Where we stand
and where we are headed

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3rd CPNSH workshop, 24-25 March 2005, SLAC

Towards a Report

Topics

- Higgs sector CP violation + related issues
  - Higgs sector CP violation (2HDM, MSSM, NMSSM, etc)
  - determination of CP phases
  - related issues for e.g. sparticle prod + decays
- Non-standard Higgs (NSH) physics in general
  - MSSM + extra singlets (NMSSM, MNSSM)
  - Little Higgs models
  - Higgs in extra dimensions
  - strong EWSB
  - higgsless theories
  - ....
- Coherent picture of models and signatures, implications for experiments at colliders, flavor physics, cosmology, etc. ...

Motivation - CPV

Once the Higgs particle is discovered, its profile must be measured precisely and its quantum numbers (spin, CP, ...) must be checked in order to understand EWSB.

CP violation in extended Higgs sectors, as expected in extensions of the SM, has become a subject of great interest and can change Higgs phenomenology at colliders quite substantially.

$\Rightarrow$ Investigate potentials of future colliders (LHC, e^+e^- LC, $\gamma\gamma$) for

- establishing the CP properties and/or
- finding effects due to CP-violation

$\Rightarrow$ Investigate implications for cosmology

NB: We actually *do* need addtional sources of CPV beyond the SM
in order to explain the baryon assymmetry in the Universe....

Motivation - NSH

Scalar sectors in extensions of the (MS)SM typically contain additional, non-standard Higgs particles or other scalars without a VEV, which

- can mix with the usual SM-like Higgs boson and/or
- can be present in its decays,

leading to significant changes in the Higgs collider phenomenology.

Examples: singlet Higgs in NMSSM, radions, sleptons in RPV SUSY.

Understanding the structure of the scalar sector is important for a full understanding of electroweak symmetry breaking.

Moreover, there is still the possibility of non-standard EWSB
$\longrightarrow$ strongly-interacting W's, gauge boson KK-modes, ...

How we started

- Idea first brought up by Maria Krawczyk in Summer 2003, focus initially on CP studies.
- Michelangelo Mangano who proposed to cover non-standard Higgs scenarios in general. They talked to John Ellis, Rohini Godbole, David Miller and me .....

Led to a series of 2-days meetings

- Frist workshop 14-15 May 2004 at CERN
- Second workshop 2-3 Dec 2004 at CERN [American contrib!]
- Meeting on ’Flavor and the LHC’, 31 Jan - 1 Feb 2005 at CERN
  $\longrightarrow$ Separate group investigating the synergy between experiments at colliders and at flavor factories, led by T. Hurth and M. Mangano
- Now third CPNSH workshop at SLAC

Contributions - brief overview

CP-violating Higgs sector + related issues

- Generic 2HDM CP violation

  contributions by J. Gunion, M. Krawczyk
  this meeting: H. Haber, I. Ginzburg

- CPV phases in the MSSM

  $\longrightarrow$ implications for Higgs studies

  M. Dubinin, R. Godbole, S. Heinemeyer, J. Kalinowski,
  J.S. Lee, M. Mühlleitner, A. Pilaftsis, J. Williams
  this meeting: M. Carena, H. Eberl, A. Pilaftsis

  $\longrightarrow$ implications for SUSY studies

  S. Hesselbach

In the MSSM, CP-violating phases of soft-breaking parameters, e.g.

$$M_1 = |M_1|\, e^{i\phi_1}, \quad A_t = |A_t|\, e^{i\phi_t}, \quad \ldots.$$

can radiatively induce CP violation in the Higgs sector.

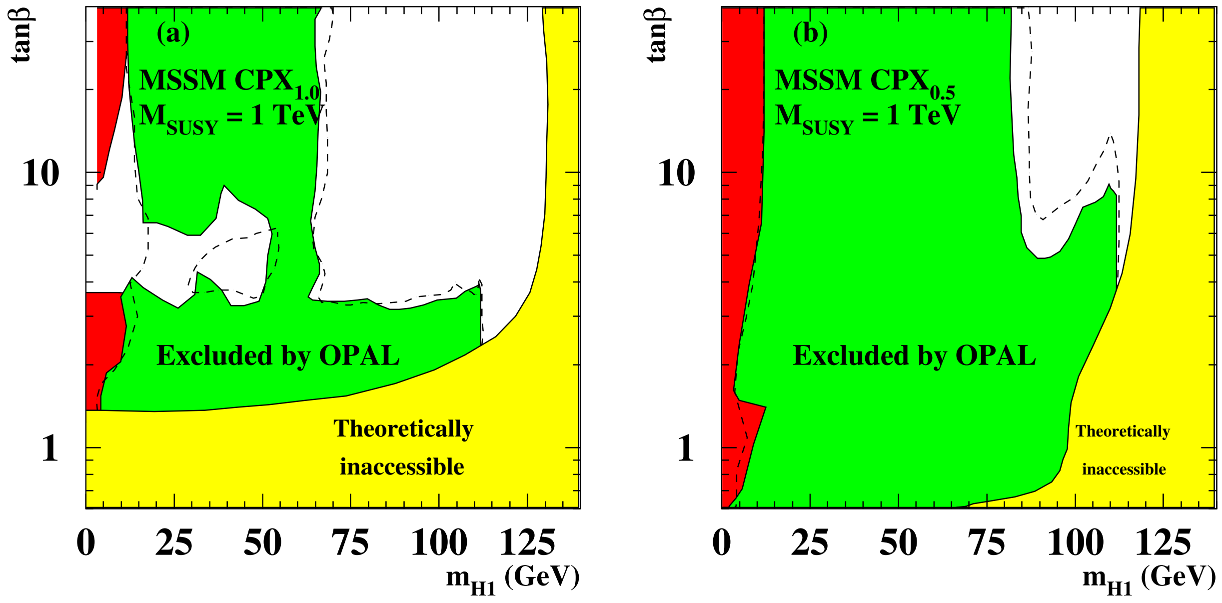
Consequences:

- Higgs-sector CP mixing: $h^0, H^0, A^0 \rightarrow H_1^0, H_2^0, H_3^0$, no longer pure scalar or pseudoscalar states !
- cross sections and branching ratios can change significantly, e.g., $gg \rightarrow H$, $e^+e^- \rightarrow ZH$, $H \rightarrow f\bar{f}/VV$, $\tilde{\chi}_2^0 \rightarrow H\tilde{\chi}_1^0$, ...
- need to study CP asymmetries, angular distributions, polarization effects

Carena, Drees, Ellis, Grzadkowski, Gunion, Haber, Kalinowski, Lee, Pilaftsis, Wagner, and many others

OPAL analysis of CPV Higgs

LEP limits on MSSM Higgs change completely
in presence of CP violation



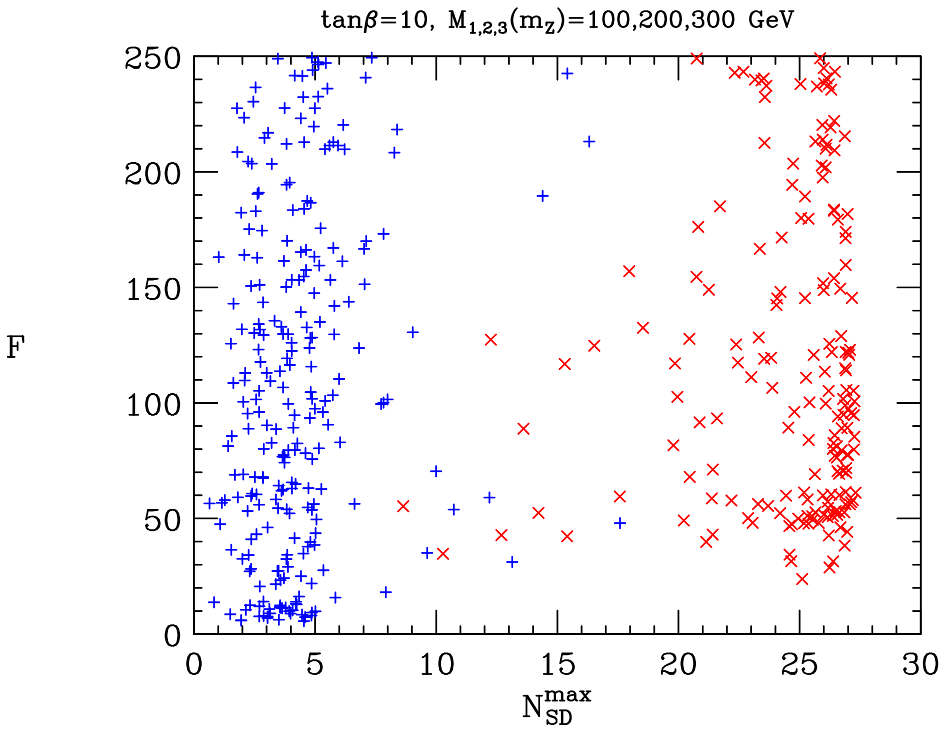
OPAL collab., hep-ex/0406057

MSSM plus an extra singlet: NMSSM, MNSSM

$$\mu H_u H_d \longrightarrow \lambda S H_u H_d \; (+\tfrac{1}{3}\kappa S^3)$$

- 3 neutral scalars, 2 neutral pseudoscalars
- modified Higgs couplings, production rates, decay BRs
- higgs-to-higgs decays (light pseudoscalars!)
- CPV in NMSSM
- NMSSM and baryogenesis

J. Gunion, D. Miller, A. Pilaftsis
at LCWS05, LHC/ILC: R. Dermisek, J. Gunion
this meeting: B. McElrath, C. Wagner



Fine-tuning vs. maximum LHC "standard" channel significance. All the best (blue) points have large $h \to aa$ decay branching ratio to escape LEP limits.

[R. Dermisek, J. Gunion]

Little Higgs models

Higgs is a component of a larger multiplet of scalars Σ.
Σ transforms non-linearly under a new global symmetry which is spontaneously broken at a scale $\Lambda_S = \mathcal{O}(10\,\mathrm{TeV})$.

- Higgs is pseudo-Goldstone boson
- modified Higgs couplings (yet again!)
- extra heavy Higgs states
- new heavy gauge bosons and heavy top T
- many model variants

A. Deandrea, T. Gregoire
at LCWS05: J. Conley, J. Reuter

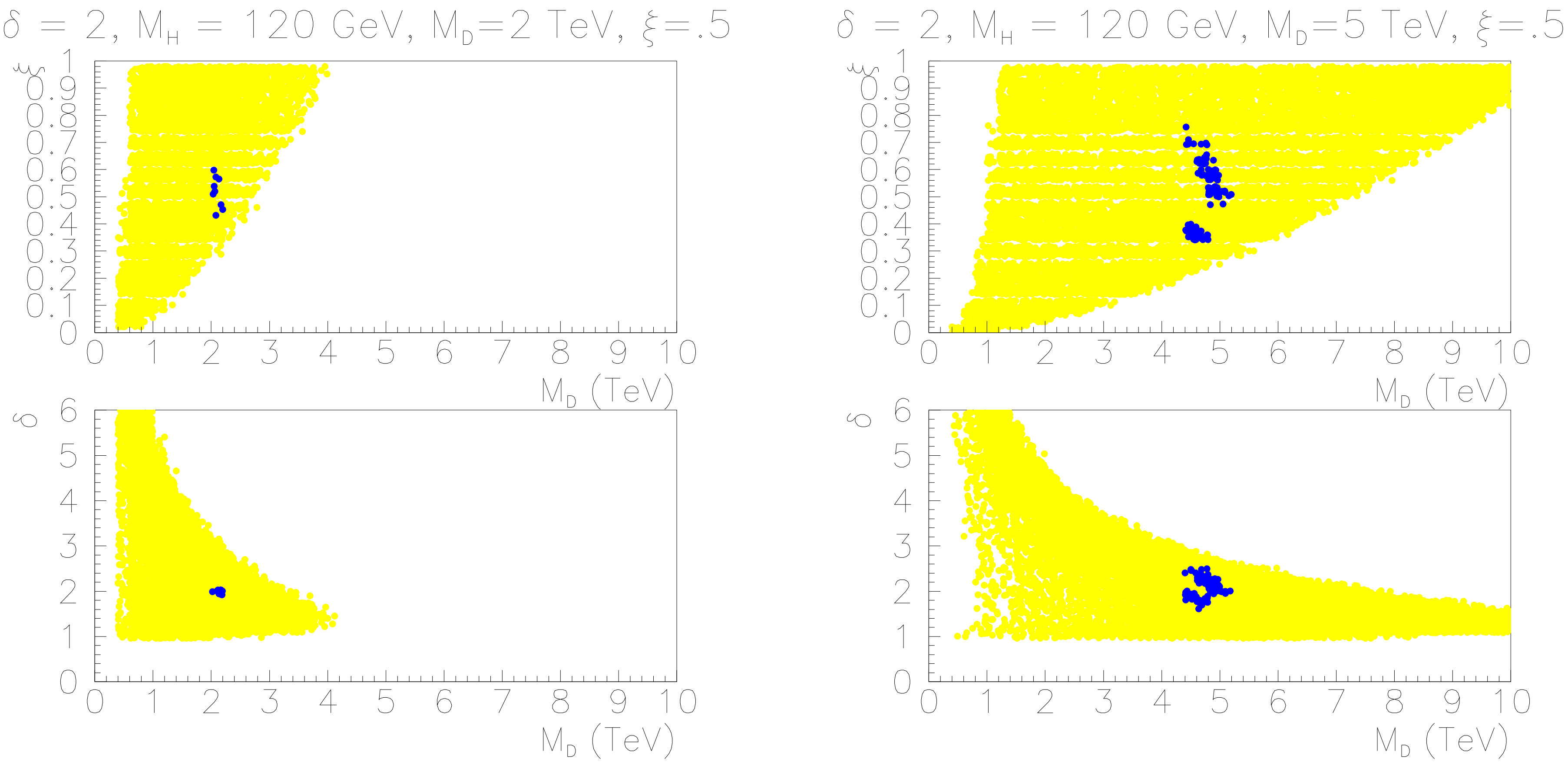
Extra Dimensions

- Rundall-Sundum model
  - One extra dimension with a warped background
  - SM fields in the bulk, Higgs on TeV brane
  - KK excitations of gauge bosons, fermions and graviton
  - Supression of $h \to WW, ZZ$, enhancement of $h \to \gamma\gamma, gg$

at LCWS05: B. Lillie

- ADD model
  - Large extra dimensions; interaction between the Higgs and the Ricci scalar curvature of the induced 4-dim metric
  - Mixing between H and the closest KK graviscalar mode
  - Invisible Higgs decays!

D. Dominici, J. Gunion



Determination of ADD parameters at LHC and ILC for $m_h = 120$ GeV. In yellow the 95% CL regions using only LHC data, in blue the regions using LHC+LC data.

[D. Dominici]

No Higgs ?

Standard Model in 1 extra warped dimension

- EWSB and mass generation through boundary conditions
- Can do without a Higgs
- Restore unitarity of $W_L W_L \to W_L W_L$ by KK exchange
- Highly constrained by precision data

CPNSH1: R. Rattazzi
at LCWS05: A. Birkedal
this meeting: B. Lillie, J. Terning

Strong electroweak symmetry breaking

- Strongly interacting W's, WW scattering!

J. van der Bij

Experimental Studies

- LEP: excellent review by M. Boonekamp at Dec04 meeting!
- Tevatron: searches for Higgs triplets, doubly charged Higgs; would need search for light pseudoscalars; news today from G. Grenier/D0
- LHC: ATLAS studies CPV, little Higgs, radions, etc.
  CMS: $H \to ZZ^{(*)} \to 4\mu$, radions
- ILC: many studies, high potential, but often just theorists' estimates of sensitivity; need exp simulations!
- Photon Collider: $\gamma\gamma \to h$ perfect laboratory. Mayda Velasco ready for take off, just waiting for benchmark points ...

NB: benchmarks needed for co-ordinated effort!

Implications for flavor physics

- Much interest from B-physics community in CPNSH
- Had a decicated sessions at the previous 2 meetings
- Separate (sub?)group formed investigating the synergy between experiments at colliders and at flavor factories
- Workshop on 31 Jan/1 Feb 2005 focused on tools, more to come
- Contact T. Hurth and M. Mangano

Cosmo connections

- Important issue; activity just starts at this meeting
- Dark matter: modification of $\tilde{\chi}^0$ annhilation cross-sections; e.g. by CPV phases, s-channel exchange of non-standard Higgs, $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to h_H \to h_L h_L$, etc. ....
- Baryogenesis with non-standard Higgs sector

this meeting: E. Senaha, C. Wagner

Where we are headed:
CPNSH report

Suggested Structure

- Part 1: Catalog of Models
  - A paedagogical introduction for each class of models explaining the main ideas and most important features
    $\longrightarrow$ guide for experimentalists, students, newcomers ....

    assigned team of authors

  Followed by a collection of:
  - Individual theory contributions lining out the details
  - Simulation studies to assess the potentials of the various colliders

    everybody who wants to contribute
    need to contact exp. collaborations

- Part 2: Catalog of Signatures
  - List of signatures and models which can generate them
  - Strategies and experimental sensitivities to distinguish between models

Benchmarks and Tools

We *do* need them!

- MSSM with CP phases
  - classic CPX scenario
  - public codes: CPsuperH and FeynHiggs (note discrepancies between them)
- NMSSM
  - several points available from J. Gunion
  - need to select 2-3 representative ones
  - public code: NMHDECAY
- NOTHING YET FOR OTHER MODELS!!!
  - jump on it!

Timeline

- Benchmarks and TOC/authors by Les Houches
- Sceleton report for Snowmass
- Draft report by the end of this year
- Need to get started NOW

Collection of material

`http://cern.ch/kraml/cpnsh/`

Discussion

Hitchhikers guide to non-standard Higgs

- Format CERN Yellow book, Phys. Rep., PoS
- Content, Authors intros/reviews + indiv. contrib.
- Benchmarks
- Timescale
- ....

set the stage at this meeting

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