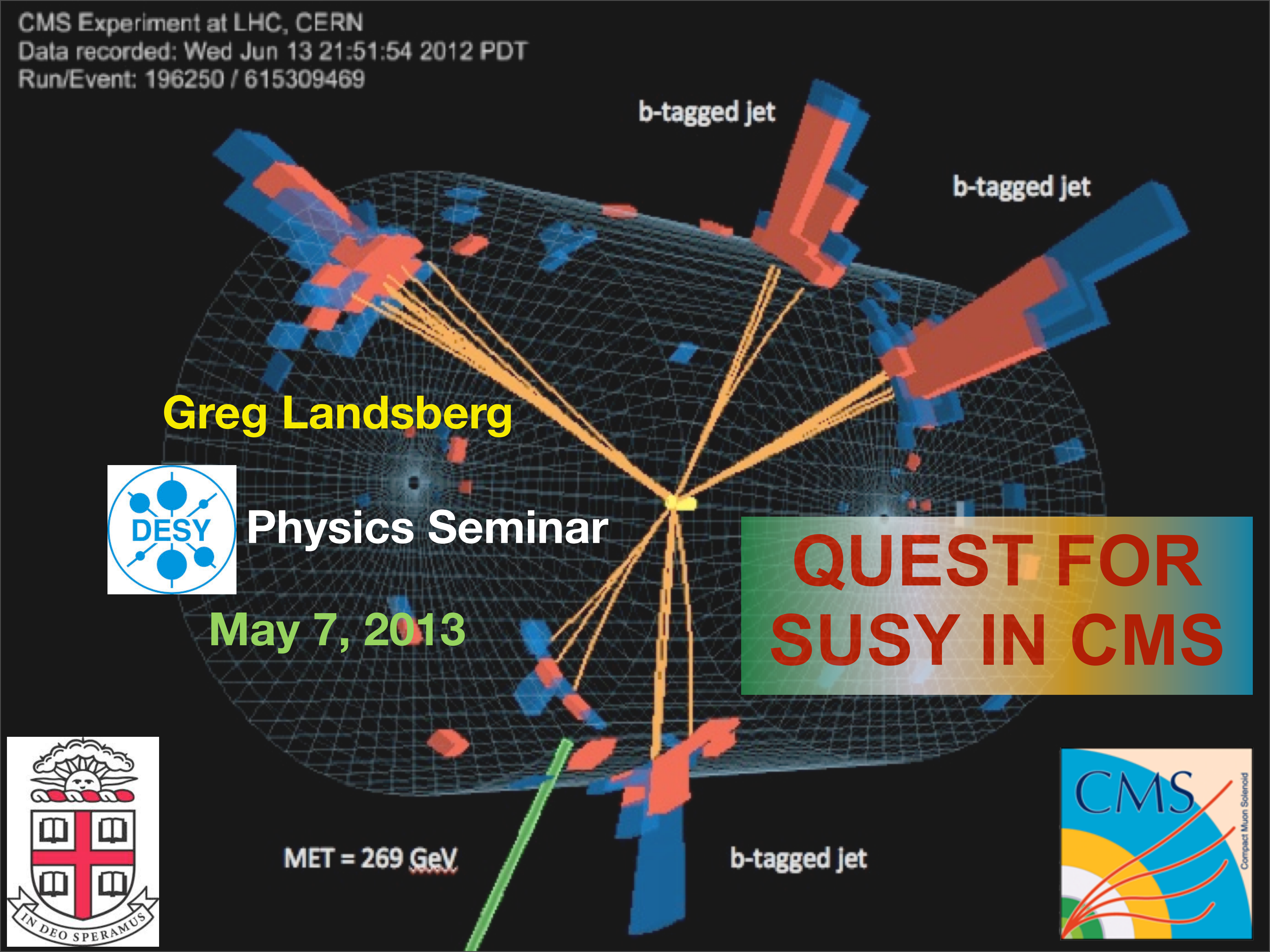
QUEST FOR SUSY IN CMS

Greg Landsberg

DESY Physics Seminar

May 7, 2013



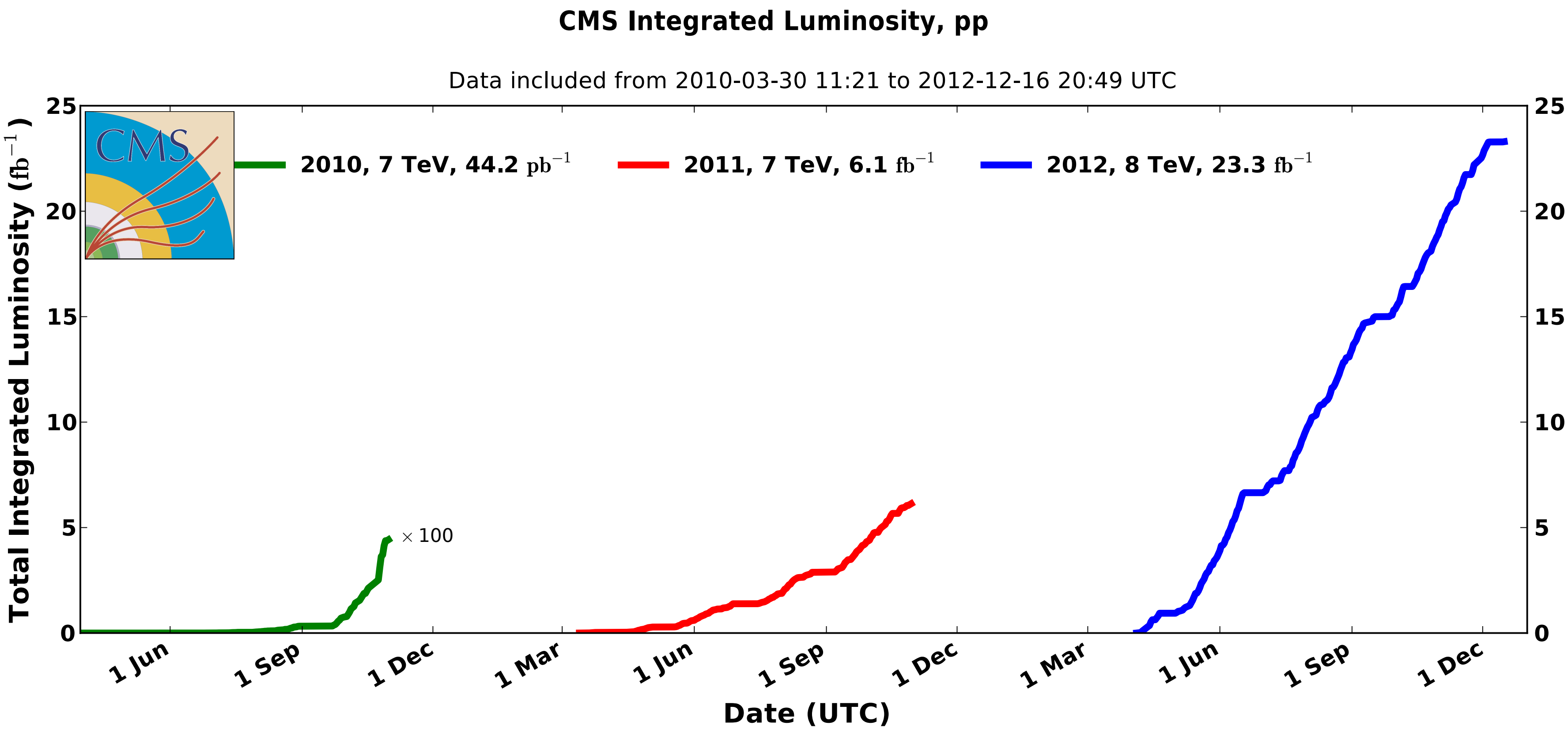
Outline

- ✦ LHC and CMS Performance
- ✦ A SUSY Primer
- ✦ Searches for SUSY
  - Great Expectations - 2010-2011
  - Looking under the lamppost(s)
  - Lessons from the Higgs discovery - 2012
  - Naturalness, as the guiding light - 2012-2013
- ✦ Open questions and what’s next
- ✦ Conclusions

The CMS Playground

The Measure of Our Success

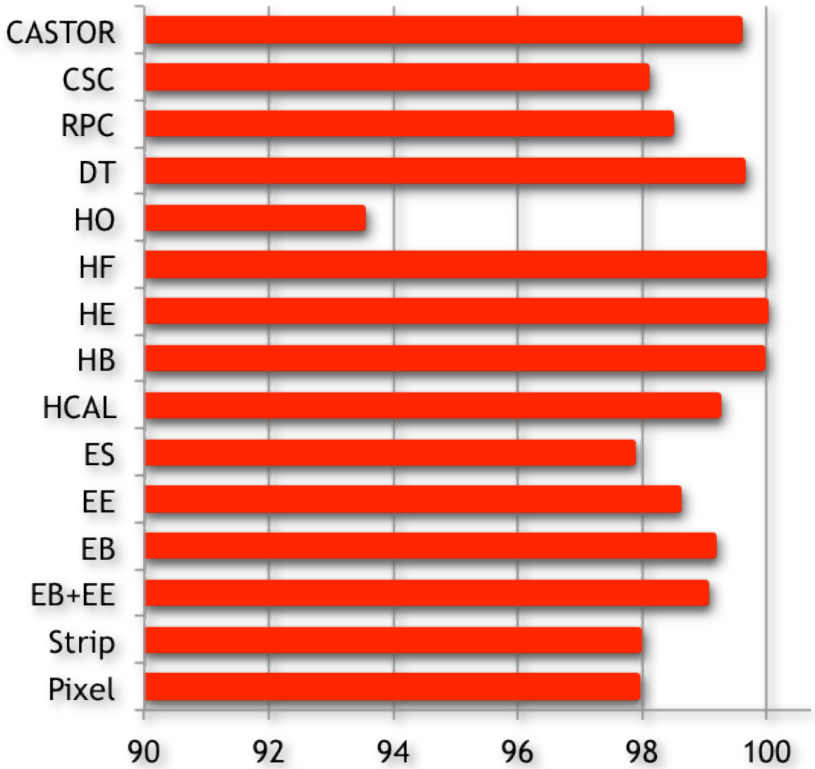
- Thank you, the LHC, for spectacular 3 years!



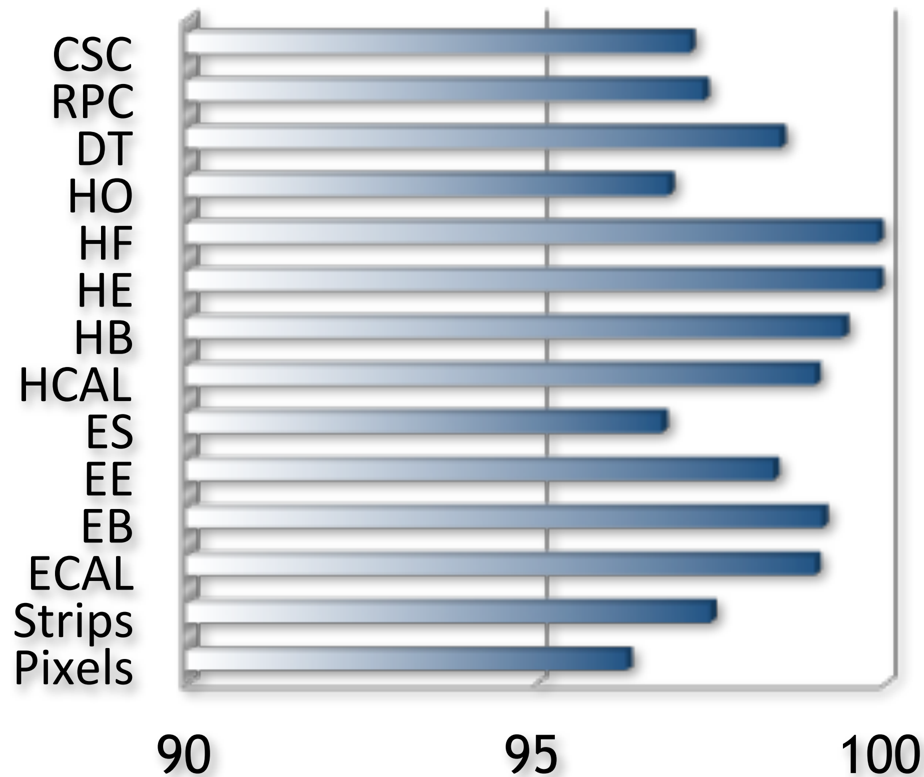
The CMS Detector Performance

- The detector has been working spectacularly with no degradation in performance over the three years of LHC Run 1
  - In some cases, original loss in performance was recovered

Operational in Dec 2010 (%)

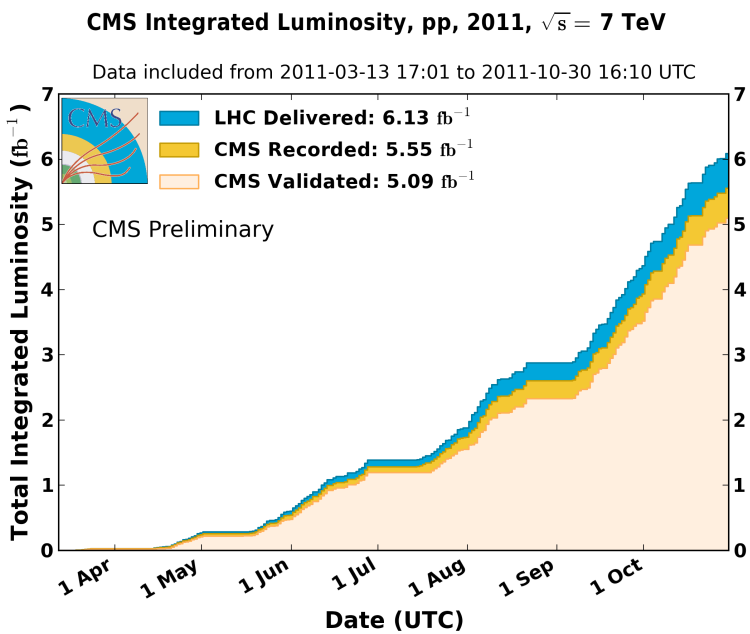


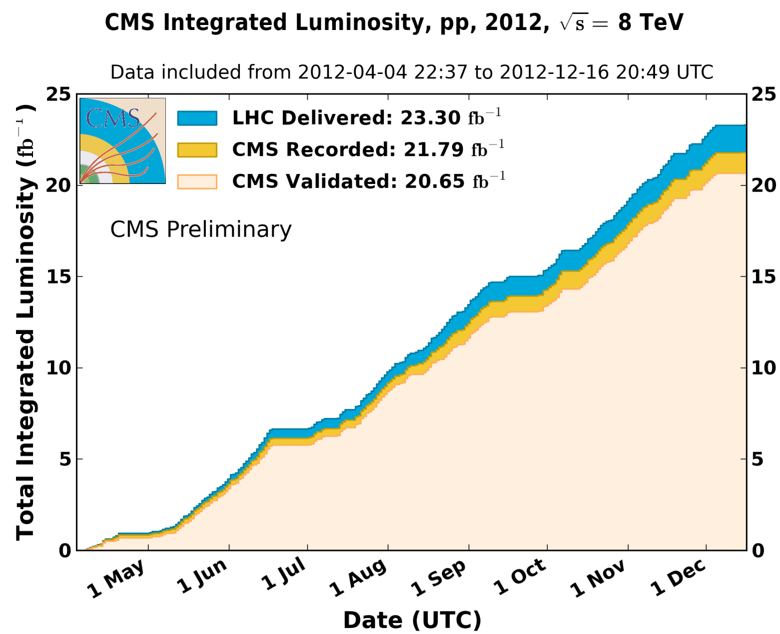
Operational in Feb 2013 (%)



Data Quality

- CMS has a dedicated team of experts monitoring quality of data online and offline, with certification of every collision run
- The certification efficiency is high: the "golden" data with all the detectors performing flawlessly is >90% of recorded data over the duration of Run 1; for muon-only analyses it's even higher (95%)





CMS Preliminary Results: Mar-Oct 2011 proton-proton collision runs

Tracker		Calorimeters			Muon Spectrometer			Magnet	Operational
Pixel	SST	ECAL	ES	HCAL	CSC	DT	RPC		
99.7	99.5	97.4	99.9	98.0	98.3	99.9	99.6	100	99.2

All good for physics: 91.7%

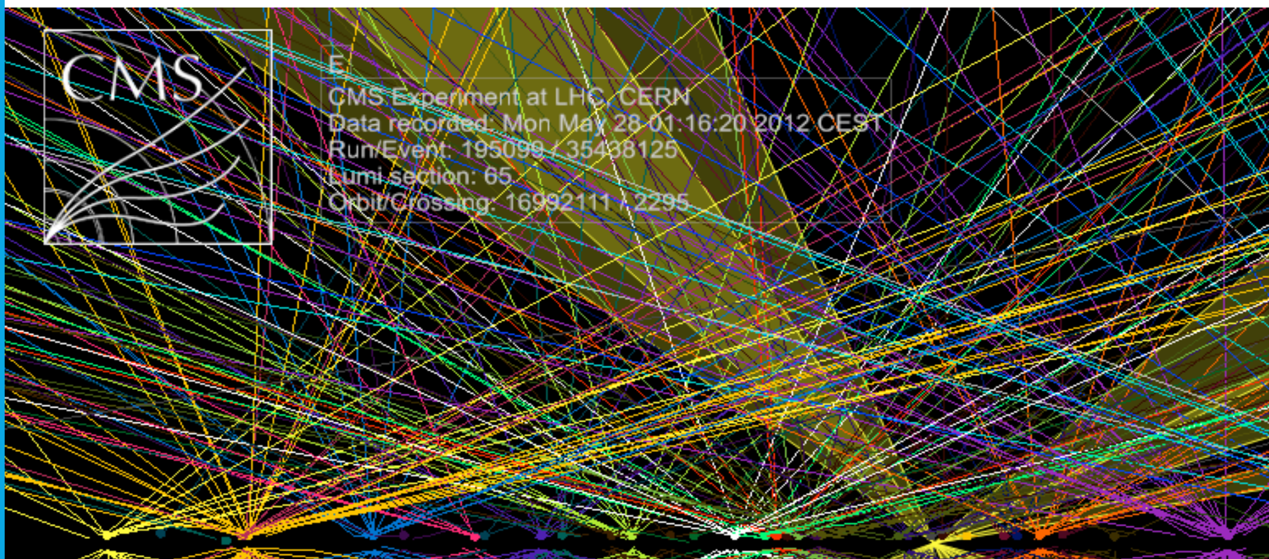
CMS Preliminary Results: Apr-Dec 2012 proton-proton collision runs

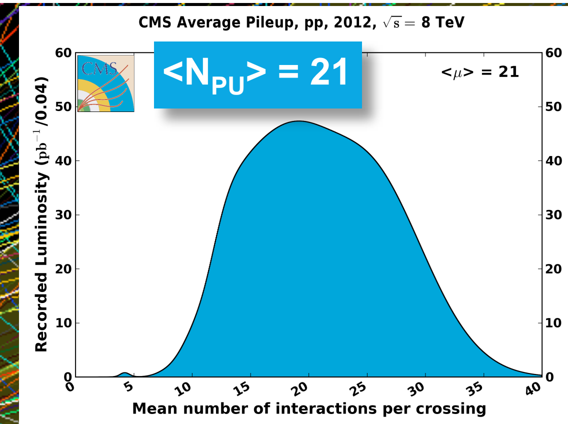
Tracker		Calorimeters			Muon Spectrometer			Magnet	Operational
Pixel	SST	ECAL	ES	HCAL	CSC	DT	RPC		
98.9	99.6	98.6	99.3	96.6	99.3	99.8	99.4	98.6	99.2

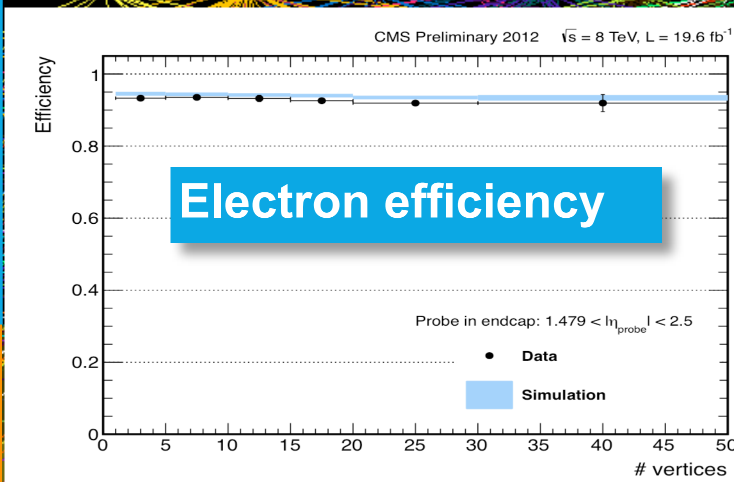
All good for physics: 90%

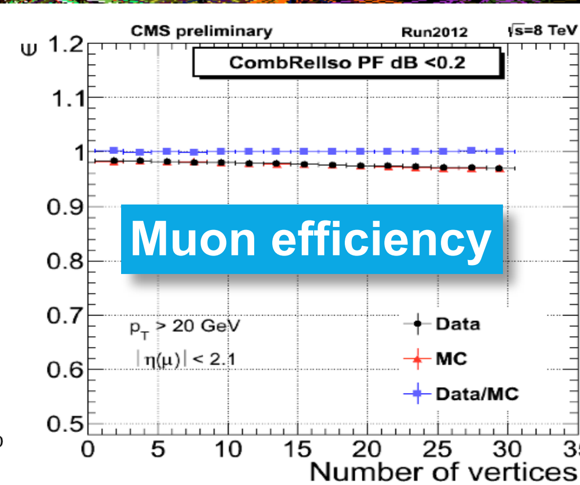
Pileup Mitigation

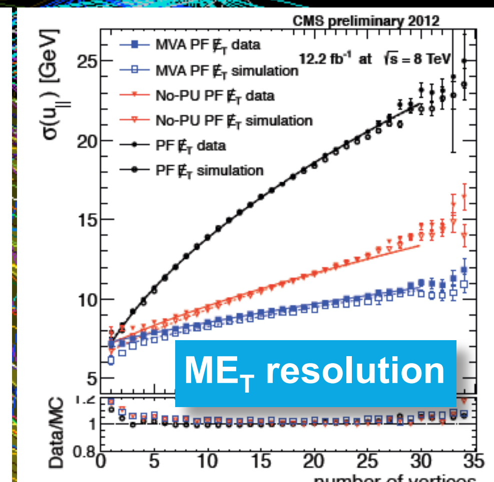
- The machine has already achieved the design level of pileup (additional interactions per beam crossing); CMS has tuned its particle ID and copes very well!











The SUSY Primer

As Confucius Once Said…

… about SUSY searches in the XXI century?..

It's very hard to find a black cat …

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It’s very hard to find a black cat …

… in a dark room …

As Confucius Once Said…

… about SUSY searches in the XXI century?..

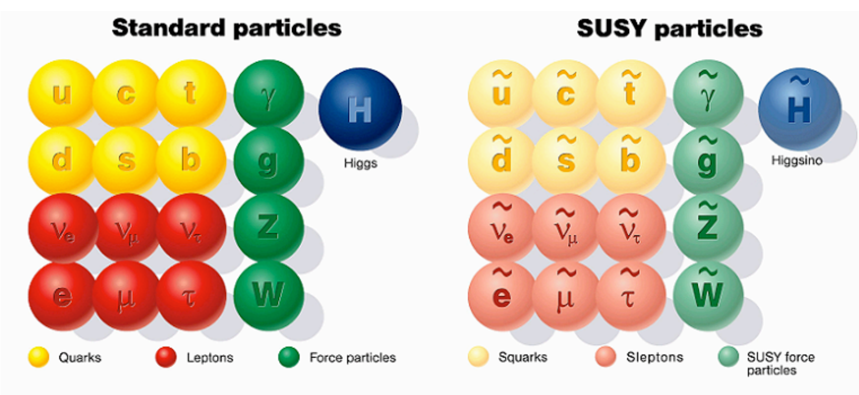
It's very hard to find a black cat …

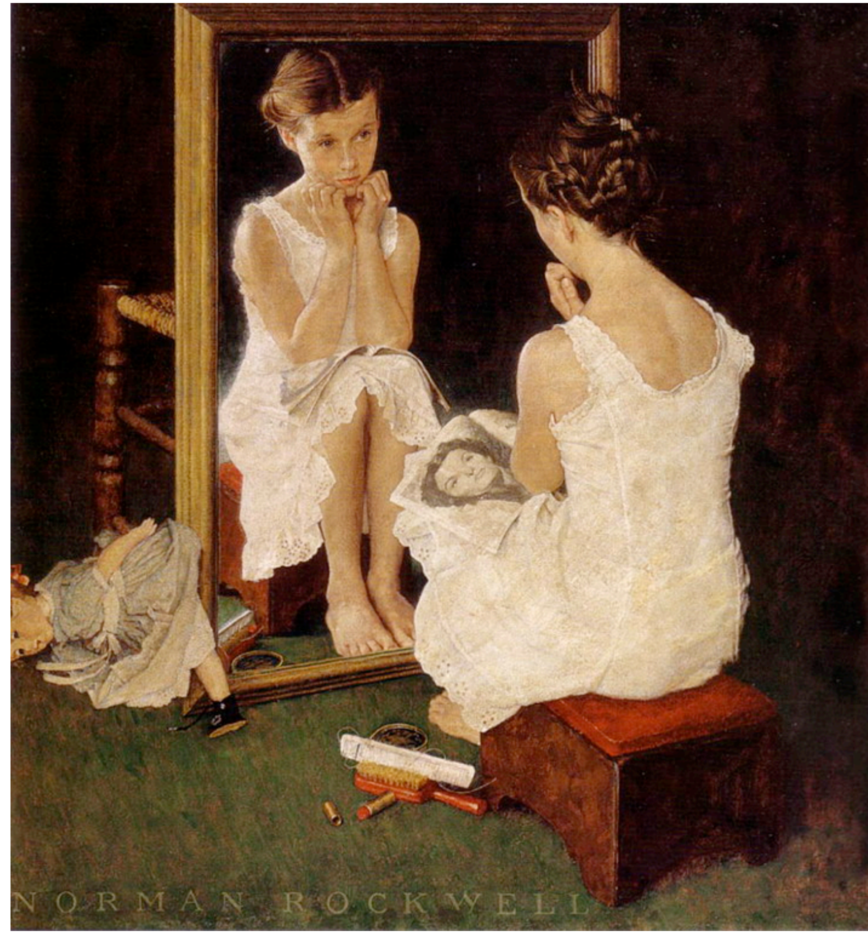
… in a dark room …

… especially if he is not there…

The Beauty in the Mirror

- The mirror world: discrete symmetry of spin
  - Every Standard Model (SM) fermion has a bosonic “superpartner,” and vice versa, e.g.:
    - Quark (J = ½) → Squark (J = 0)
    - Photon (J = 1) → Photino (J = ½)
- Supersymmetry must be “broken” as we do not see a selectron with the mass of 0.5 MeV!
- To avoid multiple constraints, typically introduce conserved R-parity [Farrar, Fayet, Phys. Lett. B **76** (1978) 575]:
  - $R = (-1)^{3B+L+2S}$ = +1 (SM) and -1 (SUSY)
- This leads to the lightest supersymmetric particle (LSP) being stable and pair-production of SUSY as the only possible mechanism





Norman Rockwell “Girl at Mirror”

The LSP is an excellent Dark Matter (DM) Candidate

SUSY: Gauge Sector

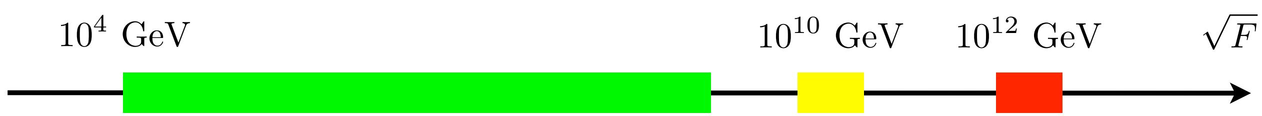
- Higgses: two complex doublets (8 degrees of freedom)
  - One gives masses to down-type, and another one – to up-type quarks
  - Ratio of vacuum expectation values is conventionally called ***tanβ***
  - 3 d.o.f. are "eaten" by massive Z, $W^{\pm}$
  - 5 remaining d.o.f. become physical states: ***h^0, H^0, $H^{\pm}$, A^0***
  - $M_H > M_h$ by definition; $M_h < 135$ GeV for SUSY to be a viable low-scale theory
  - A is a CP-odd Higgs
  - Supersymmetric partners of the two Higgs doublets mix with the partners of SM EW gauge bosons to give four neutral (neutralinos) and two pairs of charged (charginos) gauginos
- Gluino (a partner of a gluon) remains unmixed

Supersymmetry Breaking

- We know that SUSY is a broken symmetry, but we do not know how it is broken
- Several theoretical models exist:

David Shih

- Gravitino mass: $m_{3/2} = \frac{F}{\sqrt{3}M_{pl}}$
- Sparticle masses: $m^2_{soft} = \kappa^2 \left(\frac{F}{M}\right)^2 \sim \text{TeV}$ M = "Messenger scale"



Gauge mediation	Gravity mediation	Anomaly mediation
$M \ll M_{pl}$	$M \sim M_{pl}$	$M \sim M_{pl}$
$\kappa \sim \frac{\alpha}{4\pi}$	$\kappa \sim 1$	$\kappa \sim \frac{\alpha}{4\pi}$

"Low scale SUSY-breaking"

Gravitino LSP. No WIMP DM. Calculable. Solves SUSY flavor problem.

"High scale SUSY-breaking"

Neutralino or sneutrino LSP. WIMP dark matter possible. Generally not calculable. Can have severe SUSY flavor problem.

MSSM and cMSSM

- SUSY is a renormalizable and calculable theory and has been thoroughly studied theoretically over the last four decades
- MSSM has just two Higgs doublets; nevertheless the number of parameters describing the model is still very large: 124
  - 18 are the SM ones + Higgs boson mass
  - 105 genuinely new parameters:
    - 5 real parameters and 3 CP-violating phases in gaugino sector
    - 21 squark/slepton masses and 36 mixing angles
    - 40 CP-violating phases in the sfermion sector
- This makes it very challenging to search for generic SUSY, and simplifying assumptions are typically made
- One of these simplifications is constrained MSSM, or cMSSM, which assumes gaugino unification and degenerate squark/slepton masses at high energy (typical of gravity-mediated SUSY breaking)
  - That results in just five parameters fixing all the SUSY interactions: common scalar and fermion masses M_0, $M_{1/2}$, ratio of the vacuum expectations of the two Higgs doublets $\tan\beta$, sign of Higgsino mass term $\mathrm{sign}(\mu)$, and trilinear coupling A_0

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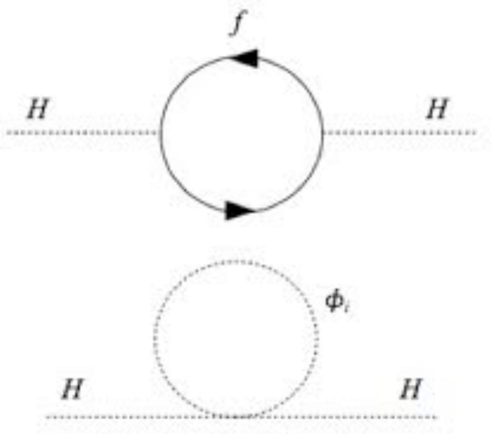
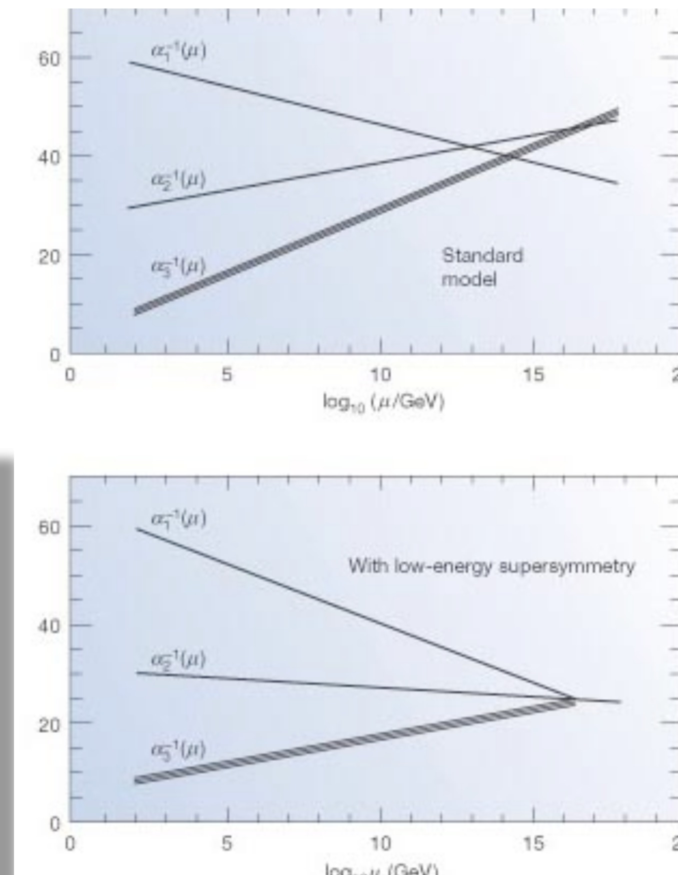
Typically most important

Three Miracles of SUSY



$$\Delta M_H^2 \sim \frac{\lambda_f^2}{4\pi^2}[(m_f^2 - m_S^2)\log(\frac{\Lambda}{m_S})]$$

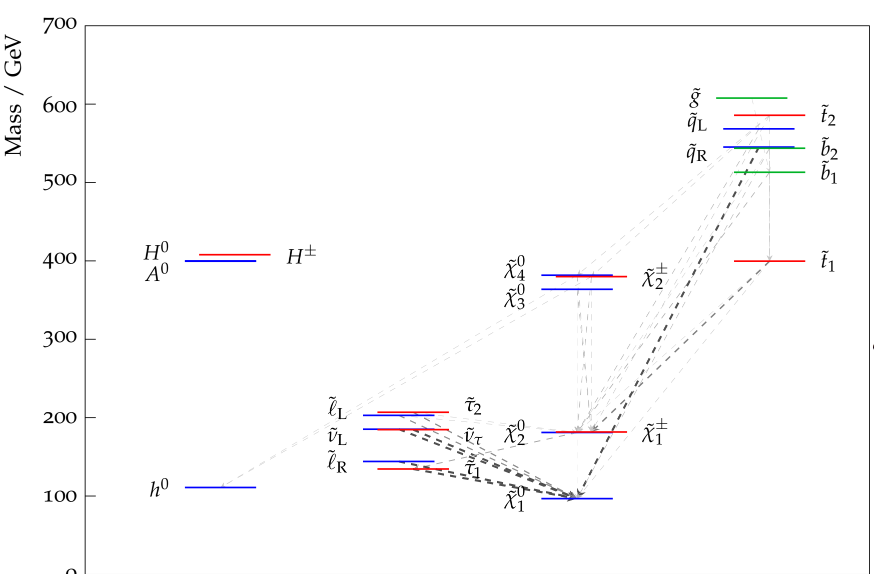
- Elegant solution to the hierarchy problem (i.e., why the Higgs mass is not at the Planck scale)
- Gauge unification

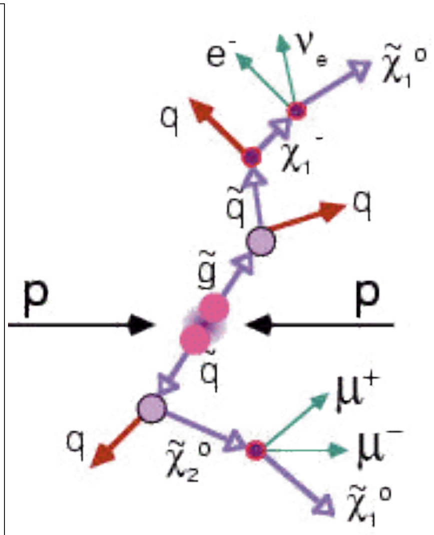


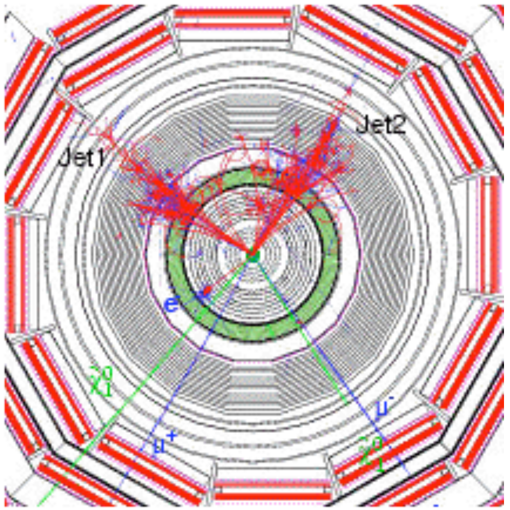
- Dark matter candidate with the right abundance

SUSY Spectra

- Typical SUSY spectrum resembles atomic transitions or meson spectroscopy
  - Generally, multiple competing decays with relative branching fractions strongly depending on SUSY parameters
- “Classical” SUSY (R-parity conserving): copious final-state particles (jets, leptons) from cascade decays and large missing transverse energy due to escaping LSP (often the lightest neutralino)
  - Generally rich signatures, but possible “nightmare” scenarios if (part of) the SUSY spectrum is sufficiently compressed

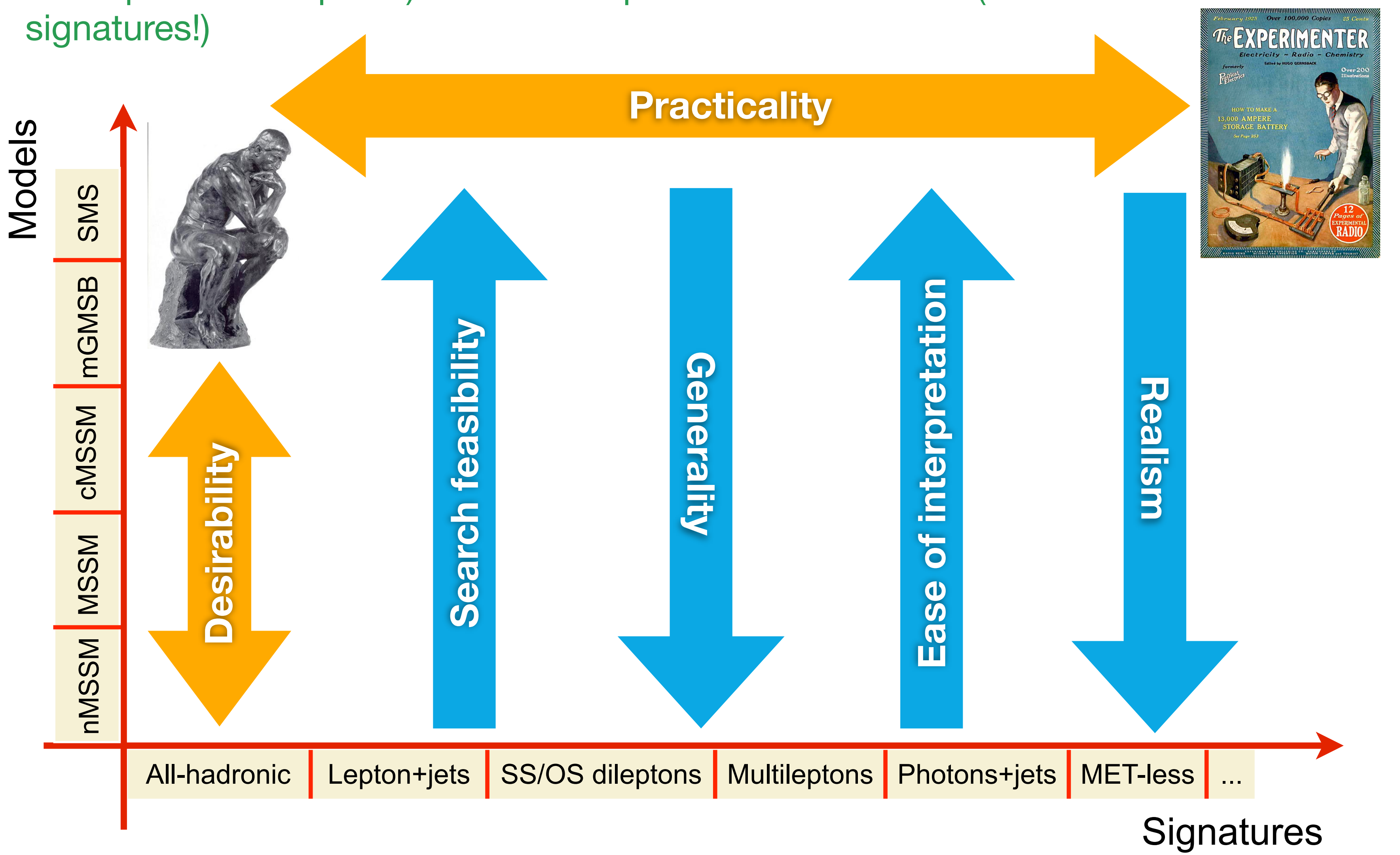






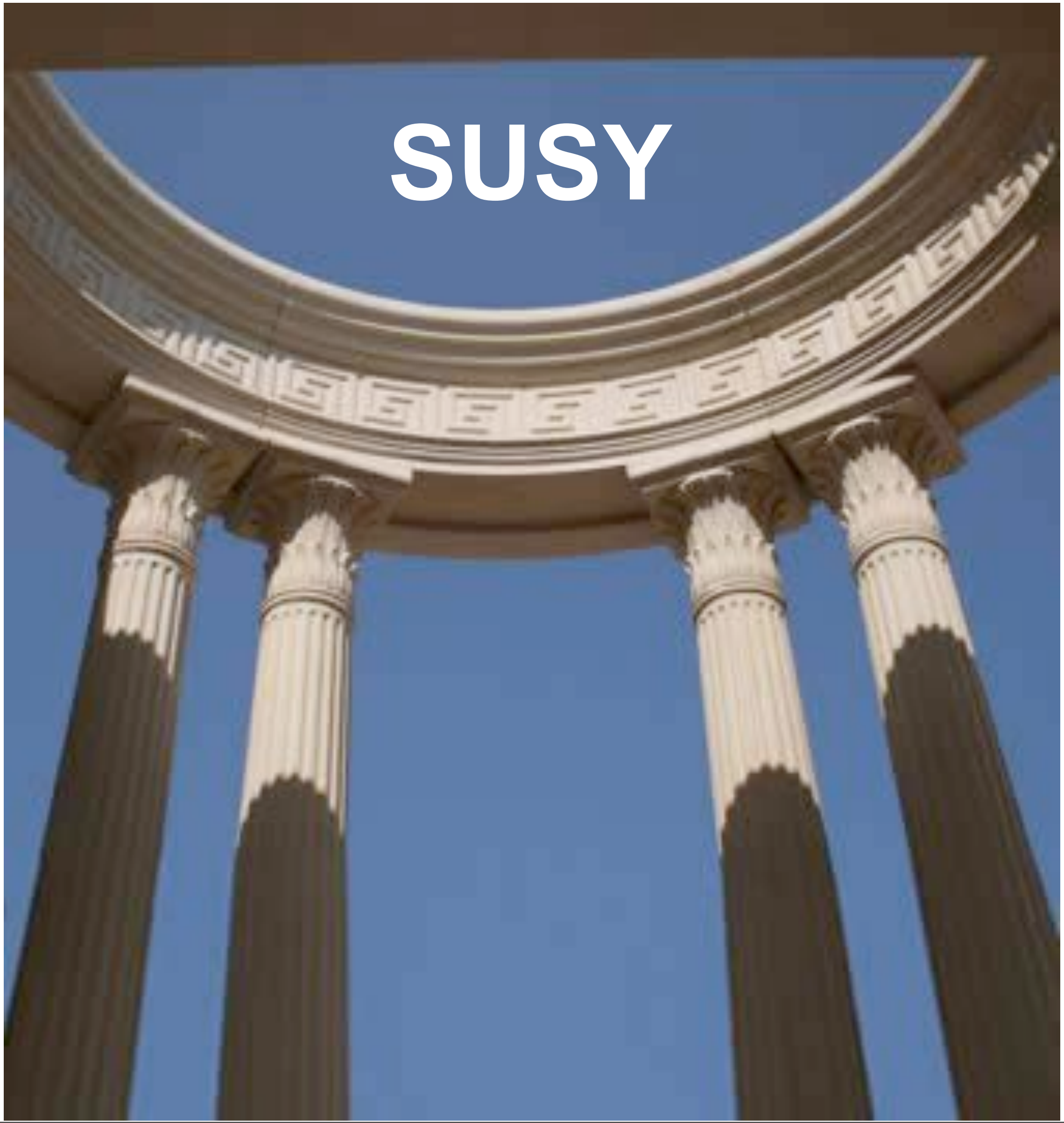
Theory vs. Experiment

- Almost inevitable conflict between what theorists optimally want (scan the entire parameter space!) and what experimenters could do (search for certain signatures!)



Four Pillars of SUSY Searches

- Signatures
- Kinematic optimization
- Background determination
- Interpretation

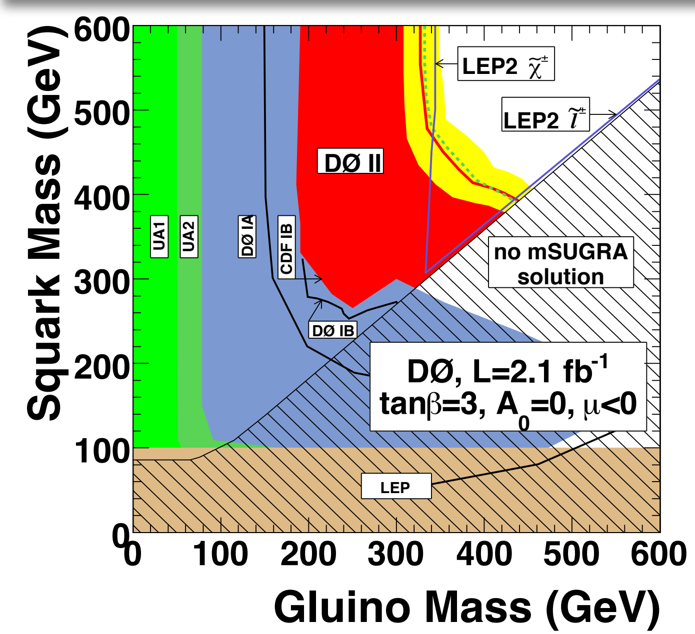


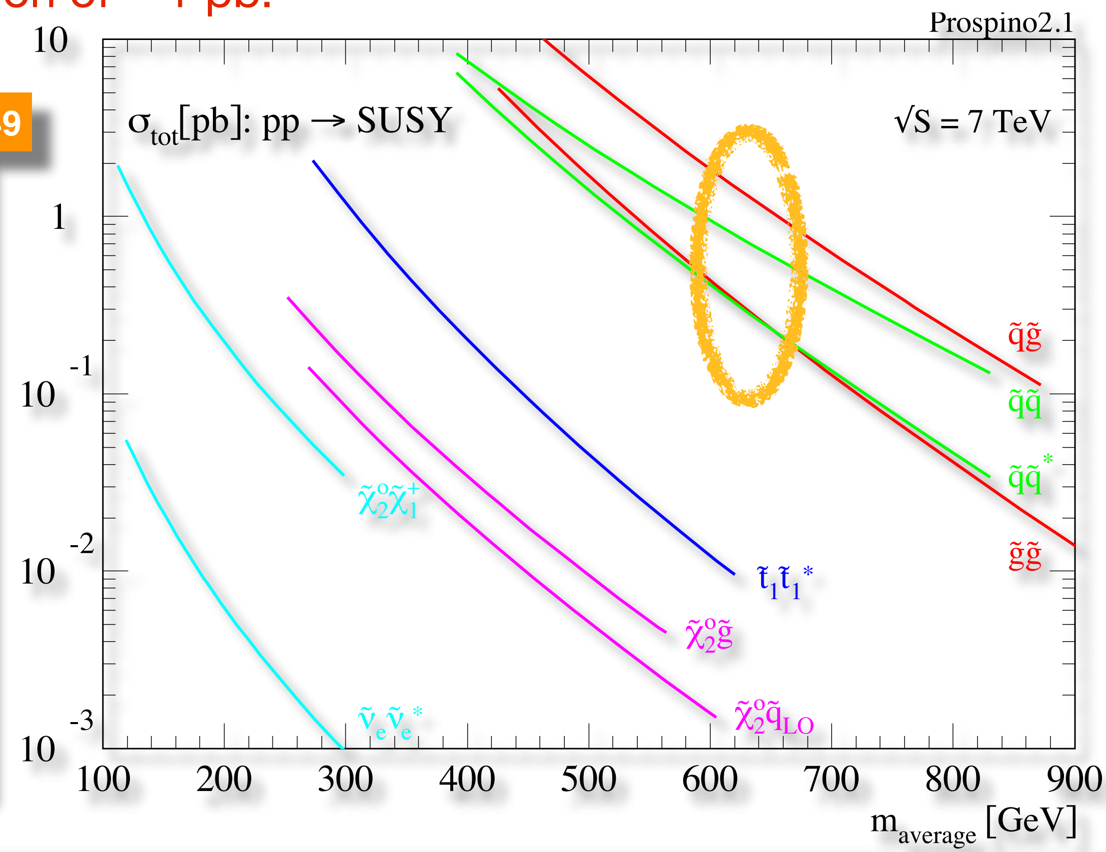
Searching Under the Lamppost

Great Expectations!

- When the LHC turned on at 7 TeV in 2010, the hopes to find SUSY almost immediately were high
  - 650 GeV squarks/gluinos (quite beyond the Tevatron reach) are pair produced at the LHC with cross section of ~ 1 pb!

D0 Collaboration, Phys. Lett. B660 (2008) 449





http://www.thphys.uni-heidelberg.de/~plehn/index.php?show=prospino&visible=tools

2010-2011 Search Strategy

- Developed very robust search strategy, with the early SUSY discovery in mind
  - Multiple methods of missing transverse energy estimation, less prone to instrumental effects and mismeasurement tails
  - Determination of major backgrounds from control samples in data - minimum reliance on the Monte Carlo!
  - Multiple complementary analysis techniques exploring various kinematic selections and analysis techniques
- The idea was to demonstrate convincingly that what is seen in one channel has corroborative evidence from the full host of measurements

Example: The α_T Variable

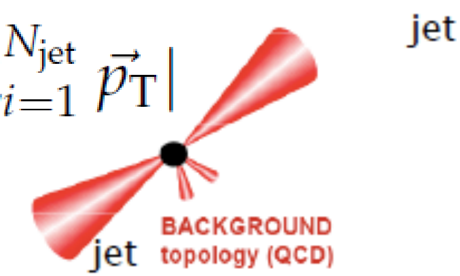
Randall, Tucker-Smith, arXiv:0806.1049

- Alternative approach to requiring large ME_T in the event; does not rely on ME_T reconstruction/tails
- Combine visible decay products in the event into two (pseudo)jets:

$$H_T = \sum_{i=1}^{N_{jet}} E_T$$

$$\not{H}_T = \left| \sum_{i=1}^{N_{jet}} \vec{p}_T \right|$$

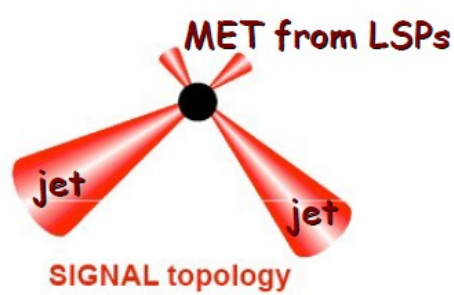
$$\alpha_T = E_T^{j_2} / M_T = E_T^{j_2} / \sqrt{H_T^2 - \not{H}_T^2}$$

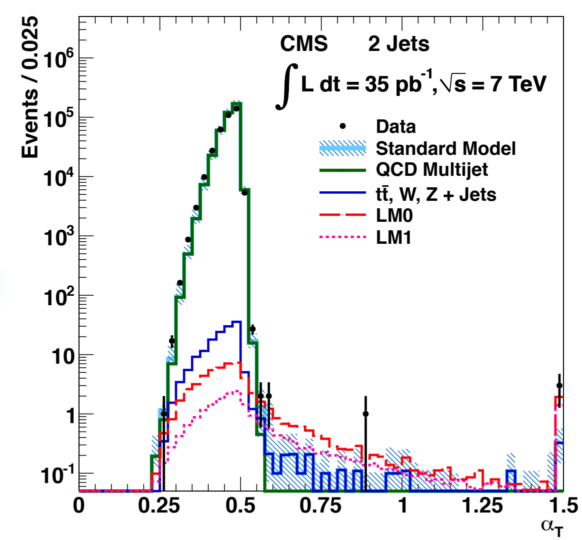


- For a perfectly balanced dijet event, $\alpha_T = 0.5$
- For QCD events with mismeasured ME_T, $\alpha_T < 0.5$
- For signal, long tail of $\alpha_T > 0.5$

CMS Collaboration arXiv:1101.1628

$$\alpha_T \equiv E_T^{j_2} / M_T(j_1 j_2) = \frac{\sqrt{E_T^{j_2} / E_T^{j_1}}}{\sqrt{2(1-\cos\Delta\varphi)}}$$

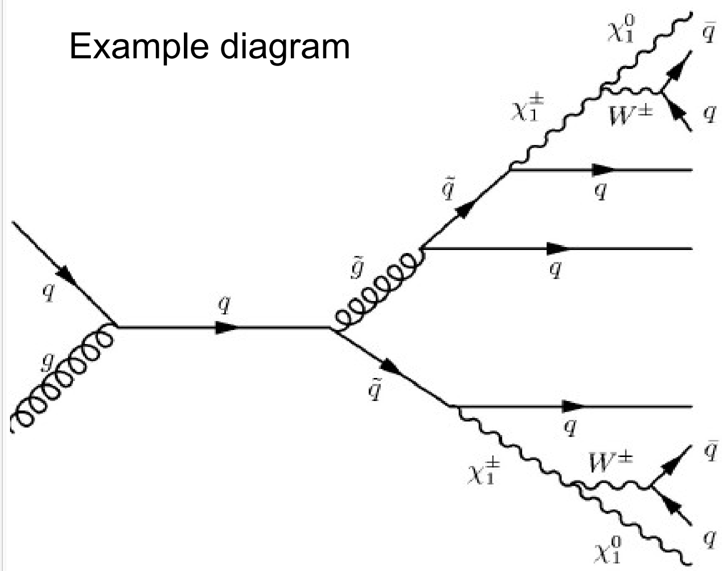




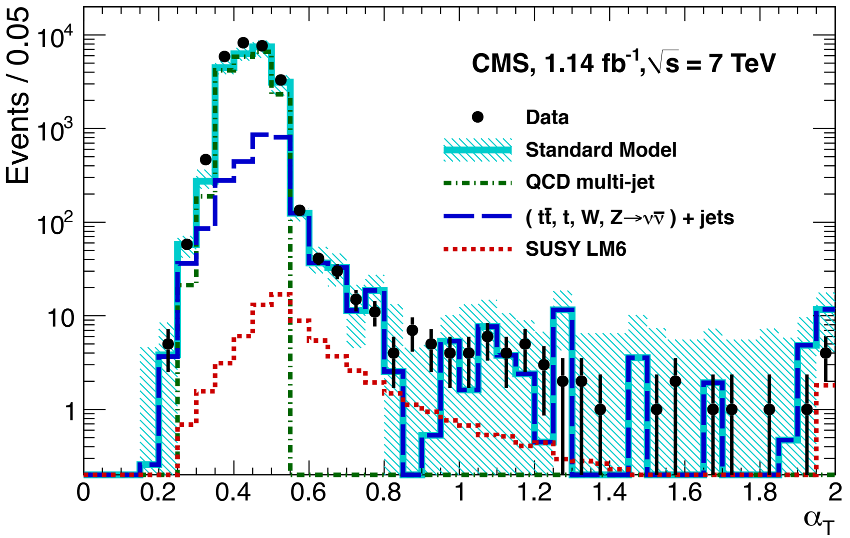
All-Hadronic Searches

- Advantages:
  - Strongly produced squarks/gluinos result in large cross section
  - Branching fraction into jets is typically large
- Disadvantages:
  - Copious QCD background from jet mismeasurement
  - Irreducible Z(νν)+jets background
  - Potential instrumental backgrounds from beam halo, faulty or noisy calorimeter channels, poorly instrumented detector areas

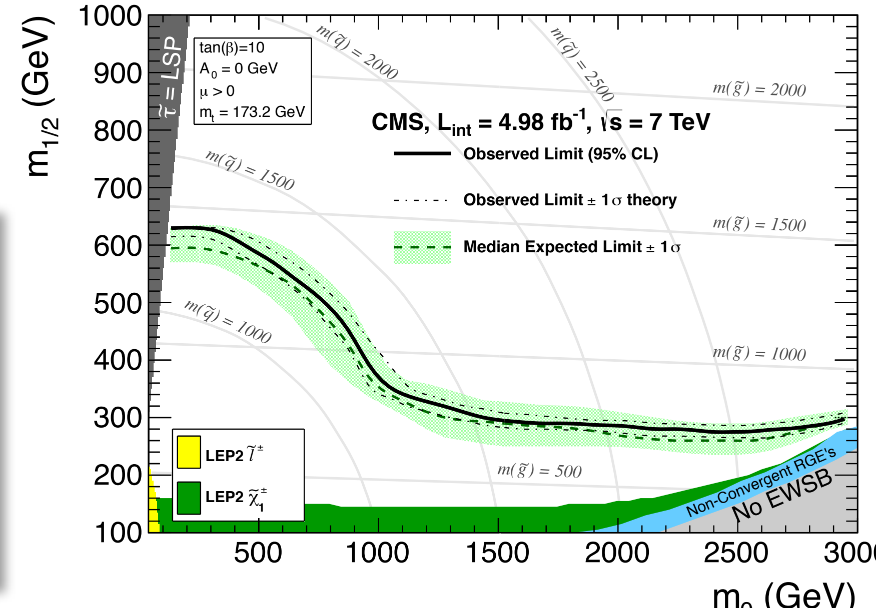
Example diagram



Limits in cMSSM

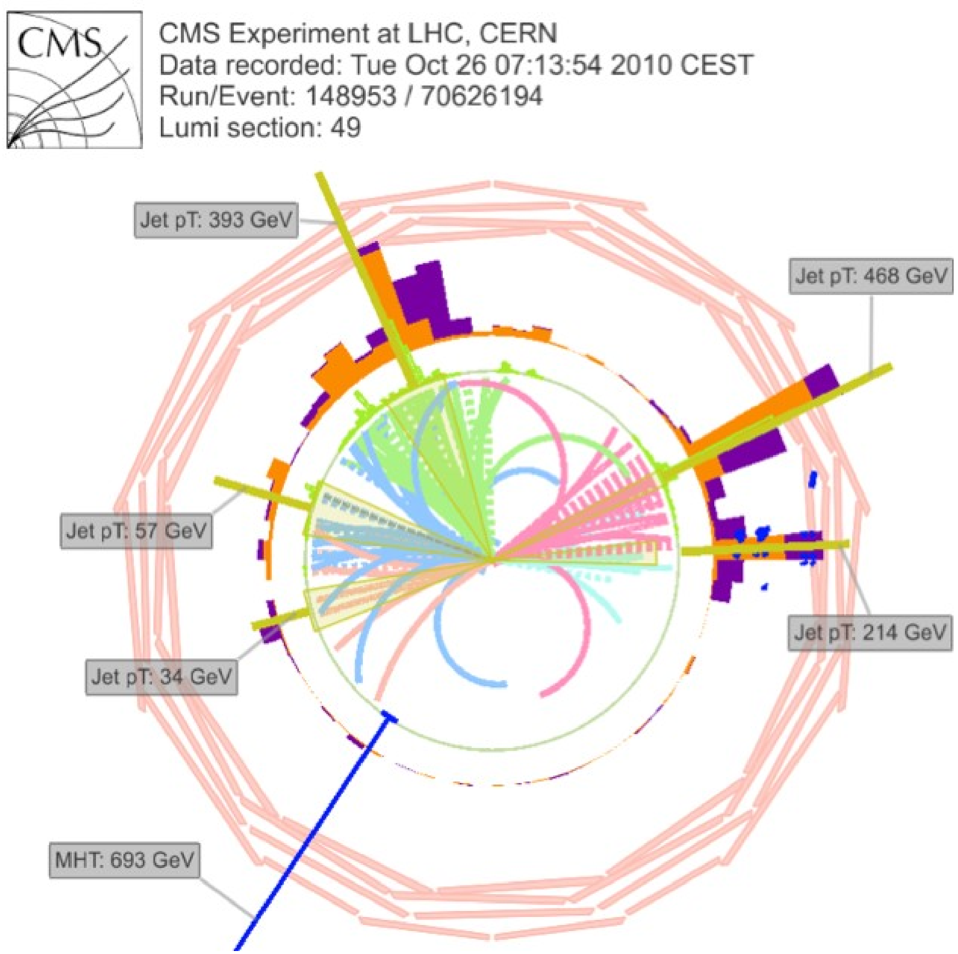


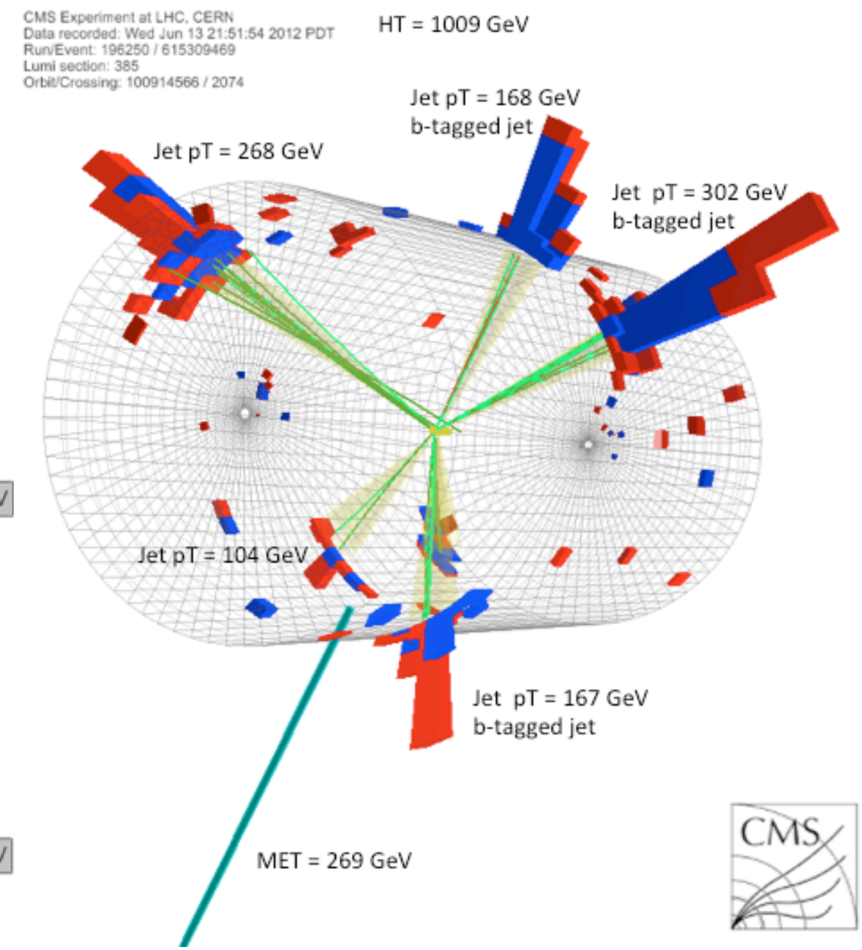
CMS Collaboration
arXiv:1109.2352



CMS Collaboration
arXiv:1210.8115

Candidate Events

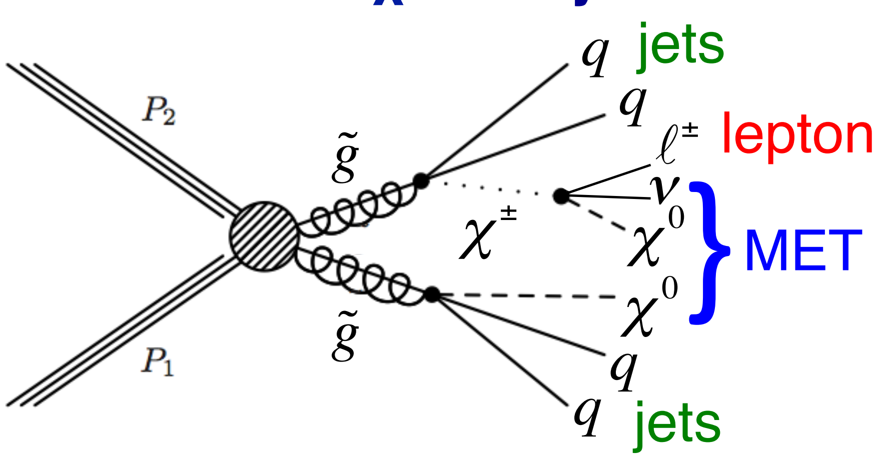


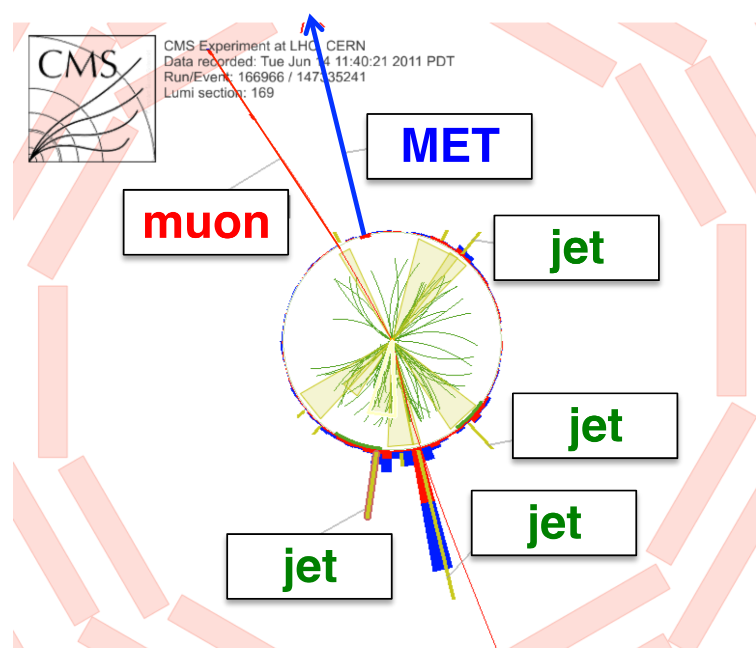


Searches with Single Lepton

- Single lepton + jets + ME_T is characteristic signature for cascade decays via chargino or slepton
- The presence of an isolated lepton reduces QCD background dramatically
- Main backgrounds: W+jets including semileptonic tt decays
- Employ several methods to estimate this dominant (~75%) background

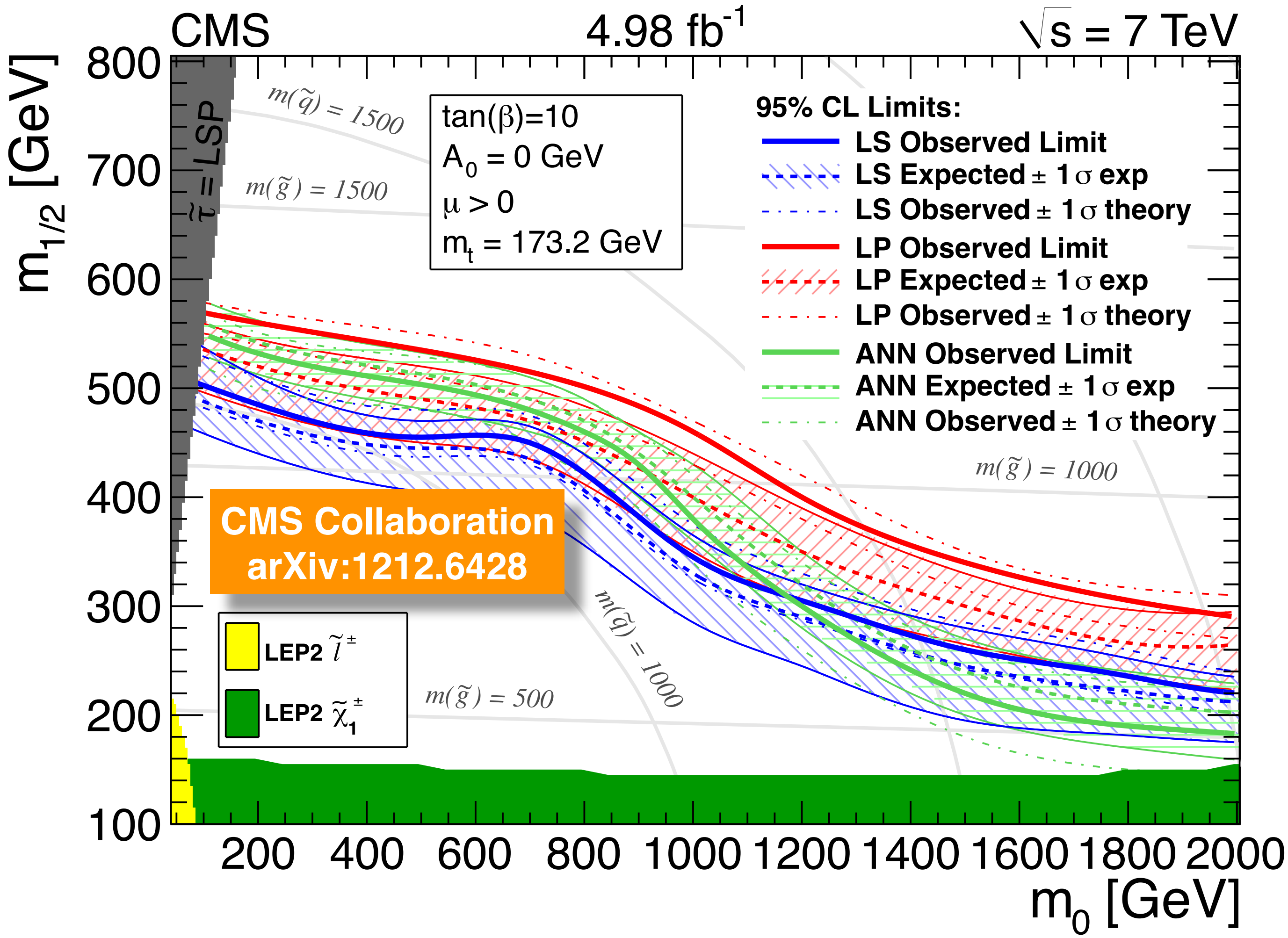
example signal:
SUSY with $\chi^{\pm}$ decay





cMSSM Limits

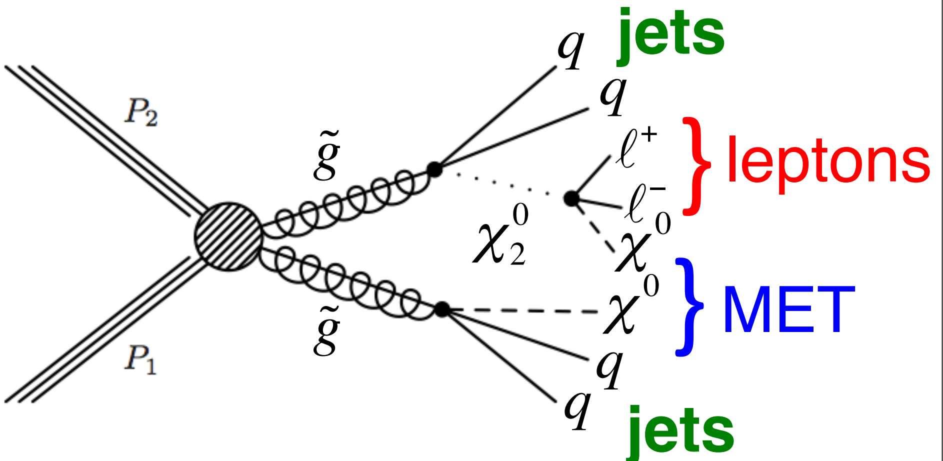
- All three methods yield comparable results, with different systematics; L_P is slightly more powerful



Dilepton SUSY Searches

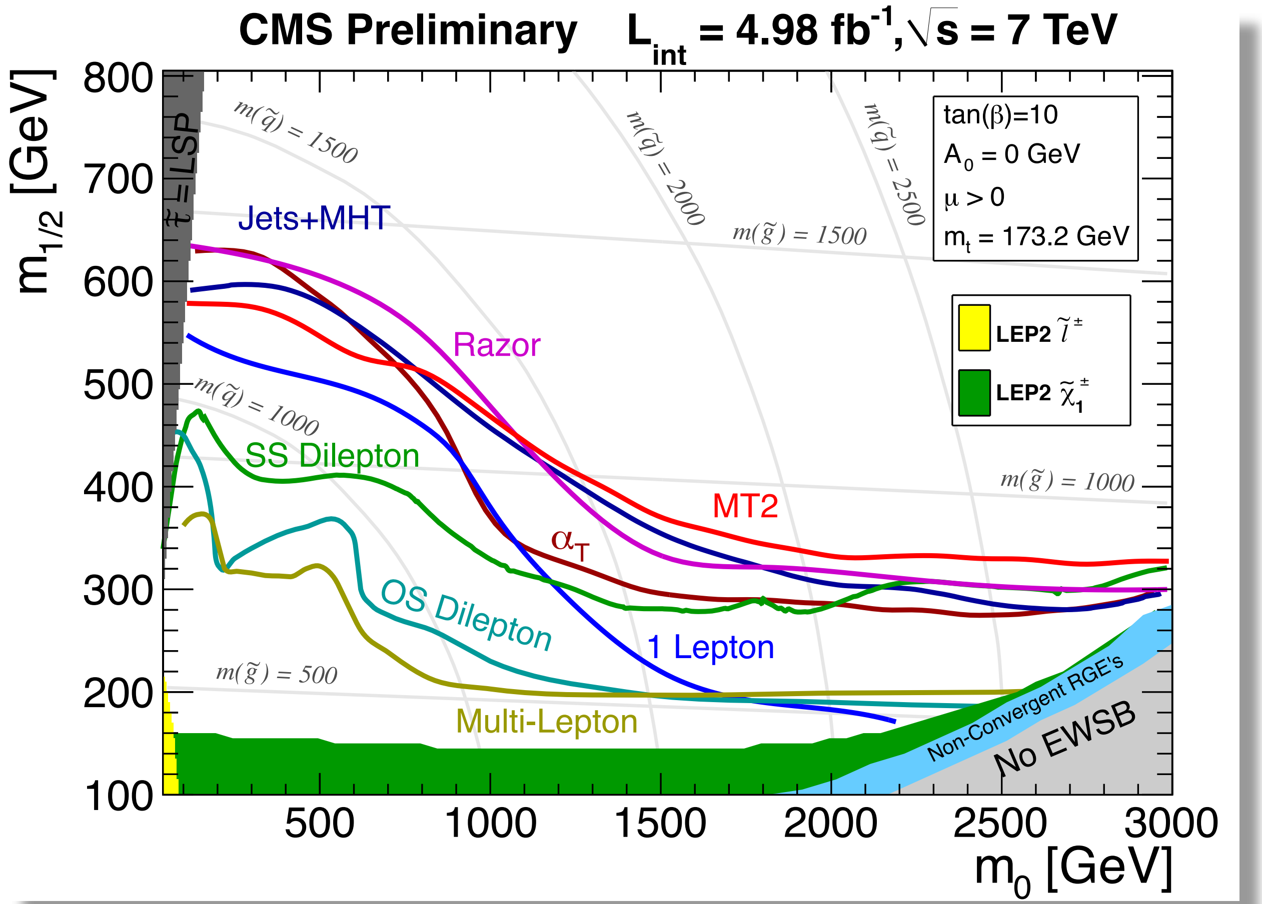
- Here, we have several types of searches:
  - Opposite-sign (OS) dileptons, from/not from Z decays
  - Same-sign (SS) dileptons (e.g., from the decays of a pair of Majorana χ_2^0 or pair of Majorana gluinos decaying through same-sign charginos)
- All of these come with extra jets and ME_T
- Each of the final states employs somewhat different selection approaches and background estimation techniques
- Can also look at 3, 4 leptons

example signal:
SUSY with $\chi_2^0 \rightarrow \ell^+ \ell^- \chi^0$ decay



cMSSM Grand Summary

- A "spaghetti plot" of "classical" SUSY searches @ 7 TeV
- What did we learn? - Not much beyond the all-hadronic limits!
  - Excluded squarks to ~1.3 TeV and gluinos to ~0.8 TeV - or did we?



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Read the fine print!

What Have We Excluded?

- We set strong limits on squarks and gluinos, and yet we have not excluded SUSY
  - Moreover, we basically excluded VERY LITTLE!
- We ventured for an “easy-SUSY” or “lazy-SUSY” and we simply failed to find it
  - So what? - Nature could be tough!
- What we’ve probed is a tiny sliver of multidimensional SUSY space, simply most “convenient” from the point of view of theory

- **It’s now time for a paradigm shift and a different search strategy!**

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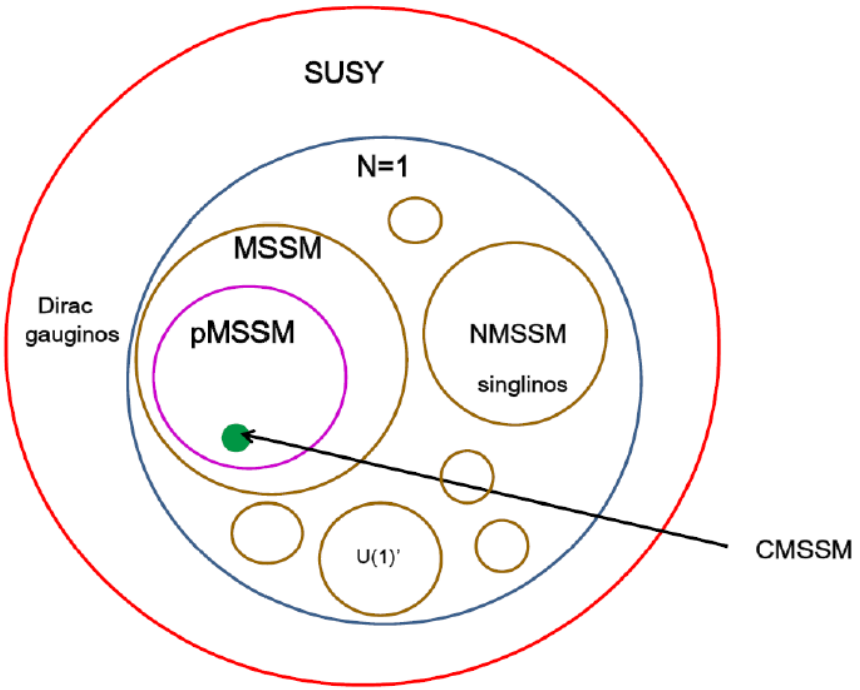
SUSY Theory phase space



T. Rizzo (SLAC Summer Institute, 01-Aug-12)

- **It's now time for a paradigm shift and a different search strategy!**

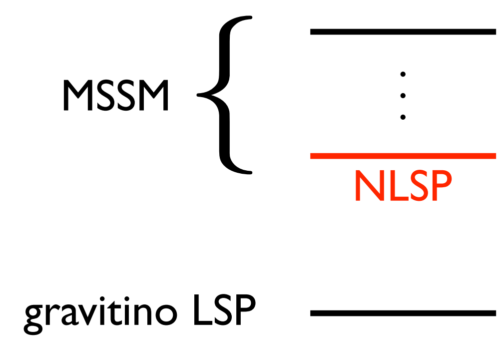
The Good News

- Our early (2010-2011) searches were signature-based
- We developed and commissioned a number of inventive and advanced methods of estimating backgrounds without reliance on MC simulations
  - Most of these tools are directly applicable to broader class of searches
- … and it's OK to look under the lamppost - but which one?

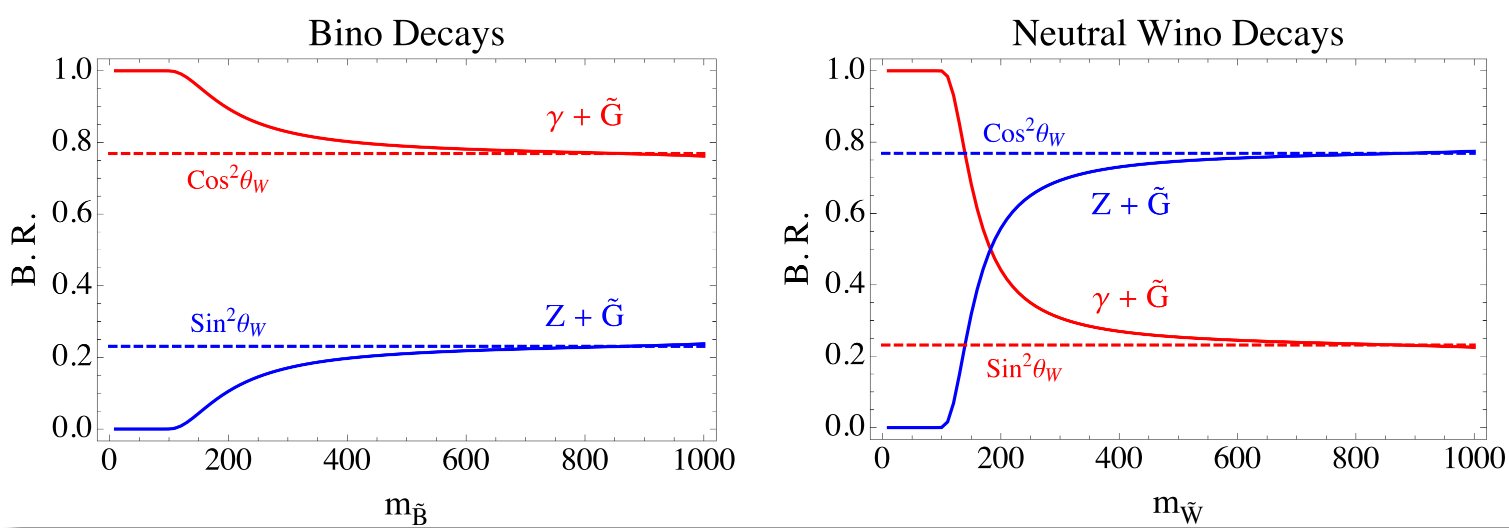
Switching the Lamppost

Searches with Photons

- So far we were focused on neutralino LSP
- In GMSB model, the LSP is gravitino and is very light (in the eV-GeV range)
  - The signature is determined by the nature of NLSP (wino, a partner of W; bino, a partner of Z; stau, ...)
  - Classical decay: wino NLSP into gravitino + photon (>20%!)
  - Decays via Z are already covered by OS dilepton searches

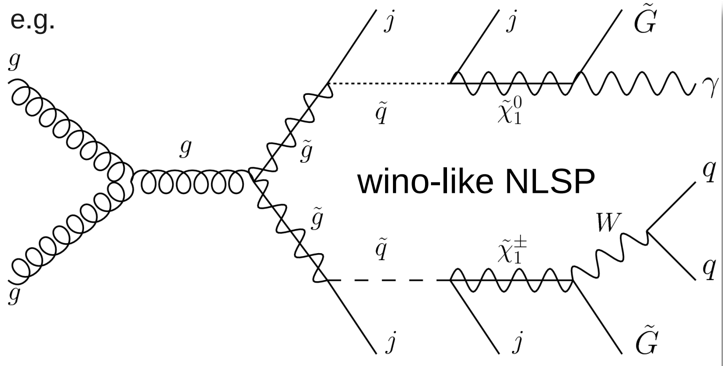


Ruderman,Shih arXiv:1103.6083

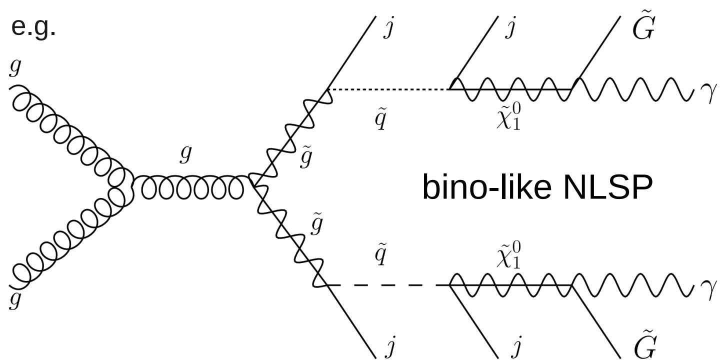


Photon Signatures

- Depending on the decay chain, we focus on the following three signatures with ME_T:
  - Photon+jets+ME_T:

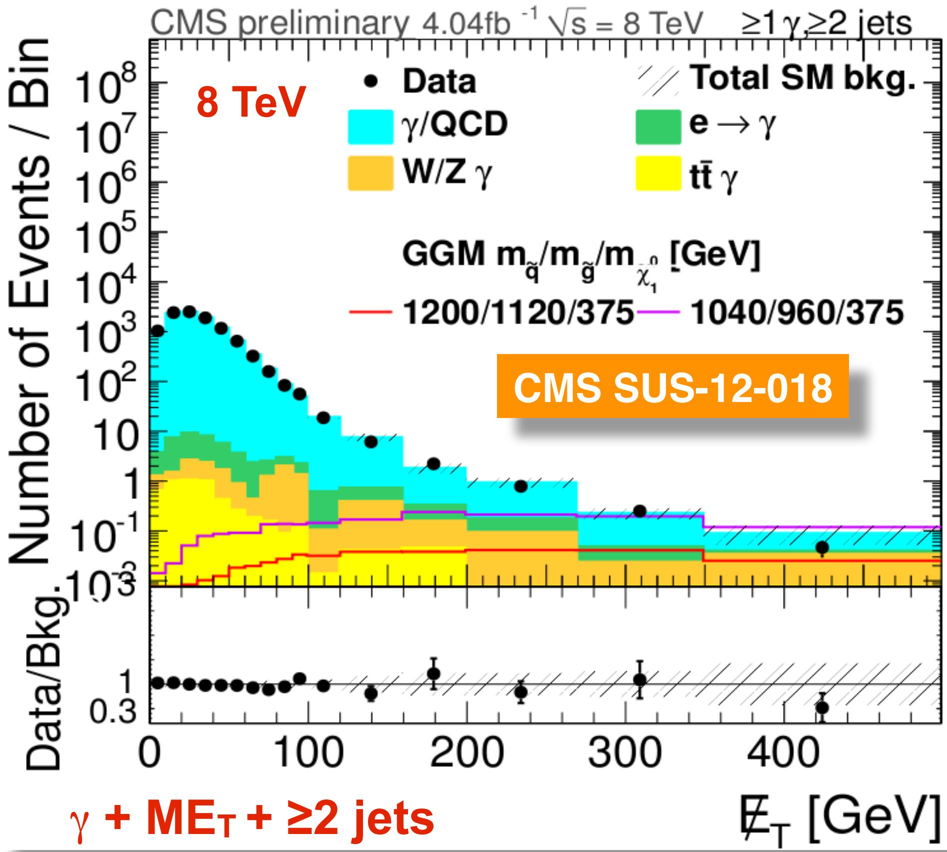


  - Diphotons+jets+ME_T:

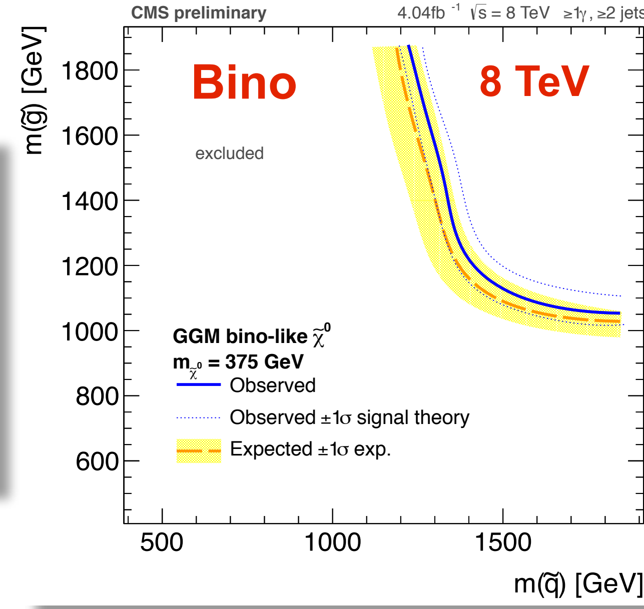


Photons+Jets+ME$_T$ Search

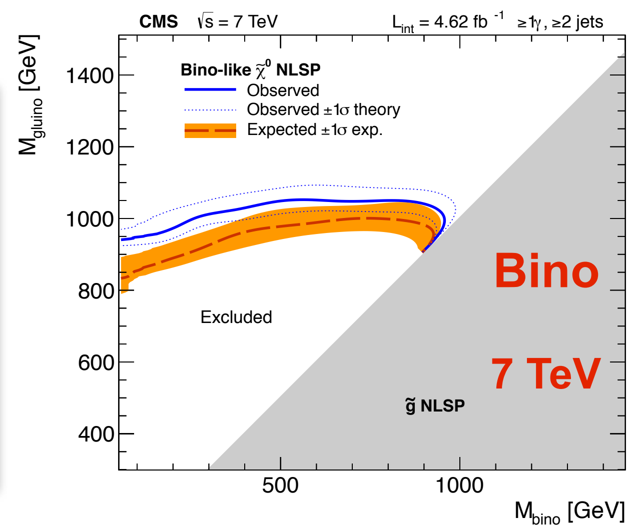
- Main backgrounds stem from γ+jets and multijets with mismeasured ME$_T$



γ + ME$_T$ + ≥2 jets



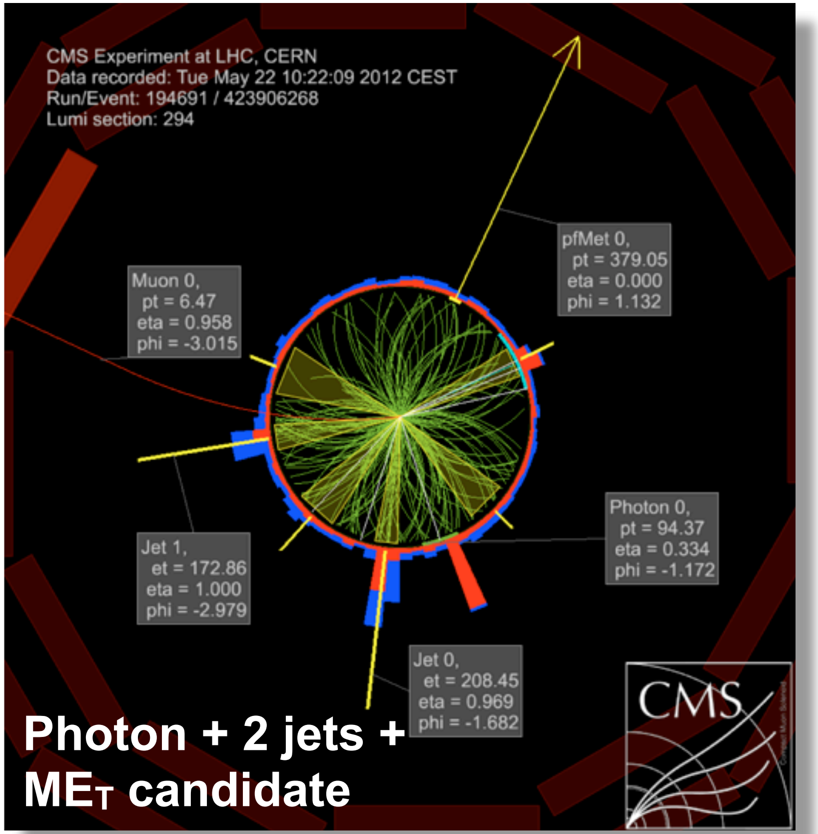
CMS SUS-12-018

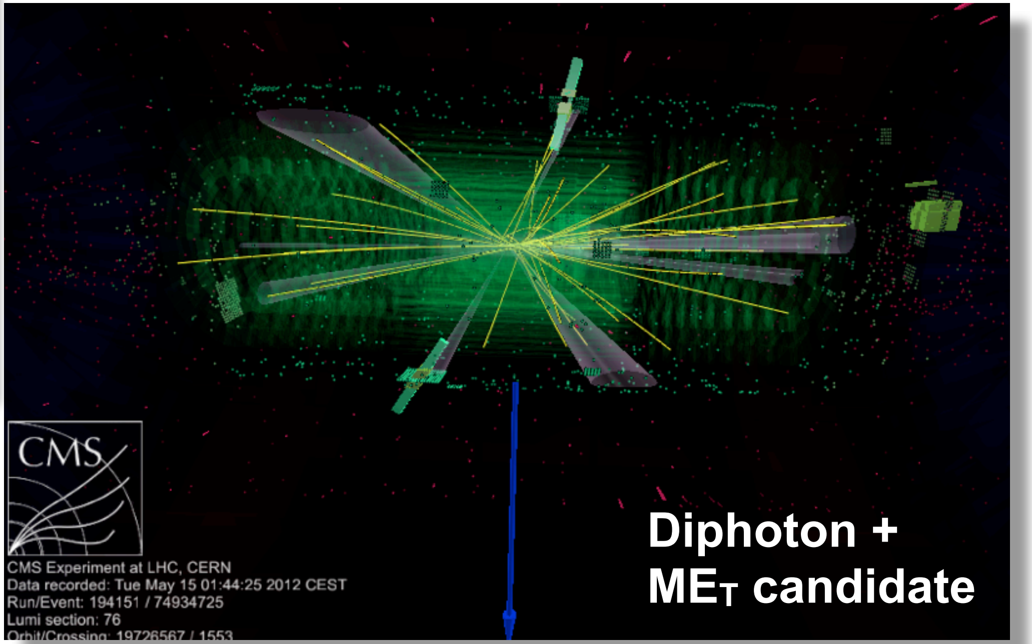


CMS Collaboration arXiv:1211.4784

Candidate Events

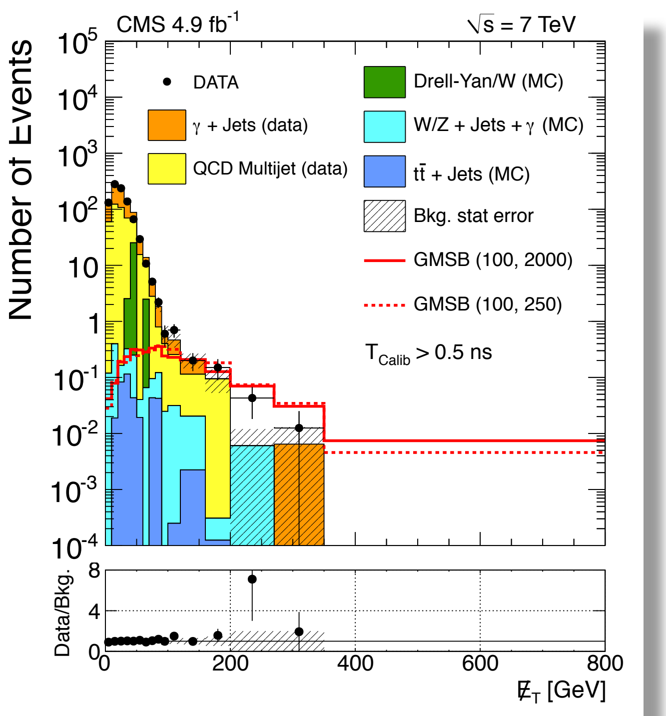
- Despite no sign of signal, some beautiful candidate events...



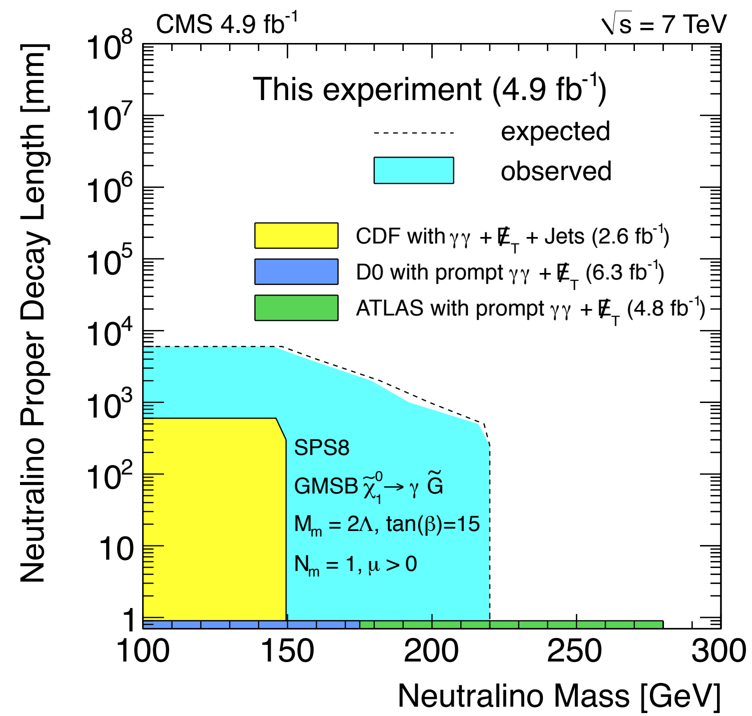


Non-Prompt Photons

- Neutralino NLSP lifetime depends on GMSB parameters:
  - $c\tau \approx 0.1\,(\sqrt{F}/100\ \text{TeV})^4 \times (100\ \text{GeV}/M(\chi_1^0))^5$ mm, where $\sqrt{F}$ is the GMSB scale
  - Can be long-lived, resulting in non-prompt photons
- Look for non-prompt photons using excellent CMS ECAL timing resolution $\sigma \sim 0.5$ns
  - Require at least one photon and ≥3 jets (to reduce γ+jets background)
  - Background is determined from data by releasing photon ID requirements
- Fit data in ME_T vs. timing plane to extract possible signal



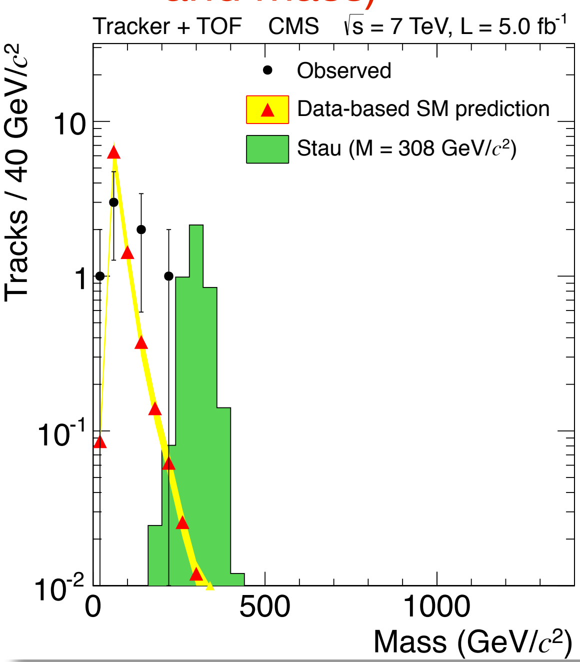
CMS Collaboration
arXiv:1212.1838

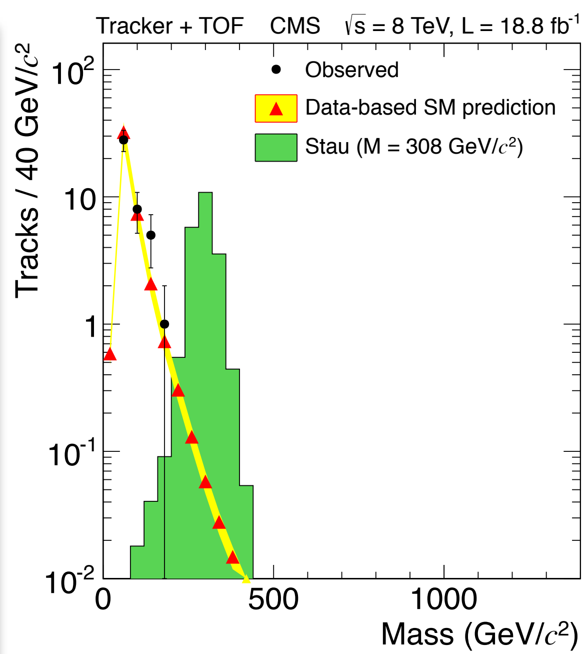


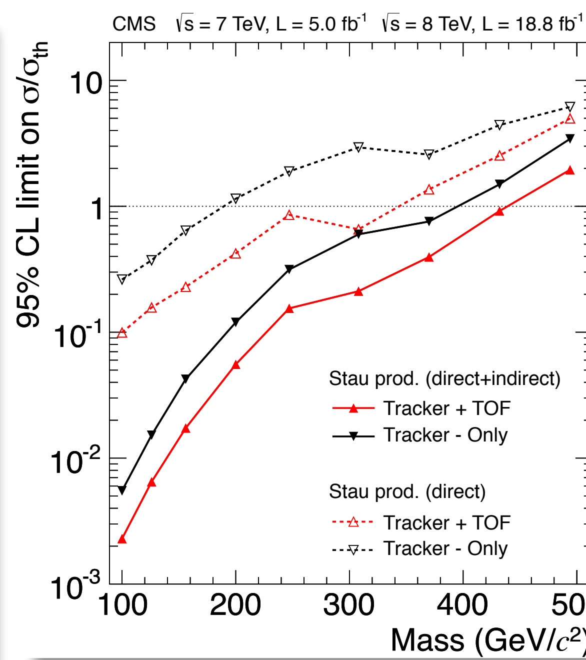
Long-Lived Staus

- Stau NLSP can also be long-lived:
  - $c\tau \approx (\sqrt{F}/100\ \text{TeV})^4 \times (100\ \text{GeV}/M(\tilde{\tau}))^5$ cm, where $\sqrt{F}$ is the GMSB scale
- In other scenarios gluinos and stops can be long-lived as well
- Look for long-lived heavy charged particles via anomalous ionization and TOF to the muon system
  - Determine mass from ionization and momentum
  - Estimate background from data with low-p_T tracks (no correlation between p_T and mass)

CMS Collaboration arXiv:1305.3792

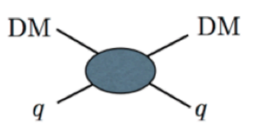




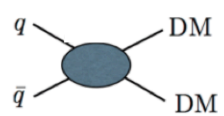


Search for Dark Matter

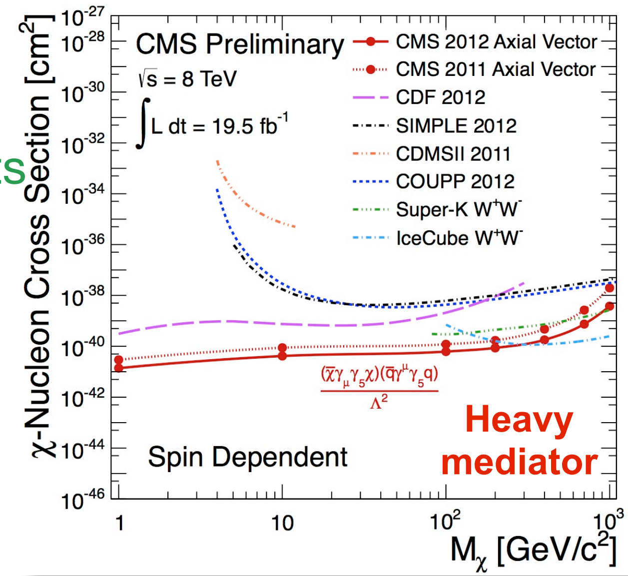
- Increased interest since the recent CDMS result (arXiv:1304.4279)!
- New search for DM, a la direct detection experiments
  - Limits are somewhat model-dependent as they are sensitive to the mass of the mediator
  - Also sensitive to DM-gluon couplings

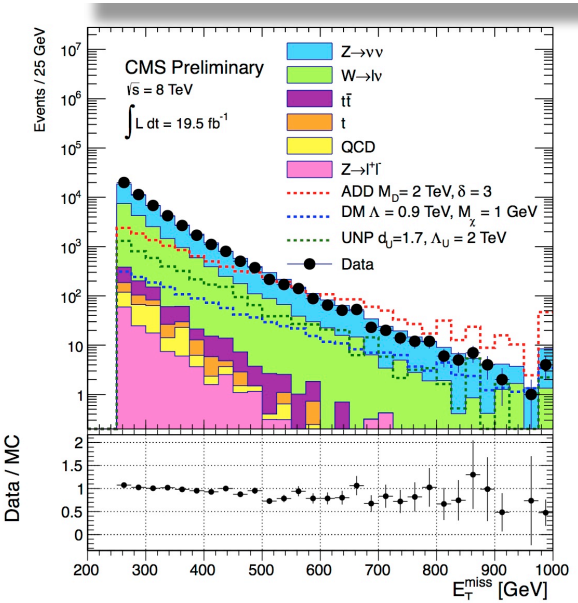


Direct Detection (t-channel)



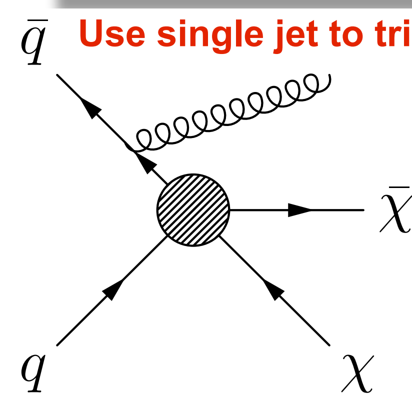
Collider Searches (s-channel)



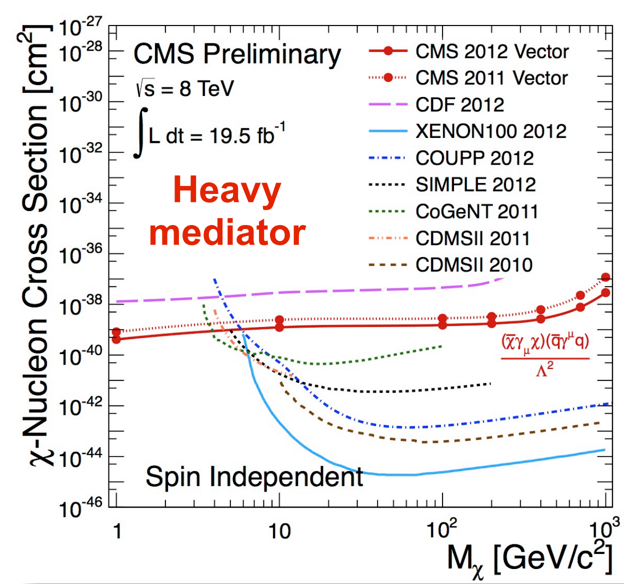


CMS EXO-12-048

Use single jet to trigger



Monojet + MET



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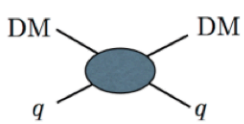

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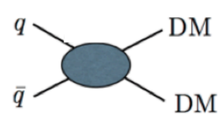

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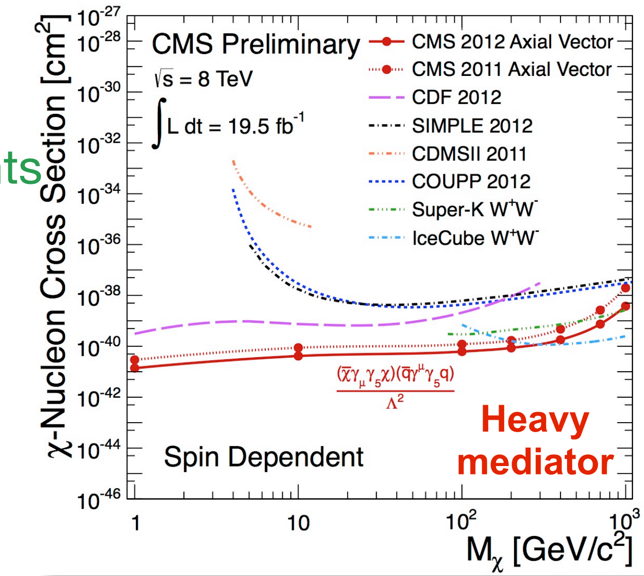

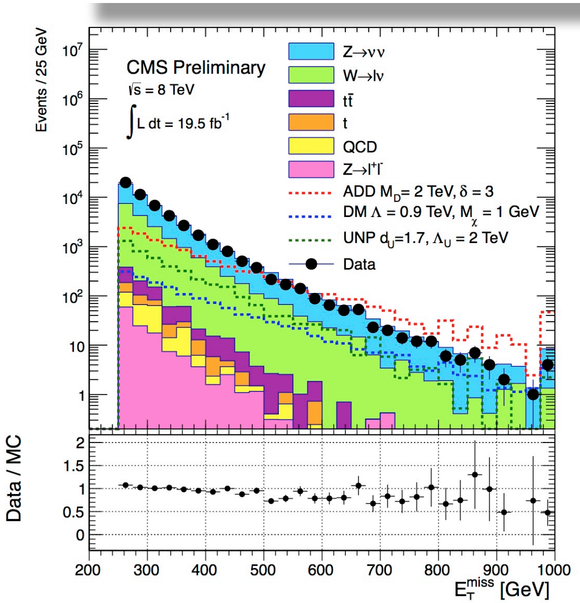

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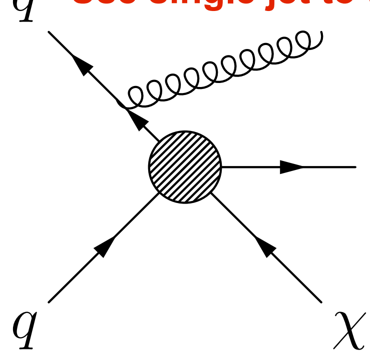

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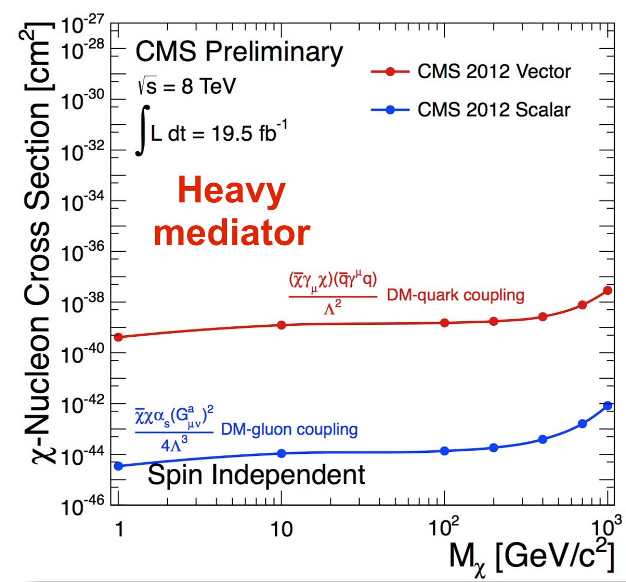


Looking Everywhere

cMSSM Limitations

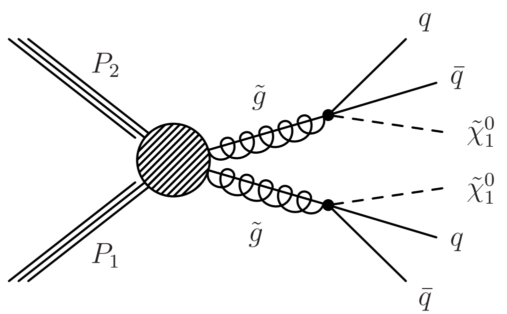
- We saw that cMSSM is too constrained and not really useful any longer as a search framework
- We learned that specific alternative scenarios can be probed and often reuse cMSSM-like searches to recast limits
- Yet, generating full SUSY spectrum even in constrained scenarios is a hard task
    - Moreover, one can't freely move "interesting" SUSY masses without reverse-engineering SUSY parameters into masses
    - Often, spectrum and kinematics is most important feature, which differs various SUSY scenarios experimentally
- How can we capture all these features in a "light" set of SUSY models?

Simplified SUSY Models

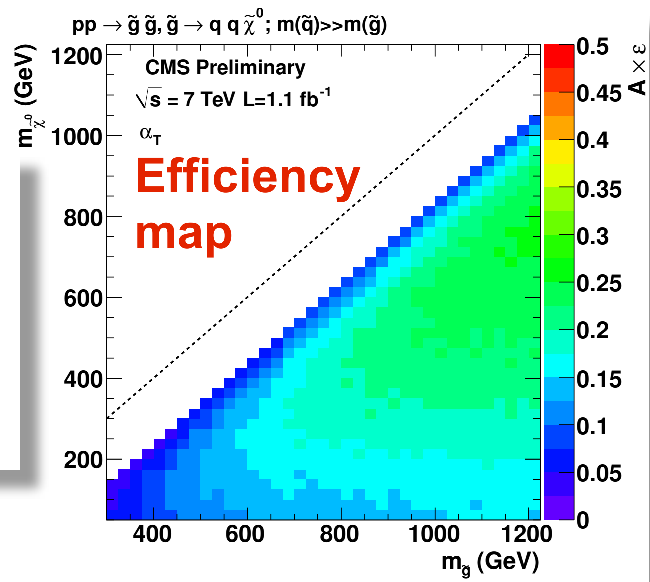
- The answer is: Simplified SUSY Models (SMS) that capture important part of the SUSY spectrum and focusing directly on the masses and decay modes of a few particles involved, ignoring the rest
  - After [Arkani-Hamed et al, hep-ph/0703088], [Alwall et al., arXiv:0809.3264], [Alwall, Schuster, Toro, arXiv:0810.3921], ...
- Example: SMS T1 model: gluino pair production with 100% decay via virtual squark into LSP + 2 jets
  - Input parameters: $M(\tilde{g})$, $M(\tilde{\chi}_1^0)$; assume $M(\tilde{q}) \gg M(\tilde{g})$

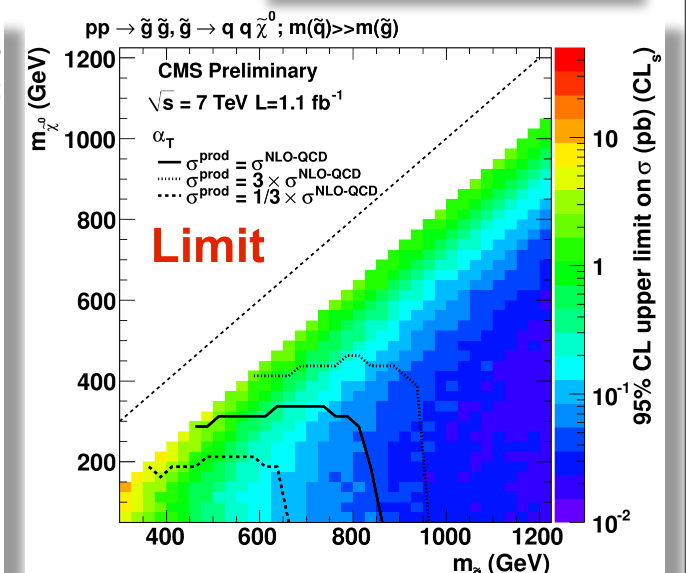
CMS Collaboration
arXiv:1109.2352
CMS SUS-11-003

Feynman diagram



α_T search reinterpretation

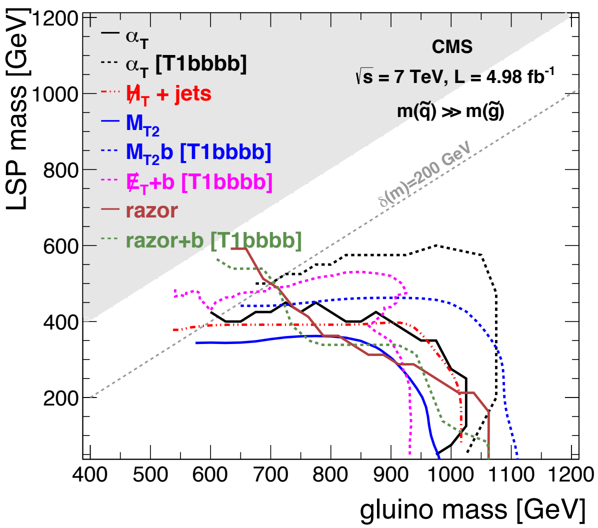




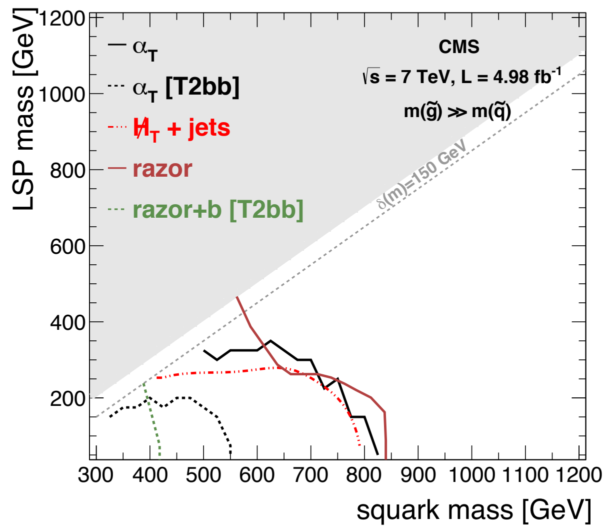
SMS: 7 TeV Searches

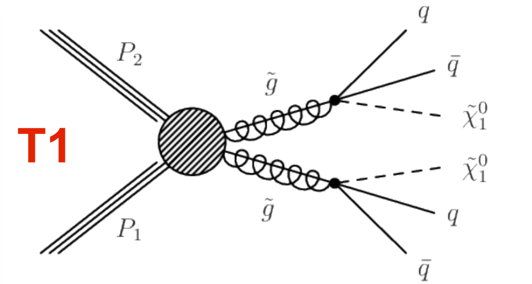
BROWN

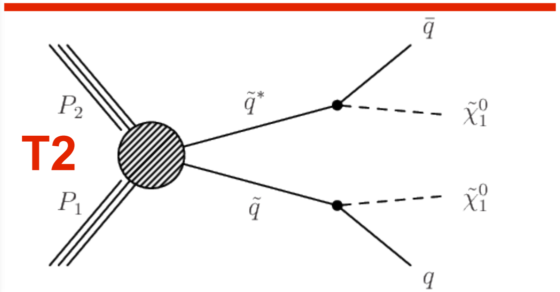
95% exclusion limits for T1: $\tilde{g} \to q\bar{q}\tilde{\chi}^0$



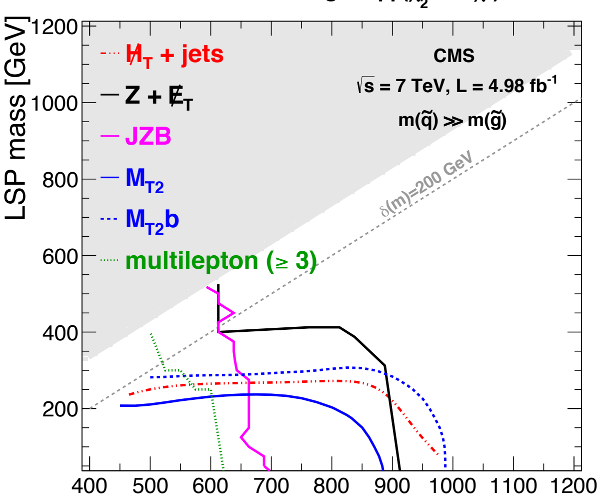
95% exclusion limits for T2: $\tilde{q} \to q\tilde{\chi}^0$





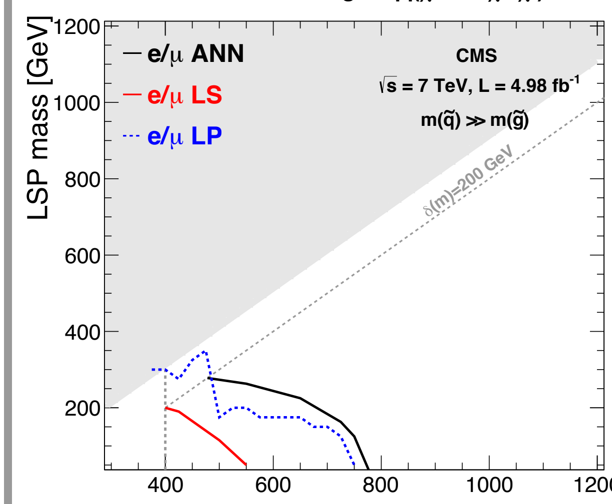


95% exclusion limits for T5zz: $\tilde{g} \to q\bar{q}\,(\tilde{\chi}^0_2 \to Z\tilde{\chi}^0)$

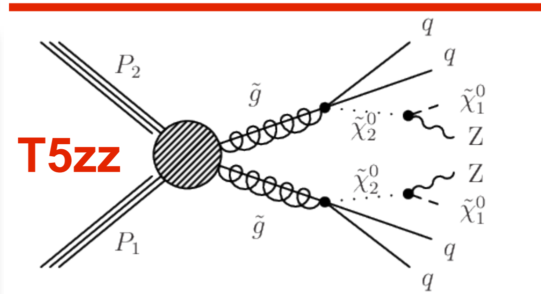


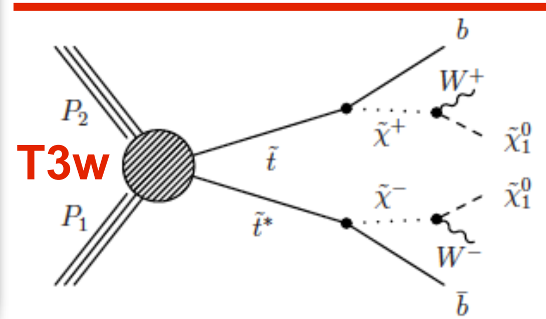
$m(\tilde{\chi}^0_2) = 0.5\, m(\tilde{\chi}^0) + 0.5\, m(\tilde{g})$

95% exclusion limits for T3w: $\tilde{g} \to q\bar{q}(\tilde{\chi}^{\pm} \to W\tilde{\chi}^0\ /\tilde{\chi}^0)$



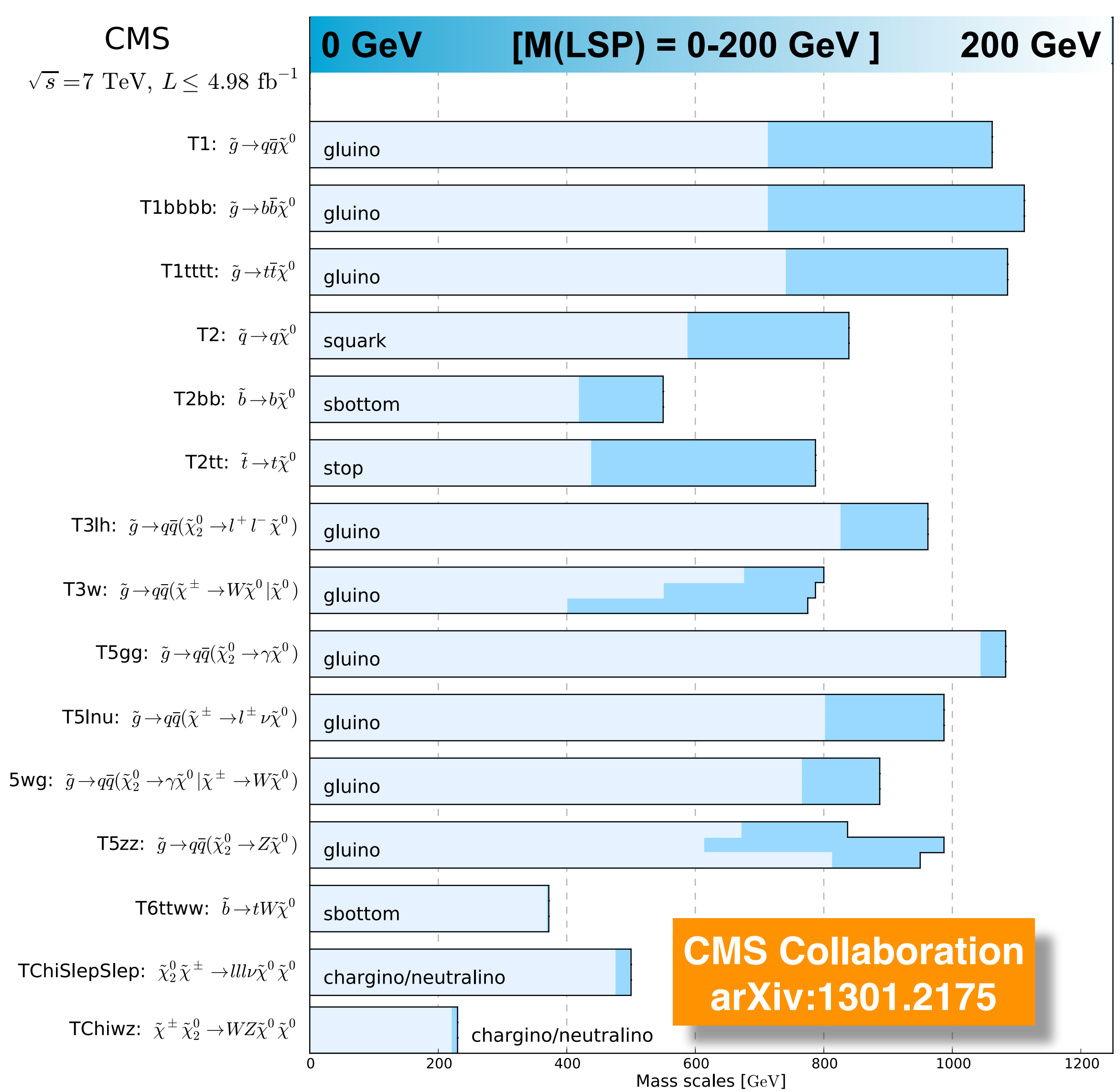
$m(\tilde{\chi}^{\pm}) = 0.5\, m(\tilde{\chi}^0) + 0.5\, m(\tilde{g})$





SMS: 7 TeV Grand Summary

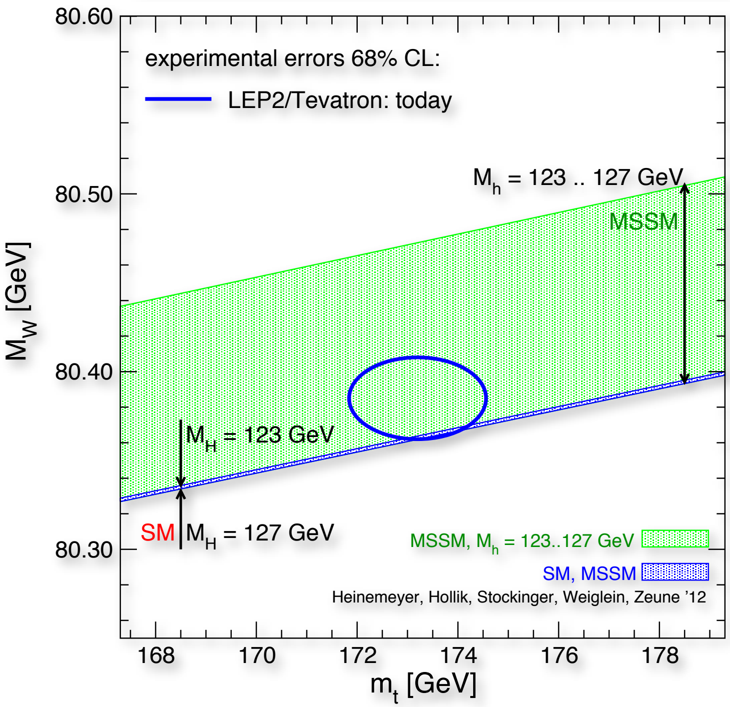
BROWN



Looking with a Flashlight

SUSY & Higgs

- Existence of several Higgs bosons is the key prediction of low-scale SUSY
  - Higgs & SUSY - a marriage made in heaven!
- The lightest one looks largely like the SM Higgs and has to be light (≲135 GeV); the other ones could be relatively heavy
- Discovery of the Higgs boson at 125-126 GeV was the crucial missing proof that low-scale SUSY can still exists, despite the fact that we haven't seen it yet
  - Precision EW data does prefer MSSM over SM (only by 1 standard deviation)
  - Had the Higgs boson been just 10% heavier, I wouldn't be giving this talk!

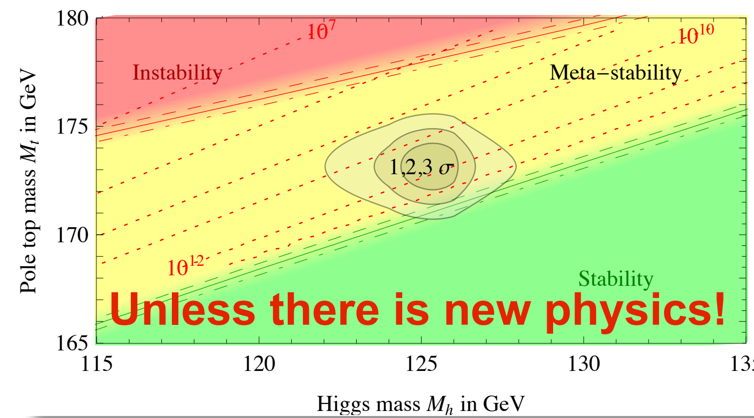


Higgs as a Vacuum Cleaner

- Stable vacuum?

- Metastable vacuum?

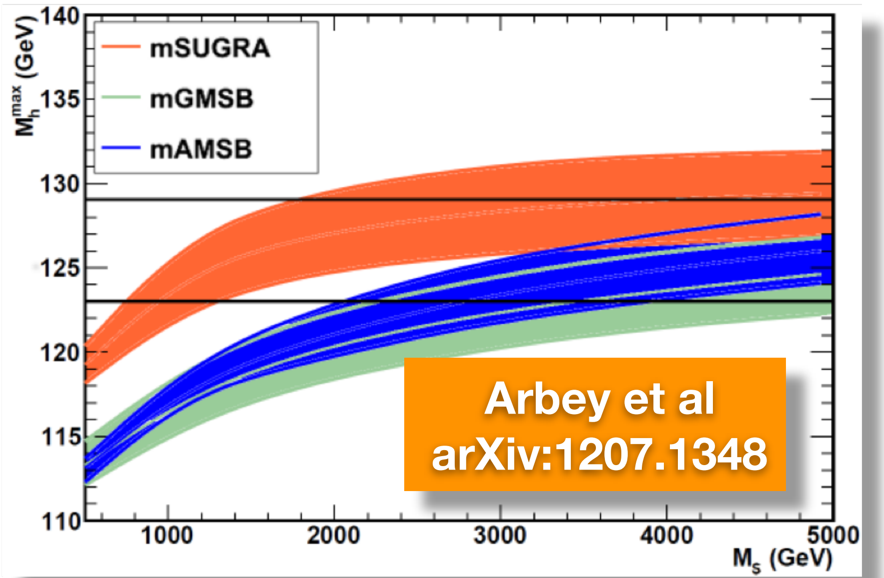
- Unstable vacuum?

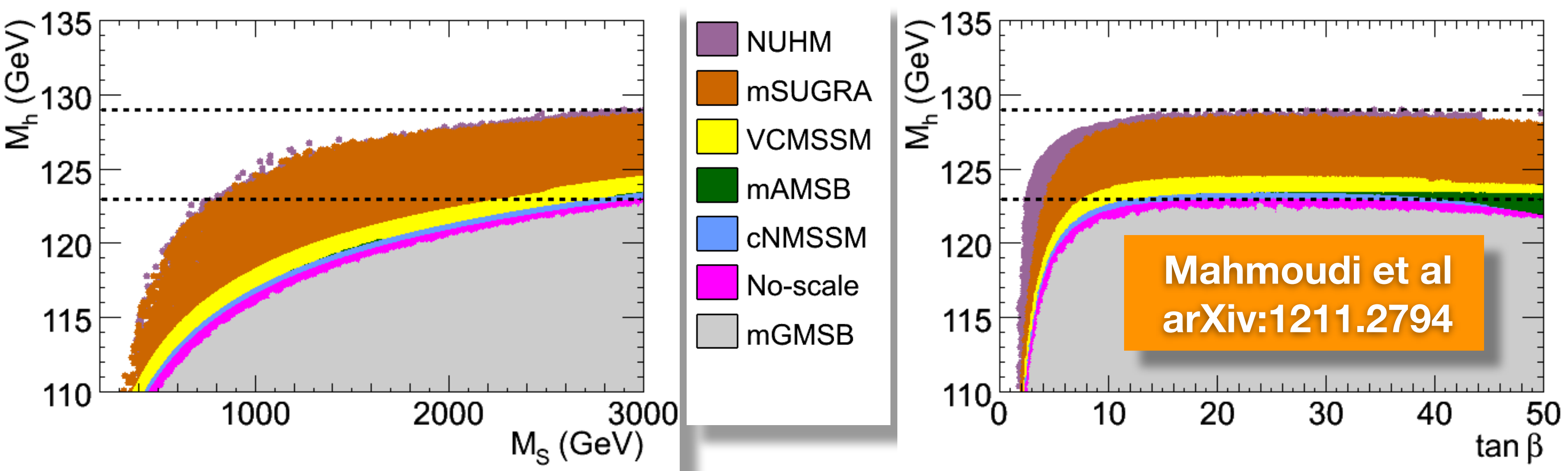


Degrassi et al, arXiv:1205.6497

SUSY: the Higgs Aftermath

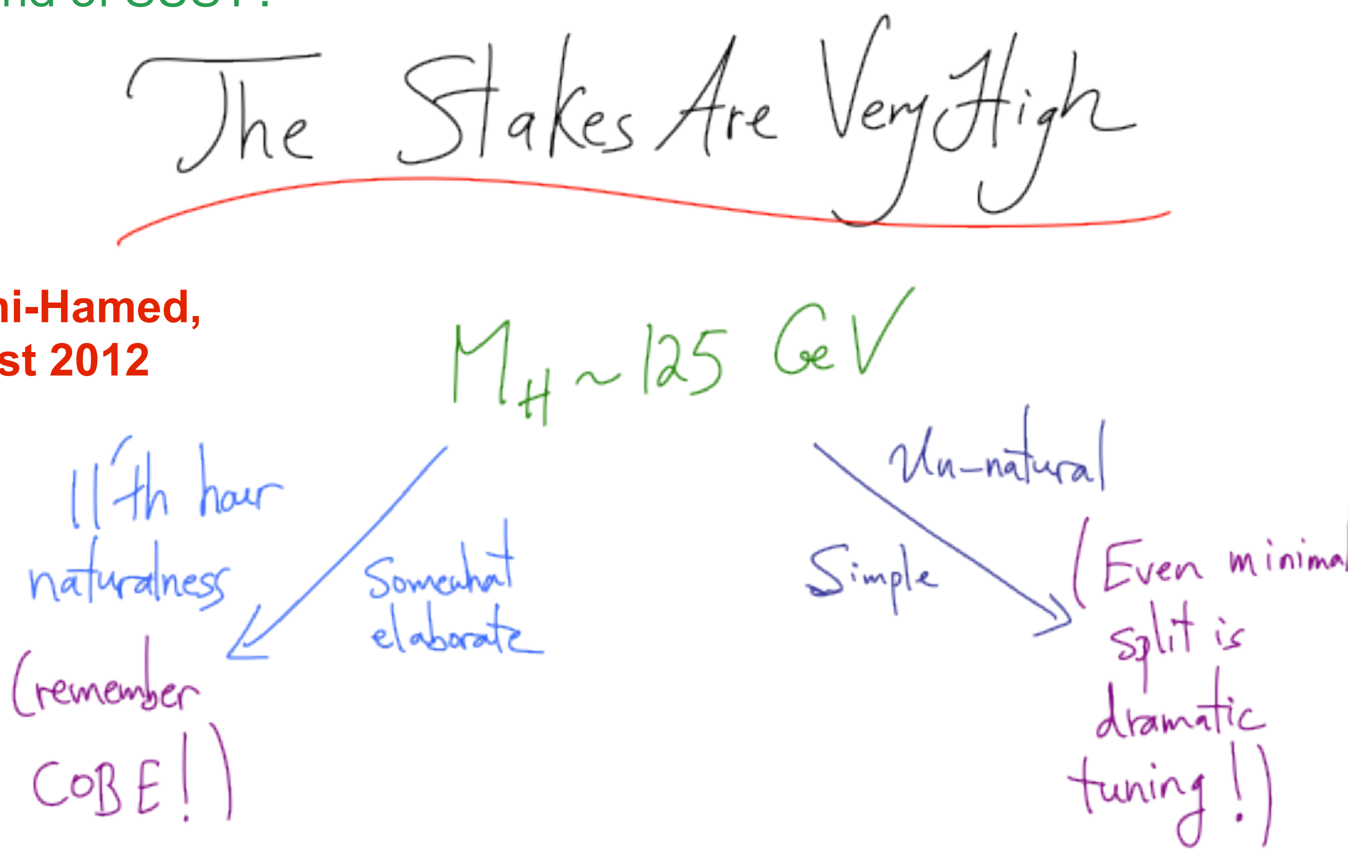
- A 125 GeV Higgs boson is challenging to accommodate in (over)constrained versions of SUSY, particularly for "natural" values of superpartner masses
- Started to constrain some of the simpler models
- Big question: if SUSY exists, can it still be "natural", i.e. offer a non-fine-tuned solution to the hierarchy problem of the standard model?
  - N.B. If not, we would be giving up one of the SUSY "miracles"!





We are at a SUSY Crossroad

- Light 125 GeV Higgs boson strongly prefers SUSY as the fundamental explanation of the EWSB mechanism (via soft SUSY-breaking terms and radiative corrections)
- But what kind of SUSY?



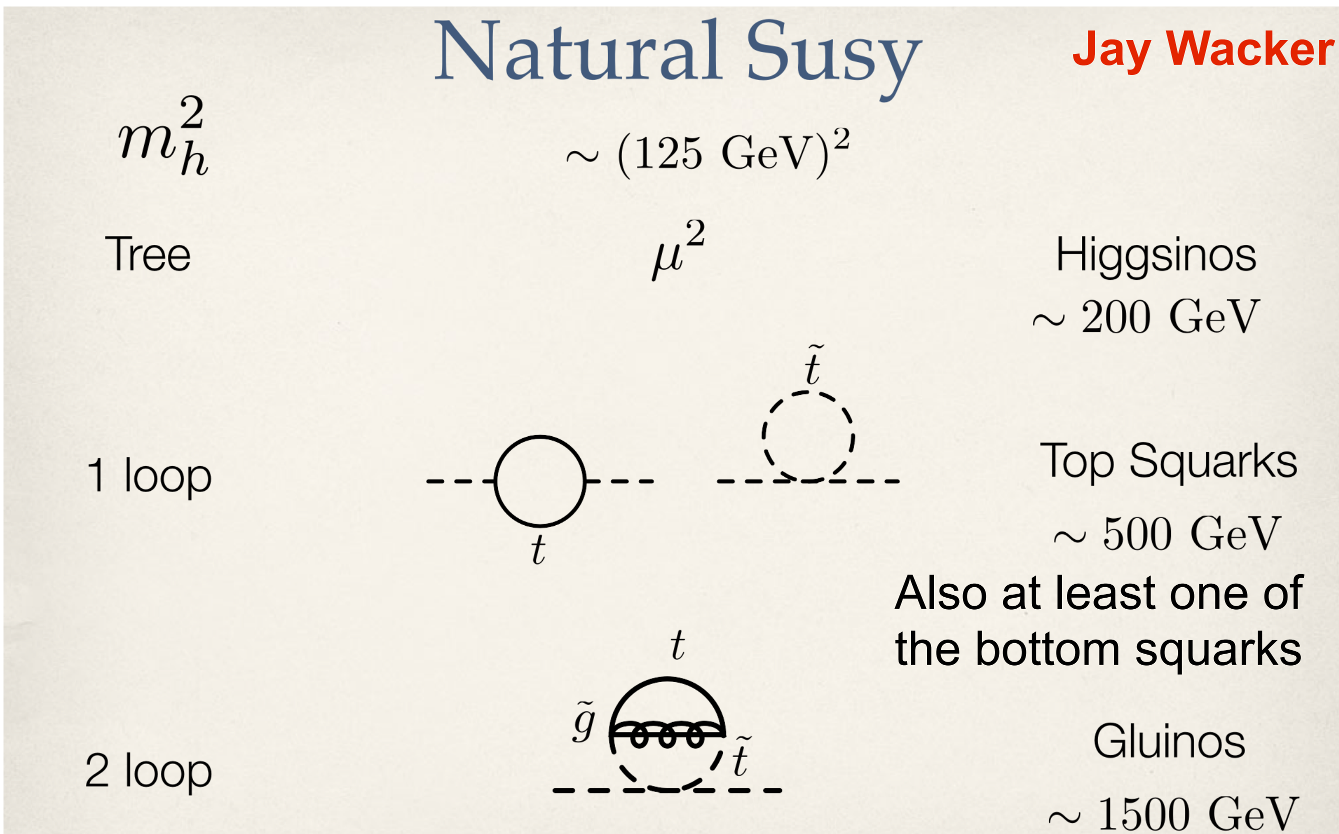
Nima Arkani-Hamed, SavasFest 2012

Implies: light stops/sbottom, reasonably light gluinos and charginos/neutralinos

Likely: long-lived particles, light neutralino, multi-TeV Z′, ...

Natural SUSY

- If SUSY is natural, we should find it soon:
  - And we most likely will find it by observing 3rd generation SUSY particles or EW boson partners first!
- Requires shifting of the SUSY search paradigm

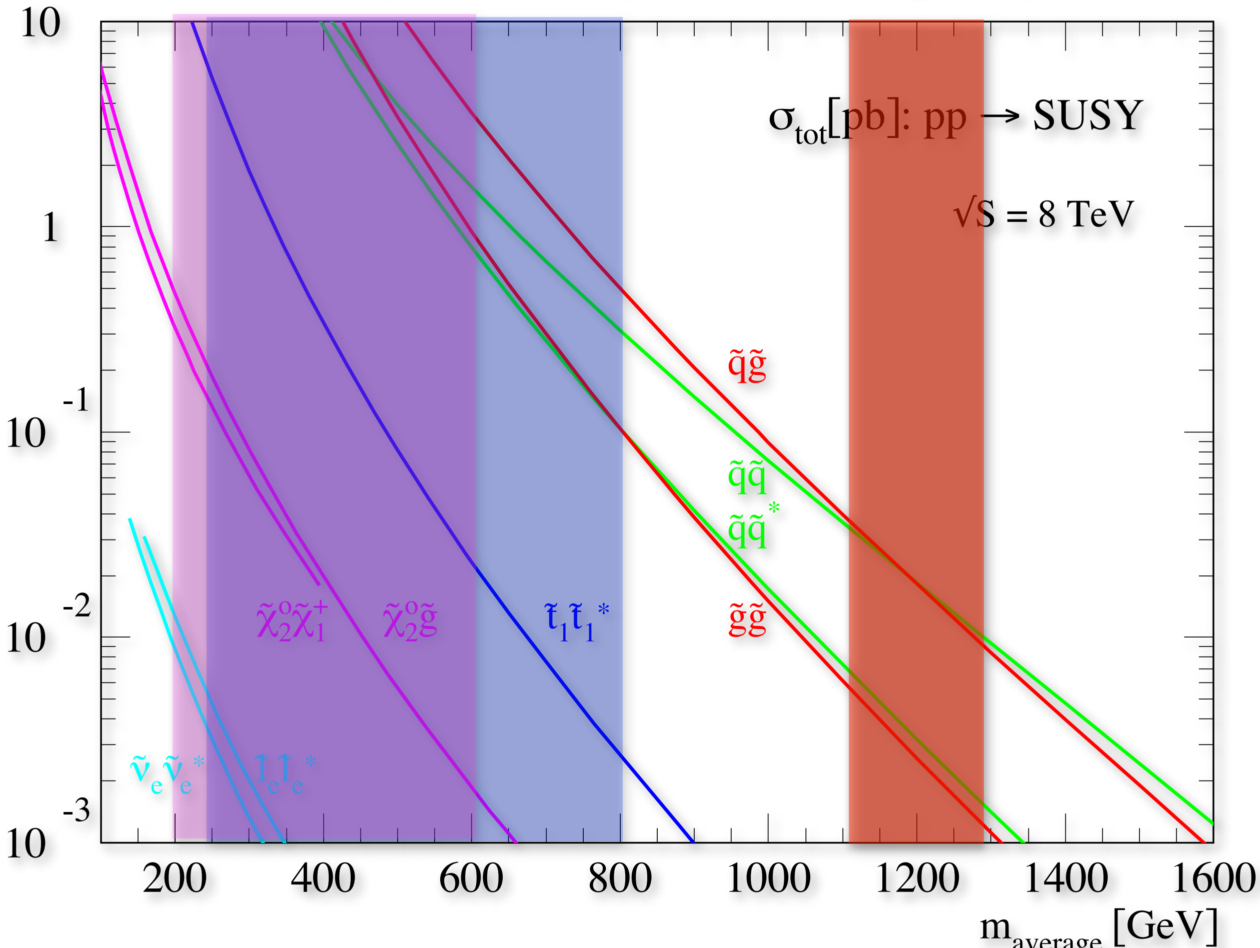


Natural SUSY Reach

- With ∫Ldt ~ 25/fb^{-1} and 1 fb cross section produce 25 events; typically 1-10 events observed after acceptance/efficiencies

σ, pb

http://www.thphys.uni-heidelberg.de/~plehn/



$\tilde{g}\tilde{g}$: M($\tilde{g}$) ≲ 1.3 TeV

$\tilde{t}_1\tilde{t}_1$: M($\tilde{t}_1$) ≲ 0.8 TeV

$\tilde{\chi}\tilde{\chi}$: M($\tilde{\chi}$) ≲ 0.6 TeV

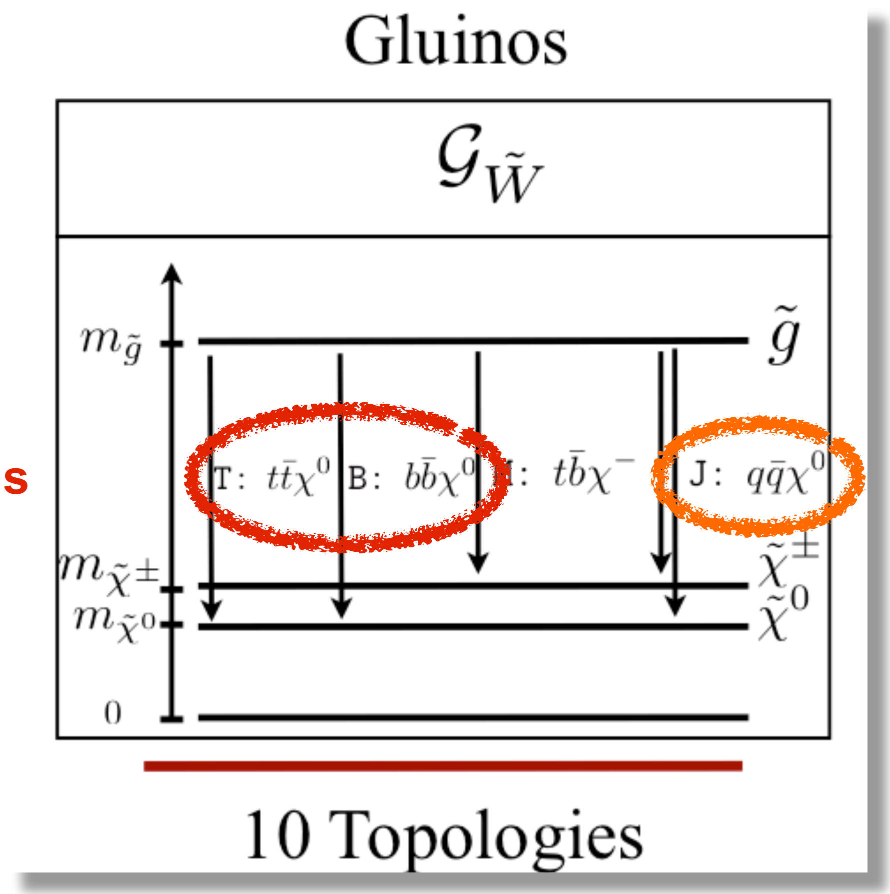
In combination, we cover most of the natural SUSY space!

Can't do this with gluinos alone!

Gluino-Induced Production

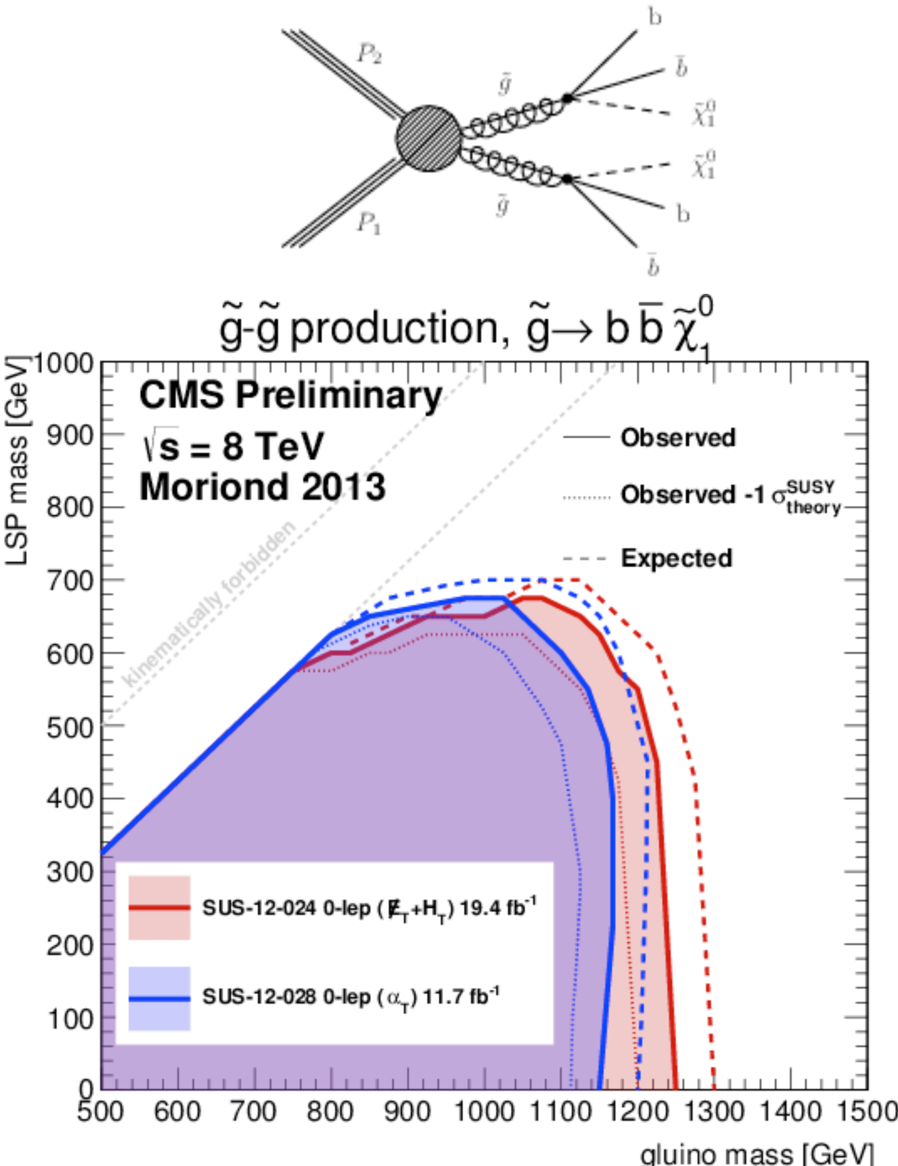
- Generally well covered by cMSSM-like searches, but has a limited reach: if gluinos are above ~1.3 TeV, we simply won't produce enough of them to see decay chains

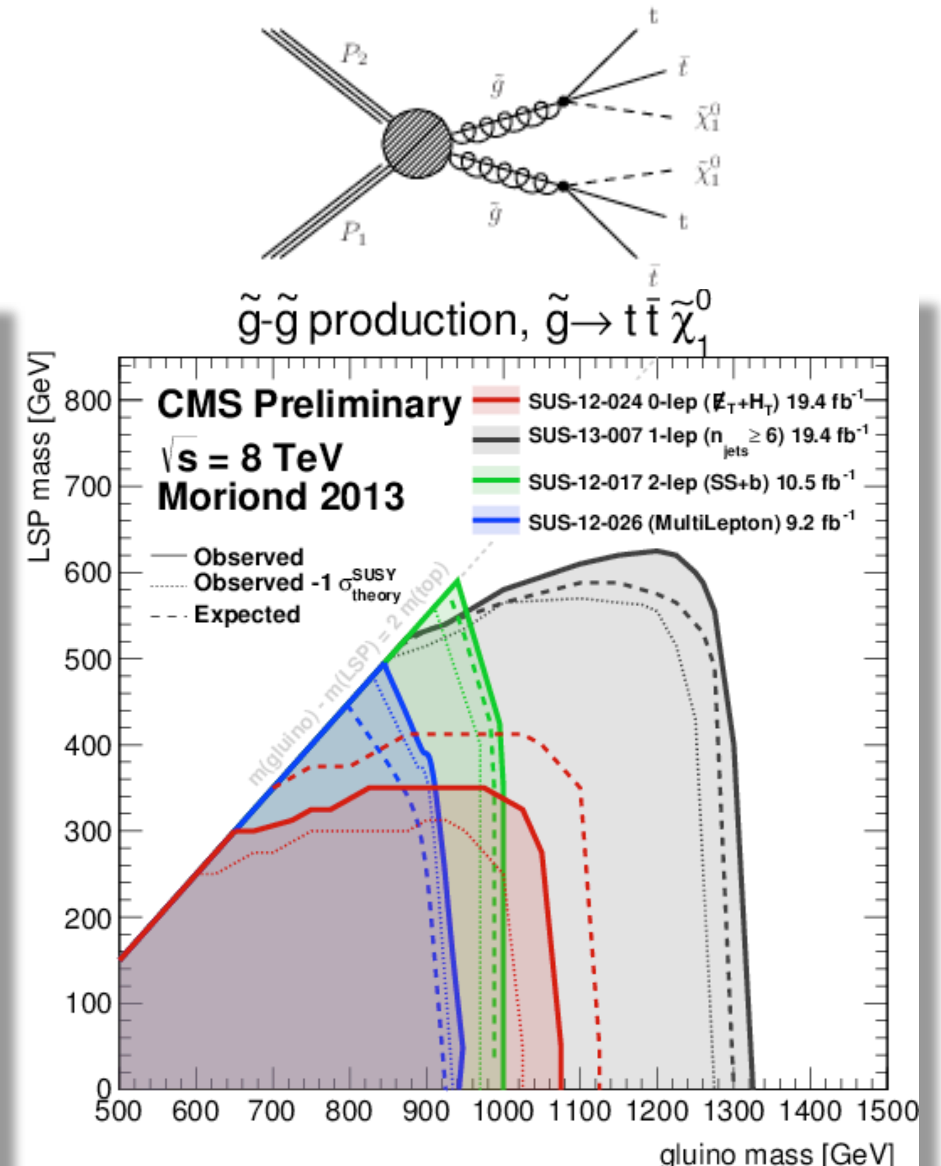
Current focus



Previous focus

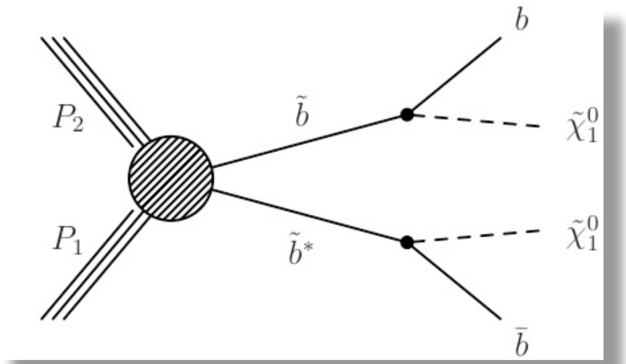
Gluino-Induced Production

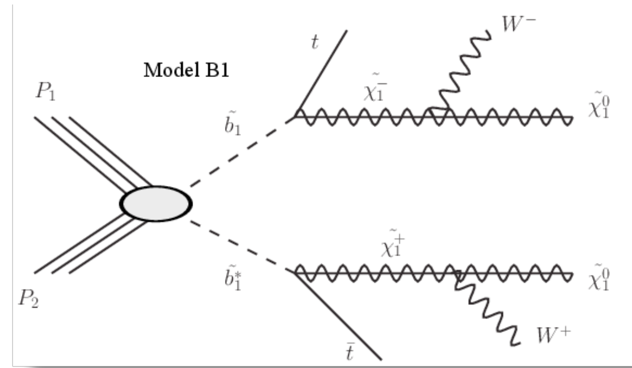


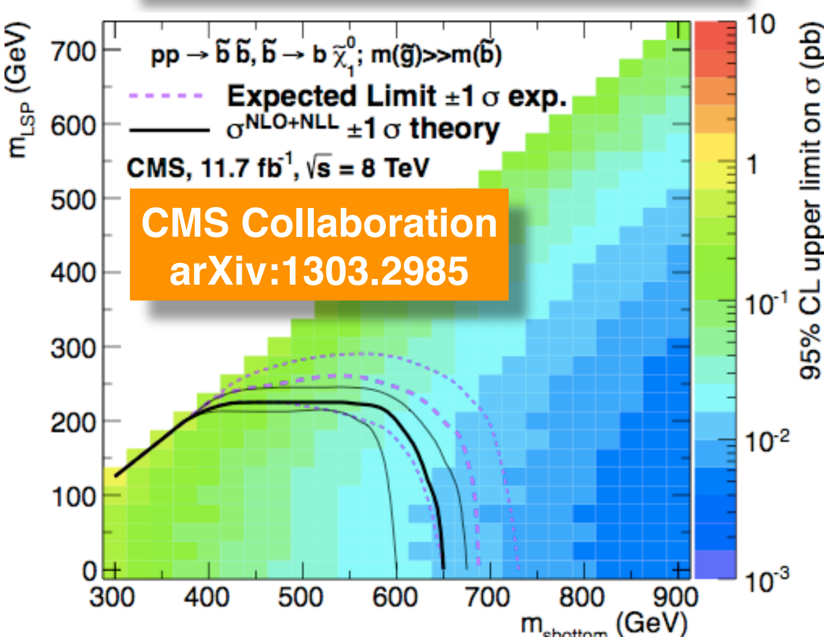


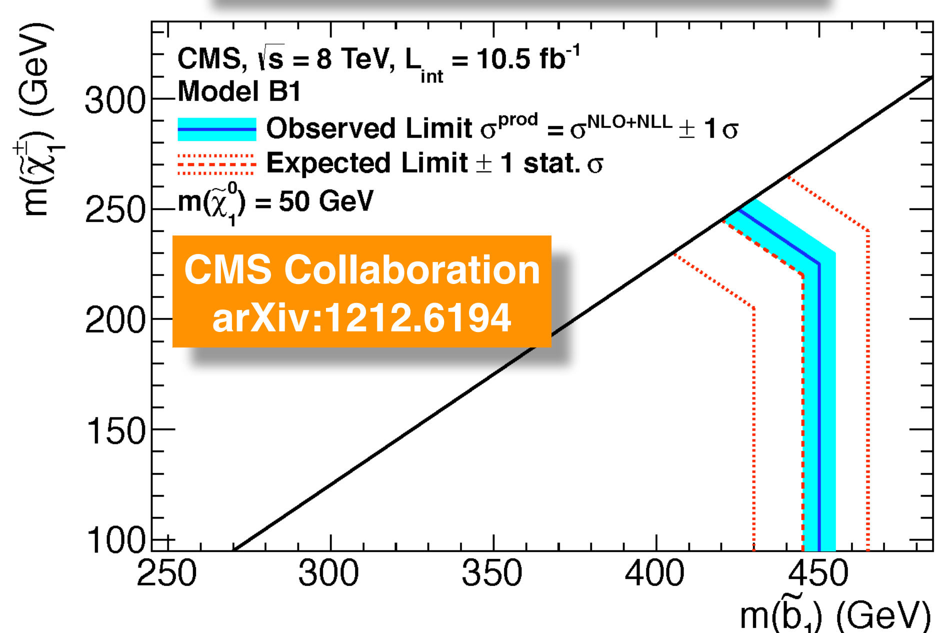
Direct Sbottom Production

- Direct sbottom pair production was looked at in the all-hadronic α_T + b-jets and same-sign dilepton + b-jets channels:



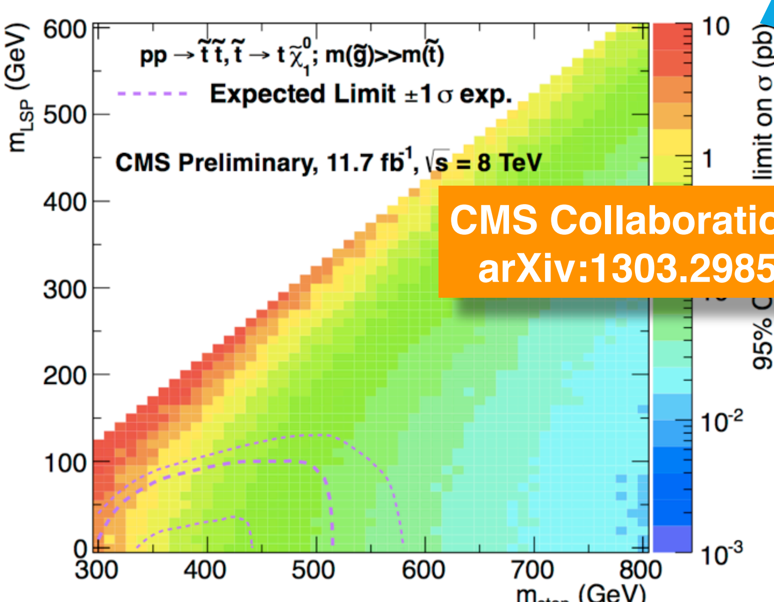




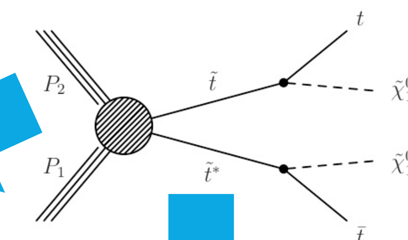


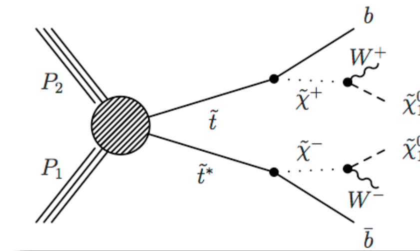
Direct Stop Production

- This is the most hopeful, and yet the toughest channel at the LHC
- Simple reinterpretation of the existing analyses is not sensitive enough
- Requires a dedicated optimized tour-de-force analysis:
  - W+jets and tt with τ_h and lost leptons (from W(μν)+jets with embedded τ_h), invisible Z decays (from Z(μμ)), and multijets (reweighted MC with kinematics and resolutions reweighted to match multijet data)
  - The 8 TeV analysis is ongoing

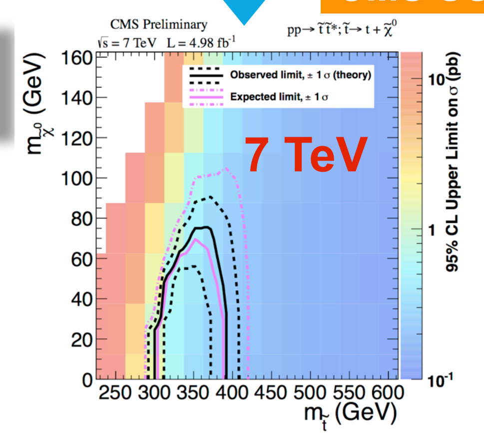


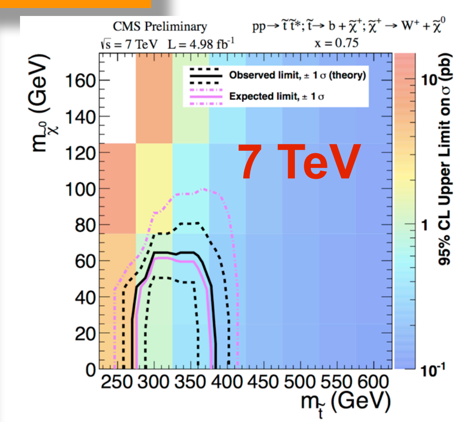
CMS Collaboration
arXiv:1303.2985





CMS SUS-11-030





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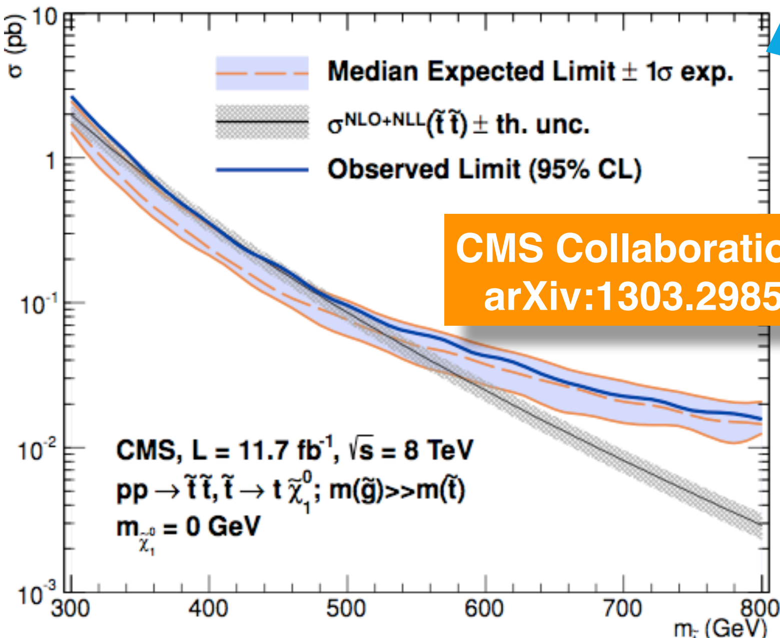
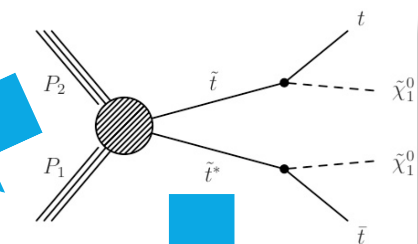
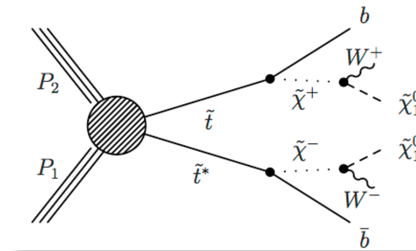
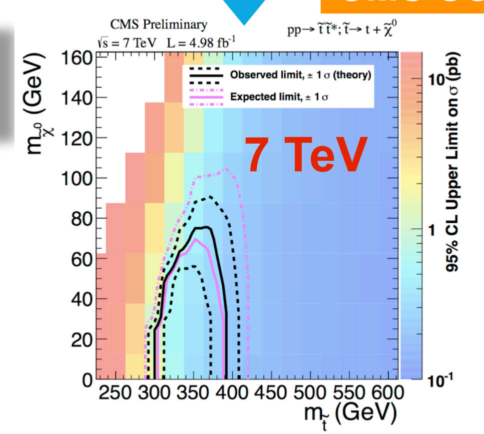


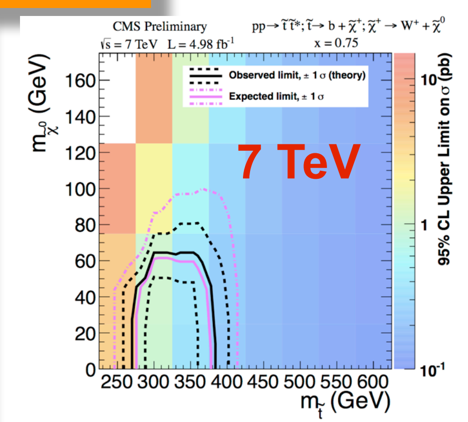
CMS Collaboration
arXiv:1303.2985





CMS SUS-11-030

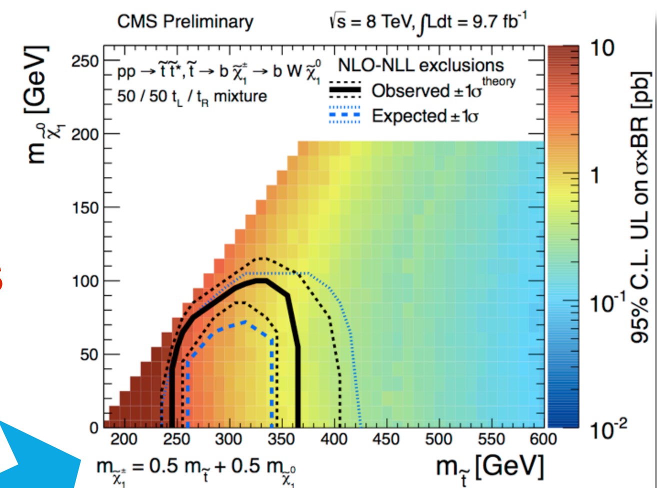


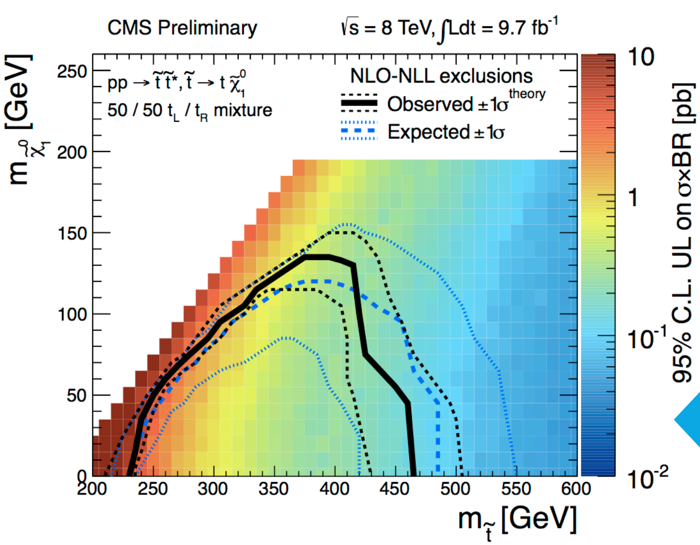


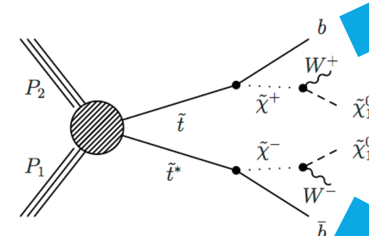
Direct Stop: l+jets+ME_T

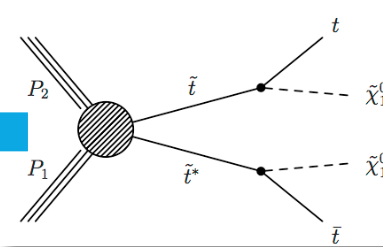
- Another important channel for direct stop production is single-lepton channel
  - Dedicated optimized analysis with multiple signal regions determined by M_T and ME_T
  - Main background is from tt to dileptons with a lost lepton or τ_h, followed by W+jets and semileptonic tt

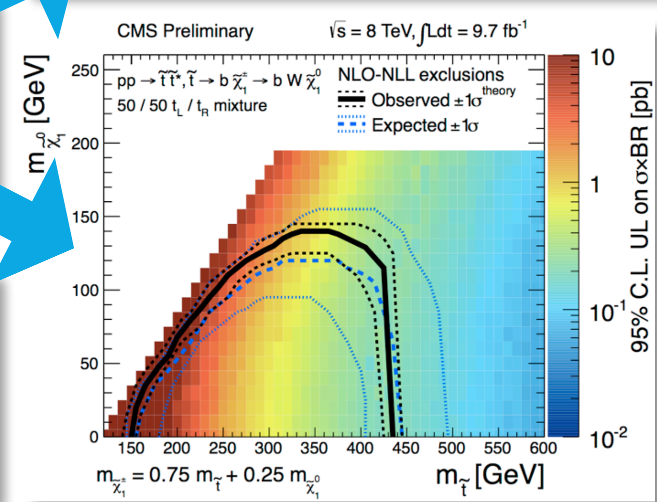
CMS SUS-11-023





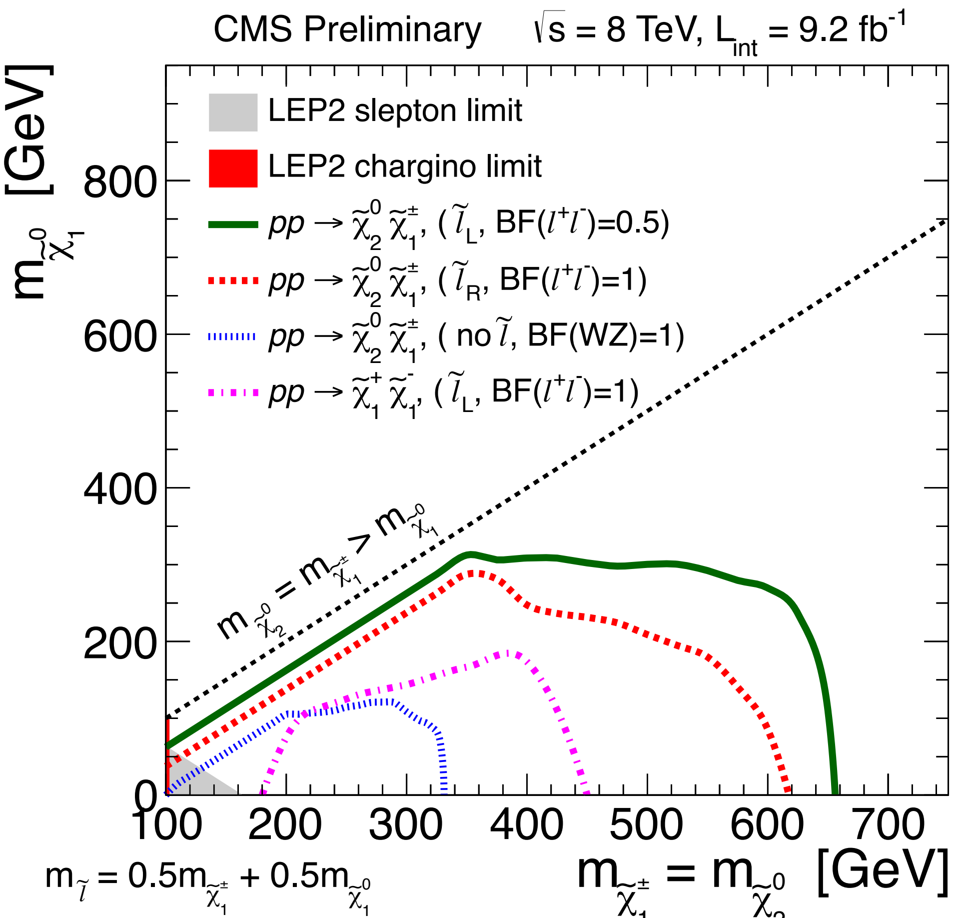






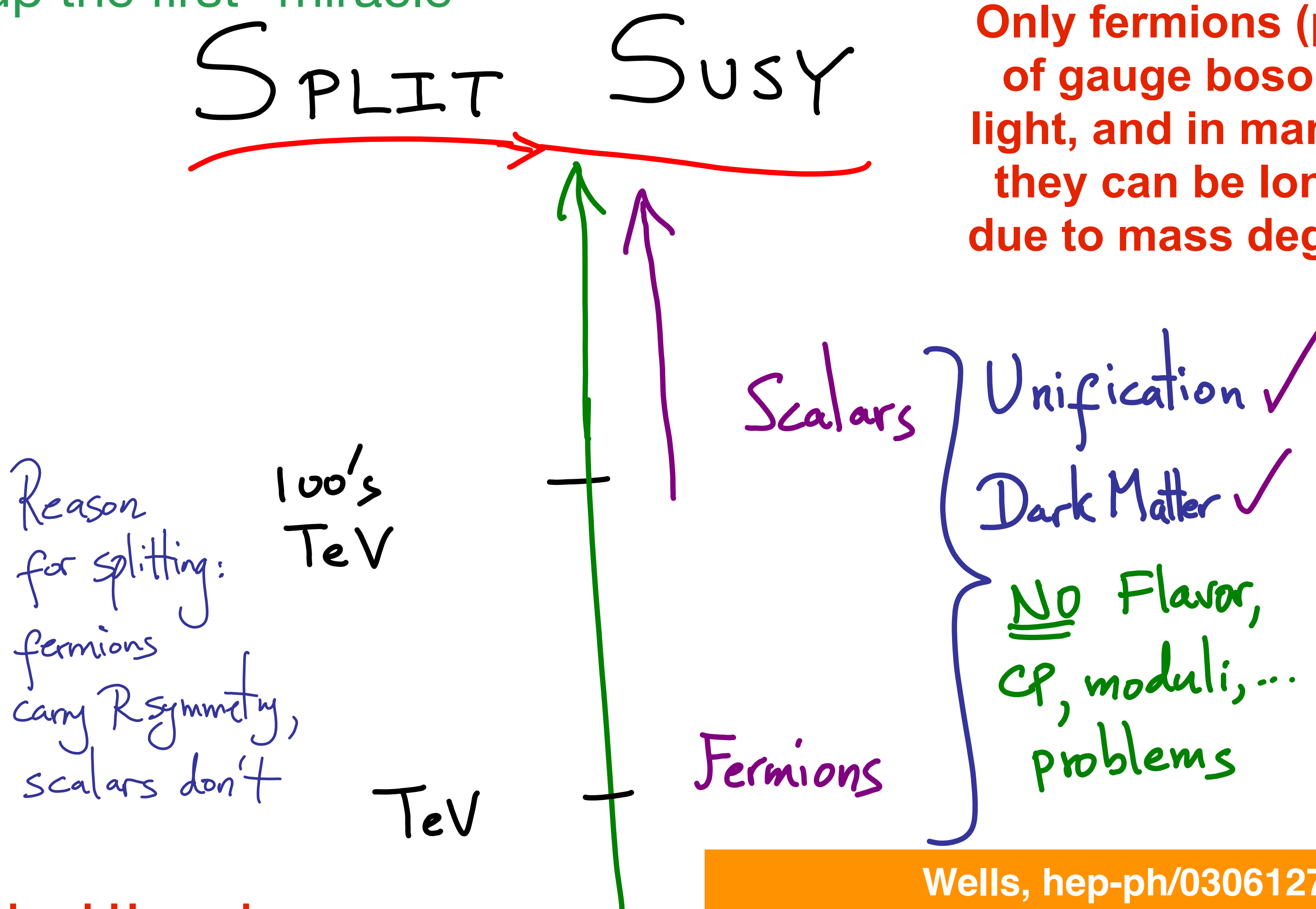
Direct EWkino Production

- Looking for direct EW production of pairs of neutralinos/charginos, typically in multilepton final states



Unnatural SUSY

- Yet, SUSY may still be a solution to EWSB, albeit we would have to give up the first "miracle"



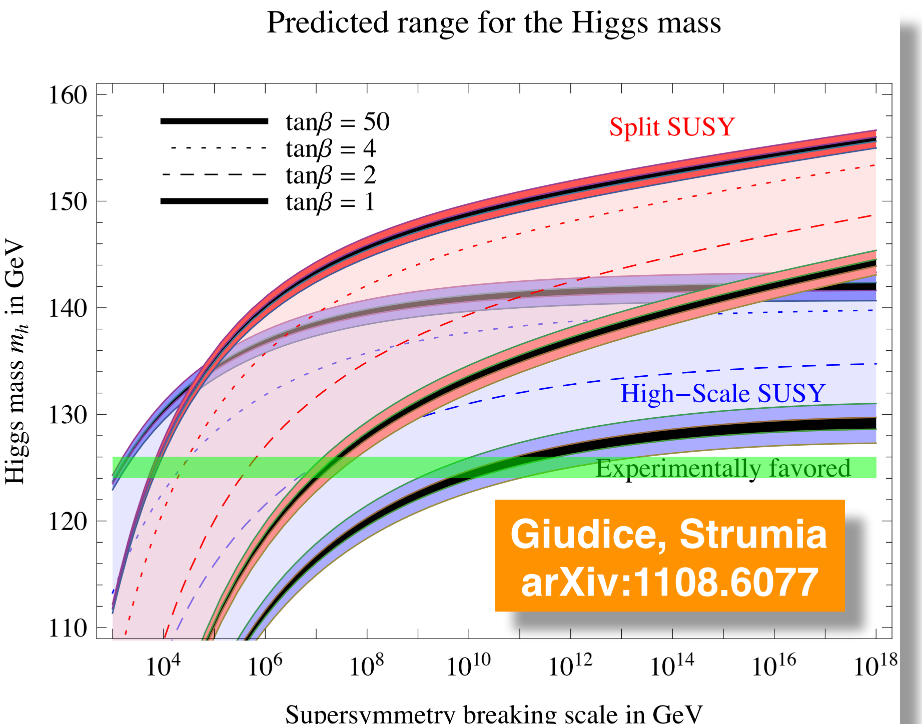
Only fermions (partners of gauge bosons) are light, and in many cases they can be long-lived due to mass degeneracy

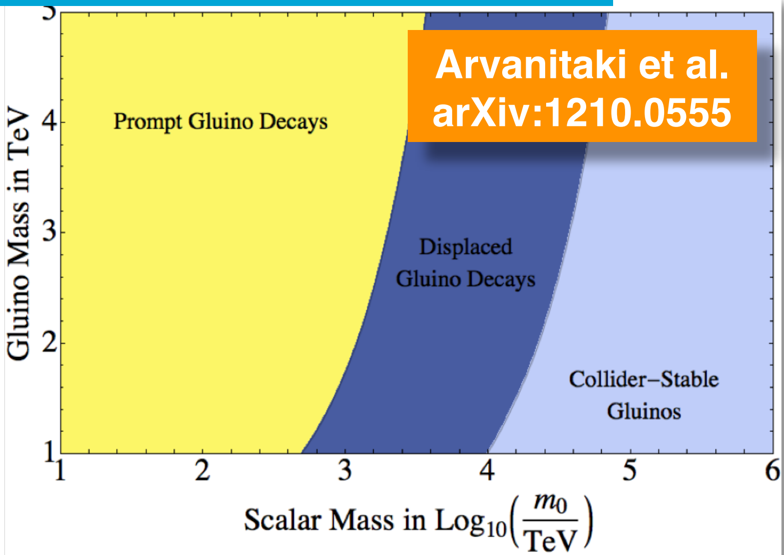
Nima Arkani-Hamed, SavasFest 2012

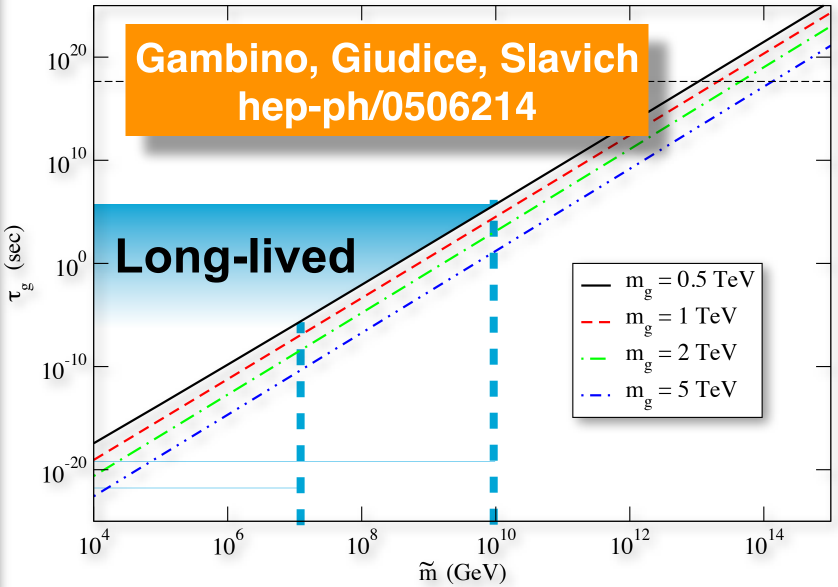
Wells, hep-ph/0306127
Arkani-Hamed, Dimopoulos, hep-th/0405159
Giudice, Romanino, hep-ph/0406088

Long-Lived Particles

- Depending on the SUSY model, the Higgs mass points to SUSY breaking scale between 10^3 and 10^7-10^{10} GeV
- Sizable fraction of this range results in long-lived particle signatures



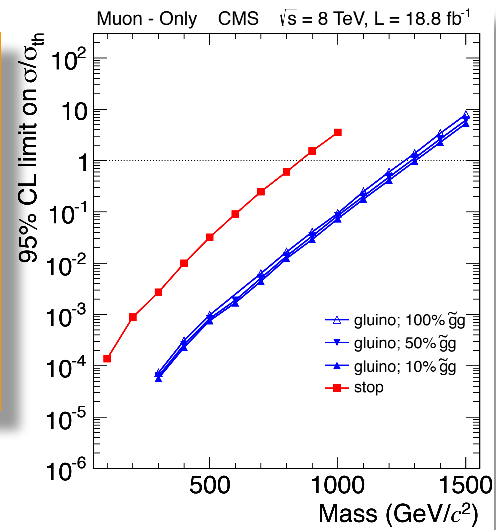


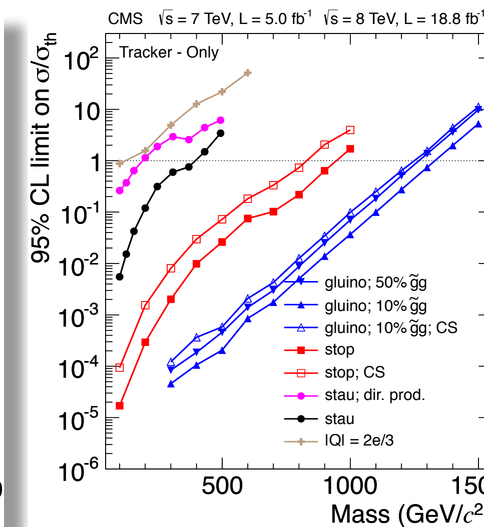


Searches for Long-Lived SUSY

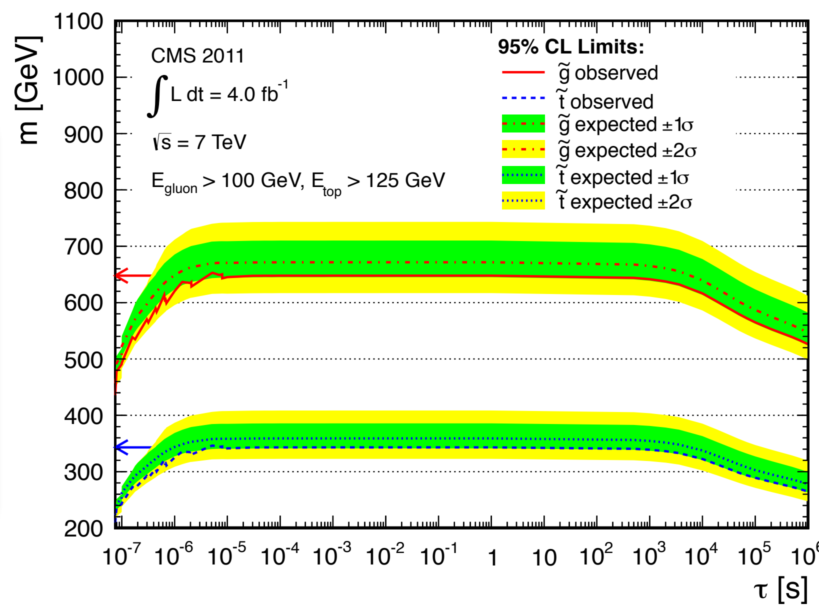
- An extension of the HSCP search to full 8 TeV statistics + 7 TeV reanalysis
  - Strong limits on gluinos (M > 1.3 TeV) and stops (M > 0.8 TeV) from the combination of muon-only and tracker-only analyses
- Dedicated search for long-lived stopped gluinos ruled out large fraction of the allowed parameter space

CMS Collaboration
arXiv:1305.3792





CMS Collaboration
arXiv:1207.0106



Road Ahead

Run 1 Loose Ends

- We are updating all the searches to the full 2012 statistics
- We are adding new ones to the portfolio:
  - Searches for compressed-spectrum SUSY
  - Search for Higgs bosons in SUSY decay chains (copious if LSP is Higgsino-like!)
  - Extension of SMS to non-100% branching fractions (e.g., T1bbtt)
  - Enhanced portfolio of RPV SUSY searches
  - New channels for long-lived particle searches (e.g., displaced jets, leptons, and tops)
- Will leave no stone unturned with the present dataset!

What's Next: Ask the Oracle?

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- Tech support: +49.180.2000.170

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- … but the number was busy all the time… ☹

Ask Eliza?

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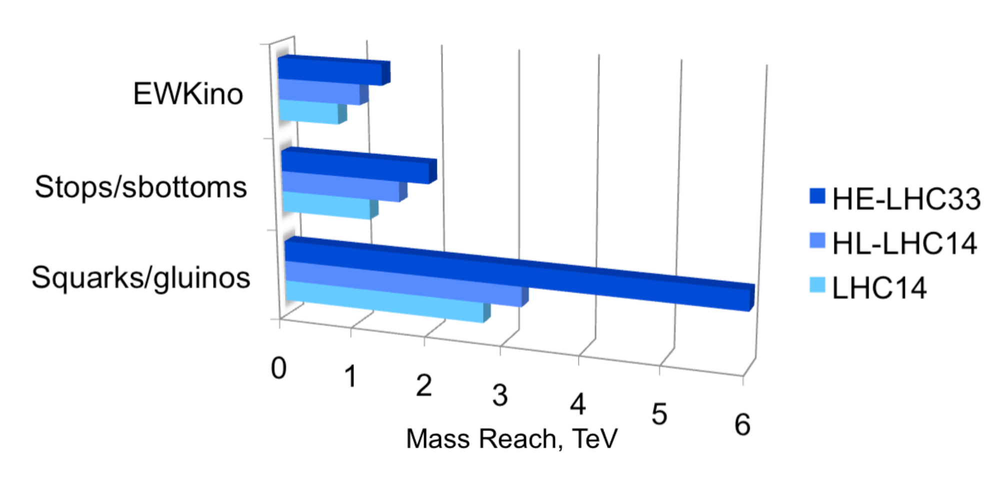
  - `Should I go on with my quest?`
  - `Please, go on!`
- **And so we will!**

Run 2 Preparations

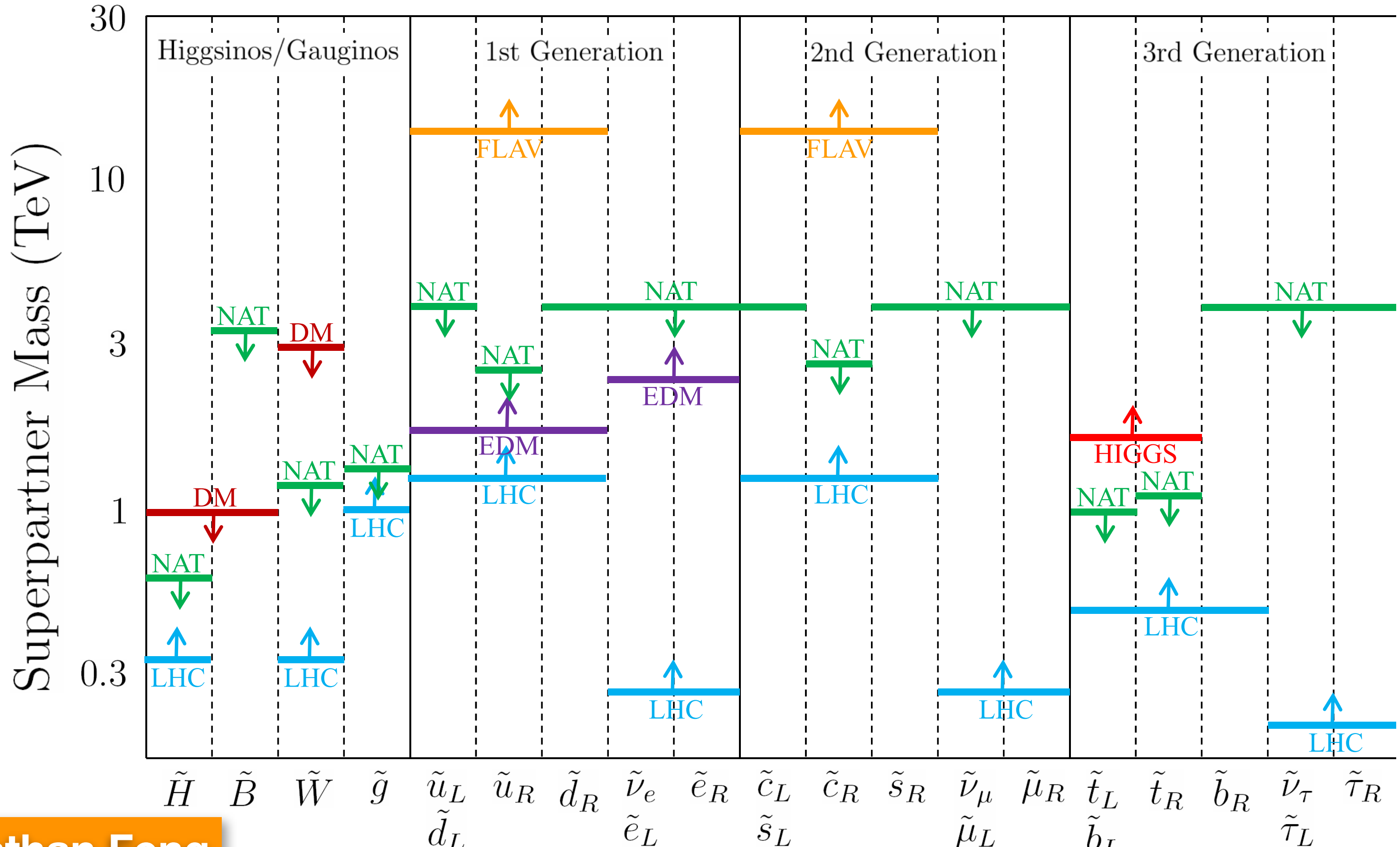
- Run 2 is going to be challenging:
  - Generally higher trigger thresholds decrease our ability to look for compressed spectrum scenarios
  - High-pileup environment is not optimum for low-ME_T searches
  - Increased energy of the machine (~13 TeV) will make it necessary to repeat the entire program of SUSY searches once again



- Reach for gluino masses up to ~2.5 TeV, stop/sbottoms - up to ~1 TeV, and chargino/neutralinos up to ~0.7 TeV would allow to ultimately test natural SUSY models

SuperSymmetry or SuperCemetery?

- SUSY is being squeezed from both ends, but still a lot of unexplored territory to cover
- Run 2 of the LHC will be crucial to find SUSY at low scale or prove that it is irrelevant for EWSB and other low-energy phenomena



Jonathan Feng

Conclusions

- SUSY remains one of the most challenging enigmas in particle physics
- The LHC has closed vast territory of SUSY parameter space and shattered many hopes
  - Yet, it didn't rule out SUSY, not even natural SUSY yet
- CMS has developed a number of innovating experimental techniques to look for SUSY in various scenarios and is now applying it to the shifting paradigm of SUSY searches in the wake of the Higgs boson discovery
- Final results from Run 1 of the LHC started pouring out
  - There is still hope we will see SUSY with the present data, but it won't be an "easy SUSY"!
- Run 2, scheduled to start in 2015 will ultimately answer if SUSY is responsible for EWSB and if it is, whether it is natural or not
- Stay tuned!

Thank You!