$h \to \mu^+\mu^-$ AT THE LHC*

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I. $h\mu^+\mu^-$ coupling: SM and beyond

II. LHC & LC: WW fusion

III. LHC: gluon-fusion and combined

*T. Han and B. McElrath, hep-ph/0201023.

Once a Higgs boson is discovered, it is of most importance to study its properties.

Higgs boson couplings to fermions reveal mechanism of fermion mass generation:

$$m_f = \lambda_f \frac{v}{\sqrt{2}.}$$

- At the LHC, access to h^0 couplings to
  $WW,\ ZZ,\ t\bar{t},\ \tau^-\tau^+$

as well as the loop-induced $gg,\ \gamma\gamma$.

- At a Linear Collider, extend to $b\bar{b},\ c\bar{c}$.

- Naturally, the next coupling is $h^0\mu^+\mu^-$
  - † check proportionality to m_μ
  - † lepton-flavor non-universality
  - † easy channel to identify

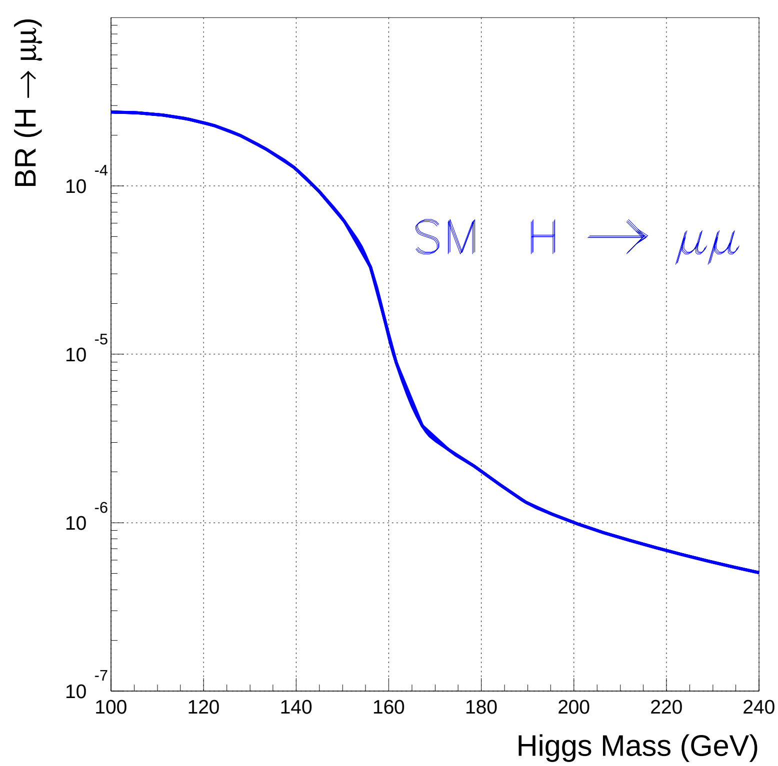
I. $h\mu^+\mu^-$ coupling: SM and MSSM

The coupling at tree-level:

$h\mu\mu$	$H\mu\mu$	$A\mu\mu$
$-\frac{\sin\alpha}{\cos\beta} \to 1$	$\frac{\cos\alpha}{\cos\beta} \to \tan\beta$	$-i\gamma_5 \tan\beta$

the limit is for $M_A \gg M_Z$,
and $h\mu\mu$ goes to the SM.

The BR in the SM:



II. LHC & LC: WW fusion

$$WW,\ ZZ \to \mu^+\mu^-$$

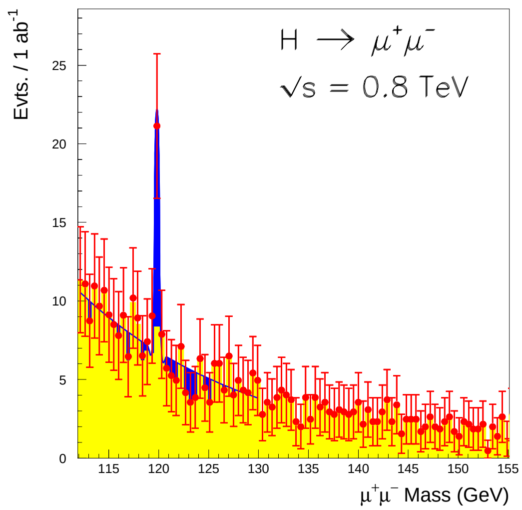
AT the LHC, vLHC:†

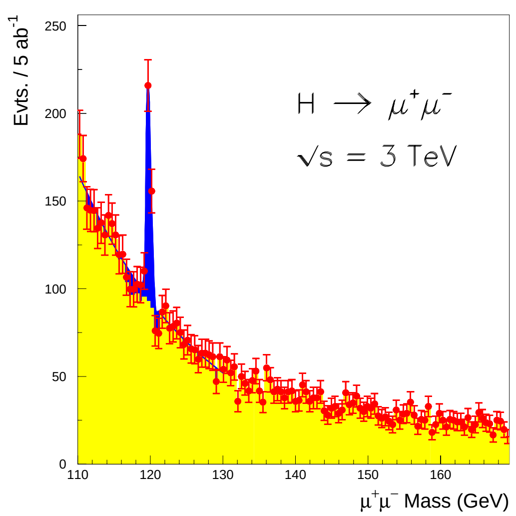
$p_{T_j} \geq 20$ GeV $\quad \triangle R_{jj} \geq 0.6$
$|\eta_j| \leq 4.5 \quad |\eta_{j_1} - \eta_{j_2}| \geq 4.2 \quad \eta_{j_1} \cdot \eta_{j_2} < 0$
and $m_{jj} > 500$ GeV (LHC); $\quad m_{jj} > 1000$ GeV $(VLHC)$

$\sqrt{S}$	M_H	σ_H	σ_Z^{ew}	σ_{Zjj}	S/B	σ	$\frac{\triangle\sigma}{\sigma}$%	$\mathcal{L}[fb^{-1}]$
14	120	0.22	2.60	0.33	1/7.5	1.8	60	2300
14	140	0.10	1.11	0.19	1/7.5	1.2	85	4900
40	120	0.52	3.32	0.79	1/5.3	3.3	35	700
40	140	0.25	1.51	0.41	1/5.0	2.4	50	1400
200	120	2.36	29.2	4.0	1/8.0	5.7	20	230
200	140	1.14	13.4	2.0	1/7.9	4.0	27	500

†T. Plehn and D. Rainwater, hep-ph/0107180.

At the LC:‡





‡M. Battaglia and A. De Roeck, hep-ph/0111307.

III. LHC: gluon-fusion and combined

Gluon-fusion signal:

$$gg \to h \to \mu^+\mu^-$$

Major background:

$$q\bar{q} \to Z^*, \gamma^* \to \mu^+\mu^-$$

Kinematical cuts:

$$p_T > 20 \text{ GeV}, \quad \eta < 2.5.$$

(veto central jets)

To estimate the signal significance, take

$$m_h - 2.24 \text{ GeV} < m(\mu^+\mu^-) < m_h + 2.24 \text{ GeV}.$$

SM cross sections in fb for both gluon fusion and weak-boson fusion signals, and the corresponding backgrounds after all cuts. A 90% muon identification efficiency factor is included. The weak-boson fusion results are taken from Plehn&Rainwater.

m_h(GeV)	Gluon fusion		W boson fusion	
	signal	backgrnd	signal	backgrnd
115	4.50	2085	0.092	0.82
120	3.89	1441	0.081	0.62
130	2.63	821	0.062	0.40
140	1.51	526	0.037	0.28

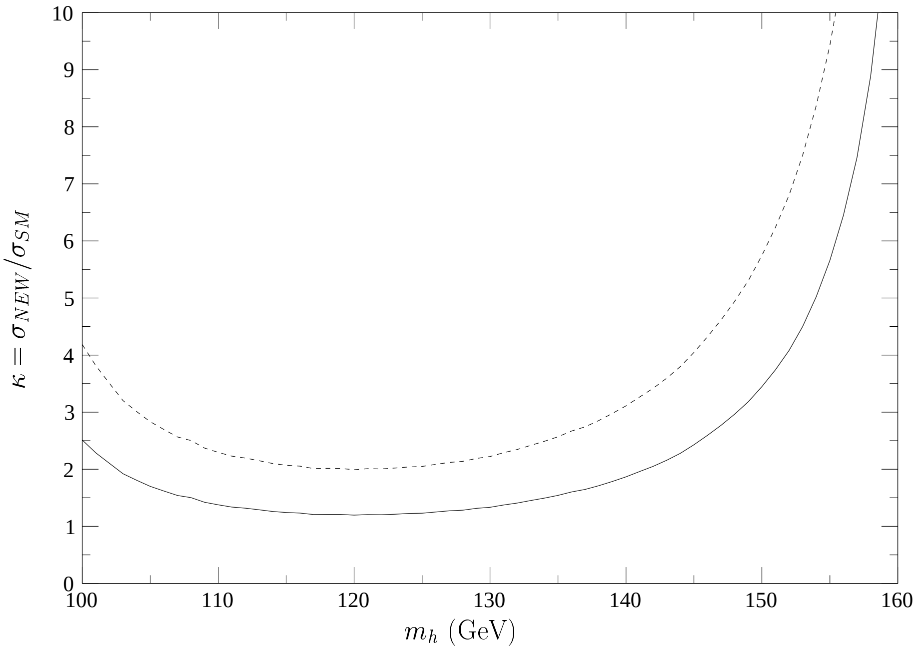
Combined results:

m_h(GeV)	L for 3σ (fb^{-1})			σ's for 300 fb^{-1}		
	WW, gg	gg	WW	WW, gg	gg	WW
115	238	464	489	3.37	2.41	2.35
120	227	430	482	3.45	2.51	2.37
130	267	535	532	3.18	2.25	2.25
140	531	1047	1076	2.26	1.61	1.58

For LHC luminosity upgrade:

Expected signal significance of a SM $gg \to H \to \mu\mu$ signal for various mass values, as obtained by combining ATLAS and CMS and for an integrated luminosity of 3000 fb^{-1} per experiment

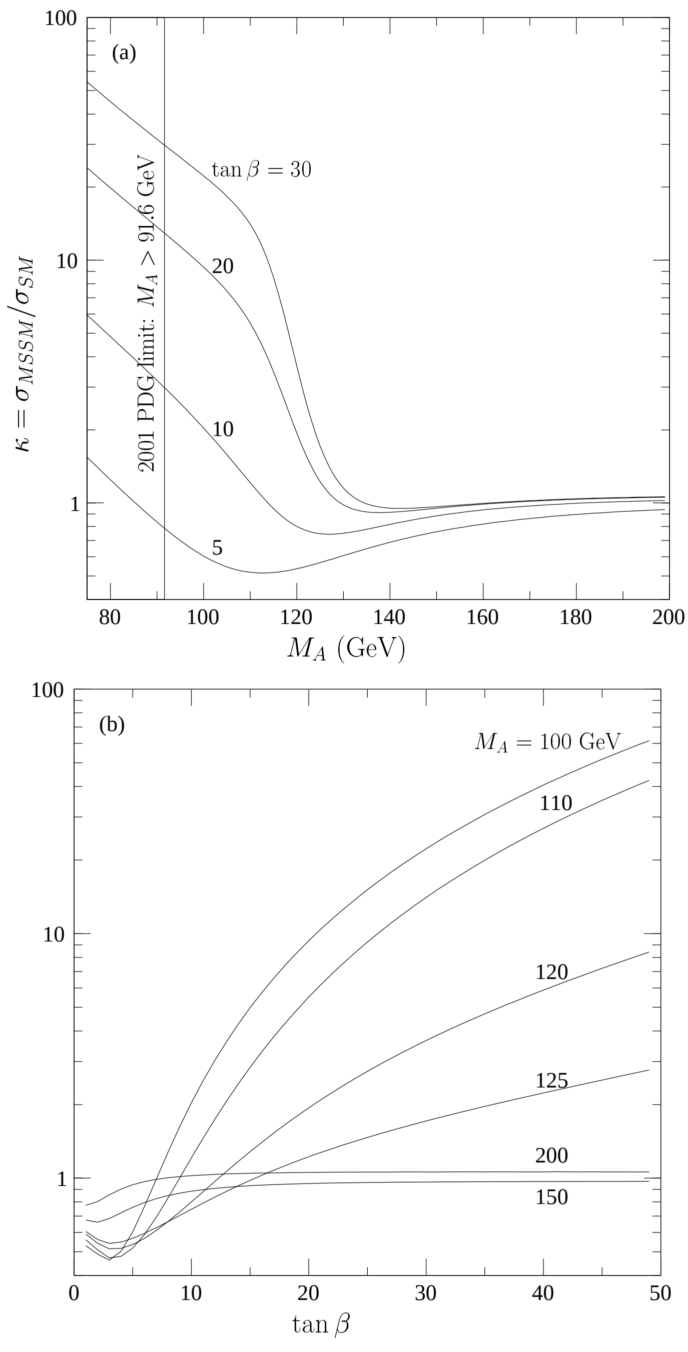
m_H (GeV)	$S/\sqrt{B}$	$\frac{\delta\sigma \times BR(H\to\mu\mu)}{\sigma \times BR}$
120 GeV	7.9	0.13
130 GeV	7.1	0.14
140 GeV	5.1	0.20
150 GeV	2.8	0.36



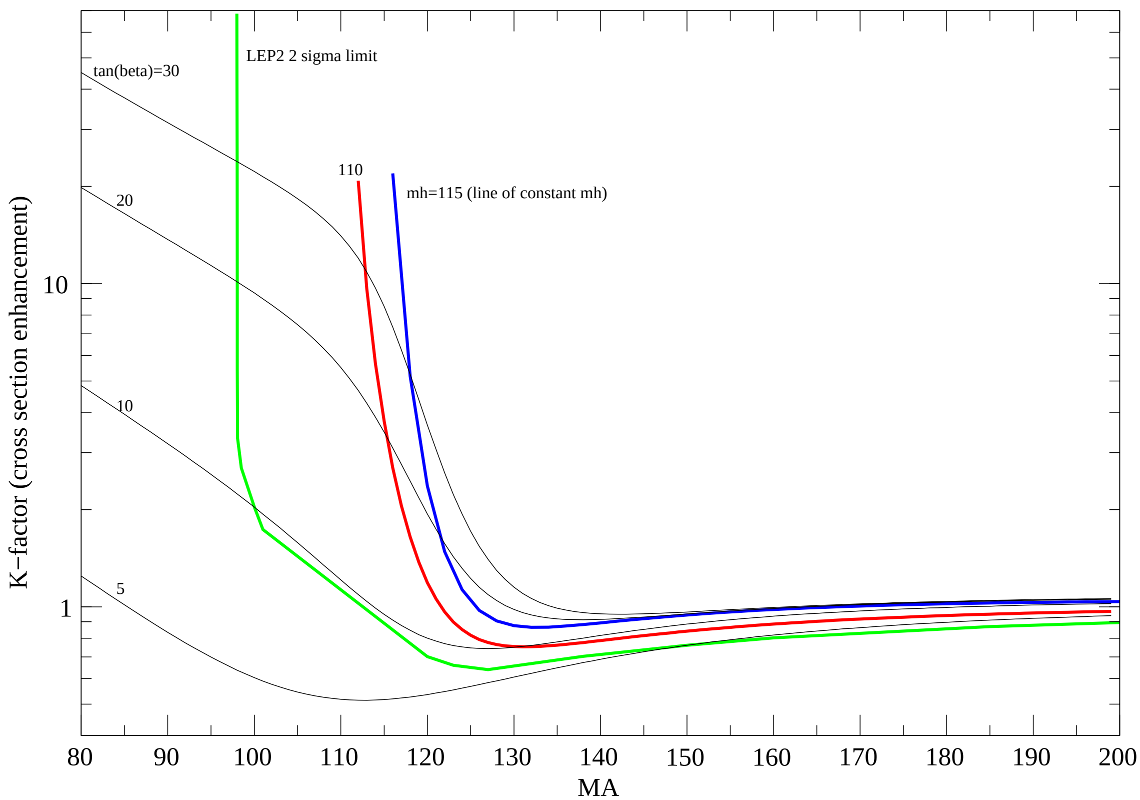
The enhancement factor κ over the SM rate required to observe the $gg \to h \to \mu^+\mu^-$ signal at the 3σ (solid) and 5σ (dashed) level with 300 fb^{-1} delivered luminosity, including both the ATLAS and CMS detectors.

Given a κ factor, the luminosity at S significance is:

$$\mathcal{L} = S^2 \frac{\sigma_B}{\kappa^2 \sigma_S^2}$$



The enhancement of h production of the MSSM relative to the SM in the maximal stop mixing scenario as a function of (a) M_A and (b) $\tan\beta$.



The enhancement of h production of the MSSM relative to the SM in the maximal stop mixing scenario as a function of M_A.

Summary:

- By including both the gluon fusion channel and the weak-boson fusion channel, and by including the ATLAS and CMS detector, 300 fb^{-1} can lead to a statistical significance of 3σ over a Higgs mass range of

  110 GeV$< m_h <$140 GeV.

  In contrast to WW fusion only: 1.8σ for $m_h =$120 GeV.

- This corresponds to the $h\mu\mu$ coupling determination about 14%$-$17% (assuming $ht\bar{t}$, $hb\bar{b}$ couplings SM-like).

  In contrast to LC case: 800 GeV with 1 ab^{-1},

  15% coupling measurement for $m_h =$120 GeV.

- For MSSM with large $\tan\beta$ and $M_A <$ 130 GeV, we may easily observe this channel at the LHC:

  multiple contribution from h, H, A,

  and determine the branching fraction to an accurate level.