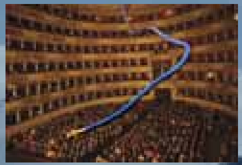
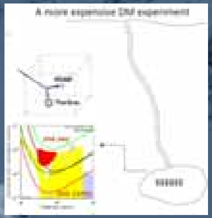
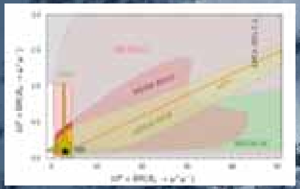
EW MORIOND 2012

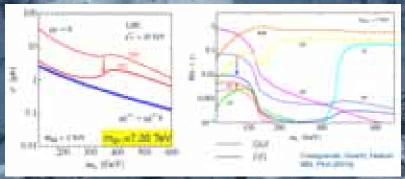
Theory Summary

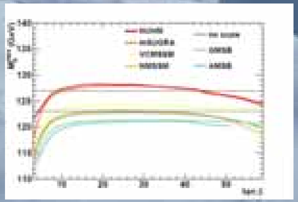
Wilfried Buchmuller
DESY



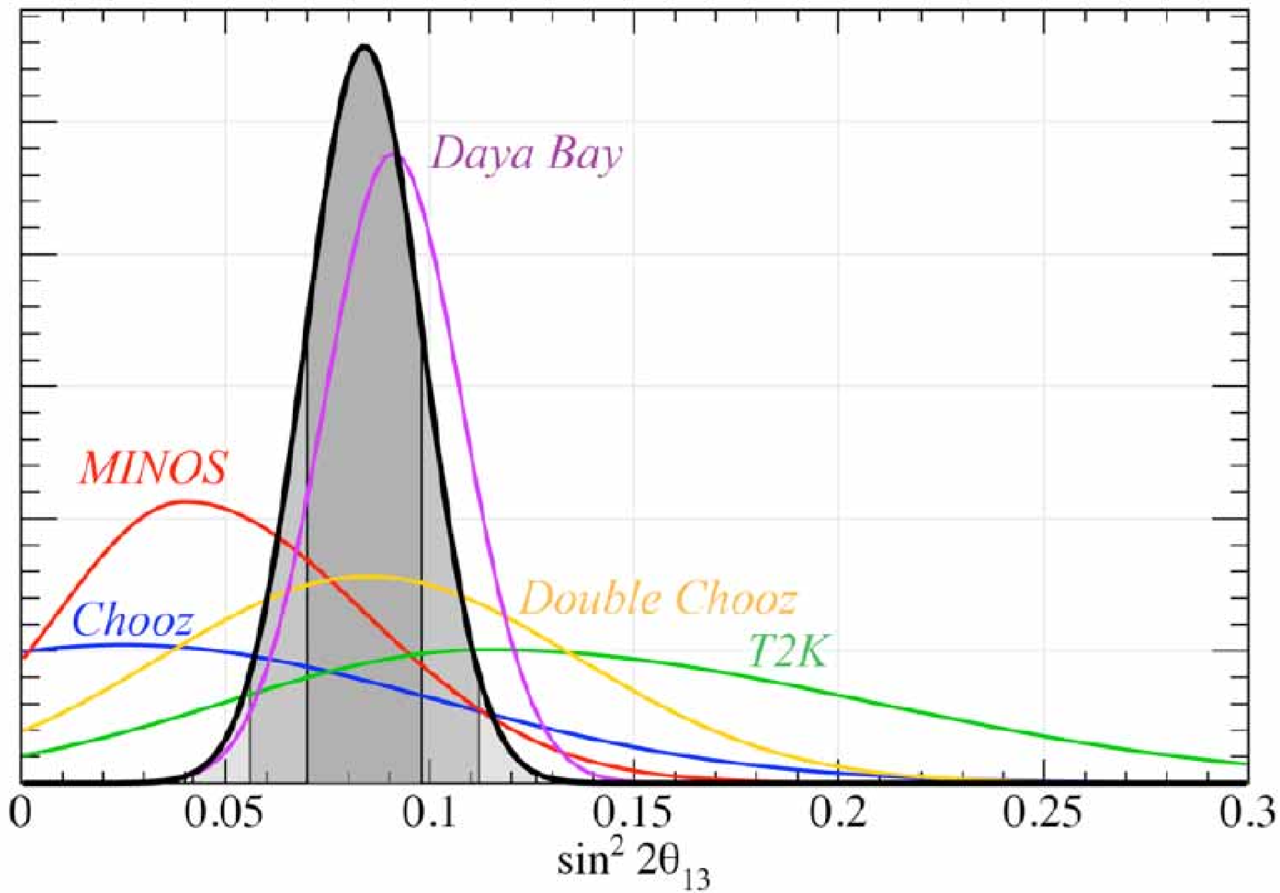








Neutrino Physics



Ideogram of recent θ_{13} results for normal hierarchy, $\delta_{CP}=0$, and maximal θ_{23}

Messier

Very important result!

Implications:

Kayser

- Good prospects to measure neutrino mass hierarchy & CP violation
- Model building: `tri-bi-maximal' mixing vs `anarchy'
- Role of sterile neutrinos? Various anomalies in oscillation experiments; effect on BBN (CMB)? Have to be taken into account in $0\nu2\beta$ decay

Mitra

N_{eff} From CMB

Model	Data	N_{eff}	Ref.
N_{eff}	W-5+BAO+SN+H_0	$4.13^{+0.87(+1.76)}_{-0.85(-1.63)}$	[26]
	W-5+LRG+H_0	$4.16^{+0.76(+1.60)}_{-0.77(-1.43)}$	[26]
	W-5+CMB+BAO+XLF+f_{gas}+H_0	$3.4^{+0.6}_{-0.5}$	[29]
	W-5+LRG+maxBCG+H_0	$3.77^{+0.67(+1.37)}_{-0.67(-1.24)}$	[26]
	W-7+BAO+H_0	$4.34^{+0.86}_{-0.88}$	[18]
	W-7+LRG+H_0	$4.25^{+0.76}_{-0.80}$	[18]
	W-7+ACT	5.3 ± 1.3	[23]
	W-7+ACT+BAO+H_0	4.56 ± 0.75	[23]
	W-7+SPT	3.85 ± 0.62	[24]
	W-7+SPT+BAO+H_0	3.85 ± 0.42	[24]
	W-7+ACT+SPT+LRG+H_0	$4.08^{(+0.71)}_{(-0.68)}$	[30]
	W-7+ACT+SPT+BAO+H_0	3.89 ± 0.41	[31]
$N_{eff}+f_\nu$	W-7+CMB+BAO+H_0	$4.47^{(+1.82)}_{(-1.74)}$	[32]
	W-7+CMB+LRG+H_0	$4.87^{(+1.86)}_{(-1.75)}$	[32]
$N_{eff}+\Omega_k$	W-7+BAO+H_0	4.61 ± 0.96	[31]
	W-7+ACT+SPT+BAO+H_0	4.03 ± 0.45	[32]
$N_{eff}+\Omega_k+f_\nu$	W-7+ACT+SPT+BAO+H_0	4.00 ± 0.43	[31]
$N_{eff}+f_\nu+w$	W-7+CMB+BAO+H_0	$3.68^{(+1.90)}_{(-1.84)}$	[32]
	W-7+CMB+LRG+H_0	$4.87^{(+2.02)}_{(-2.02)}$	[32]
$N_{eff}+\Omega_k+f_\nu+w$	W-7+CMB+BAO+SN+H_0	$4.2^{+1.10(+2.00)}_{-0.61(-1.14)}$	[33]
	W-7+CMB+LRG+SN+H_0	$4.3^{+1.40(+2.30)}_{-0.54(-1.09)}$	[33]

More precise information will come from the Planck satellite.

extra radiation?

Einstein vs OPERA

OPERA:

$$\frac{v_\nu - c}{c} = (2.48 \pm 0.28\,(\text{stat}) \pm 0.30\,(\text{sys})) \times 10^{-5}$$

- Neutrino propagate in a metric $g^{(\nu)}_{\alpha\beta} = g_{\alpha\beta} + \delta g_{\alpha\beta}$ different from gravitational $g_{\mu\nu}$ by $|\delta g_{\alpha\beta}| = \epsilon \sim 10^{-5}$

$$(\eta_{\alpha\beta} + \delta g_{\alpha\beta})\, \overline{\nu}\, \gamma^\alpha\, \partial^\beta \nu$$

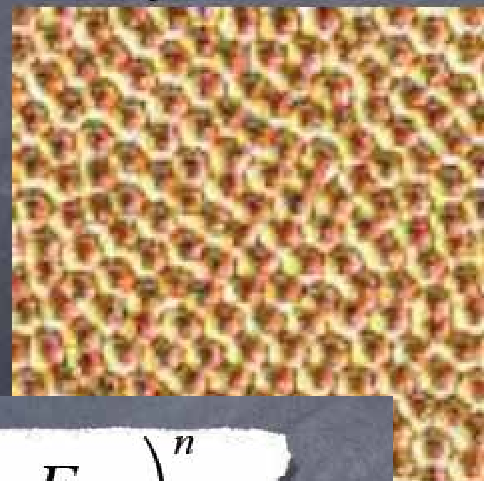
- Only possible if the Lorentz symmetry is spontaneously broken by a background

Vikman

Mild version of Lorentz symm breaking,…but massive \`graviton' with Compton wavelength of the earth

Lorentz Violation (or deformation) appears in various Quantum Gravity Theories.

Energy dependent dispersion and speed of light.



$$E^2 - p^2 - m^2 \approx \pm \left(\frac{E}{\xi_n m_{pl}} \right)^n$$

$$v \approx c \left[1 \pm \frac{(1+n)}{2} \left(\frac{E}{\xi_n m_{pl}} \right)^n \right]$$

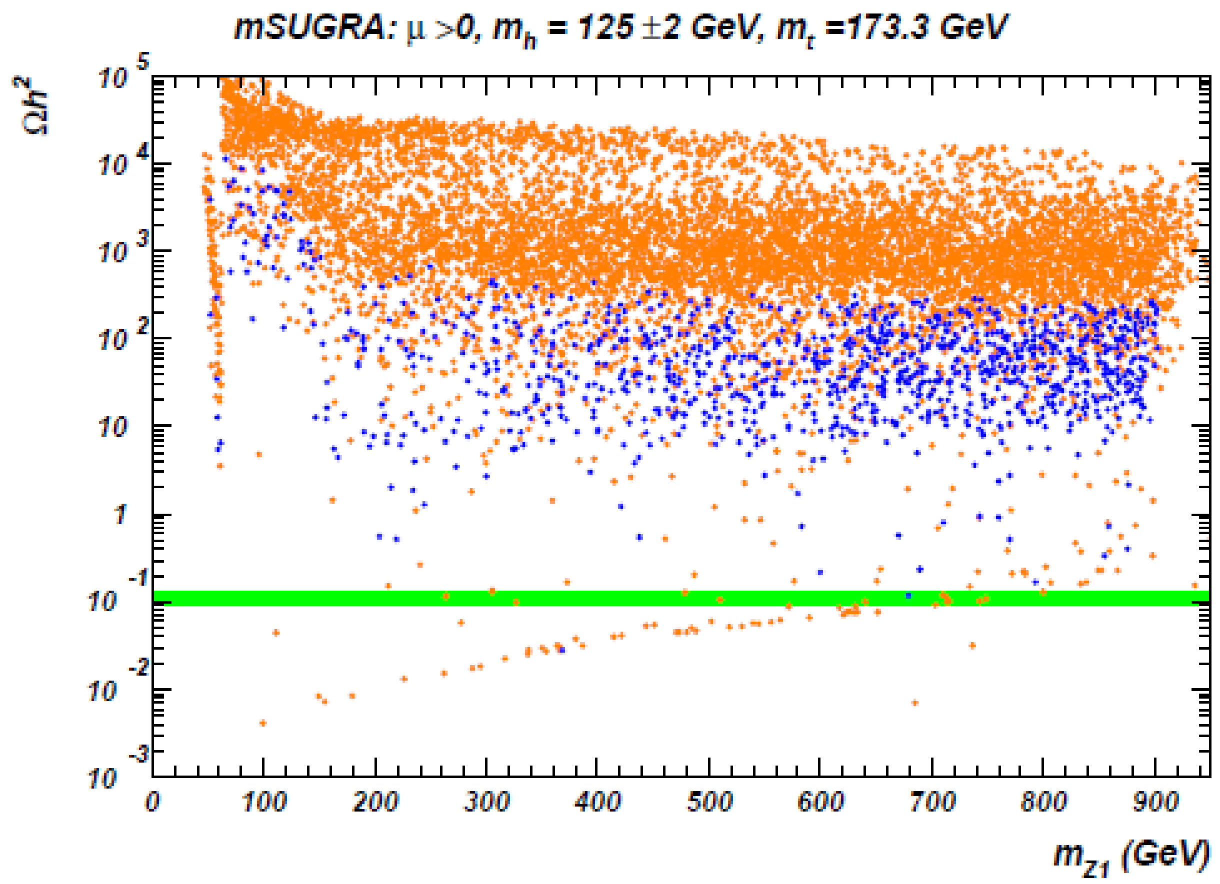
Drastic violation of Lorentz symm; photon/ neutrino comparison interesting

Piran

Dark Matter

- One of the most outstanding problems today; connects collider physics with direct searches & indirect detection
- Candidates: "standard" (WIMP, axion) & "nonstandard" (sterile neutrino, gravitino, axino,...)
- Numerous experimental bounds, standard freeze-out scenario severely constrained

Problematic: Dark Matter (neutralino) (Baer et al, 1202.4038)



DM abundance typically much too large; blue: $m_0 < 5$ TeV, orange: 5 TeV $< m_0 < 20$ TeV: green: allowed by WMAP

Singlet Scalar coupled to Higgs

Silveira, Zee (1985); McDonald (1993); Burgess, MP, ter Veldhuis(2000)

DM through the Higgs portal – *minimal model of DM*

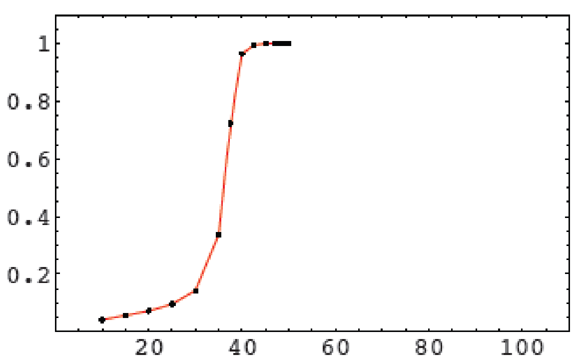
$$-\mathcal{L}_S = \frac{\lambda_S}{4}S^4 + \frac{m_0^2}{2}S^2 + \lambda S^2 H^\dagger H$$

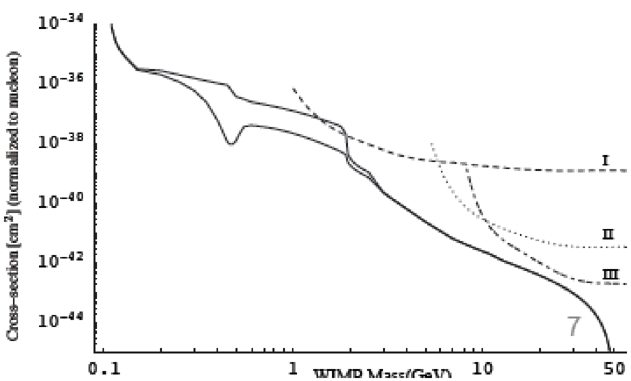
$$= \frac{\lambda_S}{4}S^4 + \frac{1}{2}(m_0^2 + \lambda v_{EW}^2)S^2 + \lambda v_{EW} S^2 h + \frac{\lambda}{2}S^2 h^2$$

125 GeV Higgs is "very fragile" because its with is ~ y_b^2 – very small

$R = \Gamma_{SM\ modes}/(\Gamma_{SM\ modes}+\Gamma_{DM\ modes})$. Light DM can kill Higgs boson easily

(missing Higgs Γ: van der Bij et al., 1990s, Eboli, Zeppenfeld,2000)





Pospelov

Strongly constrained by `Higgs discovery'

Secluded WIMPs and Dark Forces

MP, Ritz, Voloshin; Finkbeiner and Weiner, 2007. Original model: Holdom 86

$$\mathcal{L}_{\mathrm{WIMP+mediator}} = -\frac{1}{4}V_{\mu\nu}^2 - \frac{\kappa}{2}V_{\mu\nu}B_{\mu\nu} - |D_\mu\phi|^2 - U(\phi\phi^*) + \bar{\psi}(iD_\mu\gamma_\mu - m_\psi)\psi.$$

This Lagrangian describes an extra U(1)' group (**dark force**), and some matter charged under it. Mixing angle κ controls the coupling to the SM.

ψ – Dirac type WIMP; V_μ – mediator particle.

Two kinematic regimes can be readily identified:

- $m_{mediator} > m_{WIMP}$

  $\psi^+ + \psi^-$ -> virtual V^* -> SM states

κ has to be sizable to satisfy the constraint on cross section

2. $m_{mediator} < m_{WIMP}$

   $\psi^+ + \psi^-$ -> on-shell $V + V$, followed by V -> SM states

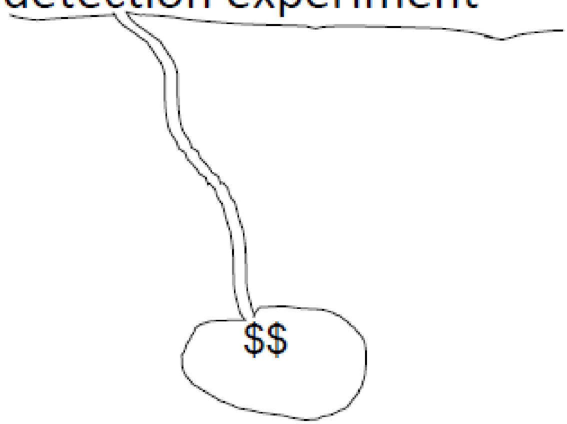
There is almost no constraint on κ other than it has to decay before BBN. κ^2 » 10^{-20} can do the job.

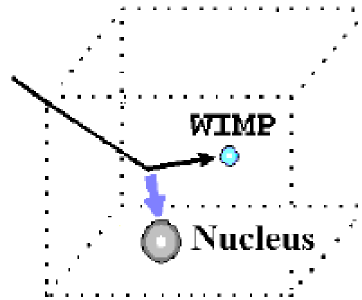
Dark Matter may come with additional mediating force

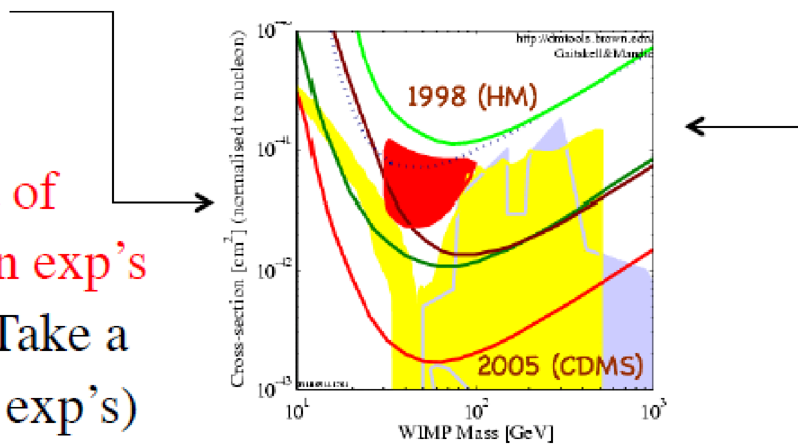
Currently all "direct DM detection" experiments search for the same thing

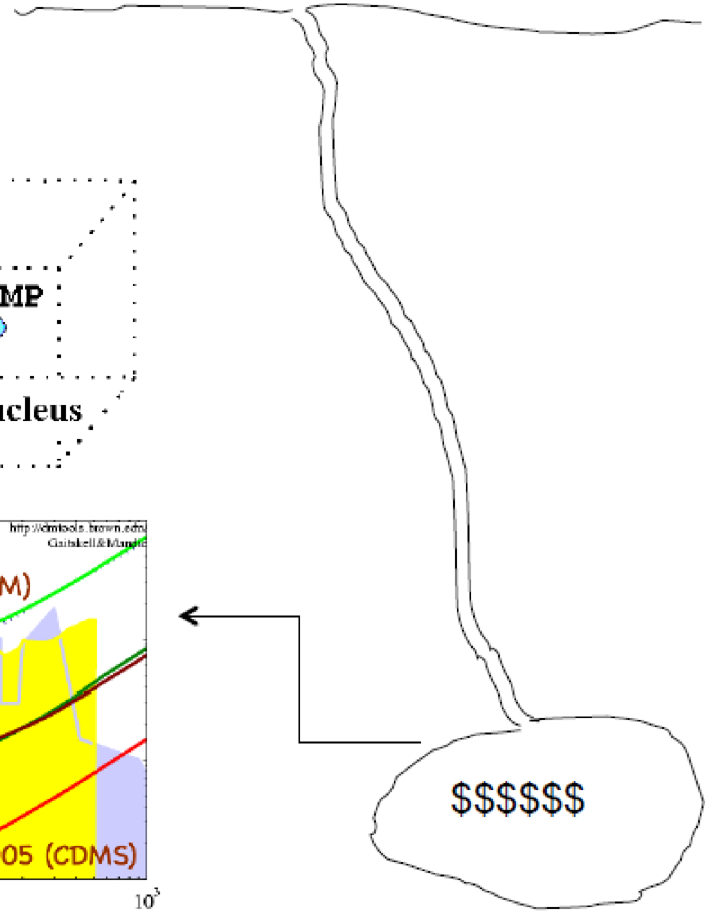
An average Dark Matter detection experiment

A more expensive DM experiment









Diversifying physics output of direct detection exp's is needed !!! (Take a cue from HEP exp's)

Pospelov

Other signals than WIMP scattering? Super-WIMP absorption?

Comments on DM:

- So far we have only one number (relic density) and upper bounds (direct & indirect detection)
- Important: theoretical justification, connection with other observables (gravitino, neutralino, axion,…)
- Consistent cosmology: DM, BBN, baryogenesis, inflation,…

Flavour Physics

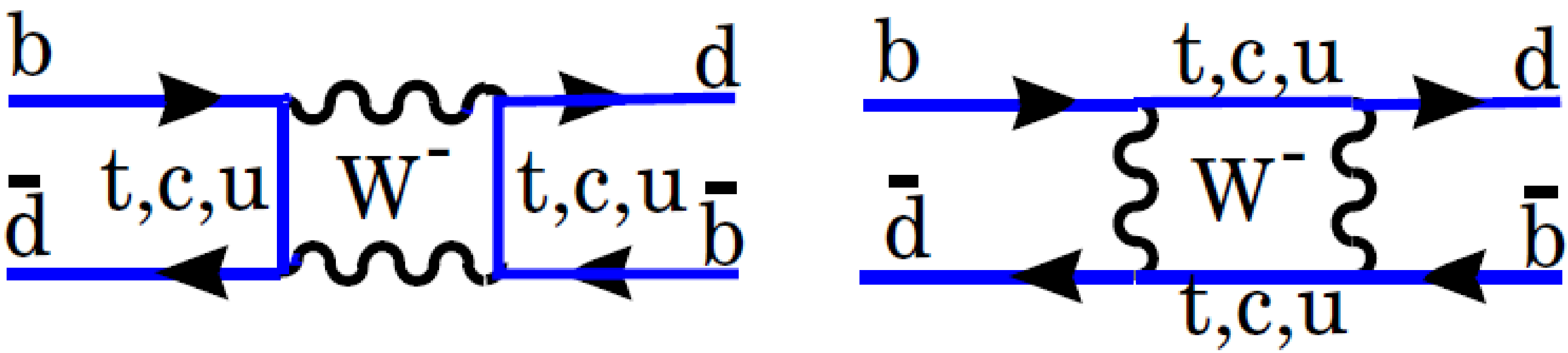
- B's: mixings and rare decays
- D's: direct CP violation
- top: NP in charge asymmetry?
- Hadronic matrix elements
- SUSY flavour violation
- Flavour in extra dimensions

B-meson mixing

Time evolution of a decaying particle: $B(t) = \exp\left[-im_B t - \Gamma_B/2t\right]$
can be written as

$$i\frac{d}{dt}\begin{pmatrix} |B(t)\rangle \\ |\bar{B}(t)\rangle \end{pmatrix} = \left(\hat{M} - \frac{i}{2}\hat{\Gamma}\right)\begin{pmatrix} |B(t)\rangle \\ |\bar{B}(t)\rangle \end{pmatrix}$$

BUT: In the neutral B-system transitions like $B_{d,s} \to \bar{B}_{d,s}$ are possible due to weak interaction: **Box diagrams**



Lenz

B-meson mixing important problem since 25 years!

Theory 1102.4274 vs. Experiment : HFAG 11

Theory	Experiment
$\Delta M_d = 0.543 \pm 0.091\, ps^{-1}$	$\Delta M_d = 0.507 \pm 0.004\, ps^{-1}$ ALEPH, CDF, D0, DELPHI, L3, OPAL, BABAR, BELLE, ARGUS, CLEO
$\Delta M_s = 17.30 \pm 2.6\, ps^{-1}$	$\Delta M_s = 17.70 \pm 0.12\, ps^{-1}$ CDF, D0, LHCb

Important bounds on the unitarity triangle and new physics

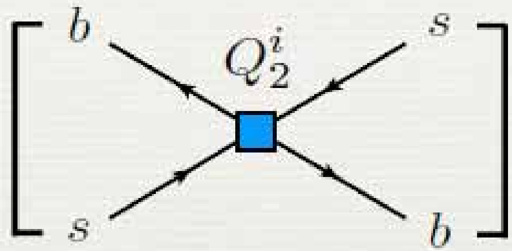
LP 2011 $\Delta\Gamma_s = (0.123 \pm 0.031)\,\text{ps}^{-1} \Rightarrow \frac{\Delta\Gamma_s^{\text{Exp}}}{\Delta\Gamma_s^{\text{SM}}} = 1.41 \pm 0.50$

Moriond 2012 $\Delta\Gamma_s = (0.116 \pm 0.019)\,\text{ps}^{-1} \Rightarrow \frac{\Delta\Gamma_s^{\text{Exp}}}{\Delta\Gamma_s^{\text{SM}}} = 1.33 \pm 0.39$

HQE works well, impressive agreement with SM!

- Generic, sufficiently heavy new physics (NP) in M_{12} (Γ_{12}) can be described via effective $\Delta B = 2$ ($\Delta B = 1$) interactions:

$(M_{12})_{\rm NP} \propto C_2^i$

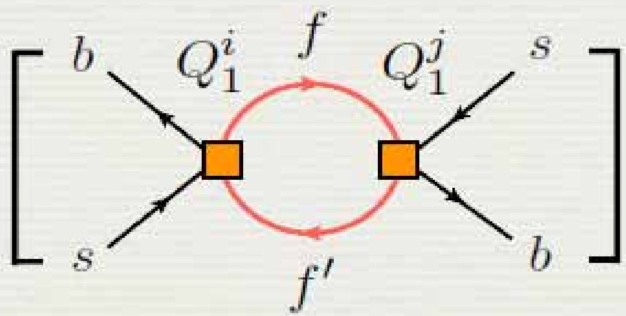


$\sim \frac{1}{\Lambda_{\rm NP}^2}$

NP scale

very sensitive to new particles: SUSY, extra dimensions, ...

$(\Gamma_{12})_{\rm NP} \propto C_1^i C_1^j \; \mathrm{Im}$



$\sim \frac{1}{(4\pi)^2} \frac{1}{\Lambda_{\rm NP}^4}$

free of NP (?), since coefficients would also give B decays into light final states X ($M_X < m_b$)

loop factor

Haisch

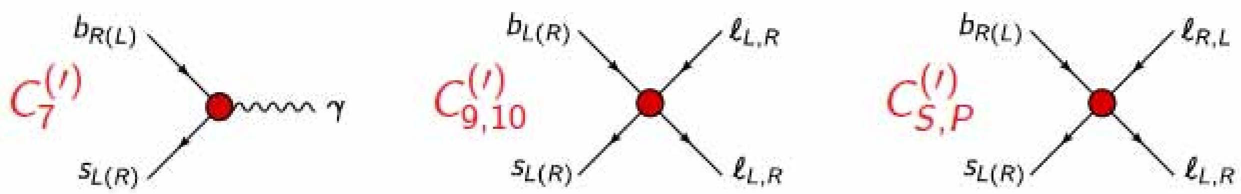
No NP in Bs mixing and decays; bounds on new physics scale: 1–3 TeV

$b \to s$ effective Hamiltonian

$$\mathcal{H}_{\text{eff}}^{\Delta F=1} = -\frac{4G_F}{\sqrt{2}} V_{tb} V_{ts}^* \sum (C_i \mathcal{O}_i + C_i' \mathcal{O}_i')$$

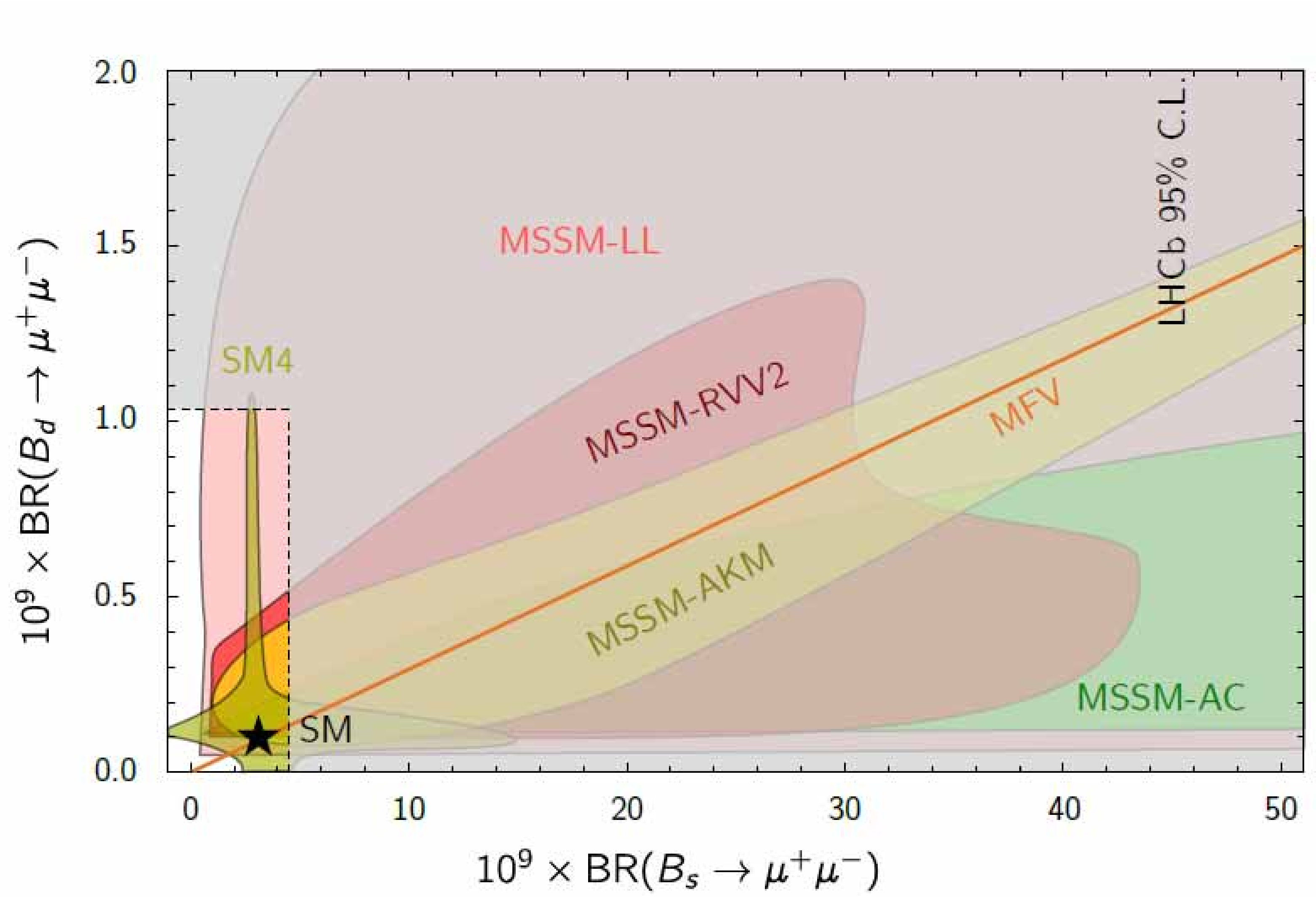
Wilson coefficient — Dimension-6 operator

Straub



	mag. dipole operator	semileptonic operators	scalar operators	(neglecting: tensor op.s)
$B \to (X_s, K^*)\gamma$	x			
$B \to (X_s, K^{(*)})\ell^+\ell^-$	x	x		
$B_s \to \mu^+\mu^-$		x	x	

agreement with SM model constrains Wilson coefficients



New experimental bounds already exclude large part of model parameter space

Direct CPV in D-Decays

- the topic of the talk

$$\Delta A_{CP} = A_{CP}(D \to K^+K^-) - A_{CP}(D \to \pi^+\pi^-)$$

  - experiment (WA): $\Delta A_{CP} = (-0.67 \pm 0.16)\%$

Di Canto, La Thuile 2012

- could it be New Physics?
- could it be Standard Model?
- could we have anticipated such a large value?
  - how large is the SU(3) breaking in charm?

Zupan

Interesting effect, complicated story …

Transverse momentum of the $t\bar{t}$ pair

- the inclusive asymmetry is robust against higher order corrections [see also Melnikov]
- but diff. distributions might be quite sensitive ($t\bar{t}$+jet @NLO [Dittmaier, Uwer, Weinzierl / Alioli, Moch, Uwer])
- virtual + soft (positive) vs. real (negative)

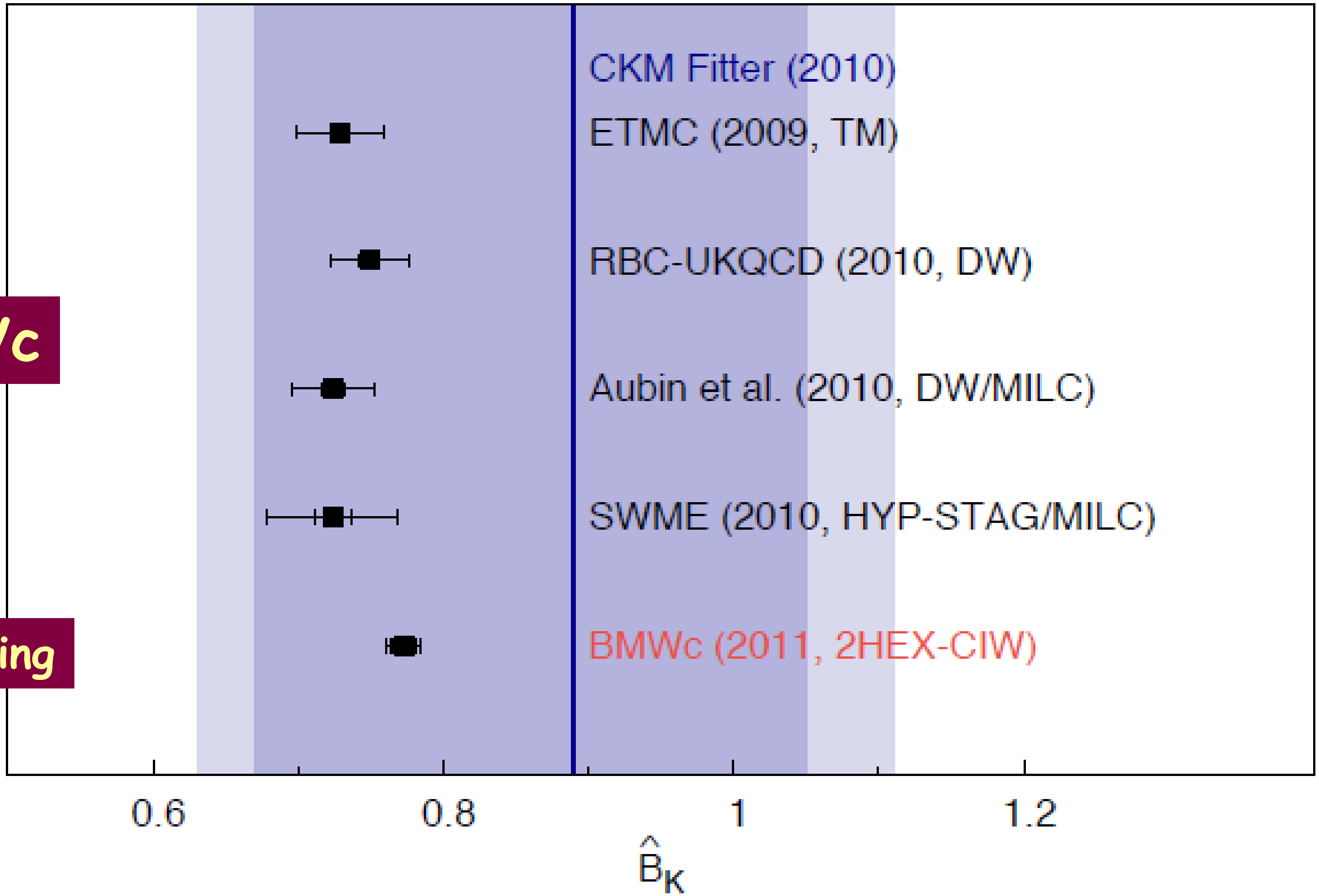
	$A_{t\bar{t}}$	$m_{t\bar{t}} < 450$ GeV	$m_{t\bar{t}} > 450$ GeV
$p_\perp^{t\bar{t}} < 10$ GeV	0.136 (16)	0.097 (8)	0.201 (19)
$p_\perp^{t\bar{t}} < 20$ GeV	0.115 (13)	0.082 (7)	0.171 (16)
Inclusive	0.087 (10)	0.062 (5)	0.128 (11)

[Kühn, GR, arXiv:1109.6830]

Rodrigo

top charge asymmetry: 3.4σ effect in CDF, NP?
New results from 2012 LHC run, Tevatron update

Hadronic matrix elements: K-meson mixing



BMWc

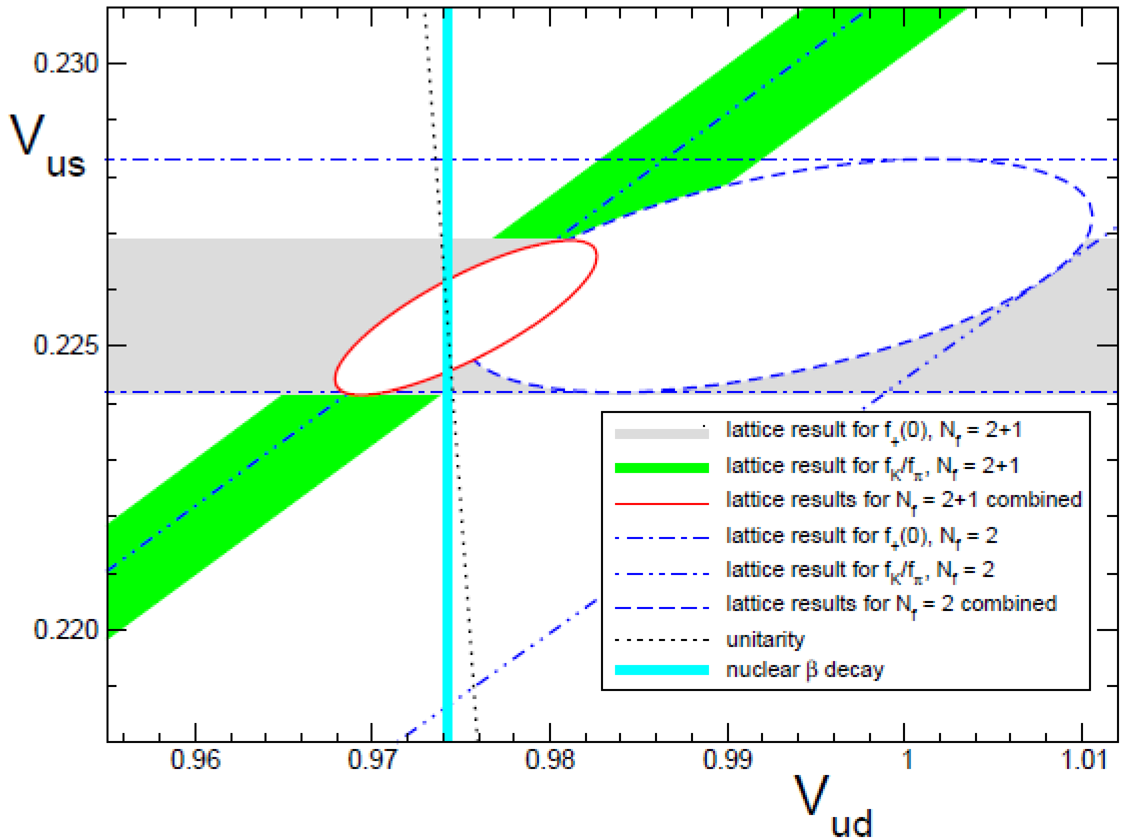
Hoelbling

amazing accuracy...

Unitarity test of the Standard Model

FLAG

Colangelo



Strong constraint on right-handed currents

Bernard, Oertel, Passemar, Stern (08-09), Buras, Gemmler, Isidori (10)

Consistency of CKM unitarity with lattice (2+1 flavour)

SUSY_FLAVOUR v2.0

A.C., Janusz Rosiek, arXiv:1203.XXXX

Calculates in the generic MSSM:

- EDMs and anomalous magnetic moments
- $\bar{D}-D, \bar{B}_{s,d}-B_{s,d}, \bar{K}-K$
- $b\to s\gamma, \mu\to e\gamma, \tau\to\mu\gamma, \tau\to e\gamma$
- $K_L\to\pi\nu\bar{\nu}, K^+\to\pi^+\nu\bar{\nu}$
- $B_{s,d}\to l^+l^-, K_L\to l^+l^-$
- $B\to\tau\nu, B\to D\tau\nu$

Valuable tool for all SUSY model builders

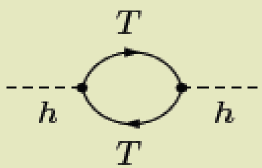
Crivellin

Including the important resummation of all chirally enhanced effects A.C., L. Hofer, J. Rosiek arXiv:1103.4272

Flavor Structure in the SM and Beyond

$$\mathcal{L}_{\rm EFT} = \Lambda_{\rm UV}^2\,\Phi^\dagger\Phi - \lambda(\Phi^\dagger\Phi)^2 + \mathcal{L}_{\rm SM}^{\rm gauge} + \mathcal{L}_{\rm SM}^{\rm Yukawa} + \frac{\mathcal{L}^{(5)}}{\Lambda_{\rm UV}} + \frac{\mathcal{L}^{(6)}}{\Lambda_{\rm UV}^2} + \dots$$

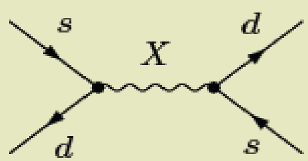
electroweak symmetry breaking $\Downarrow$ Higgs mass



$$\sim \frac{g_T^2}{16\pi^2}\Lambda_{\rm UV}^2$$

no fine-tuning $\Downarrow$

$\Downarrow$



$$\sim \frac{g_X^2}{\Lambda_{\rm UV}^2}$$

bounds on flavor mixing $\Downarrow$ assuming *generic* flavor structure

Neubert

$\Lambda_{\rm Higgs} \lesssim 1$ TeV

$\Lambda_{\rm flavor} \gtrsim 10^3$ TeV

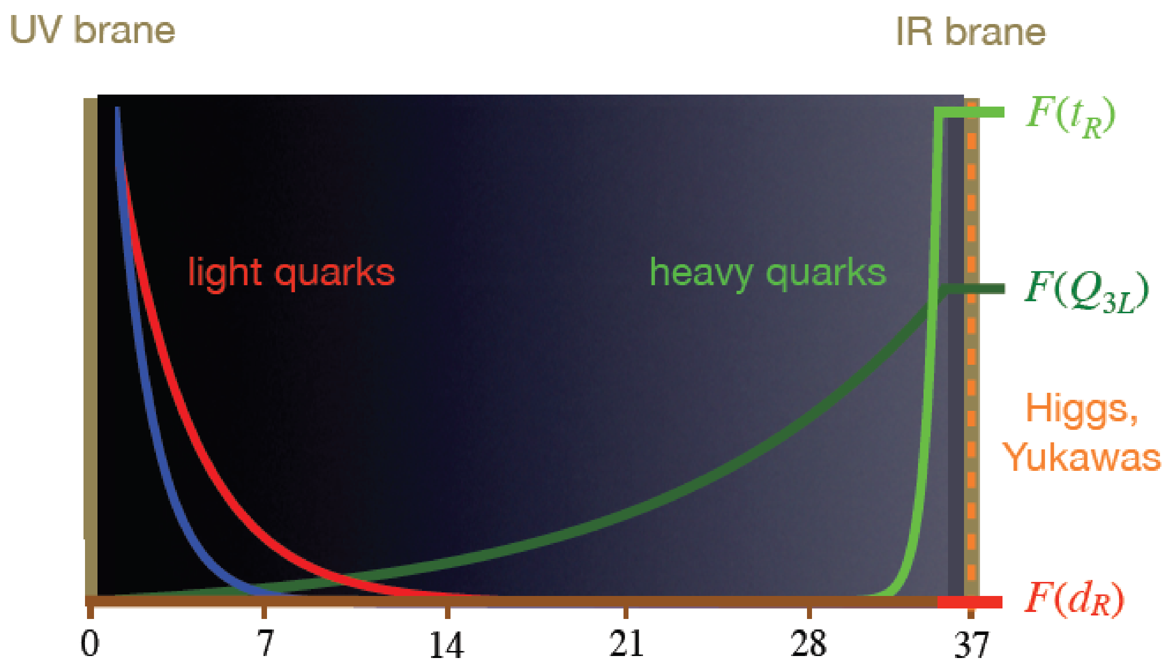
Possible solutions to flavor problem explaining $\Lambda_{\rm Higgs} << \Lambda_{\rm flavor}$:

(i) $\Lambda_{\rm UV} >> 1$ TeV: **Higgs fine tuned**, new particles too heavy for LHC

(ii) $\Lambda_{\rm UV} \approx 1$ TeV: quark flavor-mixing protected by a **flavor symmetry**

Warped extra dimensions interesting example of connection between flavour and Higgs physics

Flavor structure in RS models



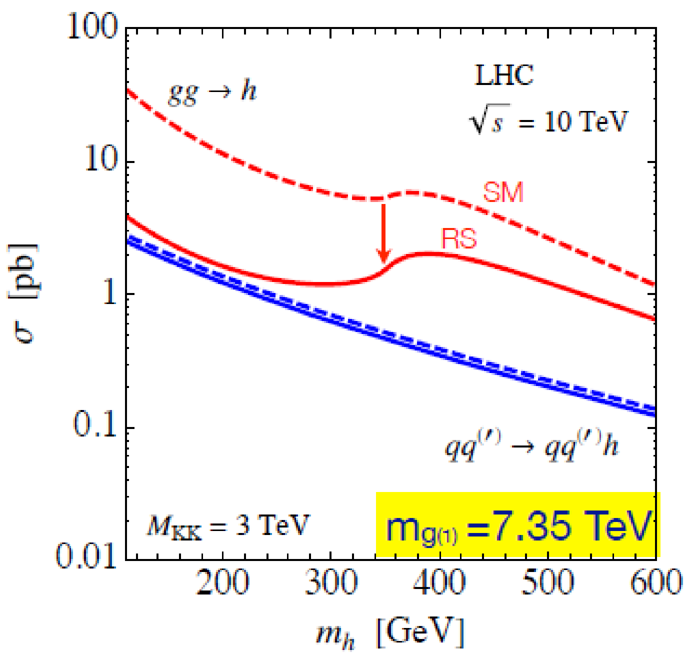
Localization of fermions in extra dimension depends exponentially on O(1) parameters related to the 5D **bulk masses.** Overlap integrals $F(Q_L)$, $F(q_R)$ with IR-localized Higgs sector are **exponentially small** for light quarks, while O(1) for top quark: effective Yukawa couplings exhibit **realistic hierarchies**

Grossman, Neubert (1999); Ghergetta, Pomarol (2000)

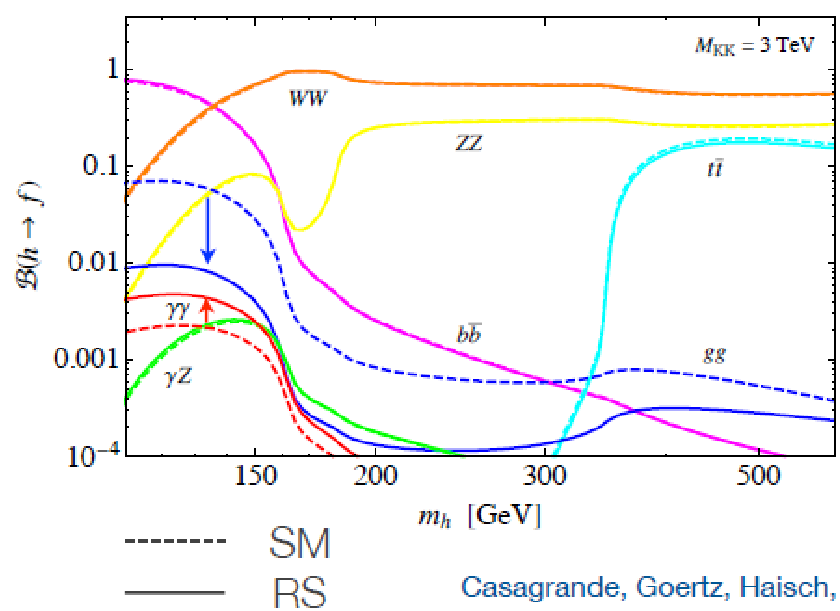
Phenomenologically attractive mass matrices of Froggatt-Nielsen type, geometrical interpretation of parameters; can be consistent with Bs mixing and decays

Higgs production cross sections

Find **spectacular effects** on Higgs production via gluon fusion, even for KK masses out of production reach at LHC ($m_{g^{(1)}} \approx 2.45 M_{\rm KK}$):



Correspondingly, find **significant enhancement** (suppression) of the **h→γγ** (h→gg) branching ratios:



Casagrande, Goertz, Haisch, MN, Pfoh (2010)

Significant deviations from SM Higgs couplings, soon relevant checks from the LHC

Electroweak Symmetry Breaking

- Two alternatives:
  (A) Dynamics of EWSB at TeV scale
  (technicolour, compositeness, RS, large extra dimensions)
  (B) Extrapolation to GUT scale (with or without supersymmetry)
- Restoration of EW symmetry (electroweak phase transition, connection to cosmology)
- Check of the Higgs profile

Generalized Higgs sector

How well can we determine the SM Higgs couplings?
Can we distinguish a non-Standard-Model-like Higgs sector?

- Theory: Standard Model plus free Higgs couplings
  Couplings from modified version of HDecay [Djouadi, Kalinowski, Spira]
- For Higgs couplings present in the Standard Model $i = W, Z, t, b, \tau$
  $$g_{iiH} \longrightarrow g_{iiH}^{\mathrm{SM}} \ (1 + \Delta_i) \qquad (\rightarrow \Delta = -2 \text{ means sign flip})$$
- For loop-induced Higgs couplings $i = \gamma, g$
  $$g_{iiH} \longrightarrow g_{iiH}^{\mathrm{SM}} \ \left(1 + \Delta_i^{\mathrm{SM}} + \Delta_i\right)$$

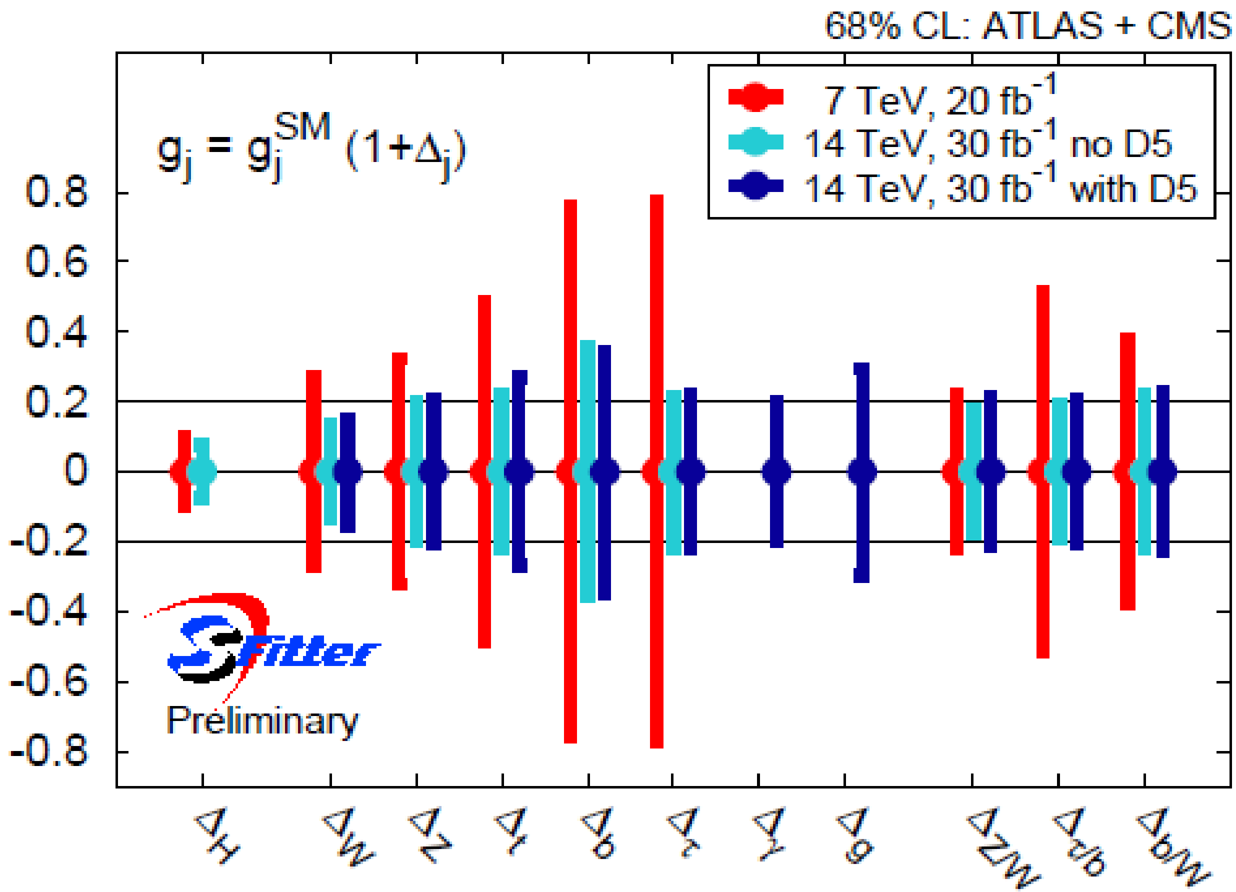
  where g_{iiH}^{SM}: (loop-induced) coupling in the Standard Model
  Δ_i^{SM}: contribution from modified tree-level couplings to Standard-Model particles
  Δ_i : additional (dimension-five) contribution

Rauch

Checks of the Higgs profile: couplings to gauge bosons and fermions

Expectations for $m_H = 125$ GeV

If there is indeed a SM Higgs boson at $\sim$ 125 GeV ...



First significant checks already this year!

EW breaking by new strong interactions

Motivation: strong dynamics is realized in Nature

Can we provide an effective low-energy perturbative description?

- CHPT

(QCD: approximate $SU(2)_L \times SU(2)_R \to SU(2)_V \leftrightarrow$ pions)

What is the nature of the Goldstone bosons which provide $W_L^{\pm}$, Z_L?

- π^a are composite fields

How is perturbative unitarity restored?

- resonances

spin-1 resonances

- Motivation: QCD $\to$ vector meson dominance
- technicolor, deconstruction

scalar resonance

- PG composite scalar

spin-1 resonances - distinctive feature of strong electroweak symmetry breaking models

Dynamical symmetry breaking: intuition and techniques from QCD; key question: unitarization of WW scattering; predictions for spin-1 resonances and composite scalar

Kaminska

How to tell apart 1st generation RH or LH compositeness?

Martin and VS JHEP (2010)
Redi,VS, Weiler in preparation

Composite baryons and elementary quarks mix

$$\mathcal{L}_{mixing} = \lambda^u_{L,R} u_{L,R} \bar{U}_L + (u \to d) \qquad y \propto \lambda_L \lambda_R$$

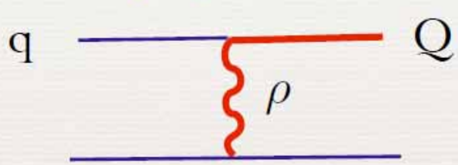
1st generation compositeness! Flavor?

MFV if composite sector flavor invariant

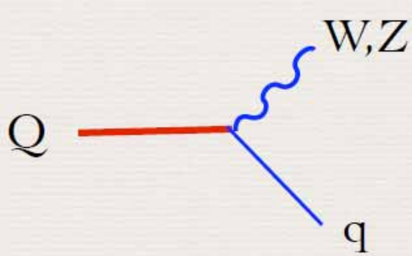
Redi, Weiler '11

MFV → half of the proton could be composite

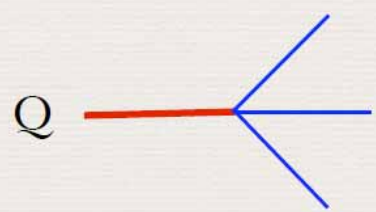
Signature: single production heavy quark



LH compositeness



RH compositeness



In case of strong EWSB also composite fermions expected; connection to extra dimensions (RS); surprizing signatures conceivable due to chiral nature of weak interactions

Sanz

Gauge-Higgs unification

A_M *in 5 dim.*

4-dim. components A_μ — extra-dim. component A_y

$\cup$ 4D gauge fields: γ , W , Z

$\cup$ 4D Higgs fields: H

Aharonov-Bohm phase

⇓

EW symmetry breaking

Hosotani mechanism

can give 125 GeV Higgs
with non-SM couplings
or stable Higgs

Hosotani

Physics

HEIDI Models (with S. Dilcher and B. Puliçe)

Higher dimensional singlet $\Rightarrow$ Few Parameters !

In terms of the modes H_i the Lagrangian is the following:

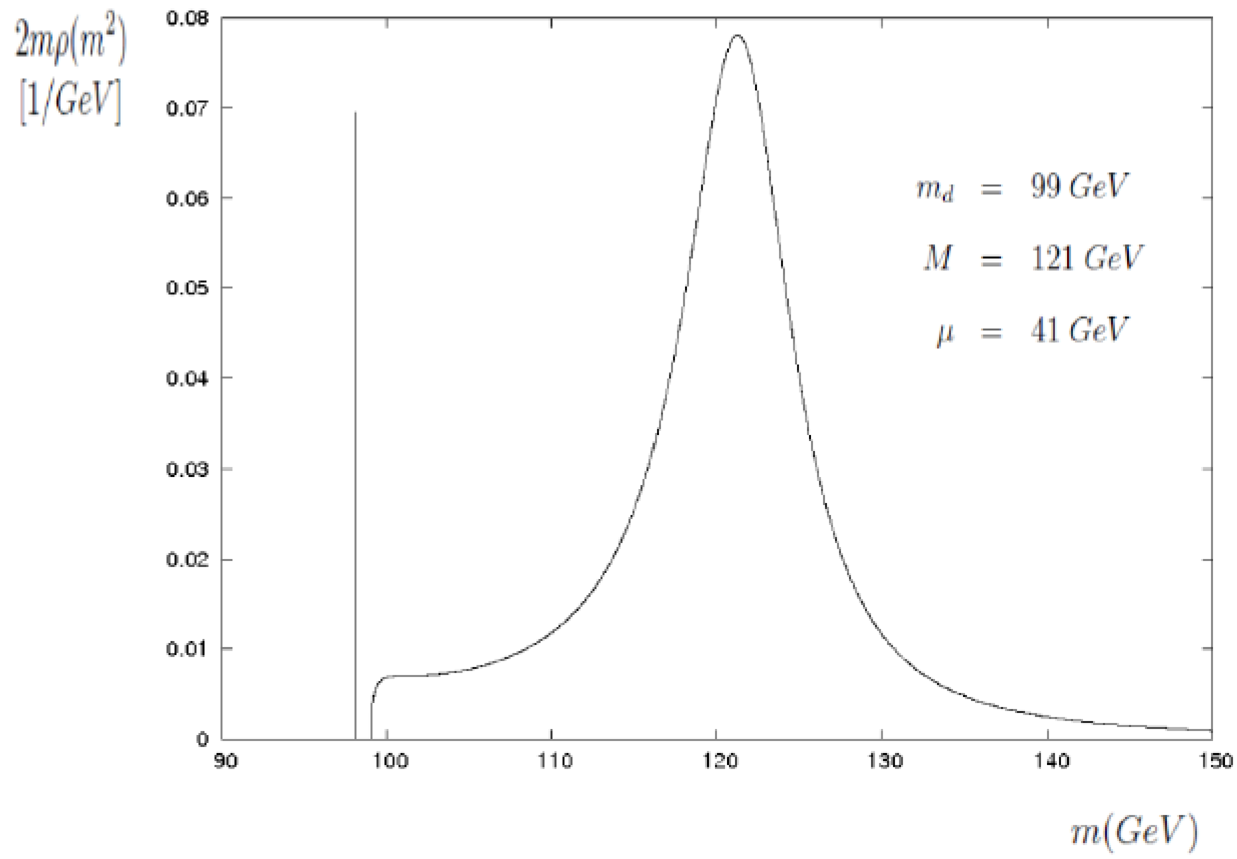
$$\begin{aligned} L &= -\frac{1}{2} D_\mu \Phi^\dagger D_\mu \Phi - \frac{M_0^2}{4} \Phi^\dagger \Phi - \frac{\lambda}{8} (\Phi^\dagger \Phi)^2 \\ &- \frac{1}{2} \sum (\partial_\mu H_k)^2 - \sum \frac{m_k^2}{2} H_k^2 \\ &- \frac{g}{2} \Phi^\dagger \Phi \sum H_k - \frac{\zeta}{2} \sum H_i H_j \end{aligned}$$

van der Bij

$m_k^2 = m^2 + m_\gamma^2 \vec{k}^2$, where $\vec{k}$ is a γ-dimensional vector, $m_\gamma = 2\pi/L$ and m a d-dimensional mass term for the field H.

$$S = \int d^{4+\gamma}x \prod_{i=1}^{\gamma} \delta(x_{4+i}) \left(g_B H(x) \Phi^\dagger \Phi - \zeta_B H(x) H(x) \right)$$

Many singlets could couple to the SM via the Higgs, yielding many copies of the Higgs boson: interesting phenomenology!



Unfamiliar spectral functions for Higgs field conceivable; can be verified/falsified at the LHC

Extrapolation to the GUT scale

Forces and matter of the Standard Model naturally fit into the 'unification' (GUT) group $SU(5)$ (Georgi, Glashow '74), or larger extensions,

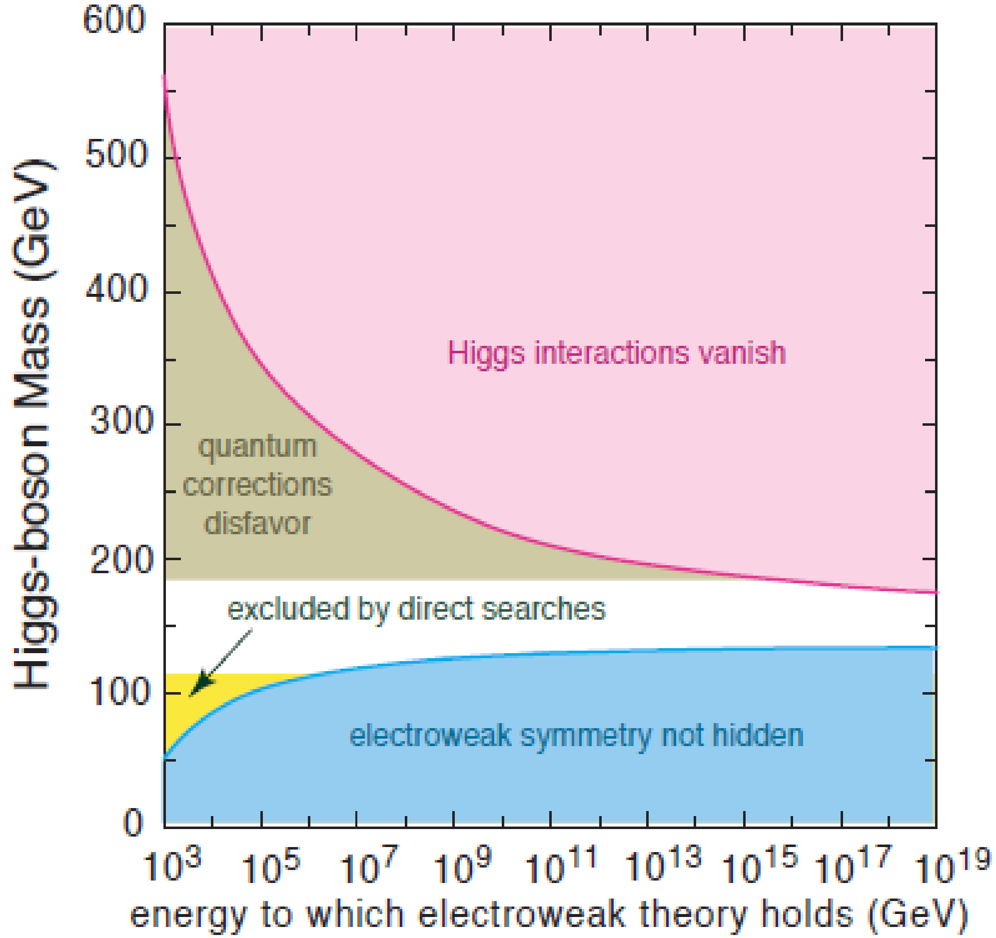
$$SU(5) = \begin{pmatrix} SU(3) & * \\ * & SU(2) \end{pmatrix}$$

with quarks and leptons represented by $\mathbf{10}$, $\mathbf{5}^*$ and $(\mathbf{1} = \nu^c)$,

$$\begin{pmatrix} 0 & u^c & u^c & u & d \\ & 0 & u^c & u & d \\ & & 0 & u & d \\ & & & 0 & e^c \\ & & & & 0 \end{pmatrix} \oplus \begin{pmatrix} d^c \\ d^c \\ d^c \\ \nu \\ e \end{pmatrix} \oplus (\nu^c) \ .$$

Hope: extrapolation possible up to the GUT scale $\Lambda_{\mathrm{GUT}} \sim 10^{15}\ \mathrm{GeV}$, where the 'running' gauge couplings become equal.

Fermi scale requires `fine-tuning' of 10^{-26}, motivation for supersymmetry



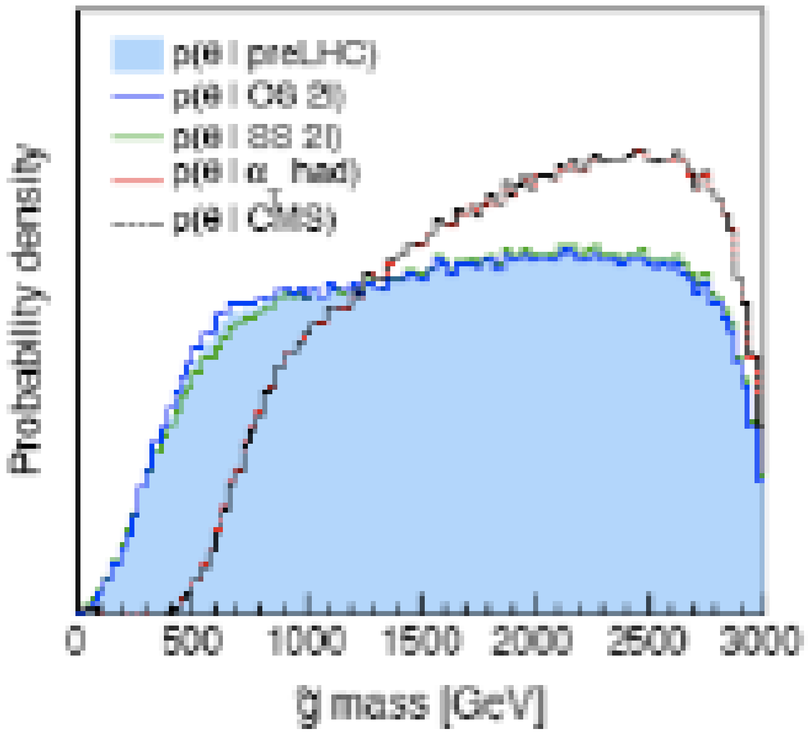
Extrapolation to GUT scale requires Higgs mass in narrow range; hints from LHC, if confirmed, triumph of electroweak theory! [from Quigg '07]

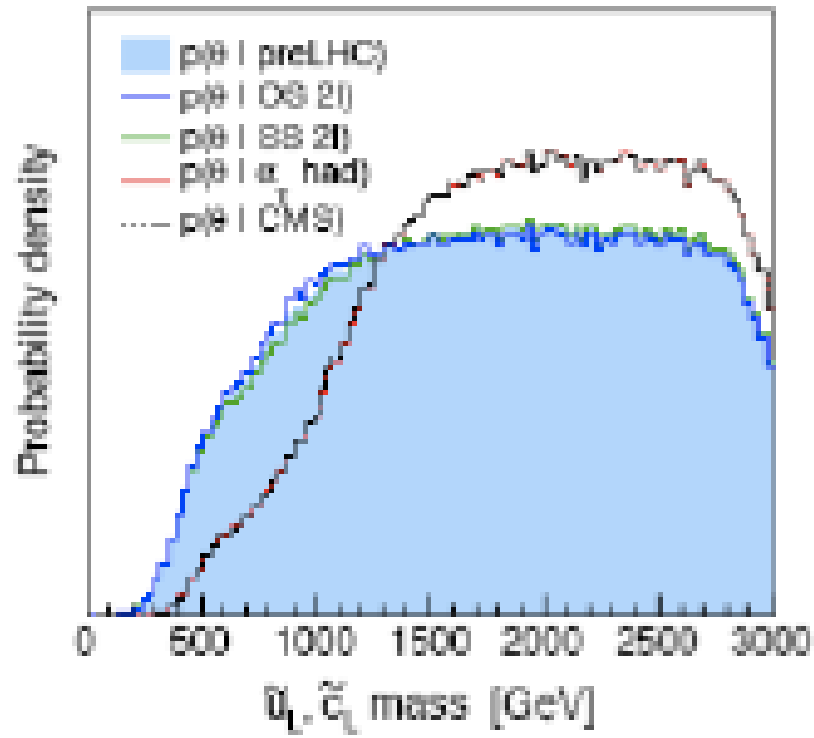
Supersymmetry

Is SUSY in trouble ?

Kraml

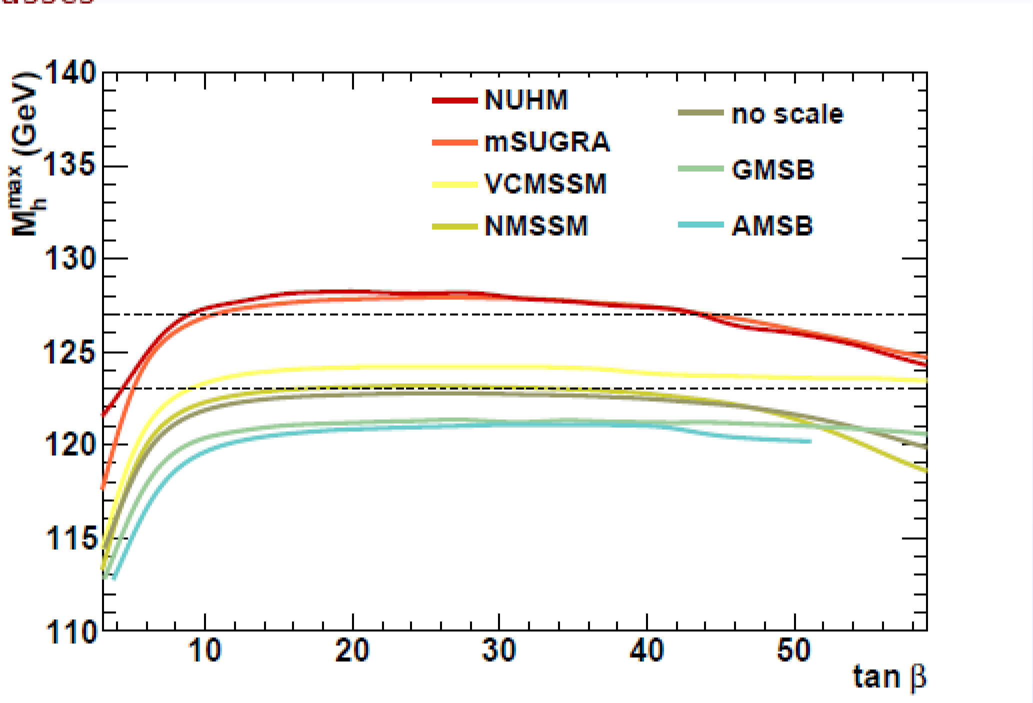
So far no excess in missing energy events,…,
go beyond CMSSM, consider pMSSM





`probability densities' for superparticle masses shifted to higher energies, but still in LHC range

Maximal Higgs masses



Mahmoudi

A. Arbey, M. Battaglia, A. Djouadi, F.M., J. Quevillon, Phys.Lett. B708 (2012) 162

model	AMSB	GMSB	mSUGRA	no-scale	cNMSSM	VCMSSM	NUHM
$M_h^{\max}$	121.0	121.5	128.0	123.0	123.5	124.5	128.5

End of AMSB and GMSB in their minimal versions!

Higgs mass of 125 GeV severe constraint on all models!

What is the problem?

Tree level bound on Higgs boson mass,

$$m_{h^0} < m_Z |\cos 2\beta| \ ,$$

hence $\mathcal{O}(100\%)$ quantum corrections to $m^2_{h^0}$ required,

$$125^2 \ \simeq \ 91^2 + 86^2 \ ;$$

in MSSM via top/stop loops ($m_S^2 = m_{\tilde{t}_1} m_{\tilde{t}_2}$; X_t: stop mixing parameter; $\tan\beta \gg 1$),

$$\frac{m_Z^2}{m_{h_0}^2} = \left[1 + \frac{3}{2\pi^2}\frac{y_t^4}{g_1^2 + g_2^2}\left(\log\frac{m_S^2}{m_t^2} + \frac{X_t^2}{m_S^2}\left(1 - \frac{X_t^2}{12\, m_S^2}\right)\right)\right]^{-1} ,$$

decreases only logarithmically with m_S; large stop masses required!

Large quantum corrections from top/stop

`Sum rule' for the Fermi scale (SUSY breaking & radiative EWSB):

Fermi scale in terms of scalar and gaugino masses at GUT scale ($\tan\beta \gg 1$),

$$
\begin{aligned}
\widehat{m}_Z^2 = & -2\left(|\mu|^2 + m_{H_u}^2\right)\Big|_{m_S} \\
& = \Big(2.20\, M_3^2 - 0.44\, M_2^2 - 0.02\, M_1^2 + 0.20\, M_2 M_3 + 0.03\, M_1 M_3 \\
& \quad + 0.64\, m_U^2 + 0.61\, m_Q^2 - 0.03\, m_D^2 - 1.36\, m_{H_u}^2 - 0.03\, m_{H_d}^2 \\
& \quad + 0.20\, A_0^2 - 0.42\, A_0 M_3 - 0.12\, A_0 M_2 - 0.02\, A_0 M_1 \\
& \quad - 1.68\, |\mu|^2\Big)\Big|_M .
\end{aligned}
$$

To obtain Fermi scale, $\widehat{m}_Z^2 \sim v_F^2 \sim (100\ \mathrm{GeV})^2$, cancellations on r.h.s. required at the level of 1% or less; possible, but what is the mechanism behind this? Various models make various suggestions, at present no consensus (supersymmetry turns 'hierarchy problem' into 'little hierarchy problem').

What is natural ?

Our scenario

[Kersten & L.V-S in prep.]

High Scale

- Gaugino masses $m_{3/2}\, k_a(1+\Delta_a)$, $M_2 > M_1, M_3$, $k_a < 1$
- Scalar masses $m_{3/2} \leq O(10)$ TeV
- Trilinear masses $m_{3/2}$

Necessary to achieve a good value of m_h

- tan β small

$pp \to \quad \tilde{g}\tilde{g}, \quad \tilde{\chi}_1^0\tilde{\chi}_1^\pm, \quad \tilde{\chi}_1^\pm\tilde{\chi}_1^\mp$

EW Scale

$m_{\tilde{f}_2} \approx m_{\tilde{f}_3} \sim 2m_{\tilde{f}_1} \sim O(m_{3/2})$

$900\text{GeV} < m_{\tilde{g}} < 1800\text{GeV}$

$4 < \tan\beta < 20$

- Typical decays

Primary

$$\begin{aligned}\tilde{g} &\to \tilde{\chi}_2^0\, t\bar{t}\\ &\to \tilde{\chi}_1^0\, b\bar{b}\\ &\to \tilde{\chi}_1^0\, q\bar{q}\\ &\to (\tilde{\chi}_1^-\bar{d}u + h.c.)\end{aligned}$$

Secondary

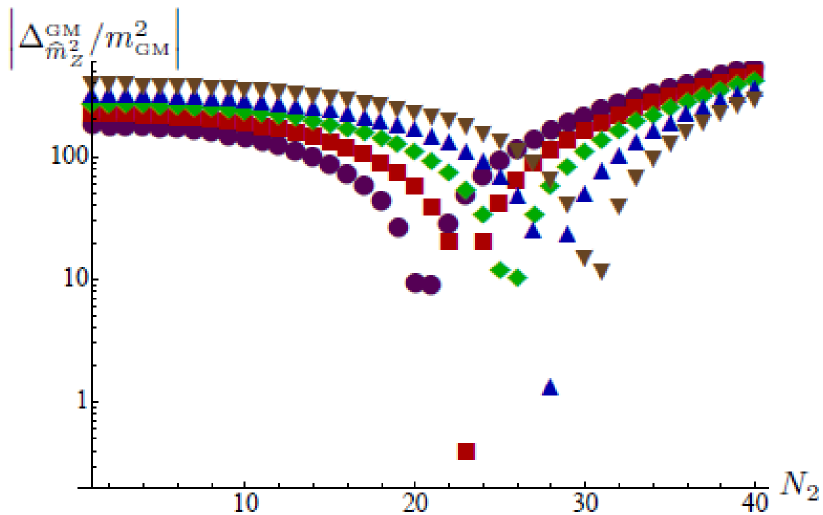
$$\begin{aligned}\tilde{\chi}_2^0 &\to \chi_1^\pm W^* \to \chi_1^\pm \ell\nu_\ell, \quad \chi_1^\pm q q'\\ \chi_1^\pm &\to \chi_1^0 \ell\nu_\ell, \quad \chi_1^0 q q'\end{aligned}$$

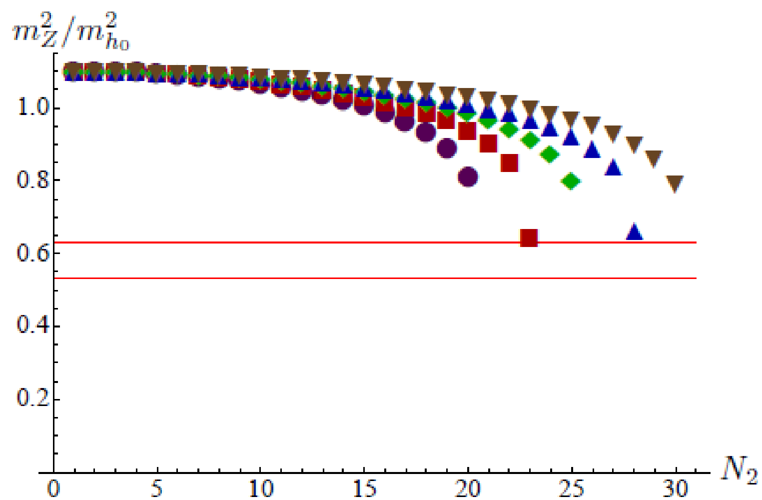
Velasco-Sevilla

Focus points with high-scale gauge mediation

- $m_{\rm GM} = m_{3/2} \cdot \frac{M_{\rm Planck}}{M_{\rm mess.}} \cdot \frac{g^2}{16\pi^2} \simeq m_{3/2} \simeq 100$ GeV
- N_2 and N_3 integers: scan for $N_3 = 8, 9, 10, 11, 12$

Brummer





\`small' Fermi scale together with \`large' Higgs mass,
Light higgsinos of 160 GeV, multi-TeV gluinos & squarks,
Monojet/photon searches for dark matter!

SUSY with Intermediate Scales

- Physics at scales intermediate between EW and GUT is common in many models:
  - ✓ seesaw mechanism for neutrino masses
  - ✓ multiscale models: Pati-Salam or L-R symmetric groups
  - ✓ FN models with messengers
  - ✓ ...

- If the intermediate scale fields are not singlets ⇒ the running of gauge couplings (and all the parameters) is modified ⇒ modification of the SUSY spectrum
  ⇒ interesting phenomenological consequences

we can test very high scales with the LHC!

- $\frac{\mu}{M_1}$ increases ⇒ $\tilde{\chi}_1^0$ more and more $\tilde{B}$-like
  ⇒ focus point for DM disfavored

- $\frac{m_{\tilde{\tau}}}{M_1}$ increases ⇒ $\tilde{\tau}$ coannihilation region disfavored

→ *obtaining the correct DM relic density is more difficult*

specific predictions for DM and low mass spectrum, visible in cascade decays

Biggio

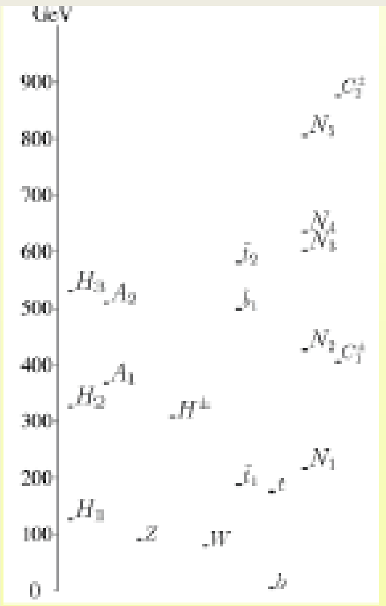
Supersymmetry AND Compositeness?

- Overkill?
- But problems of two types of theories complementary
- Ideas already existing trying to combine ideas
- Seiberg duality AUTOMATICALLY HAS BOTH
  - At least existing examples
- Idea in Seiberg duality:
  - Strongly interacting theory has dual weakly coupled GAUGE description
  - One way to understand emergence of gauge bosons is through supersymmetry protecting gauge group away from Higgs stage

applies new ideas of strongly interacting SUSY gauge theories to EWSB

Randall

Spectrum I: Stealth Stop



H_1	125 GeV	$\tilde{b}_1$	499 GeV
$\tilde{t}_1$	188 GeV	A_2	509 GeV
N_1	216 GeV	H_3	530 GeV
$H^{\pm}$	307 GeV	$\tilde{t}_2$	580 GeV
H_2	326 GeV	N_3	602 GeV
A_1	368 GeV	N_4	635 GeV
C_1	406 GeV	N_5	805 GeV
N_2	426 GeV	C_2	876 GeV

Light stop, nearly degenerate with top,
Light neutralino-not quite as light
Sbottom, other stop 500 GeVish
Aside from gauginos, all else heavy

specific predictions for the LHC, will be tested in the coming months ...

NOTs -- New Odd Tracks

- Irregular tracks can come in many forms.
- In many cases, peculiar properties may lead to a systematic mis-reconstruction of their tracks by the standard algorithms.
- Consequently, particles of this kind may evade detection.
- Refer to such particles as NOTs and classify signatures: [Meade, Papucci, TV, 20011]
  - Kinks.
  - Displaced vertices.
  - Anomalous dE/dx.
  - Anomalous timing.
  - Intermittent hits.
  - Anomalous curvature.
  - Stub Tracks.

Long Lived Particles

Volansky

Conclusions

- NEUTRINOS: fast progress possible because of large mixing angle θ_{13}
- DARK MATTER: standard freeze-out scenario severely constrained
- FLAVOUR: impressive agreement with Standard Model
- EWSB: hints for Higgs mass at 125 GeV very exciting; compositeness or extrapolation to GUT scale?
- SUPERSYMMETRY: data suggest `split spectrum'; hope for states in LHC reach

THANKS !!!

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