Associated MSSM Higgs production with heavy quarks at the LHC

(and a brief summary of other work...)

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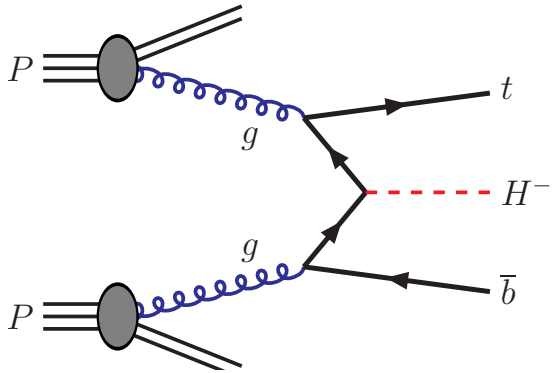
Associated MSSM Higgs production with heavy quarks

- Associated $Q\bar{Q}$-Higgs production



  - is a crucial MSSM Higgs discovery channel
  - directly measures the heavy-quark–Higgs Yukawa coupling

- In the MSSM one has $pp \to Q\bar{Q} + h, H, A$ and $pp \to Q\bar{Q}' + H^{\pm}$

- The relative importance depends on the MSSM parameters, in particular $\tan\beta$, e.g.:

$$g_{bbH}^{\mathrm{MSSM}} = -\frac{\sin\alpha}{\cos\beta}\, g_{bbH}^{\mathrm{SM}} \xrightarrow{\tan\beta \gg 1} \tan\beta\, g_{bbH}^{\mathrm{SM}}$$

Associated MSSM Higgs production with heavy quarks

One objective within project B5 has been to calculate the SUSY-QCD corrections to heavy quark Higgs associated production in the MSSM:

- Neutral MSSM Higgs-boson production with heavy quarks: NLO supersymmetric QCD corrections
  Stefan Dittmaier, Petra Häfliger, MK, Michael Spira, Manuel Walser, Phys. Rev. D90 (2014) 035010

- Charged-Higgs-boson production at the LHC: NLO supersymmetric QCD corrections
  Stefan Dittmaier, MK, Michael Spira, Manuel Walser, Phys.Rev. D83 (2011) 055005

- MSSM Higgs-boson production in bottom-quark fusion: electroweak radiative corrections
  Stefan Dittmaier, MK, Alexander Mück, Tobias Schlüter, JHEP 0703:114,2007

Associated MSSM Higgs production with heavy quarks

A lof of time in recent years went into calculating numbers which have been used by ATLAS and CMS to interpret MSSM Higgs searches:

CERN–2013–004
29 July 2013

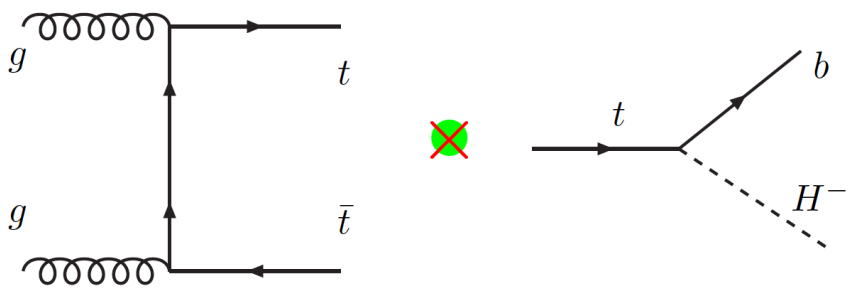
ORGANISATION EUROPÉENNE POUR LA RECHERCHE NUCLÉAIRE
CERN EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Handbook of LHC Higgs cross sections:
3. Higgs Properties

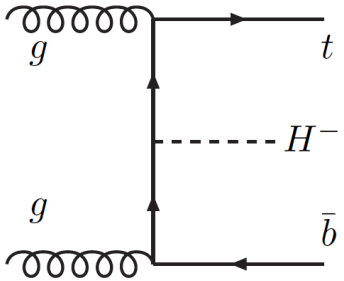
Report of the LHC Higgs Cross Section Working Group

Charged Higgs boson production at the LHC

- $pp \to t\bar{t}$ with $t \to bH^{\pm}$ for $M_{H^{\pm}} \lesssim m_{\mathrm{top}}$



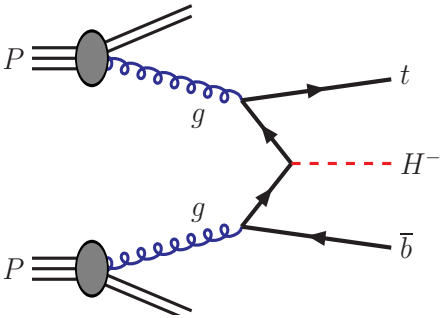
- $pp \to tbH^{\pm}$ for $M_{H^{\pm}} \gtrsim m_{\mathrm{top}}$



alternative production mechanisms like $q\bar{q}' \to H^{\pm}$, $pp \to H^{\pm} + \mathrm{jet}$, $pp \to H^{\pm}W^{\mp}$, or Higgs pair production are suppressed...

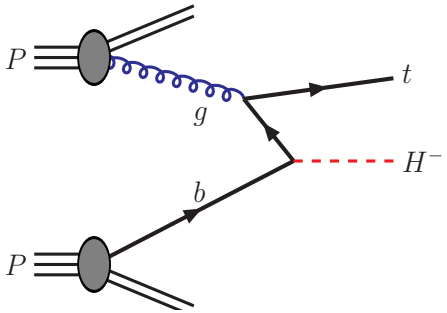
Heavy charged Higgs production

4-flavour scheme



+ exact $g \to b\bar{b}$ splitting & mass effects
− no summation of $\ln(M_H/M_b)$ terms

5-flavour scheme



+ summation of $\ln(M_H/M_b)$ terms
− LL approximation to $g \to b\bar{b}$ splitting

- Santander matching [Harlander, MK, Schumacher, CERN-PH-TH/2011-134]

Combine the two schemes with a weight that depends logarithmically on $m_{\mathrm{H}}/m_{\mathrm{b}}$:

$$\sigma^{\text{matched}} = \frac{\sigma^{\text{4FS}} + w\,\sigma^{\text{5FS}}}{1+w}\,,$$

with the weight w defined as $w = \ln(m_{\mathrm{H}}/m_{\mathrm{b}}) - 2$.

Heavy charged Higgs production

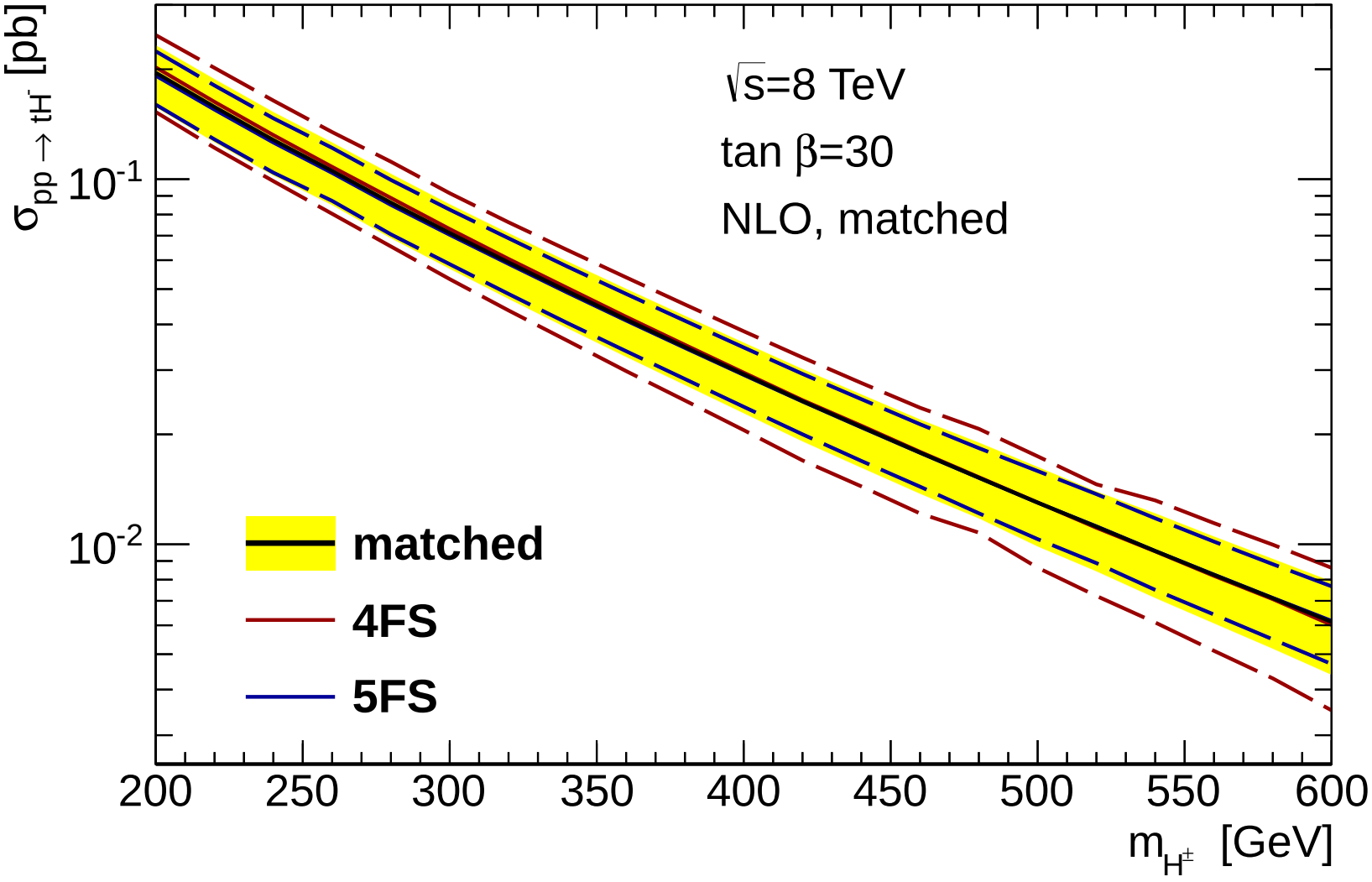
- The 4FS and 5FS calculations are available in NLO-SUSY QCD
  [Plehn PRD67 (2003) 014018; Dittmaier, Krämer, Spira, Walser (PRD83 (2011) 055005)]

- The scale in the 5FS calculation has been set according to the scheme proposed by Maltoni, Ridolfi, Ubiali (JHEP 1207 (2012) 022)

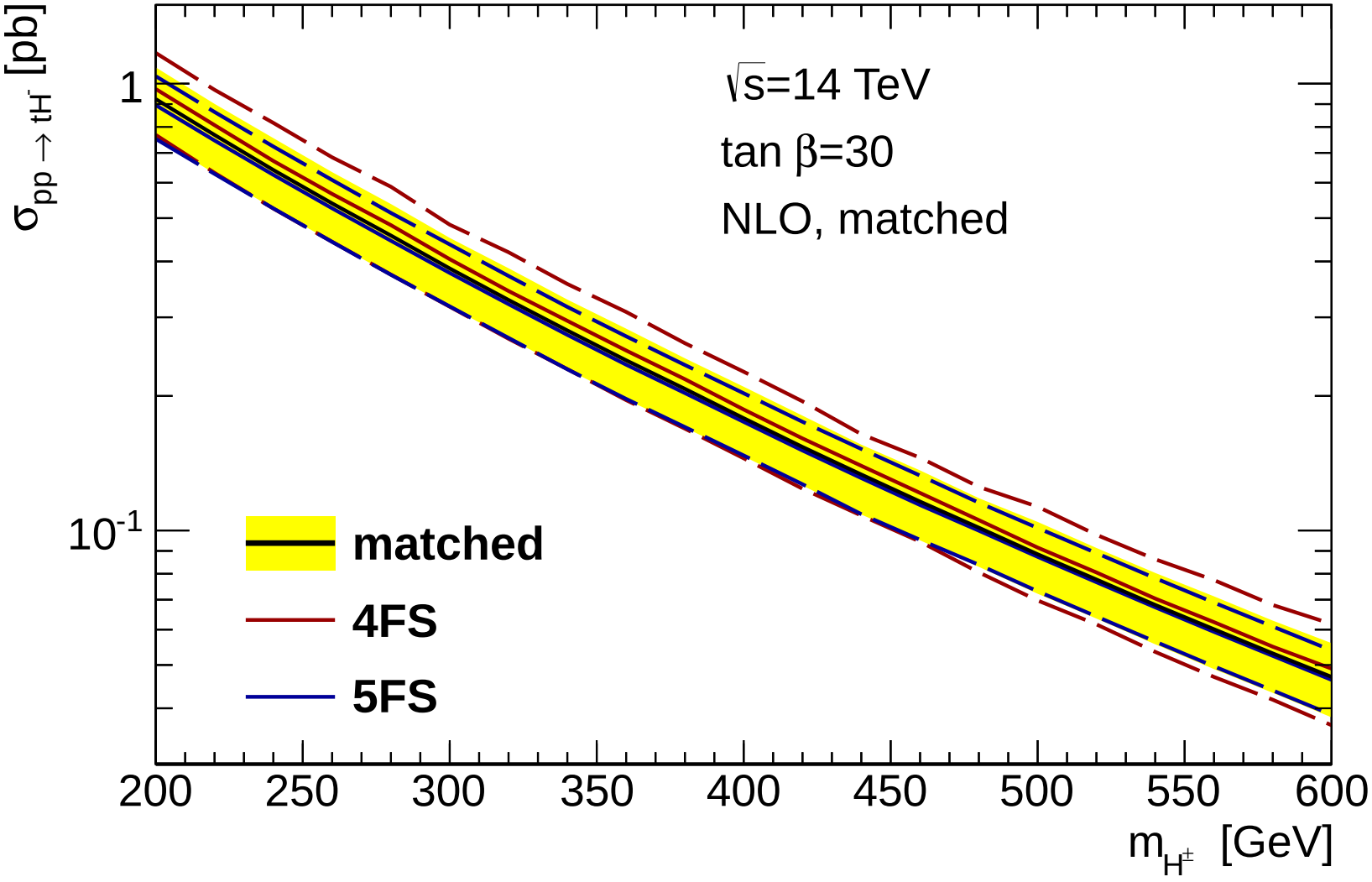
	8 TeV		14 TeV	
M_{H} [GeV]	$\tilde{\mu}$ [GeV]	$(m_{\mathrm{t}} + M_{\mathrm{H}})/\tilde{\mu}$	$\tilde{\mu}$ [GeV]	$(m_{\mathrm{t}} + M_{\mathrm{H}})/\tilde{\mu}$
200	70	5.5	75	4.9
400	95	6.2	105	5.4
600	115	6.7	135	5.8

- Theoretical uncertainties include scale variation as well as pdf, m_b and α_{s} uncertainty, evaluated according to the PDF4LHC and Higgs cross section working group recommendations [Flechl, Klees, MK, Spira, Ubiali 2014]

Heavy charged Higgs production: 8 TeV



Heavy charged Higgs production: 14 TeV



Heavy charged Higgs production

$\sqrt{s}$ [TeV]	$m_{H^\pm}$ [GeV]	$\sigma_{\rm NLO}$ [pb]	$\Delta^\pm_\mu$ [%]	$\delta^\pm_{\rm PDF+\alpha_s+m_b}$ [%]	$\Delta^\pm_{\rm tot}$ [%]
8	200	0.192	±10	±7	±17
	400	0.0291	±10	±10	±20
	600	0.00617	±10	±15	±25
14	200	0.895	±10	±7	±17
	400	0.175	±9	±8	±18
	600	0.0463	±9	±9	±18

- overall theoretical uncertainty $\approx 20\%$,

  with about equal contributions from scale and parametric uncertainties.

Heavy charged Higgs production: MSSM parameter dependence

- dominant SUSY-QCD (non-decoupling) contributions from corrections to bottom-Higgs Yukawa coupling Δ_b: [Dittmaier, MK, Spira, Walser]

$$\sigma_{\rm NLO} = \sigma_0 \times (1 + \delta^{\tan\beta-\rm resum.}_{\rm SUSY-QCD}) \times (1 + \delta_{\rm QCD} + \delta^{\rm remainder}_{\rm SUSY-QCD})$$

$M_{\rm H^\pm}$ [GeV]	σ_0 [fb]	$\delta_{\rm QCD}$	$\delta^{\tan\beta-\rm resum.}_{\rm SUSY-QCD}$	$\delta^{\rm remainder}_{\rm SUSY-QCD}$
214	545	0.57	−0.30	−0.002
310	234	0.61	−0.30	−0.002
407	109	0.63	−0.30	−0.002

for $\tan\beta = 30$ and SUSY point SPS4.

Non-universal SUSY corrections $\delta^{\rm remainder}_{\rm SUSY-QCD}$ can reach up to $\mathcal{O}(10\%)$ for smaller values of $\tan\beta$.

- MSSM EWK corrections may be significant for a light MSSM spectrum [Jin et al., Belyaev et al., Beccaria et al., Hollik et al.]

. . . more B5 projects (last four years)

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Precision calculations (mostly for BSM processes)

- NLL/NNLL threshold resummation for squark and gluino production
  $\rightarrow$ see Eric Laenen's talk

- NLO-QCD corrections for SUSY particle production and decay with parton showers
  Ryan Gavin, Christian Hangst, MK, Margarete Mühlleitner, Mathieu Pellen, Eva Popenda, Michael Spira, Alexander Wlotzka

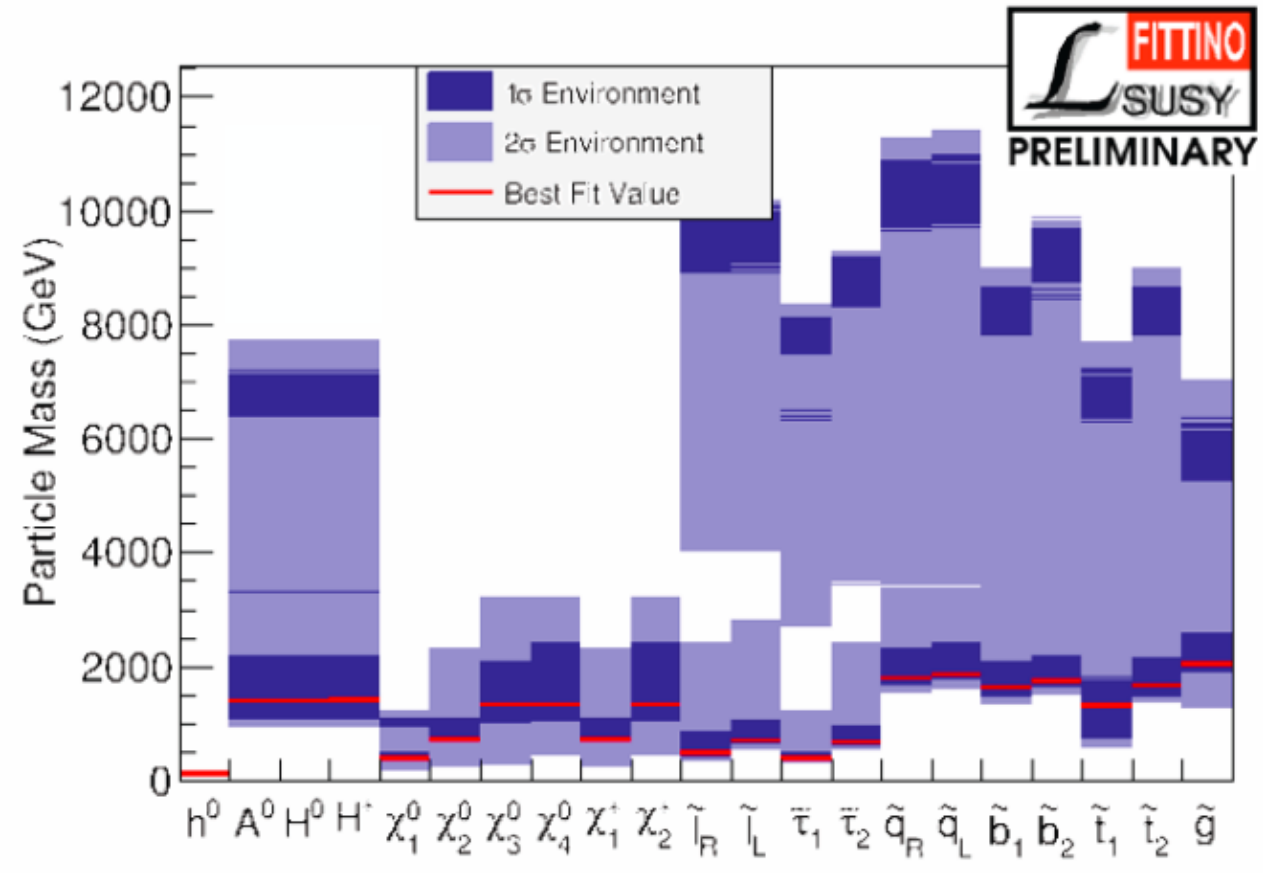
- Matching and mono-jets for compressed SUSY spectra
  Herbi Dreiner, MK, Jamie Tattersall

- Electroweak corrections to dark matter annihilation
  Leila Ali Cavasonza, MK, Mathieu Pellen

- Matching of electroweak corrections and parton showers
  Alexander Mück, Lennart Oymanns, Manfred Kraus and Christian Weiss

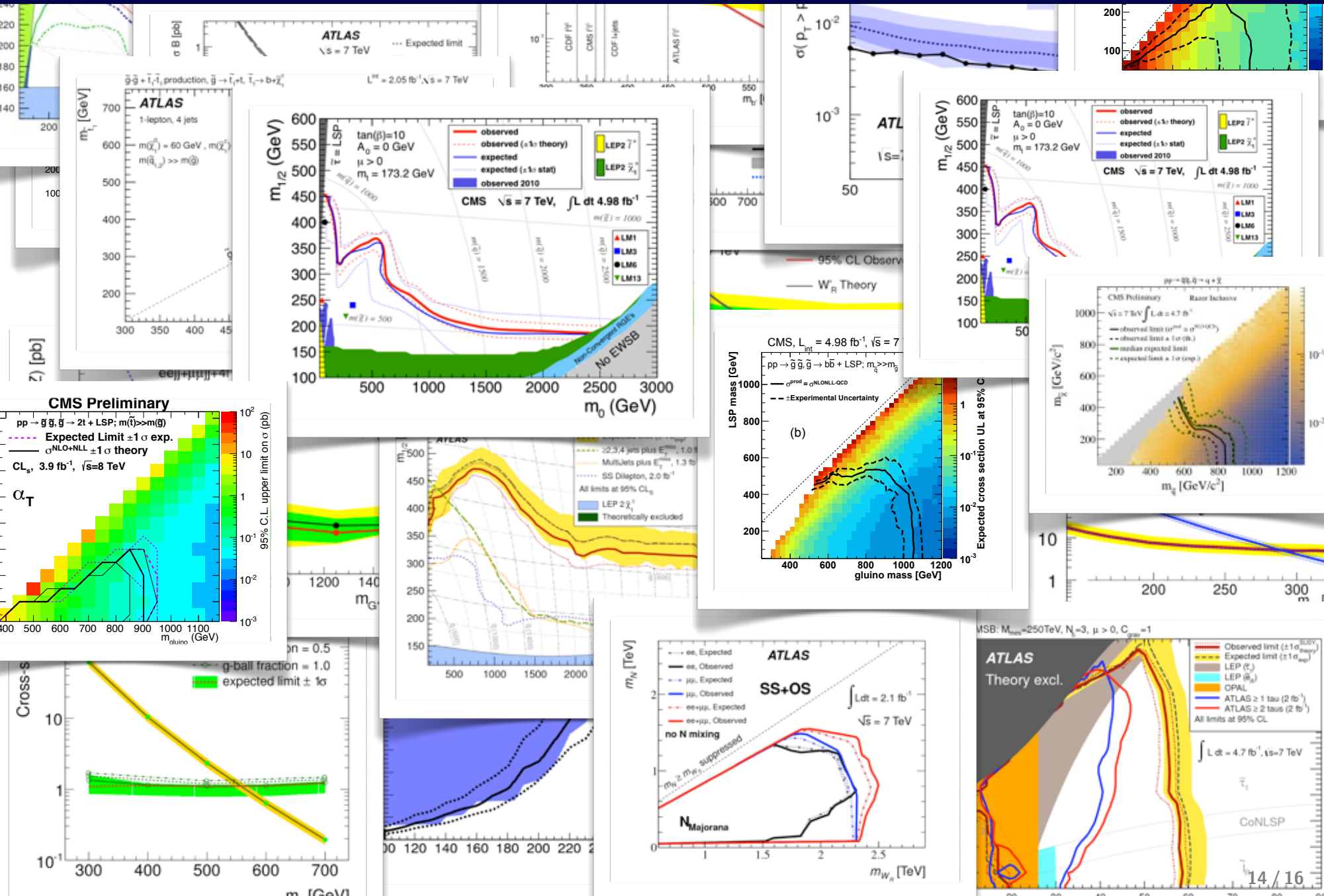
. . . more B5 projects (last four years)

Global fits of supersymmetric models



→ can we exclude simple SUSY models like the constrained MSSM?

. . . more B5 projects: current and beyond



. . . more B5 projects: current and beyond

- *Simplified models for new physics searches at the LHC*

  Lisa Edelhäuser, Jan Heisig, MK, Lennart Oymanns, Jory Sonneveld

- *Effective field theories for BSM (Higgs) physics*

  Anke Biekötter, Alexander Knochel, MK, Da Liu, Francesco Riva; Lisa Edelhäuser, Alexander Knochel