XLIII rd

rencontres de Moriond

since

1966

B-Physics, Direct Dark Matter Detection and Supersymmetric Higgs Searches at Colliders

Marcela Carena
Theoretical Physics Department
Fermilab

Rencontres de Moriond EW 2007
La Thuile
March 11, 2007

ELECTROWEAK INTERACTIONS AND UNIFIED THEORIES
Theory Summary

Marcela Carena
Theoretical Physics Department
Fermilab

XLIIIrd Rencontres de Moriond, La Thuile, March 1-8, 2008

Rencontres de Moriond

A very special conference

- A superb academic level of presentations which trigger plenty of questions and discussions that become the seed of new ideas.
- A perfect venue for rewarding interactions among theorists and experimentalists
- A prime place for students to experience the excitement of our field
- A relaxed social environment in gorgeous surroundings

Van tells us -every year- :

“Moriond started as a meeting among friends:
cooking, skiing and sharing their passion for physics”

The **Moriond Spirit** has survived till today
Moriond is a meeting among the **High Energy Physics Family,**
always growing and expanding.

On behalf of all the participants,
I would like to thank the organizers for their outstanding work

and

very specially to Prof. Jean Tran Thanh Van,
for his dedication, for consecutive 43 years, to make
“Les Rencontres des Moriond”
the most exciting Winter conference in our field!

This year we had 31 Theory talks covering a large amount of the latest ideas and developments in our field during the past year.

A lot of new material to digest, for the youngests and also for the seniors!

The Young Scientist Forums

- Presentations in a wide variety of scientifically interesting topics, well balanced and to the point. And all that in only 5 minutes!!

**Radiative correction to Hbb production at LHC by Le Duc Ninh

** CP violation from non unitary leptonic mixing by J. Lopez Pavon

** Leptonic Flavour Violation in type III Seesaw by Florian Bonnet

** Neutrinos and Leptogenesis by Steve Blanchet and Emiliano Molinari

** Dark Matter: SUSY candidates, detection and mass measurements:
by Sezen Sekmen, Chiara Arina and Nicolas Bernal

The YSF's are an essential part of this conference!

Outline

- The Standard Model Paradigm and what it fails to explain
- Models of New Physics to explain the EWSB dynamics

  ** Supersymmetry ** Strong Dynamics

  ** Extra Dimensions ** Higgs SM extensions

  Many possibilities:

  SM-like fundamental scalar Higgs, Composite Higgs,

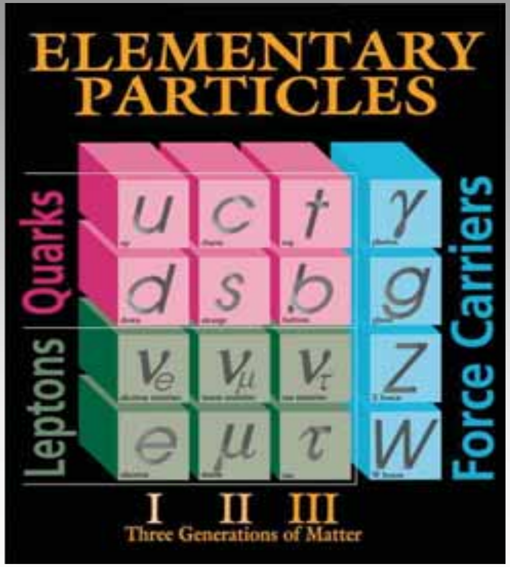
  NO HIGGS, Higgs as a Pseudo Nambu-Goldstone boson
- Dark Matter candidates in models of New Physics
- Flavour Physics

  ** Quark flavour ** Lepton flavour, neutrinos, leptogenesis, neutrinos and the cosmos
- Ideas under development
- Search for new physics signals

Standard Model

explains data collected in the past several years and

describes processes up to energies of ≈100 GeV



However, it is only an effective theory. At least Gravity should be included at $M_{Pl} = 10^{19}$ GeV

- **Many open questions**

⋆ Origin of Mass of fundamental particles

⋆ Generation of big hierarchy of scales $M_{Pl}/M_Z = 10^{17}$, $M_Z/M_\nu = 10^{12}$

⋆ Generation of hierarchies of fermion masses

⋆ Neutrinos: are they encoding a secret message?

⋆ Connection of electroweak and strong interactions with gravity

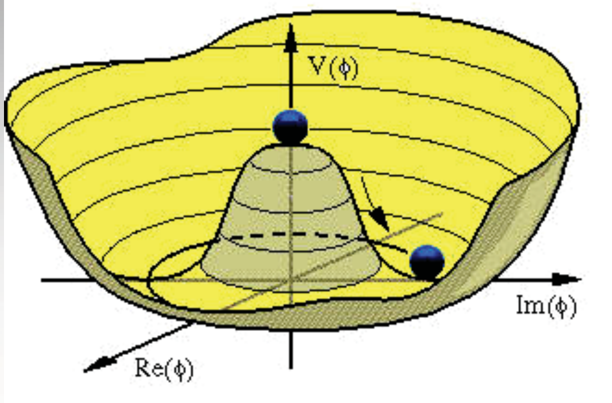
⋆ explanation of matter-antimatter asymmetry of the universe

⋆ Dark matter

⋆ Dark energy

EWSB in the SM: The Higgs Mechanism

A self interacting complex scalar doublet with no trivial quantum numbers under $SU(2)_L$ x $U(1)_Y$



The Higgs field acquires non-zero value to minimize its energy

$$V(\Phi) = \mu^2 \Phi^+ \Phi + \frac{\lambda}{2} \left(\Phi^+ \Phi\right)^2 \qquad \mu^2 < 0$$

Higgs vacuum condensate v ==> scale of EWSB

$SU(3)_C$ x $SU(2)_L$ x $U(1)_Y$ ==> $SU(3)_C$ x $U(1)_{em}$

Higgs gives mass to W,Z and SM fermions: $\boxed{M_V^2 = g_{\phi VV}\, \mathrm{v}/2}$ $\boxed{m_f = \mathrm{h_f\ v}}$

- One extra physical state -- Higgs Boson -- left in the spectrum $\boxed{m_{H_{SM}}^2 = 2\lambda\ \mathrm{v}^2}$

Associated to the SM EWSB mechanism: The Hierarchy problem

$$\text{Why } \mathrm{v} \ll \mathrm{M_{Pl}}\, ?$$

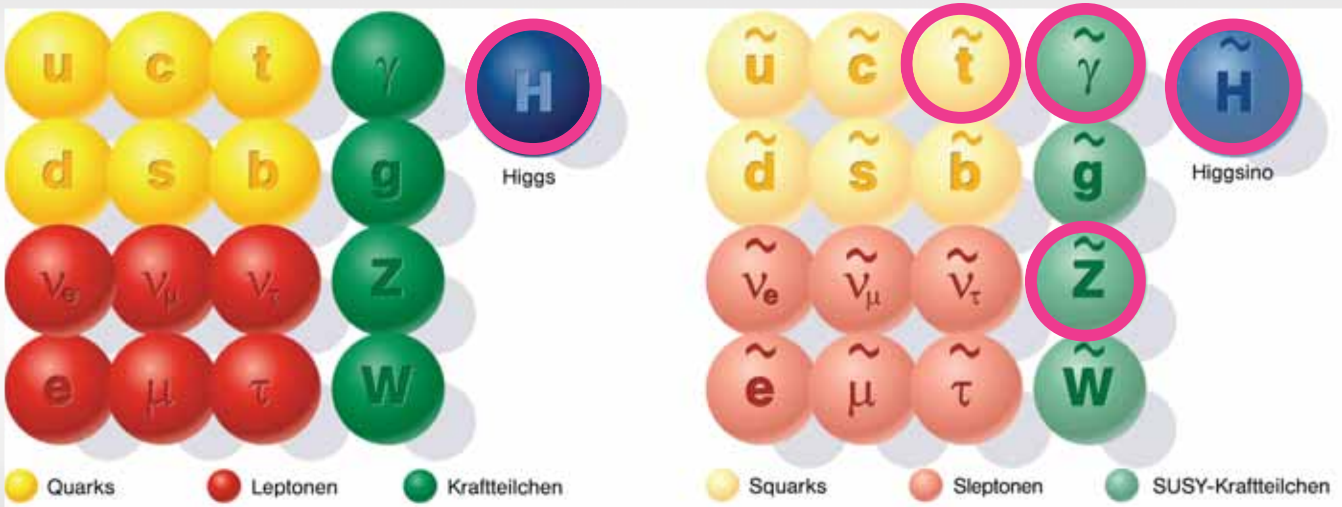
New Physics to explain the hierarchy or extreme fine tuning to cancel quadratic divergences in the Higgs sector

A new Symmetry in Nature? SUPERSYMMETRY

Fermion-Boson Symmetry:

For every fermion there is a boson with equal mass and couplings

SM particles ↔ **SUSY particles**



- Contains a good Dark matter candidate
- Provides a technical solution to the hierarchy problem
- Is consistent with gauge coupling unification

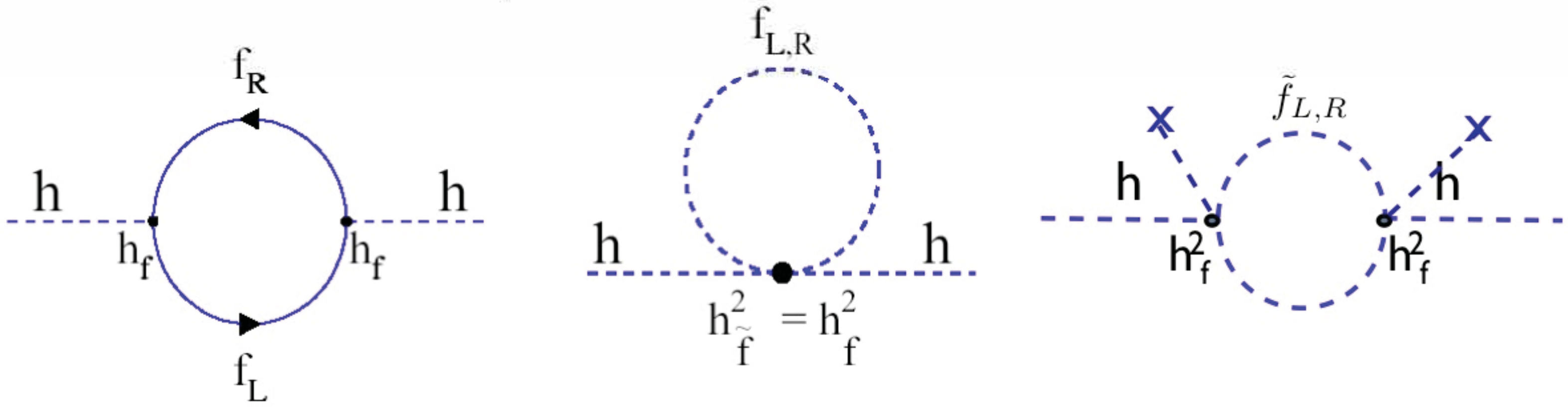
No SUSY partner degenerate in mass with its SM particle has been observed

SUSY solution to the hierarchy Problem

Cancellation of quadratic divergences in Higgs mass quantum corrections has to do with SUSY relation between couplings and bosonic and fermionic degrees of freedom

$$\Delta\mu^2 \approx g^2_{hf\bar{f}}[m_f^2 - m_{\tilde{f}}^2]\ln(\Lambda^2_{eff} / m_h^2)$$

SUSY must be broken in nature



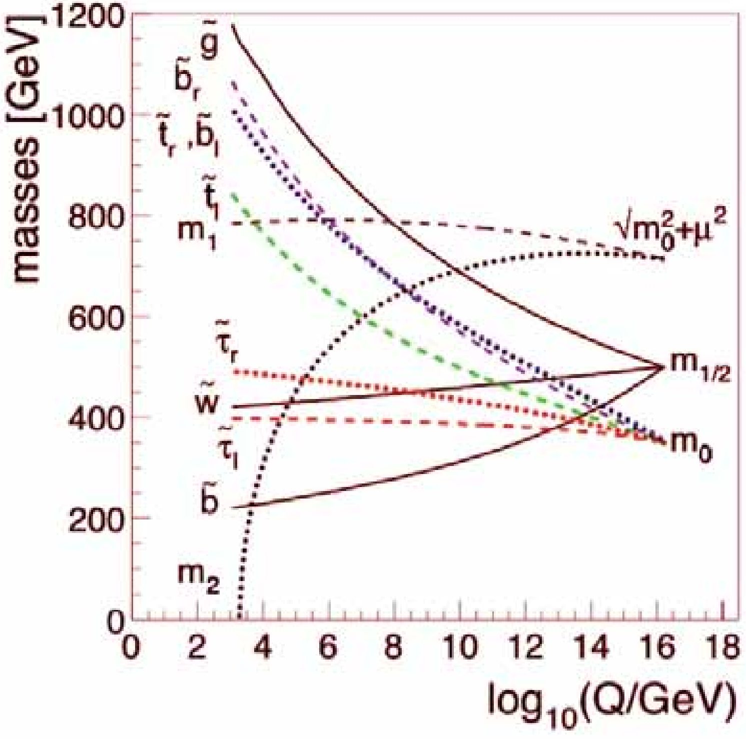
In low energy SUSY: quadratic sensitivity to Λ_{eff} replaced by quadratic sensitivity to SUSY breaking scale

The scale of SUSY breakdown must be of order 1 TeV, if SUSY is associated with scale of electroweak symmetry breakdown

EWSB in SUSY: radiatively generated

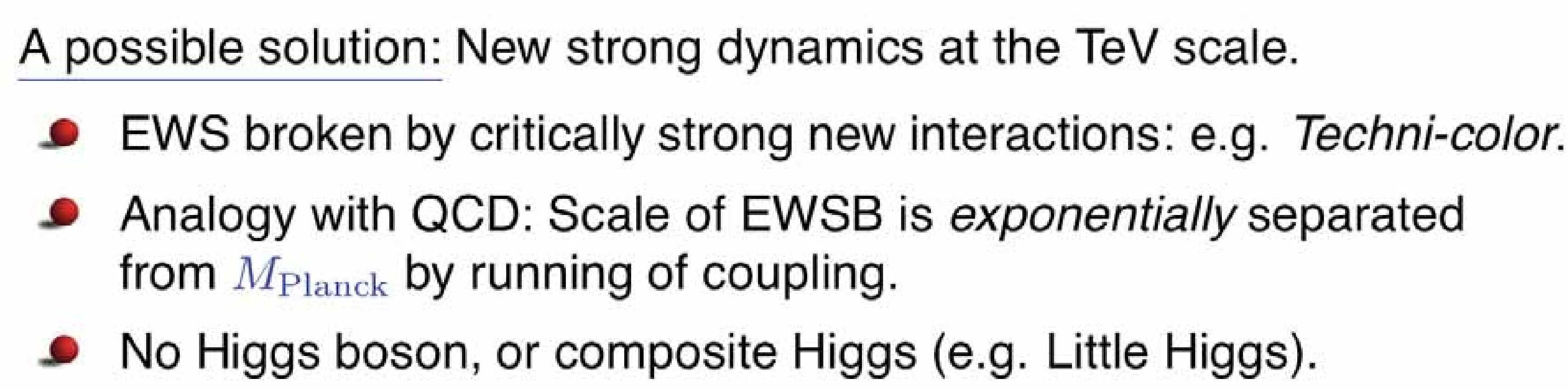
In the evolution of masses from high
energy scales
==> a negative Higgs mass parameter
is induced via radiative corrections

==> important top quark Yukawa effects!



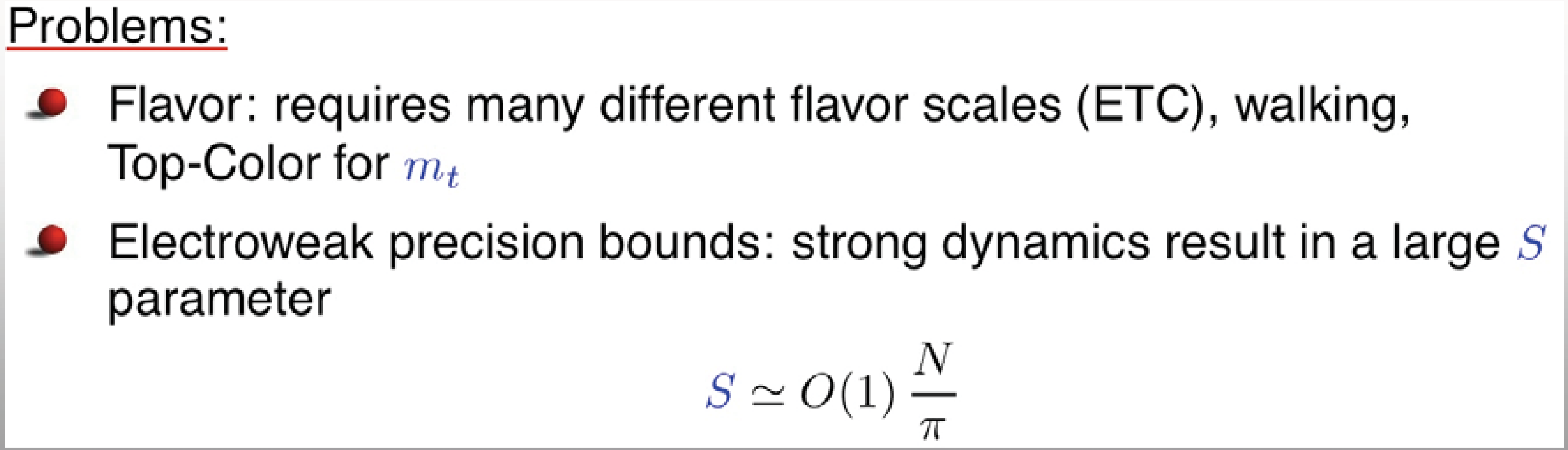
EWSB and Strong Interaction Dynamics

Talk by Gustavo Burdman



A possible solution: New strong dynamics at the TeV scale.

- EWS broken by critically strong new interactions: e.g. *Techni-color*.
- Analogy with QCD: Scale of EWSB is *exponentially* separated from M_{Planck} by running of coupling.
- No Higgs boson, or composite Higgs (e.g. Little Higgs).



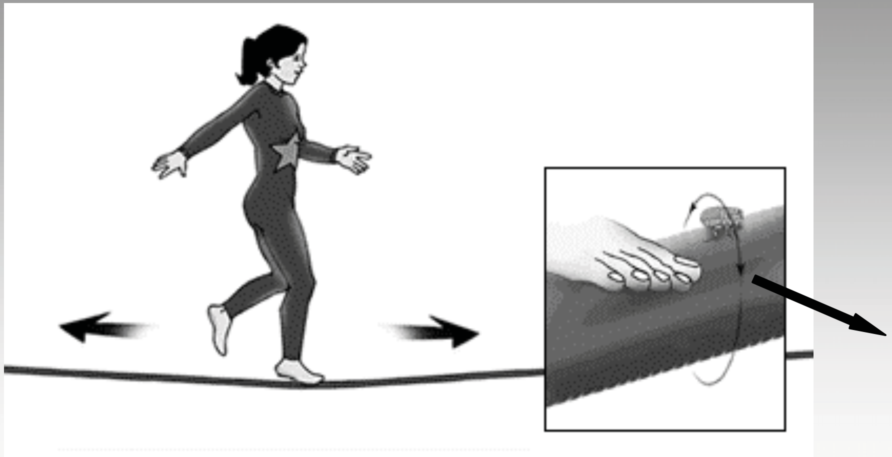
Problems:

- Flavor: requires many different flavor scales (ETC), walking, Top-Color for m_t
- Electroweak precision bounds: strong dynamics result in a large S parameter

$$S \simeq O(1)\,\frac{N}{\pi}$$

These theories require a UV completion

Are there Extra Dimensions (ED) of space?



- ED are a prediction of Strings
- **Can stabilize the Higgs mass**
- Can provide a DM candidate

each point in space would have additional dimension attached to it

Gravity in ED $\Longrightarrow$ fundamental scale, pushed down to ew. scale by geometry

Gravity flux in flat ED ➔ Newton's law modified: $M_{Pl}^2 = (M_{Pl}^{\mathrm{fund.}})^{2+d}\, R^d$

This lowers the fundamental Planck scale dep. on size & number of ED

$M_{Pl}^{\mathrm{fund.}} \simeq 1\ \mathrm{TeV} \Longrightarrow \mathrm{R}= 1\ \mathrm{mm},\ 10^{-12}\ \mathrm{cm}$ if d =2,6

Solution to Hierarchy problem <==> New problem: Why R so large?

If SM propagates in the ED ==> Universal Extra Dimensions (UED)

, they should be quite small: $R \leq 10^{-17}\ \mathrm{cm} \approx 1/\ \mathrm{TeV}$

Warped ED: Elegant solution to the Hierarchy Problem

Talks by Gustavo Burdman, Lisa Randall

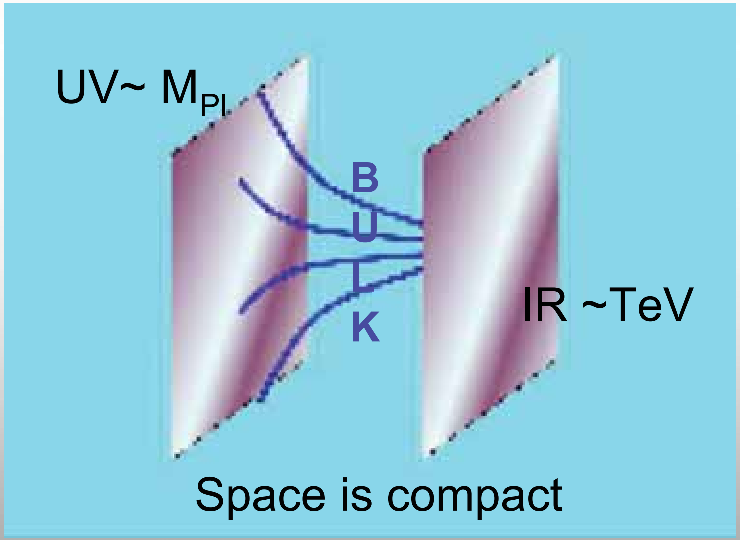
All fundamental parameters at the Planck scale, and yet, due to the curvature of the extra-dimensional metric and the Higgs field localization, the Higgs v.e.v. is naturally of order of the TeV scale

Randall, Sundrum'99

- Newton's law modified: 5d Planck mass relates to M_{Pl}: $M_{Pl}^2 = \frac{(M_{Pl}^{fund.})^3}{2k}(1 - e^{-2kL})$

➔ Natural energy scale at the UV brane: $M_{Pl}^{fund.}$

At the TeV brane, all masses affected by an exponential warp factor: $e^{-kL} << 1$



Assuming fundamental scales all of same order:

$$M_{Pl} \approx M_{Pl}^{fund.} \approx \mathrm{k}$$

Solution to the hierarchy problem:

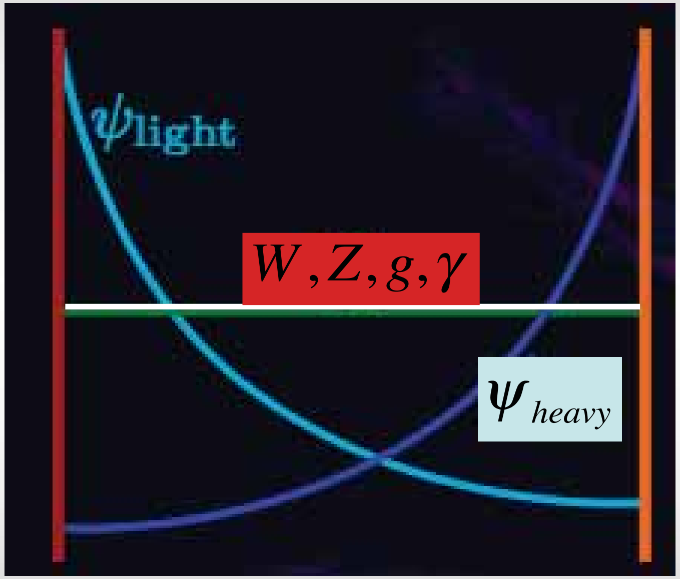
Higgs field lives on the TeV brane

$$\mathrm{v} \sim \tilde{\mathrm{k}} \equiv \mathrm{k\,e}^{-\mathrm{kL}} \approx M_{Pl}\, \mathrm{e}^{-\mathrm{kL}} \sim \mathrm{TeV}$$ with kL~30

As a particle moves in ED its kinetic energy is converted to a group of massive particles in our 4D world ==> SM particles + Gravitons + tower of Kaluza Klein Gravitons

Warped Extra dimensions with Matter in the bulk

- Allowing gauge fields and matter to propagate in the bulk
  ⇒ models of EWSB, flavor, GUTs, etc.
- Bulk Randall-Sundrum models:



UV brane

IR brane
Higgs + KK modes

Hierarchical fermion masses from localization
[masses depend from overlap with Higgs]

FCNC and higher dimensional operators suppressed for the light fermion families

KK modes localize in the IR for
- Weak bosons, Gluons, Fermions
- As well as gravitons

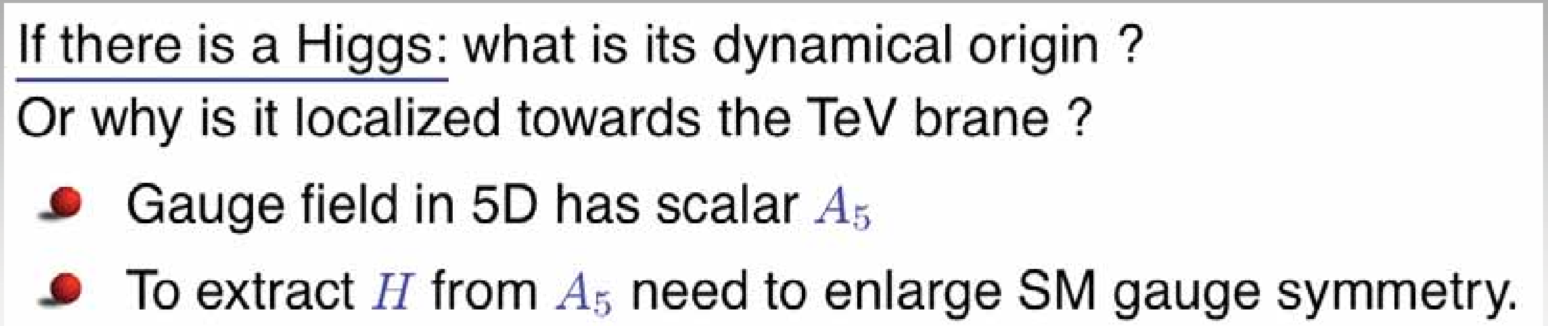
Large corrections to the SM gauge boson masses and couplings due to Higgs induced mixing ==> strong EW constraints on the spectrum

$$\tilde{k} \geq 1.5\ \text{TeV} \Rightarrow \text{KK gauge boson masses} > 3\text{TeV}$$

AdS$_5$ models of EWSB

Talk by Gustavo Burdman

Gauge Higgs Unification models

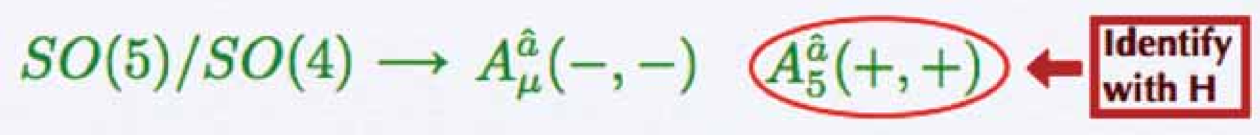


If there is a Higgs: what is its dynamical origin ?

Or why is it localized towards the TeV brane ?

- Gauge field in 5D has scalar A_5
- To extract H from A_5 need to enlarge SM gauge symmetry.

- Gauge sector enlarged in the bulk: $SU(2)_L$ x $SU(2)_R$~S0(4) ==> SO(5)
- Extra Gauge Bosons have the quantum numbers of the Higgs



$$SO(5)/SO(4) \longrightarrow A^{\hat{a}}_{\mu}(-,-) \quad A^{\hat{a}}_{5}(+,+) \longleftarrow \boxed{\text{Identify with H}}$$

- No tree-level Higgs Potential ==> Induced at one-loop level
- Dynamical EWSB: Driven by the top Yukawa

Spectrum:

KK gauge boson's of few TeV and KK fermions as light as 500 GeV

Higgsless Models

- EWSB is broken by BC's (Csaki, Grojean, Pilo, Terning)
- Unitarization of WW and WZ scattering achieved by KK resonance exchange

==> sum rules for the couplings of KK gauge bosons with W and Z

==> KK gauge bosons need to be narrow resonances

mass of the lightest KK gauge bosons below about 1 TeV

Problems with EW precision constraints

S parameter too large (can be ameliorated by delocalization of fermions but then no solution to fermion mass hierarchy)

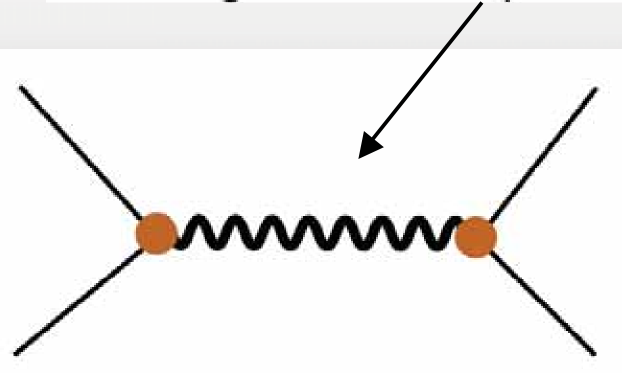
Z-->bb deviates from data (even after using a protective symmetry)

EWSB from fourth generation in AdS$_5$

Top-condensation models (Nambu; Bardeen, Hill, Lindner):
EWS broken by $\langle \bar{t}t \rangle \neq 0$

- Top quark is too light: $m_t \sim 600$ GeV if $\Lambda \sim O(1)$ TeV. Or $\Lambda \sim 10^{15}$ GeV if $m_t \sim 200$ GeV.
- $\Rightarrow$ Heavy fourth generation $M_4 \sim 600$ GeV.

- Need 4th-generation strongly coupled to new interaction
- If 4th-generation propagates in AdS$_5$ bulk and is highly localized on the TeV brane (G.B., Da Rold)
  4th-generation quarks are strongly coupled to KK gluon:



4th generation fermions condensate
and develop EWSB

Dynamical mass M$_4$

Low energy effective theory for the Higgs
Other fermions acquire mass from bulk Higher Dim Op.

A model of EWSB triggered by DM

Michel Tytgat

The Inert doublet model:

The SM with two Higgs doublets
and a Z_2 symmetry →

$H_1 \rightarrow H_1 \qquad H_2 \rightarrow -H_2$

All SM fields are even (*e.g.* no FCNC)

$\langle H_1 \rangle = \frac{v}{\sqrt{2}}$

$\langle H_2 \rangle = 0 \rightarrow H_0\ A_0\ \&\ H^+$

$$V = \mu_1^2|H_1|^2 + \mu_2^2|H_2|^2 + \lambda_1|H_1|^4 + \lambda_2|H_2|^4 + \lambda_3|H_1|^2|H_2|^2 + \lambda_4|H_1^\dagger H_2|^2 + \frac{\lambda_5}{2}\left[(H_1^\dagger H_2)^2 + h.c.\right]$$

In the conformal limit: $\mu_1 = \mu_2 = 0$

EWSB triggered at the loop level: some loops with H_2 can be large and compensate for the large negative contributions of the top quark

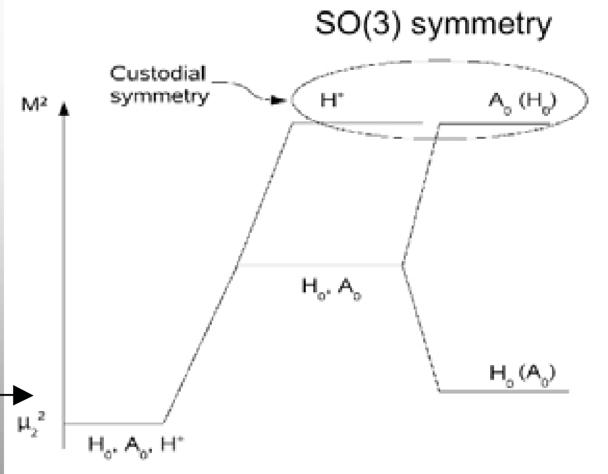
- Radiative EWSB requires large quartic couplings

→ A_0 and/or H^+ heavy, above ~ 350 GeV

- DM requires a light H_0 ~ 60-70 GeV

→ Large mass splittings within the Inert Doublet

$\alpha T = 0$ if $M_{A_0} = M_{H^+}$ or $M_{H_0} = M_{H^+}$ →



H_0 stable neutral scalar = Spin 0 dark matter

EWSB and cosmology: SM Higgs = inflaton

Talk by Fedor Bezrukov

- Problem in cosmology: Without inflation how to explain universe is almost flat, homogeneous and isotropic ?
- Many models of inflation require an additional scalar: the inflaton with a large mass 10^{13} GeV and a tiny self quartic coupling ~ 10^{-13} to yield a flat potential. Many BSM may have such a scalar candidate. What about the SM Higgs?

$$m_H \sim 100-200 \text{ GeV and } \lambda \sim 1$$

SM Higgs solution: Non-minimal coupling to gravity ξ

$$S_J = \int d^4x\sqrt{-g}\left\{-\frac{M^2+\xi h^2}{2}R + g_{\mu\nu}\frac{\partial^\mu h \partial^\nu h}{2} - \frac{\lambda}{4}\left(h^2-v^2\right)^2\right\}$$

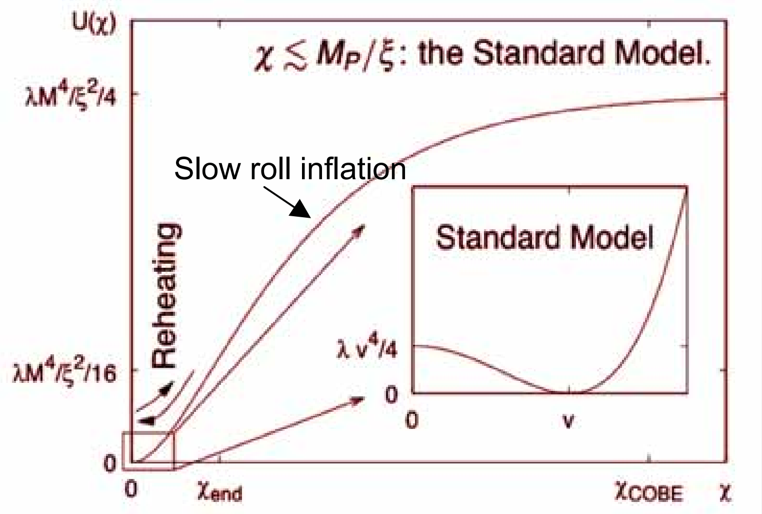
For some intermediate choice of M and ξ inflation and SM particle physics work

Considering the number of e-foldings N_{COBE} and proper normalization

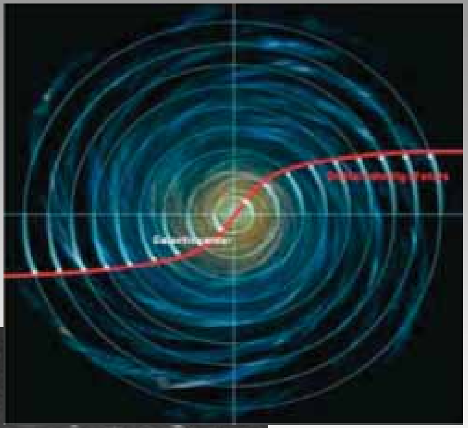
→ connection between ξ and the Higgs mass

Inflation possible without new fields

- Higgs mass $130\,\text{GeV} < M_H < 190\,\text{GeV}$
- No new physics up to at least $M_P/\xi \sim 10^{14}\,\text{GeV}$

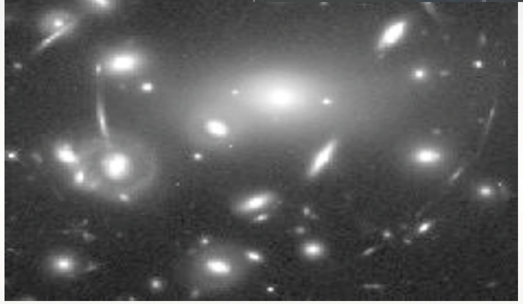


The Mystery of Dark Matter



- Rotation curves from Galaxies.

Luminous disk → not enough mass to explain rotational velocities of galaxies → Dark Matter halo around the galaxies

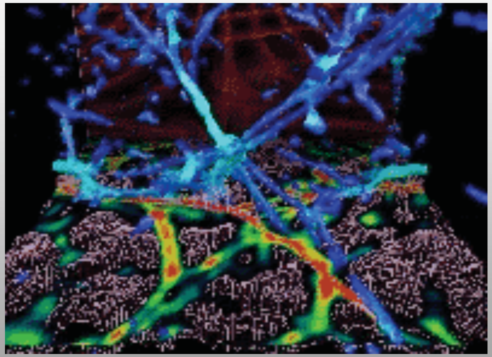


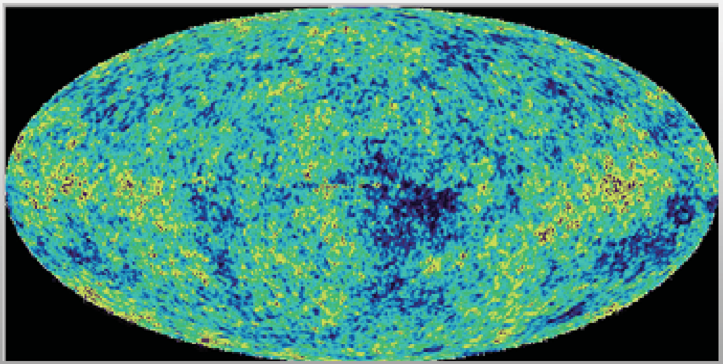
- Gravitational lensing effects

Measuring the deformations of images of a large number of galaxies, it is possible to infer the quantity of Dark Matter hidden between us and the observed galaxies

- Structure formation:

Large scale structure and CMB Anisotropies





The manner in which structure grows depends on the amount and type of dark matter present. All viable models are dominated by cold dark matter.

Cosmology data ↔ Dark Matter ↔ New physics at the EW scale

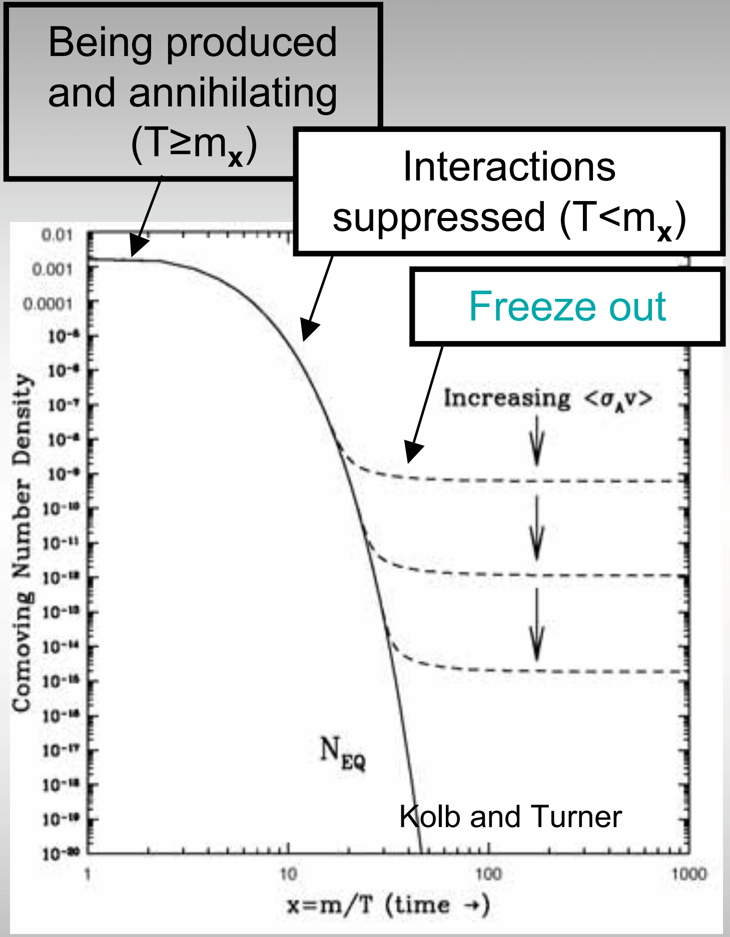
Evolution of the Dark Matter Density

- Heavy particle initially in thermal equilibrium
- Annihilation stops when number density drops

$$H > \Gamma_A \approx n_\chi < \sigma_A v >$$

- i.e., annihilation too slow to keep up with Hubble expansion ("freeze out")
- Leaves a relic abundance:

$$\Omega_{DM} h^2 \approx \; < \sigma_A v >^{-1}$$



Being produced and annihilating ($T \geq m_x$)

Interactions suppressed ($T < m_x$)

Freeze out

Kolb and Turner

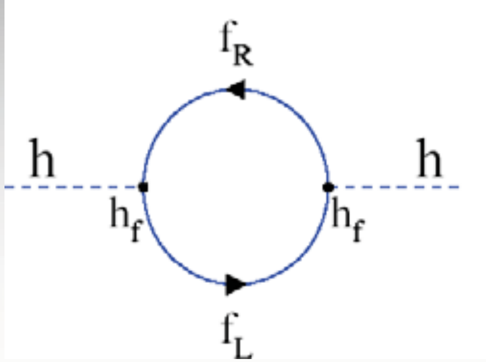
If m_x and σ_A determined by electroweak physics,

$\sigma_A \approx k\alpha_W^2 / m_X^2 \approx$ a few pb then Ω_{DM} $h^2 \sim 0.1$ for $m_x \sim 0.1$-1 TeV

Remarkable agreement with WMAP-SDSS → $\boxed{\Omega_{DM} h^2 = 0.104 \pm 0.009}$

The EWSB mechanism + Collider data ↔ Dark Matter

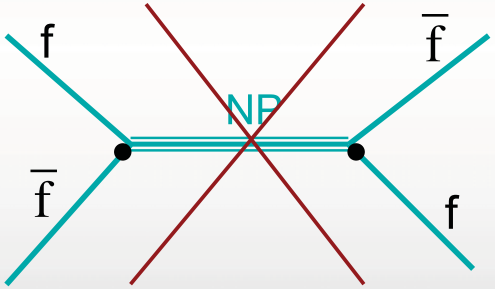
EWSB scale << M_{Pl} → Hierarchy problem



Quantum corrections to the Higgs potential mass parameter μ are quadratically divergent

Need new particle/s with masses of order of the EWSB scale to cancel them

Precision data from LEP, SLD and Tevatron constrains the existence of interactions of SM particles with a single new particle with mass below a TeV.



Therefore many models of EWSB introduce an extra discrete symmetry which predicts a stable Weakly Interacting Massive Particle (WIMP)

Solution to the hierarchy problem plus EW precision data lead naturally to the existence of a WIMP
→ Dark Matter

SUSY Dark Matter

Sabine Kraml

If SUSY comes with a new conserved parity, $R_P = (-1)^{3B+L+2S}$
then the lightest SUSY particle (LSP) is stable

⇩

DARK MATTER CANDIDATE ☺

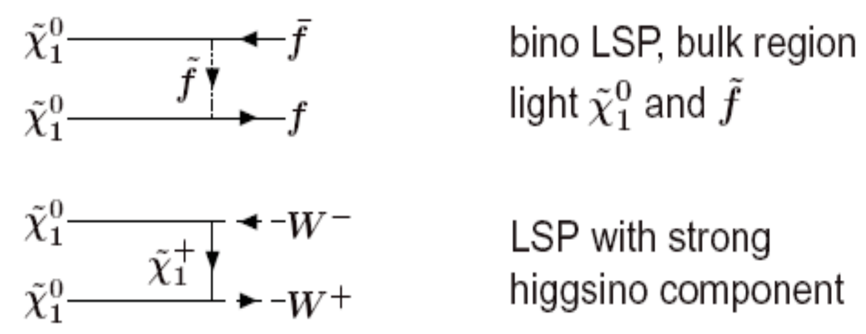
Lightest neutralino,
Gravitino, sneutrino

C. Arina

With seesaw extensions

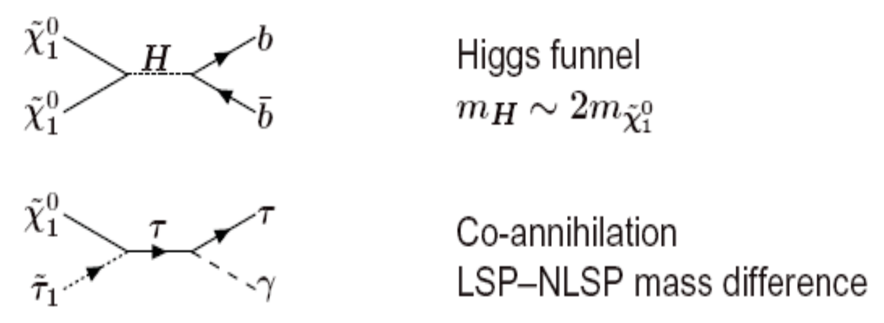
Neutralino Dark Matter

χ^0 LSP as thermal relic: relic density computed as thermally averaged cross section of all annihilation channels → $\Omega h^2 \sim \langle \sigma v \rangle^{-1}$



bino LSP, bulk region
light $\tilde{\chi}_1^0$ and $\tilde{f}$

LSP with strong
higgsino component



Higgs funnel
$m_H \sim 2m_{\tilde{\chi}_1^0}$

Co-annihilation
LSP–NLSP mass difference

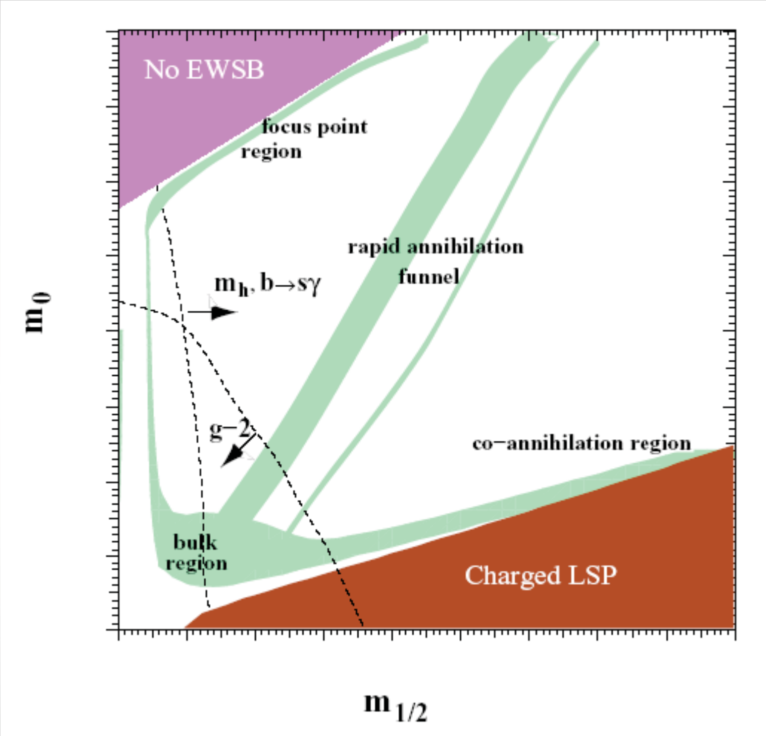
The LSP annihilation cross section is typically suppressed for most regions of SUSY spectrum → too much relic density

☞ $0.094 < \Omega h^2 < 0.136$ puts strong constraints on the parameter space of any model variant

CMSSM: GUT-scale boundary conditions:

m_0, $m_{1/2}$, A_0,

plus tanb, sgn(μ) →



Simple SO(10) SUSY GUTs: dual requirement of Yukawa unification and DM relic density is extremely predictive S. Sekmen

→ Very distinct LHC signatures: ~500-600 GeV gluinos and 50-75 GeV χ_1

Collider -Direct detection- indirect detection interplay

- Spectacular missing Energy signatures at LHC from cascade decades into LSP. Mass measurement only at a few %
- If we can measure the properties of the SUSY particles precisely enough, (masses and couplings of most of the SUSY spectrum) then we can compute σv → collider predicion of Ωh^2
- We can also compute the direct and indirect detection rates

direct detection: m_χ, $\sigma(\chi N)v$,

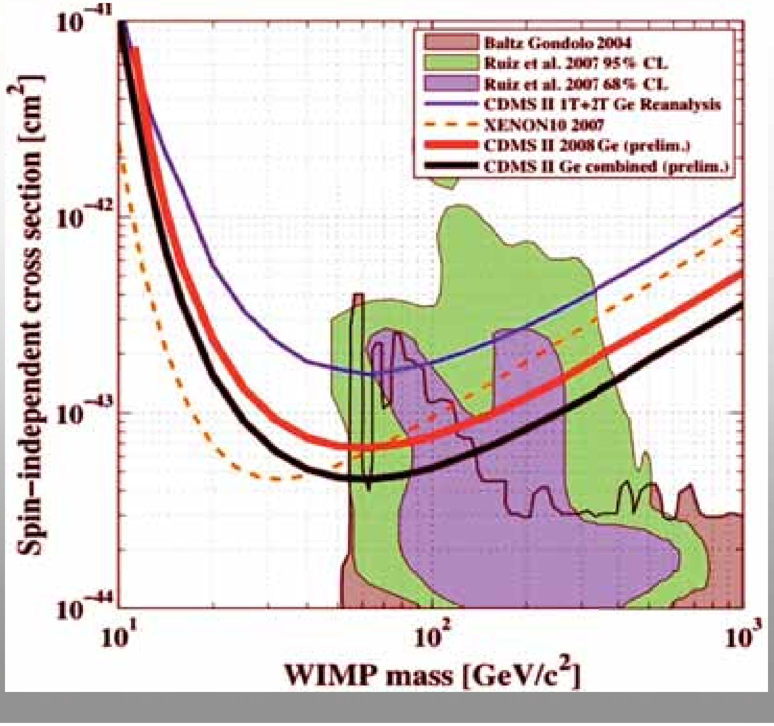
local DM density

indirect detection: $<\sigma v>_{v \to 0}$,

density profile, propagation model

Latest CDMS result:

Starts probing interesting region of SUSY parameter space



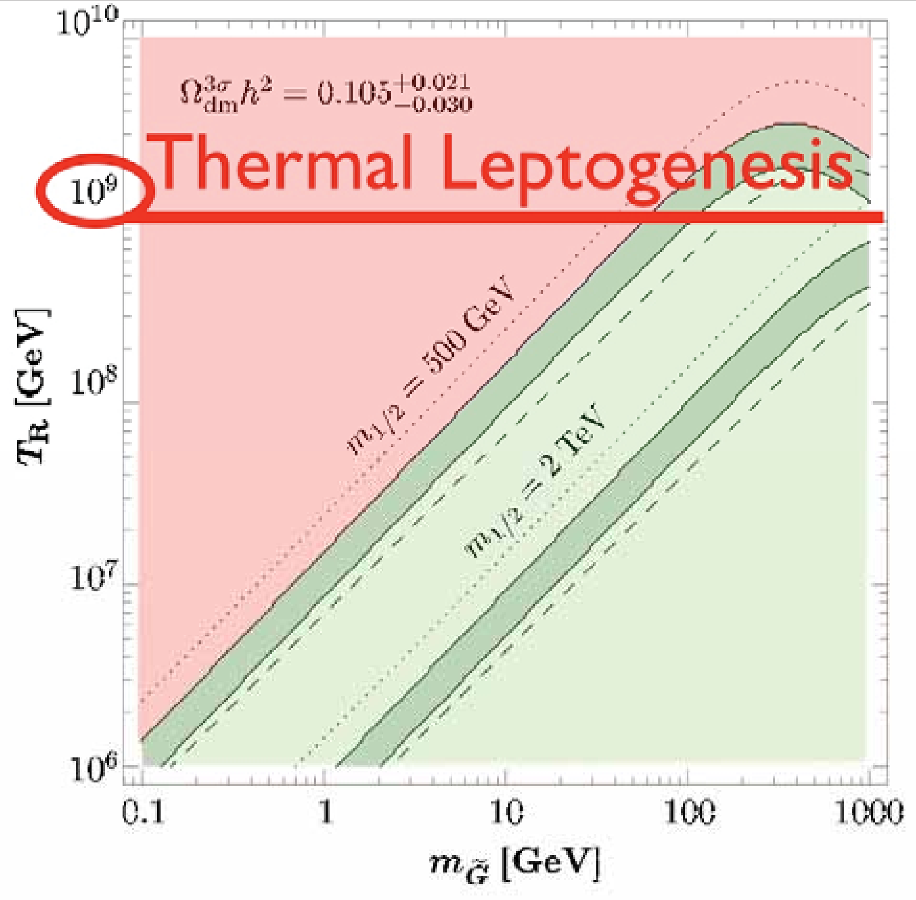
Gravitino Dark Matter

Talk by Frank Steffen

Gravitino DM from Thermal Production (TP)

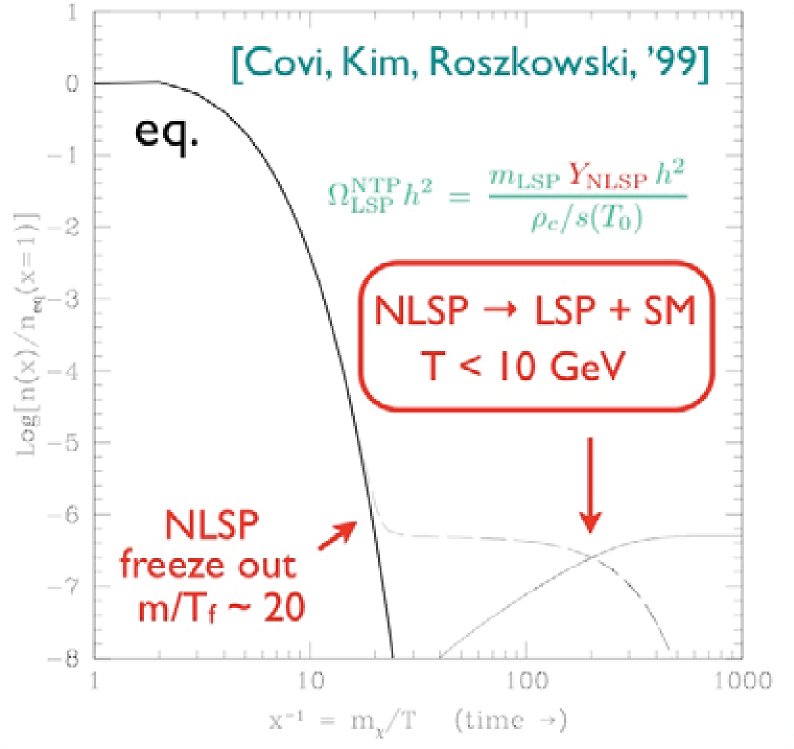
- Gravitino are typically not in thermal equilibrium with primordial plasma after inflation (super weak interactions). At high T they are produced in thermal scattering of particles:

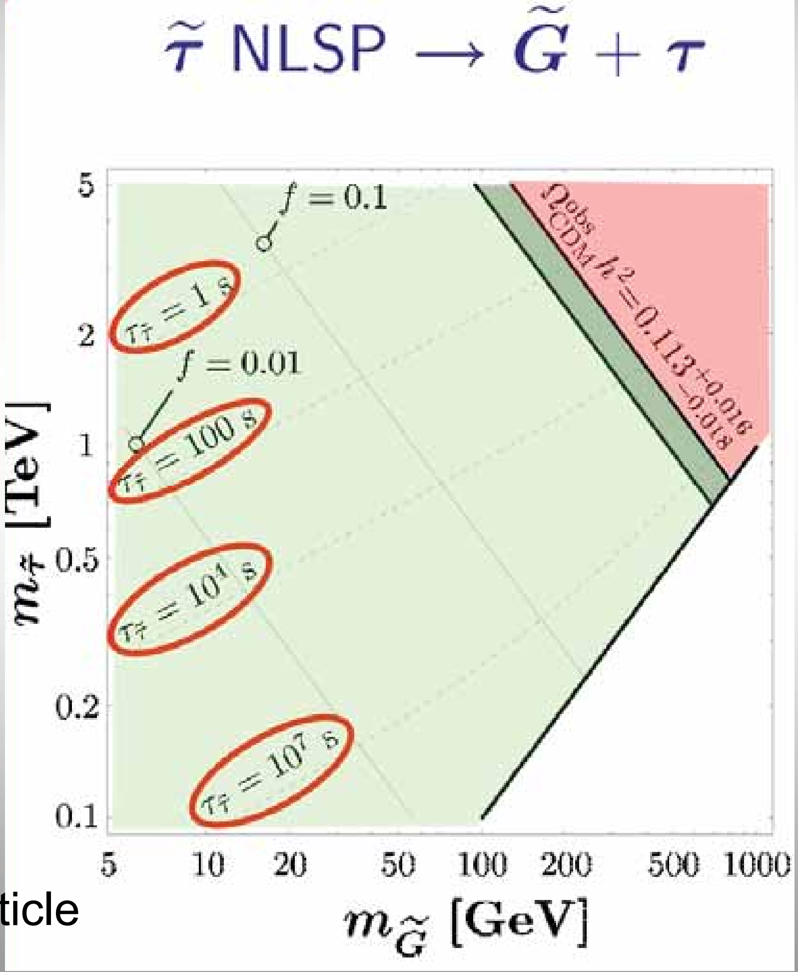
$$\Omega^{\mathrm{TP}}_{\tilde{G}} h^2 = \sum_{i=1}^{3} \omega_i\, g_i^2 \left(1 + \frac{M_i^2}{3 m_{\tilde{G}}^2}\right) \ln\left(\frac{k_i}{g_i}\right) \times \left(\frac{m_{\tilde{G}}}{100\ \mathrm{GeV}}\right)\left(\frac{T_{\mathrm{R}}}{10^{10}\ \mathrm{GeV}}\right)$$



Gravitino Non-Thermal Production (NTP)

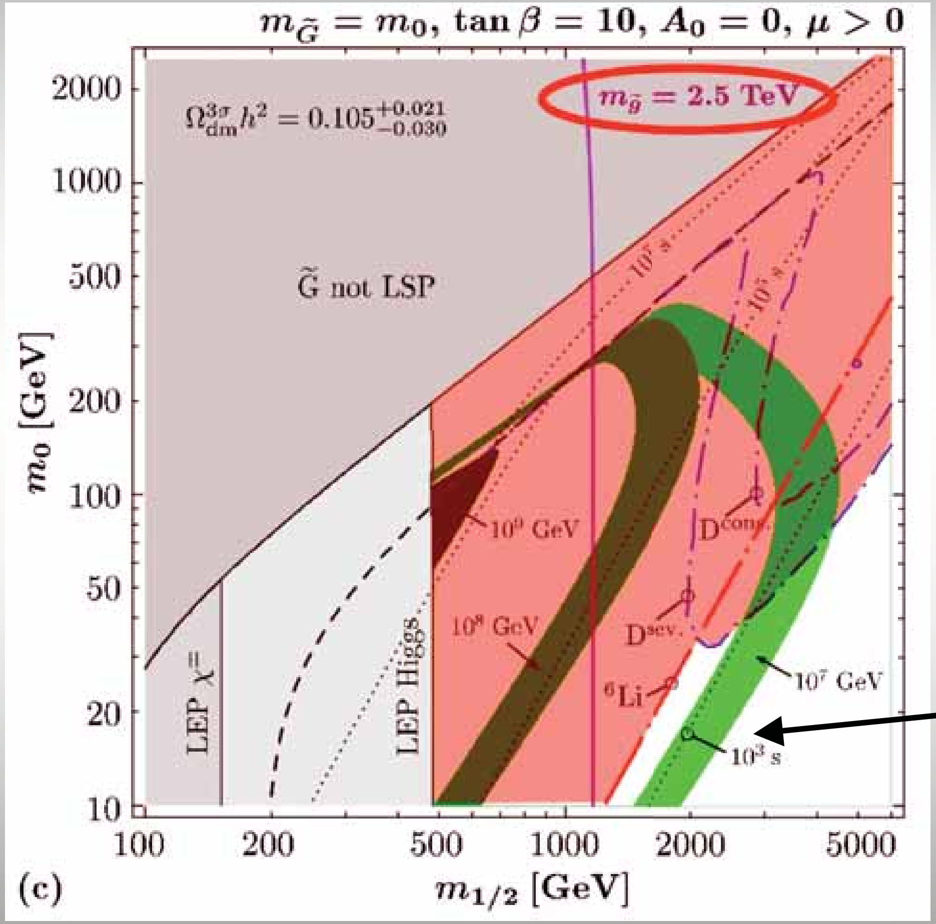
- Thermally produced gravitinos do not affect thermal evolution of the NLSP prior to its decay, typically after decoupling from thermal plasma





DM at LHC ==> through long lived charged particle
Very different from missing energy signal!

CMSSM with TP and NTP
Constrains from DM density and BBN



Lower bound on $m_{1/2}$
and upper bound on T_R
(lower than required by thermal leptogenesis)

$$m_{1/2} \geq 0.9\,\mathrm{TeV}\left(\frac{m_{\widetilde{G}}}{10\ \mathrm{GeV}}\right)^{2/5}$$

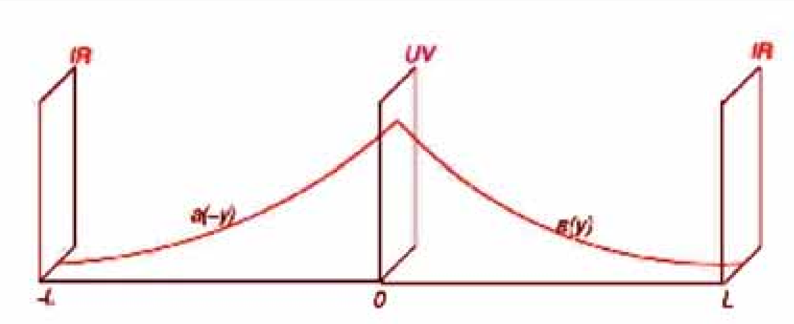
$$T_{\rm R} \lesssim 4.9 \times 10^7\ \mathrm{GeV}\left(\frac{m_{\widetilde{G}}}{10\ \mathrm{GeV}}\right)^{1/5}$$

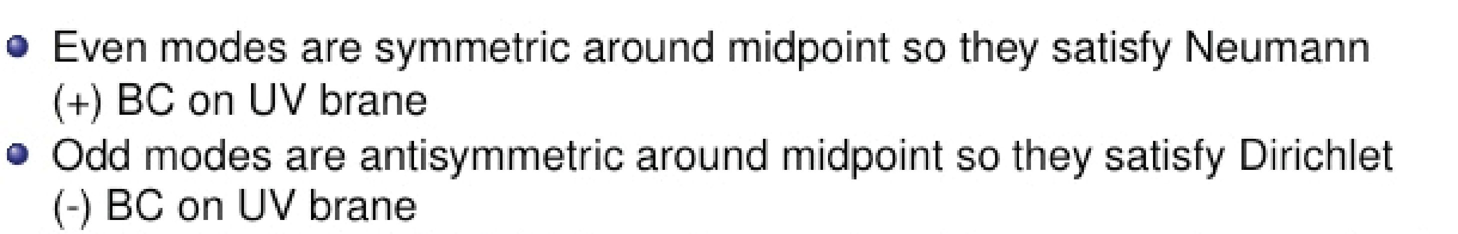
- Depending on the gravitino mass, this scenario can lead to sparticle masses harder to probe at LHC

Dark Matter in models of Warped Geometry

Talk by Adam Falkowski

- Similar to UED models: KK parity as a reflexion around a midpoint
- Problems: RS has no Z_2 parity
  gauge boson KK modes above 3 TeV due to precision tests
- Solution: KK parity by glueing two copies of AdS space



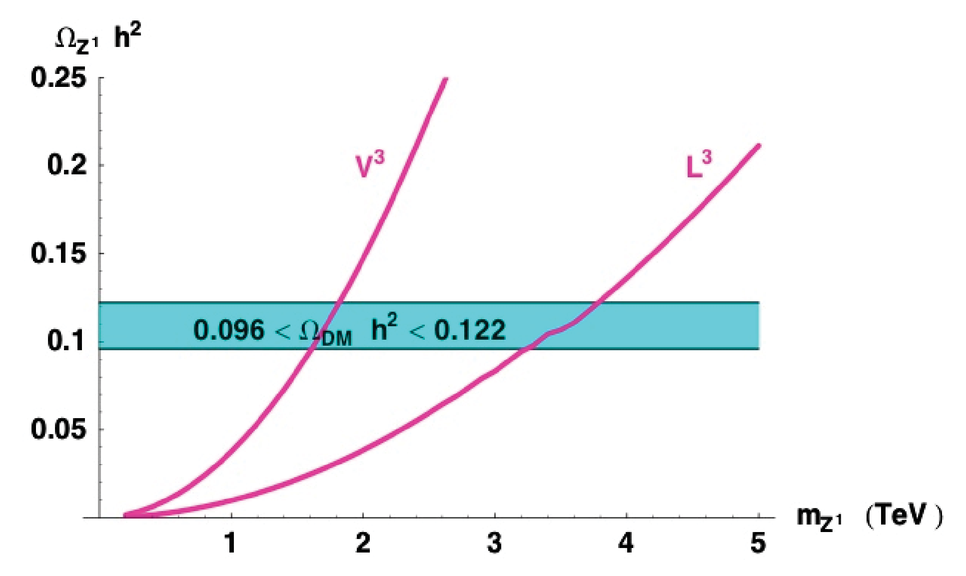


- Even modes are symmetric around midpoint so they satisfy Neumann (+) BC on UV brane
- Odd modes are antisymmetric around midpoint so they satisfy Dirichlet (-) BC on UV brane

- Alternative solution: Instead of full KK parity, Z_2 symmetry for a subset of bulk fields

Two examples of Warped DM

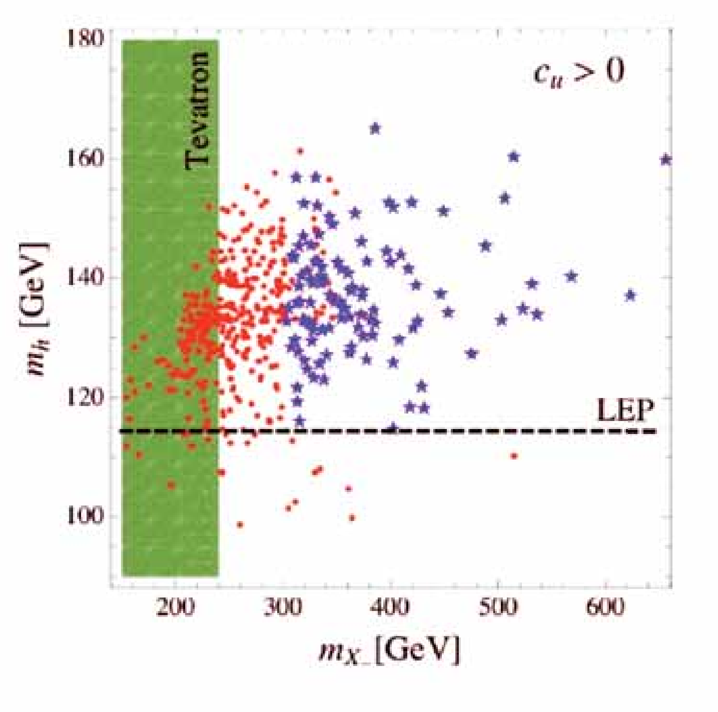
Agashe, Falkowski, Low, Servant



DM candidate in the case of 2 AdS copies glue together.

Large Brane kinetic terms neccesary to have lightest KK DM particle of about 1 TeV

Panico,Ponton, Santiago, Seronet



DM candidate in a model of Gauge-Higgs Unification.

Lightest KK DM particle as low as 300 GeV possible

Flavour Physics

- Many beautiful experimental measurements
- No striking signature of New Physics (NP) $(\sin 2\beta_s$ fluctuation@Tevatron$)$
- Still some room for NP in the flavour sector

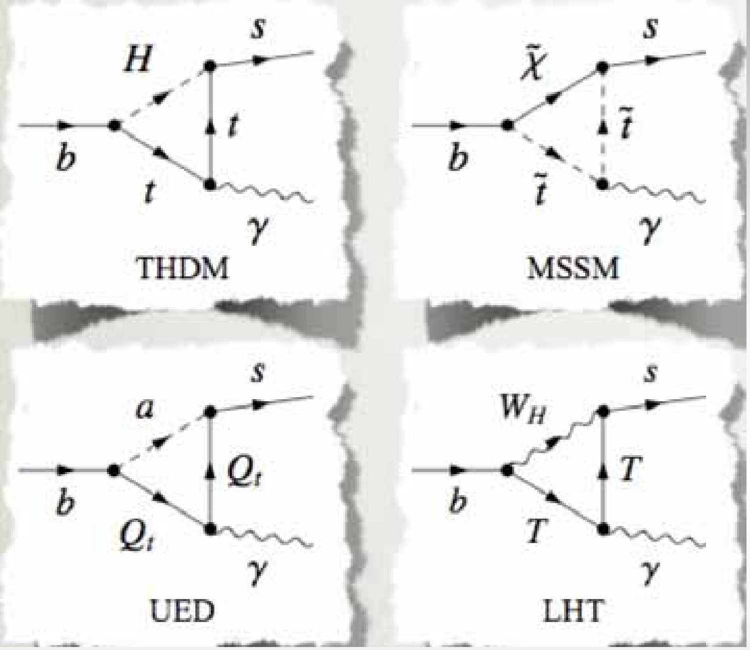
Two alternatives: explore specific NP models or try a model independent approach.

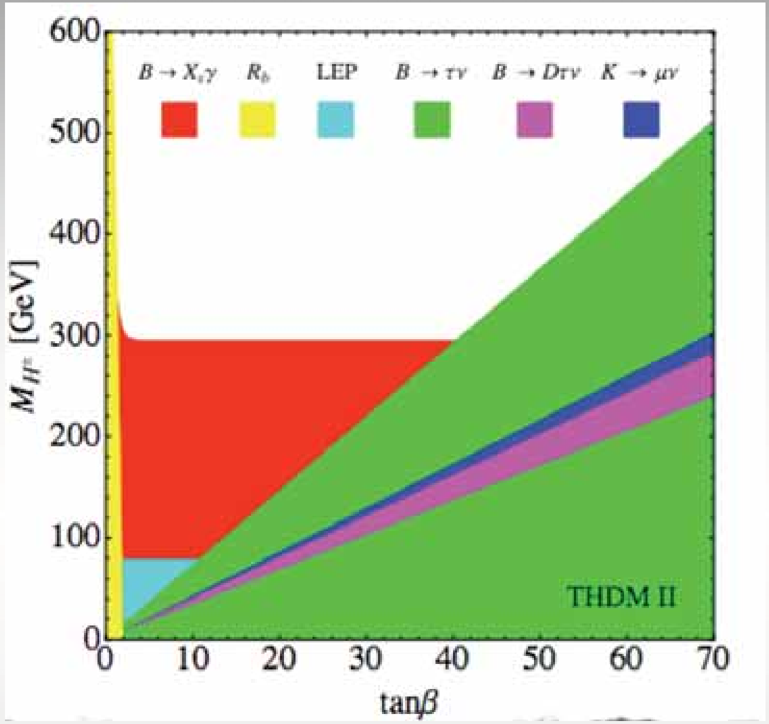
In each case it is possible to consider the Minimal Flavor Violation (MFV) hypothesis:

All flavour symmetry breaking is proportional to SM Yukawas.
CKM is the only source of flavour mixing.
No CP violation beyond that of the CKM

$B \to X_s\gamma$: SM and Beyond

Talk by Uli Haisch





- Inclusive radiative B-meson decay provides stringent constraints on various NP scenarios at EW scale, since it is accurately measured and its theoretical determination is rather precise

New Physics corrections of only a few percent are likely,
precise SM calculations of $b \to s\gamma$
are necessary

Much work done recently to include:

$$+\mathcal{O}(\alpha_s)+\mathcal{O}(\alpha)+\mathcal{O}(\alpha_s^2)+\mathcal{O}\left(\frac{\Lambda^2}{m_b^2}\right)+\mathcal{O}\left(\frac{\Lambda^2}{m_c^2}\right)+\mathcal{O}\left(\alpha_s\frac{\Lambda}{m_b}\right)$$

$$\mathrm{BR}(B\to X_s\gamma)_{\mathrm{SM}}^{E_\gamma>1.6\ \mathrm{GeV}}=(3.15\pm0.23)\times10^{-4}$$

Considering world average measurement,

$$\mathrm{BR}(B\to X_S\gamma)^{\exp}=(3.55\ \pm0.24^{+0.09}_{-0.10})\times\ 10^{-4}$$

and large theoretical uncertainty

$2\ \sigma$ allowed range for new physics ==>

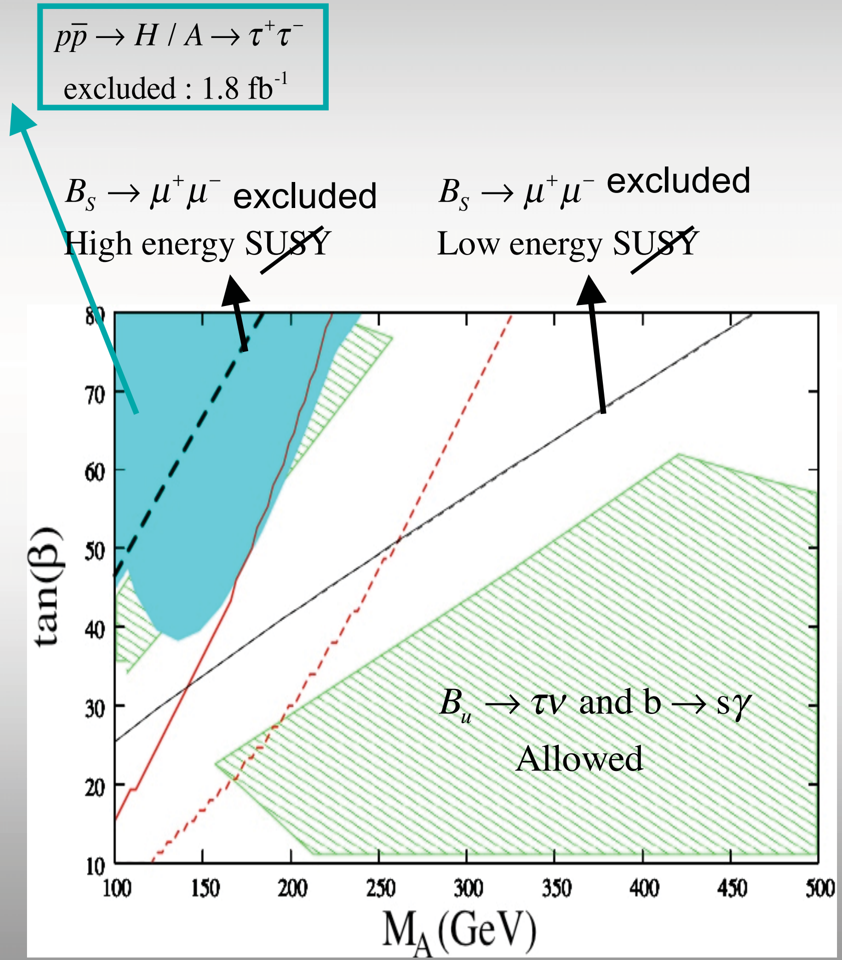
$$\boxed{0.89\le\frac{\mathrm{BR}(B\to X_S\gamma)^{\exp}}{\mathrm{BR}(B\to X_S\gamma)^{SM}}\ \le\ 1.39}$$

Supersymmetry:

Important radiative corrections to charged-Higgs-top & stop chargino loops
Strong restriction on SUSY parameter space

Two UED: Virtual one-loop KK contributions and quadratic divergent mass corrections to KK scalar masses lead to a strong suppression to this decay rate

SUSY Minimal Flavor Violation


$p\bar{p} \rightarrow H / A \rightarrow \tau^+\tau^-$

excluded : 1.8 fb^{-1}

$B_S \rightarrow \mu^+\mu^-$ excluded

High energy ~~SUSY~~

$B_S \rightarrow \mu^+\mu^-$ excluded

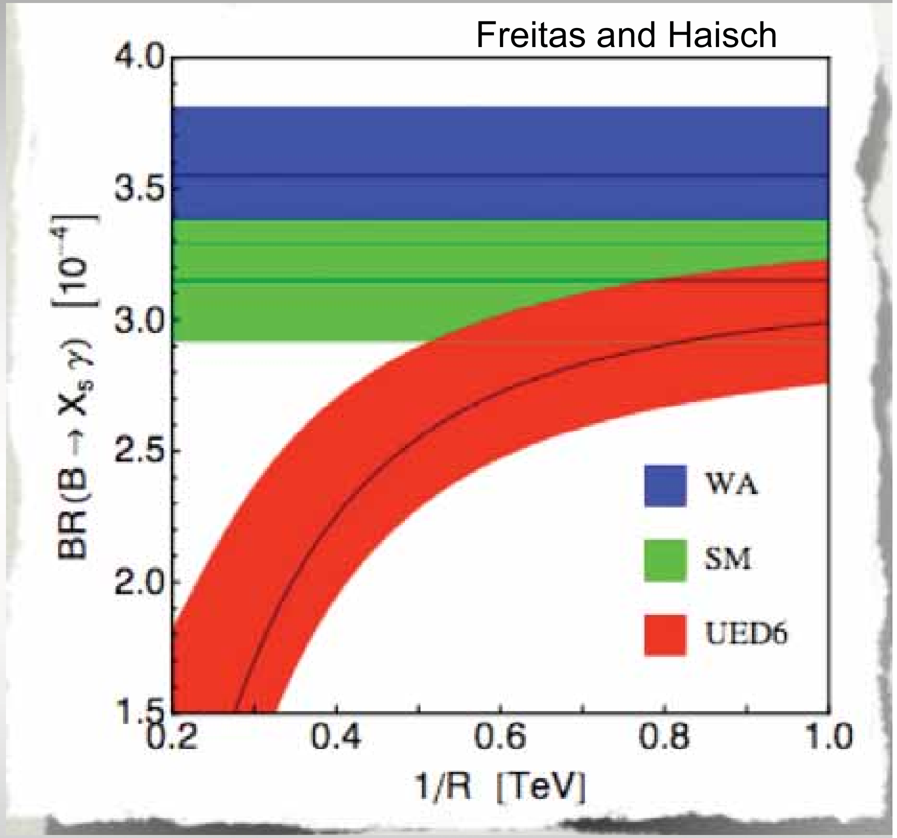
Low energy ~~SUSY~~

$B_u \rightarrow \tau\nu$ and $b \rightarrow s\gamma$

Allowed

M.C. , Menon and Wagner

Two UED


Freitas and Haisch

$B \rightarrow s\gamma \Rightarrow$ bound on 1/R > 650 GeV

at variance with DM limit

Model independent $\Delta F = 1$ constraints on MFV

Talk by Jernej Kamenik

$$\mathcal{H}_{eff}^{\Delta F=1} = \frac{G_F \alpha_{em}}{2\sqrt{2}\pi \sin^2\theta_W} V_{ti}^* V_{tj} \sum_n C_n \mathcal{Q}_n \; + \; \text{h.c.}$$

Independent NP contributions to the various operators: $C_i = C_i^{SM} + \delta C_i$

$$\mathcal{Q}_{7\gamma} = \tfrac{2}{g^2} m_j \bar{d}_{iL} \sigma_{\mu\nu} d_{jR} (e F_{\mu\nu}) \qquad \mathcal{Q}_{8G} = \tfrac{2}{g^2} m_j \bar{d}_{iL} \sigma_{\mu\nu} T^a d_{jR} (g_s G^a_{\mu\nu})$$

$$\mathcal{Q}_{9V} = 2\bar{d}_{iL} \gamma_\mu d_{jL} \, \bar{\ell} \gamma_\mu \ell \qquad \mathcal{Q}_{10A} = 2\bar{d}_{iL} \gamma_\mu d_{jL} \, \bar{\ell} \gamma_\mu \gamma_5 \ell$$

$$\mathcal{Q}_{S-P} = 4(\bar{d}_{iL} d_{jR})(\bar{\ell}_R \ell_L) \qquad \mathcal{Q}_{\nu\bar{\nu}} = 4\bar{d}_{iL} \gamma_\mu d_{jL} \bar{\nu}_L \gamma_\mu \nu_L$$

Theoretically most clean observables used to bound NP contributions

$Br(B \to X_s l^- l^+)$; $Br(B \to X_s \gamma)$; $Br(B_s \to \mu^- \mu^+)$; $Br(K^+ \to \pi^+ \nu \bar{\nu})$

The bound on the effective scale of new physics associated with the operators contributing to $\Delta F = 1$ transitions is ~ 1-2 TeV

Similar studies for $\Delta F = 2$ transitions assoicted with K and B oscillations yields a stronger bound of about 5 TeV

More on Flavour

- $D^0 - \bar{D}^0$ Mixing and New Physics:

Involves intermediate down type quarks. It is small in the SM since b contribution is negligible due to small CMK elements Vcb Vub.

Predicting SM value depends on the size of $SU(3)_F$ breaking

Review by Alexey Petcov : Many New Physics models that may give large contributions, constraining the NP spectra.

- Flavor-Symmetric (FS) Jarlskog invariants*:* by Paul Harrison

Based on Jarlskog observation that models of masses and mixings should be weak basis invariant, one can define FS Jarlskog invariants to describe the mixing matrix of quarks and leptons. Some applications are underway.

- CKMfitter winter 2008 update*:* by S. Descotes-Genon

Impressive consistency with CKM picture of CP violation.

Some discrepancy in Vcs between fitted value and lattice (uncontrolled systematics in full unquenched lattice calc. for f_{Ds}?)

$\Sigma^+ \to p\,\mu^+\mu^-$ and new physics

Talk by German Valencia

- Three decay events observed, with intriguing closeness in the invariant mass of the muons
- Although total rate consistent with SM prediction, uncertainties are large and they may come from new physics
- Easiest way to explain data, by avoiding existing bounds on light scalar particles : Pseudoscalar particle, with mass 214 MeV
- Such a light particle may appear "naturally" in the NMSSM

- If this is the right explanation, several tests proposed to check the existence of such a particle:

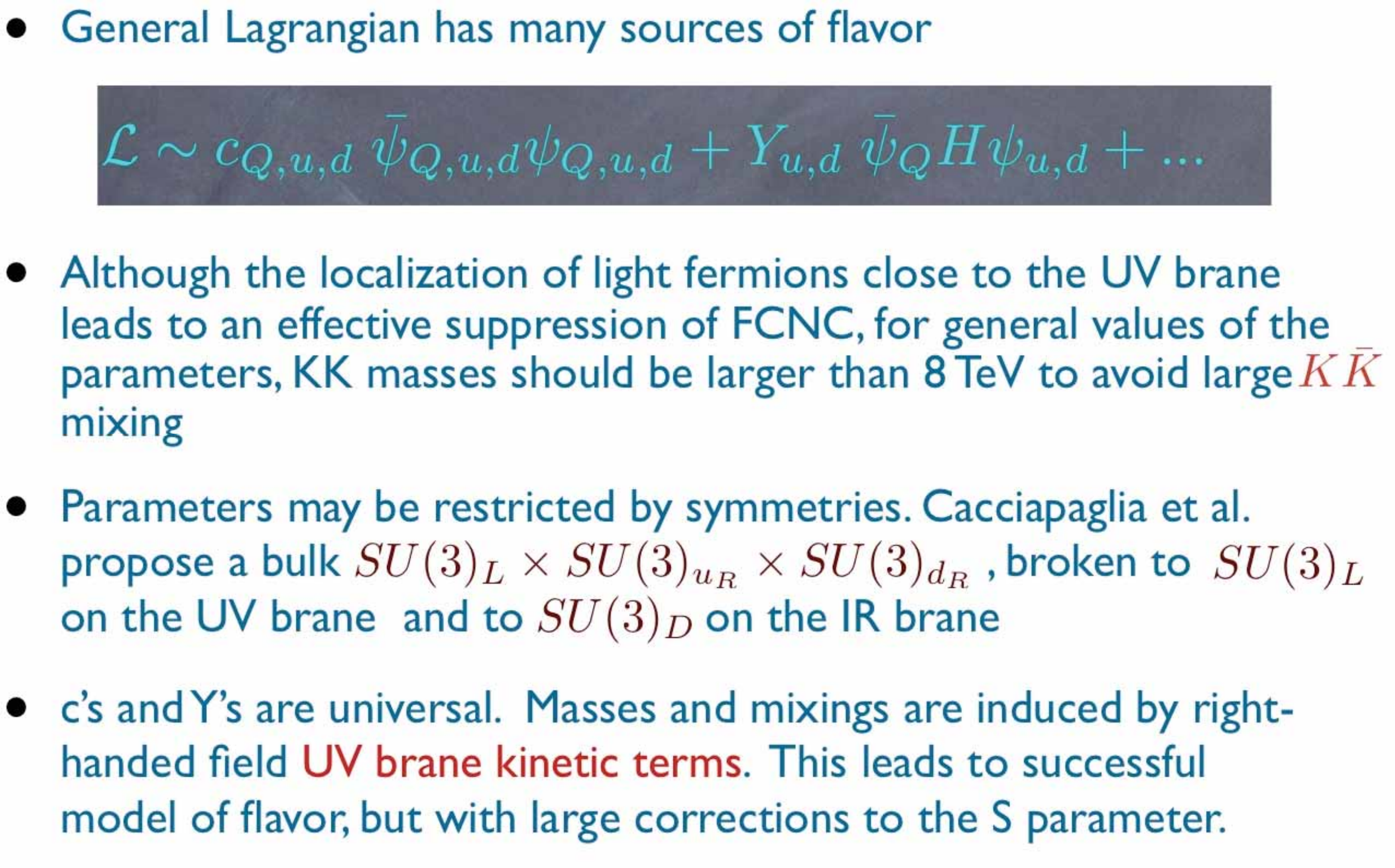
$$\Upsilon_{1S} \to \gamma A_1^0, \quad \phi \to \gamma A_1^0$$

$$B(K_L \to \pi^+\pi^- P^0 \to \pi^+\pi^-\mu^+\mu^-) \approx (1.8^{+1.6}_{-1.4}) \times 10^{-9}$$

$$B(K_L \to \pi^0\pi^0 P^0 \to \pi^0\pi^0\mu^+\mu^-) \approx (8.3^{+7.5}_{-6.6}) \times 10^{-9}$$

Flavour in Warped Geometry

Talk by Giacomo Cacciapaglia



- General Lagrangian has many sources of flavor

$$\mathcal{L} \sim c_{Q,u,d}\, \bar{\psi}_{Q,u,d} \psi_{Q,u,d} + Y_{u,d}\, \bar{\psi}_Q H \psi_{u,d} + \ldots$$

- Although the localization of light fermions close to the UV brane leads to an effective suppression of FCNC, for general values of the parameters, KK masses should be larger than 8 TeV to avoid large $K\bar{K}$ mixing
- Parameters may be restricted by symmetries. Cacciapaglia et al. propose a bulk $SU(3)_L \times SU(3)_{u_R} \times SU(3)_{d_R}$, broken to $SU(3)_L$ on the UV brane and to $SU(3)_D$ on the IR brane
- c's and Y's are universal. Masses and mixings are induced by right-handed field UV brane kinetic terms. This leads to successful model of flavor, but with large corrections to the S parameter.

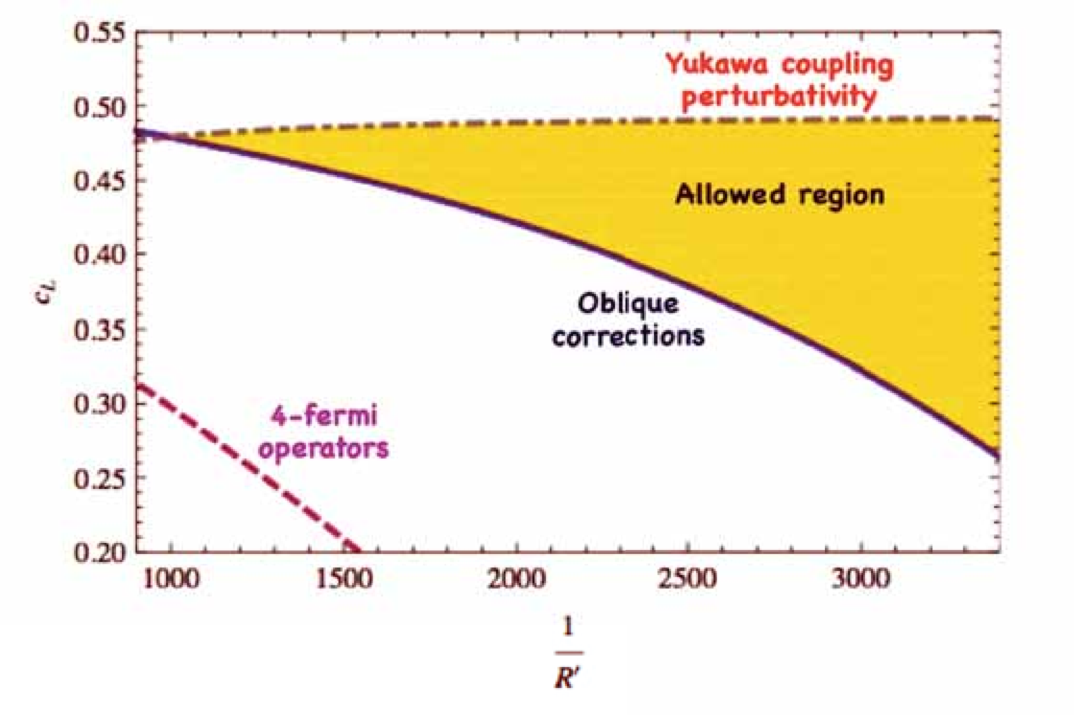
- S parameter in this representation is associated with large modification of the couplings to weak gauge bosons, induced by the gauge boson zero mode-KK mode mixing and the proximity of fermions to the IR brane to generate the top quark mass.

- This may be solved by further breaking of flavor symmetry by IR boundary mass terms in the up sector.

$$Q_L \begin{pmatrix} m_u & & \\ & m_c & \\ & & m_t \end{pmatrix} t_R + m_b \, Q_L \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix} b_R$$

- In addition, custodial symmetry is enlarged to prevent modifications to the Zbb coupling.

Consistency with flavour and precision electroweak constraints is achieved for light KK modes, $m_{KK} \sim 2.5/R'$



Alternative scenario:

$$c_{u,d} \sim Y_{u,d}^{\dagger} Y_{u,d} + \ldots \qquad c_Q \sim r\, Y_u^{\dagger} Y_u + Y_d^{\dagger} Y_d +$$

For small r, the down sector can be diagonalized exactly and all dominant sources of flavor violation are hence proportional to r. Bounds on KK masses due to FV can be relaxed to approximately 2 TeV.

Fitzpatrick, Perez, Randall, hep-ph/0710.1869

Neutrinos: a New Window to Flavor

- The observations of neutrino flavor-change imply that neutrinos have masses and that leptons mix
- Neutrino mass eigenstates ν_i are not the same as the weak eigenstates ν_α associated with a given lepton flavor l_α

Mass eigenstate

Flavor eigenstate

$$|\nu_i> = \sum_\alpha U_{\alpha i}\, |\nu_\alpha> .$$

MNS Leptonic Mixing Matrix

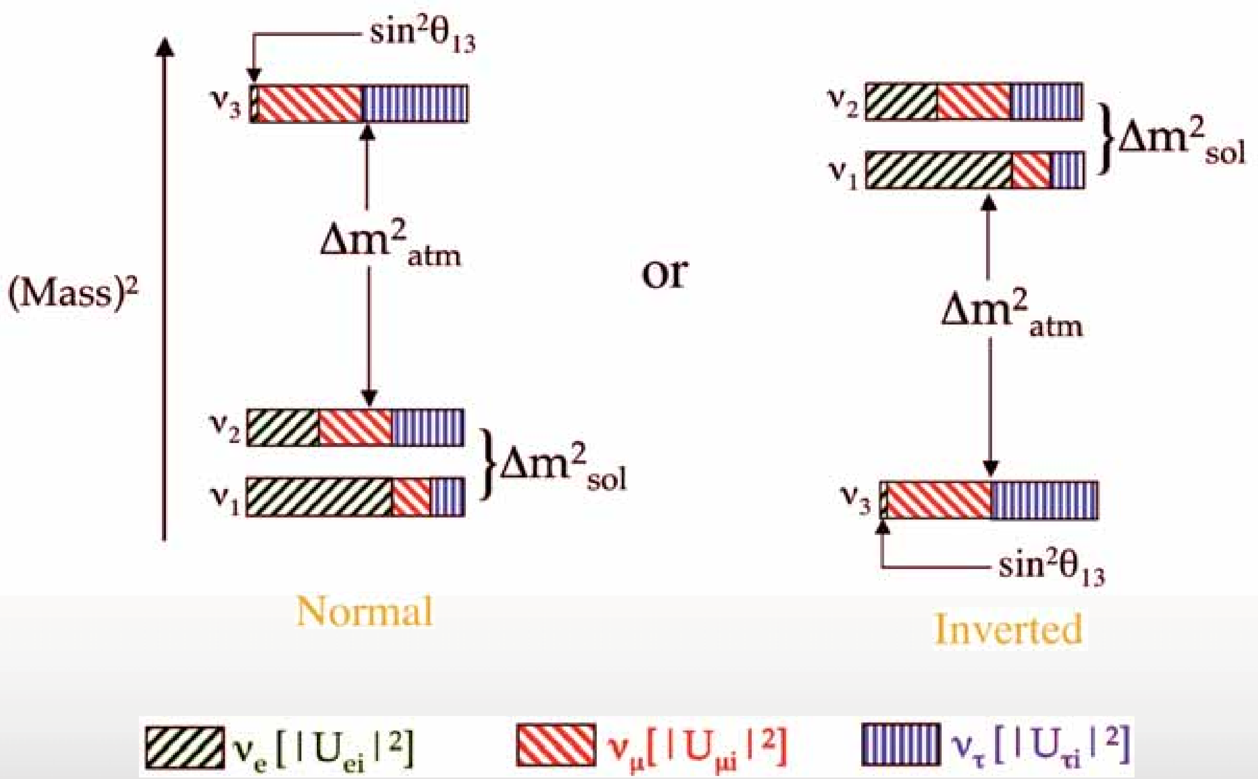
For 3 neutrinos U contains 3 angles and 3 phases

$$U = \overset{\text{Atmospheric}}{\begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix}} \times \overset{\text{Cross-Mixing}}{\begin{bmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{bmatrix}} \times \overset{\text{Solar}}{\begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix}} \times \underset{\text{Majorana } \cancel{CP} \text{ phases}}{\begin{bmatrix} e^{i\alpha_1/2} & 0 & 0 \\ 0 & e^{i\alpha_2/2} & 0 \\ 0 & 0 & 1 \end{bmatrix}}$$

$$\theta_{12} \approx \theta_{\text{sol}} \approx 35^\circ,\ \theta_{23} \approx \theta_{\text{atm}} \approx 37\text{-}53^\circ,\ \theta_{13} \lesssim 10^\circ$$

δ would lead to $P(\bar{\nu}_\alpha \to \bar{\nu}_\beta) \neq P(\nu_\alpha \to \nu_\beta)$. $\cancel{CP}$ measurable if $s_{13} \neq 0$

In a 3 ν framework data yield the spectrum, with approx flavor content:



Given that

$$\Delta m^2_{atm} >> \Delta m^2_{sol}$$

it is natural to expect a hierarchical spectrum:

$$m_3 >> m_2 \approx m_1$$

or

$$m_2 \approx m_1 >> m_3$$

Normal or inverted

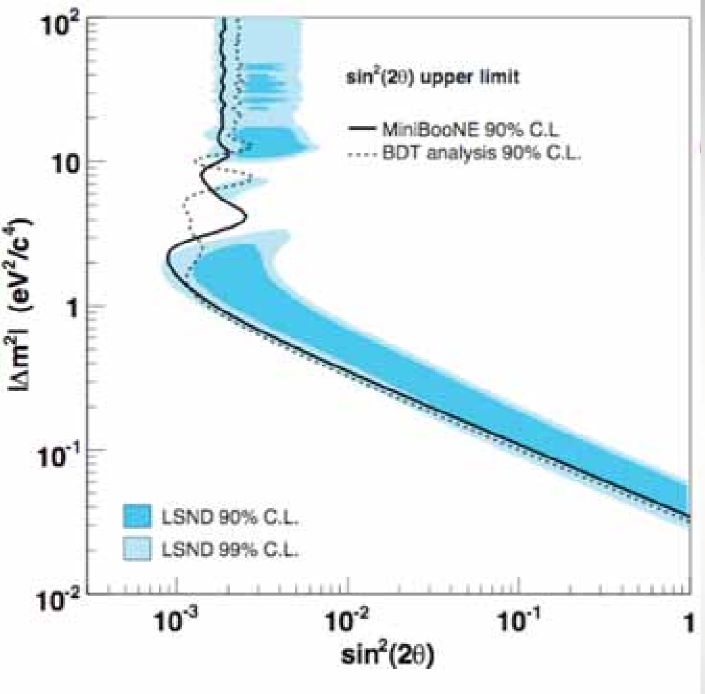
$$|\Delta m^2_{12}| = \Delta m^2_{sol} \simeq 7.5 \times 10^{-5}\,\mathrm{eV}^2 \qquad |\Delta m^2_{32}| = \Delta m^2_{atm} \simeq 2.4 \times 10^{-3}\,\mathrm{eV}^2$$

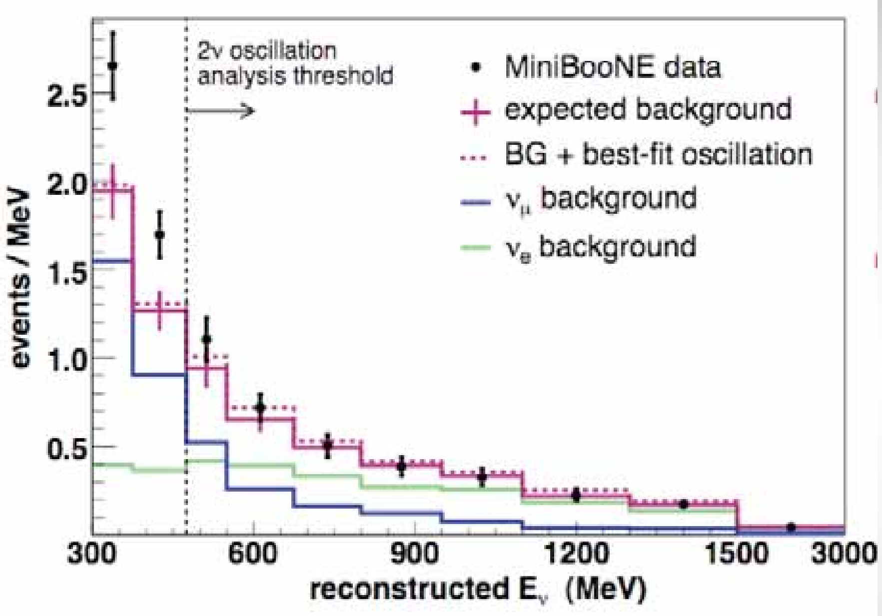
LSND result $\Delta \mathrm{m}^2 \sim 1\ \mathrm{eV}^2$ cannot be reconciled with 3ν's

MiniBoone latest results do not confirm LSND $\Rightarrow$

MiniBoone: No evidence for $\nu_\mu \to \nu_e$ appearance at LSND's L/E

However, observes small excess at low energies not understood



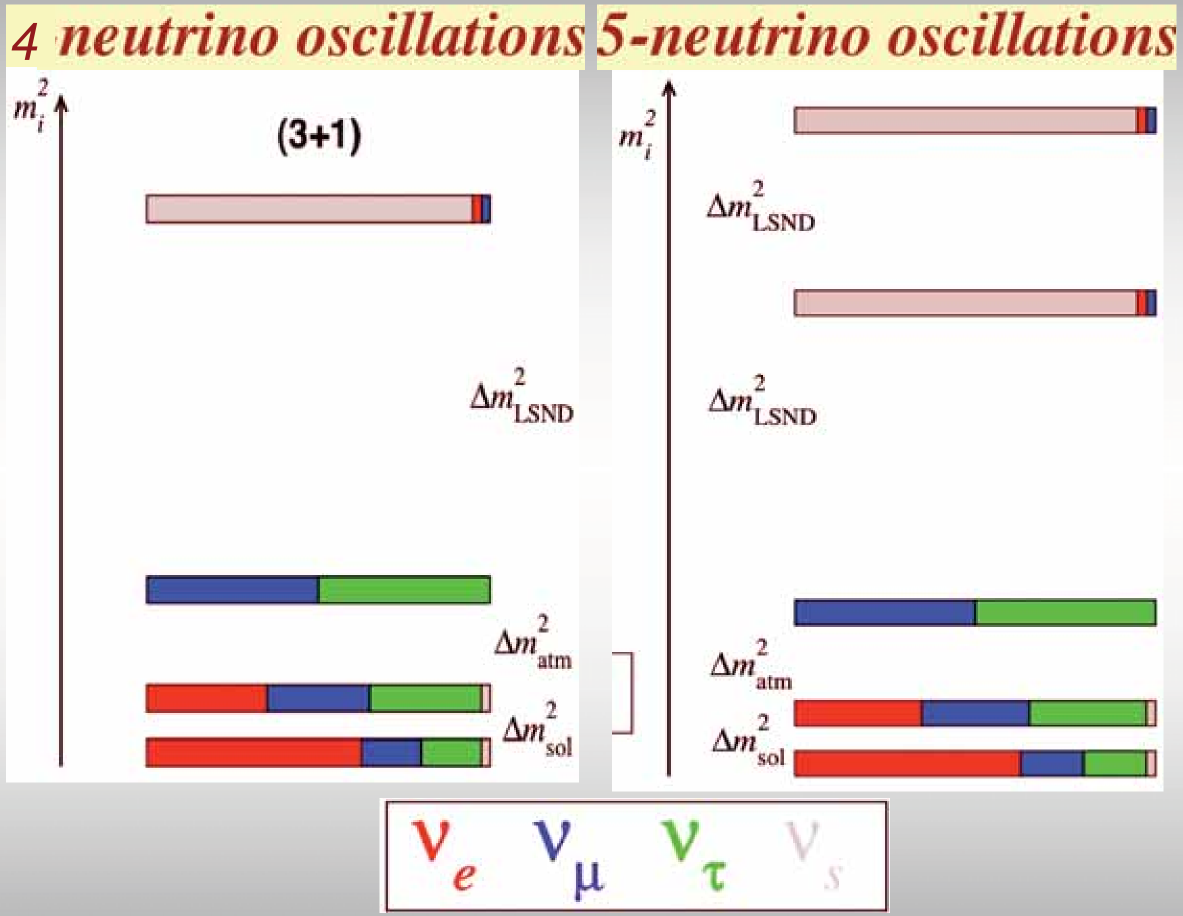


- LSND was wrong
- The physics causing the excess in LSND doesn't scale with L/E
- Difference between neutrinos and antineutrinos?

Many theoretical ideas trying to explain this neutrino puzzle

Adding Sterile Neutrinos to fit LSND and Miniboone data

Talk by Thomas Schwetz-Mangold



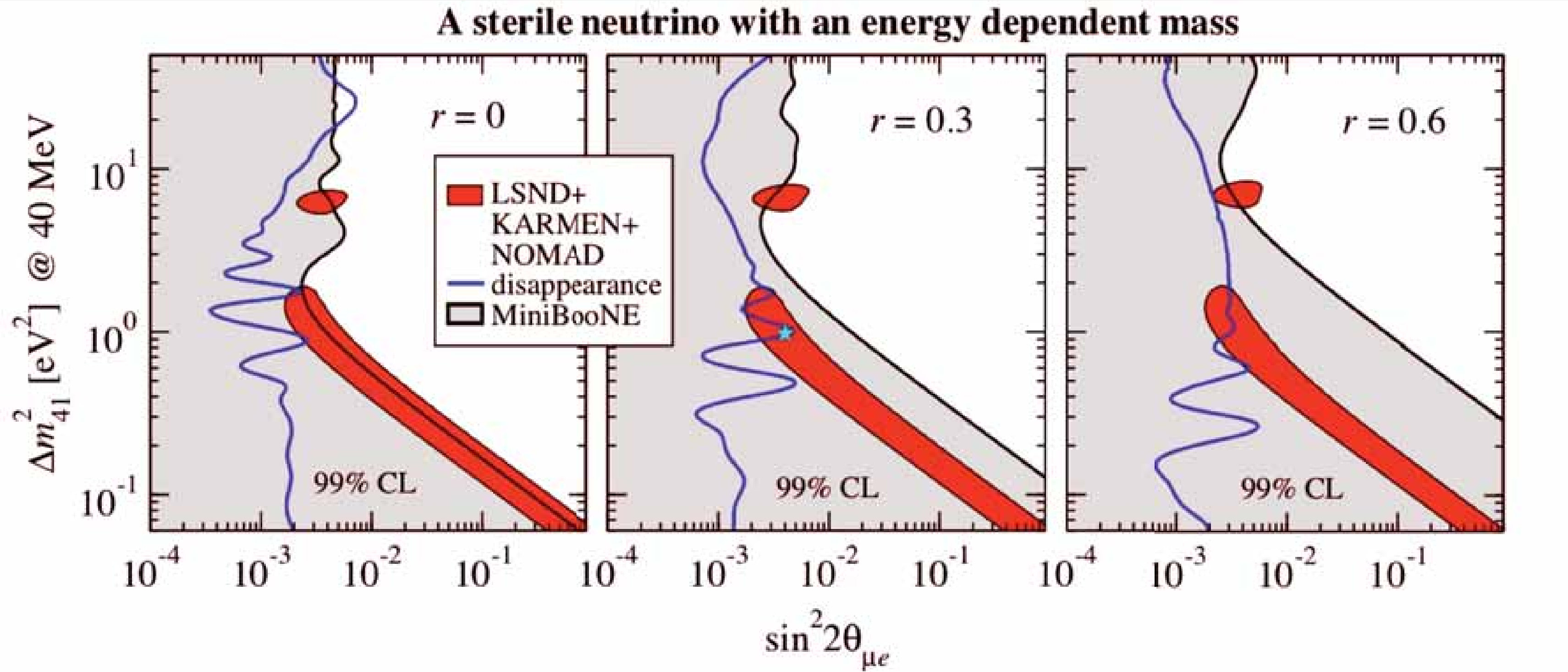
3+1 scheme: global fit of appearance and disappearance exp. off by 4 sigma

3+2 scheme:perfect fit to appearance data
(even MB low energy)
but disappearance is off
(& spoils MB low energy fit)

More sterile neutrinos do not help

All these sterile neutrino schemes have problems with cosmology

Many exotic physics models fail – sterile neutrino oscillations with an exotic energy dependence can fit all data (except the MB excess)



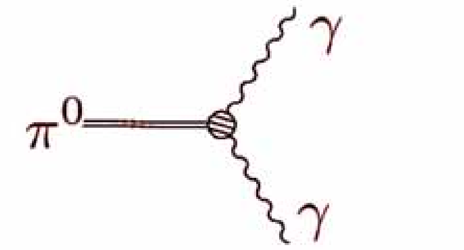
Anomaly mediated Neutrino-Photon interactions at Finite Baryon Density

Talk by Richard Hill

- It is well known that the pion decays into photons may be understood from the axial current anomaly

$$\partial_\mu J_5^\mu \propto \epsilon^{\mu\nu\rho\sigma} F_{\mu\nu} F_{\rho\sigma}$$

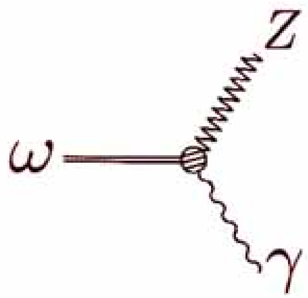
$$\mathcal{L} \sim \epsilon^{\mu\nu\rho\sigma} \pi F_{\mu\nu} F_{\rho\sigma}$$



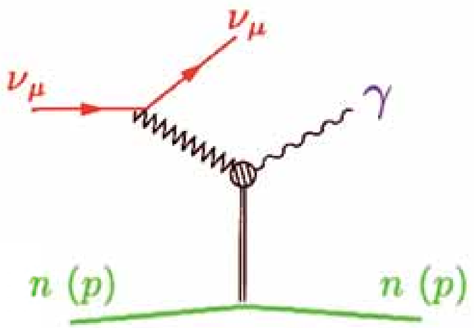
- Are there similar effects associated with the anomalous baryon current ?

$$\partial_\mu J^\mu_{\text{baryon}} \propto \epsilon^{\mu\nu\rho\sigma} \partial_\mu Z_\nu F_{\rho\sigma}$$

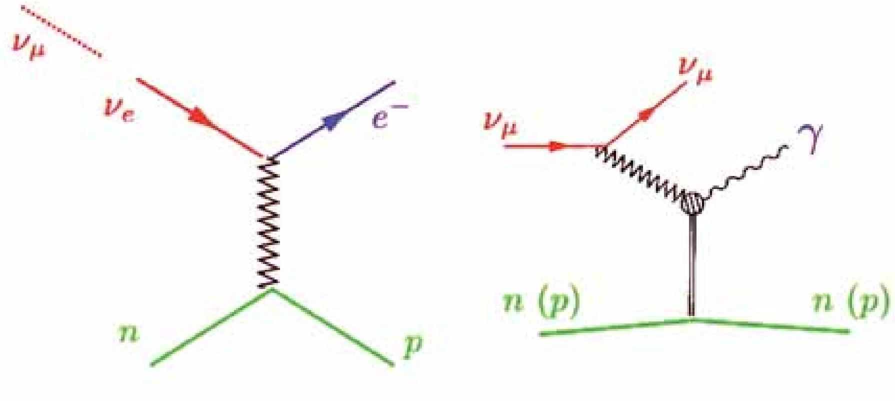
$$\mathcal{L} \sim \epsilon^{\mu\nu\rho\sigma} \omega_\mu Z_\nu F_{\rho\sigma}$$



- These effects can mediate neutrino-photon interactions at finite baryon density!



Can this explain the MiniBoone excess?



$\nu_e \rightarrow e$ "signal"

$\nu_\mu \rightarrow \gamma$ "background"

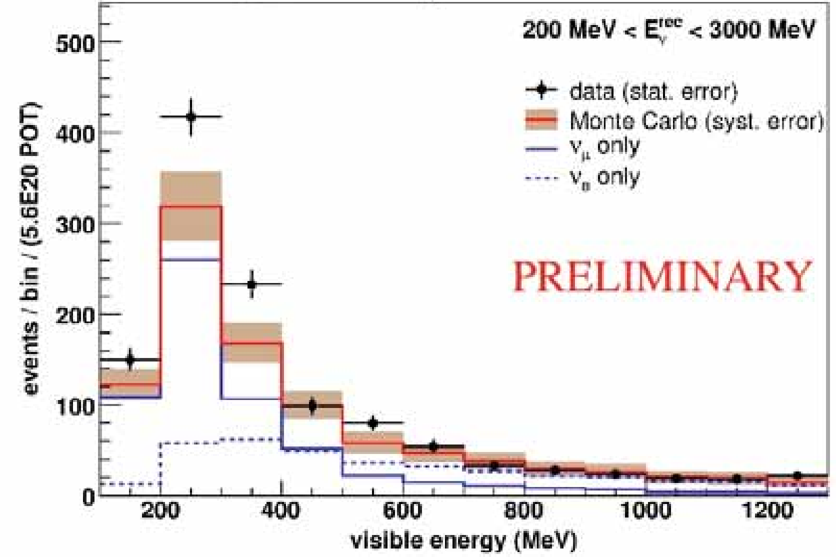
Photon may be interpreted as an electron

Background: three body process
==> underestimated neutrino energy

Excess is consistent, within uncertainties with anomalous neutrino photon interactions

More detailed analysis in progress

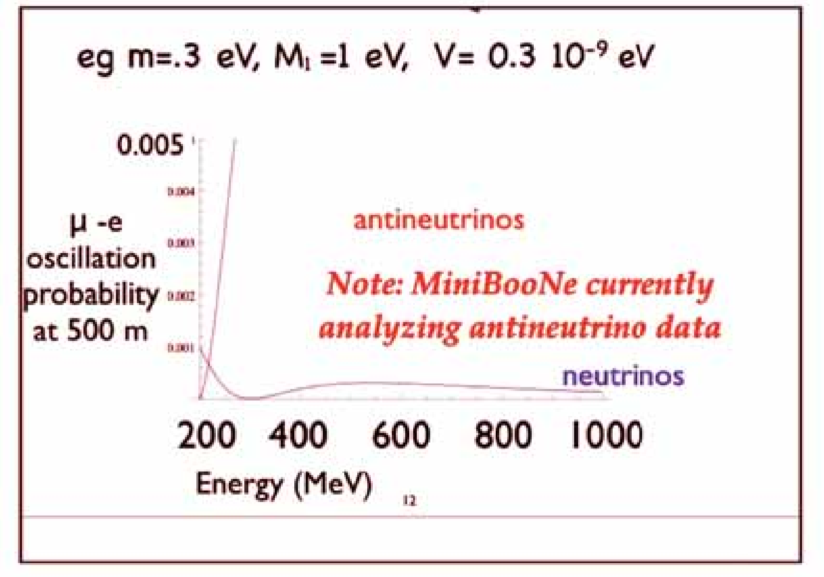
visible energy, 200<E_ν<3000 MeV



A new (B-L) gauge interaction to explain SBL neutrino oscillations

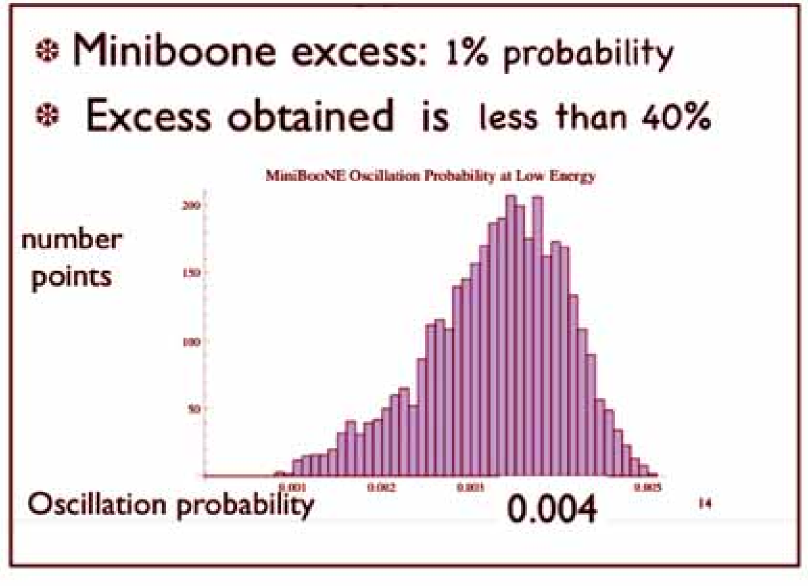
Talk by Ann Nelson

- These interactions would create a new MSW like effect in matter.
- This effect will be different for neutrinos and antineutrinos, and it will be proportional to $2\ E\ \rho_{B-L}\ g^2/M_V^2$
- Miniboone and LSND have similar L / E but different energies



eg m=.3 eV, M_l =1 eV, V= 0.3 10^{-9} eV

Note: MiniBooNe currently analyzing antineutrino data



- Miniboone excess: 1% probability
- Excess obtained is less than 40%

To avoid experimental constraints, the new gauge boson coupling should be small, $g<10^{-5}$, while the gauge boson mass should be smaller than 30 KeV and dependent on the enviroment. This is natural if it gets mass through a scalar charged under (B-L)

Are neutrinos encoding a secret message?

What we need to know:

- How many neutrino species are there? Are there sterile neutrinos?
- What are the precise values of neutrino mass eigenstates?
- Are neutrinos their own particles?
- Do neutrino matter interactions violate CP?
- Which is the mass ordering?
- What is the pattern of mixing among the different type of neutrinos? Which is the value of θ_{13} ?
- Is neutrino CP violation the reason we exist?

The existence of the neutrino’s tiny masses raises the possibility that their masses come from unknown physics, related to Unification

How to extend the SM to include neutrinos?

Dirac masses (L conserved) : SM + 3 singlets ν_{Ri}

$$L_{\nu\ \mathrm{mass}} = \bar{l}_{L_i} h_{\nu_{ij}} \Phi^C \nu_{R_j} + h.c. \xrightarrow{\langle\Phi\rangle = v} \bar{\nu}_{L_i} m_{D_{ij}} \nu_{R_j}$$

$m_\nu \neq \mathrm{I}$ (mixing)

α, β are mass eigenstates

$$\bar{\nu}_{L_i} m_{D_{ij}} \nu_{R_j} \to \bar{\nu}_{L\alpha} m^{diag}_{D\alpha\beta} \nu_{R\beta} \quad \Rightarrow \quad m_\nu^{\mathrm{diag}} = V^{(\nu_L)\dagger} m_D \tilde{V}^{(\nu_R)}$$

with $U_{\mathrm{MNS}} \equiv V^{(\nu_L)\dagger} V^{(l)}$

Majorana masses

The R-handed neutrino can have the usual Higgs coupling and a Majorana mass term (i,j family indices)

$$L_{\nu\ \mathrm{mass}} = h_{\nu_{ij}} \mathrm{v}\ \bar{\nu}_{L_i} \nu_{R_j} + \frac{M_{ij}}{2} \overline{\nu^C_{R_i}} \nu_R + h.c.$$

Diagonalization of the (ν_L, ν_R) system ==> three light neutrino modes ν_i

$$m_\nu = -m_D M^{-1} m_D^T$$

For M~ 10^{15} GeV and m_D~100 GeV
==> m_ν ~10^{-2} eV: consistent with data

Low energy effects of Majorana neutrino Masses

Talks by Thomas Hambye, F. del Aguila, Jorn Kersten

- The effects of a heavy right -handed neutrino on SM particle interactions can be described by a low energy effective theory in term of higher dimensional operators with dimensions=5,6 … suppressed by inverse powers of the heavy neutrino mass: 1/M, $1/M^2$,….

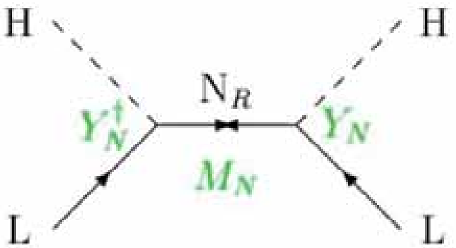
there is only one: $\mathcal{L} \ni \frac{\lambda}{M}(LLHH)$ Defines the mass $\Rightarrow m_\nu = \frac{\lambda}{M} v^2$

$\uparrow$

Majorana

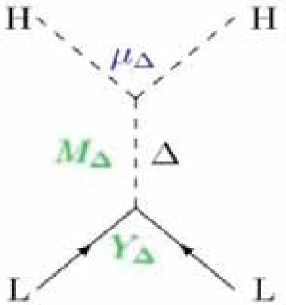
Three basic ways to generate 5 D operators.

Right-handed singlet:
(type-I seesaw)



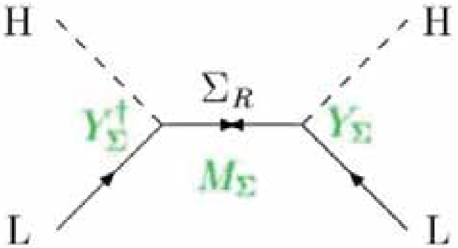
$$m_\nu = Y_N^T \frac{1}{M_N} Y_N v^2$$

Scalar triplet:
(type-II seesaw)



$$m_\nu = Y_\Delta \frac{\mu_\Delta}{M_\Delta^2} v^2$$

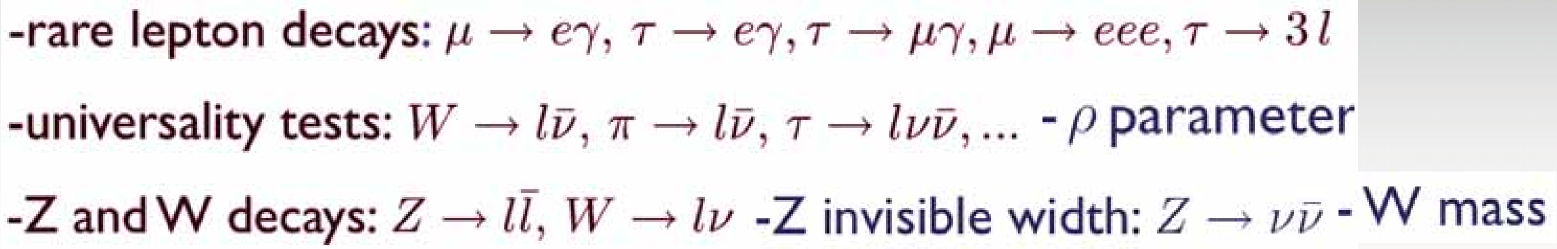
Fermion triplet:
(type-III seesaw)



$$m_\nu = Y_\Sigma^T \frac{1}{M_\Sigma} Y_\Sigma v^2$$

- Dimension 6 operators define the interactions,, and they are different types for the different types of Seesaw mechanisms

  ==> they are the key to distinguish among them
- Bounds on Yukawa couplings from D=6 operators induced processes



-rare lepton decays: $\mu \to e\gamma$, $\tau \to e\gamma, \tau \to \mu\gamma, \mu \to eee, \tau \to 3\,l$

-universality tests: $W \to l\bar{\nu}$, $\pi \to l\bar{\nu}$, $\tau \to l\nu\bar{\nu}, \ldots$ - ρ parameter

-Z and W decays: $Z \to l\bar{l}$, $W \to l\nu$ -Z invisible width: $Z \to \nu\bar{\nu}$ - W mass

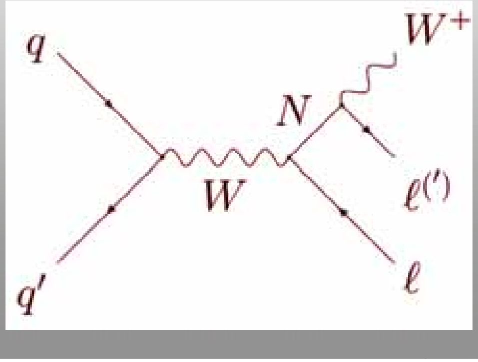
In general, $|Y| \le 10^{-1}\left[M/1\text{Tev}\right]$ or stronger

Rich Phenomenology: talk by F. Del Aguila

Coefficients of d=5 and d=6 operators have different Yukawa dependence

$c_{d=5}$ may be small due to cancellations among Yukawas, or one can invoke L number conservation and add a small perturbation to generate ν masses

- *Y related to LV can be sufficiently large with M~ 100 GeV- 100 TeV and there may be "some" reach at colliders in type I Seesaw.*
- *T ype II and Type III: pair production of triplets via gauge interactions.*



Same sign dileptons

Lepton Flavour Violation in SUSY Seesaw

Talk by Ernesto Arganda,

In the context of MFV

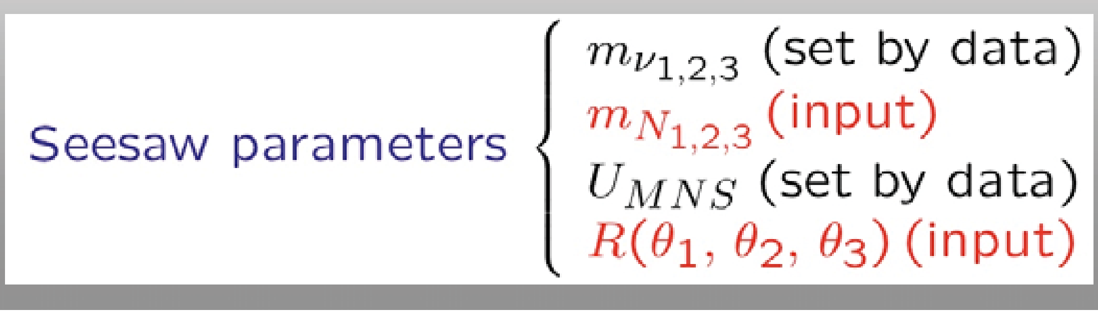
(= flavour symmetry violation in the lepton sector is proportional to the SM U_{MNS})

Leptonic FCNCs are induced by the RG evolution of the Lepton Soft SUSY breaking parameters proportional to the $h_\nu h_\nu^\dagger$. For sizeable h_ν which depends on the parameters of the seesaw mechanism, sizeable FLV process could be observed.

There is also an strong dependence on the SUSY parameters;

$$\mathbf{CMSSM} + 3\nu_R\ \mathbf{(Majorana)} + 3\tilde{\nu}_R$$

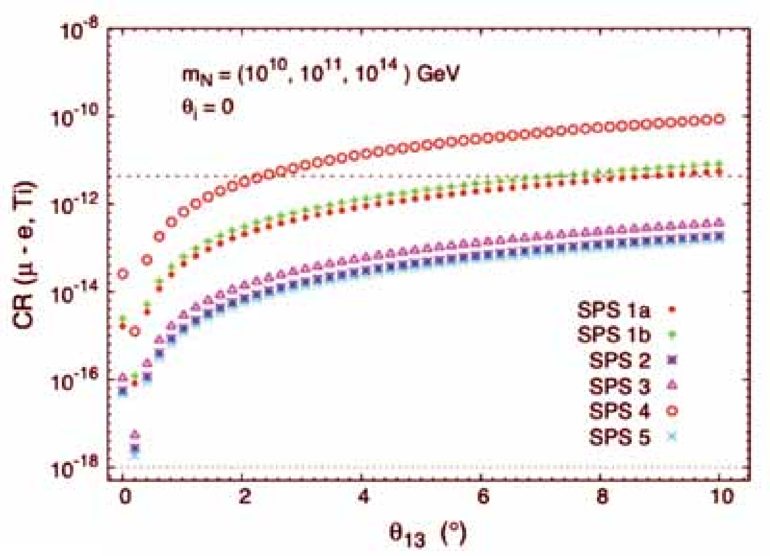
- ⋆ Universal soft Higgs masses: CMSSM-seesaw
  $(M_0, M_{1/2}, A_0, \tan\beta, \mathrm{sign}(\mu))$



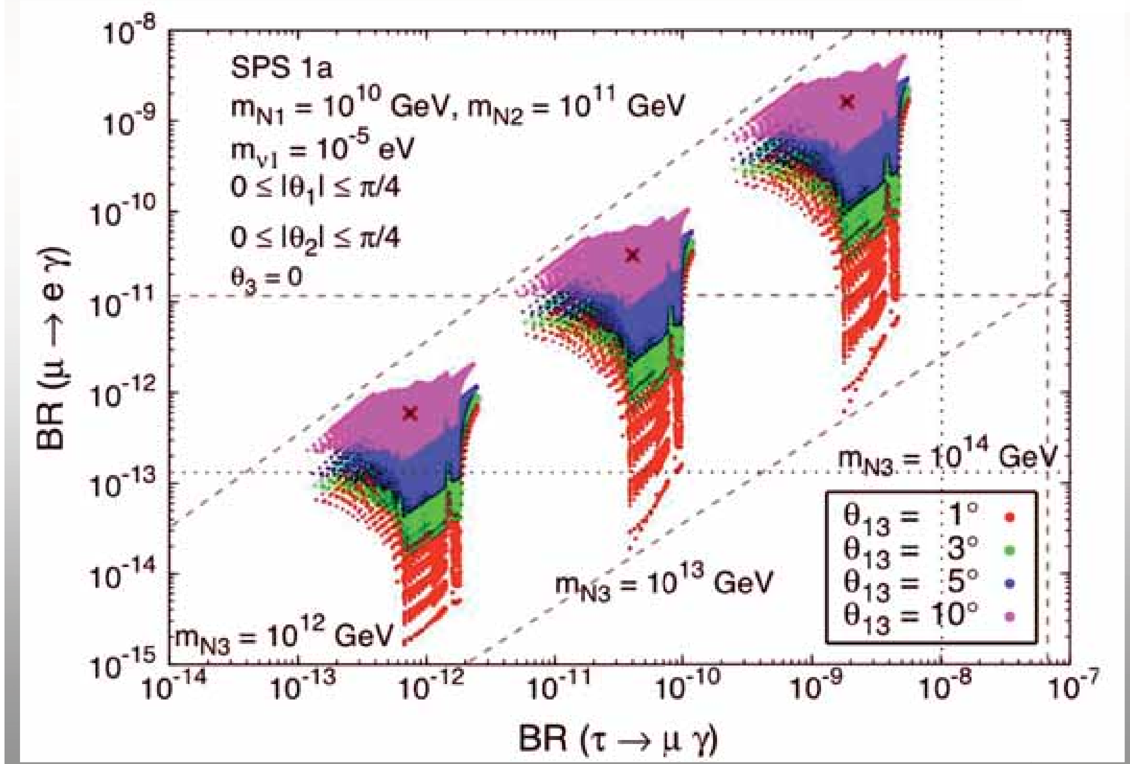
$$\text{Seesaw parameters} \begin{cases} m_{\nu_{1,2,3}} \ \text{(set by data)} \\ m_{N_{1,2,3}} \ \text{(input)} \\ U_{MNS} \ \text{(set by data)} \\ R(\theta_1, \theta_2, \theta_3) \ \text{(input)} \end{cases}$$

$(\theta_i \neq 0 \Rightarrow \text{beyond MFV})$

High sensitivity to θ_{13}



and on the heavy Neutrino Masses and Hierarchy



LFV observables,
together
with low energy neutrino data
can provide insight into the
heavy neutrino sector
and seesaw
parameters

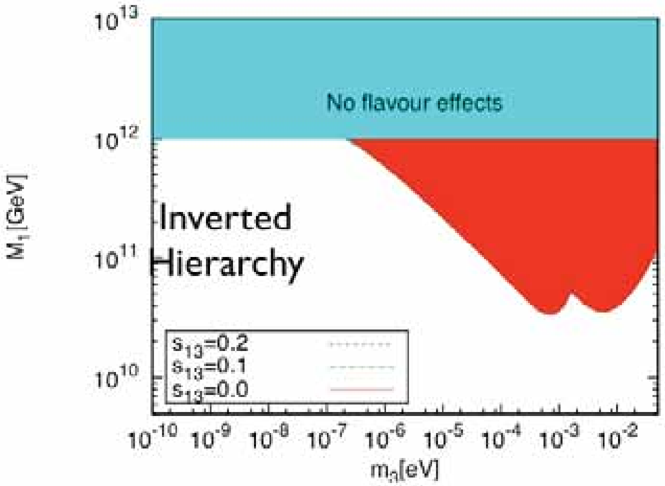
Leptogenesis

Talks by De Simone, Blanchet,Molinari

- Baryogenesis induced by out of equilibrium and CP- and violating decay of heavy right-handed Majorana neutrinos
- Created lepton asymmetry is converted into a baryon asymmetry via anomalous sphaleron processes.
- In the case of hierarchical neutrinos, $M_1 \ll M_2 \ll M_3$, enough CP-asymmetry is obtained only for $M_1 \; (T_{\rm reh}) \geq 3(1.5)10^9 \mathrm{GeV}$
- Moreover, whenever reheating temperature is smaller than 10^{12} GeV , tau Yukawa coupling (flavor) effects become important, and should be taken into account (flavored leptogenesis)

In flavored leptogenesis, phases in $U_{\rm PMNS}$ matrix (Dirac or Majorana) may be enough to explain the primordial CP-asymmetry.

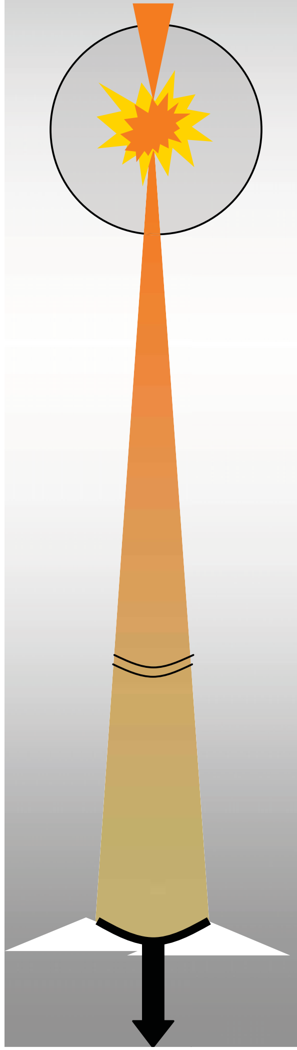
For quasi-degenerate right-handed neutrinos, CP-violating effects may become resonant and masses could be much smaller, even of order of the TeV scale. Quantum Boltzman equations may be important and should be taken into account



Neutrinos from the Cosmos

Gamma ray bursts, dark matter annihilation from the halo, Supernovae

Talks by Hylke Koers, Sergio Palomares-Ruiz, Antonio Marrone



- Neutrinos emission in gamma-ray bursts

Interesting discussion about gamma ray bursts as candidate sources for neutrinos and gamma rays.

** Neutrinos are expected to be very useful probes to gain insight on the dynamics of the outflow, however, neutrino emmited peaked at E~ 50-70 GeV ==> out of the reach of IceCube.

** Gamma ray emission: High energy gamma rays produced in the decay of π^0 in inelastic np collisions. Their energy is reprocessed and outputted as lower energy photons of 10 GeV (detectable at GLAST) or 100 KeV, depending on the model. Together with the prompt emission would provide evidence of a specific gamma ray bursts model: the fireball model

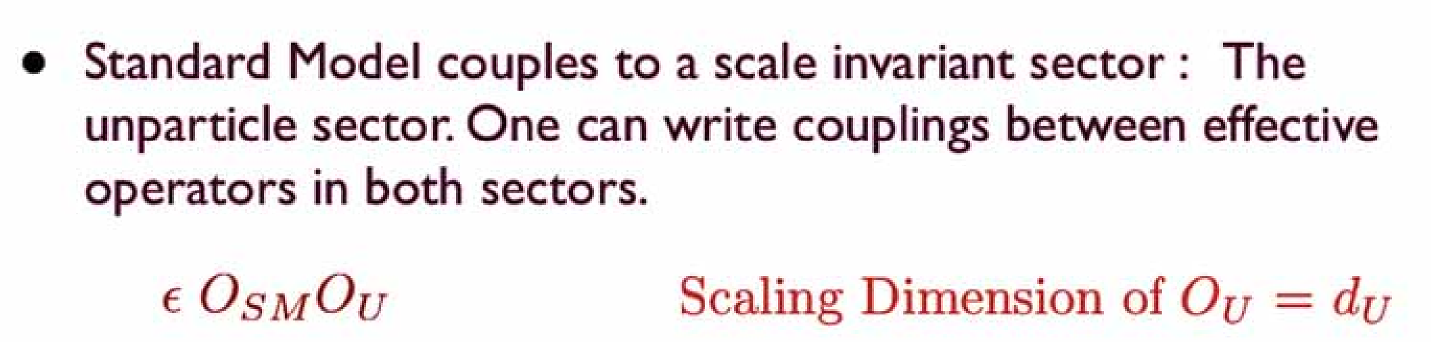
Interesting topics under development

On the Finitness of Supergravity Talk by Kellogg Stelle

Advances in computational physics open the possibility that maximal supergravity might be free of the ultraviolet divergences that have plagued quantum gravity theories. These advances based on the use of unitarity and dimensional regularization make it possible to calculate 3-loops N=8 Supergravity and find them finite. Is this a sign that there are behaviours that cannot be understood from non-renormalization theorems?

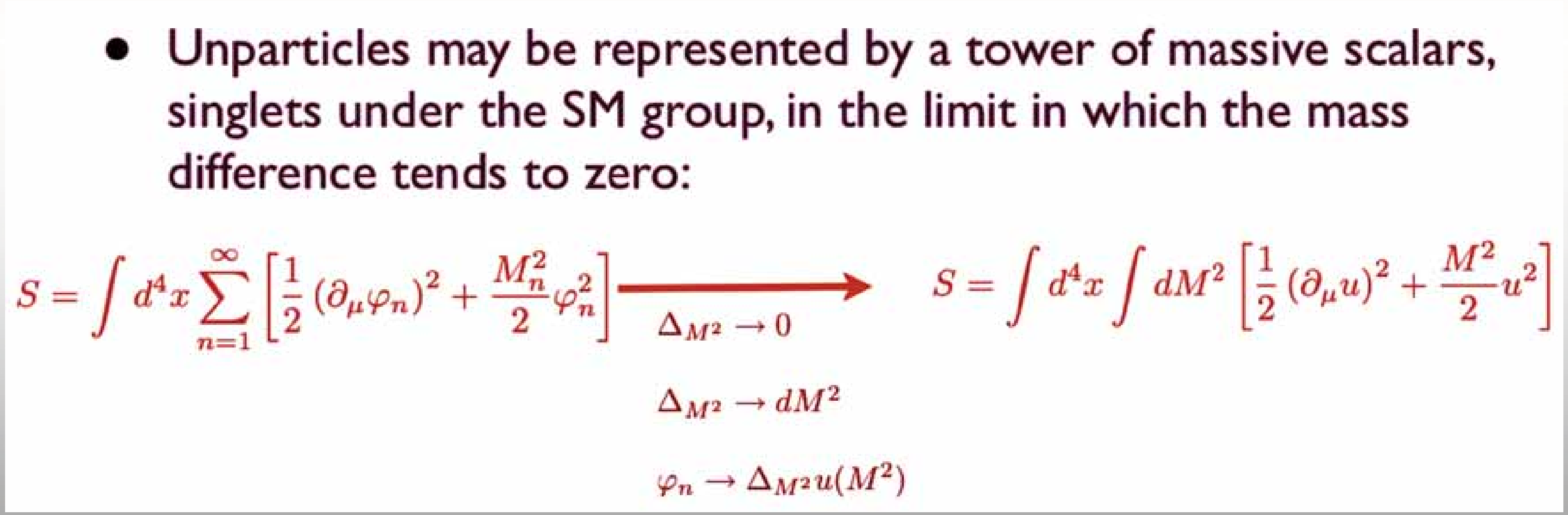
The Unparticle-Higgs Connection

Talk by Jose Ramon Espinosa



- Standard Model couples to a scale invariant sector : The unparticle sector. One can write couplings between effective operators in both sectors.

$\epsilon\, O_{SM} O_U$ Scaling Dimension of $O_U = d_U$



- Unparticles may be represented by a tower of massive scalars, singlets under the SM group, in the limit in which the mass difference tends to zero:

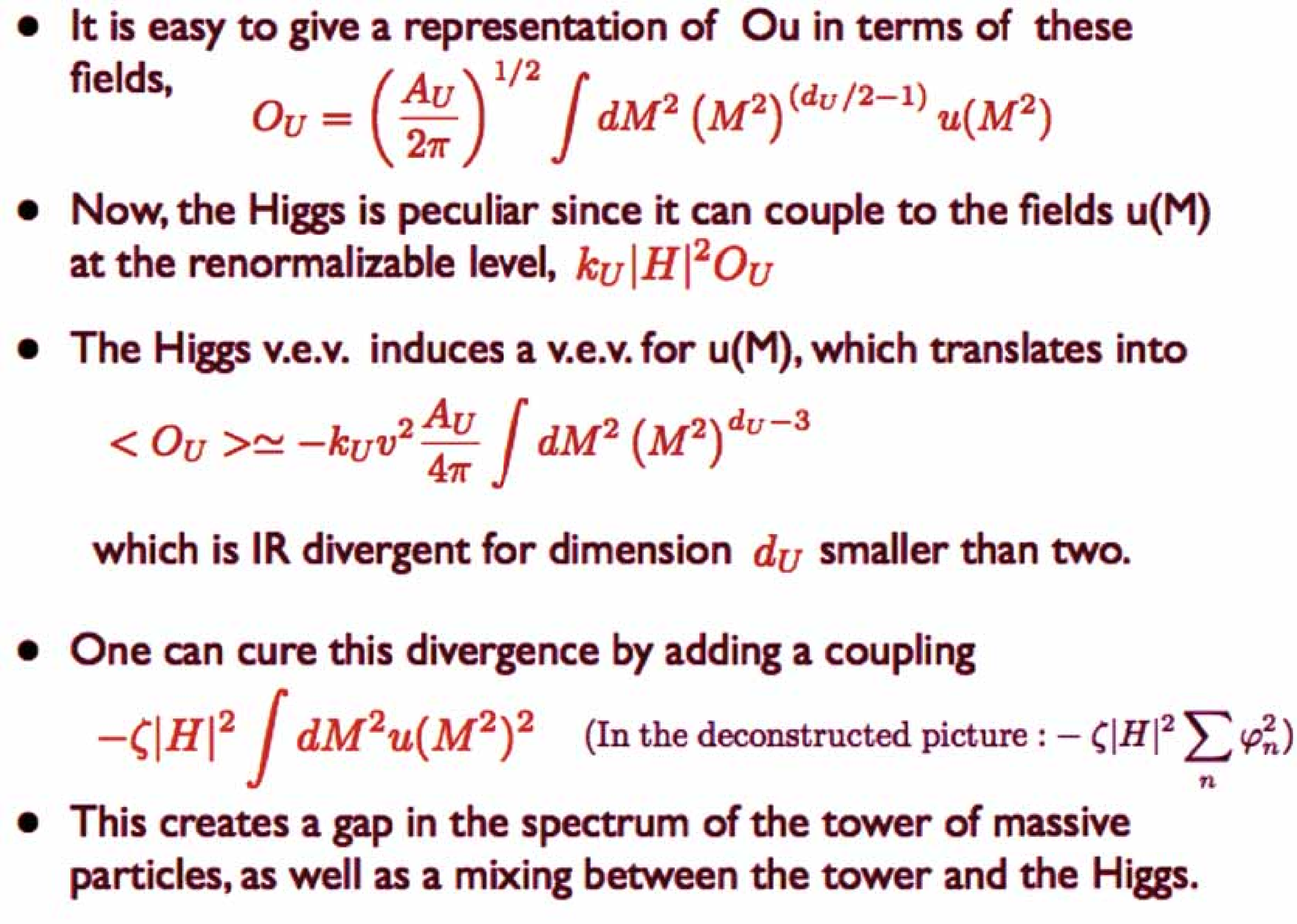
$$S = \int d^4x \sum_{n=1}^{\infty} \left[\frac{1}{2}(\partial_\mu \varphi_n)^2 + \frac{M_n^2}{2}\varphi_n^2\right] \xrightarrow[\Delta_{M^2} \to 0]{} S = \int d^4x \int dM^2 \left[\frac{1}{2}(\partial_\mu u)^2 + \frac{M^2}{2}u^2\right]$$

$\Delta_{M^2} \to dM^2$

$\varphi_n \to \Delta_{M^2} u(M^2)$

- Scale invariance recovered due to the possibility of rescaling M^2

Coupling to the SM Higgs Sector

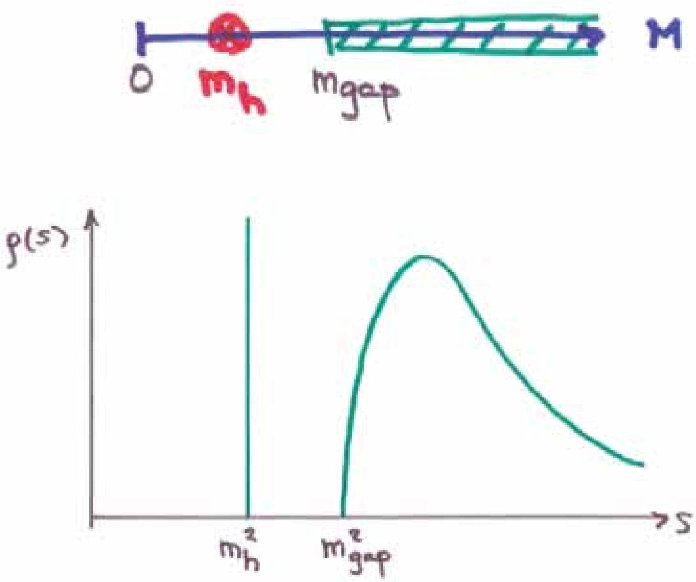


- It is easy to give a representation of Ou in terms of these fields, $$O_U = \left(\frac{A_U}{2\pi}\right)^{1/2} \int dM^2 \, (M^2)^{(d_U/2-1)} \, u(M^2)$$
- Now, the Higgs is peculiar since it can couple to the fields u(M) at the renormalizable level, $k_U |H|^2 O_U$
- The Higgs v.e.v. induces a v.e.v. for u(M), which translates into $$< O_U > \simeq -k_U v^2 \frac{A_U}{4\pi} \int dM^2 \, (M^2)^{d_U-3}$$ which is IR divergent for dimension d_U smaller than two.
- One can cure this divergence by adding a coupling $$-\zeta|H|^2 \int dM^2 u(M^2)^2 \quad \text{(In the deconstructed picture : } -\zeta|H|^2 \sum_n \varphi_n^2\text{)}$$
- This creates a gap in the spectrum of the tower of massive particles, as well as a mixing between the tower and the Higgs.

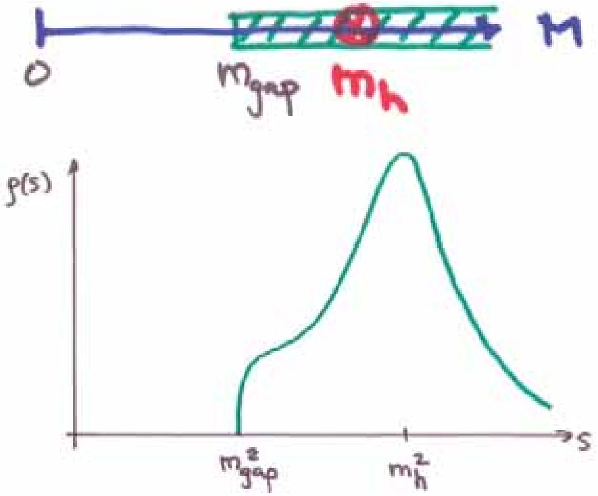
Phenomenology

Dependence on the Higgs mass being smaller or larger than the gap mass

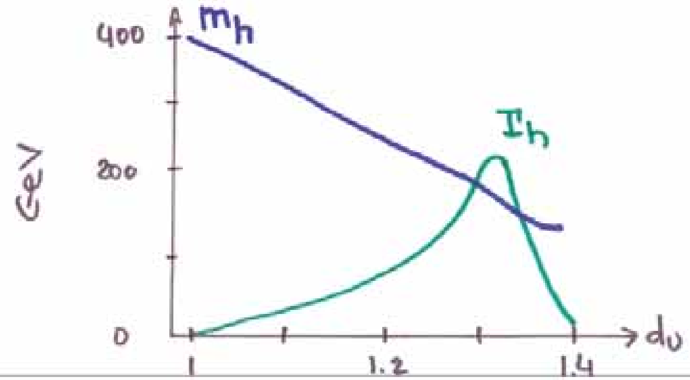
$$m_{\mathrm{gap}}^2 = \zeta v^2$$



Mixing induces coupling of unparticles to ZZ !
Also, ZZ coupling of Higgs is weakened, while its mass is reduced.



Higgs pole is immersed in unparticle continuum. Large effective Higgs width appears



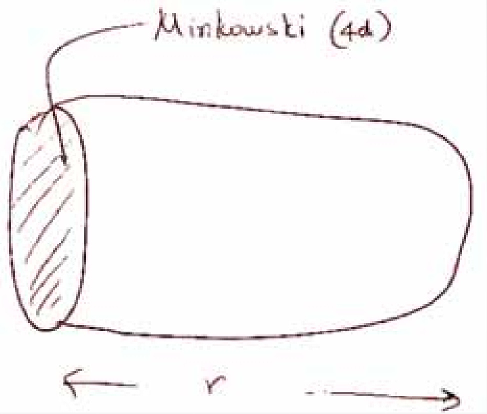
Holography and QCD

Talk by Elias Kiritsis

Correspondence between gravity in AdS5 and gauge theory in 4D

$$AdS_5 \quad \to \quad ds^2 = \frac{\ell^2_{\rm AdS}}{r^2}(dr^2+\eta_{\mu\nu}dx^\mu dx^\nu) \quad , \quad R = -\frac{6}{\ell^2_{\rm AdS}}$$

- The extra coordinate r is the "holographic coordinate". There is Poincaré invariance in the 4d coordinates x^μ.
- The space is non-compact with a boundary at r=0 (isomorphic to Minkowski space).
- The holographic coordinate can be interpreted as a RG scale M.



- The graviton $\quad g_{\mu\nu} \quad \to \quad T_{\mu\nu} \sim Tr[F^2_{\mu\nu} - \frac{1}{4}\eta_{\mu\nu}F^2]$
- The dilaton scalar $\quad \phi \quad \to \quad Tr[F^2]$
- The RR (pseudoscalar) axion $\quad a \quad \to \quad Tr[F\wedge F]$

with effective string theory action

$$S_{\rm string} \sim M_P^3 \int d^5x\sqrt{g}\,\left[e^{-2\phi}\left(R - \frac{4}{3}(\partial\phi)^2 + \cdots\right) + (\partial a)^2 + \cdots\right]$$

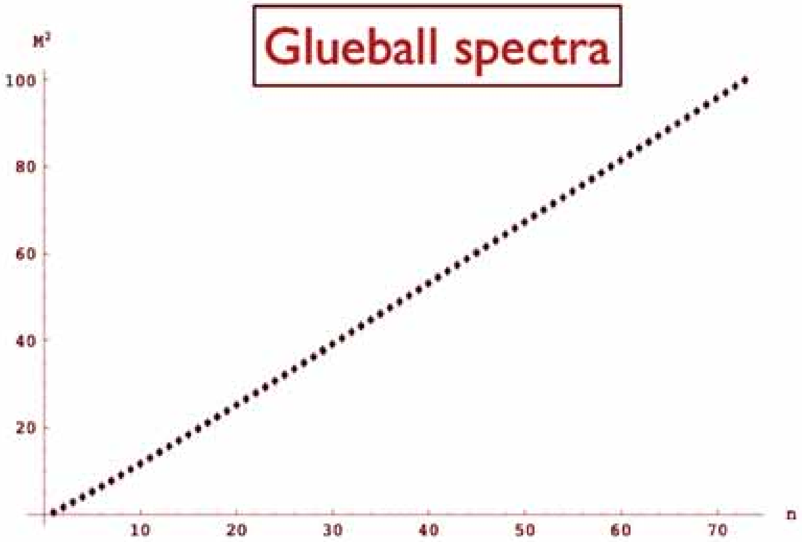
- Fluctuations of $g_{\mu\nu}$ gives a tower of bound states with spin 2 (2^{++} glueballs). The dilaton gives the tower of 0^{++} glueballs. The axion gives the tower of 0^{+-} glueballs, etc.

♠ The crudest model: use a slice of AdS_5, with a UV cutoff, and an IR cutoff.
Polchinski+Strassler, also Randall-Sundrum I

Although it leads to a good description of the meson spectrum, it has shortcomings, like an improper description of the masses of the highest excited states of the glueball spectra

It can be improved by a proper treatment of the dilaton action. Results with improvement :

Glueball spectra



Comparison with lattice values (Ref I)

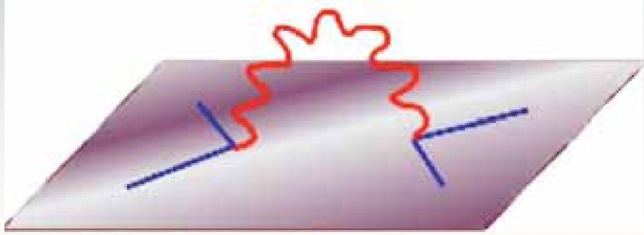
J^{PC}	Ref I (MeV)	Our model (MeV)	Mismatch
0^{++}	**1475 (4%)**	**1475**	0
2^{++}	2150 (5%)	2055	4%
0^{-+}	**2250 (4%)**	**2243**	0
0^{++*}	**2755 (4%)**	**2753**	0
2^{++*}	2880 (5%)	2991	4%
0^{-+*}	3370 (4%)	3288	2%
0^{++**}	3370 (4%)	3561	5%
0^{++***}	3990 (5%)	4253	6%

Many open questions: Meson and baryon spectrum, strong CP problem, finte T properties, etc.

Collider Signatures of Warped ED

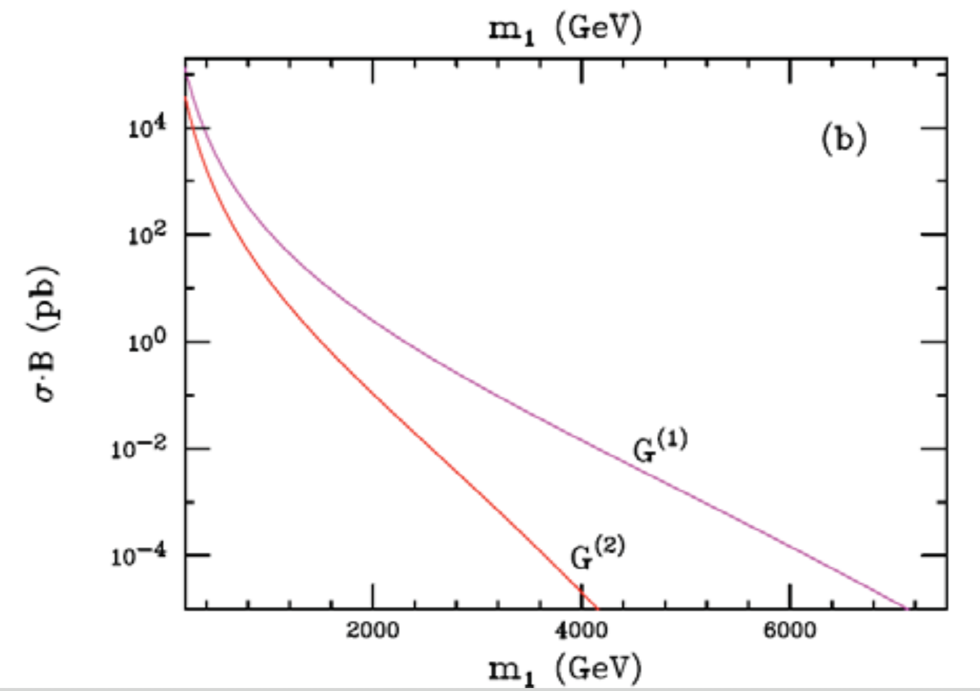
Talk by Lisa Randall

If only Gravity propagates in the Warped Extra dimension



KK Gravitons, with masses of the order of the TeV scale and couplings of order 1/TeV to SM particles

Produced as resonances or contribute to fermion pair production at colliders



Large Production cross sections

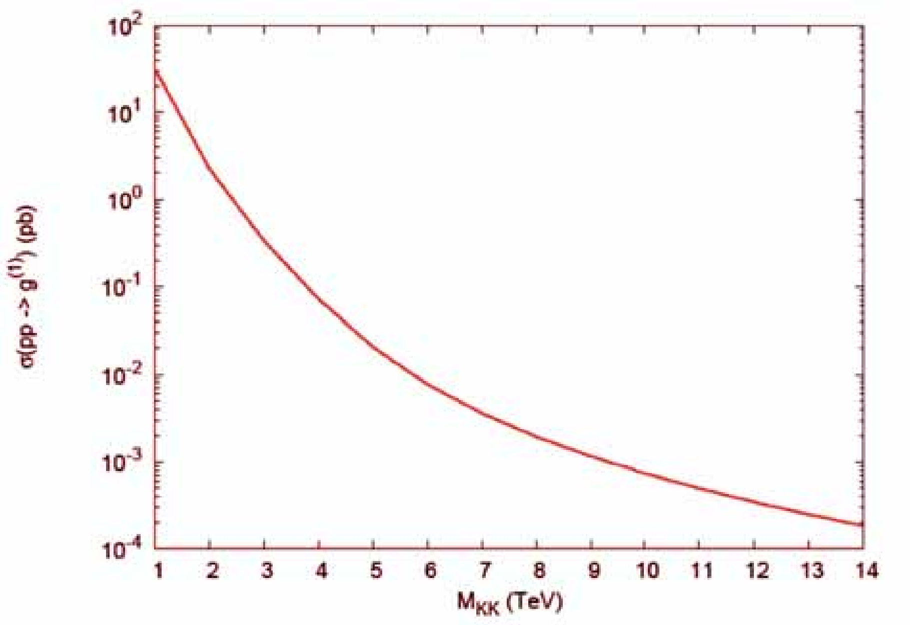
If SM particles propagate in the bulk ==> lower production cross section for KK Graviton (due to light quark & gluon profiles) and main decay to top pairs

Not such a promising signature

Search for KK glouns at the LHC

L. Randall, B. Lillie, L.T. Wang

- Gluon KK modes are localized towards the IR brane, but its wave function is flat in the bulk, away from IR brane
- This leads to couplings of gluon KK mode with all light fermions of about a fifth of the strong gauge coupling. Equality of couplings of light fermions serves to cancel FCNC



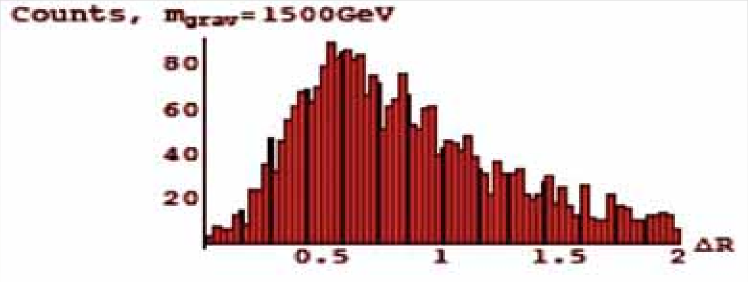
Resulting cross sections still sizable, for KK gluons up to about 4 TeV.

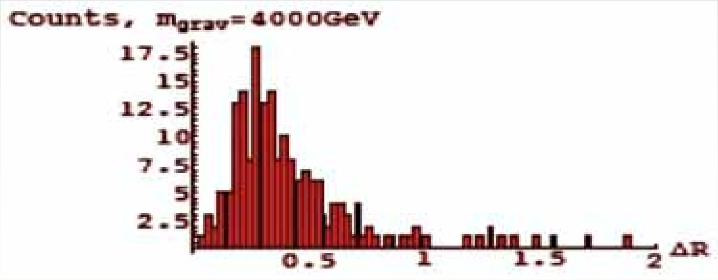
Dominant decay mode of the KK gluon is into third generation quarks, in particular into the right-handed top quark in the simplest models.

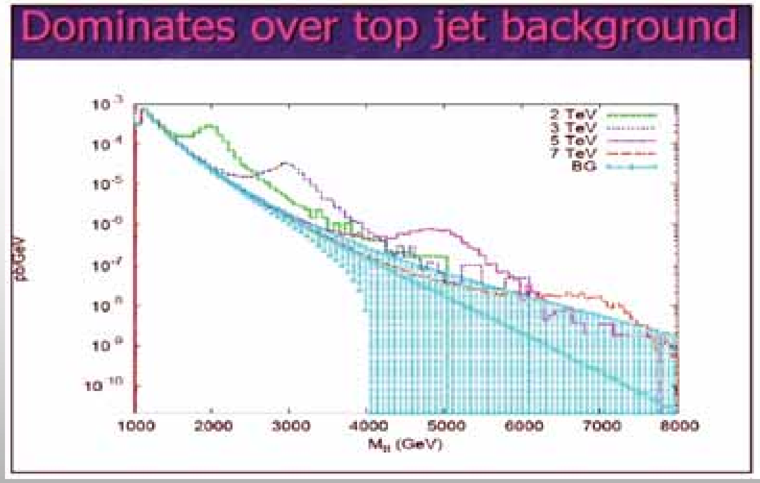
Total cross-section for production of the first KK gluon, as a function of KK mass

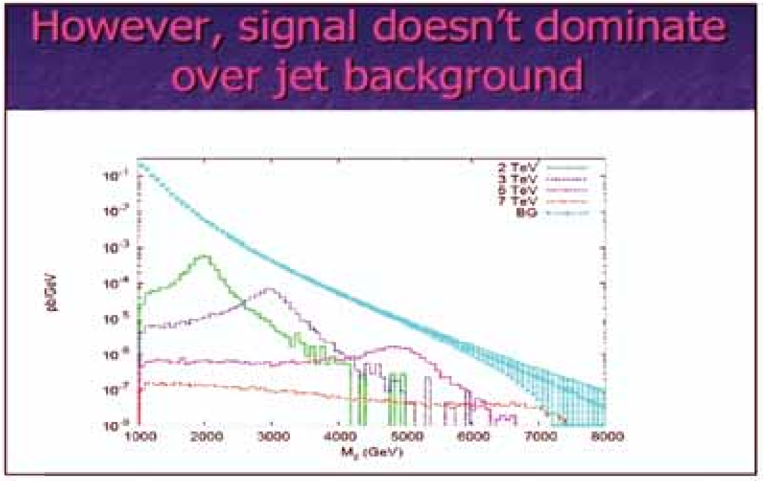
KK gluon decay properties

- For heavier KK gluons, top quarks form their decays become more boosted. The W’s and b’s are no longer isolated and the top looks more like a massive jet. This can be seen from the angular separation of the top decay products ΔR






Dominates over top jet background


However, signal doesn’t dominate over jet background

•Reach up to a few TeV KK gluons but efficient energetic top jet ID required
•For sufficiently large KK gluon mass top must be treated as a massive jet and require the jet invariant mass to be close to the top

Additional KK gluon decay modes

- In simple Gauge-Higgs unification models, consistency with precision measurements demands the presence of light KK right handed top quark states.

M.C., E. Ponton, J. Santiago and C. Wagner

- The KK gluon may decay into these additional KK modes, which are strongly coupled to it and decay mostly into weak gauge bosons and third generation quarks,

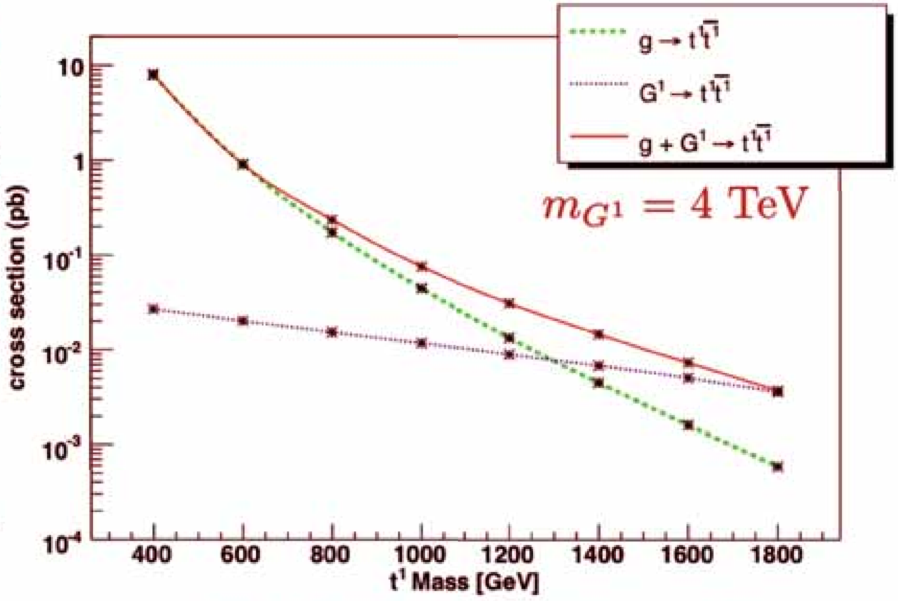
$$\Gamma(t^1 \to Wb) = 2\,\Gamma(t^1 \to tZ) = 2\,\Gamma(t^1 \to Ht)$$

- Fermion KK modes enhance the width of KK gluon and reduces the branching ratio of its decay into top quarks

Gluon KK search becomes very difficult, but search for fermion KK modes still possible, due to constructive interference of contributions to the gluon and KK gluon induced production cross section.

Reach of t^1 up to masses of about 1.5 TeV may be achieved.

Single t^1 production may be used as a complementary channel.



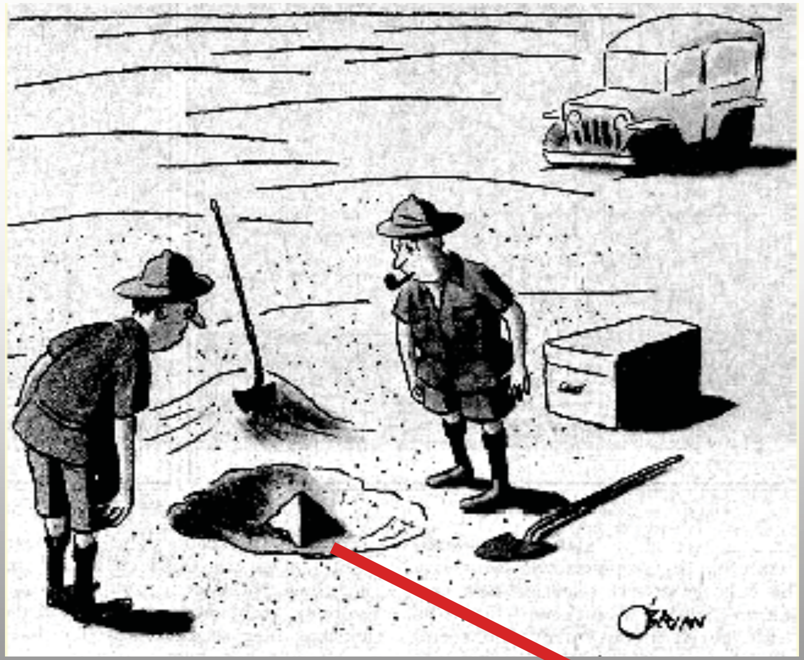
M.C., A. Medina, B. Panes, N. Shah and C. Wagner

At the TeV scale we expect discoveries

Precision measurements and astrophysical observations point to it

- Particle Accelerators reproduce in a controlled lab enviroment forms of matter and energy last seen in the early universe

- Particles are the tools we use to find new forces, new dimensions of space.



"This could be the discovery of the century. Depending, of course, on how far down it goes"

In the coming Moriond meetings, we expect to have an exciting new picture emerging !