Theory Perspectives for the LHC

Sven Heinemeyer, IFCA (CSIC, Santander)

Valencia, 11/2010

1. LHC perspectives and why theorists are important
2. Higgs at the LHC
3. Supersymmetry at the LHC
4. Conclusions

1. LHC perspectives and why theorists are important

The (more or less) official (optimistic?) LHC time line:

03/2010: first collisions at record breaking energy

2010: $\lesssim 0.05$ fb^{-1} (at $\sqrt{s} = 7$ TeV)

2011: $\lesssim 1$ fb^{-1} (at $\sqrt{s} = 7$ TeV) $\Rightarrow$ first physics results?

2012: shutdown, further splice checks, repairs, ...

2013 – 2015: 10 fb^{-1} per year $\Rightarrow$ physics results with "low" luminosity

2016: shutdown, preparation for "high luminosity"

2017 – 2019: 100 fb^{-1} per year $\Rightarrow$ physics results with "high" luminosity

2020: upgrade to SLHC?

2021 + X (X $>$ 0): SLHC?

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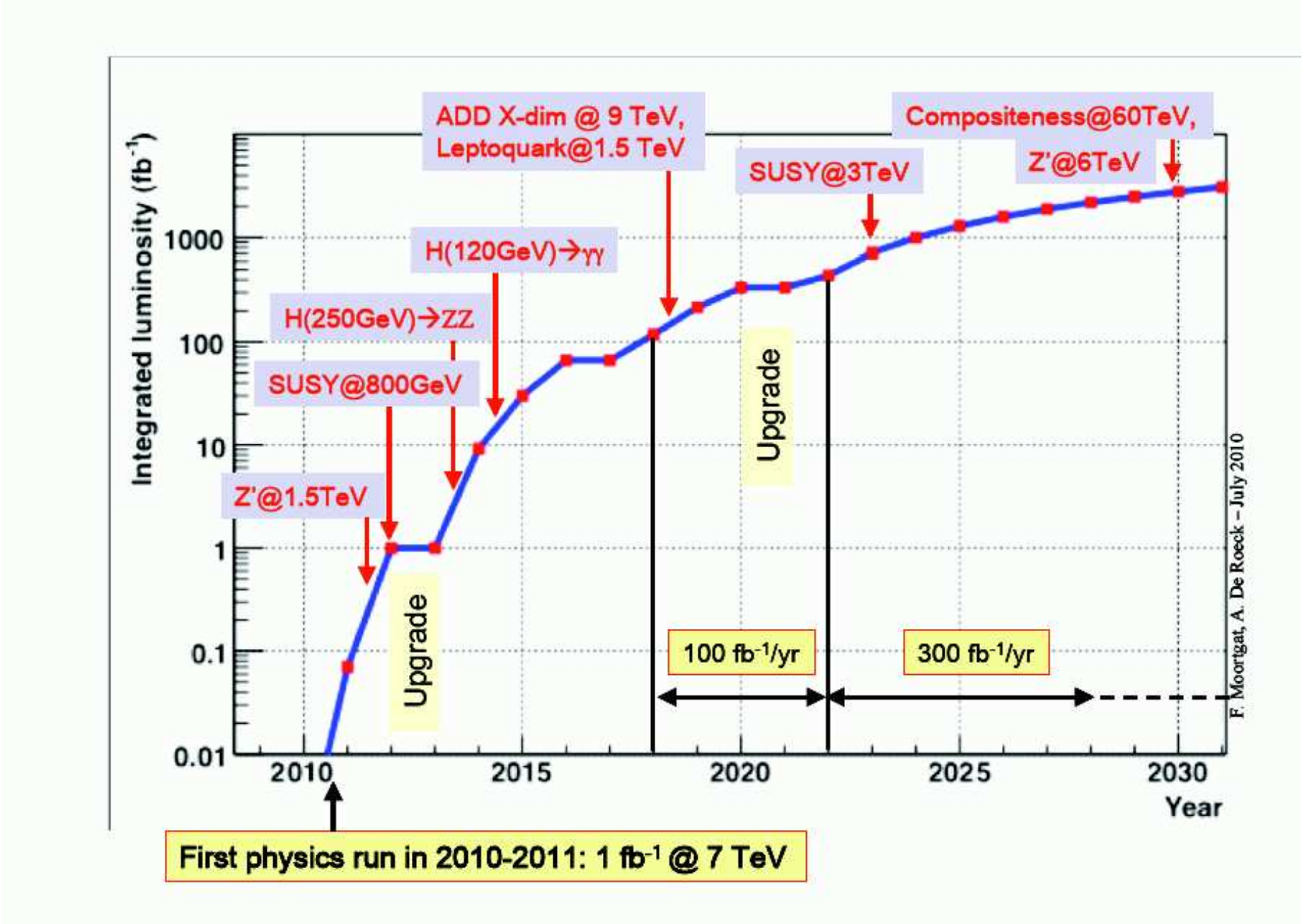
WE LIVE IN AN EXCITING TIME!!!

LHC experimental expectations:

[*A. De Roeck et al. '10*]



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LHC will provide (high?) accuracy measurements !

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Theoretical calculations should be viewed as an essential part of all (current and future) High Energy Physics programs

To the Young Physicists:

Don't worry: there is a lot of important work to do!

For experimentalists:
- analysis of all the new data

For theorists:
- many calculations in the known models are missing to match the LHC precision
- new data often requires new models (or extensions)

For experimentalists $\oplus$ theorists:

imho: collaboration between theory and experiment is crucial

Theory $\leftrightarrow$ tools $\leftrightarrow$ experimental analyses

Theoretical models $\leftrightarrow$ experimental analyses

We should try to profit from the proximity (within Spain?)

Two options for this talk

1. Focus on SM physics and QCD, event generators etc.

2. Focus on new discoveries, new physics

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Both is important:

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2. The hunt for new physics is on!
   The truth is out there! NOW is the time!

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$\Rightarrow$ I will focus on the 2nd option

2. Higgs at the LHC

Discovering the Higgs boson

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Discovering the Higgs boson

What has to be done?

1. Find the new particle	T
2. measure its mass ($\Rightarrow$ ok?)	T
3. measure coupling to gauge bosons	
4. measure couplings to fermions	
5. measure self-couplings	
6. measure spin, ...	

T = Tevatron,

Discovering the Higgs boson

What has to be done?

1. Find the new particle	T	L
2. measure its mass ($\Rightarrow$ ok?)	T	L
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6. measure spin, ...		

T = Tevatron, L = LHC,

Discovering the Higgs boson

What has to be done?

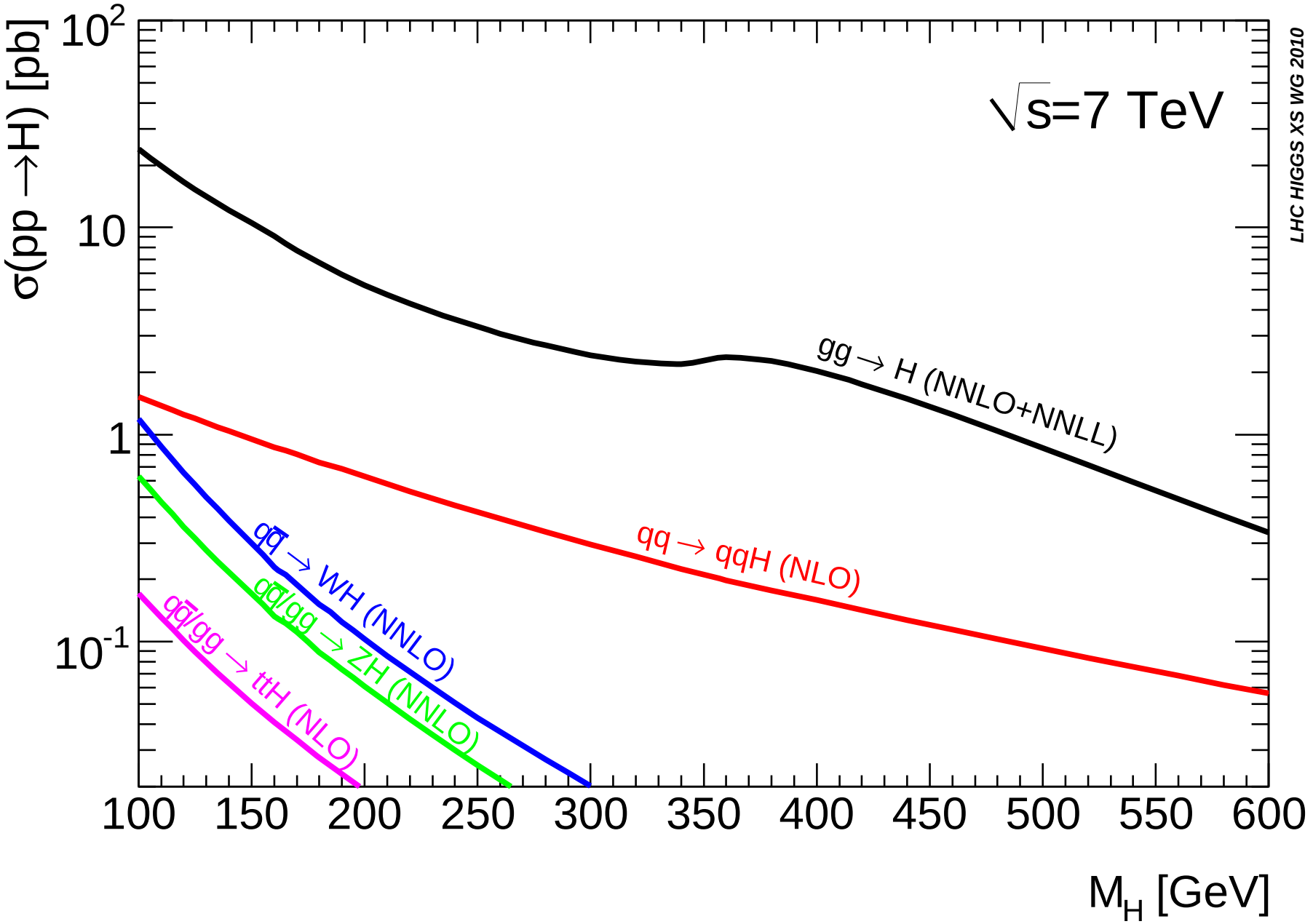
1. Find the new particle	T	L	I
2. measure its mass ($\Rightarrow$ ok?)	T	L	I
3. measure coupling to gauge bosons		L	I
4. measure couplings to fermions		L	I
5. measure self-couplings			I
6. measure spin, ...		L	I

T = Tevatron, L = LHC, I = ILC

We need the ILC to find the Higgs
and to establish the Higgs mechanism!
But the LHC can do a crucial part already!

Latest theory predictions for the SM Higgs (I)

[*LHC Higgs XS WG '10*]



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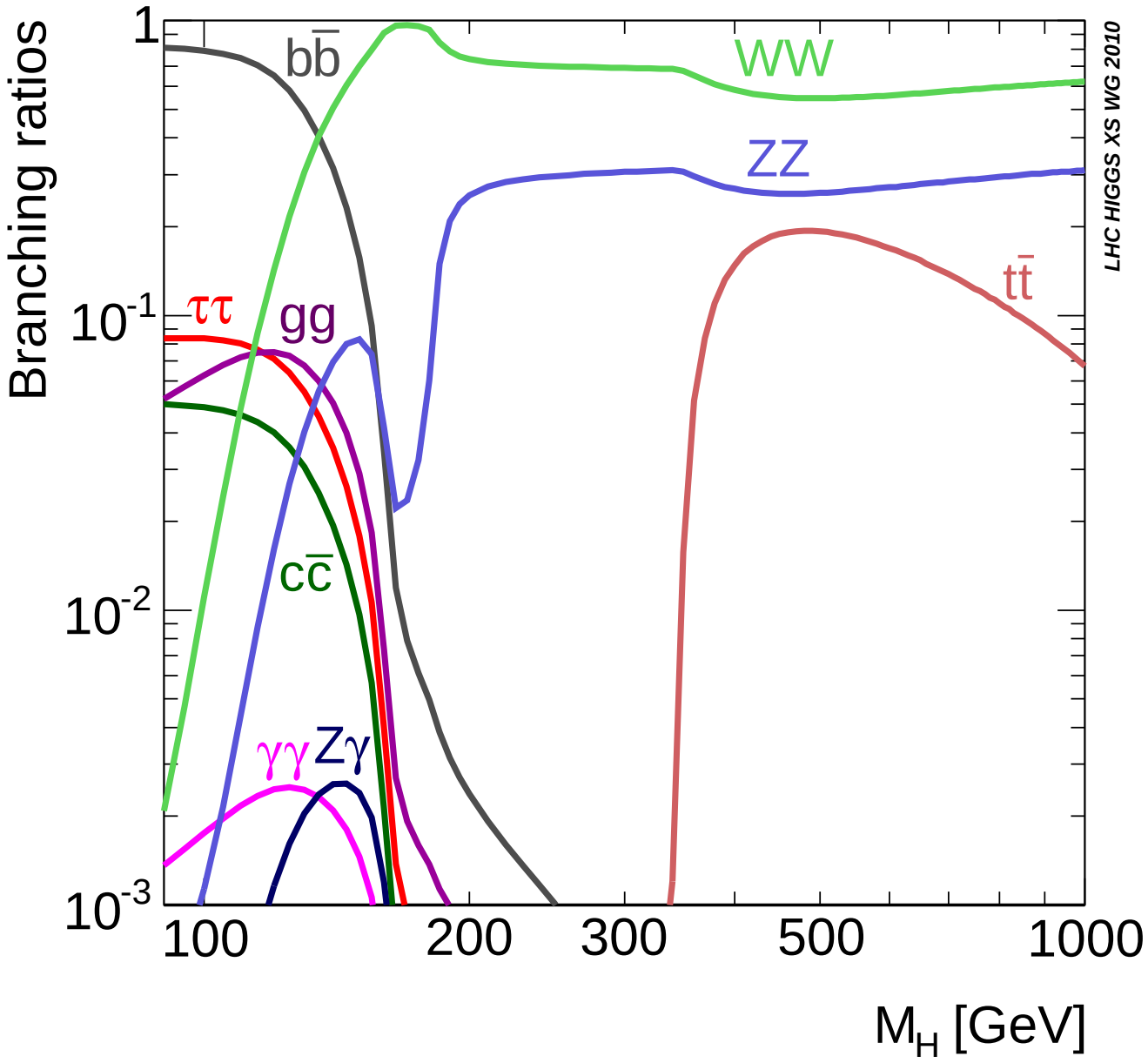

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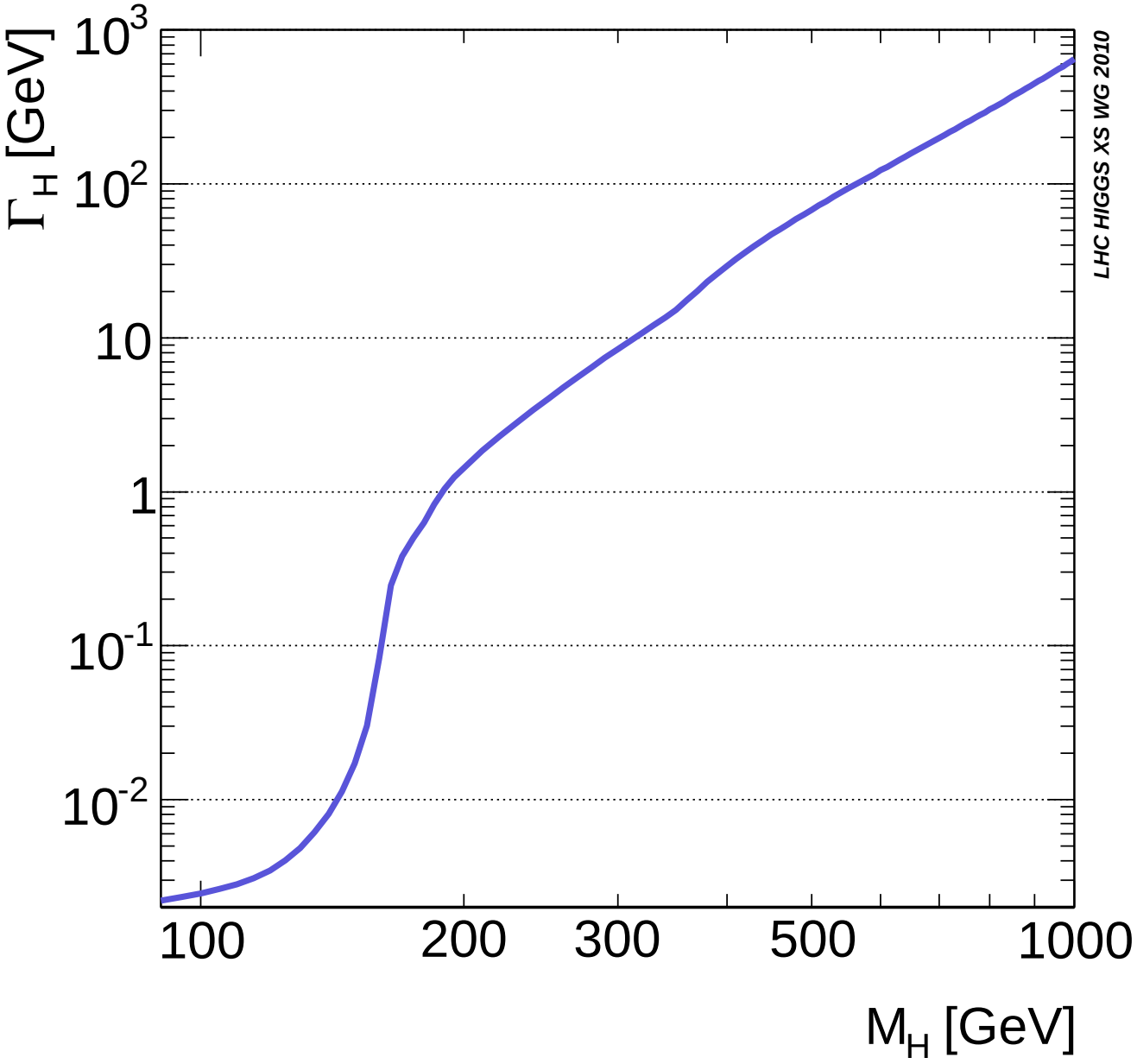


Successful example: LHC Higgs Cross Section Working Group

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CrossSections

- Mixed group of ATLAS/CMS experimentalists and theorists (crucial!)
- Subgroups for each LHC Higgs production cross section or BRs
- Goal: obtain best theory predictions to facilitate
  - "best" Higgs boson search
  - "best" combination of ATLAS and CMS
  - "best" extraction of parameters
- Much to do for theorists:
  - improve cross section/BR calculation
  - calculation of distributions
  - extract/fit Higgs couplings
  - ...
- For CPAN: are we happy with the spanish contribution?

Much work to do in (other) models for Higgs bosons:

1. Two Higgs Doublet Model (THDM)
   → some calculations available

2. Minimal Supersymmetric Standard Model (MSSM)
   → quite thoroughly studied, several code(s) exist

3. MSSM with extra singlet (NMSSM)
   → some calculations available

4. MSSM with more extra singlets
   → hardly anything done

5. SM/MSSM with Higgs triplets
   → hardly anything done

6. ...

⇒ Which model is realized in nature?
⇒ Where are more theory calculations needed?

3. Supersymmetry at the LHC

The Minimal Supersymmetric Standard Model (MSSM)

Superpartners for Standard Model particles

$$\left[u, d, c, s, t, b\right]_{L,R} \quad \left[e, \mu, \tau\right]_{L,R} \quad \left[\nu_{e,\mu,\tau}\right]_{L} \qquad \text{Spin } \tfrac{1}{2}$$

$$\left[\tilde{u}, \tilde{d}, \tilde{c}, \tilde{s}, \tilde{t}, \tilde{b}\right]_{L,R} \quad \left[\tilde{e}, \tilde{\mu}, \tilde{\tau}\right]_{L,R} \quad \left[\tilde{\nu}_{e,\mu,\tau}\right]_{L} \qquad \text{Spin } 0$$

$$g \quad \underbrace{W^{\pm}, H^{\pm}} \quad \underbrace{\gamma, Z, H_1^0, H_2^0} \qquad \text{Spin 1 / Spin 0}$$

$$\tilde{g} \qquad \tilde{\chi}^{\pm}_{1,2} \qquad\qquad \tilde{\chi}^{0}_{1,2,3,4} \qquad\qquad \text{Spin } \frac{1}{2}$$

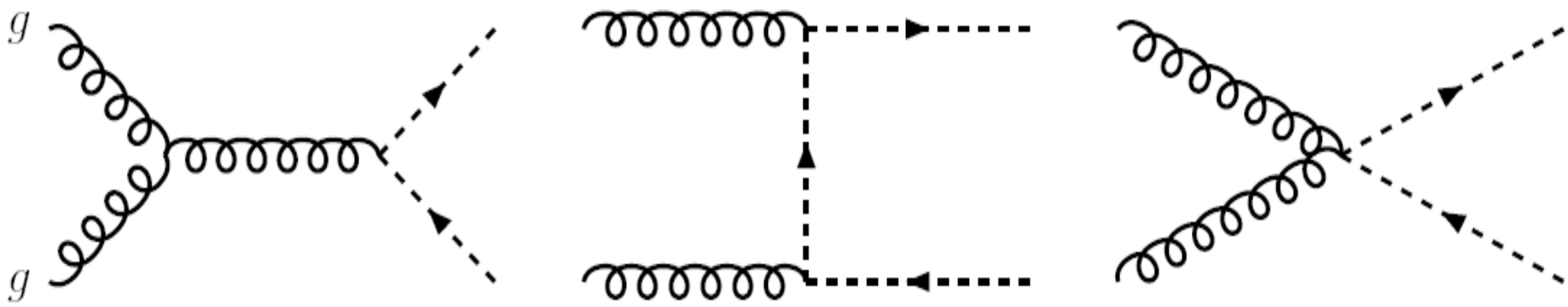
Enlarged Higgs sector: Two Higgs doublets

Problem in the MSSM: many scales

Problem in the MSSM: complex phases

SUSY particle production at the LHC:

⇒ colored (s)particles are copiously produced



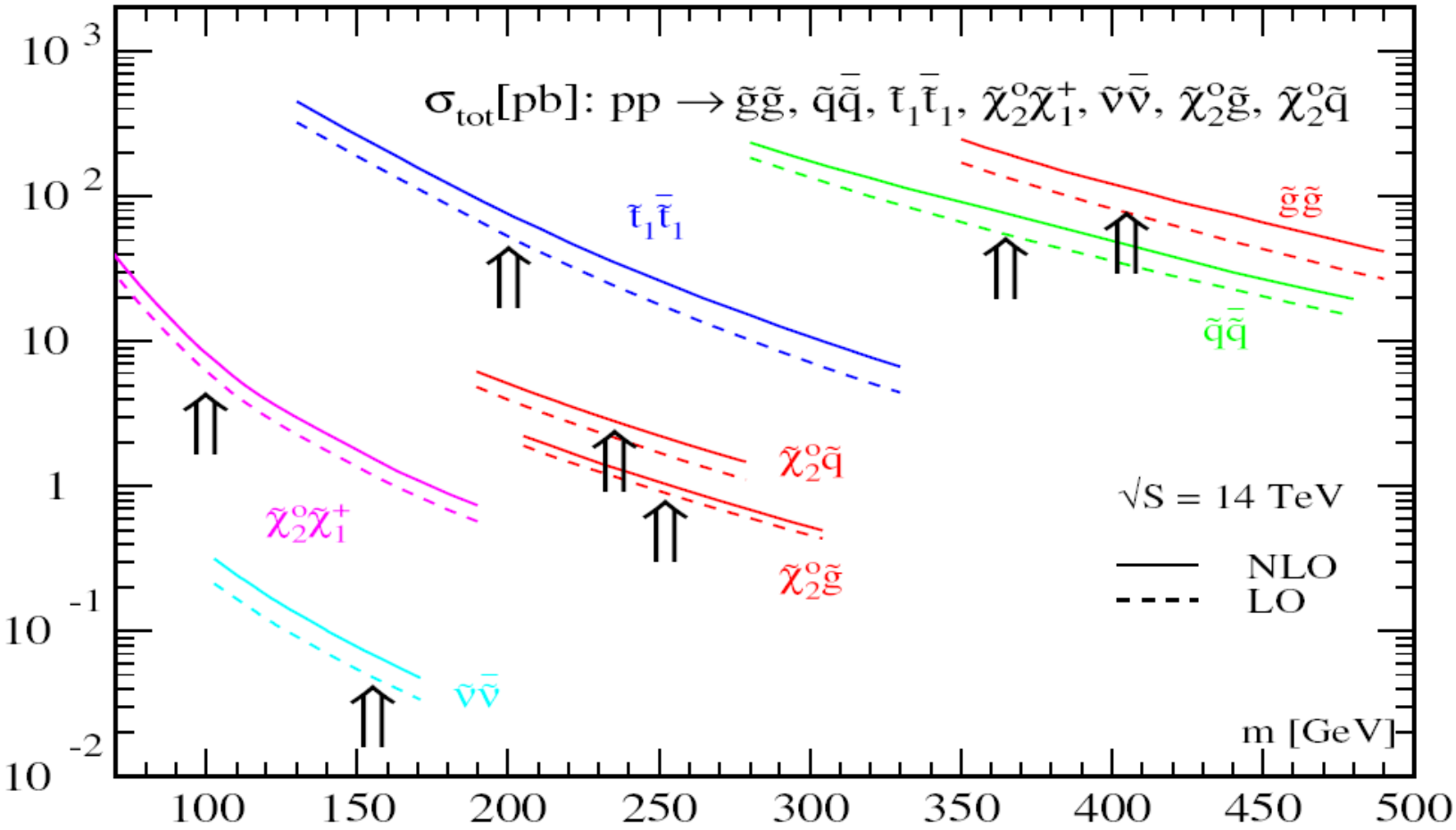
⇒ production of gluinos, squarks, . . .

As in QCD: NLO corrections are crucial!

⇒ more theory input needed!

Example for SUSY production:

[*Prospino collaboration*]



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Production of SUSY particles at the LHC

will in general result in complicated final states

$\Rightarrow$ cascade decays

$$\tilde{g} \to \bar{q}\tilde{q} \to \bar{q}q\tilde{\chi}_2^0 \to \bar{q}q\tilde{\tau}\tau \to \bar{q}q\tau\tau\tilde{\chi}_1^0$$

Production of uncolored particles via cascade decays often dominates over direct production

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– some branching ratios at NLO

– some di-lepton edges at NLO

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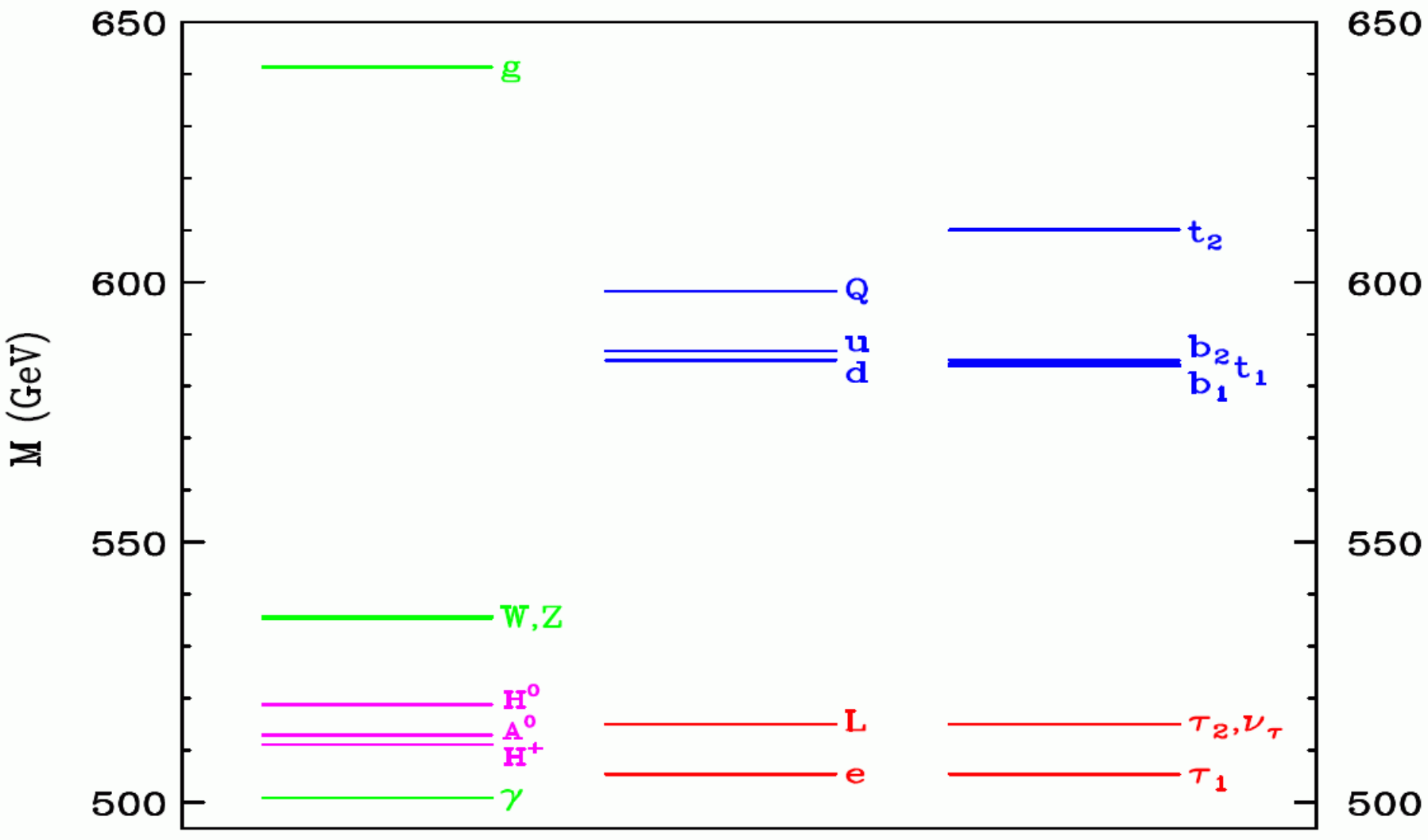
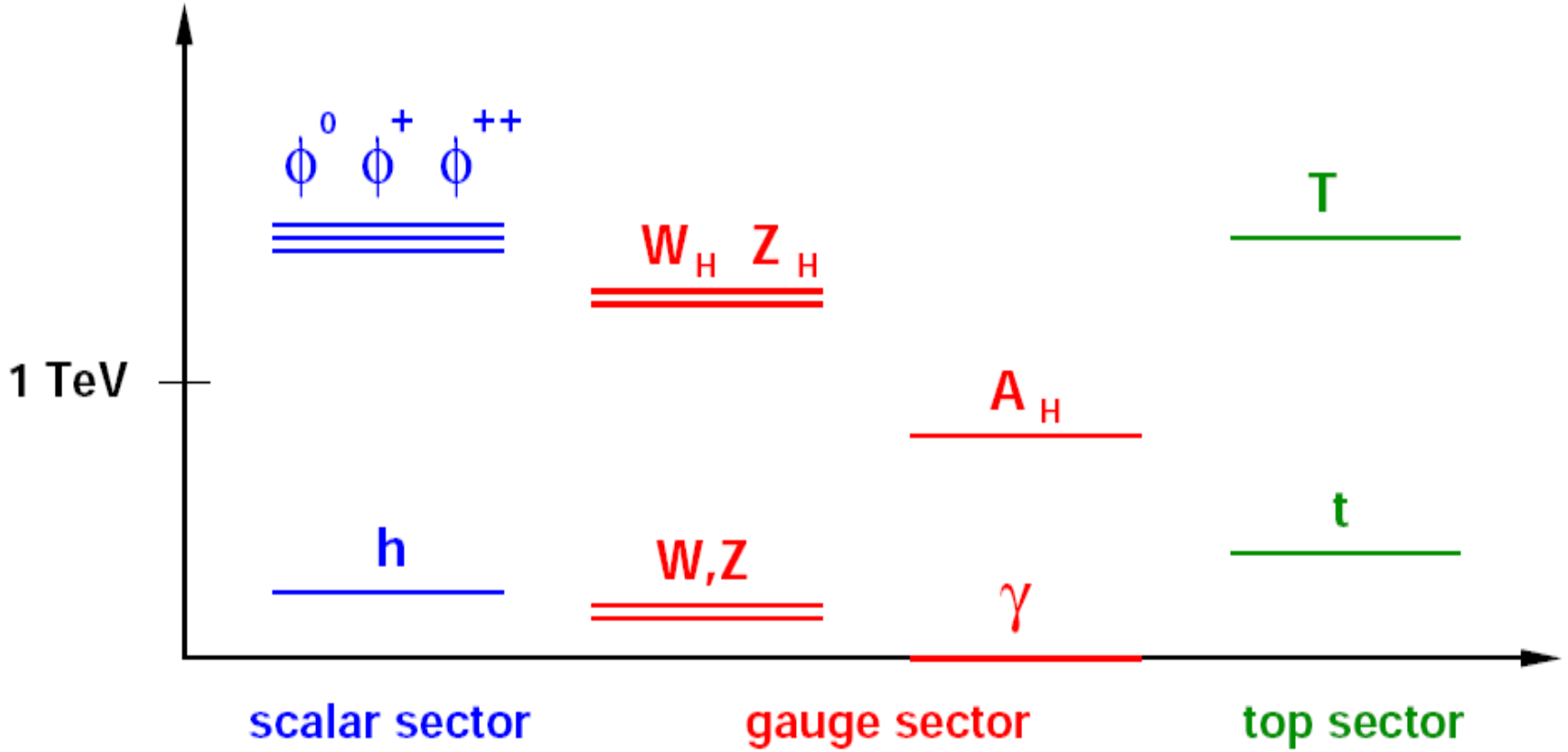
⇒ connection to Dark Matter:
measurement of lightest neutralino properties!

Another model beyond the SM: Extra dimensions

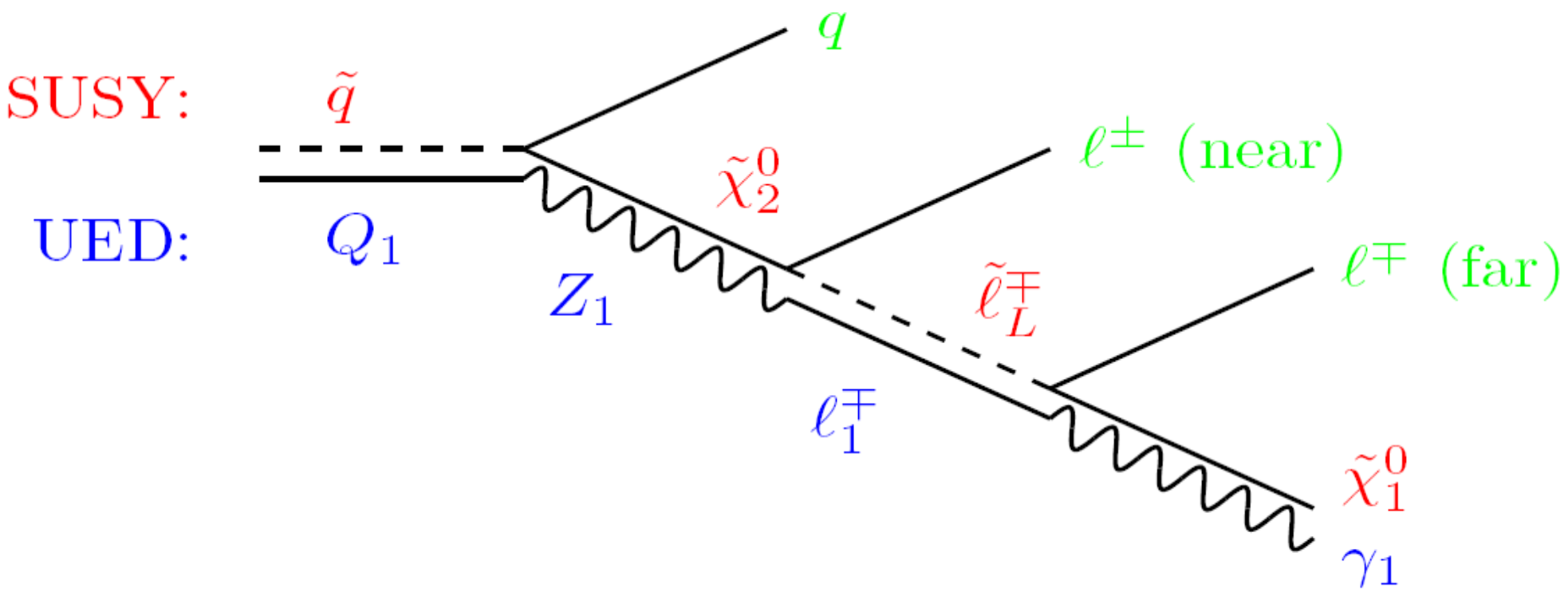


Another model beyond the SM: Little Higgs



Comparison of SUSY with e.g. Extra Dimensions:

⇒ cascades may look very similar:



$\Rightarrow$ In order to establish SUSY experimentally:

Need to demonstrate that:

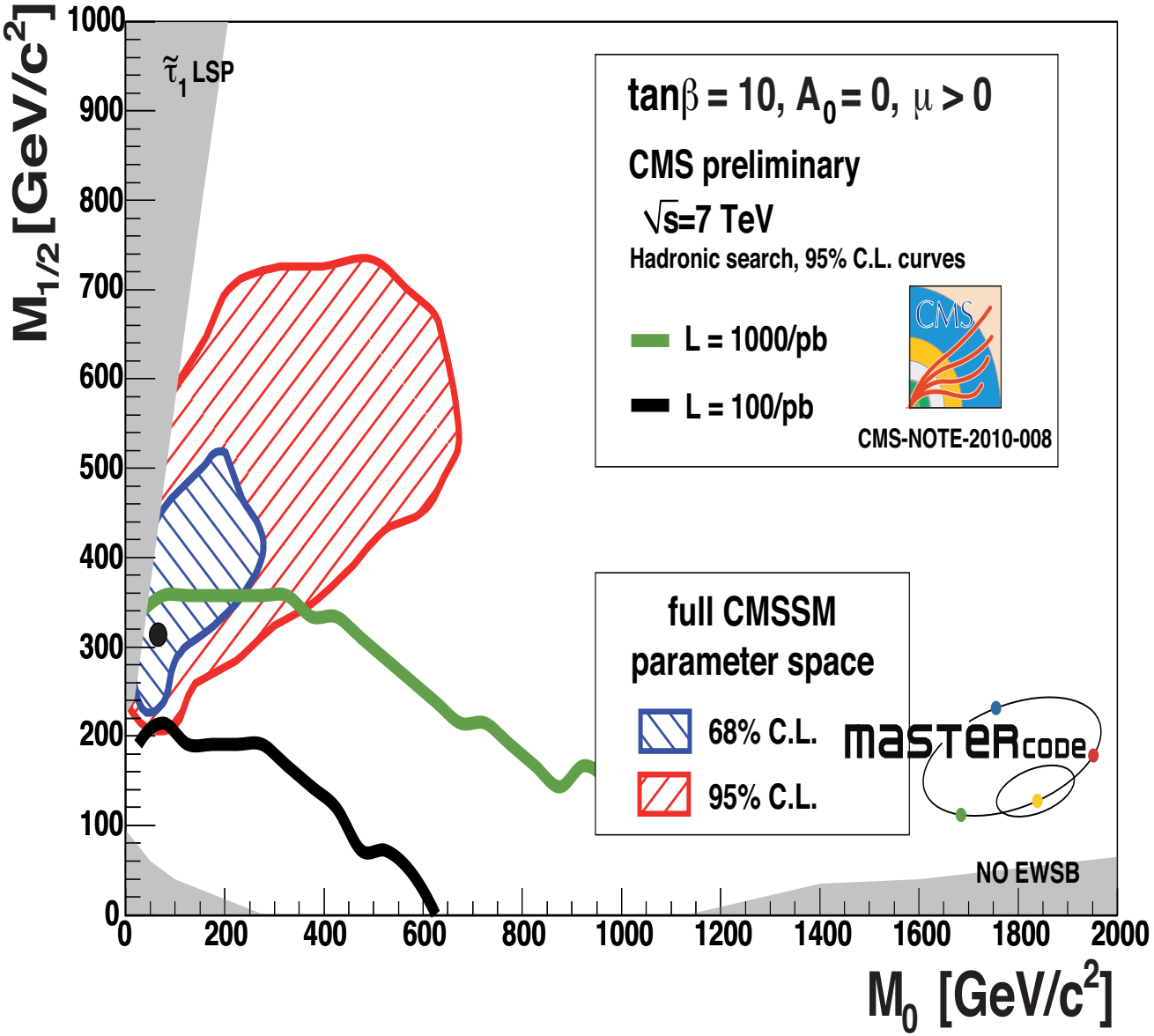
- every particle has superpartner
- their spins differ by 1/2
- their gauge quantum numbers are the same
- their couplings are identical
- mass relations hold

$\Rightarrow$ Precise measurements of masses, branching ratios, cross sections, angular distributions, . . . mandatory for

- establishing SUSY experimentally
- disentangling patterns of SUSY breaking

$\Rightarrow$ all at the loop level
$\Rightarrow$ new ideas needed
$\Rightarrow$ more theory input needed!

Next-to-final goal: reconstruct the SUSY Lagrangian



So far:
without LHC data

⇒ only simplified models possible

⇒ huge effort from theory ⊕ experiment

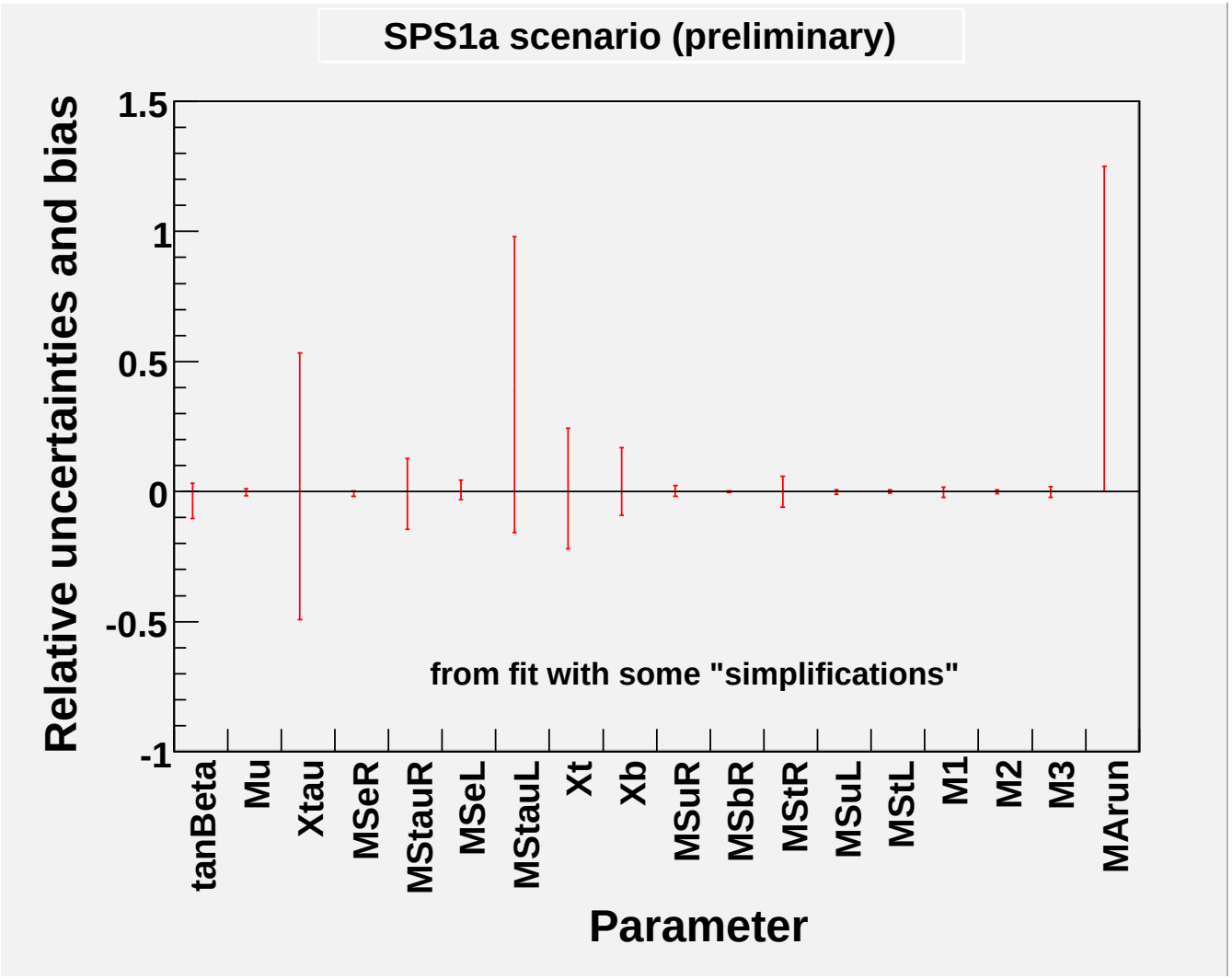
⇒ more theory input needed!

Near future:
include LHC data!

⇒ possibly 2011 already!

Next-to-final goal: reconstruct the SUSY Lagrangian with LHC data

⇒ use all available information: masses, BRs , . . .



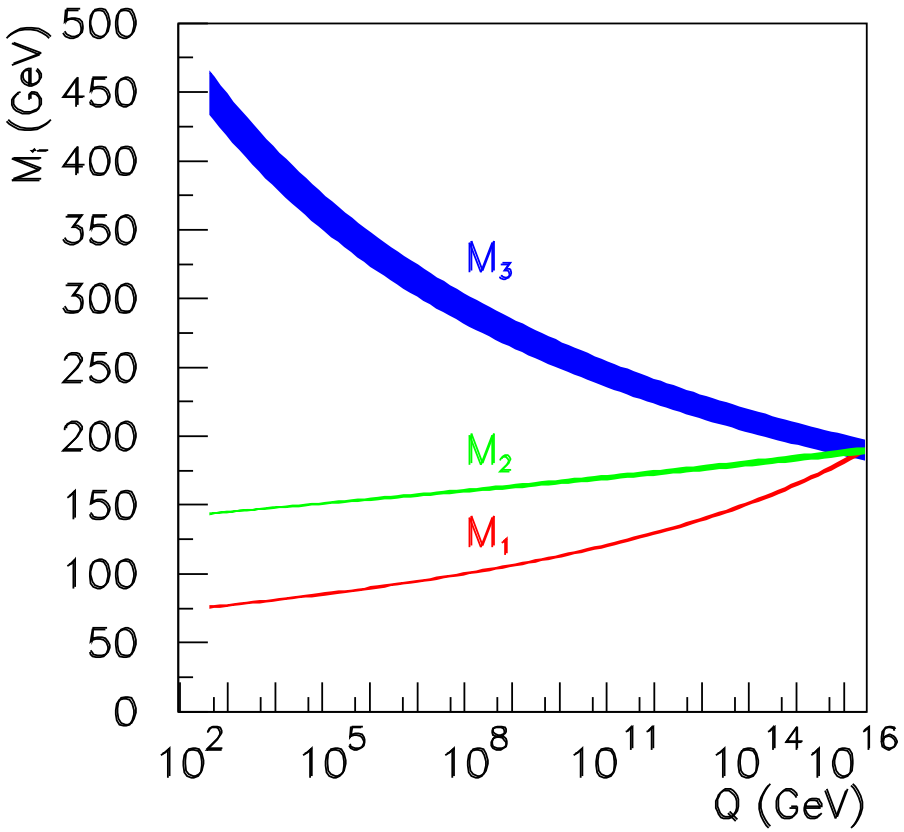
[*P. Bechtle, K. Desch, M. Uhlenbrock, P. Wienemann '08*]

Final goal: reconstruct soft SUSY-breaking mechanism

$\Leftrightarrow$ GUT scale physics

$\Rightarrow$ use all parameters at low energies $\Rightarrow$ scale up to the GUT scale

$\Rightarrow$ What unifies where? $\Rightarrow$ soft SUSY-breaking meachism



$\Rightarrow$ more theory input needed!

- h.-o. corrections for masses
- h.-o. corrections for BRs, ...
- h.-o. corrections for RGEs
- new GUT models?

DATA RULES!

[*G. Blair, W. Porod, P. Zerwas '01*]

More joint theory $\oplus$ experiment efforts:

1. Allianz SUSY-Fitter WG

– started by the "Terascale Alliance" (Germany)
– specific for SUSY
– goal: facilitate SUSY fits incl. LHC data
– "the effort" to measure SUSY pararameters at the LHC

2. LHC Physics Center at CERN (LPCC)

– organized by CERN (head: Mangano)
– interpretation of LHC data
– in principle: all models covered
– leading effort to interpret LHC data (beyond exp. analyses)

For CPAN: are we happy with the spanish contribution?

4. Conclusions

- The LHC is re-discovering the SM
  Important improvements for the W boson, top quark, B physics ...
  $\Rightarrow$ sensitive test of the SM

- The Higgs mechanism continues to be our best bet for EWSB

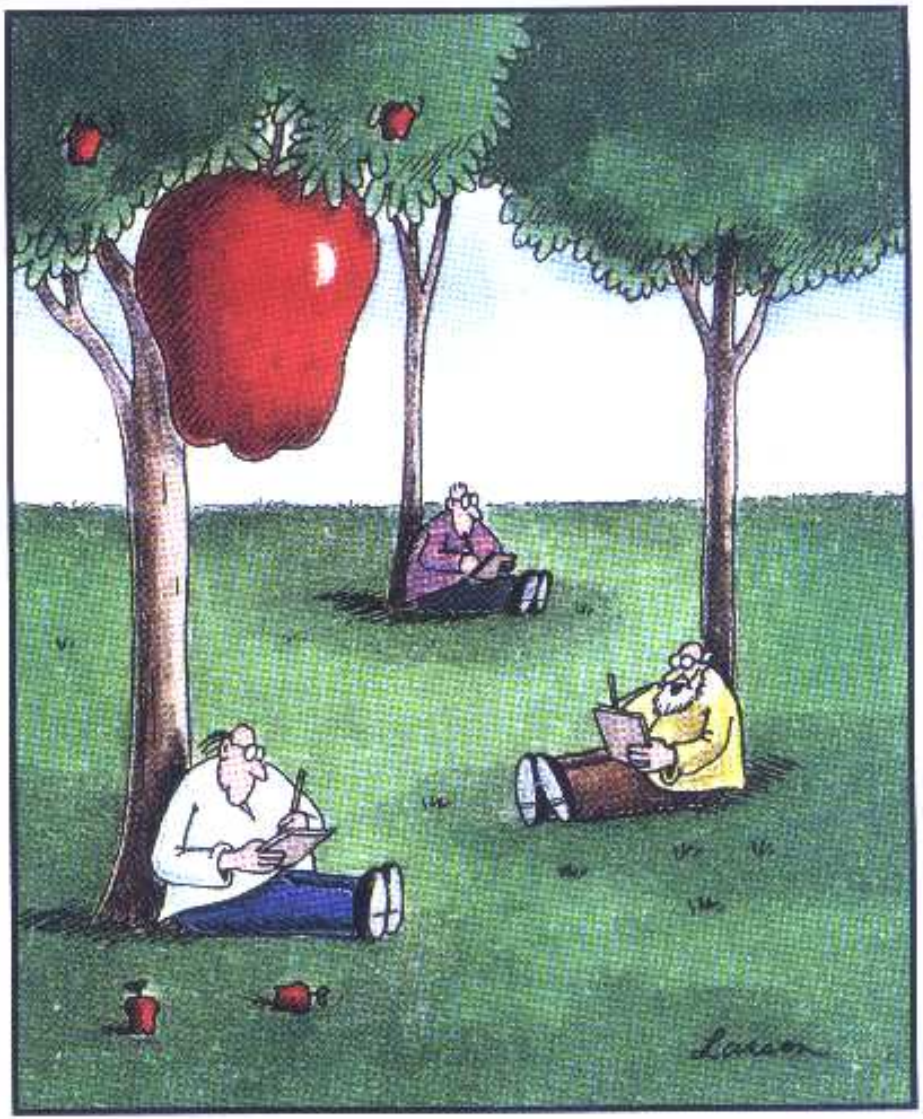
- Low-energy Supersymmetry continues to be our best bet for physics beyond the Standard Model

- Within the next years the LHC will bring a decisive test of our ideas about SM extensions and the Higgs

- All this requires extensive theory input!
  Measured data is only meaningful if it is matched with theoretical calculations (masses, couplings, cross sections, BRs etc.) at the same level of accuracy

$\Rightarrow$ Very exciting prospects for the coming years!

Some more ancient theory perspectives:



"Nothing yet. ... How about you, Newton?"

"Nothing yet. How about you, Newton?"

Back-up

Interested in Theory Predictions?

Interested in

- theory predictions for the Tevatron?
- theory predictions for the LHC?
- theory predictions for the ILC?
- phenomenology analyses in Higgs/SUSY?

$\Rightarrow$ You can do your PhD at IFCA (Santander, Spain)

contact: Sven.Heinemeyer @ cern.ch

Santander, Spain: (15 minutes by foot from the institute :-)

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