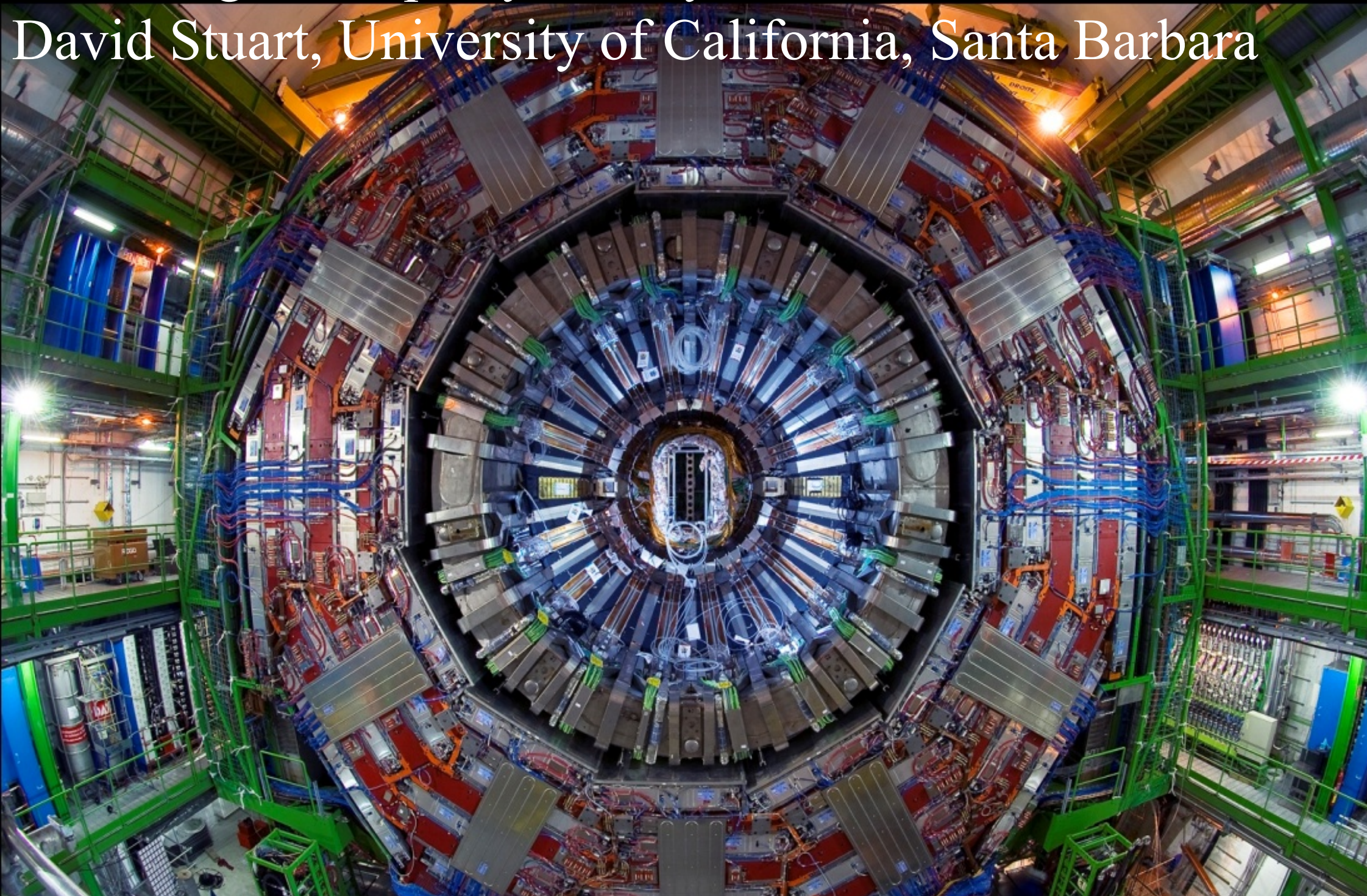
Searching for Supersymmetry at the LHC

David Stuart, University of California, Santa Barbara



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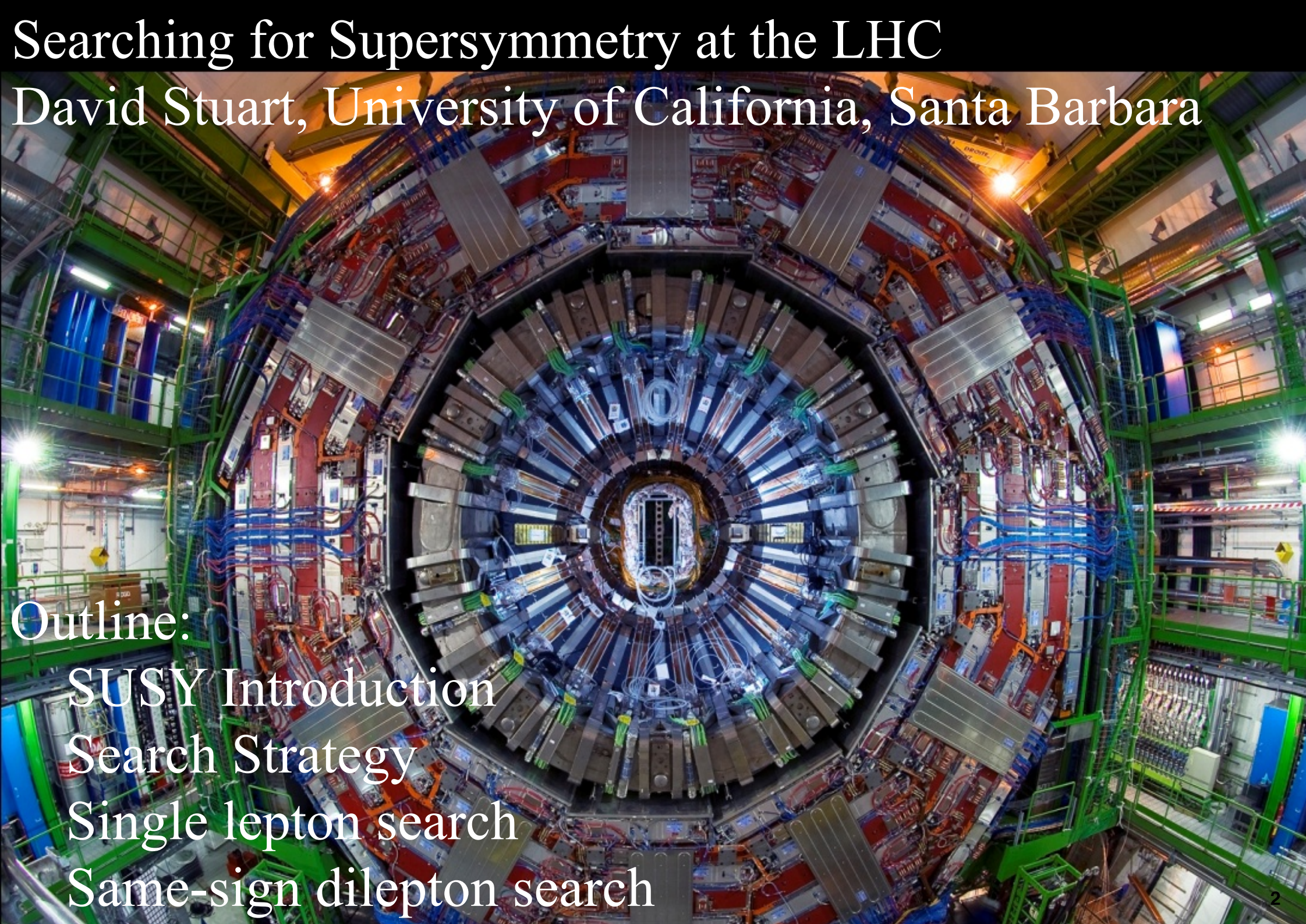
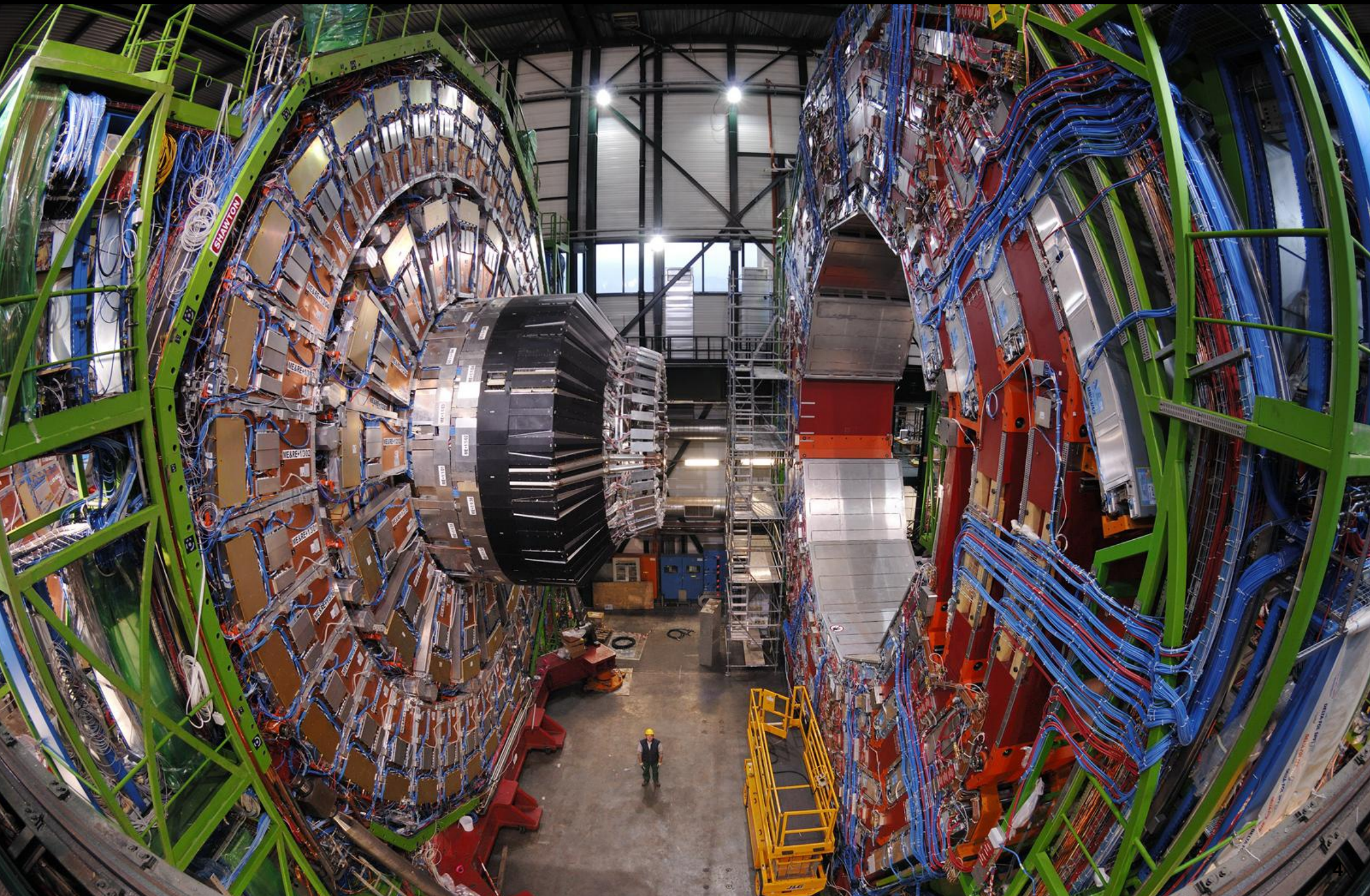
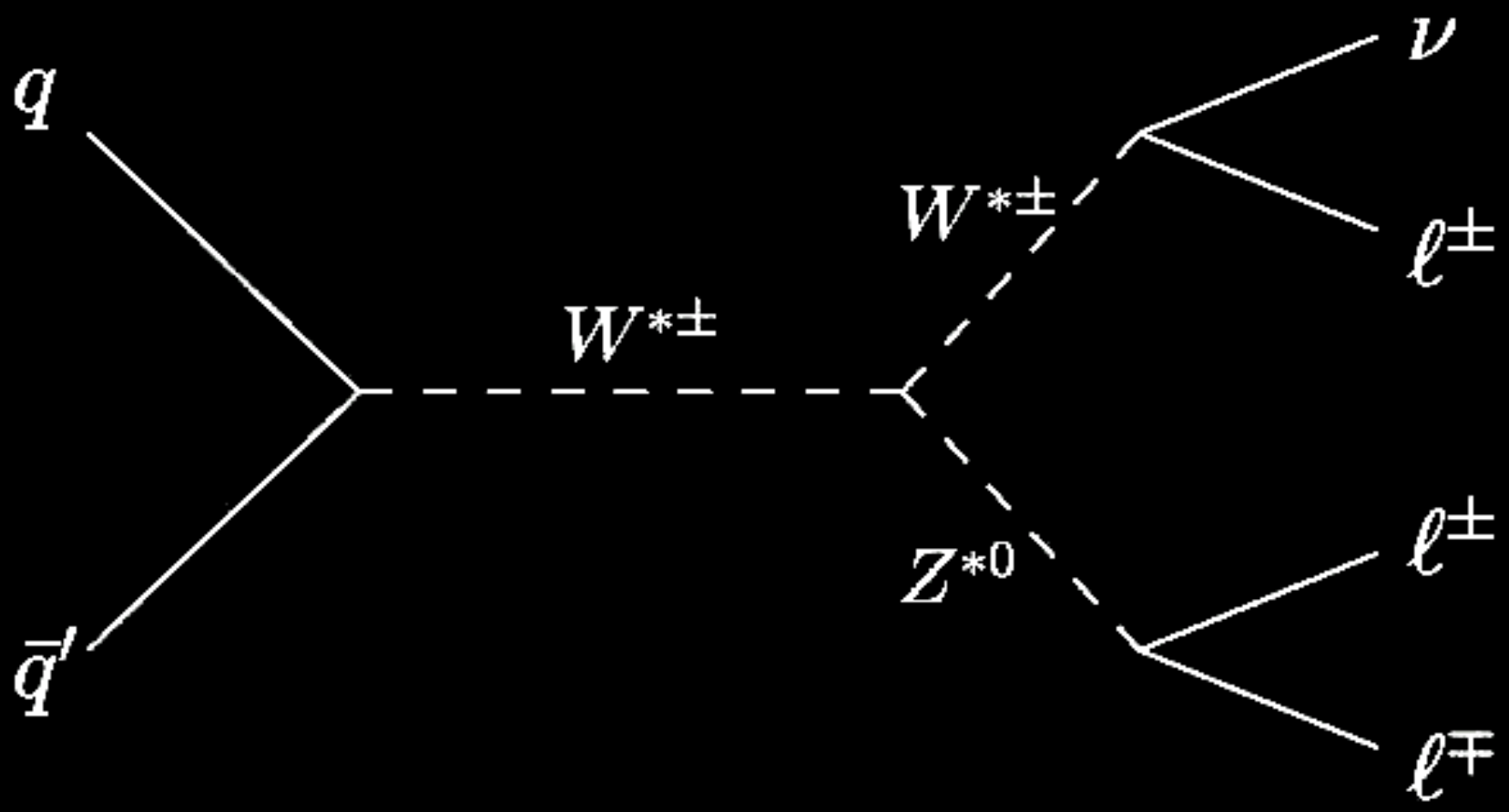


Outline:

- SUSY Introduction
- Search Strategy
- Single lepton search
- Same-sign dilepton search

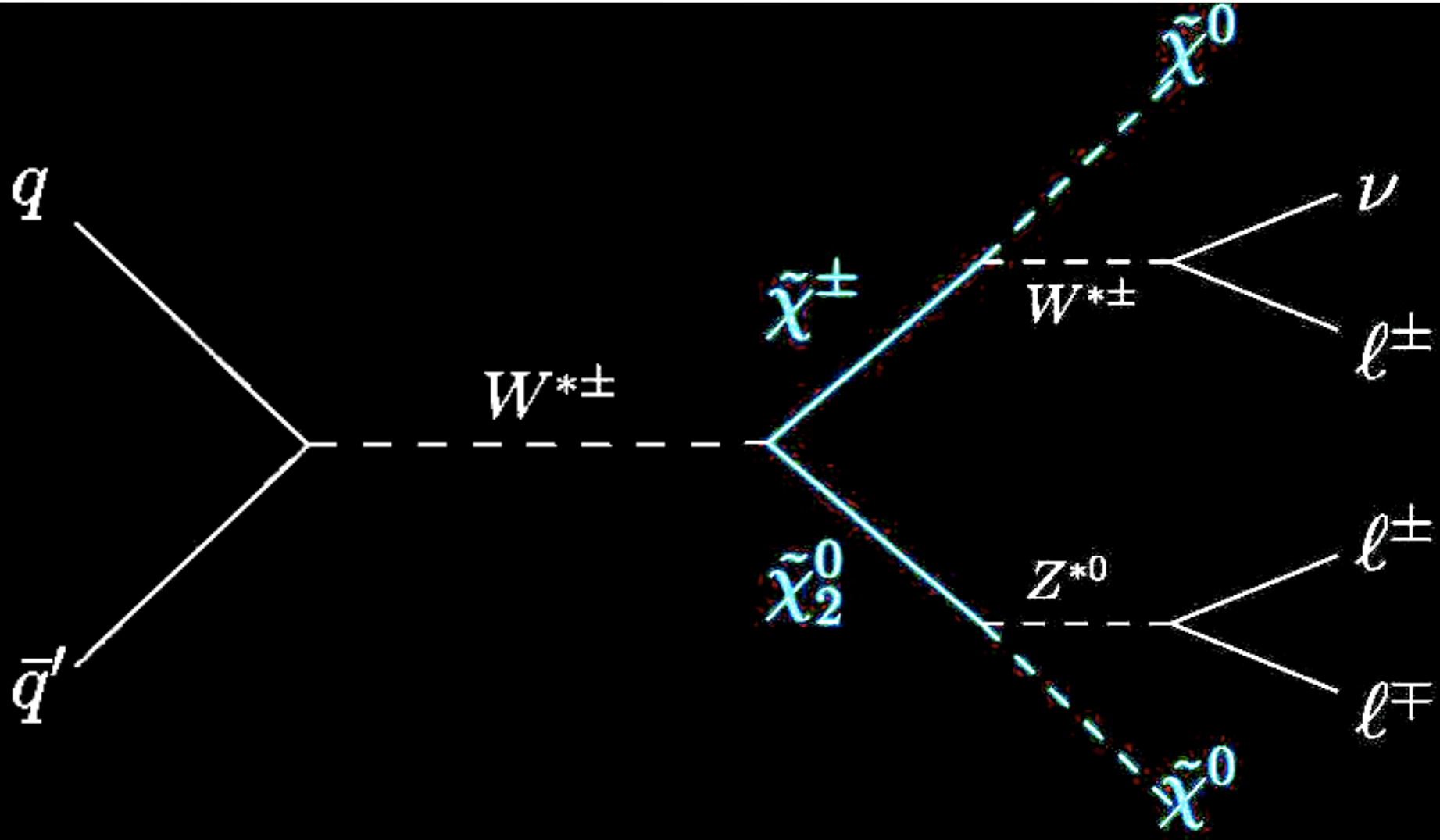

SHAVTON

How to search for SUSY?



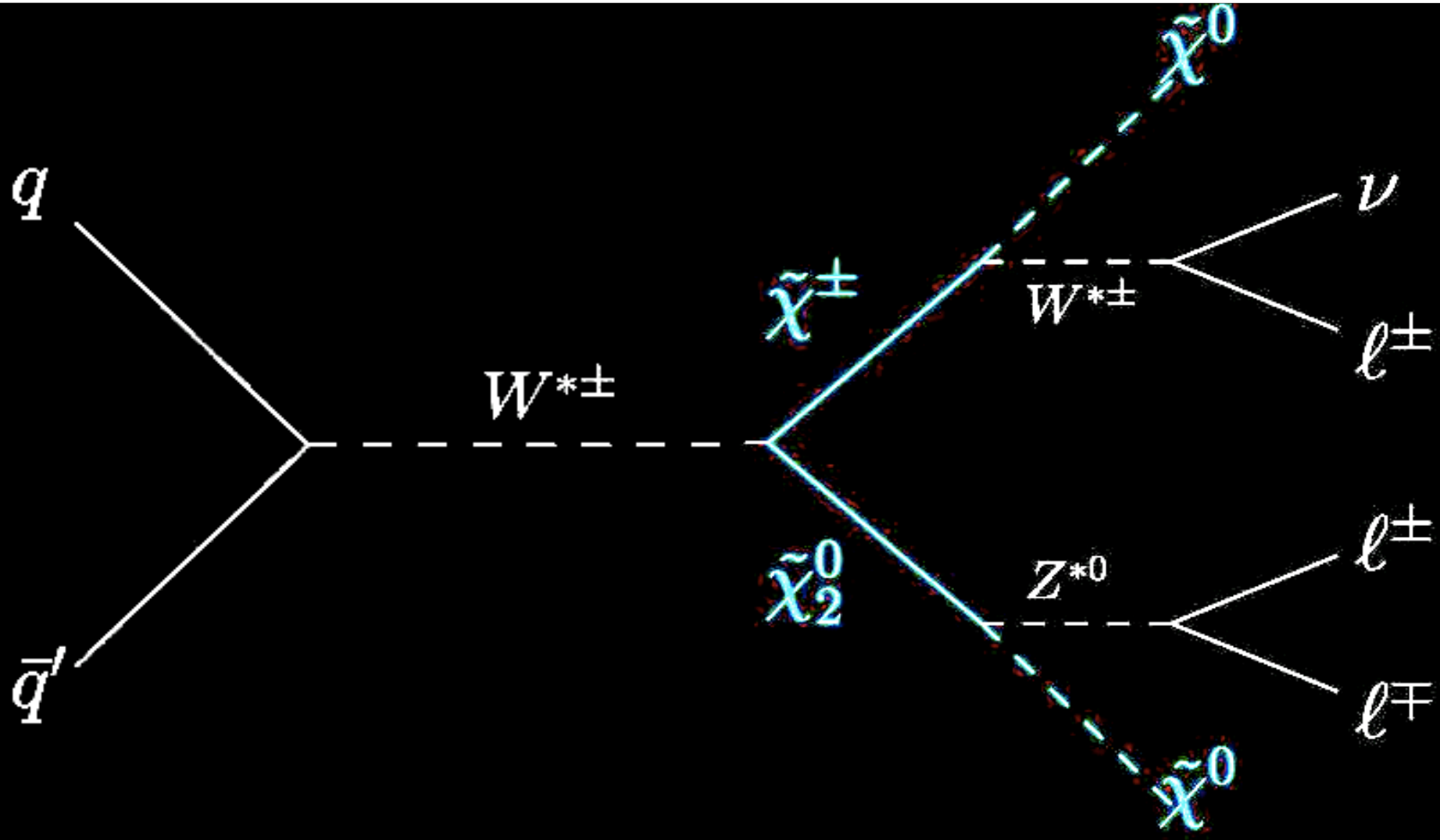
The same diagram that produces WZ in SM…

How to search for SUSY?



…could produce Winos and Zinos.

How to search for SUSY?

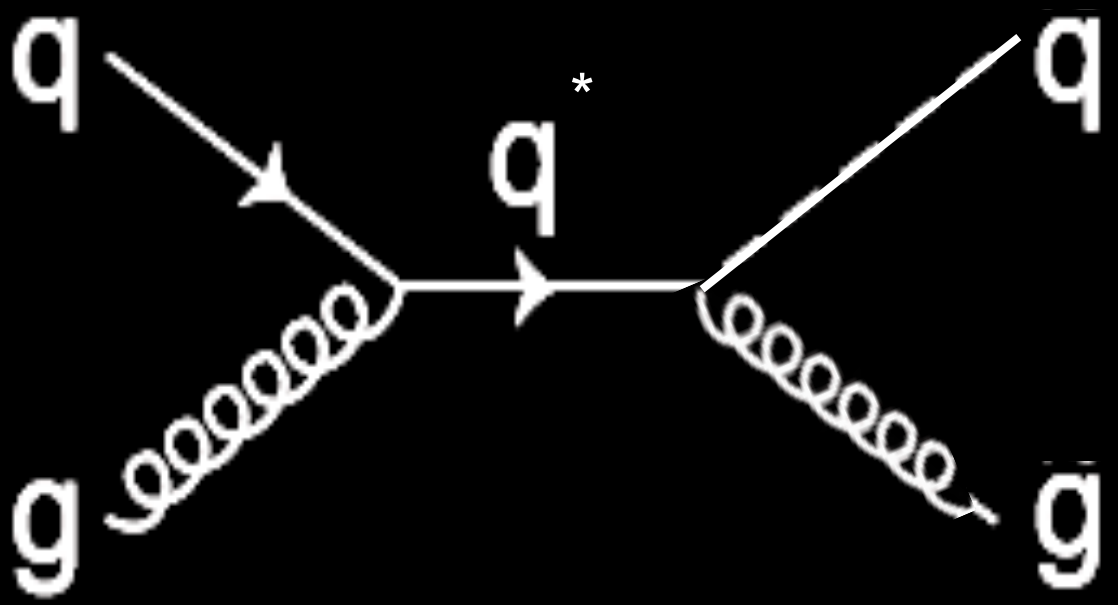


…could produce charginos and neutralinos.

Lightest SUSY particle (LSP) is stable if R-Parity conserved.

How to search for SUSY?

Strong production also possible…



How to search for SUSY?

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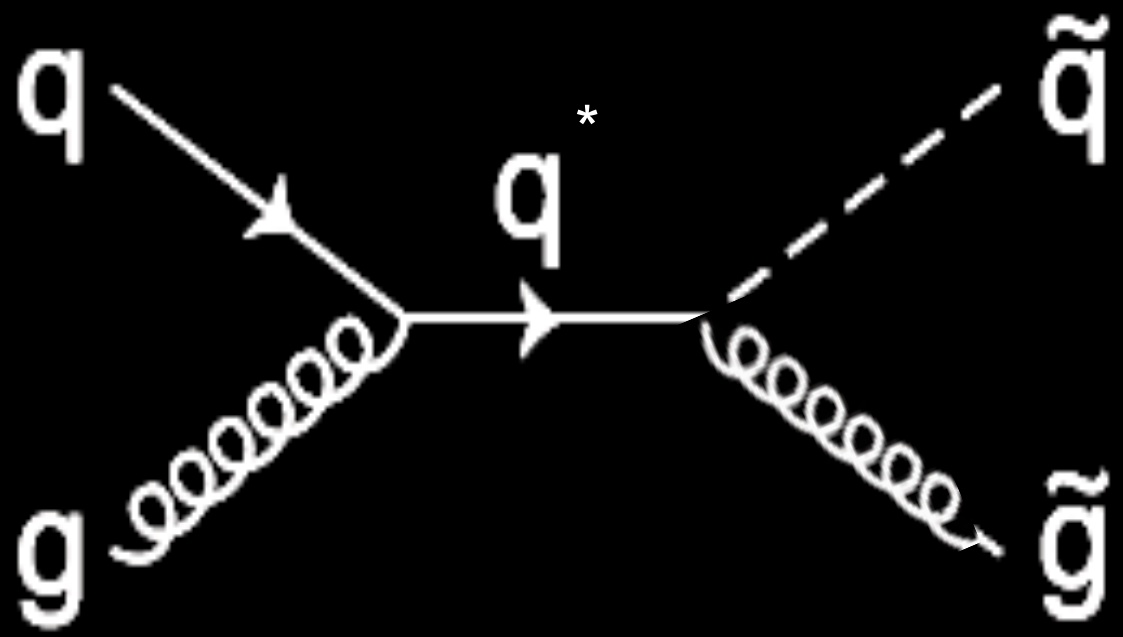
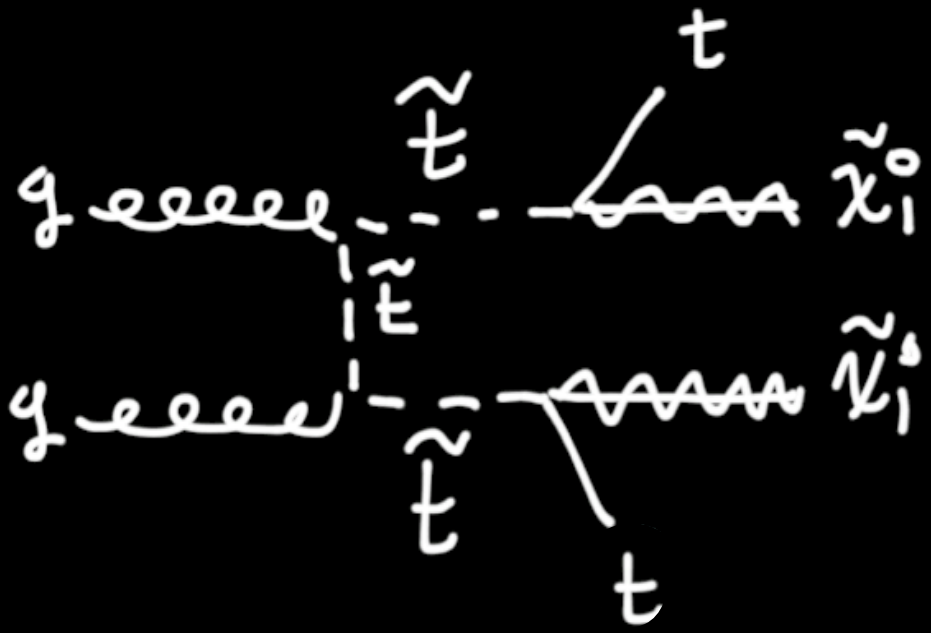
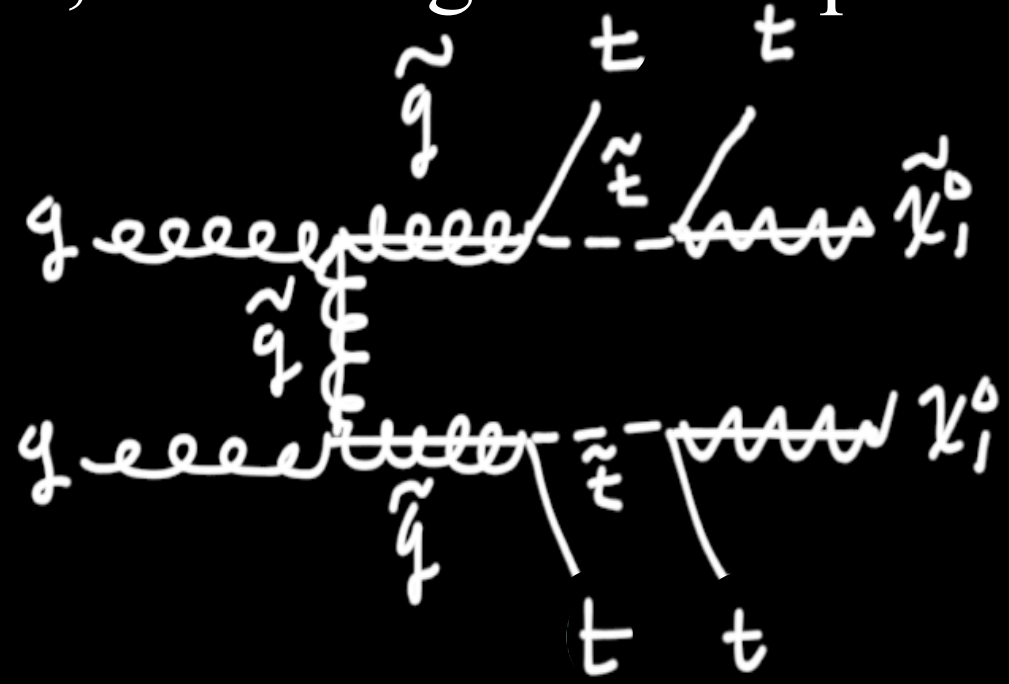


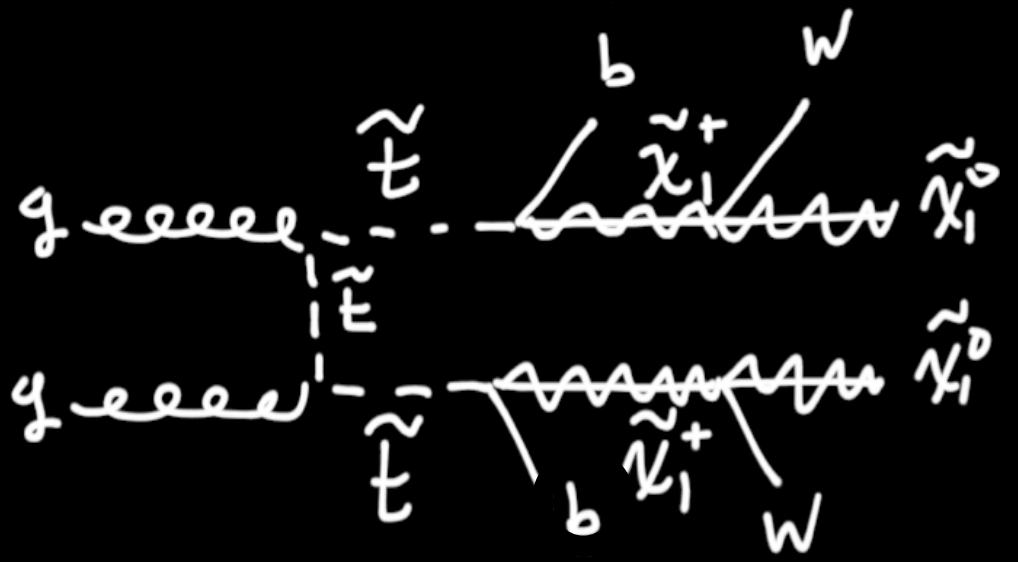
How to search for SUSY?

Strong production also possible, including scalar tops.





Can lead to complex & varied final state signatures



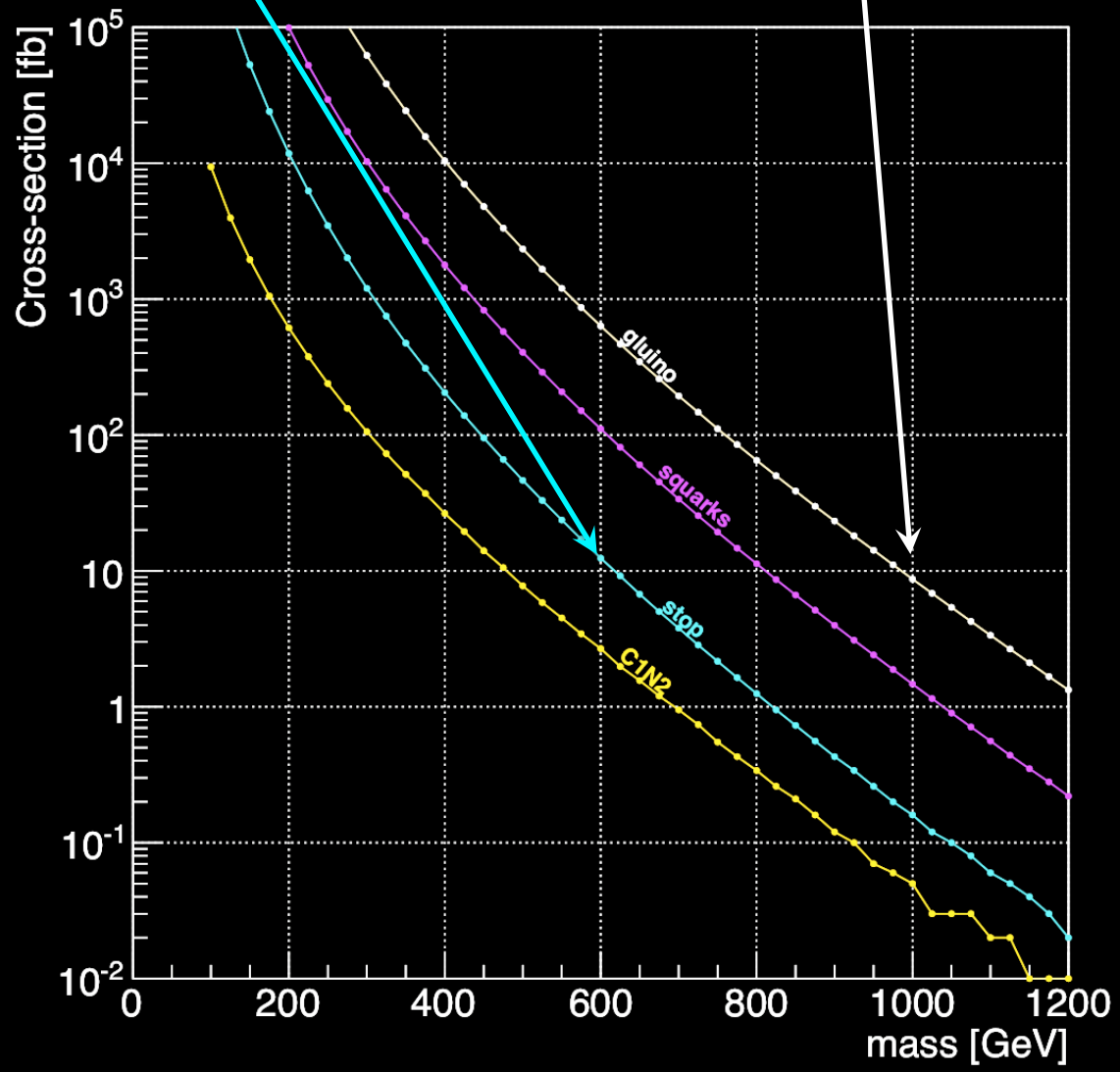
How to search for SUSY?

Cross-section is calculable given masses.

E.g.: 10/fb for 600 GeV stop or 1 TeV gluino

Could produce thousands at lower masses.

The challenge is to discriminate them.



Varied final state search modes

Multijets + MET

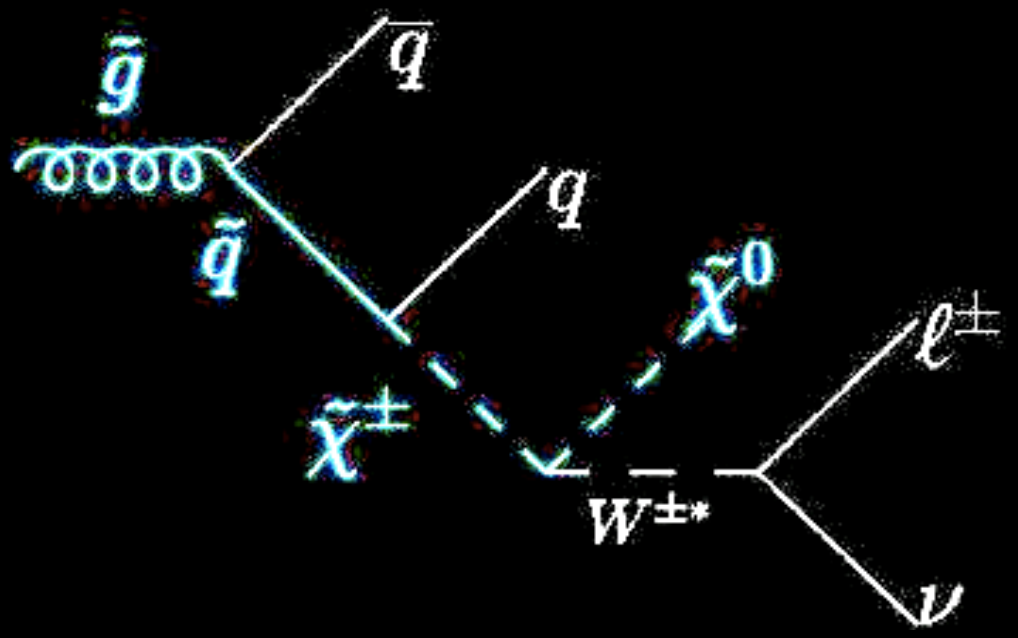
Lepton + jets + MET

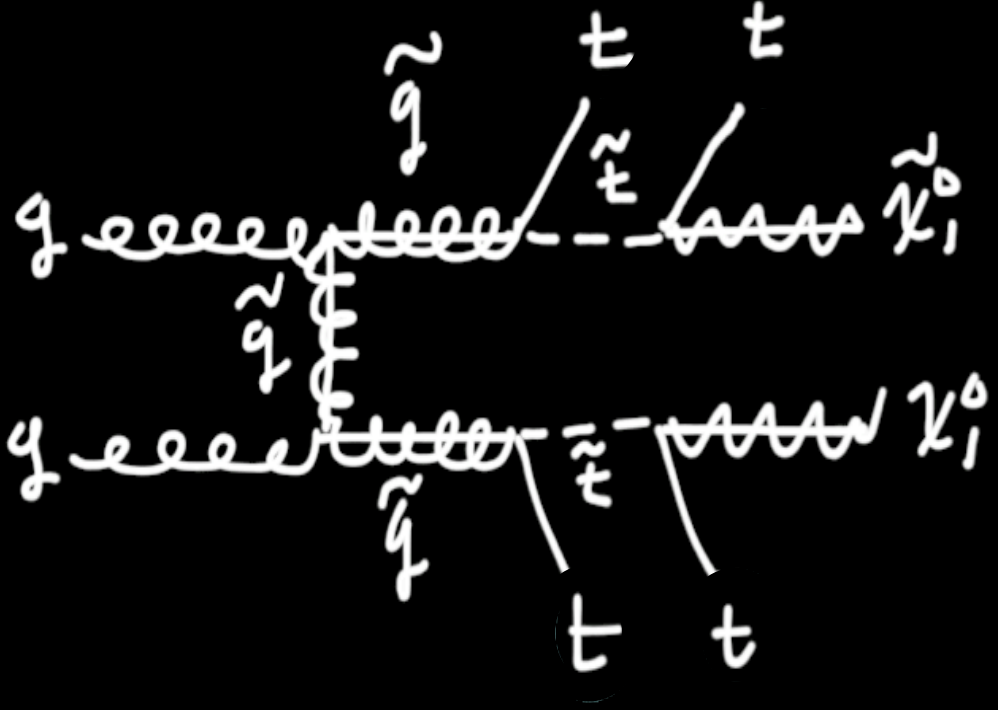
Dileptons + jets + MET

Same sign dileptons + jets + MET

Trileptons + jets + MET

w/ or w/o b-tagged jets





I will describe two searches…

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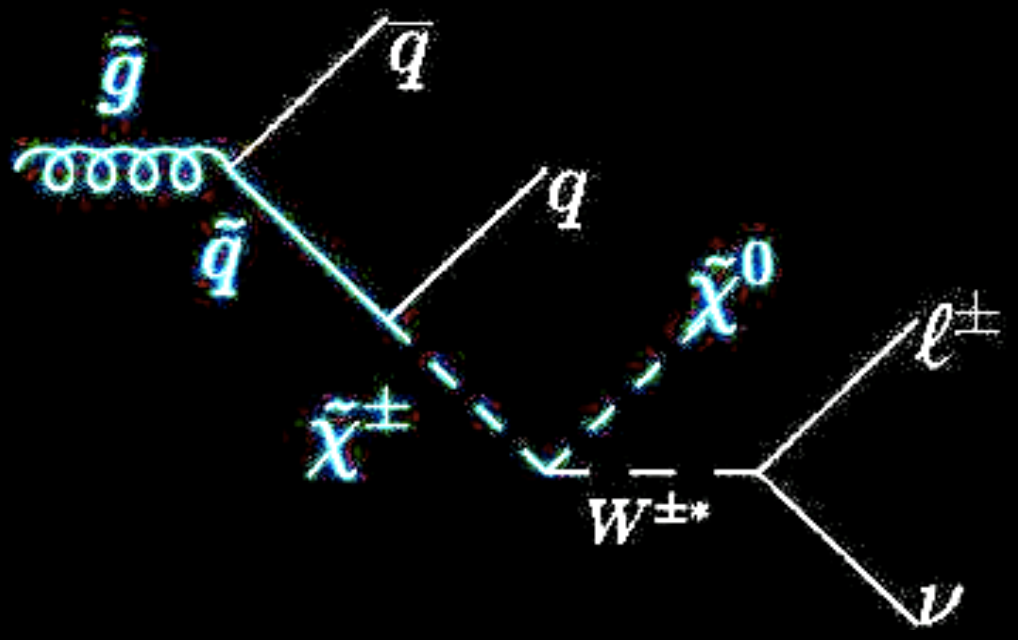
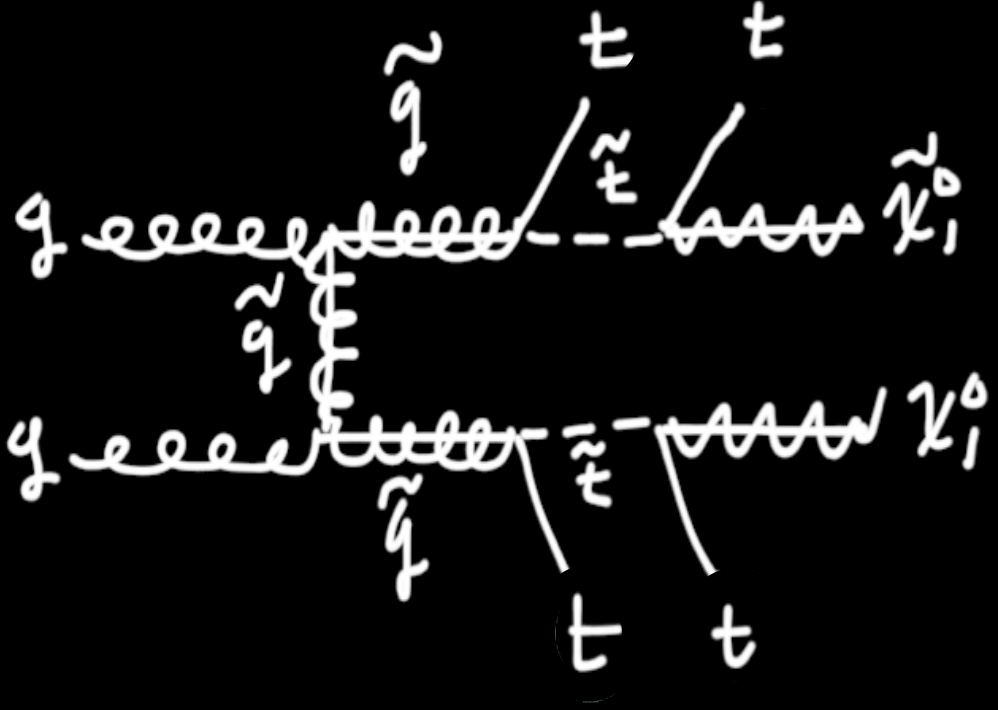




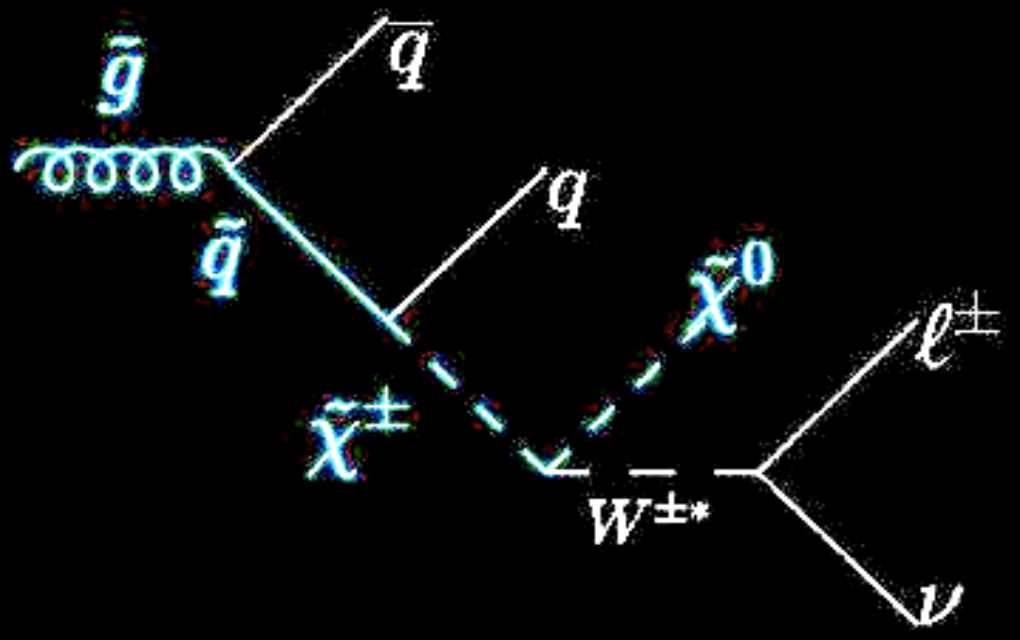
Single lepton + jets + MET

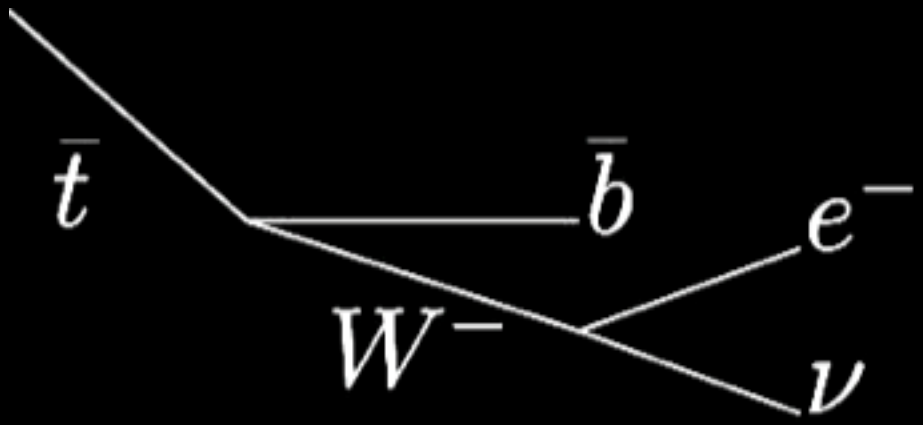
Many jets and
large total energy

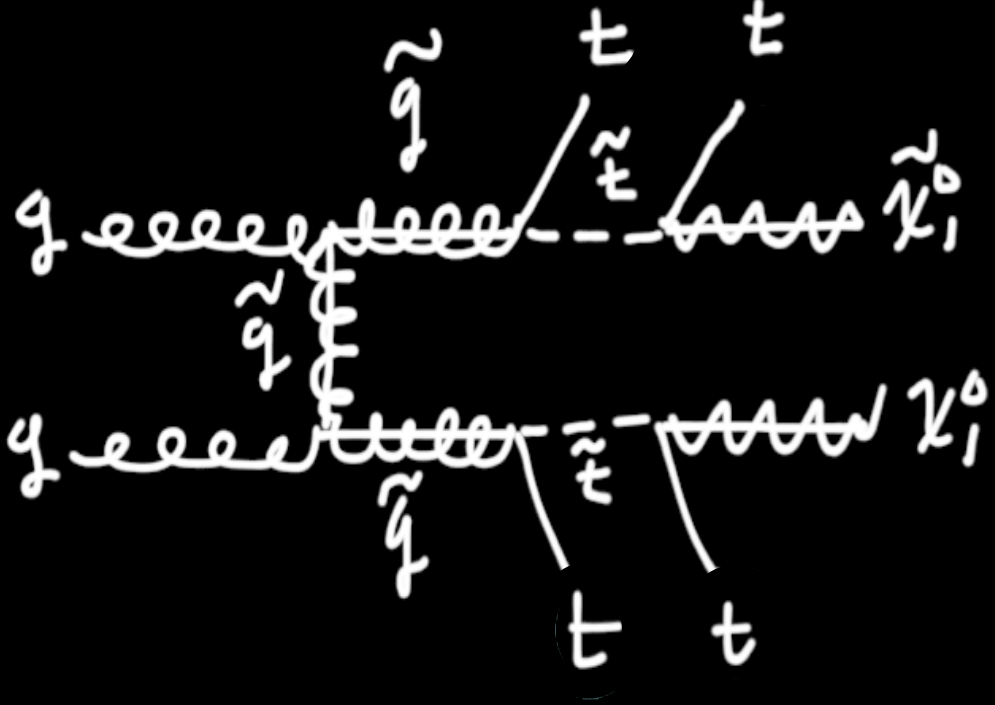
$$H_T \equiv \Sigma_{jets} |\vec{p}_T|$$

Large missing energy,

$$MET \equiv \Sigma_{obj} \vec{p}_T$$







Single lepton + jets + MET

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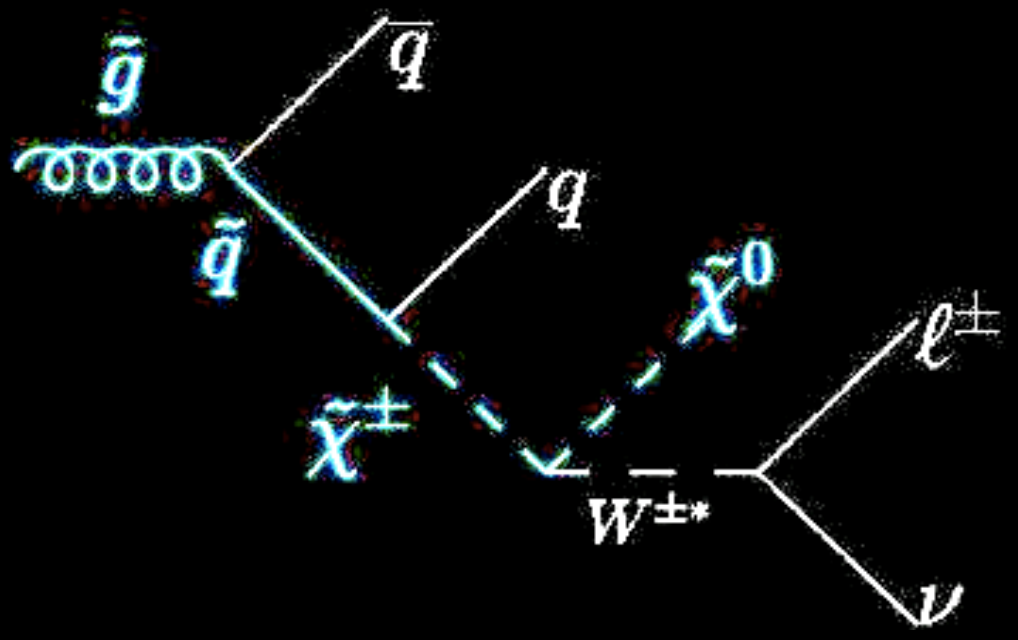


Large missing energy,

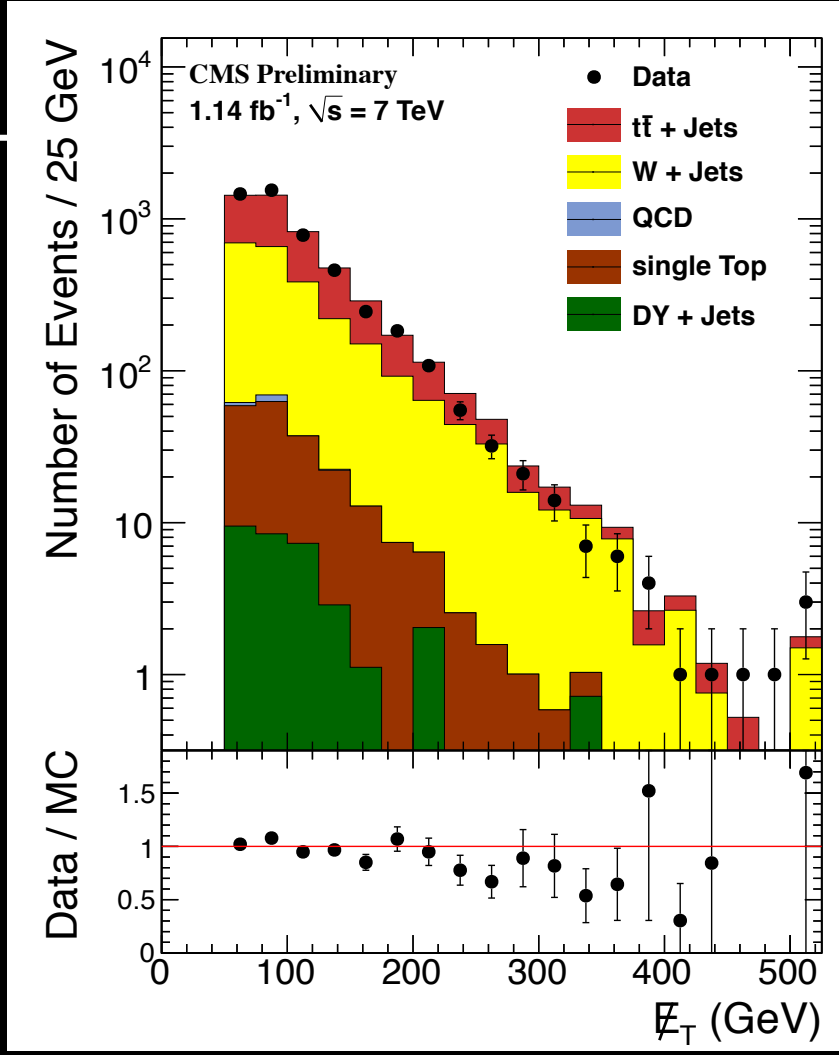
$$MET \equiv \Sigma_{obj} \vec{p}_T$$

Trigger	Jets	Leptons	HT	MET
Single lepton pT>5 GeV HTtrig>70 pT(e)>17	≥4 jets, pT>40 |η|<2.4	pT(e)>20 or pT(mu)>20 isolated, veto dileptons	HT>500	MET >250

Single lepton + jets + MET

Key experimental challenge is to predict the MET spectrum.

Monte Carlo untrustworthy: e.g., tails of kinematics & resolution, and W/top mix.



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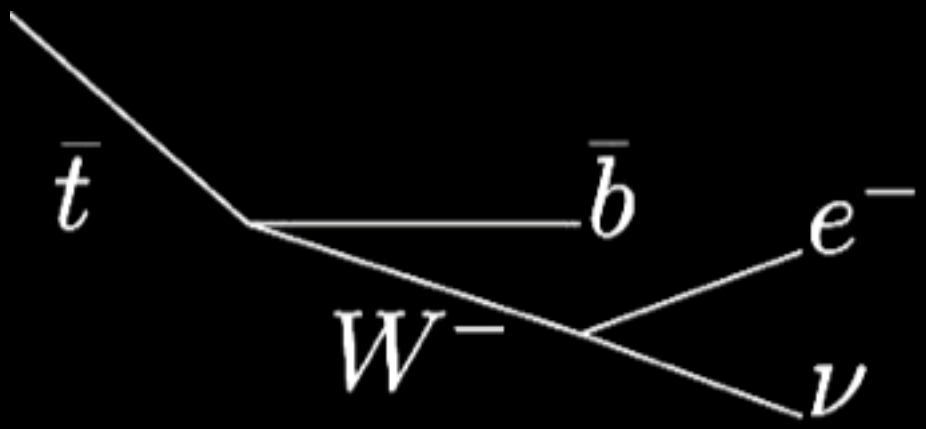
Predicting the MET spectrum

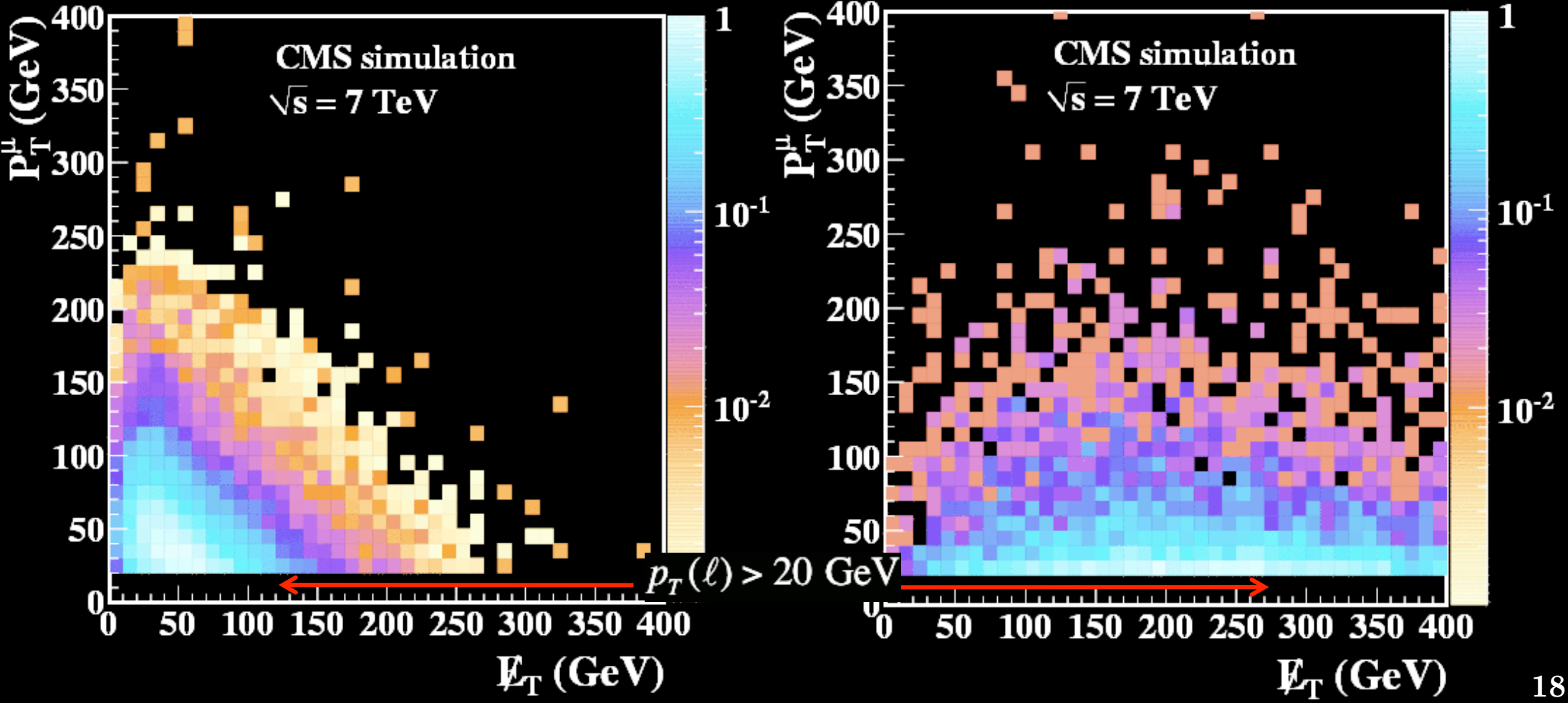
Three sources of MET:

1. Neutrino p_T
2. Resolutions
3. Missed MET



Predicting the MET spectrum; ν p_T

Don't know tail of top quark p_T distribution.
But, subsequent decay is well predicted.
Measure μ p_T spectrum to obtain ν p_T spectrum.



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But, subsequent decay is well predicted.
Measure μ p_T spectrum to obtain ν p_T spectrum.

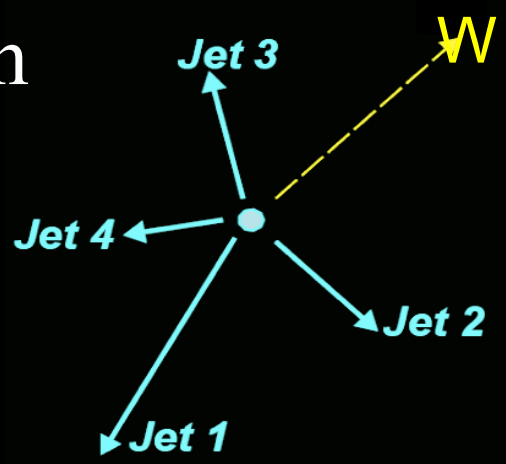
There are several important corrections due to:

- Polarization
- Lepton p_T threshold
- Contamination to μ p_T spectrum

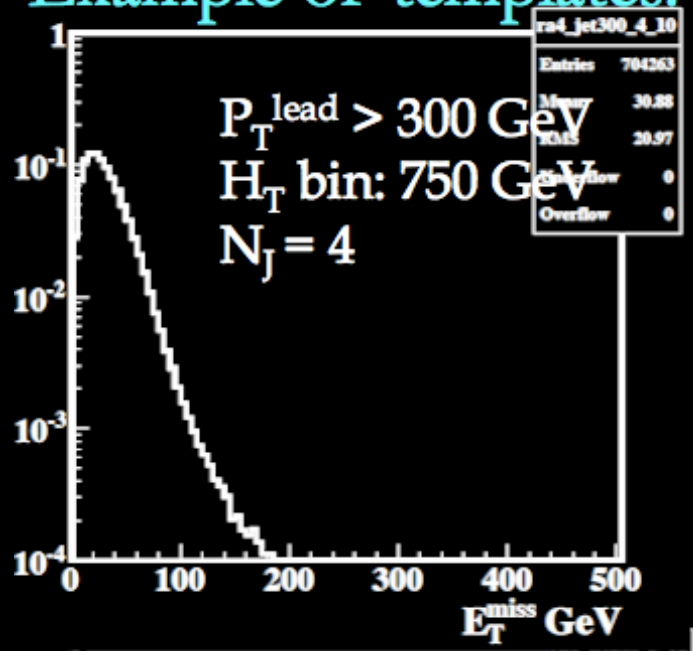
Small & measureable in Monte Carlo simulation

Predicting the MET spectrum; resolution

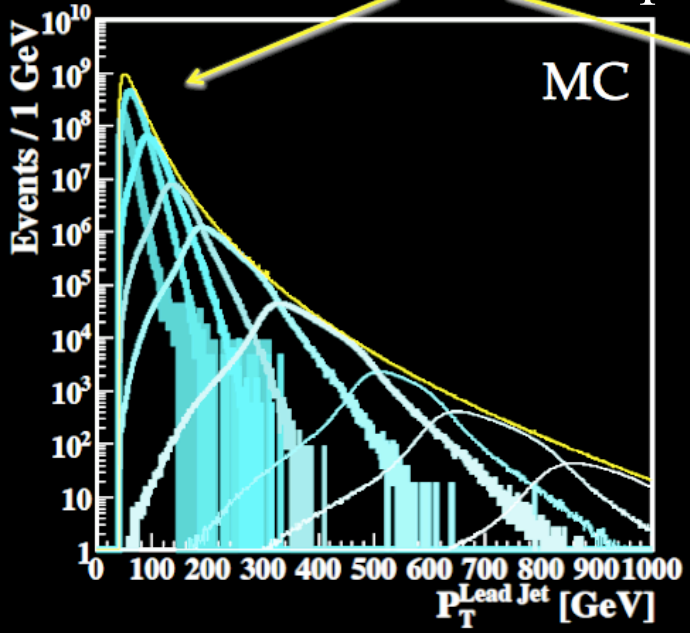
Resolution effects come from the jet system; measure it in equivalent events and add vectorially.

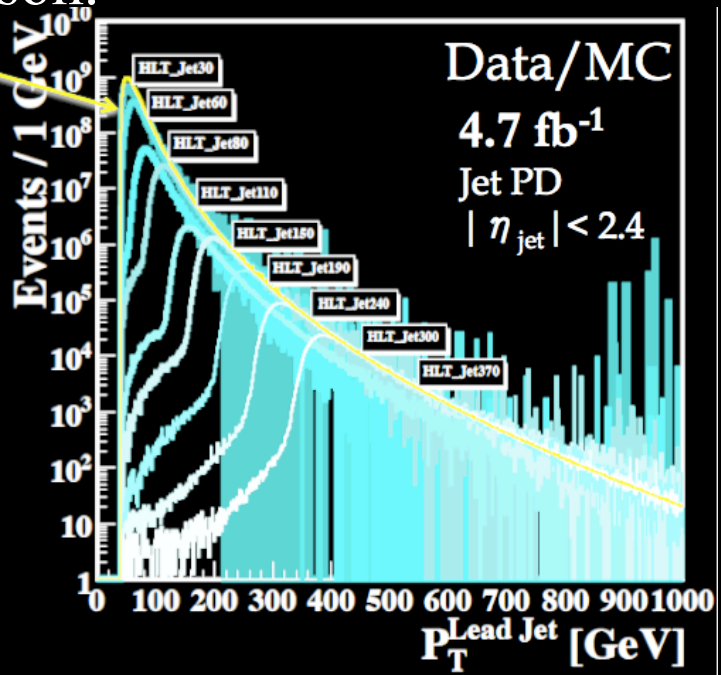


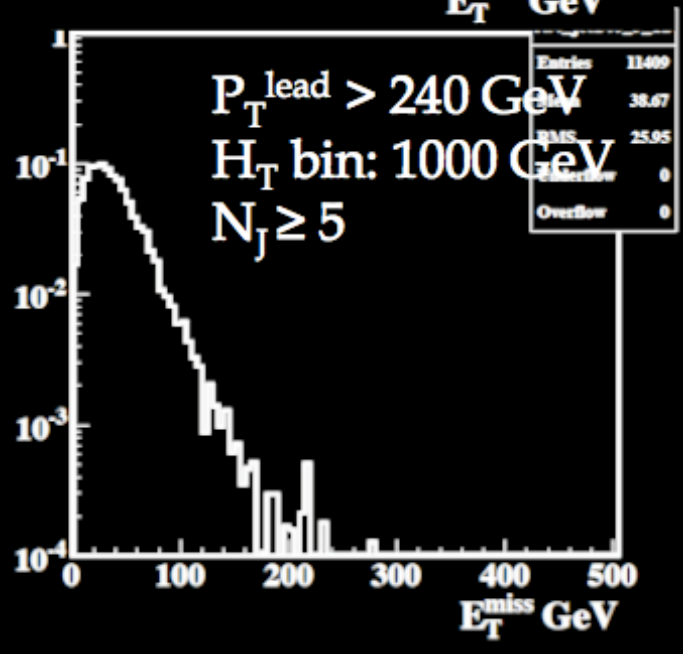
Example of templates:



O(1B) events of data, "stitched" together.
Reasonable MC comparison.







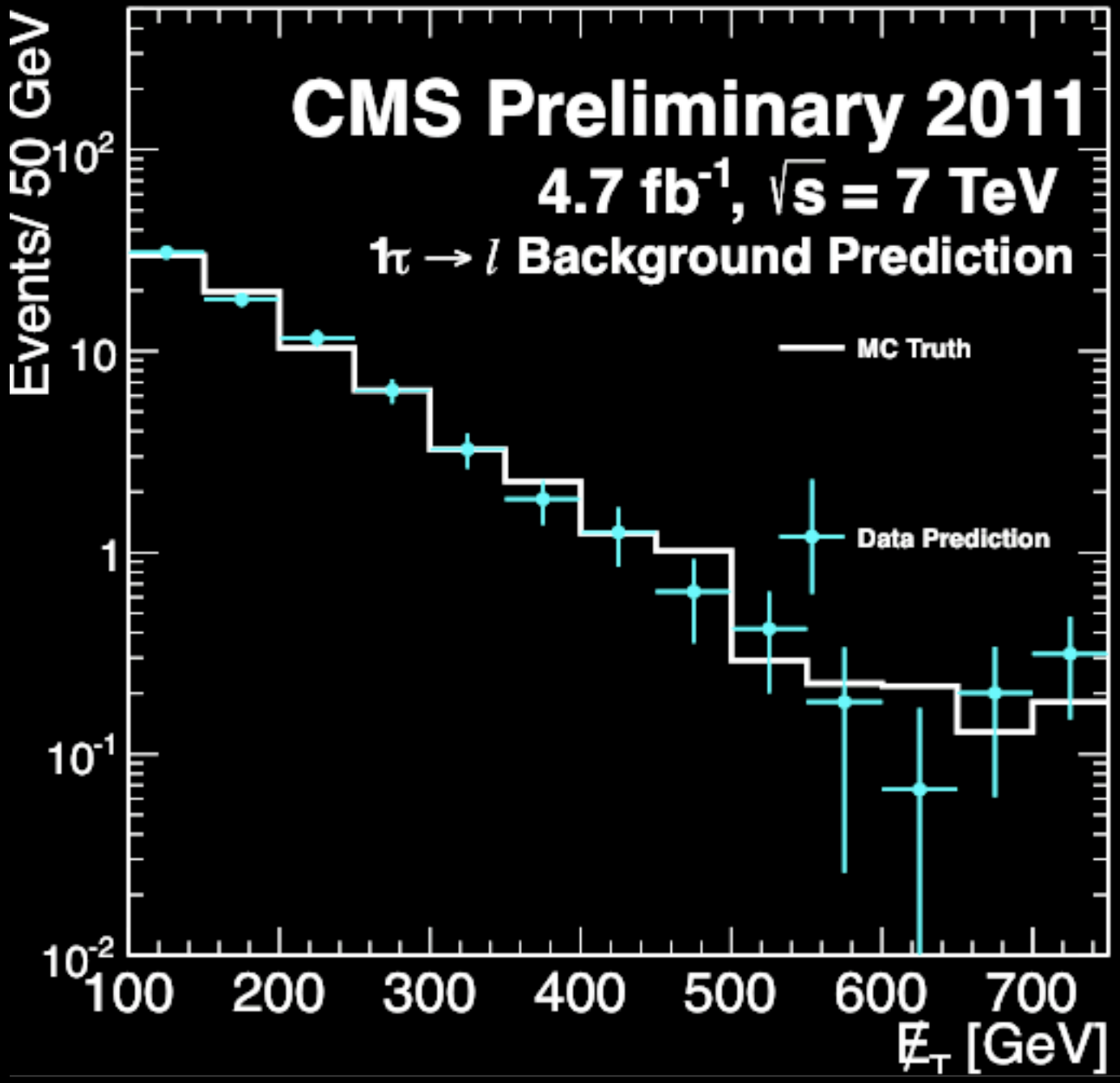
Predicting the MET spectrum; Missing MET

"Missing MET" from other neutrinos or lost leptons:

$W \rightarrow \tau\nu \rightarrow \mu\nu\nu$

contributes different MET shape.

Measure from μ events with emulated τ decay.



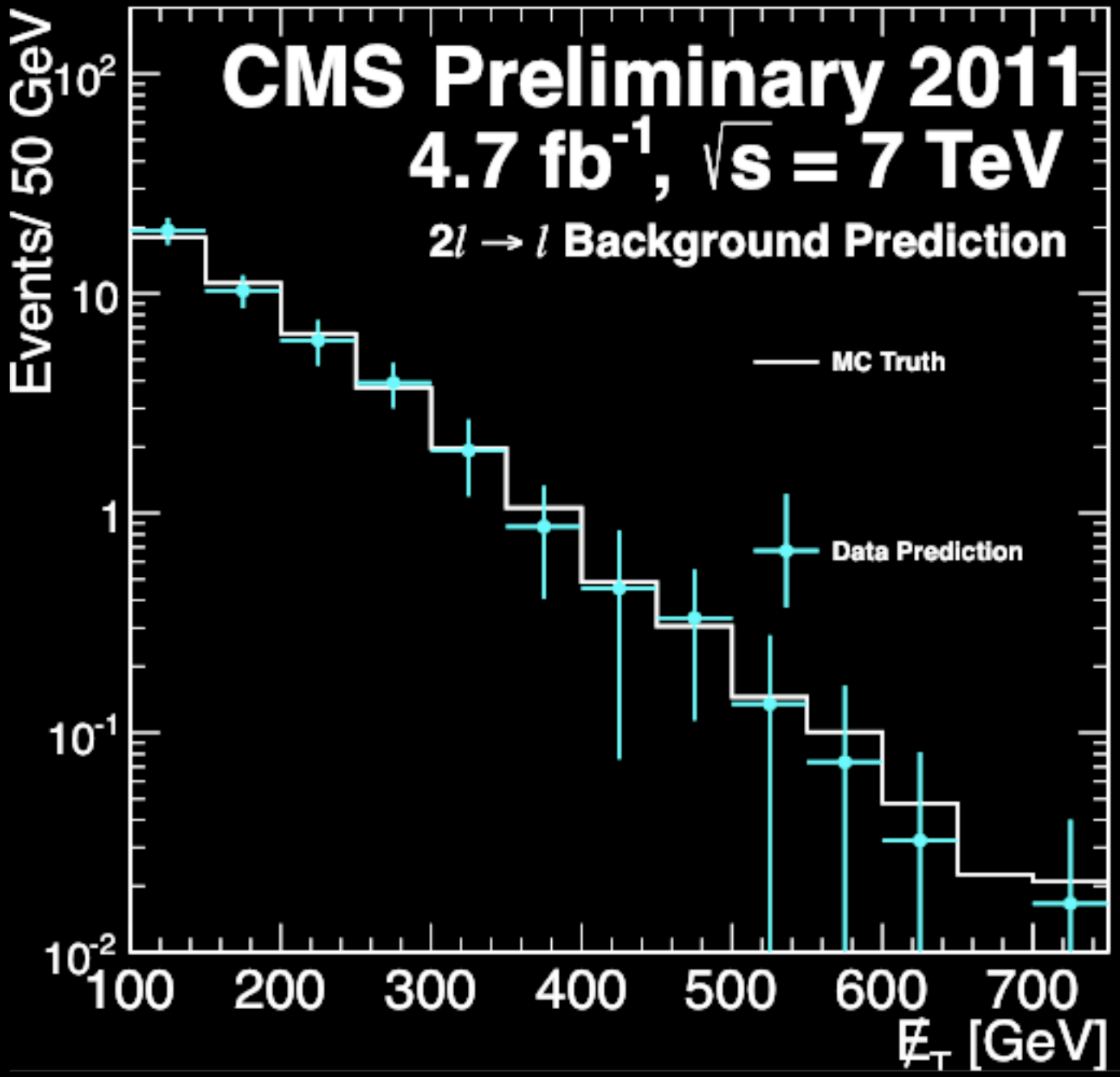
Predicting the MET spectrum; Missing MET

"Missing MET" from other neutrinos or lost leptons:

"Lost dilepton" events with the other W decaying as

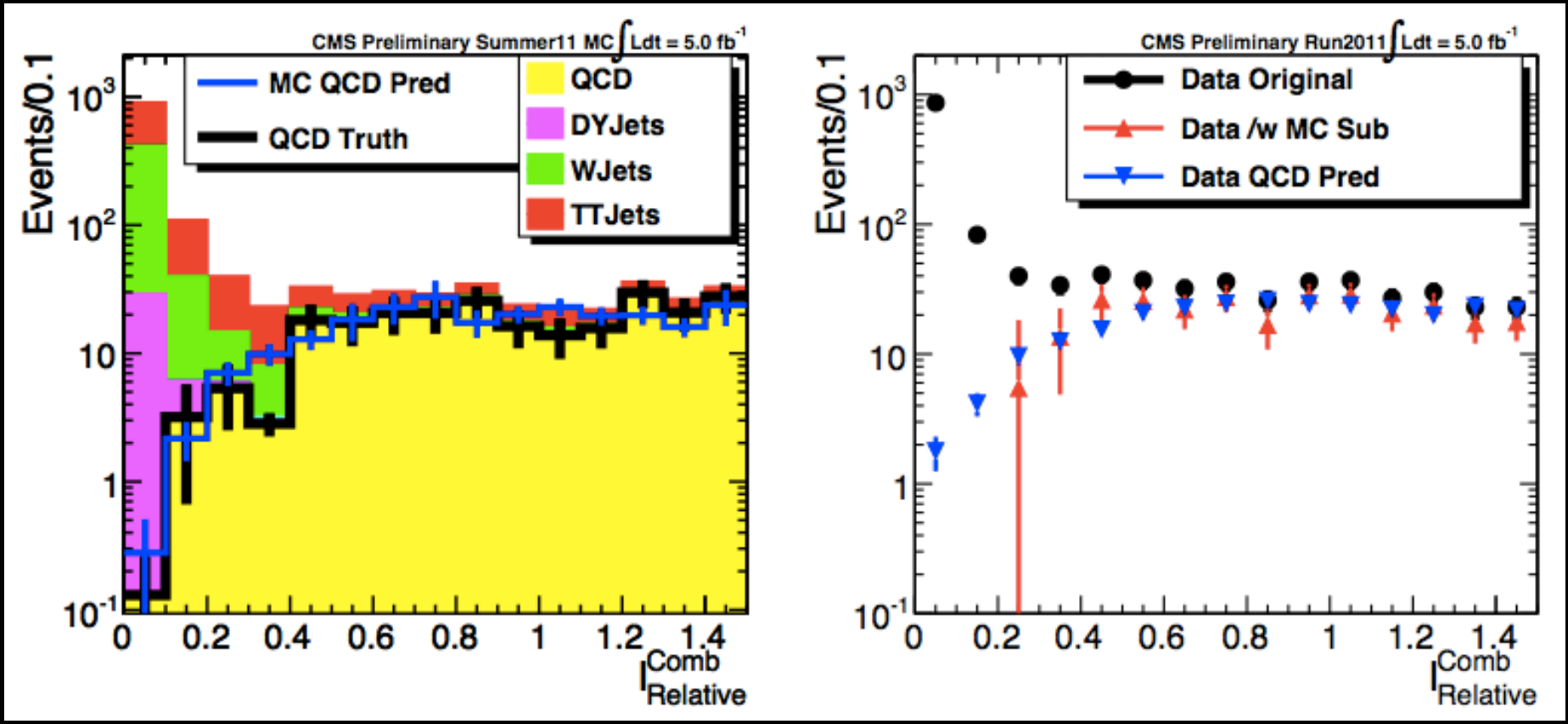
$W \rightarrow \mu\nu$ or
$W \rightarrow \tau\nu$ (hadronic)

Measure with dilepton events and τ emulation.



Predicting the MET spectrum; QCD

Multijet events contribute via fake leptons to either the μ p_T prediction sample or the final high MET sample.
Measured based on isolation shape extrapolation.



Negligible for MET; small for μ p_T; large for e p_T.
Prediction uses only μ p_T spectrum, w/ a μ→μ+e correction.

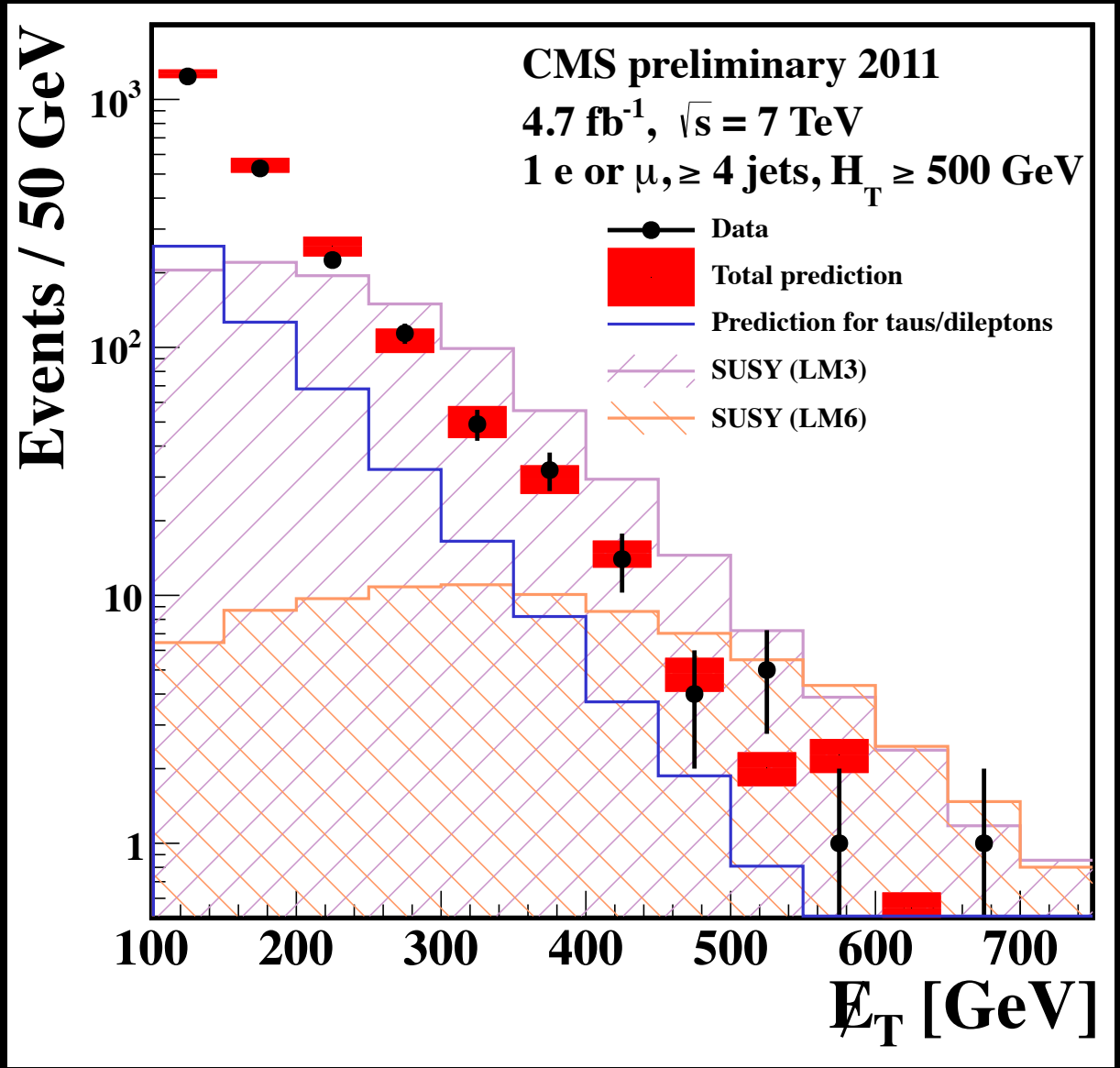
Predicting the MET spectrum; results

Single lepton MET contribution dominates.

Uncertainty dominated by muon sample size.

Benchmark models would contribute to both high and low MET regions.

HT > 500 GeV



Predicting the MET spectrum; results

Single lepton MET contribution dominates.

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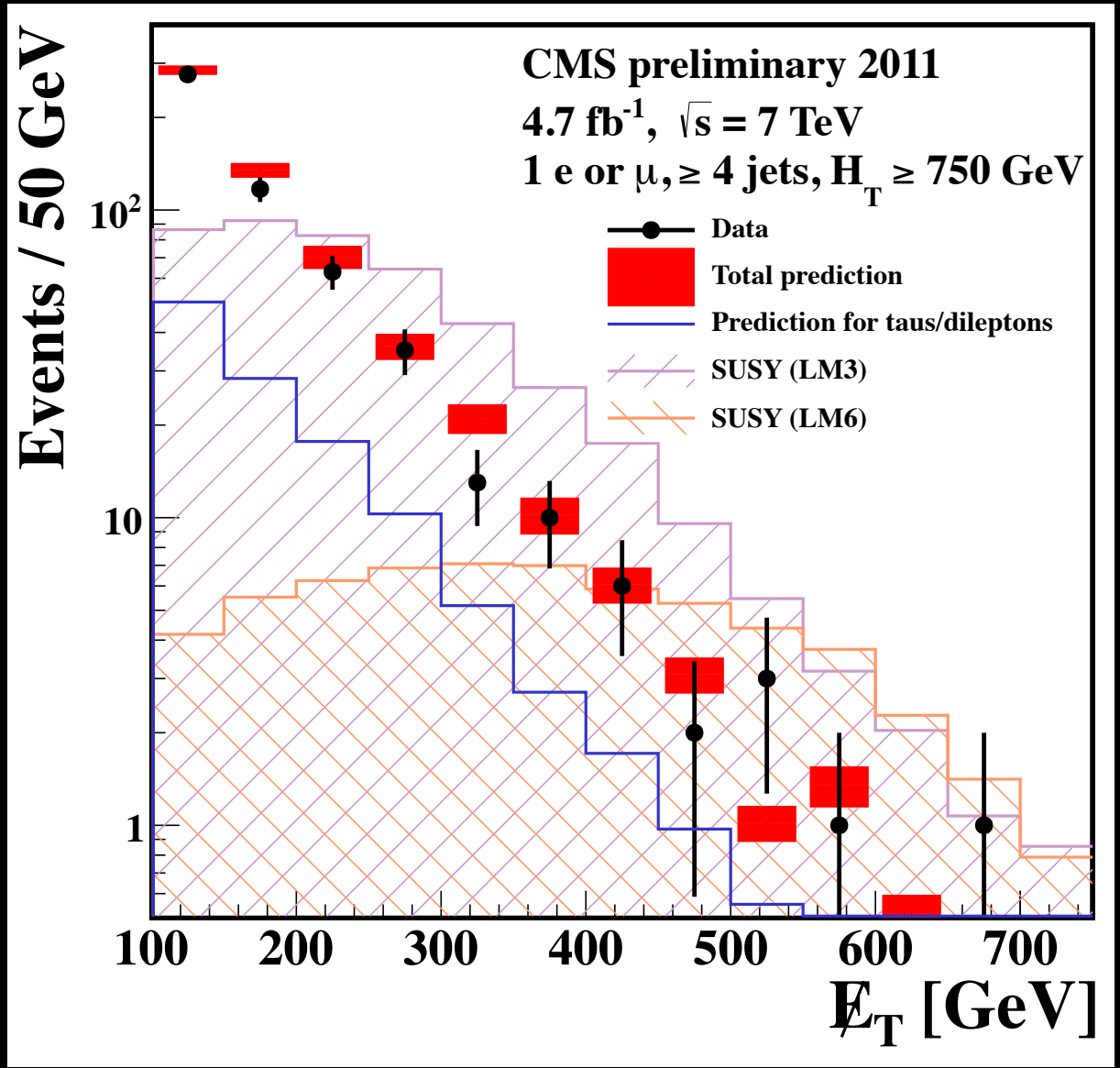
HT > 750 GeV



Predicting the MET spectrum; results

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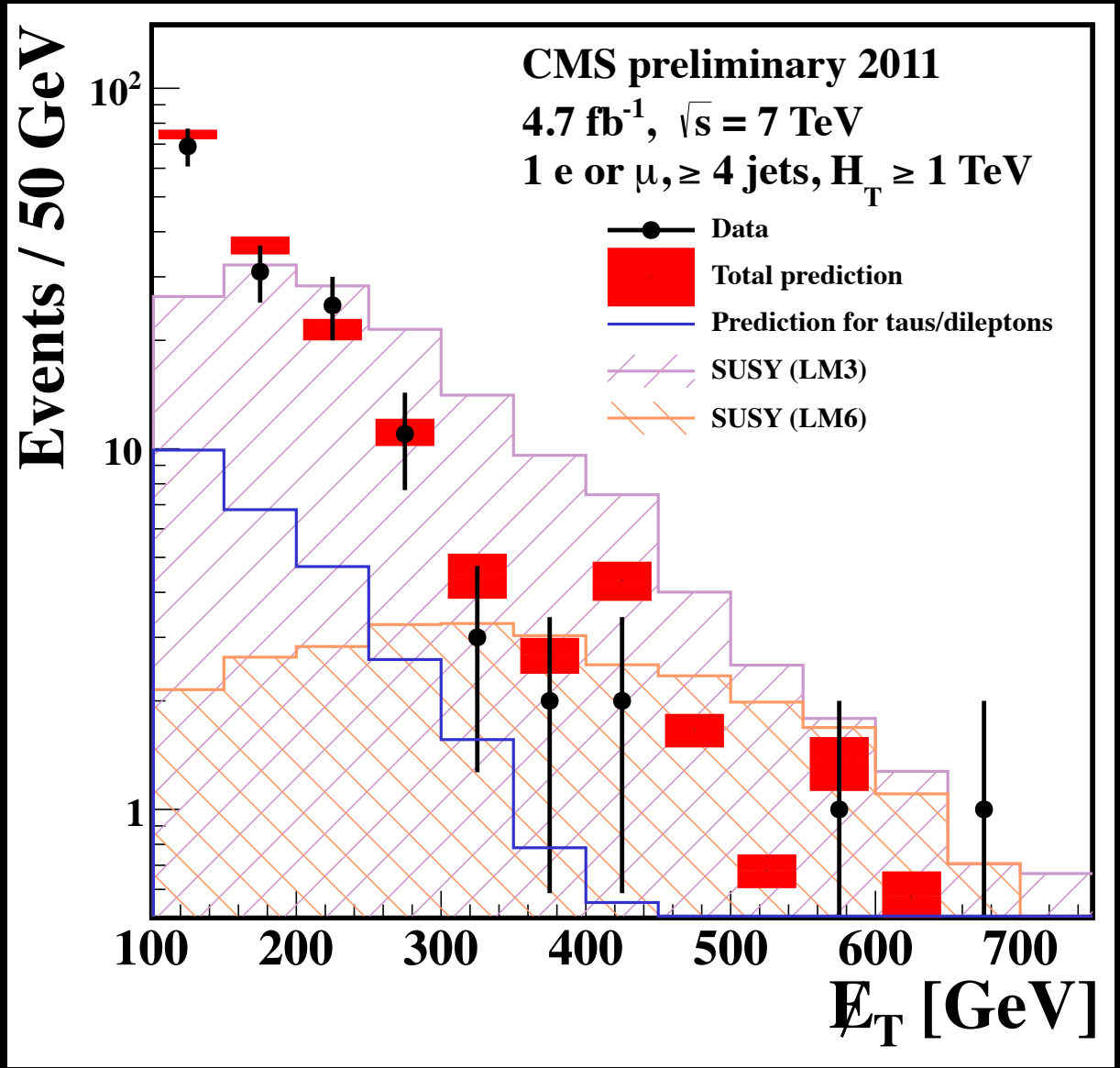
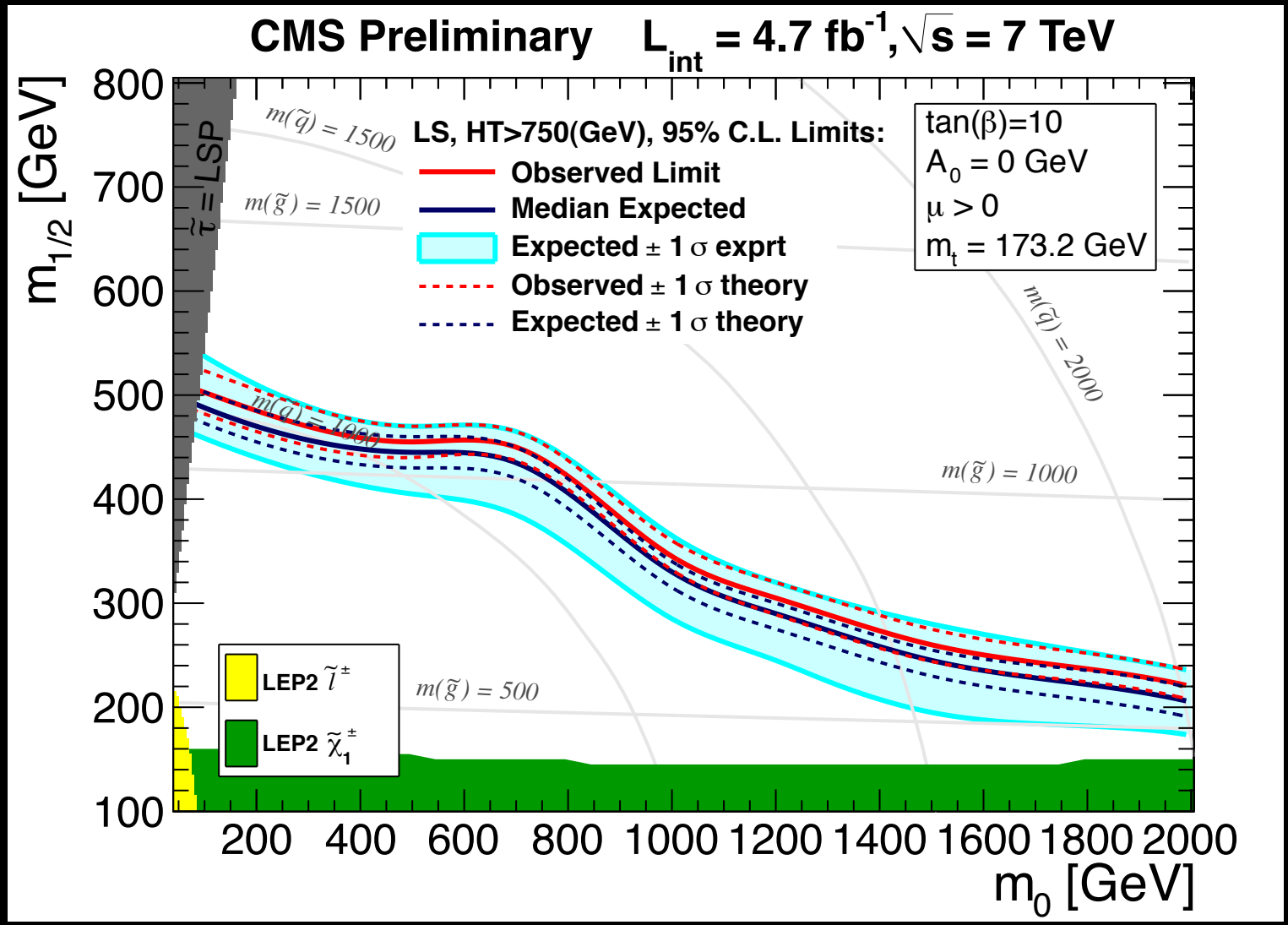
HT > 1000 GeV



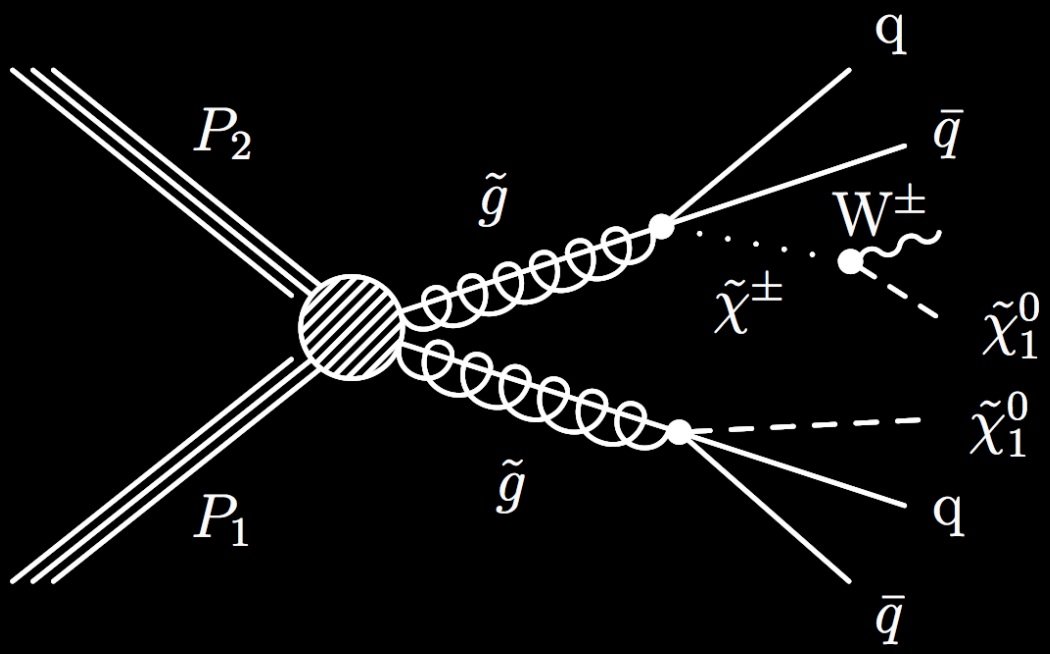
Interpreting the results

The cMSSM plane has been a popular benchmark but it is constrained…

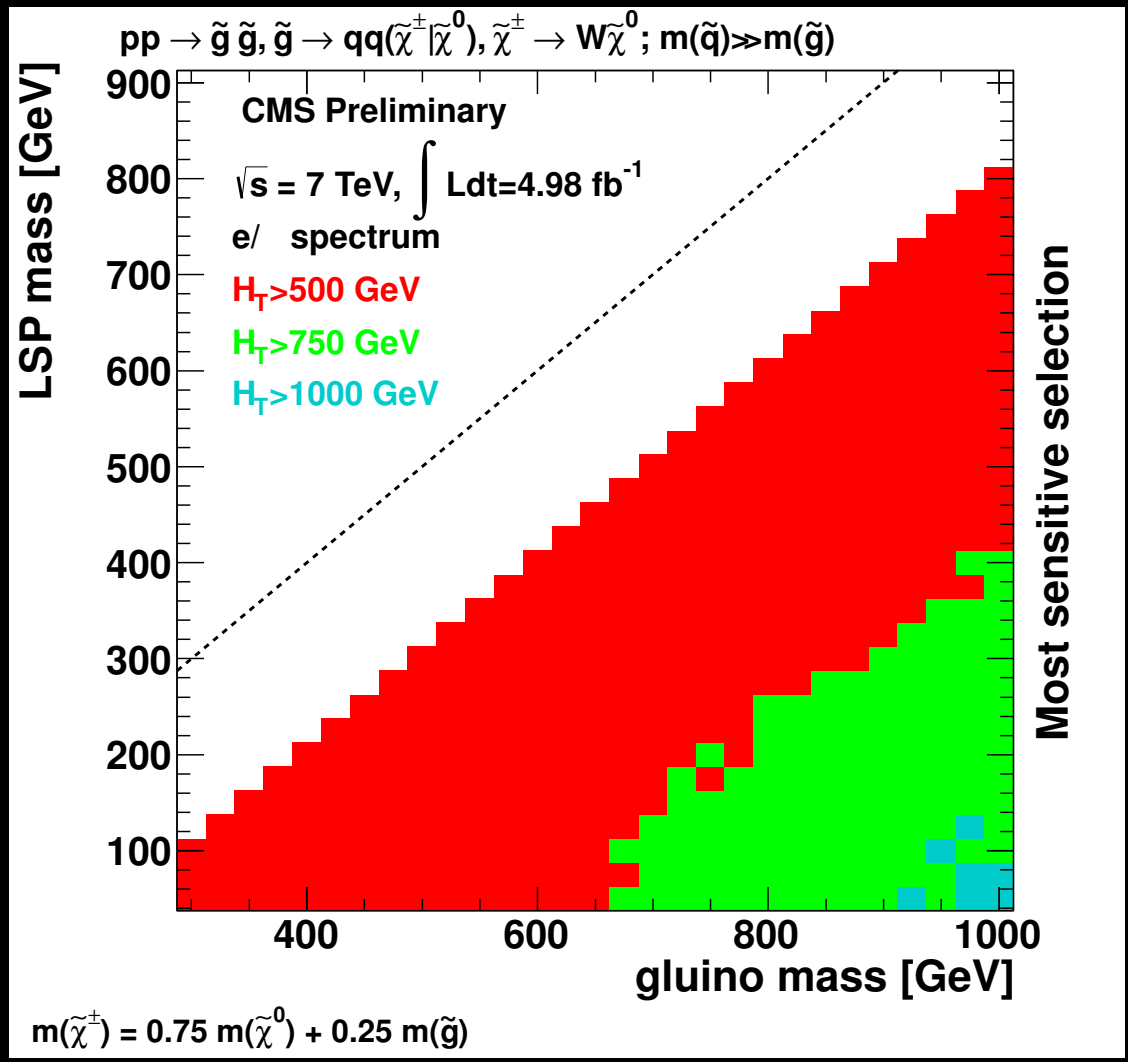


Interpreting the results w/ simplified models

More directly probes sensitivity of the kinematics.
Use gluinos w/ 3-body decays to $\tilde{\chi}^{\pm}$ & $\tilde{\chi}^{0}$.



Higher HT cuts better for higher gluino mass, unless $\tilde{\chi}^{0}$ is heavy.



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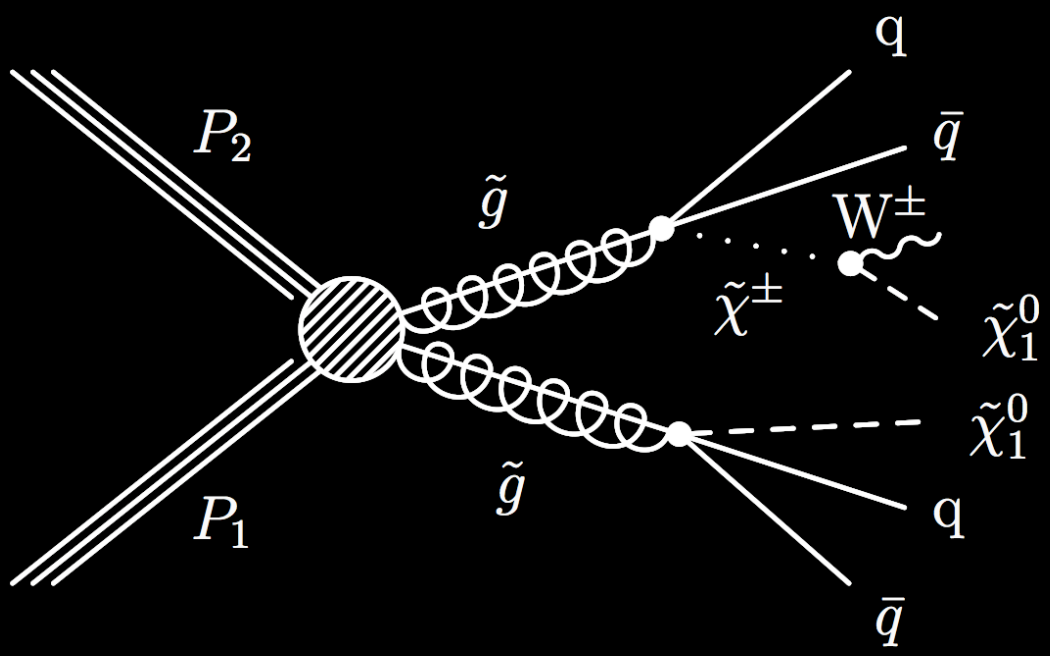
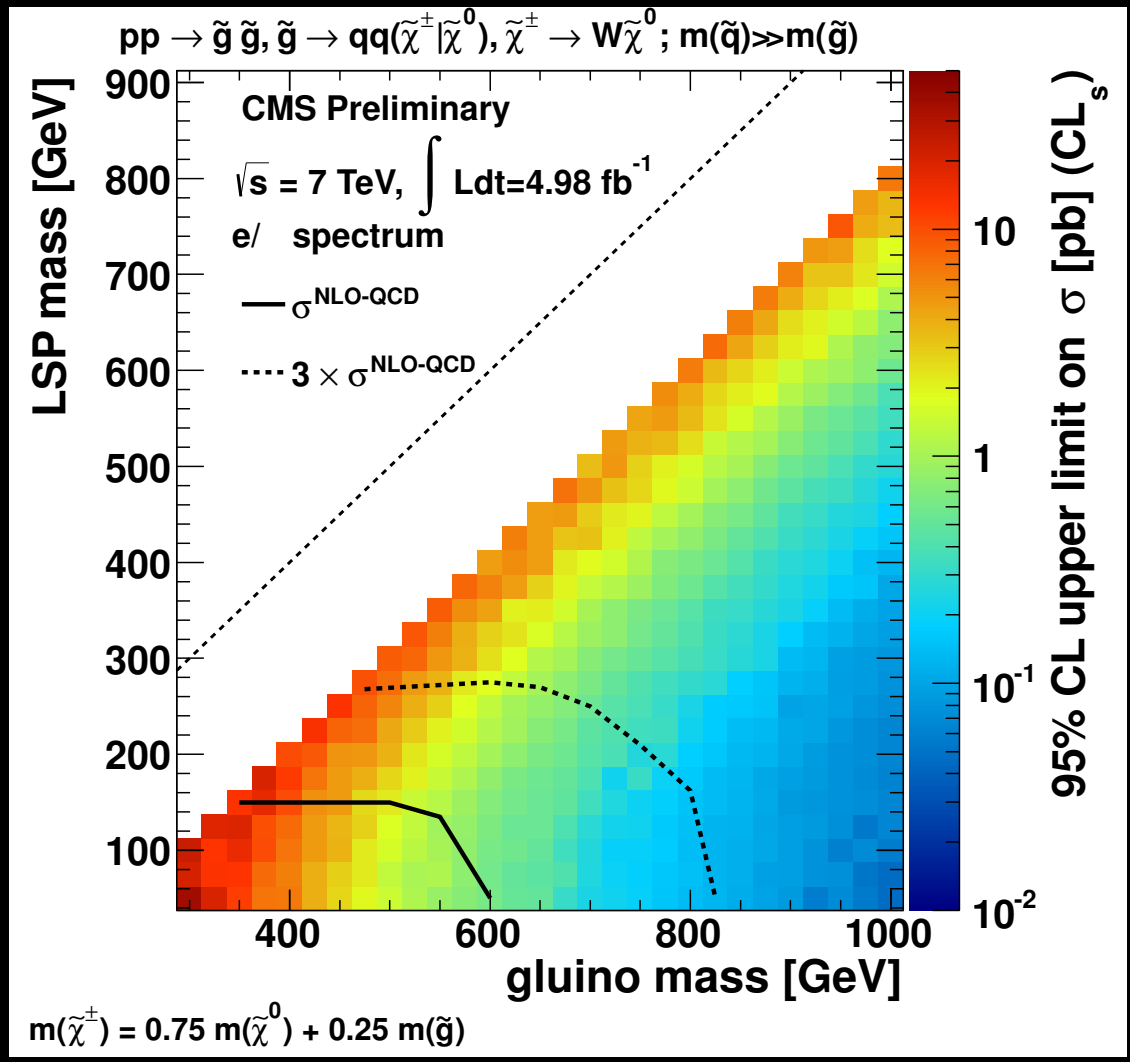


σ limits improve w/ $m_{\tilde{g}}$ and $m_{\tilde{g}} - m_{\tilde{\chi}^0}$.



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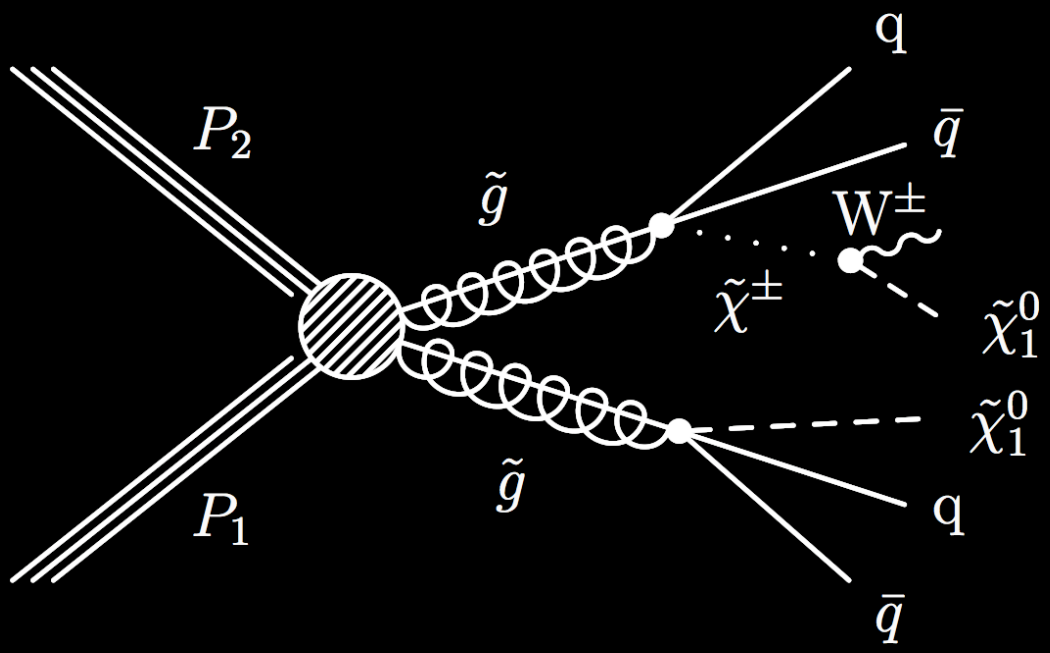


$m_{\tilde{\chi}^{\pm}}$ changes sensitivity
by about a factor of 2
on the cross-section.

I will describe two searches…

Multijets + MET

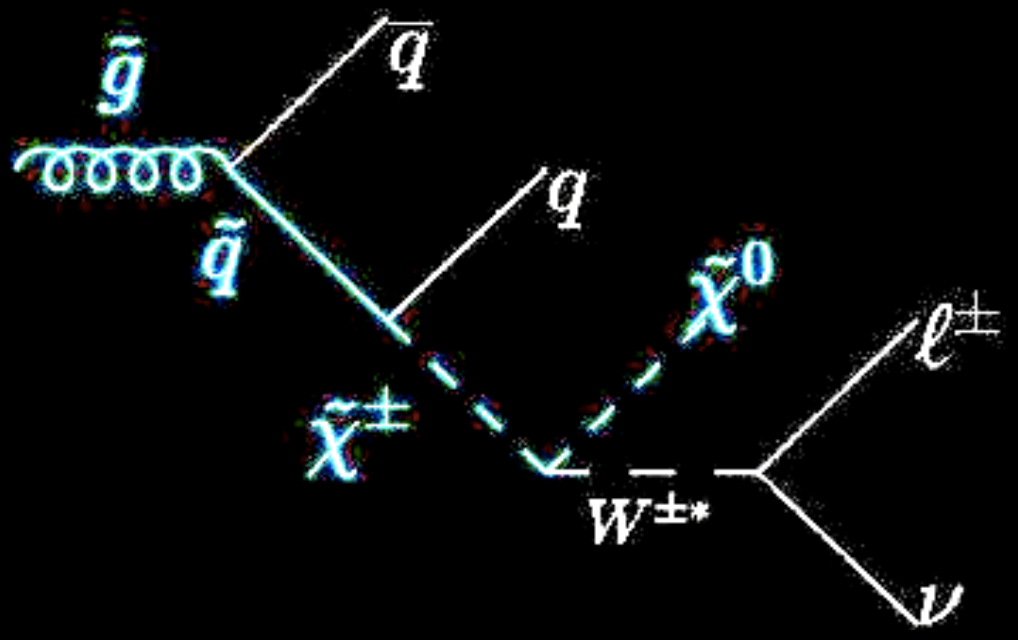
Lepton + jets + MET

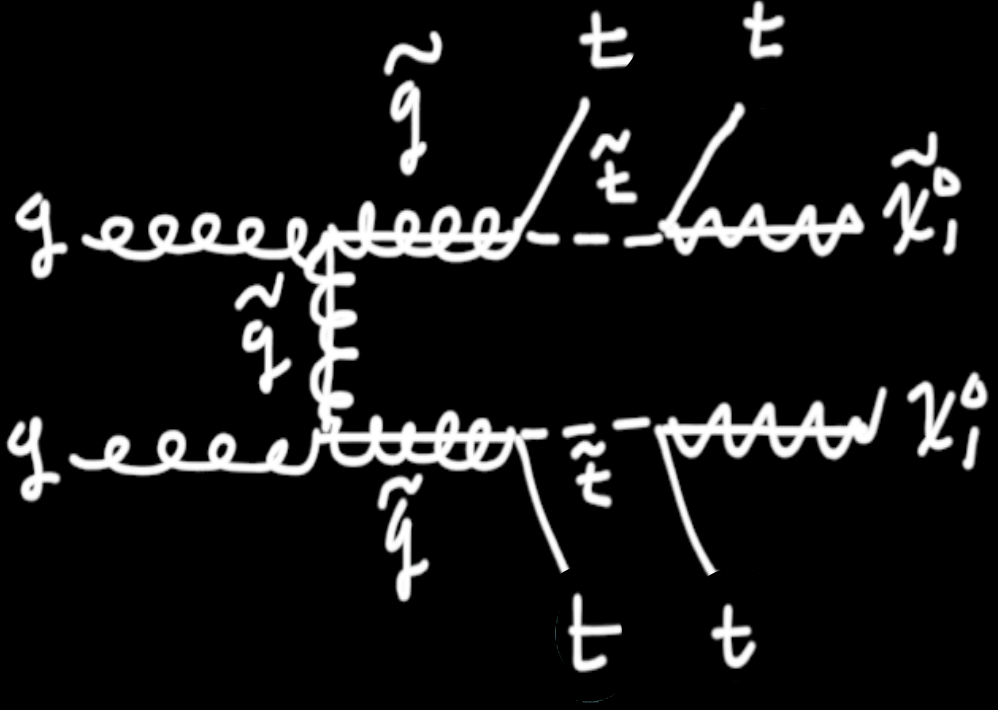
Dileptons + jets + MET

Same sign dileptons + jets + MET

Trileptons + jets + MET

w/ or w/o b-tagged jets





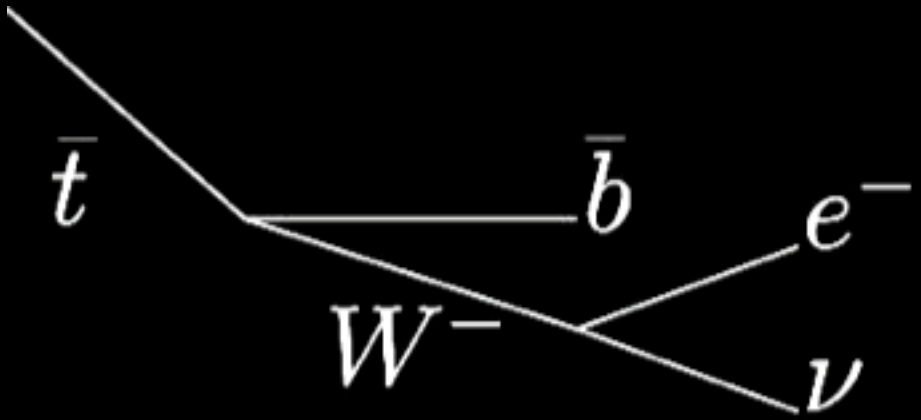
Same-sign dileptons + jets + MET

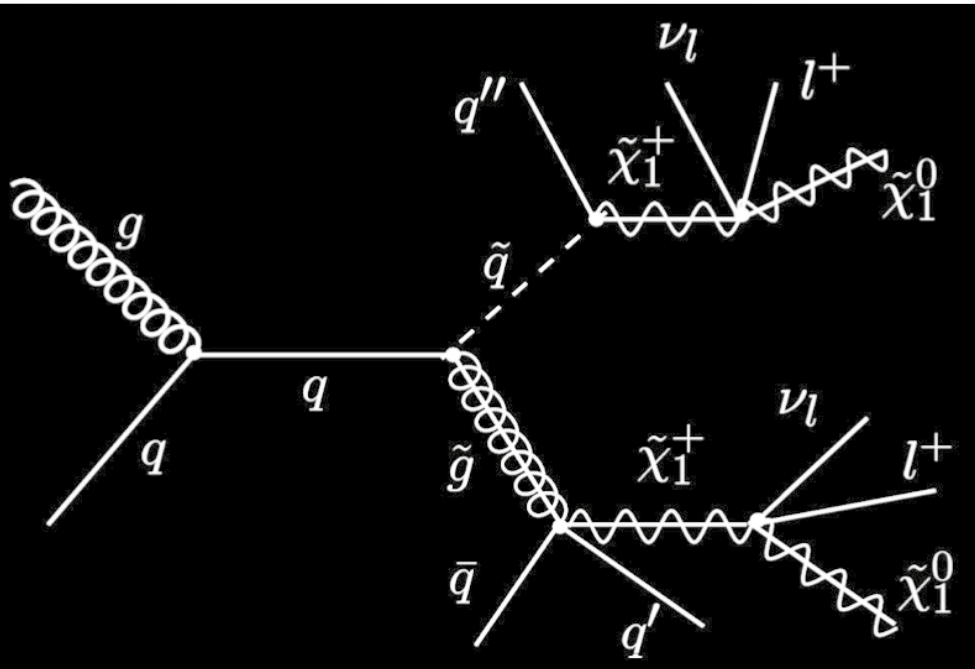
Jets, H_T, and MET

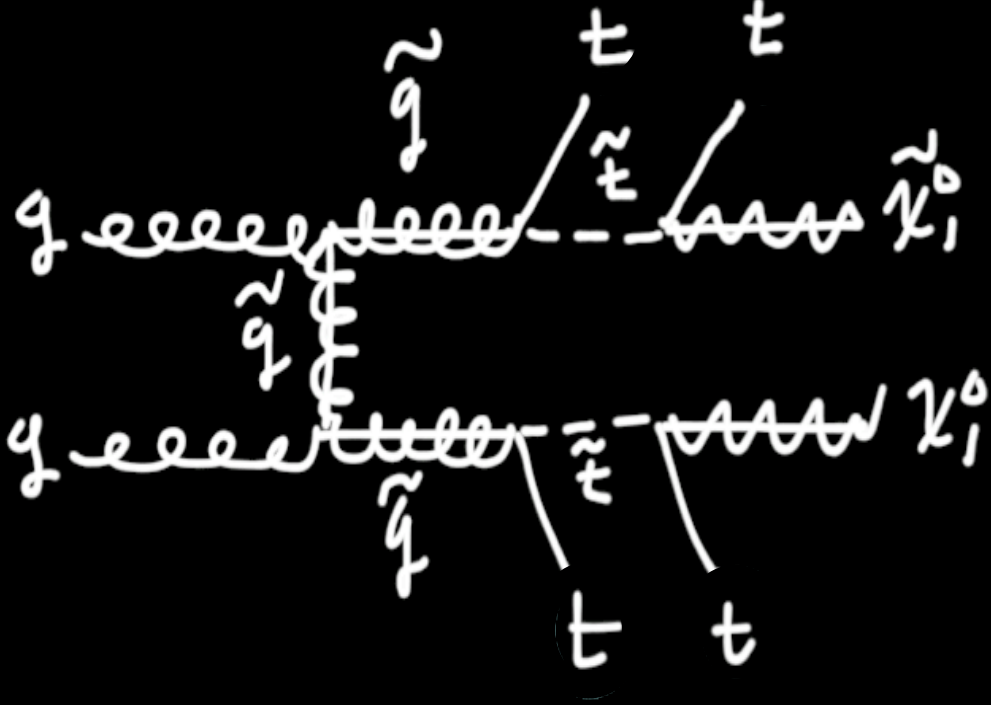
Same-sign dileptons from majorana gluino or multi-tops.

Potentially many b's.

SS is the "anchor".







Same-sign dileptons + jets + MET

Backgrounds from:

- Charge flips
- Irreducible rare processes
- Fake leptons

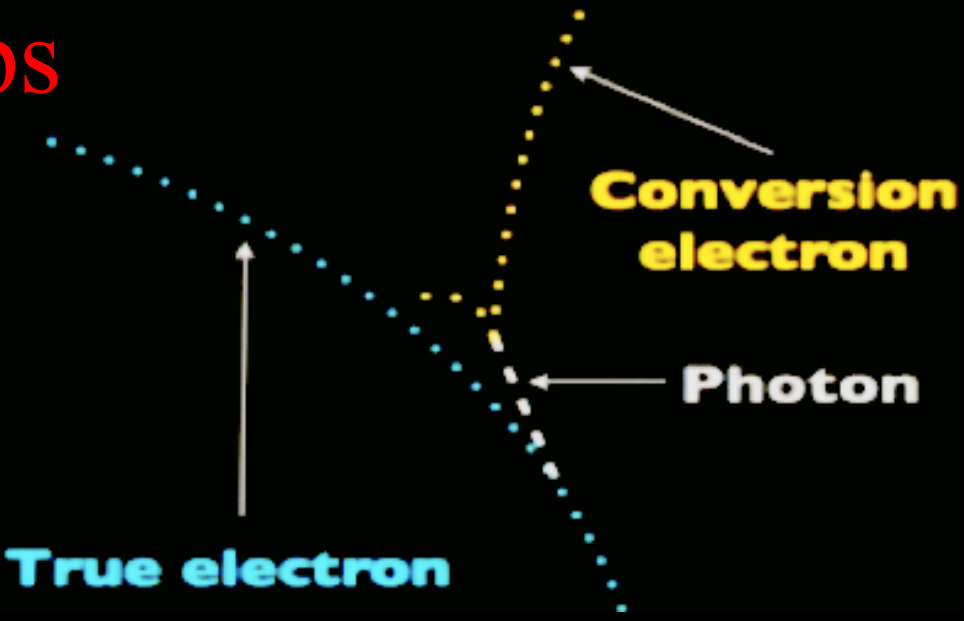
Same-sign dileptons + jets + MET

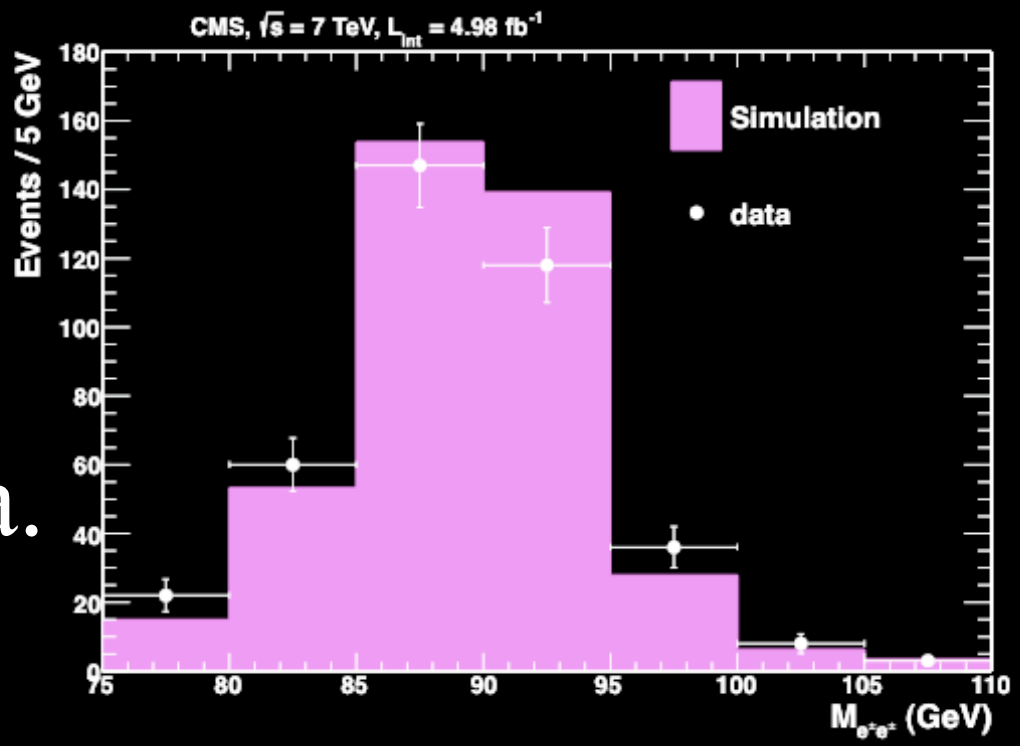
Background from charge flips

Negligible mis-assignment from resolution effects; the only source for μ's.

Electron brem's dominate.

Calculated w/ simuluation
η dependent: 1.0-30 x 10^{-4}
Calibrated w/ $Z \rightarrow e^{\pm}e^{\pm}$ data.

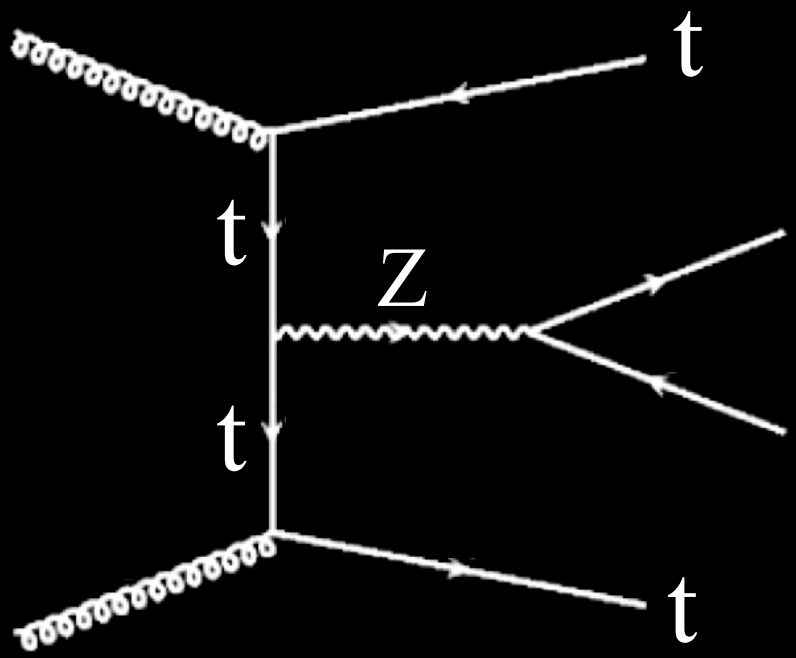


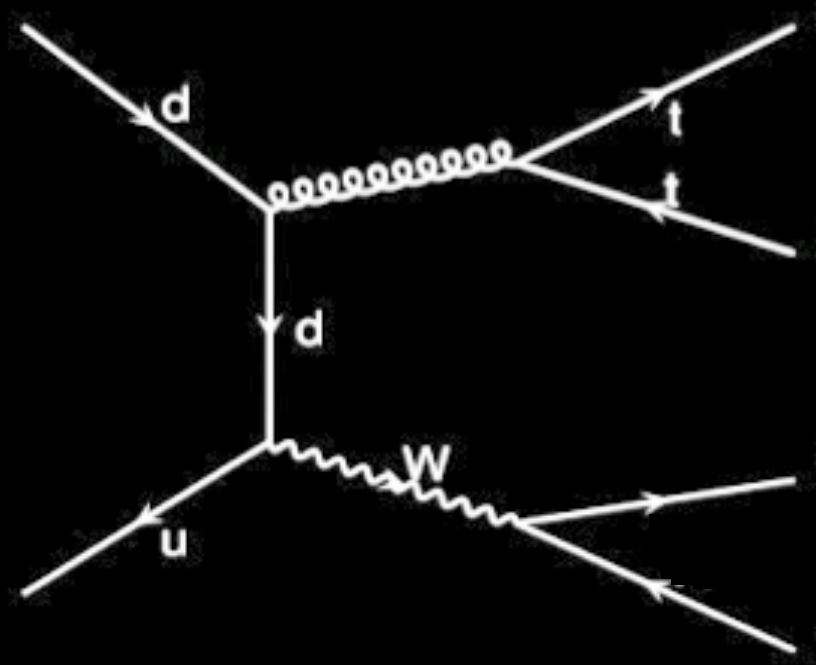


Same-sign dileptons + jets + MET

Background from rare processes

ttW, ttZ, $W^{\pm}W^{\pm}qq$, WZ, WWW, WWZ.
Not yet observed, but calculable.
Use NLO σ with 50% uncertainty.



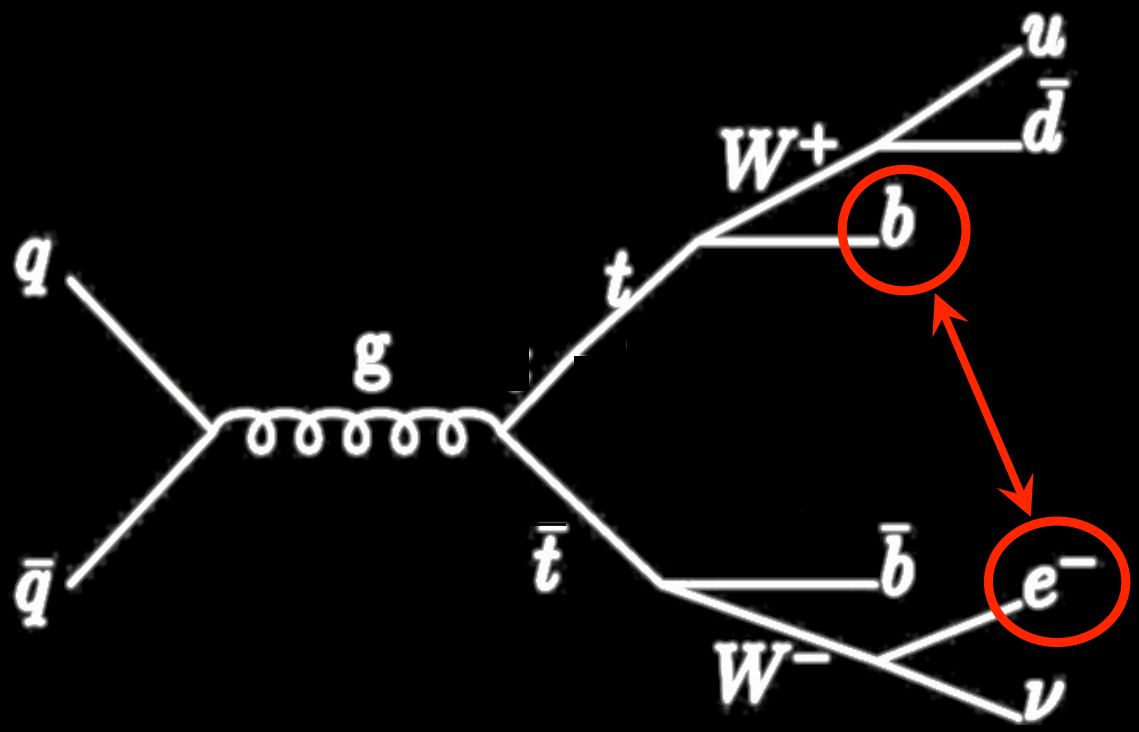


Same-sign dileptons + jets + MET

Background from fake leptons dominates.

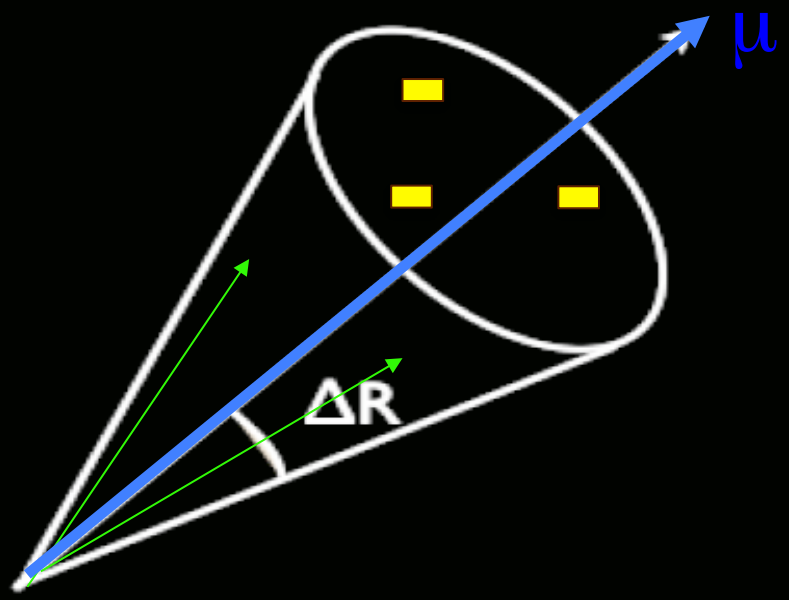
- Fake lepton from jet.
- Fake lepton from semi-leptonic b-decay.

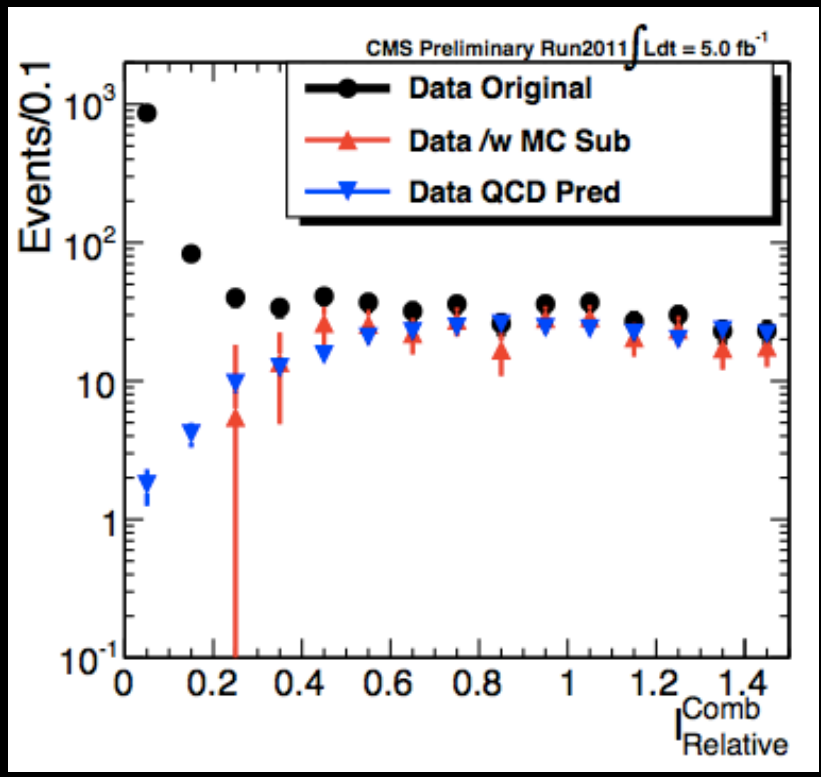
b-daughters dominate,
particularly for μ case.



Same-sign dileptons + jets + MET

Measure fake lepton background using the isolation distribution: Iso $\equiv \Sigma_{cone}$ E summing tracks and calorimeter deposits around the lepton.



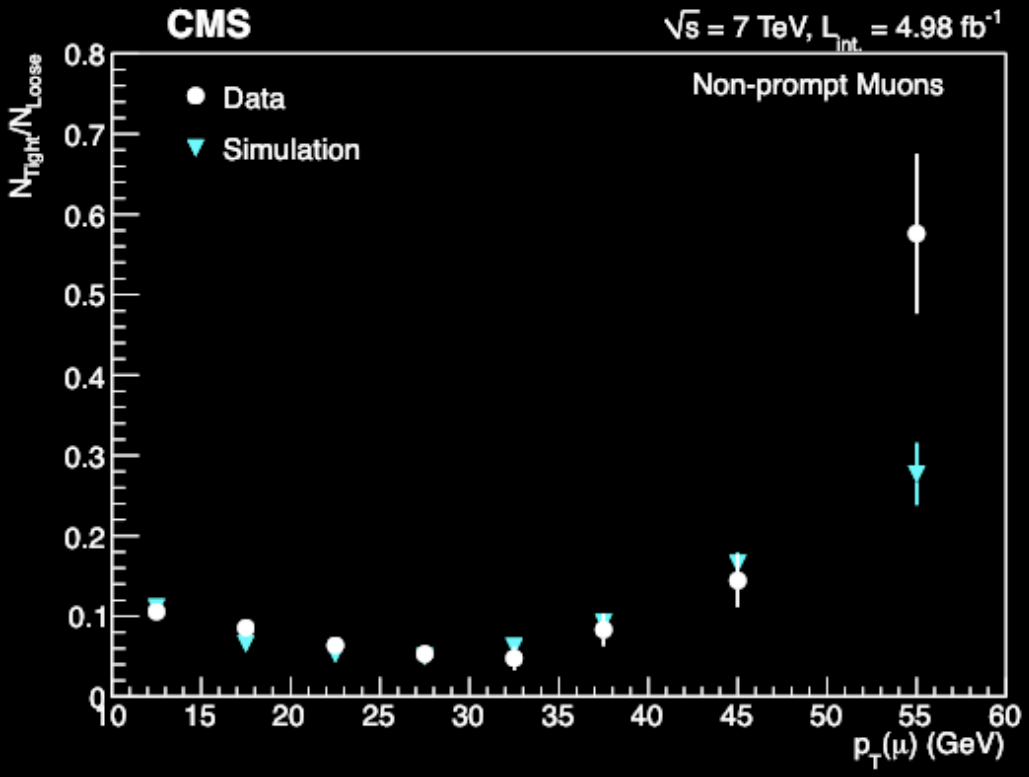


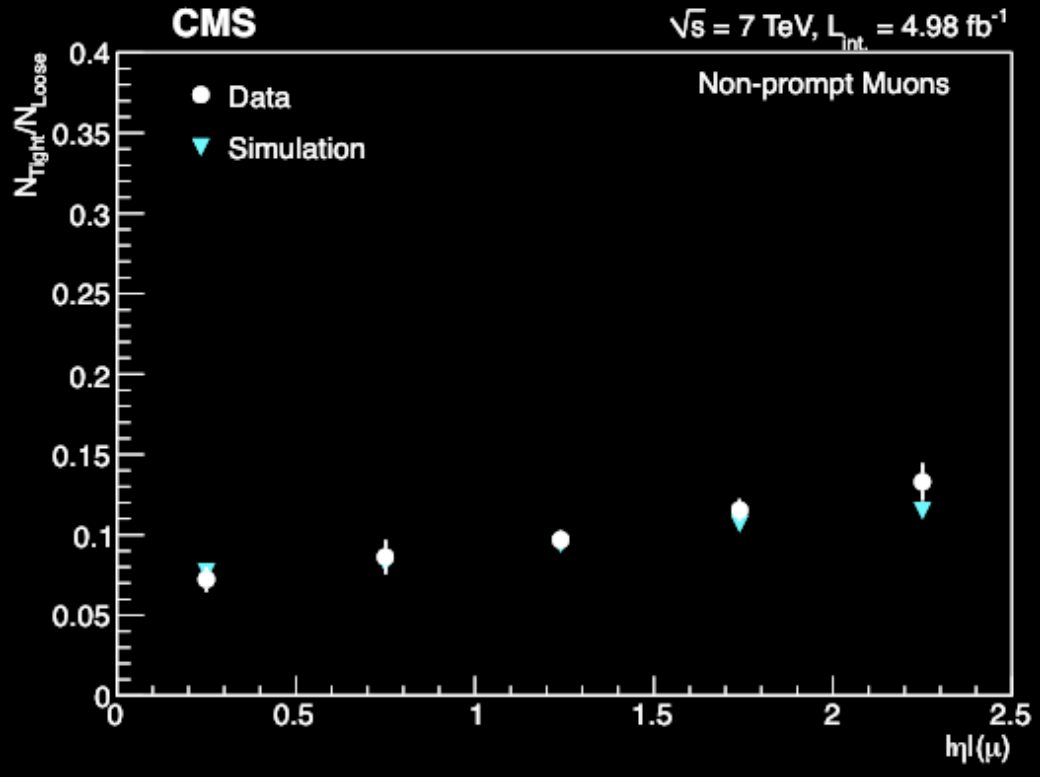
Relative Iso divides out lepton p_T.

Same-sign dileptons + jets + MET

Measure "fake rate" a.k.a. "tight-to-loose ratio" in generic jet data as a function of the kinematics.

For muons, loose ≡ Iso<0.4 and $|d_0|$<2mm

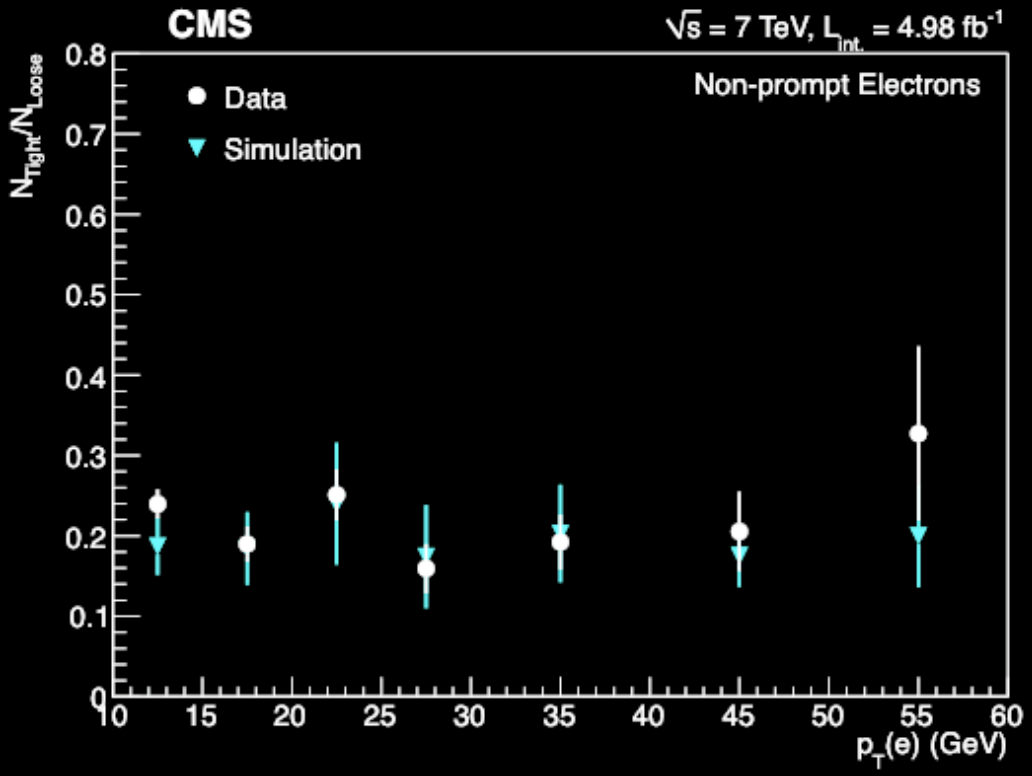


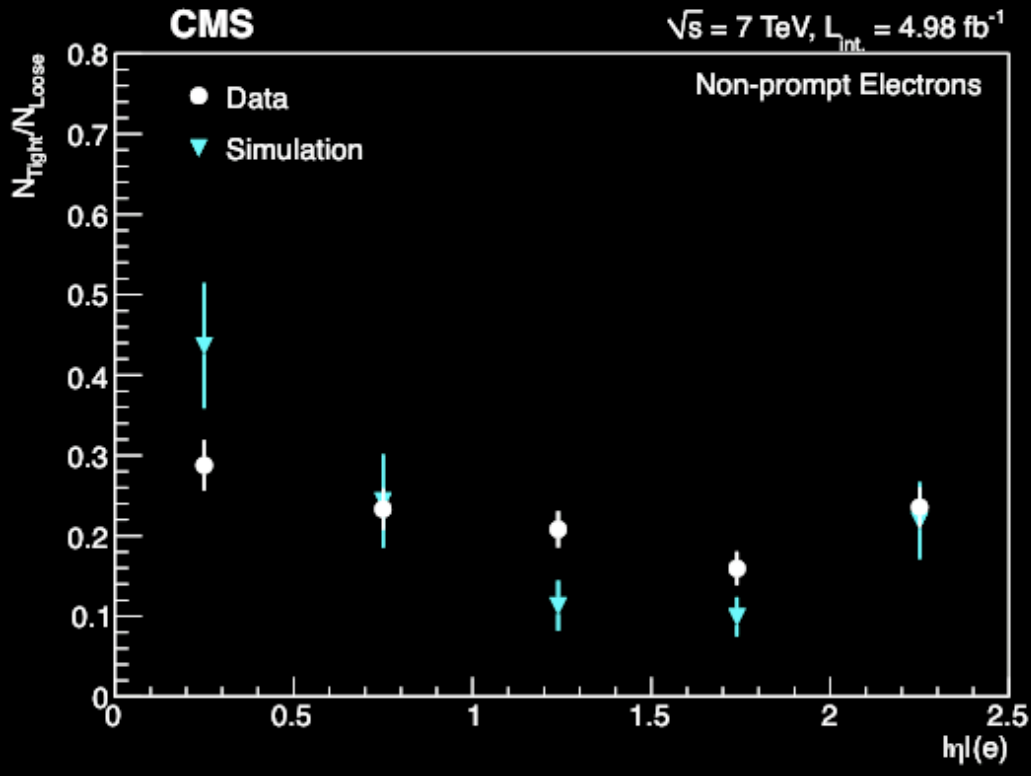


Same-sign dileptons + jets + MET

Measure "fake rate" a.k.a. "tight-to-loose ratio" in generic jet data as a function of the kinematics.

For electrons, loose ≡ Iso<0.6 and relaxed ID

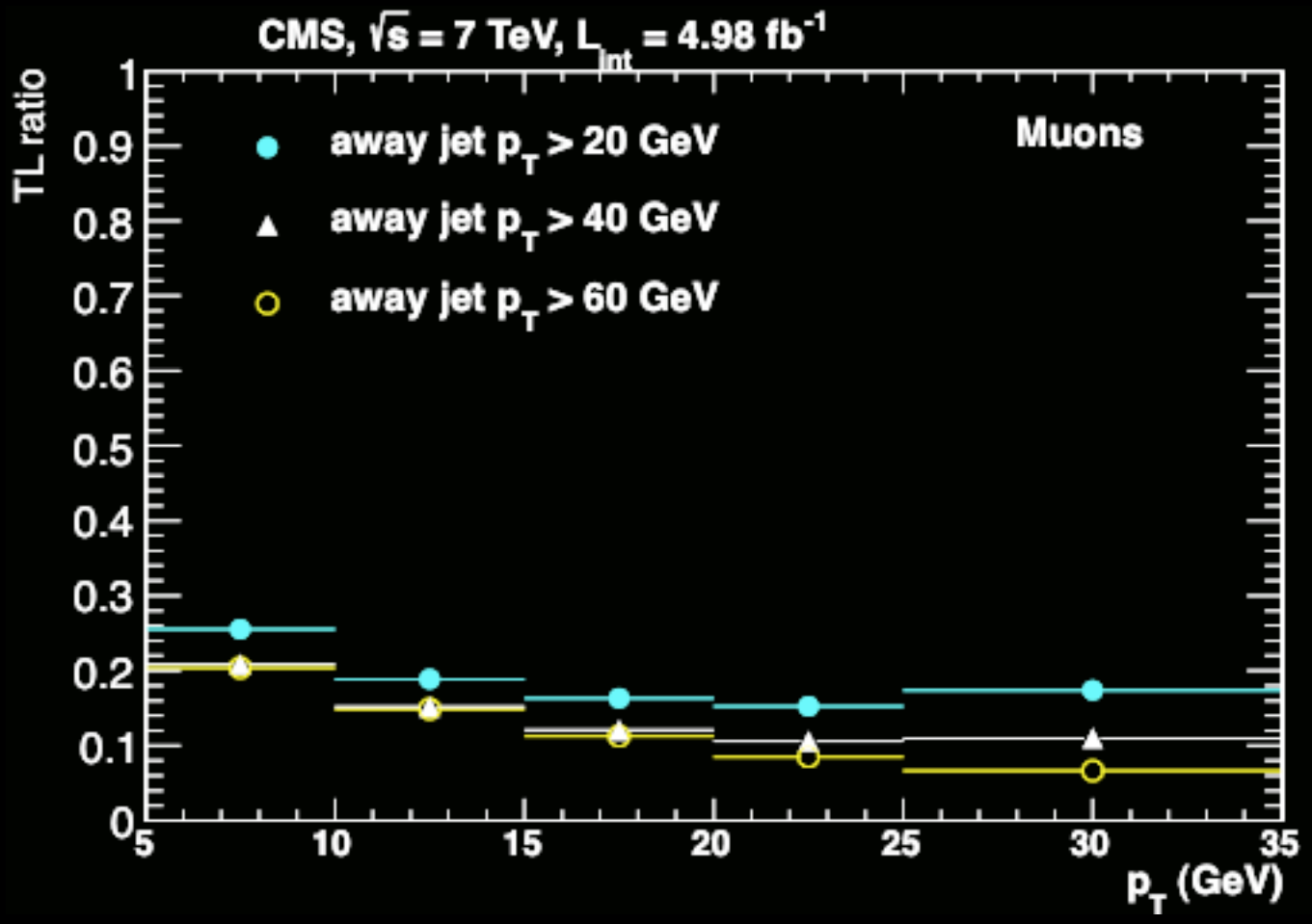




Same-sign dileptons + jets + MET

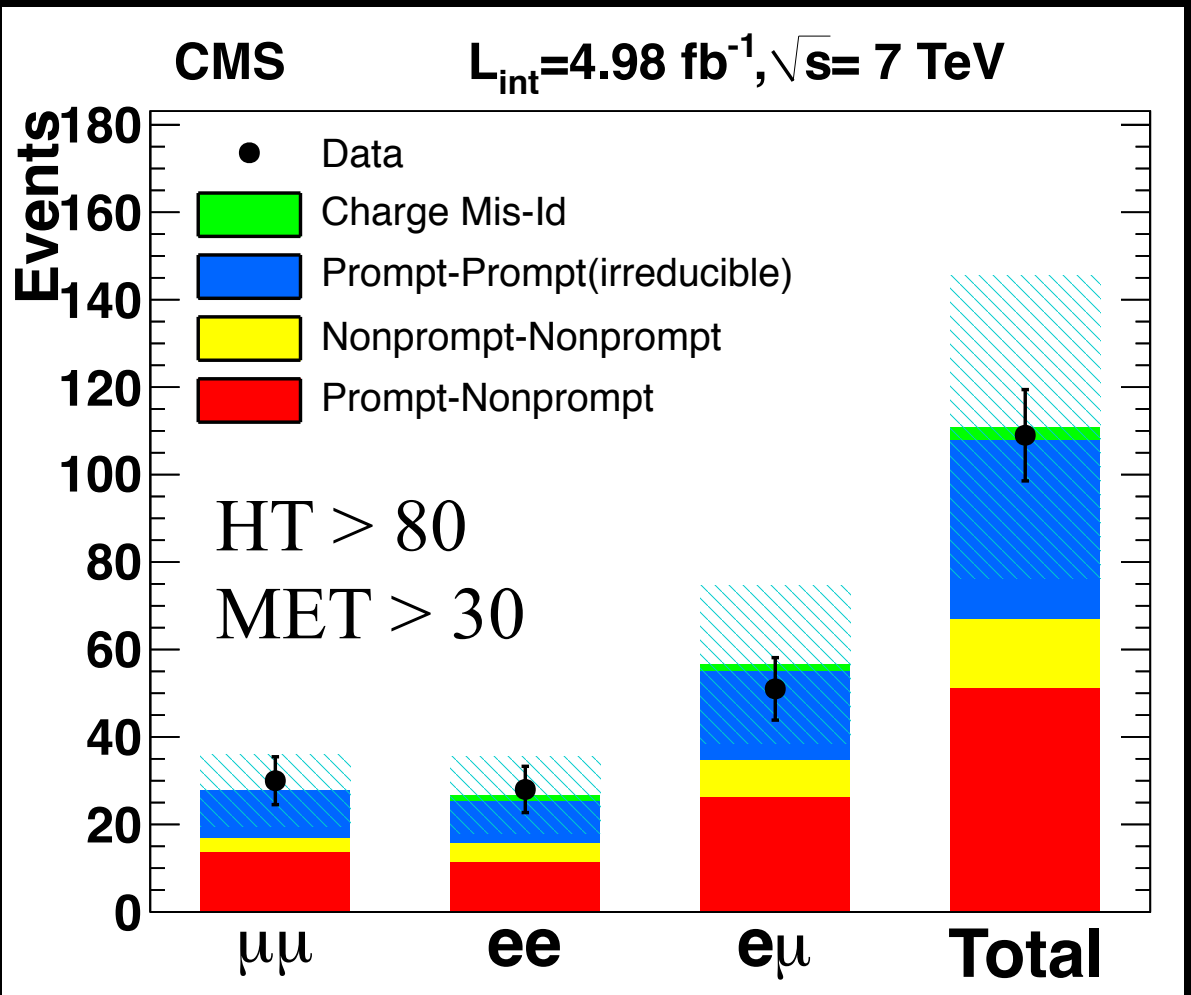
The fake rates depend strongly on kinematics, e.g., flavor content, particularly for electrons, and parton p_T, measured with away jet p_T.

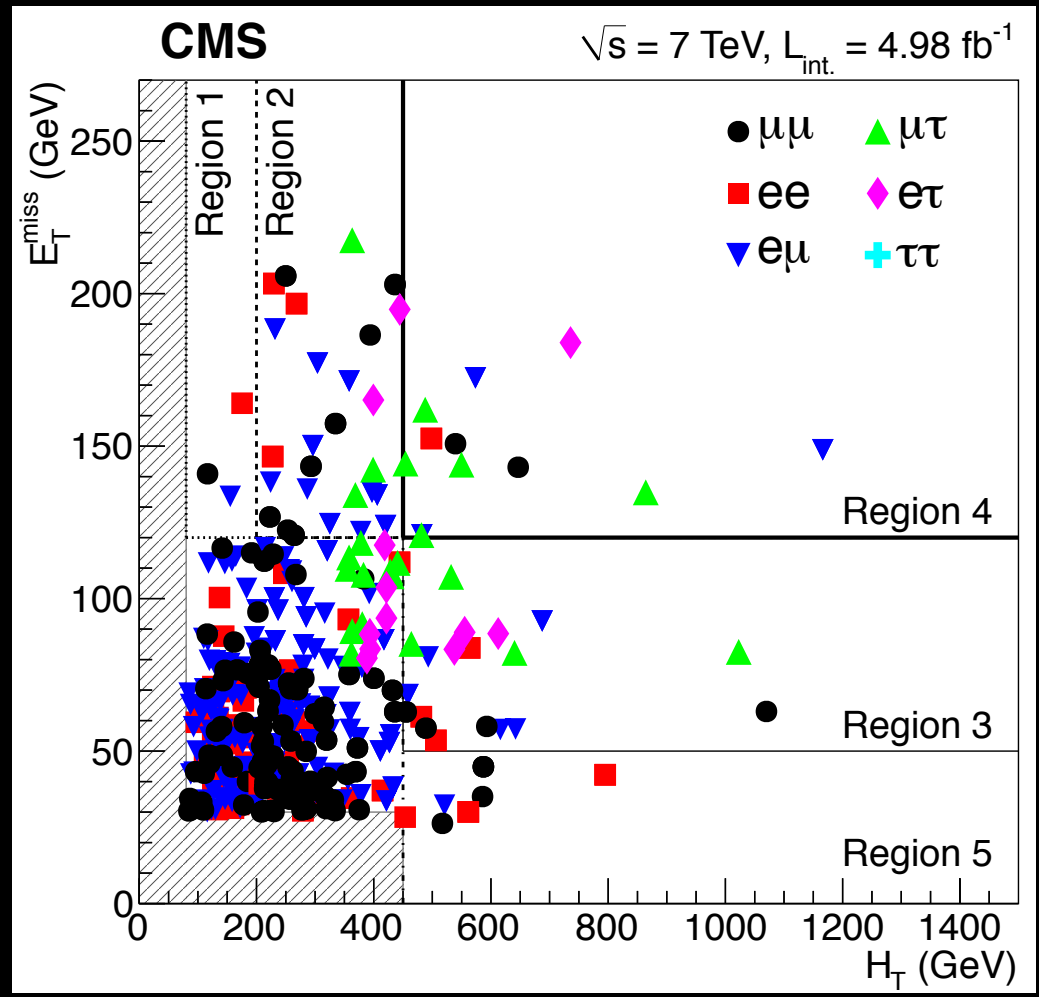
But cannot know parton p_T in the signal sample.
⇒50% syst. uncert.



Same-sign dileptons + jets + MET: Results

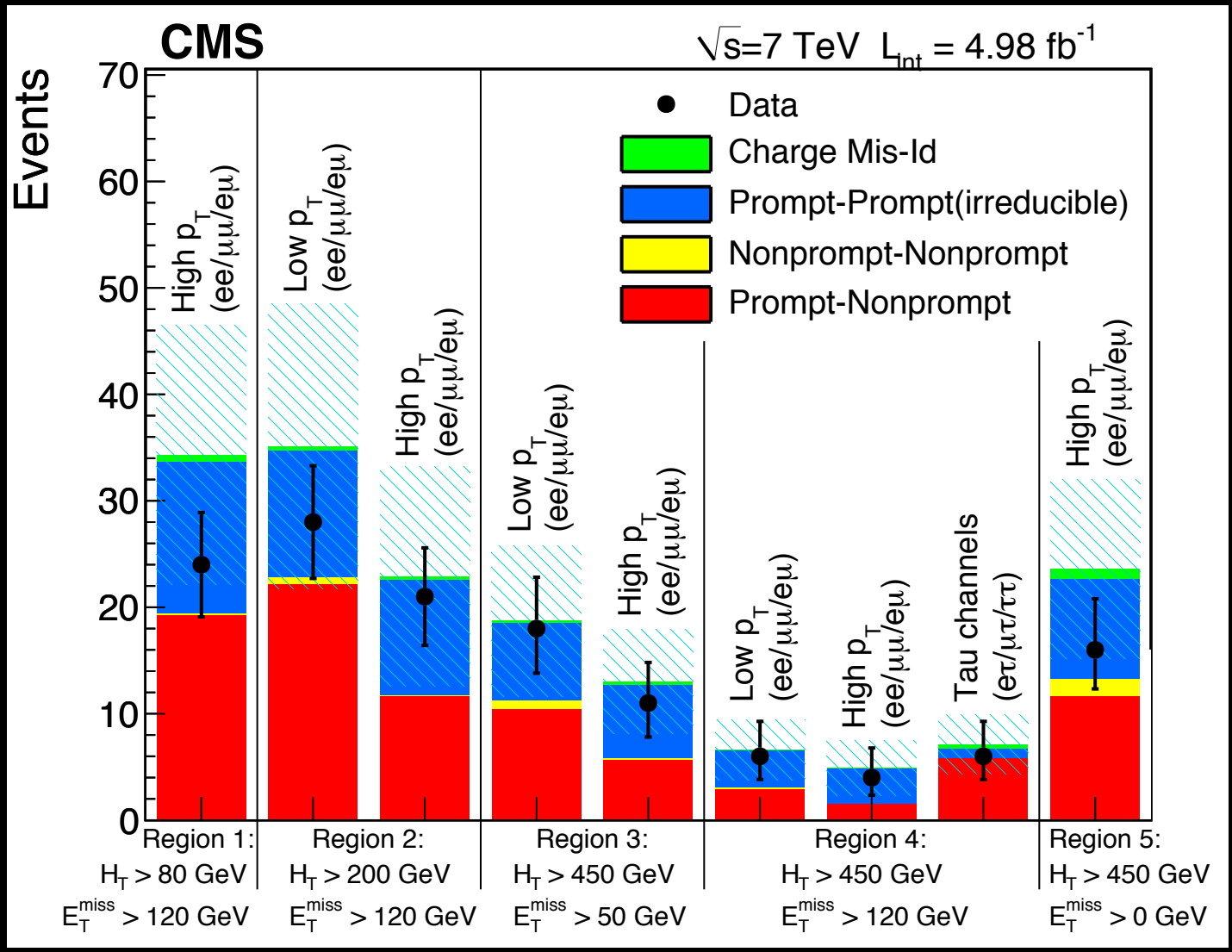
Total background prediction is a mix of irreducibles and fakes.
Model sensitivity depends on HT and MET cuts.





Same-sign dileptons + jets + MET: Results

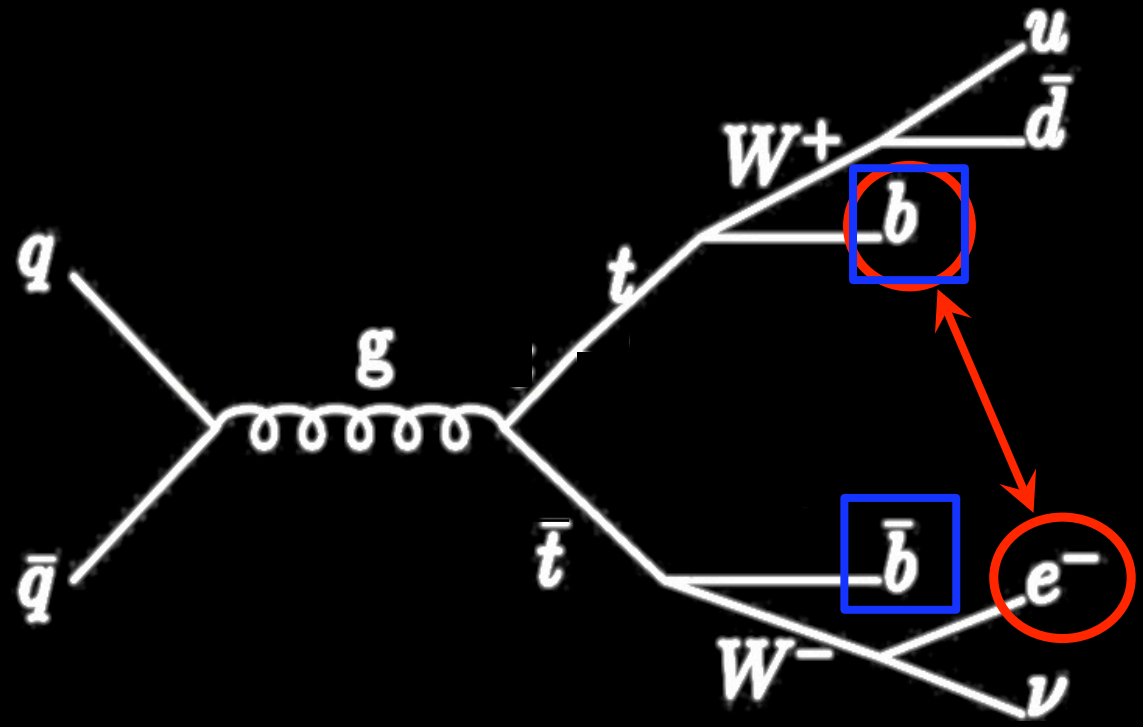
Also look at taus and lower p_T e/μ (10,5).
Consistency across a range of samples.



Same-sign dileptons + jets + MET: b-tags

Requiring ≥2 b-tags strongly suppresses the top fake lepton contribution.

There are two b's in top events, but they cannot contribute simultaneously a tag and a fake.



Same-sign dileptons + jets + MET: b-tags

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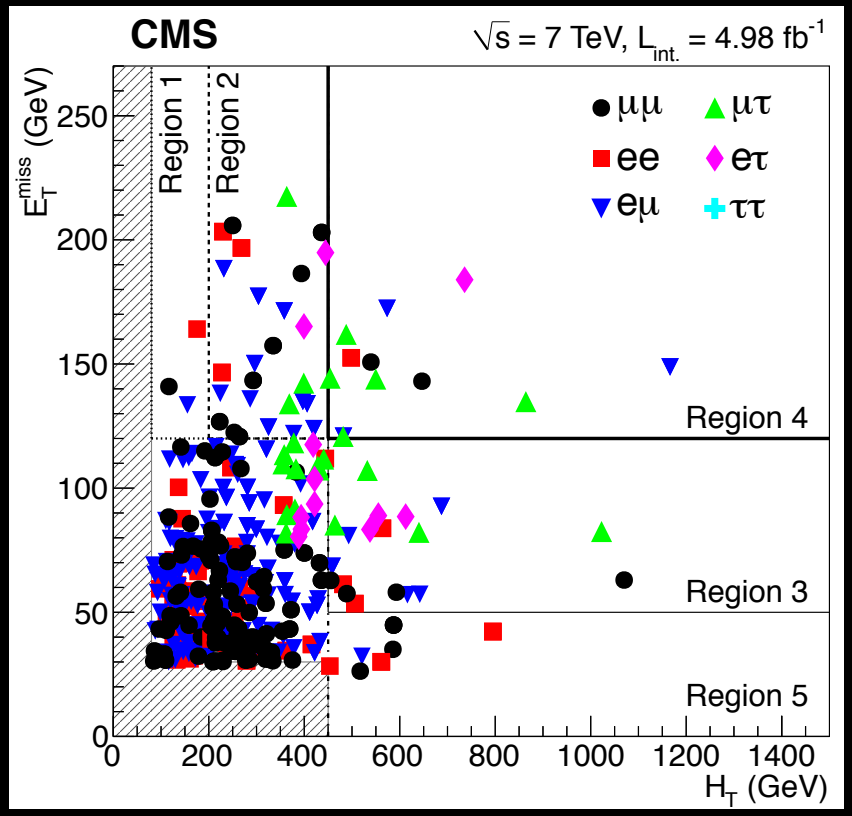
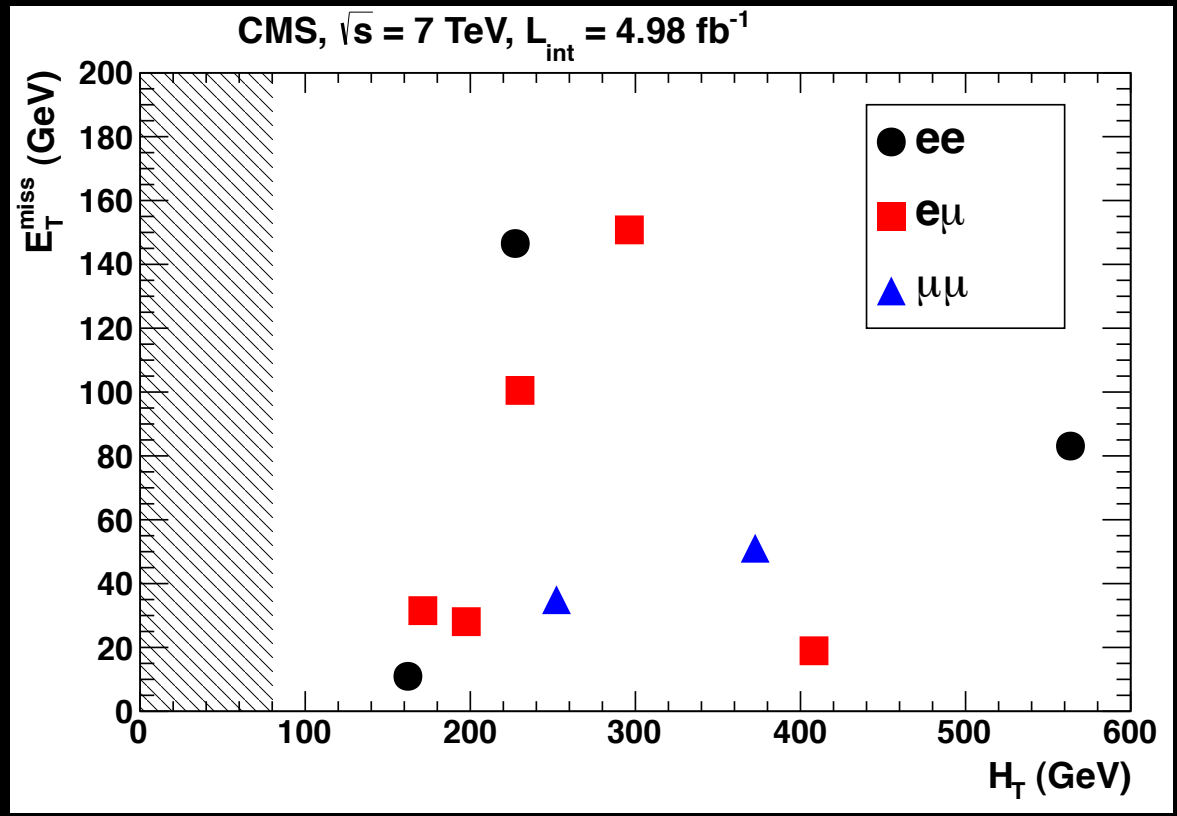




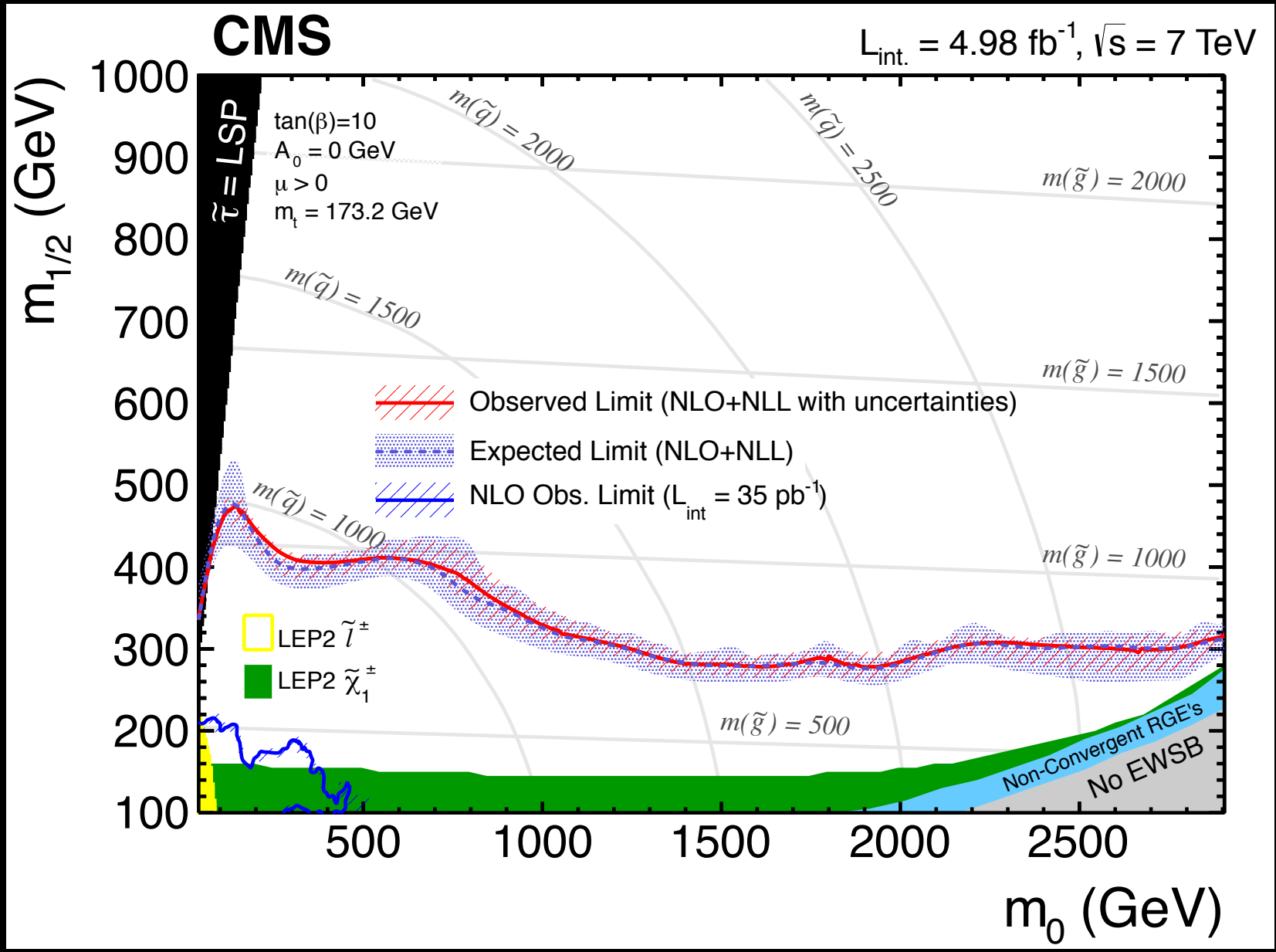
Same-sign dileptons + jets + MET: b-tags

High HT or ≥3 b-tags gives very low background probes for 4 top signatures.

	SR0	SR1	SR2	SR3	SR4	SR5	SR6	SR7	SR8
No. of jets	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3	≥ 2
No. of b-tags	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 2	≥ 3	≥ 2
Lepton charges	$++/--$	$++/--$	$++$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$	$++/--$
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 0 GeV	> 30 GeV	> 30 GeV	> 120 GeV	> 50 GeV	> 50 GeV	> 120 GeV	> 50 GeV	> 0 GeV
H_{T}	> 80 GeV	> 80 GeV	> 80 GeV	> 200 GeV	> 200 GeV	> 320 GeV	> 320 GeV	> 200 GeV	> 320 GeV
Charge-flip BG	1.4 ± 0.3	1.1 ± 0.2	0.5 ± 0.1	0.05 ± 0.01	0.3 ± 0.1	0.12 ± 0.03	0.03 ± 0.01	0.008 ± 0.004	0.20 ± 0.05
Fake BG	4.7 ± 2.6	3.4 ± 2.0	1.8 ± 1.2	0.3 ± 0.5	1.5 ± 1.1	0.8 ± 0.8	0.15 ± 0.45	0.15 ± 0.45	1.6 ± 1.1
Rare SM BG	4.0 ± 2.0	3.4 ± 1.7	2.2 ± 1.1	0.6 ± 0.3	2.1 ± 1.0	1.1 ± 0.5	0.4 ± 0.2	0.12 ± 0.06	1.5 ± 0.8
Total BG	10.2 ± 3.3	7.9 ± 2.6	4.5 ± 1.7	1.0 ± 0.6	3.9 ± 1.5	2.0 ± 1.0	0.6 ± 0.5	0.3 ± 0.5	3.3 ± 1.4
Event yield	10	7	5	2	5	2	0	0	3
N_{UL} (12% unc.)	9.1	7.2	6.8	5.1	7.2	4.7	2.8	2.8	5.2
N_{UL} (20% unc.)	9.5	7.6	7.2	5.3	7.5	4.8	2.8	2.8	5.4
N_{UL} (30% unc.)	10.1	7.9	7.5	5.7	8.0	5.1	2.8	2.8	5.7

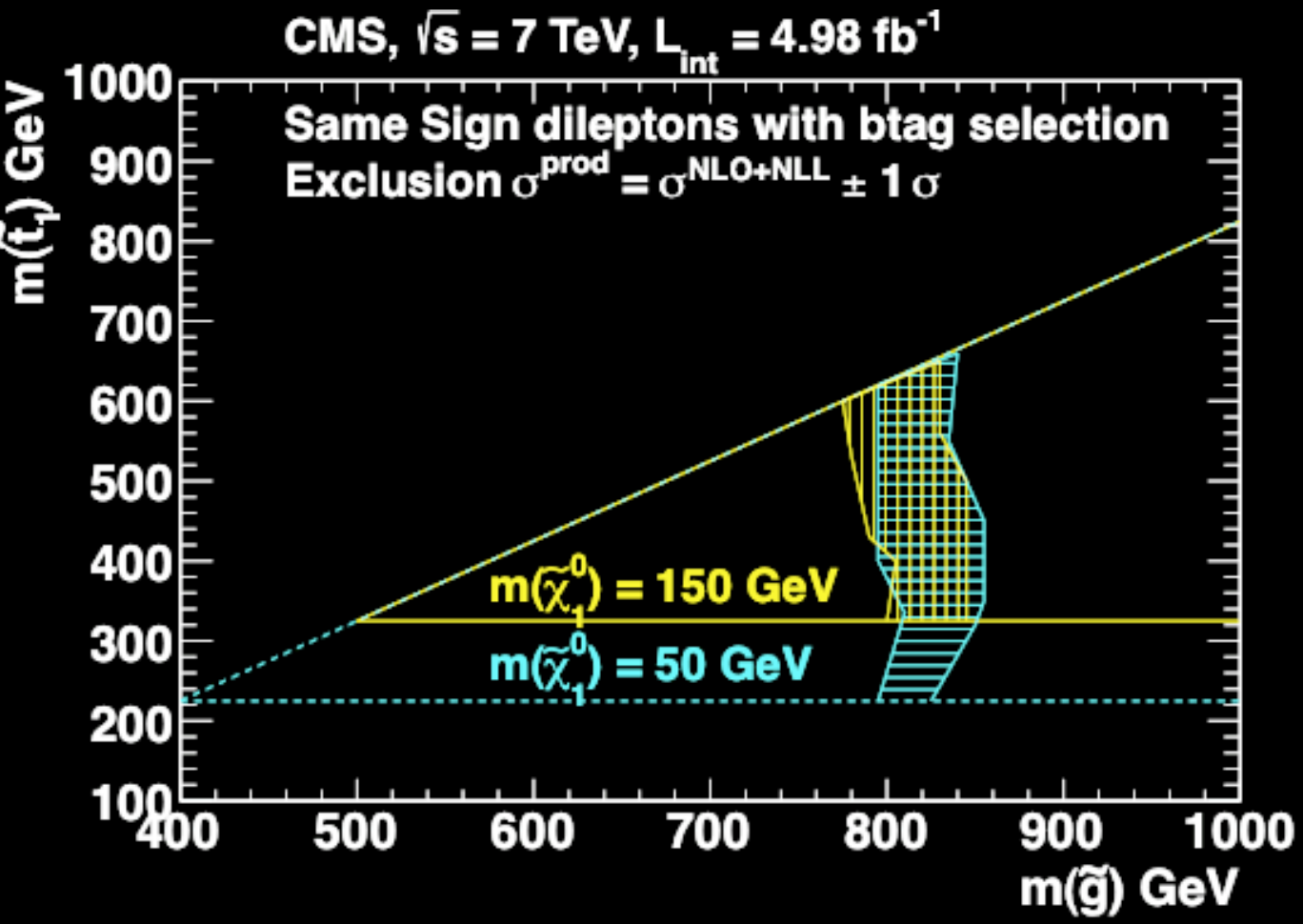
Same-sign dileptons + jets + MET: interpretation

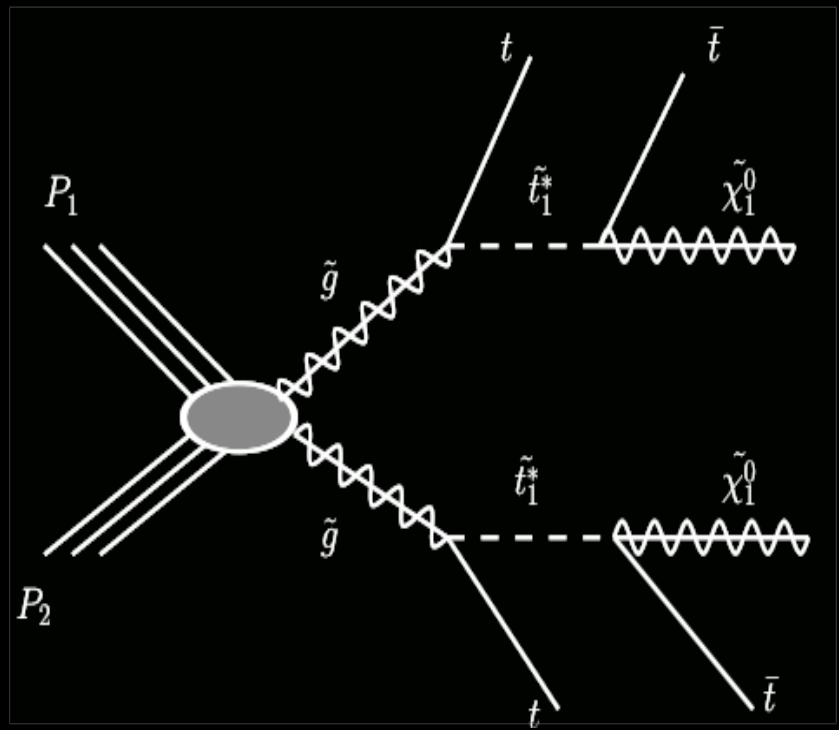
Limits in cMSSM similar to others, almost.



Same-sign dileptons + jets + MET: interpretation

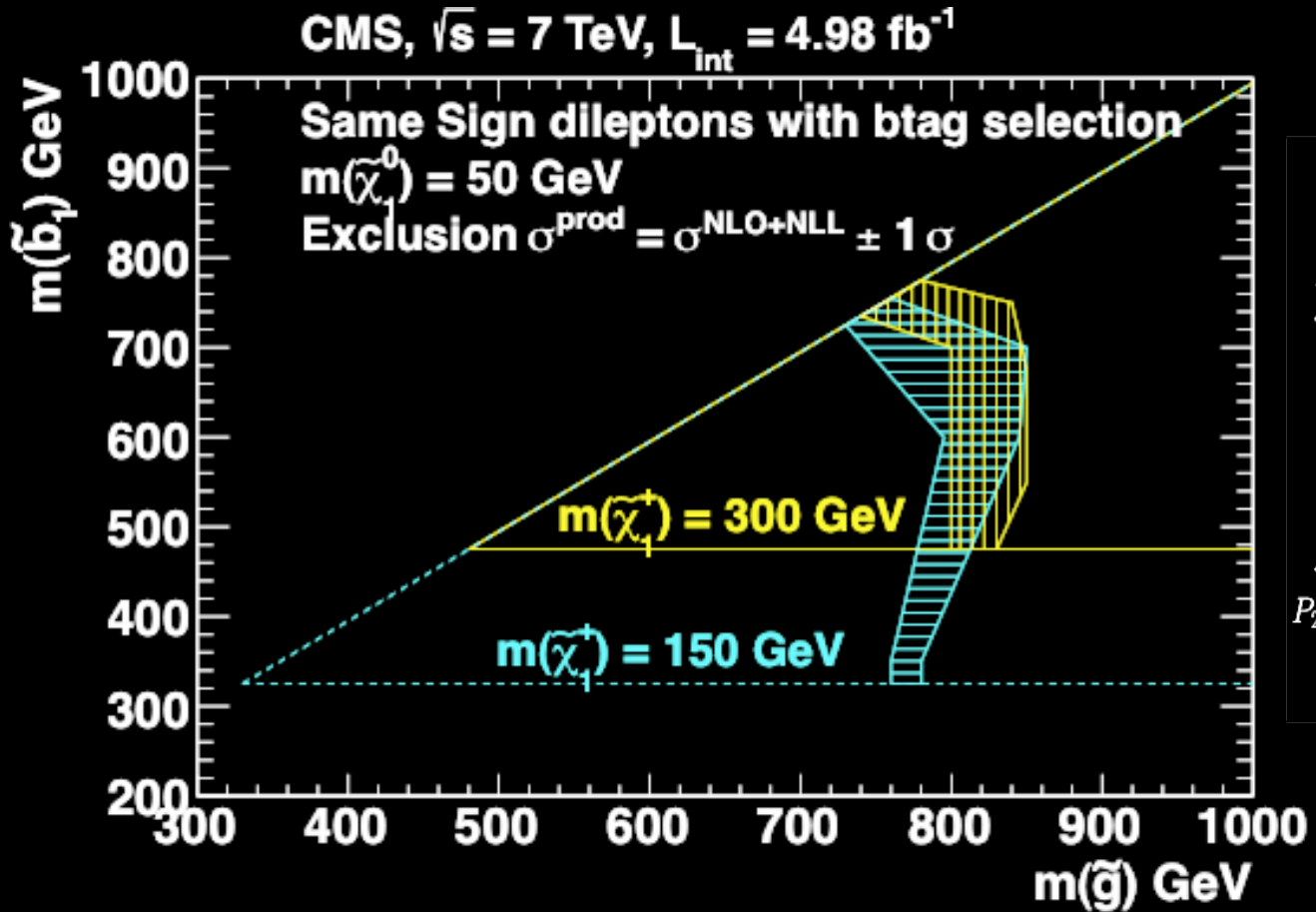
High HT or ≥3 b-tags gives very low background probes for 4 top signatures.

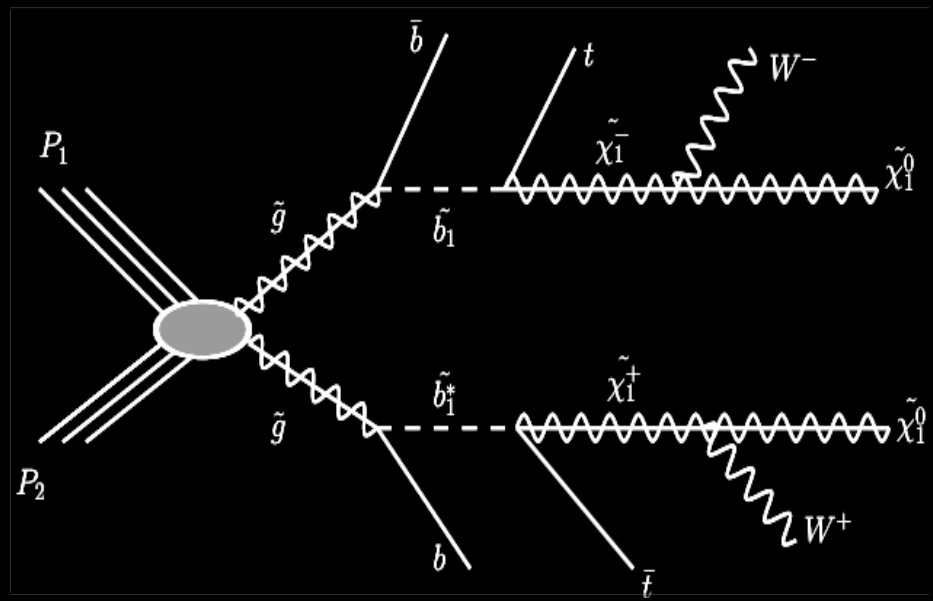




Same-sign dileptons + jets + MET: interpretation

High HT or ≥3 b-tags gives very low background probes for sbottom decays through stop.





Summary: Many others…

Multijets + MET

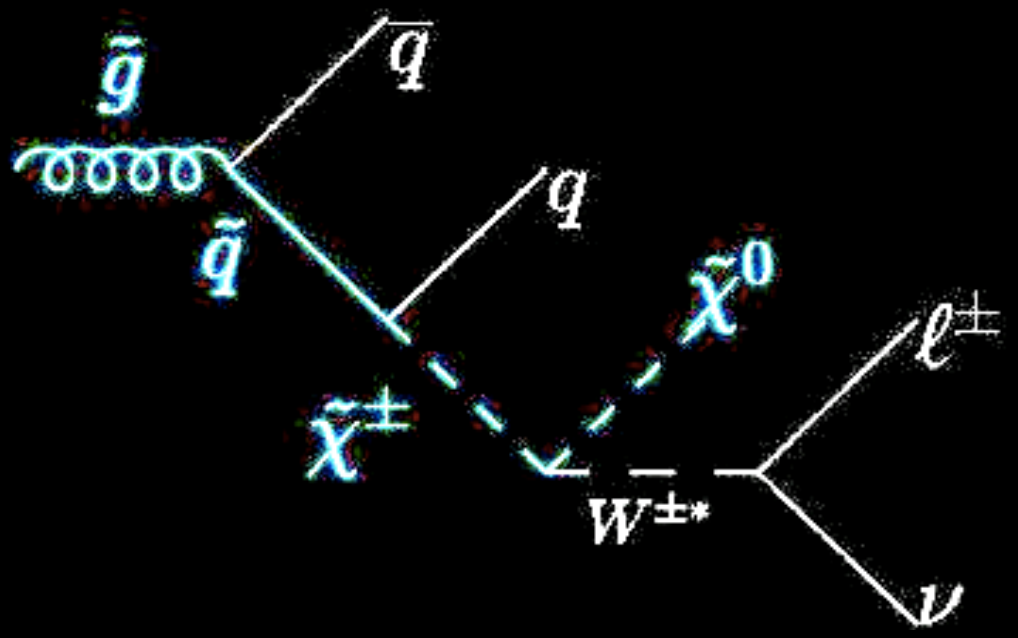
Lepton + jets + MET

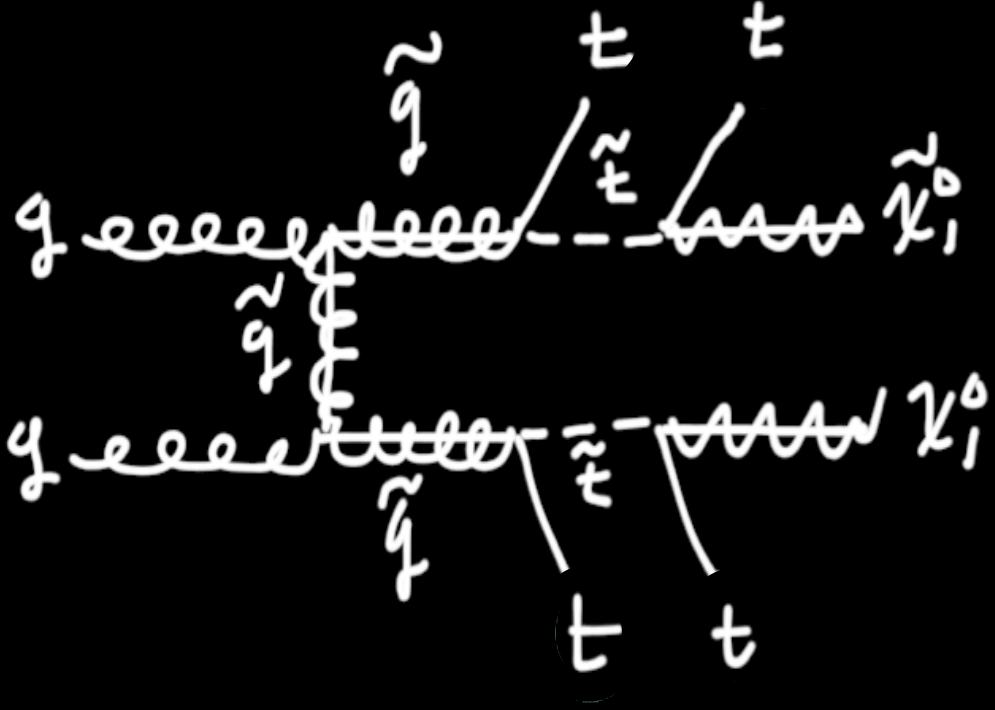
Dileptons + jets + MET

Same sign dileptons + jets + MET

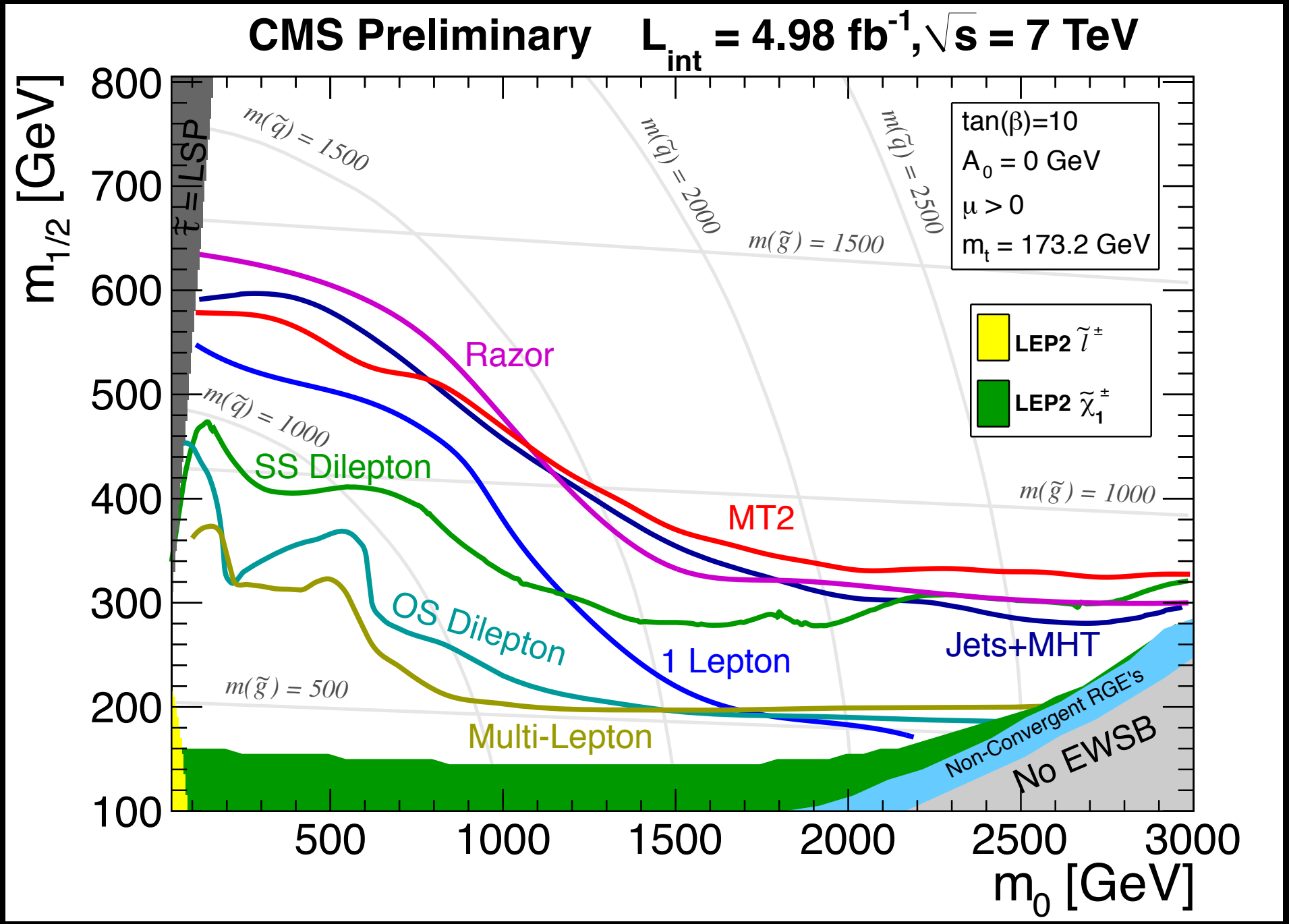
Trileptons + jets + MET

w/ or w/o b-tagged jets

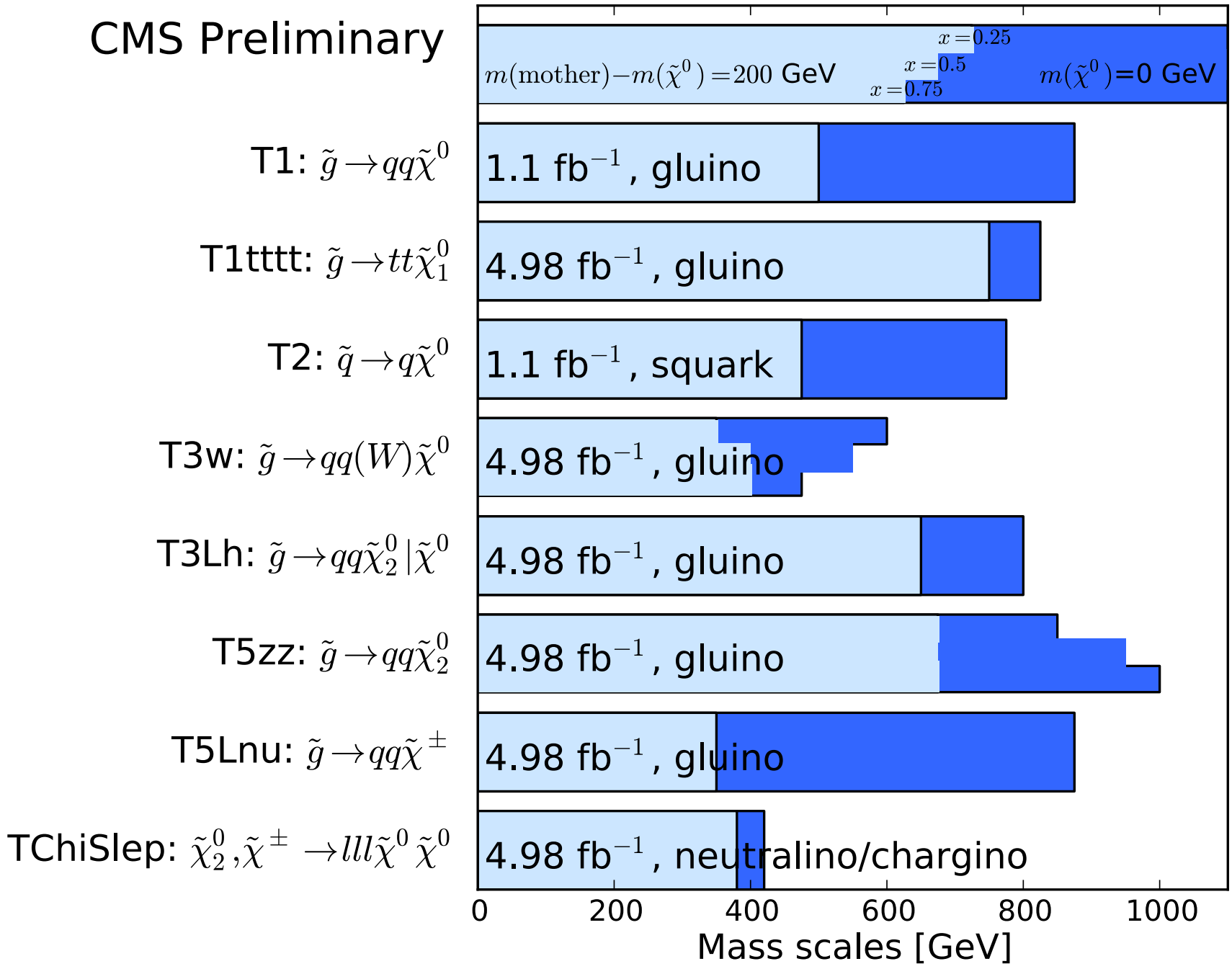




Summary: Many others…



Summary: Many others…



Summary: Many others…

And many more to come…

Accelerator running well; high and increasing luminosity.