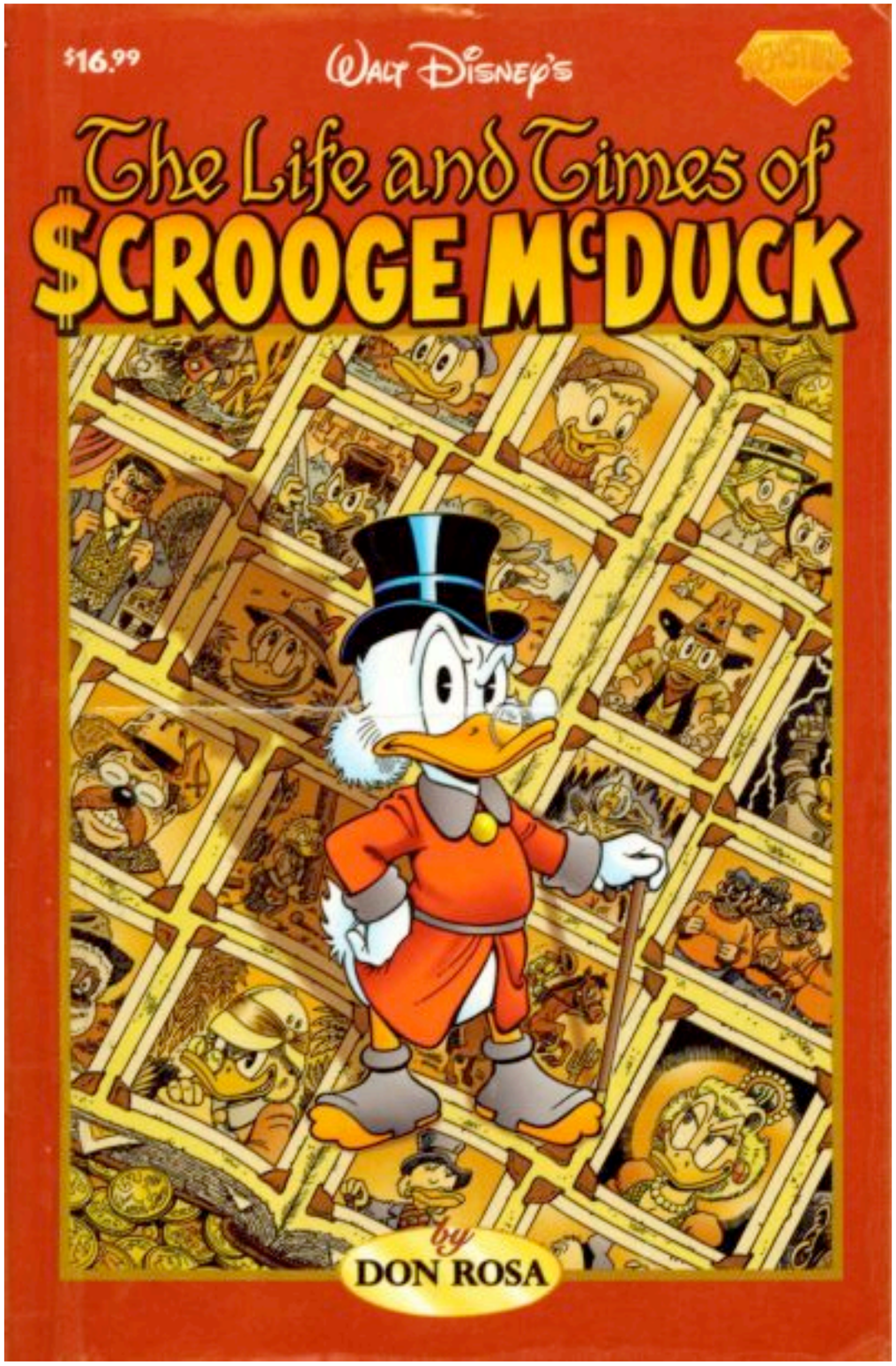
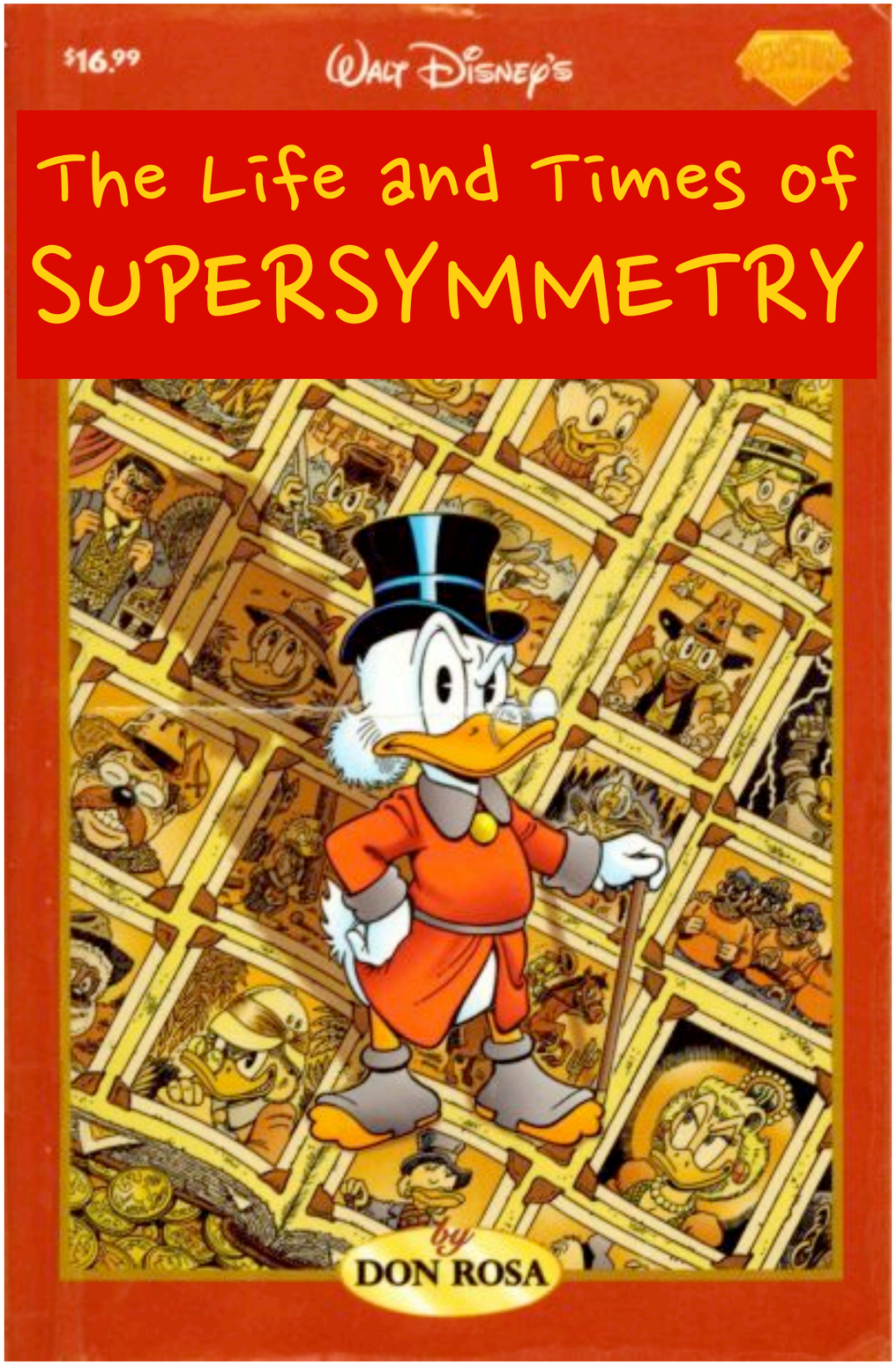
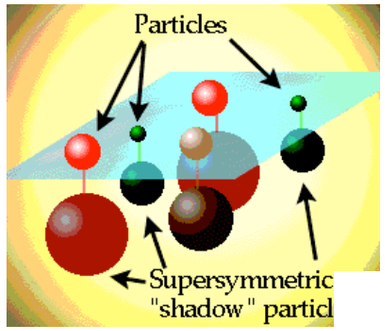
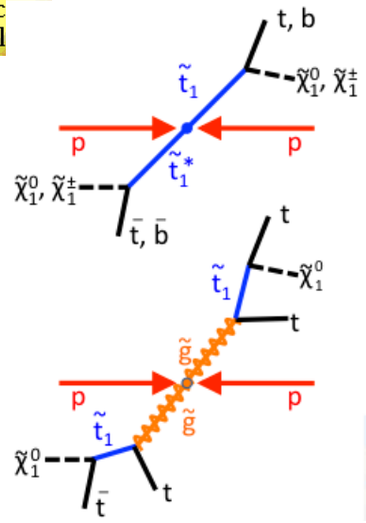
Hi!

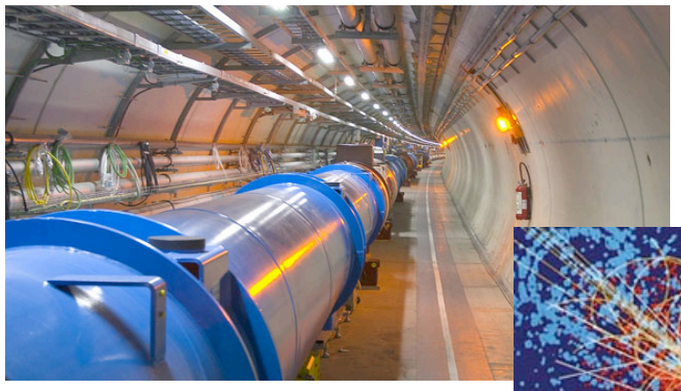

$16.99
Walt Disney's
The Life and Times of
$CROOGE McDUCK
by
DON ROSA

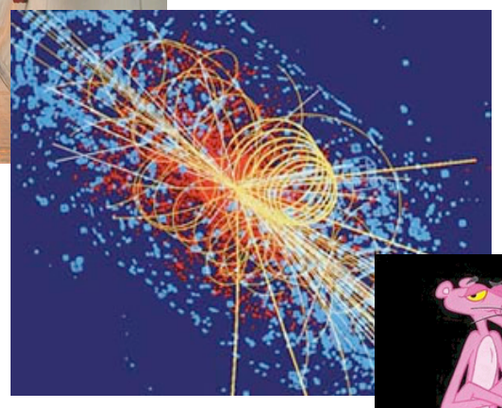

$16.99
Walt Disney's
The Life and Times of
SUPERSYMMETRY
by
DON ROSA

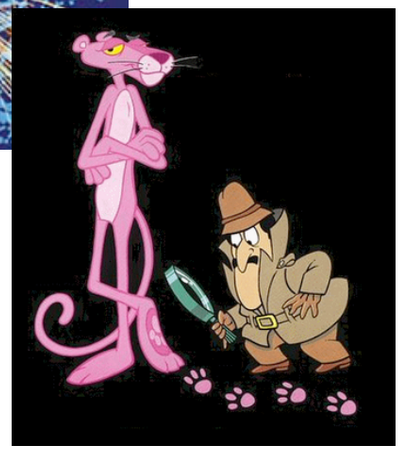
The life and times of Supersymmetry











Suchita Kulkarni
LPSC Grenoble

What is supersymmetry (SUSY)?

The Algebra

- The SM is based on the Poincaré algebra, a symmetry between space and time.
- Is it possible to extend this algebra to include also a symmetry between fermions and bosons ("supersymmetry") ?
- Yes, but we need to extend the field content of SM,

$$\Psi(x,\theta) = \phi(x) + \sqrt{2}\,\theta^\alpha \psi_\alpha(x) + \theta\theta F(x)$$

meaning, super-partners are an algebraic requirement of SUSY algebra

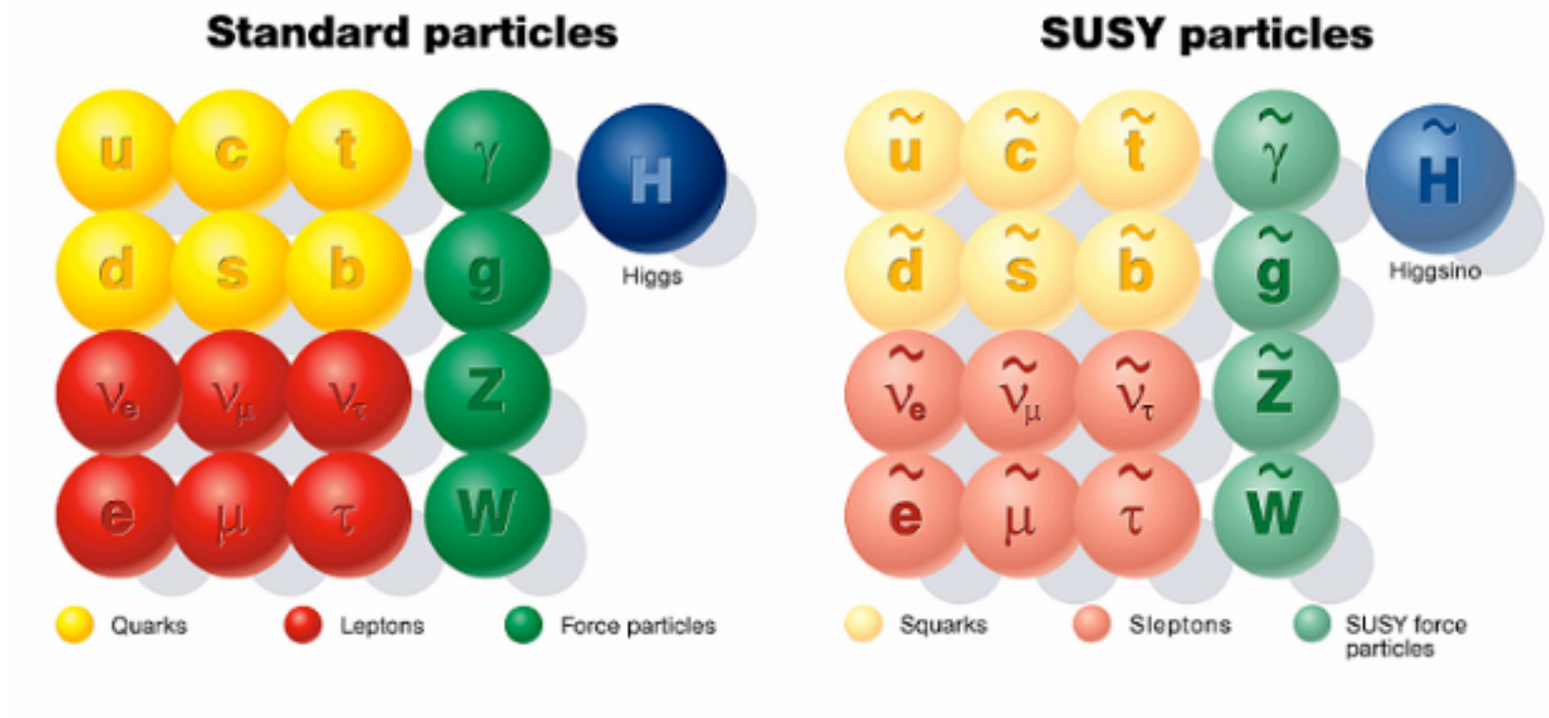
- The straightforward application of above field content to build Lagrangian gives:

RPC

$$\mathcal{W} = \sum_{i,j=1}^{3} \left[(h_E)_{ij}\, H_1 L_i E_j^c + (h_D)_{ij}\, H_1 Q_i D_j^c + (h_U)_{ij}\, Q_i H_2 U_j^c \right] - \mu H_1 H_2$$

What is SUSY?

Particle content



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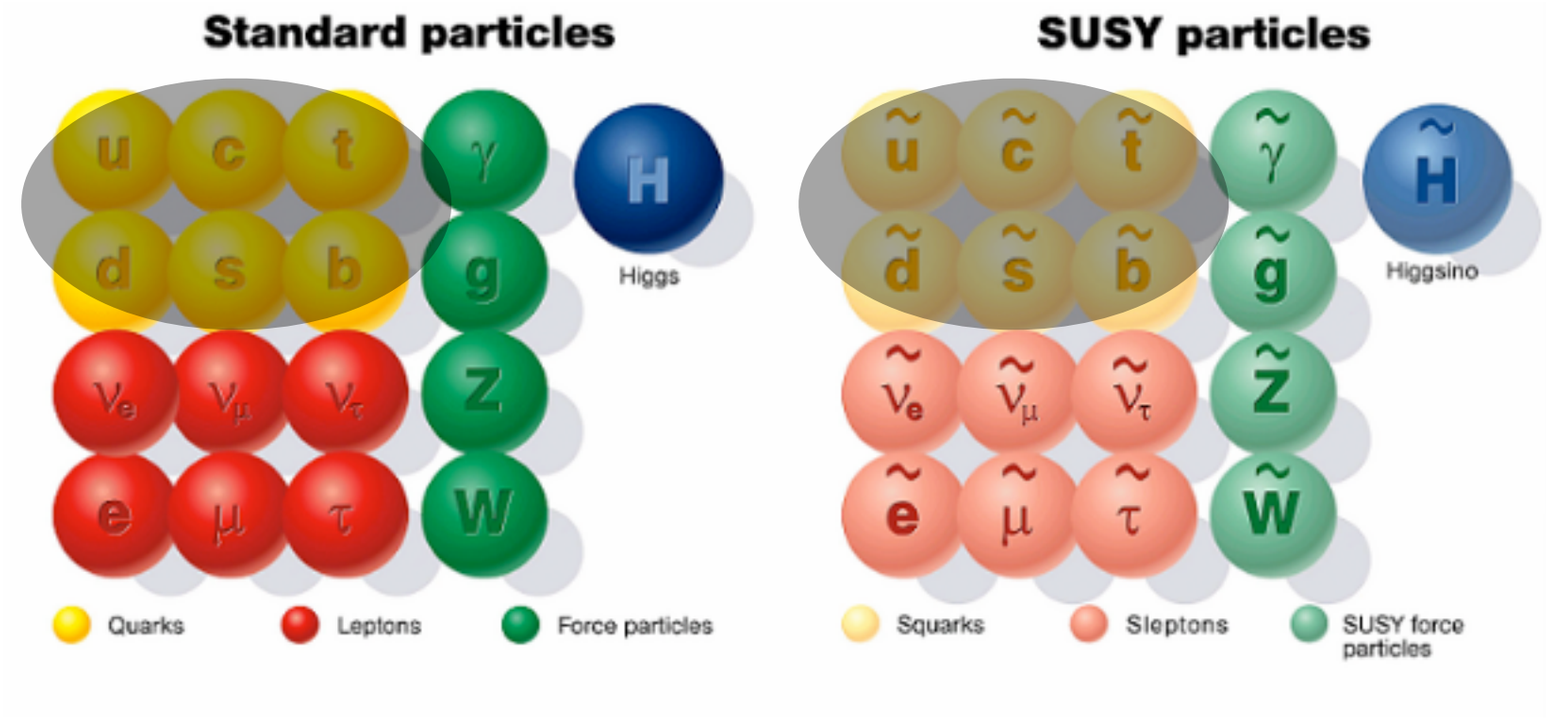

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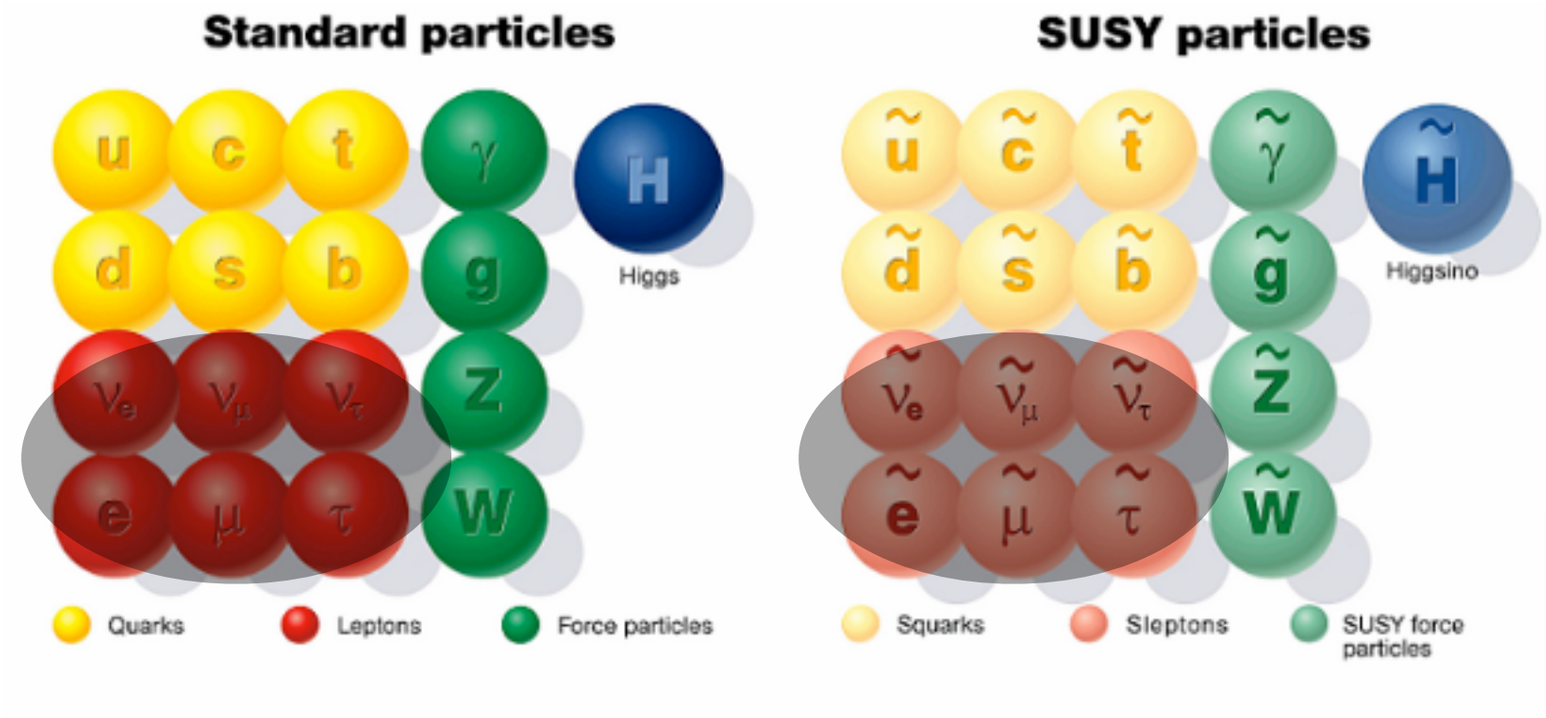

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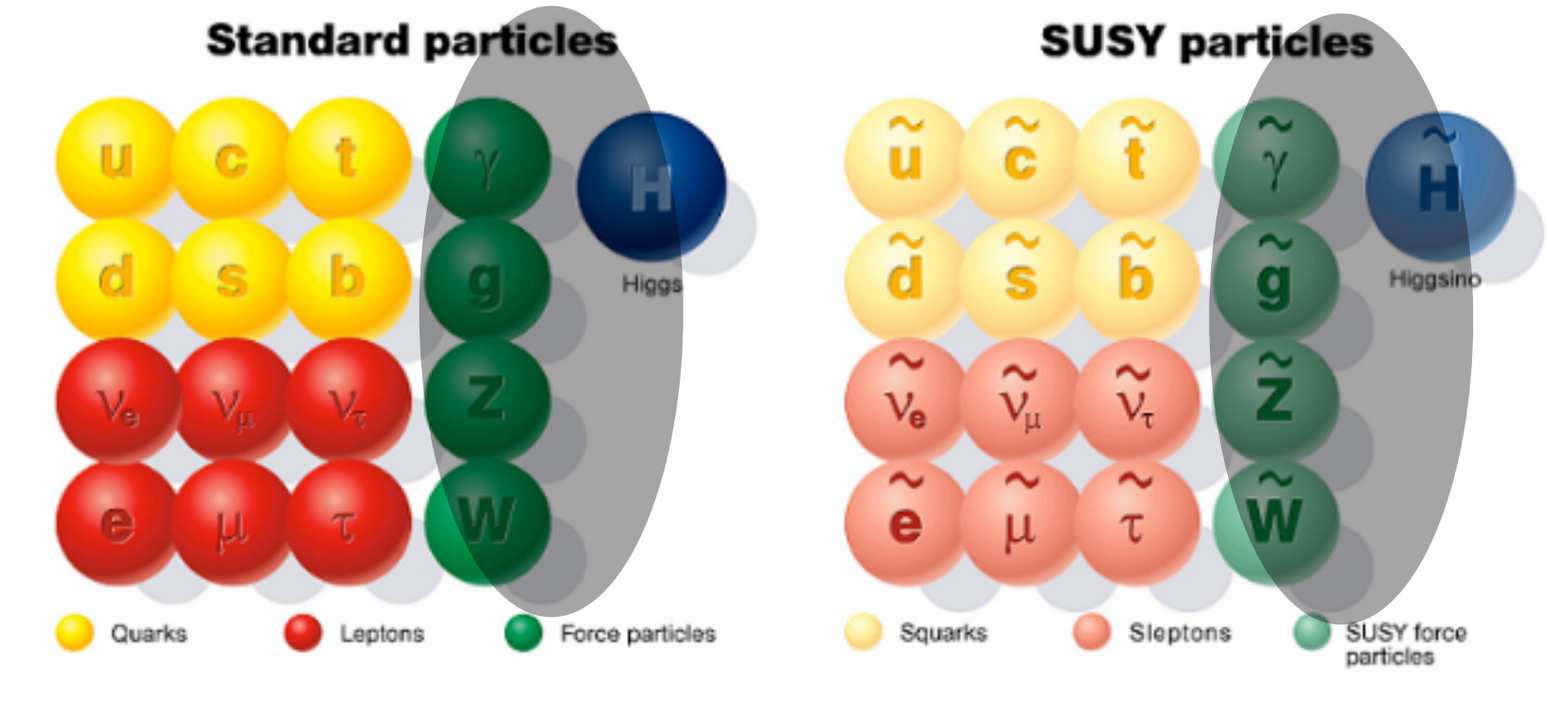

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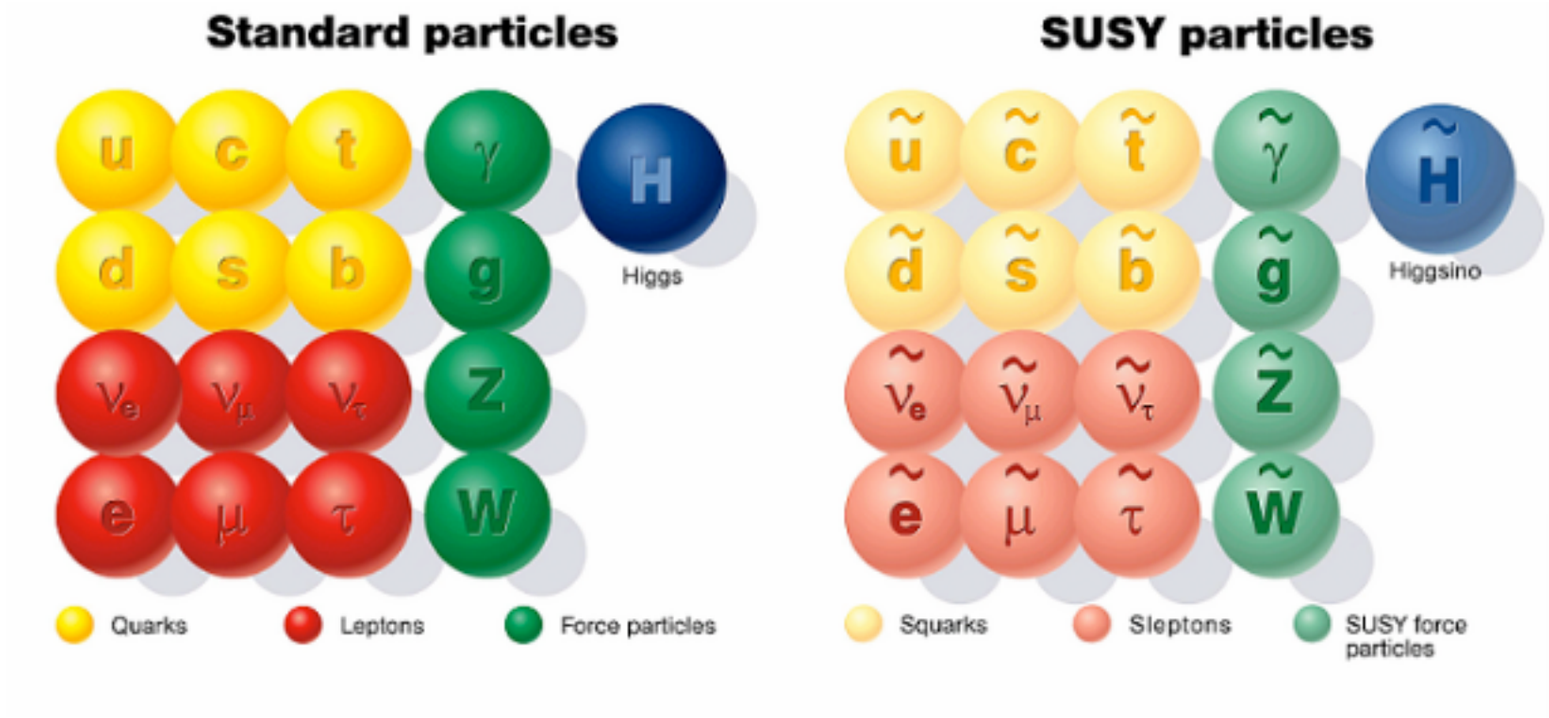

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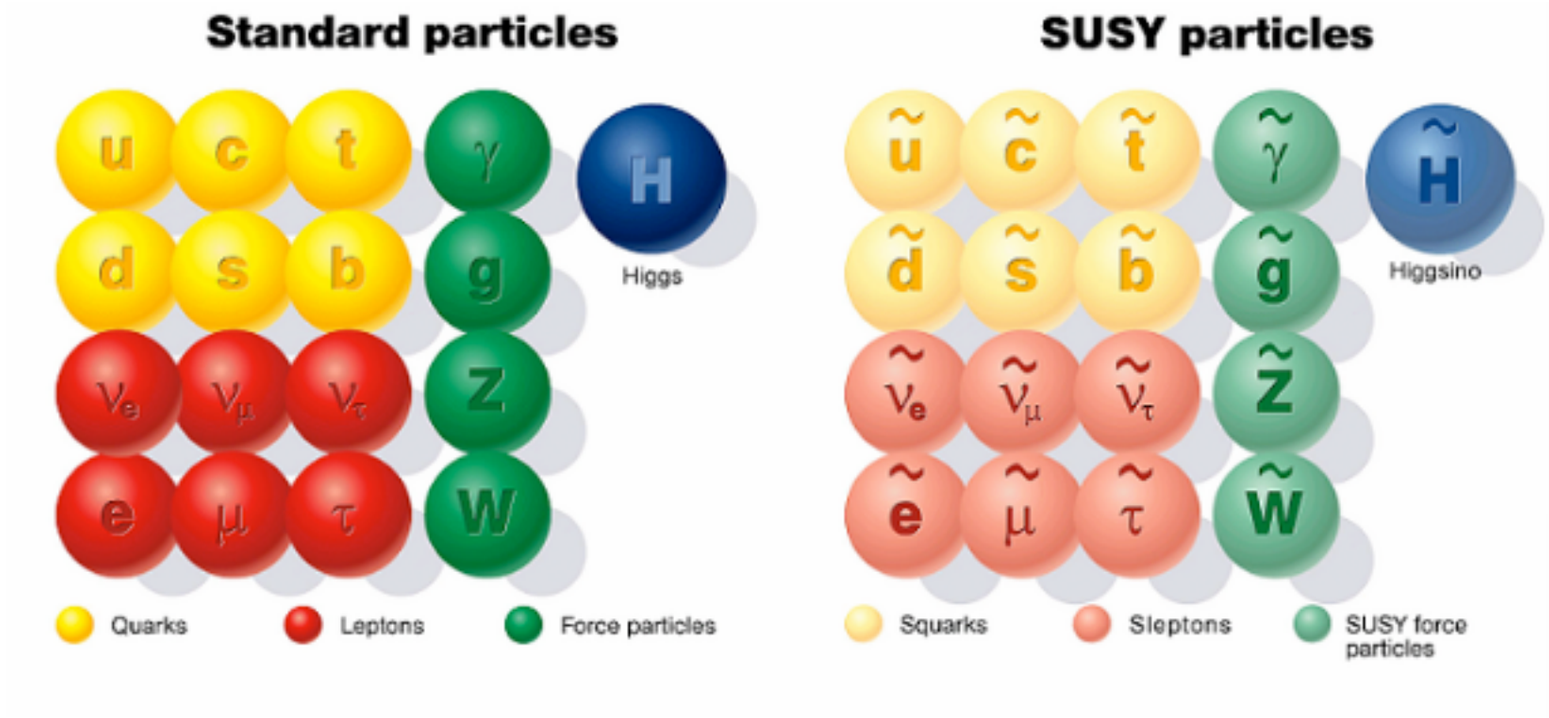

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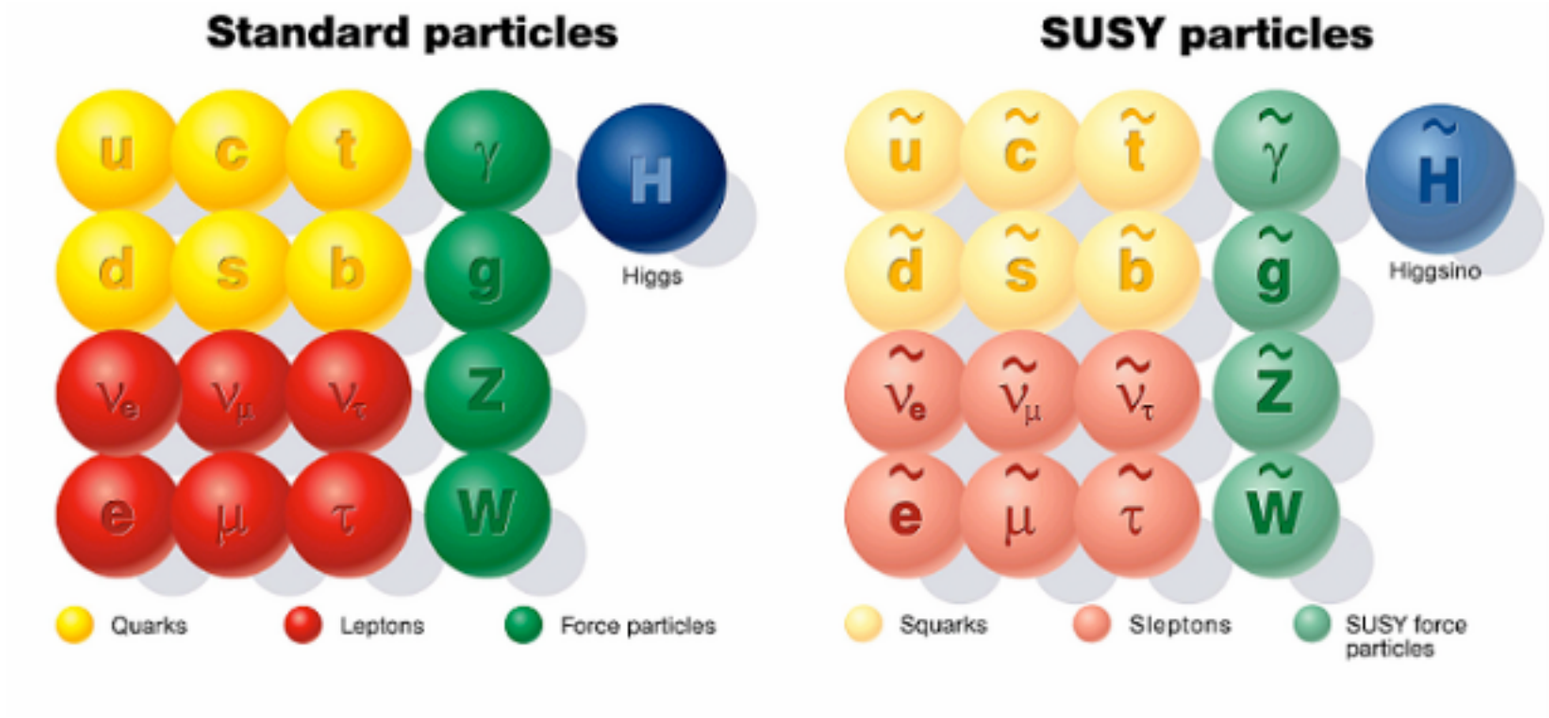

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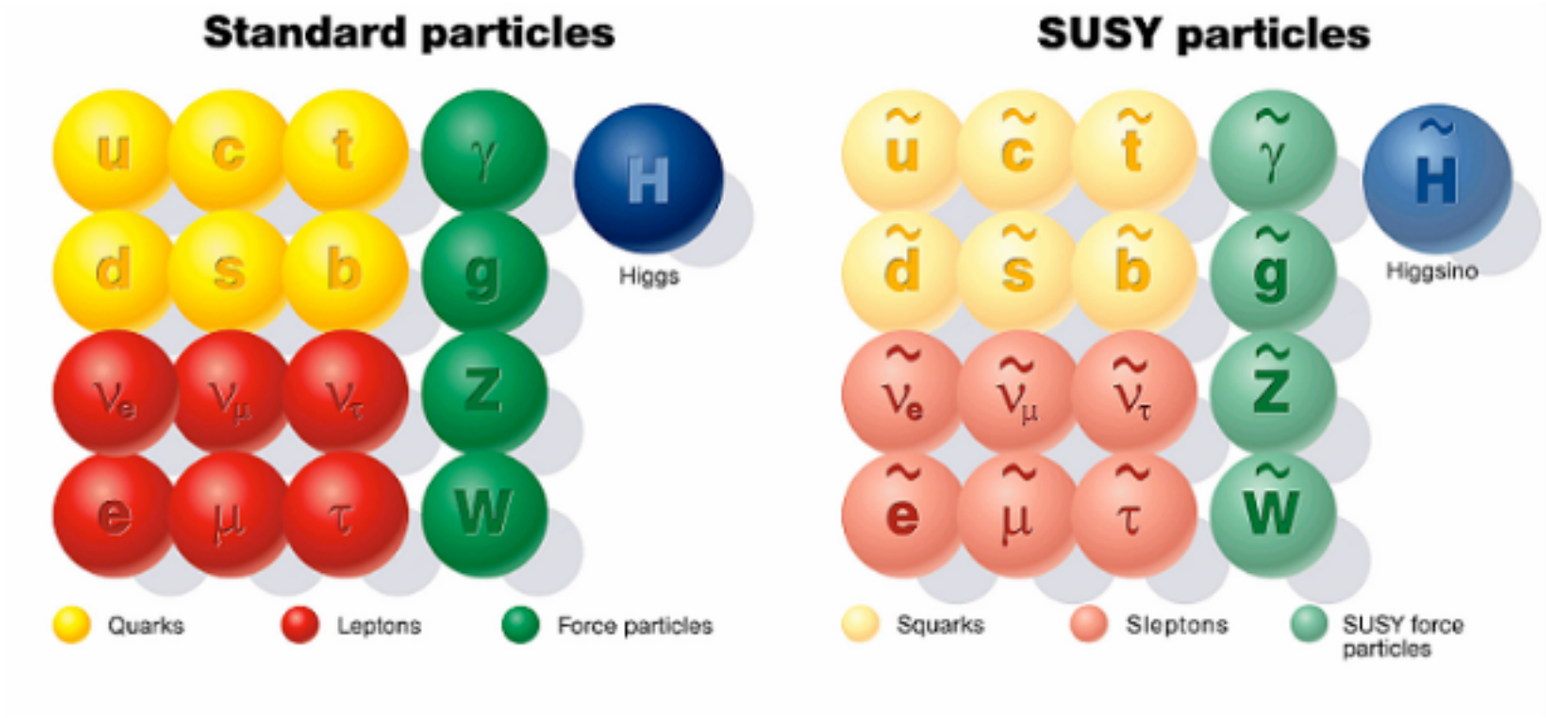

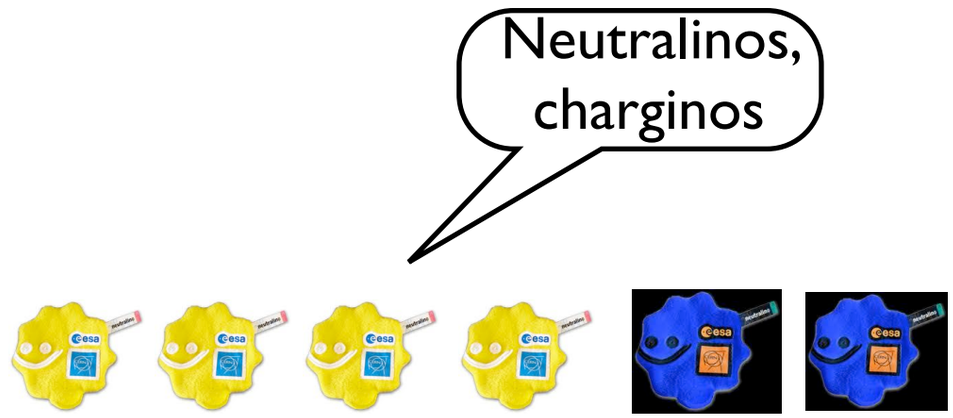

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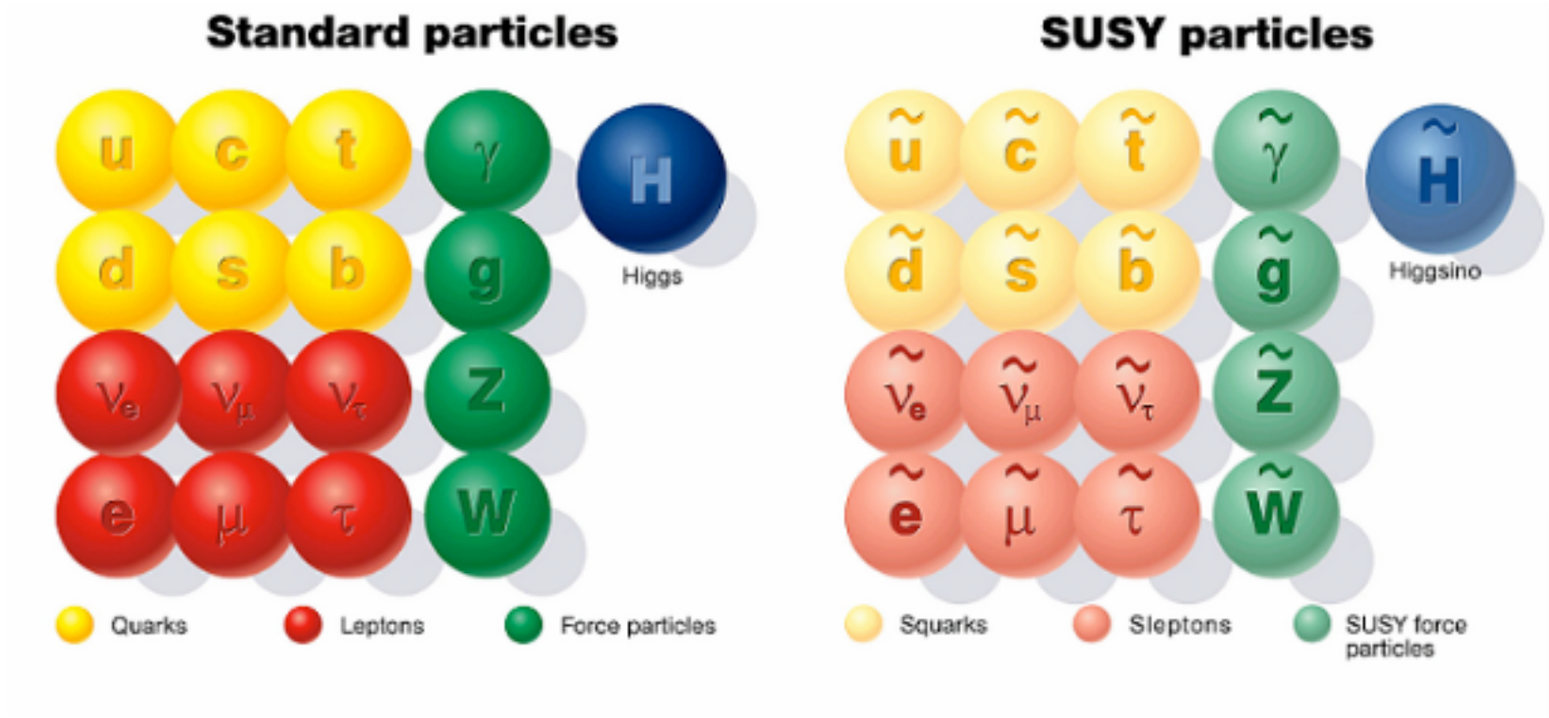
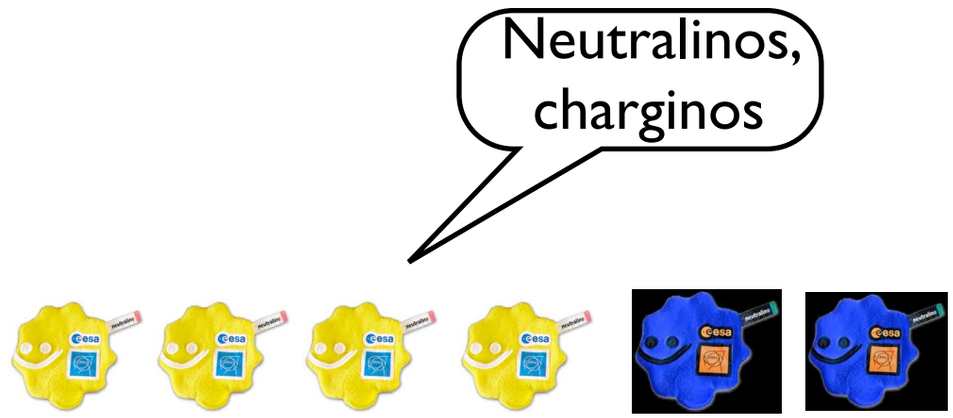
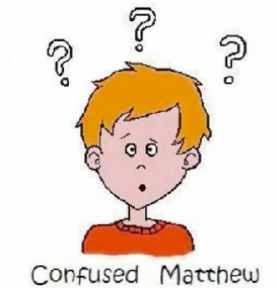




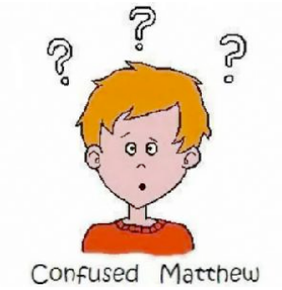
- No evidence of SUSY particles at colliders, SUSY particles are heavier than particles - mechanism of making them heavy is called SUSY breaking

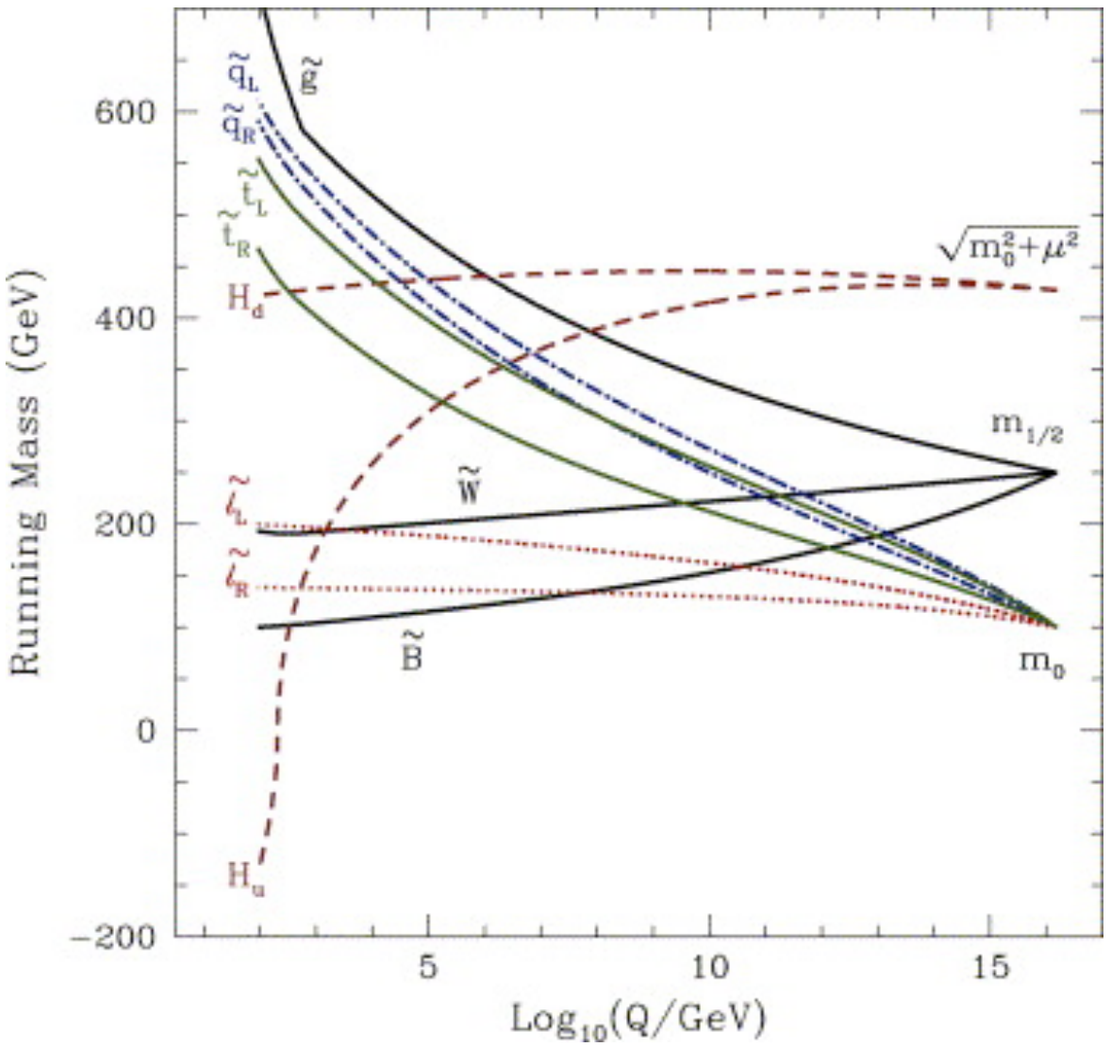
Where is SUSY



- In general 105 total free parameters, as the SM has Yukawa couplings
- Simplifications made on the basis of theoretical motivations (e.g. GUT idea)
  - cMSSM: simplistic GUT scale model - 5 free parameters at GUT scale
    - m_0 ... common scalar mass parameter,
    - $m_{1/2}$ ... common gaugino mass parameter,
    - A_0 ... trilinear coupling parameter, $\tan\beta$ ... ratio of the Higgs VEVs,
    - sign(μ) .... μ = Higgsino mass parameter
  - pMSSM: weak scale model with 19 free parameters at the weak scale; assumptions: minimal flavor violations, no additional CP-phases
- We expect new physics at the TeV scale (Higgs mass stabilization), so typical SUSY mass scale should be about 1 TeV, in particular for stops and gluino cf. Akin's talk
- Mass orderings and mass differences depend on the details of the model (→ initial values of the free parameters at the GUT or the weak scale)

Where is SUSY





Approximate mass relations for gluino, neutralino and squarks

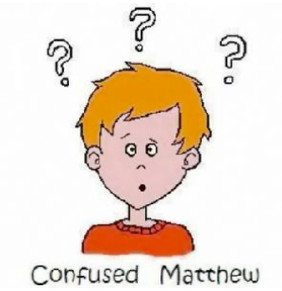
$$m_{\tilde{g}} \approx 2.8\, m_{1/2}$$
$$m_{\chi_1^0} \approx 0.4\, m_{1/2}$$

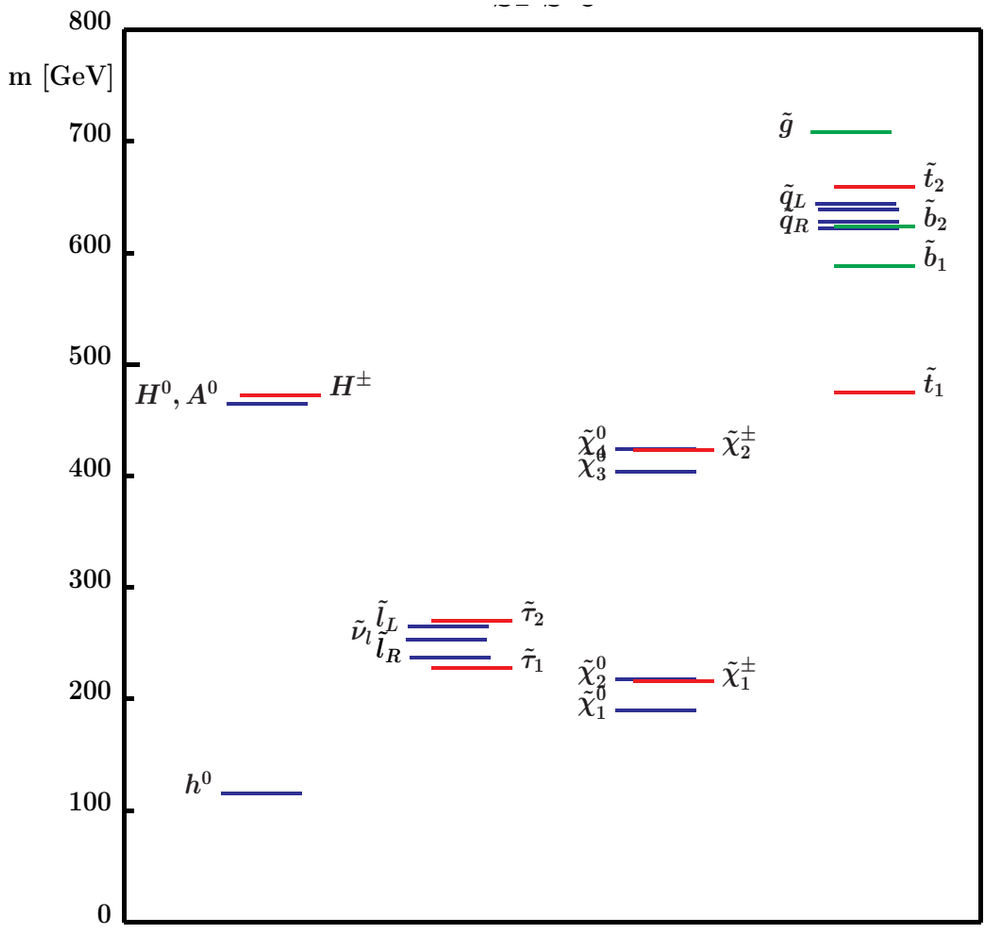
$$m_{\tilde{q}} \approx \sqrt{m_0^2 + K\, m_{1/2}^2}$$

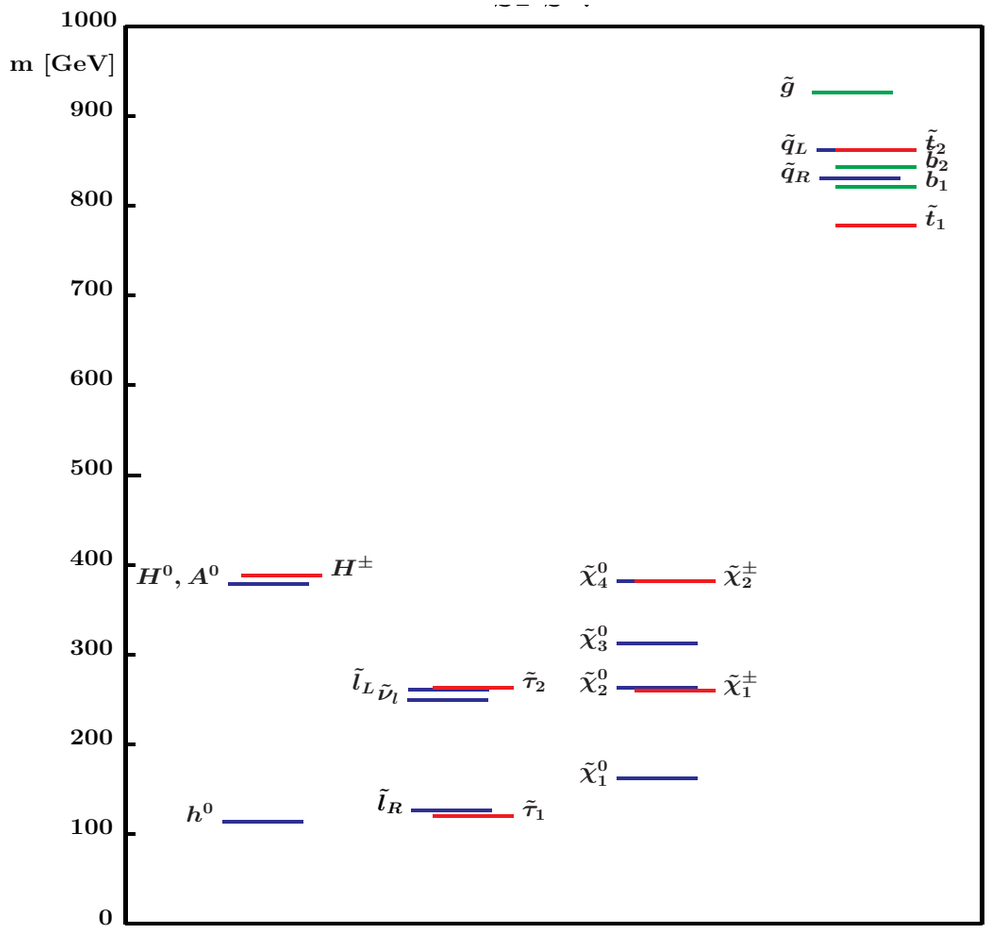
$$K \approx 4.5 - 6$$

- Within unified models, the low scale parameters depend on high scale parameters through renormalization group running
- Different high scale parameters can lead to completely different mass spectra

Where is SUSY







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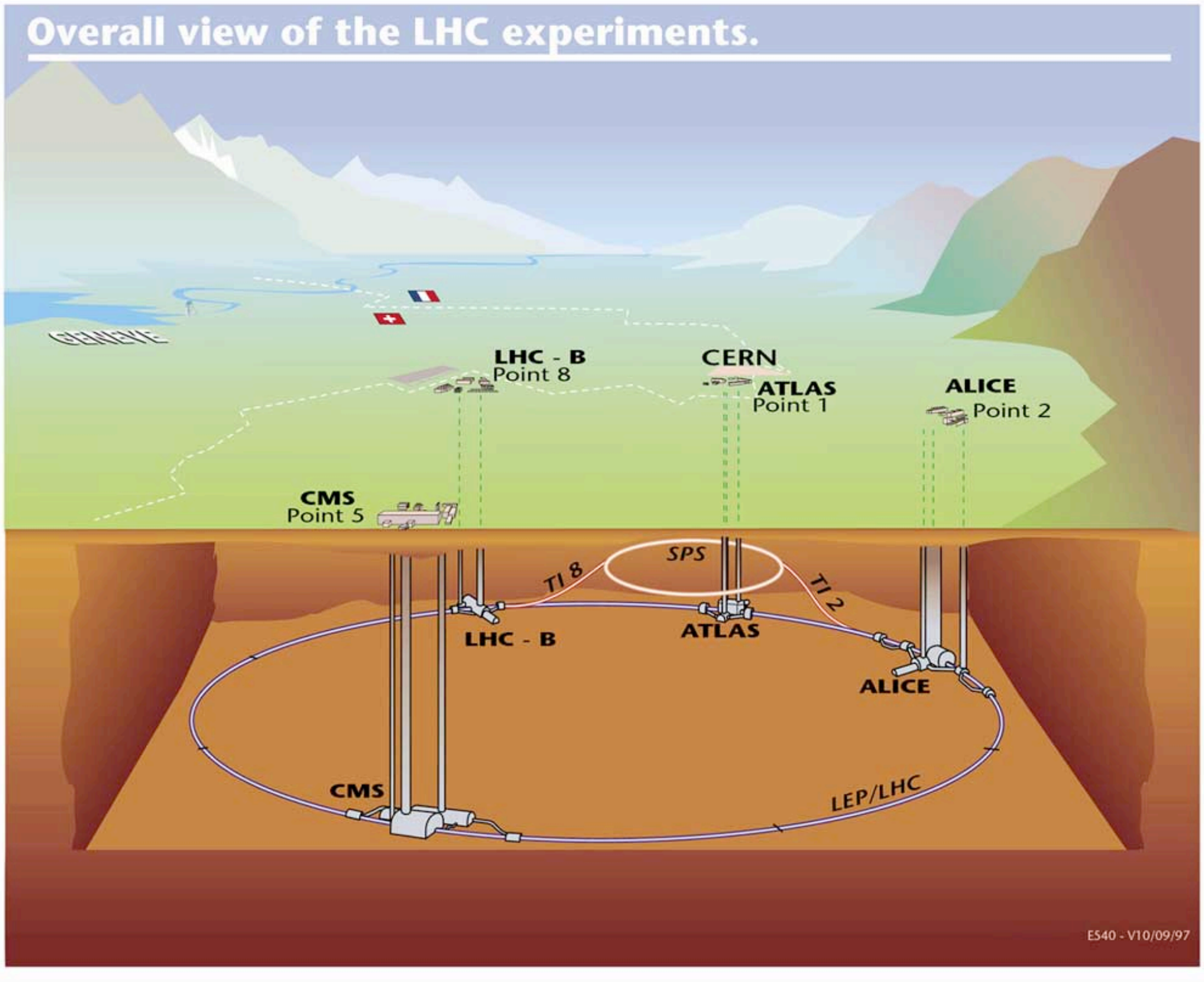
SUSY in the Laboratory

The Experiment



SUSY in the Laboratory

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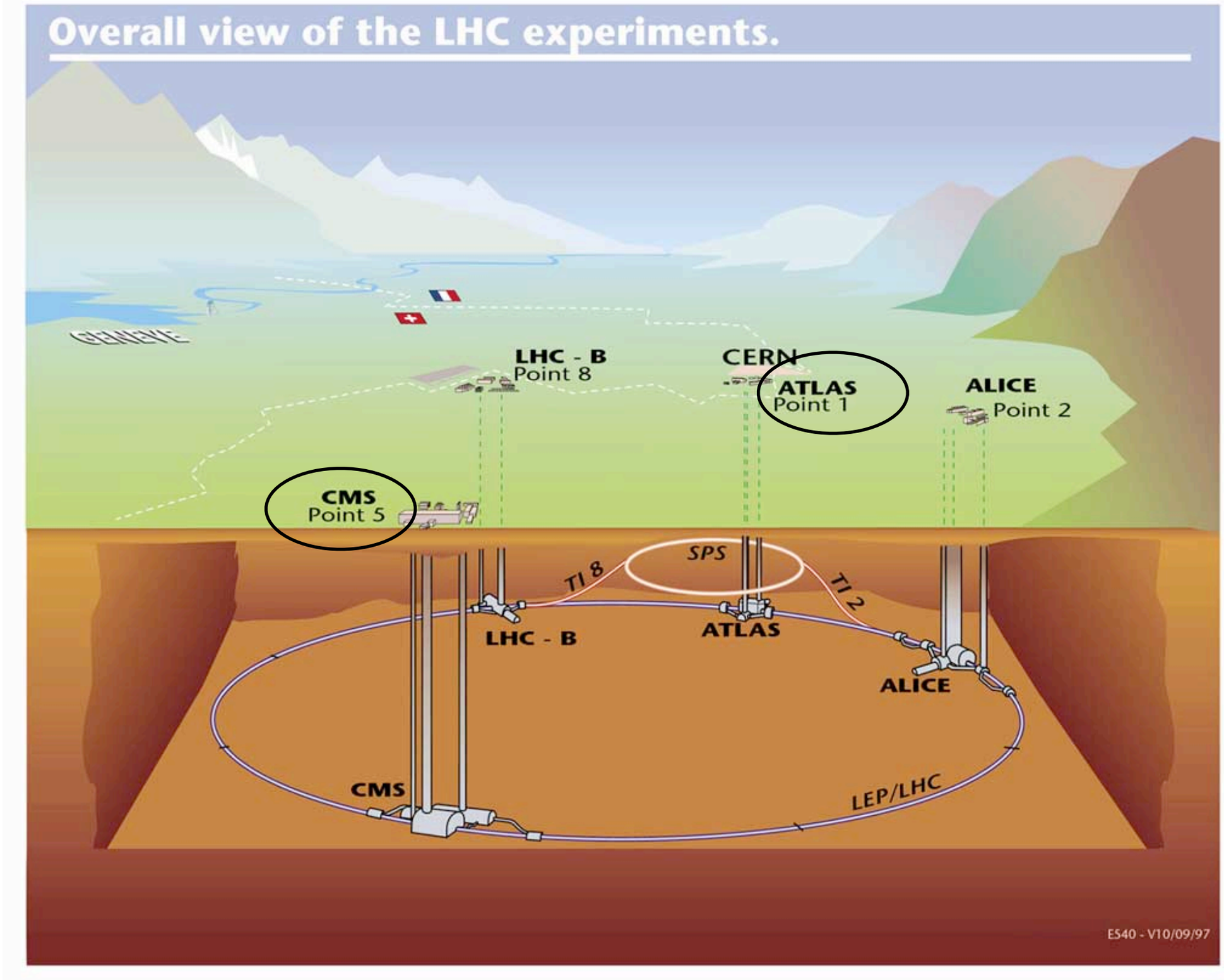

SUSY in the Laboratory

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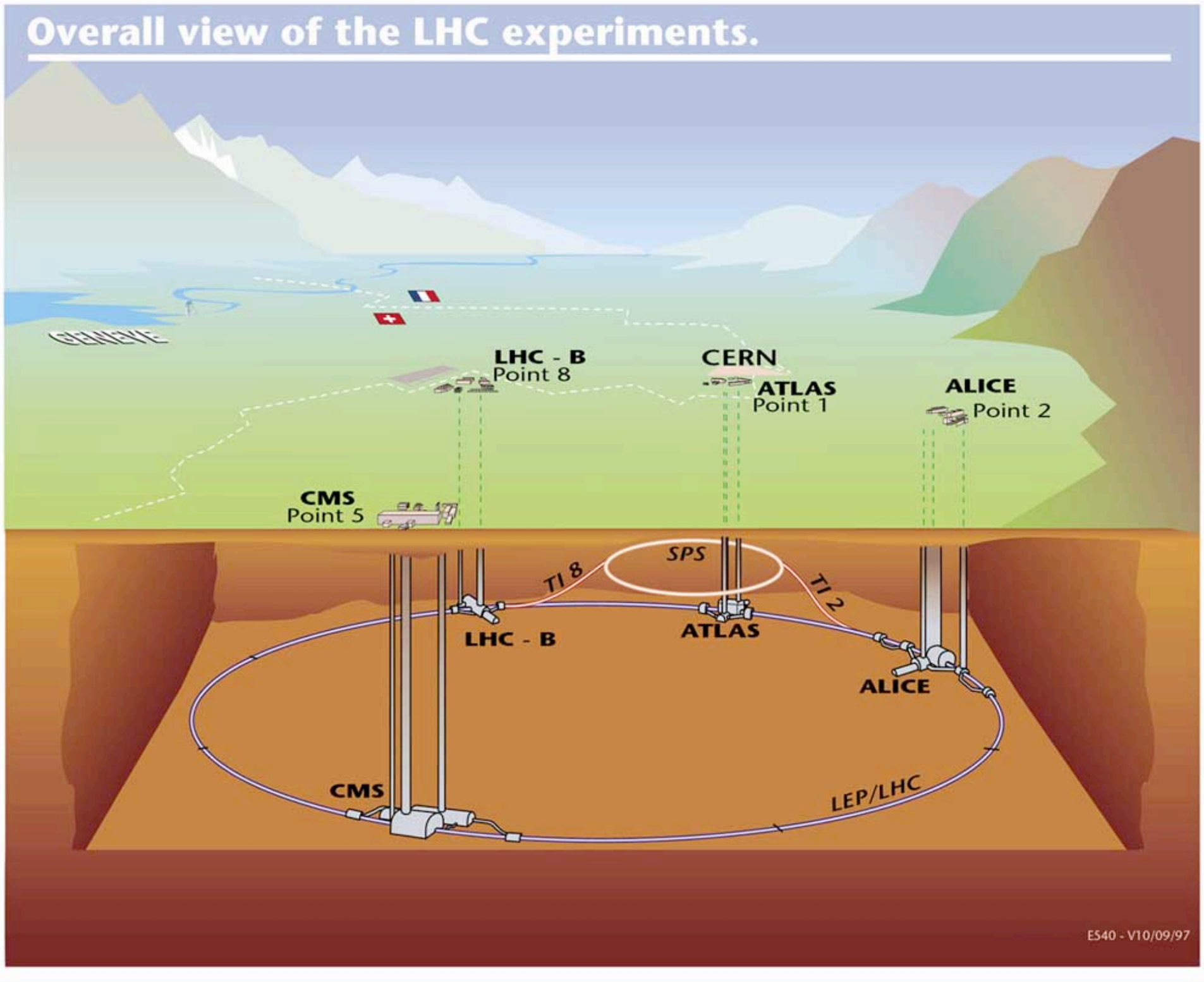
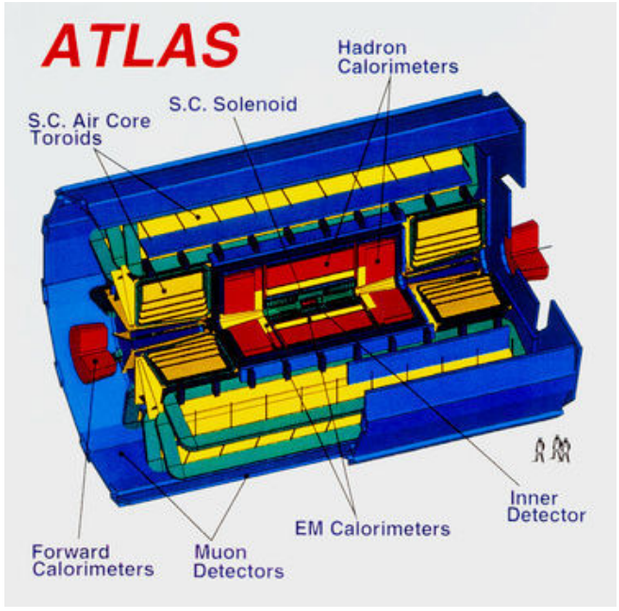
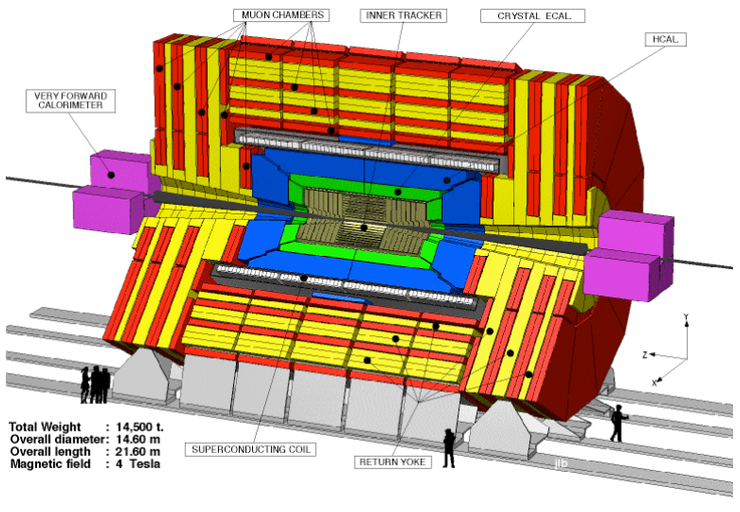
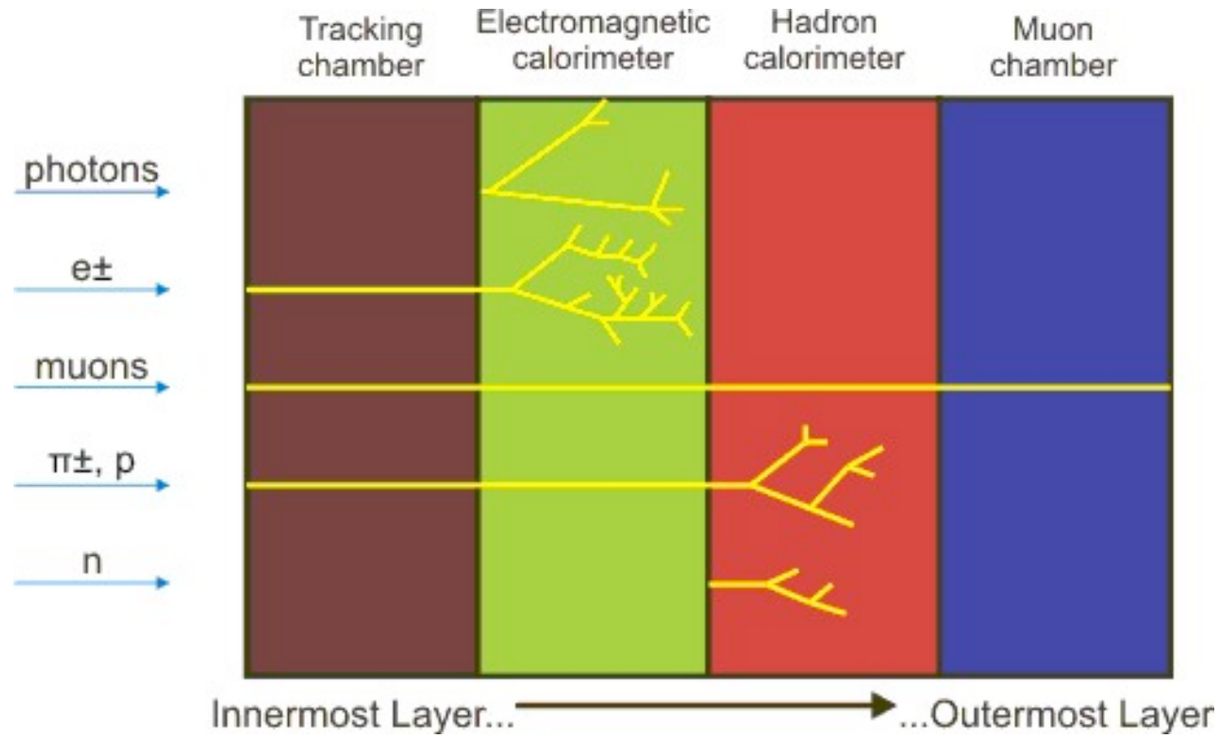


SUSY in the lab

Detection principle







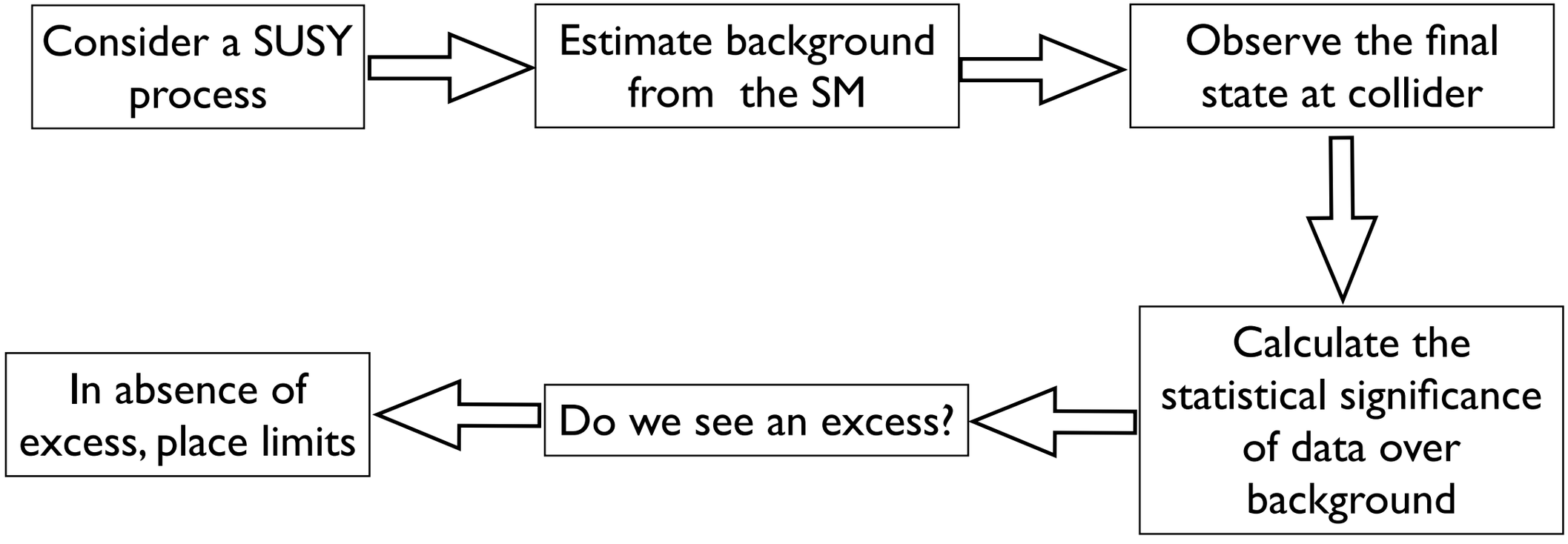
NB a weakly interacting, stable (or long-lived) neutral particle will escape the detector leaving a deficit in the total amount of energy involved in the interaction.

Ex. : neutrino, lightest SUSY particle

SUSY in the lab

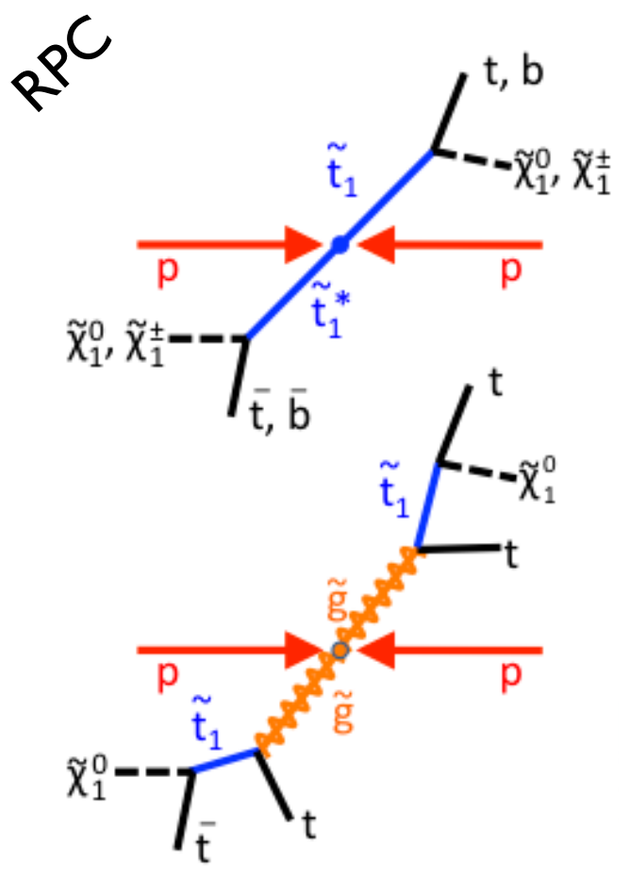
Signal processing

- We want SUSY to explain stable, electrically neutral dark matter
- Such guys will escape the detector just like neutrino
- Missing energy most anticipated signature

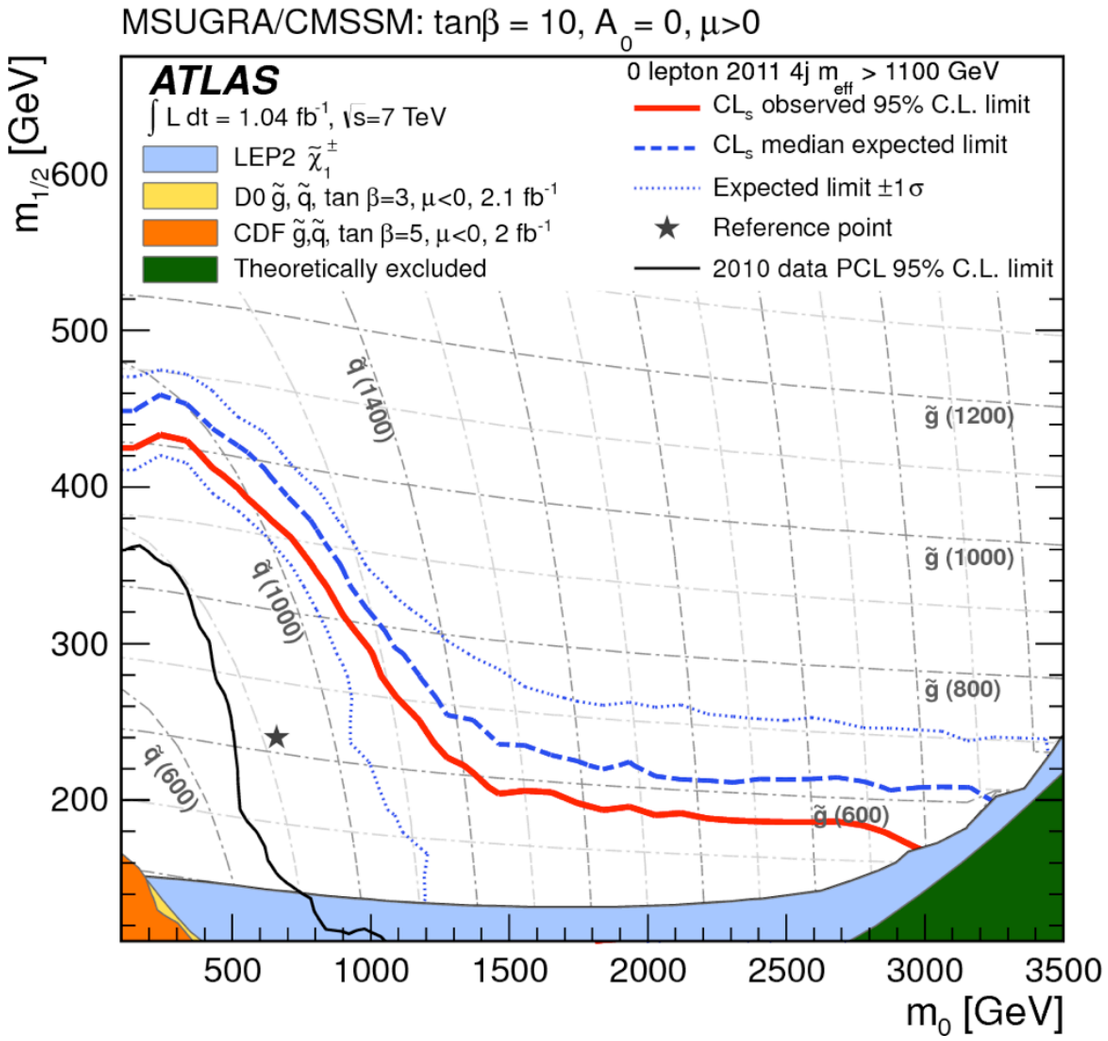


SUSY in the lab

LHC search results



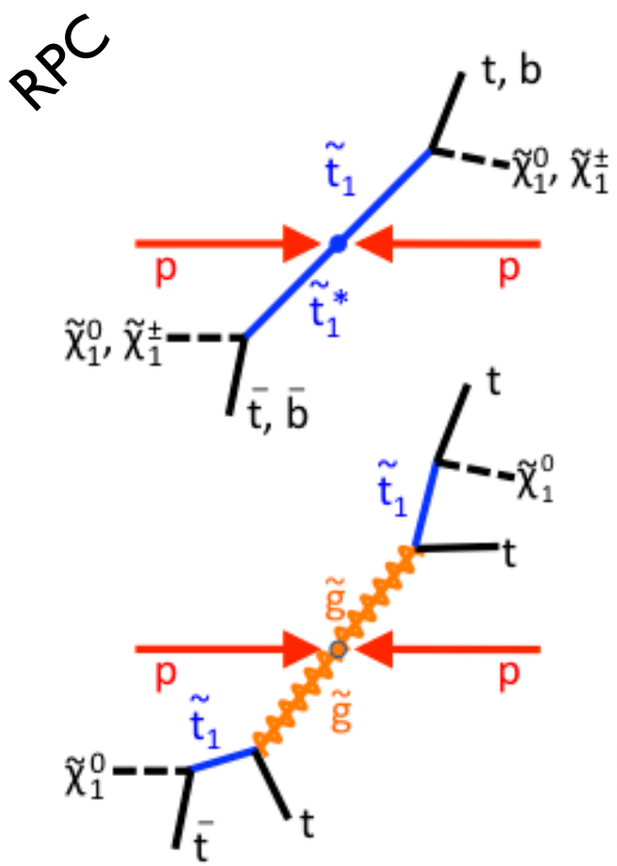
- Final state 0 leptons + 2 to 4 jets + MET
- Backgrounds: W + jets, Z + jets and ttbar
- Results interpreted in cMSSM



- Caution: This is only one of many channels/topologies
- We need to combine all limits together

SUSY in the lab

LHC search results



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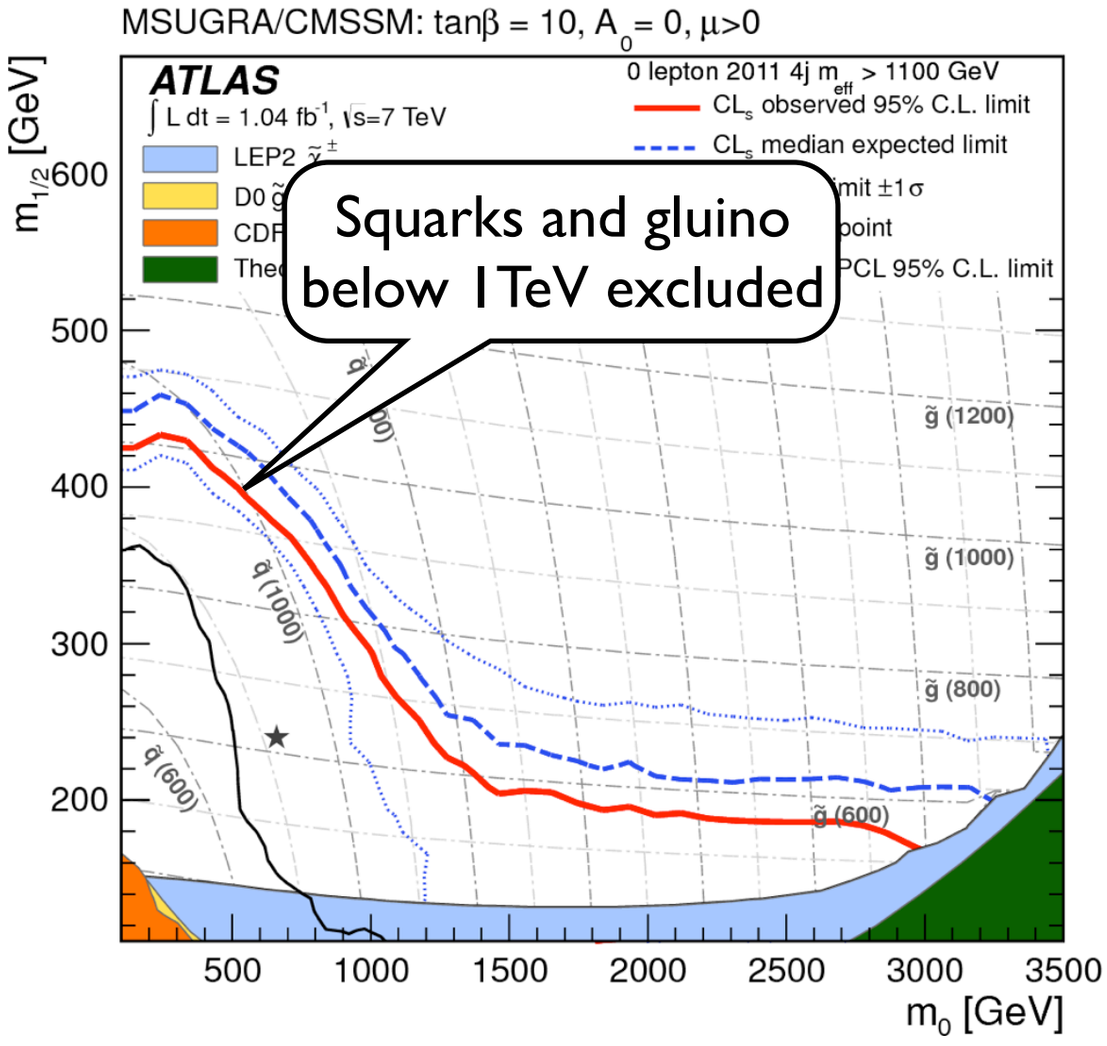

SUSY in the sky

Dark matter

- Dark matter occupies about 20% of the energy budget of the Universe
- Does not interact directly with photons, electrically neutral and stable
- In the early Universe

SUSY in the sky

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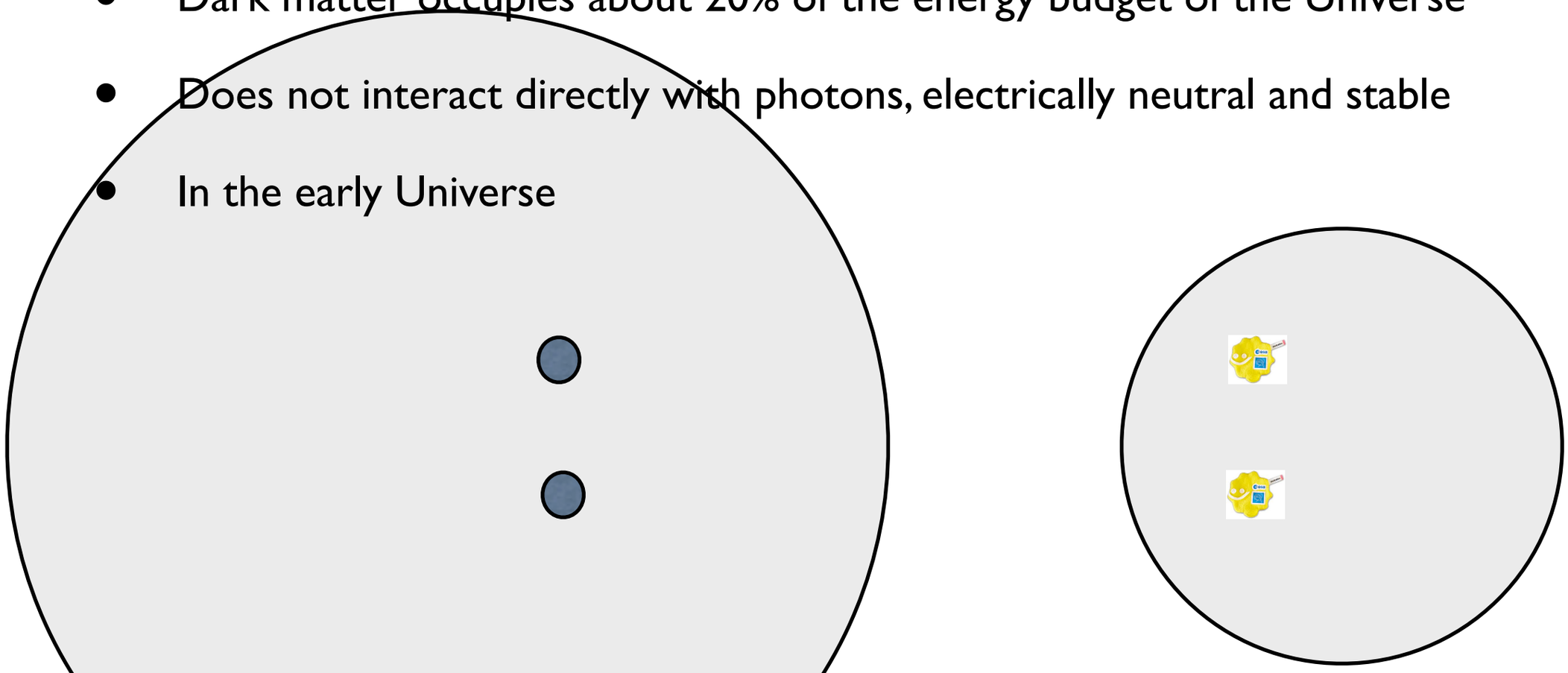

- Expansion slower than interaction
- Dark matter can annihilate into the SM particles

SUSY in the sky

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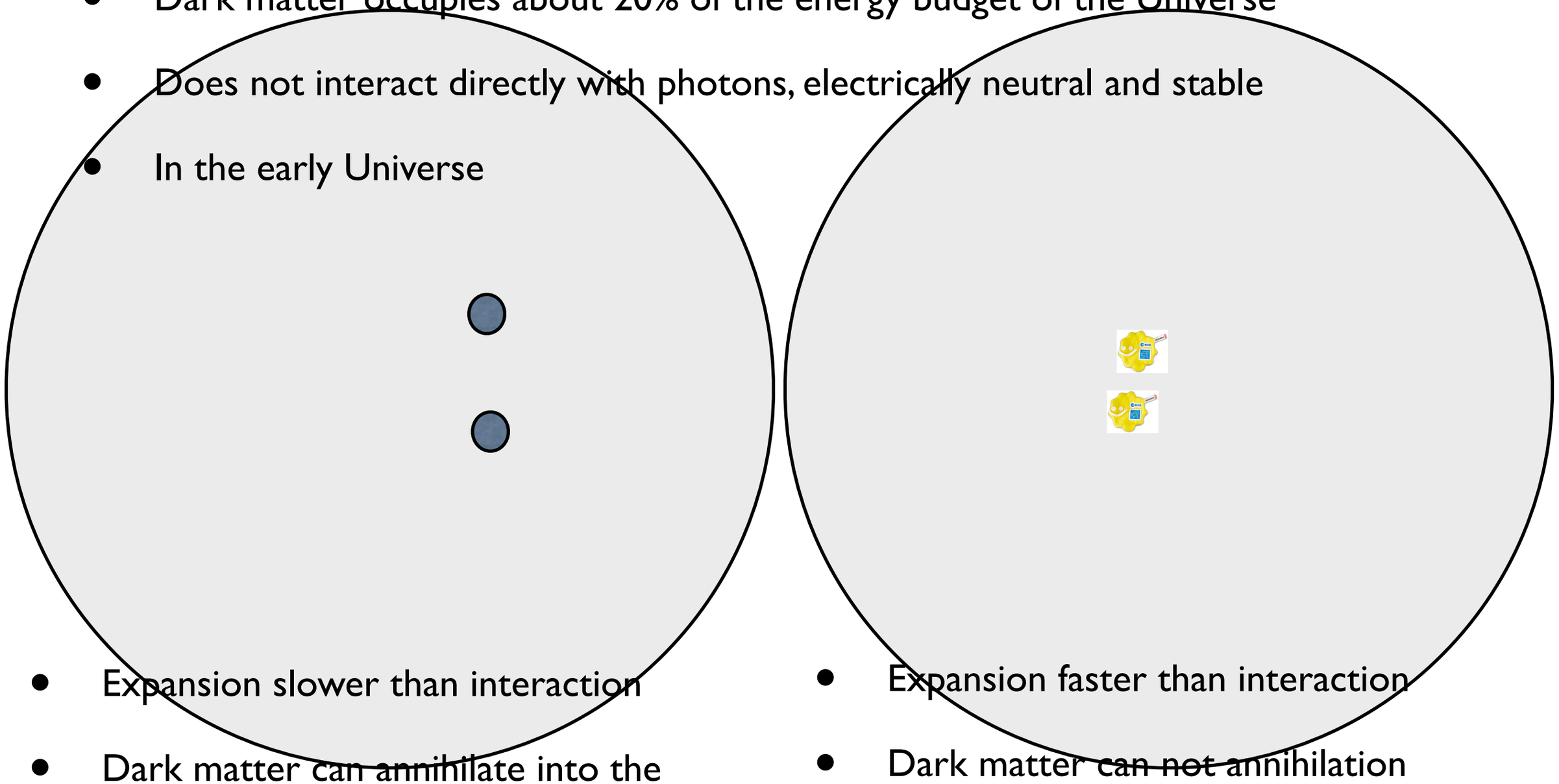


- Expansion slower than interaction
- Dark matter ~~can~~ annihilate into the SM particles

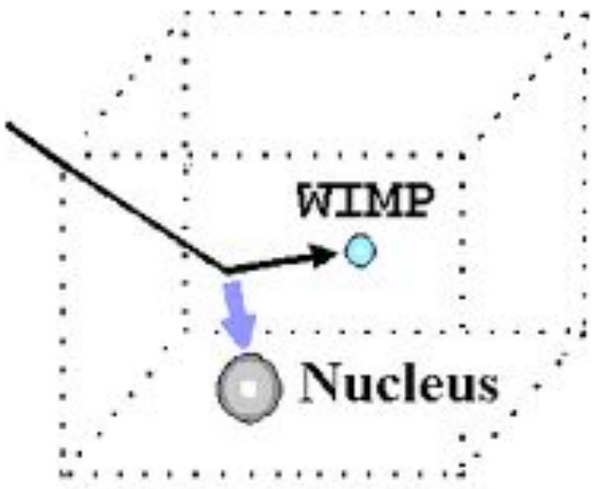
- Expansion faster than interaction
- Dark matter ~~can not~~ annihilation into the SM particles
- Relic density - remaining amount of dark matter after this stage

SUSY in the sky

Dark matter detection principle

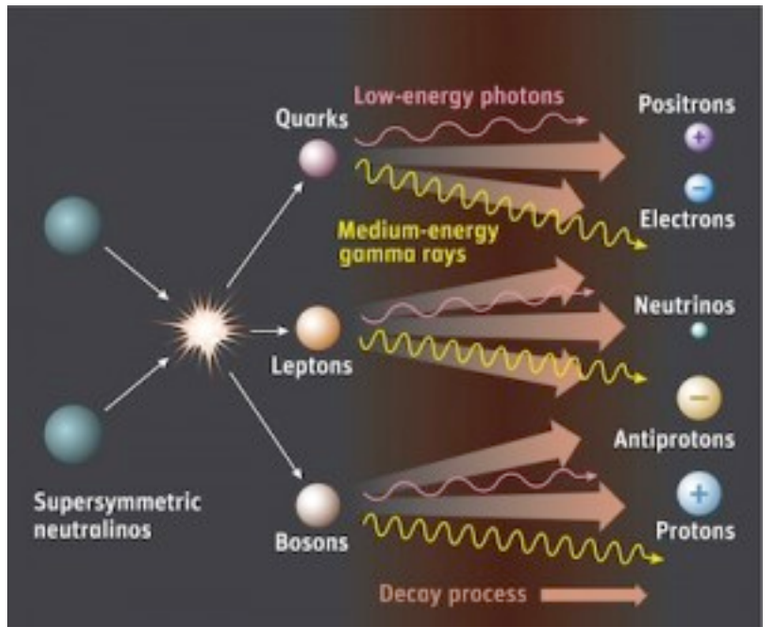
- Search for DM either via direct detection or indirect detection

Direct detection



- Scattering of dark matter particles with the nuclei in the detectors

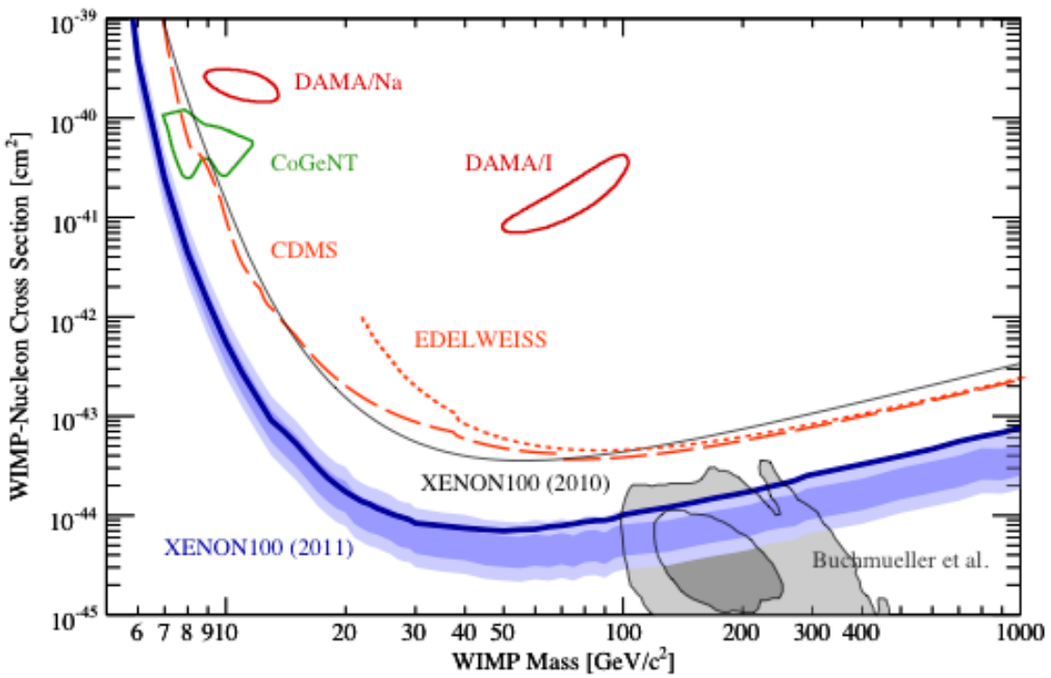
Indirect detection



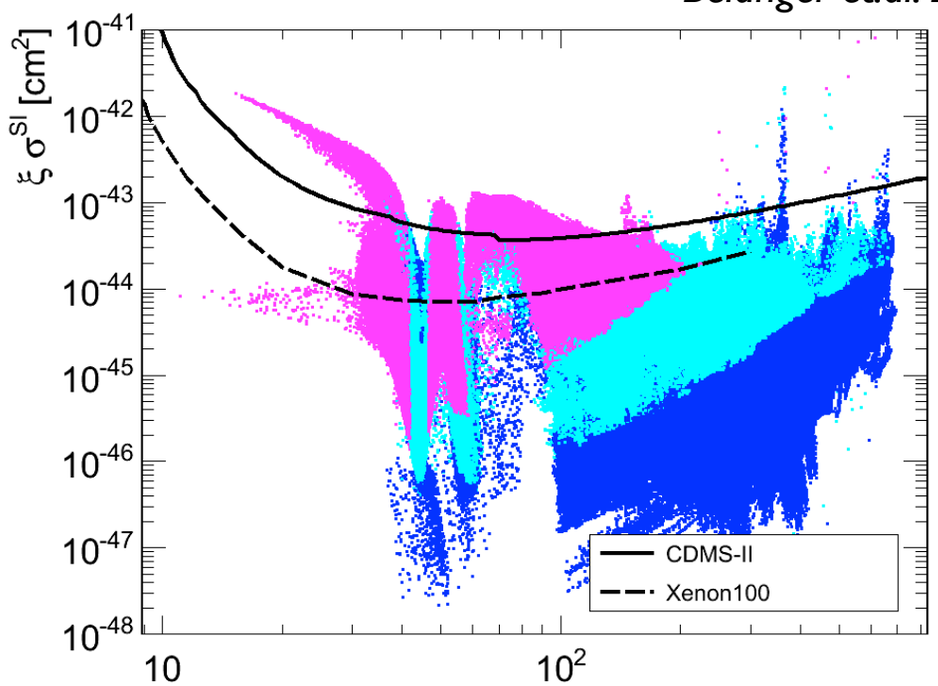
- Annihilation into e.g. photons via secondary decays

SUSY in the sky

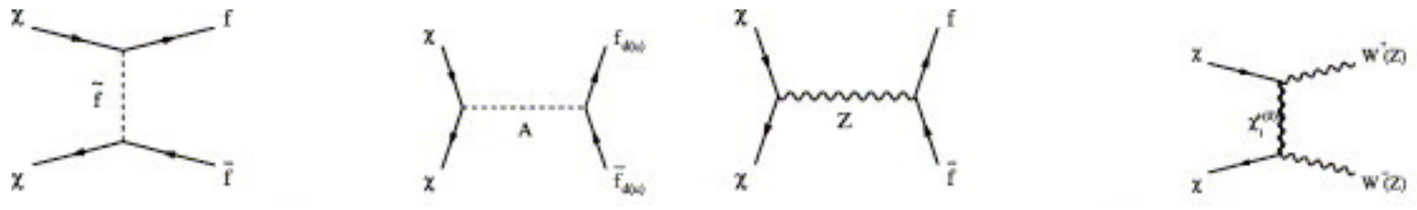
Impact on neutralino dark matter



Belanger et.al. LAPTh



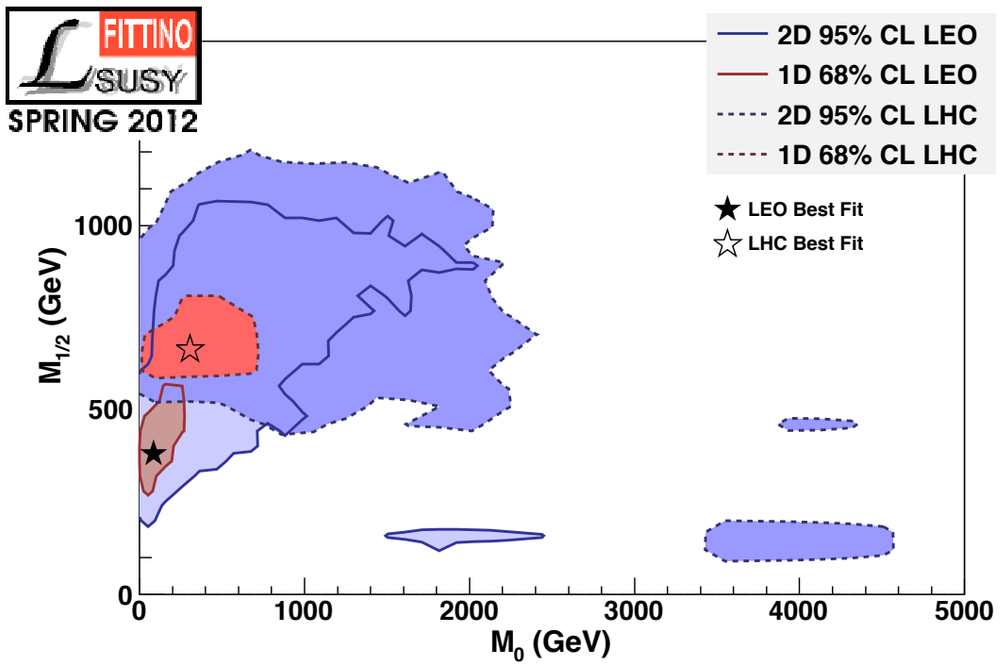
- Results of these experiments constrain cross-section and mass of dark matter candidate



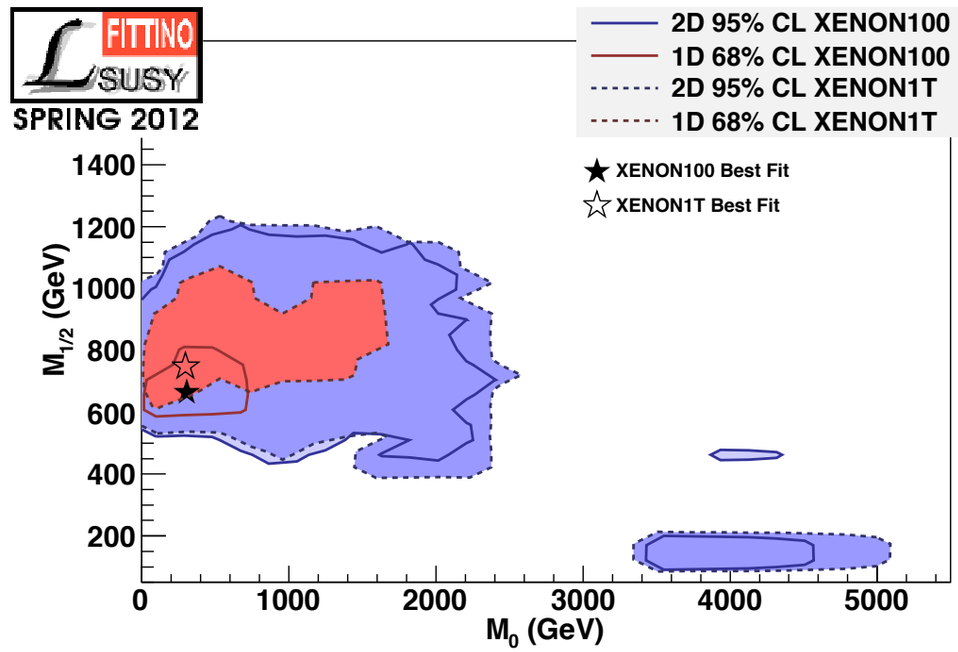
- Neutralino annihilates into SM particles as shown above
- Limits from direct detection experiments can restrict neutralino mass and cross-section

Putting things together

Fit only for LHC results



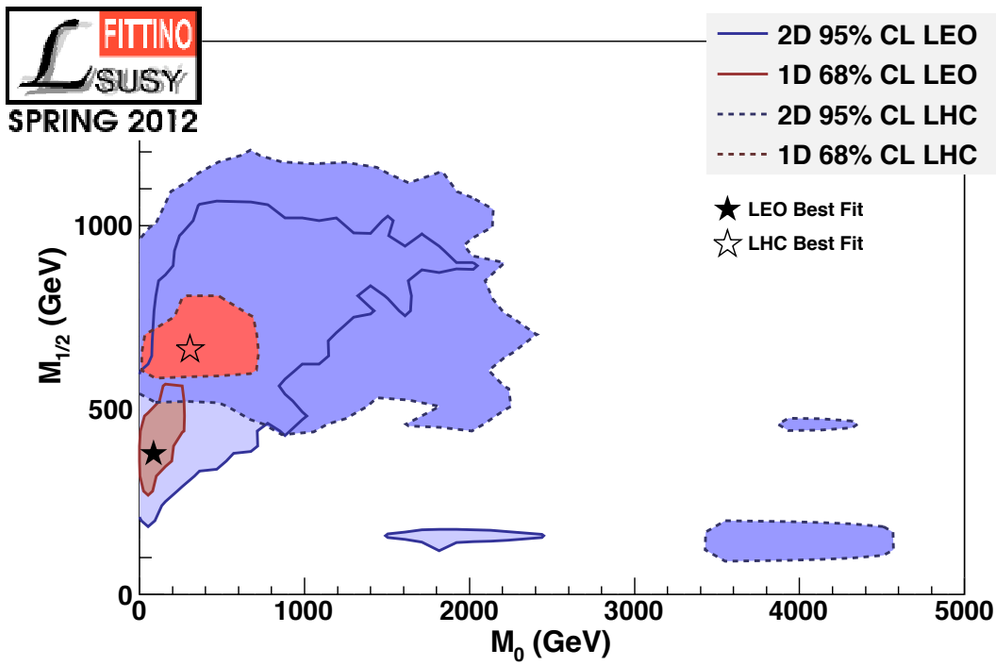
Fit including DM direct detection



Caution: Results applicable only for constrained model

Putting things together

Fit only for LHC results



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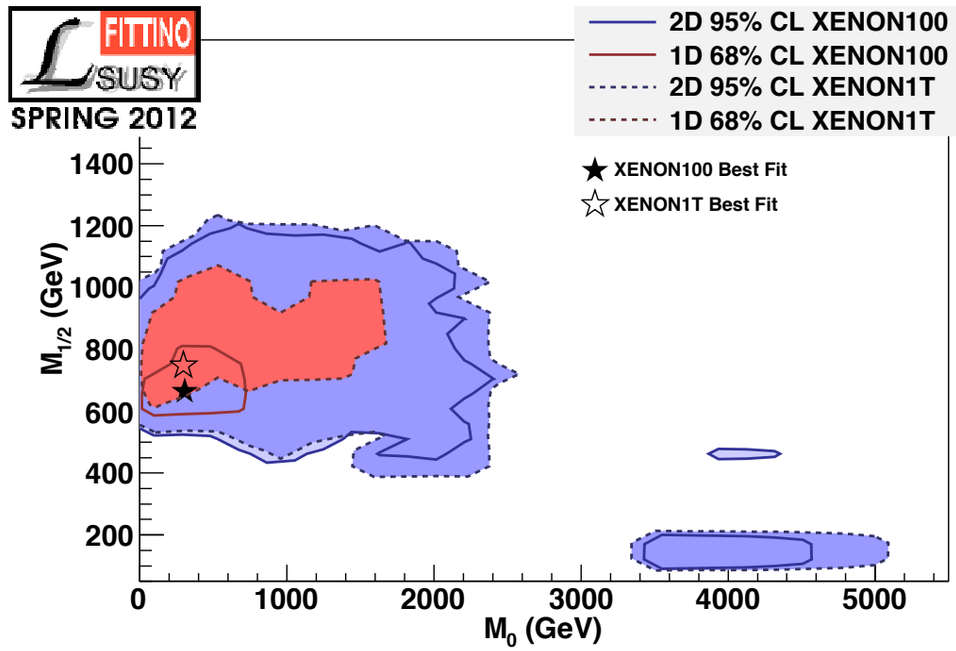


Recall approximate mass relations for gluino, neutralino and squark masses in the cMSSM

$$m_{\tilde{g}} \approx 2.8\, m_{1/2}$$
$$m_{\chi_1^0} \approx 0.4\, m_{1/2}$$

$$m_{\tilde{q}} \approx \sqrt{m_0^2 + K\, m_{1/2}^2}$$

$$K \approx 4.5 - 6$$

Caution: Results applicable only for constrained model

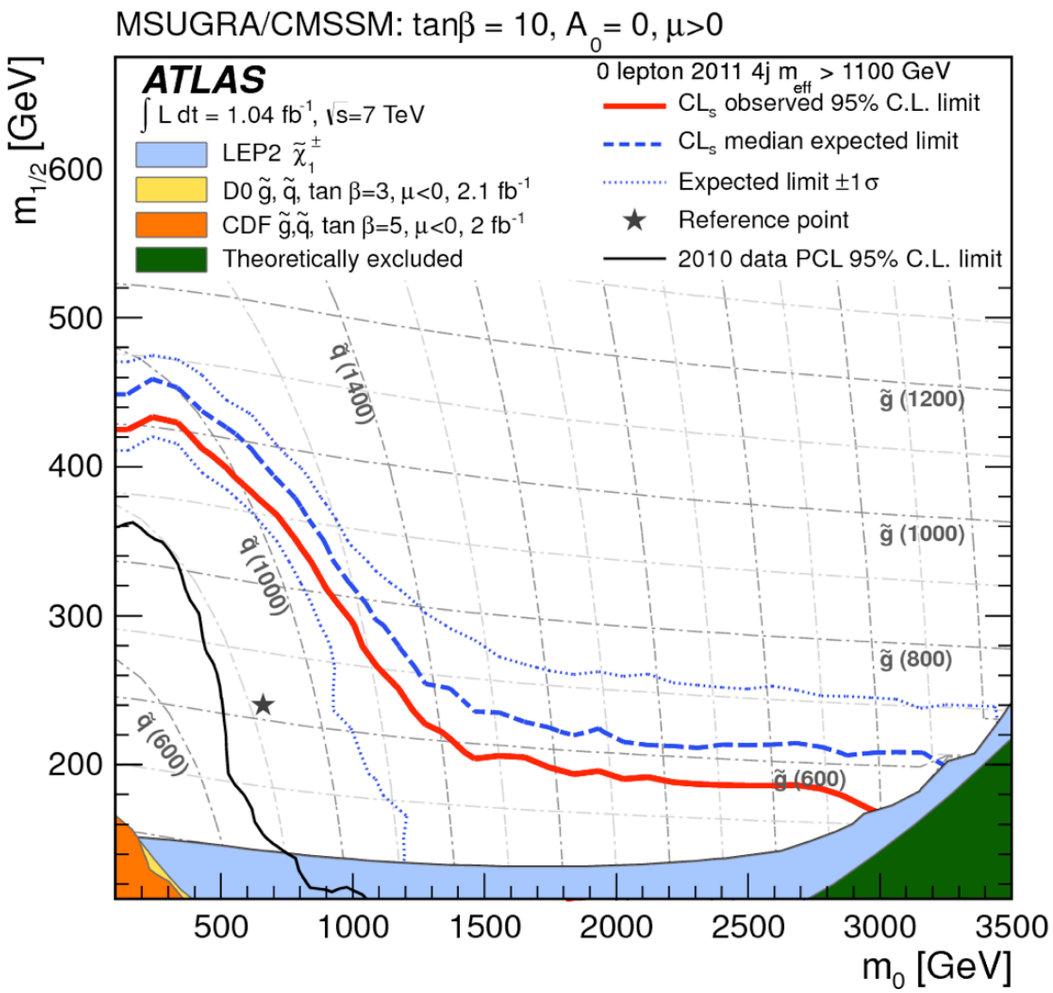
Is SUSY running away from us?

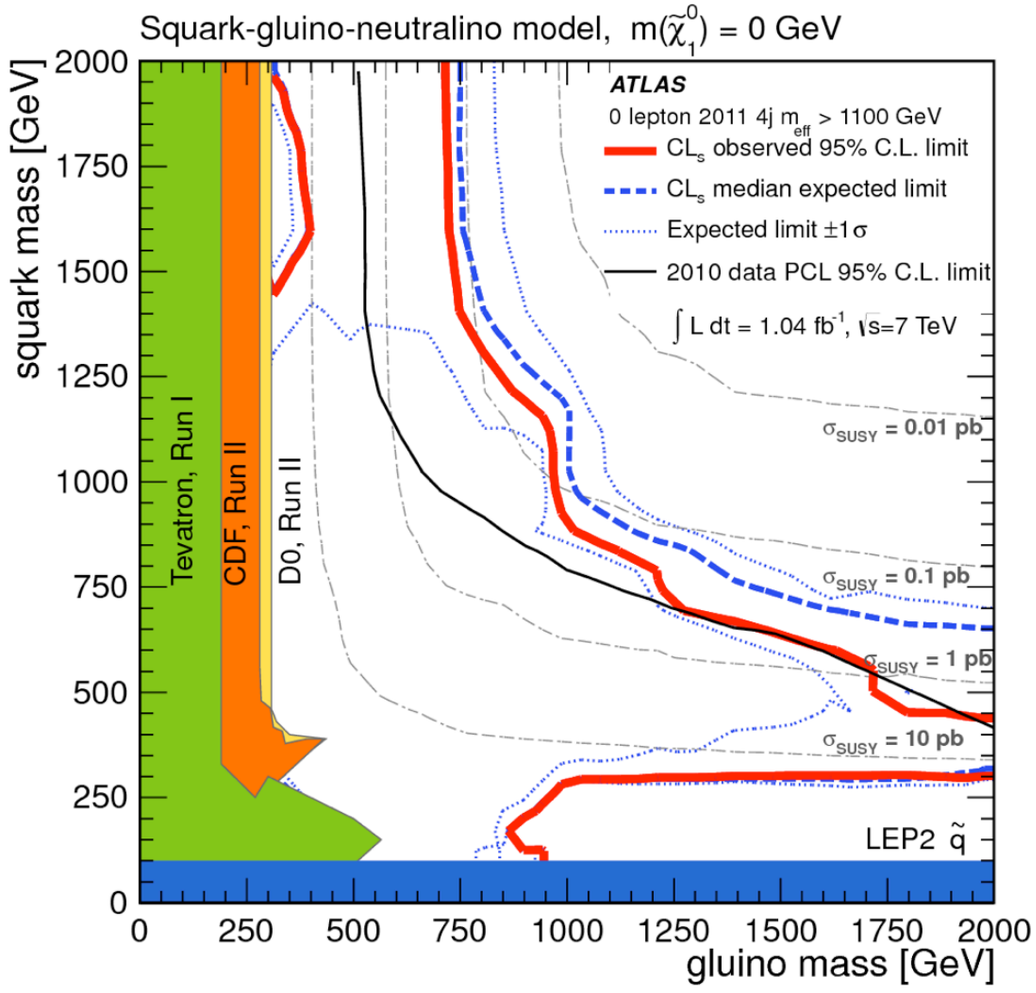
or SUSY doesn't exist?

And we should look for something else?

Is it time to worry?

Simplified models



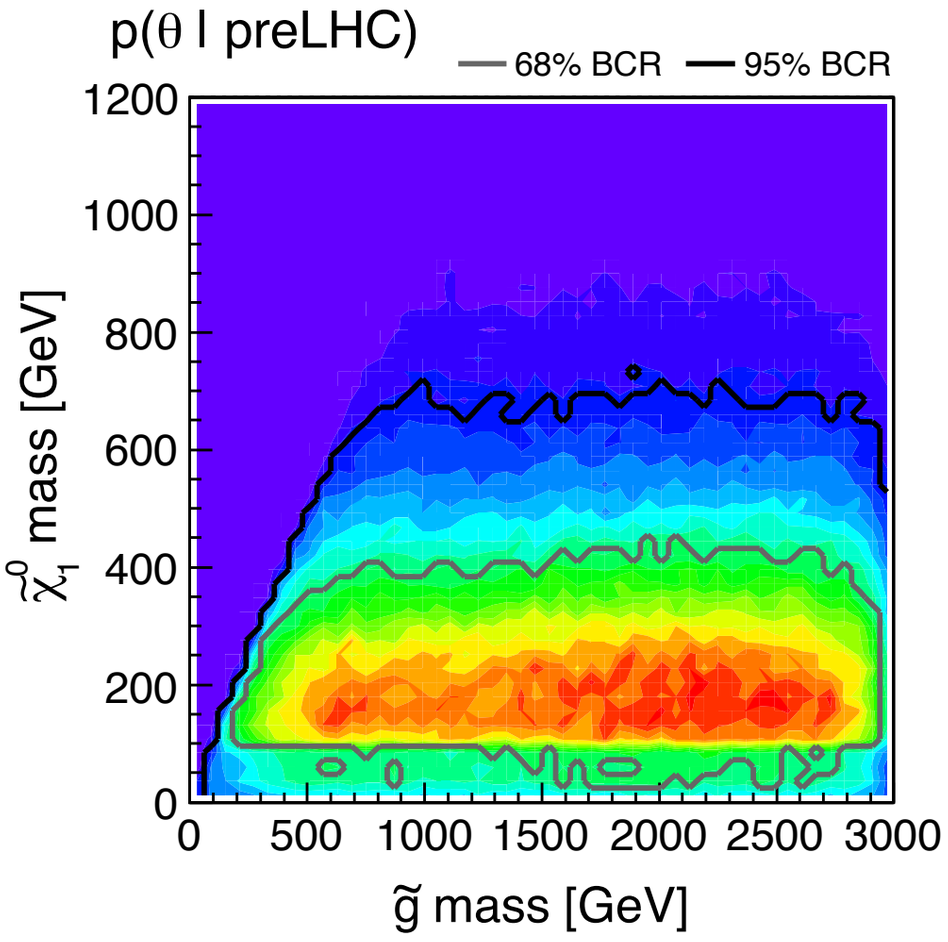


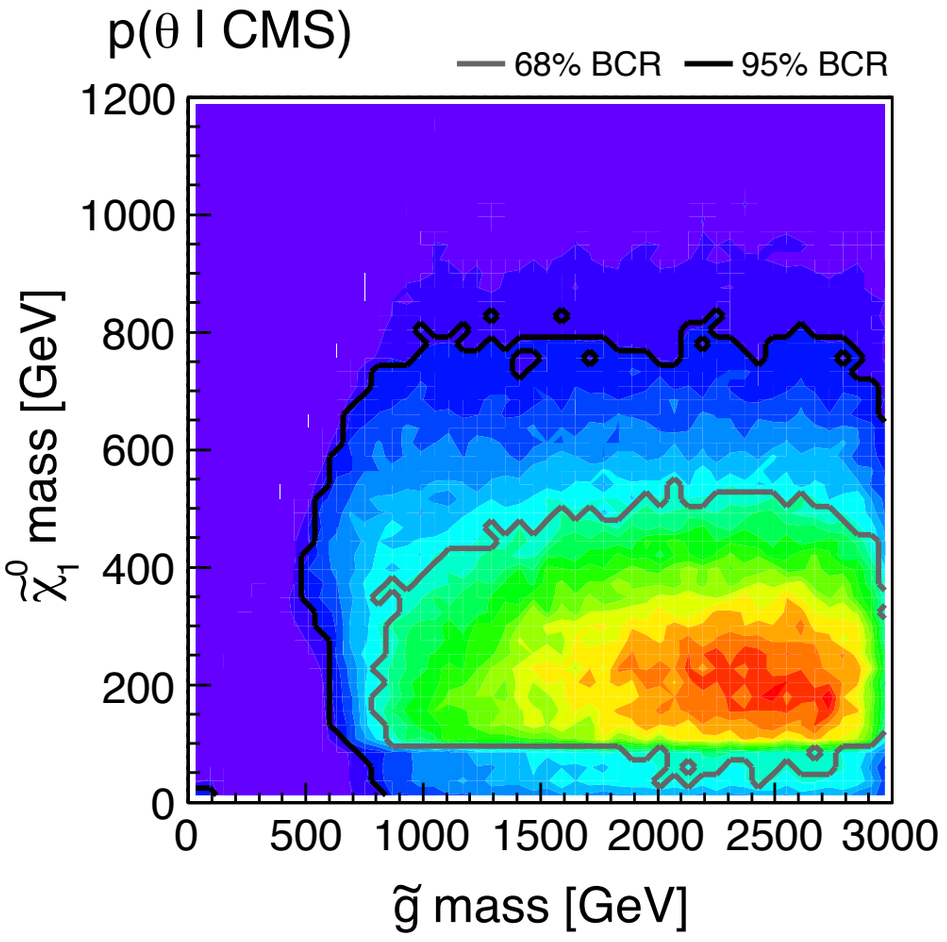
- Simplified models of SUSY assume a specific decay chain and mass difference between two particles
- These place limit on the masses of particles than the underlying free parameters
- These limits differ to those from limits within cMSSM

Is it time to worry?

pMSSM analysis

S. Kraml et al, LPSC





- General weak-scale MSSM with 19 free parameters
- Neutralino and gluino masses not related to each other
  → mass differences between these particles could be large or very small
- Can lead to scenarios which are experimentally very challenging
- cMSSM limits cover only a small region of the general parameter space

Is it time to worry?

pMSSM analysis

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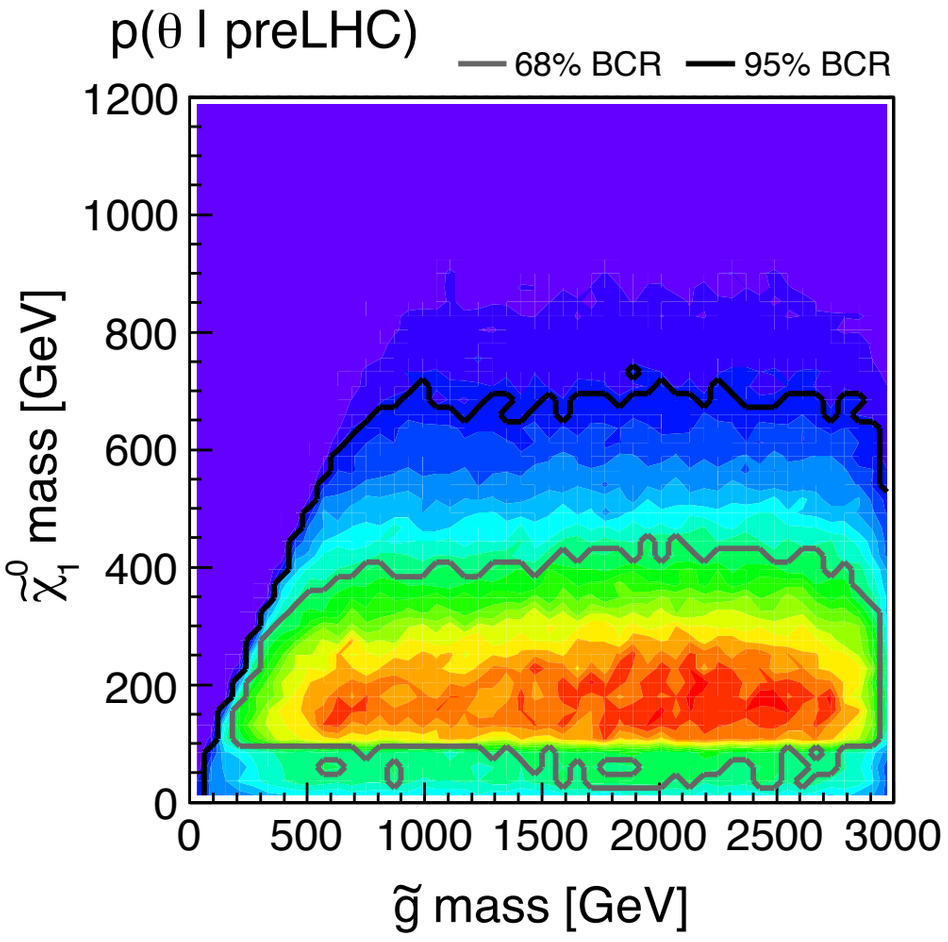

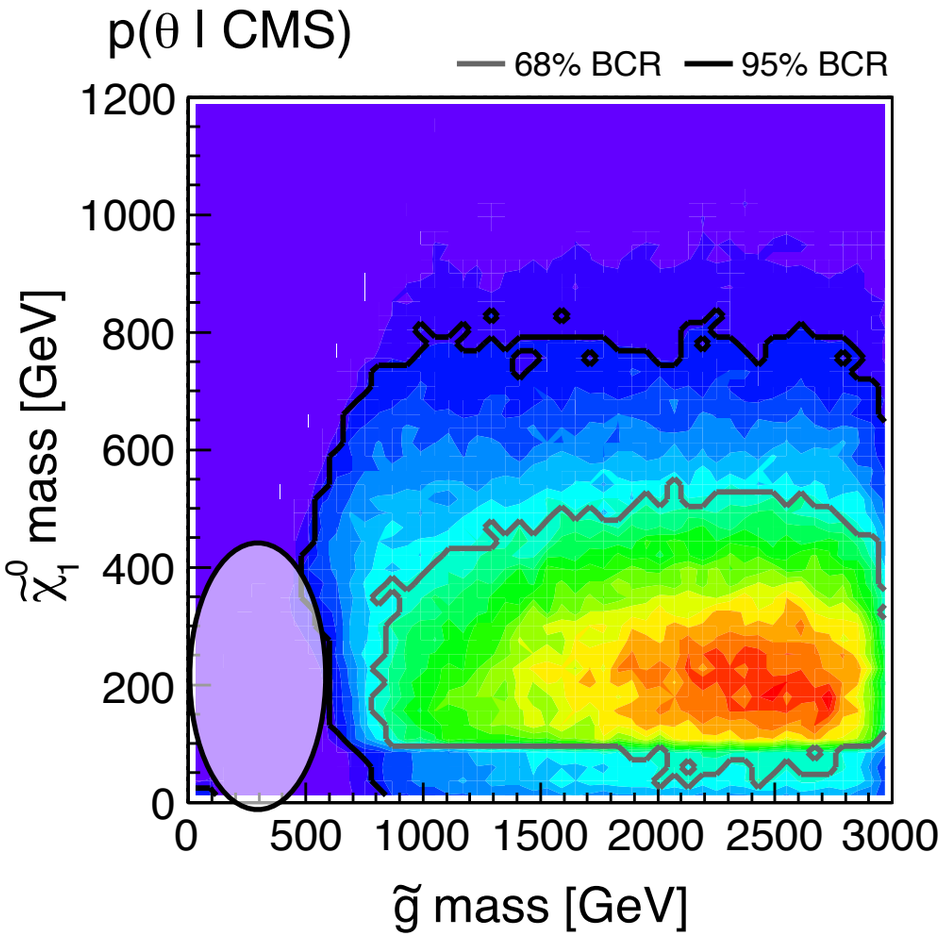

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LPSC theory group:

SUSY activities include

- Implications of LHC results in SUSY scenarios - do current searches cover all the parameter space of generic SUSY models? Are there scenarios which are being left out? Can current analyses be improved?

  close collaboration with experiments

- Implications of a 125 GeV Higgs for SUSY - if the hints for a Higgs signal are confirmed, what would it imply for SUSY models?

- Alternative dark matter scenarios - talk focused on neutralino dark matter, SUSY however provides various dark matter candidates. What is their phenomenology (astrophysics, colliders)? How do they impact the LHC searched?

- Alternative cosmological scenarios - Could dark matter be made of more than one component? What are the effects of altering the conditions in the early Universe on dark matter phenomenology?

Conclusions

- Searches for SUSY have just begun
- SUSY seems to be tightly constrained only within very restricted model space e.g. cMSSM
- For generic models, the current search results are not applicable and experiments have started making efforts to explore such models
- There is a lot of space out there for a generic SUSY models study