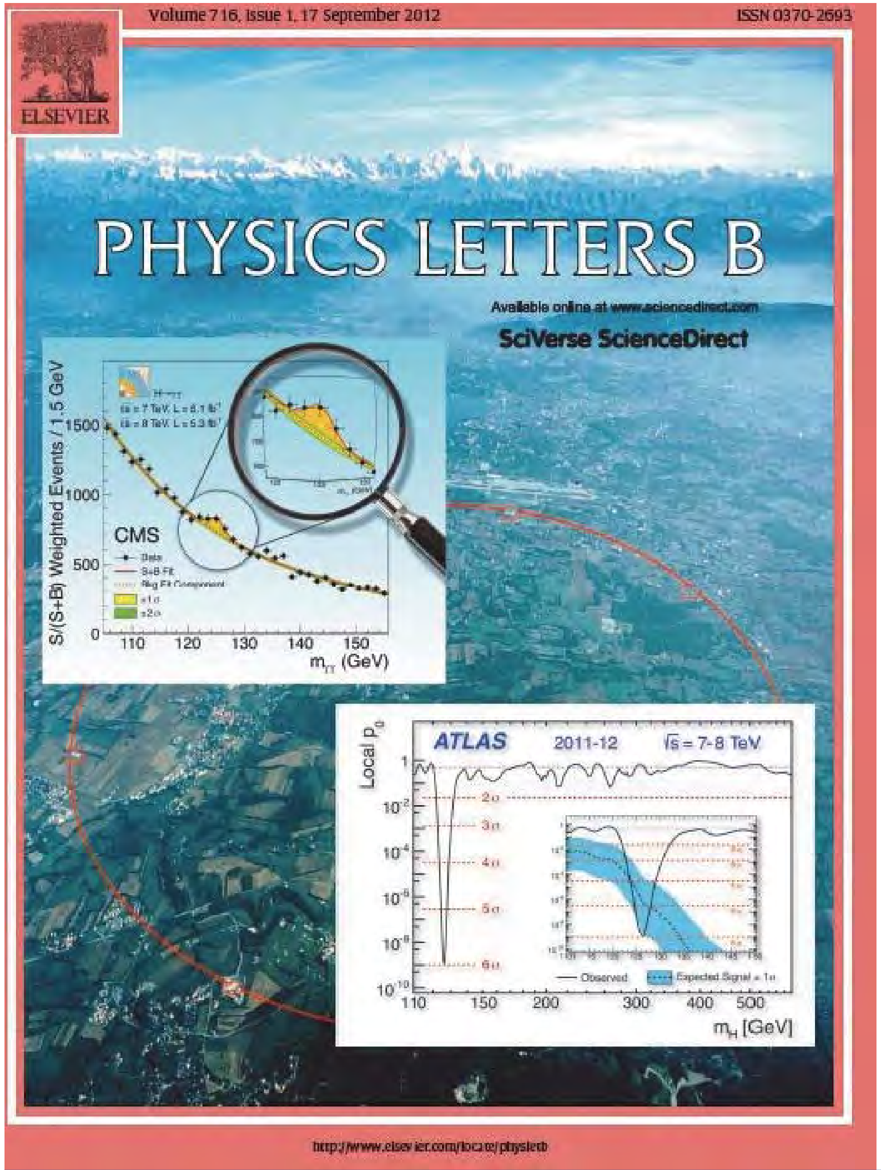
Accelerator dark matter searches: complementarity to indirect and direct searches

M. Antonelli

LNF-INFN



Discovery of a new boson declared by ATLAS and CMS on July 4 2012...

Higgs measurements lessons

- The discovery of the Higgs boson, and its first studies at run-I, represent a turning point in our understanding of fundamental interactions
- All degrees of freedom predicted by the SM have been experimentally confirmed.
- Assuming h(125) is the the excitation of the Higgs field, then
  - m_h is compatible with the indirect constraints from e.w. precision observables *(→ no clear clue for NP around the TeV scale)*
  - the leading Higgs couplings are compatible with SM expectations *(→ no clear clue for extra light Higgses and/or NP around few 100 GeV)*
  - the Higgs field has a small self-interaction ($\lambda \approx 1/2\, m_h^2/v^2 \approx 0.13$) and the SM potential is unstable but sufficiently metastable up to the Planck scale *(→ no need for NP below the Planck scale…. but it looks very fine tuned)*

Who's next?

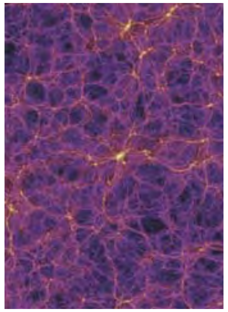
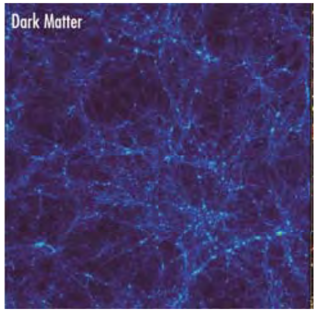
- Still... the SM suffers of a series of theoretical & cosmological problems:
  - Fine-tuning/UV sensitivity of the Higgs-mass term ["hierarchy *problem"]*
  - Unexplained hierarchical structure of the Yukawa couplings ["flavor *puzzle"]*
  - No explanation for the quantization of the U(1) charges [hint *of unification?]*
  - No natural inclusion of neutrino masses [hint *of unification?]*
  - Non coherent inclusion of gravity at the quantum level
  - No good candidate for dark matter & no explanation of dark energy

Common view: the SM is an *effective theory,* or the low-energy limit of a more fundamental theory, with new degrees of freedom at high energies.

MOST WANTED

DARK MATTER

Seen making gravitational interactions: rotational curves, CMB, gravitational lensing. BBN, bullet

Multimedia: Images

Aliases: Wimp, Neutralino…..

DESCRIPTION

Age: approximately 14 billions years

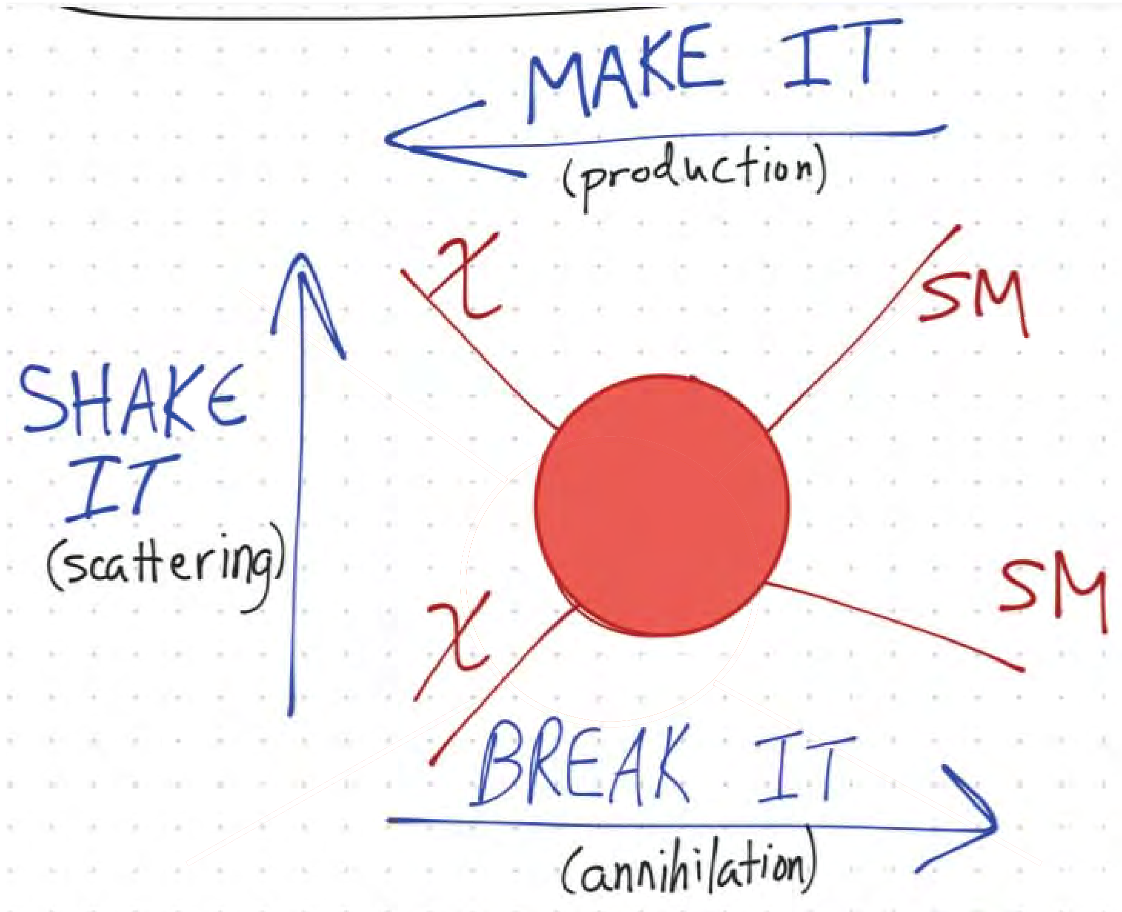
Weight: approximately 0.01-1 TeV

Interaction: gravitational, “weak”

Distinctive features: tendency to escape

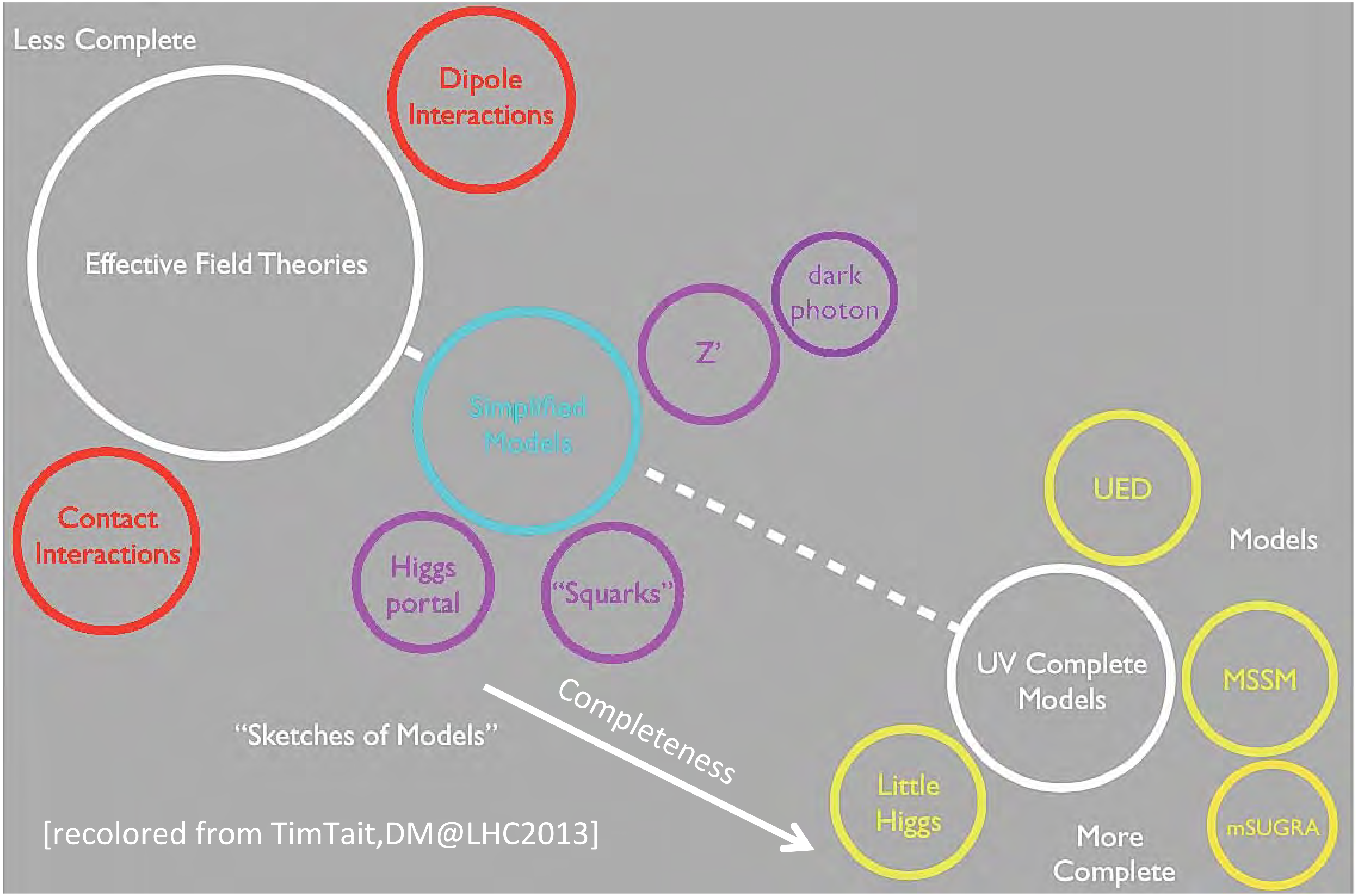
REWARD

Searching in all ways

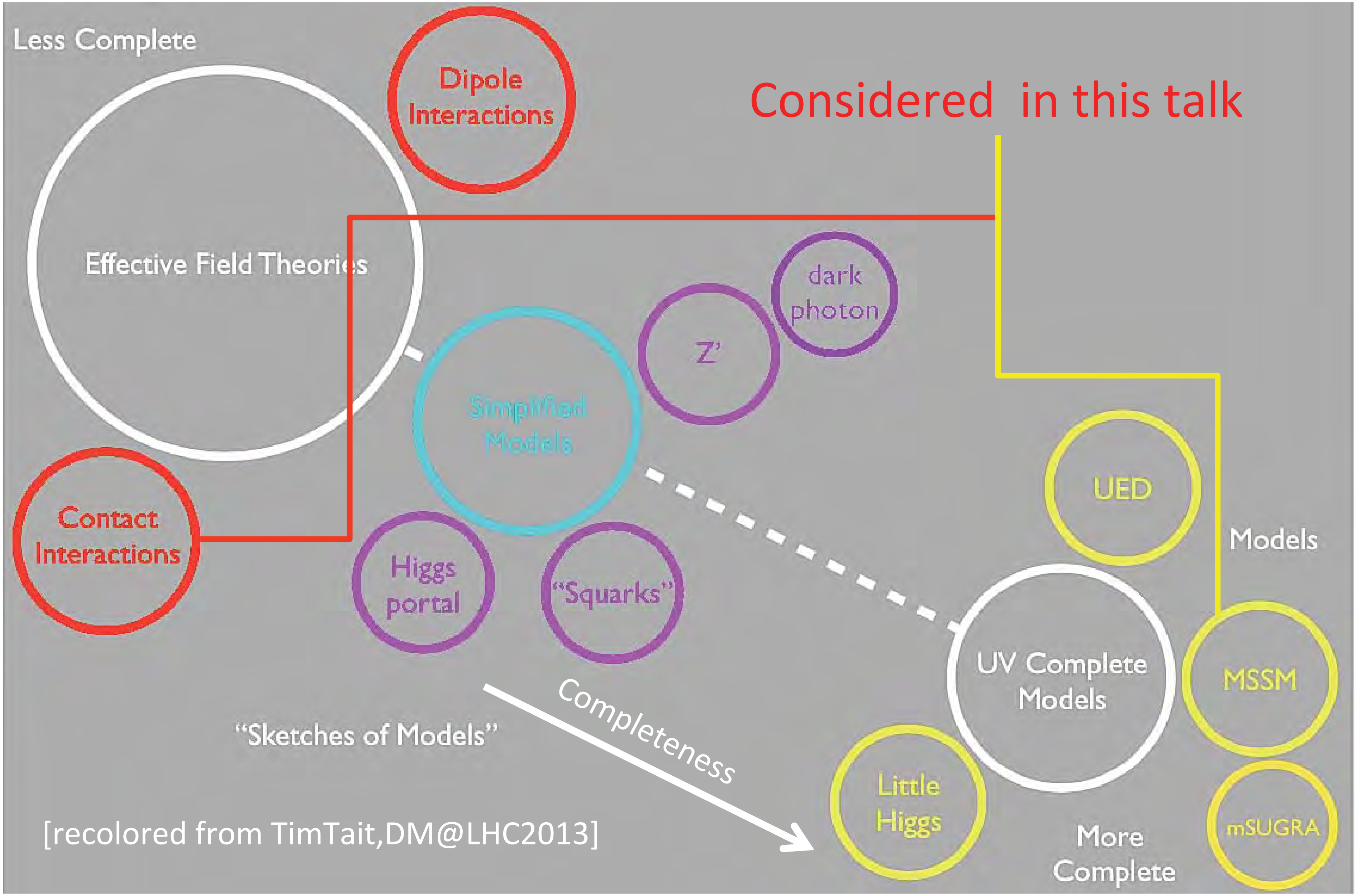


- dark matter searches of all kinds put constraints on different observables
- Without some kind of theoretical structure, we can’t compare them.
- VERY Important to asses if searched topologies are exhaustive

Dark Matter theories



Dark Matter theories



LHC Experiments

The Large Hadron Collider

- Circumference 27 km
- 9533 magnets (1332 dipoles)
- 4 main experiments.

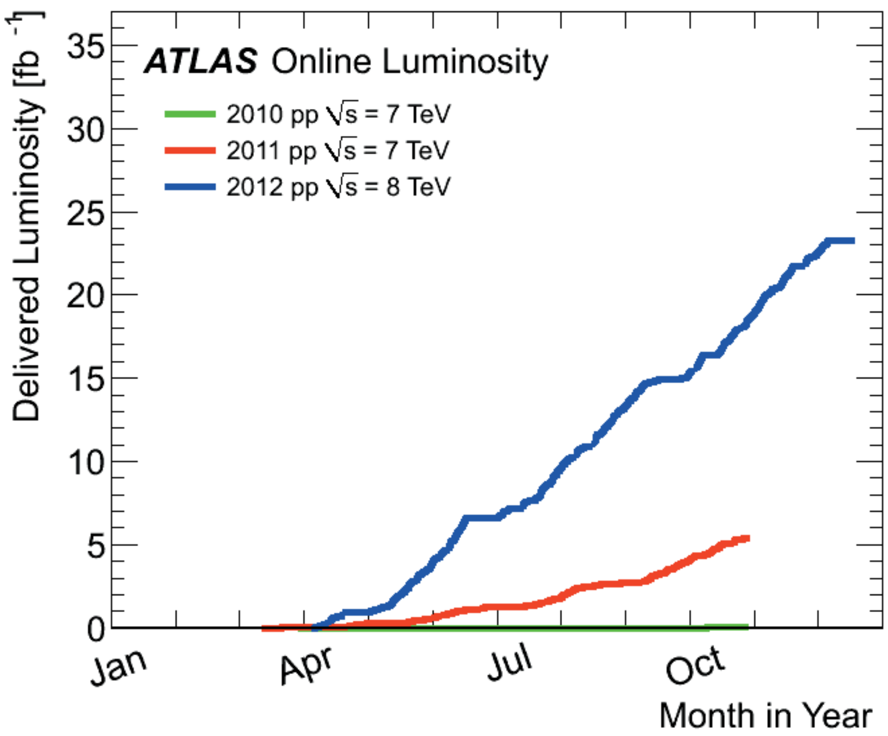
Center-of-Mass Energy:

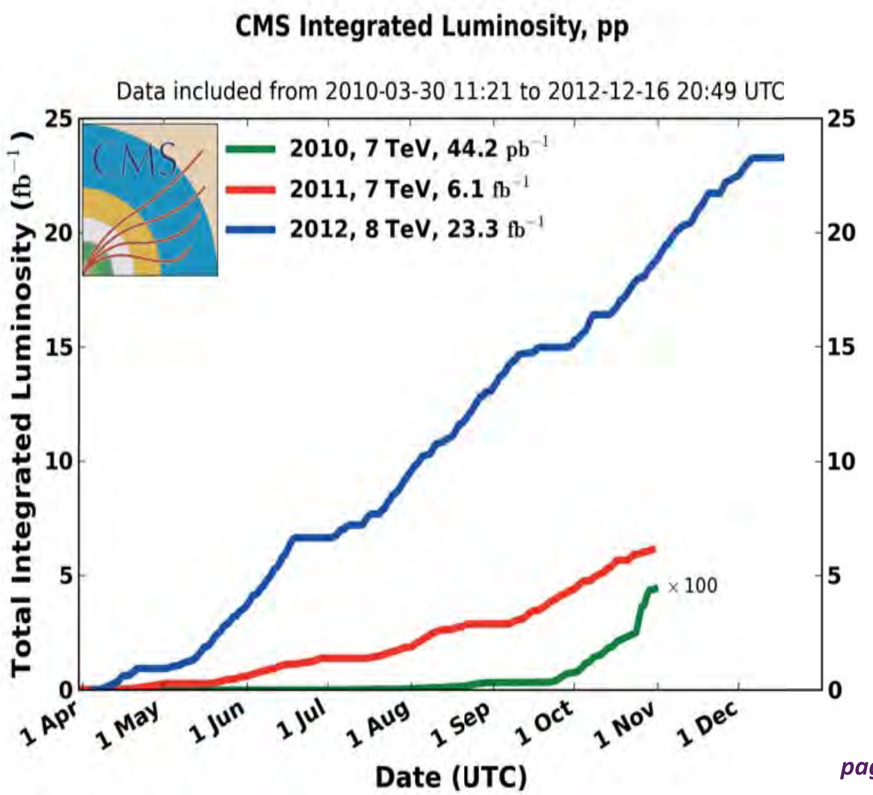
- Nominal: 14 TeV
- beginning of Run-II: 13 TeV
- Spring-Autumn 2012: 8 TeV
- 2011- beg. 2012: 7 TeV
- 2011: 900 GeV

ATLAS and CMS during LHC Run-I

	√S	Delivered (fb^{-1})	Recorded (fb^{-1})
pp 2011	7 TeV	**5.61**	**5.25**
pp 2012	8 TeV	**23.3**	**21.7**

	√S	Delivered (fb^{-1})	Recorded (fb^{-1})
pp 2011	7 TeV	**6.1**	**5.55**
pp 2012	8 TeV	**23.3**	**21.79**



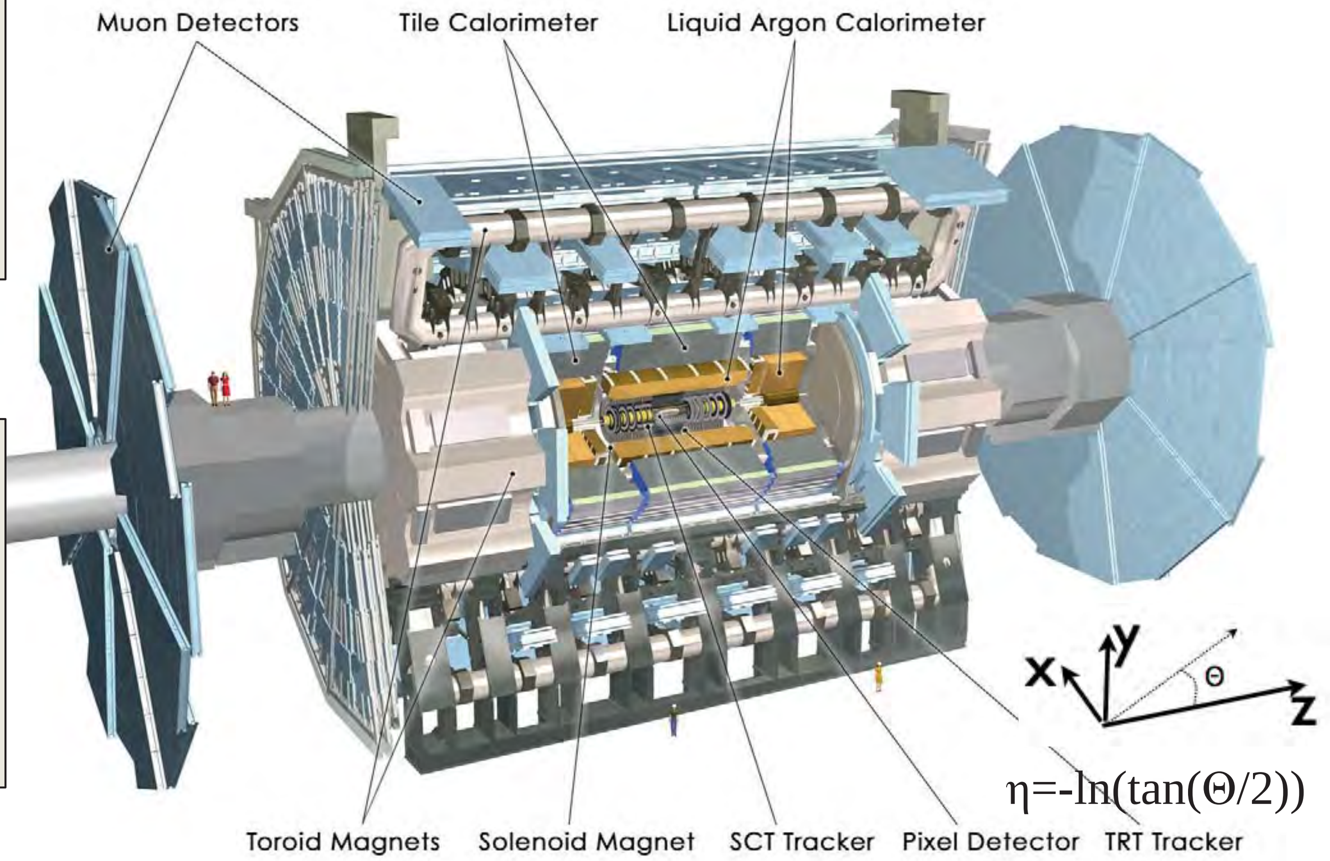


ATLAS detector: general structure

EM Calorimeter: (|η|<4.9) Pb-LAr accordion structure provides e/γ trigger, identification, measurement:
σ/E ~10%√E
Hadronic (Tile): provides trigger, jet measurement, E_T^{miss}
σ/E ~50%√E ⊕ 0.03. (|η|<1.7)

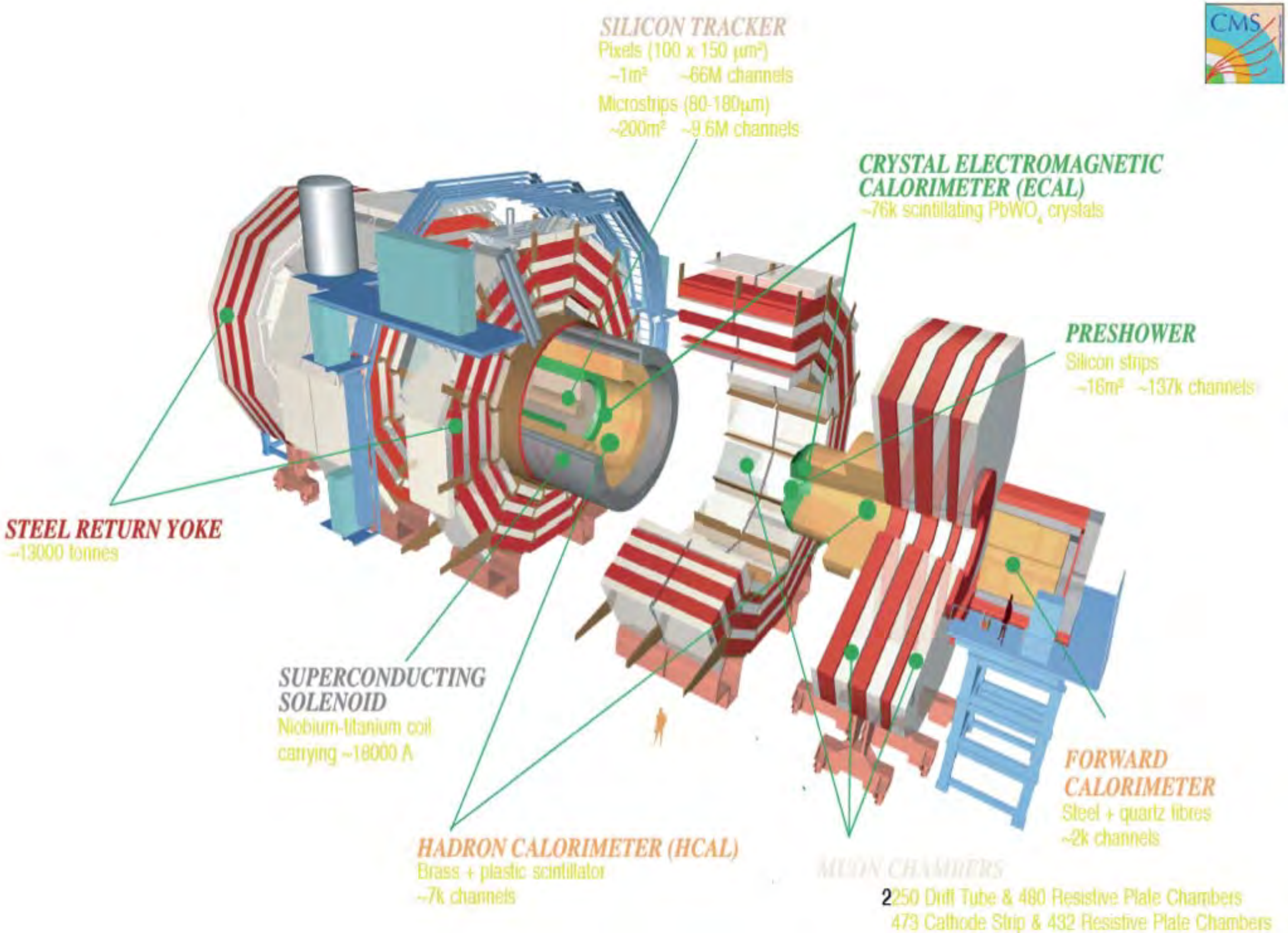
The Inner Detector provides around 3 pixel, 8 SCT and 30 TRT measurements per charged track at η = 0. Coverage: |η| < 2.5 (2.0 for TRT)
Resolution goal:
$\sigma_{p_T} / p_T = 0.05\% \, p_T \oplus 1\%$

Muon spectrometer: high precision tracking and trigger chambers.
|η| coverage up to 2.7.
Magnetic field produced by 3x8 air-core toroids.

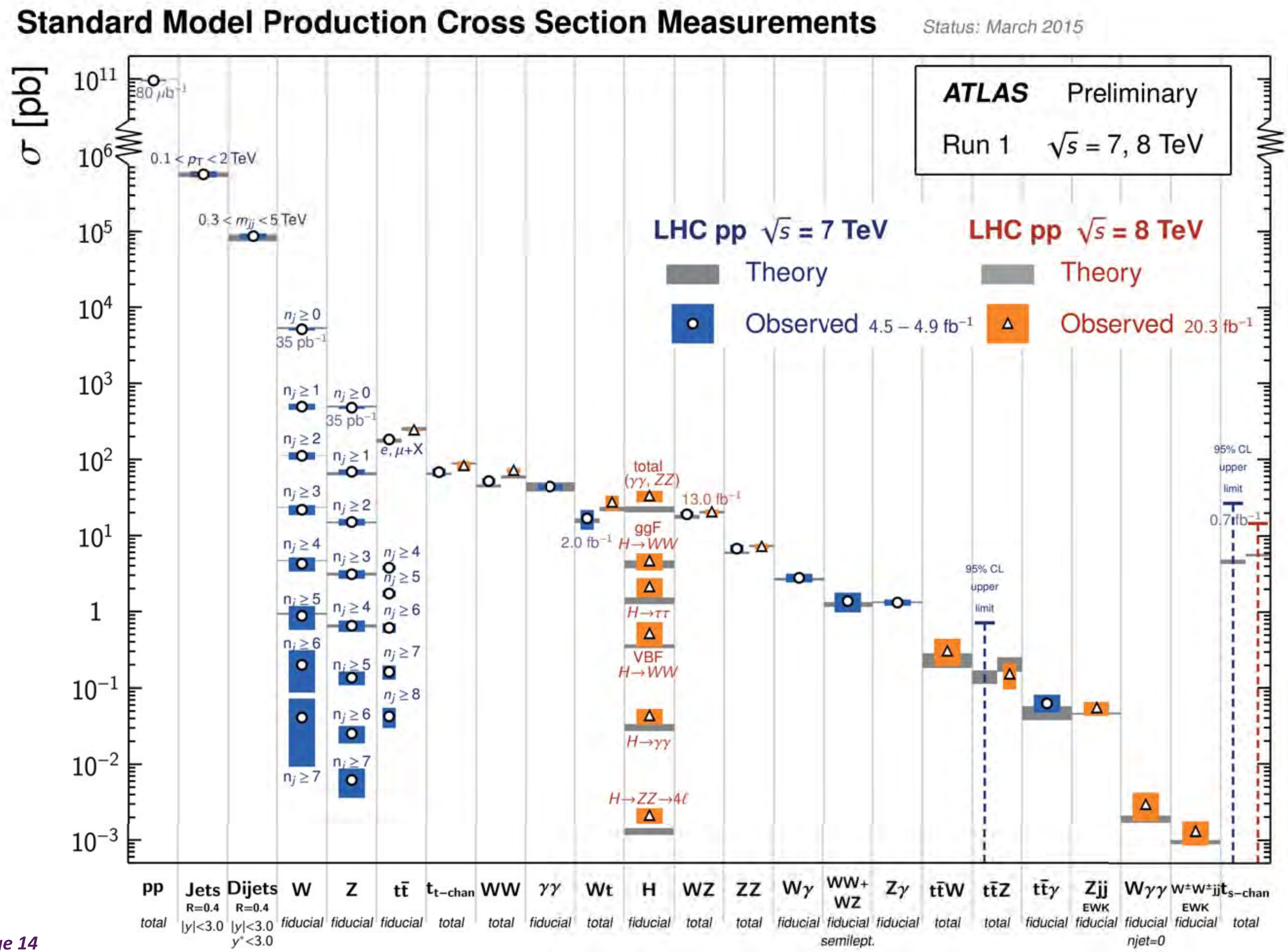


$\eta = -\ln(\tan(\Theta/2))$

ATLAS & CMS detector: general structure



Standard Model processes at the LHC



Effective theory

CONTAT INTERACTION

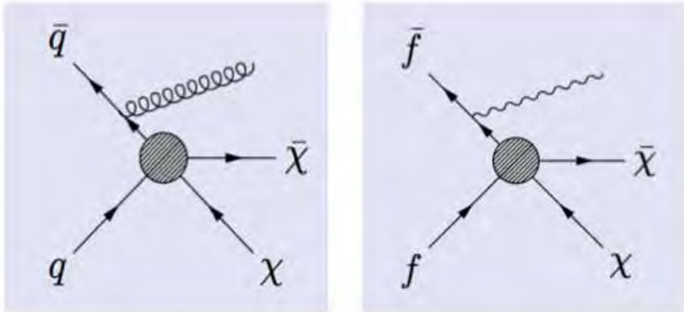
J. Goodman et al., Phys.Rev.D82:116010,2010

(model independent approach)

Effective Lagrangian approach (contact interaction) with parameters M_* (Λ) and m_χ

$M_*^2 \sim M^2/g_1 g_2$ [$M > 2\, m_\chi$, $g_1 g_2 < (4\pi)^2$]

assuming the interaction is mediated by a heavy particle with mass M and couplings g_1 and g_2



Different operators are considered with different structures and here χ will be taken as Dirac fermions

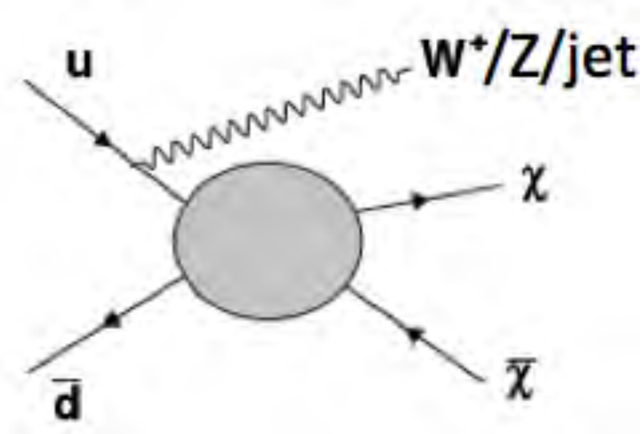
C1	qq	scalar	$\frac{m_q}{M_*^2}\chi^\dagger\chi\bar{q}q$
C5	gg	scalar	$\frac{1}{4M_*^2}\chi^\dagger\chi\alpha_s(G^a_{\mu\nu})^2$
D1	qq	scalar	$\frac{m_q}{M_*^3}\bar{\chi}\chi\bar{q}q$
D5	qq	vector	$\frac{1}{M_*^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
D8	qq	axial-vector	$\frac{1}{M_*^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$
D9	qq	tensor	$\frac{1}{M_*^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$
D11	gg	scalar	$\frac{1}{4M_*^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$

Important note:

Not clear whether the effective approach under- or over-estimates the cross sections since this depends on the details of the unknown UV limit of the theory

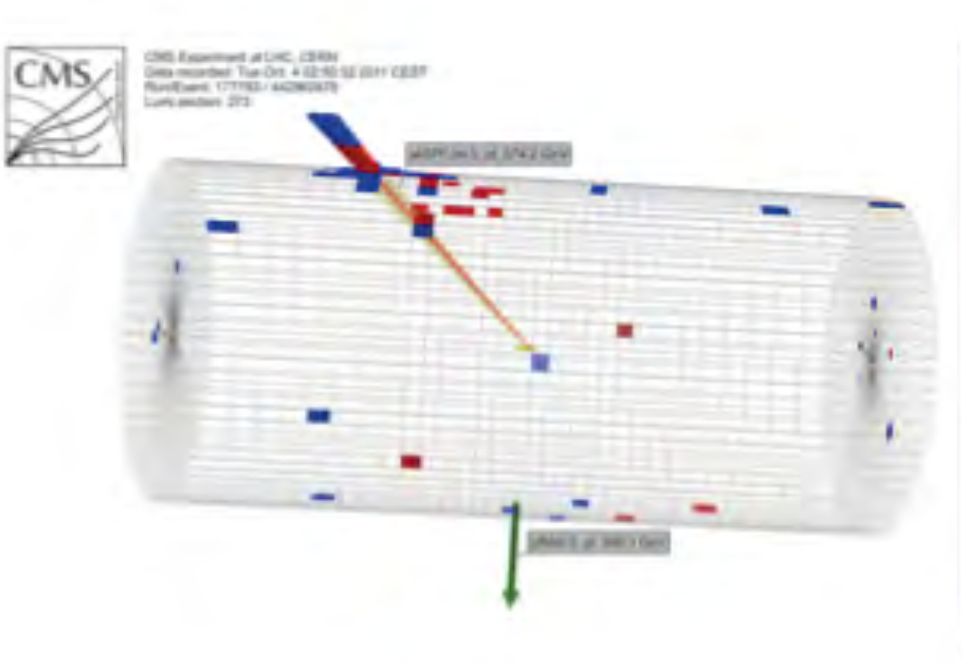
Strictly speaking theory only applicable when M is much larger than the energy scale present in the reaction [$Q^2 \ll (4\pi M_*)^2$, $m_\chi < 2\pi M_*$]

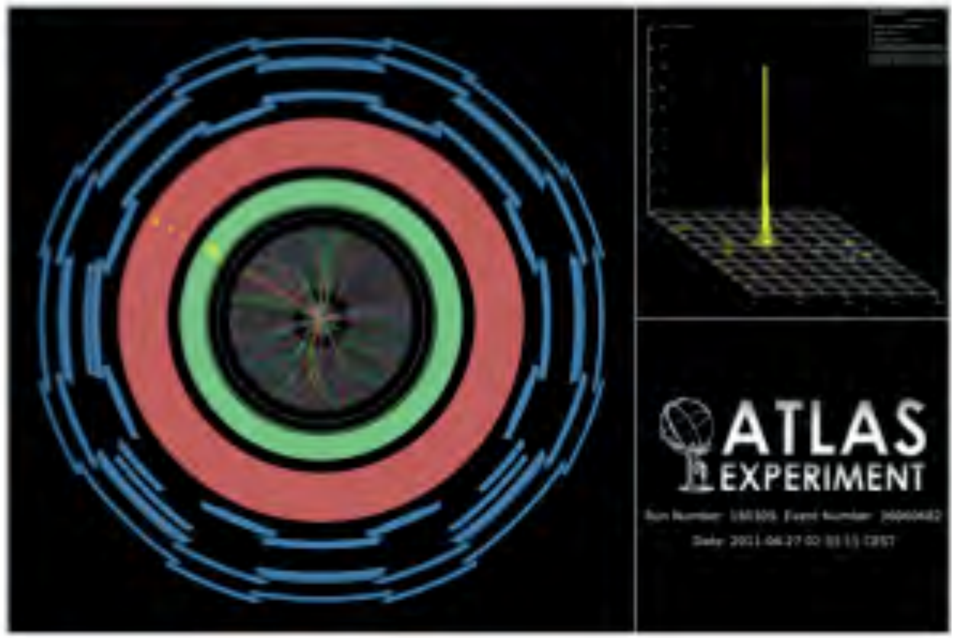
DM Searches: MONO-X



At colliders (LHC) WIMPs can be produced in leading to “nothing to detect” in the final state

Such events are tagged via the presence of an energetic jet or a photon (or a W/Z) from initial state radiation

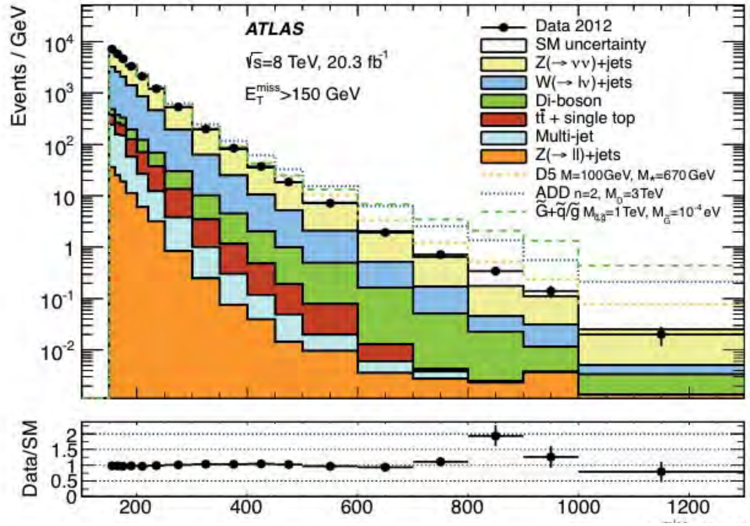


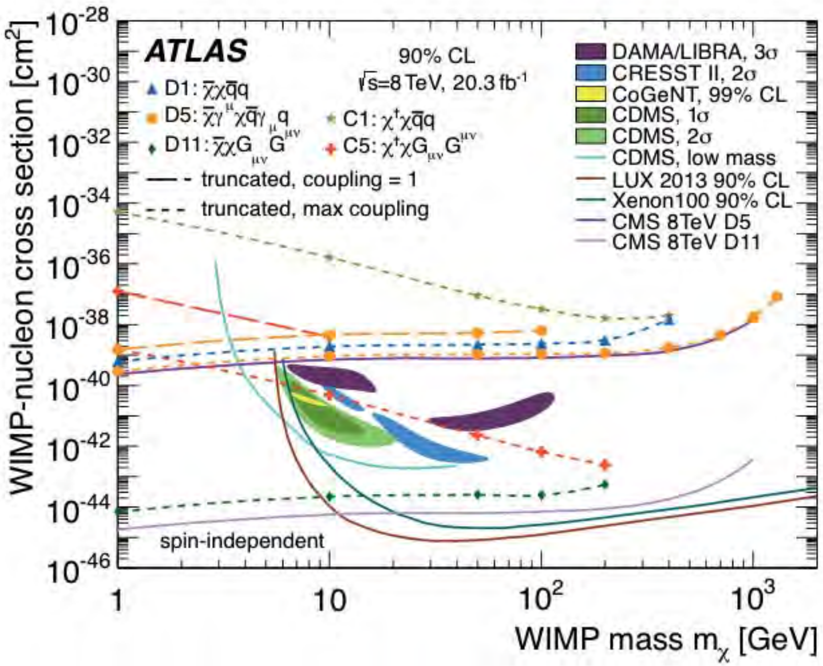


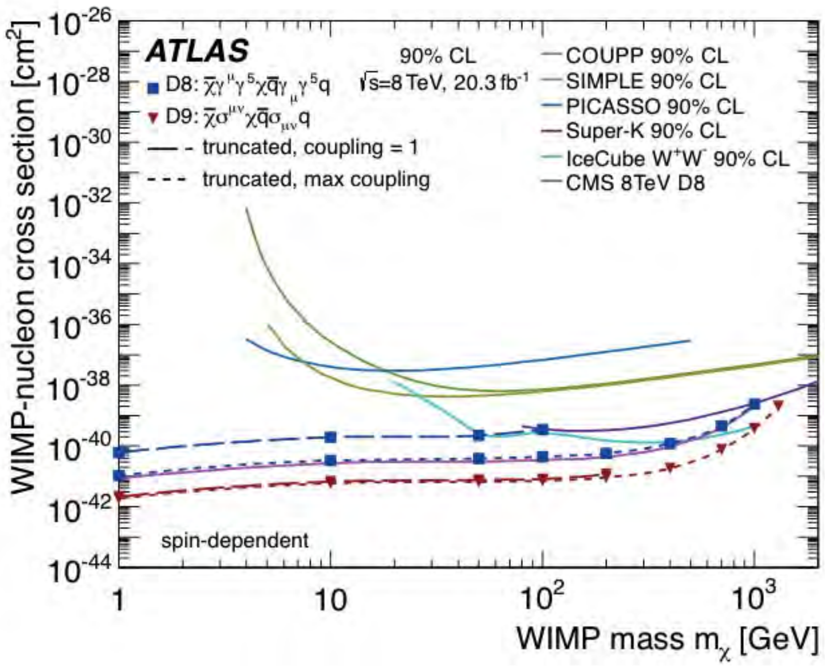
DM Searches: MONO-jet

Basic selection:

Etmiss > 150 GeV, pT(j1)/Etmiss> 0.5,
Njet(pT>30 GeV)<3

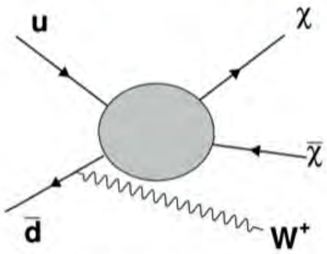


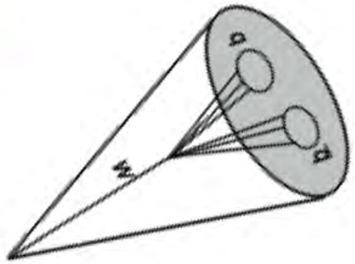




MONO-Z/W

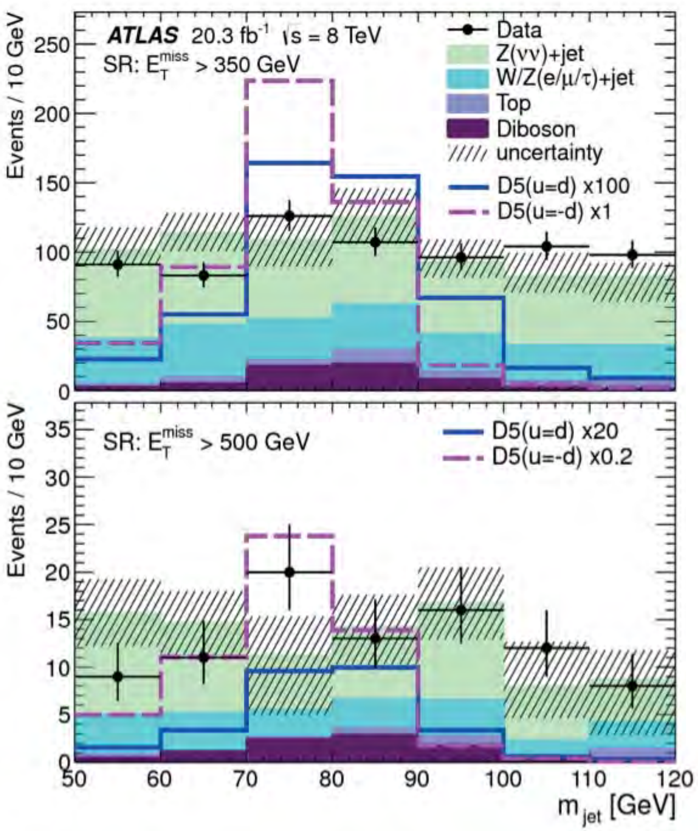
8 TeV
20 fb^{-1}

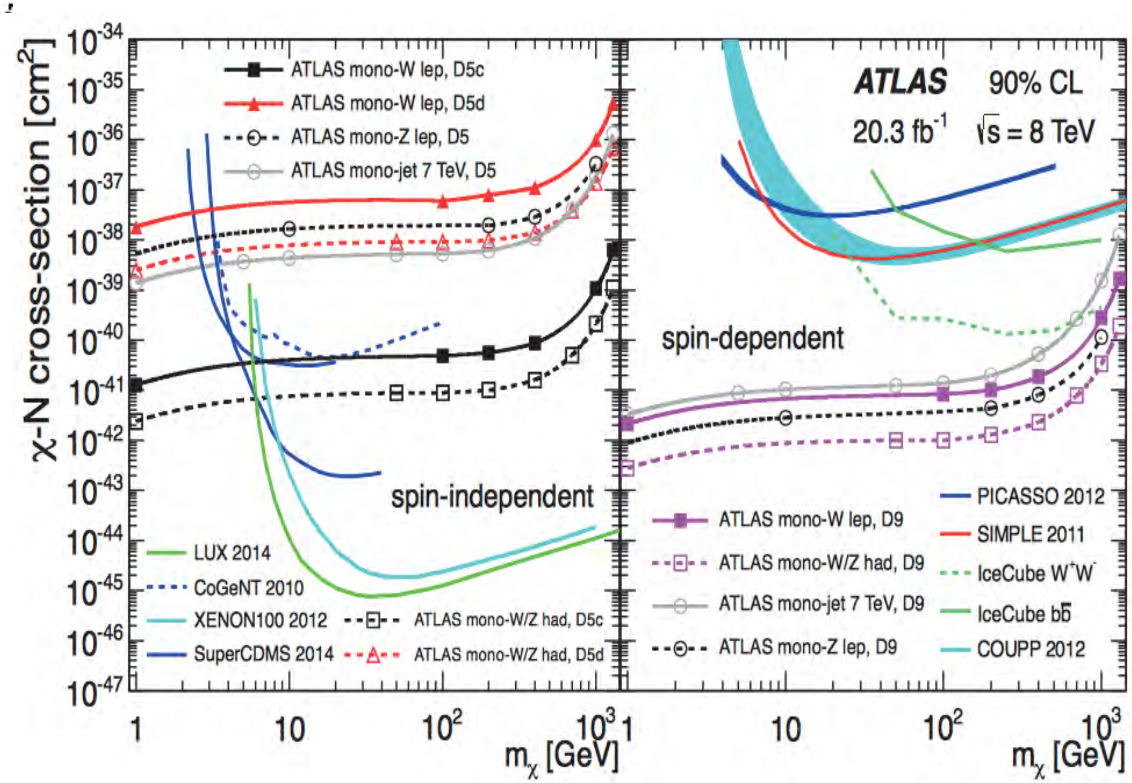




Based on the W/Z hadronic decay products reconstructed as subjets from CA R=1.2 jets
Jet P_t > 250 GeV, $|\eta|$ < 2.1, 50 < M_{jet} < 120 GeV

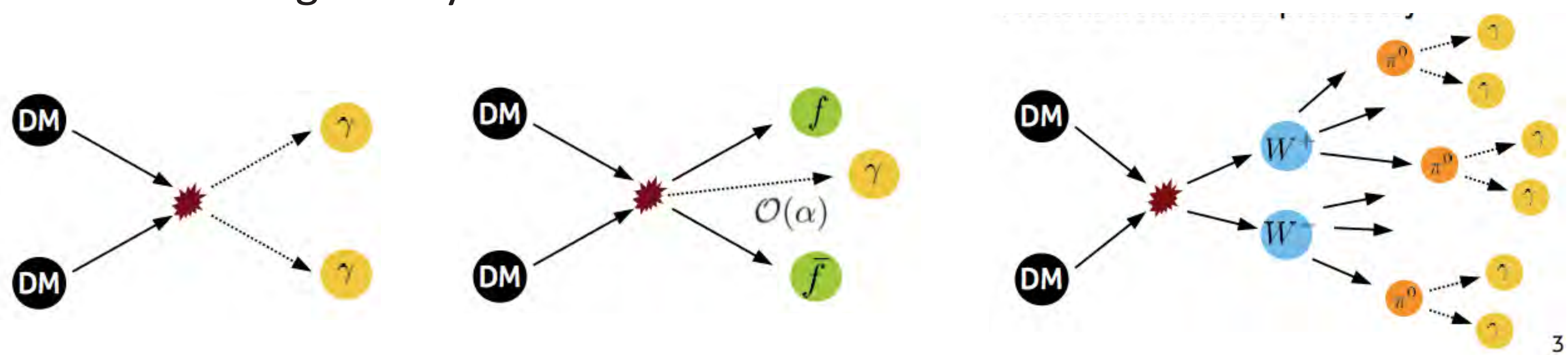
No additional jet (anti-kT 0.4) with p_T > 40 GeV





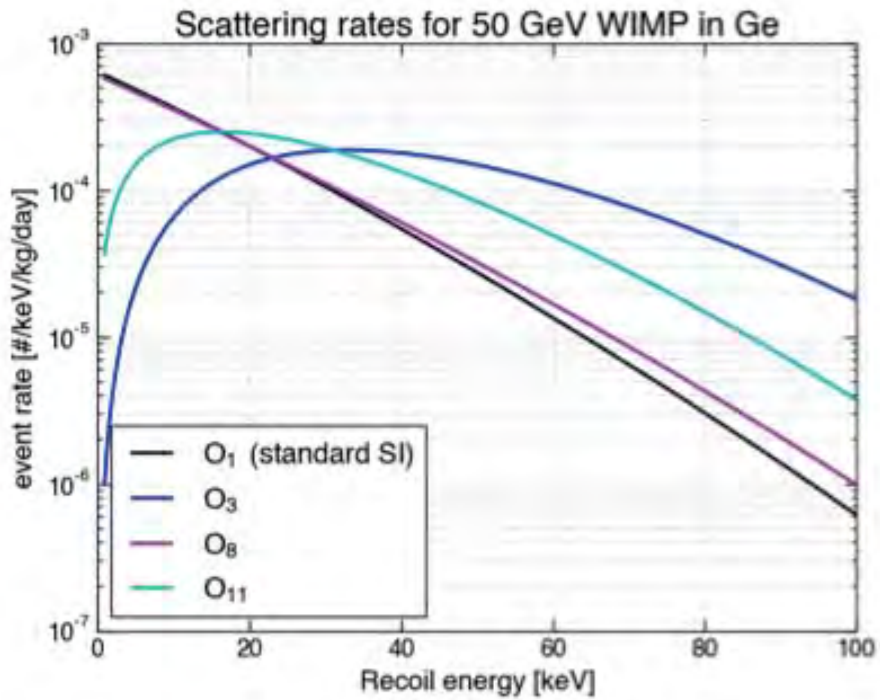
Dark matter searches interplay: EFT

- Need results from various experiments given in the same framework:
  - Collider searches: OK (it's a must)
  - Direct searches: need interpretation
  - Indirect searches: need interpretation
- *Caveat:* EFT might be a too simplified picture
  - Collider/direct searches: mass sensitivity might be above theory cut-off !
    ➔ underling theory dependence
  - Indirect searches: signature result of cascade decays/multiple interactions
    ➔ final state as result of various contact terms it might depend on the underling theory



EFT signal in direct detection

- Momentum-transfer and velocity dependence in EFT models affects shape of spectrum
- Analysis and limit algorithms require modeling signal as well as background
- This could lead to bias if true dark matter spectrum doesn't match spectrum expected by limit algorithms

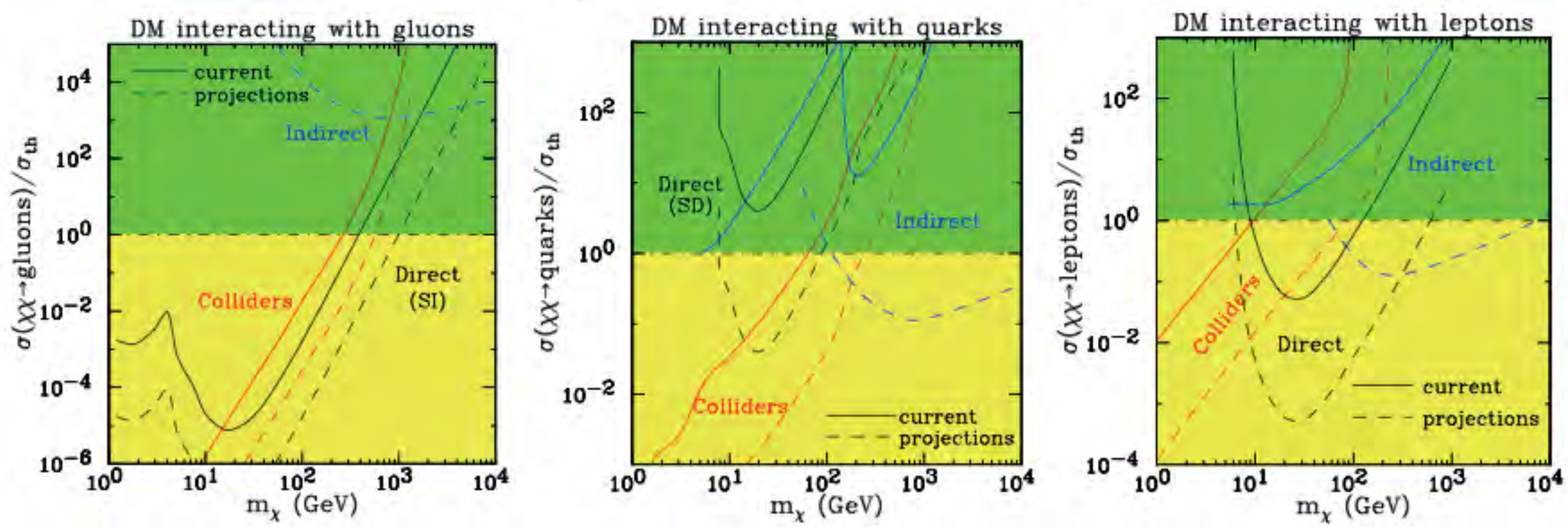


[Kristi Schneck for the SuperCDMS Collaboration @
Effective Theories and Dark Matter 2015, Mainz, Germany
Based on Fitzpatrick, Haxton, et al. arXiv: 1203.3542, 1211.2818, 1308.6288, 1405.6690]

EFT results from all searches:

2013 Snomass Report example S. Arrenberg et al arXiv:1310.8621v1

EFT lagrangian: $$\frac{1}{M_q^2}\,\bar{\chi}\gamma^{\mu}\gamma_5\chi\sum_q \bar{q}\gamma_{\mu}\gamma_5 q + \frac{\alpha_S}{M_g^3}\,\bar{\chi}\chi G^{a\mu\nu}G^{a}_{\mu\nu} + \frac{1}{M_\ell^2}\,\bar{\chi}\gamma^{\mu}\chi\sum_\ell \bar{\ell}\gamma_{\mu}\ell\,.$$



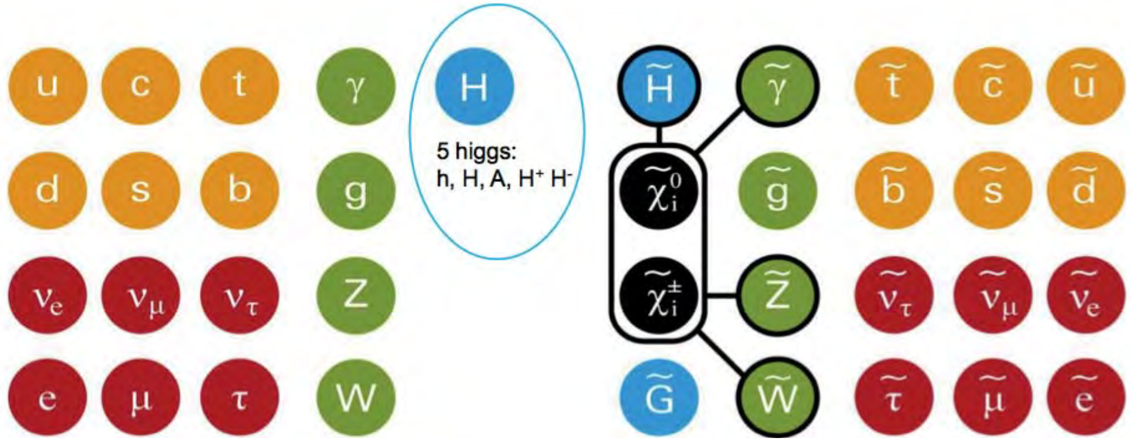
σ_{th} value to provide the observed thermal relic density (σ/σ_{th}=1)

- Very good complementarity:
  - Colliders do better for lighter WIMPs
  - Direct searches do better around 100 GeV
  - indirect detection is more sensitive to heavy WIMPs.

SUSY Introduction

MSSM

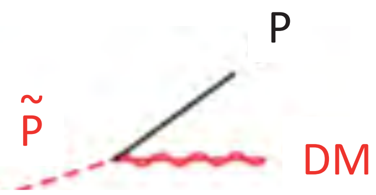
- Still... MSSM offers of a series good answers:
  - Mitigation of fine-tuning/UV sensitivity of the Higgs-mass term [“hierarchy *problem”]*
  - *125 GeV Higgs is consistent with the MSSM max allowed expectation values*
  - Easier gauge coupling unification (more degrees of freedom)[hint *of unification?*]
  - A way out for a coherent inclusion of gravity at the quantum level
  - Good candidate for dark matter
- Lagrangians with spin statistics invariance: fermion and boson fields together as components of a superfield



  - *A lot of degrees of freedom (124) many new particles to search for*

MSSM: R-Parity and dark matter candidate

- Good candidate for dark matter
- New conserved quantum number to prevent fast proton decay in many SUSY models
  - R-parity $R = (-1)^{B+L+2S} = +1\ (-1)$ SM (SUSY) particles
  - lightest SUSY particles (LSP) is stable is a good dark matter candidate
  - Typical decay

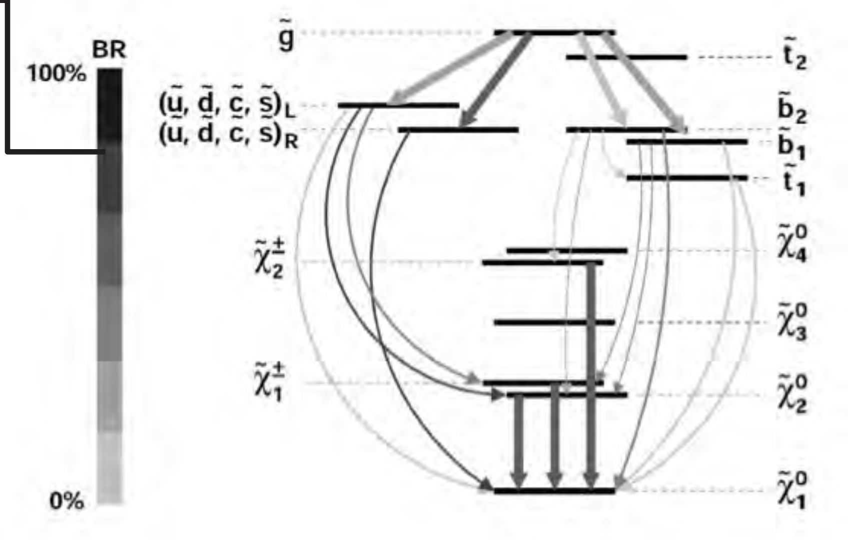


  - SUSY particles are pair produced
  - Typical signature is Missing Transverse Energy

MSSM: models with DM

- 124 parameters in MSSM (of course there are many constraints from experimental measurements)
- Searches within certain well defined scenarios or more constrained models (only few covered here):
- MSUGRA inspired searches
  - lightest neutralino (χ) is typically the LSP or the sneutrino ($\tilde{\nu}$)
- "Natural" MSSM scenarios
  - Low mass stop to mitigate the hierarchy *problem*
- Phenomelogical MSSM (pMSSM)
  - The most general CP/R parity-conserving MSSM
  - Minimal Flavour Violation at the TeV scale
  - The first two sfermion generations are degenerate
  - The three trilinear couplings are general for the 3 generations

MSUGRA typical spectrum

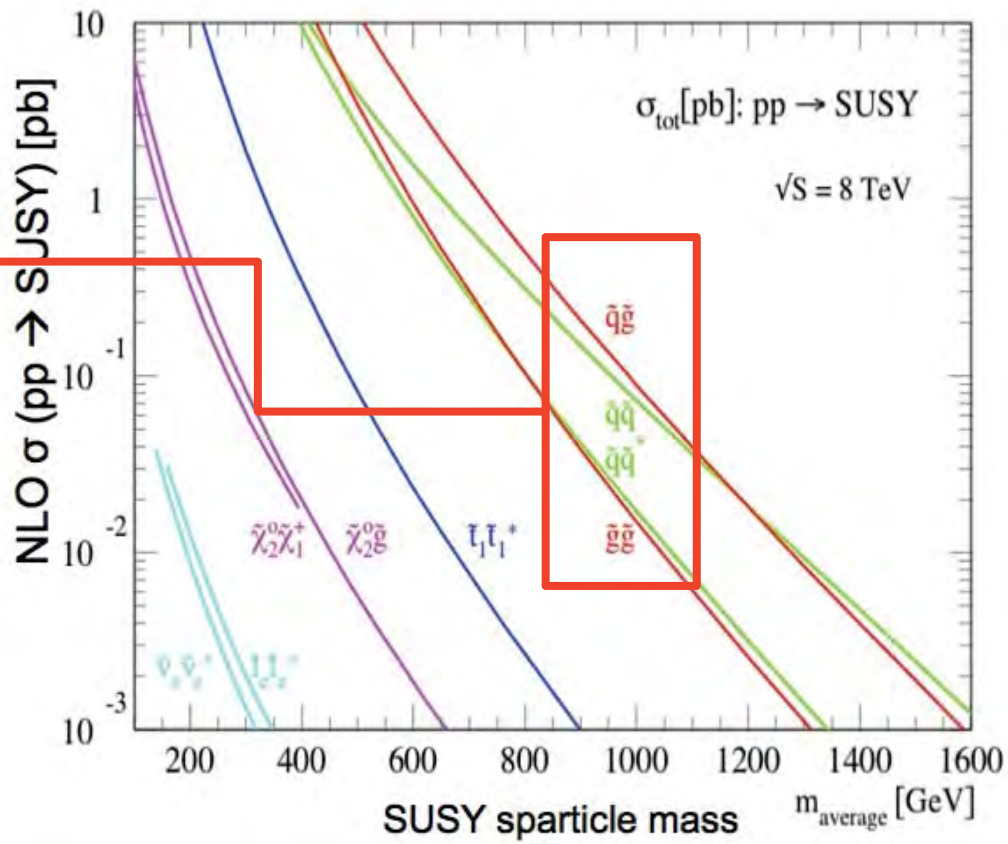


[Djouadi et al., hep-ph/9901246]

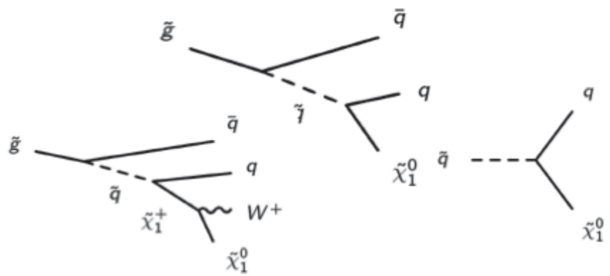
10 sfermion masses, 3 gaugino masses 3trilinearcouplings, 3 Higgs/Higgsino parameters.

MSUGRA: search strategy

- 4 parameters model MSUGRA: m0, m1/2, A, tanβ, sign(μ)
- Searches strategy is driven by the production cross-section and integrated luminosity



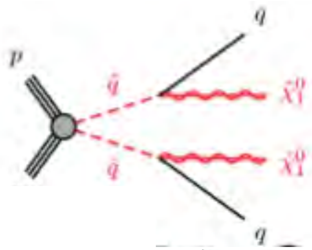
- Start with inclusive searches for production of gluino and squarks via strong interaction
- final states depend on the decays of squark/gluino: jets + ETmiss + leptons



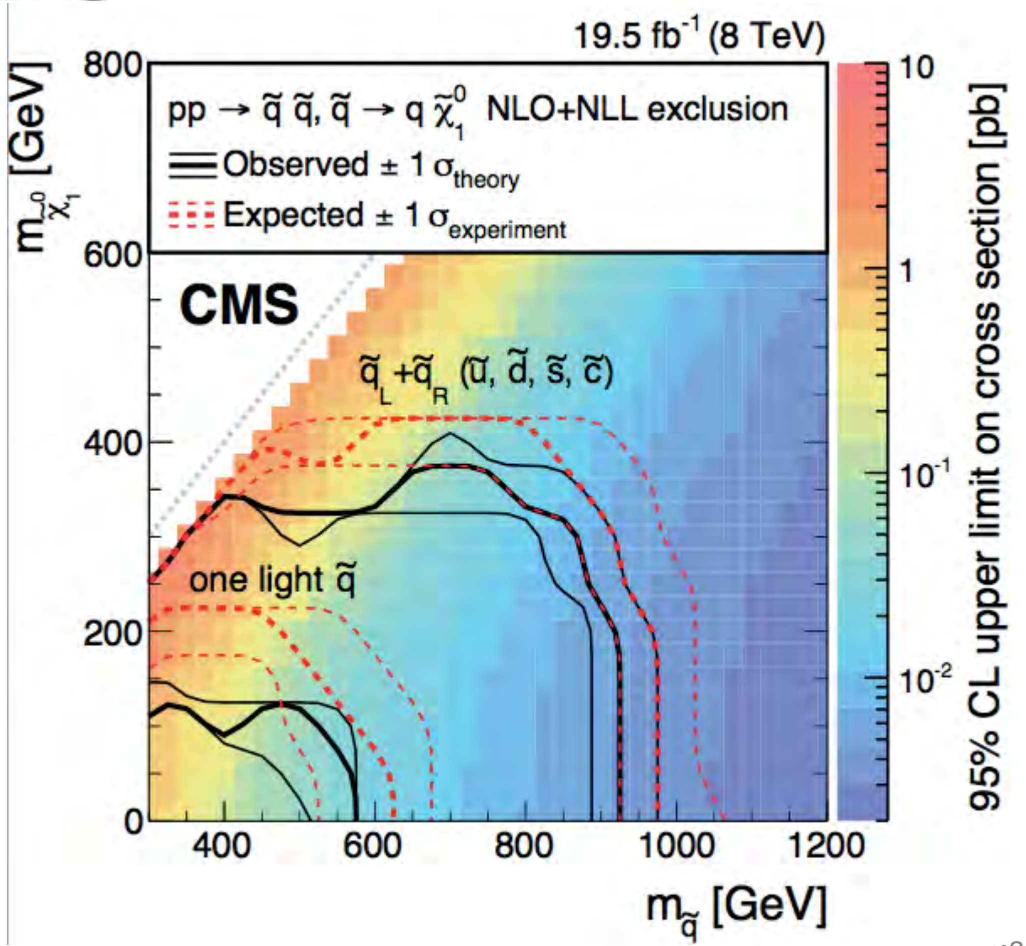
Squark Gluino searches: simplified model

Squark production

$$pp \rightarrow \tilde{q}\,\tilde{q},\ \tilde{q} \rightarrow q\,\tilde{\chi}^0_1$$



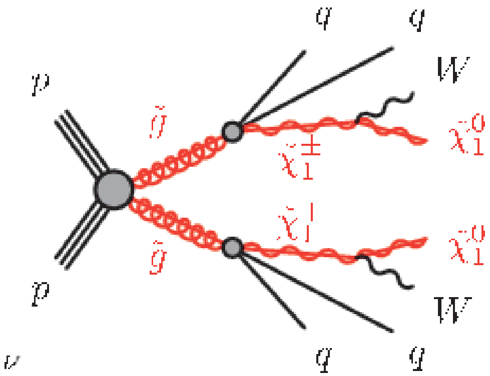
- assume 100% BR for the stated process in the simplified model grids
- weaker limits with reduced number of squarks kinematically available
- limits for massless LSP: m(squark) < 850 GeV, m (gluino) < 1.2 TeV
- computed excluded cross section for each model in parameter space



MSUGRA: search strategy

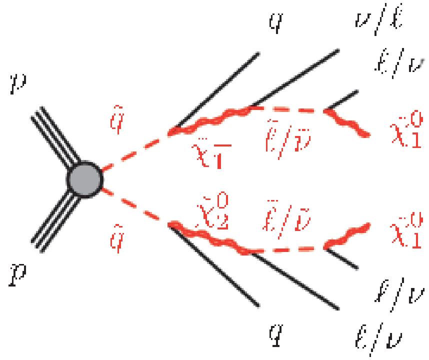
- Many final states are searched for
  - Jet rich signatures

  0 lepton + multi-jet searches



  - Lepton rich signatures

  1,2 lepton searches



- Simplified models used in many cases for optimization/interpretation

  -Specific decay chain with 100% Br

  -Free parameters are sparticle masses

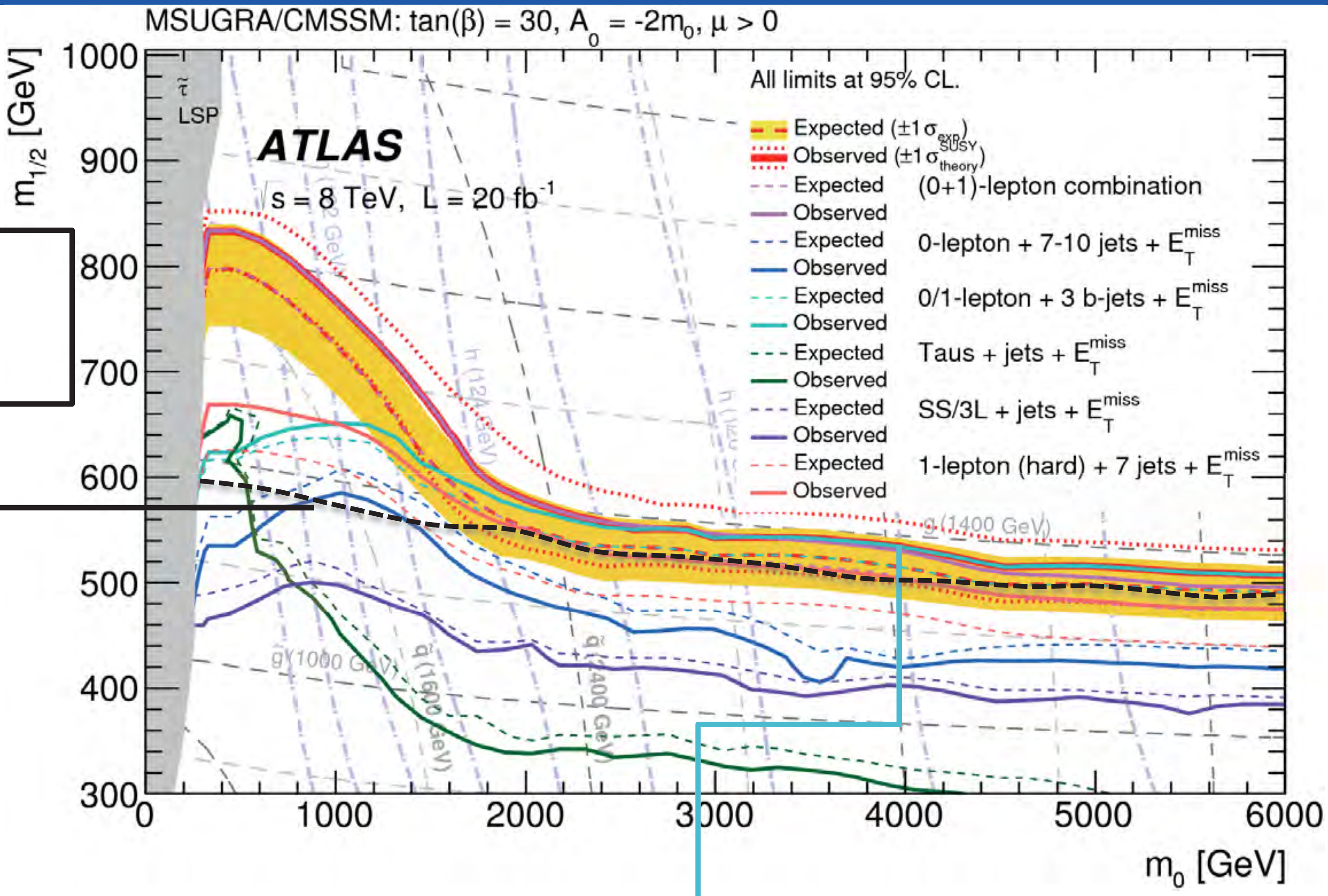
  -3rd generation squarks often decoupled

- Analyses are optimized for various:

  -Δm between the states (typically $\Delta m = M_{NLSP} - M_{LSP}$) ➔ softer/harder decay products

  -Steps in the decay chain ➔ smaller/larger final particles multiplicity

Squark Gluino searches: MSUGRA

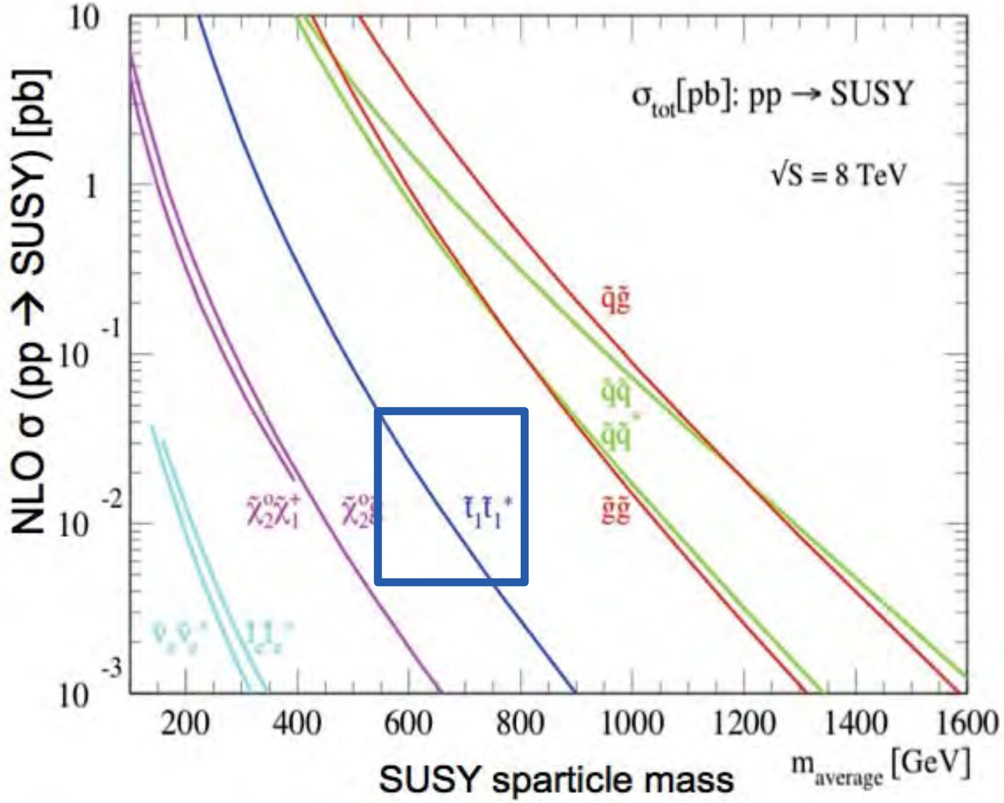


1.3 TeV gluinos excluded for any squark mass

0/1-lepton + 3 b- jets analysis strongest at low $m_{1/2}$, high m_0 → mostly g→t/b (light gluinos)

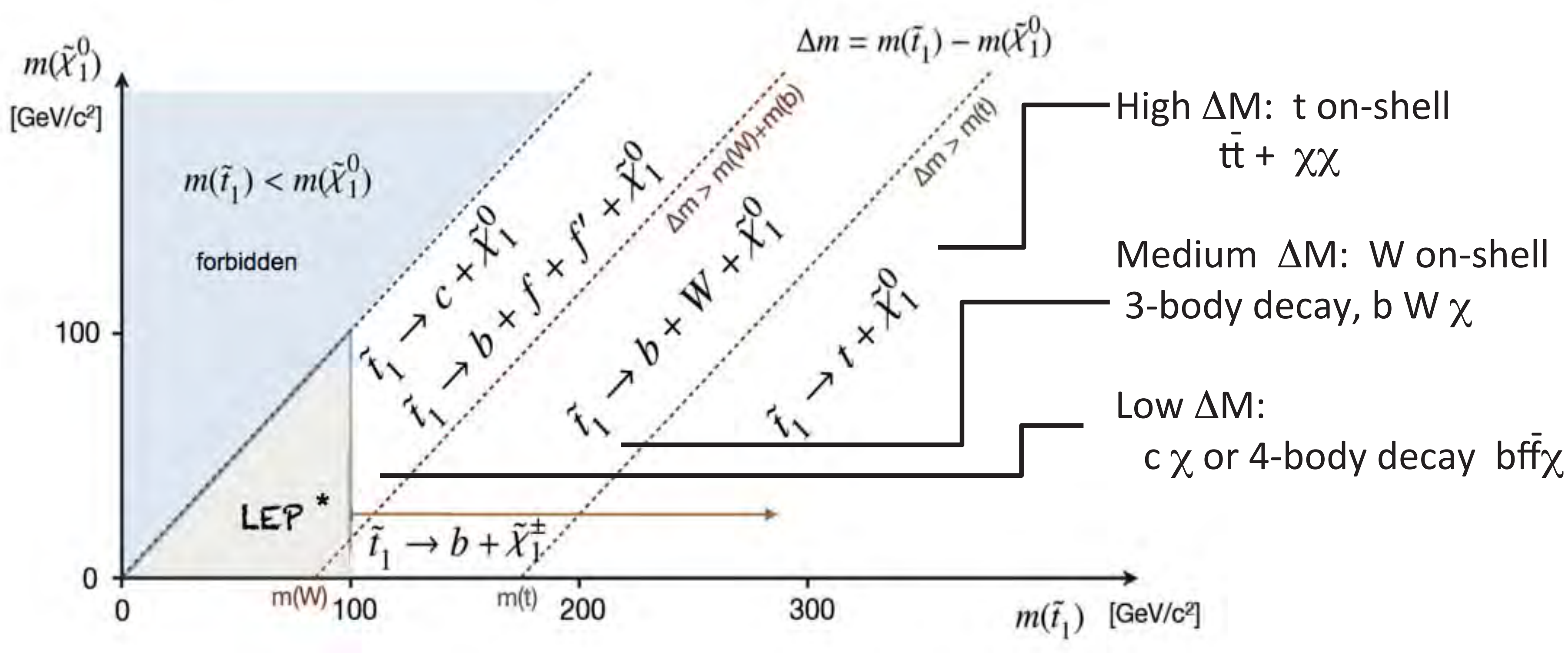
“Natural” SUSY searches

- Only need light $\tilde{t}/\tilde{b}$ to cancel quadratic divergences corrections *to* m_H
- Assume other SUSY particles to be heavier but χ and $\chi^{\pm}$ eventually
- Consistent with higgs mass value and large mixing in the $\tilde{t}$ sector
- High production cross section

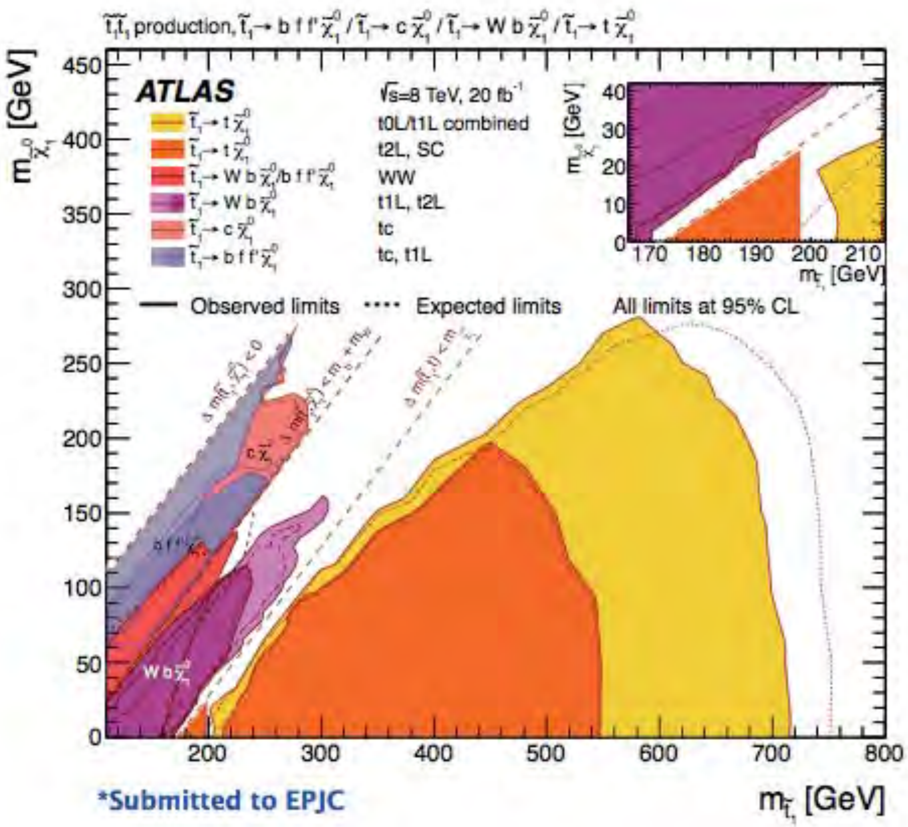


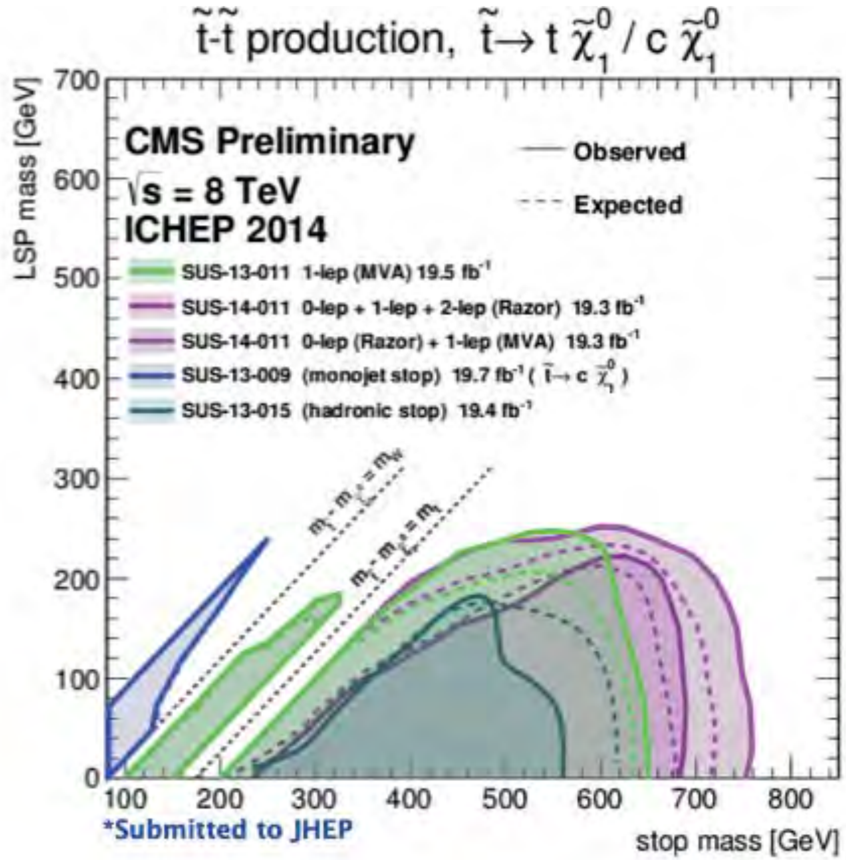
"Natural" SUSY searches

- Only need light $\tilde{t}/\tilde{b}$ to cancel quadratic divergences corrections *to* m_H
- Assume other SUSY particles to be heavier but χ and $\chi^{\pm}$ eventually
- Consistent with higgs mass value and large mixing in the $\tilde{t}$ sector
- Signatures: $\tilde{t} - \chi$ mass plane



Searches for $\tilde{t} \rightarrow bW\chi$, $c\chi$, $t\chi$

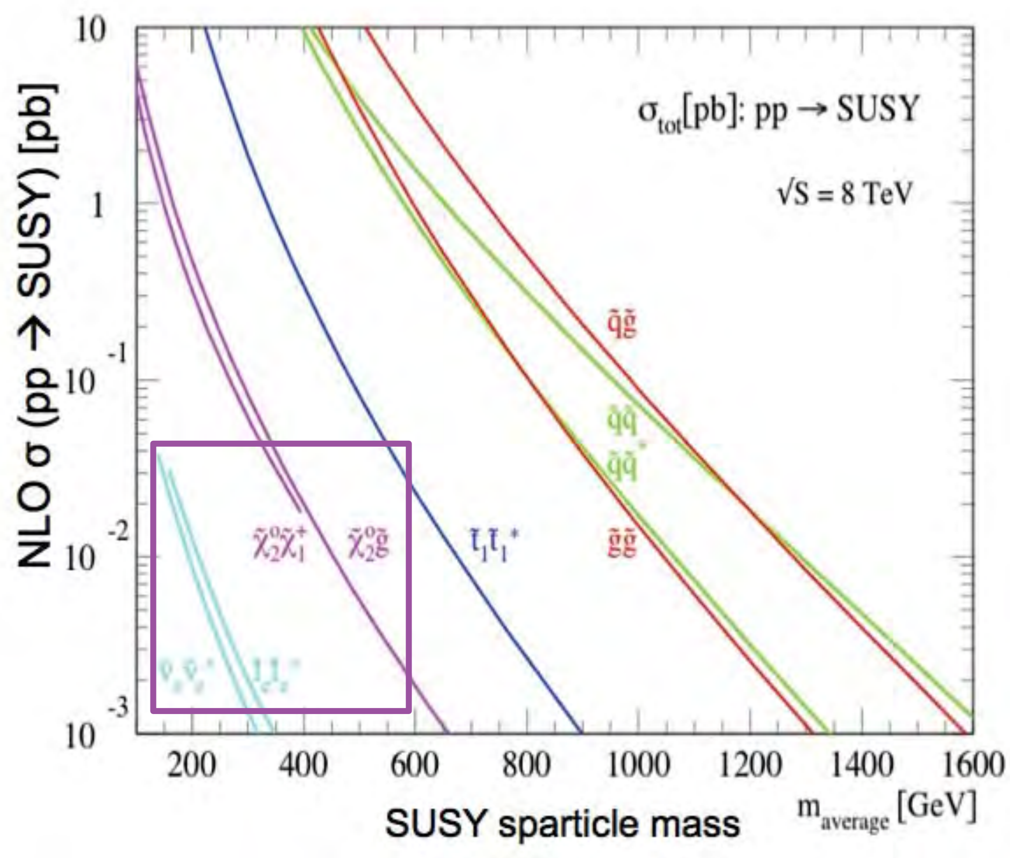




- Typical corridors in exclusion plots at small ΔM, (low visible energy) recovered in many cases thanks to dedicated searches (e.g. ISR)

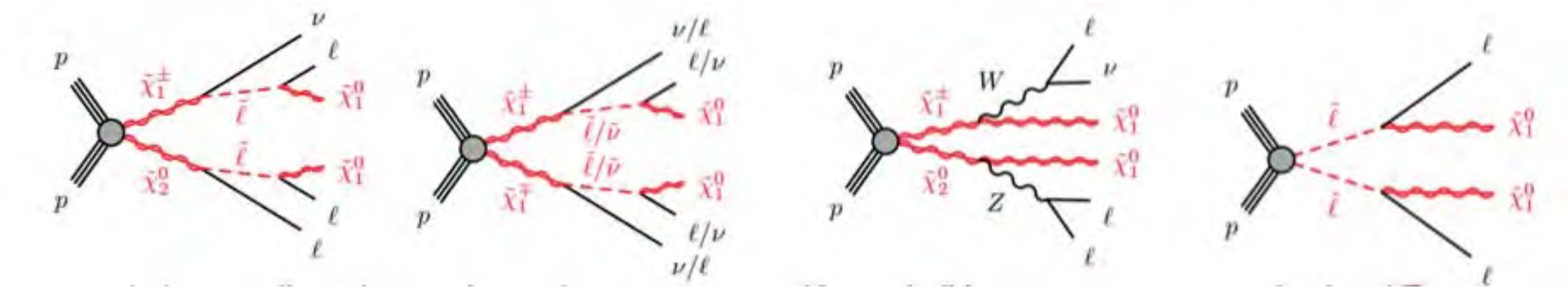
EW SUSY production

- May dominate if squarks/gluinos are heavy and neutralinos/ charginos are light
- Made possible by the high integrated luminosity
- electroweak SUSY particle production ($\chi^{\pm}\chi$, $\chi\chi$,$\tilde{l}\tilde{l}$, ...)



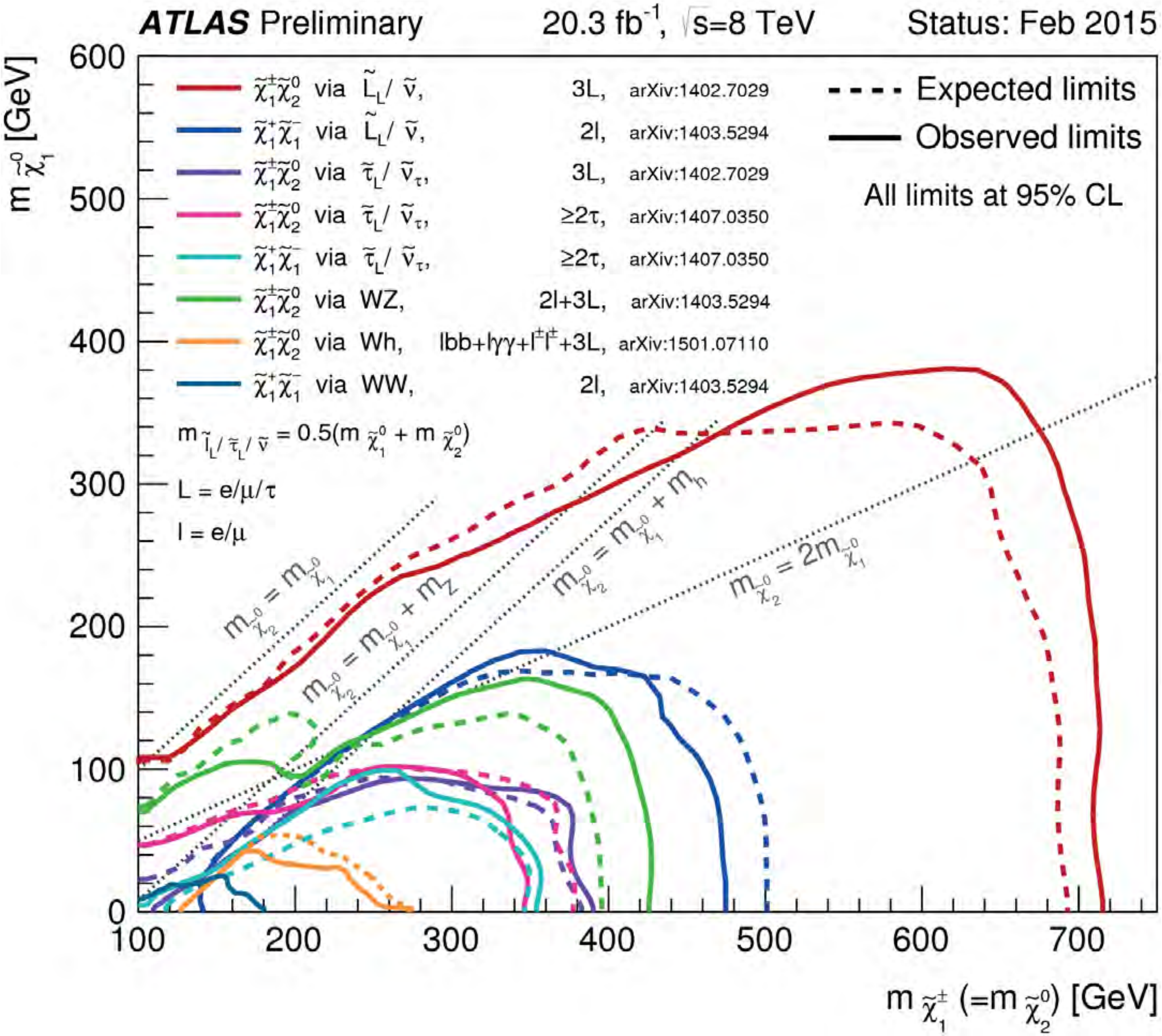
EW SUSY production

- May dominate if squarks/gluinos are heavy and neutralinos/ charginos are light
- Made possible by the high integrated luminosity
- electroweak SUSY particle production ($\chi^{\pm}\chi$, $\chi\chi$,ll , ...)
- via intermediate W, Drell-Yan processes or intermediate sleptons



- search strategy depends on the slepton masses, gauge mixture and masses of charginos/ neutralinos
- characteristic: multi-lepton signatures with low hadronic activity low SM background

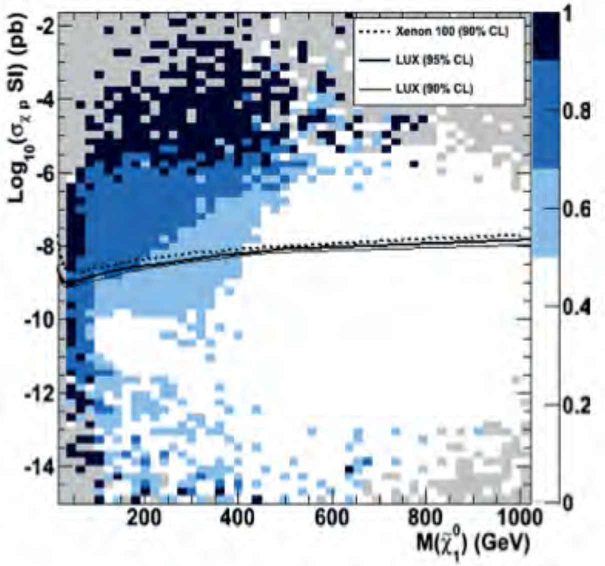
χ±/χ Exclusion plots

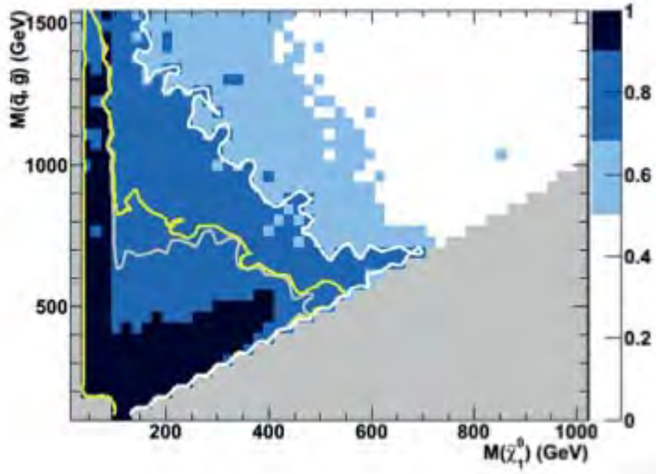


MONO-X and SUSY Searches get together

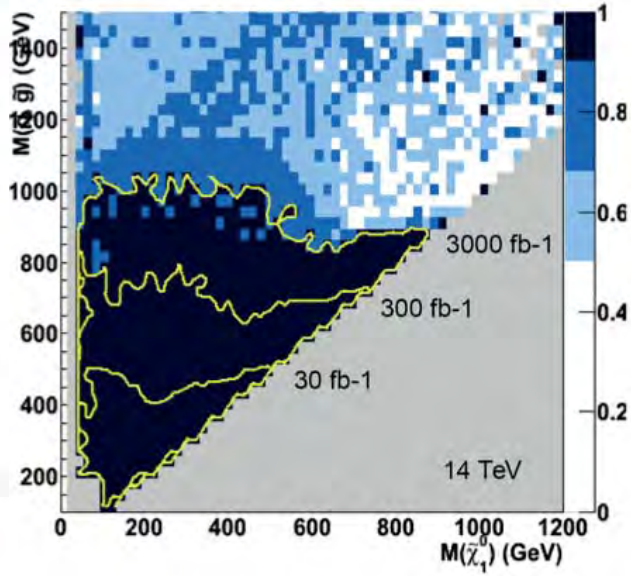
pMSSM framework

Expected sensitivity
at next LHC 14 TeV





A. Arbey, M. Battaglia, FM, arXiv:1311.7641

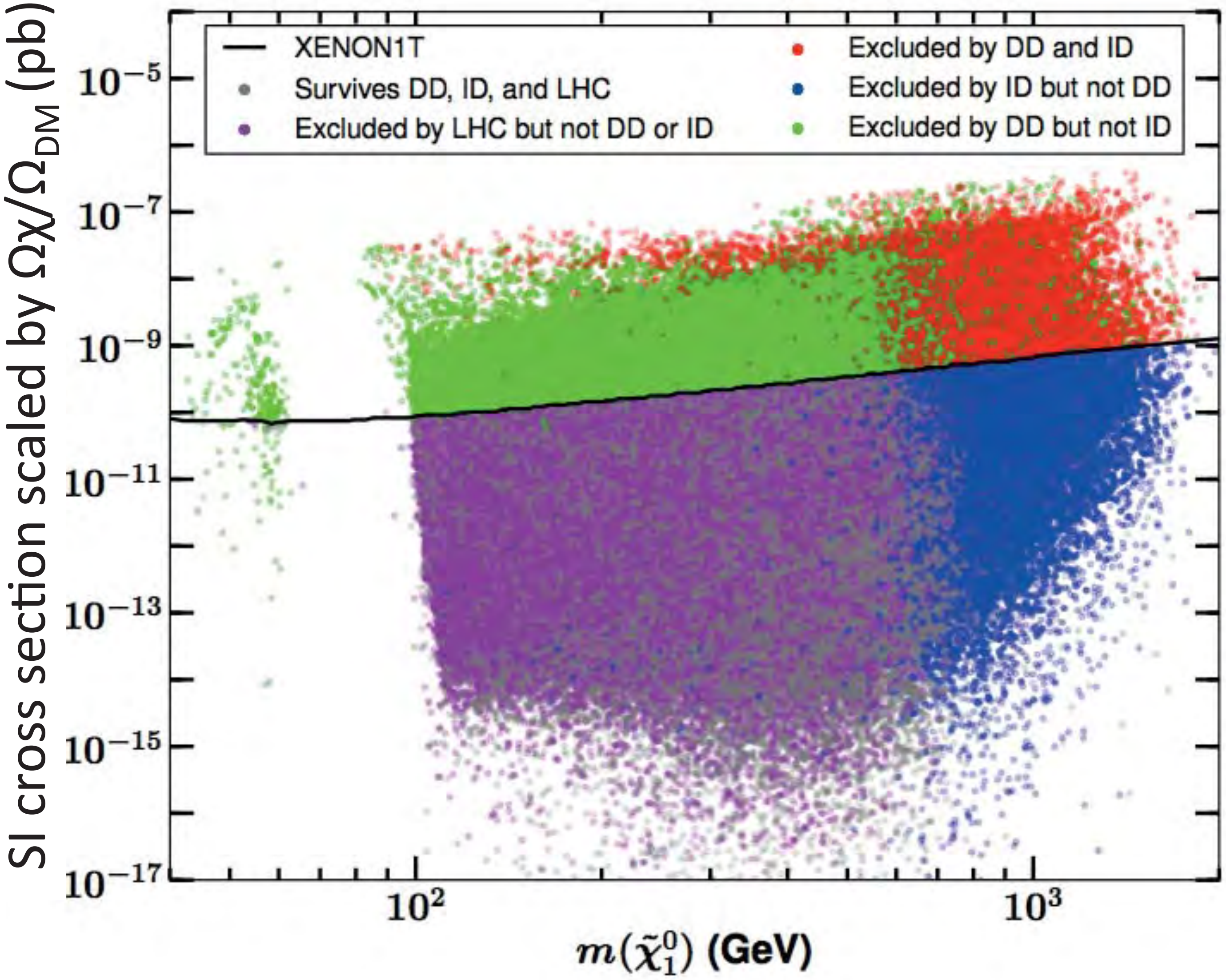


Color scale: fraction of points excluded by jets/leptons+MET searches, monojet analyses and LUX direct DM search

Grey line: 68% C.L. exclusion by jets/leptons+MET searches
Yellow line: + monojet analyses
White line: + LUX direct DM search

pMSSM scan

S. Arrenberg et al arXiv:1310.8621v1



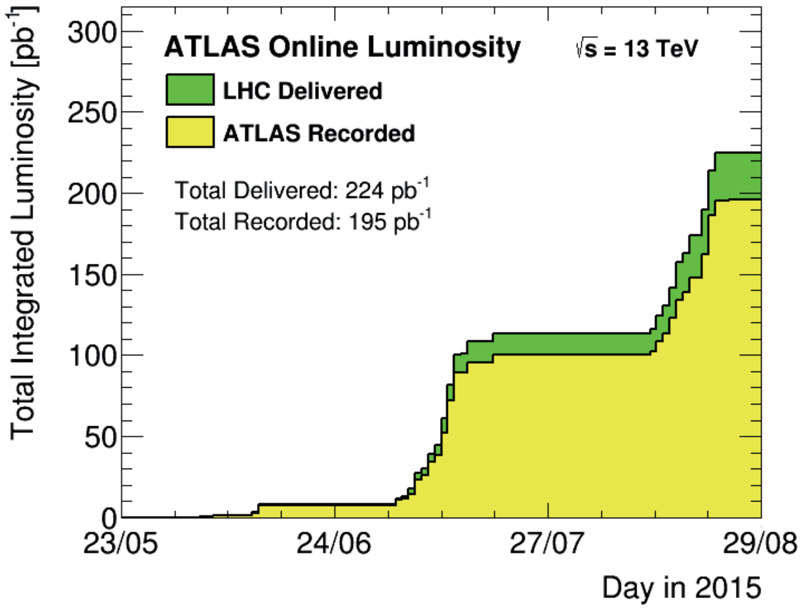
225K models

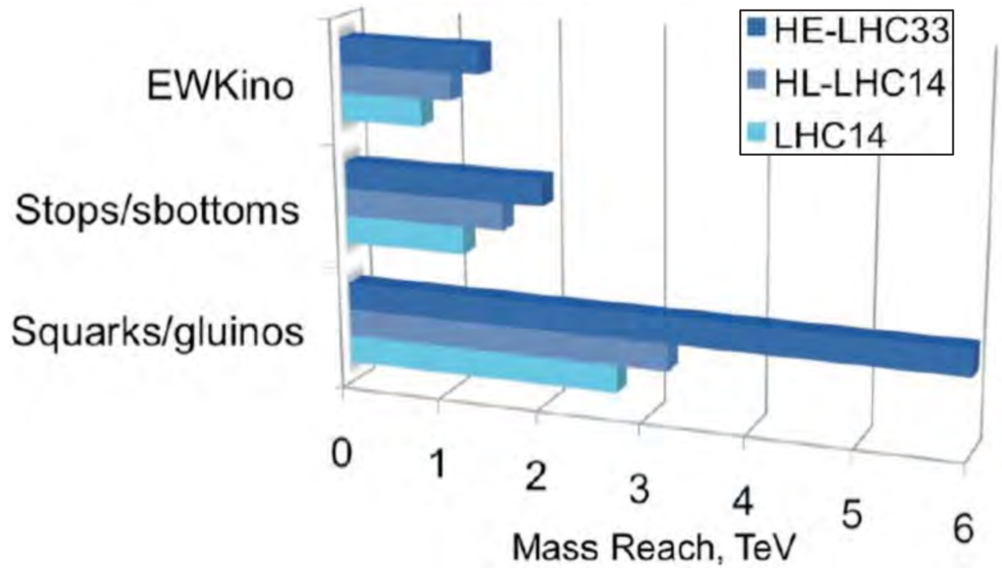
$m_{\tilde{L}(e)_{1,2,3}}$	100GeV – 4TeV
$m_{\tilde{Q}(q)_{1,2}}$	400GeV – 4TeV
$m_{\tilde{Q}(q)_3}$	200GeV – 4TeV
$\|M_1\|$	50GeV – 4TeV
$\|M_2\|$	100GeV – 4TeV
$\|\mu\|$	100GeV – 4TeV
M_3	400GeV – 4TeV
$\|A_{t,b,\tau}\|$	0GeV – 4TeV
M_A	100GeV – 4TeV
$\tan\beta$	1 - 60
$m_{3/2}$	1 eV–1TeV ($\tilde{G}$ LSP)

VERY good complementarity

LHC today and tomorrow

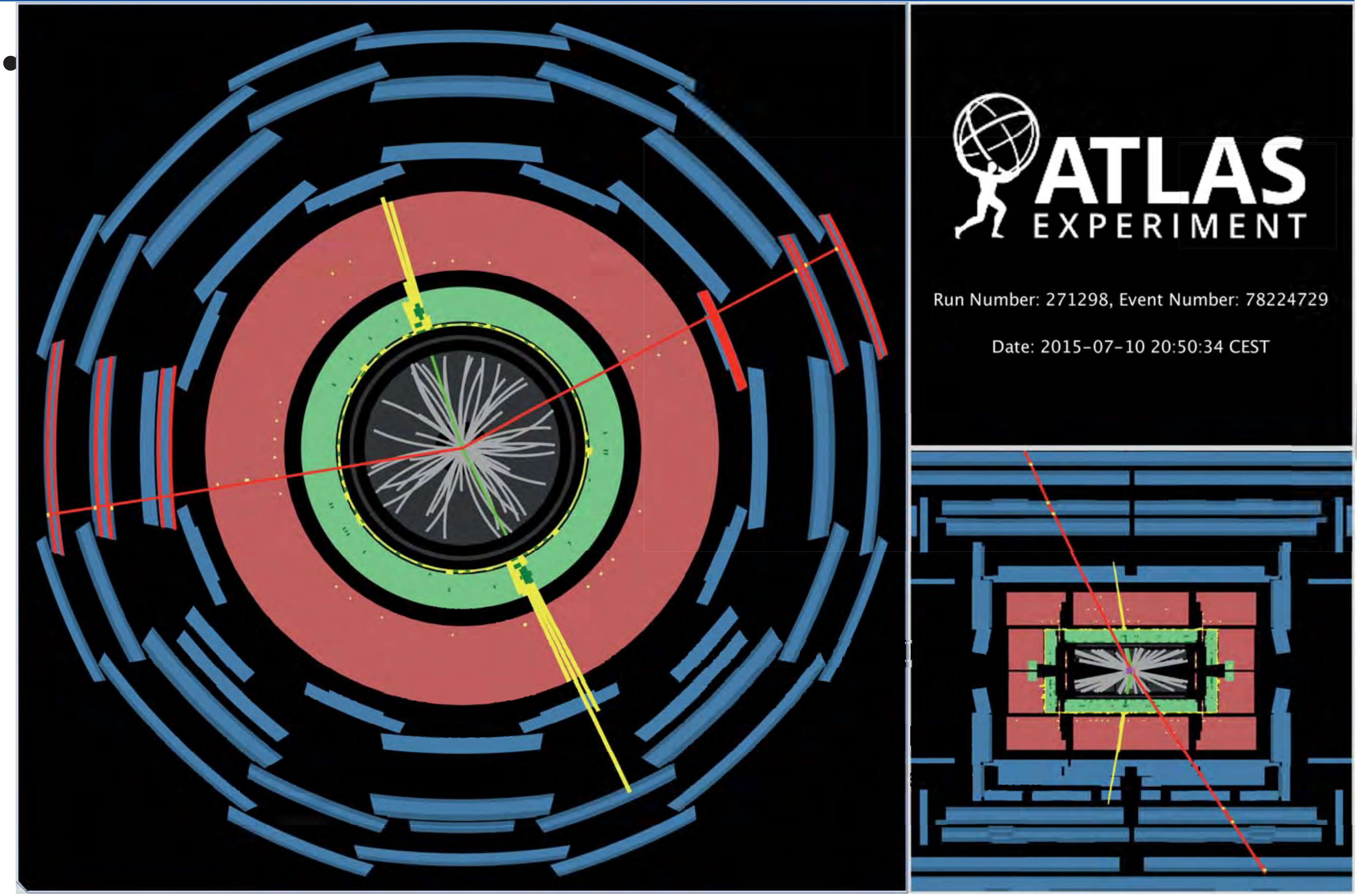
- LHC today status 13 TeV run





  - Take-home (simplified) messages :
    - Absence of discovery at LHC-14 wipes out SUSY below ~1 TeV
      - And below several TeV for non-SUSY New Physics
    - No excess at LHC-14 makes a discovery quite unlikely at HL-LHC
    - Energy does better than luminosity for direct search for New Physics

Event display at 13 TeV



Conclusion

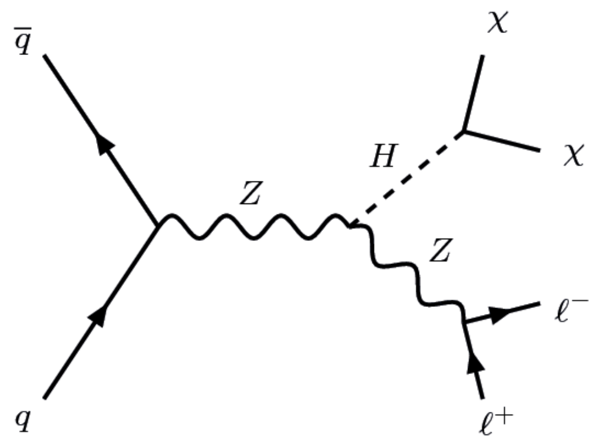
- Extensive search for DM have been performed at LHC: huge amount different signatures from many scenarios covered
- Severe upper limits DM production cross section and on SUSY particles
- Models parameter Space sizably reduced
- Very good complementarity with indirect and direct searches
- New experimental efforts ongoing/planed for all kind of searches

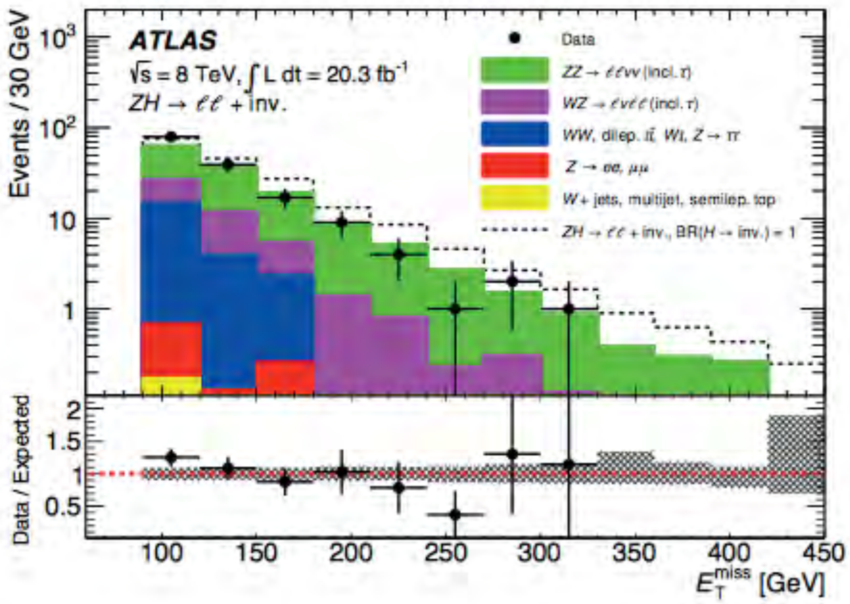
LHC 13 TeV run just started

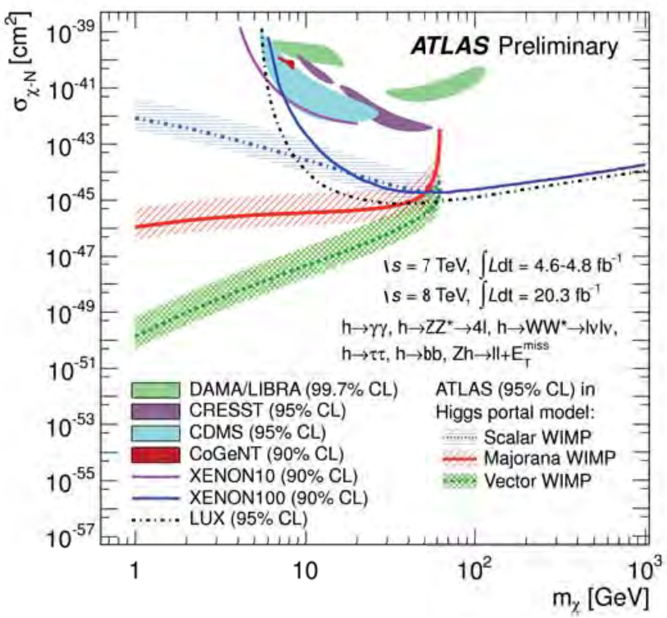
Stay tuned and cross your fingers

Higgs decay to DM: MONO-Z

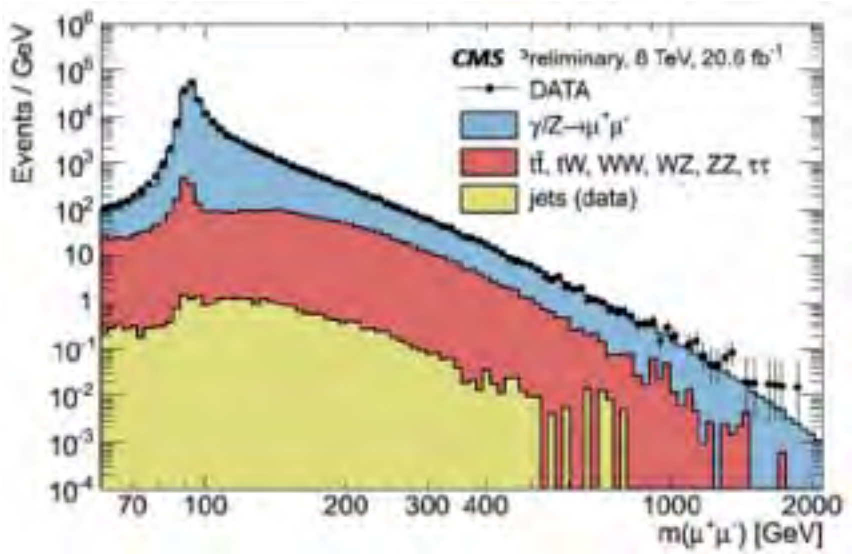
- Dark matter direct detection experiments probe the Higgs sector of the MSSM!
- MONO-Z like signature
- 5-standard channel + Zh→ ll DM DM:
  BRi,u < 0.37 (0.39) obs. (exp.) at 95% CL into limits on DM rate (depends on WIMP spin)

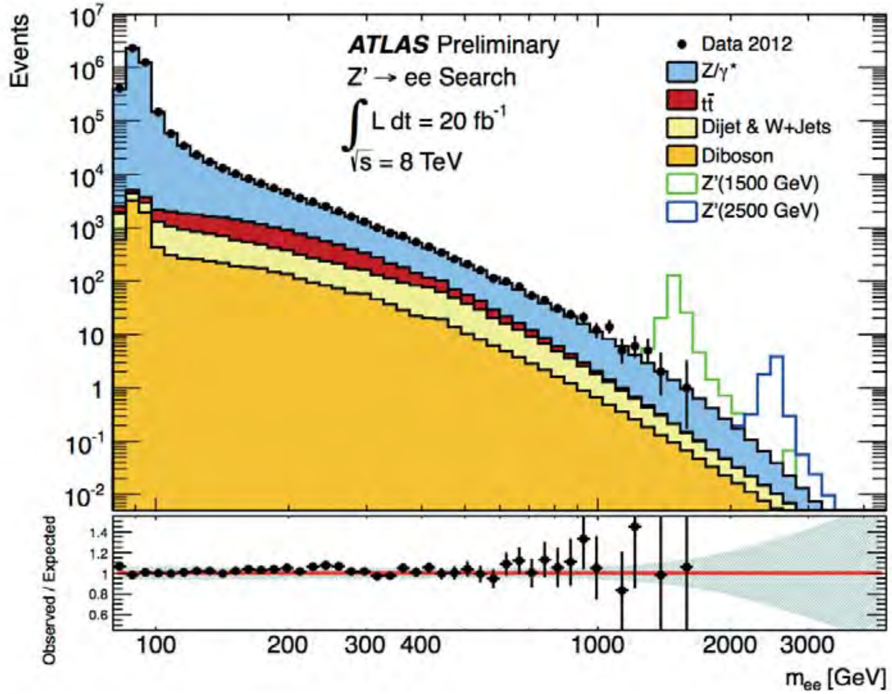


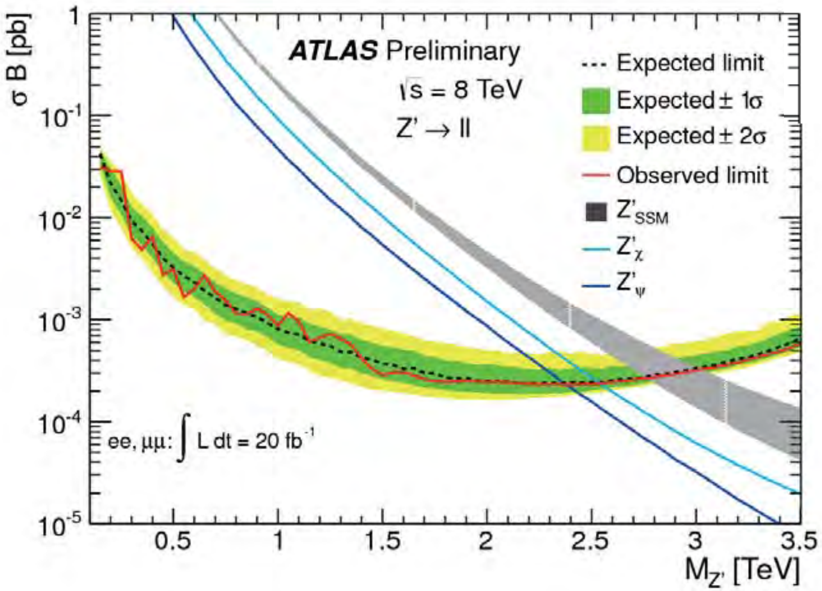




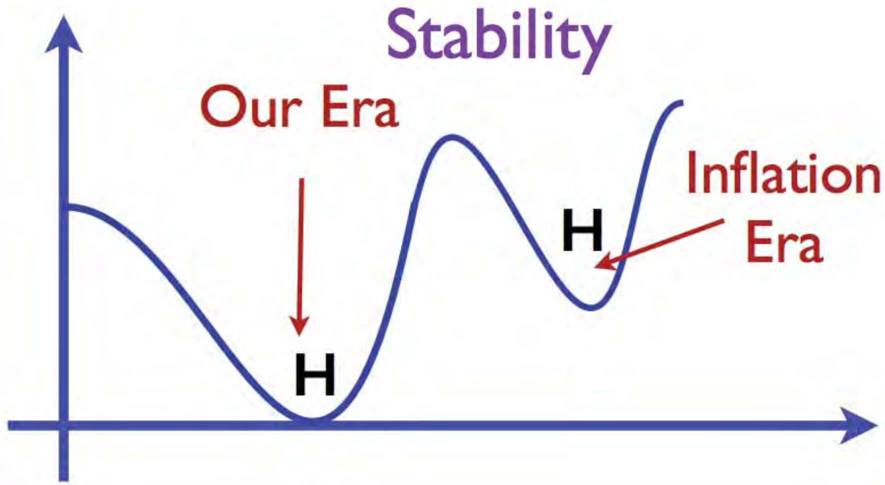
Search for resonances in dilepton

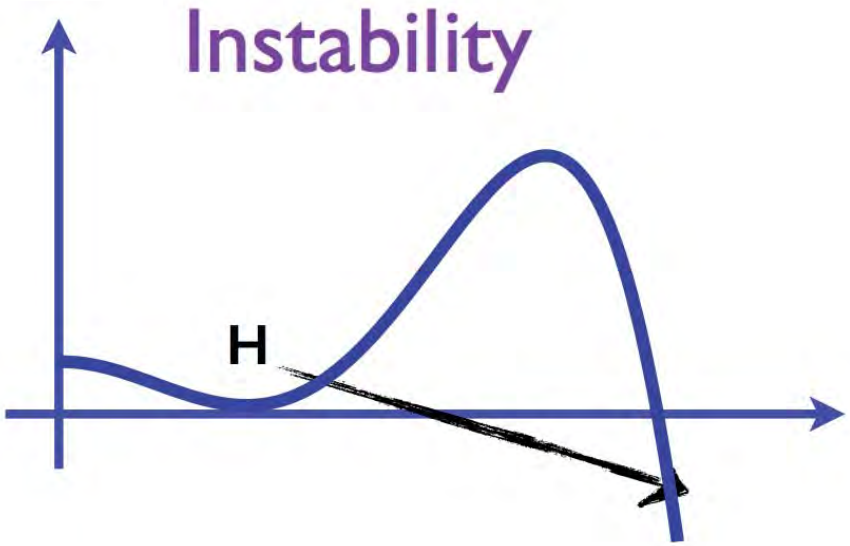


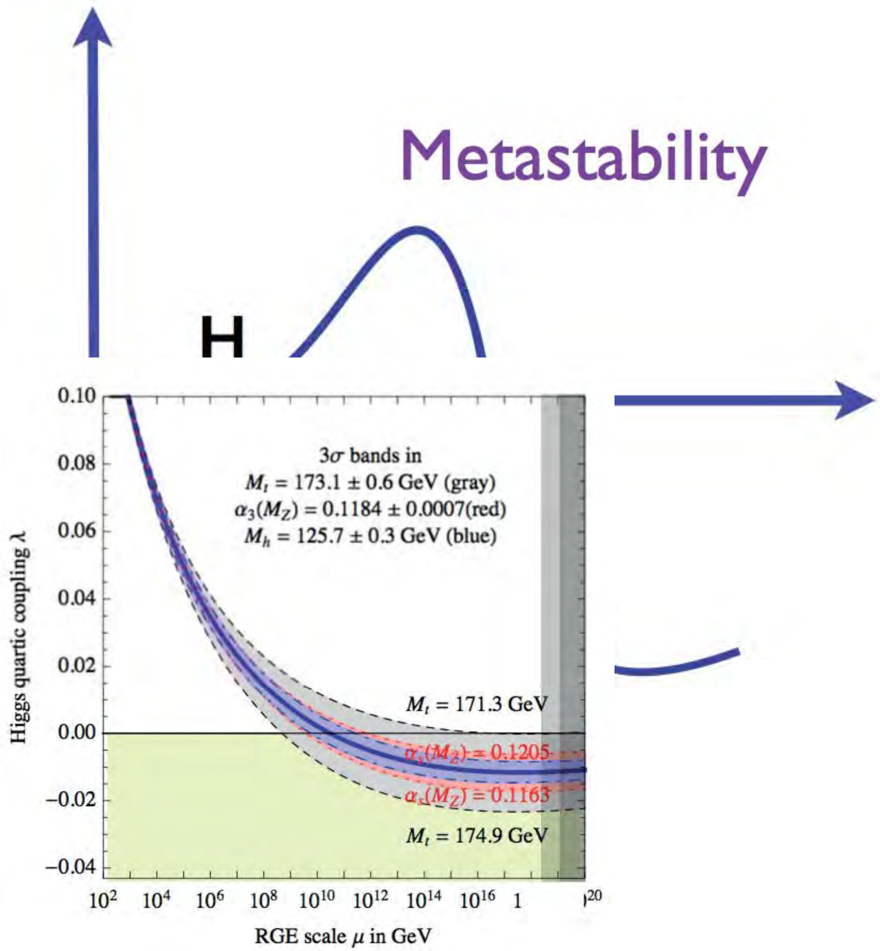




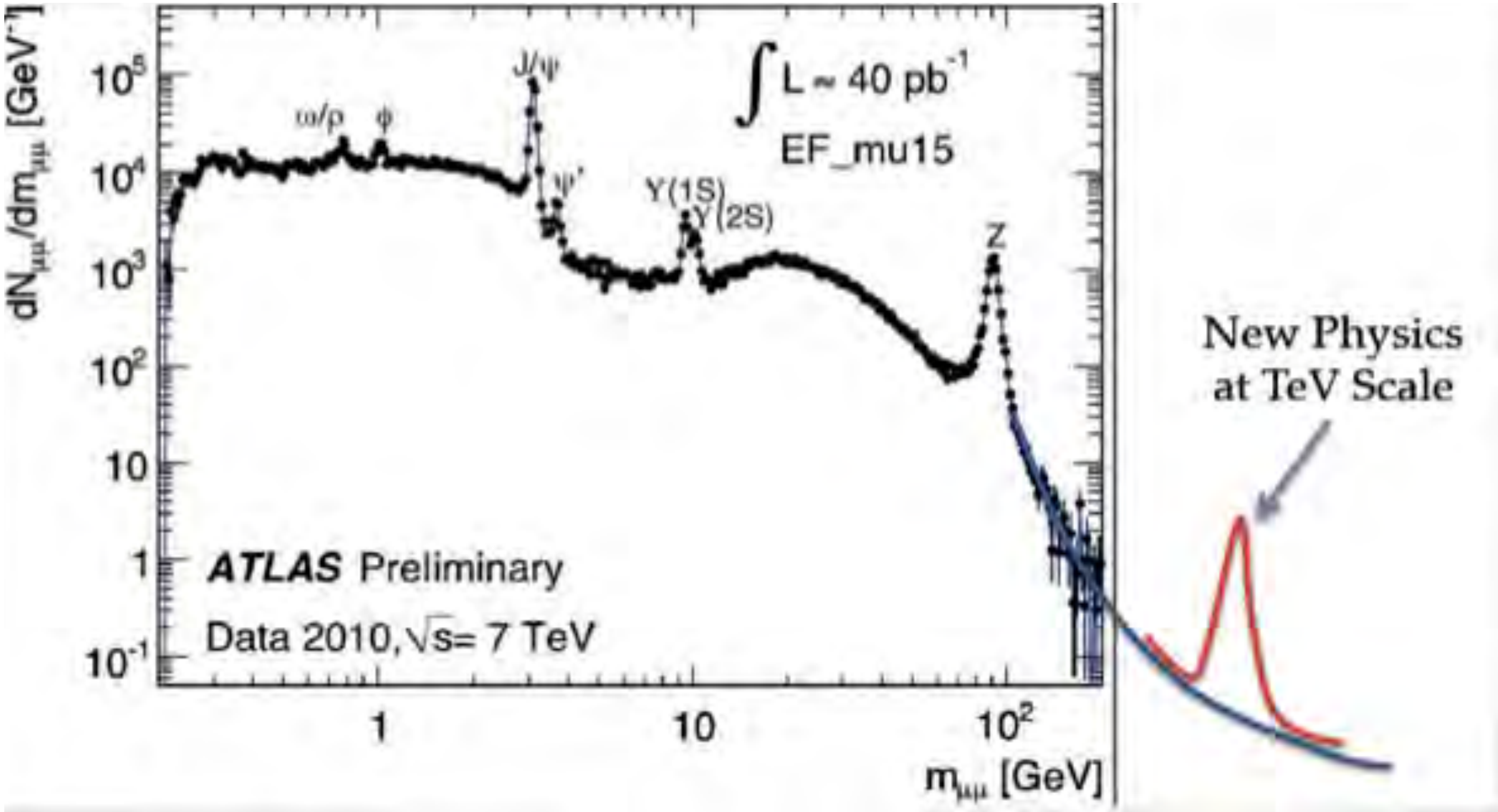
Higgs potential: 3 scenarios





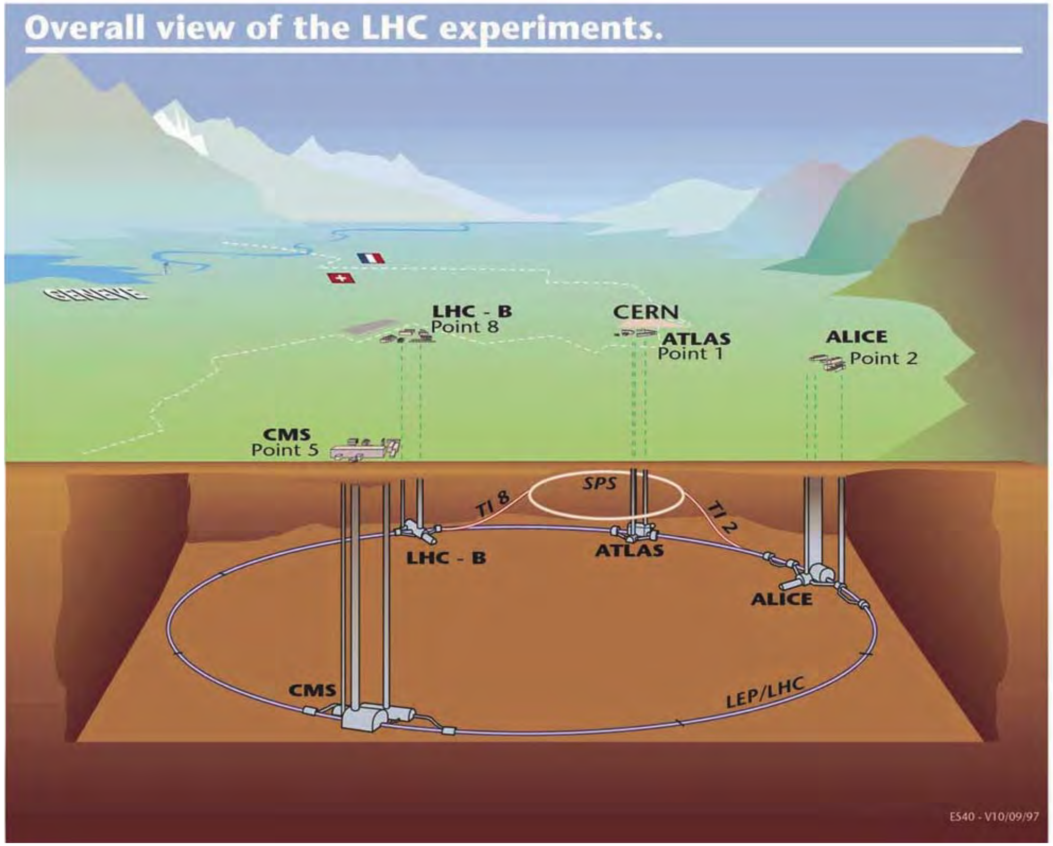


Z' Searches: resonances in dilepton



Very classic signature

CERN Large Hadron Collider



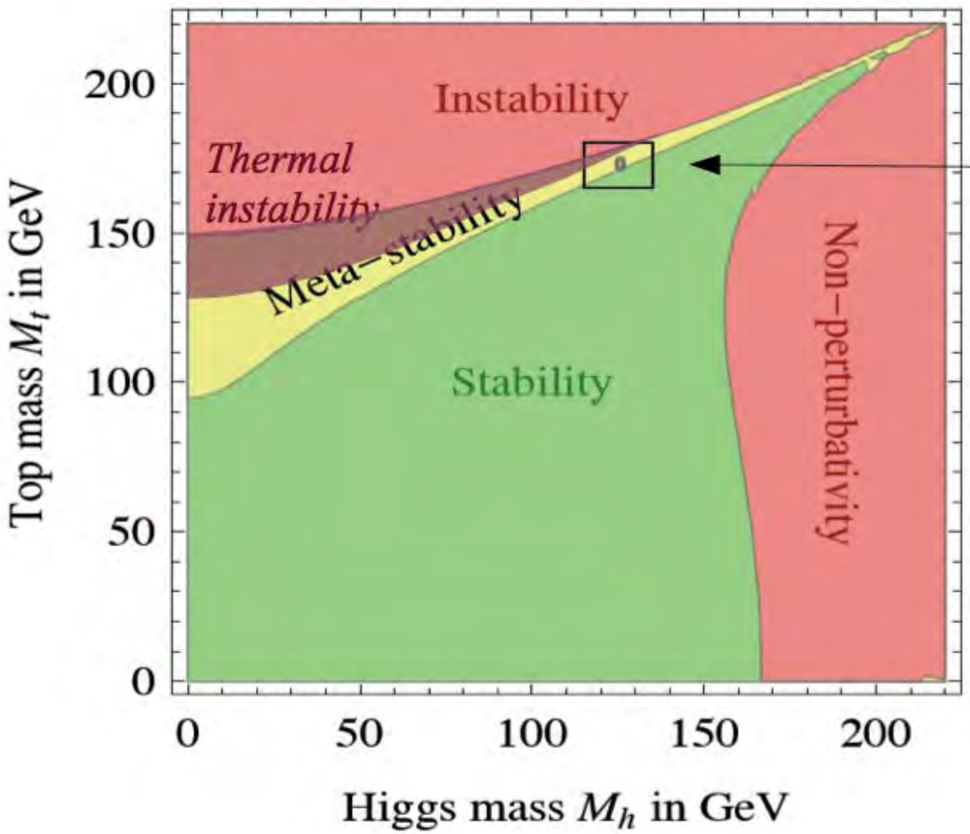
Number of events second generated in LHC collisions

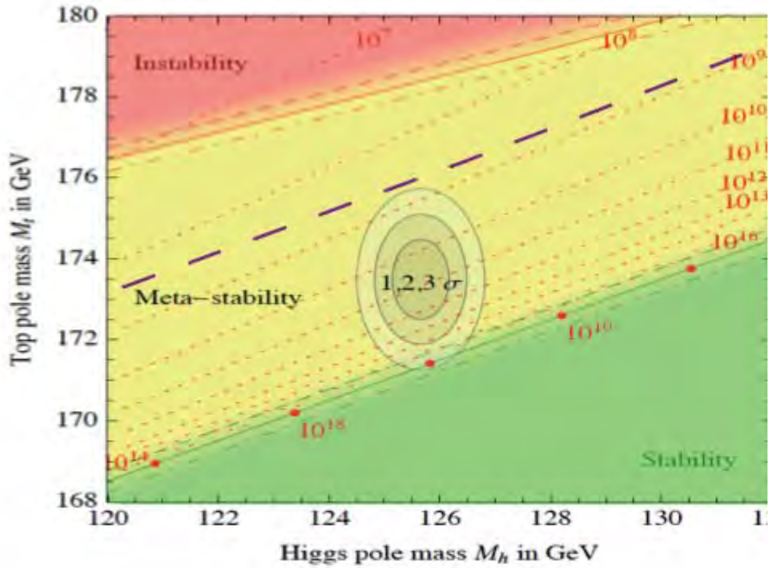
$$\frac{\partial N_{events}}{\partial t} = L\sigma$$

$$L = \frac{N_1 N_2}{4\pi\sigma_x\sigma_y} F$$

	2010	2011	2012	Nominal
Energy	7 TeV	7 TeV	8 TeV	14 TeV
Bunch spacing	150 ns / 368	50 ns / 1380	50 ns / 1380	25 ns / 2808
L ($cm^{-2}s^{-1}$)	2×10^{32}	3.3×10^{33}	7×10^{33}	10^{34}

Introduction





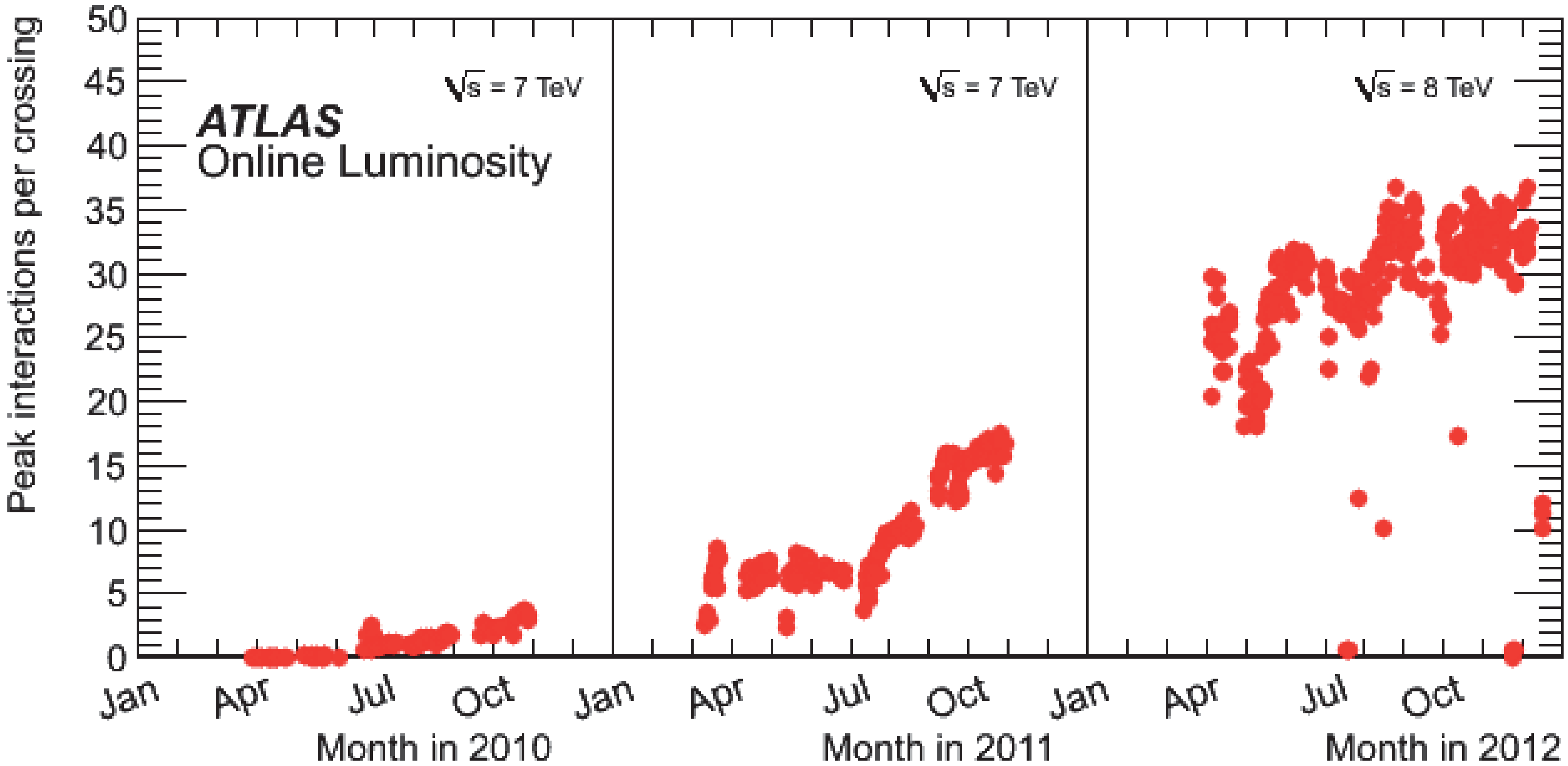
...and the situation will not change significantly with more precise measurements of m_h

In-time pile-up collisions

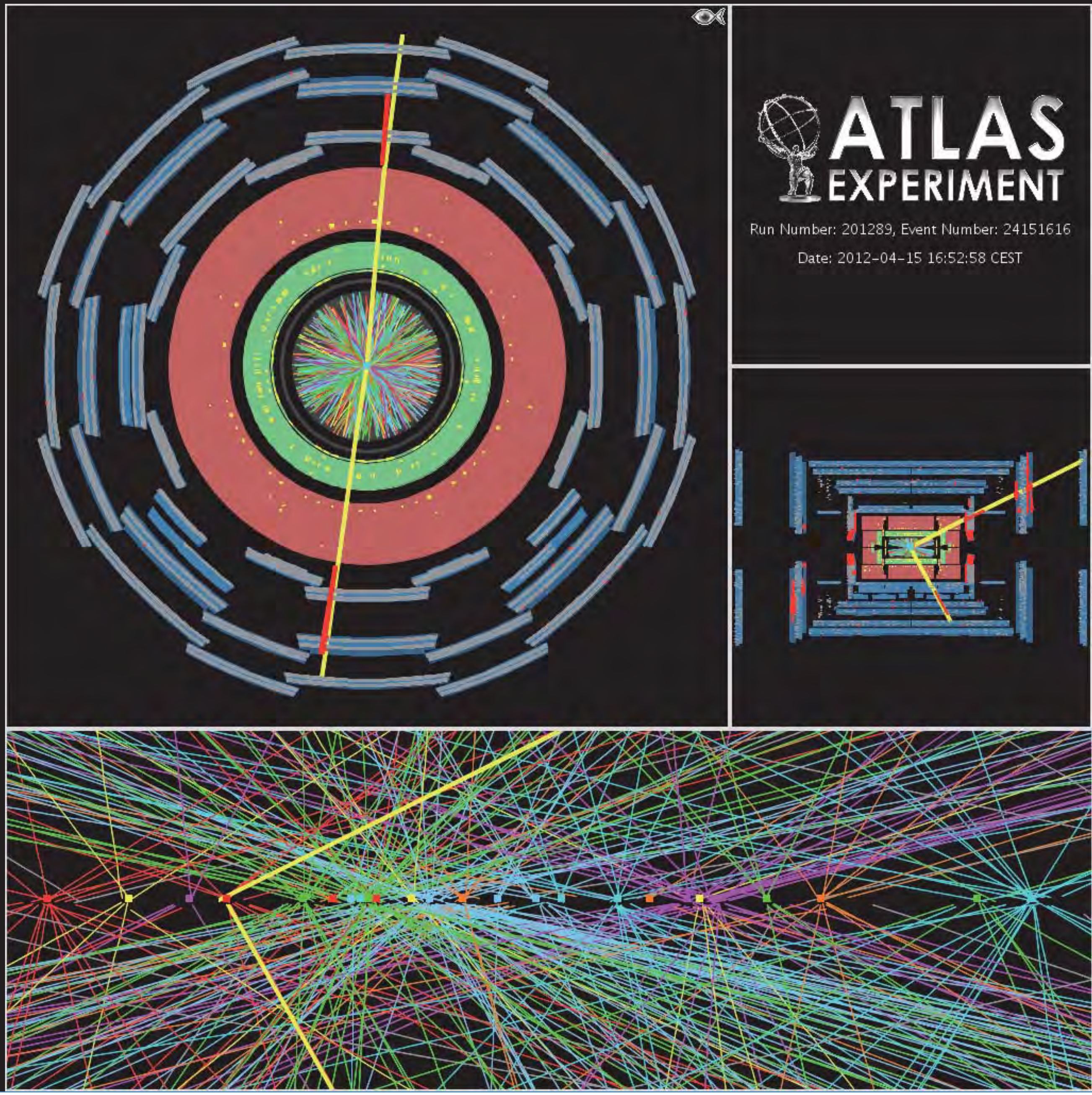
Long and very narrow beam spot in ATLAS and CMS.

– Design parameters: in transverse plane $\sigma_{x,y}$ ~ 15µm; In the longitudinal direction σ_Z~5.6cm.

– In-time pile-up: superposition of many pp interactions in the same bunch crossing.



A candidate Z→μμ event with 25 reconstructed pile-up vertices



MSSM Higgs searches

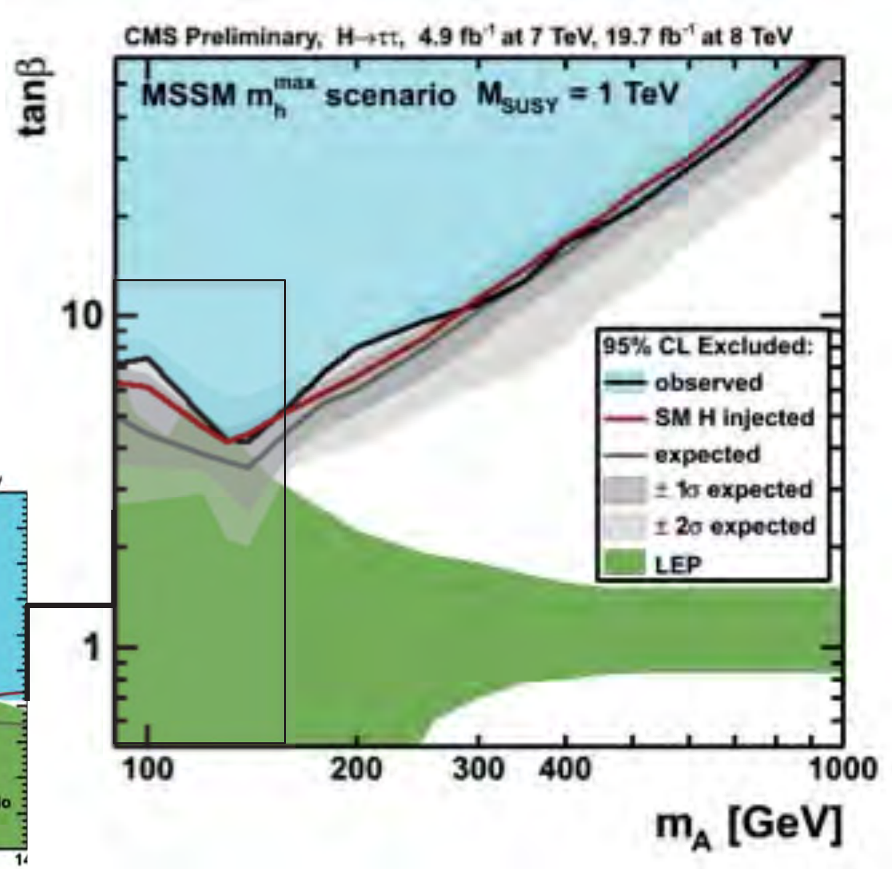
Neutral MSSM higgs: Φ(h,H,A)→ ττ

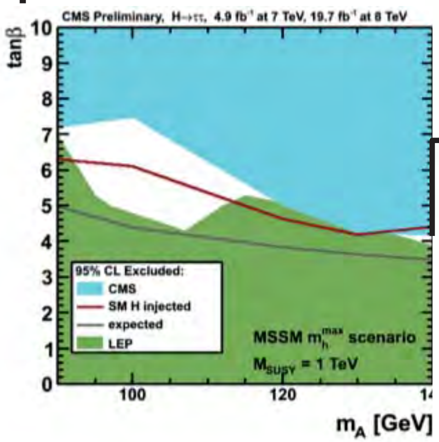
- High sensitivity at large tan(β)

Enhanced coupling to down type fermions

- Address specifically associated production with b
- No additional signal observed in ττ final state
- Result interpretation (limits) within specific models

m_h^{max}scenario: stop mixing term determined form maximization of lightest higgs boson mass



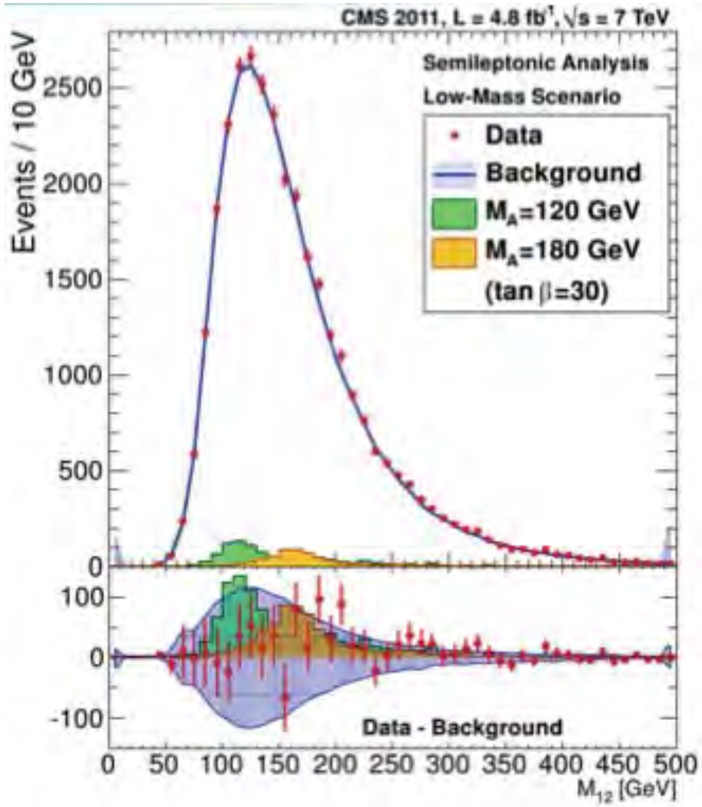


Neutral MSSM higgs: Φ(hHA)→ bb

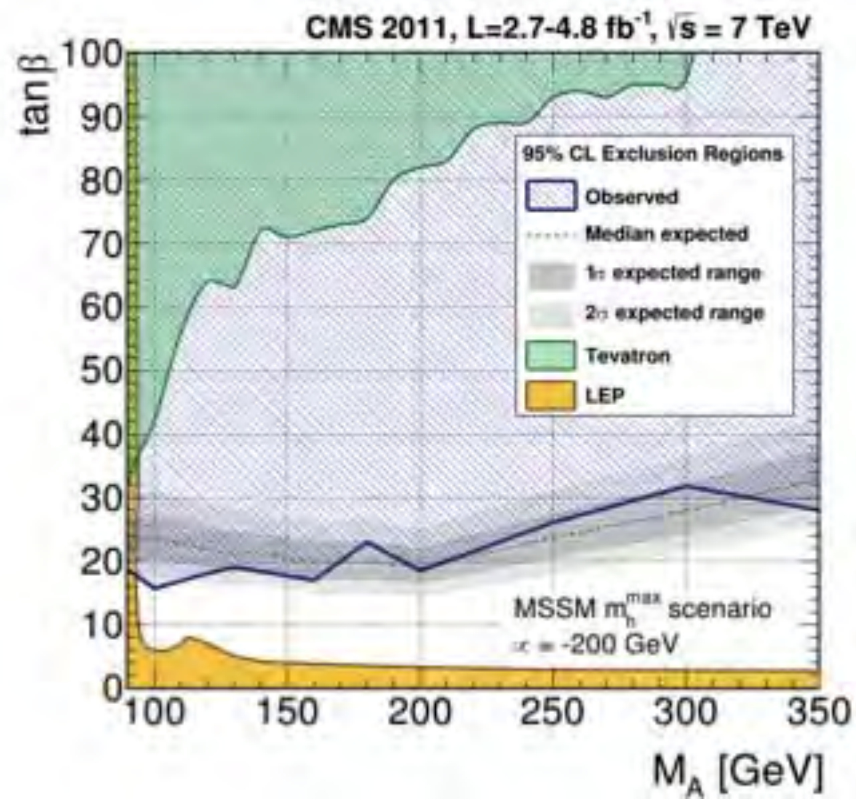
- High sensitivity at large tan(β)

Enhanced coupling to down type fermions

- No signal observed



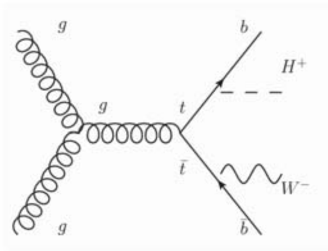
m_h^{max}scenario: stop mixing term determined form maximization of lightest higgs boson mass

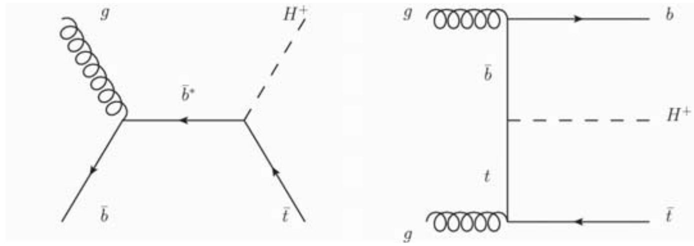


Charged higgs: t→H± b, tH±b (H±→τν)

- Two searches:

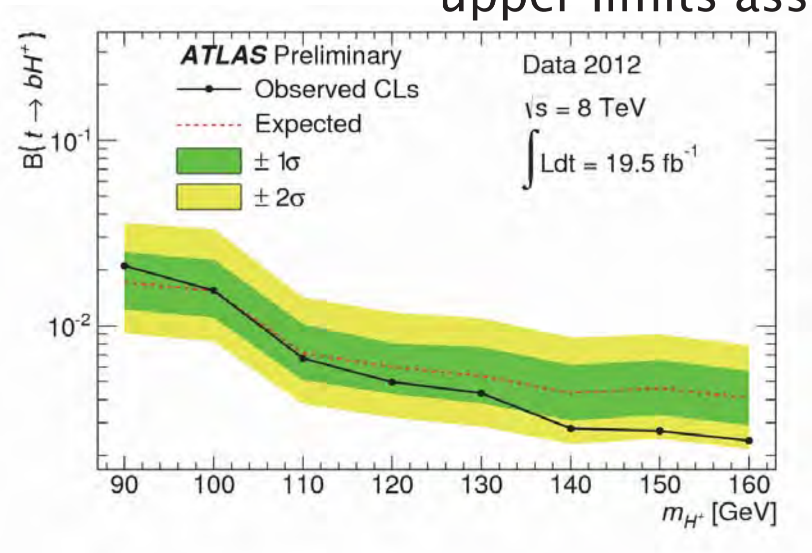
MH<m_t MH>m_t

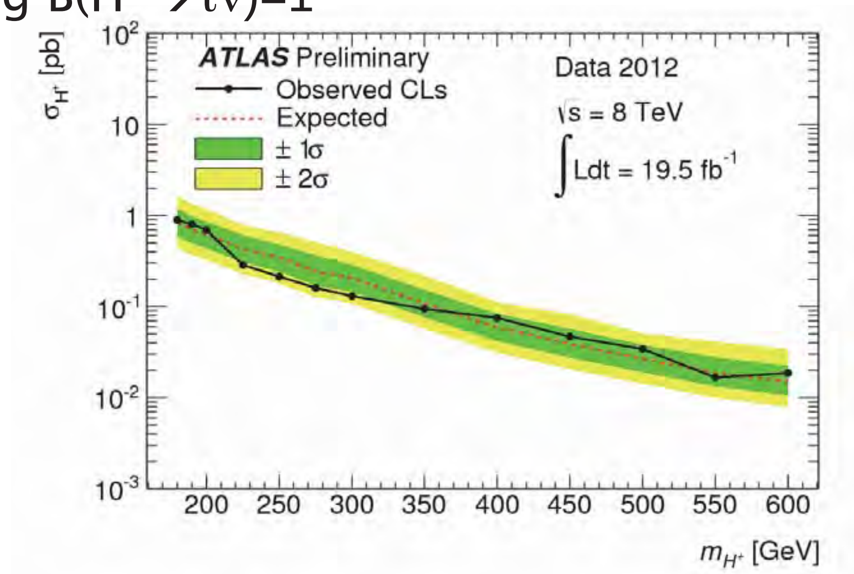




No excess found

upper limits assuming B(H±→τν)=1

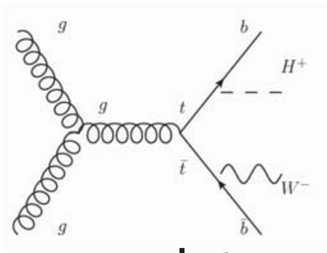




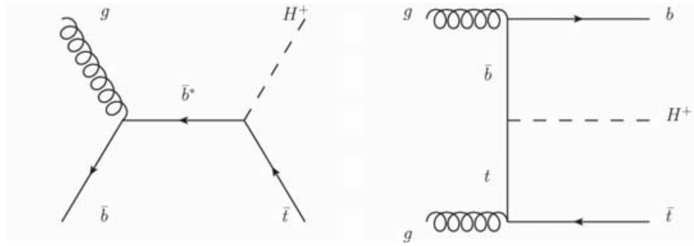
Charged higgs: t→H± b, tH±b (H±→τν)

- Two searches:

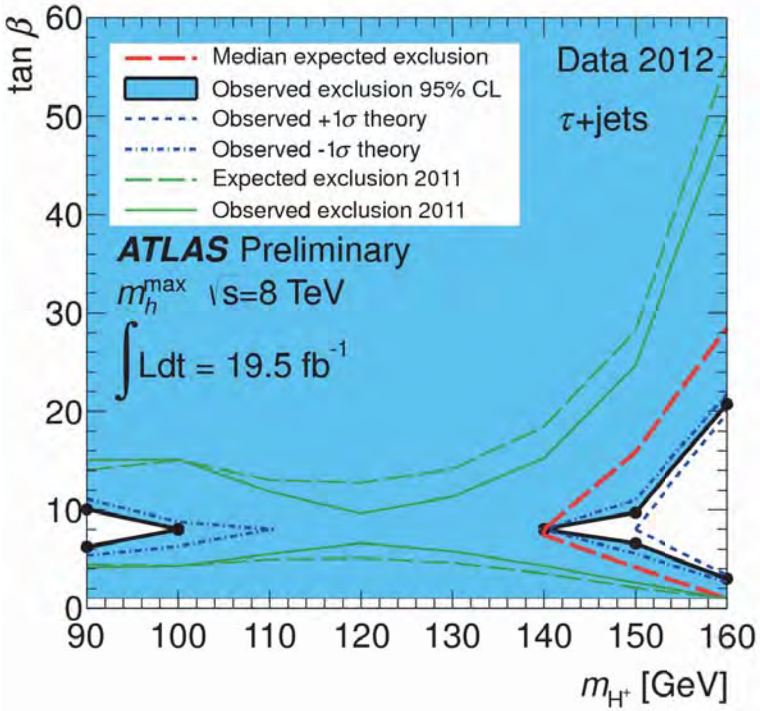
MH<m_t

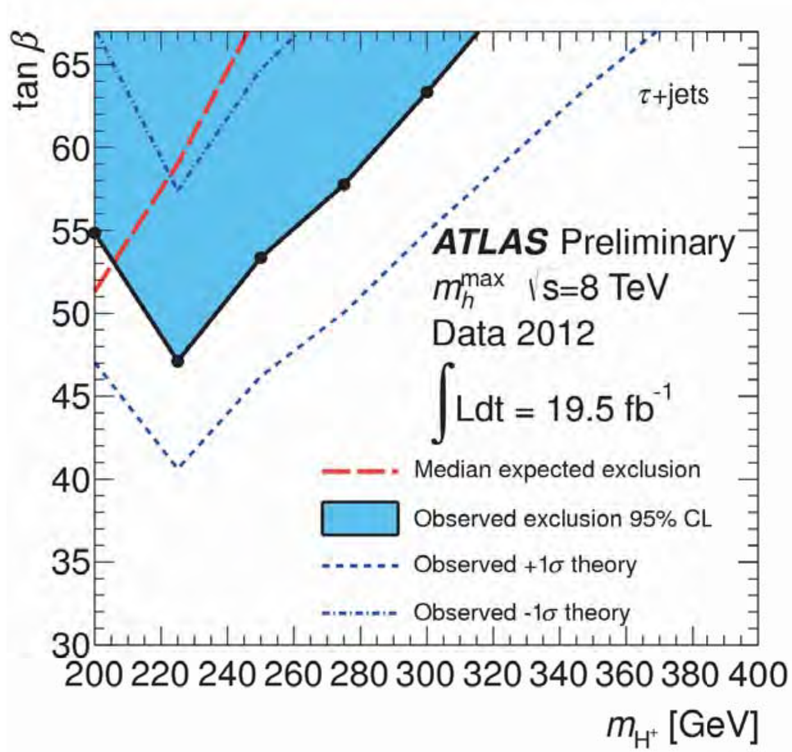


MH>m_t



Interpretation in the m_h^{max} scenario

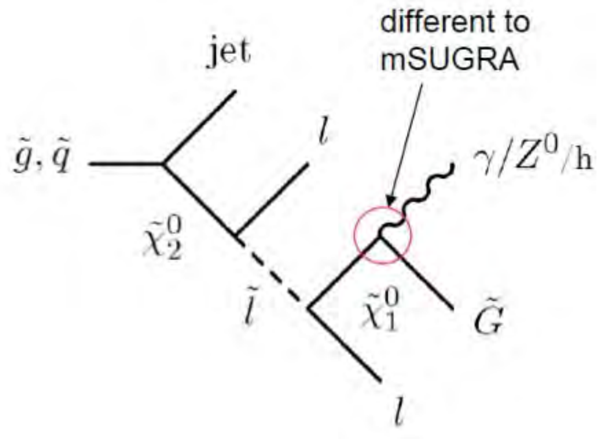




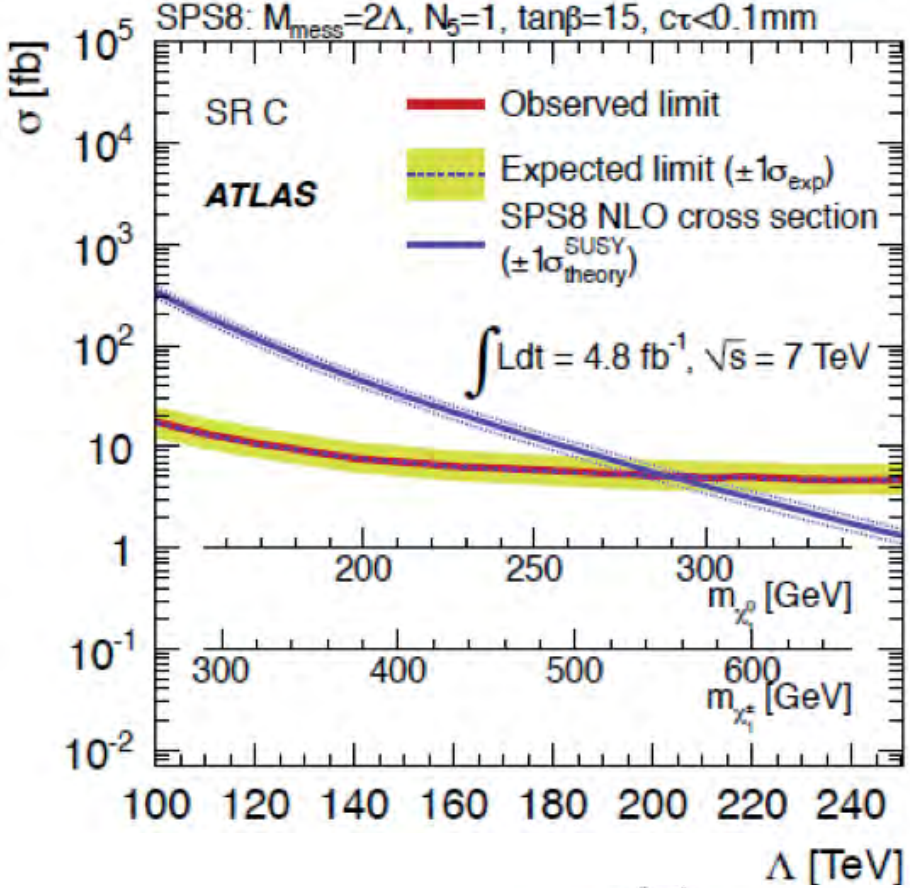
Gauge Mediated SUSY Breaking models

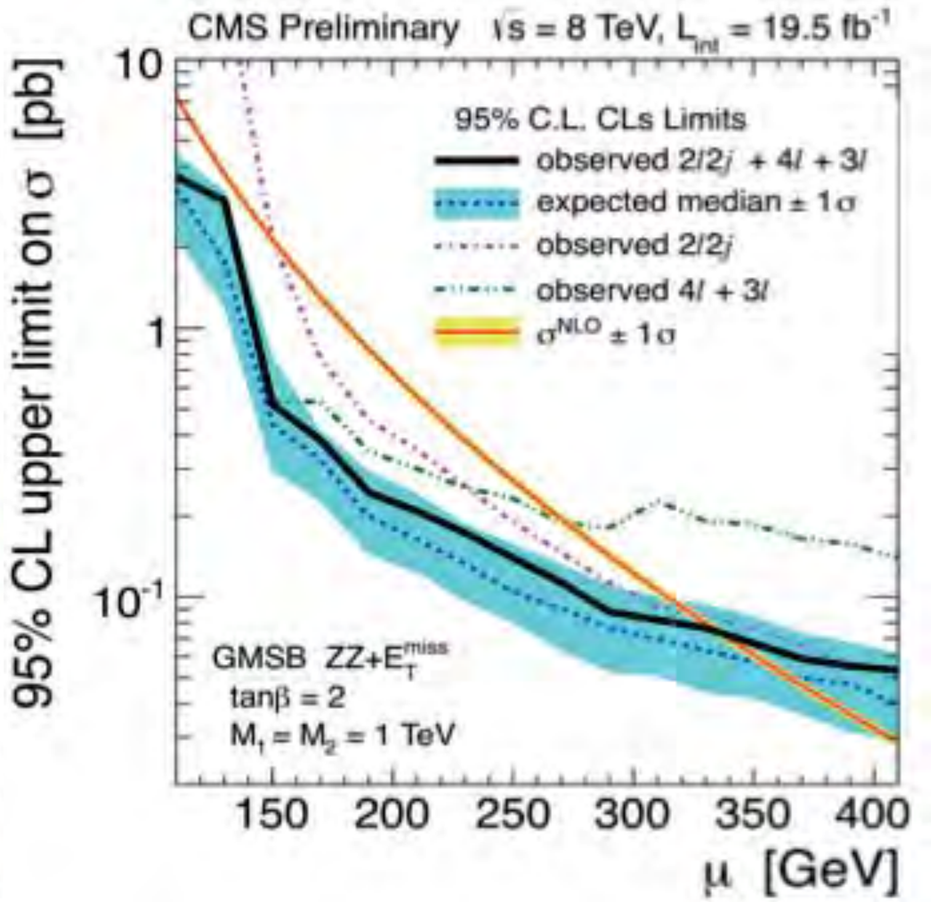
- SUSY breaking occurs in an hidden sector transmitted to SUSY particles via gauge interactions ➔ light neutralino or sleptons (stau)
- LSP is the gravitino $\tilde{G}$ practically massless from the experimental point of view
- NLSP typically decay: Sparticle ➔ $\tilde{G}$ SMparticle
  - NLSP may have relatively high lifetime
    (couples via gravitational interaction with strength prop. $M_{\tilde{G}}$)

typical decay chain
with χ NLSP
Final states with γ,Z,h depending
χ composition

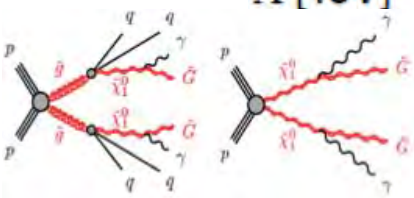


GMSB searches: χ NLSP small lifetime

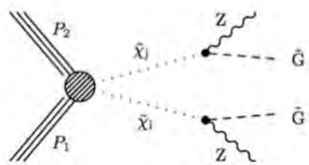




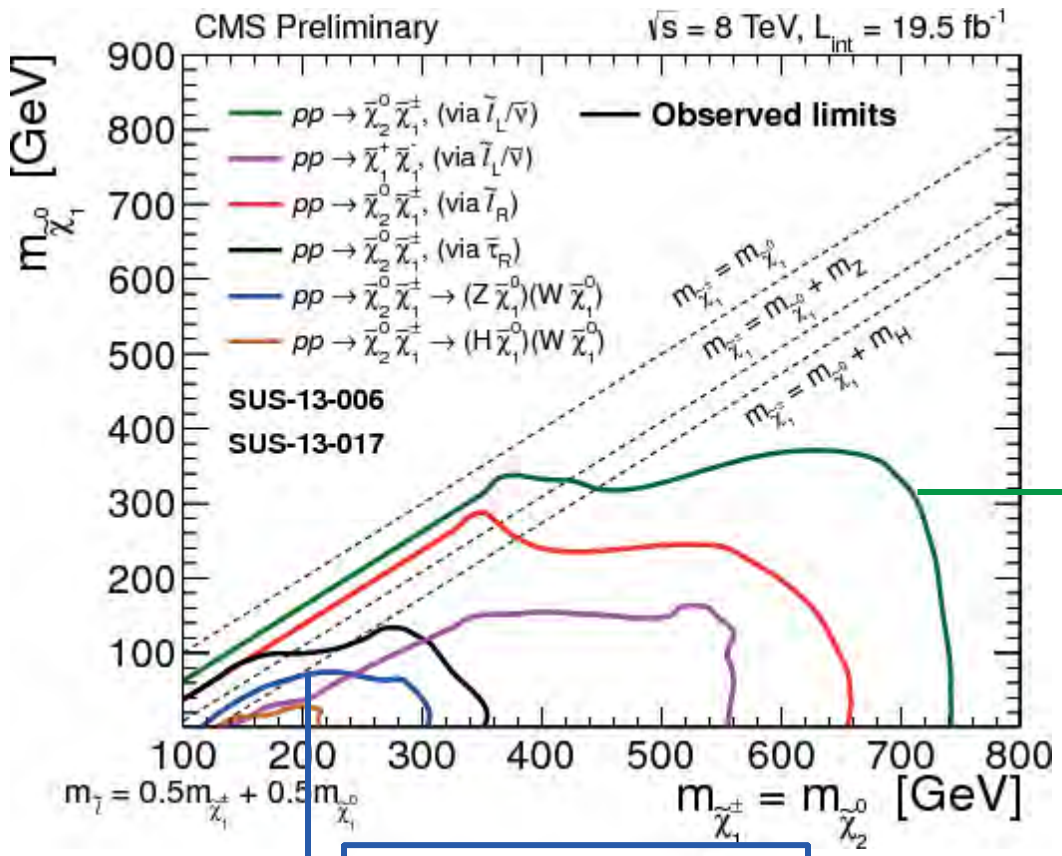
Neutralino ~ Bino:
dominant χ ➔G γ
prompt photons and ETmiss

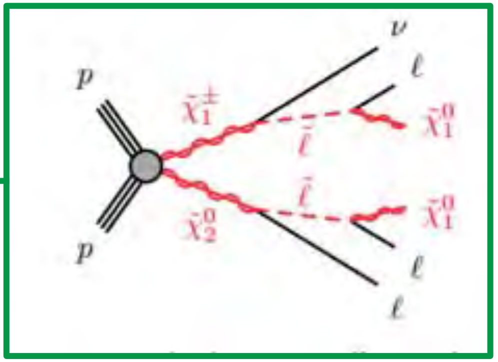


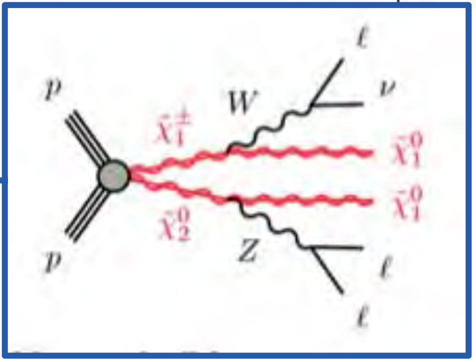
Neutralino ~ higgsino:
dominant χ ➔G Z
Z+dijet + 4-lept. analyses



$\chi^{\pm}\chi_2$ production trilepton signature



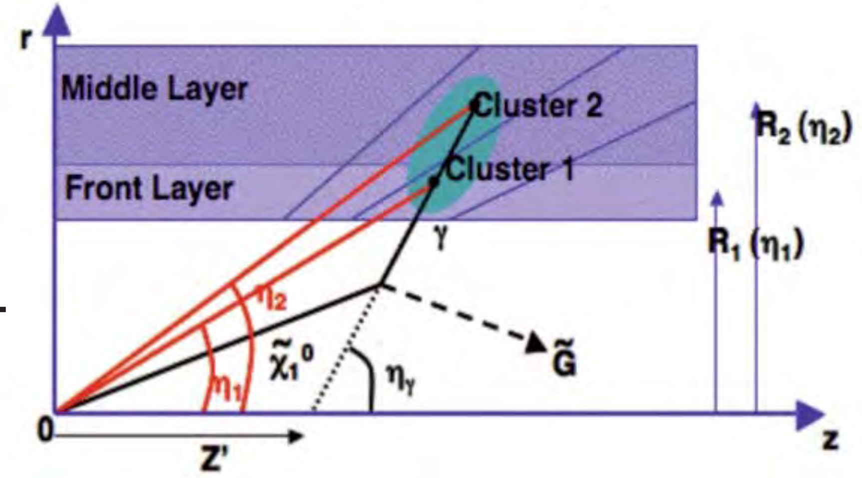


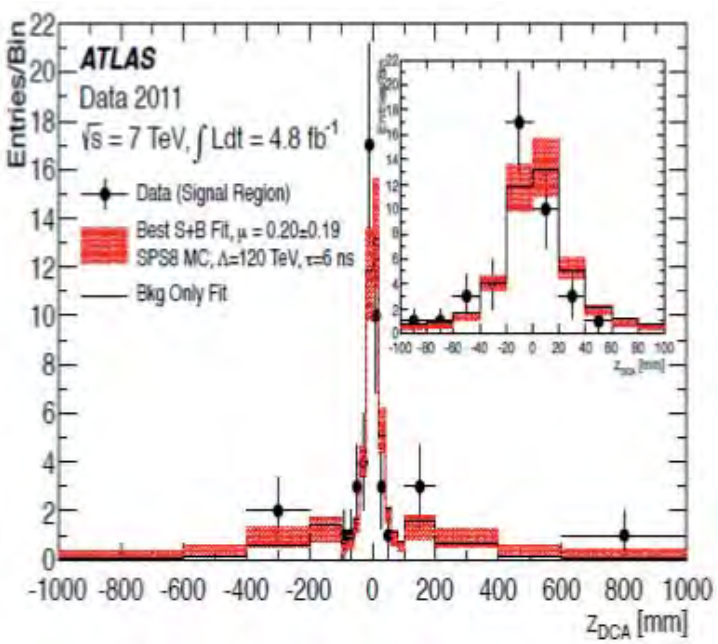


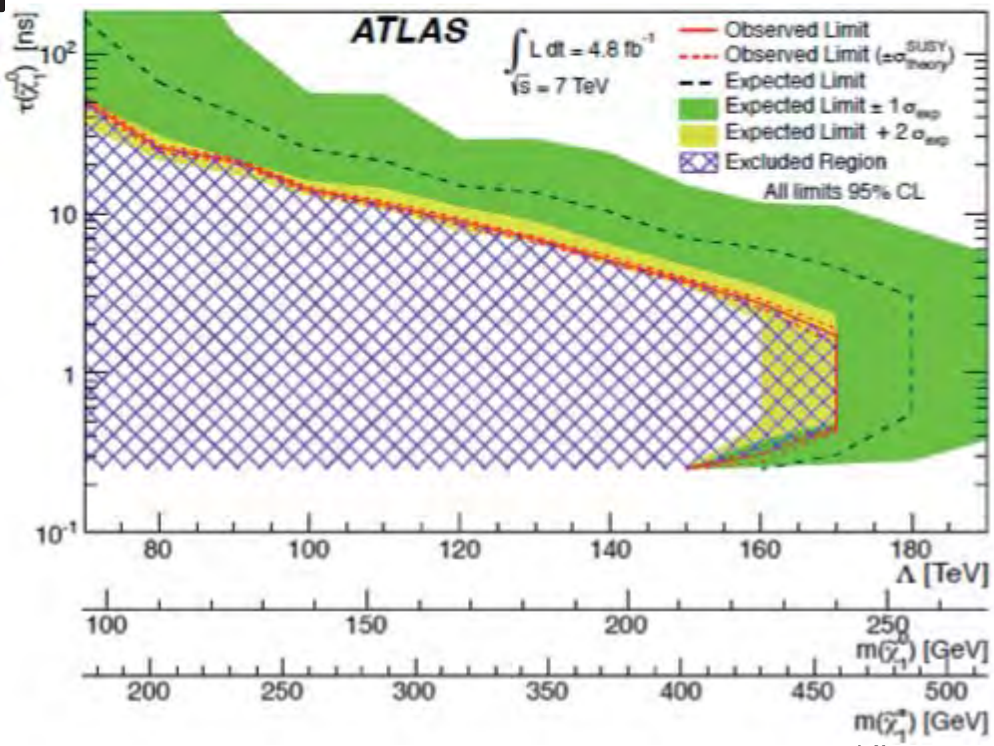
GMSB searches: χ NLSP medium lifetime

Neutralino ~ Bino:
dominant χ ➔G γ
non pointing photons and Etmiss

- Made possible thanks to the ATLAS longitudinal calorimeter segmentation







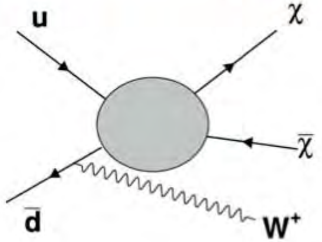
MONO-W

CMS-PAS-EXO-13-004

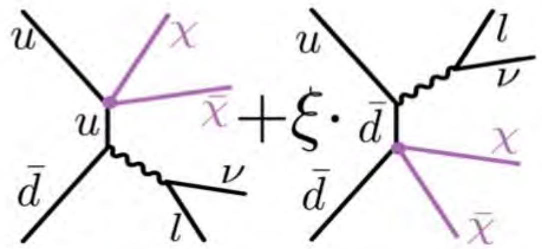
8 TeV

20 fb^{-1}

Search for mono-W (electron/muon)
Interpreted in terms of DM-DM + W



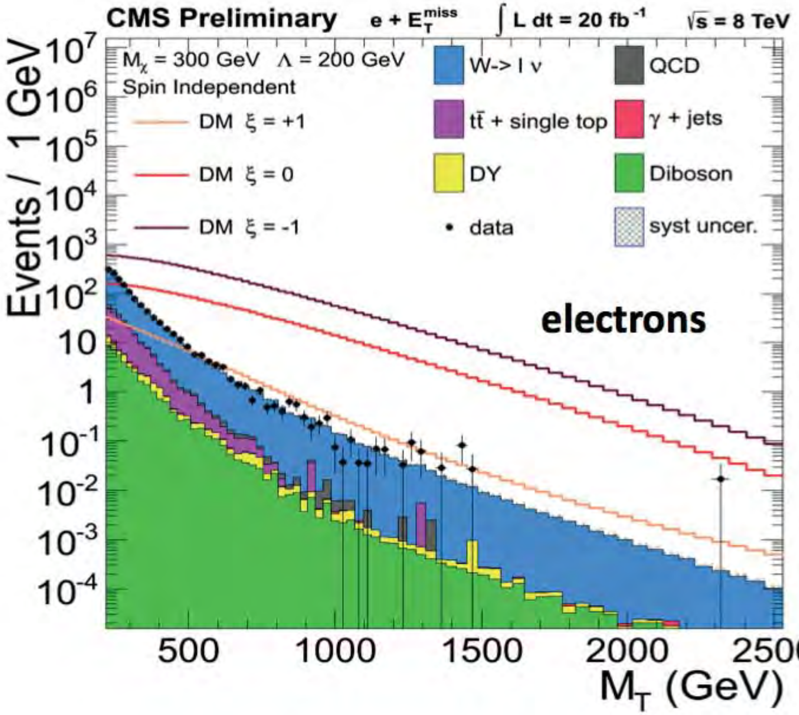
Considering vector and axial-vector operators and interference between different contributions (ξ = +1, -1 , 0)

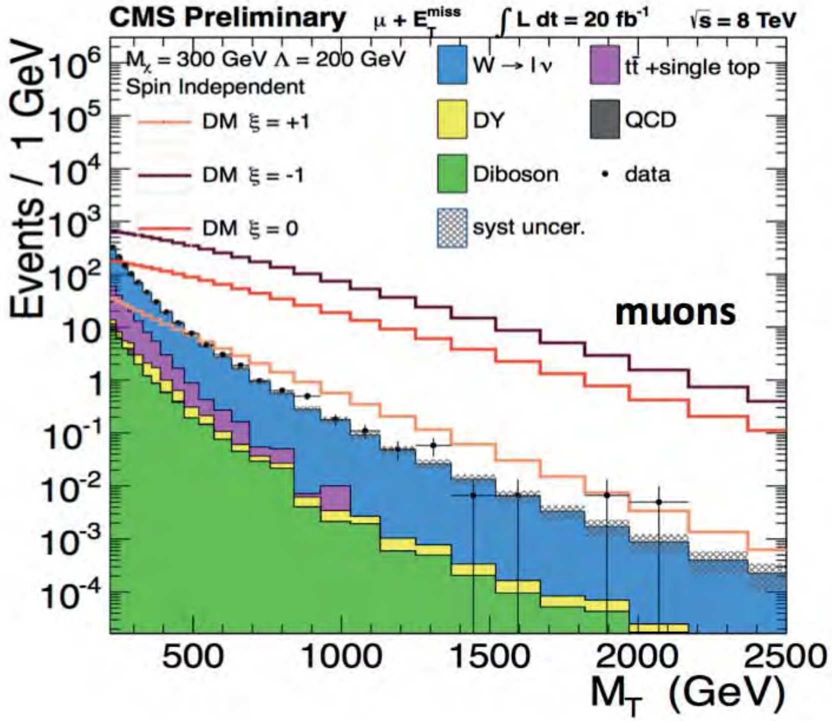


$$\text{(V)}\quad \frac{1}{\Lambda^2}\bar{\chi}\gamma^{\mu}\chi \qquad \xi_i\bar{q}_i\gamma_{\mu}q_i$$

$$\text{(AV)}\quad \frac{1}{\Lambda^2}\bar{\chi}\gamma^{\mu}\gamma^5\chi \qquad \xi_i\bar{q}_i\gamma_{\mu}\gamma^5 q_i$$

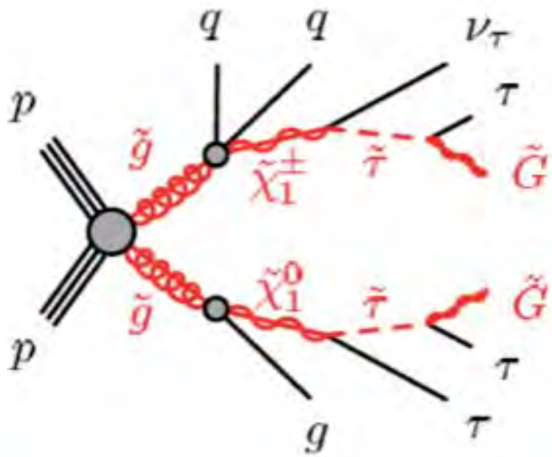
$$M_T = \sqrt{2 \cdot p_T^{\ell} \cdot E_T^{\text{miss}} \cdot (1 - \cos\Delta\phi_{\ell,\nu})}$$

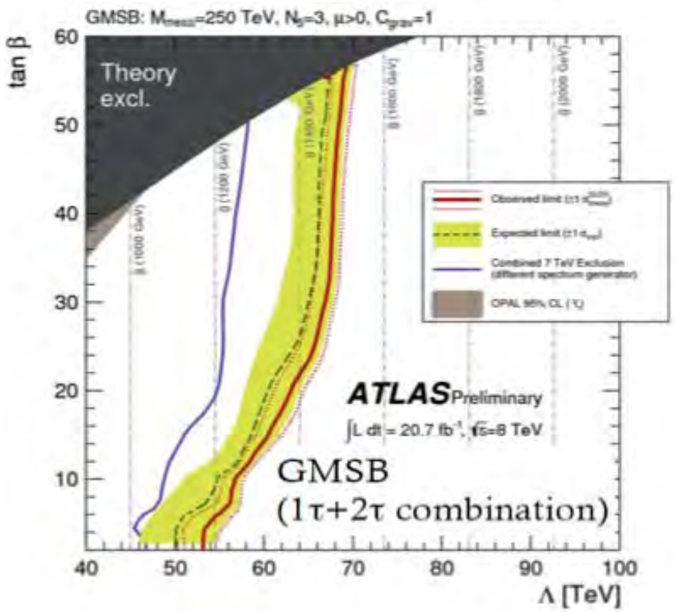




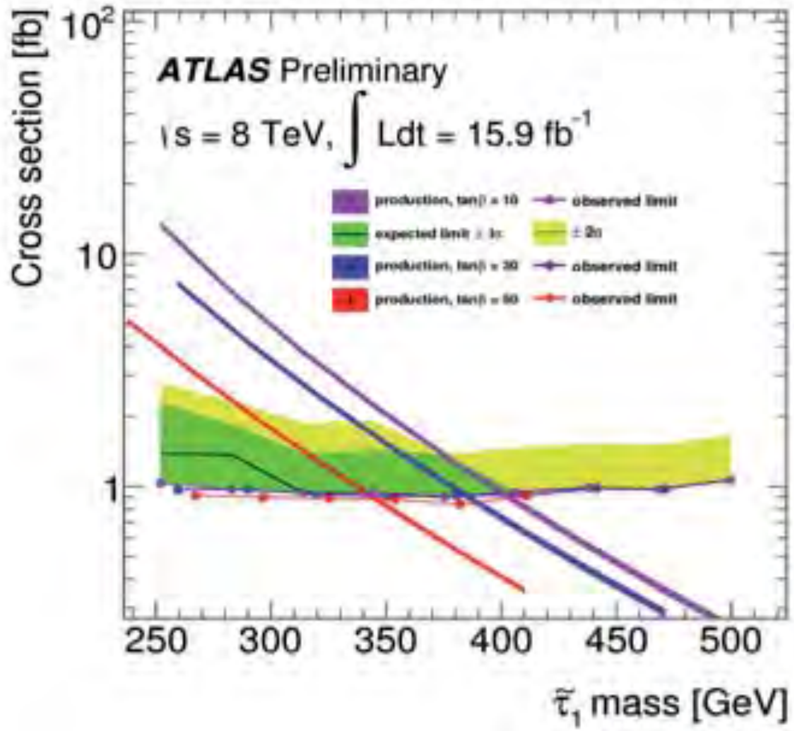
GMSB : τ̃ NLSP short and long lifetime

dominant τ ➔G τ
τ 's and Etmiss





Long lifetime: decay outside ATLAS
Signature: muon like with high mass
measure mass with ionization deposits
in pixel and Calo and with ToF in muon
detector (MDT and RPC) + momentum

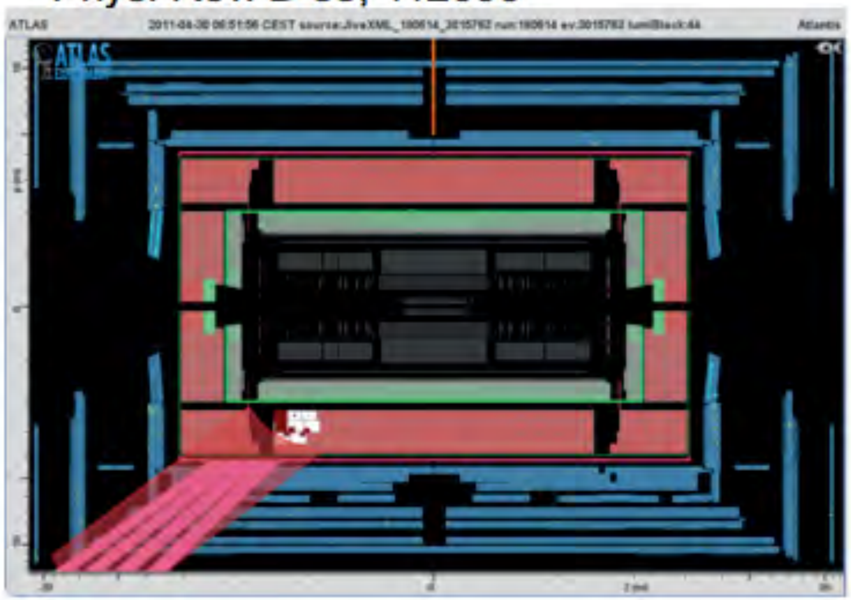


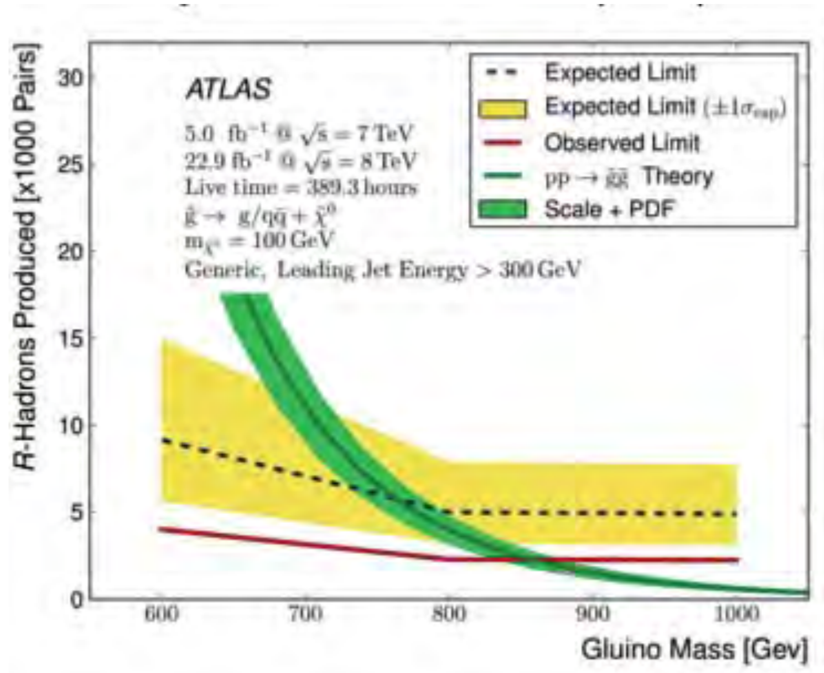
Squarks/gluinos with long lifetime

Predicted in exotics models (e.g. in Split- SUSY, Stop can be long lived at very small ΔM in the FCNC decay to c χ)

can stuck in the detector and decay later use empty LHC bunches to search for hadronic calorimeter activities Spectacular signature

Phys. Rev. D 88, 112003





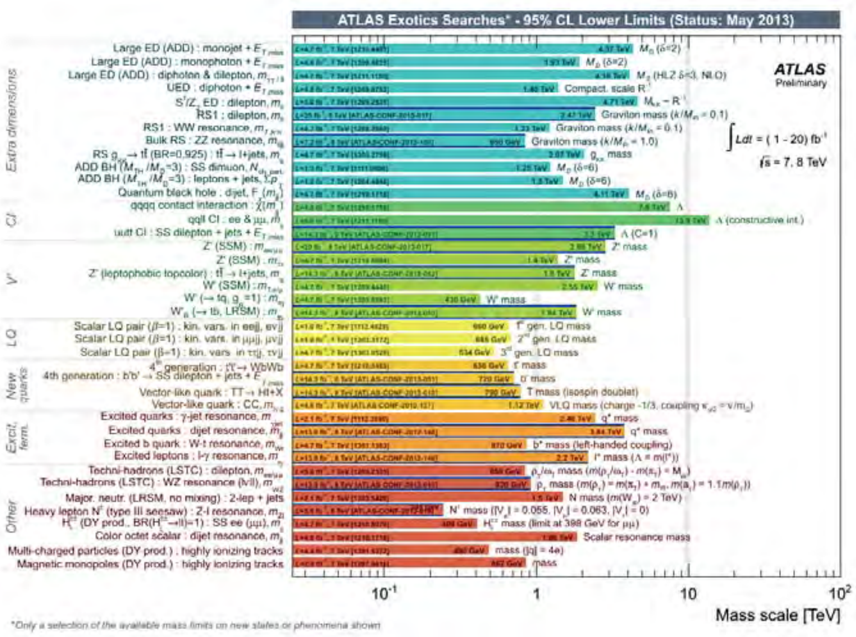
Exotics searches

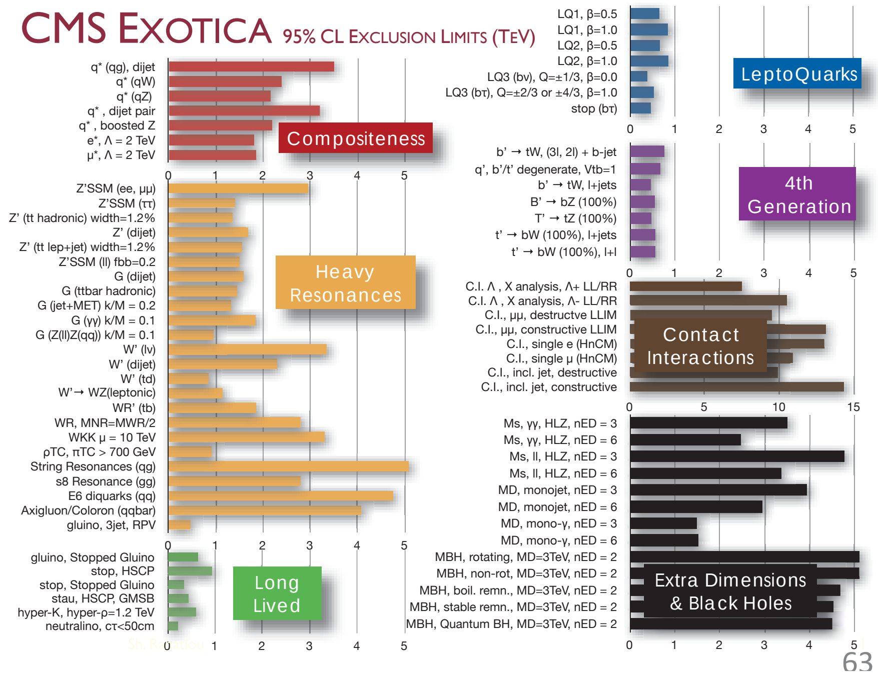
What will be reported

- 1 Object
  - Mono-X (Dark matter, gravitnos (SUSY),...)
- 2 Objects
  - Dilepton (Z')

  Apologize for the rest

What will not be reported





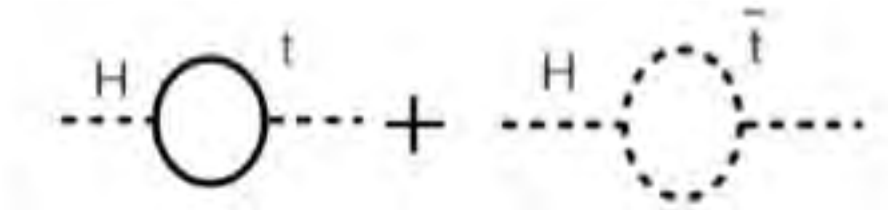
MSSM Higgs

- 5 Higgs bosons (2 scalar field doublets to give mass to up and down type fermions):
  - Mitigation of fine-tuning/UV sensitivity of the Higgs-mass term ["hierarchy *problem*"]

protection of the higgs mass thanks to the fermionic field associated to it

Practically quadratic divergences of loops with

SM particles cancelled by those with SUSY partners

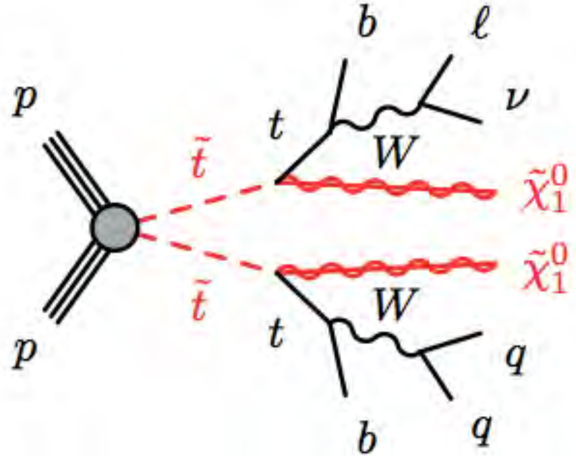


  - Cancellation amount depends on SUSY breaking
  - *Lightest Higgs mass predicted to be below M_Z at tree level*

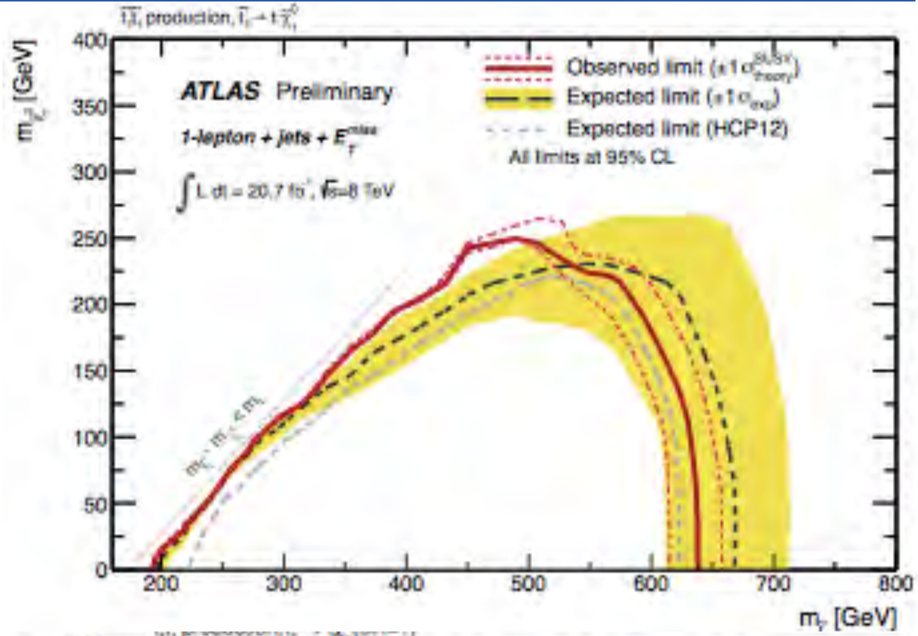
"Natural" quantum corrections (dominated by stop loop) sets upper limit on Mh around 135 GeV*

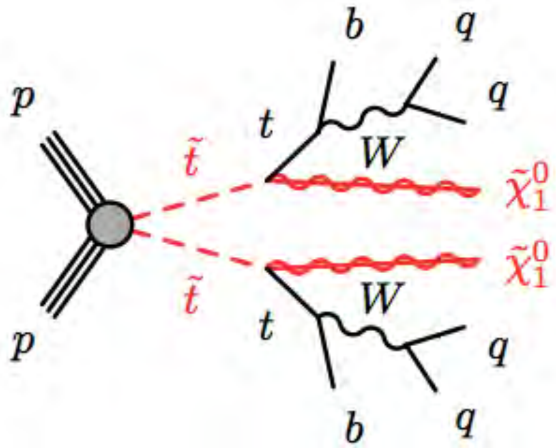
125 GeV Higgs is consistent with the MSSM max allowed expectation values

Searches for $\tilde{t} \rightarrow t\chi$

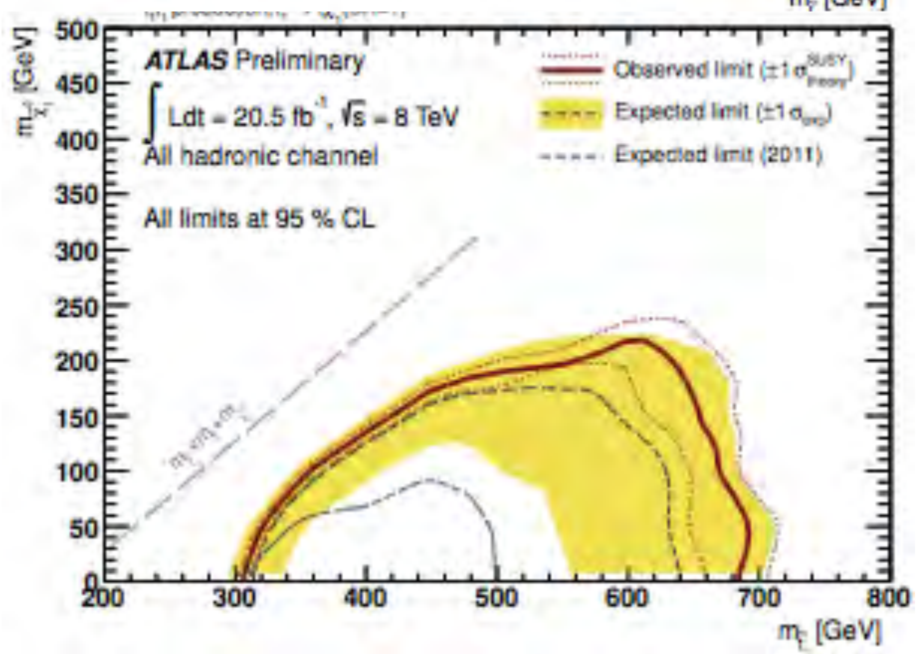


Semi-leptonic t̄t + ETmiss analyisis

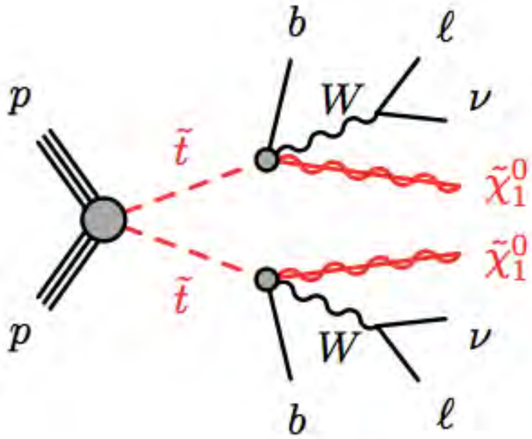


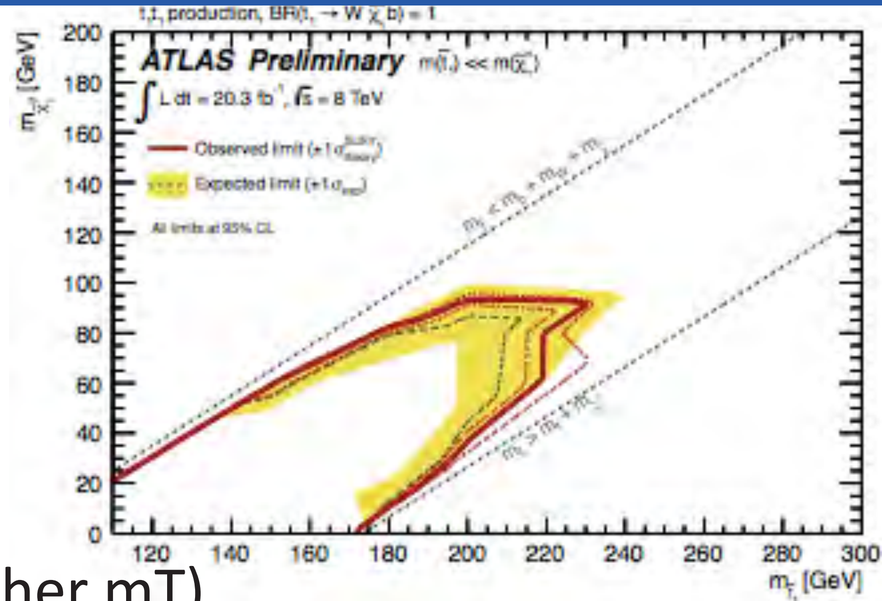


Hadronic t̄t + ETmiss analyisis



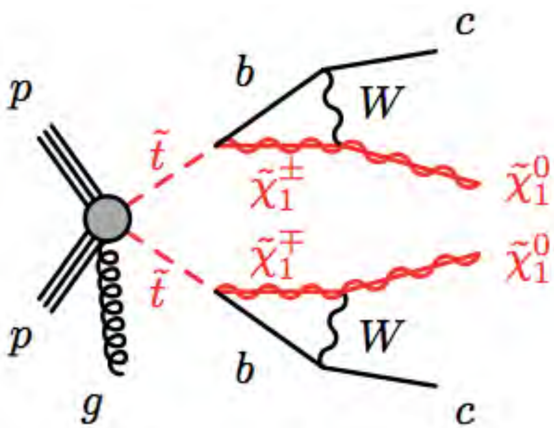
Searches for $\tilde{t} \rightarrow bW\chi$, $c\chi$

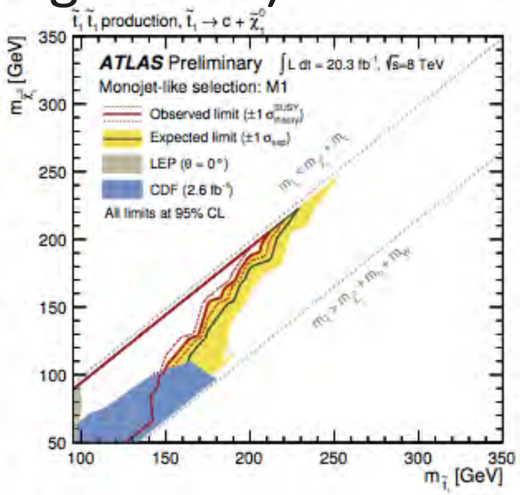


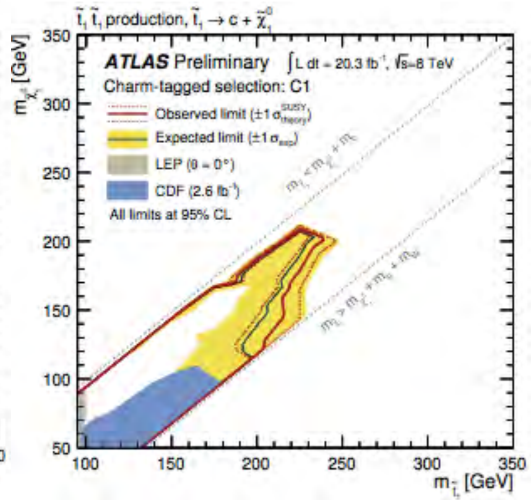


3 body decay 2 leptons

(very similar to tt signature but higher mT)







Monojet like signature and/or charm tagging

Address very low ΔM case (with very small missing E_T) with ISR events