TOP QUARK STUDIES FROM CMS AT LHC

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PHYSICS AT LHC
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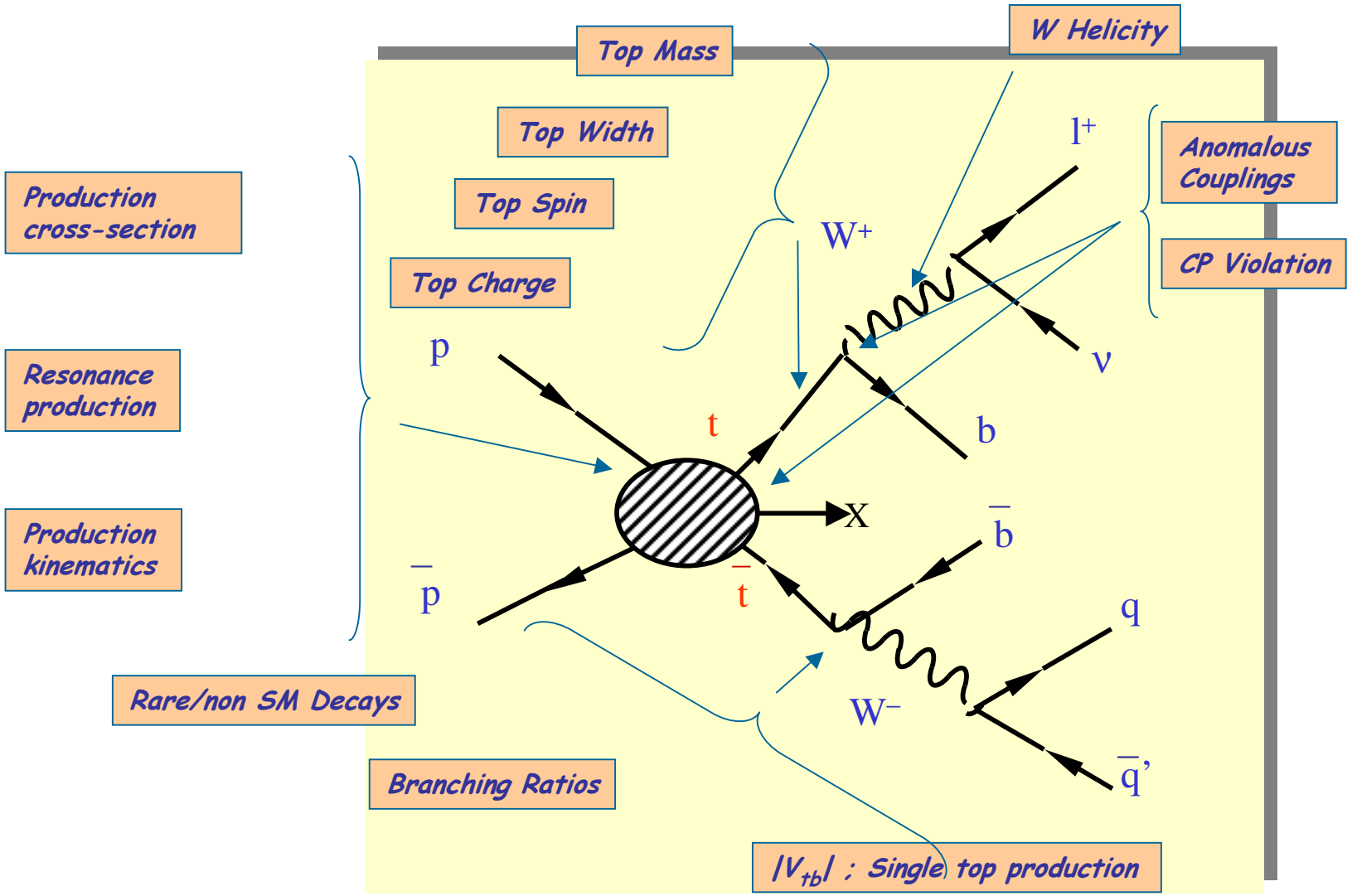
Top Quark Physics



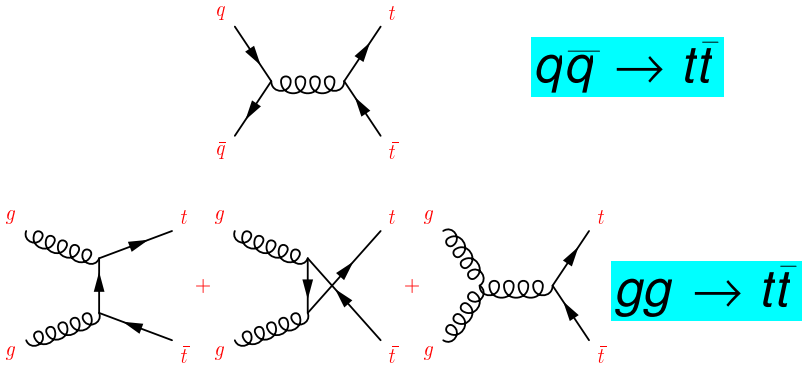
Topics in This Talk

- Top production properties
  - Top cross section
  - Top mass
- Top spin effects
  - Top-antitop spin correlations
- Anomalous couplings
  - FCNC in top physics
- Non-Standard-Model decays of top
  - Search for charged Higgs

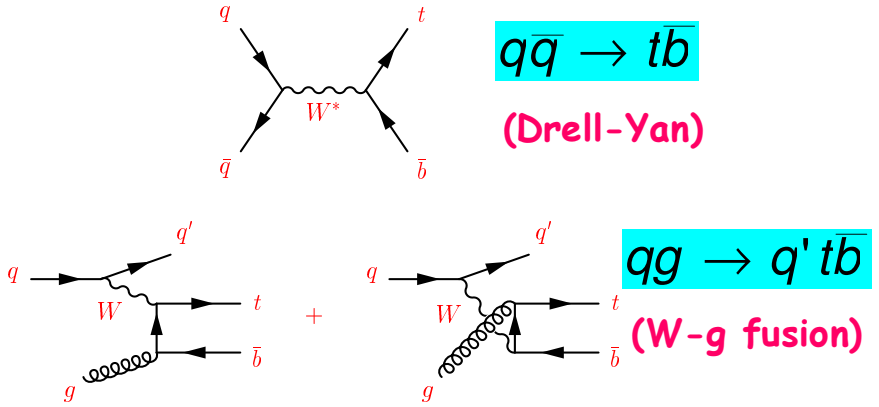
- Single top production; top partial width, V_{tb} and spin effects…
  $\Rightarrow$ see talk by Sherstnev
- More in proceedings of "SM physics (and more) at the LHC" CERN 2000-004

Top Quark Production and Decay

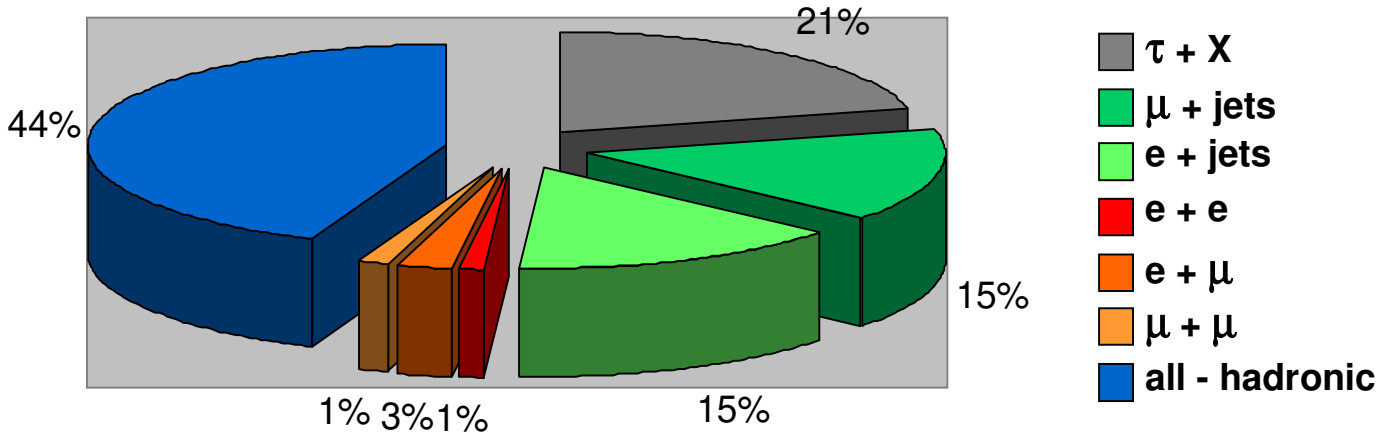
- Strong t $\bar{t}$ pair production



EW single top quark production



- Standard Model: t → Wb dominates, BR for t $\bar{t}$ final states

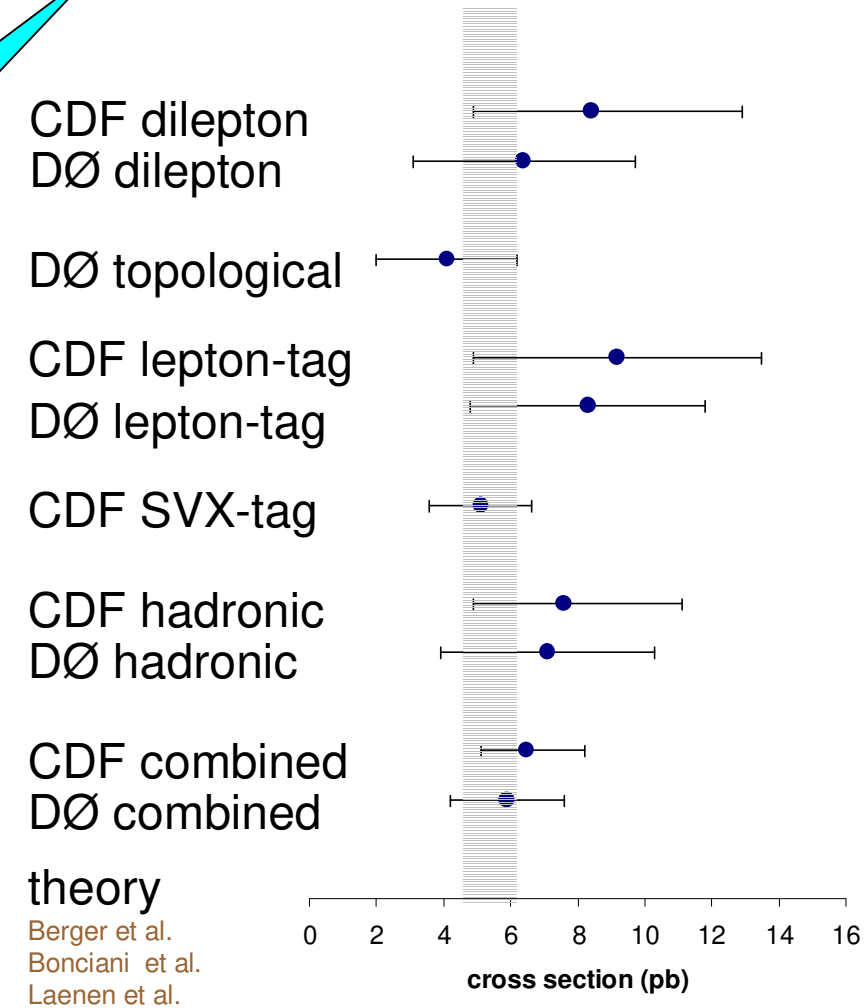


$t\bar{t}$ Production Cross Section

- **Motivation**
  - $t\bar{t}$ cross section is a test of QCD predictions
    - Inclusive and differential cross sections
  - A discrepancy may indicate possible new physics
    - Production via a high mass intermediate state
    - Non Wb decay model
- **Measurements performed using various final states**
  - Dilepton channels
    - ee, eμ and μμ
  - Lepton + jets channels
    - e+jets, μ+jets: topological analysis and b-tagging
  - All hadronic channel
    - Topological variables and b-tagging
    - Neural networks techniques
  - Trilepton channels

Tevatron $t\bar{t}$ Cross Section

RUN 1



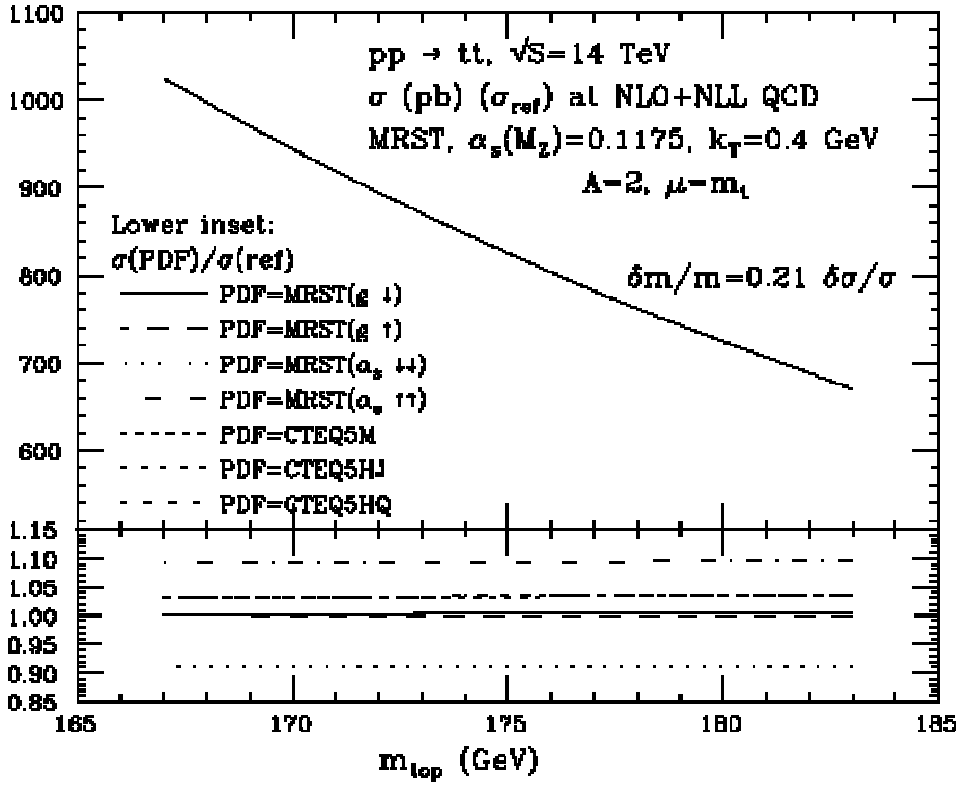
$8.4^{+4.5}_{-3.5}$ pb
6.4 ± 3.3 pb
4.1 ± 2.1 pb
9.2 ± 4.3 pb
8.3 ± 3.5 pb
5.1 ± 1.5 pb
$7.6^{+3.5}_{-2.7}$ pb
7.1 ± 3.2 pb
$6.5^{+1.7}_{-1.4}$ pb
5.9 ± 1.7 pb
4.7 - 6.2 pb

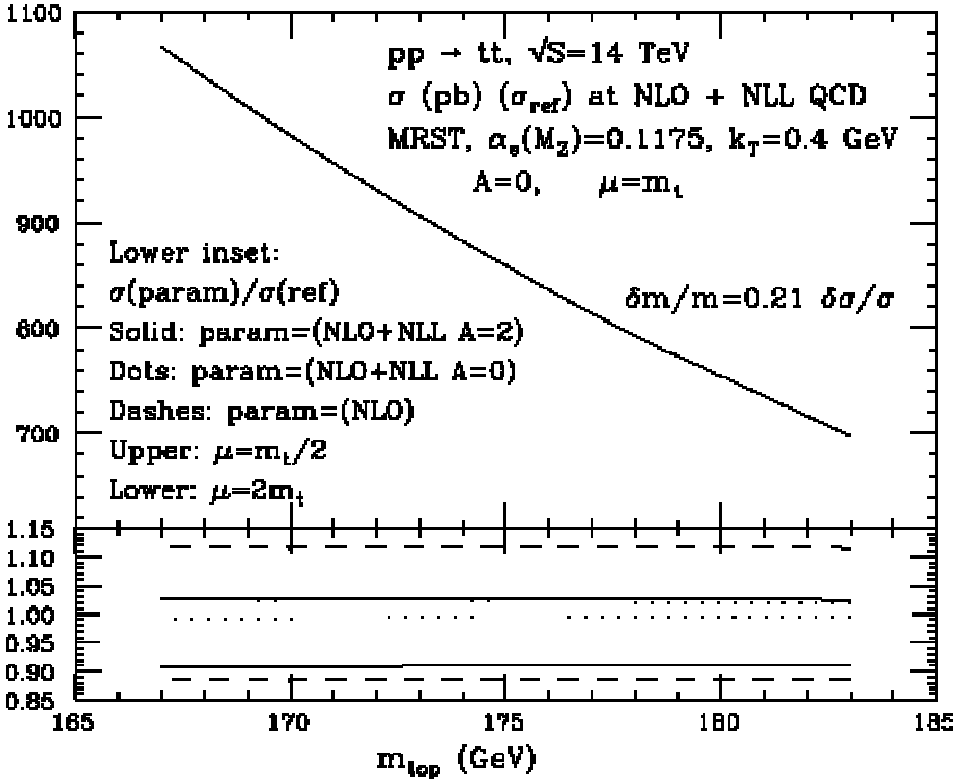
DØ: PRL 79 1203 (1997); CDF: PRL 80 2773 (1998)(+updates)

$t\ \bar{t}$ Production at LHC

- $t\ \bar{t}$ cross section at LHC ($\sqrt{s}$ = 14 TeV) ≈ 830 pb
  - LHC is a Top factory: 10^8 $t\ \bar{t}$ in 100 fb^{-1}
    - ➔ Measurement of σ with high statistical precision
    - ➔ Measurement of $d\sigma/p_T$ up to TeV in p_T
      - ❖ Full understanding of top needed for evaluation of backgrounds to Higgs, SUSY, etc.
- Challenge is to control systematics
  - Experiment: a few percent?!
  - Theory: currently 12% but expect improvements (next slide)
- Relation to top mass:
  - Within SM expect $\Delta m_t/m_t \approx 0.2\ \Delta\sigma(t\ \bar{t})/\sigma(t\ \bar{t})$
  - If 5% precision in cross section is achieved
    - ➔ Indirect determination of m_t with $\Delta m_t \approx 1.8$ GeV!

Theoretical Uncertainties





PDF: ±10%

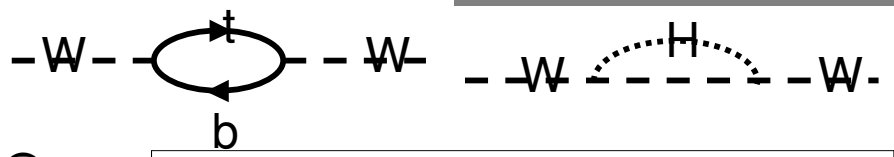
scale: ±6%

Top Quark Mass

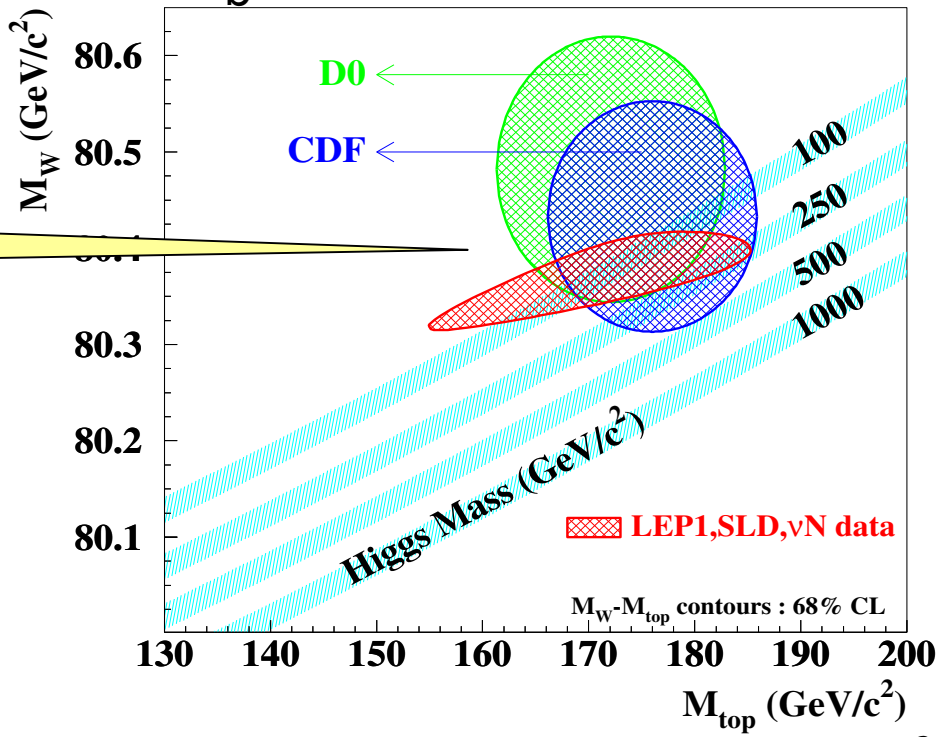
- Fundamental parameter of Standard Model
  - Tevatron Run 1: 174.3 ± 5.1 GeV
- Affects predictions of SM via radiative corrections

Measurements of
M_W = 80.398±0.041 GeV
and m_t constrain M_H

$$\delta M_W \propto m_t^2, \ln(M_H)$$



Light Higgs !



- Large mass of top quark
  - Yukawa coupling ≈ 1
  - Clues about electroweak symmetry breaking!

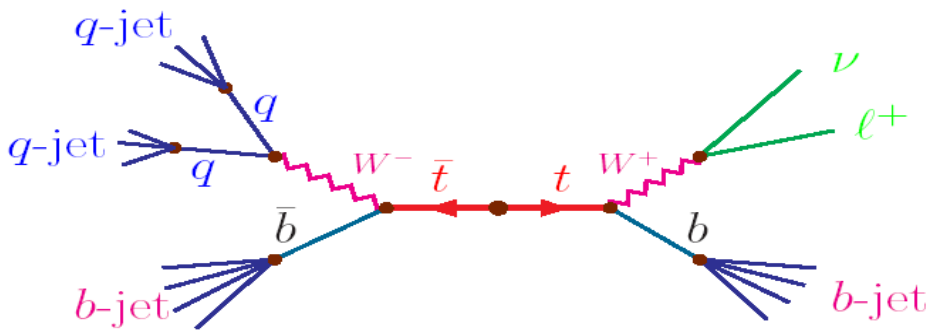
CMS Top Mass Studies

- **Lepton + jets**

  - Δm_t = 1.0 – 1.5 GeV depending on p_T modeling and calibration precision

  - W-jj, b-jet resolution, combinatorics…

$$t\bar{t} \rightarrow bW^+\bar{b}W^- \rightarrow \ell^\pm\nu b\bar{b}q\bar{q}'$$



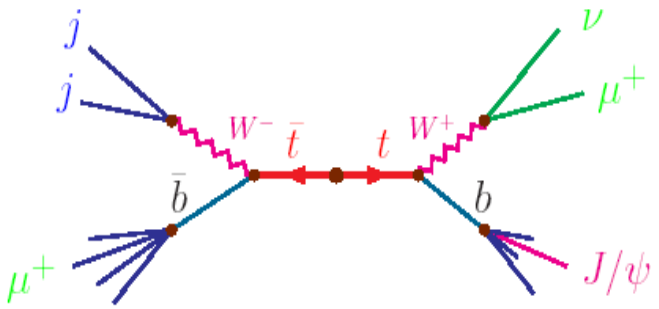
- **Dilepton**

  - $\Delta m_t \leq 2$ GeV obtained from correlation between M(e μ) and m_t

$$t\bar{t} \rightarrow bW^+\bar{b}W^- \rightarrow e^\pm\mu^\mp\nu\nu b\bar{b}$$

Promising Channel

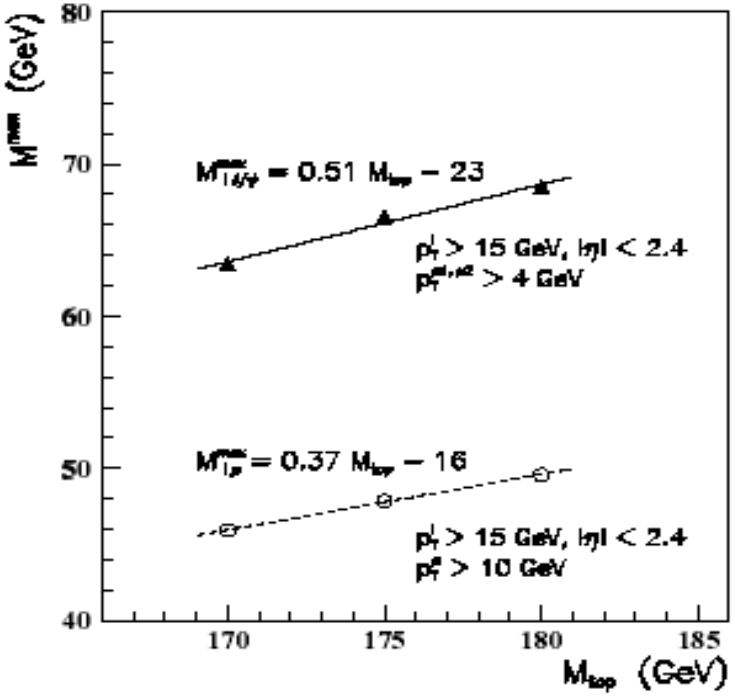
➢ l + J/ψ channel $t \to bW^+, W^+ \to \ell\nu, b \to J/\psi X, \Longrightarrow t \to \ell J/\psi$



- $\Delta m_t \leq 1$ GeV strong correlation between M(l J/ψ) and m_t

- Sensitivity to b fragmentation function
- Small BR (5×10^{-5})

  ➔ Suitable for high luminosity data !



$t\,\bar{t}$ Spin Correlations

- $t\,\bar{t} \rightarrow l^+\,l'^-\,X$ (l=e,μ) with pure V-A top decays

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_+ d\cos\theta_-} = \frac{1 + C\kappa_+\kappa_-\cos\theta_+\cos\theta_-}{4}$$

where

$$\kappa_+\kappa_- = -1$$

L. Sonnenchein
CMS PhD thesis

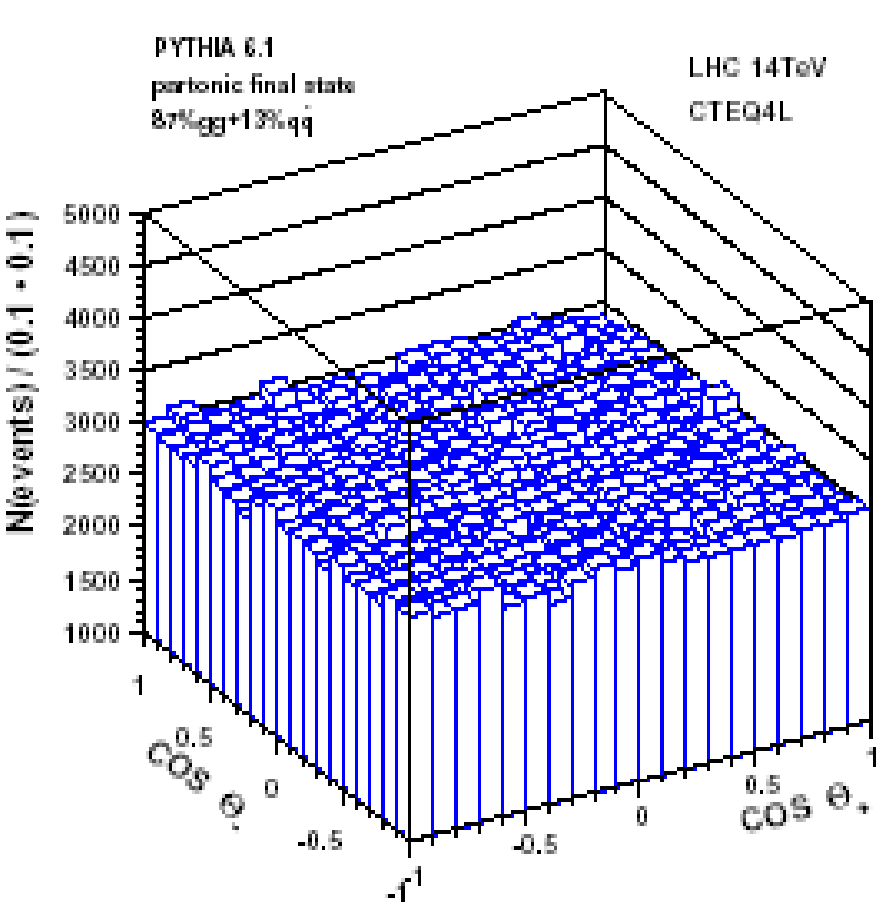
$\theta_+(\theta_-)$ = angle between t ($\bar{t}$) in $t\,\bar{t}$ CMS and l^+ (l^-) direction in t ($\bar{t}$) rest frame.

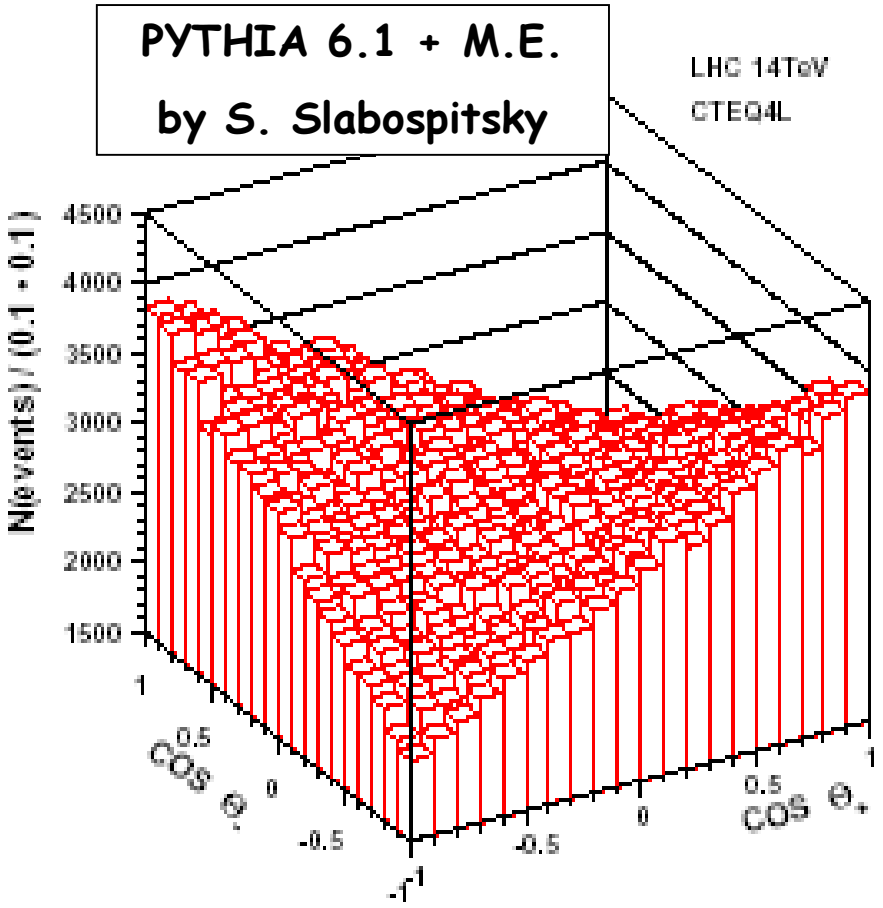
C = degree of spin correlation in helicity basis

- Expect C = 0.332 for LHC using CTEQ4L

CMS Study

Fit $\Rightarrow$ C = -0.021 ± 0.022 **C = 0.331 ± 0.023**

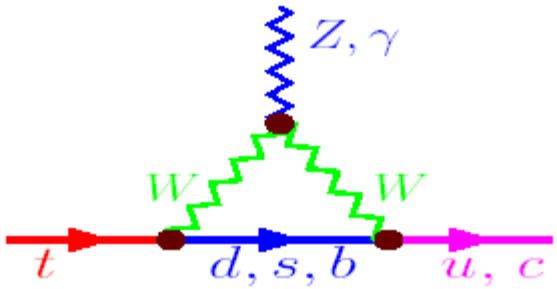




ISR, FSR, multiple int., detector response included, corrected for selection cuts

FCNC in Top Quark Physics

- Flavor Changing Neutral Current couplings tVc and tVu; V = g, γ, Z
  - Absent at tree-level and highly suppressed in SM
  - Present through loop contributions



- Observation of top quark FCNC processes
  - ➔ New Physics!

$t \rightarrow$	SM	two-Higgs	SUSY	CDF & LEP2 Present Limits
$g\ q$	5×10^{-11}	10^{-6}	10^{-3}	BR < 17%
$\gamma\ q$	5×10^{-13}	10^{-6}	10^{-5}	BR < 3.2%
$Z\ q$	$\sim 10^{-13}$	10^{-9}	10^{-4}	BR < 18%

FCNC in Top Decays

- **t $\bar{t}$ pair production**

$$pp \to t\bar{t}X, \quad t(\bar{t}) \to q\gamma(qg, qZ), \; \bar{t}(t) \to bW(W \to \ell\nu)$$

$$\begin{aligned} t \to q\gamma \quad &\Longrightarrow \quad t\bar{t} \to \gamma + \ell^{\pm} + \geq 2\text{jets} \\ t \to qg \quad &\Longrightarrow \quad t\bar{t} \to \ell^{\pm} + \geq 3\text{jets} \\ t \to qZ \quad &\Longrightarrow \quad t\bar{t} \to 3\ell^{\pm} + \geq 2\text{jets} \end{aligned}$$

- **Background processes**
  - $t\bar{t}$ (830 pb); single top (240 pb)
  - $W(\to e, \mu) + jets$ ($\sim$ 7500 pb for $\hat{k}_T > 20$ GeV)
  - $WW + WZ + ZZ$ (110 pb)
  - $W\gamma$ (17.3 pb)

Branching Ratios

- Expected constraints on "BR" = Γ(tVq) / Γ(SM)
  - Tevatron Run 2
  - LHC – CMS
  - Linear e^+ e^- collider

$t \rightarrow$	Tevatron Run II	LHC (100 fb^{-1}) decay	LHC (100 fb^{-1}) production	LC (e^+e^-)
$g\,q$	06%	1.6×10^{-3}	1×10^{-5}	–
$\gamma\,q$	0.28%	2.5×10^{-5}	3×10^{-6}	4×10^{-6}
$Z\,q$	1.3%	1.6×10^{-4}	1×10^{-4}	2×10^{-4}

BR's significantly constrained – allowing test of SUSY scenarios

Non-SM Decays of Top

- **Supersymmetry**
  - Presently observed bosons and fermions would have more massive superpartners (SUSY is a broken symmetry)

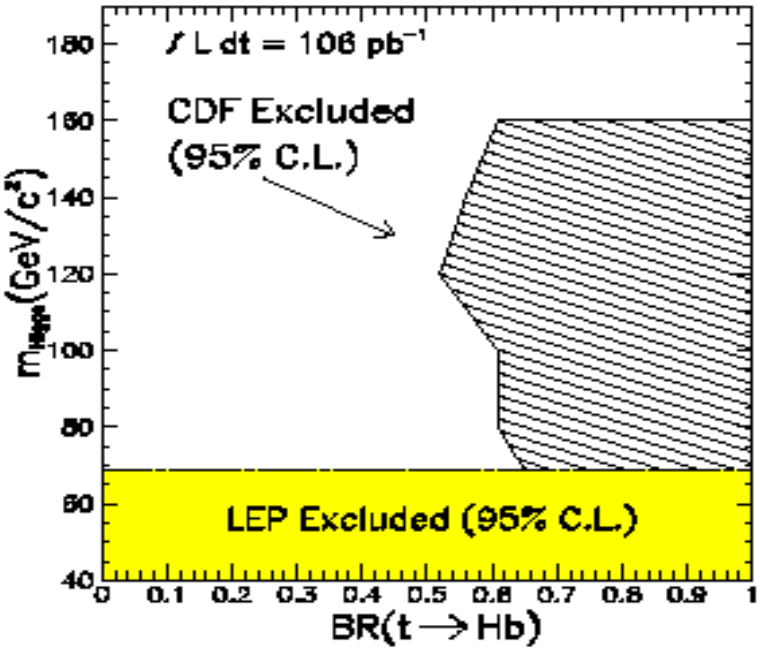
- **SUSY Higgs sector – two Higgs doublets (MSSM)**
  - 5 states (h^0, H^0, A^0, H^+, H^-) survive after giving W & Z masses
  - $H^{\pm}$ LEP limit 77.4 GeV (LEP Working Group 2000)
  - Decay $t \rightarrow H^+ b$ can compete with $t \rightarrow W^+ b$
  - $H^{\pm}$ couples to heaviest fermions $\Rightarrow$ detection through breakdown of e / μ / τ universality in $t\bar{t}$ production

Tevatron Search - Run 1

CDF

Direct search for $t \to H^+ b$; with $H^+ \to \tau \nu$ for large tan β

PRD 62, 012004 (2000)

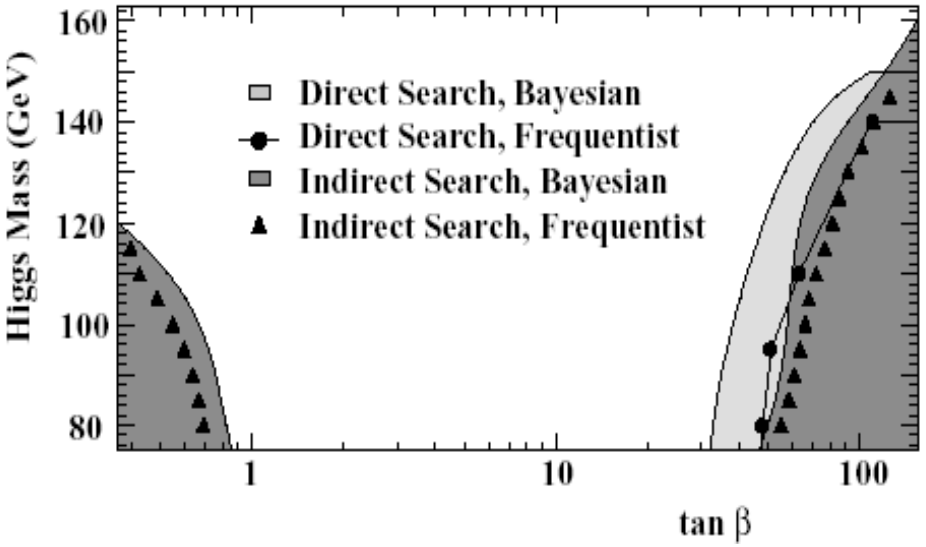


DØ

Indirect search for $t \to H^+ b$; disappearance of SM $t \to W^+ b$

Direct search for $t \to H^+ b$; with $H^+ \to \tau \nu$ for large tan β

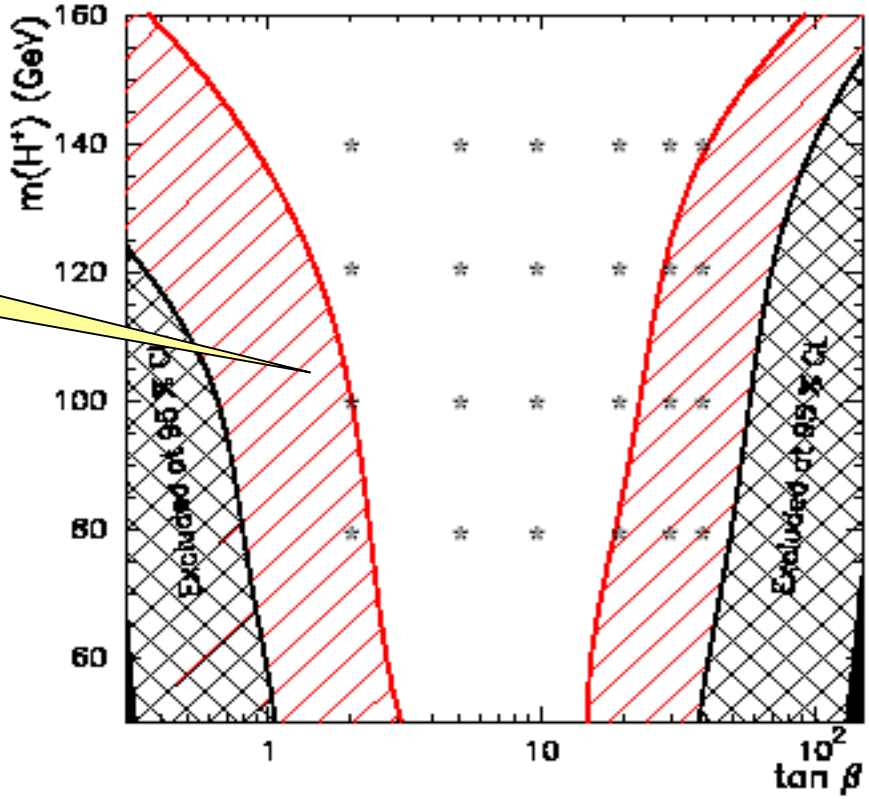
PRL 88, 151803 (2002)



$B(t \to H^+ b) < 0.36$ @ 95% CL if $B(H^+ \to \tau \nu) \approx 1$ and $M_H < 160$ GeV

Expectation from Tevatron Run 2

Excluded regions expected from Run 2

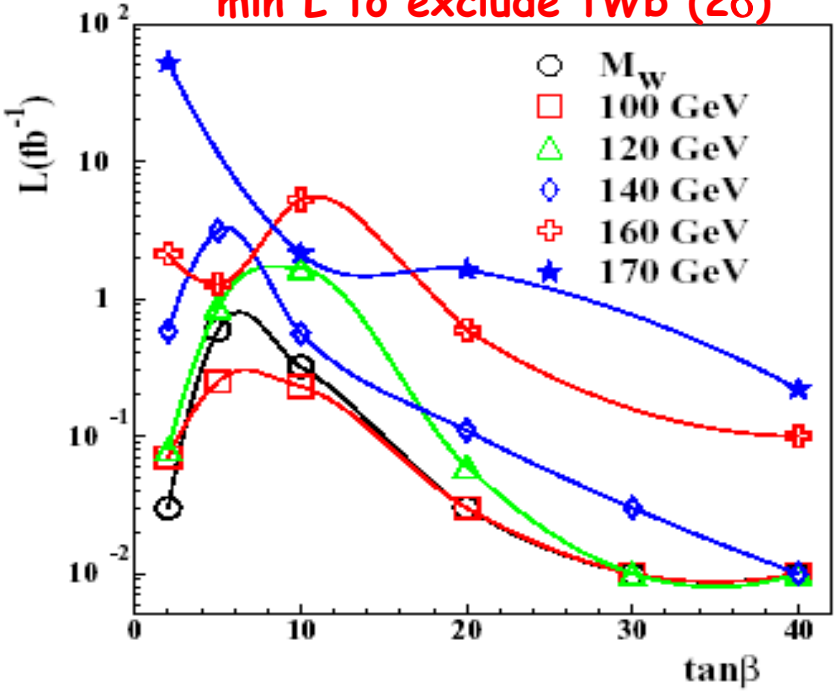


Large regions of parameter space for $M_H < m_t$ remain to be searched!

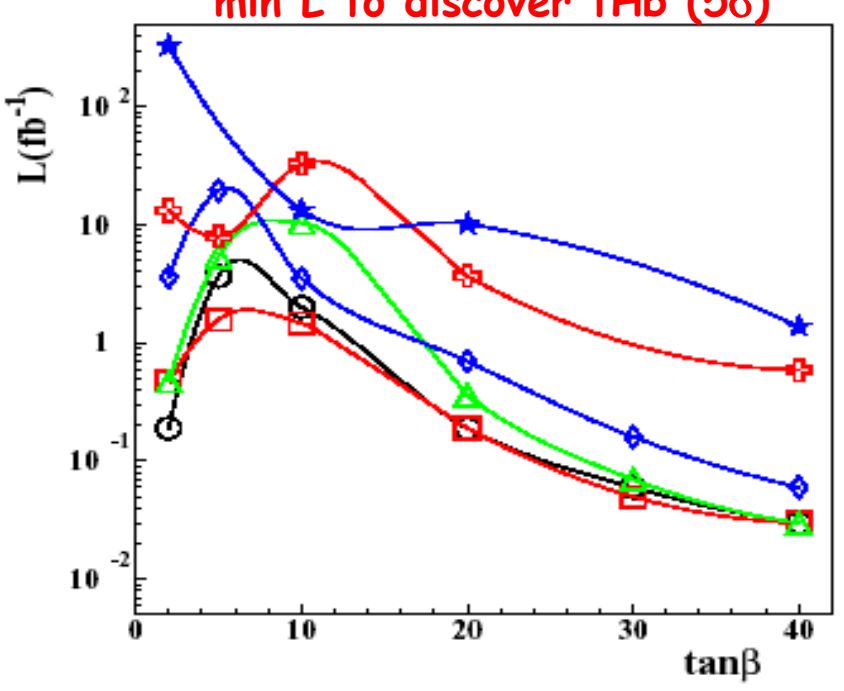
CMS Search

- One CMS study searches for excess of τ jets in $t\bar{t}$ events
  - τ jets identified as narrow hadronic jets
  - dilepton deficit used to enhance the search

min L to exclude tWb (2σ)



min L to discover tHb (5σ)

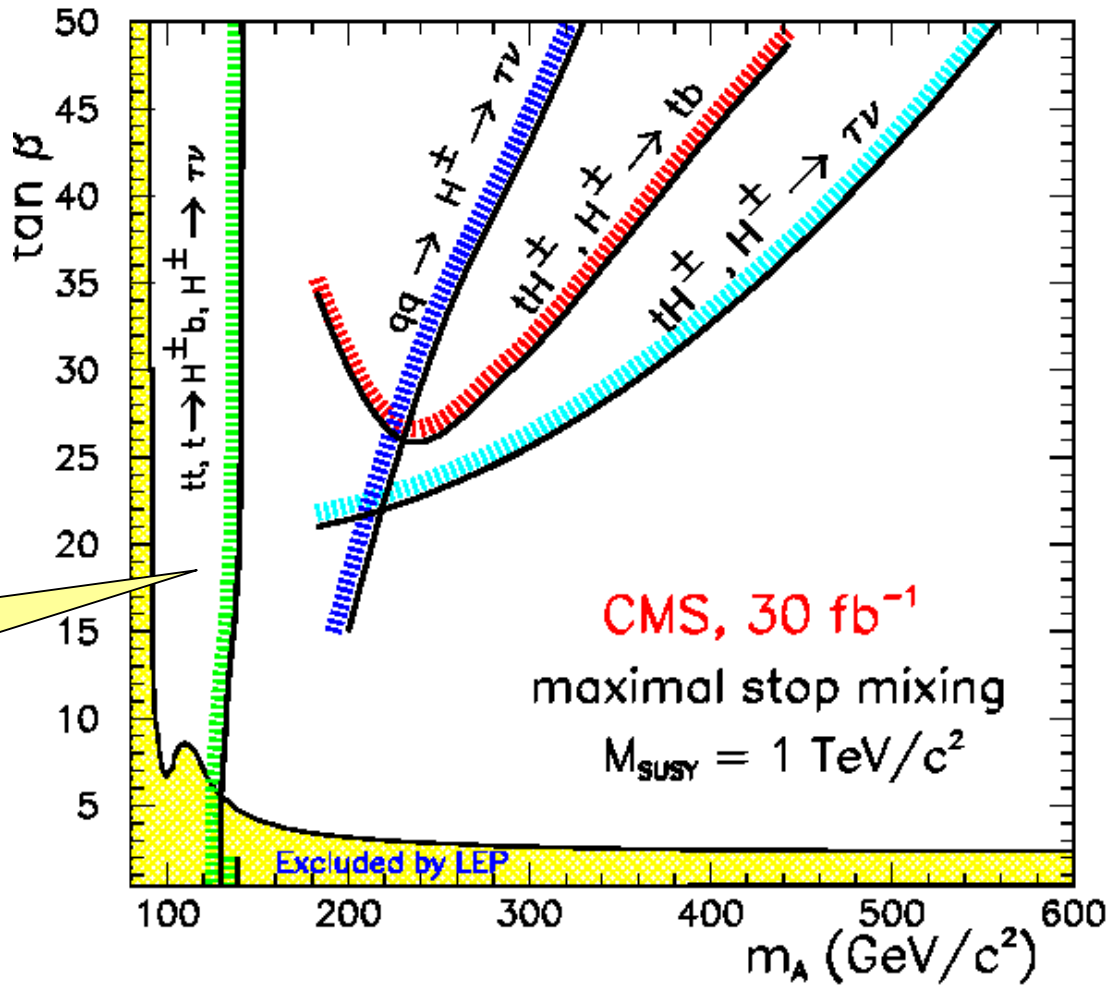


Possible to explore M_H < 160 GeV and 2<tanβ<40 with 30 fb^{-1}

Charged Higgs Boson

- 5 σ discovery reach for light and heavy Higgs
  - See talks by A. Nikitenko R. Kinnunen

Search in top quark decays



Summary

- Top quark physics is rich, exciting and doable at low luminosity LHC
  - SM: EW and QCD tests
  - BSM: probe SUSY
- Today's signal, tomorrow's background
  - Top quark (pair and single) production is the main background to processes with multi lepton + jets in final state, e.g. SUSY
- Although top will be explored at Tevatron, it will have to be re-visited at LHC for high statistics studies
  - $\Delta m_t \leq 1$ GeV
  - BR for FCNC $tVq \approx 10^{-3} - 10^{-6}$

❖ Lots of work and fun ahead… ☺