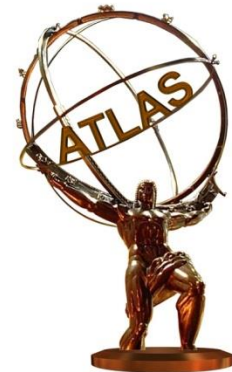


News on Exclusive Production of the MSSM Higgs bosons



Marek Taševský

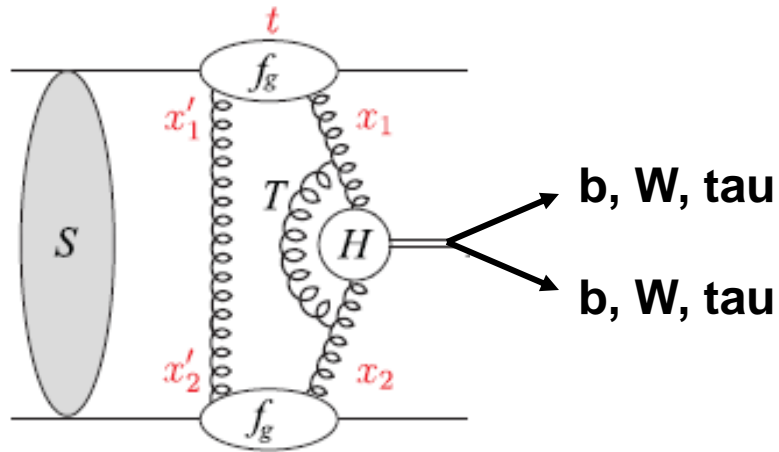
Institute of Physics, Academy of Sciences, Prague

(in collaboration with S. Heinemeyer, V. Khoze and G. Weiglein)

Low-x workshop 2013, Eilat, Israel - 02/06 2013

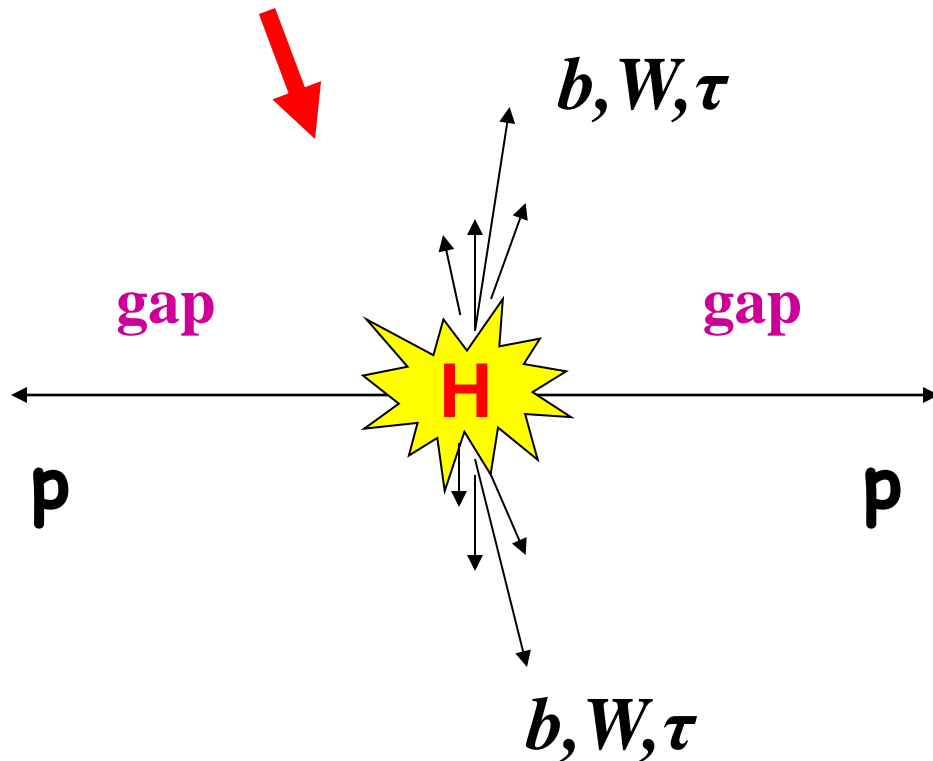
LHC Higgs observation and MSSM exclusion bounds from all LHC data
New MSSM benchmark scenarios

Central Exclusive Diffraction: Higgs production



1) Protons remain undestroyed, escape undetected by central detector and can be detected in forward detectors

2) Rapidity gaps between leading protons and Higgs decay products



x-section predicted with uncertainty of 3 or more

Huge contribution by KMR group
(but see also Cudell et al.
Pasechnik & Szczurek, Forshaw & Coughlin)

bb: at 120 GeV needs a special diffractive trigger

WW: promising for $M > 130$ GeV
use leptonic triggers

$\tau\tau$: interesting around 100 GeV
under study

Central Exclusive Diffraction: Higgs production

Advantages:

- I) Forward proton detectors give much better mass resolution than the central detector
- II) $J_z = 0$, C-even, P-even selection rule:
 - strong suppression of CED $gg \rightarrow bb$ background (by $(m_b/M_H)^2$)
 - produced central system is dominantly $0^{++} \rightarrow$ **just a few events are enough to determine Higgs quantum numbers.** Standard searches need high stat. (ϕ -angle correlation of jets in VBF of Higgs) and coupling to Vector Bosons
- III) Access to main Higgs decay modes in one (CED) process: bb , WW , $\tau\tau$
 - ↓
 - information about Yukawa coupling (Hbb difficult in standard searches due to huge bg.)**
- IV) In MSSM, CED Higgs process give very important information on the Higgs sector.
- V) Correlations between outgoing proton momenta provide a unique possibility to hunt for CP-violation effects in the Higgs sector.

Find a CED resonance and you have confirmed its quantum numbers!!

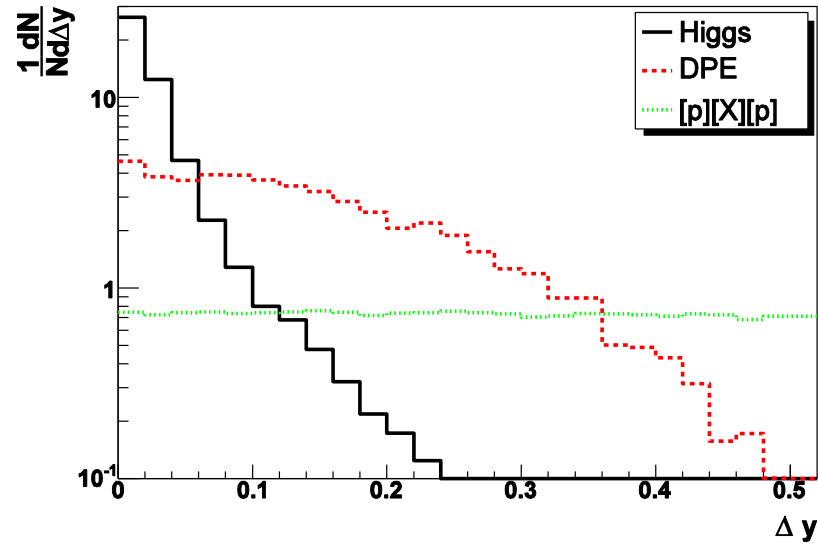
Disadvantages:

- Low signal x-section (but large S/B)
- Large Pile-up

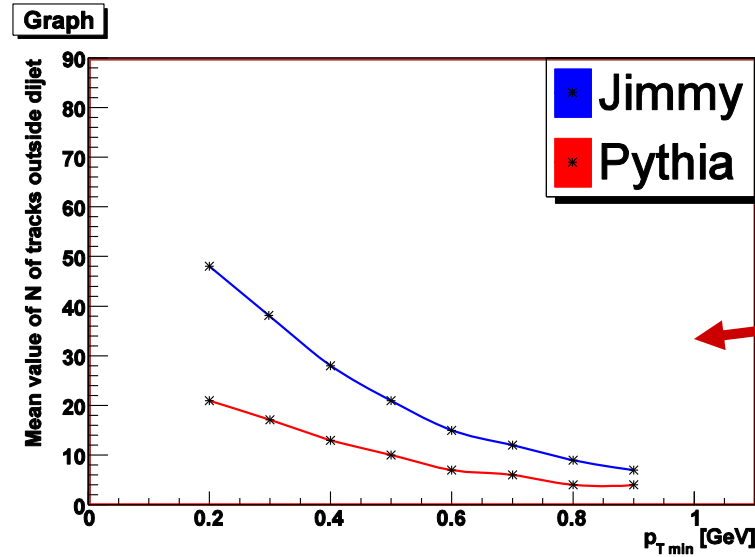
Experimental analysis strategy for $H \rightarrow b\bar{b}$

- 1) **Proton detection:** in Forward proton taggers at 220m and 420m
- 2) **jets:** two b-tagged jets: $E_{T1} > 45 \text{ GeV}$, $E_{T2} > 30 \text{ GeV}$, $|\eta_{1,2}| < 2.5$, $3.0 < |\varphi_1 - \varphi_2| < 3.3$
- 3) **Exclusivity cuts:** $0.75 < R_j < 1.2$, $|\Delta y| < 0.1$
- 4) **L1 triggers** (not included in CMS+Totem analysis):
 - 420+220:** J20J40 + FD220 + $\eta < 0.5 + |\Delta\eta| < 2 + f_T > 0.45 \rightarrow$ special diffractive trigger
 - 420+420:** J20J40 + $\eta < 0.5 + |\Delta\eta| < 2 + f_T > 0.45 \rightarrow$ FD420 cannot be included in L1
- 5) **Mass windows:** $117.6 < M_{420} < 122.4$,
 $114.2 < M_{420+220} < 125.8$ (3σ – windows)
- 6) **Pile-up combinatorial bg suppressors:**
Few tracks outside the dijet
reduction factor ~ 20 from fast timing detector

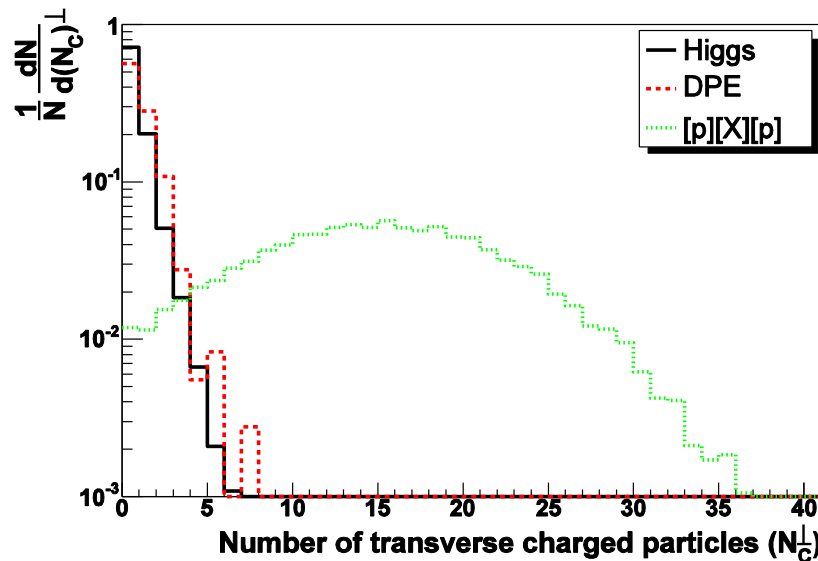
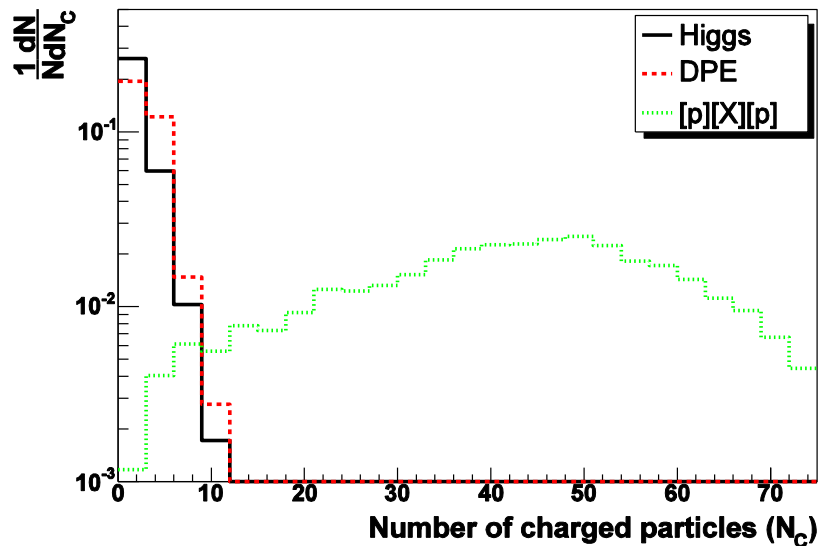
PU background suppressors



$$\Delta y = (\eta_{\text{jet1}} + \eta_{\text{jet2}}) / 2 - y_X$$



This difference has big impact on PU-bg rejection



Summary on exclusive SM Higgs

M_H [GeV]	σ (bb) [fb]	σ (WW*) [fb]	Acc (420+420)	Acc(420+220)
120	1.9	0.37	0.20	0.17
130		0.70	0.15	0.24
140	0.6	0.87	0.11	0.31
160	0.045	1.10	0.04	0.43
180	0.0042	0.76	0.01	0.53

AFP 220/420:
2.5mm/4mm
from the beam
(1mm dead space)

Cross-sections
by KMR group

Experimental analyses:

CMS:

$H \rightarrow bb$: fast simulation, $100 < M_H < 300$ GeV, $d_{220} \sim 1.5$ mm, $d_{420} \sim 4.5$ mm, $Acc = Acc(\xi, t, \phi)$

- published in CMS-Totem document **CERN/LHCC 2006-039/G-124**
- signal selection efficiencies used in MSSM study
(EPJC 53 (2008) 231, EPJC 71 (2011) 1649)

ATLAS:

$H \rightarrow bb$: 1) gen.level + smearing of basic quantities, $M_H = 120$ GeV

- one MSSM point ($\tan\beta = 40$): JHEP 0710 (2007)090

2) fast simulation, $M_H = 120$ GeV: ATL-COM-PHYS-2010-337

3) Dedicated L1 trigger for $H \rightarrow bb$: ATL-DAQ-PUB-2009-006

All analyses on $H \rightarrow bb$ get very similar yields for signal and background

$H \rightarrow WW$: fast + full simulation, $M_H = 160$ GeV:

ATL-COM-PHYS-2010-337

Due to stringent cuts to suppress PU bg, experimental efficiencies for SM Higgs and hence significances are modest. **Try MSSM !**

Efficiencies for SM $H \rightarrow bb$ (CMS+Totem)

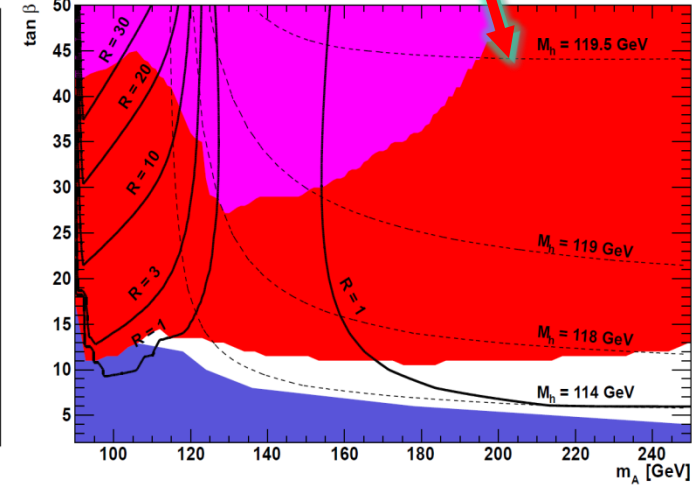
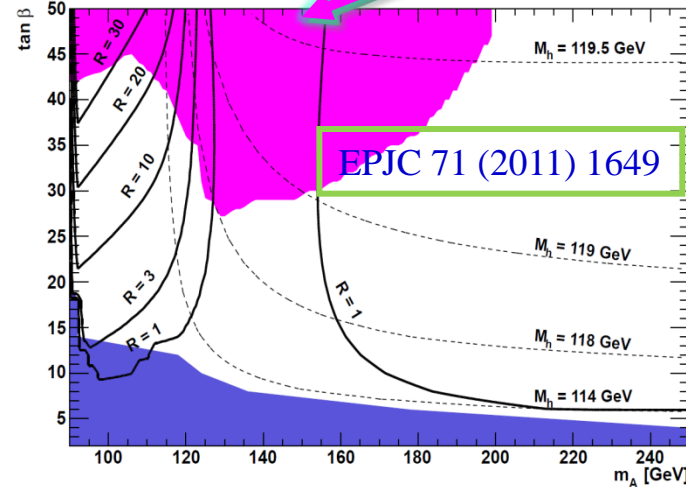
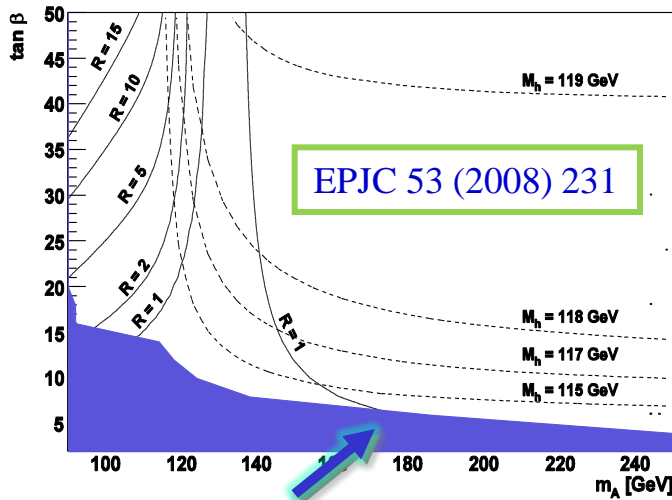
M_H [GeV]	Acc ₄₂₀	Acc _{comb}	Acc ₂₂₀	ϵ_{420}	ϵ_{comb}	ϵ_{220}
100	0.37	0.13	0.0	0.012	0.008	0.0
120	0.31	0.25	0.0	0.017	0.025	0.0
140	0.25	0.37	0.0	0.016	0.051	0.0
160	0.19	0.49	0.0	0.015	0.076	0.0
180	0.14	0.60	0.0	0.012	0.096	0.0
200	0.09	0.69	0.0	0.004	0.11	0.0
300	0.0	0.76	0.13	0.0	0.125	0.02

Ratios $R = \text{MSSM}[M, \tan\beta] / \text{SM}[M]$

$h \rightarrow bb$, nomix, $\mu = 200$ GeV

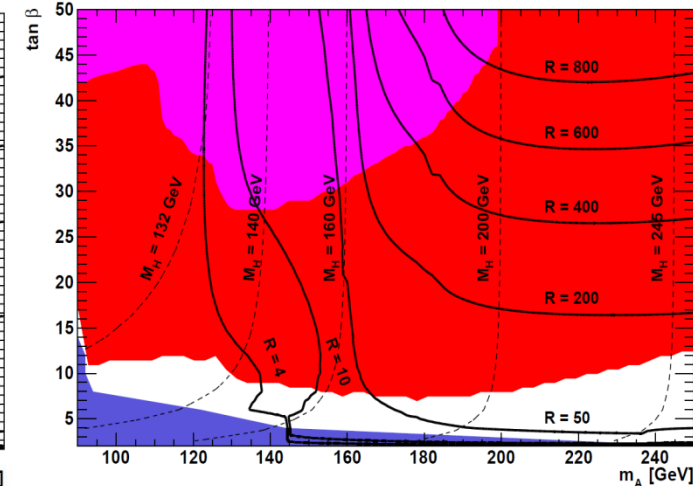
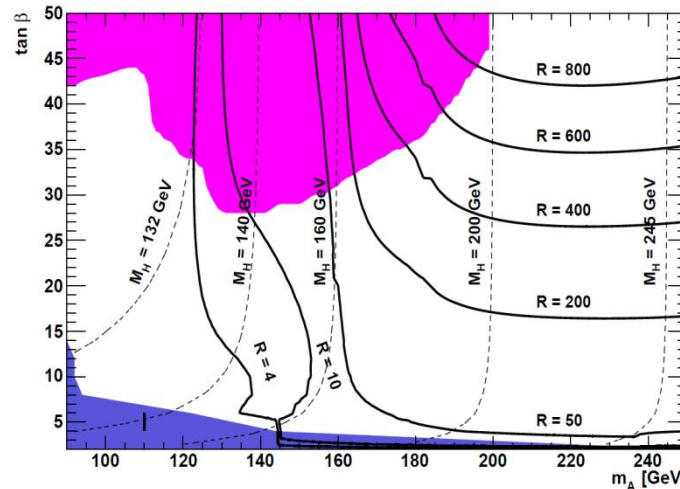
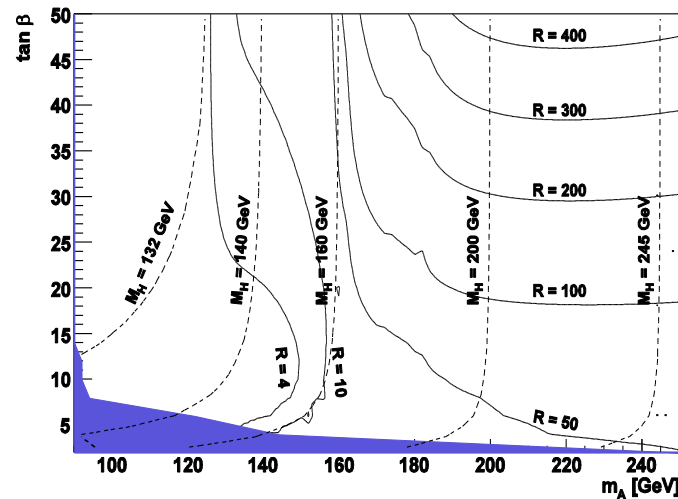
Tevatron exclusion region

LHC exclusion region



LEP exclusion region

$H \rightarrow bb$, $m_{H\max}$, $\mu = 200$ GeV

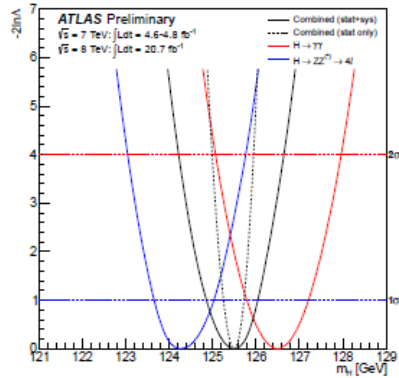


Nature of discovered Higgs boson

Summary of LHC Higgs searches
by M.P.Sanders at DIS2013

All 2011 and 2012
data analyzed

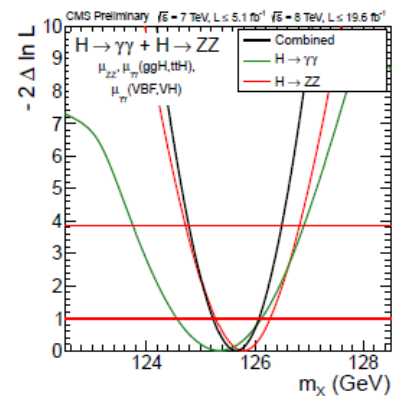
Higgs Boson Mass



ATLAS, $H \rightarrow 4l/\gamma\gamma$ combination

$$m_H = 125.5 \pm 0.2(\text{stat})^{+0.5}_{-0.6}(\text{sys}) \text{ GeV}$$

$$\Delta m_H = 2.3^{+0.6}_{-0.7}(\text{stat}) \pm 0.6(\text{sys}) \text{ GeV} [2.5\sigma]$$

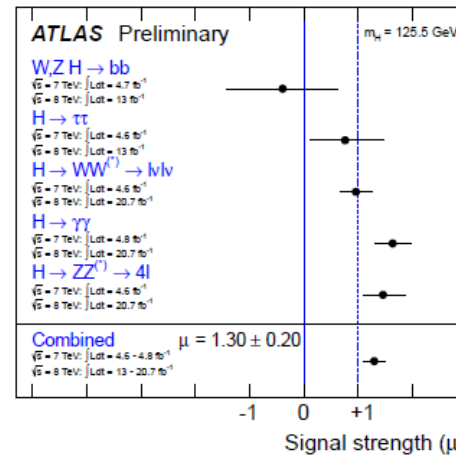


CMS, $H \rightarrow 4l/\gamma\gamma$ combination

$$m_H = 125.7 \pm 0.3(\text{stat}) \pm 0.3(\text{sys}) \text{ GeV}$$

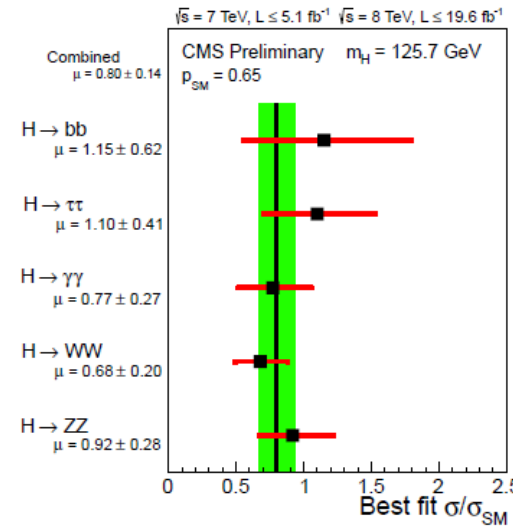
Higgs Signal Strength

ATLAS combination



$$\mu = 1.30 \pm 0.20$$

CMS combination



$$\mu = 0.80 \pm 0.14$$

⇒ Consistent with standard model Higgs

Nature of discovered Higgs boson

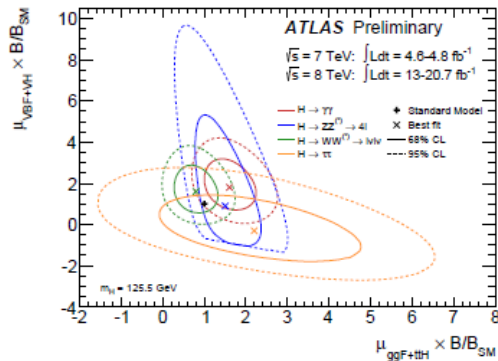
Summary of LHC Higgs searches
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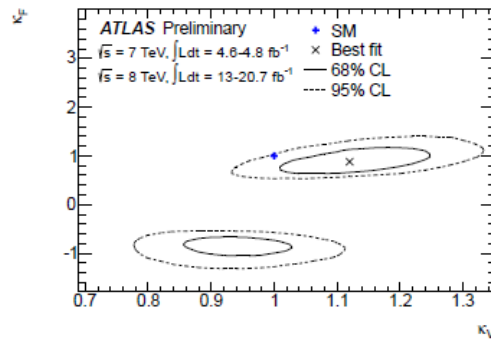
Higgs Couplings (ATLAS)

Spin/Parity Combination (ATLAS)

Probe production modes with
boson and fermion couplings



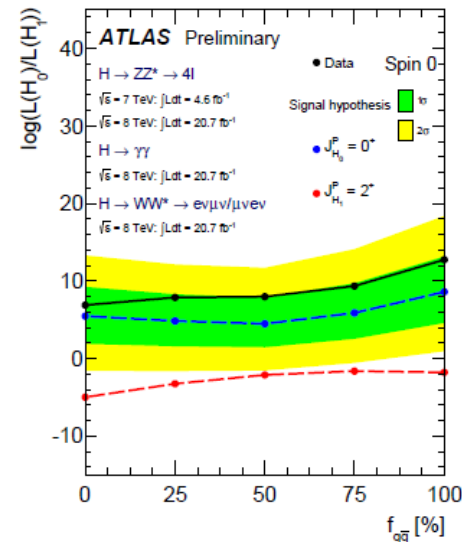
Determine scale factors κ
for HVV and Hff couplings



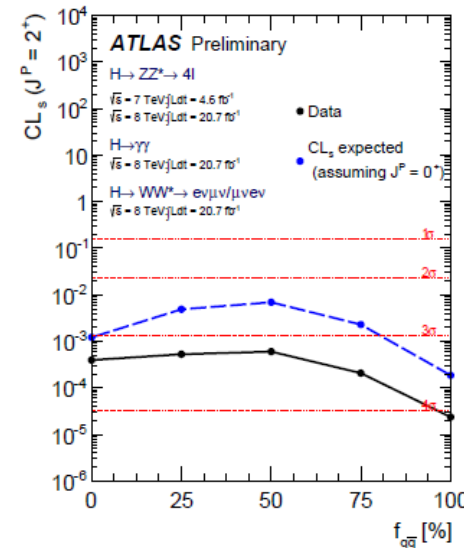
⇒ Consistent with SM Higgs

Similar results from CMS

Test $J^P = 0^+$ vs 2_m^+ with $H \rightarrow \gamma\gamma$, $H \rightarrow l\nu l' \nu'$, $H \rightarrow 4l$



⇒ $J^P = 2_m^+$ excluded at $> 99.9\%$ CL



New MSSM benchmark scenarios

- M. Carena, S. Heinemeyer, O. Stal, C. Wagner, G. Weiglein: 1302.7033

The well-known benchmark scenarios Mhmax, nomixing, small α_{eff} and gluophobic Higgs used in the past do not permit the interpretation of the observed Higgs signal at ~ 125.5 GeV in as the light CP-even Higgs boson of MSSM.

New low-energy MSSM scenarios that are compatible with the mass and production rates of the observed Higgs boson signal at ~ 125.5 GeV:

1. **Mhmax:** mass of the light CP-even Higgs boson is maximized for fixed $\tan \beta$ and large M_A
2. **Mhmod+:** modified Mhmax: reduces the mixing in the stop sector compared to the value that maximizes M_h
3. **Mhmod-:** similar to Mhmod+
4. **Lightstop:** suppression of the lightest CP-even Higgs gluon fusion rate
5. **Lightstau:** enhanced decay rate of $h \rightarrow \gamma\gamma$ at large $\tan \beta$
6. **Tauphobic:** the lightest Higgs has suppressed couplings to down-type fermions
7. **LowMh:** fixes the value of M_A (=110 GeV) and varies μ

Light Higgs ~ SM-like

1-6: the discovered Higgs is the CP-even lightest Higgs; look for the heavy partner

7: the discovered Higgs is the CP-even heavy Higgs; look for the lighter partner

The LHC exclusion regions inferred from analyses searching for MSSM Higgs bosons:

using HiggsBounds

$[\varphi=h,H,A]$: 1) $pp \rightarrow \varphi \rightarrow \tau^+\tau^-$ (inclusive); $bb^-\varphi, \varphi \rightarrow \tau^+\tau^-$ (with b-tag); 2) $bb^-\varphi, \varphi \rightarrow bb^-$ (with b-tag),
 $pp \rightarrow tt^- \rightarrow H^{+-}W^{\mp}bb^-, H^{+-} \rightarrow \tau\nu_\tau, gb \rightarrow H^-t$ or $gb^- \rightarrow H^+t^-, H^{+-} \rightarrow \tau\nu_\tau$

Strategy

- 1) Try out all scenarios. Look only at $h/H \rightarrow bb^-$
- 2) Look at MSSM CED cross sections: Take the KMR formula for production of SM Higgs in Central exclusive processes and use MSSM partial widths and branching fractions for $h/H \rightarrow bb^-$
- 3) Calculate cross sections of background processes.
- 4) Plot signal cross sections and signal/background ratios in tables $M_A - \tan\beta$
- 5) Where not hopeless, look also at statistical significances. For that we need experimental acceptances and efficiencies.
- 6) Compare with the region of the observed Higgs signal (125.5 GeV \pm 3 GeV) and with the LHC exclusion regions.

The whole procedure described in more detail in EPJ C53 (2008) 231 and EPJ C71 (2011) 1649.

Signal and Background calculation

Take the experimental efficiencies ϵ and calculate

Signal processes: use approximate formula

$$\sigma^{\text{excl}} = 3\text{fb} * \left(\frac{136}{16+m}\right)^{3.3} \left(\frac{120}{m}\right)^3 \cdot \frac{\Gamma(h/H \rightarrow gg)}{0.25 \text{ MeV}} \cdot \frac{\text{BR}^{\text{MSSM}}}{\text{BR}^{\text{SM}}} * \epsilon$$

$\Gamma(h/H \rightarrow gg)$, BR^{MSSM} , BR^{SM} evaluated with *FeynHiggs* [T. Hahn, S. Heinemeyer, W. Hollik, H. Rzehak, G. Weiglein] (1998-2010)

Background for $h, H \rightarrow b\bar{b}$ obtained from

$$\sigma_B \approx 2\text{fb} \left[\frac{3}{4} \frac{\Delta M}{(4 \text{ GeV})} \left(\frac{120}{M}\right)^6 + \frac{1}{4} \frac{\Delta M}{(4 \text{ GeV})} \left(\frac{120}{M}\right)^8 C_{\text{NLO}} \right] * \epsilon$$

Backgrounds intensively studied by KMR group:

[DeRoeck, Orava+KMR, EPJC 25 (2002) 392, EPJC 53 (2008) 231]

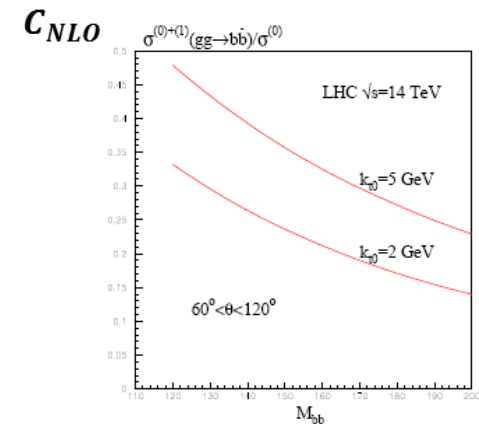
- 1) Admixture of $|J_z|=2$ production
- 2) NLO $gg \rightarrow bbg$, large-angle hard gluon emission
- 3) LO $gg \rightarrow gg$, g can be misidentified as b
- 4) b -quark mass effects in dijet processes, HO radiative corrections

b -jet angular cut applied: $60^\circ < \theta < 120^\circ$ ($|\Delta\eta_{\text{jet}}| < 1.1$) $P(g/b) \sim 1.3\%$ (ATLAS)

Four major bg sources: $\sim (1/4 + 1/4 + 1.3^2/4 + 1/4)$ fb at $M_h = 120$ GeV, $\Delta M = 4$ GeV

Pile-up background is heavily reduced after applying stringent cuts.

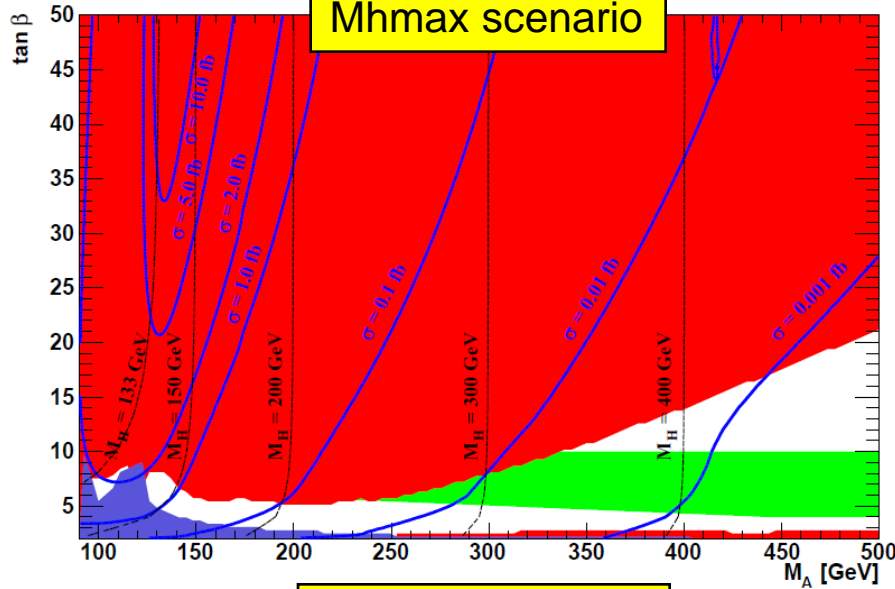
Remaining Pile-up bg considered to be negligible.



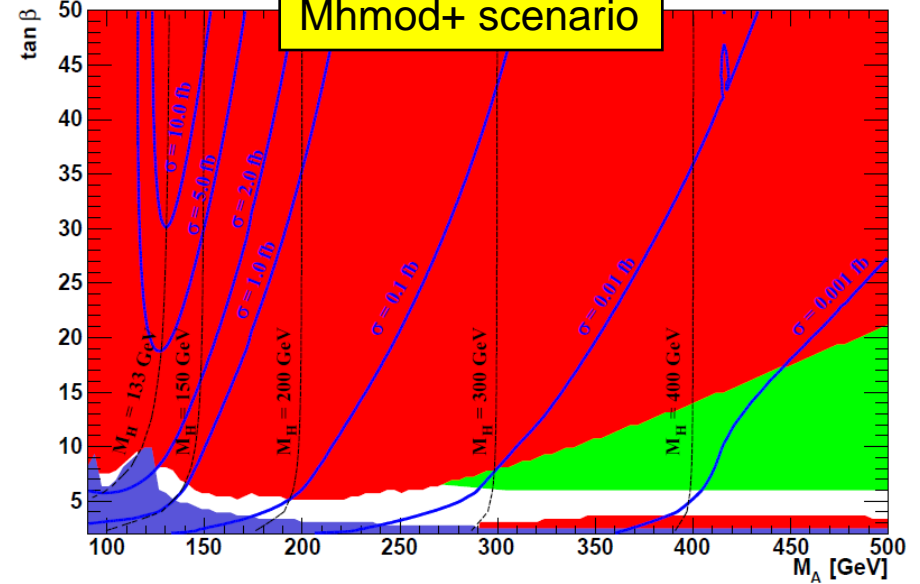
The mass dependence of the ration of the NLO exclusive $b\bar{b}$ cross section to that calculated in Born approximation.

CED $H \rightarrow bb$ signal x-sections

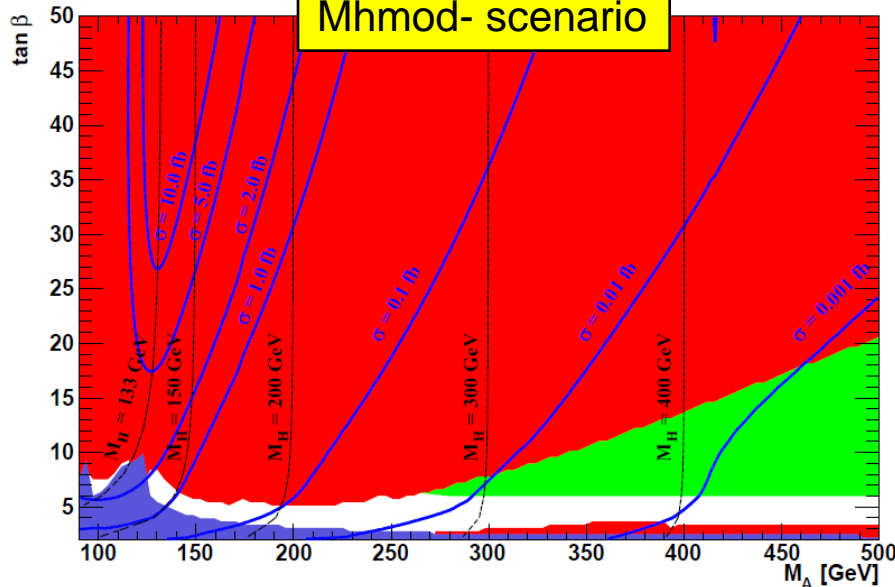
Mhmax scenario



Mhmod+ scenario



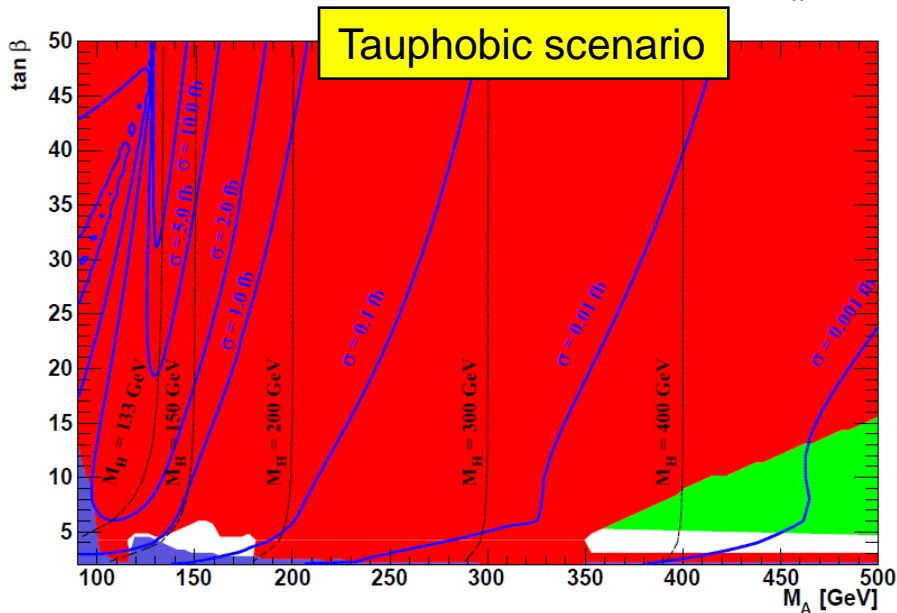
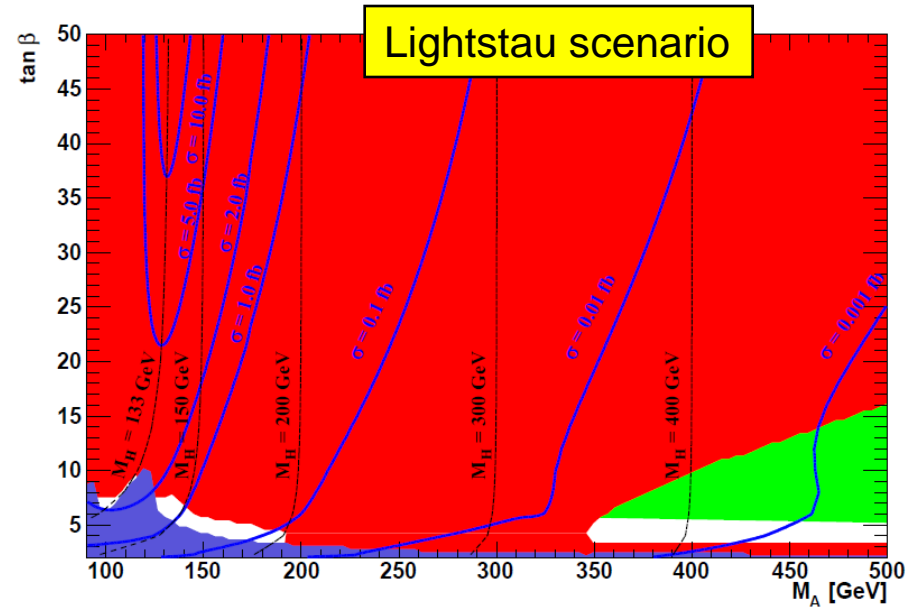
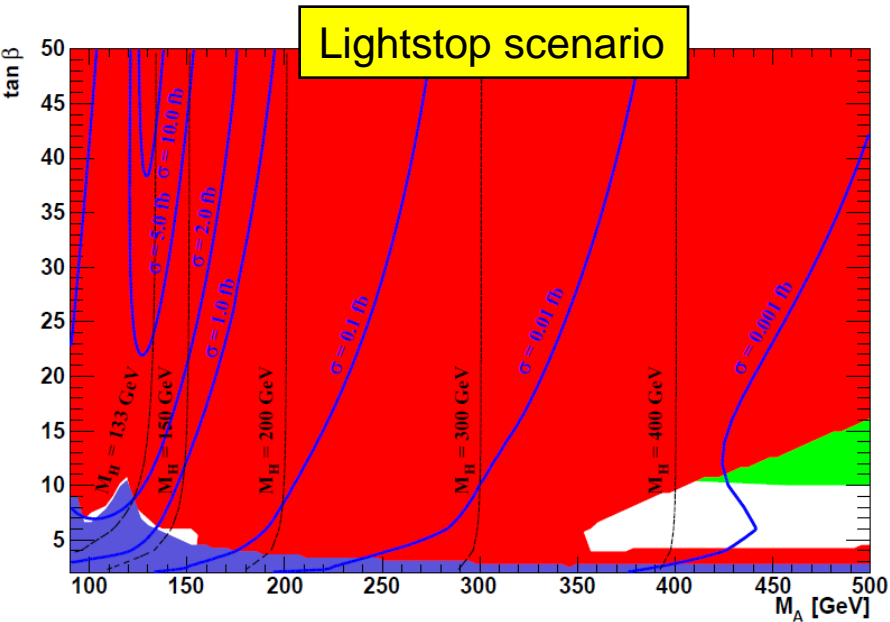
Mhmod- scenario



- $122.5 < M_h < 128.5$ GeV
- LHC exclusion regions
- LEP exclusion regions

$M_h \sim 125.5 \pm 3$ GeV (theory + exper. uncert.)
 Cross-sections come from KMR calculations.
 They still need to be multiplied by experim. efficiencies ($\sim 10\%$) to get significances.
Signal yields in the allowed region are tiny.

CED $H \rightarrow bb$ signal x-sections

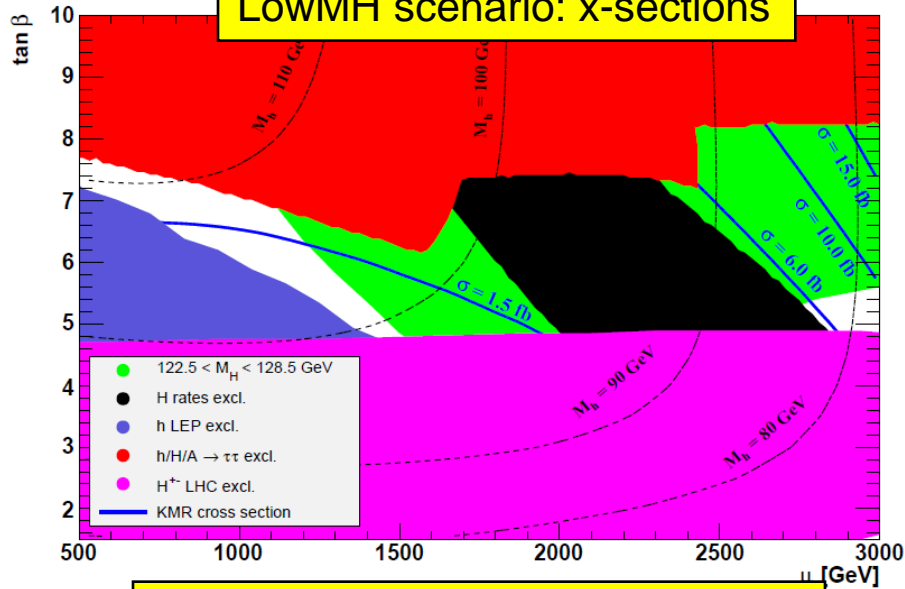


- $122.5 < M_h < 128.5$ GeV
- LHC exclusion regions
- LEP exclusion regions

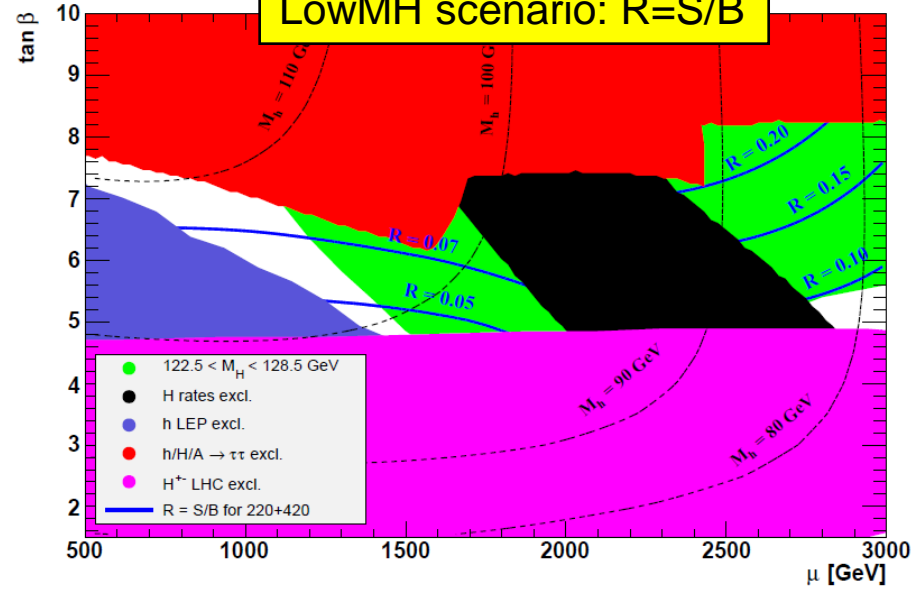
$M_h \sim 125.5 \pm 3$ GeV (theory + exper. uncert.)
 Cross-sections come from KMR calculations.
 They still need to be multiplied by experim. efficiencies ($\sim 10\%$) to get significances.
Signal yields in the allowed region are tiny.

CED $h \rightarrow bb$ at LowMH scenario

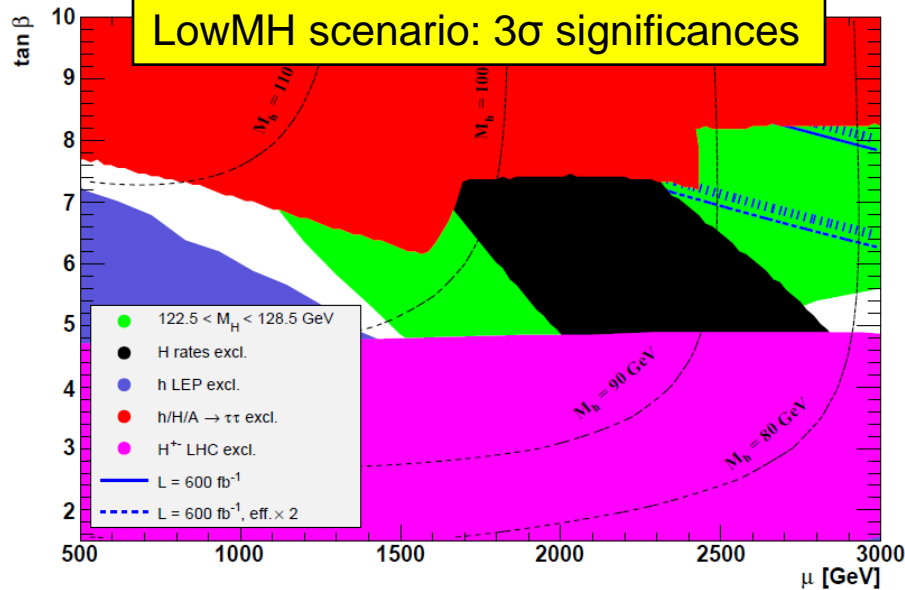
LowMH scenario: x-sections



LowMH scenario: $R=S/B$



LowMH scenario: 3σ significances

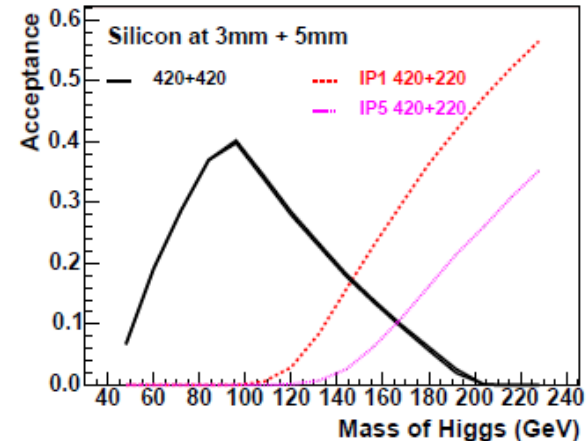
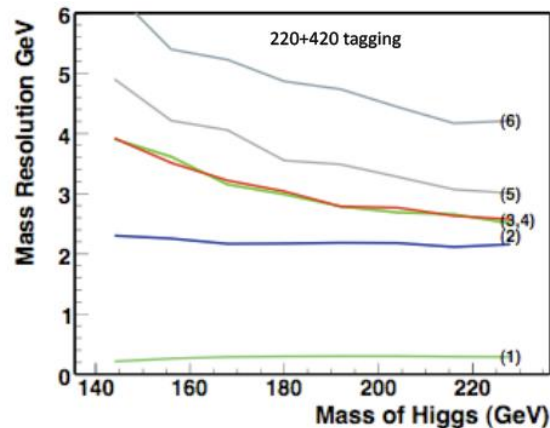
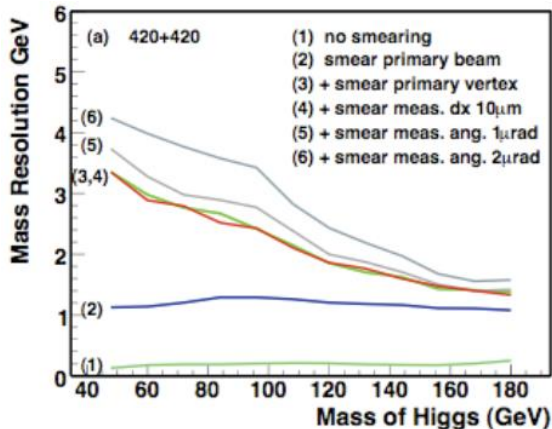


- $122.5 < M_h < 128.5$ GeV
- H \rightarrow ZZ, WW rates exclusion
- h LEP exclusion
- h/H/A $\rightarrow \tau\tau$ exclusion
- H^{+-} LHC exclusion

$M_h \sim 125.5 \pm 3$ GeV (theory + exper. uncert.)
 Ratios and significances include the experim. efficiencies
Signal yields are descent here.

LowMH considerations

- ❑ Ratios S/B and 3σ -significances include the experimental efficiencies.
- ❑ 3σ is reachable only for large integrated luminosity ($\sim 1000 fb^{-1}$). This means we need to combine data from both CMS and ATLAS.
- ❑ In this scenario, the Higgs boson found at $M_H \sim 125.5$ GeV is the heavy one; we need to search for the lighter one \rightarrow picture shows the region of interest $M_h \sim 80-90$ GeV.
- ❑ The region of interest $M_h \sim 80-90$ GeV is experimentally difficult:
 1. Only 420+420 configuration relevant
 2. 420m station can hardly be put into L1 trigger (at least in ATLAS)
 3. Slightly worse missing mass resolution than for higher masses
 4. Worse situation also in the central detector (L1 triggers highly prescaled, Pile-up issue)



Summary

CED Higgs production has a great potential compared to the standard LHC searches:

- excellent mass resolution
- good S/B
- complementary information about the Higgs sector in MSSM
- complementary information about quantum numbers (a few events are enough and no need for coupling to vector bosons)
- information about CP-violation effects
- information about Yukawa Hbb coupling

7 new MSSM benchmark scenarios tried out: only lowMH scenario looks promising for CED Higgs.

- This scenario is reachable only using 420+420 because the mass of the searched object is low ($80 < M_h < 90$ GeV). Big demands on experimental procedure (e.g. L1 trigger).
- AFP/HPS may be the unique way to reach such low-mass Higgs or it may confirm what ATLAS and CMS have already found there.

1) Allowed MSSM phase space is very limited. LHC analyses show that the discovered Higgs is more and more SM like. Event yield for the exclusive SM Higgs is low but can be perhaps increased by tuning the selection procedure (we know the mass of Higgs).

2) Whether Higgs is SM or MSSM, the low-mass exclusive Higgs needs stations at 420 m.

3) HPS and Totem consider the 420 stations in their plans (?).

BACKUP SLIDES

MSSM and CED go quite well together

Extended Higgs sectors: “typical” features

Search for heavy MSSM Higgs bosons ($M_A, M_H \gg M_Z$):

Decouple from gauge bosons

⇒ no HVV coupling

⇒ no Higgs production in weak boson fusion

⇒ no decay $H \rightarrow ZZ \rightarrow 4\mu$

Large enhancement of coupling to $b\bar{b}, \tau^+\tau^-$ for high $\tan\beta$

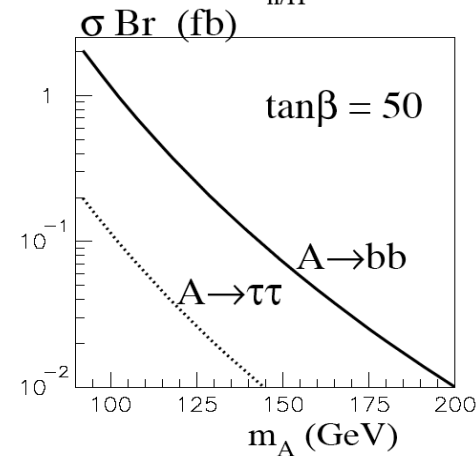
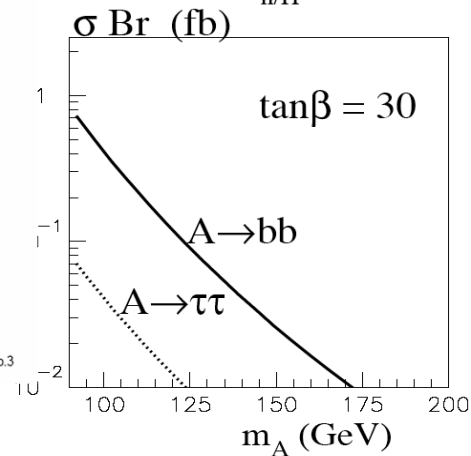
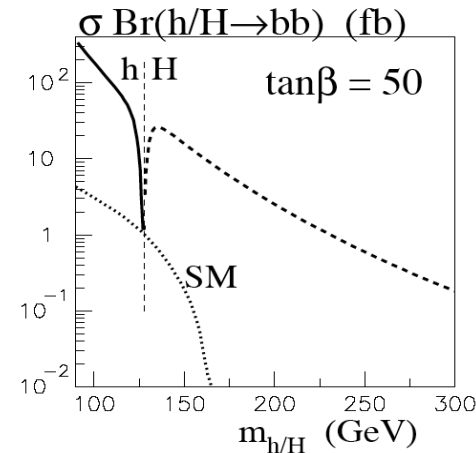
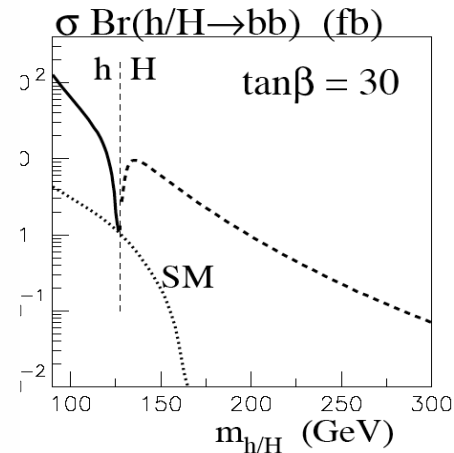
⇒ Decays into $b\bar{b}$ and $\tau^+\tau^-$ play a crucial role

“Typical” features of models with an extended Higgs sector:

- A light Higgs with SM-like properties, couples with about SM-strength to gauge bosons
- Heavy Higgs states that decouple from the gauge bosons

Studying the MSSM Higgs Sector by Forward Proton Tagging at the LHC, Georg Weiglein, EPS07, Manchester, 07/2007 – p.3

Central exclusive diffractive production



[Kaidalov+KMR, EPJC 33 (2004) 261]

Note: low M_A and large $\tan\beta$ now excluded (see next slide)