In Wait for New Physics

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- *Local renormalizable QFT (generalization of the SM)*

✓ *Two-Higgs doublet model, ...*
✓ *MSSM, NMSSM, ℝMSSM, ...*
✓ *Technicolor Model, ...*
✓ *Extra Symmetries, U'(1), SU'(2), ...*
✓ *GUTs*
✓ *? ...*

- *Radical change of paradigm (non-standard approach)*

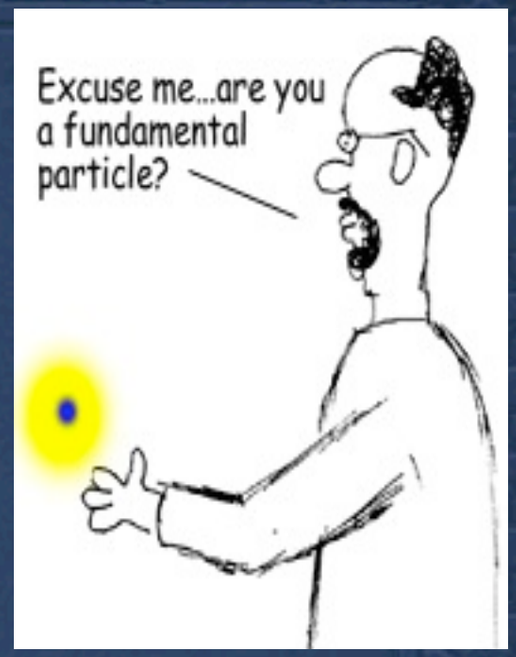
✓ *Extra dimensions, ...*
✓ *Strings, ...*
✓ *Branes, ...*
✓ *Non-renormalizable interactions, ...*
✓ *Effective theories, ...*
✓ *? ...*

The SM and Beyond

The problems of the SM:

- Inconsistency at high energies due to Landau poles
- Large number of free parameters
- Still unclear mechanism of E... reaking
- CP-violation is not u...
- The origin of the ... nclear
- Flavour mixing a... of generations is arbitrary
- Formal unification ...ong and electroweak interactions

Where is the Dark matter?



The way beyond the SM:

- The SAME fields with NEW interactions and NEW fields ⇒ GUT, SUSY, String, ED
- NEW fields with NEW interactions ⇒ Compositeness, Technicolor, preons

Advantage of the Standard approach

- *Solid QFT background (UV, IR divergences are under control)*
- *Causality, Unitarity of the S-matrix are guaranteed*
- *Dimensionless couplings => calculable Rad Corr*

$$\log \frac{Q^2}{M^2} \quad if \quad Q^2 > M^2$$

No rising x-sections

$$\frac{Q^2}{M^2} \quad if \quad Q^2 < M^2$$

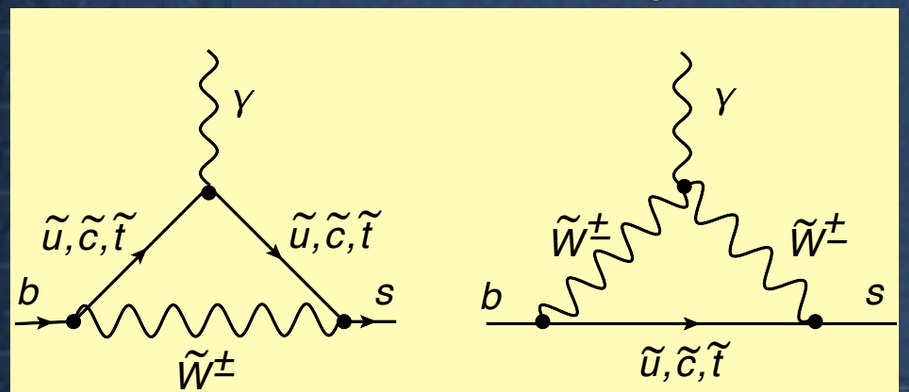
Th ↑ *Ex* ↓

When enchancement is possible?

- *Resonance (Z-peak at LEP, Higgs boson peak, etc in s-channel)*
- *Parameter dependence (tan_β in MSSM, ...)*
- *However, one would not expect* $\frac{M^2_{new}}{M^2_{SM}}$ *terms, only* $\frac{M^2_{SM}}{M^2_{new}}$ *due to decoupling of heavy particles, unless one has* $\log \frac{M^2_{new}}{M^2_{SM}}$

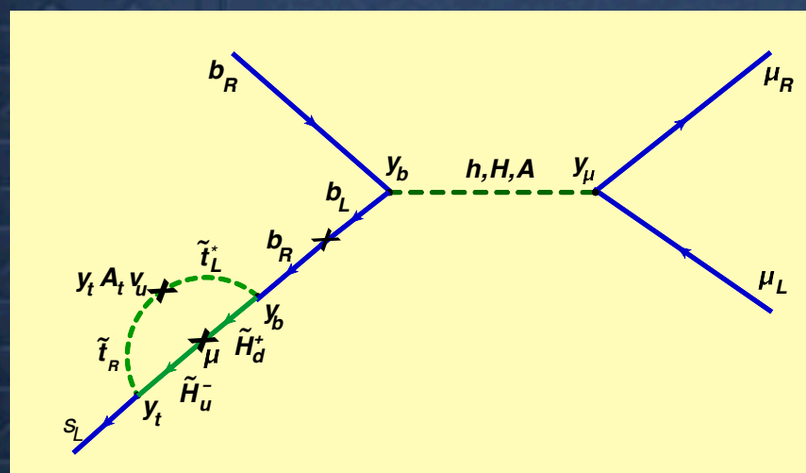
Example of tan β enhancement in MSSM

- $b \to s\gamma$ *Decay*



$$\mathcal{B}R^{SUSY}(b \to s\gamma)\Big|_{\chi^\pm} \propto \mu A_t \tan\beta f(\tilde{m}^2_{t_1}, \tilde{m}^2_{t_1}, m_{\chi^\pm}) \frac{m_b}{v}$$

- $b \to \mu^+\mu^-$ *Decay*



$$\tan\beta \leq \frac{m_t}{m_b} \sim 55$$

$$Br[B_s \to \mu\mu] \sim \left| \left(\frac{\tan^3\beta}{4\sin^2\theta_W} \right) \frac{\sin 2\theta_{\tilde{t}}}{2} \left(\frac{m^2_{\tilde{t}_1} \log\left[\frac{m^2_{\tilde{t}_1}}{\mu^2}\right]}{\mu^2 - m^2_{\tilde{t}_1}} - \frac{m^2_{\tilde{t}_2} \log\left[\frac{m^2_{\tilde{t}_2}}{\mu^2}\right]}{\mu^2 - m^2_{\tilde{t}_2}} \right) \right|^2$$

Conclusion for the LHC

- *Be ready for small effects => high resolution, high statistics*

This is the main stream and our best hope for NP !

- *Look for effects that are forbidden in the SM but allowed albeit small in BSM*

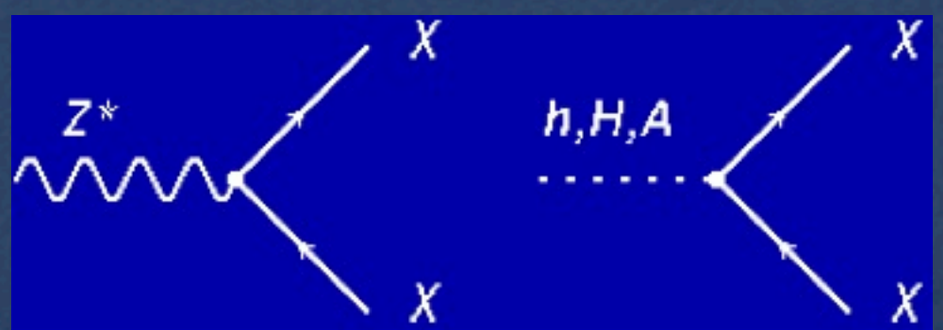
1. Proton decay - Unfortunately not seen (SuperK)
2. Violation of baryon, lepton numbers - possible in GUTs but are $\sim 1/M^2_{GUT}$
3. Violation of CP, CPT, ...
4. Violation of Lorenz invariance, electric charge, ..
(not in the Standard approach)

Astrophysics & Particle Physics

- *Common view on the Universe*
- *But ... many problems of astrophysical nature*

What is the impact on Particle physics from Astrophysics today?

- *$\not{CP}$ is crucial for the Baryon assymetry of the Universe, but the SM does not provide enough of $\not{CP}$ - might be a problem*
- *Dark matter if explained by WIMPs should be detected in direct and indirect searches and at the LHC*

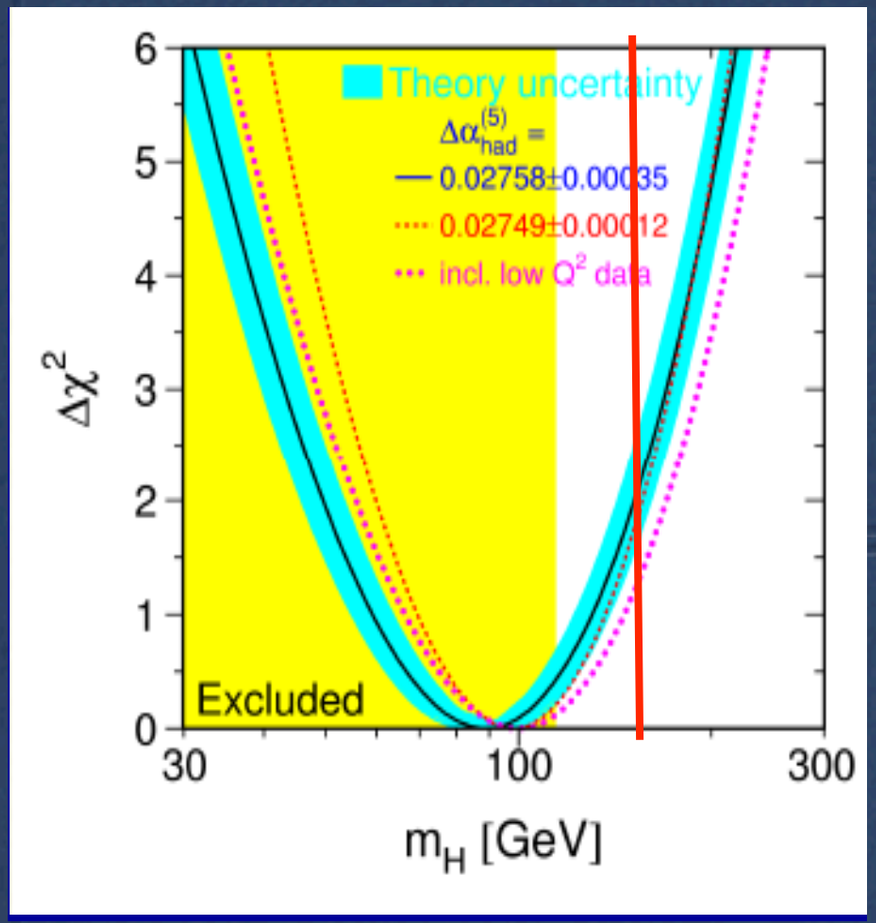


Signature: missing energy and momentum

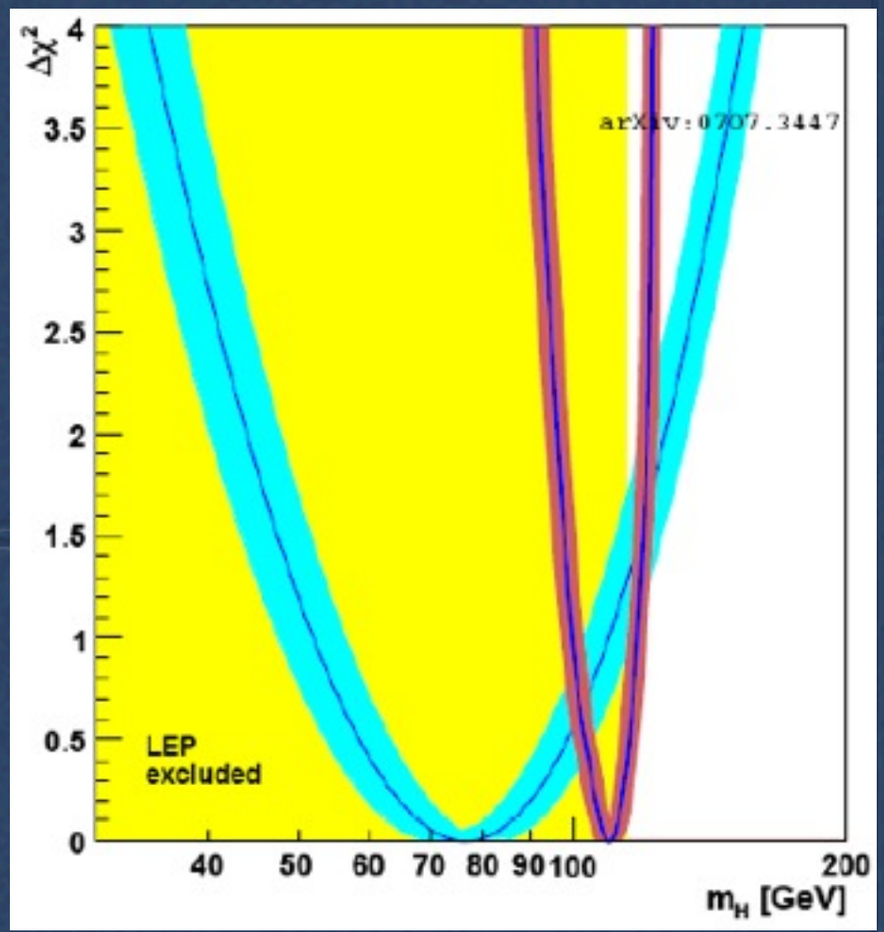
The Higgs Boson

Fit of the Electro-weak data

SM



MSSM



χ^2 versus M_H for SM Fit

- M_H=89 +42-30 @68%CL
- M_H < 165 GeV @95%CL

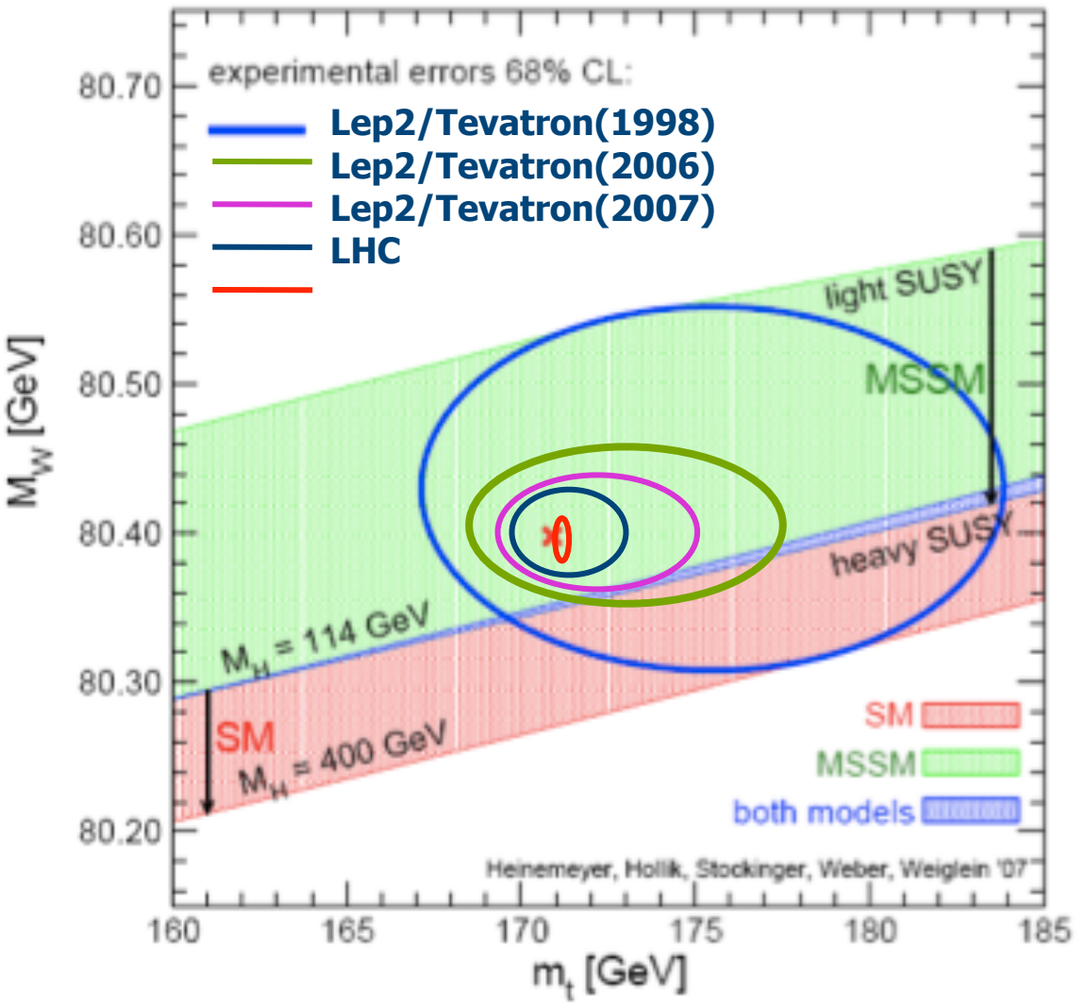
for m_{top}=172.5 GeV

This is a model dependent analysis
A Higgs boson might be elesewhere

Measurement of M_w and m_t and comparison with SM and MSSM

Example: Prediction for M_W in the SM and the MSSM :

[S.H., W. Hollik, D. Stockinger, A.M. Weber, G. Weiglein '07]

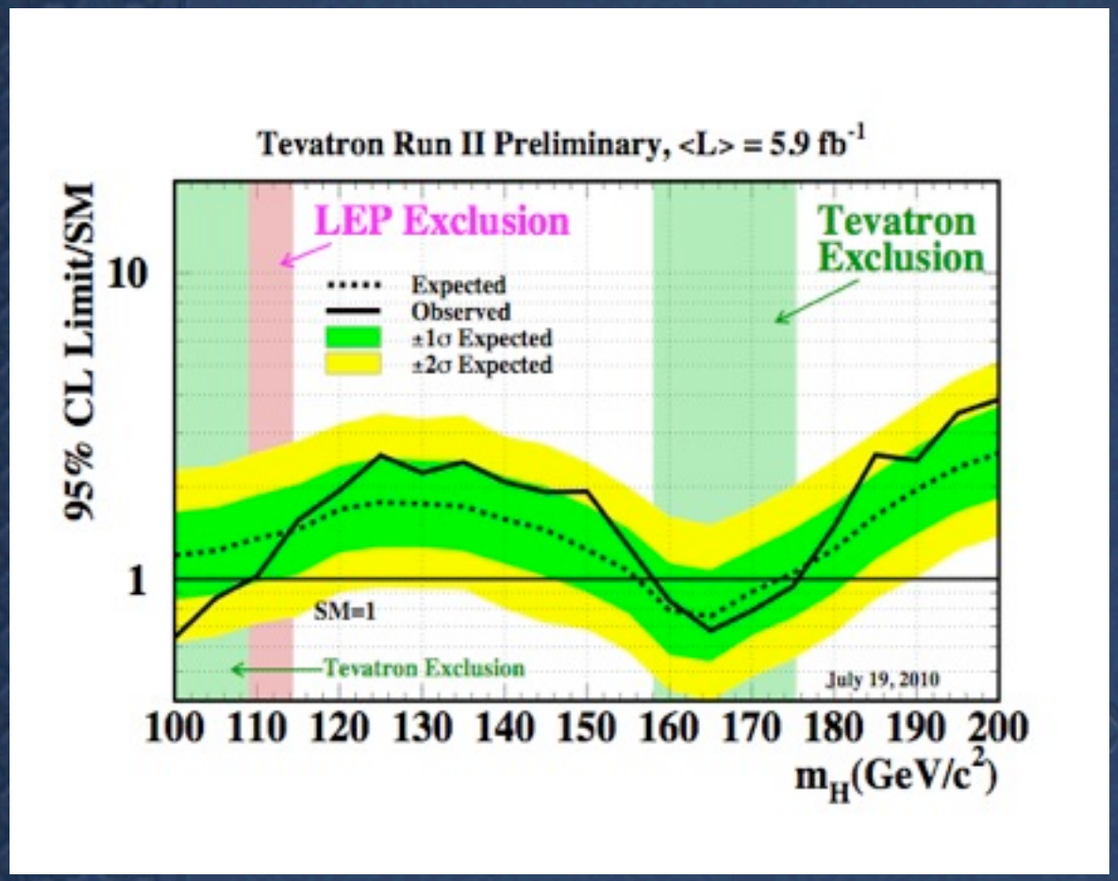


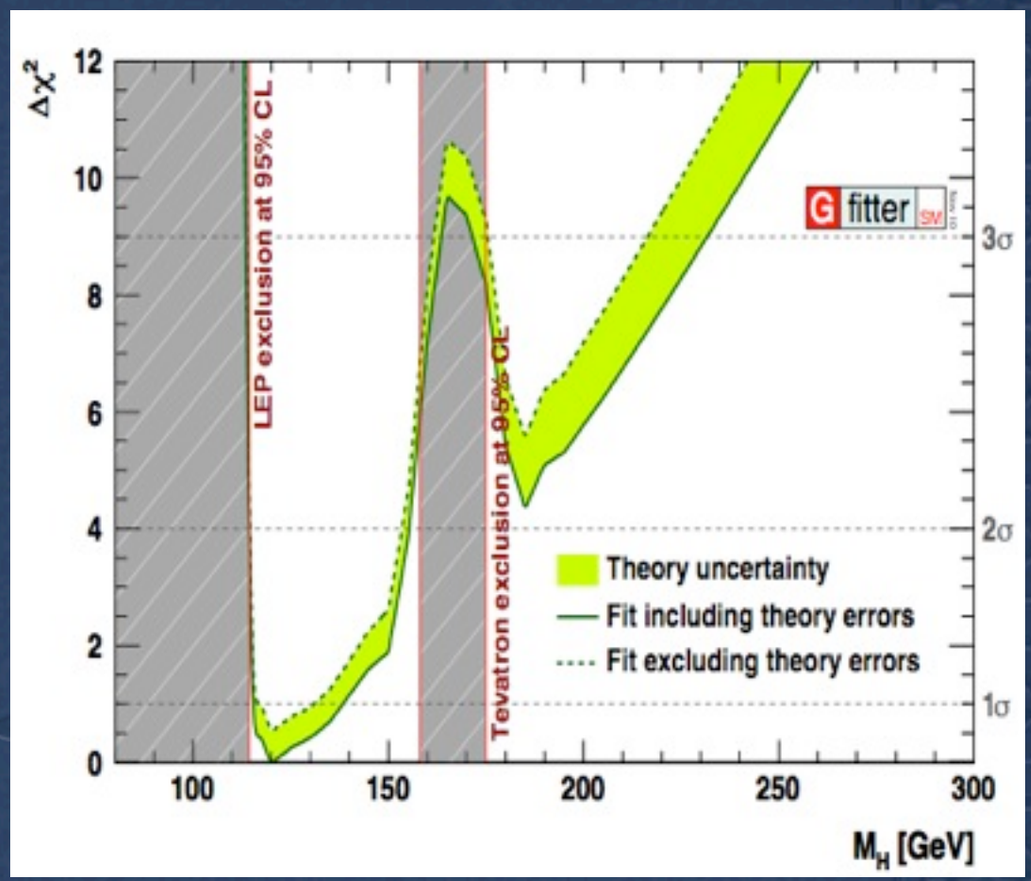
MSSM band:
scan over
SUSY masses

overlap:
SM is MSSM-like
MSSM is SM-like

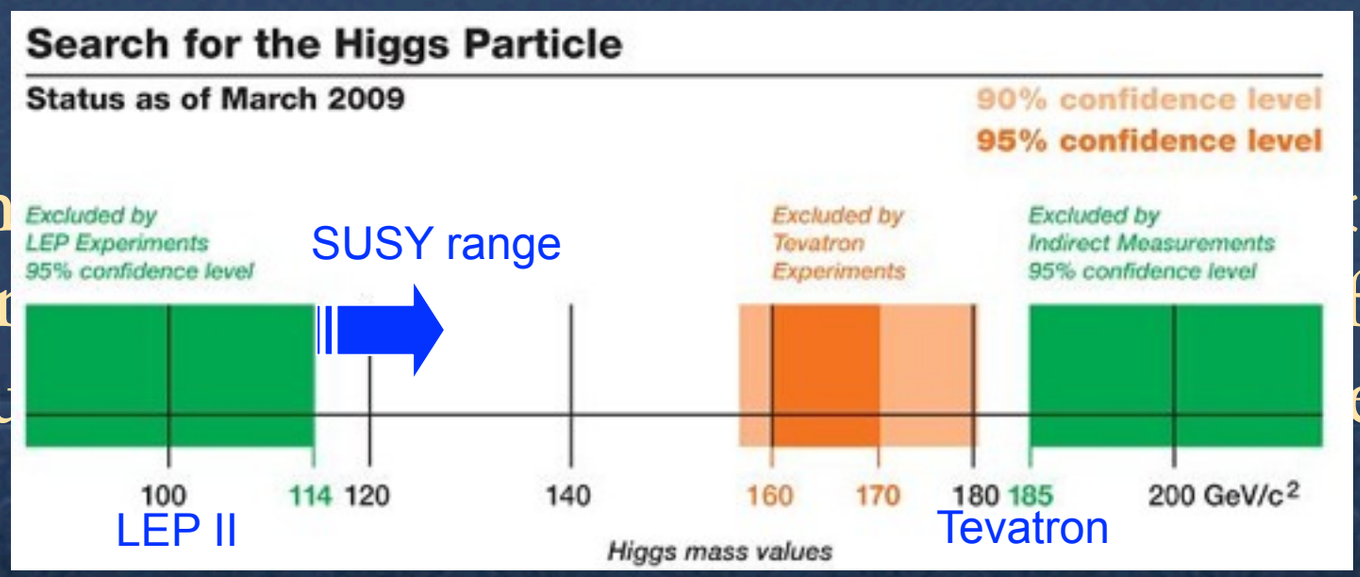
SM band:
variation of $M_H^{\rm SM}$

Tevatron searches for Higgs

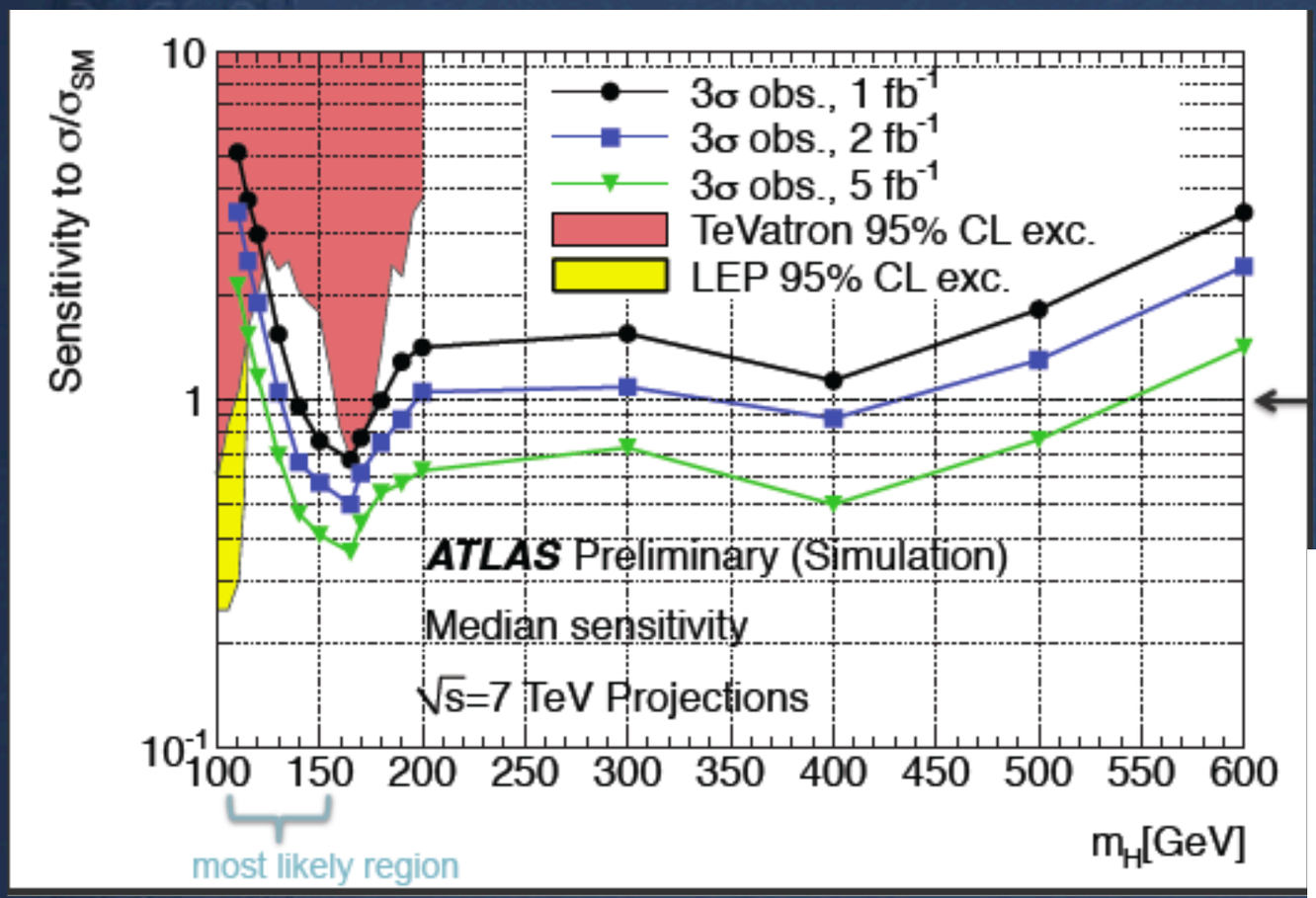




Tevatron [illegible] 175 GeV, However [illegible] f the SM backgrou [illegible] ements

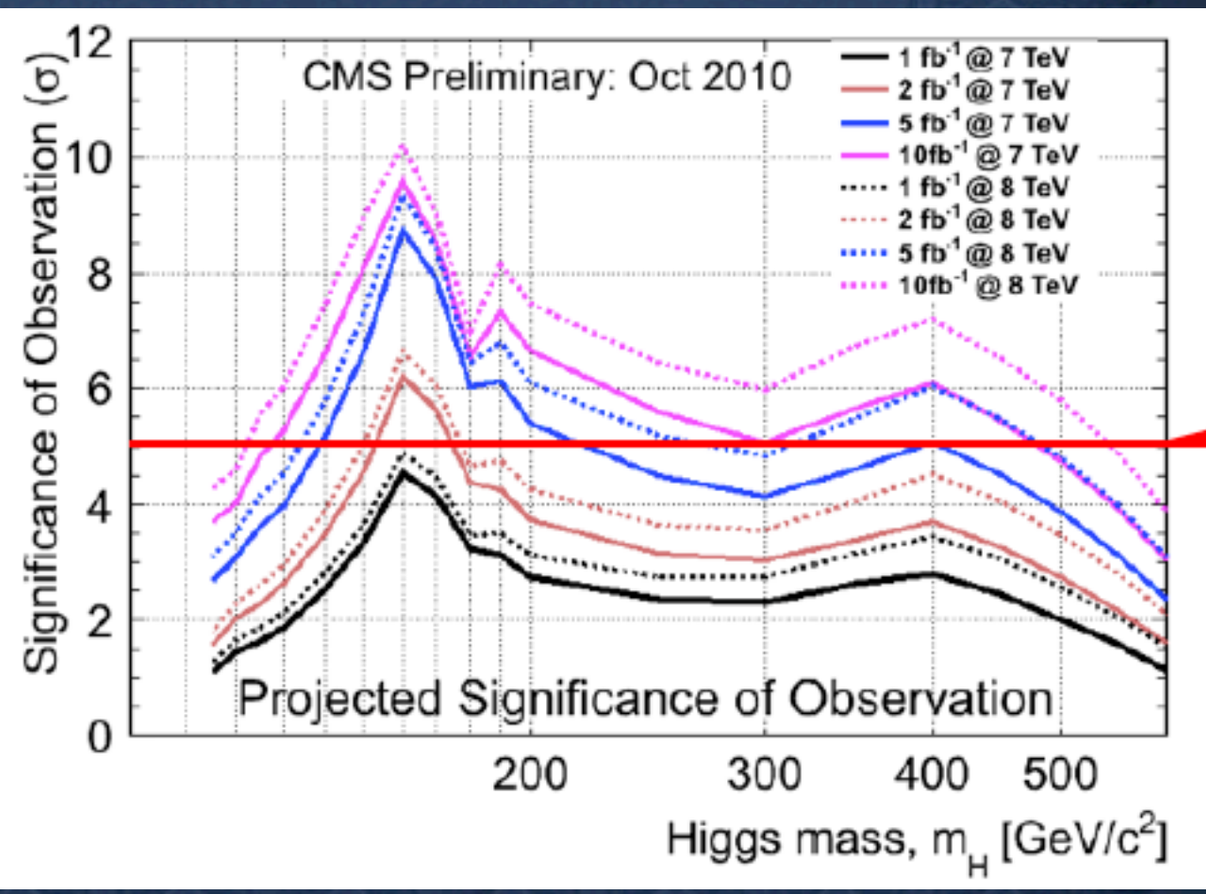


Hunt for the Higgs Boson



The promissed 1 fb^{-1} might give a hint but is not enough

3 or 5 fb^{-1} might give the positive answer but 115-120 GeV region is hard



What if no Higgs boson is found?

Alrernative to the SM Higgs boson:

- *Two-Higgs Doublet Models*
- *Inert Higgs Model*
- *Little Higgs Models*
- *Twin Higgs Model*
- *Gauge-Higgs Unification Models*
- *Higgsless Models*

- *Dynamical symmetry breaking without scalar fields*

Supersymmetry

Why SUSY ?

Local gauge invariance $\partial_\mu \to D_\mu = \partial_\mu + A_\mu$ → *Vector field*

Covariant derivative

Maxwell ED

Local SUSY → *Local coordinate transf* → *graviton*

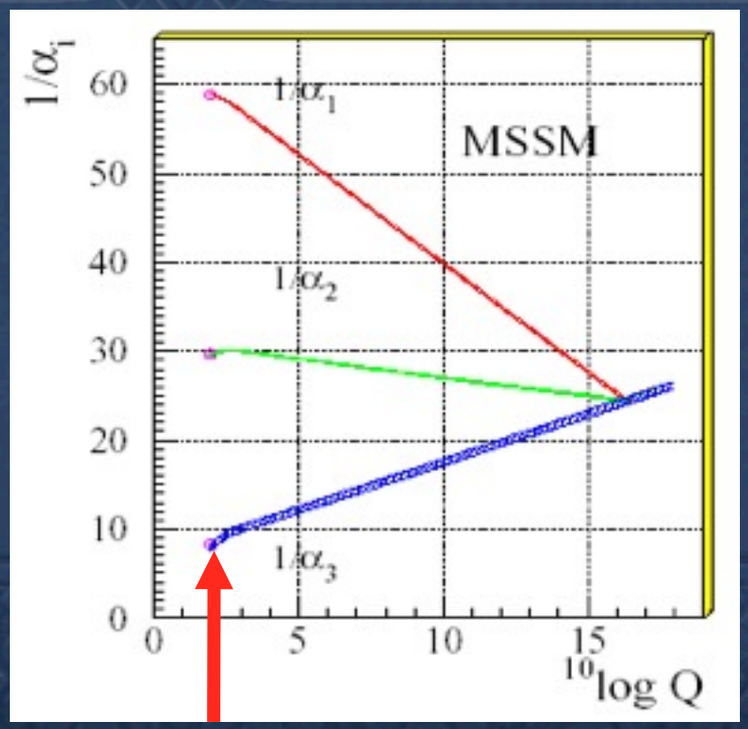
$$x_\mu \to x_\mu + i\theta\sigma_\mu\bar{\xi} - i\xi\sigma_\mu\bar{\theta},$$

Einstein GR

Why Low-energy SUSY ?

- *Gauge coupling unification*

$M_{SUSY} \sim TeV$



Change of the slope at the scale

$M_{SUSY} \sim TeV$

Why SUSY?

Maxwell ED

Local gauge invariance $\partial_\mu \to D_\mu = \partial_\mu + A_\mu$ → *Vector field*

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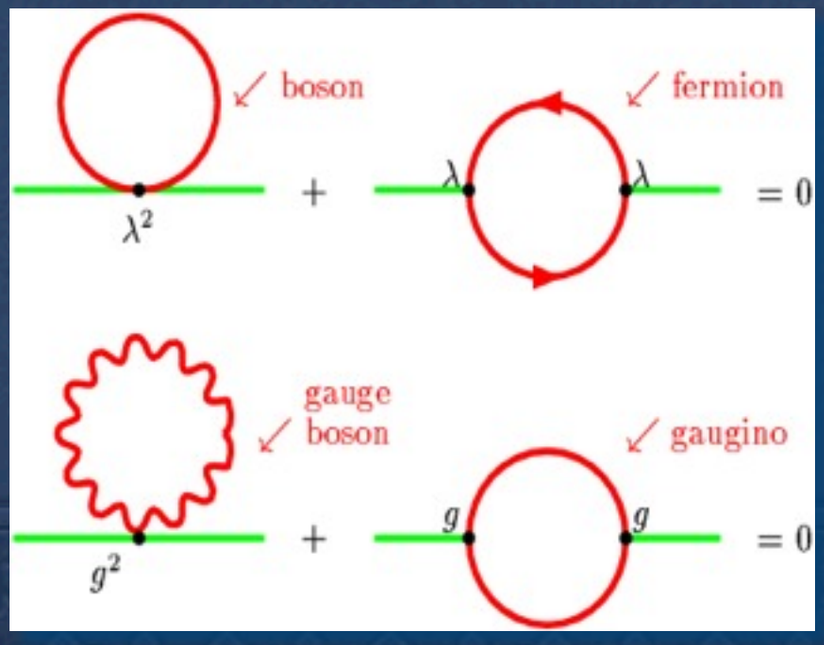
Local SUSY → *Local coordinate transf* → *graviton*

$$x_\mu \to x_\mu + i\theta\sigma_\mu\bar{\xi} - i\xi\sigma_\mu\bar{\theta},$$

Why Low-energy SUSY ?

- *Hierarchy problem*

$M_{SUSY} \sim TeV$



Mass stabilization if

$gM_{SUSY} \sim M_W$

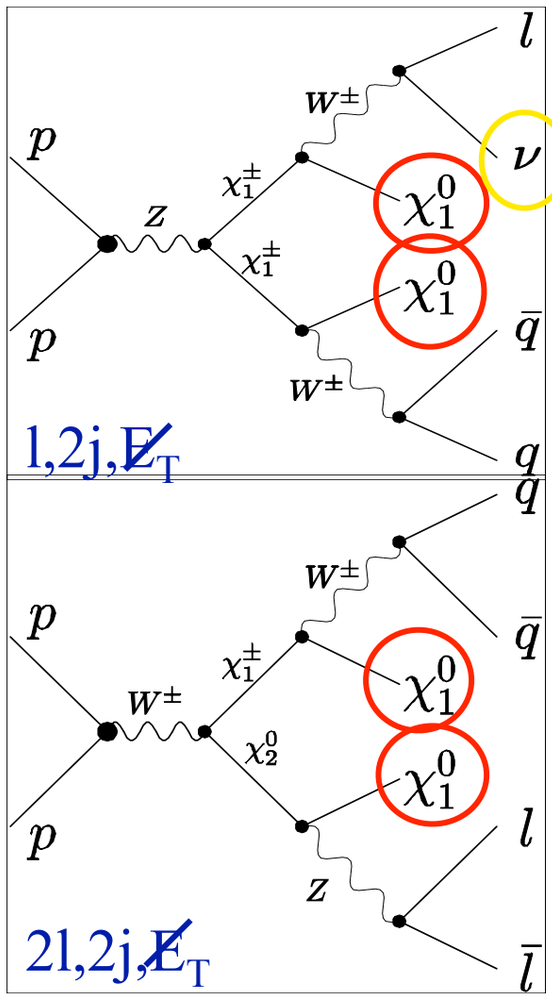
Particle Content of the MSSM

Superfield	*Bosons*	*Fermions*	$SU_c(3)$	$SU_L(2)$	$U_Y(1)$
Gauge					
G^a	*gluon* g^a	*gluino* $\tilde{\mathrm{g}}^a$	8	1	0
V^k	*Weak* $\mathrm{W}^k(W^\pm, Z)$	*wino, zino* $\tilde{w}^k(\tilde{w}^\pm, \tilde{z})$	1	3	0
V'	*Hypercharge* $\mathrm{B}(\gamma)$	*bino* $\tilde{b}(\tilde{\gamma})$	1	1	0
Matter					
L_i	sleptons $\tilde{L}_i = (\tilde{\nu}, \tilde{e})_L$	leptons $L_i = (\nu, e)_L$	1	2	−1
E_i	$\tilde{E}_i = \tilde{e}_R$	$E_i = e_R$	1	1	2
Q_i	squarks $\tilde{Q}_i = (\tilde{u}, \tilde{d})_L$	quarks $Q_i = (u, d)_L$	3	2	1/3
U_i	$\tilde{U}_i = \tilde{u}_R$	$U_i = u_R^c$	3^*	1	−4/3
D_i	$\tilde{D}_i = \tilde{d}_R$	$D_i = d_R^c$	3^*	1	2/3
Higgs					
H_1	Higgses H_1	higgsinos $\tilde{H}_1$	1	2	−1
H_2	H_2	$\tilde{H}_2$	1	2	1

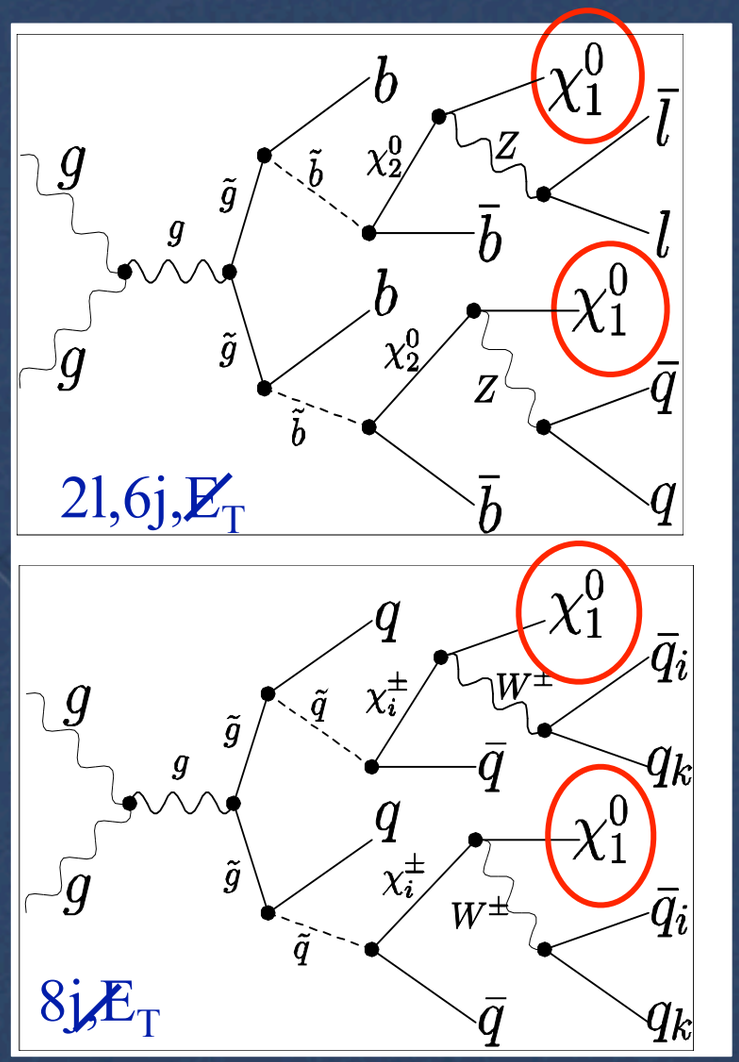
The role of background

Search for superpartners within the MSSM

weak int's



strong int's

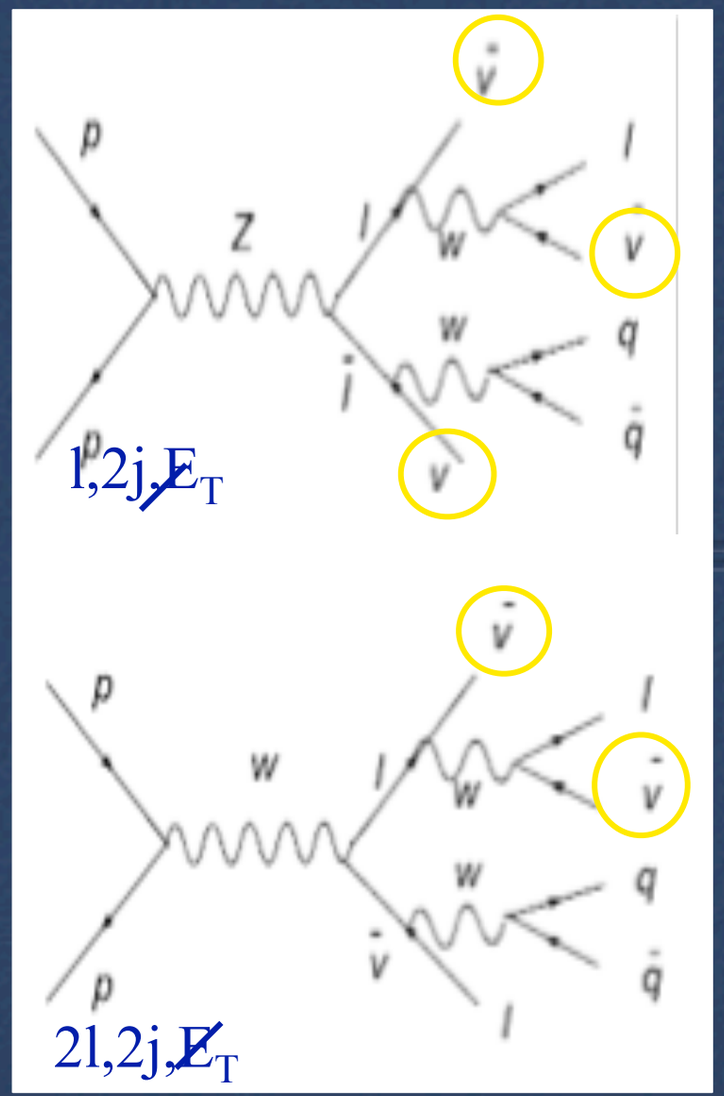


Typical SUSY signature: Missing Energy and Transverse Momentum

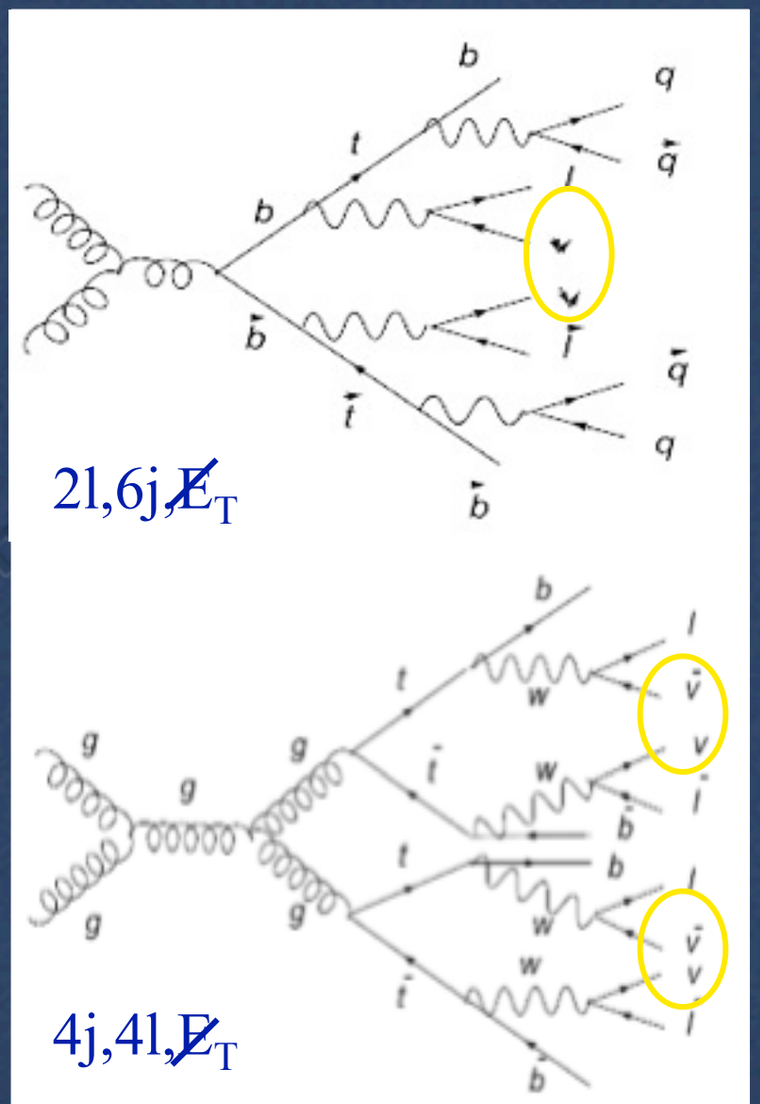
The role of background

Search for superpartners within the MSSM

weak int.'s

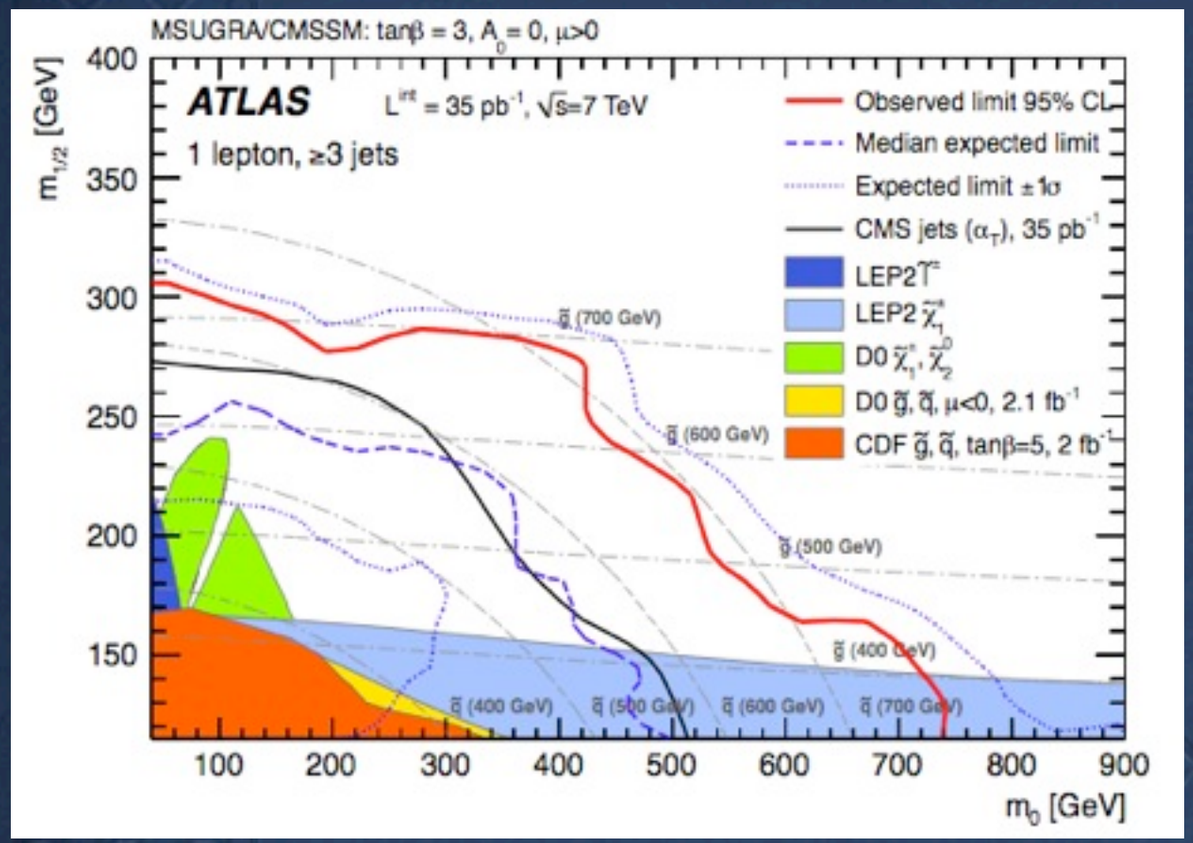


strong int.'s



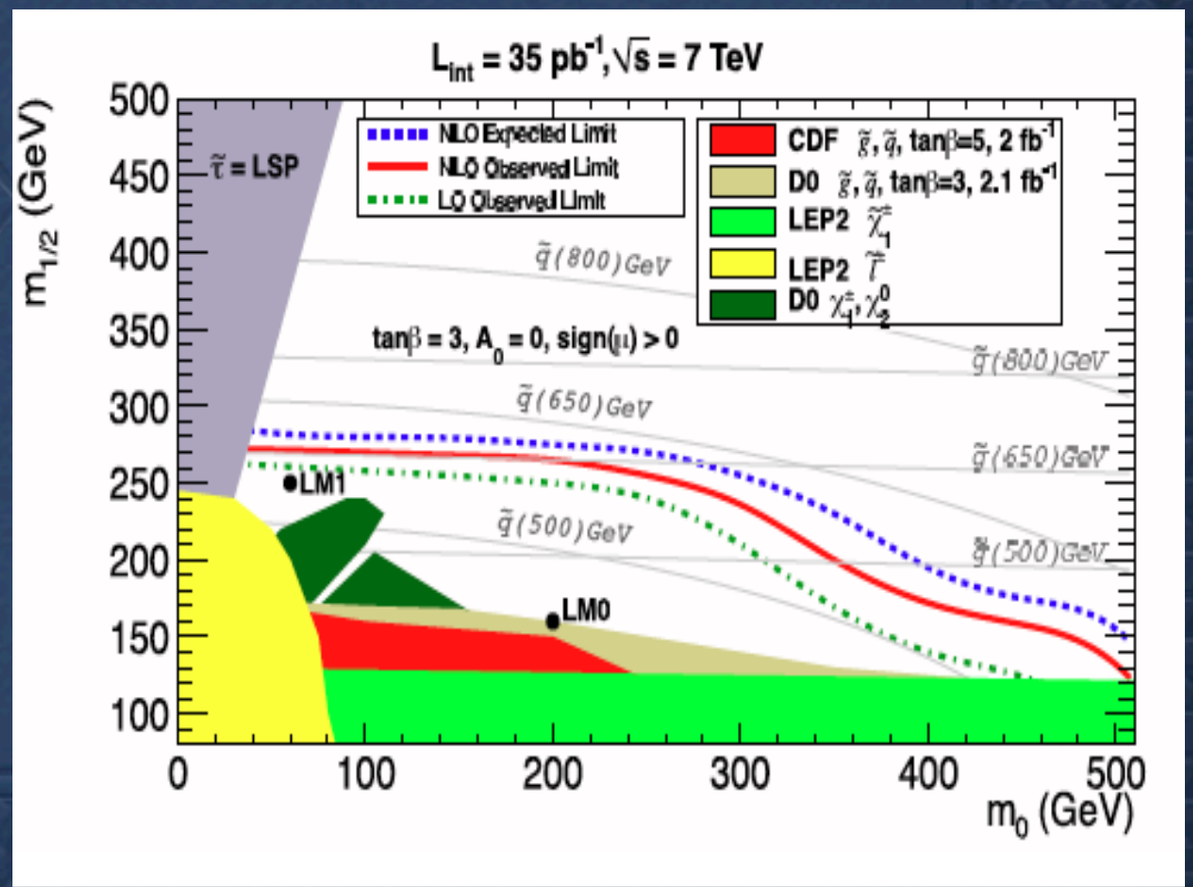
The x-sections are usually smaller than for creation of SUSY

Search for SUSY @ LHC



Search for high-mass squark and gluino production in events with large missing transverse energy and two or more jets

Noticable progress after Tevatron



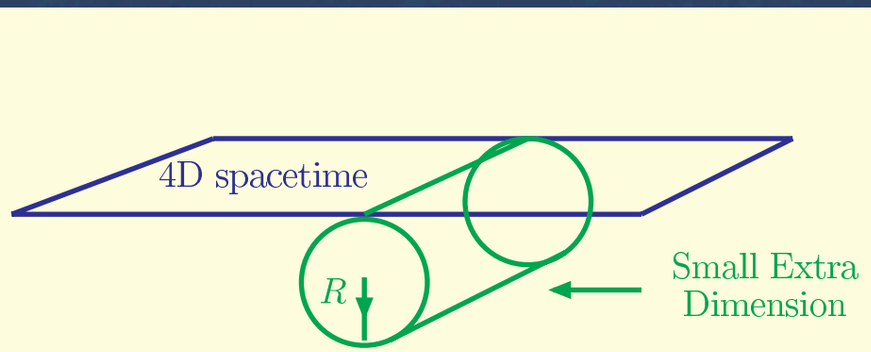
- *Too many free parameters in SUSY breaking part.*
- *So far SUSY passes all consistency tests*
- *All analyses are model dependent.*

What if no SUSY is found?

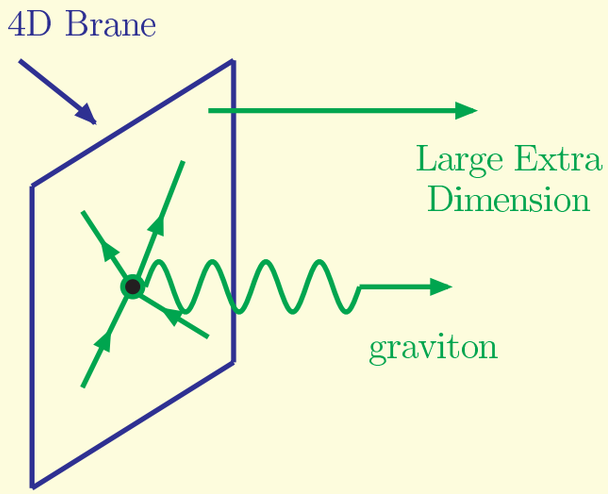
- *Very exotic scenario is realized (doubtful)*
- *Susy threashold is above few TeV*
  (no gauge coupling unification, hierarchy problem needs fine-tuning)
- *Susy breaking pattern has to be changed*
  (most questionable part of the MSSM)
- *MSSM is not the right model (what else?)*
- *Susy is not the right way (tell me what is better)*

Extra D

Do we live in multi-D world?



Kaluza-Klein Picture



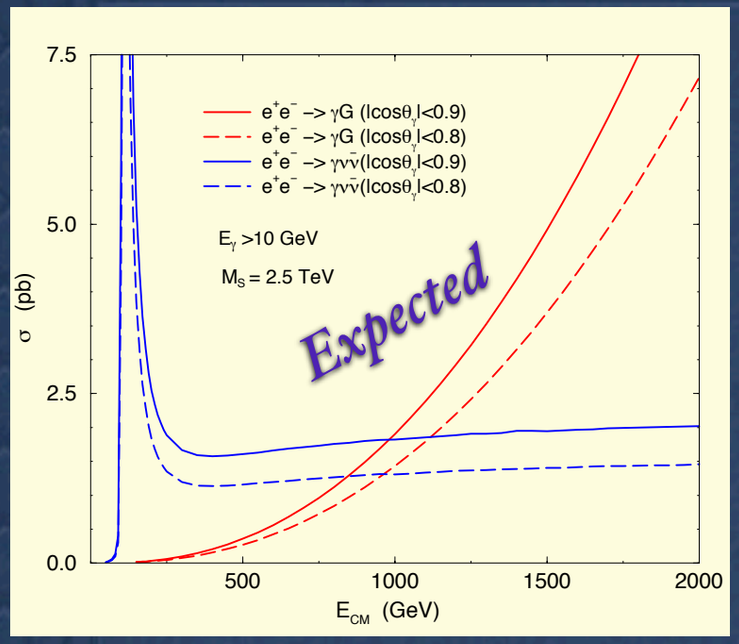
Brane-world Picture

- *Is it really probable? Why not? Strings ...*
- *Is there anything special at TeV scale? No*

Signatures:

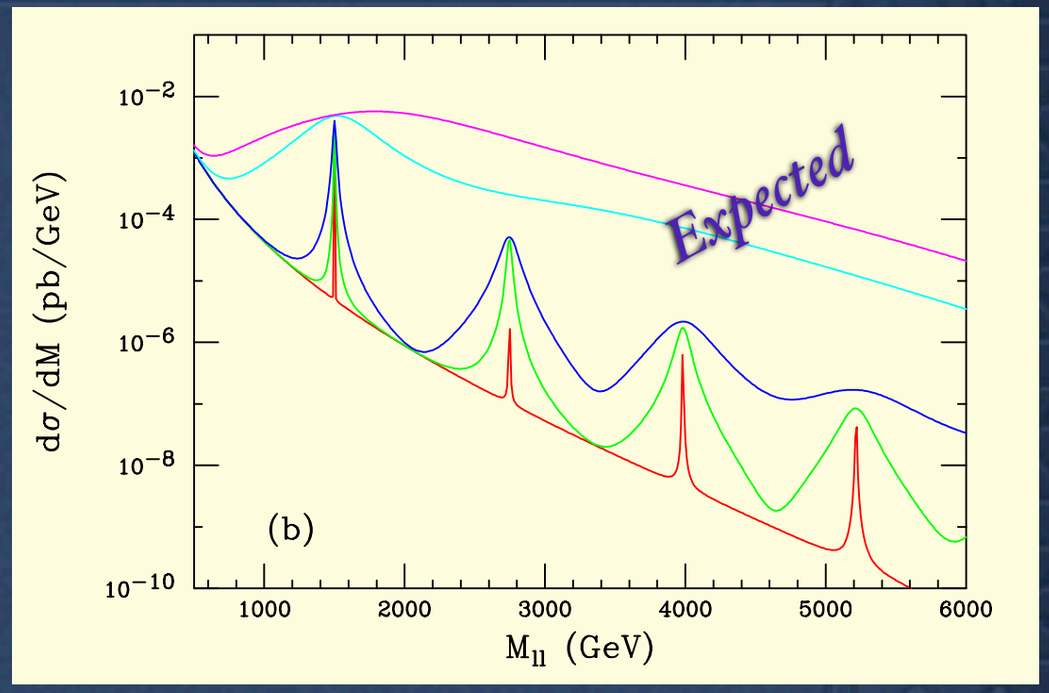
- *Low scale gravity*
- *Infinite tower of new states*
- *Graviton emission and graviton exchange*
- *ADD model: high multilpicity => rising x-secion*
- *RS model => resonance production*

Search for extra D signals

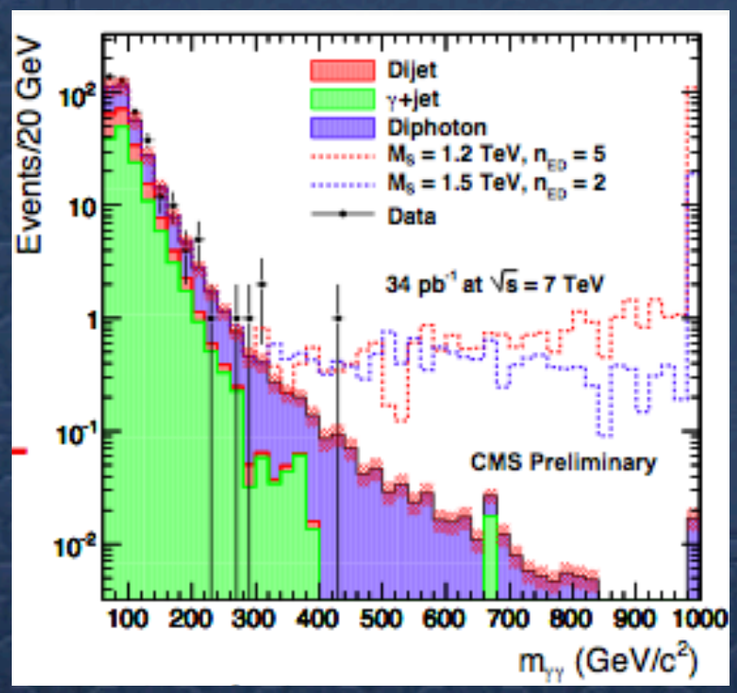


< = *ADD*

RS =>



Diphoton mass spectrum



No signal up to

GRW	Hewett		HLZ (limits in TeV)					
	λ > 0	λ < 0	n=2	n=3	n=4	n=5	n=6	n=7
1.93	1.72	1.70	1.88	2.29	1.93	1.74	1.62	1.53
1.82			1.79	2.22	1.82	1.61	1.45	1.29

No black holes up to 3.5-4.5 TeV

Conclusions

- *First results of the LHC are promising*
- *Big hopes for the 2011-2012 run*
- *Higgs or no Higgs?*
- *SUSY or no SUSY?*
- *Extra D or no Extra D?*
- *Deviation from the SM or not?*
- *I am sure new physics is on agenda*