Implications of the latest experimental results for physics at a future Linear Collider

Georg Weiglein

DESY

Granada, 09 / 2011

- Introduction
- Physics of electroweak symmetry breaking
- New physics addressing the hierarchy problem
- Implications for Linear Collider physics

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LHC results so far, executive summary:

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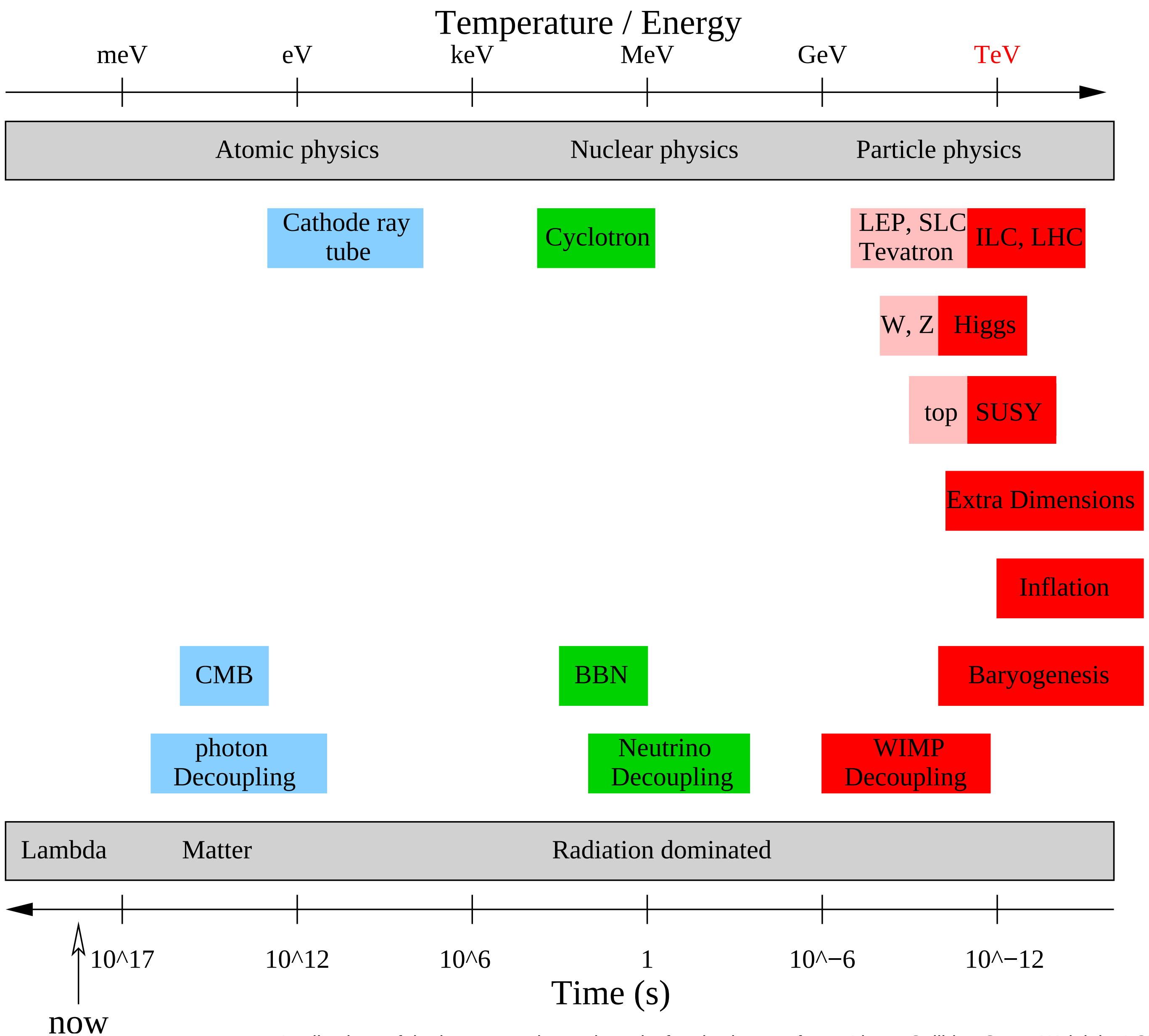
Latest experimental results:

There will be no discussion of LC implications of $v > c$ neutrinos in this talk . . .

LHC physics: exploring the Terascale

$$1\ \text{TeV} \approx 1000 \times m_{\text{proton}} \Leftrightarrow 2 \times 10^{-19}\ \text{m}$$



What can we learn from exploring the new territory of TeV-scale physics?

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- How do elementary particles obtain the property of mass: what is the mechanism of electroweak symmetry breaking? Is there a Higgs boson (or more than one)?
- Do all the forces of nature arise from a single fundamental interaction?
- Are there more than three dimensions of space?
- Are space and time embedded into a "superspace"?
- What is dark matter? Can it be produced in the laboratory?
- Are there new sources of $\mathcal{CP}$-violation?
Can they explain the asymmetry between matter and anti-matter in the Universe?
- ...

Higgs: last missing ingredient of the Standard Model

But: *the Standard Model cannot be the ultimate theory*

- The Standard Model does not include gravity

  $\Rightarrow$ breaks down at the latest at $M_{\text{Planck}} \approx 10^{19}$ GeV

- "Hierarchy problem": $M_{\text{Planck}}/M_{\text{weak}} \approx 10^{17}$

  How can two so different scales coexist in nature?

  Via quantum effects: physics at M_{weak} is affected by physics at M_{Planck}

  $\Rightarrow$ Instability of M_{weak}

  $\Rightarrow$ Would expect that all physics is driven up to the Planck scale

- Nature has found a way to prevent this
  The Standard Model provides no explanation

Hierarchy problem: how can the Planck scale be so much larger than the weak scale?

$\Rightarrow$ Expect new physics to stabilise the hierarchy

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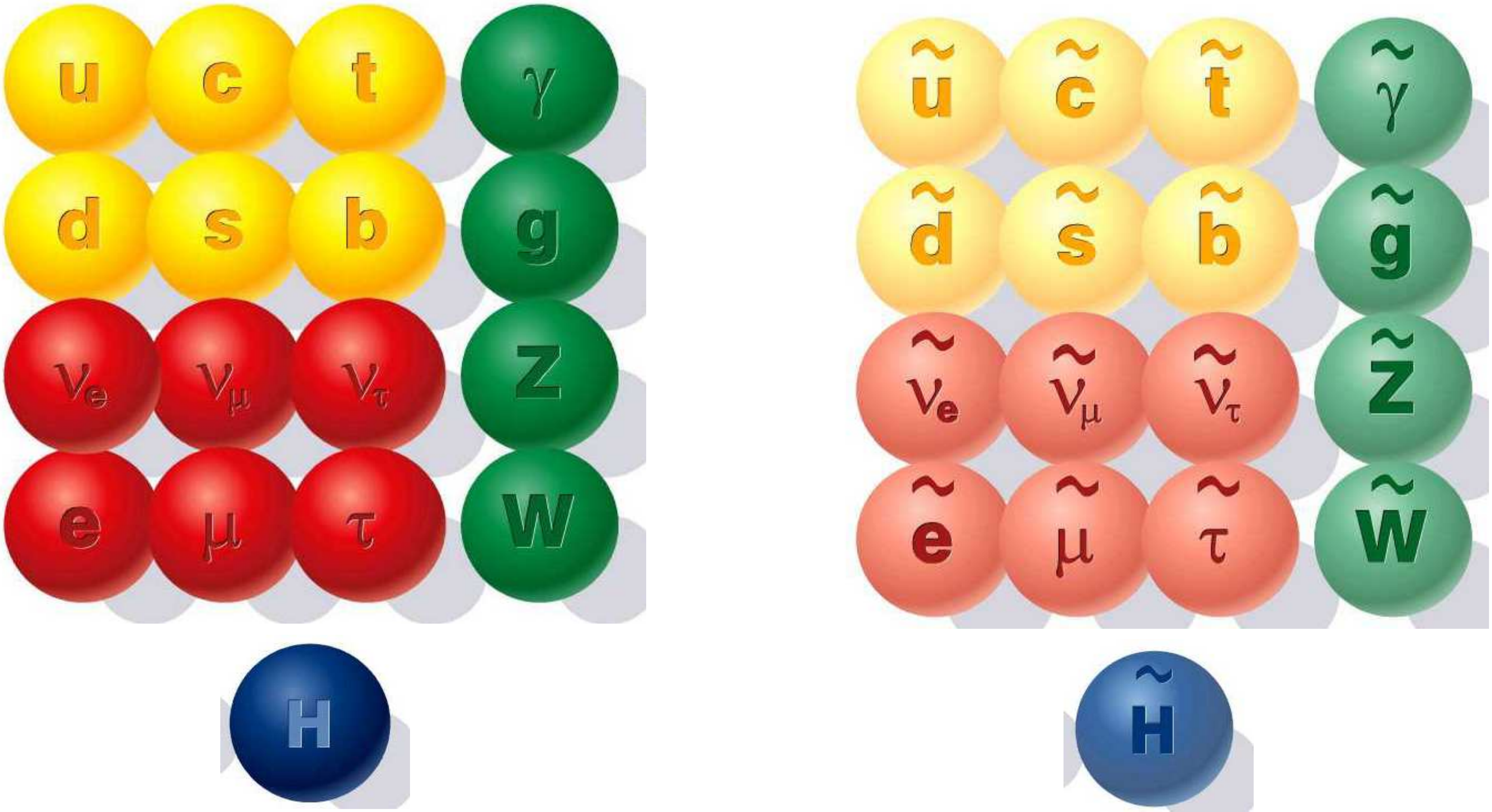
Extra dimensions of space:

Fundamental Planck scale is $\sim \mathrm{TeV}$ (large extra dimensions),

hierarchy of scales is related to a “warp factor”
(“Randall–Sundrum” scenarios)

Supersymmetry (SUSY)

Supersymmetry: fermion $\longleftrightarrow$ boson symmetry,
leads to compensation of large quantum corrections



The Minimal Supersymmetric Standard Model (MSSM)

Superpartners for Standard Model particles:

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

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

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

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General parametrisation of possible SUSY-breaking terms
$\Rightarrow$ free parameters, no prediction for SUSY mass scale

Hierarchy problem $\Rightarrow$ expect observable effects at TeV scale

How does SUSY breaking work?

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Strong phenomenological constraints on flavour off-diagonal and $\mathcal{CP}$-violating SUSY-breaking terms

$\Rightarrow$ Good phenomenological description for universal SUSY-breaking terms ($\approx$ diagonal in flavour space)

Simplest ansatz: the Constrained MSSM (CMSSM)

Assume universality at high energy scale ($M_{\rm GUT}$, $M_{\rm Pl}$, ...)
renormalisation group running down to weak scale
require correct value of $M_{\rm Z}$

$\Rightarrow$ CMSSM characterised by

$$m_0^2,\ m_{1/2},\ A_0,\ \tan\beta,\ \mathrm{sign}\,\mu$$

CMSSM has been the "favourite toy" for both theorists and experimentalists so far

CMSSM is in agreement with the experimental constraints from electroweak precision observables (EWPO)
$+$ flavour physics $+$ cold dark matter density $+$ ...

SUSY-breaking scenarios

"Hidden sector": $\longrightarrow$ Visible sector:

SUSY breaking MSSM

"Gravity-mediated": SUGRA
"Gauge-mediated": GMSB
"Anomaly-mediated": AMSB
"Gaugino-mediated"

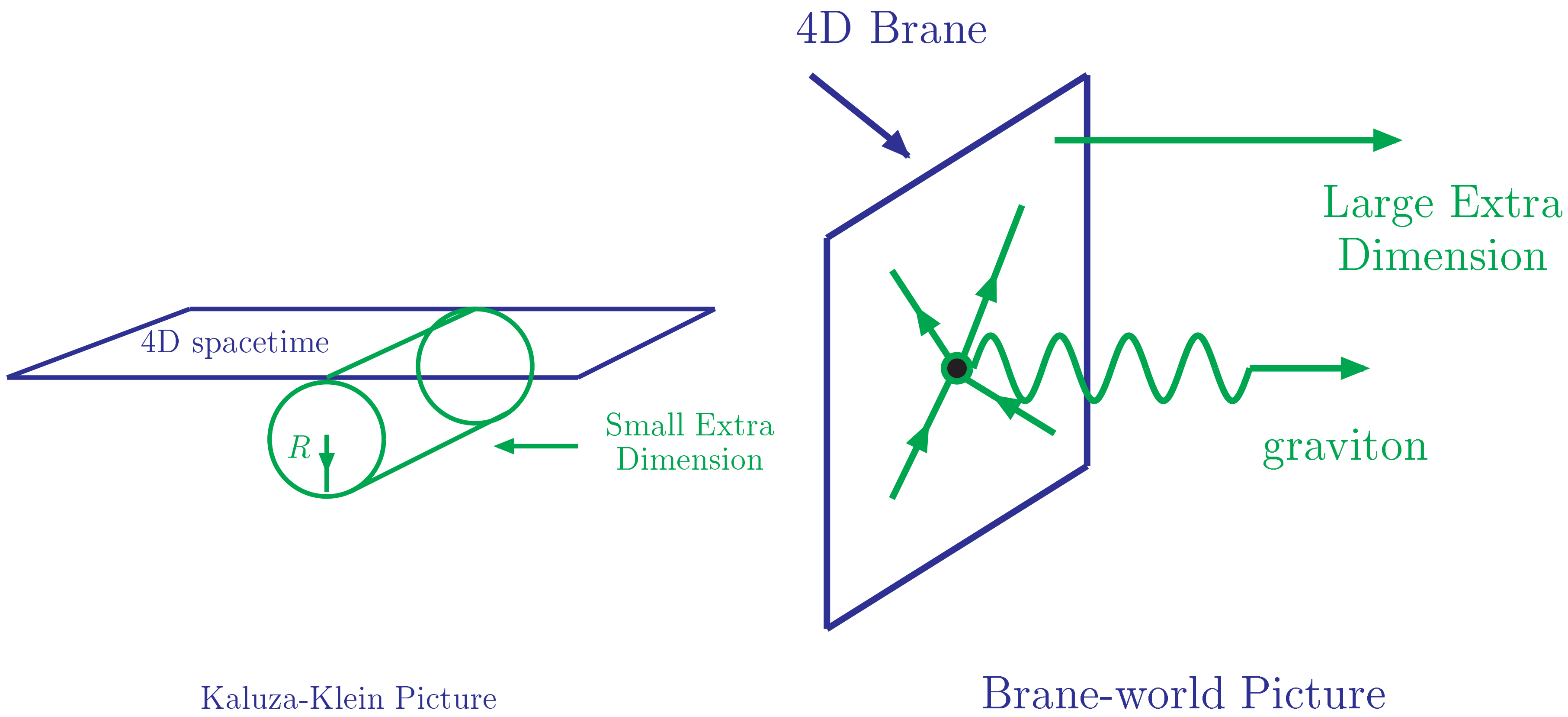
...

SUGRA: mediating interactions are gravitational

GMSB: mediating interactions are ordinary electroweak and QCD gauge interactions

AMSB, Gaugino-mediation: SUSY breaking happens on a different brane in a higher-dimensional theory

Models with extra dimensions of space

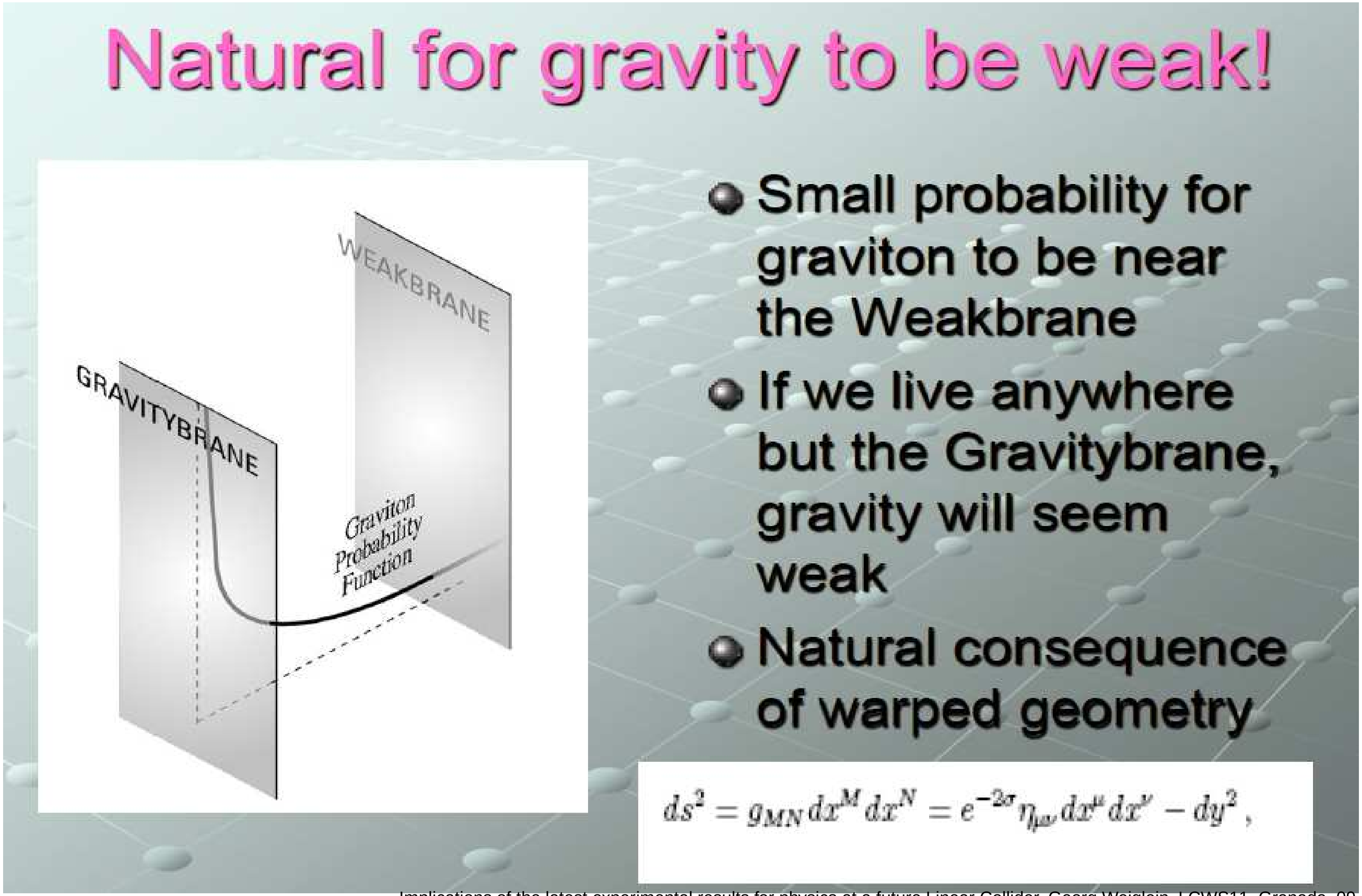


Hierarchy between M_{Planck} and M_{weak} is related to the volume or the geometrical structure of additional dimensions of space

$\Rightarrow$ observable effects at the TeV scale

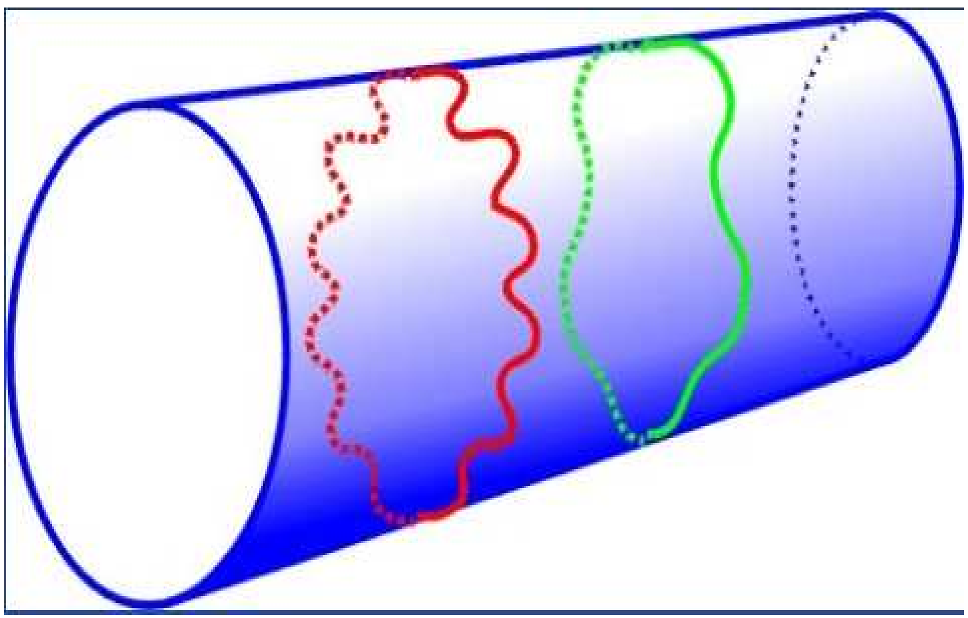
Gravity in a warped spacetime geometry

[*L. Randall, LHC2TSP Workshop ’11*]



Phenomenological consequences of extra dimensions

The wave function of a free particle must be $2\pi R$ periodic



$$e^{ip.x_5} = e^{ip.(x_5+2\pi R)}$$

$$p = \frac{n}{R}$$

$\Rightarrow$ momentum is quantised

$\Rightarrow$ Looks in 4-dim like a series of new, more massive partners associated with each known particle: "Kaluza–Klein tower"

Workshop "Implications of LHC results for TeV-scale physics"

Kick-off meeting:

29/08/2011–02/09/2011, CERN, $\gtrsim 200$ participants

$\Rightarrow$ Discuss impact of experimental results on future strategy for particle physics

Results will be summarised in a document to be submitted as input for the 2012 update of the European Strategy for Particle Physics (in time for “Orsay-type” meeting of strategy update, 09/2012)

Main organisers:

O. Buchmueller, P. De Jong, A. De Roeck, J. Ellis, C. Grojean, S. Heinemeyer, J. Hewett, K. Jakobs, M. Mangano, F. Teubert, G. W.

Workshop "Implications of LHC results for TeV-scale physics"

Three working groups:

- WG1: Signals of electroweak symmetry breaking
  Conv.: *S. Heinemeyer, M. Kado, C. Mariotti, G. W., A. Weiler*

- WG2: Signatures with missing energy
  Conv.: *R. Cavanaugh, J. Hewett, S. Kraml, G. Polesello*

- WG3: Other signatures of possible BSM physics
  Conv.: *C. Grojean, D. Martinez, J. Santiago Perez, P. Savard, S. Worm*

$\Rightarrow$ It is now the right time to join in to this activity!

Physics of electroweak symmetry breaking

What is the mechanism of electroweak symmetry breaking?

- Standard Model (SM), SUSY, . . . :
  Higgs mechanism, elementary scalar particle(s)

- Strong electroweak symmetry breaking:
  a new kind of strong interaction

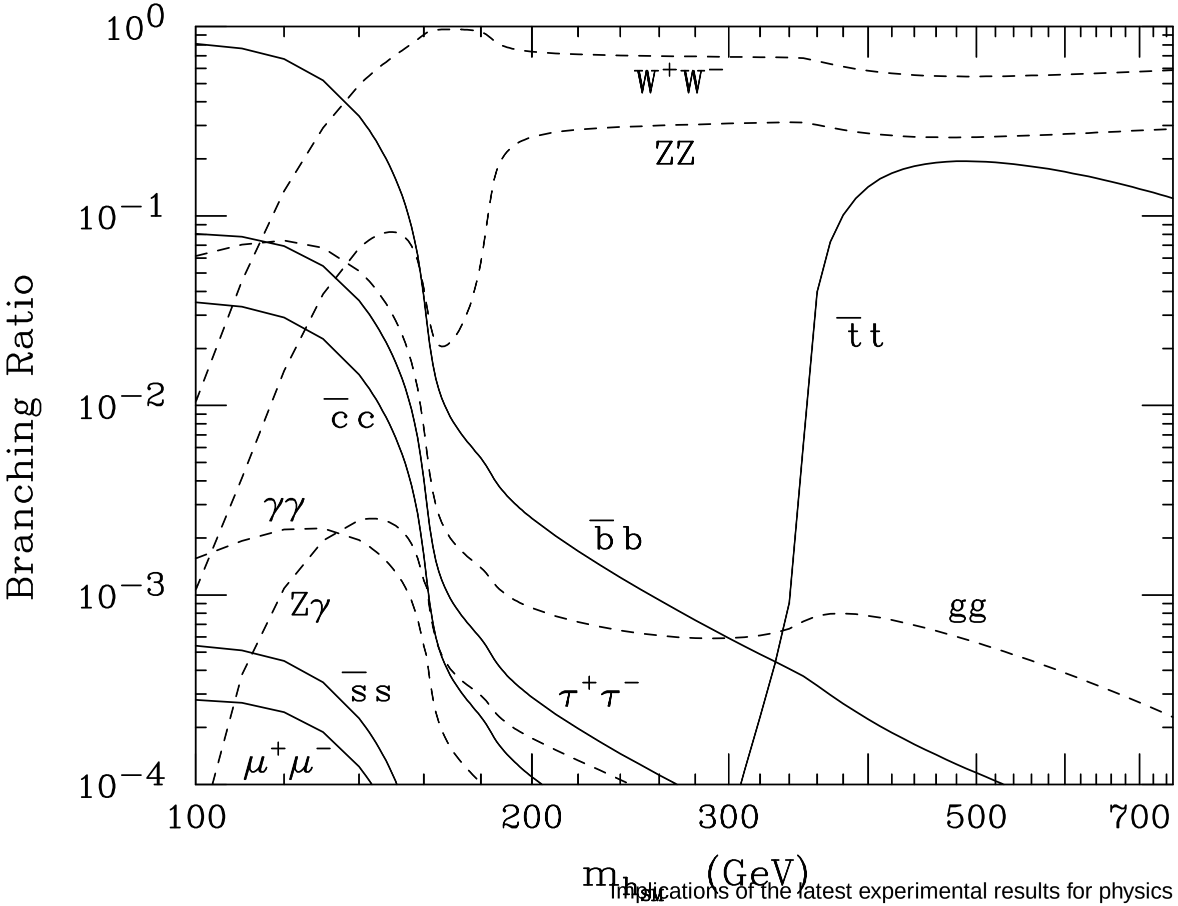
- Higgsless models in extra dimensions: boundary conditions for SM gauge bosons and fermions on Planck and TeV branes in higher-dimensional space

$\Rightarrow$ New phenomena required at the TeV scale

Higgs phenomenology: SM and beyond

Standard Model: a single parameter determines the whole Higgs phenomenology: M_H

Branching ratios of the SM Higgs:



$\Rightarrow$ dominant BRs:

$M_H \lesssim 140$ GeV:

$H \to b\bar{b}$

$M_H \gtrsim 140$ GeV:

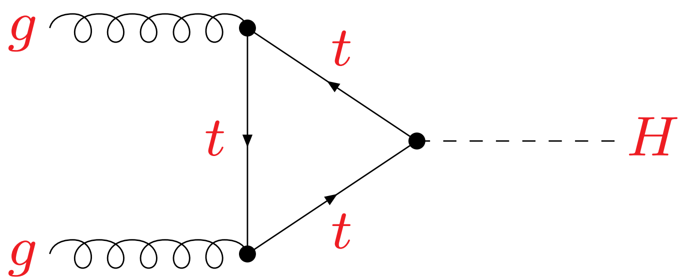
$H \to W^+W^-, ZZ$

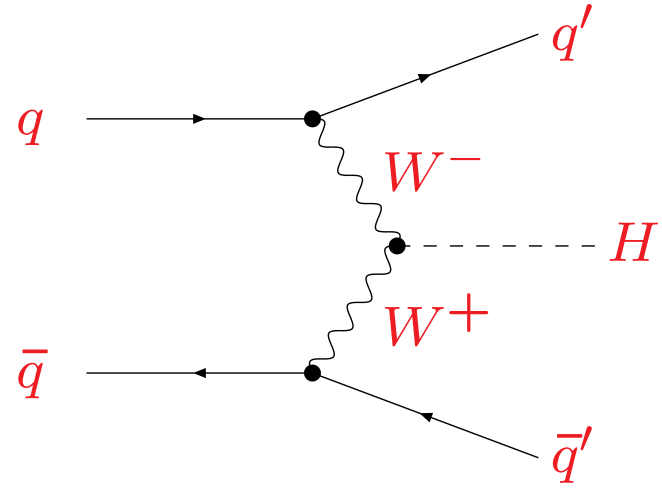
Production of a SM-like Higgs at the LHC

SM Higgs production at the LHC:

Dominant production processes:

gluon fusion: $gg \to H$, weak boson fusion (WBF): $q\bar{q} \to q'\bar{q}'H$

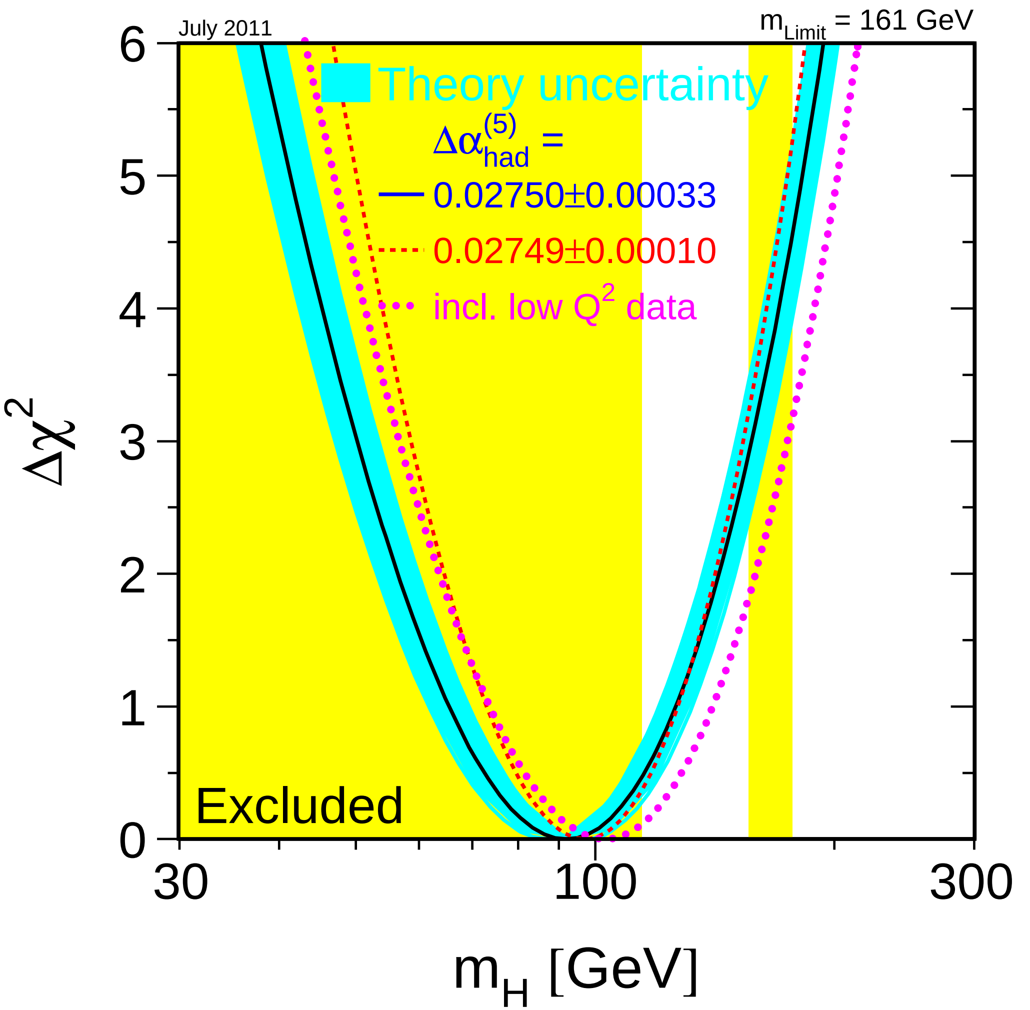




Constraints on the SM Higgs from electroweak precision data

Indirect constraint on $M_{\mathrm{H_{SM}}}$, no direct search limits included in the fit

[*LEPEWWG '11*]



$\Rightarrow$ Preference for a light Higgs, $M_{\mathrm{H_{SM}}} < 161\ \mathrm{GeV}$, 95% C.L.

Higgs physics beyond the SM

In the SM the same Higgs doublet is used “twice” to give masses both to up-type and down-type fermions

$\Rightarrow$ extensions of the Higgs sector having (at least) two doublets are quite “natural”

$\Rightarrow$ Would result in several Higgs states

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Example: SUSY in the “decoupling limit”

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Example: SUSY in the "decoupling limit"

But there is also the possibility that none of the Higgs bosons is SM-like

Higgs physics in Supersymmetry

“Simplest” extension of the minimal Higgs sector:

Minimal Supersymmetric Standard Model (MSSM)

- Two doublets to give masses to up-type and down-type fermions (extra symmetry forbids to use same doublet)
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$\Rightarrow$ Two parameters instead of one: $\tan\beta \equiv \frac{v_u}{v_d}$, M_A (or $M_{\mathrm{H}^\pm}$)

$\Rightarrow$ Upper bound on lightest Higgs mass, M_h (*FeynHiggs*):
[*S. Heinemeyer, W. Hollik, G. W. '99*], [*G. Degrassi, S. Heinemeyer, W. Hollik, P. Slavich, G. W. '02*]

$$M_\mathrm{h} \lesssim 130\,\mathrm{GeV}$$

Very rich phenomenology

BSM $\oplus$ Higgs phenomenology

- Large enhancement / suppression of standard search channels possible
  Example: large enhancement of $H\bar{b}b$ coupling
  $\Rightarrow$ large suppression of BR($h \to \gamma\gamma$), BR($h \to WW^*$), ...
- New channels, different phenomenology:
  - Experimental evidence for dark matter
    $\Rightarrow$ if dark matter particle is lighter than $M_{\mathrm{H}}/2$
    $\Rightarrow$ large branching fraction into invisible particles
    $\Rightarrow$ large suppression of all other BRs
  - Higgs production in decays of BSM particles
  - $h_i \to h_j h_j$ decays
  - Higgs–radion mixing, ...
  - Higgses with nearly degenerate masses: large interference effects, resonance-type behaviour possible

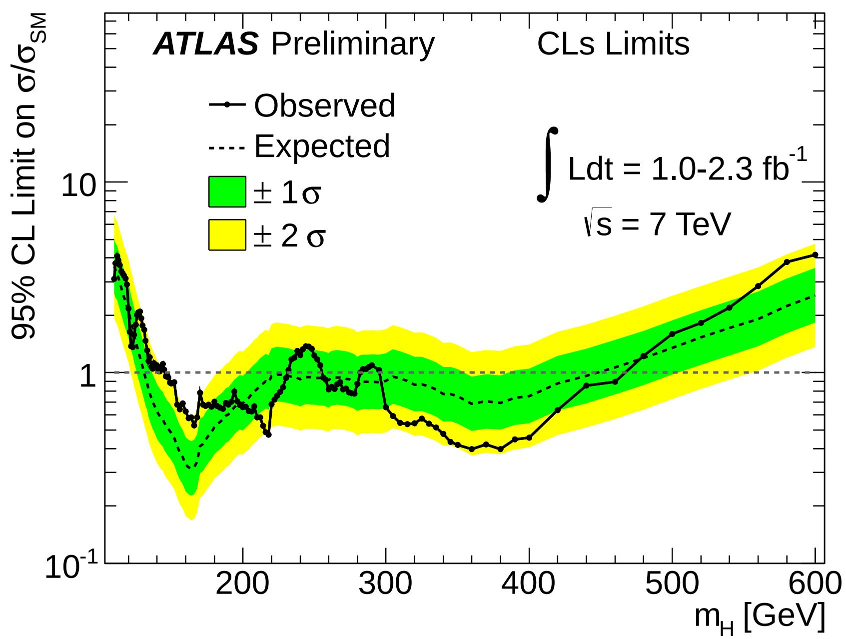
How to infer the underlying physics from the experimental signatures?

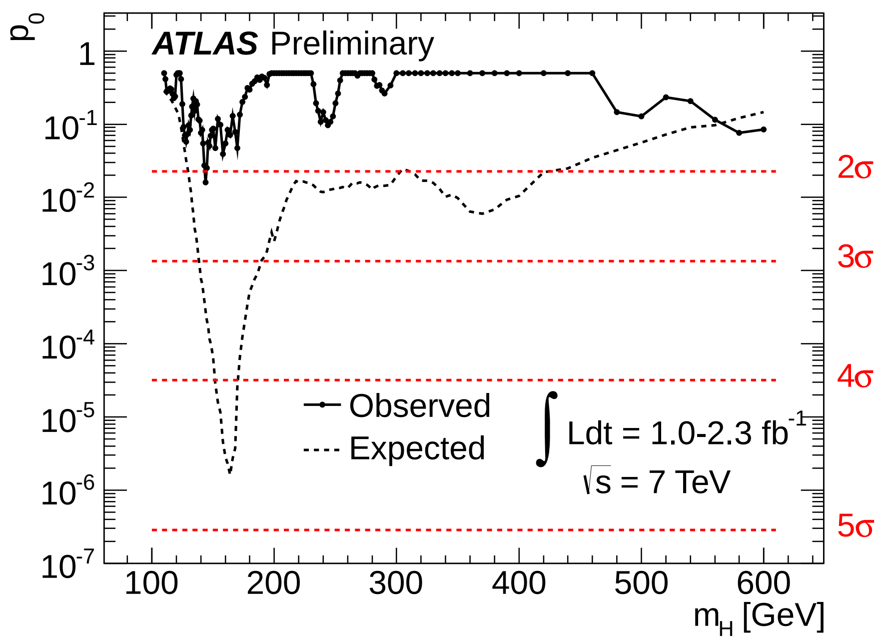
- A Higgs or not a Higgs?
- Fundamental or composite?
- SM, MSSM or beyond?
- Is there other new physics; what is it?
- How does the observed new physics fit into the global picture (ew precision observables, flavour physics, . . .)?
- . . .

$\Rightarrow$ Intense effort will be needed to identify the nature of electroweak symmetry breaking

Higgs searches: what did we learn so far?

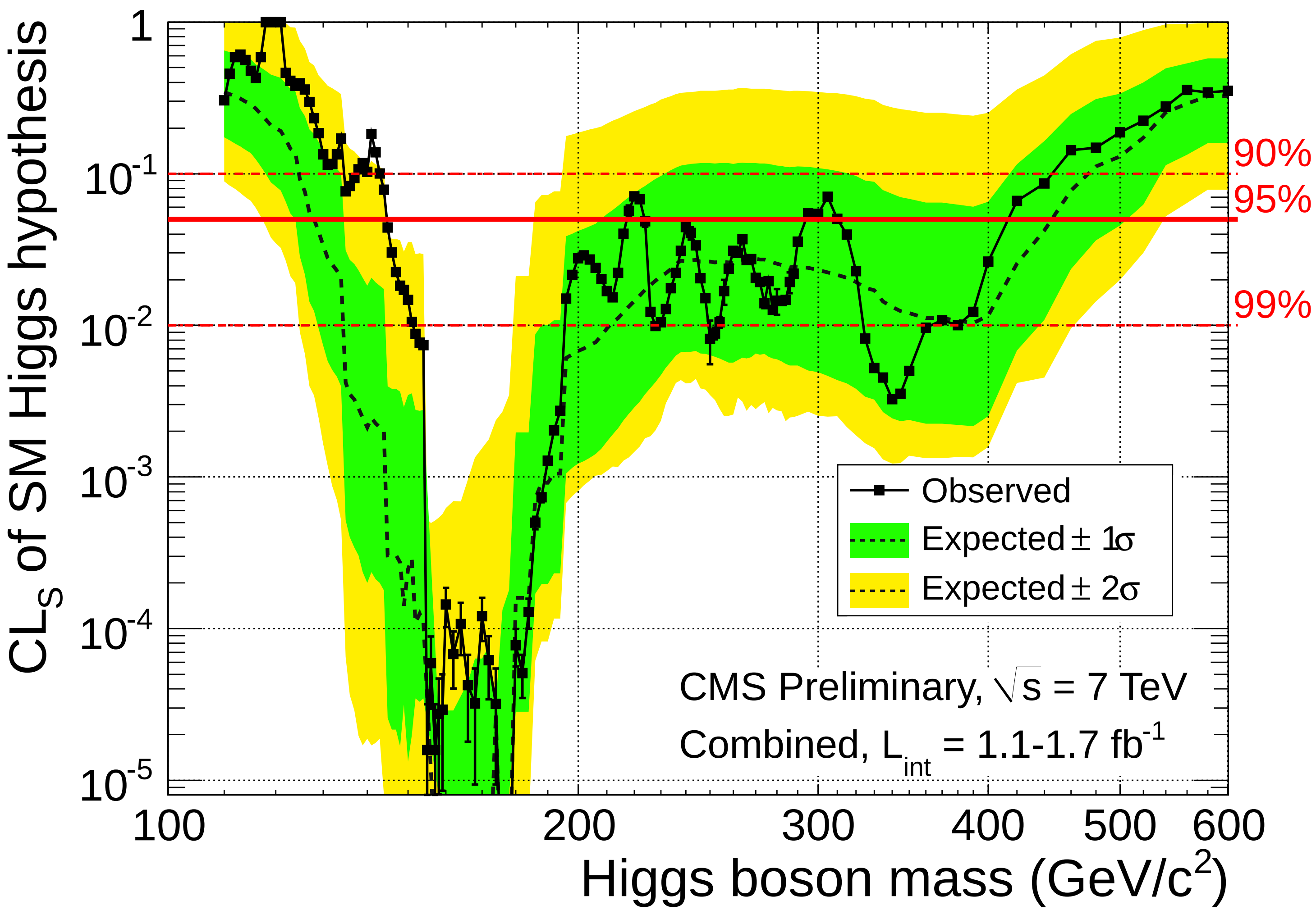
ATLAS SM Higgs search: combined upper limit normalised to the SM expectation (left) and observed result vs. expectation for a SM Higgs signal (right) [*ATLAS Collaboration '11*]





SM Higgs search: combined CMS results

Combined confidence limit vs. expectation for a SM Higgs signal [*CMS Collaboration '11*]



SM Higgs searches, high-mass region

- LHC excludes (at least at 90% C.L.) the range of $145\ \mathrm{GeV} \lesssim M_{\mathrm{H_{SM}}} \lesssim 460\ \mathrm{GeV}$

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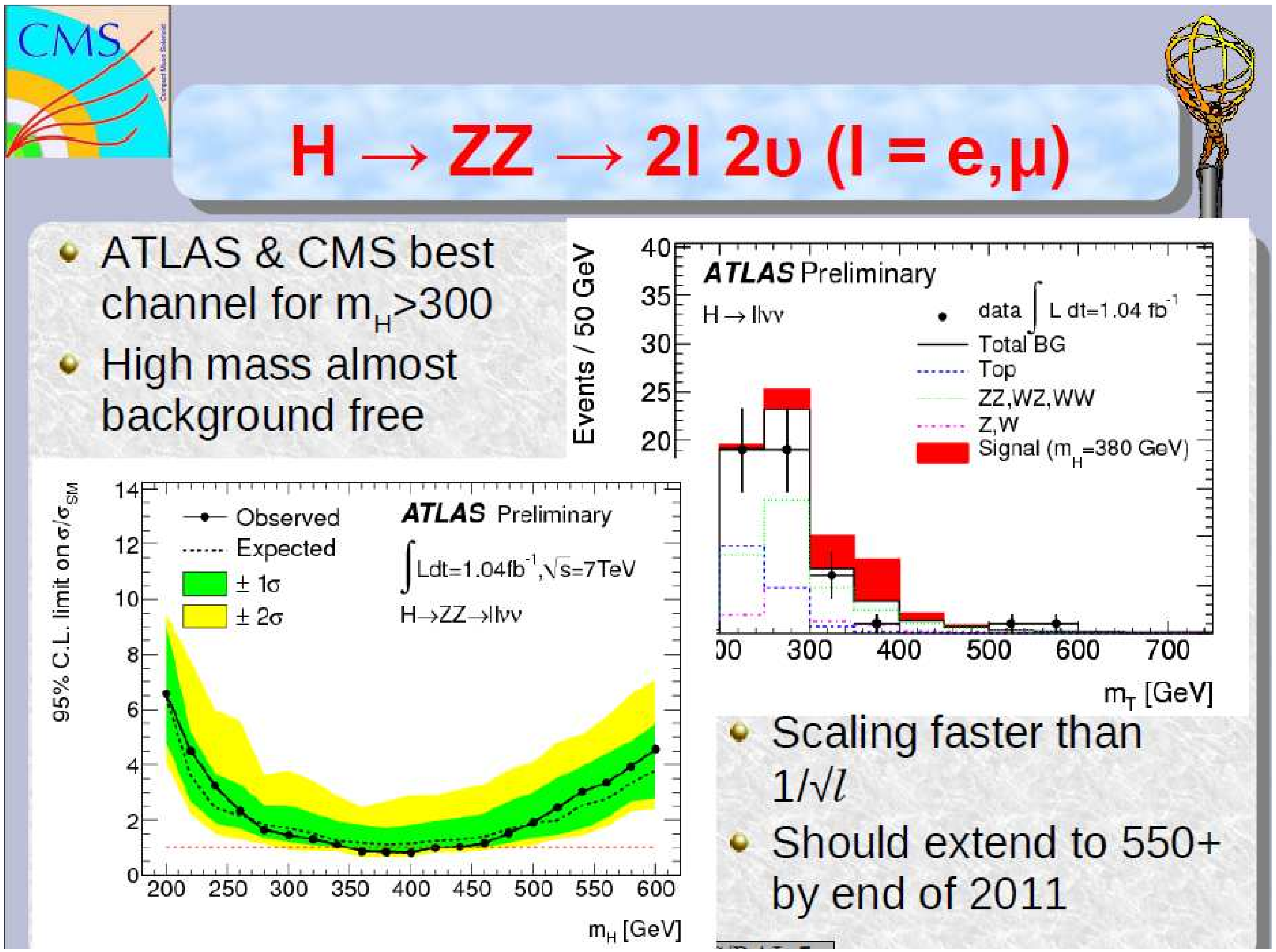
- A high mass Higgs?

  ATLAS sees an excess beyond $M_{\mathrm{H_{SM}}} = 460\ \mathrm{GeV}\ \ldots$

  However: a heavy SM-like Higgs appears to be theoretically questionable

Prospects for SM Higgs searches in the high mass region

[*W. Murray, LHC2TSP Workshop '11*]

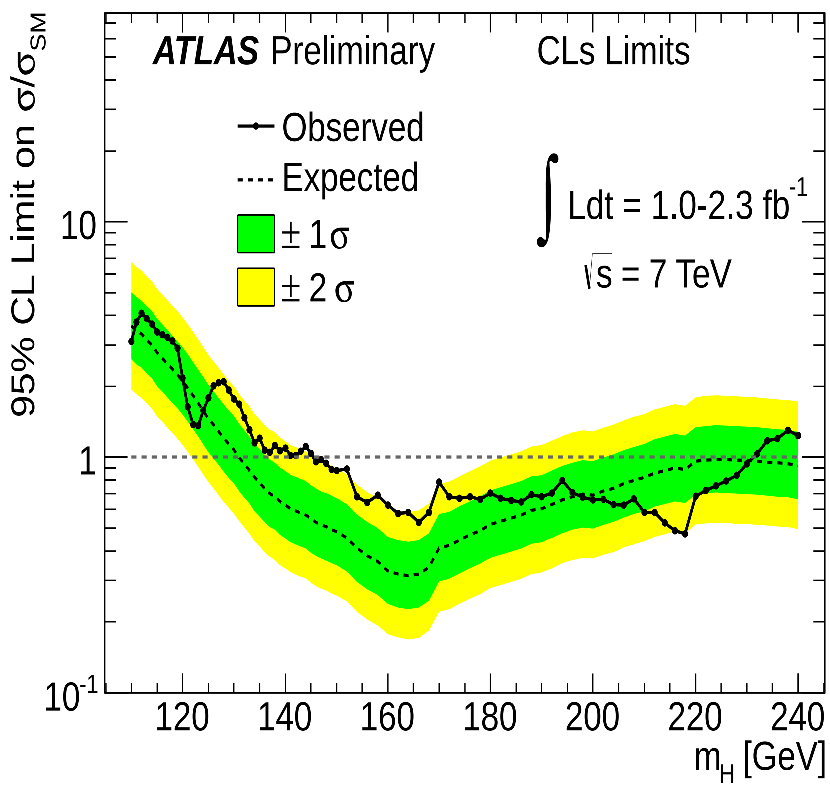


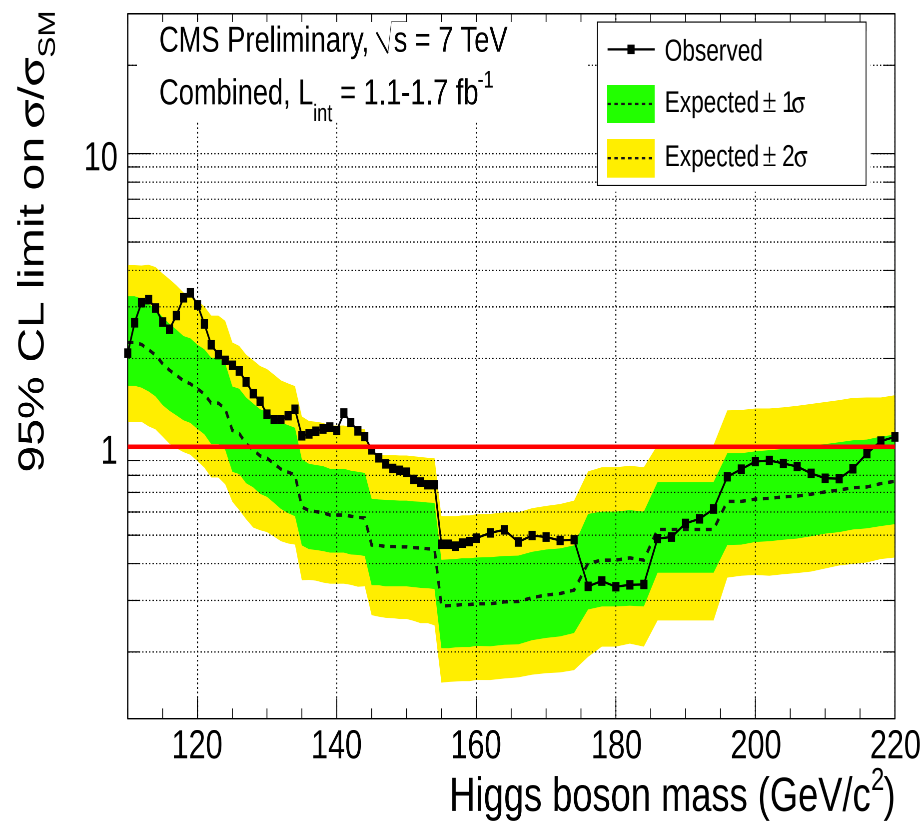
⇒ Large increase in coverage expected

SM Higgs search: ATLAS and CMS results in the low mass region

Combined upper limit normalised to the SM expectation, low mass region

[*ATLAS Collaboration '11*] [*CMS Collaboration '11*]

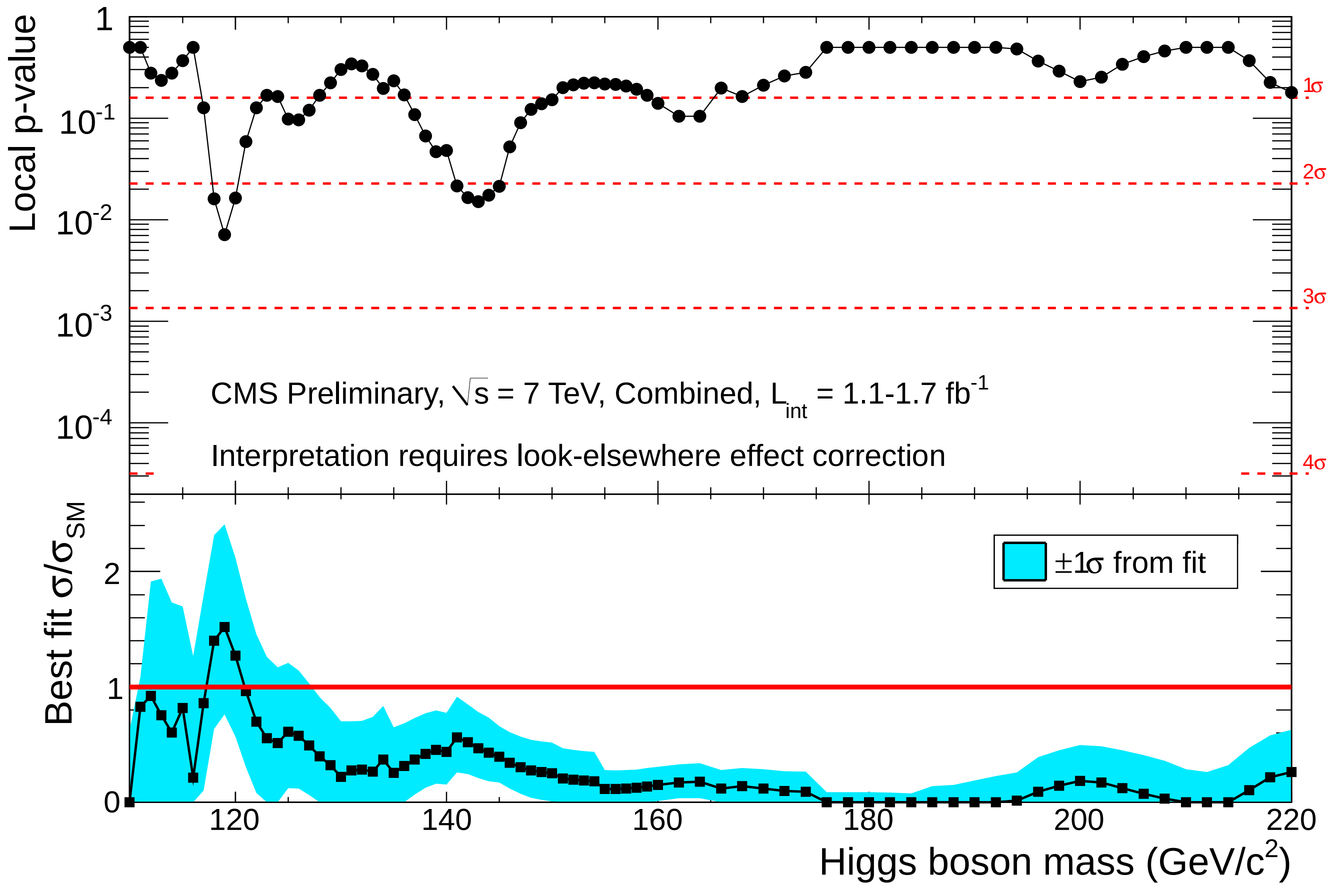




$\Rightarrow$ Broad excess in low mass region

CMS results for SM Higgs searches: local p value and observed best-fit signal strength

[*CMS Collaboration '11*]



⇒ With LEE: probability to see an excess at least as large as the one observed in the data is ≈ 0.4

Best compatibility with a SM Higgs for $M_{\mathrm{H_{SM}}} \lesssim 125\ \mathrm{GeV}$

ATLAS results for SM Higgs searches:
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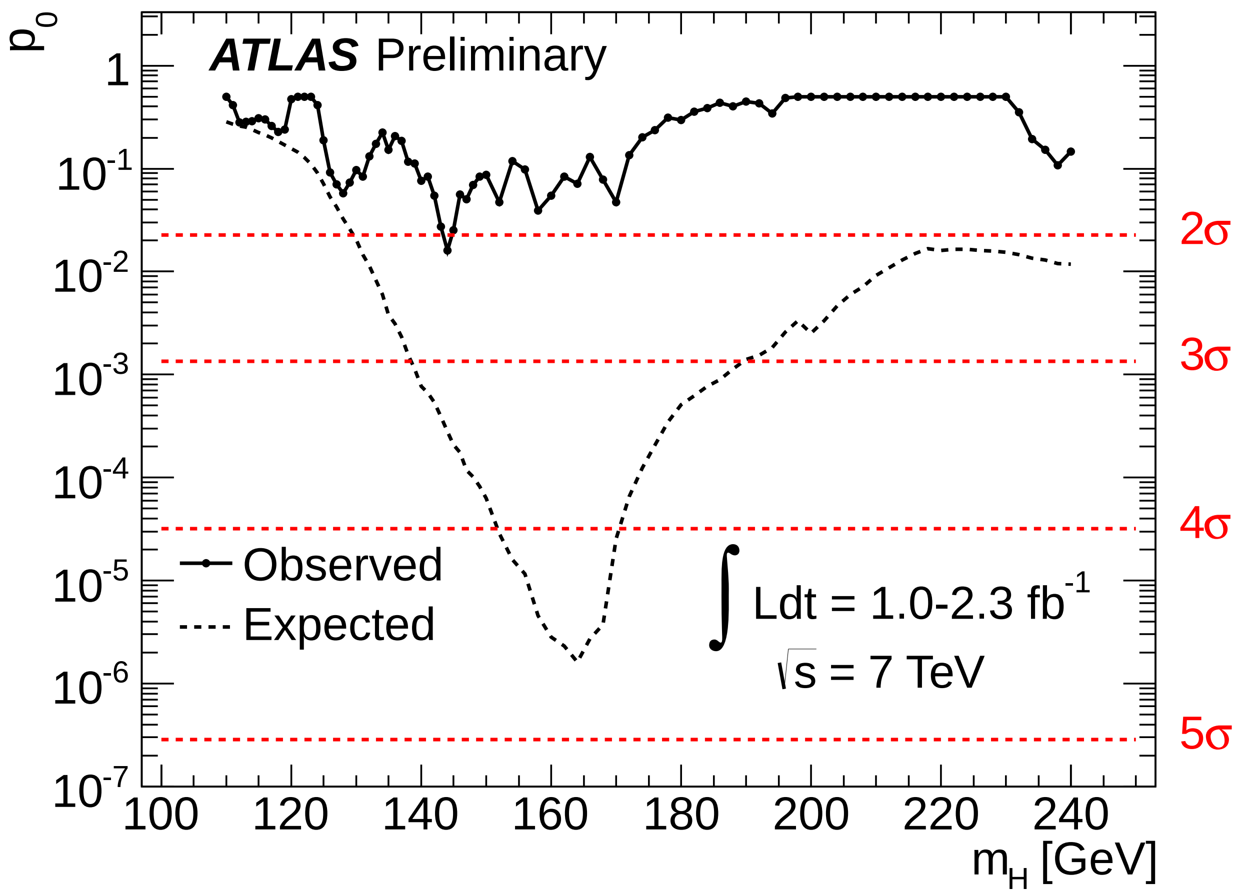
[*ATLAS Collaboration '11*]

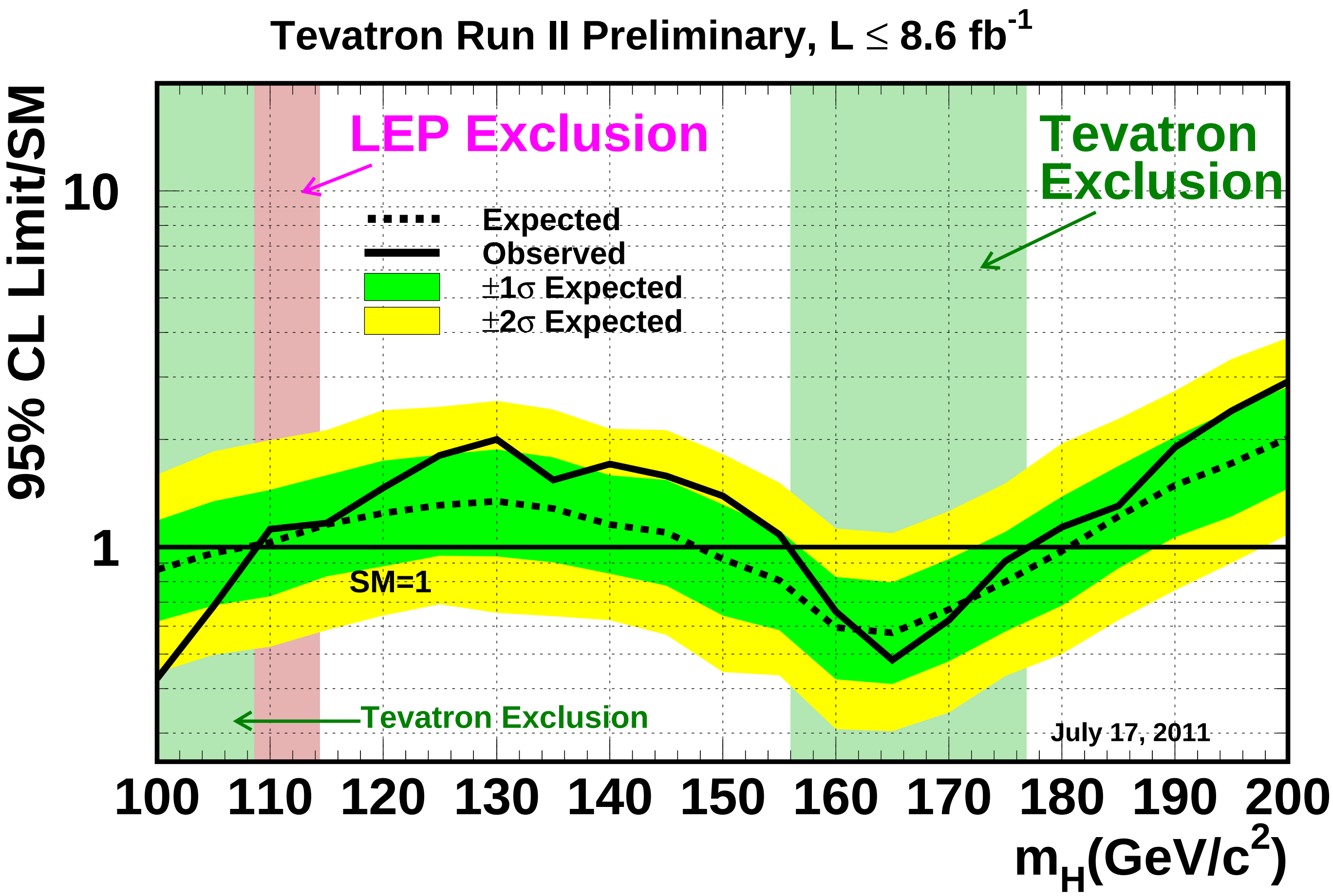


⇒ Best compatibility with a SM Higgs for $M_{H_{SM}} \lesssim 130$ GeV

Slight deficit w.r.t. SM expectation

SM Higgs search: Tevatron results, CDF + D0

CDF + D0 combined upper limit normalised to the SM expectation [*CDF and D0 Collaborations '11*]



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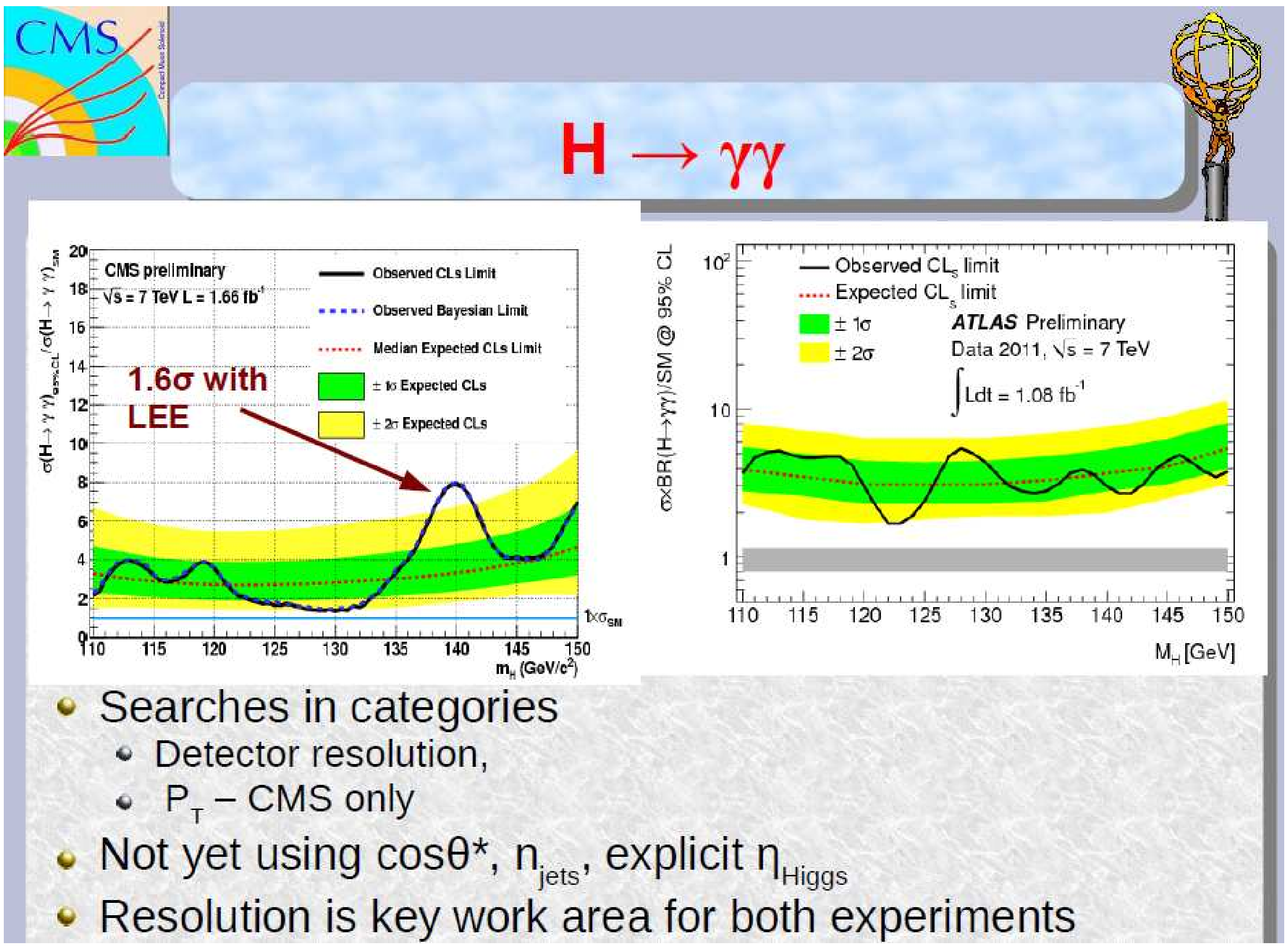
- What about a Higgs with $M_{\mathrm{H}} \approx 145 \text{ GeV}$ with somewhat reduced $\sigma \times \mathrm{BR}(H \to WW^*)$ compared to SM case?

  Difficult to get sufficiently large $\mathrm{BR}(H \to WW^*)$ in the MSSM, can better be accomodated in the NMSSM

CMS excess in $H \to \gamma\gamma$ search

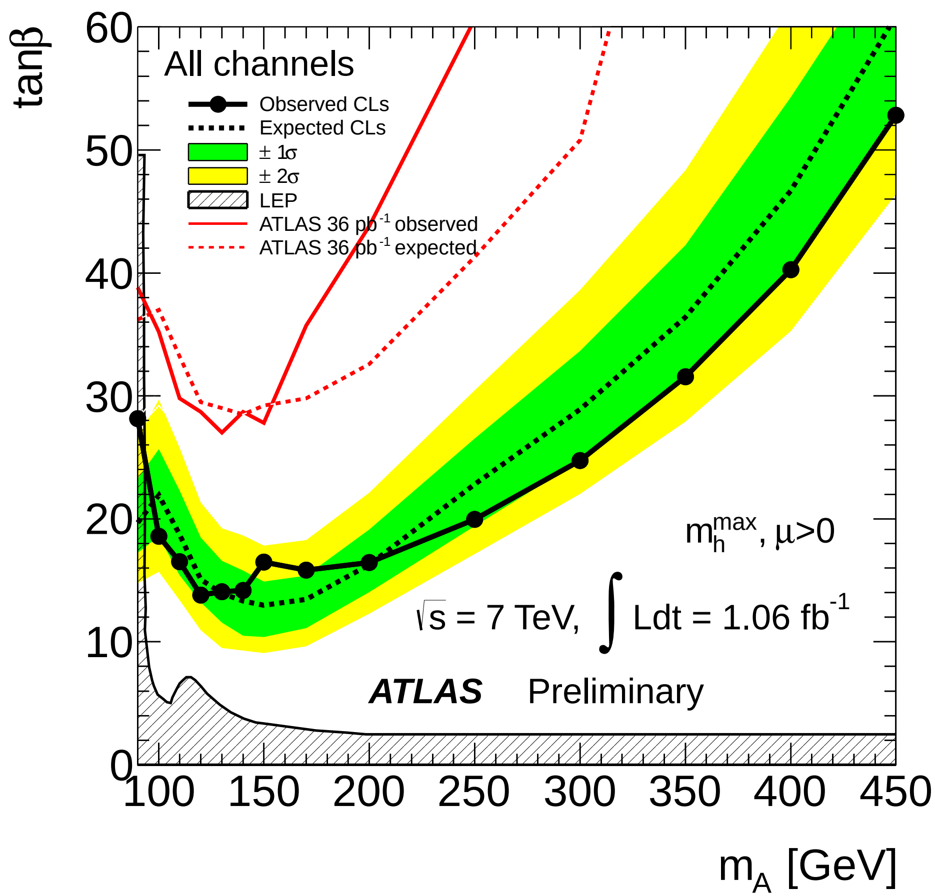
[*W. Murray, LHC2TSP Workshop '11*]

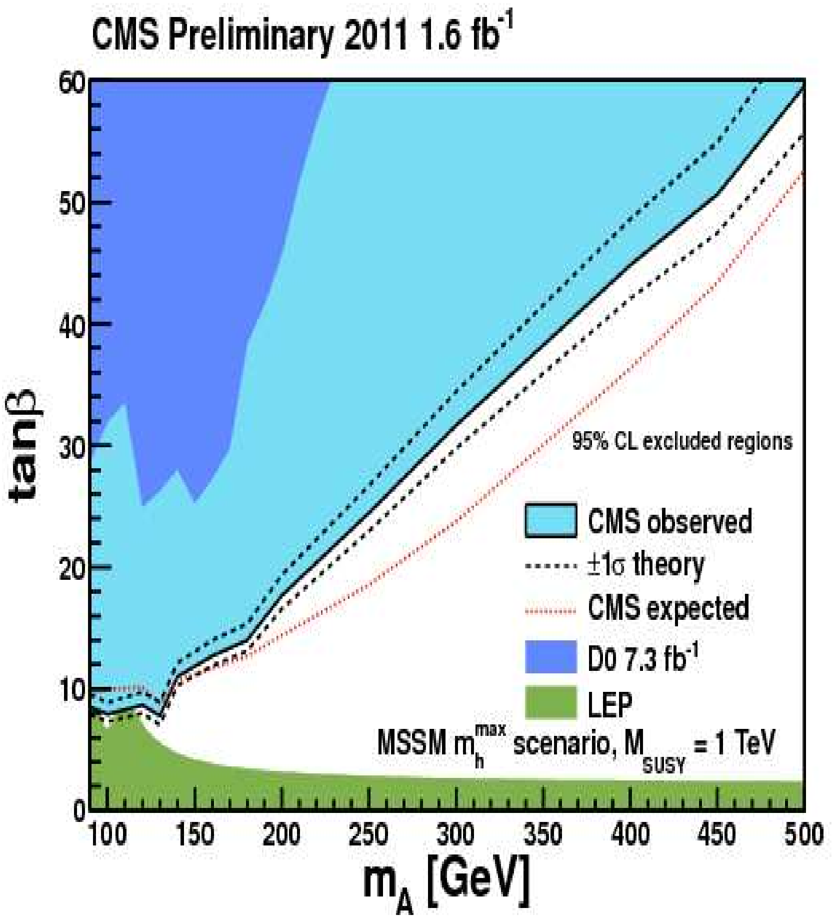


$\Rightarrow 1.6\sigma$ excess at $M_{\rm H} \approx 140$ GeV after taking into account LEE

Search for the heavy SUSY Higgs bosons H, A: limits in the M_A–$\tan\beta$ plane

[*ATLAS Collaboration ’11*] [*CMS Collaboration ’11*]



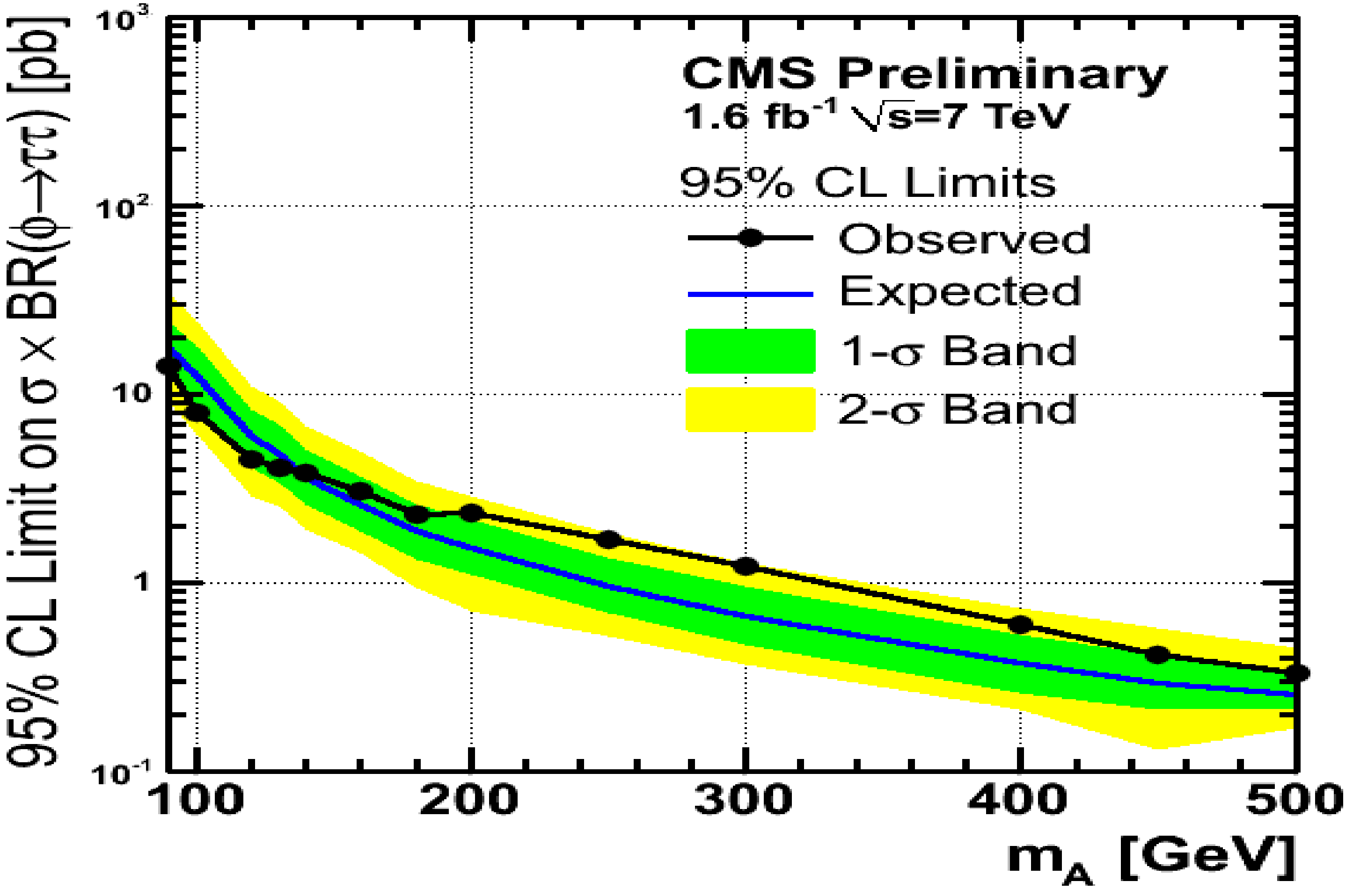


⇒ Large coverage in M_A–$\tan\beta$ plane

LHC + LEP start to close the region of very low M_A

Search for the heavy SUSY Higgs bosons H, A: cross section limit from CMS

[*CMS Collaboration '11*]



$\Rightarrow$ Excess for $M_\mathrm{A} \gtrsim 200\ \mathrm{GeV}$

Fundamental or composite Higgs?

Renewed interest in composite Higgs models, mostly from extra dimensions

[*N. Arkani-Hamed, A. Cohen, H. Georgi '01*]

[*K. Agashe, R. Contino, A. Pomarol '05*], . . .

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Signatures at LHC: new resonances, W', Z', t', KK excitations

Under pressure from electroweak precision tests

Effective field-theory description of a composite Higgs

Agreement with electroweak precision data can be improved if there is a strongly interacting light Higgs, e.g.

Little Higgs [*N. Arkani-Hamed, A. Cohen, E. Katz, A. Nelson '02*]

Holographic Higgs [*R. Contino, Y. Nomura, A. Pomarol '03*], [*K. Agashe, R. Contino, A. Pomarol '05*], . . .

Effective Lagrangian formalism for model-independent analysis of effects of a Strongly-Interacting Light Higgs (SILH) [*G. Giudice, C. Grojean, A. Pomarol, R. Ratazzi '07*]

$\Rightarrow$ Specific pattern of modified Higgs couplings

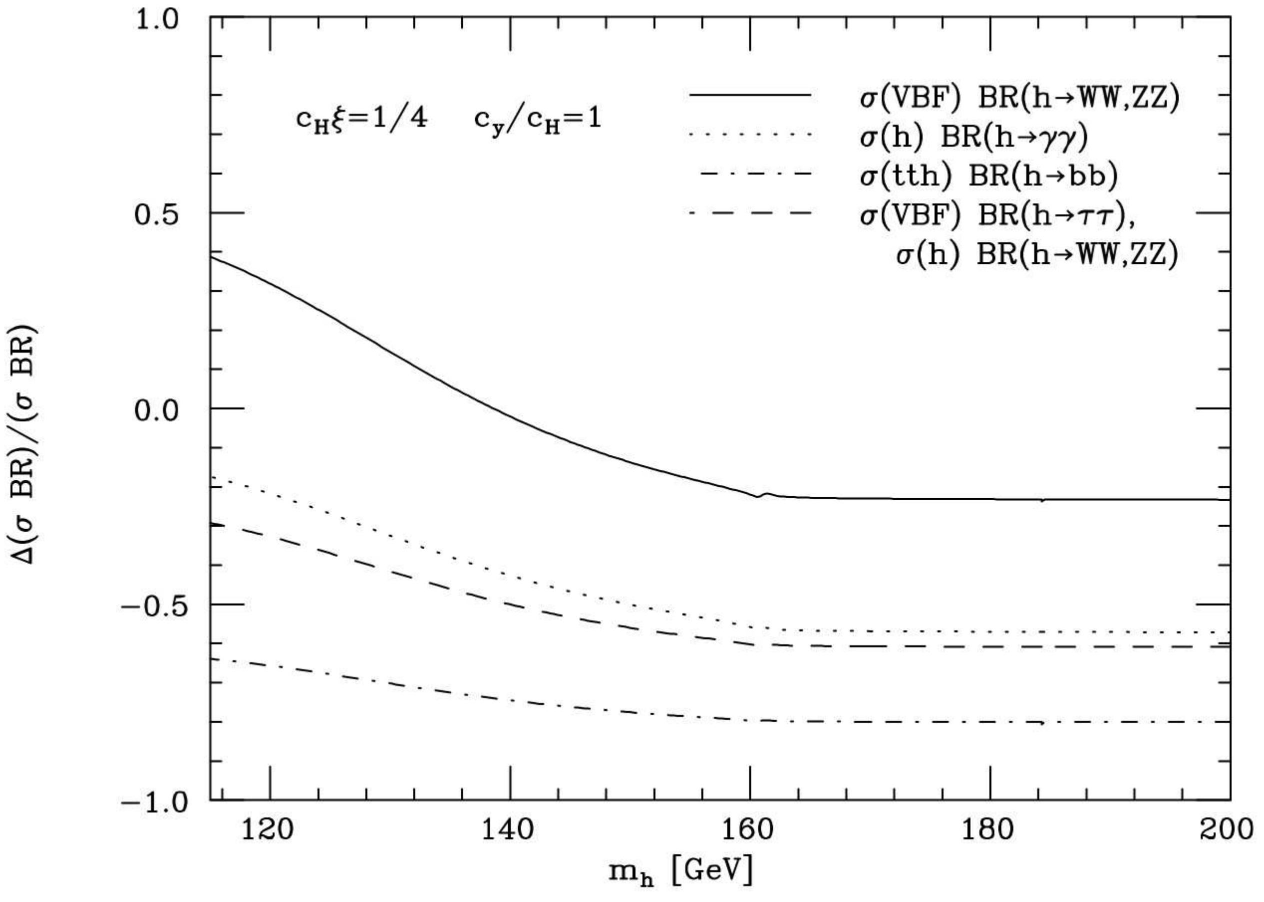
Strong WW scattering at high energies despite light Higgs

$\Rightarrow$ Need precision measurement of Higgs couplings

$+$ test of longitudinal gauge-boson scattering

Strongly-Interacting Light Higgs: deviation of $\sigma \times \mathrm{BR}$ *from the case of a SM Higgs*

[*G. Giudice, C. Grojean, A. Pomarol, R. Ratazzi '07*]



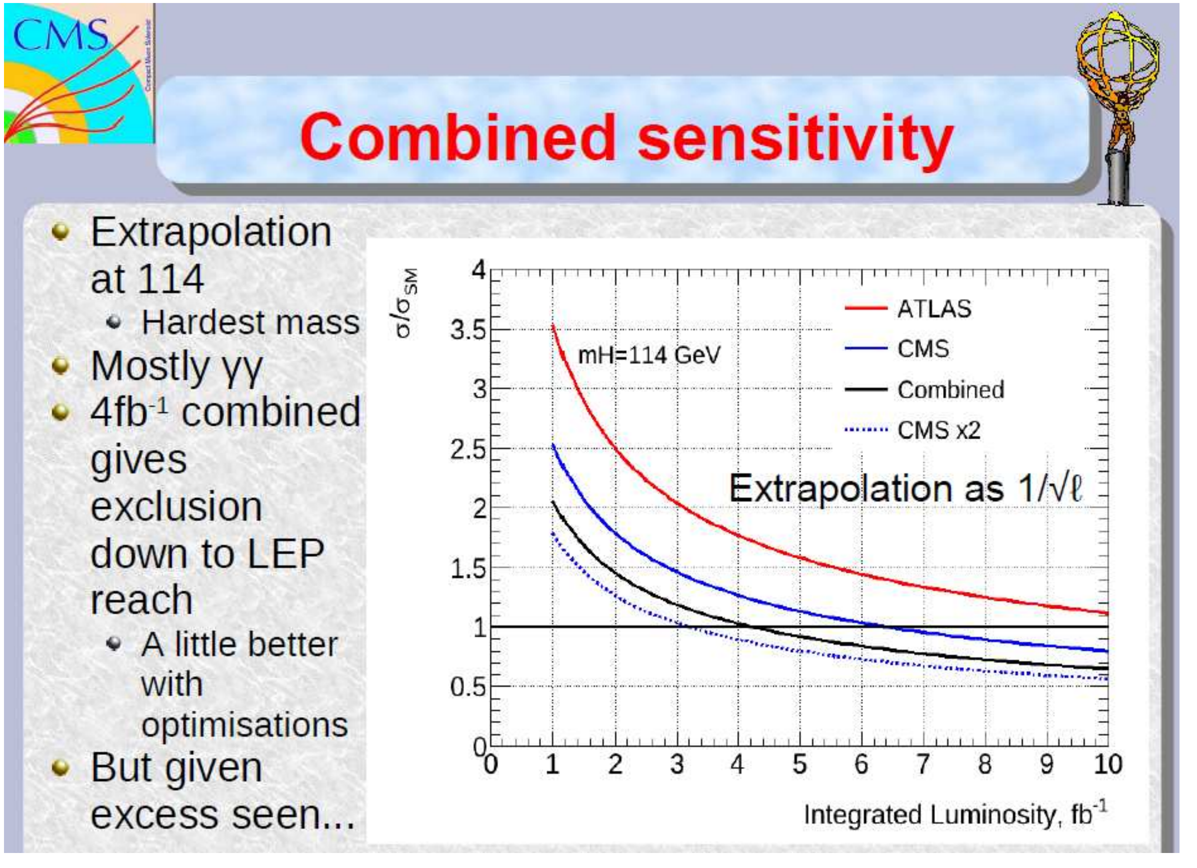
Sensitivity at LHC: 20–40%, ILC: $\mathcal{O}(1\%)$

$\Rightarrow$ ILC can test scales up to ~ 30 TeV

Further prospects

Prospects for searches for a $114\ \mathrm{GeV}$ SM-like Higgs:

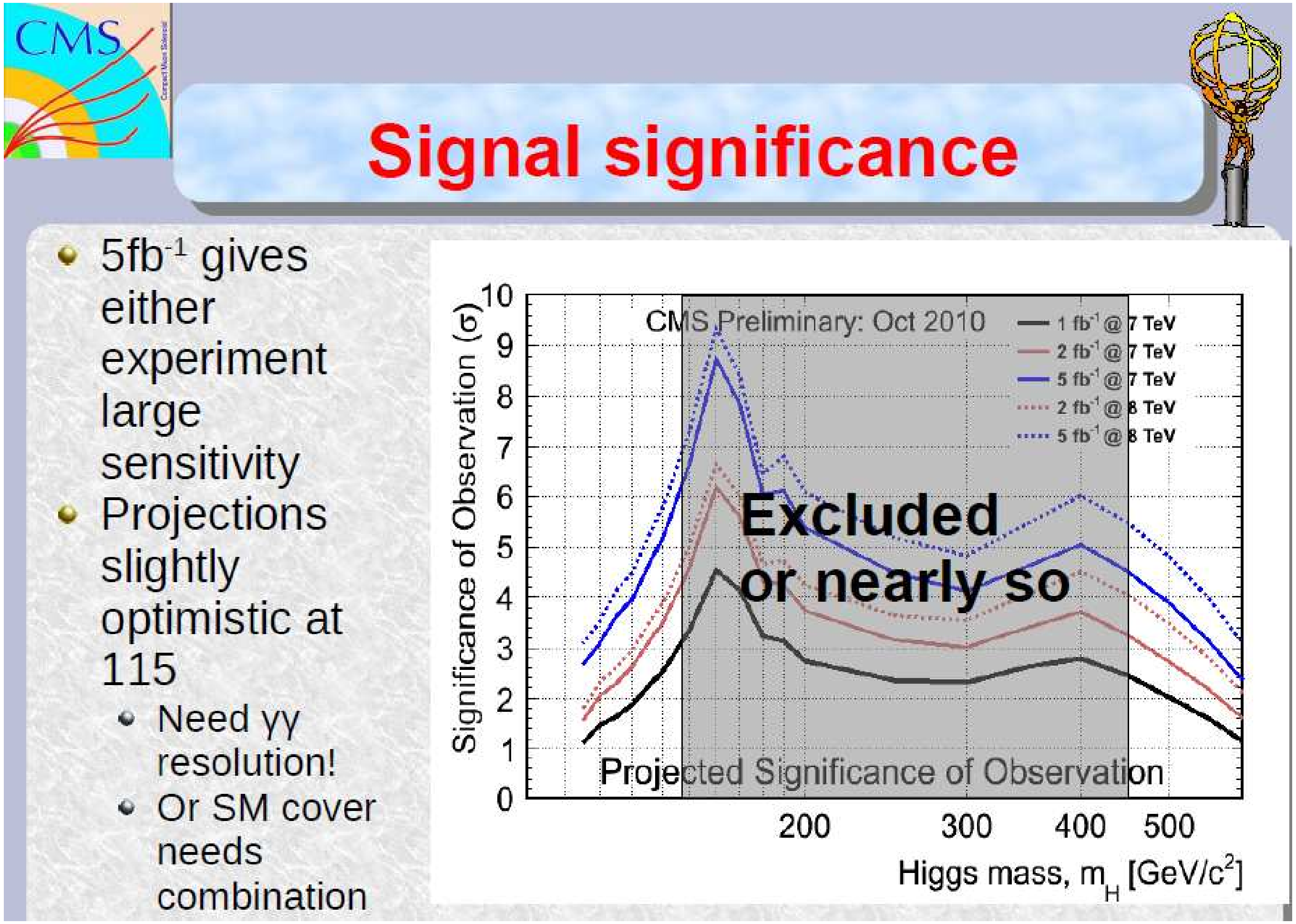
[*W. Murray, LHC2TSP Workshop '11*]



$\Rightarrow$ 2011 data, when combined between ATLAS $+$ CMS, should provide 2σ sensitivity down to $M_{\mathrm{H}} = 114\ \mathrm{GeV}$

Prospects for the signal significance

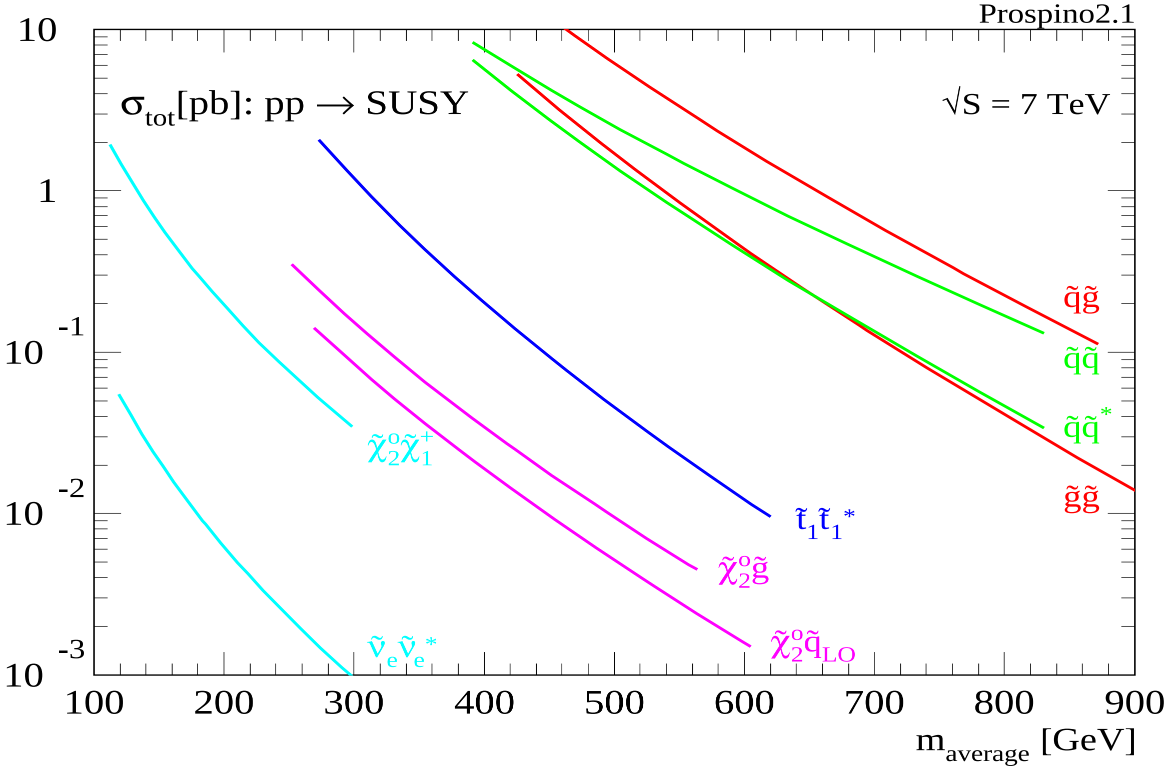
[*W. Murray, LHC2TSP Workshop '11*]



$\Rightarrow$ With 2012 data, ATLAS $+$ CMS combined: expect sensitivity of at least 3.5σ

New physics addressing the hierarchy problem

SUSY production cross sections at the LHC with $7\ \mathrm{TeV}$:



⇒ Highest cross section for gluino and squarks of the first two generations

Squark and gluino couplings $\sim \alpha_s$; cross sections mainly determined by $m_{\tilde{q},\tilde{g}}$, small residual model dependence

SUSY searches at the LHC

Dominated by production of coloured particles:
gluino, squarks (mainly first two generations)

Very large mass reach in the searches for
jets $+$ missing energy

$\Rightarrow$ gluino, squarks accessible up to 2–3 TeV at LHC ($14\ \mathrm{TeV}$)

Coloured particles are usually heavier than the colour-neutral ones

$\Rightarrow$ long decay chains possible; complicated final states

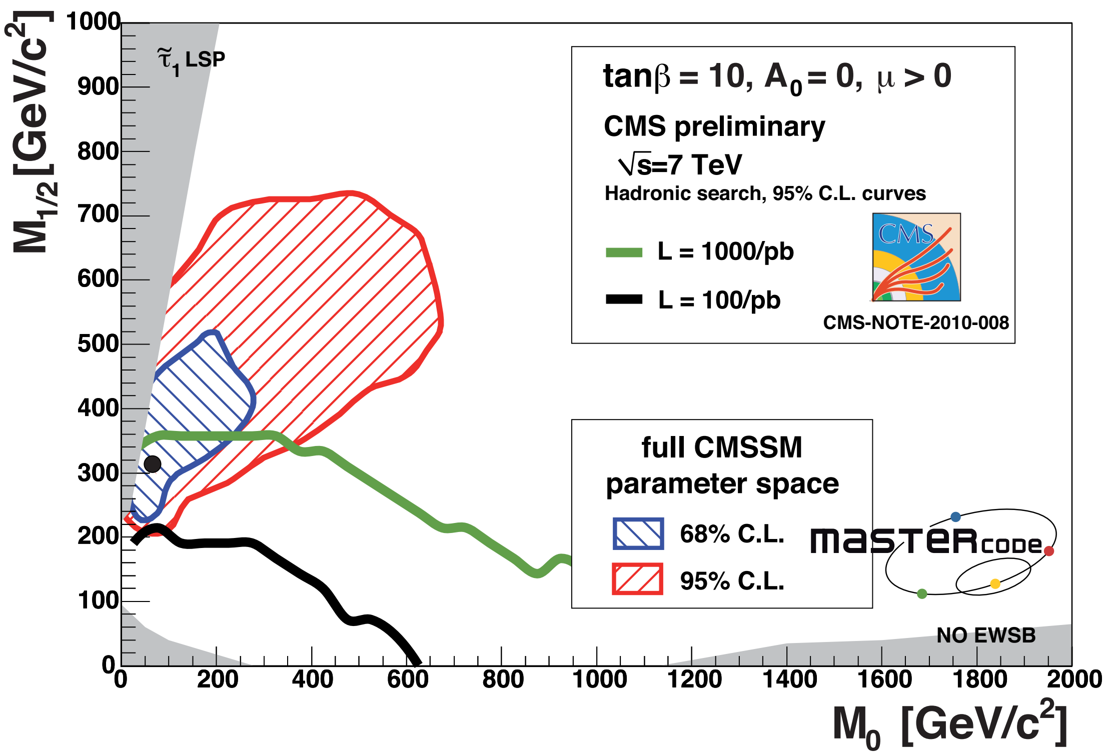
e.g.: $\tilde{g} \to \bar{q}\tilde{q} \to \bar{q}q\tilde{\chi}_2^0 \to \bar{q}q\tilde{\tau}\tau \to \bar{q}q\tau\tau\tilde{\chi}_1^0$

Many states produced at once, difficult to disentangle

Pre–LHC: Fit results for the CMSSM from precision data

Comparison: preferred region in the m_0–$m_{1/2}$ plane vs. prospective CMS 95% C.L. reach for $0.1, 1\ \mathrm{fb}^{-1}$ at $7\ \mathrm{TeV}$

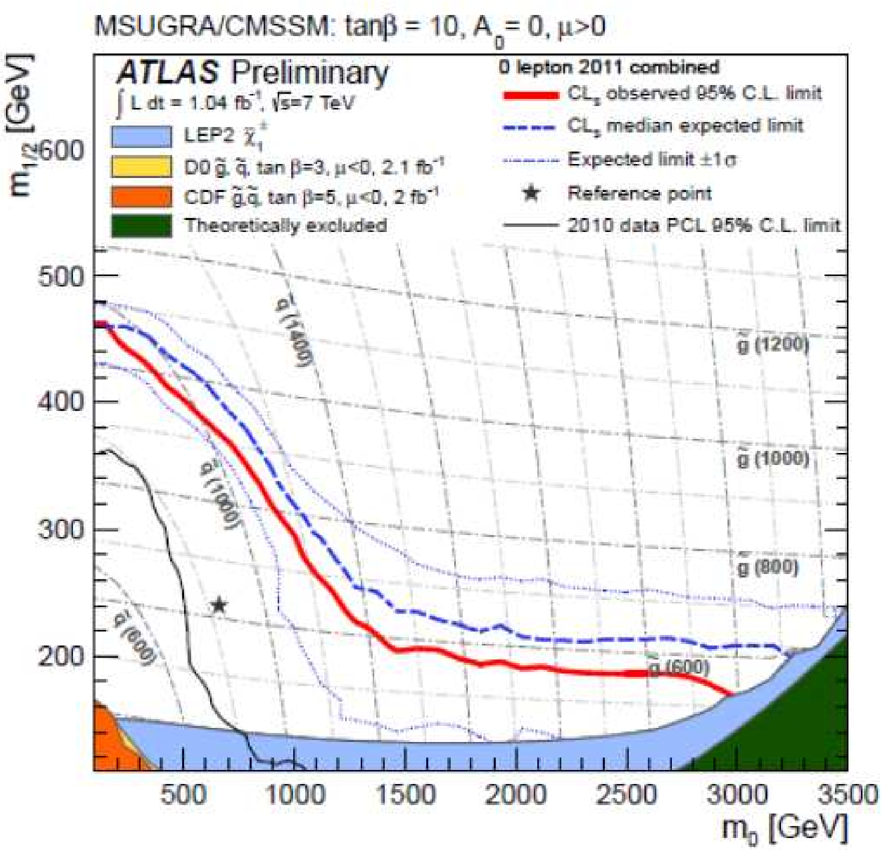
[*O. Buchmueller, R. Cavanaugh, A. De Roeck, J. Ellis, H. Flächer, S. Heinemeyer, G. Isidori, K. Olive, P. Paradisi, F. Ronga, G. W. '10*]



⇒ Best fit point was within the 95% C.L. reach with $1\ \mathrm{fb}^{-1}$

SUSY search results for the CMSSM

[*ATLAS Collaboration '11*]



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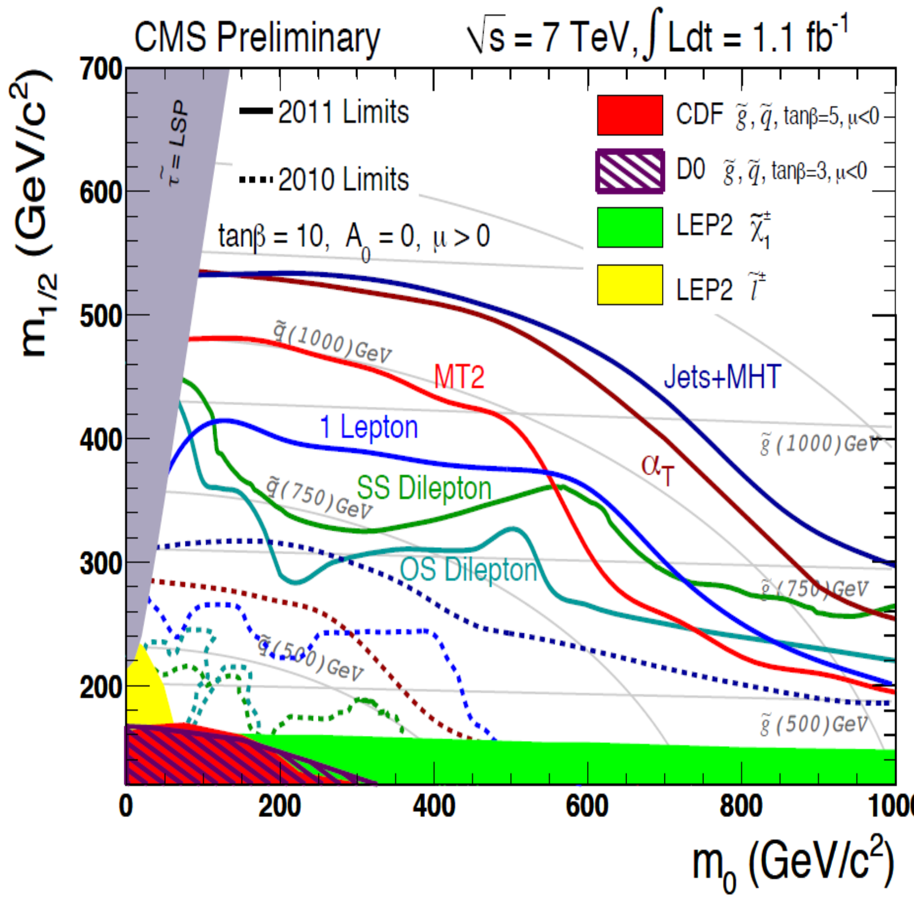


⇒ High sensitivity from search for jets + missing energy

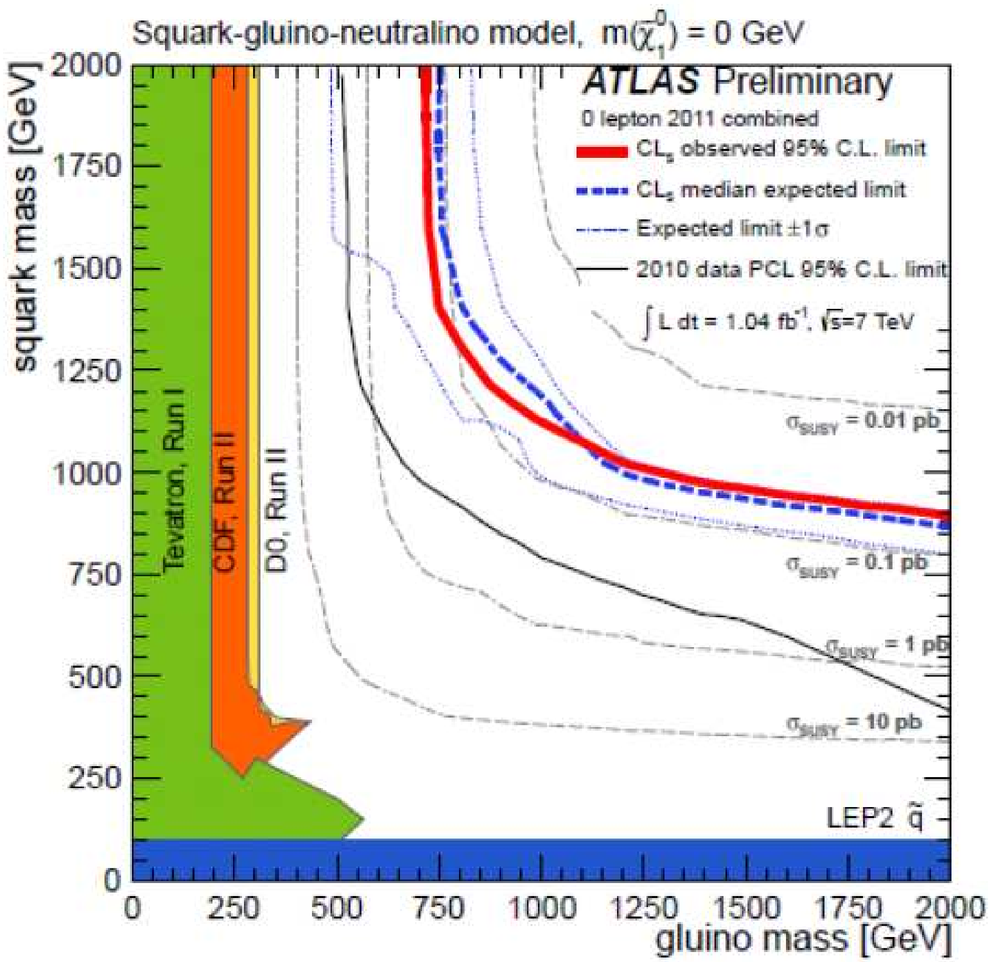
Previous best-fit point is excluded

CMSSM starts to get under pressure

Interpretation of SUSY search result in "simplified model"

"Simplified model": squarks of first two generations, gluino + massless neutralino (LSP), all other SUSY particles heavy

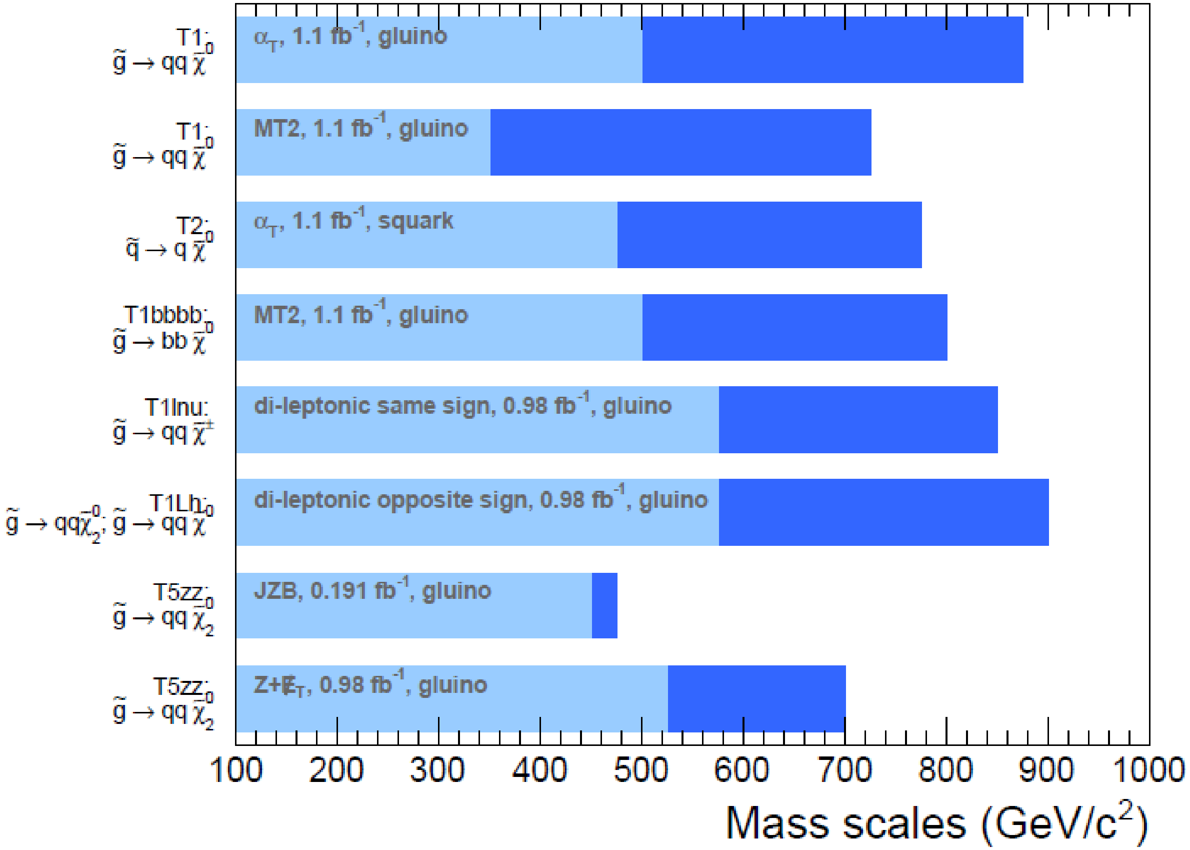
[*ATLAS Collaboration '11*]



Limits for gluinos and squarks in simplified models, LSP mass varied from 0 to $m_{\tilde{g}} - 200$ GeV

[*CMS Collaboration '11*]

Ranges of exclusion limits for gluinos and squarks, varying $m(\tilde{\chi}^0)$
CMS preliminary



For limits on $m(\tilde{g})$, $m(\tilde{q}) >> m(\tilde{g})$ (and vice versa). $\sigma^{prod} = \sigma^{NLO\text{-}QCD}$.

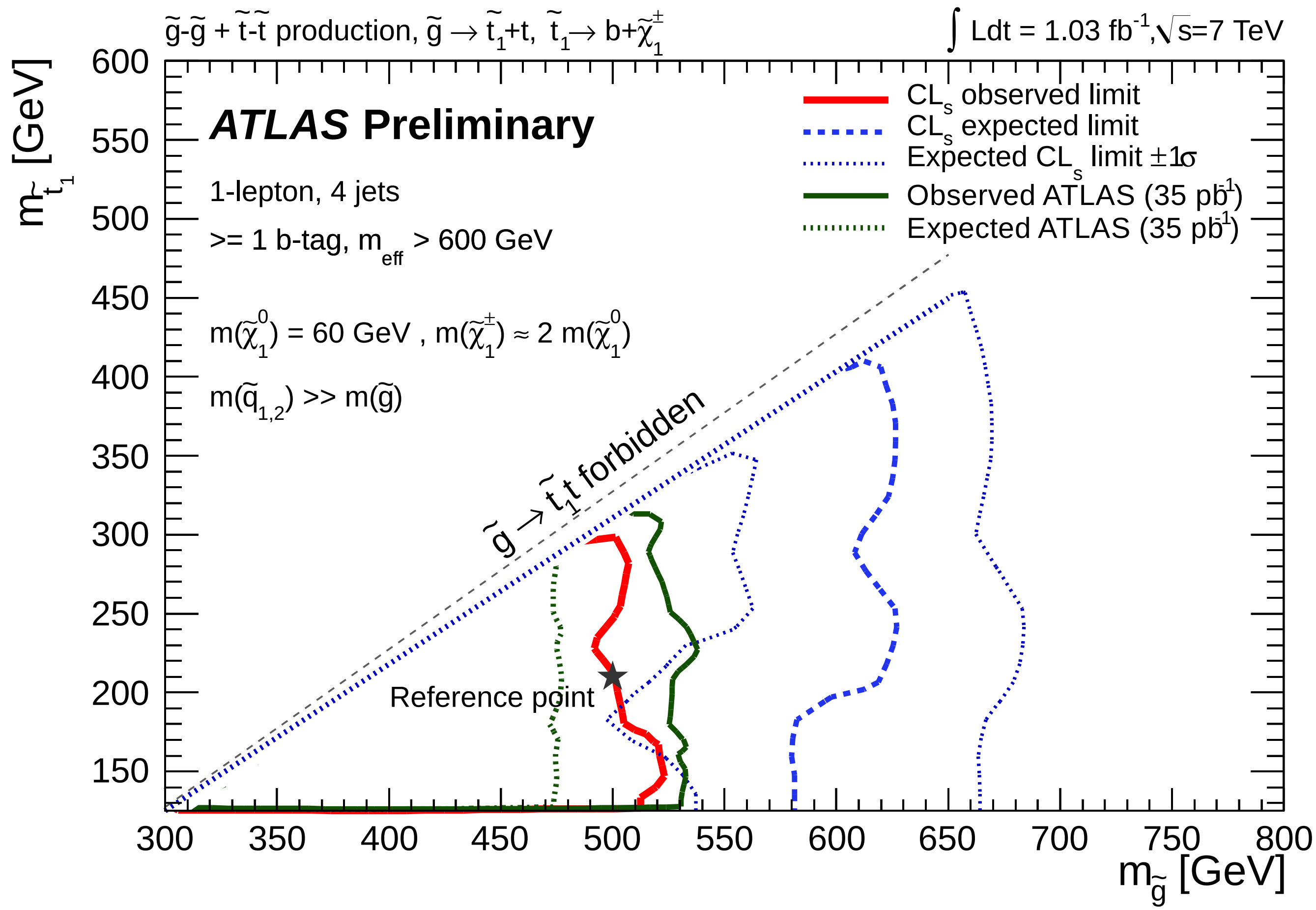
$m(\tilde{\chi}^{\pm}), m(\tilde{\chi}^0_2) \equiv \frac{m(\tilde{g}) + m(\tilde{\chi}^0)}{2}$.

$m(\tilde{\chi}^0)$ is varied from 0 GeV/c^2 (dark blue) to $m(\tilde{g})$-200 GeV/c^2 (light blue).

$\Rightarrow$ Large dependence on LSP mass

Excitement at SUSY ’11

Stop production in gluino decays [*ATLAS Collaboration ’11*]



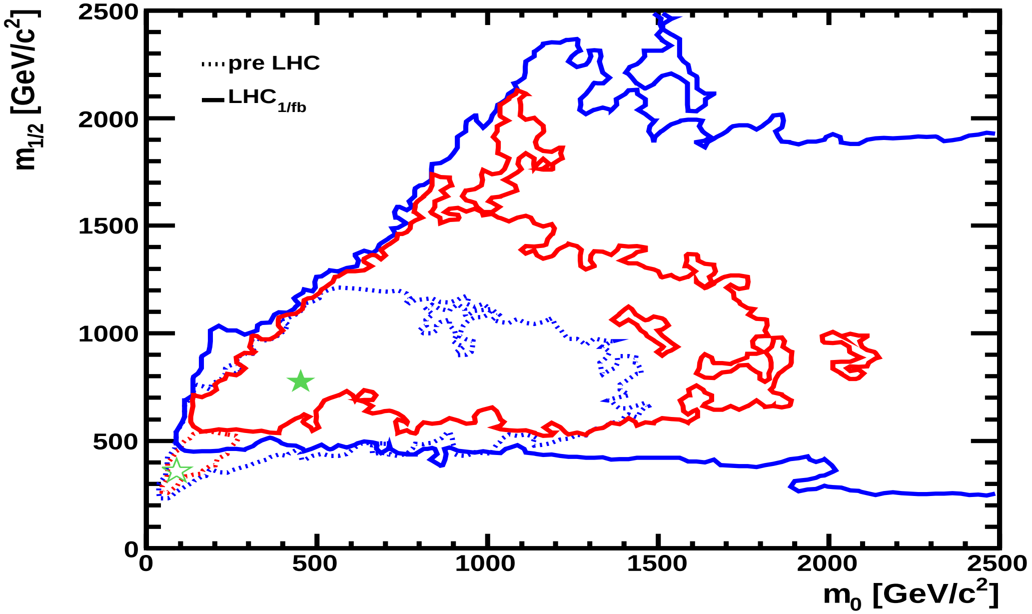
$\Rightarrow$ Observed limit decreased with 30 $\times$ more luminosity

1.2 σ excess in both electron and muon channels

Global fit in the CMSSM including 2011 LHC data ($1\ \mathrm{fb}^{-1}$) and XENON100 results

68% and 95% CL contours, pre- and post-LHC

[*O. Buchmueller, R. Cavanaugh, A. De Roeck, M. Dolan, J. Ellis, H. Flächer, S. Heinemeyer, G. Isidori, D. Martínez Santos, K. Olive, S. Rogerson, F. Ronga, G. W. '11*]



$\Rightarrow$ Preferred region "opens up", overall χ^2 worsened
Shift towards higher mass scales, higher values of $\tan\beta$

Comparison: GMSB yields much larger splitting between coloured and colour-neutral part of the spectrum

Status of SUSY searches

- Search for jets ($+$ leptons) $+$ missing energy

  $\Rightarrow$ Bounds on gluino and squarks of first two generations of $\mathcal{O}(\text{ TeV})$

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- Reduced sensitivity to compressed spectra

- Limited sensitivity to 3rd generation squarks

  Hardly any direct constraints from the LHC on colour neutral SUSY particles up to now

SUSY searches: what next?

[*S. Padhi (CMS), LHC2TSP Workshop '11*]

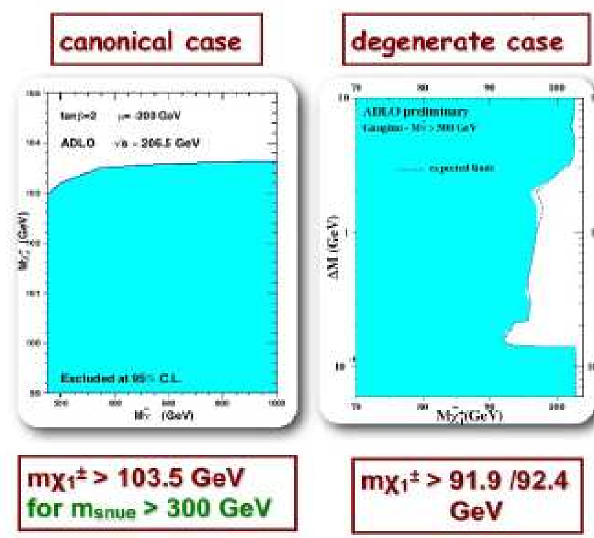
Assuming colored particles (1^{st} and 2^{nd} generation squarks and gluinos) are beyond the LHC range:

a) Need dedicated exclusive studies to constrain stops and sbottoms

- With and without the cross section help from the colored particles
- See also M. Papucci's EPS-2011 talk
- http://indico.in2p3.fr/contributionDisplay.py?contribId=904&sessionId=6&confId=5116

b) Need dedicated activity on EWK inos

- Current limits on Chargino/neutralinos are low
- Explore LHC reach for the electroweak sector (See also Shufang Su SUSY-11 talk)

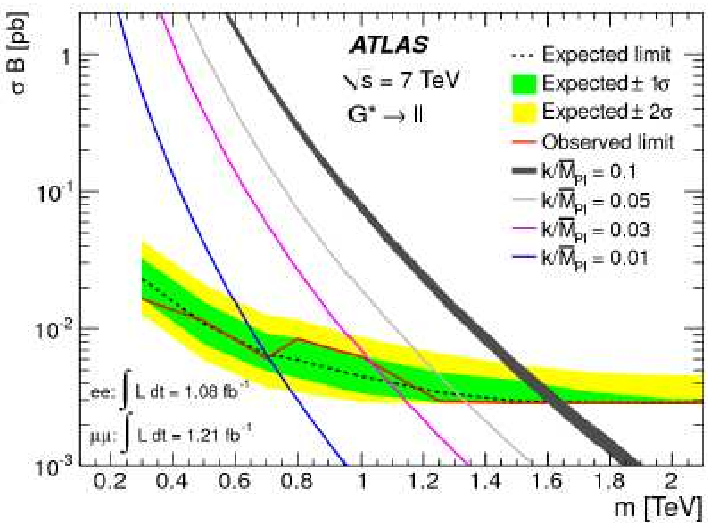


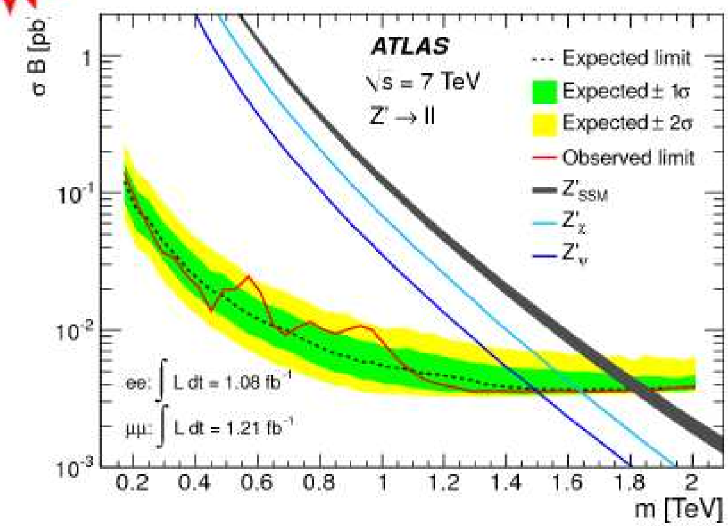
Search for dilepton resonances: ATLAS

[*ATLAS Collaboration '11*]

Search for Heavy Resonance: dileptons

arXiv:1108.1582





	RS Graviton			
Model/ Coupling	0.01	0.03	0.05	0.1
Mass limit [TeV]	0.71	1.03	1.33	1.63

E_6 Z' Models					
Z'_ψ	Z'_N	Z'_η	Z'_I	Z'_S	Z'_χ
1.49	1.52	1.54	1.56	1.60	1.64

RS graviton ($k/M_{Pl} = 0.1$):
$m(G_{kk}) > 1.63$ TeV @ 95% C.L.

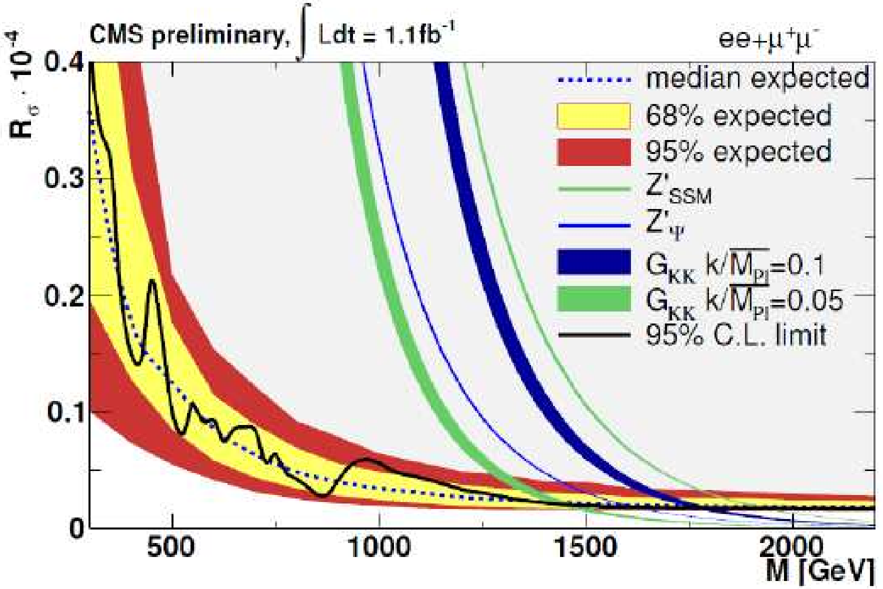
Sequential SM:
$m(Z'_{SSM}) > 1.83$ TeV @ 95% C.L.

As expected with current data

Search for dilepton resonances: CMS

[*CMS Collaboration '11*]

Limits with dimuons, dielectrons



EXO-11-019

Z'_{SSM}: 1940 GeV

Z'_{ψ}: 1620 GeV

KK: 1450 GeV ($\frac{k}{M}$ =0.05)

KK: 1780 GeV ($\frac{k}{M}$ =0.1)

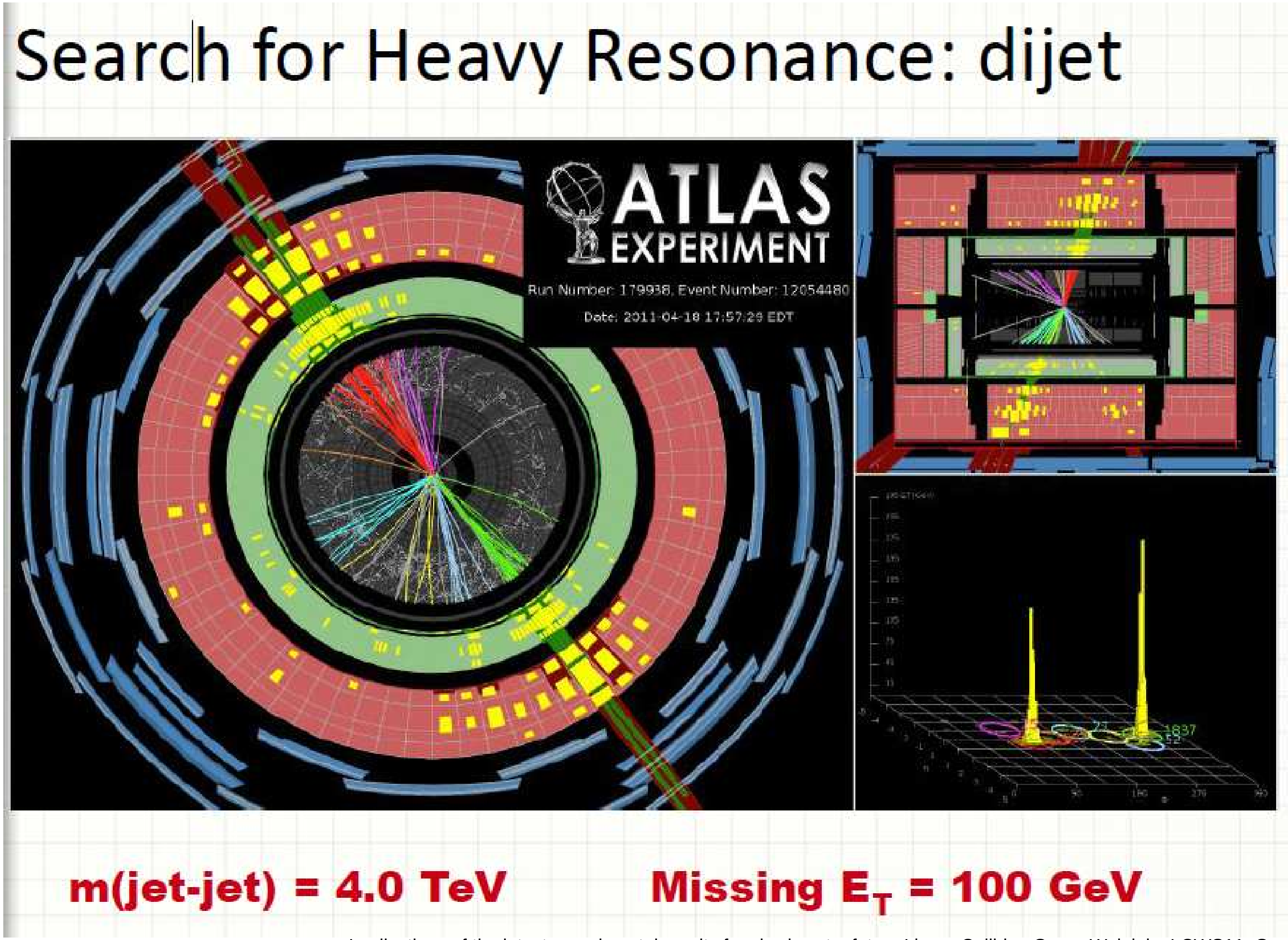
Λ_T [TeV] (GRW)	M_s [TeV] (HLZ)					
	$n=2$	$n=3$	$n=4$	$n=5$	$n=6$	$n=7$
ADD k-factor: 1.0						
2.62	2.58	3.12	2.62	2.36	2.20	2.08
2.56	2.58	3.10	2.56	2.27	2.09	1.95
ADD k-factor: 1.3						
2.70	2.72	3.22	2.70	2.44	2.28	2.16
2.66	2.72	3.20	2.66	2.37	2.17	2.02

Exclusion limits for SSM, superstring-inspired, RS KK (1.5-2 TeV, as well as ADD models for several parameters (2-3 TeV)

EXO-11-039

Search for dijet resonances: ATLAS

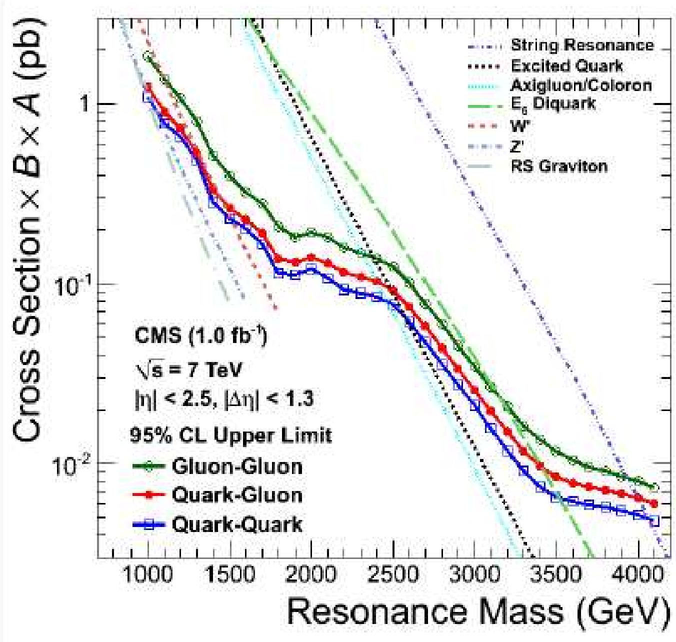
[*ATLAS Collaboration '11*]



Search for dijet resonances: CMS

[*CMS Collaboration ’11*]

Resonances: limits with dijets



Derived limits for several models, with excluded masses up to 4 TeV

Model	Excluded Mass (TeV)	
	Observed	Expected
String Resonances	4.00	3.90
E_6 Diquarks	3.52	3.28
Excited Quarks	2.49	2.68
Axigluons/Colorons	2.47	2.66
W′ Bosons	1.51	1.40

arXiv.1107.4771
(submitted to PLB)
EXO-11-015

Status of search for heavy resonances

- No evidence for a signal

- Limits of $\mathcal{O}(1 - 4 \text{ TeV})$

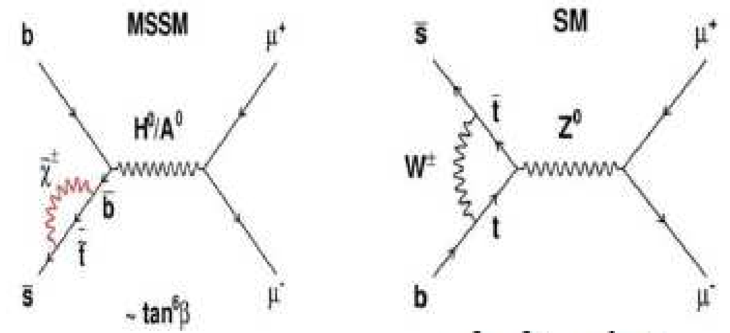
Search for the rare decay $B_s \to \mu^+\mu^-$

B physics rare decay par excellence:

$BR(B_s \to \mu\mu)_{SM} = (3.2 \pm 0.2) \times 10^{-9}$

[A.J.Buras, arXiv:1012.1447]

Precise prediction (which will improve) !

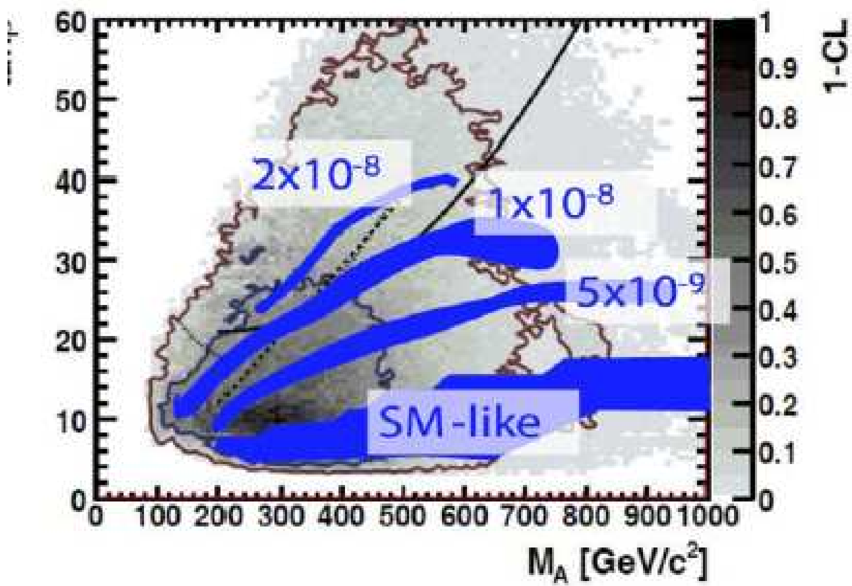


Very high sensitivity to NP, eg. MSSM:

$$Br^{MSSM}(Bq \to l^+l^-) \propto \frac{m_b^2 m_l^2 \tan^6\beta}{M_{A0}^4}$$

One example [O. Buchmuller et al, arXiv:0907.5568] : NUHM (= generalised version of CMSSM)

$BR(B_s \to \mu\mu)$ - highly discriminatory



BR UL 95% CL as of Spring 2011:

CDF (3.7 fb^{-1}): $< 4.3 \times 10^{-8}$

D0 (6.1 fb^{-1}): $< 5.1 \times 10^{-8}$

LHCb (37 pb^{-1}): $< 5.6 \times 10^{-8}$

Recent exciting hint from CDF (7 fb^{-1}):

$BR = 1.8^{+1.1}_{-0.9} \times 10^{-8}$!?!

[arXiv:1107.2304]

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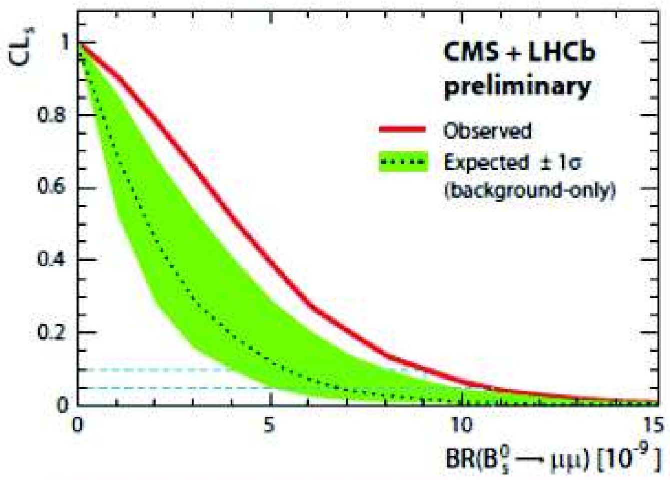
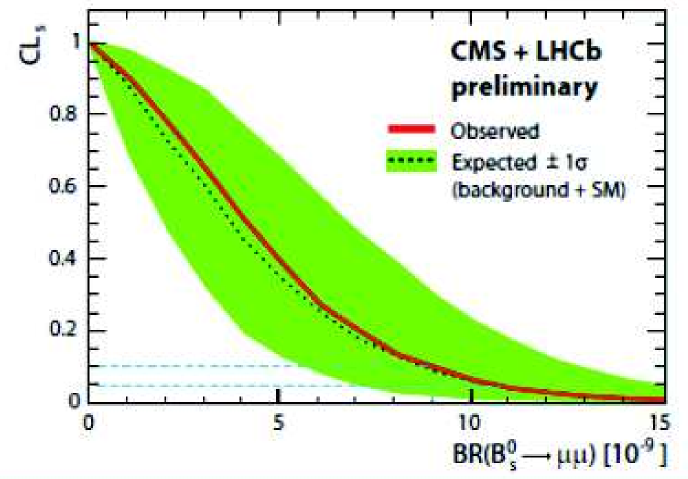
$\mathrm{BR}(B_s \to \mu^+\mu^-)$: *combined result from LHCb and CMS*

$B_s \to \mu^+\mu^-$: combination with CMS

- LHCb and CMS have performed a preliminary combined limit [LHCb-CONF-2011-043, CMS PAS BPH-11-019]
  - LHCb $\mathrm{BR}(B_s \to \mu^+\mu^-) < 1.5\ (1.2) \times 10^{-8}$ at 95%(90%) c.l.
  - CMS: $\mathrm{BR}(B_s \to \mu^+\mu^-) < 1.9\ (1.6) \times 10^{-8}$ at 95%(90%) c.l





LHCb+CMS limit: $\mathrm{BR}(B_s \to \mu^+\mu^-) < 1.1\ (0.9) \times 10^{-8}$ at 95%(90%) c.l.

This is ~ 3 times the SM BR

40

$\Rightarrow$ Very good agreement with SM expectation (so far)

Implications for Linear Collider physics

Summary / interpretation of LHC results:

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  Slight excess in the low-mass region, compatible with SM-like Higgs of 115–$120\ \mathrm{GeV}$

  $\Rightarrow$ Preference for low-mass region has further strengthened

Summary / interpretation of LHC results

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$\Rightarrow$ Experimental situation for colour–neutral sector $+\,\tilde{t}$, $\tilde{b}$ is essentially unchanged compared to the pre-LHC case

LC implications (personal view)

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In view of the current experimental situation the strongest physics case exists for a

"Higgs factory": LC with $\sqrt{s} \lesssim 250$ GeV
($+$ running at WW threshold and Z resonance)

or a

"Higgs $+$ top factory": LC with $\sqrt{s} \lesssim 350$ GeV

$\Rightarrow$ – Decay-mode independent search (recoil method)
- Absolute measurement of ZZH coupling
- Precise measurement of Higgs mass, width, couplings,
- branching ratios (also Higgs $\to$ invisible)
- Determination of Higgs spin and quantum numbers, ...
- Precision top $+$ electroweak physics

Extension to higher energies?

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Results from the LHC run 2011 / 2012 will provide important further information $\Rightarrow$ Let's stay tuned!