$H \rightarrow \mu^+\mu^-$ in the LHC Standard model /MSSM

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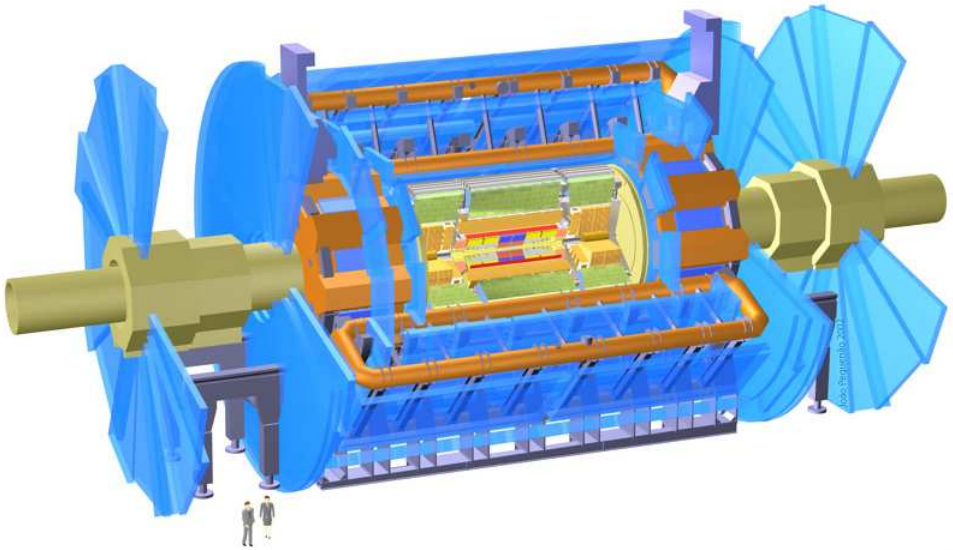
$H \rightarrow \mu^+\mu^-$ in the LHC
Standard model /MSSM

- Muons in CMS and ATLAS
- Background processes
- The Standard Model case:
  - event rates (gg and WBF)
  - discovery potential
  - outlook: vLHC sLHC
- The MSSM case:
  - MSSM parameters
  - event rates ($gg \rightarrow X$, $gg \rightarrow Xbb$)
  - background subtraction
  - discovery potential
- Conclusions



ATLAS:

2 T solenoid + 0.6 T toroid

silicon + TRT tracker

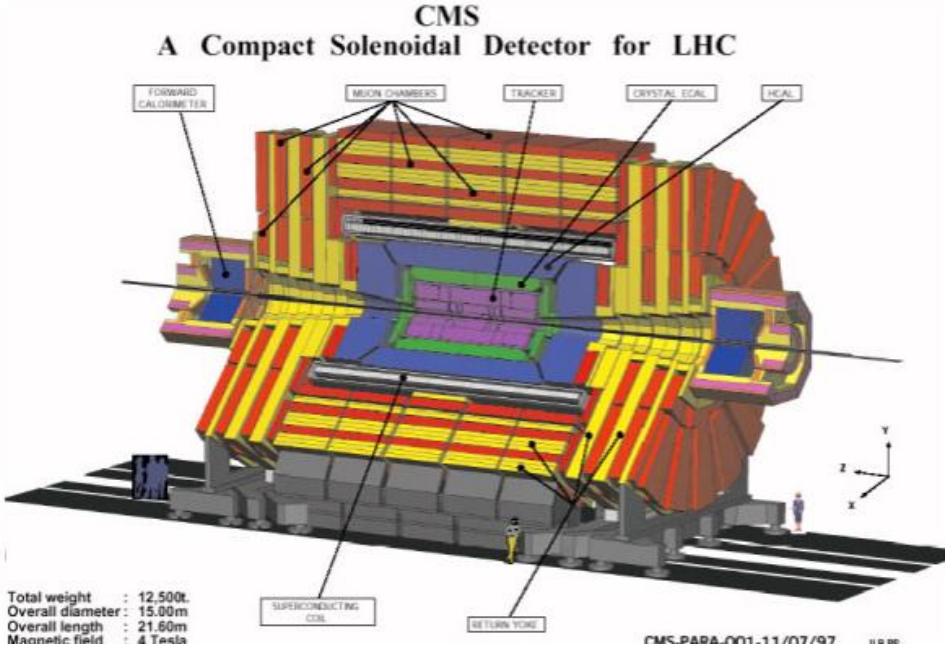
4 types of muon chambers

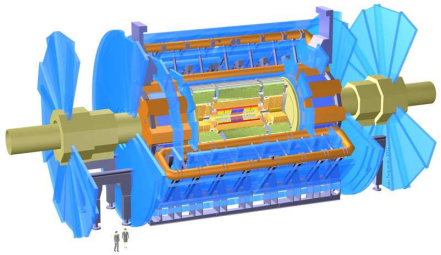
CMS

4 T solenoid

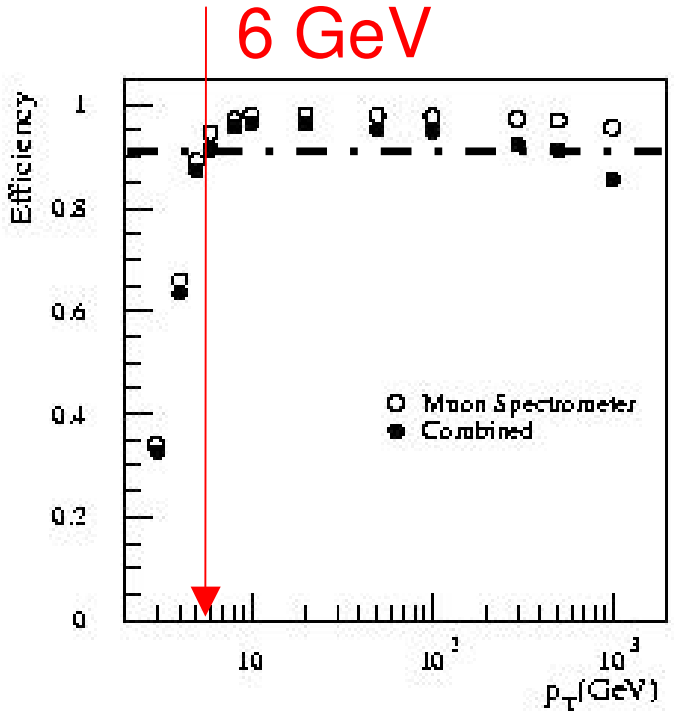
all silicon tracker

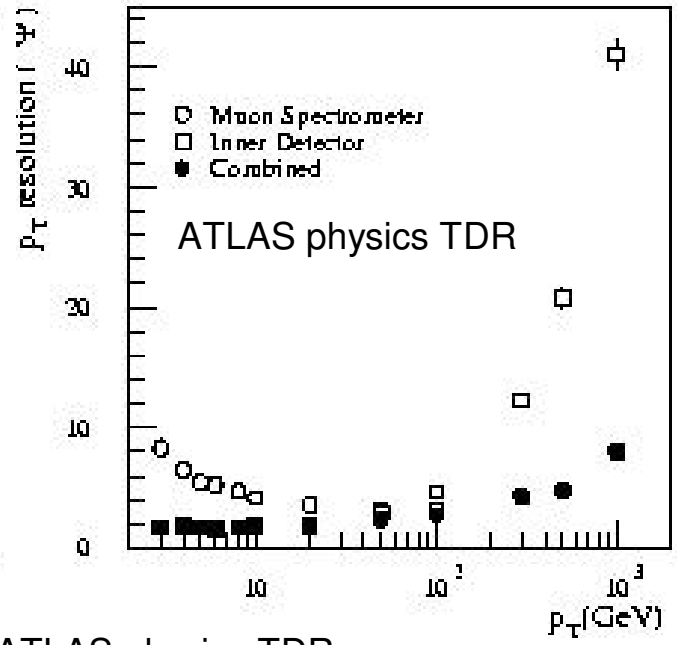
3 types of muon chambers





ATLAS

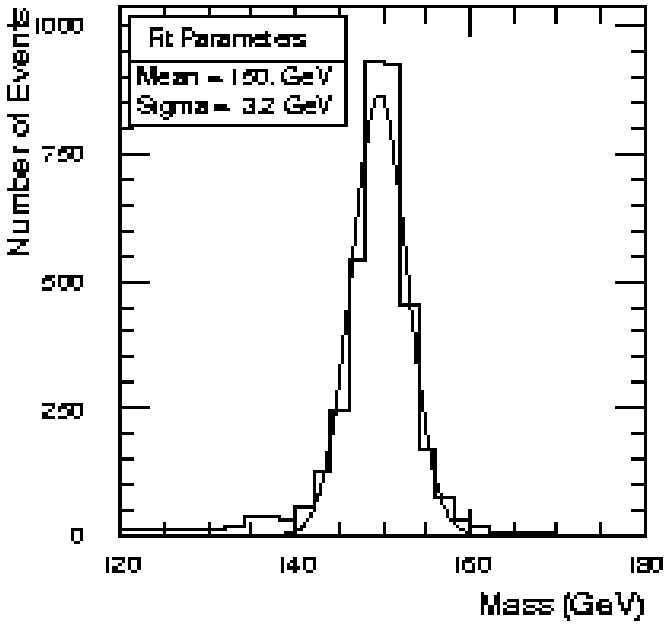


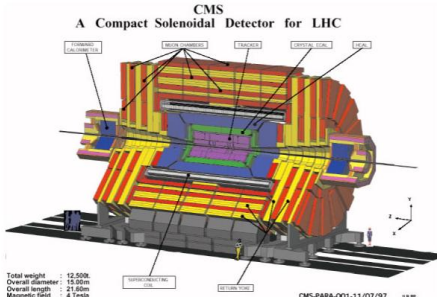


ATLAS physics TDR

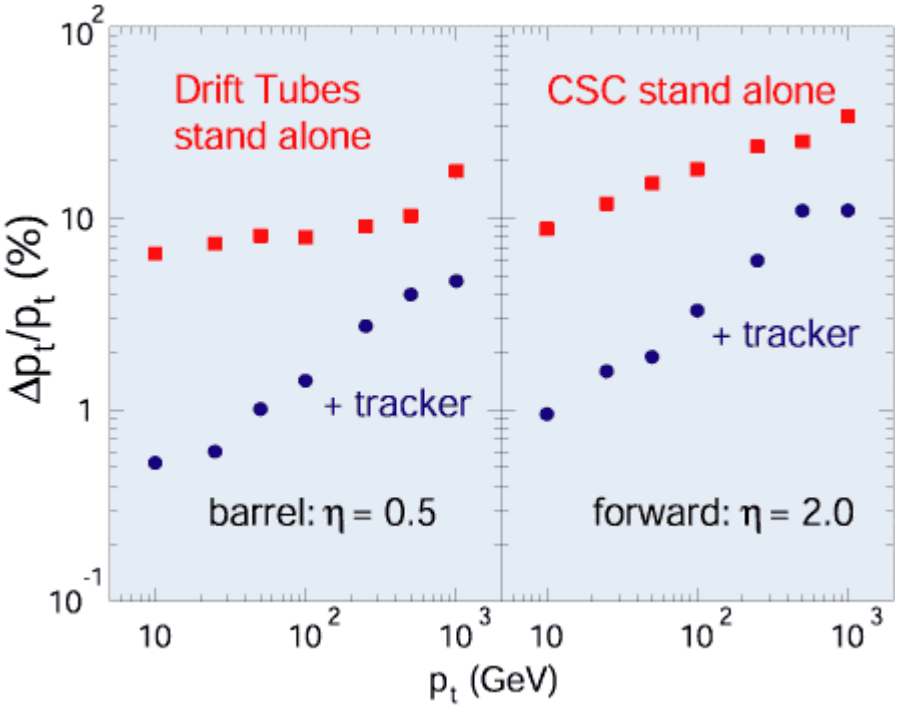
efficient muon reconstruction, identification, charge assignment, AND
trigger (p_T > 6 GeV)

good momentum $\sigma(p_T) \sim 2\ \%\ (p_T \sim 100$ GeV
and mass resolution $\sigma(M_{\mu\mu}) \sim 1.3$-$1.6$ GeV





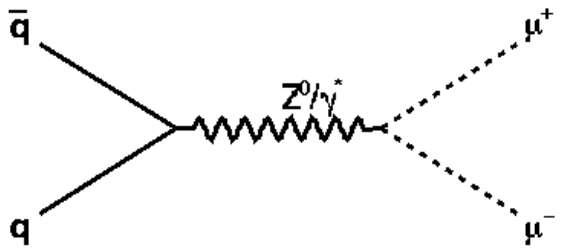
CMS



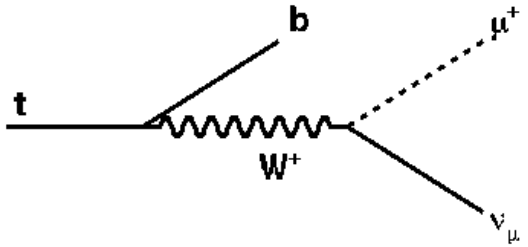
efficient muon reconstruction, identification, charge assignment (> 99%),
AND trigger for p_T > 4 GeV (>2 GeV in the end - caps)
$\sigma(p_T)$ ~ 1 - 2. % (at 50 GeV)

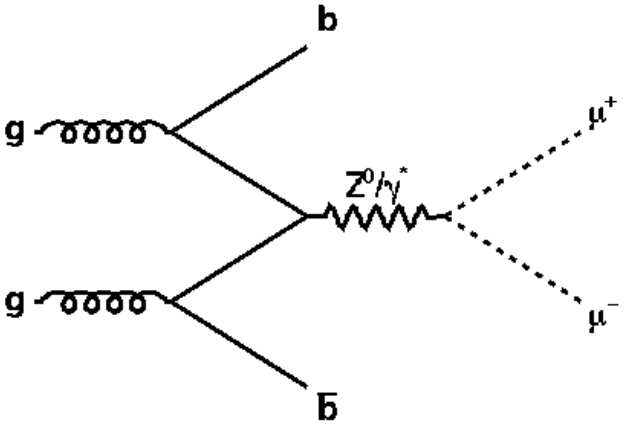
Background processes

Z/γ^* production



$t\bar{t}$ continuum





process	$\sigma \times$ B.R. (pb)
DY Z $\rightarrow\mu\mu$	2700
Zbb $\rightarrow\mu\mu$bb	~50
tt continuum	5.7

Standard Model Higgs

Detection of the muon decay would permit to:

accurately measure m_H

measure the coupling to second generation fermions
(in addition to that to 3rd generation: b, t, τ and gauge bosons: γ, W/Z)

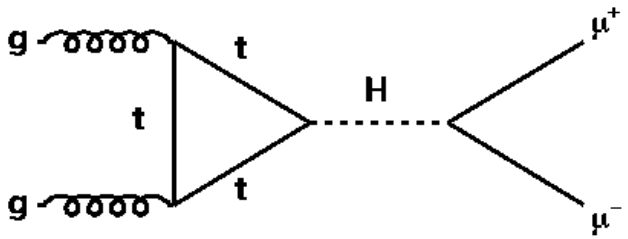
HOWEVER

B.R. ($H \rightarrow \mu^+\mu^-$) =	~2 10^{-4}	for $m_H < 2\ m_W$
	vanishing	for $m_H > 2\ m_W$

Standard Model Higgs

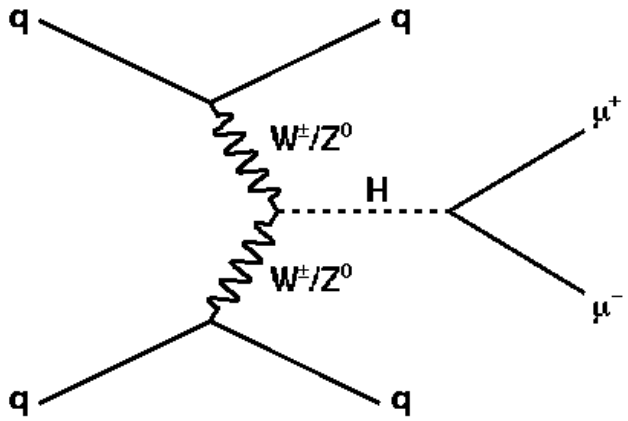
production through:

gluon fusion



Main production mechanism in the LHC. Large Drell-Yan background.

weak boson fusion



Small cross-section (~50 times less than gluon fusion), but forward jets provide distinctive signature.

Standard Model Higgs

Several generator-level studies have been performed, taking into account:

- the detector acceptance
- kinematical limits for trigger/reconstruction
- efficiency factors

[1]: T. Han & B. McElrath, *h* $\rightarrow \mu^+\mu^-$ *via gluon fusion at the LHC*, hep- ph/0201023
[2]: T. Plehn & D. Rainwater, *Higgs decays to muons in weak boson fusion*, hep- ph/0107180

MH (GeV)	gluon fusion	WBF	combined
115	2.41	2.35	3.37
120	2.51	2.37	3.45
130	2.25	2.25	3.18
140	1.61	1.58	2.26

Expected significance for the SM $H \rightarrow \mu^+\mu^-$ *channel in the LHC: ATLAS + CMS each with an integrated luminosity of 300 fb^{-1} from [1]*

Higher luminosity: sLHC

[3] F. Gianotti et al., *Physics potential and experimental challenges of the LHC luminosity upgrade*, hep- ph0204087

MH (GeV)	Gluon fusion	coupling
120	7.9	13 %
130	7.1	14 %
140	5.1	20 %
150	2.8	36 %

Expected significance for the SM $H \rightarrow \mu^+\mu^-$ channel in the sLHC: ATLAS + CMS each with an integrated luminosity of 3000 fb^{-1}) from [3]

Larger center - of- mass energy: vLHC

Reference [2] gives an example of a 200 TeV hadron collider, where the WBF production alone yields a 5 σ discovery with 300 fb^{-1}

Standard Model Higgs

CONCLUSIONS:

- The decay of the standard model Higgs boson to muons is expected to yield a ~3σ signal after 300 fb^{-1}, combining the gluon and weak boson fusion channels in ATLAS and CMS.

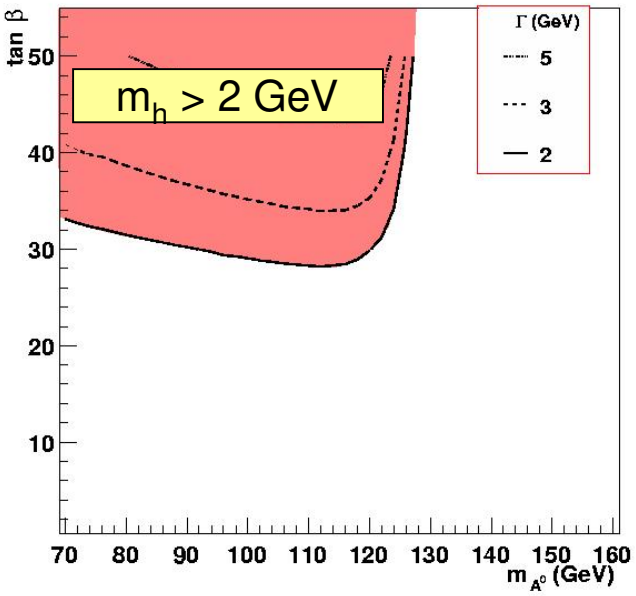
- A 5σ discovery requires:
  luminosity upgrade (sLHC) or,
  larger c.m. energy, i.e. a vLHC with $\sqrt{s}$ ~ 200 TeV or,
  enhanced production (for the MSSM, see following slides)

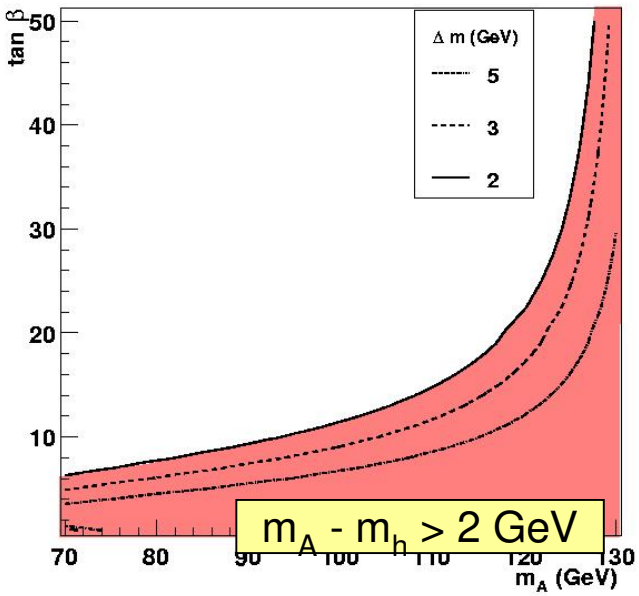
MSSM Higgs

The MSSM Higgs sector: h^0, A^0, H^0, $H^\pm$

In the maximal mixing scenario,consider two cases:
mA < 130 GeV h^0 and A^0 degenerate for large tan β
mA > 130 GeV A^0 and H^0 degenerate for large tan β

The total width increases towards large tan β





MSSM Higgs

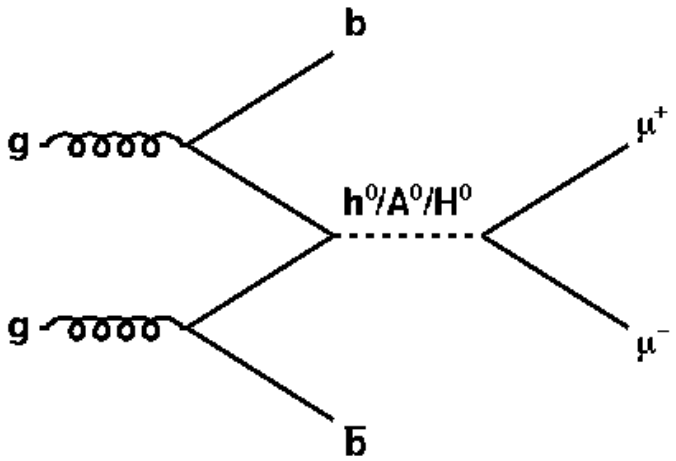
Tree level corrections to MSSM couplings w.r.t SM coupling

MSSM	h	A	H
down quarks/leptons	$-\sin\alpha / \cos\beta$	$-i\gamma_5 \tan\beta$	$\cos\alpha / \cos\beta$
up quarks	$\cos\alpha / \sin\beta$	$-i\gamma_5 \cot\beta$	$\sin\alpha / \sin\beta$

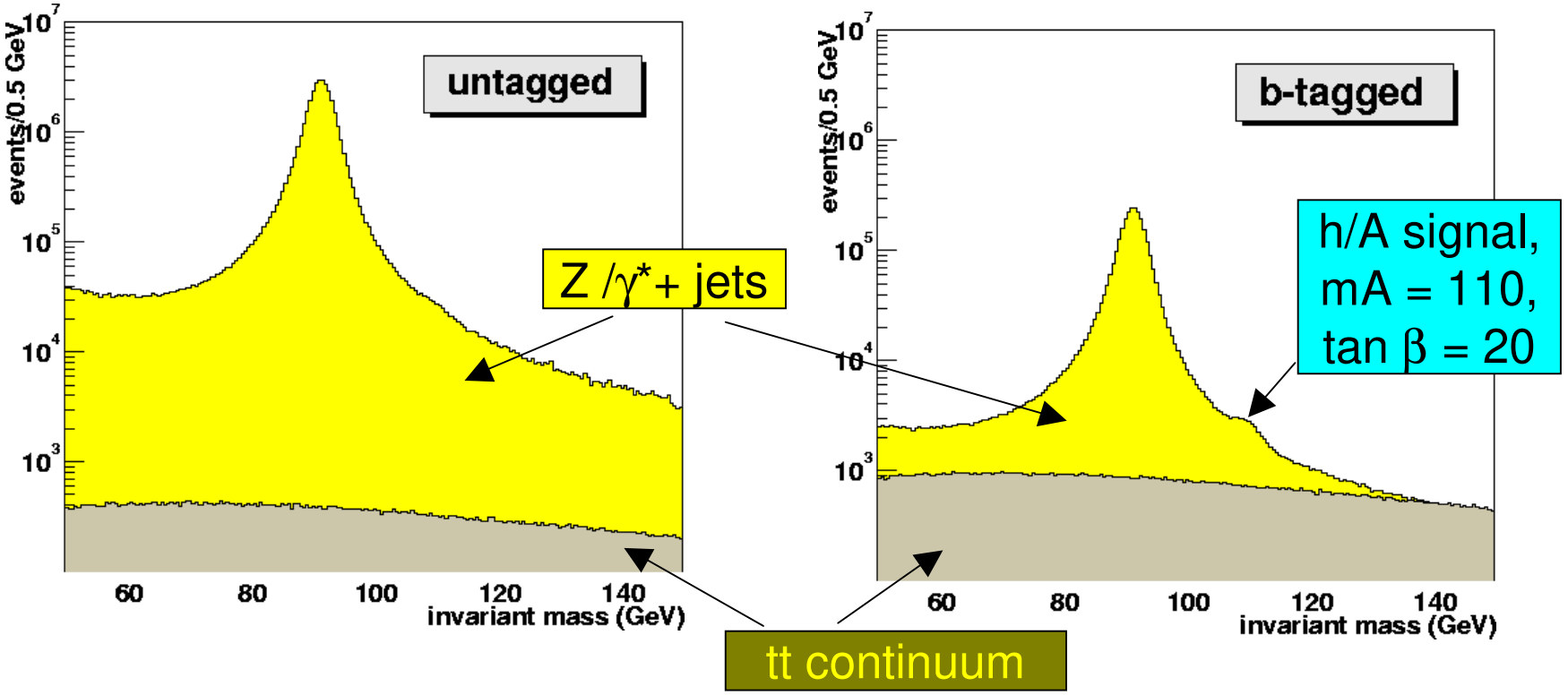
Small branching ratio ($3\ 10^{-4}$) to muons

Higgs- to- b coupling grows with tan β

Enhanced associated production +
b- jets to distinguish final state.



MSSM Higgs



b- tagging helps against DY,
but not against tt continuum

MSSM Higgs

Several more or less recent studies:

H/A, CMS: L. Bellucci, *MSSM neutral Higgs boson searches at CMS in the $\mu^+\mu^-$ channel*, Ph.D. thesis, U. degli Studi Firenze.

I.K. Furic, R. Kinnunen, Study of H/A $\rightarrow\mu^+\mu^-$ *in CMS, CMS note 1998/039*

H/A, ATLAS: ATLAS physics TDR

h/A, ATLAS: S. Gentile, M. Paniccia, P. Violini, *Search for super-symmetric neutral h boson in the decay $\rightarrow\mu^+\mu$ in the ATLAS detector,* ATL- PHYS- 2003- 013,
S. Gonzalez de la Hoz, E. Ros, M. Vos, *Analysis of the process $pp\rightarrow bbh/A\rightarrow bb\mu^+\mu^-$ in the MSSM with mA < 125 GeV,* ATL- PHYS- 2002- 021.

Overview ATLAS MSSM results:

M. Schuhmacher, this conference.

Overview ATLAS+CMS MSSM results:

R. Kinnunen, *Higgs physics at the LHC*, CMS conference report 2002/020

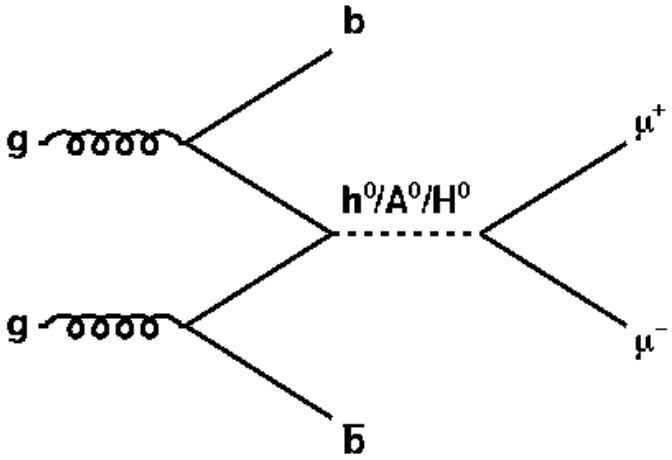
MSSM Higgs: cross sections

Three theoretical approaches to the cross section calculation of associated production of bosons with b-quarks

explicit Matrix Elements for gg -> bbX
(LO, preliminary results for NLO)

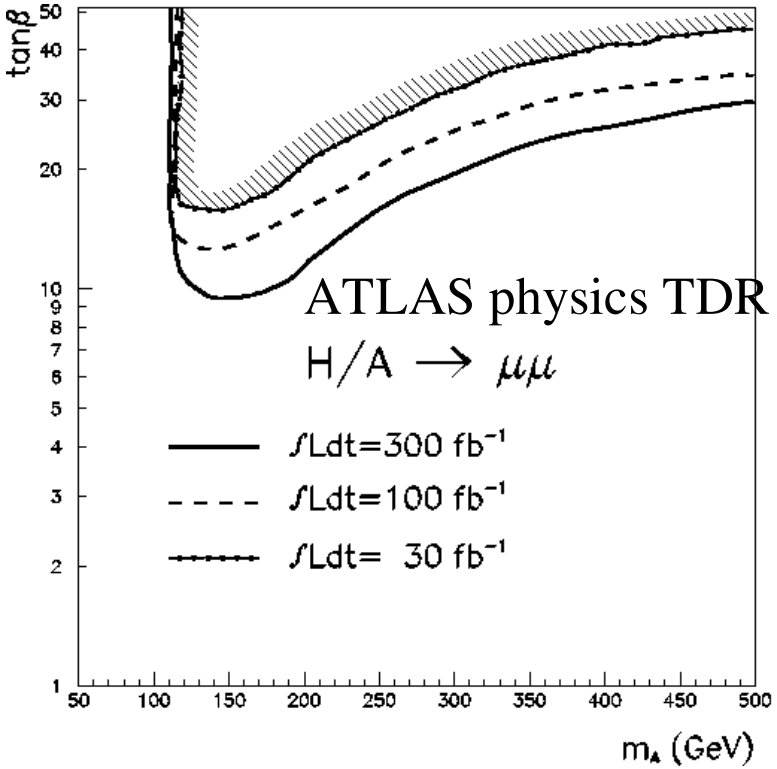
Shower approach resums large logs in b PDF
(NNLO available)

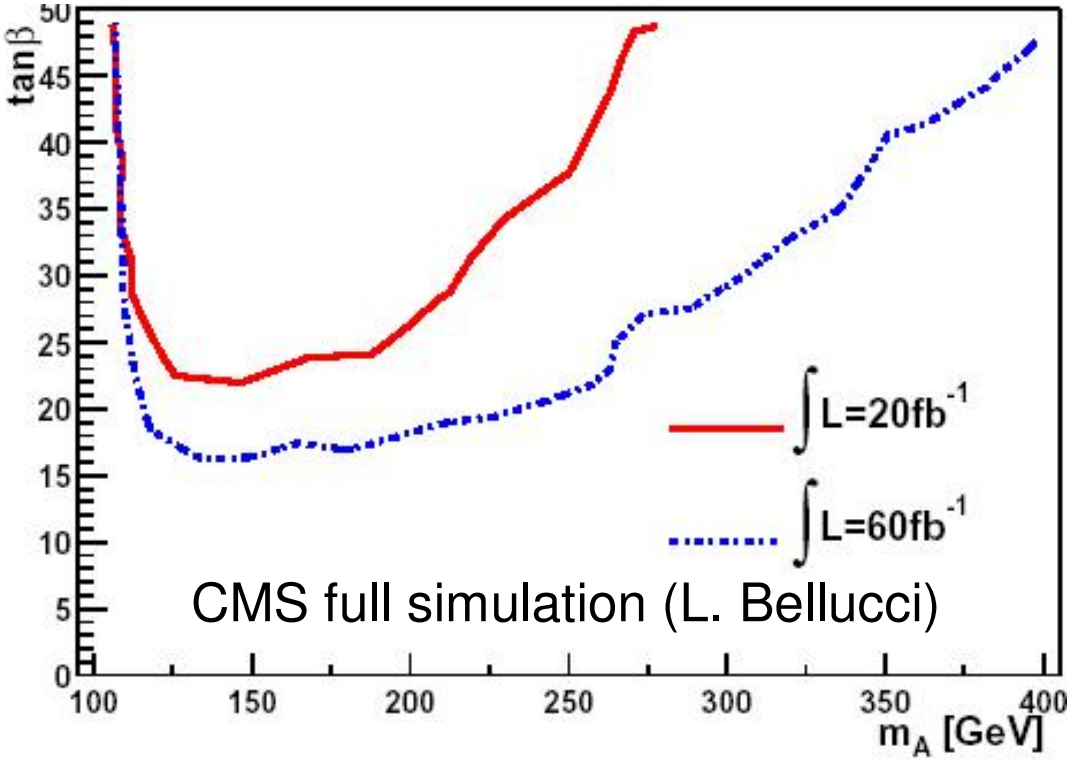
Intermediate approach (one g-> bb, one PDF)



Large variation in predictions for inclusive cross-sections
Better agreement on exclusive results (i.e. p_T (b-jets) > 15 GeV)
Choose scale Q < m_H + preliminary NLO ME results -> convergent results
Here: LO Matrix Element cross-sections used ->
large K- factor expected

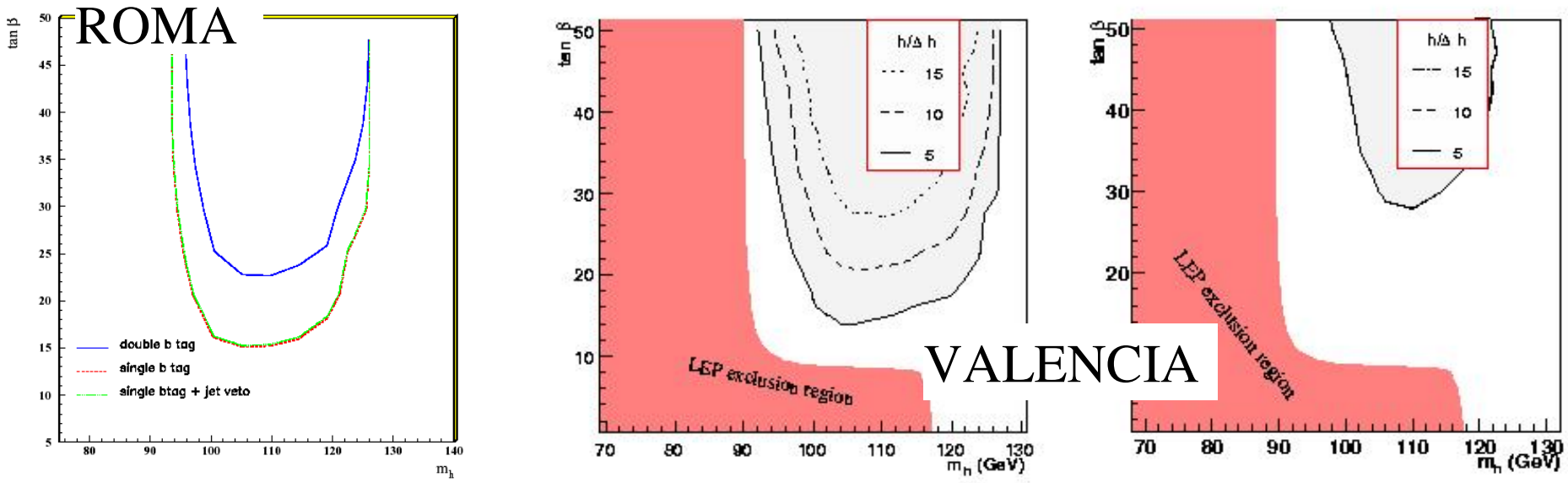
MSSM Higgs : A^0/H^0





ATLAS and CMS studies predict approximately the same discovery region (given some integrated luminosity) for both experiments.

MSSM Higgs h^0/A^0



ATLAS, 300 fb^{-1}, matrix element cross sections, no K factors

Use b-tag to reduce Z background

Two independent methods to extract the signal from the irreducible background.

-- using the b- jet + $e^+ e^-$ sample

-- using the untagged $\mu^+ \mu^-$ + jets sample

The results are compatible.

MSSM Higgs

If the muonic channels are discovered, they will allow to:

- rule out SM (combined with another channel, or even alone)

- constrain MSSM parameters, using the mass peak:
- center: precisely measure m_A (provided masses are degenerate)
- width : measure tan b (for tan b > 20)
- height: depends on the H- μ and H- b couplings and tan β

$H \rightarrow \mu^+\mu^-$: conclusions

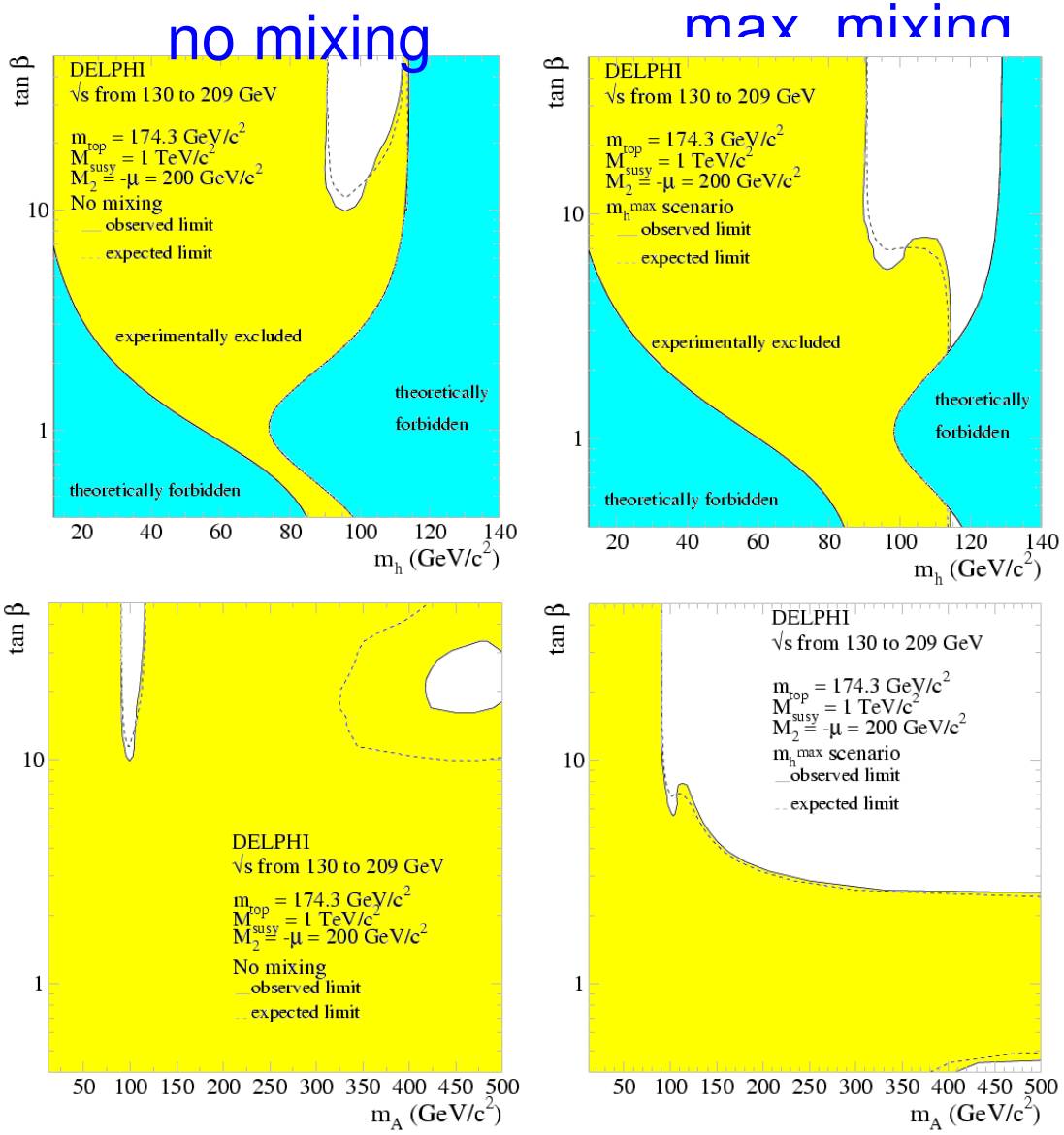
- $H_{SM} \rightarrow \mu^+ \mu^-$ /m_H < 140 GeV) yields a 3 σ signal after 300 fb^{-1}, combining the ATLAS and CMS, gluon fusion and WBF results.

- an **sLHC** ($\int L = 3000\ fb^{-1}$) or **vLHC** ($\sqrt{s} = 200$ GeV) yields a >5σ discovery

- Muonic decays of MSSM Higgs bosons cover two important regions of parameter space:

H^0 / A^0: with 50 fb^{-1}	$m_A \in$ <120 - 250> GeV , tan β > 15
h^0 / A^0: with 300 fb^{-1}	$m_A \in$ <105-125> GeV, tan β > 15.

Appendix: LEP results

LEP (DELPHI) results:

the DELPHI collaboration, *final results from DELPHI searches for SM and MSSM neutral Higgs bosons*, hep-ex/0303013