News on Exclusive Production of the MSSM Higgs bosons

Marek Taševský

Institute of Physics, Academy of Sciences, Prague

(in collaboration with S. Heinemeyer and V. Khoze)

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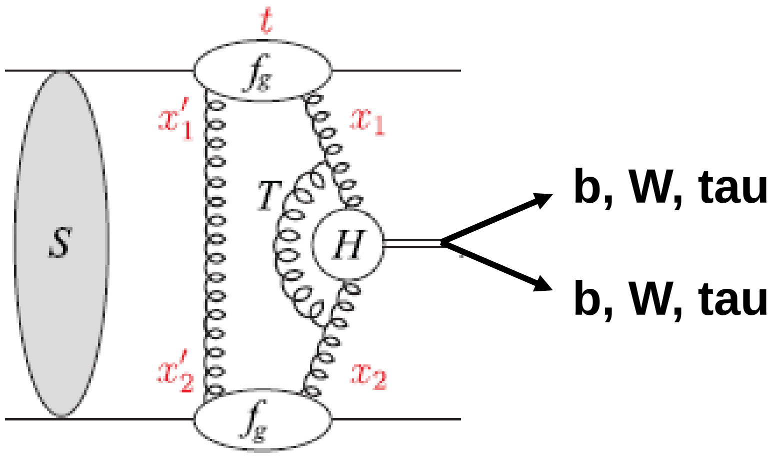
LHC Higgs observation and MSSM exclusion bounds from all LHC data

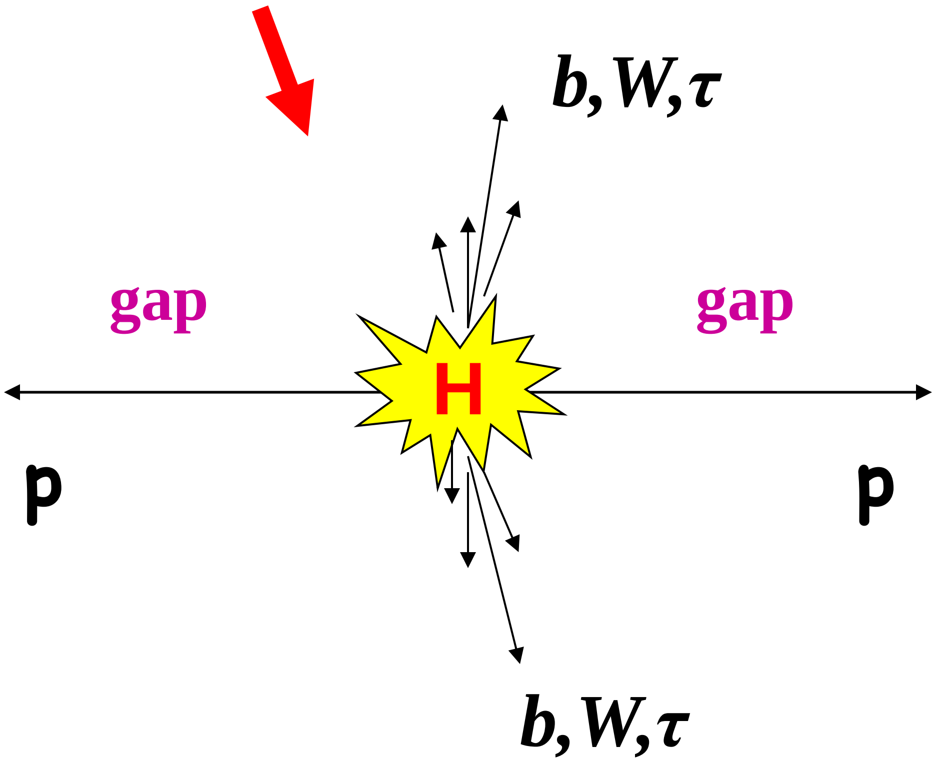
New MSSM benchmark scenarios

Central Exclusive Diffraction: Higgs production



1) Protons remain undestroyed, escape undetected by central detector and can be detected in forward detectors
(see Mike’s and Tomas talk)

2) Rapidity gaps between leading protons and Higgs decay products



x-section predicted with uncertainty of 3 or more (see Valery’s talk)

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

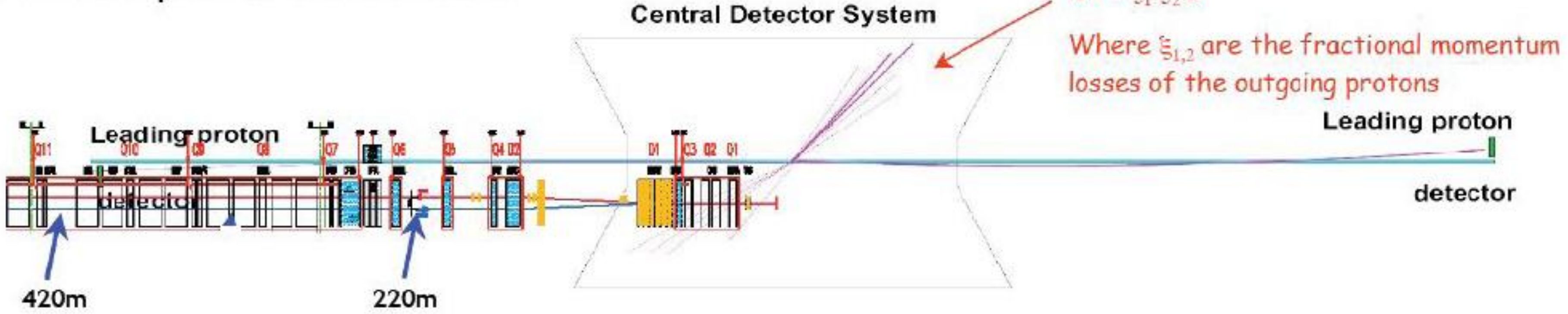
ττ : interesting around 100 GeV

Forward Proton detectors at LHC

Exclusive Higgs production only detectable with forward proton detectors that measure precisely ξ.

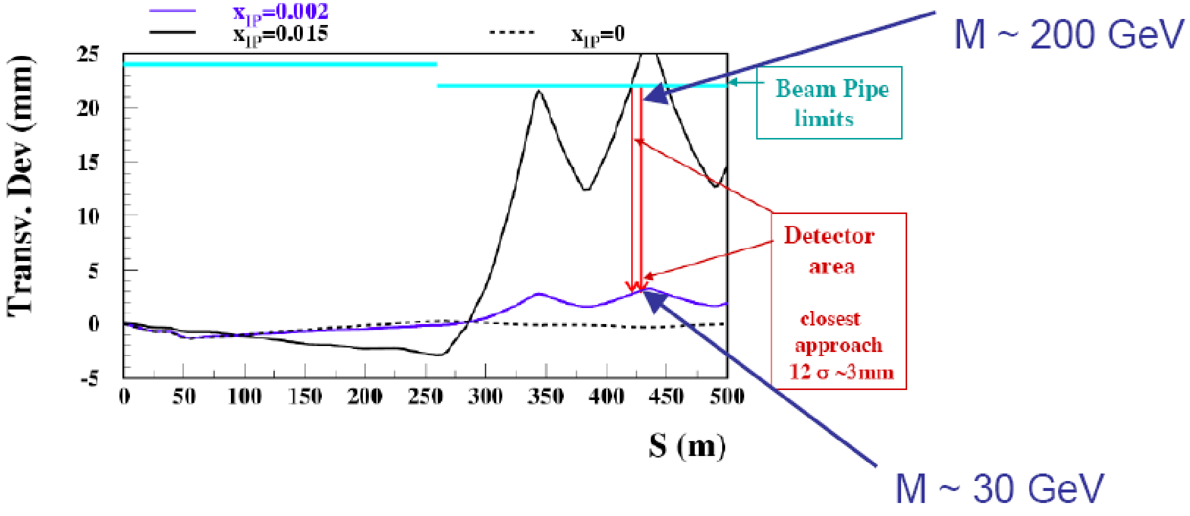
(See more about upgrade proposals AFP and PPS)

Measure forward protons from DPE/CEP.



$M^2 = \xi_1 \xi_2 S$

Where $\xi_{1,2}$ are the fractional momentum losses of the outgoing protons



M ~ 200 GeV

M ~ 30 GeV

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→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 (CED) process: bb, WW, tautau

↓

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.

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

Experimental analysis strategy for $H\to bb$

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, $|\eta_{1,2}| < 2.5$, $3.0 < |\varphi_1 - \varphi_2| < 3.3$

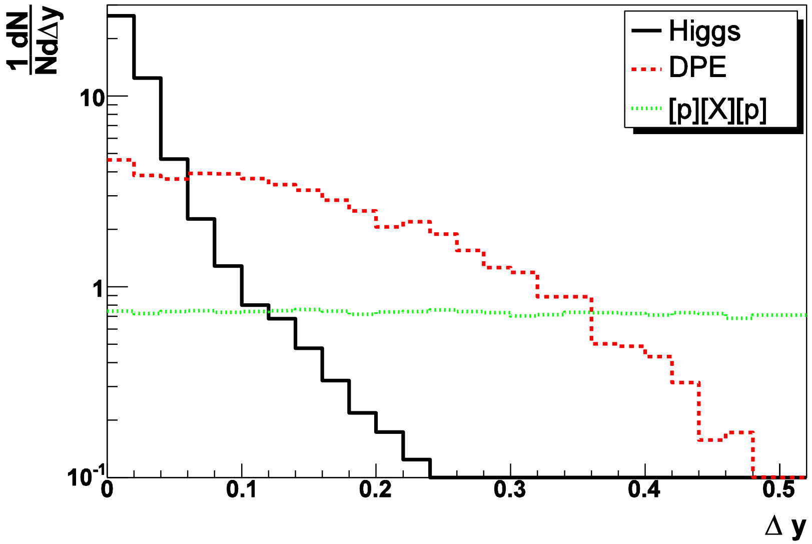
3) Exclusivity cuts: $0.75 < R_j < 1.2$, $|\Delta y| < 0.1$

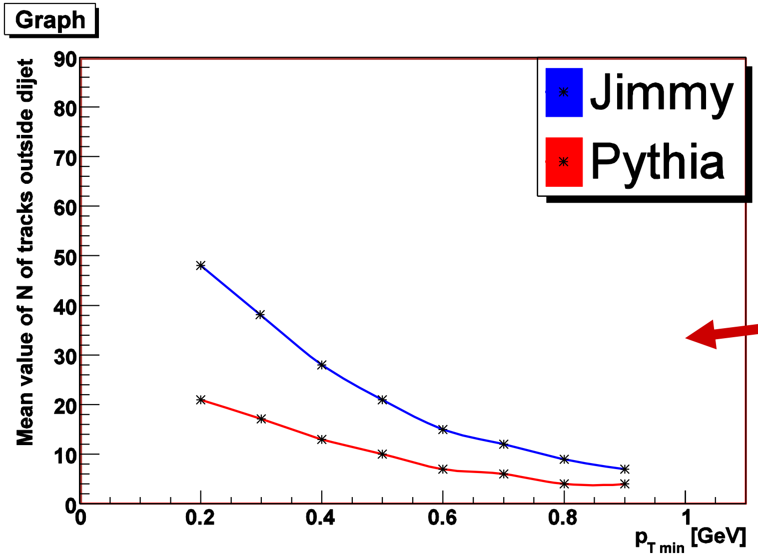
4) L1 triggers (not included in CMS+Totem analysis)**:**
420+220: J20J40 + FD220 + $\bar{\eta} < 0.5$ + $|\Delta\eta| < 2$ + $f_T > 0.45$ → special diffractive trigger
420+420: J20J40 + $\bar{\eta} < 0.5$ + $|\Delta\eta| < 2$ + $f_T > 0.45$ → FD420 cannot be included in L1

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

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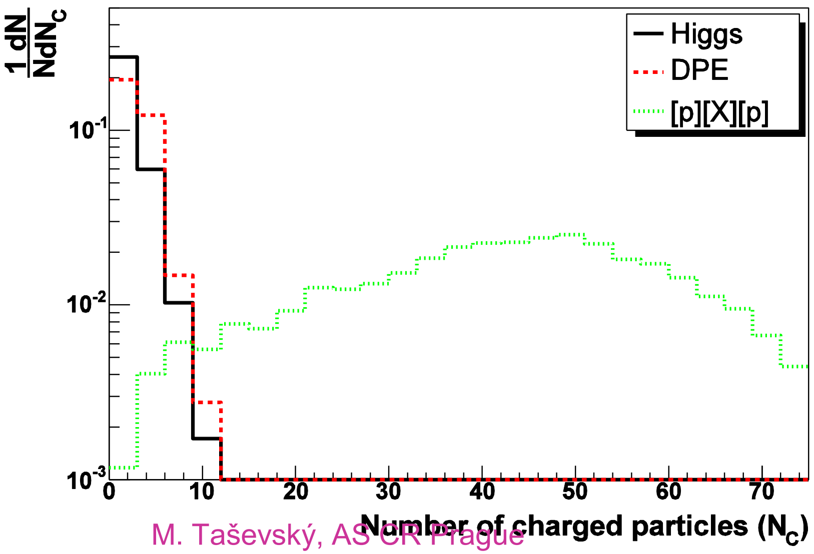
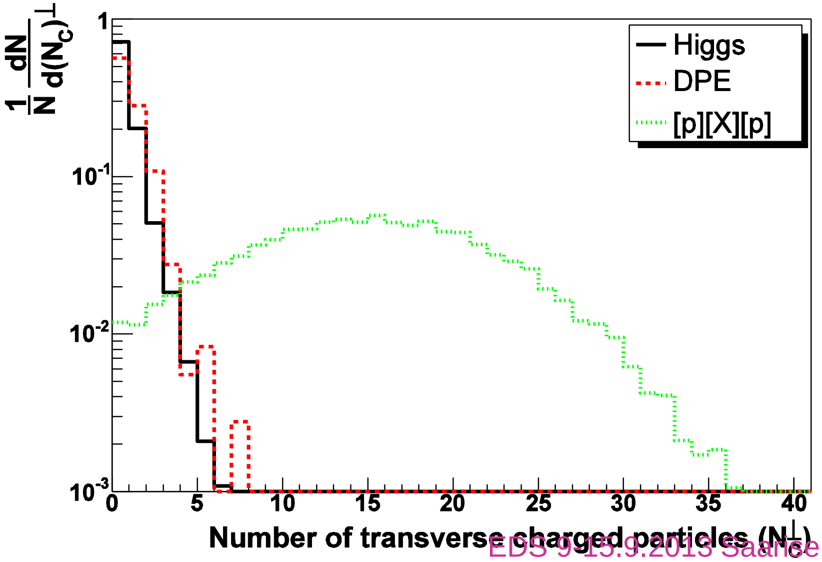
$$\Delta y = (\eta_{jet1}+\eta_{jet2})/2-y_X$$





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:

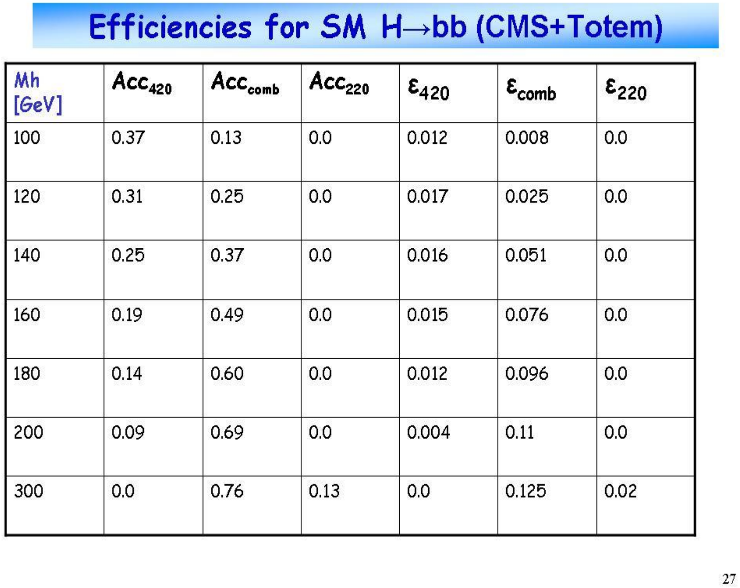
H→bb: 1) gen.level + smearing of basic quantities, M_H = 120 GeV
- one MSSM point (tanβ = 40): JHEP 0710 (2007)090

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



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

27

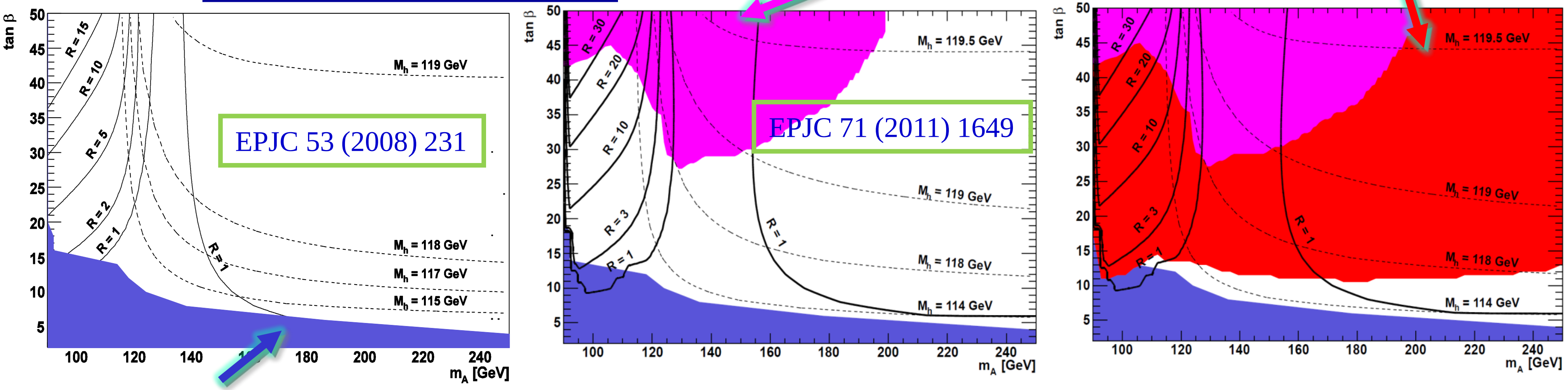
Due to stringent cuts to suppress PU bg, experimental efficiencies for SM Higgs and hence significances are modest. **Try MSSM !**

Ratios R=MSSM[M,tanβ] / SM[M]

h→bb, nomix, μ=200 GeV

Tevatron exclusion region

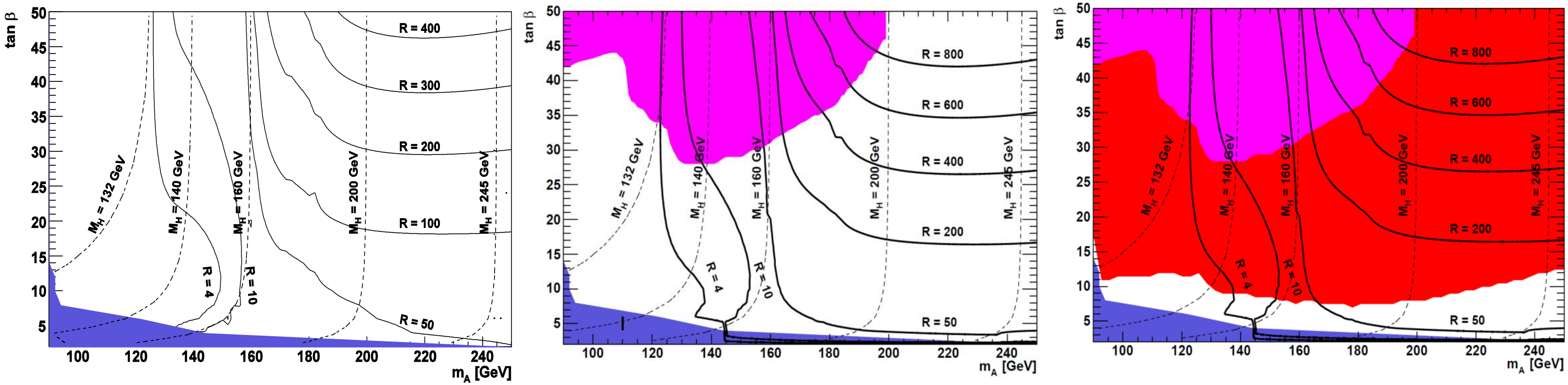
LHC exclusion region


EPJC 53 (2008) 231

EPJC 71 (2011) 1649

LEP exclusion region

H→bb, mhmax, μ=200 GeV



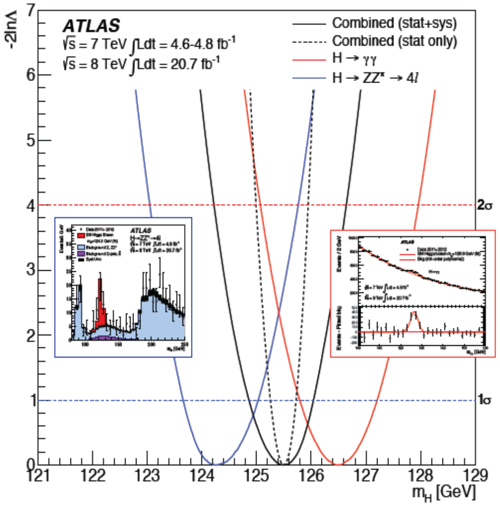
Nature of discovered Higgs boson

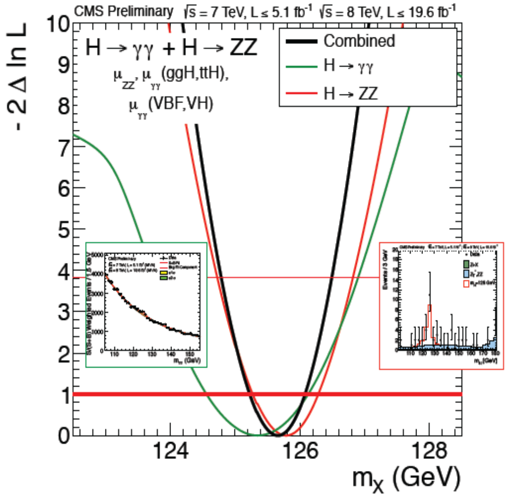
Summary of LHC Higgs searches by F. Cerutti at EPS2013

All 2011 and 2012 data analyzed

Mass Measurement

Measured from γγ and ZZ*(4ℓ) mass spectra: needed to predict σ×BR





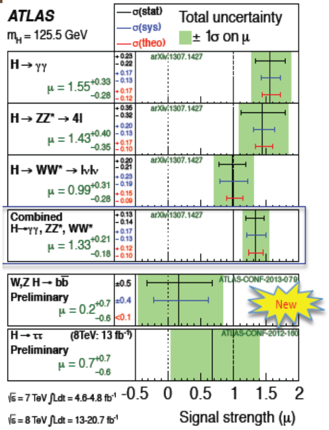
ATLAS: $M_H = 125.5 \pm 0.2_{stat} \pm 0.6_{sys}$ GeV

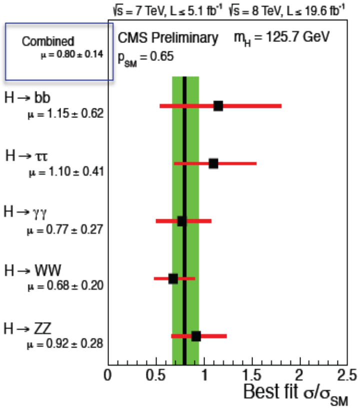
CMS: $M_H = 125.7 \pm 0.3_{stat} \pm 0.3_{sys}$ GeV

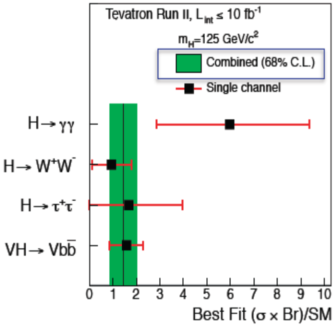
New From γγ: Γ_H<6.9 GeV at 95% CL (direct)

**Independent of signal strengths: used by ATLAS and CMS coupling/spin analyses*

The signal Strength μ







- Combined μ → Best accuracy but no strong physics motivation:
  - **ATLAS (γγ, WW* and ZZ*)** **μ = (1.33 ± 0.20)** (1.23±0.18 including bb and ττ)
  - **CMS (γγ, ττ, bb, WW* and ZZ*)** **μ = (0.80 ± 0.14)**
  - **TEVATRON (bb, γγ, ττ, WW*)** **μ = (1.44 ± 0.60)**

Compatible with SM Higgs boson expectation: Accuracy ~ 15%

Nature of discovered Higgs boson

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All 2011 and 2012
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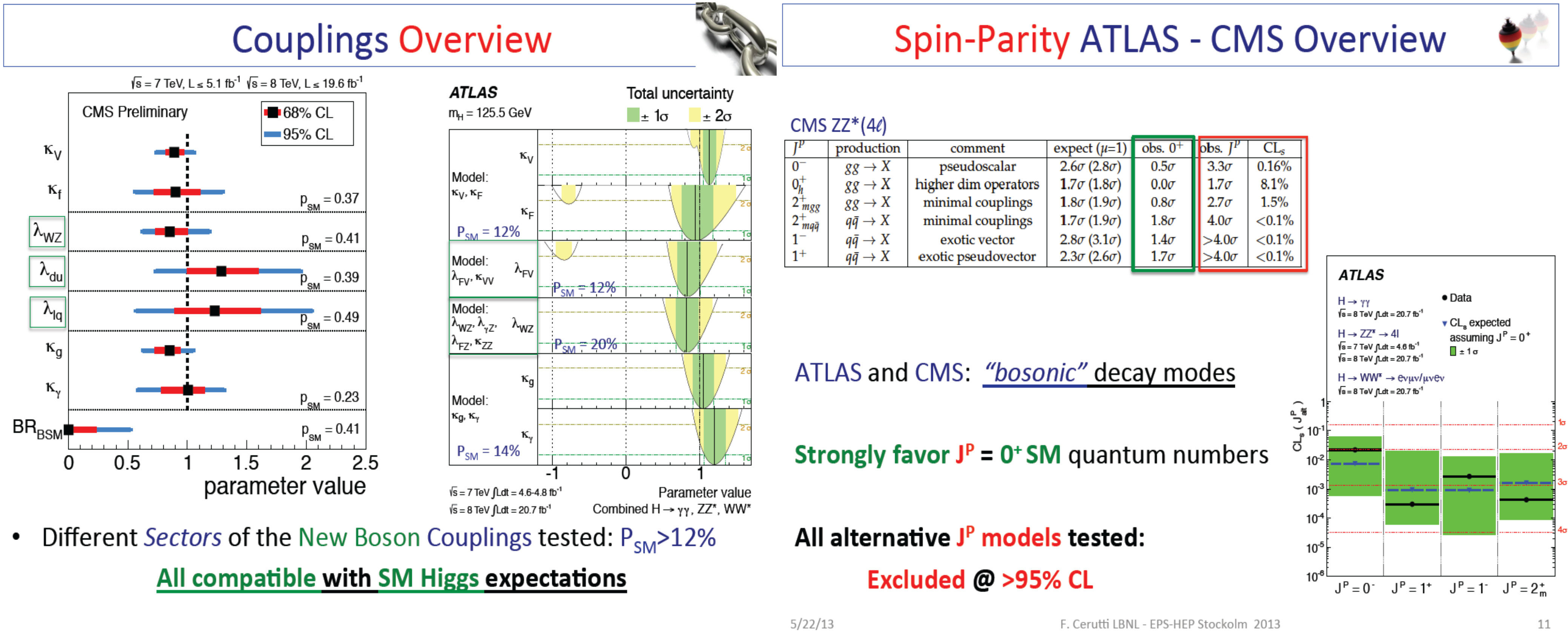


Couplings Overview

- Different *Sectors* of the New Boson Couplings tested: P_{SM}>12%

All compatible with SM Higgs expectations

Spin-Parity ATLAS - CMS Overview

CMS ZZ*(4ℓ)

J^P	production	comment	expect (μ=1)	obs. 0^+	obs. J^P	CL_s
0^-	$gg \to X$	pseudoscalar	2.6σ (2.8σ)	0.5σ	3.3σ	0.16%
0^+_h	$gg \to X$	higher dim operators	1.7σ (1.8σ)	0.0σ	1.7σ	8.1%
2^+_{mgg}	$gg \to X$	minimal couplings	1.8σ (1.9σ)	0.8σ	2.7σ	1.5%
$2^+_{mq\bar{q}}$	$q\bar{q} \to X$	minimal couplings	1.7σ (1.9σ)	1.8σ	4.0σ	<0.1%
1^-	$q\bar{q} \to X$	exotic vector	2.8σ (3.1σ)	1.4σ	>4.0σ	<0.1%
1^+	$q\bar{q} \to X$	exotic pseudovector	2.3σ (2.6σ)	1.7σ	>4.0σ	<0.1%

ATLAS and CMS: *"bosonic"* decay modes

Strongly favor $J^P = 0^+$ SM quantum numbers

All alternative J^P models tested:

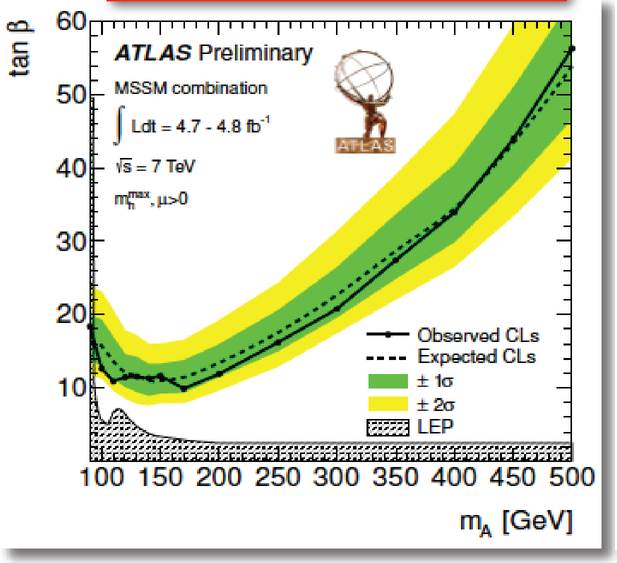
Excluded @ >95% CL

5/22/13 F. Cerutti LBNL - EPS-HEP Stockolm 2013 11

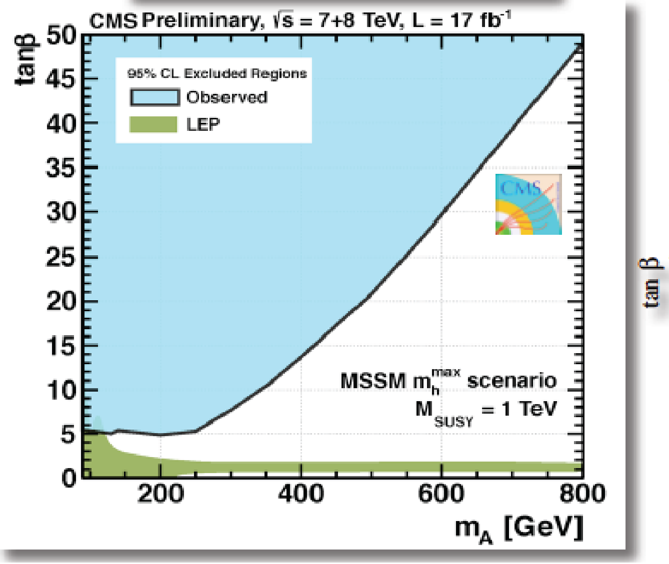
MSSM Higgs Searches

- Most recent results on the H/A($\tau\tau$), including the new LHCb search exploiting τ's in the forward region
- Also, limits on charged Higgs from top decays in $\tau\nu$ (ATLAS+CMS) and cs (ATLAS) channels and search for NMSSM $h \to a^0a^0 \to 4\mu$ (CMS, D0), 4γ (ATLAS) and $a_1 \to 2\mu$ (ATLAS & CMS), as well as Υ(1S,2S) $\to a^0\gamma \to \tau\tau\gamma, \mu\mu\gamma$ (BaBar, Belle); and $gg\gamma$, and $ss\gamma$ (BaBar)

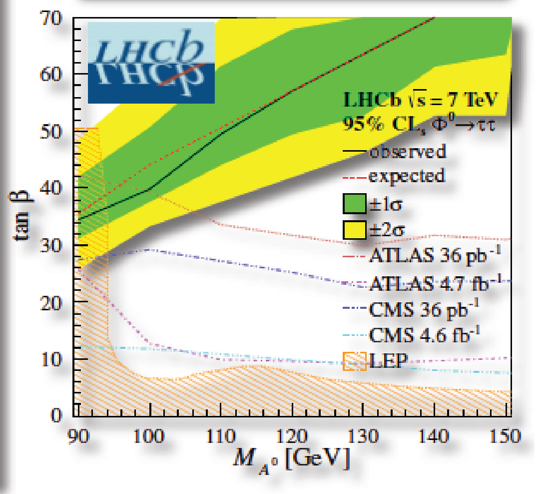
ATLAS-CONF-2012-094



CMS PAS HIG-12-050



LHCb Collaboration
arXiv:1304.2591



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); $bb^-\varphi, \varphi \rightarrow \tau^+\tau^-$ (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** $\rightarrow b\bar{b}$

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

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

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

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

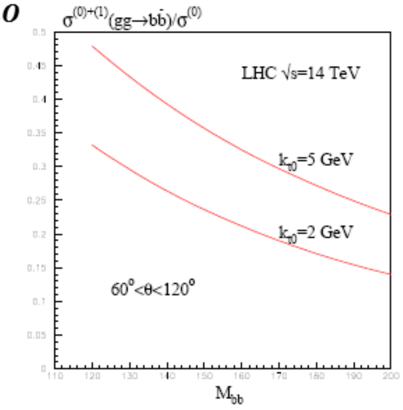
b-jet angular cut applied: 60°< θ <120° ($|\Delta\eta_{\rm jet}| < 1.1$) P(g/b)~1.3%(ATLAS)

Four major bg sources: ~($1/4+1/4+1.3^2/4+1/4$) fb at M_h=120 GeV, ΔM=4 GeV

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

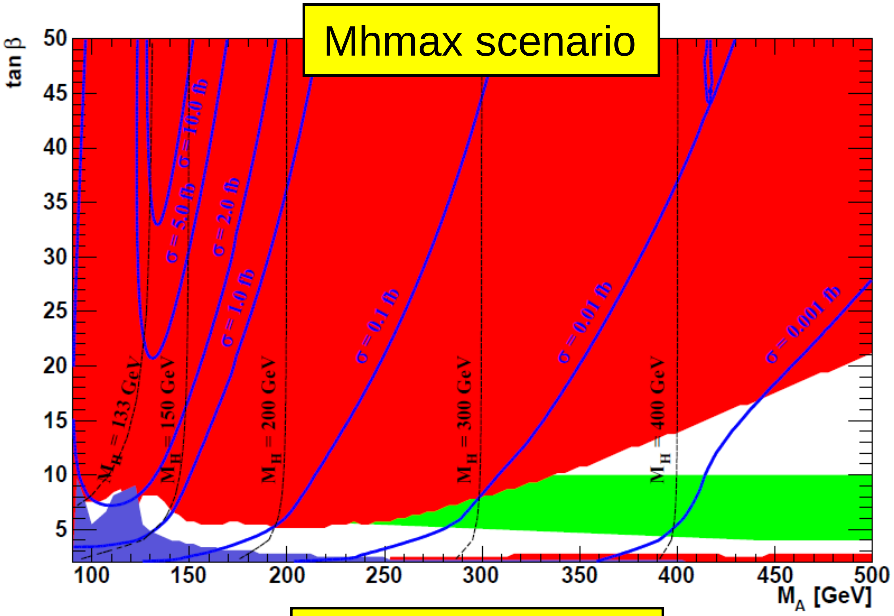
Remaining Pile-up bg considered to be negligible.

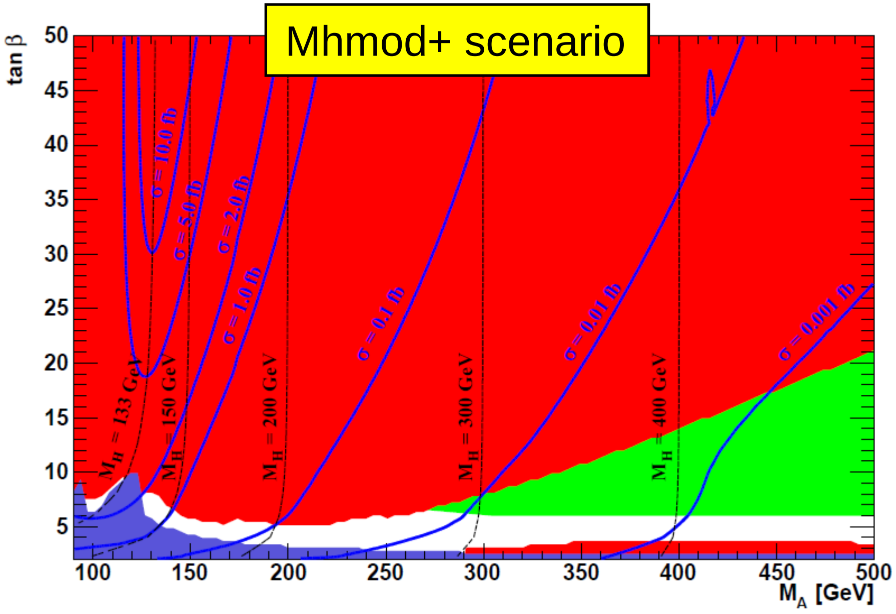
C_{NLO}

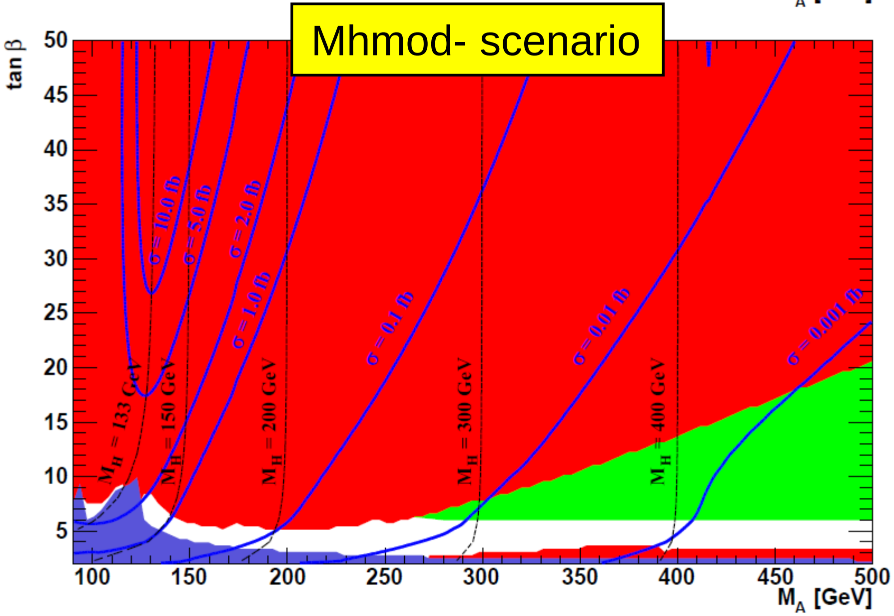


The mass dependence of the ration of the NLO exclusive $b\bar{b}$ cross section to that calculated in Born approximation.

CED H→bb signal x-sections


Mhmax scenario


Mhmod+ scenario


Mhmod- scenario

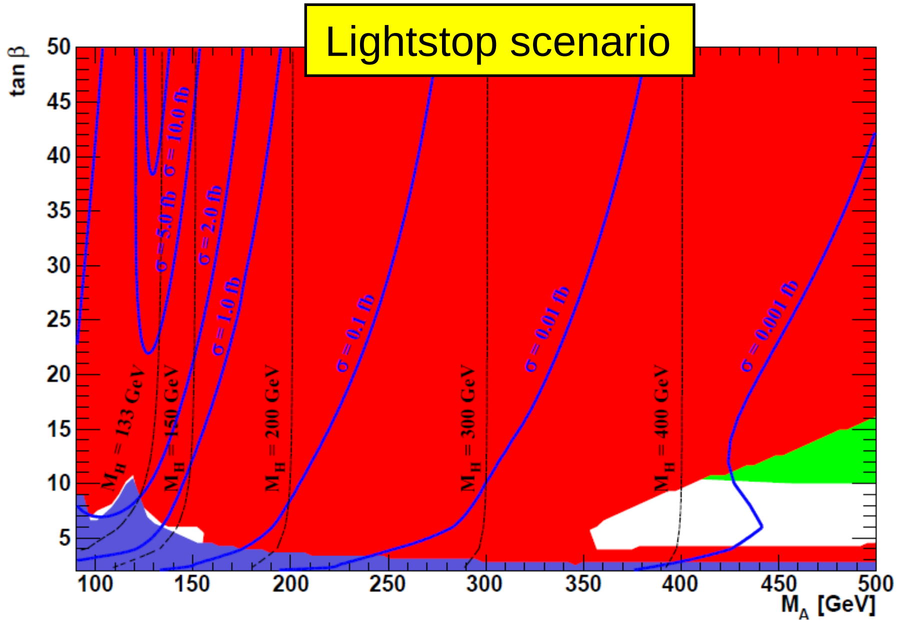
🟩 **122.5 < M_h < 128.5 GeV**

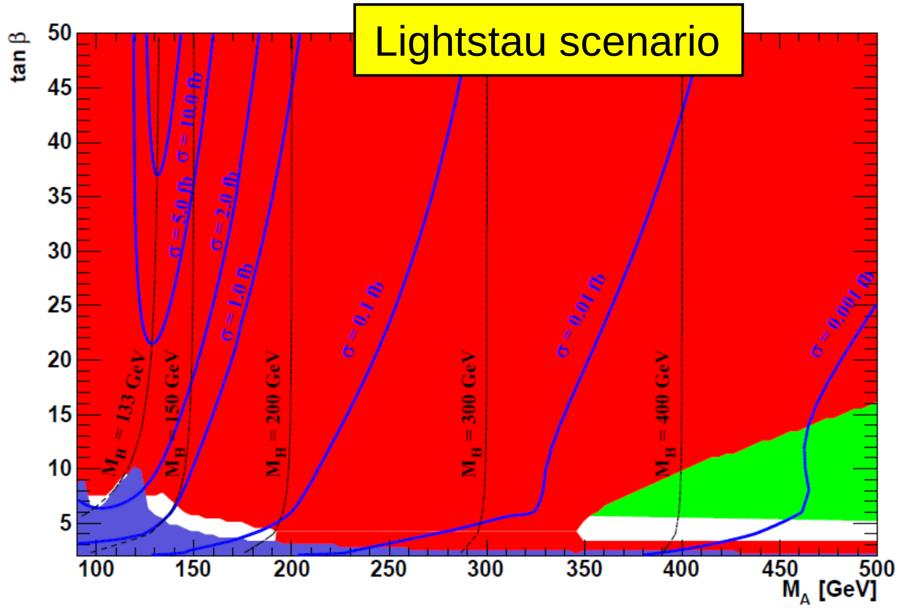
🟥 **LHC exclusion regions**

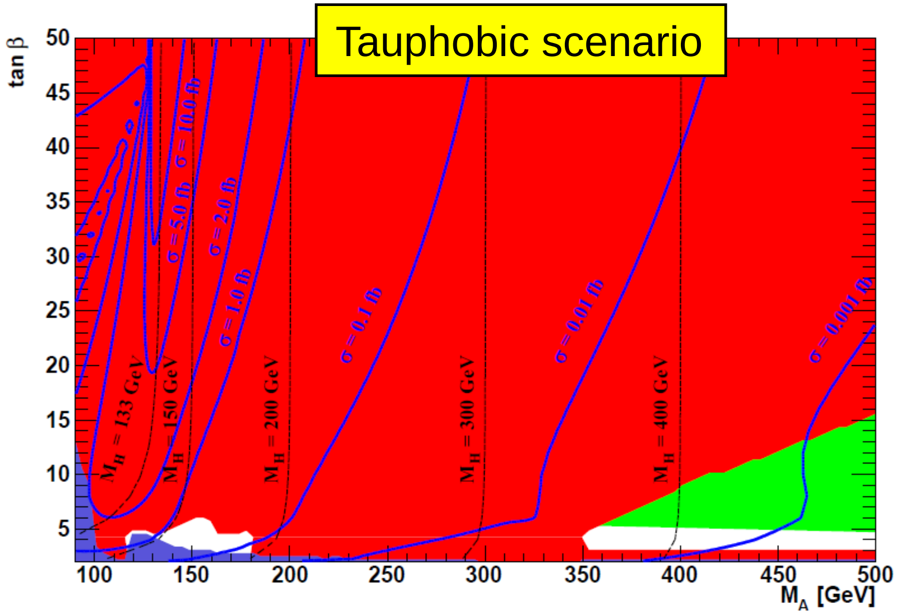
🟦 **LEP exclusion regions**

M_h ~ 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.

CED H→bb signal x-sections


Lightstop scenario


Lightstau scenario


Tauphobic scenario

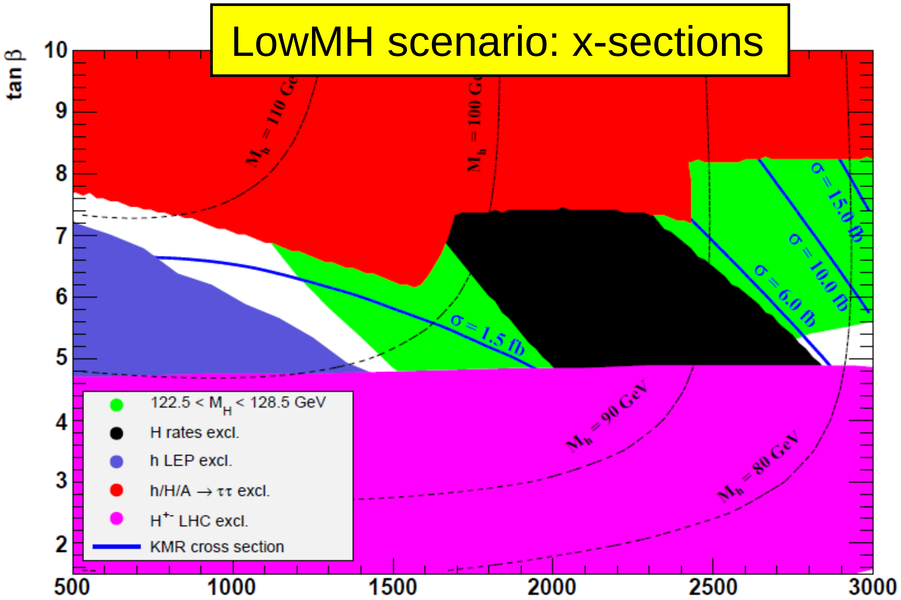
🟩 **122.5 < M_h < 128.5 GeV**

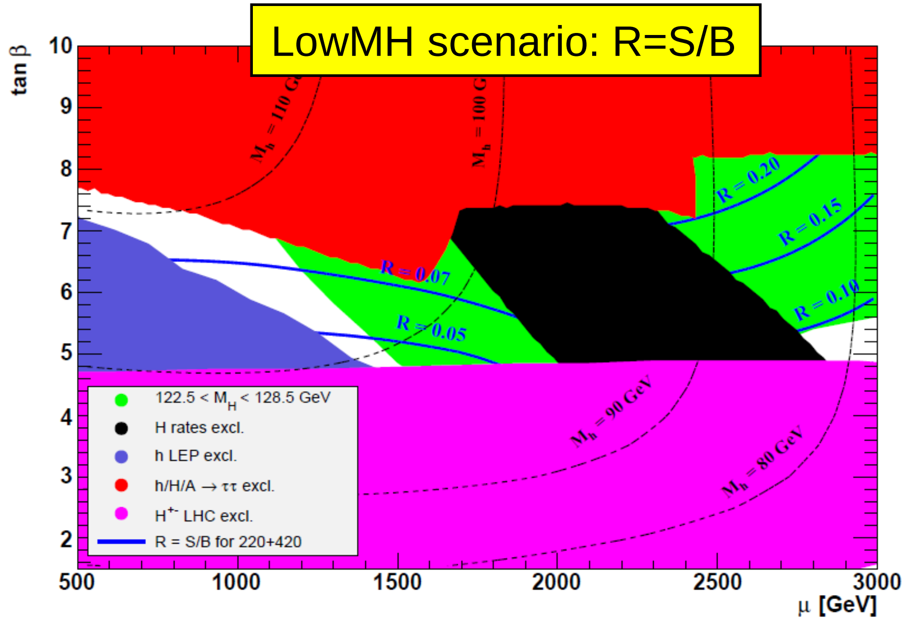
🟥 **LHC exclusion regions**

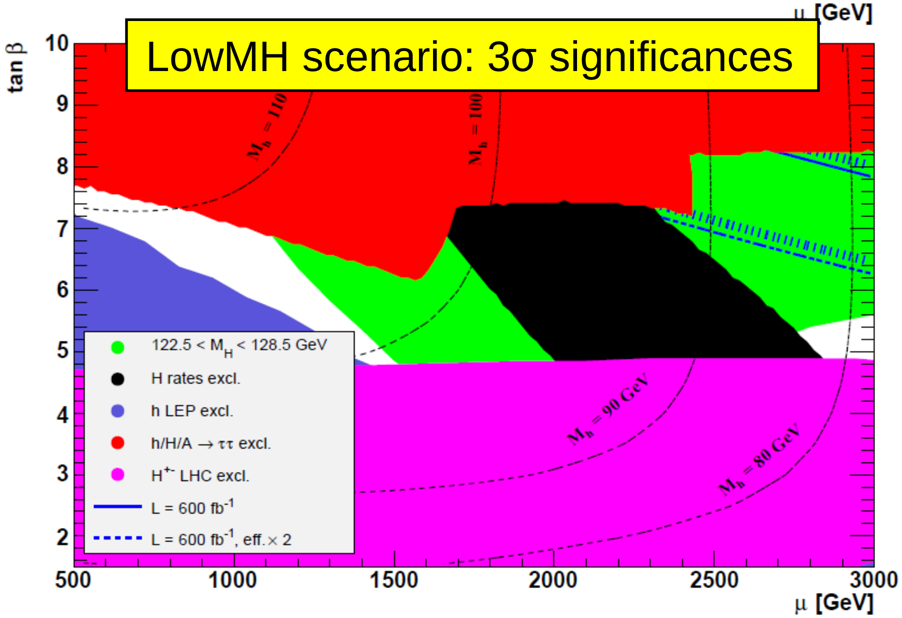
🟦 **LEP exclusion regions**

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.

CED h→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 → ZZ, WW rates exclusion
🟦	h LEP exclusion
🟥	h/H/A → ττ exclusion
🟪	H^{+-} LHC exclusion

M_h ~ 125.5 +- 3 GeV (theory + exper. uncert.)

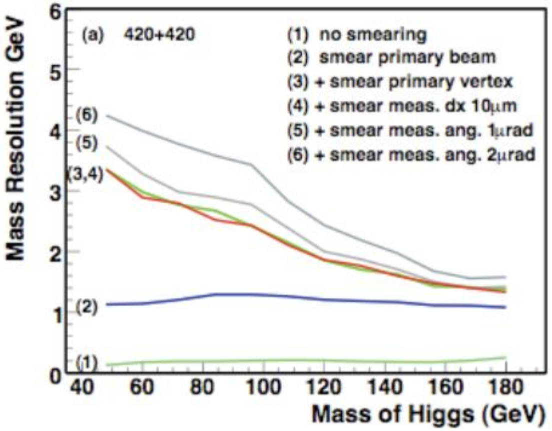
Ratios and significances include the experim. efficiencies

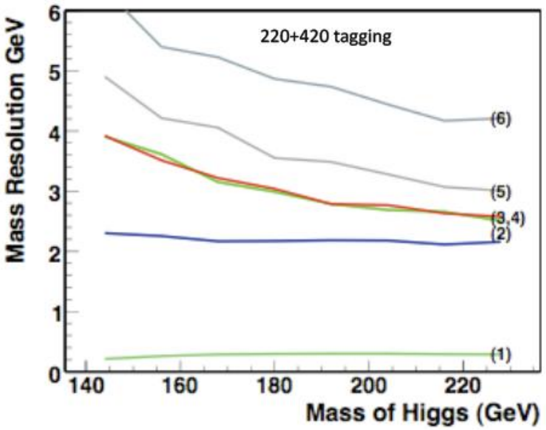
Signal yields are descent here.

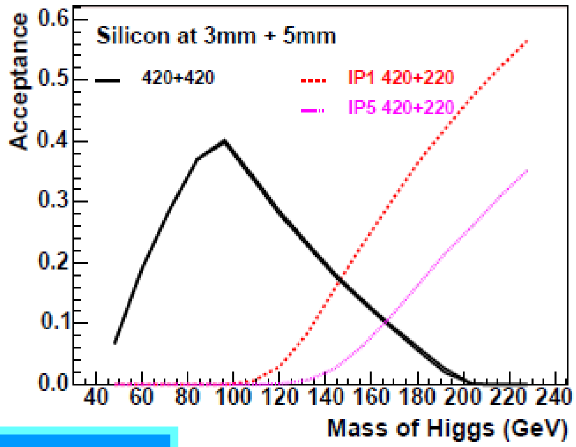
Experimental considerations

- 3-σ significances are reachable only for large integrated luminosity (~ 1000 fb^{-1}). This means we need to combine data from both AFP and PPS.
- In this scenario, the Higgs boson found at ~125.5 GeV is the heavy one; we need to search for its lighter partner → the picture shows the region of interest is M_h ~ 80 – 90 GeV.

- The only conceivable time slot to install AFP420 is in LS2 (2018-2019). It could likely operate only for μ < 50 → a few years after LS2 and in special low-μ runs.
- The region of interest M_h ~ 80 – 90 GeV is experimentally more difficult than the 120 GeV region:
  1. Only 420+420 configuration relevant
  2. 420 station can hardly be put into L1 trigger (in ATLAS)
  3. Slightly lower mass acceptance and slightly worse missing mass resolution
  4. Worse situation also in the central detector (higher prescales of L1 triggers, lower b-tag efficiency)
- BUT: experimental procedure may be improved:
  we know the mass; improved gluon-b misidentification; improved fast timing resolution; …







FP420 R&D Report JINST 4 (2009) T10001

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.

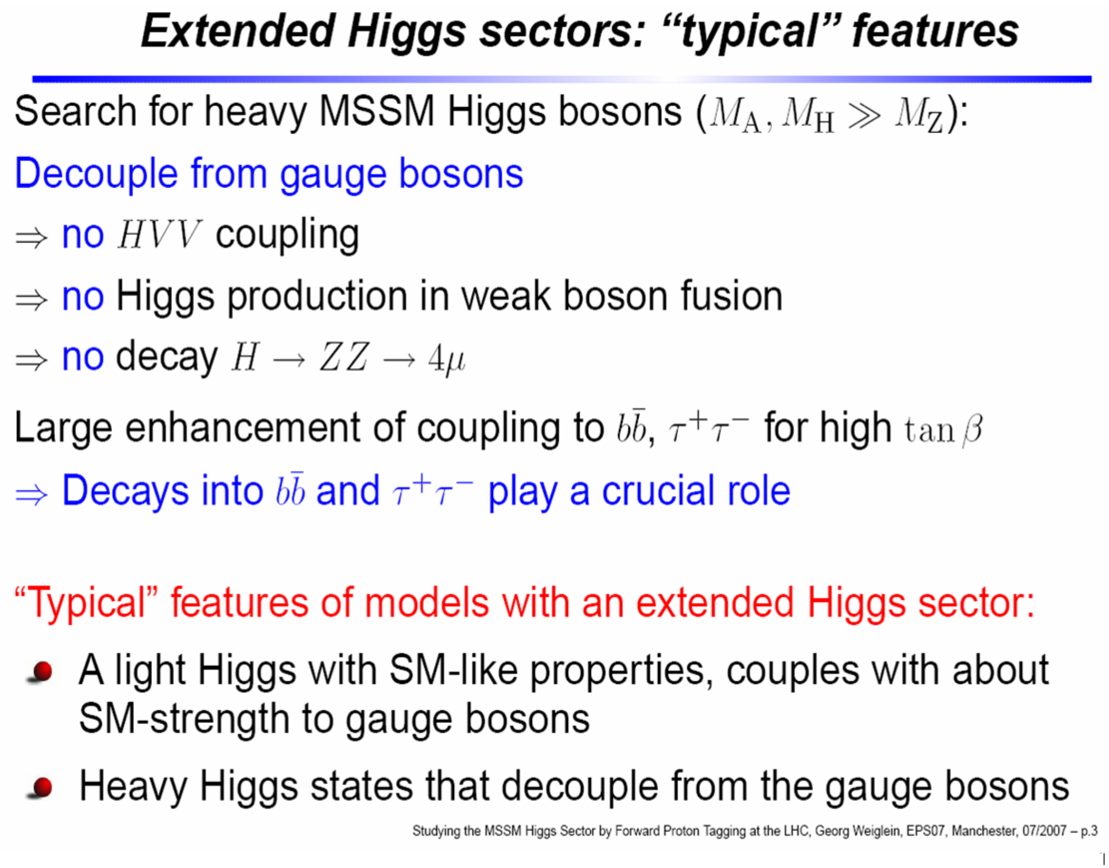
- This scenario is reachable only using 420+420 because the mass of the searched object is low (80 < M_h < 90 GeV). Big demands on experimental procedure (e.g. L1 trigger).
- AFP/PPS may be the unique way to reach such low-mass Higgs or it may confirm what ATLAS and CMS have already found there.

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, gluon-b misidentification improved).

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 $H \to ZZ \to 4\mu$

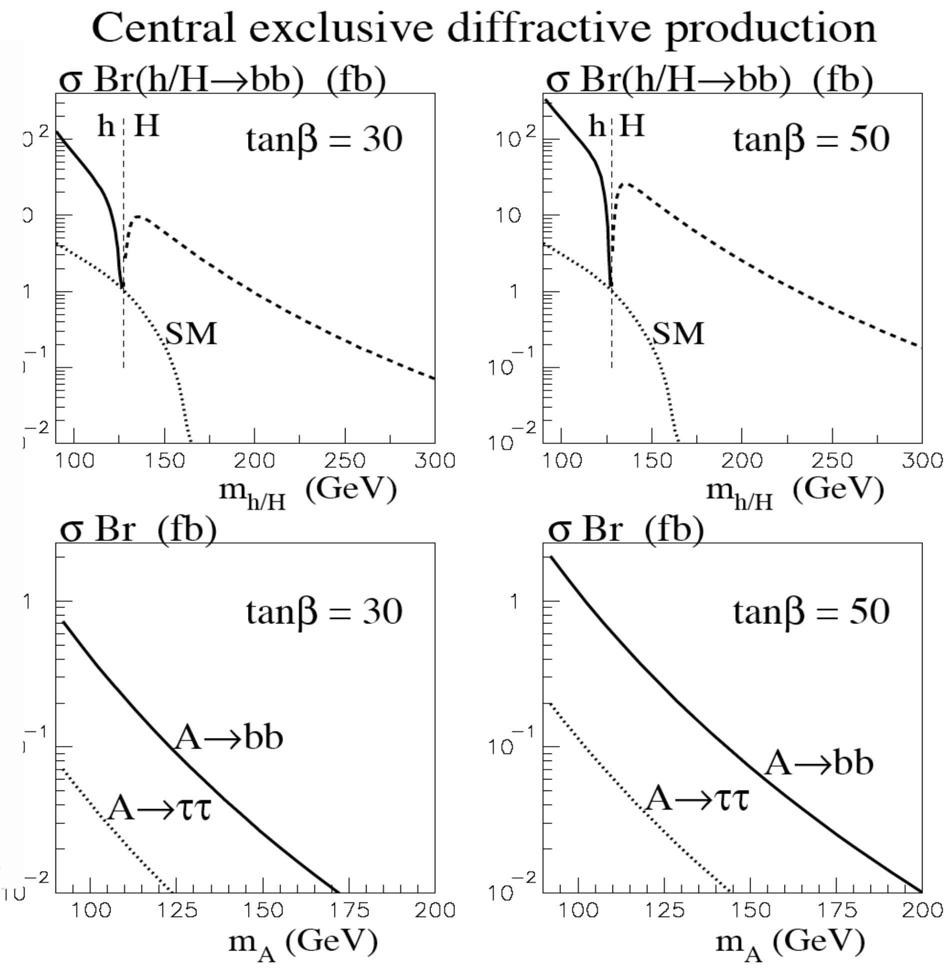
Large enhancement of coupling to $b\bar{b}$, $\tau^+\tau^-$ for high $\tan\beta$

$\Rightarrow$ 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)

Advantages vs. Disadvantages of adding AFP420

Advantages

I) Enlargement of mass acceptance

II) Excellent mass resolution

III) Can be put far from the beam (up to 7 mm w/o influencing acceptance): this leads to smaller
  - beam background
  - machine impedance
  - RF heating
  - prob. of nuclear interactions

IV) Easier alignment/calibration using physics processes (+ some help for 210?)

V) Access to the low-mass MSSM Higgs boson and other physics processes

Disadvantages

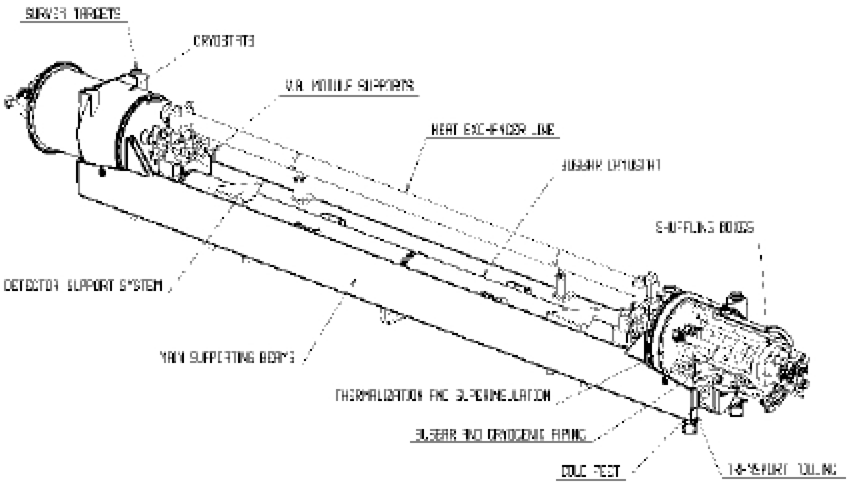
I) 420m: cold region of LHC → need for new connection cryostat

II) New connection cryostat is expensive (~ 1.5M CHF for 2 cryostats)

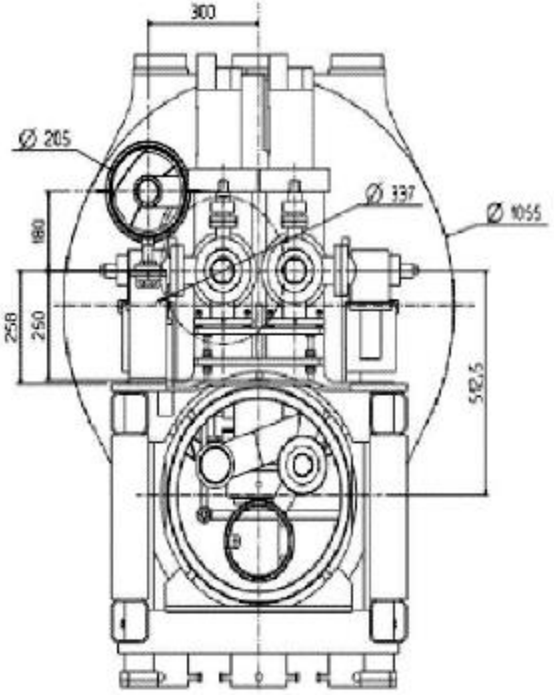
III) AFP420 can hardly be put into L1 trigger [can only be put after later upgrade (~2023)]

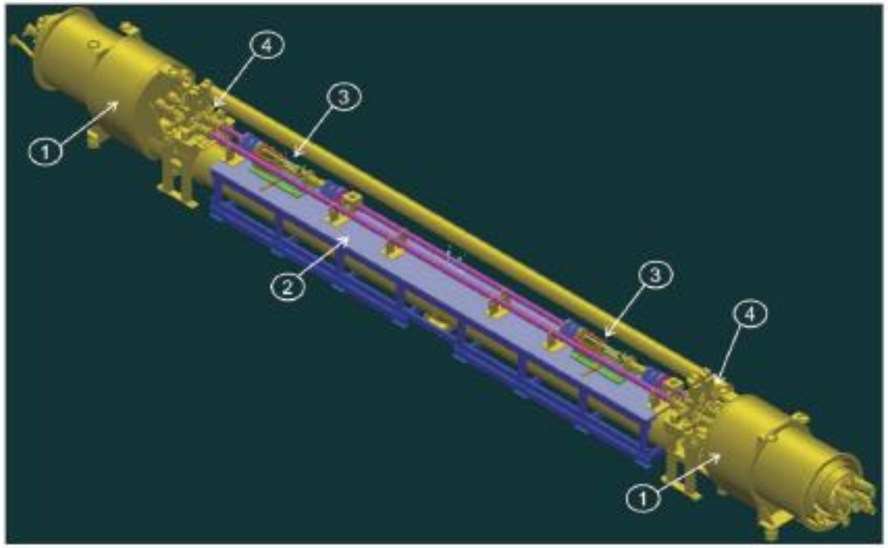
IV) Lack of support, no really interested institutes

New connection cryostat



The complete design with all services was ready in 2009! But of course needs to be revisited and updated.





Final engineering design ready in ~three months, followed by ECR - installation of 2 NCC possible for end 2009: *Thierry Renaglia* (TS/MME), Mimmo Dattola (Torino) and K. Potter (Cockroft) + V. Parma (AT/MCS) + R. Veness (AT/VAC)

	Normal Days
Warmup from 1.9K to 4.5 K	1
Warmup from 4.5K to 300 K	15
Venting	2
Dismantling interconnection	10
Removal of the connection cryostat	2
Installation of the FP420 cryostat	5
Realization of the interconnections	15
Leak test and electrical test	4
Closing of the vacuum vessel	1
Evacuation/repump	10
Leak test	2
Pressure test	4
Cool-down from 300 K to 4.5 K	15
Cool-down from 4.5K to 1.9 K	3
Total [days]	89

T. Renaglia (Cern TS/MME)
D. DAttola (Torino)
K. Potter (Manchester)
V. Parma, R. Verness (Cern AT/MCS)