New physics at the LHC

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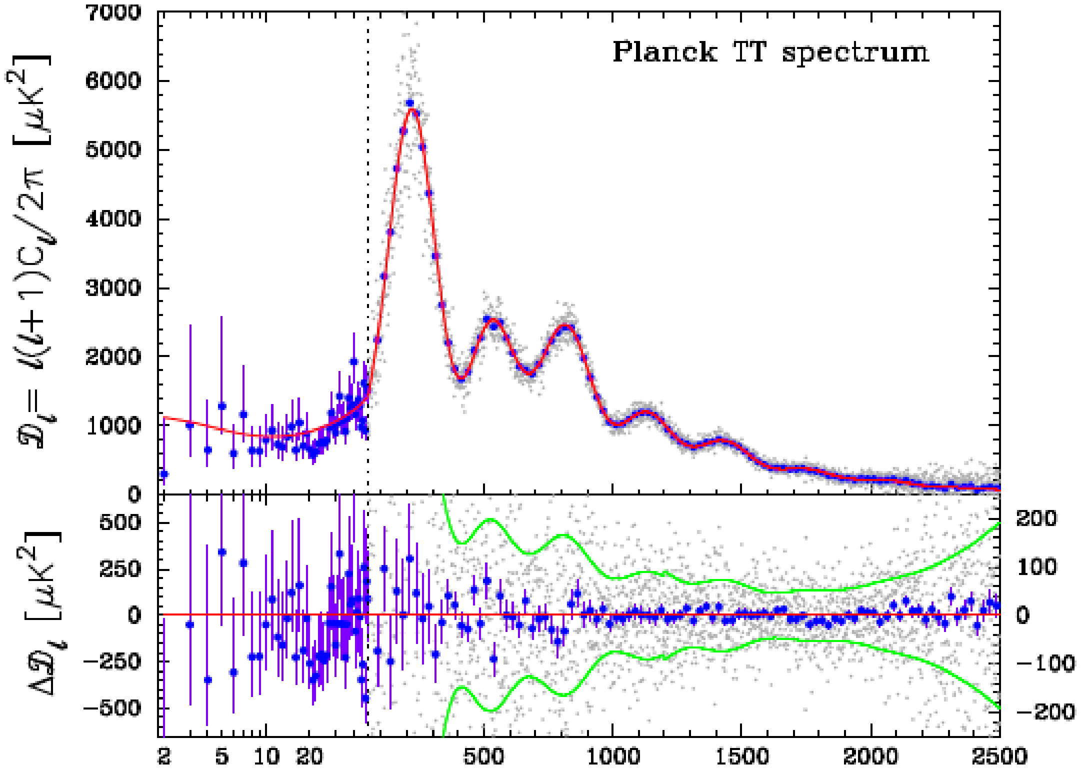
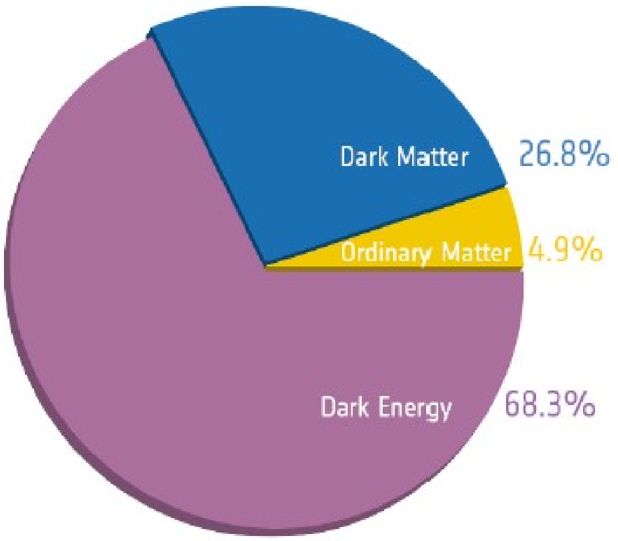
Motivations for going beyond Standard Model

- Observations unexplained by SM
  - Dark matter problem
  - Matter-antimatter asymmetry problem
- Fine-tuning problems
  - Hierarchy problem associated with Higgs
  - Flavour problem
  - Strong CP problem
- "Why so" puzzles
  - Charge quantisation
  - Gauge coupling unification
  - Proton stability
  - Fermion mass hierarchy
  - Why three generations

Amount of Dark matter in the universe





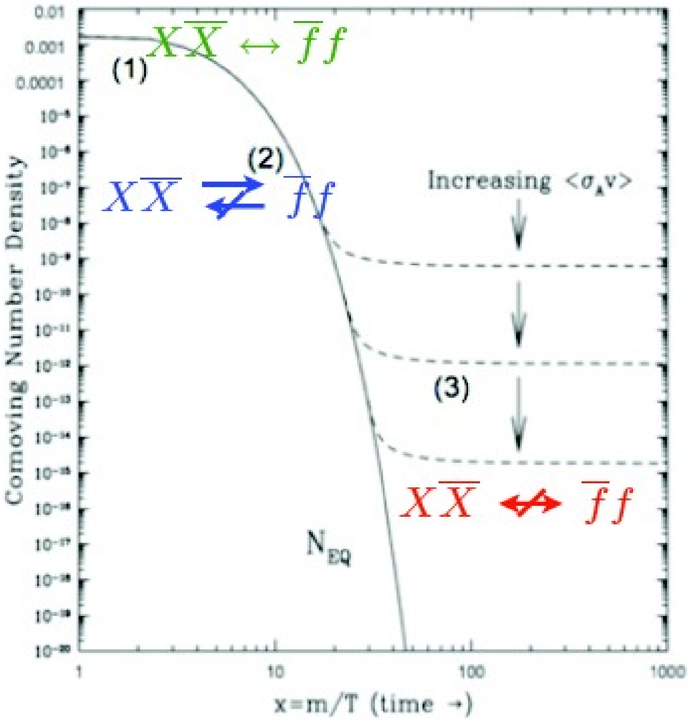
Extremely precise results on Dark Matter abundance from measurement of anisotropies in Cosmic Microwave Background (CMB)

If Dark Matter is made of Weakly Interacting Massive Particles (WIMP), what we observe is the relic abundance of these particles after the cooling of the universe

The "WIMP miracle": DM may be relevant for LHC

The WIMP relic abundance follows from the generic thermal freeze-out mechanism in the expanding universe

$$\dot{n} + 3Hn = -\langle \sigma v \rangle (n^2 - n_T^2)$$



freese-out :

$$H \sim \frac{\sqrt{g}T^2}{M_P} \sim \Gamma = n\sigma v$$

Thermal relic: $\Omega h^2 \propto 1/\langle\sigma_{anni} v\rangle$

$\Rightarrow \langle\sigma_{anni} v\rangle \approx 1$ pb

$\sigma \sim \alpha^2/m^2$

$\Rightarrow m \sim 100$ GeV

The "WIMP miracle"

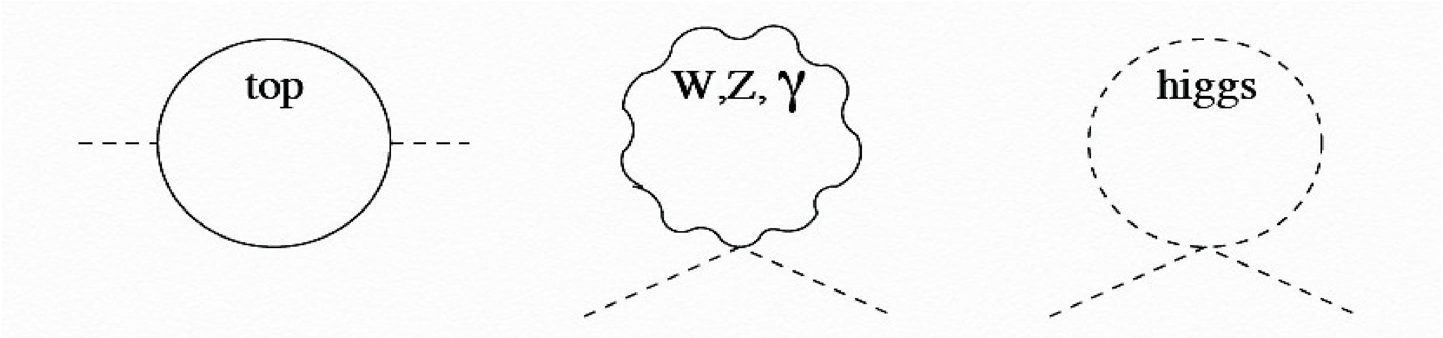
$$\Omega_{DM} \approx \frac{O(1)\ \text{pb}}{\sigma_{anni}}$$

→ a particle with a typical EW-scale cross section

$\sigma_{anni} \approx 1$ pb leads to the correct dark matter abundance.

The naturalness problem

Key assumption: SM is Effective Field Theory valid up to scale Λ >> TeV
Radiative corrections to Higgs mass:



+smaller Yukawa

$$\delta m_H^2 = \frac{3\Lambda^2}{8\pi^2 v^2}\left(2m_W^2 + m_Z^2 + m_H^2 - 4m_t^2\right) \sim -(0.23\ \Lambda)^2$$

If Λ=5 TeV already need cancellation between tree level and radiative corrections of 2 orders of magnitude

We have observed a 125 GeV scalar

We need to understand why it is so light

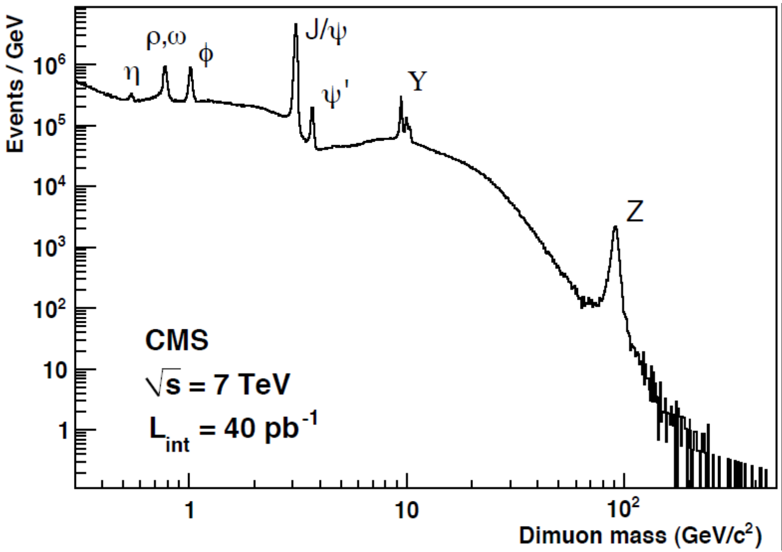
All proposed solutions imply new physics at the TeV scale

Search for this physics high priority at the LHC

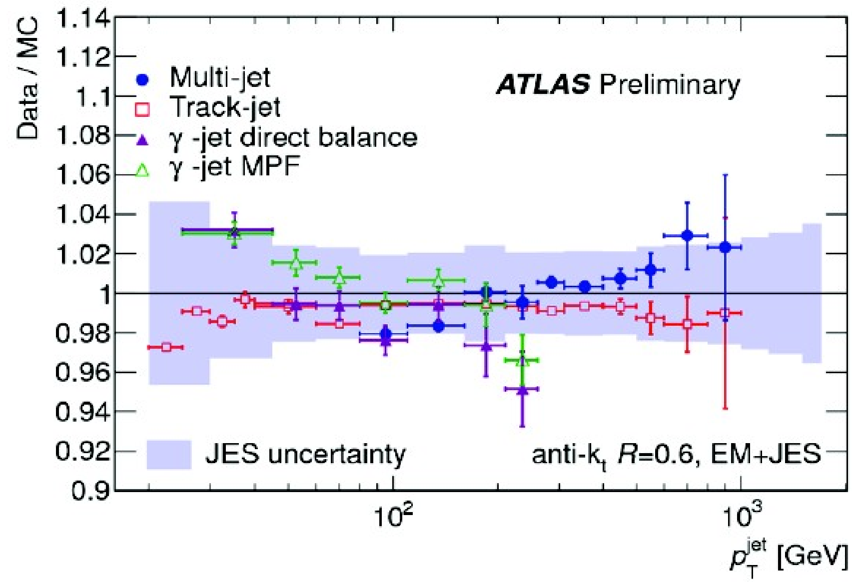
Discovering new physics: preliminaries

- Once good data on disk:
  - Calibration has to be determined and applied
  - Detector objects to be reconstructed
  - Reconstructed data to be made available on the grid
    - Complete calibration loop within 48 hours of data taking
- Starting from reconstructed data, two steps necessary before going for new physics searches:
  - Understanding of detector performance for main objects: leptons, jets, photons, b-jets, τ-jets, Etmiss
  - Measurements of Standard Model processes to ensure that our detector understanding is adequate to look for deviations

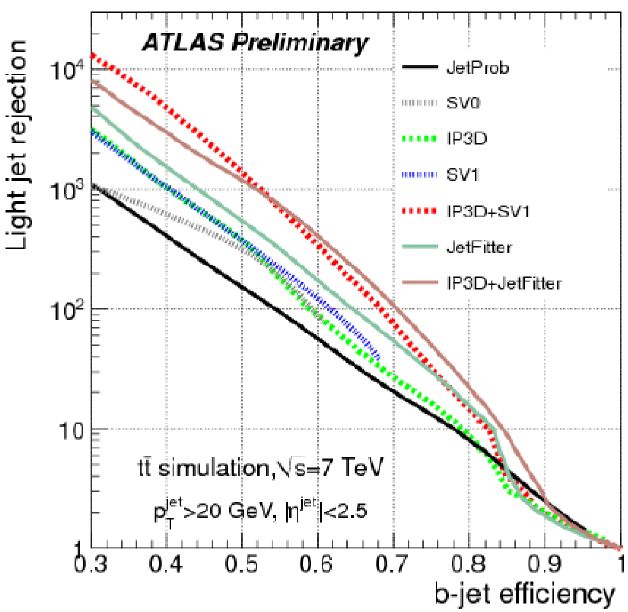
Performance examples



Leptons: need excellent id capabilities
And resolution

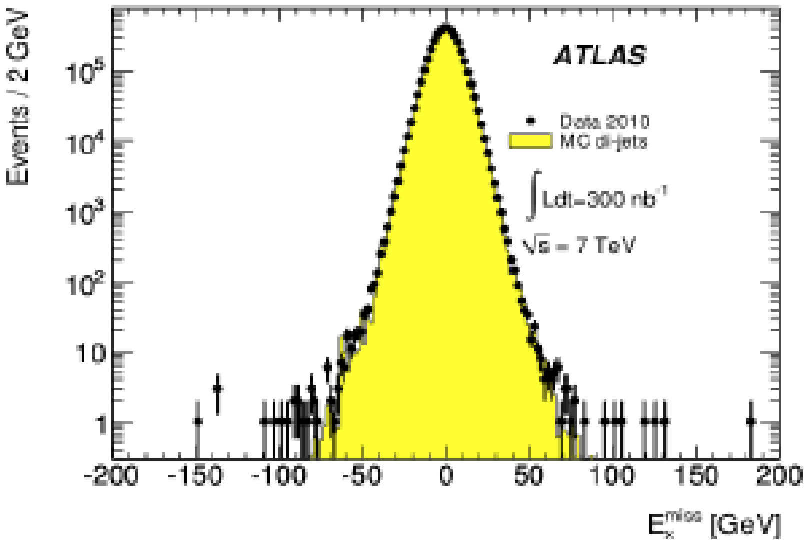


Jet energy scale to 2-4% for
Jet PT>20 GeV



B-tagging: key to detailed searches
Advanced methods validated with 2011 data
For 60% efficiency rejection of several hundreds
On light jets

Etmiss measurement



Key ingredient in SUSY analysis

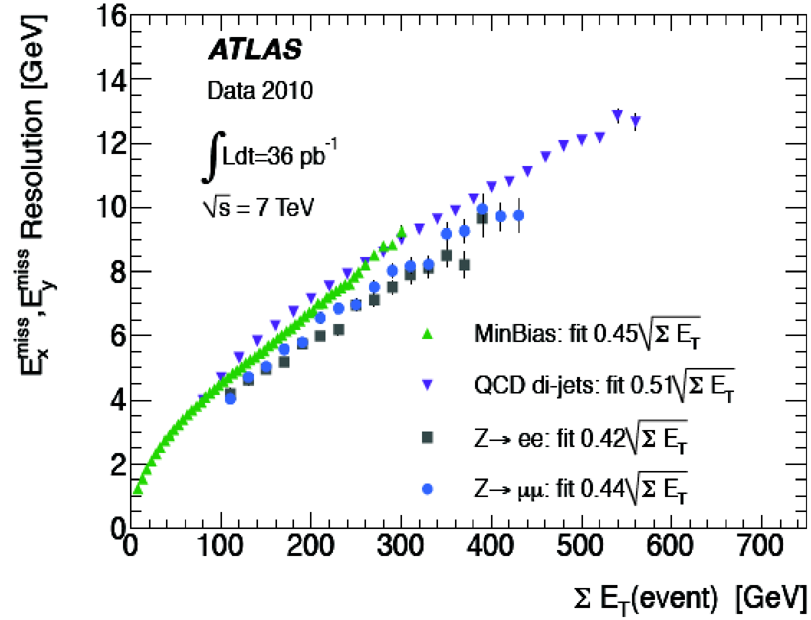
$$E_{x(y)}^{\text{miss}} = E_{x(y)}^{\text{miss,calo}} + E_{x(y)}^{\text{miss},\mu}$$

$$E_{x(y)}^{\text{miss,calo}} = E_{x(y)}^{\text{miss},e} + E_{x(y)}^{\text{miss},\gamma} + E_{x(y)}^{\text{miss},\tau} + E_{x(y)}^{\text{miss,jets}} + E_{x(y)}^{\text{miss,softjets}} + (E_{x(y)}^{\text{miss,calo},\mu}) + E_{x(y)}^{\text{miss,CellOut}}$$

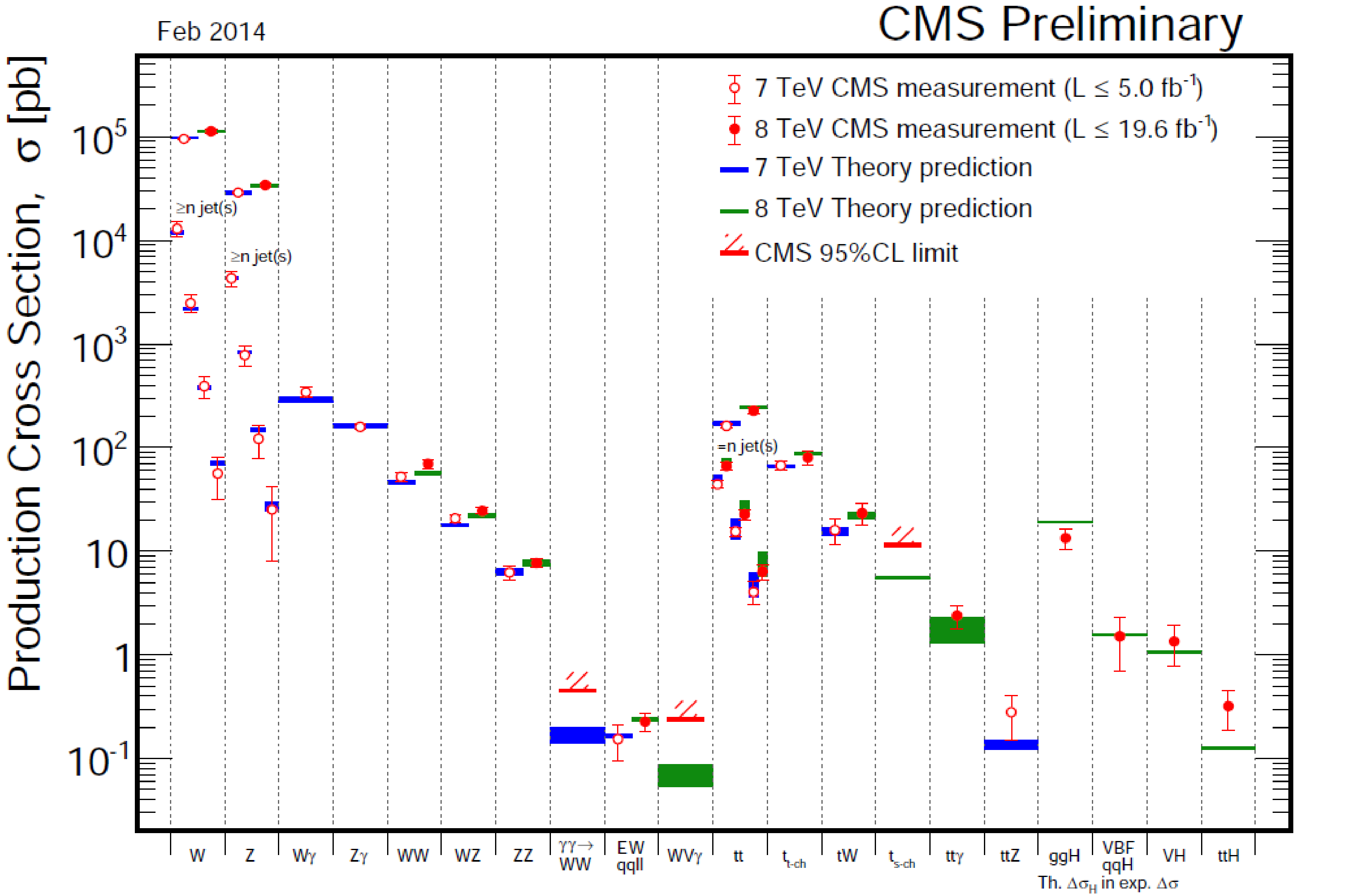
Vector sum of the measured energy deposit of all objects in the detector

Any local malfunction in the detector would Be registered as a tail in Etmiss distribution

From early data taking tails under control and measurement resolution in agreement with expected value



Standard Model measurements



No exotic source of bosons/top in excess of 10-20% of SM

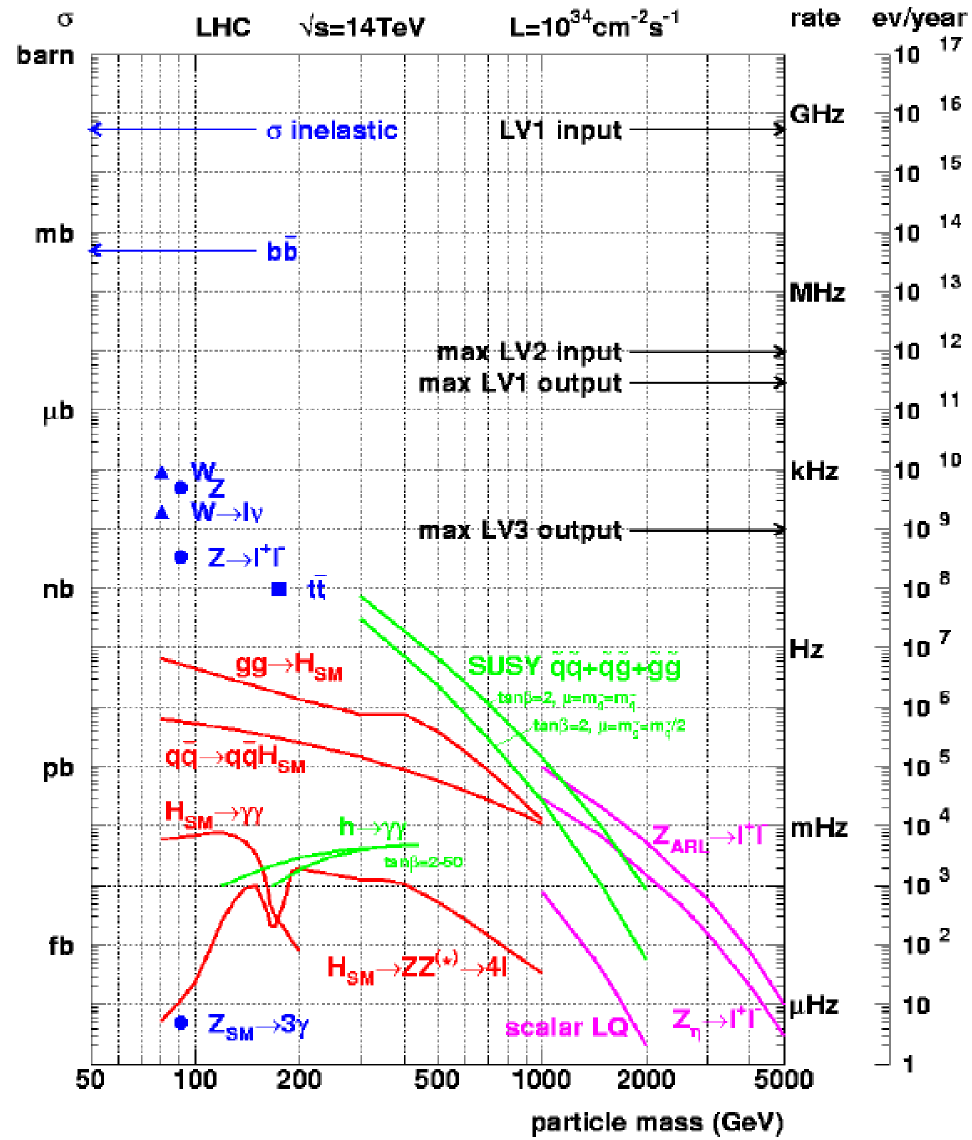
But this is only the start of the story

The problem: signal much smaller than bkg

For each signal need to devise selections reducing background by several orders of magnitude:

Need to predict SM in extreme corners of kinematic space

Necessary to complement MC with data-driven estimate

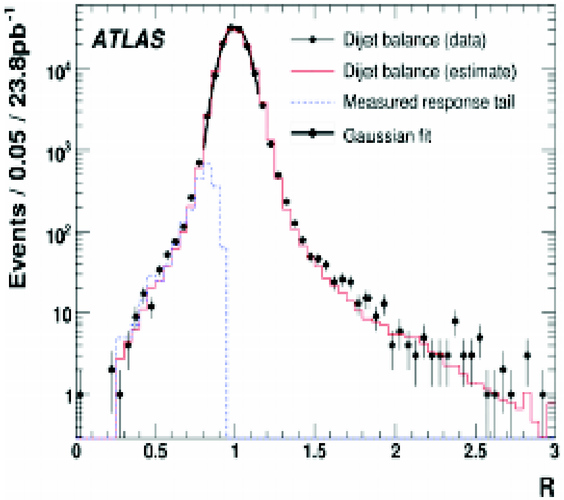


Selections and backgrounds

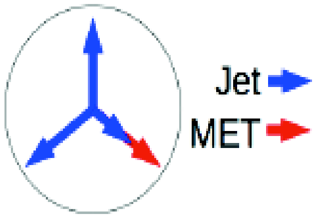
- QCD jet production overwhelming at LHC, need to add something else
- Signatures classified in terms of
  - non-QCD objects: leptons (e,μ), Etmiss, τ-jets, b-jets
  - Number of QCD jets
- For each signature two types of backgrounds
  - Irreducible backgrounds: basic signature identical to signal
  - Reducible backgrounds: mimic signature because of detector effects – examples:
    - Fake Etmiss in multijet events
    - Fake leptons
- For each type of background need to develop specific strategies

Fake Etmiss estimate

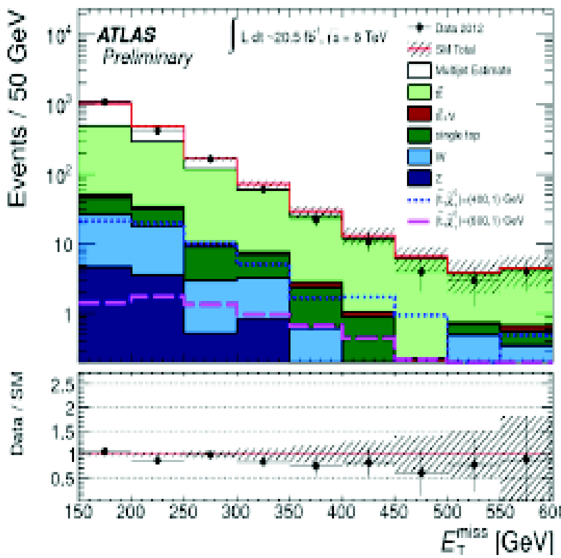
- Large E_T^{miss} can be induced by a jet mis-measurement.
- Relevant for processes with high cross section and no "real" E_T^{miss} (multi-jet, $Z \rightarrow ll$)



- Derive a **"jet response function"** from MC and **adapt it to data:**
  - **core:** p_T balance in di-jet events
  - **tail:** three-jet (Mercedes) events



- Use response function to smear jets in real data events with low MET:
  - Obtain events with large "fake" E_T^{miss}
- Validate the estimation in a dedicated control region



Fake lepton estimate

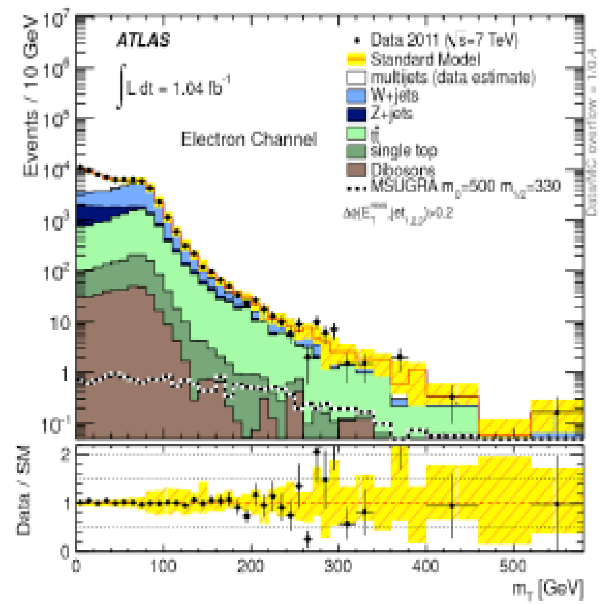
- General approach to **fake lepton background estimation** based on a loose/ tight matrix method
- Example with 1 lepton (easily extendable to multi-lepton signatures):

- A fake lepton lepton can arise from:
  - Off-axis HF semileptonic decays
  - Photon conversion

- Strategy: **define a "loose"** (pre-selected) **and a "tight"** (signal) lepton selection.
- Then, solve the following system of equations

$$N^{loose} = N^{loose}_{real} + N^{loose}_{fake}$$

$$N^{tight} = \varepsilon_{real} N^{loose}_{real} + \varepsilon_{fake} N^{loose}_{fake}$$

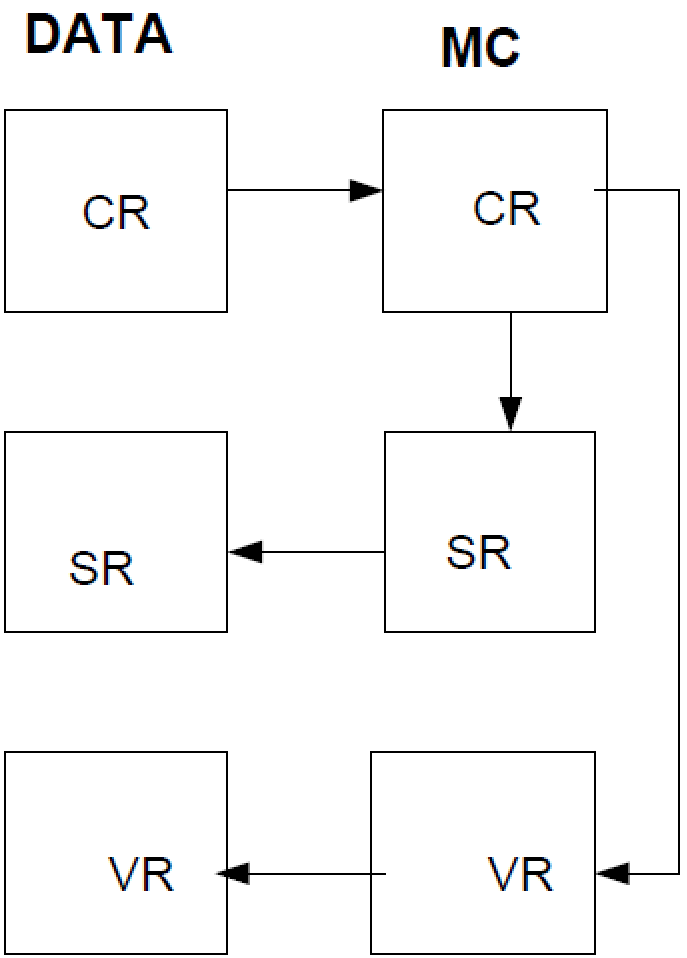


Need to be measured independently from data

Simply count how many of them

$$N^{tight}_{fake} = \frac{\varepsilon_{fake}}{\varepsilon_{real} - \varepsilon_{fake}} \left(N^{loose} \varepsilon_{real} - N^{tight} \right)$$

Background predictions: CR method



Control Region: CR
No signal expected

Signal Region: SR
Where signal is expected

Validation Region (VR)
No signal expected

Transfer factor (TF)=

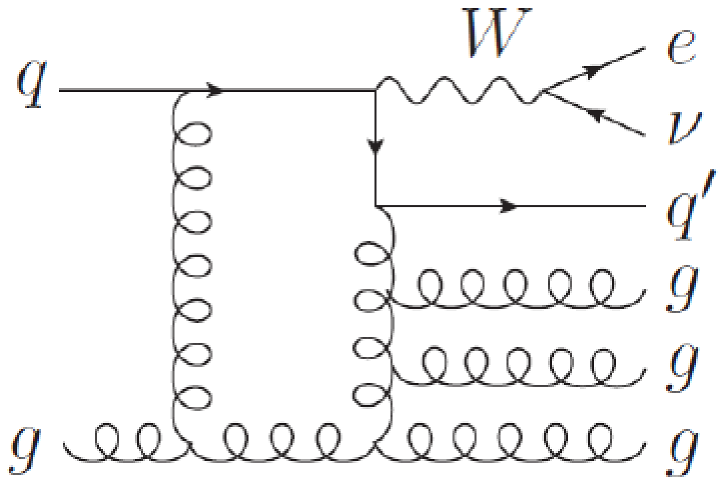
N(MC,SR)*/N(MC,CR)

N(DATA,SR)=N(DATA,CR)*TF

Key is clever Choice of CR

Estimate relies on the MC to predict TF correctly
Use VR to give you confidence on prediction

Example

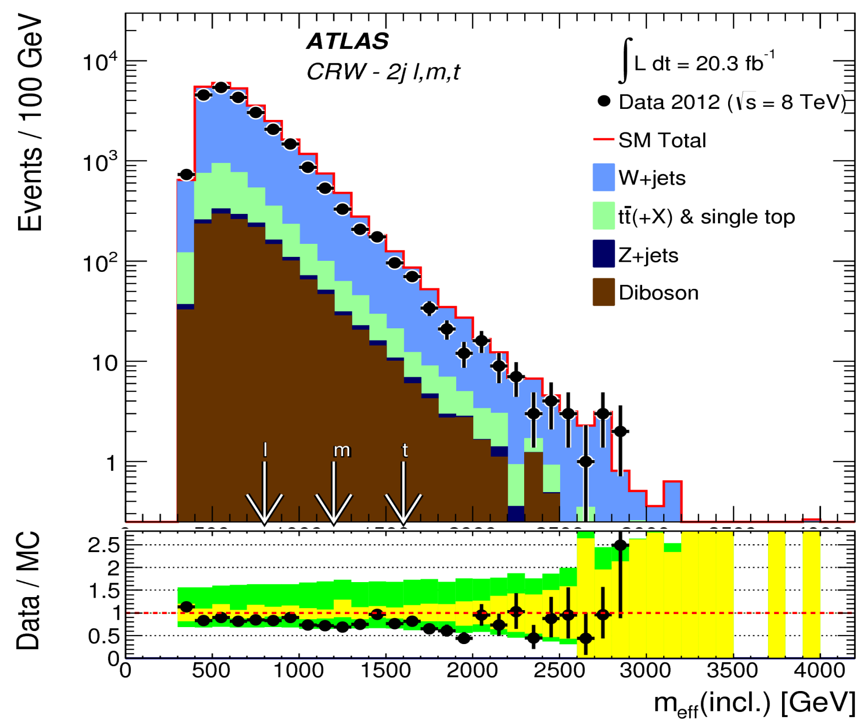


Multijet+ Etmiss:
Background from W+jets
Where lepton is not detected

- Too low pt
- Outside acceptance
- Id inefficiency

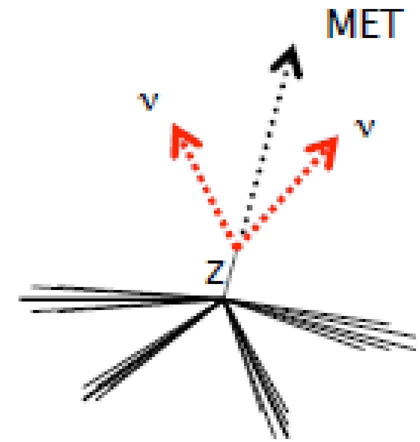
Discriminant variable:
Meff: sum of pt of jets and Etmiss

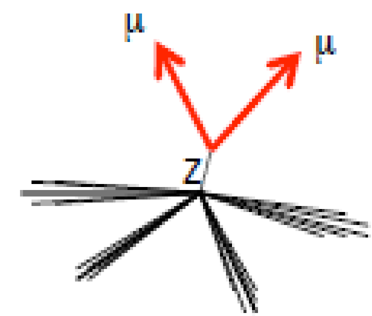
Leptonic decay of W well predicted by MC
Measure Meff in a sample with One reconstructed lepton
Predict with MC when leptons get lost



Example 2

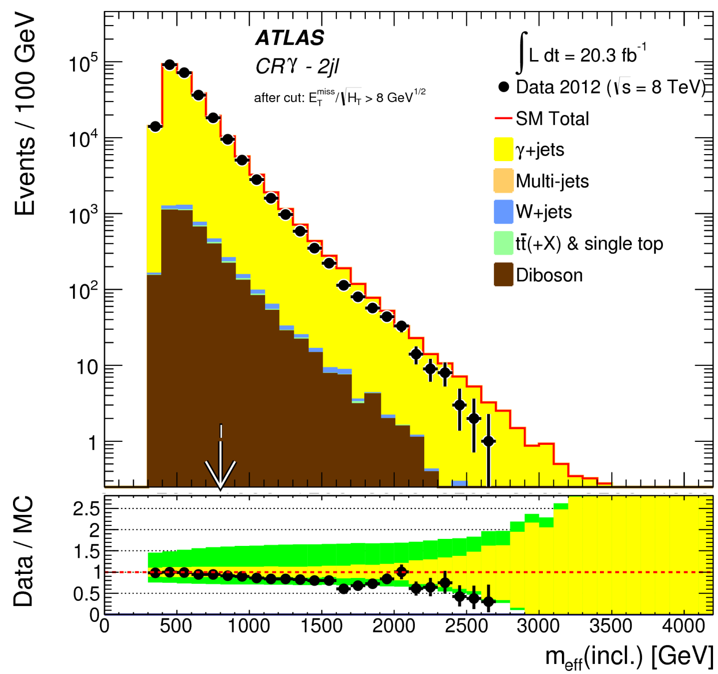
- Replacement Method: Z-> νν + jets
- Main irreducile background to multijets+Etmiss
- Apply the analysis cuts except Etmiss to a replacement process
  - Take Z->μμ and replace leptons with Etmiss
  - Take prompt photon events and replace photon with Etmiss
- Transfer the measured Etmiss spectrum in replacement process to the original process via MC

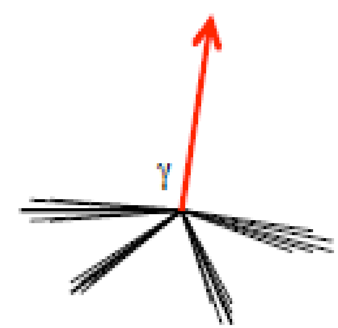




Z → ll + jets

MC still has a key role in transferring the result from the Replacement process to the original one



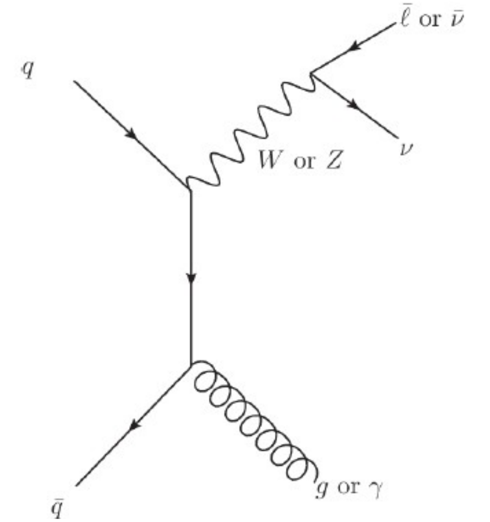


Transfer is 'easy' for Z->μμ,
And more complex for prompt Photon → Larger systematics

γ + jets

Statistical error much bigger For Z->μμ

ABCD Method

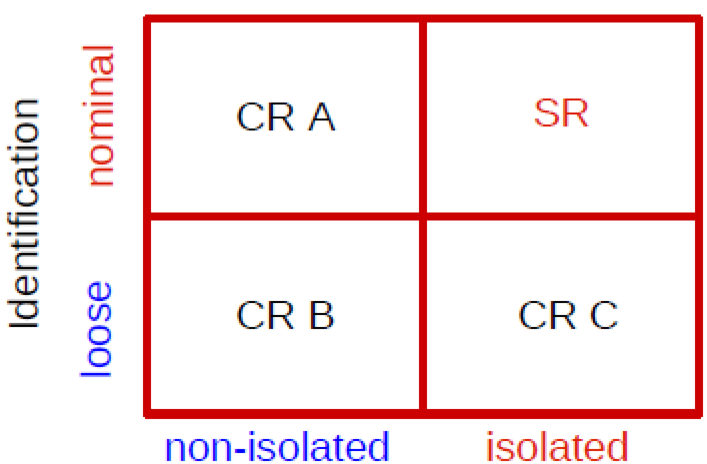


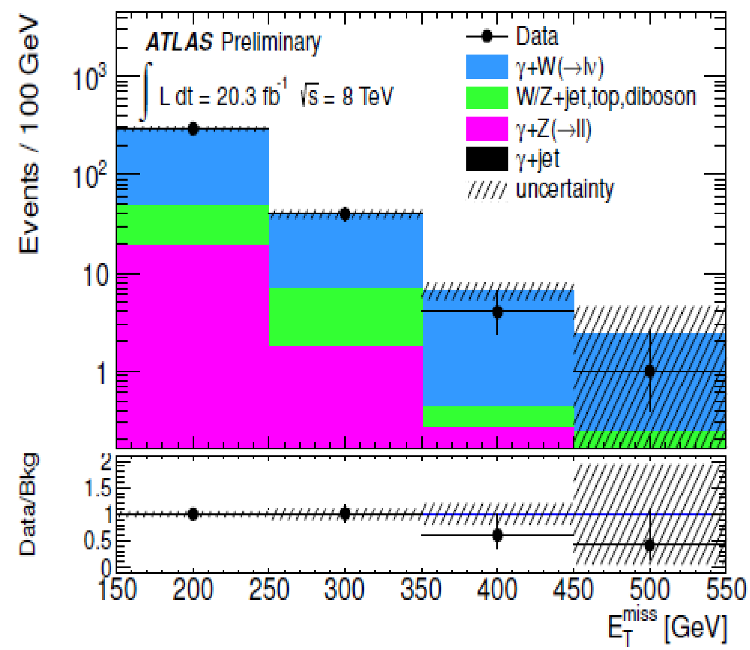
In a search for mono-photon+Etmiss, background from W/Z+jets where the jet is identified as a photon
Use CR with one or two lepton+Etmiss recoiling against a jet + estimate transfer factor from jet to fake photon

Photons separated from jets with two criteria:

- Shower shape and track veto
- Isolation: no activity in cone around photon

By releasing one or both of these criteria
Create 3 control regions
If the two criteria are independent:



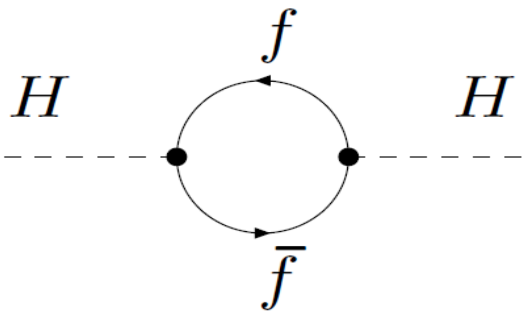


$$N_{\mathrm{SR}} = N_{\mathrm{CR\ C}} \times \frac{N_{\mathrm{CR\ A}}}{N_{\mathrm{CR\ B}}}$$

SUSY

SUSY solution to naturalness problem

Correction to higgs mass from fermion loop:



$$\Delta m_H^2 \sim \frac{\lambda_f^2}{4\pi^2}(\Lambda^2 + m_f^2) +$$

Where Λ high energy cutoff

For Λ~M_{Planck}~10^{18} GeV corrections explode

Correction from scalar $\tilde{f}$

$$\Delta m_H^2 \sim -\frac{\lambda_{\tilde{f}}^2}{4\pi^2}(\Lambda^2 + m_{\tilde{f}}^2) + \ldots\ldots$$

Corrections have opposite sign. Cancellations if for each fermion degree of freedom one has scalars such that: $\lambda_{\tilde{f}}^2 = \lambda_f^2 \quad m_{\tilde{f}} = m_f$

Achieved in theory invariant under transformation Q:

$$Q|\text{boson}\rangle = |\text{fermion}\rangle \qquad Q|\text{fermion}\rangle = |\text{boson}\rangle$$

Supersymmetry

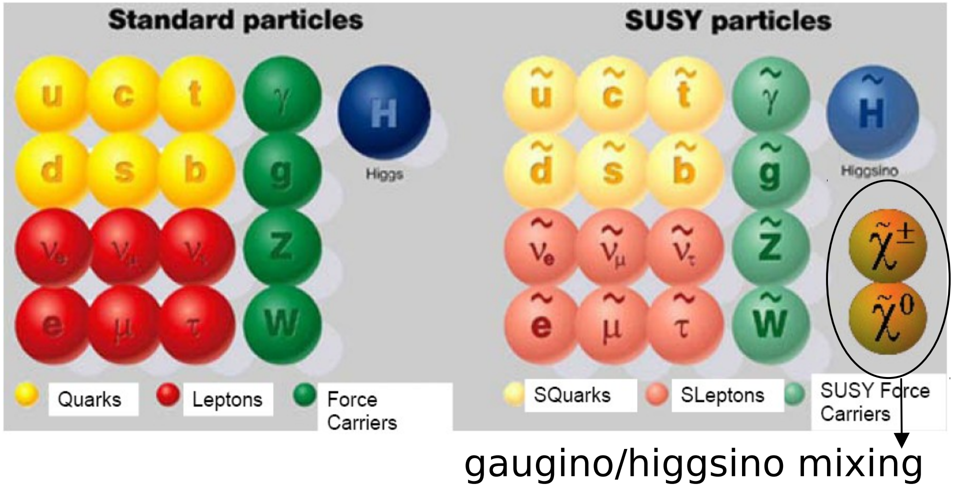
Very general class of theories, specialize to minimal model: MSSM

Minimal Supersymmetric Standard Model (MSSM)

Minimal particle content:

•A superpartner for each SM particle

•Two Higgs doublets and spartners:
5 Higgs bosons: h,H,A,H+,H-



•Insert in Lagrangian all soft breaking terms: 105 parameters.

•If we assume that flavour matrices are aligned with SM ones (minimal flavour violation): 19 parameters

Additional ingredient: R-parity conservation: $R=(-1)^{3(B-L)+2S}$

•Sparticles are produced in pairs

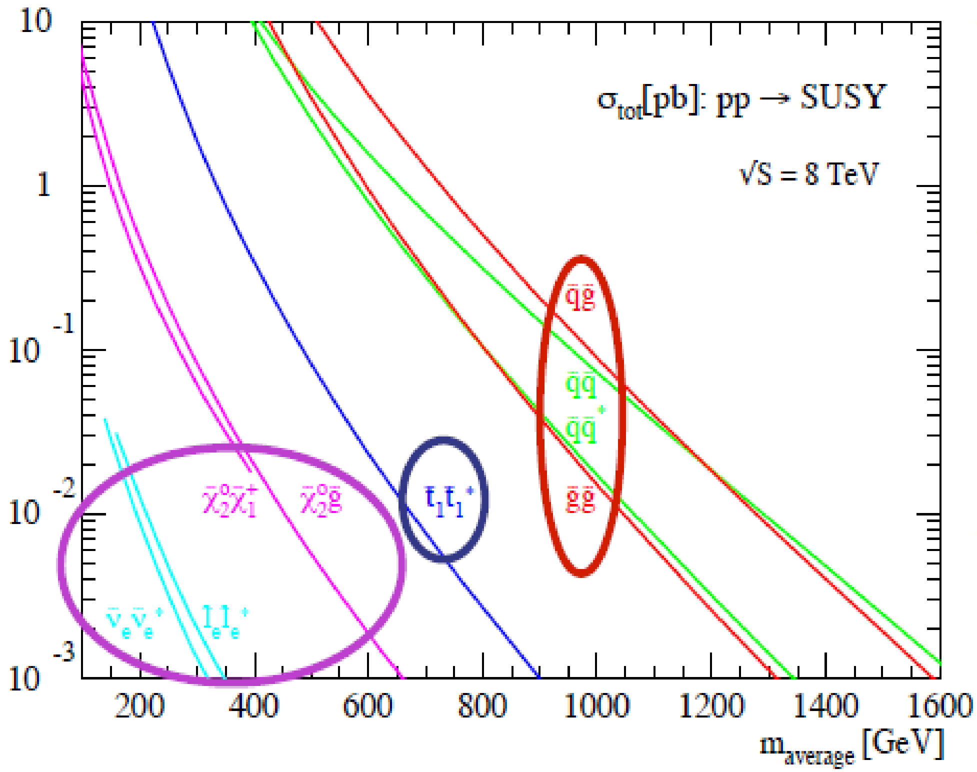
•The Lightest SUSY particle (LSP) is stable, neutral weakly interacting

- Excellent dark matter candidate
- It will escape collider detectors providing Etmiss signature

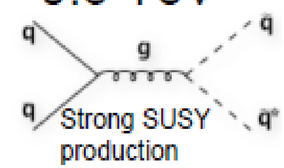
Models with R-parity violating terms are also studied: no E_T^{miss} signature, but often 'easier' kinematic signatures

SUSY search strategy

- SUSY pair productions at the LHC:



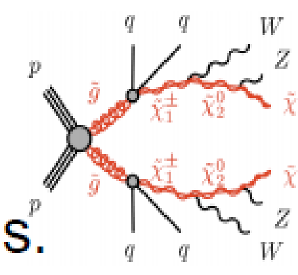
  - **gluinos and 1st and 2nd gen. squarks** with high cross-section, reachable up to > 1 TeV mass
  - **3rd gen. squarks with moderate cross-section**, up to ~0.5 TeV



  - **charginos, neutralinos and sleptons** with small cross-section, becoming feasible with the current dataset.

- Sparticles decay into characteristic signatures: e.g. E_T^{miss}, (*b*/*c*-) jets, leptons, and photons.

→ Designed various analyses to cover many signatures.



All hadronic signature optimisation

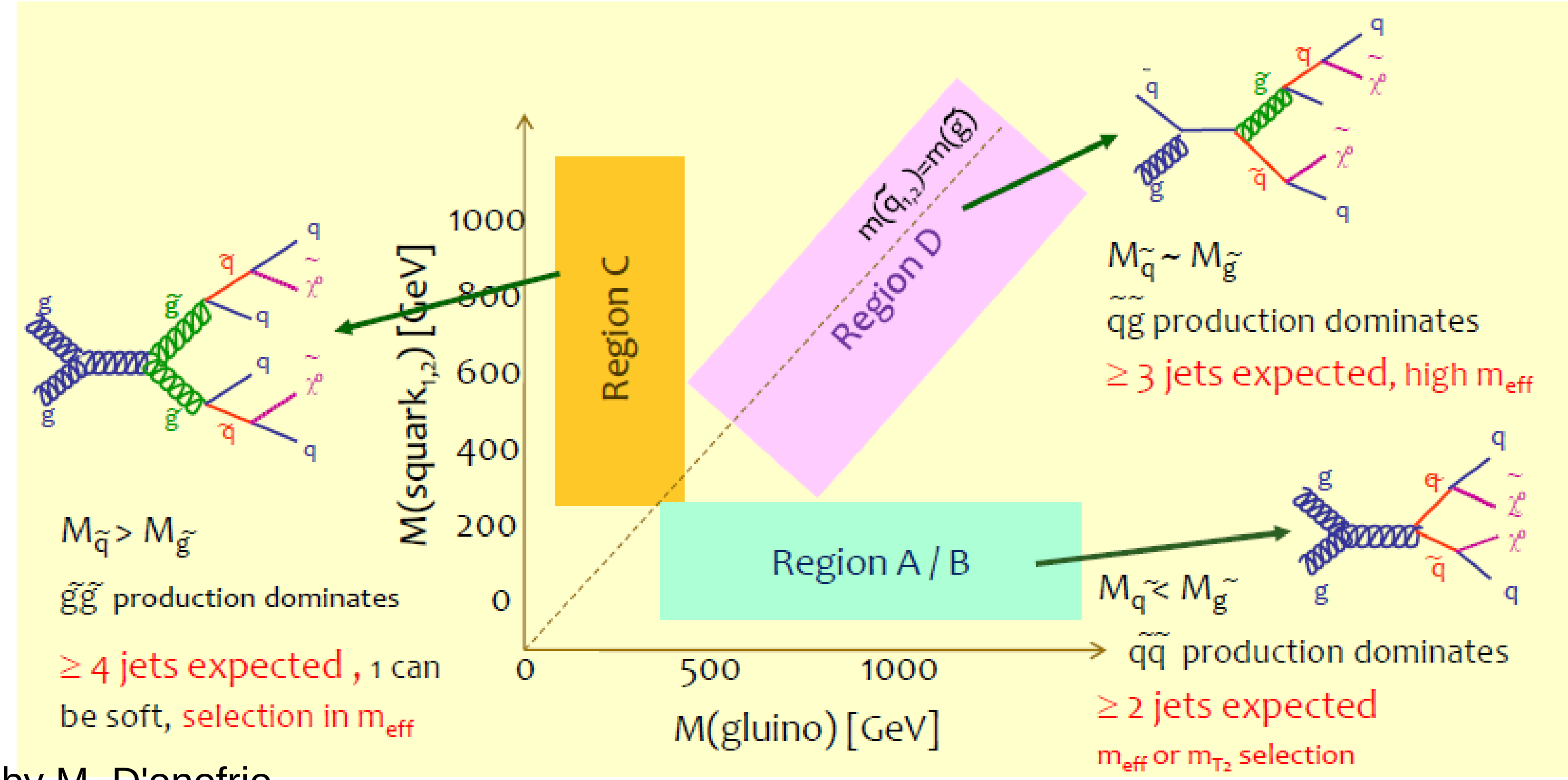


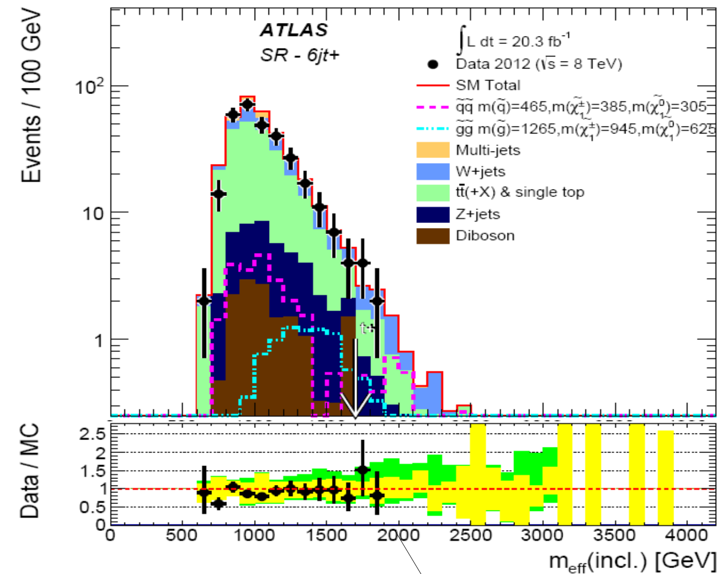
Figure by M. D'onofrio

Require 2 to >=6 (8) Jets and Etmiss.   Signal regions classified according to:

- Number of jets (ATLAS and CMS)
- ETmiss (ATLAS) HTmiss (-vector sum of jet pT) (CMS)
- Meff = Etmiss+ scalar sum of jet pT (ATLAS)
- HT= scalar sum of jet PT (CMS)

Results

Good agreement between data and prediction in all signal regions
→ Interpret in term of coverage of SUSY space



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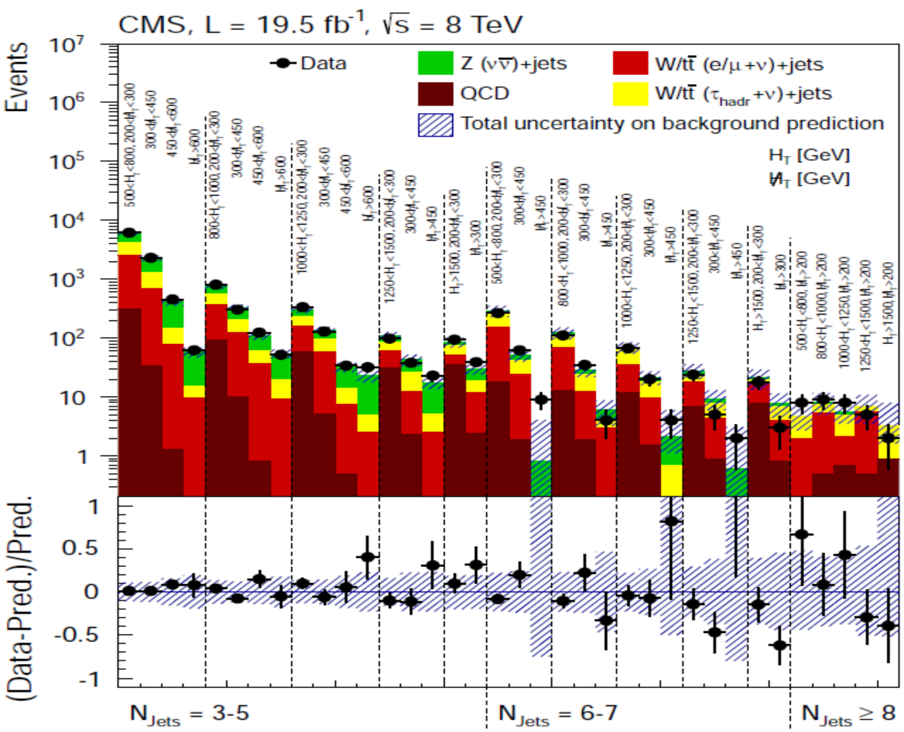
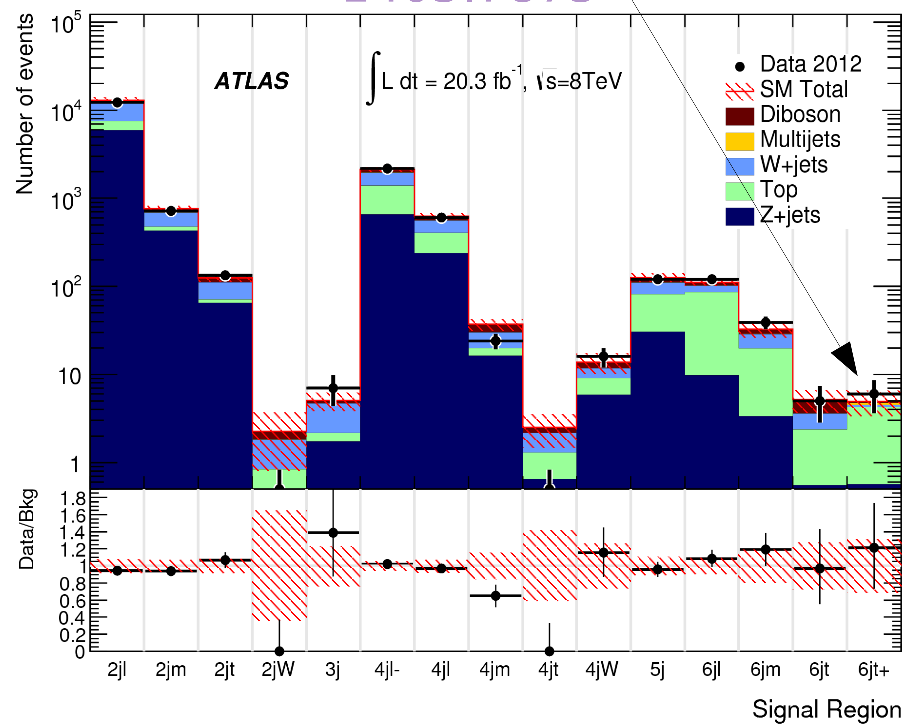
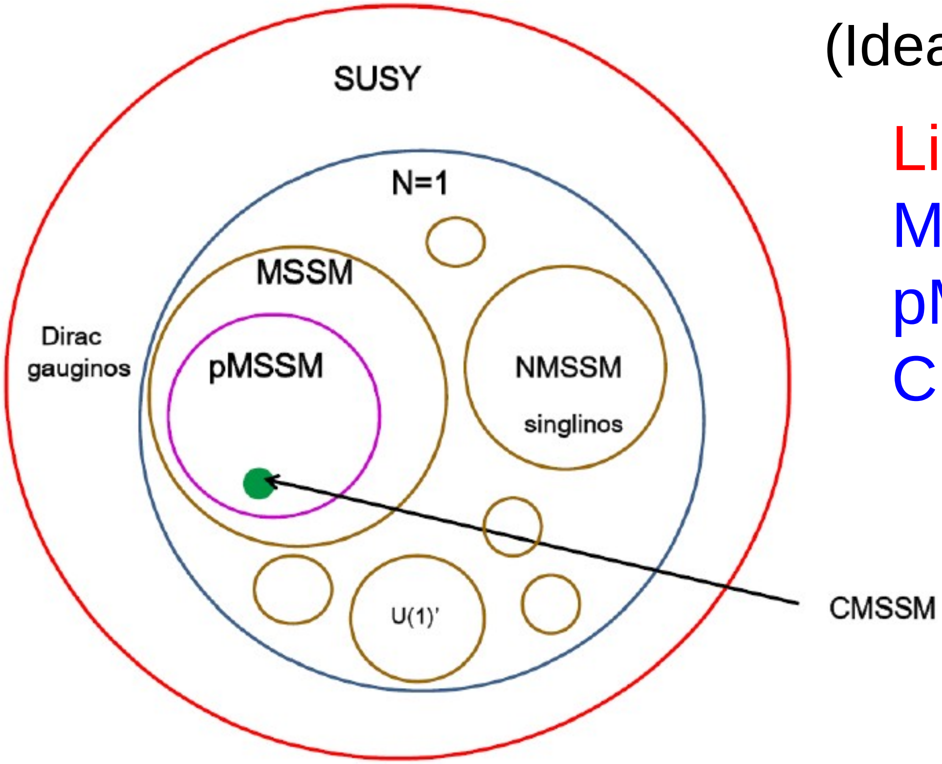




Interpretation

SUSY theory space



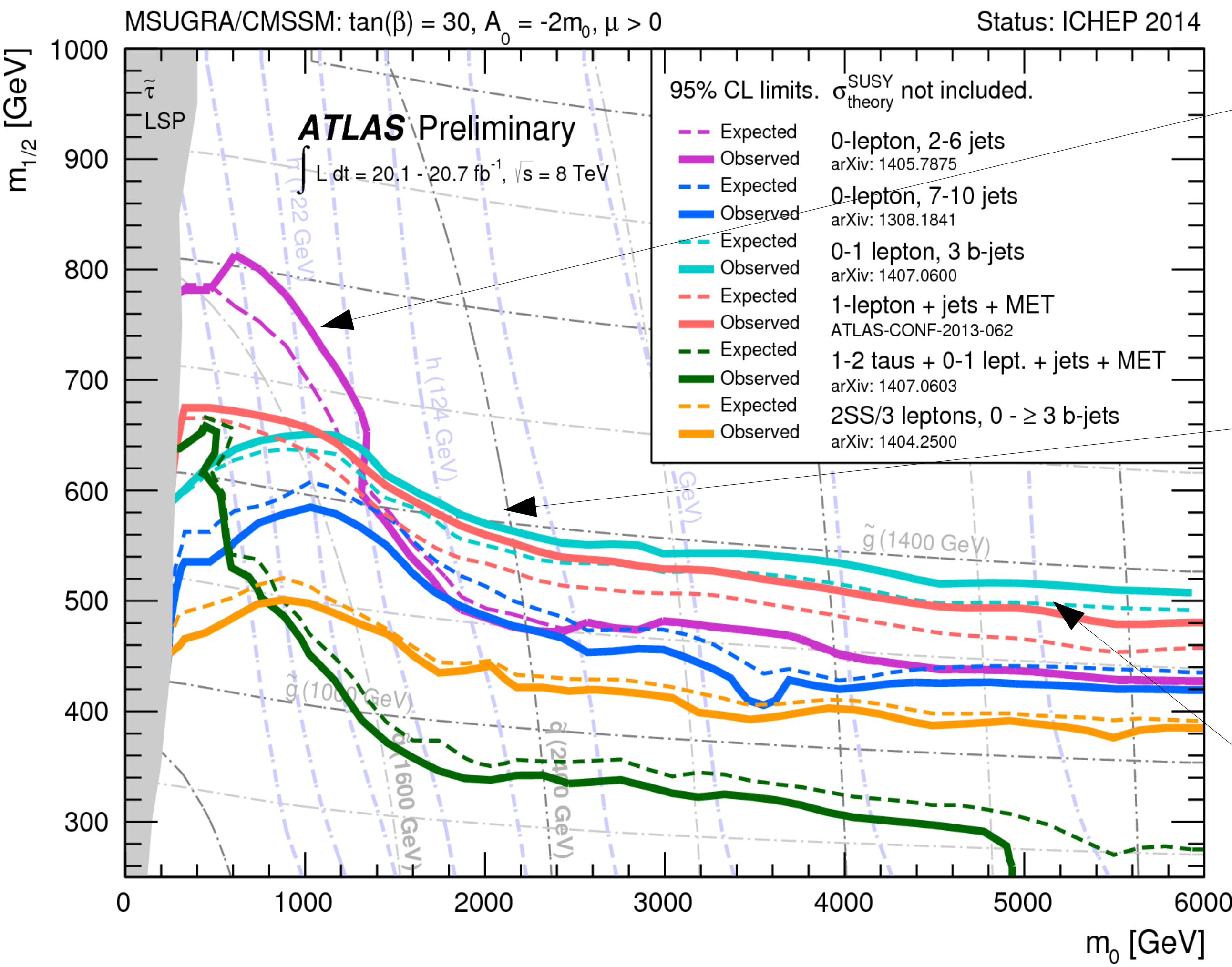
For interpretations need to reduce
To small parameter dimensionality
(Ideally 2)

Limiting to MSSM:
MSSM: ~109 parameters
pMSSM: 19 parameters
CMSSM: 4 parameters

The smaller the number
Of parameters, the smaller
The fraction of SUSY space
explored

CMSSM interpretation

CMSSM has 4 parameters. For fixed tanβ phenomenology essentially Only dependent on the mass of the scalars (M0) and of the fermions (M1/2) at SUSY breaking scale. Useful benchmark of different topologies



Low jet multiplicity
0 lepton analysis:
Excellent coverage
Where squark
Production dominant

Intermediate m0:
1l+jets gives large
contribution

High m0: only gluino production, decay mainly into 3rd generation:
0l + 3b best analysis

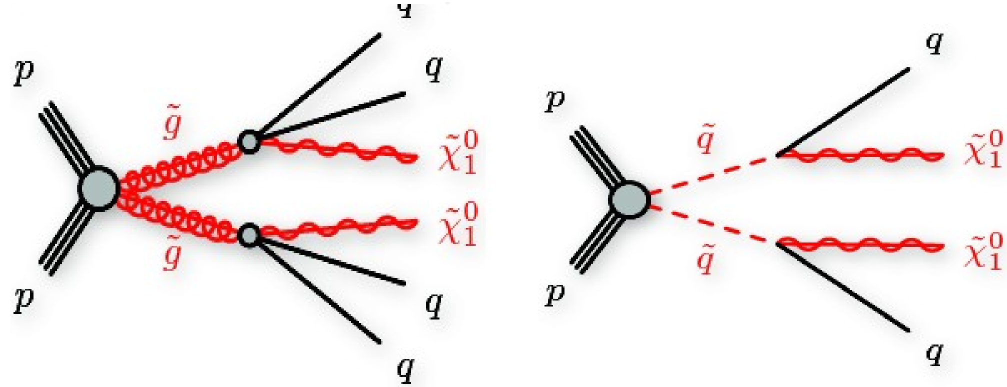
pMSSM interpretation

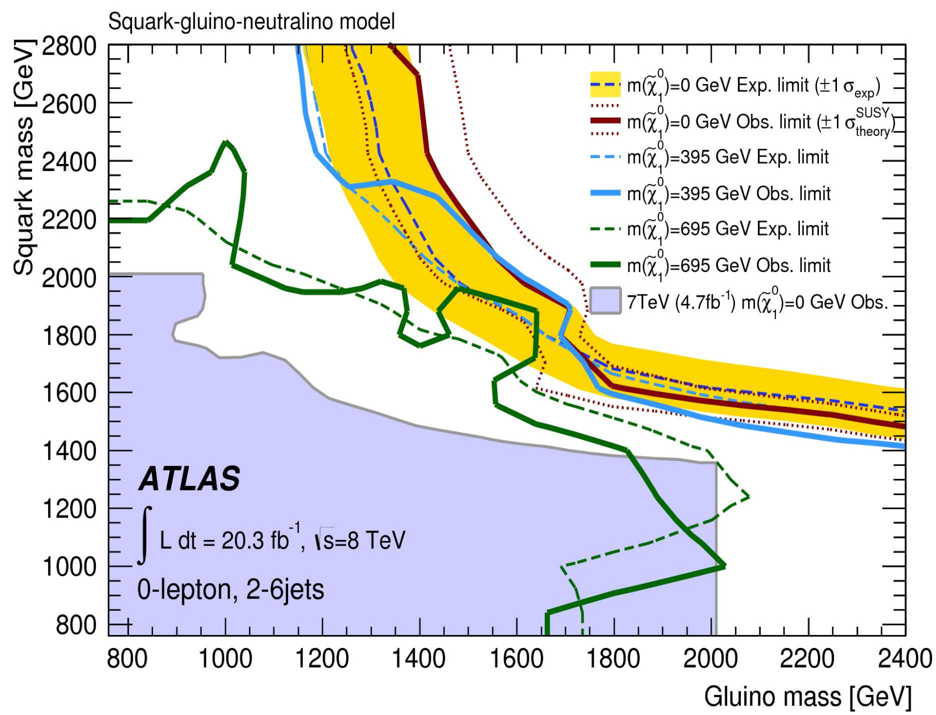
pMSSM: slice: fix all but two parameters, and choose Signature where reach mostly determined by free parameters

Example: 1-step decays of squark and gluinos: 0 lepton signature

All other sparticles decoupled

Except LSP: only two decays allowed





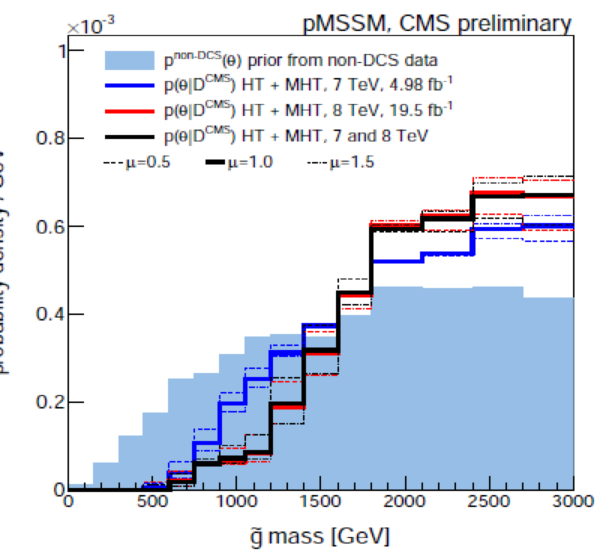
Squark-gluino excluded up to ~1.5 TeV

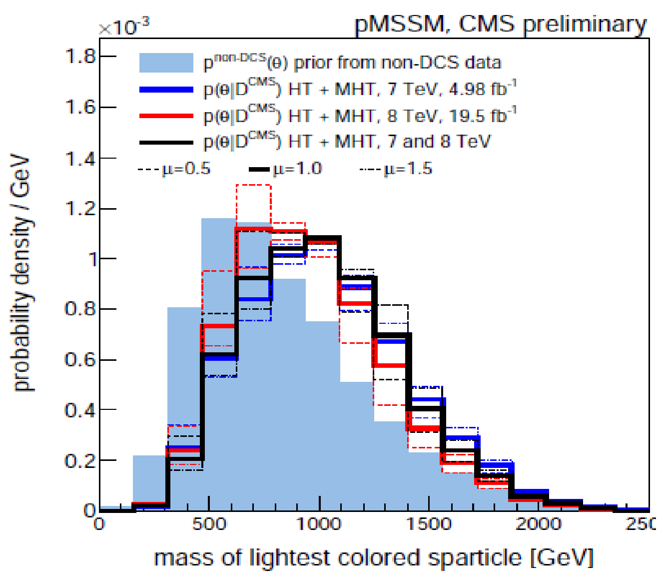
BUT

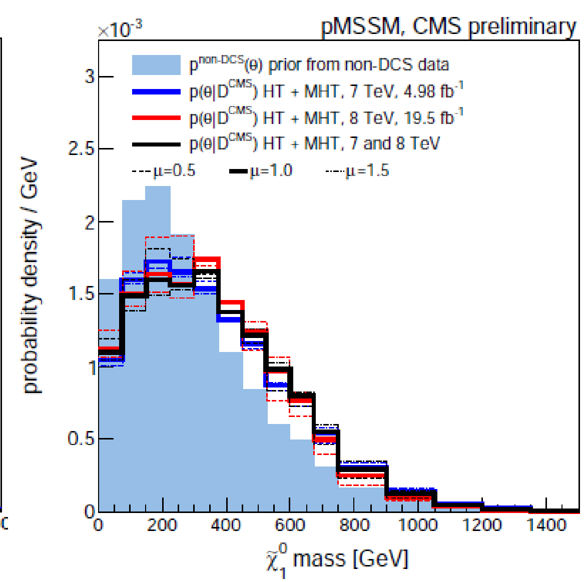
Dependence on neutralino mass

pMSSM interpretation (CMS)

- Select large grid of points in 19-parameters space compatible with LEP and flavour constraints, neutralino LSP and sparticles lighter than 3 TeV
- Build likelihood with results of CMS EW and inclusive Ht + Etmiss (+b-jets) searches
- Show marginalized distributions for sparticle masses
  - Blue are prior distributions
  - Lines are posteriors from CMS searches



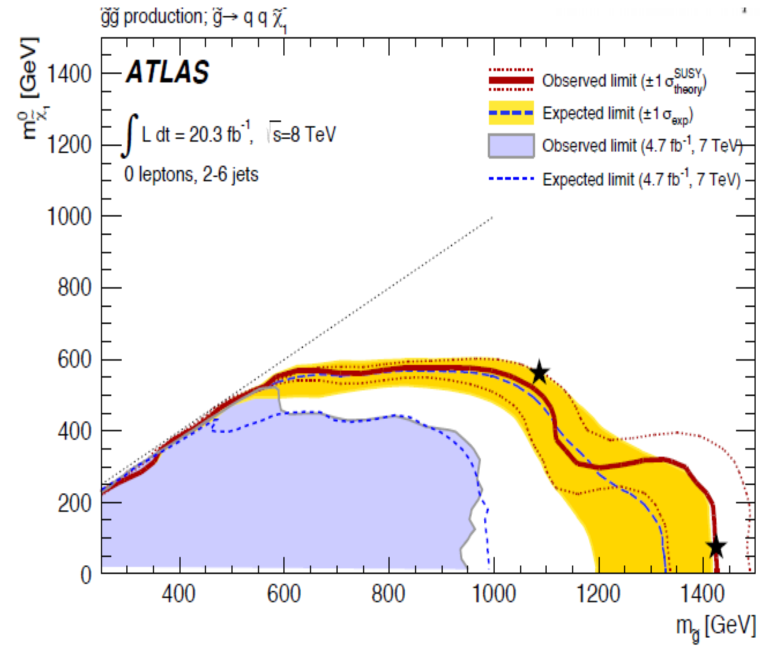


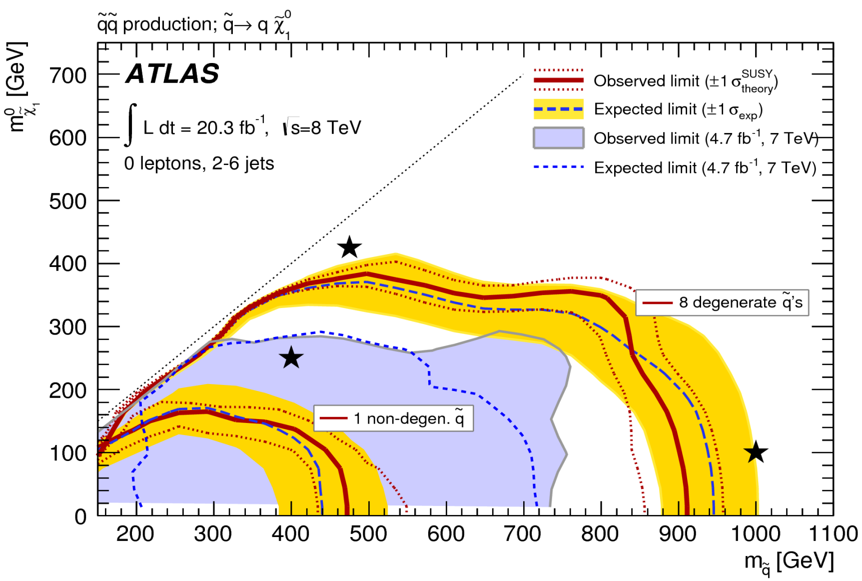


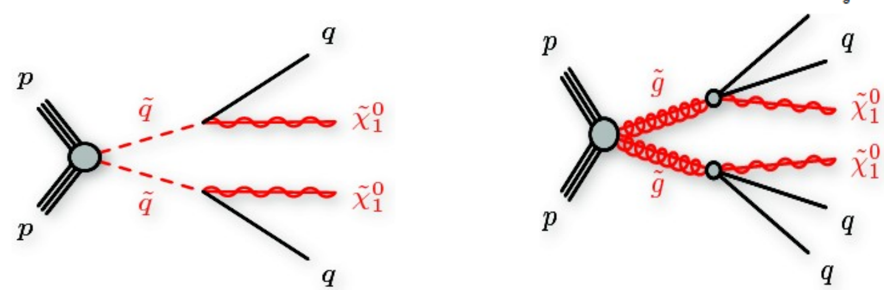
“simplified model” interpretation

Simplified models as a tool for analysis optimisation and display:

- Generate events with given decay chain on both legs
- Assume 100% BR in both legs and the SUSY production cross-section
- Express reach in 2d mass plane
- No statement on theory but very clear Representation of our potential for a specific kinematics



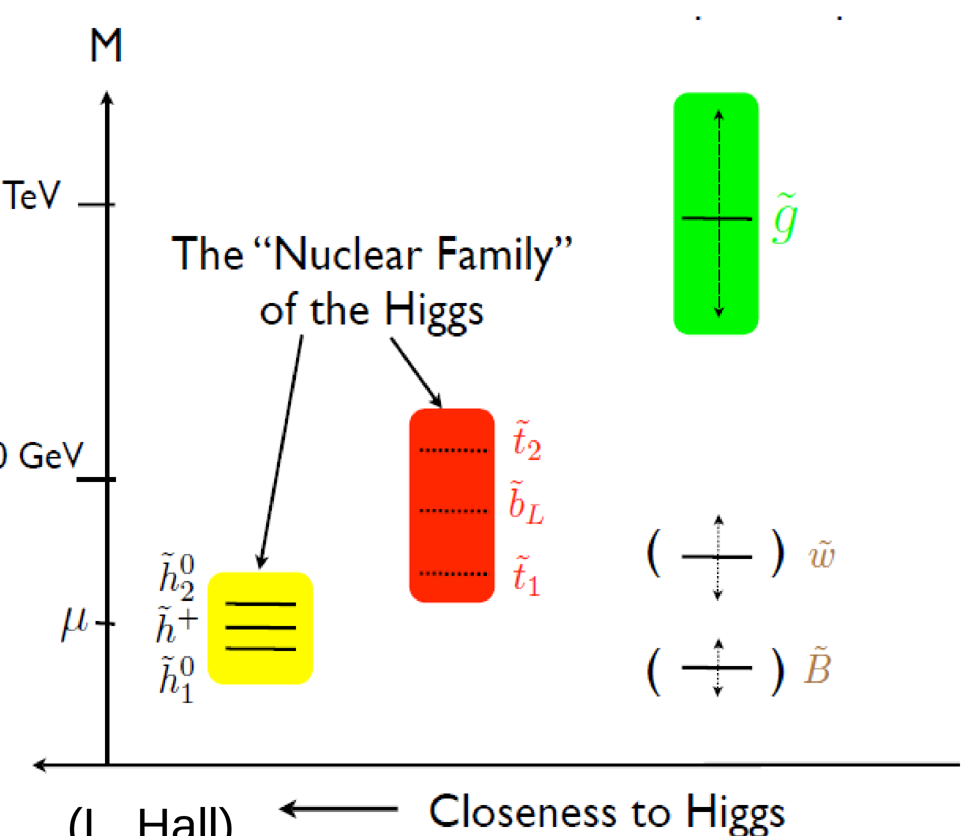




For low LSP mass, exclude gluinos with mass below ~1.4 TeV
And squarks with mass below ~900 GeV

'Natural' SUSY

Inclusive searches with multijet+Etmiss+ (0-2) leptons push masses Of squarks of first two generations and gluinos uncomfortably high
→ dedicated searches for part of SUSY spectrum most relevant to naturalness

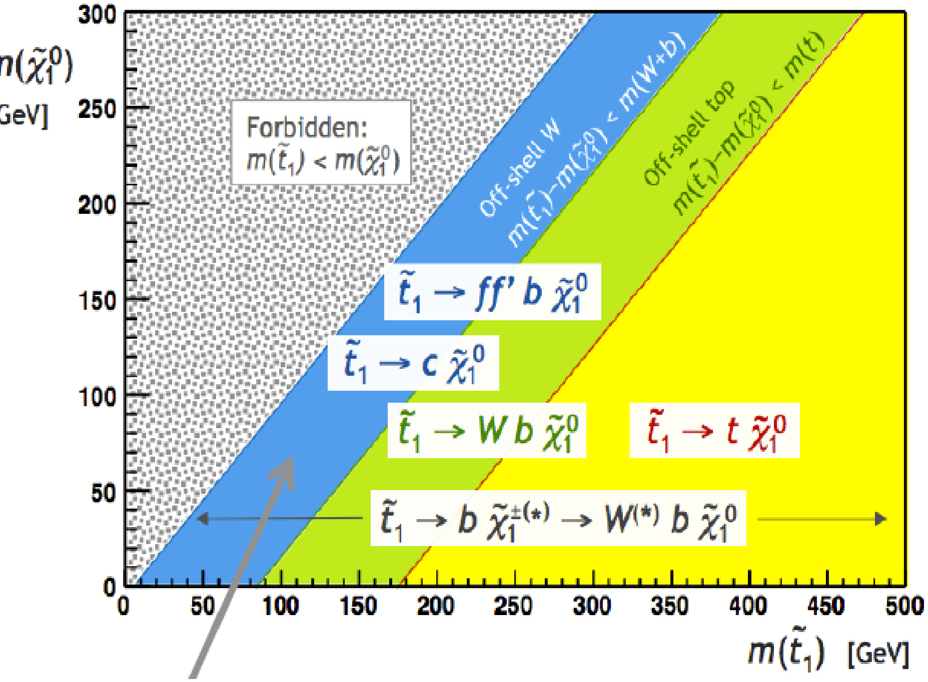


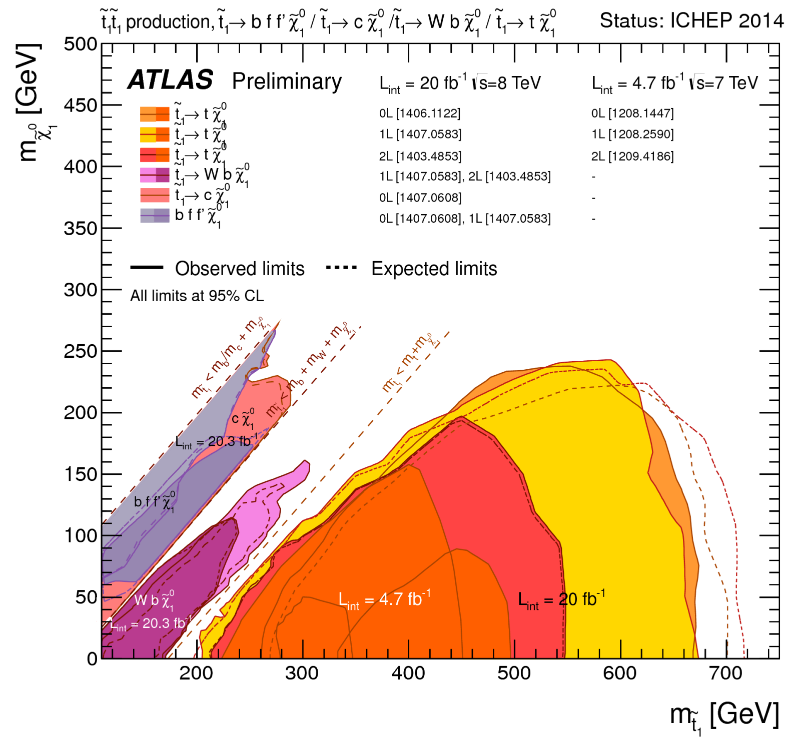
(L. Hall)

Assume other squarks too heavy
Three steps:

- Search for gluino decay through real/virtual 3rd generation quarks
    - b-jets in decay
    - high multiplicity
- Search for direct production of stop/sbottom
- Try to cover all possible phenomenology in terms of decay patterns
- Search for direct production of Ewkino
  (4 parameters + slepton sector)

Search for direct stop pair production





Extensive search in all possible decay channels:

2-body stop → top LSP, stop → chargino b, stop → charm LSP

3-body stop → W b LSP 4-body: stop → ffbar b LSP

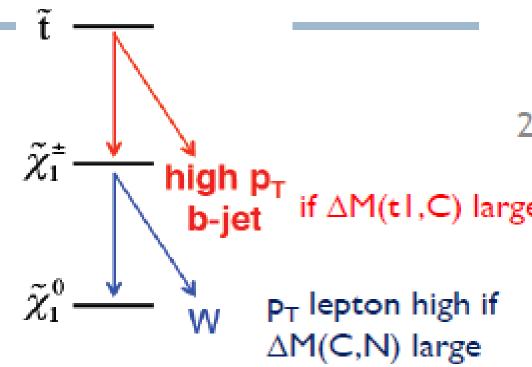
Up to ~700 GeV stop mass in configurations with large visible energy

Difficult region for m(stop)=m(top)+m(LSP)

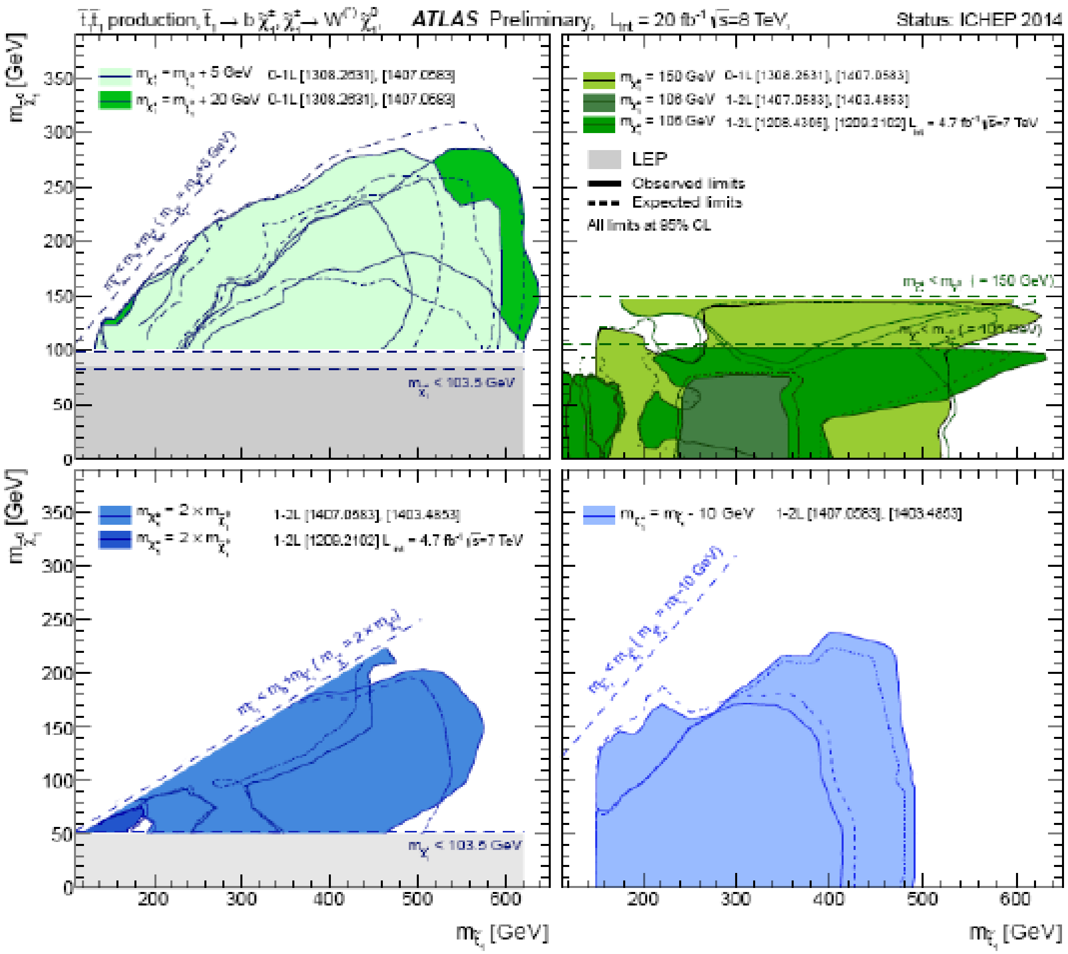
For compressed topologies reach up to ~250 GeV with some remaining holes

Direct stop to chargino

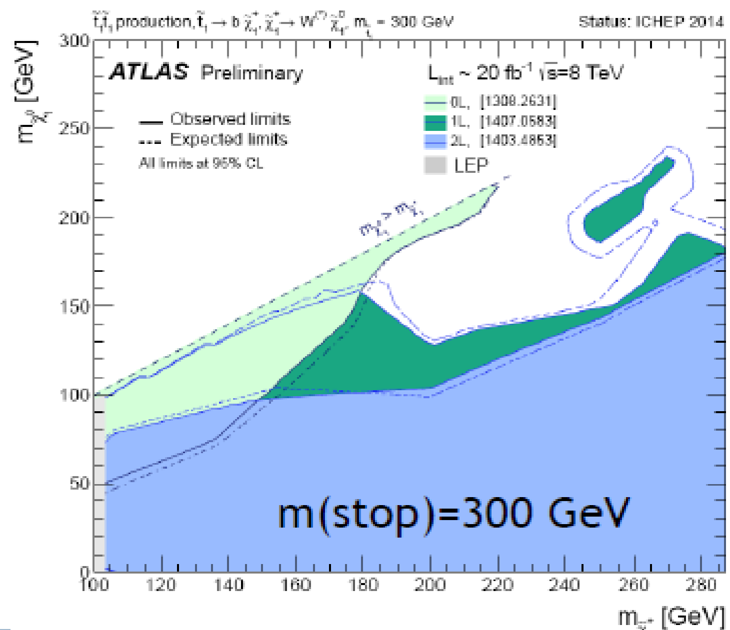
3 parameters: m(stop), m(chargino), m(LSP), show 2-d slices



- Various assumptions of ΔM(stop-chargino) and ΔM(chargino-neutralino)

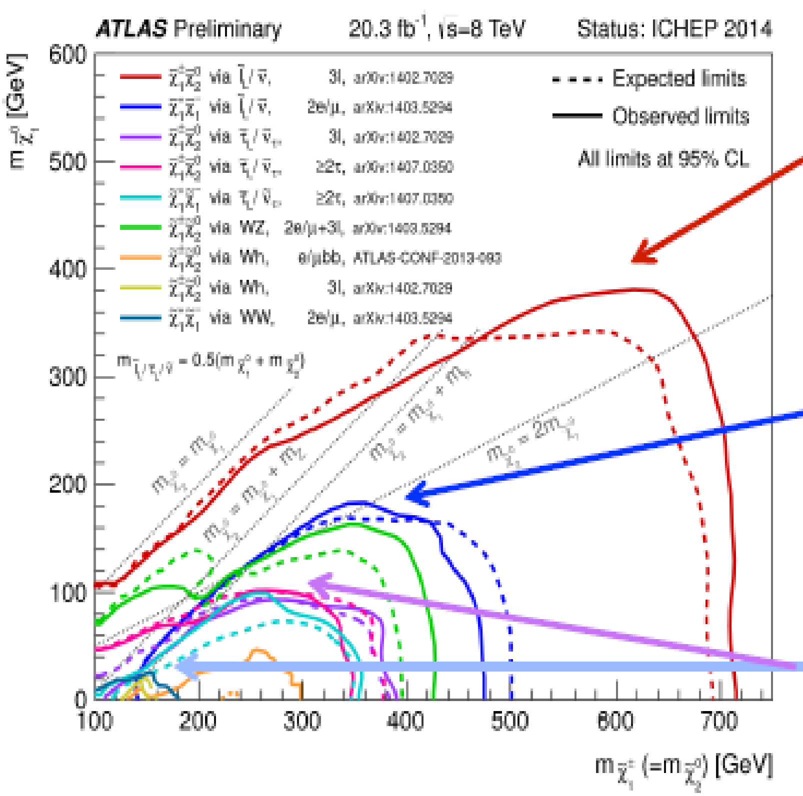


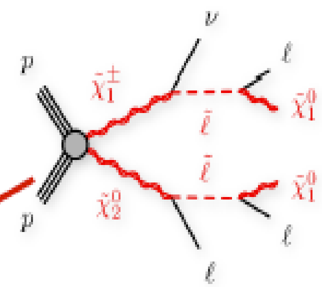
Fixed mass stop, function of chargino-neutralino mass



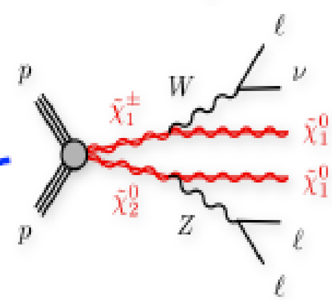
Electroweak SUSY production

- Clean signature: multi leptons, depending on slepton masses and gauge mixture.
- Many possible models are covered by several comprehensive analyses.

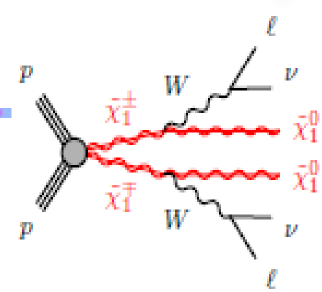




Large cross-section.
3 lepton final states if light sleptons:
exclusion up to m_{LSP}<~380 GeV.



If heavy slepton, smaller cross-section to lepton WZ/h with 3/2 leptons:
up to m_{LSP}<~180 GeV

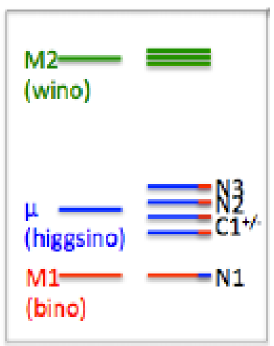


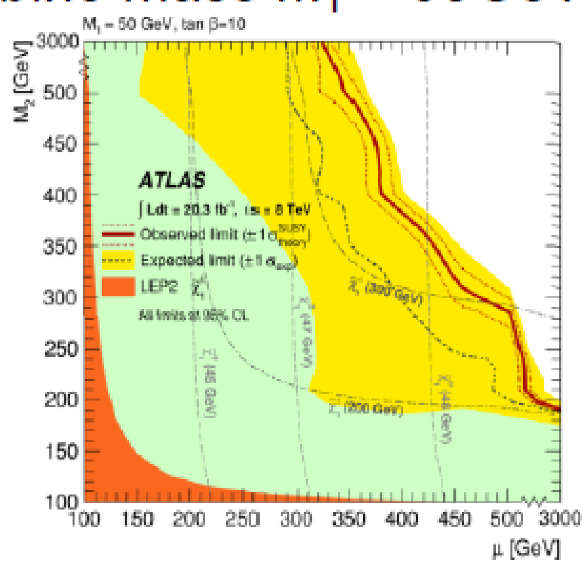
Tiny cross-section of chargino pair production via WW with 2 leptons.
Sensitivity increased if light stau.

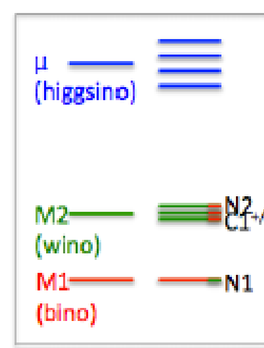
Interpretation of EW production in pMSSM

JHEP 05 (2014) 071

- Phenomenological MSSM (pMSSM) can put generic constraints on most of the phenomenological features of the RPC MSSM.
- Interpretation of 2-lepton+3-lepton analyses in pMSSM:
  - on higgsino μ- wino M_2 mass-plane also with very large slepton masses.
  - Assumption is bino mass M_1 = 50GeV and tanβ = 10.



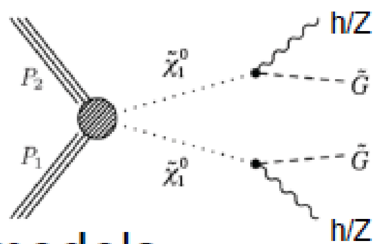




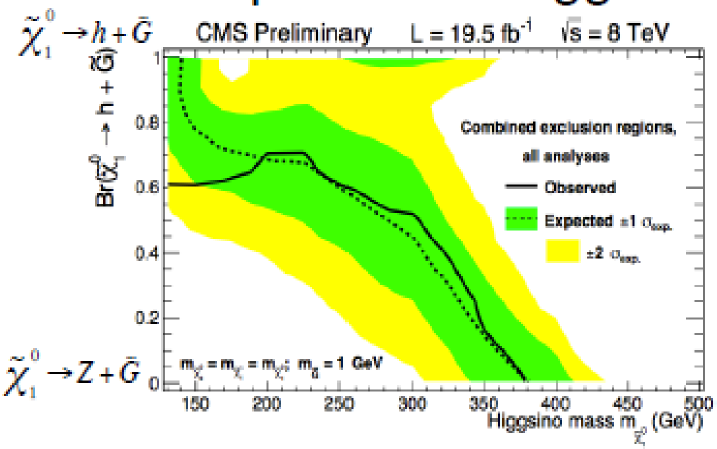
Search for EW production with Higgs

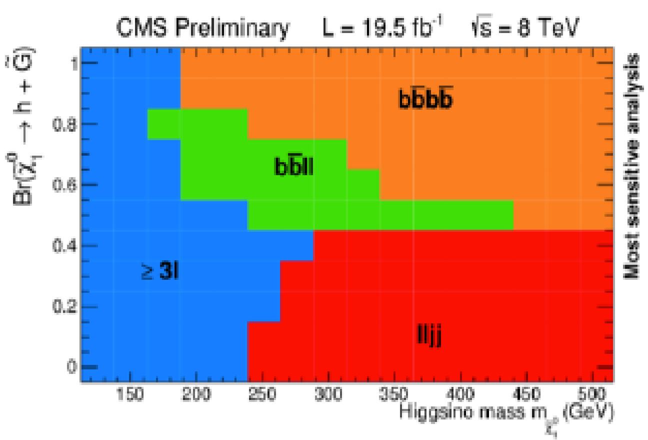
CMS-SUS-14-002, arXiv:1409.3168

- Higgs discovery opens up new SUSY searches:
  - Lightest neutral *CP*-even Higgs (h) expected to be SM-like, if others heavy.
  - Neutralino can decay to h/Z+LSP.
- CMS performed comprehensive search program with di-boson + E_T^{miss} including hh, Zh, Wh.
  - $h \rightarrow ZZ$, WW, $\gamma\gamma$, *bb*

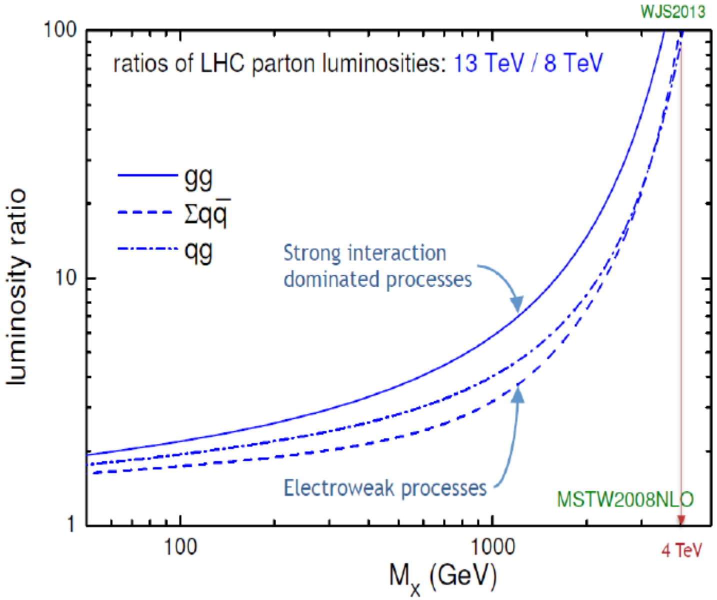


- Interpretation: Higgsino NLSP in GMSB models



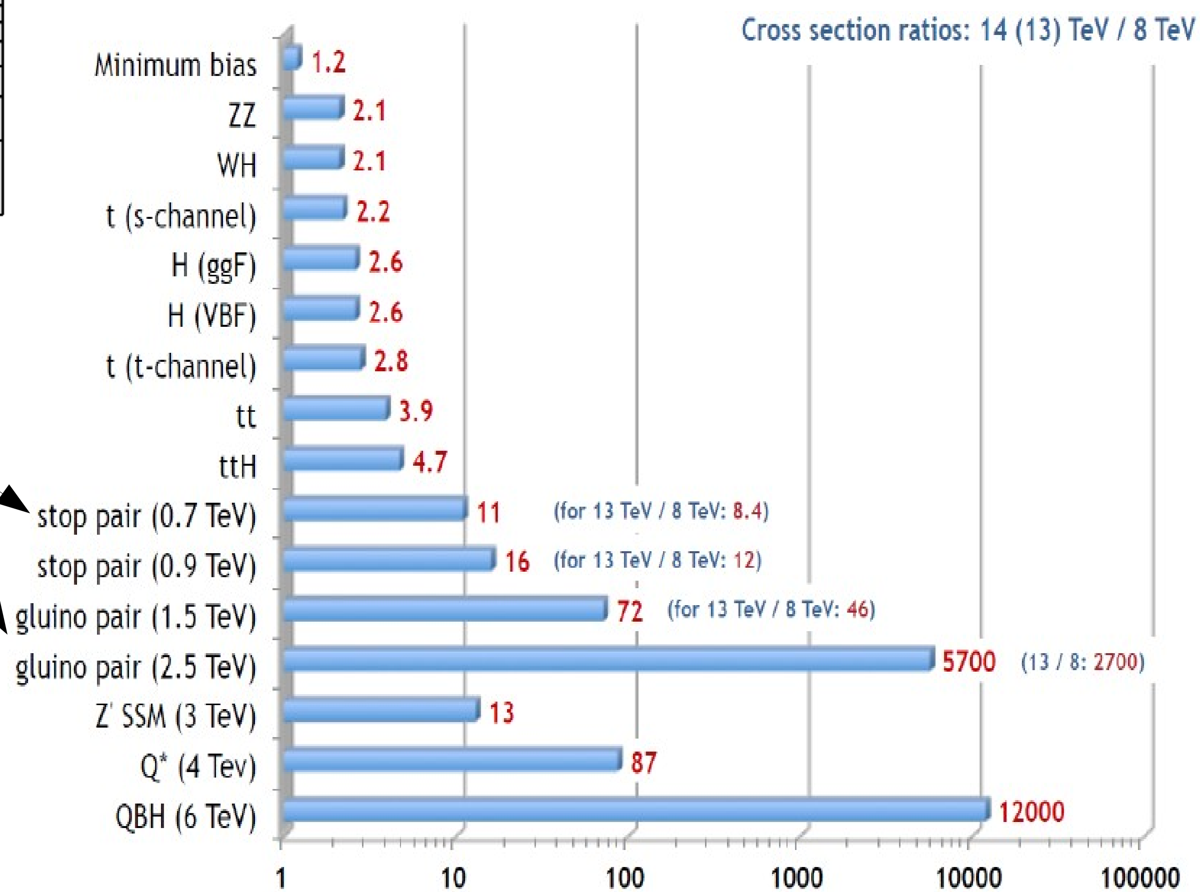


Prospects for SUSY in Run2



Ingredient number 1: CMS Energy

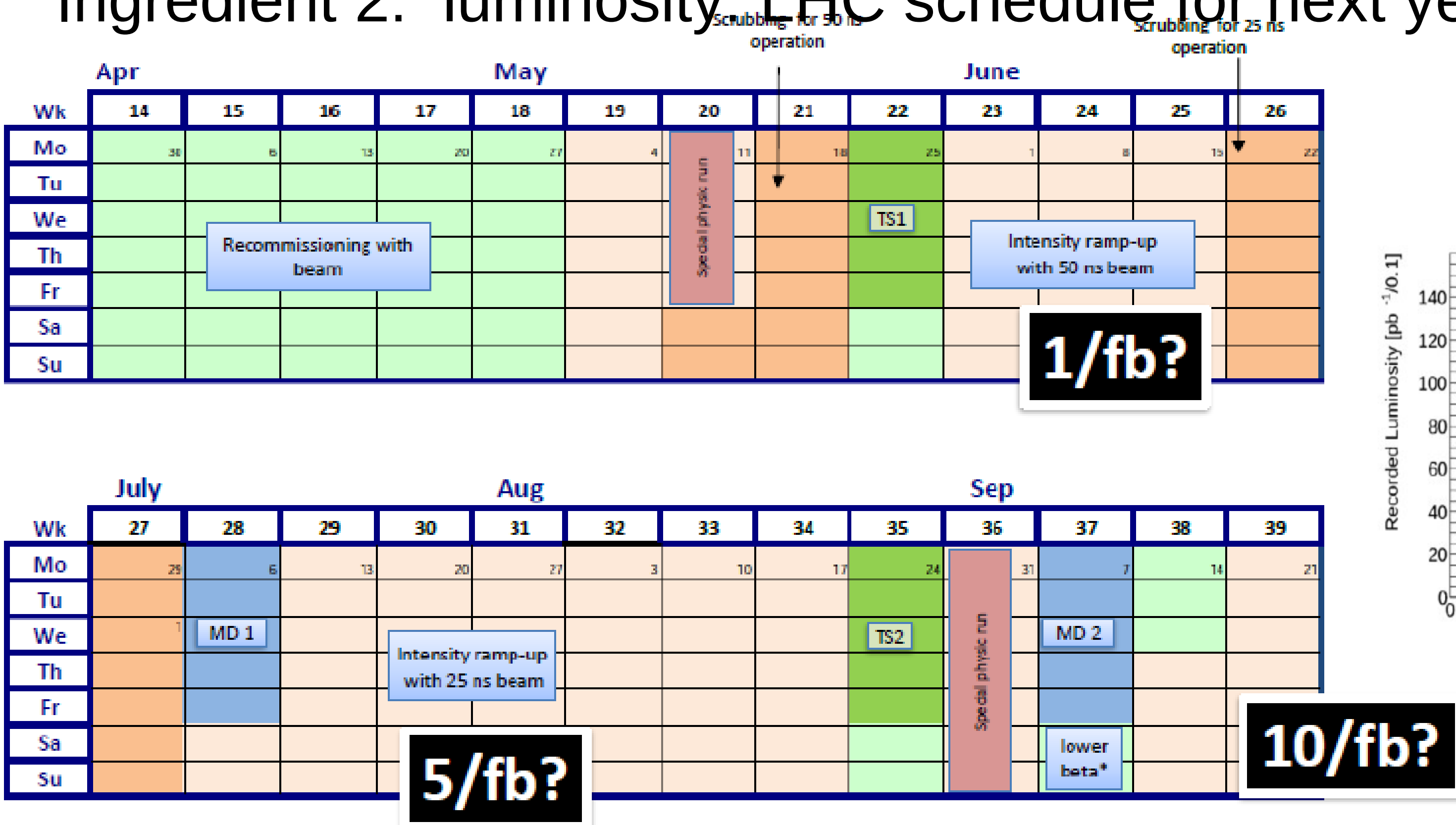
~Reach we had with 8 TeV
20 fb-1

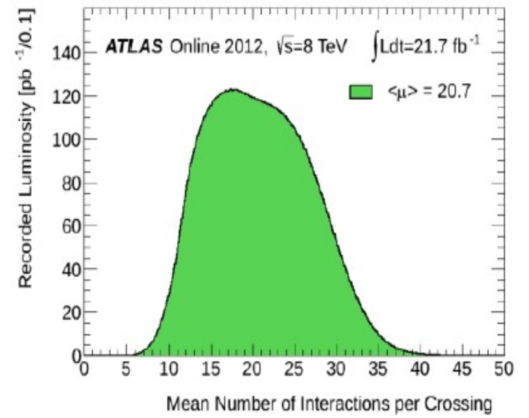


With 1 fb-1 we will produce ~twice as many gluino pairs at 1.5 TeV as in full Run 1

With 5 fb-1 we will produce ~twice as many stop pairs at 0.7 TeV as in full Run 1

Ingredient 2: luminosity: LHC schedule for next year

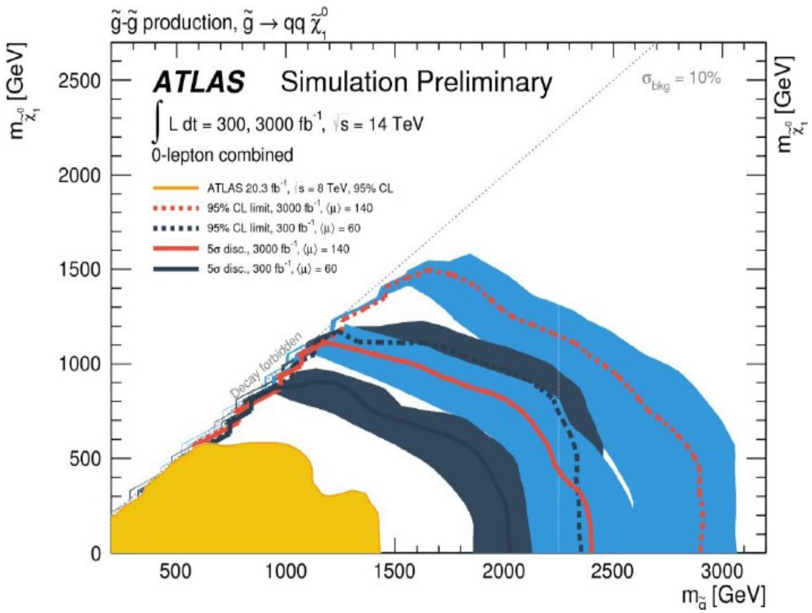


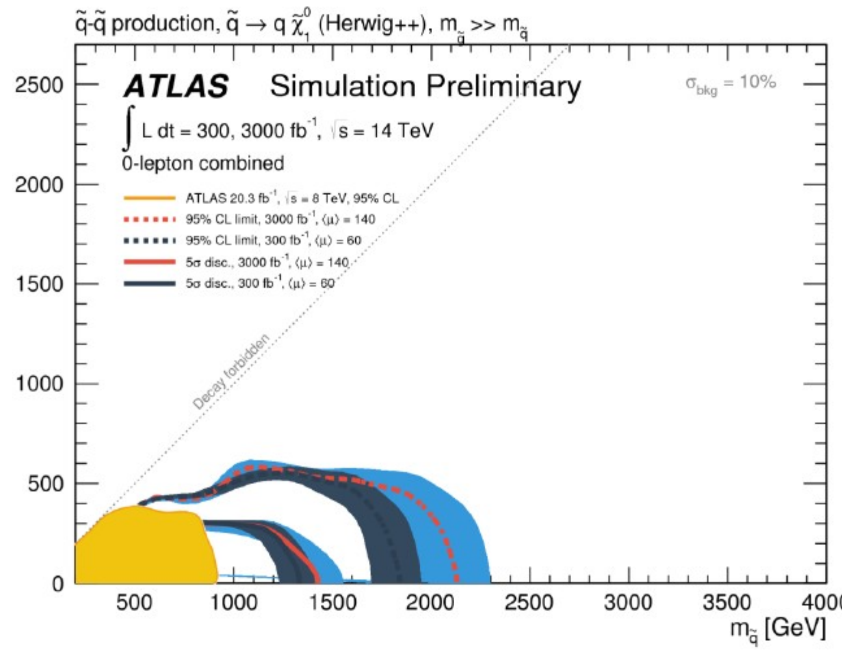


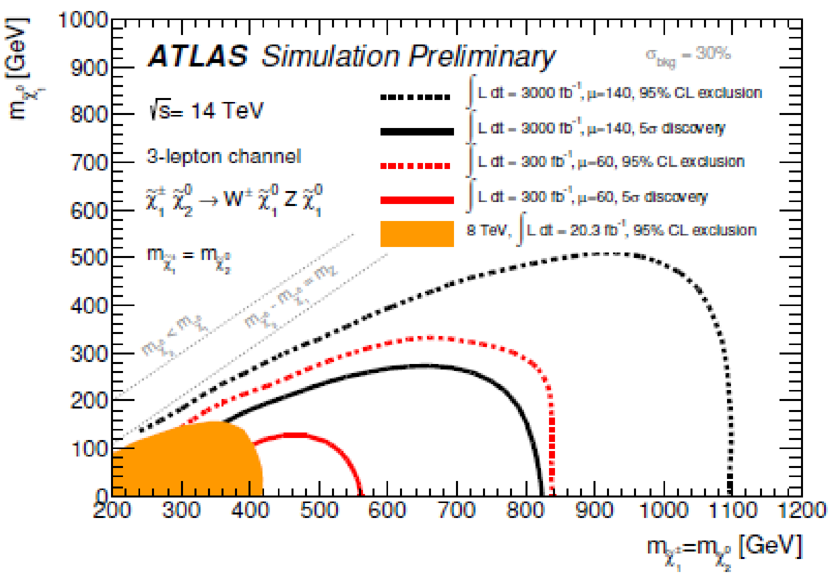
https://espace.cern.ch/be-dep/BEDepartmentalDocuments/BE/LHC_Schedule_2015.pdf

	Nc	Beta *	ppb	EmitN	Lumi	Days (approx)	Int lumi	Pileup
50 ns	1300	80	1.2e11	2.5	4.6e33	21	~1 fb^{-1}	27
2015.1	2496	80	1.1e11	2.5	7.4e33	44	5.1 fb^{-1}	22
2015.2	2496	40	1.1e11	2.5	1.3e34	46	9.2 fb^{-1}	39

Longer term perspective



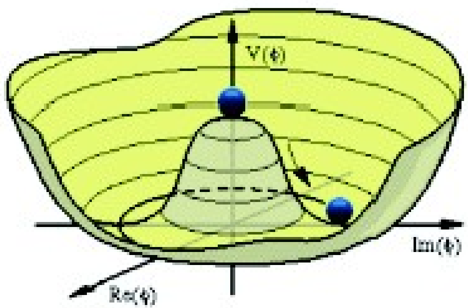


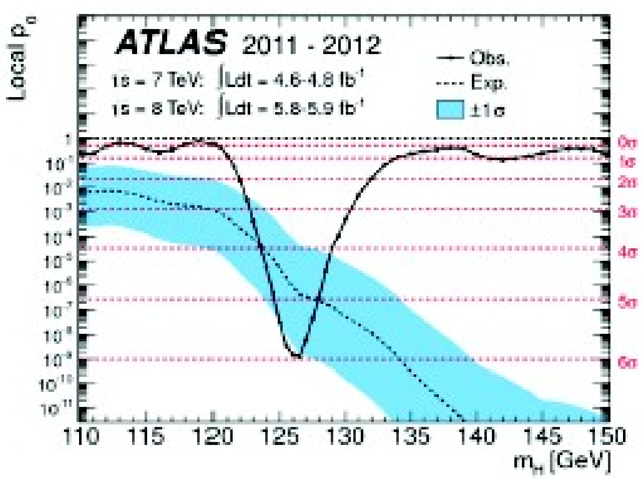


For high luminosity running need
To take into account large pileup
Which will smear Etmiss.
Simulation done in two scenarios:
<μ>=60 for 300 fb^{-1}
<μ>=140 for 3000 fb^{-1}

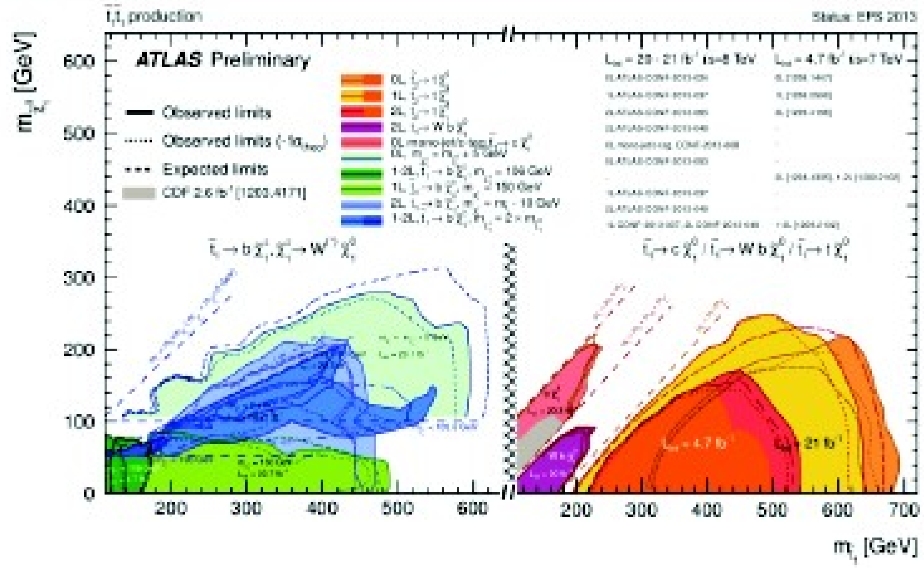
Exotic searches

- No precise model to guide us.





- No unified parameter phase space to map results

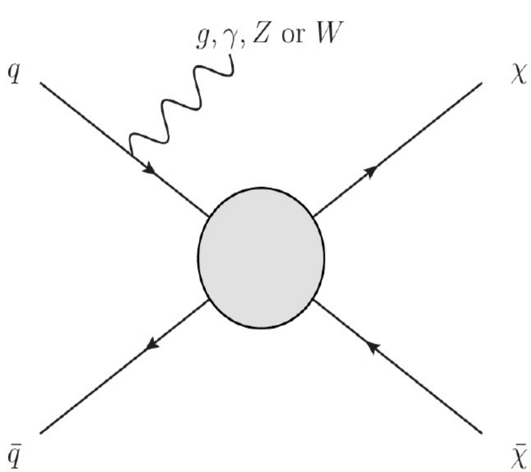


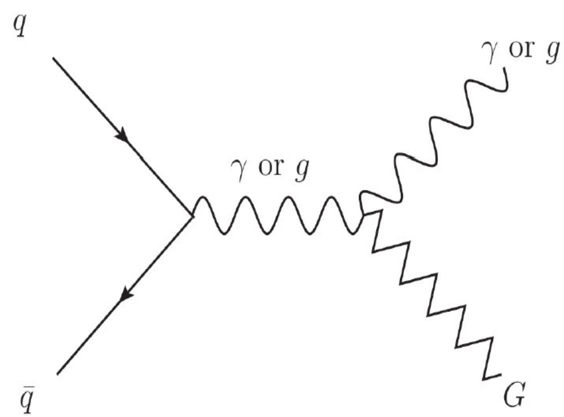
Strategy

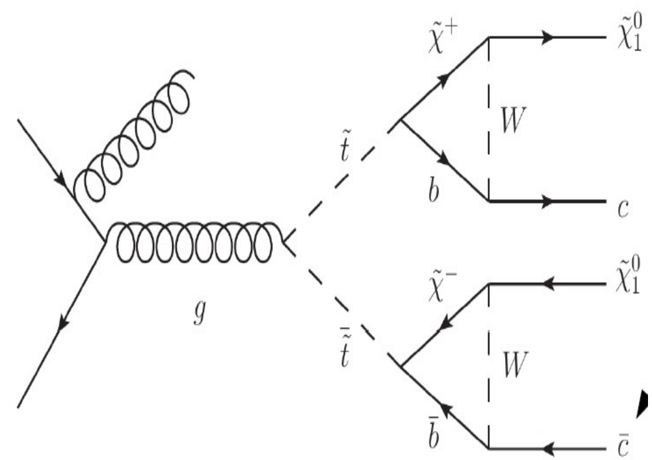
- Address wider range of final state topologies
- Concentrate on topologies:
  - Giving easily identifiable signature
  - Largely model independent or predicted by several classes of models. Examples
    - Mono-object+Etmiss
    - Resonances
    - High multiplicity final states
  - Predicted by well motivated theoretical speculation. Examples from naturalness:
    - Top partner
    - Contact interactions
- Concentrate in the following on Mono-X, most recent and hottest topic

The mono-X signature

- A single high pt object (jet, photon, W, Z) associated with large Etmiss can be produced by several different BSM processes such as:
  - Invisible particles produced in association with QCD or EWK initial state radiation (ISR). Example: Dark Matter
  - Two-body production of gravitino/on recoiling against photon/gluon
  - Production of particles decaying into an almost degenerate invisible particle: need to rely on ISR to extract visible signal.

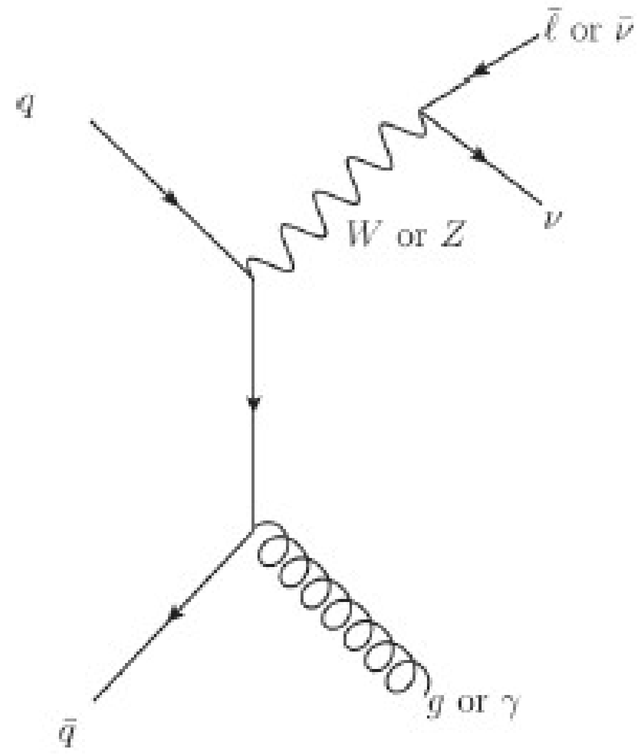






The mono-X signature

- Simple final state with well-known backgrounds from electroweak processes



Use same estimation techniques as described for multijet+MET SUSY searches,

Main differences:

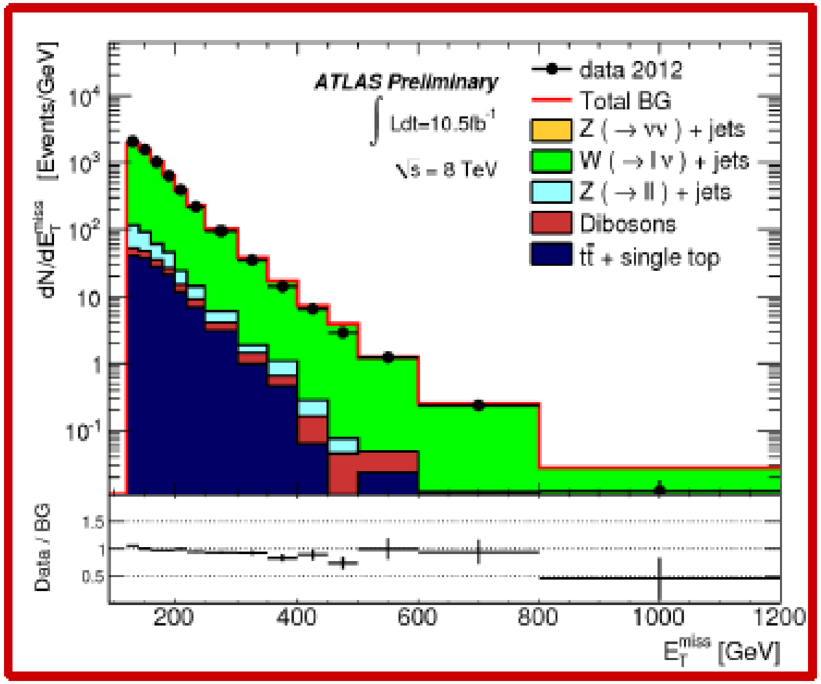
- Low jet multiplicity
- Hard kinematics

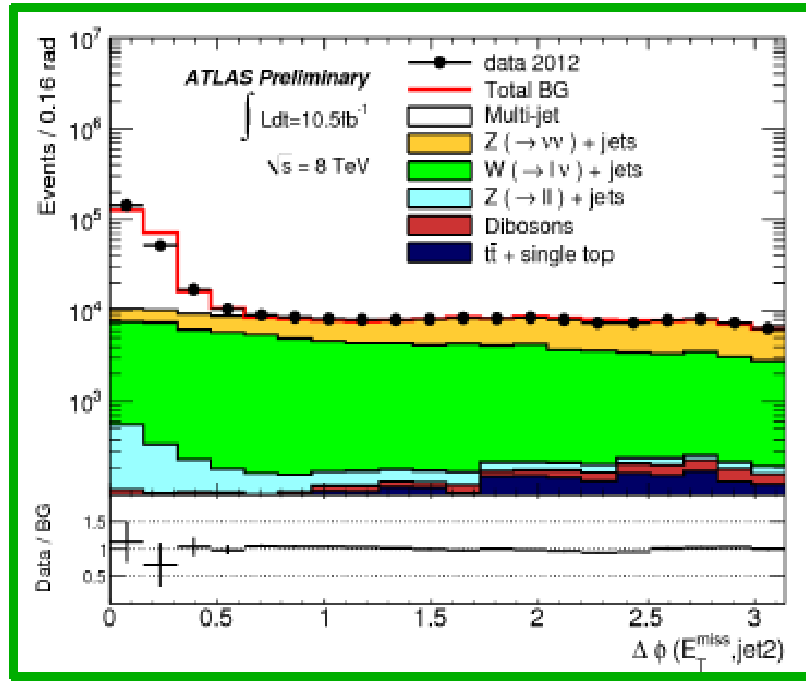
The mono-x analyses

- Select events with a high pt object (jet, photon, lepton hadronically decaying W/Z) and large MET
- Veto events in which:
  - A lepton is identified: *remove electroweak background*
  - There are more than 2 jets: *remove top or multijets*
  - MET is pointing along an jet: *remove fake MET from mismeasured jets*
- Estimate from data main backgrounds:
  - $(Z \to \nu\nu)$+ X (irreducible)
  - $(W \to l\nu)$+X, $(Z \to ll)$+X, with lost lepton
  - Multi-jets, γ+jets with fake MET
  - Non-collision events
- Estimate from MC smaller backgrounds: top, diboson

Monojet Analysis: Backgrounds

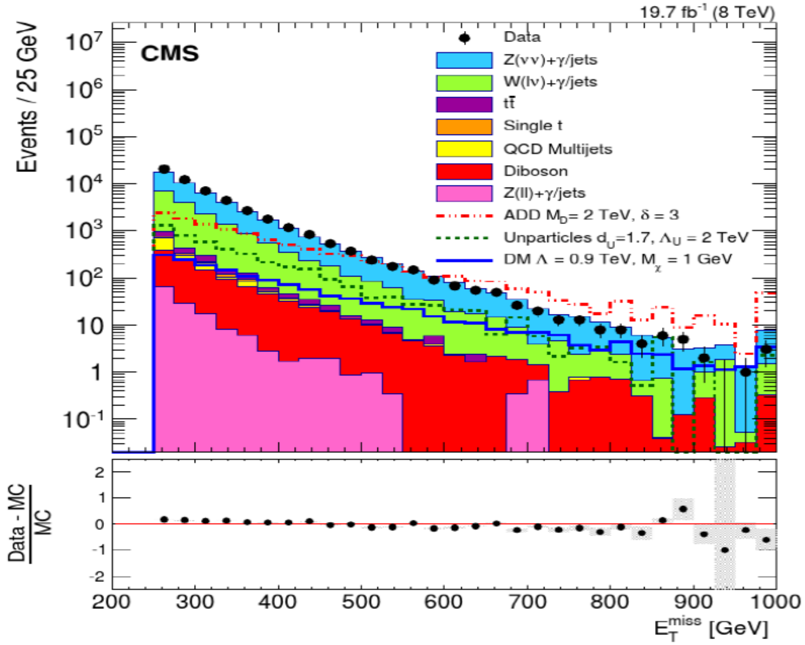
- $Z \to \nu\bar{\nu}(\mu\bar{\mu}, e\bar{e}, \tau\bar{\tau}) + \text{jets}$ and $W \to e\nu(\mu\nu, \tau\nu) + \text{jets}$ are estimated using CR with leptons enriched in $W \to \mu\nu + \text{jets}$ and $W \to e\nu + \text{jets}$ (also cross checked with a $Z \to \mu\bar{\mu} + \text{jets}$ CR)

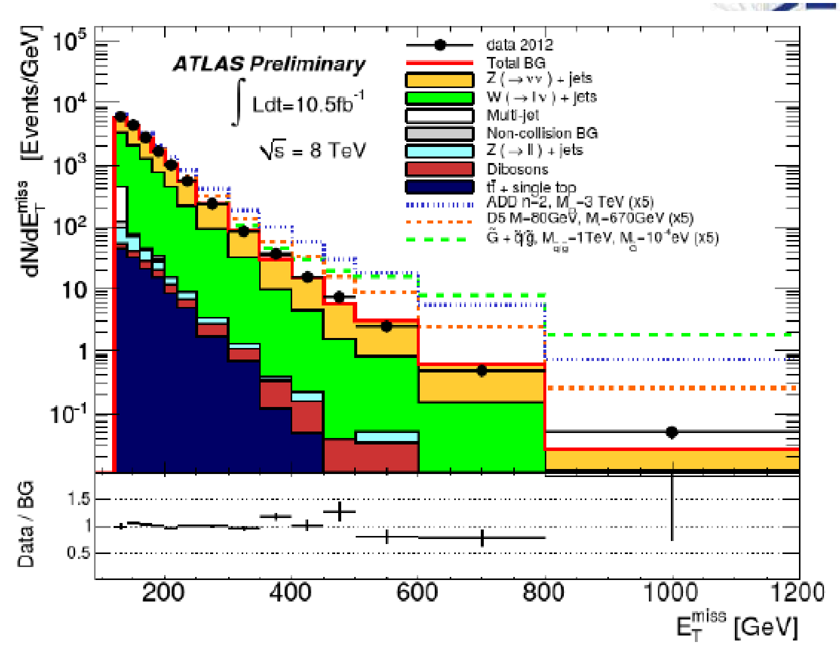


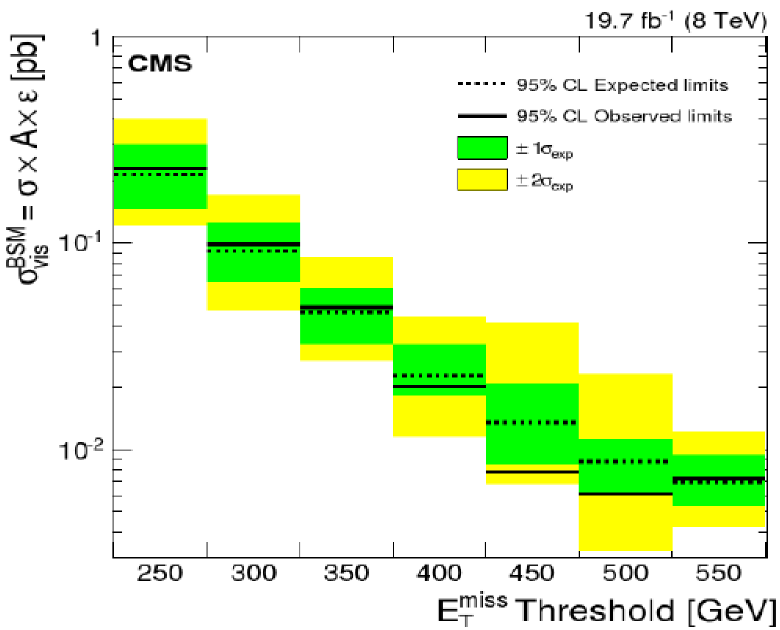


- Multijet background estimated using a MET+ 2(3) jets CR where Δφ(MET,jet2(3))<0.5

Monojet Analysis: Results







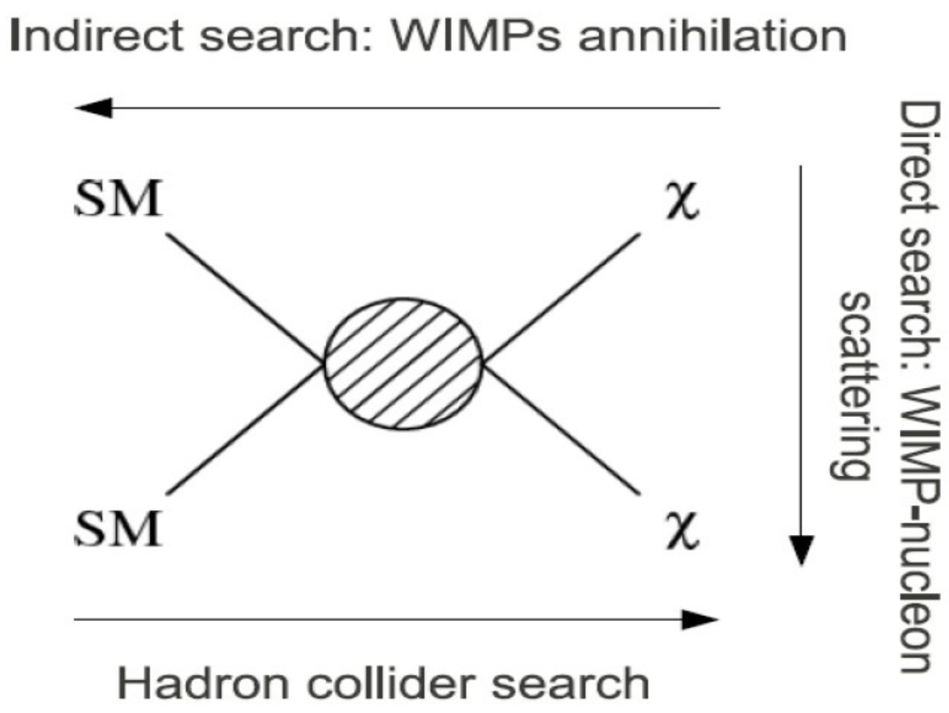
ATLAS results for 10 fb-1 at 8 TeV
CMS results for 19.5 fb-1

Good agreement of data with SM Expectation used to set a Model-indpendent limit on Cross-section for new physics

Monojet/monophoton analysis: interpretations

- Dark Matter production
- Graviton production in Extra Dimensions
- Gravitino production in GMSB models
- Degenerate SUSY models:
  - Light stop
  - Higgsinos

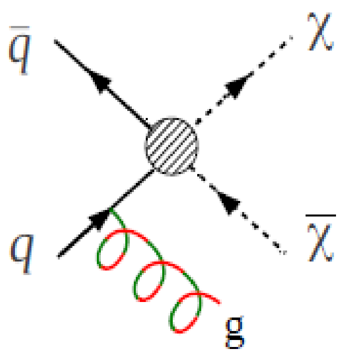
Dark matter interpretation



DM production at Colliders test same process as direct and indirect searches.
Need to put some theory in the blob to allow comparison

Two main model approaches

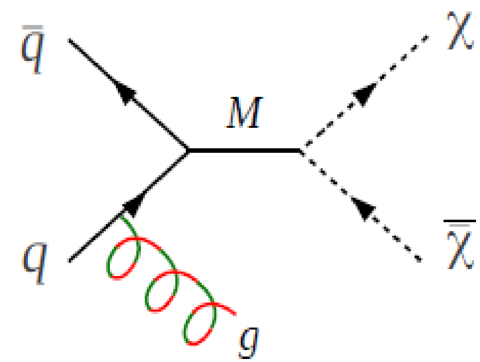
Can't resolve mediator → use Effective Field Theory of contact interaction at scale Λ:



$$O_V \sim \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$$

$$O_A \sim \frac{(\bar{\chi}\gamma_\mu\gamma^5\chi)(\bar{q}\gamma^\mu\gamma^5 q)}{\Lambda^2}$$

Light mediator of mass M → use Simplified Theory:



$$\mathscr{L}_V \sim \frac{i g_\chi g_q}{q^2 - M^2}(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)$$

$$\mathscr{L}_A \sim \frac{i g_\chi g_q}{q^2 - M^2}(\bar{\chi}\gamma_\mu\gamma^5\chi)(\bar{q}\gamma^\mu\gamma^5 q)$$

Nomenclature for the interactions:

"V" → vector; "A" → axial-vector; "S" → scalar (describes gluon fusion with $O_S \sim \frac{\bar{\chi}\chi \;\; \alpha_s (G^a_{\mu\nu})^2}{4\Lambda^3}$)

EFT and ST are equivalent for $q \ll M$ → $\Lambda = \frac{M}{\sqrt{g_\chi g_q}}$

EFT vs simplified model

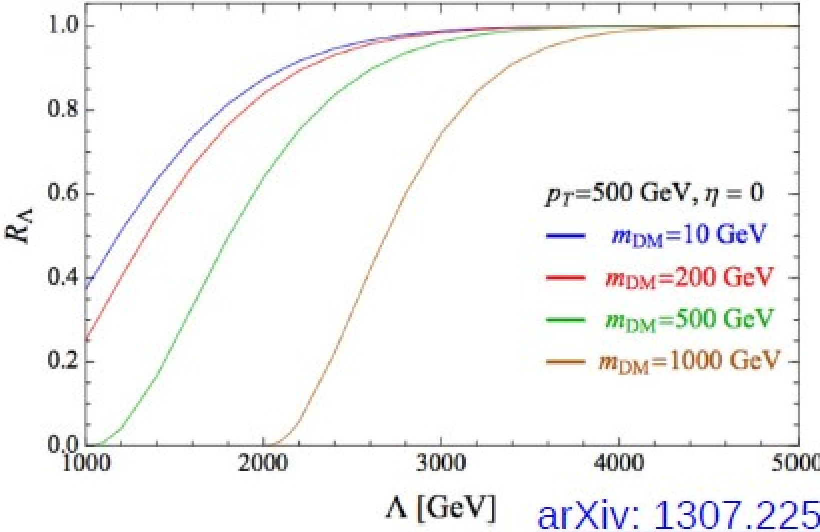
EFT

- Simple parameter space Λ and m_χ
- Breaks down when $q>\Lambda$

Simplified model

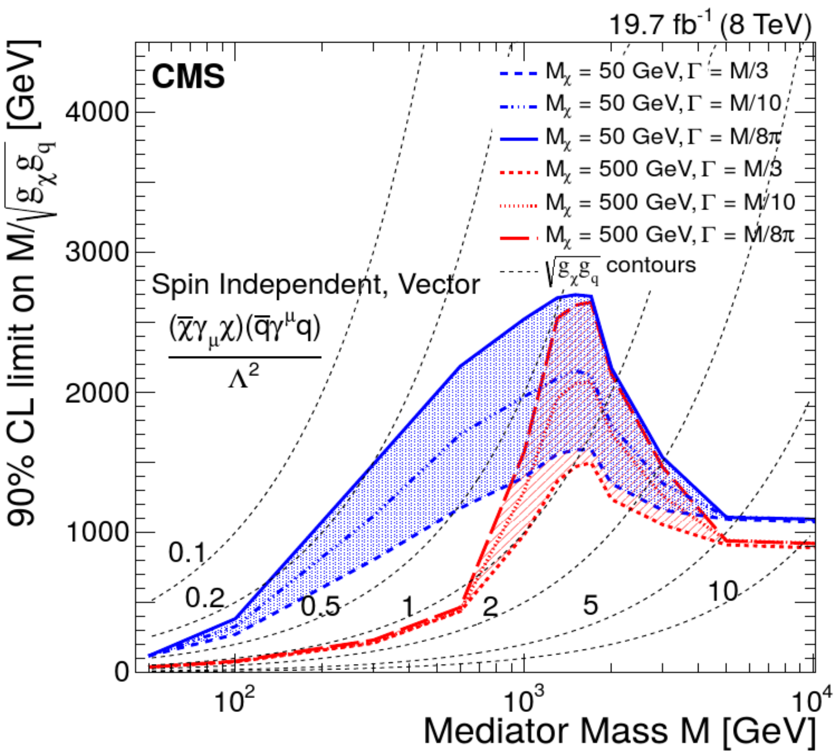
- UV complete
- Larger parameter space:
- M, m_χ, g_q, g_χ

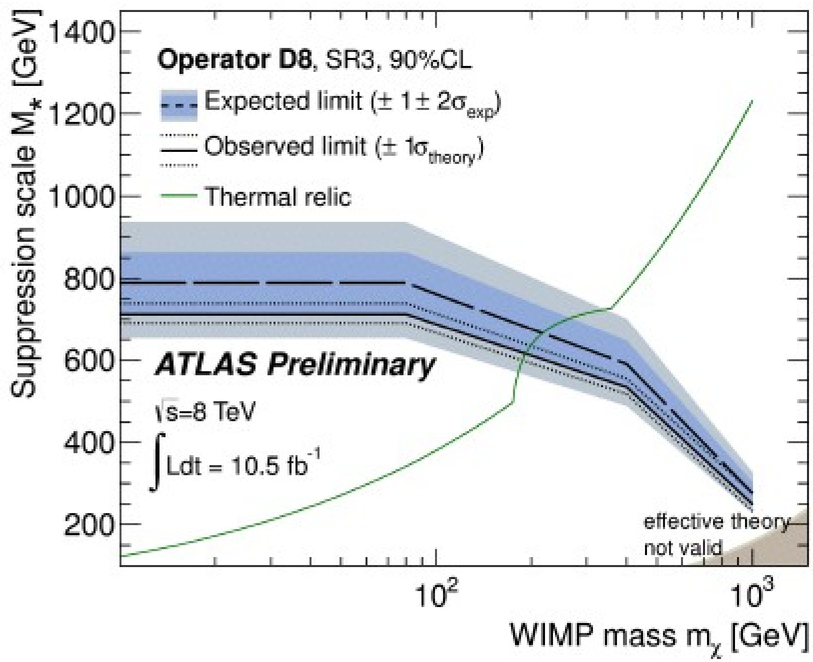
fraction of events with $q < \Lambda$:



arXiv: 1307.2253

Example of limits in two approaches



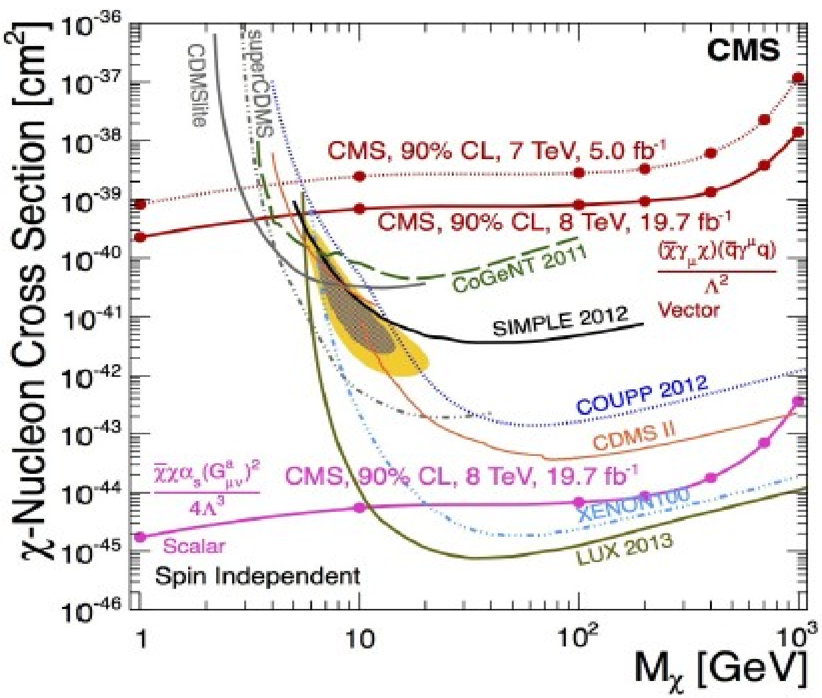


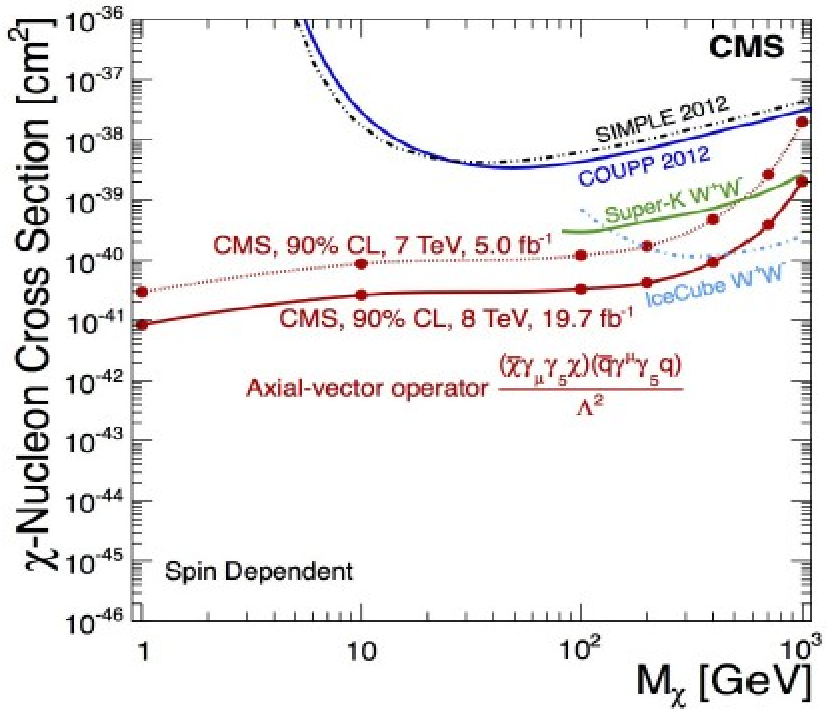
- Light mediator or large couplings are ruled out
- Resonant structure
- Reduced to EFT for high M

D8 == Axial Vector

For a wide range of χ masses
The limit is order 0.8 TeV

EFT WIMP interpretation





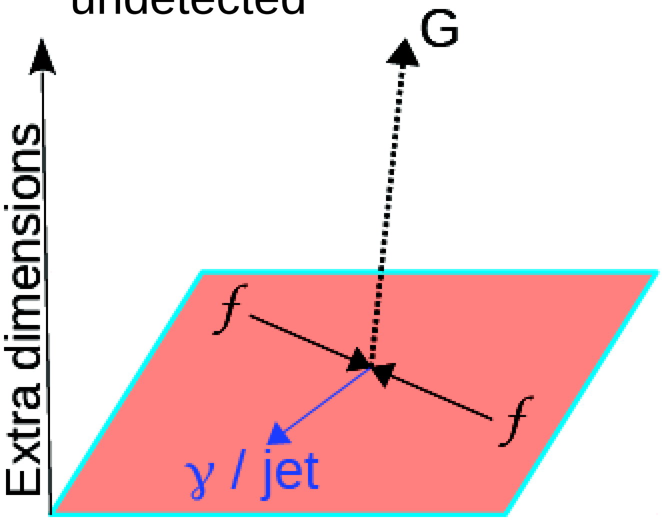
Direct detection experiments use the same EFT
Limits can be translated on limits on x-nucleon cross-section
EFT always valid for direct detection (low q).
For colliders, would need to integrate out high q events, depending on assumed mediator mass.

Interpretation: graviton in extra-dimensions

ADD model: gravity propagates in n Extra Dimension compactified on a radius R.
Characteristic scale of gravity is MD given by

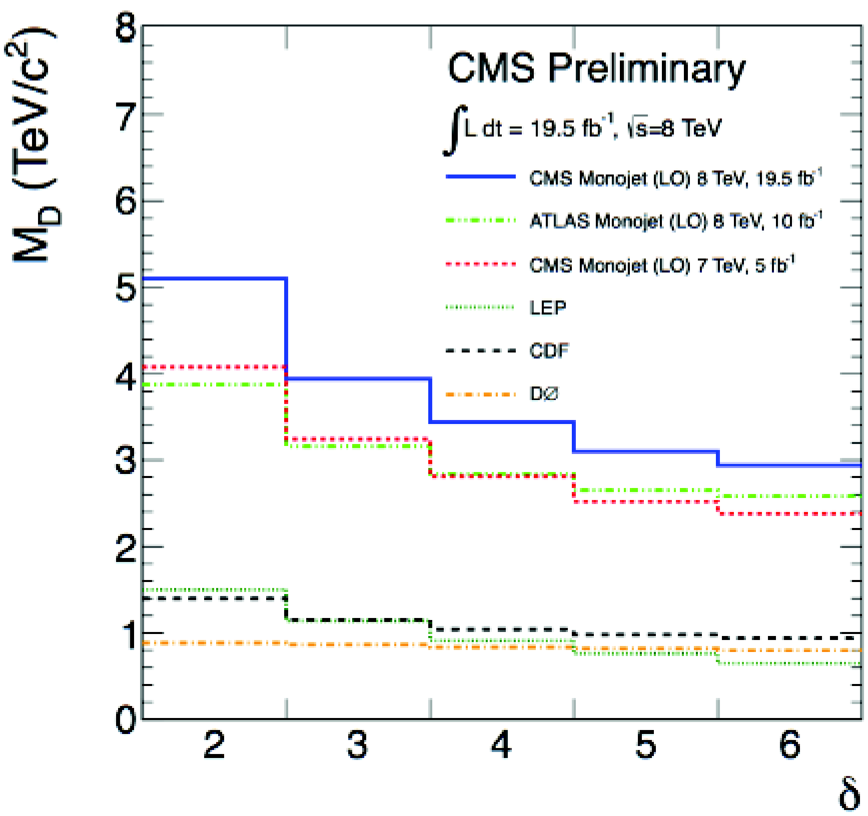
$$M_{Pl}^2 = M_D^{2+n} R^n$$

Graviton escapes in ED and goes undetected



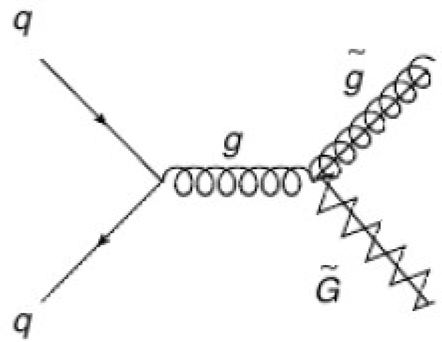
Can produce a KK tower of graviton states
Recoiling against a jet or a photon

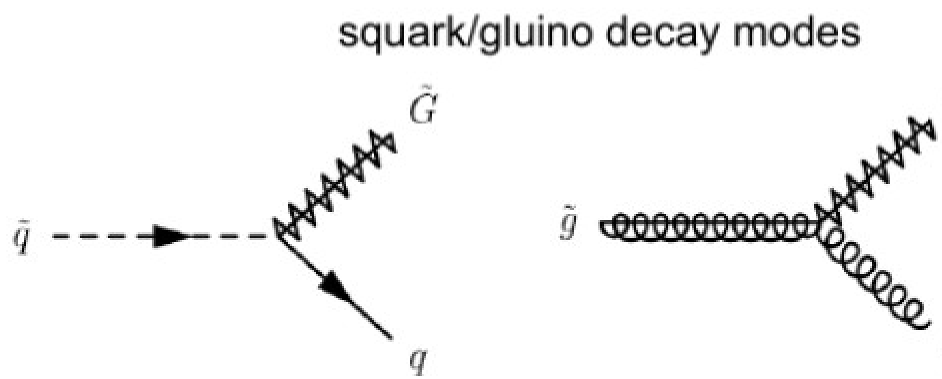
$$\sigma_{KK} \sim \frac{1}{M_D^2}\left(\frac{\sqrt{s}}{M_D}\right)^n$$



Limit on MD between 3and 5 TeV depending on n

Interpretation: gravitinos in GMSB



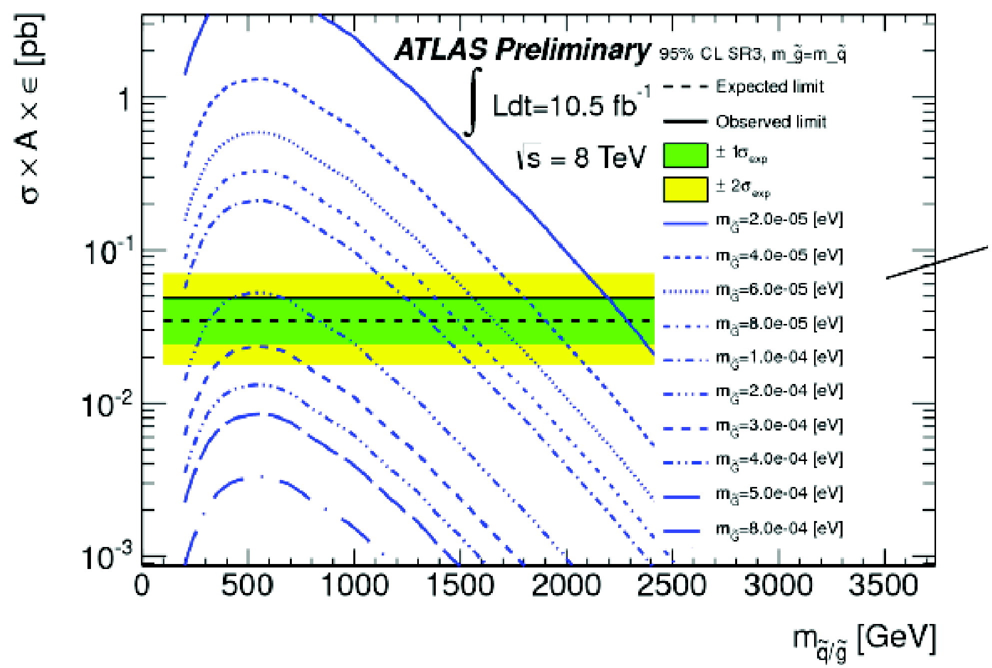


In GMSB model light gravitino often LSP

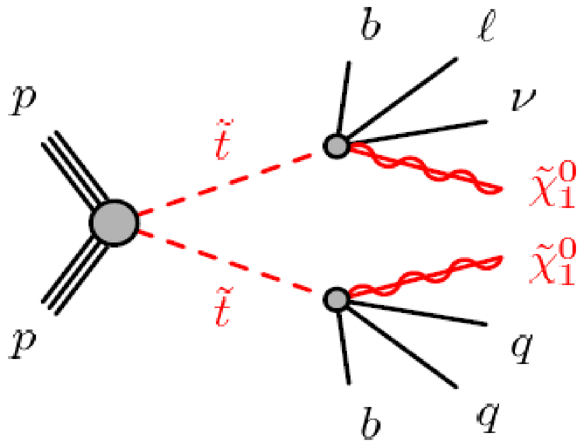
Study associated production of Gravitino with squark/gluino

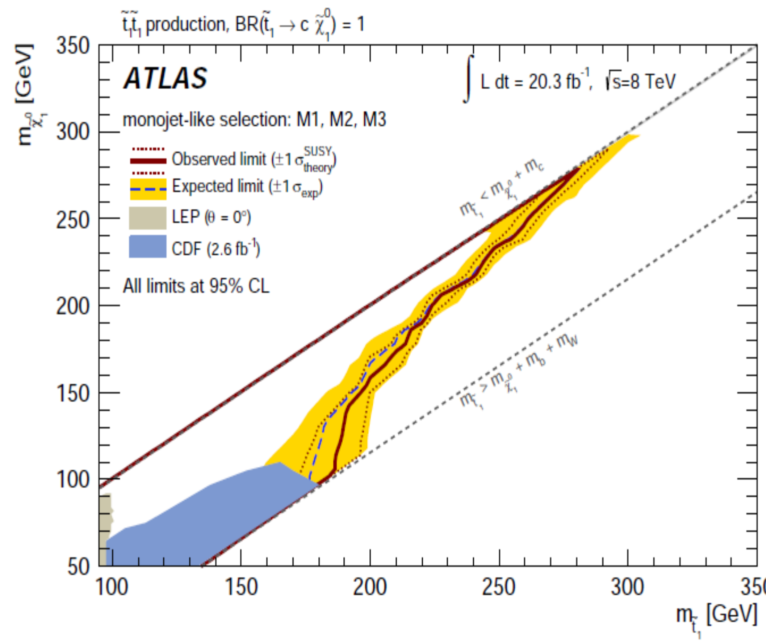
Squark/gluino in turn decay into jet+Gravitino: monojet signature

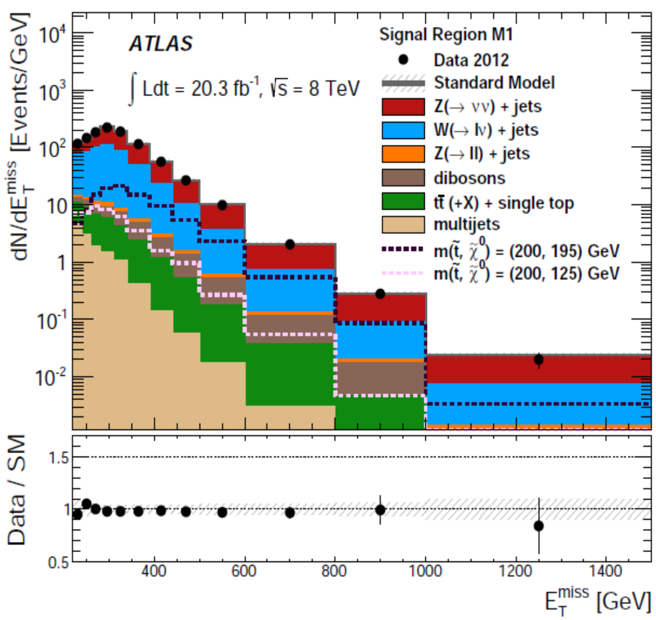
For a 1 TeV squark/gluino exclude A gravitino with mass above 1e-4eV



Interpretation: stop



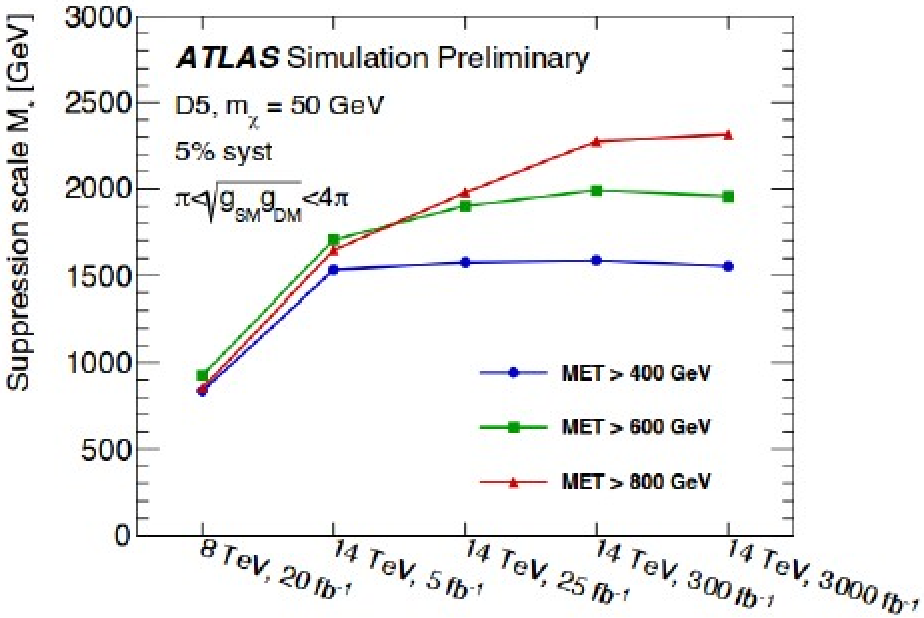


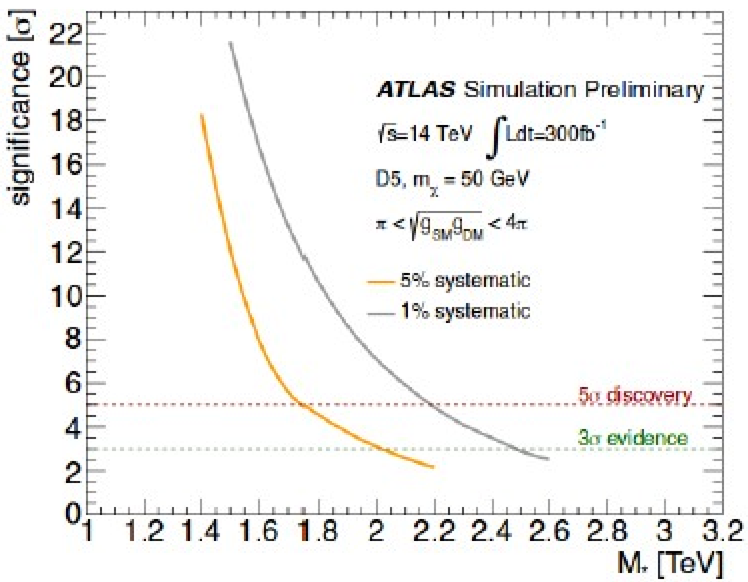


Search for 4-body decay of stop
Require:
One high pT jet and MET,
No more than 3 jets with pt>30 GeV
Lepton Veto
$\Delta\phi$(jets, MET)>0.4

M1: Ptj>280 GeV, Etmiss>220 GeV

Outlook on monojet searches





Significant improvement in sensitivity expected with early run 2 data:

Exclusion limit on mediator mass improved by a factor 2 with firs few fb^{-1}

5σ discovery potential for M* ~1.7 TeV with 300 fb^{-1}

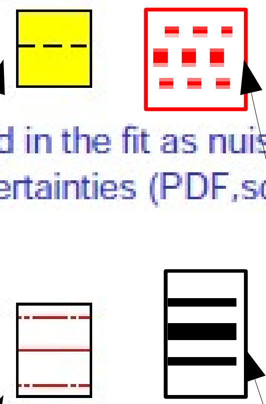
Conclusions

- Searches for new physics performed on very broad range of signatures, addressing many BSM models on Run 1 LHC data
- Null results strongly constrain BSM model space
- Squarks of first two generations and gluinos heavy >~TeV
- Good Run 1 coverage also for production of stop and EWKinos
- Through mono-X analysis constraints on production of Dark Matter
- Run 2 will open a further kinematic region, experiments are ready to take advantage of the opportunity

Interlude: what are all those lines on limit plots?

❑ Exclusion limits : a new standard ATLAS/CMS procedure (>June 2012)

- Ease the life of theorist by separating the signal theoritical and experimental systematics

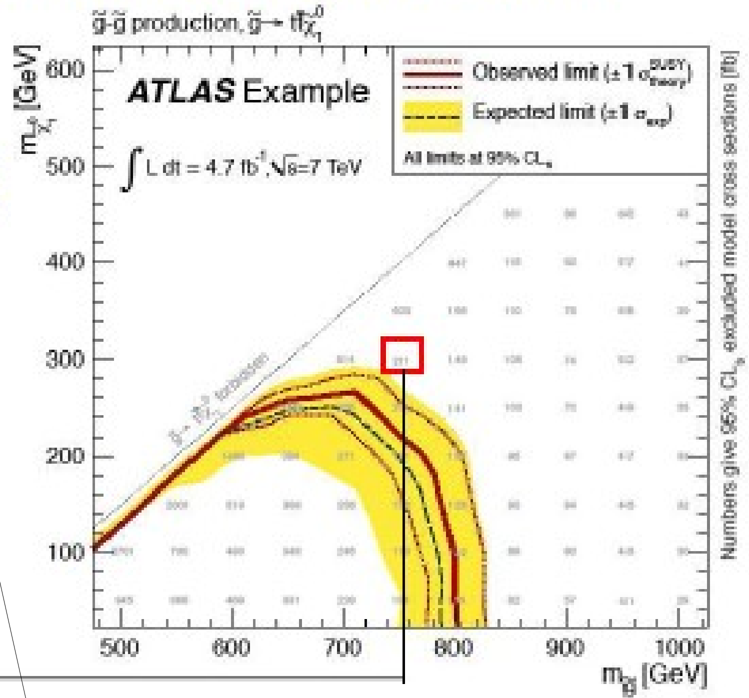


Expected limit:

- **Central value:** all uncertainties included in the fit as nuisance parameters, except theoretical signal uncertainties (PDF,scales)
- **±1σ band** : ±1σ results of the fit

Observed limit:

- **Central value**: Idem as for expected limit
- **±1σ band** : re-run and increase/decrease the signal cross section by the theoretical signal uncertainties (PDF, scales)

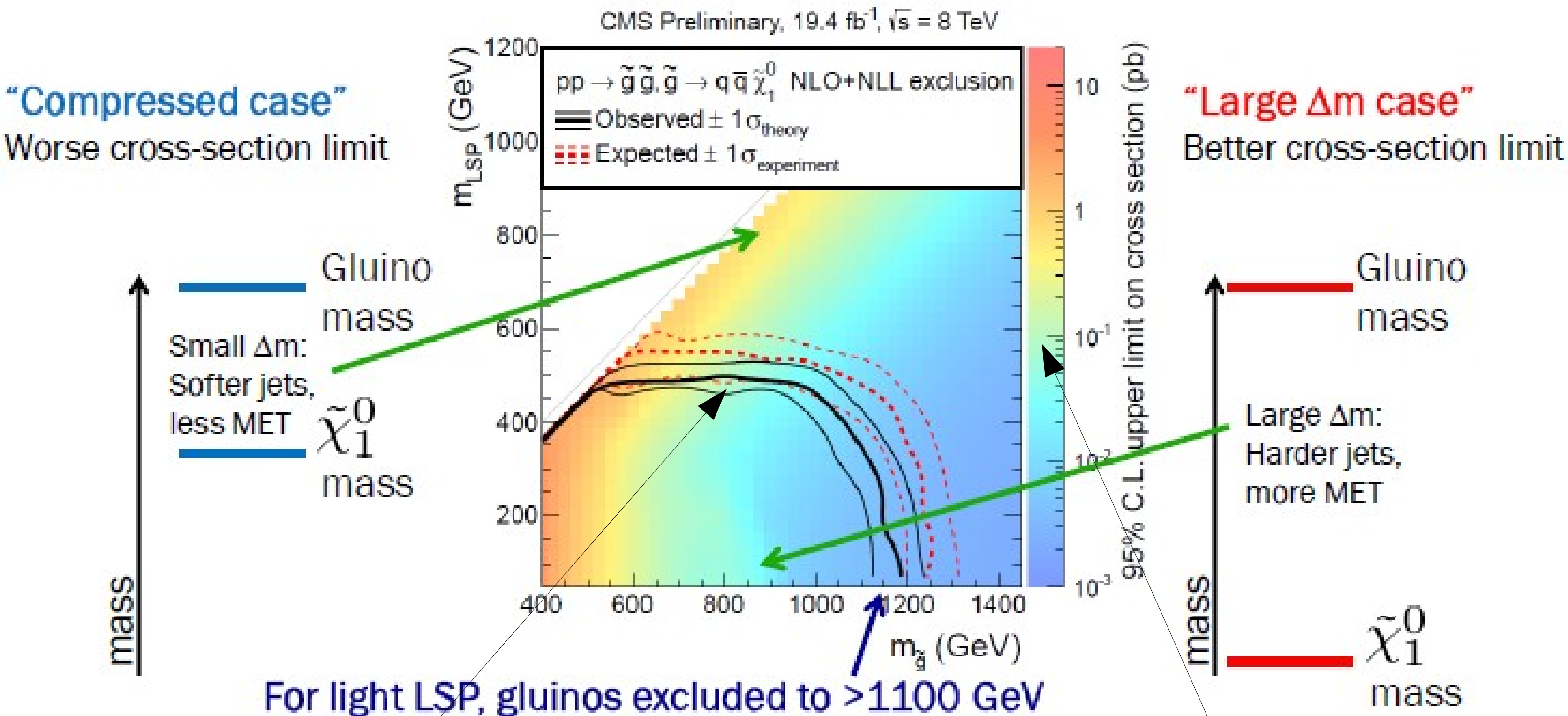


Excluded Model Cross section (SMS)

➔ Number quoted in paper correspond to observed -1 σ observed (conservative)

ATLAS CMS

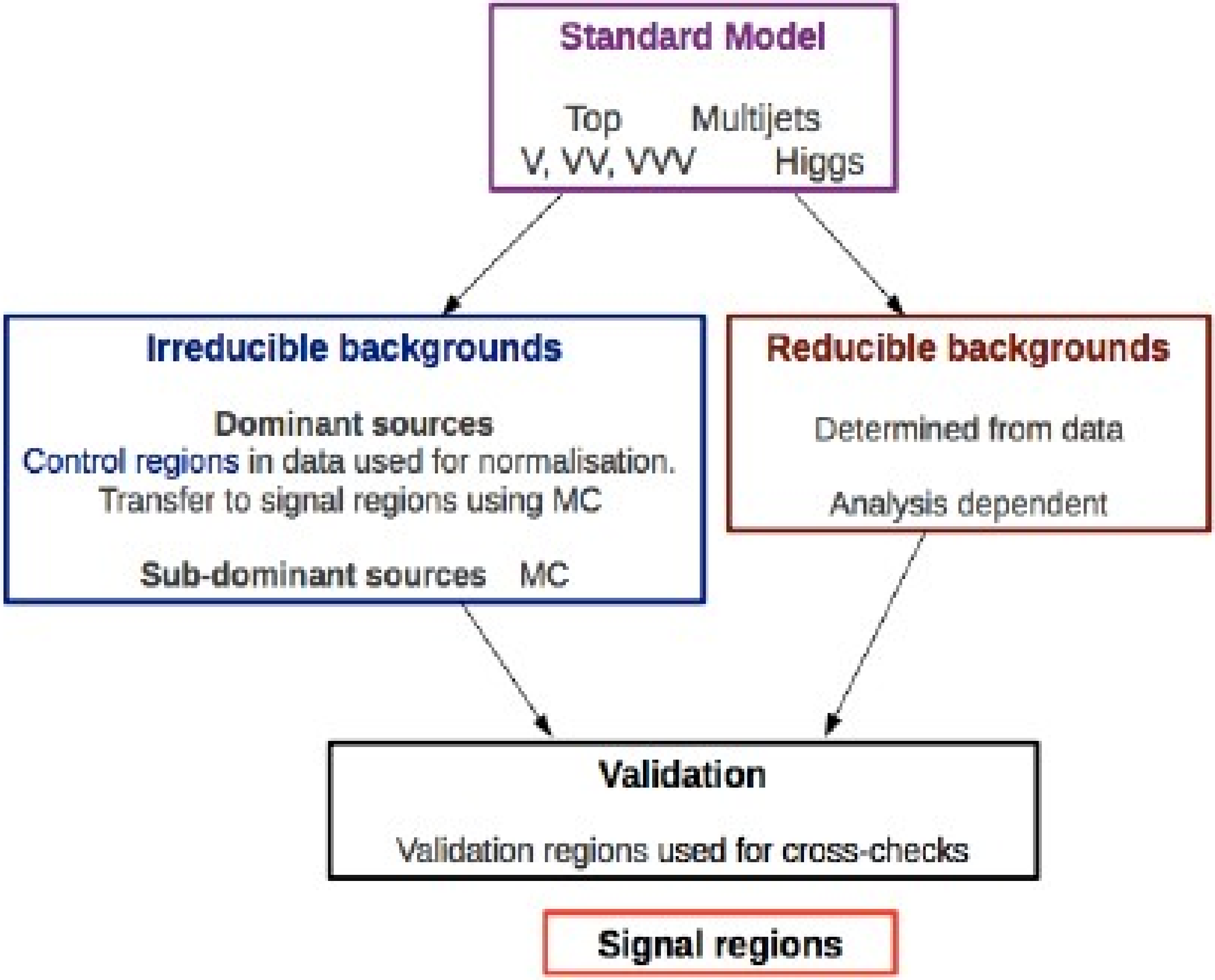
How to read a simplified model plot



Lines are model dependent, assume
- Production cross-section for initial state
- Branching fraction for decay

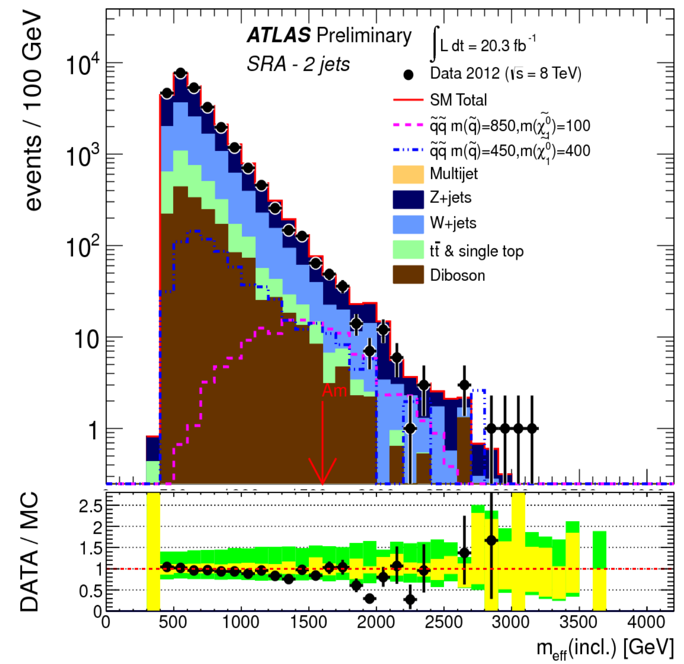
Color of plot is important:
It gives excluded cross section
In model-indipendent way,
Can be used to exclude different
Model with same topology

Flow of background evaluation

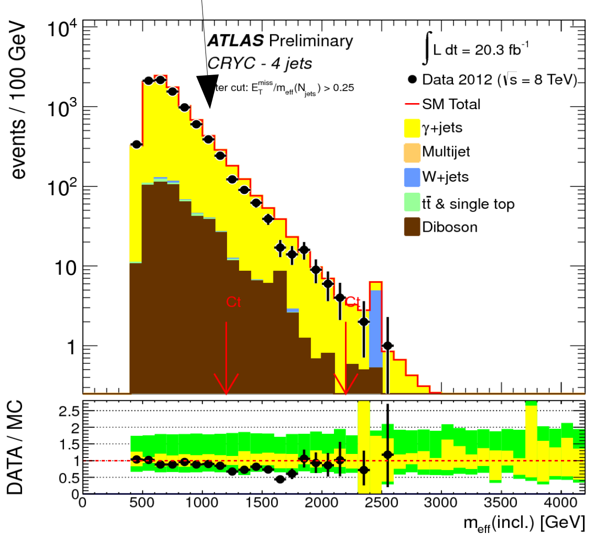


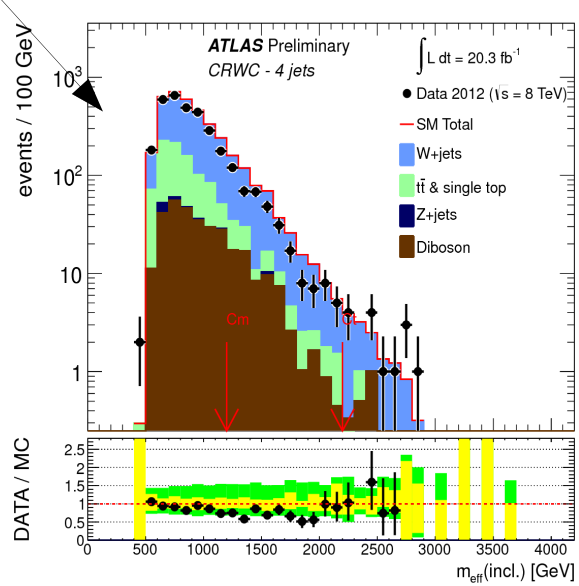
Background evaluation

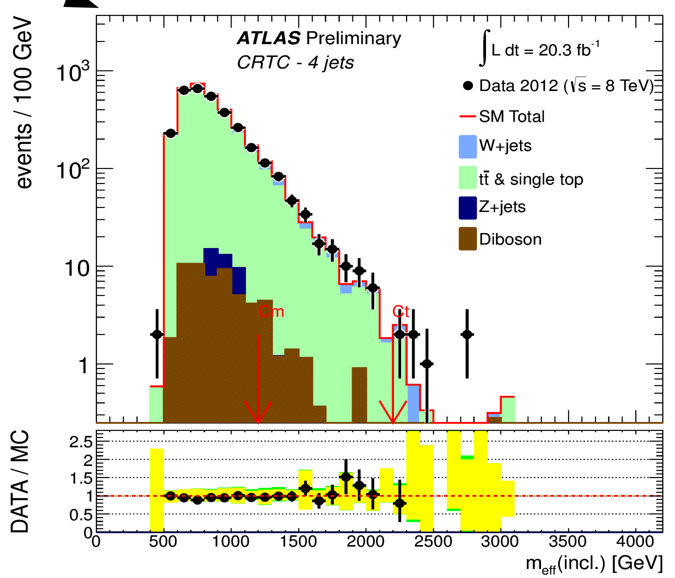
CR	SM Process	CR Process	CR Selection
CRY	$Z \to \nu\nu + jets$	$\gamma + jets$	Isolated photon
CRW	$W \to \ell\nu + jets$	$W \to \ell\nu + jets$	trans. mass, b-veto
CRT	$t\bar{t}$ and single top	$t\bar{t}$ and single top	trans. mass, b-tag
CRQ	multijets	multijets	Reverse anti QCD cuts



4 main backgrounds. For each signal region 4 control regions to constrain backgrounds







Dark Matter interpretation

- Need to assume model for DM interaction for connecting Collider data to DM experiments
- Use Effective Field (EFT) theory with contact interaction
- Ignore the nature of the mediator, write interaction as set of generic operators

Valid if the scale of interaction Is less than the mediator mass M

Name	Initial state	Type	Operator
D1	qq	scalar	$\frac{m_q}{M_\star^3}\bar{\chi}\chi\bar{q}q$
D5	qq	vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
D8	qq	axial-vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$
D9	qq	tensor	$\frac{1}{M_\star^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$
D11	gg	scalar	$\frac{1}{4M_\star^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$