Search for New Phenomena in the CDF Top Quark Sample

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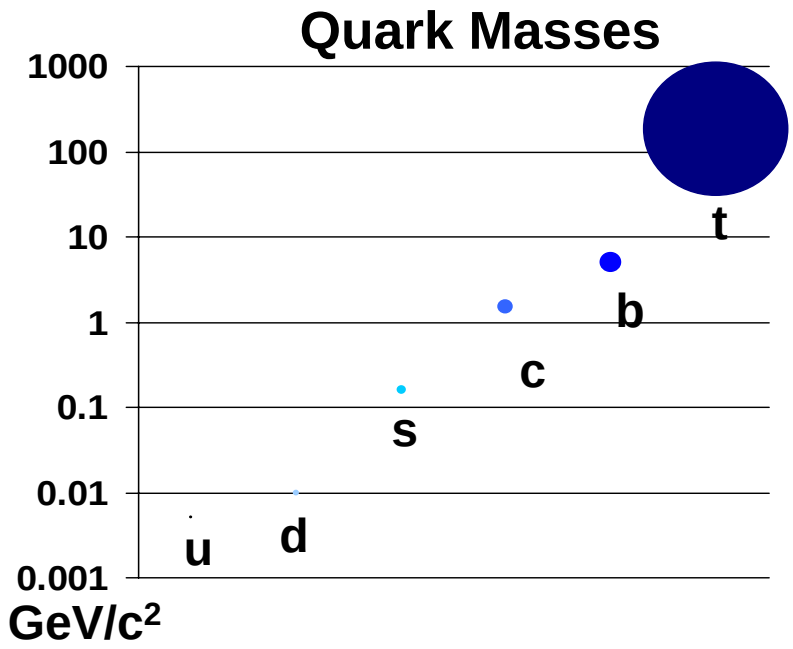
For the CDF Collaboration

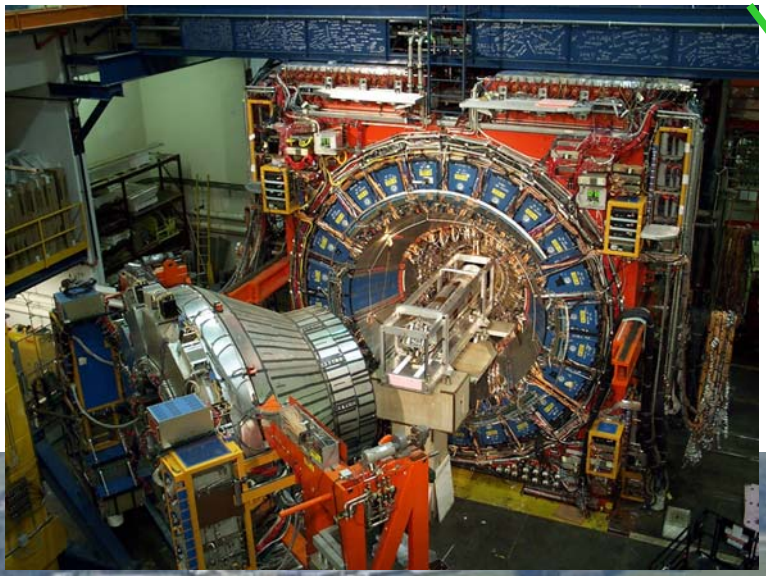
Why Look in Top Sample?

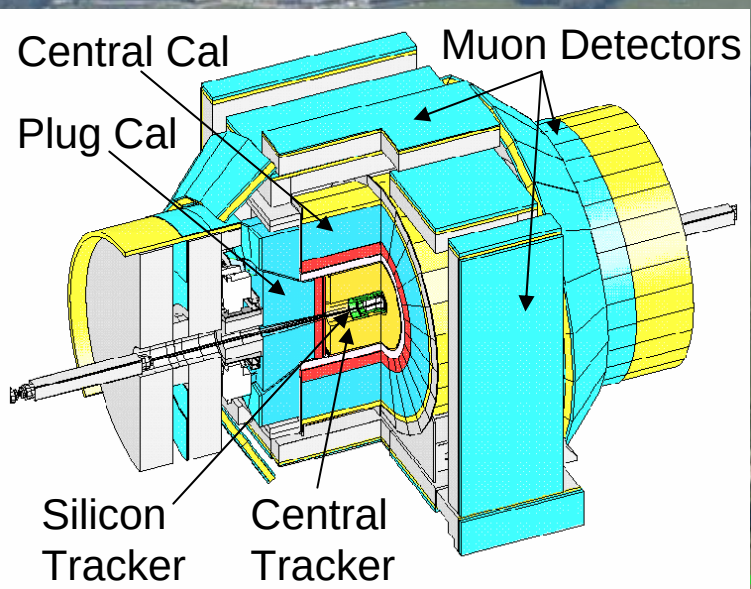
- Top only recently discovered
  - Turned ~10 years old last year
  - Samples still relatively small
  - Still plenty of "room" for unexpected phenomena
- Top is really massive
  - Comparable to gold nucleus!
  - Yukawa coupling near unity
  - Special role in EWSB?
- Many models include new physics coupling to top



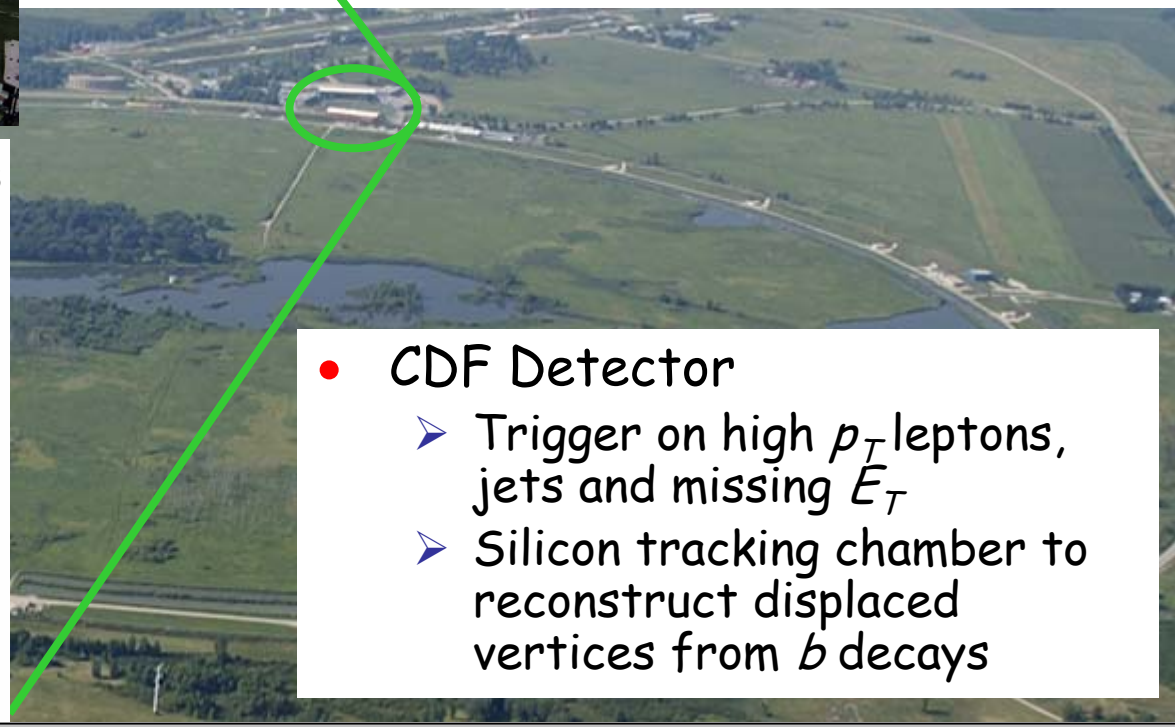
5 orders of magnitude between quark masses!

The Tevatron and CDF





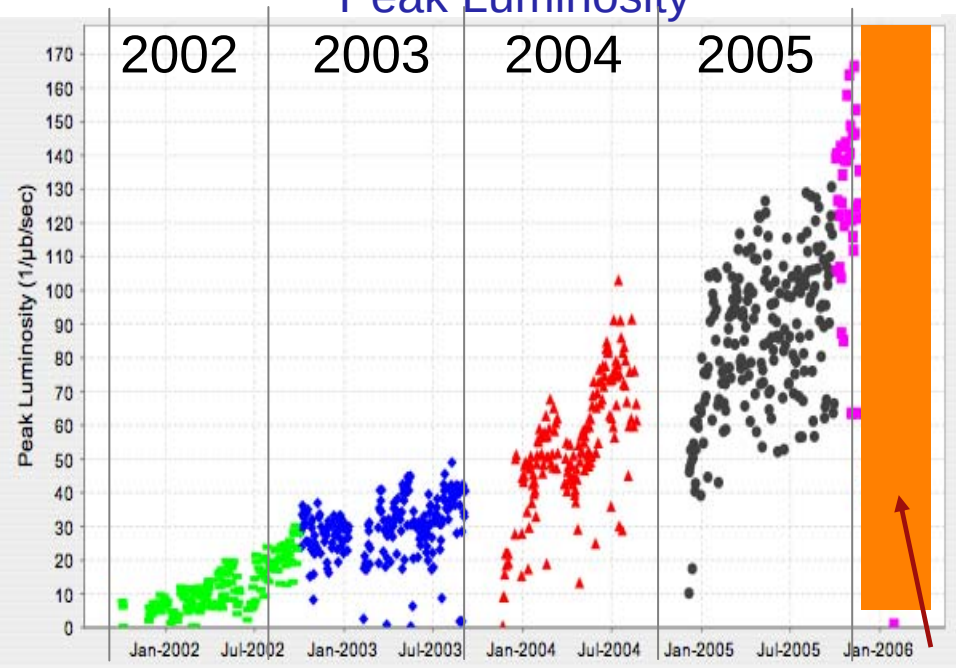
- Tevatron accelerator
  - Highest energy accelerator in the world (E_{cm} = 1.96 TeV)
  - World record for hadron collider luminosity (L_{inst} = 1.72E32 $cm^{-2}s^{-1}$)
  - Only accelerator currently making top quarks



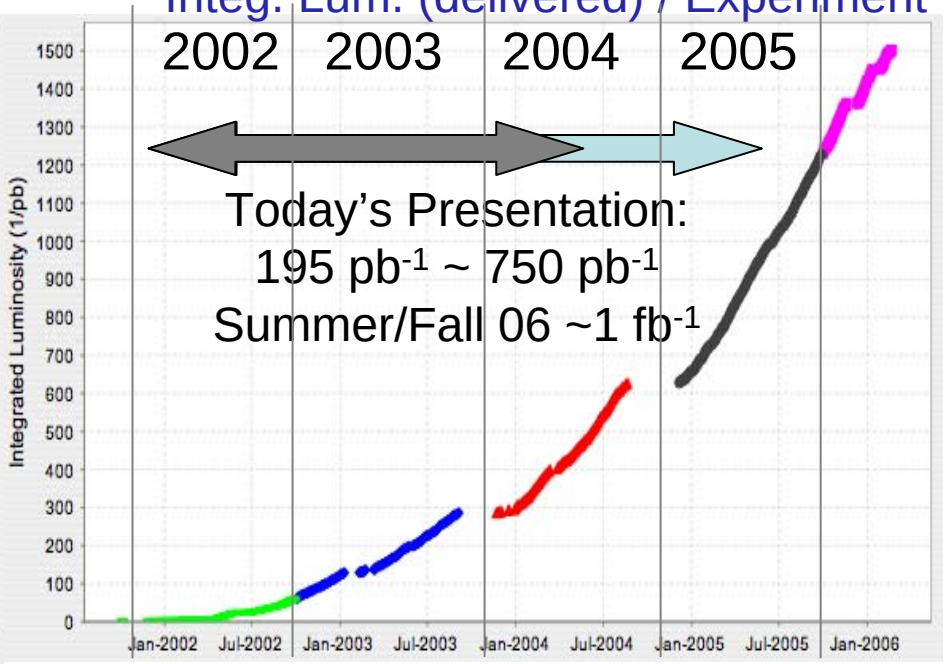
- CDF Detector
  - Trigger on high p_T leptons, jets and missing E_T
  - Silicon tracking chamber to reconstruct displaced vertices from b decays

Tevatron Performance

Peak Luminosity



Integ. Lum. (delivered) / Experiment

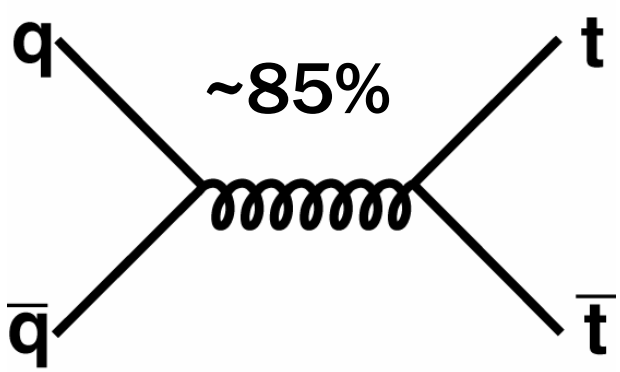


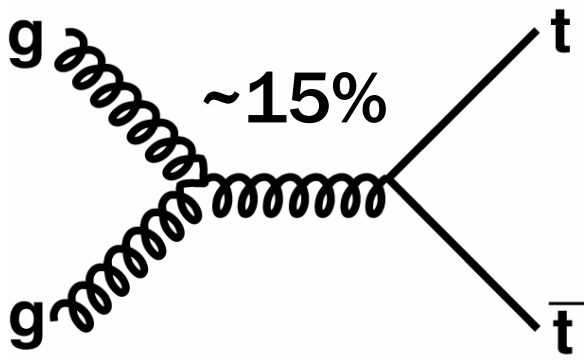
Includes machine studies and diffractive program (low L)

- Integrated luminosity at CDF
  - Total delivered: ~1.5 fb^{-1} /expt.
  - Total recorded: ~1.2 fb^{-1} /expt (~ 10× Run I!)
  - So far for top analyses, used up to 750 pb^{-1}
  - 1 fb^{-1} analyses in progress → Ready for summer/fall 06
- Doubling time: ~1 year
- Future: ~2 fb^{-1} by 2006, ~4 fb^{-1} by 2007, ~8 fb^{-1} by 2009

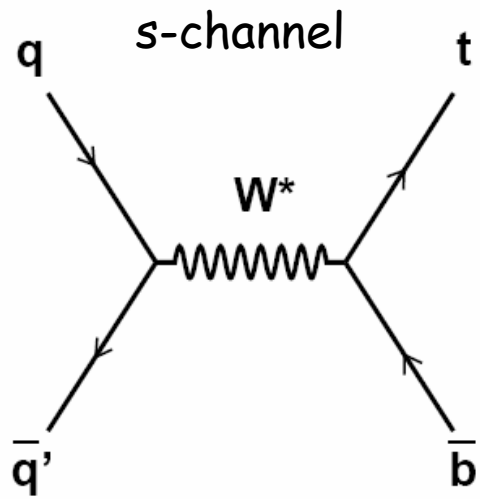
Top Quark Production at Tevatron

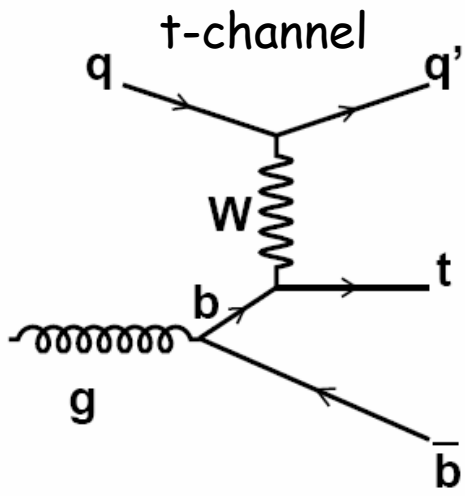
- QCD pair production
  - σ_{NLO} = 6.7 pb
  - First observed at Tevatron in 1995





- EWK single-top production
  - s-channel: σ_{NLO} = 0.9 pb
  - t-channel: σ_{NLO} = 2.0 pb
  - Not observed yet

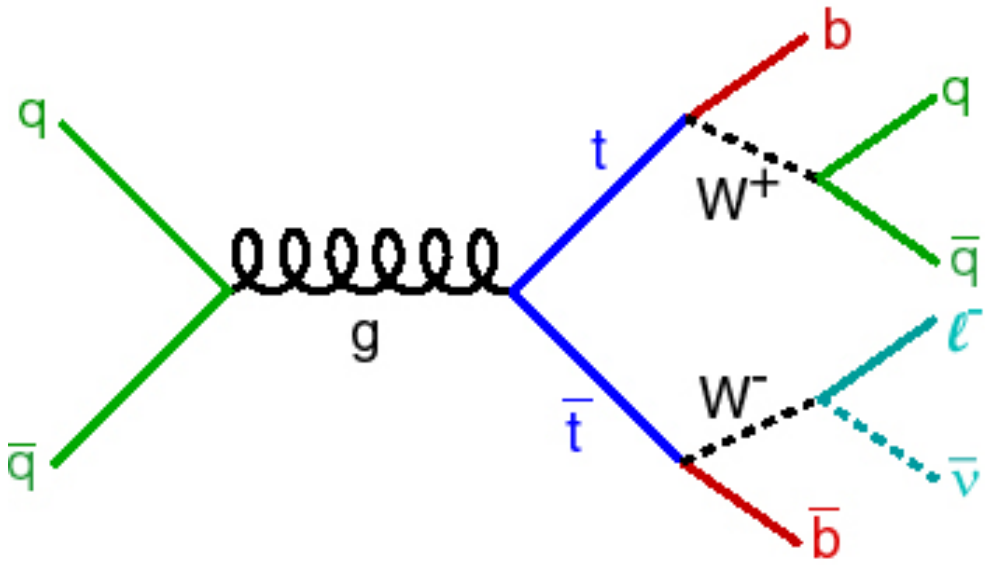


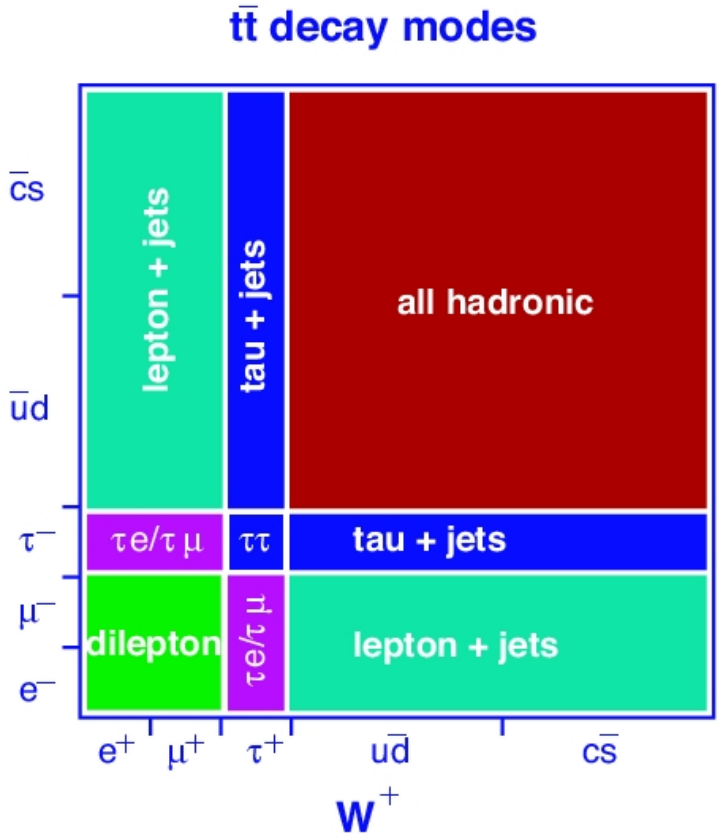


- Other? ???

SM Top Quark Decays

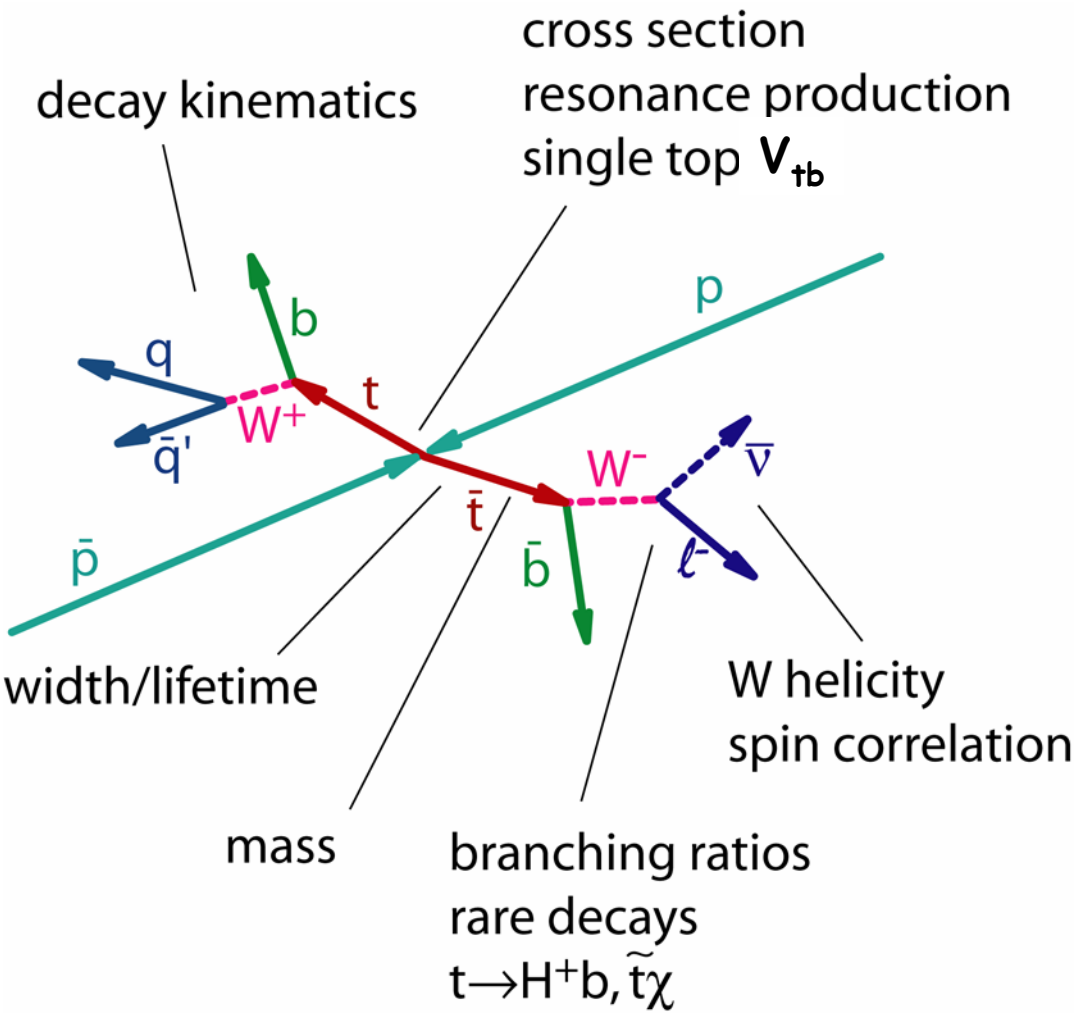
BR($t \to Wb$) ~ 100%





- Particular analysis usually focuses on one or two channels
- New physics can impact different channels in different ways
- Comparisons between channels important in search for new physics

Searching for New Physics

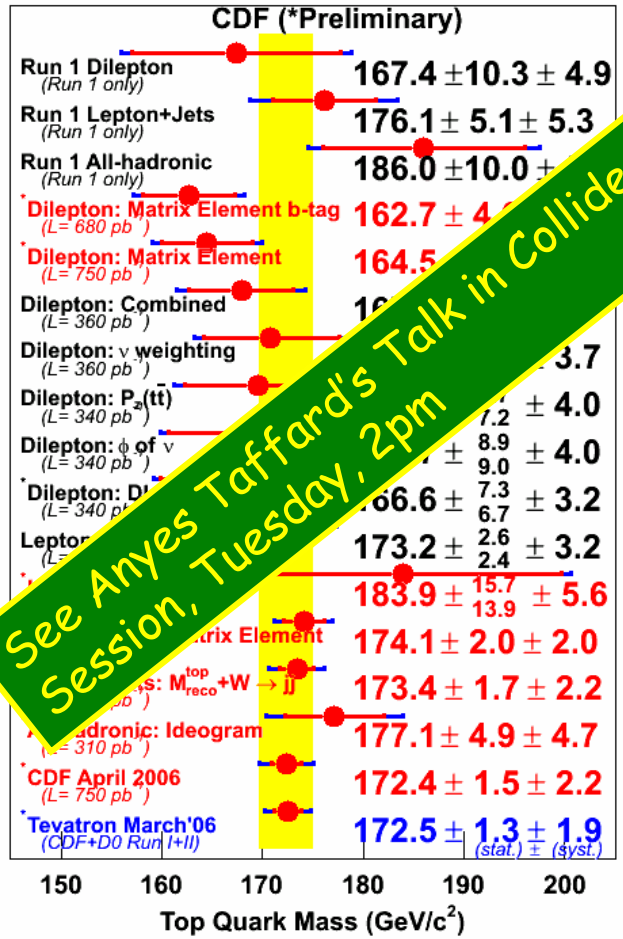


- Precision study of top properties
  - Non-SM behavior from top quark
  - Evidence of something other than top in sample
- Direct search for new phenomena in top sample
  - Resonant production
  - Non-SM decays
  - New particles with "top-like" signature
  - New particles produced in association with top

See pp→ttH in Shin-Shan Yu's talk next

Same Properties in Many Channels

Top Mass



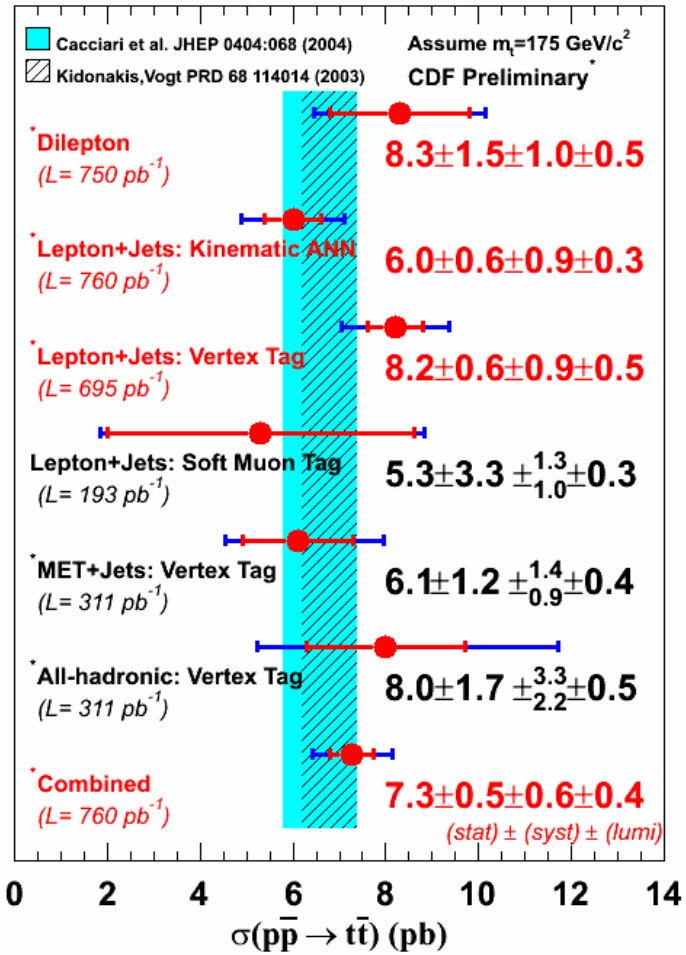
See Anyes Taffard's Talk in Collider Session, Tuesday, 2pm

Most recent results shown in red

Check for consistency between different decay channels

Check for consistency between different methods in same decay channel

Top Cross Section

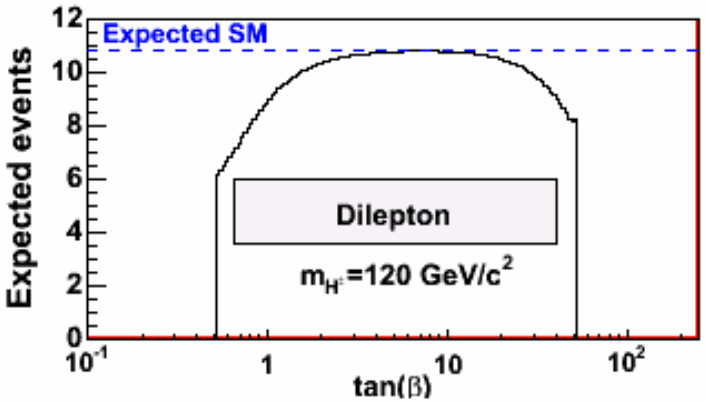


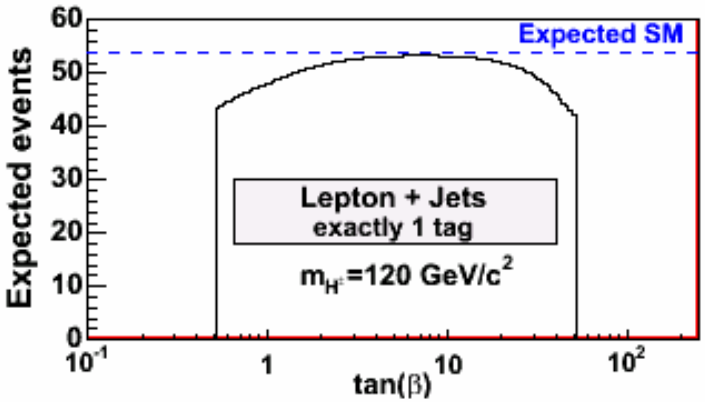
- So far no significant inconsistencies seen
- Able to combine results to achieve greater precision

Search for t →H⁺b

Phys.Rev.Lett. 96 (2006) 042003

- Compare top yield in four different channels
  - Measurements consistent with SM
- Consider correlated effect of t→H⁺b decays on four channels
- Exclude when changes make expectation inconsistent with data
- Limits for 6 sets of MSSM parameters and less model-specific scenarios

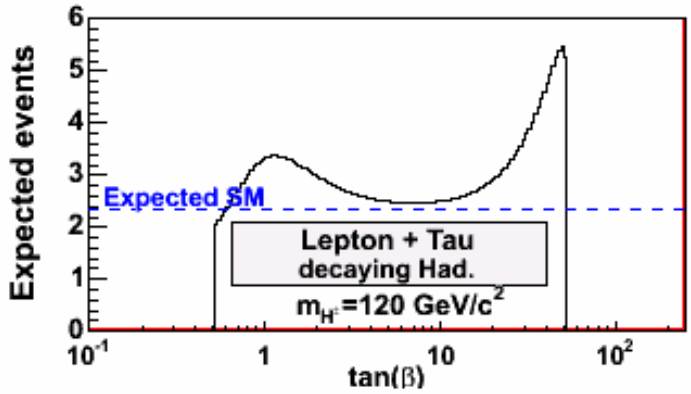


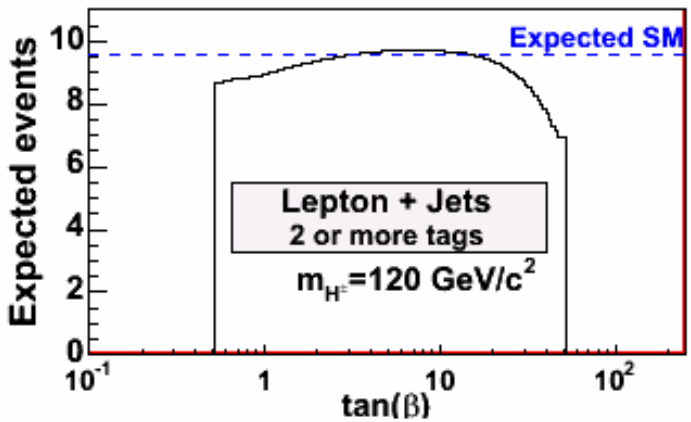


Varying model parameters changes:
BR(t→H⁺b)

BR(H⁺→τν)
BR(H+→cs)
BR(H+→t*b)
BR(H+→W⁺h⁰)
BR(H+→W⁺A⁰)

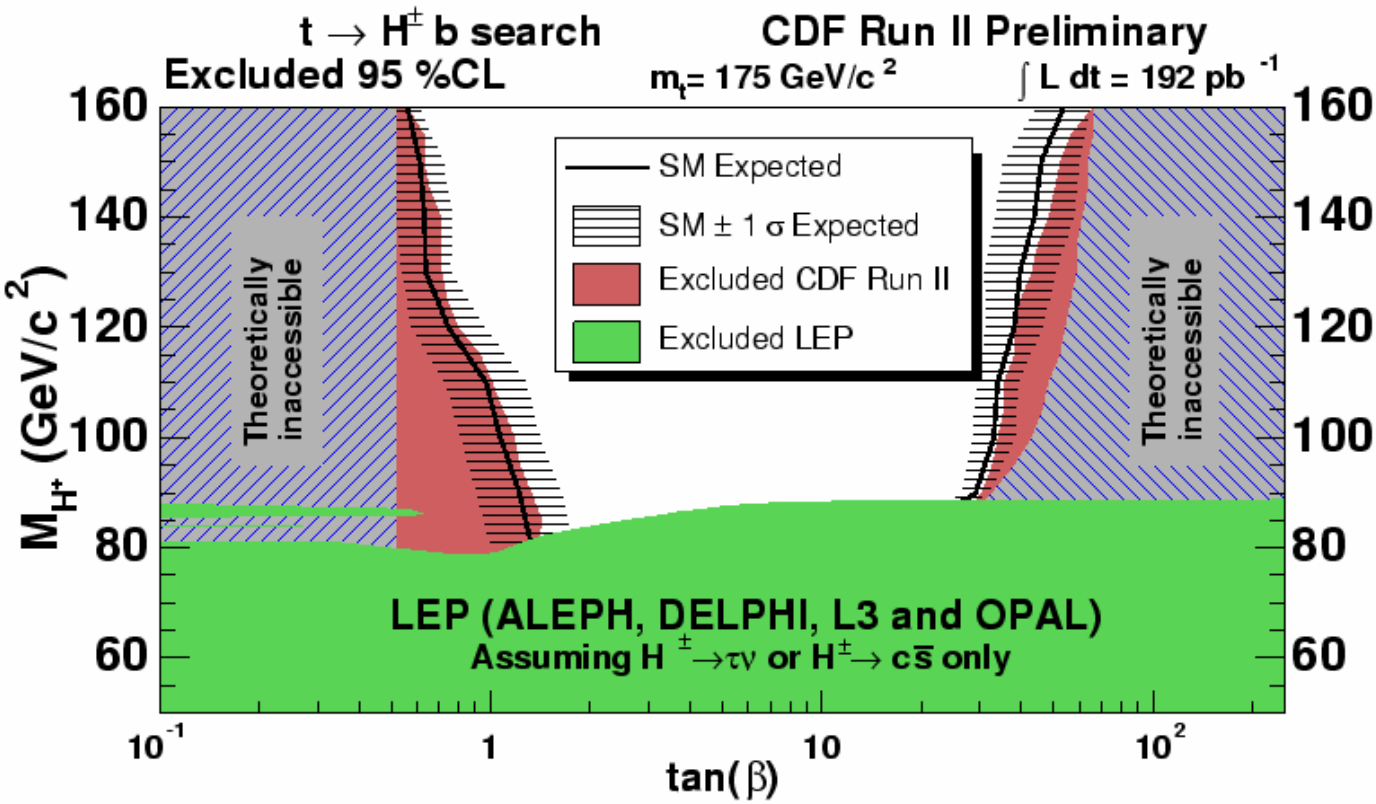
Shown here:
Variations as a function of tanβ particular set of MSSM parameters





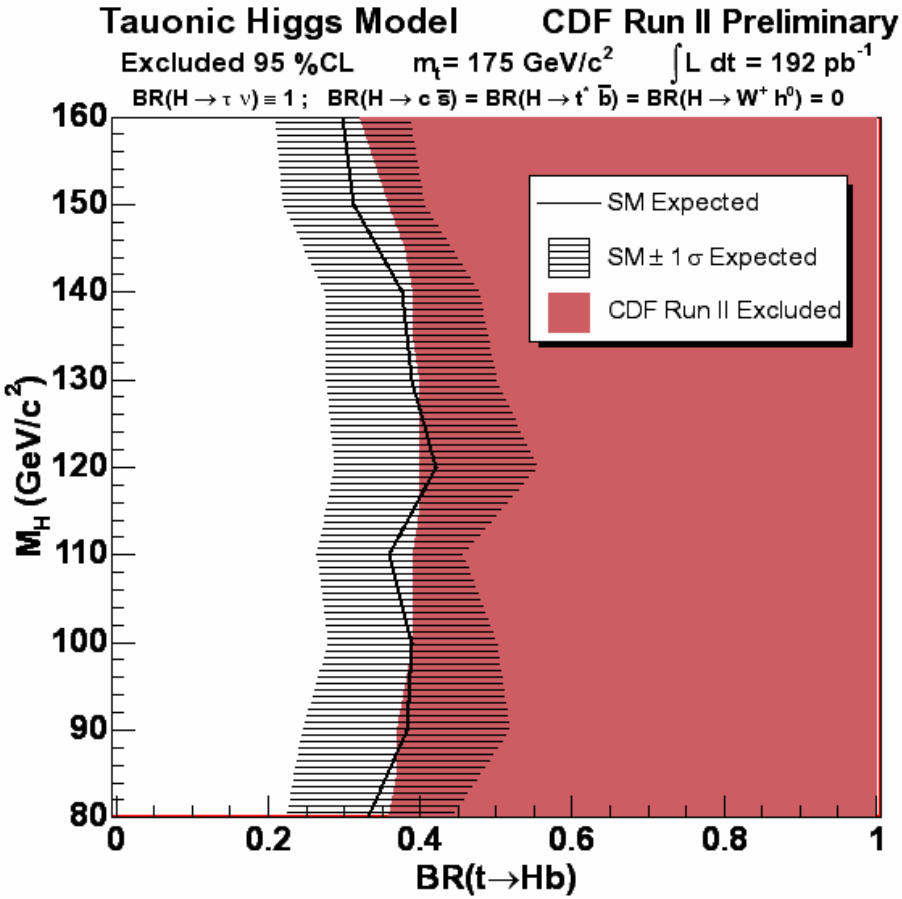
MSSM Limits

- Calculate BR(t→H⁺b) and H⁺ BR's as a function of M_{H^+} and tan(β)
- Use 6 different MSSM "benchmarks"
  - Results for "Benchmark #1" shown below (others in backup slides)

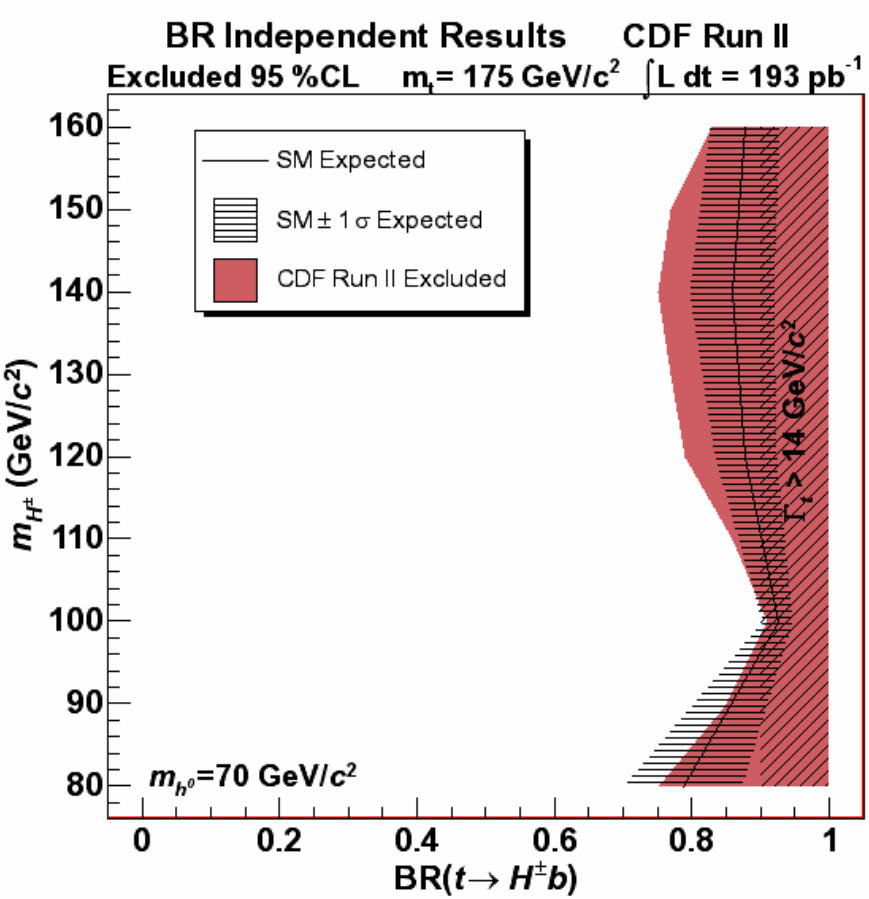


Less Model Dependent Limit

- "Tauonic Higgs" Model
  - Assume BR($H^+ \rightarrow \tau\nu$) = 1
  - i.e. MSSM with high tan(β)



- "Worst" Limit
  - Find arbitrary combination of H^+ BR's that give least stringent limit

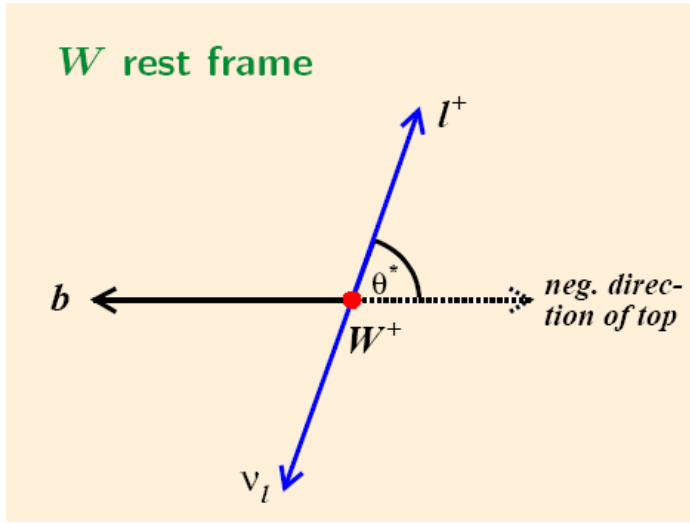


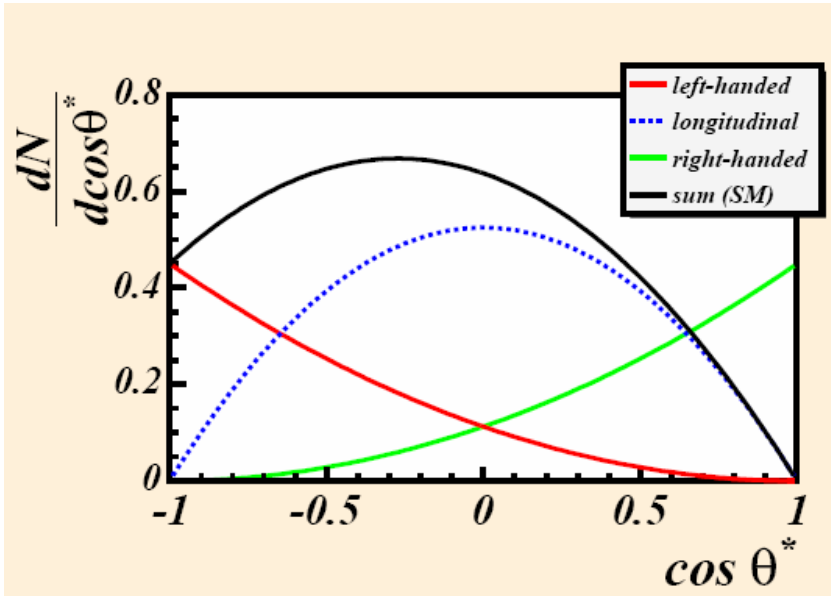
W Helicity in Top Decay

- Helicity of W determined by V-A struture of EWK interaction
  - 70% longitudinal
  - 30% left-handed
  - Right handed forbidden
- Can be tested by measuring W helicity angle: θ^*
- Can also use $M_{lb}^2 \approx 0.5(m_t^2 - m_W^2)\cos\theta^*$
- CDF results

$$F_0 = 0.85^{+0.15}_{-0.22} \pm 0.06,\ F_+ \text{ fixed to } 0$$

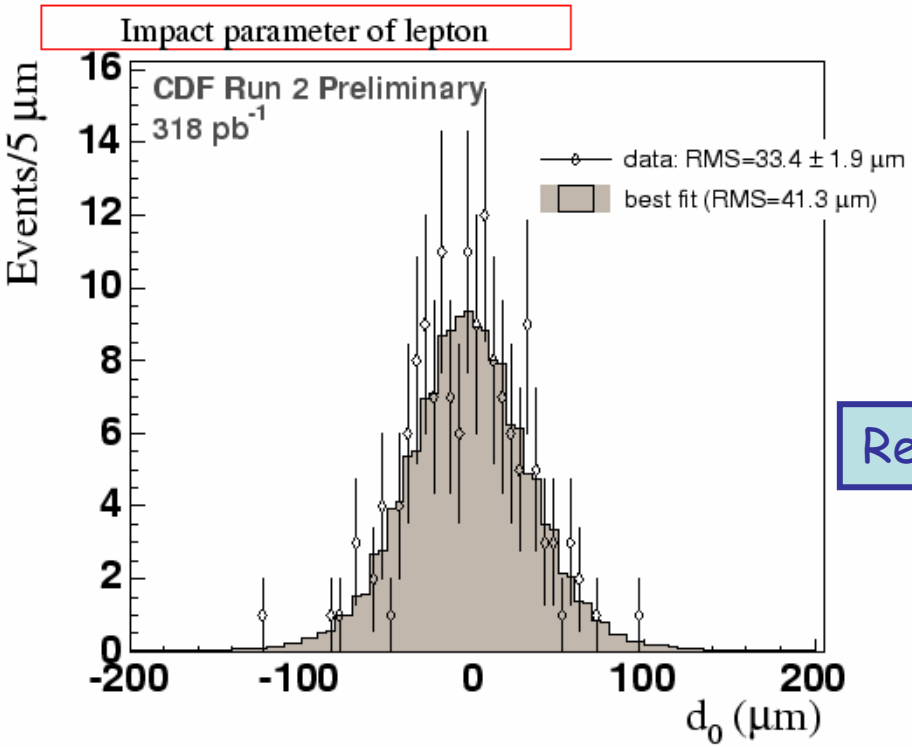
$$F_+ < 0.09 \text{ at } 95\% \text{ CL},\ F_0 \text{ fixed to } 0.7$$

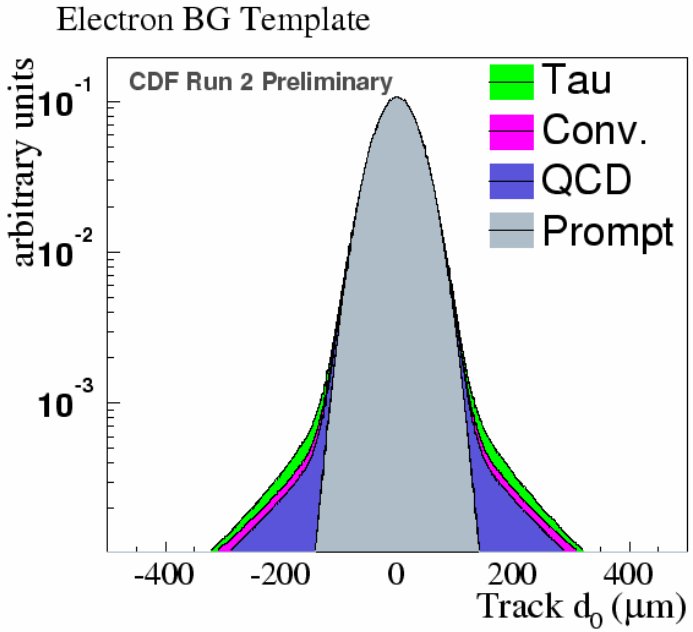




Top Quark Lifetime

- Measure impact parameter of lepton from Lepton + Jets top decay
- Evidence of displaced top suggests
  - Production via decay of long-lived particle
  - New long-lived particle in top sample
  - Anomalous top lifetime





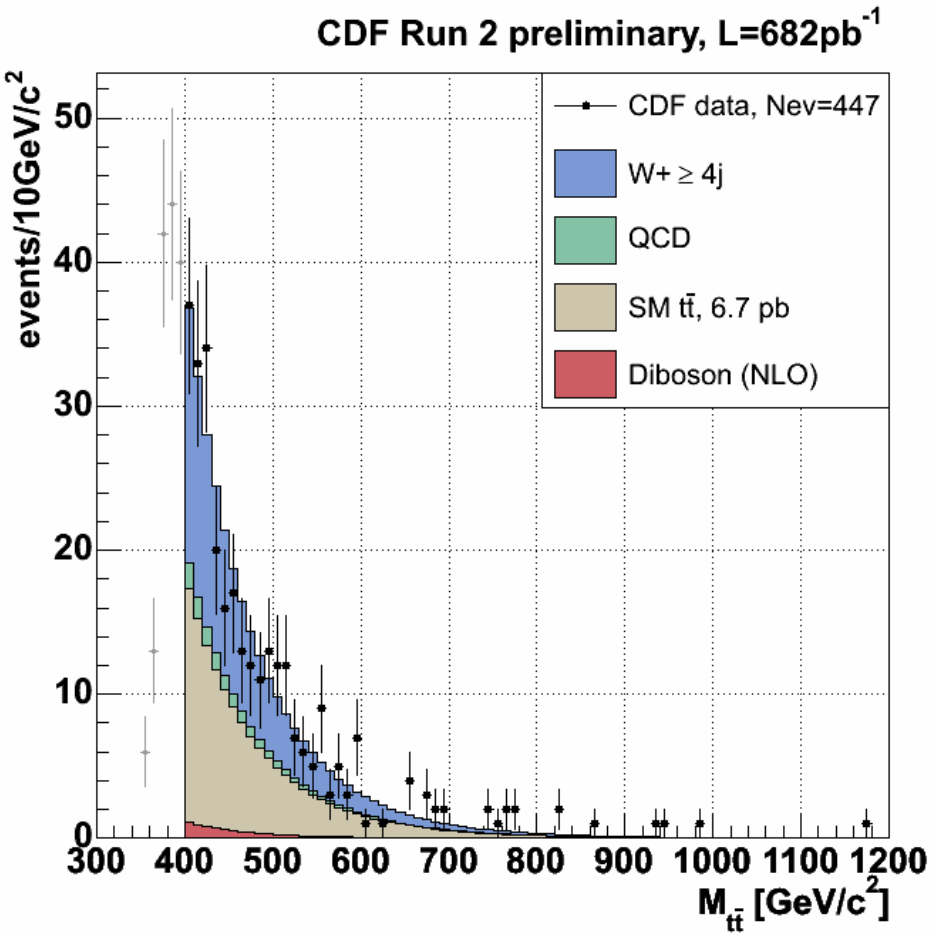
Templates for SM processes

Result: $c\tau < 52.5$ μm at 95% confidence level

Search for Resonant Production

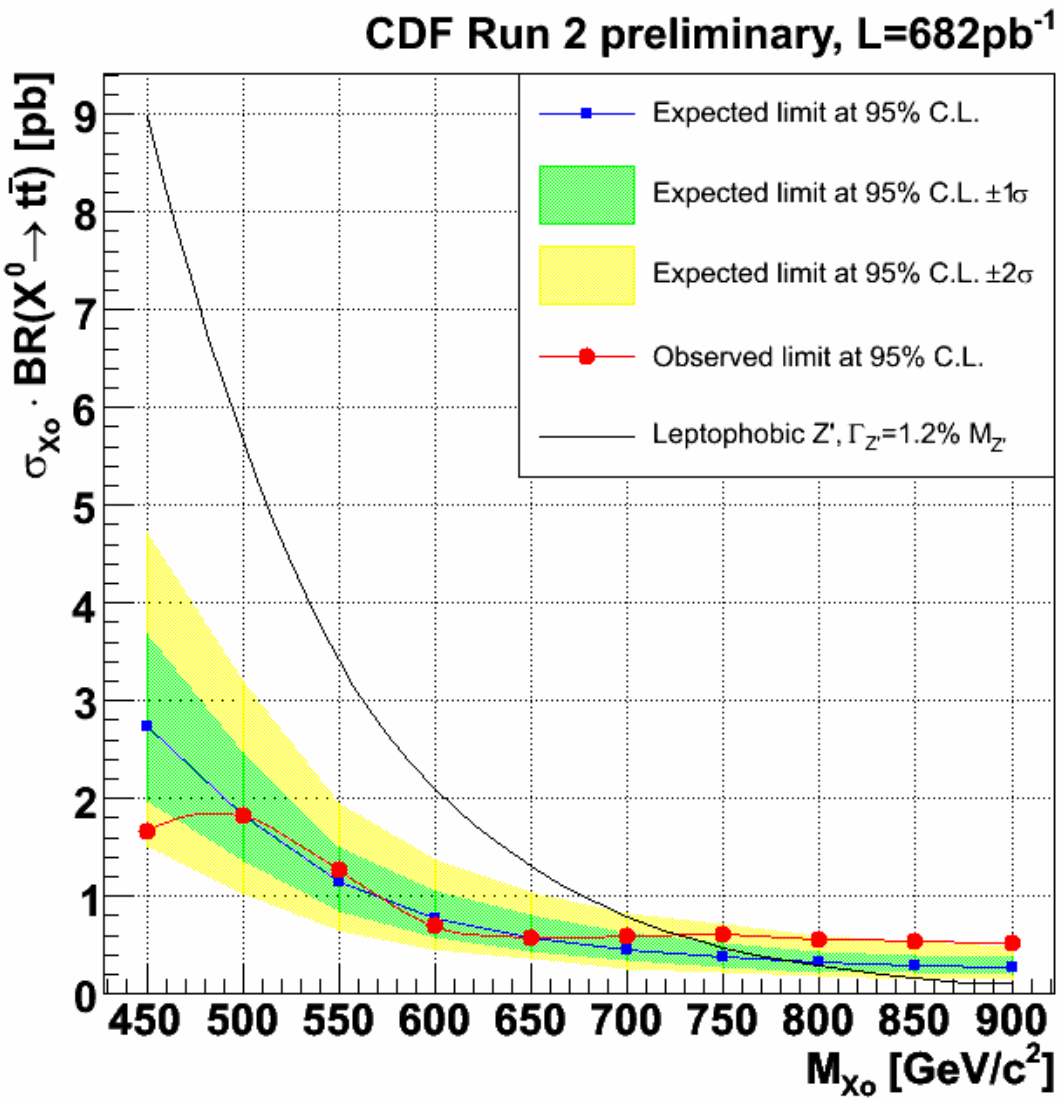
- Motivation
  - Some models predict particles decaying to top pairs
  - Should be visible as resonance in *tt* invariant mass spectrum
- Example model: Topcolor assisted technicolor
  - Extension to technicolor that includes new strong dynamics
  - Couples primarily to 3rd generation
  - Includes new massive guage bosons: topgluons and Z'

$$p\bar{p} \rightarrow X^0 \rightarrow t\bar{t}$$



Search for Resonant Production

- Look for generic, spin 1 resonance (X^0) decaying to top pairs
  - Assume Γ_{X0} = 1.2%×M_{X0}
  - Test masses between 450 GeV and 900 GeV in 50 GeV increments
- Results
  - No evidence for resonance
  - Set 95% confidence level limit for σ_{X0} at each mass
  - Exclude leptophobic Z' with $M_{z'}$ < 725 GeV

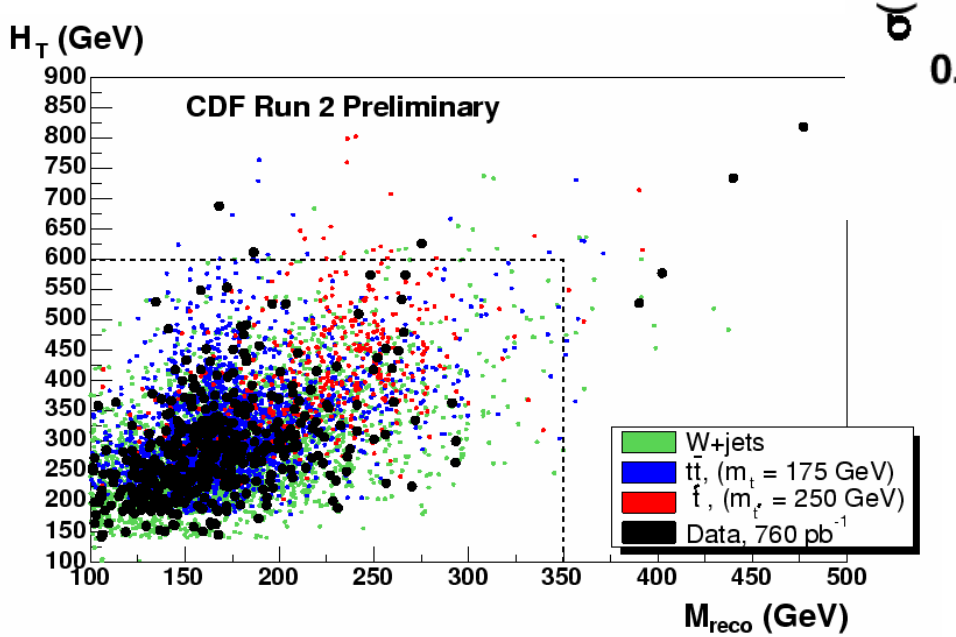


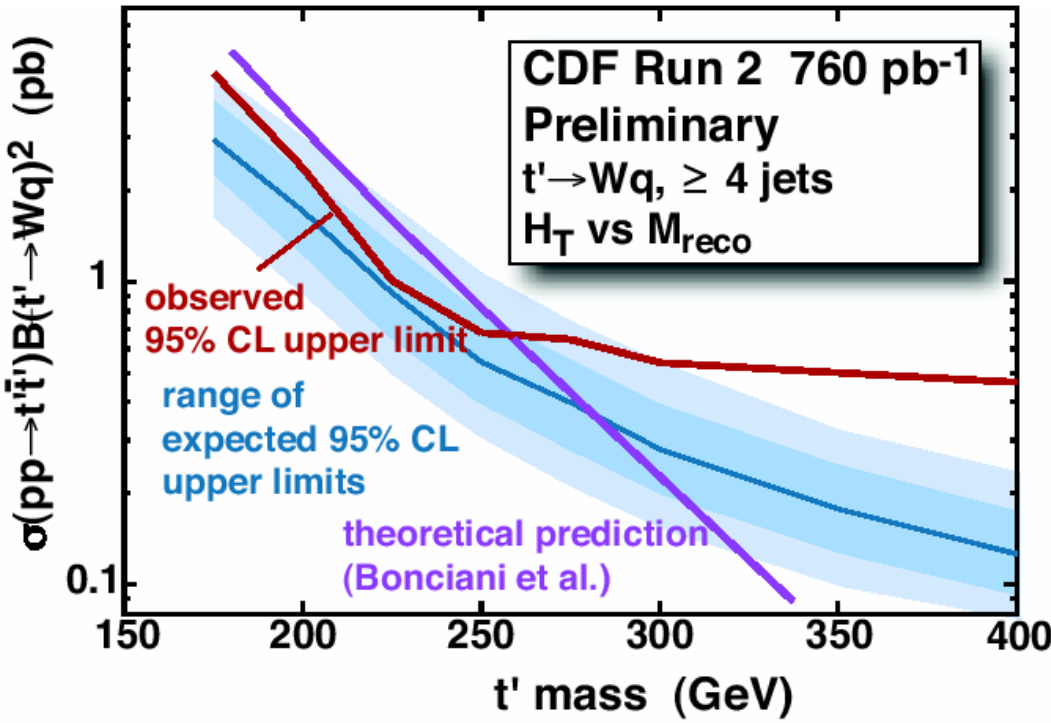
t′ Production

- Consider possible contribution to "top" sample from heavier particles with "top-like" signature (t′)
- Examples
  - 4th chiral generation consistent with precision EWK data [Phys. Rev. D64, 053004 (2001)]
  - "Beautiful Mirrors" Model: additional generation of quarks that mix with 3rd generation [Phys. Rev. D65, 053002 (2002)]
- Consider decay of $t' \rightarrow Wq$
  - Happens when $m_{t'} < m_{b'} + m_W$
  - Precision EWK data suggests mass splitting between b′ and t′ small
- Search for by fitting H_T vs M_{reco}
  - H_T = sum of transverse momenta of all objects in event
  - M_{reco} = Wq invariant mass reconstructed with a χ^2 fitter (same technique used in top mass reconstruction)

t′ Search Results

- No evidence for t′ observed
- Set 95% confidence level limits on $\sigma_{t'} \times BR(t' \rightarrow Wq)^2$





- Exclude $m_{t'} < 258$ GeV for BR(t′→Wq) = 100%
- Interesting behavior in high mass tails

Conclusions

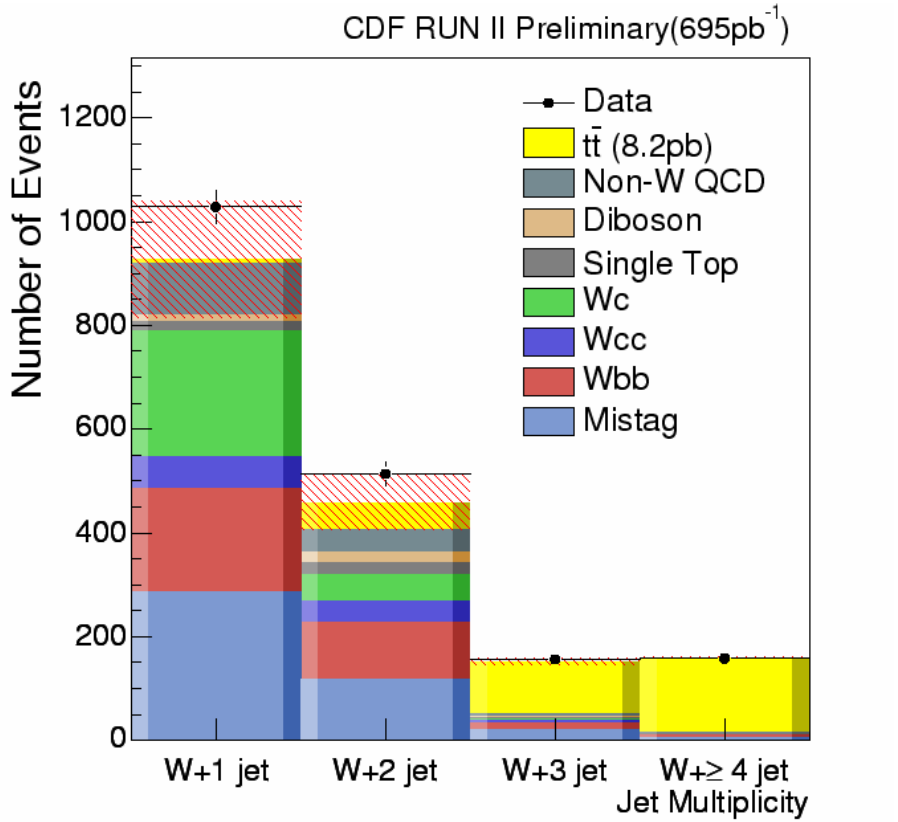
- This is an exciting time to be at the Tevatron
  - 1 fb^{-1} sample currently in hand and being analyzed
    - Top sample has grown from ~30 events in Run I to ~ several hundred
  - Larger samples coming soon
  - Analysis techniques becoming increasingly mature and sophisticated
  - Look forward to 1 fb^{-1} publications this fall
- No evidence for new physics in top sample so far
  - Have many more top measurements than covered in this talk (see CDF public results webpage)
  - Increasing precision continues to test consistency of measurements in different channels
  - Many new analyses on their way (as well as updates of current results)
    - Single-top
    - Top charge
    - Flavor changing neutral currents
    - Direct search for $t \rightarrow H^+ b$

Backup Slides

Same Channel, Different Methods

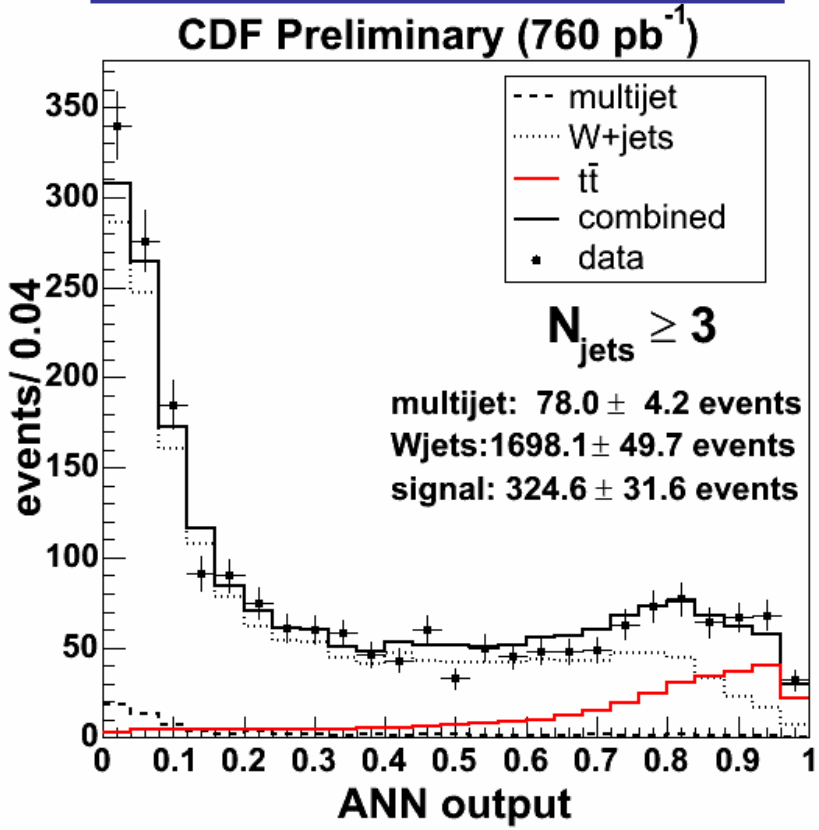
- Lepton + Jets: Vertex Tag
  - Reduce background by *b*-tagging
  - Counting experiment: no fitting
  - Background rate from MC and data

8.2 ± 0.6 (stat) ± 1.0 (syst) pb



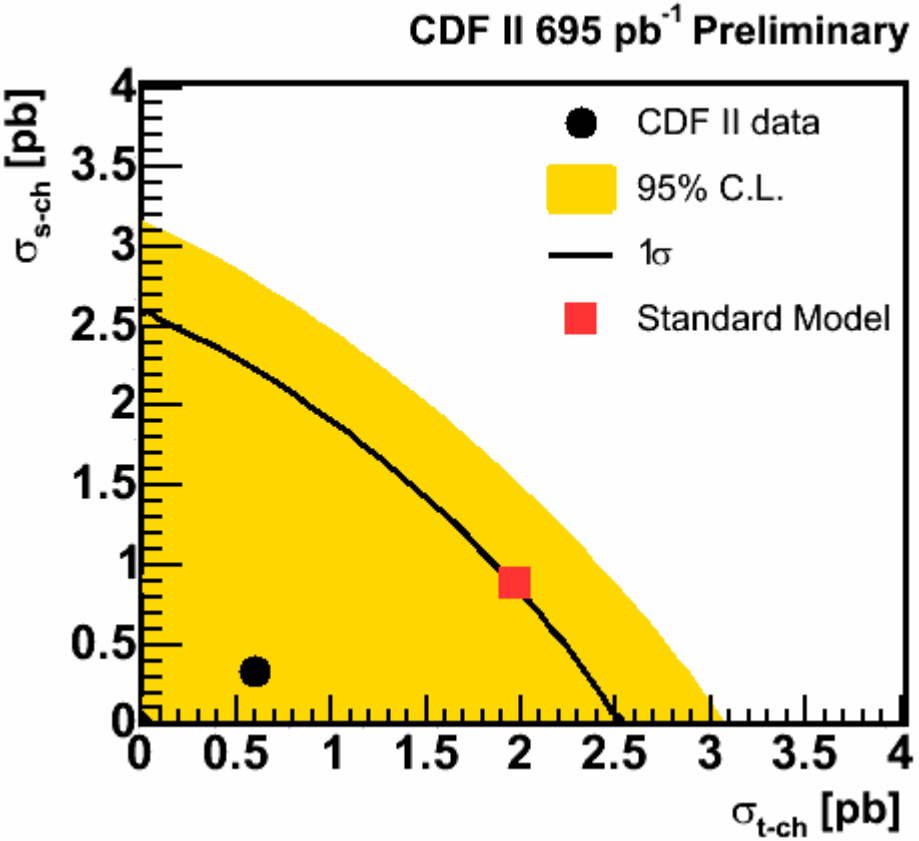
- Lepton + Jets: Kinematic fit
  - Do not require *b*-tags
  - Use kinematic variables in neural net
  - Shapes from MC; fit to data

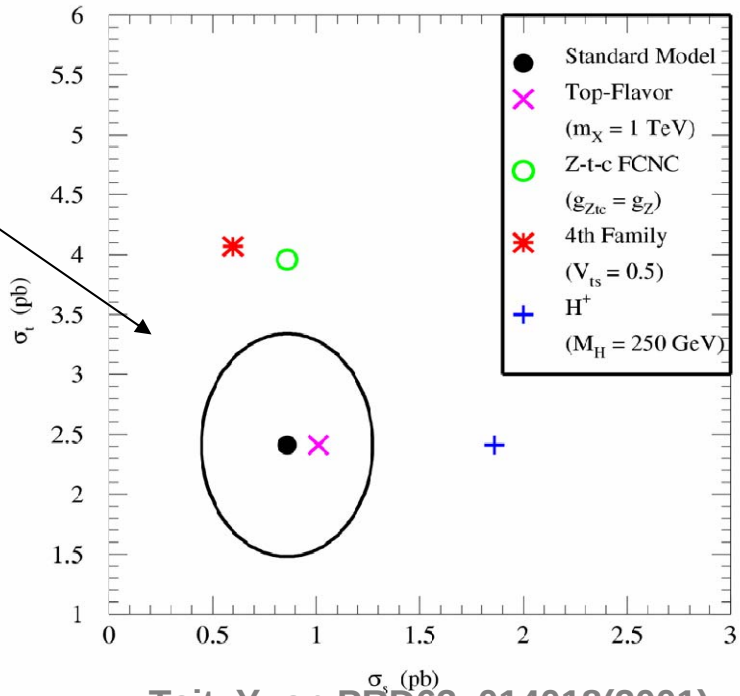
6.0 ± 0.6 (stat) ± 0.9 (syst) pb



Single Top

- Beyond the Standard Model
  - Sensitive to a 4th generation
  - Flavor changing neutral currents
  - Additional heavy charged bosons (W′ or H+)
- Can affect s- and t-channel differently



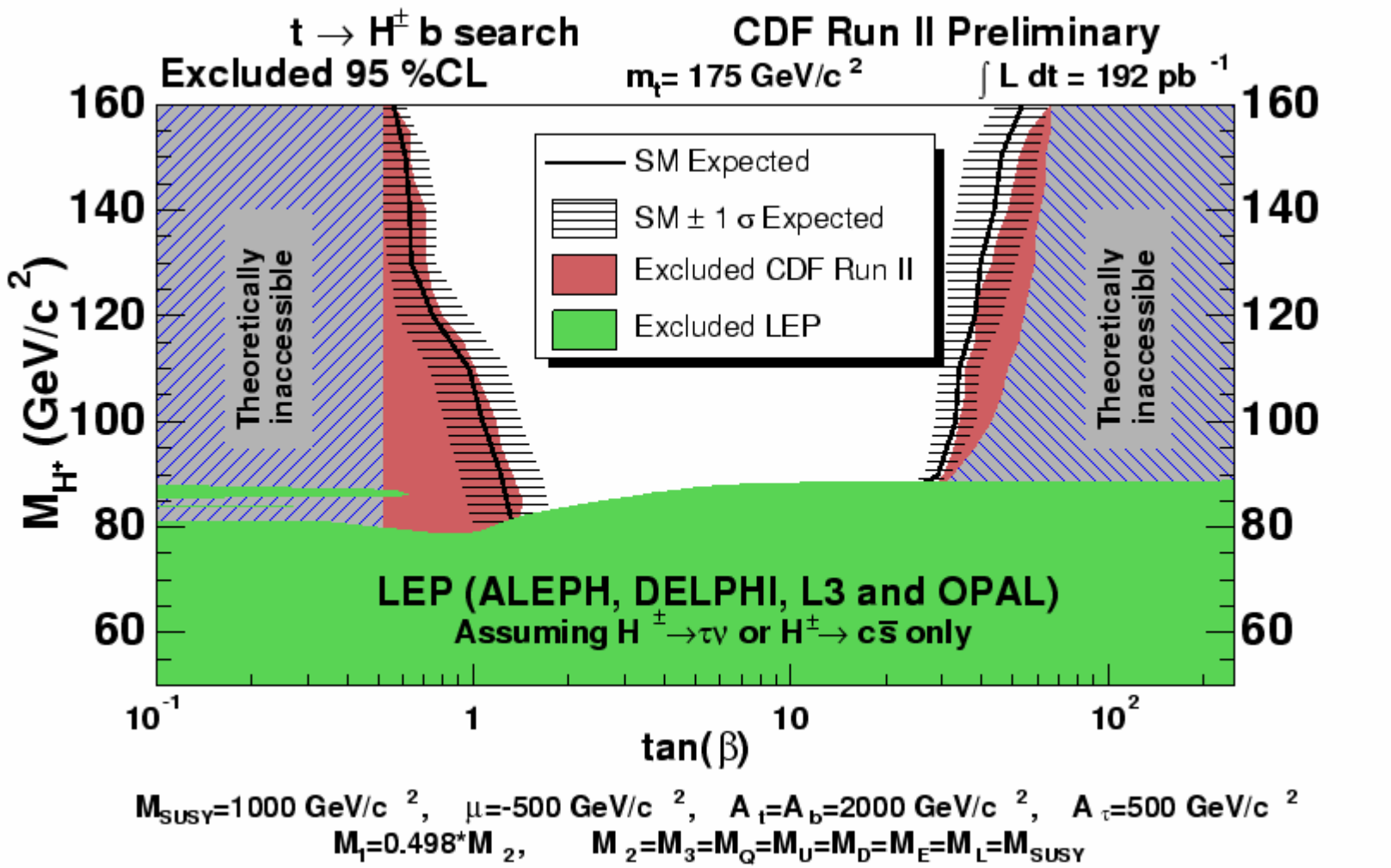


Tait, Yuan PRD63, 014018(2001)

- CDF measures separate and combined limits for s- and t-channel
- Combined 95% CL Limit: $\sigma_{s+t} < 3.4$ pb

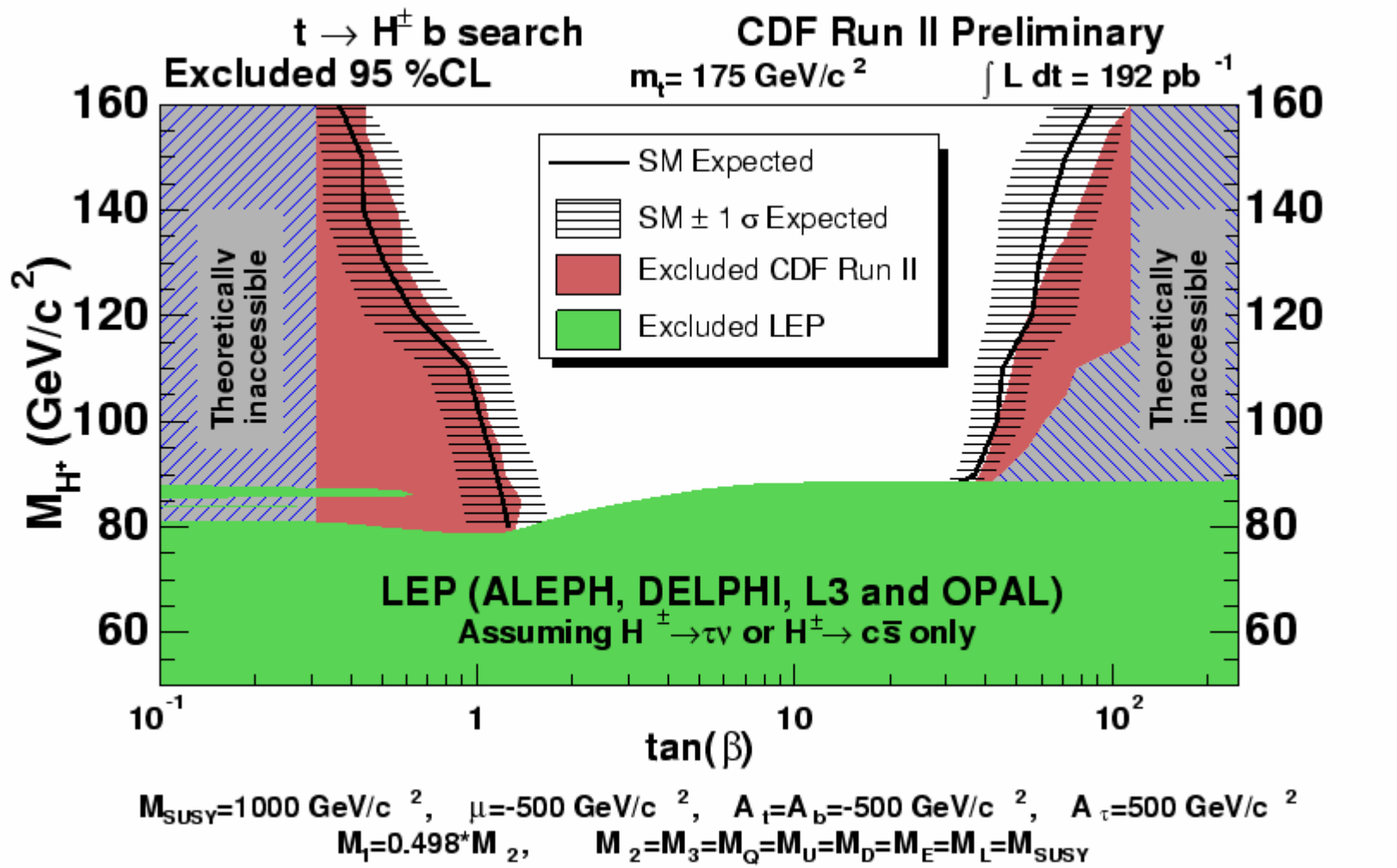
MSSM Benchmark #1

This benchmark enhances the BR(t→H⁺b) at large tan(β) since its very low value of μ, while at tan(β) ~1, where the decay H⁺→Wh⁰ occurrs, the maximum stop mixing condition is achieved maximizing the value of the h⁰ mass.



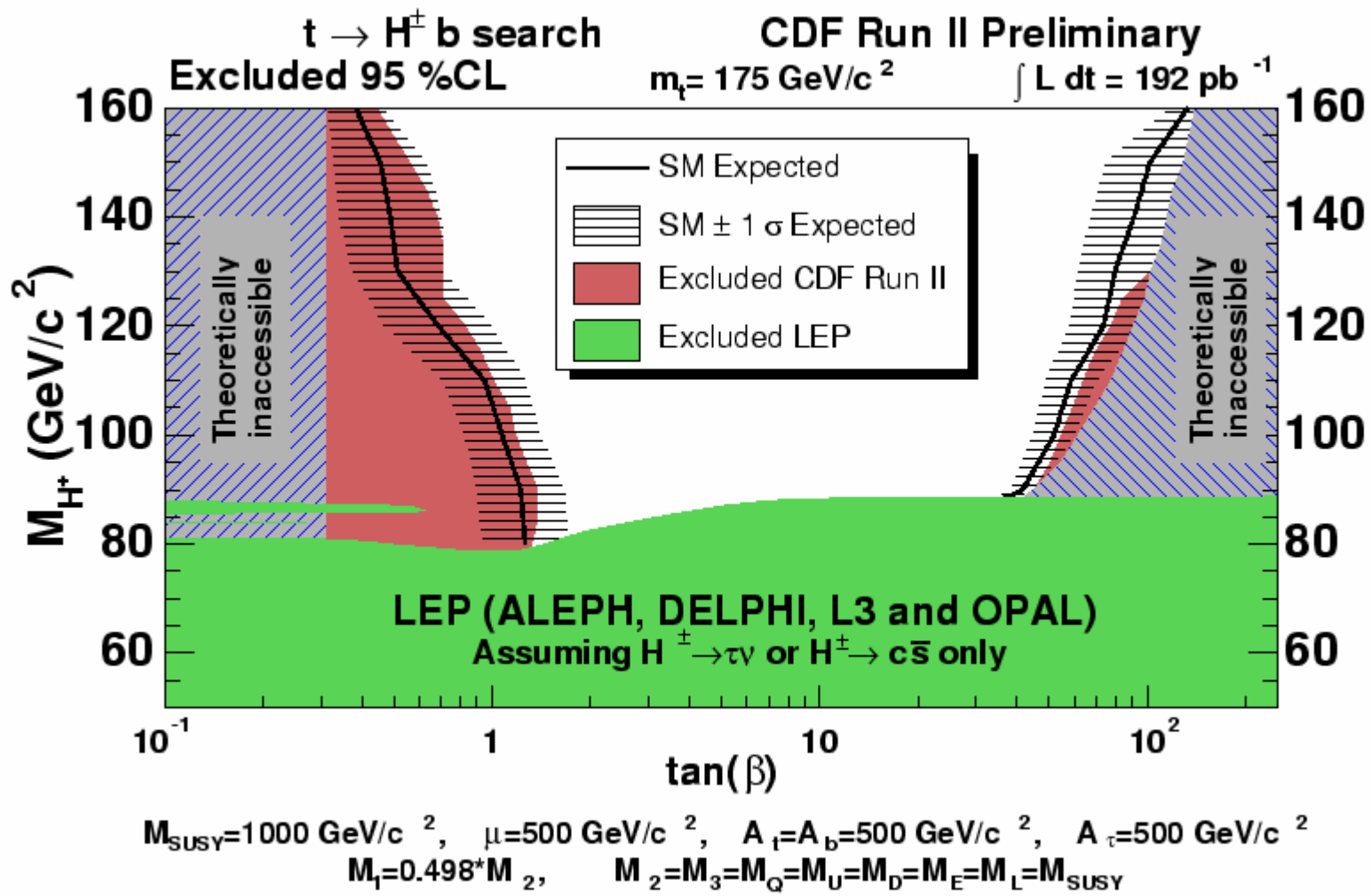
MSSM Benchmark #2

This benchmark enhances the BR(t→H⁺b) at large tan(β) since its very low value of μ, while at tan(β) ~1, where the decay H⁺→Wh⁰ occurrs, the minimum top mixing condition is achieved minimizing the value of the h^0 mass.



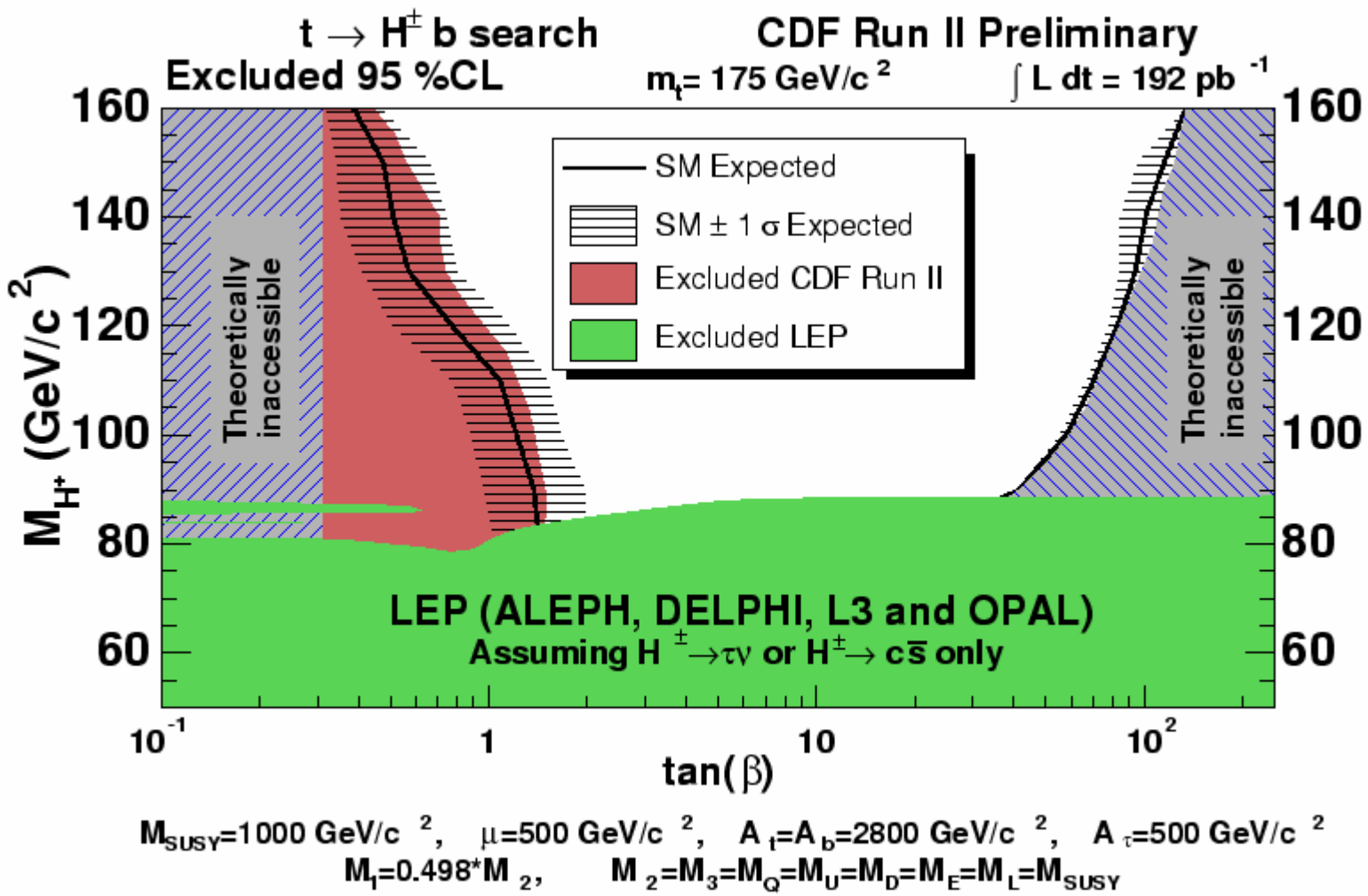
MSSM Benchmark #3

This benchmark suppresses the BR(t→H⁺b) at large tan(β) since its very high value of μ, while at tan(β) ~1, where the decay H⁺→Wh⁰ occurrs, the minimum top mixing condition is achieved minimizing the value of the h⁰ mass.



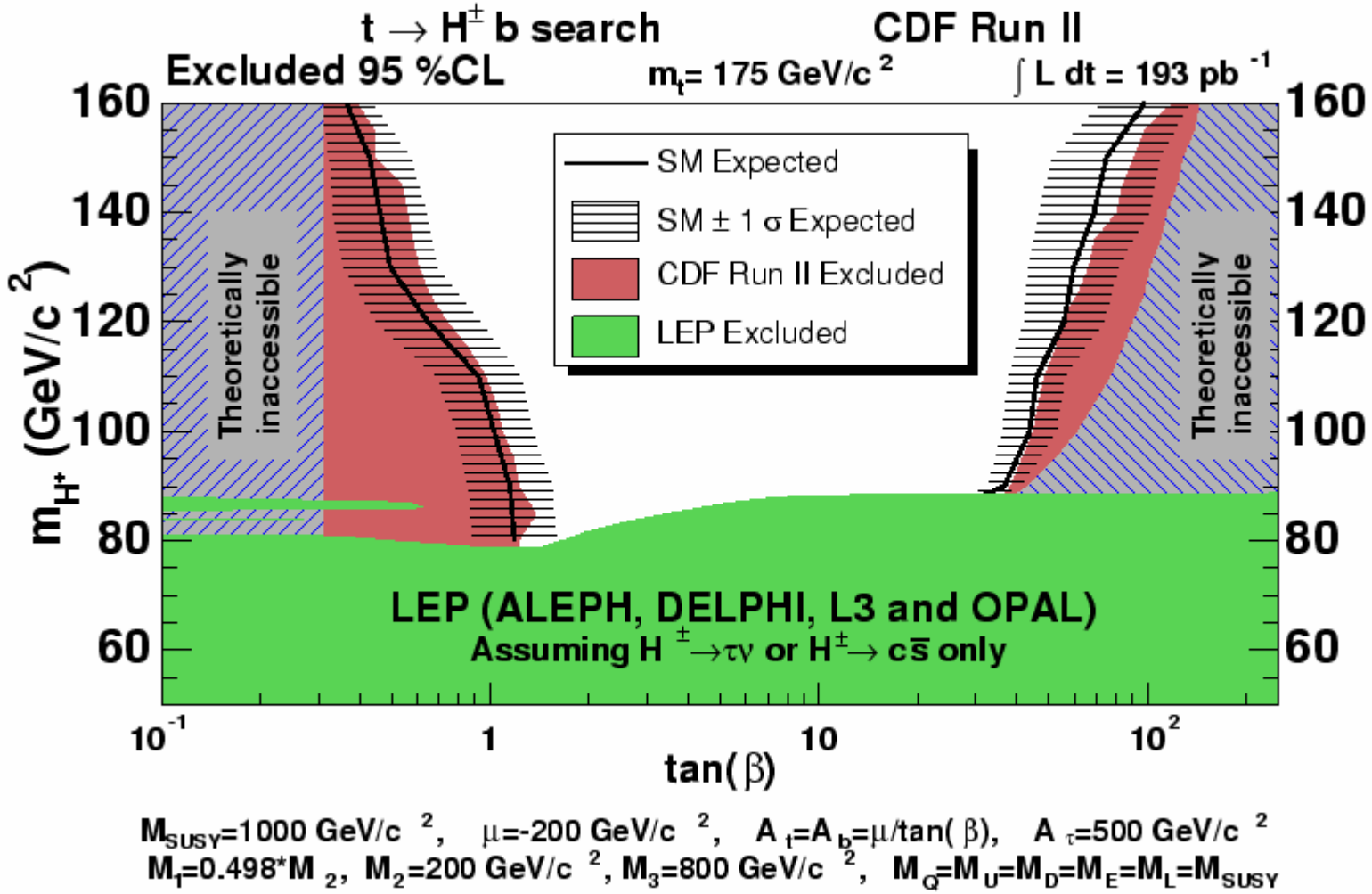
MSSM Benchmark #4

This benchmark suppresses the BR(t→H⁺b) at large tan(β) since its very high value of μ, while at tan(β) ~1, where the decay H⁺→Wh⁰ occurrs, the maximum stop mixing condition is achieved maximazing the value of the h^0 mass.



MSSM Benchmark #5

This is the typical benchmark scenario developed for the search of h^0 at LEP (hep-ph/9912223). The value of A_t is computed as a function of tan(β), allowing for the minimum mass of the h^0 for each value of tan(β).



MSSM Benchmark #6

This is the typical benchmark scenario developed for the search of h^0 at LEP (hep-ph/9912223). The value of A_t is computed as a function of tan(β), allowing for the maximum mass of the h^0 for each value of tan(β).