Review of Searches for New Physics at ATLAS and CMS

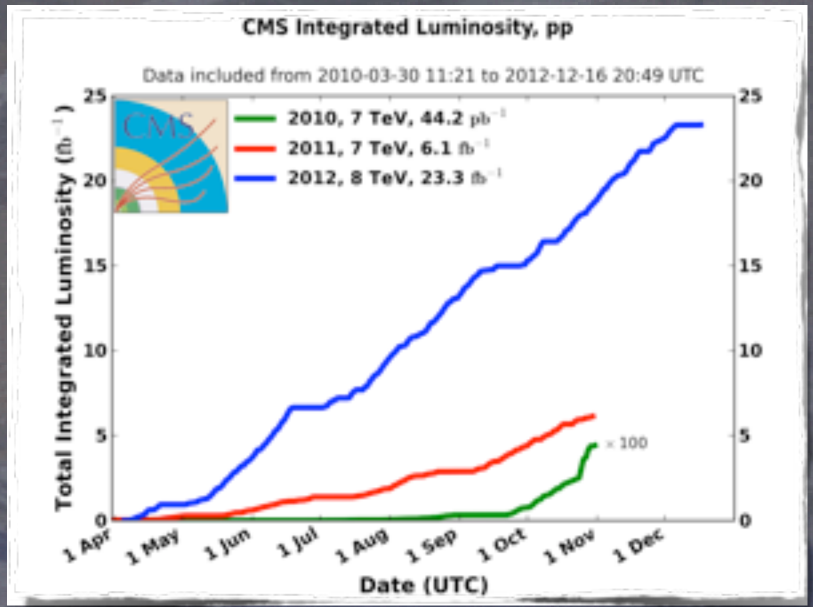
Maurizio Pierini

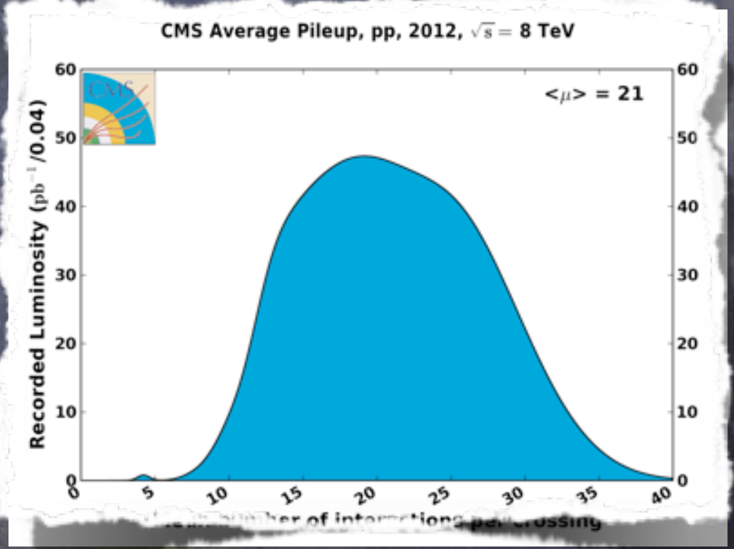
Outline

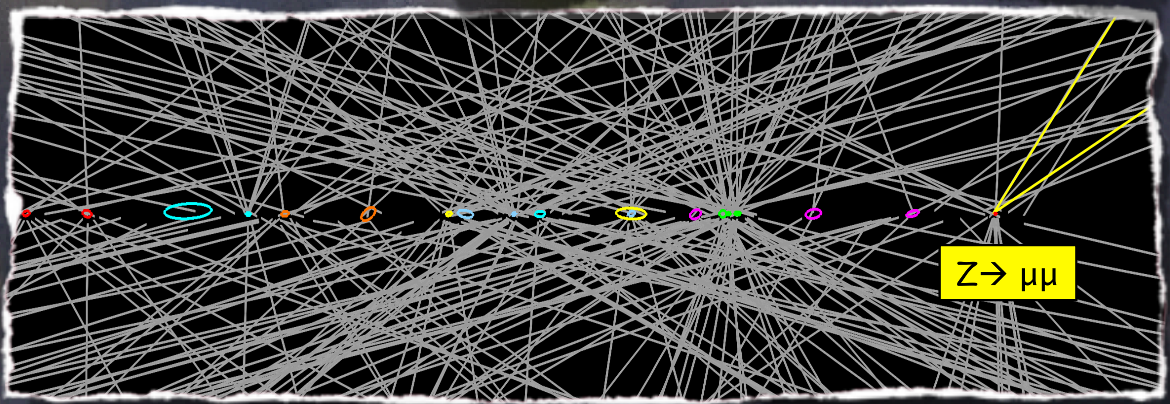
- The global picture
- A few examples
  - Natural SUSY with MET
  - Monojet search
  - Long-living particles
  - New Resonances to boosted V and top
  - Top partners
  - New Resonances to ff
- What Next?

It was a long journey

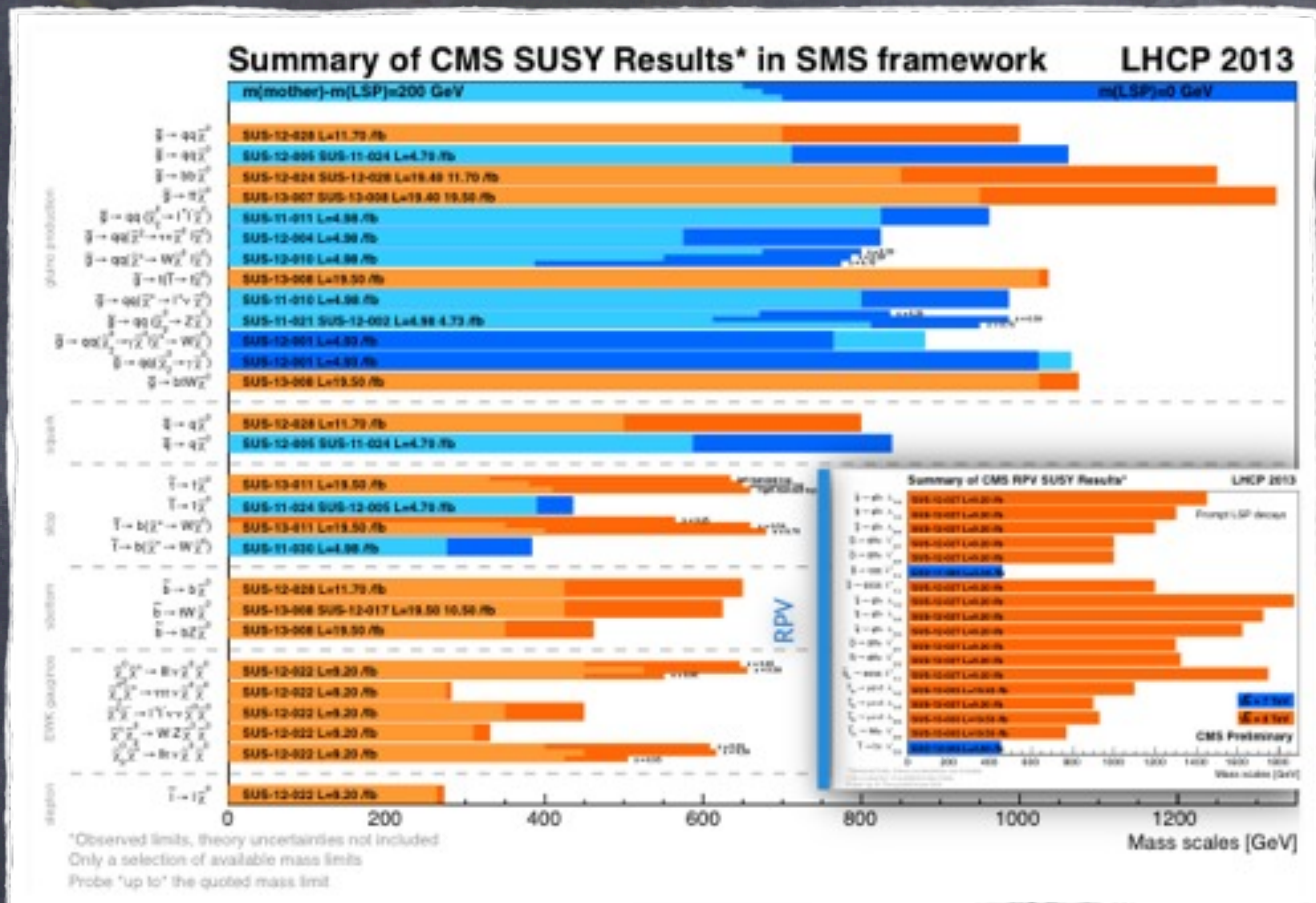
- The LHC and the detectors behaved incredibly well
- The collected statistics increased constantly, new territories explored every six months
- The environment changed dramatically:
  - Higher rates forced us to use tighter triggers
  - The pileup increase made the object identification (leptons, jets, etc) more challenging
  - Higher luminosity and no new-physics signal made us sensitive to the background from rare processes (e.g. ttV, VV+bjets, etc)

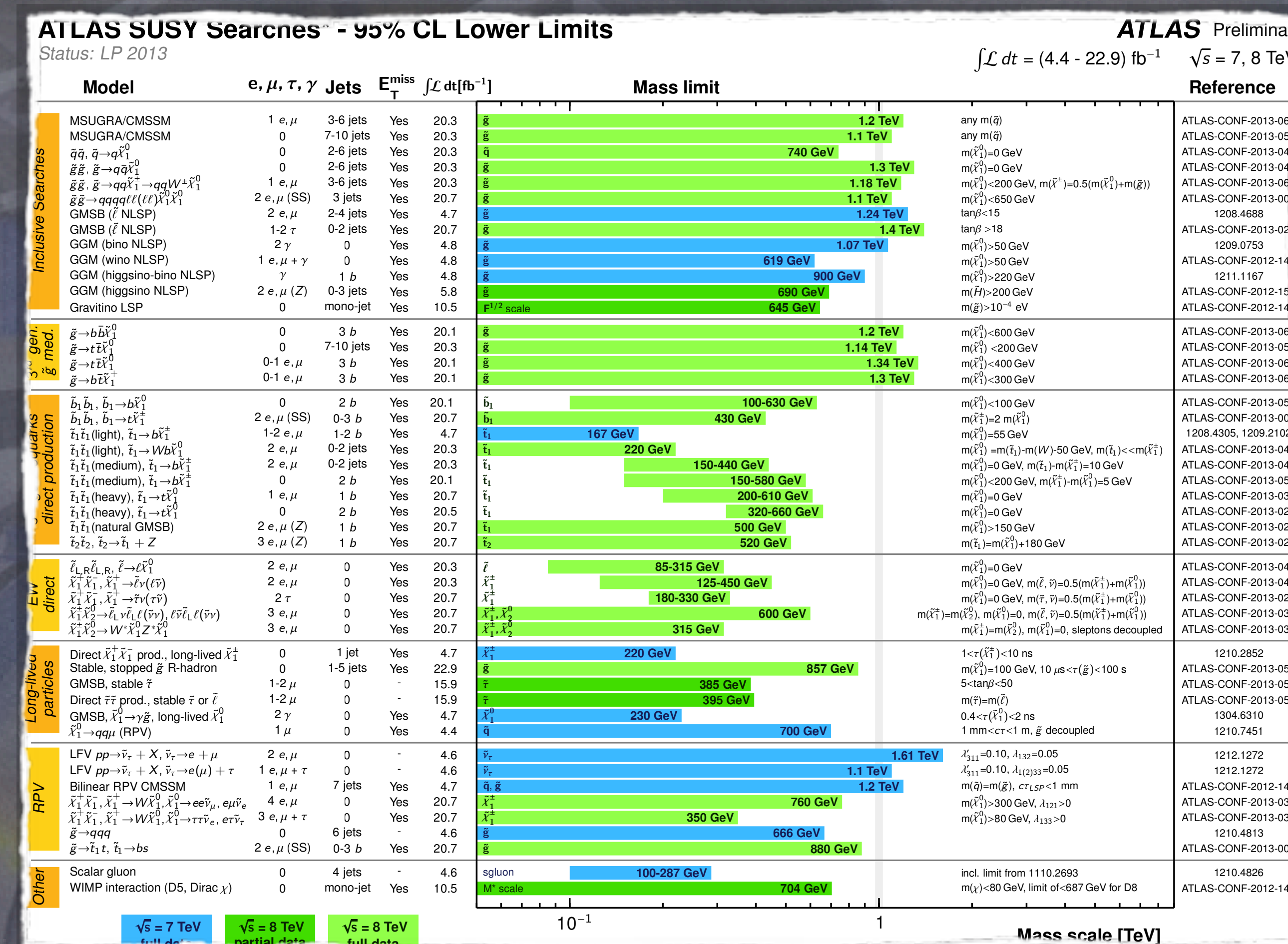






The Global Picture



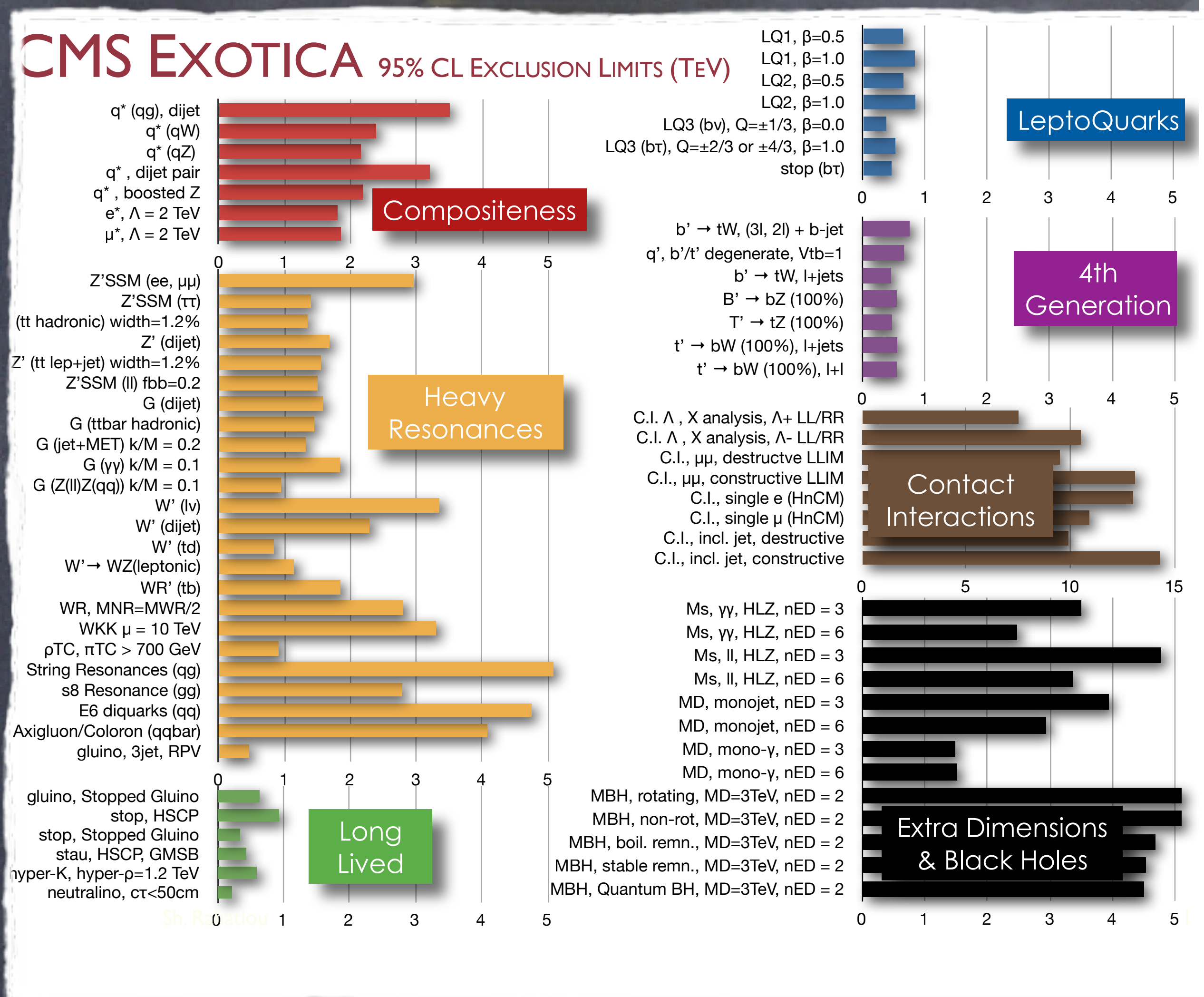


Definitely too much to be covered in one talk

I will try to give you a general idea

You will find more on the ATLAS and CMS twiki pages

The Global Picture



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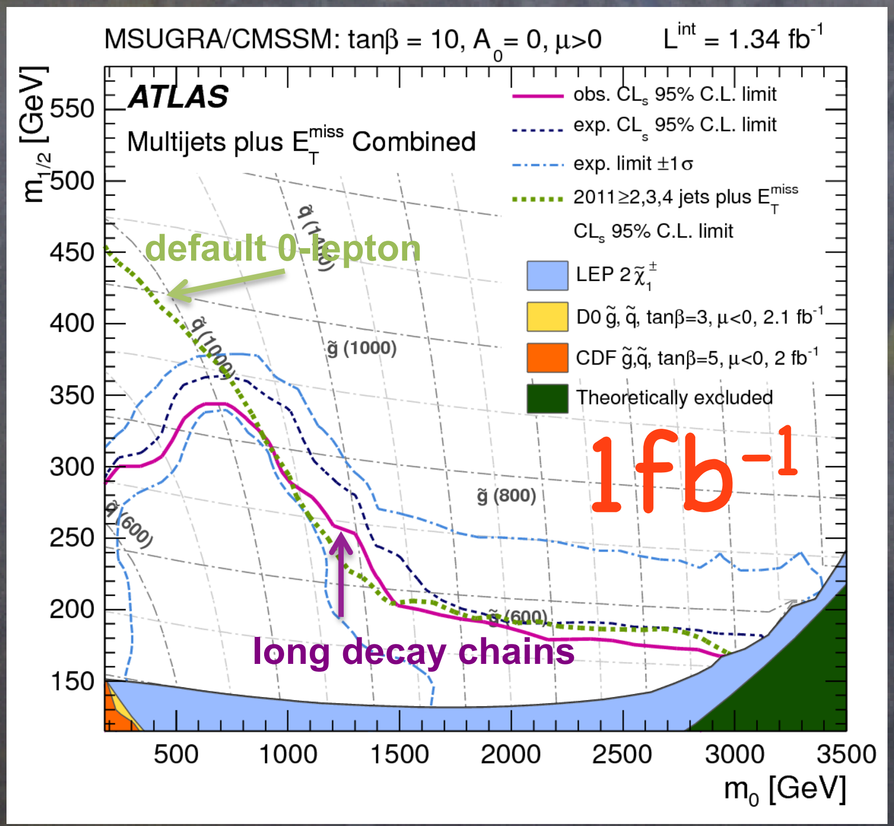
Legacy of the 7 TeV run

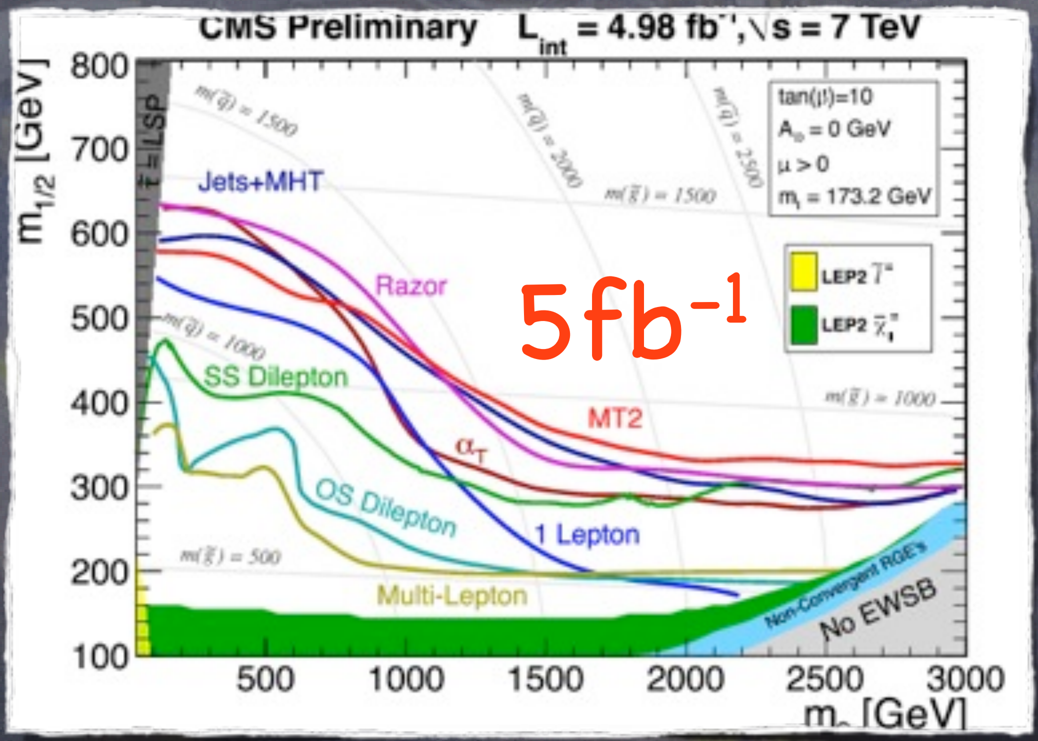
Already with $1fb^{-1}$ the exclusion curve removed a large fraction of the accessible parameter space

Adding statistics moved the limit by ATLAS and CMS more in the unexplored territory

After this, any improvement on the high-mass front became adiabatic

This was not true anymore if one changes the SUSY paradigm





The ballpark of what we could discover was gone quite quickly

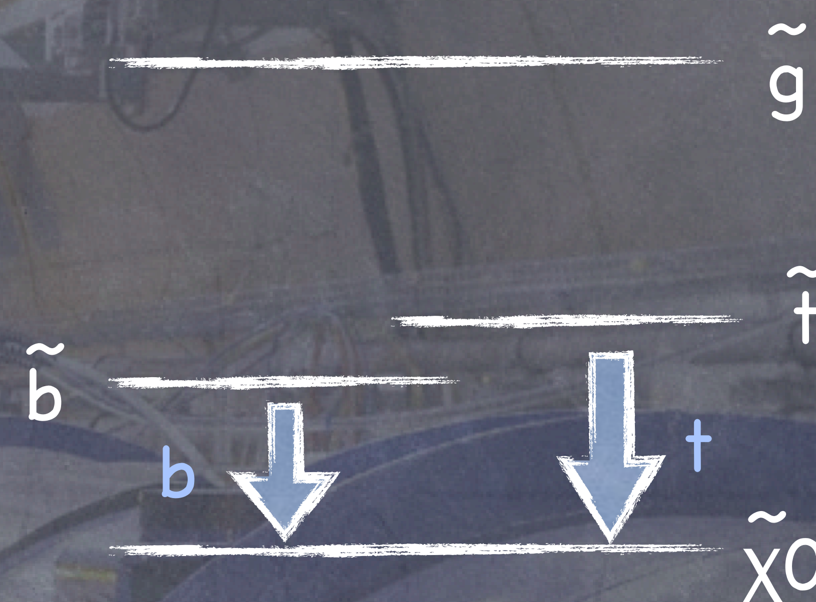
The Higgs was found

We turned our attention to some special kind of SUSY

Natural SUSY with 8 TeV data

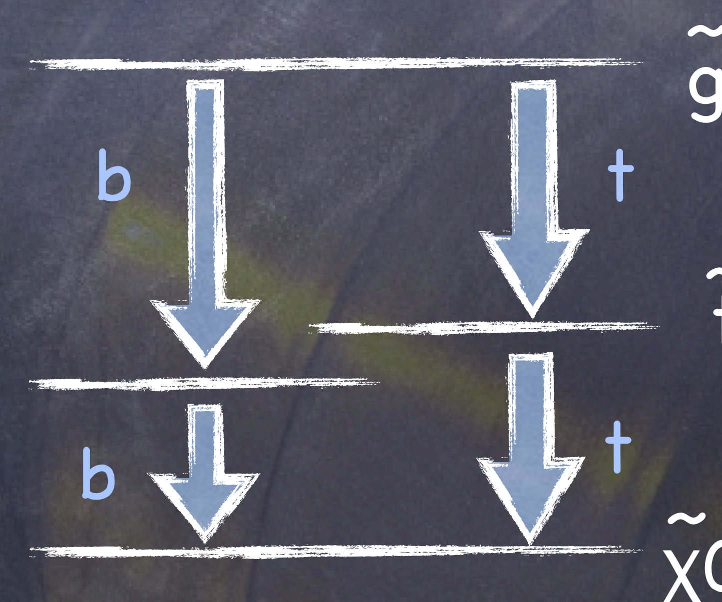
- Direct squark searches

  Smaller cross section
  Final state similar to tt in the bulk of the parameter space
  Reduced bkg discrimination power
  Only handle if gluino heavy



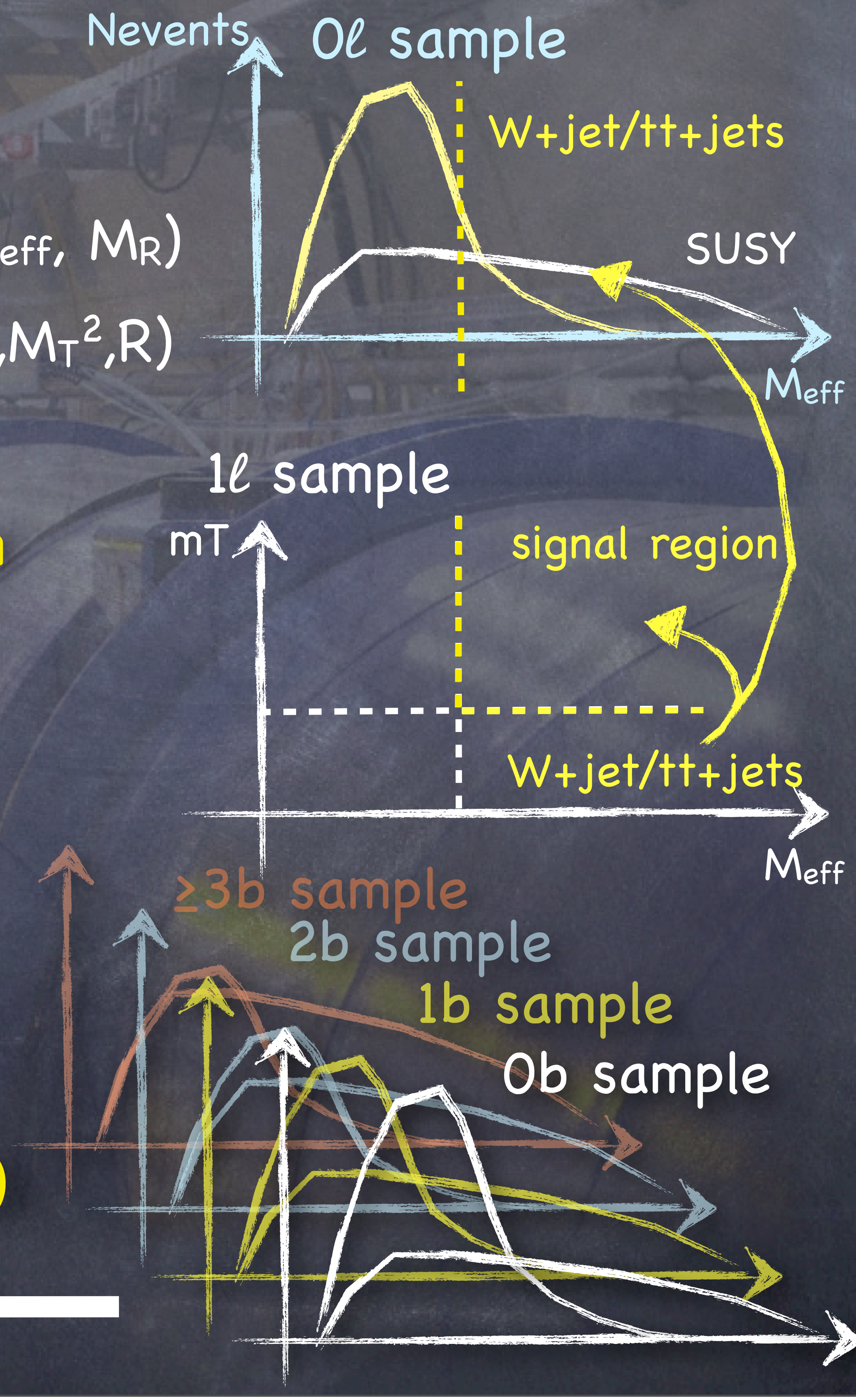
- Gluino-mediated searches

  Larger cross section
  4b quarks in the final state, with or w/o leptons
  More handles for bkg discrimination
  Gluinos might be too heavy for these searches to be effective

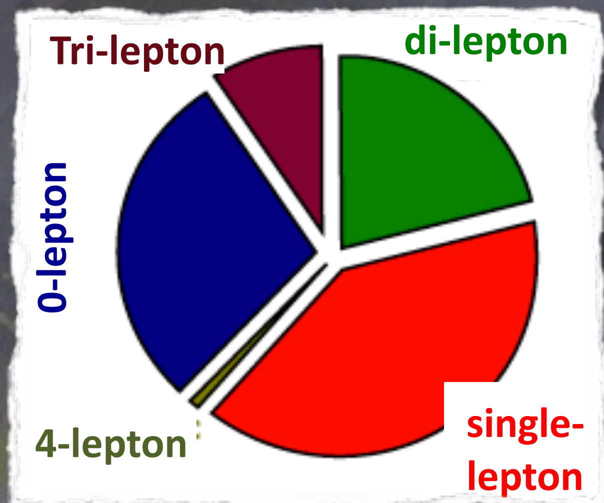


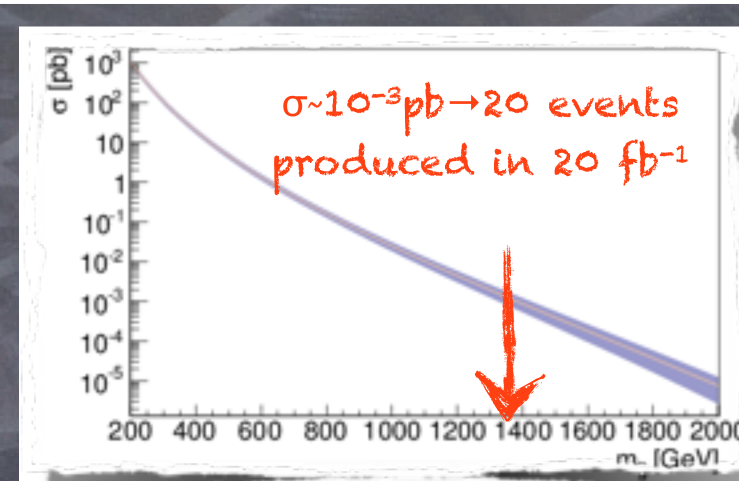
The Search Strategy

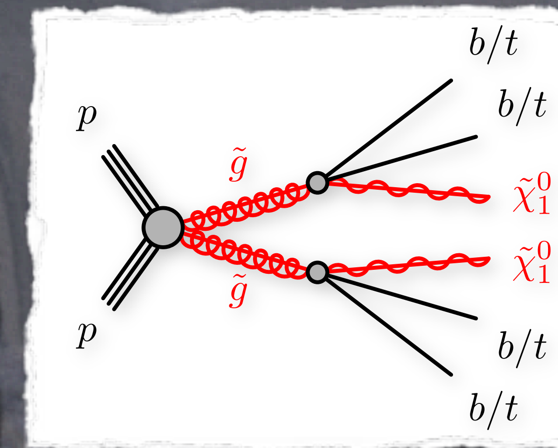
- The main ingredient to the search is a kinematic plane.
  - A measurement of the event energy (HT, M_{eff}, M_R)
  - A measurement of the unbalancing (MET, α_T, M_T^2, R)
- The background on the tail is measured from the core, using transfer factors from MC
- The searches are repeated for different final states
  - number of jets
  - number of btags
  - number of leptons
- Searching for specific signals (e.g. stop production) advanced techniques (e.g. BDT) could be used

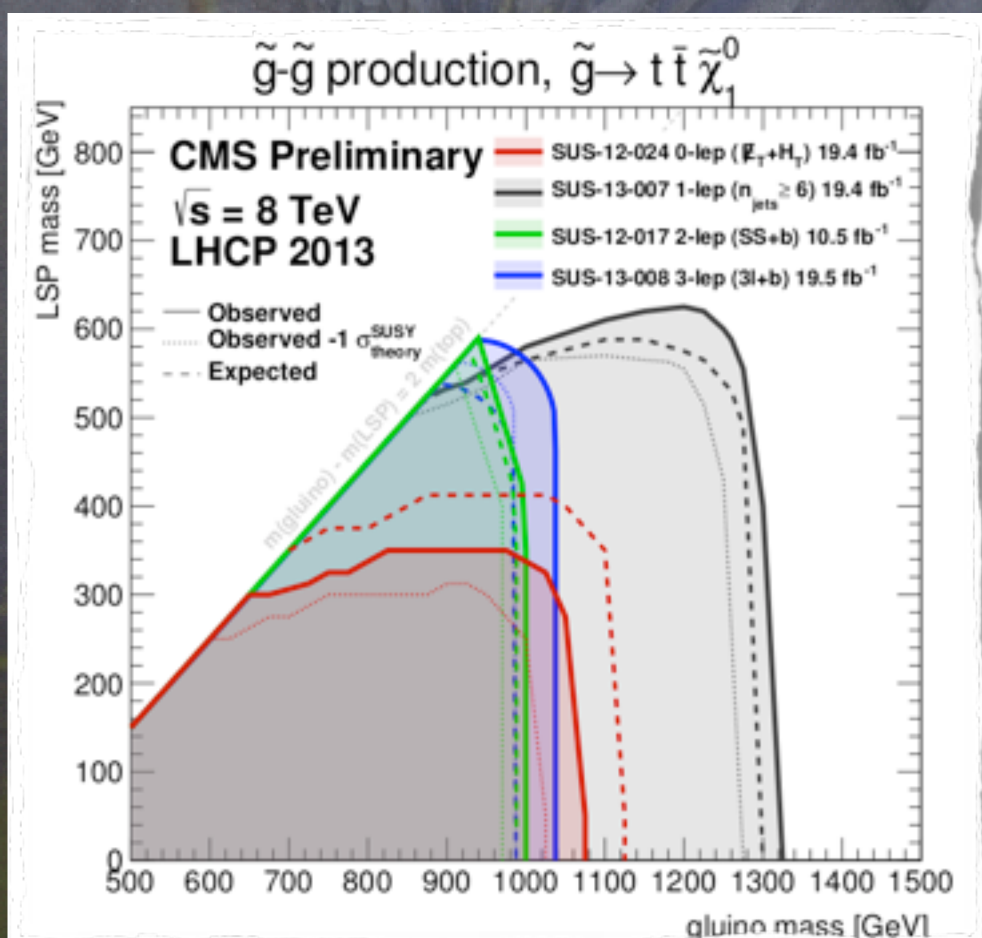


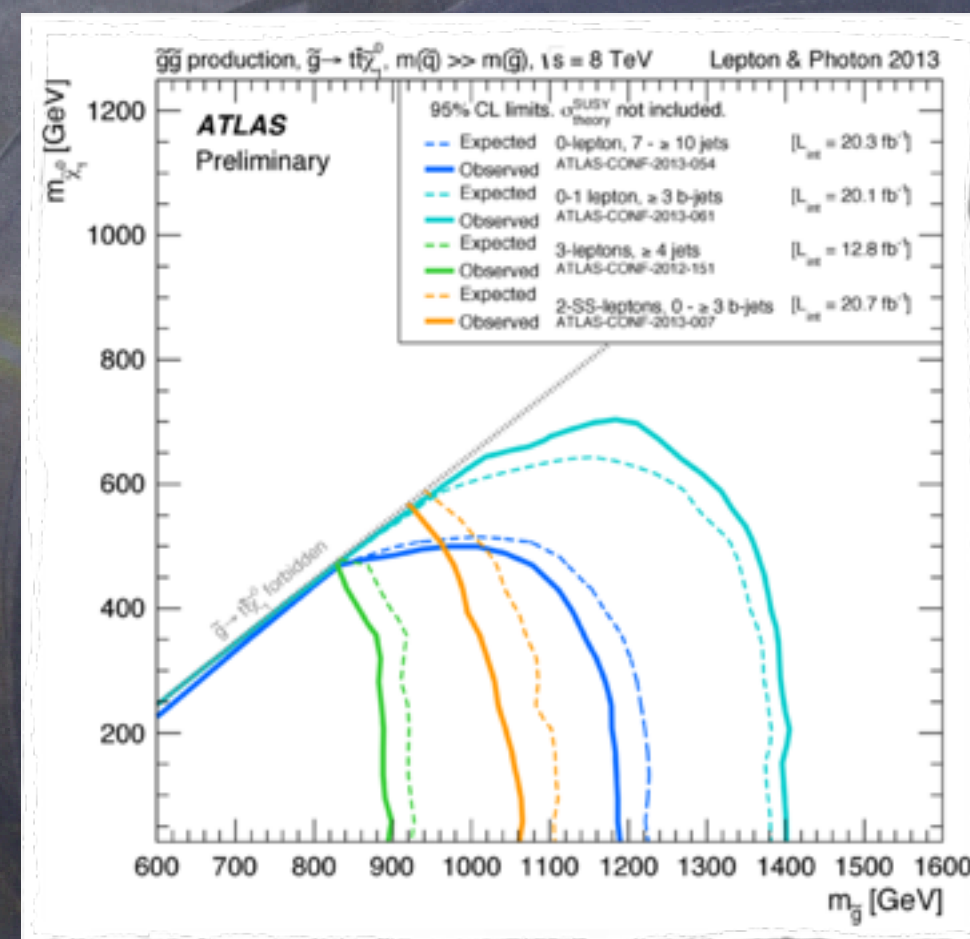
Gluino-Gluino Search: 4t+MET



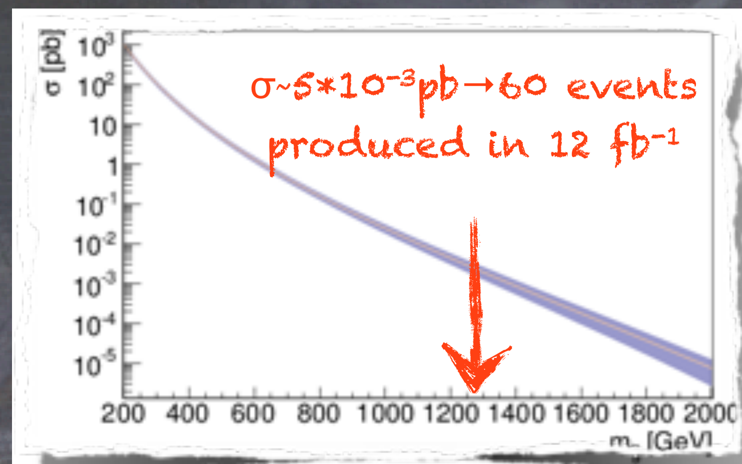


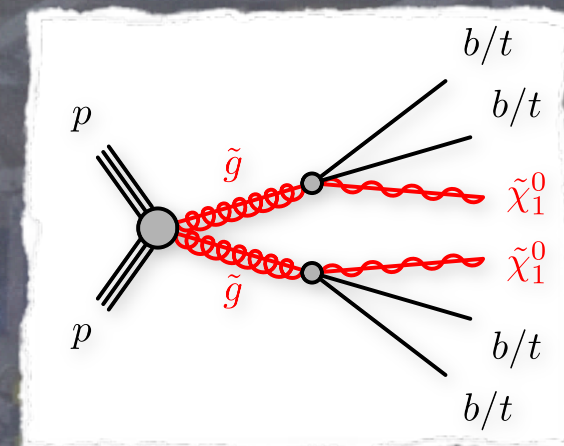


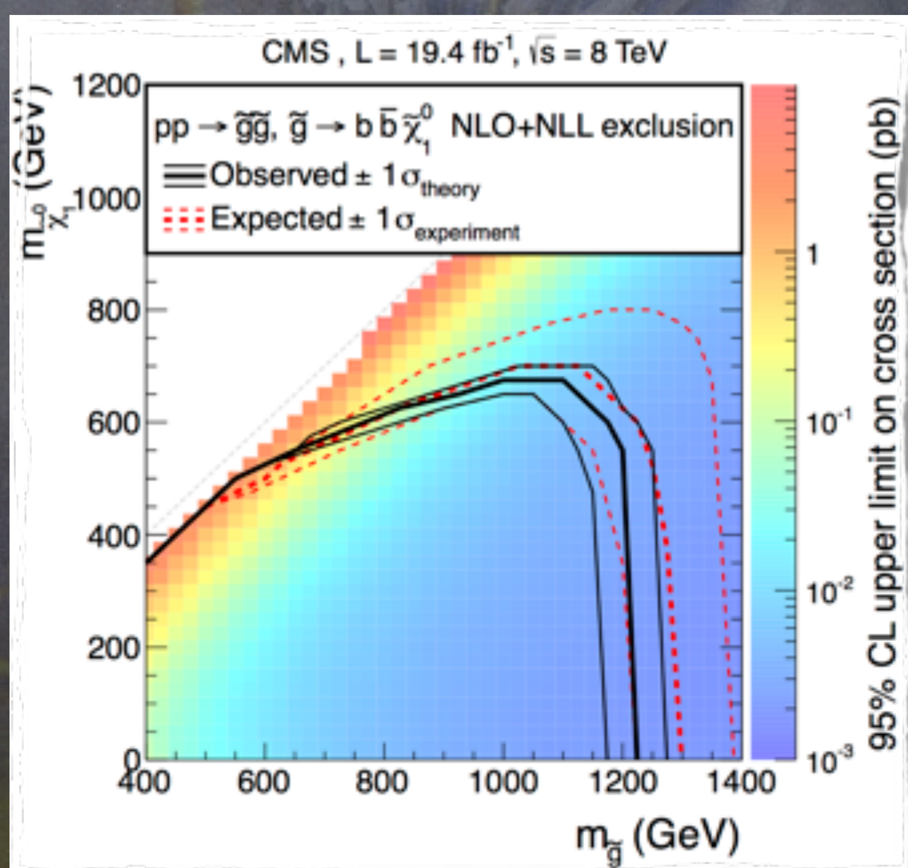


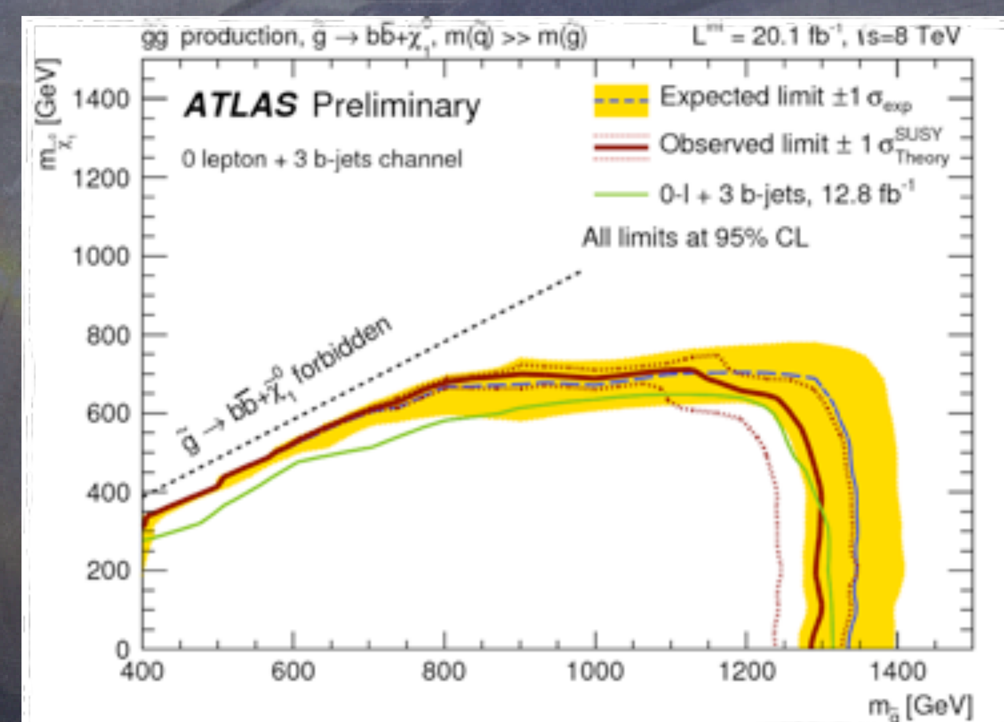


Gluino-Gluino Search: 4b+MET

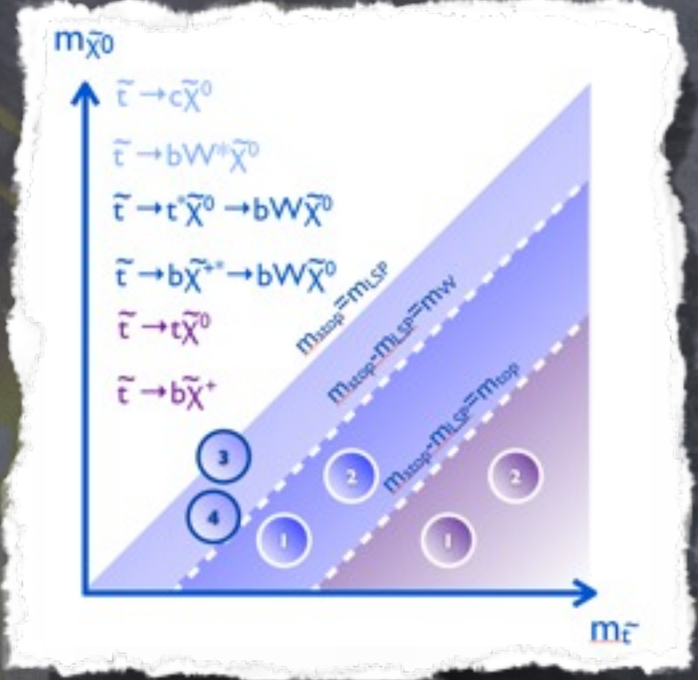


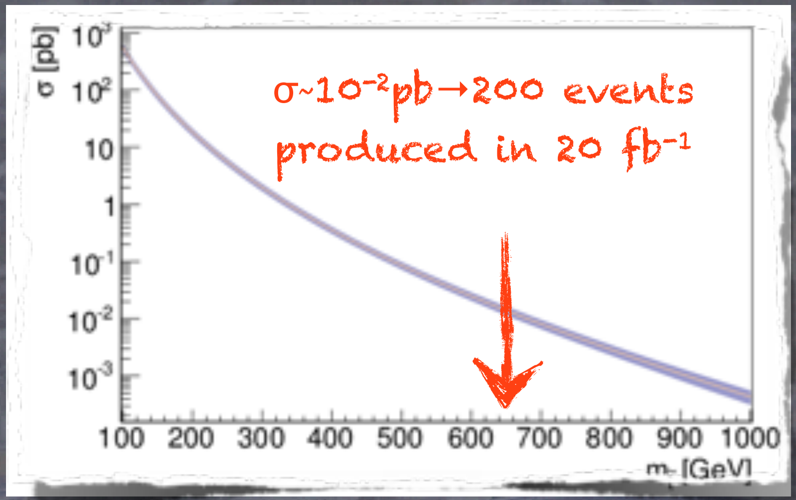


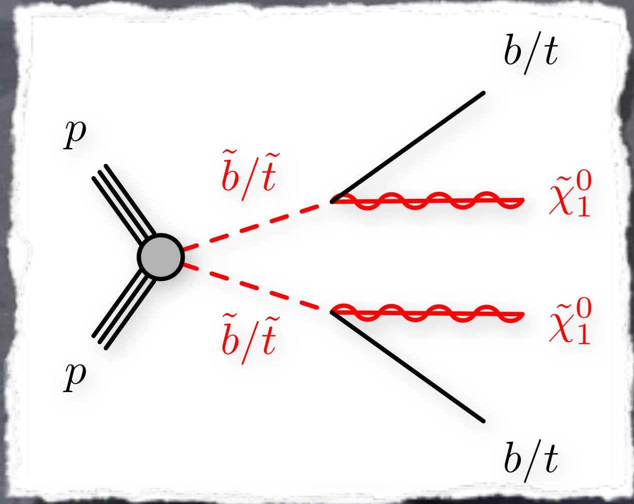


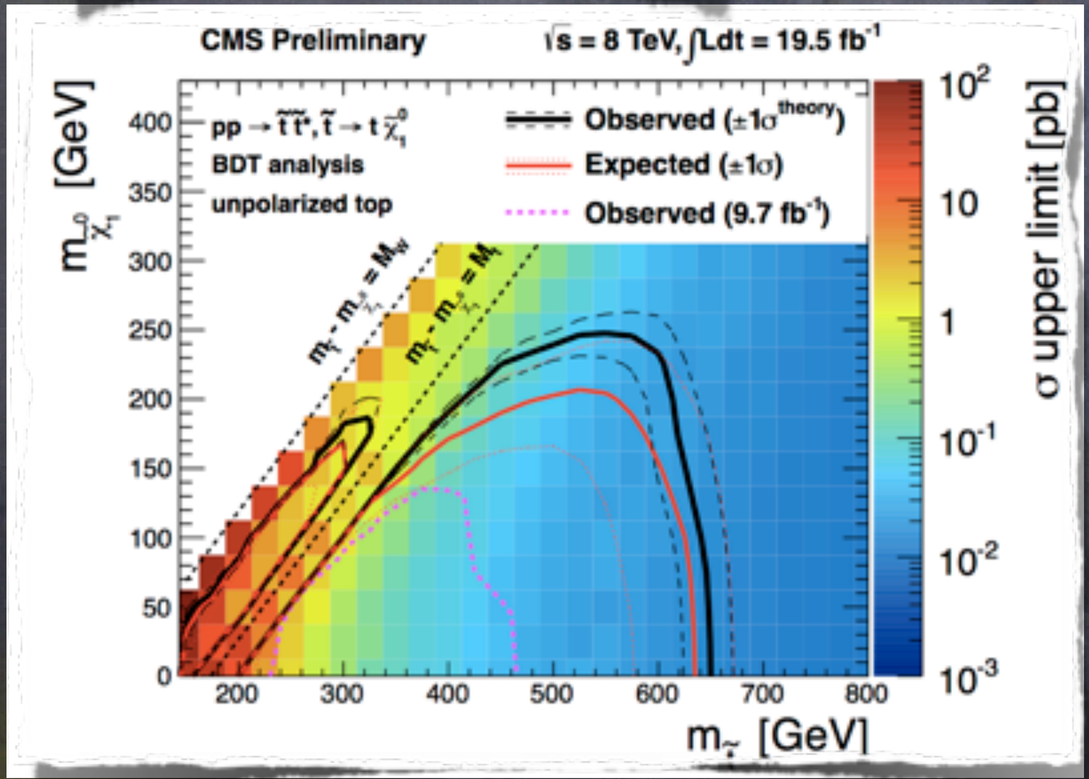


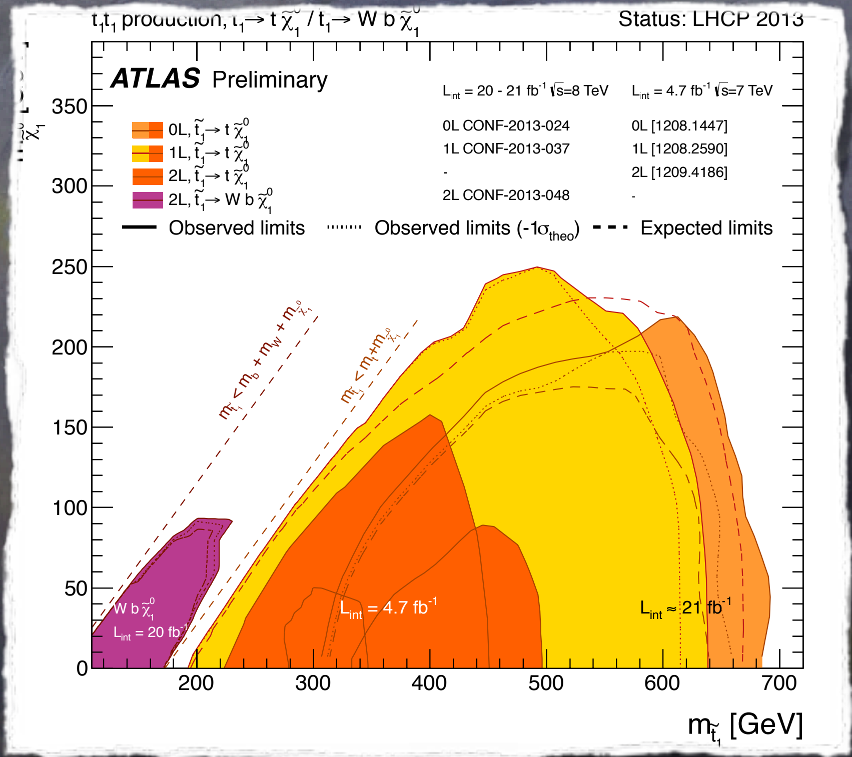
Stop-Stop Search: tt+MET



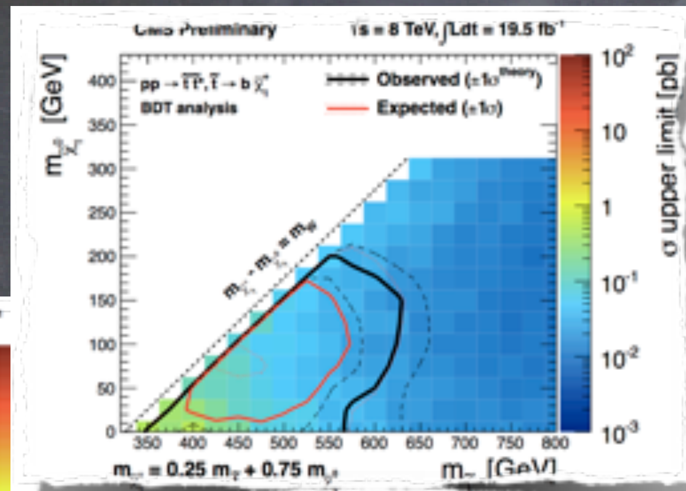


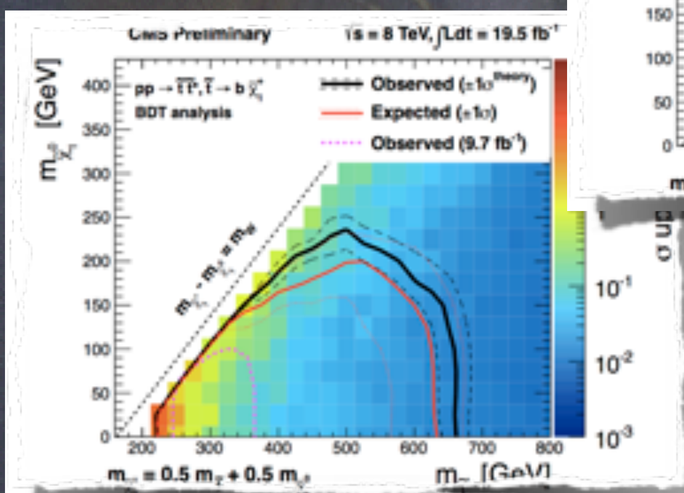


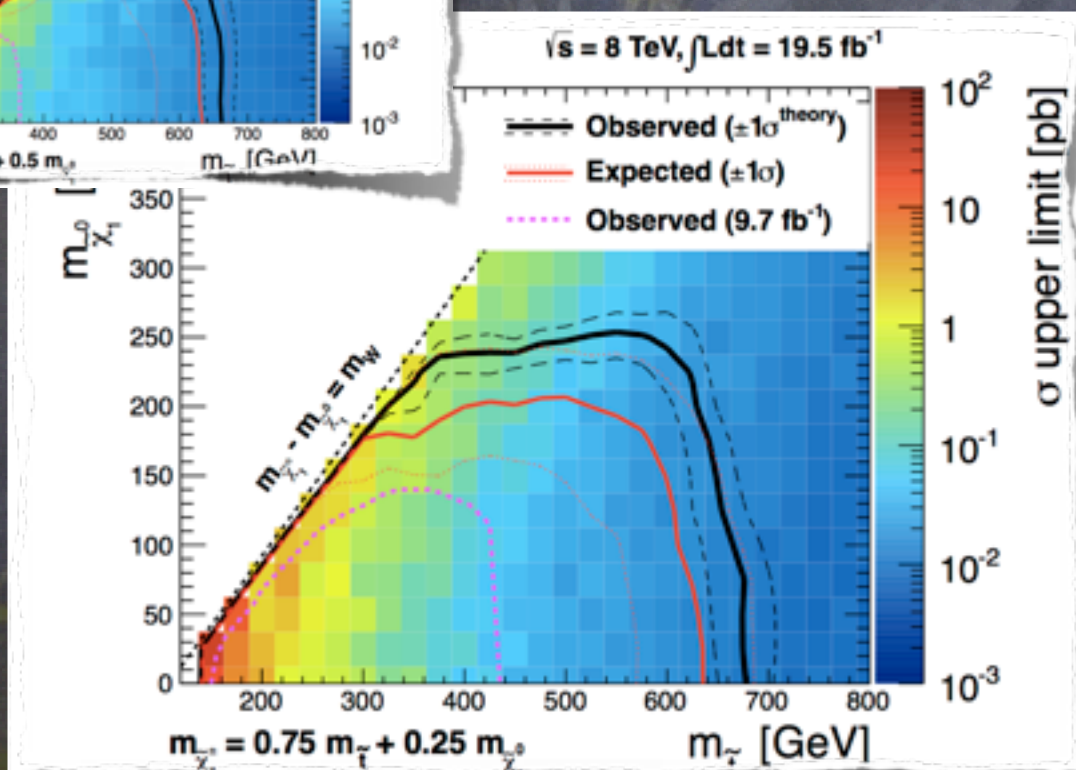


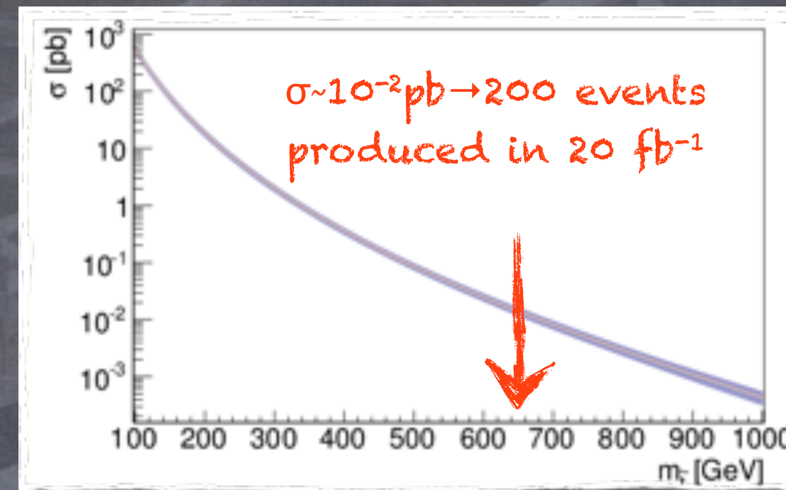


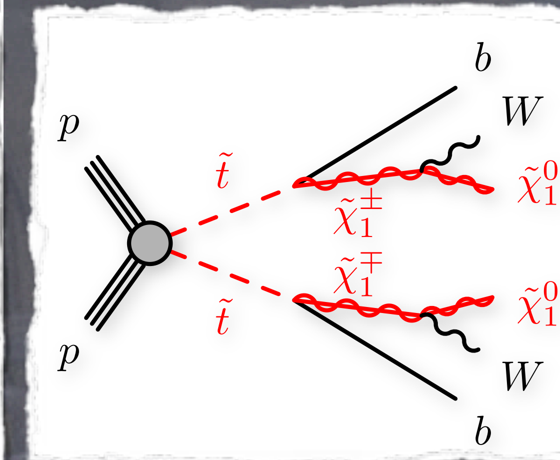
Stop-Stop Search: bbWW+MET

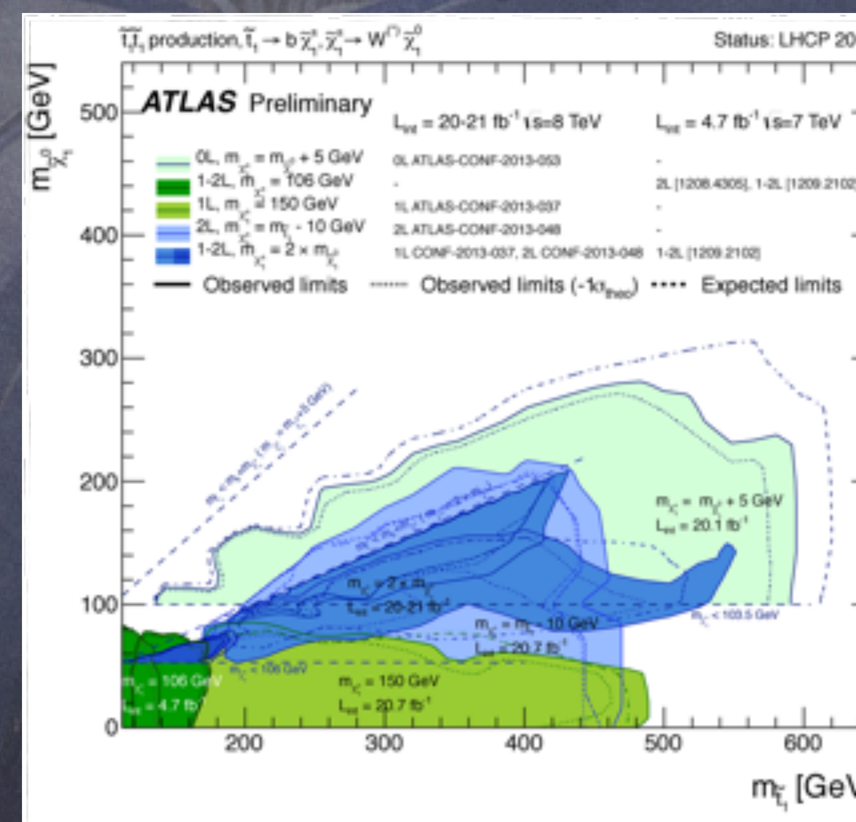






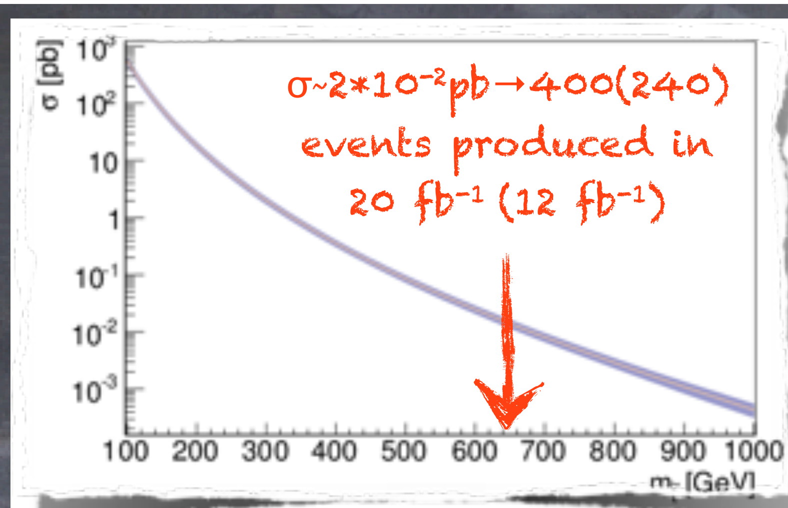


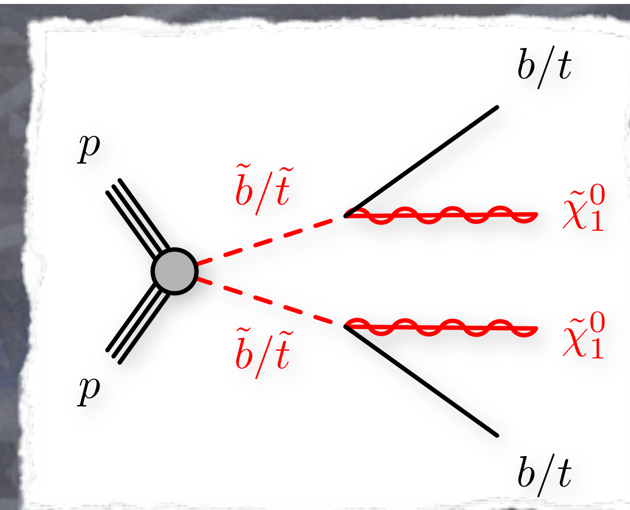


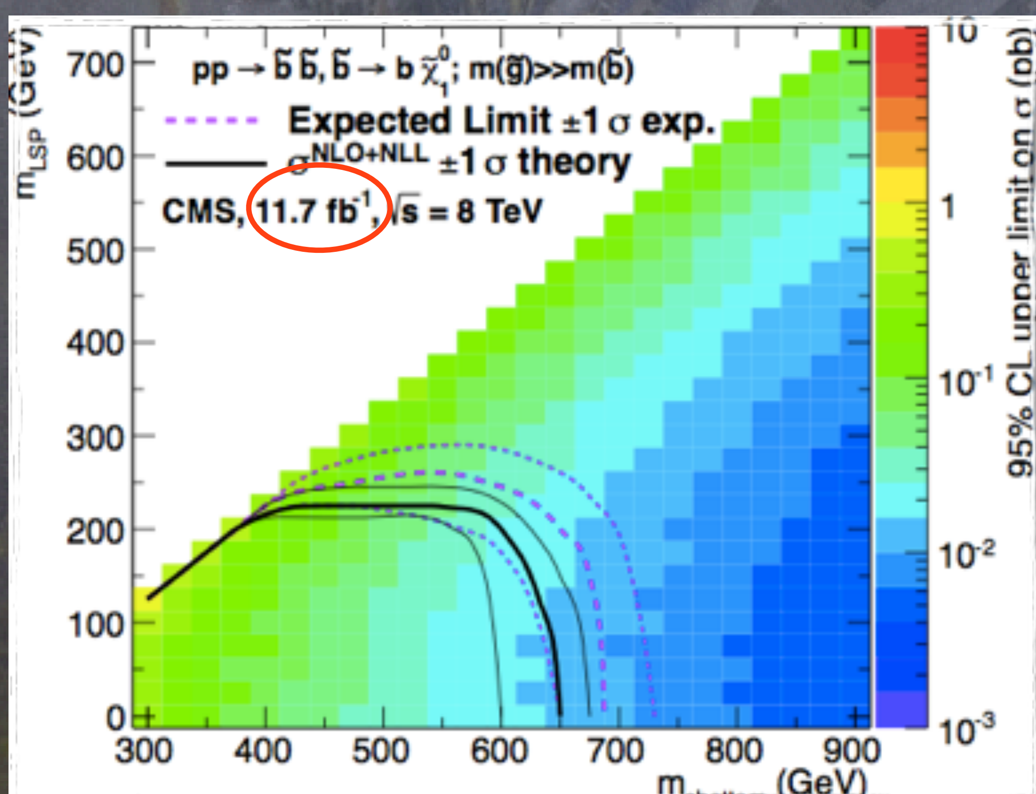


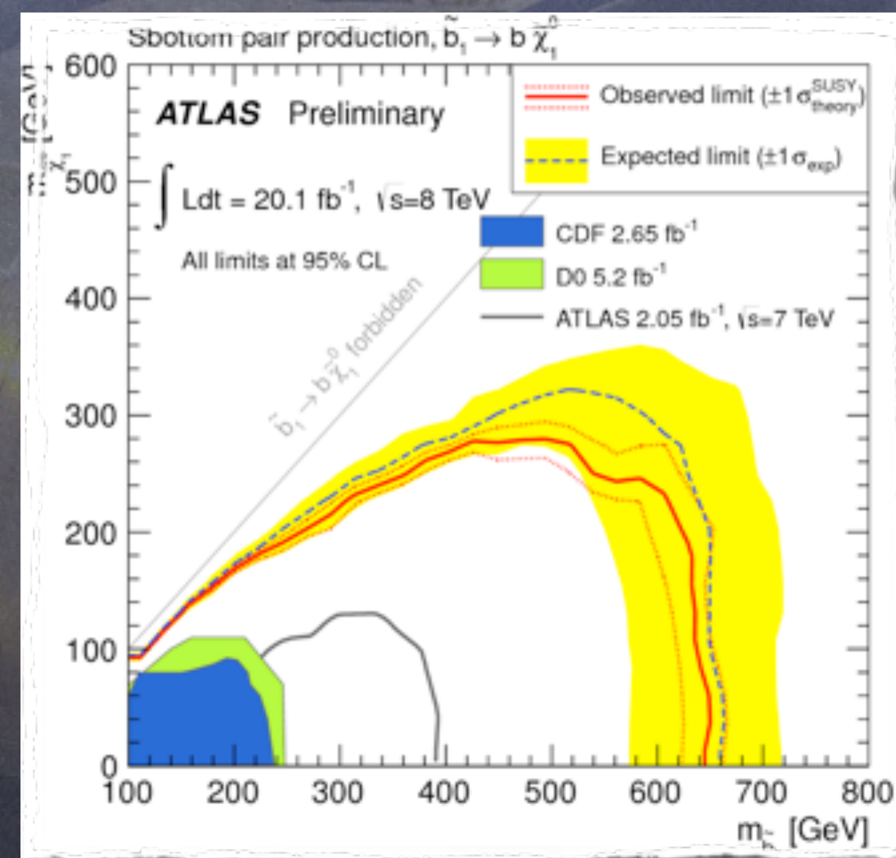
The limit depends on how close the χ^+ and χ^0 masses are

Sbottom-Sbottom Search:bb+MET









Hunting in the corners

Compressed Spectra

- The decay products of the produced sparticles are too soft to be detected
- Could trigger the events only through associated jet production (e.g. monojet)
- For very compressed spectra, the decay products could become long living (e.g. ewikinos)

RPV models

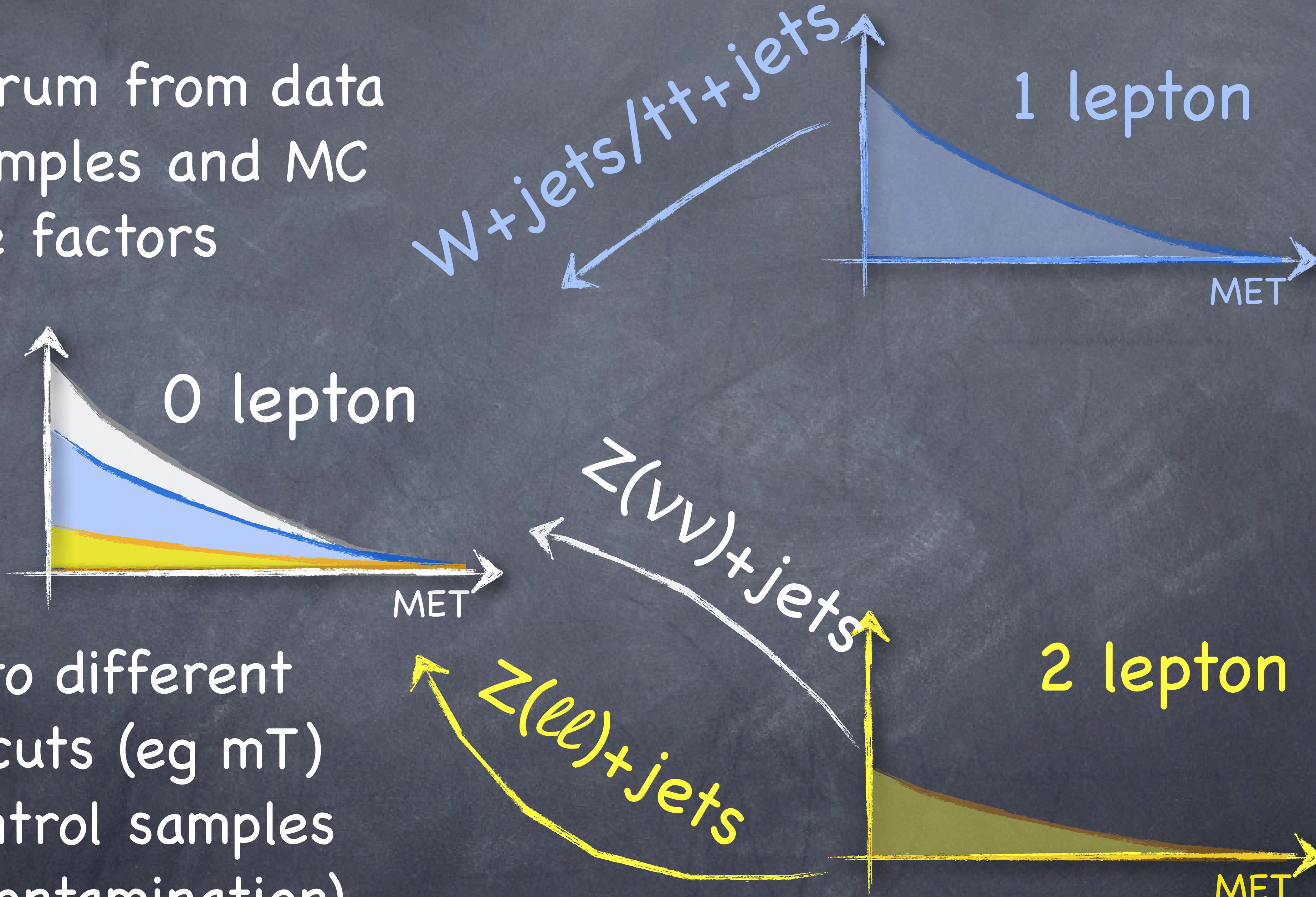
- searches for leptonic RPV in place since the beginning of the run
- hadronic RPV more challenging (no MET to kill SM bkgs) but not impossible (can use the resonance peak)
- MFV SUSY offers special opportunities (bjet excess). Some bound from existing searches (e.g. 3l+b or 2l+b). More to come

Split SUSY

- the accessible sparticles are the gluino and the ewkino sector
- Even in this case, one would need associated jet production
- Even in this case, should look for displaced jets (long-living gluino)

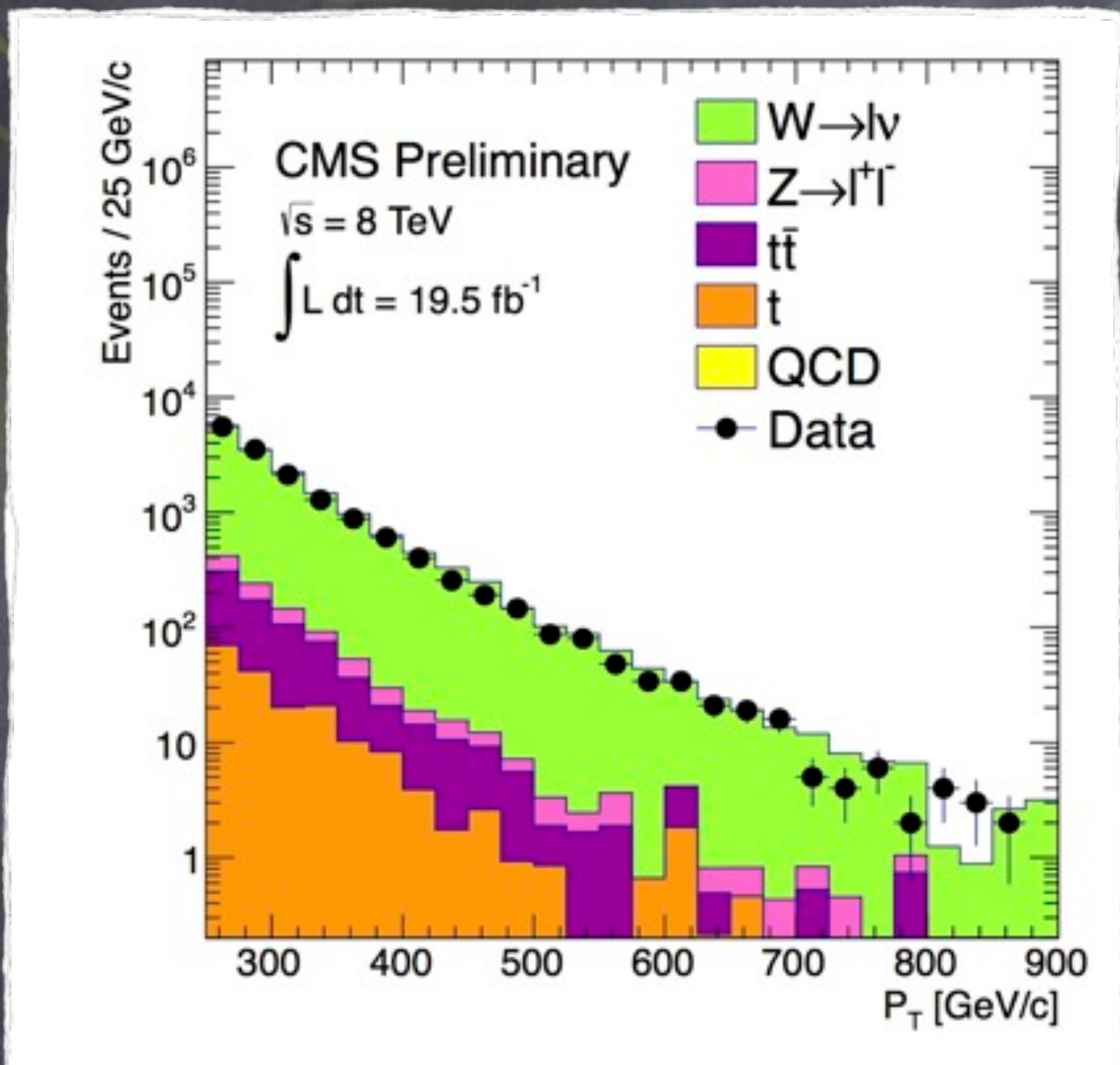
The Monojet Search

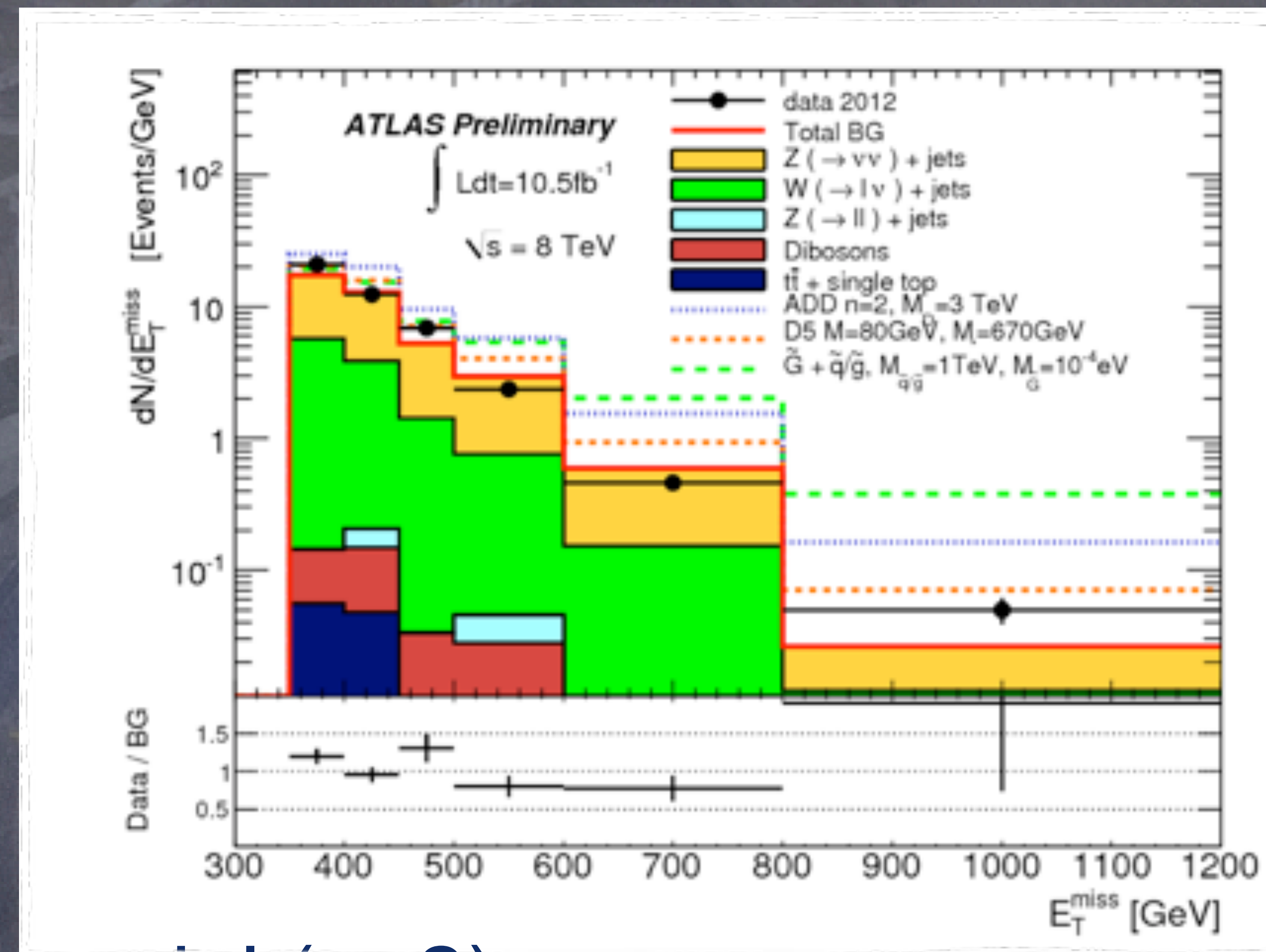
MET spectrum from data control samples and MC scale factors



No need to different kinematic cuts (eg mT) for bkg control samples (no signal contamination)

The Monojet Search





Good control over the kinematic variables

MC prediction OK

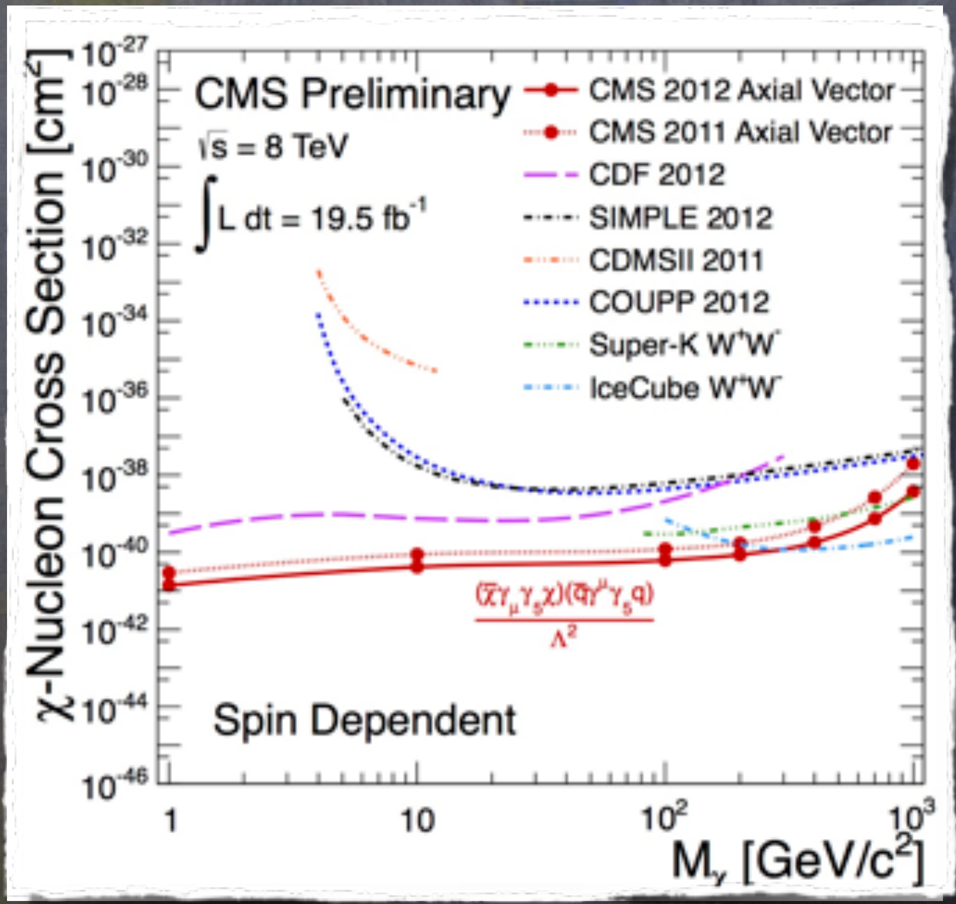
Large sensitivity to NP on the MET tail

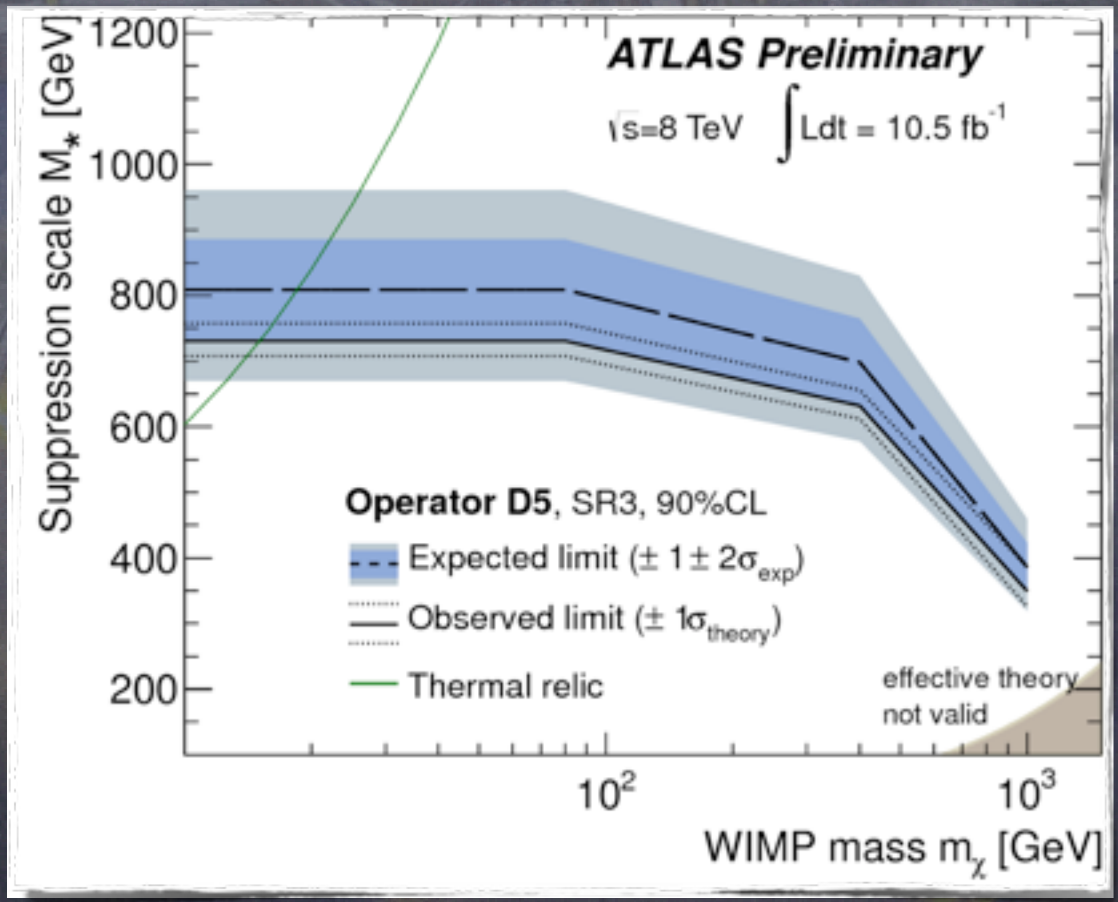
No evidence for a deviation from SM

The Monojet Search

Result translated in a limit using effective operators , suppressed by M*

Results can be compared to direct DM searches under the assumptions implicit in the effective-operators sapproach

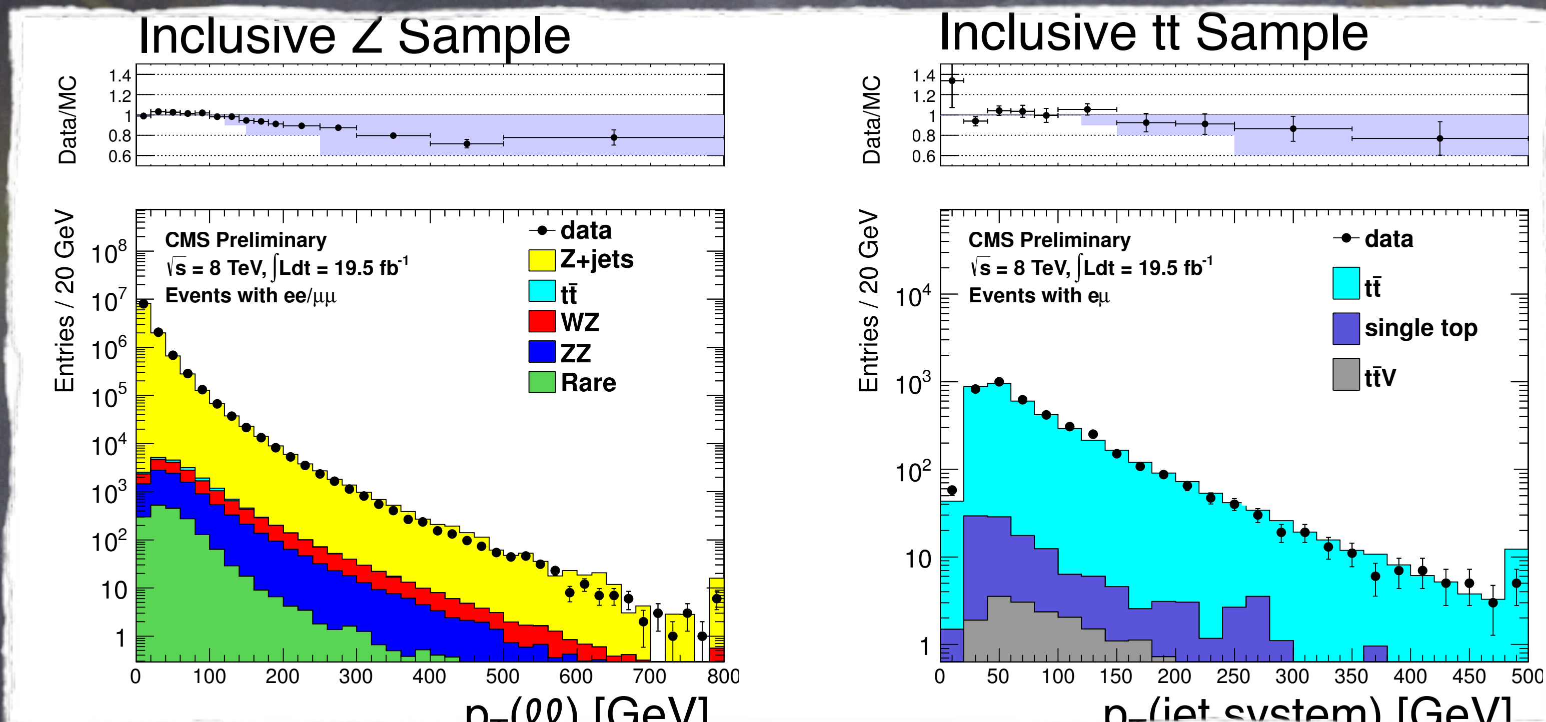


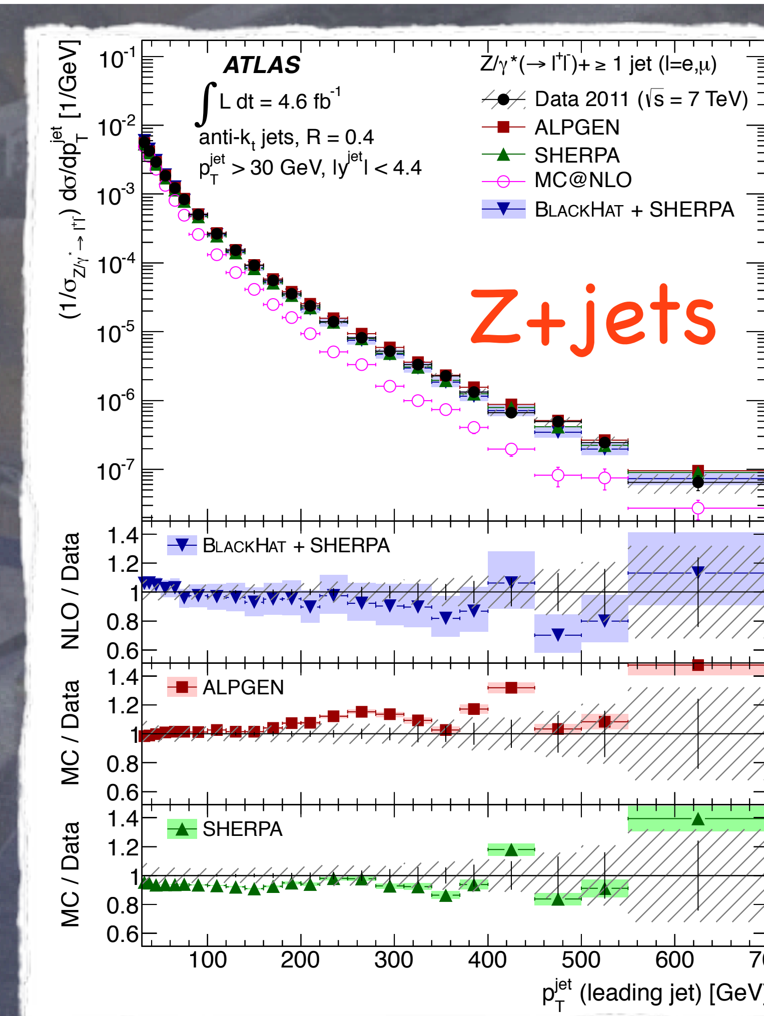


Also limits from ADD models (n=2): 4.2 TeV (ATLAS) ; 5 TeV (CMS)

Do we control the jet radiation?

LO ME+PS generators model the associated jet production in a fair way





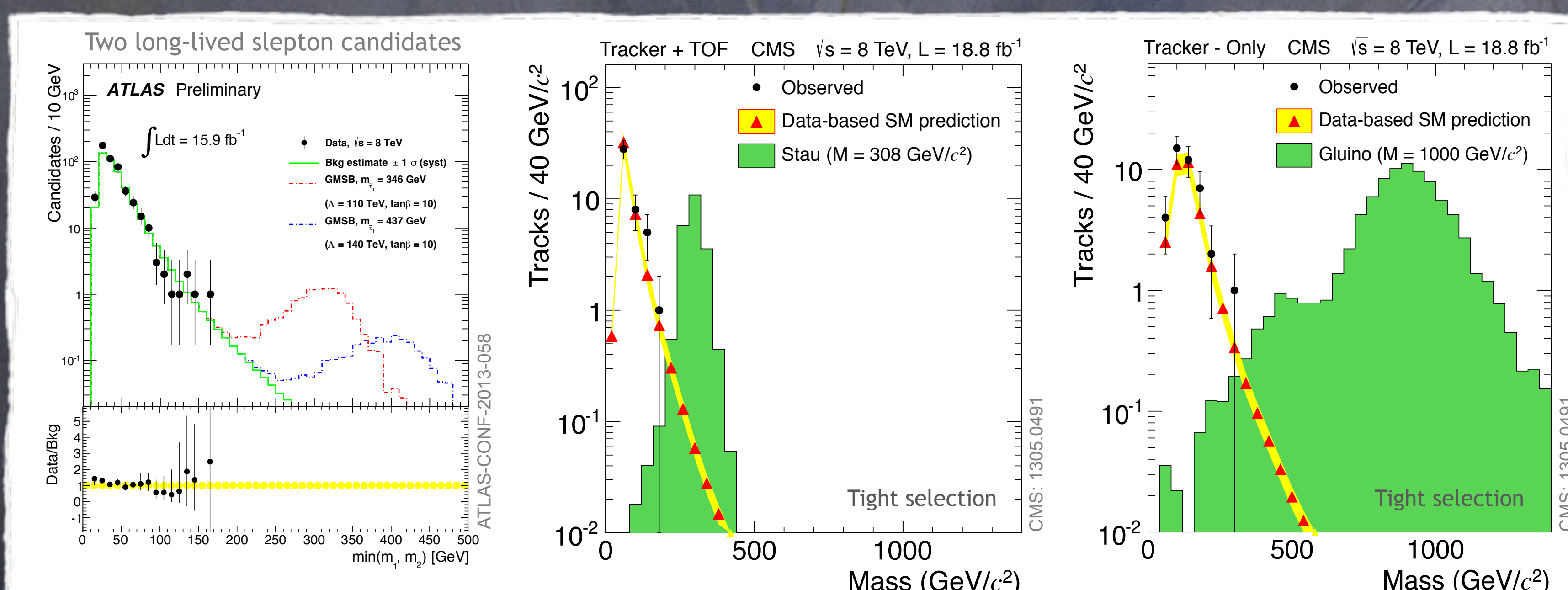
The study of SM processes (e.g. V+jets or tt+jets):

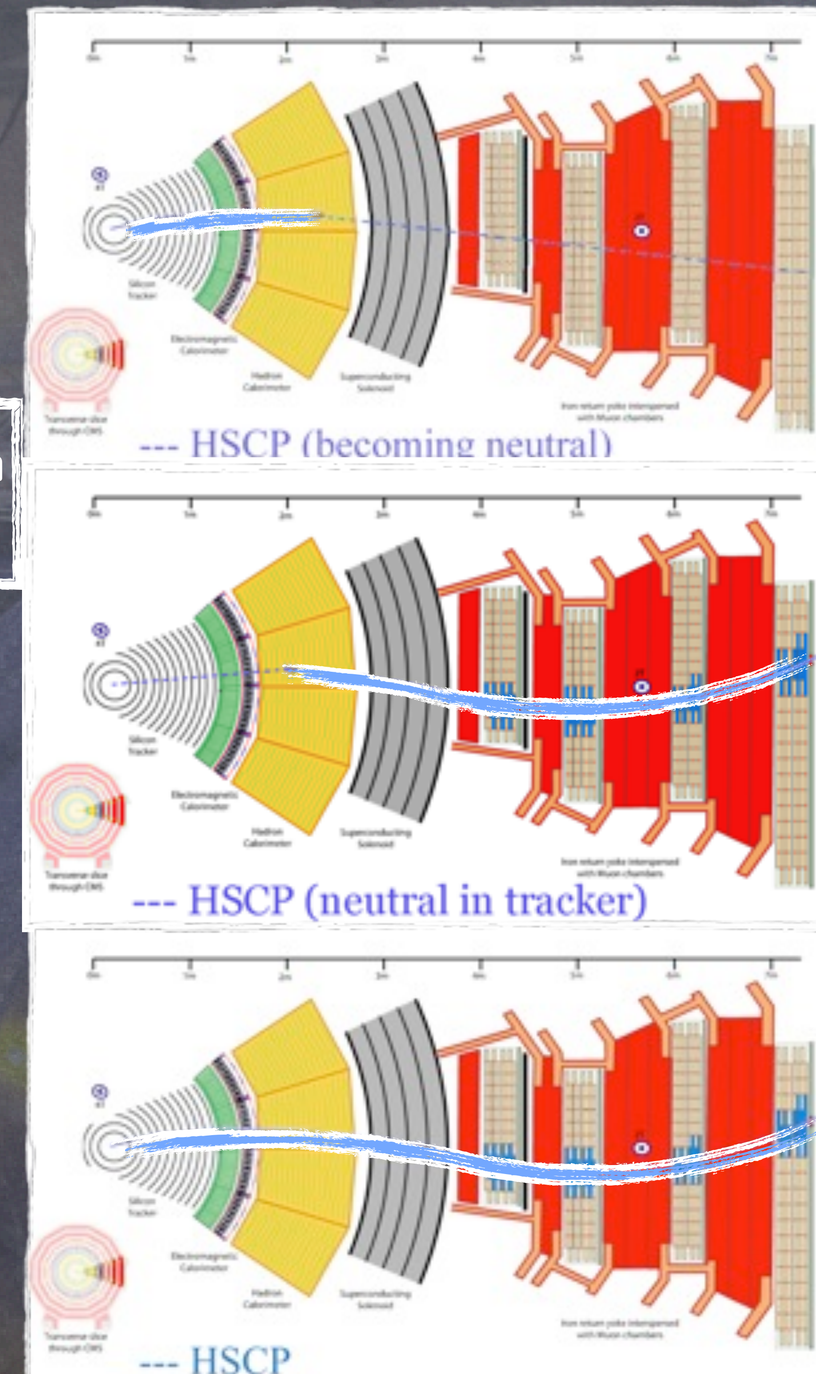
- make us confident that we control the signal efficiency for monojet-like signatures
- provide us with a measurement of the systematic error (and a MC weight) to correct the signal Monte Carlo

Long-living particles

Long-living particles are detected measuring the ionization, the time of flight, and the momentum

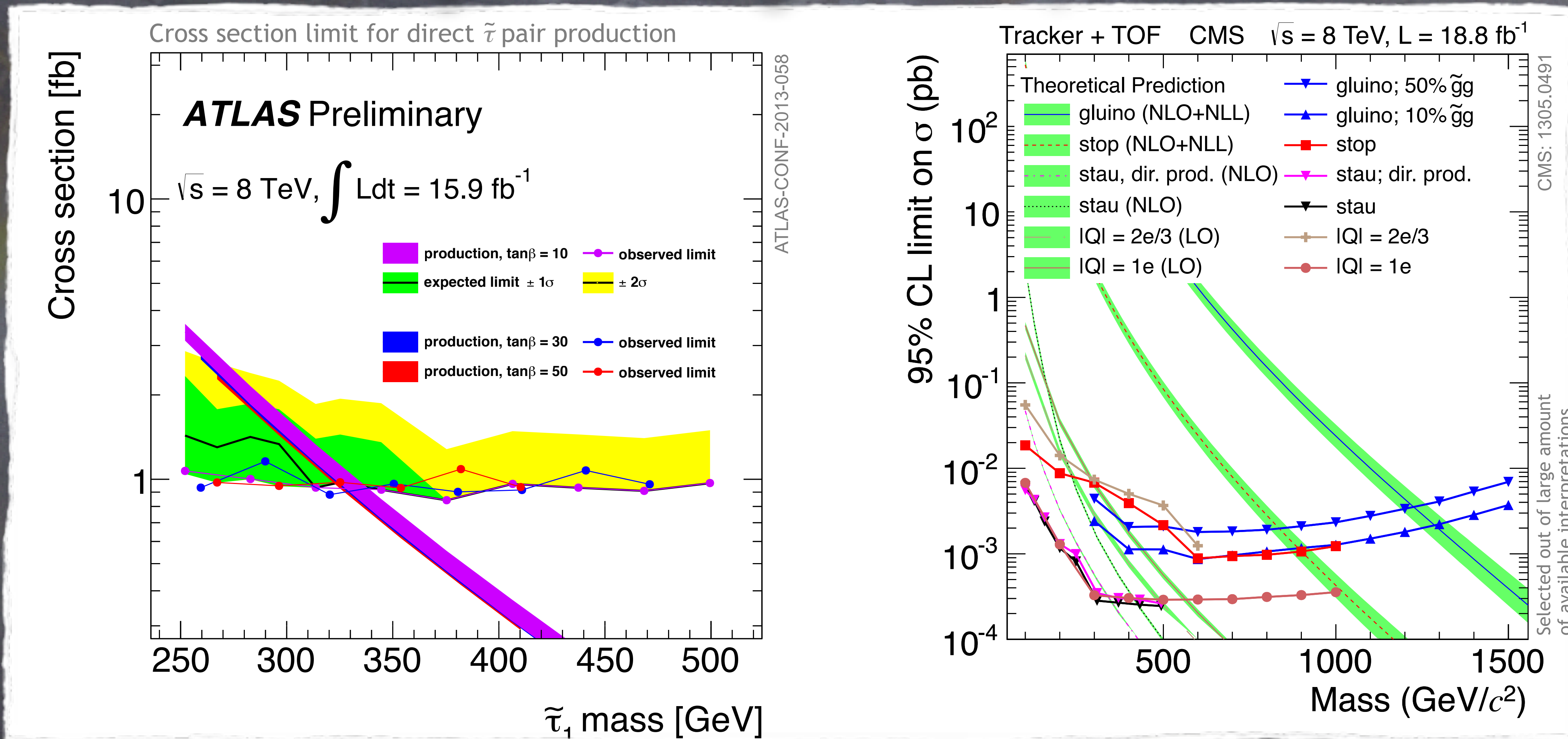
Different parts of the detector are used, together (to improve the precision) or individually (to be sensitive to different NP scenarios): tracker / calorimeter / muon system (ATLAS only)





Long-living particles

Strong limits on gluino, stop, and stau



If Not SUSY

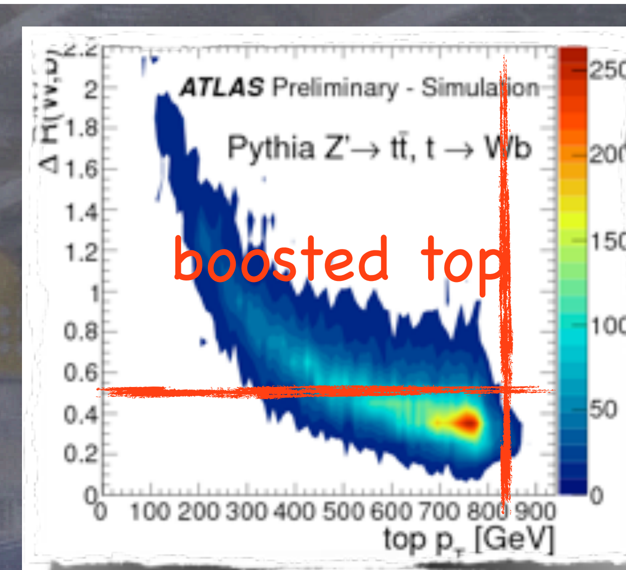
- New Resonances to ff
- New Resonances to VV/VH/HH
- New Partners of Top and Bottom
- Many other possibilities I have no time to cover

what was planned before data

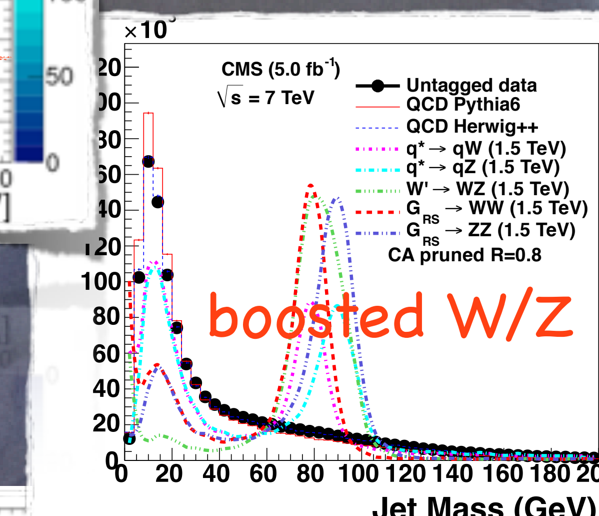
the substructure revolution

The Substructure Revolution

- Pushing the searches to higher mass values, we are confronting ourselves with W,Z,H, and top produced at large boost



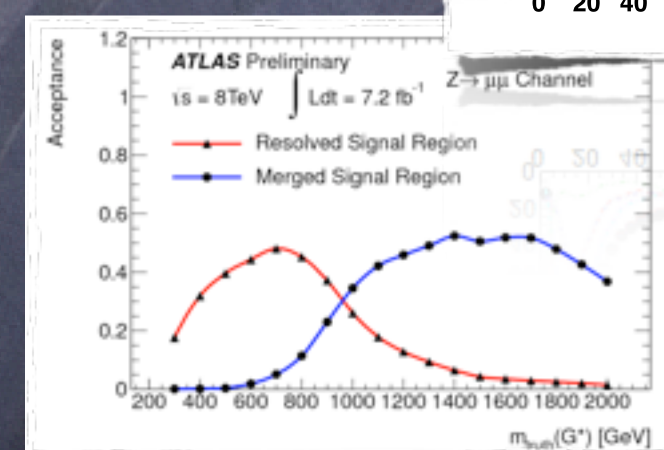
- After a mass-dependent threshold, the particles acquire enough mass to look like a single fat jet once they decay hadronically



$$p^\mu = (E, \vec{p}) \rightarrow \quad p_1^\mu = (E_1, \vec{p_1}), \quad p_2^\mu = (E_2, \vec{p_2})$$

$$\theta \approx 2\frac{m}{E}$$

- In this case, we don't reconstruct them anymore from jets, but as a single massive jet

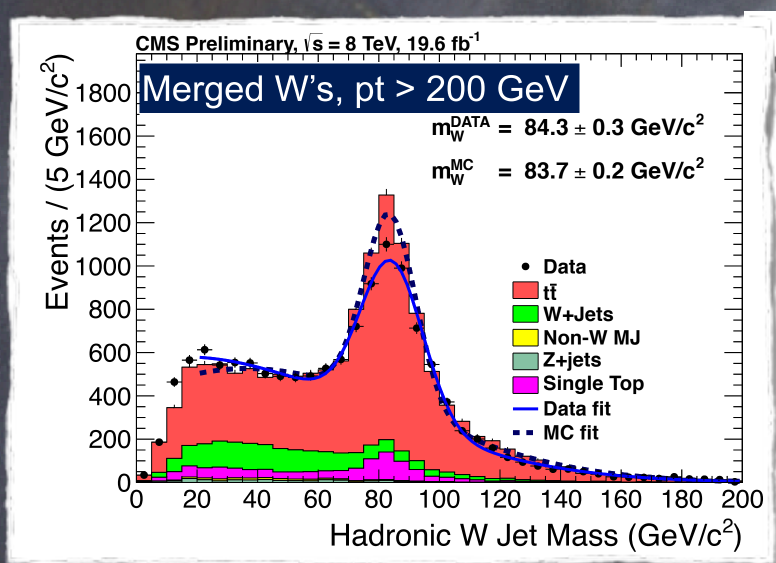


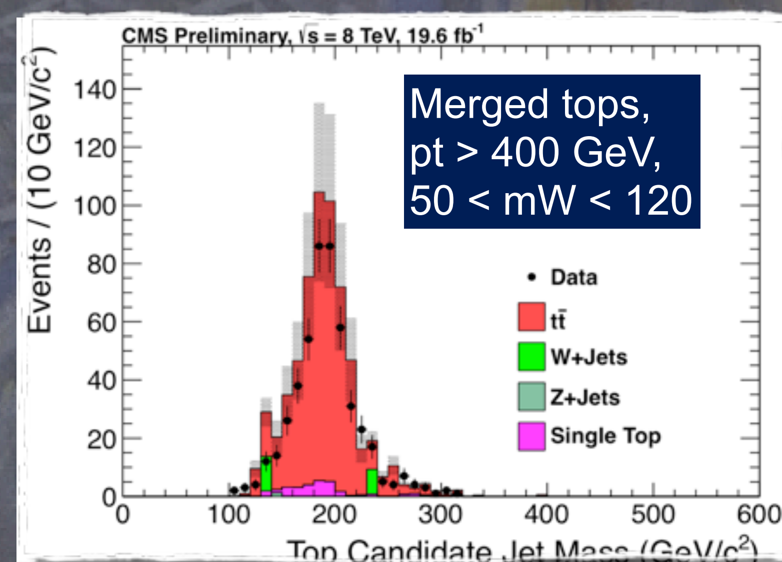
- The jet mass becomes a powerful discriminator against ordinary backgrounds

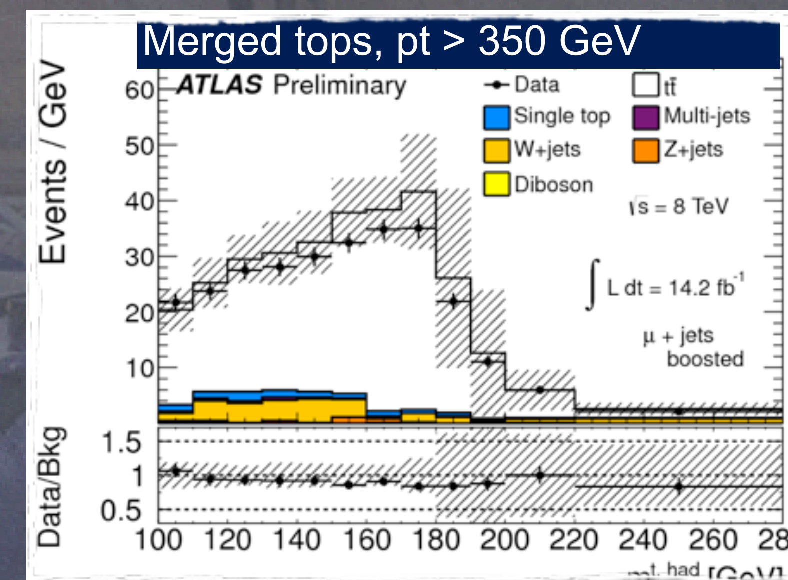
- We can then look inside the jet to see if it looks more like more jets merging (massdrop, subjettiness, etc)

The Substructure Revolution

- The technique is tested on data control samples (e.g. boosted Ws and tops in ttbar events)







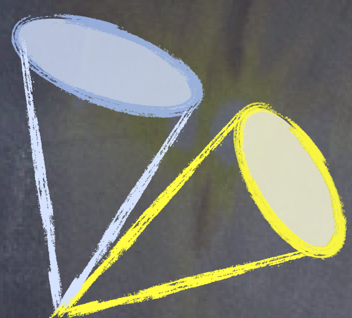
- These studies allow to check and correct the MC simulation of the signals

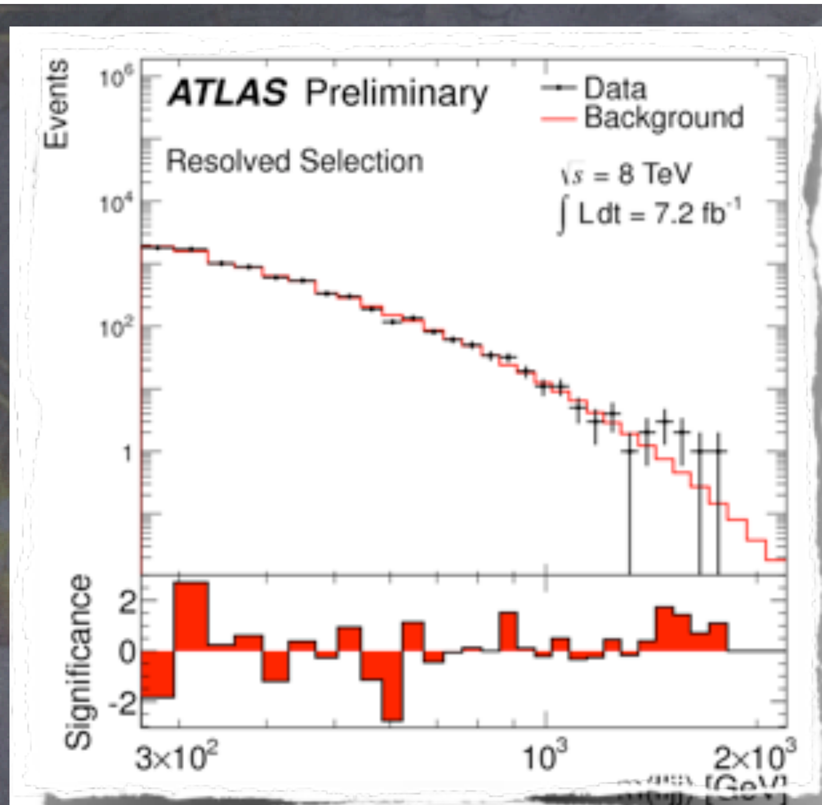
- This allows to optimize the V-tagging, H-tagging, and t-tagging to improve the searches

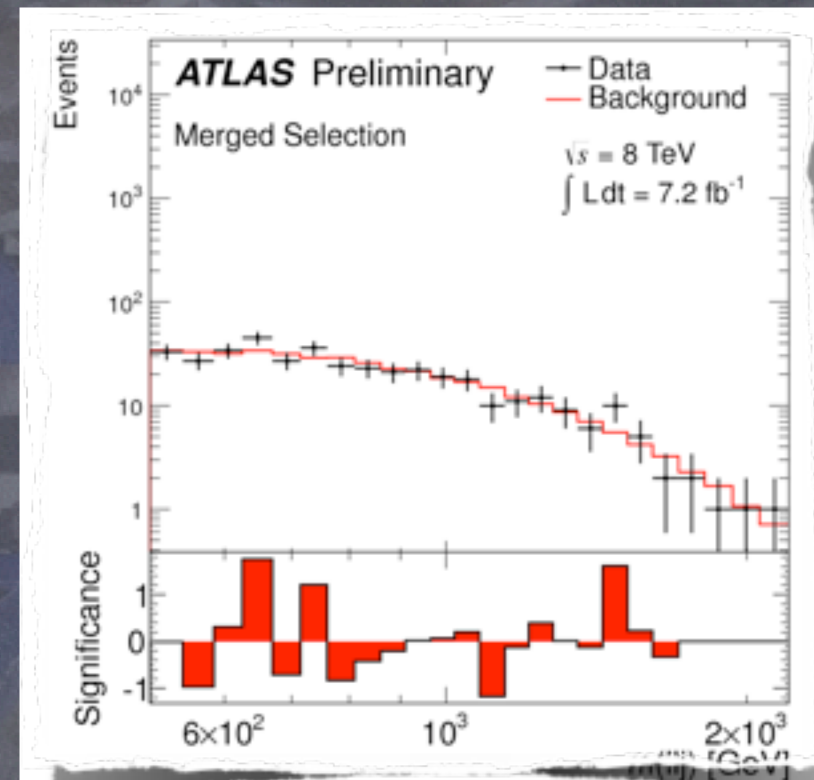
- A new domain of jet physics which will be more important with 13 TeV collisions

Resonances to VV

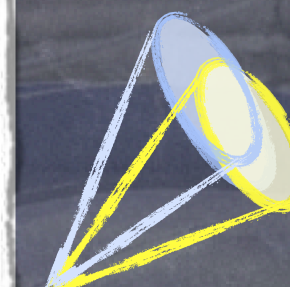
resolved topology (small masses)

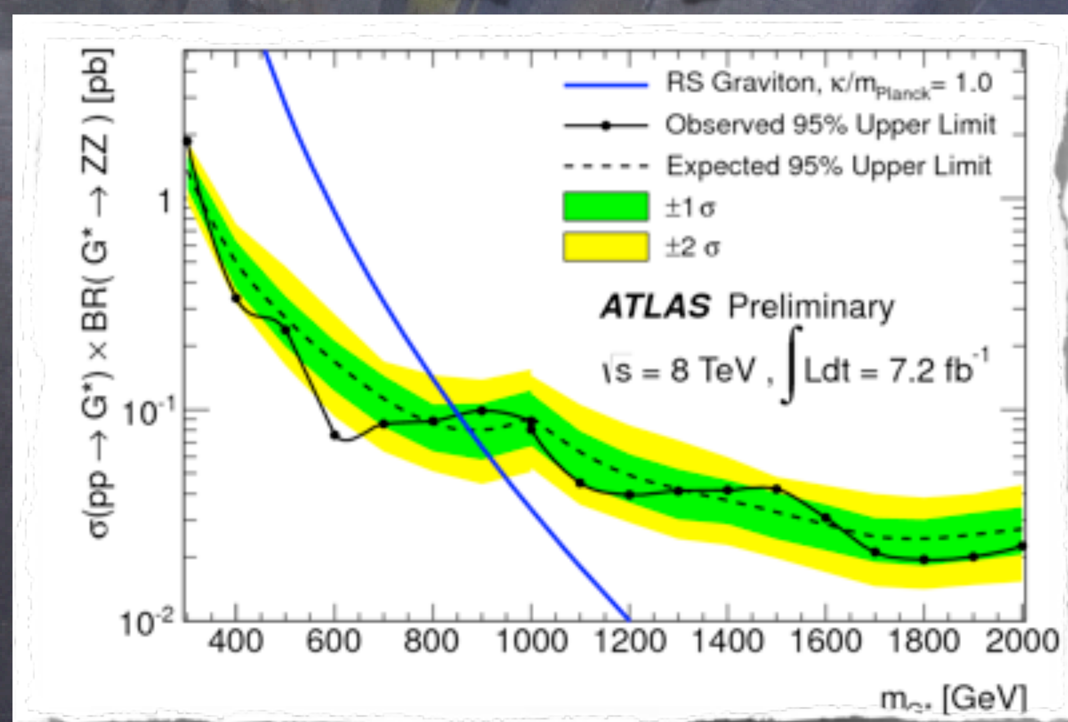




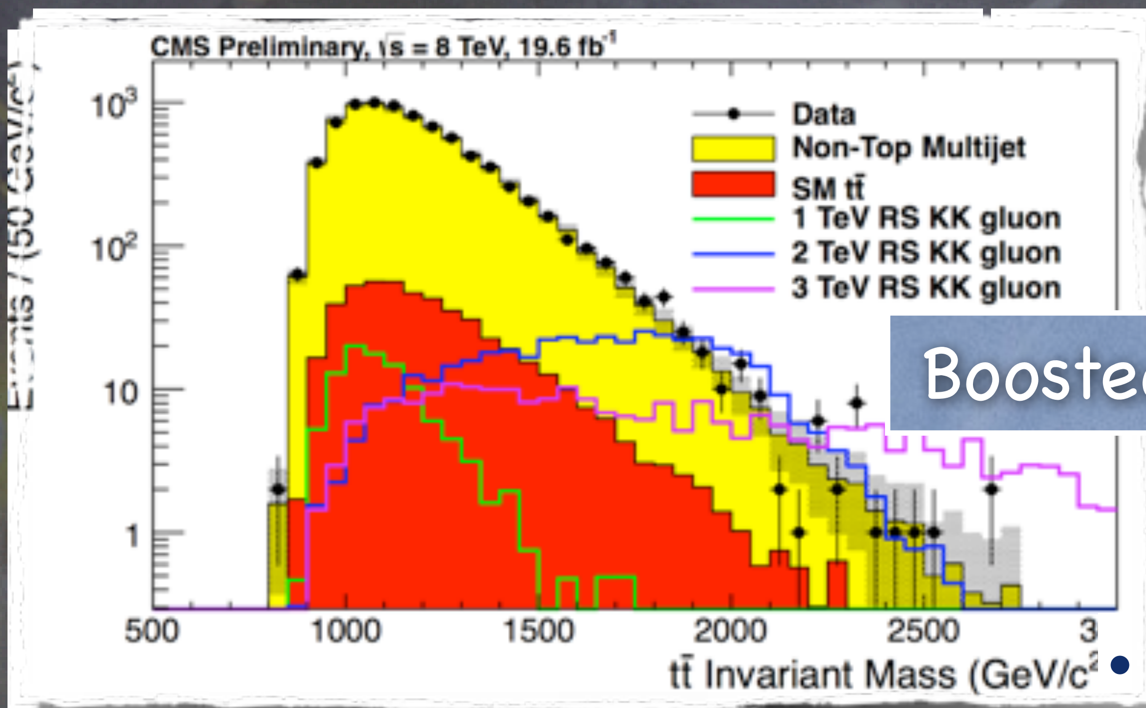


merged topology (large masses)

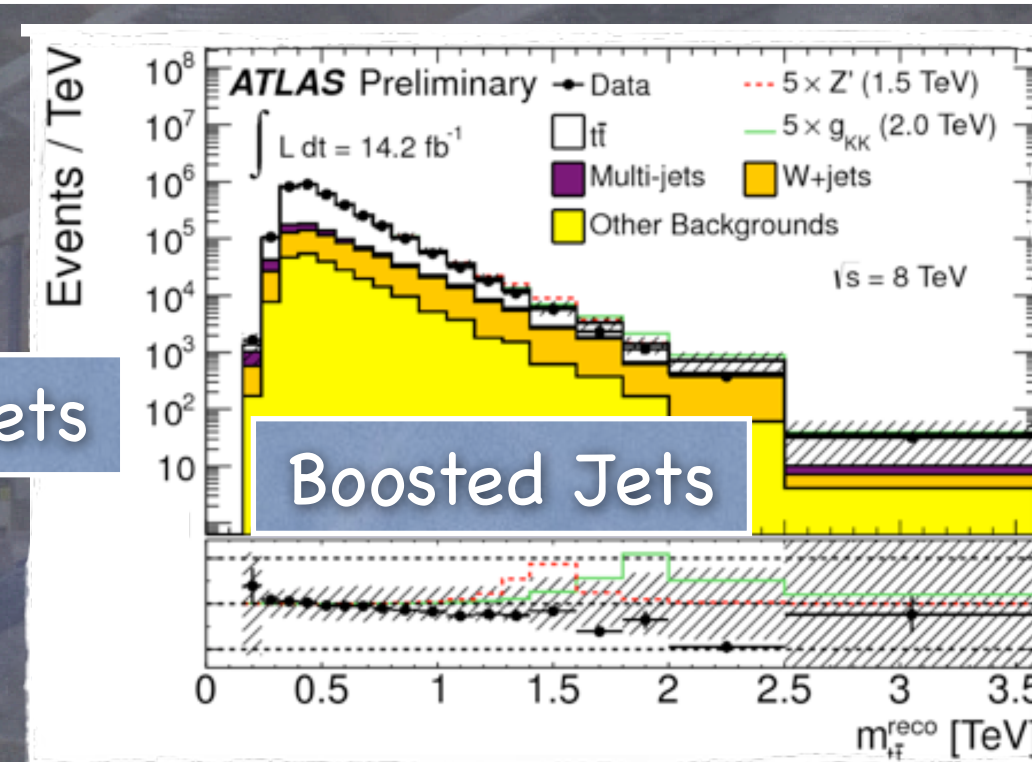




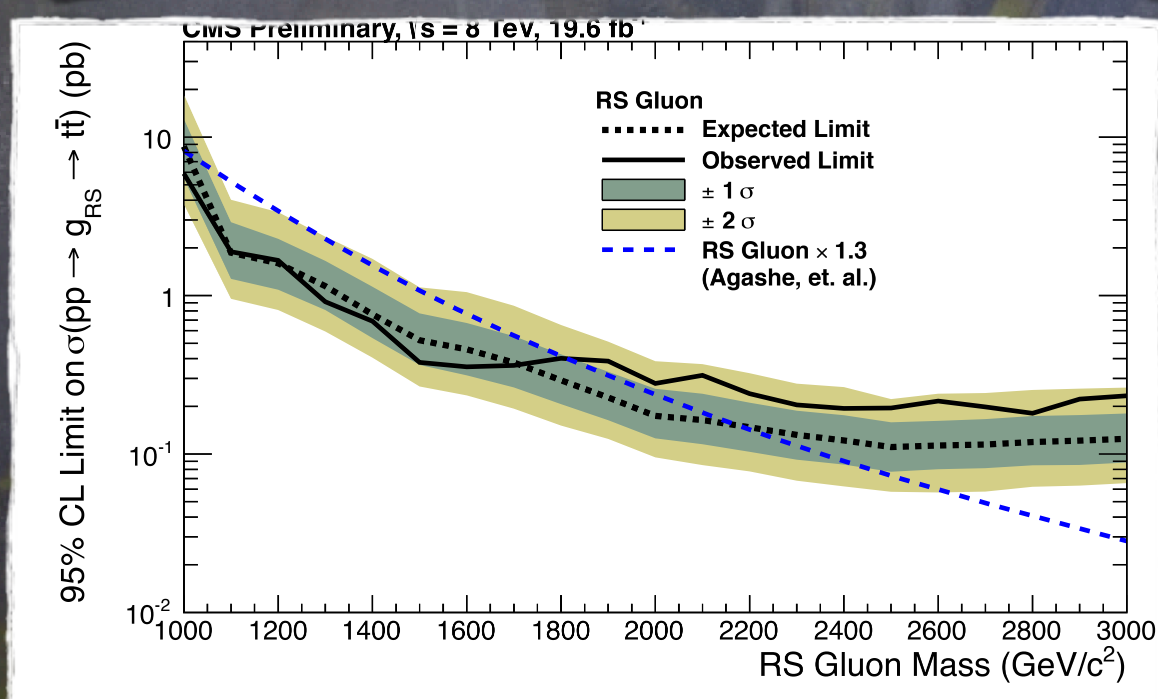
Resonances to ttbar

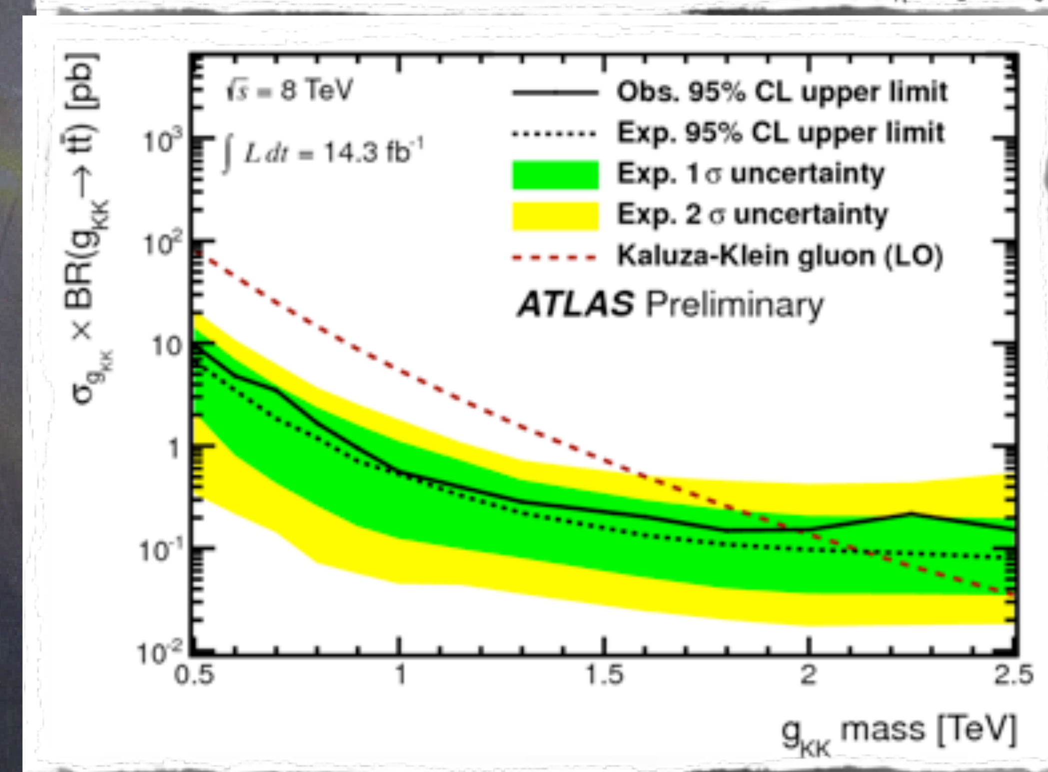


Boosted Jets



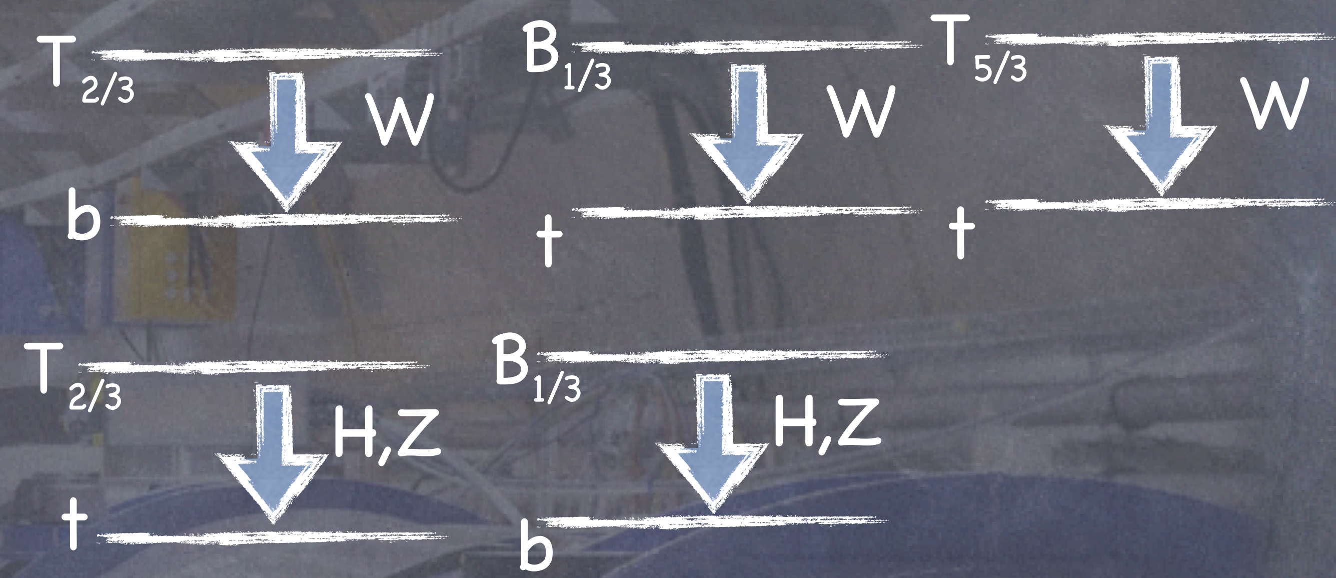
Boosted Jets



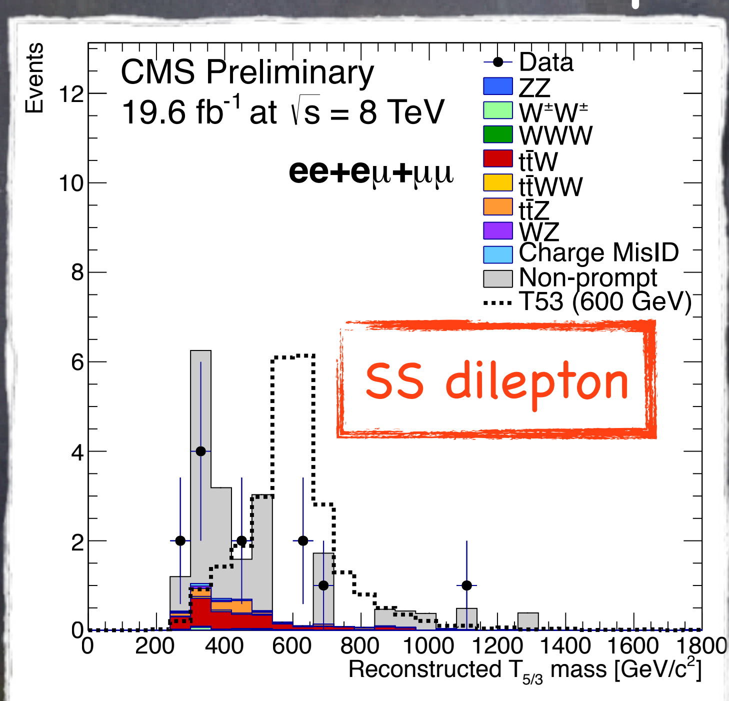


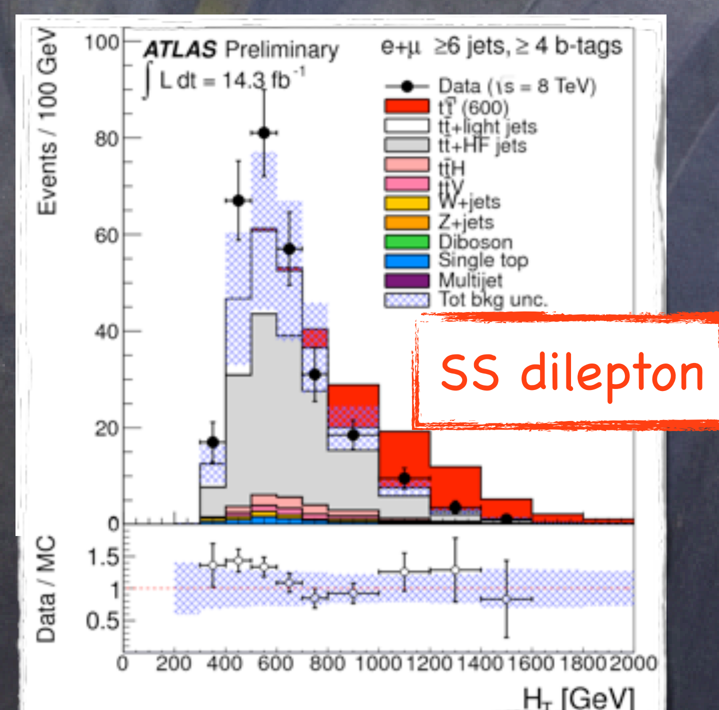
Top&Bottom Partners

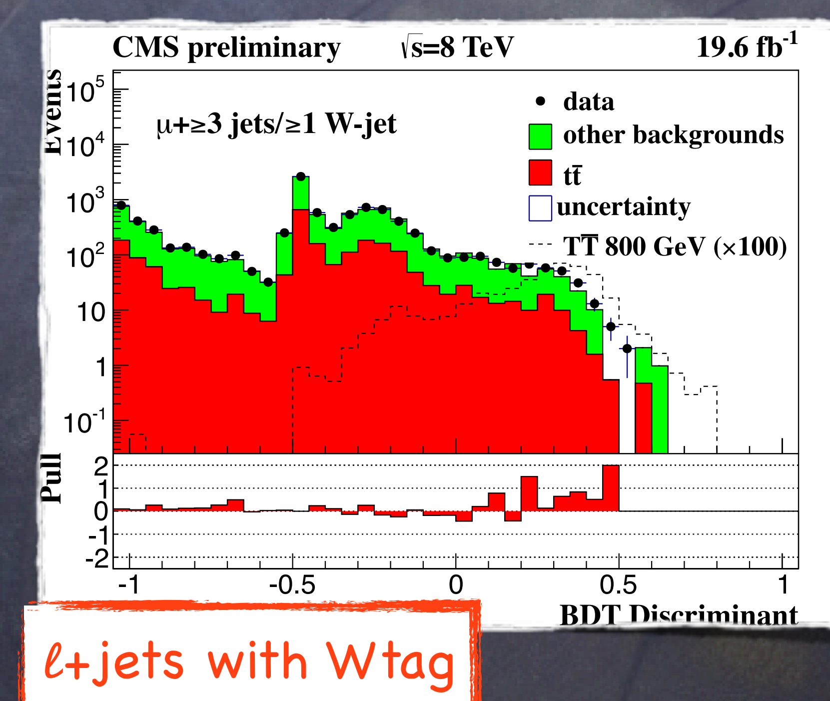
- New heavy colored objects decaying to a b or t + one boson (W,Z,H)
- Searched for mainly in pair production, with both merged or resolved decay products



- Different techniques (exclusive vs inclusive vs multivariate analyses)



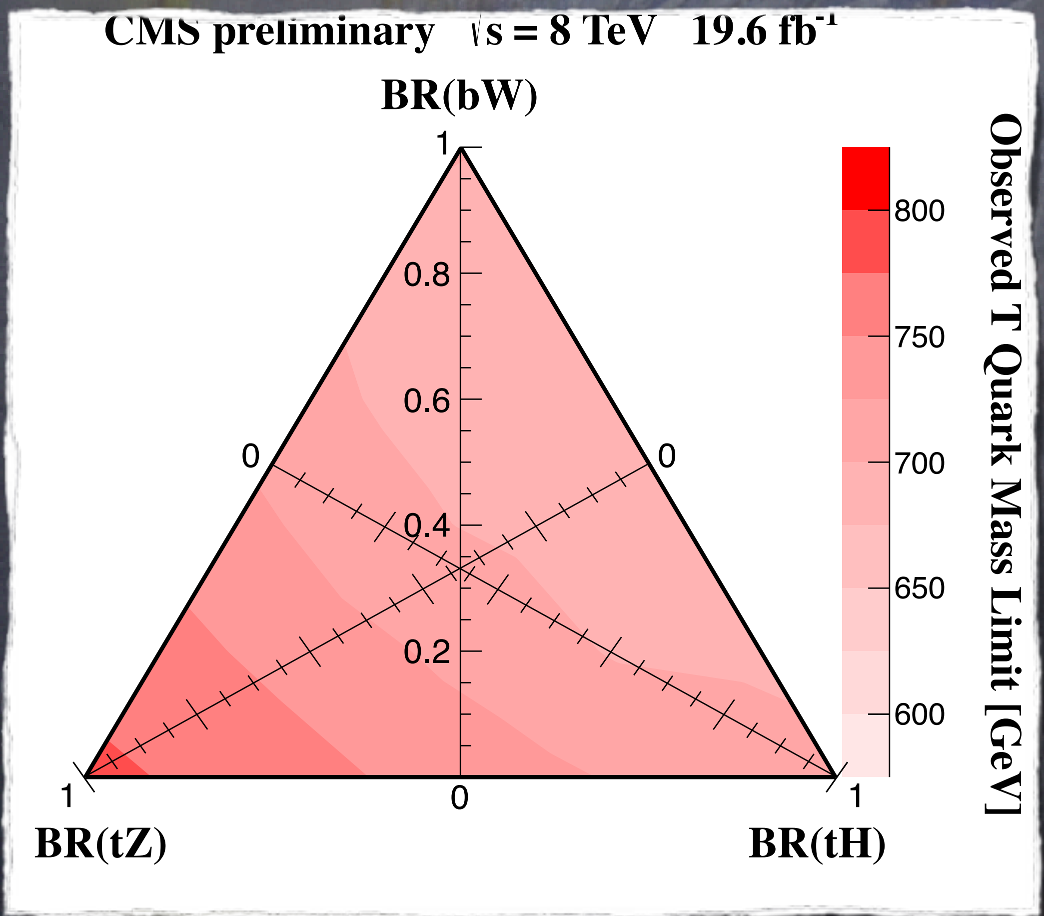


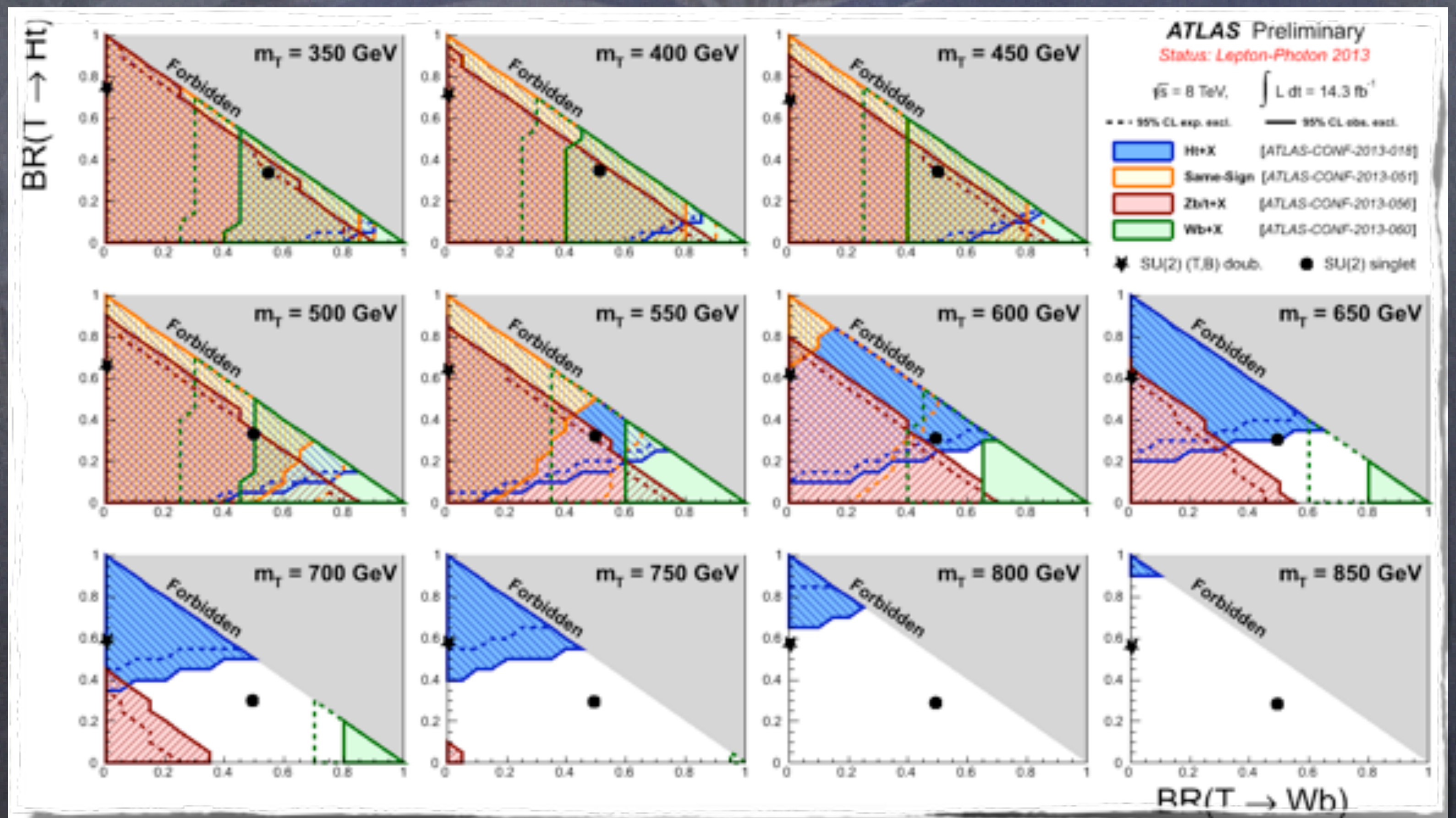


- When possible, exploit number of btags to suppress SM backgrounds

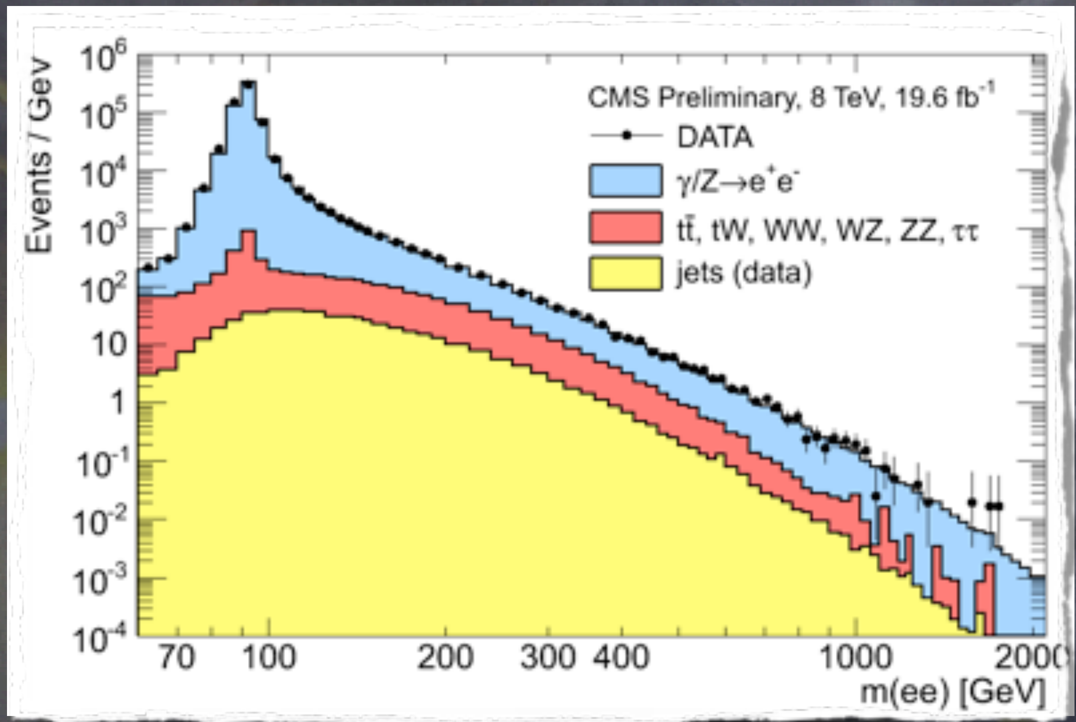
Top&Bottom Partners

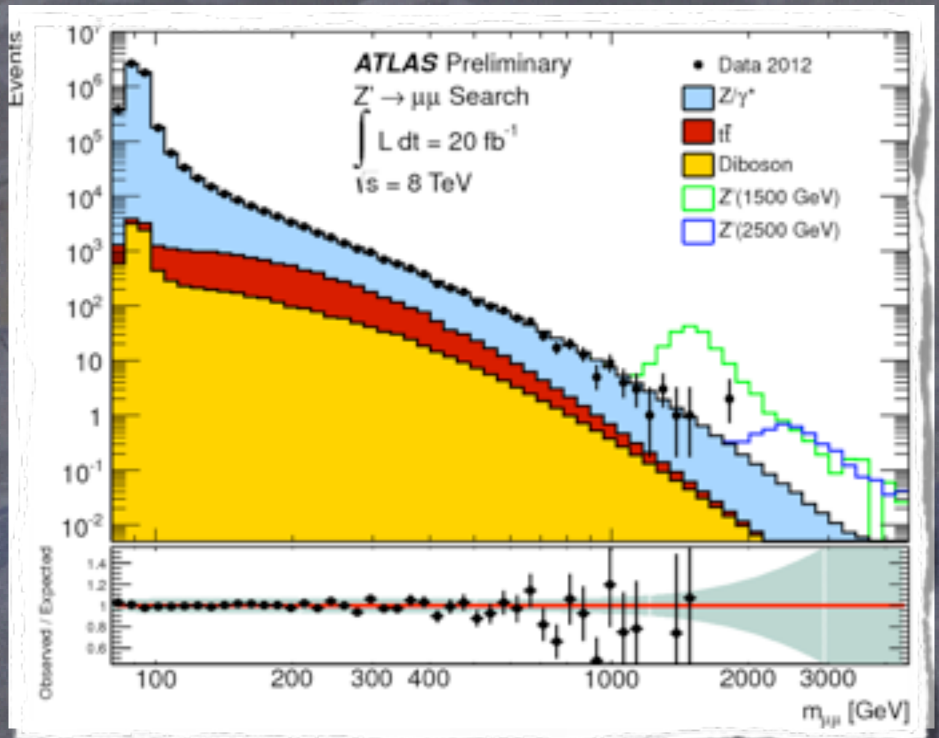
The limit is studied vs the BR to the three open channels
Plane fully explored for masses ~ 600 GeV
Masses up to 800 GeV excluded for some BR choice

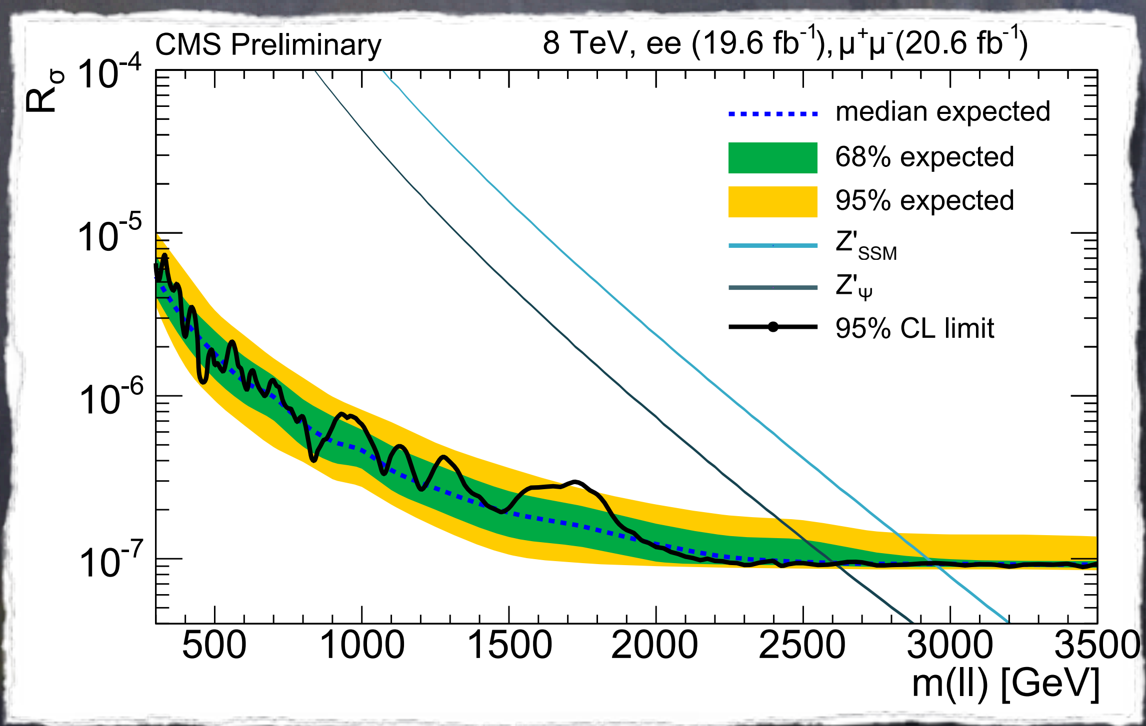


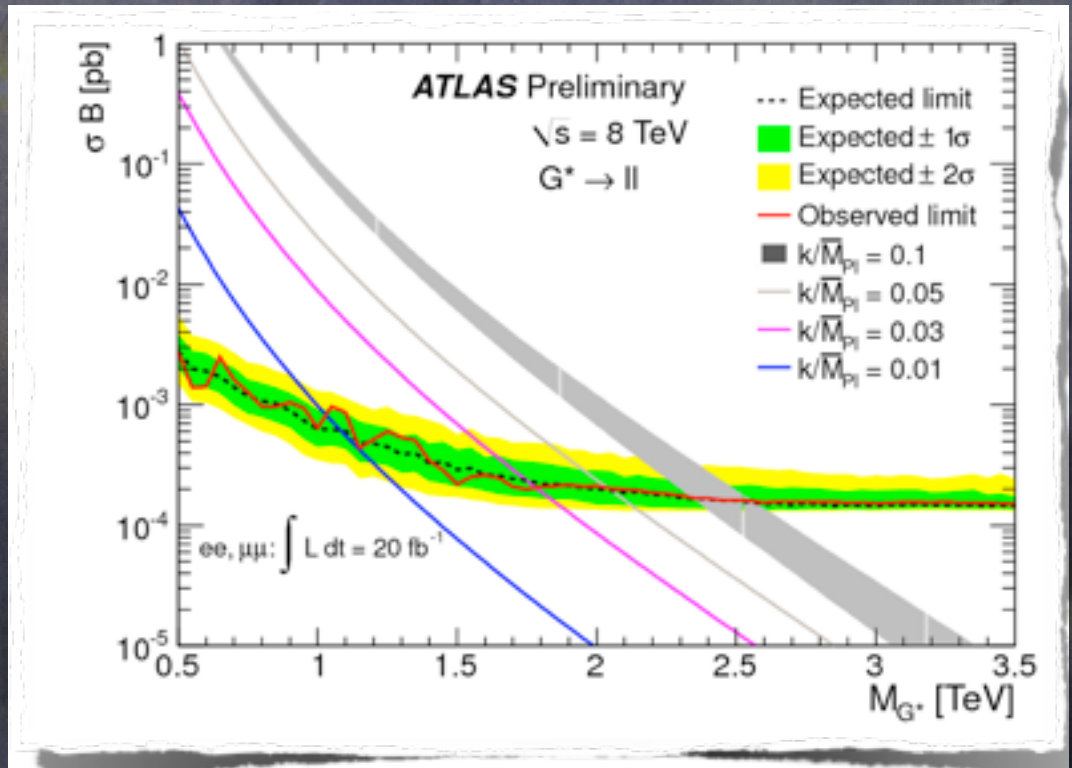


Resonances to $\ell\ell$



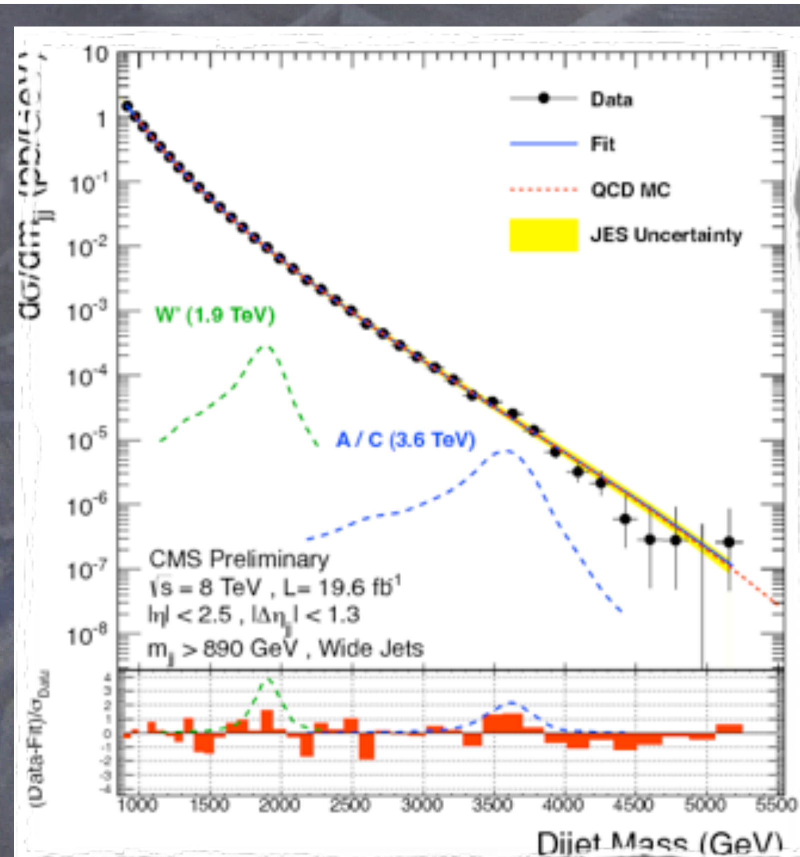


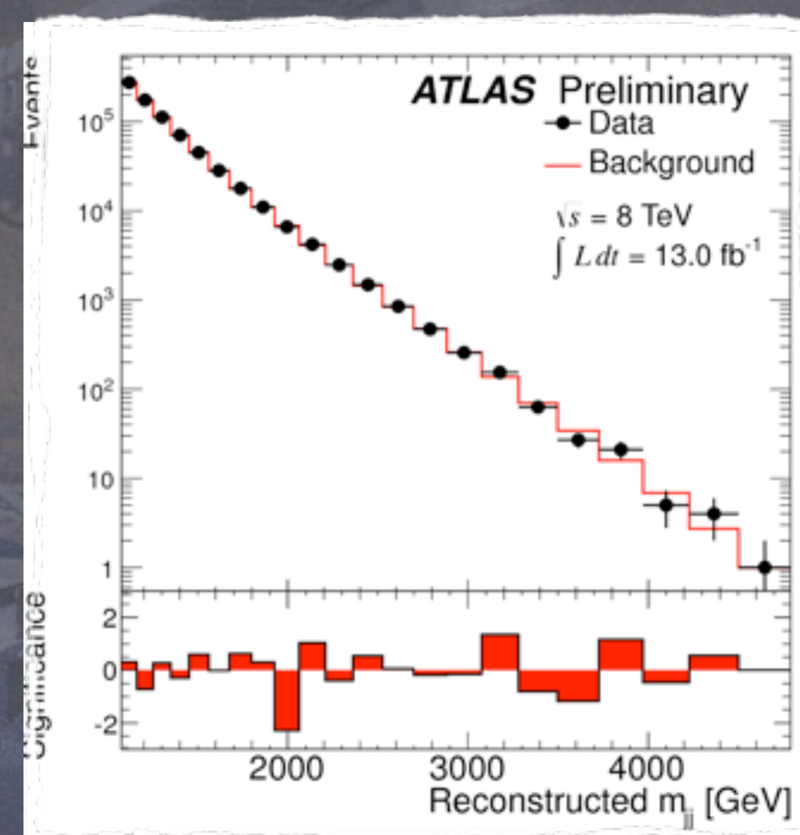


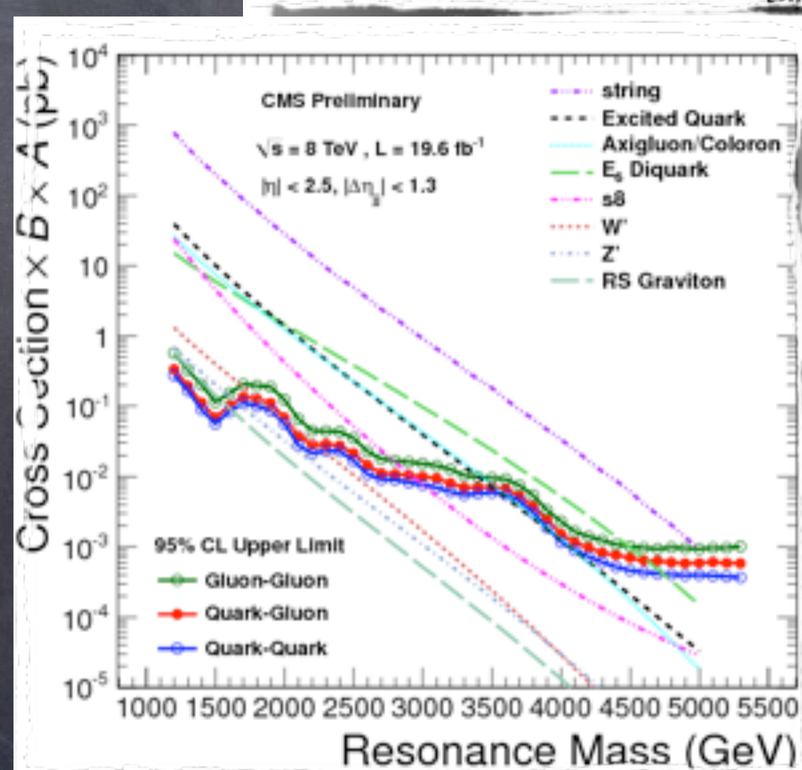


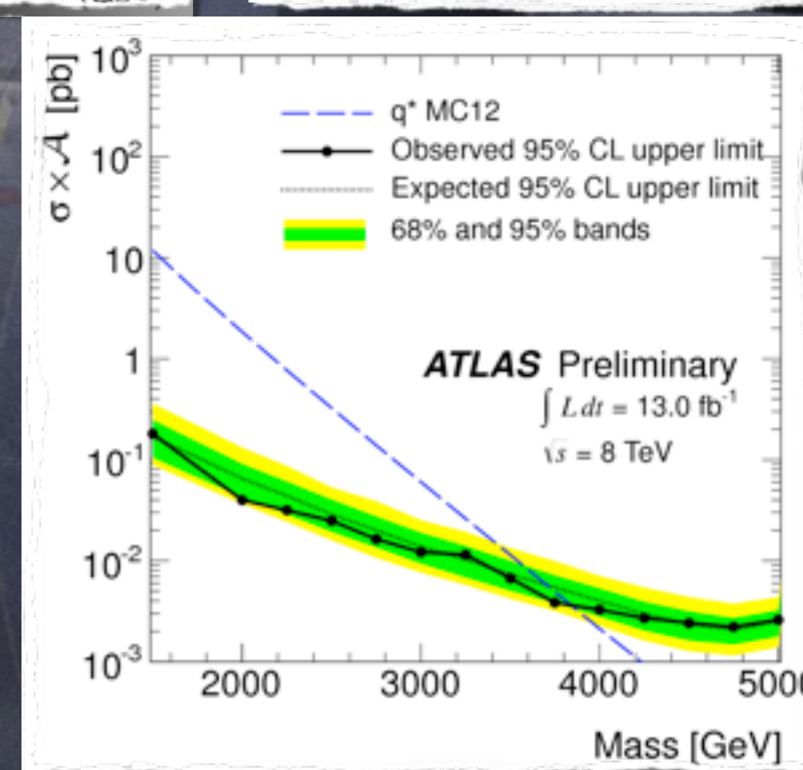
Resonances to dijet

Results in agreement with SM until 5 TeV (highest explored energy)









The Next Run

What Next?

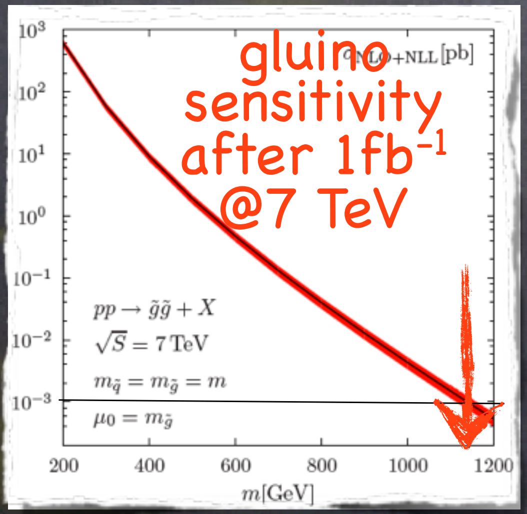
For the restart

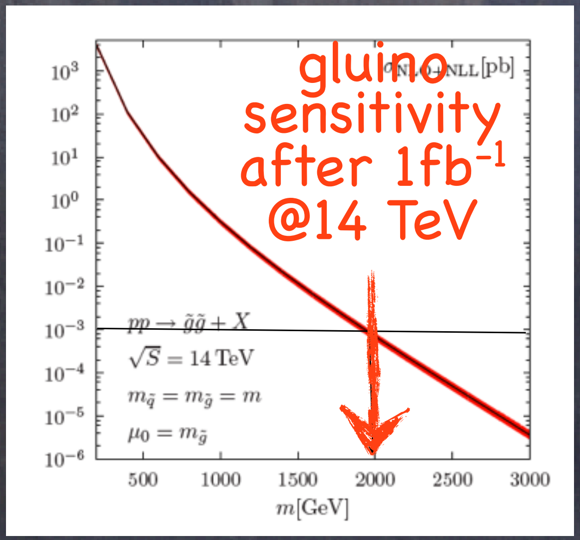
We will most likely have a rump-up as fast as for Run-I (experienced gained operating the LHC and the detectors)

We will benefit immediately of the higher energy to probe the existence of heavy objects

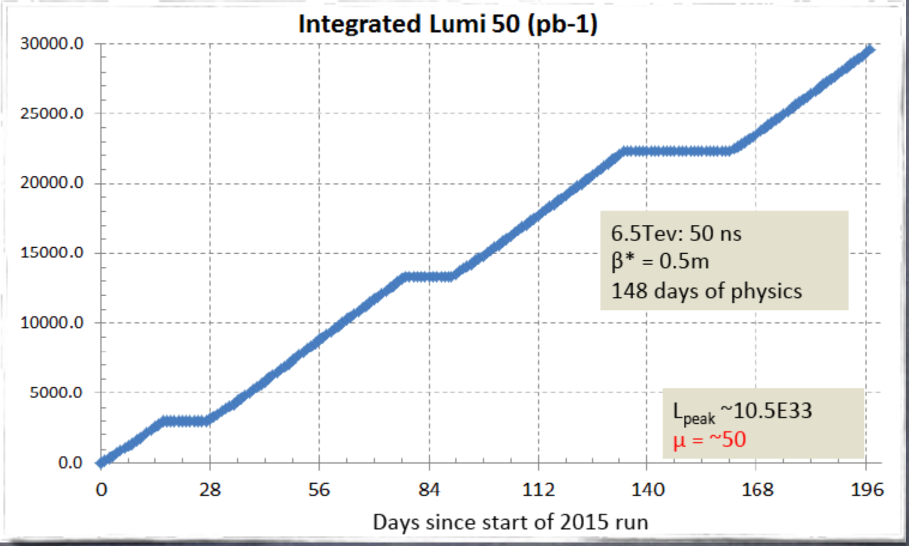
Cumulating more data on the longer term we will also improve the intermediate mass range

We will get to the sensitivity of Run-I after the first 1-3 fb^{-1}

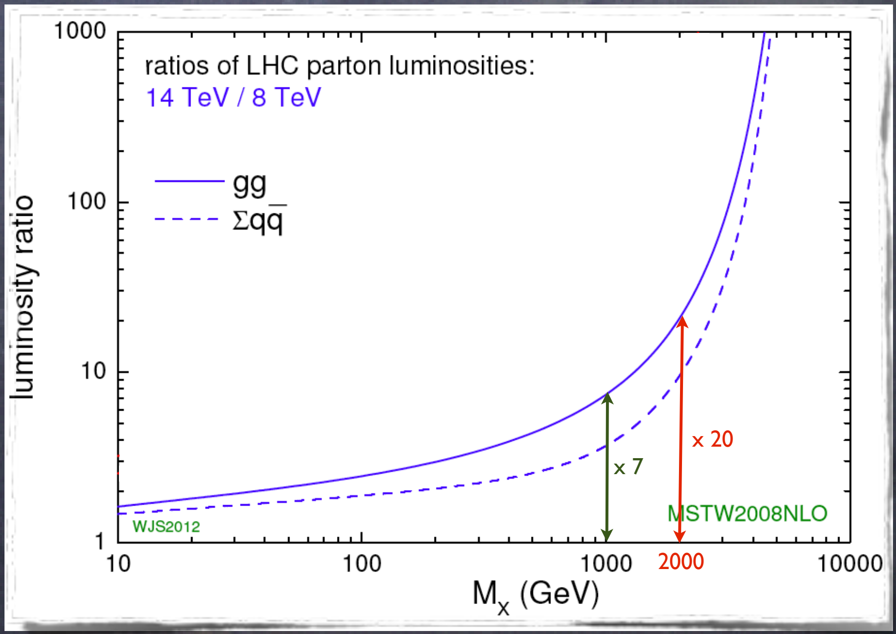




estimated performances for 50 ns collisions@13 TeV



The gain in energy is particularly pronounced for heavy objects



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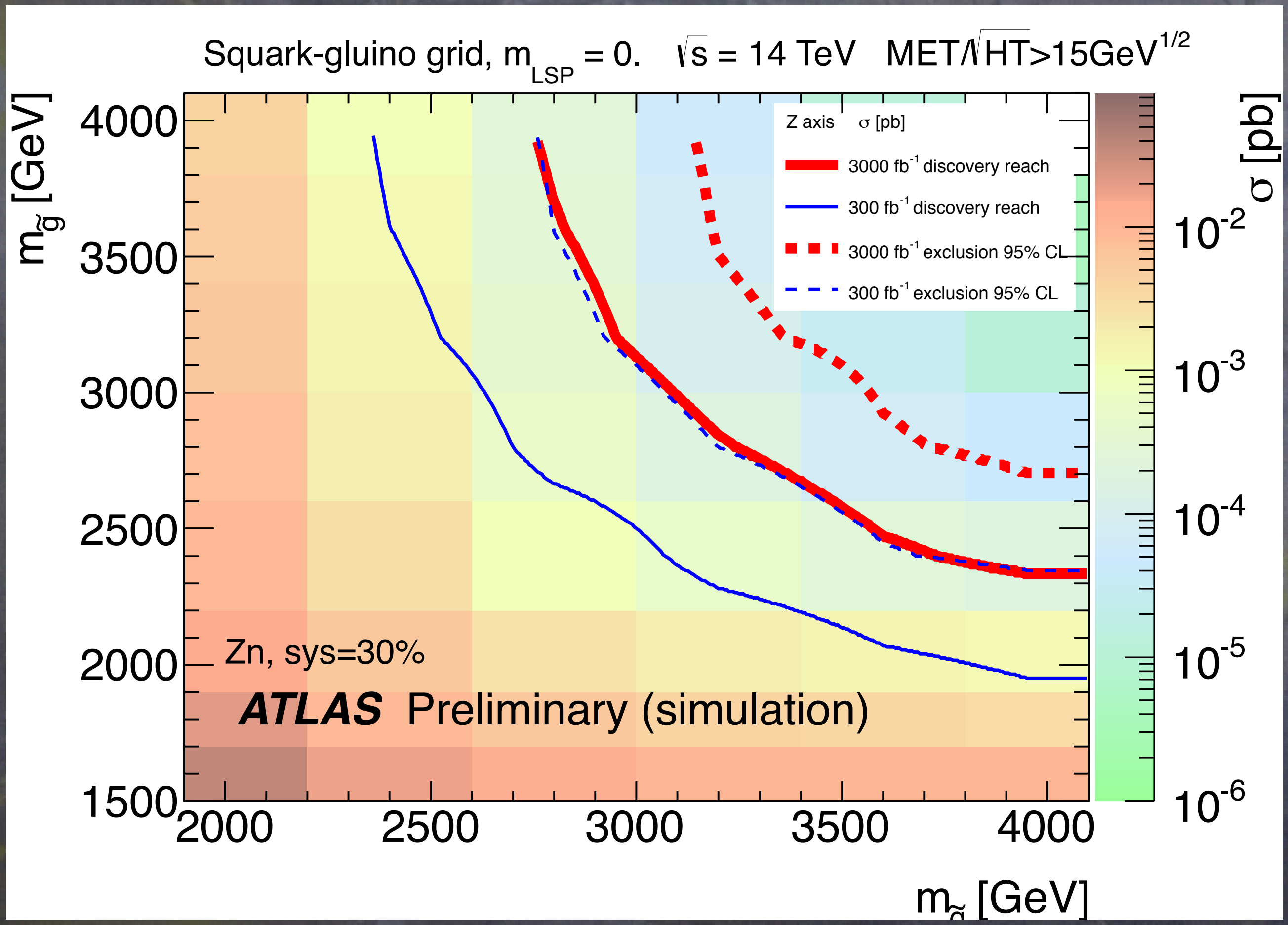
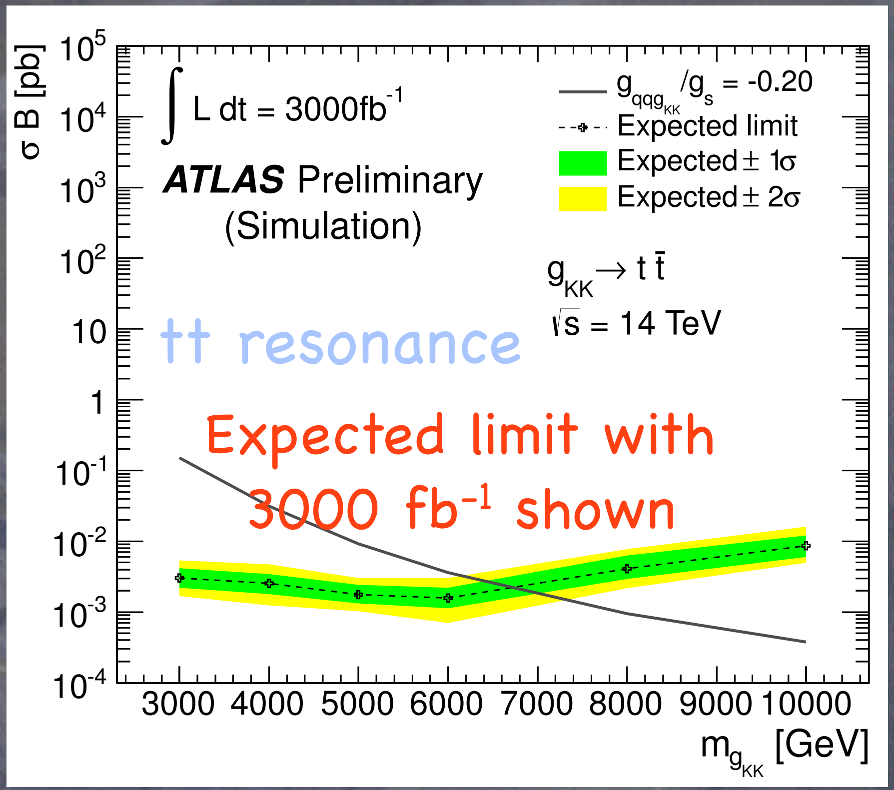
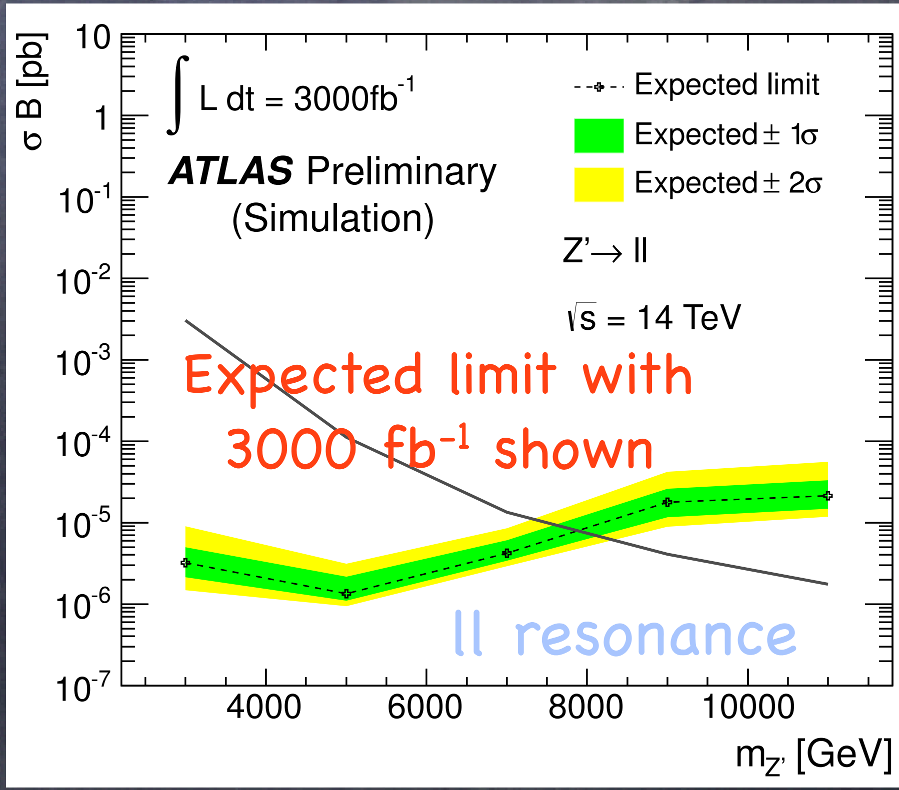
Snowmass Extrapolations

- Dominated by physics backgrounds Z(νν)+jets and top pairs
- Large missing energy requirement robust against pileup



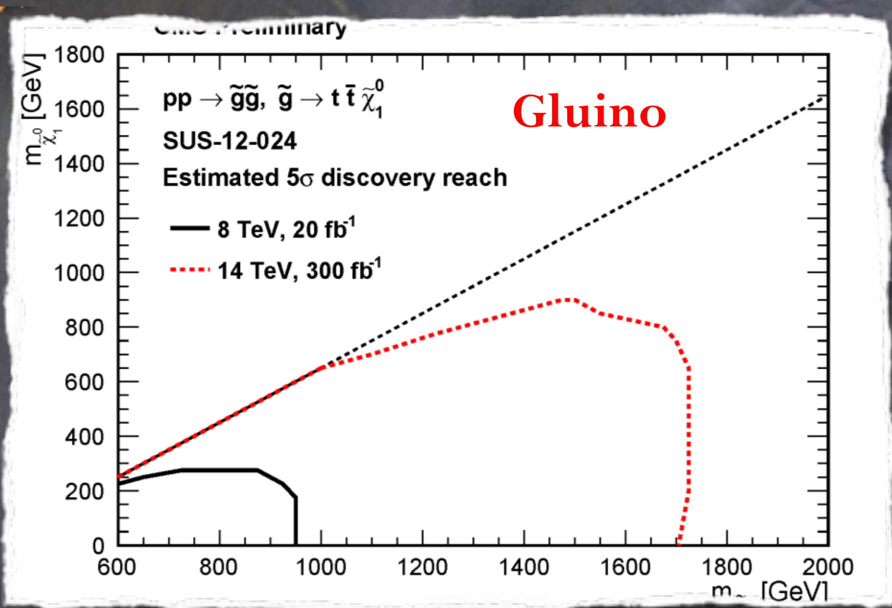


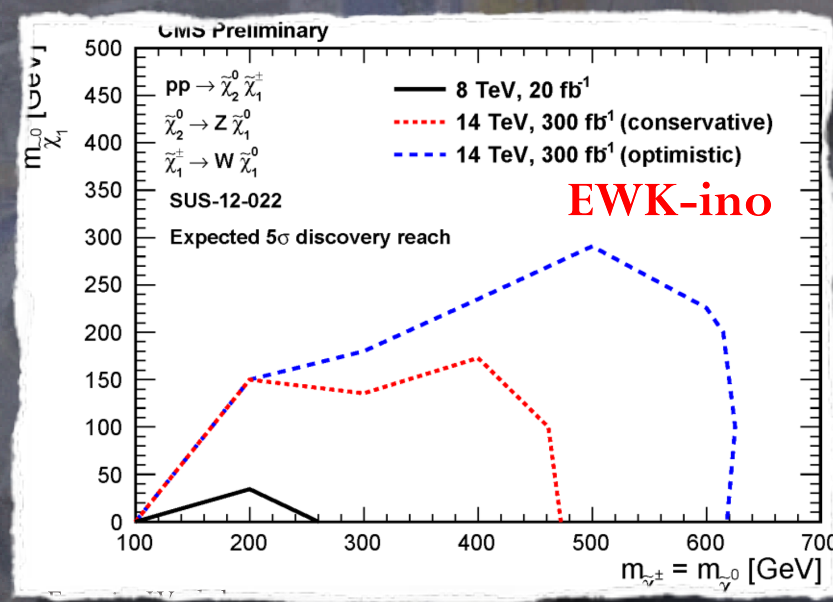


Similar extrapolations from CMS

Snowmass Extrapolations

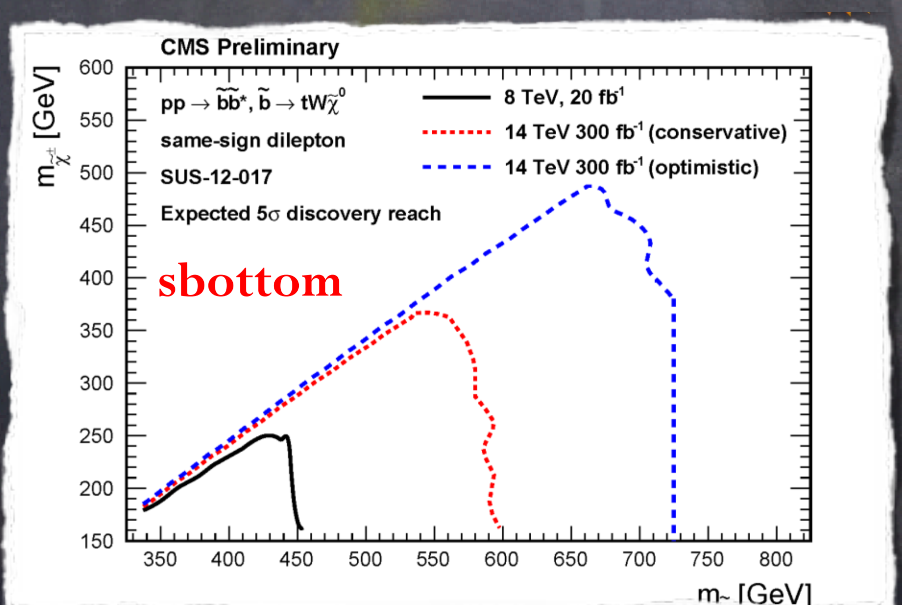
- Extrapolated with pessimistic (same systematics as now) and optimistic (scale systematics with luminosity) models
- The true value should be in the middle
- 5σ discovery reach shown

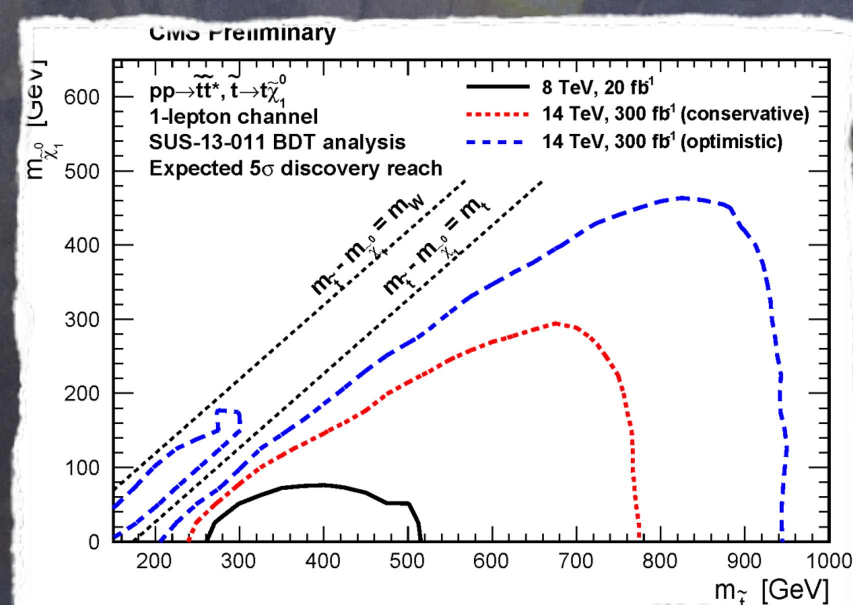




5σ discovery reach

- Guino: up to 1.7 TeV
- Sbottom: ~600 – 700 GeV
- EWK-ino: ~500 – 600 GeV





Similar extrapolations from ATLAS

Summary

- No evidence of new physics so far
- We improved the techniques and we learned a lot. It was a good training exercise for the next run (and we got the Higgs "for free")
- We are still looking at the 8 TeV data extending the searches to the unexplored (and more difficult) corners
- We will have 1 year to plan in advance the analysis of the first fb-1 of 13 (?) TeV collisions and then the long term high-statistics analyses

References

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

Backup

dE/dX in the tracker

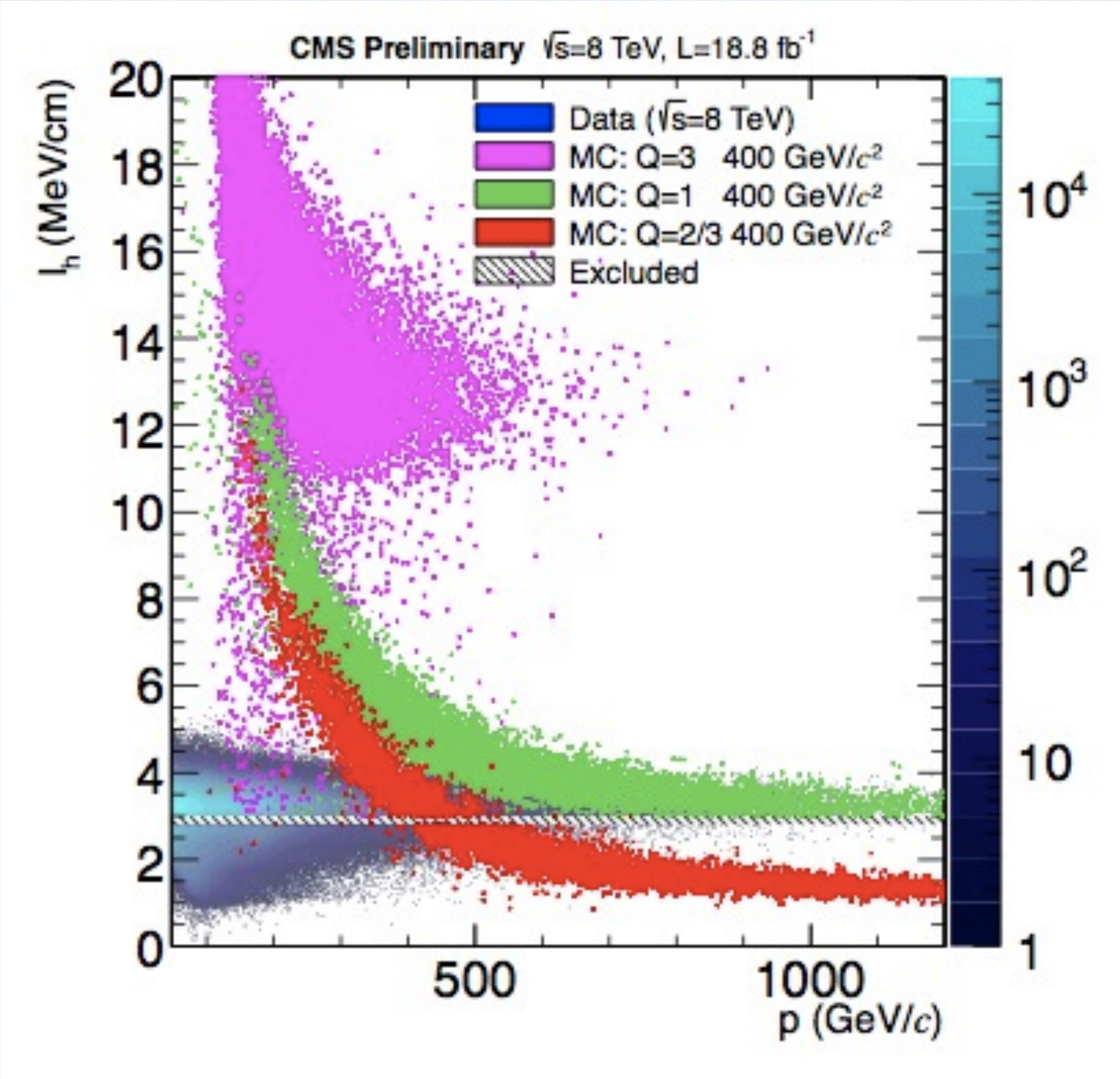
- Measure the charge released in the tracker
- Compute ionization, which gives a measurement of p/m through charge-dependent empirical coefficients

charge/unit path (fixed k=2)

$$I_h = \left(\frac{1}{N}\sum_i c_i^k\right)^{1/k} = K\frac{m^2}{p^2} + C$$

empirical coefficients

Ih vs pT distributions provides S vs B discrimination



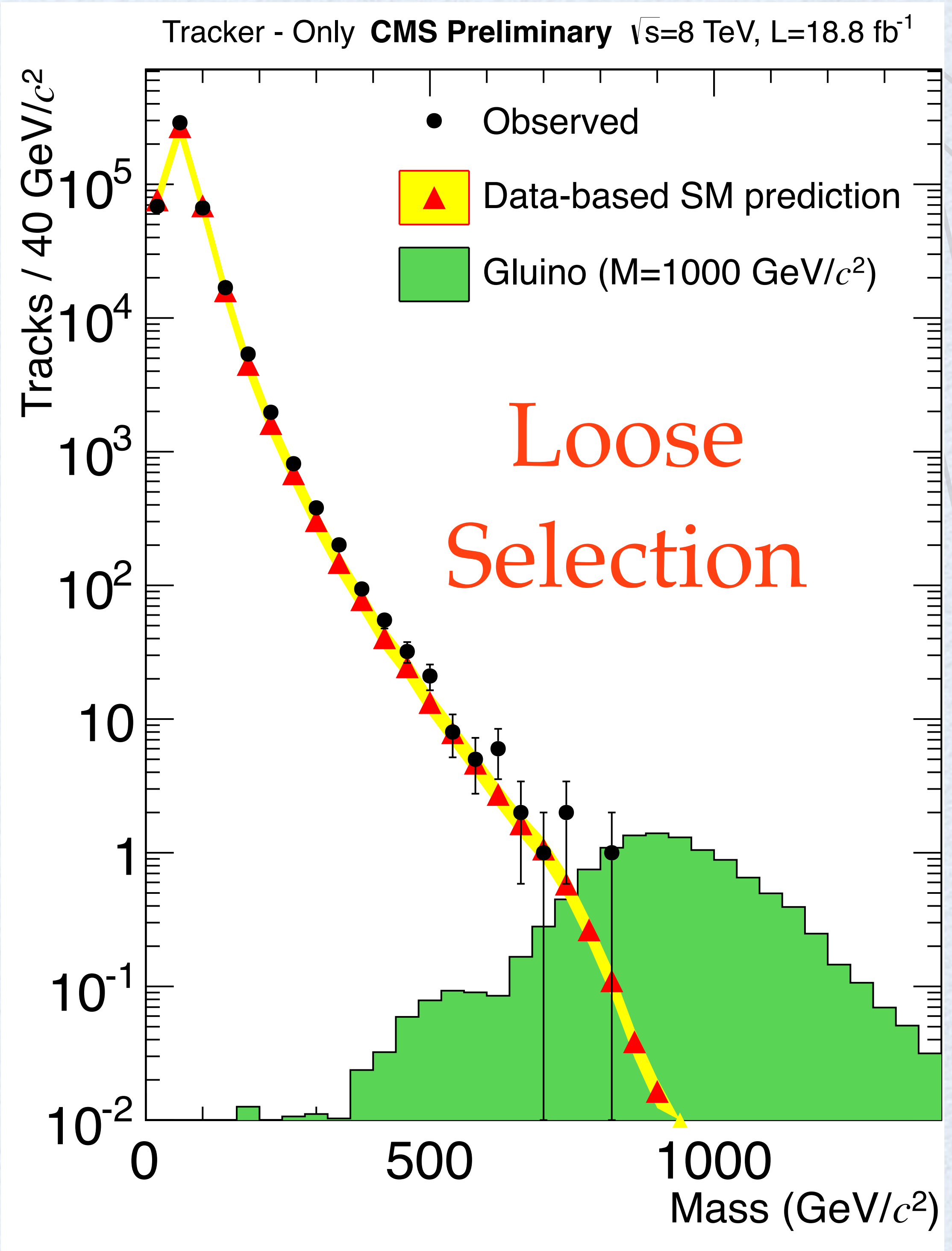
dE/dx in the Tracker

- Additional discrimination from p-value of MIP-ionization pdf (for data-driven BKG determination)

probability MIP to produce <= observed ionization

$$I_{as} = \frac{3}{N} \times \left(\frac{1}{12N} + \sum_{i=1}^{N} \left[P_i \times \left(P_i - \frac{2i-1}{2N} \right)^2 \right] \right)$$

- Measurement of mass from the knowledge of $I_h(p)$ [measured on data sideband]



TIME OF FLIGHT

- Use arrival time in the muon chambers to measure the TOF

- For a single hit determines β^{-1}

$$\beta^{-1} = 1 + \frac{c\delta_t}{L}$$

- For a track, weighted average of the single hits

$$w_i = \frac{(n-2)}{n}\frac{L_i^2}{\sigma_{DT}^2}$$

$$w_i = \frac{L_i^2}{\sigma_i^2}$$

DTs ($\sigma \sim 3$ ns)

CSCs ($\sigma \sim 7$ ns for cathode, 9 ns for anode)

For both $\sigma(\beta^{-1}) \sim 0.07$