Search for stop decays to charm + LSP at CMS

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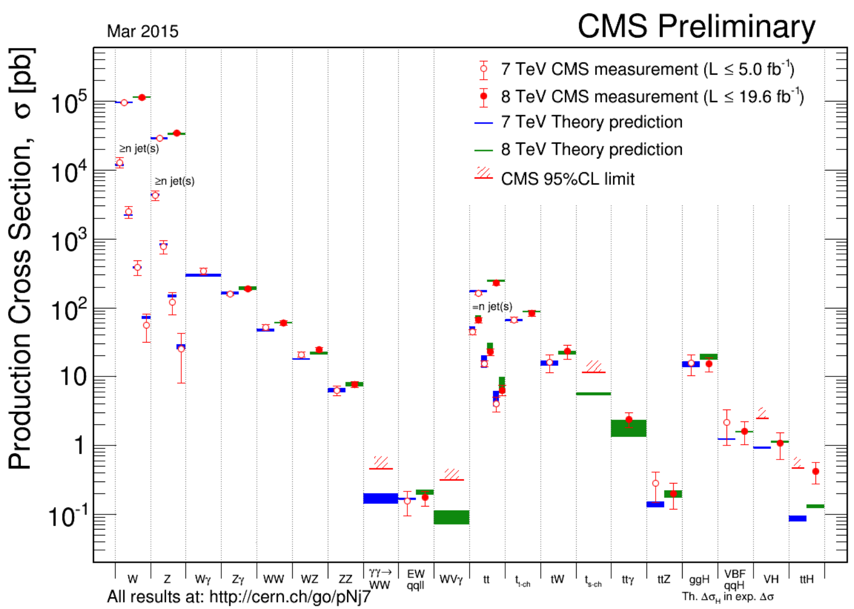
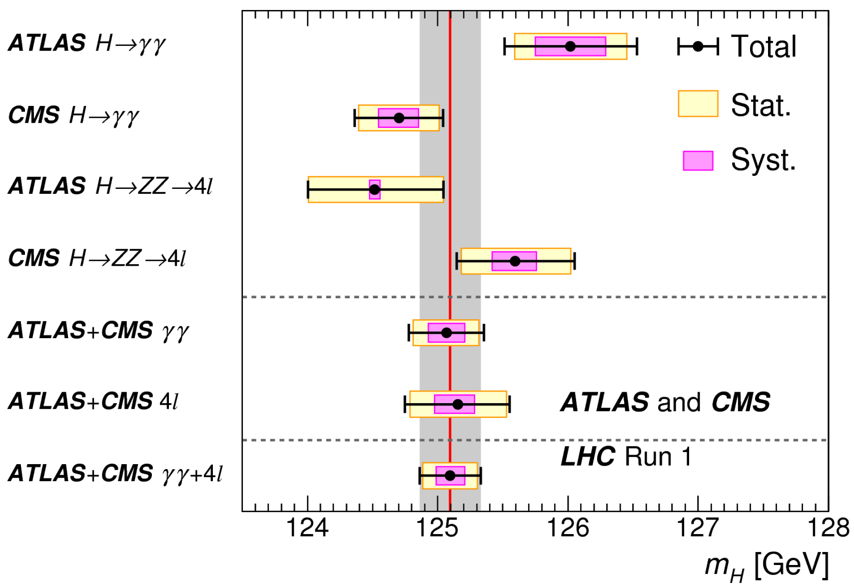
Success of the Standard Model

- Standard Model (SM) has been a great success and makes precision predictions at the LHC



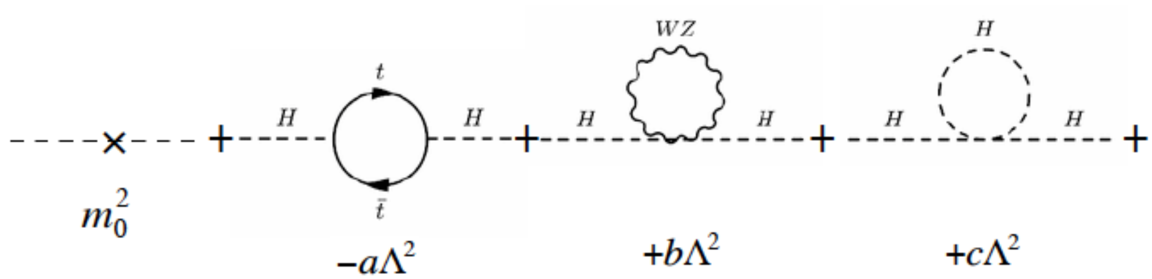
- On July 4th 2012, a new boson was discovered by the CMS and ATLAS experiments at the LHC
- Very good consistency with the SM hypothesis of the Higgs boson



arXiv:1403.07589

Limitation of the SM

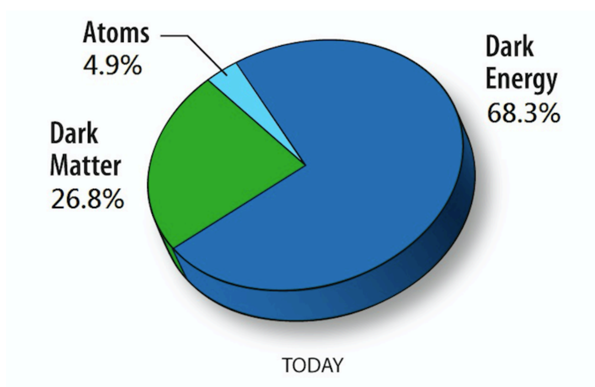
- The light Higgs boson mass poses a hierarchy problem



If the Λ is at Planck Scale: $m_H^2 = m_0^2 + (-a + b + c + \cdots)10^{38} \approx 125^2$

Enormous fine tuning

- The SM does not have a cold dark matter candidate



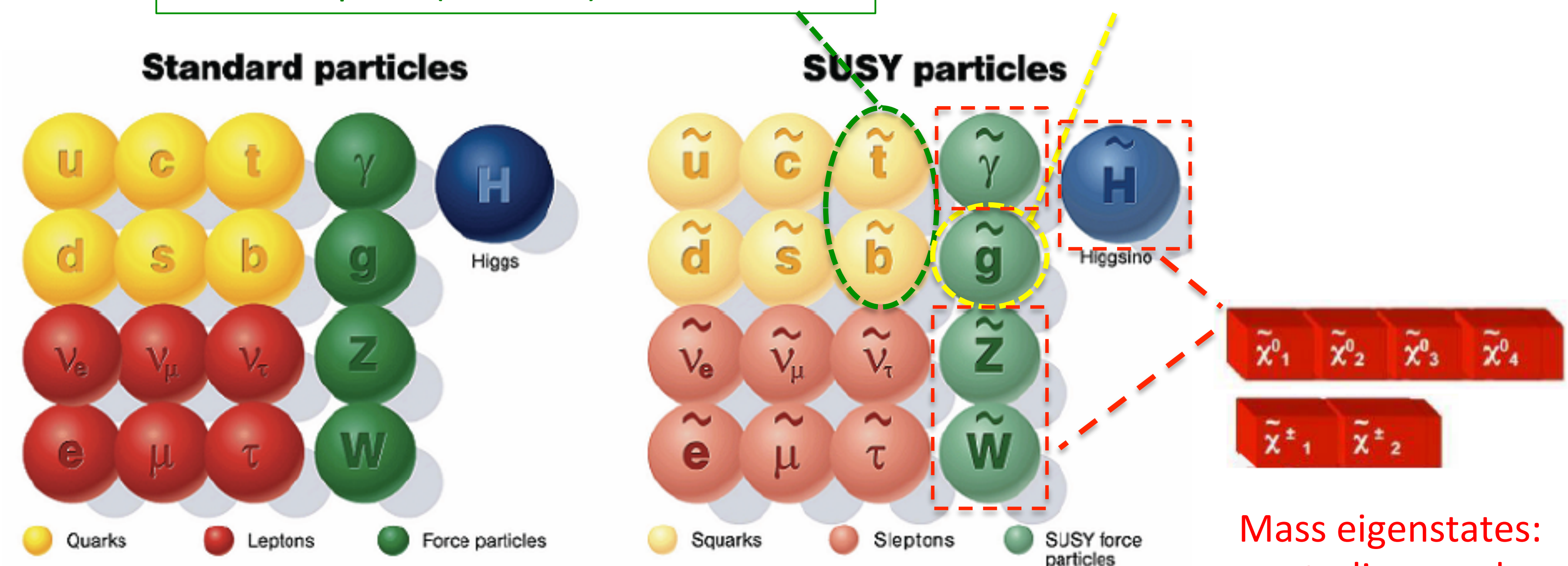
Approximately a quarter of our universe is composed of non-baryonic, cold dark matter

Beyond the SM: Supersymmetry (SUSY)

- SUSY is a fundamental global symmetry between fermions and bosons
  - Spin ½ particle (fermion) <-> an integer spin (boson)

3rd generation squarks: top squark(stop) bottom squark (sbottom)

Superpartner of gluon: gluino



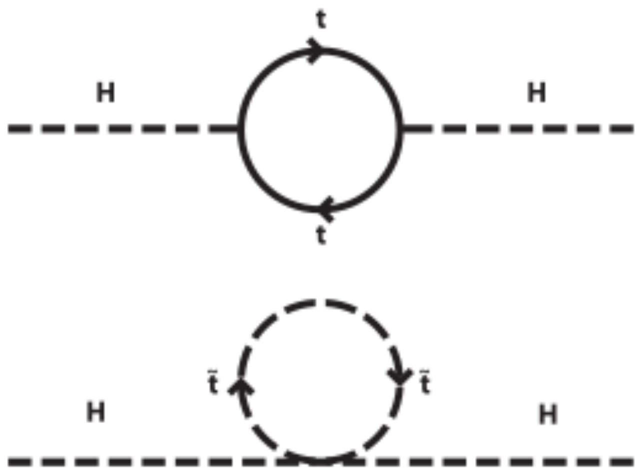
Mass eigenstates: neutralinos and charginos

Why SUSY?

- In models with R-parity conservation, the lightest supersymmetric particle (LSP) is a WIMP and a dark matter candidate

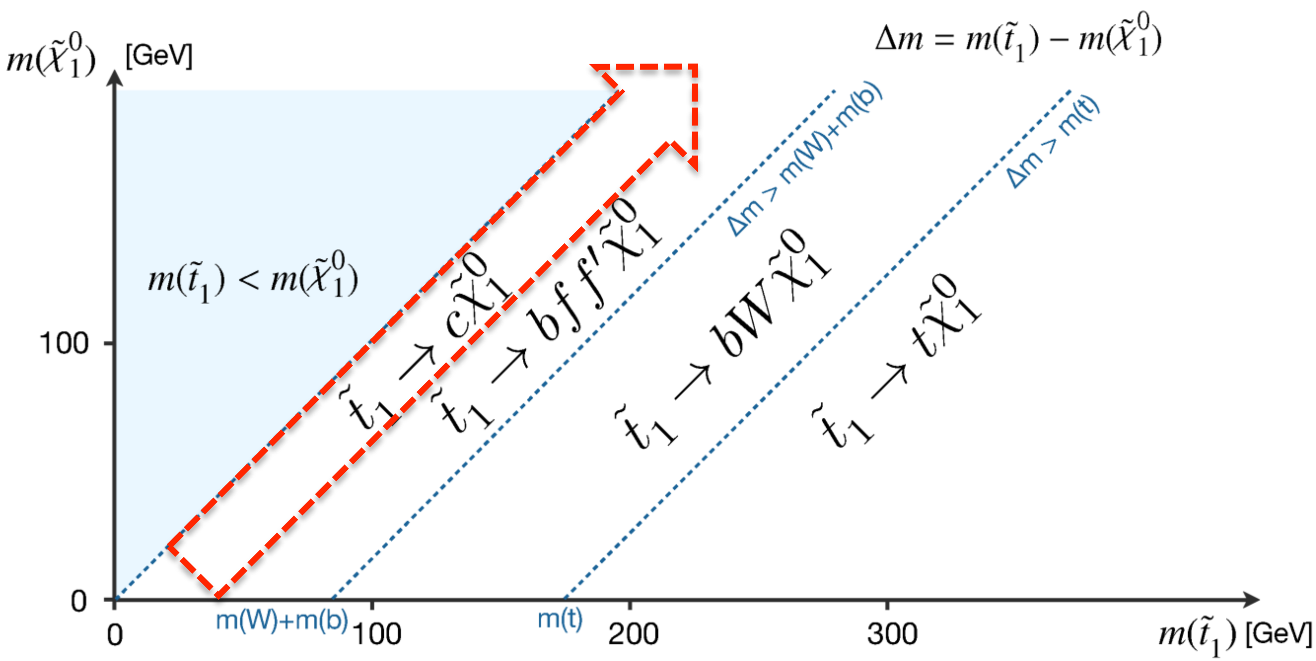
- SUSY provides a solution to the hierarchy problem
- Cancellation of the Higgs boson quadratic mass renormalization between top and stop

It would be important to search for stop, which decays to LSP in associate with SM particles



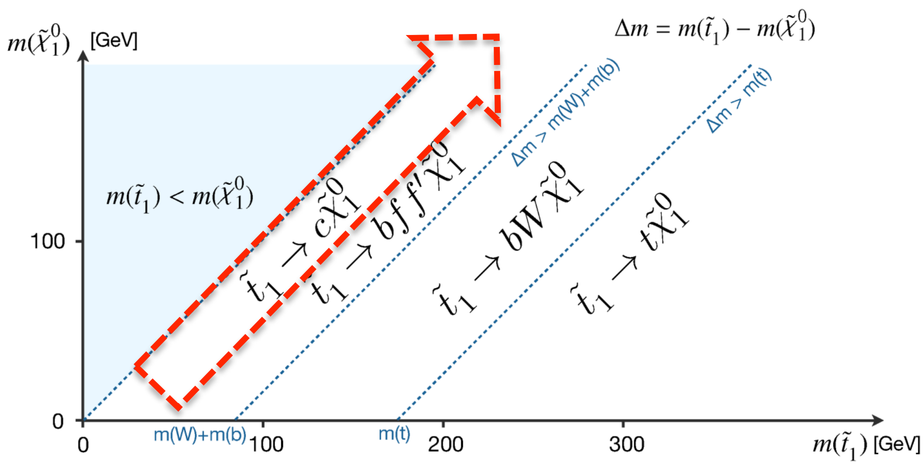
Search for Stop

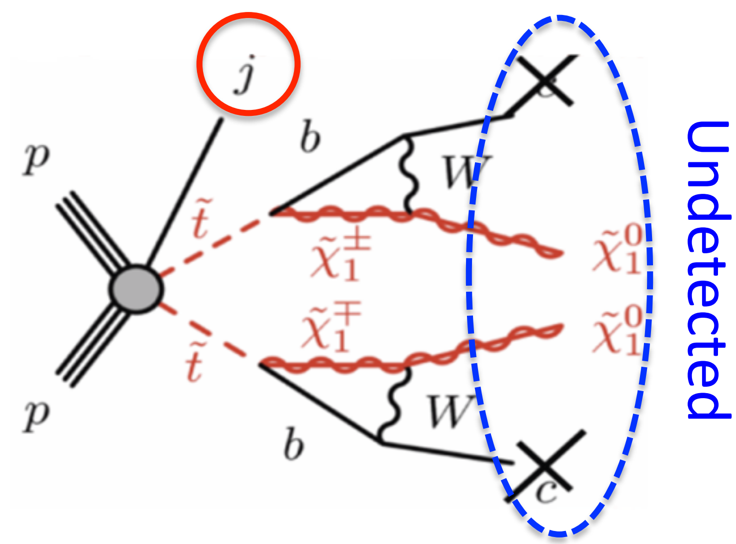
- SUSY provides very broad and vastly different signatures
- Stop has several decay modes, depending on the mass difference Δm = m(stop) – m(LSP)
- When Δm < m(W) + m (b), stop can decay to bjj+LSP (off-shell W) or c + LSP
  - Assuming 100% branch fraction to the FCNC loop induced decay $\tilde{t}_1 \to c\tilde{\chi}_1^0$



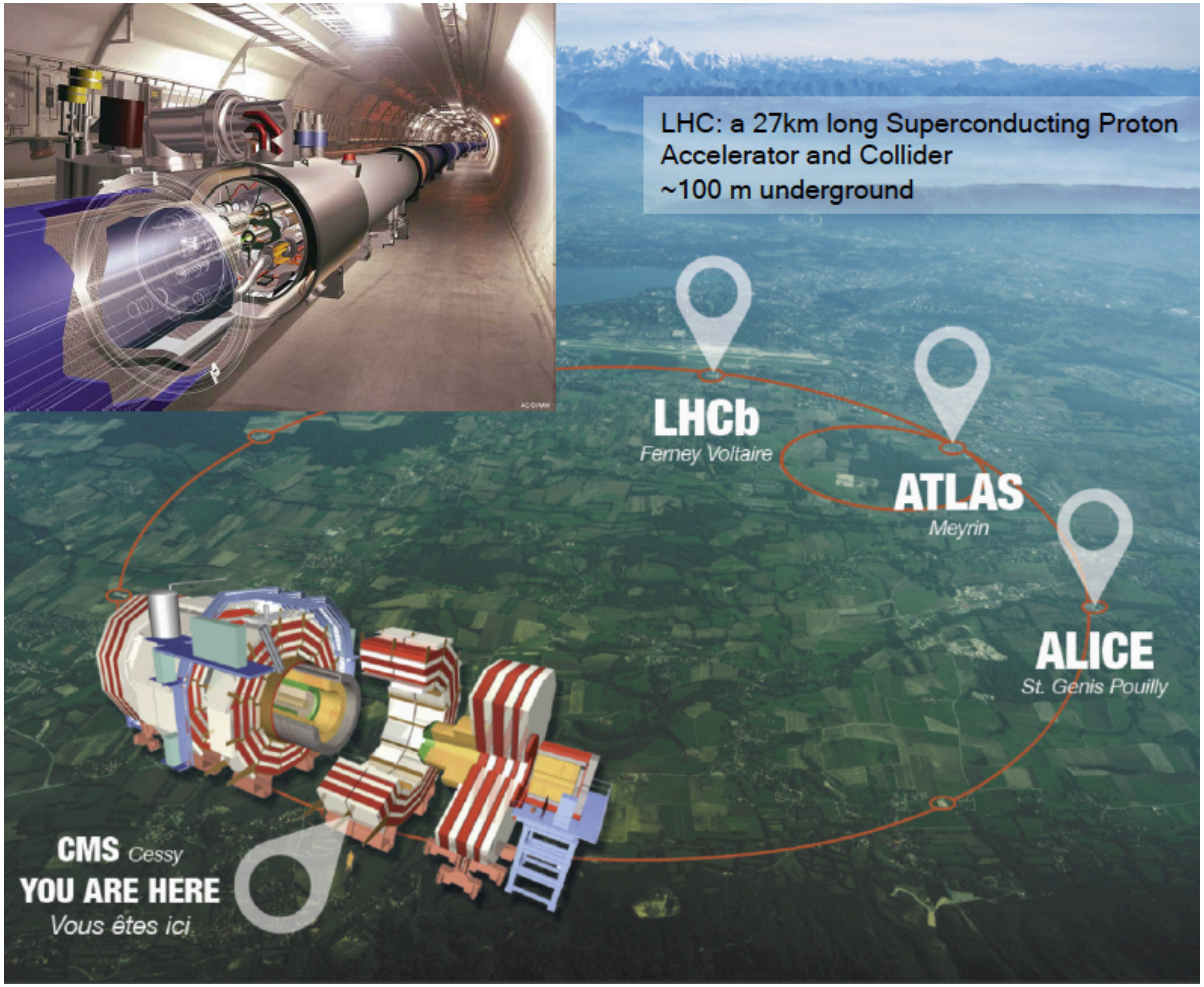
Search for Stop to Charm + LSP

- When stop and LSP are mass degenerate, it is generally difficult to search for due to soft decay products
  - Too soft to be detected by the detector
  - Traditional searches are not sensitive to this compressed region
- If a large initial state radiated (ISR) jet exists, the top squarks are boosted to recoil ISR jet
  - Only high P_T jet and large missing transverse energy (MET) in the detector



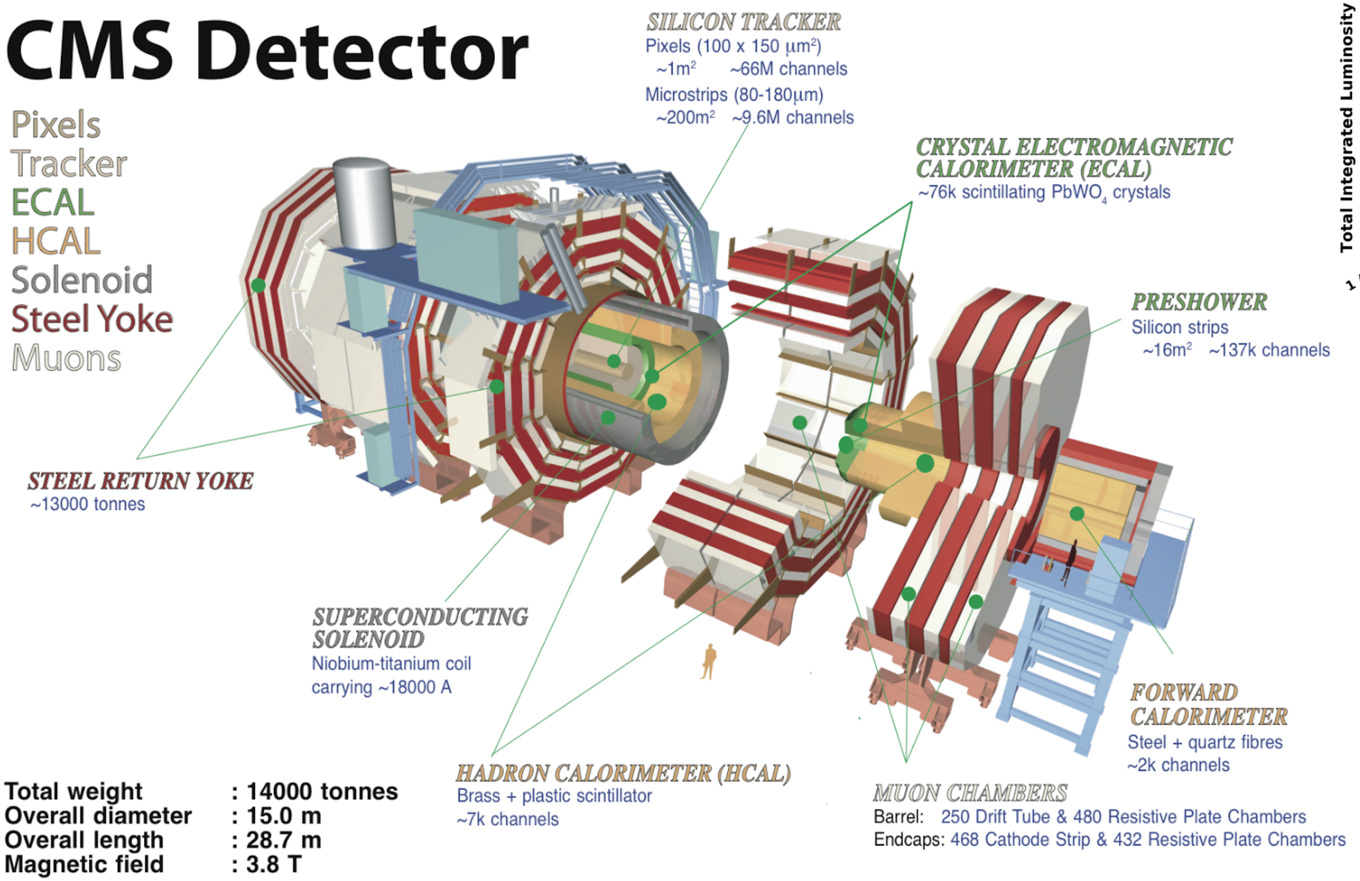


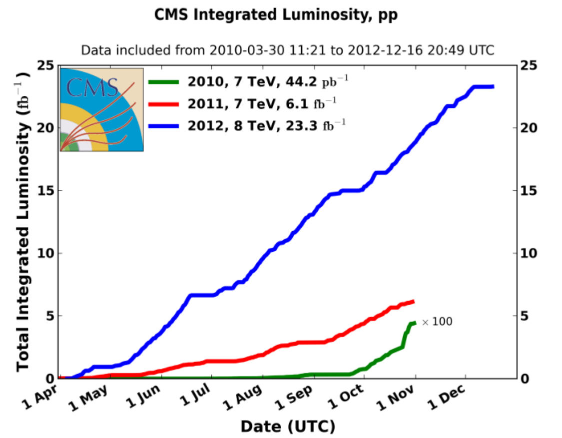
The Large Hadron Collider



The CMS Detector

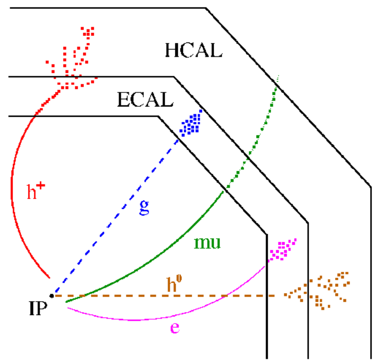
The CMS detector was a huge success during Run 1



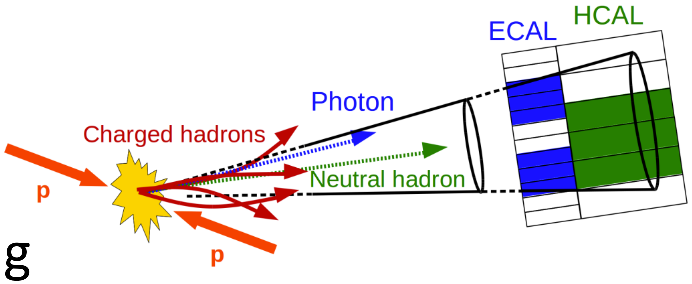


Event Reconstruction at CMS

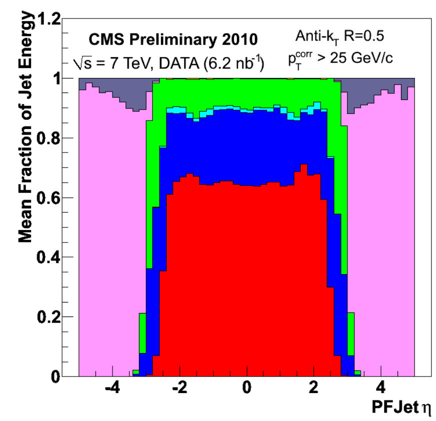
- Particle Flow is an event reconstruction technique that aims to reconstruct and identify all stable particles produced in a proton-proton collision, through the optimal combination of all CMS sub-detectors information



- Jets are reconstructed using particles identified by the Particle Flow algorithm
- Jets are clustered with anti-k_T algorithm using a cone size of 0.5
  - Require jet pass loose jet ID

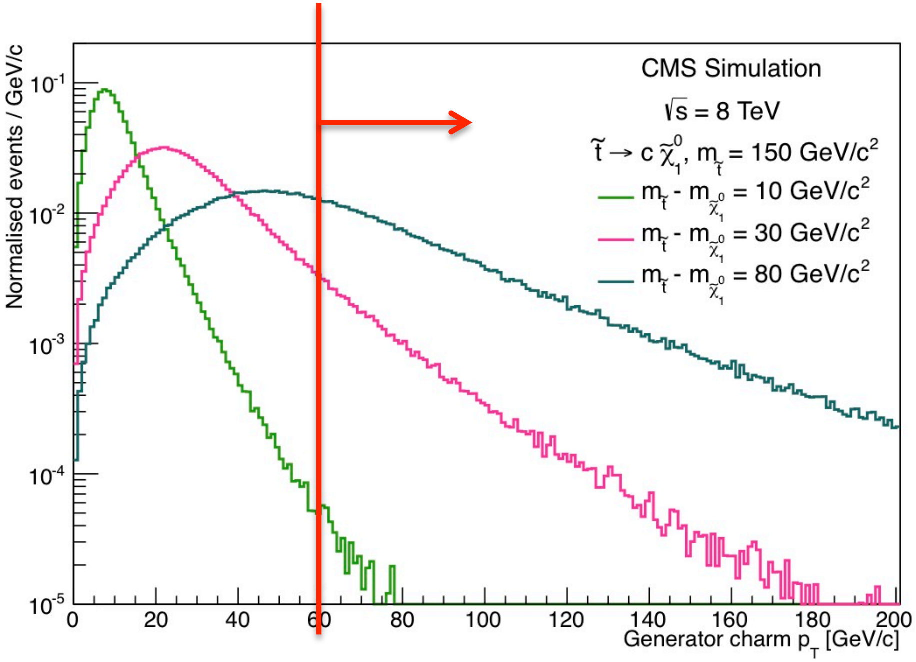


- MET is the magnitude of the vector sum of all particles in the event, excluding muons
  - Optimized definition for background estimation



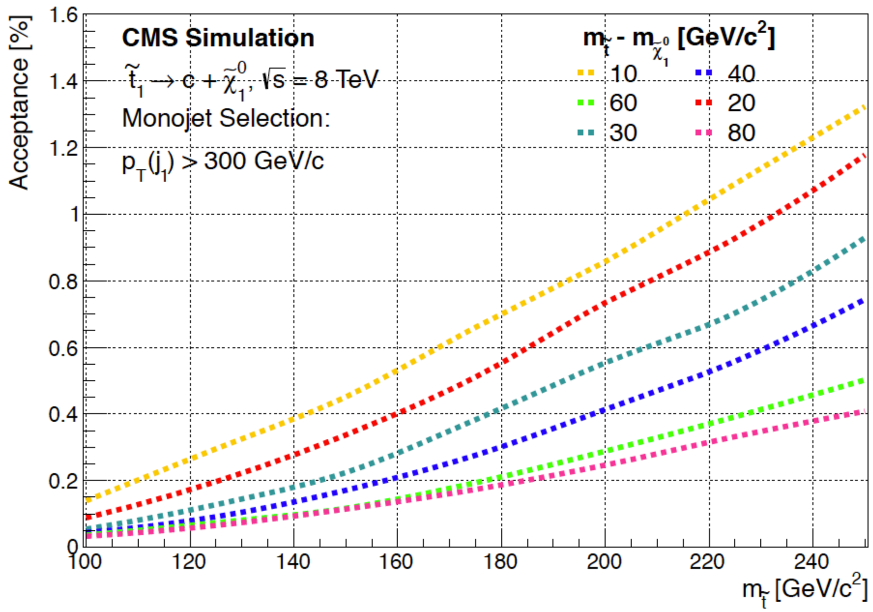
Search Strategy

- Targeting events with high P_T jets and large missing E_T
- Allowing second jet in the event
  - To allow an additional ISR or FSR (final state radiation) jet
  - Increased signal acceptance
- Soft jet produced by charm from the stop decay might also appeared in second leading jet
  - Optimized jet P_T cut for jet counting to mimic classic monojet requirement



Event Selection

- Filter out noisy events based on jet constituents
- Counts at most 2 jets with p_T > 60GeV/c, $|\eta|$< 4.5
- MET > 250GeV
- Leading jet with p_T > 110GeV/c, $|\eta|$< 2.4
- $\Delta\phi(j_1, j_2)$ < 2.5
- Veto leptons



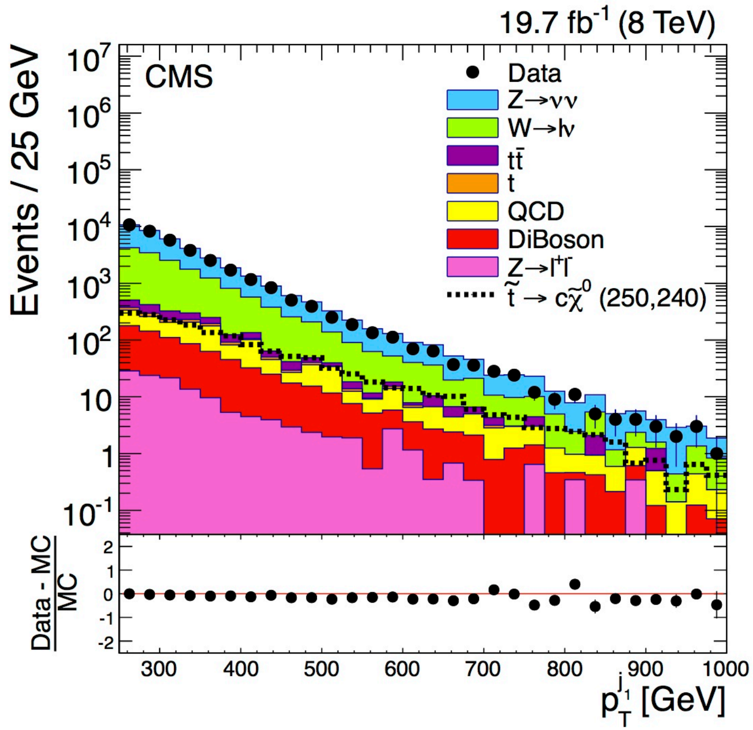
- Signal acceptance for different m_{stop} and Δm
- The smaller Δm, the larger acceptance
  - surviving the jet count cut
- Larger m_{stop}, larger acceptance
  - more boosted system with larger $p_T(j_1)$, MET

Background Estimations

- Z(υυ) + jets: Largest contribution ~60%
  - Estimate with data driven method using control sample of Z(μμ) events
- W(lυ) + jets: Second largest contribution ~35%
  - Estimate with data driven method using control sample of W(μυ) events
- QCD: ~2%
  - Estimate using MC with scale factor taken from QCD enrich sample
- ttbar: ~2%
  - Using MC with NNLO cross section
- Diboson: ~2%
  - WW, WZ, ZZ: Using MC with NLO cross section
  - WG, ZG: included in Z(υυ) and W(lυ)+jets estimation
- Z(ll) + jets and single top: < 1%
  - Using MC with NNLO cross section

Results

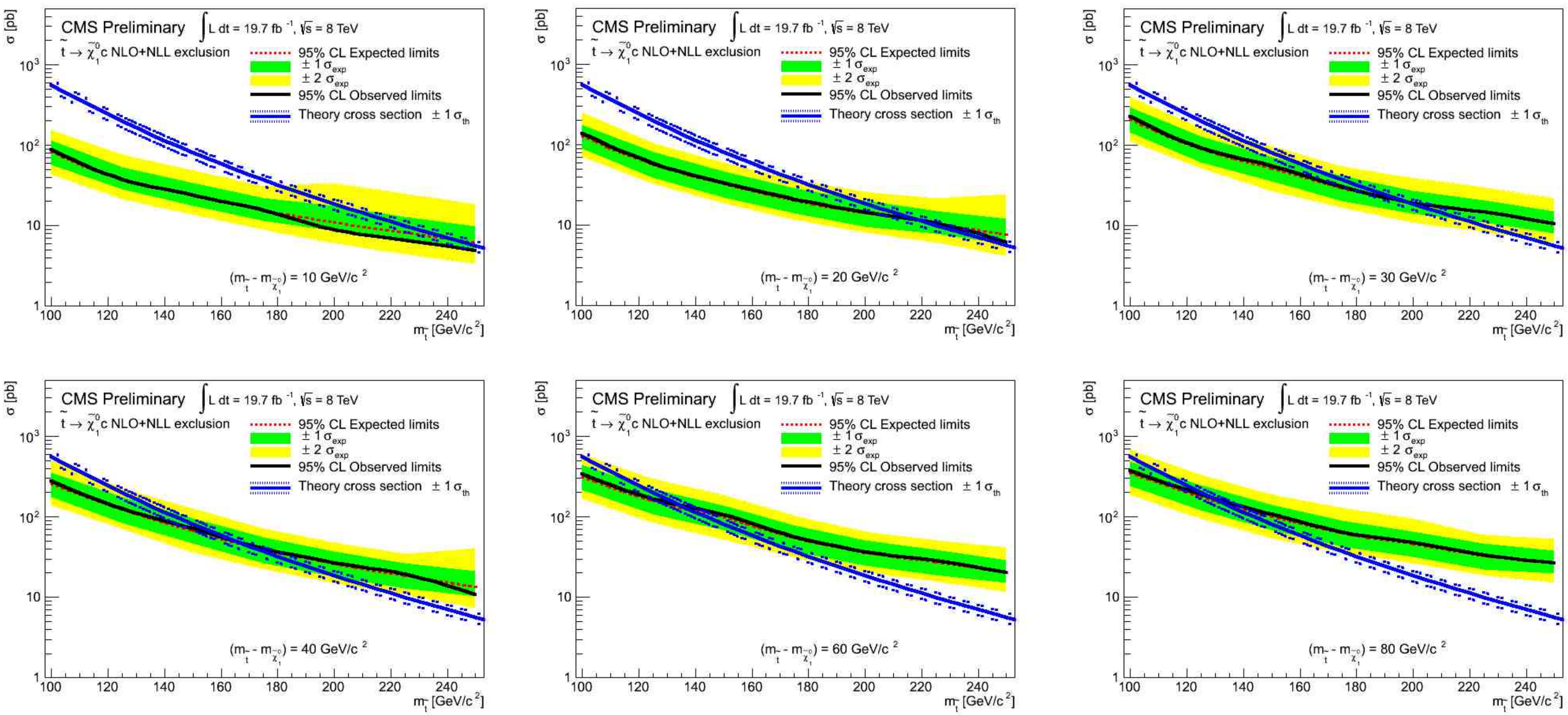
- Good agreement between observed data and predictions
- Bin results in inclusive $p_T(j_1)$ bins rather than MET
  - Charm jets reduce MET in boosted events



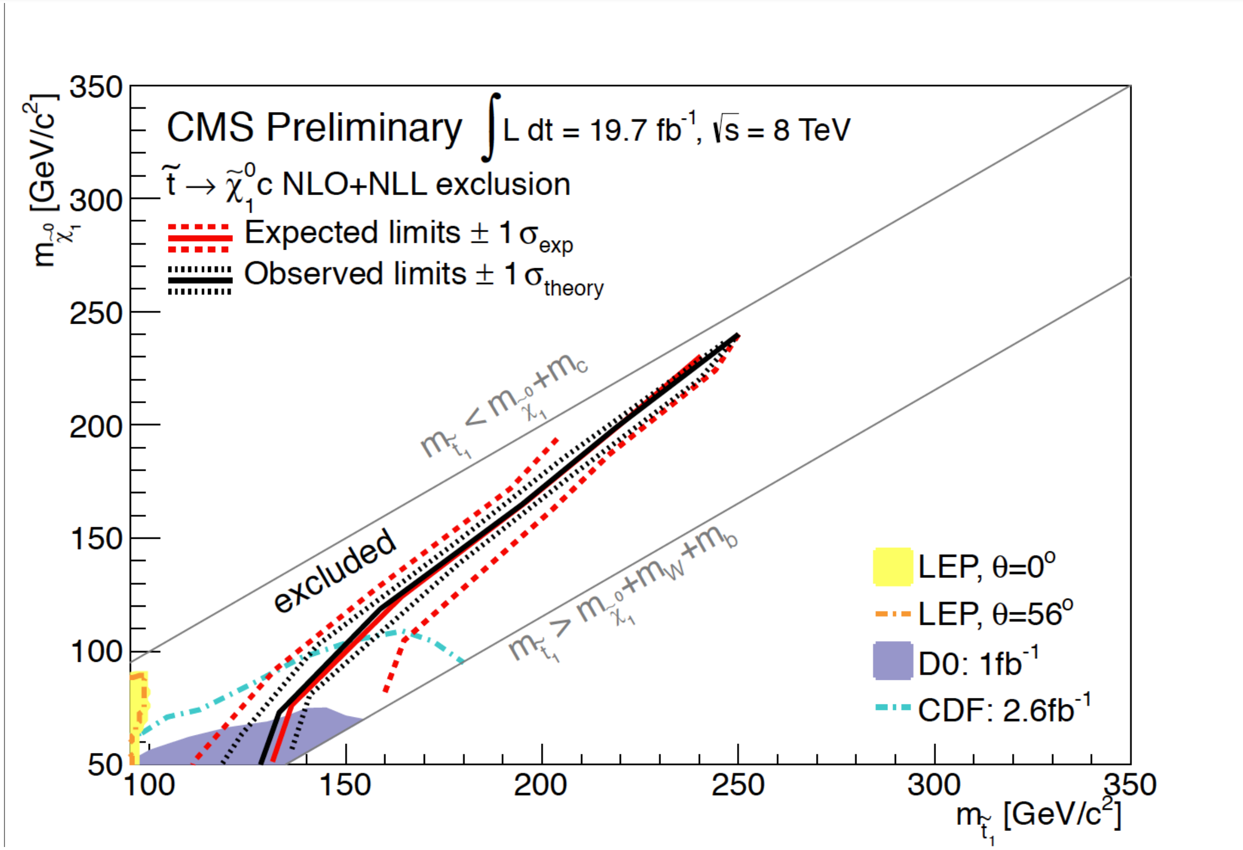
Monojet search	SM Pred.	Obs.
$p_T^{j1} > 250$ GeV	35900±1500	36600
$p_T^{j1} > 300$ GeV	17400±800	17600
$p_T^{j1} > 350$ GeV	8060±440	8120
$p_T^{j1} > 400$ GeV	3910±250	3900
$p_T^{j1} > 450$ GeV	2100±160	1900
$p_T^{j1} > 500$ GeV	1100±110	1000
$p_T^{j1} > 550$ GeV	563±71	565

Optimize Limit

- Taking optimal $p_T(j_1)$ bin for each individual mass point
- Set 95% CL limits using CL_s method



Limit: m_{stop} VS m_{LSP}



arXiv:1503.08037

- Limit on (m_{stop}, m_{LSP}) mass plane
- Reach m_{stop} up to 250GeV, and up to diagonal line, to mass differences -> 0GeV
  - Powerful search tool for compressed spectra!

Summary

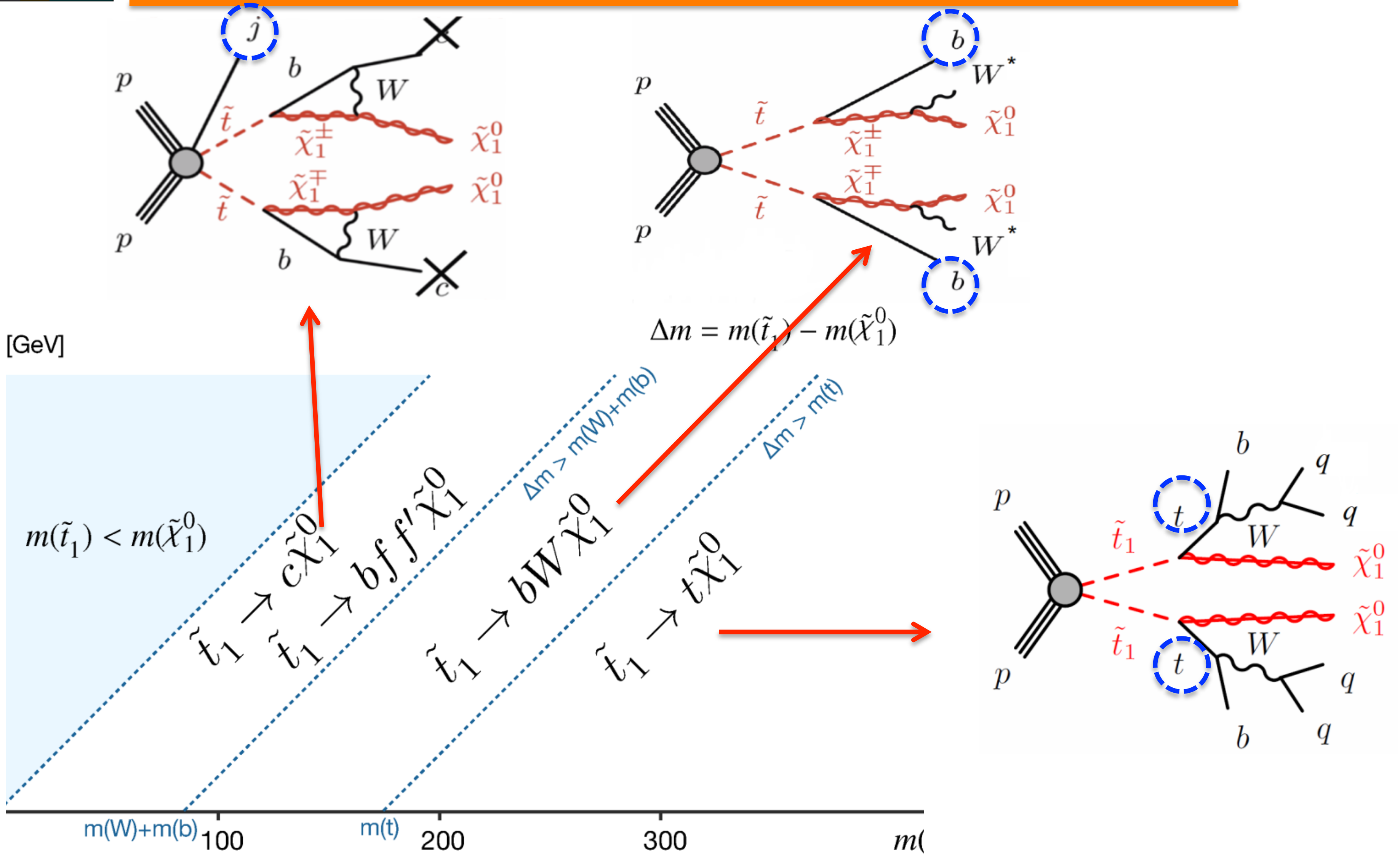
- A search optimized for compressed stop decaying to charm and LSP is presented
- It sets limits for stop mass up to 250GeV for mass differences $m_{stop} - m_{LSP} < 10GeV$
- Monojet-like search is a powerful tool for compressed scenarios

- Extensive SUSY searches have been done in LHC Run 1
- No SUSY signals have been found so far

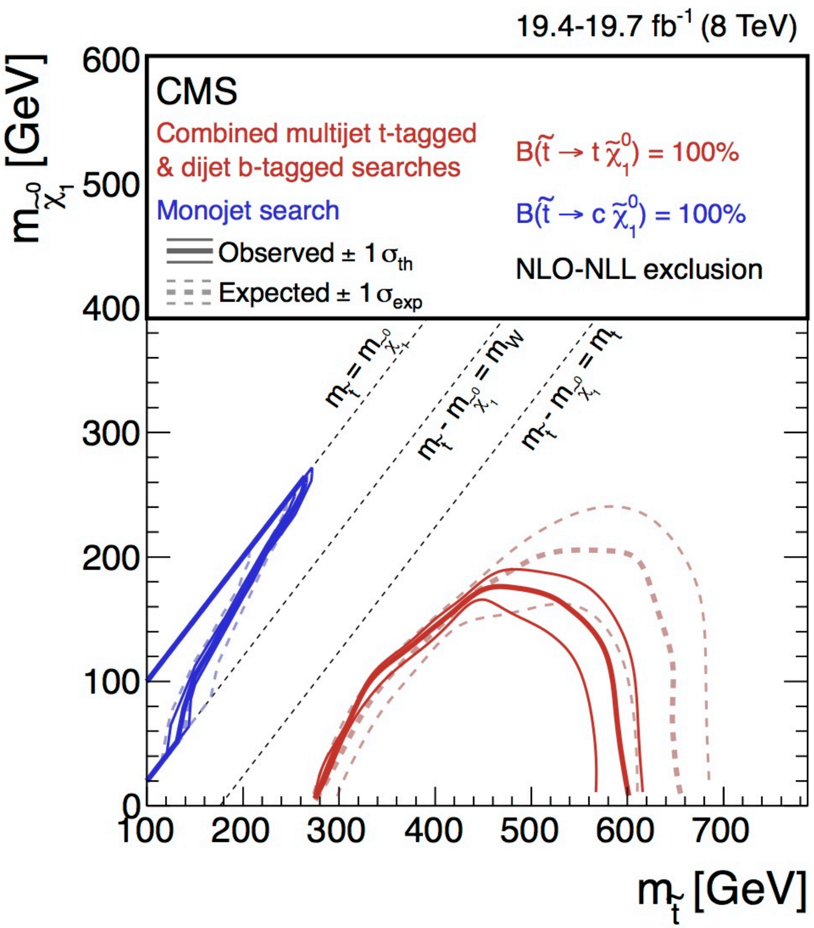
- Ongoing LHC Run 2 preparation and improvements for all aspects
- Stay tuned for more to come at 13TeV!

BACKUP

Production of Stop Pairs



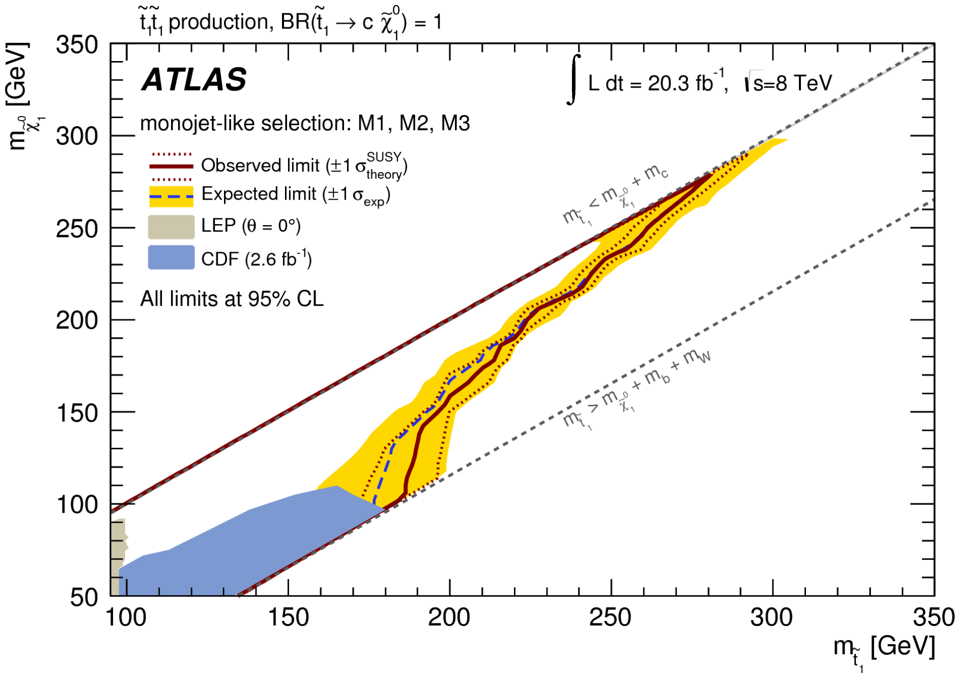
Stop Searches In All Hadroinc Final State



arXiv:1503.08037

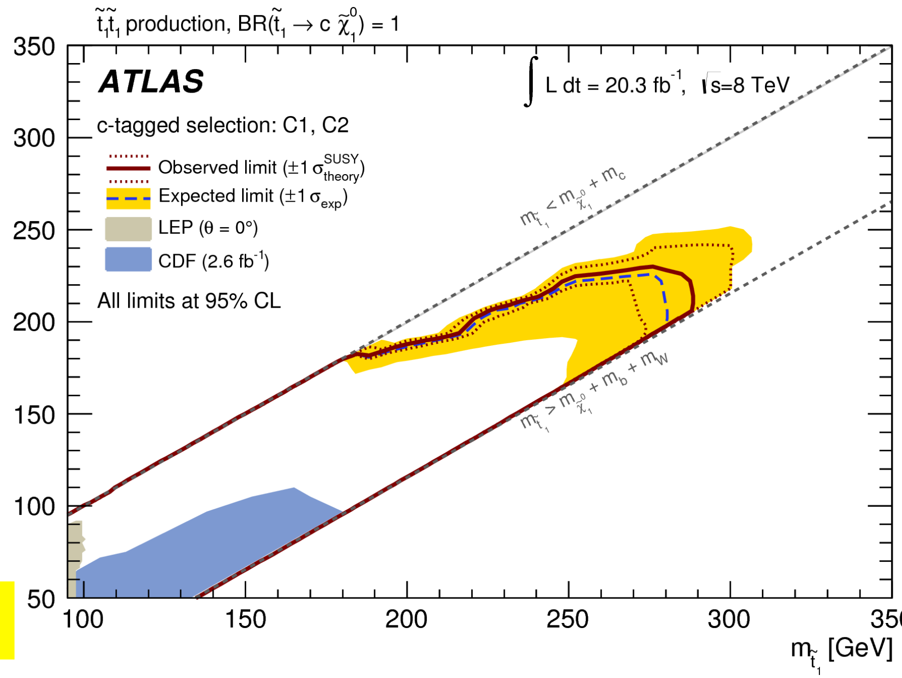
- Traditional searches for stop in all hadronic final states targeting large Δm phase space
  - Multijet t-tagged contributes more to the high stop mass and low LSP mass region
  - Dijet b-tagged contributes more to the diagonal region
- Monojet search covered the compressed region

Search for Stop to Charm + LSP at ATLAS



- Monojet-like selection set limit up to stop mass ~ 270 GeV

- Used charm-tagged selection designed for moderate Δm region



arXiv:1407.0608

Z(υυ) + jets Estimation

- Use Z(μμ) events to estimate number of Z(υυ) events
- Mimic neutrinos by interpreting muons as invisiable

No. events in Z(μμ) data control sample

No. events from non Z+jets processes, take from MC

$$N(Z \rightarrow \nu\nu) = \frac{N_{obs} - N_{bgd}}{A \cdot \epsilon} \times R$$

Correct for acceptance & efficiency of muon selection

$$R = \frac{B(Z \rightarrow \nu\nu)}{B(Z \rightarrow \mu\mu)} = 5.942 \pm 0.019$$

(PDG)