Charge-back from the Higgs Group

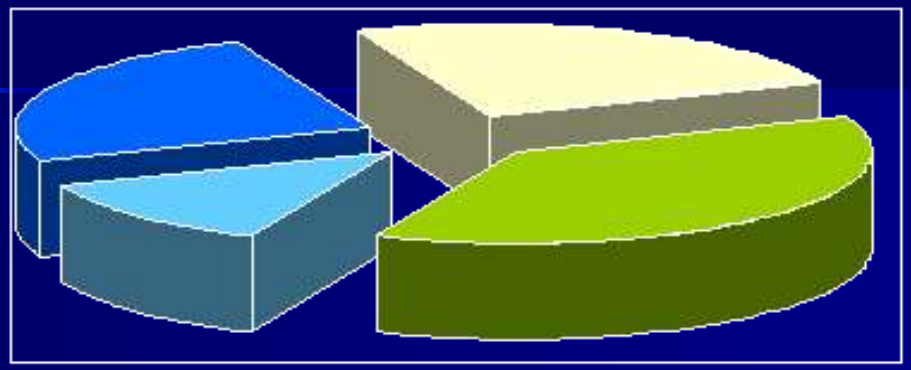
Conveners:

Experiment: Klaus Desch, Pierre Lutz , Eilam Gross

Theory: Wolfgang Kilian ,Bernd Kniehl

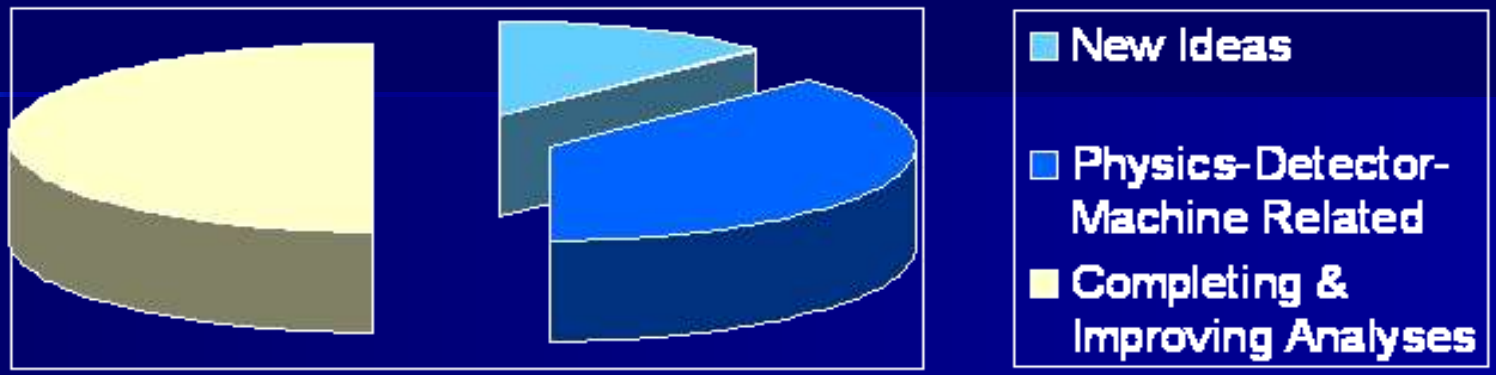
- A telegraphic description of the talks
- What are the challenges we are facing and how some of them were already fulfilled in this workshop
- Conclusions

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: 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- ttH
  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
  - ttH
  - H→WW

Complete Existing Analyses - Dig Deeper

Hadronic Higgs BRs Kuhl

Discrepancy between TDR analysis (Battaglia) and snowmass results (Brau,Potter) : (BR(H→ cc)): 8%- 19%

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

Hadronic Higgs BRs

- All channels:
  - $\Delta(\sigma\ BR(H\rightarrow bb))$:1.1%
  - $\Delta(\sigma\ BR(H\rightarrow cc))$:12.1%
  - $\Delta(\sigma\ BR(H\rightarrow gg))$:8.3%

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

- Individual channels:

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

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

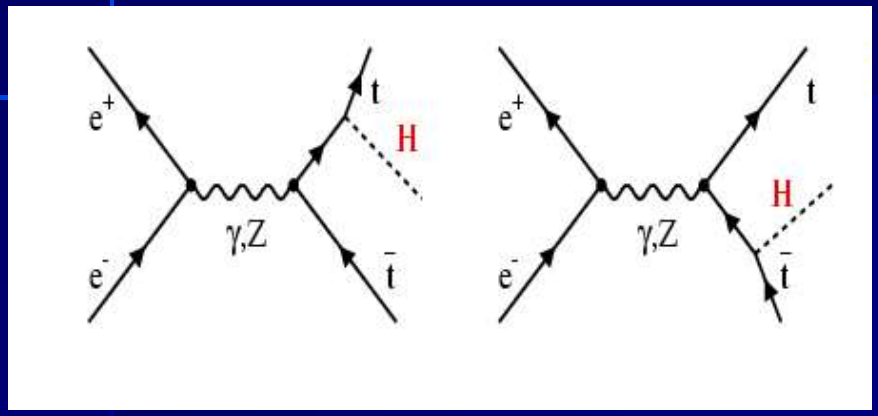
Hadronic Higgs BRs

	Δ(σBR(HZ→ bb)	Δ(σBR(HZ→ cc))	Δ(σBR(HZ→ gg
This analysis	1.1	12.1	8.3
Amsterdam (w/o Z→υυ)	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) (?)

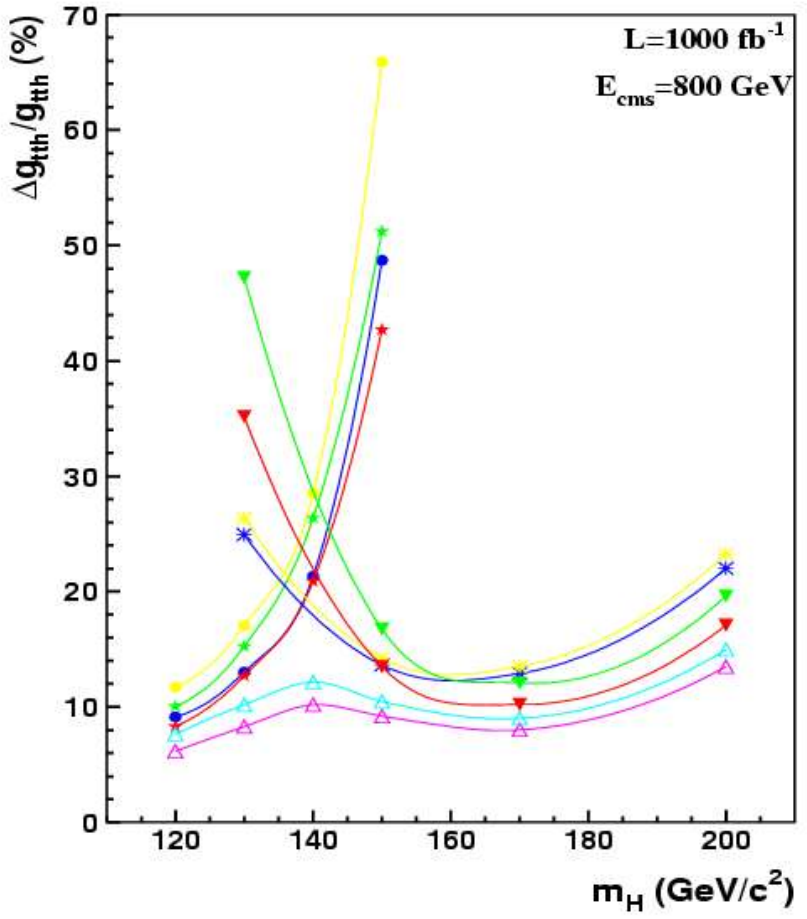
Completing Analyses: ttH
(Gay)



- 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 addopted: 5% or 10%

ttH Results

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



- 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 $Z \to jj$, $H \to WW^* \to jj\, \ell^{\pm}\nu$

How it depends on the detector performances on jet reconstruction

Summary on BR(H to WW*) studies

For mH=120 GeV

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

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

ZH with $Z \to q\bar{q} \to$ jets and WW*→e(μ) ν+2jets

(st… …)

$\Delta B/B(H \to WW^*) = 0.027$!!

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 (Slavich, Weiglein)

- SuSpect and FeynHiggs for calculating the Higgs SUSY spectrum
- For the wonders of FH 2.1

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 ☺)

	SPS1a	SPS1b	SPS2	SPS3	SPS4	SPS5
SuSpect	110.6	114.7	114.6	113.7	112.6	112.9
SoftSusy	110.8	114.8	114.8	113.9	112.6	113.5
SPheno	112.0	116.2	115.7	115.1	114.2	115.1
FeynHiggs*	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 addres

Percent-level accuracy requires a more careful investigation

Possible issues:

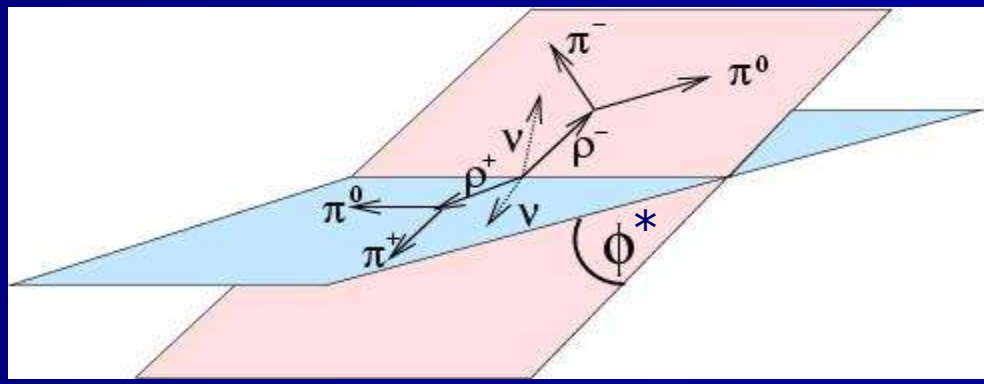
- b/c-tagging (was O(5%) at LEP – need to be much better)
  - resolution modelling – alignment…
  - b/c fragmentation
- beamstrahlung/ISR (-> kinematic fits)
- overlaid events ?
- energy calibration ?
- BG modeling ?
- how much can we learn from data?

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"

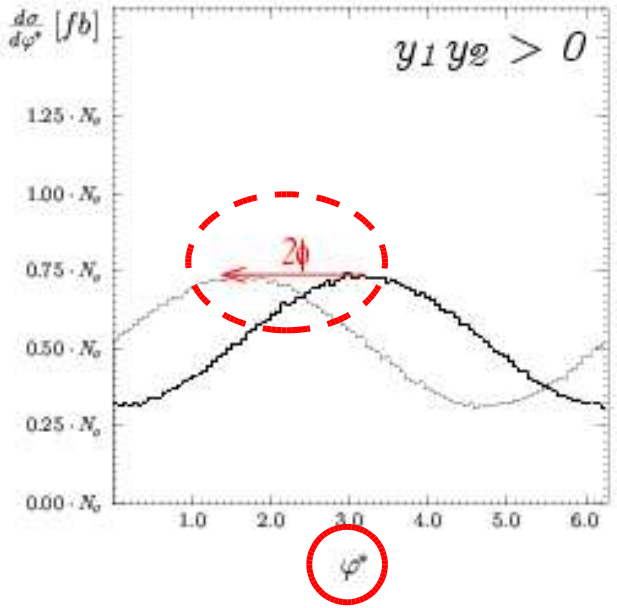
New Ideas on Existing Analyses
The CP Higgs Mixed State
(Worek)

- 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



$$\left(E_{\pi^+} - E_{\pi^0}\right) \bullet \left(E_{\pi^-} - E_{\pi^0}\right) > 0$$

The CP Higgs Mixed State
(Worek)



$$y_1 y_2 > 0\,; \qquad y_1 y_2 < 0$$

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

- *Only events where the signs of y1 and y2 are the same whether calculated using the method without or with the help of the τ impact parameter.*
- *The thick line corresponds to a scalar Higgs boson, the thin line to a mixed one.*

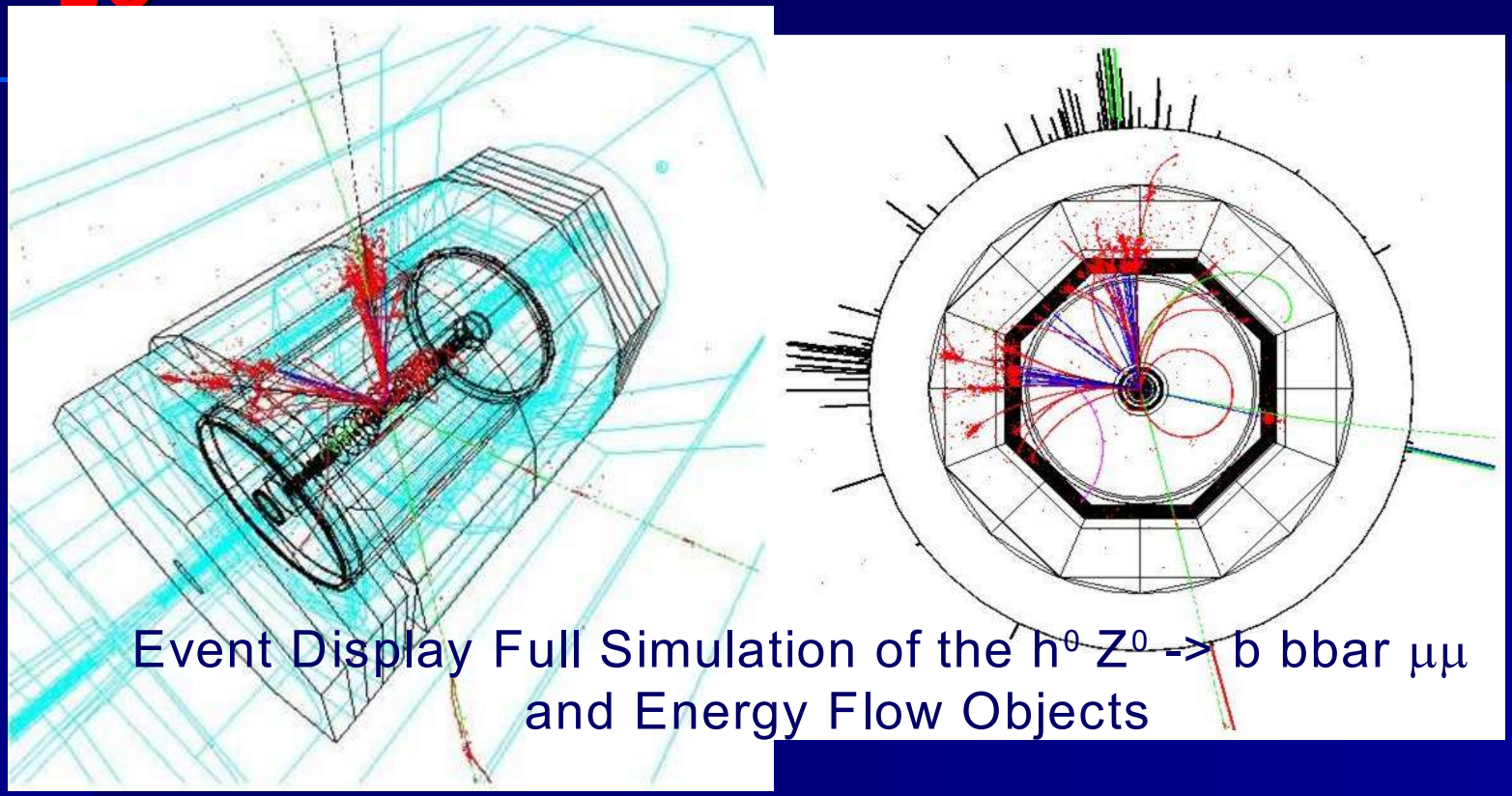
Precision on $\phi \sim 6^\circ$ *for* $1000\ fb^{-1}$ *and* $\sqrt{s} = 350$ *GeV*

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 LC (Saveliev)



Event Display Full Simulation of the $h^0 Z^0$ -> b bbar $\mu\mu$ and Energy Flow Objects

- 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 $\gamma\gamma \to$ *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→bb,cc and calorimetric options
  (examples in this WS: H→WW, Higgs Hadronic BRs)

H→WW

Three detector performance models

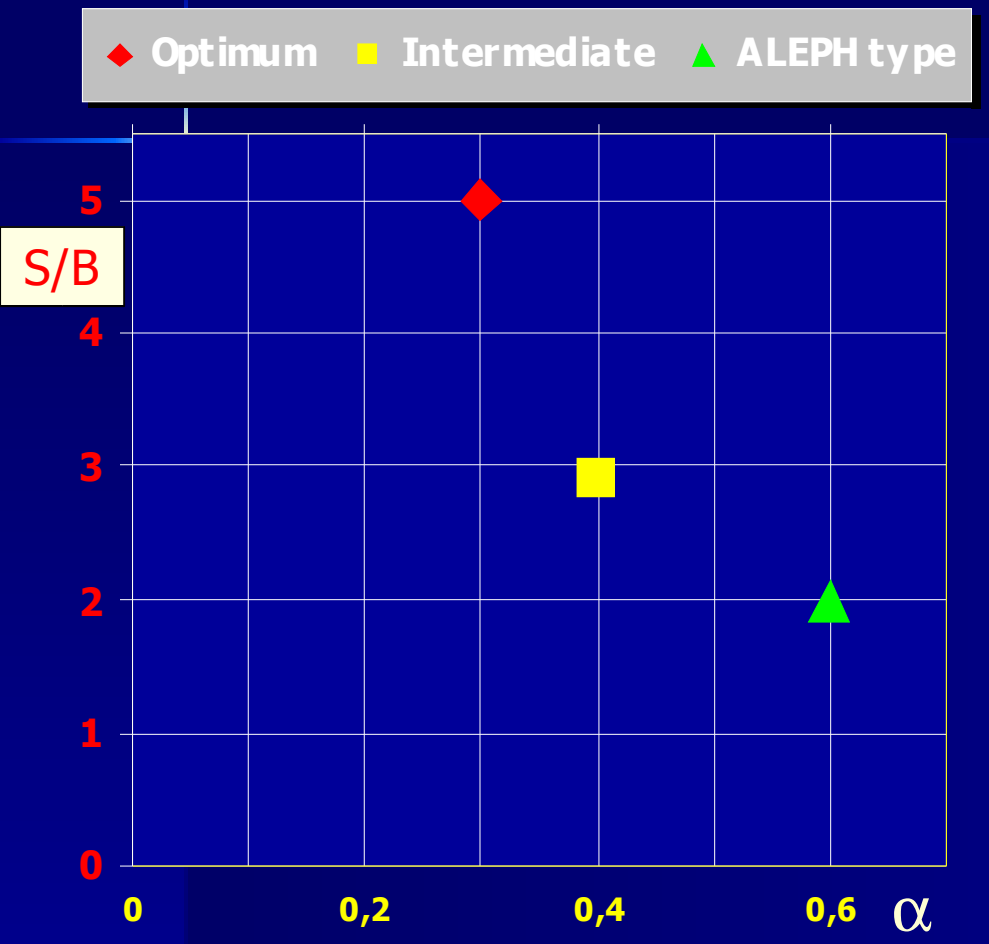
- Optimised on jets (Type TDR-TESLA) (ΔEj/Ej ~ 0.3 Ej)
- ALEPH type (but improved for polar angle behaviour) (ΔEj/Ej ~ 0.6 Ej)
- Intermediate performance (ΔEj/Ej ~ 0.4 Ej)
  - This is a typical example of one of the directions we aim at this workshop now: Det/Machine-Physics interplay

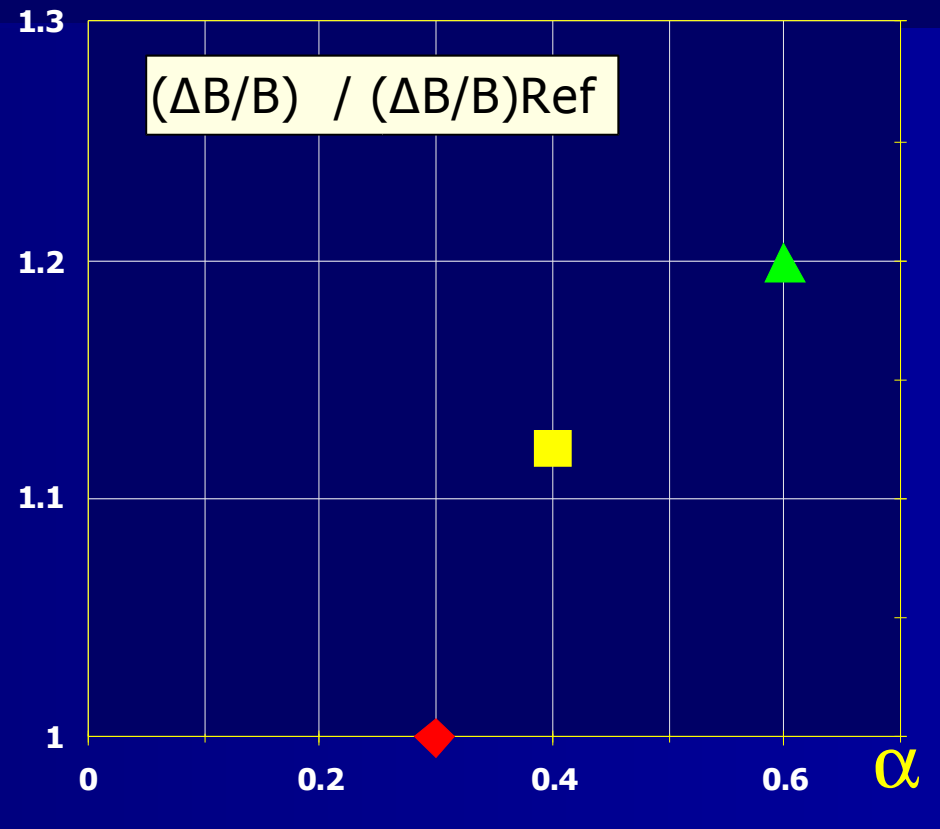
RESULTS in pictures

(Mh=120, √s=360, L=500fb^{-1})

Jet energy resolution as

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





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:

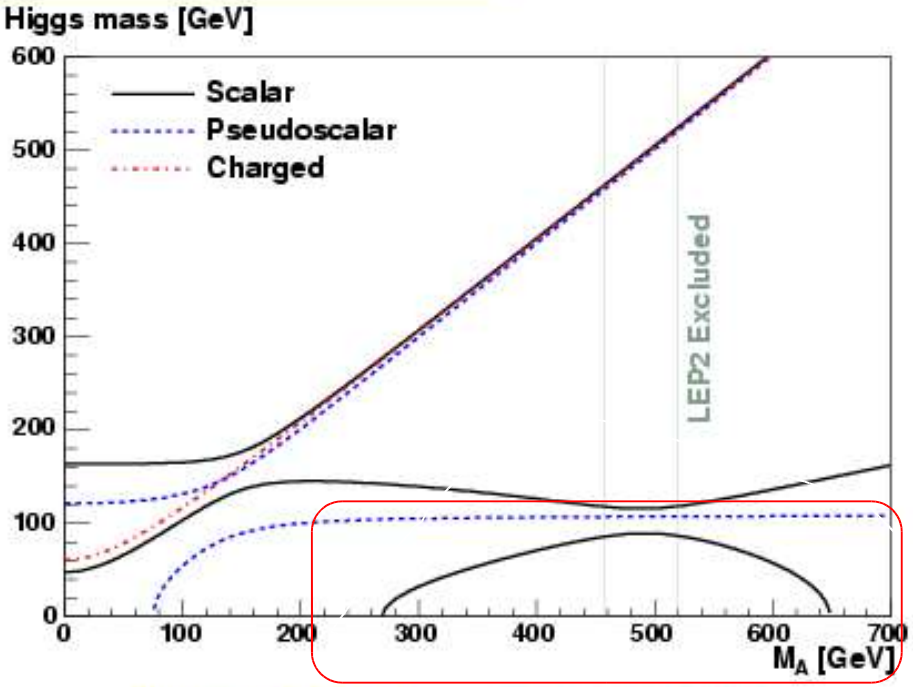
- Direct Search (LHC) M_V, F, c, c'
- LC: Contact Terms $e^+e^- \to e^+e^-, \mu^+\mu^-$
  $\Rightarrow M_{B'} \sim 5 - 10\,\text{TeV}$, $e^+e^- \to \nu\bar{\nu}\gamma \Rightarrow M_{B'} \sim 5\,\text{TeV}$
- Higgs-strahlung, WW fusion: $HZff$, $HWff$ angular distr./energy dependence $\Rightarrow f_{VJ}$
- 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

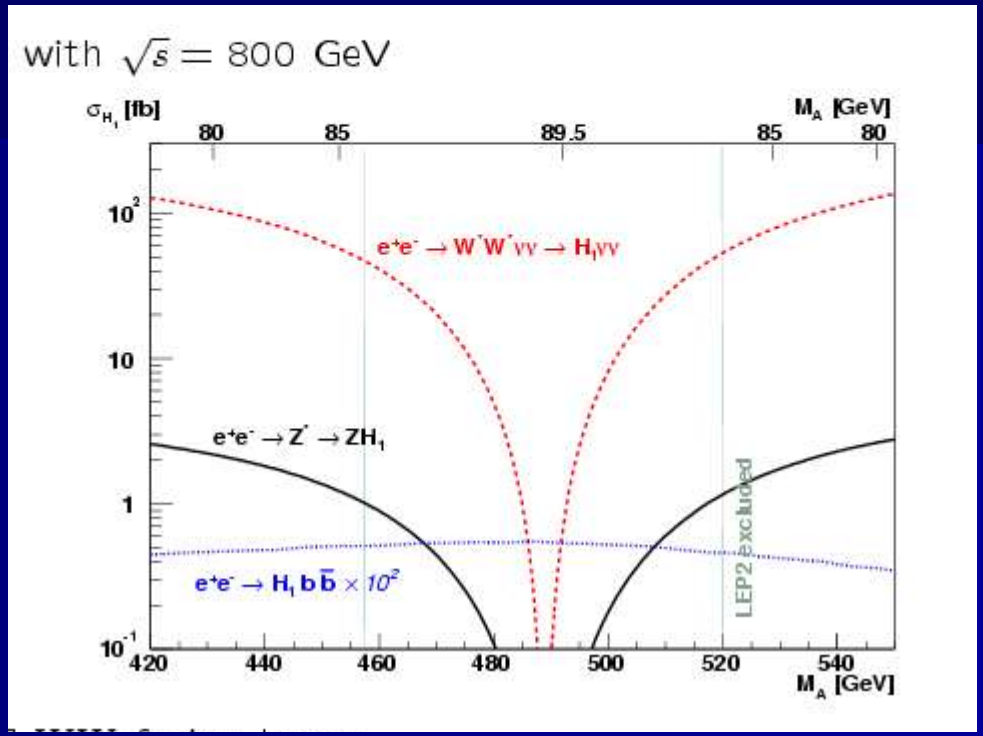


- Spectrum "like MSSM" + 2 extra states

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 bb and $\gamma\gamma$ decay modes.

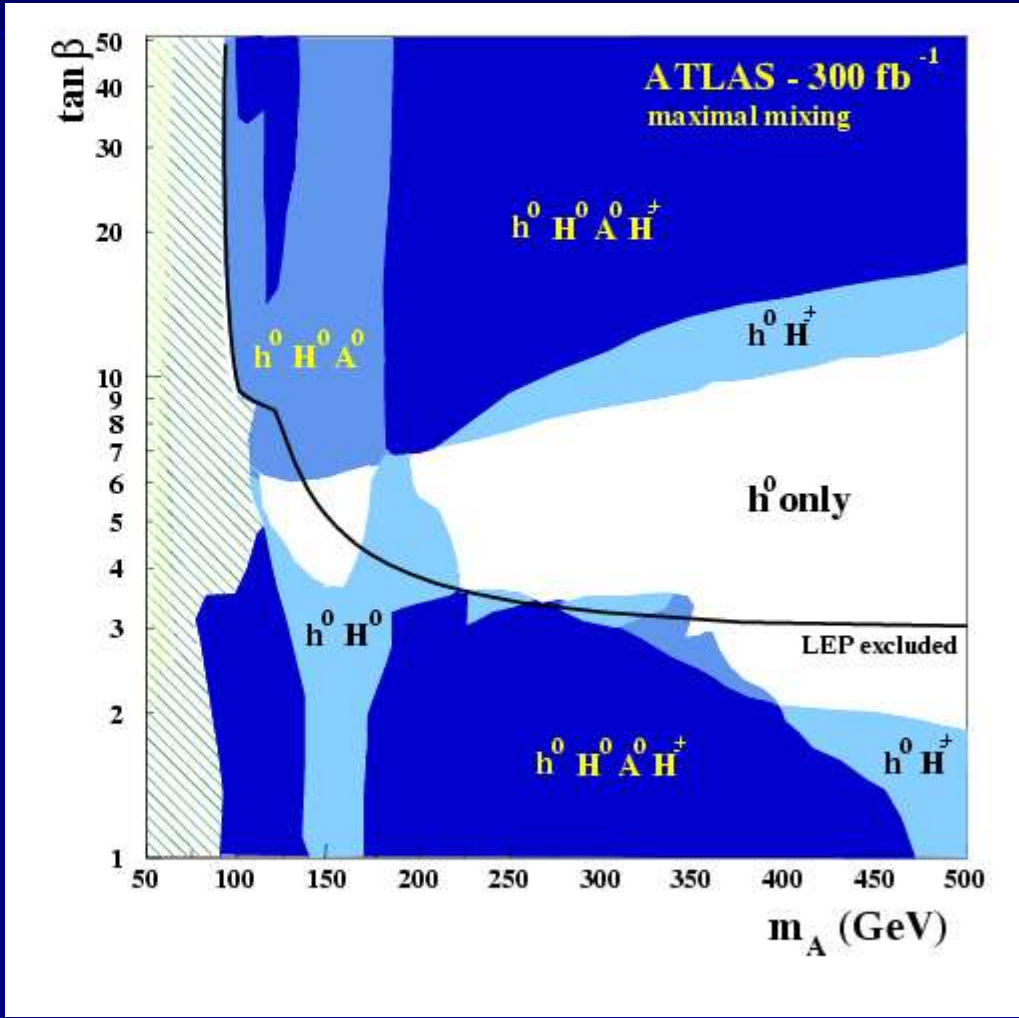


Explore New Horizons

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

Heavy SUSY Higgses
(Raspereza)

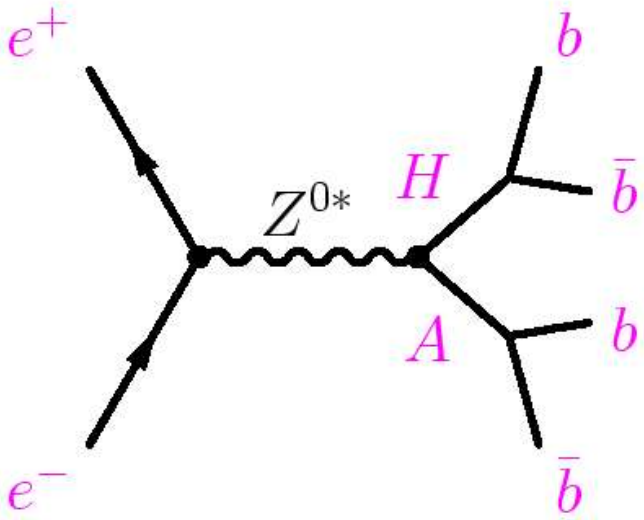
- A challenging plot
- Here is an example for a LC as a possib;e discovery machine



Heavy SUSY Higgses
(Raspereza)

Topologies Analysed

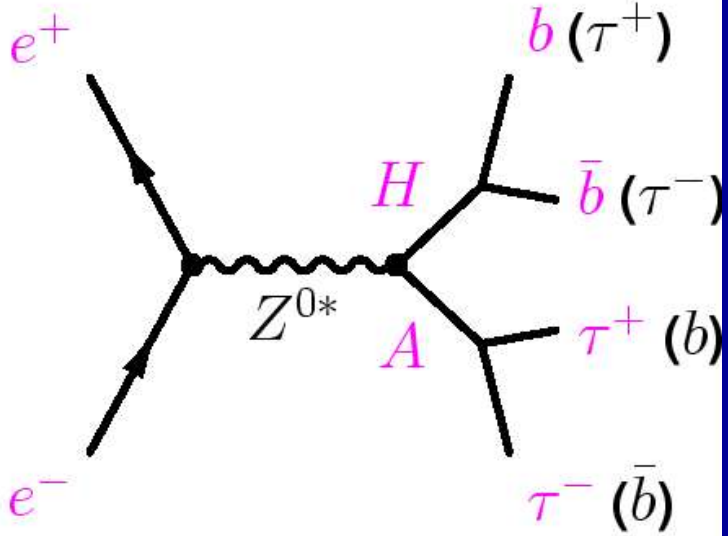
$HA \to b\bar{b}b\bar{b}$



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

$L = 500fb^{-1}$

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



$(\sigma * BR)$ - ?

M_H - ? M_A - ?

$\Gamma_{H,A}$ - ?

Heavy SUSY Higgses (Raspereza)

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

	500 GeV		800 GeV	
	$b\bar{b}b\bar{b}$	$b\bar{b}\tau^+\tau^-$	$b\bar{b}b\bar{b}$	$b\bar{b}\tau^+\tau^-$
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

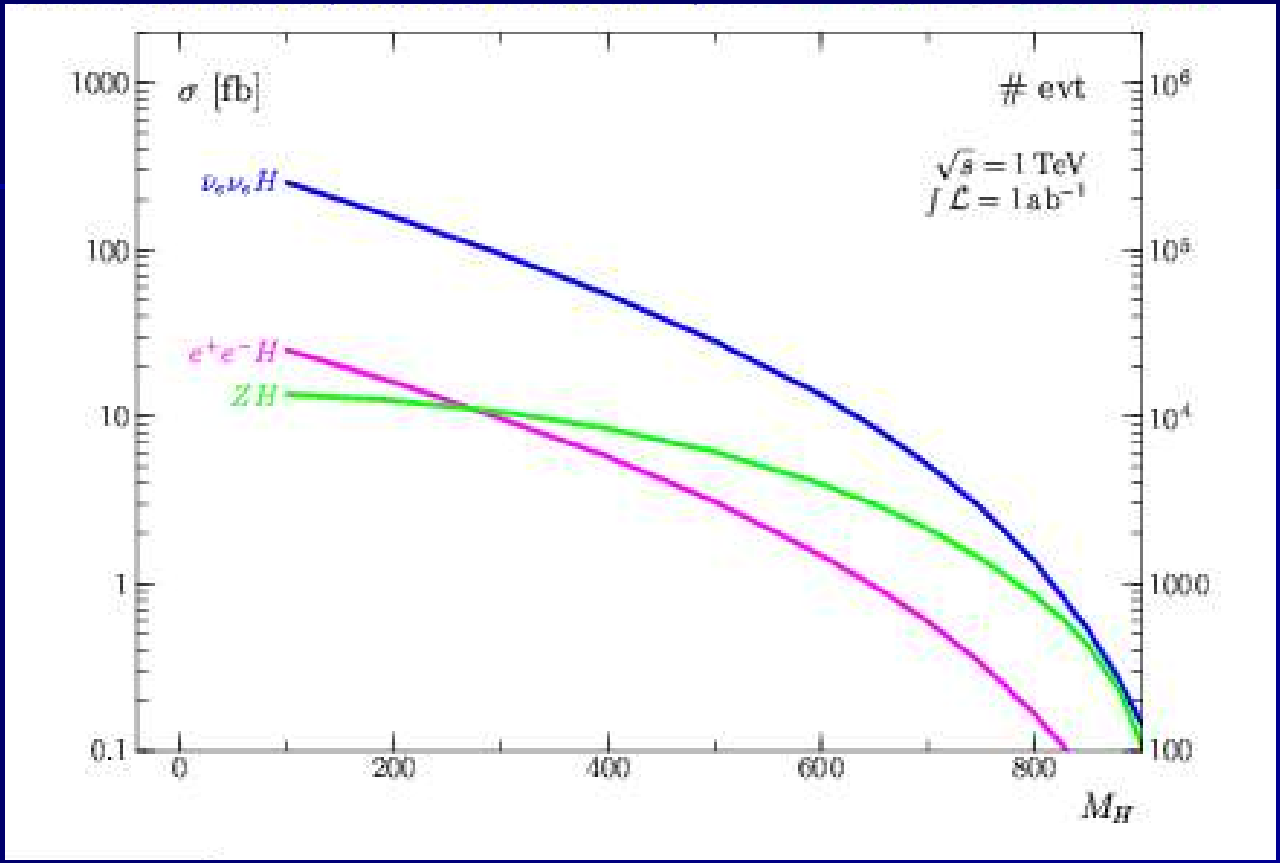
- First look at SPS1A point @ $\sqrt{s}$=1TeV with $b\bar{b}b\bar{b}$ channel is encouraging :
  $\delta(m_H + m_A) \sim 2GeV$, $\delta\sigma_{HA\to b\bar{b}b\bar{b}}/\sigma_{HA\to b\bar{b}b\bar{b}} \sim 10\%$
- Higgs width measurement is feasible in the $b\bar{b}\tau^+\tau^-, \tau^+\tau^- b\bar{b}$ 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)

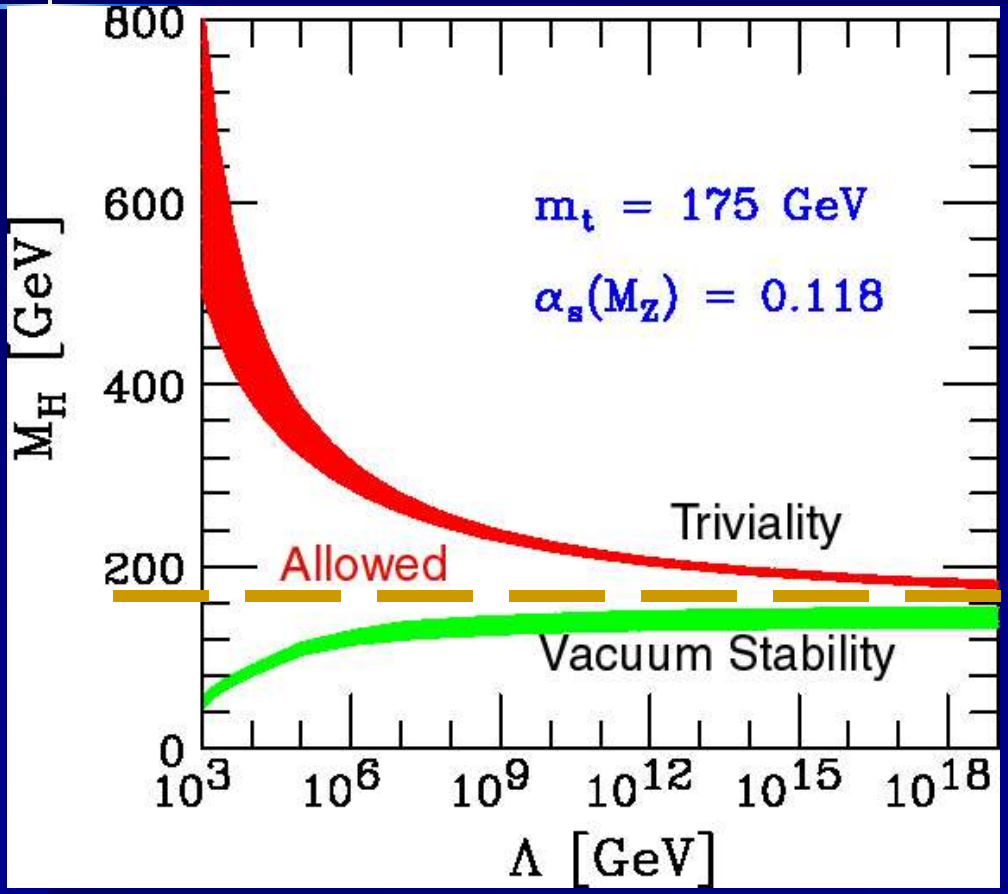


- An important & straightforward channel at 1000 GeV is the ZZ fusion!
- So many Higgs accessible production modes must tell an interesting story!
- Exploration to heavier Higgs bosons is

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