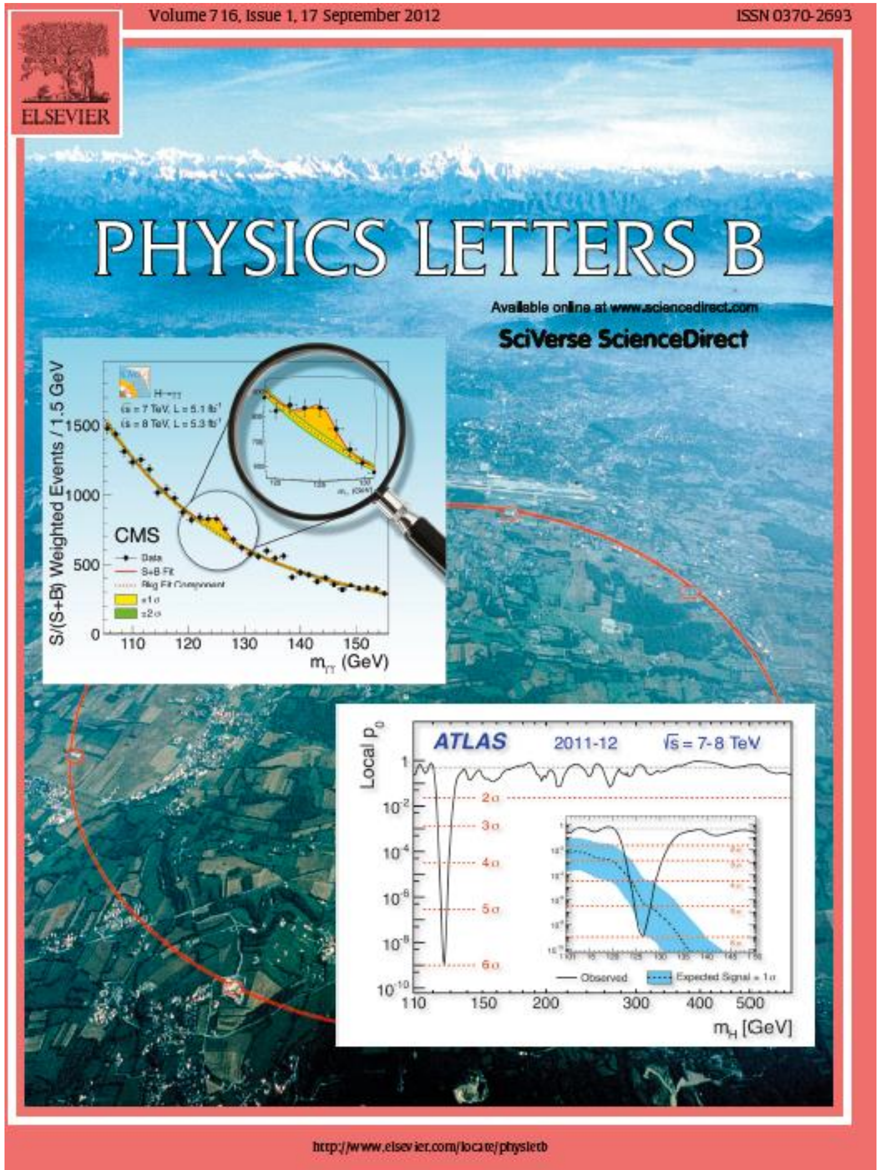
Accelerator dark matter searches: complementarity to indirect and direct searches

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?

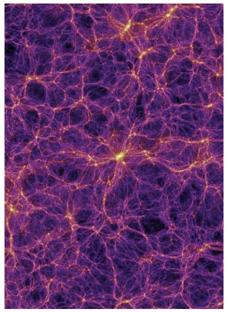
- Still... the SM suffers of a series of theoretical & cosmological problems:
  - Fine-tuning/UV sensitivity of the Higgs-mass term ["hierarchy *problem"]*
  - Unexplained hierarchical structure of the Yukawa couplings ["flavor *puzzle"]*
  - No explanation for the quantization of the U(1) charges [hint *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

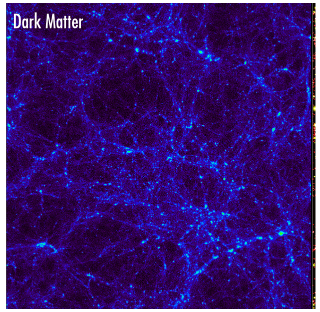
Common view: the SM is an *effective theory,* or the low-energy limit of a more fundamental theory, with new degrees of freedom at high energies.

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

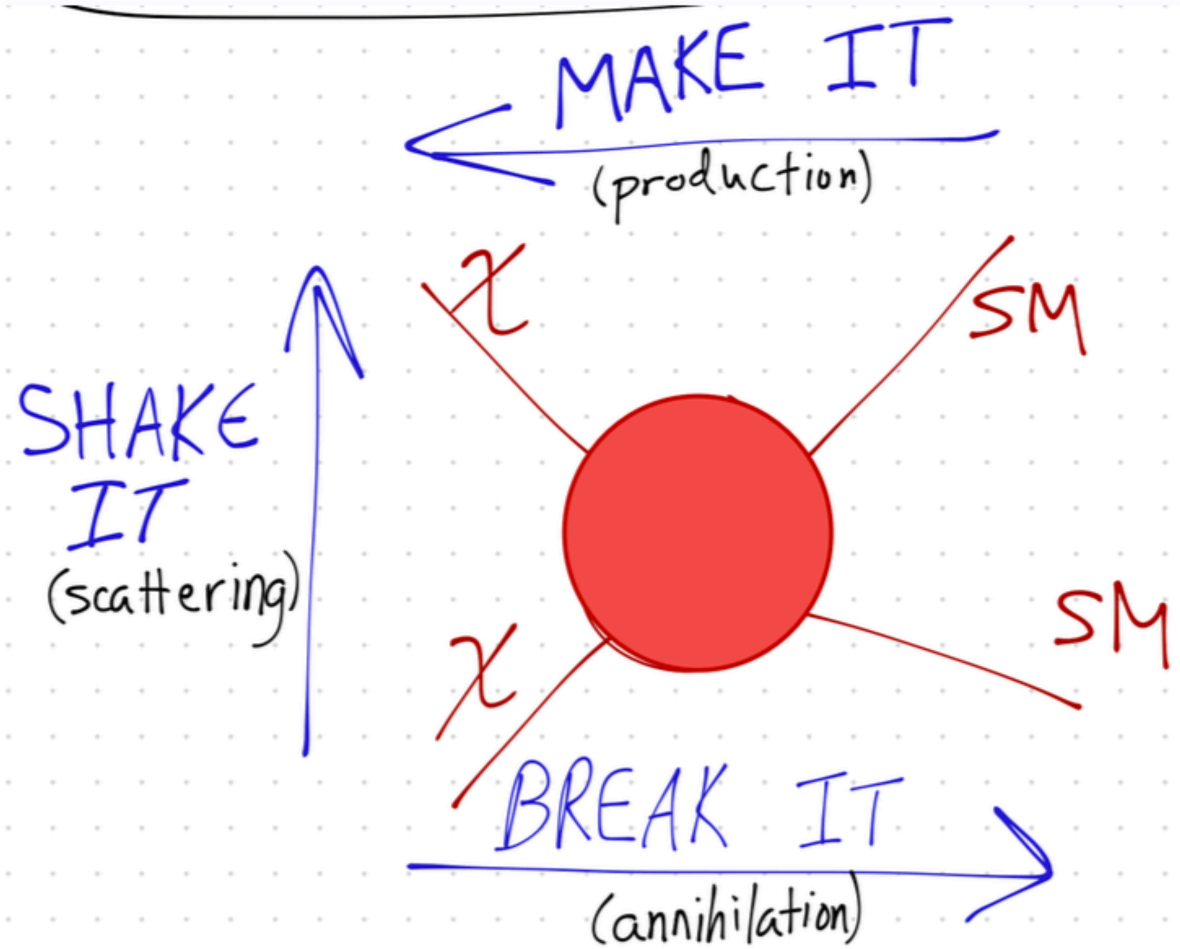
Weight: approximately 0.01-1 TeV

Interaction: gravitational, “weak”

Distinctive features: tendency to escape

REWARD

Searching in all ways

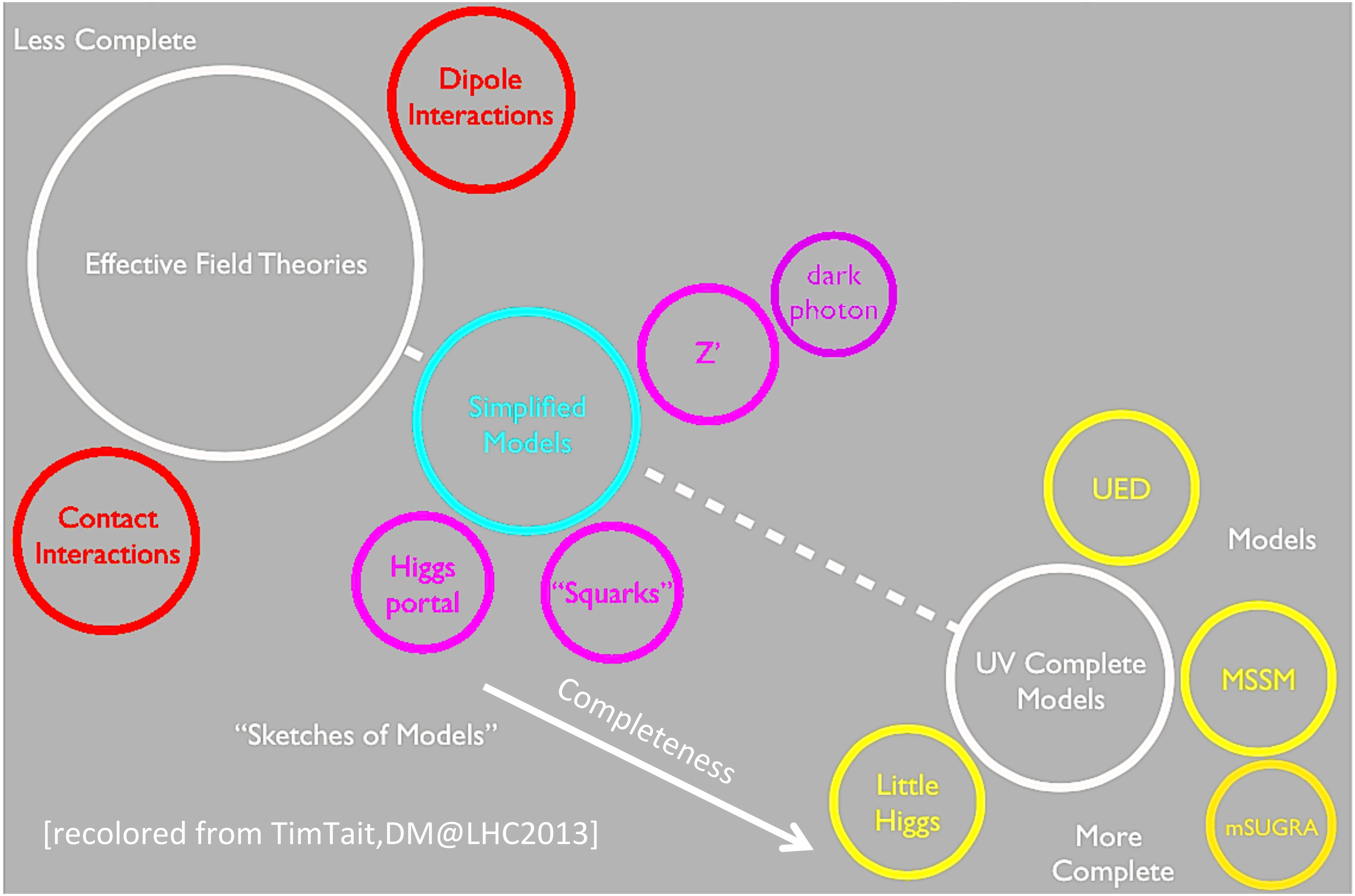


Dark matter searches of all kinds put constraints on different observables

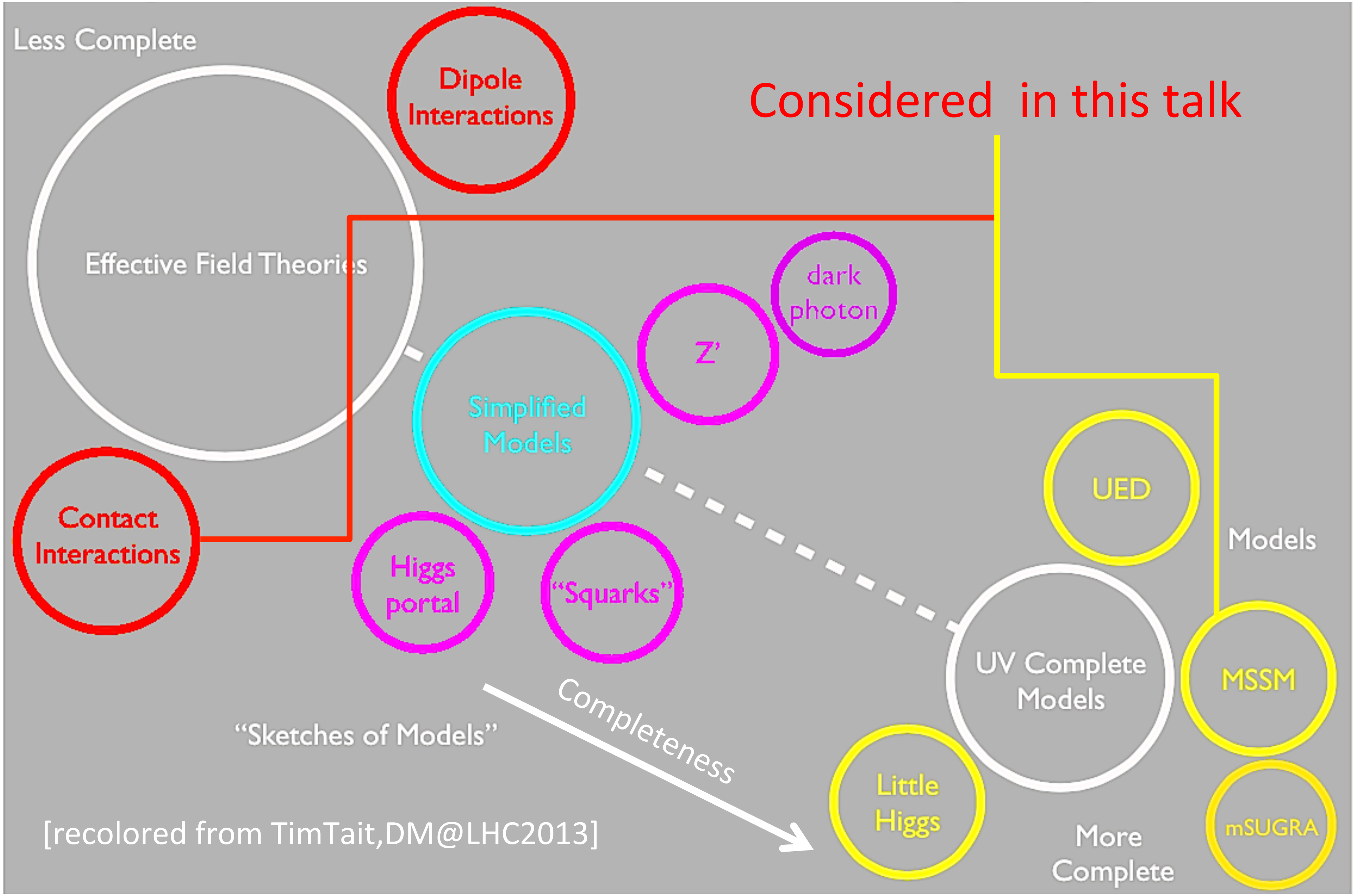
Without some kind of theoretical structure, we can't compare them.

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.

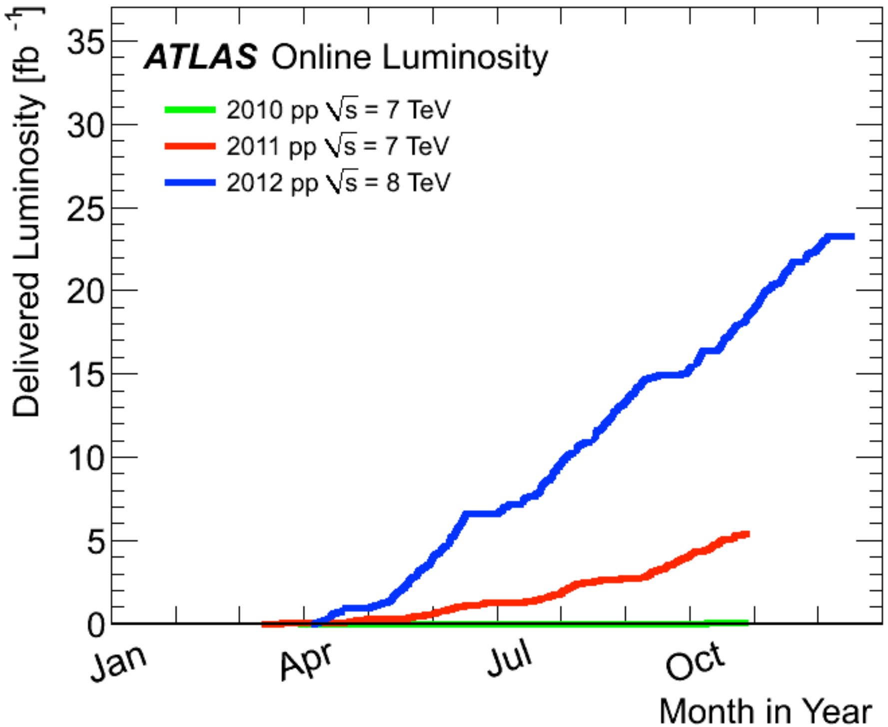
Center-of-Mass Energy:

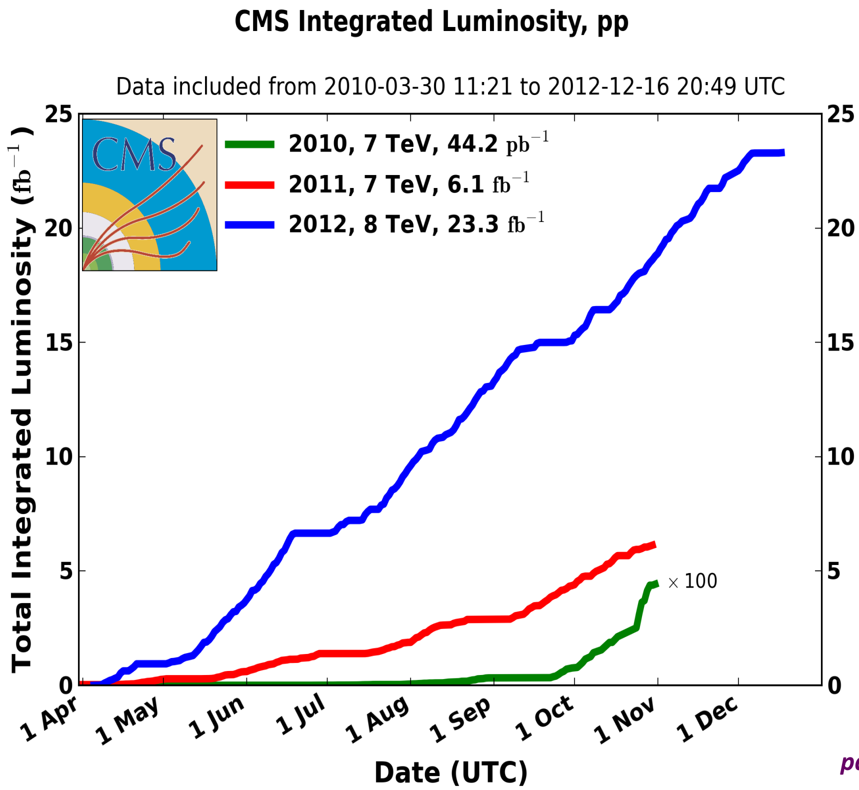
- Nominal: 14 TeV
- beginning of Run-II: 13 TeV
- Spring-Autumn 2012: 8 TeV
- 2011- beg. 2012: 7 TeV
- 2011: 900 GeV

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 and CMS during LHC Run-II

	√S	Delivered (fb^{-1})	Recorded (fb^{-1})
pp 2015	13 TeV	**4.2**	**3.9**
pp 2016	13 TeV	**0.78**	**0.73**

	√S	Delivered (fb^{-1})	Recorded (fb^{-1})
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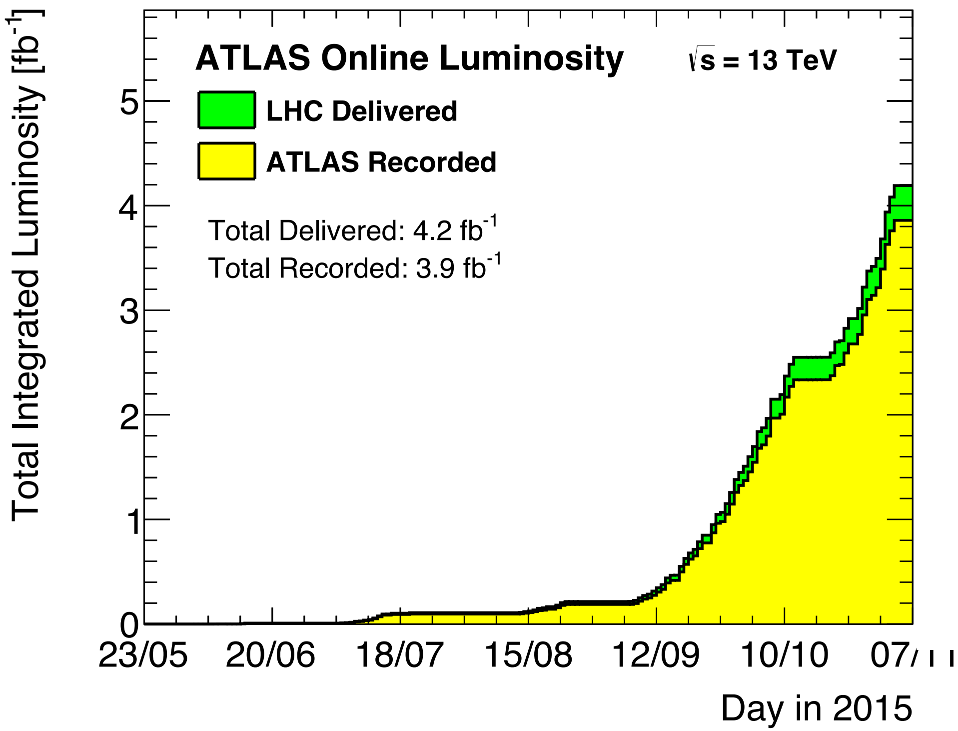

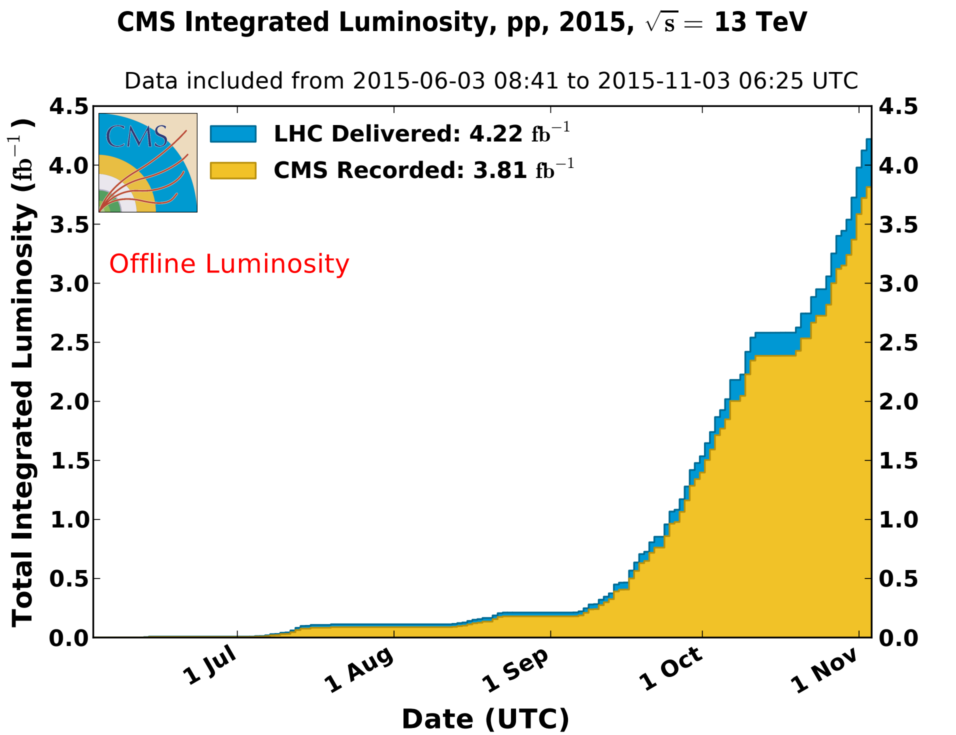

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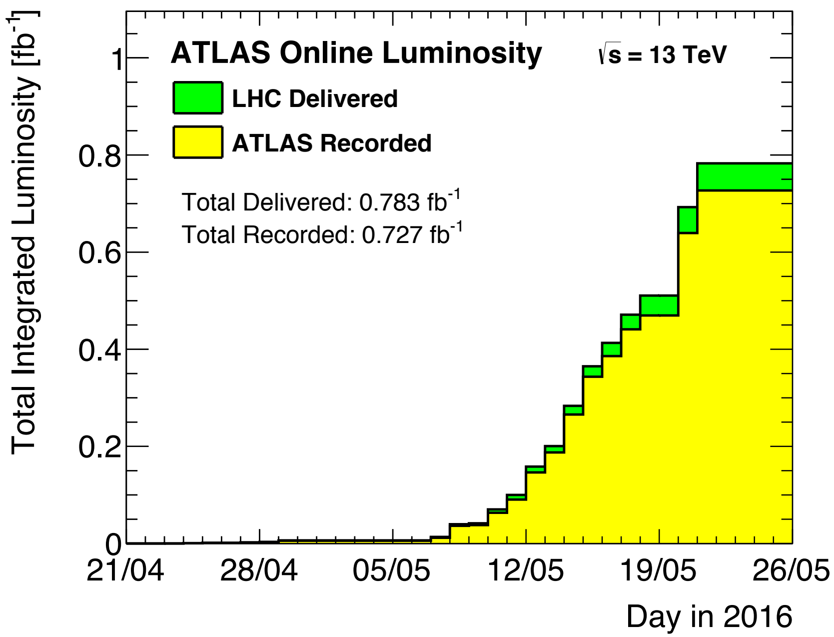
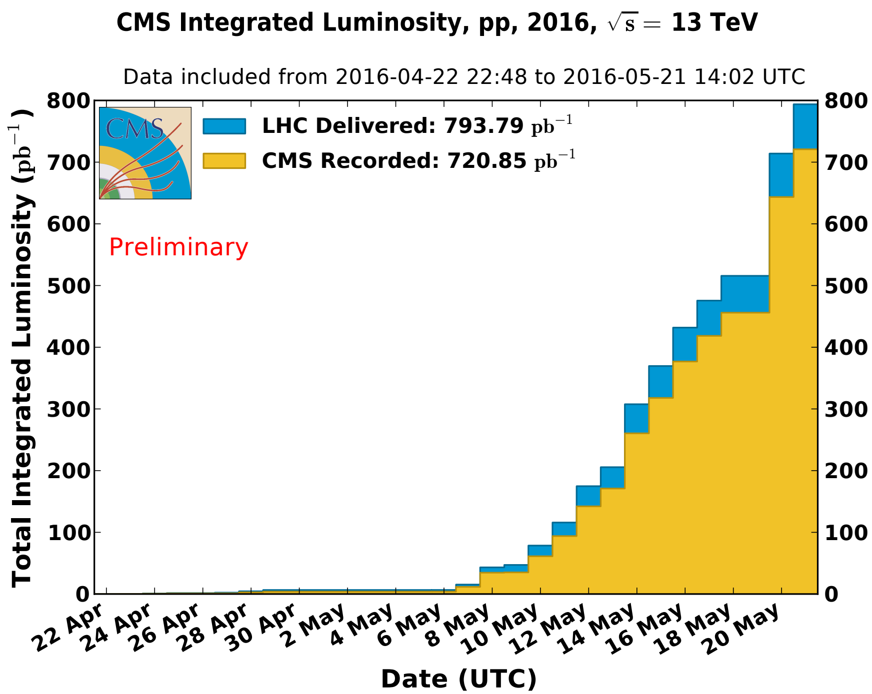




ATLAS detector: general structure

EM Calorimeter: (|η|<4.9) Pb-LAr accordion structure provides e/γ trigger, identification, measurement:

$\sigma/E \sim 10\%\sqrt{E}$

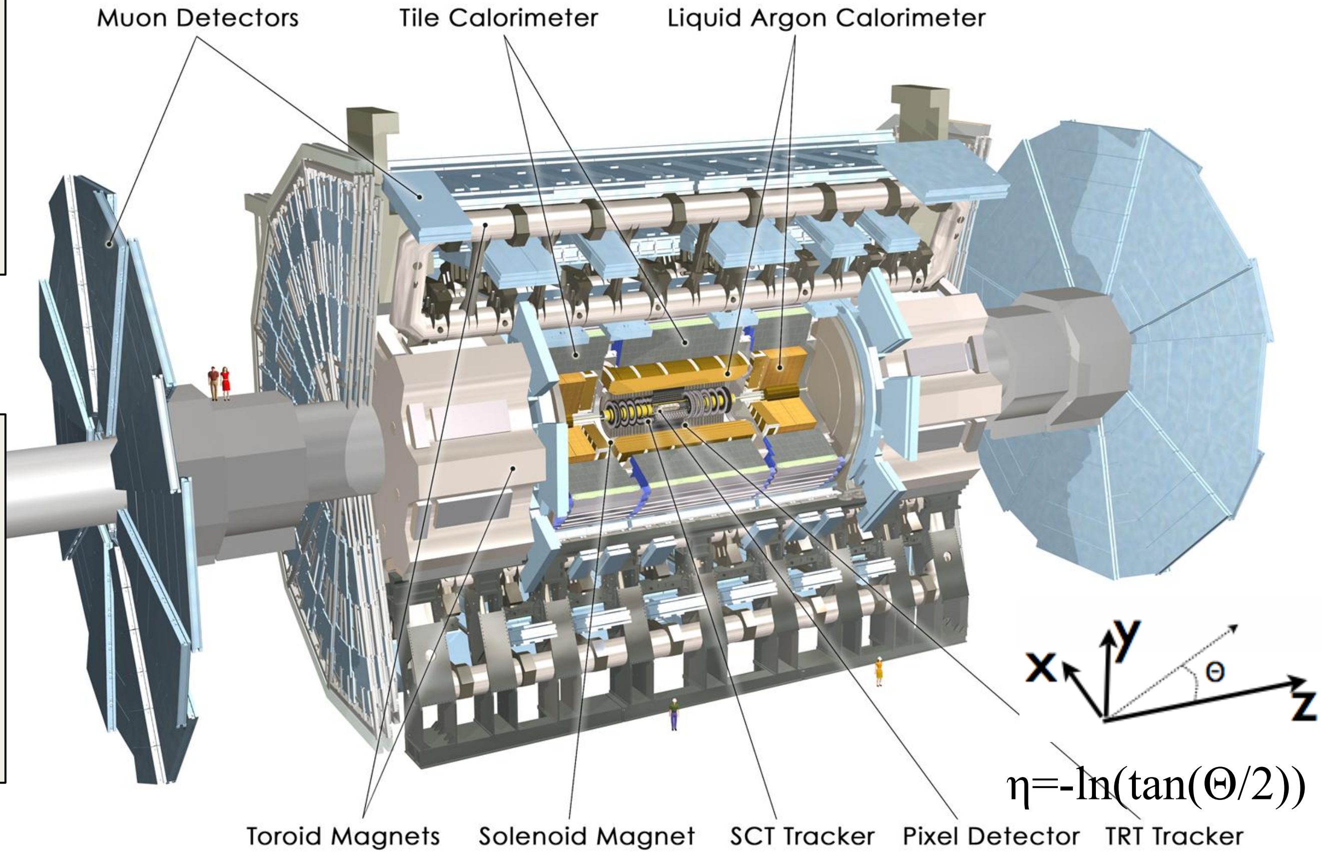
Hadronic (Tile): provides trigger, jet measurement, E_T^{miss}

$\sigma/E \sim 50\%\sqrt{E} \oplus 0.03$. (|η|<1.7)

The Inner Detector provides around 3 pixel, 8 SCT and 30 TRT measurements per charged track at $\eta = 0$. Coverage: $|\eta| < 2.5$ (2.0 for TRT)

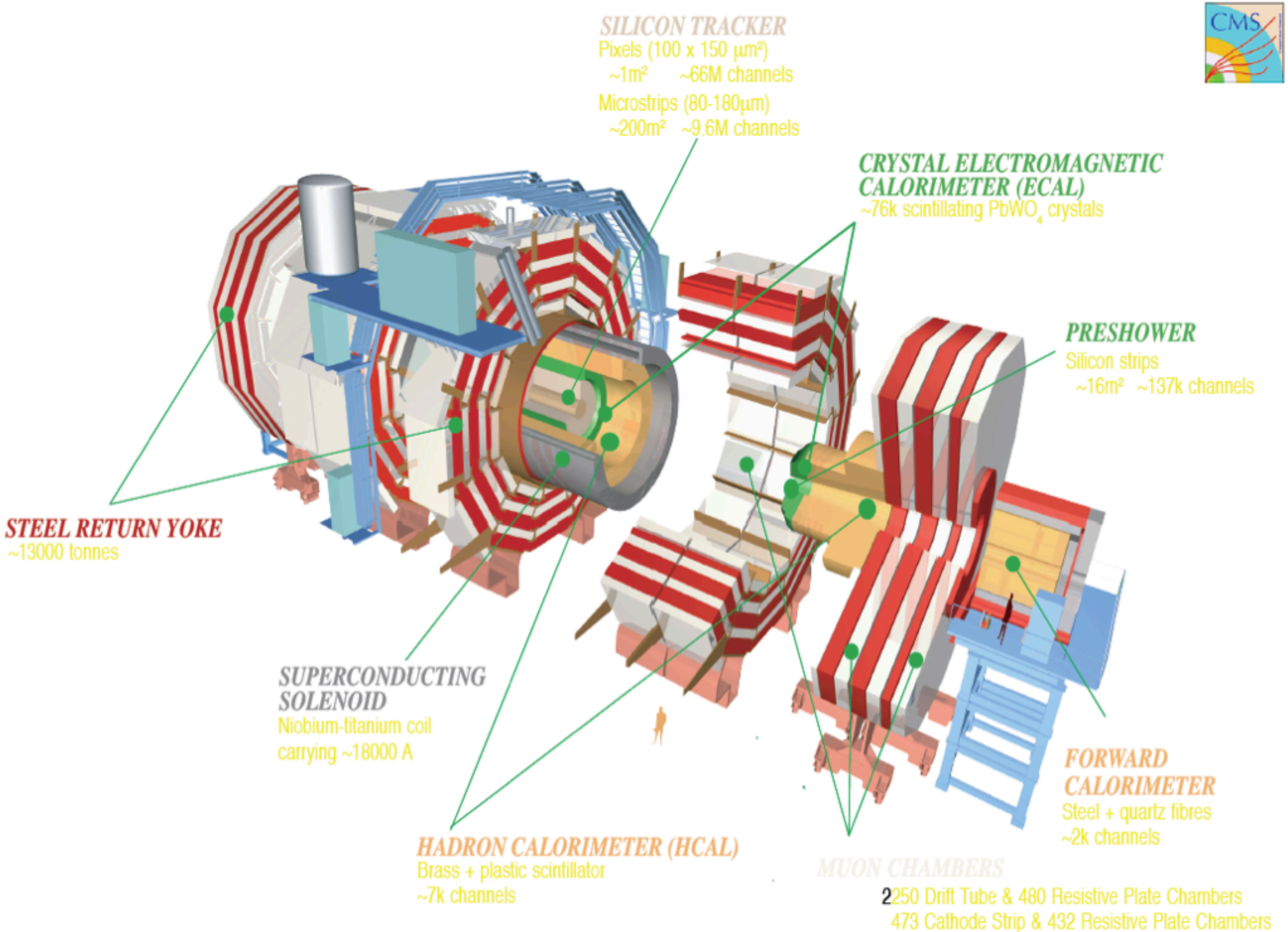
Resolution goal:

$\sigma_{pT} / p_T = 0.05\%\, p_T \oplus 1\%$



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

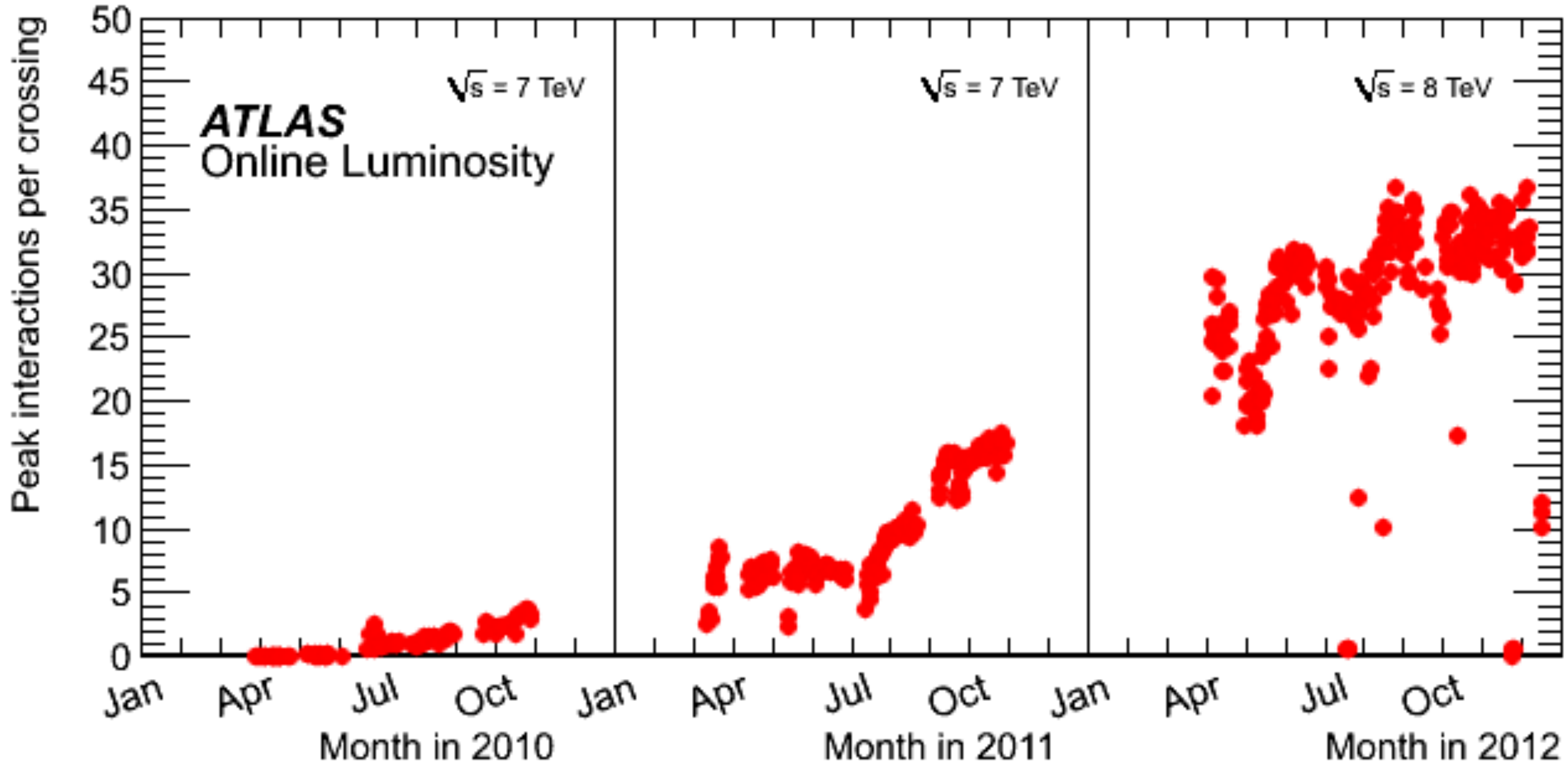
ATLAS & CMS detector: general structure



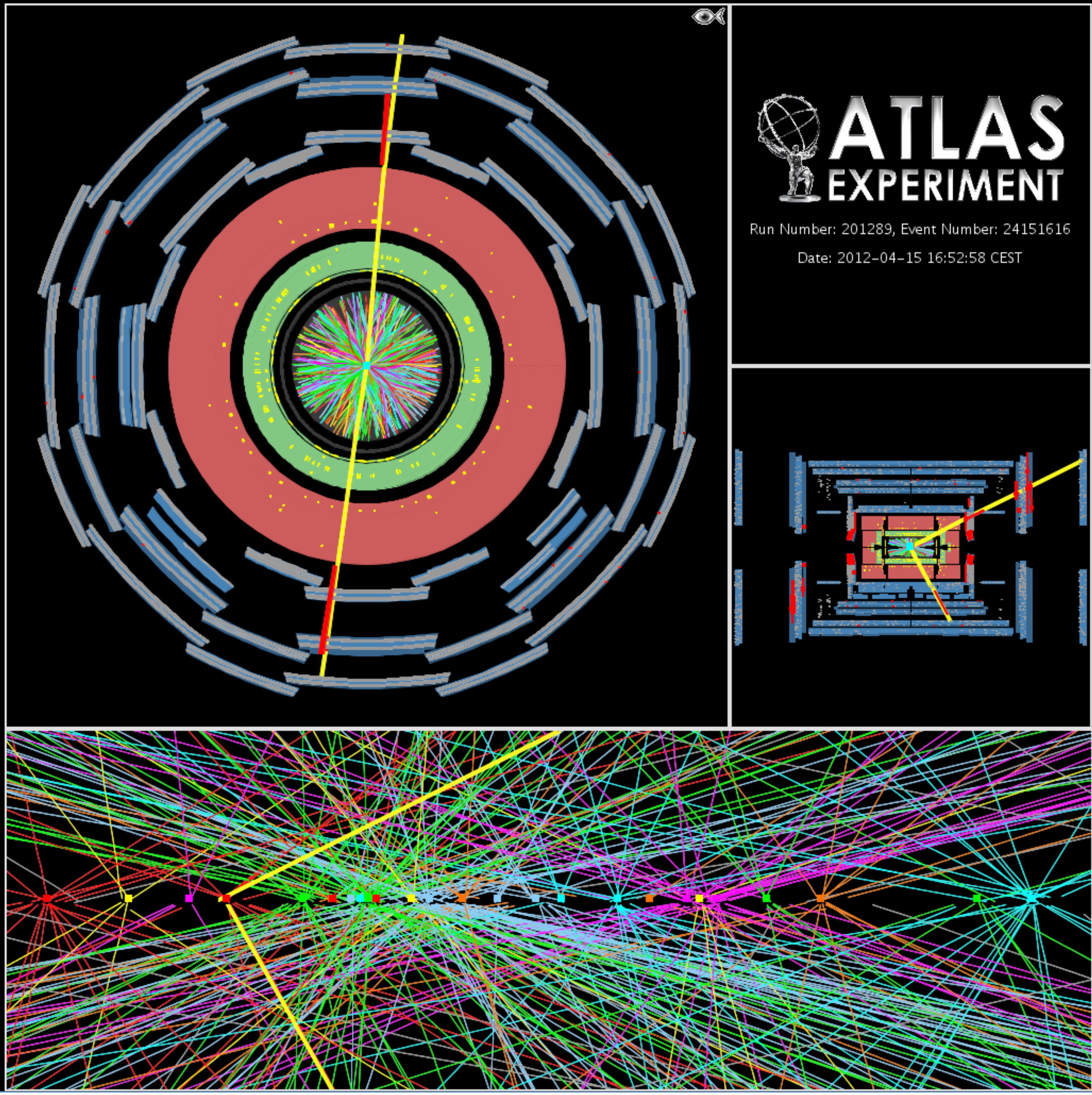
In-time pile-up collisions

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 $Z \rightarrow \mu\mu$ event with 25 reconstructed pile-up vertices



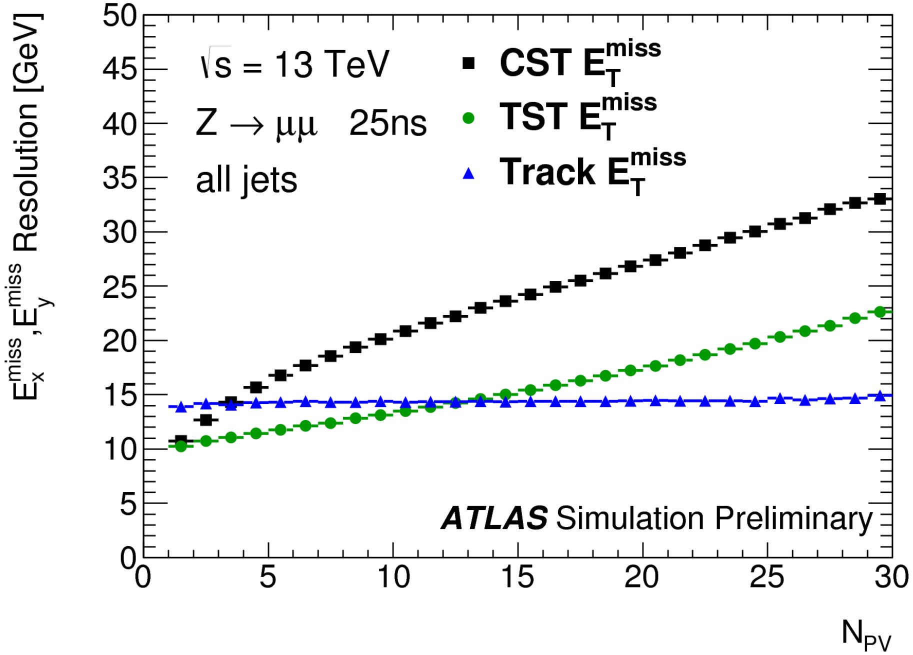
Pile-up effects and mitigation

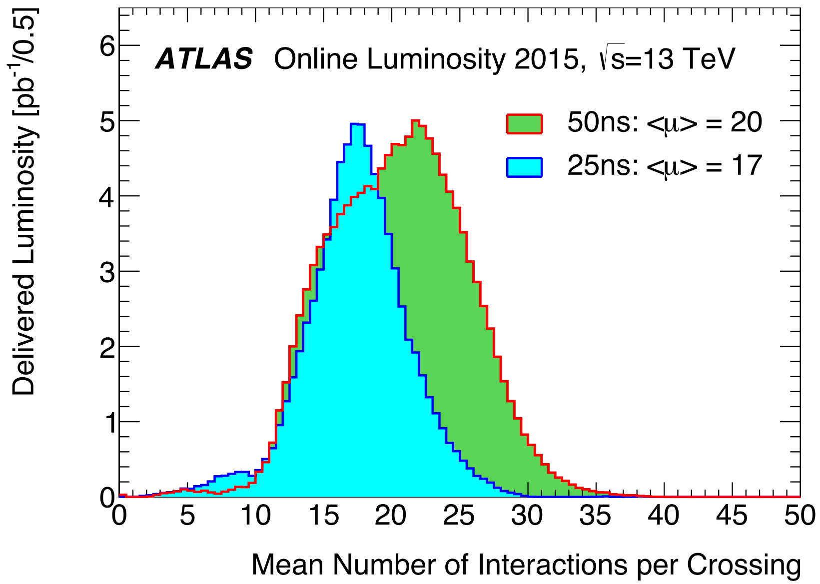
Performances deterioration due to Pile-up present on all reconstructed "objects"

- Calorimetric objects are the most affected
- Particularly important for low energy components
- MET (being a global object) is the most affected

➡

- Same L with x2 bunches (25 ns bunch spacing)
- Use of tracks (PF or sort of)
- Track info at low level of trigger (FTK – Track trigger)





Effective theory

CONTAT INTERACTION

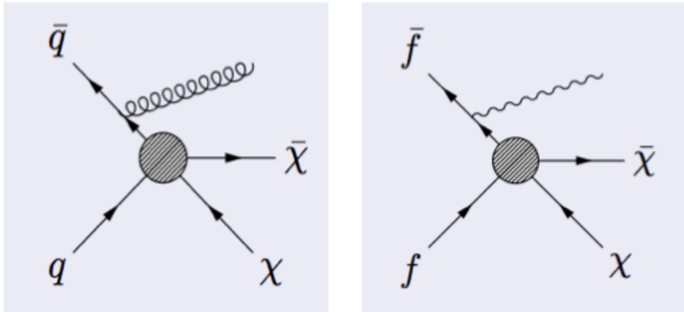
J. Goodman et al., Phys.Rev.D82:116010,2010

(model independent approach)

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

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

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

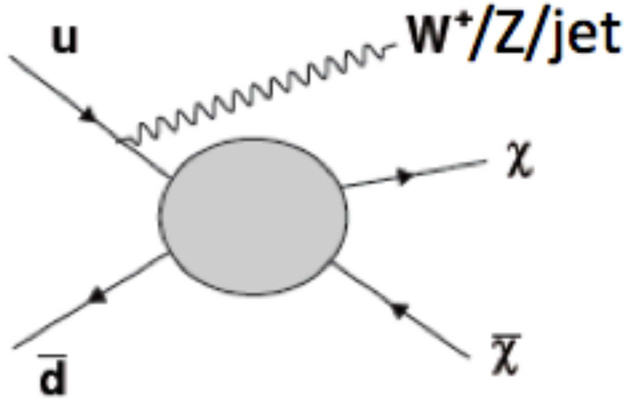
C1	qq	scalar	$\frac{m_q}{M_\star^2}\chi^\dagger\chi\bar{q}q$
C5	gg	scalar	$\frac{1}{4M_\star^2}\chi^\dagger\chi\alpha_s(G^a_{\mu\nu})^2$
D1	qq	scalar	$\frac{m_q}{M_\star^3}\bar{\chi}\chi\bar{q}q$
D5	qq	vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
D8	qq	axial-vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\g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

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

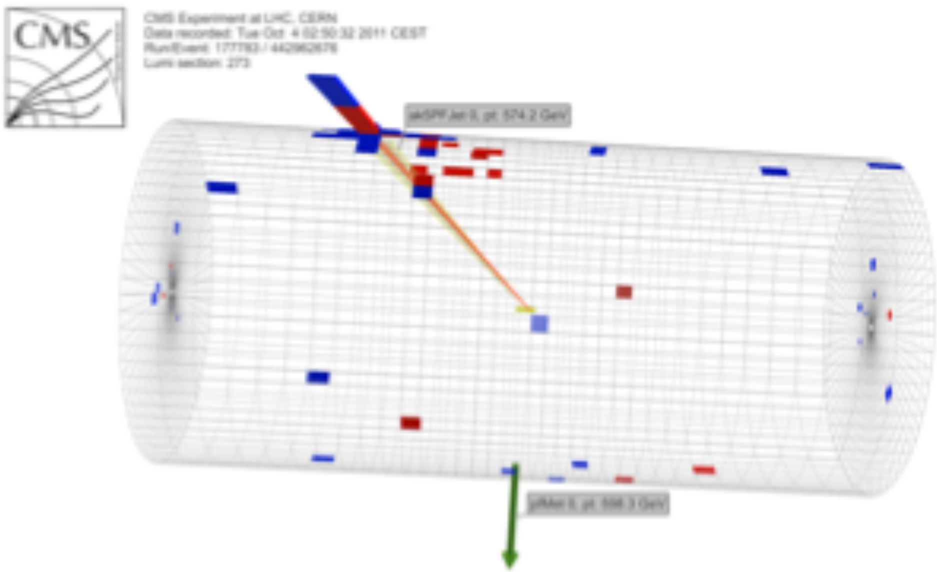
Strictly speaking theory only applicable when M is much larger than the energy scale present in the reaction $[Q^2 << (4\pi M_*)^2\ ,\ m_\chi < 2\pi M_*]$

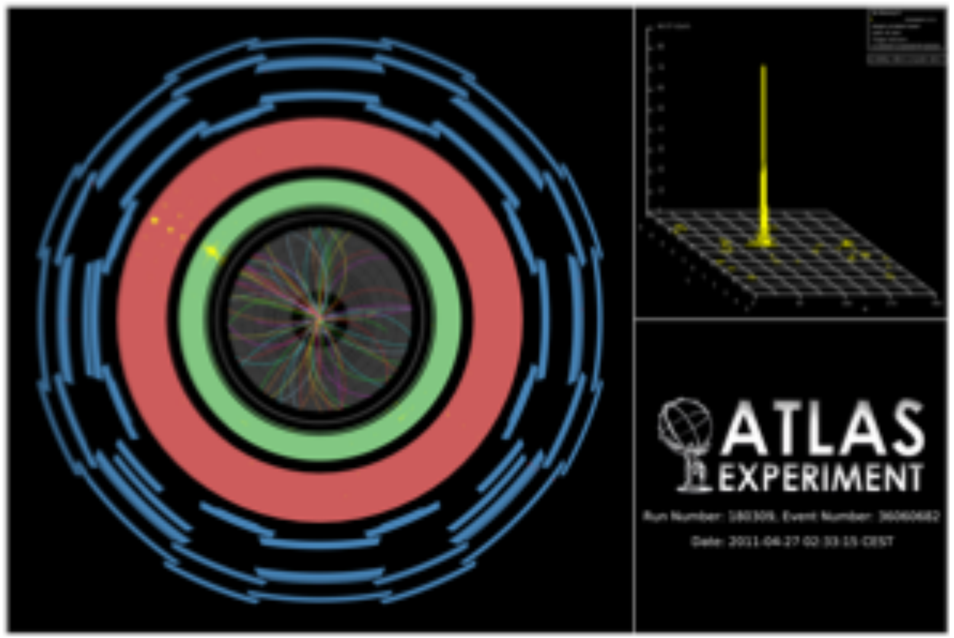
DM Searches: MONO-X



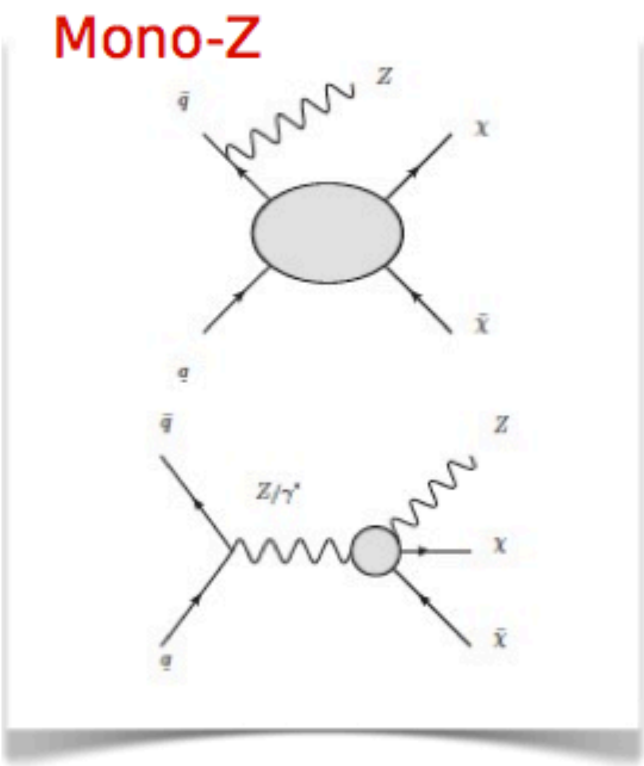
At colliders (LHC) WIMPs can be produced in leading to "nothing to detect" in the final state

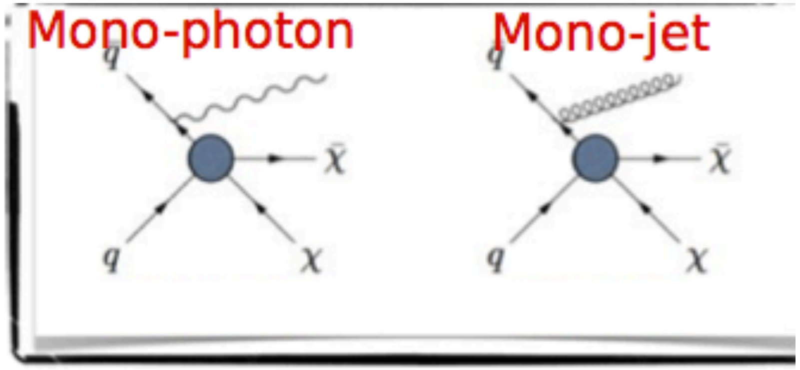
Such events are tagged via the presence of an energetic jet or a photon from initial state radiation

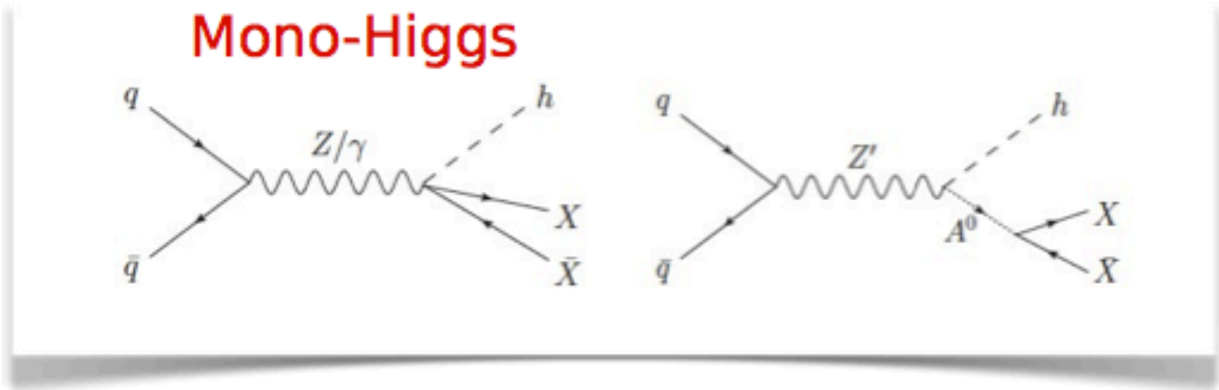


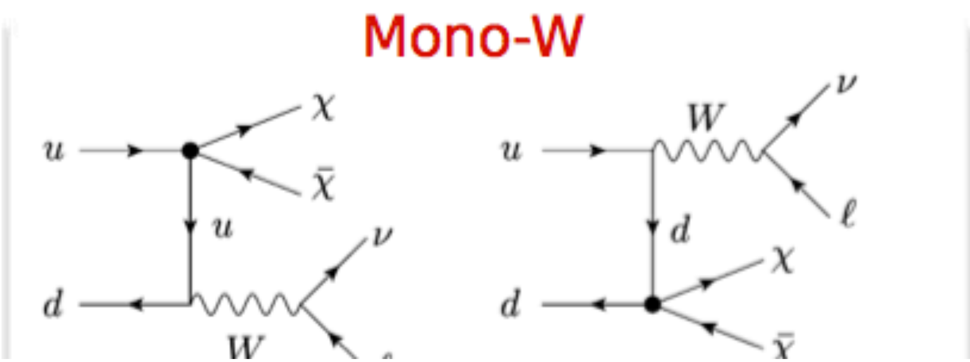


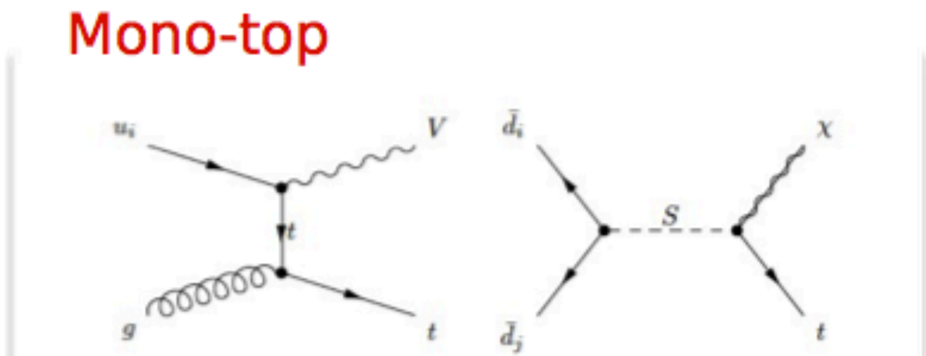
DM Searches: MONO-MANIA @ LHC



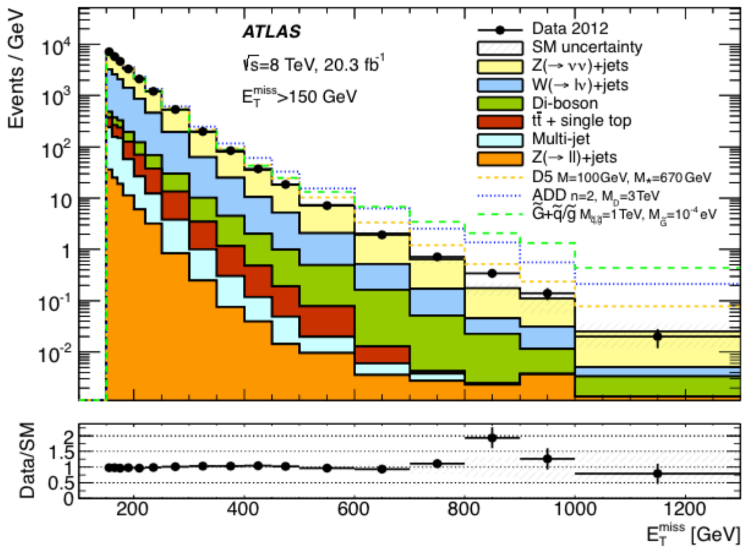






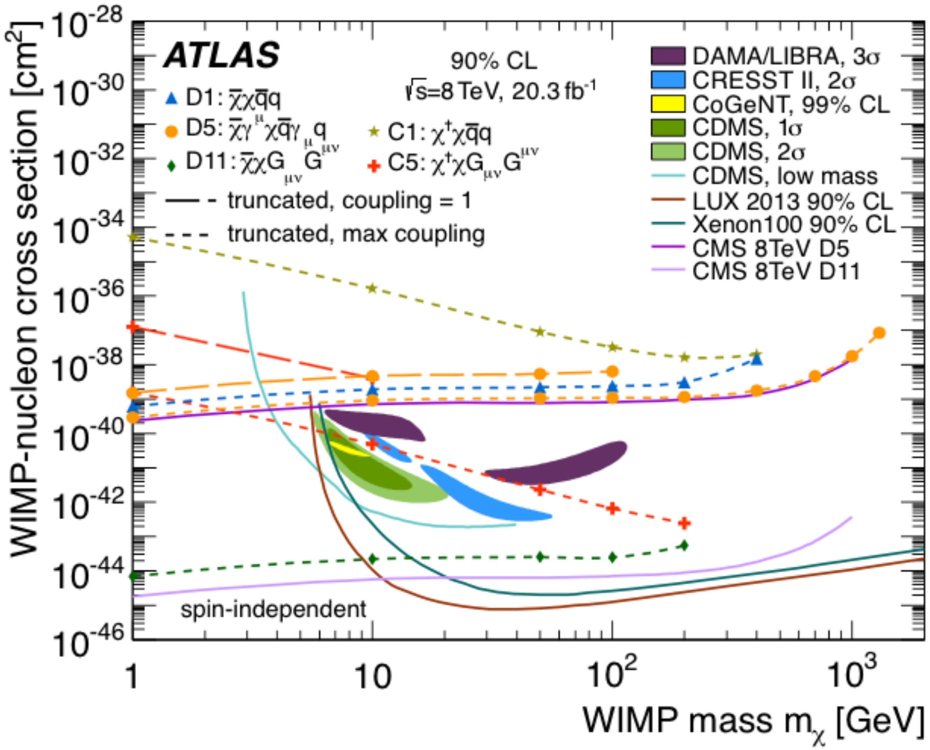


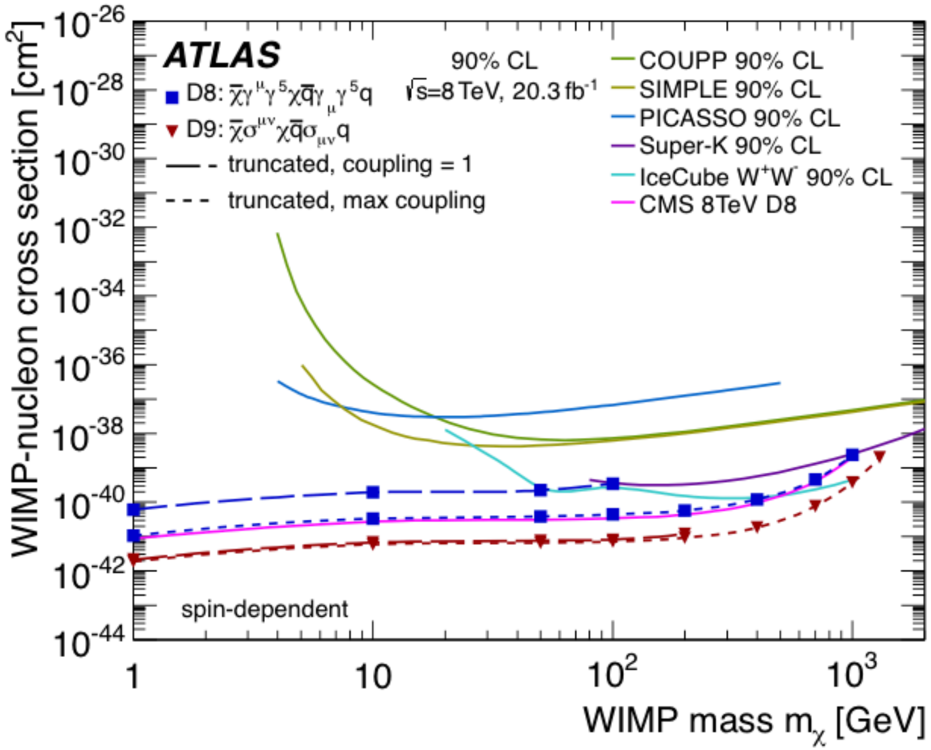
DM Searches: MONO-jet



Basic selection:

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

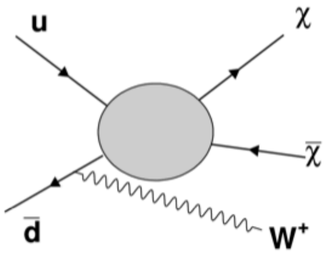


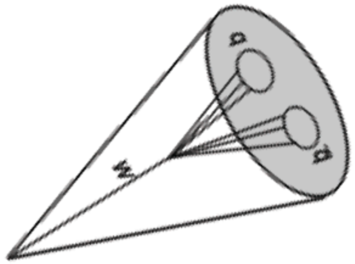


MONO-Z/W

8 TeV

20 fb^{-1}

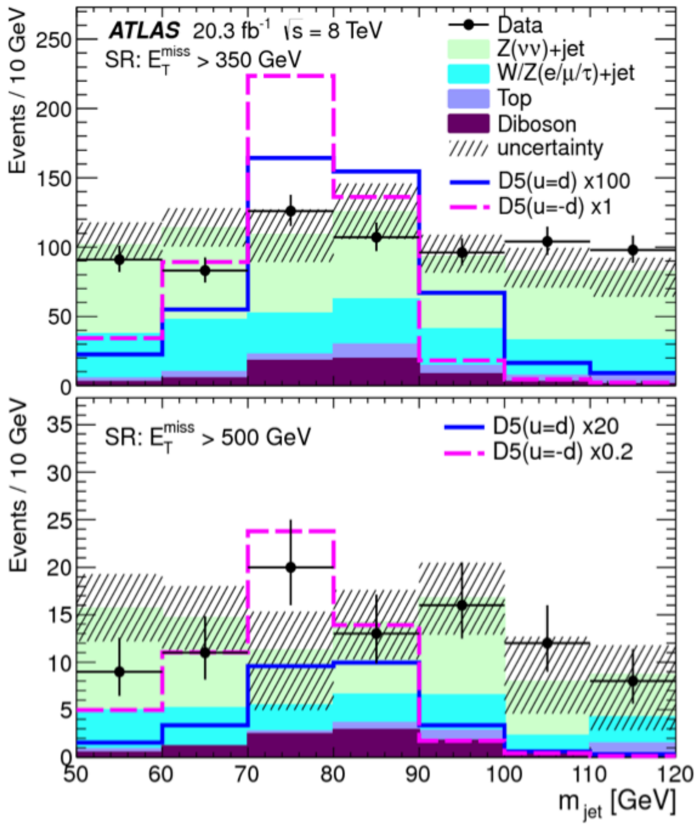


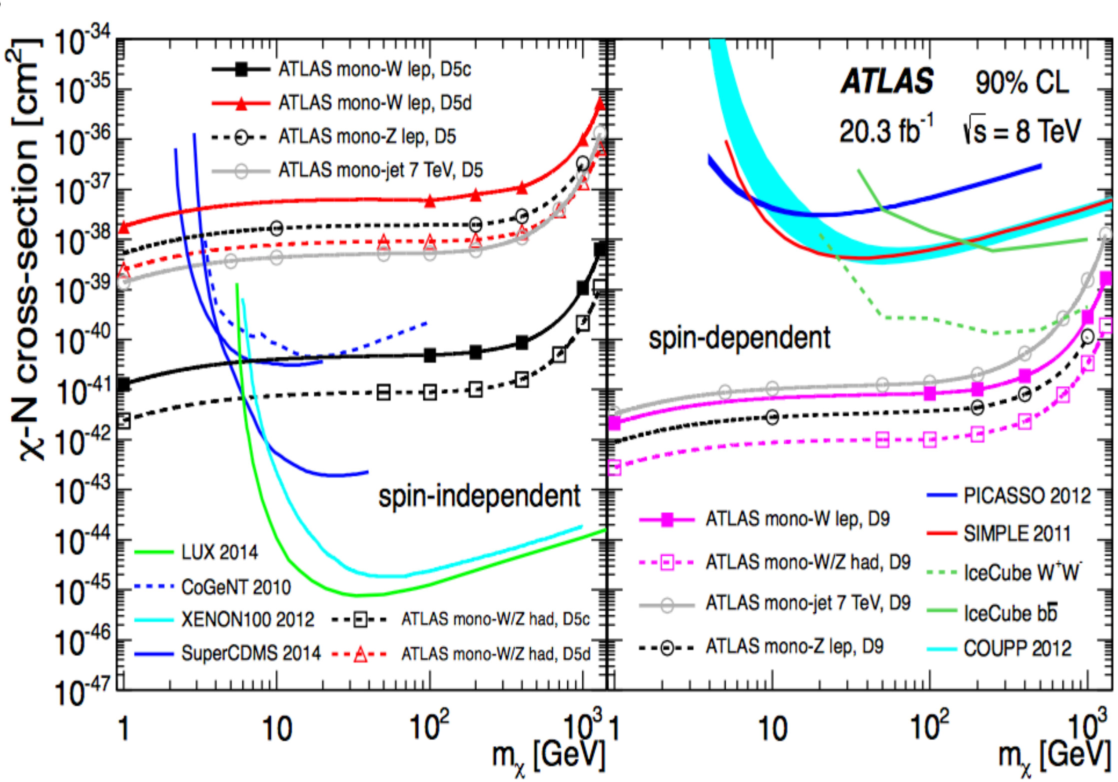


Based on the W/Z hadronic decay products reconstructed as subjets from CA R=1.2 jets

Jet P_t > 250 GeV, $|\eta|$ < 2.1, 50 < M_{jet} < 120 GeV

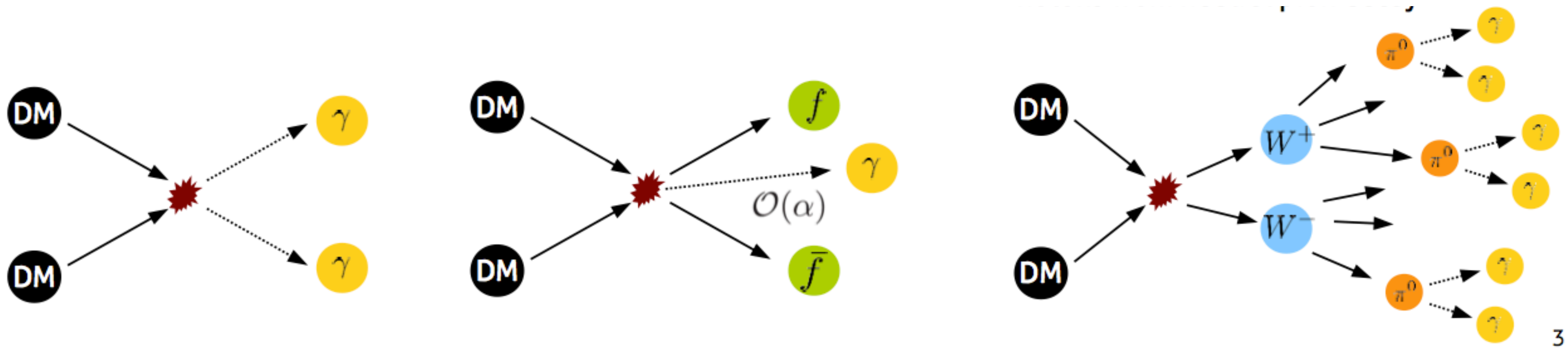
No additional jet (anti-kT 0.4) with p_T > 40 GeV





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



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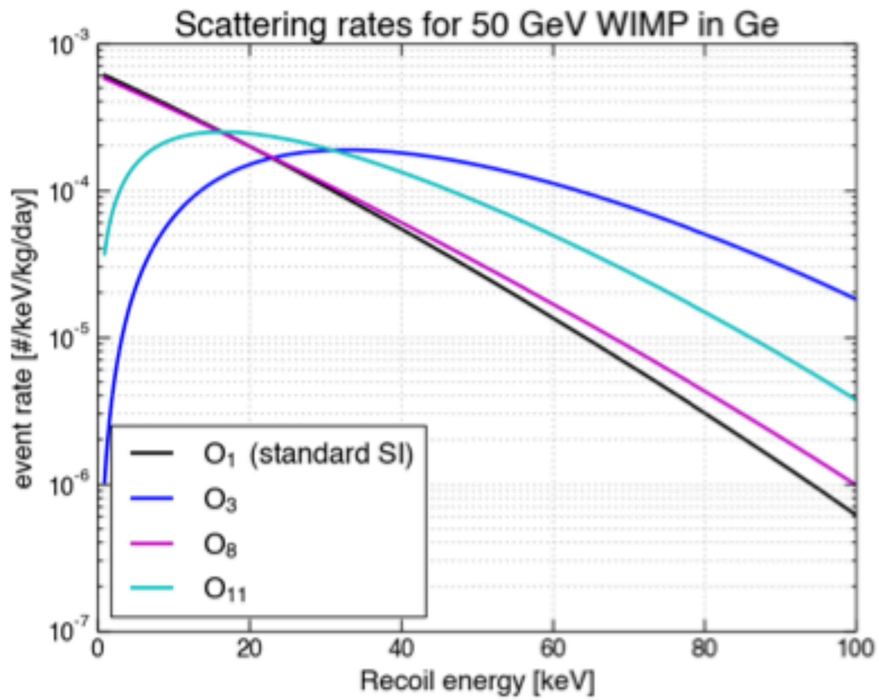
EFT signal in direct detection

- 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

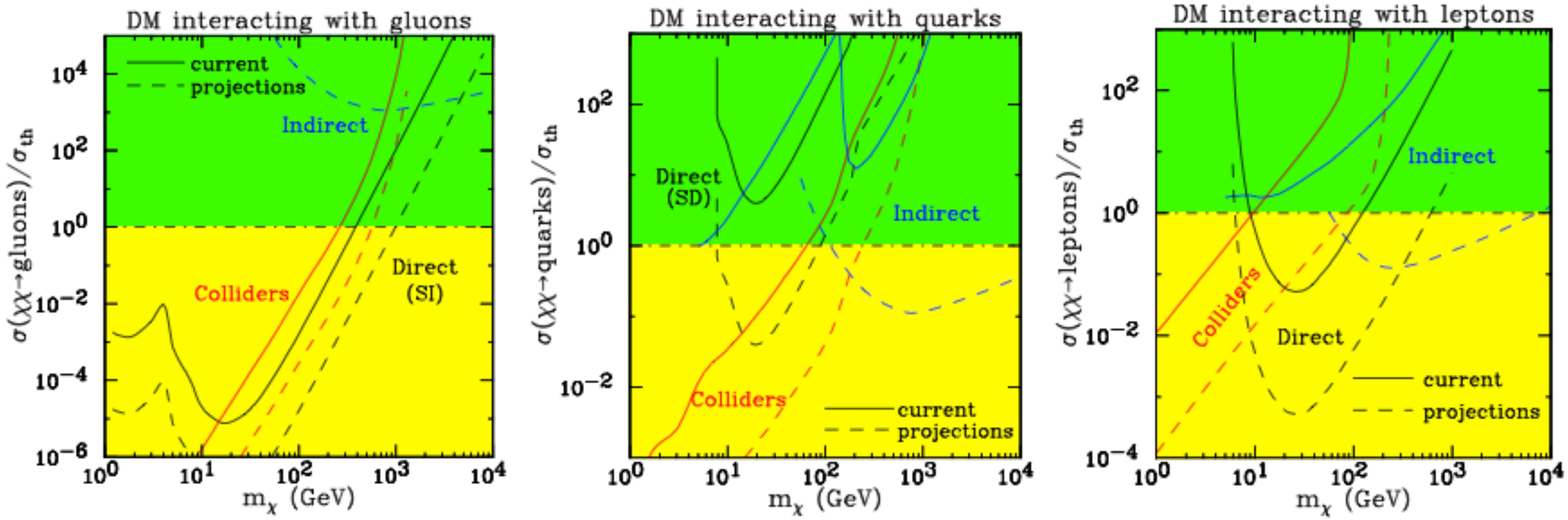


[Kristi Schneck for the SuperCDMS Collaboration @
Effective Theories and Dark Matter 2015, Mainz, Germany
Based on Fitzpatrick, Haxton, et al. arXiv: 1203.3542, 1211.2818, 1308.6288, 1405.6690]

EFT results from all searches:

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

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

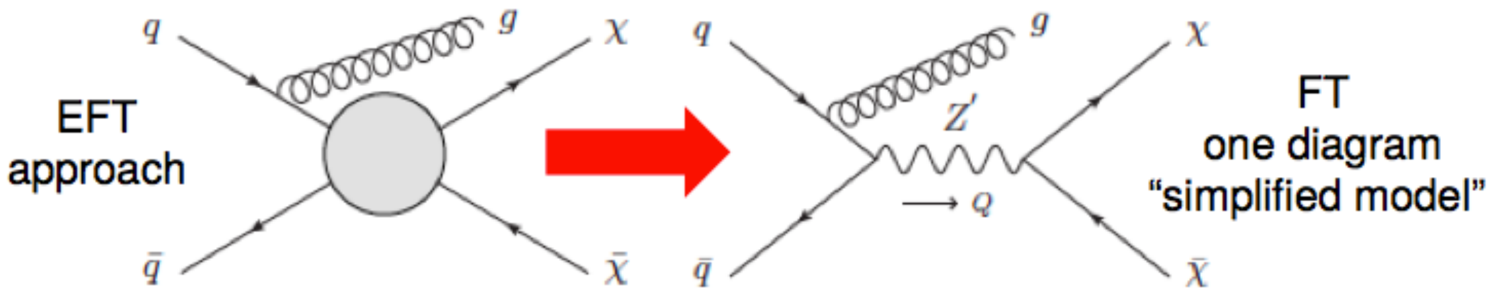


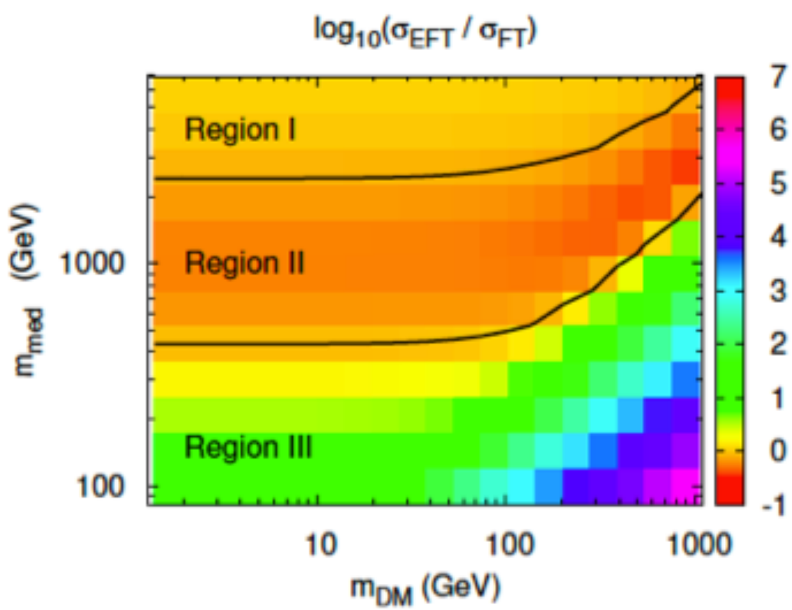
σ_{th} value to provide the observed thermal relic density (σ/σ_{th}=1)

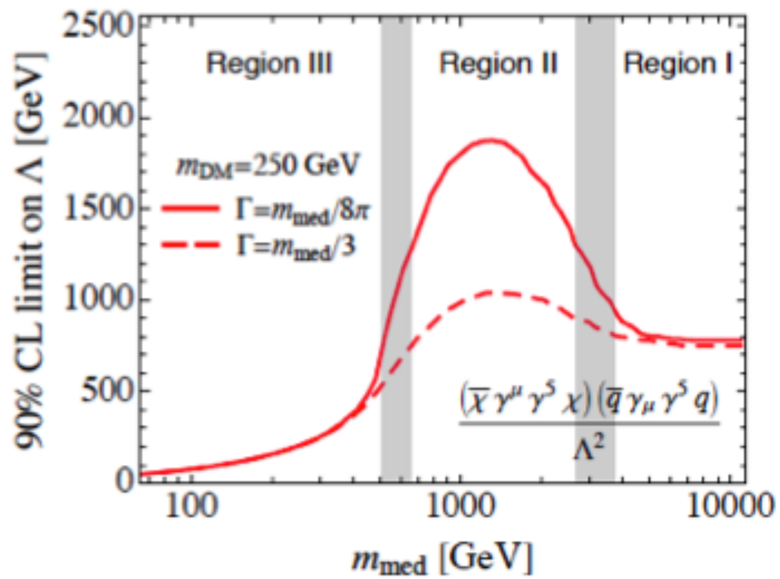
- Very good complementarity:
  - Colliders do better for lighter WIMPs
  - Direct searches do better around 100 GeV
  - indirect detection is more sensitive to heavy WIMPs.

EFT validity: any better simplified models ?

arXiv:1308.6799, arXiV:1407.8257, arXiV:1411.0535, arXiV:1410.6497 arXiv:1603.04156







Region I: Heavy M_{med} EFT is OK

Region II: Medium M_{med} Resonant enhancement EFT limits are too conservative!

Region III: Low M_{med} EFT limits are too aggressive!

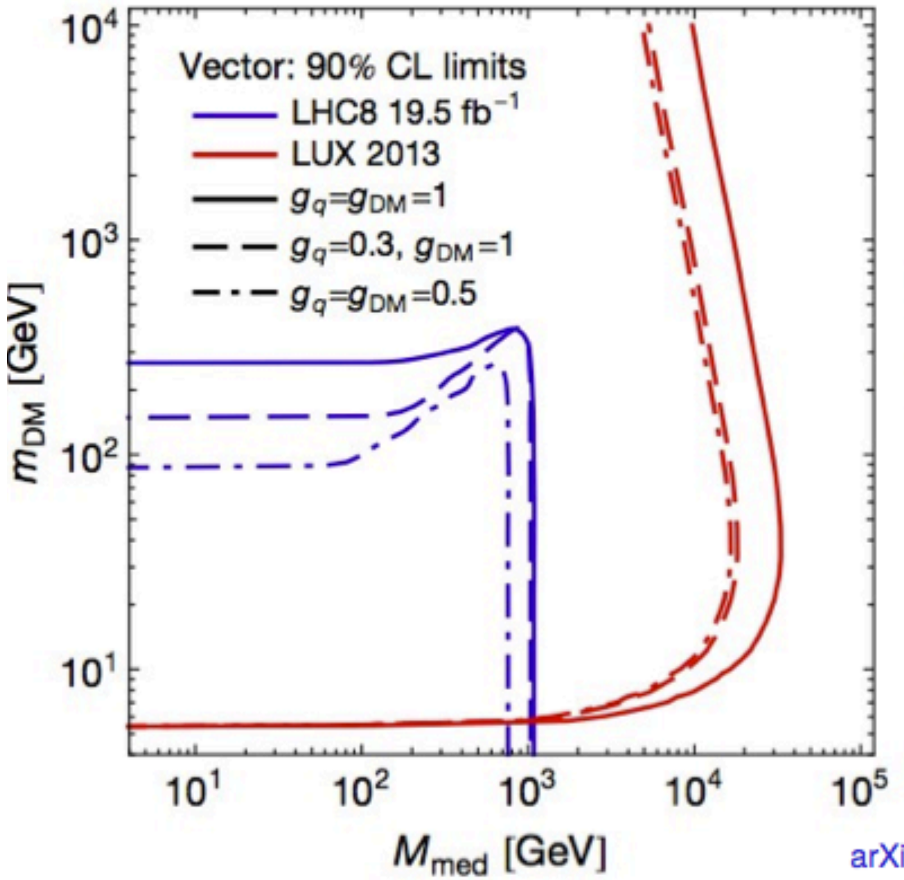
EFT validity: any better simplified models ?

arXiv:1308.6799, arXiV:1407.8257, arXiv:1411.0535, arXiv:1410.6497, arXiv:1603.04156

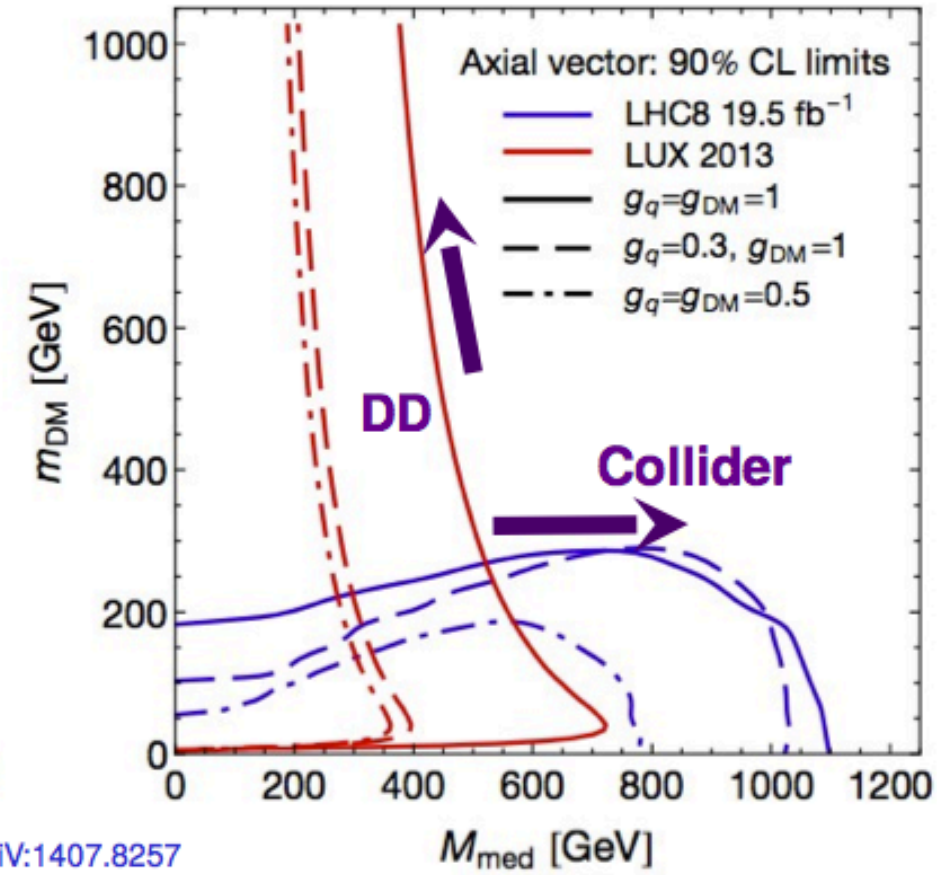
LHC WG created on purpose , arXiv:1603.04156

M_{DM}	M_{med}
g_q	g_{DM}

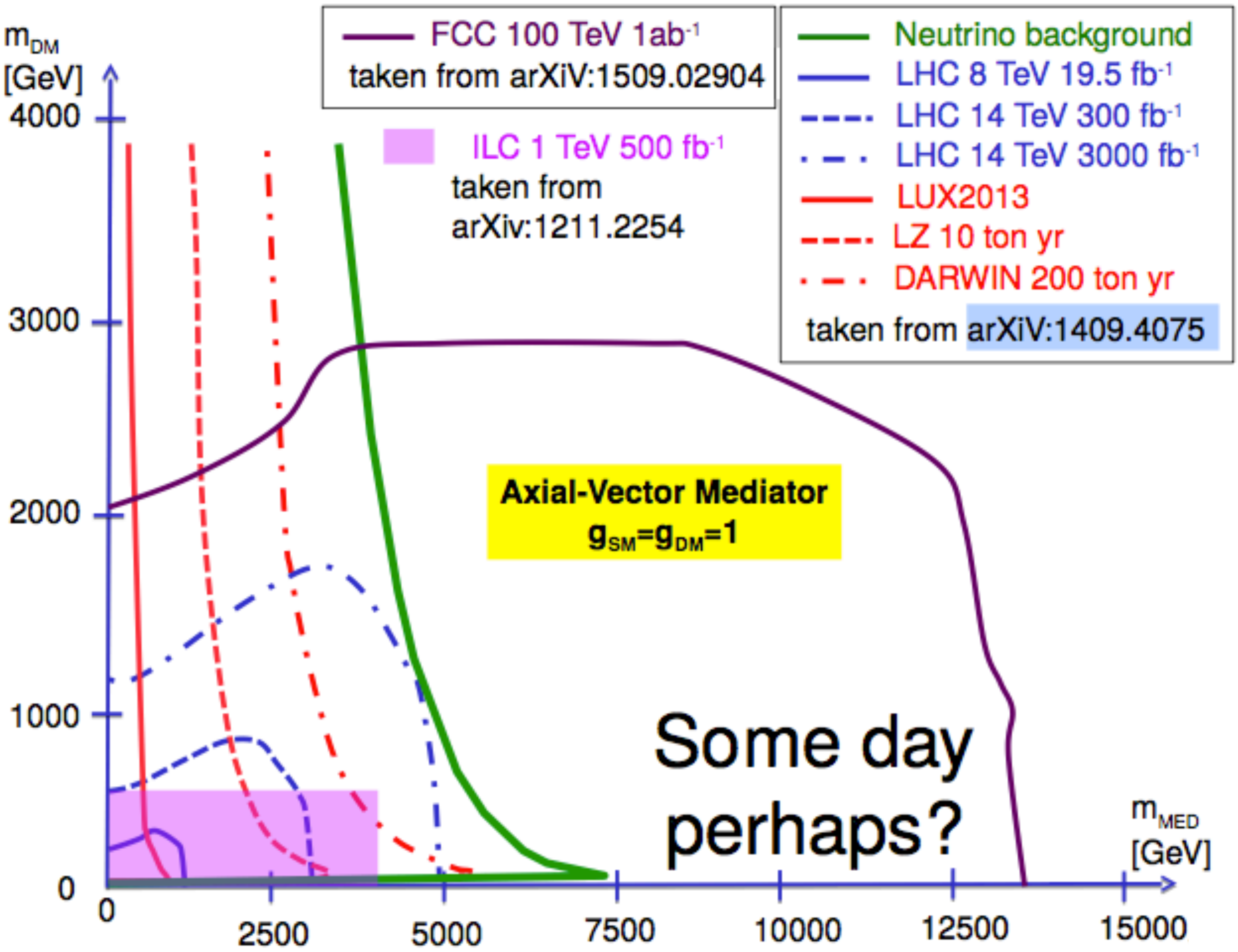
Vector



Axial vector



arXiV:1407.8257

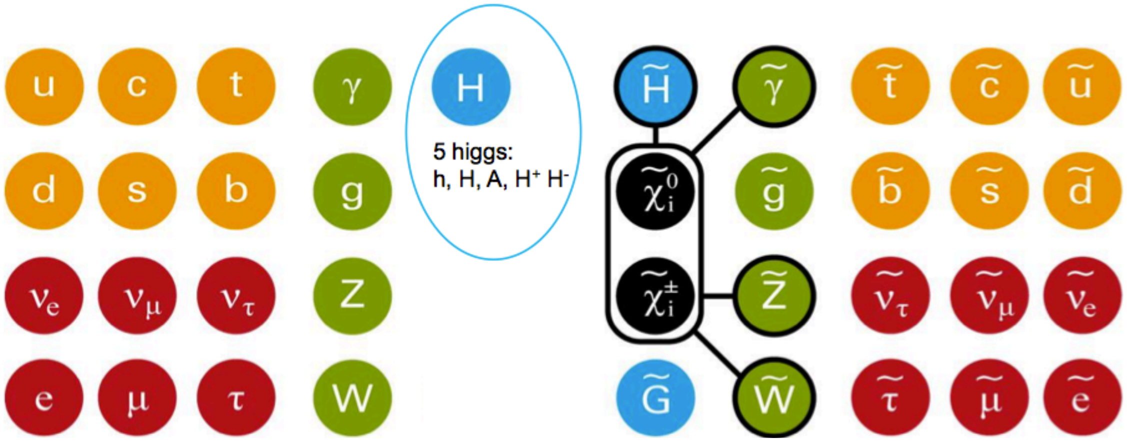


m_{DM} [GeV]
4000
3000
2000
1000
0
FCC 100 TeV 1ab^{-1}
taken from arXiV:1509.02904
ILC 1 TeV 500 fb^{-1}
taken from arXiv:1211.2254
Neutrino background
LHC 8 TeV 19.5 fb^{-1}
LHC 14 TeV 300 fb^{-1}
LHC 14 TeV 3000 fb^{-1}
LUX2013
LZ 10 ton yr
DARWIN 200 ton yr
taken from arXiV:1409.4075
Axial-Vector Mediator
$g_{SM}=g_{DM}=1$
Some day perhaps?
m_{MED} [GeV]
0
2500
5000
7500
10000
12500
15000

SUSY Introduction

MSSM

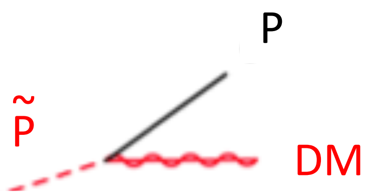
- Still... MSSM offers of a series good answers:
  - Mitigation of fine-tuning/UV sensitivity of the Higgs-mass term ["hierarchy *problem"]*
  - *125 GeV Higgs is consistent with the MSSM max allowed expectation values*
  - Easier gauge coupling unification (more degrees of freedom)[hint *of unification?*]
  - 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

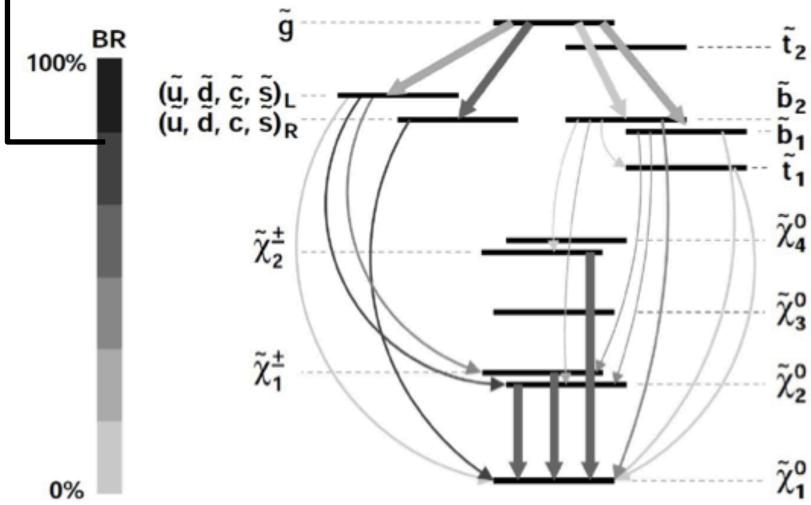


  - SUSY particles are pair produced
  - Typical signature is Missing Transverse Energy

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

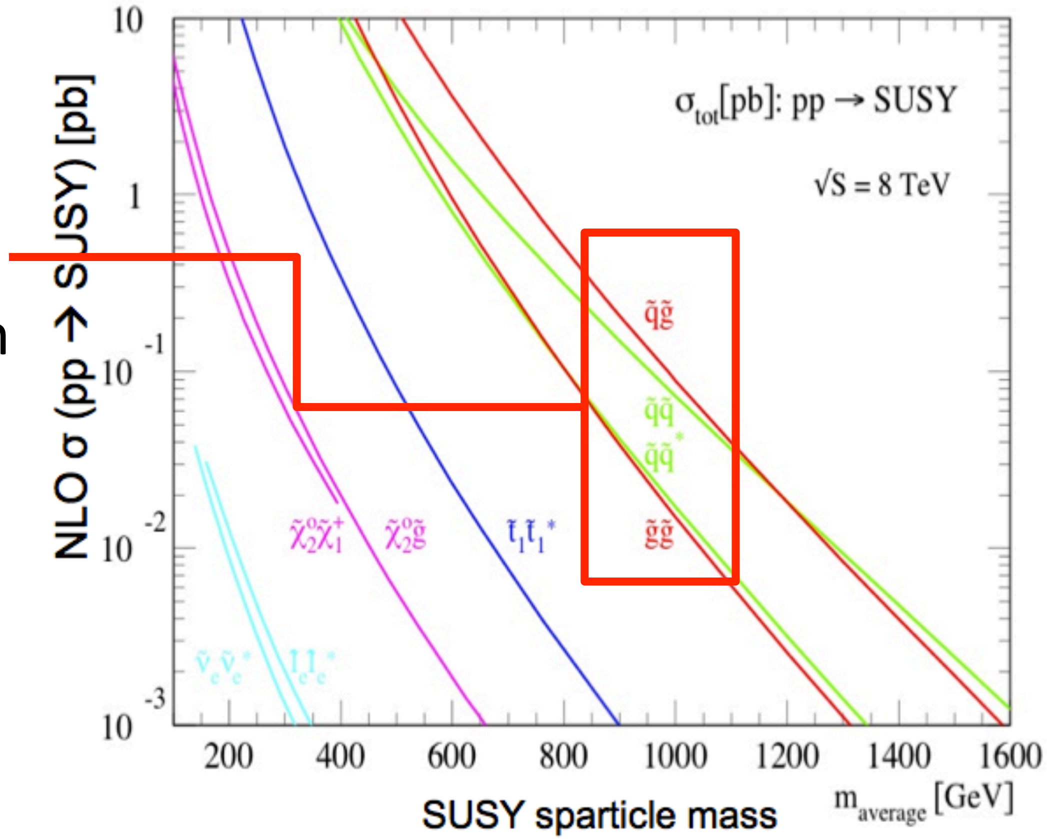


[Djouadi et al., hep-ph/9901246]

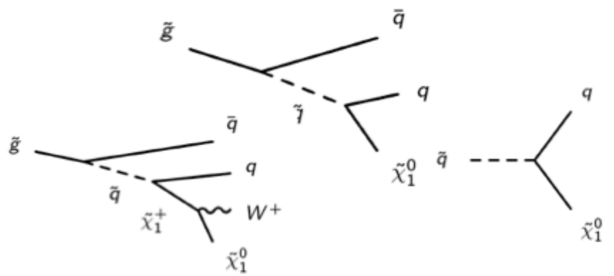
10 sfermion masses, 3 gaugino masses 3trilinearcouplings, 3 Higgs/Higgsino parameters.

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



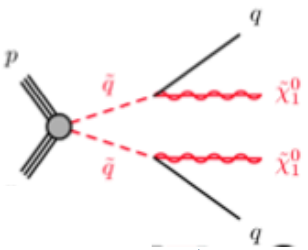
- Start with inclusive searches for production of gluino and squarks via strong interaction
- final states depend on the decays of squark/gluino: jets + ETmiss + leptons



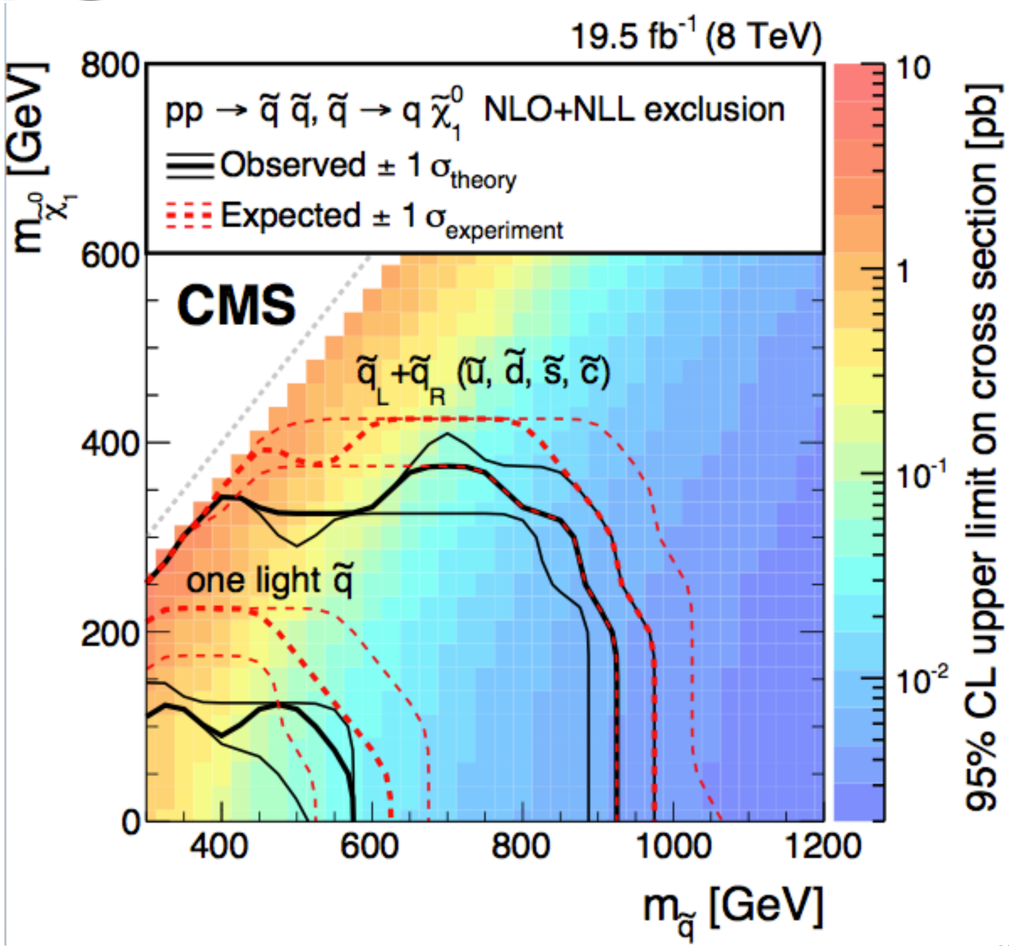
Squark Gluino searches: simplified model

Squark production

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



- 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



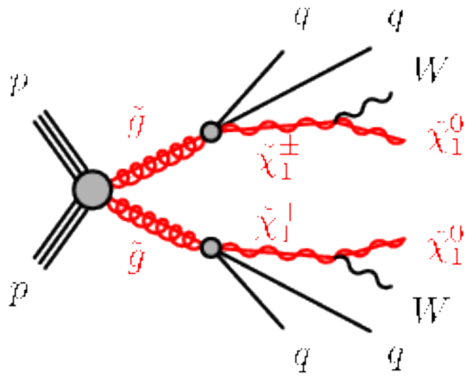
MSUGRA: search strategy

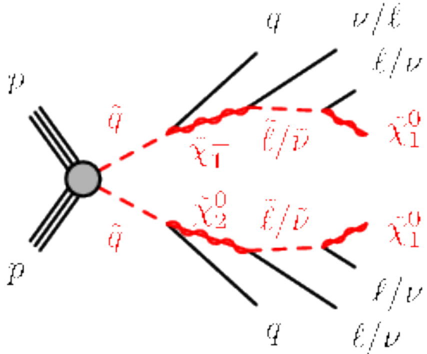
- Many final states are searched for
  - Jet rich signatures

  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

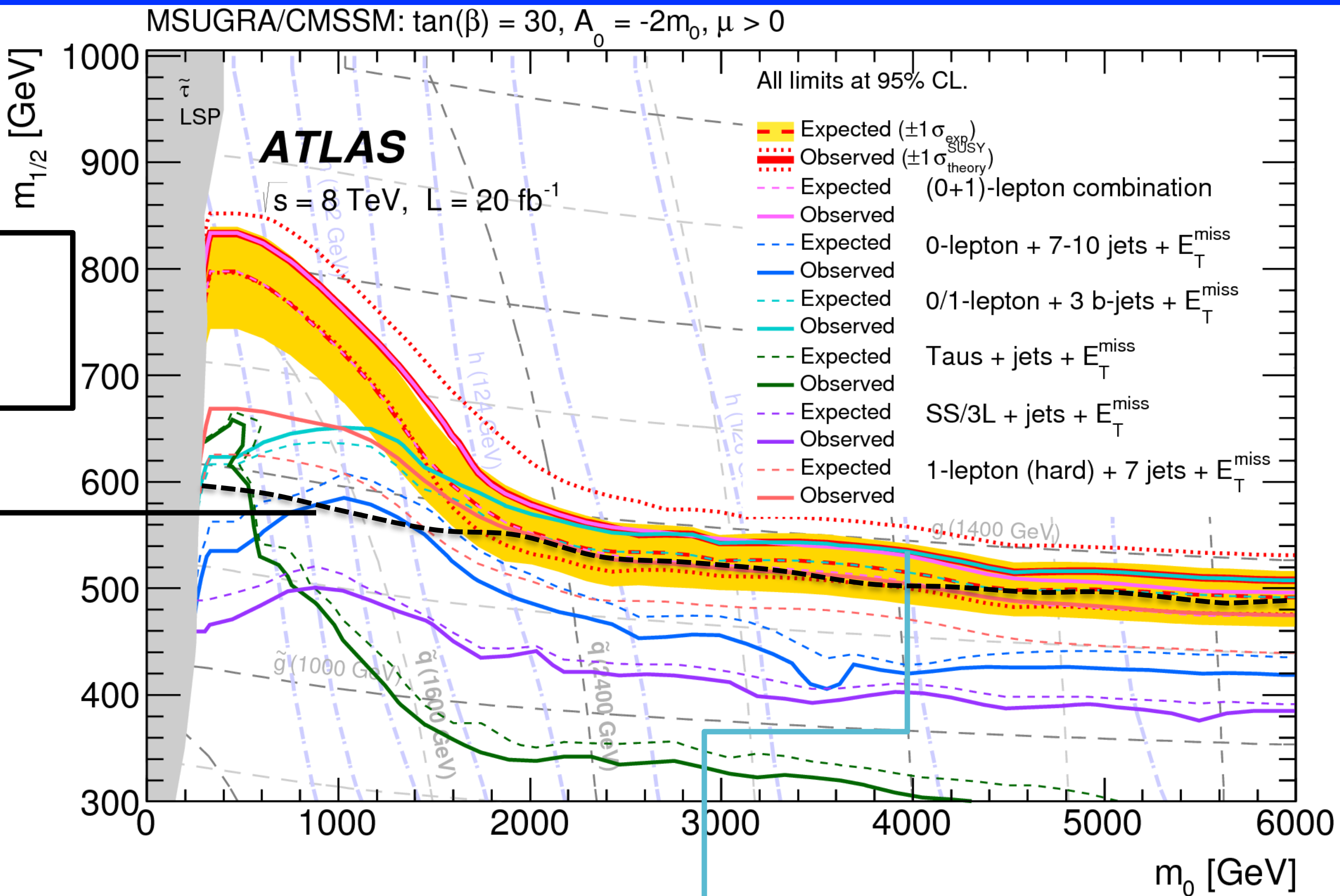
  -3rd generation squarks often decoupled

- 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

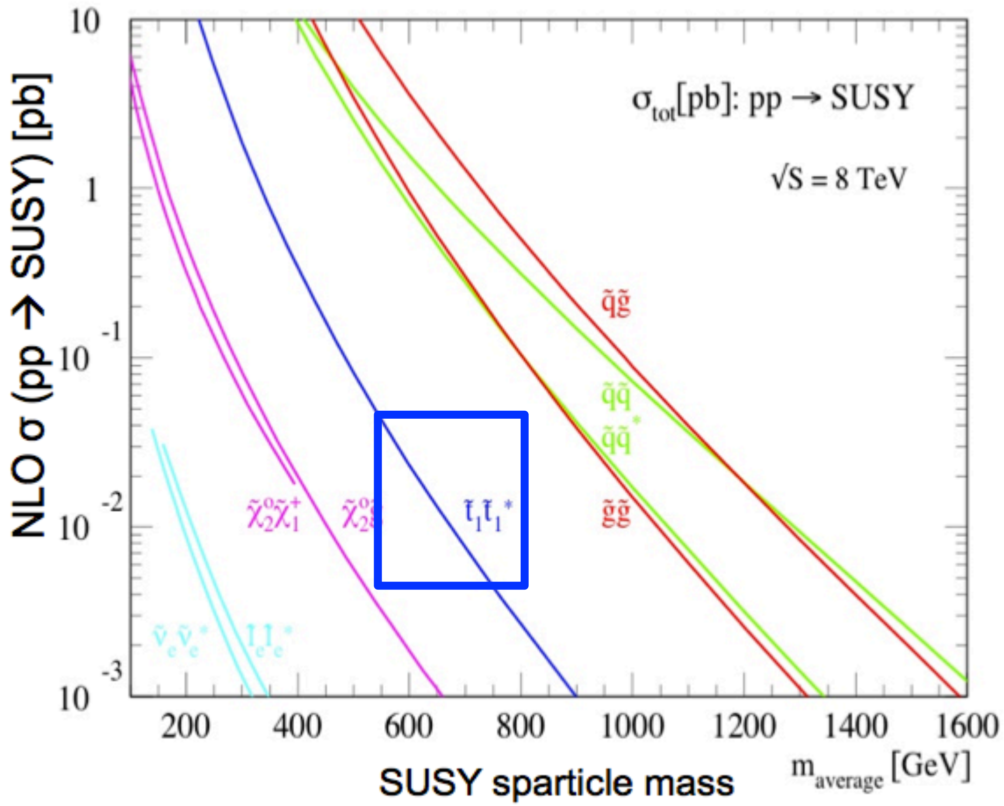


1.3 TeV gluinos excluded for any squark mass

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

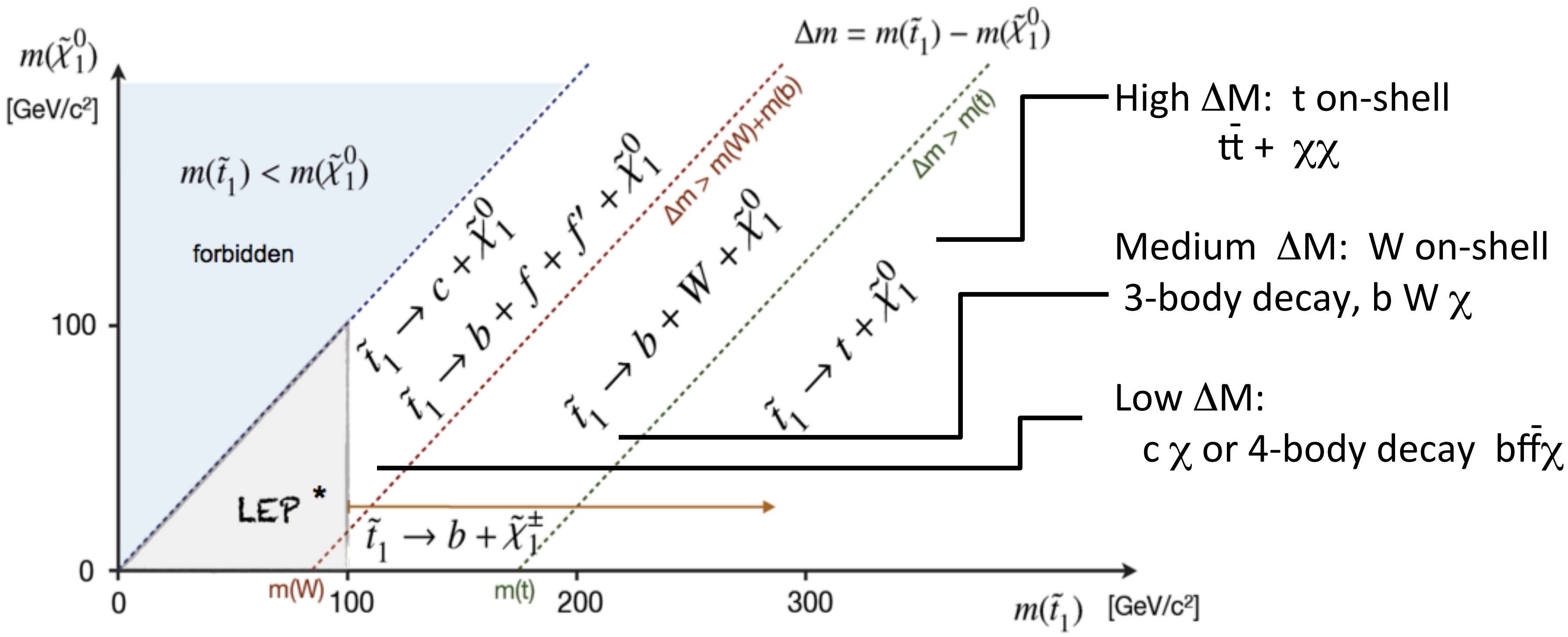
"Natural" SUSY searches

- 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

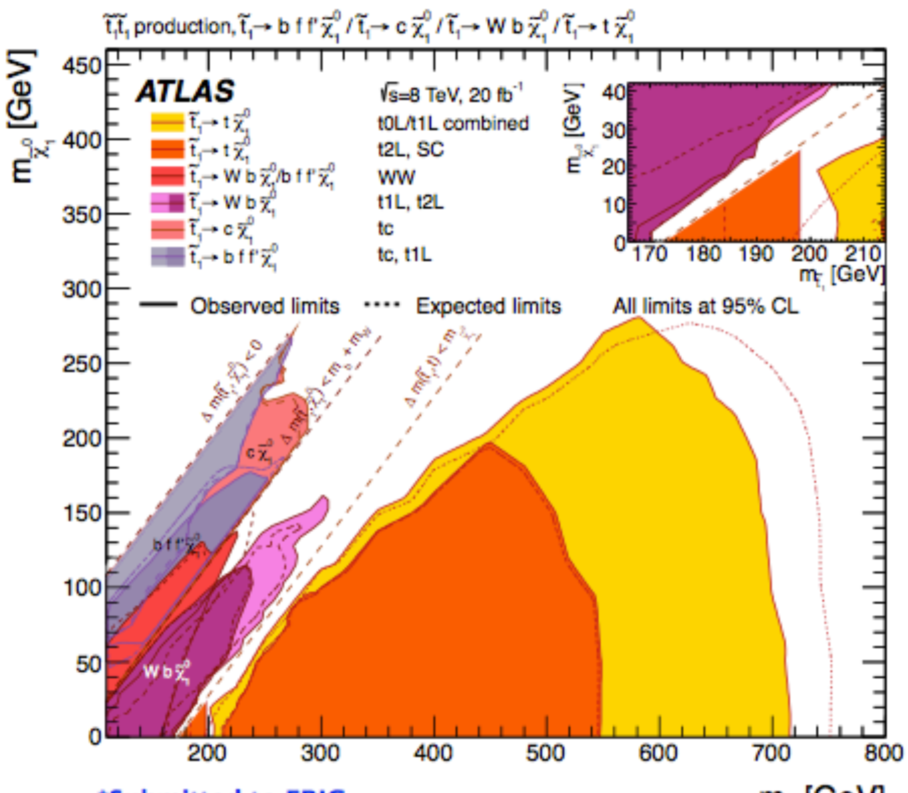


"Natural" SUSY searches

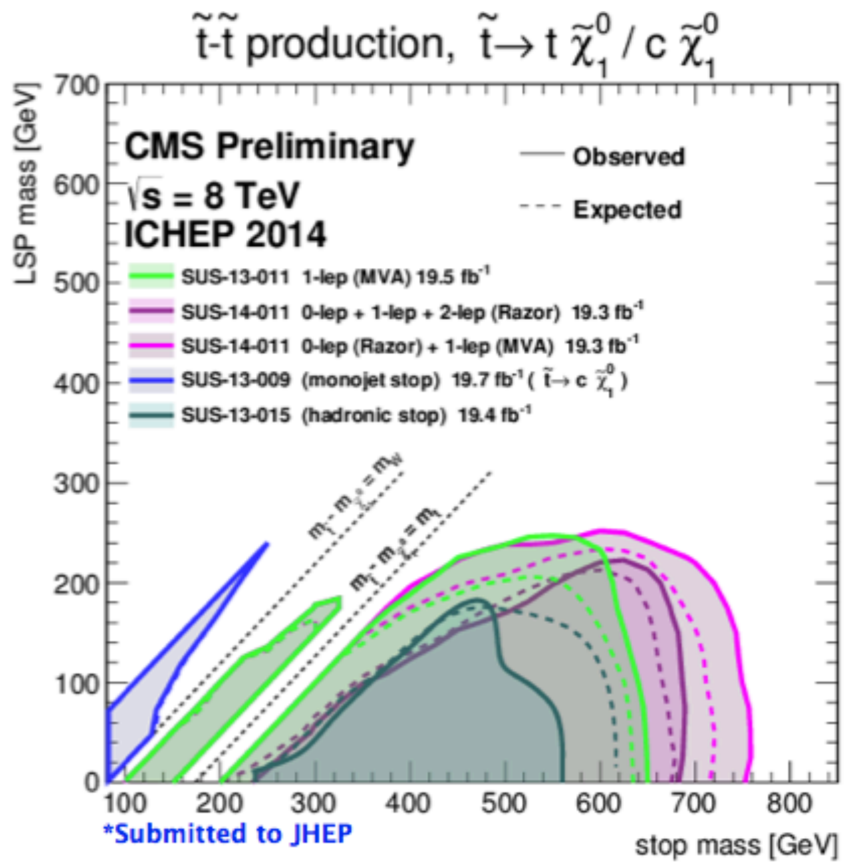
- Only need light $\tilde{t}/\tilde{b}$ to cancel quadratic divergences corrections *to* m_H
- Assume other SUSY particles to be heavier but χ and $\chi^{\pm}$ eventually
- Consistent with higgs mass value and large mixing in the $\tilde{t}$ sector
- Signatures: $\tilde{t} - \chi$ mass plane



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



*Submitted to EPJC

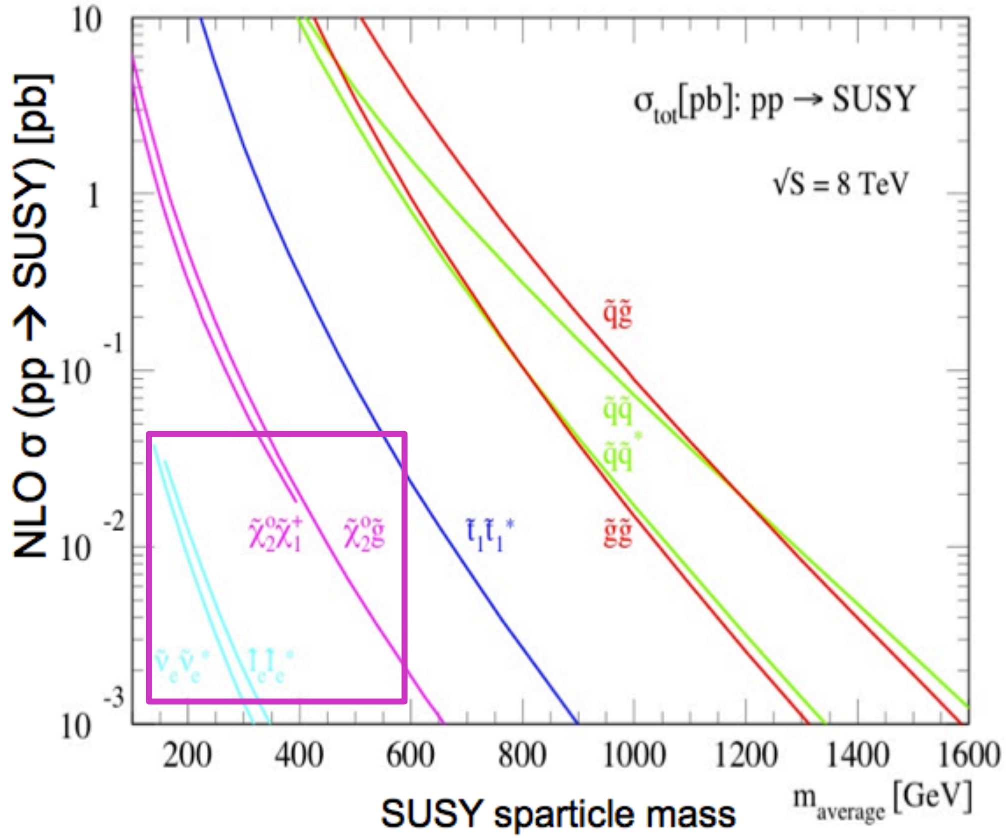


*Submitted to JHEP

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

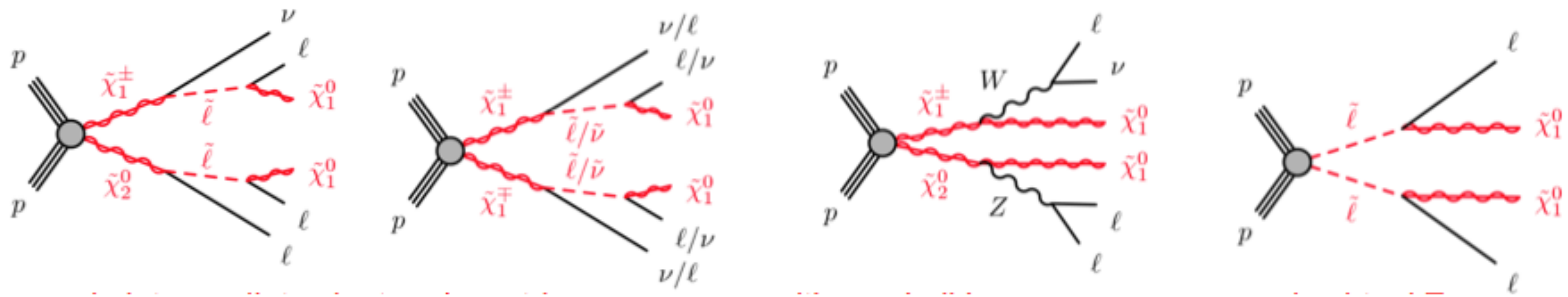
EW SUSY production

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



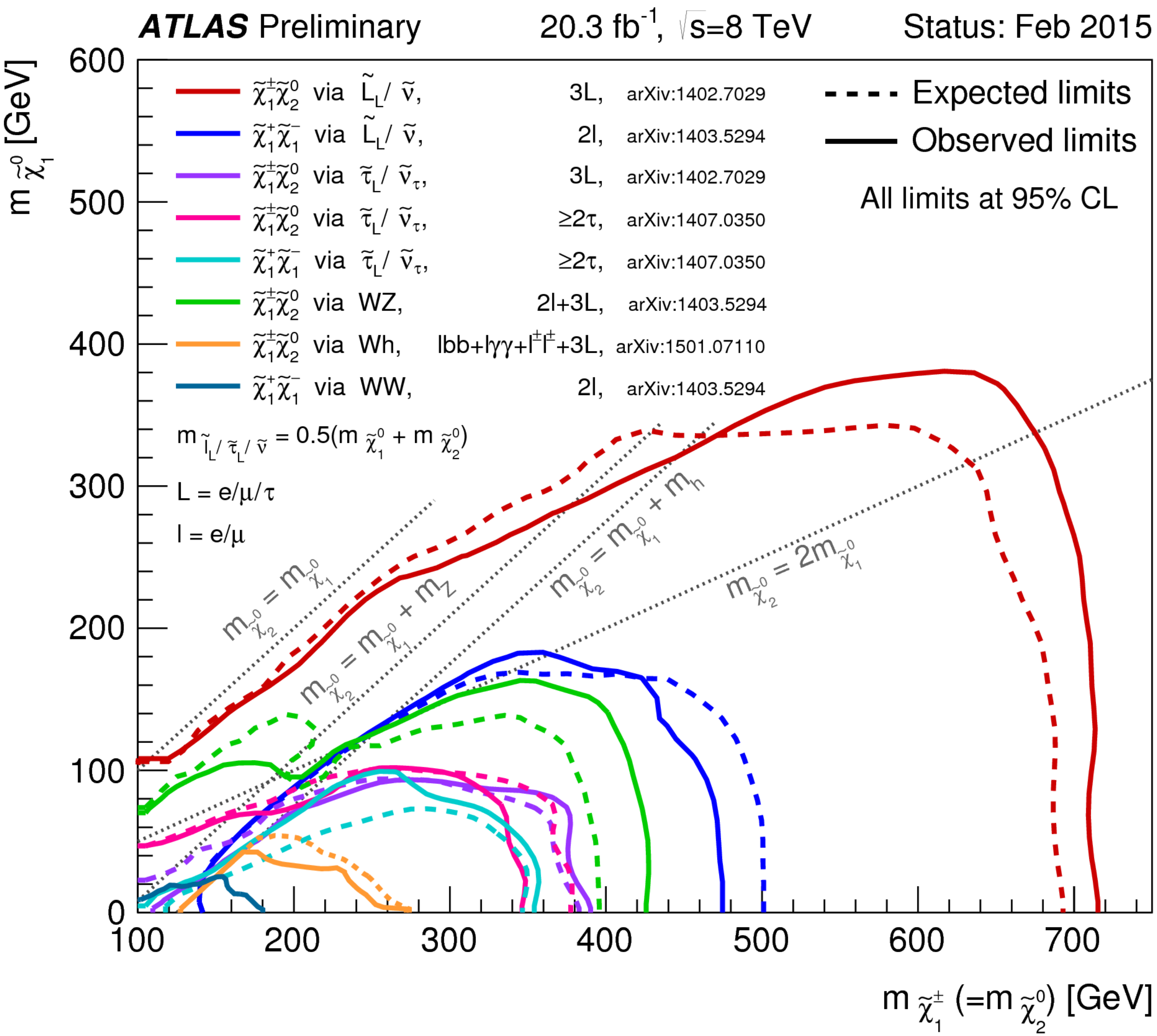
EW SUSY production

- 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

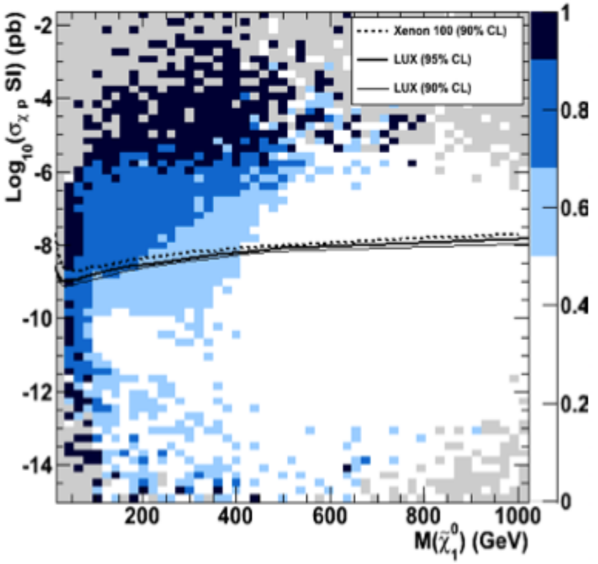
χ±/χ Exclusion plots

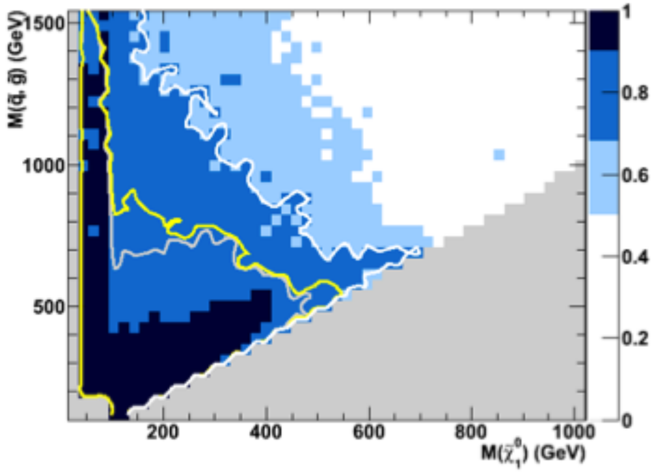


MONO-X and SUSY Searches get together

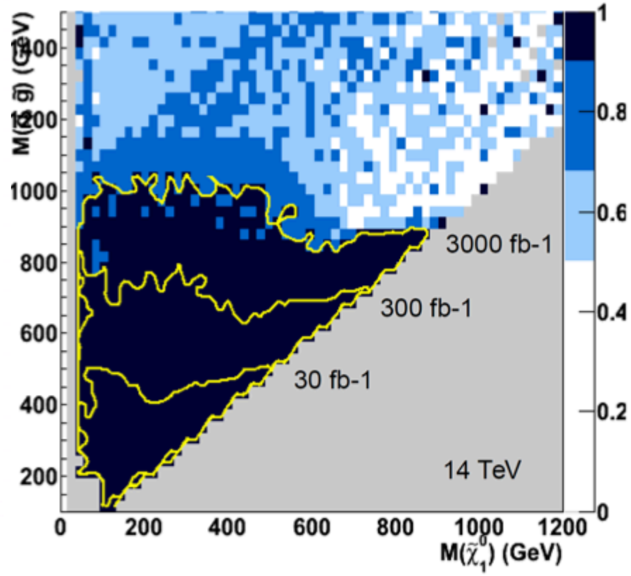
pMSSM framework

Expected sensitivity at next LHC 14 TeV





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

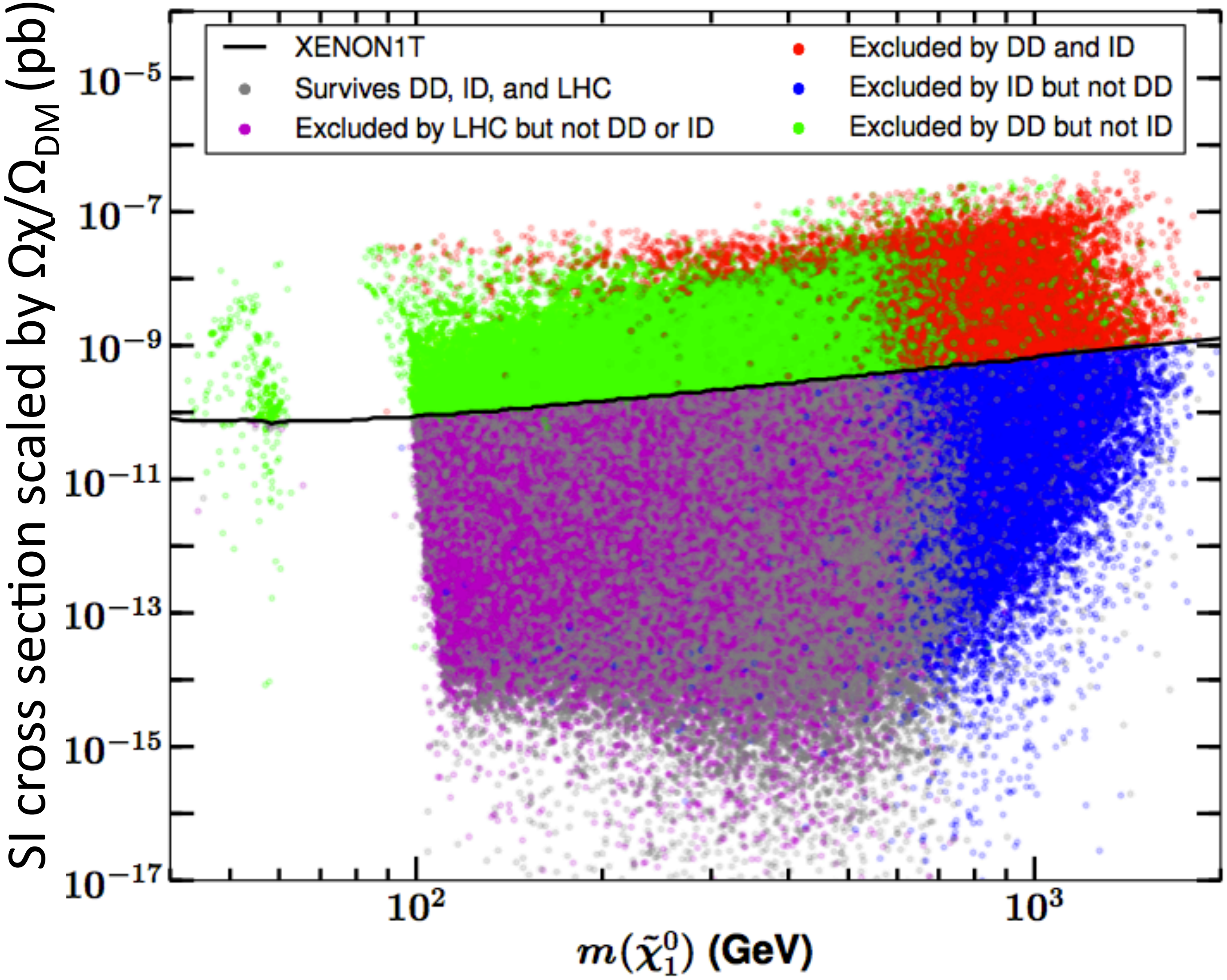


Color scale: fraction of points excluded by jets/leptons+MET searches, monojet analyses and LUX direct DM search

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

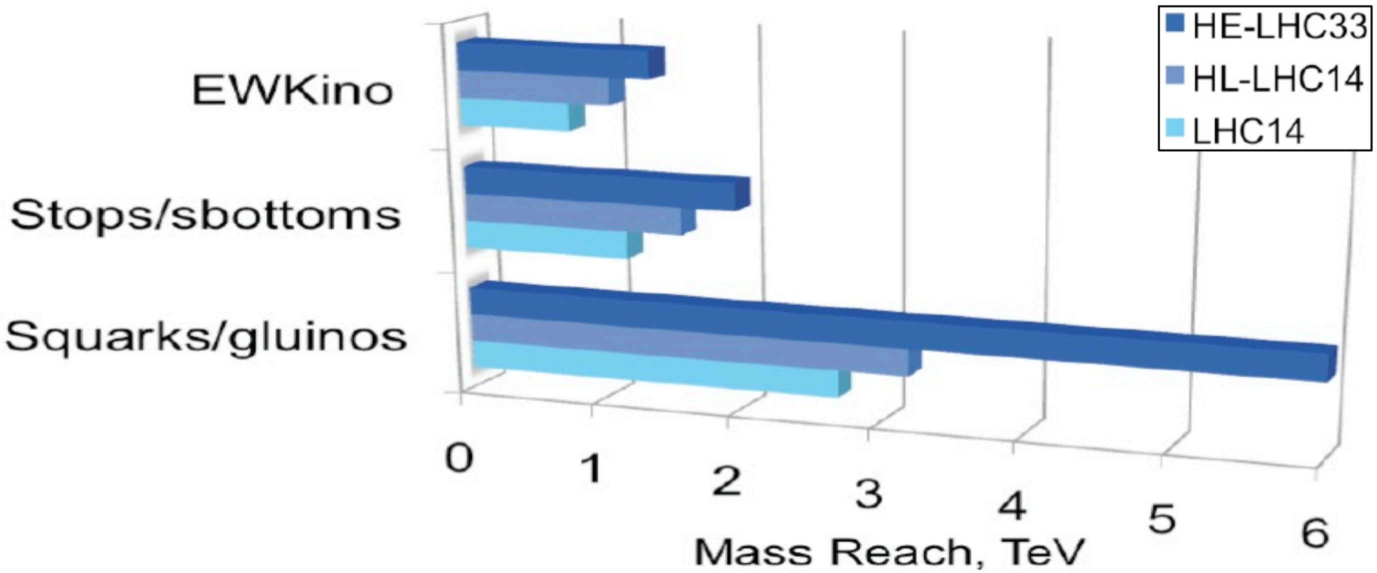


225K models

$m_{\tilde{L}(e)_{1,2,3}}$	100GeV – 4TeV
$m_{\tilde{Q}(q)_{1,2}}$	400GeV – 4TeV
$m_{\tilde{Q}(q)_3}$	200GeV – 4TeV
$\lvert M_1\rvert$	50GeV – 4TeV
$\lvert M_2\rvert$	100GeV – 4TeV
$\lvert\mu\rvert$	100GeV – 4TeV
M_3	400GeV – 4TeV
$\lvert A_{t,b,\tau}\rvert$	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



- Take-home (simplified) messages :
  - Absence of discovery at LHC-13 wipes out SUSY below ~1 TeV
    - And below several TeV for non-SUSY New Physics
  - No excess at LHC-13 makes a discovery quite unlikely at HL-LHC
  - Energy does better than luminosity for direct search for New Physics

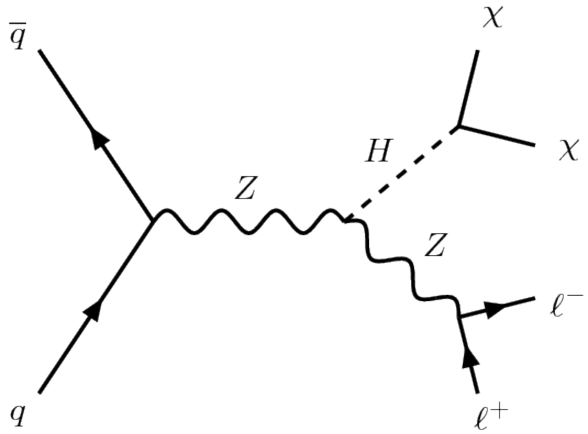
Conclusion

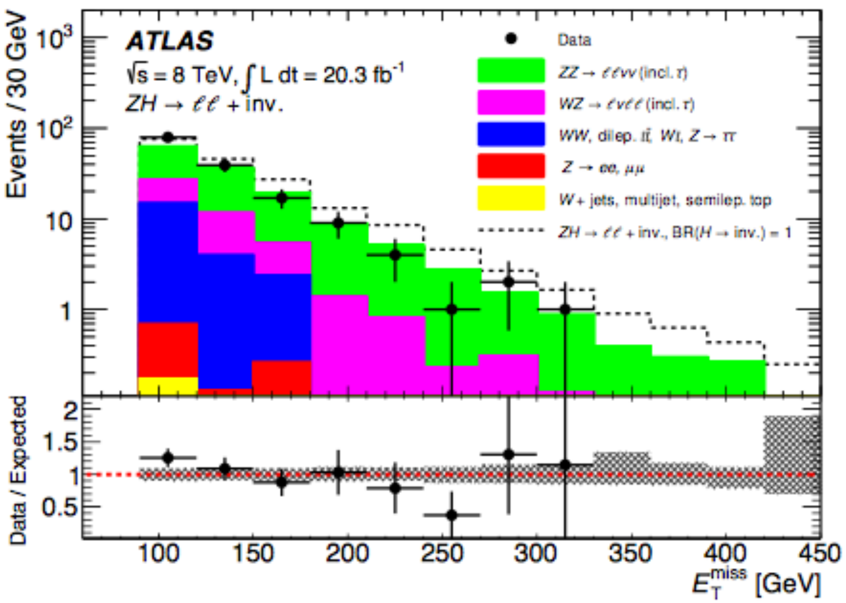
- Extensive search for DM have been performed at LHC: huge amount different signatures from many scenarios covered
- Severe upper limits DM production cross section and lower limits on mass of SUSY particles
- Models parameter Space sizably reduced
- Very good complementarity with indirect and direct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

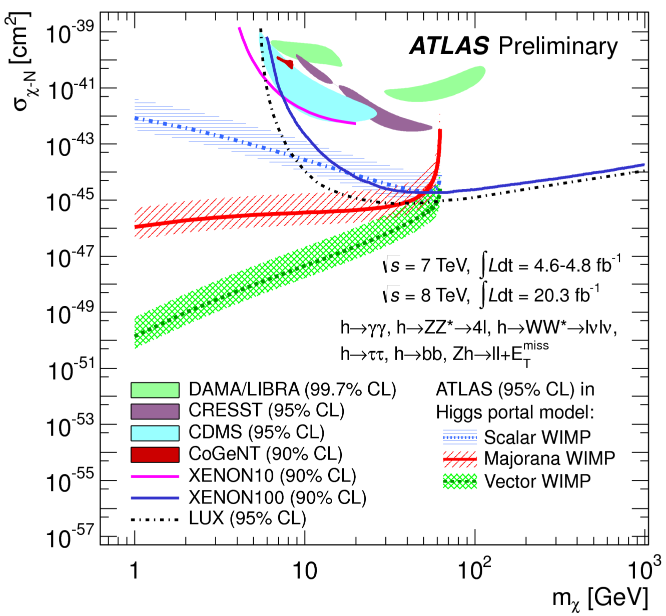
Stay tuned and cross your fingers

Higgs decay to DM: MONO-Z

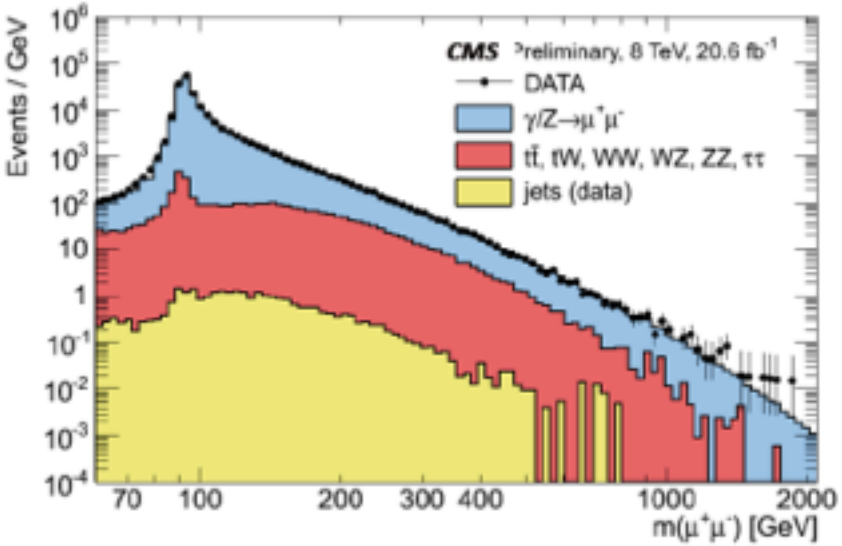
- Dark matter direct detection experiments probe the Higgs sector of the MSSM!
- MONO-Z like signature
- 5-standard channel + Zh⟶ ll DM DM: BRi,u < 0.37 (0.39) obs. (exp.) at 95% CL into limits on DM rate (depends on WIMP spin)

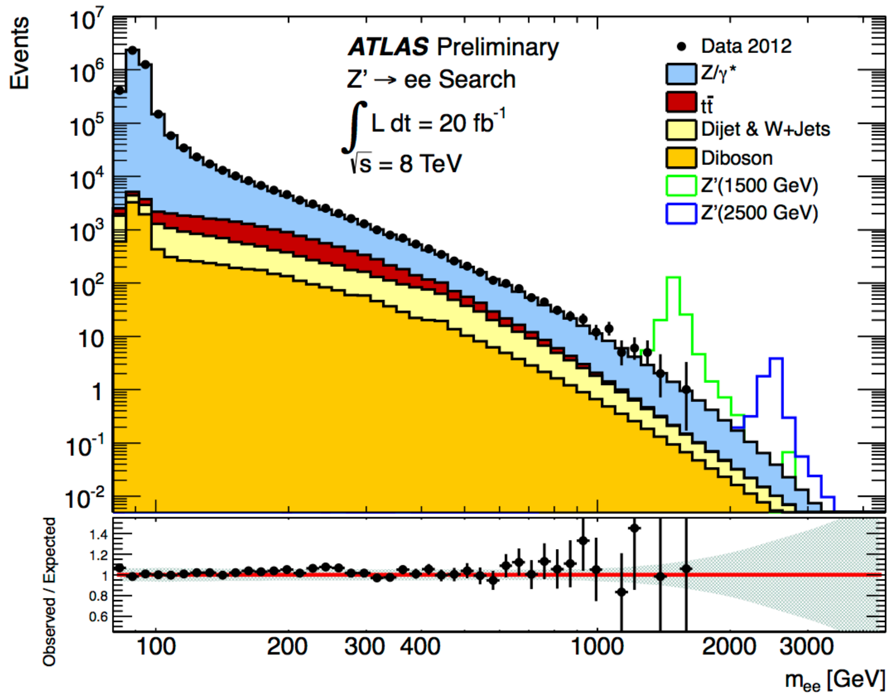


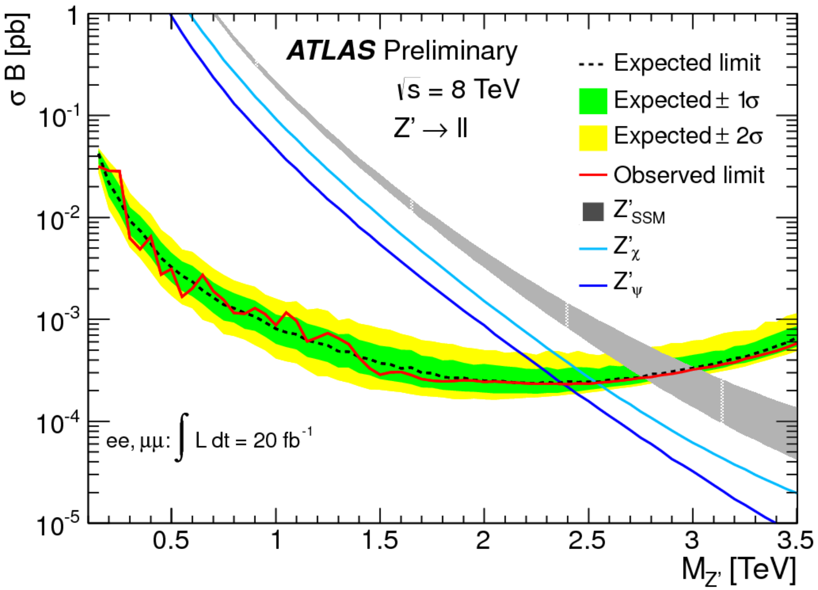




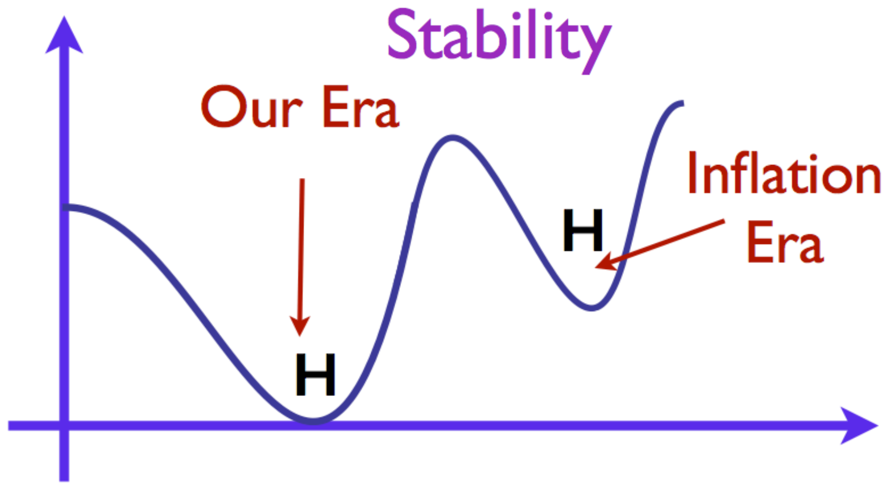
Search for resonances in dilepton

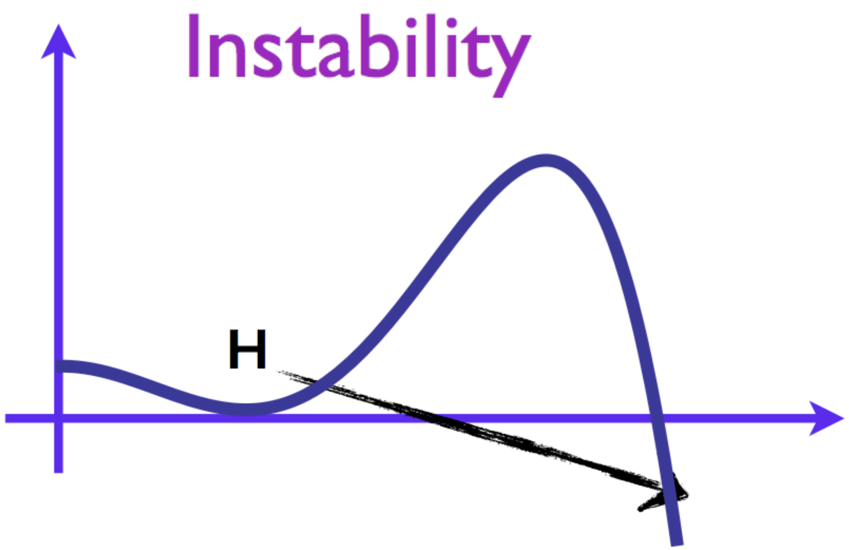


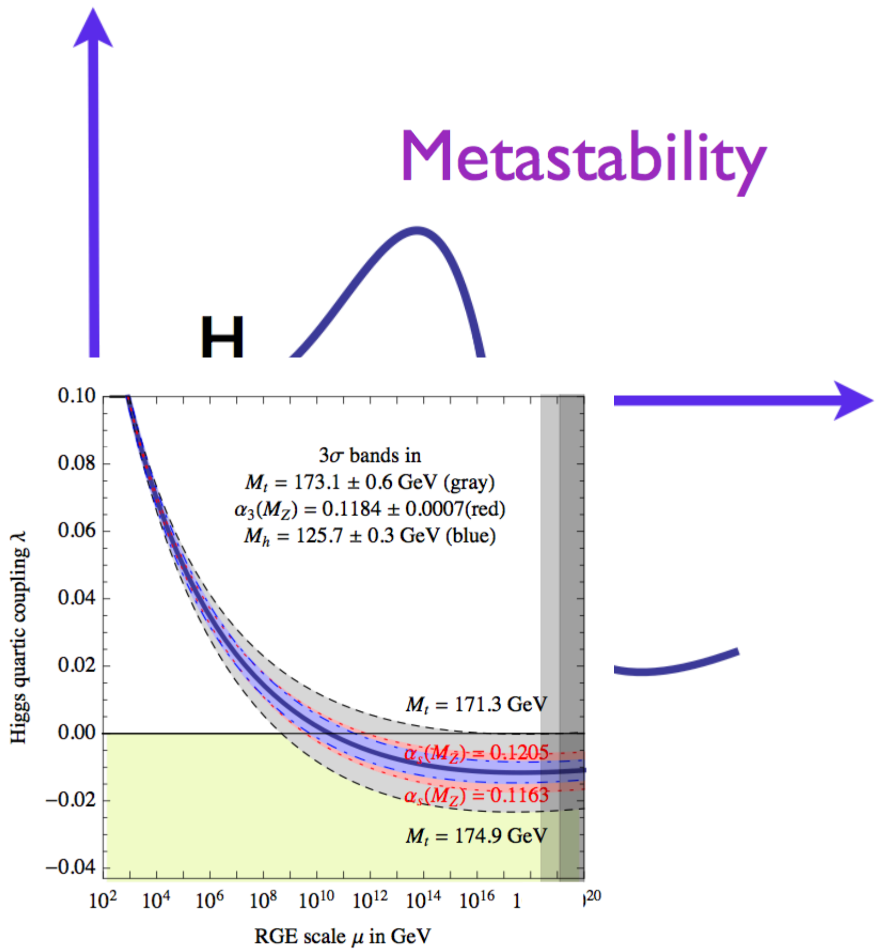




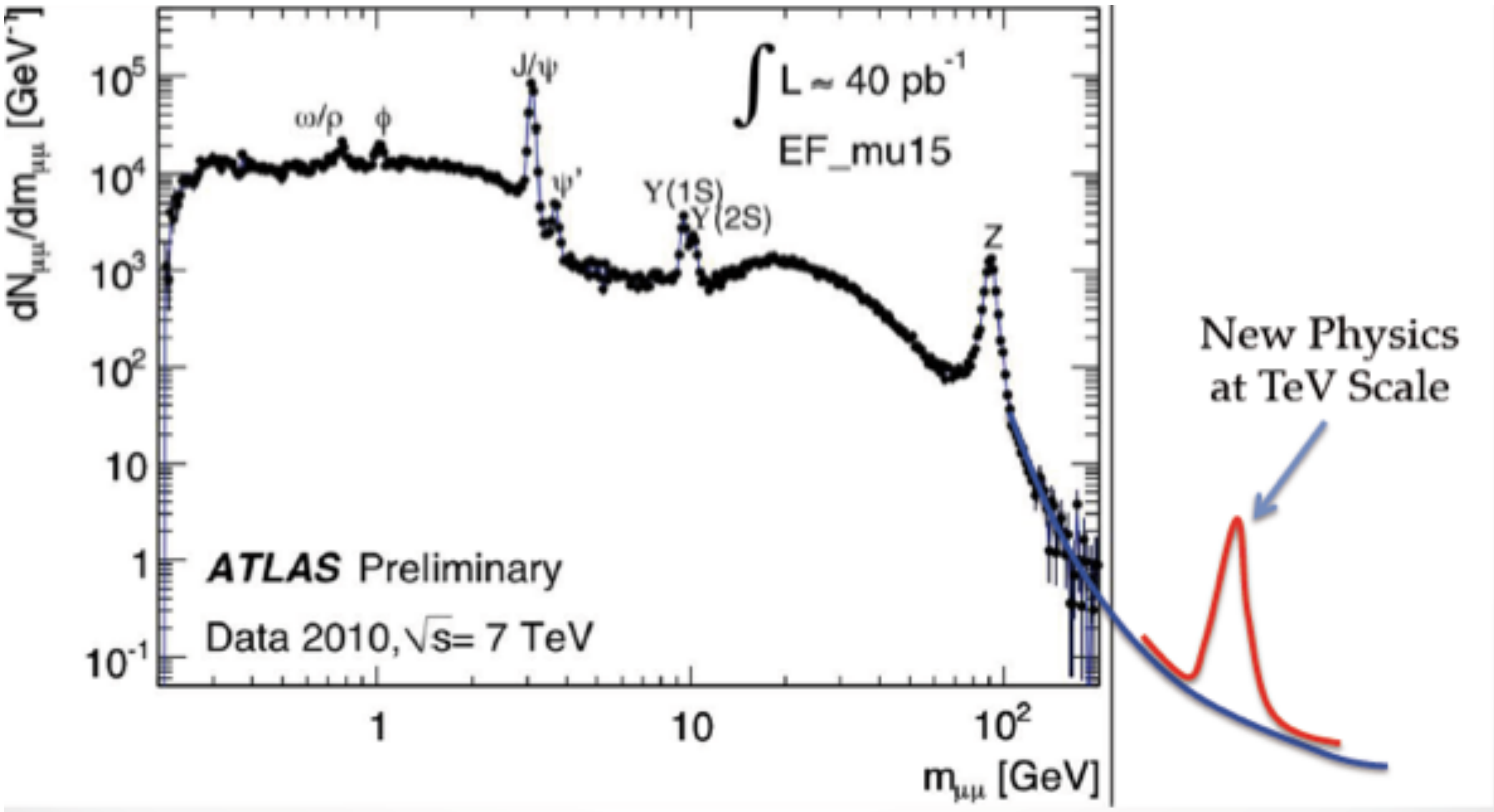
Higgs potential: 3 scenarios





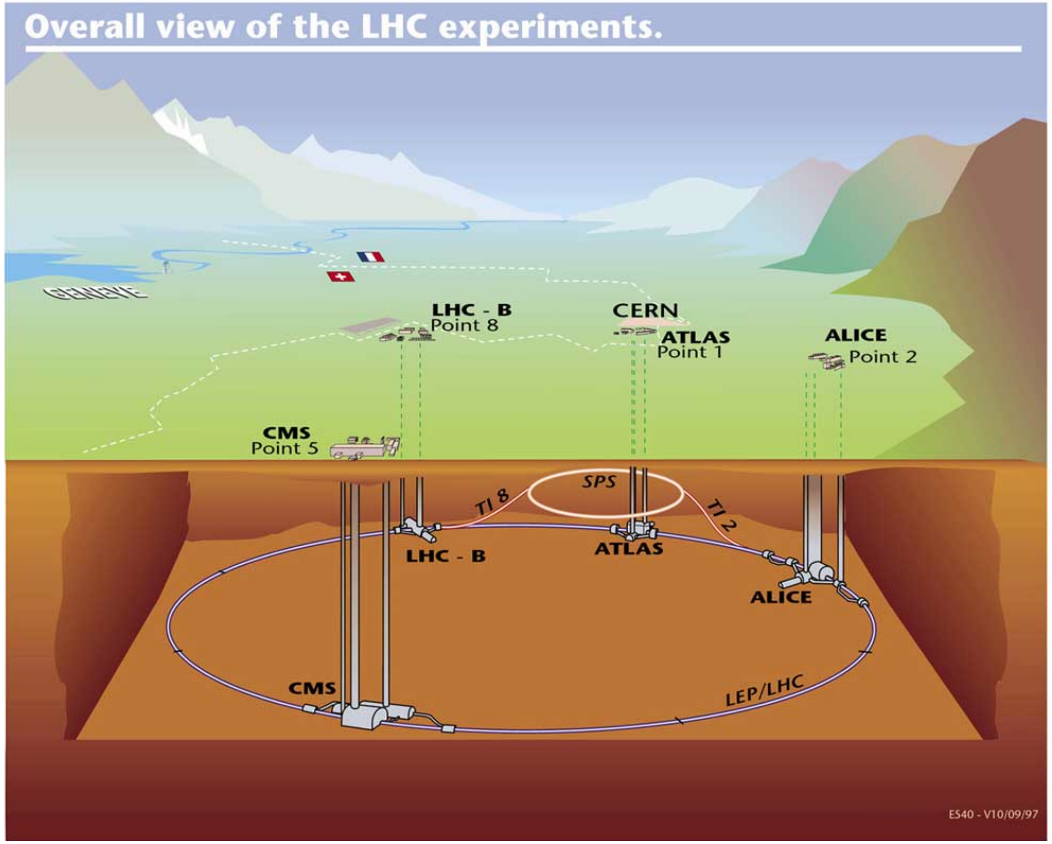


Z' Searches: resonances in dilepton



Very classic signature

CERN Large Hadron Collider



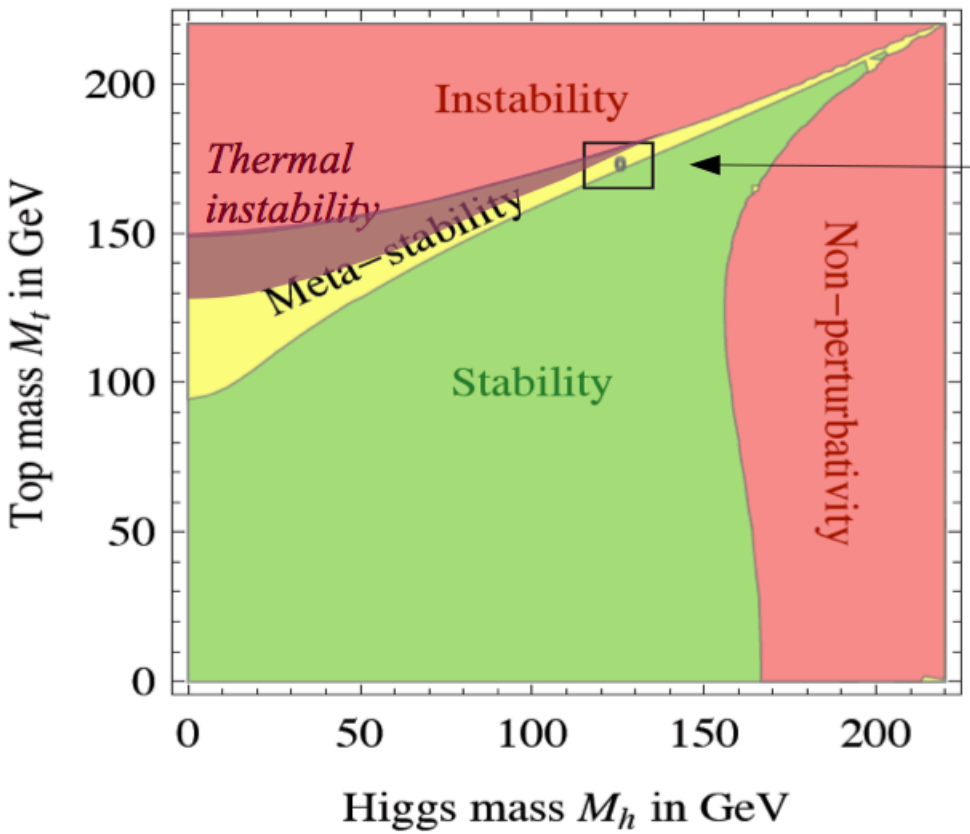
Number of events second generated in LHC collisions

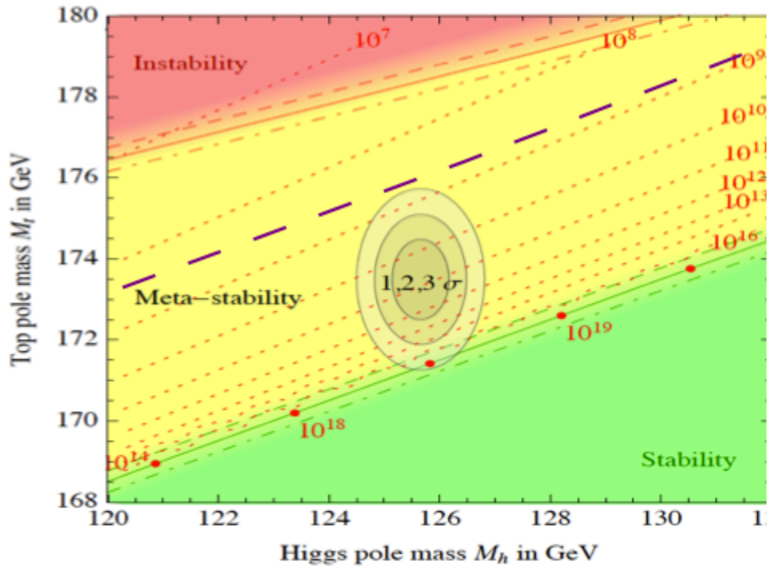
$$\frac{\partial N_{events}}{\partial t} = L\sigma$$

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

	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

MSSM Higgs searches

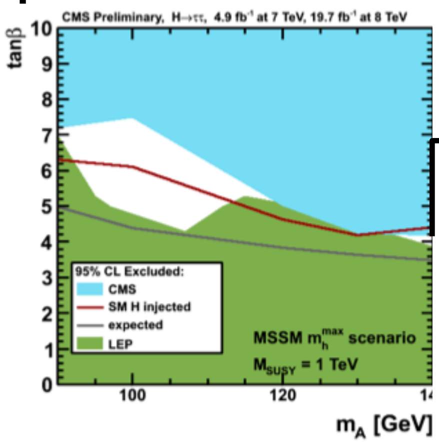
Neutral MSSM higgs: $\Phi(h,H,A) \to \tau\tau$

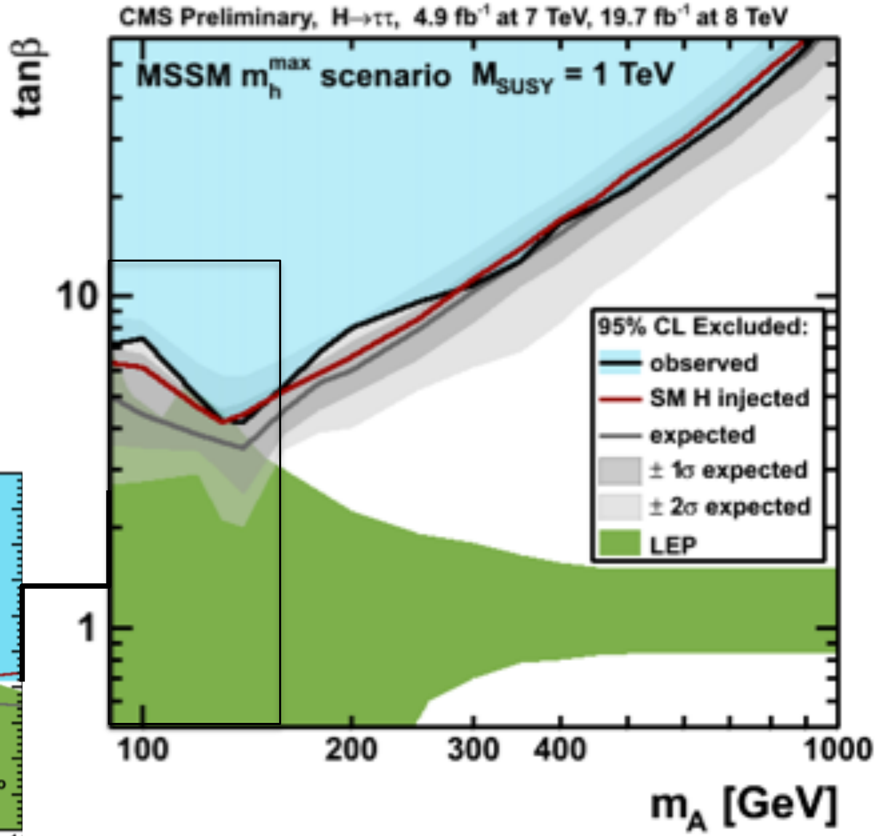
- High sensitivity at large tan(β)

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



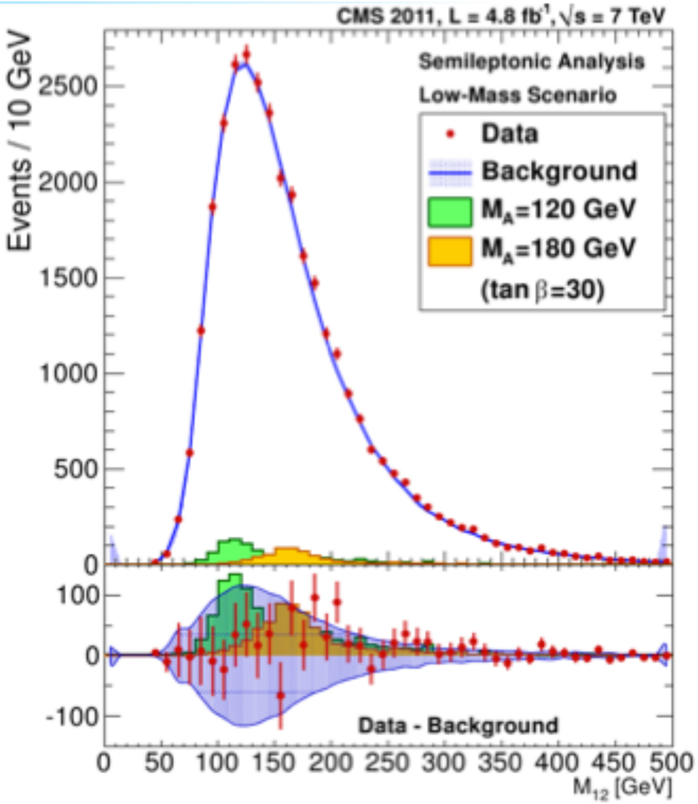


Neutral MSSM higgs: Φ(hHA)→ bb

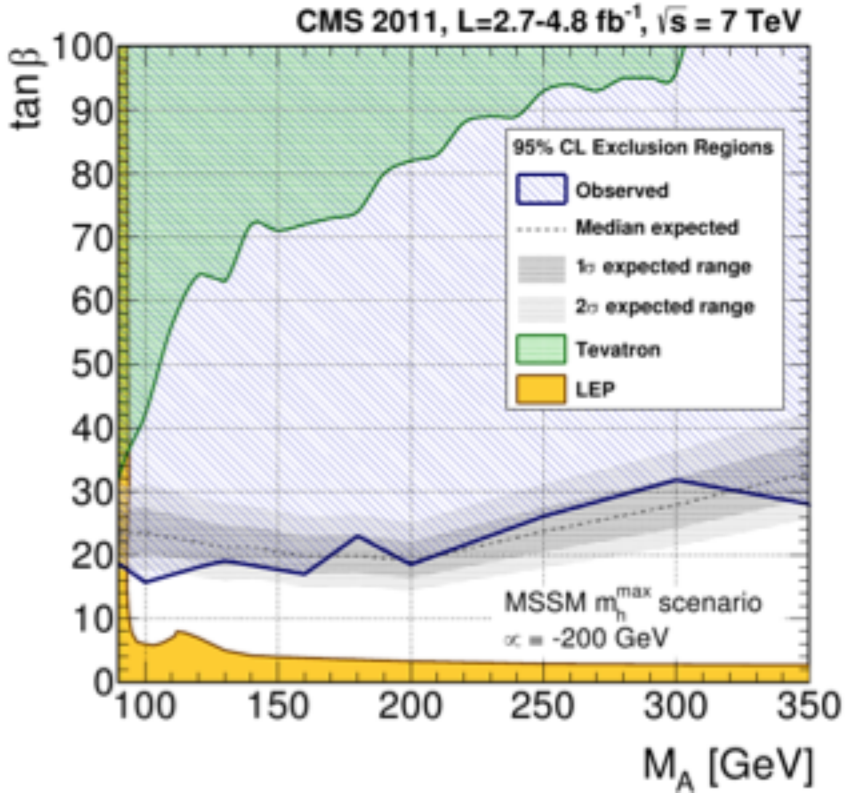
- High sensitivity at large tan(β)

Enhanced coupling to down type fermions

- No signal observed



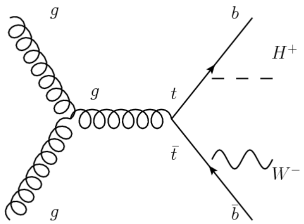
m_h^{max}scenario: stop mixing term determined form maximization of lightest higgs boson mass



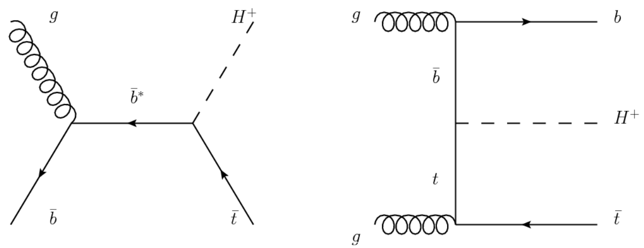
Charged higgs: t→H± b, tH±b (H±→τν)

- Two searches:

MH<m_t

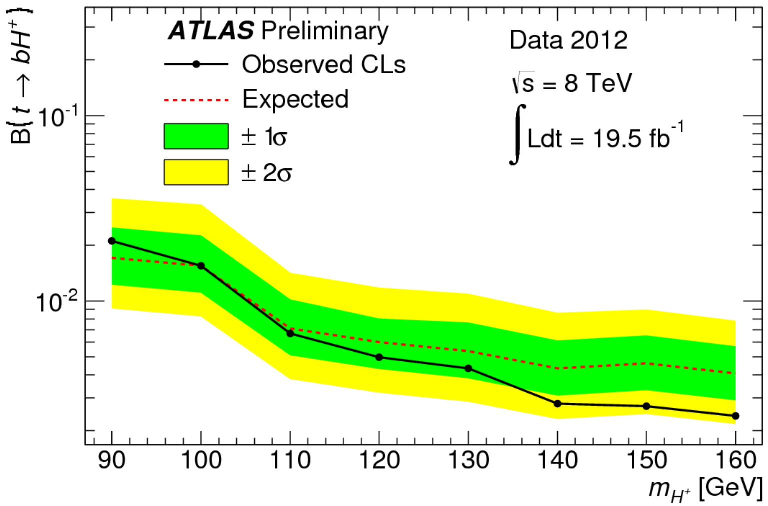


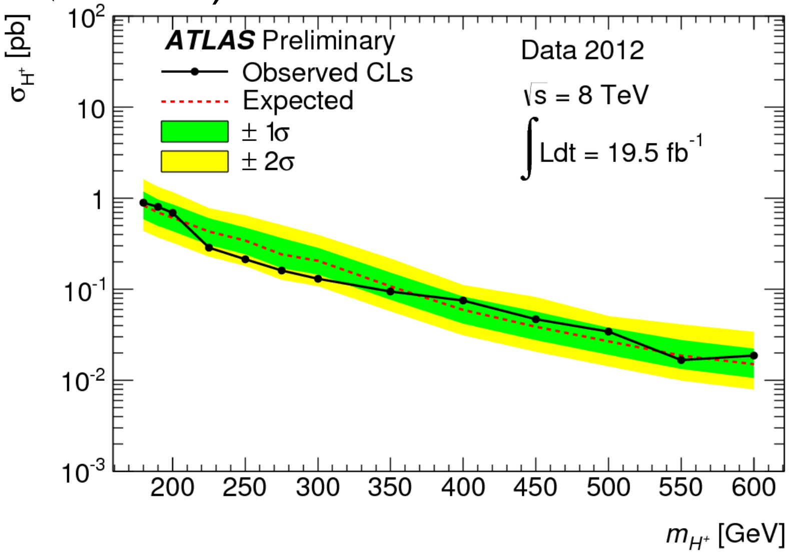
MH>m_t



No excess found

upper limits assuming B(H±→τν)=1

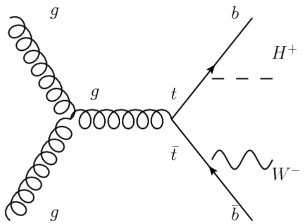




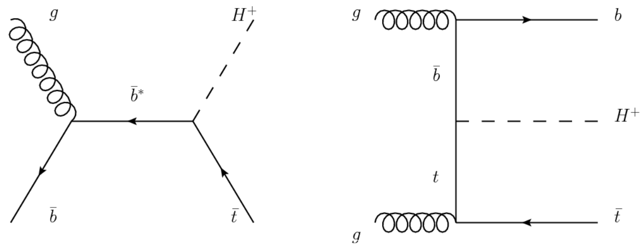
Charged higgs: $t \to H^{\pm} b$, $tH^{\pm}b$ ($H^{\pm} \to \tau\nu$)

- Two searches:

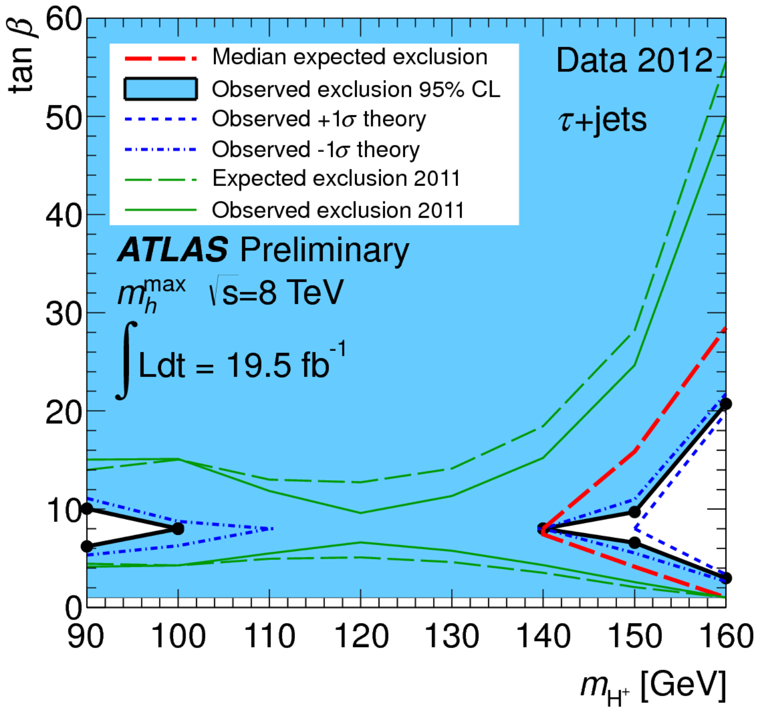
$MH < m_t$

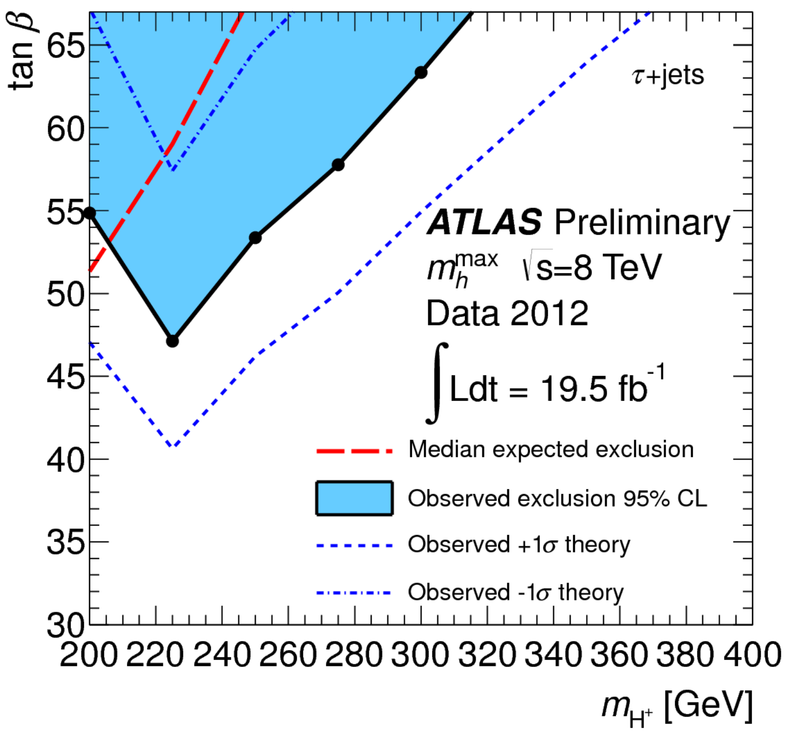


$MH > m_t$



Interpretation in the m_h^{max} scenario

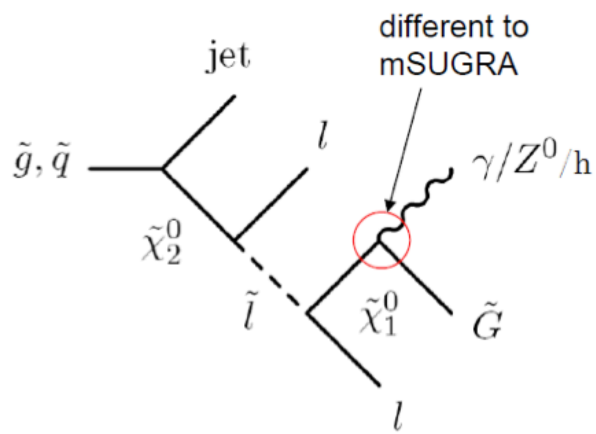




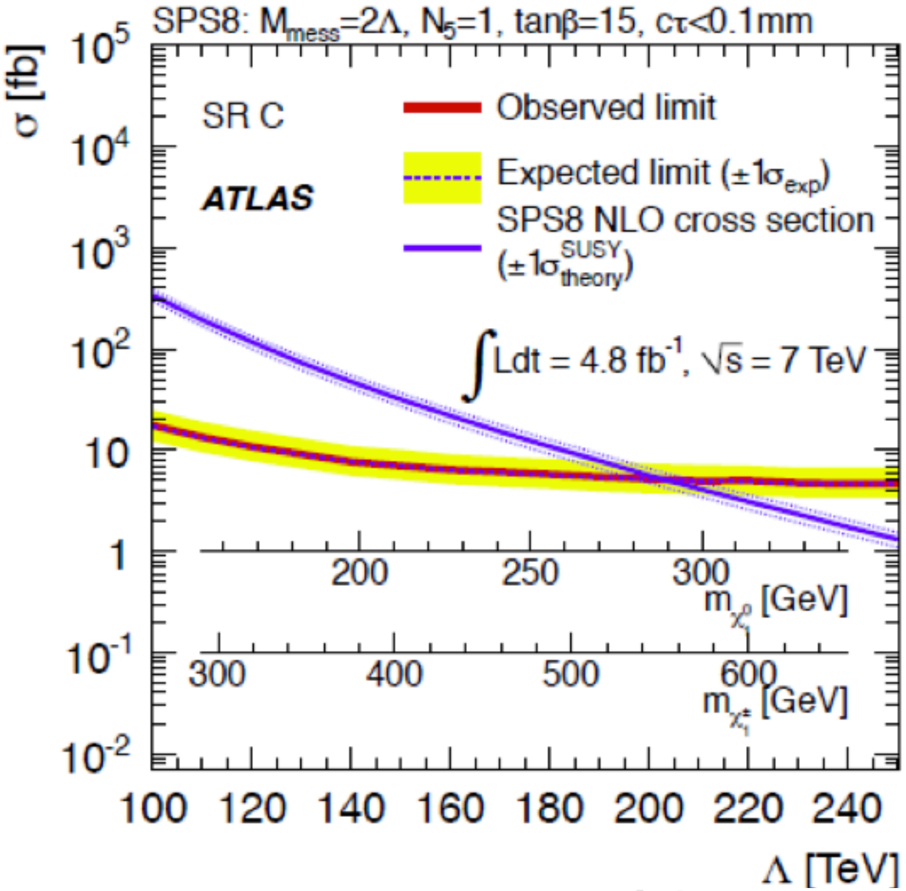
Gauge Mediated SUSY Breaking models

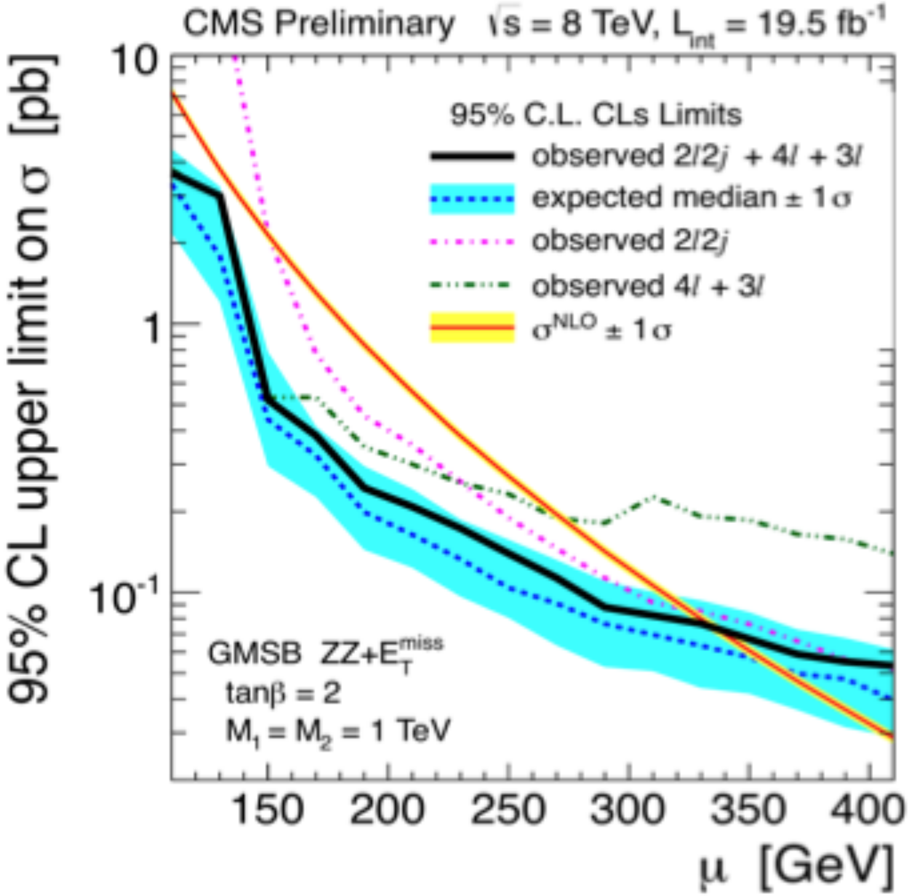
- SUSY breaking occurs in an hidden sector transmitted to SUSY particles via gauge interactions ➔ light neutralino or sleptons (stau)
- LSP is the gravitino $\tilde{G}$ practically massless from the experimental point of view
- NLSP typically decay: Sparticle ➔ $\tilde{G}$ SMparticle
  - NLSP may have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

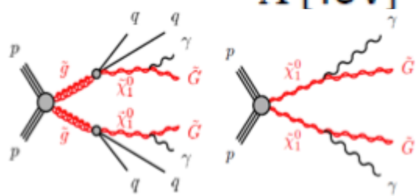


GMSB searches: χ NLSP small lifetime

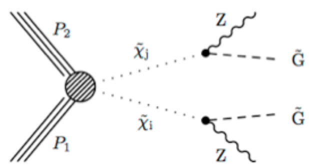




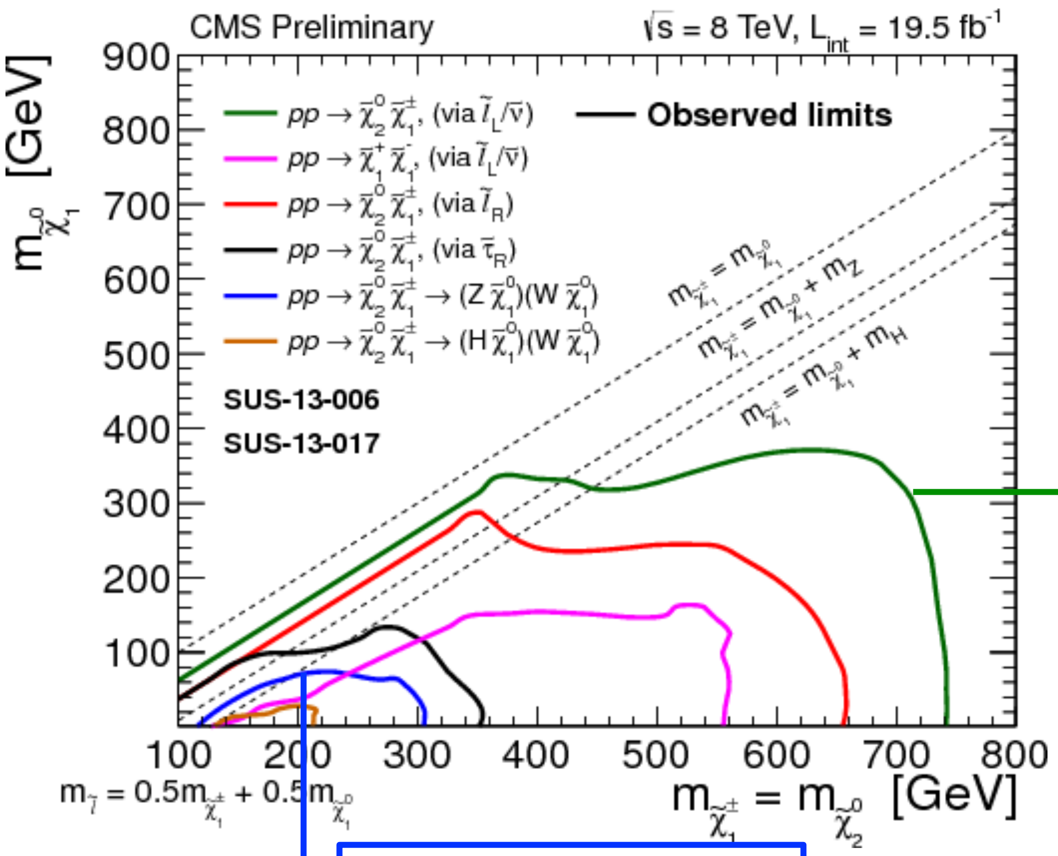
Neutralino ~ Bino:
dominant $\chi \rightarrow G\,\gamma$
prompt photons and ETmiss

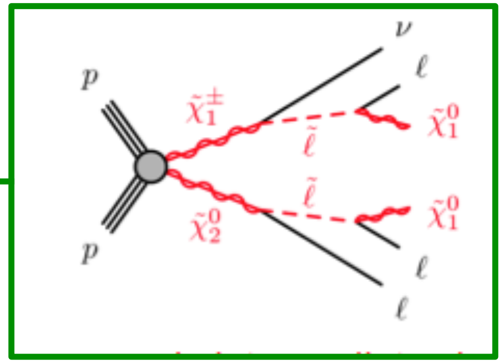


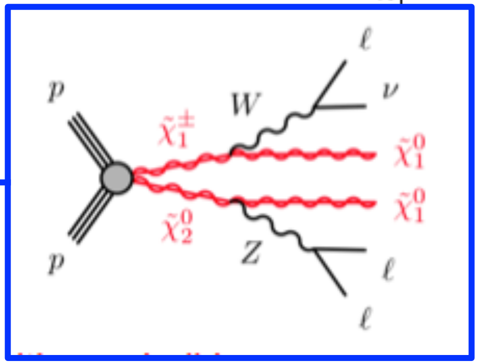
Neutralino ~ higgsino:
dominant $\chi \rightarrow G\,Z$
Z+dijet + 4-lept. analyses



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



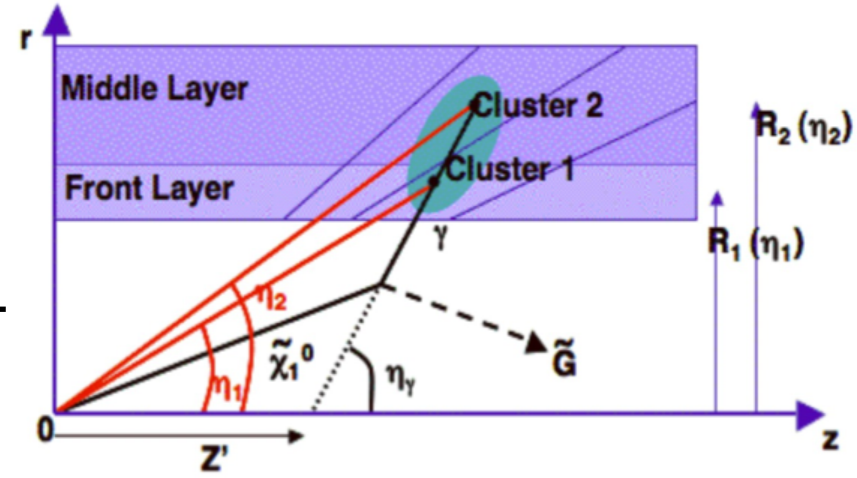


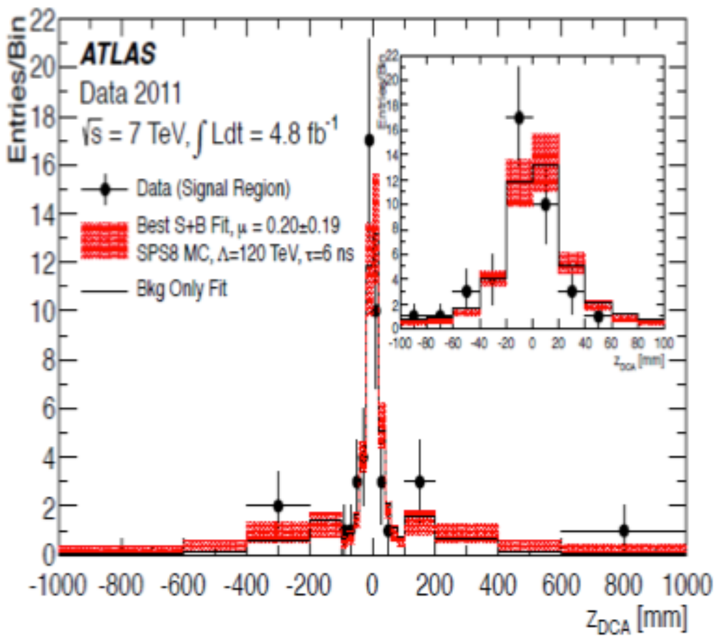


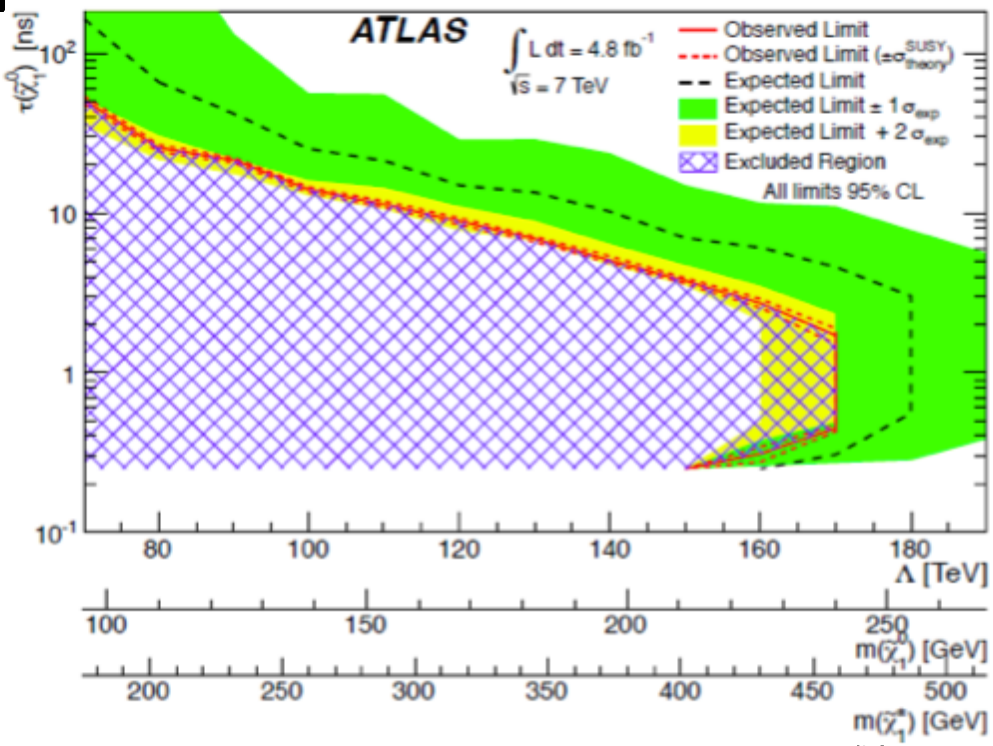
GMSB searches: χ NLSP medium lifetime

Neutralino ~ Bino:
dominant $\chi \rightarrow G\,\gamma$
non pointing photons and Etmiss

- Made possible thanks to the ATLAS longitudinal calorimeter segmentation





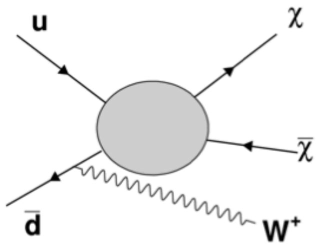


CMS-PAS-EXO-13-004

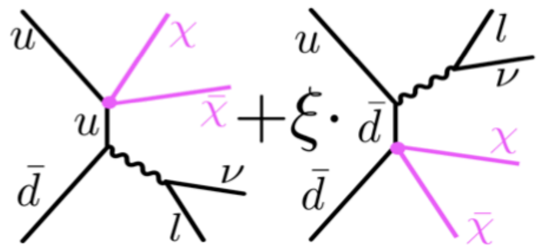
MONO-W

8 TeV

20 fb^{-1}



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

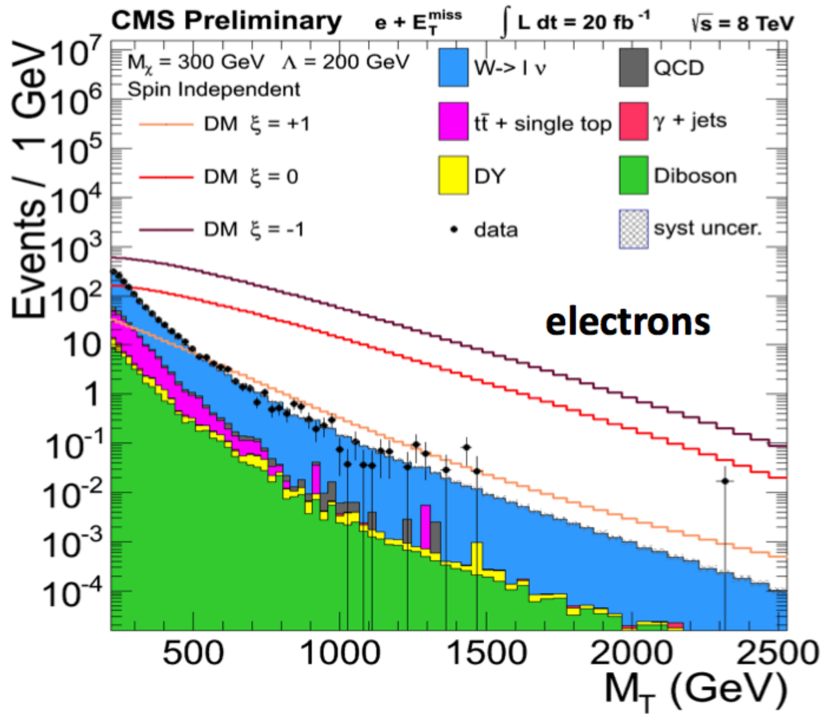


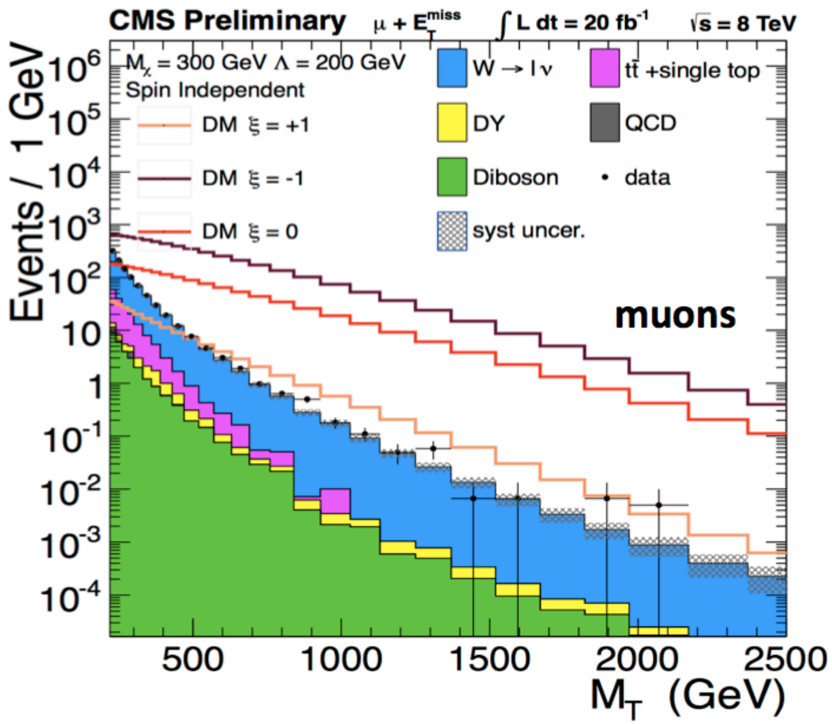
Considering vector and axial-vector operators and interference between different contributions (ξ = +1, -1 , 0)

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

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

$$M_\mathrm{T} = \sqrt{2 \cdot p_\mathrm{T}^\ell \cdot E_\mathrm{T}^\mathrm{miss} \cdot (1 - \cos\Delta\phi_{\ell,\nu})}$$

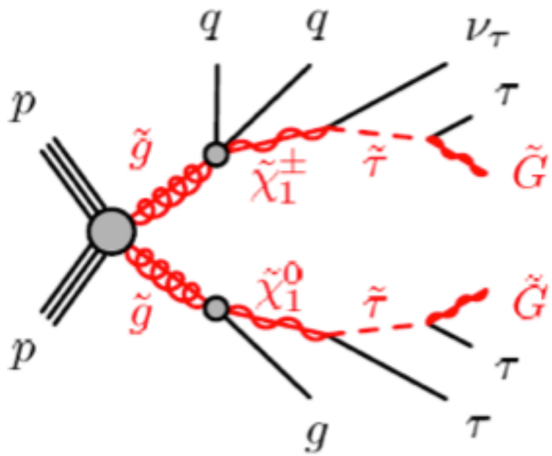


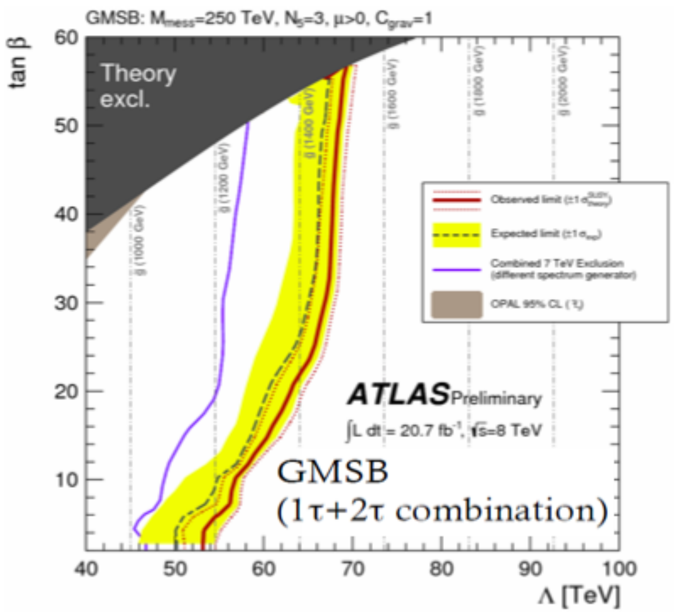


GMSB : $\tilde{\tau}$ NLSP short and long lifetime

dominant $\tilde{\tau} \rightarrow \tilde{G}\,\tau$

τ 's and Etmiss

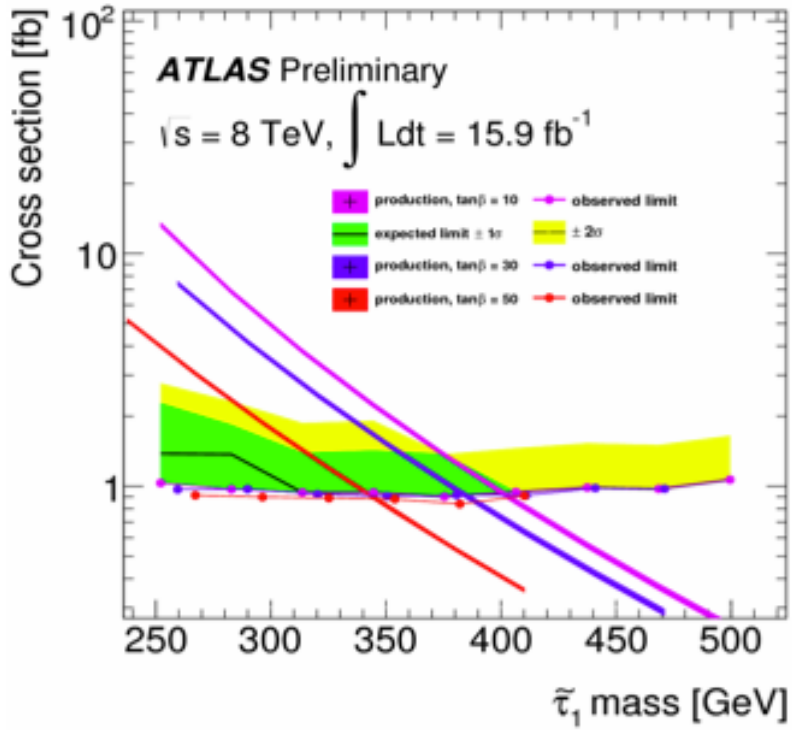




Long lifetime: decay outside ATLAS

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

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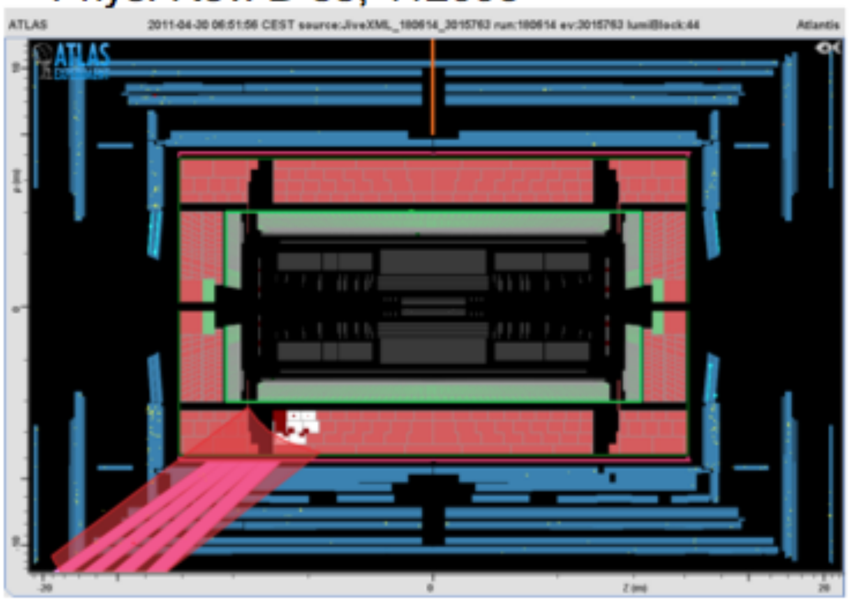
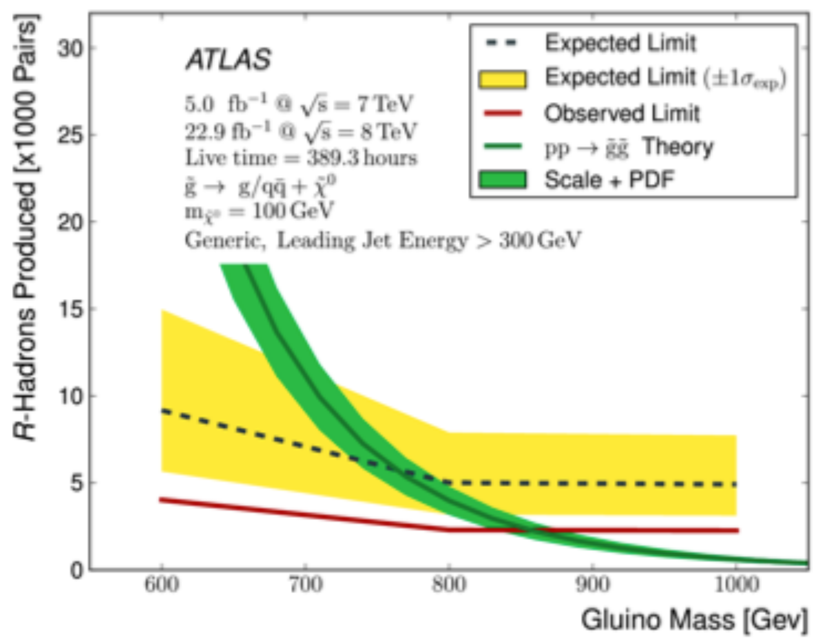




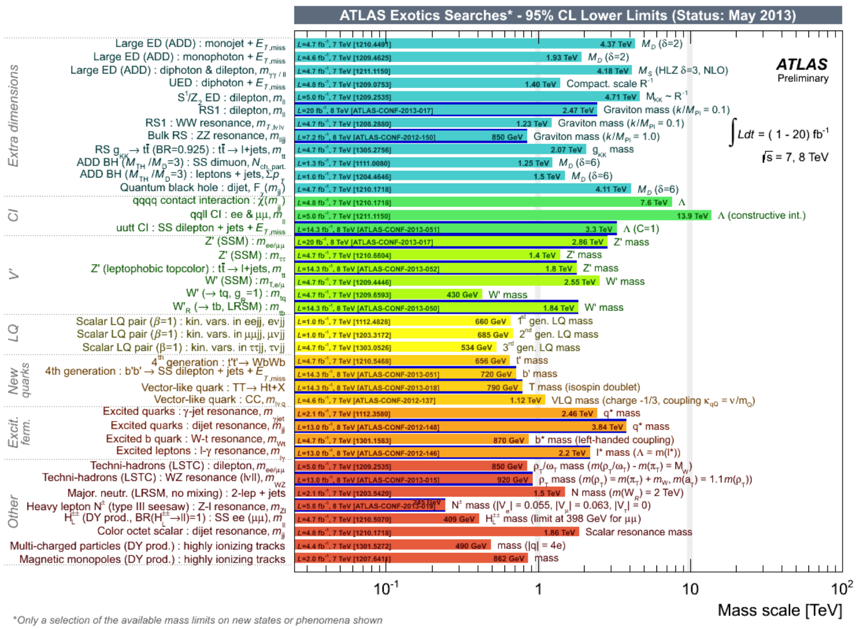
Exotics searches

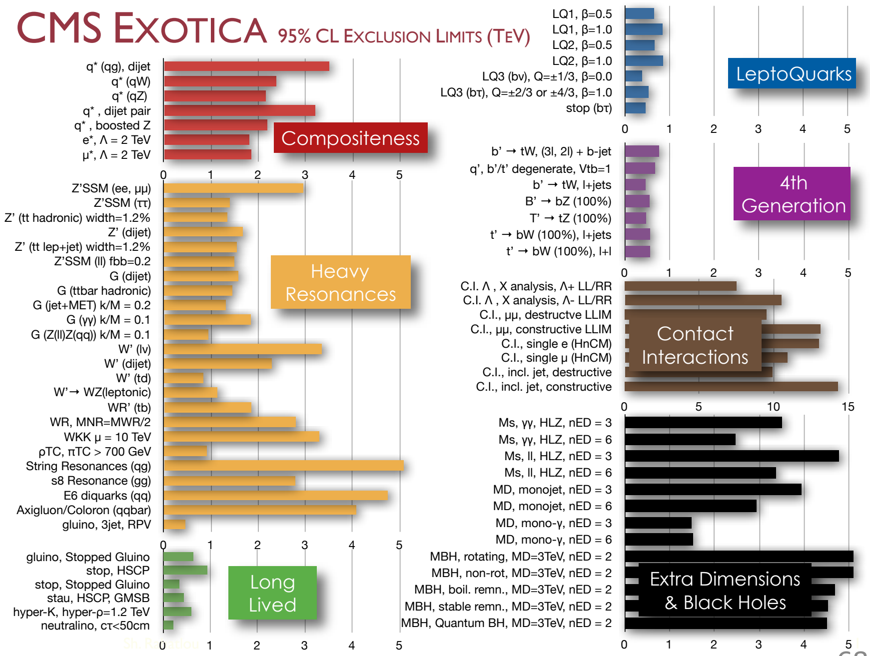
What will be reported

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

  Apologize for the rest

What will not be reported





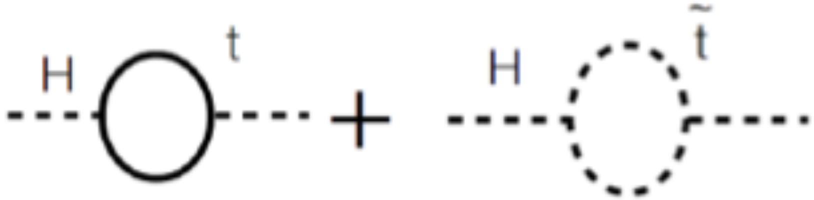
MSSM Higgs

- 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

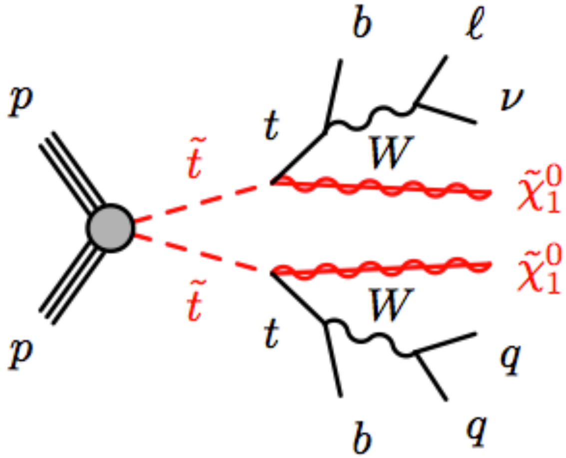


  - Cancellation amount depends on SUSY breaking
  - *Lightest Higgs mass predicted to be below M_Z at tree level*

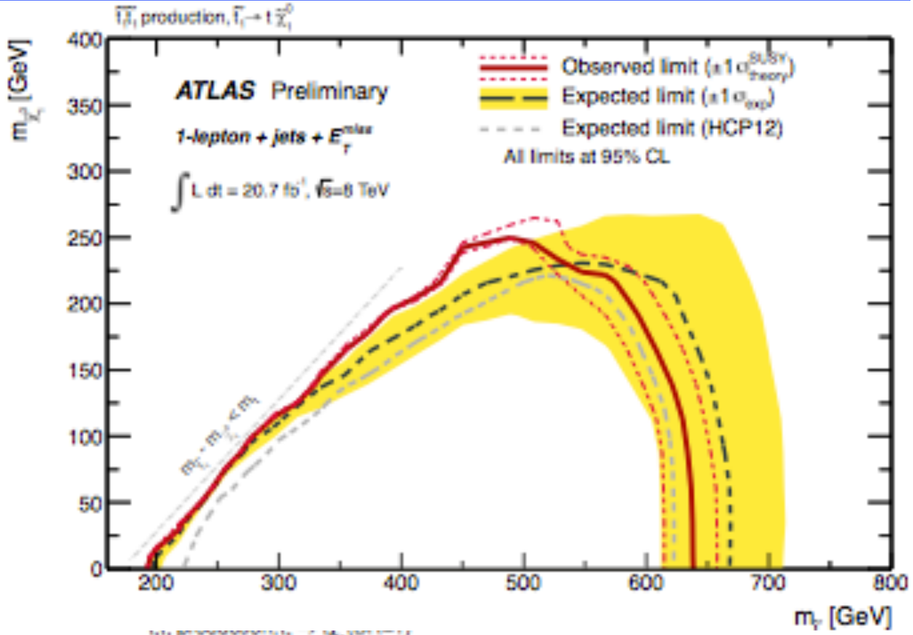
"Natural" quantum corrections (dominated by stop loop) sets upper limit on Mh around 135 GeV*

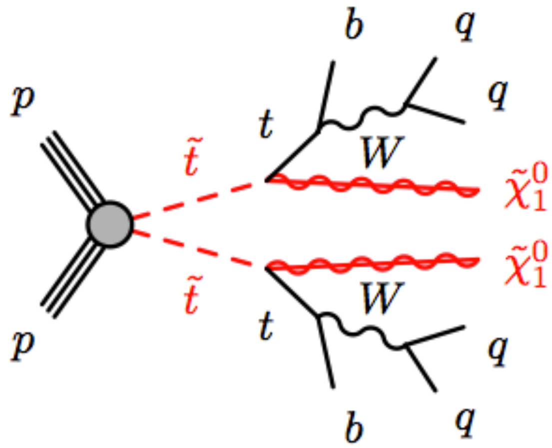
125 GeV Higgs is consistent with the MSSM max allowed expectation values

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

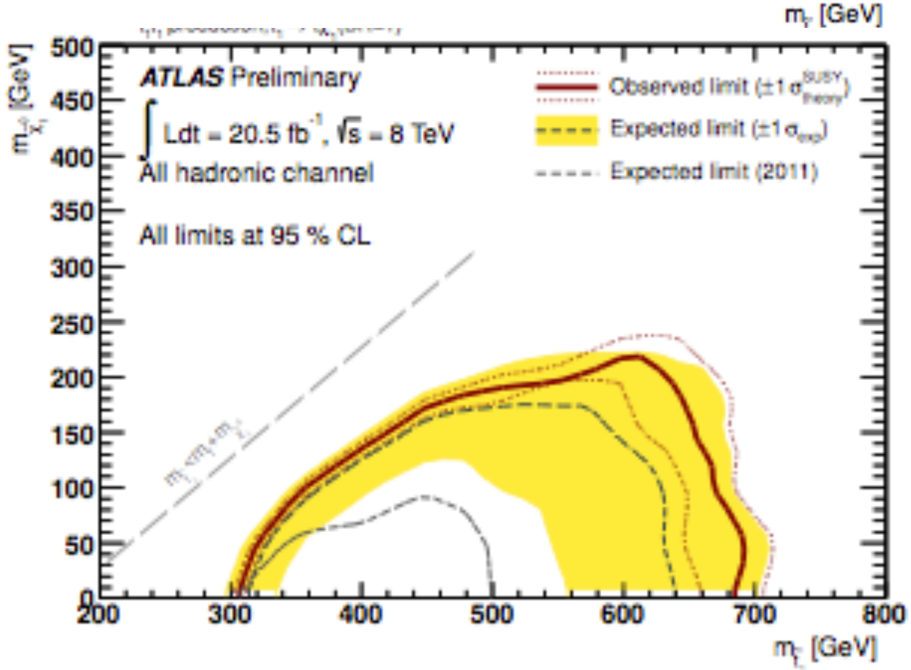


Semi-leptonic $\bar{t}t$ + ETmiss analyisis

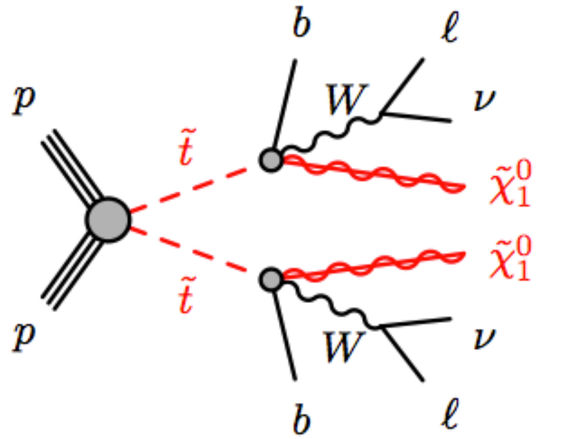


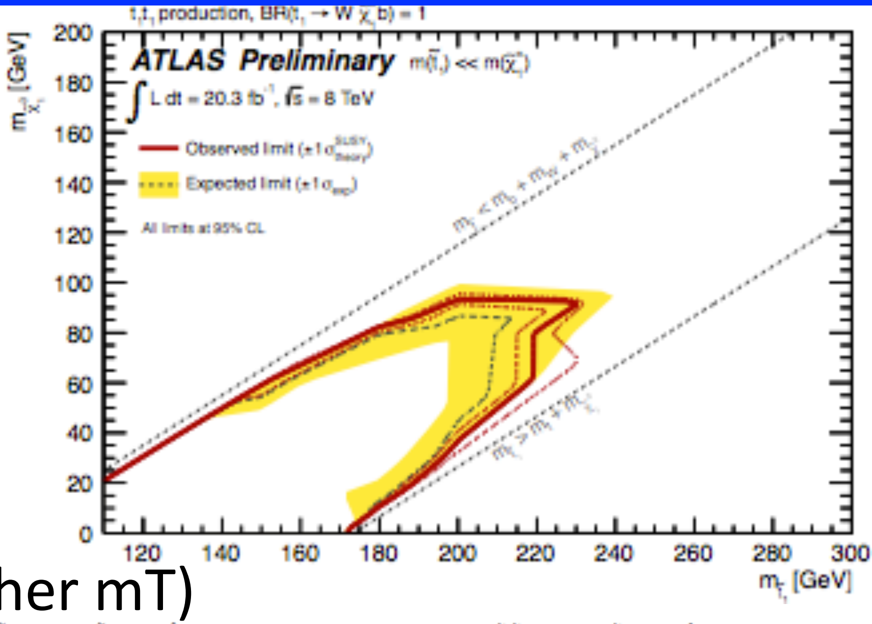


Hadronic $\bar{t}t$ + ETmiss analyisis

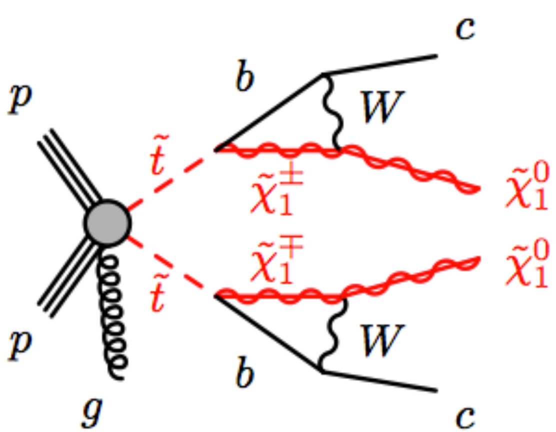


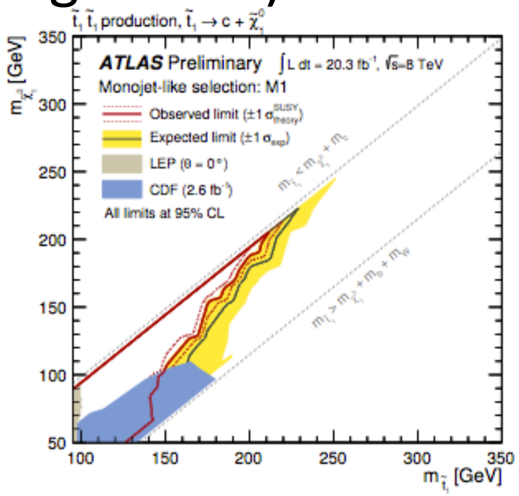
Searches for $\tilde{t} \rightarrow bW\chi$, $c\chi$

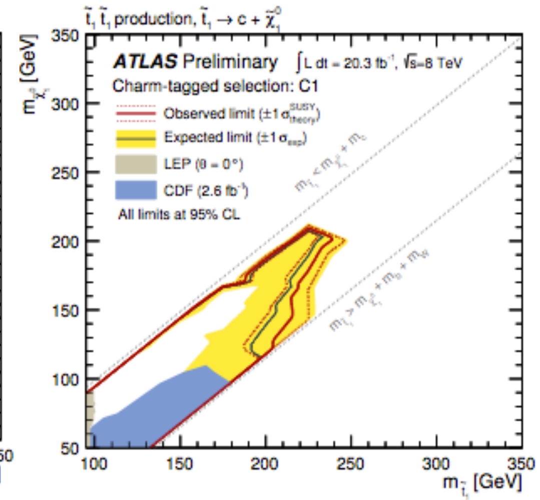




3 body decay 2 leptons
(very similar to tt signature but higher mT)







Monojet like signature and/or charm tagging
Address very low ΔM case (with very small missing E_T) with ISR events

Standard Model processes at the LHC