

# Charge-back from the Higgs Group

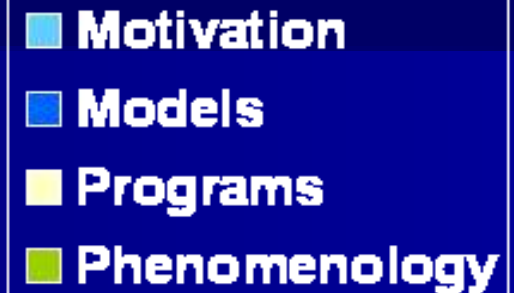
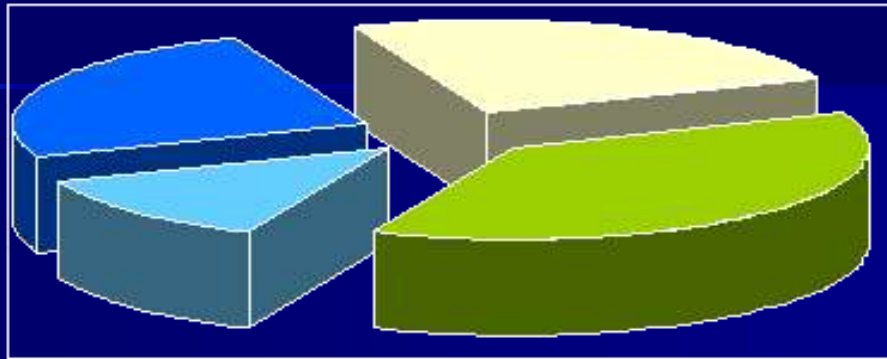
## Conveners:

Experiment: Klaus Desch, Pierre Lutz, Eilam Gross

Theory: Wolfgang Kilian, Bernd Kniehl

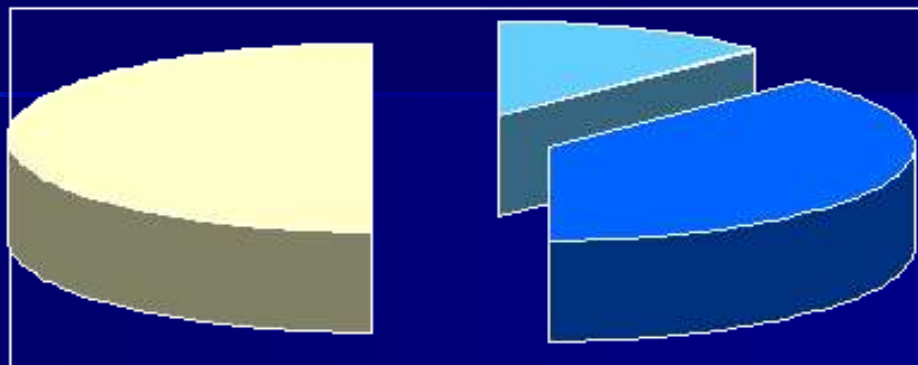
- A telegraphic description of the talks
- What are the challenges we are facing and how some of them were already fulfilled in this workshop
- Conclusions

# Theory Talks



- **Motivation:** Kilian- Open Questions, New Channels
  - **Models:** Reuter- Little Higgs;  
Miller Red Haired - NMSSM
  - **Model Programs:** Slavich- SuSpect;  
Weiglein- FeynHiggs
  - **Phenomenology:** Brein-  $ee \rightarrow W-H^+$ ;  
Penaranda- THDM;  
Krawzyk-  $g-2$
- implications

# Experimental Talks



- New Ideas
- Physics-Detector-Machine Related
- Completing & Improving Analyses

- New Ideas: Worek -  $CP$  Higgs Mixed States
- Physics-Det-Mach Related:
  - Niezurawski- Overlying Events in  $\gamma\gamma \rightarrow H$
  - Saveliev- First Look at  $ZH \rightarrow llH$  Full Sim
  - Brient: Calorimetry &  $H \rightarrow WW$
- Completing Analyses:
  - Brient-  $H \rightarrow WW$
  - Kuhl-  $H \rightarrow$ Hadrons BR
  - Gay-  $t\bar{t}H$
  - Raspereza- MSSM  $ee \rightarrow HA$  at 800-1000 GeV

# Challenges

- The wise people committee is around the corner, wise input must be delivered
- Challenges are twofold:
  - Dig deeper into what we have already explored
  - Explore new horizons

# Dig Deeper into What We Have Already Explored

- In this workshop we have seen some very good examples of digging deeper:
  - Hadronic BRs
  - $t\bar{t}H$
  - $H \rightarrow WW$

# Complete Existing Analyses - Dig Deeper

## Hadronic Higgs BRs

Kuhl

Discrepancy  
between

TDR analysis

(Battaglia) and

snowmass

results (Brau, Potter) :

$(BR(H \rightarrow cc))$ :

8% - 19%

- This channel is a benchmark for detector performance:
  - b-tag  $\rightarrow$  Use of **SI** for vertexing
  - Lepton/Vertex momentum  $\rightarrow$  **TPC**
  - Jets reconstruction  $\rightarrow$  **Calorimeter**/Particle flow
  - Missing Energy/ISR  $\rightarrow$  **Hermeti**

# Hadronic Higgs BRs

- All channels:

- $\Delta(\sigma \text{ BR}(H \rightarrow bb))$ :1.1%
- $\Delta(\sigma \text{ BR}(H \rightarrow cc))$ :12.1%
- $\Delta(\sigma \text{ BR}(H \rightarrow gg))$ :8.3%

$\sqrt{s}=350 \text{ GeV}, 500 \text{ fb}^{-1}$

- Individual channels:

	$Z \rightarrow qq$	$Z \rightarrow ll$	$Z \rightarrow \nu\nu$
$\Delta(\sigma \text{ BR}(H \rightarrow bb))$	1.5	3.0	2.1
$\Delta(\sigma \text{ BR}(H \rightarrow cc))$	17.5	33.0	20.5
$\Delta(\sigma \text{ BR}(H \rightarrow gg))$	14.4	18.5	12.3

- Note: All channels play a role
- A use of an event by event b-tag was made

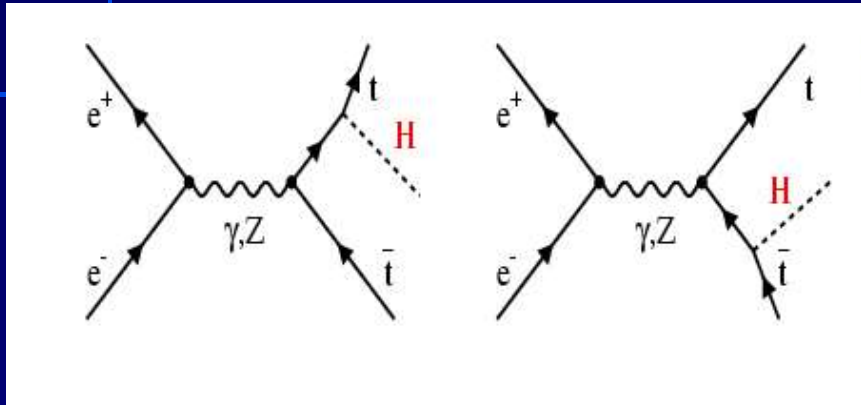
# Hadronic Higgs BRs

	$\Delta(\sigma\text{BR}(HZ \rightarrow bb))$	$\Delta(\sigma\text{BR}(HZ \rightarrow cc))$	$\Delta(\sigma\text{BR}(HZ \rightarrow gg))$
This analysis	1.1	12.1	8.3
Amsterdam (w/o $Z \rightarrow \nu\nu$ )	1.1	12.8	11.3
TDR( Battaglia) *	0.9	8.0	5.1
Snowmass(Brau,Potter)	1.6	19.0	10.4

## ■ Still to do (TRUE FOR ALL)

- Dependence of detector performance: Results for other detector configurations (?)
- Systematics (e.g. B/D-fragmentation, B/D-multiplicity)
- Use full simulation (Brahms, Mokka) for events after soft preselection (to be processed:~ 1M events) (?)

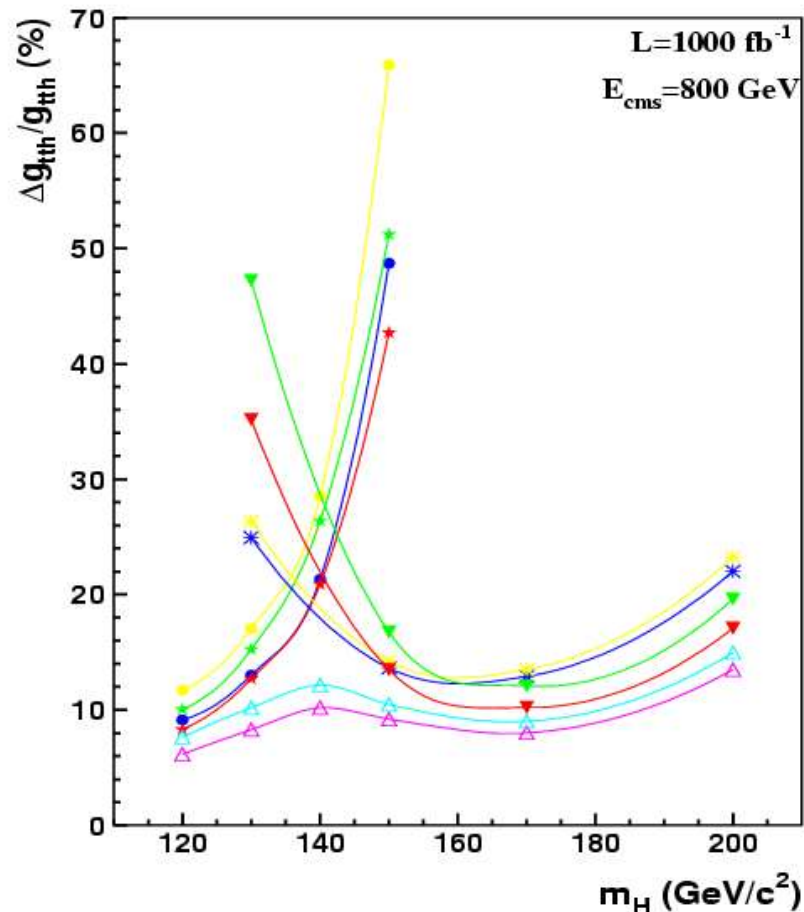
# Completing Analyses: $t\bar{t}H$ (Gay)



- Final results were shown
- For the first time non-resonant 6-f BG was studied!
- In this channel a simple approach to BG systematics was adopted: 5% or 10%

# ttH Results

- $H \rightarrow bb$  semilep;  $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 5\%$
- $H \rightarrow bb$  semilep;  $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 10\%$
- $H \rightarrow bb$  hadro;  $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 5\%$
- $H \rightarrow bb$  hadro;  $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 10\%$
- $H \rightarrow WW$  2 like sign lep;  $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 5\%$
- $H \rightarrow WW$  2 like sign lep;  $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 10\%$
- $H \rightarrow WW$  1 lep;  $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 5\%$
- $H \rightarrow WW$  1 lep;  $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 10\%$
- 4 channels combined;  $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 5\%$
- 4 channels combined;  $\Delta\sigma_{BG}^{eff}/\sigma_{BG}^{eff} = 10\%$



- 6f non-resonant BG not included BUT hardly affect Results
- BG systematics was estimated to be 5-10%, results are dependent on it!

# The Higgs branching ratio into $WW^*$

J-C. BRIENT  
Laboratoire Leprince-Ringuet

What is the expected precision using the indirect method and ZH production with  $Z \rightarrow jj$ ,  $H \rightarrow WW^* \rightarrow jj \ell^\pm \nu$

How it depends on the detector performances on jet reconstruction

# Summary on BR(H to WW\*) studies

For  $m_H=120$  GeV

ZH with  $Z \rightarrow e^+e^-, \mu^+\mu^-$ , H  $\rightarrow$  WW\* (all channels)

(study direct method...)  $\Delta B/B = 0.036$  (Stat)

ZH with  $Z \rightarrow qq\bar{q} \rightarrow$  jets and WW\*  $\rightarrow e(\mu)$   
 $\nu+2$  jets

(study indirect method...)  
 **$\Delta B/B(H \rightarrow WW^*) = 0.027$  !!**

PLEASE Albert,... NOTE that it is NOT **0.061** !!  
like I read it in the Albert's talk at FNAL (October 2003)

Albert, cool down, Klaus Desch has admitted his fault!

# Digging Deeper

- Improved Calculations

# Improved Theoretical

## Tools

- *SuSpect* and *FeynHiggs* for calculating the Higgs SUSY spectrum  
(Slavich, Weiglein)

- For the wonders of ELL2.1

Georg taught me of a new kind of systematics:

### State of the art systematics

This is a growing systematics

It increases with time

As a calculation becomes out of date, its accompanied systematics is growing (HDECAY

☺)

	SFS1a	SFS1b	SFS2	SFS3	SFS4	SFS5
<i>SuSpect</i>	110.6	114.7	114.6	113.7	112.6	112.9
<i>SoftSusy</i>	110.8	114.8	114.8	113.9	112.6	113.5
<i>SPheno</i>	112.0	116.2	115.7	115.1	114.2	115.1
<i>FeynHiggs*</i>	112.5	116.7	116.5	115.8	114.6	115.9

# Digging Deeper

- Digging deeper means getting a better estimation of systematics; their sources and affects.

# Systematics (Desch)

In most of our studies systematic errors are not fully addressed

Percent-level accuracy requires a more careful investigation

Possible issues:

- b/c-tagging (was  $O(5\%)$  at LEP - need to be much better)
  - resolution modelling - alignment...
  - b/c fragmentation
- beamstrahlung/ISR (-> kinematic fits)
- overlaid events ?
- energy calibration ?
- BG modeling ?
- how much can we learn from data?

# Digging Deeper

- Digging deeper means also to think what have we missed with a specific analysis
- Try to think if you can come with a new idea

Instead of "more of the same"  
make it "more general, less  
model

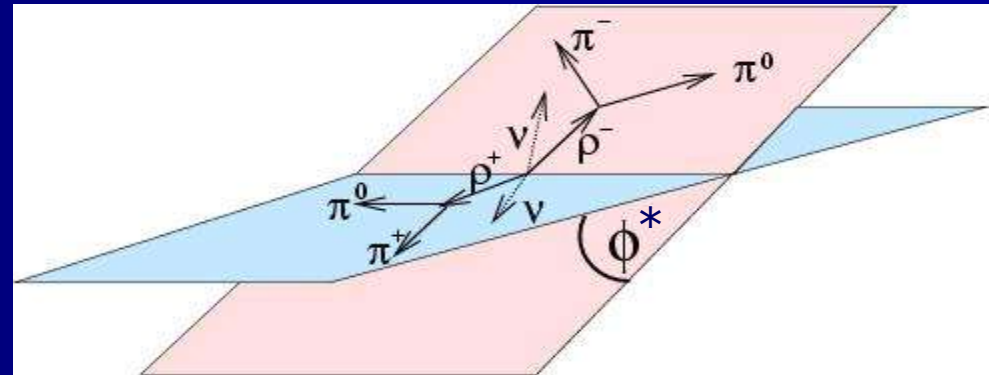
dependent"

# New Ideas on Existing Analyses

## The CP Higgs Mixed State

(Worek)

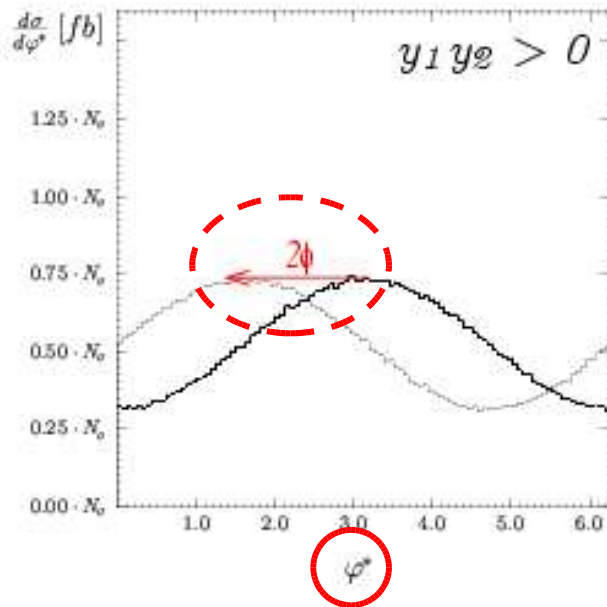
- Look at  $H \rightarrow \tau\tau \rightarrow \rho\nu\rho\nu$
- Look at the acoplanarity angle of the pion pairs
- Divide sample into same-sign energy difference and opposite-sign energy difference



$$(E_{\pi^+} - E_{\pi^0}) \cdot (E_{\pi^-} - E_{\pi^0}) > 0$$

# The CP Higgs Mixed State

(Worek)



$$y_1 y_2 > 0 ; \quad y_1 y_2 < 0$$

$$y_1 = \frac{E_{\pi^+} - E_{\pi^0}}{E_{\pi^+} + E_{\pi^0}} ; \quad y_2 = \frac{E_{\pi^-} - E_{\pi^0}}{E_{\pi^-} + E_{\pi^0}}$$

- Only events where the signs of  $y_1$  and  $y_2$  are the same whether calculated using the method without or with the help of the  $\tau$  impact parameter.
- The thick line corresponds to a scalar Higgs boson, the thin line to a mixed one.

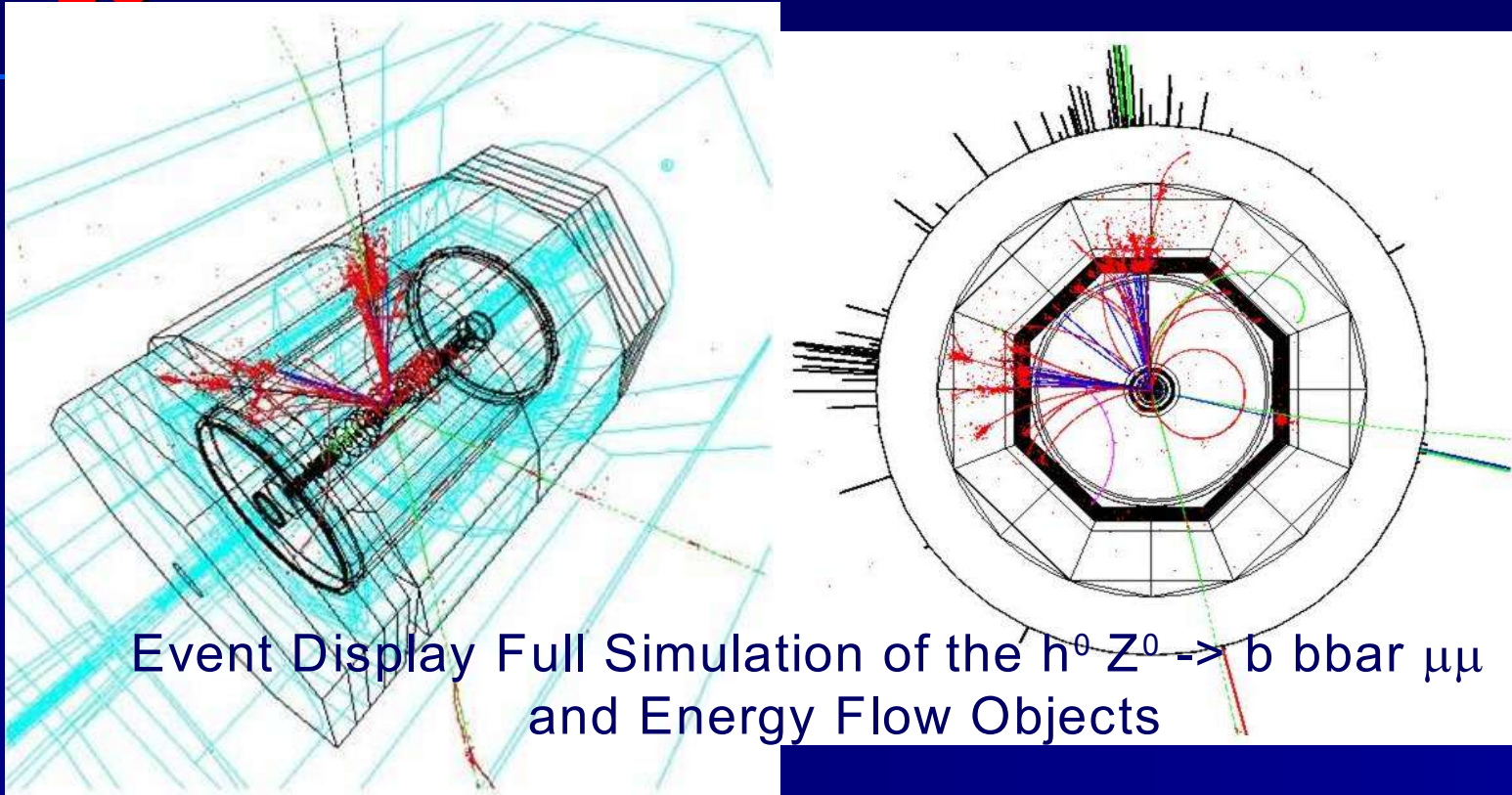
Precision on  $\phi \sim 6^\circ$  for  $1000 \text{ fb}^{-1}$  and  $\sqrt{s} = 350 \text{ GeV}$

# Digging Deeper

- It seems that digging deeper must take us now to Full Simulation  
(Benchmark processes: Higgs Mass, Higgs BRs...)

# Time for Full Simulation

BRAHMS(G3) Simulation Display TESLA  
(Saveliev)  
LC



- For the first time large samples of events fully simulated exist allowing the study of jets, b-tag, resolutions...

Go for it!

# Physics-Machine interplay

- But another aspect of digging deeper is...
- Reexamine influence of machine parameters (Luminosity, Energy, Beam Size, Backgrounds) on physics performance
- Continue quantitative evaluation of the running options in  $\gamma\gamma$ ,  $e\gamma$ ,  $e^-e^-$  modes (mass reach, light Higgs couplings, ...)

# Machine-Physics Interplay Underlying Events

- So far only one serious study of underlying events in  $WW$  fusion was performed (Battaglia, Schulte)

Niezurawski

Overlaying events  $\gamma\gamma \rightarrow \text{hadrons}$  (OE) included in analyses for:

- SM higgs at  $M_h = 120, 130, 140, 150, 160$  GeV
- MSSM higgses at  $M_A = 200, 250, 300, 350$  GeV  
with  $\tan \beta = 7$ ,  $M_2 = \mu = 200$  GeV (following M. Mühlleitner *et al.*)

# Dig deeper the Physics-Detector interplay

- Study the dependency of physics observables as a function of detector/machine parameters
- In particular study the vertexing options on  $H \rightarrow bb, cc$  and calorimetric options  
(examples in this WS:  $H \rightarrow WW$ , Higgs Hadronic BRs)

# $H \rightarrow WW$

## Three detector performance models

- **Optimised** on jets (Type TDR-TESLA ) ( $\Delta E_j/E_j \sim 0.3 E_j$ )
- **ALEPH type** (but improved for polar angle behaviour) ( $\Delta E_j/E_j \sim 0.6 E_j$ )
- **Intermediate** performance ( $\Delta E_j/E_j \sim 0.4 E_j$ )
  - This is a typical example of one of the directions we aim at this workshop now: Det/Machine-Physics interplay

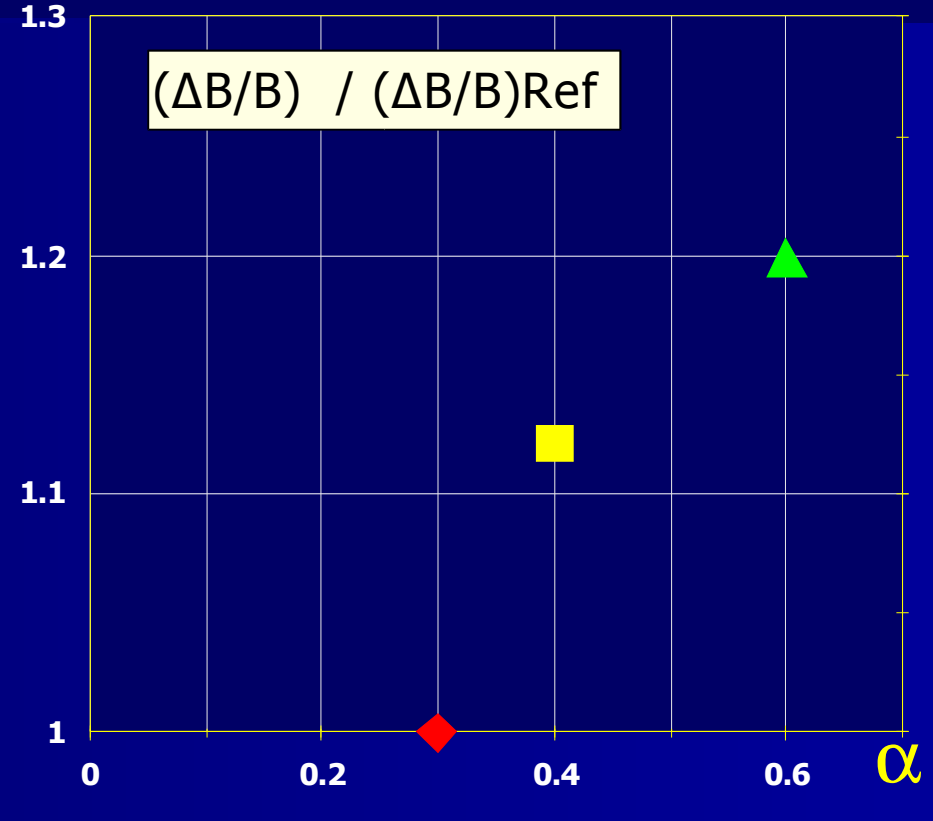
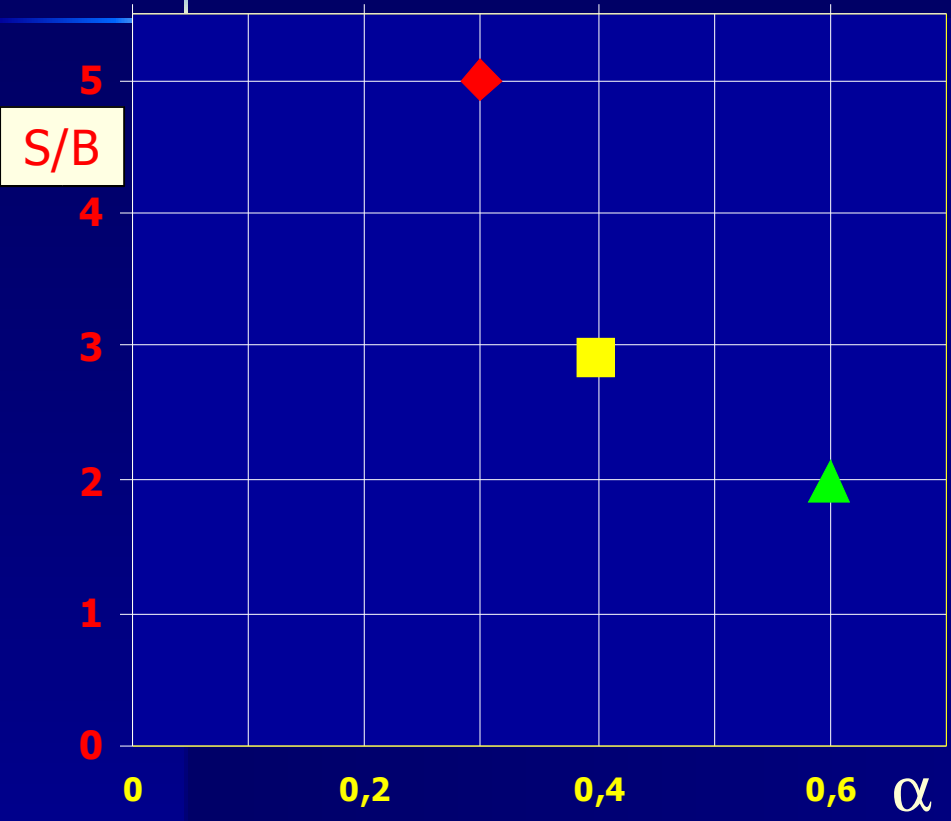
# RESULTS in pictures

( $M_h=120$ ,  $\sqrt{s}=360$ ,  $L=500\text{fb}^{-1}$ )

Jet energy resolution as

$$\Delta E/E = \alpha \sqrt{E}$$

◆ Optimum    ■ Intermediate    ▲ ALEPH type



Variation of the expected precision

# Explore New Horizons

- Exploring New Horizons is also twofold:
  - New Models  
(examples: Little Higgs, NMSSM...)
  - Now that we have seen the prospective excellent performance of the Machine, we **MUST** study a LC at 800-1000 GeV!  
**MUST!**
  - This opens a whole new study field for student projects! This is **CREAM!**  
(examples given in this WS, ZZ fusion)

# New Models open a Whole New world to explore (Reuter; Miller)

## ■ Little Higgs:

- The LC is not a discovery machine for the Little Higgs because its mass spectrum lies at the TeV region
- However,

### Signals:

- Anom. Triple Gauge Couplings:  $WWZ$ ,  $WW\gamma$
- Anom. Higgs Coupl.:  $H(H)WW$ ,  $H(H)ZZ$
- Anom. Top Couplings:  $ttZ$ ,  $tbW$

# Little Higgs Models

- LC can play an important role in complementing the direct LHC LHM parameters via precision

m

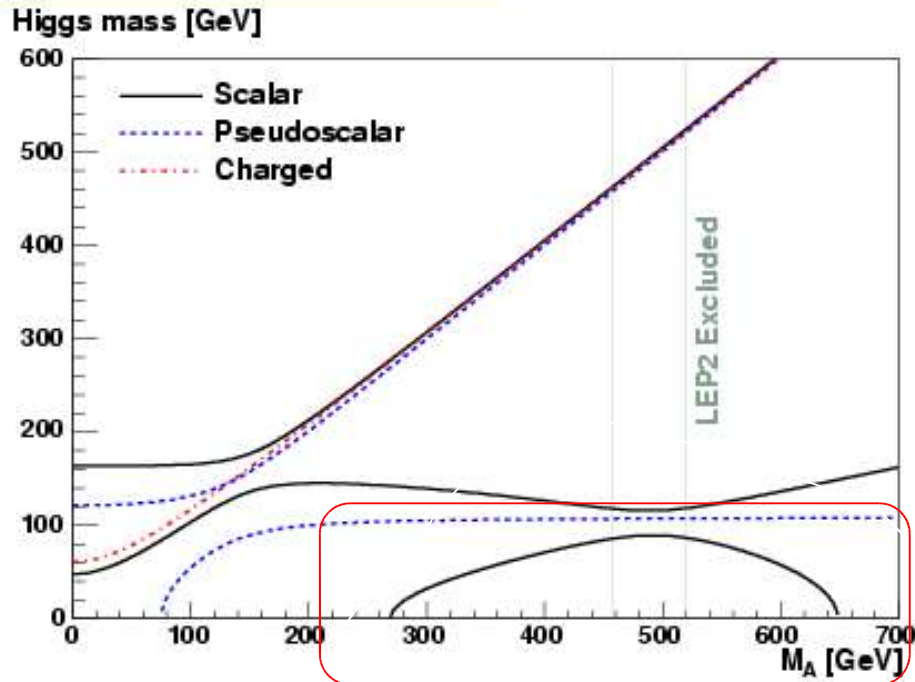
## Vectors:

- Direct Search (LHC)  $M_V, F, c, c'$
  - LC: Contact Terms  $e^+e^- \rightarrow e^+e^-, \mu^+\mu^-$   
 $\Rightarrow M_{B'} \sim 5 - 10 \text{ TeV}, e^+e^- \rightarrow \nu\bar{\nu}\gamma \Rightarrow M_{B'} \sim 5 \text{ TeV}$
  - Higgs-strahlung, WW fusion:  $HZff, HWff$  angular distr./energy dependence  $\Rightarrow f_{VJ}$
  - Check from TGC (LC: per mil precision), **GigaZ**
- $\Rightarrow$  **Determination of all coefficients in the gauge sector**

# New Models: NMSSM

(Miller)

## ◇ The Higgs Mass Spectrum



- Spectrum “like MSSM” + 2 extra states

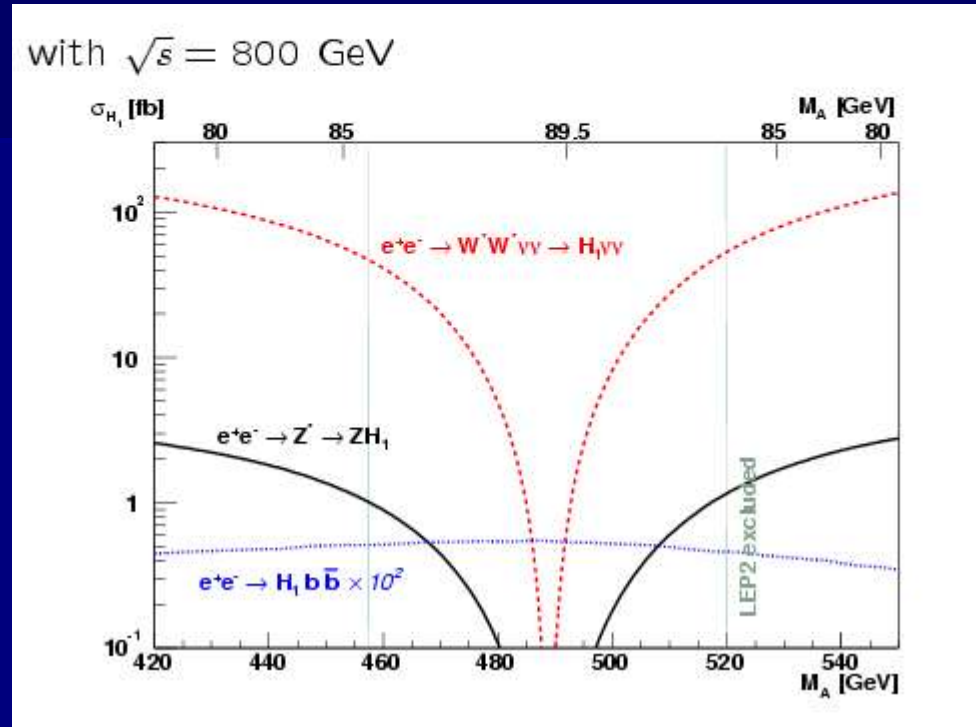
3 scalars:  $H_1$ ,  $H_2$ ,  $H_3$

2 pseudoscalars:  $A_1$ ,  $A_2$

Charged:  $H^\pm$

# NMSSM

- At a LC, the clean environment allows the exploration of the additional singlet NMSSM Higgs via its  $b\bar{b}$  and  $\gamma\gamma$  decay modes.



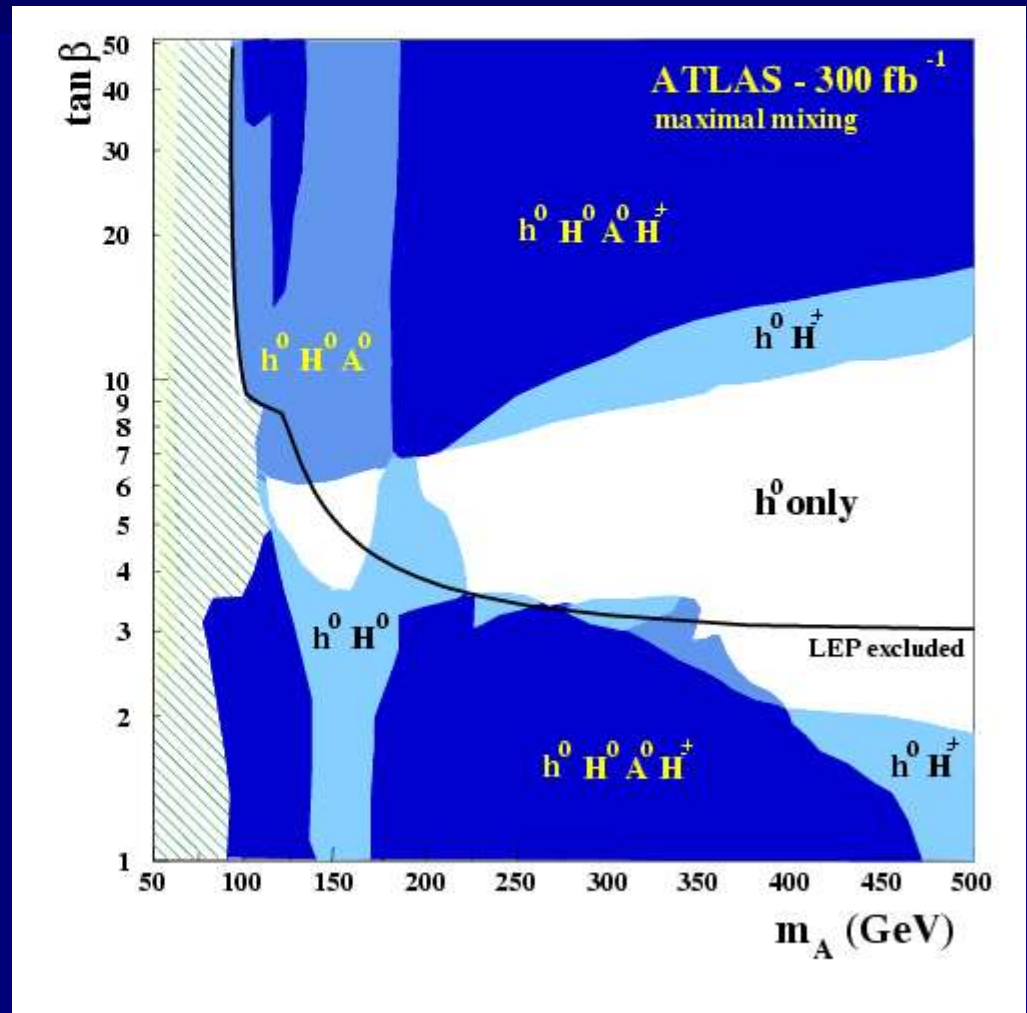
# Explore New Horizons

- Go to heavy Higgs bosons.  
(example in this WS HA at 800 GeV)

# Heavy SUSY Higgses

(Raspereza)

- A challenging plot
- Here is an example for a LC as a possible discovery machine

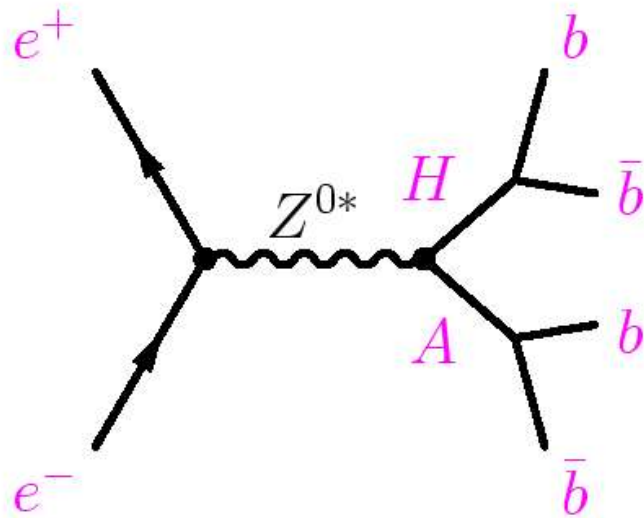


# Heavy SUSY Higgses

(Raspereza)

## Topologies Analysed

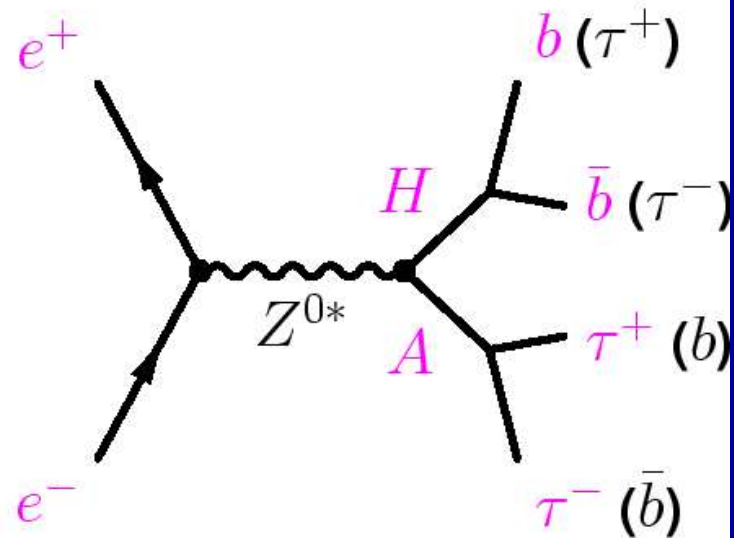
$$HA \rightarrow b\bar{b}b\bar{b}$$



$$\sqrt{s} = 500\text{GeV}, 800\text{GeV}$$

$$L = 500\text{fb}^{-1}$$

$$HA \rightarrow b\bar{b}\tau^+\tau^- (\tau^+\tau^-b\bar{b})$$



$$(\sigma * BR) - ?$$

$$M_H - ? M_A - ?$$

$$\Gamma_{H,A} - ?$$

# Heavy SUSY Higgses (Raspereza)

- Signal is observed in both  $HA \rightarrow b\bar{b}b\bar{b}$  and  $HA \rightarrow b\bar{b}\tau^+\tau^-$  channels up to  $m_{H,A} \sim (\sqrt{s}/2 - 50)$  GeV

	500 GeV		800 GeV	
	$b\bar{b}b\bar{b}$	$b\bar{b}\tau^+\tau^-$	$b\bar{b}b\bar{b}$	$b\bar{b}\tau^+\tau^-$
Typical errors :				
error on mass [MeV]	180-550	200 - 1500	520-1050	1000 - 2300
error on cross section [%]	1.6 - 3.7	5.0 - 23.0	3.0 - 6.6	10.0 - 17.0

- First look at SPS1A point @  $\sqrt{s}=1\text{TeV}$  with  $b\bar{b}b\bar{b}$  channel is encouraging :

$$\delta(m_H + m_A) \sim 2\text{GeV}, \quad \delta\sigma_{HA \rightarrow b\bar{b}b\bar{b}} / \sigma_{HA \rightarrow b\bar{b}b\bar{b}} \sim 10\%$$

- Higgs width measurement is feasible in the  $b\bar{b}\tau^+\tau^-$ ,  $\tau^+\tau^-b\bar{b}$  channels with absolute precision of 0.5 – 3.0 GeV for  $m_{H,A} \lesssim 200$  GeV. For higher Higgs boson masses more luminosity is needed to achieve comparable precision

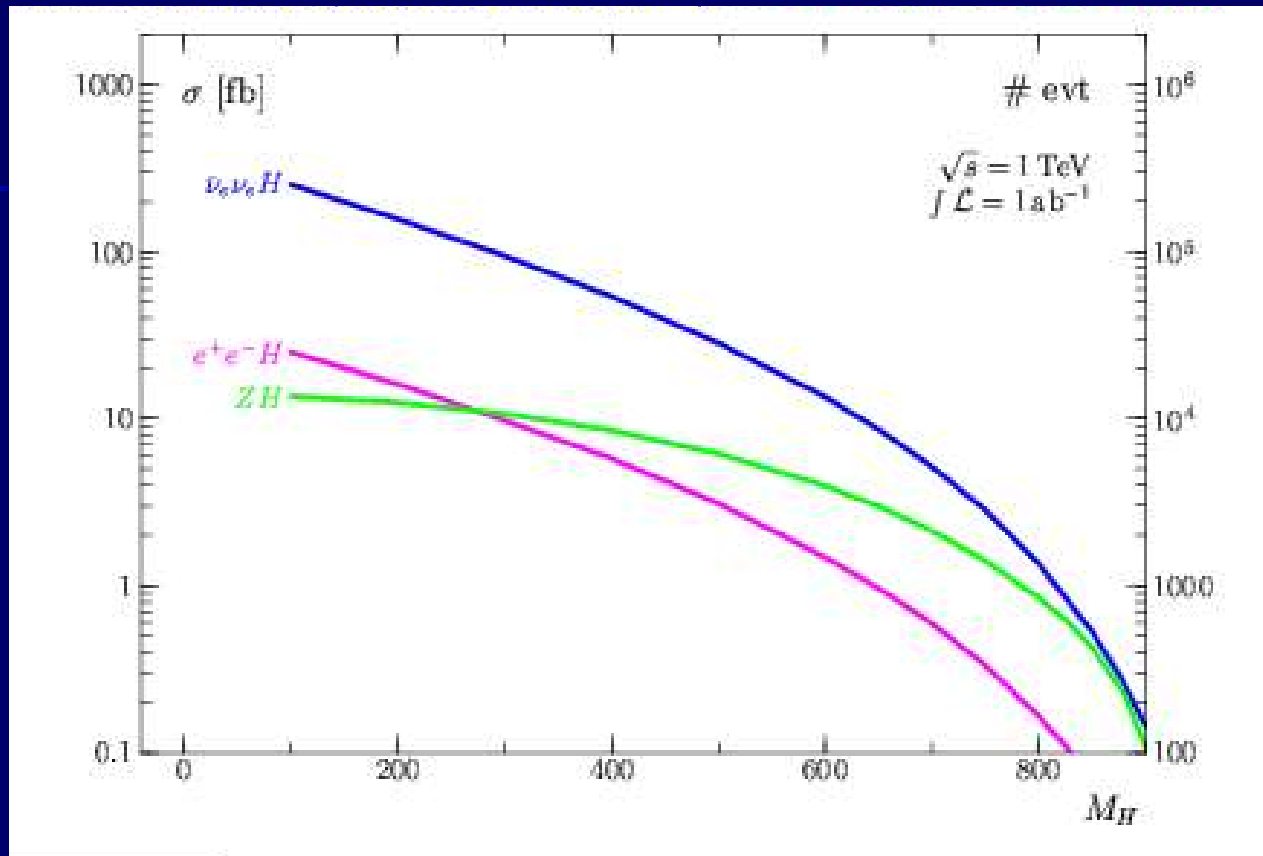
- The use of SPS SUSY points is becoming an international language now
- Higgs width measurement is feasible
- Results can seriously serve as inputs into SUSY Higgs analyses

# Explore New Horizons

- And why have we considered 120 GeV as our bench mark?

# LC1000

(Kilian)

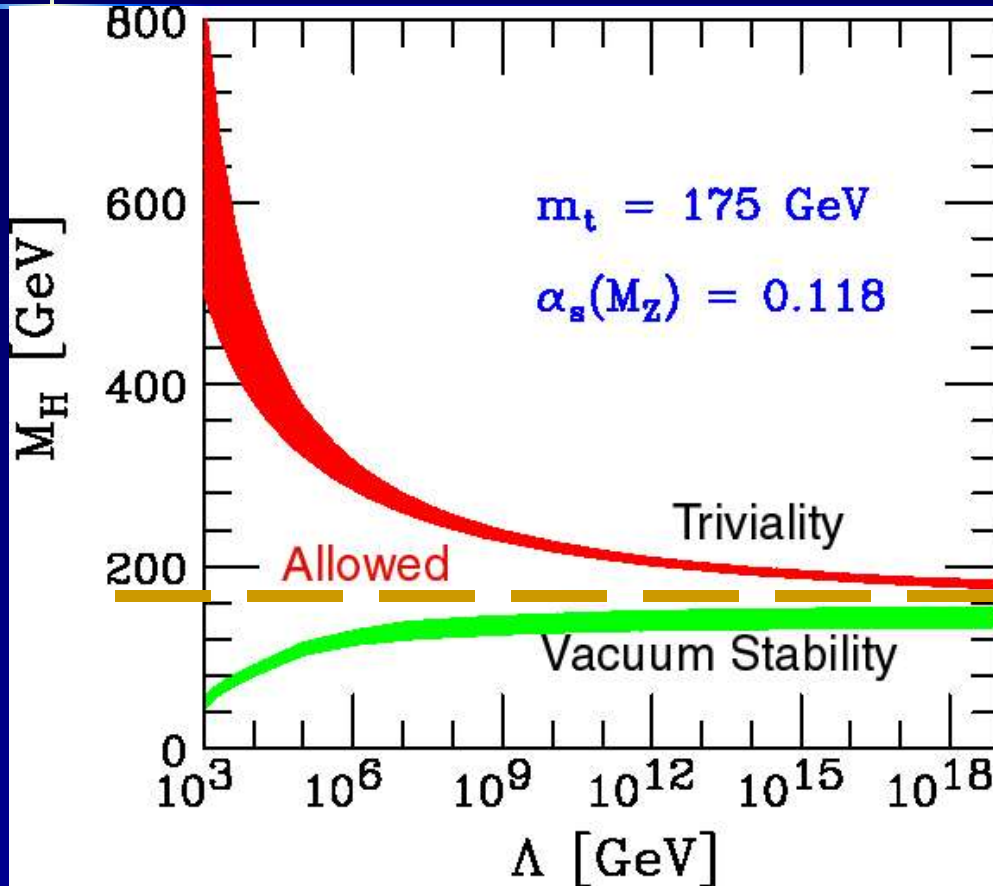


- An important & straightforward channel at 1000 GeV is the  $ZZ$  fusion!
- So many Higgs accessible production modes must tell an interesting story!
- Exploration to heavier Higgs bosons is mandatory.

# Explore New Horizons

- Klaus to Gudi (Shouting):
- Who told you SUSY is true!!!!

# A challenge



Who is willing to  
bet there is a 160 GeV  
Higgs Boson  
and that's IT!  
No SUSY  
No Technicolor  
No Little Higgs  
Nada de Nada

# Conclusions

- We are facing wise people, we need to generate some wise input and we are capable of producing it.
- We have the tools and the knowledge.
- Dig deeper and Explore new horizons.
- There is a lot of cream still to be explored; Higher CM Energy (1TeV), Full Simulation, Heavy Higgs bosons, Sophisticated Systematics studies, New "Beyond the SM" Models and more and more and more....
- Just point out your finger and choose your joystick!
- The game has only strated, LC2002 was upgraded to LC2004 - Upgrade is free