Status of CP Studies in the Higgs Sector at ATLAS

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RHEINISCHE FRIEDRICH-WILHELMS-UNIVERSITÄT

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2nd CPNSH WS, December 2004

CPNSH

- **CP studies in H→ZZ→4 leptons**

  in ttH, H→ $\gamma\gamma$
- **Discovery potential in CPX scenario**
- **Conclusions**

bmb+f - Förderschwerpunkt
ATLAS
Großgeräte der physikalischen Grundlagenforschung

CP study for H→ZZ→4 leptons (Bij, Buszello, Marquard)

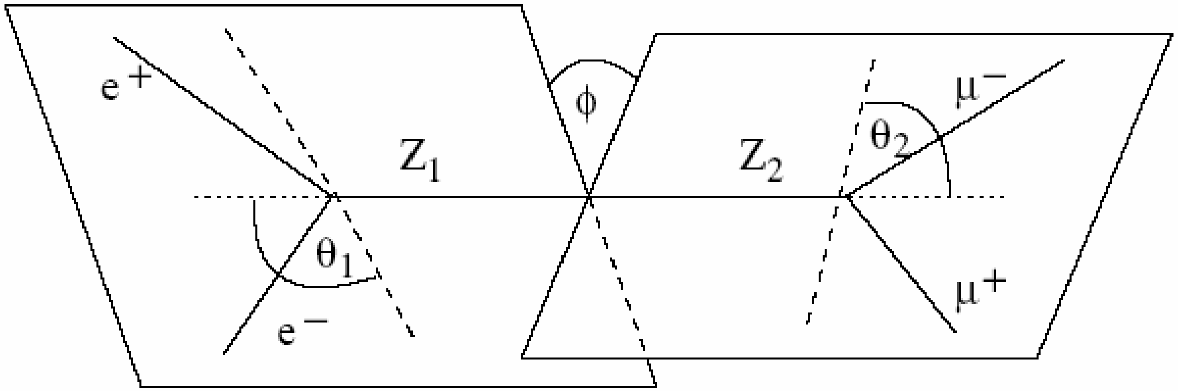
for details see: C. Buszellos and P.Marquards talks at 1st CPNSH WS and Eur.Phys.J.C32(04)209 and hep-ph/04106181

general description of interaction btw. boson a. weak gauge bosons

$$\mathcal{L}_{scalar} = \mathrm{X} g^{\mu\nu} + \mathrm{Y} p^{\mu} p^{\nu}/M_h^2 + \mathrm{P}\epsilon_{\mu\nu\rho\sigma} p_1^{\rho} p_2^{\sigma}/M_h^2$$

$$\mathcal{L}_{vector} = \mathrm{X_V}(g^{\rho\mu} p_1^{\nu} + g^{\rho\nu} p_2^{\mu}) + \mathrm{P_V}(\epsilon_{\mu\nu\rho\sigma} p_1^{\sigma} - \epsilon_{\mu\nu\rho\sigma} p_2^{\sigma})$$

SM: X=1
rest = 0



Decay plane angle

$$F(\phi) = 1 + \alpha \cdot \cos(\phi) + \beta \cdot \cos(2\phi)$$

Polar angle

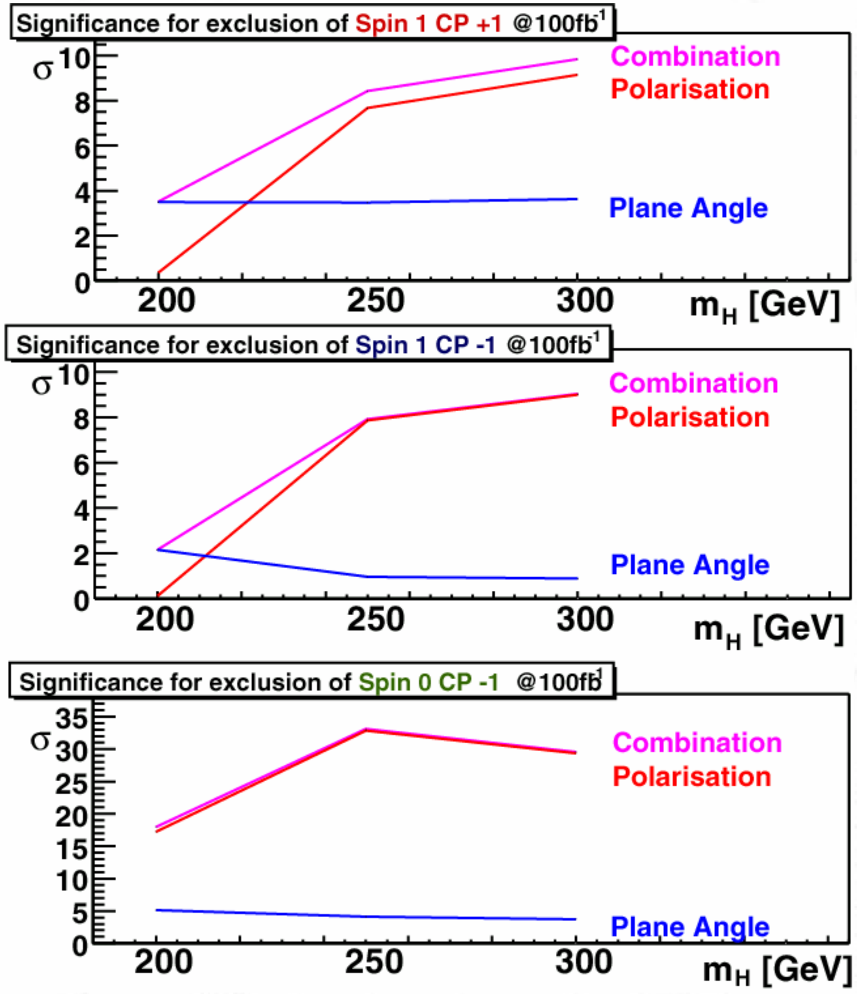
$$G(\theta) = T \cdot (1 + \cos^2(\theta)) + L \cdot \sin^2(\theta)$$

$$R := \frac{L - T}{L + T}$$

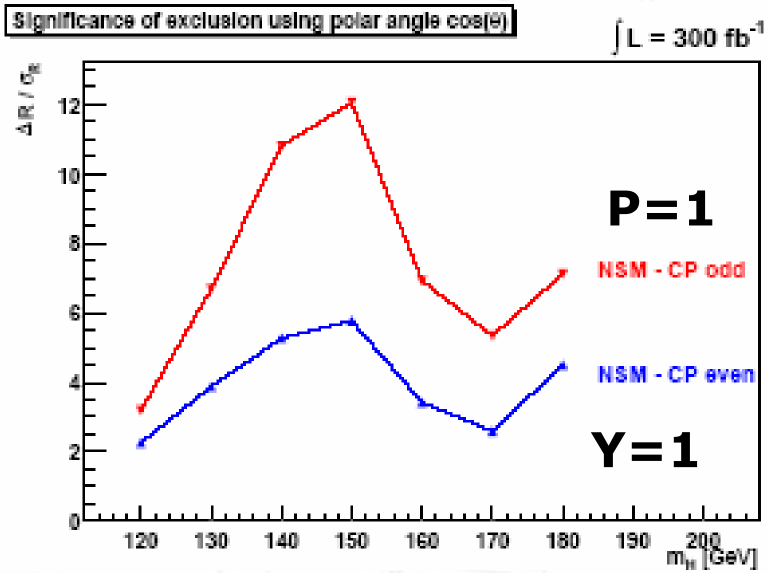
studied in fast simulation, only irreducible ZZ BG considered

Discrimination between pure CP and Spin States

H→ZZ



H→ZZ*



additional information in offshell Z mass

also prel. results from VBF with H→WW→llνν

sensitive vars.: azimuth angle btw. tagging jets, inv. ll-mass

Measurement of relative couplings of CP mixed scalar

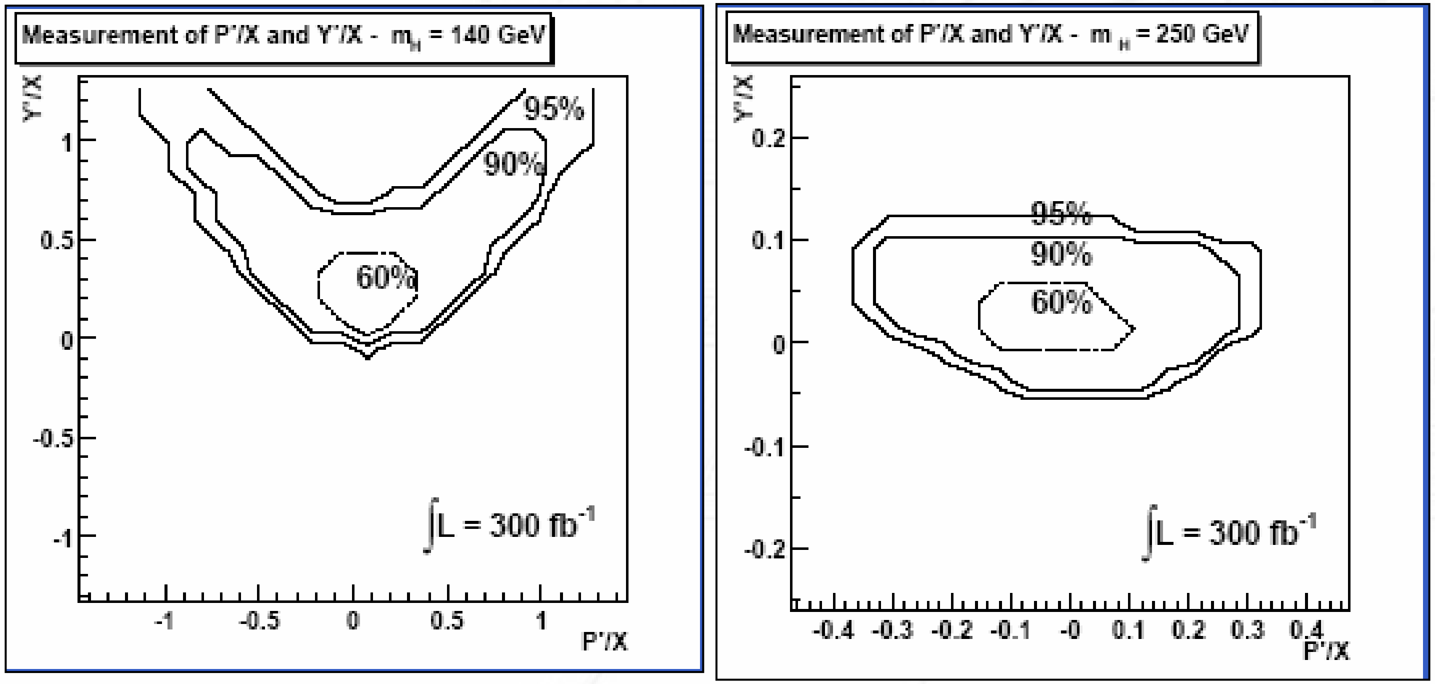
$$\mathcal{L}_{scalar} = Xg^{\mu\nu} + Yp^{\mu}p^{\nu}/M_h^2 + P\epsilon_{\mu\nu\rho\sigma}p_1^{\rho}p_2^{\sigma}/M_h^2$$

consider two non vanishing couplings

Define rescaled couplings: $P' = \frac{\Gamma_{SM}}{\Gamma_P} P \qquad X' = \frac{\Gamma_{SM}}{\Gamma_P} X$

$$L(P,Y) = \sum log \frac{\mathcal{M}^2(\phi,\theta_1,\theta_2,P,Y,X=1)}{\int \mathcal{M}^2(\phi,\theta_1,\theta_2,P,Y,X=1)d\phi d\theta_1 d\theta_2}$$

maximum likelihood fit to P'/X and Y'/X



mass range between

130 GeV

and

250 GeV

studied

CP study for ttH, H→ γγ (Scott McGarvie)

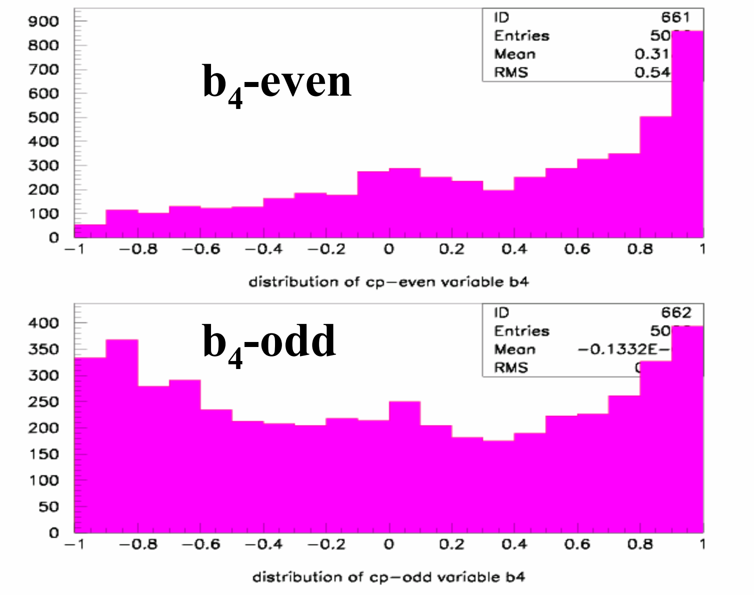
using ideas from Gunion, He (*PRL 76, 24, 4468 (1996)*)

for details see talk at 1st CPNSH Workshop by Scott

$$\mathcal{L} \equiv \bar{t}(c + id\gamma_5)th$$

c: CP-even coupling = 1 in SM

d: CP-odd coupling = 0 in SM



sensitivity of several observables has been compared.

best for now is B4

$$b_4 = \frac{p_t^z p_{\bar{t}}^z}{|\vec{p}_t||\vec{p}_{\bar{t}}|}$$

requires reconstruction of top momenta

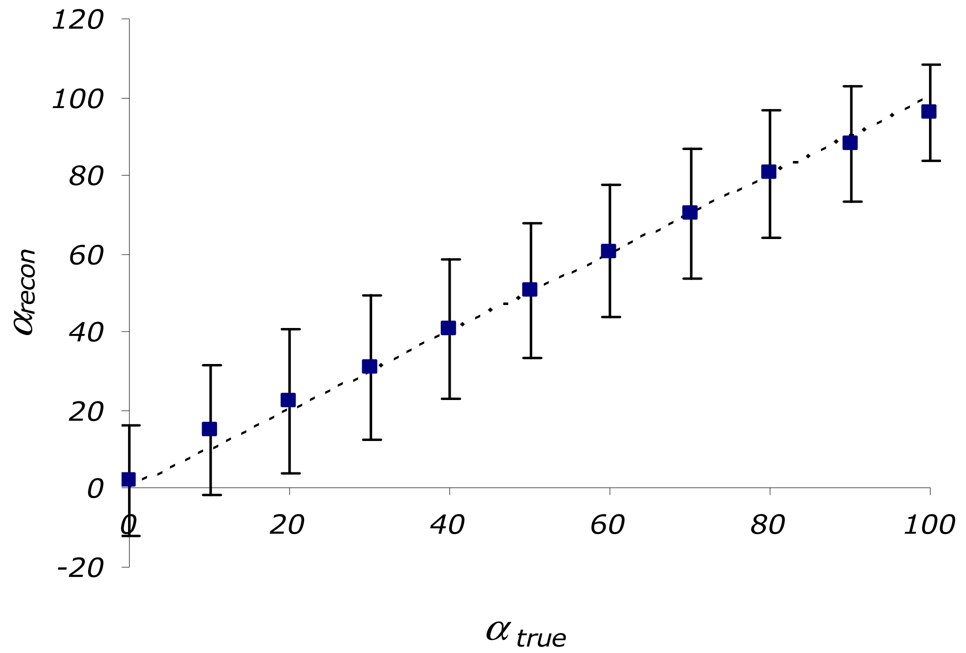
plan: try and use "optimal observable"

CP study ttH, H→ γγ: parton level

ATLAS TDR: expect ~50 signal events for M_H =110 GeV and 300 fb^{-1}

maximum likelihood fit for α to B_4 distributions

$$f(x,\alpha) = \alpha\, f_{CP\text{-}even}(x) + (1-\alpha) f_{CP\text{-}odd}(x)$$



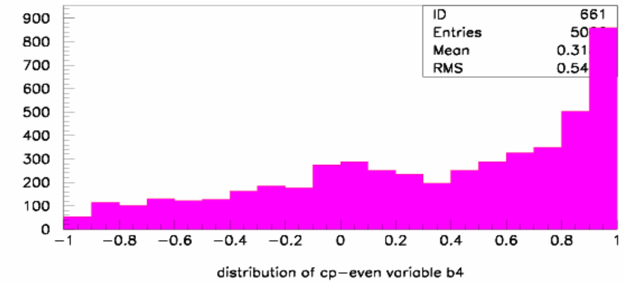
results from a lot of MC experiments

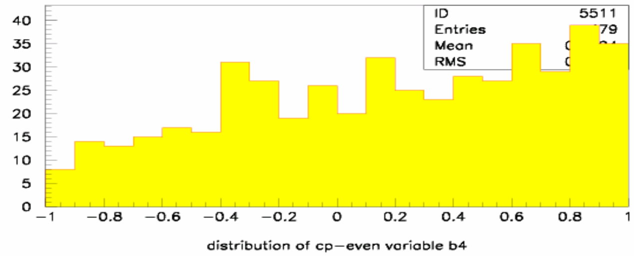
- **measurement of α is unbiased**
- **error on α is around 15-20%**

CP study ttH, H→ γγ: from parton to detector level

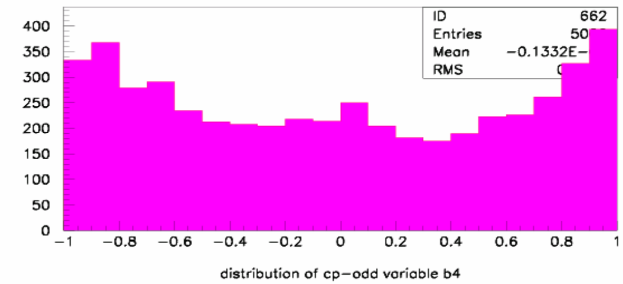
parton level | **detector level**

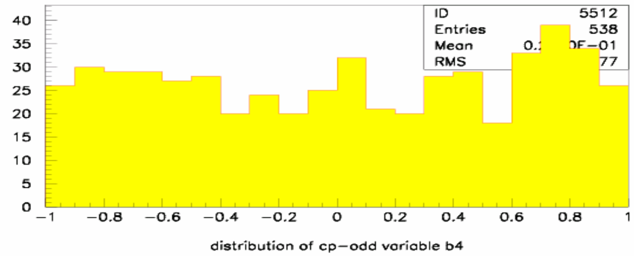
CP even





CP odd





γ

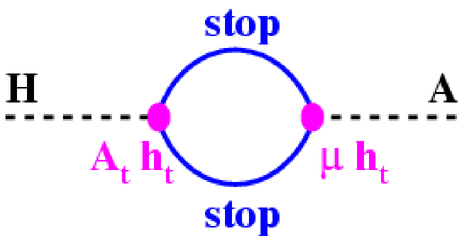
- **assume 50 selected signal evts :→ increase in width to 25%**
- **but currently: efficiency lower by factor 3 w.r.t TDR due to full reconstruction of final state**
- **plans: optimise selection → recover signal efficiency**
  consider backgrounds (with Madgraph, Alpgen, etc.)

The CP violating CPX scenario

- **MSSM Higgs Sector CP conserving at Born level**
- **CP effects via complex couplings in loops: Complex MSSM**

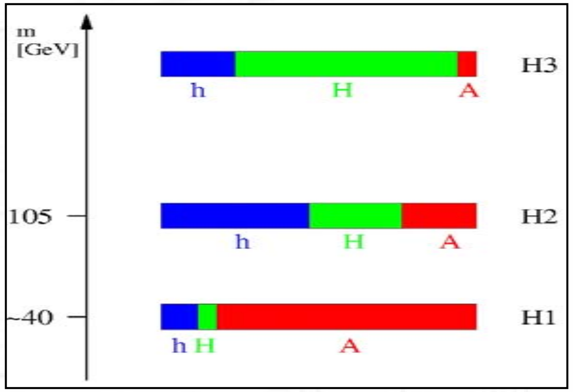
A_t, A_b

M_{gluino}



$$\begin{pmatrix} h_1 \\ h_2 \\ h_3 \end{pmatrix} = \begin{pmatrix} u_{11} & u_{12} & u_{13} \\ u_{21} & u_{22} & u_{23} \\ u_{31} & u_{32} & u_{33} \end{pmatrix} \cdot \begin{pmatrix} H \\ h \\ A \end{pmatrix}$$

- **mass eigenstates H_1, H_2, H_3**
  not equal CP eigenstates h,A,H



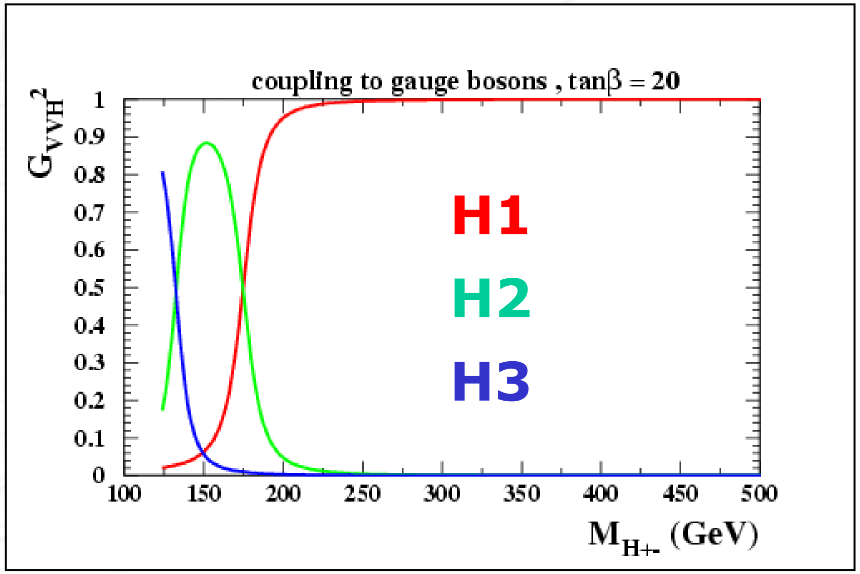
Maximise effect → CPX scenario (Carena et al., Phys.Lett B495 155(2000))

$arg(A_t)=arg(A_b)=arg(M_{gluino})=90$ degree, large ratio $\mu A_t/m_{susy}$

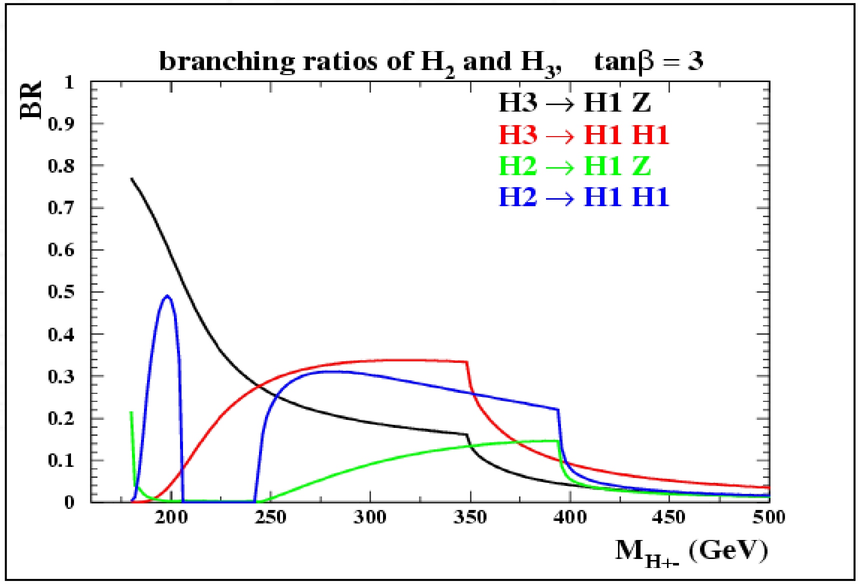
- **scan of Born level parameters: $\tan\beta$ and M_{H+-}**

Phenomenology in the CPX scenario

- H_1,H_2, H_3 couple to W,Z can be produced in VBF



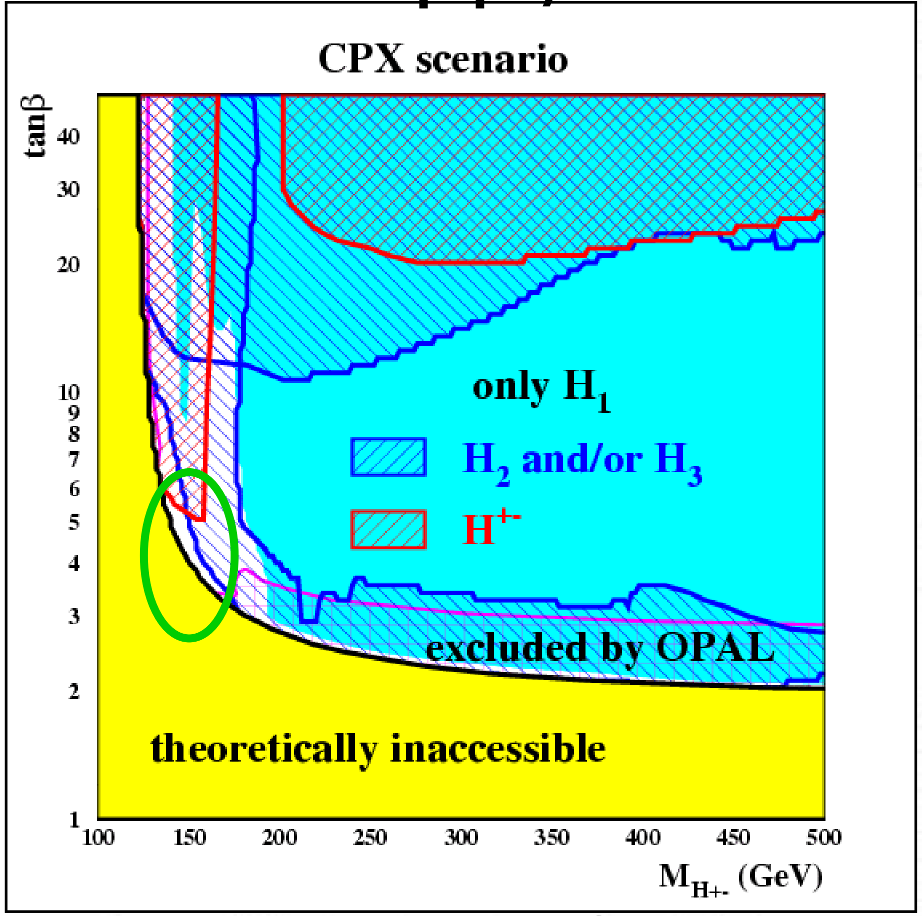
- H_2,H_3 → H_1H_1, ZH_1,WW, ZZ decays possible



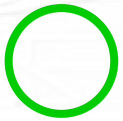
Overall Discovery Potential: 300 fb^{-1}

ATLAS preliminary at

SUSY04 hep-ph/0410112



- FH2.1 with M_t=175 GeV
- OPAL exclusion for M_t=174.3GeV
- small uncovered area at low M_{H+-}



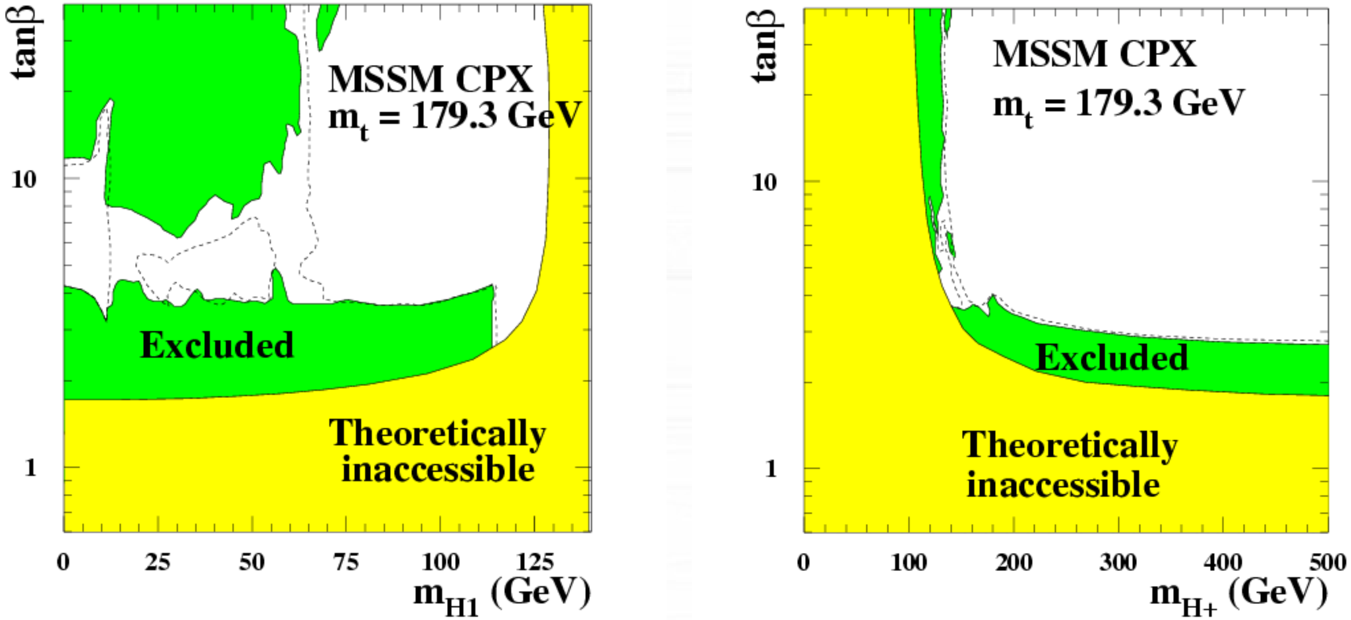
M_{H1}: < 70 GeV
M_{H2}: 105 to 120 GeV
M_{H3}: 140 to 180 GeV

small masses below 70 GeV
not yet studied in ATLAS

- border at low tanb for H1 mostly determined by availability of inputs (VBF >110 GeV, ttH and $\gamma\gamma$ > 70 GeV)
- border at low M_{H+-} due to decoupling of H_1 from W,Z and t

The preliminary results from LEP combination

LHWG-Note 2004-01



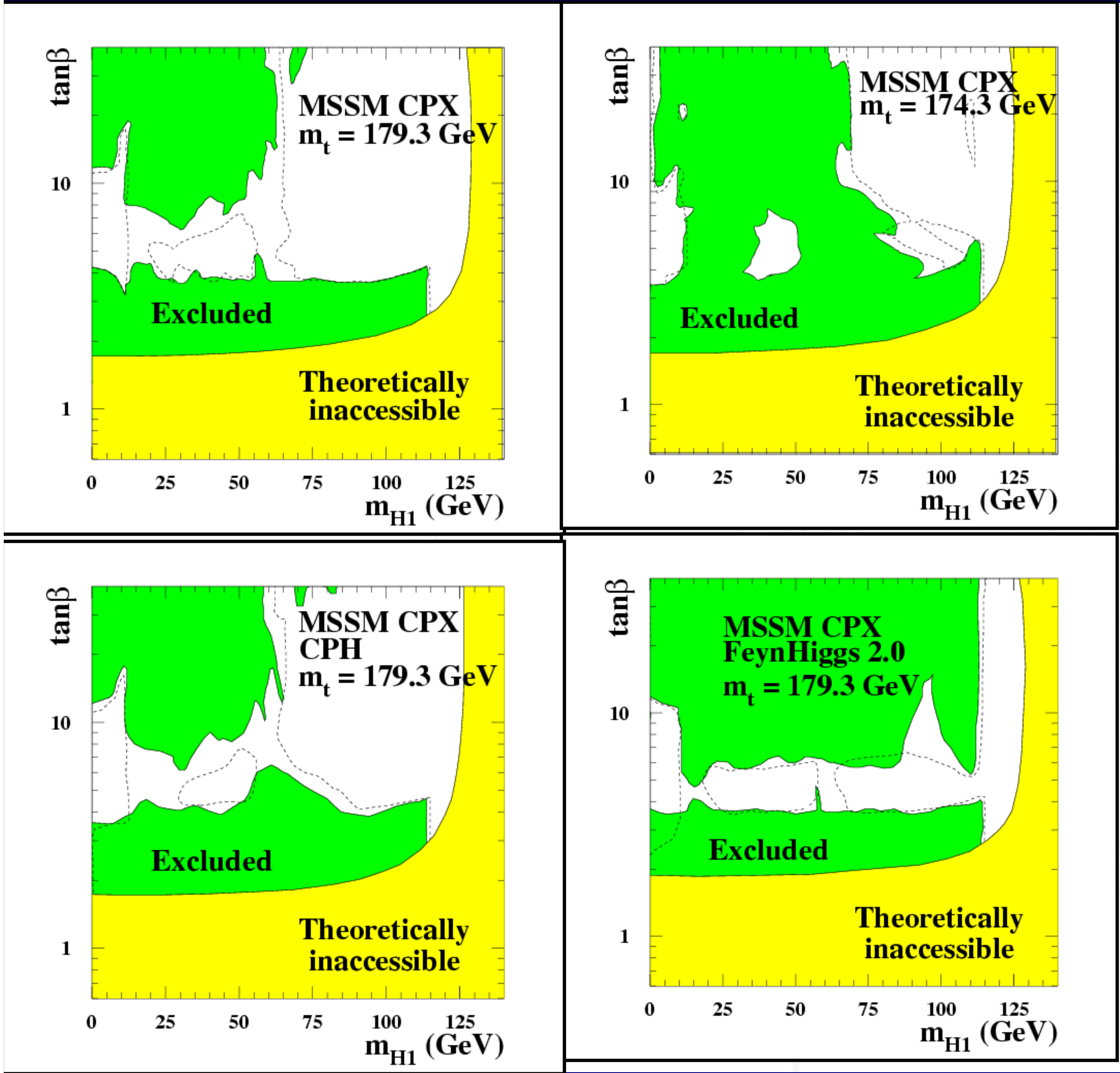
No limit on mass of H1

LEP uses FeynHiggs (FH) 2.0 and CPH for masses and couplings, BRs from HZHA

Exclusion plot: conservative result from CPH and FH

ATLAS uses FeynHiggs (FH) 2.1 and CPSUPERH (CSH) for masses, couplings and branching ratios

The preliminary results from LEP combination

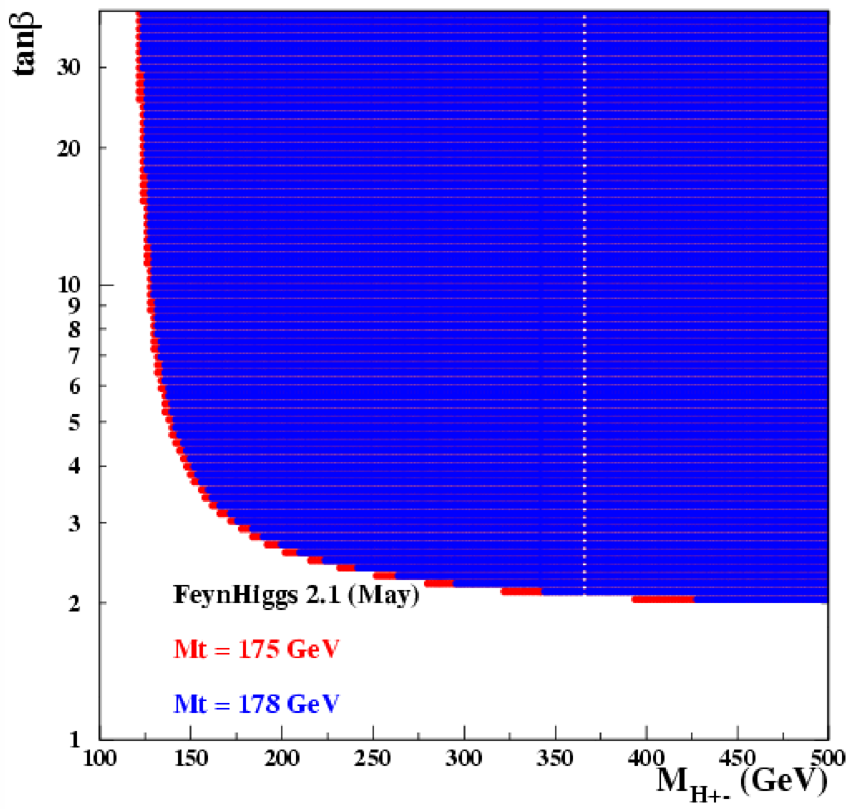


strong dependence on m_{top}

strong dependence on program used

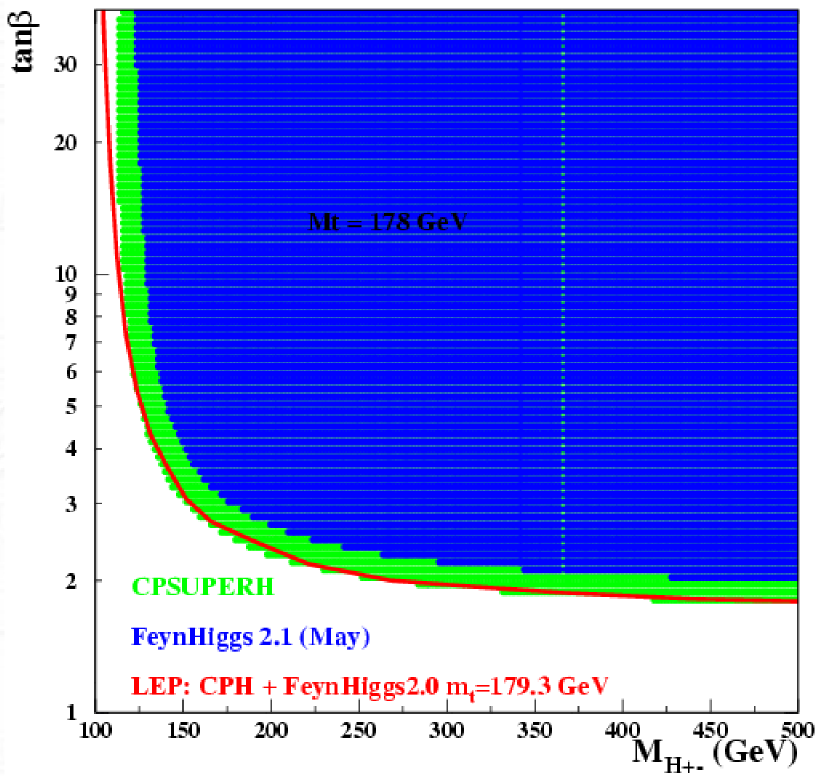
Comparison of theoretical allowed regions

FH: Mt= 175 vs 178GeV



small difference due to M_t

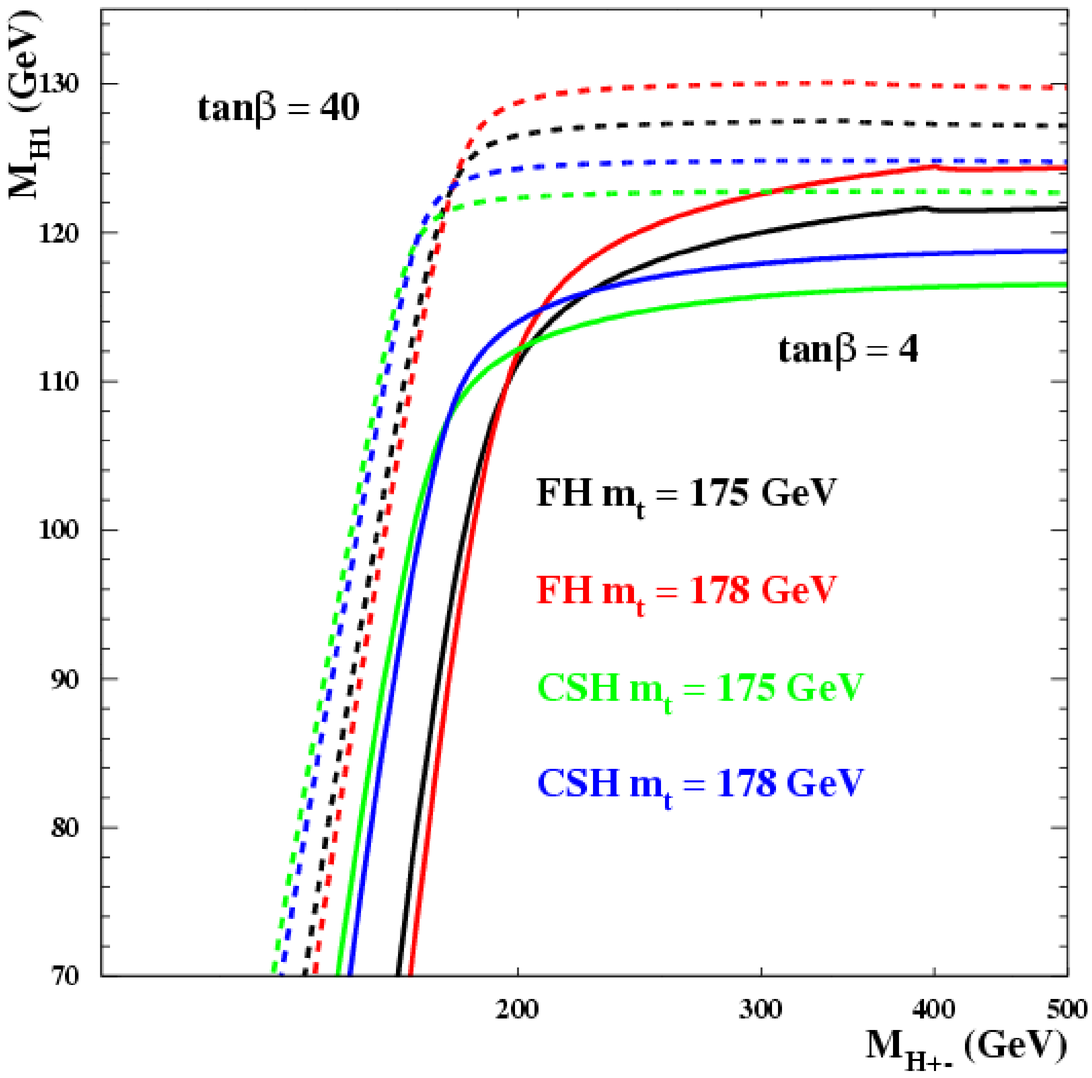
FH vs CPSUPERH: M_t= 178GeV



significant diff. due to program

Caution, when applying LEP exclusion!

Mass of Lightest Higgs Boson H1

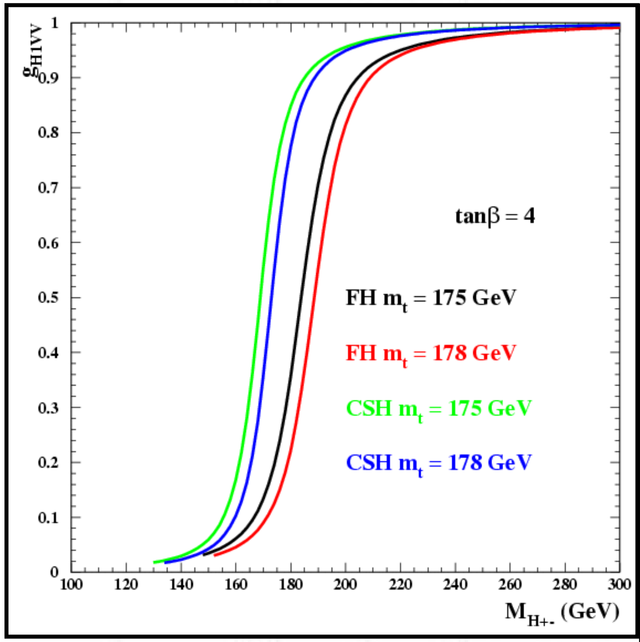


Difference of up to 5 GeV in mass prediction

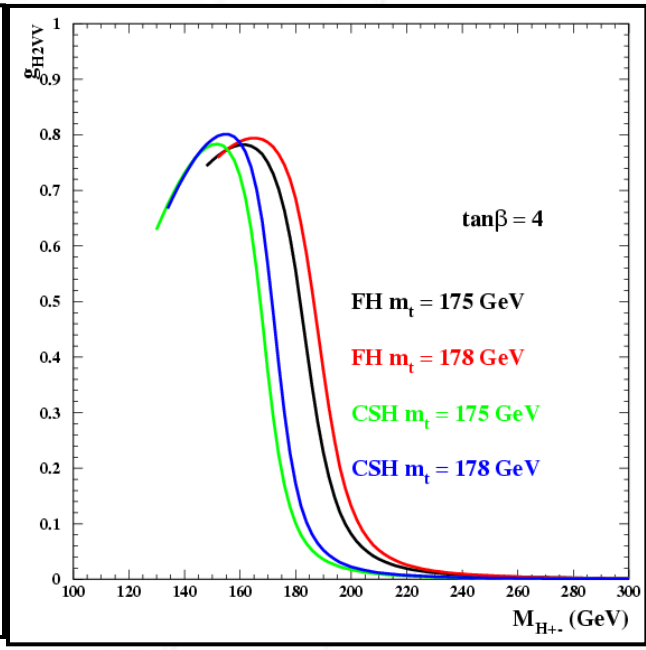
between Feynhiggs and CPSUPERH

Coupling to Weak Gauge Bosons

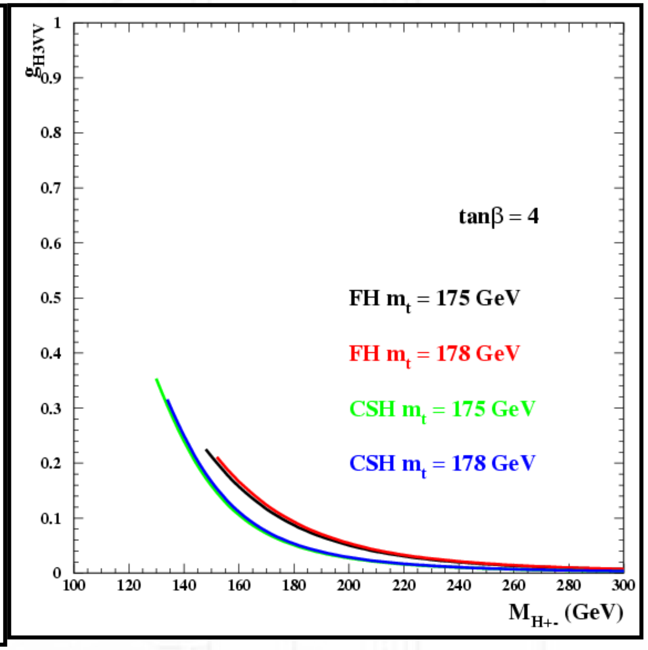
VVH1



VVH2

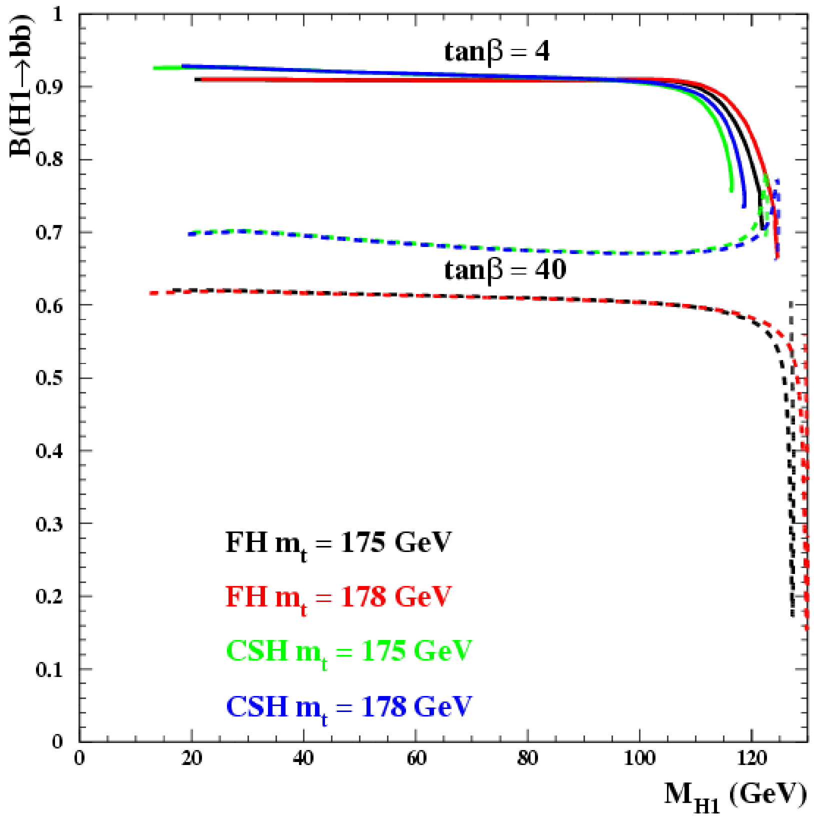


VVH3

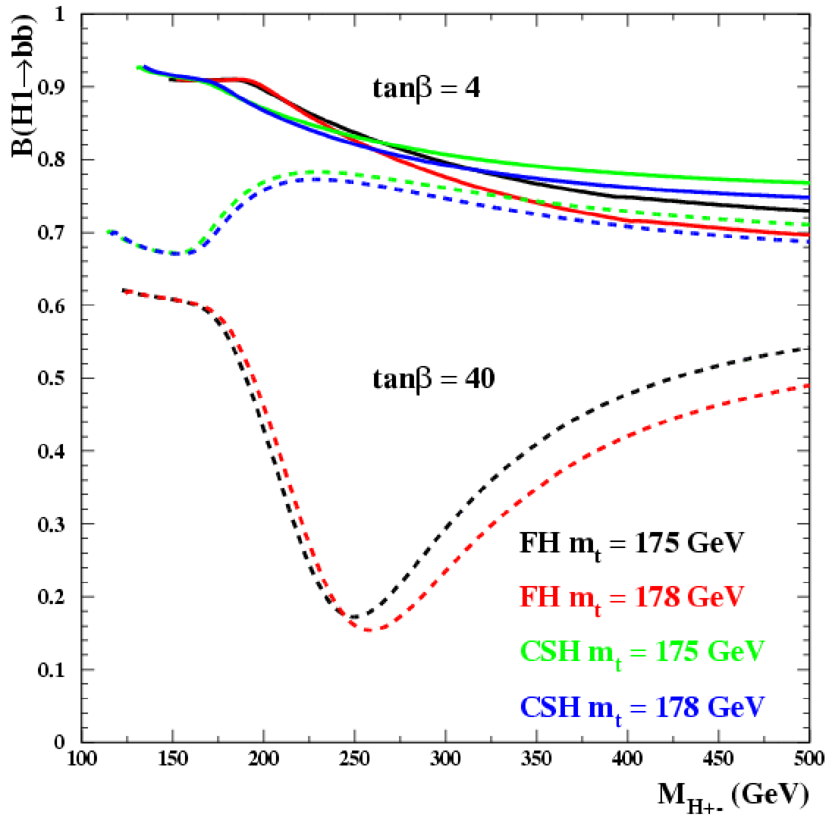


Branching ratio H1→bb

B(H1→bb) vs MH1

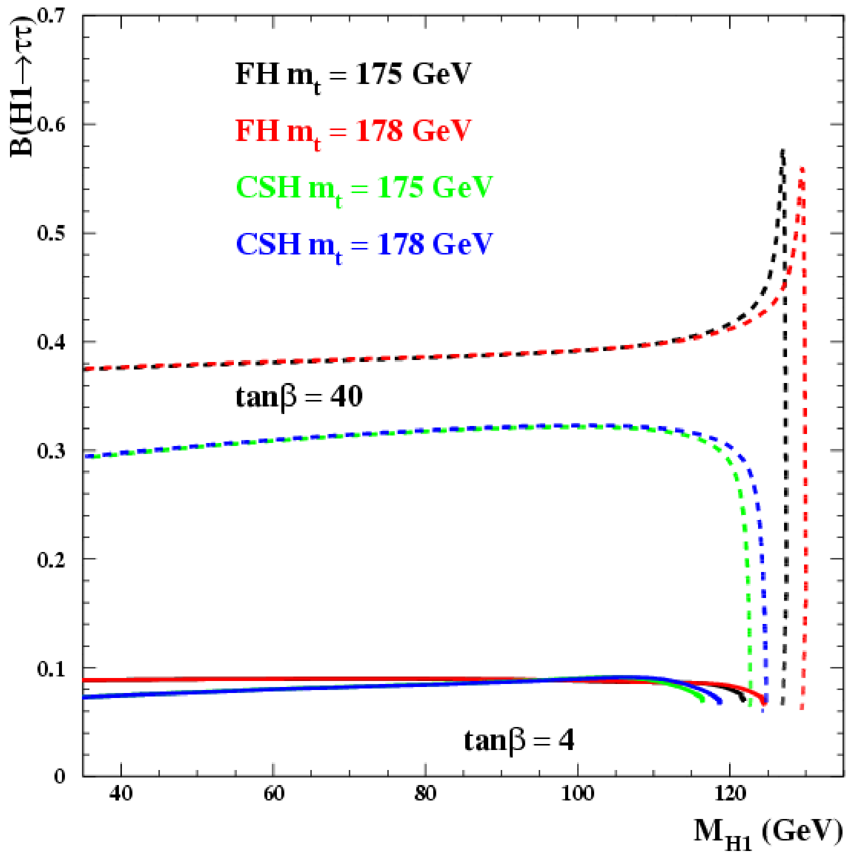


B(H1→bb) vs MH+-

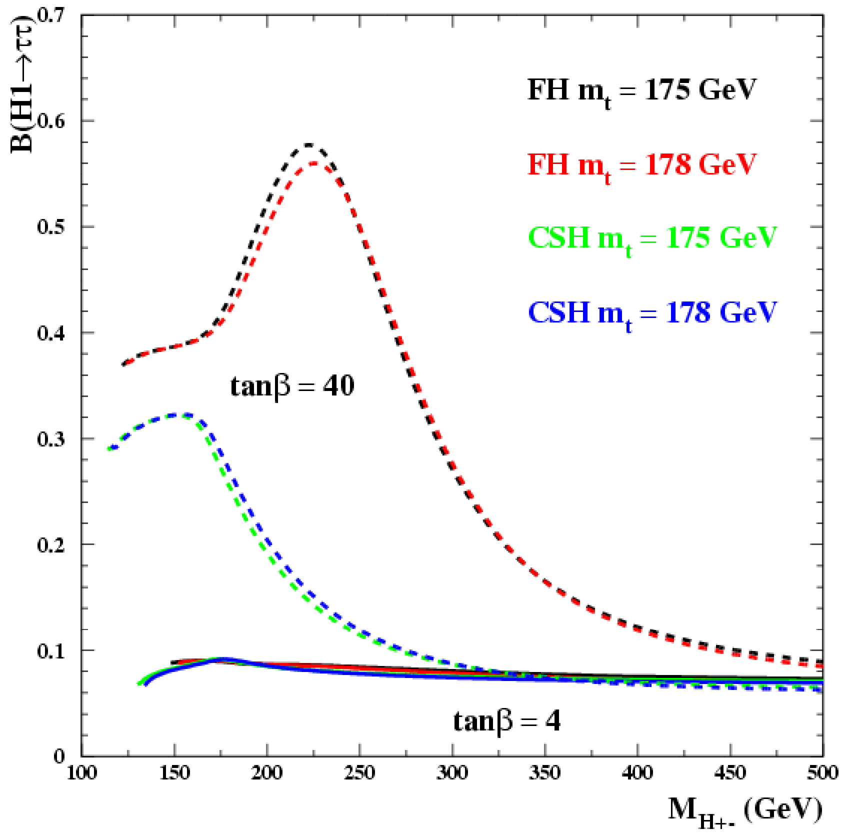


Branching ratio H1→ττ

B(H1→ττ) vs MH1



B(H1→ττ) vs MH+-

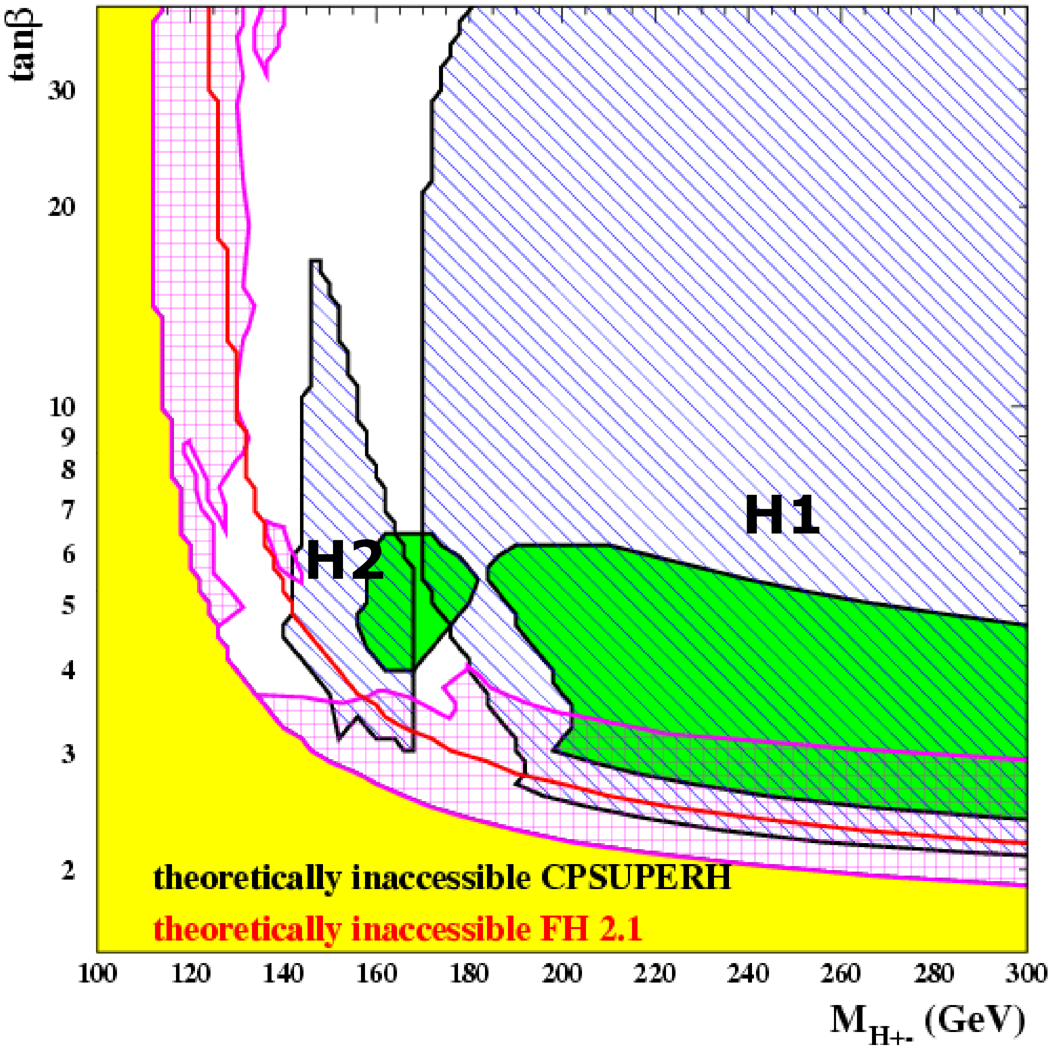


Question to our theoretical friends:

do we have to live with this differences?

Discovery potential: ttH with H1/2→bb

M_t = 178 GeV



Feynhiggs

CPSUPERH

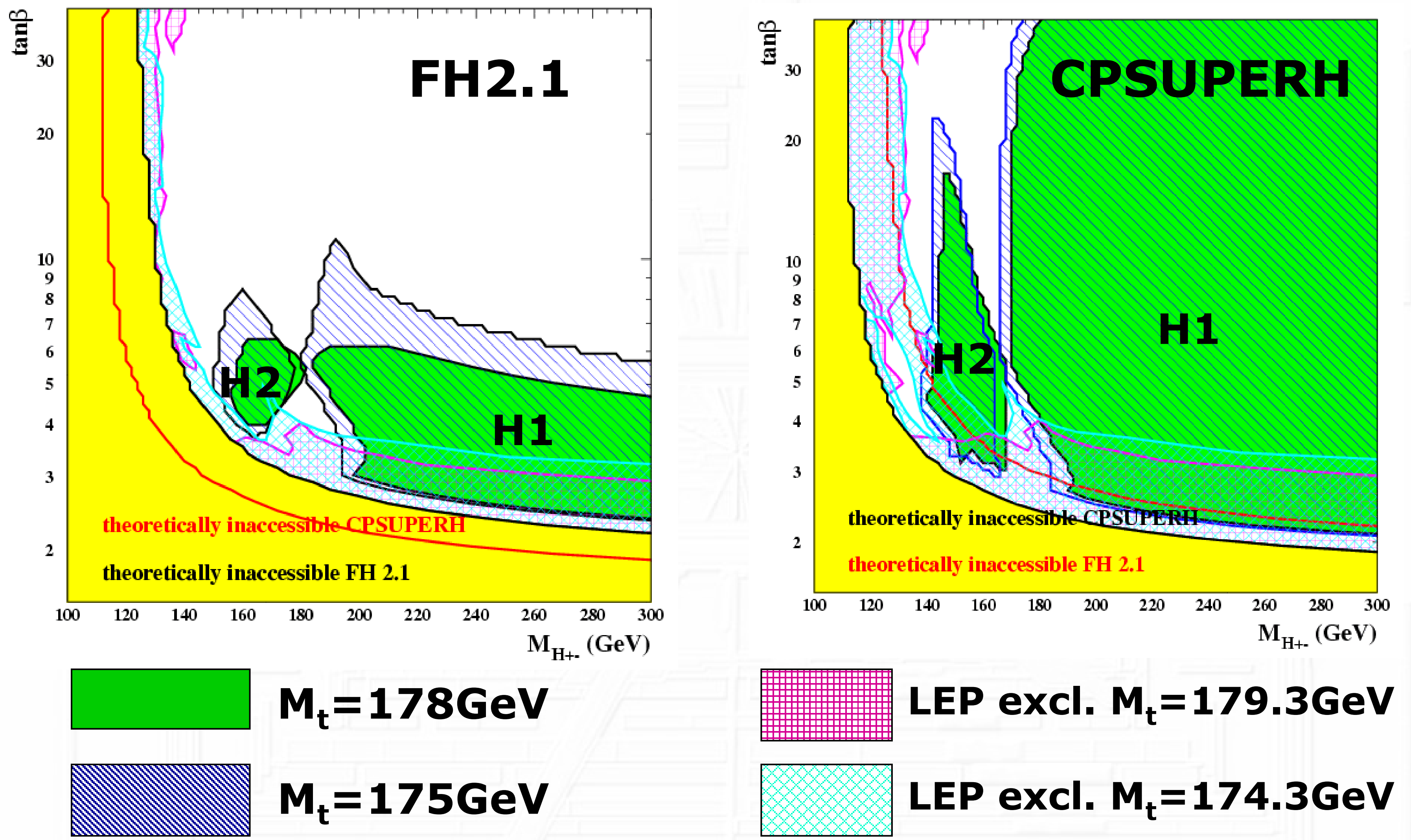
excluded by LEP

M_t=179.3GeV

Large difference in covered region!

+ significant difference in theoretically allowed region

Discovery potential: ttH with H1/2→bb

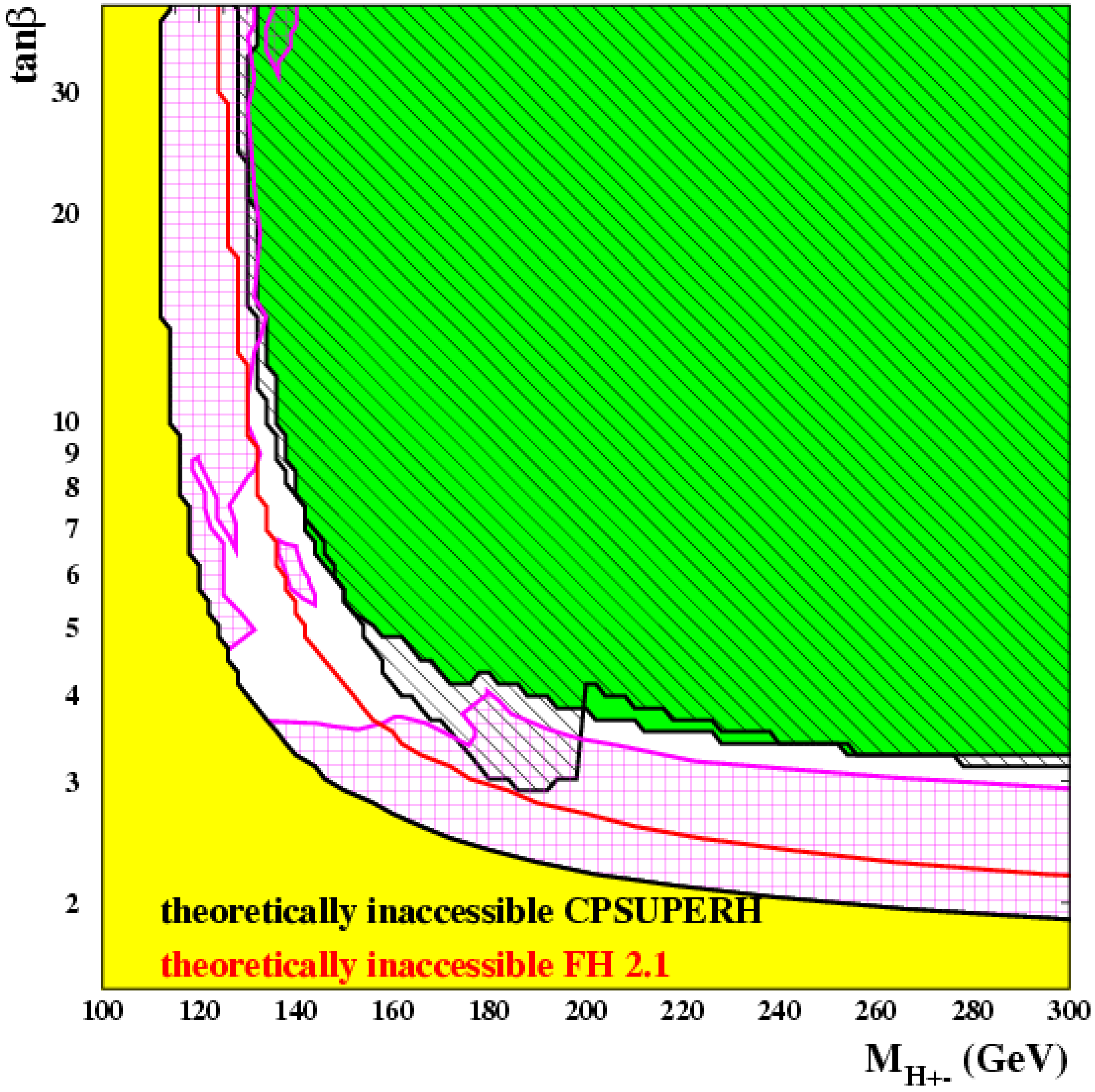


also difference due to change in $M_{t,}$

as discovery potential decreases with increasing Higgs mass

Discovery potential: VBF with H1/2→ττ

M_t = 178 GeV

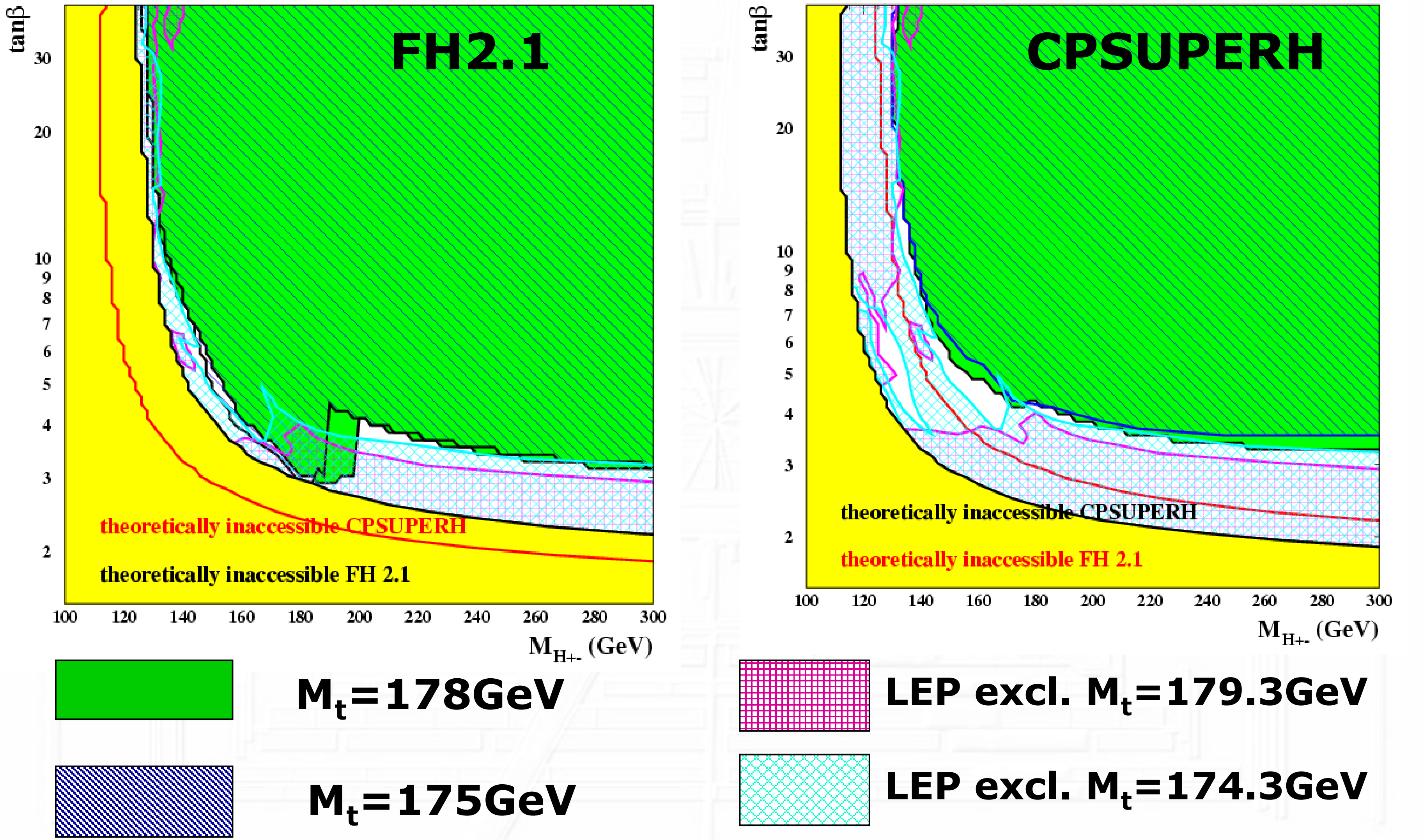


- CPSUPERH
- Feynhiggs
- excluded by LEP M_t=179.3GeV

„Smaller" difference in covered region!

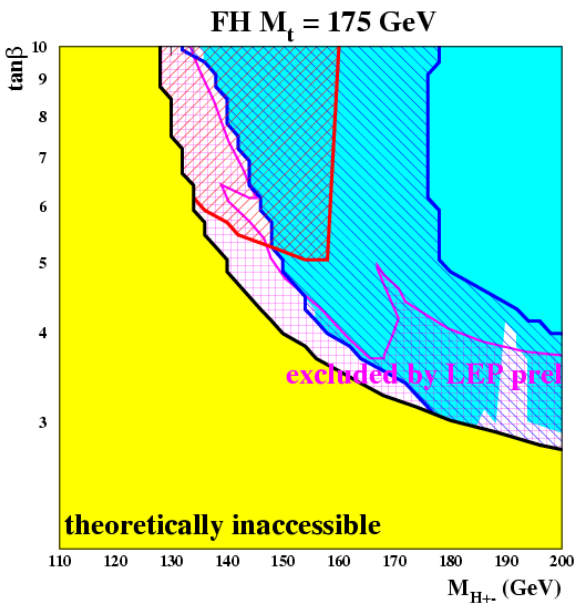
+ significant difference in theoretically allowed region

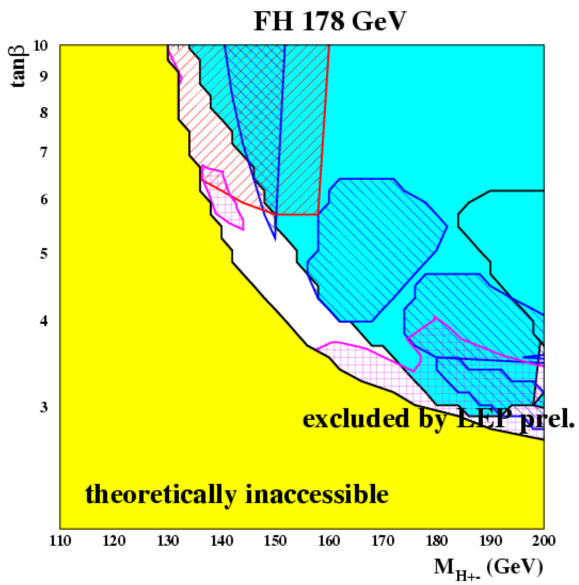
Discovery potential: VBF with H1/2→ττ

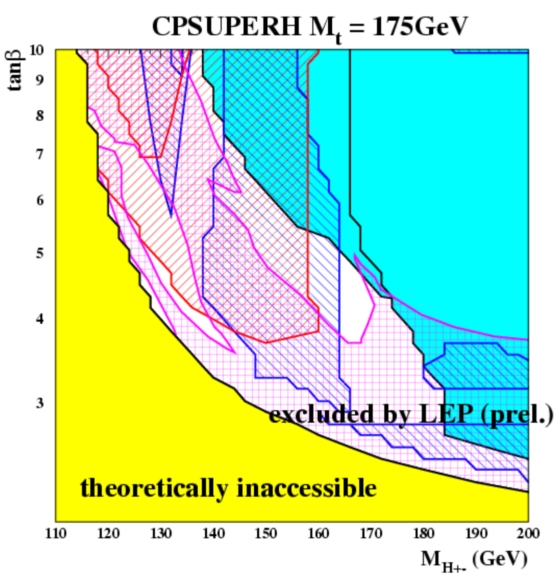


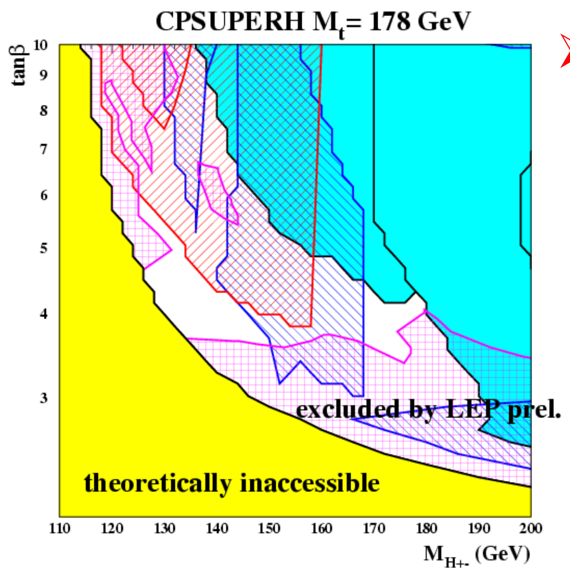
Also difference due to change in M_t

Discovery potential in vincinity of „hole“









very preliminary results

- **size and location of „hole“ depends on**
  - **assumed M_t/LEP excl.**
  - **program used FH/CSH**

- **should check sensitivity for low mass Higgs H1**

  e.g. tt→Wb H^{+-} b

  with H^{+-}→WH_1→Wbb

Conclusions

❖ **Studies concerning CP determination of Higgs bosons**

a) quite advanced studies in $H \rightarrow ZZ \rightarrow 4$ leptons and VBF, $H \rightarrow WW$

b) progress in ttH, $H \rightarrow \gamma\gamma$ for low mass Higgs, seems promising

❖ **Discovery Potential in CPXD Scenario**

a) size and location of „hole" depends on

assumed M_t / LEP exclusion and program used FH/CSH

→ careful watch assumptions when looking at plots

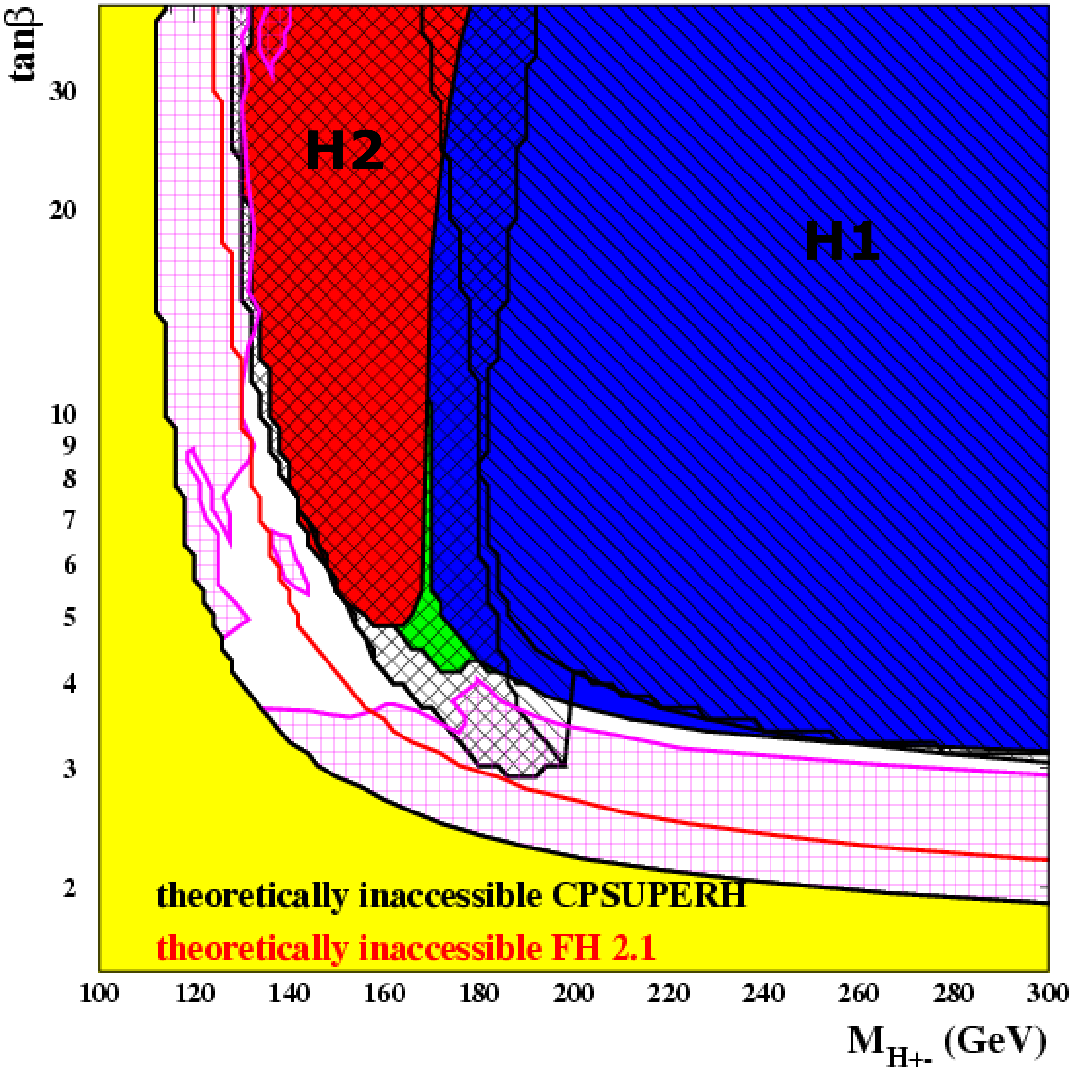
b) in any case: should study sensitivity for low mass Higgs H_1

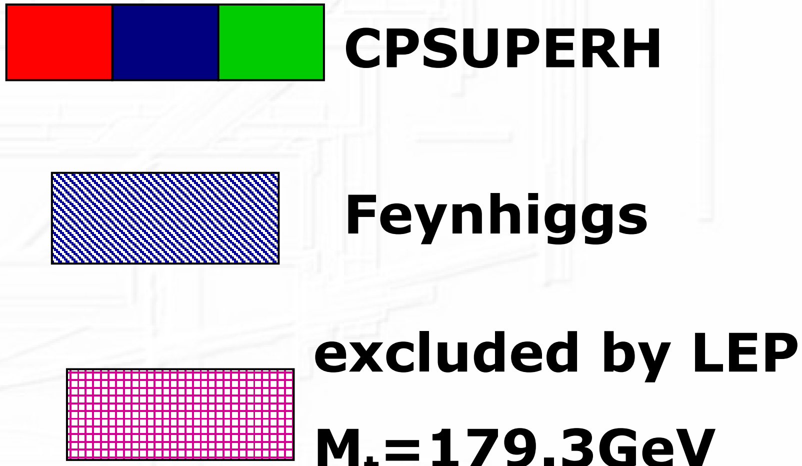
(might be relevant also in other SM extensions e.g. NMSSM)

Thanks for programs and discussions concerning CPX to:
Philipp Bechtle, Sven Heinemeyer, Jae Sakis Lee,
Tilman Plehn, David Rainwater, Michael Spira, Georg Weiglein…

Discovery potential: VBF with H1/2→ττ

M_t = 178 GeV



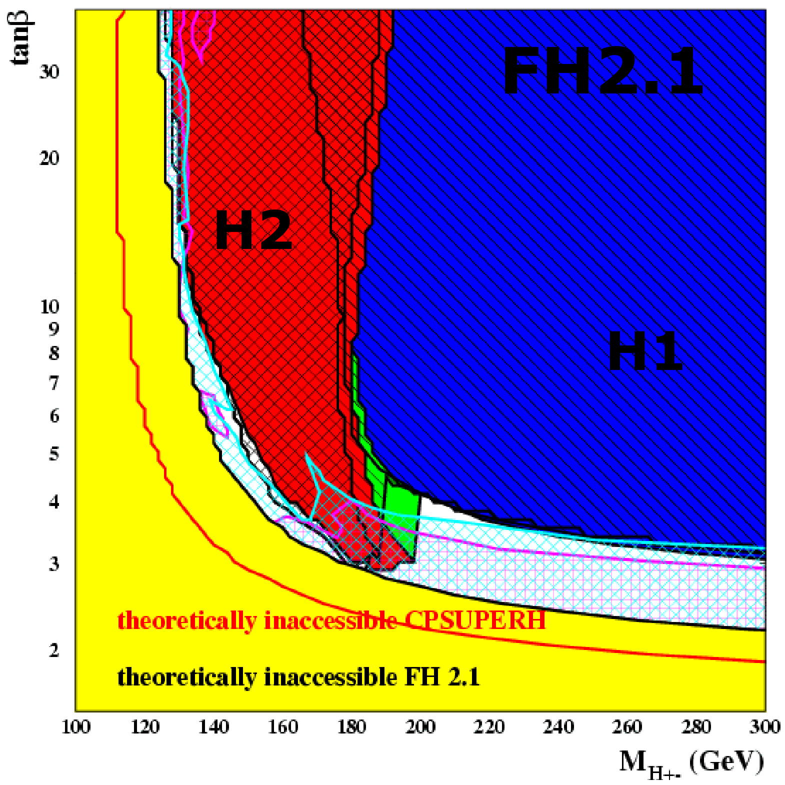


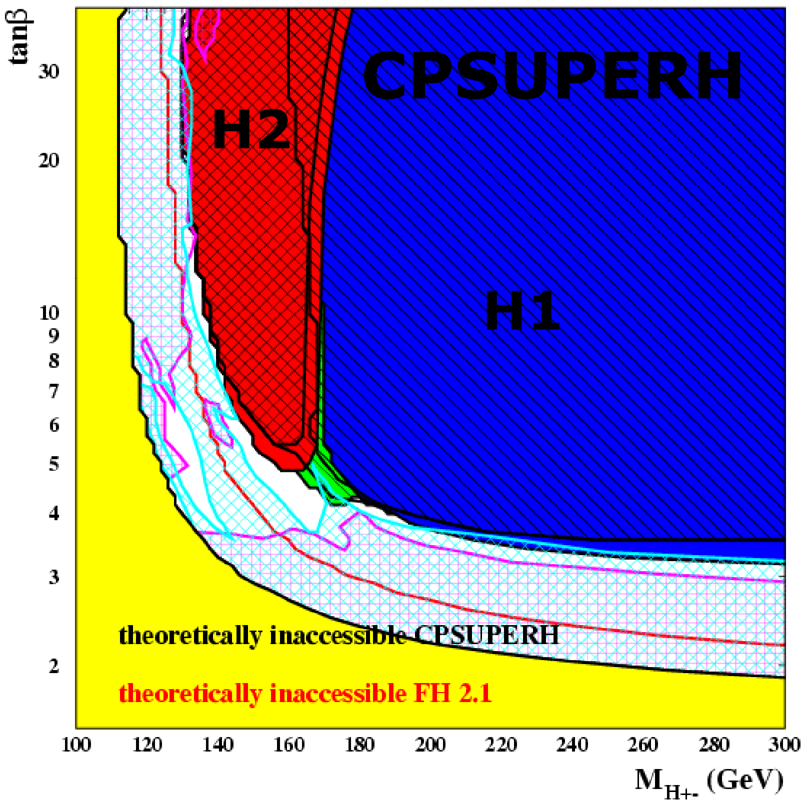
„Smaller" difference

in covered region!

+ significant difference
in theoretically
allowed region

Discovery potential: VBF with H1/2→ττ





M_t=178GeV

M_t=175GeV

LEP excl. M_t=179.3GeV

LEP excl. M_t=174.3GeV

Also difference due to change in M_t

Experimental Issues

- **LHC: pp collisions at 14 TeV starting in 2007**

  first years low lumi. running: > 10 fb^{-1}/yr

  then high lumi. running: 100 fb-1/yr
  → 20 overlapping events per bunch crossing

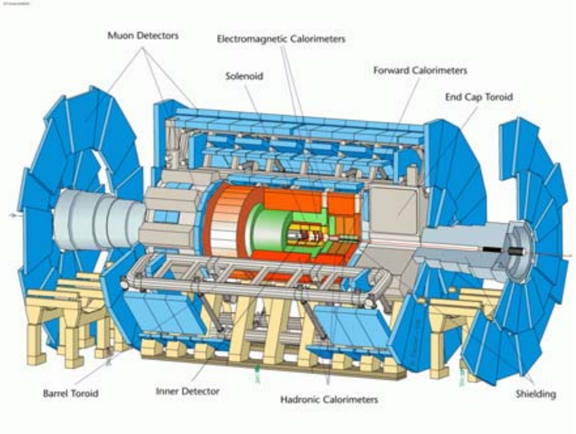
- **key performance numbers**

  obtained from full simulation:

  e.g. efficiencies for trigger,

  b-tag, τ-id, lepton id. and isolation

  forward jets, mass resolutions ....



- **efficiencies and background expectations from fast simulations**

  (complete analysis with full detector simulation on the way!)

- corrections due to larger total decay width taken into account
- signal overlap/ mass degeneracy of Higgs bosons considered
- discovery = 5 sigma excess using Poissonian statistics
- no systematic uncertainties considered for discovery potential

Experimental Inputs From

channel	lumi	Mass range	Publication
VBF, H→$\tau\tau$,WW,$\gamma\gamma$	low	M>110 GeV	SN-ATLAS-2003-024
ttH, H→bb	low+high	M>70GeV	ATL-PHYS-2003-003
bbH/A→$\mu\mu$	low+high	70<M<135GeV M> 120 GeV	ATL-PHYS-2002-021 ATL-PHYS-2000-005
bbH/A→$\tau\tau$: $\tau\tau$→lep.had $\tau\tau$→had. Had	low low	M>120GeV M > 450 GeV	ATL-PHYS-2000-001 ATL-PHYS-2003-008 ATL-PHYS-2003-008
gb→tH+-, H→$\tau\nu$,tb	low+high	M >180 GeV	SN-ATLAS-2002-017
tt→bW bH+-, H+-→$\tau\nu$	low	M < 170 GeV	ATL-PHYS-2003-58
H/A→$\tau\tau$	low+high	M > 350 GeV	TDR
A→Zh→llbb, H→hh→$\gamma\gamma$bb	low+high	60 <ML<130 100<MH<360	TDR TDR
H→$\gamma\gamma$	low+high	M > 70 GeV	TDR
ZZ→4l	low+high	M > 100 GeV	TDR
WW→lνlν	low+high	140<M <120GEV	TDR
WH→lνbb	low	70<M<130GeV	TDR

Discovery potential in vincinity of „Hole“