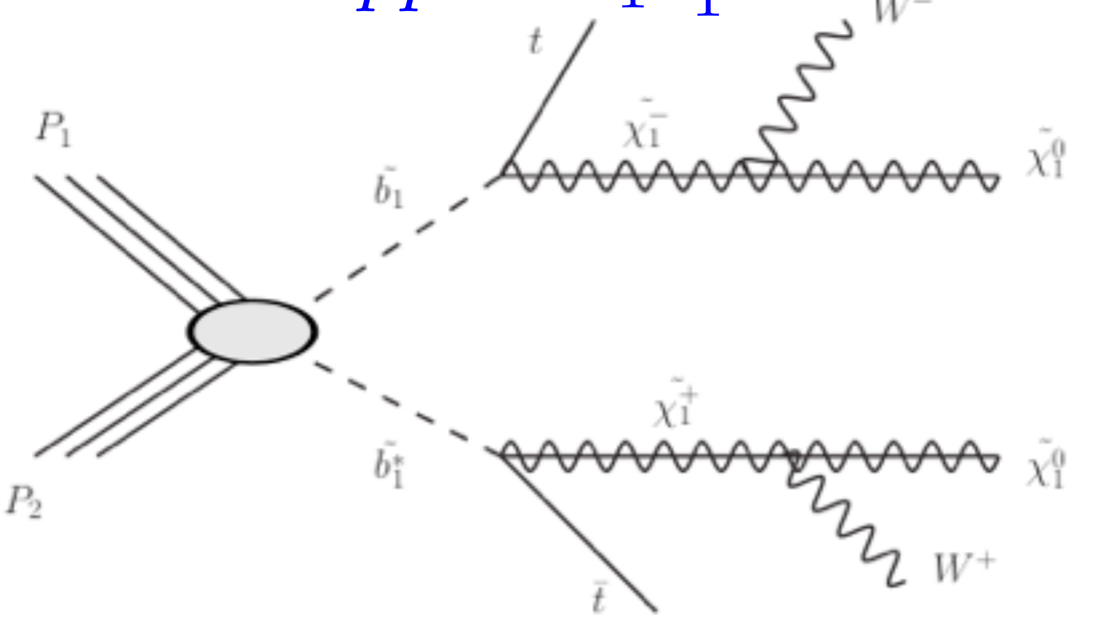




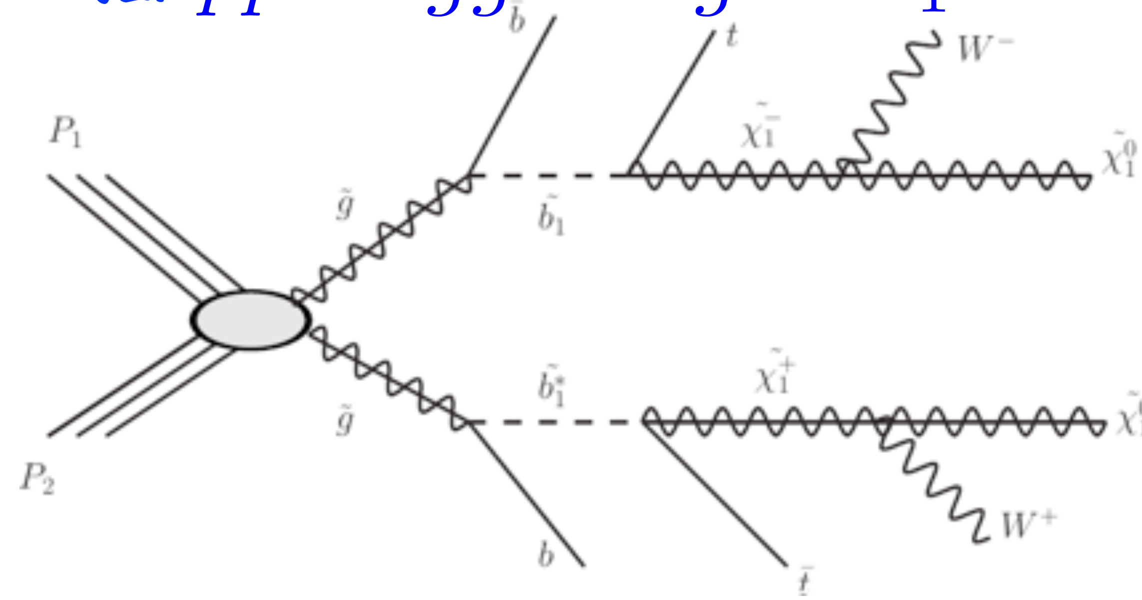
SS with bees: SUSY stop production

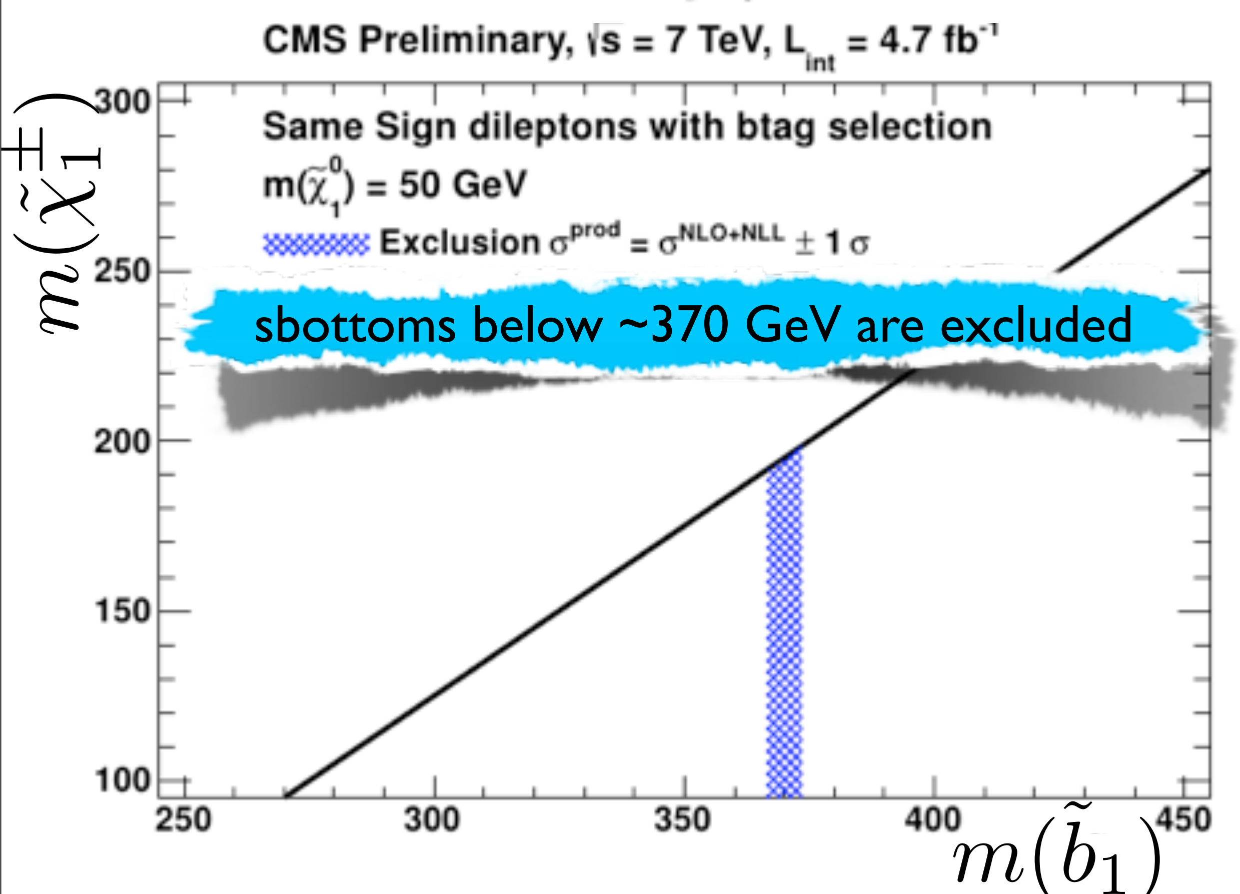
- $t\bar{t}W^+W^-\tilde{\chi}_1^0\tilde{\chi}_1^0$ final state via sbottoms $\tilde{b}_1 \to t(\tilde{\chi}_1^- \to W^-\tilde{\chi}_1^0)$

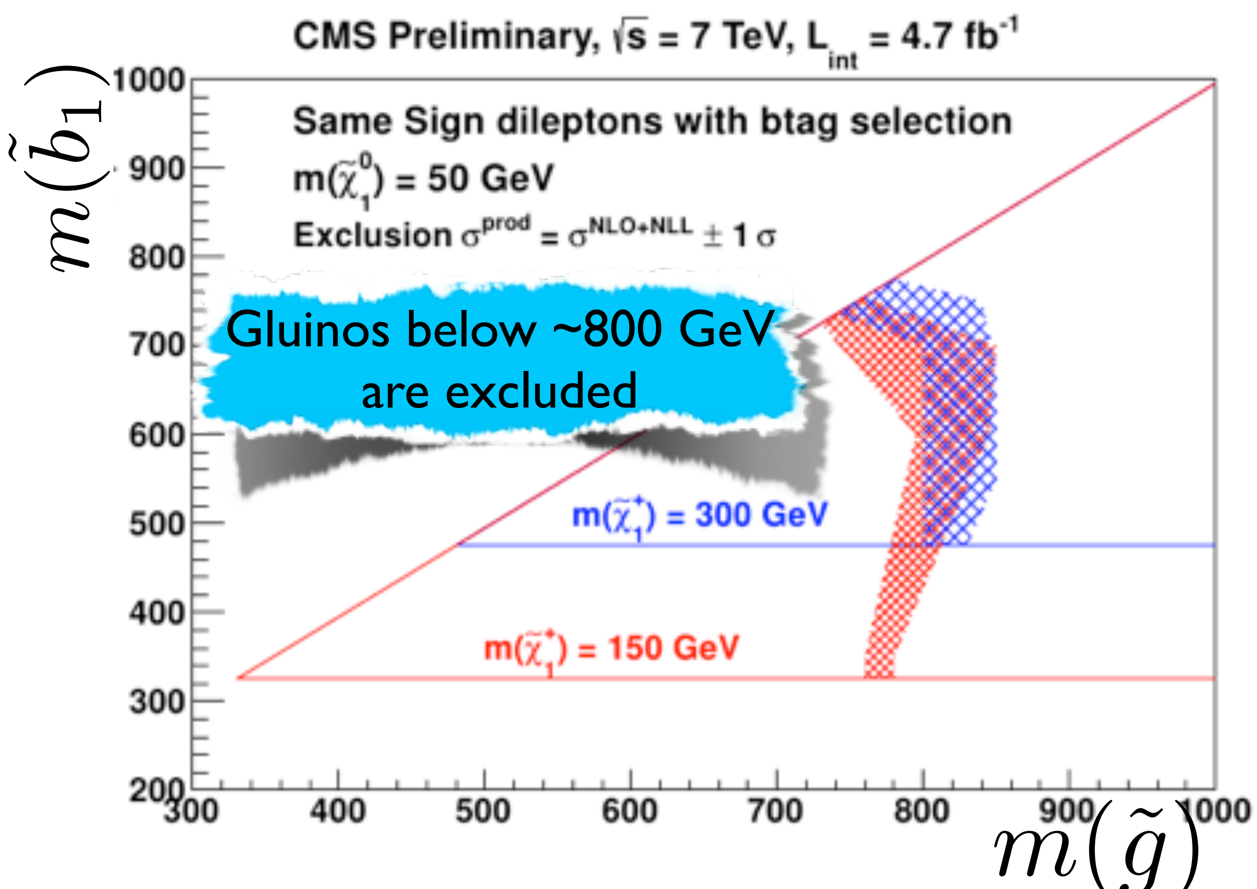
✓ B1: $pp \to \tilde{b}_1\tilde{b}_1^*$



B2: $pp \to \tilde{g}\tilde{g}$ $\tilde{g} \to \tilde{b}_1\bar{b}$







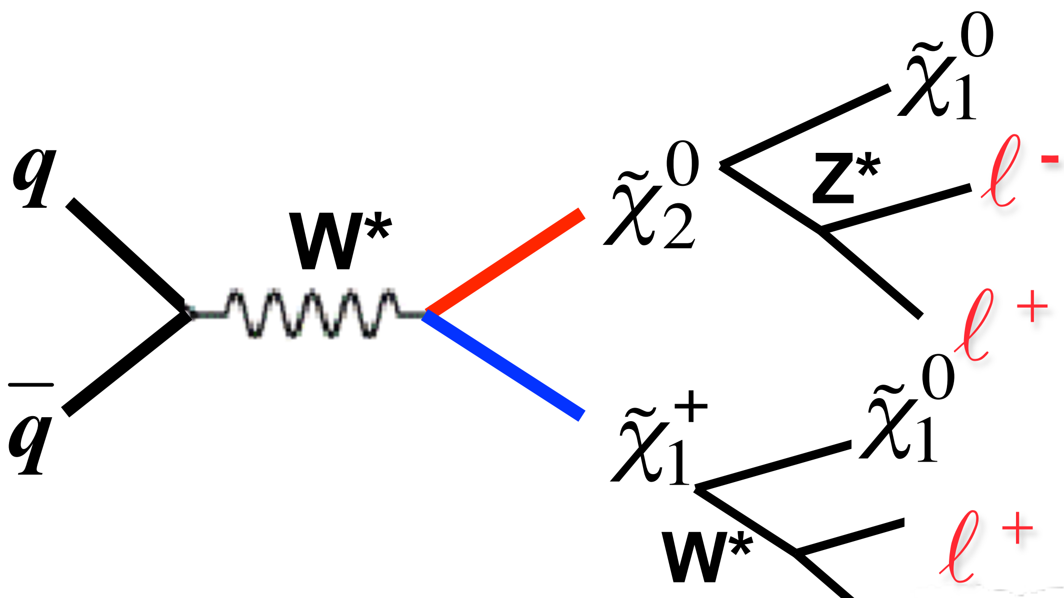
Multilepton SUSY searches

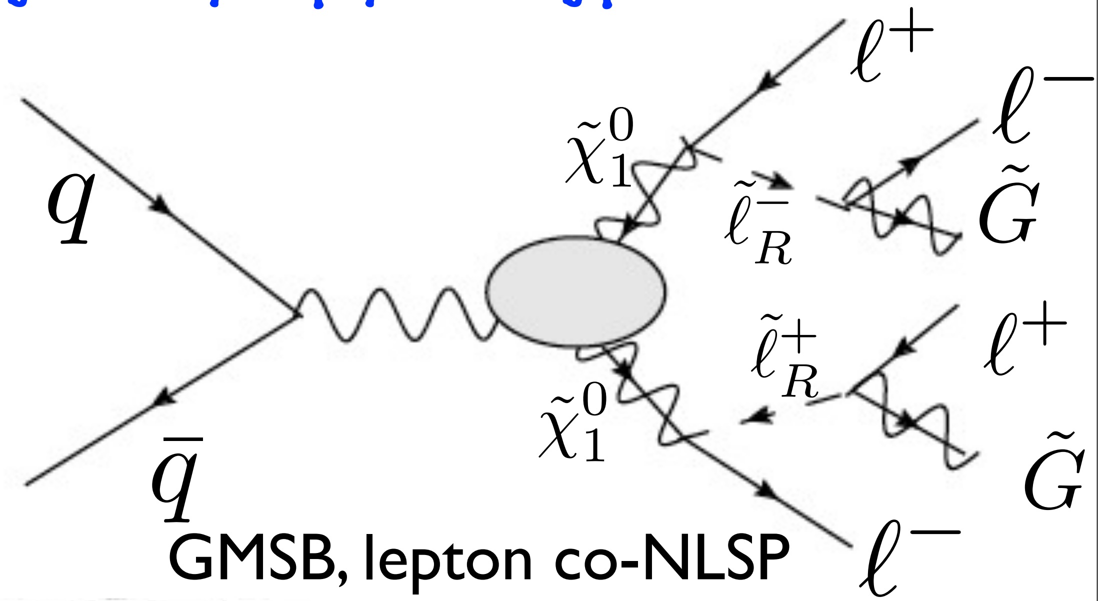
SUS-11-013/EXO-11-045

- Multilepton phase space
  - ✓ R-parity conserving (has LSPs) — slicing in HT and MET
  - ✓ R-parity violating (no LSPs) — slicing in ST = (HT + MET + leptonPt)
- Backgrounds highlights
  - ✓ Sources with genuine lepton <== from Simulation
  - ✓ jet→ misidentified lepton <== from Data and simulation
  - ✓ γ and γ^* asymmetric conversion <== from Data
- Results
- Interpretations, constraining SUSY phase space

Multilepton phase space

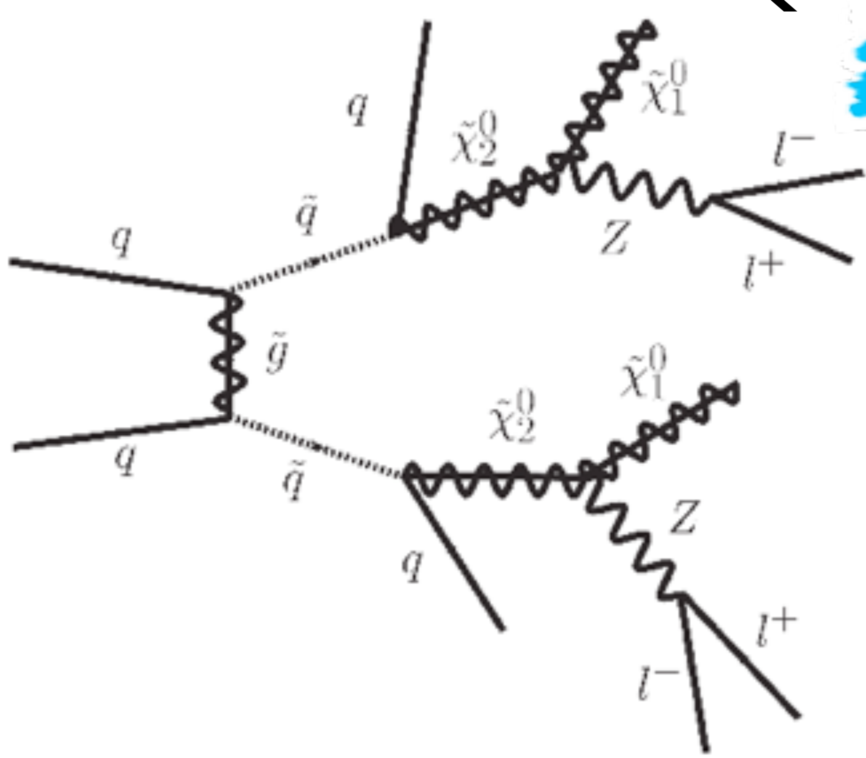
- Trilepton and quadlepton final states can be produced in BSM/SUSY
- Need to cover many options: with or without τ's, Z, MET, jets
  - ✓ $e/\mu/\tau_{trk}$ as low as pt>8 GeV, $\tau_{tk\pi 0}$ pt>15 GeV. Triggers may imply leading pt>20 GeV

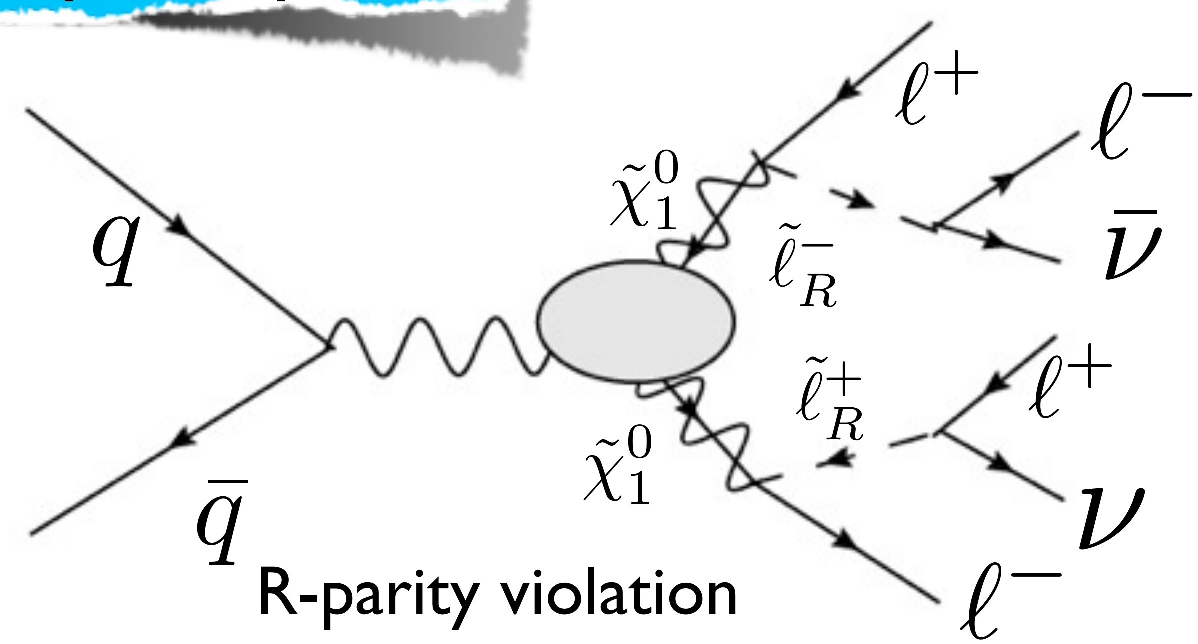




GMSB, lepton co-NLSP

Trileptons or quadleptons

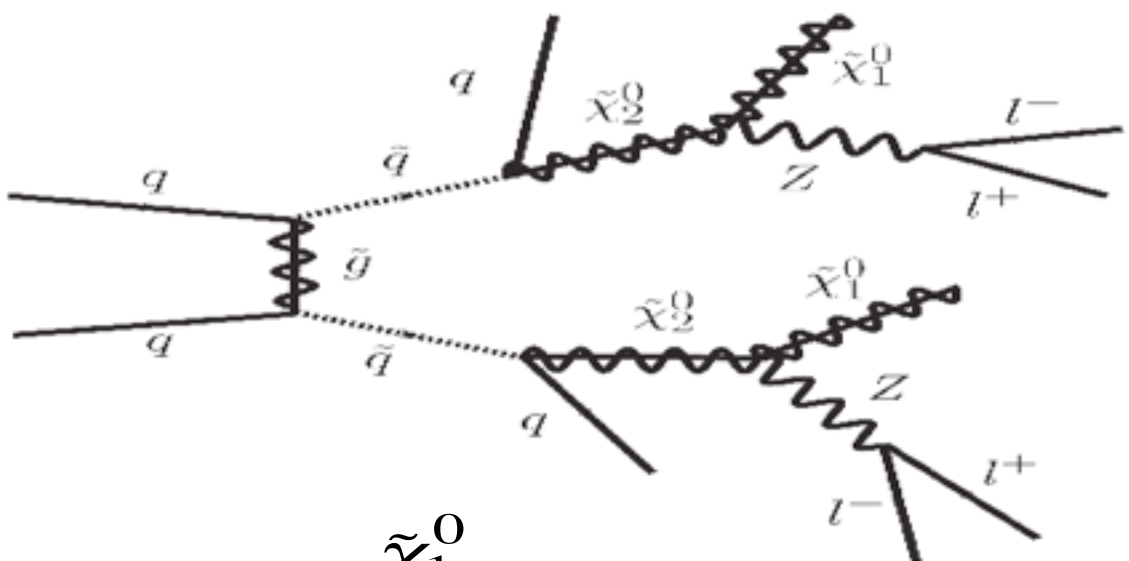


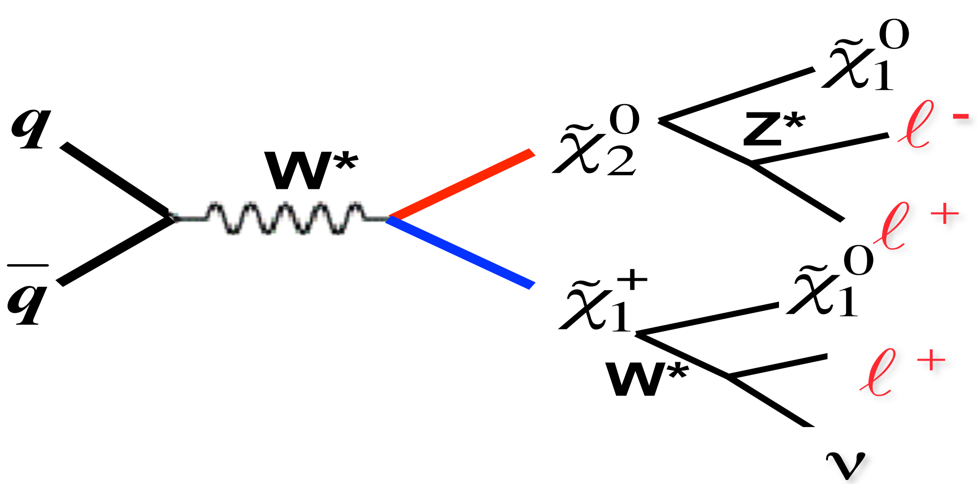


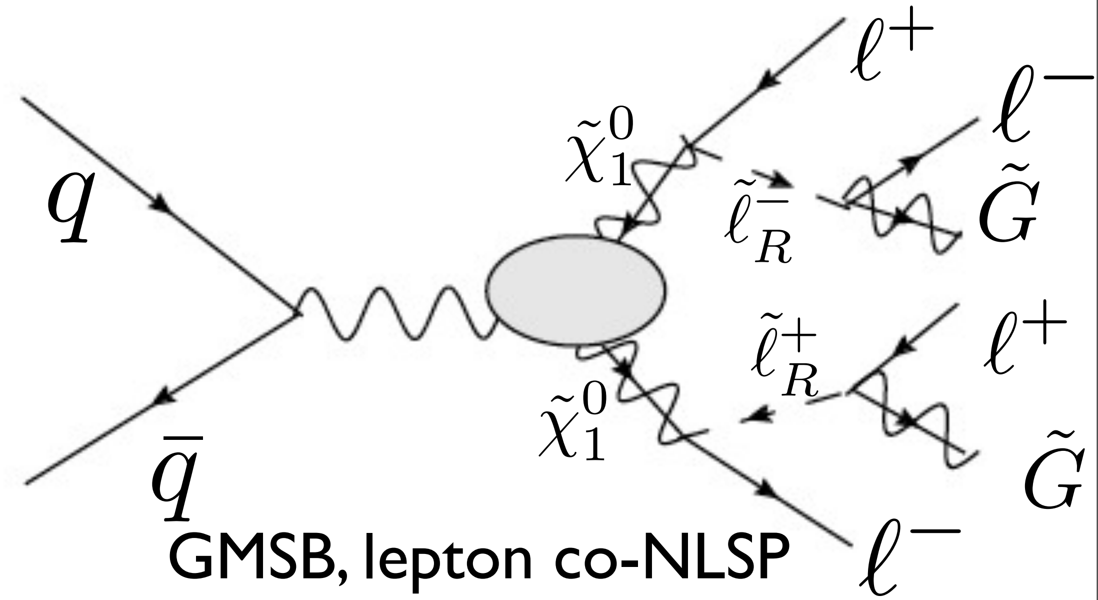
R-parity violation

Multileptons: R-parity

- R-parity conserving SUSY model points have extra MET from LSP
- Consider HT from jets and MET separately
  - ✓ HT low/high relative to 200 GeV; MET low/high relative to 50 GeV
- Slice-and-dice: put a 2x2 HT-MET on top of lepton/tau/Z categories
- Total of 52 exclusive (non-overlapping) final states used as signal regions
  - ✓ Combined coherently all together for SUSY model interpretations



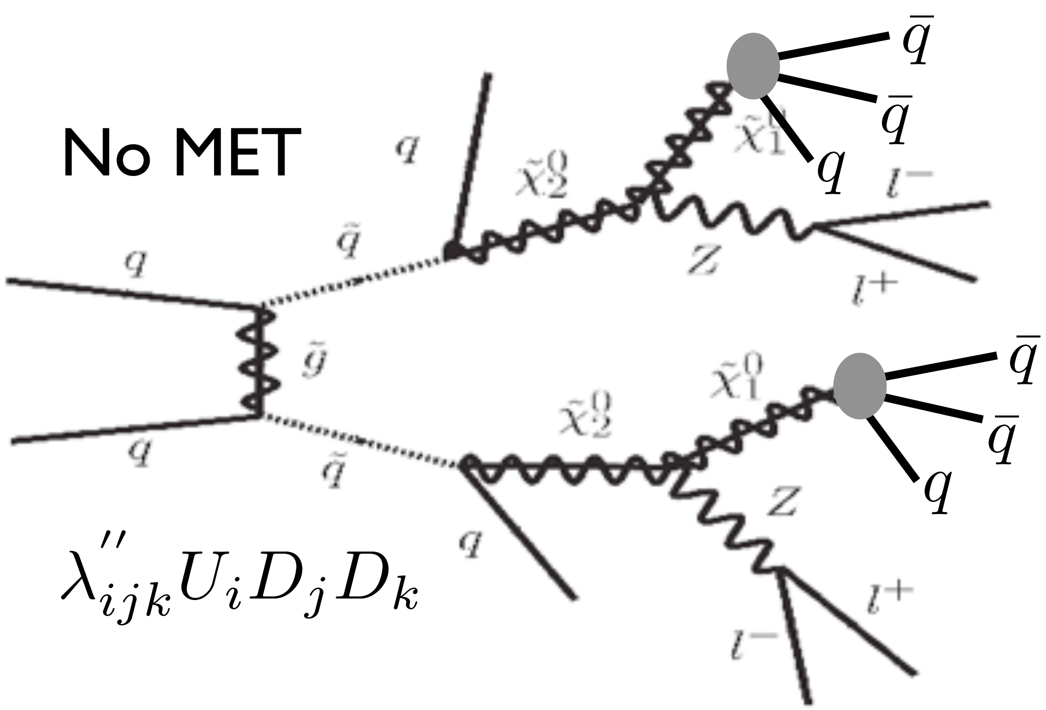




Multileptons: no R-parity

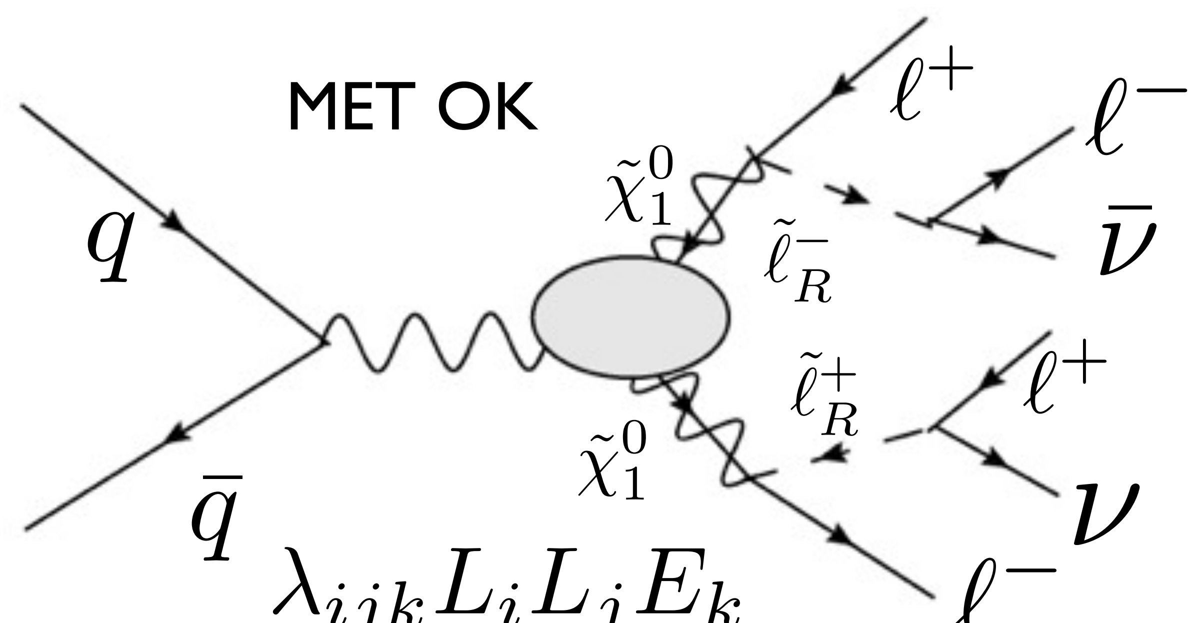
- R-parity violating scenarios may or may not have extra MET
  - ➡ To uniformly address this, use discriminator ST = HT + MET + leptonPt
    - ✓ Low-ST region ST< 300 GeV; medium-ST for ST 300— 600 GeV; high-ST for ST> 600 GeV
- Slice-and-dice, similar to R-parity conserving case
- Total of 54 exclusive (non-overlapping) final states
    - ✓ Combined coherently all together for SUSY model interpretations

No MET



$\lambda''_{ijk} U_i D_j D_k$

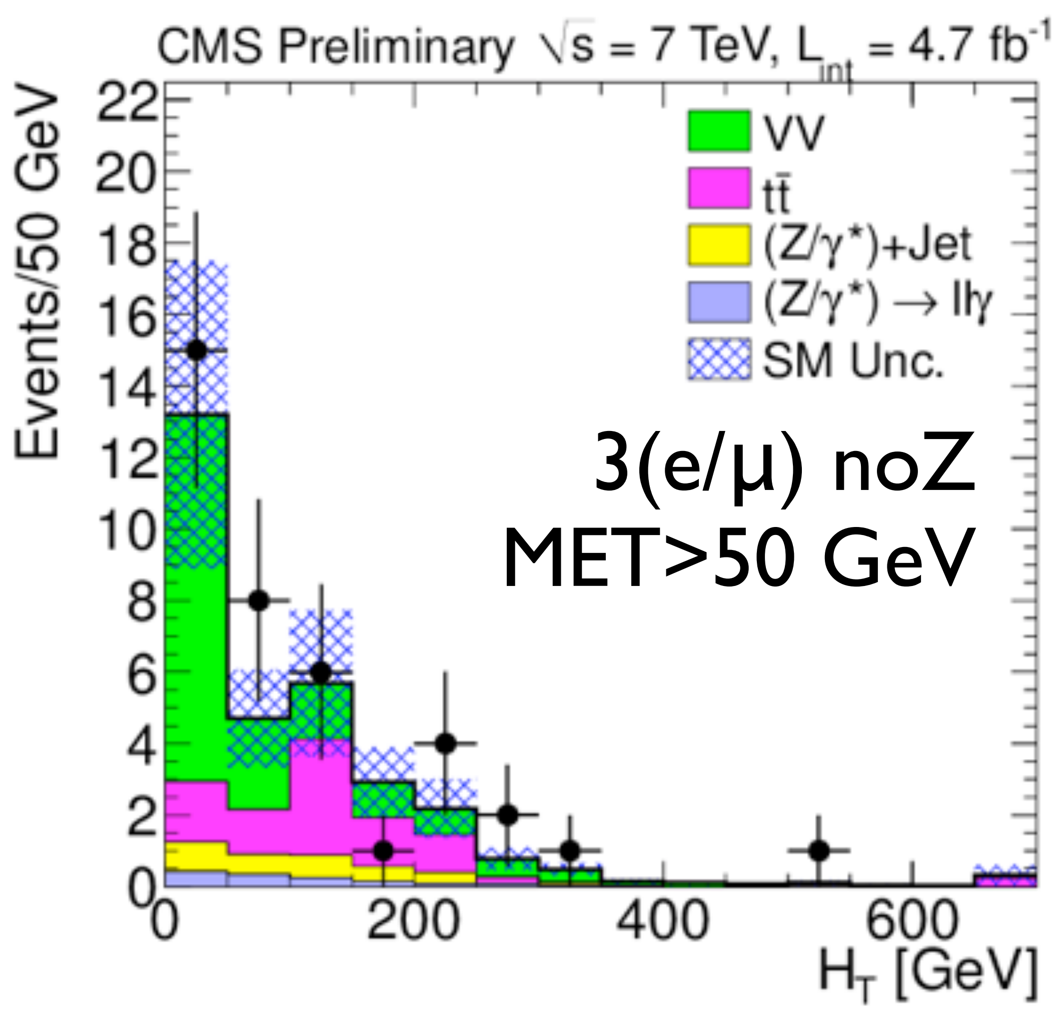
MET OK

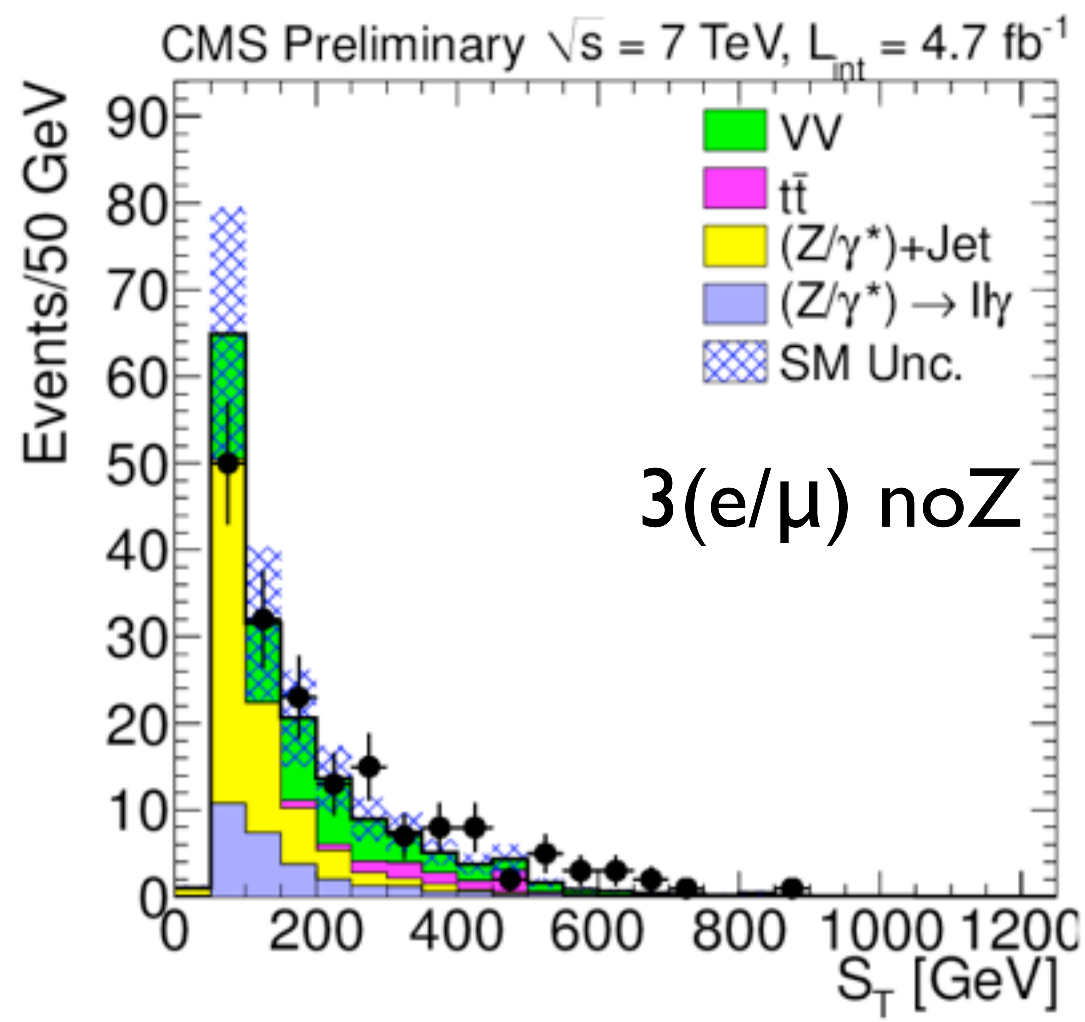


$\lambda_{ijk} L_i L_j E_k$

Multileptons: backgrounds

- Familiar set of backgrounds
  - ✓ Genuine multileptons from SM: dibosons (WZ/ZZ), multiboson, tt(W/Z)
    - ✳ **Use simulation, as in same-sign analysis**
  - ✓ jet → lepton misidentification
    - ✳ **Note: tt background is from simulation; rest from data-driven**
  - ✓ Z + asymmetric conversion: includes $\gamma^* \rightarrow ee/\mu\mu$





jet→ Lepton misID

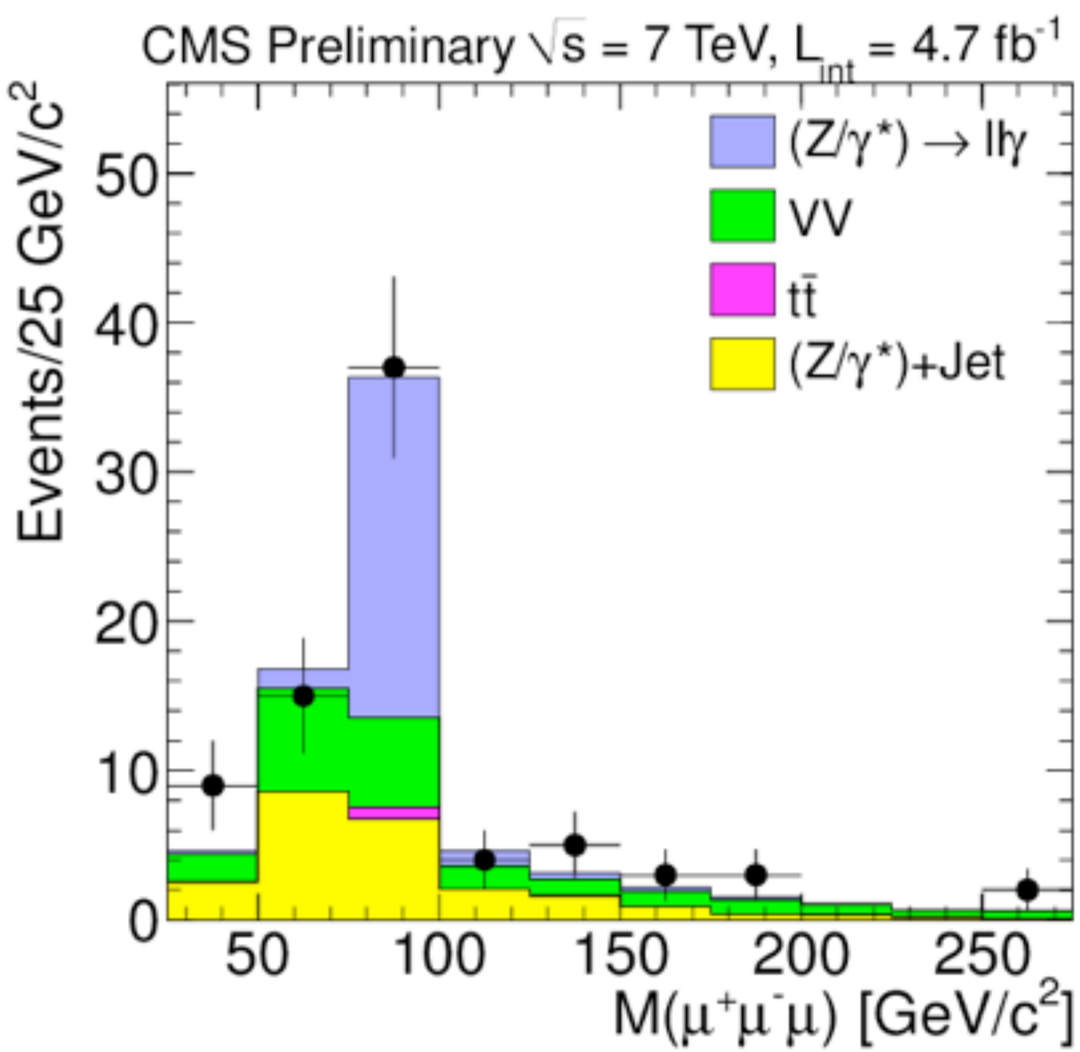
- Similar background to that in same-sign analysis
- The method to estimate differs notably for e/μ
  - ➡ A: tt is estimated directly from simulation
  - ➡ B: (tt overlap removed) jet → lepton background is estimated using *isolated tracks*
    - ✓ Step 1: measure [(isolated track)→ (isolated lepton)] probability in multijet data
    - ✓ Step 2: use 2 [or 3] lepton+(isolated track) sample X Prob to estimate this background

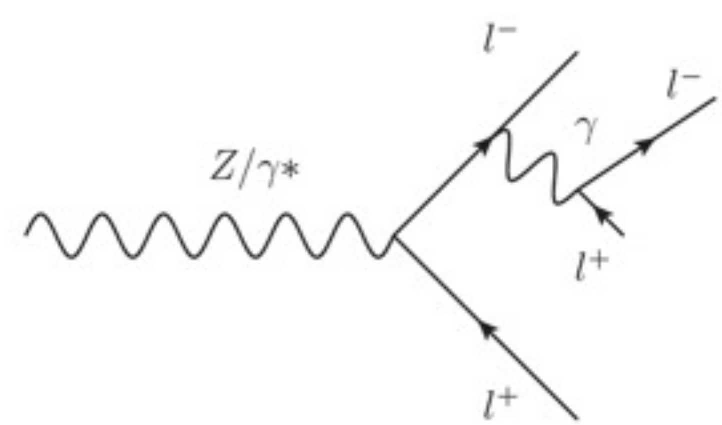
$\gamma^* \rightarrow$ ee/μμ background

- Noticeable source of trileptons (at least in low MET/HT)

- Use FSR Zγ data events for calibration
  - ✓ Ratio of μμγ vs μμe or μμμ near-Z
    - R(e) ≈ 1%,   R(μ) ≈ 0.4%

$$R = \frac{N_{\mu\mu e/\mu}(75\text{ GeV} < m_{\mu\mu e/\mu} < 105\text{ GeV})}{N_{\mu\mu\gamma}(75\text{ GeV} < m_{\mu\mu\gamma} < 105\text{ GeV})}$$

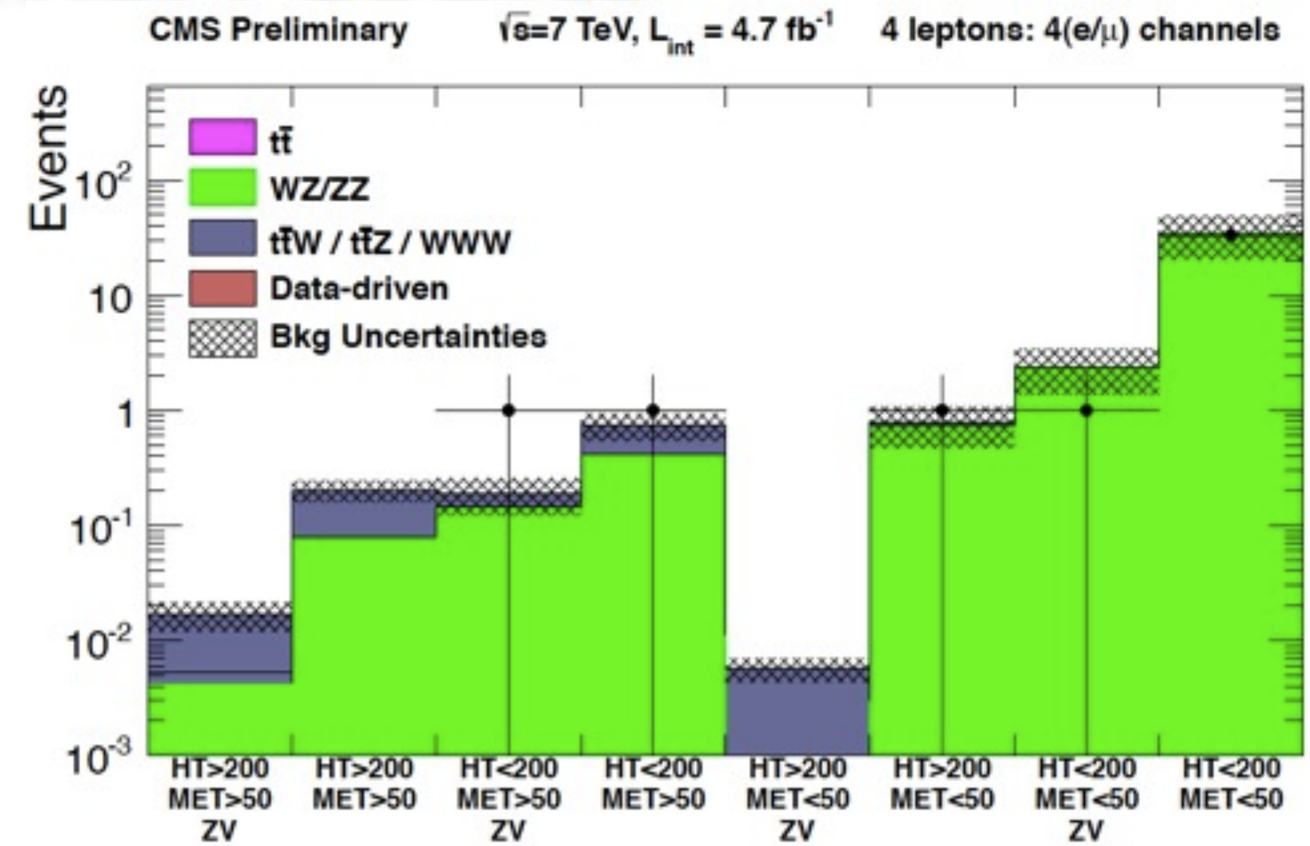


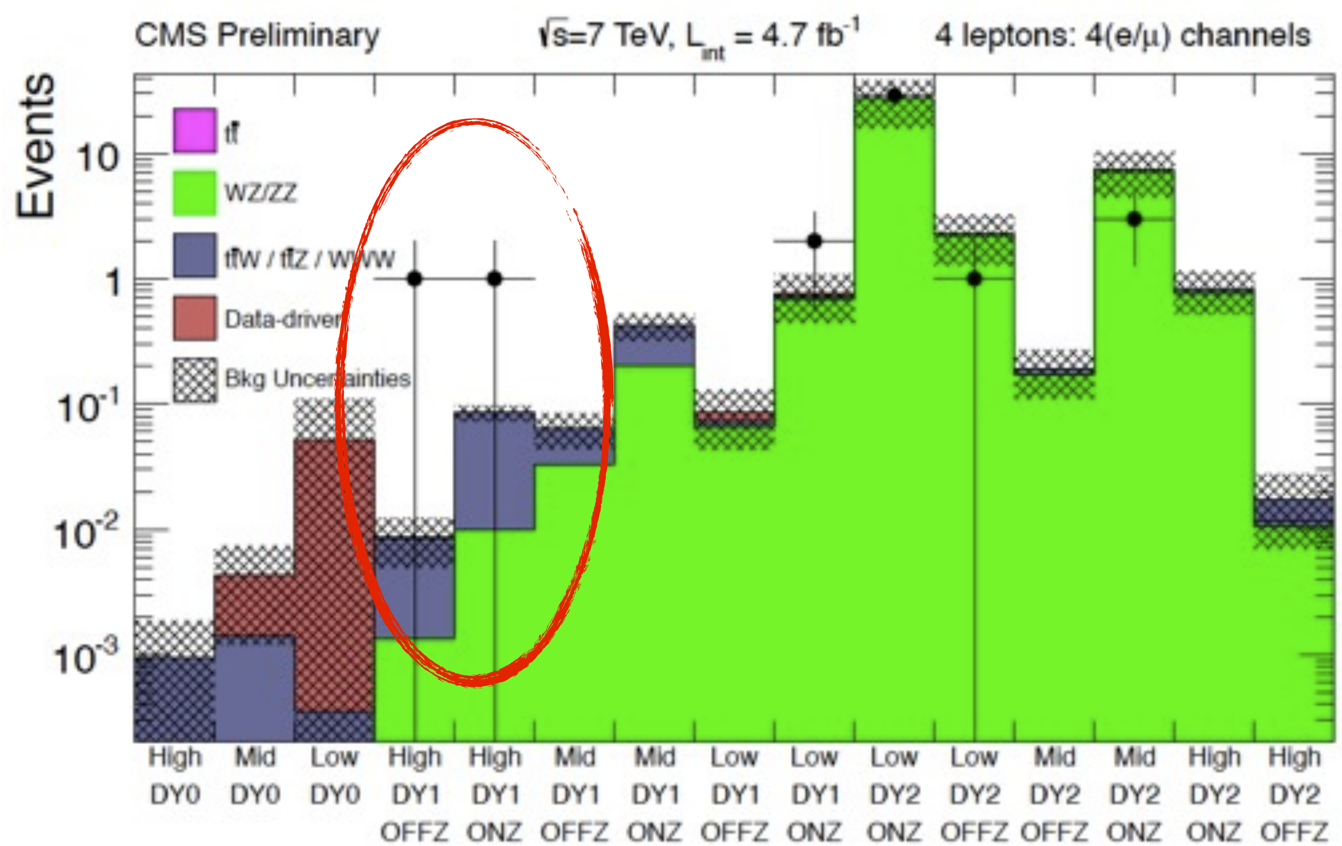


Multileptons: results

- No significant deviations observed, given the number of bins
  - ✓ See full tables in the backup.
  - ✓ Showing here just a few bar-charts for illustration

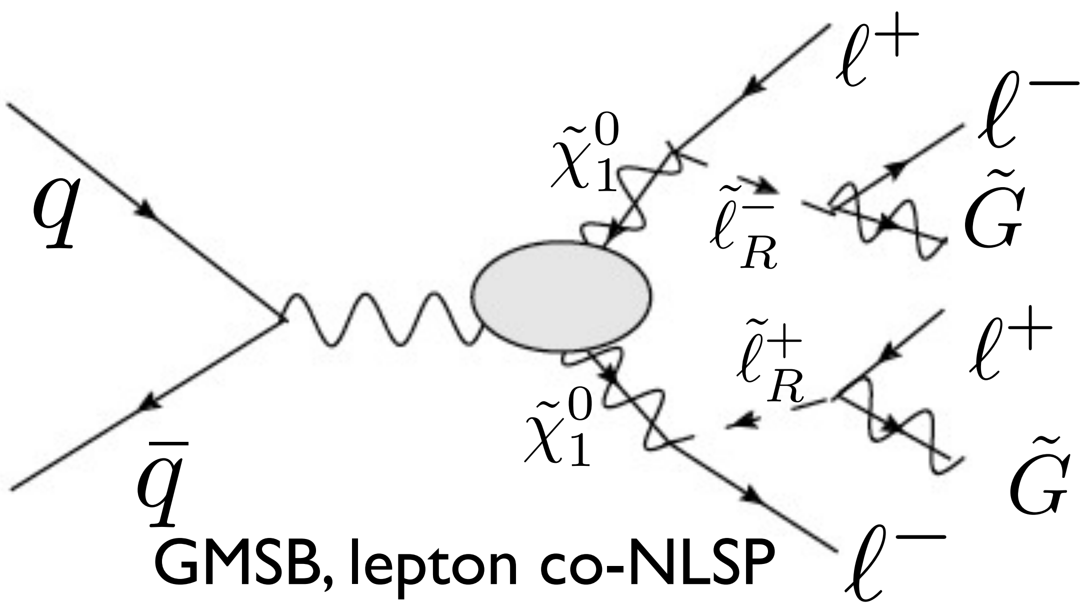
- It's curious to note some events fell into more rare category in ST

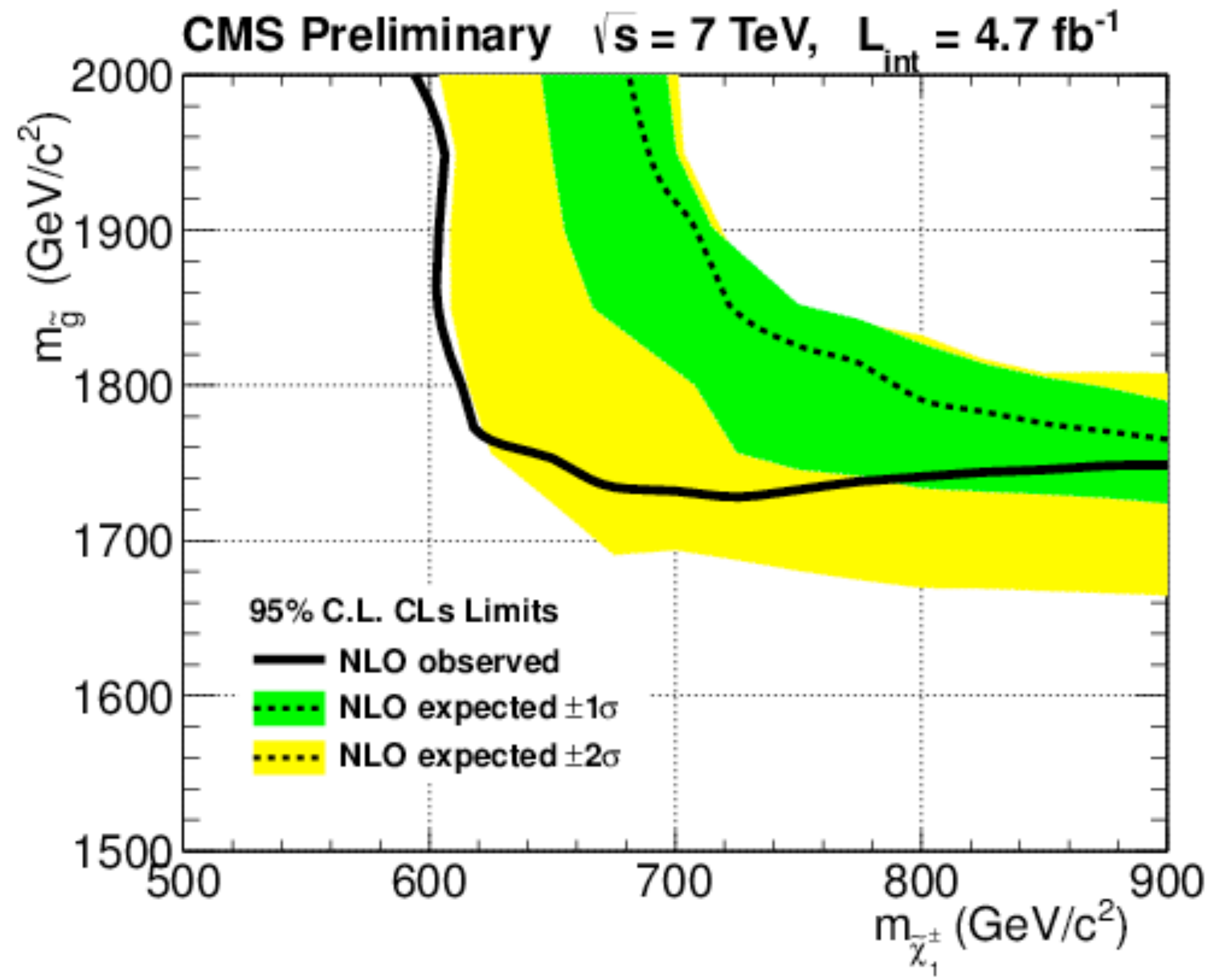




Interpretation: with R-parity

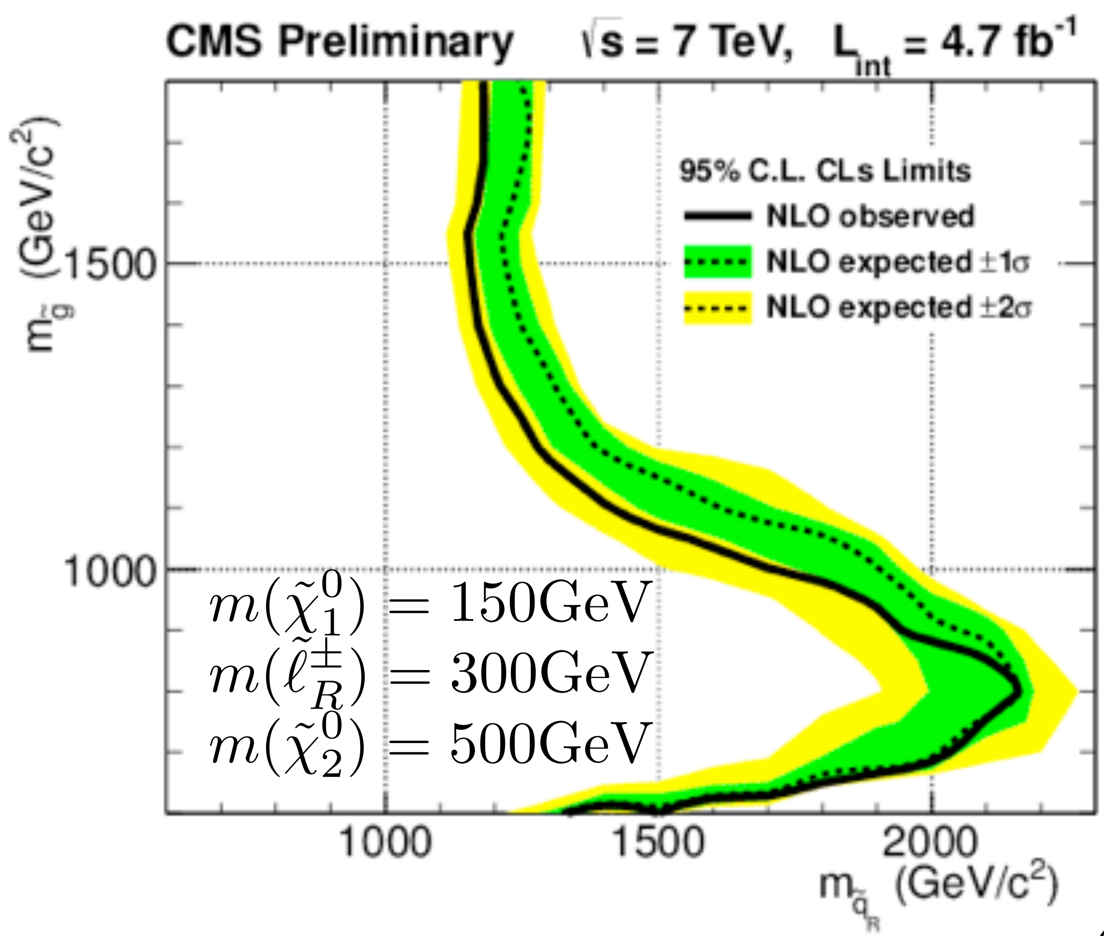
- Slepton co-NLSP GMSB scenario: bino-like neutralino, slepton co-NLSP
  - ✓ Selected phase space has many leptons

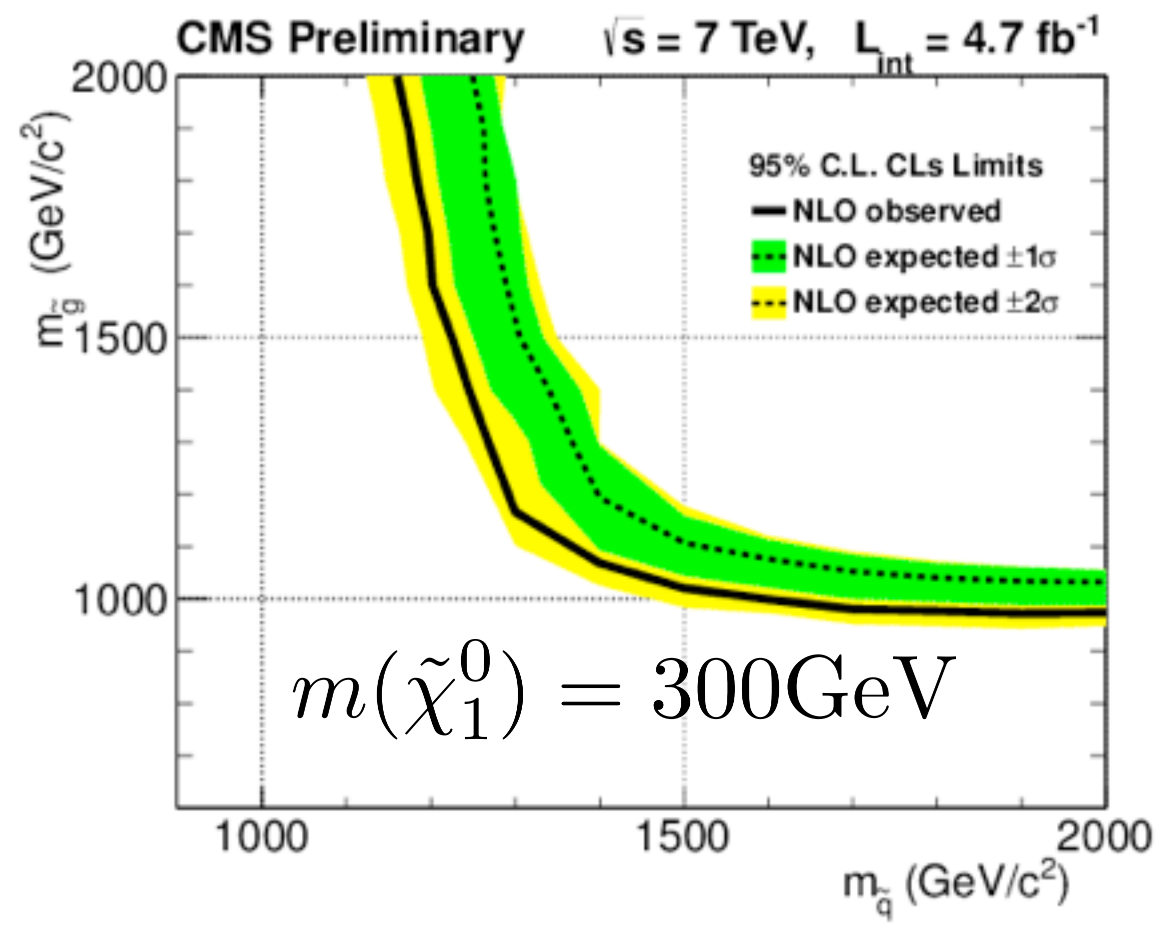


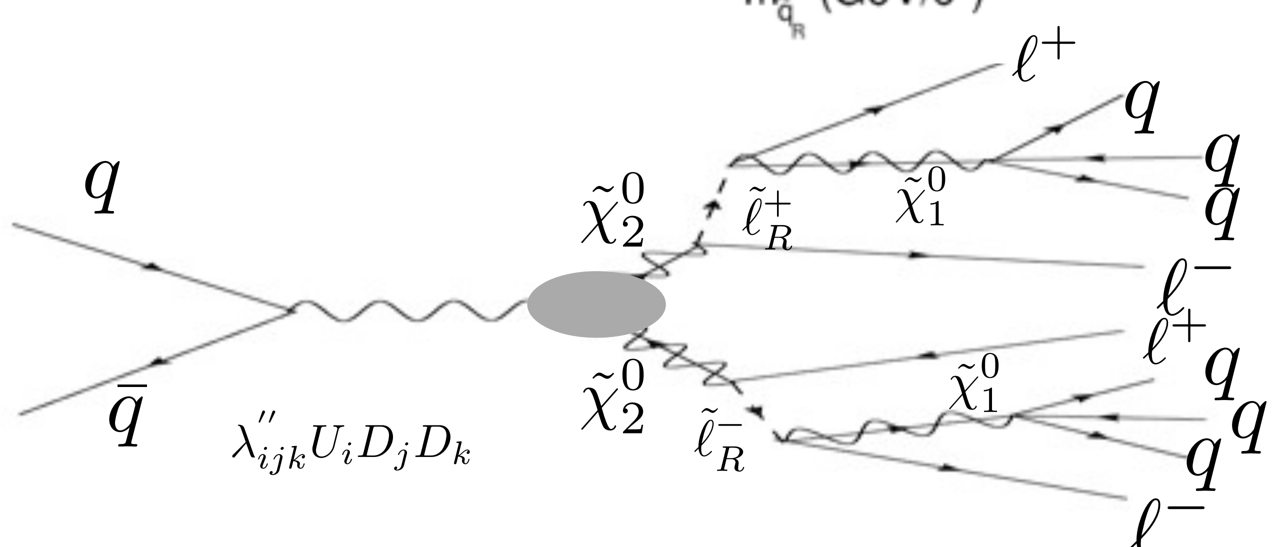


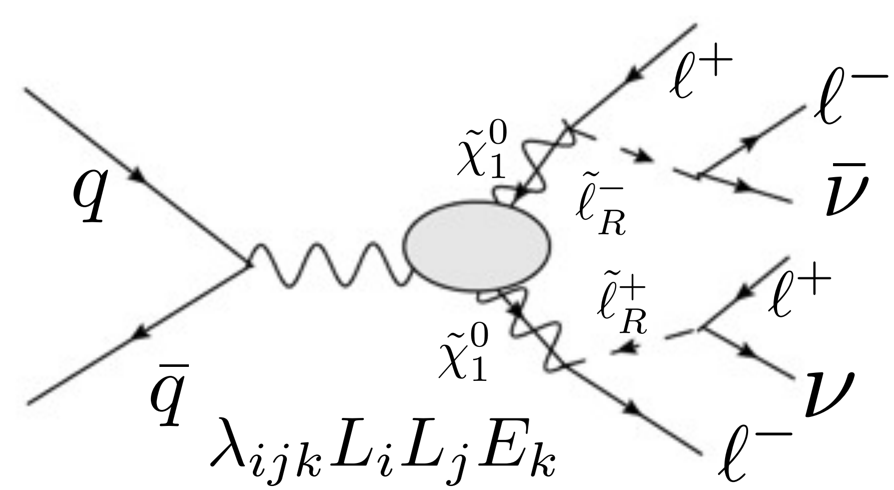
Interpretation: R-parity violation

- Hadronic and leptonic RPV cases
  - ✓ Selected phase space naturally gives multileptons









Summary

- Same-sign dilepton and multilepton SUSY searches making progress using full 2011 dataset
    - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

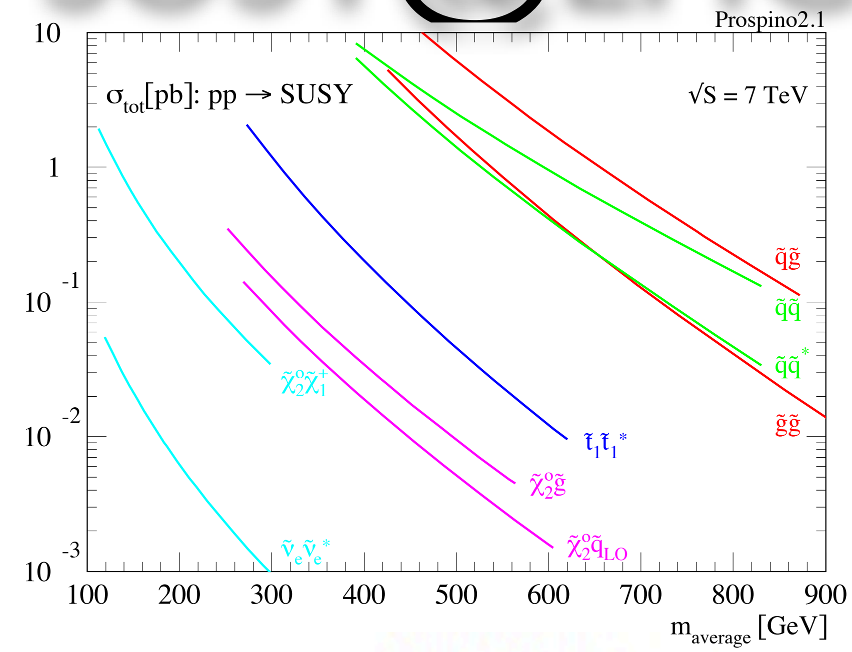
  ✓ New: same-sign dileptons with b-tags (SUS-11-020)

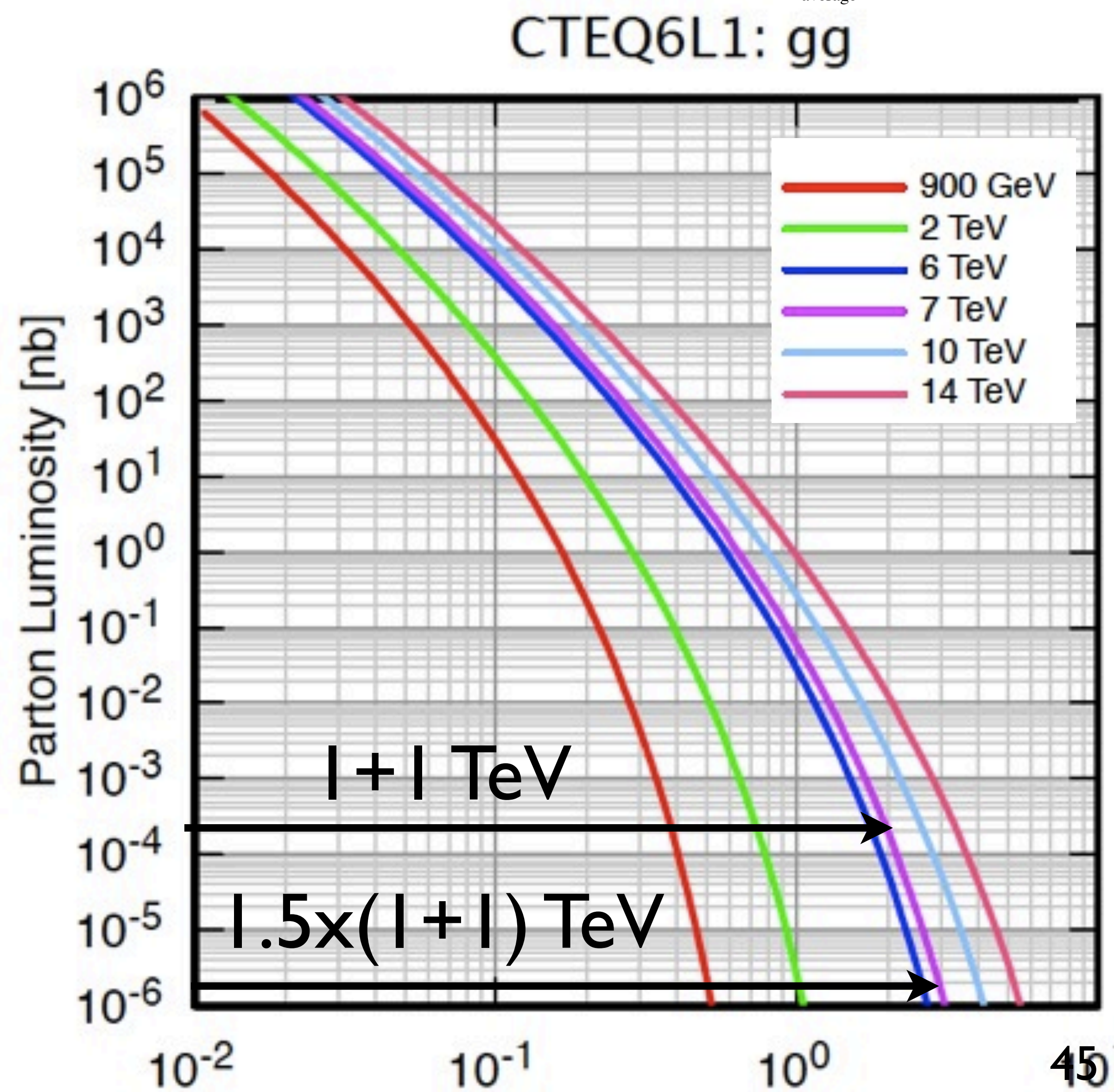
  ✓ Updates: same-sign dilepton (SUS-11-010), multilepton (SUS-11-013) analyses

- No discoveries in 2011
- More data coming in 2012

Future prospects for SUSY@LHC

- Look at how sensitivity can increase with more luminosity
- Parton luminosities begin to turn over:
  - ✓ next 50% in reach will require 100 times more lumi (even forgetting backgrounds)
- We need more energy to go to higher masses than 7 or 8 TeV
  - ✓ For now (most 2012) direct heavy production reach is near saturation
- Next most reasonable strategy is go after processes with lower mass and lower xsections.





Multileptons: HT-MET sliced

Selection	N(τ)=0 obs	N(τ)=0 expect	N(τ)=1 obs	N(τ)=1 expect	N(τ)=2 obs	N(τ)=2 expect
4ℓ Lepton Results						
4ℓ >50,H_T >200,noZ	0	0.017 ± 0.005	0	0.08 ± 0.06	0	0.6 ± 0.6
4ℓ MET>50,H_T > 200, Z	0	0.20 ± 0.04	0	0.25 ± 0.11	0	0.7 ± 1.0
4ℓ MET>50,H_T <200,noZ	1	0.19 ± 0.07	3	0.56 ± 0.16	1	1.4 ± 0.6
4ℓ MET>50,H_T <200, Z	1	0.74 ± 0.20	4	2.2 ± 0.6	0	1.1 ± 0.7
4ℓ MET<50,H_T >200,noZ	0	0.006 ± 0.001	0	0.13 ± 0.08	0	0.25 ± 0.07
4ℓ MET<50,H_T >200, Z	1	0.78 ± 0.31	0	0.52 ± 0.20	0	1.13 ± 0.42
4ℓ MET<50,H_T <200,noZ	1	2.4 ± 1.0	5	3.7 ± 1.2	17	10.5 ± 3.2
4ℓ MET<50,H_T <200, Z	33	35 ± 14	20	16.1 ± 4.9	62	42 ± 16
3ℓ Lepton Results						
3ℓ MET>50,H_T >200,no-OSSF	2	1.5 ± 0.5	33	30.3 ± 9.6	15	13.5 ± 2.6
3ℓ MET>50,H_T <200,no-OSSF	7	6.5 ± 2.3	159	140 ± 37	82	106 ± 16
3ℓ MET<50,H_T >200,no-OSSF	1	1.2 ± 0.7	16	16.5 ± 4.5	18	31.9 ± 4.8
3ℓ MET<50,H_T <200,no-OSSF	14	11.6 ± 3.6	446	354 ± 55	1006	1025 ± 171
3ℓ MET>50,H_T >200,noZ	8	4.8 ± 1.3	16	31.0 ± 9.5	–	–
3ℓ MET>50,H_T >200, Z	20	17.8 ± 6.0	13	24.0 ± 4.9	–	–
3ℓ MET>50,H_T <200,noZ	30	25.9 ± 7.3	114	106 ± 27	–	–
3ℓ MET<50,H_T >200,noZ	11	4.4 ± 1.5	45	51.8 ± 6.2	–	–
3ℓ MET>50,H_T <200, Z	141	126 ± 47	107	115 ± 16	–	–
3ℓ MET<50,H_T >200, Z	15	18.4 ± 4.5	166	244 ± 24	–	–
3ℓ MET<50,H_T <200,noZ	123	142 ± 36	3721	2906 ± 412	–	–
3ℓ MET<50,H_T <200, Z	657	749 ± 181	17857	15516 ± 2421	–	–
Total	1066	1148 ± 191	22725	19557 ± 2457	1201	1235 ± 173
Total 4ℓ	37	39 ± 15	32	23.6 ± 5.1	80	58 ± 16
Total 3ℓ	1029	1109 ± 191	22693	19533 ± 2457	1121	1177 ± 172
Total	1066	1148 ± 191	22725	19557 ± 2457	1201	1235 ± 173

Multileptons: ST-sliced

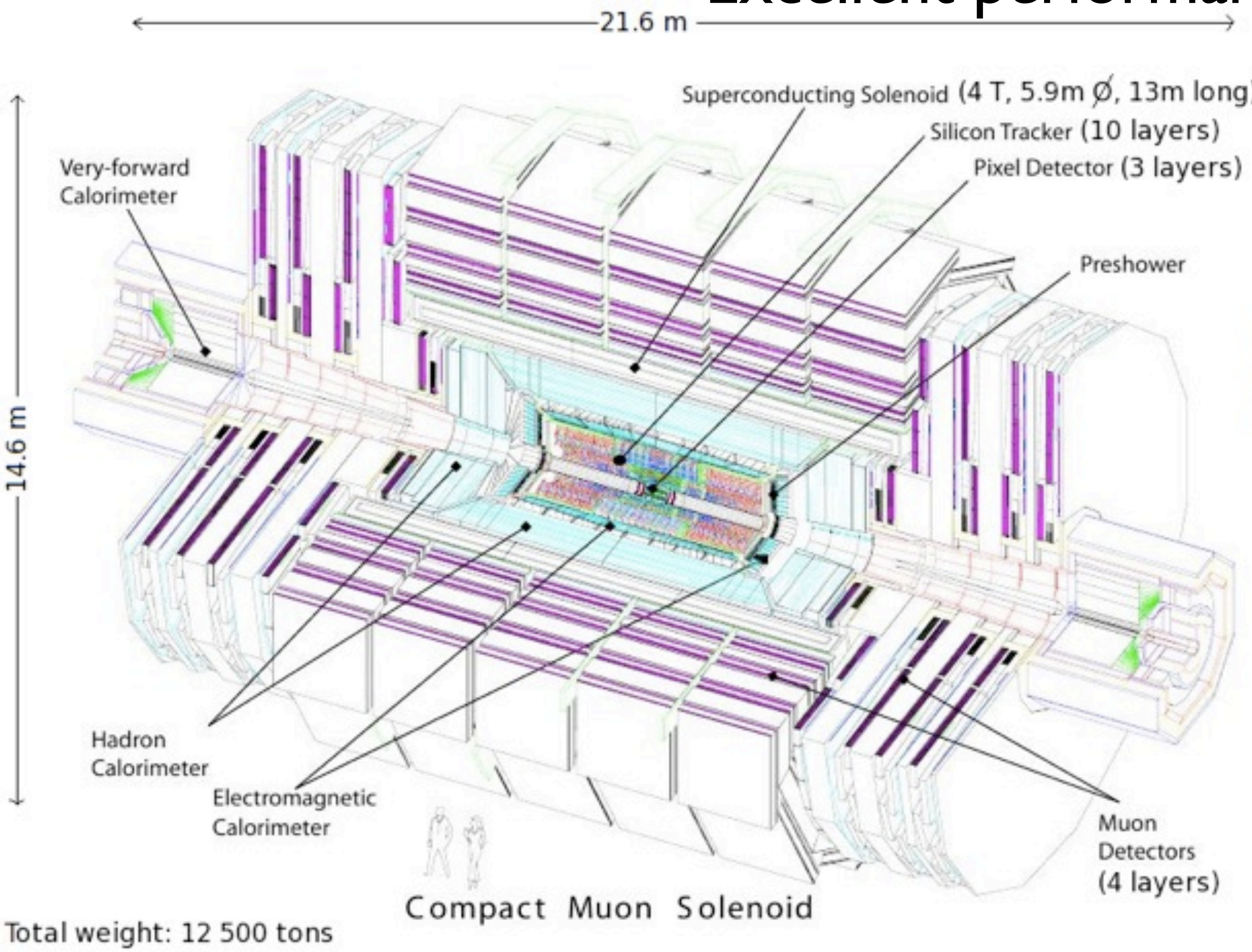
Selection	N(τ)=0 obs	N(τ)=0 expect	N(τ)=1 obs	N(τ)=1 expect	N(τ)=2 obs	N(τ)=2 expect
4ℓ Lepton Results						
4ℓ (DY0) S_T(High)	0	0.0009 ± 0.0009	0	0.01 ± 0.09	0	0.17 ± 0.07
4ℓ (DY0) S_T(Mid)	0	0.004 ± 0.002	0	0.27 ± 0.10	2	2.5 ± 1.1
4ℓ (DY0) S_T(Low)	0	0.04 ± 0.02	0	2.98 ± 0.48	4	3.4 ± 1.0
4ℓ (DY1,ZV) S_T(High)	1	0.009 ± 0.004	0	0.09 ± 0.07	0	0.11 ± 0.05
4ℓ (DY1) S_T(High)	1	0.09 ± 0.01	0	0.48 ± 0.14	0	0.42 ± 0.15
4ℓ (DY1,ZV) S_T(Mid)	0	0.06 ± 0.02	1	0.83 ± 0.24	1	0.92 ± 0.29
4ℓ (DY1) S_T(Mid)	0	0.42 ± 0.10	5	3.9 ± 1.1	3	3.4 ± 0.9
4ℓ (DY1,ZV) S_T(Low)	0	0.08 ± 0.04	7	5.4 ± 2.2	19	13.6 ± 6.4
4ℓ (DY1) S_T(Low)	2	0.75 ± 0.32	19	16.9 ± 4.6	95	60 ± 31
4ℓ (DY2,ZV) S_T(High)	0	0.02 ± 0.01	–	–	–	–
4ℓ (DY2) S_T(High)	0	0.84 ± 0.32	–	–	–	–
4ℓ (DY2,ZV) S_T(Mid)	0	0.19 ± 0.08	–	–	–	–
4ℓ (DY2) S_T(Mid)	3	7.4 ± 3.0	–	–	–	–
4ℓ (DY2,ZV) S_T(Low)	1	2.3 ± 1.0	–	–	–	–
4ℓ (DY2) S_T(Low)	29	27 ± 11	–	–	–	–
3ℓ Lepton Results						
3ℓ (DY0) S_T(High)	2	1.12 ± 0.43	17	11.0 ± 3.2	20	22.3 ± 6.0
3ℓ (DY0) S_T(Mid)	5	7.3 ± 3.0	113	96 ± 31	157	181 ± 24
3ℓ (DY0) S_T(Low)	17	13.3 ± 4.1	522	413 ± 63	1631	2016 ± 253
3ℓ (DY1,ZV) S_T(High)	6	3.3 ± 0.9	10	13.0 ± 2.3	–	–
3ℓ (DY1) S_T(High)	17	17.6 ± 5.6	35	39.0 ± 4.7	–	–
3ℓ (DY1,ZV) S_T(Mid)	32	24.6 ± 6.4	159	141 ± 27	–	–
3ℓ (DY1) S_T(Mid)	89	97 ± 29	441	462 ± 41	–	–
3ℓ (DY1,ZV) S_T(Low)	126	147 ± 36	3721	2981 ± 418	–	–
3ℓ (DY1) S_T(Low)	727	797 ± 189	17631	15751 ± 2452	–	–
Total 4ℓ	37	39 ± 12	32	30.8 ± 5.2	124	84 ± 32
Total 3ℓ	1021	1108 ± 195	22649	19906 ± 2489	1808	2220 ± 255
Total	1058	1148 ± 195	22681	19937 ± 2489	1932	2304 ± 257

Backup slides

CMS Detector: 2008 JINST 3 S08004

CMS Detector

Excellent performance from first days of collisions



Tracker: $\sigma/p_T \simeq 1.5 \times 10^{-4} \times p_T \oplus 0.005$

Muon standalone @ 1 TeV: $\sigma/p_T \simeq 0.10$

Electromagnetic energy resolution

$$\frac{\sigma(E)}{E} = \frac{3\%}{\sqrt{E}} + 0.3\%$$

Hadronic energy resolution

$$\frac{\sigma(E)}{E} = \frac{100\%}{\sqrt{E}} + 5\%$$

- Trigger system setup to reduce input rate of 40MHz down to 100-200 Hz
  - ✓ Hardware level-1 40MHz → 100 kHz followed by PC farm with near-final reconstruction resolution
  - ➡ No triggering on inner tracks at L1 (available only in a couple of years)
  - ➡ Final trigger stage can select muons, electrons, photons, jets, MET, displaced vertices