# The Quest for Bottom and Top squarks: past, present and future at the ATLAS experiment

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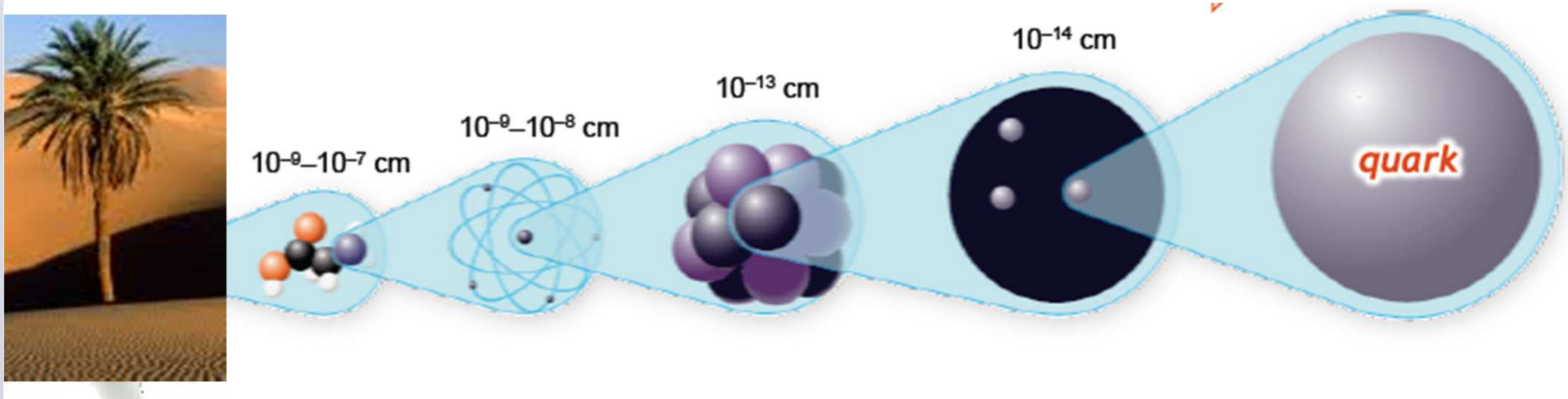
*Colloquium University of Geneva*, November 26th 2013

# The Standard Model of Particle Physics

The Standard Model (SM) of particle physics describes matter in terms of its fundamental constituents and their interactions.



# Constituents

- Matter is made out of 3 generations of quarks and leptons: *E.g.*, hadrons as proton(neutron) = uud(udd). Fermions (spin ½)

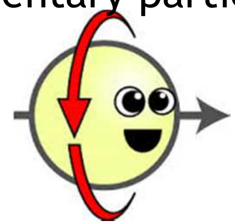
Mass →
Charge →
Spin →

| | | | |
|---|---|---|---|
| 2.4 MeV/$c^2$, 2/3, 1/2, u, up | 1.27 GeV/$c^2$, 2/3, 1/2, c, charm | 173.3 GeV/$c^2$, 2/3, 1/2, t, top | quarks |
| 4.8 MeV/$c^2$, -1/3, 1/2, d, down | 104 MeV/$c^2$, -1/3, 1/2, s, strange | 4.2 GeV/$c^2$, -1/3, 1/2, b, bottom | |
| 0.511 MeV/$c^2$, -1, 1/2, e, electron | 105.7 MeV/$c^2$, -1, 1/2, μ, muon | 1.777 GeV/$c^2$, -1, 1/2, τ, tau | leptons |
| < 2.2 eV/$c^2$, 0, 1/2, $\nu_e$, e neutrino | < 0.17 MeV/$c^2$, 0, 1/2, $\nu_\mu$, μ neutrino | < 15.5 MeV/$c^2$, 0, 1/2, $\nu_\tau$, τ neutrino | |

Particle **Mass** → eV/$c^2$
1 eV = 1.6 x $10^{-19}$ J, 1 GeV = $10^9$ eV

Particle **Charge** → in unit of electron charge

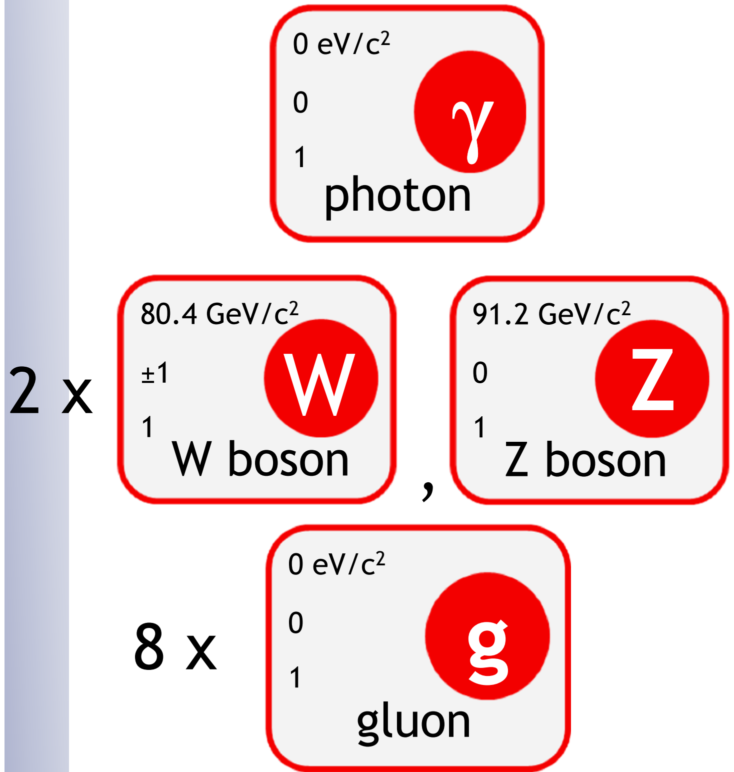
Particle **Spin** → angular momentum carried by elementary particles



**Every fermion has an antimatter version: same mass, opposite charge**

# Forces

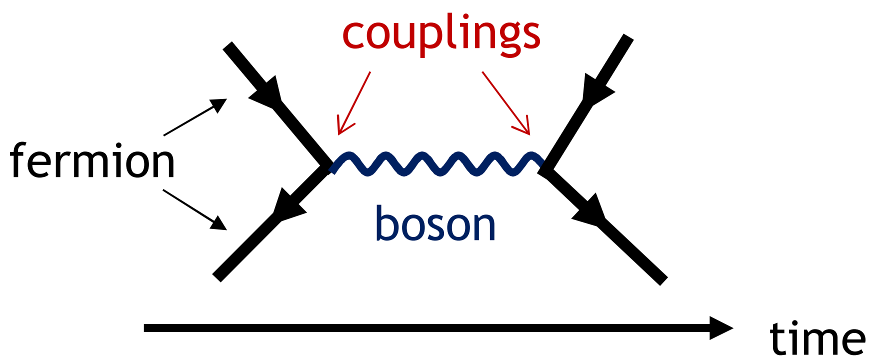
- Matter held together by **Forces** carried by Bosons
- **3 forces considered in SM of particle physics**
  - Electromagnetic (EM), Weak and Strong forces (carriers: spin 1)
  - The 4th force, gravity, not included in the SM theoretical framework
  - Couplings: $g$, $g_{W}$, $g_s$



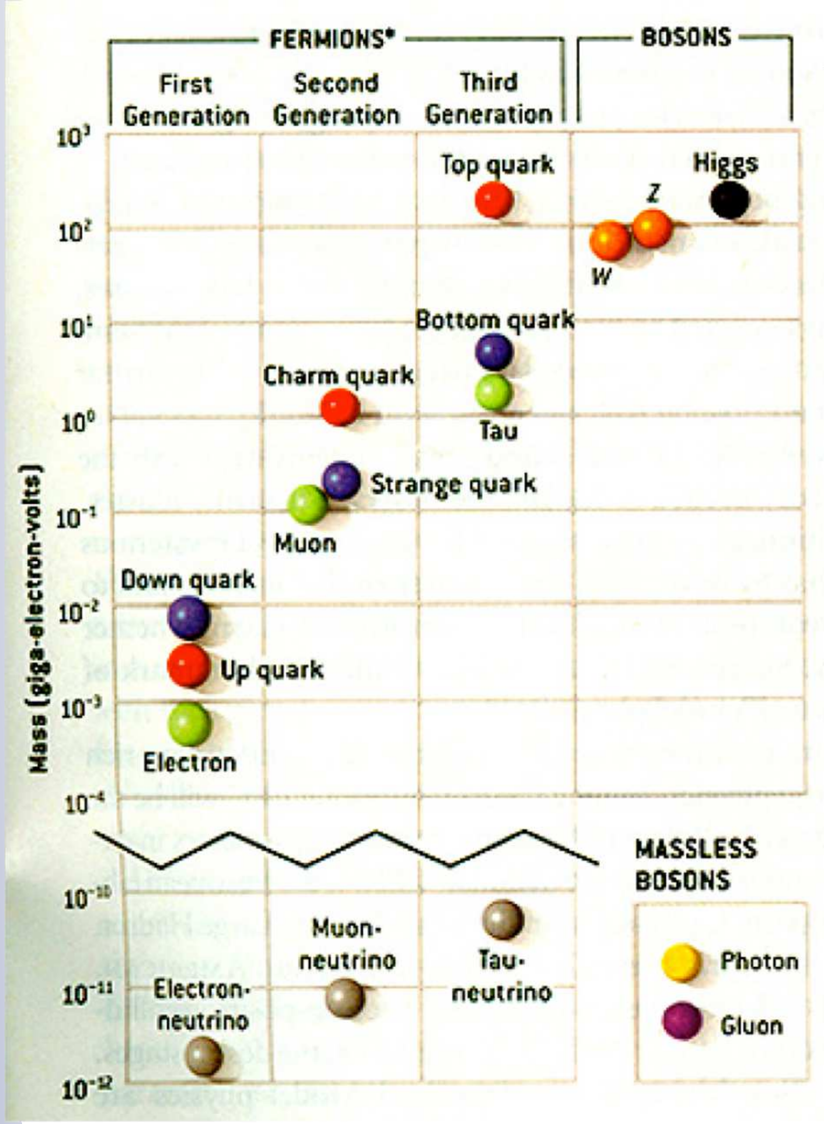

γ: responsible for EM force, transmits light
**W,Z:** responsible for weak force, cause particles to change and decay
**gluon:** responsible for strong force, holds nuclei together

Representation of interactions: Feynman diagram

*At tree level*



# The origin of masses: the Higgs boson




- SM particles have no inherent mass
- Gain mass by passing through a field → the ***Higgs field***:
  - Couples to particles to give mass (value related to coupling strength)
  - particle associated to the field: spin 0 **Higgs** boson (its mass, $m_H$, not predicted by the SM)

'Mechanism' theorized in 1964

→ Higgs boson observed at the Large Hadron Collider 50 years later → 126 GeV!

*Higgs and Engler on July 4, 2012*

# A successful story but ..

- The SM has mapped the subatomic world with remarkable success
  - Confirmed to better than 1 % uncertainty by 100's of precision measurements, the recent discovery of the higgs boson being the last piece to complete the picture.

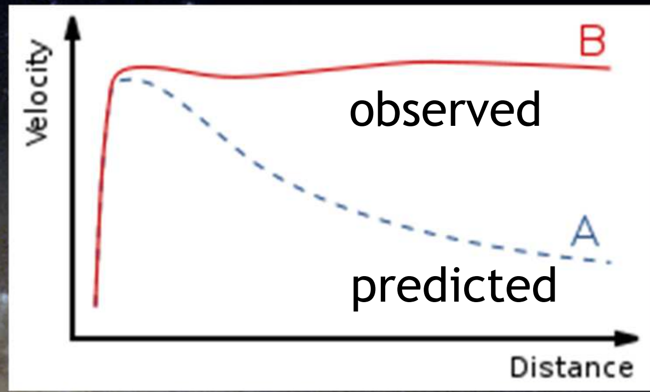
**DOES THE HIGGS DISCOVERY COMPLETE OUR UNDERSTANDING OF NATURE ?**

**NO!**

**The Standard Model is theoretically incomplete**

# What is the Dark Matter?

Galaxy rotation

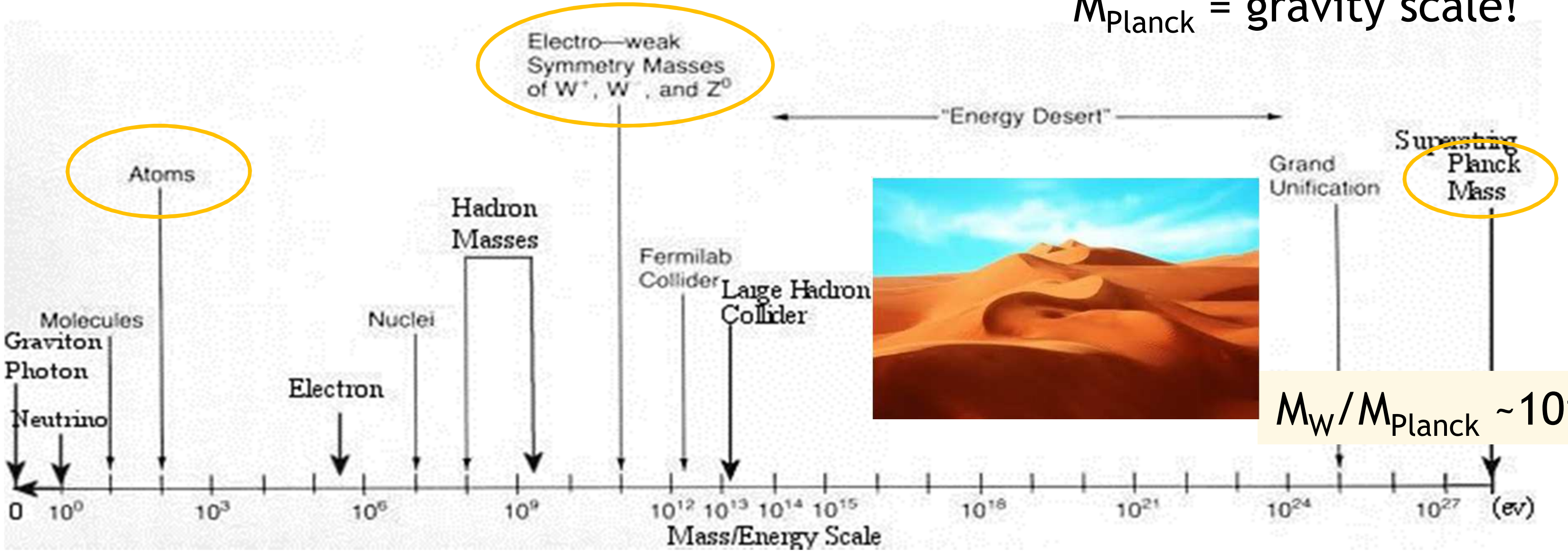



**Standard Model ordinary matter only accounts for less than 20% of the matter of the Universe**

# The hierarchy Problem

- **Why is gravity so weak?** weak force is $10^{32}$ times stronger!
  - Also expressed in terms of energy scale

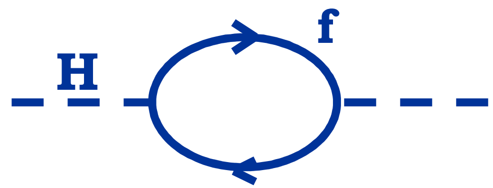
$M_W$ = weak scale
$M_{Planck}$ = gravity scale!




$M_W/M_{Planck}$ ~$10^{-16}$ !

- The 'size' of the higgs field could be as large as the Planck scale
  - in clear disagreement with observation ($m_H$, $m_{W/Z}$)

need an incredible fine-tuning to get it to the right level → makes the **SM 'unnatural'**

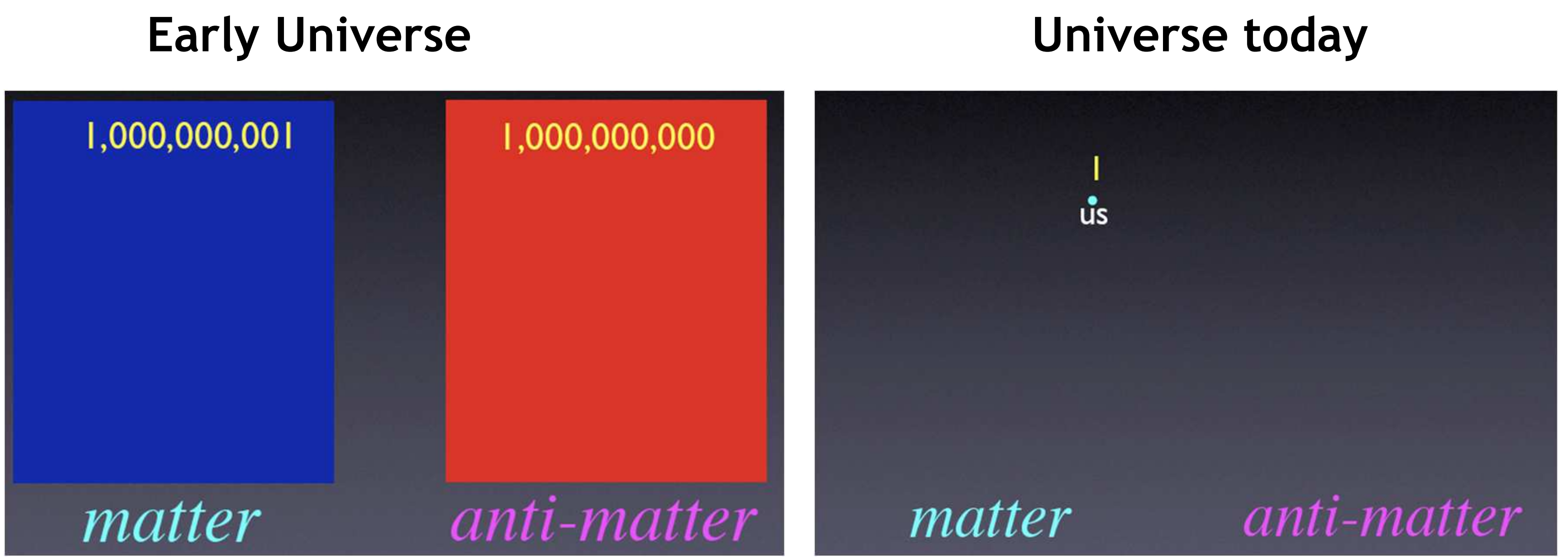



Fermion loop

$\Delta m_H^2 \sim \Lambda^2$ , $\Lambda = M_{pl}$ ?

# (Some) More Problems …

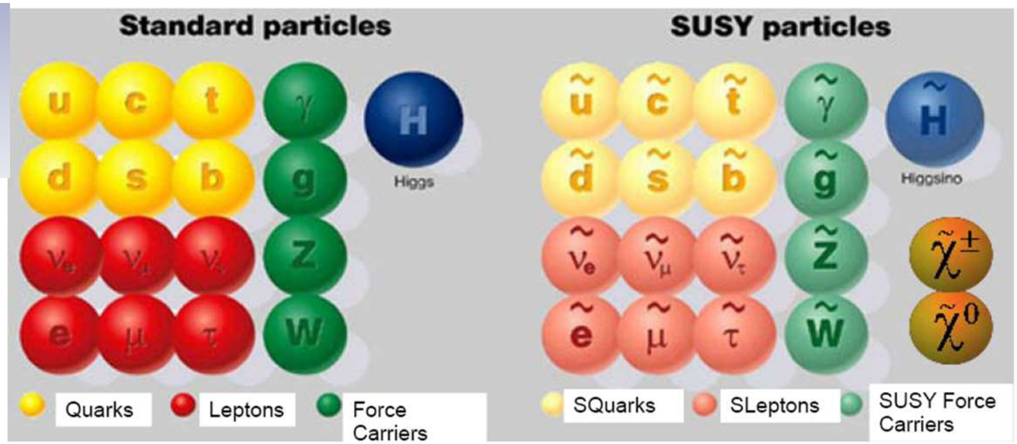
- Matter asymmetry not explained by the Standard Model




- SM cannot explain **number of fermion generations**
  - or their **large mass hierarchy**
    - $m_{top}/m_{up}$~100,000

# Supersymmetry (SUSY)

New spin-based symmetry relating fermions and bosons




Q|Boson> = Fermion

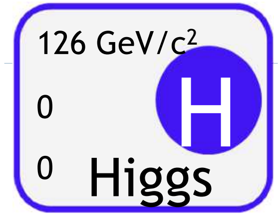
Q|Fermion> = Boson

- SuperSymmetric extension of the Standard Model:
  - Mirror spectrum of particles
  - Enlarged Higgs sector:
    - (at least) 5 'higgses' (two charged, three neutral)
    - the lightest could be SM-like

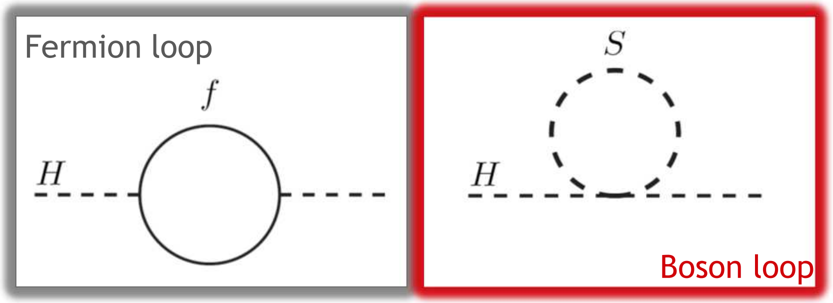
Superpartners (also called sparticles) have ½ integer difference in spin but otherwise equal quantum numbers

# What's Nice about SUSY?

- The **lightest of the higgs** is predicted to be close to $M_Z$: found at 126 GeV ☺



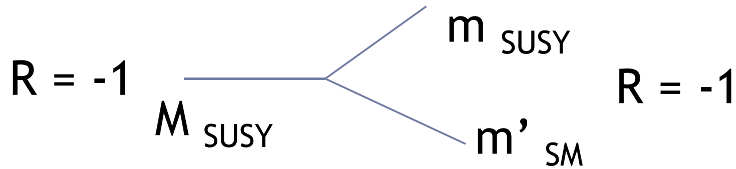

- Naturally solve the hierarchy problem
  - Corrections to the Higgs mass due to its coupling with fermions is compensated by the presence of bosons
  - No fine-tuning required !




- Define R-parity = $(-1)^{3(B-L)+2S}$
  - B=baryonic number (1/3 for q, 0 for l)
  - L=leptonic number (0 for q, 1/3 for l)
  - S = spin (1/2 for fermion, 1 for boson)

→

- R = 1 for SM particles
- R = -1 for SUSY partners

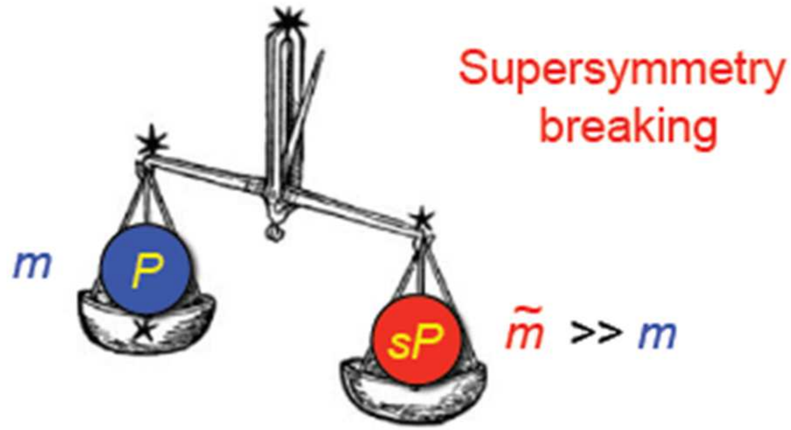



- If R-parity is conserved, the **Lightest SUSY particle (LSP)** cannot decay → is stable: **SUSY provides the perfect candidate for Dark Matter (DM)**

# The problem with SUSY: breaking!

No SUSY partners
have been found yet

Supersymmetry cannot be an exact symmetry of our world (spin-0 electrons do not exist)




- SUSY must be ‘Broken’
  - SUSY-breaking terms should preserve the nice aspects of SUSY
- Several mechanisms proposed

**SUSY Breaking determines the characteristics of the new particles:** lots (> 100) of new parameters (e.g. masses)

# SUSY new particles

SM

SUSY

| Eigenstates of mass | Spin 0 | Spin 1/2 | Spin 1 |
|---|---|---|---|
| | $\tilde{l}$, $\tilde{q}$ | $l$, $q$ | |
| | $h^0, H^0, A^0, H^\pm$ | $\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$ | |
| | | $\tilde{\chi}_1^\pm, \tilde{\chi}_2^\pm$, $\tilde{g}_a$ | $\gamma, Z^0, W^\pm$, $g_a$ |

‘organized’ in super-multiplets

- **Squark & slepton:** superpartners of quarks and leptons.
  Ex: **top and bottom squarks**, also called **stop and sbottom**

- **Neutralinos:** mixtures of photon, Z, neutral higgs superpartners
- **Charginos** : mixture of W and charged higgs superpartners
- **Gluinos:** superpartner of the gluon

**How arbitrary can sparticle masses be?** ***Need some guiding principle!***

# Natural models: fine tuning

**Can be guided by the principle of Naturalness****

Fine tuning → quantified in terms of stability of the main scale of the model with respect to its parameters. In this case, EWK scale (MZ):

model parameters

$$max_{a_i}\left(\left|\frac{a_i}{m_Z^2}\frac{\partial m_Z^2(a_i)}{\partial a_i}\right|\right) < \Delta$$

tolerated fine tuning

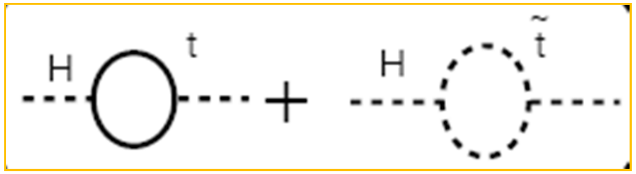
Low level of fine tuning → A **Natural** model

The relevant parameters $a_i$ in SUSY are those more closely related to the higgs → principally, the **stop mass**; but also sbottom and gluino masses

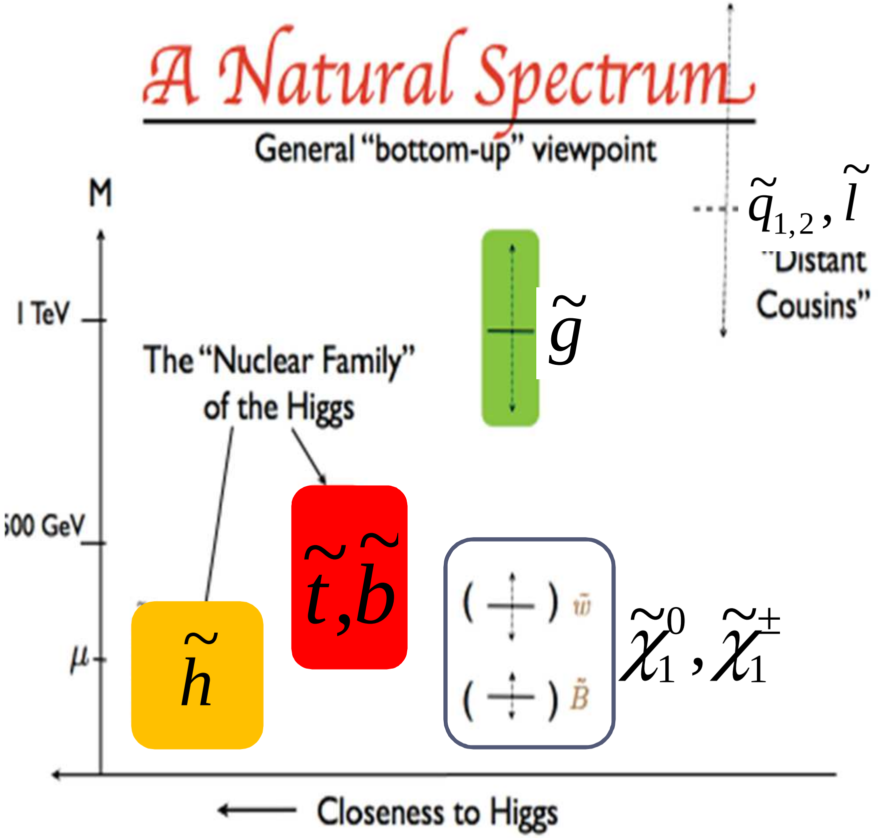
**Riccardo Barbieri, Gian F. Giudice (1988). "Upper Bounds on Supersymmetric Particle Masses". *Nucl. Phys. B* **306**: 63

# Naturalness

The top is the heaviest particle → biggest contribution to Higgs mass correction




→ Top superpartner must be 'light' for the higgs mass to be at O(100 GeV)
*[but also W/Z superpartners]*




***Light* stop** (< 1 TeV) $\tilde{t},\tilde{b}$

*But also*: possibly light sbottom (related!)

***Light* neutralino**, O(100 GeV): often Lightest SUSY particle, good candidate for DM $\tilde{\chi}_1^0, \tilde{\chi}_1^\pm$

*But also*: possibly light charginos (related!)

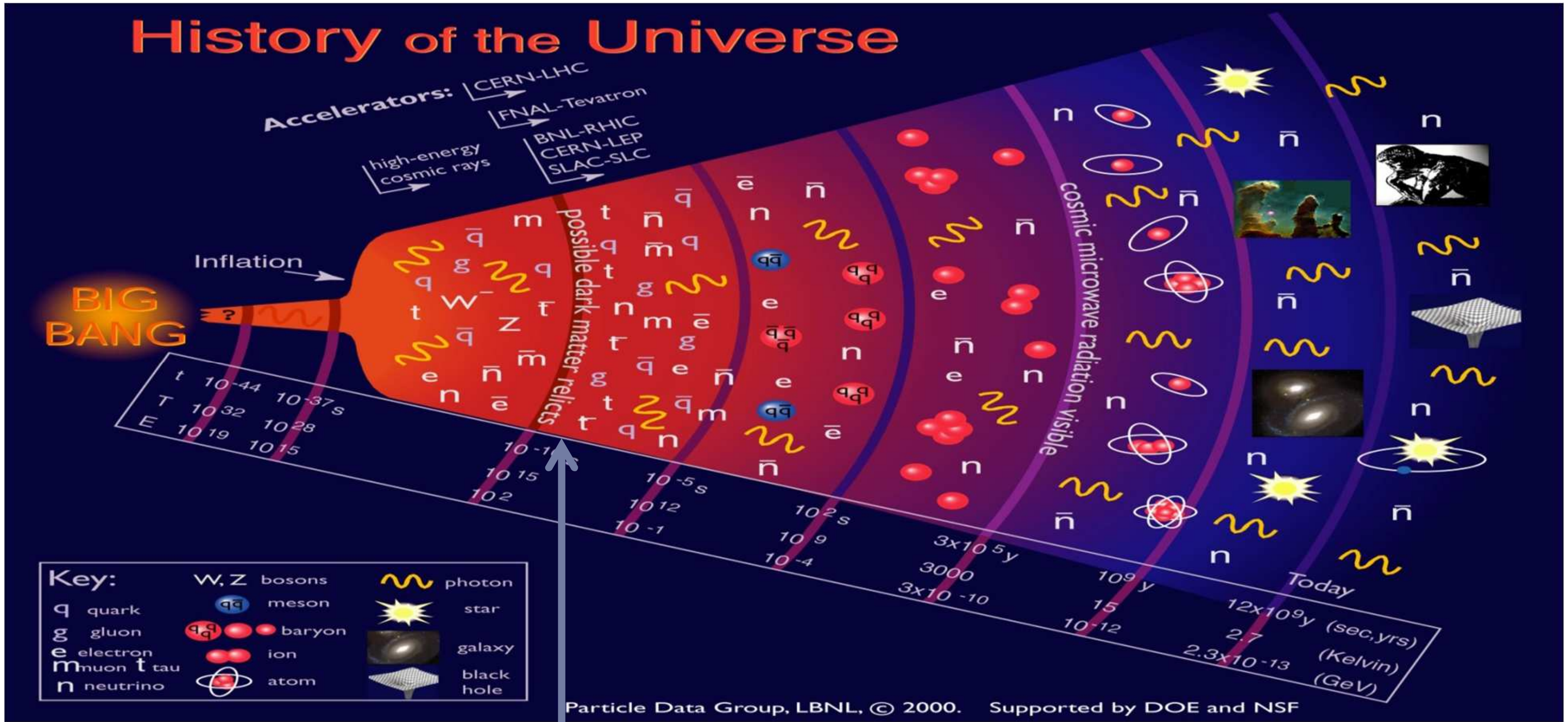
***Light* gluinos** (< 2 TeV) $\tilde{g}$

**‘Light’:** particles with mass 1 TeV = 1000000000000 ev

*To compare:* Core of the Sun T = 1000 ev

→ Need extremely high energies to produce them

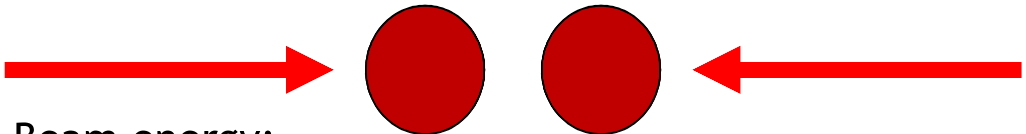
→ Back to the condition of the Universe $10^{-10}$ s after the Big Bang




**Conditions ‘recreated’ in particle accelerators: collisions between fundamental constituents of matter at extremely high energies**

# The Large Hadron Collider

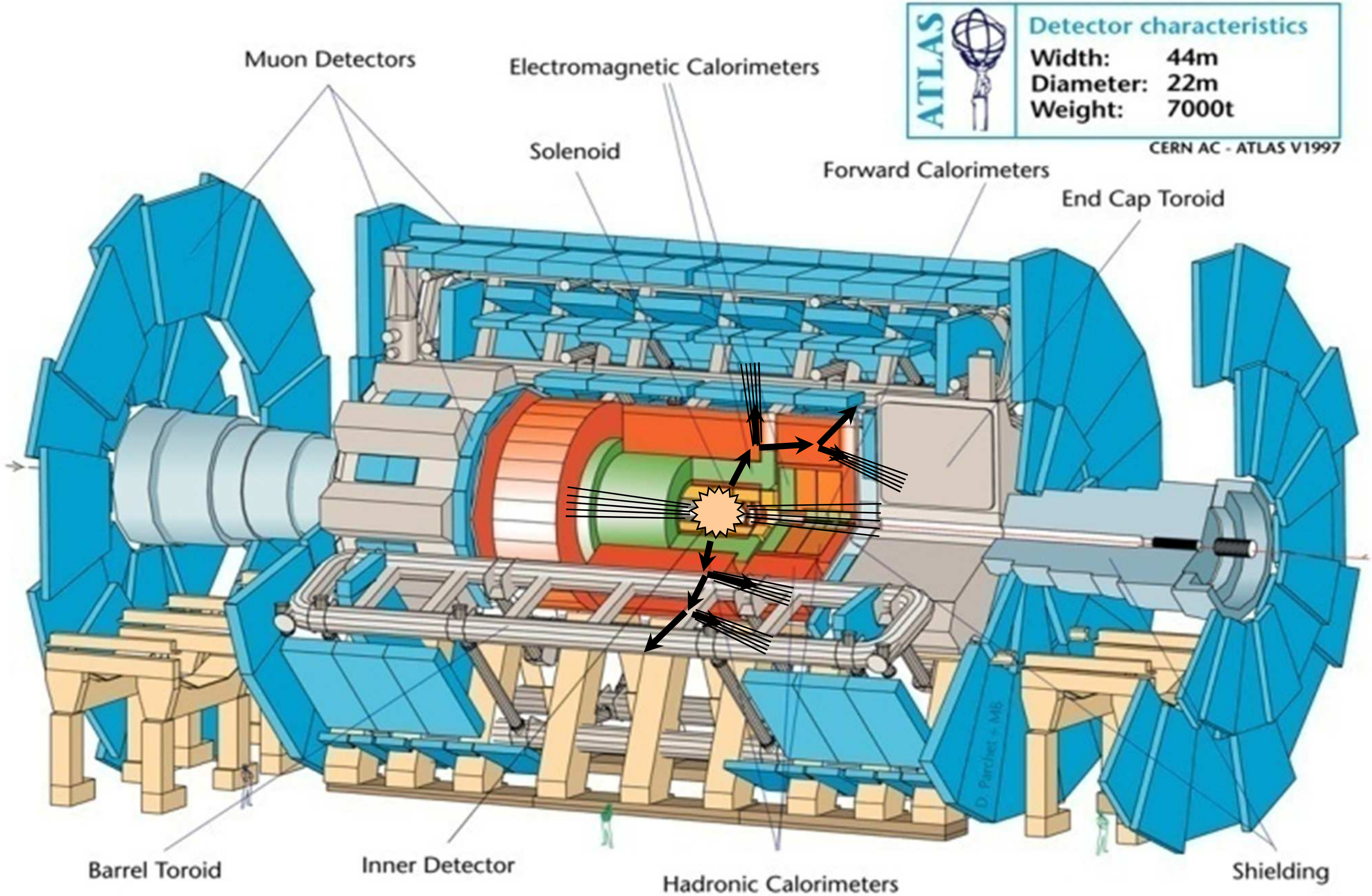

Beams of protons (set in bunches) accelerated by electromagnetic force to 99,9999991% the speed of light



Beam energy:
3.5 TeV (2011), 4 TeV (2012)

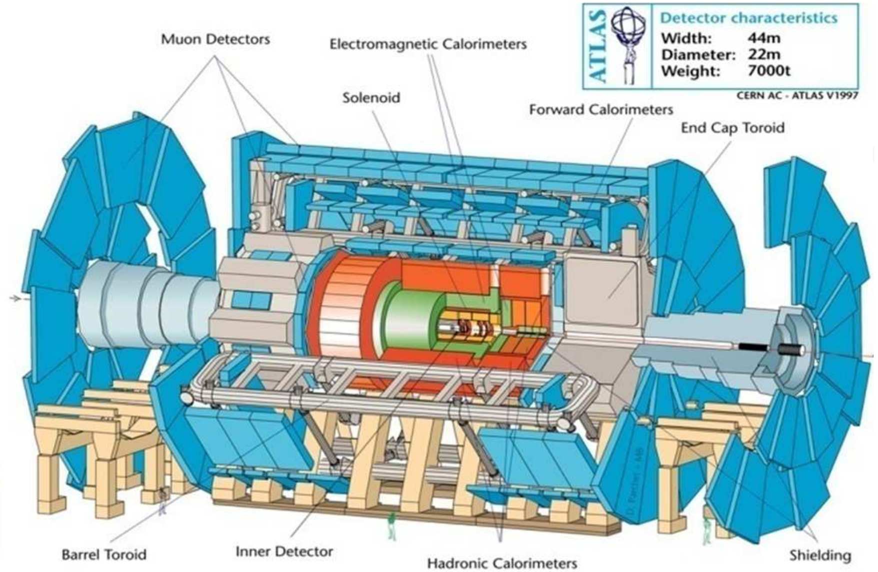
Centre of mass energy $\sqrt{s}$ = 7 or 8 TeV

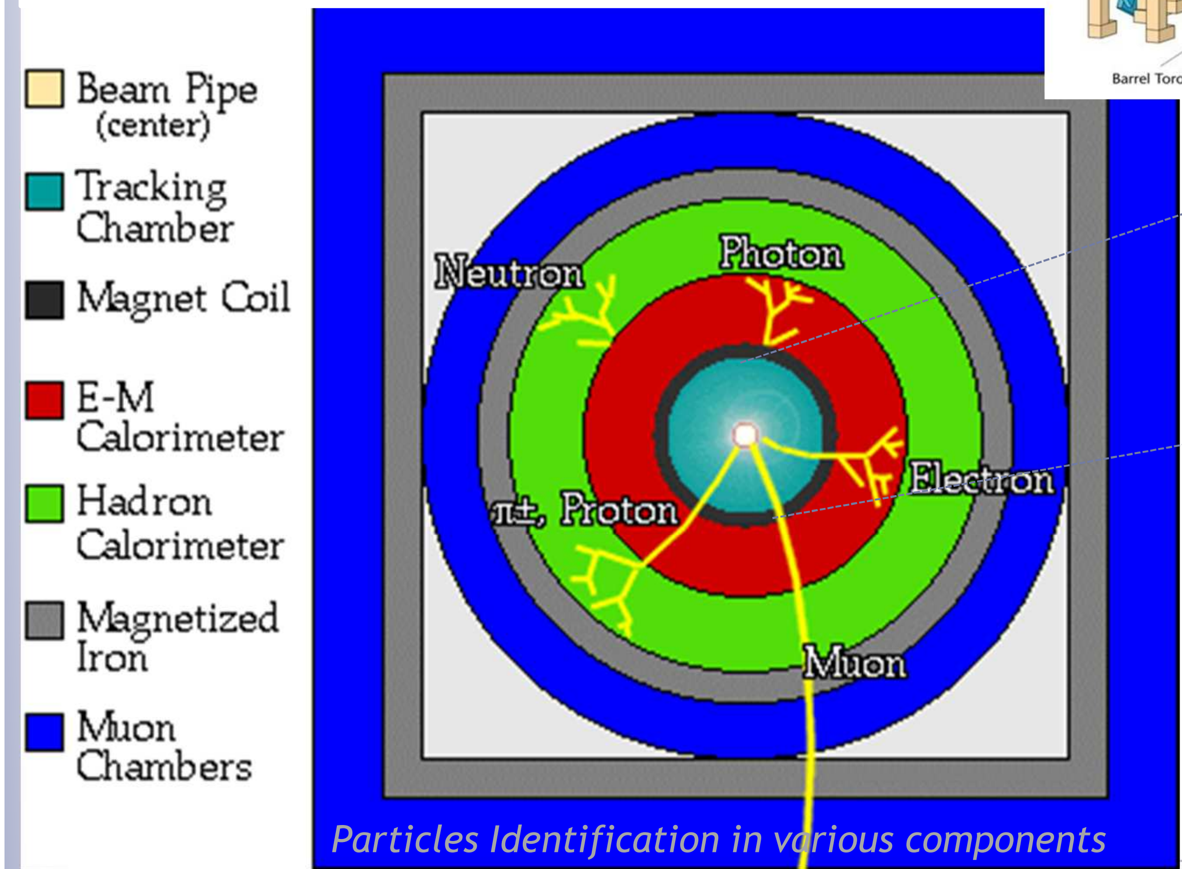
# The ATLAS experiment



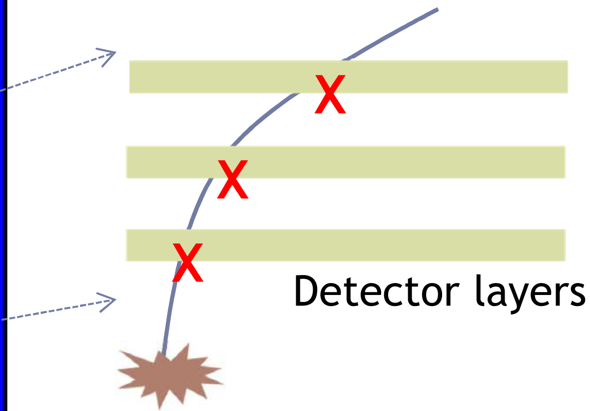
# The ATLAS experiment

- Detector designed to separate electrons, photons, muons, neutral and charged hadrons
- A transverse view:



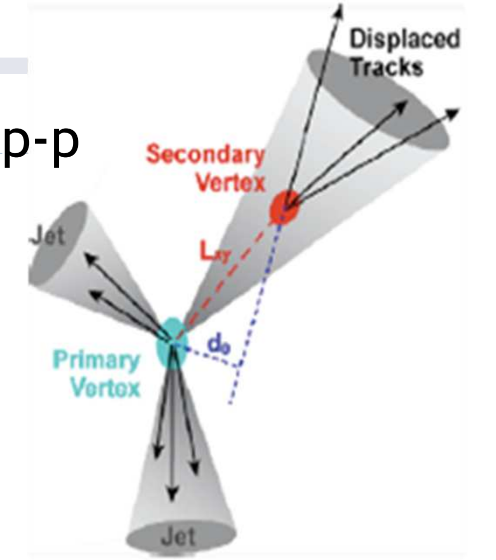

*Particles Identification in various components*




**Transverse momentum, $p_T$**

Head-on collisions: Visible transv. momentum conserved → $\sum_i p_T^i \approx 0$

# Physics objects




- **Jets** → initiated by quarks or gluons produced in the p-p collision. Result in clusters of hadrons and leptons in calorimeters
  - **B-jets** → jet identified as originated from B-hadron which do not decay promptly but fly for few mm
- **Photons** → EM cluster w/o matching track
- **Electrons** → same with matching track
- **Muons** → track in Tracker and Muon chambers
- **Tau (hadronic)** → narrow jets with 1 or 3 tracks
- **Missing ET (MET)** → unbalanced transverse momentum
  - **Real MET:** presence of neutral weakly interacting particle in the event (i.e. neutrinos, or the lightest SUSY particle)
  - **Fake MET:** mismeasurements + detector malfunctions, poorly instrumented regions

# Cross Sections at the LHC

Cross section ($\sigma$): the probability for a specific process to occur in a collision
[barn = $10^{-28}$ m$^2$]

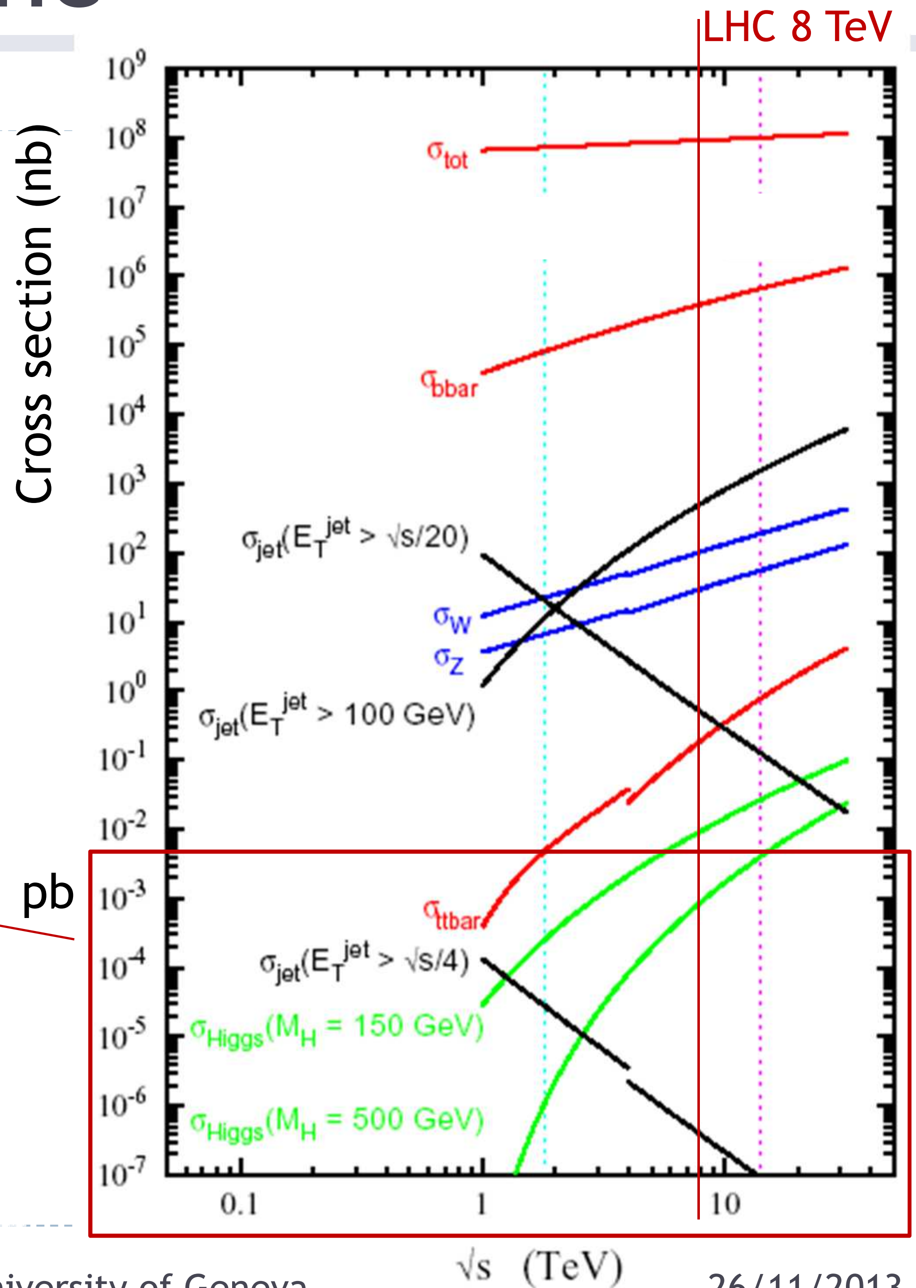
- A lot more "uninteresting" than "interesting" processes
- Interesting events gets selected:
  - Online, by trigger:
    - Selection mechanism to find events which contain interesting features
  - Offline, by physics analysis
    - Offline selection designed to suppress background compared to the signal of interest

Typical SUSY particle production rate

Integrated Luminosity = amount of data collected by ATLAS

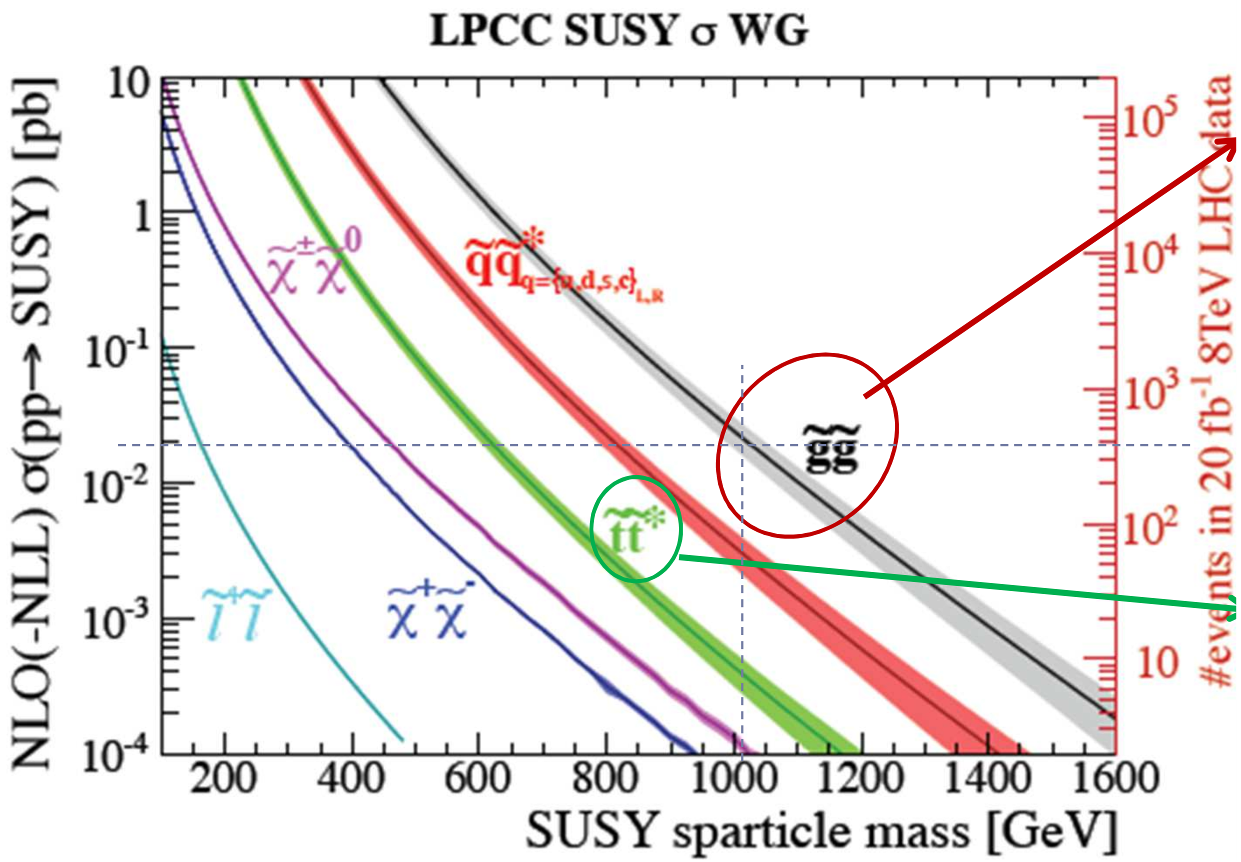
**5 fb$^{-1}$ 2011 @ 7 TeV**

**20 fb$^{-1}$ 2012 @ 8 TeV**



# SUSY production processes and rates

- If R-parity is conserved, sparticles are pair-produced




**Gluino production:**
- high production rate (σ) up to 1 TeV mass

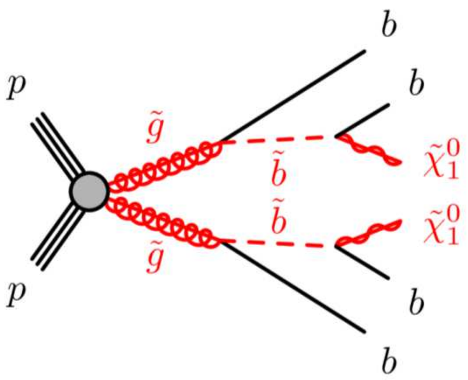
**Stop and sbottom**
- moderate production rate up to ~0.6 TeV

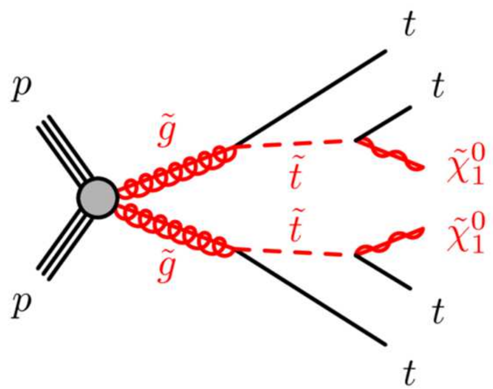
**Focus on 'strong' production in Natural SUSY: gluino decaying in stop+top or sbottom+bottom, and direct stop and sbottom production**

Lightest SUSY particle is DM candidate (Here: LSP = neutralino)

# Searches for natural SUSY: gluinos

- Only gluino, stop and sbottom masses are accessible → can search for third generation squarks produced via <u>gluinos:</u>
  - High production rate
  - Spectacularly rich final states. Examples:

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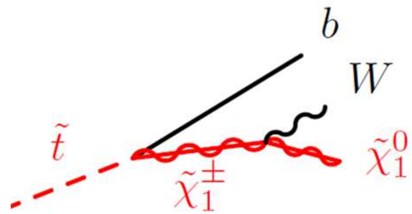
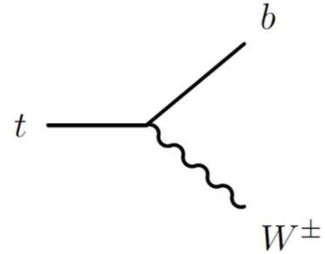


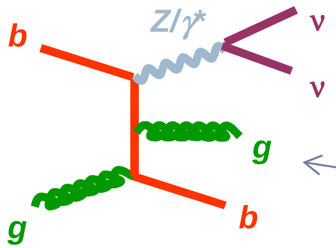

Final state events:
4 b-jets and Missing ET

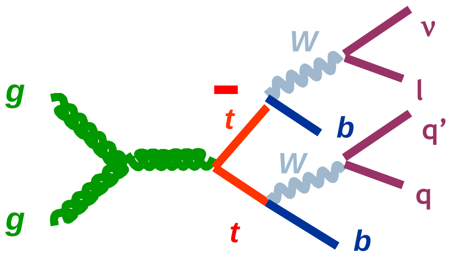
Final state events:
4 b-jets + Missing ET + 4 W bosons, W → l ν or W → qq'

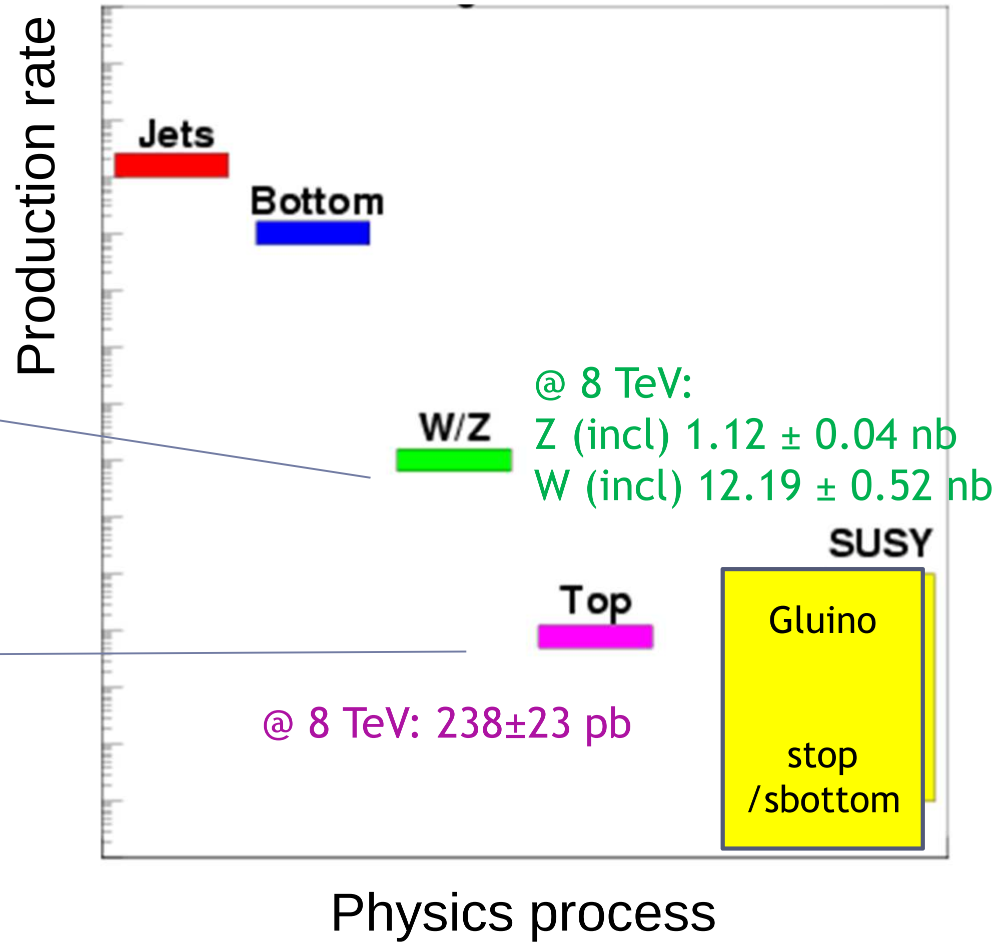
→ Many jets, many b-jets, possibly leptons, high MET if m(neutralino) is light

# SM background

- SM processes might have very high production rate and can **mimick** SUSY event topologies



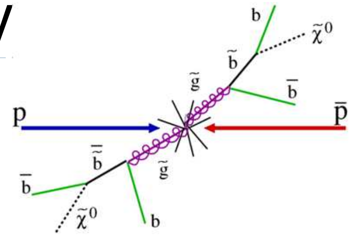



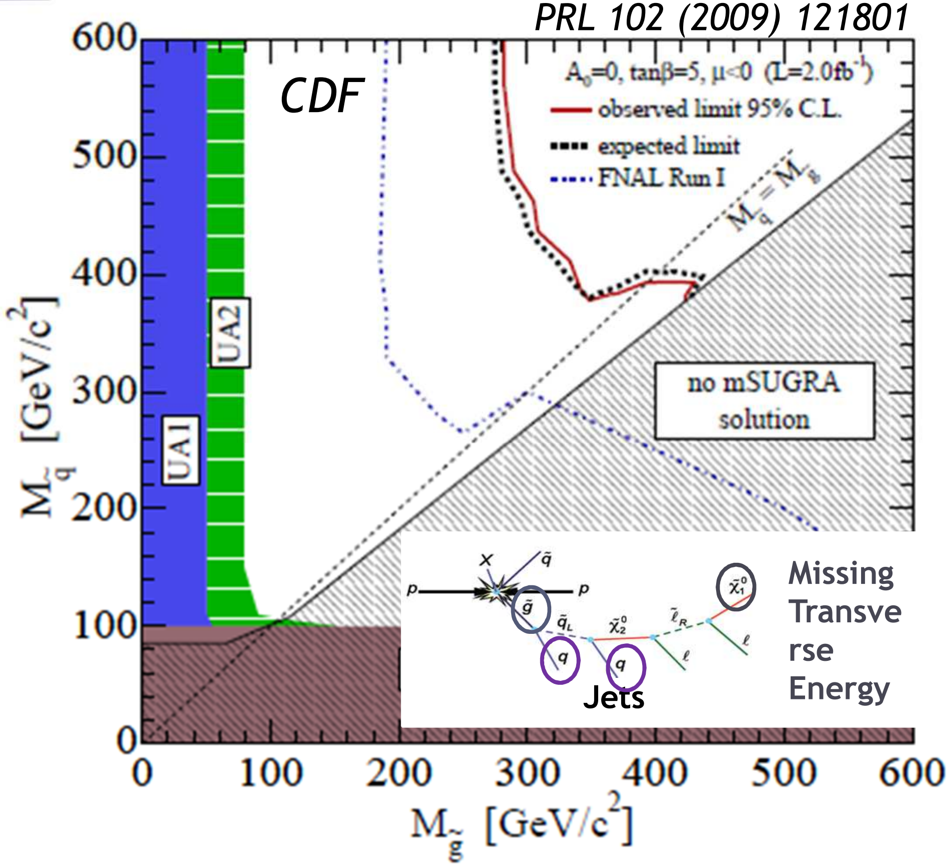

- **Searching for new particles:** **reject** as efficiently as possible SM processes, and determine residual contributions

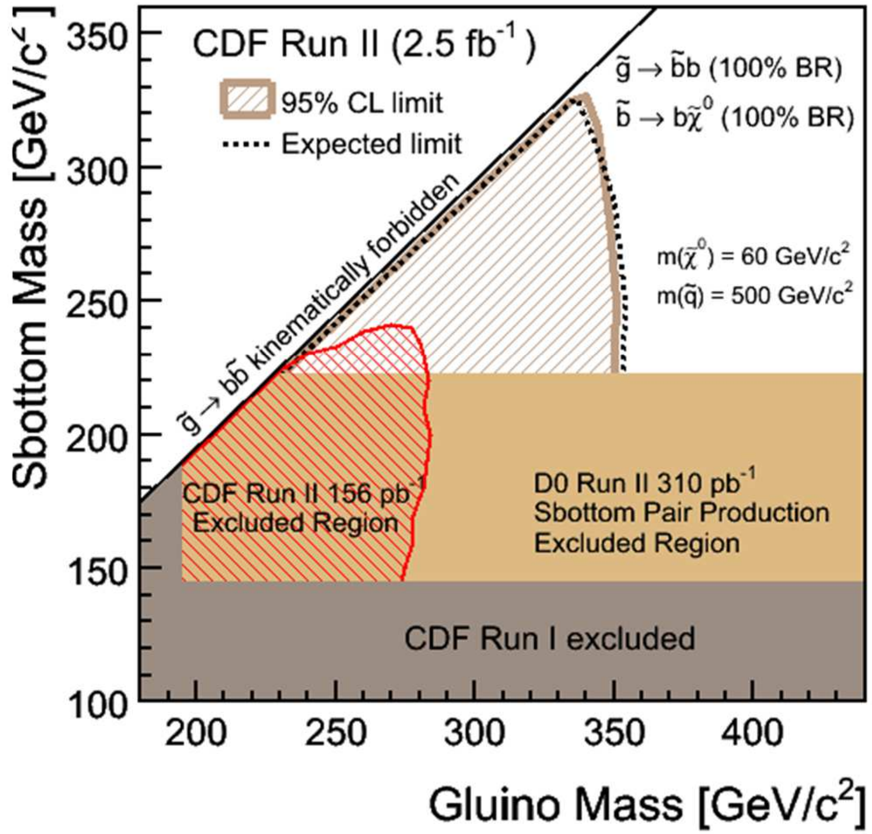
*E.g.: Can exploit the fact that gluinos should be 'heavy'. How much ?*

# Pre-LHC constraints on gluino masses

- From CDF and D0 experiments at TeVatron ($p\bar{p}$): $\sqrt{s}$=1.96 TeV
  - Searches for gluinos decaying via first, second generation or bottom squarks. No reach for gluinos in stop+top!

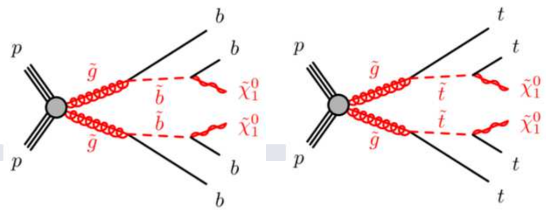




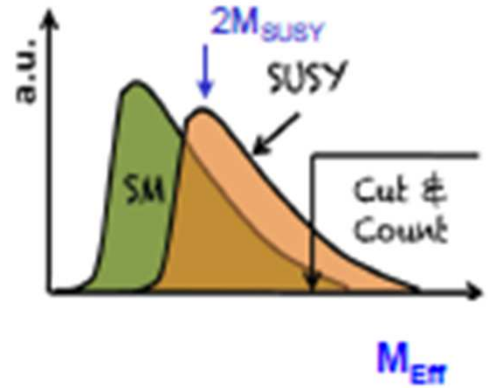

**exclude gluino masses below 300-400 GeV for neutralino masses < 100 GeV**

# Stop and sbottom via gluinos



- Searching for something heavy!
- Exploit high transverse momentum of decay products, large MET

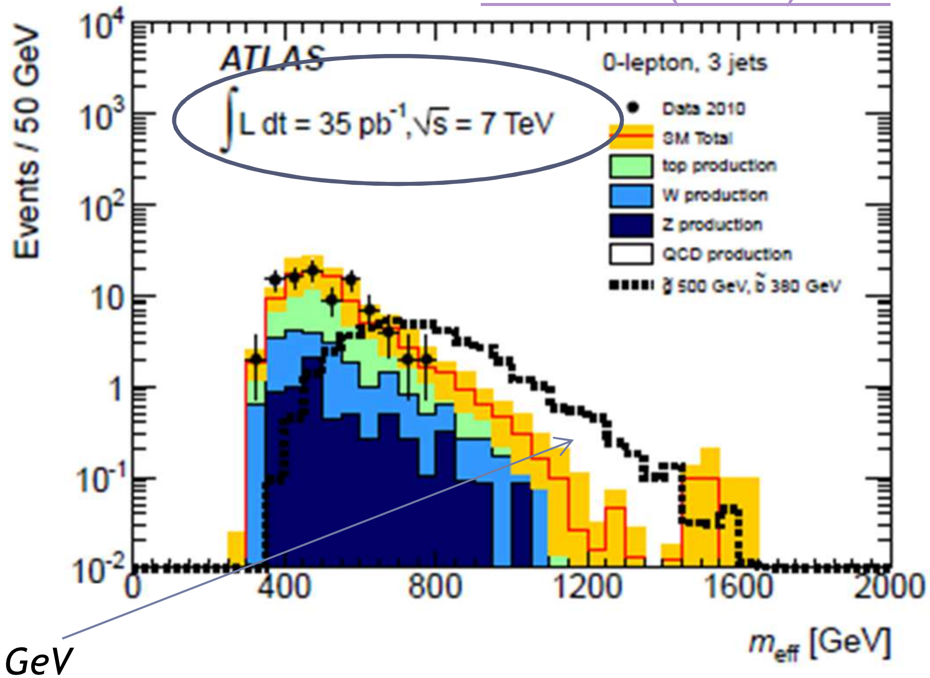
$M_{eff}$ = MET + Σ $p_T$ jets + Σ $p_T$ leptons




- Exploit the presence of b-jets

PLB 701 (2011) 398

- Classify search regions (Signal Region) in terms of N b-jets, N leptons, $M_{eff}$, MET

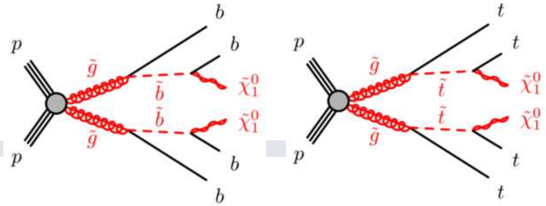



- Careful studies of SM background:

*e.g.* top pair production

*Example of Signal: M gluino = **500 GeV**, M sbottom = 350 GeV, M neutralino = 60 GeV*

# Stop and sbottom via gluinos



- Searching for something heavy!
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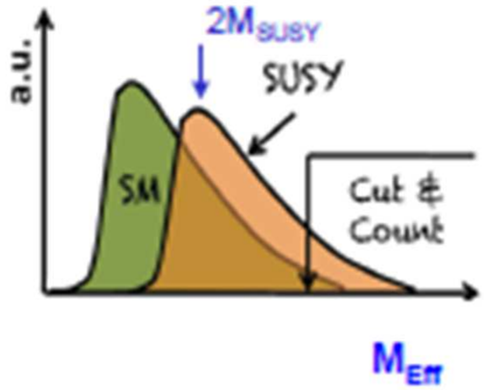
$$M_{eff} = MET + \Sigma\, p_T \text{ jets} + \Sigma\, p_T \text{ leptons}$$

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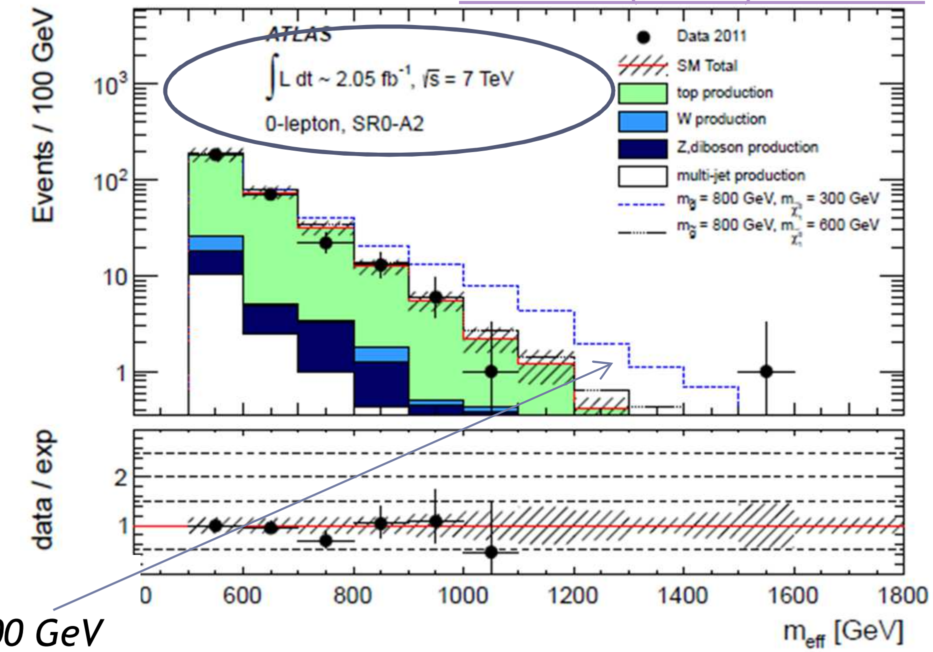
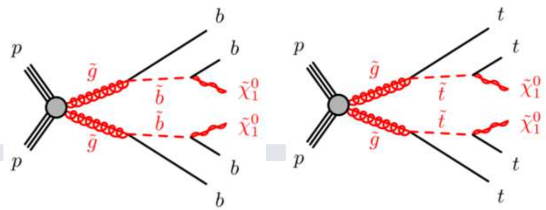



- Careful studies of SM background:

*e.g.* top pair production

*Example of Signal: M gluino =* ***800 GeV,***
*M sbottom = 2000 GeV,M neutralino = 300 GeV*

# Stop and sbottom via gluinos



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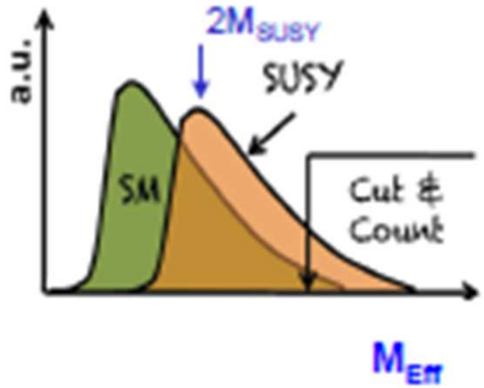
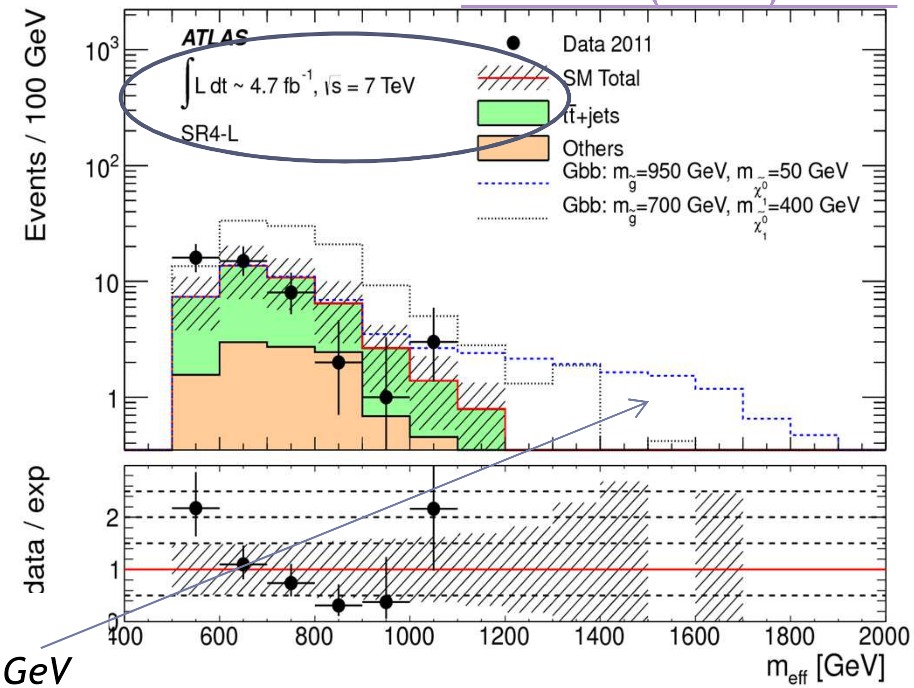
- Exploit high transverse momentum of decay products, large MET

$M_{eff}$ = MET + Σ $p_T$ jets + Σ $p_T$ leptons




- Exploit the presence of b-jets

EPJC 72 (2012) 2174



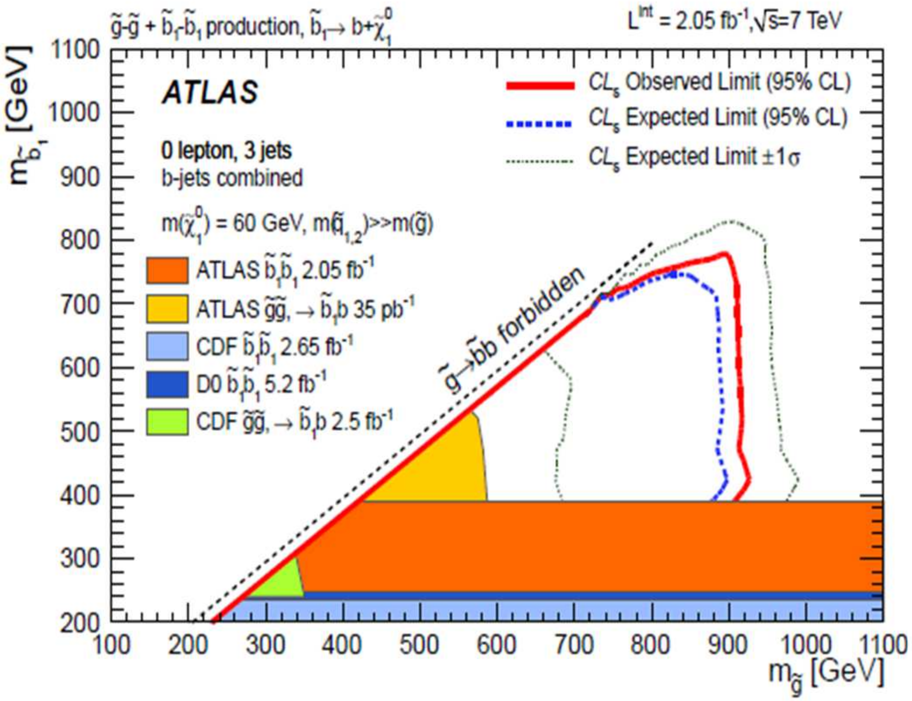

- Classify search regions (Signal Region) in terms of N b-jets, N leptons, $M_{eff}$, MET
- Careful studies of SM background:

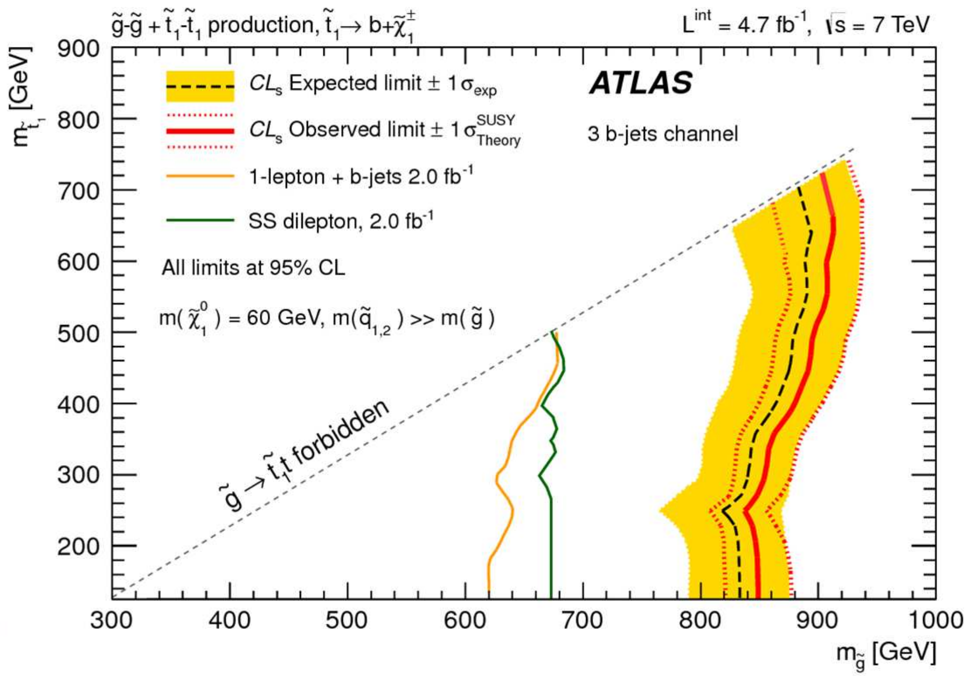
*e.g.* top pair production

*Example of Signal: M gluino = **950 GeV**, M sbottom = 2000 GeV, M neutralino = 50 GeV*

# Constraints on masses

- Null results interpreted in various Natural SUSY models
- Constraints on masses depend on the assumed mass hierarchy of gluino, sbottom, stop, neutralinos



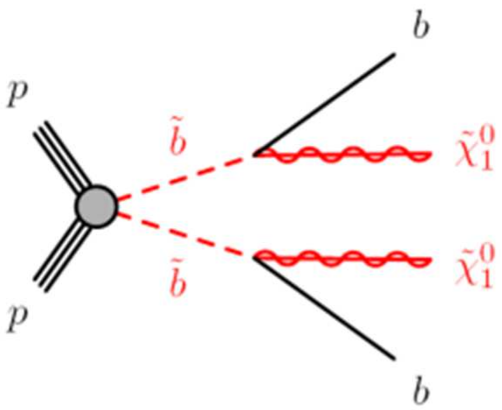



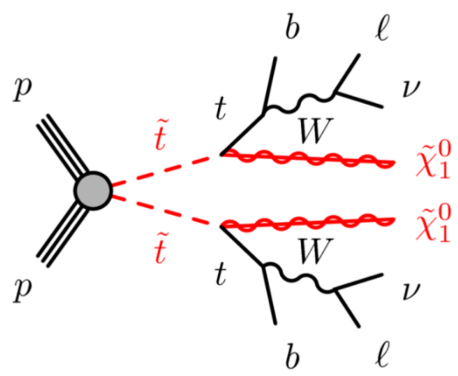

**Already using 7 TeV data, for Mneut < 100-200 GeV: exclude up to 800-1000 GeV gluinos and 700-900 GeV stop and sbottom.**

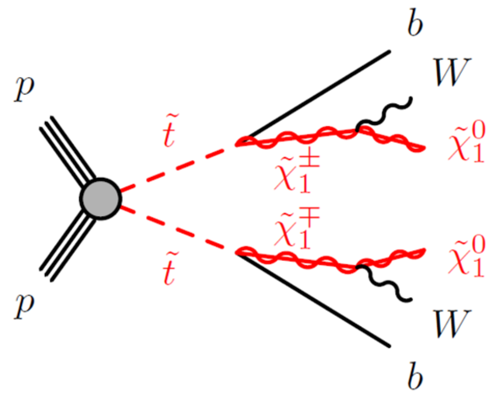
**State of the art at 8 TeV: gluino in 3rd generation squarks excluded up to 1.34 TeV**

# Direct production of sbottom/stop

- Most ‘direct’ way to search for Natural SUSY in strong production
- Challenges:
  - Relatively low production rate:
    - at mass = top mass, x-section is 1/6 of ttbar x-section
  - Can’t always exploit the high transverse momentum of decay products:
    - Could be as light as the top quark
  - Various decay modes must be considered. *Few examples:*



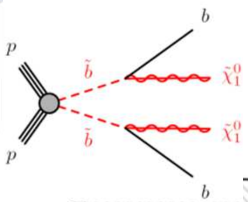




Final state events:
2 b-jets and Missing ET

Final state events:
2 b-jets + Missing ET + 2 W bosons,
W → l ν or W → qq’

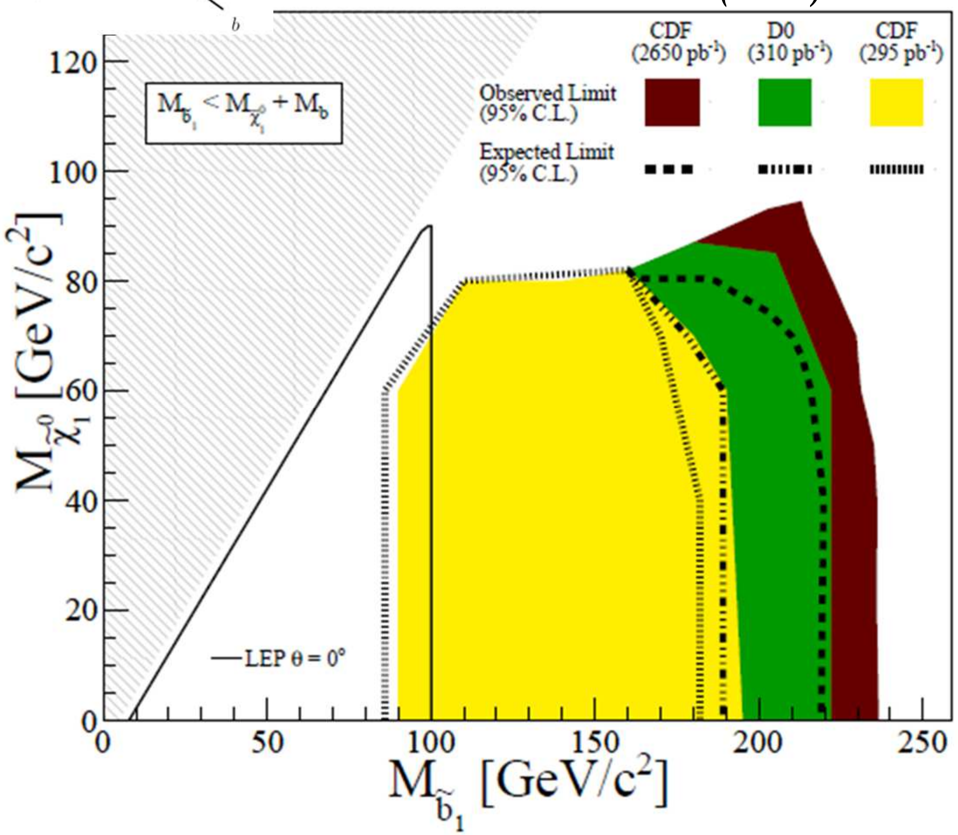
# Pre-LHC constraints on stop and sbottom

From Tevatron experiments and LEP experiments (e+e- collider, √s up to 209 GeV)

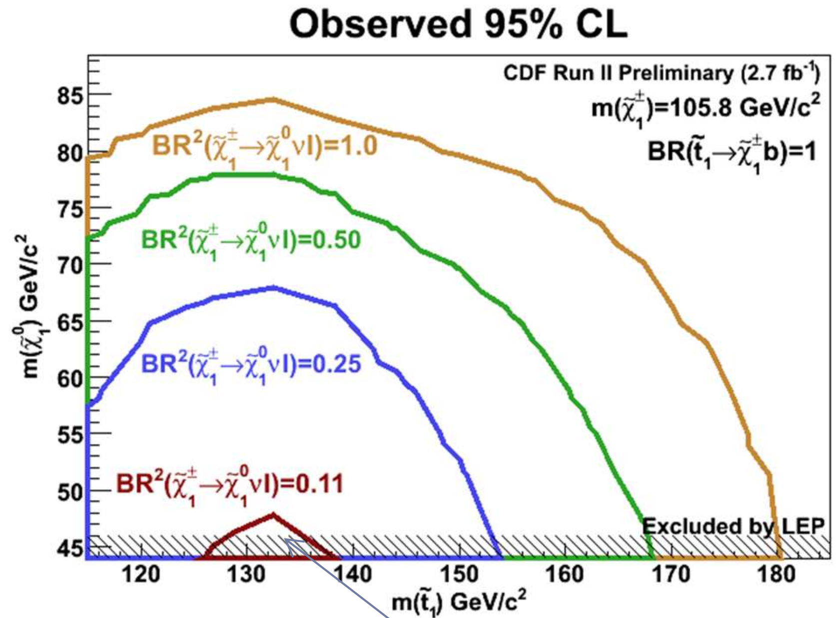


*Sbottom:*
2 b-jets and Missing ET

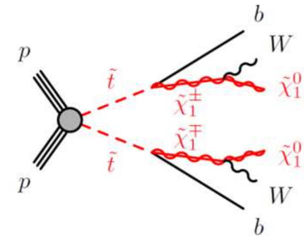
*PRL 105 (2010) 081802*




*Stop:*
2 leptons + 2 b-jets and Missing ET

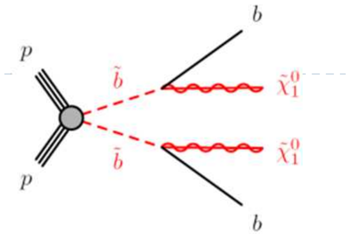



weak constraints in the most likely scenarios!



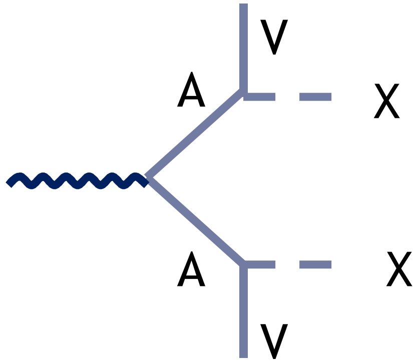
**In general pre-LHC constraints below 250 GeV for sbottom, lower for stop**

# Direct sbottom at ATLAS



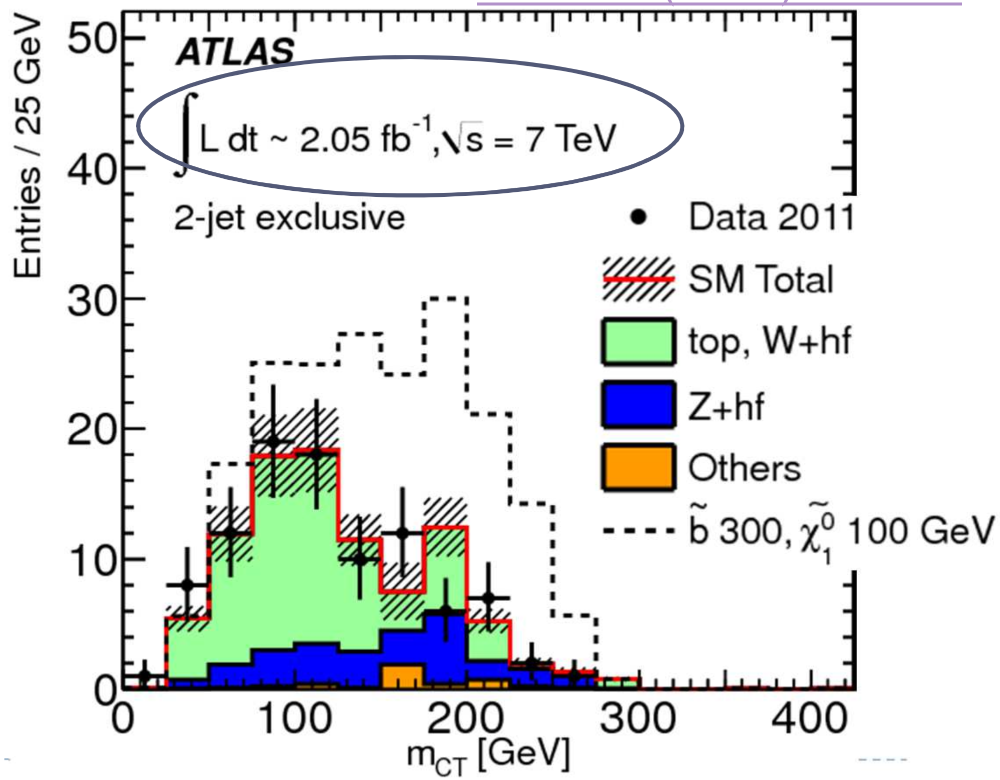
- Consider events with 2 b-jets, MET and nothing else
- Main SM background: top pair production
- To reject it efficiently:
  - exploit mCT (contransverse mass) observable, sensitive to pair production of heavy particles (A) decaying in visible (V) + invisible (X)

PRL 108 (2012) 181802




- In this case:
  - A = sbottom, V = b-jet, X = Neutralino
  - mCT: has an endpoint at 140 GeV for the top background. For signal:

$$m_{cT}^{\max} = \frac{m^2(\tilde{b}) - m^2(\tilde{\chi}_1^0)}{m(\tilde{b})}$$



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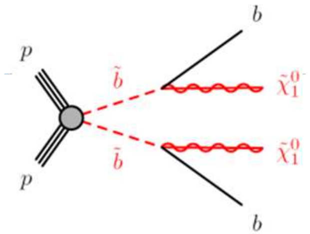
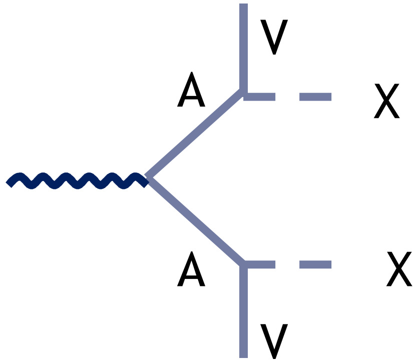
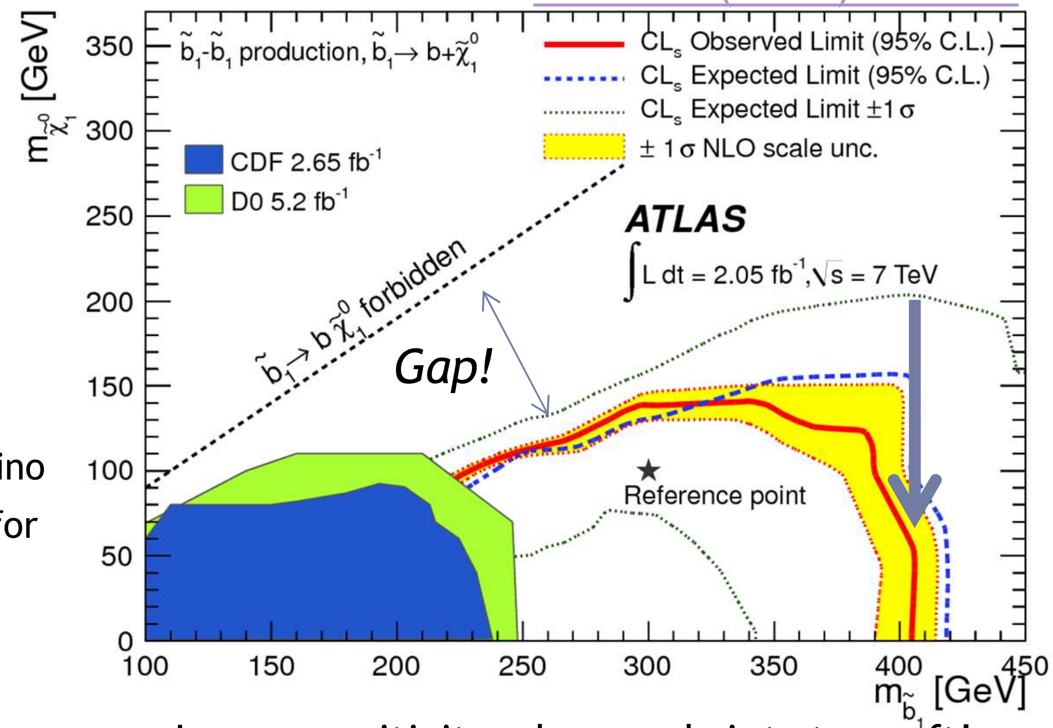





PRL 108 (2012) 181802

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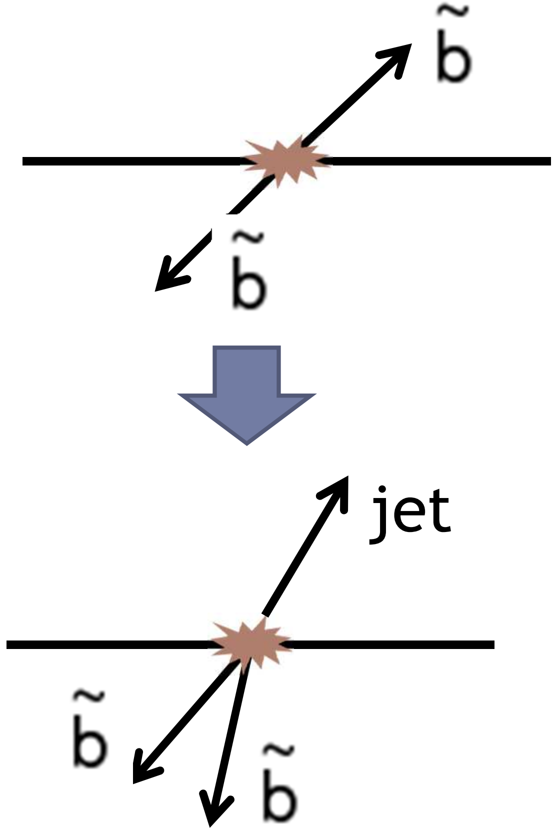
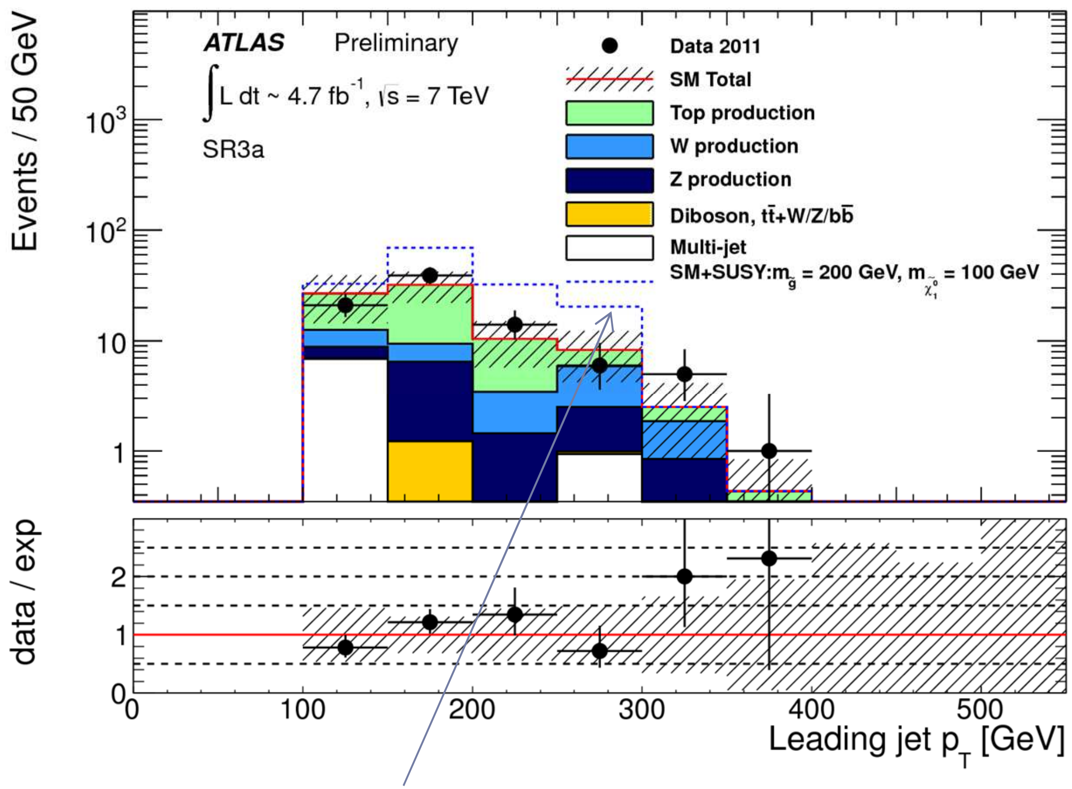
  - mCT: has an endpoint at 140 GeV for the top background. For signal:
  - $$m_{cT}^{max} = \frac{m^2(\tilde{b}) - m^2(\tilde{\chi}_1^0)}{m(\tilde{b})}$$

Loose sensitivity when $p_T$ b-jets too soft!

# Direct sbottom at ATLAS

- With more luminosity, develop methods to fill the gap in scenarios with low ΔM (sbottom-neutralino) – compressed
- Exploit production of hard jets from colliding partons (Initial State Radiation, ISR)



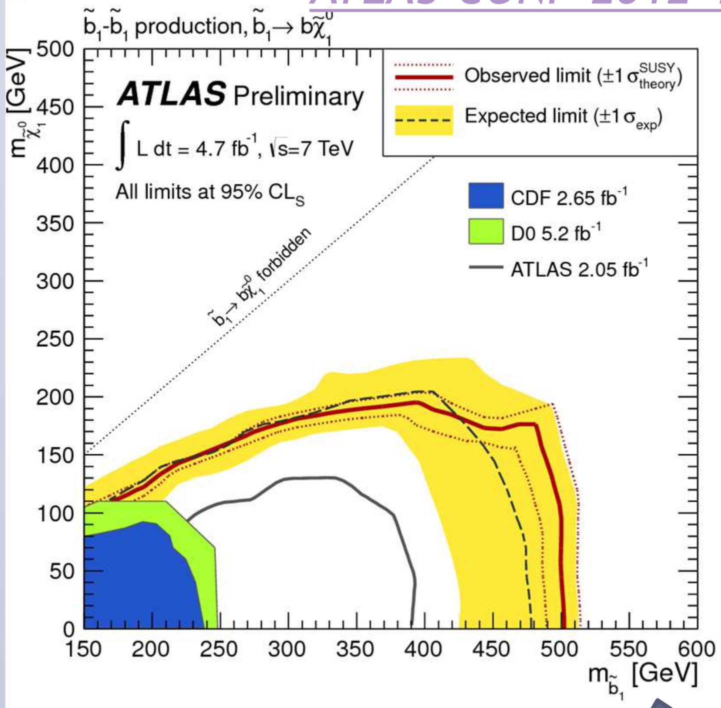




M sbottom = 200 GeV,M neutralino = 100 GeV

# Direct sbottom at ATLAS

- Improve sensitivity already using 7 TeV data (4.7 $fb^{-1}$)
- With 4 times more luminosity and increased energy gap is almost filled

*ATLAS-CONF-2012-106*




7 TeV, 4.7 $fb^{-1}$

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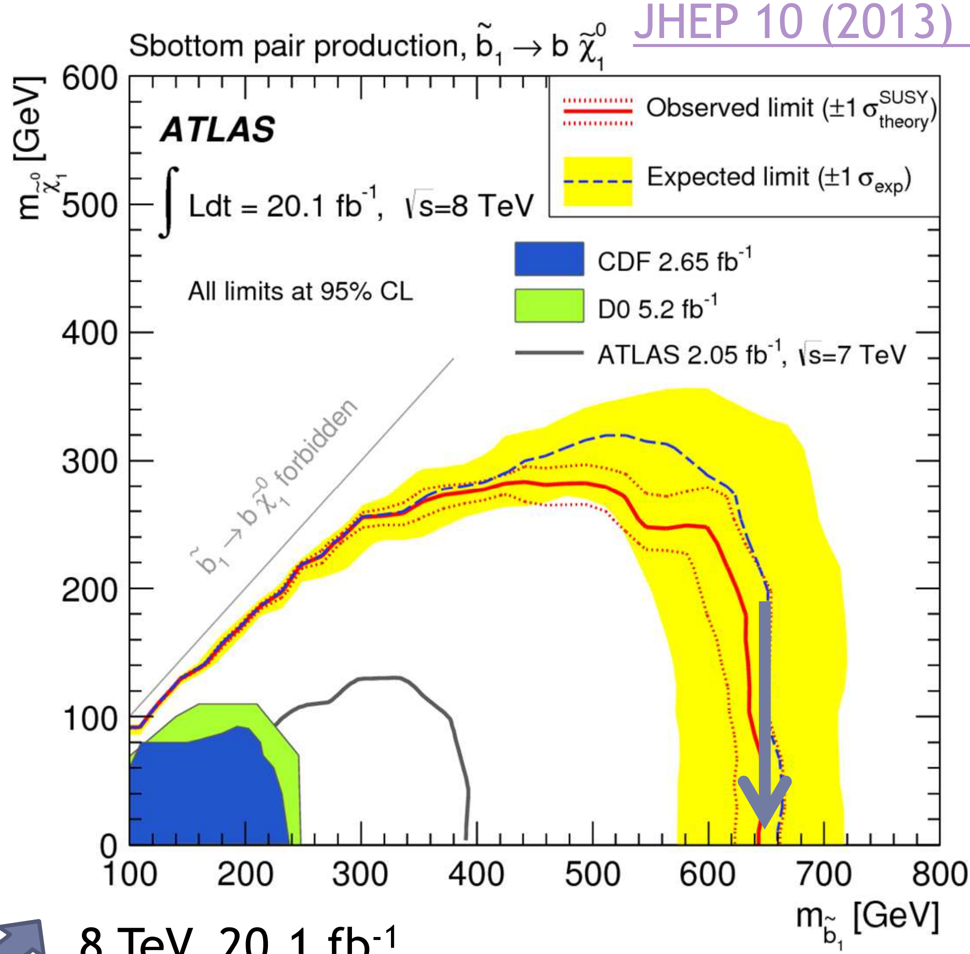
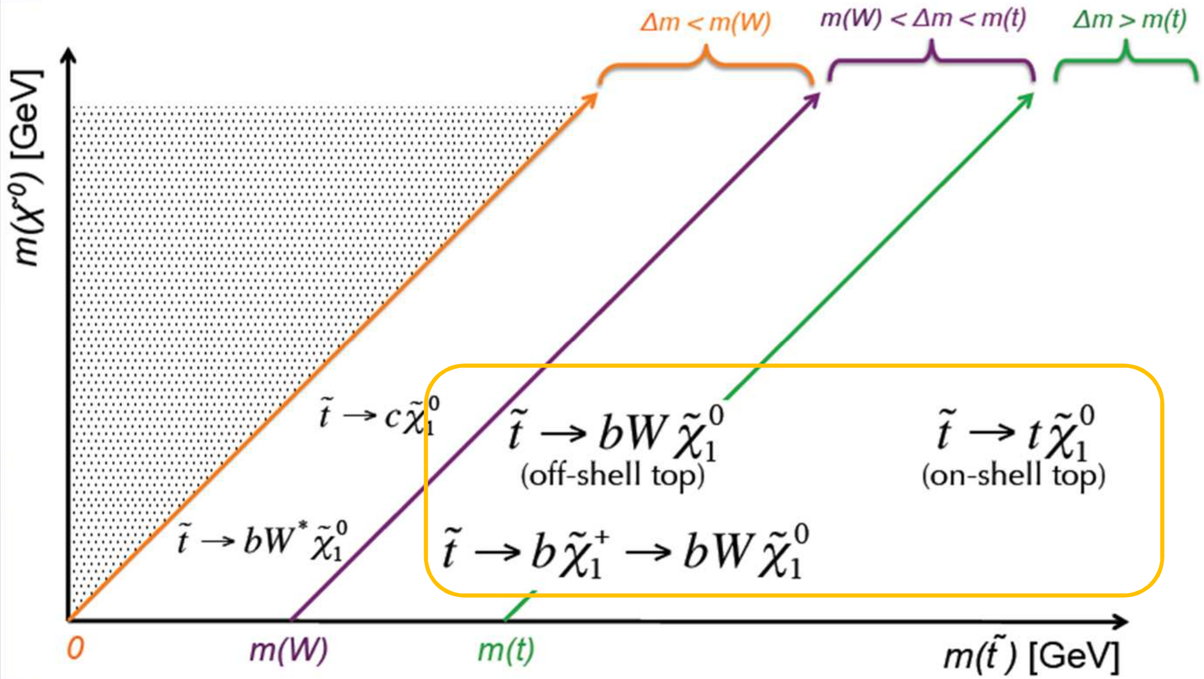


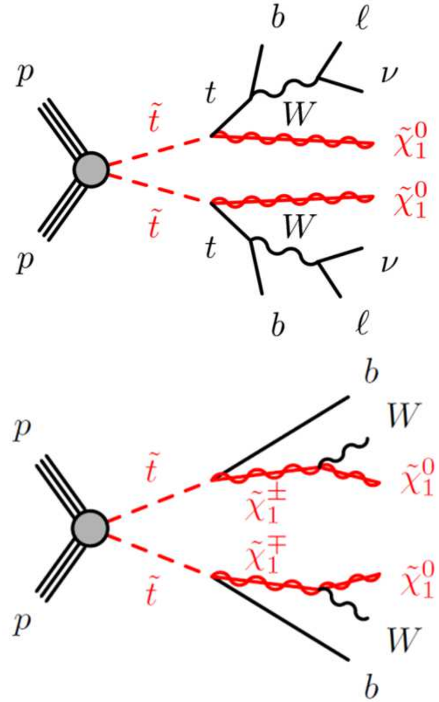

8 TeV, 20.1 $fb^{-1}$

# Direct stop production at ATLAS

- Top squarks have the most crucial role in Natural SUSY
  - Several decays possible
    - Assume 1 decay mode at a time (BR=100%)
  - Need dedicated searches

At the end of 2011, ATLAS put together a **strategy** to cover a wide range of masses, various decay modes and several hypotheses of SUSY mass hierarchy



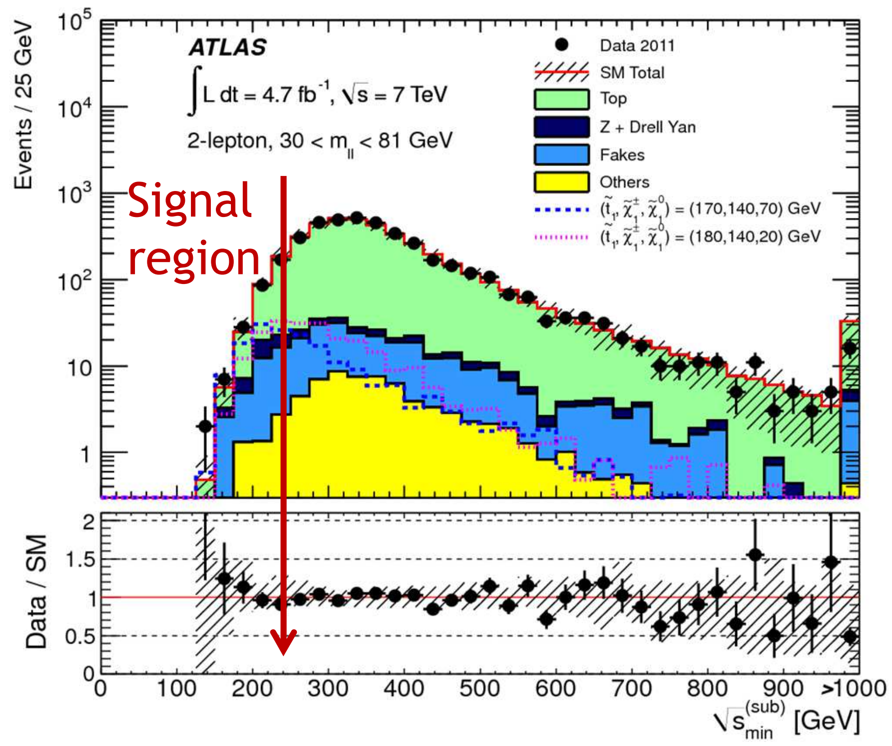



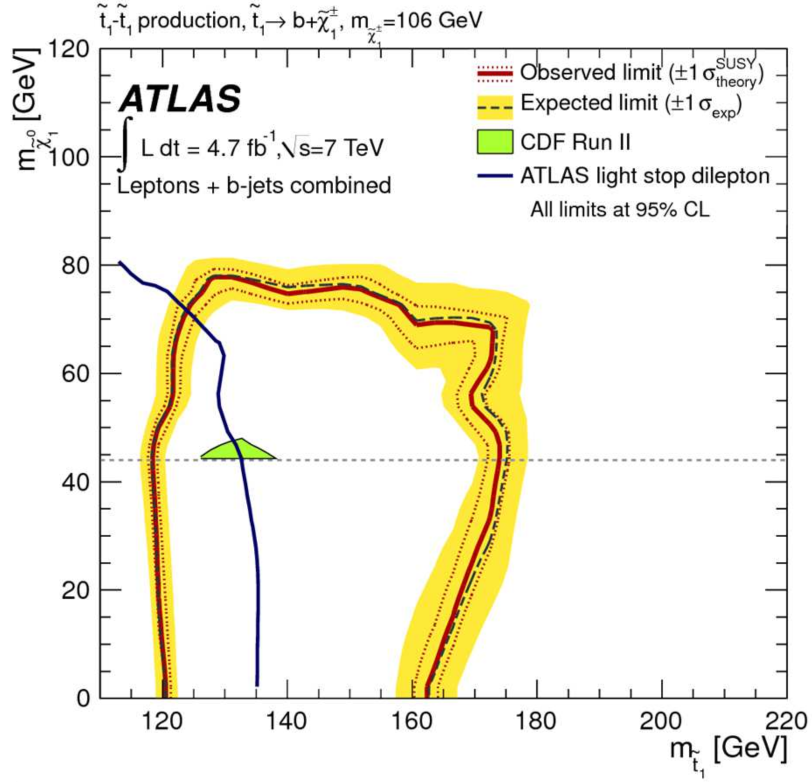
# 7 TeV, 4.7 fb$^{-1}$ searches for stop

- *Example:* m(stop) close to m(top)
  - Again, need to adopt complex kinematic variables to extract signal from overwhelming SM background!

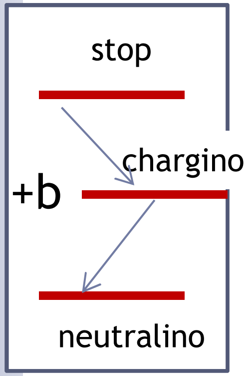
1/2 leptons + 2 b-jets (+0/2 jets) + Missing ET

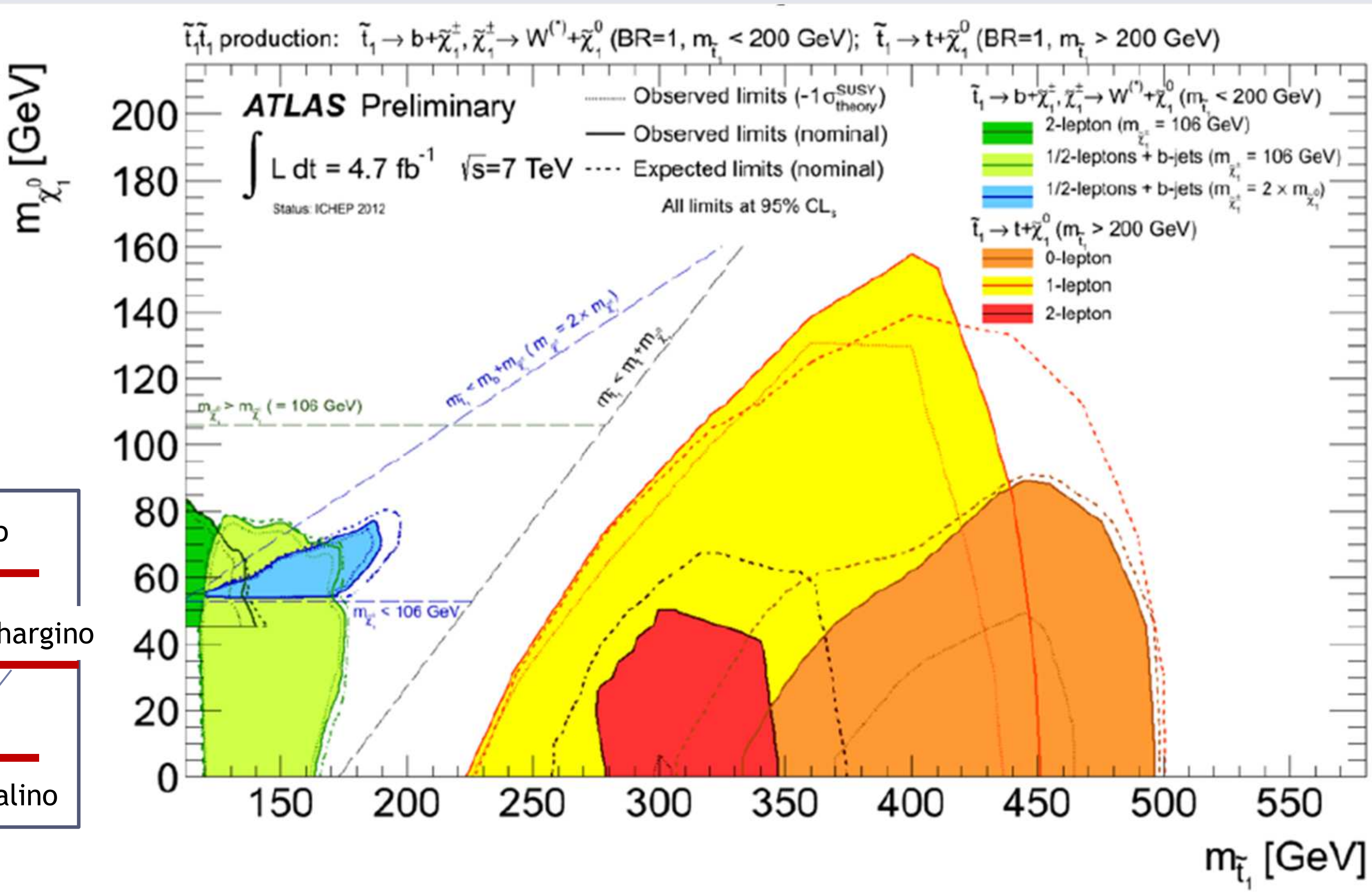
PLB 720 (2013) 13

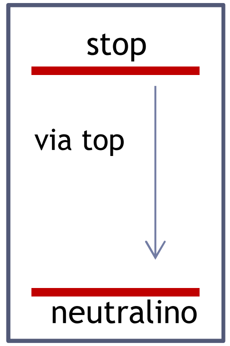


# The golden plot

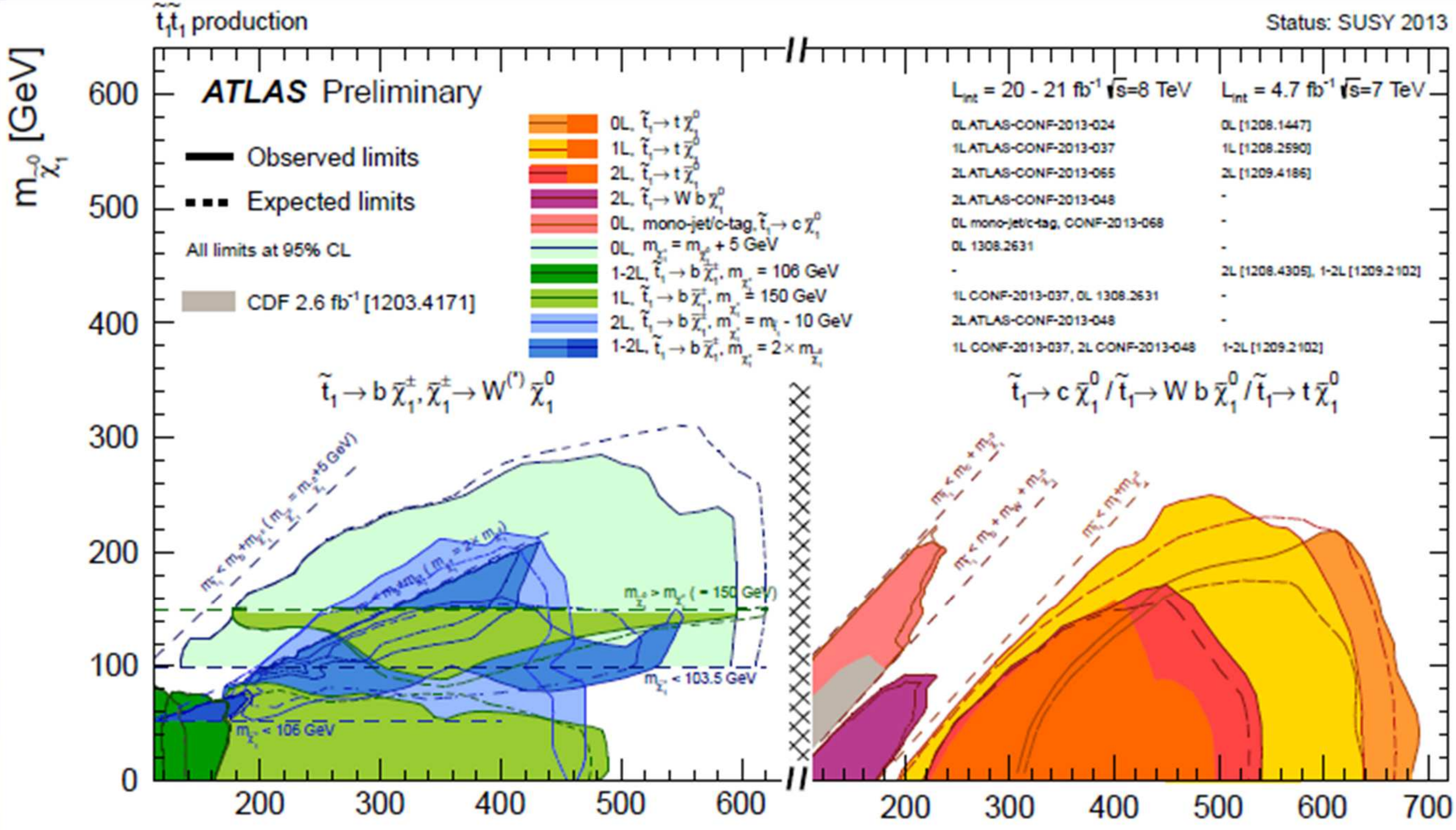



- Presented for the first time at ICHEP 2012, inspired an enourmus number of theory papers, experts workshops and blogs !
  - It was not at all obvious that could reach such sensitivity with 5 $fb^{-1}$!

# Where we are now

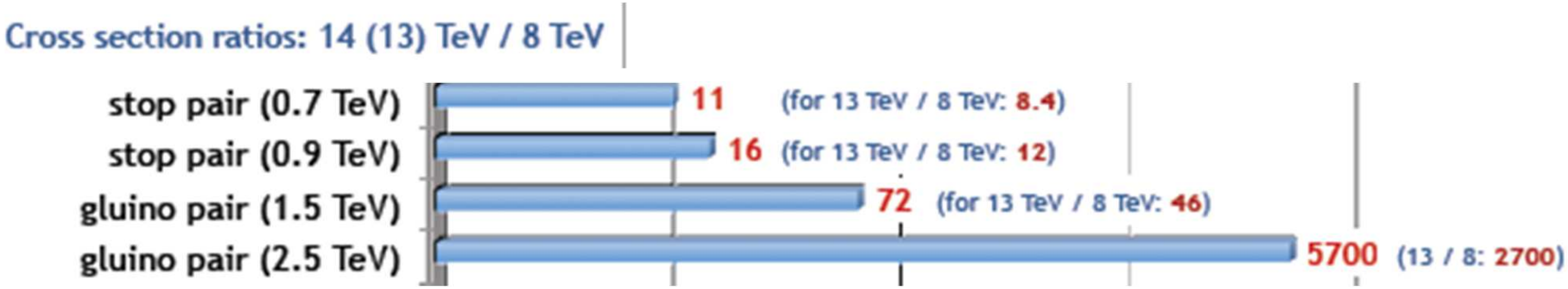



Large regions of SUSY parameter space excluded

But a lot more to be done to cover gaps / find the stop

# The near future

- Explore more challenging scenarios where stop and sbottom could hide
  - I.e. stop close to top mass, compressed scenarios
  - Mixed decays: relax assumption that only 1 decay mode is realized in nature → much more difficult to decouple it from SM
- Get ready for Run II
  - Start in 2015 with 13 TeV center of mass energy




  - Expect to have sensitivity up to 2 TeV gluinos and up to 900 GeV for stop and sbottom depending on the SUSY model

# The far future: High Luminosity LHC

- Foresee an additional major Run for LHC, before upgrade of the accelerator. Then: High Luminosity LHC (around 2023)
  - Expect a major upgrade of the ATLAS detector
  - Expect to collect up to 3000 $fb^{-1}$
    - Factor of 10 in integrated luminosity wrt previous run

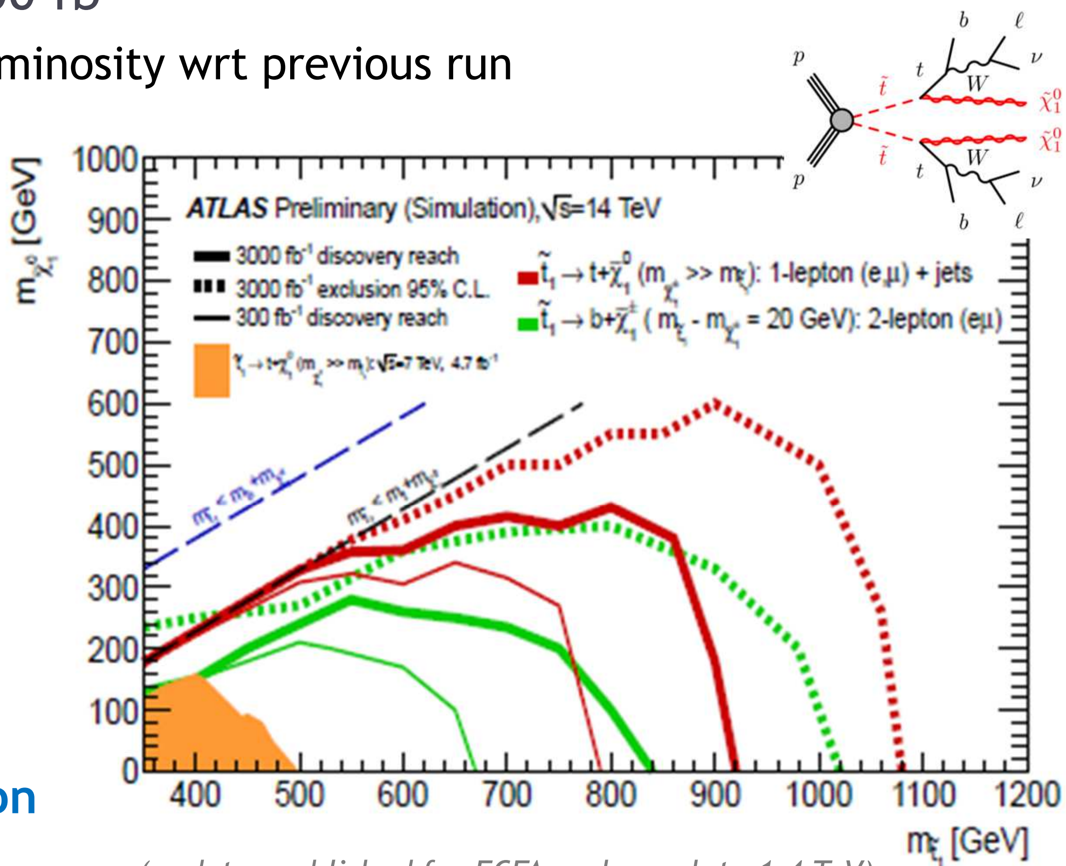
- For SUSY:
  - Extend sensitivity
  - Allow signal characterization

in case of evidence in 300 $fb^{-1}$

→ Feasibility studies presented to support the HL-LHC Case

(European Strategy, Krakow, August 2012)

ATL-PHYS-PUB-2012-001



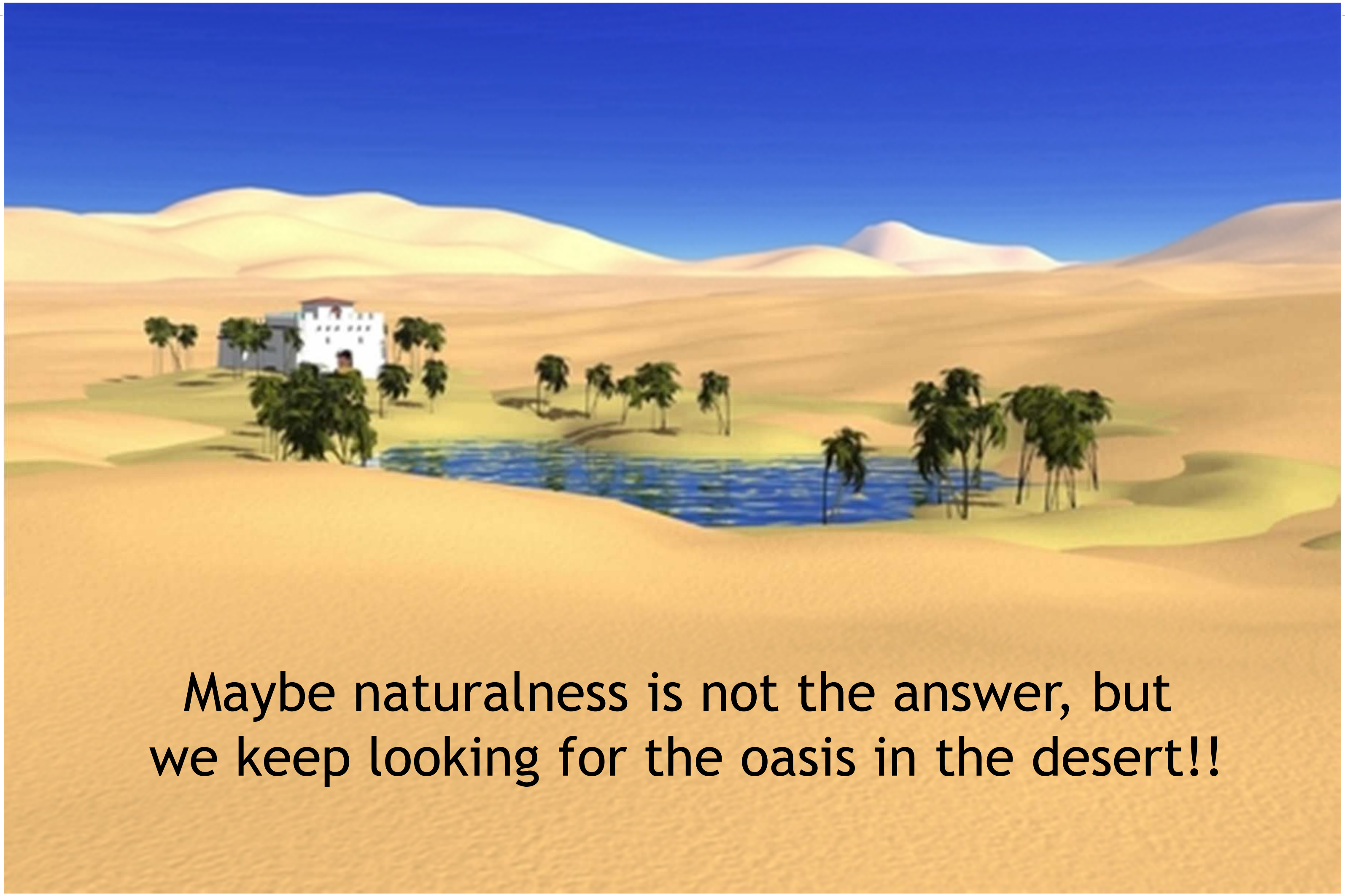

**Stop pair production**

*(updates published for ECFA push reach to 1.4 TeV)*

# Conclusions

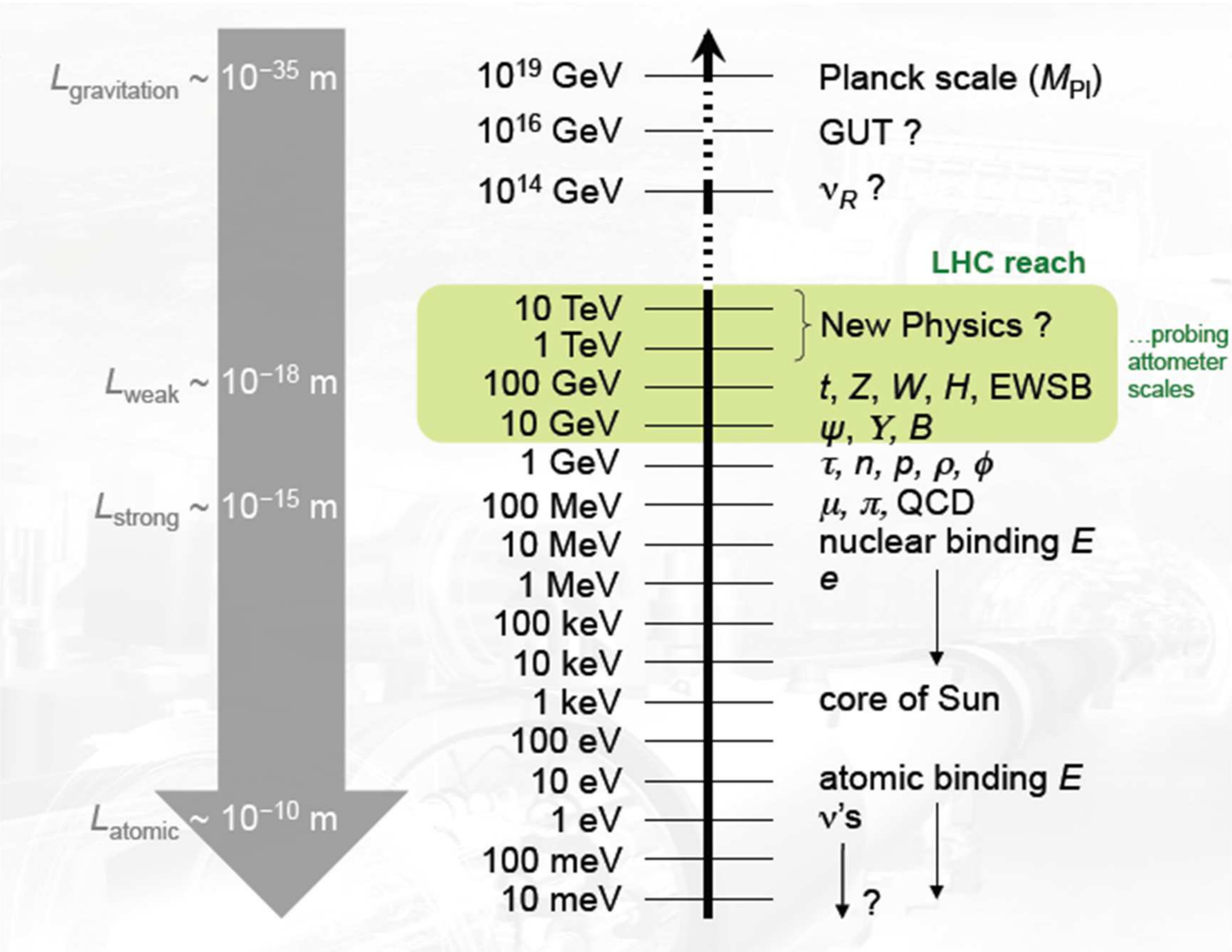
- Supersymmetry is (still) one of the most compelling theories for particle physics beyond SM to date
- Naturalness might be the guiding principle (although not the only one!)
  - Searches focused on gluino, sbottom and stop
- Thourough strategy defined to search for natural SUSY since beginning of ATLAS Run I:
  - No evidence of SUSY yet, stringent constraints set:
    - M(gluino) excluded up to 1400 TeV
    - M(sbottom) and M(stop) excluded up to 650 GeV
  - Weaker constraints for compressed scenarios
- Much more to explore: intense (and broad) program of SUSY searches in preparation for 13/14 TeV data

# Conclusions



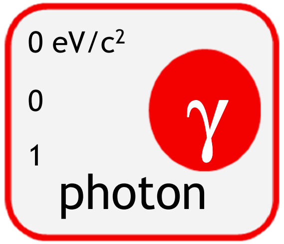
# Back up

# Particle physics scale

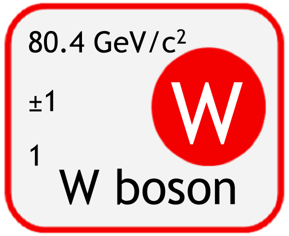


# Forces

- Matter held together by **Forces** carried by Bosons (spin 1)
  - **3 forces considered in SM of particle physics**
    - Electromagnetic (EM), Weak and Strong forces
    - Couplings: g, $g_{W}$, $g_{s}$
    - The 4$^{th}$ force, gravity, not included ! Carrier: graviton




2 x

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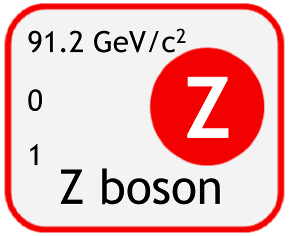
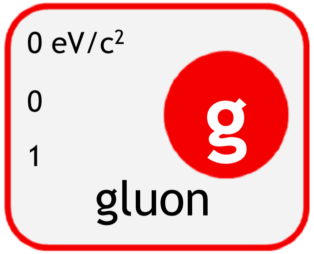


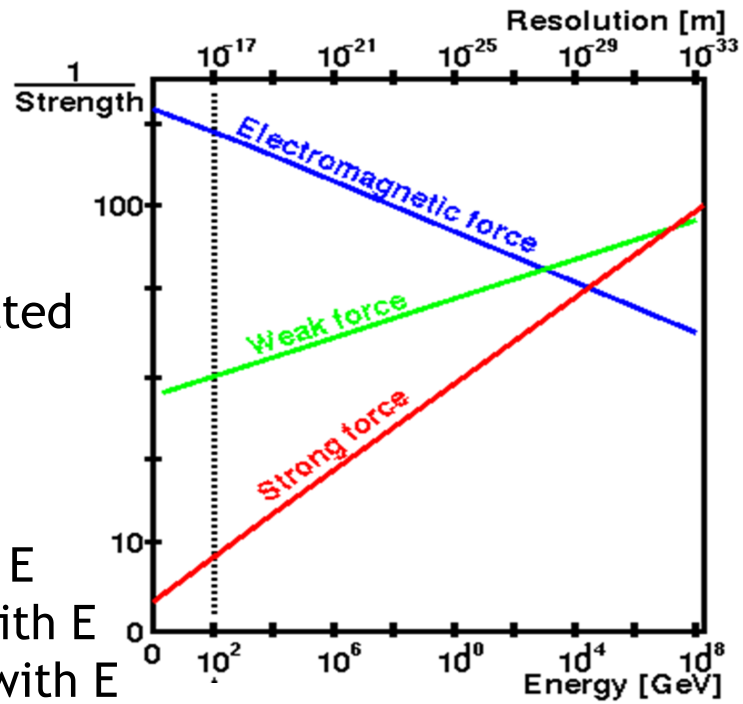

8 x




Forces "run" with energy ….. and don't agree at high energy

1/coupling plotted

1/EM falls with E
1/Weak rises with E
1/Strong rises with E

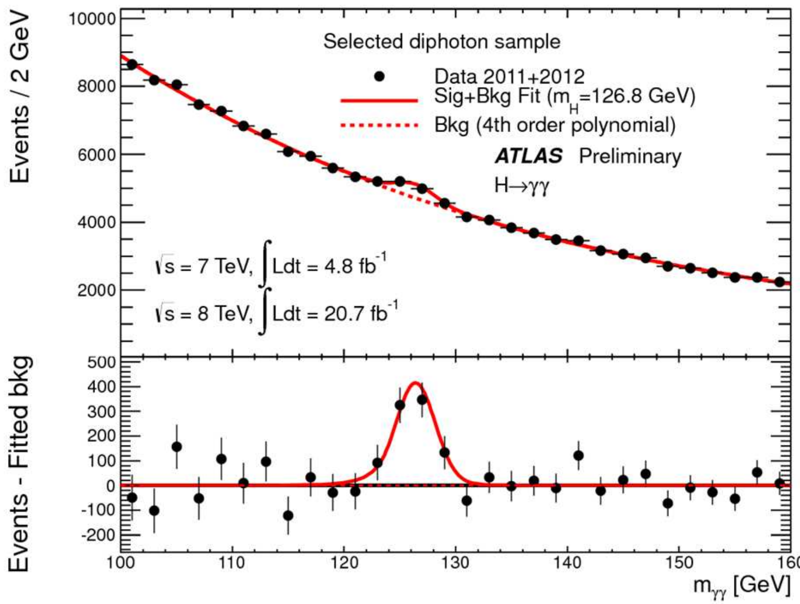


# The Higgs boson


- **Everything with mass gets it by interacting with the Higgs field**
- Relates $M_W$, $M_Z$ and weak, electromagnetic couplings:
  - Unifies weak and electromagnetic forces → electroweak
  - $\tan\theta_W = g_W / g$, $M_W = M_Z \cos\theta_W$

'Mechanism' theorized in 1964 → Higgs boson found at the Large Hadron Collider 50 years later!

*Higgs and Engler on July 4, 2012*

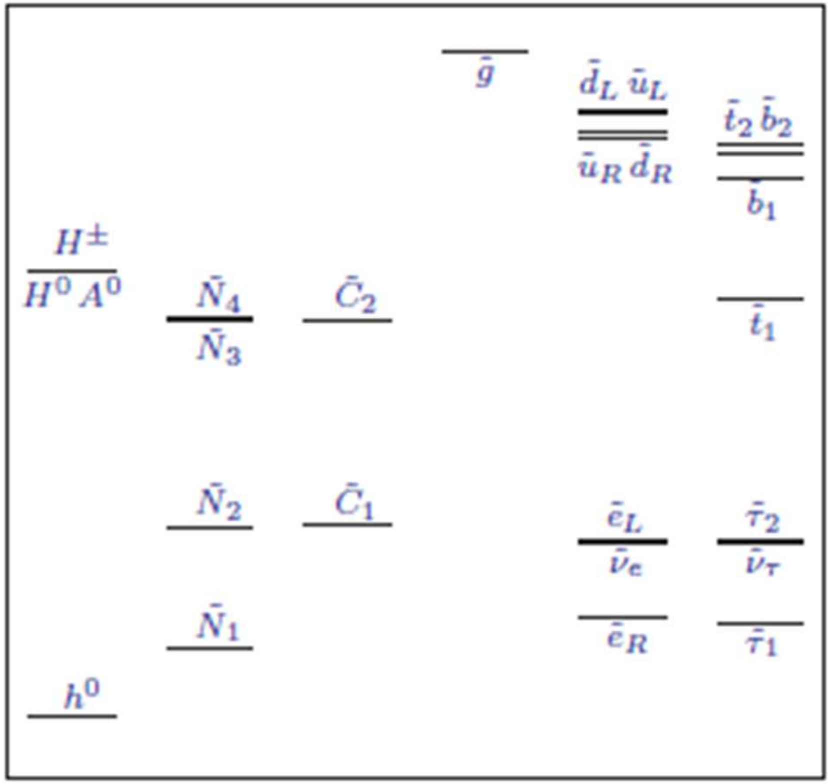



*Higgs mass peak in diphoton events*

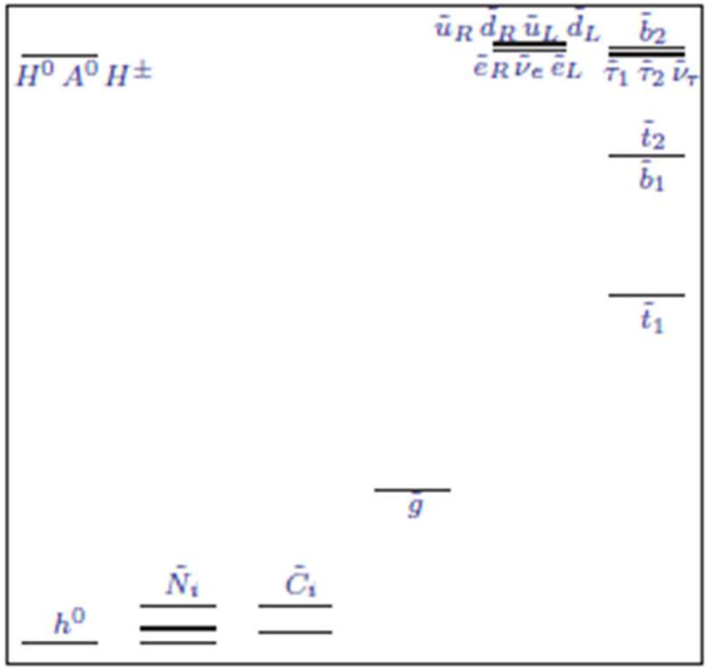
# Possible SUSY mass spectra

lots (> 100) of new parameters (e.g. masses)

## Particle spectrum unknown



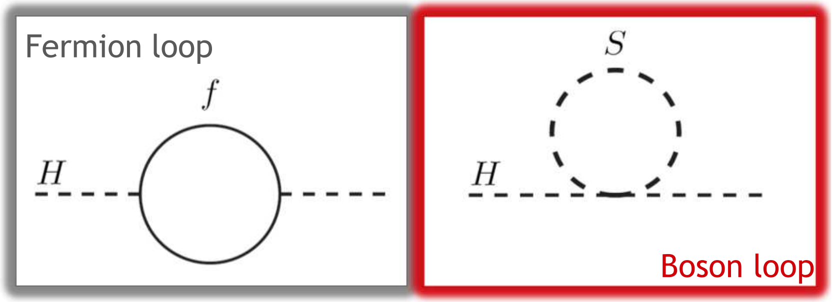

But also this:




*Need some guiding principle!*

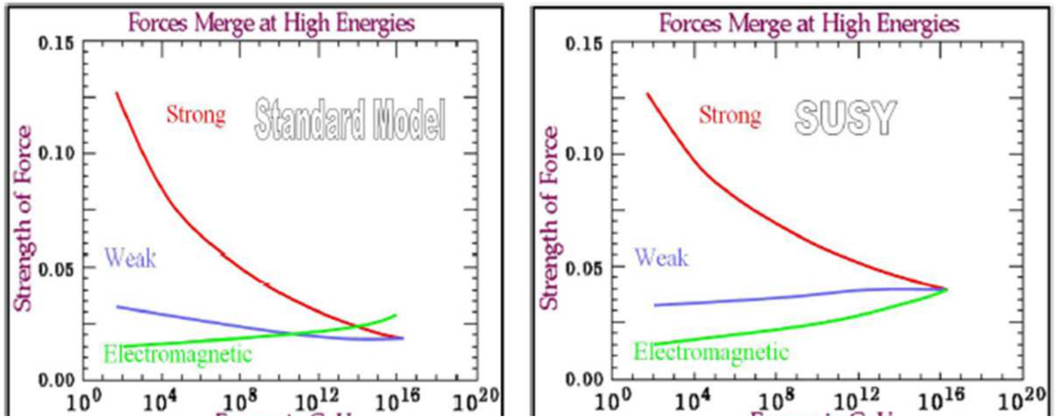
# What's Nice about SUSY?

- The **lightest of the higgs** is predicted to be close to $M_Z$: found at 126 GeV ☺




- Naturally solve the hierarchy problem
  - Corrections to the Higgs mass due to its coupling with fermions is compensated by the presence of bosons
  - No fine-tuning required !

- Enables forces to unify




Energy (GeV)

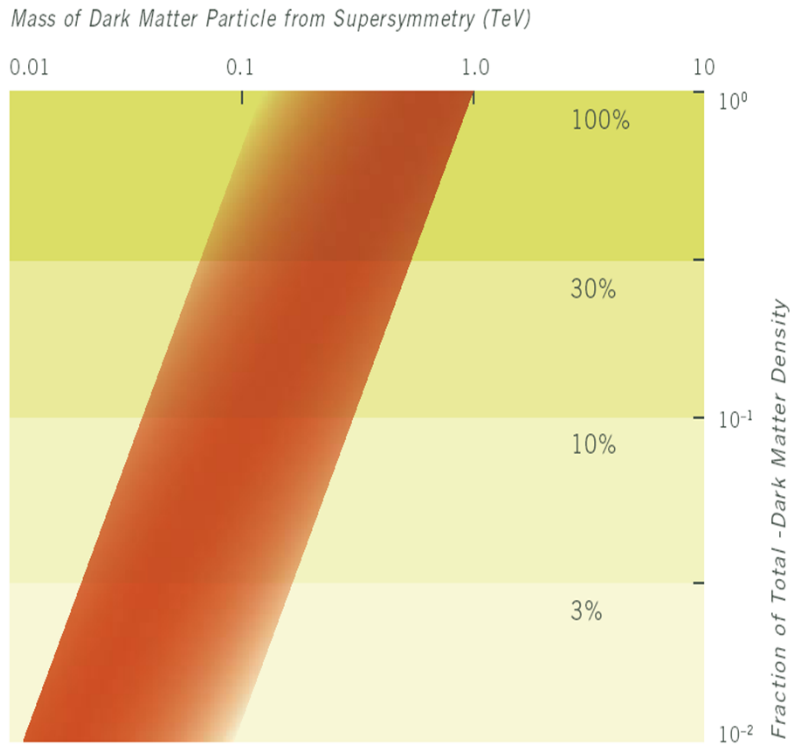
- If R-parity is conserved, the **Lightest SUSY particle (LSP)** cannot decay → is stable: **SUSY provides the perfect candidate for Dark Matter (DM)**

# The LSP and Dark Matter

- The amount of dark matter relic density is inversely proportional to the annihilation cross section:

$$\Omega_{DM} \sim \langle\sigma_A v\rangle^{-1}$$

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




HEPAP 2006 LHC/ILC Subpanel

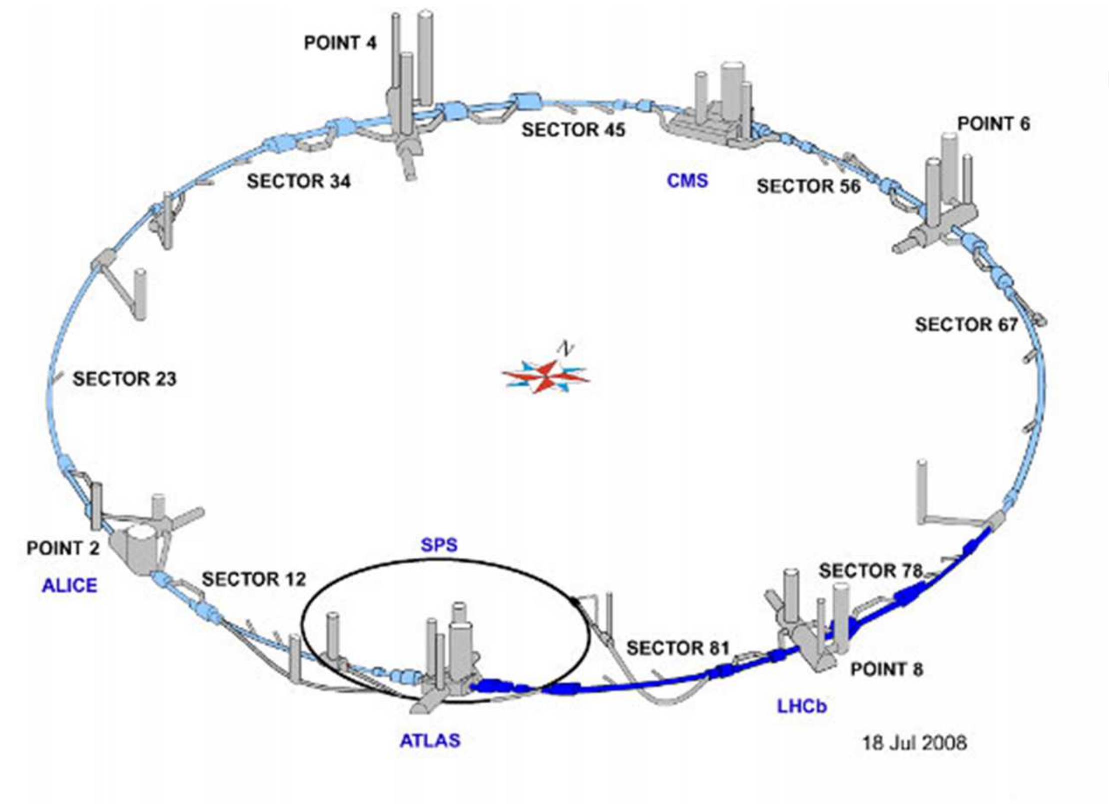
Remarkable "coincidence":

$\Omega_{DM} \sim 0.1$ for m ~ 100 GeV – 1 TeV!

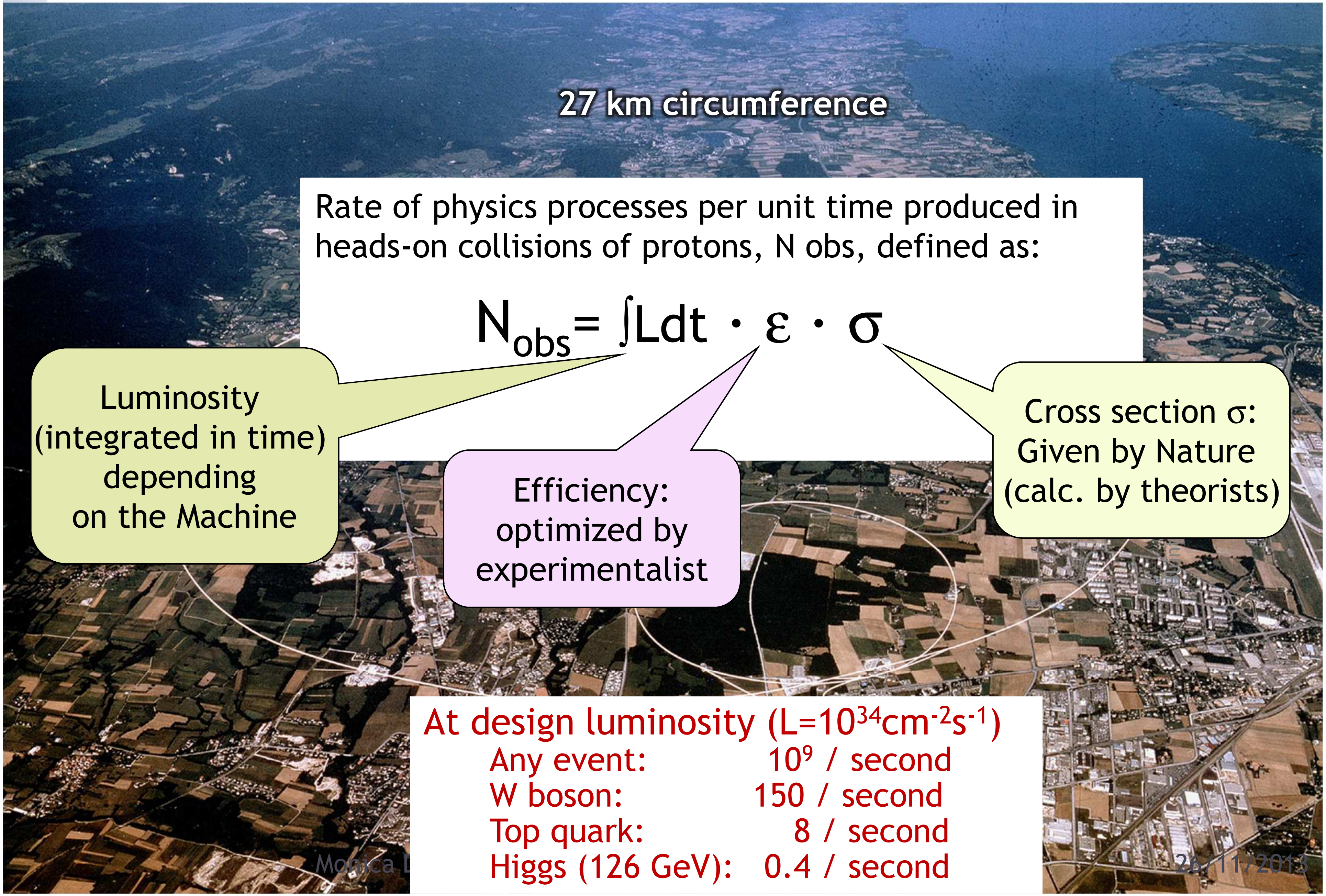
Supersymmetry independently predicts particles with about the right density to be dark matter !

# LHC operations

| | 2011 | 2012 |
|---|---|---|
| Colliding bunches | 1331 | 1331 |
| Bunch spacing | 50 ns | 50 ns |
| **Luminosity** | $3.6 \times 10^{33}$ cm$^{-2}$ s$^{-1}$ | $6.8 \times 10^{33}$ cm$^{-2}$ s$^{-1}$ |
| Pile-up interactions | ~20 | ~35 |



# Hadron Colliders: The LHC




Rate of physics processes per unit time produced in heads-on collisions of protons, N obs, defined as:

$$N_{obs} = \int L dt \cdot \varepsilon \cdot \sigma$$

Luminosity (integrated in time) depending on the Machine

Efficiency: optimized by experimentalist

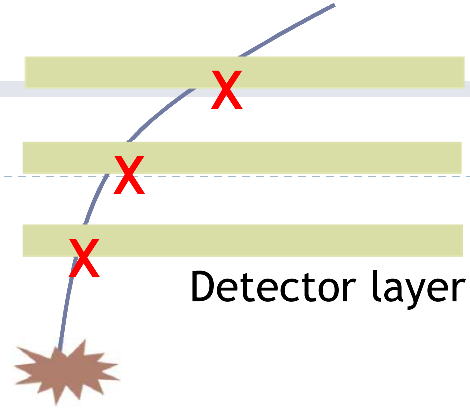
Cross section $\sigma$: Given by Nature (calc. by theorists)

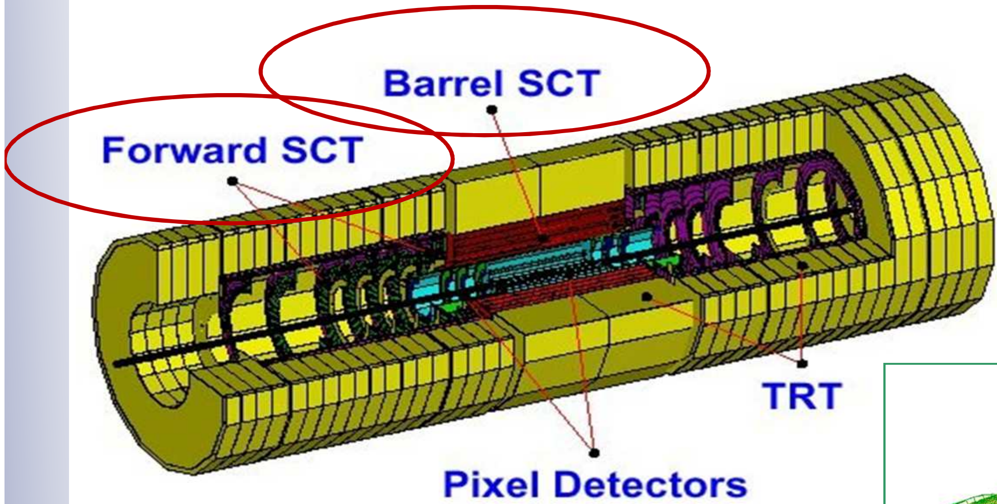
At design luminosity ($L=10^{34} cm^{-2} s^{-1}$)

| | |
|---|---|
| Any event: | $10^9$ / second |
| W boson: | 150 / second |
| Top quark: | 8 / second |
| Higgs (126 GeV): | 0.4 / second |

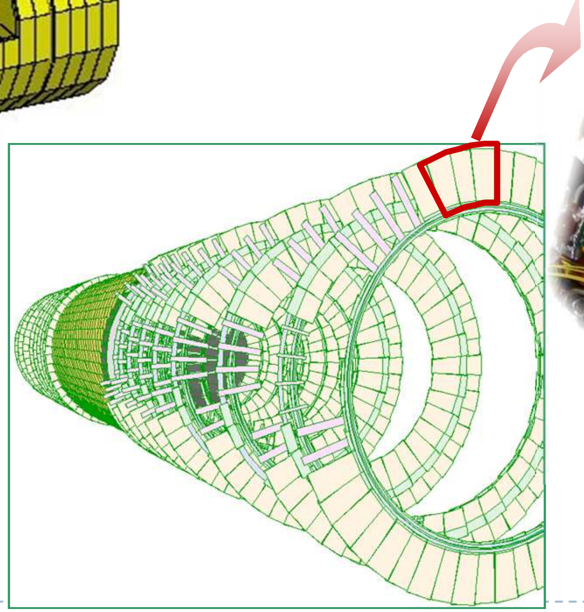
# Inner Detector

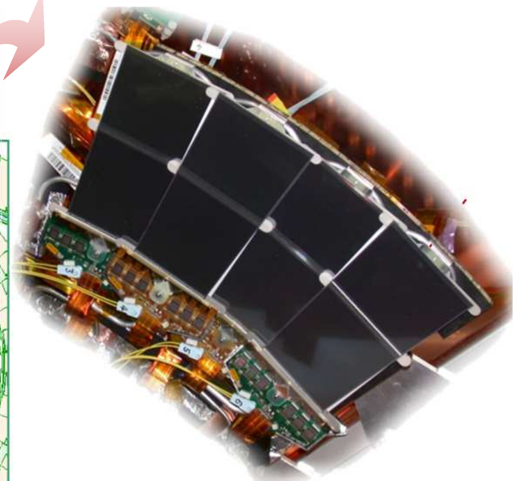
- Core of the experiment: reconstruct the path of charged particles from primary interactions *(tracks)*
- Immerse in Magnetic Field (2 Tesla)




Pixels: ~ 2.3 $m^2$ of silicon sensors
**Silicon micro-strips (SCT):** 60 $m^2$ of silicon sensors
Transition Radiation Chambers





Precision: 20 μm (r-φ), 580 μm (r-z)

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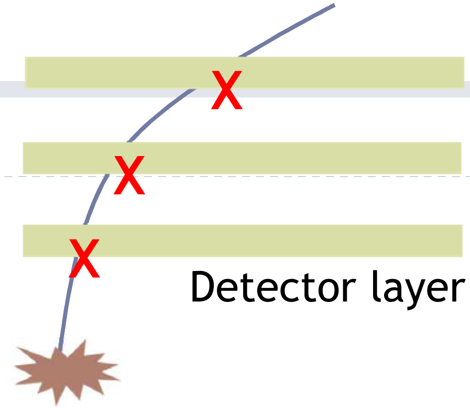
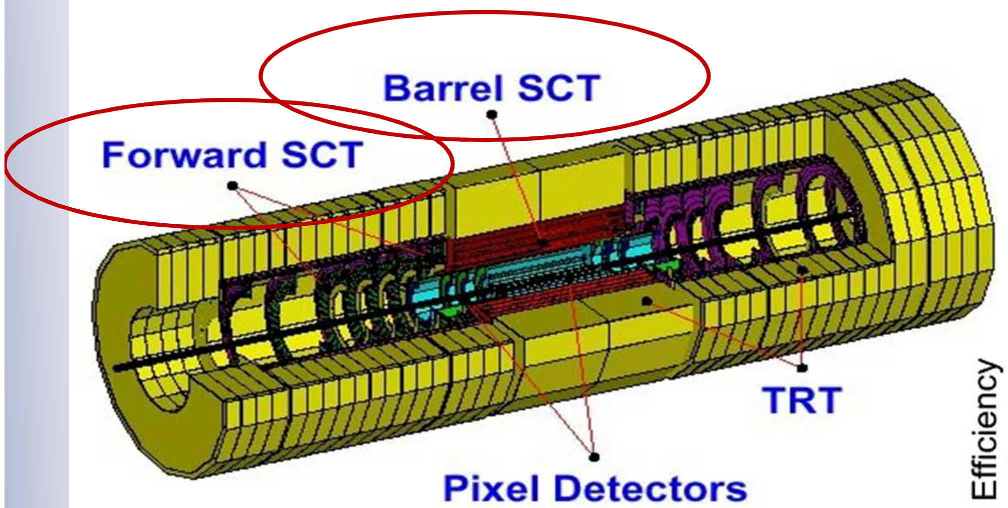
- Immerse in Magnetic Field (2 Tesla)



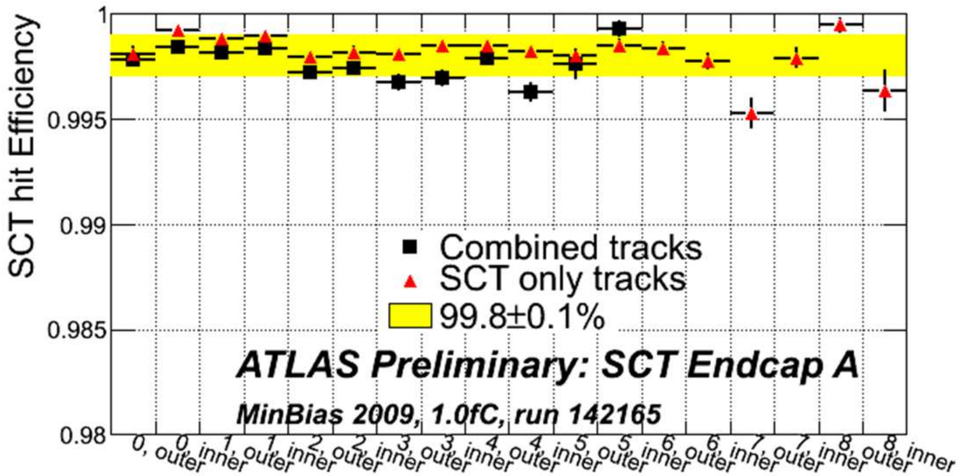

Pixels: ~ 2.3 m$^2$ of silicon sensors

**Silicon micro-strips (SCT):** 60 m$^2$ of silicon sensors

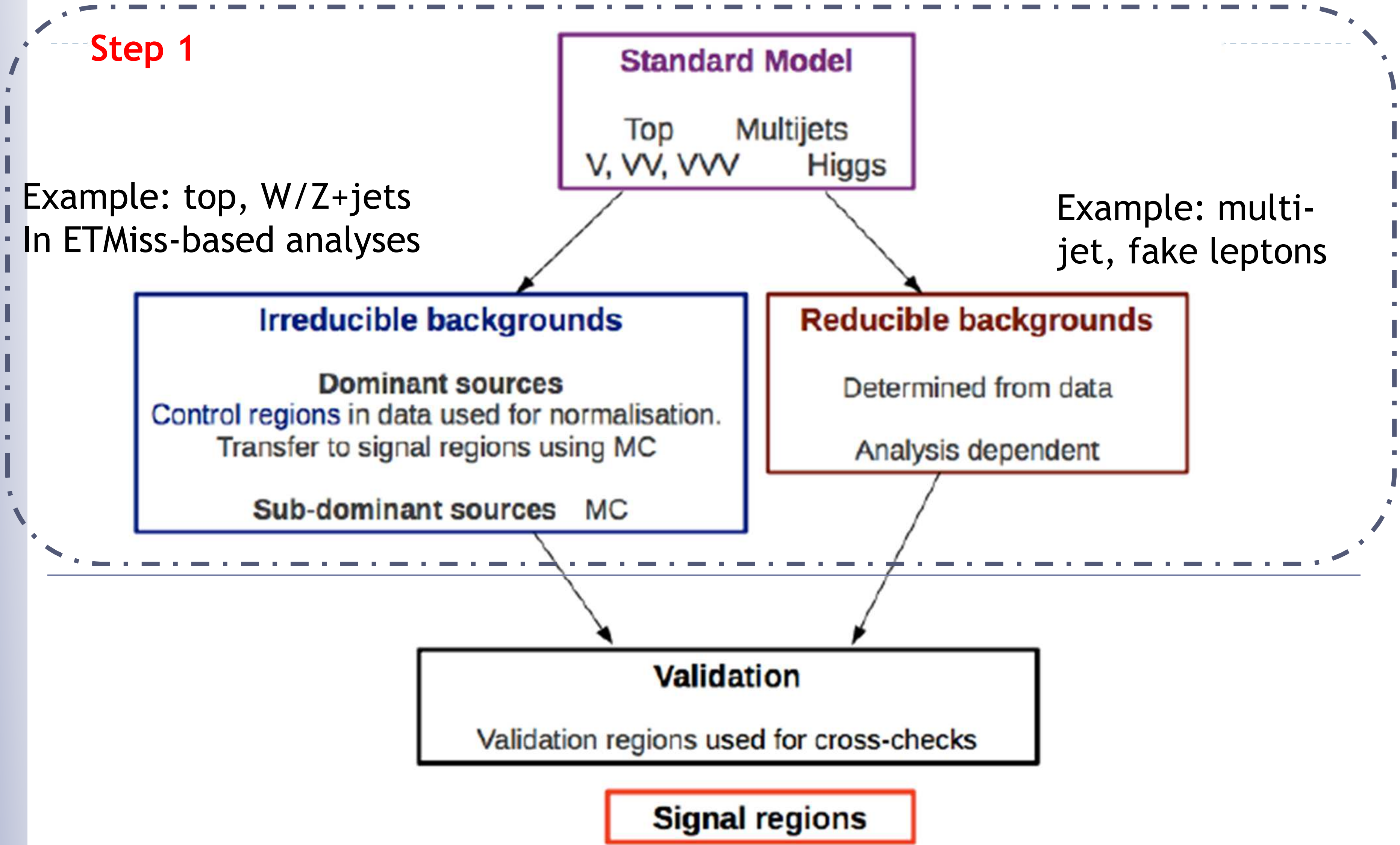
Transition Radiation Chambers

Precision: 20 $\mu$m (r-$\varphi$), 580 $\mu$m (r-z)

**Constant monitoring of detector performance is crucial !**

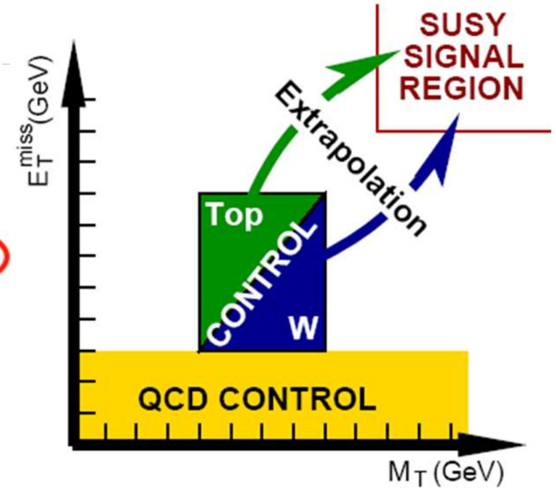


# Background strategy



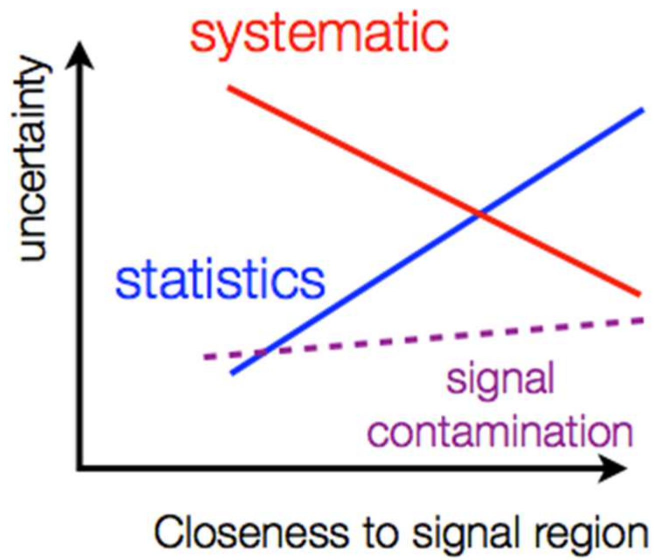
# Irreducible background

- Normalisation done in dedicated Control Regions (CR)



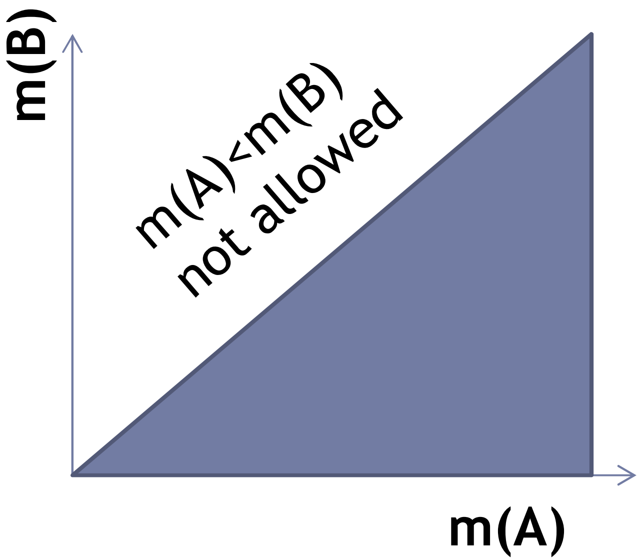

$$N^i_{SR} = \frac{N^{i,MC}_{SR}}{N^{i,MC}_{CR}}\left(N^{i,data}_{CR} - \sum_{j=process} N^{j,MC}_{CR}\right) = T\left(N^{i,data}_{CR} - \sum_{j=process} N^{j,MC}_{CR}\right)$$

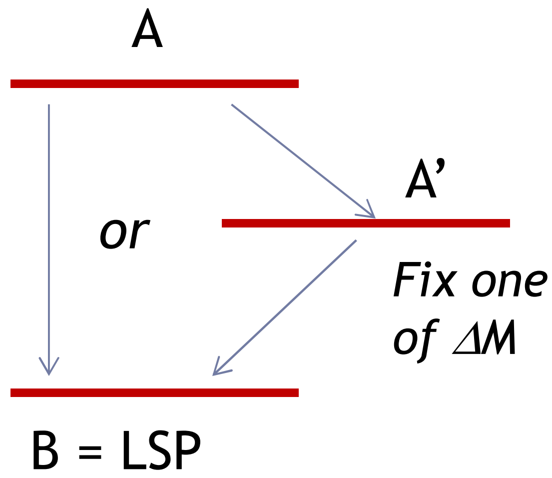
- Assuming $\Sigma N_{CR}^{j,MC}$ is small:
  - systematic uncertainties associated to the transfer factor
  - Need to define the regions keeping good statistics, low systematics uncertainties and low signal contamination



# Simplified models (SMS)

- From 29 sparticles consider 2 or 3, **decouple** all others, force a specific decay mode (100% Branching Ratio)
- Assumptions on the chirality and nature of particle involved




Very helpful to design analyses.

Well suited for **natural SUSY** and **direct production**
**→ an example:** **stop pair production**