PHYSICS AT THE LHC

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DESY Summerstudent Programme

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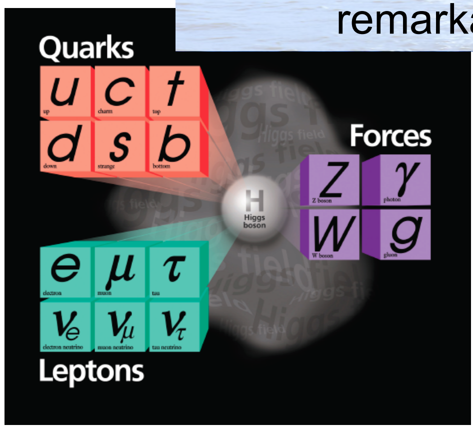
STRUCTURE OF LECTURES

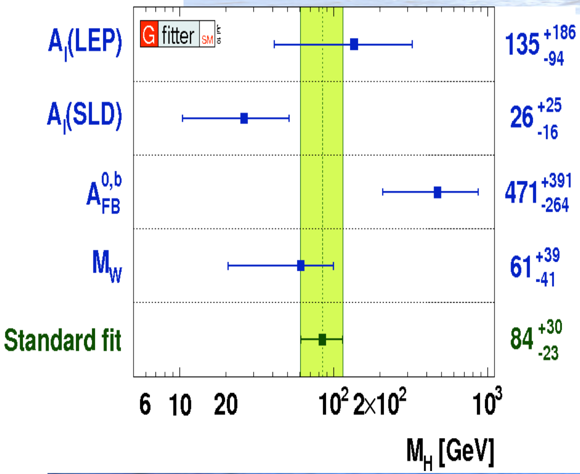
Lecture 1 (TSS) LHC: Motivation, machine, experiments Luminosity and its measurement Basics of pp physics Soft QCD Hard QCD: Jets, photons, jet algos QCD lessons learned Heavy ions and ALICE	**Lecture 3 (GS)** Heavy quarks and resonances Strangeness, charm, J/Psi, b physics, rare decays, B mixing, CP b tagging; Outlook on LHCb Top: cross section and mass, etc. Single top, V_{tb}, 4^{th} generation SM consistency and new physics
Lecture 2 (GS) Electroweak physics: Z, W, Z/W+jets Candles for calibration, W mass, PDFs Diboson physics, TGCs (SM) Higgs: Motivation / mechanism Results: LEP, Tevatron, LHC – limits? BSM appetizer	**Lecture 4 (TSS)** SUSY – Motivation and theory Exp. signatures Limits and a little of statistics Signal interpretation SUSY and Higgs Other BSM physics and exotica

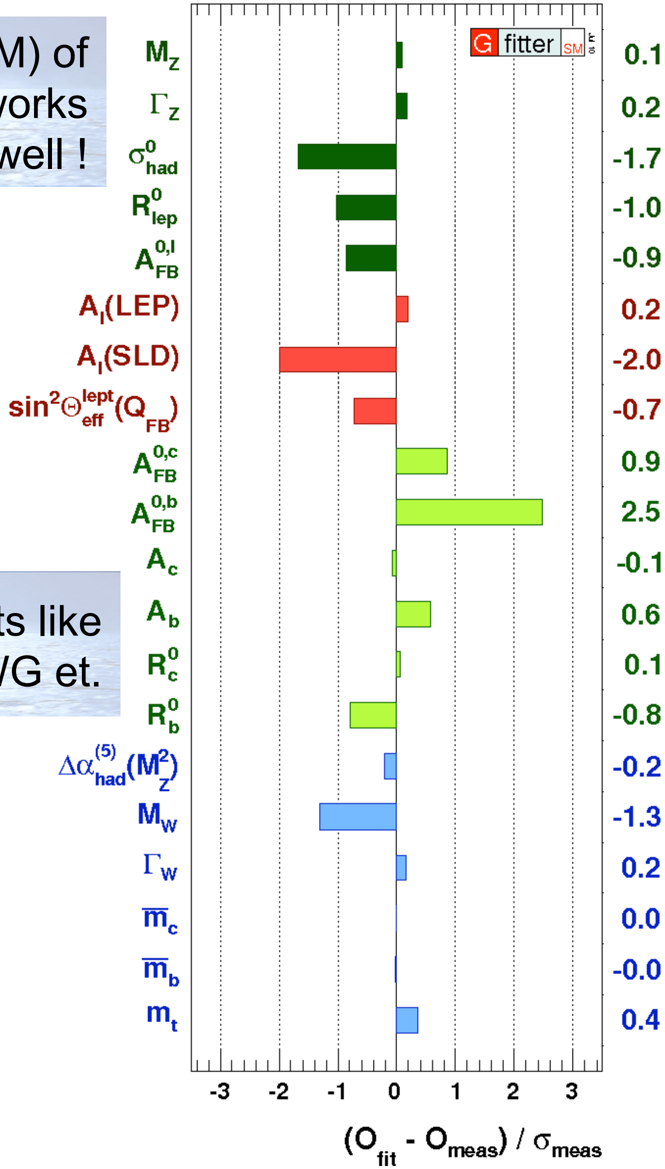
WHY THE LHC?????

Standard model (SM) of particle physics works remarkably well !



E.g. global SM fits like Gfitter, LEP EW WG et.





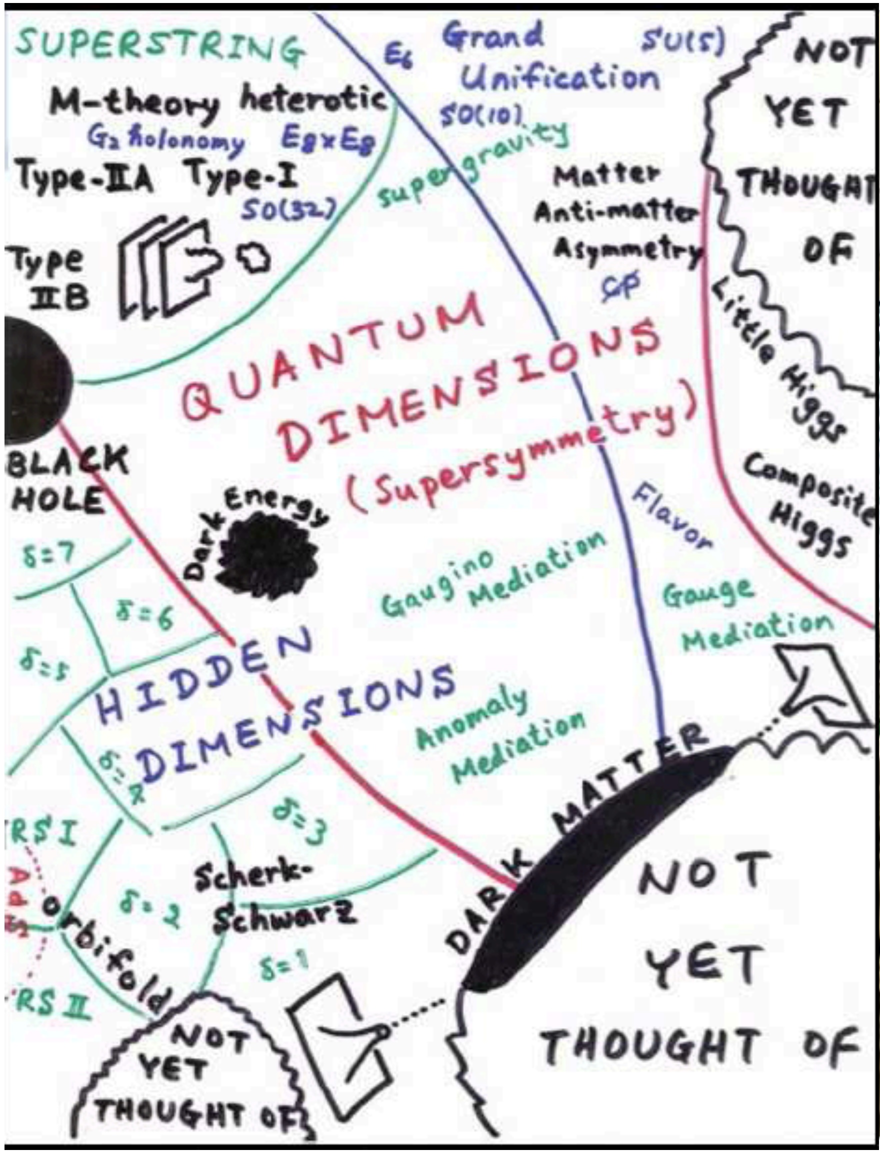
- No Higgs: divergence of SM at 1 TeV?
- SM NOT beautiful! Free parameters?
- SM: no coupling / mass unification!
- SM: No dark-matter candidate!
- Gravity?
- Gauge structure?
- Three generations?
- Hierarchy?
- Baryon asymmetry?
- Connection between quarks and leptons?
- …

WHY THE LHC?????

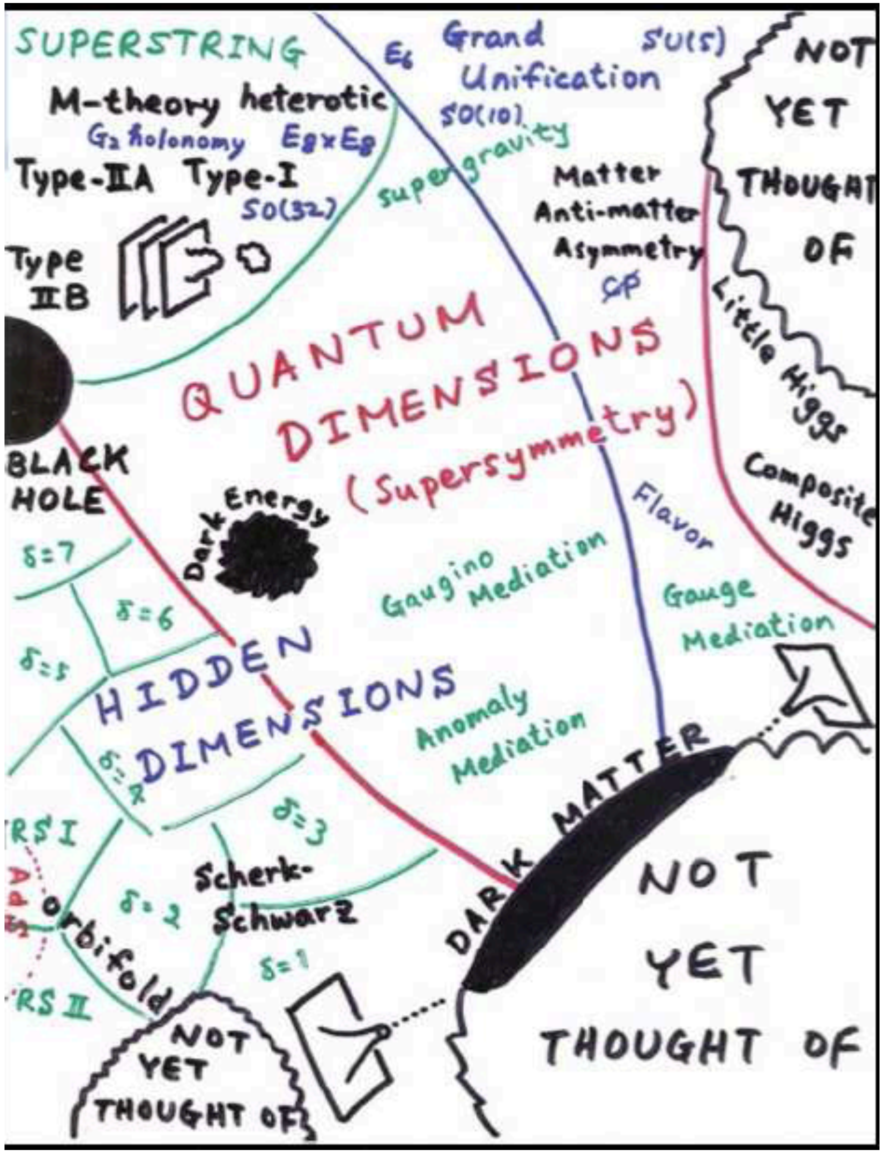
For 40 years we have searched and produced models to be searched for …

Now we are (almost) there!!!

WHY THE LHC?????


SUPERSTRING
M-theory
heterotic
G_2 holonomy
$E_8 \times E_8$
Type-IIA
Type-I
SO(32)
Type IIB
BLACK HOLE
E_6
Grand Unification
SU(5)
SO(10)
supergravity
Matter Anti-matter Asymmetry
CP
NOT YET THOUGHT OF
Little Higgs
Composite Higgs
QUANTUM DIMENSIONS
(Supersymmetry)
Dark Energy
Flavor
Gaugino Mediation
Gauge Mediation
HIDDEN DIMENSIONS
Anomaly Mediation
δ=7
δ=6
δ=5
δ=3
δ=2
δ=1
RS I
RS II
AdS
orbifold
Scherk-Schwarz
DARK MATTER
NOT YET THOUGHT OF
NOT YET THOUGHT OF

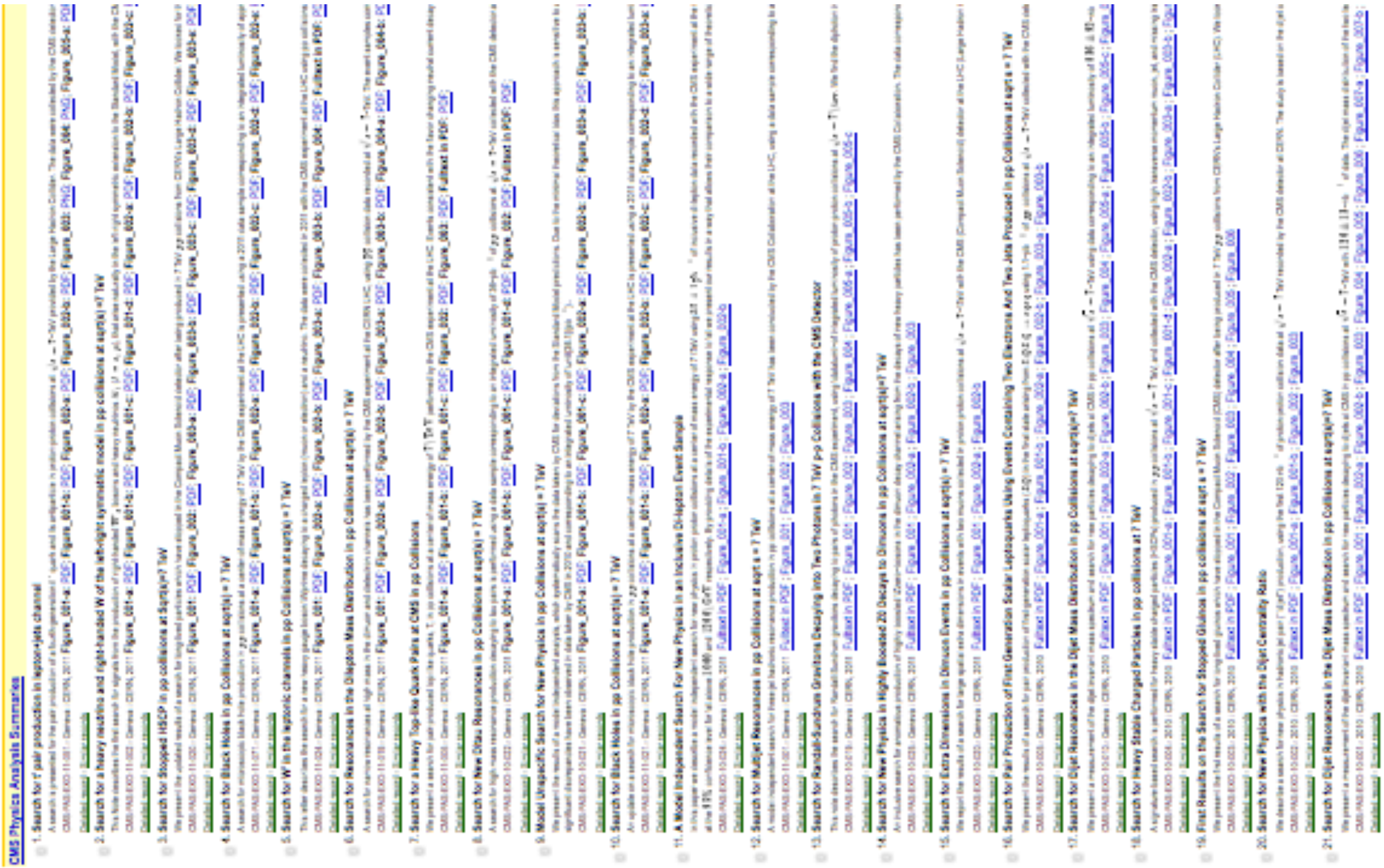
NEW PHYSICS …



How to search for new physics ???

- model-independent or
- specific final-state signatures (with large deviations from SM expectation)

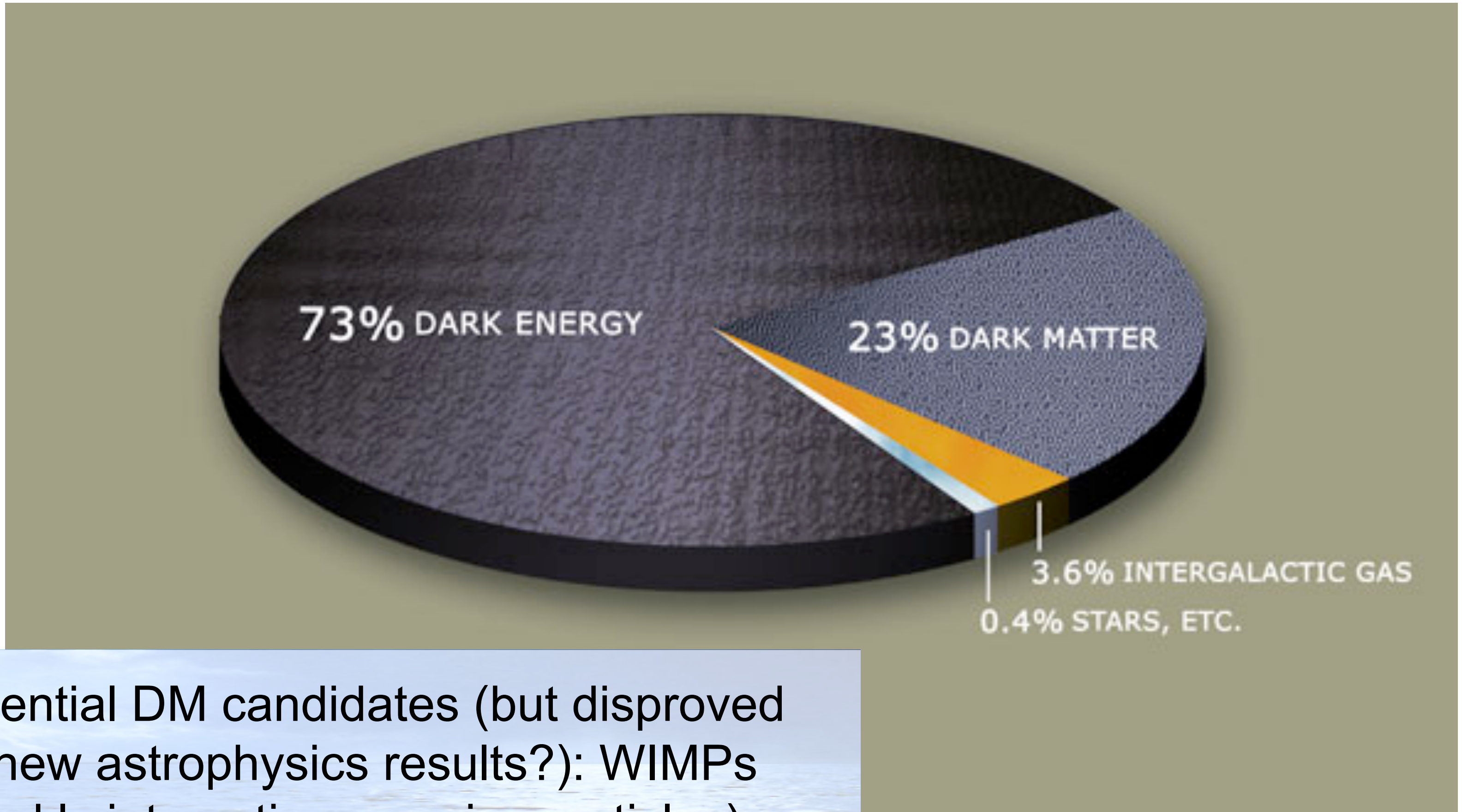
NEW PHYSICS …



CMS Physics Analysis Summaries

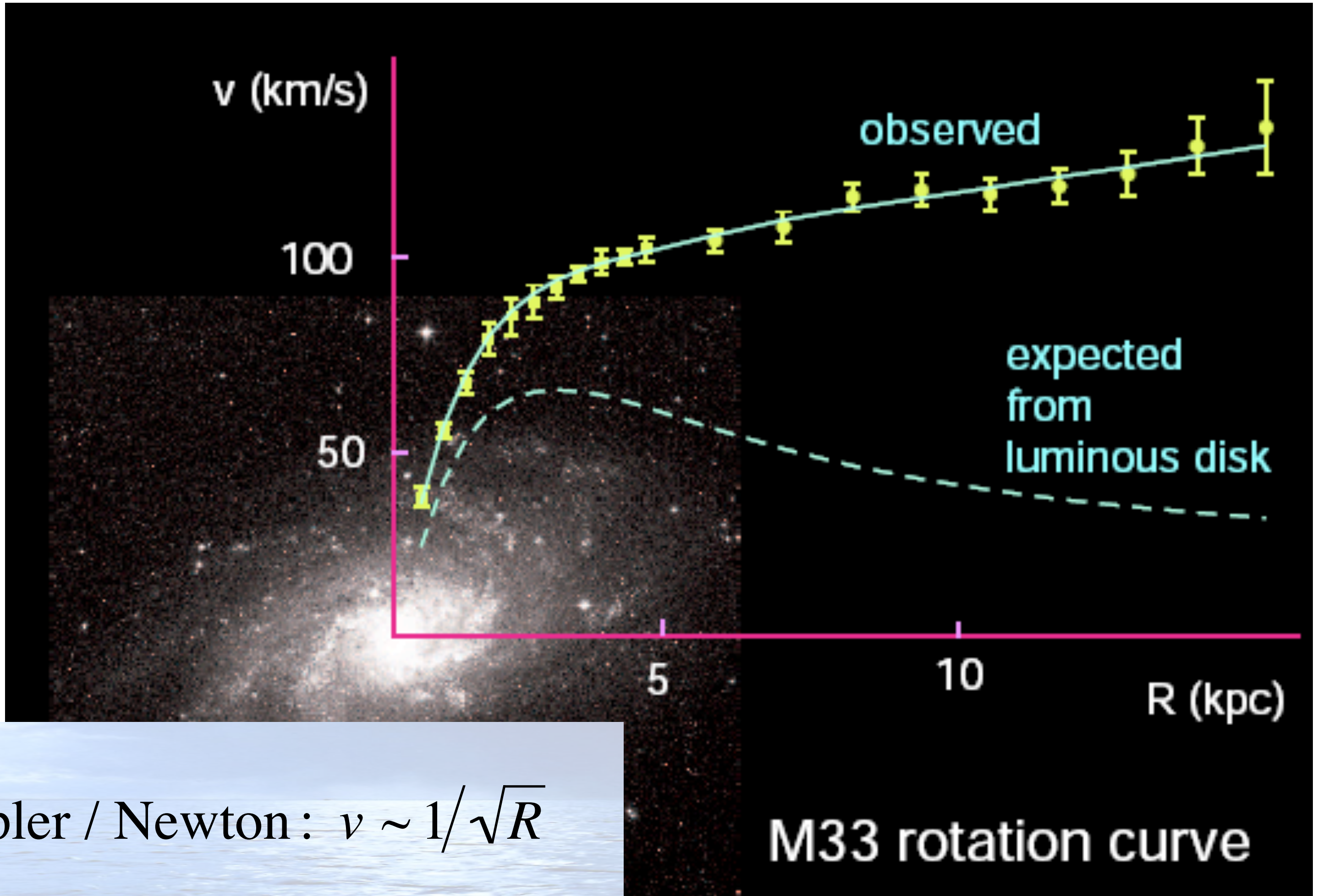
1. Search for t' pair production in lepton+jets channel
2. Search for a heavy neutrino and right-handed W of the left-right symmetric model in pp collisions at sqrt(s) = 7 TeV
3. Search for Stopped HSCP in pp collisions at Sqrt(s)=7 TeV
4. Search for Black Holes in pp Collisions at sqrt(s) = 7 TeV
5. Search for W' in the leptonic channels in pp Collisions at sqrt(s) = 7 TeV
6. Search for Resonances in the Dilepton Mass Distribution in pp Collisions at sqrt(s) = 7 TeV
7. Search for a Heavy Top-like Quark Pairs at CMS in pp Collisions
8. Search for New Dijet Resonances in pp Collisions at sqrt(s) = 7 TeV
9. Model Unspecific Search for New Physics in pp Collisions at sqrt(s) = 7 TeV
10. Search for Black Holes in pp Collisions at sqrt(s) = 7 TeV
11. A Model Independent Search For New Physics in an Inclusive Di-lepton Event Sample
12. Search for Multijet Resonances in pp Collisions at sqrt s = 7 TeV
13. Search for Randall-Sundrum Gravitons Decaying into Two Photons in 7 TeV p-p Collisions with the CMS Detector
14. Search for New Physics in Highly Boosted Z0 Decays to Dimuons in pp Collisions at sqrt(s)=7 TeV
15. Search for Extra Dimensions in Dimuon Events in pp Collisions at sqrt(s) = 7 TeV
16. Search for Pair Production of First Generation Scalar Leptoquarks Using Events Containing Two Electrons And Two Jets Produced in pp Collisions at sqrt s = 7 TeV
17. Search for Dijet Resonances in the Dijet Mass Distribution in pp Collisions at sqrt(s)=7 TeV
18. Search for Heavy Stable Charged Particles in pp collisions at 7 TeV
19. First Results on the Search for Stopped Gluinos in pp collisions at sqrt s = 7 TeV
20. Search for New Physics with the Dijet Centrality Ratio
21. Search for Dijet Resonances in the Dijet Mass Distribution in pp Collisions at sqrt(s)=7 TeV

NEW PHYSICS: MOTIVATION



Potential DM candidates (but disproved by new astrophysics results?): WIMPs (weakly interacting massive particles).
WIMP candidates occur in many BSM models.

NEW PHYSICS: MOTIVATION

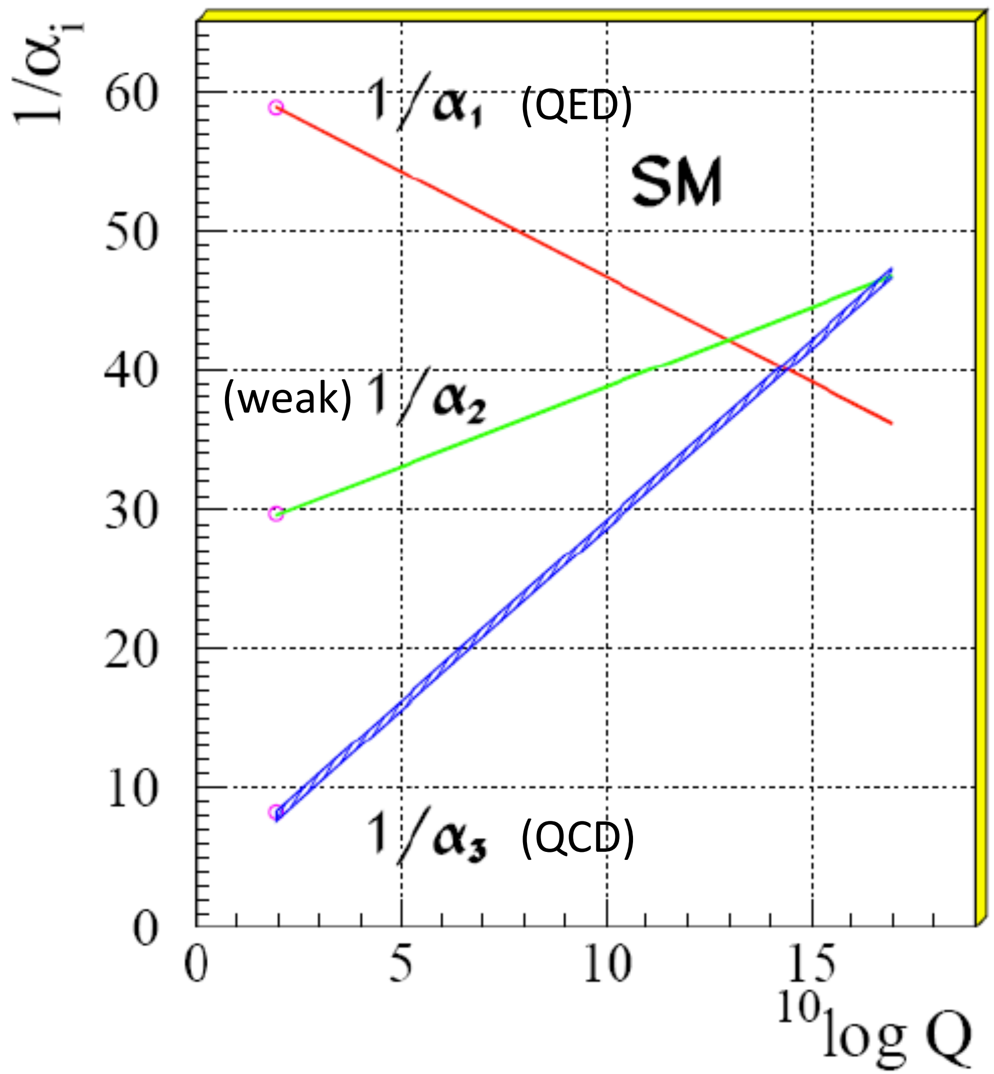


(fig. 1)

Kepler / Newton : $v \sim 1/\sqrt{R}$

NEW PHYSICS: MOTIVATION

For reasons of simplicity and beauty: Want all 3 SM interactions to unite at high scale !



NEW PHYSICS: MOTIVATION

$$\mathcal{L}_{GWS} = \sum_f (\bar{\Psi}_f (i\gamma^\mu \partial\mu - m_f)\Psi_f - eQ_f \bar{\Psi}_f \gamma^\mu \Psi_f A_\mu) +$$

$$+\frac{g}{\sqrt{2}} \sum_i (\bar{a}_L^i \gamma^\mu b_L^i W_\mu^+ + \bar{b}_L^i \gamma^\mu a_L^i W_\mu^-) + \frac{g}{2c_w} \sum_f \bar{\Psi}_f \gamma^\mu (I_f^3 - 2s_w^2 Q_f - I_f^3 \gamma_5)\Psi_f Z_\mu +$$

$$-\frac{1}{4}|\partial_\mu A_\nu - \partial_\nu A_\mu - ie(W_\mu^- W_\nu^+ - W_\mu^+ W_\nu^-)|^2 - \frac{1}{2}|\partial_\mu W_\nu^+ - \partial_\nu W_\mu^+ +$$

$$-ie(W_\mu^+ A_\nu - W_\nu^+ A_\mu) + ig' c_w (W_\mu^+ Z_\nu - W_\nu^+ Z_\mu|^2 +$$

$$-\frac{1}{4}|\partial_\mu Z_\nu - \partial_\nu Z_\mu + ig' c_w (W_\mu^- W_\nu^+ - W_\mu^+ W_\nu^-)|^2 +$$

$$-\frac{1}{2} M_\eta^2 \eta^2 - \frac{g M_\eta^2}{8 M_W} \eta^3 - \frac{g'^2 M_\eta^2}{32 M_W} \eta^4 + |M_W W_\mu^+ + \frac{g}{2} \eta W_\mu^+|^2 +$$

$$+\frac{1}{2}|\partial_\mu \eta + i M_Z Z_\mu + \frac{ig}{2c_w} \eta Z_\mu|^2 - \sum_f \frac{g}{2} \frac{m_f}{M_W} \bar{\Psi}_f \Psi_f \eta$$

Neither simple nor beautiful ?

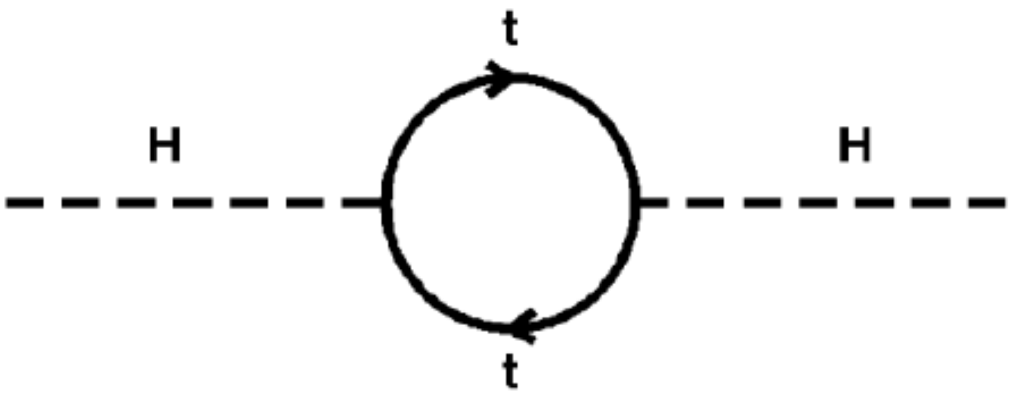
NEW PHYSICS: MOTIVATION – SUSY?

We know: m_H < 140 GeV!
But: loop corrections to m_H?

Expect: $\Delta m_H^2 \propto \Lambda^2$

$$m_H^2 \approx M_{Pl}^2 \approx 10^{2\cdot 19}\,\mathrm{GeV}^2$$

Which "fine-tuning" can re-arrange the "hierarchy"???



Solution: Introduce "shadow world", related via symmetry!
One SUSY partner for each SM state!

Fermion loops cancel boson loops and vv!

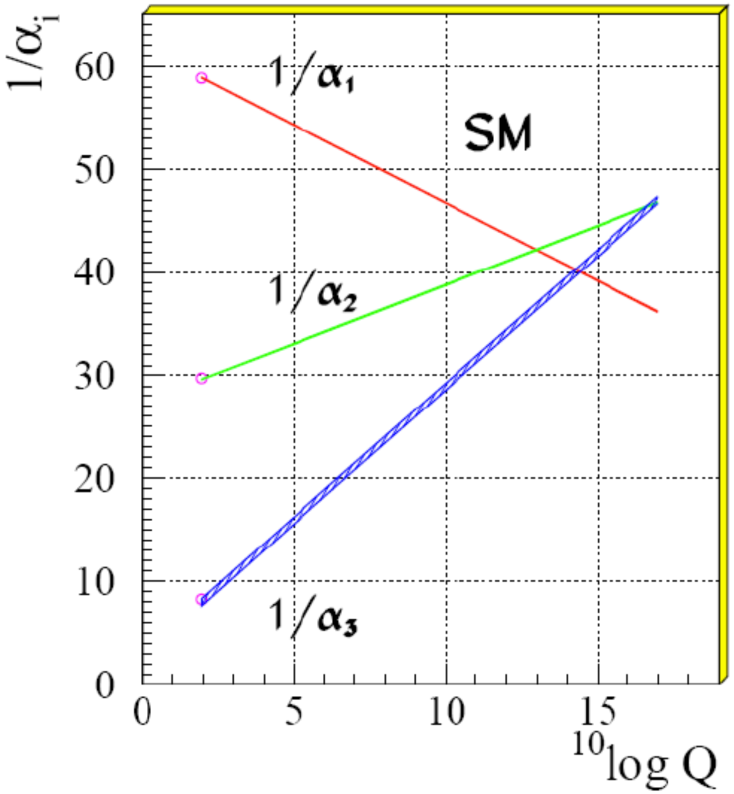
Works as long as mass difference not too large
➔ SUSY particles < 1 TeV!!!

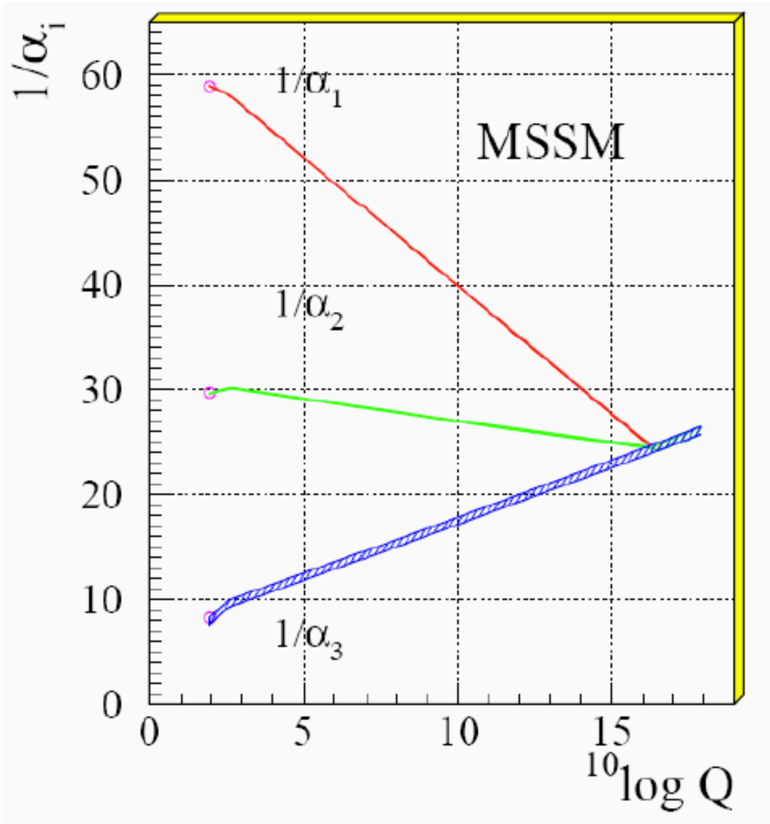
INTRODUCING SUSY

FERMIONS			BOSONS		
spin	Name	Symbols	Name	Symbols	spin
½	leptons	e, ν_{eL}	sleptons	$\tilde{e}_L, \tilde{e}_R, \tilde{\nu}_{eL}$	0
		$\mu, \nu_{\mu L}$		$\tilde{\mu}_L, \tilde{\mu}_R, \tilde{\nu}_{\mu L}$	
		$\tau, \nu_{\tau L}$		$\tilde{\tau}_L, \tilde{\tau}_R, \tilde{\nu}_{\tau L}$	
½	quarks	u, d	squarks	$\tilde{u}_L, \tilde{d}_L, \tilde{u}_R, \tilde{d}_R$	0
		c, s		$\tilde{c}_L, \tilde{s}_L, \tilde{c}_R, \tilde{s}_R$	
		t, b		$\tilde{t}_L, \tilde{b}_L, \tilde{t}_R, \tilde{b}_R$	
½	gluinos	$\tilde{g}$	gluons	g	1
½	charginos	$\tilde{\chi}_1^{\pm}, \tilde{\chi}_2^{\pm}$	EW bosons	$\gamma, Z^0, W^{\pm}$	1
½	neutralinos	$\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$	higgs	$h^0, H^0, A^0, H^{\pm}$	0

SM particles (observed)	SM particles (not yet observed)	Super Partners (not yet observed)

SUSY: MOTIVATION

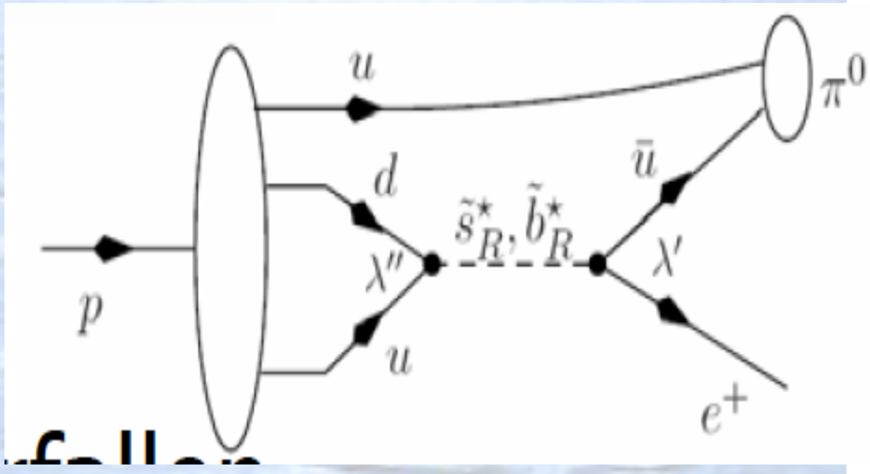




SUSY: BASICS

- New symmetry between bosons and fermions
  ➔ Partner particle for each SM particle –
  same quantum numbers and couplings except for spin!

- Solves many of the mentioned problems
  - natural light Higgs,
  - hierarchy
  - DM (e.g. neutralino χ_0 as mixture of SUSY partners of Z,γ,H)
  - inclusion of gravitation
  - gauge structure
  - Unification



- Freedom: symmetry breaking, QN conservation
  - R parity: $R = (-1)^{3B+L+2S}$
    If R violated ➔ proton decay!
  - RP conservation: Pairwise production, cascade decay, stable LSP (lightest SUSY particle)

SUSY: MODELS

- SUSY is a broken theory!!!

  Resulting disadvantage: many free parameters (masses, mixings, in MSSM 125!)

- Models for SUSY breaking:
  - … introduce assumptions --. Drastic reduction of parameters
  - … allow predictions for sparticle mass spectra
  - … examples: mSUGRA, GSMB, …

- Example mSUGRA:
  - … unification of SUSY spin-0 and SUSY spin-1/2 particle masses at GUT scale
  - … only 5 parameters left: tanβ, m_0, $m_{1/2}$, sign(μ), A_0

$$\frac{1}{2}M_z = \frac{m_{H_1}^2 - m_{H_2}^2 Tan^2\beta}{Tan^2\beta - 1} - |\mu|^2 > 0$$

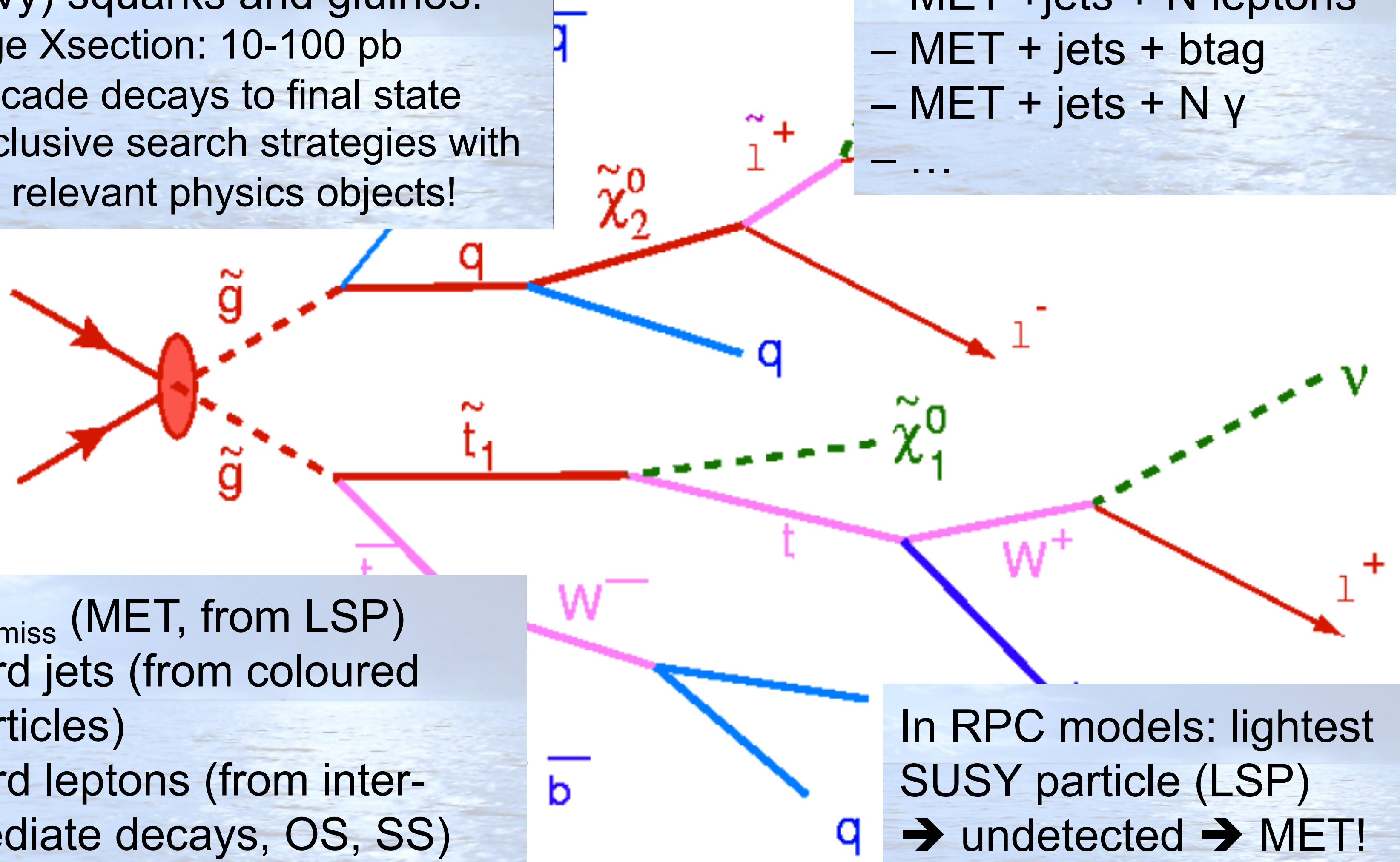
  - … calculation of masses at lower scales (“running masses”)
  - … LSP as DM candidate!

SUSY: INCLUSIVE SEARCHES

RPC SUSY: pair production of (heavy) squarks and gluinos:
- large Xsection: 10-100 pb
- cascade decays to final state

➔ inclusive search strategies with all relevant physics objects!

- MET + jets
- MET +jets + N leptons
- MET + jets + btag
- MET + jets + N γ
- …

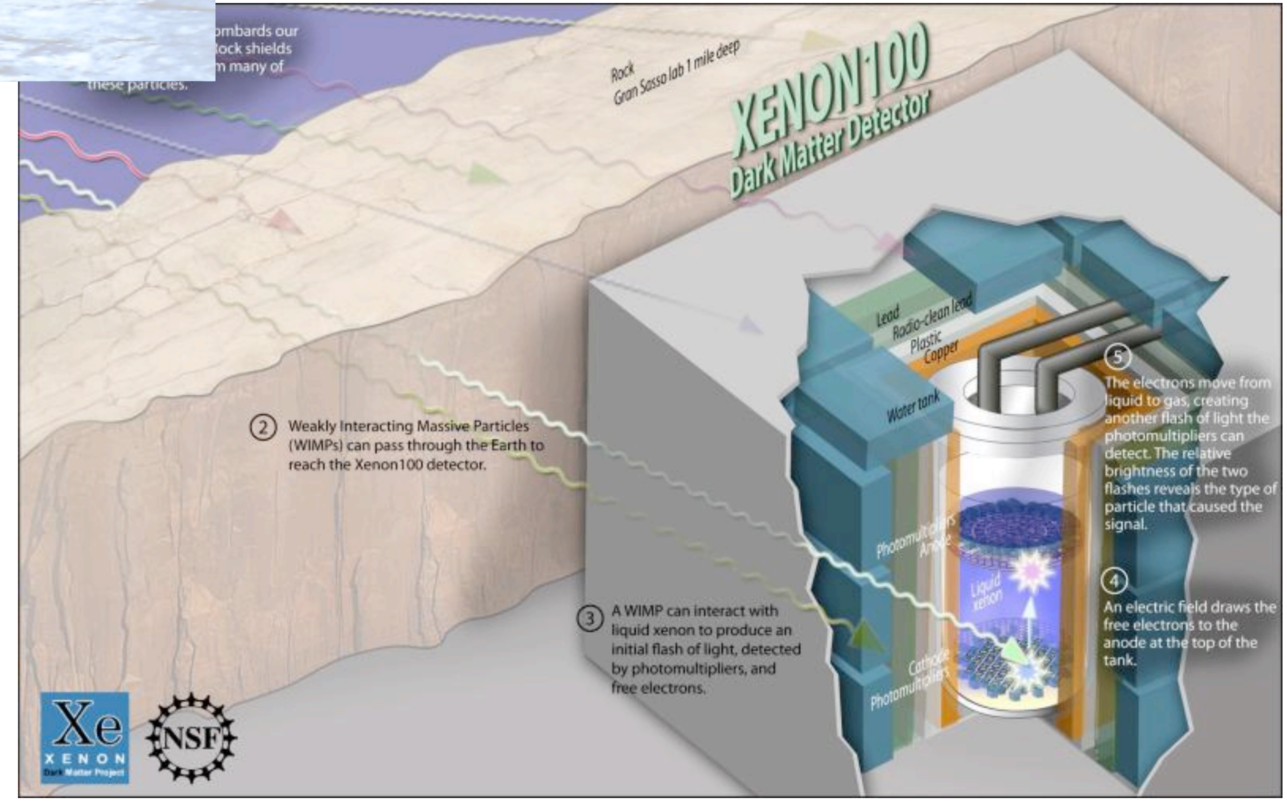


- $E_{T,miss}$ (MET, from LSP)
- hard jets (from coloured particles)
- hard leptons (from inter-mediate decays, OS, SS)

In RPC models: lightest SUSY particle (LSP) ➔ undetected ➔ MET!

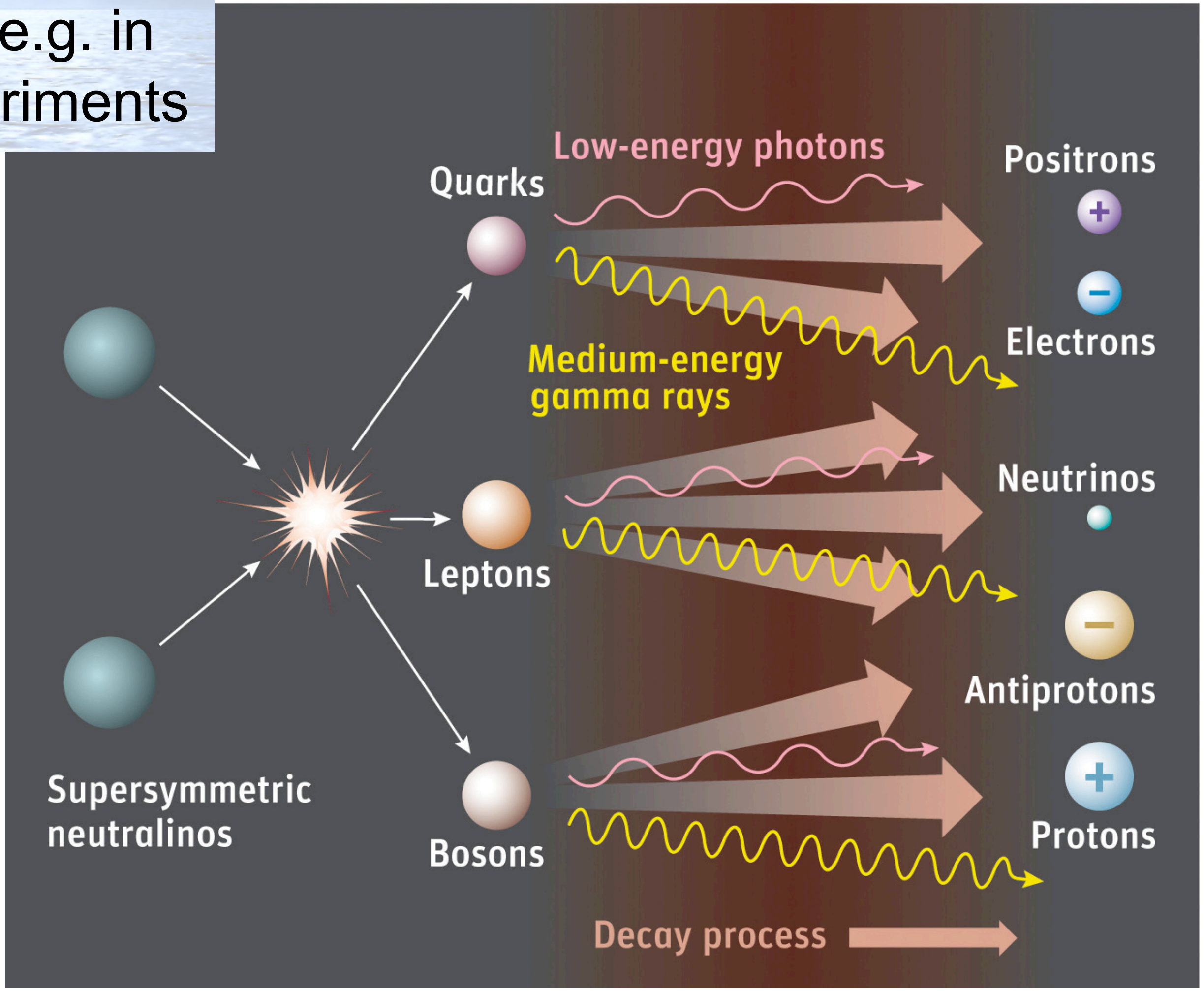
SUSY: SEARCHES

- Direct DM searches: e.g. cryogenic detectors and measurement of nuclear recoil. Issue: background! etc.



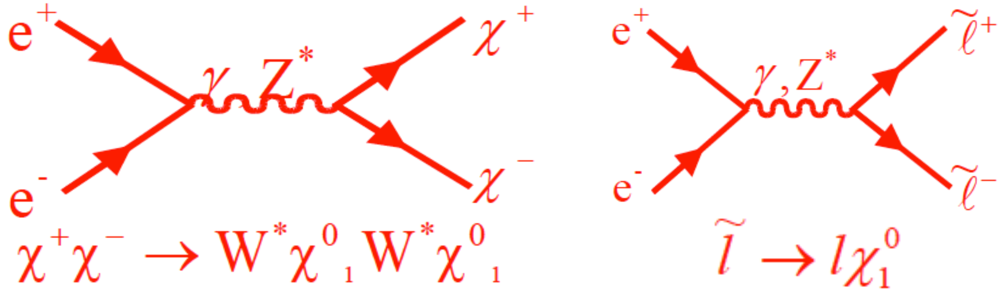
SUSY: SEARCHES

- Direct DM searches
- Indirect searches e.g. in astrophysics experiments



SUSY: SEARCHES (AT LEP)

- Direct DM searches
- Indirect searches e.g. in astrophysics experiments
- Searches at colliders: PETRA, SppS, HERA, LEP, Tevatron

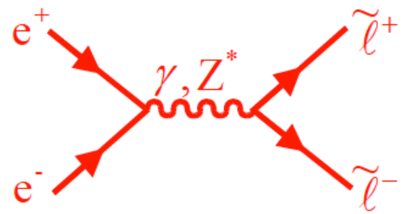


- Fixed initial conditions
- Production of sparticles up to half CMS energy
- So far only exclusion of parameter regions!

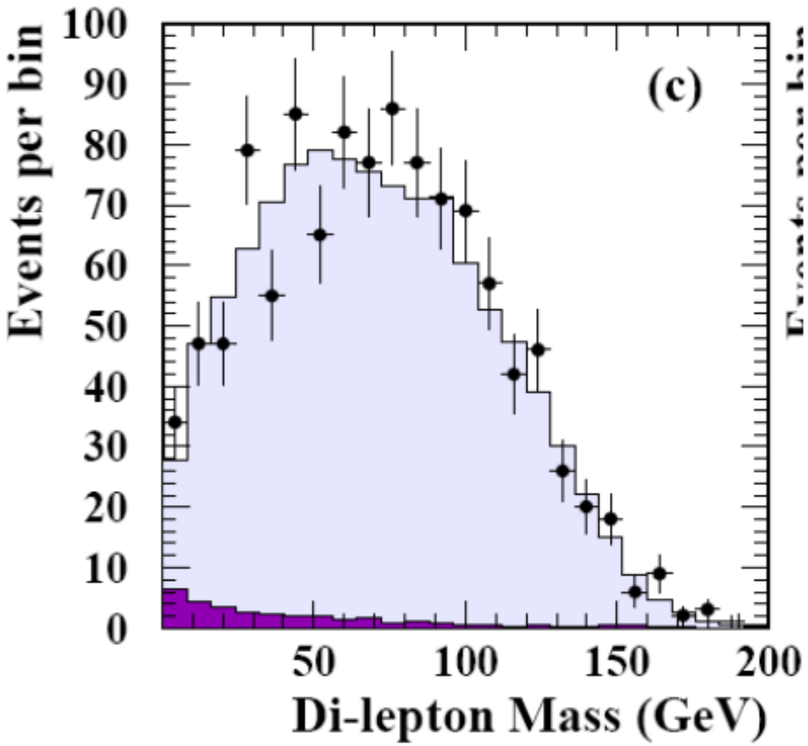
SUSY: SEARCHES (AT LEP)

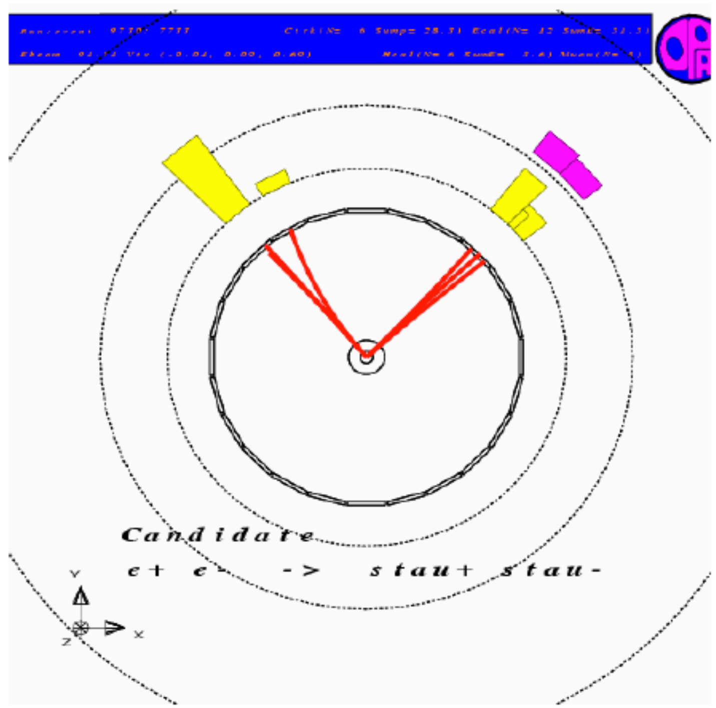
- Direct DM searches
- Indirect searches e.g. in astrophysics experiments
- Searches at colliders:

$$\chi^+\chi^- \rightarrow W^*\chi^0{}_1 W^*\chi^0{}_1$$



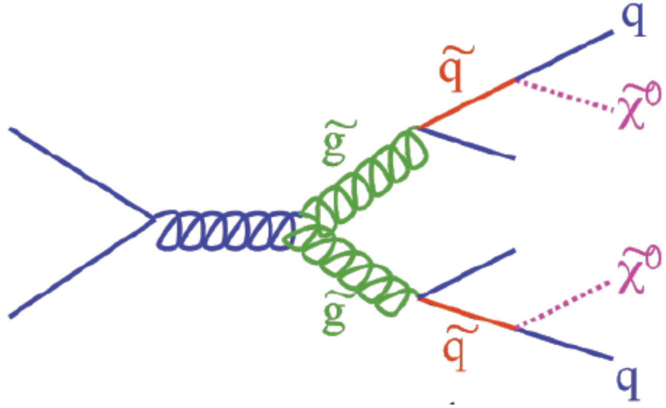
$$\tilde{l} \rightarrow l\chi_1^0$$

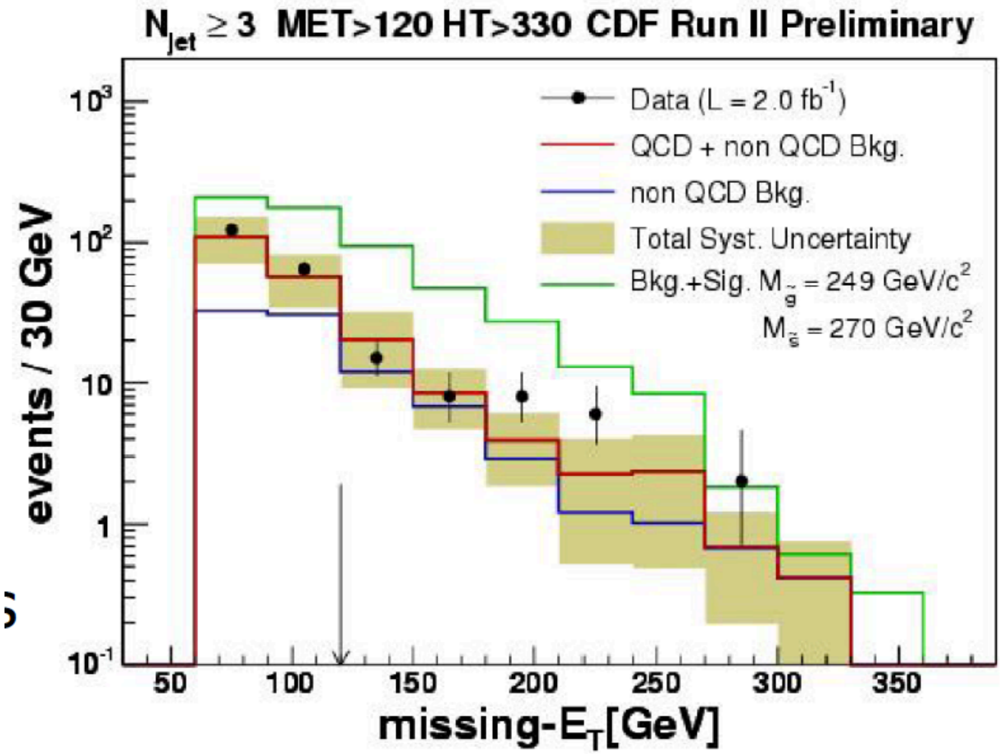


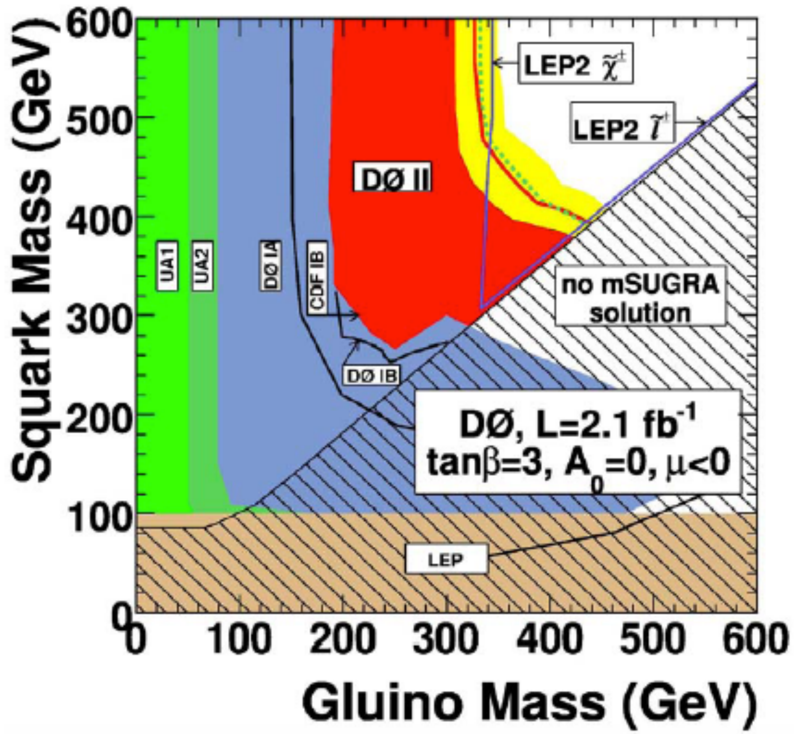


SUSY: SEARCHES (TEVATRON)

- Direct DM searches
- Indirect searches e.g. in astrophysics experiments
- Searches at colliders







SUSY: LIMITS AND SIGNIFICANCES

Do we see a significant excess of data over SM expectation? Or can we exclude a certain (mass) hypothesis?

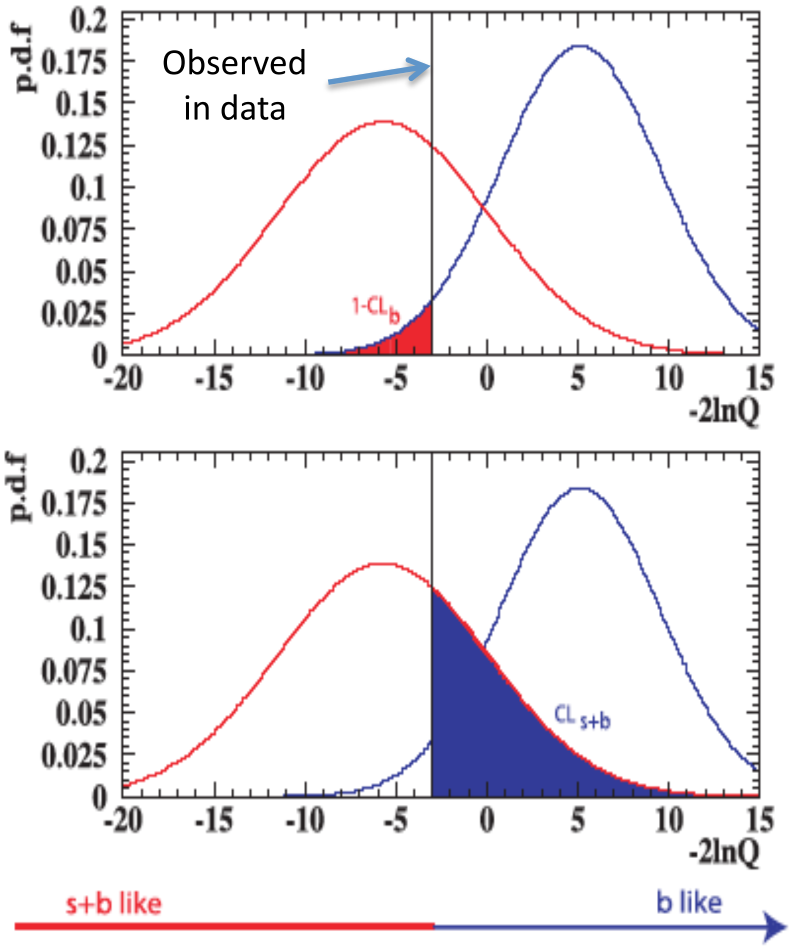
Define test statistics Q as ratio of likelihoods for s / no s hypotheses:

$$-2\ln Q = -2\ln\frac{P_d(s+b)}{P_d(b)} = -2\sum_i s_i + 2\sum_i d_i \ln\left(1+\frac{s_i}{b_i}\right)$$

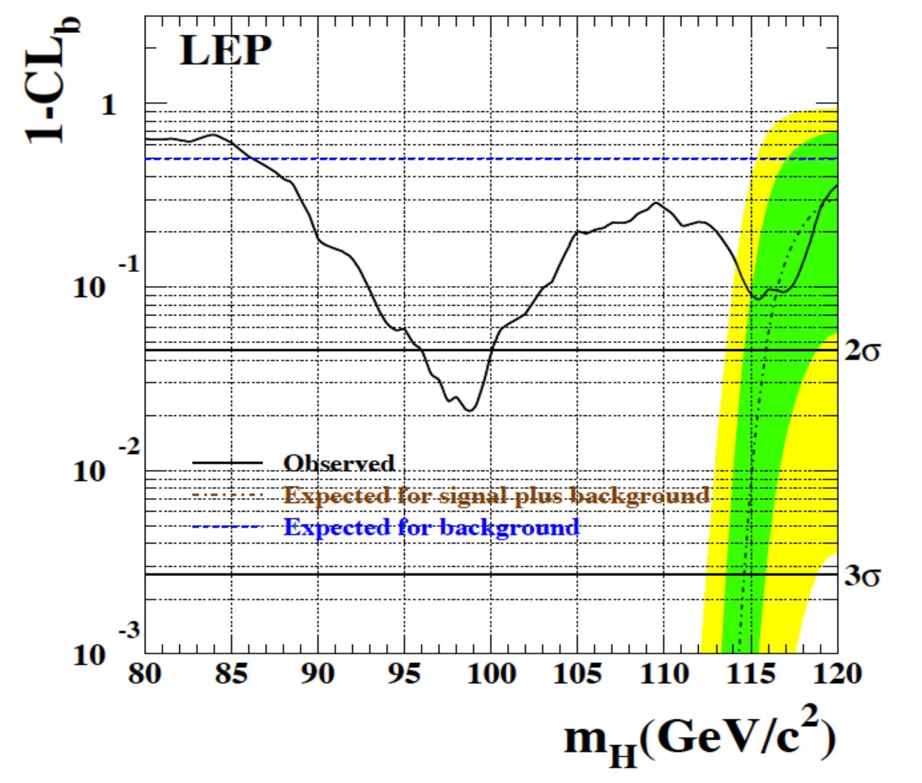
Then perform toy experiments with and without s for different parameters (e.g. m_H):

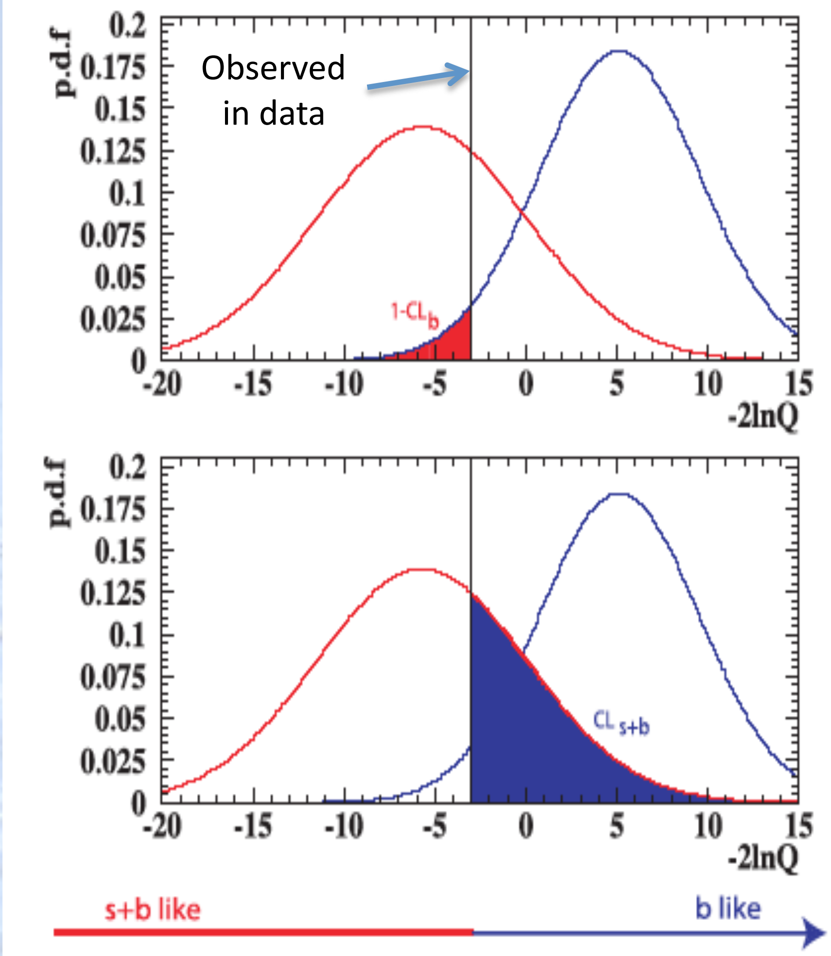
$1\text{-}CL_b$: Probability to observe more s-like outcome in b-only case

CL_{s+b}: Probability to observe more b-like outcome in signal case



SUSY: LIMITS AND SIGNIFICANCES



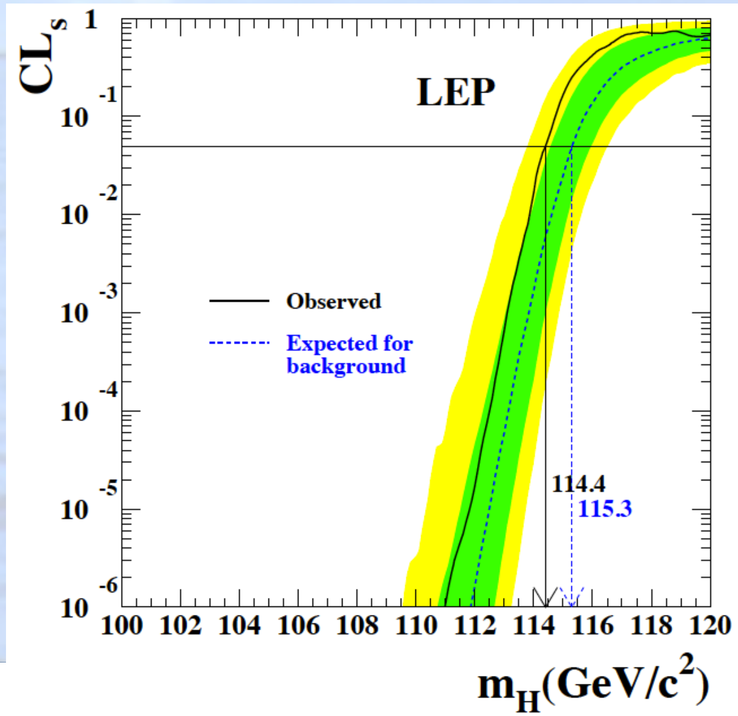


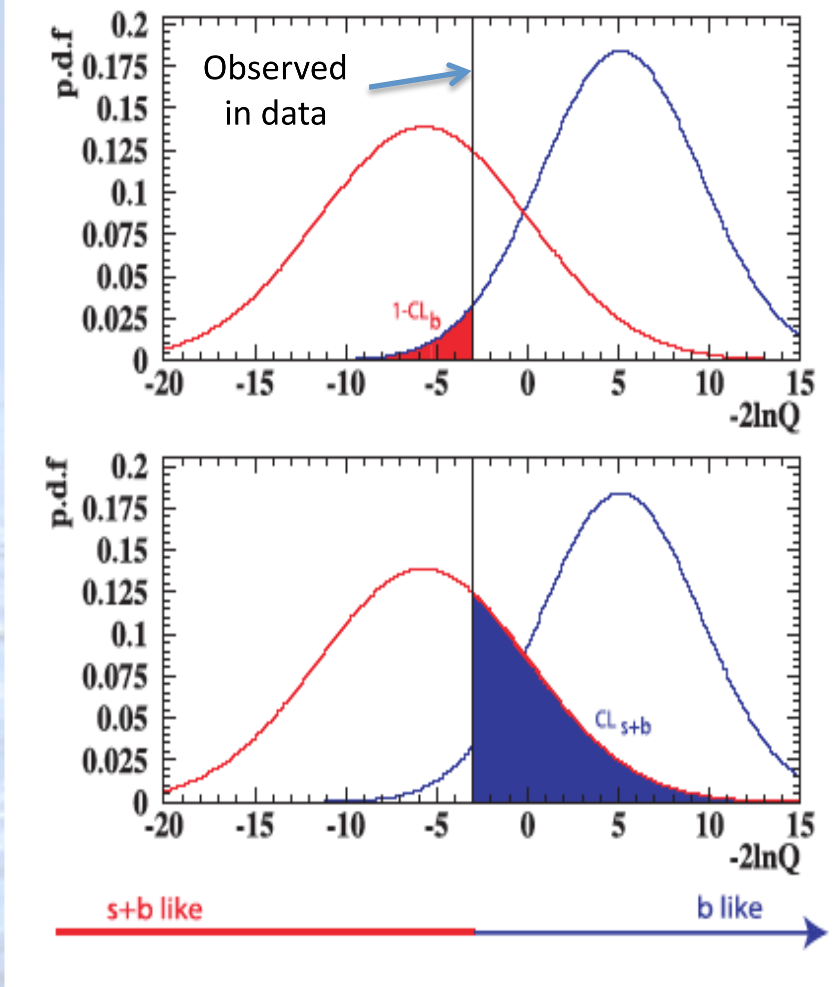
1-CL$_b$: Probability to observe more s-like outcome in b-only case

CL$_{s+b}$: Probability to observe more b-like outcome in signal case

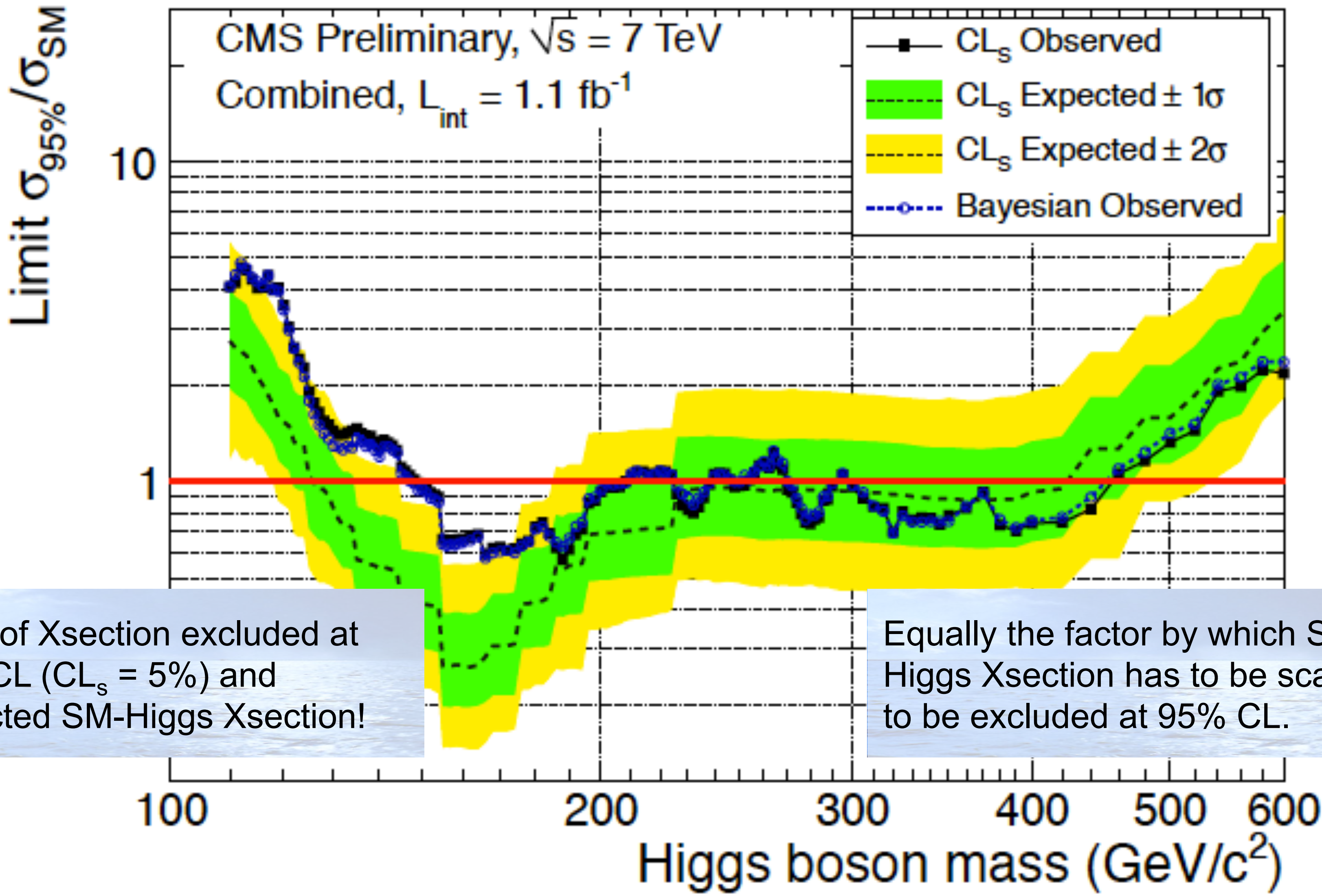
SUSY: LIMITS AND SIGNIFICANCES

$1\text{-}CL_b$: Probability to observe more s-like outcome in b-only case
CL_{s+b}: Probability to observe more b-like outcome in signal case
No excess in $1\text{-}CL_b$ ➔ Look at $CL_s = CL_{s+b} / CL_b$:
If CL_s small, then signal is very unlikely ➔
$CL_s < 5\%$ ➔ exclusion at 95% confidence level.





SUSY: LIMITS AND SIGNIFICANCES



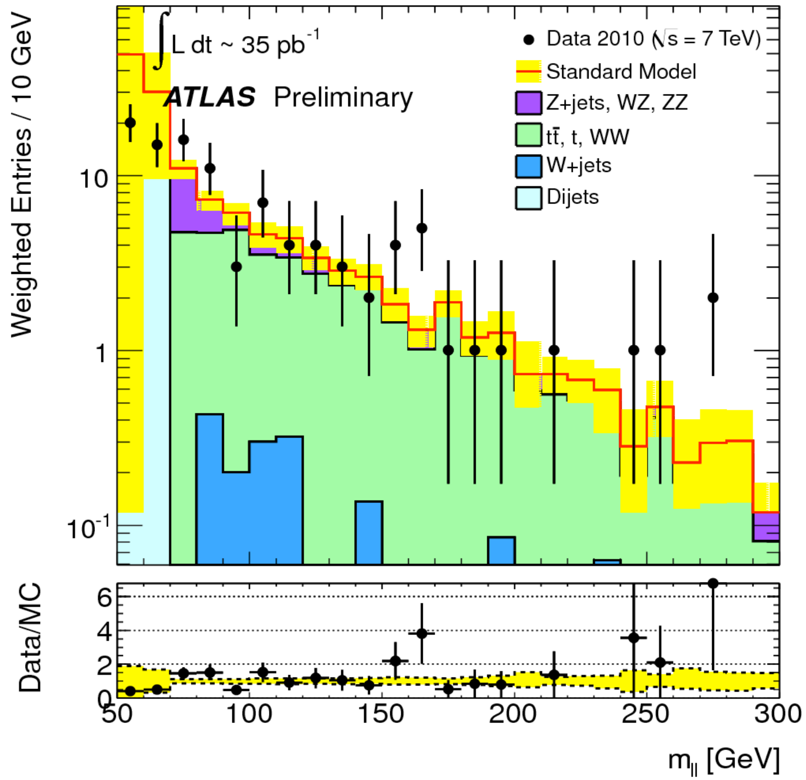
Ratio of Xsection excluded at 95% CL (CL_s = 5%) and predicted SM-Higgs Xsection!

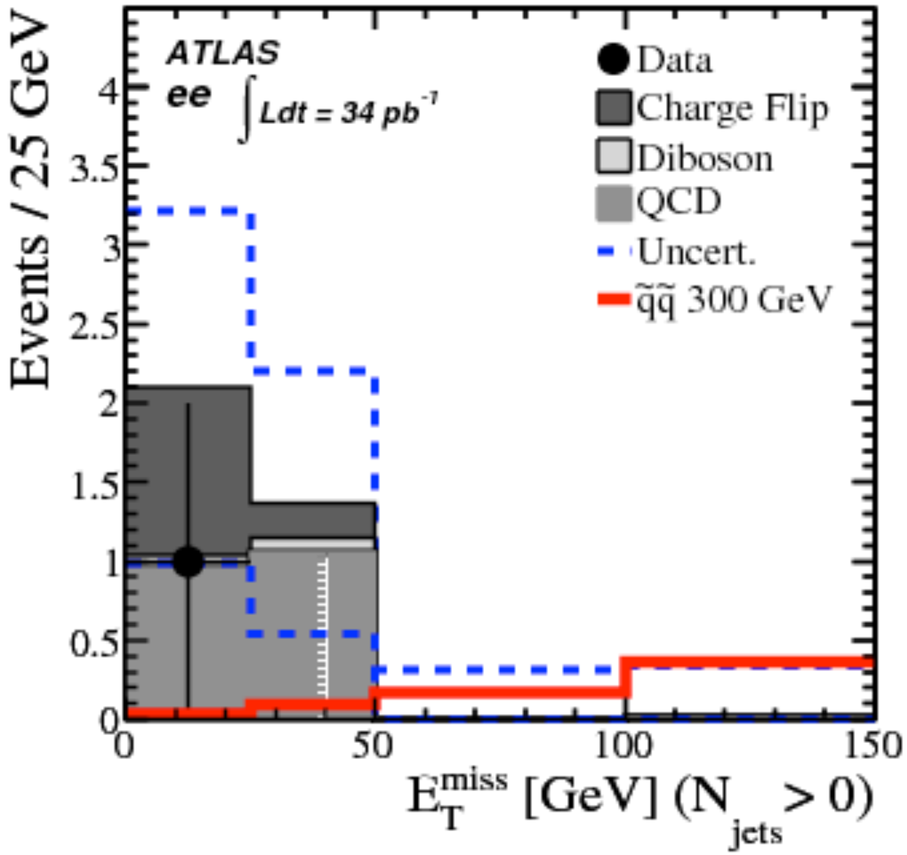
Equally the factor by which SM-Higgs Xsection has to be scaled to be excluded at 95% CL.

SUSY AT LHC (1 EXAMPLE)

Inclusive spectra as fastest way to discovery of SUSY-like physics.

Challenging – requires excellent understanding of all detector components with little data!

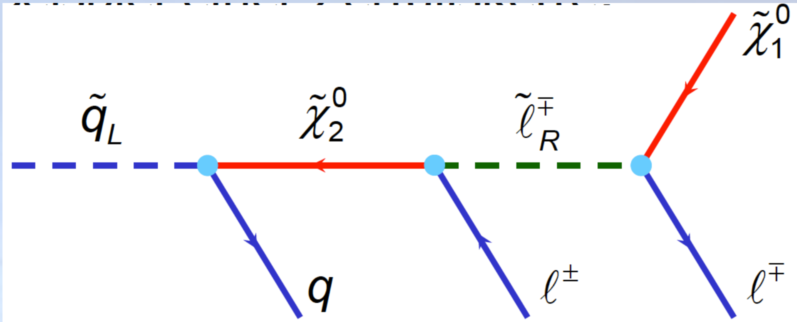




INTERPRETATION AND MASS EDGES

SUSY discovery “easy”, but interpretation challenging (ILC!)

- need to measure masses to identify model (parameters)
- but 2 LSPs ➔ no mass peaks of decaying resonances!



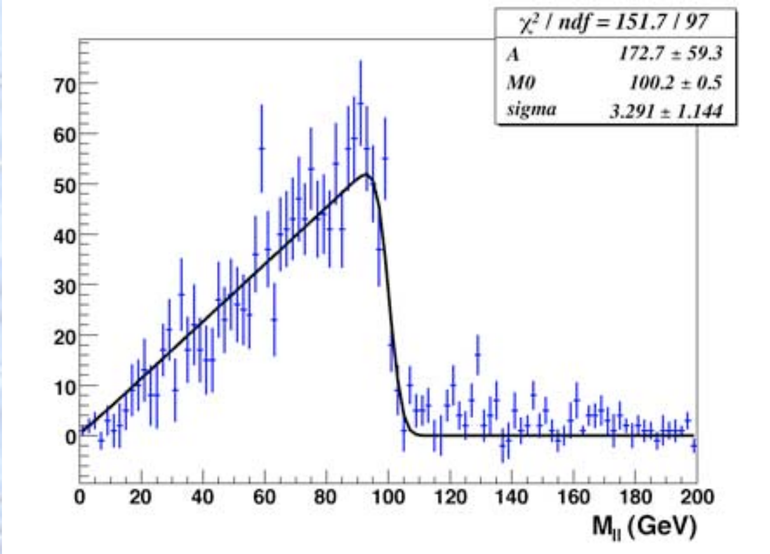
One way: mass edges!

Intermediate states define max dilepton mass:

$$m_{\ell\ell}^{\max} = \frac{1}{m_{\tilde{\ell}_R}} \sqrt{\left(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\ell}_R}^2\right)\left(m_{\tilde{\ell}_R}^2 - m_{\tilde{\chi}_1^0}^2\right)}$$

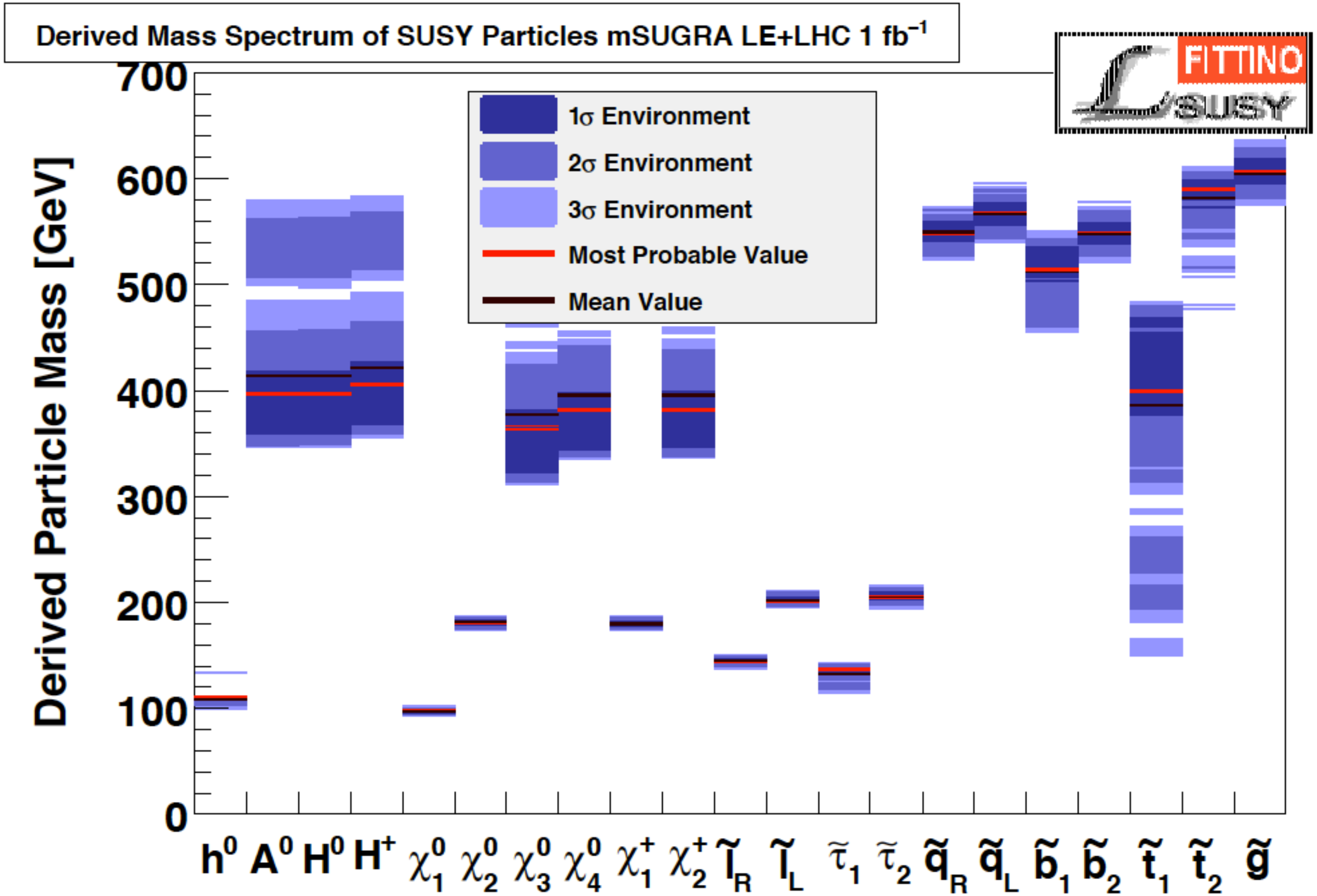
Works also for other combinations, e.g.

$$m_{q\ell\ell}^{\max} = \frac{1}{m_{\tilde{\chi}_2^0}} \sqrt{\left(m_{\tilde{q}_L}^2 - m_{\tilde{\chi}_2^0}^2\right)\left(m_{\tilde{\chi}_2^0}^2 - m_{\tilde{\chi}_1^0}^2\right)}$$

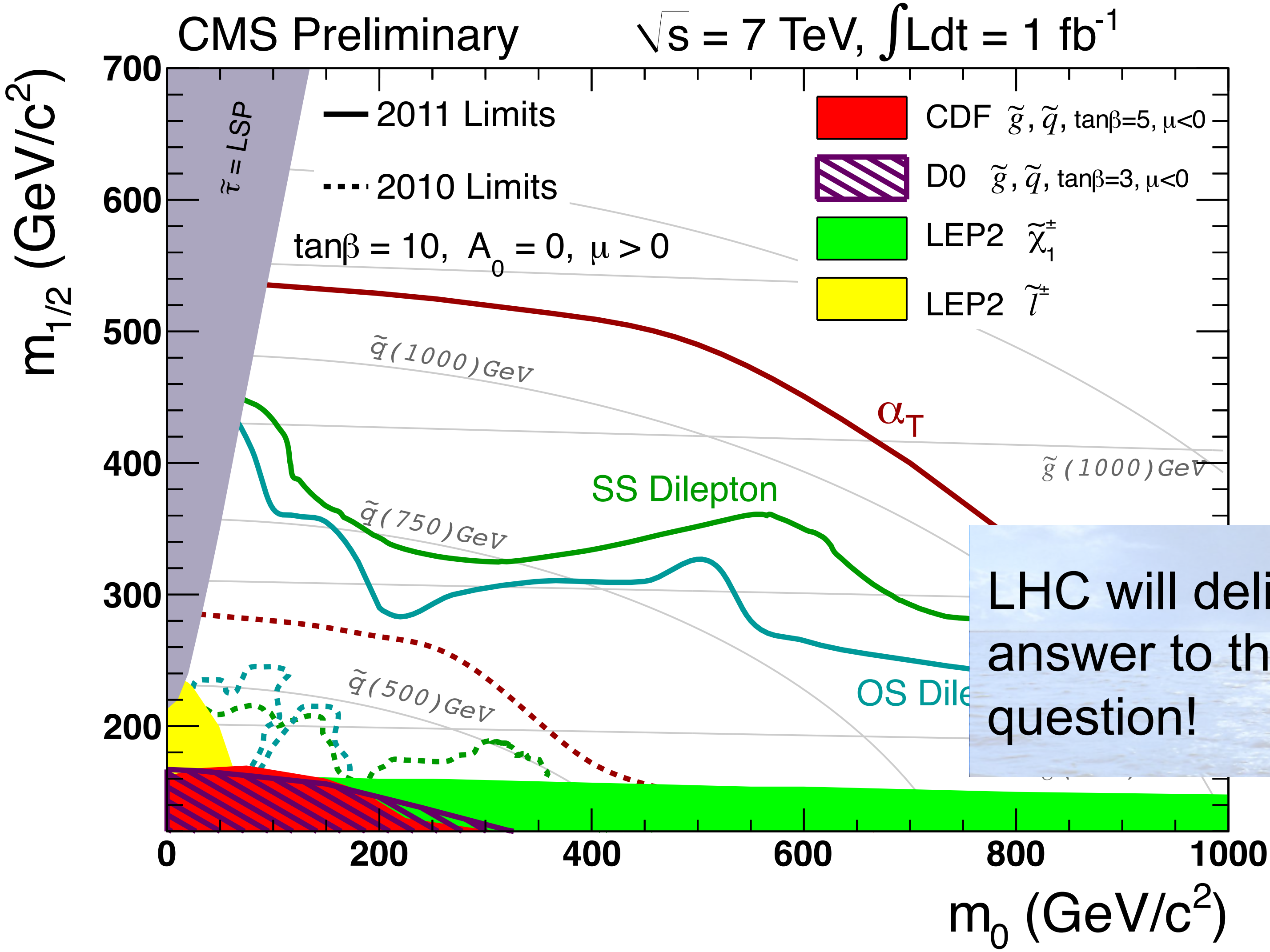


Different end-points
→ clues about masses!

SUSY: MASS SPECTRUM EXAMPLE

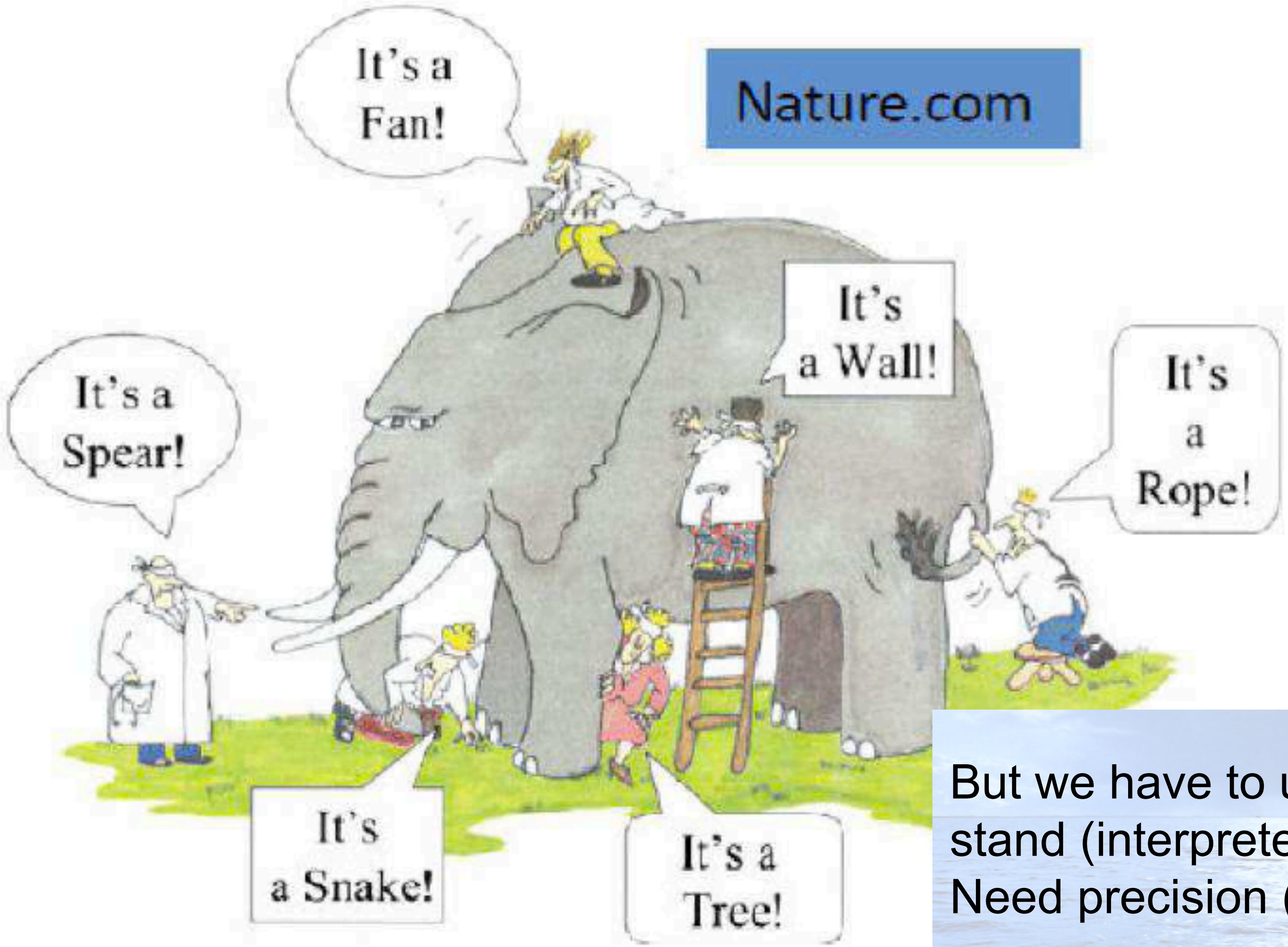


SUSY: COMBINED CMS RESULTS



LHC will deliver the answer to the SUSY question!

SUSY: THE FUTURE?



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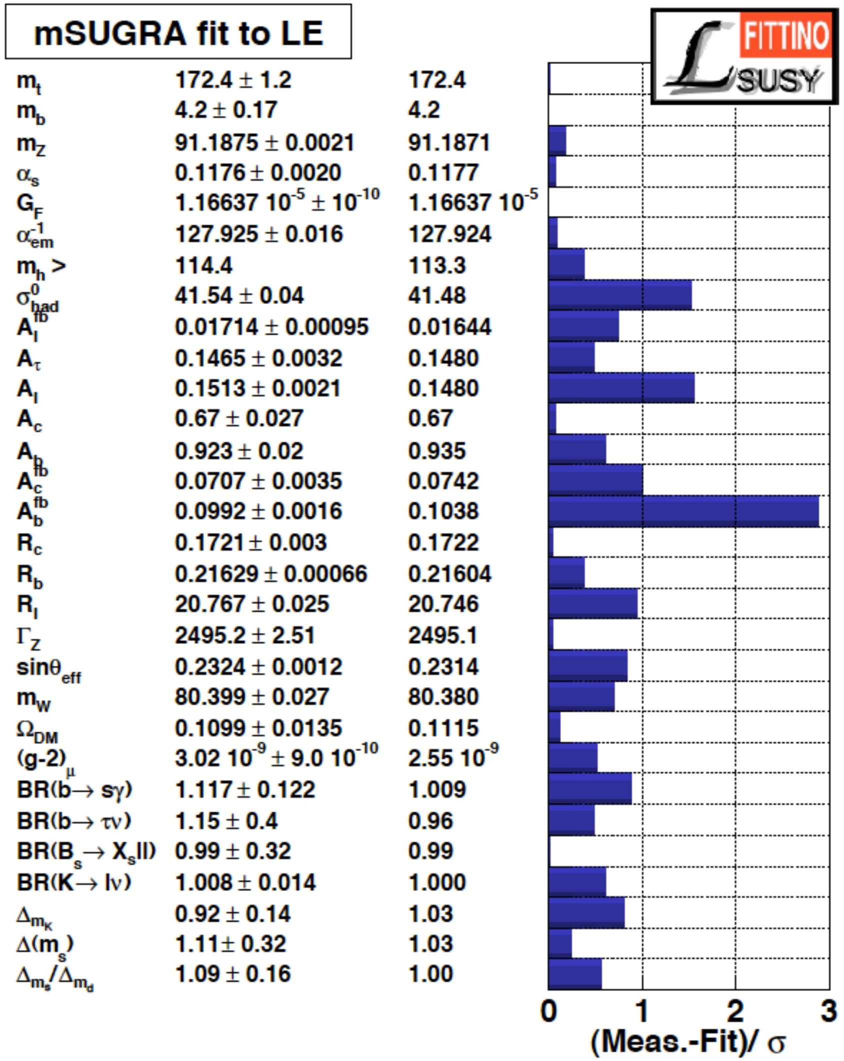
But we have to understand (interprete) it.
Need precision (LC)?

SUSY: THE FUTURE?



Fittino results (thanks to P. Bechtle) for SM+mSUGRA fit to measured observables.

Chi2 = 20.6 at 23 d.o.f

Parameter	Value and Uncertainty
$\tan\beta$	13.2 ± 7.2
M_{12}	331.5 ± 86.6
M_0	$76.2^{+79.8}_{-29.2}$
A_0	383.1 ± 647.0
α_s	0.1177 ± 0.0020
α_{em}	127.924 ± 0.014
m_Z	91.1871 ± 0.0020
m_t	172.4 ± 1.1
G_F	$1.16637 \cdot 10^{-5} \pm 1 \cdot 10^{-10}$

OTHER MODELS

SUSY not only solution to SM problems! Also other models introduce some necessary new particles to achieve goals.

Requests:

- electrically neutral
- heavy to participate in gravitation
- stable

➔ Weakly interacting massive particles (WIMPs) with masses 100 GeV – 1 TeV to satisfy requirements (mainly explain DM density via correct annihilation cross section).

Grand unified theories

Lepto-quarks

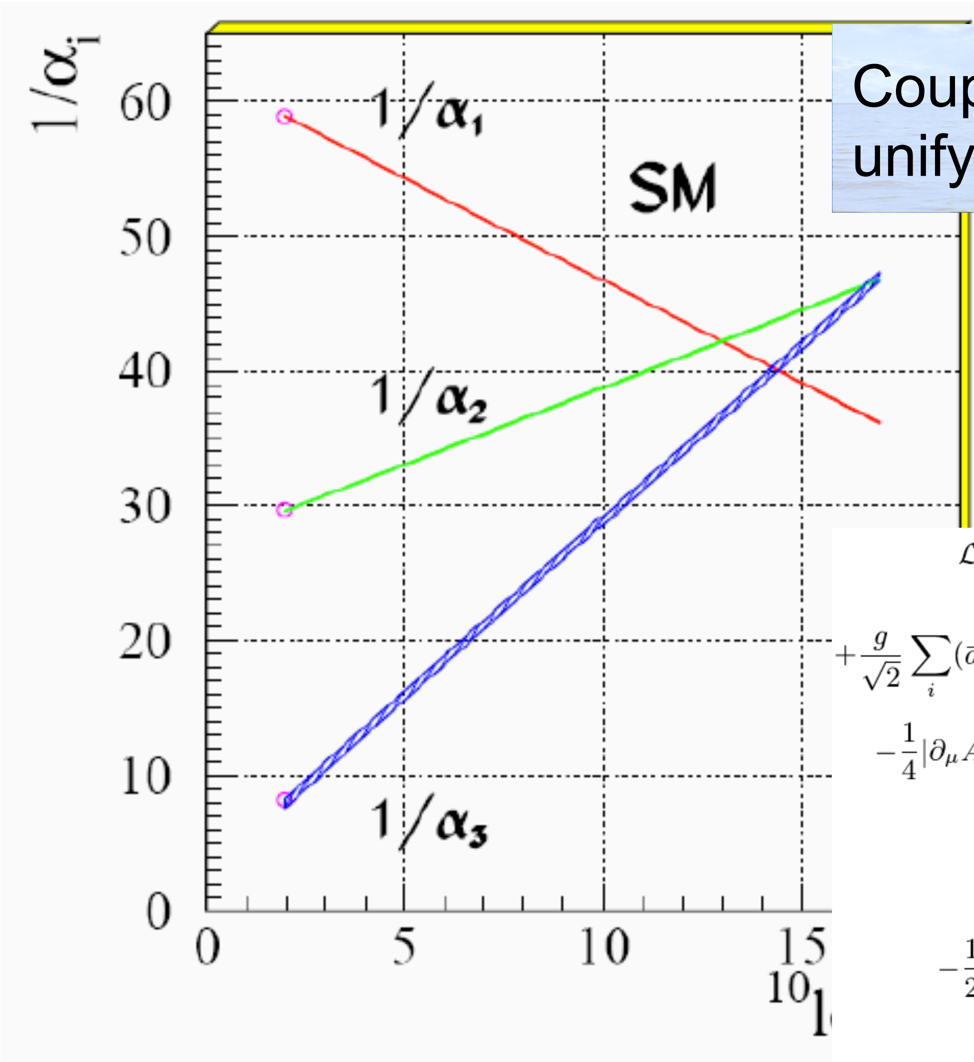
Heavy gauge bosons Z’,W’ etc.

technicolor

You name it!

New extra dimensions
- ADD / LED
- RS / WED
- UED

GRAND UNIFIED THEORIES (GUTs)



Couplings "almost" unify at high scales

SM "almost" simple and beautiful!

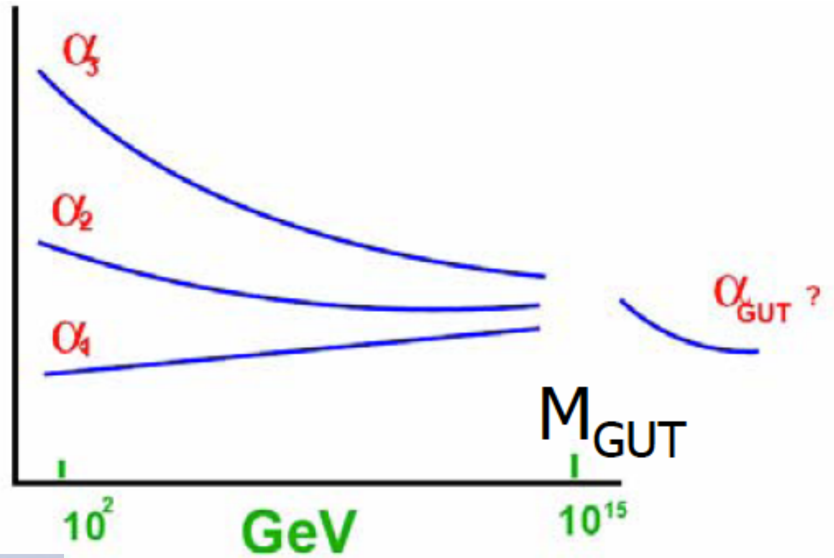
$$
\begin{aligned}
\mathcal{L}_{GWS} = & \sum_f (\bar{\Psi}_f(i\gamma^\mu \partial\mu - m_f)\Psi_f - eQ_f\bar{\Psi}_f\gamma^\mu\Psi_f A_\mu) + \\
& + \frac{g}{\sqrt{2}}\sum_i (\bar{a}^i_L\gamma^\mu b^i_L W^+_\mu + \bar{b}^i_L\gamma^\mu a^i_L W^-_\mu) + \frac{g}{2c_w}\sum_f \bar{\Psi}_f\gamma^\mu(I^3_f - 2s^2_w Q_f - I^3_f\gamma_5)\Psi_f Z_\mu + \\
& -\frac{1}{4}|\partial_\mu A_\nu - \partial_\nu A_\mu - ie(W^-_\mu W^+_\nu - W^+_\mu W^-_\nu)|^2 - \frac{1}{2}|\partial_\mu W^+_\nu - \partial_\nu W^+_\mu + \\
& -ie(W^+_\mu A_\nu - W^+_\nu A_\mu) + ig' c_w(W^+_\mu Z_\nu - W^+_\nu Z_\mu|^2 + \\
& -\frac{1}{4}|\partial_\mu Z_\nu - \partial_\nu Z_\mu + ig' c_w(W^-_\mu W^+_\nu - W^+_\mu W^-_\nu)|^2 + \\
& -\frac{1}{2}M^2_\eta\eta^2 - \frac{gM^2_\eta}{8M_W}\eta^3 - \frac{g'^2 M^2_\eta}{32M_W}\eta^4 + |M_W W^+_\mu + \frac{g}{2}\eta W^+_\mu|^2 + \\
& +\frac{1}{2}|\partial_\mu\eta + iM_Z Z_\mu + \frac{ig}{2c_w}\eta Z_\mu|^2 - \sum_f \frac{g}{2}\frac{m_f}{M_W}\bar{\Psi}_f\Psi_f\eta
\end{aligned}
$$

GRAND UNIFIED THEORIES (GUTs)

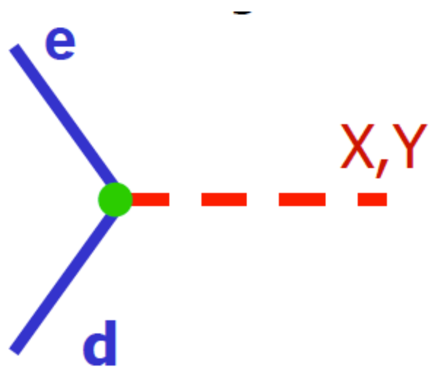
Assumption:
SM SU(3)×SU(2)×U(1) embedded in larger symmetry, e.g.

$$SU(5) \supset SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$$

Spontaneous breaking of GUT symmetry G_{GUT} at high scale!



- ➔ Existence of leptoquarks!
- ➔ Explanation of electric charge: sum of charges in multiplet 0!
- ➔ Prediction for weak mixing angle.
- ➔ Proton should decay!
- ➔ complex models: unification!



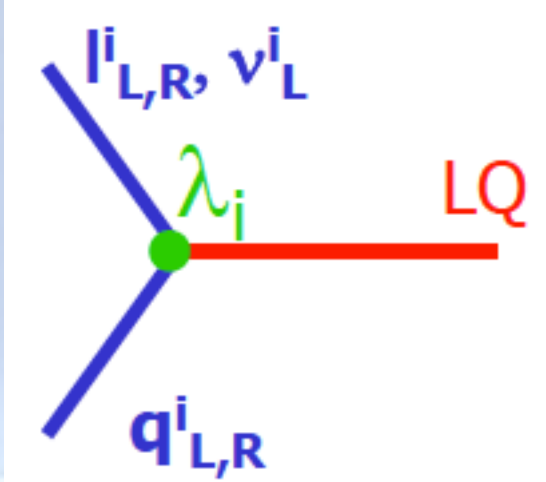
$$\begin{pmatrix} \bar{d}_r \\ \bar{d}_b \\ \bar{d}_g \\ e^- \\ \nu_e \end{pmatrix}$$

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \subset SU(5) \subset SO(10) \subset E(6)$$

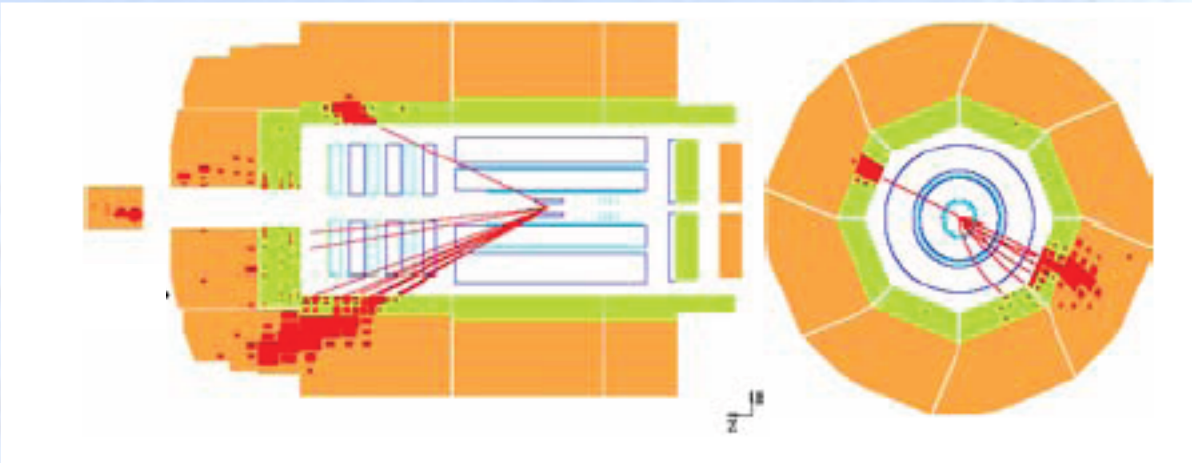
LEPTOQUARKS (AT HERA)

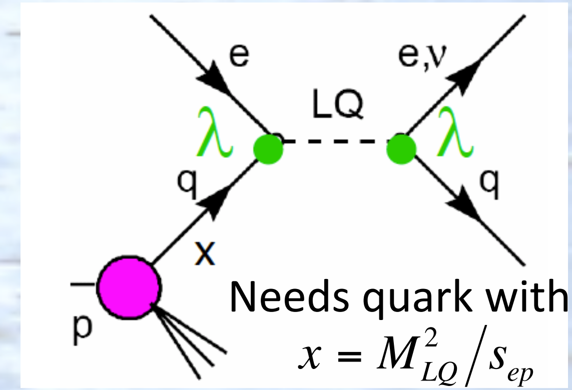
In GUT-inspired models: (always) lepto-quarks – bosons with L,B≠0.

At colliders: test of (general) models with certain assumptions
e.g. BRW model (renormalisable, LQ-coupling invariant under SU(3)×SU(2)×U(1)…)



Searches for LQ: resonant production @HERA:



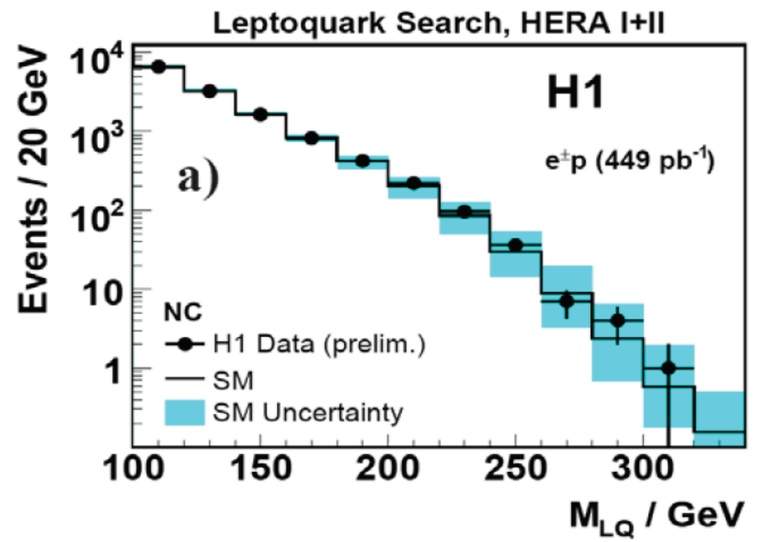


Signature: high-p_T jets with and e/$E_{T,miss}$. Indistinguishable from NC/CC!!

LEPTOQUARKS AT HERA

… but different kinematics
→ optimise selection.

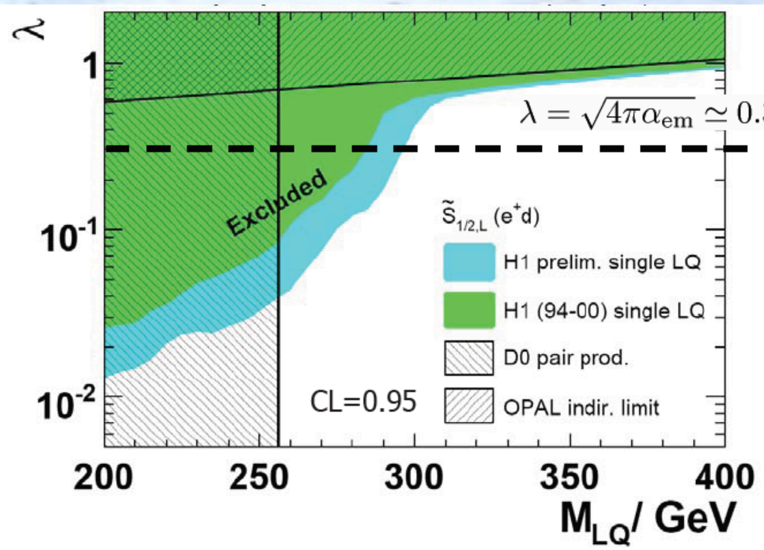
Search for LQ in invariant-mass spectrum of jet and e/$E_{T,Miss}$.



Unfortunately no signal
➔ for each mass hypothesis: exclusion limit for coupling λ!

For M_{LQ} < 320 GeV in s channel: strong limits for large q(x) because

$$\sigma_{prod} \propto \lambda^2 q(x = M_{LQ}^2 / s_{ep})$$

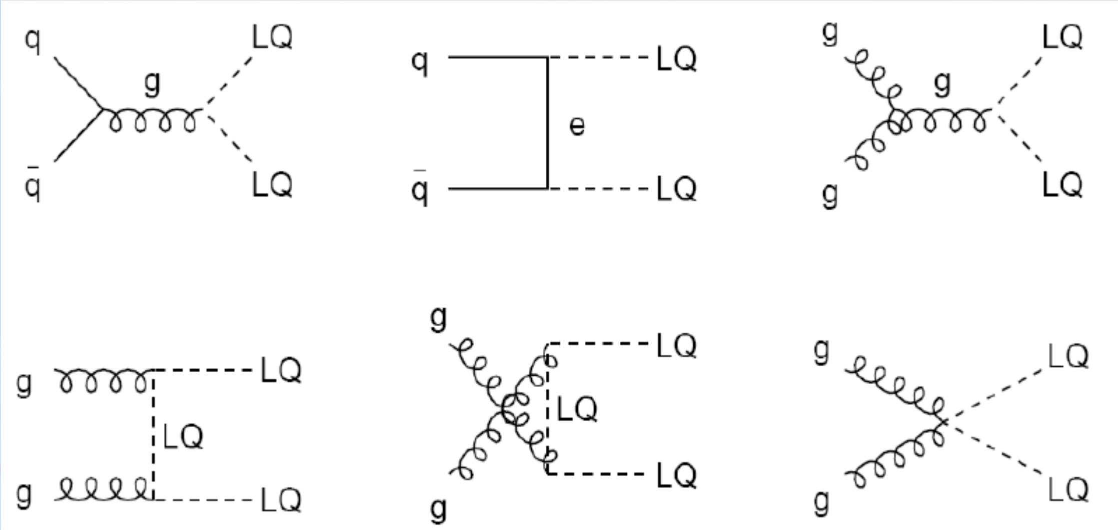


Higher masses: little sensitivity in t channel.

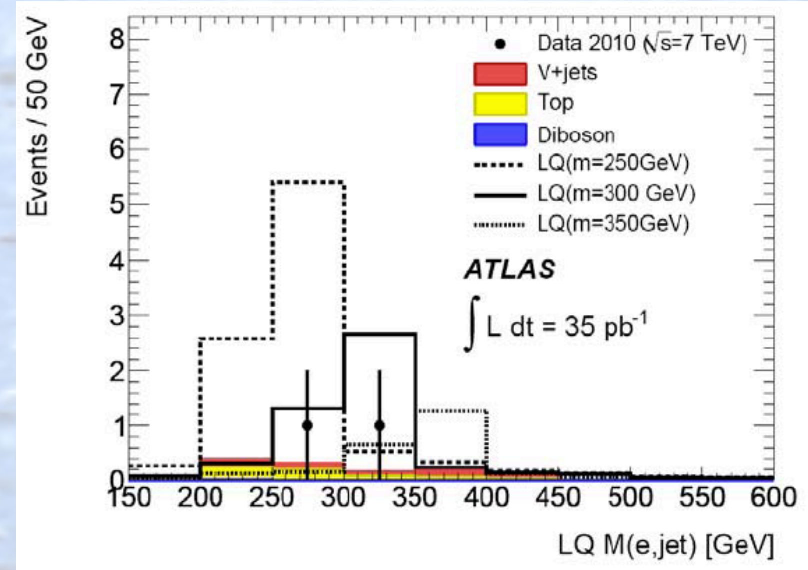
LEPTOQUARKS IN PP(BAR)

At Tevatron / LHC:
Search for 2j+2l
(note: σ independent of λ because of gauge couplings to gluons)

Tevatron: no indications, limits at about 270 GeV



LHC: similar to Tevatron!
Issue: background suppresion:
- QCD: require two high-p_T leptons!
- Drell-Yan: require high M_{ll} and M_{lq}!
- tt production: require low $E_{T,miss}$!



Simulations: clear resonance peaks visible. Limit: 400 GeV!

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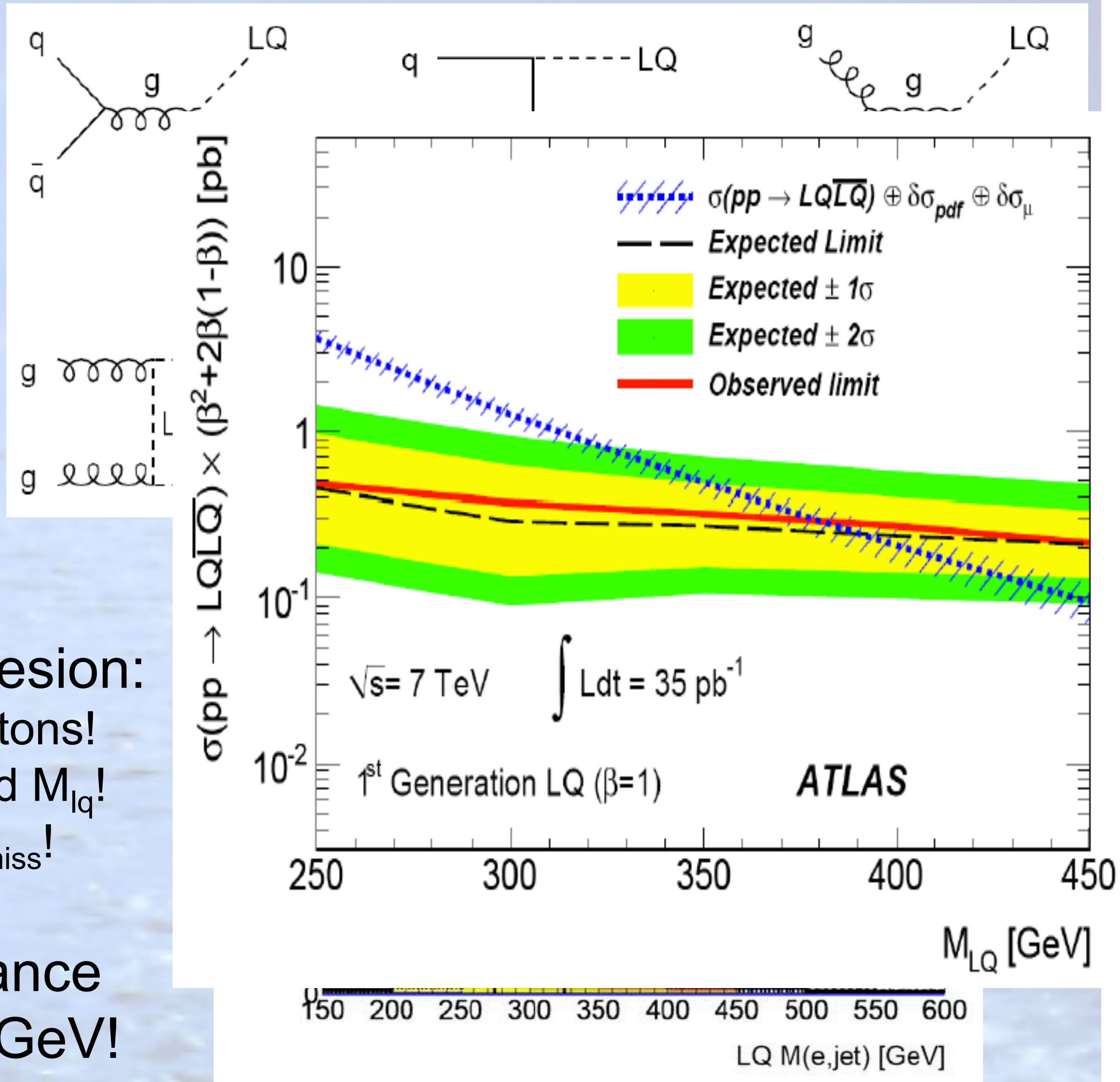


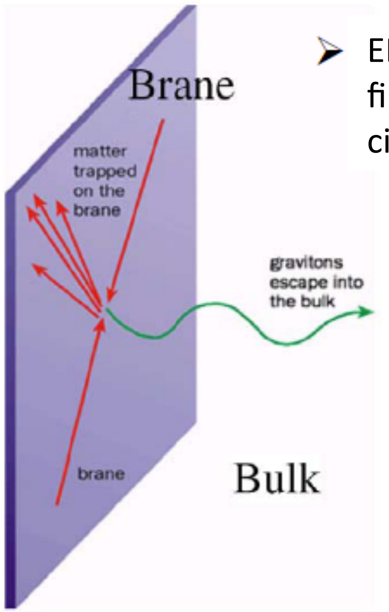
EXTRA DIMENSIONS

Remember hierarchy problem:

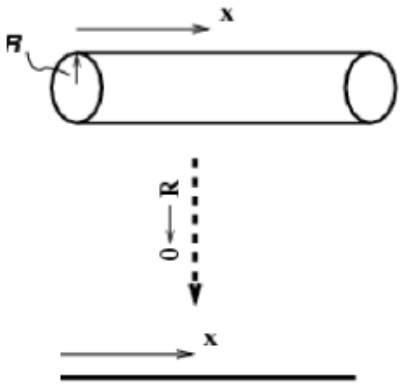
$$M_{Pl} = \sqrt{\frac{\hbar c}{G_N}} \sim 1.2 \cdot 10^{19}\ \text{GeV} \ >> M_{EW}$$

Or: why graviation so weak?

Consequence: m_H unstable!



- ED are assumed to be finite – compactified on circle or n-dim torus.



Arkani-Hamed, Dimopoulos, Dvali (ADD, 98): 4+n dimensions !!!

- n additional dimensions in which (only) gravitation is felt – gravitation weak because it is dilute!
- M_{Pl} seems large only in 4D; real fundamental scale M_D smaller, gravitation in 4+n stronger!

➔ Hierarchy problem solved if M_D ~ 1TeV

Without proof:

With M_D ~ 1 TeV:

$$M_{Pl}^2 = 8\pi R^n M_D^{n+2}$$

n=1	R ~ 10^{12} m
n=2	R ~ 0.4 mm
n=3	R ~ 1 nm
n=4	R ~ 1 fm

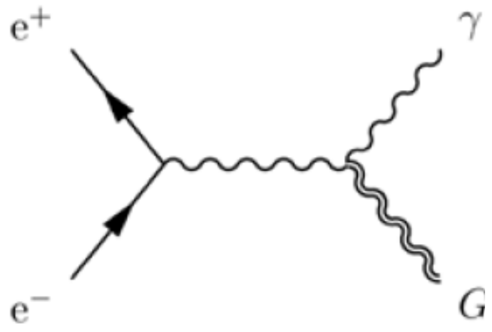
Change of law of gravity: n=1 excluded!

ED as solution? Now question: size of M_D!

SEARCH FOR EXTRA DIMENSIONS

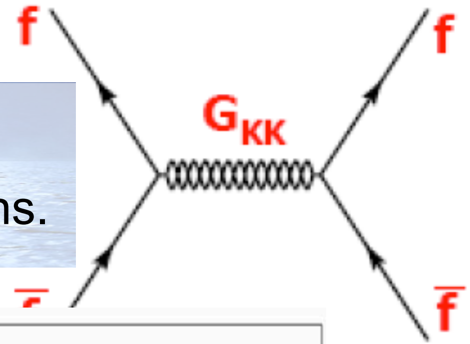
ED curled up (compactified) → gravitons behave like particle in box → equidistant mass states: Kaluza-Klein towers!

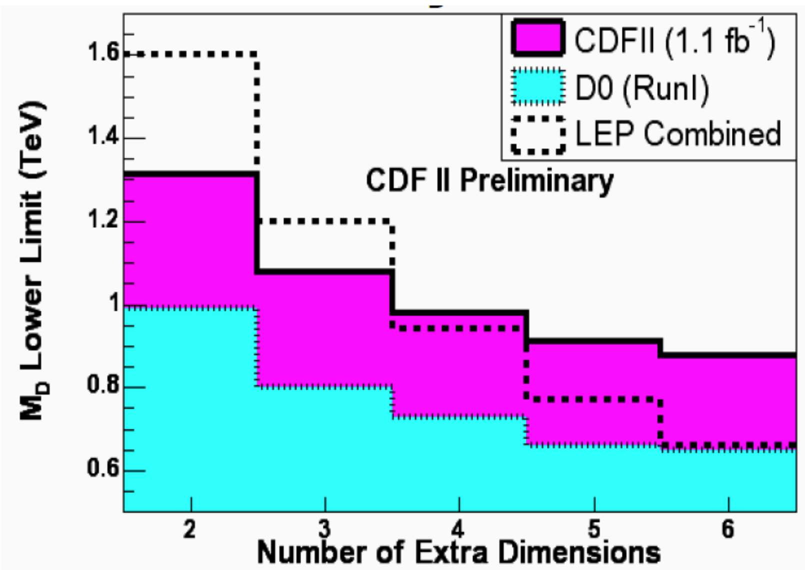
Large extra dimensions: ΔM small → continuum of states!

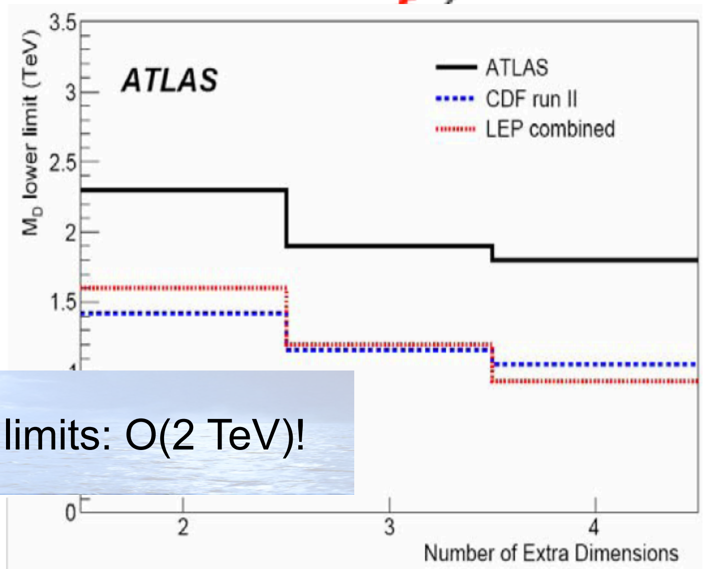


Direct production: G couples weakly → ET,Miss, mono-photons, monojets

Virtual KK exchange → modification of Xsections.







Mass limits: O(2 TeV)!

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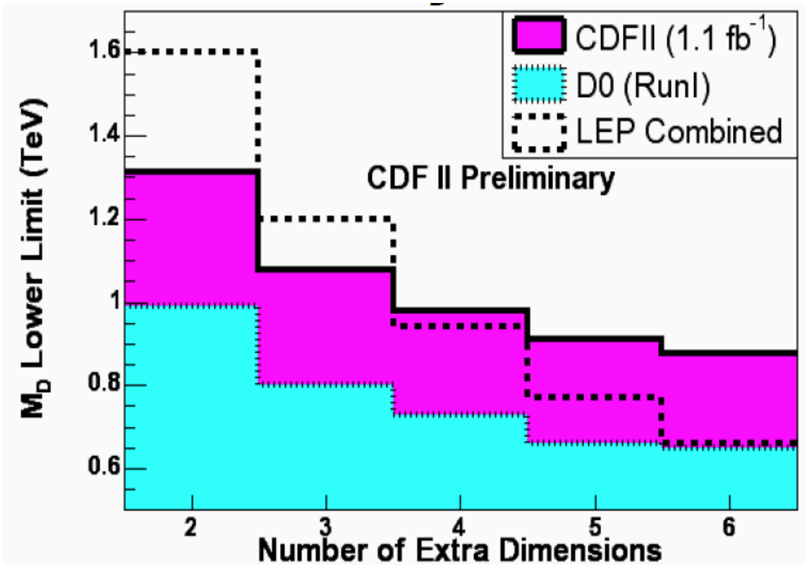
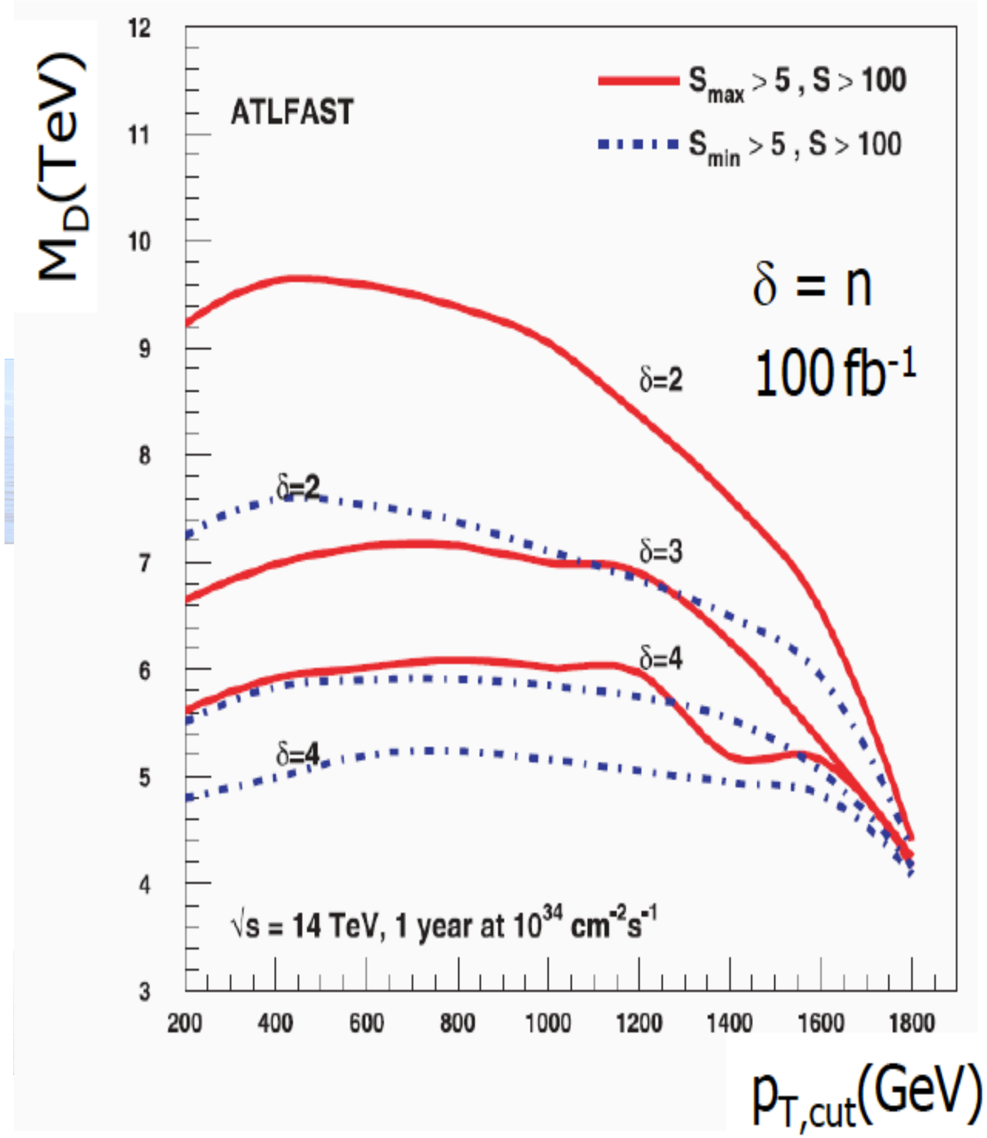
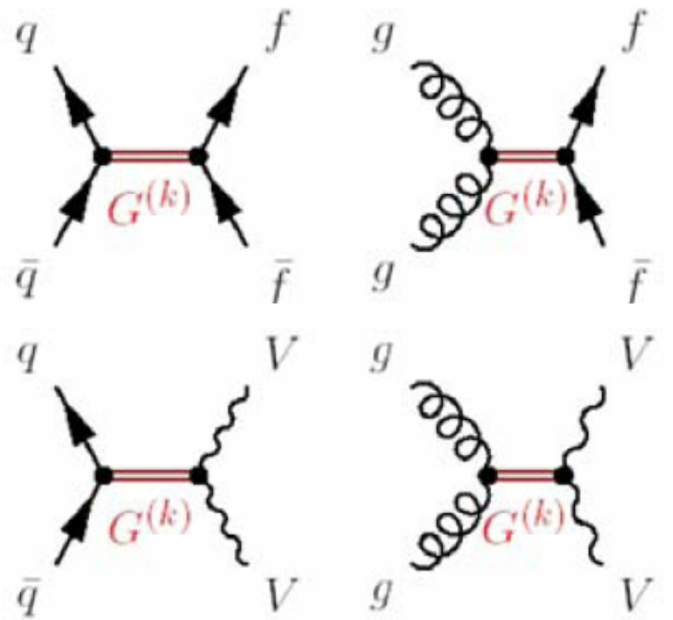


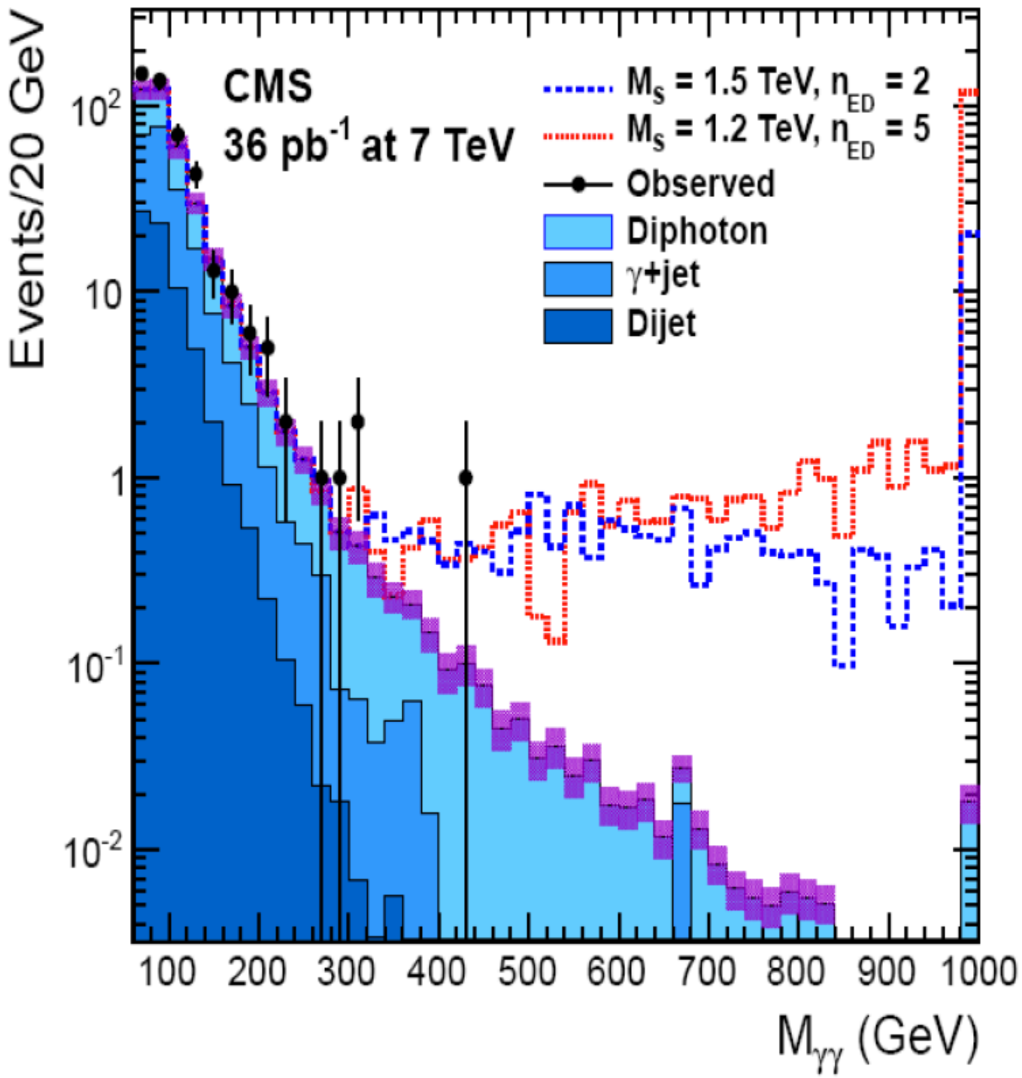


SEARCH FOR EXTRA DIMENSIONS

ED searches with virtual gravitons: Deviation from SM expectation?



So far nothing observed
➔ limits!



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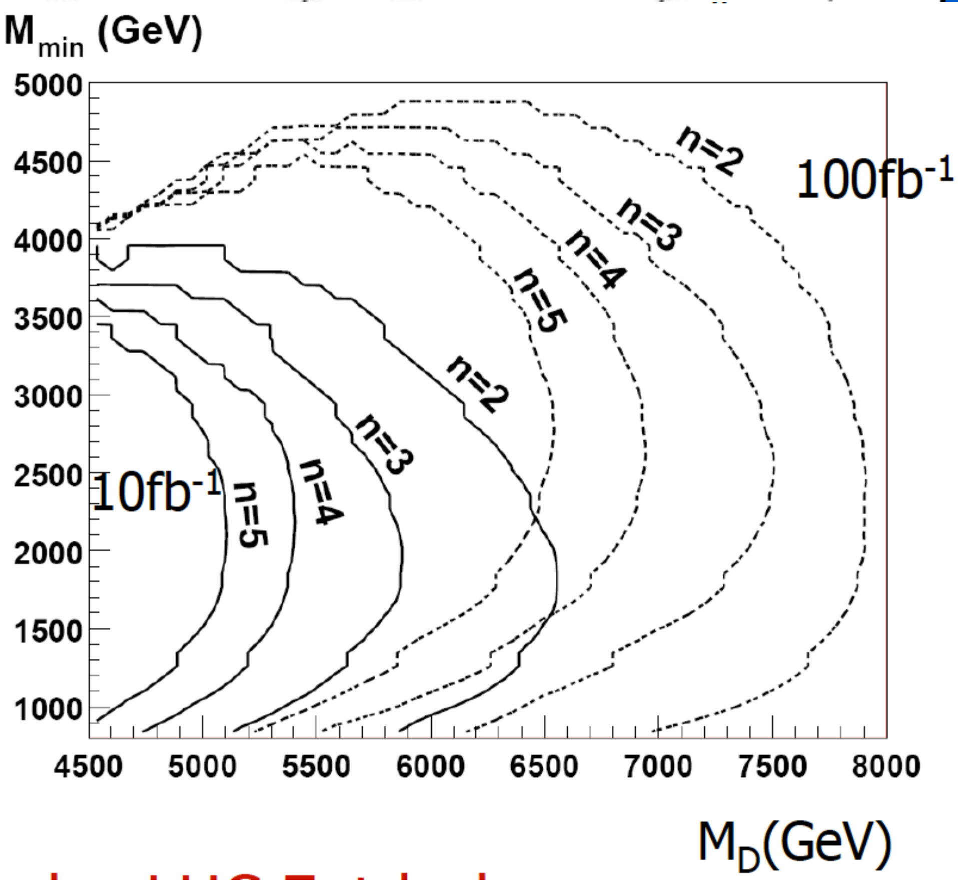
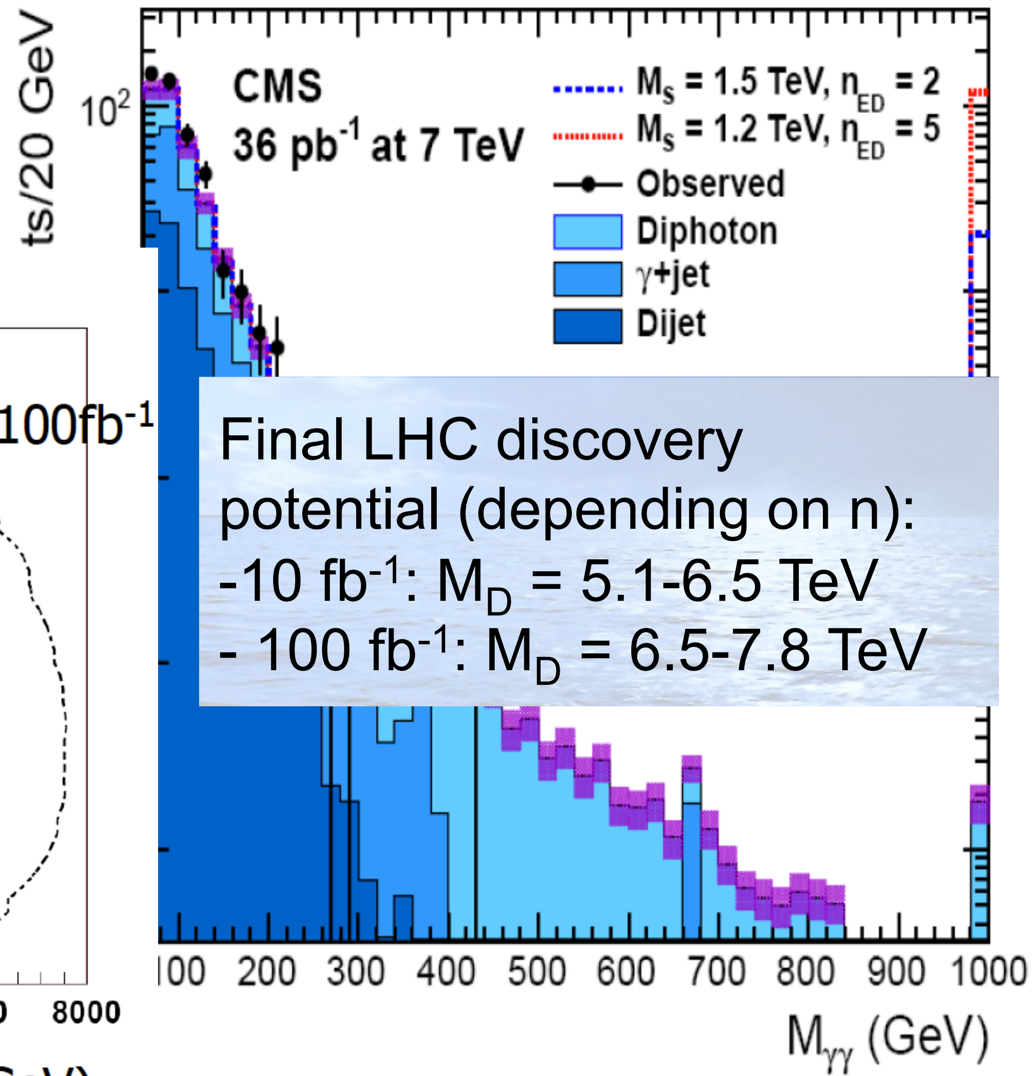




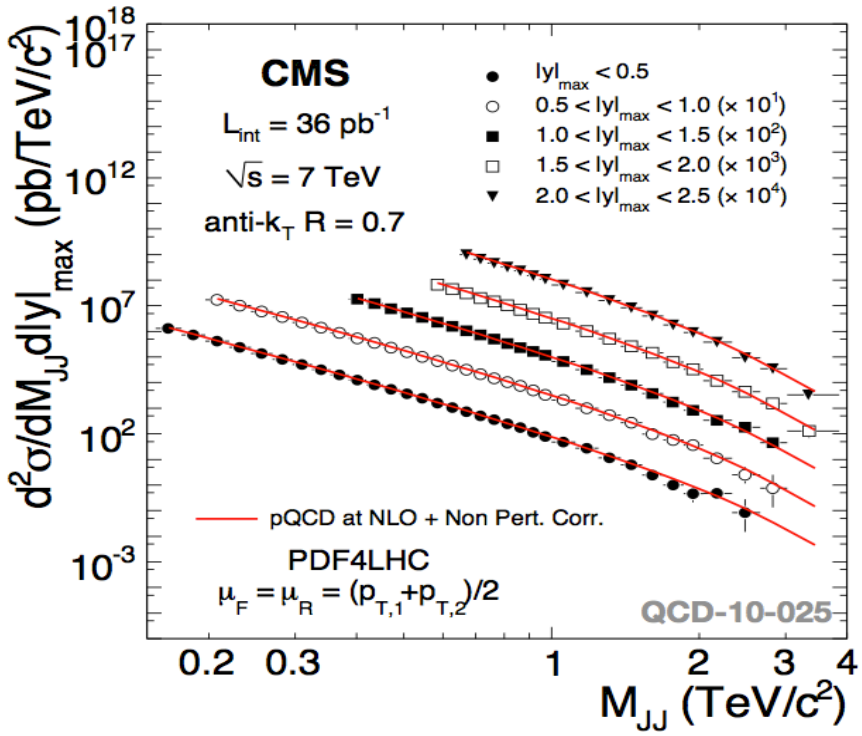
Final LHC discovery potential (depending on n):

- $10\ fb^{-1}$: M_D = 5.1-6.5 TeV
- $100\ fb^{-1}$: M_D = 6.5-7.8 TeV

Z', NEW PHYSICS IN DIJETS

Remember: Dijet spectra:
Excellent description by NLO pQCD!!

Many new physics models decaying to a pair of jets
Example: Z'→qq (GUT-like models)



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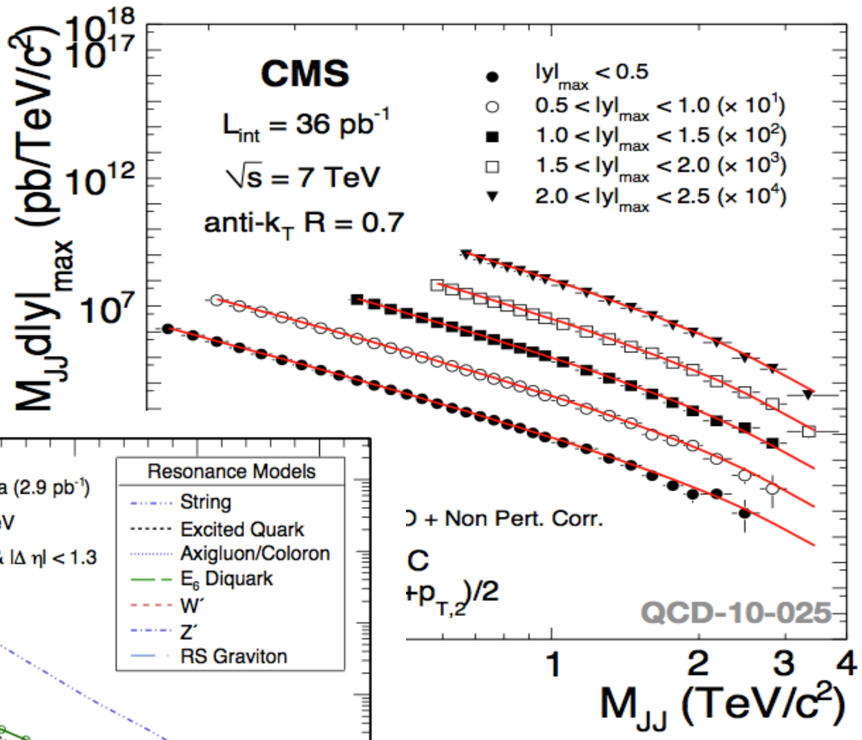
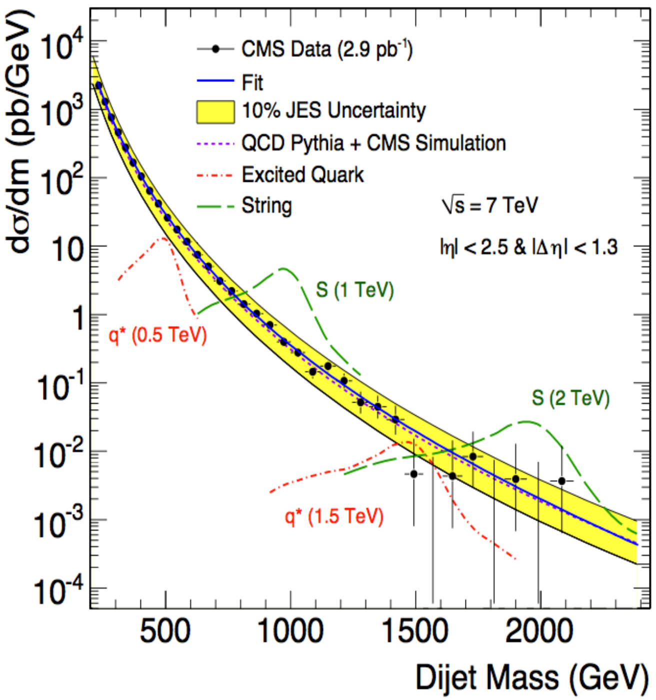
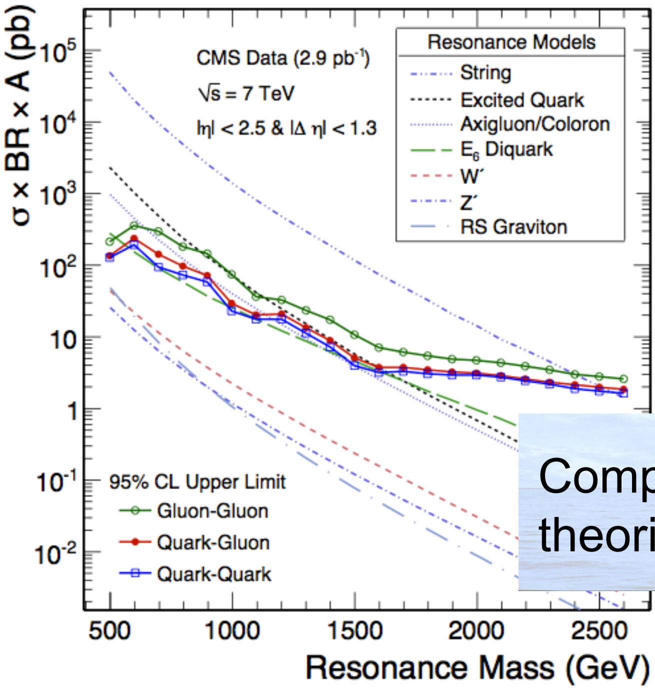
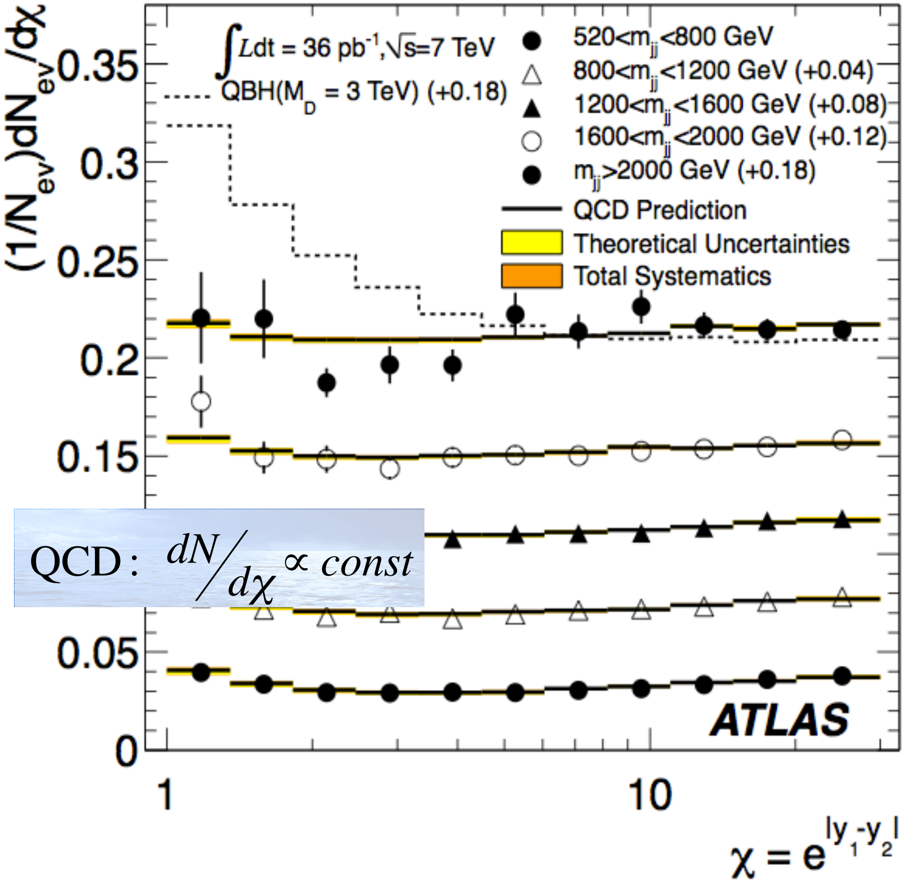






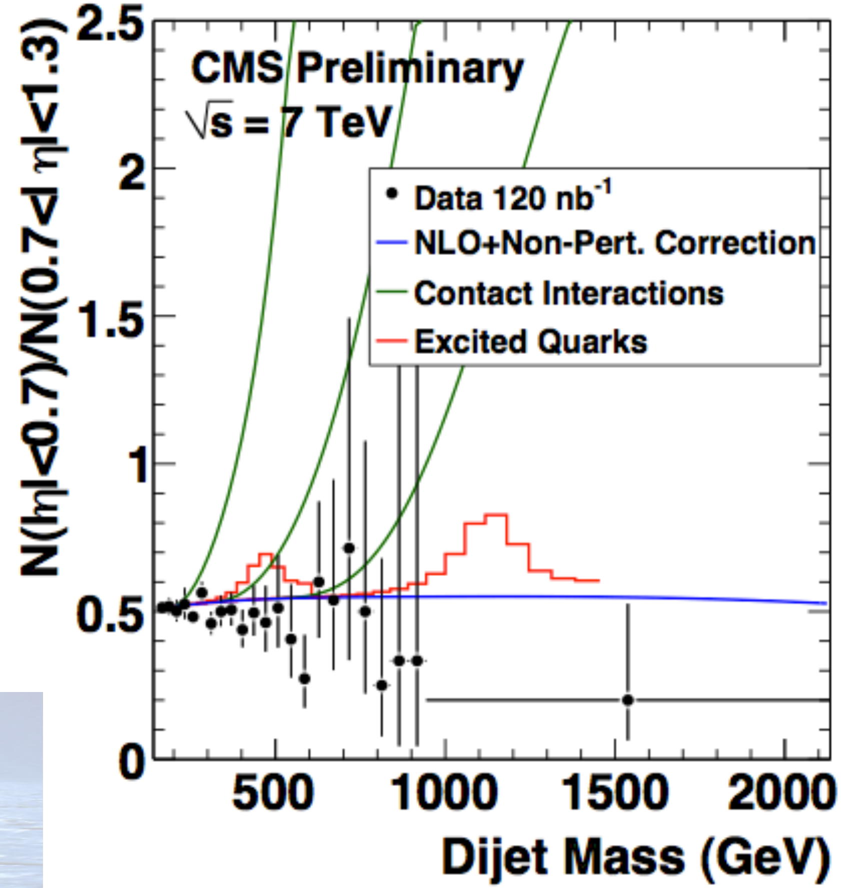
Comparison of data and theories / models → limits?

Z', NEW PHYSICS IN DIJETS



$$\text{QCD}: \ dN/d\chi \propto const$$

Dijet centrality ratio: ratio of dijets in central to dijets in non-central region → Cancellation of uncertainties!!!

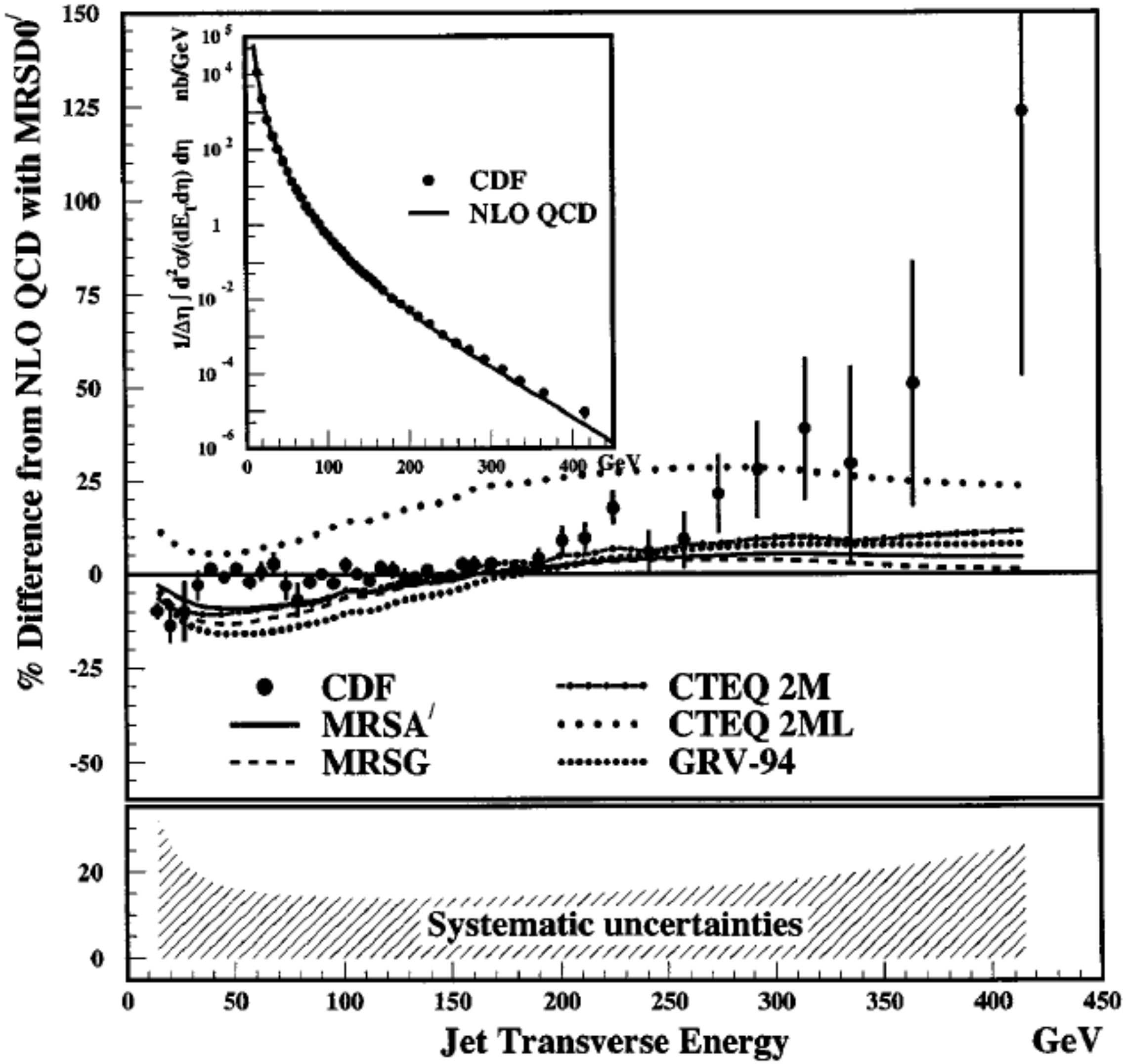


- New heavy physics mainly central (χ=1).
- Complementarity: χ sensitive to spin, centrality ratio to mass

Z', NEW PHYSICS IN DIJETS

Model and Analysis Strategy	95% C.L. Limits (TeV) Expected	Observed
Excited Quark q^*		
Resonance in m_{jj}	2.07	2.15
$F_\chi(m_{jj})$	**2.12**	**2.64**
Randall-Meade Quantum Black Hole for $n = 6$		
Resonance in m_{jj}	**3.64**	**3.67**
$F_\chi(m_{jj})$	3.49	3.78
θ_{np} Parameter for $m_{jj} > 2$ TeV	3.37	3.69
11-bin χ Distribution for $m_{jj} > 2$ TeV	3.36	3.49
Axigluon		
Resonance in m_{jj}	**2.01**	**2.10**
Contact Interaction Λ		
$F_\chi(m_{jj})$	**5.7**	**9.5**
F_χ for $m_{jj} > 2$ TeV	5.2	6.8
11-bin χ Distribution for $m_{jj} > 2$ TeV	5.4	6.6

WORD OF WARNING

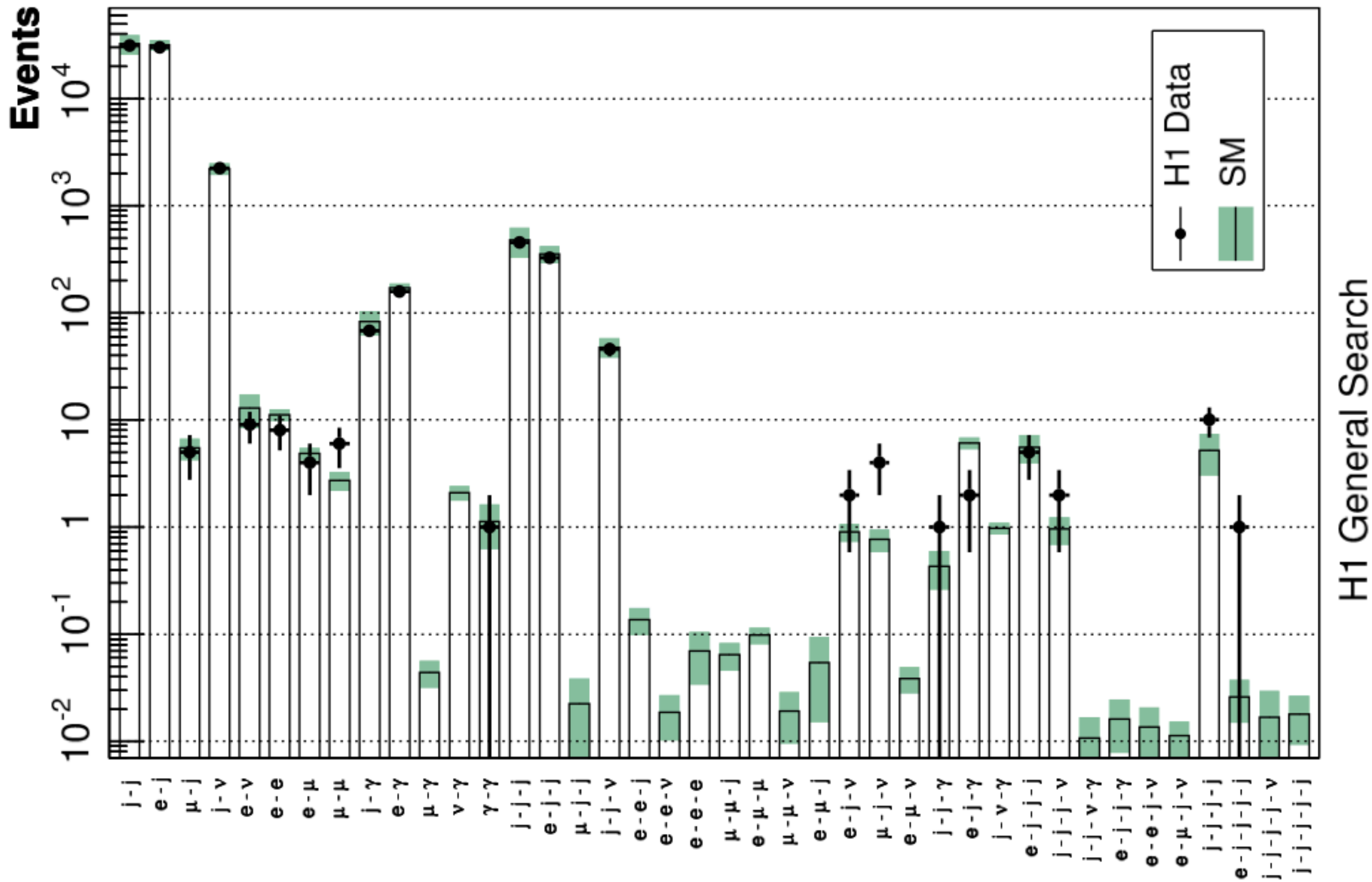


Possible explanations: quark substructure, compositeness, contact interactions, …

Later explained in terms of re-definition of gluon density of the proton.

Don't see new physics where it is not; don't hide new physics in re-parametrisation of old …

MODEL INDEPENDENT SEARCHES



SUMMARY