Motto: "Space can not be asymmetric"- Landau
I do not want to hear anything about parity nonconservation-this is nonsense!
Dau, have patience for about 15 minutes... Dau agreed.
Over night Landau solved the parity non-conservation problem- two papers on CP parity and two-component neutrino were ready.
Landau considered CP conservation as the exact law of nature, Joffe constucted a CP violating Lagrangian - but Landau did not want to listen.

CP-violation and Nonstandard Higgs Physics

a CP-nSH meeting 14-15 May 2004 at CERN

Maria Krawczyk, Warsaw U.

* collaboration with Rohini Godbole, Sabine Kraml, David Miller
John Ellis, Michalangelo Mangano
America: JoAnne Hewett, Tom Rizzo

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

Symmetry $\rightarrow$ basic idea of modern particle physics

STANDARD MODEL

$$\mathrm{SM}=\mathrm{SU}(2)_{I_{weak}}\times\mathrm{U}(1)_{Y_{weak}}\times\mathrm{SU}(3)_{color}$$

Origin of masses of elementary particles :
$\rightarrow$ spontaneous symmetry breaking

Higgs mechanism in SM and beyond (MSSM, 2HDM,...) :
Higgs Particle (s) predicted

Higgs sector- a clue to further understanding of matter

THE THEORY OF MATTER $\Leftrightarrow$ STANDARD MODEL

F. Wilczek, LEPFest, Nov.2000 (hep-ph/0101187)

Theory of Matter = $SU(2)_{I_{weak}} x U(1)_{Y_{weak}} x SU(3)_{color}$

Theory of Matter refers to the core concepts

- quantum field theory
- gauge symmetry
- spontaneous symmetry breaking
- asymptotic freedom

- the assignments of the lightest quarks and leptons

Standard Models: choose the number of Higgs (scalar) doublets.

Nonstandard Higgs scenarios are based on more radical assumptions

CP violation

CP violation exists in the Standard Model -

- However CP violating parameters (ϵ parameters, el. dipole moment of n and e) can be accounted in various models, with very different CP violation pattern

- Beyond SM - additional sources of CP violation possible

- Cosmology - CP violation related to baryon asymmetry of the universe SM can not describe the observed matter-antimatter difference

CP violation in Standard Model

Yukawa interaction is a source of CP violation in SM,
CP is violated if $\mathrm{Im}\,\mathrm{det}[Y^d Y^{d\dagger}, Y^u Y^{u\dagger}] \neq 0$ (Jarlskog'85)
$\longrightarrow$ CP violation is related to complex Yukawa couplings.
Many phases, however they are dependent (not physical) $\rightarrow$
only one single phase is a source of CP violating in SM: δ_{KM}

In Standard Model

- CP is explicitely broken
- phase in CKM is the only source of CP violation
- CP violation appears only in charged current interaction of quarks
- CP violation would vanish in absence of flavour changing interaction
- CP is not an approximate symmetry ($\delta_{KM} = \mathcal{O}(1)$)

(ϵ, ϵ' - small $\rightarrow$ small flavor violation ie. small mixing angles)

very small θ_{QCD} (below 10^{-9}) - CP violating parameter related to strong interction, it is flavor diagonal - another puzzle of SM

scalar (Higgs) sector conserves CP

(eg. Nir paper' 1999)

CP in Nature

- CP is spontaneously broken (?)
- there are many independent sources of CP violation (?)
- CP violation in lepton sector and/or neutral current interaction and/or in other sector (Higgs) (?)
- CP violation in flavour diagonal interaction (?) ...

Important to search for CP violation in many different systems

Models with Two Higgs Doublets, Three Higgs Doublets, MSSM...

Lee, Weinberg, Pomarol, Branco,..

Example: Two Higgs Doublet Model(s) or MSSM
in the CP invariant case: h, H (CP even), A (CP odd) and $H^{\pm}$
if CP is violated - h_1, h_2, h_3 have no defined CP parity, mixing among neutrals possible: such CP violation will change events rates.
In generic case structure of couplings different and asymmetries in distributions expected

MSSM many phases -124? only 44 independent...

2HDM models with CP violation

I. Ginzburg, MK, P. Osland, hep-ph/0101208,0101229,0211371,0408011

2HDM Potential: quartic and quadratic terms separated:

$$
\begin{aligned}
V = & \tfrac{1}{2}\lambda_1(\phi_1^\dagger\phi_1)^2 + \tfrac{1}{2}\lambda_2(\phi_2^\dagger\phi_2)^2 \\
& + \lambda_3(\phi_1^\dagger\phi_1)(\phi_2^\dagger\phi_2) + \lambda_4(\phi_1^\dagger\phi_2)(\phi_2^\dagger\phi_1) \\
& + \tfrac{1}{2}\left[\lambda_5(\phi_1^\dagger\phi_2)^2 + \text{h.c.}\right] \\
& + \left\{\left[\lambda_6(\phi_1^\dagger\phi_1) + \lambda_7(\phi_2^\dagger\phi_2)\right](\phi_1^\dagger\phi_2) + \text{h.c.}\right\} \\
& - \tfrac{1}{2}\left\{m_{11}^2(\phi_1^\dagger\phi_1) + \left[m_{12}^2(\phi_1^\dagger\phi_2) + \text{h.c.}\right] + m_{22}^2(\phi_2^\dagger\phi_2)\right\}
\end{aligned}
$$

soft violation of Z_2 symmetry

No (ϕ_1, ϕ_2) mixing if Z_2 symmetry satisfied:
$\phi_1 \to -\phi_1$, $\phi_2 \to \phi_2$ (or vice versa) $\Rightarrow \lambda_6 = \lambda_7 = m_{12}^2 = 0$

14 parameters: $\lambda_1, \lambda_2, \lambda_3, \lambda_4$, $\lambda_5, \lambda_6, \lambda_7$, m_{11}^2, m_{22}^2, $\mathrm{Re}\, m_{12}^2$,$\mathrm{Im}\, m_{12}^2$

Hard violation of Z_2 symmetry: quartic terms with λ_6, λ_7

CP - Z_2 violation (FCNC)

Lee, Diaz-Cruz, Mendez, Haber, Pomarol, Barroso, Santos, Hollik, Djouadi, Illana, Branco,Gunion, Akeroyd, Arhrib, Dubinin, Semenov, Kalinowski, Zerwas...

Nonstandard Higgs scenarios

MSSM + extra singlet(s)

little Higgs,

Higgs in extra dimensions,

alternative EWSB,

Higgsless theories, etc.

Purpose od CP and nonStandard Higgs study group CP-nSH

The purpose of this study group is to bring together experimentalists and theorists working on CP in the Higgs sector, CP violation and (other) non-standard Higgs physics

Topics:

◇ CP studies of the Higgs sector (including CP violation) in the SM, 2HDM and MSSM ...

◇ associated issues of CP violation e.g. in the MSSM, cosmological implications

◇ non-standard scenarios like MSSM + extra singlet(s), little Higgs, Higgs in extra dimmensions, alternative EWSB, Higgsless theories, etc.

Plan to:

- summarize information on existing analyses
- identify crucial missing elements
- define benchmark scenarios
- stimulate studies on missing analyses
- find strategies for analysing non-standard scenarios and for distinguishing between them
- perform realistic simulations

Higgs CP and CP violation

* Overview: CP studies of the Higgs sector, (hep-ph/0404024) contribution to the LHC / LC Study Group document
R. Godbole, S. Kraml, M. Krawczyk, D. Miller, P. Nieżurawski, A. Żarnecki

* 2HDMs with CP violation (introduction in preparation)

* Higgs-sector CP violation in the MSSM
- Introduction and benchmarks (J.S. Lee)
- TOOLS: CPsuperH/Feynhiggs comparison (S. Heinemeyer)

Non-standard scenarios

* Overview: New Approaches to EWSB & TeV Physics, talk by J. Hewett at the ALCPG workshop, Victoria, 28 July 2004.

* ATLAS tutorial on EWSB, 8 Oct 2002

Meetings

Working group meetings

* First meeting, 14-15 May 2004 at CERN

* Second meeting probably late November or early December 2004

Related meetings and activities

* Les Houches 2003, Physics at TeV Colliders, 26 May - 6 June 2003

* Victoria Linear Collider workshop, 28-31 July 2004, Victoria, Canada

* TEV4LHC workshop, September 2004, Fermilab, US ....

Talks at First Meeting

1. CP studies of the Higgs sector *R. Godbole*
2. Status of predictions for Higgs production at the LHC *D. Zeppenfeld*
3. Two-Higgs-doublet models *M. Krawczyk*
4. MSSM Higgs sector with CP violation *J.S Lee*
5. Search for neutral Higgs bosons in CP-violating MSSM at OPAL *P. Ferrari*
6. CPsuperH / Feynhiggs comparison *S. Heinemeyer*
7. Large mixing in the CP violating Higgs sector in the decoupling limit *J. Kalinowski*
8. Higgs bosons in the two-doublet model with explicit CP violation *M. Dubinin*
9. Expected CMS statistics for H $\rightarrow ZZ^* \rightarrow$ 4l;MC needs for CP/spin studies of Higgs *A. Nikitenko*
10. ME-Generator for non-SM Higgs-couplings & analysis of spin/CP-dependent variables *C. Buszello*

11. Likelihood-based analysis of SM-Higgs coupling structure at the LHC *P. Marquard*
12. Discovery potential of Higgs bosons in the CPX scenario in ATLAS *Schumacher*
13. CP of a light Higgs scalar in tth production at the LHC *S. McGarvie*
14. Higgs sector CP violation in top quark pair production at the LHC *W. Bernreuther*
15. Tau polarization at a photon collider *R. Godbole*
16. Impact of SUSY CP phases on stop, sbottom and stau decays *S. Hesselbach*
17. Double Higgs production in 2HDM in the decoupling limit *A. Polosa*

Non-standard Higgs scenarios

1. Non-standard Higgs physics *R. Rattazzi*
2. NMSSM *D. Miller*
3. Higgs bosons in minimal nonminimal supersymmetric standard model *A. Pilaftsis*
4. Little Higgs *T. Gregoire*
5. Little Higgs and EW precision data *A. Deandrea*
6. Little Higgs in ATLAS *M. Lechowski*
7. Higgs in strong electroweak symmetry breaking *J. van der Bij*
8. Higgs in extra dimensions *I. Antoniadis*
9. Radion searches at the LHC and CLIC *A. De Roeck*
10. SUSY Higgs production a 5D SUGRA-insprired model *S. Fitzgerald*
11. Invisible Higgs in theories of large extra dimensions at an e+e- collider *A. Datta*
12. CP violation with 5D QED *B. Grzadkowski*

CP violation in Higgs sector at various colliders

Once the Higgs particle is discovered, we need to check among others quantum numbers like spin, CP property :
CP-even or CP-odd Higgs if CP is a good symmetry,
otherwise type and parameters of CP violation..

In the extended Higgs sector more than one Higgs bosons
Example: Two Higgs Doublet Model(s) or MSSM
in the CP invariant case: h, H (CP even), A (CP odd) and $H^{\pm}$
if CP is violated - h_1, h_2, h_3 have no defined CP parity, mixing among neutrals possible: such CP violation will change events rates.
In generic case structure of couplings different and asymetries in distributions are observed

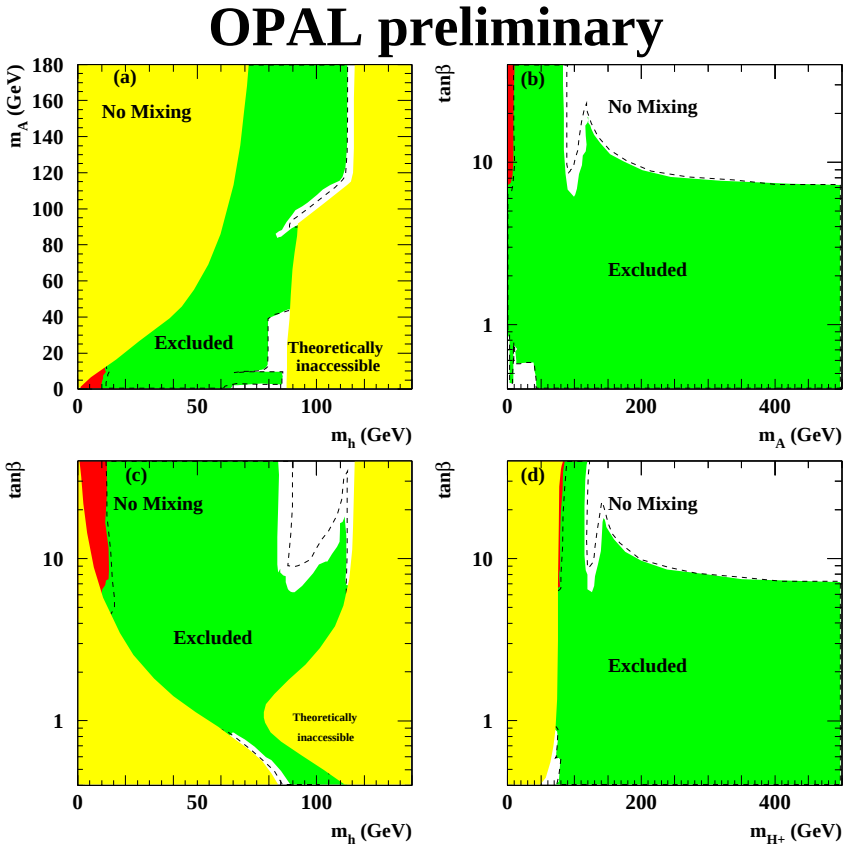
The future colliders are in some cases complementary:

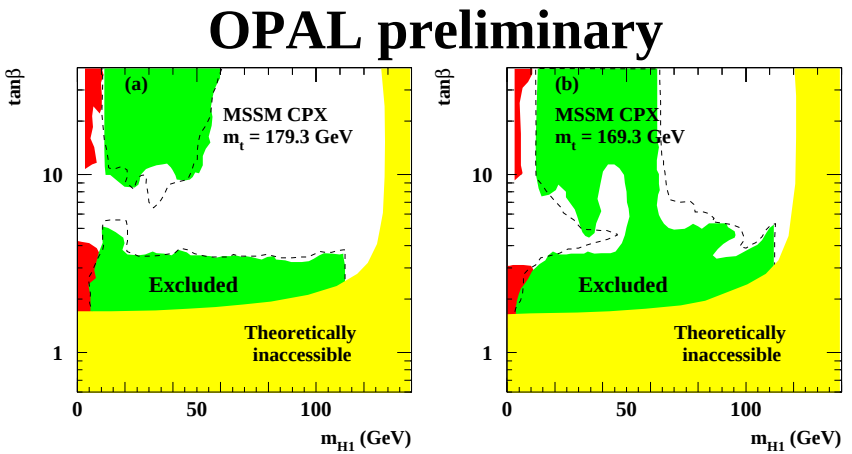
LHC - LC - PLC

Strong case of Photon Linear Collider - which may run as a Higgs factory eg. Miller et al, Gunion, Grzadkowski, Hagiwara, Godbole,NZK

Illustration from LEP: CP violation MSSM

Very light h_1 allowed in CP viol. MSSM Aachen,July 03





CP conserv. CP violation

very active field, many theor. analyses ..

Carena,Drees,Ellis,Haber,Lee,Pilaftsis,Wagner,Choi, Kalinowski, Zerwas, Holik..

instead of summary - An Invitation

Study Group:

CP violation and non-Standard Higgs Physics

There is a very wide spectrum of models which can be tested at *existing* and *future* colliders, at low and high energy machines

Basic questions which have to be answered ...

Join us!