Prospects for Supersymmetry at 13 TeV: CMS perspective

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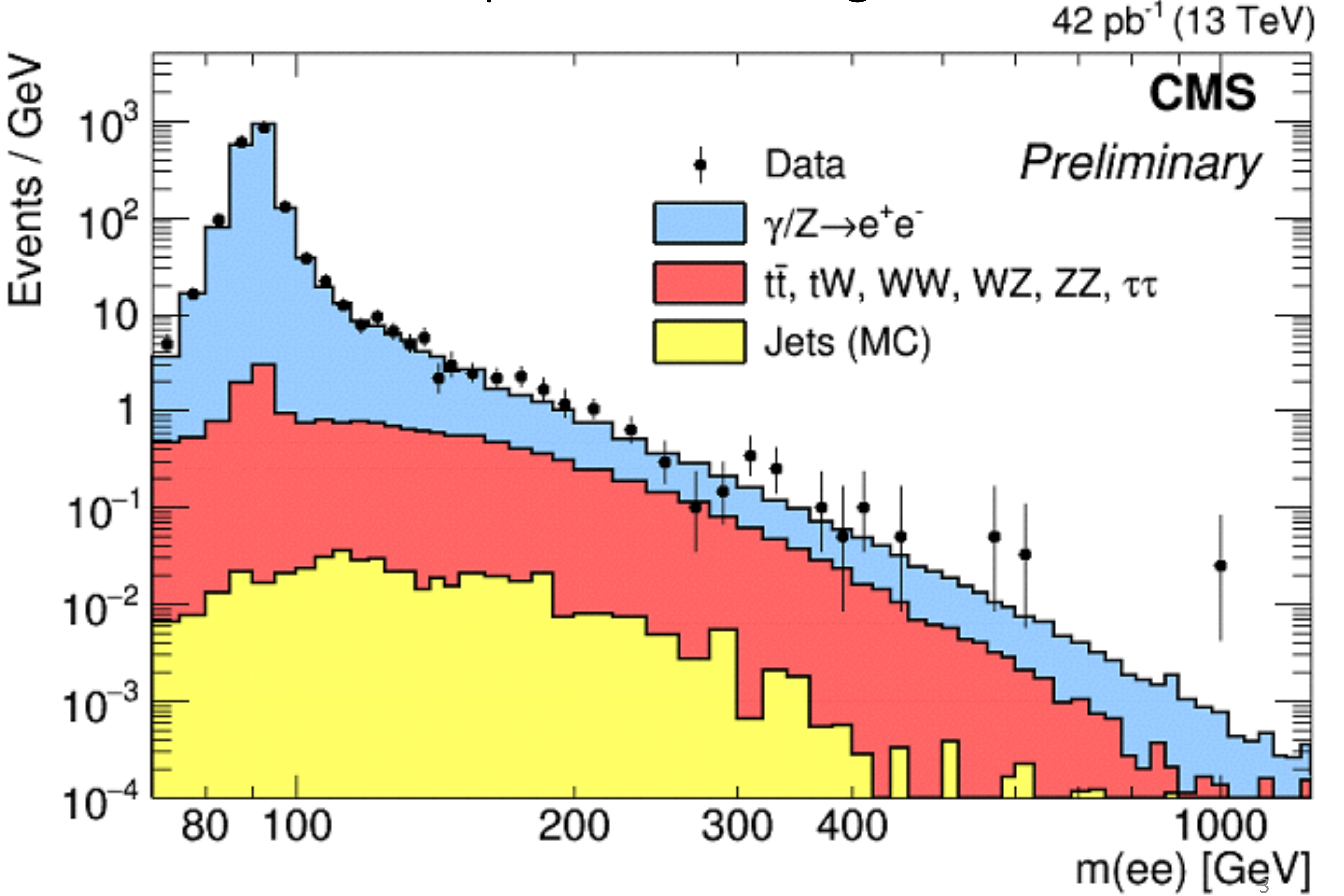
Princeton University

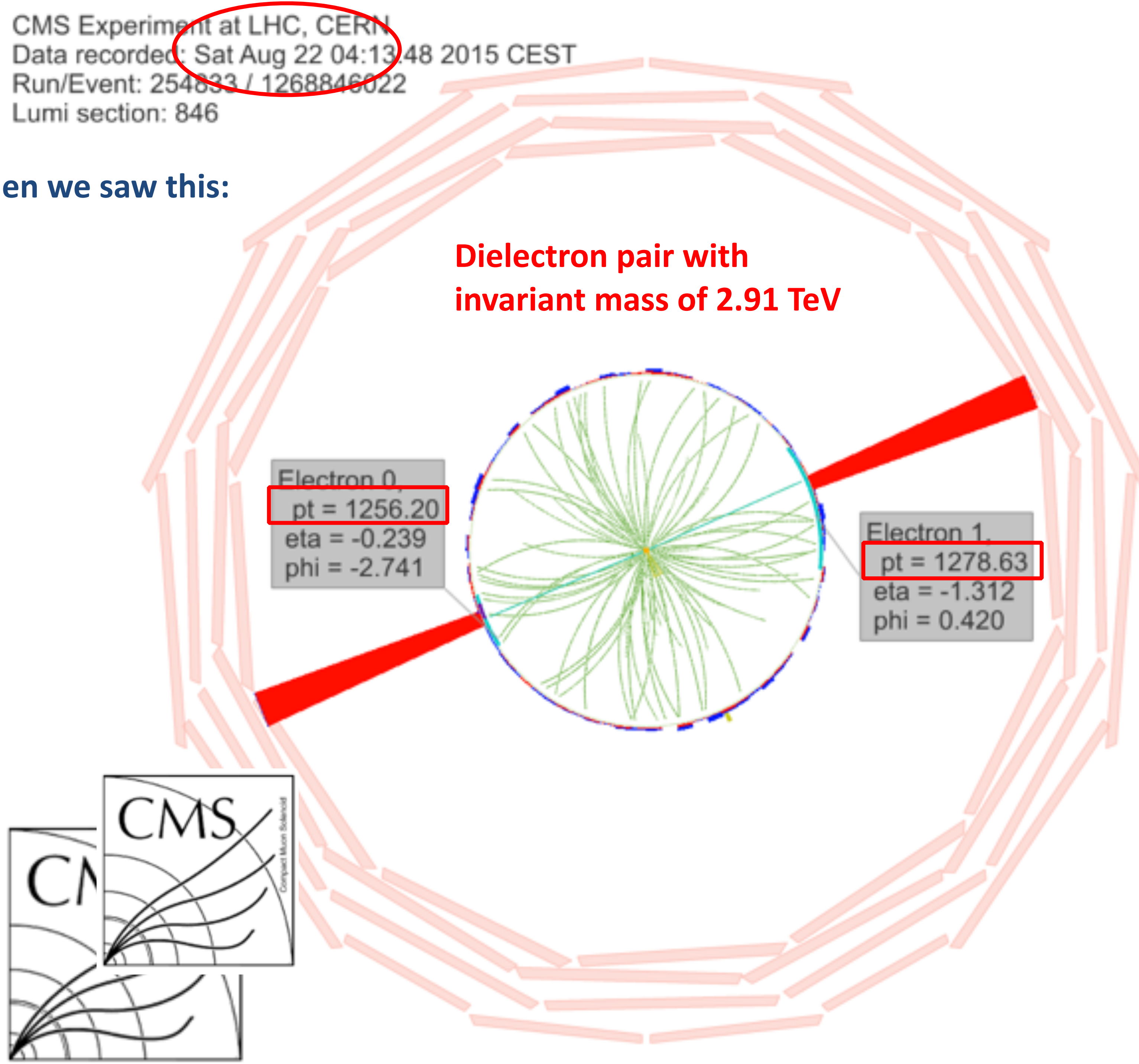
GGI 2015: Gearing up for 13 TeV
1/9/2015

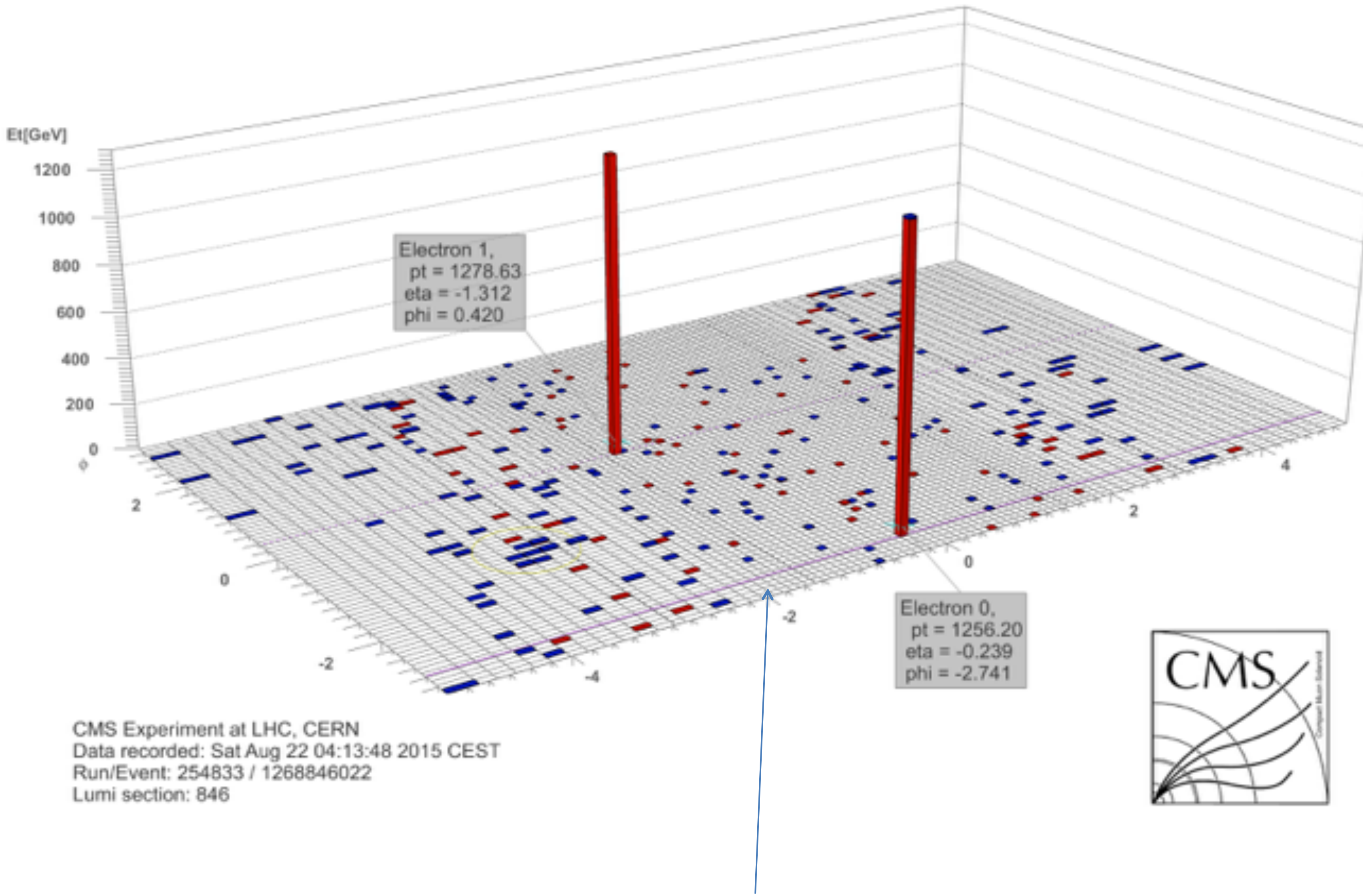
First, some exotic fun…

CMS dielectron mass spectrum as of Aug. 22



And then we saw this:

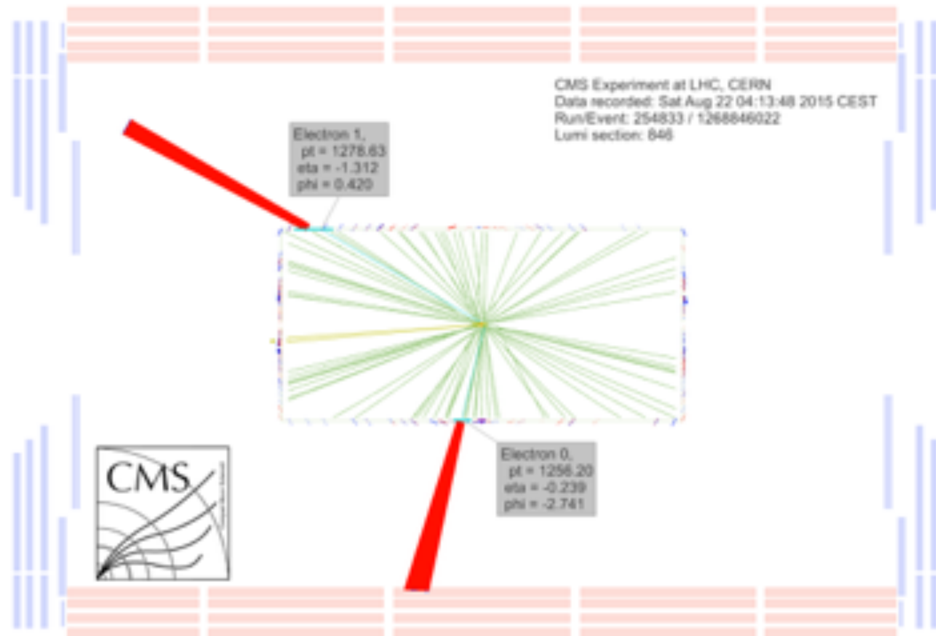




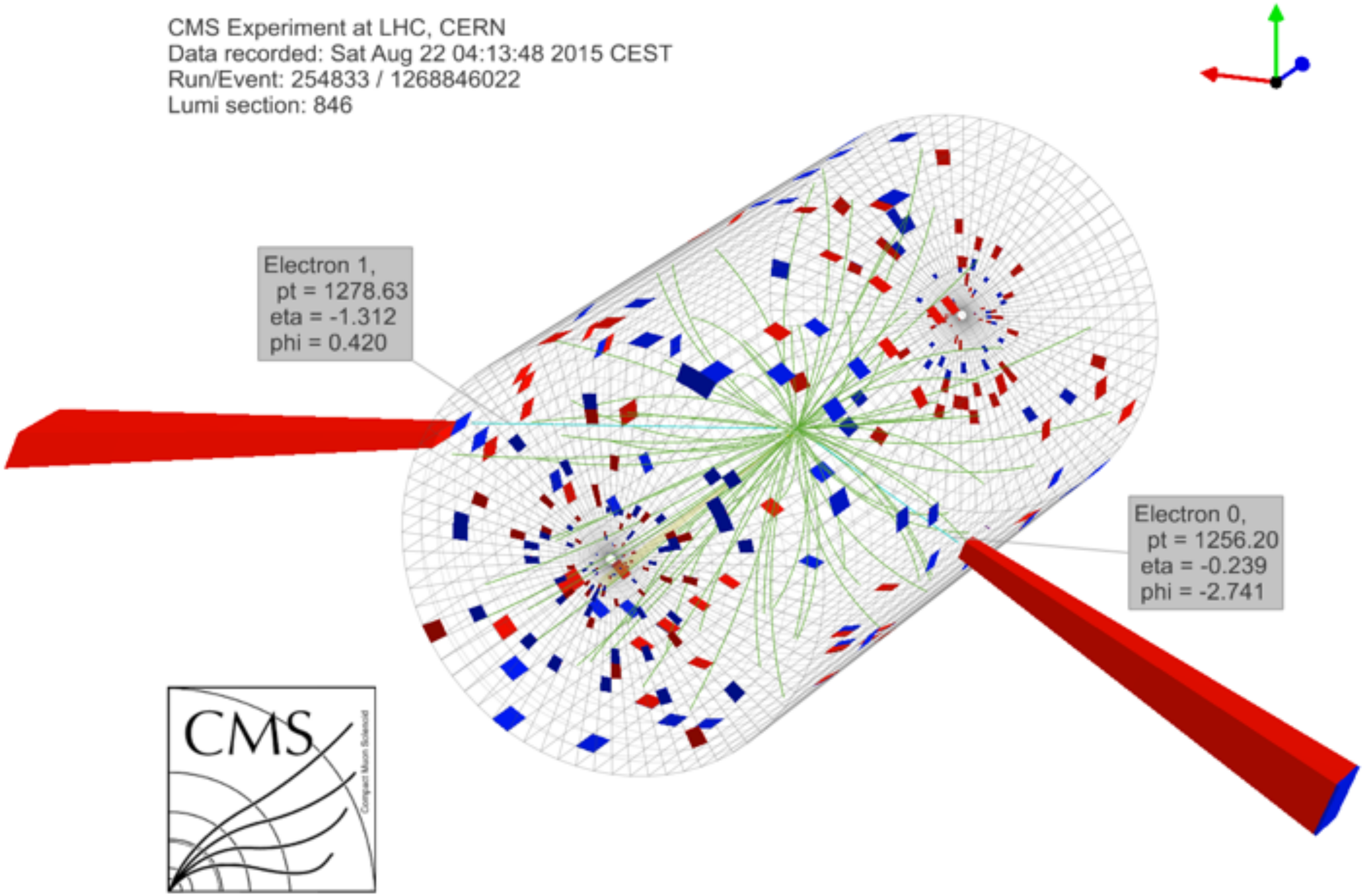
Extremely clean event, MET very low and aligned with one of the electrons (the lower pT one)

Event Kinematic Details

	electron 0	electron 1
E_T	*1260 GeV*	*1280 GeV*
η	*-0.24*	*-1.31*
φ	*-2.74 rad*	*0.42 rad*
charge	*-1*	*+1*
mass	*2.91 TeV*	
$\cos \vartheta^*_{CS}$	*-0.49*	
y	*-0.78*	



- for $\cos \theta^*_{CS}$, it is assumed that quark direction is along the boost of the di-electron system
- SM Drell-Yan events favour positive values of $\cos \theta^*_{CS}$


CMS Experiment at LHC, CERN
Data recorded: Sat Aug 22 04:13:48 2015 CEST
Run/Event: 254833 / 1268846022
Lumi section: 846
Electron 1,
pt = 1278.63
eta = -1.312
phi = 0.420
Electron 0,
pt = 1256.20
eta = -0.239
phi = -2.741
CMS
Compact Muon Solenoid

SM Background Expectations

mass range	SM Bkg Expection
>1 TeV	***0.21***
> 2 TeV	***0.007***
> 2.5 TeV	***0.002***

electrons are required to satisfy:
E_T > 35 GeV
$|\eta| < 1.4442$ or $1.566 < |\eta| < 2.5$
pass high energy ele selection

in addition one electron must have $|\eta| < 1.4442$

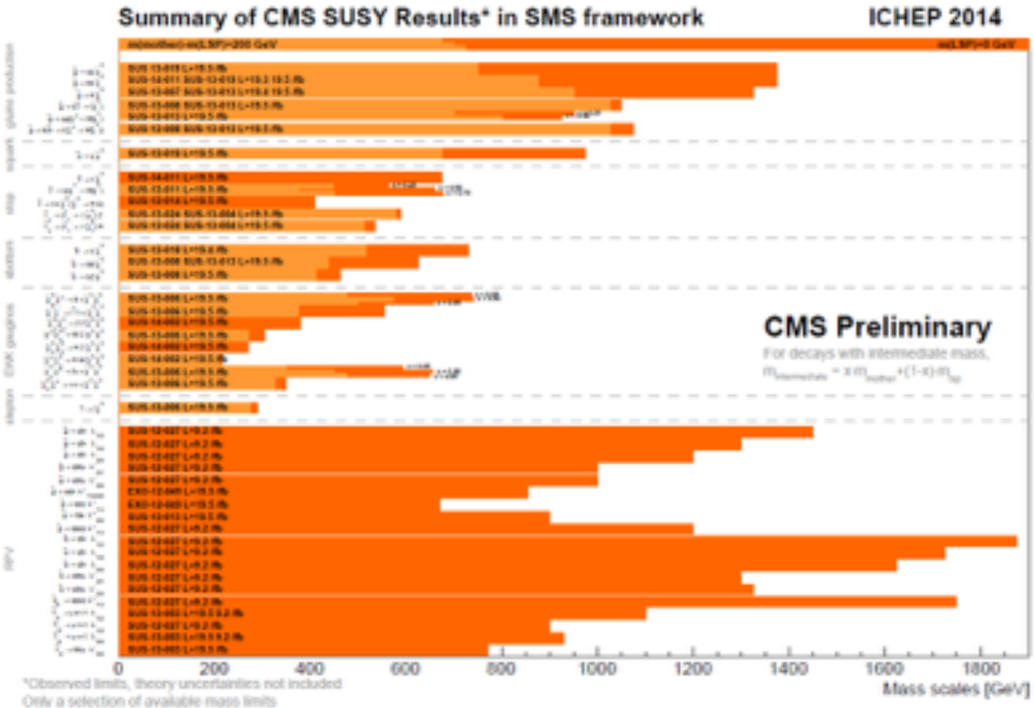
- the values of this table have been obtained from the mass spectrum distribution in CERN-CMS-PD-2015-037 and scaled to the luminosity of $65pb^{-1}$, which is the luminosity of full 50ns dataset
  - to ensure a smooth distribution, the mass spectrum was fitted with the bkg function used by the RunI analysis (10.1007/JHEP04(2015)025)
- the mass spectrum is obtained directly from Monte Carlo simulated events
  - the Monte Carlo generators used are listed in the next slide
- the theoretical uncertainties on the background estimate are expected to be the dominant uncertainties on background estimate

Monte Carlo Generators used for Background Expectation

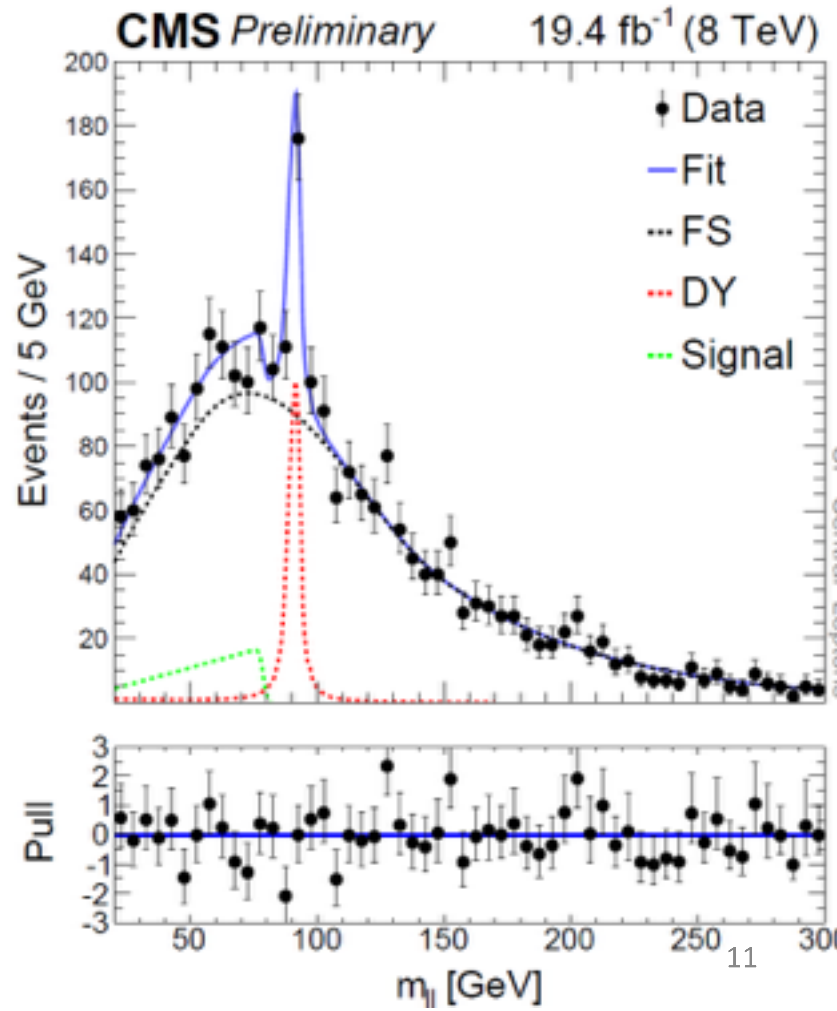
- SM Drell-Yan:
  - MadGraph5_aMCatNLO hadronised with PYTHIA 8
- ttbar, tW :
  - POWHEG hadronised with PYTHIA 8
- jets:
  - PYTHIA 8
- WW, WZ, ZZ :
  - PYTHIA 8
- W+jets:
  - MadGraph5_aMCatNLO hadronised with PYTHIA 8

Now on to supersymmetry…

Run 1 searches came up empty, …



Exclusions from a few hundred to a few thousand GeV

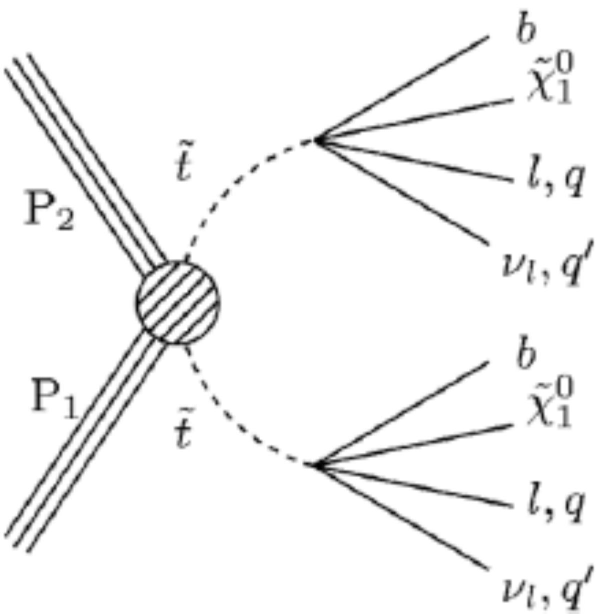


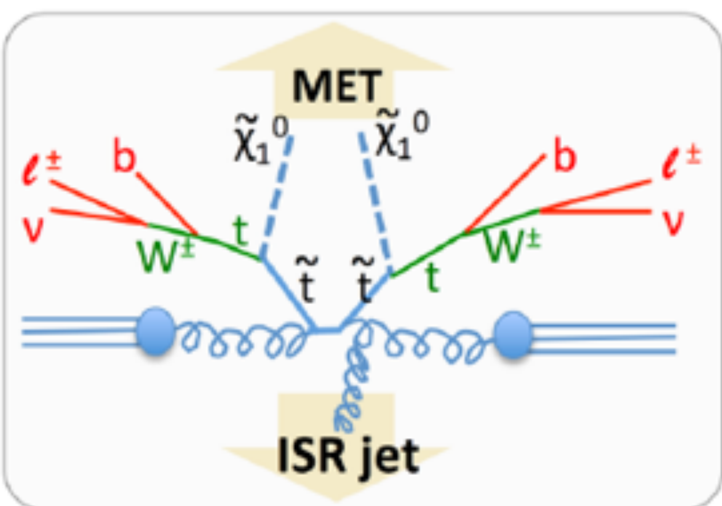
but some interesting hints to follow up in Run 2: e.g., dilepton edge analysis with ~2.5 σ local significance

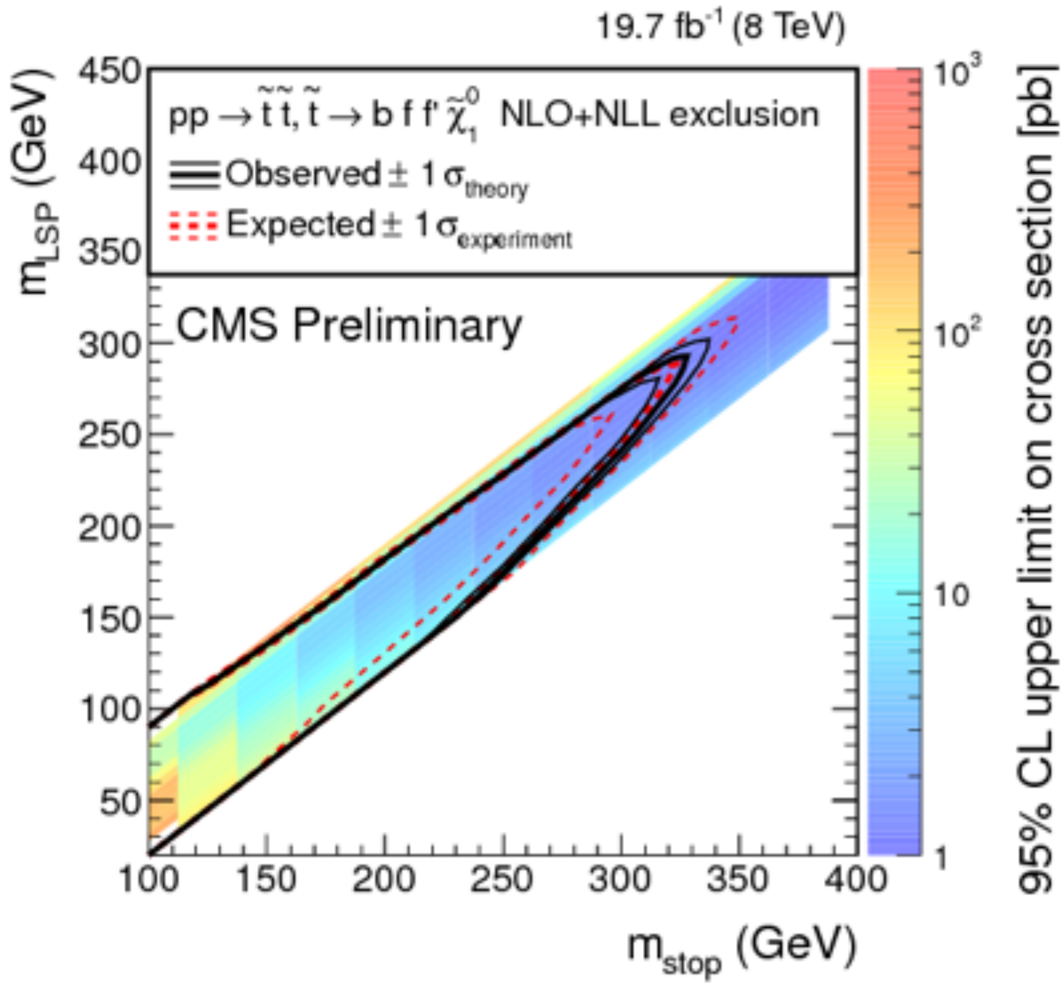
Moving forward in Run 2

- To make progress in Run 2 we need new experimental and theoretical ideas (unless SUSY is just out of cross section reach and we only need more data, but this is the less interesting option for this discussion)
  - Previously unexplored or not fully explored phase space
  - New tools: experimental signatures and methods
  - New classes of models
- Experiment:
  - New ideas in selecting events (MVAs, mini-isolation)
  - Target previously hidden regions of phase space
    - VBF and ISR for compressed spectra
  - New experimental tags (e.g., Higgs125)
  - New decay topologies (e.g., long-lived sparticles)
  - Boosted topologies

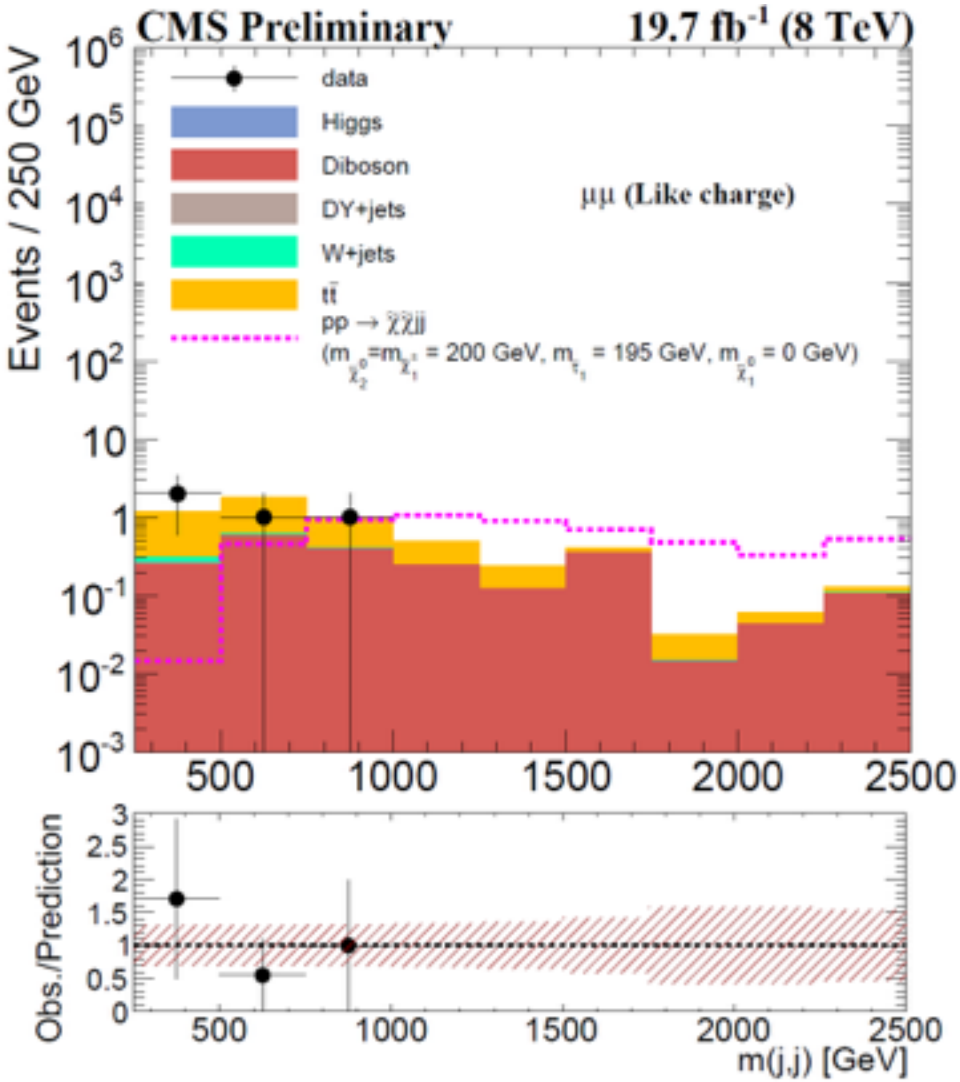
Targeting Compressed Spectra: ISR

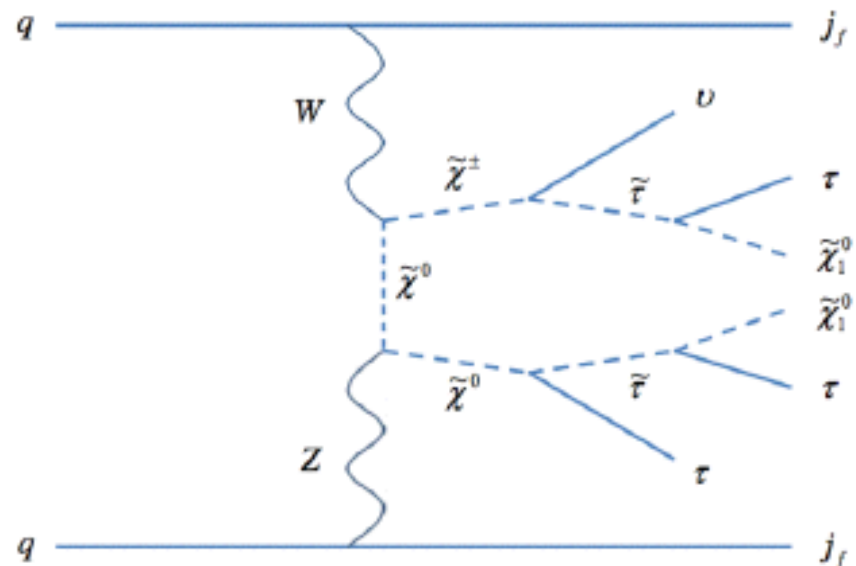




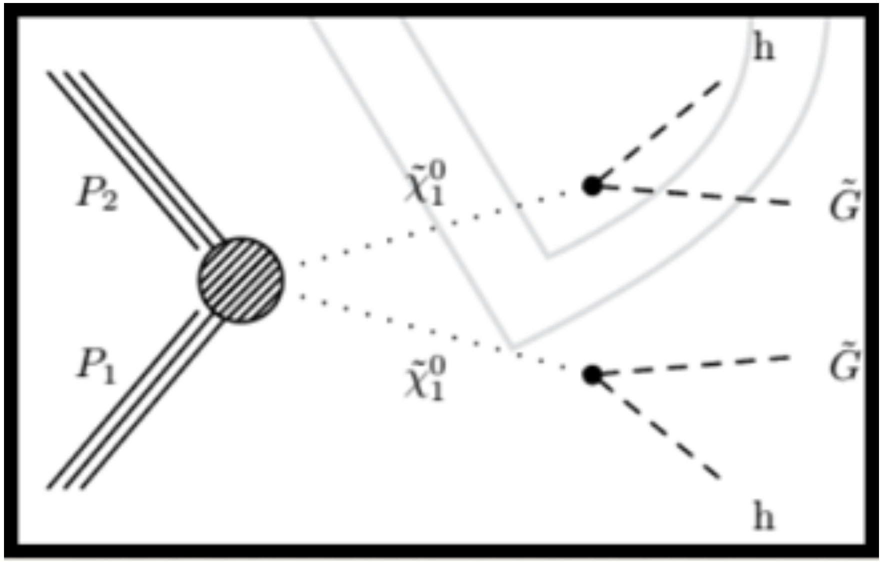


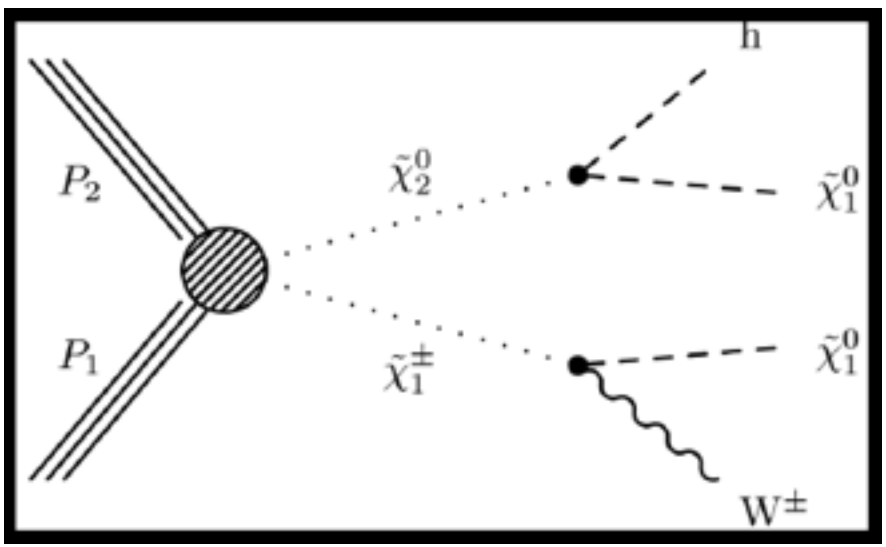
Targeting Compressed Spectra: VBF





Extending new tags: h(125) + razor



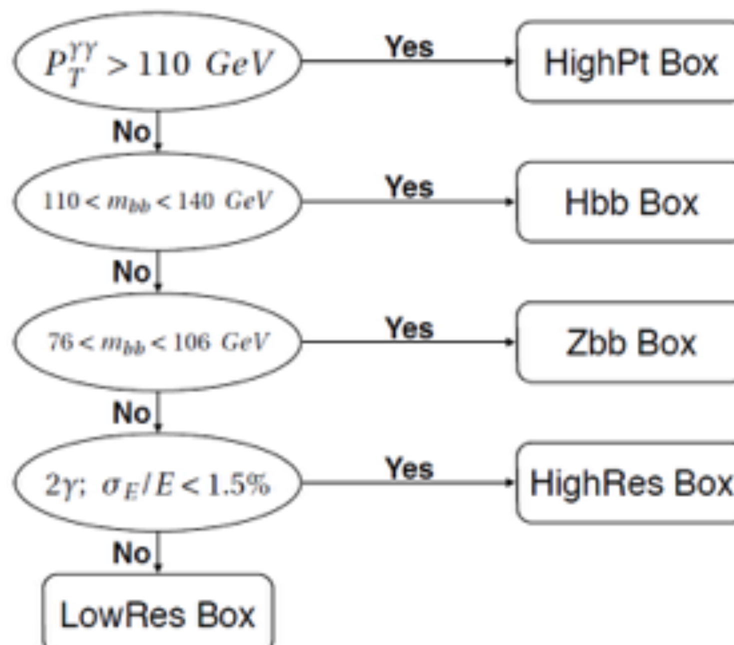


Trying to catch SUSY with a SM Higgs

- Either in hhGG or hWχχ

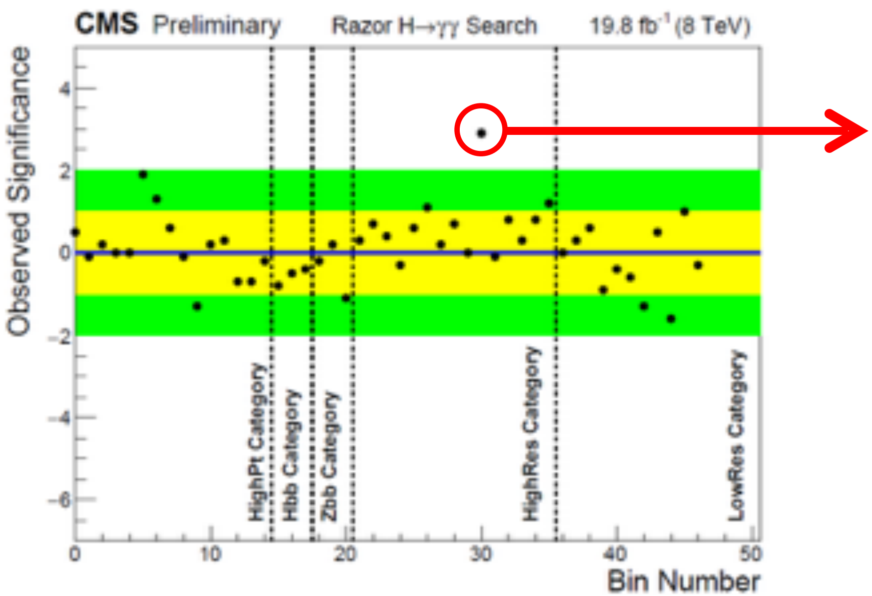
Broad inclusive search

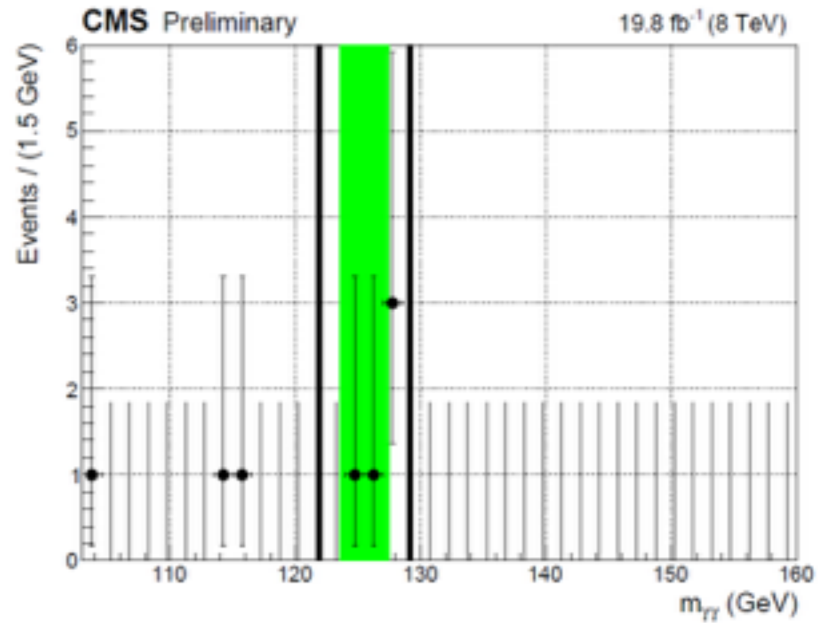
- Trying to cast a wide net
- Two photons + >= 1 jet
- Look for b tags and classify events

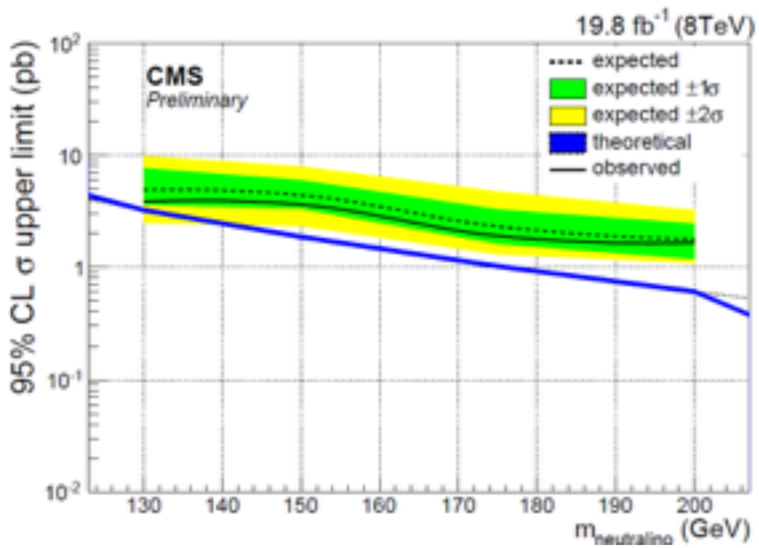


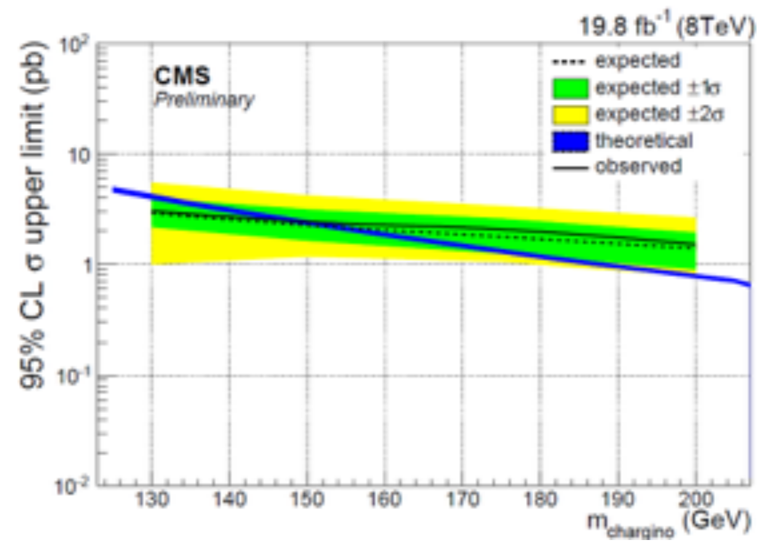
SUS-14-017 (NEW!)

H(γγ) Razor Search Results





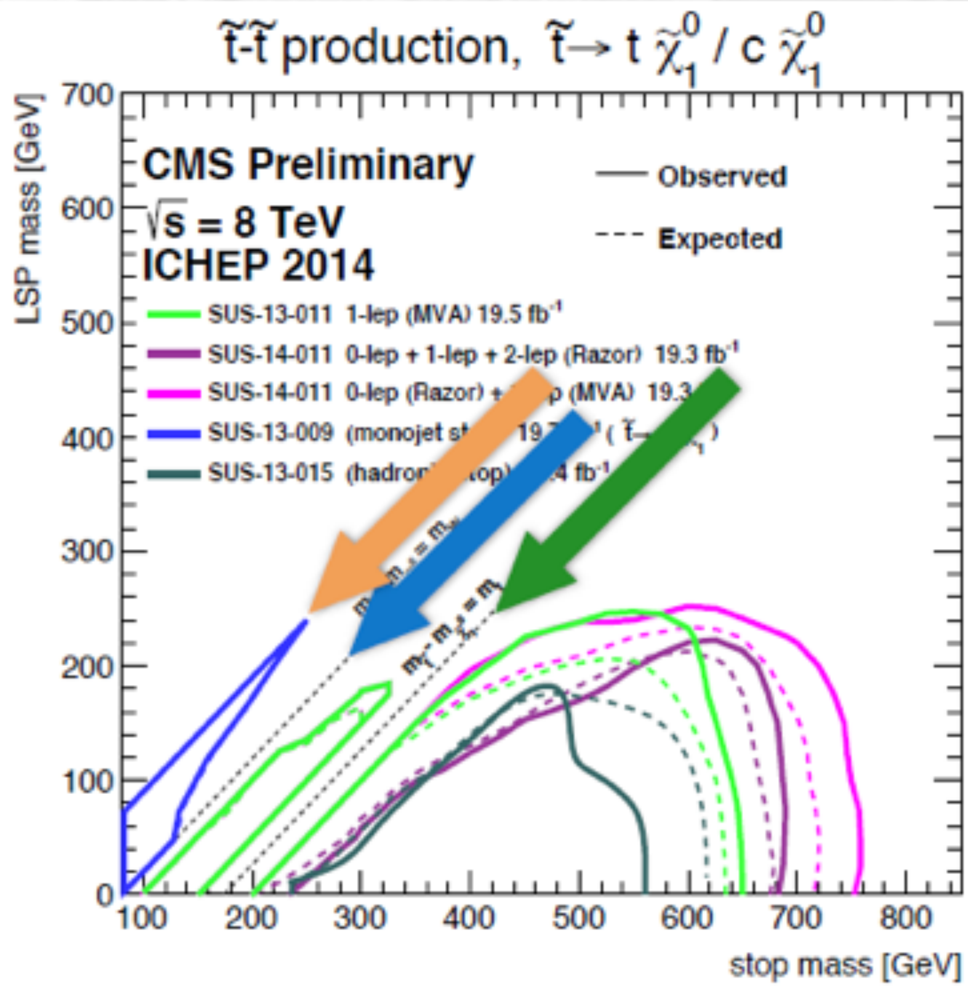




Statistics dominated -> will benefit a lot from Run 2 data

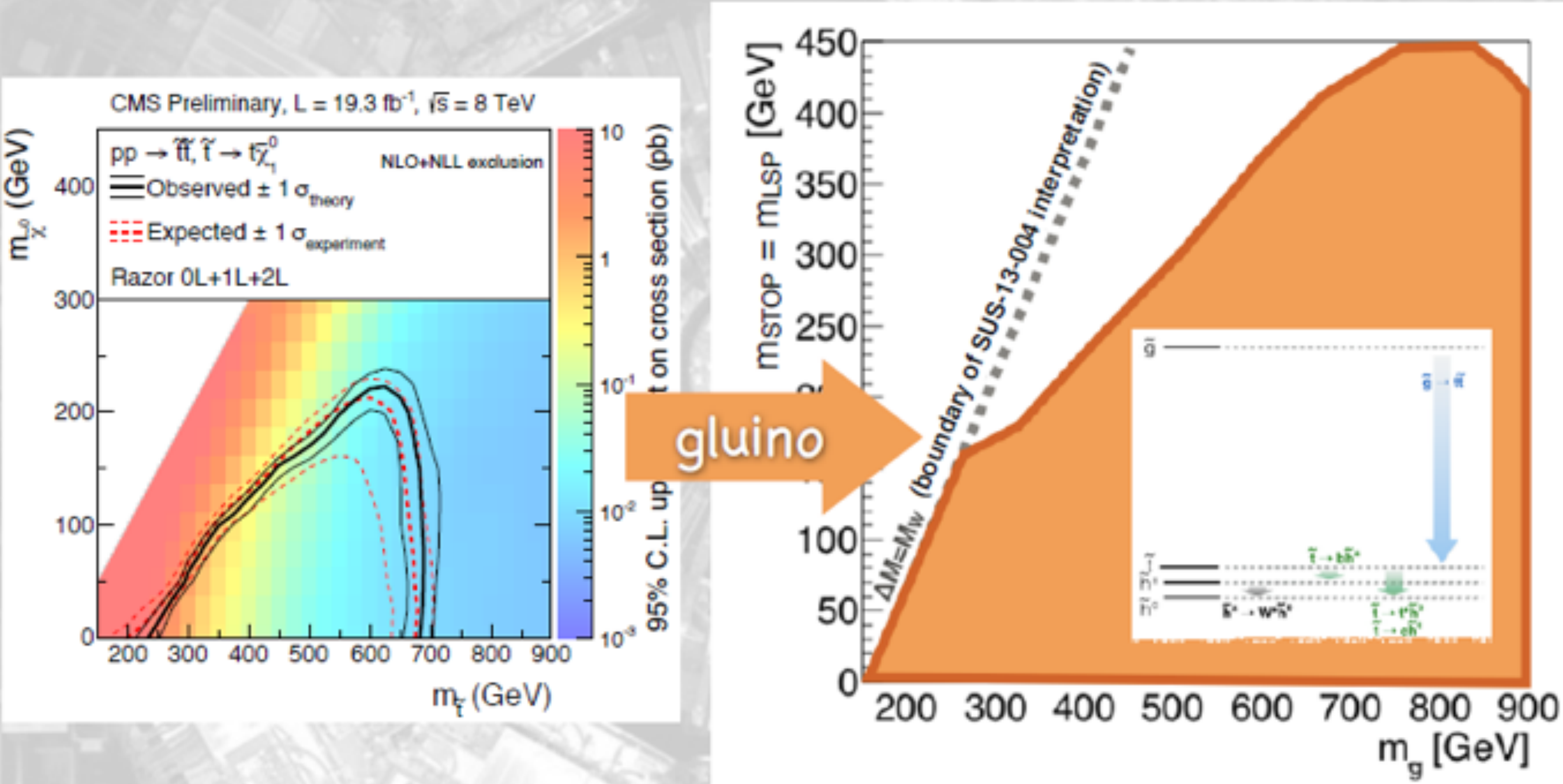
Stop Blind Spots

- $m_{\tilde{t}} \sim m_{\tilde{\chi}^0}$: stop decay products are soft, difficult to trigger on, low efficiency (e.g. with high-pT monojet-like ISR jet)
- $m_{\tilde{t}} - m_{\tilde{\chi}^0} \sim m_W$: the events look like WW production (large SM background)
- $m_{\tilde{t}} - m_{\tilde{\chi}^0} \sim m_t$: the events look like tt (large SM background)



M. Pierini – CERN seminar, Oct. 2014

...through gluino decays



42 reinterpreting stop bounds in SUS-13-004

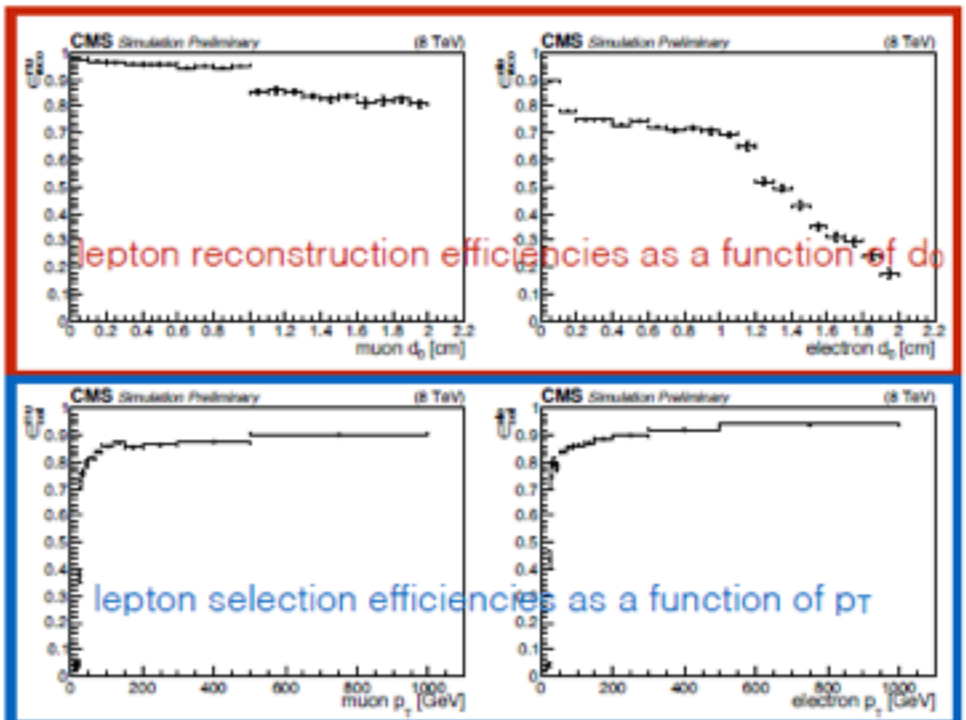
Long-lived Searches

Both analyses give useful information to recast their results

E-mu Search

Single limit plot but provide efficiency curves

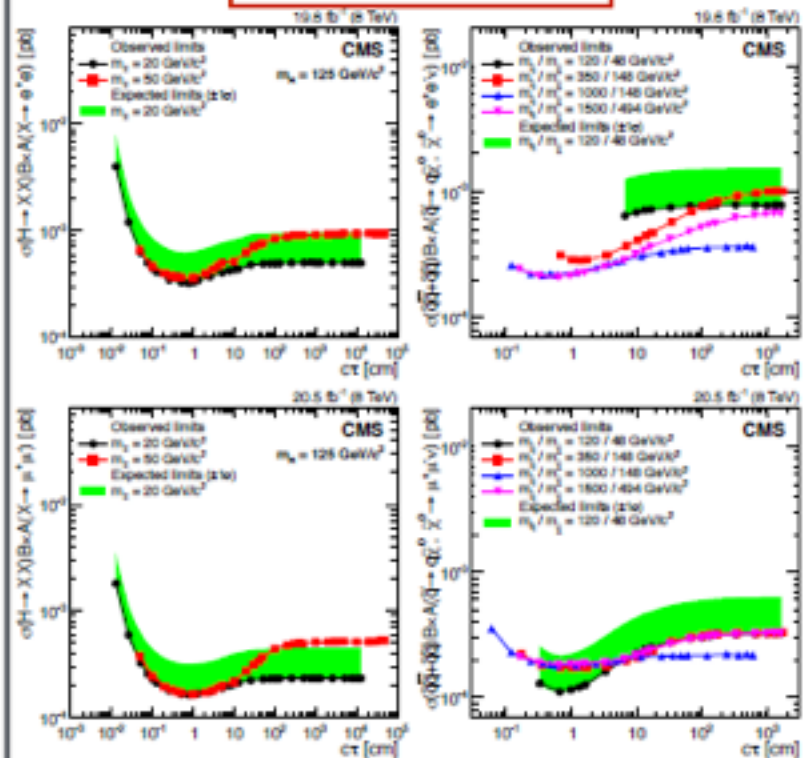
https://twiki.cern.ch/twiki/bin/view/CMSPublic/DisplacedSusyParametrisationStudyForUser



Dilepton same vertex Search

Provide limit plots in which the acceptance is factorised

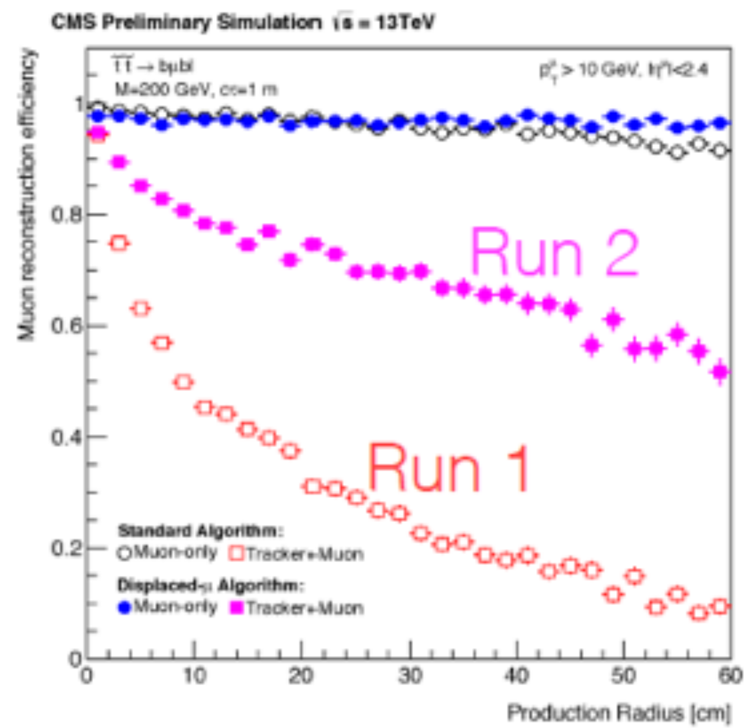
PRD 91(2014)052012



Prospects for Long-lived Searches

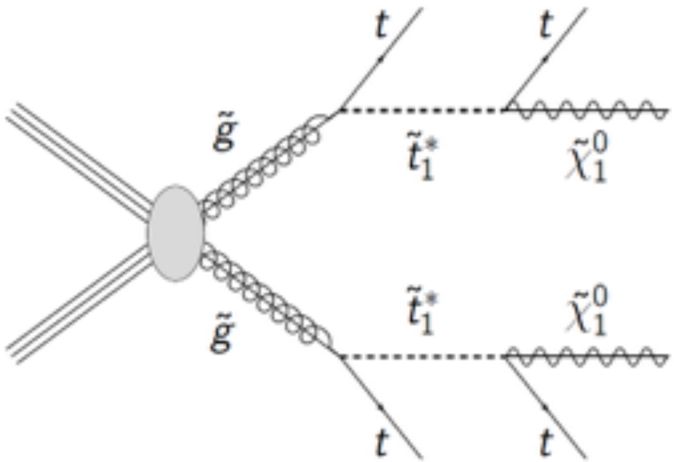
- The final states of the two analyses will be covered in single paper
- Many extensions can be done at 13 TeV
  - Same sign leptons

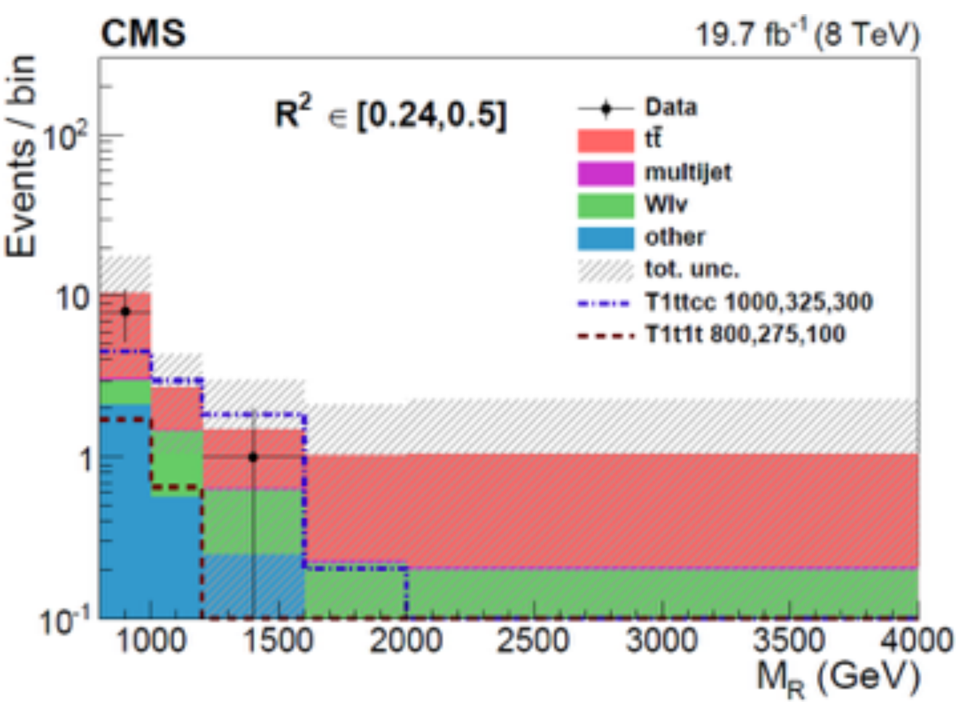
Significant improvement in the muon acceptance has been achieved for Run2

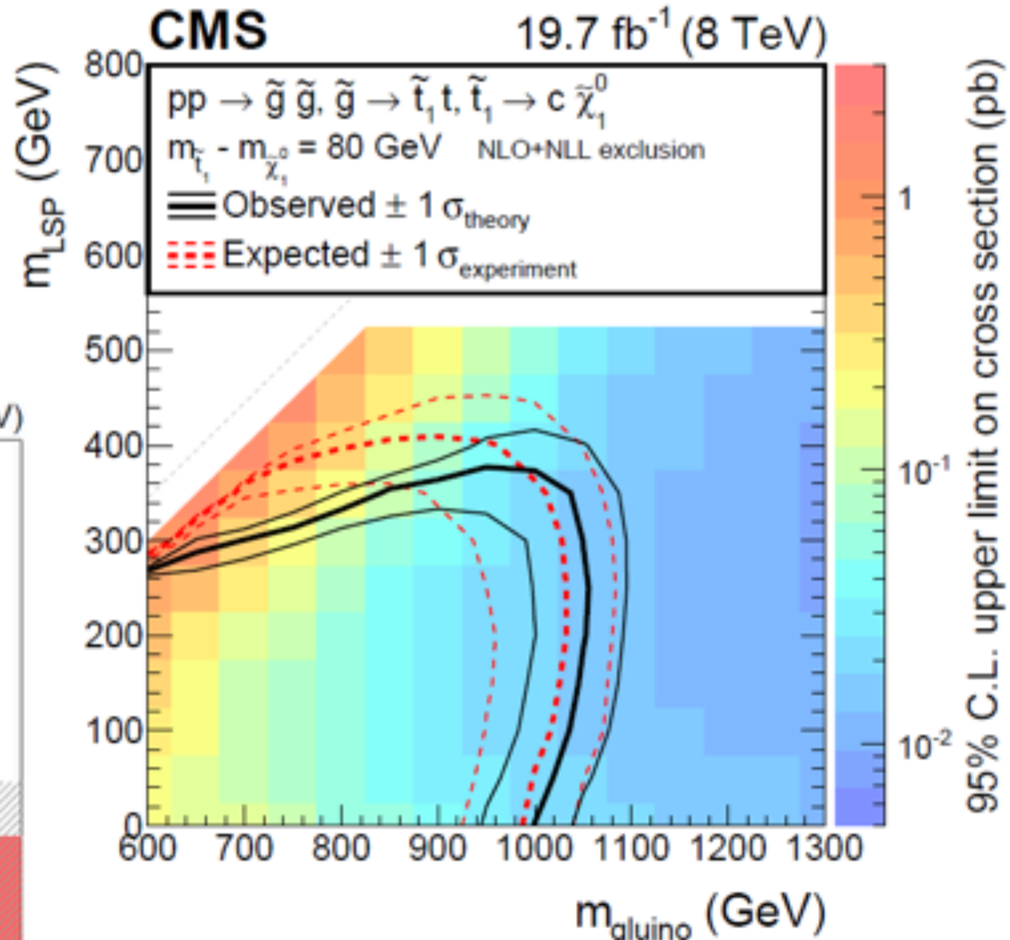


Highly Boosted SUSY: razor search

Targeting heavy stops and/or phase space where m(G) – m(stop) is large







First 13 TeV Performance

Commissioning the performance of key observables used in SUSY searches with the first 13 TeV data

CMS Collaboration
August 2015

Using 42±5 pb^{-1} of data from July's 50 ns running period, we commission the ingredients for the SUSY search program: measure trigger efficiencies, check MC modeling of the shapes* of key observables, and test background estimation methods.

Details described in DPS CMS DP-2015/035

* MC normalized to data for shape comparisons

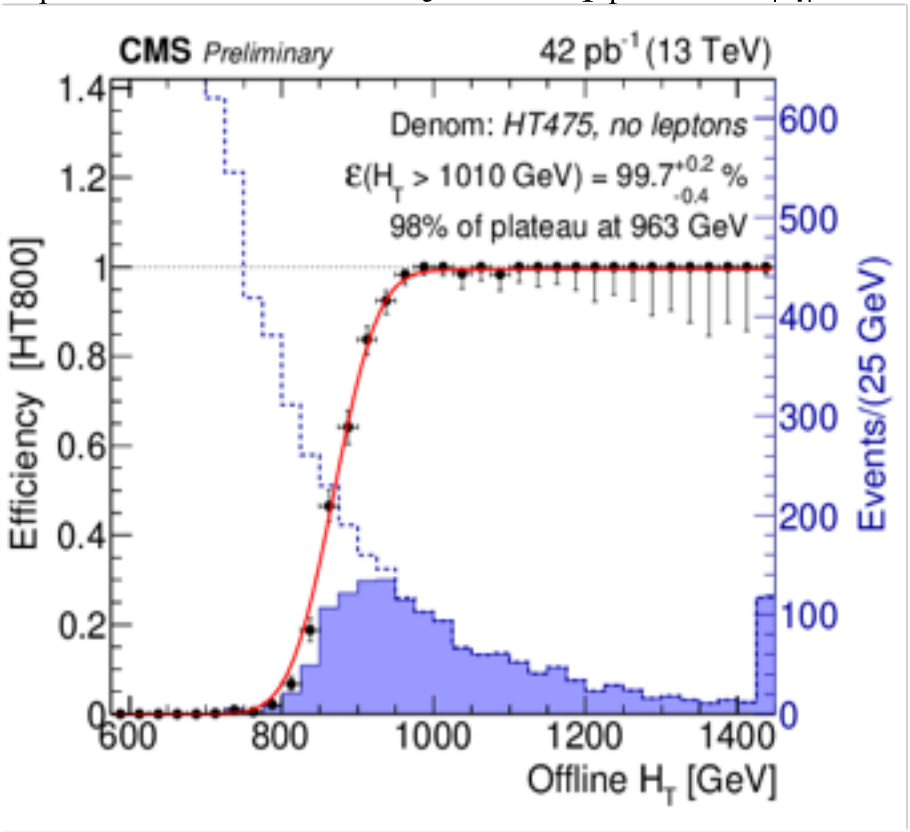
Trigger efficiencies: HT, MET

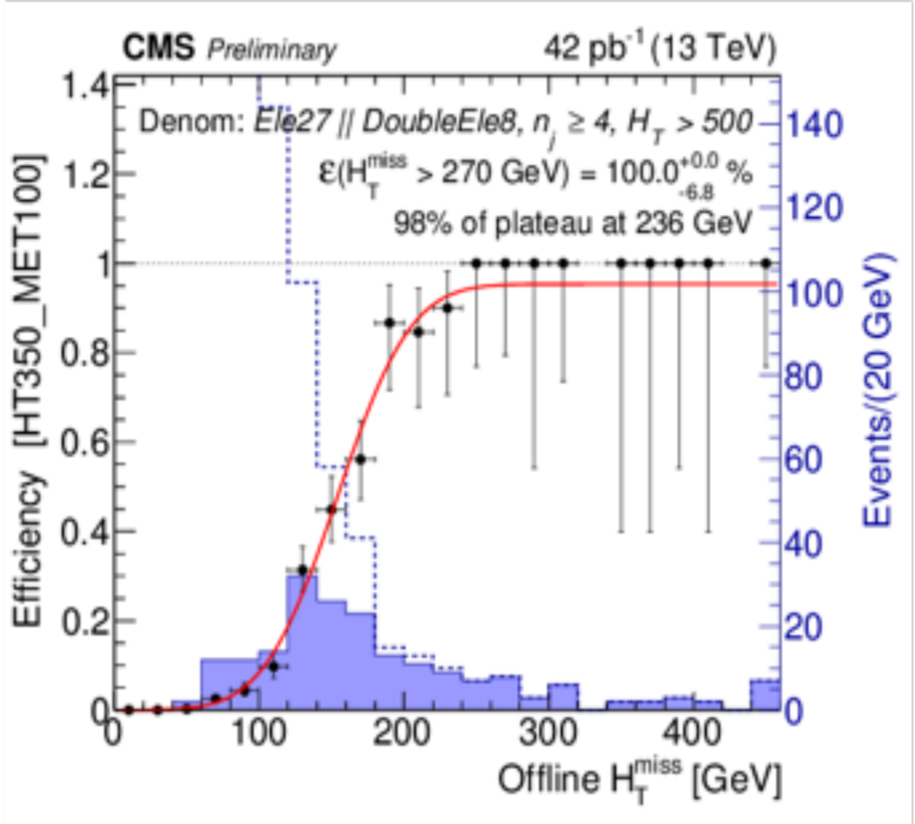
HT800 trigger provides common sample for high mass hadronic gluino search
HT350_MET100 trigger targets lower mass, e.g., compressed models

Measure rates and efficiencies with 50 ns data.

H_T^{miss} = vector sum of AK4 jets.

H_T = scalar sum of AK4 jets with p_T>40 and $|\eta|$<3.

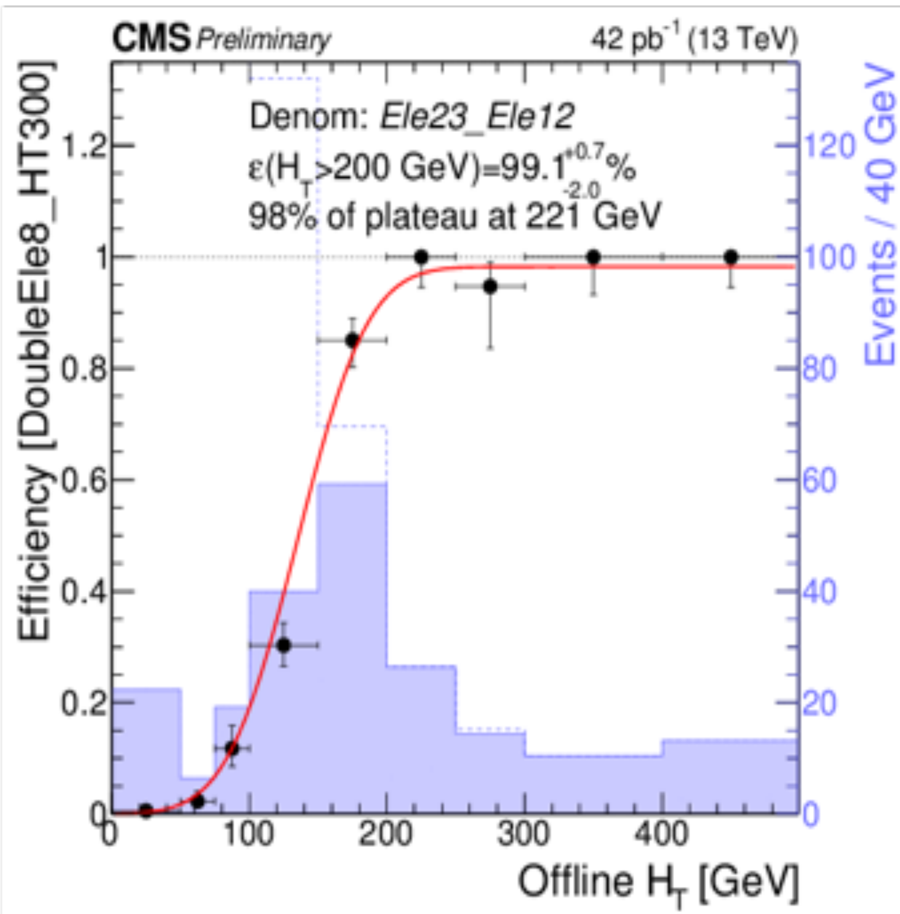


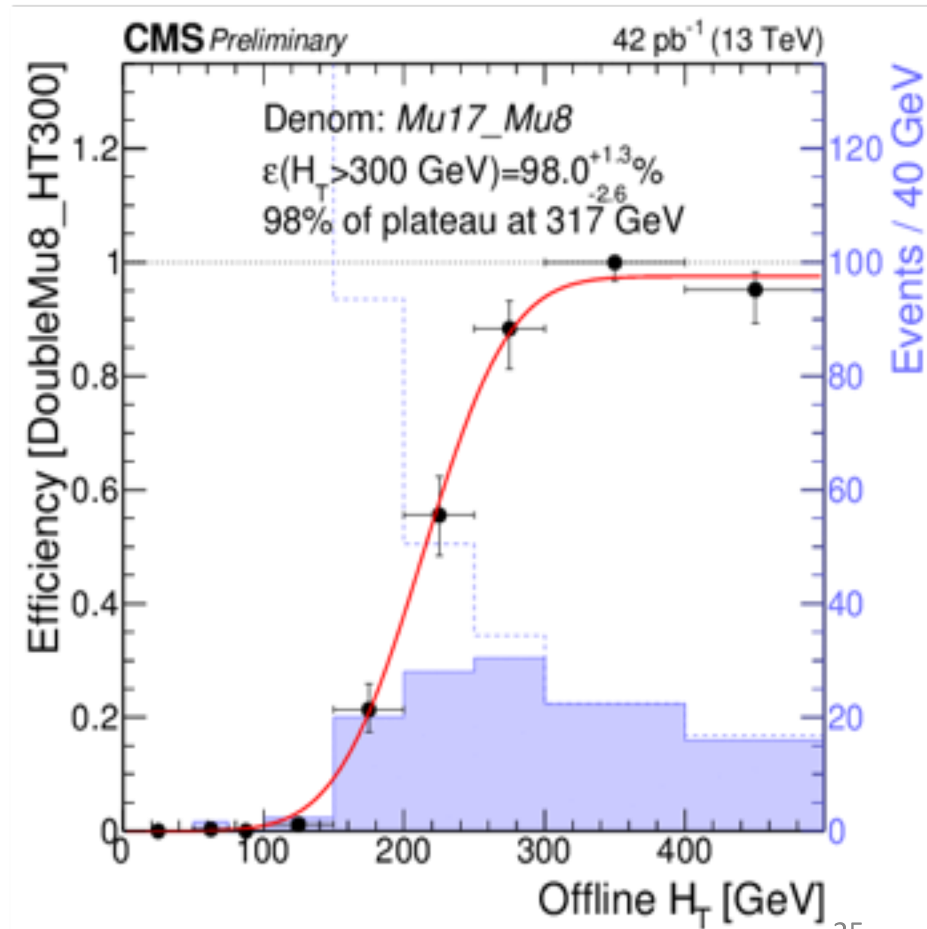


Trigger efficiencies: dilepton

Dilepton searches use a combination of pure dilepton and dilepton+HT triggers.

Measure rates and efficiencies with 50 ns data.



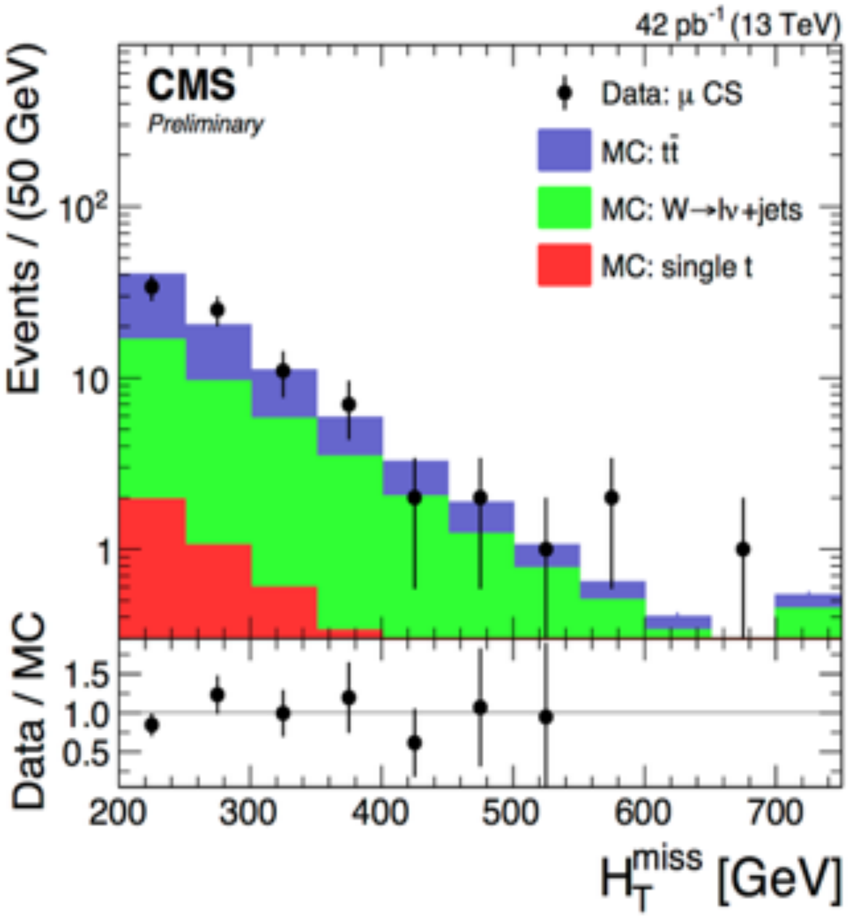


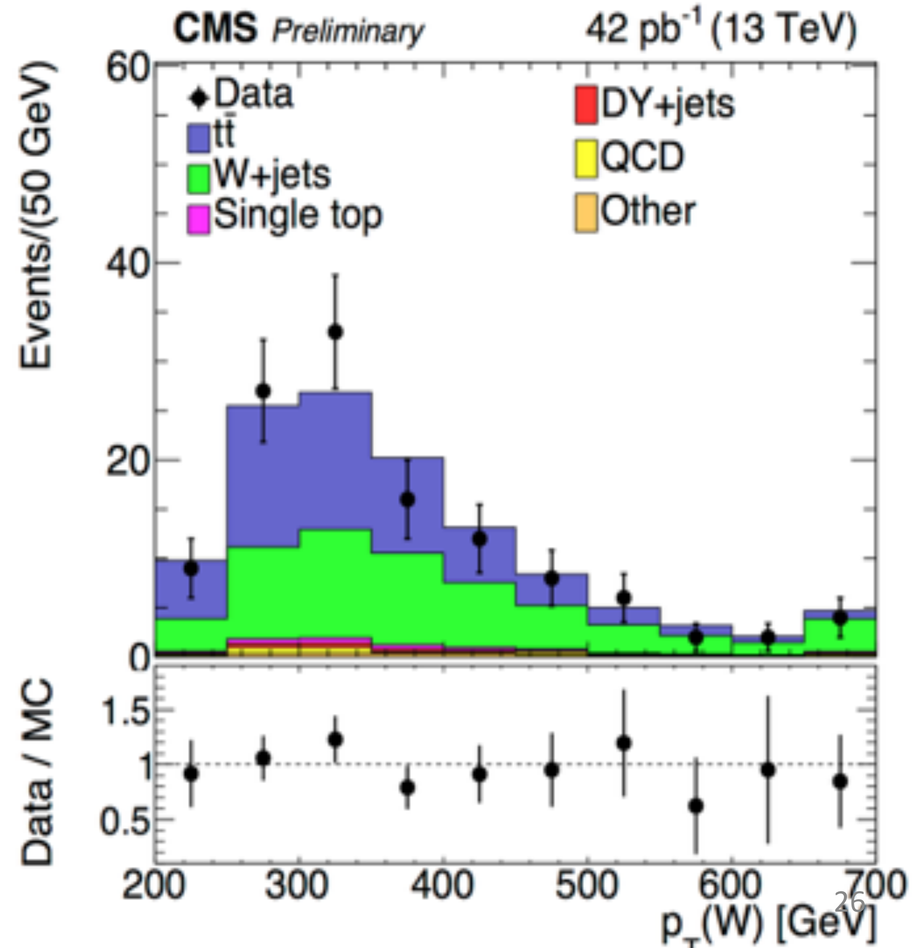
All-hadronic search in H_T and H_T^{miss}

SUS-13-012/12-024

Inclusive search at high H_T and H_T^{miss} in bins of N_{jet} and N_b.

An important background is W or top with missed leptons. Measure this bkgd in single μ control sample, as a function of kinematics. Measure the hard-to-model W p_T and use well known W decay properties from MC.

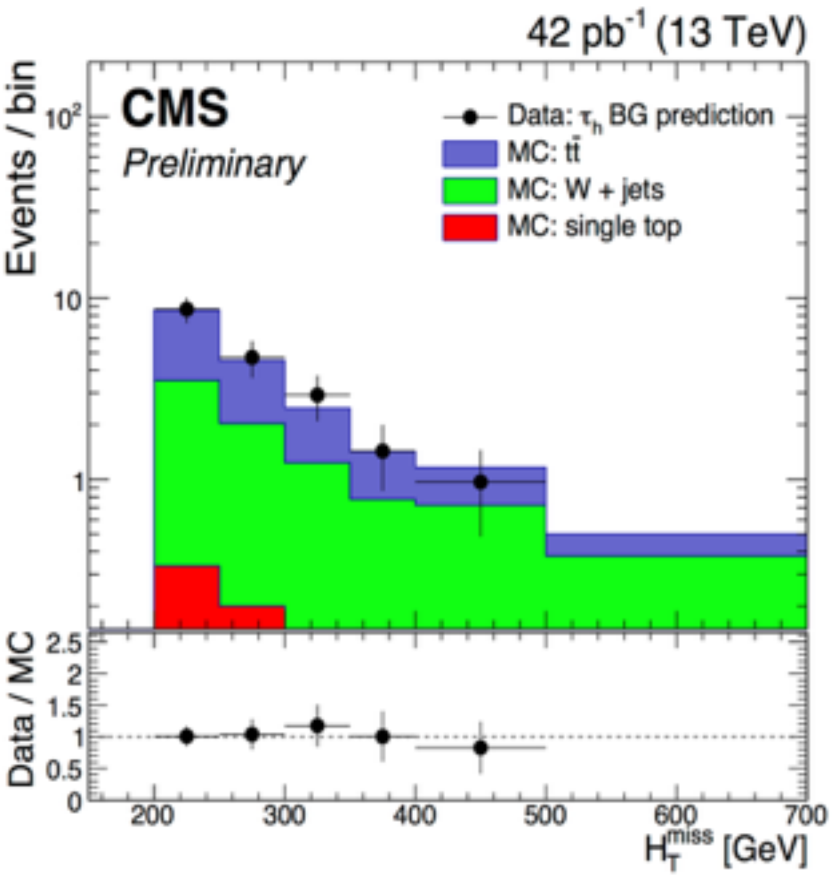


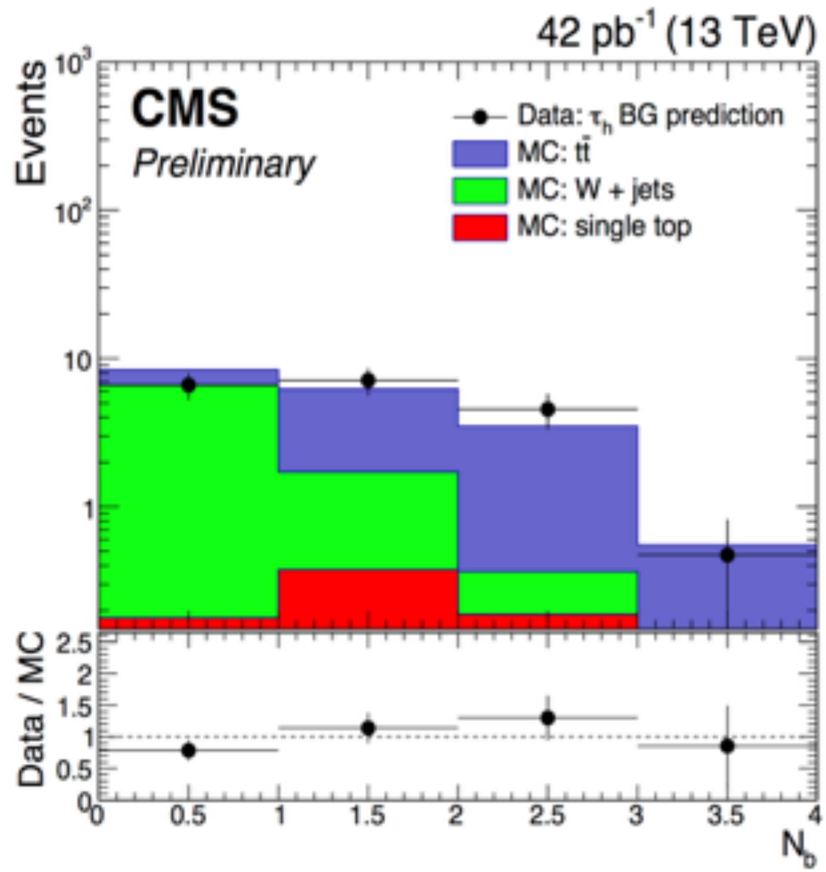


All-hadronic search in H_T and H_T^{miss}

Inclusive search at high H_T and H_T^{miss} in bins of N_j and N_b.

Another important background is W or top with hadronic τ decays.
Measure with muon control sample by emulating τ jet from muon.





All-hadronic search using M_{T2}

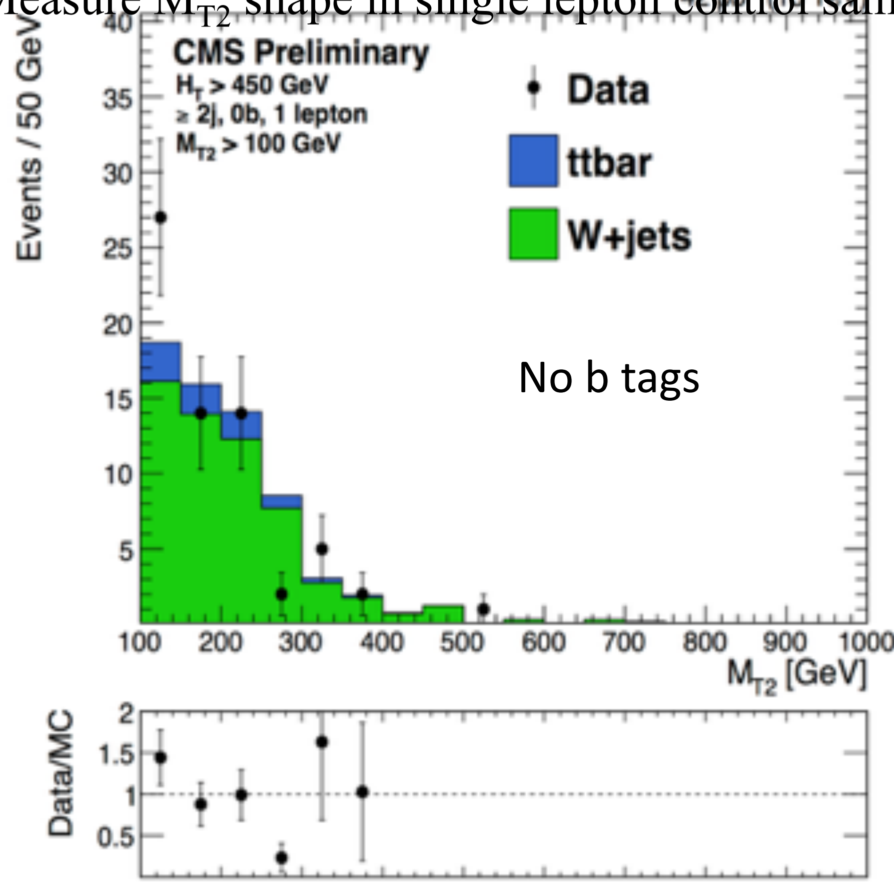
SUS-13-019

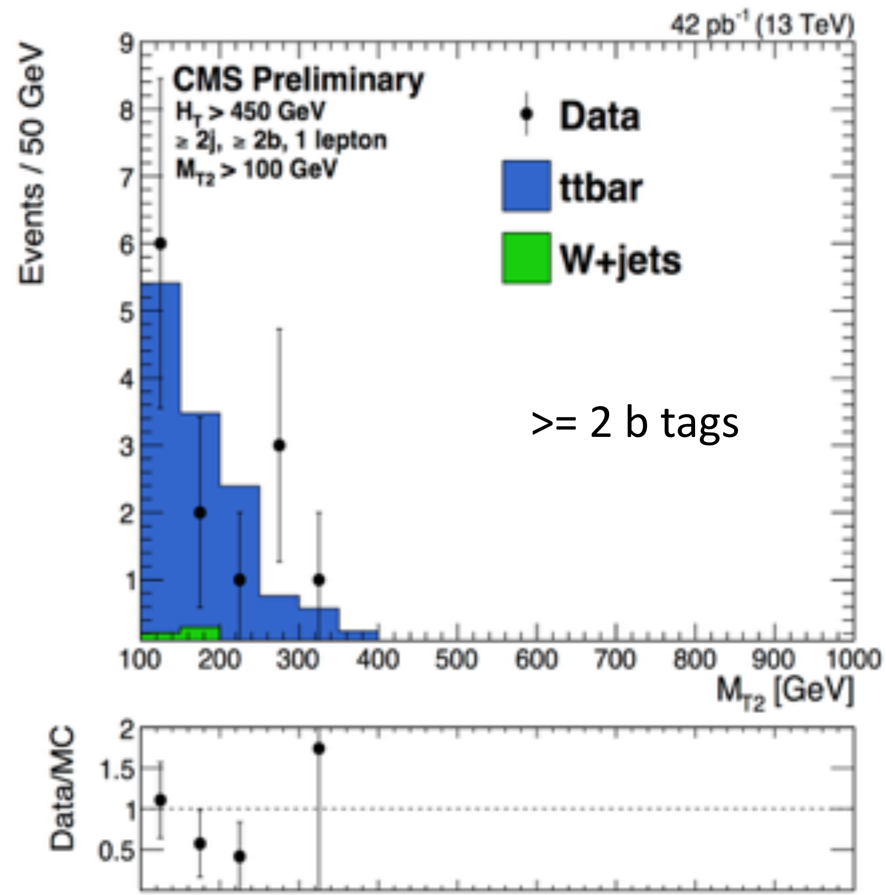
Inclusive search with M_{T2} in bins of H_T, N_{jet} and N_b.

M_{T2} = sTransverse mass, designed for final states w/ 2 missing particles

An important background is **W or top with missed leptons or taus**

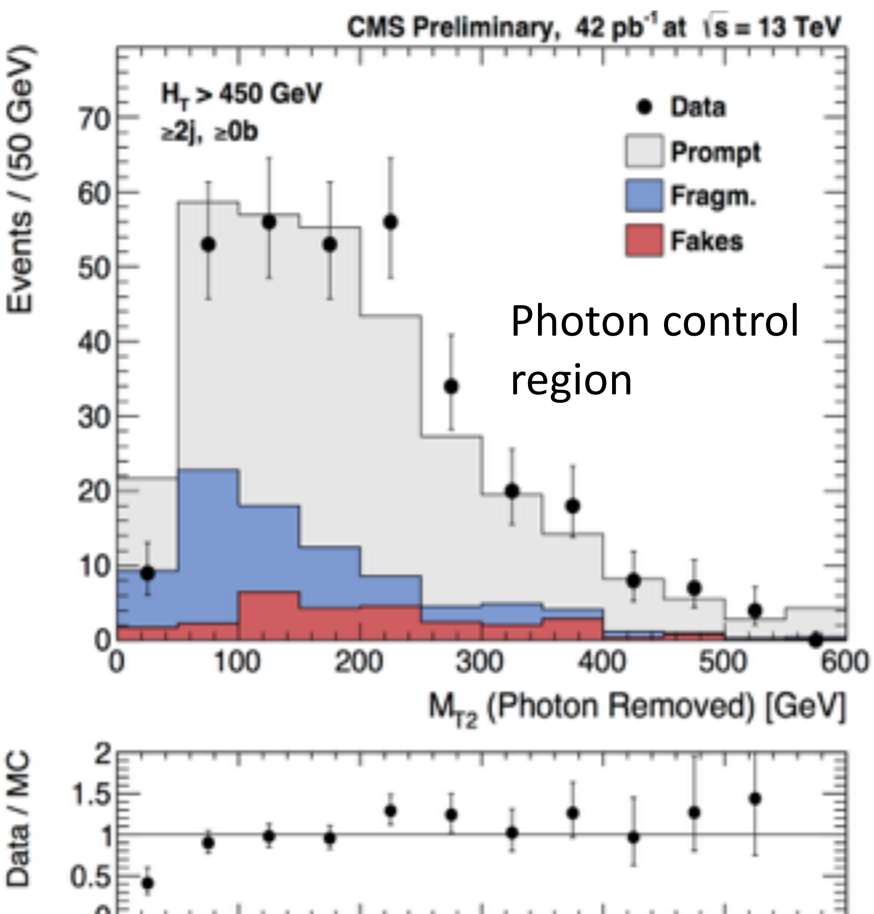
Measure M_{T2} shape in single lepton control sample

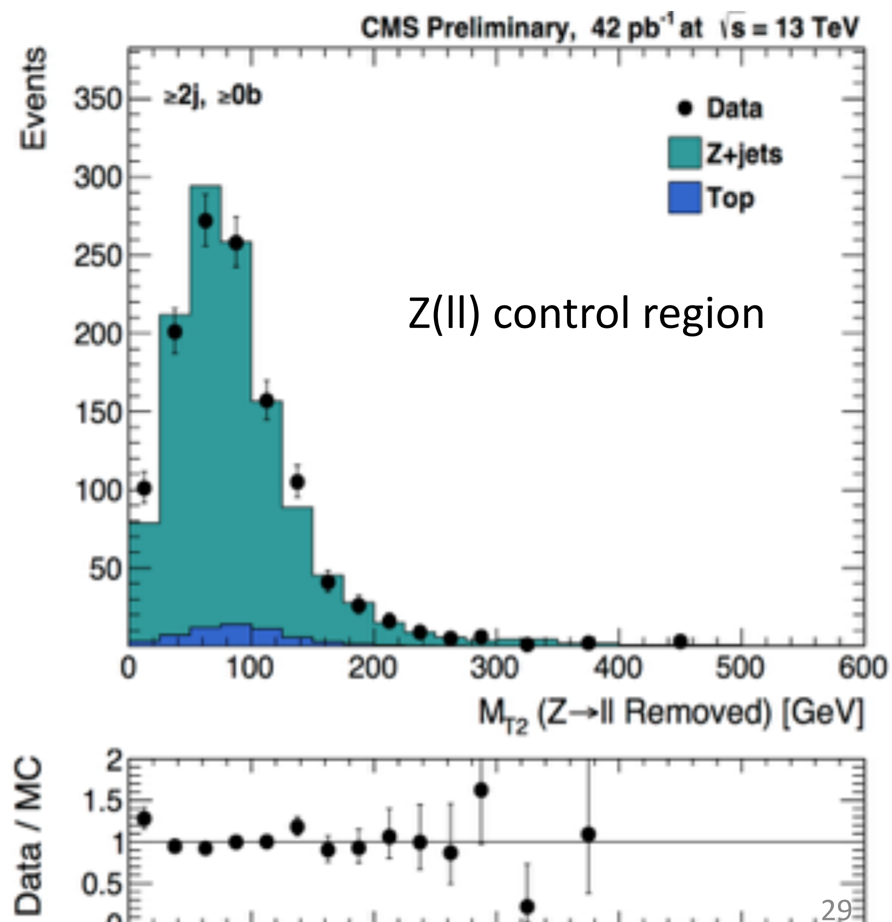




All-hadronic search using M_{T2}

Control regions to study **$Z \to \nu\nu$** background. Estimate with photon sample, multiplied by Z/γ ratio. Check modeling of MT2 variable in $Z \to \ell\ell$ and γ samples.

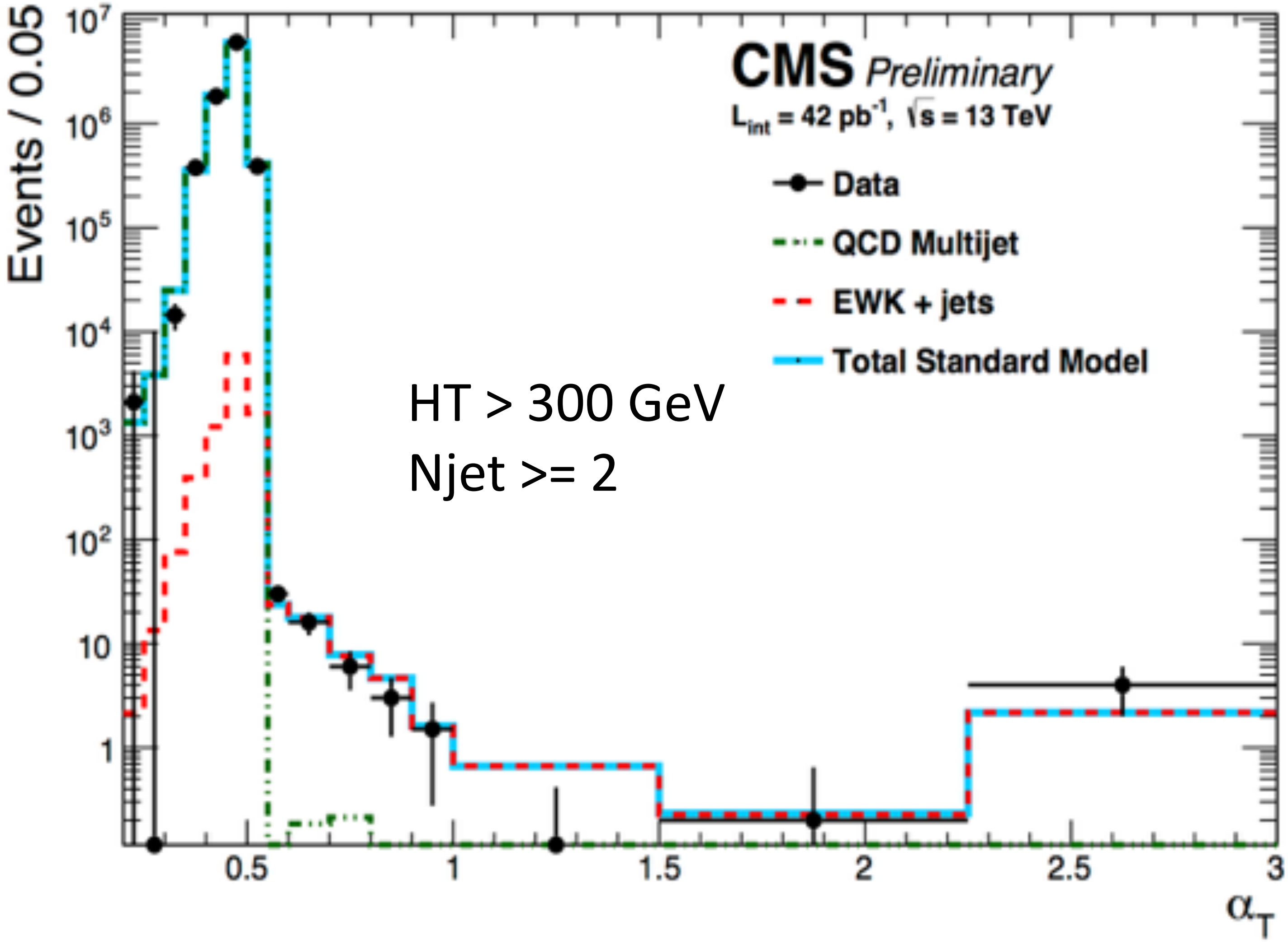




All-hadronic search using AlphaT

Inclusive search with α_T in bins of H_T, H_T^{miss}, N_j and N_b.

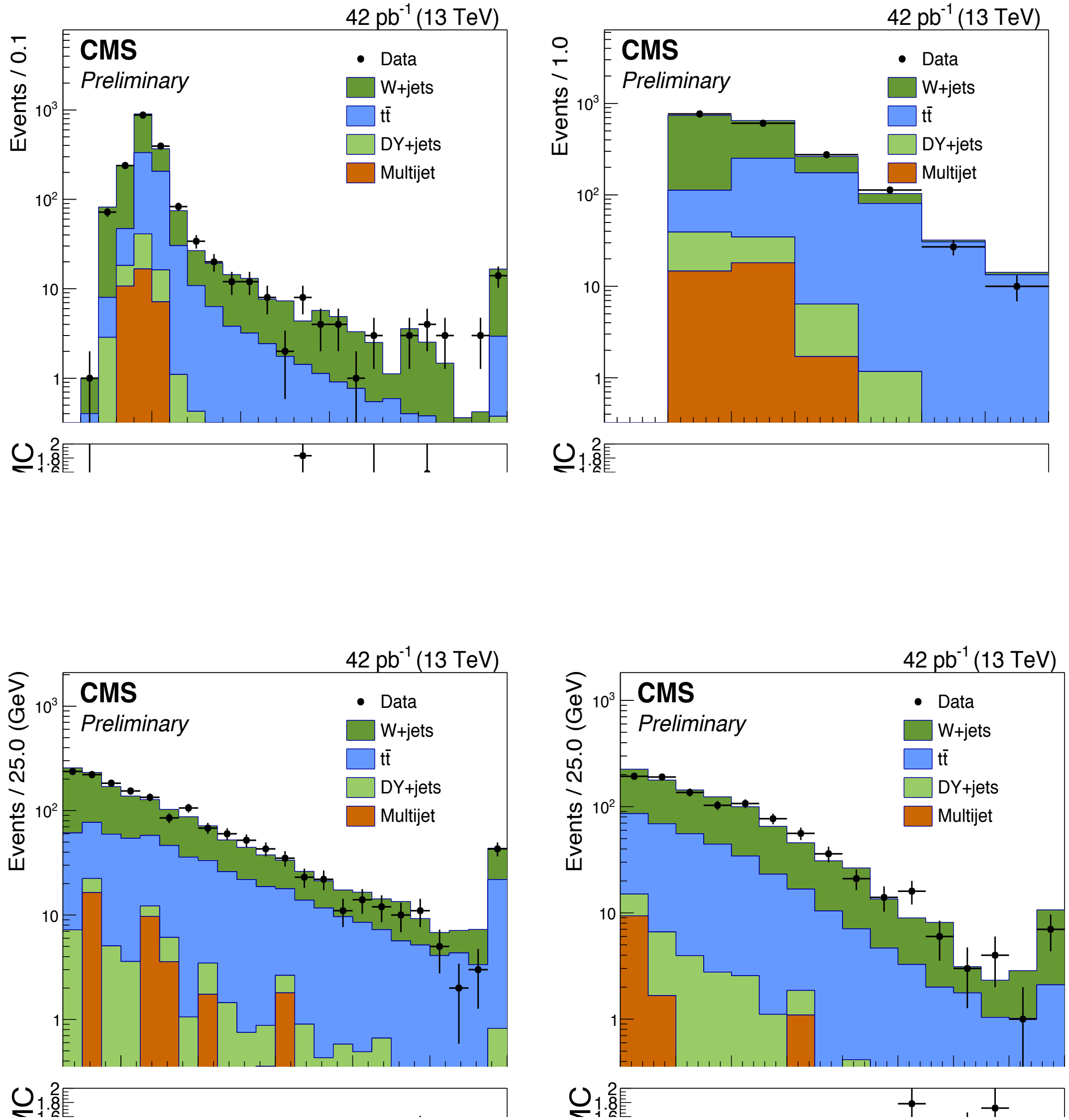
AlphaT is a QCD killer, leaving a top and EWK dominated background.



All-hadronic search using AlphaT

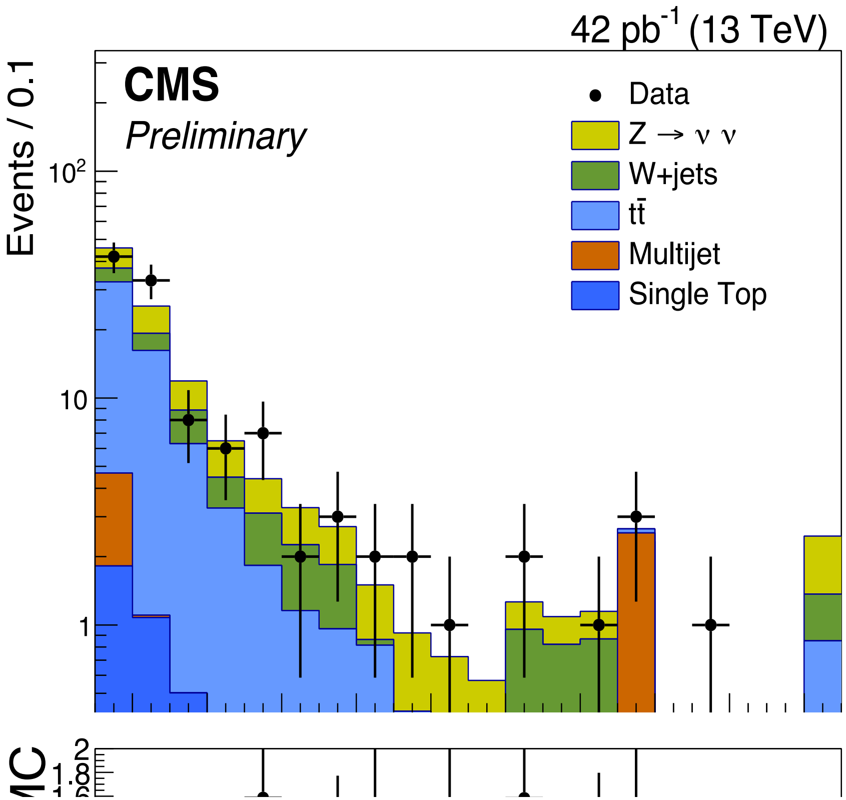
Inclusive search with α_T in bins of H_T, H_T^{miss}, N_j and N_b.

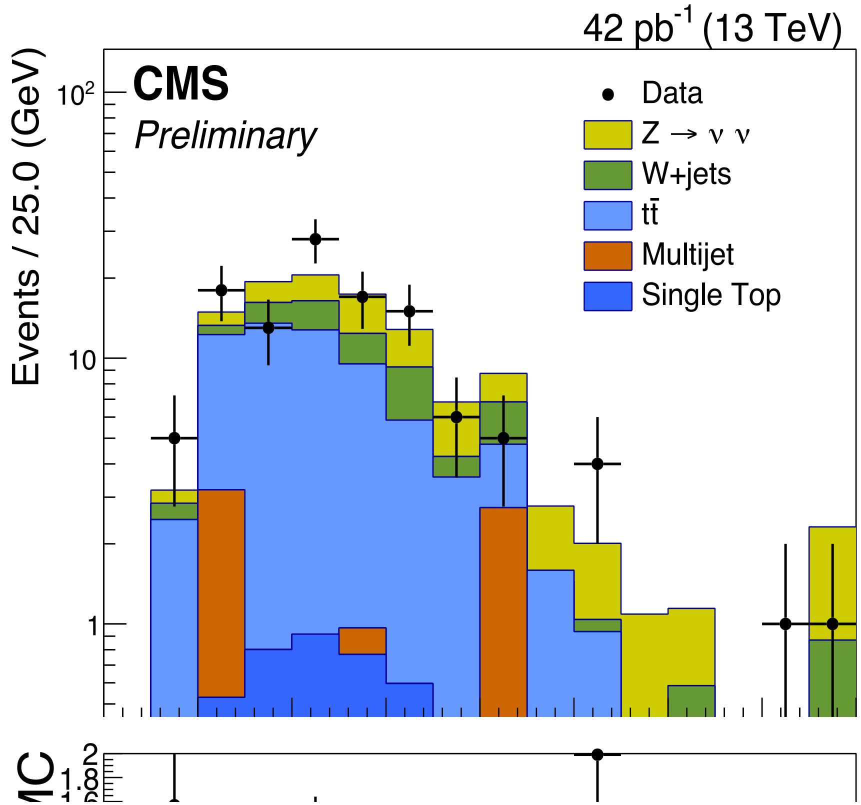
Background measured with MC transfer factors from single lepton sample. Validate modeling in key variables using **single muon control sample.**



All-hadronic search using AlphaT

Inclusive search with α_T in bins of H_T, H_T^{miss}, N_j and N_b.



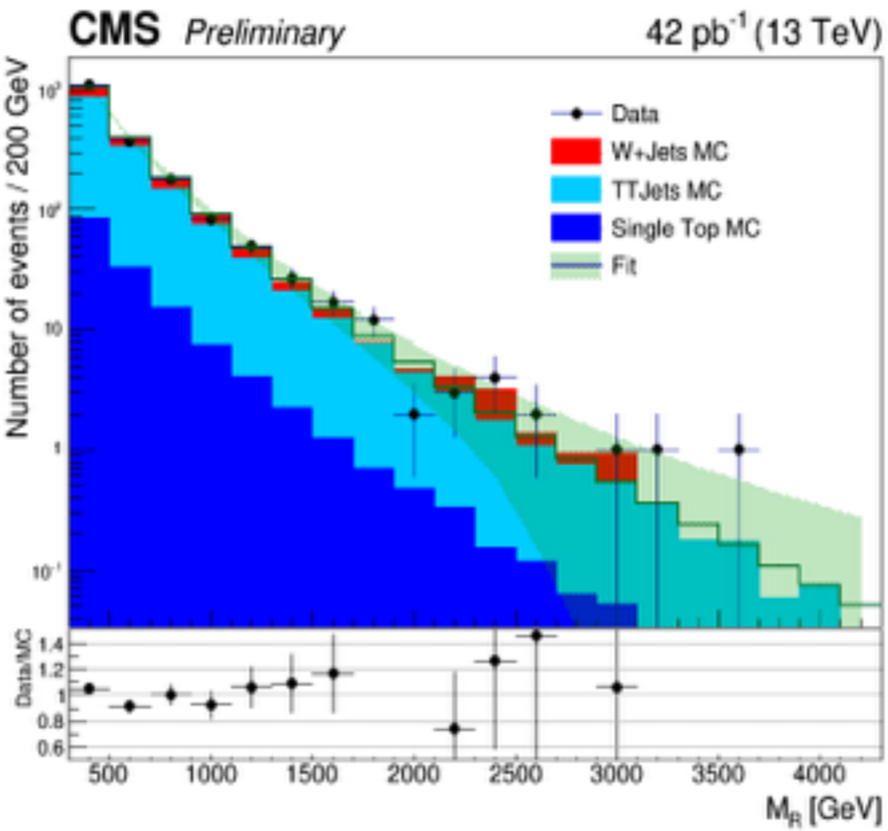


Signal region with HT > 225 GeV and >= 1 b tag

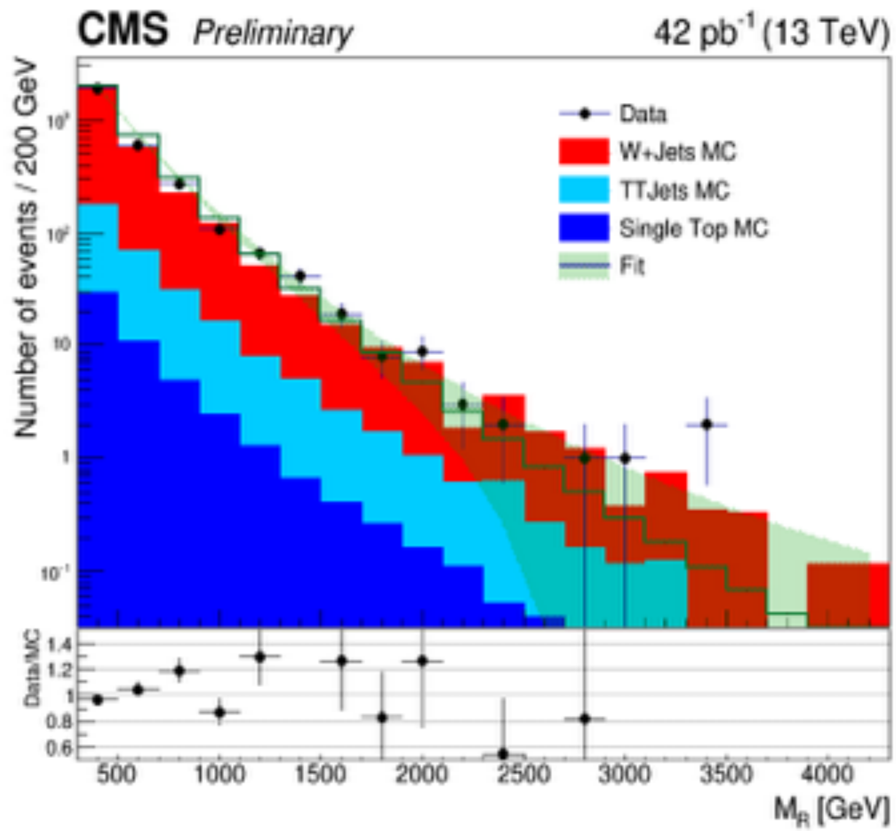
Search using Razor variables

The razor variables M_R and R provide a broad peak for signal and QCD suppression, respectively. Top & EWK bkgs fall ~ exponentially.

Check performance of sideband fit and MC modeling in W and top control samples.



ttbar control region



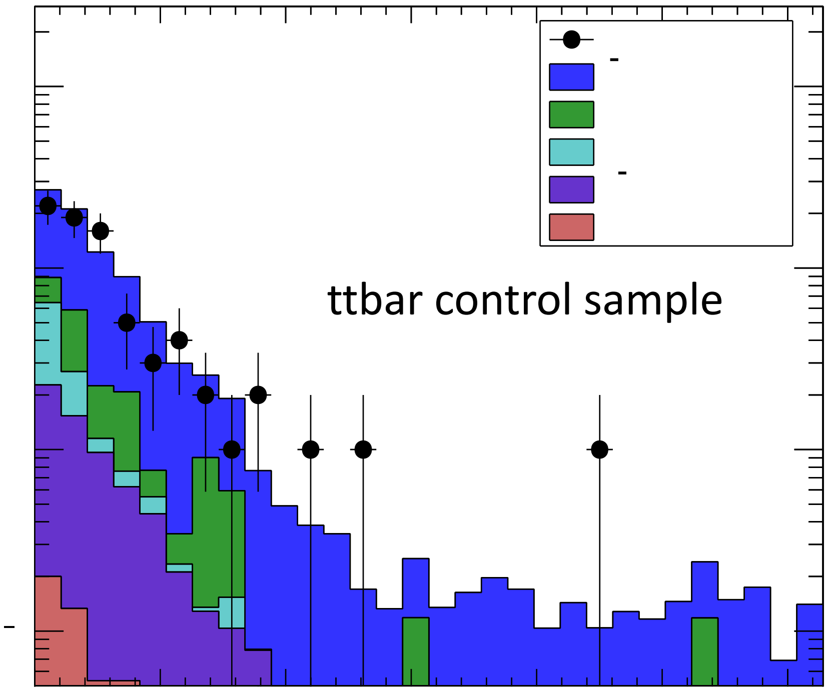
W+jets control region

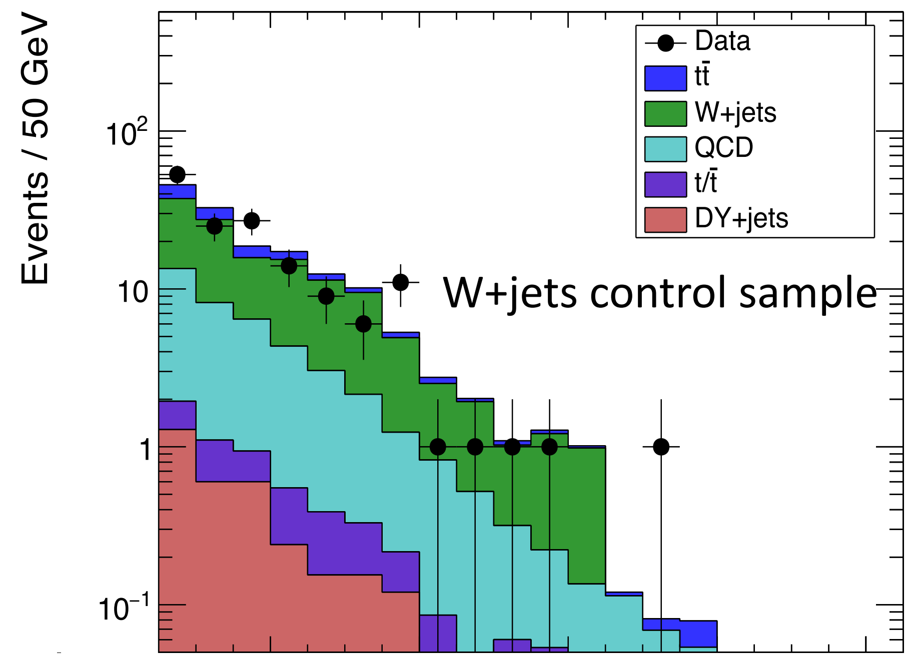
Single lepton search using Δϕ(lepton,W)

SUS-13-007

Requiring Δϕ(lepton,W)>1 suppresses single lepton W and top decays.
Cutting on L_T = scalar sum of E_T^{miss} and lepton p_T allows lower E_T^{miss}.

Validate variables in W and top control samples with first data.

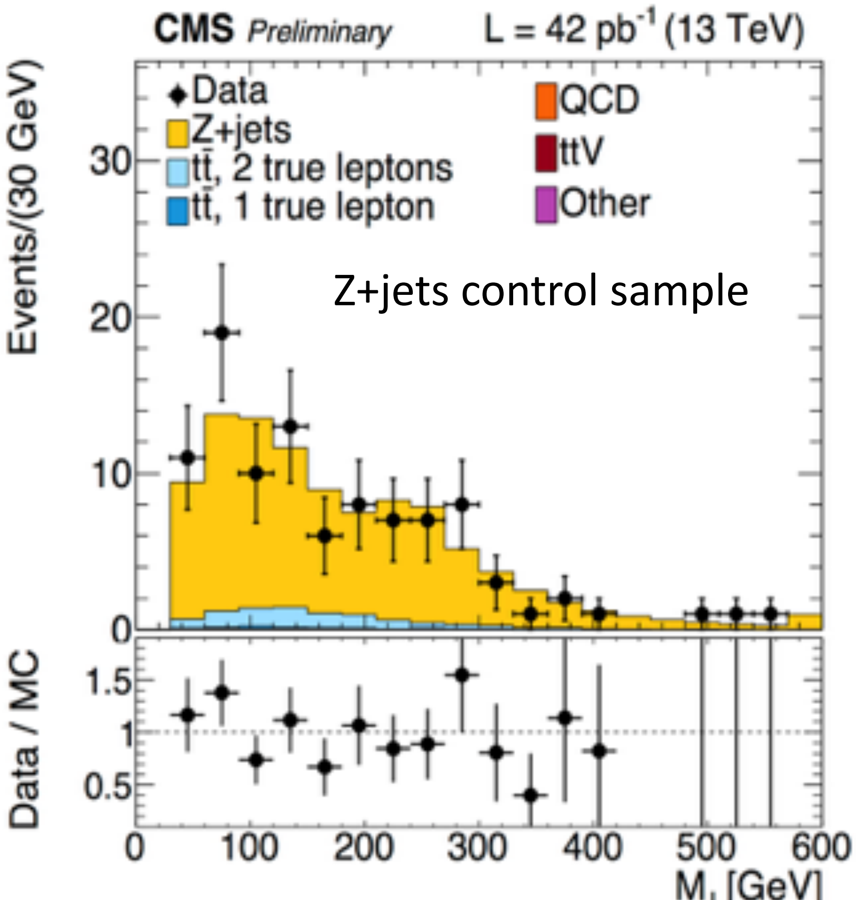


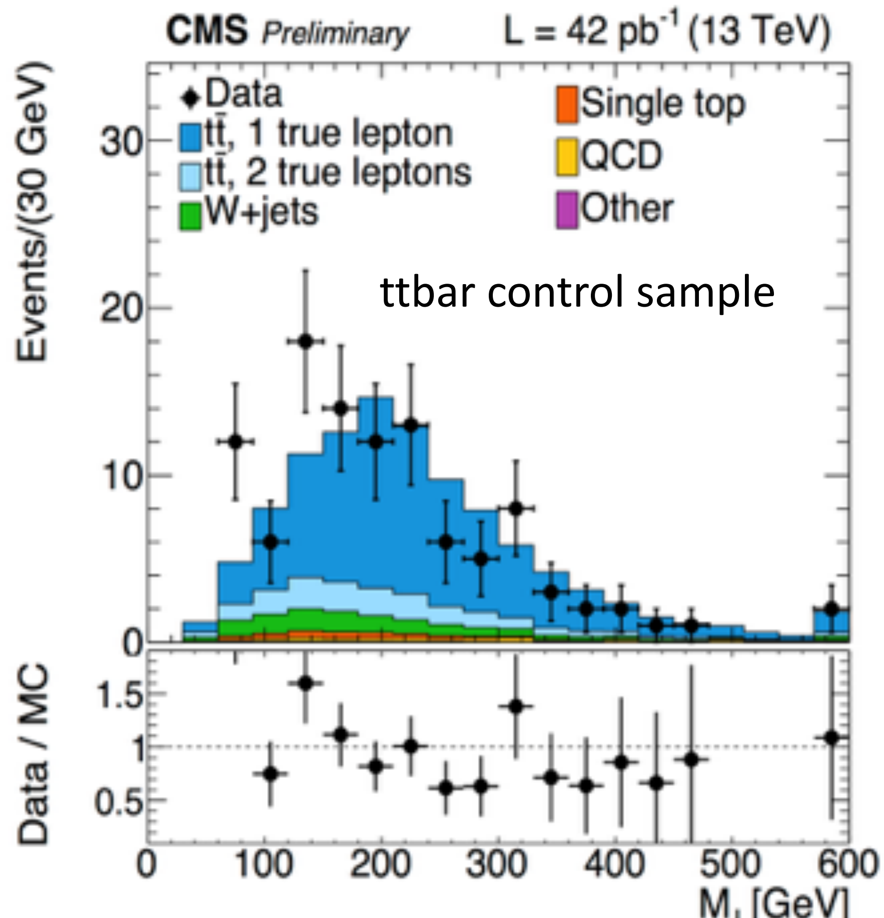


Single lepton search using sum of jet's mass

Study using M_J = sum of large-R jets (R=1.2) together with M_T.
M_T cut leaves mostly dilepton top; search in bins of E_T^{miss}, N_b, N_{jet} where a M_J tail beyond $2m_t$ arises mostly from ISR.

Study contributions to M_J in Z+jets sample and ttbar samples

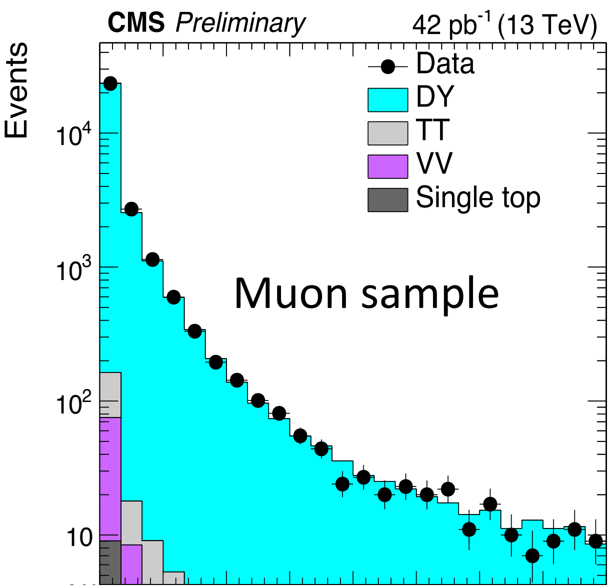


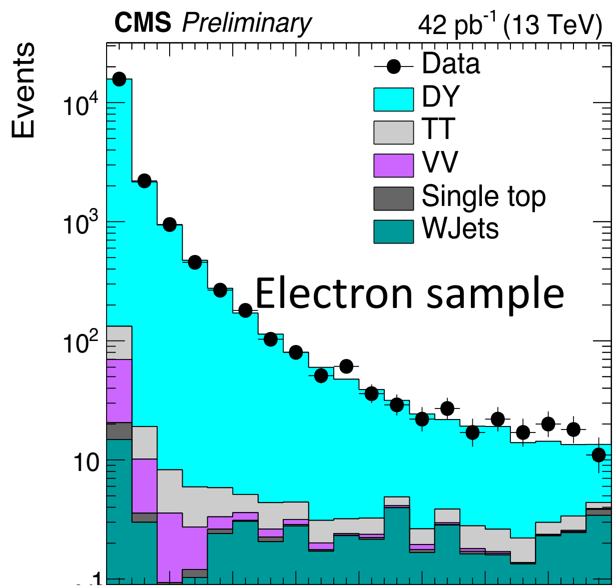


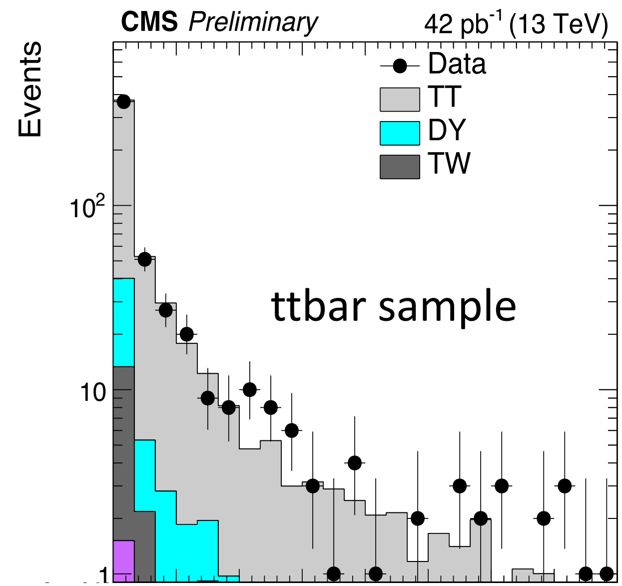
Same sign dilepton search

Low background search, with contributions from rare SM (e.g., ttW), "fake" leptons (e.g., b decay), and electron charge mis-identification.

Measure the lepton fake rate as a function of kinematics using observables such as isolation.



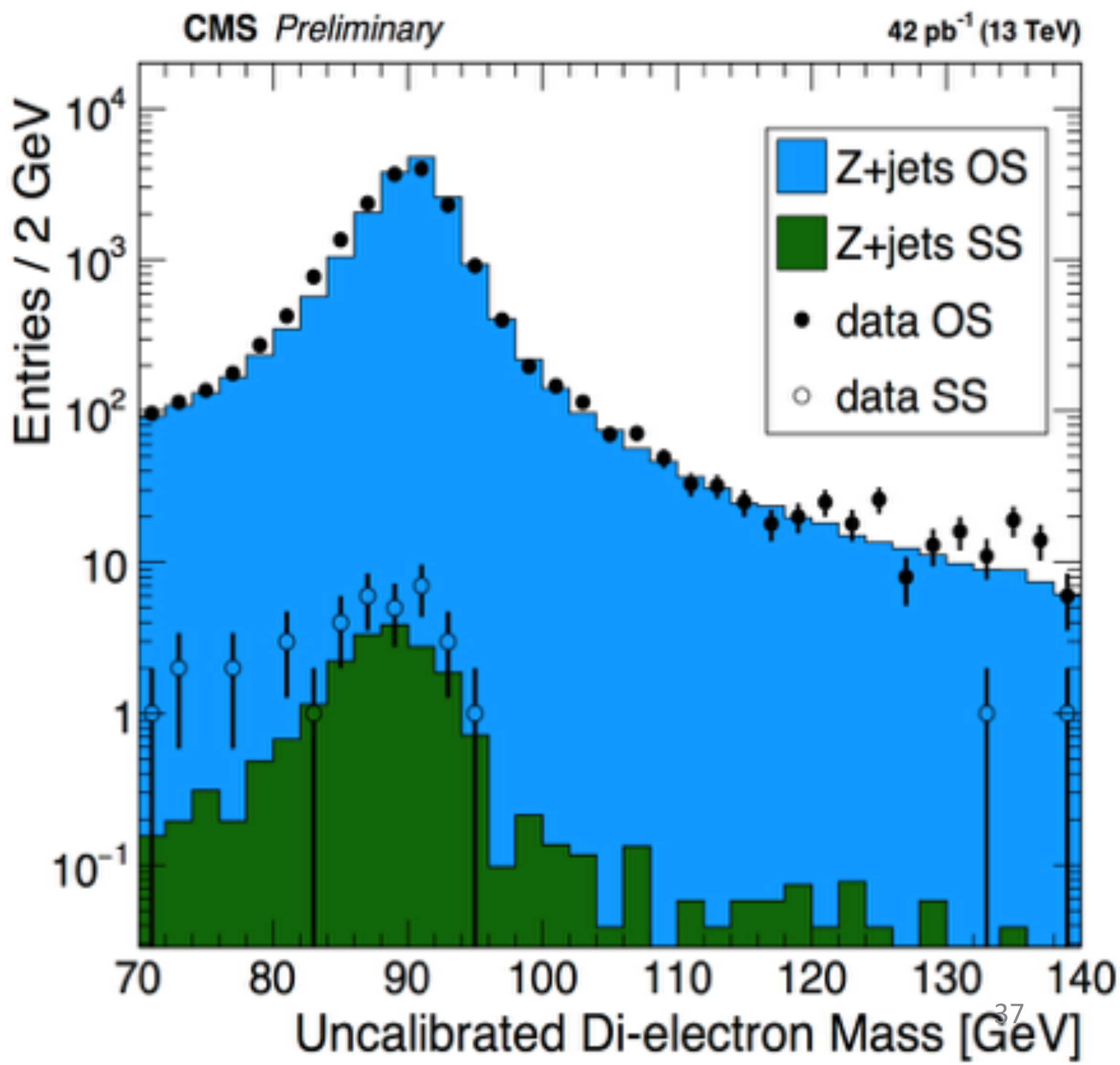




Same sign dilepton search

Low background search, with contributions from rare SM (e.g., ttW), "fake" leptons (e.g., b decay), and electron charge mis-identification.

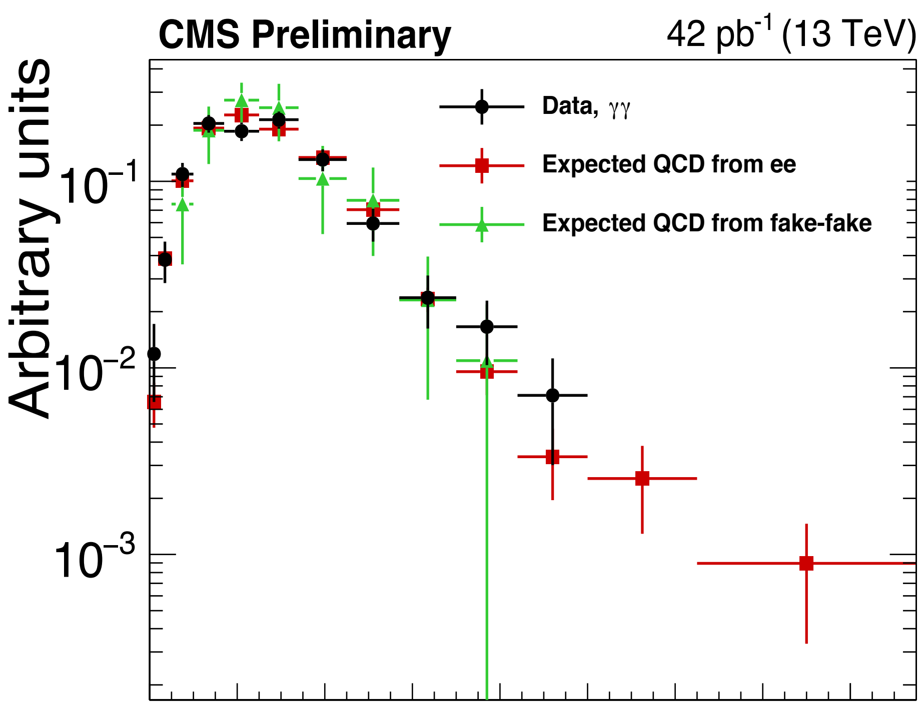
Charge mis-identification for electrons is expected to be small. Measure it with Z→ee events.



Diphoton + E_T^{miss} search

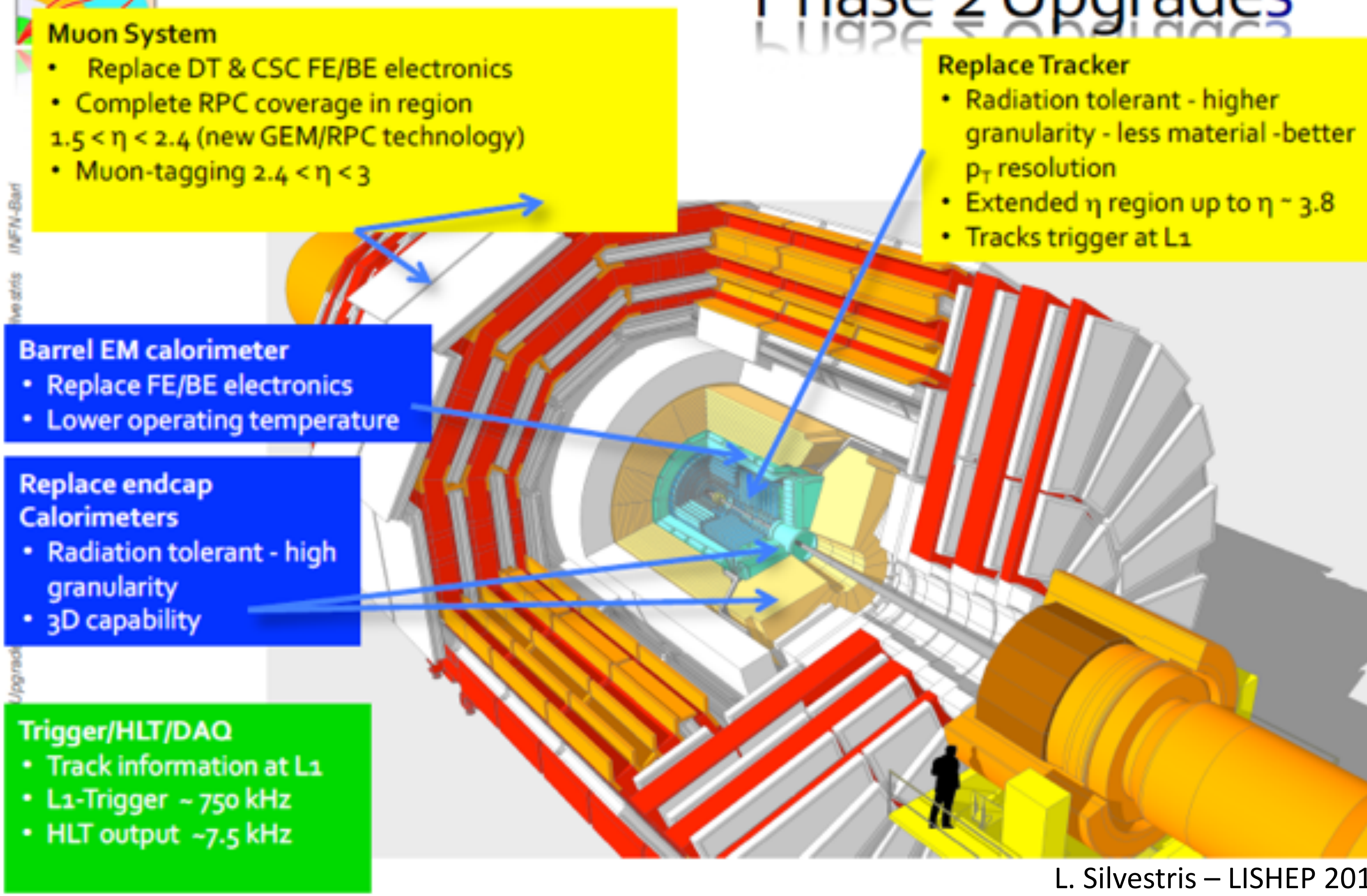
Search for General Gauge Mediation models where $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$ leads to $\gamma\gamma E_T^{miss}$+jets signature.

Fake E_T^{miss} resolution affected by p_T of diEM system. Measure it in $Z \rightarrow ee$ and fake-fake samples.
Reweighting the diEM p_T of these samples to a signal sample provides E_T^{miss} prediction for that sample



Prospects for 300 and 3000 fb^{-1}

Phase 2 Upgrades



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Extended tracker coverage (η ~ 3.8) – PU mitigation

Extended muon coverage (η ~ 3) – higher acceptance

Trigger upgrade: track trigger @ L1, increased bandwidth (7.5 kHz @ HLT)

High granularity endcap calorimeter – PU mitigation, VBF acceptance, q/g discrimination

Benchmark Models

- CMS studied 5 benchmark models satisfying:
  - The model should not be already excluded by existing SUSY & BSM higgs searches, and be consistent with existing measurements of the 125 GeV higgs, relic density, etc.
  - The model should contain production and decay channels that could be discovered with up to 300 fb^{-1}
    - To study how a discovery could be characterized @ HL-LHC
  - The model should be theoretically well motivated
    - Natural SUSY inspired models (NM's) and co-annihilation models motivated by dark matter

Discovery Scenarios

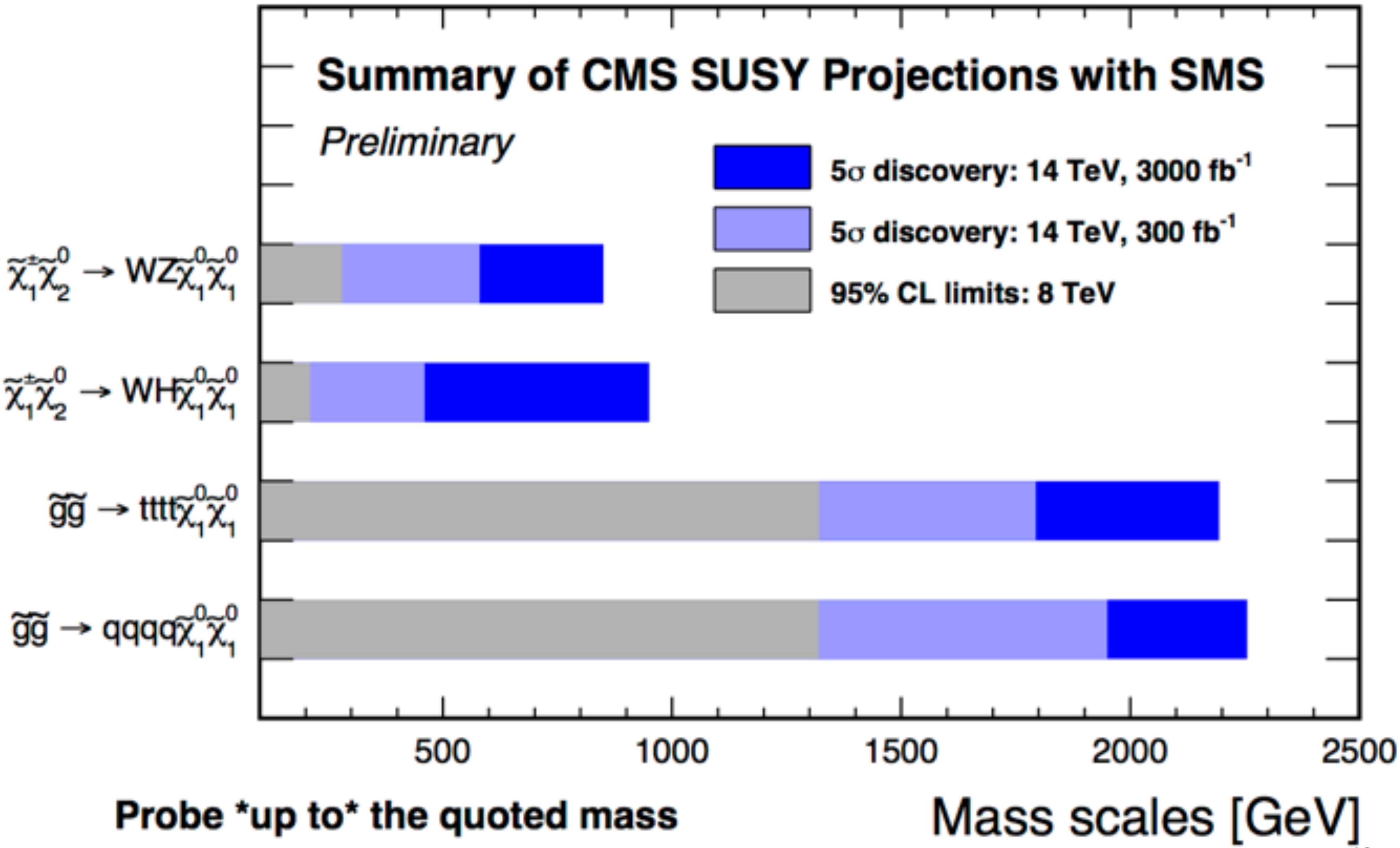
Experimental signature

SUSY models

Analysis	Luminosity (fb^{-1})	Model				
		NM1	NM2	NM3	STC	STOC
all-hadronic (H_T-H_T^{miss}) search	300					
	3000					
all-hadronic (M_{T2}) search	300					
	3000					
all-hadronic $\tilde{b}_1$ search	300					
	3000					
1-lepton $\tilde{t}_1$ search	300					
	3000					
monojet $\tilde{t}_1$ search	300					
	3000					
$m_{\ell^+\ell^-}$ kinematic edge	300					
	3000					
multilepton + b-tag search	300					
	3000					
multilepton search	300					
	3000					
ewkino WH search	300					
	3000					

$< 3\sigma$	$3-5\sigma$	$> 5\sigma$

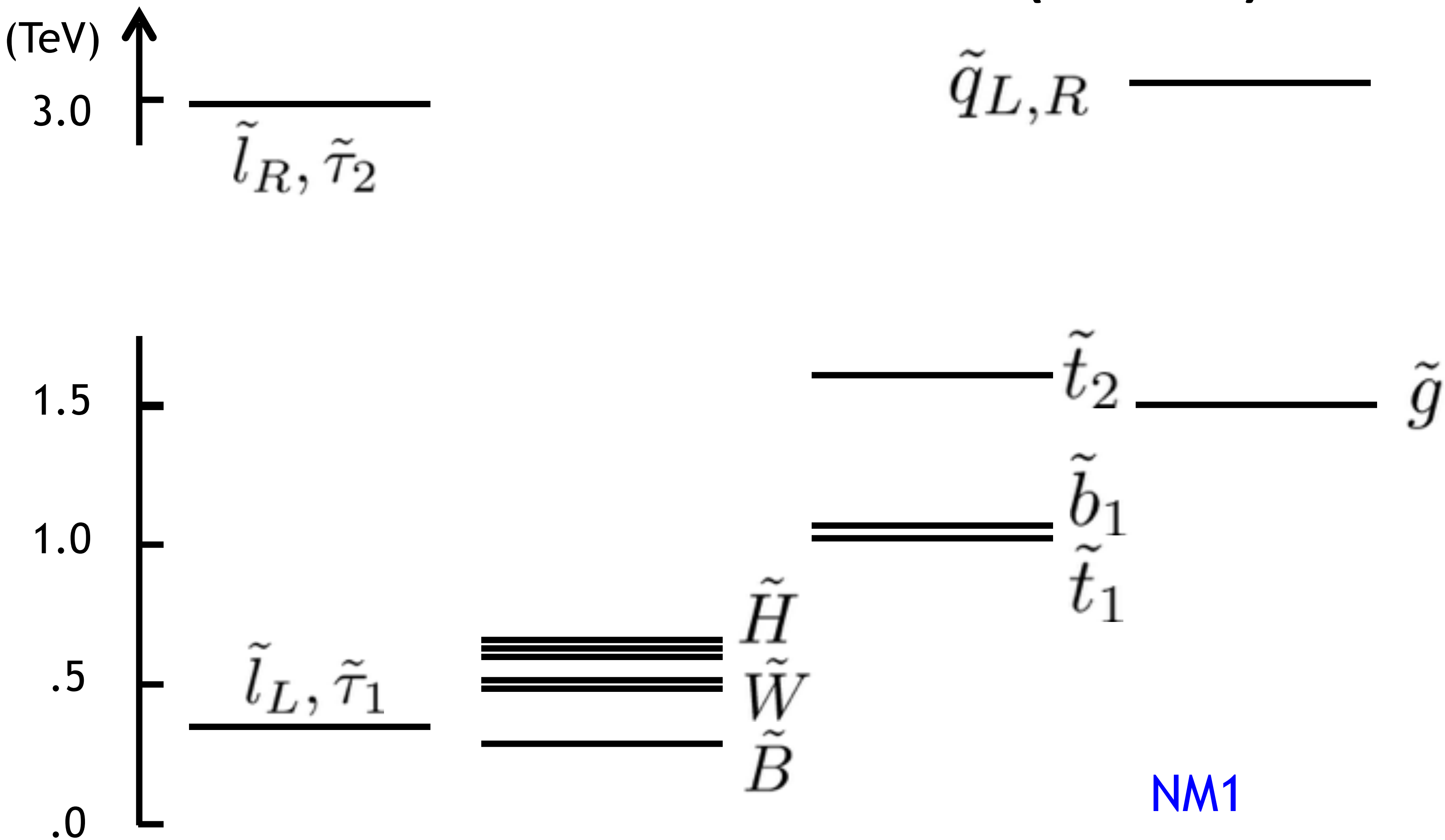
Discovery Reach



Probe *up to* the quoted mass

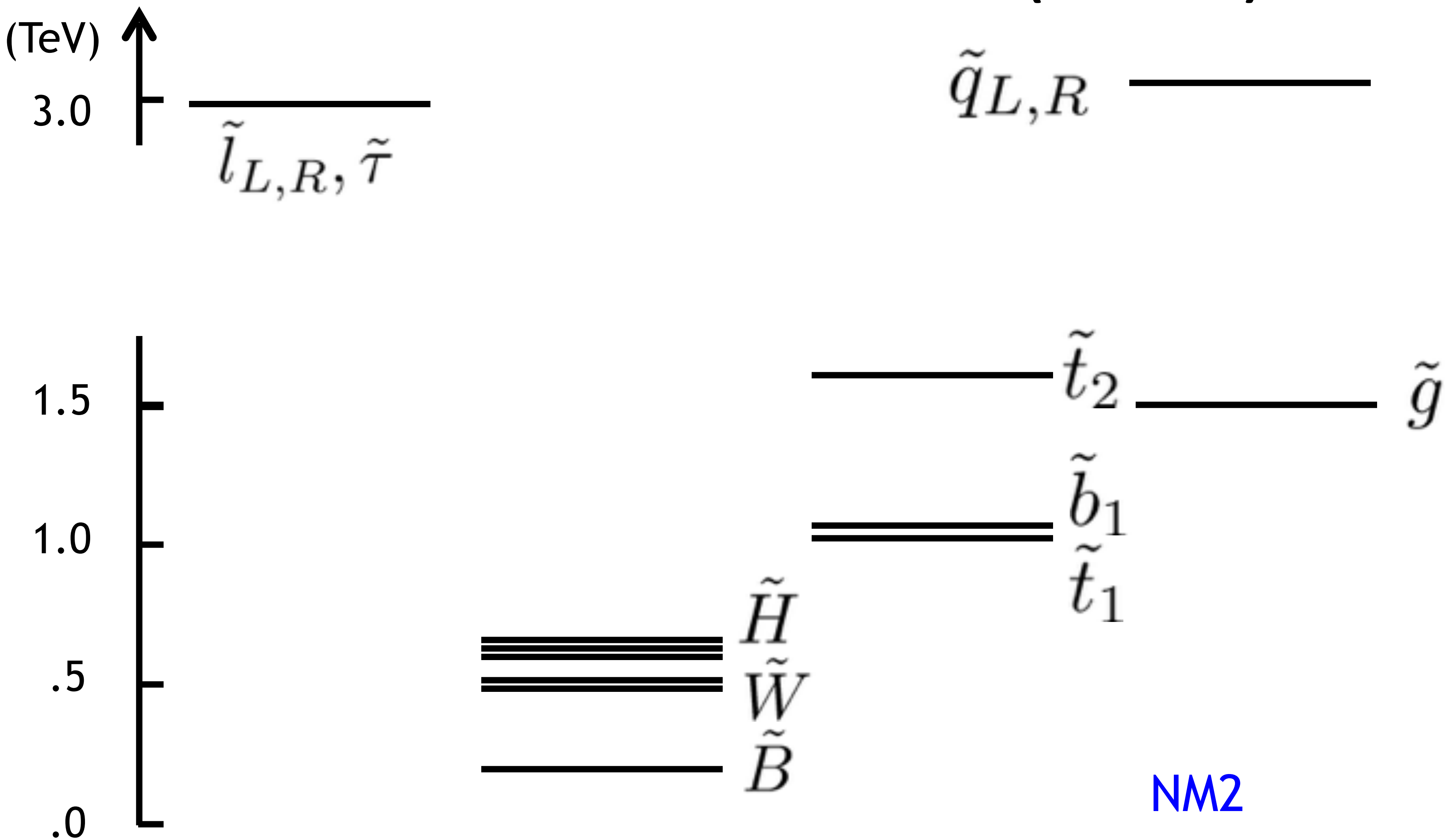
Backup

Natural SUSY Models (NM’s)



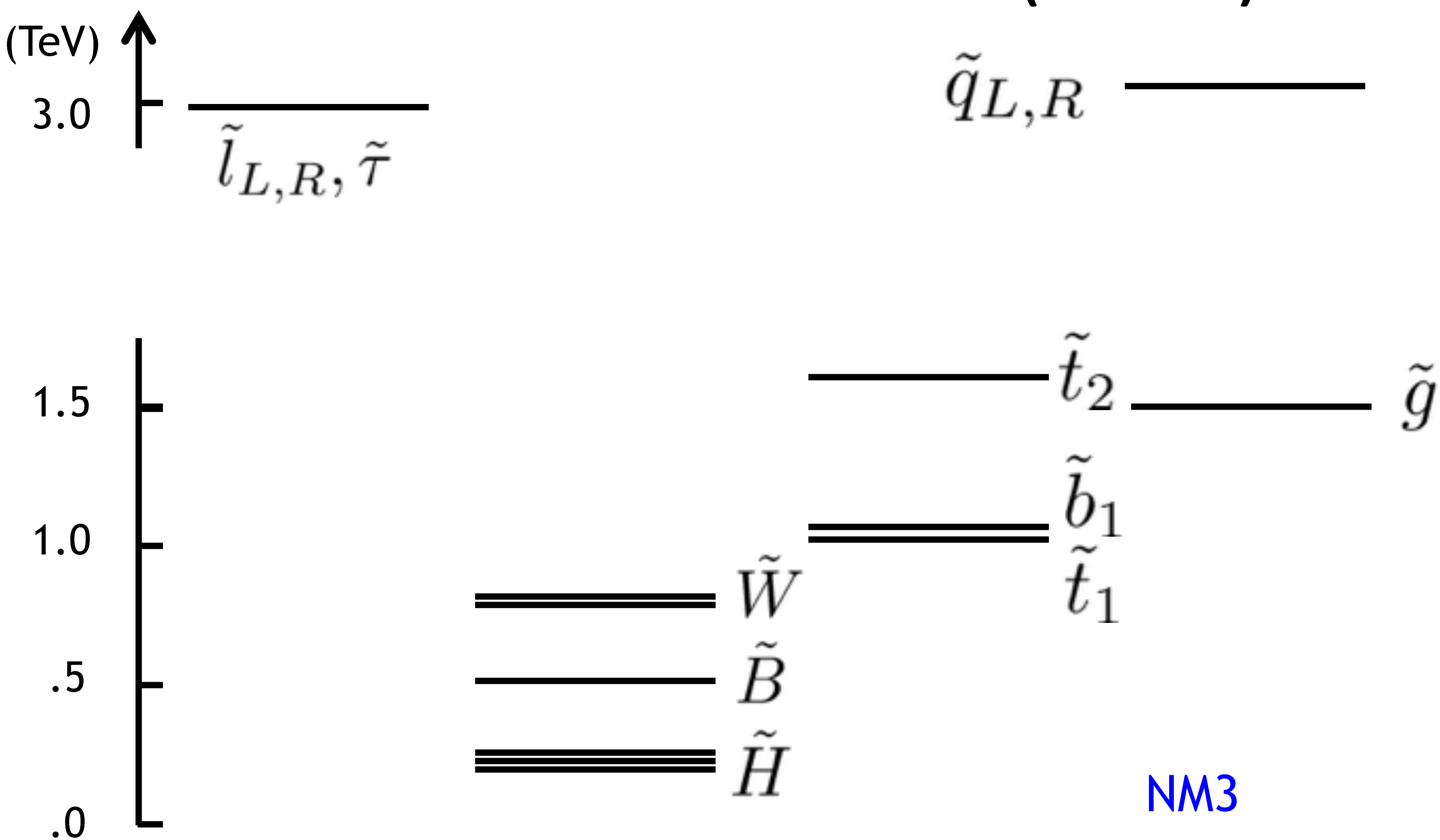
https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsSUS14012/NM1_slha.txt

Natural SUSY Models (NM's)



https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsSUS14012/NM2_slha.txt

Natural SUSY Models (NM's)



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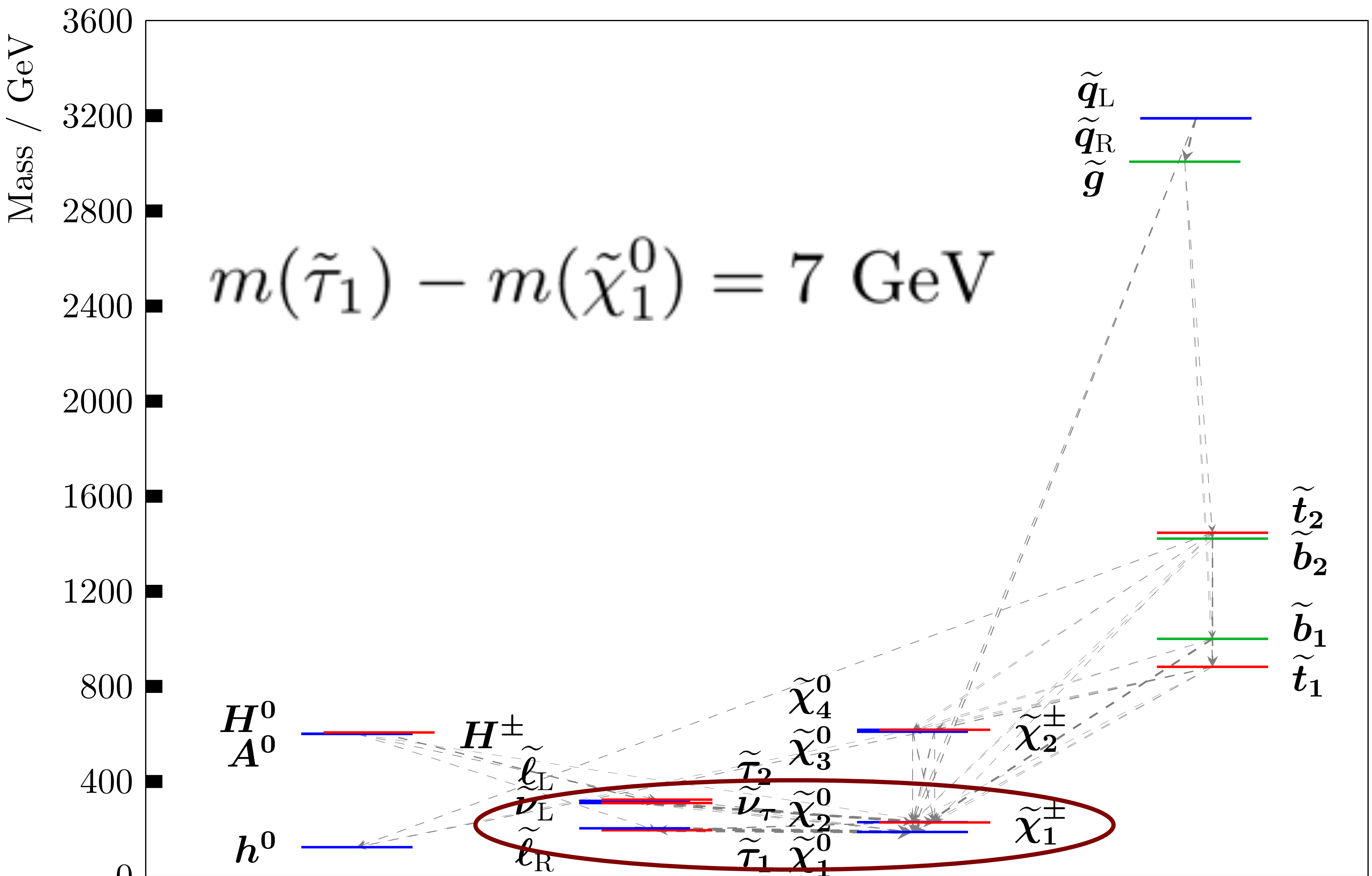
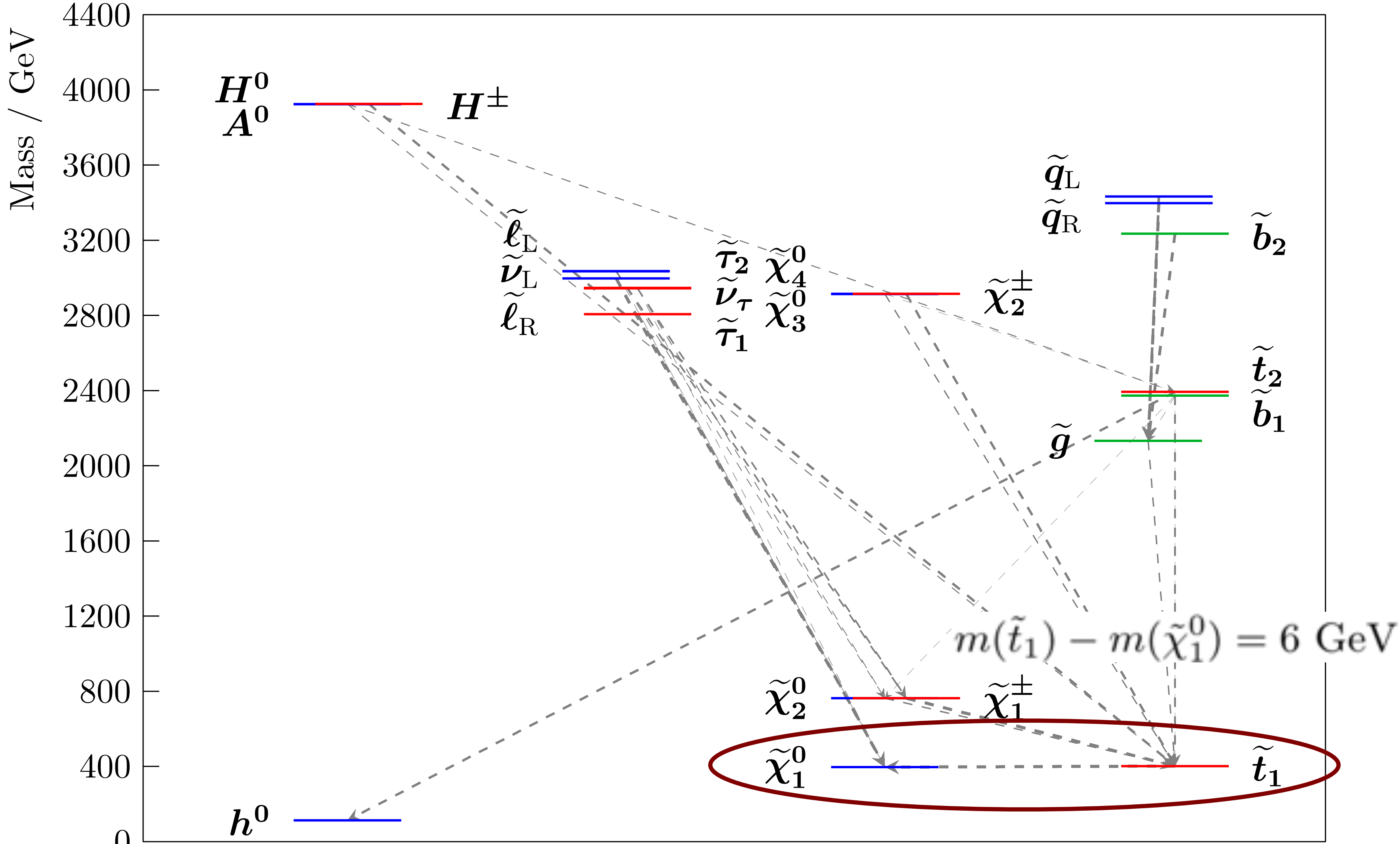
Co-annihilation Models: stau (STC)



https://twiki.cern.ch/twiki/pub/CMSPublic/PhysicsResultsSUS14012/STC_slha.txt

Co-annihilation Models: stop (STOC)



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