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Estimating the precision of a tanβ determination with $H_{SUSY} \rightarrow \tau\tau$ in CMS

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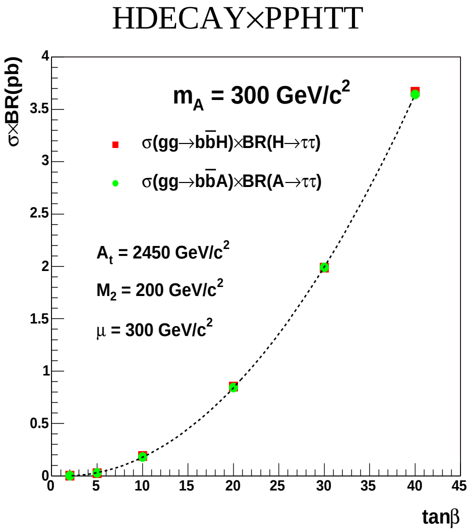
Motivation

- Tanβ is one of the most important parameters in MSSM, it enters in all sectors of the theory
- Value of tanβ can be measured at LHC with
  - ► Sfermion or neutralino sector at low tanβ
  - ► The Higgs sector using event rates at large tanβ
  - ► It may be possible to measure the value of tanβ from the width $\Gamma(H \to \mu\mu)$

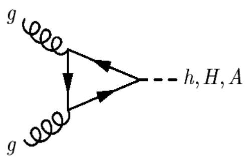


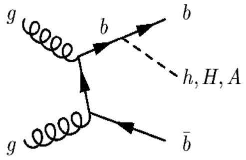
- In MSSM Higgs couplings to down type fermions tanβ enhanced
  - ➤ Exploited in $gg \to H_{SUSY}/gg \to bbH_{SUSY}$, $H_{SUSY} \to \tau\tau$
  - ➤ Dominant parts of the cross section are proportional to $\tan^2\beta$_eff*)
  - ➤ Branching ratio $BR(H_{SUSY} \to \tau\tau)$ ~ constant as a function of tanβ

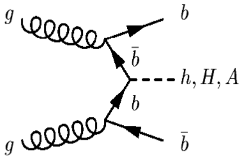
⇒ Uncertainty of the tanβ measurement only half of the uncertainty of the rate measurement

*) tanβ_eff will later be called as tanβ

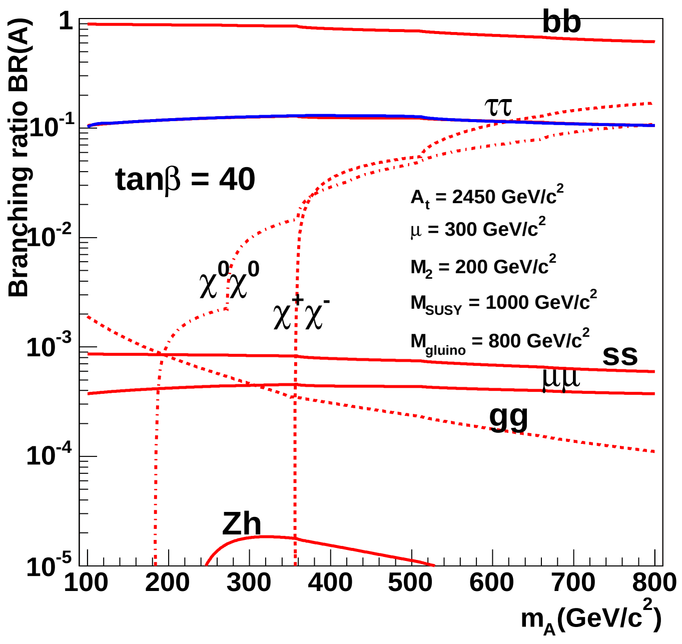
- At large tanβ (tanβ > 10) the Higgs production is predominantly in association with two b quarks (90%), loop mediated gluon fusion has less importance

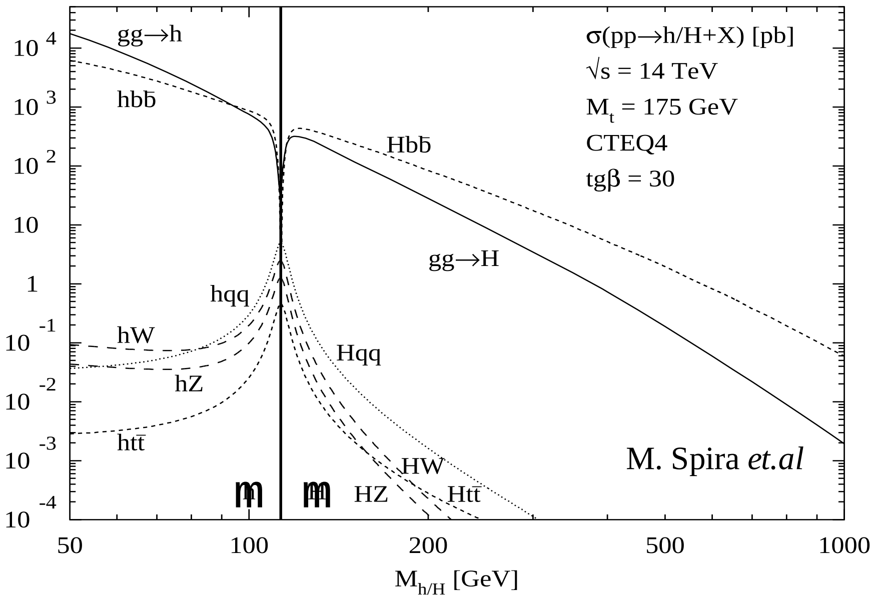






HDECAY





Selected SUSY scenario: LEP benchmark scenario max m_h

SUSY parameters chosen

$M_{SUSY} = 1$ TeV

$A_t = \sqrt{6}\, M_{SUSY}$

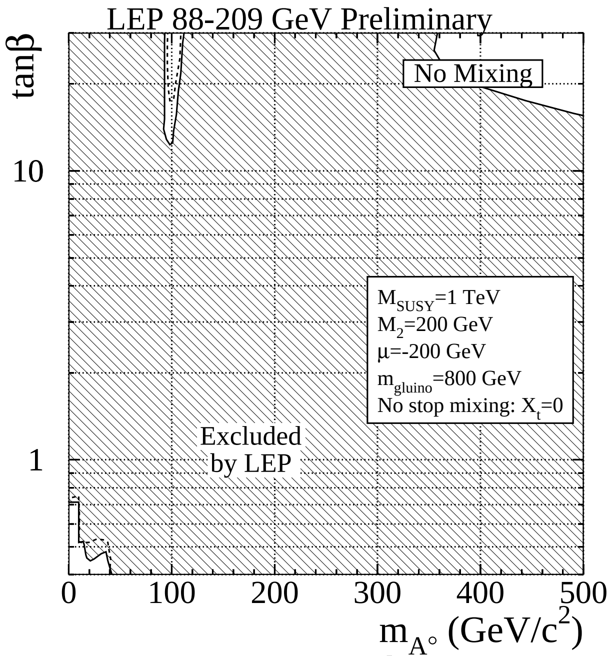
$\mu = 300$ GeV

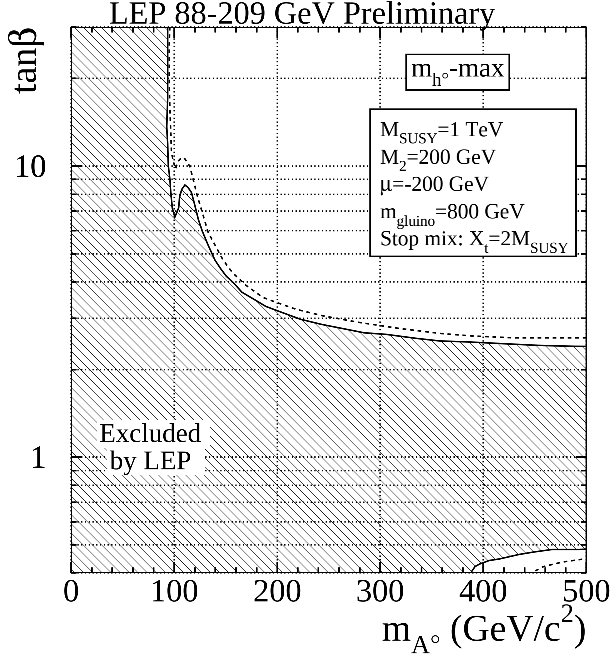
$M_2 = 200$ GeV

$m_{gluino} = 800$ GeV

Stop mixing has only small effect on the observability of the $H_{SUSY} \rightarrow \tau\tau$ channels

At large $m_{A,}$ $H_{SUSY} \rightarrow \tau\tau$ sensitive to gaugino sector, especially if tanβ not very high. Affects mostly the fully hadronic final state due lower tanβ reach.





Simulation methods

Event generation: pythia6, toprex+tauola for tt and tW backgr
Signal cross section and branching ratios from PPHTT/HDECAY
(M. Spira *et. al*.)

Studies with parameterized fast simulation, partly with full simulation

Full simulations for detector sensitive issues:
- tau trigger, tau identification, mass reconstruction,
- b tagging, impact parameter resolution

Full simulation results used as efficiencies or they are parameterized

Final states and main backgrounds

$H \to \tau\tau \to e\mu + X$

Branching ratio $BR(\tau\tau \to e\mu) \sim 6.3\%$

$H \to \tau\tau \to ll + X$

Branching ratio $BR(\tau\tau \to ll) \sim 12.5\%$

$H \to \tau\tau \to l + jet + X$

Branching ratio $BR(\tau\tau \to lj) \sim 45.6\%$

$H \to \tau\tau \to jet + jet + X$

Branching ratio $BR(\tau\tau \to jj) \sim 41.5\%$

Main backgrounds:

$Z,\gamma^* \to \tau\tau$	(all channels)
$Z,\gamma^* \to ll$	(ll)
tt	(all channels)
tW	(all channels)
bb	(eμ,ll,lj)
W+jet	(lj,jj)
QCD	(jj)

Background suppression after HLT:

- lepton isolation
- τ-jet identification
- τ impact parameter
- b-tagging
- jet veto
- positive neutrino energy

Trigger

$H \to \tau\tau \to e\mu + X$

Single muon trigger, eff = 0.85

trigger threshold effect 0.9×

muon reco efficiency0.97×

calorimetric isolation 0.97

$H \to \tau\tau \to ll + X$

Single muon trigger+di-electron trigger, eff = 0.82

di-electron trigger: (eff/electron)

trigger threshold effect 0.95×

Level-1 electron efficiency 0.872×

Level 2.5 electron efficiency 0.946

$H \to \tau\tau \to l + jet + X$

Single muon trigger + e+τjet trigger, eff = 0.73

e+τjet trigger: electron trigger threshold effect 0.95×

Level 1 electron efficiency 0.872×

HLT electron efficiency 0.77×

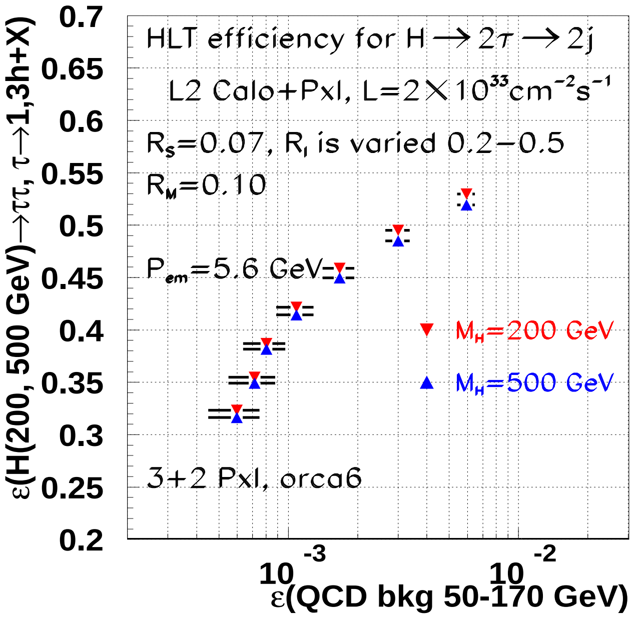
tau trigger threshold effect 0.95

$H \to \tau\tau \to jet + jet + X$

Di-τ trigger, eff = 0.38

L1 efficiency 0.9 × HLT efficiency 0.42

QCD rejection vs HLT efficiency



Kinematic cuts selected above the trigger thresholds, 20 GeV for leptons and 45 GeV for τ jets

τ jet identification

- Level-1 and HLT τ trigger thresholds (95% points)
  1τ jet:86 GeV, 2τ jet:59 GeV, e-τ jet:45 GeV
- Offline selections:
  - leading track $p_T > 40$ GeV
  - 1 or 3 tracks in cone 0.04 around the leading track
  - no other tracks with $p_T > 1$ GeV in isolation cone 0.4
- Very efficient against QCD, bb, W+jet backgrounds:

  suppression of QCD di-jet events ~1000 per jet

  9% efficiency per $H\rightarrow\tau\tau\rightarrow$2jet event

  including trigger+offline τ selections ($m_H = 500$ GeV)

b tagging in gg→bbH/bbA

- B jets in bbH/bbA soft and distributed over wide rapidity range

⇒ B tagging efficiency low even with perfect ip measurement

- Tagging method:

  counting significant tracks with $p_T > 1$ GeV, $\sigma_{ip} > 2$ (signed).

- B tagging efficiency ~35% for genuine b's with ~1% mistagging rate

Single or double b tagging?

gg→bbH/bbA, H/A→ττ→lepton+jet+X,
number of selected events for 30fb^{-1}, all selection cuts

$m_A = 200$ GeV, $\tan\beta = 20$	N_S	N_B	signif	$\mathrm{sqrt}(N_S+N_B)/N_S$
1b-tagging+jet veto	157	70	18.8	9.6%
2b-tagging	9	44	1.3	80.9%

- Best results with one tagged b per event
  - allows central jet veto to be used to suppress efficiently tt backgr.

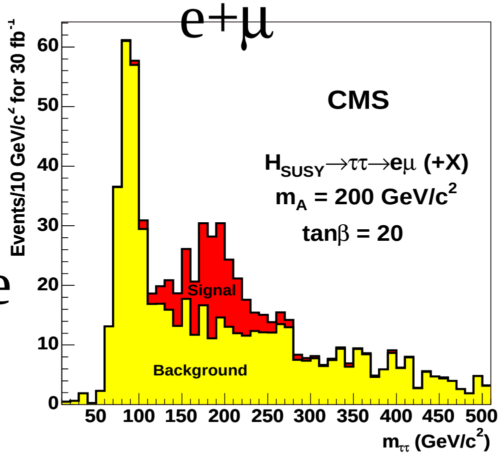
$H_{SUSY}\rightarrow\tau\tau$, reconstructed Higgs boson mass

- Neutrinos in the final state

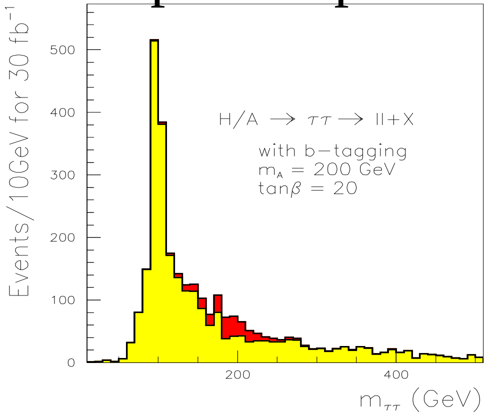
\- collinear approximaton used

- Mass reconstruction possible if τ's not back-to-back: $\Delta\phi(\tau_1,\tau_2)<175^o$ required
- Positive neutrino energy required
- Suppresses tt background: all neutrinos not emitted along the tau

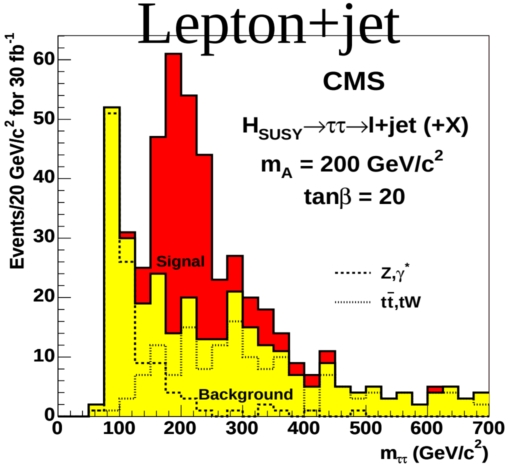
e+μ



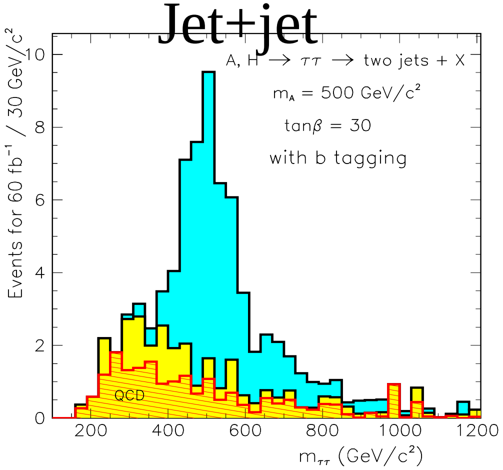
Lepton+lepton



Lepton+jet

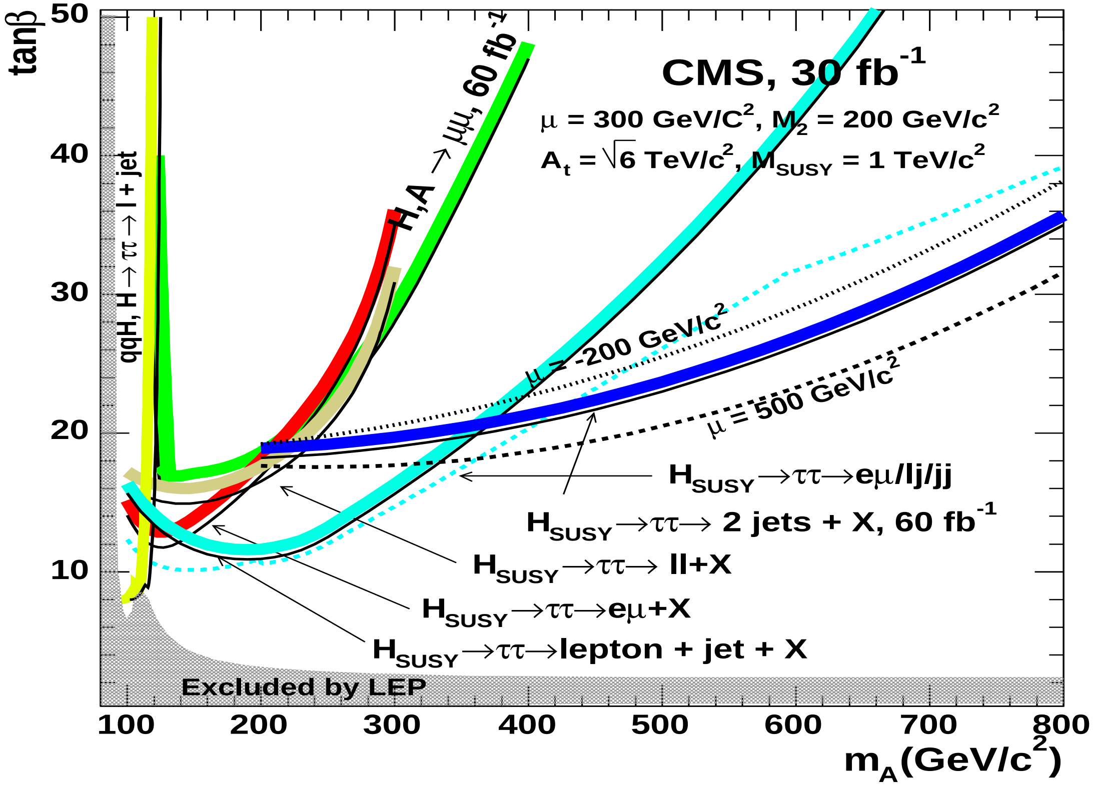


Jet+jet



5σ discovery contours

30 fb^{-1} at low luminosity (2×10^{33} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$)
max m_h SUSY scenario



$H_{SUSY}\rightarrow\tau\tau\rightarrow X$ most promising channel for discovering heavy neutral MSSM Higgs boson at large tanβ

Uncertainty of $\tan\beta$ measurement

At large $\tan\beta$ $\sigma \sim \tan^2\beta \times X$, subleading $\tan\beta$ dependence small, can be absorbed into $\tan\beta_{eff}$

$$N_S = \tan^2\beta \times X \times L \times \varepsilon_{sel}$$

$$\tan\beta = \tan\beta_0 \pm \Delta stat \pm \Delta syst$$

Max error:

$$\Delta\tan\beta/\tan\beta = ½(\Delta N_S/N_S + \Delta L/L + \Delta X/X)$$

$$= ½(\mathrm{sqrt}(N_S+N_B)/N_S + \Delta L/L + \Delta X/X)$$

Luminosity error assumed $\Delta L/L \sim 5\%$

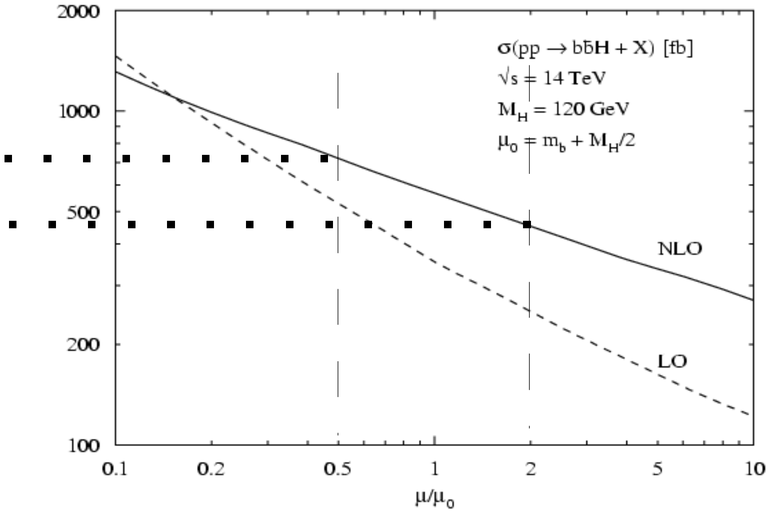
Theoretical error $\Delta\sigma/\sigma \sim 20\%$, $\Delta BR/BR \sim 3\%$

Uncertainties of the background and signal selection efficiency, and the accuracy of the SUSY parameter measurement not yet taken into account. (Uncertainty of the selection (s+b) efficiency expected ~5%)

Theoretical uncertainty

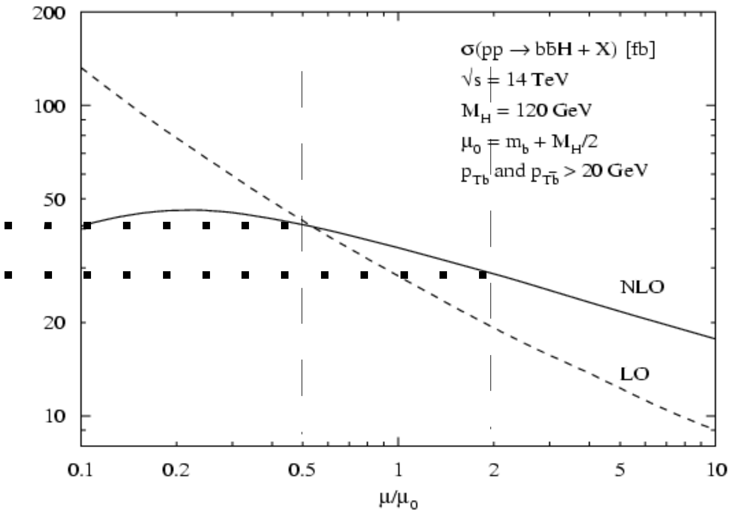
- Uncertainty of the NLO cross section for gg→bbH/A
  20-30% Dittmaier, Kramer, Spira, hep-ph/0309204
- The error depends on the transverse momentum range of the spectator quarks:
  - if both associated b's have $p_T > 20$ GeV in bbH/A, the error reduces to 10-15%
- We use 1b-tagging and 20% theoretical error

~22%



Hep-ph/0309204

2b, p_T>20GeV, ~17%



Hep-ph/0309204

Uncertainty of the mass measurement

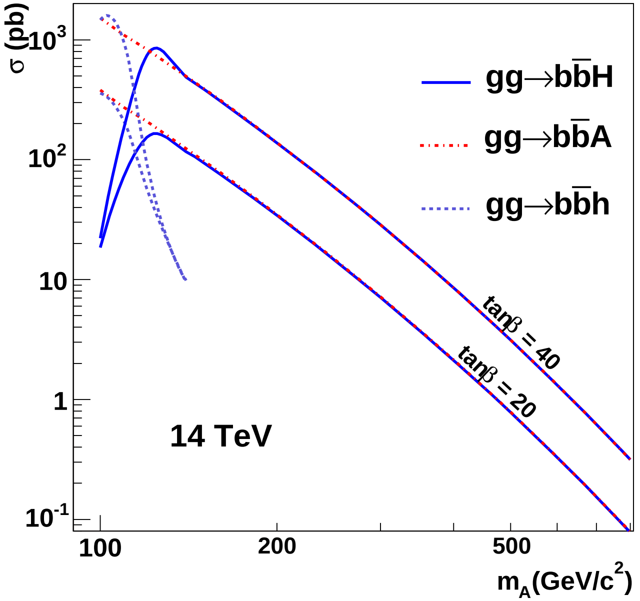
Production cross section depends on Higgs mass, which is measured with some accuracy. This induces errors on the cross section.

Mass resolution from Gaussian fit to the signal, $m = m_0 \pm \Delta m$

$$\Delta m = \sigma_{Gauss}/N_S$$

$$\Delta\sigma/\sigma = (\sigma(m_0) - \sigma(m_0 \pm \Delta m))/\sigma(m_0)$$

At 5σ limit $\Delta\sigma/\sigma \sim 10\%$ for $H_{SUSY} \rightarrow \tau\tau$ channels



Uncertainty of the SUSY parameters measurement

- In addition to mA and tanβ, Higgs sector sensitive to A_t,μ,M_2,M_{SUSY}
- These parameters need to be measured using e.g. global fit to SUSY parameters. The error of this measurement gives error to the Higgs production rate (σ×BR)
- The error is still unknown *)
- To get a feeling how large the errors might be, let's take e.g. 20% uncertainty of the SUSY parameters

	$\sigma(gg \to b\bar{b}H) \times BR(H \to \tau\tau)$			
	tanβ = 20		tanβ = 40	
	m_A = 200 GeV/c^2	m_A = 500 GeV/c^2	m_A = 200 GeV/c^2	m_A = 500 GeV/c^2
$\mu\pm20\%$	(+1.4 -1.1)%	(+13.7 -25.9)%	(+2.0 -2.3)%	(+6.9 -11.3)%
$M_2\pm20\%$	(+0.055 -0.26)%	(+9.5 -18.2)%	(+0.013 -0.066)%	(+2.9 -6.3)%
$A_t\pm20\%$	(+1.3 -0.022)%	(+0.82 +0.19)%	(+0.65 -0.26)%	(+0.27 +0.53)%
$M_{SUSY}\pm20\%$	(+1.6 -1.0)%	(+1.4 -0.78)%	(-1.8 +2.7)%	(-1.5 +2.7)%

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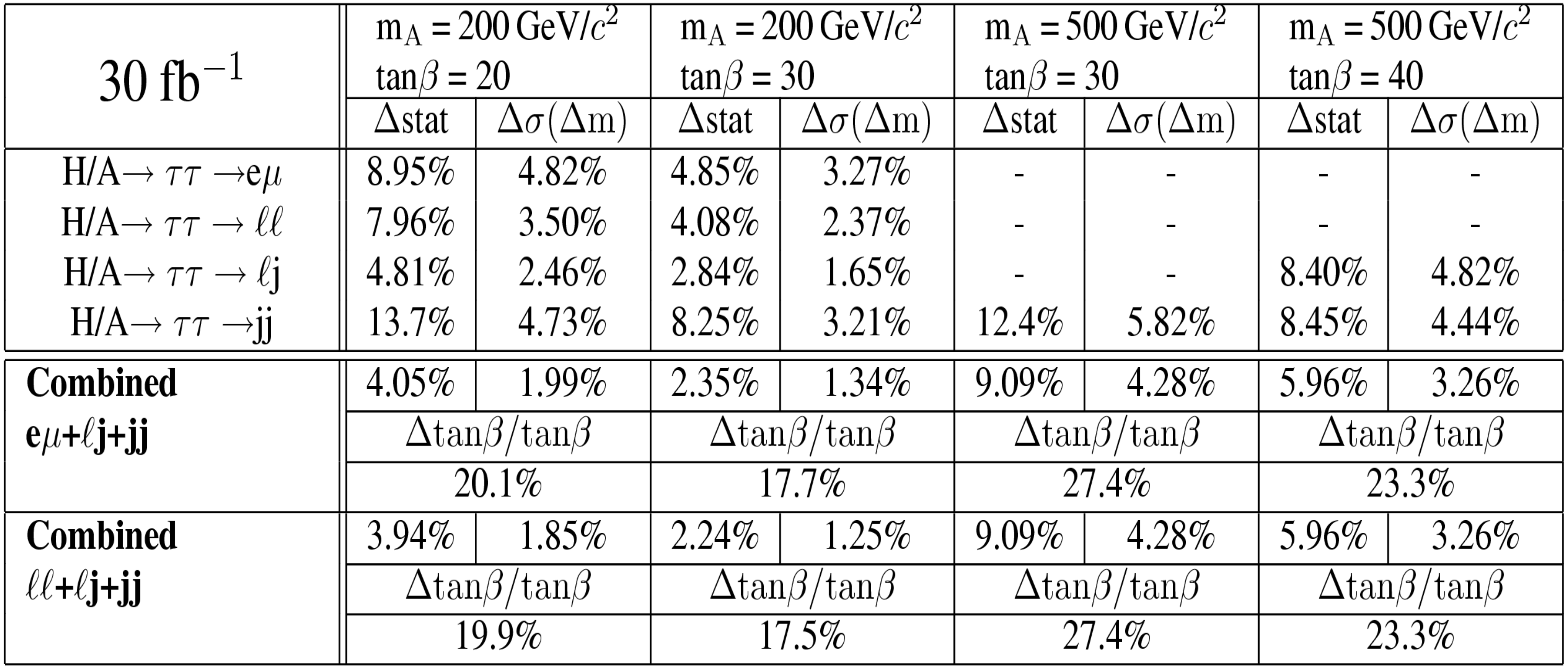
*) some initial studies will be published in LHC/LC document on global fit

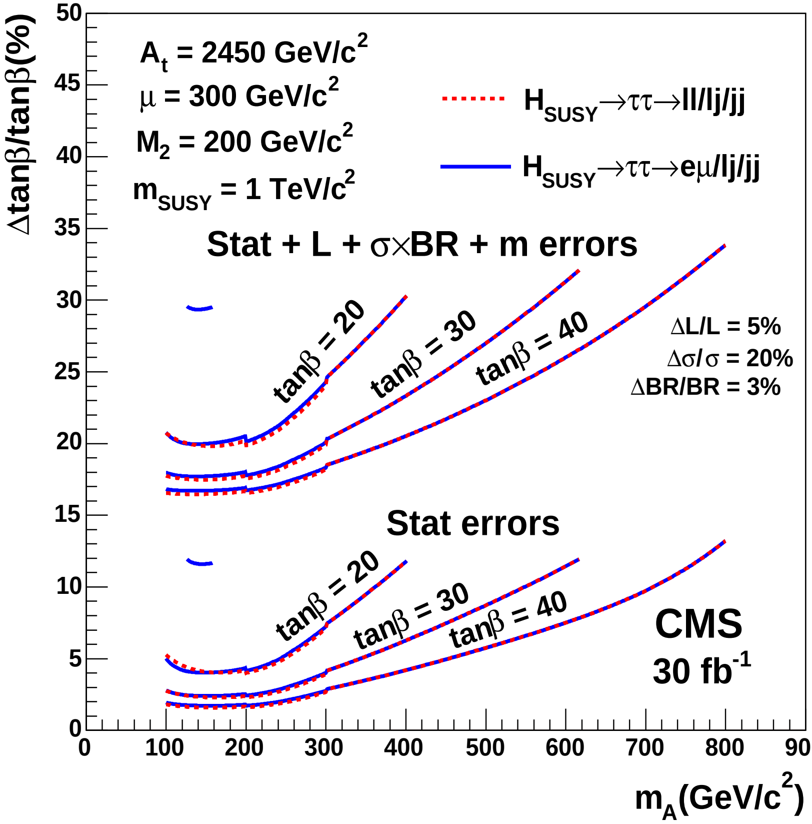
Uncertainty of tanβ measurement, 30fb^{-1}

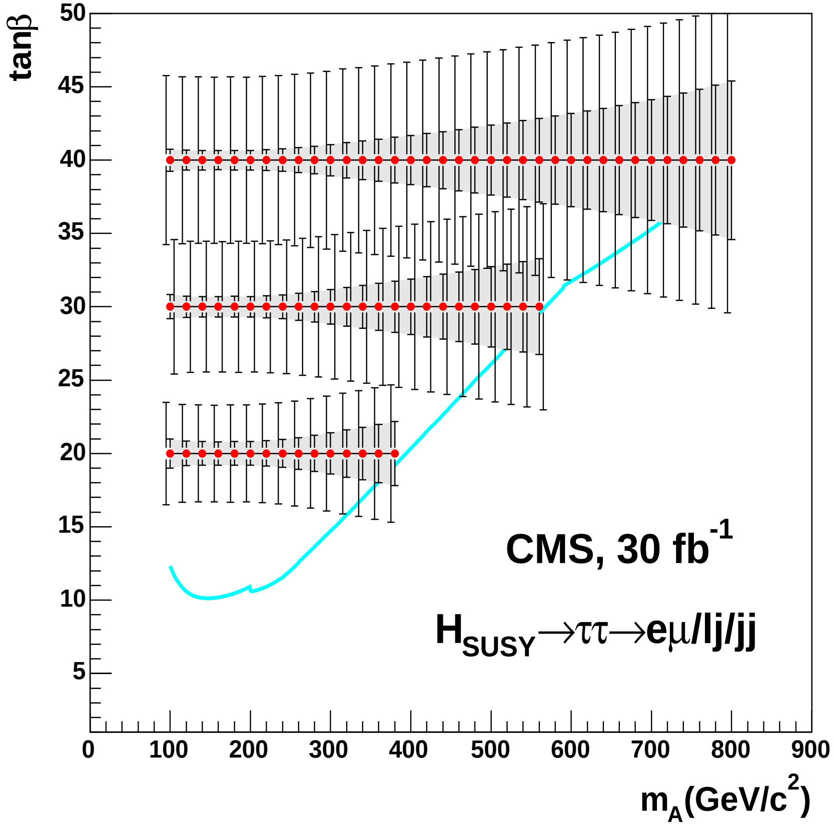


30 fb^{-1}	$m_A = 200$ GeV/c^2 $\tan\beta = 20$		$m_A = 200$ GeV/c^2 $\tan\beta = 30$		$m_A = 500$ GeV/c^2 $\tan\beta = 30$		$m_A = 500$ GeV/c^2 $\tan\beta = 40$	
	Δstat	$\Delta\sigma(\Delta m)$	Δstat	$\Delta\sigma(\Delta m)$	Δstat	$\Delta\sigma(\Delta m)$	Δstat	$\Delta\sigma(\Delta m)$
H/A→ $\tau\tau$ →eμ	8.95%	4.82%	4.85%	3.27%	-	-	-	-
H/A→ $\tau\tau$ → $\ell\ell$	7.96%	3.50%	4.08%	2.37%	-	-	-	-
H/A→ $\tau\tau$ → ℓj	4.81%	2.46%	2.84%	1.65%	-	-	8.40%	4.82%
H/A→ $\tau\tau$ →jj	13.7%	4.73%	8.25%	3.21%	12.4%	5.82%	8.45%	4.44%
Combined **eμ+ℓj+jj**	4.05%	1.99%	2.35%	1.34%	9.09%	4.28%	5.96%	3.26%
	$\Delta\tan\beta/\tan\beta$		$\Delta\tan\beta/\tan\beta$		$\Delta\tan\beta/\tan\beta$		$\Delta\tan\beta/\tan\beta$	
	20.1%		17.7%		27.4%		23.3%	
Combined **$\ell\ell$+ℓj+jj**	3.94%	1.85%	2.24%	1.25%	9.09%	4.28%	5.96%	3.26%
	$\Delta\tan\beta/\tan\beta$		$\Delta\tan\beta/\tan\beta$		$\Delta\tan\beta/\tan\beta$		$\Delta\tan\beta/\tan\beta$	
	19.9%		17.5%		27.4%		23.3%	

Uncertainty of tanβ measurement

Small error bars (gray): stat error only
Large error bars: total error





Conclusions

- The precision of a tanβ determination is estimated using $H_{SUSY} \rightarrow \tau\tau$ in CMS with $30fb^{-1}$
- The uncertainty includes
    - Statistical error
    - Error of the mass measurement
    - Theoretical error (cross section and branching ratio)
    - Luminosity error
- What is <u>not</u> included:
    - Uncertainty of the SUSY parameter measurement (μ,M_2,..)
    - Uncertainty of the signal selection and background determination
- With signal significance >5σ, the study gives better than 35% accuracy for the tanβ determination at the benchmark point considered
- Errors are dominated by theoretical uncertainty