Status of Exclusive Production of the Higgs bosons at LHC

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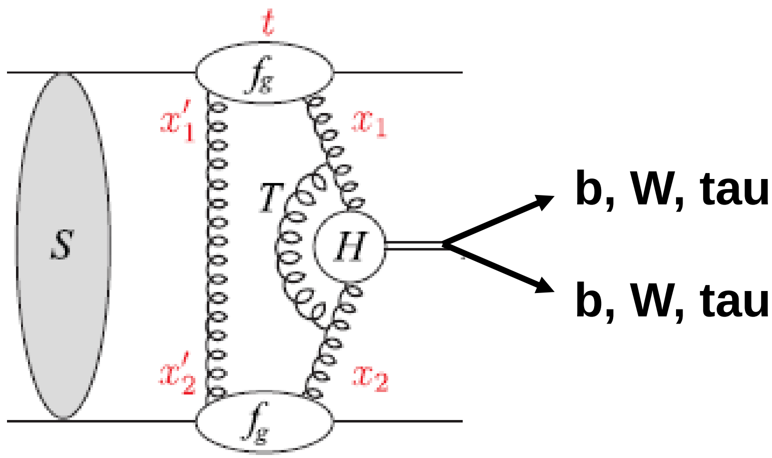
Low-x workshop 2014, Kyoto, Japan - 18/06 2014

LHC Higgs observation and MSSM exclusion bounds from all LHC data

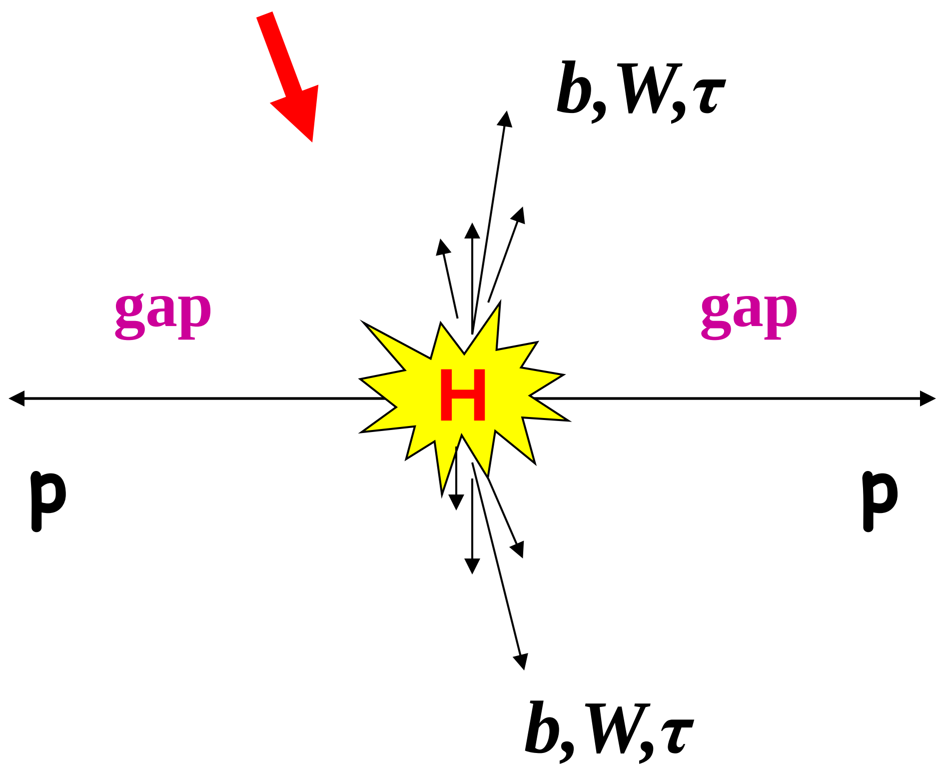
New MSSM benchmark scenarios

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

ττ : interesting around 100 GeV under study

Central Exclusive Production: Higgs

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 CEP $gg \to bb$ background (by $(m_b/M_H)^2$)
- produced central system is dominantly 0^{++} → **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

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

III) Access to main Higgs decay modes in one (CEP) process: bb, WW, tautau

↓

information about Yukawa coupling
(Hbb difficult in standard searches due to huge bg.)

IV) In MSSM, CEP 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.

Disadvantages:

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

with Valery's remarks

Most recent predictions

arXiv:1301.2552

Harland-Lang, Khoze, Ryskin & Stirling: 0.5 to 2 fb
Depending on parton distribution functions. CTEQ6L gives upper value and provides best agreement with CDF di-photon data. $S^2 = 1\%$ and $|y| < 2.5$

arXiv:1011.3653

Cudell, Dechambre, Hernández: 0.3 to 2 fb
'Our predictions are significantly lower than those of KMR'. $S^2 = 5\%$ (?). Gluon constrained by CDF dijet data.

No Sudakov derivative

Ryutin: 0.55 fb
$S^2 = 3\%$.

arXiv:1211.2105

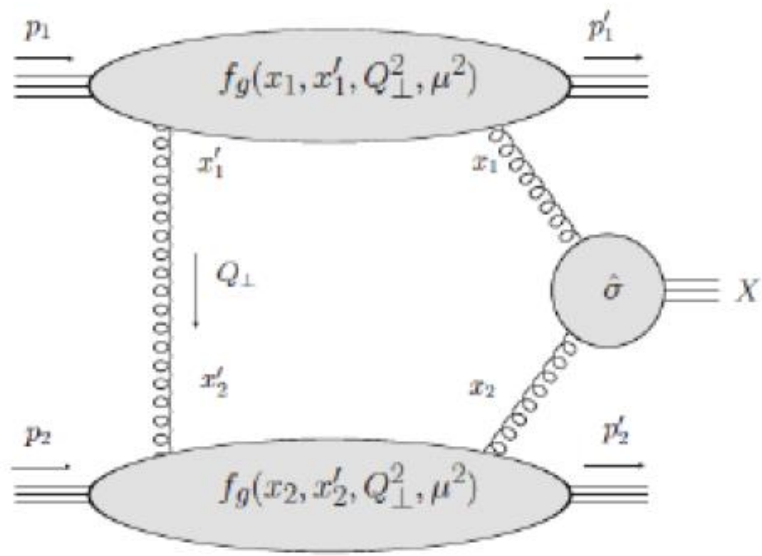
No Sudakov derivative

Maciula, Pasechnik & Szczurek: $0.2 \sim 0.4$ fb
$S^2 = 3\%$.

Higher scale in Sudakov

arXiv:1011.5842

Rg outside



Agreed uncertainty of a factor 3

Jeff Forshaw's Conclusion on Higgs CEP Theory (CERN, 11. 04.2013, CERN) , 2.

with Valery's remarks

1. The pQCD part of the calculation is under "reasonable" control (off-diagonal gluon uncertainty dominates). ?

2. Need a good model of factorization breaking exchanges (a.k.a. gap survival). Central production of other high-mass systems (di-photons & dijets) will really help us to understand it.

   (nowadays GLM and KMR are in a broad agreement on survival)

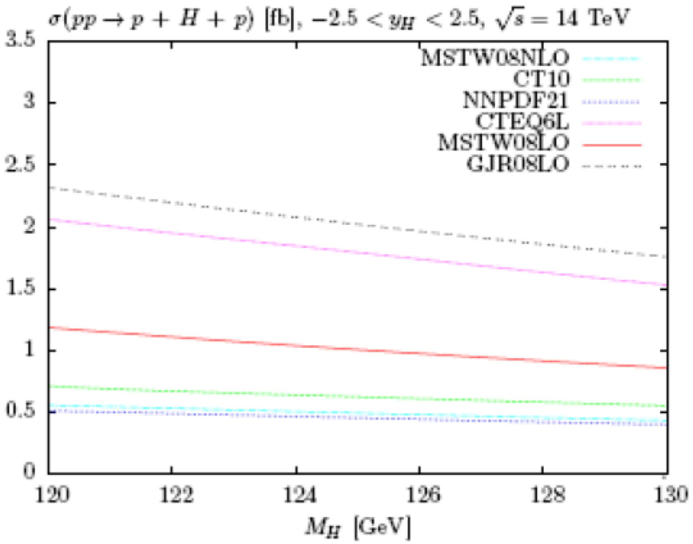
3. Correct treatment of Sudakov and TOTEM data pull cross section down. (taken into account in SuperCHIC)

4. Higher order corrections and CDF data push cross section up. (in progress)

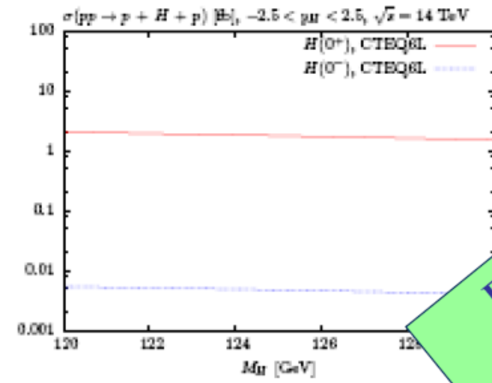
5. Nobody is claiming a cross section above 2 fb.

D'ACCORD

KMR x-section predictions



SuperCHIC



Find a CEP reso
confirmed its

Figure 6: Cross sections for the CEP of scalar $J^P = 0^+$ and pseudoscalar $J^P = 0^-$ particles of the Higgs sector as a function of the Higgs mass, M_H, integrated over the rapidity interval $-2.5 < y_H < 2.5$.

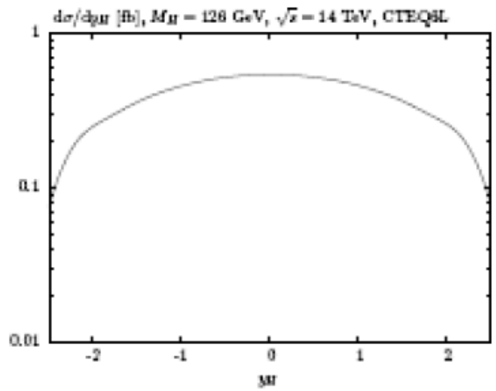
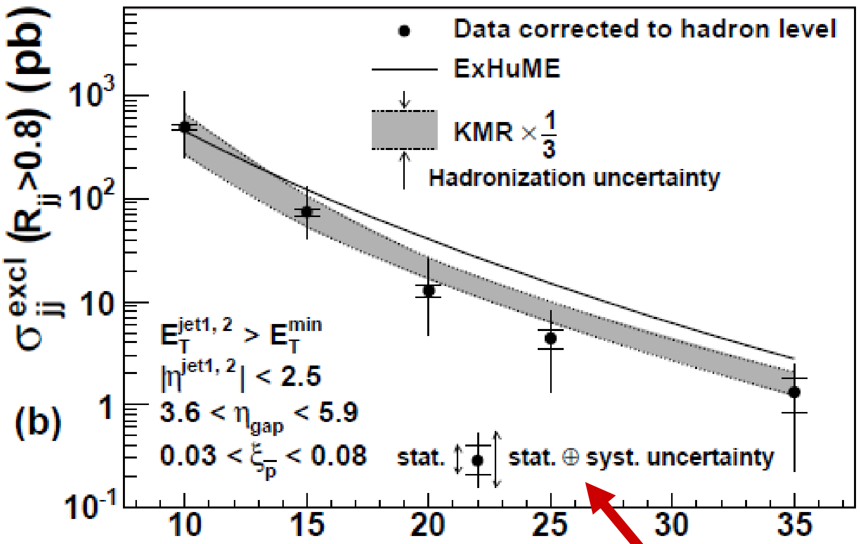
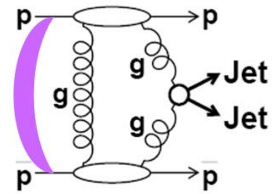


Figure 5: Rapidity distribution $d\sigma/dy_H$ for a $M_H = 126$ GeV SM Higgs boson, using CTEQ6L PDFs.

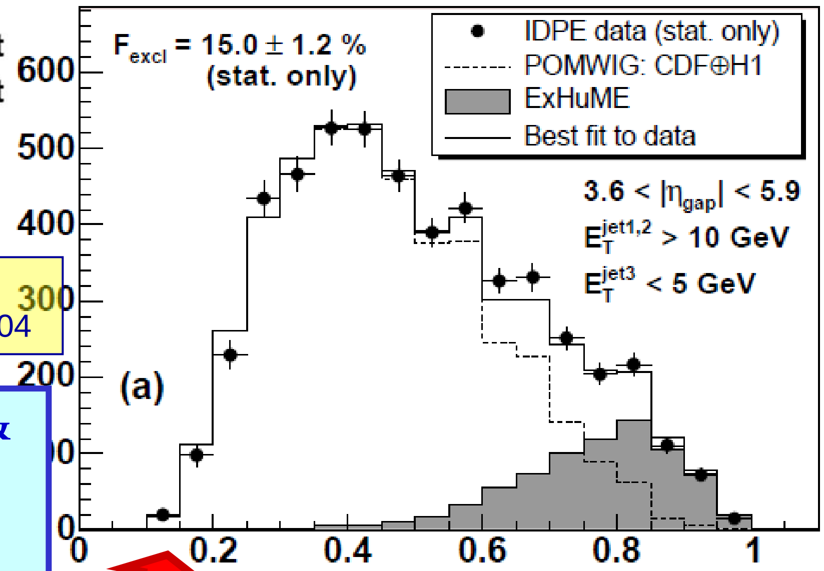
- Cross section $\sim$ fbs, i.e. roughly 4 orders of mag. lower than inclusive case (price paid for exclusivity).
- Uncertainties (Survival factors, higher–order corrections, PDFs) exist in theoretical calculation. But $\gamma\gamma$ CEP cross section tends to lie a little above theory estimates $\to$ favours the higher predictions shown.

Evidence of exclusive dijets at Tevatron





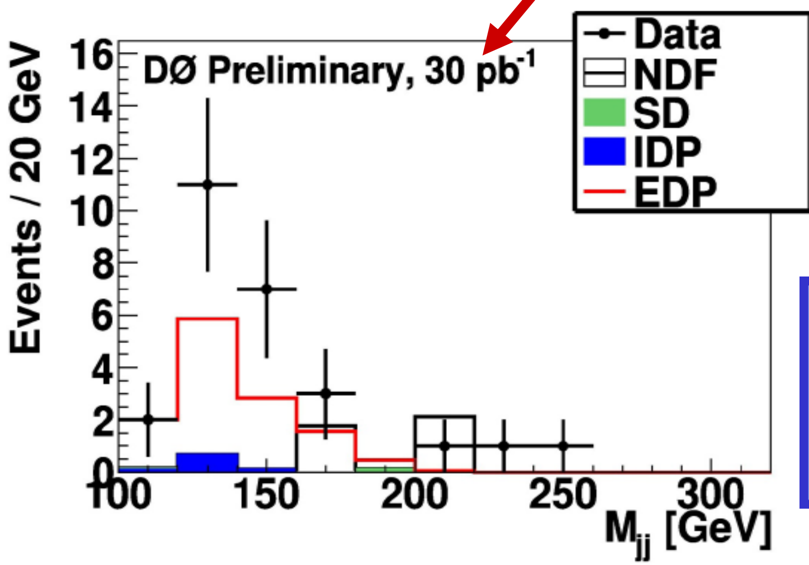
CDF Collaboration
PR D77 (2008) 052004



E_{Tjet} > 10 GeV & R_{JJ} >0.8: CED with significance of 6σ

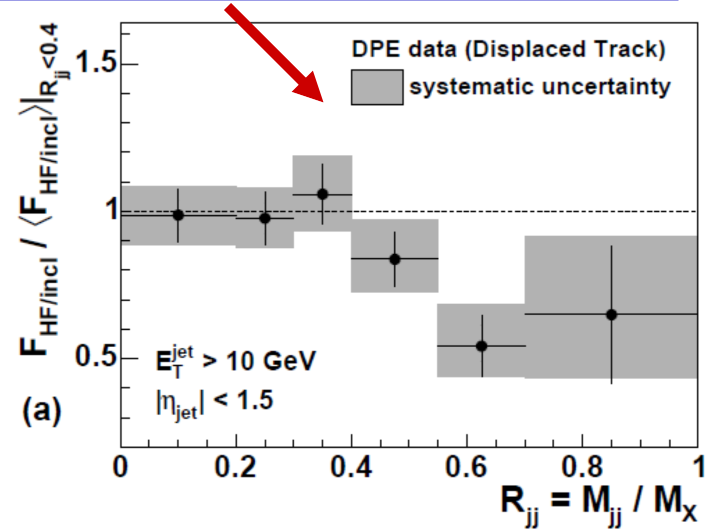
Data consistent with KMR predictions

Suppression of $b\bar{b}$ production as expected



D0 collaboration
PL B705 (2011) 193

M_{JJ} > 100 GeV! & exp(-ΣE_T) > 0.85: CED with significance of 4.1σ



New Durham Studies

(known unknowns)

- Account for the b-dependence of the survival factors $S^2_{\rm enh}$, $S^2_{\rm eik}$ (KMR,GLM-new results)

  (Uri's talk)

- NLO effects in the unintegrated parton densities ↑

  (N)NLO-effects in hard ME.

- A systematic account of self–energy insertions in the propagator of the screening gluon ↑

- The dependence on the gluon PDF is amplified by the fact that the CEP cross section is essentially proportional to $(xg(x))^4$.

  CDF $\gamma\gamma$ data *may* suggest more 'LO–type' PDFs ($\rightarrow$ more optimistic Higgs cross sections) are appropriate. ↑

Improvements of models for soft diffraction: removing tensions with Totem data on $\sigma_{\rm el}$ and $\sigma_{\rm tot}$,
agreement with the LHC results on low mass SD,
agreement with the Tevatron/LHC data on CEP processes
subprogram to SuperCHIC to calculate S² -KHARYS -13

(KMR, arXiv:1306.2149)

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Experimental analysis strategy for H→bb

1) Proton detection: in Forward proton taggers at 220m and 420m

2) jets: two b-tagged jets: $E_{T1} > 45$ GeV, $E_{T2} > 30$ 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 + $\bar{\eta} < 0.5$ + $|\Delta\eta| < 2$ + $f_T > 0.45$ → special diffractive trigger

420+420: J20J40 + $\bar{\eta} < 0.5$ + $|\Delta\eta| < 2$ + $f_T > 0.45$ → FD420 cannot be included in L1

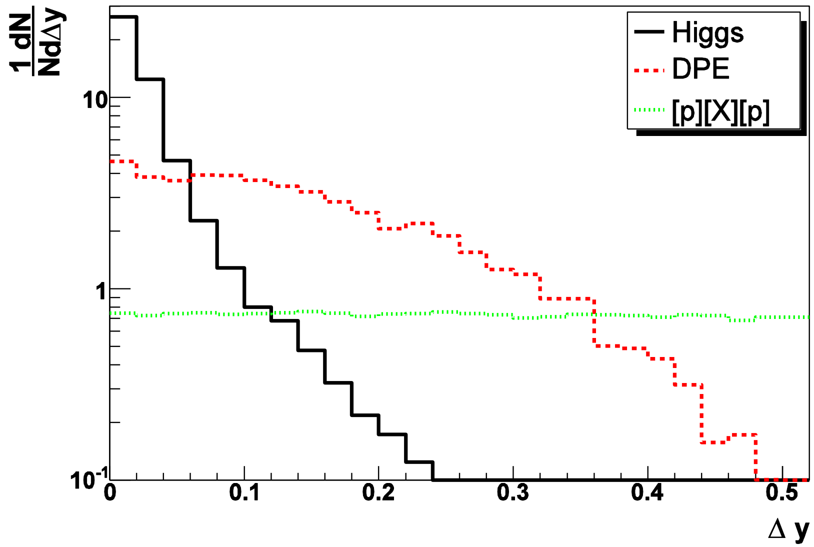
5) Mass windows: $117.6 < M_{420} < 122.4$,
$114.2 < M_{420+220} < 125.8$ (3σ – windows)

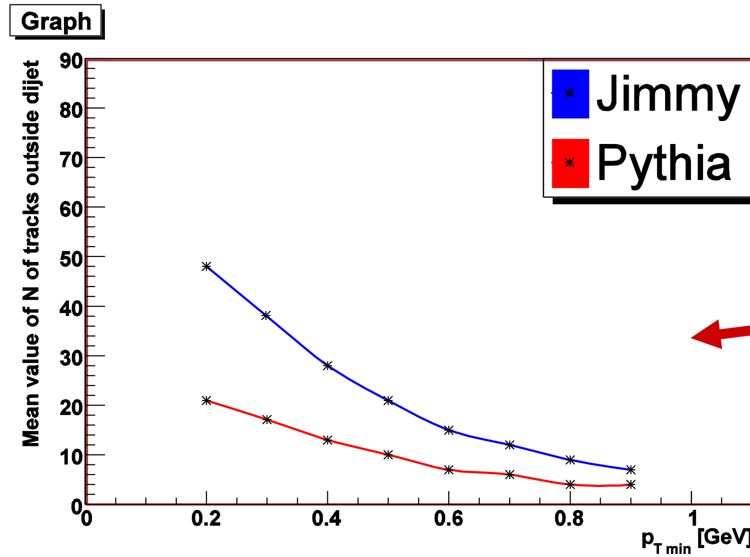
6) Pile-up combinatorial bg suppressors:

Few tracks outside the dijet

reduction factor ~20 from fast timing detector

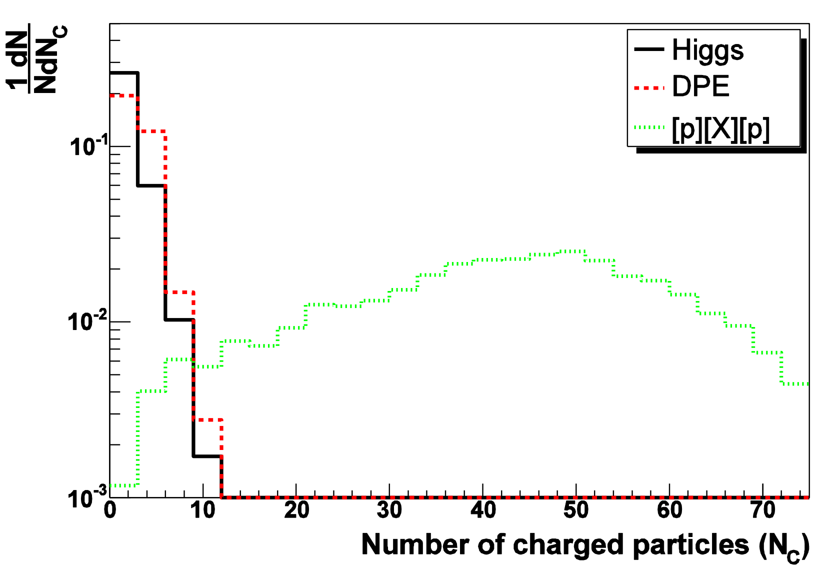
PU background suppressors

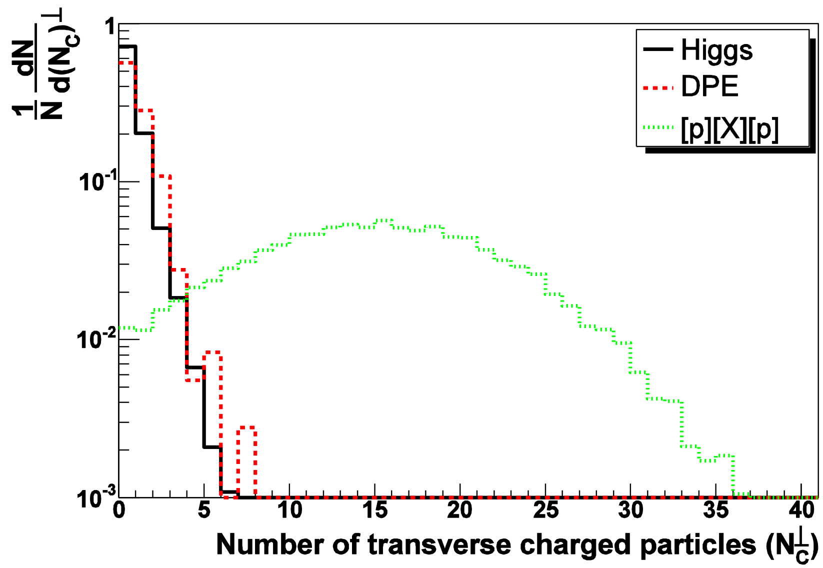




This difference has big impact on PU-bg rejection

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





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→bb: fast simulation, $100 < M_H < 300$ GeV, d_{220}~1.5mm, d_{420}~4.5mm, Acc=Acc(ξ,t,φ)
- 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→bb: 1) gen.level + smearing of basic quantities, M_H = 120 GeV
- one MSSM point (tanβ = 40): JHEP 0710 (2007)090

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

3) Dedicated L1 trigger for H→bb: ATL-DAQ-PUB-2009-006

All analyses on H→bb get very similar yields for signal and background

H→WW: fast + full simulation, M_H = 160 GeV:
ATL-COM-PHYS-2010-337 EPJC 45 (2006) 401

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

Efficiencies for SM H→bb (CMS+Totem)

Mh [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

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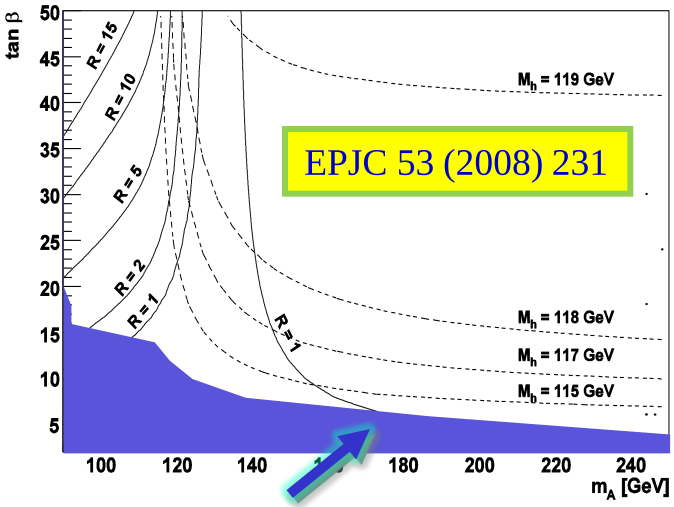
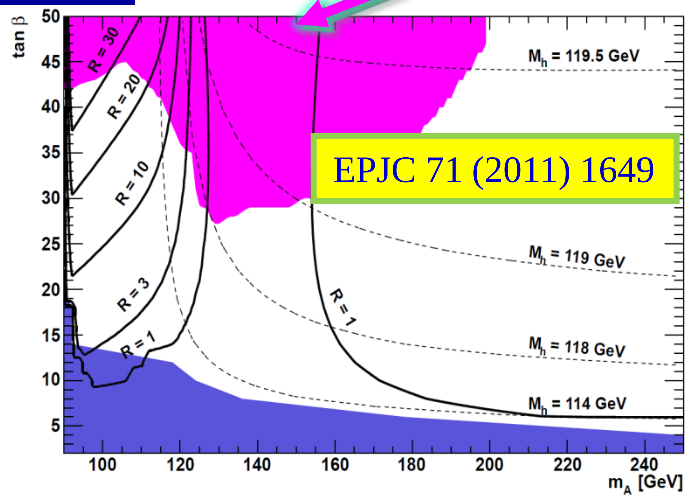
Ratios R=MSSM[M,tanβ] / SM[M]

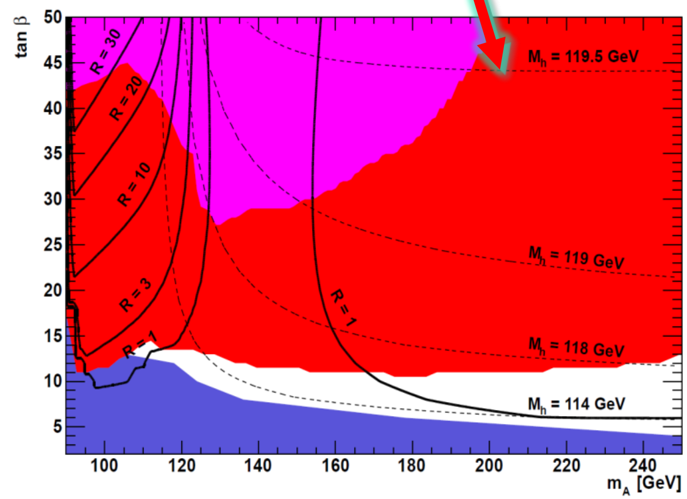
h→bb, nomix, μ=200 GeV

Tevatron exclusion region

LHC exclusion region

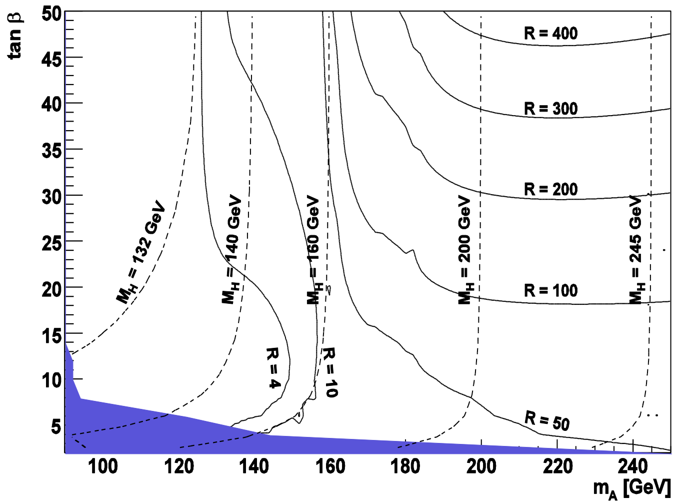


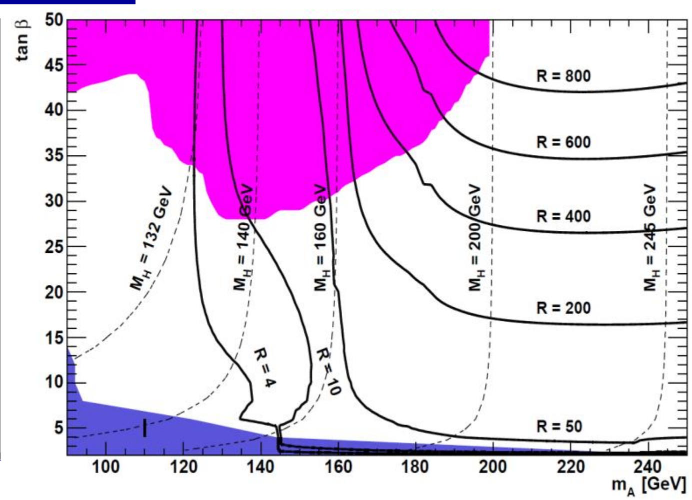


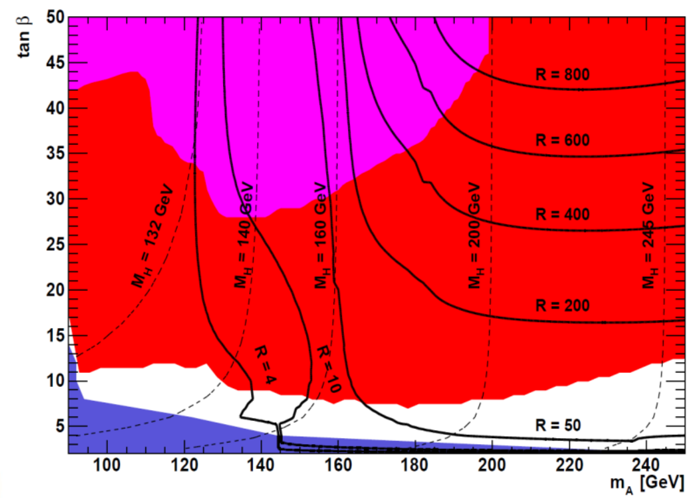


LEP exclusion region

H→bb, mhmax, μ=200 GeV







Nature of discovered Higgs boson

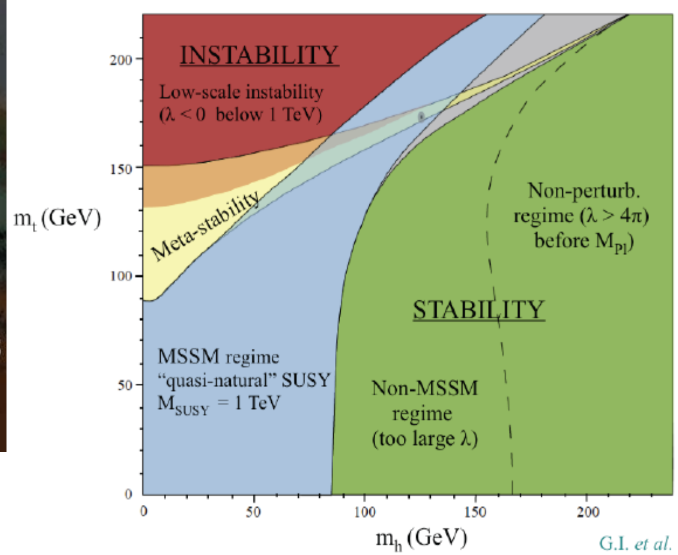
Summary of LHC Higgs searches by Y. Sirois at DIS2014

All 2011 and 2012 data analyzed

Conclusions

- The boson discovered at the LHC by ATLAS and CMS Experiments has properties so far consistent with the "Higgs" scalar boson expected from the BEH mechanism (minimal scalar sector of the SM)
- The precision reachable at the LHC or HL-LHC is possibly sufficient for the observation of deviations caused by extra structure or an extended scalar sector
- The capacity to establish additional new physics heavily depends on the progress in experimental and theory modeling of SM processes in the years to come (including extensive usage of V+jets, VV, and VVV production

Nature has been generous ... and malicious

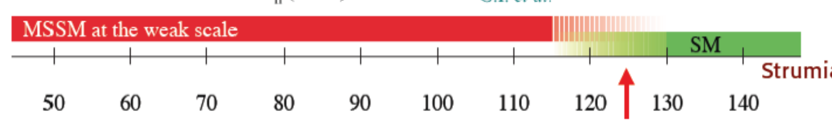


G. Isodori et al.

We live in a very particular corner of the parameter space !

Assuming validity of the SM up to the Planck scale, the faith of the Universe depends on the precise values of M_{top} and M_H !

The Higgs quartic coupling λ (quasi-)vanish at Planck scale



The "SM-like" Higgs boson at 125 GeV is also SUSY compatible we are left with no indication for the scale of SUSY breaking !

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 β 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 β
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

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

Strategy

1) Try out all scenarios. Look only at **h/H** $\rightarrow b\bar{b}$

MT, EPJC 73 (2013) 2672

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** $\rightarrow b\bar{b}$

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 efficiences.

6) Compare with the region of the observed Higgs signal (125.5 GeV +- 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

HKRSTW, EPJC 53 (2008) 231

Signal processes: use approximate formula

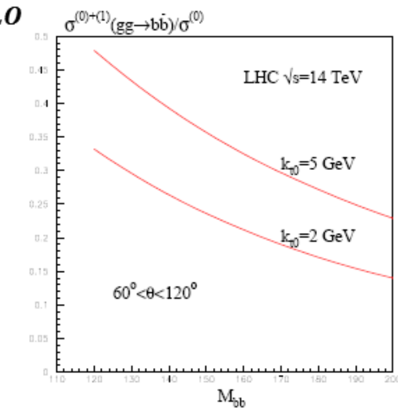
$$\sigma^{\rm excl} = 3{\rm fb} * \left(\frac{136}{16+m}\right)^{3.3}\left(\frac{120}{m}\right)^{3}\cdot\frac{\Gamma(h/H\to gg)}{0.25\,{\rm MeV}}\cdot\frac{{\rm BR}^{\rm MSSM}}{{\rm BR}^{\rm SM}} * \varepsilon$$

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

Background for $h, H\to b\bar b$ obtained from

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

C_{NLO}



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

Backgrounds intensively studied by KMR group:

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

1) Admixture of |Jz|=2 production

2) NLO gg→bbg, large-angle hard gluon emission

3) LO gg→gg, g can be misidentified as b

4) b-quark mass effects in dijet processes, HO radiative corrections

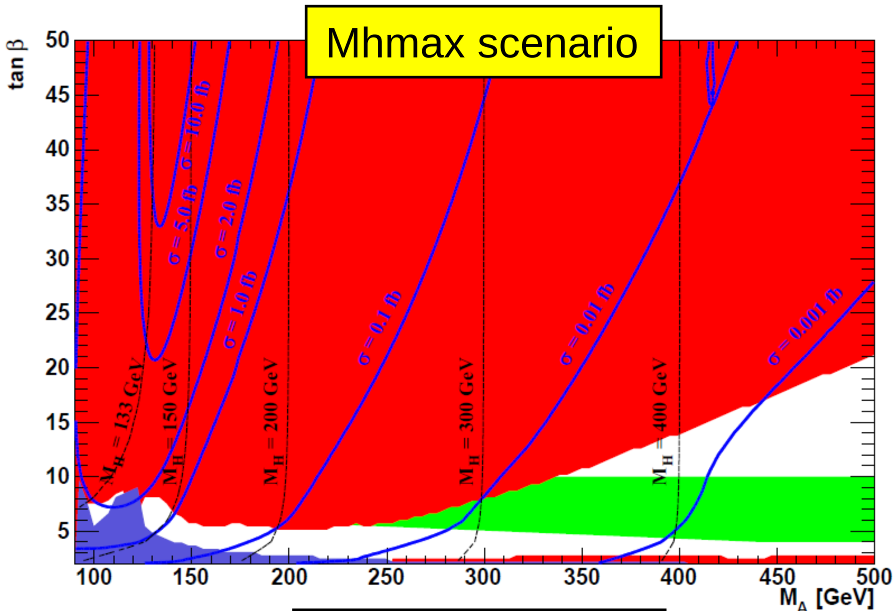
b-jet angular cut applied: $60° < \theta < 120°$ ($|\Delta\eta_{jet}| < 1.1$) P(g/b)~1.3%(ATLAS)→1%(CMS)

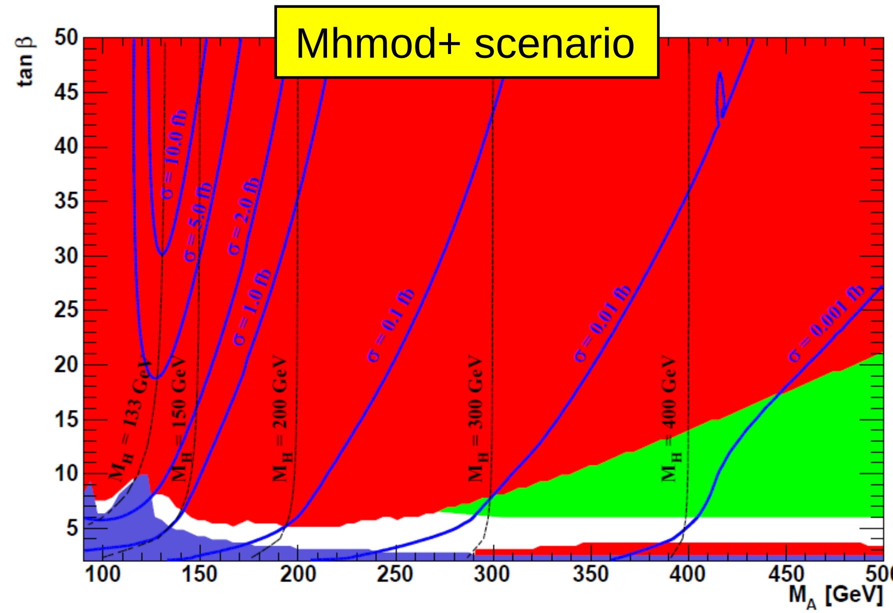
Four major bg sources: ~(1/4+1/4+1.3²/4 +1/4) fb at M_h=120 GeV, ΔM=4 GeV

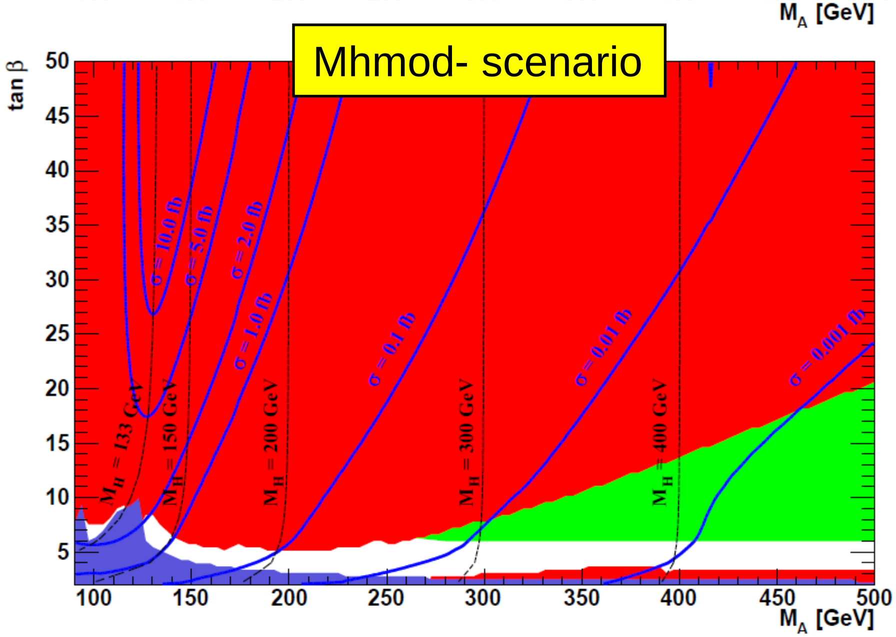
Pile-up background is heavily reduced after applying stringent cuts.

Remaining Pile-up bg considered to be negligible.

CEP H→bb signal x-sections







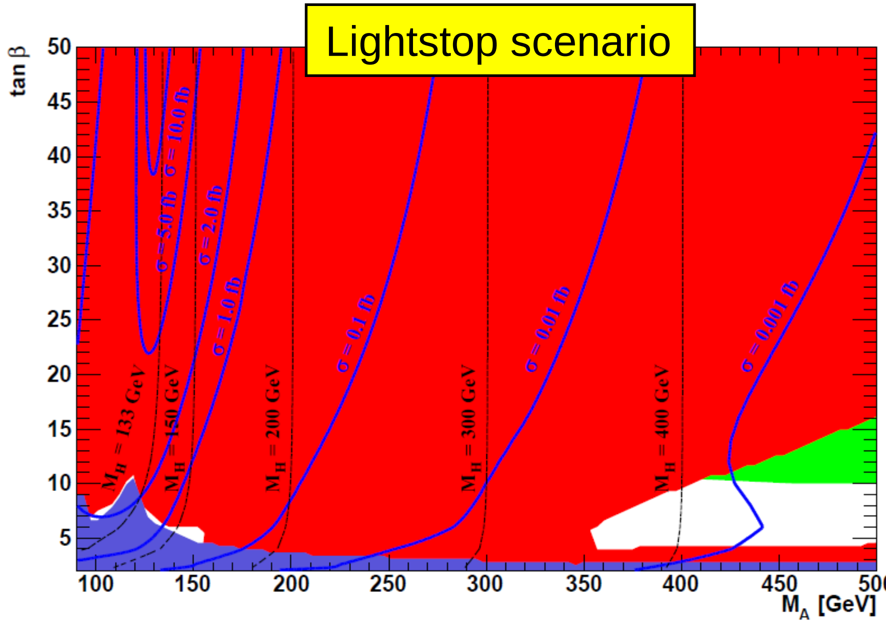
$122.5 < M_h < 128.5$ GeV

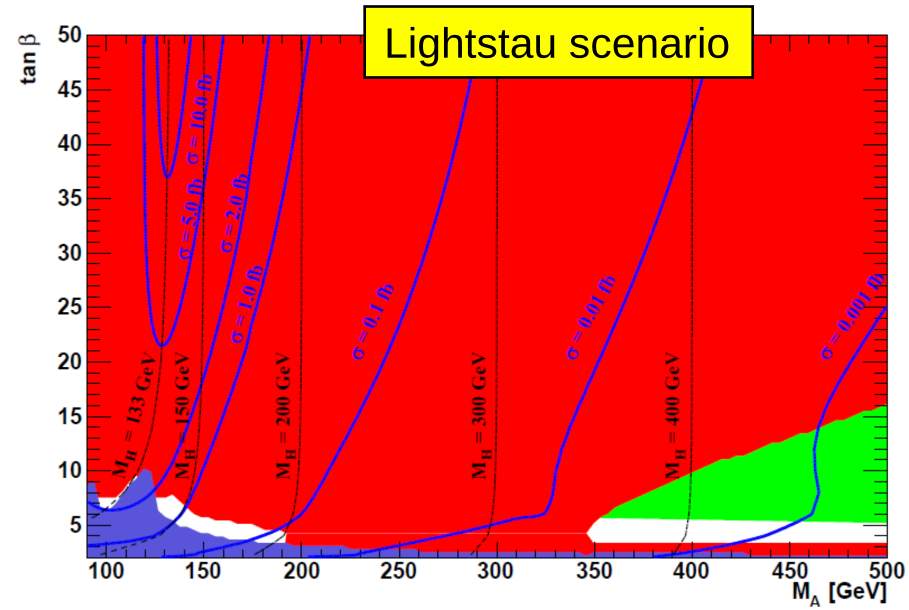
LHC exclusion regions

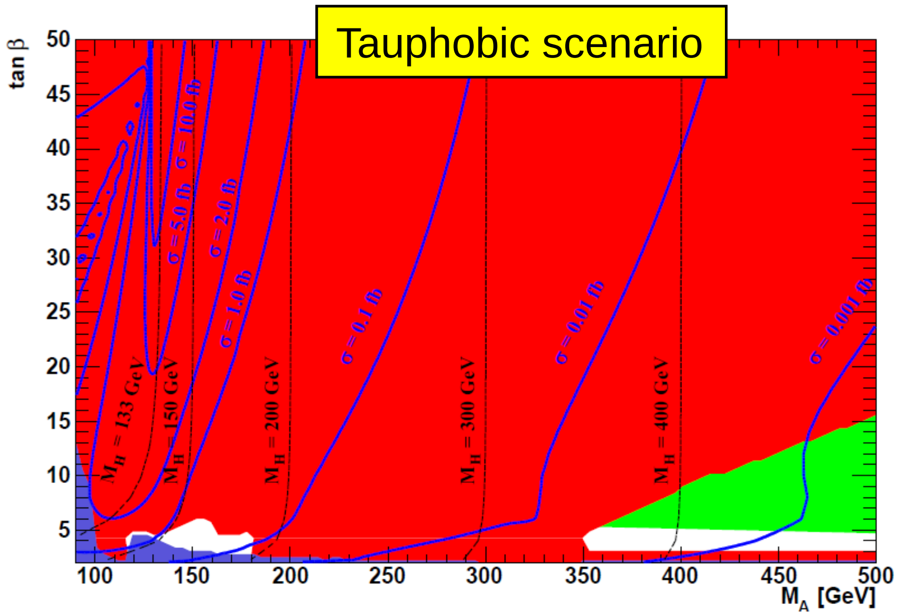
LEP exclusion regions

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

CEP H→bb signal x-sections







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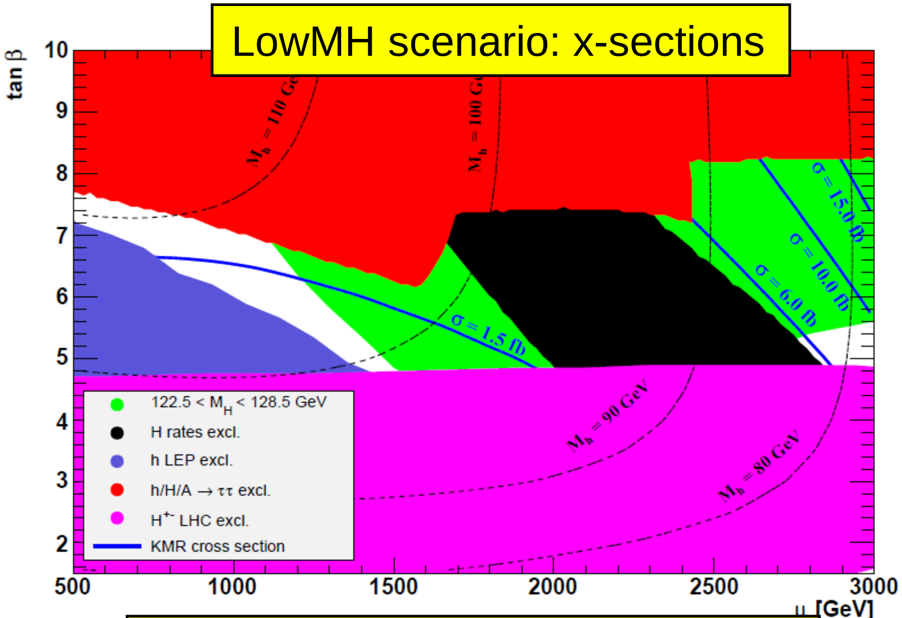
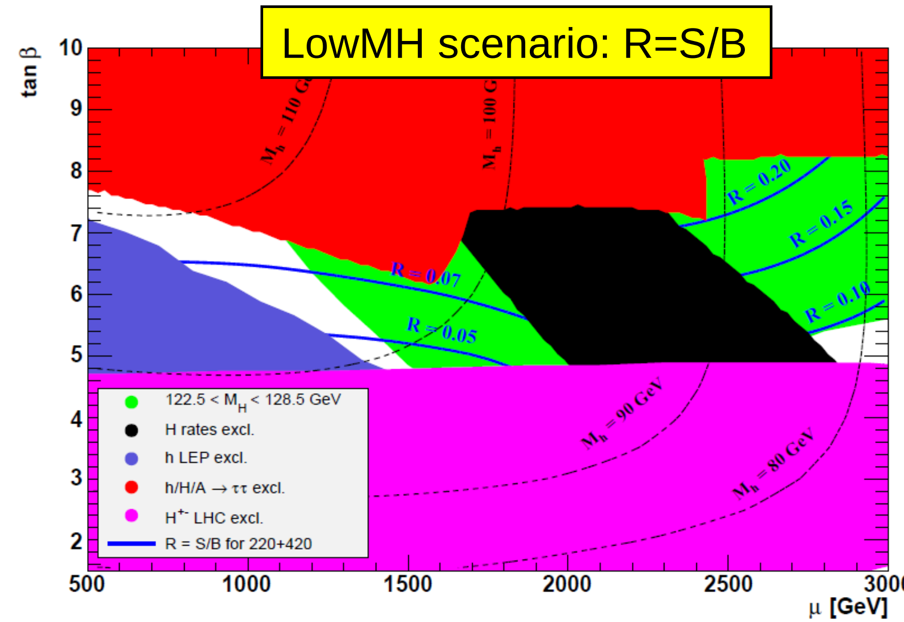
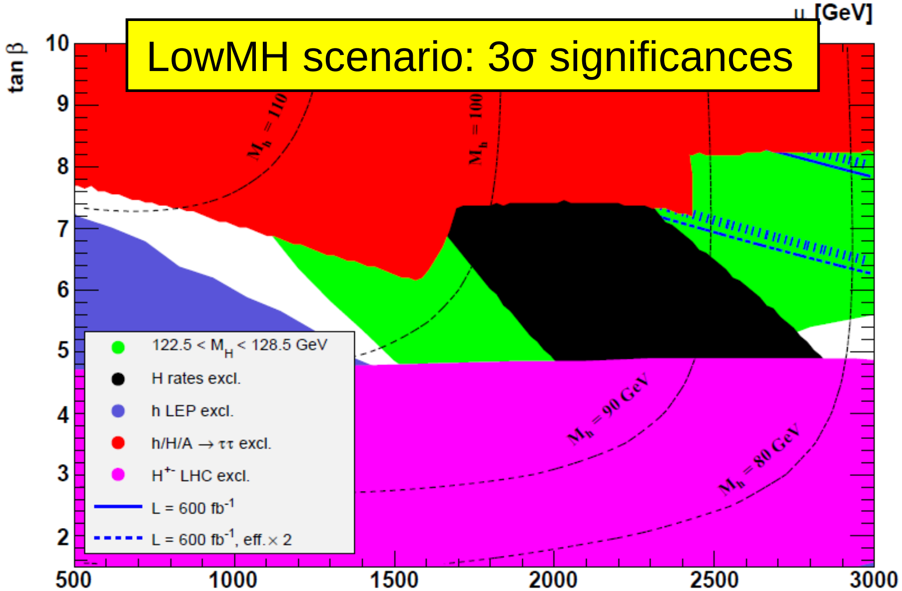
CEP h→bb at LowMH scenario







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

MT, EPJC 73 (2013) 2672

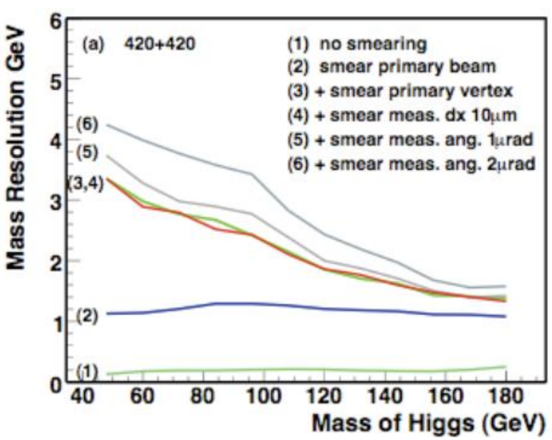
M_h ~ 125.5 +- 3 GeV (theory + exper. uncert.)
Ratios and significances include the experim. efficiencies
Signal yields are descent here.

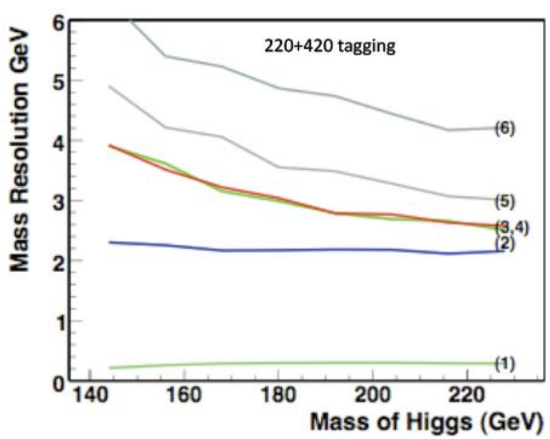
BUT: recent ATLAS charged Higgs searches may exclude the whole parameter space (waiting for CMS confirmation)

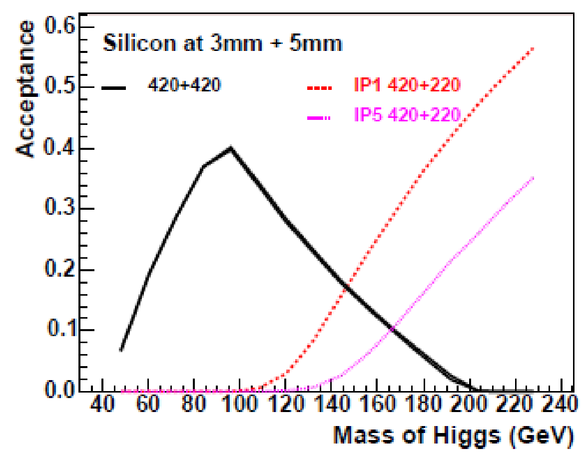
LowMH considerations

MT, EPJC 73 (2013) 2672

- Ratios S/B and 3σ-significances include the experimental efficiencies.
- 3σ is reachable only for large integrated luminosity (~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 ~ 125.5 GeV is the heavy one; we need to search for the lighter one → picture shows the region of interest M_h ~ 80-90 GeV.
- The region of interest M_h ~ 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)







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Summary

CEP 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 CEP Higgs.

BUT: recent ATLAS charged Higgs searches may exclude the whole parameter space (waiting for CMS confirmation)

- This scenario is reachable only using 420+420 because the mass of the searched object is low (80 < Mh < 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 may be increased by tuning the selection procedure (we know the mass of Higgs). There is room for improvement.

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

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

$\Rightarrow$ no HVV coupling

$\Rightarrow$ no Higgs production in weak boson fusion

$\Rightarrow$ no decay $H \to ZZ \to 4\mu$

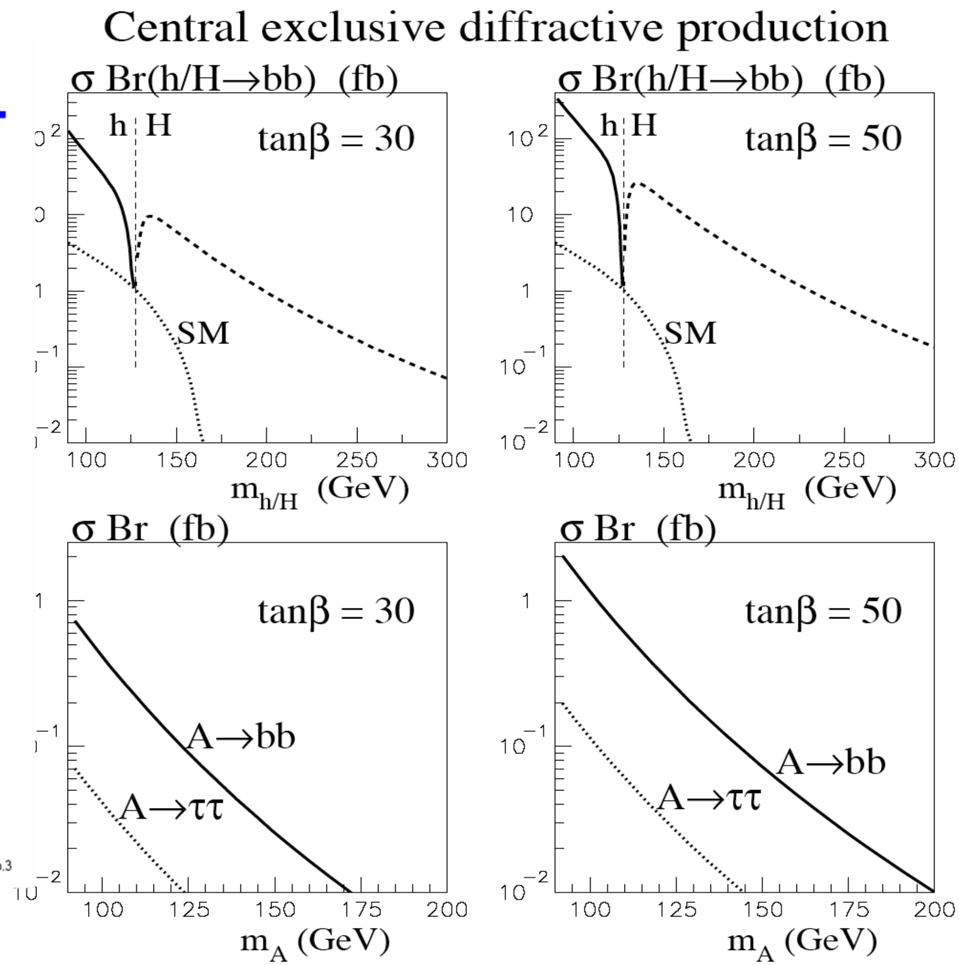
Large enhancement of coupling to $b\bar{b}$, $\tau^+\tau^-$ for high $\tan\beta$

$\Rightarrow$ 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



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

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